


Duluth Urban WRAPS HSPF Model Report (REVISED)

Prepared for

Minnesota Pollution Control Agency

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1 Introduction

The MPCA is developing HSPF models for most HUC8 watersheds in Minnesota. These models are intended to provide information that supports total maximum daily load studies (TMDLs), watershed restoration and protection strategies (WRAPS), and comprehensive watershed planning under Minnesota's Watershed Approach (Figure 1-1.). In addition to simulating hydrology, these models are designed to support biological stressor identification and analysis of pollution-related impairments such as elevated turbidity and the effects of elevated nutrient concentrations. The models are also useful to support analysis needed to develop TMDLs for dissolved oxygen and temperature, as well as to provide a tool for evaluating appropriate point source effluent limits for permitted facilities.

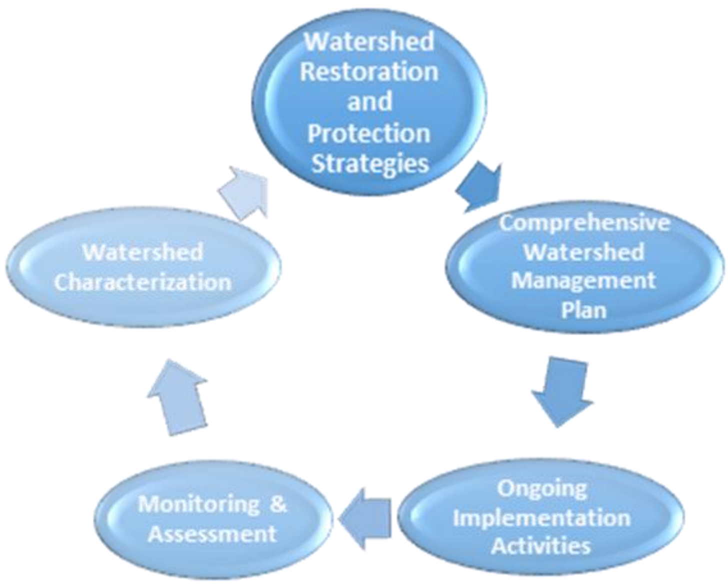

Figure 1-1. Minnesota's Watershed Approach

A watershed model is a tool to aid understanding of processes and consequences of human activities in a river basin, but is only one among a variety of tools. In particular, watershed models are not substitutes for the direct monitoring of physical and biological conditions. When properly calibrated to represent observations, the models can, however, provide a reasonable mechanism for the extrapolation of monitoring data in space (to unmonitored locations) and in time (to unmonitored or future time periods). The watershed model also enables experiments to investigate how changes (such as changes in land use, management practices, or climate) may affect conditions in the watershed and allow stakeholders to plan accordingly. To be useful for these purposes the credibility of the model (and its associated level of uncertainty) must be established through comparison to real world data.

The MPCA and partners are developing WRAPS for major HUC8 watersheds in the state. In northeast Minnesota, due to the unique nature of the urbanized area within and surrounding Duluth, this area will have a separate WRAPS study that will not follow HUC8 watershed boundaries but will include portions of three HUC8 watersheds: Lake Superior South (04010102), St. Louis River (04010201), and Cloquet (04010202) (Figure 1-2.). Tetra Tech has developed HUC12-scale Hydrologic Simulation Program - FORTRAN (HSPF) models for the St. Louis River, Cloquet River, and Lake Superior South watersheds as part of previous projects (Tetra Tech, 2016a; Tetra Tech 2016b; Tetra Tech, 2016c). These models were used primarily to initialize model parameters for the upland and reach simulations. Time series for nitrogen deposition and one meteorological station (Duluth International Airport) were utilized from the other models, and extended through the end of 2016 (the HUC8 models were developed through Water Year 2014).

The Duluth WRAPS modeling project was initiated to provide a finer-scale HSPF model for the developed areas in order to better simulate stormwater and urban conditions in the highly developed environment of Duluth and surrounding areas. In addition, chloride is modeled in this case due to concerns over road salt and its impact on aquatic life in the urban portion of this watershed. This report transmits and describes the hydrologic and water quality calibration of a watershed model of the Duluth WRAPS study area, developed using the HSPF model (Bicknell et al., 2014). Modeling was initially conducted in 2015 – 2016 to support activities for the Duluth WRAPS project. The model was updated in 2019 to extend the simulation period through 2016, incorporate more recent flow and water quality data, and utilize recently published stream geomorphic information.

The modeled area covers approximately 140.6 square miles of St. Louis and Lake Counties in northeast Minnesota, and includes developed areas within Duluth, Hermantown, Proctor, and surrounding rural land (Figure 1-2.). The majority of the study area is composed of small creeks and rivers draining to the St. Louis River estuary (Figure 1-3.) and directly to Lake Superior (Figure 1-4.). A small catchment draining to Wild Rice Lake to the northwest is also included in the model to represent runoff from Duluth International Airport. Larger subwatersheds include (from south to north) Mission Creek, Kingsbury Creek, Keene Creek, Miller Creek, Chester Creek, Tischer Creek, Amity Creek, and Lester River. Fourteen of the named streams in the WRAPS area are designated trout streams: Mission, Stewart, Sargent, Knowlton, Kingsbury, Merritt, Keene, Coffee, Buckingham, Miller, Chester, Tischer, Amity, and Lester. A number of water bodies in the study area are listed as impaired on the 2018 303(d) list (Table 1-1.).

The flood of June 19-20, 2012 is arguably the largest and most catastrophic precipitation event ever recorded in the study area. Rainfall estimates exceeded seven inches over the two-day period, and peak-of-record streamflows were recorded at several USGS gages in the region (Czuba *et al.*, 2012). The flood was exacerbated by soils being saturated by heavy rain during the spring leading up to the storm. Analyses of flow exceedance at gages in the region indicated that the flood recurrence interval ranged from 500 to 1,000 years or greater.

The creeks and rivers in the study area experienced significant channel erosion and bluff collapse as a result of the flood (Fitzpatrick *et al.*, 2016). Headwater streams with gentle slopes in wetland areas were largely unaffected by the flood. However, mainstem channels with entrenched valleys in the middle portion of study area watersheds showed significant changes, including widening, bluff erosion, bank erosion, and lateral migration. Incision was uncommon in most of the middle mainstem reaches. In steep bedrock channels of the middle and lower mainstem, channel expansion was common. In lower mainstem segments (notably those with low slopes), gravel bar formation and aggradation occurred, but bank erosion and widening were also common. While sediment transport rates were very high during flood flows, the supply often exceeded the capacity; as a result, depositional gravel bars formed throughout the study area, notably behind bridge culverts.

One objective of this project was to use the model to characterize conditions in the study area during and following the flood. All model time series were developed or extended through the end of 2016, and water quality monitoring data were gathered through 2016 to allow for post-flood comparison of model results to observations. However, there were not sufficient channel cross section data to create unique representations of channel characteristics before and after the flood. The model does incorporate the 2012 storm and provides predictions of channel sediment transport during the event. These results are discussed further in Section 5.7.

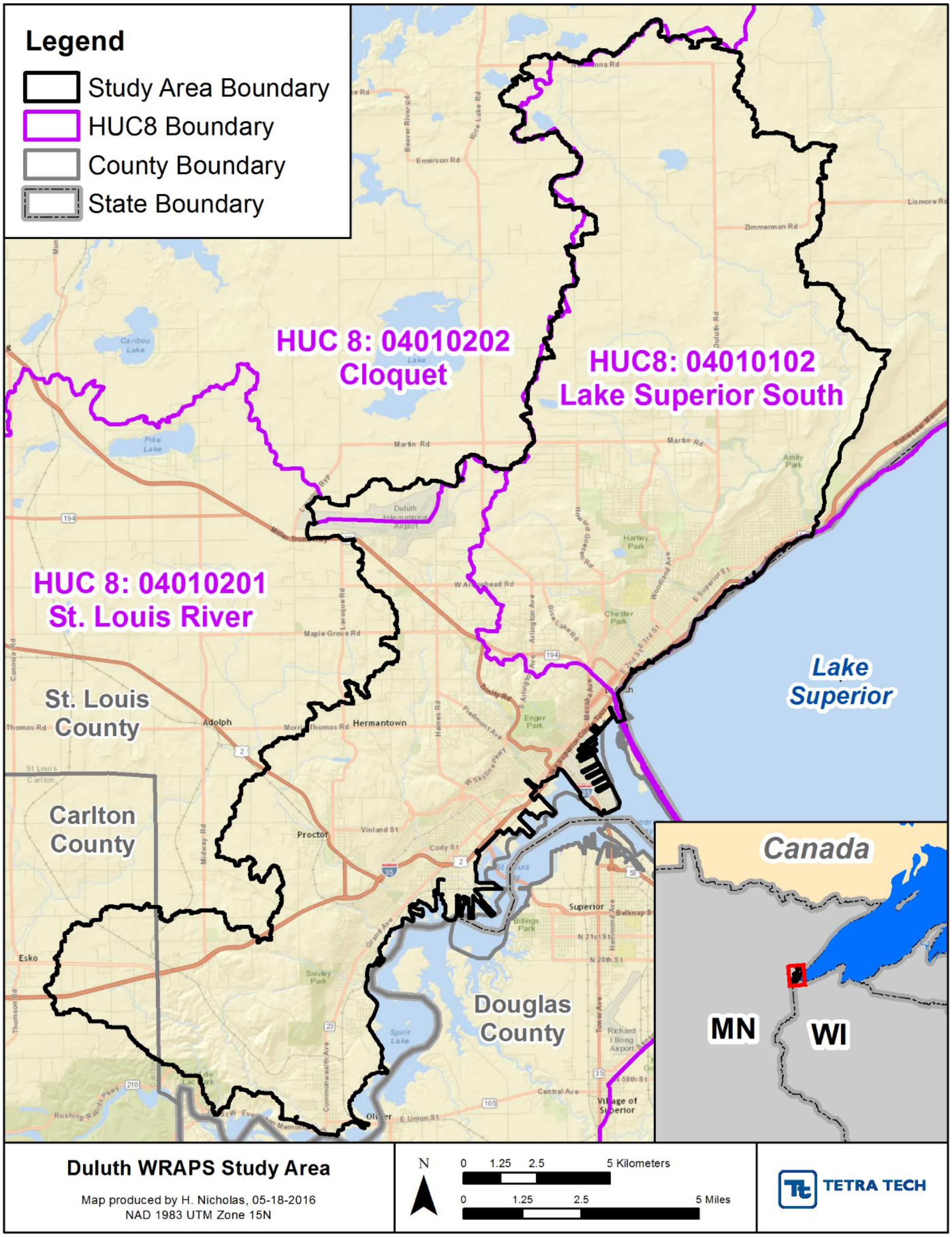

Figure 1-2. Duluth Urban WRAPS Study Area

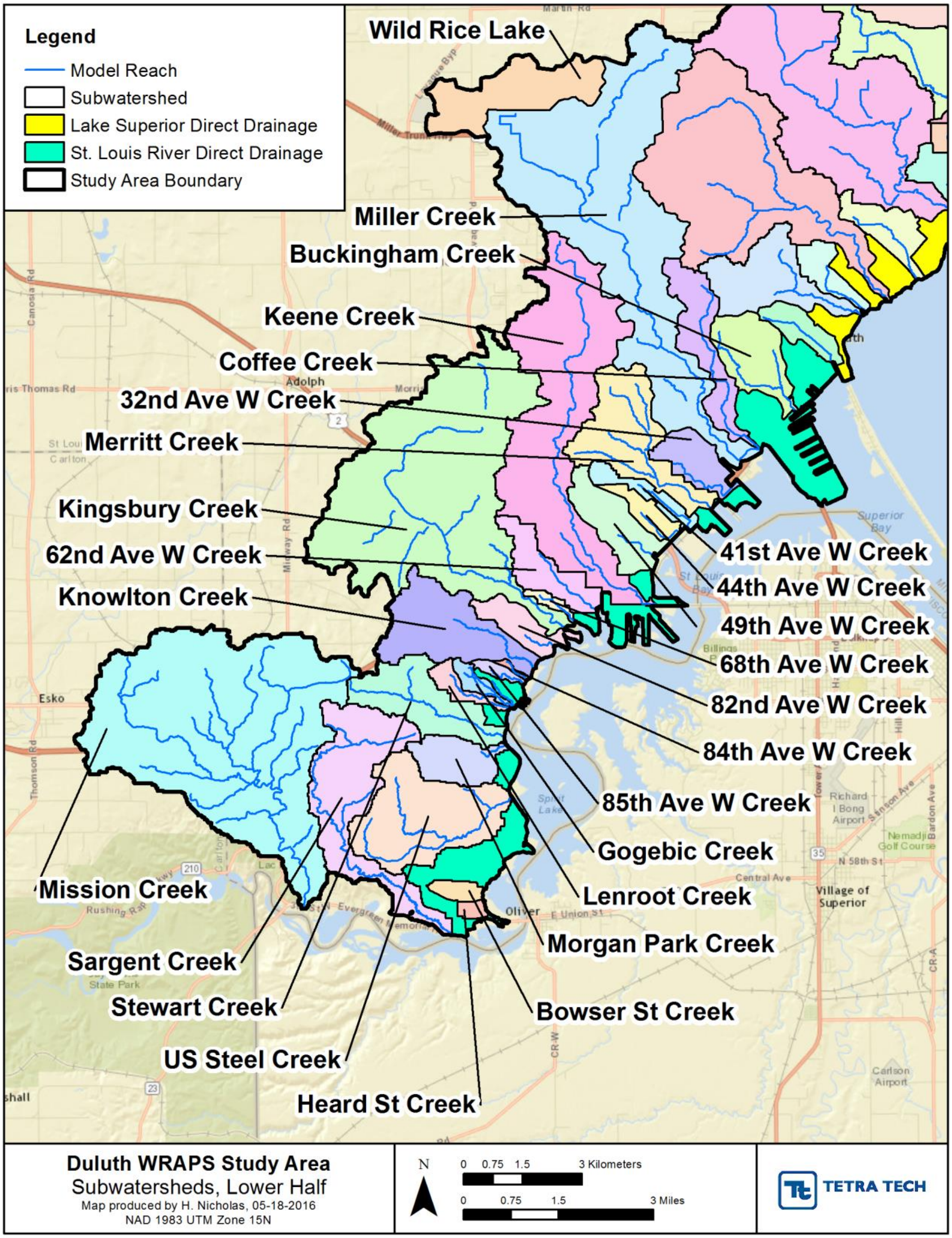

Figure 1-3. Duluth WRAPS Study Area Subwatersheds draining to the St. Louis River Estuary and Wild Rice Lake

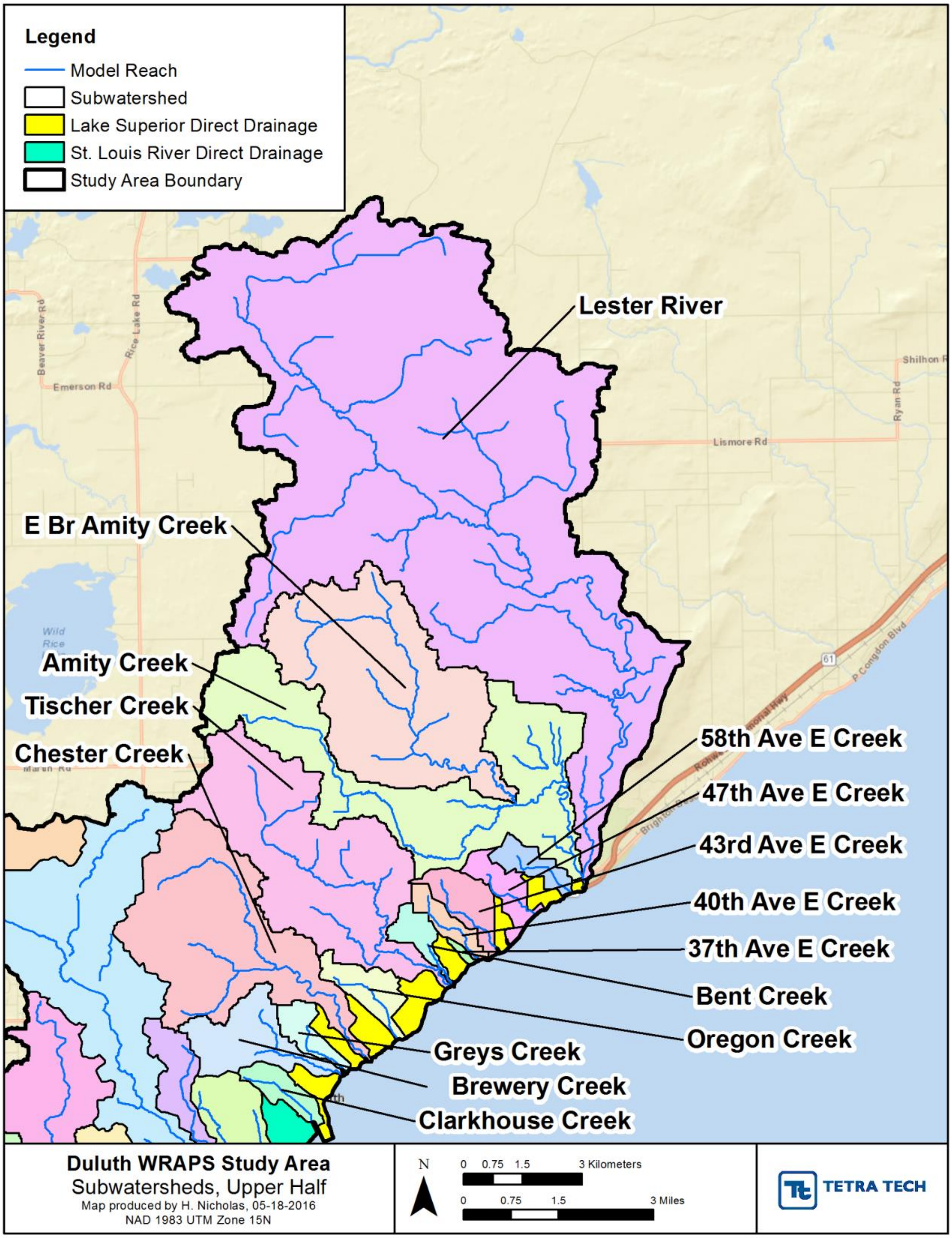

Figure 1-4. Duluth WRAPS Study Area Subwatersheds draining to Lake Superior

Table 1-1. 2018 303(d) Impaired Streams in the Duluth WRAPS Study Area

Stream	AUID	Reach Description	Reach Length (miles)	Impairment Parameter
Amity Creek	04010102-511	Unnamed Cr to Lester R	2.3	Turbidity
Amity Creek, East Branch	04010102-540	Unnamed Cr to Amity Cr	3.6	Turbidity
Tischer Creek	04010102-544	Unnamed Cr to Lk Superior	1.5	*E. coli*
Chester Creek	04010102-545	E Br Chester Cr to Lk Superior	2.7	*E. coli*
Lester River	04010102-548	Headwaters to T52 R14W S14, south line	1.7	Mercury
Lester River	04010102-549	T52 R14W S23, north line to Lk Superior	20.2	Mercury, Turbidity
Miller Creek	04010201-512	Headwaters to St Louis R	9.6	Chloride, *E. coli*, Lack of Cold Water Assemblages, Macroinvertebrate Index of Biotic Integrity, Temperature
Kingsbury Creek	04010201-626	Mogie Lk to St Louis R	6.9	Fish Index of Biotic Integrity, Macroinvertebrate Index of Biotic Integrity
Keene Creek	04010201-627	Headwaters to St Louis R	6.8	*E. coli*
Sargent Creek	04010201-848	Headwaters to St Louis R	6.8	*E. coli*
Stewart Creek	04010201-884	T49 R15W S21, west line to St Louis R	2.8	*E. coli*
Unnamed creek (Merritt Creek)	04010201-987	Unnamed Cr to St Louis R	1.2	*E. coli*

2 Watershed Model Development

The data used to develop the HUC8 models for the St. Louis River, Cloquet River, and Southern Lake Superior watersheds were evaluated in the context of the finer-scale model development planned for the Duluth WRAPS area. Additional, finer-scale data were available to support model development in the Duluth area, as described below. The time period being evaluated with the model is between October 1, 1995 and December 31, 2016. The model initiates the simulation on October 1, 1994, with the first year designated as a spin-up period to allow time for water and pollutant mass storages to reach approximate dynamic equilibrium with inputs. This is done since initial conditions for factors such as soil water storage or pollutant storage on the land surface are not available from observations.

2.1 Upland Representation

The HSPF model for the Duluth Urban WRAPS watershed was set up using a Hydrologic Response Unit (HRU) approach. HSPF requires a basis for distributing hydrologic and water quality parameters to appropriately represent variability throughout the watershed based on land surface and subsurface characteristics. Land unit representation should be sensitive to the features of the landscape including land use, impervious features, soils, and other potential factors. In urban areas, it is important to estimate the division of land use into pervious and impervious components. In rural areas, vegetative cover is more important. In general, the HRU approach holds that landscapes possess an identifiable spatial structure, and that the corresponding patterns of runoff and stream chemistry are strongly influenced by climate, geology, and land use. An HRU is defined as a unit of land with relatively homogenous hydrologic properties determined by its underlying characteristics.

When considering land use and its effect on hydrology and pollutant loading, it is helpful to draw a distinction between land use and land cover. In this report, “land use” refers to how a piece of land is used or managed by its owner. For instance, a group of parcels may be assigned a land use of “single-family residential.” The entire land area is used for human habitation and other typical activities (lawn mowing and fertilization, yards receiving pet waste, etc.). “Land cover,” on the other hand, refers to the type of vegetated or impervious surface present on the land. Areas with single-family residential land use are made up of several land covers, including managed pervious surfaces (lawns, landscaped areas, etc.), impervious surfaces (roofs, driveways, sidewalks, roads), and possibly forest or other natural covers in rural areas. HSPF represents land area as land cover, but the user may differentiate between similar types of surfaces. For instance, impervious surface is often represented with multiple classes (e.g., residential, commercial, industrial). This allows for differences in land use that affect hydrologic and pollutant processes to be represented in the model. Capturing differences in the behavior of land use is especially important in urban areas, such as Duluth. Due to the prevalence of urbanized areas and the need to represent hydrologic and pollutant loading response differently for various types of developed land, HRU development was conducted somewhat differently than typically done for HSPF model development for Minnesota watershed projects.

The HRUs developed for the Duluth WRAPS HSPF model account for land use, land cover, and meteorological inputs (which vary spatially as described in Section 2.2). Several GIS datasets were used to facilitate the best representation of land cover within areas of a defined land use. The primary source was the National Land Cover Dataset for 2011 (NLCD[1]; Jin et al., 2013). NLCD is based on interpretation of satellite imagery at a 30-meter resolution, and is subject to some degree of uncertainty, but is useful for characterizing overall land cover in the study area, especially developed areas. LANDFIRE[2], a national vegetation mapping program that grew out of a need to support fire and fuels

1 http://www.mrlc.gov/nlcd2011.php

2 http://www.landfire.gov/index.php

management planning was used to enhance classification of vegetation types, notably deciduous and evergreen forest. The LANDFIRE Existing Vegetation Cover (EVC) grid was used to distinguish areas that were truly forested versus locations where managed land (such as lawns) were located underneath trees. Aerial photography was reviewed and compared to percent canopy in the EVC data, and a 50 percent or greater canopy cover threshold was found to best represent forested land. The LANDFIRE Existing Vegetation Type (EVT) grid provided supplemental information for identifying agriculture and developed land with minimal infrastructure. Wetland areas in the majority of the study area were identified and classified using a GIS wetlands inventory[3] prepared by the Natural Resources Research Institute (NRRI) of the University of Minnesota, Duluth. NLCD data were used for wetlands classification in the northern part of the watershed outside of the NRRI study area, and the LANDFIRE EVT grid was used to identify a few remaining wetland areas. Rock outcrop locations from the Minnesota Geological Survey[4] were also included in the model land cover, since outcrop areas have greater runoff potential than areas with soil cover. Compiled model land cover is shown in Figure 2-1.. More recent land cover data has become available since the initial models were developed, however, these data are not included in the model at this time.

Land use in the model is based primarily on data provided by the City of Duluth, which included a parcel GIS database and a right-of-way GIS database. The parcel database included a description of the primary land use of each polygon, as well as other information. There were several dozen land use classes, so these were simplified to represent areas that were residential, developed with relatively low intensity uses (e.g., institutional), developed with high intensity uses (primarily commercial and industrial), and areas that were undeveloped. Some residential parcels were found to be undeveloped in aerial photographs, so these were identified where the building value attribute in the database was equal to zero. The right-of-way database included some easements and utility rights-of-way in addition to roads and railways. Platted but undeveloped road rights-of-way were also included. Road and railway rights-of-way were identified and included in the final land use classification used for model development. The area within Carlton County did not have a GIS layer of parcel data available to the public, so it was placed in a temporary class called "Carlton County". Road rights-of-way in Carlton County were identified with a combination of GIS road lines for Carlton County and aerial photos. The remaining areas in Carlton County were classified using NLCD 2011 land cover data. Model land use is shown in Figure 2-2..

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[3] http://gisdata.nrri.umn.edu/GISlab/Duluth_NRI/Wetlands/html/wetl_intro.htm

[4] http://conservancy.umn.edu/handle/11299/57196

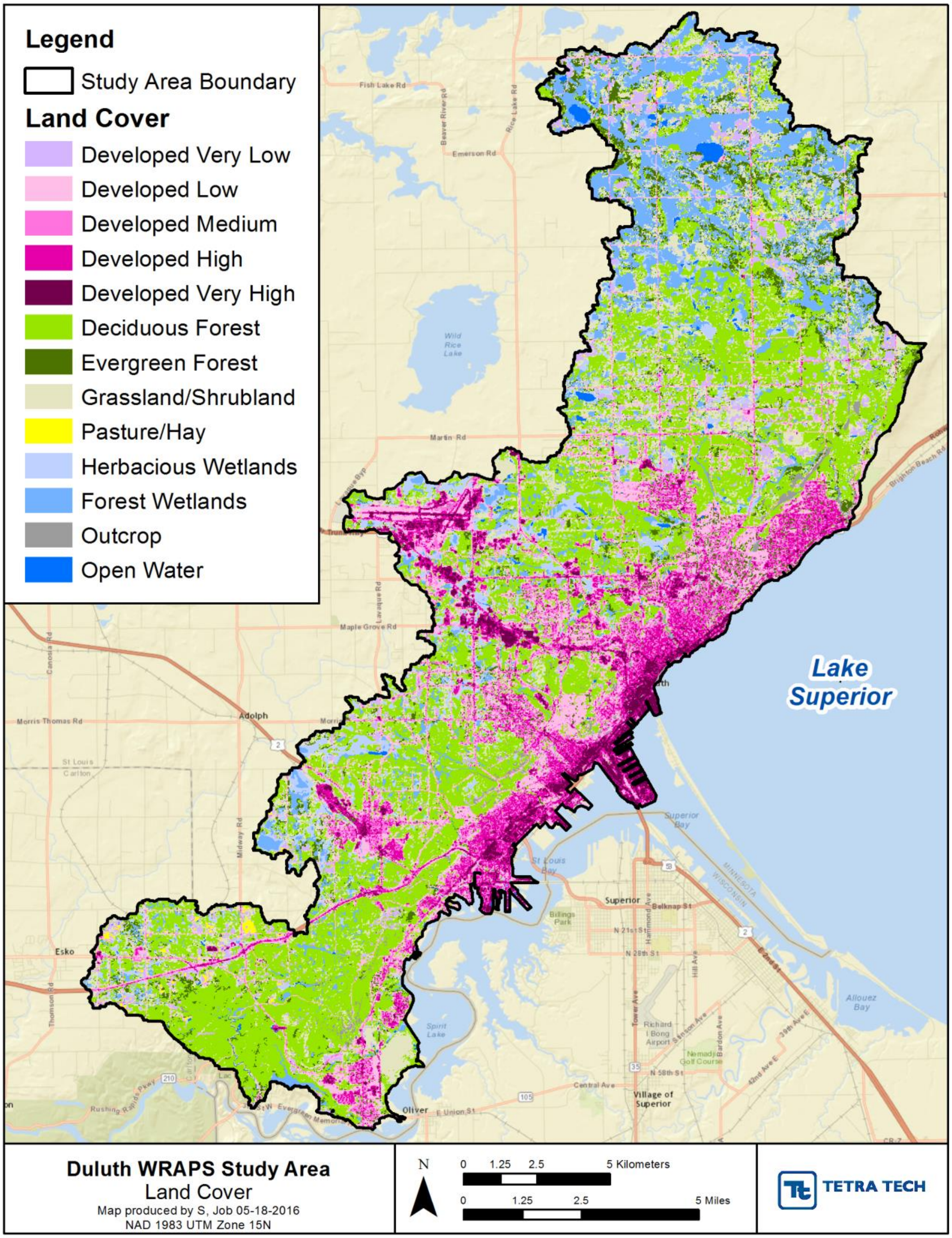

Figure 2-1. Land Cover in the Duluth WRAPS Study Area

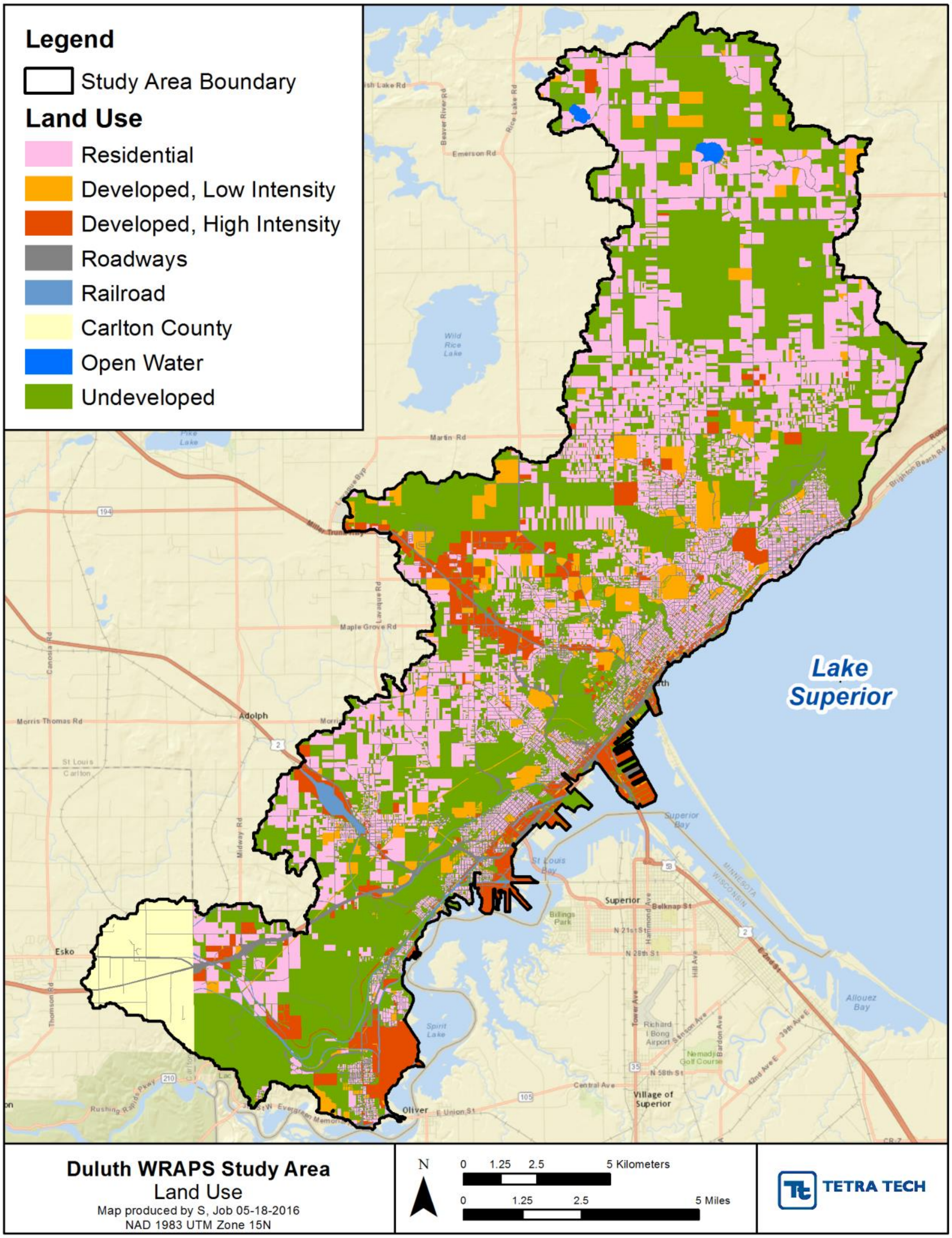

Figure 2-2. Land Use in the Duluth WRAPS Study Area

The land cover and land use GIS classification files shown previously were then overlaid spatially, allowing each area to have a combined land use + land cover assignment. Up to this point, the classification system did not account for impervious surfaces. Using a system that assigned fixed percent impervious values to land use and/or land cover classes would have been problematic in this model, since development density is spatially variable and tends toward higher percent imperviousness as one moves closer to Lake Superior. Impervious area was addressed by using the NLCD 2011 Percent Impervious grid (available at the same location as the NLCD land cover data), which is shown in Figure 2-3.. Percent impervious values from the NLCD grid were assigned to each combined land use + land cover GIS polygon from the previous processing step (outcrop areas were an exception and were assigned a fixed value of 80 percent impervious). Pervious and impervious HRU categories were then assigned to each combined land use + land cover (Table 2-1.). The HRU categories reflect a combination of gradations of developed pervious and impervious uses, as well as undeveloped and agricultural land covers. In some cases the land use and land cover categories were inconsistent (e.g., Open Water + Evergreen Forest). Mostly this is an artifact of the land cover data being based primarily on 30-meter square grid cells, whereas the land use data are based on polygons. These areas are minor fragments that will have little impact on the overall area distribution within each model catchment.

The HRU category area distribution is shown in Table 2-2.. Each model HRU has a three-digit numeric code used within the HSPF model. The first two numbers indicate the HRU category. Weather regions are assigned to HRUs by adding a multiple of 20 to the numeric code, separately for each weather region. The HRUs ultimately reflect a combination of land use, land cover, and meteorological inputs (which vary spatially). Other HSPF models developed for Minnesota watersheds typically include variations in Hydrologic Soil Group (HSG), which provides an index to infiltration capacity. However, as seen in Figure 2-4., the majority of the area where HSG is defined has an HSG of D (note that soils with dual designation are mapped as D since agricultural drainage is not present in the study area). The areas where HSG is undefined reflect urban disturbed soils. The original HSG is not known, but soils in urban areas are usually compacted during development, resulting in limited infiltration potential compared to native soils. As a result, the majority of the study area was assumed to have soils behaving like HSG D. Incorporating HSG in the HRU classification was not needed.

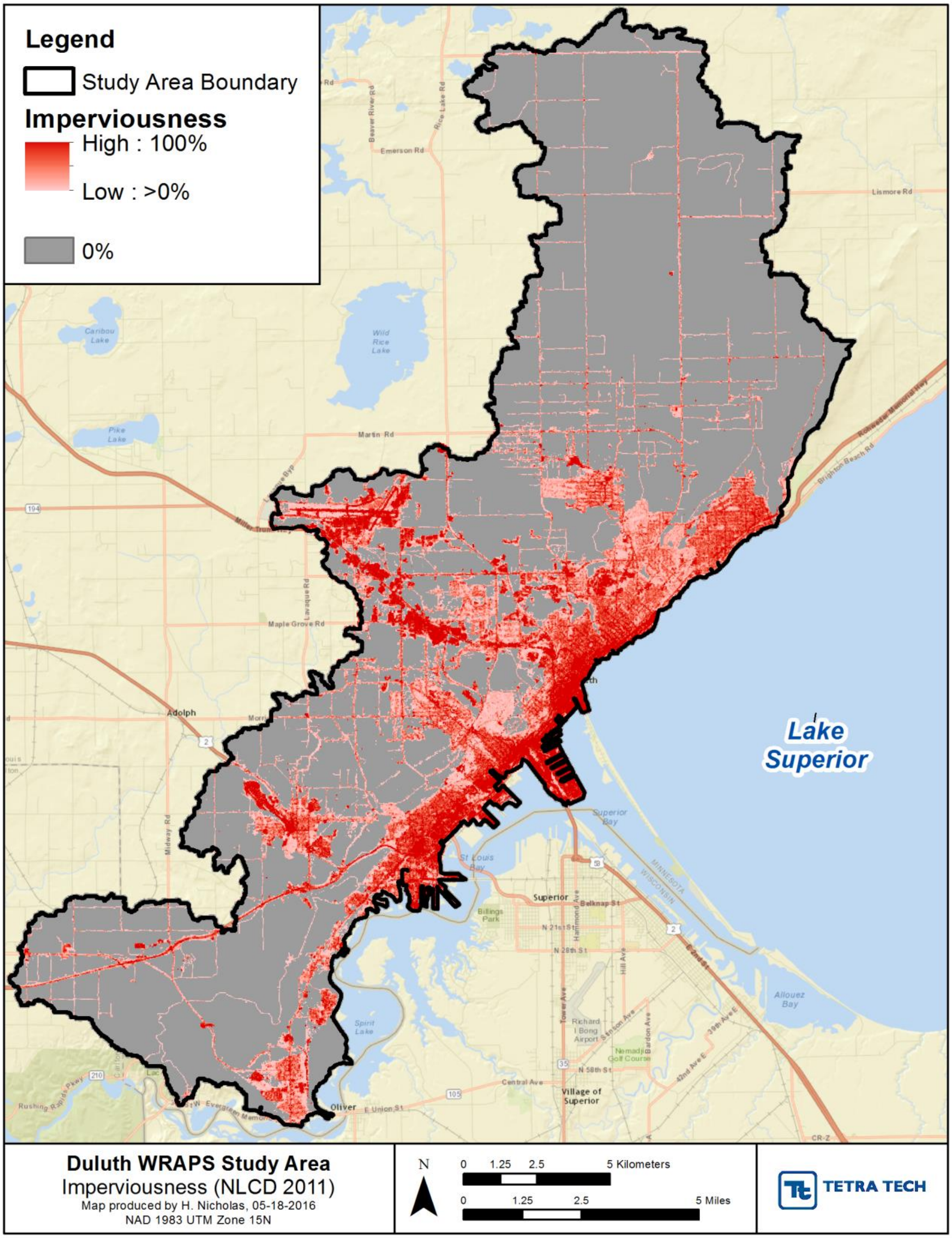

Figure 2-3. NLCD 2011 Percent Impervious Area in the Duluth WRAPS Study Area

Table 2-1. Pervious and Impervious HRU Assignment from Combined Land Use + Land Cover

Combined Land Use + Land Cover	Pervious HRU	Impervious HRU
Carlton County + Deciduous Forest	Deciduous Forest	Imp_Res
Carlton County + Dev_20	Dev_Res	Imp_Res
Carlton County + Dev_21	Dev_Res	Imp_Res
Carlton County + Dev_22	Dev_Res	Imp_Res
Carlton County + Dev_23	Dev_Res	Imp_Res
Carlton County + Dev_24	Dev_High	Imp_High
Carlton County + Evergreen Forest	Evergreen Forest	Imp_Res
Carlton County + Forest Wetlands	Forest Wetlands	N/A
Carlton County + Grassland/Shrubland	Grassland/Shrubland	Imp_Res
Carlton County + Herbaceous Wetlands	Herbaceous Wetlands	N/A
Carlton County + Open Water	Open Water	N/A
Carlton County + Outcrop	Perv_Outcrop	Imp_Outcrop
Carlton County + Pasture/Hay	Pasture/Hay	Imp_Res
Dev High + Deciduous Forest	Deciduous Forest	Imp_High
Dev High + Dev_20	Dev_High	Imp_High
Dev High + Dev_21	Dev_High	Imp_High
Dev High + Dev_22	Dev_High	Imp_High
Dev High + Dev_23	Dev_High	Imp_High
Dev High + Dev_24	Dev_High	Imp_High
Dev High + Evergreen Forest	Evergreen Forest	Imp_High
Dev High + Forest Wetlands	Forest Wetlands	N/A
Dev High + Grassland/Shrubland	Grassland/Shrubland	Imp_High
Dev High + Herbaceous Wetlands	Herbaceous Wetlands	N/A
Dev High + Open Water	Open Water	N/A
Dev High + Outcrop	Perv_Outcrop	Imp_Outcrop
Dev High + Pasture/Hay	Pasture/Hay	Imp_High
Dev Low + Deciduous Forest	Deciduous Forest	Imp_Low
Dev Low + Dev_20	Dev_Low	Imp_Low
Dev Low + Dev_21	Dev_Low	Imp_Low
Dev Low + Dev_22	Dev_Low	Imp_Low
Dev Low + Dev_23	Dev_Low	Imp_Low
Dev Low + Dev_24	Dev_Low	Imp_Low
Dev Low + Evergreen Forest	Evergreen Forest	Imp_Low
Dev Low + Forest Wetlands	Forest Wetlands	N/A
Dev Low + Grassland/Shrubland	Grassland/Shrubland	Imp_Low
Dev Low + Herbaceous Wetlands	Herbaceous Wetlands	N/A
Dev Low + Open Water	Open Water	N/A
Dev Low + Outcrop	Perv_Outcrop	Imp_Outcrop
Dev Low + Pasture/Hay	Pasture/Hay	Imp_Low

Combined Land Use + Land Cover	Pervious HRU	Impervious HRU
Open Water + Dev_21	Open Water	N/A
Open Water + Evergreen Forest	Open Water	N/A
Open Water + Forest Wetlands	Open Water	N/A
Open Water + Grassland/Shrubland	Open Water	N/A
Open Water + Herbaceous Wetlands	Open Water	N/A
Open Water + Open Water	Open Water	N/A
Railroad + Deciduous Forest	Dev_Road	Imp_Road
Railroad + Dev_20	Dev_Road	Imp_Road
Railroad + Dev_21	Dev_Road	Imp_Road
Railroad + Dev_22	Dev_Road	Imp_Road
Railroad + Dev_23	Dev_Road	Imp_Road
Railroad + Dev_24	Dev_Road	Imp_Road
Railroad + Evergreen Forest	Dev_Road	Imp_Road
Railroad + Forest Wetlands	Dev_Road	Imp_Road
Railroad + Grassland/Shrubland	Dev_Road	Imp_Road
Railroad + Herbaceous Wetlands	Dev_Road	Imp_Road
Railroad + Open Water	Dev_Road	Imp_Road
Railroad + Outcrop	Dev_Road	Imp_Road
Railroad + Pasture/Hay	Dev_Road	Imp_Road
Residential + Deciduous Forest	Deciduous Forest	Imp_Res
Residential + Dev_20	Dev_Res	Imp_Res
Residential + Dev_21	Dev_Res	Imp_Res
Residential + Dev_22	Dev_Res	Imp_Res
Residential + Dev_23	Dev_Res	Imp_Res
Residential + Dev_24	Dev_Res	Imp_Res
Residential + Evergreen Forest	Evergreen Forest	Imp_Res
Residential + Forest Wetlands	Forest Wetlands	N/A
Residential + Grassland/Shrubland	Dev_Res	Imp_Res
Residential + Herbaceous Wetlands	Herbaceous Wetlands	N/A
Residential + Open Water	Open Water	N/A
Residential + Outcrop	Perv_Outcrop	Imp_Outcrop
Residential + Pasture/Hay	Pasture/Hay	Imp_Res
Road + Deciduous Forest	Dev_Road	Imp_Road
Road + Dev_20	Dev_Road	Imp_Road
Road + Dev_21	Dev_Road	Imp_Road
Road + Dev_22	Dev_Road	Imp_Road
Road + Dev_23	Dev_Road	Imp_Road
Road + Dev_24	Dev_Road	Imp_Road
Road + Evergreen Forest	Dev_Road	Imp_Road
Road + Forest Wetlands	Dev_Road	Imp_Road

Combined Land Use + Land Cover	Pervious HRU	Impervious HRU
Road + Grassland/Shrubland	Dev_Road	Imp_Road
Road + Herbaceous Wetlands	Dev_Road	Imp_Road
Road + Open Water	Dev_Road	Imp_Road
Road + Outcrop	Dev_Road	Imp_Road
Road + Pasture/Hay	Dev_Road	Imp_Road
Undeveloped + Deciduous Forest	Deciduous Forest	Imp_Res
Undeveloped + Dev_20	Grassland/Shrubland	Imp_Res
Undeveloped + Dev_21	Grassland/Shrubland	Imp_Res
Undeveloped + Dev_22	Dev_Res	Imp_Res
Undeveloped + Dev_23	Dev_Res	Imp_Res
Undeveloped + Dev_24	Dev_High	Imp_High
Undeveloped + Evergreen Forest	Evergreen Forest	Imp_Res
Undeveloped + Forest Wetlands	Forest Wetlands	N/A
Undeveloped + Grassland/Shrubland	Grassland/Shrubland	Imp_Res
Undeveloped + Herbaceous Wetlands	Herbaceous Wetlands	N/A
Undeveloped + Open Water	Open Water	N/A
Undeveloped + Outcrop	Perv_Outcrop	Imp_Outcrop
Undeveloped + Pasture/Hay	Pasture/Hay	Imp_Res

Table 2-2. HRU Code Numbers and Contributing Area in the Duluth WRAPS Model

HRU Code	HRU Description	Area (ac)	Percent
101	Deciduous Forest	28,654	31.9%
102	Evergreen Forest	4,470	5.0%
103	Forest Wetlands	10,486	11.7%
104	Herbaceous Wetlands	3,795	4.2%
105	Open Water	663	0.7%
106	Grassland/Shrubland	11,248	12.5%
107	Perv_Outcrop	154	0.2%
108	Pasture/Hay	287	0.3%
109	Dev_Res	12,561	14.0%
110	Dev_Low	1,354	1.5%
111	Dev_High	1,510	1.7%
112	Dev_Road	5,033	5.6%
115	Imp_Outcrop	616	0.7%
116	Imp_Res	3,514	3.9%
117	Imp_Low	772	0.9%
118	Imp_High	2,165	2.4%
119	Imp_Road	2,681	3.0%

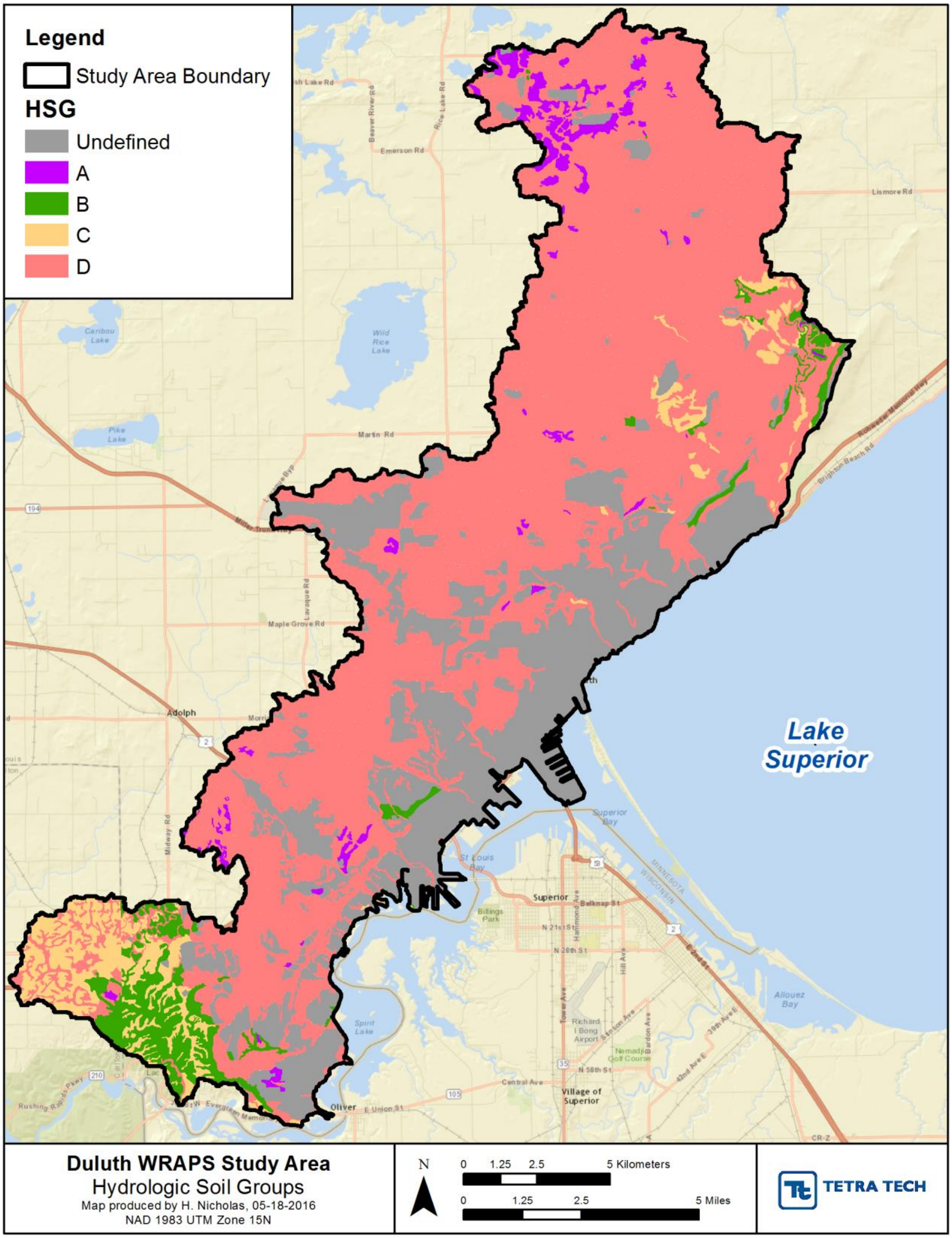

Figure 2-4. Hydrologic Soil Groups in the Duluth WRAPS Study Area

2.2 METEOROLOGY

Weather data are one of the most important inputs for continuous simulation models. The ability of a model to predict hydrologic response and pollutant generation, fate, and transport is strongly influenced by the accuracy and appropriate representation of meteorological data. This is a particularly important issue for a fine-scale model of Duluth streams where there can be substantial variability in micro climate based on elevation and proximity to Lake Superior. Meteorological data required for an HSPF model consists of hourly precipitation (PREC), air temperature (ATEM), cloud cover (CLOU), dew point temperature (DEWP), solar radiation (SOLR), wind speed (WIND) and evapotranspiration (PEVT). Several data sources were reviewed to determine the most optimal way to represent meteorology in the Duluth WRAPS study area:

- Local precipitation data from Western Lake Superior Sanitary District (WLSSD) collected on an hourly basis, generally available beginning in 2002 or 2006
- Daily cooperative observer precipitation data from the Minnesota State Climatology Database (MSCD)
- Meteorological data distributed by the National Climatic Data Center (NCDC)
- Meteorological data produced by the Parameter-elevation Regressions on Independent Slopes Model (PRISM), which provides interpolated gridded data for the entire contiguous United States

The WLSSD data provided a good spatial distribution of stations as well as relatively long monitoring periods. A review of the data did indicate a few issues. Unmonitored periods were not noted in the time series, so there was no way to identify periods of no rainfall from periods needing patching/fill from other sources. The data also contained some outliers, which appear to represent errors of unknown origin.

Previous experience with daily MSCD cooperative observer precipitation suggests that data quality issues are frequent. In addition, there were relatively few stations with long monitoring periods in the watershed. As a result, the MSCD data were screened from further consideration.

For the NCDC data, a considerable amount of daily monitoring of precipitation was concentrated in parts of the study area, but most of the stations were initiated between 2011 and 2014. However, long-term hourly monitoring of all meteorological parameters needed for the model was available only from the Duluth International Airport.

In recent years several gridded meteorological products have been made available which have shown promise for water resources applications. The PRISM Climate Group at Oregon State University maintains a meteorological data set that incorporates observed point data, a digital elevation model (DEM), and expert knowledge of complex climatic extremes (including rain shadows, coastal effects, and temperature inversions). PRISM data are provided at an approximate 4-square-kilometer resolution for the entire contiguous United States and are summarized as daily precipitation totals, and minimum/maximum daily air temperatures. The PRISM approach takes into account elevation and other factors in the spatial interpolation process, so these data are able to better quantify orographic influences and other patterns in ungaged areas. This is important for the Duluth study area, since there are distinct differences in climate as one moves away from Lake Superior. PRISM data are currently being used successfully in the Lake Superior South modeling work, and significantly improved the quality of the simulation in light of changes in precipitation gradients over relatively short distances near the lake shore. The 4x4 km grid cells provide sufficient resolution to represent variable conditions in the study area (36 cells total). A plot of annual and seasonal PRISM precipitation totals in the study area showed a gradient moving from the lakeshore to the higher elevation regions of the study area, which is consistent with local knowledge about precipitation patterns. Another gridded data source, NLDAS (North American Land Data Assimilation System) was considered, but the grid cells are significantly larger (12x12 km) and would not have captured spatial variation in precipitation.

The review of the available data indicated that the best source for precipitation was the gridded daily PRISM data. However, daily totals must to be disaggregated to hourly values for the data to be useful. The best source of hourly precipitation data in the study area is the NCDC station at Duluth International Airport. However, there are spatial variations in precipitation patterns across the study area that cannot be accounted for using a single station. The WLSSD precipitation monitoring network therefore was used to enhance the hourly disaggregation of daily PRISM values. To address the issues identified previously, the WLSSD data were processed as follows:

- Outliers and periods of clear impairment were removed from the datasets.
- Daily gaps in monitoring were identified. As noted previously, it was not known whether these represented gaps or periods with no precipitation. Days with values of zero were compared to the nearest other stations. If any of those stations had data on those days, they were used to fill the gaps.
- Since WLSSD monitoring began in 2002 or 2006 (depending on location), the disaggregation template for the preceding time period was filled using the NCDC Duluth International Airport Station.

The meteorological datasets are presented in Figure 2-5.. The WLSSD and NCDC hourly data stations are shown as green triangles. PRISM grid cells are shown with red outline, and are color-coded according to their assignment to hourly disaggregation source. The grid cell assignment is largely influenced by distance from the lake. Daily precipitation in each PRISM grid cell was disaggregated to hourly values using the assigned hourly station, with temporal adjustments to account for time zone differences between local data and PRISM (which uses 1200 UTC as the beginning of its day). Unique hourly precipitation time series were developed for each of the 36 PRISM grid cells as a result. For modeling purposes, each grid cell was assigned its PRISM code as the "weather region" identifier used in input files and subsequent documentation. The weather region IDs are shown within each cell in the figure.

PRISM also provides daily minimum and maximum air temperature. Long-term hourly air temperature data were only available from the NCDC station at Duluth International Airport, so that station was used to develop the hourly air temperature pattern for each grid cell. Other meteorological time series (cloud cover, dew point temperature, solar radiation, and wind speed) were available from the Duluth Airport station and were used for the entire modeling area. These are less likely to vary over short distances than precipitation and air temperature, and they also have less of an influence on the model simulation. The remaining parameter, potential evapotranspiration (PET), is important to the simulation. PET was estimated uniquely for each of the 36 weather regions using the Penman Pan method (Penman, 1948; Kohler et al, 1955), which includes air temperature, dew point/humidity, solar radiation, and wind travel as inputs. PRISM air temperature series were used in the calculation of PET, allowing for spatial variation.

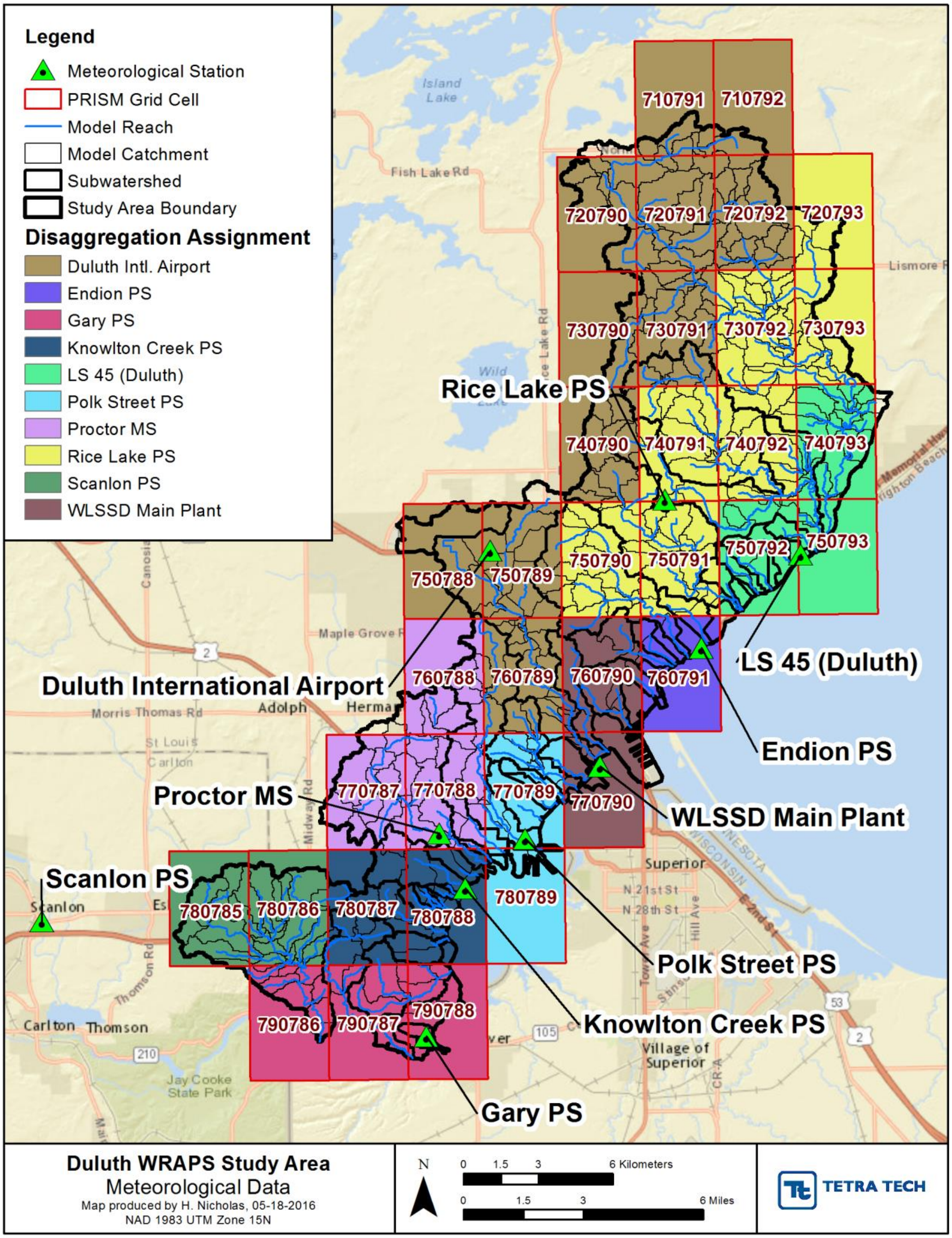

Figure 2-5. Meteorological Data Sources Used for Duluth WRAPS HSPF Model

2.3 Model Segmentation and Reach Network

2.3.1 Subbasin Delineation

Subwatersheds in the study area (as shown in Figure 1-3. and Figure 1-4.) were initially based on previously delineated watersheds in the Lake Superior South, St. Louis, and Cloquet HSPF models. The subwatersheds were further refined to provide a finer-scale resolution using storm sewer catchments provided by the City of Duluth and stormwater information from the city of Hermantown. MNDNR level 8 and 9 catchments along with LiDAR elevation data were also used to further refine model watershed boundaries, hereafter referred to as catchments.

Finally, each model catchment was evaluated to create smaller catchments for the model based on locations of flow and water quality monitoring stations (see Section 3.1), topographic changes above and below the ridgeline, and impaired waters. The model catchments delineated for the Duluth WRAPS HSPF model are shown in Figure 2-7., Figure 2-8., and Figure 2-9..

2.3.2 Reach Delineation

Three different GIS layers were used to create model reaches for representation of in-stream processes explicitly modeled in HSPF. These model reaches were created from the City of Duluth's storm sewer network, the City of Duluth's mapped streams, and the National Hydrography Dataset (NHD) High-version (Figure 2-6.). Primacy was given to the two City GIS layers, while the NHD data set was used for model reaches that had no coverage from the two City GIS layers. A "main-stem" reach was identified for each model catchment that contained any length of one or more of these three different GIS layers.

In several cases, there were model catchments without a reach (no mapped streamline). Additionally, there were several model catchments with reach lengths that would have been too short for HSPF to accurately model hydraulics. When this occurred, the reach was extended across multiple catchments. These cases (reaches missing, or reaches being too short in length) were addressed in one of two ways:

1. Reach lengths that were too short were aggregated with up and/or downstream reaches to achieve desired minimum lengths. The aggregated reach length was associated with one of the associated model catchments whereas the other catchment(s) were modeled without a reach (i.e., upland contributions were routed to the appropriate downstream model reach).
2. Some short reaches were removed and upland flow was routed to an appropriate downstream reach. This was most often done in situations where the short reach length was found in a headwater catchment and also applies to situations where a headwater reach had no mapped streamline.

An HSPF model typically has a unique reach for each catchment or subbasin, but the result of the reach delineation process led to a model where many catchments had no reaches, and multiple catchments potentially drain to one reach. This was done to preserve the fine-scale catchment boundaries from the City's stormwater data. Reach locations are shown in Figure 2-7., Figure 2-8., and Figure 2-9.. Geomorphic class of each reach is discussed in the next subsection.

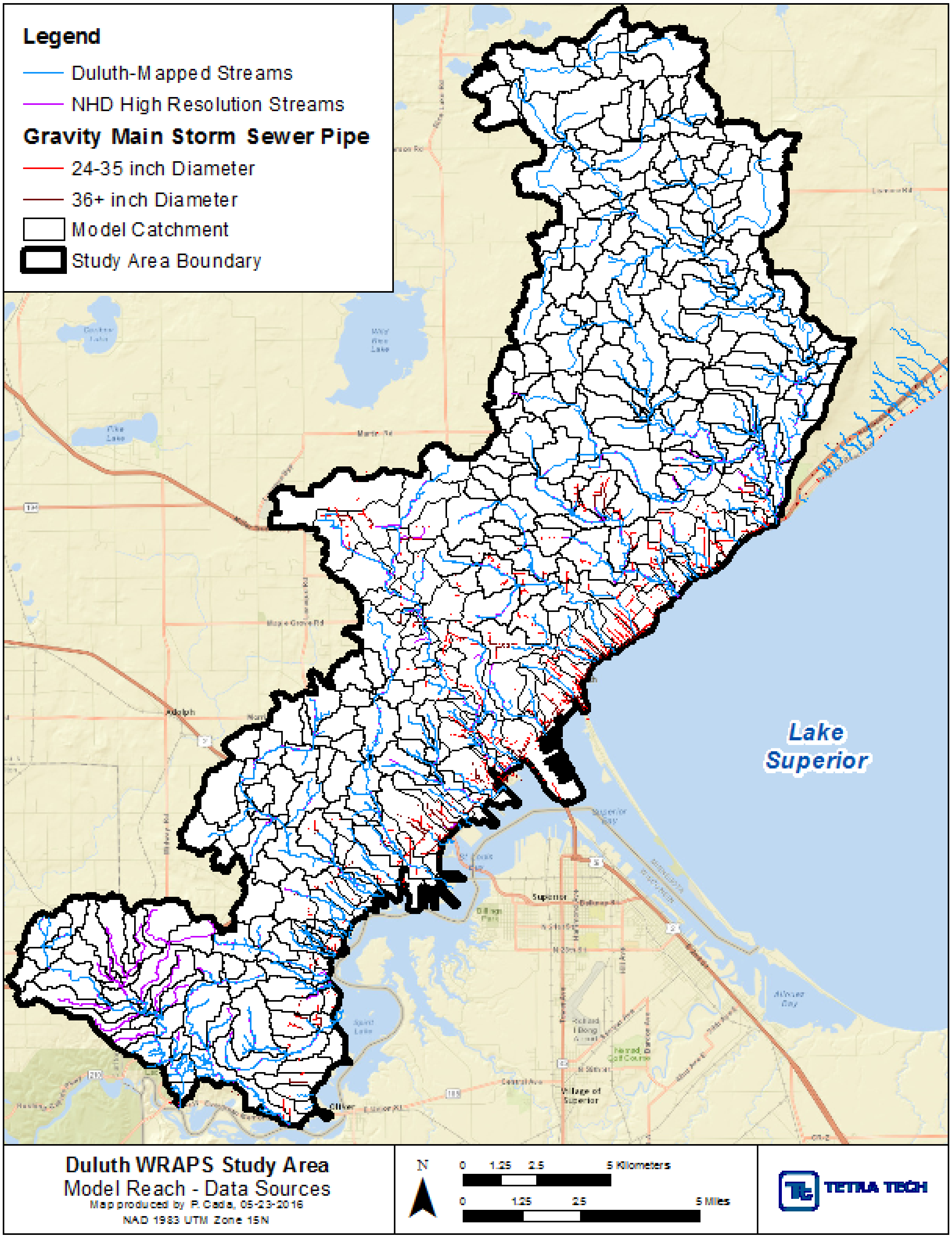

Figure 2-6. Data Sources for Model Reach Locations in the Duluth WRAPS Study Area

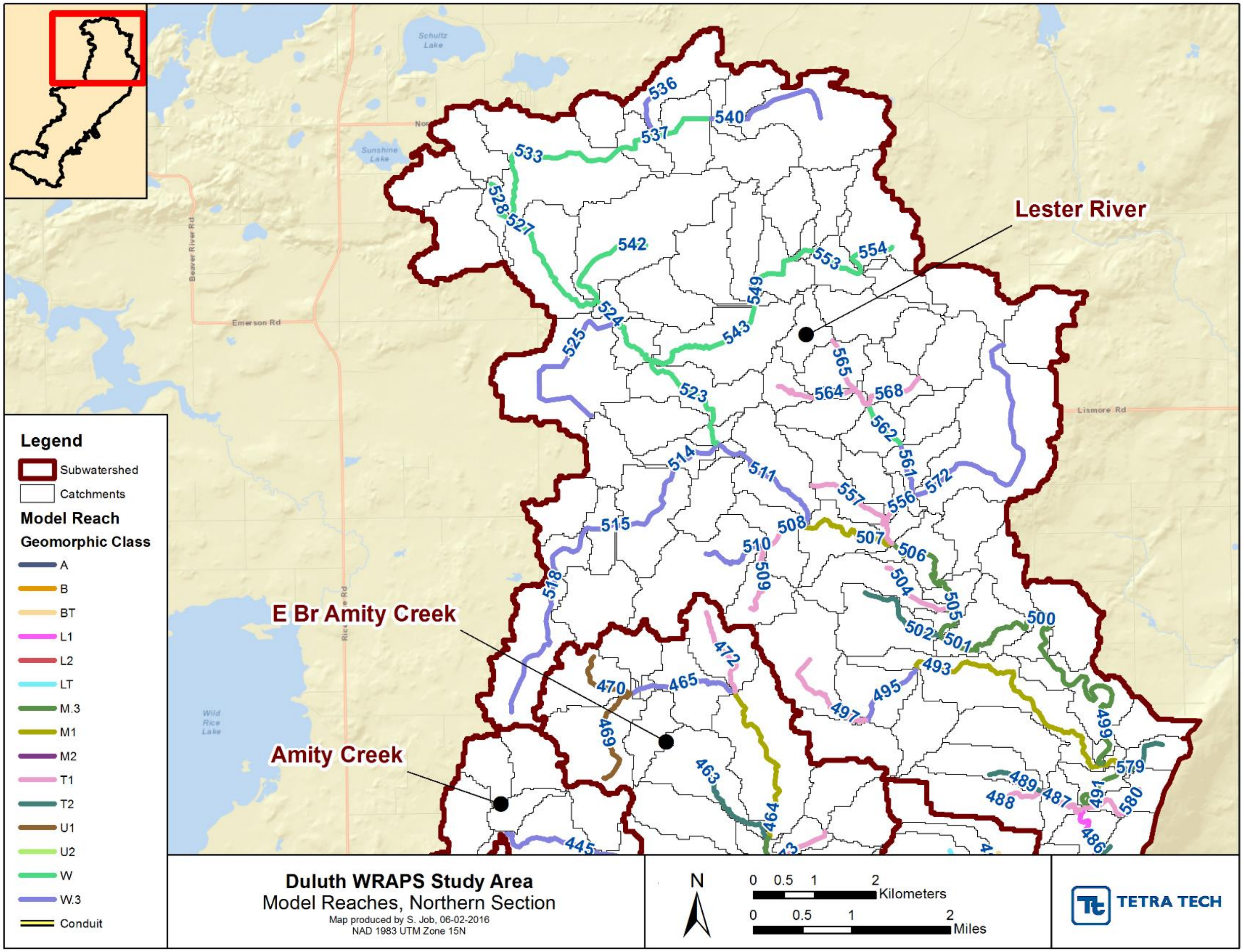

Figure 2-7. HSPF Catchments and Reaches in the Northern Portion of the Study Area

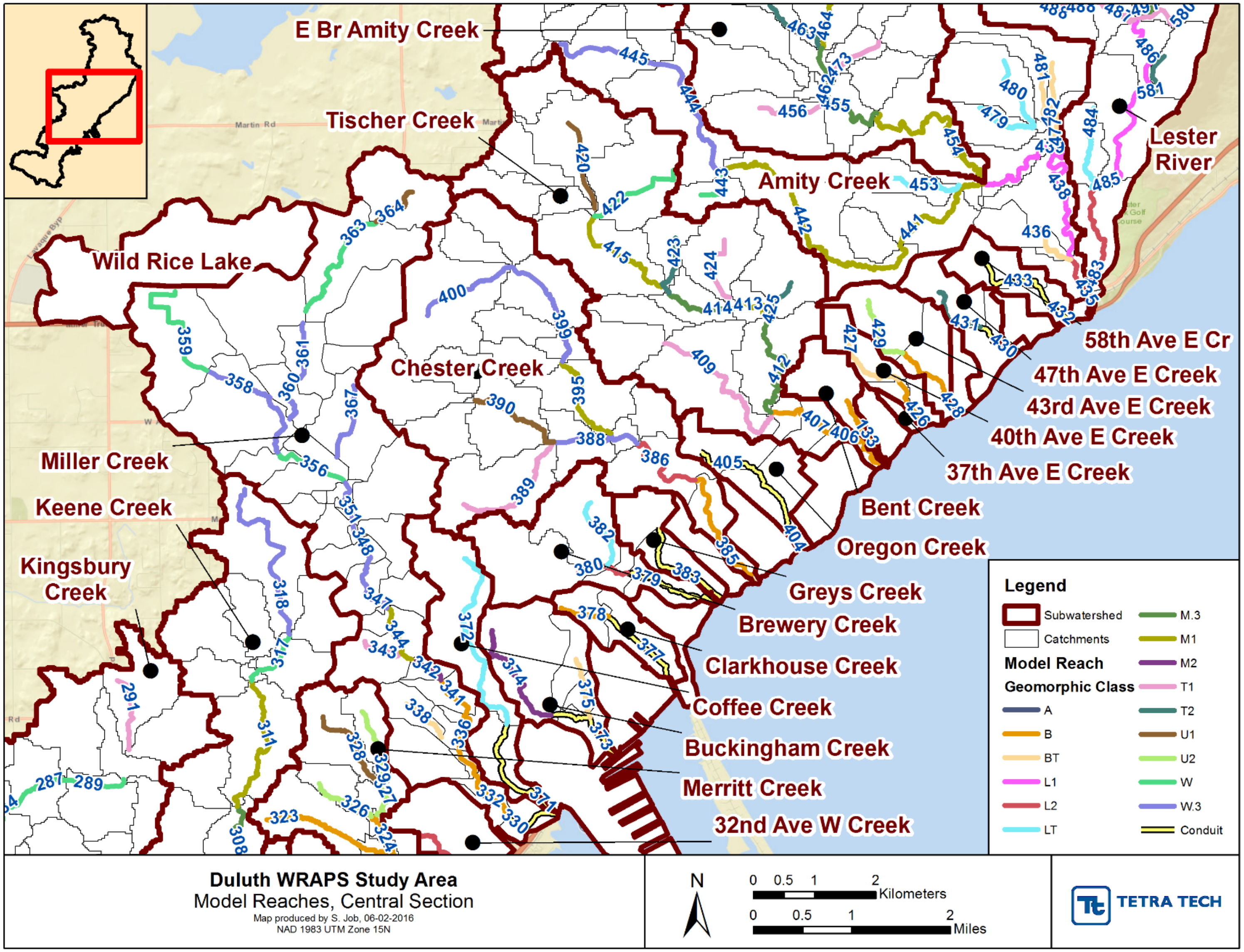

Figure 2-8. HSPF Catchments and Reaches in the Central Portion of the Study Area

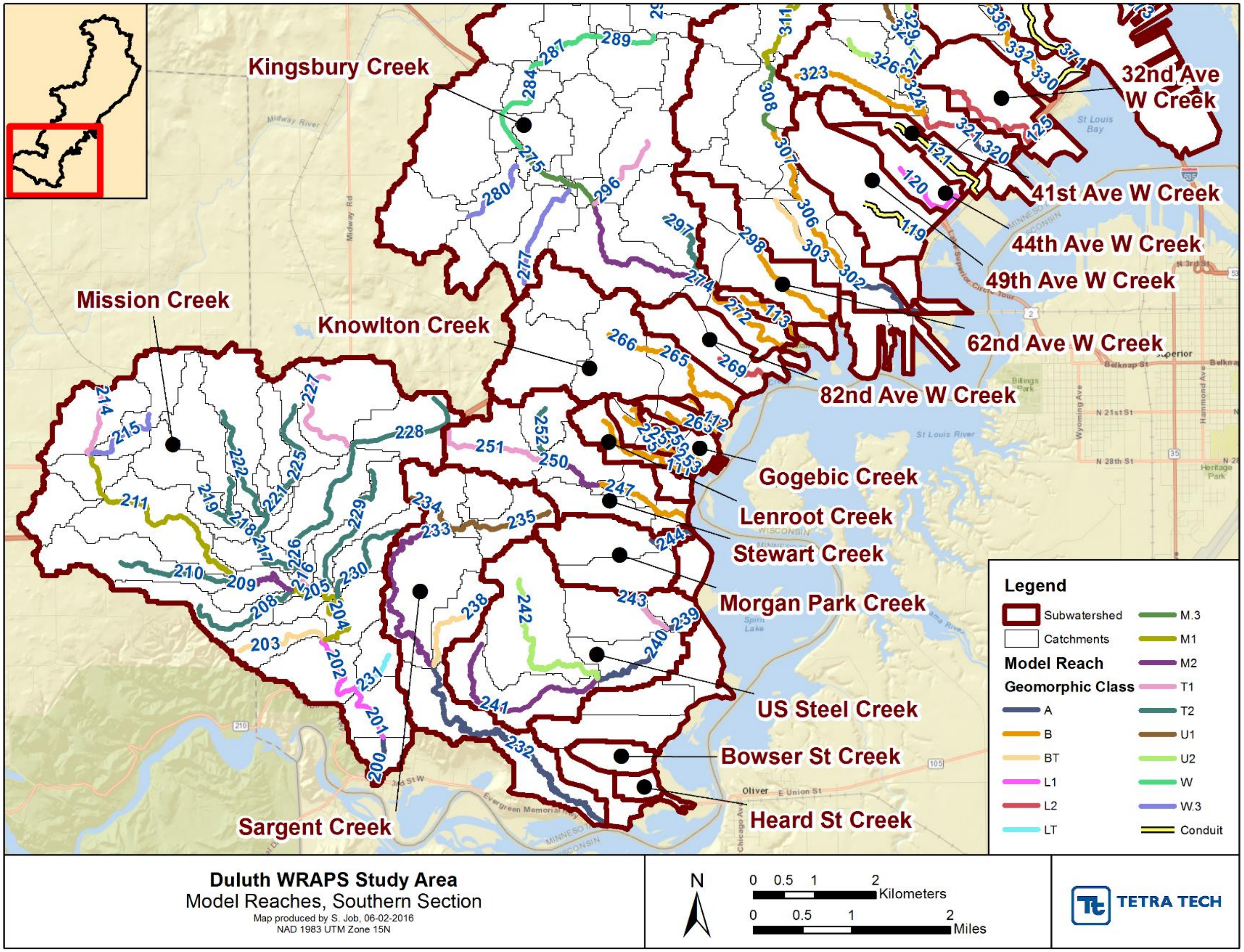

Figure 2-9. HSPF Catchments and Reaches in the Southern Portion of the Study Area

2.3.3 Reach Hydraulics

HSPF is a water balance (hydrologic) model and not a hydraulic model. HSPF represents stream reaches as one-dimensional fully mixed reactors and, while maintaining mass balance, does not explicitly conserve momentum. To simulate the details of hydrograph response to storm events HSPF relies on Functional Tables (FTables) that describe the relationship of reach discharge, depth, and surface area to storage volume. At stable median flow conditions, the model results are not particularly sensitive to the details of the FTable specification, as outflow tends to approximate the net inflows; however, the shape of the response to storm event peaks can be highly sensitive to FTable details. Given the interest of MNDNR in evaluating the distribution of flows in streams in Minnesota there is an increasing need to refine HSPF basin-scale model FTables.

By default, the BASINS version of HSPF estimates FTables by applying predetermined regressions against drainage area. A double-trapezoidal shape is assumed, with the lower trapezoid representing the channel and the upper trapezoid representing the floodplain. Key geometry parameters are estimated using the regressions, and the other geometry parameters are calculated using fixed multipliers based on typical channel shapes. However, other methods of FTable development are advantageous when local data are available, such as rating curves or cross sections. In the Duluth WRAPS study area, rating curves that included channel dimension were not available. However, a significant amount of cross-section data was available throughout the study area, including:

- USGS collected extensive cross section data in 2003 and again in 2013 following the June 2012 flood
- MNDNR collected cross section data at select locations in 2015
- MPCA collected cross section data from three locations (date not reported)
- South St. Louis Soil and Water Conservation District collected cross section data at several locations between 2013 and 2015

In concert with the stream data collection effort in 2003, USGS published an extensive report on the geomorphic characteristics and classification of streams in the WRAPS study area (Fitzpatrick *et al.*, 2006), and updated their findings following the 2012 flood (Fitzpatrick *et al.*, 2016). The reports included a classification system for characterizing the streams, based primarily on drainage network position and slope, and secondarily on geologic setting, valley type, and dominant geomorphic processes. Table 2-3. provides the geomorphic classes and most relevant characteristics for model development. Geomorphic class was used to support parameterization of the reach sediment modeling, which is discussed further in Section 5.4. In addition, geomorphic class was used as the basis for developing model FTables. Geomorphic class for each reach is shown in Figure 2-7., Figure 2-8., and Figure 2-9..

The FTable approach used in the Duluth WRAPS model assumes that each geomorphic class possesses a typical channel profile and characteristic cross-section. The geomorphic classification provides a framework for separating the most important characteristics that contribute to cross section profile. Watershed position (upper, middle lower) not only provides some scaling to upstream contributing area, but is also (to some extent) a good proxy for geology and valley type. Upper reaches tend to have low slopes with minimal floodplain development and are strongly association with wetlands. Middle reaches have greater slopes and entrenched valleys with some floodplain development. Reaches constrained by bedrock are included in the classification, as well as lower mainstem reaches with low slopes where alluvial processes are stronger.

The following process was therefore used to develop model FTables for natural channels:

1. Each reach was assigned a geomorphic class based on the methods discussed in Fitzpatrick *et al.* (2006), incorporating reach slope and watershed position.

2. Using the field cross-section data discussed above, a representative cross section was selected for each geomorphic class. Cross sections were extended into the floodplain and beyond using a high-resolution DEM from LIDAR data.
3. The USDA WinXSPRO application (Hardy *et al*., 2005) was used to produce relationships between stage, discharge, top width, and cross-sectional area for each geomorphic class cross section. Channel Manning's n values were based on Chow (1959) and incorporated channel and floodplain conditions described in Fitzpatrick *et al.* (2006). The upstream contributing area to the cross-section location was recorded.
4. FTables were then calculated separately for each set of reaches belonging to a geomorphic class. The WinXSPRO outputs for each cross section/geomorphic class were used to produce FTables for all of its geomorphic class members.
    a. For each model reach, the discharge volume, top width, and cross-sectional area were assumed to be proportional to the ratio of upstream contributing areas (model reach contributing area over cross section contributing area from Step 3).
    b. Reach length was used with top width and cross-sectional area to calculate reach surface area and volume, respectively.

Fourteen model reaches had 50 percent or greater of their lengths contained in stormwater conveyance conduits, which have significantly different hydraulic properties than natural channels. The City's stormwater GIS data provided pipe diameters for each of these reaches. The FTables for these reaches were developed using the USEPA Gray Infrastructure Tool[1], an online FTable calculator for various man-made conveyances. These reaches are identified as "Conduit" in Figure 2-8. and Figure 2-9..

There are no significant lakes or reservoirs in the study area, so no special representation of lake conditions was needed in the model.

Table 2-3. Geomorphic Class Definitions

Geomorphic Class	Slope Range	Description	Dominant Geomorphic Process	Potential Sensitivity to Disturbance
W	<0.3	Wetland very low slope	Stable	Low/moderate
W.3	0.3 - 1	Wetland low slope	Stable	Moderate
U1	1 - 2	Upper mainstem moderate slope	Incision, bank erosion	High
U2	2 - 4	Upper mainstem high slope	Incision, bank erosion, bluff erosion	Moderate
M.3	0.3 - 1	Middle mainstem low slope	Bank erosion, bluff erosion (lower risk)	Moderate/high
M1	1 - 2	Middle mainstem moderate slope	Bank erosion, bluff erosion	Moderate/high
M2	2 - 4	Middle mainstem high slope	Bank erosion, bluff erosion	Moderate/high
A	0.3 - 1	Lower mainstem low slope	Aggradation	Low
L1	1 - 2	Lower mainstem moderate slope	Stable	Low/moderate
L2	2 - 4	Lower mainstem high slope	Bank erosion (lower risk)	Low/moderate

[1] https://www3.epa.gov/ceampubl/HSPFWebTools/gray/index.html

Geomorphic Class	Slope Range	Description	Dominant Geomorphic Process	Potential Sensitivity to Disturbance
B	4 - 8+	Bedrock mainstem very high slope	Bluff erosion	Low
T1	1 - 2	Upper/middle tributary moderate slope	Incision, bank erosion, gully erosion	Moderate/high
T2	2 - 4	Upper/middle tributary high slope	Incision, bank erosion, gully erosion	Moderate/high
LT	2 - 4	Lower tributary high slope	Incision, bank erosion, gully erosion	Moderate/high
BT	4 - 8+	Bedrock tributary very high slope	Gully erosion	Moderate

2.4 Point Sources

There are no major point sources that discharge to water bodies within the Duluth WRAPS study area. The Western Lake Superior Sanitary District water treatment plant is located on the Duluth Harbor and treats wastewater from Duluth and the surrounding region, but it discharges directly to the St. Louis Estuary which is not part of the model. There are some properties with industrial stormwater permits (notably Duluth International Airport and Miller Hill Mall), but discharges from these facilities are accounted for implicitly in the HSPF representation of storm runoff.

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3 Model Calibration and Validation Approach

3.1 FLOW AND WATER QUALITY DATA

3.1.1 Flow Gaging Data

There are several gages with continuous daily flow records in the Duluth WRAPS watershed for the model simulation period (10/1/1995 – 12/31/2016). Flow data for each gage operated by MNDNR or MPCA were obtained from the HYDSTRA database. Additional earlier daily flow records for Miller Creek were obtained from the St. Anthony Falls Laboratory (SAFL) at the University of Minnesota. Field measurements of flow have also been collected by various agencies but were not used for this project since the records were not continuous.

In addition, continuous 15-minute stage data were available from the Duluth Streams program. Flow values were also reported, but the stage-flow rating curves were developed in 2003 using only a few stage-flow field measurements (personal communication from Jerry Henneck, NRRI to Scott Job, Tetra Tech, April 5, 2016), which did not take into account conditions across the full range of flows. However, additional stage-flow field measurements were taken by NRRI at most of the sites, so these were used to develop revised rating curves. In addition, the stage data were screened to remove impaired monitoring periods. Data processing and rating curve development are discussed further below.

3.1.1.1 Duluth Streams Stage Processing and Rating Curve Development

Standard rating curves follow the form given by this equation (Sauer, 2001):

$$Y = a + b(X - e)^c$$

where

Y = discharge
X = gage height
a = equation constant (usually zero)
b = multiplier
e = scale offset (used to shift rating curve
c = exponent

Amity Creek at Occidental Blvd. This station is co-located with the HYDSTRA gage. The Duluth Streams data span approximately the same time period as the HYDSTRA data. As shown in narrative records for this site, MNDNR makes frequent adjustments to the rating curve and provides assessments of data quality. Since a high-quality alternate data set was available for this location, a rating curve was not developed for the Duluth Streams stage data.

Miller Creek at Lake Superior College. Monitoring was conducted intermittently, and the periods were always brief. Only a handful of field measurements were available for rating curve development. Other continuous flow records are available for Miller Creek, so no data processing or rating curve development was performed.

Chester Creek at College of St. Scholastica. Stage was monitored from summer 2002 to present. However, there were multiple challenges for developing a rating curve. The sonde was moved during 2006; there were not enough field measurements to develop a rating curve prior to that time. For the remaining field measurements, a plot of flow versus stage revealed a significant change in the relationship following the 2012 flood, indicating a need to develop separate rating curves (Figure 3-1.). A usable rating curve could not be developed from the 2006 – 2012 pre-flood data because a) there was only one high flow measurement, resulting in considerable uncertainty in the higher flow portion of the rating curve, and b) the low flow measurements have a high degree of scatter, suggesting changes in bed depth over time.

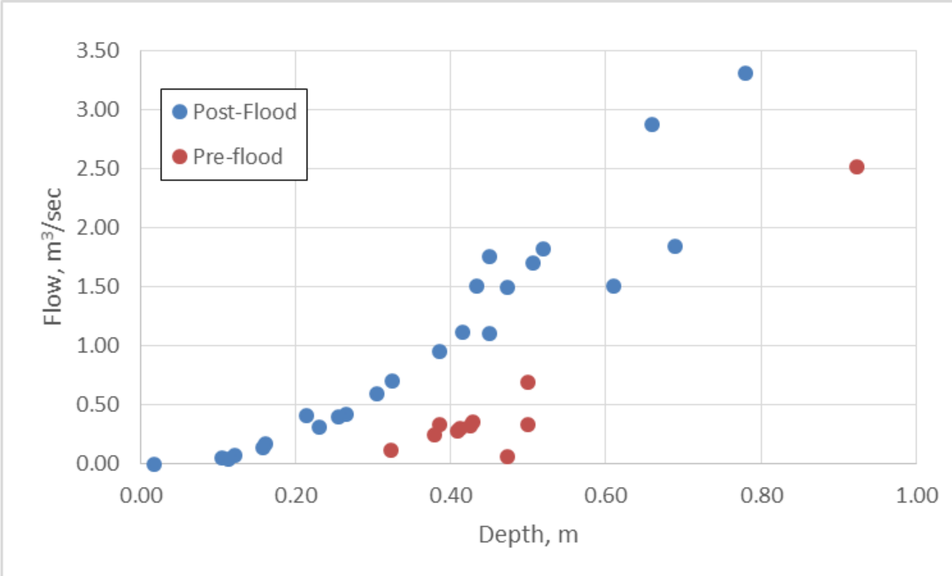

Figure 3-1. Chester Creek Field Measurements Pre- and Post-flood

A rating curve was developed minimizing error in log flow and log depth (a = 0, b = 6.1143, c = 2.0195, and e = 0). Next, the stage record was reviewed to remove periods of impairment (unstable readings indicating periods of ice-in or possible malfunction). Much of the data was censored as a result. Flow values were then calculated using the rating curve and plotted. An examination of the flow time series showed a pattern – flows between May 2013 and April 2014 were consistently an order of magnitude higher than flows for the rest of 2014 and 2015, even during similar seasons. There were insufficient flows remaining (as well as questions about the quality of the rating curve), so Chester Creek was removed from consideration for model calibration.

Kingsbury Creek at Lake Superior Zoo. Stage was monitored from summer 2002 to present. An examination of the stage time series revealed considerable impairment following the 2012 flood, with extended periods of negative stage recorded. As a result, the development of a rating curve focused on pre-flood field measurements, and was subsequently used to estimate flows up to the date of the flood. Fourteen measurements of stage and flow were taken between April 2002 and June 2012 prior to the flood. A rating curve was developed minimizing error in log flow and log depth (a = 0, b = 9.3522, c = 2.7239, and e = 0.18), which is shown in Figure 3-2.. Only one data point in excess of 3 m^3/s (about 100 cfs) was available, so the rating curve may have a large degree of error for representing high flows. In addition, no field measurements were taken from fall 2007 to spring 2011.

The pre-flood stage record was reviewed to remove periods of impairment. Periods of likely ice-in and some outliers were censored from the stage data. Flow was calculated from stage using the rating curve, and the 15-minute flows were then averaged into daily values. Daily flows were subsequently used for model calibration.

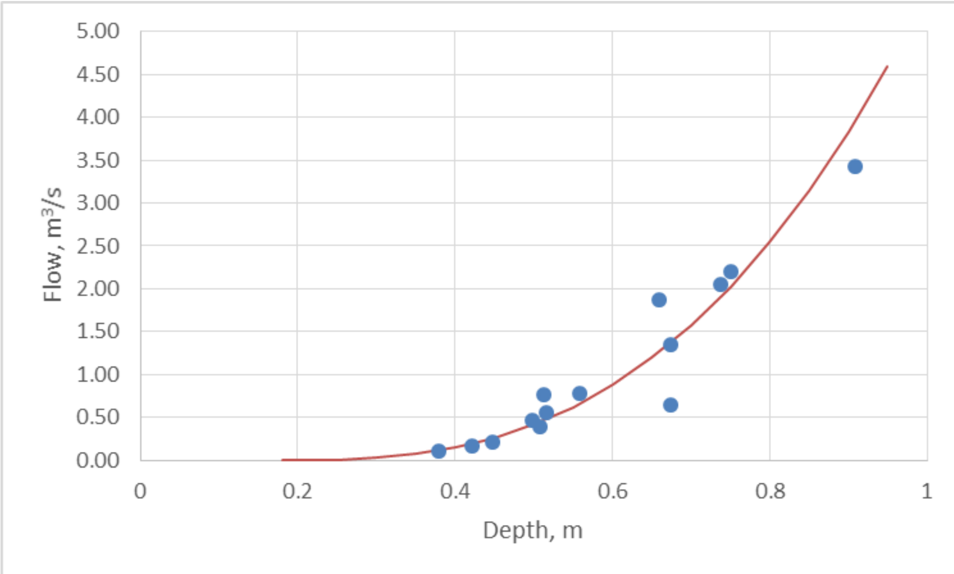

Figure 3-2. Kingsbury Creek Field Measurements and Flow Rating Curve

Tischer Creek at Wallace Ave. Stage was monitored from summer 2002 to present. An examination of the stage time series revealed considerable impairment following the 2012 flood, with periods of negative stage recorded, periods of erratic stage measurements, and changes in the stage associated with low flows (suggesting shifts in bed elevation). As a result, the development of a rating curve focused on pre-flood field measurements, and was subsequently used to estimate flows up to the date of the flood. Twelve measurements of stage and flow were taken between May 2003 and June 2012 prior to the flood. A rating curve was developed minimizing error in log flow and log depth (a = 0, b = 6.2444, c = 1.8915, and e = 0.10), which is shown in Figure 3-3.. Only one data point in excess of 2 m^3/s (about 70 cfs) was available, so the rating curve may have a large degree of error for representing high flows. In addition, no field measurements were taken from fall 2007 to spring 2011.

The pre-flood stage record was reviewed to remove periods of impairment. Periods of likely ice-in, periods with unstable readings, and some outliers were censored from the stage data. Flow was calculated from stage using the rating curve, and the 15-minute flows were then averaged into daily values. Daily flows were subsequently used for model calibration.

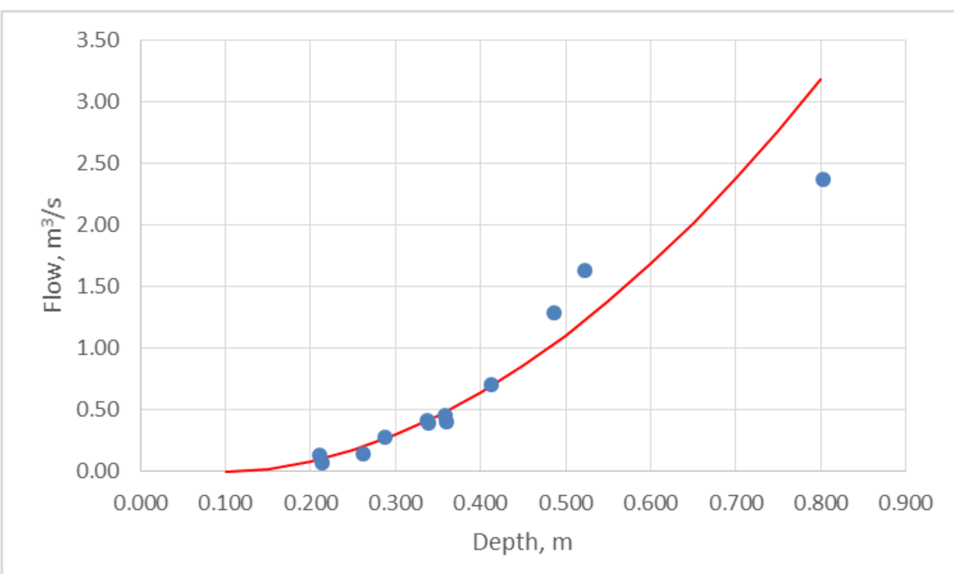

Figure 3-3. Tischer Creek Field Measurements and Flow Rating Curve

3.1.1.2 Flow Data Used for Model Development

The periods of record for selected gages are shown in Table 3-1., and the locations are mapped in Figure 3-4.. The HYDSTRA gages Amity Creek at Occidental Blvd and Miller Creek at 26th Avenue have the longest records and most reliable flow data, and were therefore selected for primary calibration and validation, respectively. Additional flow monitoring in support of the Duluth WRAPS study was initiated at multiple locations in 2015 and 2016, and the data were not available at the time of the development of the original HSPF model. These new gages were utilized during the HSPF model update conducted in 2019.

Table 3-1. Continuous Flow Monitoring Stations in the Duluth WRAPS Study Area

Station ID	Source	Location	Model Reach	Begin	End
02038001	HYDSTRA	Amity Creek at Duluth, Occidental Blvd	436+438	4/10/2002	12/2/2016
02040008	HYDSTRA	Chester Creek at Duluth, W College St	386	4/13/2015	12/2/2016
02037005	HYDSTRA	East Branch Amity Creek at Duluth, 1.8 mi ds of CSAH37	454	4/10/2011	11/14/2013
03189016	HYDSTRA	Keene Creek at Duluth, S 57th Ave W	302	4/13/2015	12/6/2016
S004-952	Duluth Streams	Kingsbury Creek at Lake Superior Zoo	272	7/16/2002	6/8/2012
02036003	HYDSTRA	Lester River near Duluth, CSAH10	499	4/21/2011	11/19/2016
03163011	HYDSTRA	Merritt Creek at Duluth, Grand Ave	321	4/13/2015	11/18/2016
03001001	HYDSTRA	Miller Creek at Duluth, 26th Ave W & W Michigan	332	4/1/2005	11/3/2010
03001012	HYDSTRA	Miller Creek at Duluth, S 24th Ave W	330	4/13/2015	11/19/2016
03-001-001	SAFL	Miller Creek Lower Site at 26th Ave	332	5/1/1997	11/24/1998
03-001-003	SAFL	Miller Creek Middle Site at Chambersburg Street	351	7/15/1997	11/24/1998
03-001-002	SAFL	Miller Creek Upper Site at Miller Hill Mall	347	3/20/1997	11/24/1998
03010003	HYDSTRA	Mission Creek nr Fond du Lac, 1 mi us of MN23	201	7/16/2015	11/17/2016
S004-364/	Duluth Streams	Tischer Creek at Wallace Ave "Mt. Royal"	409+412	10/1/2002	6/8/2012
02039008	HYDSTRA	Tischer Creek at Duluth, Wallace Ave	409+412	4/14/2015	12/3/2016

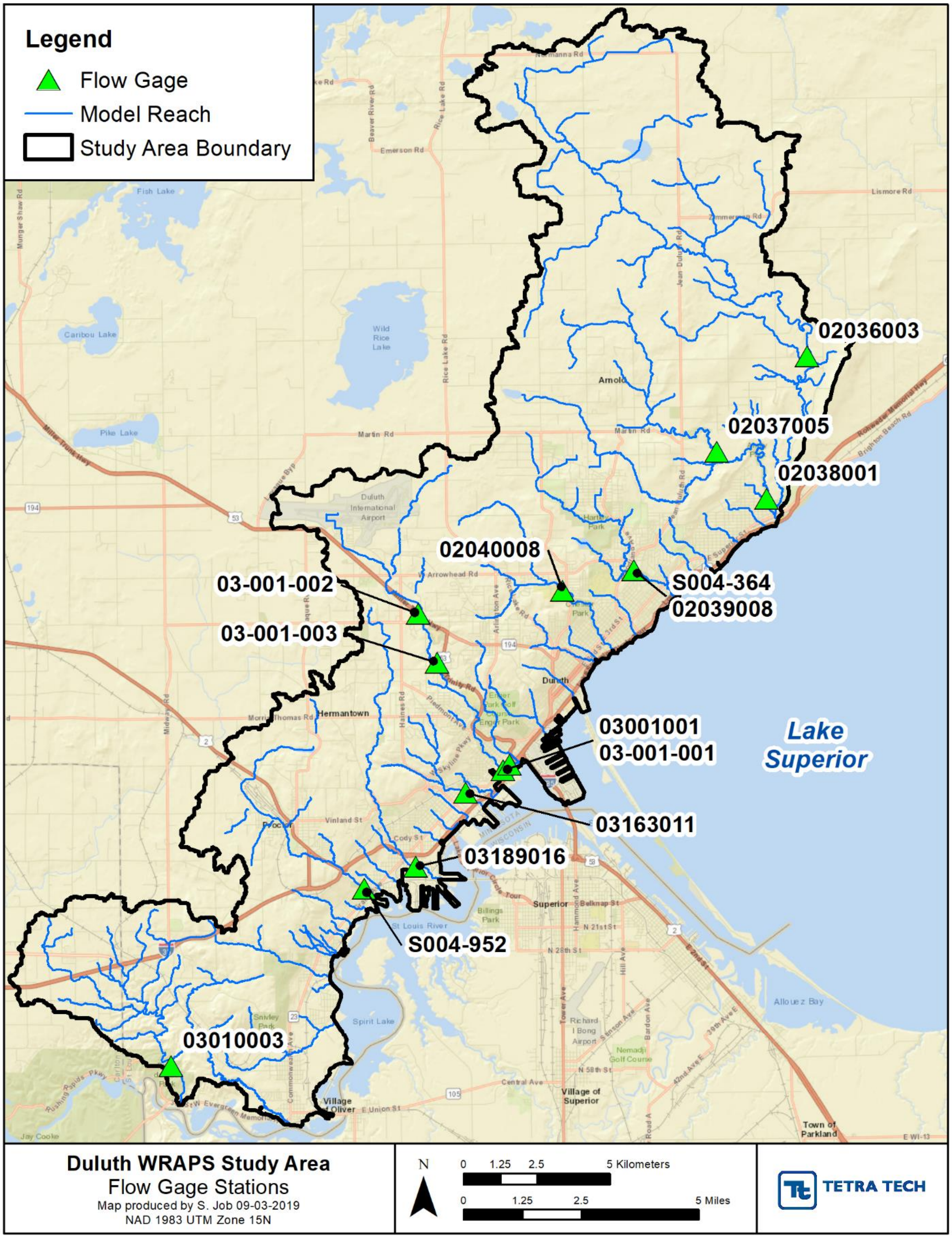

Figure 3-4. Continuous Flow Monitoring Station Locations in the Duluth WRAPS Study Area

3.1.2 Water Quality Data

Water quality data have been collected at many locations within the Duluth WRAPS watersheds. For discrete (grab) monitoring, most of these data are available in the MPCA Environmental Quality Information System[2] (EQuIS). Additional water quality data were available from USGS, MPCA (recent monitoring not available in EQuIS), and NRRI (provided by A. Crouse, University of Minnesota-Duluth).

The NRRI data were collected by A. Crouse for her master's thesis. The source(s) of the data were not documented, but many were duplicates of data in EQuIS; for the most part, unique data were co-located with major EQuIS stations but pre-dated the EQuIS observations. Continuous water quality data collected by probes were available for select parameters from HYDSTRA, Duluth Streams, and MPCA.

For the discrete monitoring data, locations for all of the data sources were mapped and paired with the corresponding model reach for calibration/validation. Stations with less than 20 observations of any of the modeled parameters were generally screened out of the station selection process. Data from different sources were often co-located at the same monitoring location. In a few cases, two separate stations were located on the same model reach. Two locations (one on Amity Creek and one on Tischer Creek) were located just downstream of a confluence, so model pollutant mass output from the two reaches was summed and divided by flow volume to calculate concentration to allow for better comparison to the monitoring data (note that HSPF output represents conditions at the reach outlet). Altogether, there were 41 monitoring stations paired with 26 model reaches (Table 3-2. and Figure 3-5.). Note that for most of these stations, only a subset of all the modeled parameters was available. Eight stations were screened out due to insufficient data for comparison to model results.

Continuous measurement of water temperature was conducted at forty-seven locations in the study area for varying durations and periods of record. Eleven locations were selected to represent a cross-section of upstream land uses and contributing areas. Specific conductance was also measured at eleven locations. Seven of these had paired samples of conductivity and chloride, from which regressions were developed to relate conductivity to chloride concentration. The conductivity-chloride regressions are discussed below. Continuous water temperature and conductivity stations used for calibration/validation are listed in Table 3-3. and shown in Figure 3-6.

Table 3-2. Water Quality Calibration Locations (Discrete Monitoring)

Station ID	Source	Location	Model Reach
S005-485	EQuIS	Amity Ck near Skyline Pkwy, N Duluth, MN	438
S001-757	EQuIS, MPCA	Amity Ck on First Brg on Occidental Blvd in Duluth	436+438
02038001	A. Crouse		
S004-950	EQuIS	Amity Ck, EB above Confluence with Amity Ck, WB in Duluth	454
S006-291	EQuIS	Amity Creek just west of East Skyline Parkway in Duluth, MN	439
02038002	A. Crouse		
S004-958	EQuIS	Buckingham Ck at W 3rd St in Duluth	374
S001-530	EQuIS	Chester Creek in Duluth, MN	386
02040002	A. Crouse		
S004-953	EQuIS	Chester Ck at College of St. Scholastica In Duluth	

[2] https://www.pca.state.mn.us/quick-links/environmental-quality-information-system-EQuIS

Station ID	Source	Location	Model Reach
S008-481	MPCA	Chester Ck just West of W College St in Duluth, MN	
S008-482	MPCA	Keene Ck at 57th Ave W in Duluth, MN	302
S004-952	EQuIS	Kingsbury Creek at Lake Superior Zoo in Duluth	272
03186001	A. Crouse		
S007-055	EQuIS	Kingsbury Ck at Walking Br, 0.1 mi SE of MN-23 / Grand Ave, 2.5 mi SE of Proctor, MN	
S000-258	EQuIS	Lester R above Superior St, Lester Pk at Duluth	483
S003-839	EQuIS	Lester River at Lester Park Br, 0.25 mi upst of mouth in Duluth	
S007-814	EQuIS	Lester River at Strand Rd / CR-10 in Duluth, MN	499
S006-281	EQuIS	Lester River just Upstream of County Road 293 (Tischer Rd)	501
02033001	A. Crouse		
S001-169	EQuIS	Miller Ck at Chambersburg Rd	347
S003-070	EQuIS	Miller Ck, Upper Gage Site at Hwy 53 in Duluth	351
03001029	A. Crouse		
S004-973	EQuIS	Miller Cr at Lk Superior College, 2 mi W of Duluth, MN	342
S003-071	EQuIS	Miller Creek, Lower Site at 26Th Ave W in Duluth	330
03001005	A. Crouse		
S008-484	MPCA	Miller Ck just East of N 24Th Ave W in Duluth, MN	
402402585	USGS	Mission Ck abv 131st Ave W near Fond du Lac, MN	201
S004-974	EQuIS	Mission Ck at MN-23, 2.6 mi WSW of Gary, MN	200
402402580	USGS	Mission Ck blw Fond du Lac Park nr Fond du Lac, MN	202
S004-972	EQuIS	Sargent Ck at Hudson Blvd, 1 mi S of Gary, MN	232
S004-970	EQuIS	Stewart Ck at US Steel RR Line, 2 mi NNE of Gary, MN	247
S006-269	EQuIS	Tischer Ck just dwnst of East Superior Street in Duluth, MN	406
S004-364	EQuIS, MPCA	Tischer Ck at Wallace Ave Mt. Royal, Duluth	409+412
02039002	A. Crouse		
S002-480	EQuIS	Tischer Ck just Dwnst from Brg Crossing on 4th St in Duluth	
S007-592	EQuIS	Tischer Ck upstr of Woodland Ave in Duluth, MN	
S004-959	EQuIS	Unnamed Stream (Coffee Ck) just E of Miller Ck on Courtland St	371
S008-483	MPCA	Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN	321
S004-975	EQuIS	Unnamed Stream (Merritt Ck) at W Superior St in Duluth, MN	320
S005-486	EQuIS	Unnamed Stream to Amity Ck, NE Duluth, MN	436

Table 3-3. Water Quality Calibration Locations (Continuous Monitoring)

Station ID	Source	Location	Model Reach	Water Temp.	Cond.
S001-757	Duluth Streams	Amity Ck on First Brg on Occidental Blvd in Duluth	436+438	X	X
	MPCA	Buckingham Creek above Twin Ponds	374	X	
S004-953	Duluth Streams	Chester Ck at College of St. Scholastica in Duluth	386		X
	MPCA	Keene Creek Central Avenue (mile 0.5)	302	X	
S004-952	Duluth Streams	Kingsbury Ck at Lake Superior Zoo in Duluth	272		X
	MPCA	Kingsbury Creek Ugstad Rd. upper crossing (mile 5.4)	287	X	
02036003	HYDSTRA	Lester River near Duluth, CSAH10	499	X	
03001003	HYDSTRA	Miller Ck at Chambersburg Rd	347	X	X
03001001	HYDSTRA	Miller Creek at Duluth, 26th Ave W & W Michigan	330	X	X
03001002	HYDSTRA	Miller Creek at Hermantown, CSAH53 by Miller Hill Mall	351	X	X
S001-372	Duluth Streams	Miller Creek at Lake Superior College	341	X	
	MPCA	Stewart Creek Skyline Parkway (mile 1.1)	250	X	
S004-364	Duluth Streams	Tischer Ck at Wallace Ave "Mt. Royal", Duluth	409+412	X	X

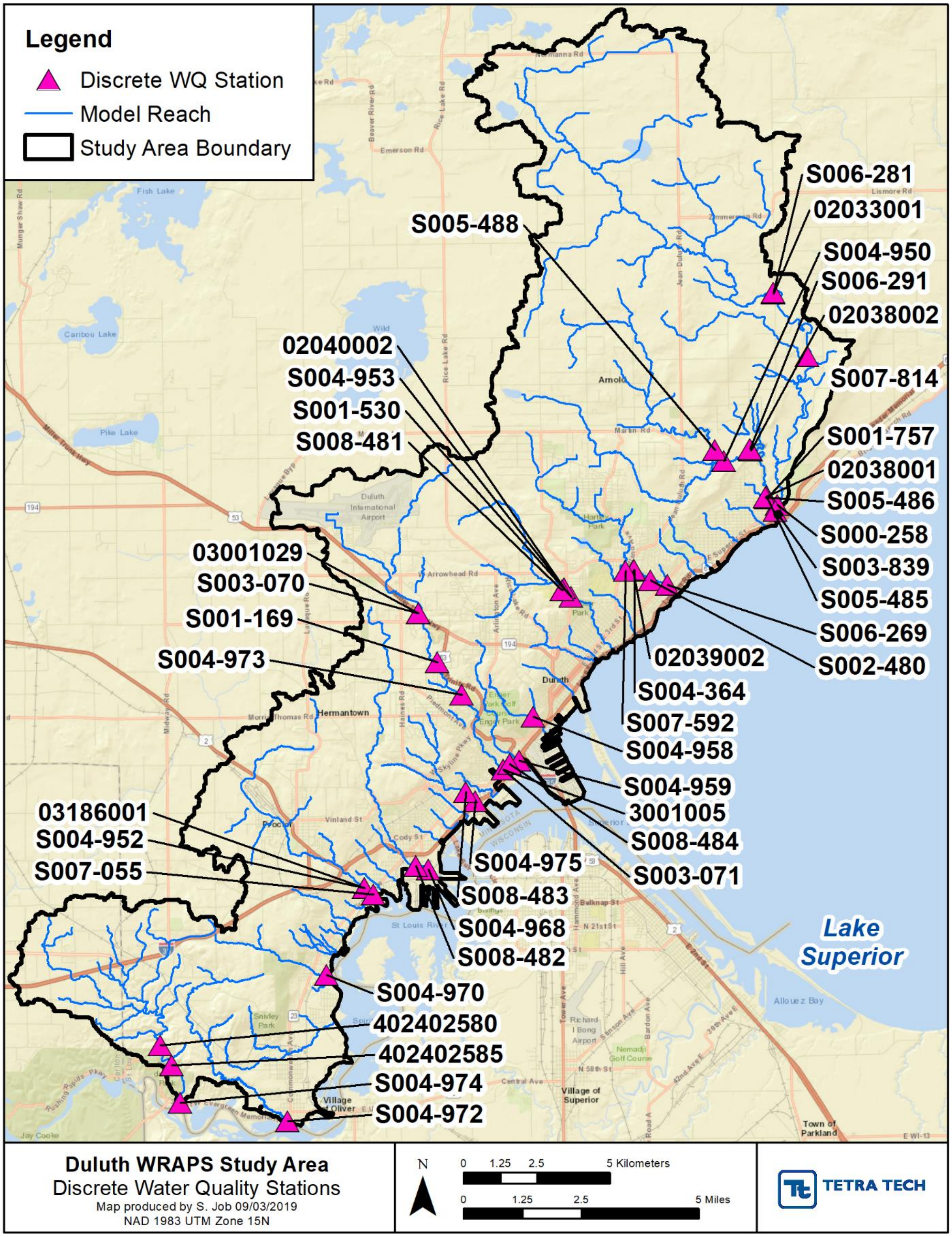

Figure 3-5. Discrete Water Quality Monitoring Station Locations in the Duluth WRAPS Study Area

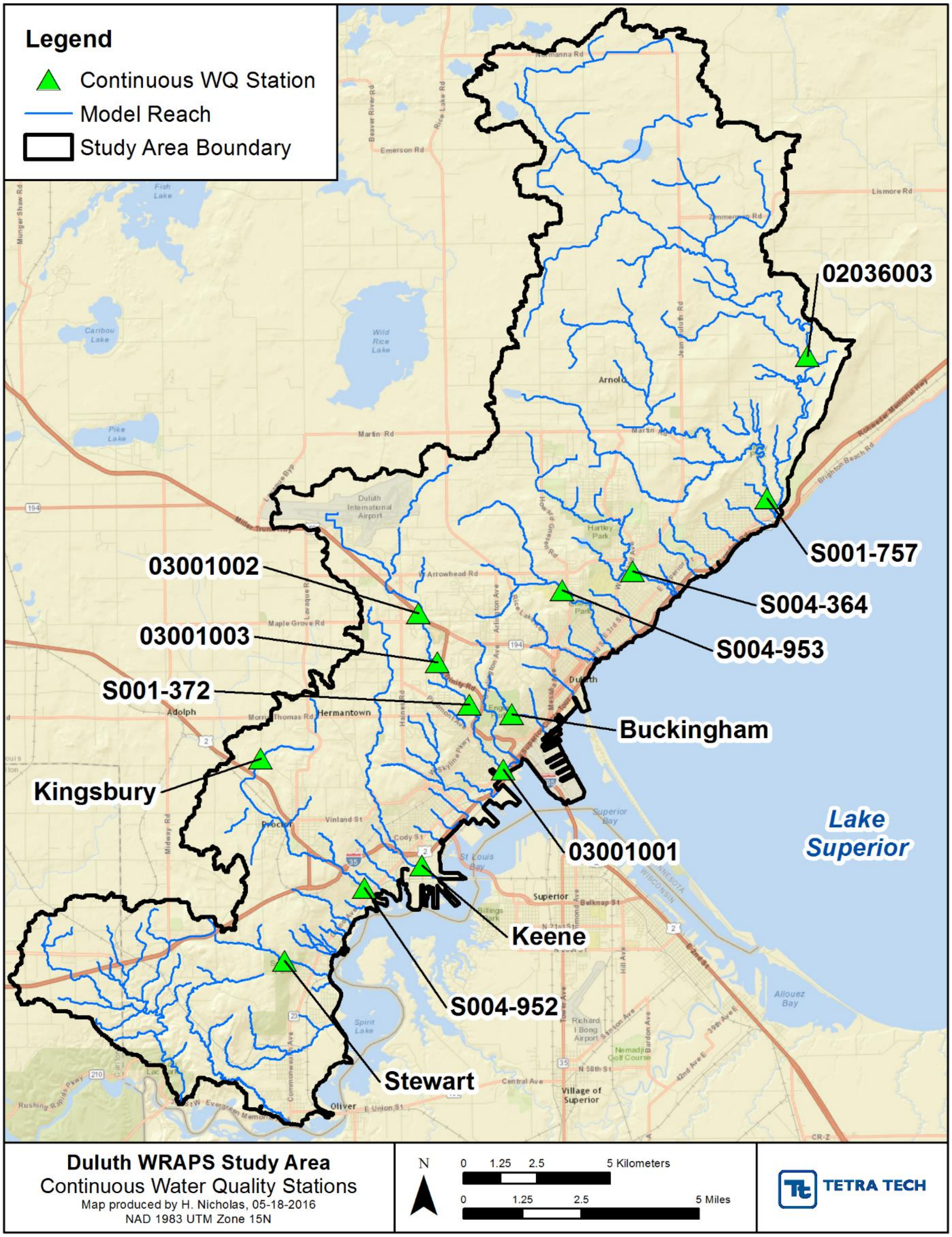

Figure 3-6. Continuous Water Quality Monitoring Station Locations in the Duluth WRAPS Study Area

3.1.2.1 Estimation of Chloride Concentration from Conductivity Data

Paired monitoring grab data of chloride concentration and conductivity were used at seven locations to develop regressions to predict chloride from conductivity, thus allowing continuous conductivity monitoring in the same locations to be used to estimate continuous chloride concentration. Plots of chloride versus conductivity were generated. An examination of the plots suggested that linear interpolation was the best option for representing the relationship across the range of sites. First, linear regression with an intercept was tested. In theory, it is possible to have no chloride but positive conductivity due to the presence of other negative ions (mainly carbonate). However, the regressions produced intercepts with both positive and negative values. To prevent calculation of negative chloride, the regressions were constrained to have an intercept of zero (equation form $y = mx$). Two chloride-conductivity plots are shown with their regressions – Amity Creek at Occidental Blvd (Figure 3-7.), and Miller Creek at Chambersburg Rd (Figure 3-8.). The Amity relationship shows considerable scatter, but a linear trend is apparent. The relationship for Miller is tighter; also note that maximum chloride concentrations are considerably higher than at Amity. The regression coefficient for Miller is more than double that of Amity, indicating that chloride makes up a greater proportion of the negative ions there. Regression coefficients for all the site are shown in Table 3-4.. Higher coefficients are associated greater urbanization. Note that the coefficients increase in Miller Creek moving from upstream to downstream locations.

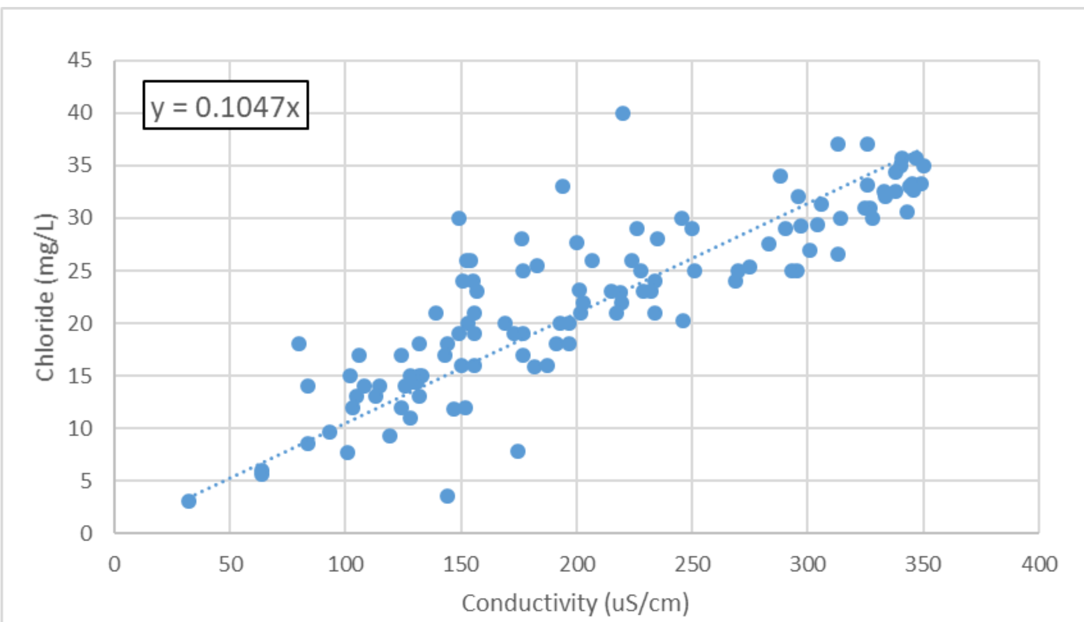

Figure 3-7. Chloride versus Conductivity, Amity Creek at First Bridge Occidental Blvd

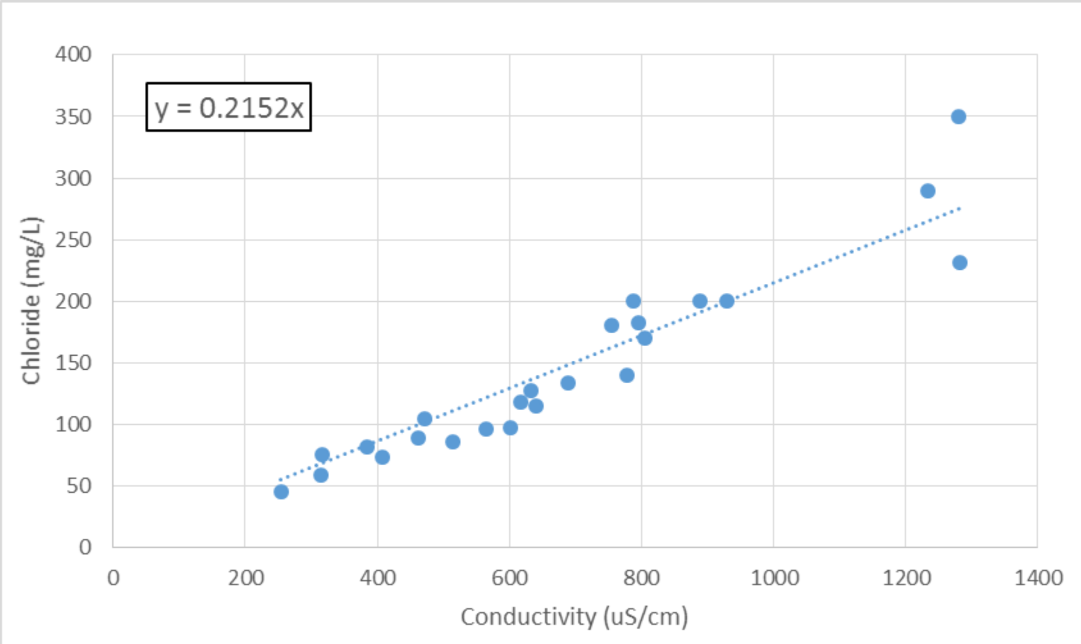

Figure 3-8. Chloride versus Conductivity, Miller Creek at Chambersburg Rd

Table 3-4. Chloride-Conductivity Regression Coefficients

Entity	Station ID	Station Name	Regression Coefficient
Duluth Streams	S001-757	AMITY CK ON FIRST BRG ON OCCIDENTAL BLVD IN DULUTH	0.1047
Duluth Streams	S004-364	TISCHER CK AT WALLACE AVE MT. ROYAL, DULUTH	0.1994
Duluth Streams	S004-953	CHESTER CK AT COLLEGE OF ST. SCHOLASTICA IN DULUTH	0.2529
Duluth Streams	S004-952	KINGSBURY CK AT LK SUPERIOR ZOO IN DULUTH	0.2355
HYDSTRA	S003-070	MILLER CREEK, UPPER GAGE SITE AY HWY 53 IN DULUTH	0.1875
HYDSTRA	S001-169	MILLER CK AT CHAMBERSBURG RD T50N/R14W/S19	0.2152
HYDSTRA	S003-071	MILLER CREEK, LOWER SITE AT 26TH AVE W IN DULUTH	0.2256

3.2 Hydrology Calibration Approach

The level of performance and overall quality of hydrologic calibration is evaluated in a weight of evidence approach that includes both visual comparisons and quantitative statistical measures. The calibration proceeds in a sequential manner through (1) general representation of the overall water balance, (2) calibration of snow depth, (3) assurance of consistency with satellite-based estimates of actual ET and soil moisture, and (4) detailed calibration relative to flow gaging for seasonal flows, shape of the flow duration curve, and hydrograph shape.

Key parameters for hydrologic calibration and information on their potential ranges are as described in BASINS Technical Note 6 (USEPA, 2000). Initial values of key parameters were related to soil and climatological properties where appropriate. Specifically, infiltration rates (INFILT) were initialized (and subsequently varied by HSG), while initial values of lower zone nominal soil storage capacity (LZSN), upper zone soil storage capacity (UZSN), and interflow inflow (INTFW) were set based on annual average rainfall, consistent with USEPA (2000). Seasonal patterns based on vegetative cover (MON-LZETPARM, MON-INTERCEP, and MON-MANNING) and snow simulations were initialized based on past experience with Minnesota models.

Given the inherent errors in input and observed data and the approximate nature of model formulations, absolute criteria for watershed model acceptance or rejection are not generally considered appropriate by most modeling professionals. Yet, most decision makers want definitive answers to the questions—"How accurate is the model?" and "Is the model good enough for this evaluation?" Consequently, the current state of the art for model evaluation is to express model results in terms of ranges that correspond to "very good," "good," "fair," or "poor" quality of simulation fit to observed behavior. These characterizations inform appropriate uses of the model: for example, where a model achieves a good to very good fit, decision-makers often have greater confidence in having the model assume a strong role in evaluating management options. Conversely, where a model achieves only a fair or poor fit, decision makers may assume a much less prominent role for the model results in the overall weight-of-evidence evaluation of management options.

For HSPF and similar watershed models, a variety of performance targets have been documented in the literature, including Donigian *et al*. (1984), Lumb et al. (1994), Donigian (2000), and Moriasi *et al*. (2007). Based on these references and past experience, the HSPF performance targets for simulation of hydrology are summarized in Table 3-5.. Model performance is generally deemed fully acceptable where a performance evaluation of "good" or "very good" is attained. It is important to clarify that the tolerance ranges are intended to be applied to mean values, and that individual events or observations may show larger differences and still be acceptable (Donigian, 2000).

The model calibration generally attempts to achieve a good balance between the relative error metrics and the Nash-Sutcliffe coefficient of model fit efficiency (NSE; Nash and Sutcliffe, 1970). Unlike relative error, NSE is a measure of the ability of the model to explain the variance in the observed data. Values may vary from $-\infty$ to 1.0. A value of NSE = 1.0 indicates a perfect fit between modeled and observed data, while values equal to or less than 0 indicate the model's predictions of temporal variability in observed flows are no better than using the average of observed data. The accuracy of a model increases as the value approaches 1.0. Moriasi et al. (2007) suggest that achieving a relative error on total volume of 10 percent or better and an NSE of 0.75 or more on *monthly* flows constitutes a good modeling fit for watershed applications.

It should be noted that many of the available gage records in these watersheds operate only on a seasonal basis, so that full evaluation of seasonal statistics (or, indeed, evaluation of the total water balance) is not possible. In addition, where winter gaging records are available they are typically imprecise and generally rated poor or fair by HYDSTRA due to interference from ice cover. As discussed in Section 3.1.1.1, flow estimates for the Duluth Streams are highly uncertain and should be considered rough estimates only.

Table 3-5. Performance Targets for HSPF Hydrologic Simulation (Magnitude of Annual and Seasonal Relative Mean Error (*RE)*; Daily and Monthly NSE)

Model Component	Very Good	Good	Fair	Poor
1. Error in total volume	≤ 5%	5 - 10%	10 - 15%	> 15%
2. Error in 50% lowest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%
3. Error in 10% highest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%
4. Error in storm volume	≤ 10%	10 - 15%	15 - 25%	> 25%
5. Winter volume error (JFM)	≤ 15%	15 - 30%	30 - 50%	> 50%
6. Spring volume error (AMJ)	≤ 15%	15 - 30%	30 - 50%	> 50%
7. Summer volume error (JAS)	≤ 15%	15 - 30%	30 - 50%	> 50%
8. Fall volume error (OND)	≤ 15%	15 - 30%	30 - 50%	> 50%
9. NSE on daily values	> 0.80	> 0.70	> 0.60	≤ 0.60
10. NSE on monthly values	> 0.85	> 0.75	> 0.65	≤ 0.65

3.3 Sediment Calibration Approach

Sediment is one of the more difficult water quality constituents to represent accurately in watershed and stream models. Important aspects of sediment behavior within a watershed system include loading and erosion sources, delivery of these eroded sediment sources to streams, drains and other pathways, and subsequent instream transport, scour and deposition processes (USEPA, 2006).

Sediment calibration for watershed models involves numerous steps in estimating model parameters and determining appropriate adjustments needed to insure a reasonable simulation of the sediment sources on the watershed, delivery to the waterbody, and transport behavior within the channel system. Rarely is there sufficient observed local data at sufficient spatial detail to obtain a unique calibration for all parameters for all land uses and each stream and waterbody reach. Consequently, model users focus the calibration on sites with observed data and review simulations in all parts of the watershed to ensure that the model results are consistent with field observations, historical reports, and expected behavior from past experience (Donigian and Love, 2003, AQUA TERRA, 2012).

Sediment calibration for the Duluth WRAPS model was undertaken in accordance with AQUA TERRA (2012) as well as the guidelines contained in BASINS Technical Note 8: Sediment Parameters and Calibration Guidance for HSPF (USEPA, 2006). Where appropriate, the St. Louis River and Lake Superior South HSPF models were used to provide starting parameter values prior to calibration. The sediment calibration required an iterative approach. The first step involved refining the upland sediment yields to values that align with reference and field data. In addition, the relative contributions of sediment from upland, gully erosion, and instream sources were adjusted as necessary. The instream simulation was then further tuned; this involved analyzing the shear stress simulation in the reaches and setting channel erosion to values that achieved a reasonable fit to observations. Next, the long-term behavior of sediment in the channels was constrained to ensure that degradation or aggradation amounts were physically realistic, in terms of the simulated magnitude of degradation and aggradation, and consistent with the geomorphic classification. The last component of the sediment calibration was to compare instream modeled sediment to stream samples that were gathered during the calibration period. The sediment parameters were refined after comparing modeled and observed sediment concentrations at several key locations in these watersheds.

The upland parameters for sediment were related to soil and topographic properties. HSPF simulates sediment yield to streams in two stages. First, HSPF calculates the detachment rate of sediment by rainfall (in tons/acre/hour) as

$$DET = (1 - COVER) \cdot SMPF \cdot KRER \cdot P^{JRER}$$

where *DET* is the detachment rate (tons/acre/hour), *COVER* is the dimensionless factor accounting for the effects of cover on the detachment of soil particles, *SMPF* is the dimensionless management practice factor, *KRER* is the coefficient in the soil detachment equation, *JRER* is the exponent in the soil detachment equation, which is recommended to be set to 1.81, and *P* is precipitation depth in inches over the simulation time interval. Direct addition of detached sediment (e.g., from wind deposition) can also be added via the parameter *NVSI*. Actual detached sediment storage available for transport (*DETS*) is a function of accumulation over time and the reincorporation rate, *AFFIX*.

The transport capacity for detached sediment from the land surface (*STCAP*) is represented as a function of overland flow:

$$STCAP = KSER \cdot (SURS + SURO)^{JSER}$$

where *KSER* is the coefficient for transport of detached sediment, *SURS* is surface water storage (inches), *SURO* is surface outflow of water (in/hr), and *JSER* is the exponent for transport of detached sediment.

DET is similar in concept to the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978), which predicts sediment detachment as a function of is the rainfall erosivity, *RE*, a soil erodibility factor, *K*, a length-slope factor, *LS*, a cover factor, C, and a practice factor, *P*:

$$DET = RE \cdot K \cdot LS \cdot C \cdot P.$$

USEPA (2006) recommends assuming *KRER* = K, and this approach was used for the Duluth WRAPS model. The distribution of K values in the study area is shown in Figure 3-9.. When the K factor was undefined in the GIS data layer, the values were assumed to be the same as neighboring HRUs with the same land use/land cover and weather region assignment.

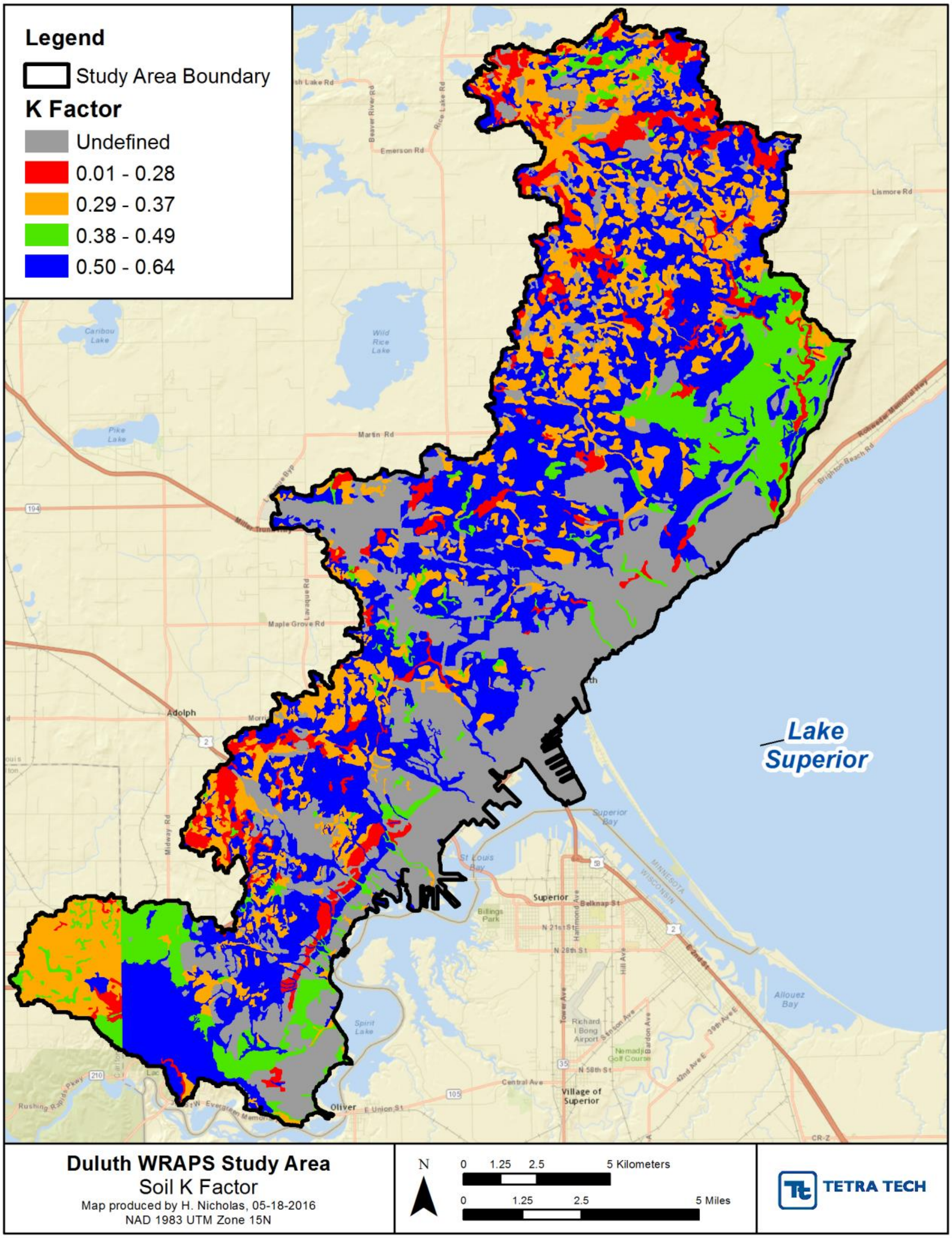

Figure 3-9. Soil K Factors in the Duluth WRAPS Study Area

Once *KRER* is established, the primary upland calibration parameter for sediment is *KSER*, which determines the ability of overland flow to transport detached sediment. HSPF can also simulate gully erosion in which sediment generated from the land surface is not constrained by rainfall detachment. For the Duluth WRAPS model, it was assumed that pervious areas near roads produce some gully erosion. Gully erosion is simulated in the model as sediment that is scoured from the soil matrix based on the following equation:

$$SCRSD = \frac{SURO}{(SURS + SURO)} \bullet KGER \bullet (SURS + SURO)^{JGER}$$

where *SCRSD* is the scour of matrix soil (tons/ac/hour), *KGER* is the cofficient for the scour of the matrix soil, and *JGER* is the exponent for scour of the matrix soil. Gully erosion simulated in the model is limited to the pervious road land use class which represents the pervious land within the road right-of-way. The pervious land gully erosion is assumed to include any gully erosion associated with gravel roads (since there is no option in HSPF for gully erosion from impervious land).

HSPF simulates sediment delivery from the land surface in a single class; this is partitioned into sand, silt, and clay at the edge of a reach. The characteristics of soils in these watersheds influences the fractions of sand, silt, and clay that are delivered to streams. In order to establish the fractions for the Duluth WRAPS model, area-weighted fractions of sand, silt, and clay were generated from SSURGO data. Data from the top soil layer was analyzed and results indicate that the surface sediment is comprised of 44% sand, 41% silt, and 15% clay.

Fine particles, however, are more easily transported and enrichment of fines takes place both in the process of pickup of detached soil particles from the land surface and during transport in ephemeral streams. The coarser sand fraction is less likely to be moved in the first place, and is more likely to be deposited out in first-order and ephemeral streams before reaching modeled stream reaches. Several methods have been suggested in the literature to calculate clay enrichment ratios (summarized in Novotny and Olem, 1994). These methods were reviewed during the sediment calibration phase of the Lake Superior South model (Tetra Tech, 2016c). Due to the high sand fraction of the watersheds in the Duluth WRAPS model a modified approach was used for dividing upland sediment in this model (a sand fraction of 10% and a clay enrichment factor of 2). As a result, 10%, 59.7%, and 30.3% of the sediment loaded to the model reaches, from PERLND's, is from sand, silt, and clay particles, respectively. The fraction loaded from IMPLND's was set to be equal to the sediment composition of the top soil layer since it was assumed that sediment composition from impervious surfaces was more related to the surrounding landscape and clay enrichment not as meaningful.

The HSPF model simulates sand, silt, and clay-sized fractions of sediment separately in the reaches. The key parameters controlling channel erosion, deposition, and sediment transport within streams and rivers are as follows (USEPA, 2006):

KSAND: Sand transport is represented with a power function based on average velocity, such that carrying capacity for sand = *KSAND* x AVVEL^{EXPSND}. *KSAND* is set to 0.1 and *EXPSND* to 2 to start calibration and adjusted to improve the comparison between simulated and observed suspended sediment concentrations at flows where cohesive silt and clay sediments do not scour as well as to ensure a reasonable evolution of sand storage over time.

TAUCD: Critical bed shear stress for deposition (lb/ft^2) represents the energy level below which cohesive sediment (silt and clay) begins to deposit to the bed. HSPF calculates bed shear stress (TAU) during each model time step for each individual reach. Initial values of TAUCD for silt and clay were estimated by reach by examining the cumulative distribution function of simulated shear stress and setting the parameter to a lower percentile of the distribution in each reach segment, as recommended by USEPA (2006). Initially the 10^{th} percentile was used for clay and the 15^{th} percentile for silt and this was adjusted during calibration.

TAUCS: The critical bed shear stress for scour (lb/ft^2) represents the energy level above which scour of cohesive sediment begins. Initial values of TAUCS were set, as recommended, at upper percentiles of the distribution of simulated TAU in each reach (the 80th percentile for clay and the 85th percentile for silt and this was adjusted during calibration.

M: The erodibility coefficient of the sediment (lb/ft^2-d) determines the maximum rate at which scour of cohesive sediment occurs when shear stress exceeds TAUCS. This coefficient is a calibration parameter. It was initially set to 0.004 for silt, 0.003 for clay.

The width of bed sediment also needs to be specified for each reach. Although this is not an important calibration parameter the width of bed sediment does influence the calibration by influencing the bed sediment mass that is available for scour. It was assumed that bed sediment width was equal to bankfull width for each reach. Bankfull width of each reach was determined by taking the bankfull depths corresponding surface area from the FTable and dividing by stream length. Review of cross section information collected in the Duluth geomorphic studies indicates that generally bankfull depth was approximately 2 feet deep for most of the streams contained in that study (Fitzpatrick *et al.*, 2006, Fitzpatrick *et al.*, 2016).

An important issue for sediment calibration is representing the correct division between sediment derived from uplands and sediment derived from reach scour. In some Minnesota watersheds, radiometric analysis using ^{210}Pb and ^{137}Cs, both of which are derived from the atmosphere and decay over time into more stable forms, has been used to identify the fraction of sediment that derives from upland sources in recent contact with the atmosphere. Such information is not available for the Duluth WRAPS watersheds at this time, but could potentially be used to further refine the sediment calibration in the future.

Calibration for sediment and other water quality parameters differs from calibration for hydrology in that pollutant concentrations are in most cases not continuously monitored. Instead, observations typically provide measurements of conditions at a point in time and point in space via a grab sample. The discrete nature of these samples presents problems for model calibration: A sample that represents a point in time could have been obtained from a system where conditions are changing rapidly over time – for instance, the rising limb of a storm hydrograph. Such samples cannot be expected to be matched by a model prediction of a daily average concentration. On the other hand, there may be large discrepancies between dynamic model predictions of hourly concentrations and data that are a result of small timing errors in the prediction of storm event flow peaks. Spatially, grab samples reflect conditions in one part of a stream reach (which may or may not be composited over the width and depth of a cross section). HSPF model results, in contrast, represent average concentrations over the length, width, and depth of a stream reach which is assumed to be fully mixed. Model predictions and field observations inevitably have some degree of mismatch in space and time and, even in the best models, will not fully match. Accordingly, a statistical best fit approach is needed.

Performance targets for sediment calibration, based on Donigian (2000), are summarized in Table 3-6. It is important to note that these targets were mostly developed for larger rivers and may not be fully appropriate to small urban streams. For consistency with other Minnesota HSPF modeling projects (and lacking an alternative), these performance targets are evaluated for both concentration and load, where load is estimated from concentration. The statistics are calculated for paired data, and the targets should only be applied in cases where there is a minimum of 20 observations. Model performance is generally deemed acceptable where a performance evaluation of “good” or “very good” is attained.

Table 3-6. Performance Targets for HSPF Sediment Simulation (Magnitude of Annual and Seasonal Relative Average Error (*RE*) on Daily Values)

Model Component	Very Good	Good	Fair	Poor
1. Suspended Sediment	≤ 20%	20 - 30%	30 - 45%	> 45%

These target ranges were mostly developed for larger rivers and may not be fully appropriate to small urban streams. One reason is that average daily model output is being compared to grab samples collected at a fixed point in time. Small urban streams are flashy during rain events, and large variations in flow and concentrations may occur over a few hours. A grab sample may not be representative of the cumulative daily average from model output. On the other hand, hourly output from the model is very likely to be displaced in time relative to actual flow peaks (due in large part to the uncertainty in the temporal and spatial distribution of precipitation).

3.4 Water Quality Calibration Approach

Water quality simulation depends on the simulation of hydrology and sediment transport. This section addresses the calibration and validation of the model simulation of water temperature, dissolved oxygen, nutrients, algae, and chloride.

Although not a primary focus of the modeling effort, water temperature simulation is important in the watershed model for several reasons: water temperature affects many biologically mediated processes that influence water quality in the streams, and the temperature of the water determines how it will mix when it enters the lake.

Daily average water temperature in shallow flowing streams is largely controlled by air temperature. Temperature cycles within the day, however, may be strongly affected by heat gain from incoming solar radiation and heat loss due to longwave back radiation. Both processes are controlled by the extent of cover and shading on the stream in addition to meteorological variables such as solar radiation and cloud cover.

A detailed diel simulation of stream water temperature is a complex undertaking. The timing and magnitude of heat fluxes are controlled by a variety of factors such as stream orientation and vegetative and topographic shading angles that cannot be fully represented in a basin-scale HSPF model. For example, a stream oriented east-west is likely to be exposed to unshaded solar radiation for a longer part of the day than a stream oriented north-south. Stream shading varies over the course of the year as canopy density changes, and may also change over time as trees grow, are cut, fall due to ice and wind storms, or due to fire. HSPF approximates all these complex details through the assignment of a temporally constant "surface exposed" (CFSAEX) factor that represents the average fraction of tree-top solar radiation reaching the water surface. Given these issues, the stream temperature calibration was checked for reasonableness, but not constrained to achieve specific statistical targets.

Loading of nutrients that may support excess algal growth is an important concern. The major nutrients controlling algal growth are phosphorus and nitrogen. Both are simulated in detail in the model. Minor nutrients (e.g., silica, iron) may also play a role in determining algal response but are not simulated in the watershed model. The first step in a sequential process for nutrient calibration is to verify that unit area loading rates were reasonable compared to literature values. Next, calibration to instream observations is carried out to refine the simulation. Plant growth has an important effect on nutrient balances during low flow conditions and serves to convert inorganic nutrients into organic forms; therefore, nitrogen and phosphorus species must be calibrated simultaneously with algae.

In forested watersheds, much of the nutrient load moves as a constituent of organic matter (including leaf litter, other debris, and dissolved organic compounds, such as humic acids), while stream concentrations of inorganic nutrients remain low in these watersheds. In contrast, agriculture and fertilized lawns may export significant amounts of nutrients in inorganic forms. Point source discharges can contain a mix of organic and inorganic nutrient forms dependent on the treatment process.

The approach taken is to simulate three components in loading from the land surface as general quality constituents (GQUALs): inorganic nitrogen (nitrate, nitrite, and ammonia), inorganic phosphorus (total orthophosphate), and organic matter. Each of these constituents is then partitioned at the point of entry into the stream network:

- Inorganic nitrogen is partitioned into dissolved nitrate, dissolved ammonium, and sorbed ammonium. Fractions of the dissolved constituents are set to reproduce observed data, while sorption of ammonium is simulated using equilibrium partitioning assumptions (the model connects inorganic N from the land surface to dissolved N in the stream reach, but equilibrium partitioning to the sorbed form occurs instantaneously). Assignment of total inorganic nitrogen from the land surface to nitrate and ammonium at the point of entry to the stream is represented by a constant ratio throughout the model, but differs for agricultural land and impervious surfaces. Partitioning of ammonium between dissolved and sorbed forms depends on local suspended sediment concentrations. A small portion of the inorganic N is routed directly to organic N to represent uptake by heterotrophic organisms in low order streams (a process not explicitly simulated by the model).
- Inorganic phosphorus is partitioned into dissolved and sorbed fractions using equilibrium partitioning assumptions. As with ammonium, the fraction that becomes sorbed depends on the local suspended sediment concentration,
- Organic matter (biomass) is partitioned into labile and refractory organic carbon, organic nitrogen, and organic phosphorus components. Initial specifications were based on expected stoichiometry of forest litter, and then revised during calibration to achieve agreement with observed concentrations.

All three upland components (inorganic nitrogen, inorganic phosphorus, and organic matter) may be loaded through either surface flow or subsurface flow (interflow and groundwater discharge). The HSPF GQUAL algorithms do not maintain a full mass balance of subsurface constituents (which would require a groundwater quality model); rather, the user specifies concentration values, which may vary monthly, for interflow and groundwater. Surface washoff loading is considered from both pervious and impervious surfaces.

Inorganic phosphorus loading from pervious surfaces is simulated as a sediment-associated process because of the strong affinity of orthophosphate for soil particles. Surface loading of inorganic phosphorus is thus determined by a potency factor applied to sediment load, which may vary on a monthly basis to reflect changes in surface soil concentration associated with the annual growth cycle. (While this reflects the physical basis of surface loading of inorganic phosphorus, it does mean that any errors in the simulation of sediment loading will also affect estimates of inorganic phosphorus loading.) Subsurface flow pathways are assumed to primarily load small amounts of dissolved inorganic phosphorus. Organic matter is also simulated as a sediment-associated load from pervious surfaces, as this primarily represents the erosion of humus, leaf litter, and other detritus.

In contrast to phosphorus, inorganic nitrogen is highly soluble, and loading in surface runoff may occur independent of sediment movement (particularly where fertilizer is applied). Further, much of the nitrate load in surface runoff represents input from atmospheric deposition. Therefore, inorganic nitrogen loading from pervious surfaces is represented via a buildup-washoff process in which the user specifies a rate of accumulation, an accumulation limit, and a flow rate sufficient to remove 90 percent of the accumulated material.

As noted above, representation of plant growth is a necessary part of the nutrient calibration process. HSPF contains routines for simulating planktonic (floating) and benthic (attached) algae. Growth, respiration, and death processes are affected and potentially limited by the availability of light, availability of inorganic nutrients, water depth, and water temperature. Because HSPF represents stream segments as one-dimensional, fully-mixed reactors, the predictions of algal response are averages throughout the stream segment volume. Planktonic and benthic algae simulations differ primarily in the way that the attenuation of light availability is calculated. For plankton light availability is calculated as the average over the euphotic depth, such that all phytoplankton are assumed to be mid-depth in the reach or the middle of the euphotic zone, whichever is smaller, then adjusted to the full volume of the reach. Benthic algae are assumed to be at the average depth of the reach. The scheme does not include a representation of floating or emergent rooted macrophytes. While these can sometimes be successfully approximated with the benthic algae routines, the light availability calculations for benthic algae are not appropriate to these types of macrophytes and the program does not consider that floating/rooted macrophytes can exchange gases with the atmosphere and obtain nutrients from the sediment.

The dissolved oxygen simulation considers reaeration, the decay of organic matter (carbonaceous biochemical oxygen demand), oxidation of ammonia and nitrite N, sediment oxygen demand, and algal photosynthesis and respiration.

The approach taken for chloride is similar to inorganic nitrogen on the upland but different instream. For the pervious and impervious uplands chloride was simulated as a as general quality constituent. Chloride may be loaded through either surface flow or subsurface flow (interflow and groundwater discharge). The HSPF GQUAL algorithms do not maintain a full mass balance of subsurface constituents (which would require a groundwater quality model); rather, the user specifies concentration values, which may vary monthly, for interflow and groundwater. Surface washoff loading is considered from both pervious and impervious surfaces. Instream, chloride was simulated as a general quality constituent subject to dilution, mixing, and advection, together with a very small rate of loss, represented by a first-order decay coefficient.

For most water quality constituents, it is unreasonable to propose that the model predict all temporal variations in concentration and load. The model should, however, provide an accurate representation of long-term and seasonal trends in concentration and load, and correctly represent the relationship between flow and load. To ensure this, it is important to use statistical tests of equivalence between observed and simulated concentrations, rather than relying on a pre-specified model tolerance on difference in concentrations.

Ideally, average errors and average absolute errors should both be low, reflecting a lack of bias and high degree of precision, respectively. In many cases, the average error statistics will be inflated by a few highly discrepant outliers. It is therefore also useful to compare the median error statistics.

General performance targets for water quality simulation with HSPF are also provided by Duda et al. (2012) and are shown in Table 3-7. As was the case for the sediment, these targets were mostly developed for larger rivers and may not be fully appropriate to small urban streams. One reason is that average daily model output is being compared to grab samples collected at a fixed point in time. Small urban streams are flashy during rain events, and large variations in flow and concentrations may occur over a few hours. A grab sample may not be representative of the cumulative daily average from model output. On the other hand, hourly output from the model is very likely to be displaced in time relative to actual flow peaks (due in large part to the uncertainty in the temporal and spatial distribution of precipitation). Regardless, these targets are used to evaluate model performance, with the caveat that Good or Very Good performance may be difficult to achieve across the spectrum of monitoring locations. The targets are calculated from observed and simulated daily concentrations, and should only be applied in cases where there are a minimum of 20 observations.

Table 3-7. Performance Targets for HSPF Water Quality Simulation (Magnitude of Annual and Seasonal Relative Average Error (RE) on Daily Values)

Model Component	Very Good	Good	Fair	Poor
Temperature	≤ 7%	8 - 12%	13 - 18%	> 18%
Water Quality/Nutrients	≤ 15%	15 - 25%	25 - 35%	> 35%

Evaluation of water quality simulations presents a number of challenges because, unlike flow, water quality is generally not monitored continuously. Grab samples at a point in space and time may not be representative of average conditions in a model reach on a given day as noted previously, especially true for flashy urban streams. Where constituent concentrations are near reporting levels, relative uncertainty in reported results is naturally high.

Evaluation of relative average error is recommended, but averages are prone to biasing by one or a few extreme outliers. Therefore, it is also useful to examine median relative errors, which are less influenced by outliers.

The performance targets for water quality simulation may be applied to either concentrations or loads. Concentrations provide the most natural metric, but error magnitude may be unduly influenced by variability at low flow conditions that has little effect on cumulative loading downstream. Loads are more meaningful for impacts in downstream lakes, harbors, and estuaries but are not directly observed and need to be estimated from flow and concentration – both uncertain. Tests on loads are performed on paired data (observed and simulated daily average concentration multiplied by flow).

Additional statistical tests are also applied as part of a weight-of-evidence examination of the water quality calibration. Two-sample *t*-tests are reported on the differences in mean concentration and mean load, with higher probability values indicating less chance that the measures are systematically different. A problem with the *t*-test is that the test is on a null hypothesis that the mean difference is exactly equal to zero, not whether the difference is physically meaningful. Therefore, a low value on the *t*-test (rejection of the null hypothesis) is generally considered of practical significance only when the mean difference is greater than 10 percent. Additional graphical tests are also performed to ensure that errors in the prediction of load and concentration do not exhibit strong bias relative to flow magnitude or season.

4 Hydrology Calibration and Validation Results

4.1 Snow Calibration

Snow accumulation and melt is a key component of the water balance in northern watersheds. During the snow calibration, daily snow depth and snow water equivalent as simulated by the HSPF model were compared to observed snow datasets available from the NCDC for Duluth International Airport (MN212248) as well as National Snow and Ice Data Center (NSIDC). The NCDC data for MN212248 were analyzed for January 1995 through December 2012 and represent observed snow depth at a single point. The NSIDC Snow Data Assimilation System (SNODAS) data products integrate snow data from satellites, ground observations and aircrafts to provide estimates of snow cover and associated parameters (Carroll *et al.*, 2001). Snow depth and snow water equivalent are available from September 2003 to present at a spatial resolution of one km by one km and a temporal resolution of 1 day for the continental United States. SNODAS products represent average conditions over each one km^2 grid cell. HSPF simulated daily time-series were compared to both NCDC and SNODAS observed time series aggregated by weather regions to evaluate calibration. Weather regions are discussed in Section 2.2 and shown in Figure 2-5.; the weather region ID is located in the center of each PRISM cell.

Values of parameters in the SNOW-PARM1 and SNOW-PARM2 blocks of the HSPF model were configured by weather region as part of the calibration process for snow. Another important feature of the snow regime in urban areas is the necessity of snow removal from roads, parking lots, and various other impervious surfaces. In many cases, snow is pushed to the side of these areas, while in more densely developed areas it is trucked to stockpiles. Using either method results in less snow water equivalent on transportation-related impervious surfaces from which snow is removed and greater snow water equivalent on adjacent areas. The plowed or stockpiled snow will have greater density and typically lower albedo (reflectivity) than natural snow; they are also more likely to be insulated from ground heat by layers of sand and dirt. Another aspect of winter urban hydrology is the use of deicing agents (e.g., salt) to reduce ice buildup on impervious surfaces. The complex details of urban snow management are approximated in the model through several parameter adjustments:

- COVIND, the water equivalent depth at which a surface is considered fully covered by snow, and thus all precipitation falls on the snow pack, is set at a higher value for impervious surfaces likely to be plowed (i.e., roads, sidewalks, and parking lots).
- TSNOW, the air temperature at which precipitation is interpreted as snow, is set at a higher value for impervious surfaces.
- MGMELT, the parameter controlling melting from ground heat, is set at a lower value for impervious surfaces likely to have snow piles.

The calibrated values of the snow parameters are provided in Table 4-1..

Table 4-1. HSPF Snow Calibration Parameter Values

Parameter	Description	Calibrated Value	Recommended Range
SHADE	Fraction shaded from solar radiation	0.85 (Evergreen Forest and Forested Wetlands)[1]	0 - 0.8
		0.50 (Deciduous Forest and Herbaceous Wetlands)	
		0.45 (Developed High Intensity Pervious)	
		0.35 (Developed Low Intensity Pervious and High Intensity Impervious)	
		0.25 (Developed Residential Pervious, Low Intensity Impervious and Open Water	
		0.15 Developed Residential Impervious	
		0.1 (Road Pervious and Impervious, Grassland/Shrubland and Pasture/Hay,)	
		0.01 (Outcrop Impervious)	
SNOWCF	Snow gage catch correction factor	1.2	1.0 - 2.0
COVIND	Snowfall required to fully cover surface	0.5 - 1.0 (higher values on impervious surfaces likely to be plowed)	0.1 - 10.0
RDCSN	Density of new snow	0.15	0.05 - 0.30
TSNOW	Temperature at which precipitation becomes snow	32.0 (34.0 for impervious surfaces)	30.0 - 40.0
SNOEVP	Snow evaporation factor	0.10	0.0 - 0.5
CCFACT	Condensation/convection melt factor	0.2[2]	0.5 - 8.0
MWATER	Liquid water storage capacity in snowpack	0.03 pervious and 0.05 impervious	0.005 - 0.2
MGMELT	Ground heat daily melt rate	0.0001 pervious and 0.00001 (lower values on impervious surface likely to have snow piles)	0.0 - 0.1

Summary snow calibration statistics for the two weather regions containing the Duluth International Airport are provided in Table 4-2.. Total error on modeled snow depth is within 16% of the NCDC observations estimates with very high correlation coefficients and Nash-Sutcliffe coefficients. These values indicate reasonable performance.

[1] The recommended range is at its highest for generalized forest. The Duluth model treats evergreen forest separately, so a higher shade value is appropriate.
[2] A value of CCFACT below the typical range was derived through calibration and is believed to represent reduced rates of heat exchange with the atmosphere in urban conditions with significant snow compaction

Table 4-2. Summary of Snow Calibration Results at Duluth International Airport

Weather Region	Snow Depth		
	Total Error*	Daily R^2	Daily NSE
750788	-3.21%	0.948	0.894
750789	15.95%	0.933	0.809

* Total error is calculated as the Δ = (simulated - observed)/observed

Representative graphical comparisons of snow depth and snow water equivalent for weather region 710791 (northern Lester River; see Figure 2-5.) are shown in Figure 4-1. and Figure 4-2., and show daily snow depth and snow water equivalents against SNODAS estimates, respectively. Graphical comparisons for all the weather regions are provided in Appendix A. The model shows a good qualitative fit for snow depth and water equivalent for all weather regions in the watershed in comparison to the SNODAS data. The model may be overestimating snow depth and snow water equivalent in the winter of 2004-2005 however it is not known whether the model is predicting high or SNODAS estimates are low.

The fit to snow depth and snow water equivalent is approximate given uncertainties that exist in the development of snow estimates from of remotely sensed data for the SNODAS dataset. It is also important to note that snow fall and melt in the model are highly sensitive to ambient air temperature. Small inconsistencies in air temperatures may have potentially significant impacts on snow behavior, including whether precipitation is interpreted by the model as snow. As shown in Table 4-1., calibration for hydrology incorporated snow catch factors that are greater than one for all of the weather regions; the snow catch factors compensate for the fact that snow depth may be under-estimated due to wind effects, characteristics of remote sensing technology, and ground gage efficiency and exposure.

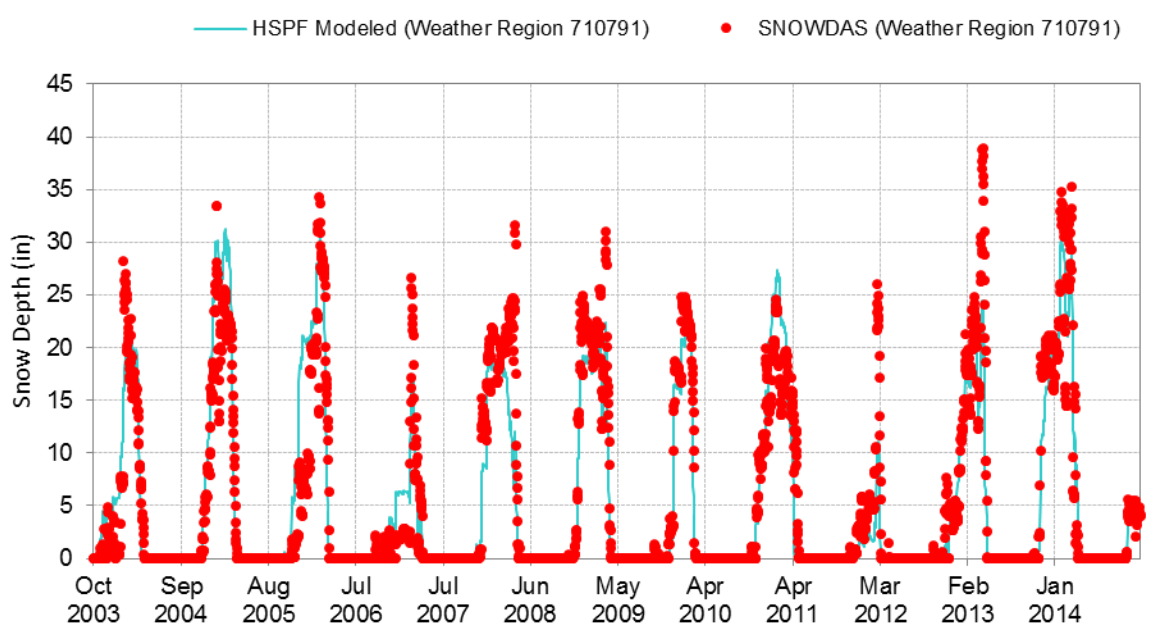

Figure 4-1. Daily Snow Depth in the Duluth WRAPS Watershed Model for Weather Region 710791 (10/1/2003 – 12/31/2014)

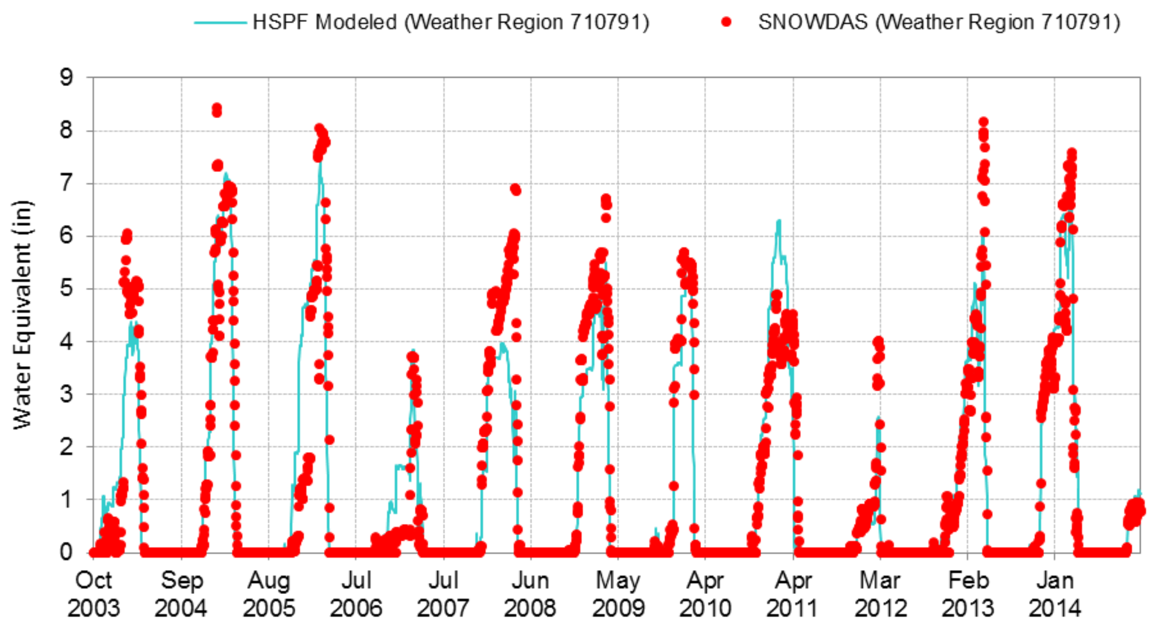

Figure 4-2. Daily Snow Water Equivalent in the Duluth WRAPS Watershed Model for Weather Region 710791 (10/1/2003 – 12/31/2014)

4.2 Constraints on Soil Moisture Balance and Evapotranspiration

Evapotranspiration is the sum of evaporation from soil, water, and leaf surfaces and transpiration of soil water by plants. Evapotranspiration (ET) is the largest component of the water balance and is thus crucial to hydrologic calibration. Actual ET is often unconstrained in watershed models due to a lack of observed data. This issue was addressed for the Duluth WRAPS watershed model through the use of remotely sensed ET data. The MODIS Global Evapotranspiration Project (MOD16) provides estimates of global terrestrial ET by using satellite remote sensing data at a spatial scale of 1 km^2 grid and at temporal scales of 8-days, months, and yearly totals from 2000 to 2014. It is important to recognize that MODIS does not directly measure evapotranspiration. Rather, an algorithm that considers MODIS land cover, albedo, leaf area index, and enhanced vegetation index is combined with daily meteorological data from NASA's Global Modeling and Assimilation Office reanalysis datasets using a Penman-Monteith type of approach (Mu *et al*., 2011). A validation study (Velpuri *et al*., 2013) showed that MODIS was able to estimate monthly ET within about 25 percent based on comparison to FLUXNET studies. These data are thus imprecise, but are useful to check that modeled ET patterns are realistic.

Monthly ET estimates for the watershed were extracted from the global MOD16 dataset. The gridded data were then aggregated to the level of the weather regions and then averaged across the model domain to generate an average monthly estimate for the study area. The average monthly estimate data were compared to actual ET (TAET) simulated by the model and used to inform the pan coefficients used to convert Penman Pan PET to land surface PET in the model. Pan evaporation coefficients for all weather regions were set to 0.70. The pattern of observed monthly evapotranspiration was also used to refine the MON-INTERCEP and MON-LZETPARM blocks in the HSPF model.

Figure 4-3. shows mean monthly simulated evapotranspiration in comparison with MODIS estimates for the Duluth WRAPS watershed model. In general, the simulated ET is similar to that estimated by MODIS (given the uncertainty level of approximately 25%), except in the winter months. MODIS estimates in the winter months are generally higher than that simulated by HSPF. It is not clear if this represents systematic over-estimation by MODIS or under-estimation by the HSPF snow sublimation algorithms; however, similar results have been observed in the St. Louis River and Superior South watersheds as well as in other Minnesota HUC8 HSPF models. MODIS also predicts a slower ramp up of spring – early summer ET than is necessary to predict summer flows. This may be because the MODIS algorithm relies on leaf area whereas a significant portion of the total evaporation during early periods of plant growth may come directly from the soil surface.

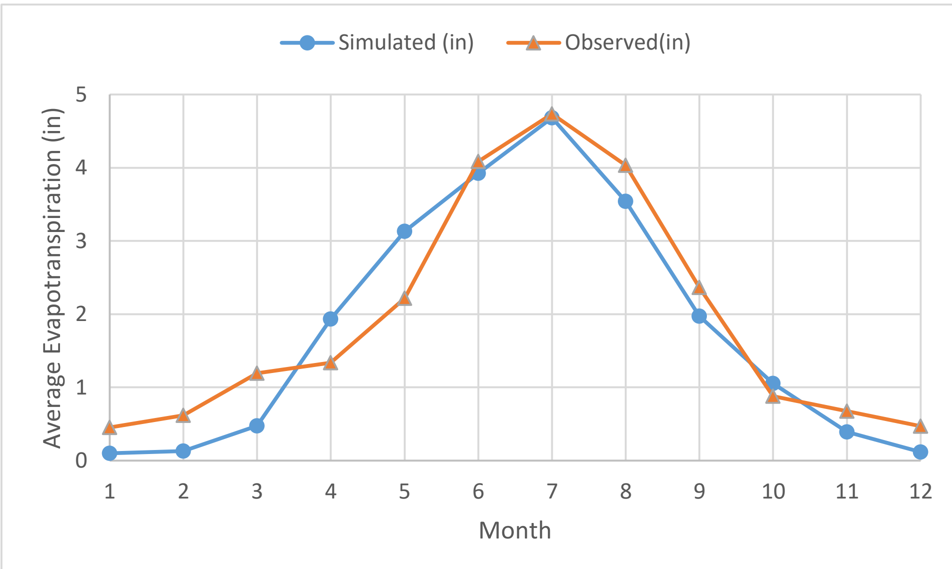

Figure 4-3. Comparison of Average Monthly Simulated Evapotranspiration to MODIS Estimates for Duluth WRAPS Model Watersheds

4.3 Flow Calibration

Table 4-3. provides the stations used for model calibration and validation along with the period of available data at each gage. Several of the available flow gages have very brief periods of record; for others, the quality of the rating curves used to convert observed depth to flow is questionable, as discussed in Section 3.1.1.1. Many of the gages do not operate in winter, and the seasonal start often occurs during spring snowmelt, so complete water balances cannot be calculated. The hydrologic response of a stream to weather events incorporates persistence due to the effects of antecedent soil moisture and groundwater stores, and statistics for short periods of record can easily be distorted by an imprecise estimation of the volume of one or two storm events. For watershed model calibration we prefer to use continuous gage records of 10 years in length to average out the impacts of these temporal distortions and specify a separate time period for model validation. Such data are not available for the Duluth WRAPS streams. During initial model development in 2016, we chose seven gage records for calibration (indicated in Table 4-3.) and reserved two records for model validation. For the 2019 model update there were six new gages with short periods of record (two seasons with gaps during winter), so these were used for additional validation. Records were also available for less than four months during 2016 at two gages on Buckingham Creek; however, the gages were not used due to the extremely short monitoring periods as well as concerns about the quality of the flow records. In general, model fit statistics for gage records less than three years in length should be considered highly uncertain.

Table 4-3. Flow Monitoring Stations in the Duluth WRAPS Study Area used for Calibration and Validation

Station ID	Source	Location	Begin	End	Cal	Val
02038001	HYDSTRA	Amity Creek at Duluth, Occidental Blvd	4/10/2002	12/2/2016	X	
S004-952	Duluth Streams	Kingsbury Creek at Lake Superior Zoo	7/16/2002	6/8/2012	X	
02036003	HYDSTRA	Lester River near Duluth, CSAH10	4/21/2011	11/19/2016	X	
03-001-001	SAFL	Miller Creek Lower Site at 26th Ave	5/1/1997	11/24/1998	X	
03-001-003	SAFL	Miller Creek Middle Site at Chambersburg Street	7/15/1997	11/24/1998	X	
03-001-002	SAFL	Miller Creek Upper Site at Miller Hill Mall	3/20/1997	11/24/1998	X	
S004-364	Duluth Streams	Tischer Creek at Wallace Ave "Mt. Royal"	10/1/2002	6/18/2012	X	
02037005	HYDSTRA	East Branch Amity Creek at Duluth	4/10/2011	11/14/2013		X
03001001	HYDSTRA	Miller Creek Lower Site at 26th Ave	4/1/2005	11/3/2010		X
02040008	HYDSTRA	Chester Creek at Duluth, W College St	4/13/2015	12/2/2016		X
03189016	HYDSTRA	Keene Creek at Duluth, S 57th Ave W	4/13/2015	12/6/2016		X
03163011	HYDSTRA	Merritt Creek at Duluth, Grand Ave	4/13/2015	11/18/2016		X
03001012	HYDSTRA	Miller Creek at Duluth, S 24th Ave W	4/13/2015	11/19/2016		X
03010003	HYDSTRA	Mission Creek nr Fond du Lac, 1 mi us of MN23	7/16/2015	11/17/2016		X
02039008	HYDSTRA	Tischer Creek at Duluth, Wallace Ave	4/14/2015	12/3/2016		X

The starting point for hydrologic parameters was provided by HSPF model applications in the adjacent Superior South, St. Louis River, and Cloquet River watersheds, all of which overlap to some extent with the Duluth WRAPS study area. These starting values were then modified during calibration to optimize model fit while remaining within ranges recommended by USEPA (2000) and AQUA TERRA (2012). Key hydrology parameters adjusted during calibration were INFILT (infiltration capacity of the soil), AGWRC (base groundwater recession), KVARY (variable groundwater recession), LZETP (lower zone e-t parameter), and the overall simulated response of the wetland land use. Final parameter values are contained in the accompanying model user control input (.uci) file.

Calibration was completed by comparing time-series daily average model results to gaged daily average flow. Key considerations in the hydrology calibration were the overall water balance, the high-flow to low-flow distribution, storm flows, and seasonal variations. The criteria pre-specified in Table 3-5. were used to evaluate the quality of model fit.

Results of the hydrologic calibration are summarized in Table 4-4.. Detailed results of the hydrologic calibration are provided in Appendix B.

Table 4-4. Summary of Hydrologic Calibration Results

Station ID	Location	Calibration Dates	Error in Total Flow Volume	Error in 50% Low Flows	Error in 10% High Flows	Daily NSE	Monthly NSE
02038001	Amity Creek at Duluth, Occidental Blvd	4/10/2002 – 12/2/2016	-5.63%	26.94%	-13.95%	0.734	0.812
S004-952	Kingsbury Creek at Lake Superior Zoo	7/16/2002 - 6/8/2012	-38.89%	-31.61%	-43.20%	0.334	0.274
02036003	Lester River near Duluth, CSAH10	4/21/2011 – 11/19/2016	-24.31%	-31.94%	-26.76%	0.598	0.810
03-001-001	Miller Creek Lower Site at 26th Ave	5/1/1997 - 11/24/1998	-8.08	-45.17	-11.64	0.469	0.714
03-001-003	Miller Creek Middle Site at Chambersburg Street	7/15/1997 - 11/24/1998	-4.55%	12.44%	-10.44%	0.427	0.739
03-001-002	Miller Creek Upper Site at Miller Hill Mall	3/20/1997 - 11/24/1998	-9.42%	-23.67%	-4.90%	0.331	0.921
S004-364	Tischer Creek at Wallace Ave "Mt. Royal"	10/1/2002 - 6/8/2012	-13.24%	-47.76%	-12.34%	0.528	0.756

In many cases, the model appears to under-predict flow volumes. Nonetheless, the error in total flow volume is rated as “good” or “very good” for four of the seven sites and as “fair” for Tischer Creek. The total volume fit is “poor” for Lester River and Kingsbury Creek. For Lester River there is no wintertime monitoring, and it appears the model may be representing snowmelt too early resulting in much of the snowmelt volume being discharged before springtime monitoring begins. Statistics for Kingsbury Creek are affected by the apparent under-estimation of two large storm peaks in November 2008 and April 2012 (see Appendix B); however, these reported peaks do not appear to be explained by the precipitation record. As discussed in Section 3.1.1.1, the flow rating curve for this station reflects limited field data for finding a stage-flow relationship and no high flows, so the specification of the rating curves for high flows is highly uncertain.

Statistics for the 10% highest flows generally match those for the total flow volume error, and are again ranked as “poor” for Kingsbury Creek and Lester River. In contrast, the fit for flows below the median ranked as “poor” at five stations, “fair” at one, and only ranked as “good” for the Miller Creek Middle site. Baseflows for many of these urban streams are less than 2 cfs, which could lead to larger uncertainty bounds in the gage record; however, it is also possible that there are unaccounted for sources of flow, ranging from lawn irrigation to regional groundwater discharge.

The degree to which relatively poor model fit statistics is due to uncertainties in the gage records is unresolved; many of the other components of the water balance appear to be well constrained, including precipitation (Section 2.2), snow depth (Section 4.1), and soil moisture and evapotranspiration (Section 4.2). In addition, it appeared that adjacent gages (such as Lester River and Amity Creek) required different sets of parameters to achieve optimal fit, so the final parameter set represents a compromise. It is believed that the most reliable flow gages are the MNDNR/HYDSTRA gages with long records on Amity Creek (a calibration station) and Miller Creek (a validation station) and greater weight should be placed on results from those stations. Relatively good performance of the models for predicting suspended sediment concentrations (Section 5.5) suggest that the model simulation of flow is reasonable.

4.4 FLOW VALIDATION

Validation of the hydrologic model uses eight gages, as noted above. Validation was completed after model calibration to test model performance.

Detailed results of the hydrologic validation are provided in Appendix C and summarized in Table 4-5.. Flow volumes are predicted well with five of the eight sites rated as “good” or “very good”. The 10% highest flows are also predicted well, with four sites rated “very good” and one site rated “good”. As was the case with the calibration, the 50% lowest flows were not predicted as well, although three sites were rated as “good” or “very good”. The success of the validation is especially encouraging given the short periods of record (only two years) at seven of the eight sites.

Table 4-5. Summary of Hydrologic Validation Results

Station ID	Location	Validation Dates	Error in Total Flow Volume	Error in 50% Low Flows	Error in 10% High Flows	Daily NSE	Monthly NSE
02037005	East Branch Amity Creek at Duluth, 1.8 mi ds of CSAH37	4/10/2011 - 11/14/2013	-27.77	-22.24	-30.02	0.706	0.683
03001001	Miller Creek at Duluth, 26th Ave W & W Michigan	4/1/2005 - 11/3/2010	-1.63%	-22.38%	-3.73%	0.548	0.766
02040008	Chester Creek at Duluth, W College St	4/13/2015 - 12/2/2016	-8.53	5.95	-10.42	0.628	0.736
03189016	Keene Creek at Duluth, S 57th Ave W	4/13/2015 - 12/6/2016	-11.36	-33.89	-7.51	0.613	0.599
03163011	Merritt Creek at Duluth, Grand Ave	4/13/2015 - 11/18/2016	2.53	-14.19	4.08	0.583	0.315
03001012	Miller Creek at Duluth, S 24th Ave W	4/13/2015 - 11/19/2016	-5.11	-46.26	0.8	0.403	0.731
03010003	Mission Creek nr Fond du Lac, 1 mi us of MN23	7/16/2015 - 11/17/2016	29.72	13.78	36.57	0.397	0.59
02039008	Tischer Creek at Duluth, Wallace Ave	4/14/2015 - 12/3/2016	0.01	-43.99	18.92	0.607	0.747

4.5 WATER BALANCE SUMMARY

The overall water balance estimated by the model for the study area is summarized in Figure 4-4.. The major component of outflow is ET, although the fraction of supply going to ET is somewhat lower than would be expected for this ecoregion (Sanford and Selnick, 2013), reflecting the large amount of urban impervious cover in the watershed, which promotes direct surface runoff. Approximately 60% of precipitation is returned to the atmosphere through evapotranspiration, while approximately 40% becomes stream flow.

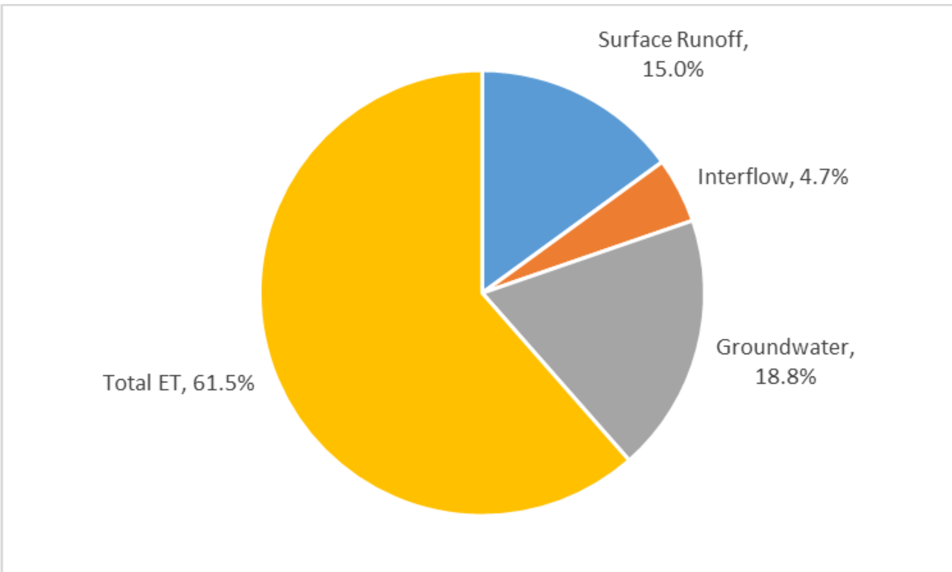

Figure 4-4. Summary Water Balance for the Duluth WRAPS Model, Oct 1995 – Sep 2016

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5 Sediment Calibration

Sediment calibration followed the sequential procedure outlined in Section 3.3. First, the simulated sediment yields from diverse land uses in the watersheds were compared to reference values. Key parameters that control the upland sediment simulation were refined to achieve reasonable yields. The next step in the sediment calibration was to represent appropriate division of sediment derived from upland build-up and washoff, gully erosion along road rights-of-way, and from near-channel sources (bluff slumping/collapse and channel incision). Lastly, the instream sediment calibration was fine-tuned; this consisted of calibrating suspended sediment in the reaches and reviewing the sediment bed simulation to ensure that the net deposition/scour in the reaches was reasonable.

The simulation of sediment depends directly on the simulation of flow. Discrepancies between simulated and gaged flow were discussed above in Section 4.3, where it was noted that it is not possible to resolve the relative contributions to apparent uncertainty from the quality of the gage records and the actual performance of the model. To the extent that these issues are due to the model itself they will also affect the sediment calibration. Because the movement of sediment is driven by flow, the quality of the sediment simulation cannot be any better than the simulation of flow, especially as regards storm events.

5.1 Detached Sediment Storage

Time series of detached sediment storage (DETS) were checked for reasonableness, defined as exhibiting a quasi-stationary equilibrium with seasonal changes from wet to dry periods. Example series from the northeastern part of the study area in the vicinity of Amity Creek are shown in Figure 5-1.. Storage on residential land uses is more dynamic than forest due to a combination of higher accumulation rates and greater transport capacity that reduces storage during runoff events.

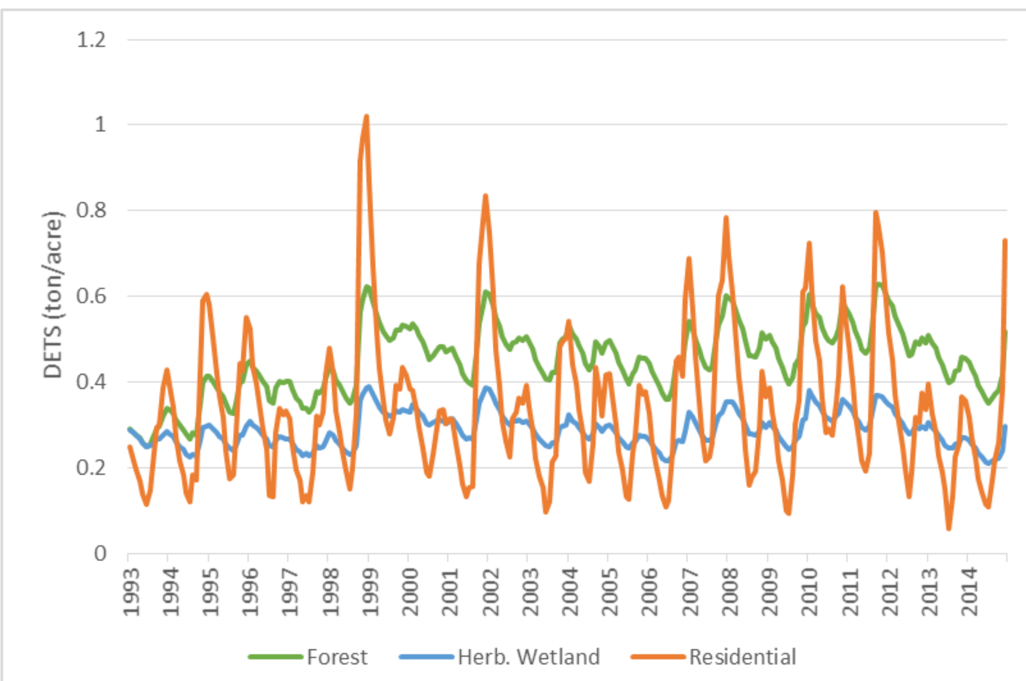

Figure 5-1. Example Detached Sediment Storage (DETS) Series in the Vicinity of Amity Creek

5.2 Upland Sediment Loading Rates

Sediment calibration for watershed models involves numerous steps in estimating model parameters and determining appropriate adjustments needed to insure a reasonable simulation of the sediment sources on the watershed, delivery to the waterbody, and transport behavior within the channel system. When performing sediment calibration in HSPF for the Duluth WRAPS project, we followed the process discussed in AQUA TERRA (2012) as well as USEPA (2006). While there are many steps in the process, the overarching goal is to achieve an appropriate balance between upland and near-channel sources. Upland sediment loading rates vary widely from place to place and are influenced by local conditions such as soil erodibility, slope, and precipitation patterns. Land use also has a strong influence on sediment yield, and most studies show the lowest rates from forest and other uses with good vegetation cover, somewhat higher rates for relatively unmanaged grasslands, high rates for developed land and pasture/hay production, and the highest rates for cropland. Loading rates from urban land can be elevated by the effects of flow concentration from impervious surfaces, higher runoff volumes, and erosion hotspots in ditches and ephemeral headwater channels receiving flow from storm drains. Studies of sediment yield do not currently exist for the area simulated in the Duluth WRAPS model. However, there are some studies from nearby watersheds and other regional information that were used to constrain upland loading rates for specific land uses. Table 5-1. provides loading rates and data sources used to inform the model calibration for upland loading rates by land use.

Table 5-1. Reference Ranges for Sediment Loading Rates

Land Use	lb/acre/year	Source	Location
Forest	32	Nieber et al., 2013	Poplar River
	24	Tetra Tech (2016c)	Lake Superior South
Grassland	58	Tetra Tech (2016c)	Lake Superior South
	40 – 220	AQUA TERRA (2015)	State of Minnesota
Pasture/Hay	150 – 225	Tetra Tech (2016c, 2016a)	Lake Superior South, St. Louis River
	400 – 2,000	AQUA TERRA (2015)	State of Minnesota
Mixed Urban	~200	MS4 summary from MPCA[1]	MS4 urban stream monitoring in Duluth
	220 – 500	AQUA TERRA (2015)	State of Minnesota
Road	206 – 258	Tetra Tech (2016c)	Lake Superior South, Lake Superior North
	208 – 270	Tetra Tech (2016a)	St. Louis River, Nemadji River

1. Spreadsheet provided by Mike Trojan, MPCA via Chuck Regan, MPCA to J. Butcher, Tetra Tech, 2/10/2015

Figure 5-2. presents the average annual calibrated unit area loads for each land use in the Duluth WRAPS watershed model. The land uses classes of Developed Residential, Developed Low Intensity, Developed High Intensity, Road, and Outcrop are made up of both pervious and impervious classes. The average area weighted percent impervious area for each land class was determined and then that information was used to determine the portion of sediment coming the pervious versus impervious land classes. The calibrated unit area loads compare reasonably well with the reference ranges and the assumed land use progression of low to high sediment yields.

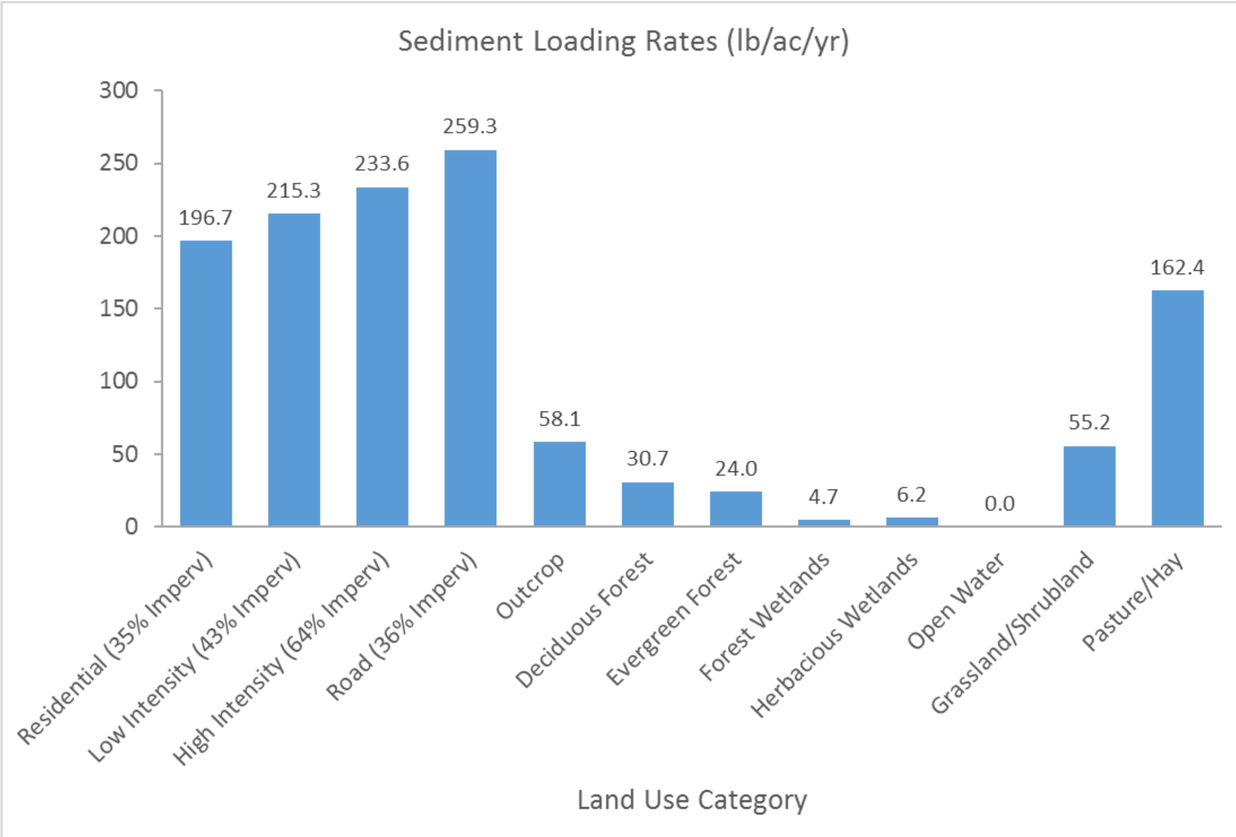

Figure 5-2. Annual Average Upland Sediment Yields (1995 – 2015) for the Duluth WRAPS Model

5.3 BLUFF LOADING AND ERODING BANKS

Geomorphic data collected throughout the Duluth WRAPS study area and other studies conducted in the Duluth region were used to inform, and in some cases, calibrate the model representation of near-channel loads (Table 5-2). A considerable amount of information is available in the publications listed below. For instance, extensive field work conducted on selected streams in the Lake Superior South watershed (a portion of which overlaps the Duluth WRAPS study area) suggest that a large fraction of the sediment load originates from eroding banks and mass collapse of bluffs (Nieber et al. 2008; Neitzel 2014). Many of these documents and resources provide general and detailed information about erosion risk and geomorphic conditions in the impaired watersheds.

Table 5-2. Studies Used to Support Representation of Near Channel Erosion in HSPF

Citation	Title
Czuba, C.R., J.D. Fallon, and E.W. Kessler, 2012	Floods of June 2012 in northeastern Minnesota: USGS Scientific Investigations Report 2012–5283
Fitzpatrick, F.A., C.A. Ellison, C.R. Czuba, B.M. Young, M.M. McCool, and J.T. Groten, 2016	Geomorphic Responses of Duluth-Area Streams to the June 2012 Flood, Minnesota: U.S. Geological Survey Scientific Investigations Report 2016-5104
Fitzpatrick, F.A., M.C. Peppler, M.M. DePhilip, and K.E. Lee, 2006	Geomorphic Characteristics and Classification of Duluth-Area Streams, Minnesota. USGS Scientific Investigations Report 2006–5029
Gran, K., and M. Wick, 2013	Duluth Flood of June 2012: Stream Visual Assessments
Groten, J.T., and G.D. Johnson, 2018	Comparability of river suspended-sediment sampling and laboratory analysis methods: U.S. Geological Survey Scientific Investigations Report 2018–5023
Hall, L.H., 2016	Monitoring Bluff Erosion Rates Using Terrestrial Laser Scanning on Minnesota's North Shore Streams
Hansen, B., D. Dutton, J. Nieber, A. Gorham, 2010	Poplar River Sediment Source Assessment
Jennings, G. and M. Geenen, 2017	Amity Creek Stressor Identification
Jereczek, J. and C. Little, 2015	Enhancing the Lake Superior North and South Watershed Assessments - Red Clay Bank Analysis
Lahti, L., B. Hansen, J. Nieber, and J. Magner, 2013	Lake Superior Streams Sediment Assessment: Phase I.
Lake Superior Streams, 2009	LakeSuperiorStreams: Community Partnerships for Understanding Water Quality and Stormwater Impacts at the Head of the Great Lakes
Manopkawee, P., 2015	Identifying Erosional Hotspots in Duluth-Area Streams after the 2012 Flood Using High-Resolution Aerial Lidar Data
MPCA, 2013	Poplar River Watershed Total Maximum Daily Load Report
MPCA, 2016	St. Louis River Watershed Stressor Identification Report
Neitzel, G.D, 2014	Monitoring Event-Scale Bluff Erosion with Repeat Terrestrial Laser Scanning, Amity Creek, Duluth, MN
Nieber, J.L., B.N. Wilson, J.S. Ulrich, B.J. Hansen, and D.J. Canelon, 2008	Assessment of Streambank and Bluff Erosion in the Knife River Watershed
Nieber, J.L., C. Arika, B. Hansen, 2013	Lower Poplar River Watershed Sediment Source Assessment
NRRI, 2014	Amity Creek Restoration Project
NRRI, 2015	LiDAR-based Bluff Assessment for Land-use Planning
South St. Louis Soil and Water Conservation District (SSLSWCD), 2017	Duluth Urban Streams - An Implementation Focused Assessment of Six Streams
Wick, M., 2013	Identifying Erosional Hotspots in Streams along the North Shore of Lake Superior, Minnesota using High-Resolution Elevation and Soils

While model development was influenced by most of the studies with information specific to the impaired watersheds, the following studies were critically important to both original model development in 2016 as well as the recent 2019 model update:

- Two USGS studies (Fitzpatrick et al., 2006 and Fitzpatrick et al., 2016) were used extensively to classify model reaches into groups with similar expected long-term near-channel sediment dynamics.
- The NRRI 2015 study identifies high risk bluff areas in Lester River, Amity Creek and Tischer Creek watersheds within the portion of the Duluth WRAPS study area that overlaps with the Superior South watershed. This was used to specify reaches configured to contribute additional loads to the channels due to collapsing bluffs.
- Hall (2016) was used to identify an additional reach in Lester River configured to contribute additional loads due to collapsing bluffs.
- MPCA (2016) was used to update modeled near-channel loads in Kingsbury to be consistent with the relative load contributions indicated from the BANCS modeling.
- SSLSWCD (2017) was used to update modeled near-channel loads in Amity Creek and East Branch Amity Creek to be consistent with the relative load contributions indicated from the BANCS modeling.

The SSLSWCD report was especially useful since the BANCS modeling was conducted for the entire Amity Creek watershed. HSPF near-channel loads were modified during the 2019 model update to be consistent with the predicted reach-scale BANCS loads. Figure 5-3 provides a comparison of HSPF and BANCS results for each HSPF reach. A power regression shows an R^2 of 0.92. It is important to note that, despite the strong correlation, BANCS channel erosion estimates are considerably higher than those modeled by HSPF. There are several likely reasons for the difference: HSPF is calibrated to TSS monitoring data; Groten and Johnson (2018) demonstrated that TSS grab sample concentrations are biased substantially low compared to equal-width increment or equal-discharge-increment suspended sediment concentrations taken in the same location at the same time. TSS grab sampling failed to capture most of the sand being transported by the stream. Since BANCS erosion estimates include the sand component, HSPF load estimates calibrated to TSS concentrations are likely to be lower. In addition, much of the bank collapse represented by the BANCS model is likely to be transported a short distance and deposited on point bars and behind culverts, and thus is not represented in TSS monitored data or HSPF reach export. Finally, BANCS is itself a model subject to uncertainty; while HSPF is also subject to uncertainty, it is ultimately calibrated to observed sediment concentrations and loads across a wide range of flows.

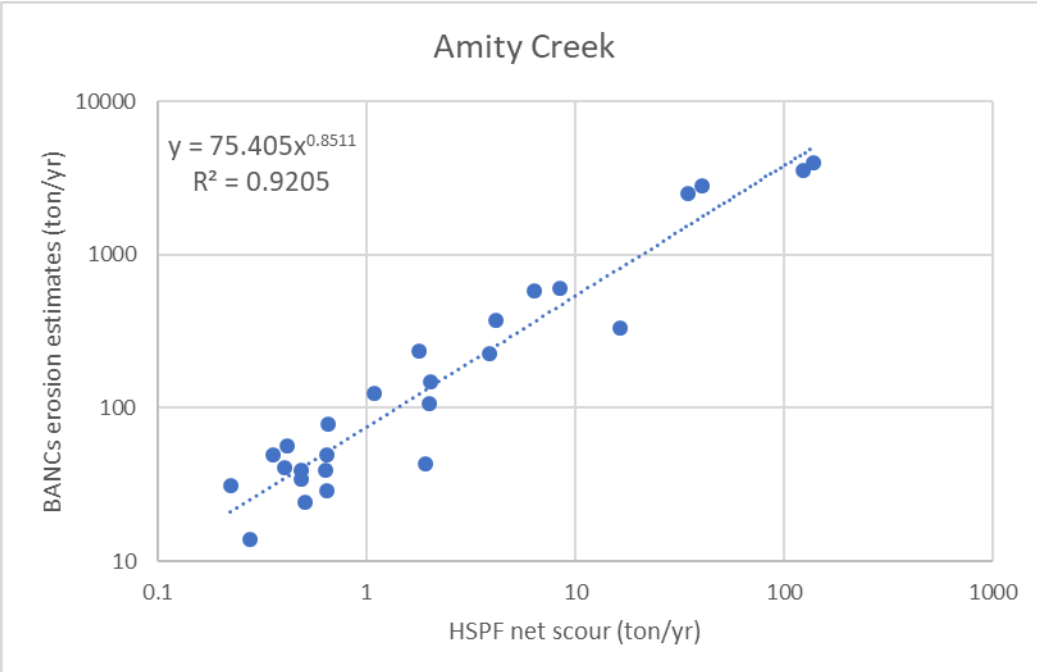

Figure 5-3. Comparison of HSPF-simulated Near-channel loads to BANCS Channel Erosion Estimates in Amity Creek

Bluff erosion is evident in many locations in the Duluth WRAPS area. HSPF can estimate the effect of near-channel erosion during high flow periods; however, HSPF is a one-dimensional flow model and some of the complicated processes associated with bluff erosion cannot be mechanistically simulated. The effects of shallow lateral flow on the mechanical strength of clay soils is a major factor in bluff collapse events, which partially decouples them from instream flow. In essence, bluff and bank collapse events are quasi-random processes. To simulate contributions from reaches with extensive bluff collapse using HSPF, an approach similar to that adopted for the Lake Superior South bluffs was used (Tetra Tech, 2016c). In that approach, the load derived from bluffs (a succession of quasi-random events) is represented by adding a constant load to the bed sediment of reaches with identified high risk bluffs in the NRRI LiDAR analysis (http://www.nrri.umn.edu/coastalgis/newweb/html/bluffs.htm; see example in Figure 5-4). The transport of this additional load is then governed by the shear stresses acting on the reach bed, which enables these loads to be mobilized into the water column during high flows. Lower critical shear stresses and higher erodibility coefficients are used for the reaches receiving bluff loads to reflect the unconsolidated nature of the bluff contributions.

The NRRI study identifies high risk bluff areas in Lester River, Amity Creek, and Tischer Creek watersheds within the portion of the Duluth WRAPS study area that overlaps with the Superior South watershed. Hall (2016) also identifies reaches with large bluff sediment mass contributions measured with terrestrial laser scanning. It is also evident that bluff collapse is an important process on lower Mission Creek, although this is outside the NRRI study area (Fitzpatrick *et al*, 2016; Manopkawee, 2015; Gran and Wick, 2013). Bluff extent on Mission Creek was estimated from aerial photography. The final model simulates bluff loads on reaches 200, 201, 407, 412, 436, 438, 483 and 485 using the constant load addition approach.

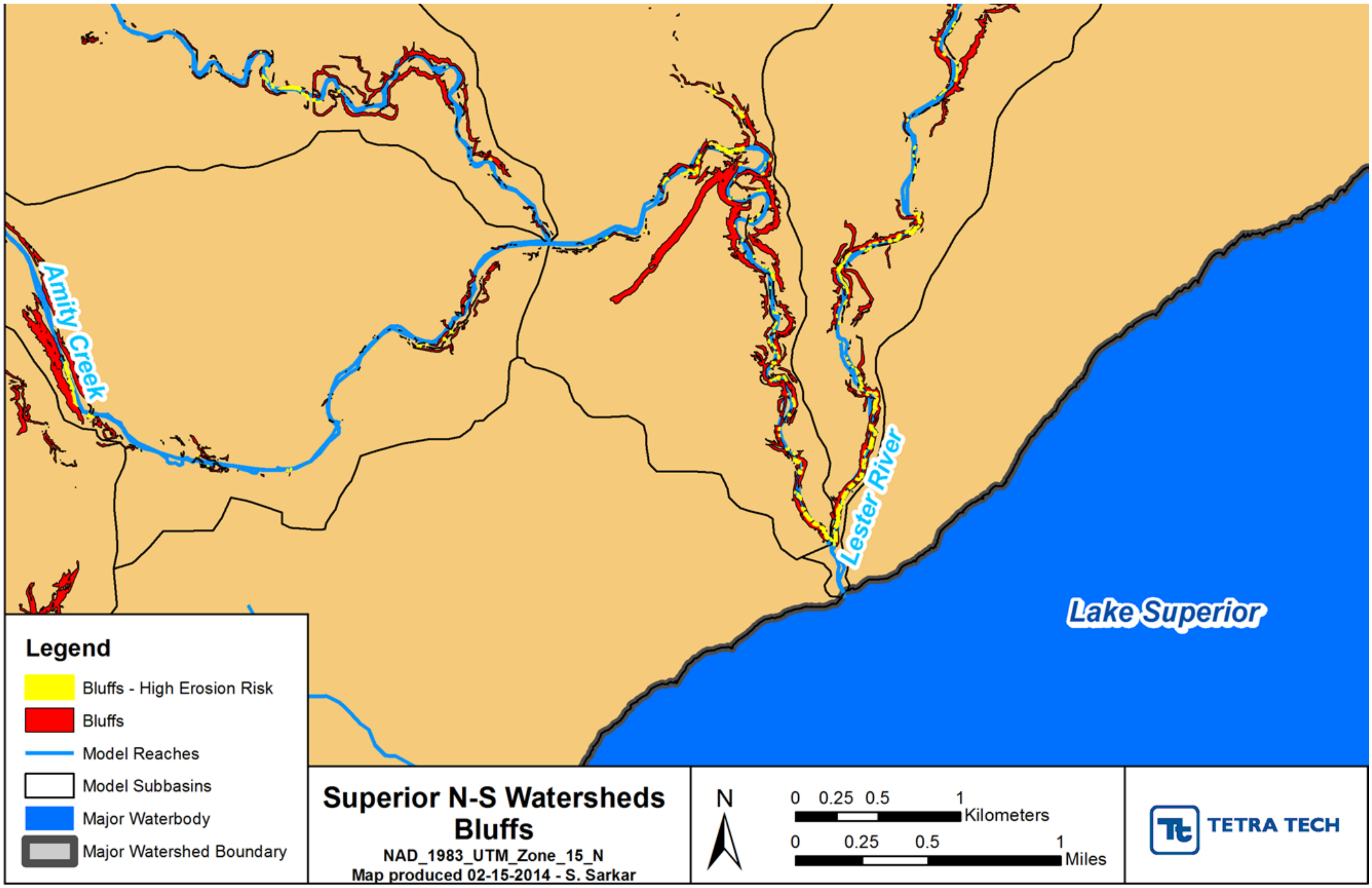

Figure 5-4. Example Areas at High Risk of Bluff Collapse in the Amity Creek and Lester River Watersheds (http://www.nrri.umn.edu/coastalgis/newweb/html/bluffs.htm)

5.4 Reach Sediment Mass Balance

Simulated net sediment scour and deposition was analyzed on a reach by reach basis to ensure that significant amounts of scour and deposition occur only in areas where reasonably expected. Reaches were grouped by their geomorphic classes that were used to develop the FTables. The overarching goal of reach sediment mass balance was to have each group represent the dominant geomorphic process of each class. The geomorphic classes, slope, class description, dominant geomorphic process, and erosion risk were provided previously in Table 2-3..

Sediment bed depth summaries for the Duluth WRAPS watersheds are shown in Figure 5-5 through Figure 5-17. The summaries plot the full simulation period change in bed depth (which is a nominal representation of both channel bed and bank erosion in the one-dimensional HSPF reach model and does not necessarily indicate an actual change in elevation) for each reach within a geomorphic class. Values less than zero indicate net degradation (erosion) and values greater than zero indicate net aggradation (deposition). The majority of the plots have the y-axis scaled from -1.0 to +1.0 for consistency; however, the plots for Class B (Figure 5-6.), Class L1 (Figure 5-7), and Geomorphic Class Conduit (Figure 5-17) were extended to show the full range for the reaches exceeding one foot of aggradation.

The patterns of aggradation and degradation generally match the geomorphic classes, for example, degradation in the L2 mainstem reaches, transport through the bedrock B reaches, and a tendency for aggradation in the A reaches. The pattern is somewhat distorted by bluff contributions in those reaches where bluff loading is simulated, which results in cycles of aggradation and degradation.

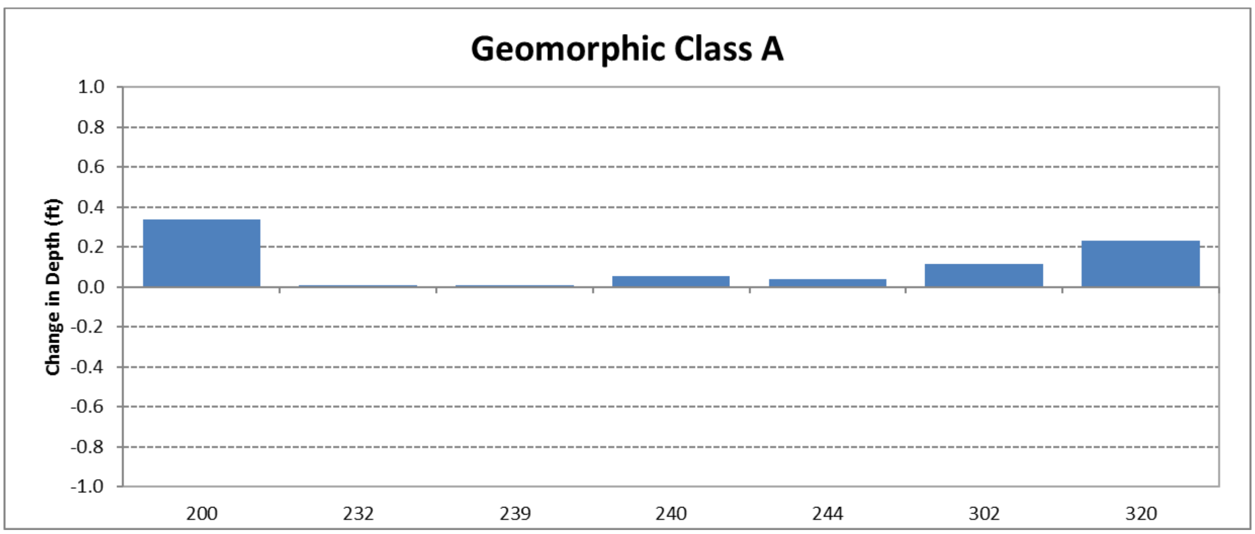

Figure 5-5. Reach Sediment Balance for Geomorphic Class A in the Duluth WRAPS Watershed

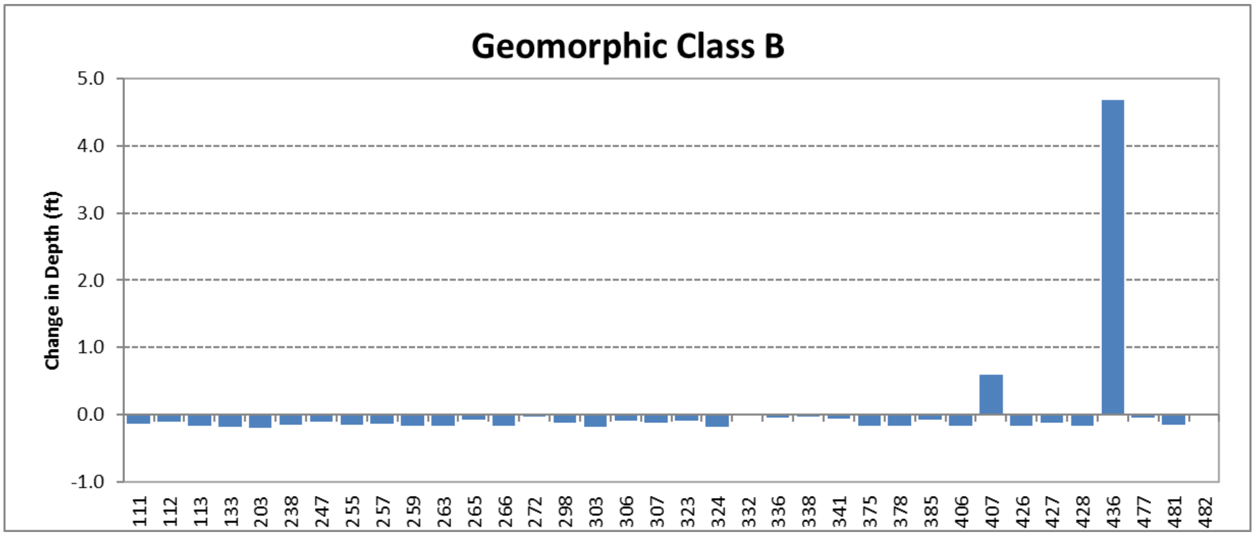

Figure 5-6. Reach Sediment Balance for Geomorphic Class B in the Duluth WRAPS Watershed

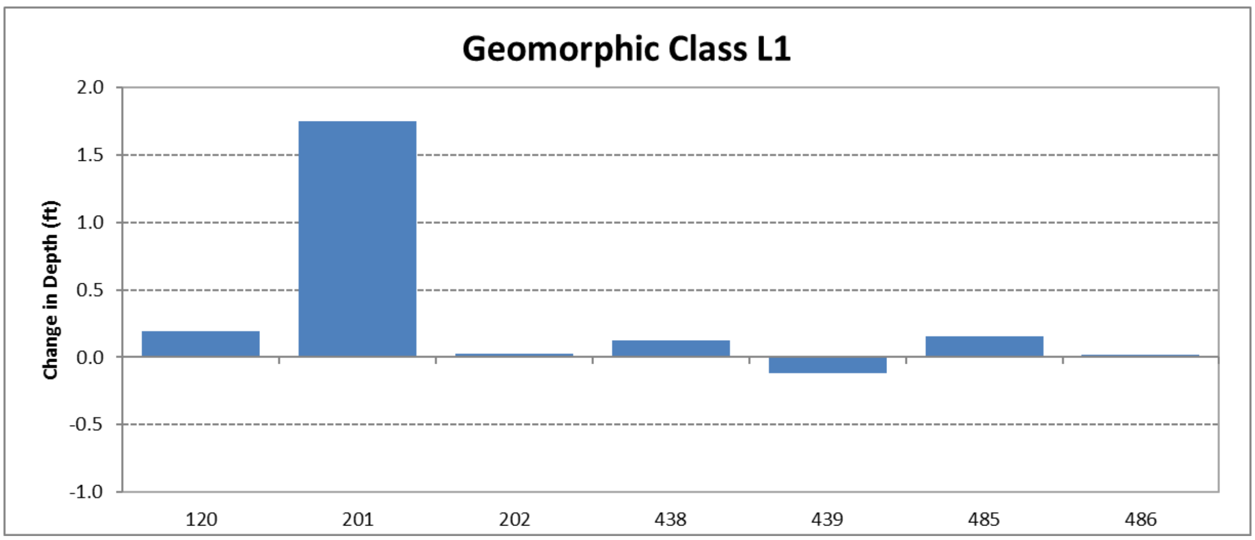

Figure 5-7. Reach Sediment Balance for Geomorphic Class L1 in the Duluth WRAPS Watershed

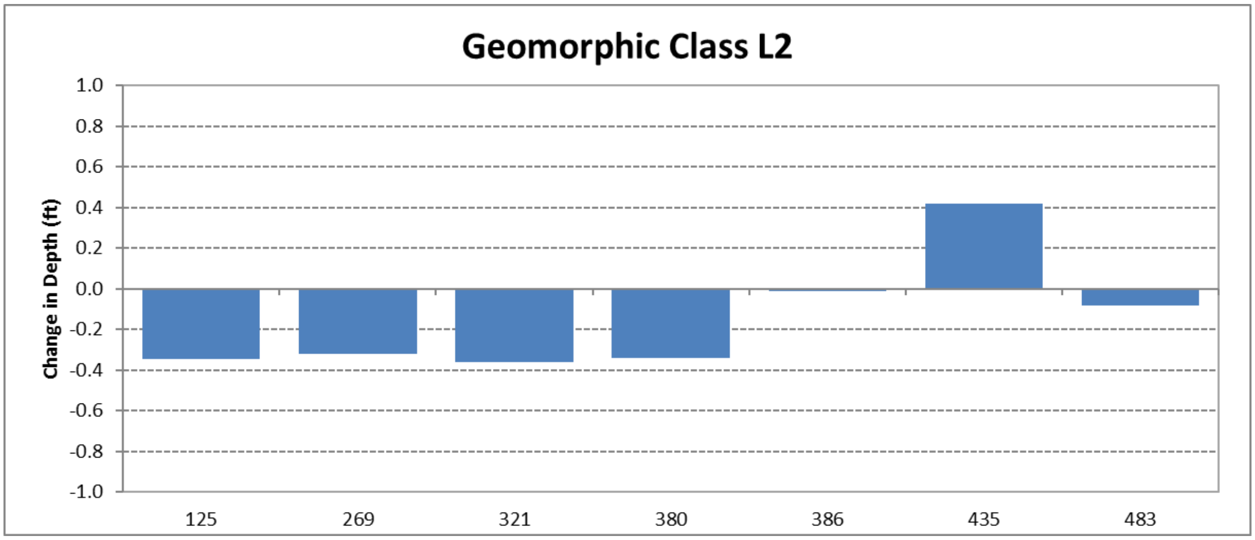

Figure 5-8. Reach Sediment Balance for Geomorphic Class L2 in the Duluth WRAPS Watershed

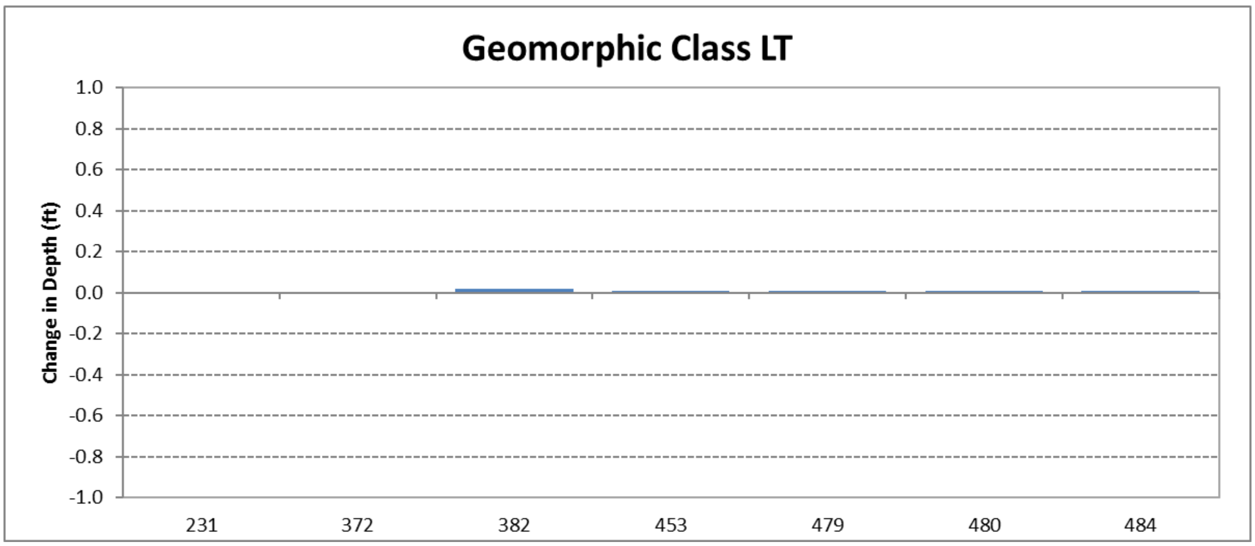

Figure 5-9. Reach Sediment Balance for Geomorphic Class LT in the Duluth WRAPS Watershed

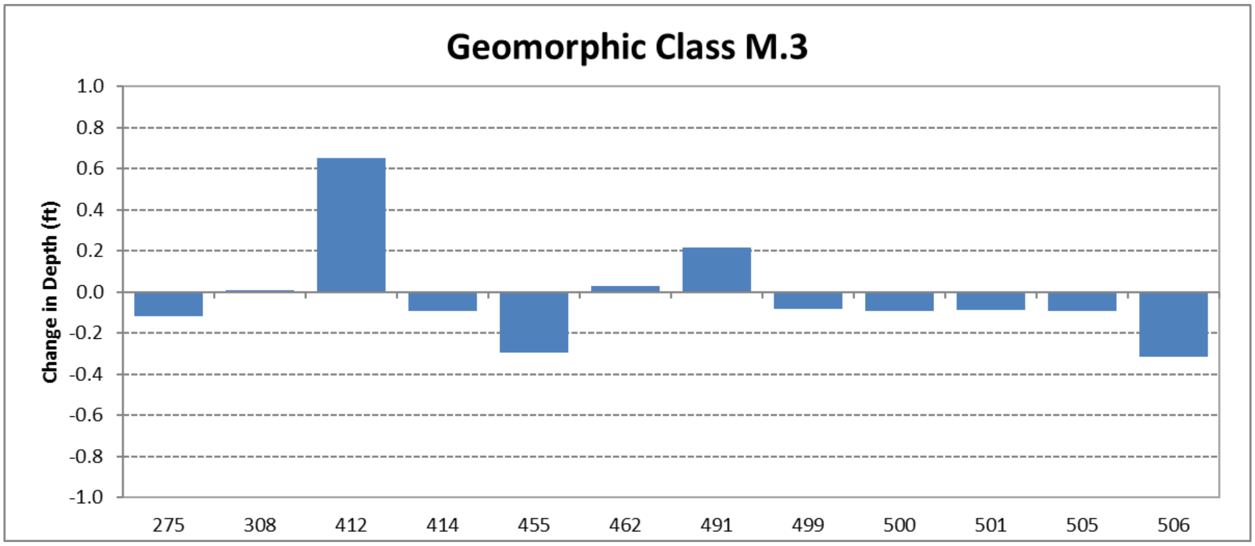

Figure 5-10. Reach Sediment Balance for Geomorphic Class M.3 in the Duluth WRAPS Watershed

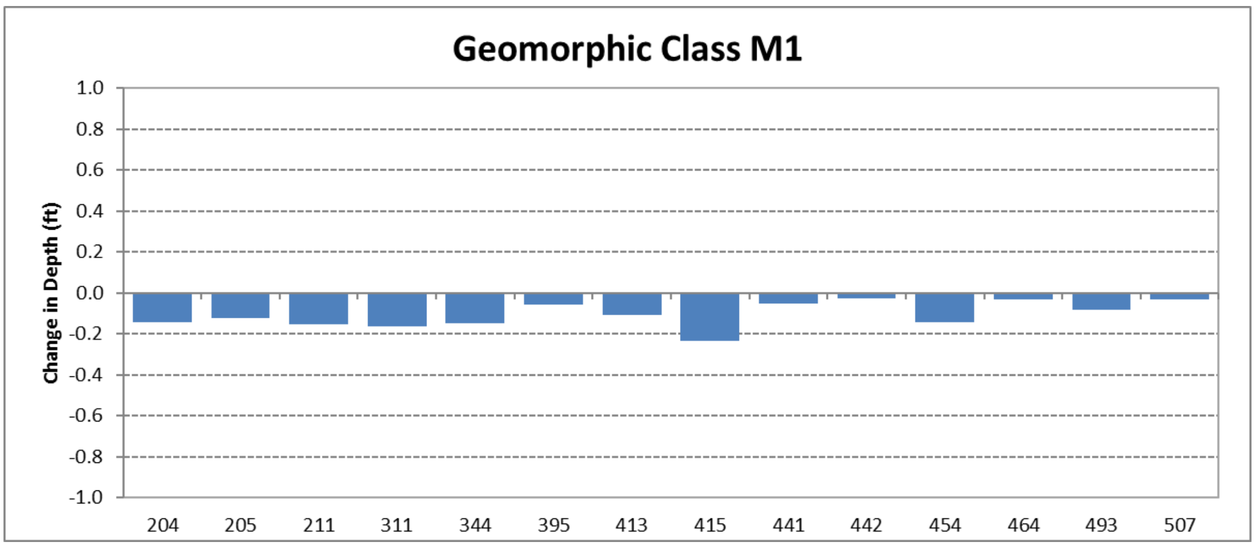

Figure 5-11. Reach Sediment Balance for Geomorphic Class M1 in the Duluth WRAPS Watershed

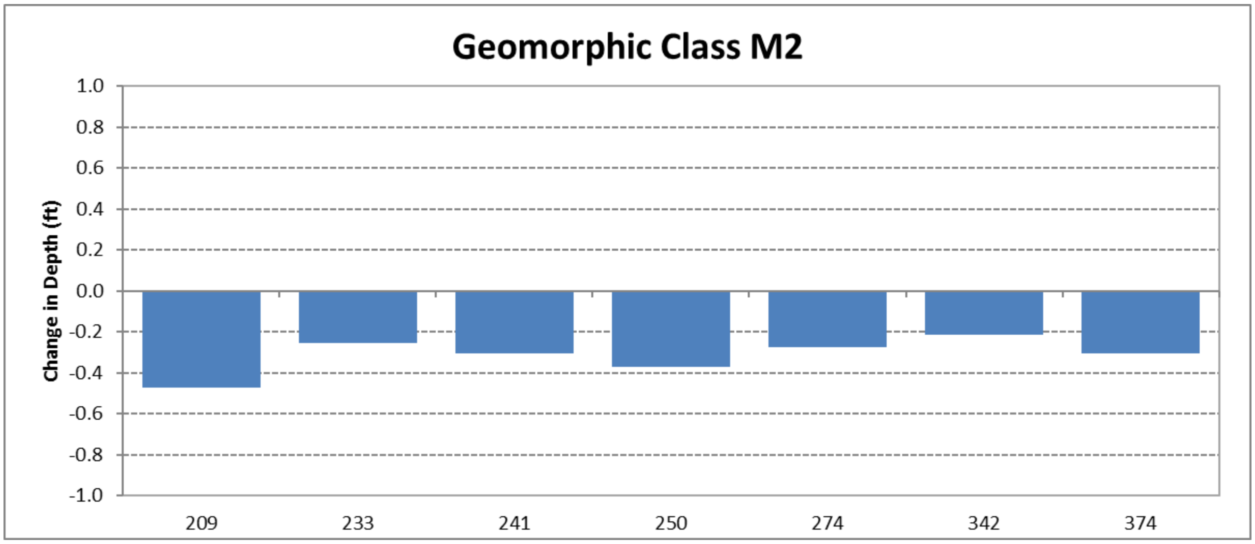

Figure 5-12. Reach Sediment Balance for Geomorphic Class M2 in the Duluth WRAPS Watershed

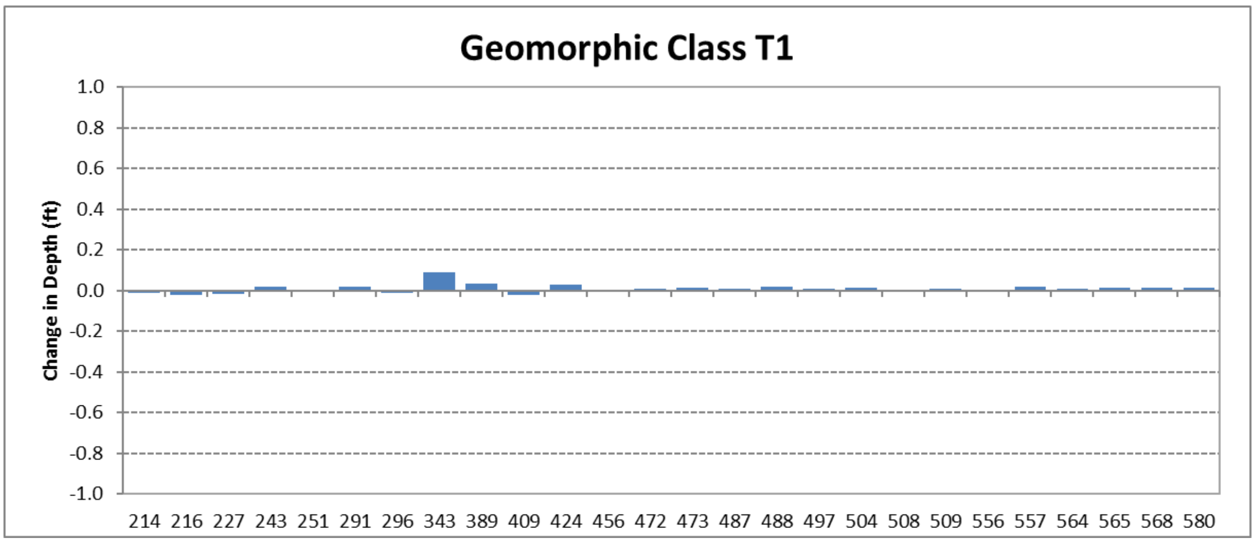

Figure 5-13. Reach Sediment Balance for Geomorphic Class T1 in the Duluth WRAPS Watershed

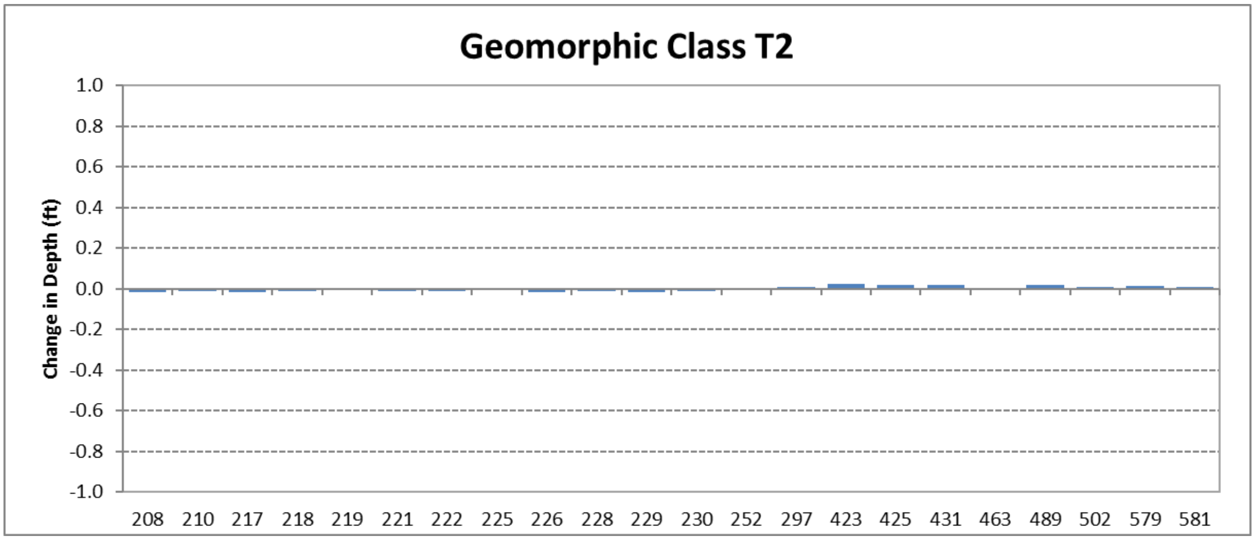

Figure 5-14. Reach Sediment Balance for Geomorphic Class T2 in the Duluth WRAPS Watershed

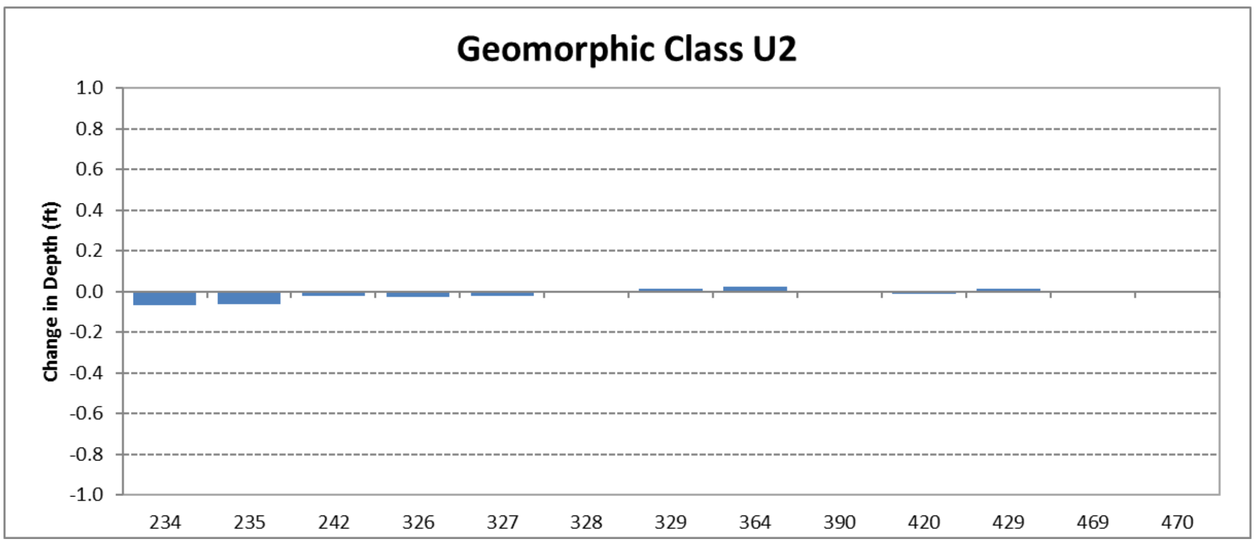

Figure 5-15. Reach Sediment Balance for Geomorphic Class U2 in the Duluth WRAPS Watershed

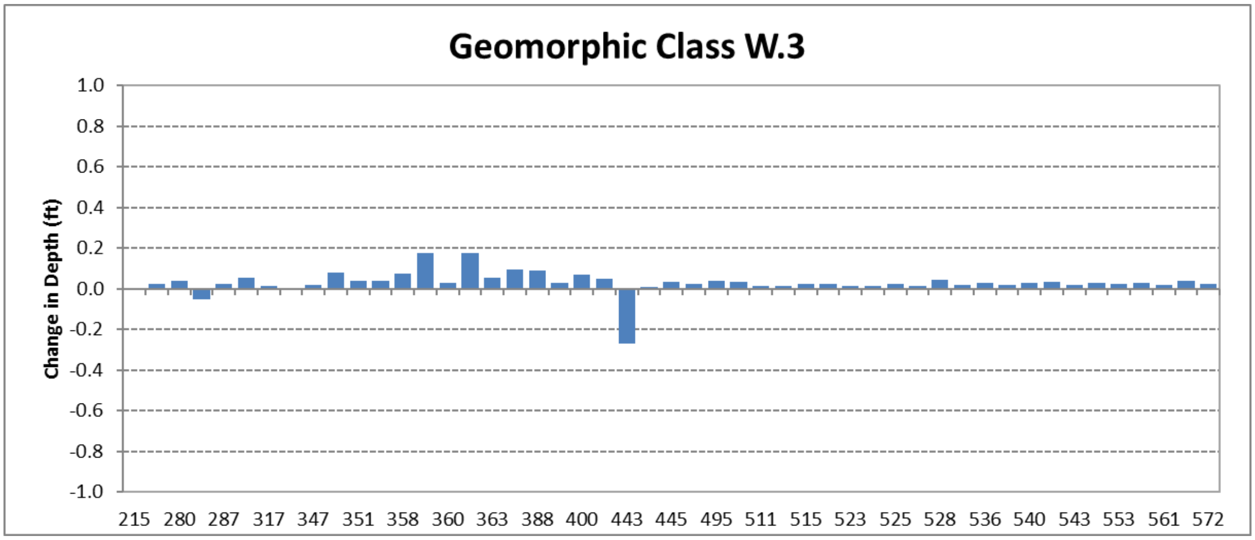

Figure 5-16. Reach Sediment Balance for Geomorphic Class W.3 in the Duluth WRAPS Watershed

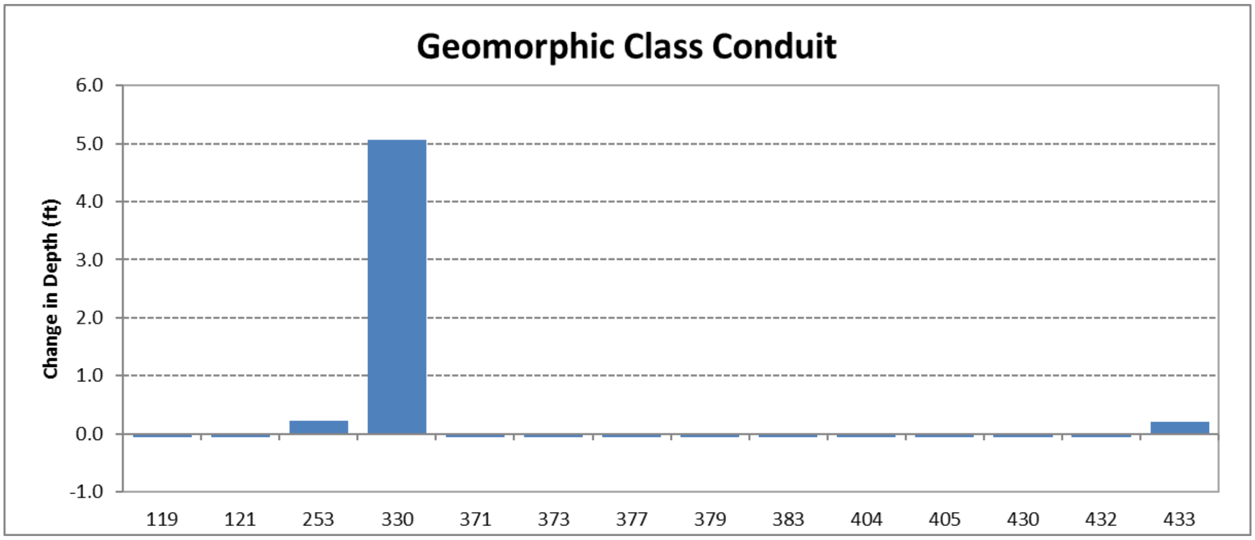

Figure 5-17. Reach Sediment Balance for Conduits in the Duluth WRAPS Watershed

5.5 Calibration to Observed Suspended Solids Data

Suspended sediment calibration took place at reaches across the study area with adequate observations and used both visual and statistical approaches. The calibration time period was selected to be 10/1/2004 through 12/31/2016. For model calibration we attempted to replicate the observed time series while at the same time minimizing relative errors associated with both concentration and load (as inferred from concentration and simulated flow). Attention was paid to matching observed and simulated relationships between load and flow through the use of power plots, while also examining the distribution of error terms relative to both season and flow. It is not uncommon for relative error to be strongly leveraged by one or more outliers (especially for load, which tends to be determined by concentrations at high flows); therefore, the median error (which is not sensitive to outliers) is reported as well as the average error.

The detailed calibration process is shown here for example for the Amity Creek at Occidental Boulevard monitoring station, while a complete set of graphical and statistical results is provided in Appendix D. A total of 143 observations are available at this station for the calibration period. The model appears to track the observed data fairly well, although several very high observations are under-estimated (Figure 5-18). For concentration, the average relative error is ranked as fair (-32.4%), while the median relative error is very good (1.11%), and the average and median relative errors on load are both ranked as very good (-10.2% and 0.03%, respectively). A log-log power plot (Figure 5-19) shows that the observed and simulated loads have a similar distribution relative to flow Lastly, the distribution of prediction errors versus flow (Figure 5-20) shows no bias relative to flow but does show the high negative error associated with the simulation underestimating the highest of observations.

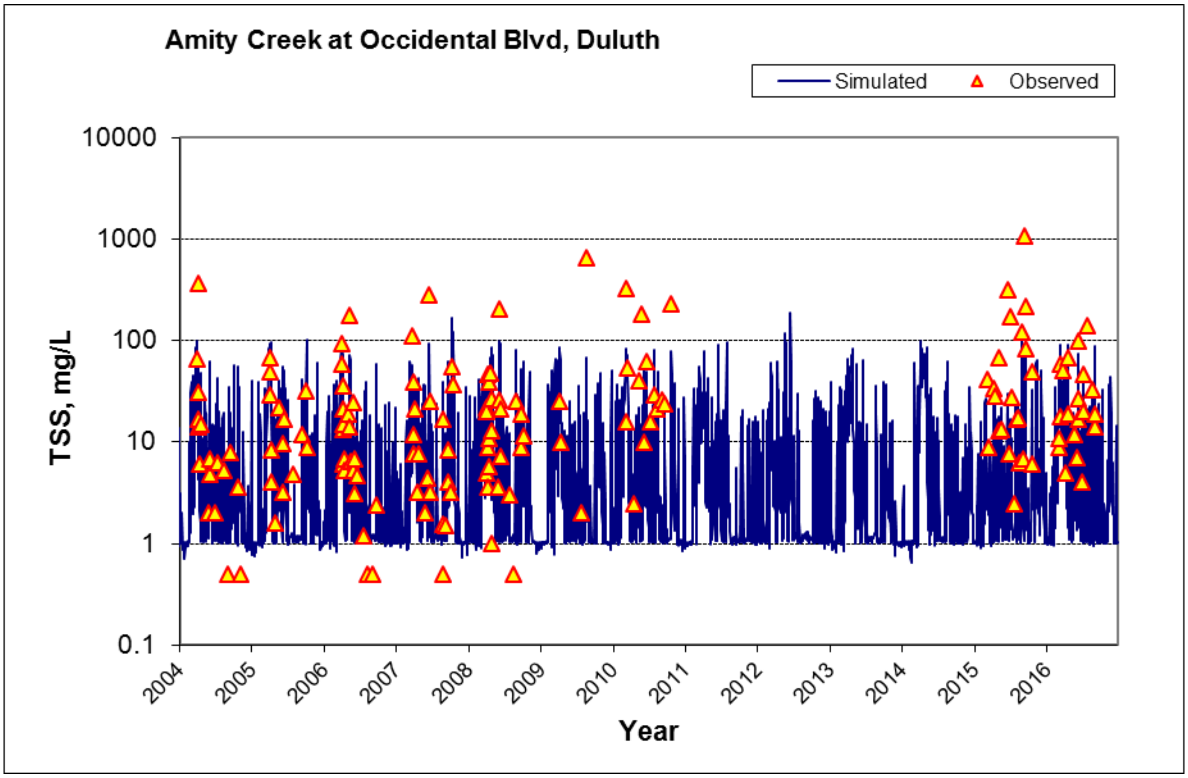

Figure 5-18. Time Series Plot for Total Suspended Sediment, Amity Creek at Occidental Boulevard (Calibration)

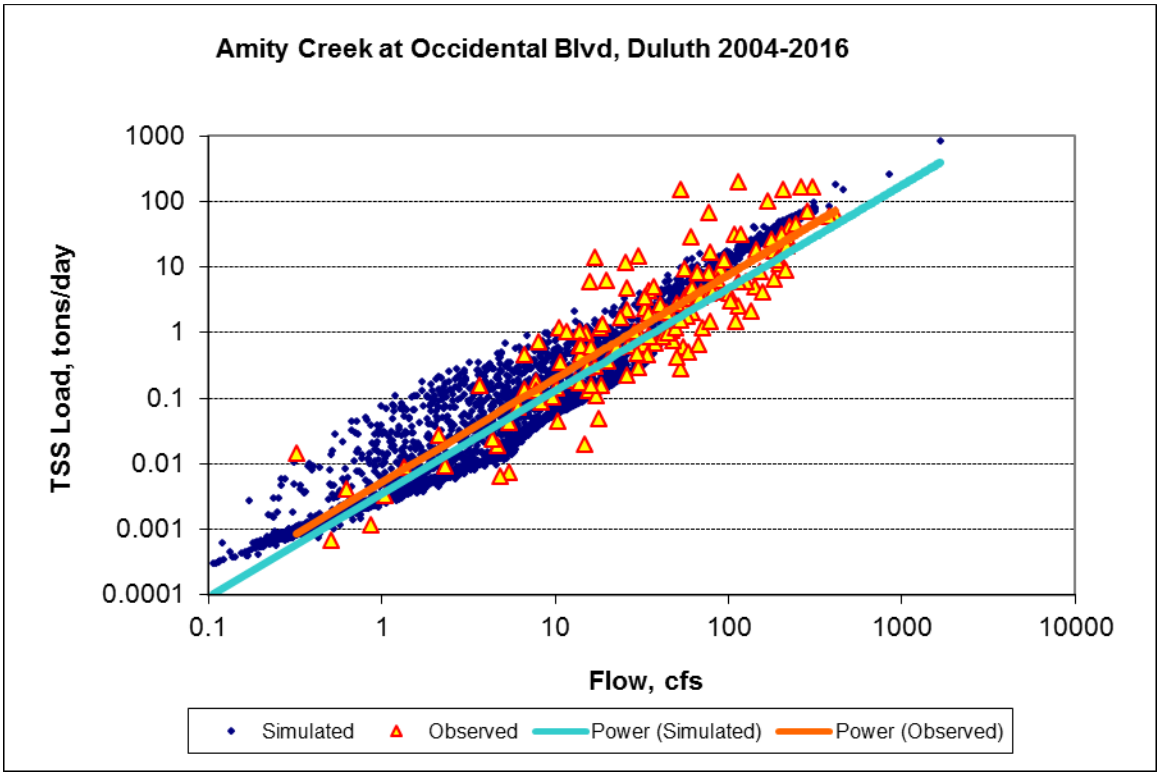

Figure 5-19. Log-log Power Plot of Simulated Total Suspended Sediment Load and Load Inferred from Observed Concentration, Amity Creek at Occidental Boulevard (Calibration)

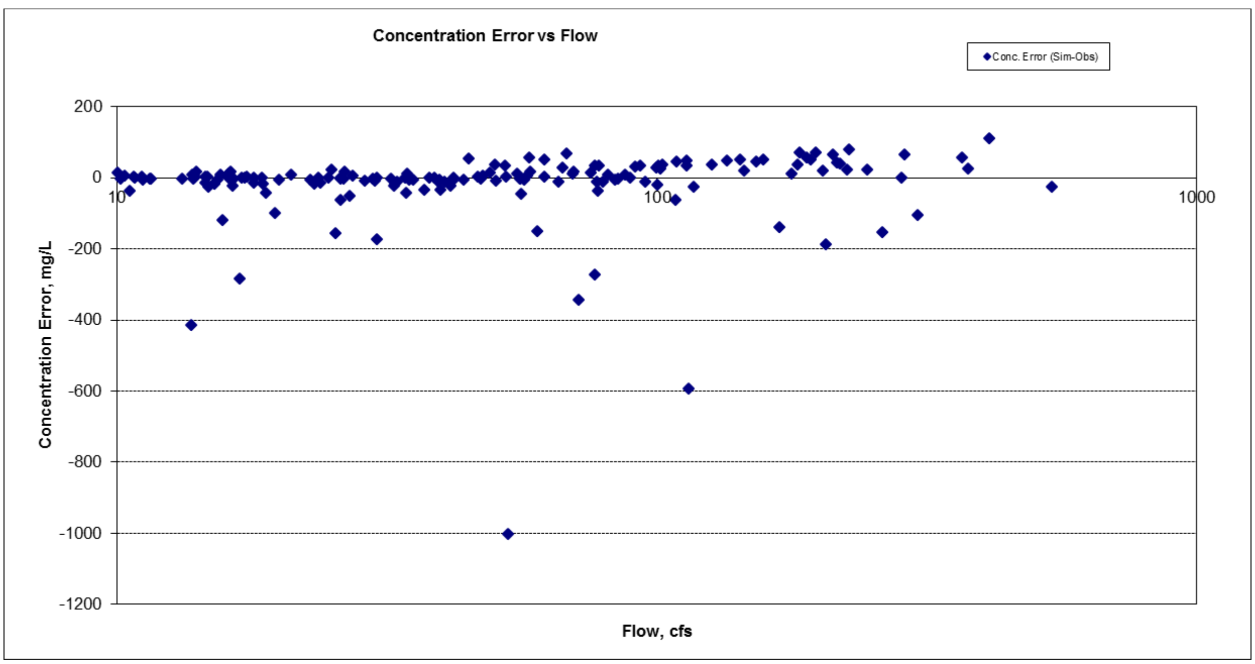

Figure 5-20. Distribution of Concentration Error for Total Suspended Sediment, Amity Creek at Occidental Boulevard (Calibration)

Sediment calibration statistics for all stations are provided in Table 5-3 (the accompanying graphics are in Appendix D). The stations are listed from north to south and show considerable variability in their observed suspended sediment conditions. The highest average concentrations are generally associated with the bluff areas on lower Amity Creek, Tischer Creek, Lester River and Mission Creek. Very low average concentrations are seen on upper Miller Creek, along with a few other locations including Coffee Creek and Buckingham Creek. Sample size also varies among sites, ranging from 18 to 143 samples during the calibration period. As noted in Section 3.3, the performance targets in Table 3-6 should "only be applied in cases where there are a minimum of 20 observations", this condition is not met for Sargent Creek or the Mission Creek site above 131st Ave. W.

Table 5-3. Summary of Sediment Calibration Results

Station ID	Location	Dates	Sample Count	Ave. Obs. (mg/L)	Relative Error on Concentration		Relative Error on Load	
					Ave.	Median	Ave.	Median
S007-814	Lester River at Strand Rd / CR-10 in Duluth, MN (R499)	4/14/2014 – 11/17/2016	85	28.9	-33.7%	-2.6%	-41.7%	-0.1%
S000-258	Lester R above Superior St, Lester Pk at Duluth (R483)	10/13/2004 - 11/17/2016	114	47.9	-14.2%	-1.1%	-32.1%	-0.0%
S004-950	Amity Ck, EB above Confluence with Amity Ck, WB in Duluth (R454)	4/8/2008 - 10/25/2012	48	21.9	-14.6%	1.1%	-19.2%	0.0%
S005-485	Amity Ck near Skyline Pkwy, N Duluth, MN (R438)	3/31/2008 - 9/24/2010	31	35.3	31.4%	6.6%	47.6%	0.9%
S005-486	Unnamed Stream to Amity Ck, NE Duluth, MN (R436)	3/31/2008 - 9/24/2010	31	69.5	10.8%	35.6%	-7.7%	5.5%
S001-757 02038001	Amity Ck on First Brg on Occidental Blvd in Duluth (R436+438)	10/25/2004 - 9/28/2016	143	47.2	-32.4%	1.1%	-10.2%	0.0%
S004-364 02039002 S002-480 S007-592	Tischer Ck at Wallace Ave Mt. Royal, Duluth Tischer Ck just Dwnst from Brg Crossing on 4th St in Duluth Tischer Ck Upstr of Woodland Ave in Duluth, MN (R409+412)	10/1/2004 - 9/8/2016	141	31.4	-1.3%	0.5%	11.8%	0.0%
S001-530 02040002 S004-953 S008-481	Chester Creek in Duluth, MN Chester Ck at College of St. Scholastica In Duluth Chester Ck just West of W College St in Duluth, MN (R386)	10/1/2004 - 9/8/2016	140	12.8	6.8%	7.7%	6.8%	1.4%
S004-958	Buckingham Ck at W 3rd St in Duluth (R374)	6/8/2010 - 10/24/2011	24	8.5	-53.1%	-7.8%	-7.0%	-4.3%

Station ID	Location	Dates	Sample Count	Ave. Obs. (mg/L)	Relative Error on Concentration		Relative Error on Load	
					Ave.	Median	Ave.	Median
S004-959	Unnamed Stream (Coffee Ck) just E of Miller Ck on Courtland St (R371)	6/8/2010 - 10/14/2011	23	6.1	-10.5%	-24.4%	97.2%	-2.6%
S003-070 03001029	Miller Ck, Upper Gage Site at Hwy 53 in Duluth (R351)	5/9/2007 - 9/24/2008	32	4.0	79.1%	1.7%	205%	0.0%
S001-169	Miller Ck at Chambersburg Rd (R347)	5/9/2007 - 9/23/2008	31	4.6	80.6%	2.7%	118%	0.0%
S003-071 03001005 S008-484	Miller Creek, Lower Site at 26Th Ave W in Duluth Miller Ck just East of N 24Th Ave W in Duluth, MN (R330)	5/9/2007 - 9/8/2016	75	16.9	-3.8%	2.7%	9.4%	0.2%
S008-483	Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN (R321)	5/9/2008 - 9/8/2016	58	17.3	-16.8%	10.2%	-11.7%	0.5%
S008-482	Keene Ck at 57th Ave W in Duluth, MN (R302)	5/9/2008 - 9/8/2016	60	24.5	-34.3%	1.6%	15.6%	0.2%
S004-952 03186001 S007-055	Kingsbury Creek at Lake Superior Zoo in Duluth Kingsbury Ck at Walking Br, 0.1 mi SE of MN-23 / Grand Ave, 2.5 mi SE of Proctor, MN (R272)	10/1/2004 - 4/21/2014	81	36.3	-7.1%	14.2%	23.0%	3.6%
S004-972	Sargent Ck at Hudson Blvd, 1 mi S of Gary, MN (R232)	5/14/2008 - 8/11/2010	18	54.6	-93.9%	-1.7%	-97.1%	-0.8%
40240258 5	Mission Ck abv 131st Ave W near Fond du Lac, MN (R201)	4/15/2015 - 8/17/2016	18	218	10.6%	-6.9%	88.9%	-0.5%
S004-974	Mission Ck at MN-23, 2.6 mi WSW of Gary, MN (R200)	5/6/2008 - 8/27/2010	33	18.4	-43.2%	2.6%	-10.9%	0.1%

Note: Statistics calculated with non-detect observations at one-half the detection limit.

Of the calibration sites with adequate sample sizes, nine are ranked as “good” or “very good”, five as “fair”, and three as “poor” for average relative error on concentration. For average relative error on load, 8 are ranked as “good” or “very good”, three as “fair, and five as “poor.”

Two of the sites with a “poor” ranking on average relative errors on concentration and load are the sites located on Upper Miller Creek. The median relative errors on concentration and load at these sites, however, are ranked as “very good” and the sediment calibration performance at lower Miller Creek (R330) is comprehensively rated as “very good”.

Amity Creek presented a challenge because the station at Occidental Boulevard is immediately downstream of the station at Skyline Parkway, but has much higher concentrations. The model calibration is thus a compromise, with over-prediction at the first station and under-prediction at the second. There are likely impacts of bluffs occurring at a finer spatial scale than is resolved in the model at this station.

Model fit is ranked "very good" for Tischer Creek and "very good" for concentration and "good" on load for Kingsbury Creek. This is of interest as both stations were noted as having a poor match between simulated and gaged flow (Table 4-4.). The attainment of a reasonable sediment calibration suggests that the apparent discrepancies in hydrology may be of lesser concern.

5.6 Suspended Solids Validation

Suspended sediment validation took place at nine stations and used both visual and statistical approaches. The validation time period was selected to be 10/1/1994 through 9/30/2004. The detailed validation process is shown here for example for Amity Creek at Occidental Boulevard monitoring station, while a complete set of graphical and statistical results is provided in Appendix D. A total of 61 samples spanning four years of observations are available at this station for the validation period. The model appears to track the observed data fairly well, although several very high observations are under-estimated (Figure 5-21). For concentration the average relative error is ranked as "poor" (-51.0%) although median relative error is "very good" (-2.8%), while the average and median relative errors on load are both "very good" at 5.3% and -0.3%. A log-log power plot (Figure 5-22) shows that the observed and simulated loads have a similar distribution relative to flow. These validation results compare well to the calibration results at the same monitoring location.

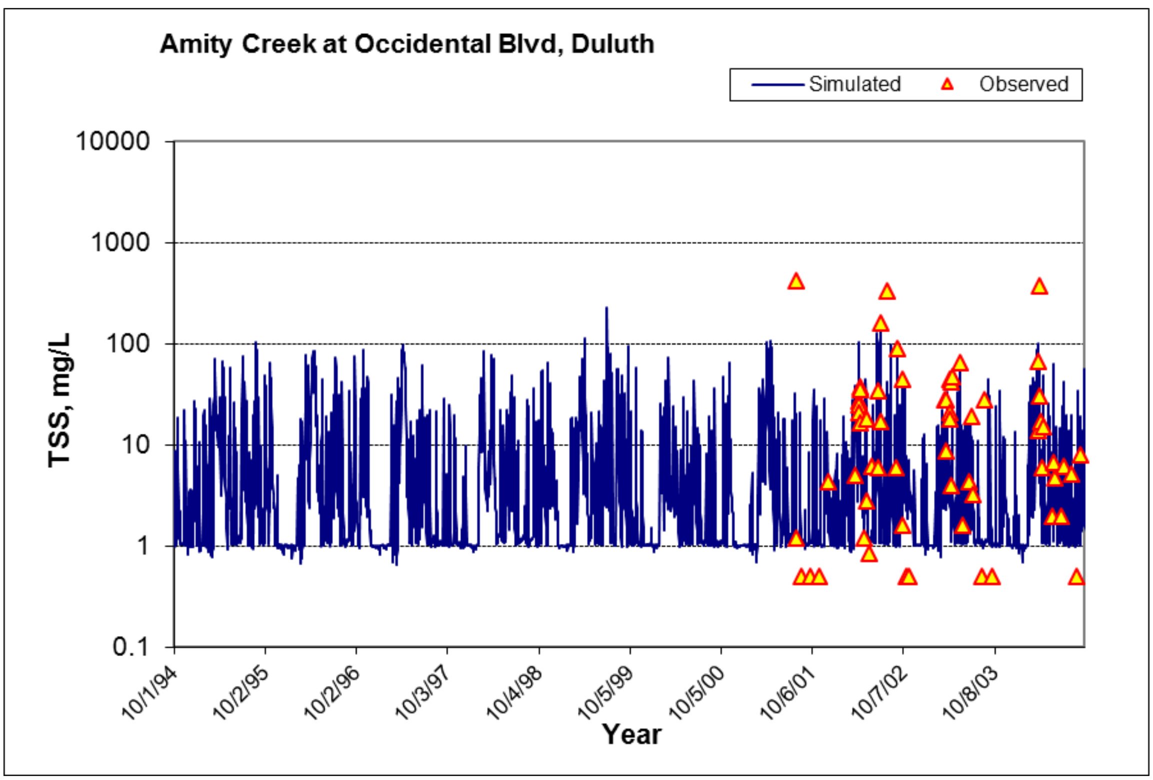

Figure 5-21. Time Series Plot for Total Suspended Sediment, Amity Creek at Occidental Boulevard (Validation)

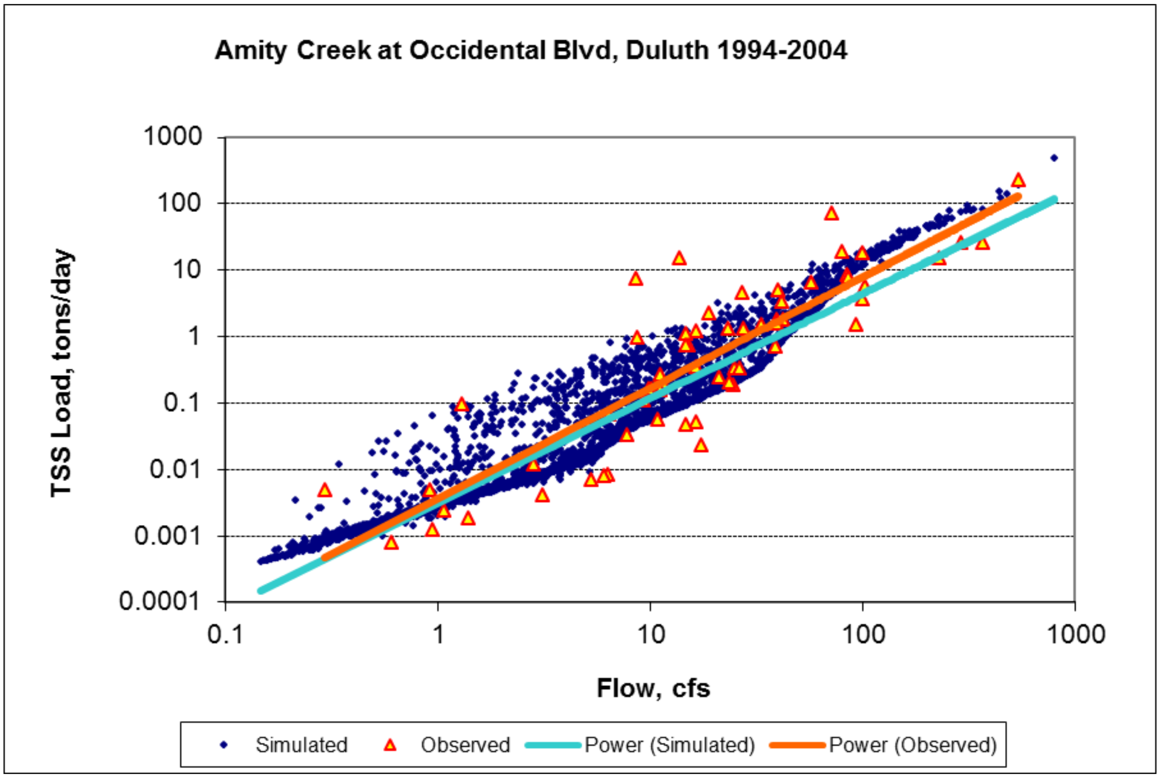

Figure 5-22. Log-log Power Plot of Simulated Total Suspended Sediment Load and Load Inferred from Observed Concentration, Amity Creek at Occidental Boulevard (Validation)

Sediment validation statistics for all stations are provided in Table 5-4 (the accompanying graphics are in Appendix D).

Table 5-4. Summary of Sediment Validation Results

Station ID	Location	Dates	Sample Count	Ave. Obs. (mg/L)	Relative Error on Concentration		Relative Error on Load	
					Ave.	Median	Ave.	Median
S006-281 02033001	Lester River just Upstream of County Road 293 (Tischer Rd) (R501)	1/12/1997 - 8/26/1999	40	6.8	31.7%	4.1%	106%	0.5%
S000-258	Lester R above Superior St, Lester Pk at Duluth (R483)	10/16/2002 - 9/8/2003	10	7.4	-71.2%	-19.3%	-73.6%	-5.5%
S006-291 02038002	Amity Creek just west of East Skyline Parkway in Duluth, MN (R439)	8/5/1997 - 6/25/1998	18	5.6	3.2%	6.3%	50.2%	2.7%
S001-757 02038001	Amity Ck on First Brg on Occidental Blvd in Duluth (R436+438)	7/31/2001 - 9/16/2004	61	36.6	-51.0%	-2.8%	5.3%	0.3%

Station ID	Location	Dates	Sample Count	Ave. Obs. (mg/L)	Relative Error on Concentration		Relative Error on Load	
					Ave.	Median	Ave.	Median
S004-364 02039002 S002-480 S007-592	Tischer Ck at Wallace Ave Mt. Royal, Duluth Tischer Ck just Dwnst from Brg Crossing on 4th St in Duluth Tischer Ck Upstr of Woodland Ave in Duluth, MN (R409+412)	3/28/2002 - 9/21/2004	42	73.3	-64.7%	-5.3%	-38.1%	-1.2%
S001-530 02040002 S004-953 S008-481	Chester Creek in Duluth, MN Chester Ck at College of St. Scholastica In Duluth Chester Ck just West of W College St in Duluth, MN (R386)	3/28/2002 - 9/21/2004	42	16.0	-23.8%	0.75%	26.3%	0.0%
S003-070 03001029	Miller Ck, Upper Gage Site at Hwy 53 in Duluth (R351)	2/8/1999 - 4/22/1999	22	6.1	11.4%	16.4%	31.0%	3.0%
S003-071 03001005 S008-484	Miller Creek, Lower Site at 26Th Ave W in Duluth Miller Ck just East of N 24Th Ave W in Duluth, MN (R330)	2/8/1999 - 7/82002	31	25.3	-54.4%	1.3%	30.1%	-0.1%
S004-952 03186001 S007-055	Kingsbury Creek at Lake Superior Zoo in Duluth Kingsbury Ck at Walking Br, 0.1 mi SE of MN-23 / Grand Ave, 2.5 mi SE of Proctor, MN (R272)	3/28/2002 - 9/21/2004	51	52.7	-58.8%	-17.1%	-17.4%	-4.1%

Note: Statistics calculated with non-detect observations at one-half the detection limit.

5.7 Response to 2012 Flood

As discussed in the Introduction, the flood of June 2012 is generally considered to be the most catastrophic flooding event on record in the Duluth region. A simple Google search for “Duluth Flood” turns up pages of results describing the event, the damages, and the aftermath. Due to the nature of the topography and geology of the study area, substantial and widespread bank and bluff erosion were observed in many reaches. One of the objectives of this project is to show how the model represents the 2012 flood.

There are a few challenges with using the model to represent a catastrophic event. It is technically possible in HSPF to represent changes in channel conditions at a fixed point in time using SPECIAL ACTIONS. As noted in Section 2.3.3, before-and-after channel profiles were available for only a handful of locations, and there were not enough data available to characterize average changes in channel profile throughout the study area. The other major challenge is that HSPF does not natively represent storm event bank erosion separately from bed dynamics. When bank erosion is a major component of reach mass balance, we typically increase channel degradation as a proxy for the sediment mass from banks. Bluff erosion is a special case; in these watersheds, bluff erosion is often a gradual process where saturated bluffs slowly slough off into the reach at random times. Section 5.3 provides a discussion of the simulation of bluff erosion as a constant load added to the reach, which becomes available for downstream transport during high flow events.

A review of model output shows that the 2012 flood is well represented. Figure 5-23 through Figure 5-25 provide time series of conditions for the most downstream reach of Lester River for the years leading up to and following the flood. In Figure 5-23, the flood flow is a full order of magnitude higher than most other large storm events. The results represent daily average flow; the instantaneous maximum flow would be even higher. Figure 5-24 provides change in bed depth over the same period. This is one of the bluff reaches, and the slow influx of sediment can be seen in the gradual aggradation. The 2012 storm is seen as a sudden drop in bed depth of nearly 0.2 feet; while this does not seem like a huge change, note that the change in depth is modeled across the entire width and length of the reach. This adds up to a considerable load, comparable to the mass wasting known to have occurred there. The spike in daily sediment export seen in Figure 5-25 is spread over two days and sums to 2,878 tons. In context, the average annual simulated discharge of sediment from Lester River is 1,522 tons/year.

Figure 5-26 presents a summary of the 2012 flood two-day sediment export for each of the named watersheds in the study area. Given large differences in watershed area, the results are scaled to show the ratio of 2012 flood sediment loads to average annual loads. Note that the 2012 flood mass is included in the average annual load calculation (which uses the full 22 years of the simulation period). If the flood mass was omitted from the average annual values, the ratios would be even higher.

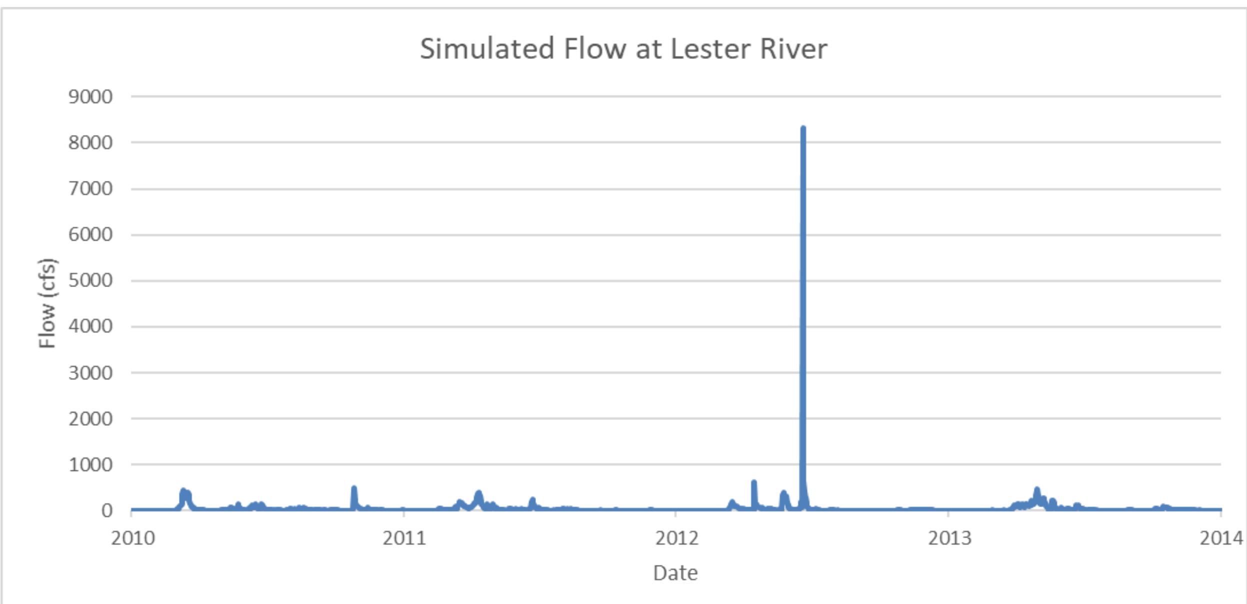

Figure 5-23. Modeled Daily Average Discharge from the Mouth of Lester River, 2010 – 2013

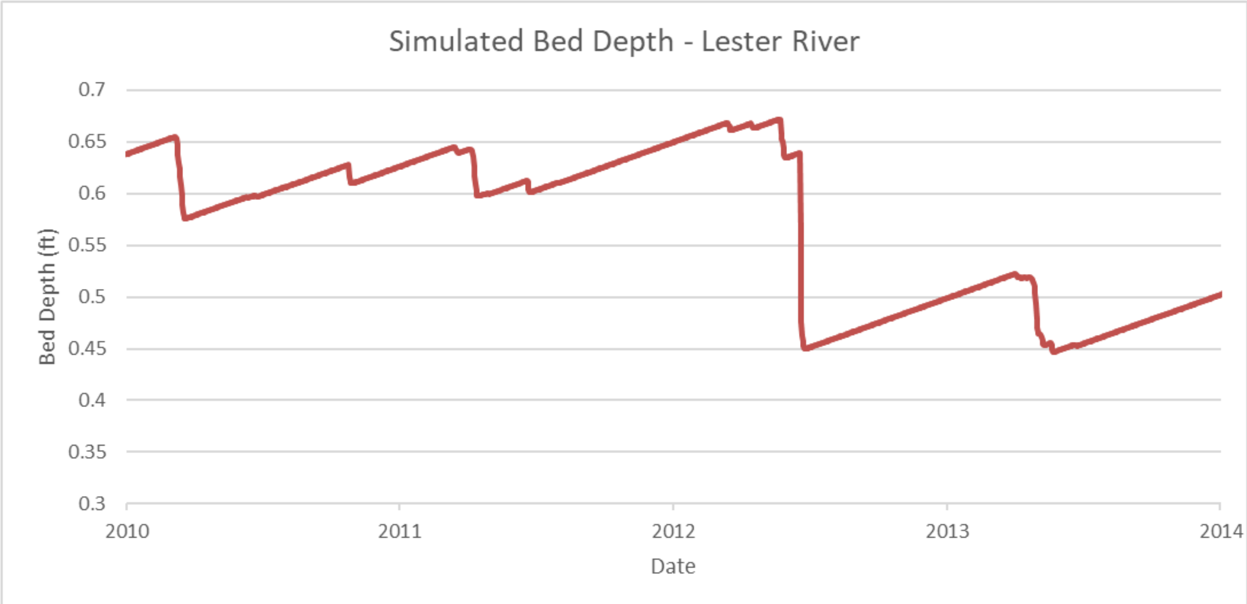

Figure 5-24. Modeled Bed Depth in the Most Downstream Reach of Lester River, 2010 – 2013

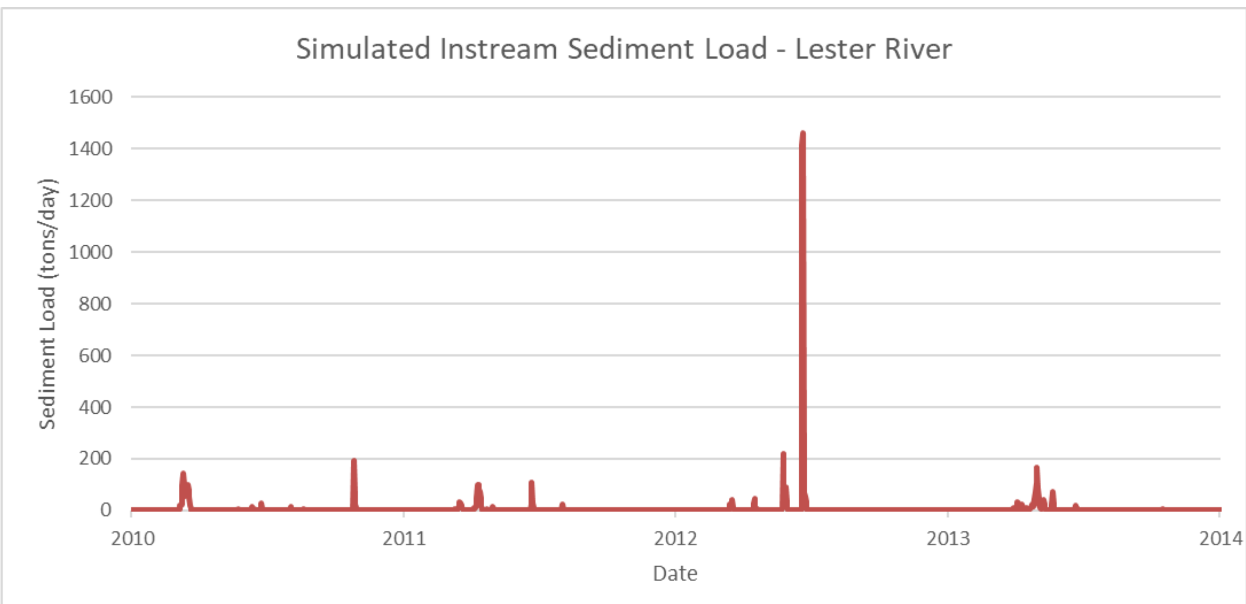

Figure 5-25. Modeled Daily Sediment Export from the Mouth of Lester River, 2010 – 2013

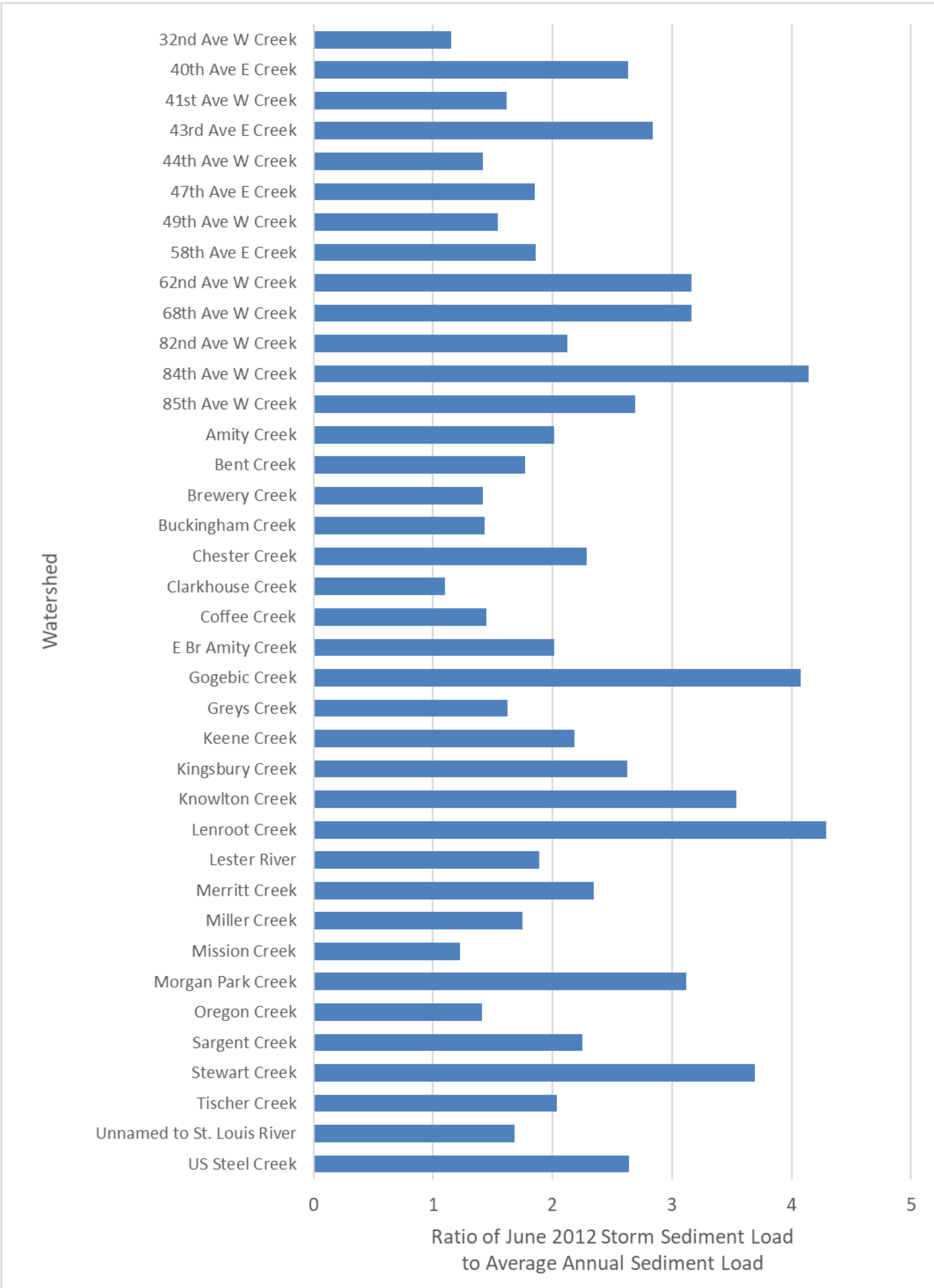

Figure 5-26. Comparison of Duluth WRAPS Watershed 2012 Flood Sediment Mass Export to Average Annual Mass Export

6 Nitrogen and Phosphorus Calibration

6.1 NUTRIENT MODEL SETUP

The nutrient simulation follows the same general approach used in other Minnesota HSPF models and recommended by AQUA TERRA (2012). Ammonia, nitrate nitrogen, orthophosphate, and generalized organic matter are simulated on the land surface, with the first two being represented by buildup-washoff processes and the second two simulated as sediment-associated using potency factors for pervious land (with a buildup-washoff approach for impervious land). Full nutrient kinetics are represented instream, including the decay of organic matter, uptake by and release from planktonic and benthic algae, nitrification, denitrification, exchanges with the sediment bed, and sorption to sediment of ammonium and ortho-phosphate.

6.1.1 Nonpoint Sources

The nutrient simulation for the uplands represents inorganic nitrogen, inorganic phosphorus, and organic matter as three distinct constituents. Inorganic phosphorus and organic matter on pervious surfaces are simulated using a sediment potency approach, while inorganic nitrogen on pervious surfaces and all three constituents on impervious surfaces are represented as a buildup/washoff process. Concentrations associated with subsurface flows are also included.

Within the stream reaches the model represents individual nutrient species (ammonia, nitrate, nitrite, organic nitrogen, orthophosphate, organic phosphorus, and organic carbon/BOD). The stream reach module is implemented with full nutrient simulation, including uptake by and release from plankton and benthic algae, decay of organic matter, oxidation of ammonium to nitrite and nitrite to nitrate nitrogen, bed exchanges of dissolved and sorbed nutrients, and ammonia volatilization.

The key parameters controlling the upland nutrient simulation are listed below:

MON-ACCUM: The monthly varying assignment of the build-up or accumulation of a constituent on a particular surface (lb/ac-d).

MON-SQOLIM: The monthly varying upper limit value beyond which a constituent can no longer accumulate on a surface (lb/ac).

MON-IFLW-CONC and **MON-GRND-CONC**: These parameters are used to assign the interflow and groundwater constituent concentrations on a monthly basis. The values for these parameters were estimated from the observed data with consideration of flow regime and then calibrated as necessary.

MON-POTFW: The monthly varying specification of constituent mass per sediment mass (lb/ton). For organic matter the assigned values were around 10^0 to 10^1. The seasonal assignment for organic matter reflects the annual cycle of growth and then litter.

The sediment potency, build-up/washoff, and subsurface flow parameters were initialized using the St. Louis watershed model. Studies of nutrient yields do not currently exist for the area simulated in the Duluth WRAPS model. However, there are some studies from nearby watersheds and other regional information that were used to constrain upland loading rates for specific land uses. Table 6-1 provides loading rates and data sources used to inform the model calibration for upland loading rates by land use. The simulated unit-area loading rates were compared to the literature-based ranges and the surface and subsurface flow parameters were revised until reasonable loading estimates were established for TN and TP. Results are provided in Figure 6-1. and Figure 6-2. for TN and TP respectively.

The mean simulated TN unit loading rate for deciduous forest and evergreen forest in the Duluth WRAPS watersheds are 4.85 lb-N/ac/yr, and 4.11 lb-N/ac/yr respectively, which are within the reported range in

Table 6-1.. The developed loading rates range from 8.24 lb-N/ac/yr to 17.91 lb-N/ac/yr. These results are similar to the values reported by the Minnesota Pollution Control Agency, which range from 2-17 lb-N/ac/yr for mixed developed land use (MPCA, 2013b). The mean simulated TN unit loading rates for forested wetlands and herbaceous wetlands are 2.05 lb-N/ac/year and 2.65 lb-N/ac/year, which are near the center of the reported range in Table 6-1.. The grassland/shubland unit loading rate is 1.45 lb-N/ac/year.

The simulated TP unit loading rate for forest in the Duluth WRAPS watersheds aligns with the reference values at 0.419 lb-P/ac/yr and 0.359 lb-P/ac/yr for deciduous forest and evergreen forest respectively. The TP unit loading rate from wetlands are at the low end of the reference range. The grassland unit loading rate is also at the low end of the range at 0.050 lb-P/ac/yr. Loading rates for developed uses range from 0.266 to 0.550 lb-P/ac/yr, comparable to the low end of reference rate range.

Table 6-1. Reference Ranges for the Nutrient Loading Rates of Land Use Categories

Land Use	TN (lb-N/ac/yr)	TP (lb-P/ac/yr)	Source
Forest	1.97 – 8	0.05 – 0.5	Clesceri et al., 1986; Loehr et al., 1989; MPCA, 2013b, MPCA, 2004; Reckhow et al., 1980; Tetra Tech, 2016b; Donigian and Mishra, 2015
Wetland	0.5 – 5.3	0.05 – 0.24	MPCA, 2013b; MPCA, 2004; Tetra Tech, 2016b; Donigian and Mishra, 2015
Pasture	2 – 23	0.11 – 0.7	Clesceri et al., 1986; McFarland and Hauck, 2001; MPCA, 2013b; MPCA 2004; Tetra Tech, 2016b; Donigian and Mishra, 2015
Developed (pervious)	2 – 17	0.38 – 1.5	Loehr et al., 1989; MPCA, 2013b; MPCA, 2004; Reckhow et al., 1980; Tetra Tech, 2016b; Donigian and Mishra, 2015
Developed (impervious)	2 – 17	0.17 -1.0	Loehr et al., 1989; MPCA, 2013b; MPCA, 2004; Reckhow et al., 1980; Tetra Tech, 2016b; Donigian and Mishra, 2015
Grassland/Shrubland	0.5 - 5	0.05 – 0.2	MPCA, 2013b; MPCA, 2004; Tetra Tech, 2016b; Donigian and Mishra, 2015

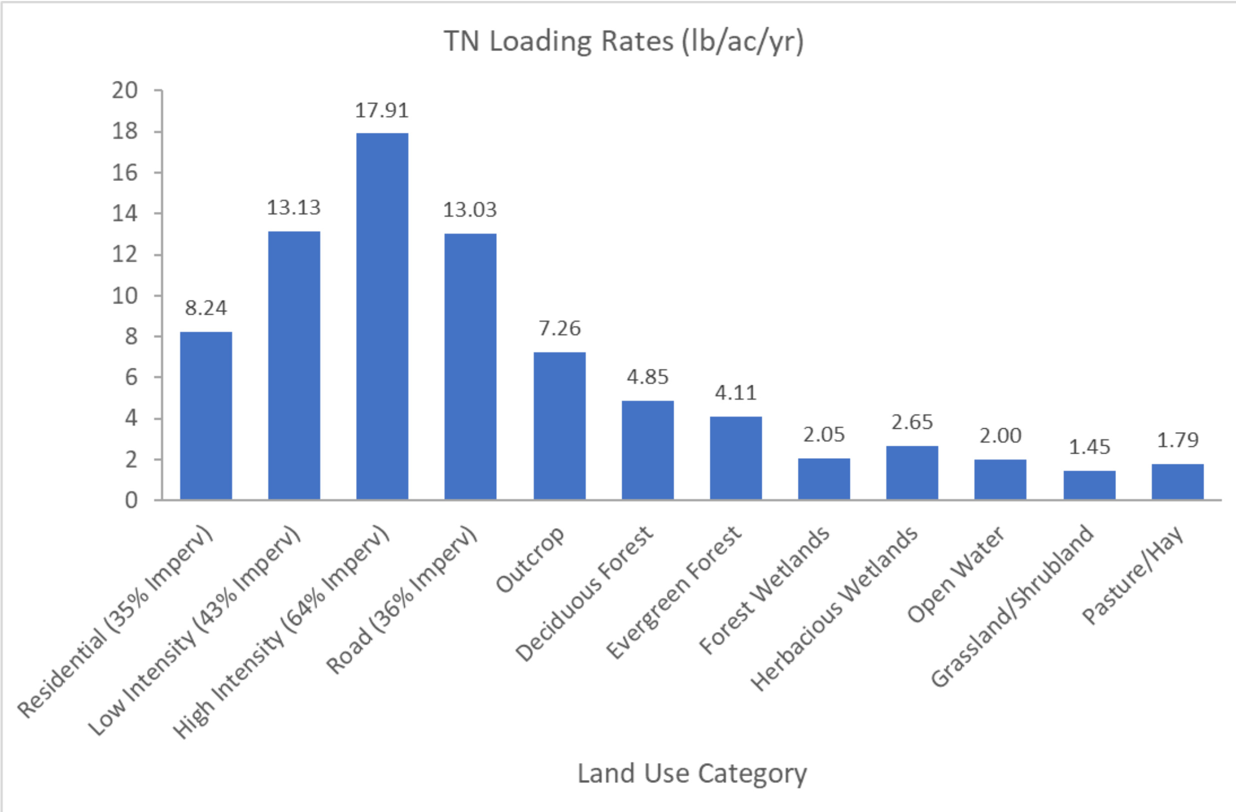

Figure 6-1. Mean Simulated Total Nitrogen Unit Loading Rates for Land Use Categories in the Duluth WRAPS Watersheds

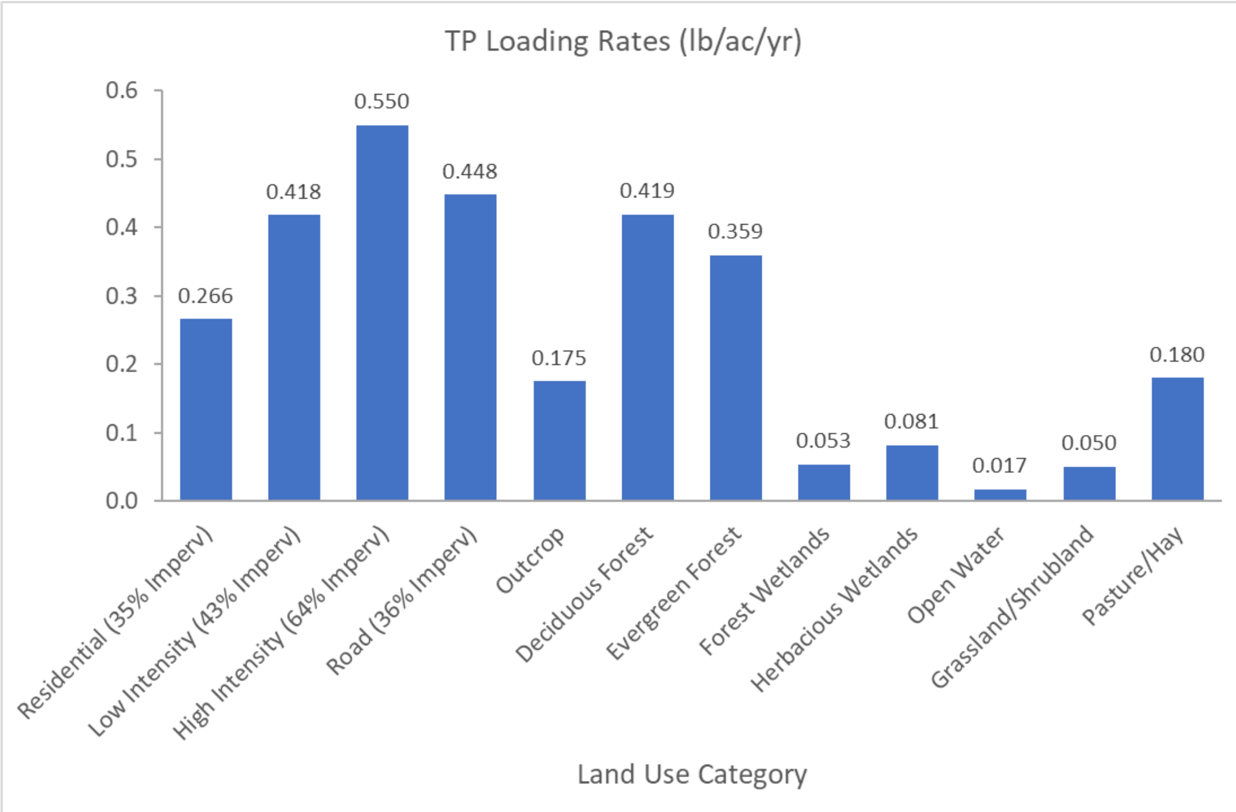

Figure 6-2. Mean Simulated Total Phosphorus Unit Loading Rates for Land Use Categories in the Duluth WRAPS Watersheds

6.1.2 Point Sources

As previously stated, no point sources are explicitly represented in the Duluth WRAPS watershed model.

6.1.3 Channel Sources

Nutrients can be gained or lost through exchanges with the sediment bed – either through releases in the dissolved form or by scour or deposition of nutrients that sorb to sediment. HSPF simulates ortho-phosphate and ammonia as sorbing to sediment and also represents release of dissolved ortho-phosphate, ammonia, and labile organic matter (as BOD, with associated nutrients) from the sediment.

Based on experience with the St. Louis River HSPF model, sorption coefficients were set for ortho-phosphate as 1,000 ml/g relative to silt and clay and 600 ml/g relative to sand; the corresponding numbers for total ammonia N were 100 and 10 ml/g. Default background sediment bed concentrations for ortho-phosphate are set at 250 mg/kg for silt and clay and 100 mg/kg for sand, and, for total ammonia N, 100 mg/kg for silt and clay and 40 mg/kg for sand.

6.1.4 Atmospheric Deposition

The model simulates wet and dry deposition of ammonia-N and nitrate-N to pervious surfaces, impervious surfaces, and water bodies. In addition, both dry and wet deposition of phosphorus to streams is simulated. Atmospheric deposition of phosphorus to the uplands is not simulated because it is implicit in the sediment potency representation of pervious land loading and the buildup/washoff representation of impervious land loading of phosphorus.

Direct phosphorus deposition to surface water is represented in the model. The phosphorus deposition rate specified is the average estimated for the Lake Superior basin in the 2007 update to *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds - Atmospheric Deposition* (Twaroski, et al. 2007) of 0.115 kg/ha/yr. The wet deposition concentration for phosphorus is set at the average concentration for Fond du Lac of 10.7 µg/L given in the same resource.

Wet deposition concentrations of ammonia and nitrate N (as mg/L) are taken from seasonal data recorded at NADP station MN16 (Marcell Experimental Forest) because other NADP stations near the watershed either did not become operational until 1997 or ended prior to 2012 and thus do not cover the full time span of the model. Dry deposition rates of ammonia and nitrate N (as lb/ac) are taken from CASTNET monitoring. There are no CASTNET stations within or particularly close to the watersheds studied here, so we use the station at Voyageurs National Park (VOY413) for the period after 1996, filling in earlier dates with monitoring from Perkinstown, WI (PRK134). In all cases, reported data were converted from molar units to mass or mass-based concentration as N.

6.2 Nutrient Calibration and Validation

Nutrients from nonpoint sources are loaded to the stream reaches. Within the stream reaches the model represents the following nutrient species: ammonia, nitrite, nitrate, organic nitrogen, orthophosphate, organic phosphorus, and organic carbon/BOD. The stream reach module simulates instream biogeochemical processes including nutrient uptake and release by plankton and benthic algae, decay of organic matter, nitrification/denitrification, absorption/desorption of nutrients on suspended sediment, and deposition and scour of sediment-stored nutrients.

The nutrient calibration and validation rely on a weight of evidence approach. Upland loading rates are constrained to be in general agreement with literature values (as described in Section 6.1.1). Model calibration then adjusts parameters to optimize the fit between model predictions and observations at multiple stations throughout the watershed and the robustness of the fit is checked with validation tests on a different time period. For the Duluth WRAPS watershed model the calibration period is 10/1/2004 through 12/31/2016 and the validation period is 10/1/1994 through 9/30/2004.

6.2.1 Comparison of Model to Observations

Comparisons between model predictions and sample observations are made in terms of both concentration and inferred load (concentration times simulated or observed and simulated flow). Complete graphical and tabular statistical results for each station are provided in Appendix E. Figure 6-3. provides an example of the primary types of calibration plots provided for each monitored nutrient parameter at each site, in this case showing the total phosphorus calibration for the Amity Creek at Occidental Boulevard station. The four panels in Figure 6-3. are:

a. Standard time series plot, showing the observations and continuous model predictions of daily average concentrations. This shows general agreement but can obscure biases in the simulation.

b. A power plot comparing the relationship of observed and simulated loads versus flow. The objective here is that the relationship to flow (summarized by the power regression lines) should be similar for the model and observations. The figure shown here shows general agreements between the regression lines

c. A scatterplot of simulated versus observed concentrations shows the degree of spread or uncertainty about the 1:1 line.

d. A plot of the residuals against flow is used to diagnose bias relative to the flow regime. In this case there is a fair balance between over and under-prediction across the range of flows, but some indication of a tendency to under-predict concentrations at the highest flows. A similar plot of residuals versus month is used to diagnose potential seasonal biases.

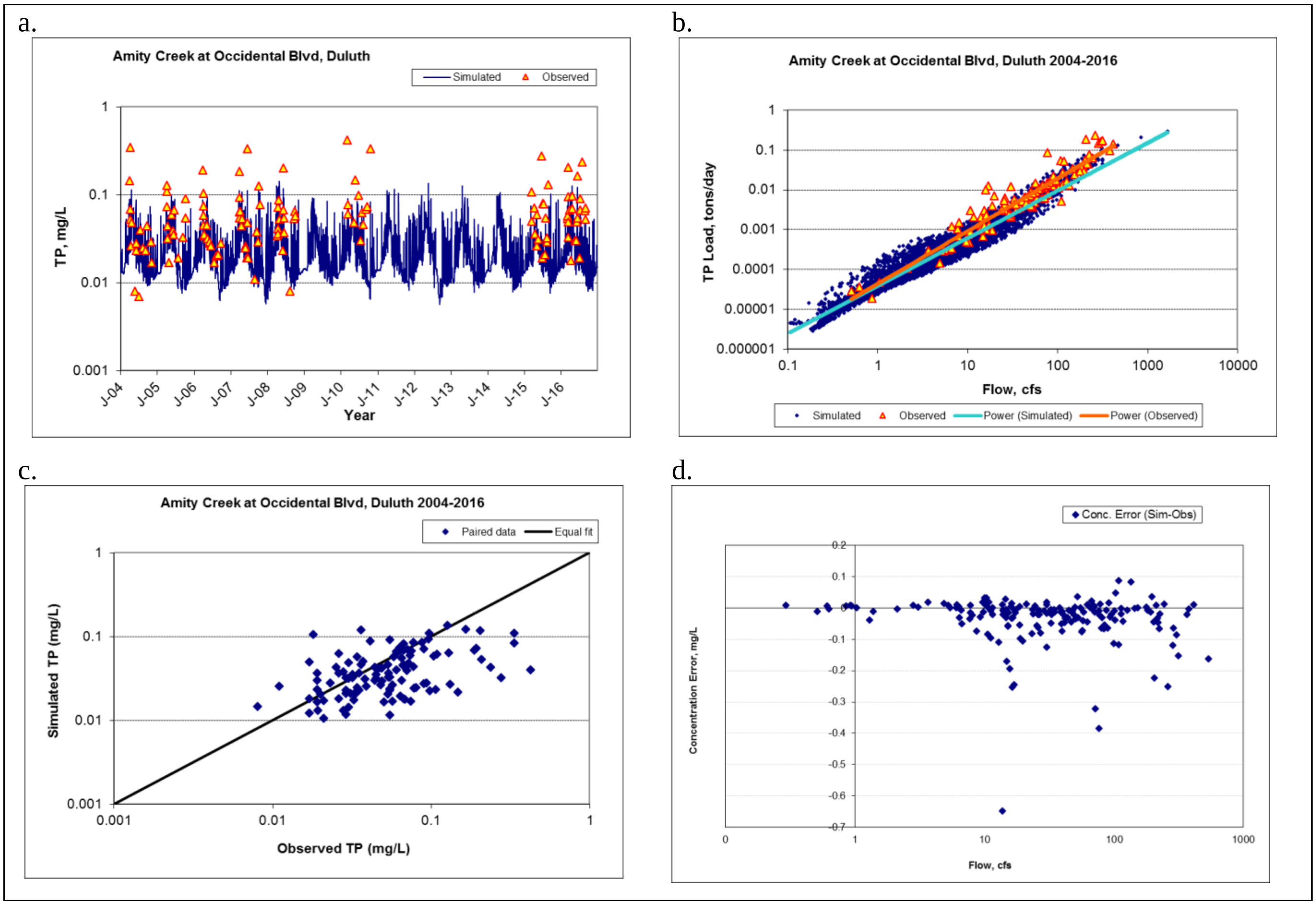

Figure 6-3. Example Calibration Plots for Total Phosphorus, Amity Creek at Occidental Boulevard

This section first provides an overview of the results with a focus on total phosphorus and total nitrogen. Results for individual nutrient species are then summarized, with full results provided in Appendix E.

Summary statistics for the calibration and validation of total phosphorus are shown in Table 6-2. and Table 6-3., respectively, while total nitrogen statistics for the calibration and validation are provided in Table 6-4. and Table 6-5., respectively. Discussion by watershed follows each of the tables.

Table 6-2. Summary of Total Phosphorus Calibration Results

Station	Count	Average Concentration (mg/L)	Concentration Average Relative Error (%)	Concentration Median Relative Error (%)	Paired Load Average Relative Error (%)	Paired Load Median Relative Error (%)
Lester River above Superior Street	30	0.022	-20.2%	-28.4%	7.1%	-7.4%
East Br Amity Cr above Confluence with Amity Cr	38	0.035	28.4%	39.8%	33.6%	1.3%
Amity Creek at Occidental Blvd, Duluth	115	0.070	-38.2%	-16.3%	-36.4%	-3.9%
Tischer Creek (multiple stations)	90	0.054	-25.2%	-9.4%	-33.5%	-1.1%
Chester Creek (multiple stations)	91	0.050	-19.9%	-8.8%	-17.1%	-0.4%
Buckingham Creek at W 3rd St	22	0.043	-36.1%	-25.8%	-31.2%	-8.6%
Coffee Creek east of Miller Creek	22	0.030	-14.3%	-20.1%	-32.7%	-3.4%
Miller Creek, Upper Gage at Hwy 53	31	0.037	-7.7%	-19.3%	50.4%	-0.9%
Miller Creek at Chambersburg Rd	32	0.046	-30.6%	3.0%	-36.6%	0.1%
Miller Creek at Lake Superior College	41	0.029	19.0%	28.5%	17.9%	0.6%
Miller Creek nr Lower Gage (multiple stations)	65	0.040	-8.3%	-5.5%	-22.2%	-0.3%
Merritt Creek at Grand Ave	72	0.044	-16.8%	1.3%	-17.9%	0.0%
Keene Creek at 57th Ave W	72	0.050	-26.3%	-7.8%	-15.6%	-0.3%
Kingsbury Creek (multiple stations)	36	0.047	-9.3%	-1.6%	0.8%	-0.7%
Stewart Creek at US Steel RR	34	0.026	-4.2%	13.8%	-20.6%	1.1%
Sargent Creek at Hudson Blvd	34	0.060	-57.5%	-12.4%	-47.4%	-1.6%
Mission Creek at MN-23	34	0.038	-21.7%	14.0%	-54.4%	2.2%

Note: Statistics calculated with non-detects set to one-half the detection limit.

During nutrient calibration it appeared that there were some differences between individual watersheds that may not be fully explained by HRU definitions. The model set up allows potential variation of parameters by weather region, but individual watersheds overlap weather regions. As a result, the calibrated parameter set is a compromise that attempts to provide a reasonable fit at all stations, including some adjacent watersheds that have rather different responses, such as upper Amity Creek and Lester River.

Overall, the calibration results for TP are ranked (according to the criteria set forth above in Section 3) as “good” or “very good” on concentration relative average error for 10 out of 17 sites. For load relative average error, the fit for 8 out of 17 sites is ranked as “good” or “very good.” The quality of fit for load is generally similar to that for concentration, indicating that the model performs similarly across the range of flows, as is shown in the plots of residuals against flow in the appendix.

The quality of model fit is less than desirable at the two Amity Creek stations, which received “poor” and “fair” rankings, although the two stations have different signs on the error statistics. Amity Creek is heavily impacted by bluff loading. The effects of bluff processes on the phosphorus balance are not well known, but the stochastic nature of bluff collapse events likely interferes with the ability of the model to predict individual observations.

Average relative error results for Buckingham Creek are ranked as “poor” and “fair” for concentration and load, respectively. The sample data set is small and time of concentration is short in this highly urban drainage. This may be a case where point-in-time samples are not representative of the daily average results from the model to which they are compared.

For Miller Creek, the fit for relative average error on load is “poor” at the two upper stations, but ranked as “good” at the mouth. In contrast, the median relative errors on load are near zero. The fit at the upper stations is impacted by a few outliers at higher flows. This likely reflects mistiming of storm events in the model.

“Poor” results with apparent under-estimation of load are also seen for the southern drainages of Sargent Creek and Mission Creek, although the median errors on loads are small. The apparent discrepancy could be due to mistiming of storm events in the model or samples that are not representative of daily average results; however, the different soils in this part of the watershed may also play a role.

Table 6-3. Summary of Total Phosphorus Validation Results

Station	Count	Average Concentration (mg/L)	Concentration Average Relative Error (%)	Concentration Median Relative Error (%)	Paired Load Average Relative Error (%)	Paired Load Median Relative Error (%)
Lester River upstream of Tischer Rd	42	0.037	-49.1%	-41.7%	-29.6%	-12.0%
Lester River above Superior Street	10	0.049	-75.2%	-17.2%	-80.1%	-7.2%
East Br Amity Cr above Confluence with Amity Cr	12	0.036	-25.7%	-10.7%	32.5%	-1.0%
Amity Creek west of Skyline Pkway	18	0.025	-13.9%	12.5%	-40.8%	1.0%
Amity Creek at Occidental Blvd, Duluth	56	0.081	-64.4%	-30.5%	-57.2%	-6.8%
Miller Creek at Chambersburg Rd	12	0.025	14.8%	-21.8%	34.6%	-1.8%

Note: Statistics calculated with non-detects set to one-half the detection limit.

Validation tests for total phosphorus are hampered by small sample sizes, with four out of six stations not meeting the sample size minimum of 20. The fit for the two Lester River stations is mostly ranked as “poor.” The average concentrations observed in Lester River during the validation period are much higher than those from the calibration period, suggesting there may have been some systematic changes in conditions over time.

For Amity Creek, two of the validation sets have somewhat better statistics than seen during the calibration period, although the fit at Occidental Boulevard is rated as “poor”, with apparent under-estimation of concentration and load, although the median error on load is ranked as “very good.” As noted with the calibration, the stochastic nature of bluff collapse events likely interferes with the ability of the model to predict individual observations at this station.

Finally, the Miller Creek station receives a “very good” ranking on average relative error for concentration, but is “fair” for average relative error on load (although the median error is “very good”). The small sample size prevents drawing firm conclusions at this site as load estimates are easily influenced by a few outliers at higher flows.

In sum, the calibration for total phosphorus appears reasonable, but the validation tests are not entirely successful, potentially due to systemic changes in watershed and stream condition over recent decades.

Table 6-4. Summary of Total Nitrogen Calibration Results

Station	Count	Average Concentration (mg/L)	Concentration Average Relative Error (%)	Concentration Median Relative Error (%)	Paired Load Average Relative Error (%)	Paired Load Median Relative Error (%)
Lester River above Superior Street	6	0.775	-60.7%	-66.2%	-67.9%	-51.1%
East Br Amity Cr above Confluence with Amity Cr	37	0.732	27.9%	26.5%	26.9%	0.5%
Amity Creek at Occidental Blvd, Duluth	20	0.929	7.6%	4.3%	-8.6%	2.5%
Tischer Creek (multiple stations)	53	0.933	12.6%	3.0%	1.1%	0.2%
Chester Creek (multiple stations)	53	0.974	-1.8%	1.0%	10.1%	0.0%
Miller Creek at Lake Superior College	10	0.906	109.4%	56.5%	110.8%	68.2%
Kingsbury Creek (multiple stations)	35	1.116	2.5%	-1.8%	2.2%	-1.3%

Note: Statistics calculated with non-detects set to one-half the detection limit.

The calibration summary for nitrogen focuses on total nitrogen; however, nitrogen monitoring typically consists of measurement of individual nitrogen species (e.g., nitrate, ammonia). The balance among species can be very sensitive to algal interactions; therefore this summary presents the more robust measure of total nitrogen, which is available for fewer stations, and full results for individual nitrogen species are provided in Appendix E. The results do not include new monitoring from 2016; the data were omitted following a careful review and comparison to historic nitrate/nitrite and total Kjeldahl nitrogen (TKN) collected at the same stations. The concentrations of the 2016 data were, on average, substantially lower across the board than the historic data concentrations across a range of flows. The reason for the discrepancy is not known, but may be due to differences in sample collections methods and/or laboratory analytical methods.

Average relative error for total nitrogen on both concentration and load is classified as “very good” for four out of seven stations (Amity, Tischer, Chester, and Kingsbury). For East Branch Amity Creek, the fit is “fair”, similar to total phosphorus. Two stations where the fit appears to be poor (Lester River and Miller Creek) have insufficient sample counts to draw firm conclusions. Results for Lester River are impacted by a large fraction of non-detects for nitrate nitrogen. For Miller Creek it appears that the model may over-predict nitrate nitrogen at higher flows, although the same parameters provide a reasonable fit at other stations (see Appendix E).

Table 6-5. Summary of Total Nitrogen Validation Results

Station	Count	Average Concentration (mg/L)	Concentration Average Relative Error (%)	Concentration Median Relative Error (%)	Paired Load Average Relative Error (%)	Paired Load Median Relative Error (%)
Lester River upstream of Tischer Rd	41	0.772	-29.3%	-36.4%	-28.1%	-26.1%
East Br Amity Cr above Confluence with Amity Cr	5	1.016	-50.4%	-36.5%	-53.1%	-1.2%
Amity Creek west of Skyline Pkway	16	0.580	47.6%	42.5%	-9.4%	4.0%
Amity Creek at Occidental Blvd, Duluth	57	0.992	-24.6%	-19.9%	-27.1%	-8.0%
Miller Creek at Chambersburg Rd	5	0.904	-31.7%	-27.7%	-40.9%	-1.4%

Note: Statistics calculated with non-detects set to one-half the detection limit.

For the validation tests, the downstream station on Amity Creek ranks as “good” for average relative errors on both concentration and load, confirming model performance. The other two Amity Creek watershed stations have insufficient total nitrogen samples to draw firm conclusions, although additional information on individual nitrogen species is provided in Appendix E.

The fit at Lester River, ranked as “fair”, is better than seen during the calibration period, but, like the calibration period, is affected by a substantial number of reported non-detect values. There is an insufficient sample size for total nitrogen on Miller Creek to draw firm conclusions.

7 Water Temperature Calibration and Validation

Instream temperature is an important parameter for simulating biochemical transformations. The HSPF modules used to represent water temperature include PSTEMP (soil temperature) and HTRCH (heat exchange and water temperature).

Simulation of soil temperature is accomplished by using three layers: surface, upper subsurface, and groundwater subsurface. The surface layer is the portion of the land segment that determines the overland flow water temperature. The upper subsurface layer determines interflow temperature while the groundwater subsurface layer determines groundwater temperature. Surface and upper subsurface layer temperatures are estimated by applying a regression equation relative to measured air temperature. The groundwater subsurface temperatures are supplied a temperature which reflects the average subsoil temperature for the region. Initial parameters for the Duluth WRAPS HSPF model are based on values used in the St. Louis River watershed HSPF model.

Soil temperature is used to determine the water temperature of the three different flow paths (surface outflow, upper subsurface/interflow outflow, lower subsurface/groundwater outflow) as the water is contributing to stream flow. Once the water is in the stream, the temperature is impacted by energy exchanges that can increase or decrease the heat content of the water. Mechanisms that can increase the heat content of the water are absorption of solar radiation, absorption of long-wave radiation, and conduction-convection. Mechanisms that decrease the heat content are emission of long-wave radiation, conduction-convection, and evaporation. Heat exchanges between the water and stream bed are also simulated.

Stream temperature follows diel cycles and is strongly affected by the pattern of shading over the course of the day and the local microclimate, as well as specific locations of groundwater discharges to streams. Local-scale variations in hydraulics can also influence temperature readings: for instance, temperatures are likely to be different in a part of a reach impounded by a beaver dam than in a free-flowing riffle. A watershed-scale HSPF model can typically match daily average water temperature but is limited in its ability to simulate the daily cycles of water temperature at specific locations. This is because HSPF represents stream segments as one-dimensional, fully-mixed reactors. These segments are typically in the range of 3 to 15 miles in length in models built at a HUC12 scale, as is the case here, and variations within the segment are averaged out. For instance, a single average value represents shading over the whole stream segment and the model does not consider the orientation or aspect of the stream segment relative to the position of the sun. HSPF, as a one-dimensional model, also does not address vertical variation in temperature, which is especially important in deeper lakes and reservoirs. In contrast, a detailed water temperature model for a stream reach (e.g., the QUAL2K model) would typically specify segments with lengths on the order of a tenth of a mile and include a detailed analysis of shading from vegetation and topography in relation to solar position throughout the day and year. For the HSPF application we used a shading factor (i.e., CFSAEX, the fraction of light not shaded out) equal to 1 for lakes and equal to 0.85 for the non-lake reaches.

As previously discussed in Section 3, continuous measurement of water temperature was conducted at several dozen locations in the study area for varying durations and periods of record. A subset of those locations was selected to represent a cross-section of upstream land uses and contributing areas. Comparisons of modeled and observed daily average water temperature time series representative of the simulation are shown for each of the locations in Figure 7-1. through Figure 7-11.. The model provides a reasonable fit and captures seasonal variation well, though there are some deviations between simulated and observed values.

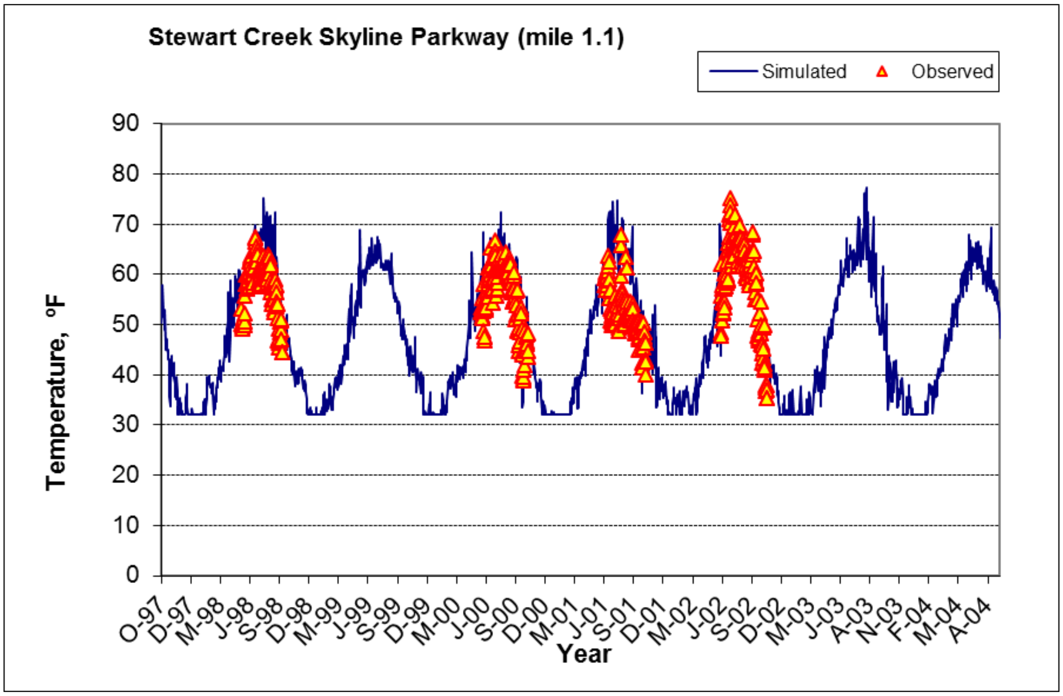

Figure 7-1. Temperature Time Series at Stewart Creek Skyline Parkway (mile 1.1) (1997-2004)

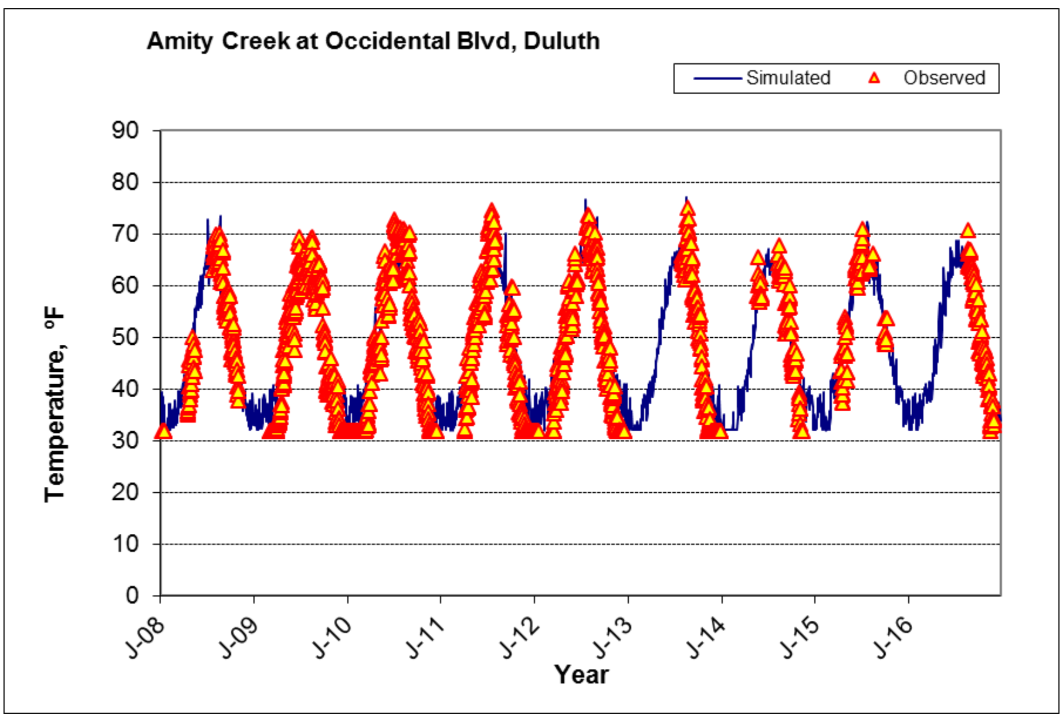

Figure 7-2. Temperature Time Series at Amity Creek at Occidental Blvd, Duluth (2008-2016)

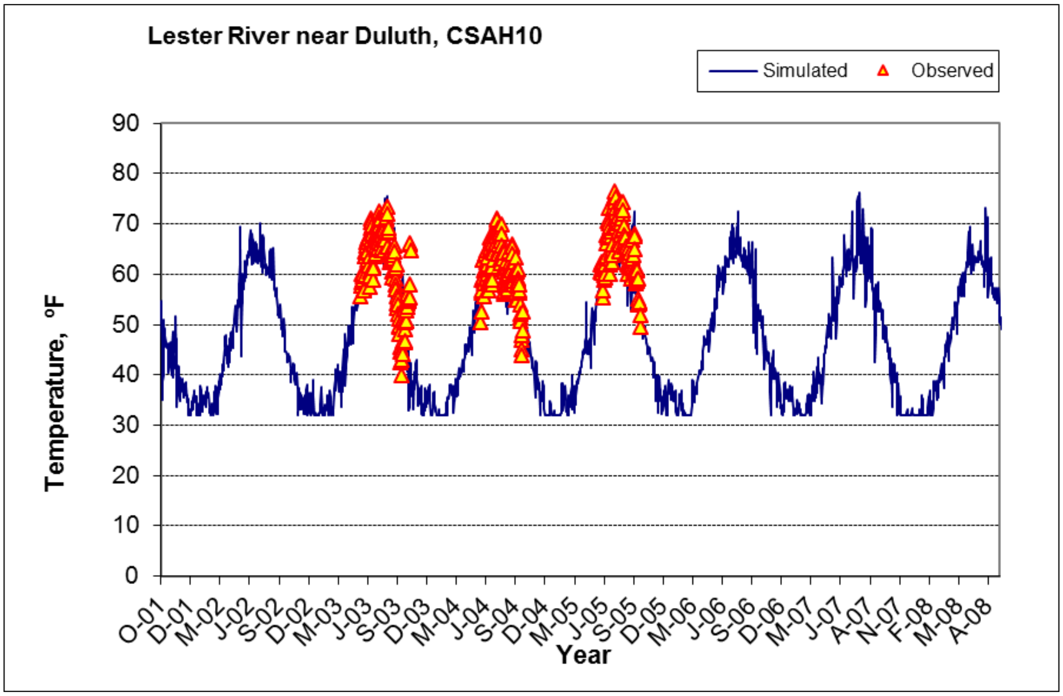

Figure 7-3. Temperature Time Series at Lester River near Duluth, CSAH10 (2001-2008)

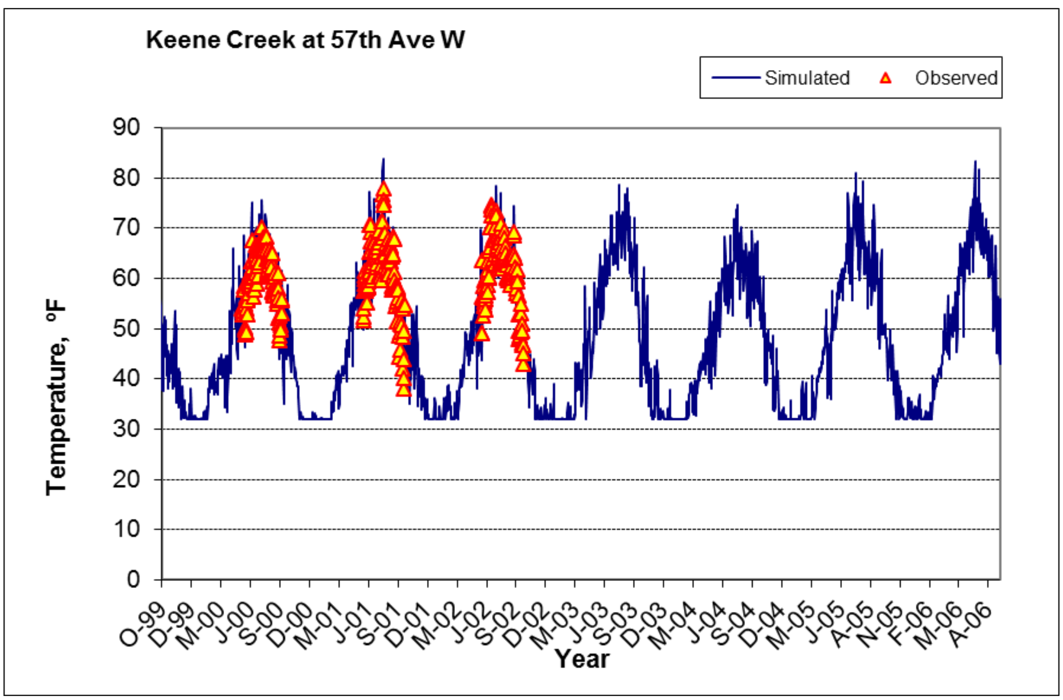

Figure 7-4. Temperature Time Series at Keene Creek at 57th Ave W (1999-2006)

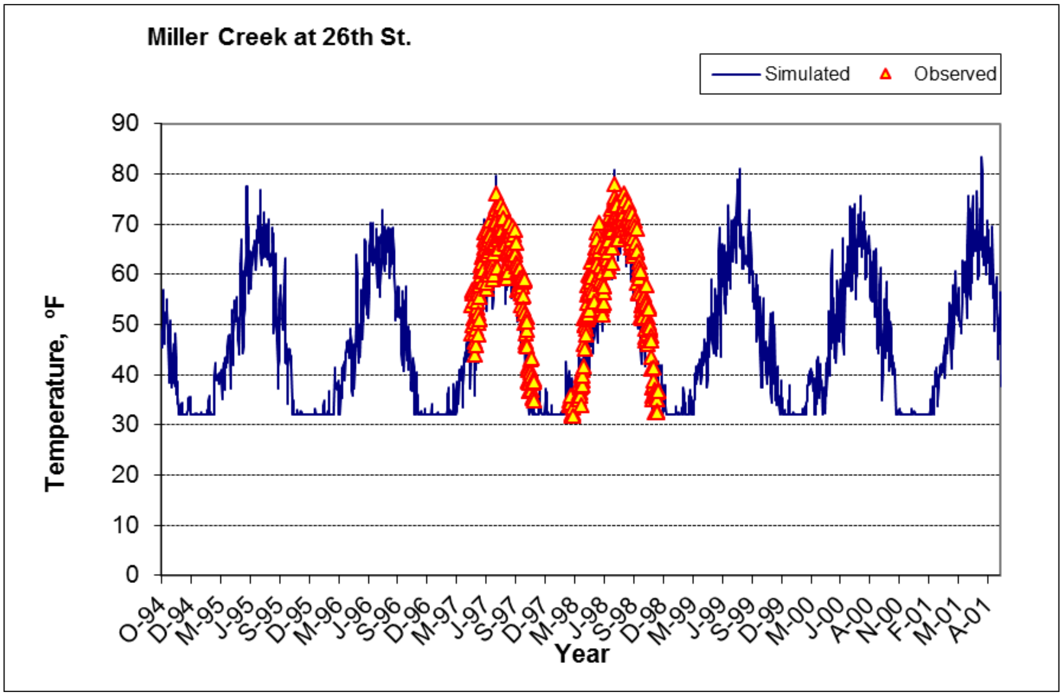

Figure 7-5. Temperature Time Series at Miller Creek at 26th St. (1994-2001)

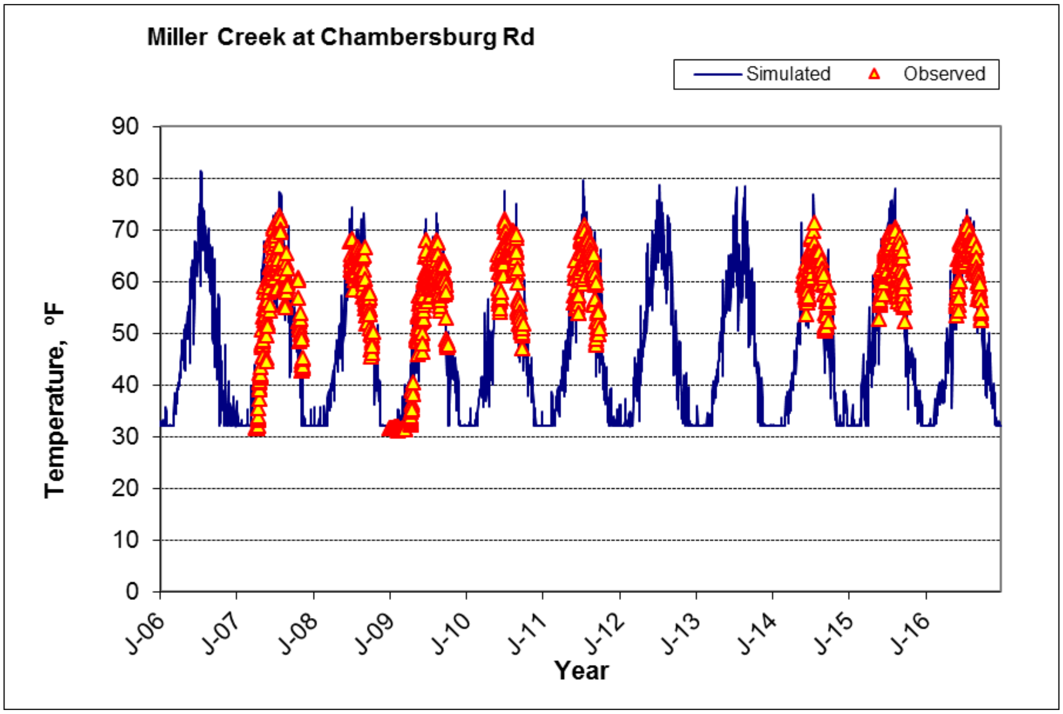

Figure 7-6. Temperature Time Series at Miller Creek at Chambersburg Rd (2006-2016)

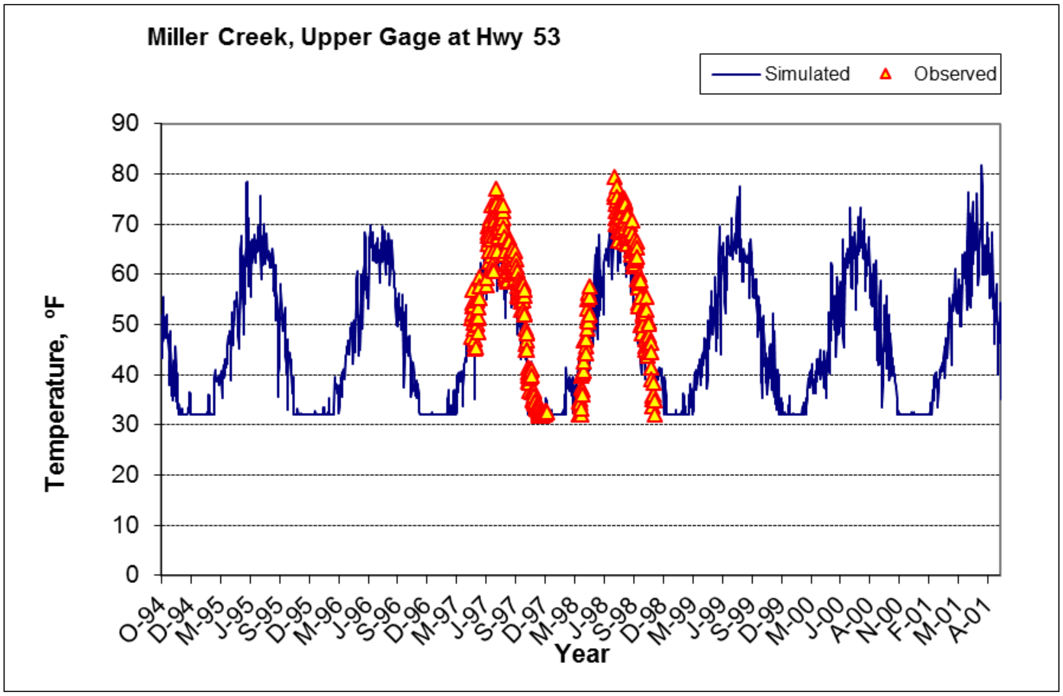

Figure 7-7. Temperature Time Series at Miller Creek at Upper Gage at Hwy 53 (1994-2001)

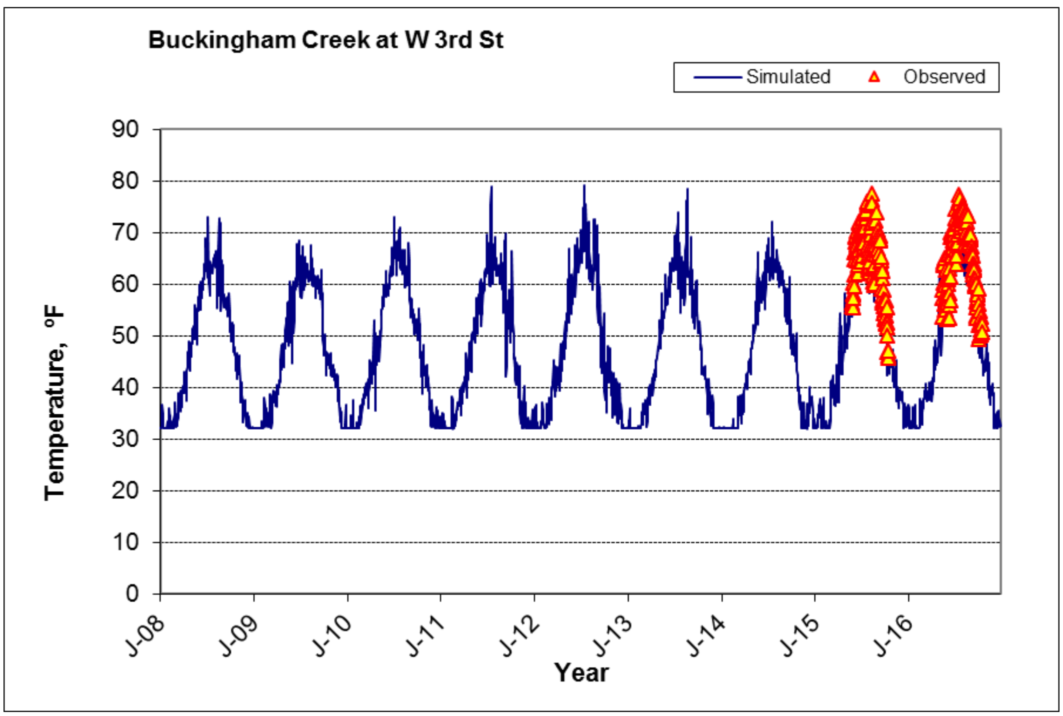

Figure 7-8. Temperature Time Series at Buckingham Creek at W 3rd St (2008-2016)

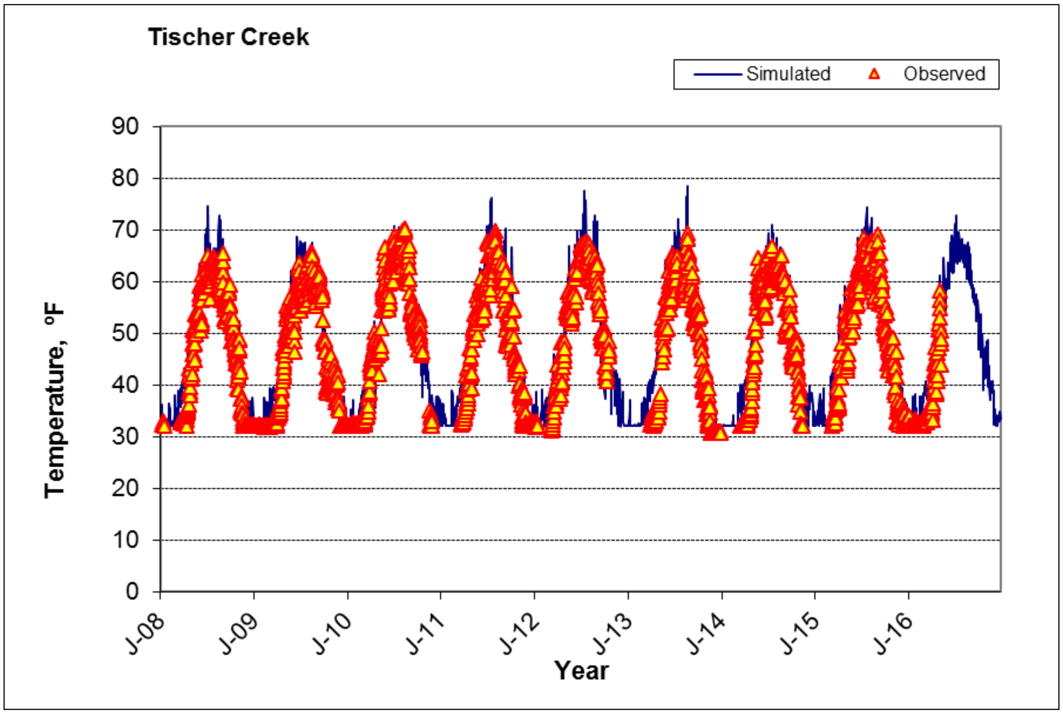

Figure 7-9. Temperature Time Series at Tischer Creek (2008-2016)

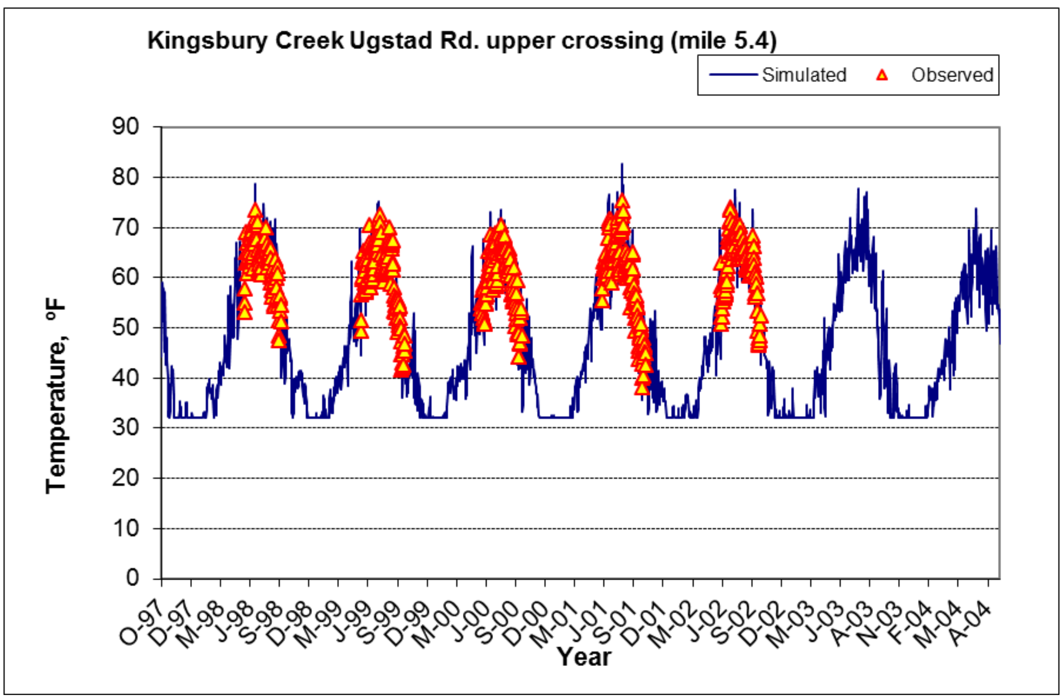

Figure 7-10. Temperature Time Series at Kingsbury Creek Ugstad Rd. upper crossing (mile 5.4) (1997-2004)

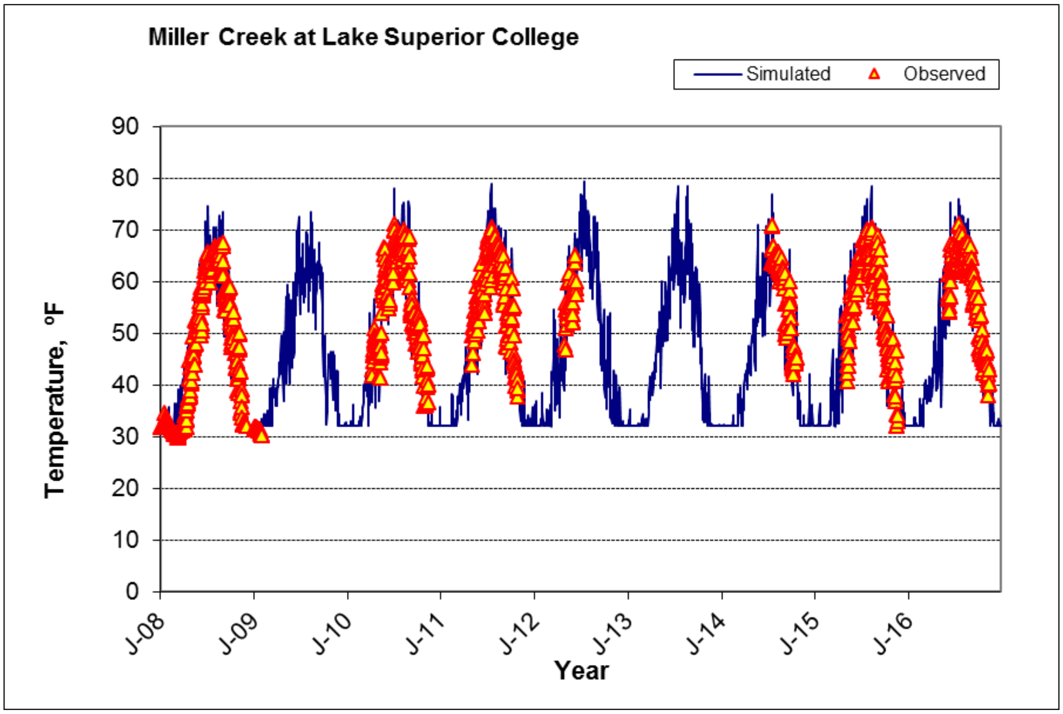

Figure 7-11. Temperature Time Series at Miller Creek at Lake Superior College (2008-2016)

Summary statistics for the calibration and validation temperature are provided in Table 7-1. and Table 7-2., respectively. Average and median relative errors are generally less than five percent, and are always less than eight percent.

Table 7-1. Summary of Water Temperature Calibration Results

Station	Count	Temperature Average Relative Error (%)	Temperature Median Relative Error (%)
Lester River near Duluth, CSAH10	129	-4.3%	-4.8%
Amity Ck on First Brg on Occidental Blvd in Duluth	2247	4.1%	4.2%
Tischer Ck at Wallace Ave "Mt. Royal", Duluth	3345	5.5%	5.1%
Buckingham Creek above Twin Ponds	306	-7.1%	-7.9%
Miller Ck at Chambersburg Rd	1116	0.5%	0.7%
Miller Creek at Lake Superior College	1550	0.8%	0.5%
Kingsbury Creek Ugstad Rd. upper crossing (mile 5.4)	156	-1.7%	-2.0%

Table 7-2. Summary of Water Temperature Validation Results

Station	Count	Temperature Average Relative Error (%)	Temperature Median Relative Error (%)
Lester River near Duluth, CSAH10	275	-3.7%	-3.1%
Tischer Ck at Wallace Ave "Mt. Royal", Duluth	634	5.4%	5.1%
Buckingham Creek above Twin Ponds	255	-1.4%	-2.1%
Miller Creek at Hermantown, CSAH53 by Miller Hill Mall	370	-4.7%	-4.2%
Miller Ck at Chambersburg Rd	494	-3.4%	-2.3%
Miller Creek at Duluth, 26th Ave W & W Michigan	449	-5.3%	-5.2%
Keene Creek Central Avenue (mile 0.5)	382	2.1%	1.5%
Kingsbury Creek Ugstad Rd. upper crossing (mile 5.4)	628	0.4%	0.7%
Stewart Creek Skyline Parkway (mile 1.1)	543	6.3%	5.6%

The model predicts averages and seasonal trends well, which is sufficient to support the representation of instream kinetics. However, as noted above, a detailed simulation of daily temperature cycles would require a finer-scale model that takes into account solar aspect and topographic and vegetative shading throughout the day.

8 Algae and Dissolved Oxygen Calibration

The dissolved oxygen (DO) balance in streams reflects a complex interaction of reaeration rate (a function of turbulence), the oxygen concentration of inflowing water, the saturation concentration of oxygen (which depends on temperature and salinity), consumption of oxygen by bacterial breakdown of carbonaceous and nitrogenous material in the water column (biochemical oxygen demand or BOD) and at the water-sediment interface (sediment oxygen demand or SOD), production of oxygen during photosynthesis by algae and macrophytes, and consumption of oxygen during nighttime algal/macrophytes respiration. The impact of plant photosynthesis/respiration and diel cycles of water temperature results in a situation where grab sample measures of DO are not very informative for model calibration. Further, the influence of algae/macrophytes on DO means that DO and algae must be calibrated simultaneously.

Due to the significant role of algal photosynthesis and respiration in the DO balance, this section first reviews the information on algal density. This is followed by a preliminary evaluation of the DO simulation.

8.1 Algae

One monitoring station had limited data on planktonic algal densities (as chlorophyll a) and no quantitative information was identified on benthic algal densities. Observations of chlorophyll *a*, the primary photosynthetic pigment in most algae, serve as an indicator of planktonic algae density – but do not provide information on benthic algae and macrophytes. Given the paucity of information on algal density, model calibration focused on ensuring that planktonic chlorophyll *a* concentrations were in a reasonable range.

The station with the only chlorophyll *a* records is Lester River above Superior St, Lester Park at Duluth, MN (Table 8-1.). All of the chlorophyll *a* samples were gathered during the summer months of June – September when algal activity peaks. Concentrations at this location ranged from 0.1 – 2.96 µg/L; the average simulated chlorophyll *a* concentration at this site is near the low end of this range at 0.29 µg/L. Concentrations as high as 11.4 µg/L are simulated in this reach, which are above the monitored concentration range. Graphical and tabular results are shown in Appendix E. Additional chlorophyll *a* sampling at this site, and at other locations throughout the Duluth WRAPS watersheds, could be used to refine the algae dynamics simulated by the watershed model.

Table 8-1. Chlorophyll *a* Concentrations (µg/L) in the Duluth WRAPS Watersheds (2003-2010)

Station	Model Reach	Sample Count 2001-2012	Monitored Range and Average Concentration	Simulated Average and Maximum Daily Concentrations
Lester R above Superior St, Lester Pk at Duluth	483	16	0.1 – 2.96 (0.96)	0.29 (11.4)

8.2 DISSOLVED OXYGEN

Simulation of dissolved oxygen (DO) in the stream depends on a complex interaction between reaeration, algal production and respiration, and biochemical oxygen demand (Figure 8-1.). Many of these processes also affect nutrient balances, so the DO calibration must be achieved consistent with the nutrient calibration. The oxygen balance is also strongly dependent on the water temperature simulation, which affects reaction rates and determines the saturation DO concentration.

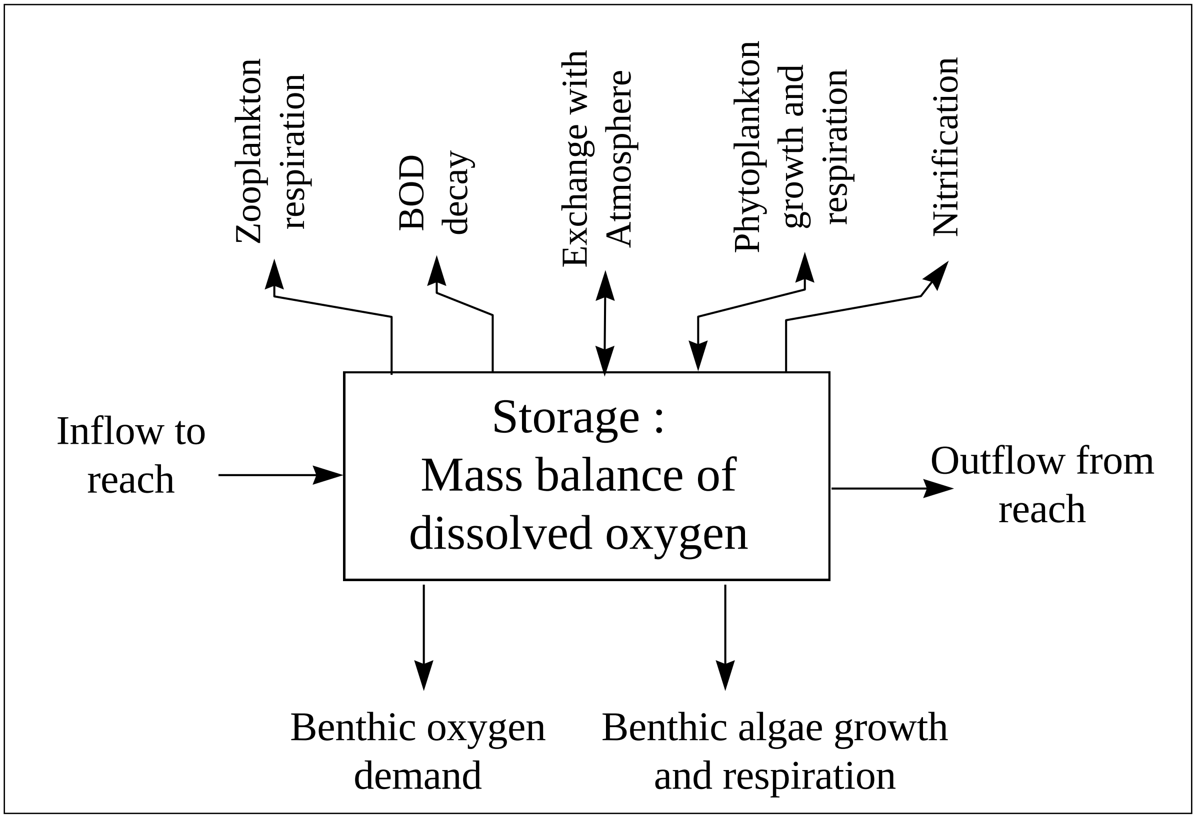

Figure 8-1. Process Diagram for Oxygen Mass Balance in HSPF

Many of the components of the oxygen mass balance in the Duluth WRAPS watersheds have little or no available monitoring data. Specifically, there are no known monitoring data for reaeration rates, benthic oxygen demand, benthic algal, zooplankton densities and there is only one station with 16 samples for biochemical oxygen demand (BOD). As noted in Section 8.1, monitoring for planktonic algae in streams is also very limited.

Reaeration: When oxygen concentrations are reduced below saturation, oxygen tends to move from the atmosphere to the water, a process known as reaeration. The rapidity of reaeration depends on how well the water is mixed and the turbulence present at the water surface. HSPF provides several options for simulating stream reaeration. For the Duluth WRAPS model the Owens, Churchill, or O'Connor-Dobbins method (O'Connor and Dobbins, 1958; Churchill et al., 1962; Owens et al., 1964) is used depending on velocity and depth of water for stream segments.

Biochemical Oxygen Demand: HSPF simulates nitrogenous and carbonaceous components of biochemical oxygen demand separately, with the nitrogenous component being determined by concentrations of reduced inorganic nitrogen species (ammonium and nitrite). Carbonaceous biochemical oxygen demand (CBOD) loading from the watershed is simulated as the labile fraction of total organic carbon, as described in Section 6.1. As the decay of CBOD results in the conversion of labile organic matter to inorganic nutrients, the representation of CBOD is largely constrained by the nutrient calibration.

The CBOD decay rate (k_d) of 0.0035 per hour (0.084 per day), which is near the low end of the range of values reported nationally for streams without untreated waste input (USEPA, 1997), was implemented and provides reasonable results.

Clean streams with low organic matter content generally have observed 5-day BOD (BOD_5) concentrations that range from 1 – 2 mg/L (Blair, 1996). Concentrations can exceed 6 mg/L in streams that contain lots of organic matter and/or bacteria (Blair, 1996). Much higher concentrations (up to 30 mg/L) were observed in the 1960s and 1970s prior to modern wastewater treatment plant improvements. The HSPF model simulates ultimate carbonaceous BOD concentrations (CBODu) and concentrations of CBODu can be triple the magnitude of BOD_5 (Chapra, 2014). Average CBODu concentrations predicted by the model are in the range of 0.1 to 2 mg/L.

Benthic Interactions. Organic soils and sediment associated with upland management practices affect the oxygen balance. These may both release BOD into the stream and exert a sediment oxygen demand (SOD) at the sediment-water interface. No direct measurements of SOD were identified, and these components are at this time a calibration adjustment factor.

Algal Dynamics: The activities of floating (planktonic) and attached (benthic) algae also affect the oxygen balance in streams. Algae produce oxygen as a byproduct of photosynthesis during sunlight hours, but are net consumers of oxygen through respiration at night. Algae can also die off, contributing to the biochemical oxygen demand.

Calibration for dissolved oxygen presents challenges as there is likely to be significant diel variability due to the influence of algal photosynthesis and respiration that limits the information value of scattered grab samples. In addition, most samples represent points in time and within the water column, with most samples being for surface waters whereas HSPF predicts averages throughout the volume of a stream reach. Continuous DO data, which is necessary for a comprehensive DO calibration, was not available for streams in the Duluth WRAPS watersheds. However, grab samples of DO concentrations were taken at multiple locations throughout the study area. These grab samples are useful for determining if DO is reasonably represented in these model reaches. There may be, however, significant spatial variability at scales smaller than the reaches in the basin-scale model due to local changes in light availability, substrate composition, and reaeration capacity.

Table 8-2. provides a summary of the range and average concentration for the monitoring data, and the range and average concentration for the full simulation period. The averages and maxima are generally comparable between the monitored and simulated values at each location. The minimum simulated value tends to be lower than the minimum observed value, but the monitoring data are limited, whereas the full simulation reflects the range for the entire 21-year simulation. Appendix E provides full graphical and tabular results; it is important to note that modeled daily average and point-in-time field measurements are not directly comparable since there are large diel swings in DO throughout the day, and the field measurement may not be reflective of the daily average.

Table 8-2. Dissolved Oxygen (DO) Concentrations (mg/L) in the Duluth WRAPS Watersheds

Station	Sample Count	Monitored Range and Average Concentration	Full Simulation Range and Average Concentration
Lester R above Superior St, Lester Pk at Duluth	122	6.49 – 15.66 (10.43)	3.68 – 14.25 (11.33)
Lester River at Strand Rd/CR-10	48	7.31 – 13.72 (10.38)	3.14 – 14.06 (10.78)
Amity Ck, EB above Confluence with Amity Ck, WB in Duluth	49	6.17 – 16.86 (11.06)	3.38 – 14.07 (10.39)
Amity Ck near Skyline Pkwy, N Duluth, MN	27	9.22 – 17.3 (12.17)	4.02 – 14.21 (10.08)
Unnamed Stream to Amity Ck, NE Duluth, MN	27	8.36 – 15.38 (11.57)	2.84 – 14.21 (8.62)
Amity Ck on First Brg on Occidental Blvd in Duluth	148	7.78 – 16.01 (11.37)	4.03 – 13.84 (9.93)
Tischer Ck at Wallace Ave Mt. Royal, Duluth Tischer Ck just Dwnst from Brg Crossing on 4th St in Duluth Tischer Ck Upstr of Woodland Ave in Duluth, MN	76	6.66 – 16.34 (10.65)	3.56 – 13.49 (9.40)
Chester Creek in Duluth, MN Chester Ck at College of St. Scholastica In Duluth Chester Ck just West of W College St in Duluth, MN	80	5.75 – 15.3 (10.35)	4.51 – 14.05 (11.14)
Buckingham Ck at W 3rd St in Duluth	26	8.38 – 12.31 (9.84)	3.94 – 14.04 (10.53)
Unnamed Stream (Coffee Ck) just E of Miller Ck on Courtland St	26	7.67 – 12.31 (9.5)	3.21 – 12.91 (8.07)
Miller Ck, Upper Gage Site at Hwy 53 in Duluth	29	0.83 – 11.13 (7.78)	2.02 – 13.94 (8.62)
Miller Ck at Chambersburg Rd	18	5.7 – 16.1 (9.14)	2.12 – 13.96 (8.70)
Miller Cr at Lk Superior College, 2 mi W of Duluth, MN	41	8.47 – 15.11 (10.42)	2.43 – 14.01 (10.25)

Station	Sample Count	Monitored Range and Average Concentration	Full Simulation Range and Average Concentration
Miller Creek, Lower Site at 26Th Ave W in Duluth Miller Ck just East of N 24Th Ave W in Duluth, MN	65	6.92 – 14.29 (10.55)	3.0 – 13.43 (9.51)
Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN	59	0.27 – 13.83 (9.65)	3.61 – 14.29 (10.96)
Keene Ck at 57th Ave W in Duluth, MN	58	6.6 – 14.57 (10.56)	3.31 – 14.29 (9.61)
Kingsbury Creek at Lake Superior Zoo in Duluth	36	7.49 – 16.12 (11.53)	2.65 – 14.25 (9.77)
Stewart Ck at US Steel RR Line, 2 mi NNE of Gary, MN	18	3.41 – 13.34 (9.21)	1.65 – 14.28 (7.16)
Sargent Ck at Hudson Blvd, 1 mi S of Gary, MN	18	6.83 – 13.39 (9.58)	2.16 – 14.28 (8.50)
Mission Ck at MN-23, 2.6 mi WSW of Gary, MN	34	0.58 – 12.03 (9.44)	2.61 – 14.31 (9.27)

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9 Chloride Calibration

Elevated chloride concentrations are a concern in several Duluth area streams. The primary source of chloride is the application of salt for de-icing on roads, parking lots, and other urban impervious surfaces. Additional loads may come from onsite wastewater disposal, natural geology, and atmospheric deposition. The long history of salt use has also resulted in increased chloride concentrations in ground water, so baseflow concentrations may be elevated above natural background.

9.1 CHLORIDE MODEL SETUP

The chloride simulation follows the same general approach used for inorganic nitrogen in the nutrient model. Chloride is simulated on the land surface by buildup-washoff processes and by specifying interflow and groundwater concentrations. For the instream simulation, chloride is represented as a general quality constituent. It is set up with a first order decay constituent to represent losses during transport, but the decay rate is set to a very small number so decay has relatively little influence on the instream concentration.

The key parameters controlling the upland chloride simulation are listed below:

MON-ACCUM: The monthly varying assignment of the build-up or accumulation of a constituent on a particular surface (lb/ac-d).

MON-SQOLIM: The monthly varying upper limit value beyond which a constituent can no longer accumulate on a surface (lb/ac).

MON-IFLW-CONC and **MON-GRND-CONC**: These parameters are used to assign the interflow and groundwater constituent concentrations on a monthly basis. The values for these parameters were estimated from the observed data with consideration of flow regime and then calibrated as necessary.

Accumulation rates for chloride on road surfaces are based on information on road salt use in Duluth (Current Results; Lake Superior Streams). The model assumes three salt applications for each day with measurable snowfall. Each application consists of 155 lb/ac of NaCl, equivalent to 94 lb/ac of chloride. Smaller accumulation rates are also assumed to developed land adjacent to roads.

The simulated unit-area loading rates of chloride from land to stream are provided in Figure 9-1.

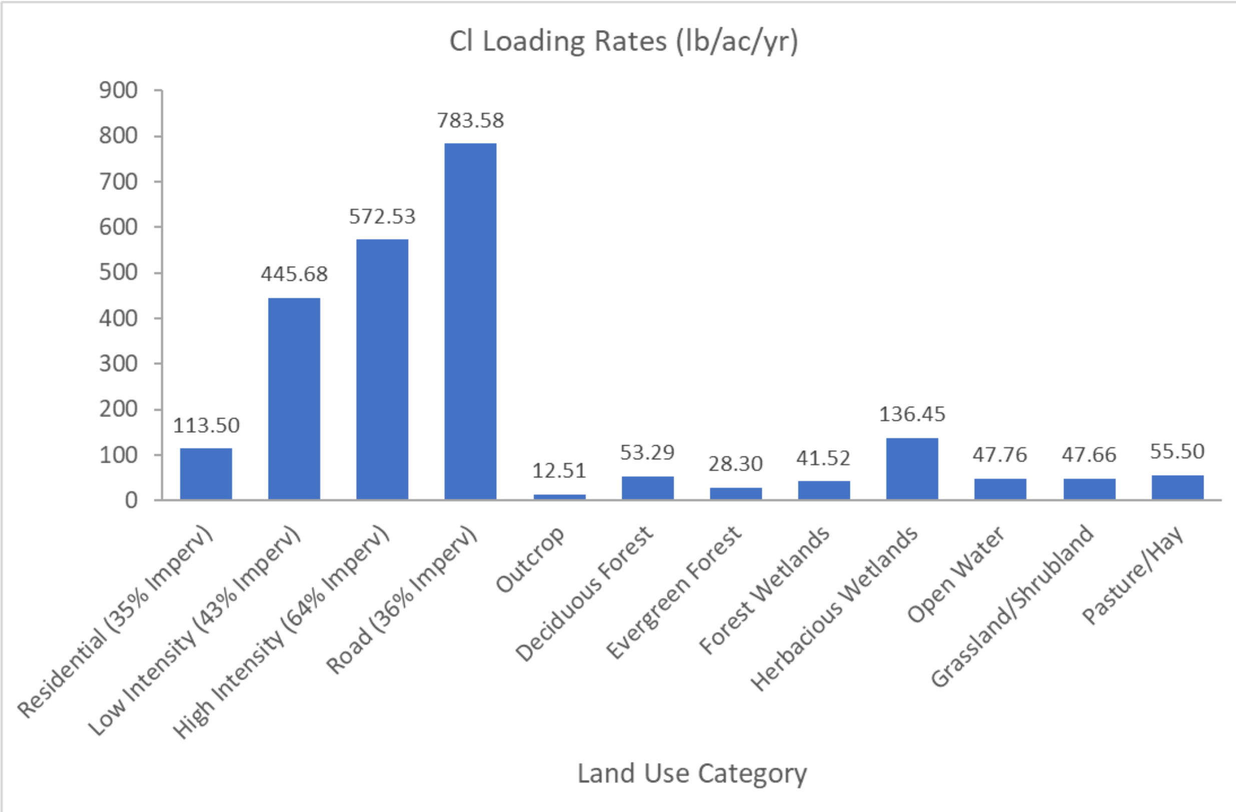

Figure 9-1. Mean Simulated Chloride (Cl) Unit Loading Rates for Land Use Categories in the Duluth WRAPS Watersheds

As previously discussed continuous measurement of water temperature was conducted at several dozen locations in the study area and seven of these had paired samples of conductivity and chloride, from which regressions were developed to relate conductivity to chloride concentration. The conductivity-chloride regressions are discussed further in Section 3.1.2.1. Additionally, 12 stations have discrete samples on which chloride was measured. Similar to nutrients and temperature comparisons between model predictions and sample observations are made in terms of both concentration and inferred load (concentration times simulated or observed and simulated flow). Complete graphical and tabular statistical results for each chloride station are provided in Appendix F. Figure 9-2. provides an example of the primary types of calibration plots provided for chloride at each site, in this case showing the calibration for the Amity Creek at Occidental Boulevard, station. The four panels in Figure 9-2. are:

a. Standard time series plot, showing the observations and continuous model predictions of daily average concentrations. This shows general agreement, but can obscure biases in the simulation.

b. A power plot comparing the relationship of observed and simulated loads versus flow. The objective here is that the relationship to flow (summarized by the power regression lines) should be similar for the model and observations. The figure shown here shows very good agreements between the regression lines

c. A scatterplot of simulated versus observed concentrations shows the degree of spread or uncertainty about the 1:1 line.

d. A plot of the residuals against flow is used to diagnose bias relative to the flow regime. In this case there is a fair balance between over and under-prediction across the range of flows. A similar plot of residuals versus month is used to diagnose potential seasonal biases.

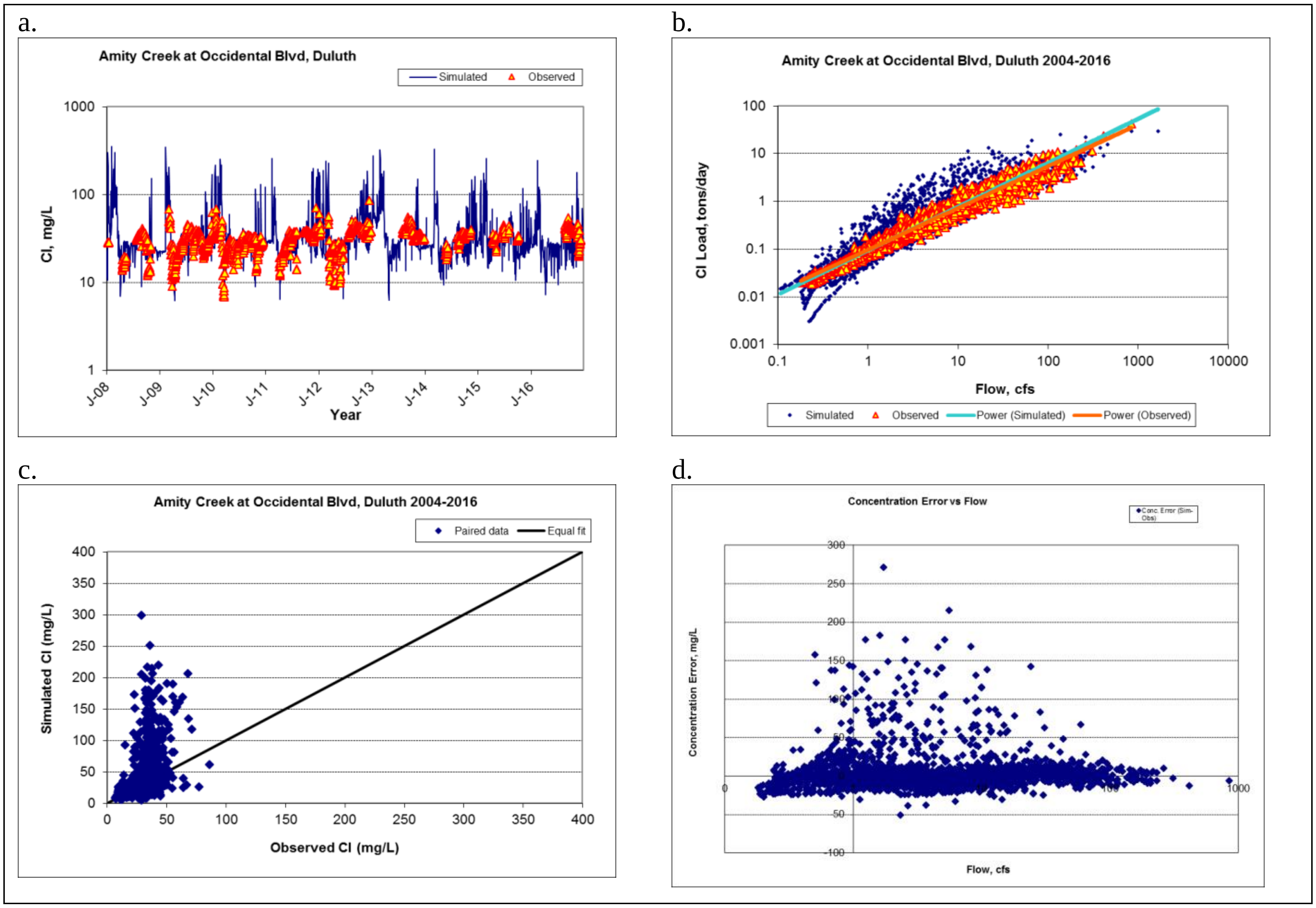

Figure 9-2. Example Calibration Plots for Chloride, Amity Creek at Occidental Boulevard

This section first provides an overview of the chloride results with full results provided in Appendix F. Summary statistics for the calibration and validation of chloride are provided in Table 9-1. and

Table 9-2, respectively. Discussion follows the tables.

Table 9-1. Summary of Chloride Calibration Results

Station	Count	Average Concentration (mg/L)	Concentration Average Relative Error (%)	Concentration Median Relative Error (%)	Paired Load Average Relative Error (%)	Paired Load Median Relative Error (%)
Lester R above Superior St, Lester Pk at Duluth	18	11.90	74.2%	-16.7%	-6.5%	-10.3%
Amity Ck, EB above Confluence with Amity Ck, WB in Duluth	19	23.03	-15.6%	-7.3%	-18.0%	-0.8%
Amity Ck on First Brg on Occidental Blvd in Duluth	118	23.82	-5.6%	-6.5%	-14.3%	-0.9%
Amity Ck on First Brg on Occidental Blvd in Duluth (continuous)	2294	31.37	14.2%	-3.2%	11.4%	-0.7%
Tischer Ck at Wallace Ave Mt. Royal, Duluth Tischer Ck just Dwnst from Brg Crossing on 4th St in Duluth Tischer Ck Upstr of Woodland Ave in Duluth, MN	79	79.44	-22.5%	-1.5%	-29.8%	-0.2%
Tischer Ck at Wallace Ave "Mt. Royal", Duluth (continuous)	3117	104.87	-23.5%	-15.9%	-25.8%	-1.9%
Chester Creek in Duluth, MN Chester Ck at College of St. Scholastica In Duluth Chester Ck just West of W College St in Duluth, MN	112	76.69	-5.3%	13.8%	-13.4%	2.9%
Chester Ck at College of St. Scholastica in Duluth (continuous)	1587	119.03	-20.8%	-11.3%	-24.7%	-2.0%
Miller Ck, Upper Gage Site at Hwy 53 in Duluth	33	77.09	31.9%	40.5%	11.7%	3.1%
Miller Ck at Chambersburg Rd	32	127.65	-18.4%	-10.6%	-23.3%	-0.9%
Miller Ck at Chambersburg Rd (continuous)	502	155.35	-22.6%	-14.8%	-29.1%	-2.2%
Miller Creek, Lower Site at 26Th Ave W in Duluth Miller Ck just East of N 24Th Ave W in Duluth, MN	71	139.46	-24.4%	-17.4%	-37.7%	-1.5%
Miller Creek at Duluth, 26th Ave W & W Michigan (continuous)	1038	214.64	-29.5%	-9.3%	-52.2%	-1.0%
Kingsbury Creek at Lake Superior Zoo in Duluth	70	64.35	15.5%	24.2%	12.9%	15.0%
Kingsbury Ck at Lake Superior Zoo in Duluth (continuous)	2979	118.11	0.7%	7.7%	8.4%	1.7%
Mission Ck at MN-23, 2.6 mi WSW of Gary, MN	18	90.22	-4.0%	12.0%	6.0%	2.7%
Keene Creek Central Avenue (mile 0.5)	38	74.17	-1.1%	7.8%	-8.4%	0.5%
Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN	38	82.11	-10.7%	3.2%	-41.1%	0.2%

Table 9-2 Summary of Chloride Validation Results

Station	Count	Average Concentration (mg/L)	Concentration Average Relative Error (%)	Concentration Median Relative Error (%)	Paired Load Average Relative Error (%)	Paired Load Median Relative Error (%)
Lester River just Upstream of County Road 293 (Tischer Rd)	30	4.79	97.7%	76.4%	68.0%	42.6%
Amity Creek just west of East Skyline Parkway in Duluth, MN	18	21.09	46.1%	52.8%	7.9%	16.4%
Amity Ck on First Brg on Occidental Blvd in Duluth	59	22.57	13.0%	12.5%	6.8%	2.2%
Tischer Ck at Wallace Ave "Mt. Royal", Duluth (continuous)	627	102.21	-22.9%	-4.6%	-37.2%	-1.0%
Chester Creek in Duluth, MN Chester Ck at College of St. Scholastica In Duluth Chester Ck just West of W College St in Duluth, MN	41	131.79	-44.8%	3.9%	-39.2%	2.1%
Chester Ck at College of St. Scholastica in Duluth (continuous)	542	103.79	-10.5%	-5.7%	-24.7%	-0.9%
Miller Creek at Hermantown, CSAH53 by Miller Hill Mall (continuous)	367	64.18	112.1%	98.4%	99.9%	24.5%
Miller Ck at Chambersburg Rd (continuous)	494	101.60	48.6%	53.4%	49.5%	10.7%
Miller Creek at Duluth, 26th Ave W & W Michigan (continuous)	449	75.87	85.4%	88.6%	45.0%	15.1%
Kingsbury Creek at Lake Superior Zoo in Duluth	38	117.70	-22.4%	15.5%	-20.6%	3.3%
Kingsbury Ck at Lake Superior Zoo in Duluth (continuous)	468	94.75	14.3%	16.9%	20.1%	7.8%

The HSPF model calibration provides a credible fit to observed chloride concentrations in most of Duluth's urban streams. The validation generally supports the calibration, although fit declines at a few of the sites – possibly representing changes in chloride application rates and groundwater concentrations over time in parts of the watershed. The model does appear to over-predict the observed chloride concentrations in Miller Creek (validation period) and low observed chloride concentrations in Lester River (calibration and validation periods) and Amity Creek (validation period).

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10 Watershed Loads

Watershed-scale average annual loads are presented in Table 10-1. for sediment, TP, TN, and chloride. These represent loads discharged to the St. Louis River Estuary and Lake Superior from all upstream sources, including upland, direct deposition, channel, and from bluffs. Loads are highly variable due to large differences in watershed areas ranging from 29 acres for 84th Ave. W. Creek to 23,699 acres for Lester River (note that the tabulation of loads and area for Lester River excludes Amity Creek).

To allow for relative comparison between watersheds, loads were scaled to watershed area and are shown in Figure 10-1. (sediment), Figure 10-2. (TP), Figure 10-3. (TN), and Figure 10-4. (chloride). Some patterns are evident. The most urbanized watersheds tend to have the highest loading rates, while Lester River (which has a low proportion of developed area) has the lowest rates for TP, TN, and chloride. However, there is some variation in the rankings which reflects different combinations of sources from upland land uses and near-channel contributions.

Table 10-1. Average Annual Loads Discharged from Duluth WRAPS Watersheds

Subbasin (HSPF Reach Outlet)	Cumulative Drainage Area (ac)	Annual Average Load			
		TSS (tons/yr)	TP (lbs/yr)	TN (lbs/yr)	Chloride (tons/yr)
32nd Ave W Creek (125)	507	43.7	107.3	4585	84.1
40th Ave E Creek (426)	251	25.6	50.7	1679	39
41st Ave W Creek (121)	293	21.5	66.4	2485	46.6
43rd Ave E Creek (428)	537	50.9	110.2	3647	65.6
44th Ave W Creek (120)	261	20.3	71.2	3003	50.5
47th Ave E Creek (430)	434	36	95	3451	48
49th Ave W Creek (119)	736	59.1	178.3	6981	127.7
58th Ave E Creek (432)	345	28.6	71.3	2884	43.5
62nd Ave W Creek (298)	632	45.1	123	3233	77.6
68th Ave W Creek (113)	88	5.7	17.4	450	9.7
82nd Ave W Creek (269)	436	26.3	85.1	2285	59.8
84th Ave W Creek (112)	29	1.6	4.1	77	2.8
85th Ave W Creek (263)	95	4.2	14.8	282	6.5
Amity Creek (435)	10,769	727.9	2026.1	34641	379.1
Bent Creek (133)	291	31.4	59.5	2146	33.8

Subbasin (HSPF Reach Outlet)	Cumulative Drainage Area (ac)	Annual Average Load			
		TSS (tons/yr)	TP (lbs/yr)	TN (lbs/yr)	Chloride (tons/yr)
Brewery Creek (379)	1,093	92.6	246.4	8942	188.3
Buckingham Creek (373)	811	54.2	154.7	3858	100.2
Chester Creek (385)	4,315	267.9	837.5	20866	448.3
Clarkhouse Creek (377)	359	37.6	99.6	4239	71.7
Coffee Creek (371)	884	77.2	182.8	5764	133.6
E Br Amity Creek (454)	5237	286.4	998.1	16843	150.4
Gogebic Creek (253)	149	5.1	25.5	431	8.7
Greys Creek (383)	342	33.3	77.6	3185	59.3
Keene Creek (302)	4,020	195.1	703.6	16213	433.3
Kingsbury Creek (272)	6,012	414.1	976.9	24240	656.4
Knowlton Creek (265)	1,362	76.2	241.9	4942	132.9
Lenroot Creek (111)	198	9	34.5	577	13.6
Lester River (483)	23,669	1521.8	3066.1	50591	298.2
Merritt Creek (320)	1,412	66.4	260	6771	158.7
Miller Creek (330)	6,212	337.9	1109.5	40324	882.6
Mission Creek (200)	6,954	1492	1745.9	20212	551.7
Morgan Park Creek (244)	579	19	110.9	2101	56.4
Oregon Creek (404)	508	55.4	127.3	5298	87
Sargent Creek (232)	1,964	95.7	360.4	5317	136.9
Stewart Creek (247)	1,108	55.6	205	3382	76.7
Tischer Creek (406)	4,570	619.1	1049.7	23031	396.6
Unnamed to St. Louis River (259)	119	8.7	24	729	17.1
US Steel Creek (239)	1,857	73.6	285.1	6165	200.1

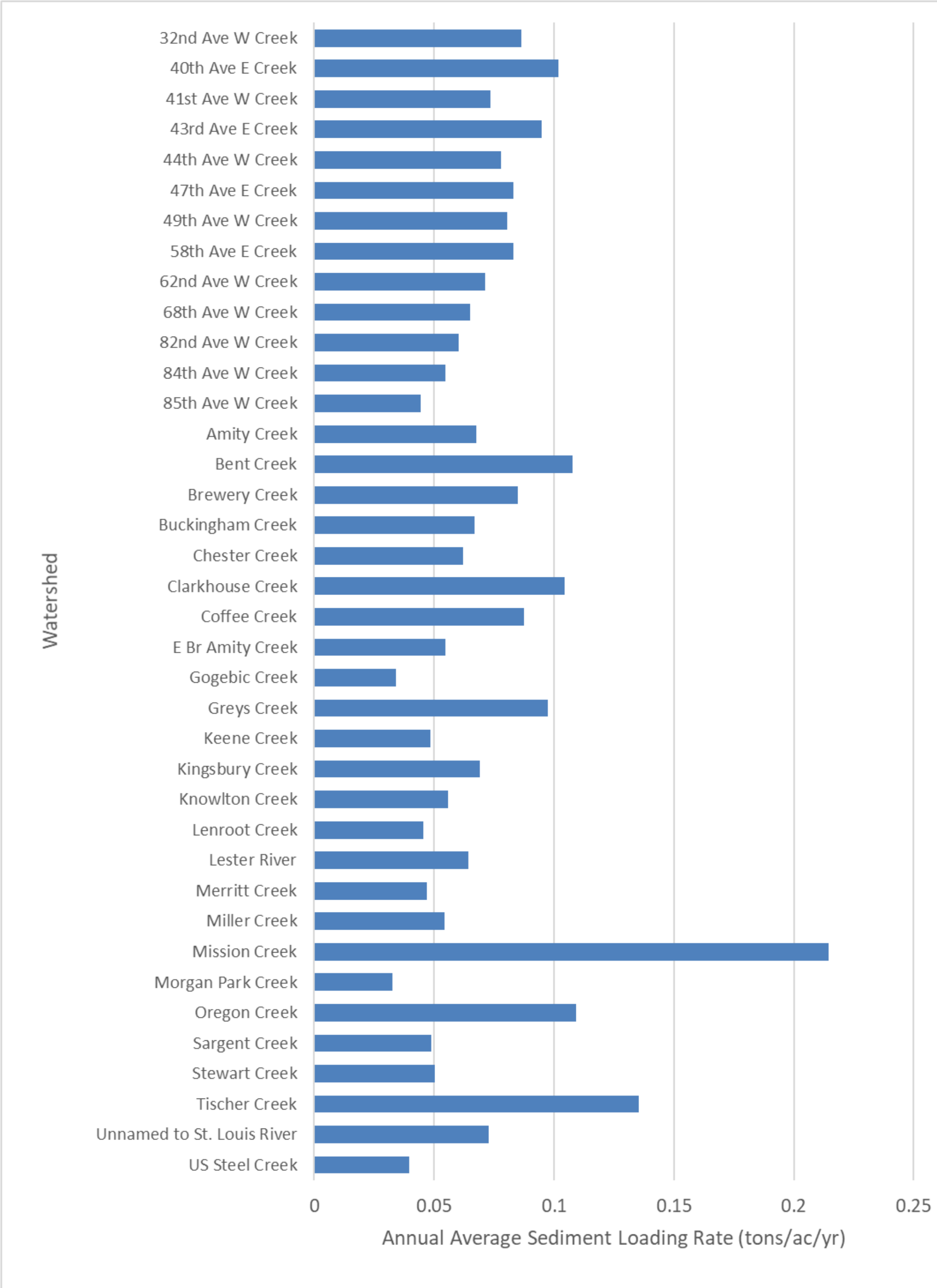

Figure 10-1. Watershed-scale Average Annual Loading Rates for Sediment

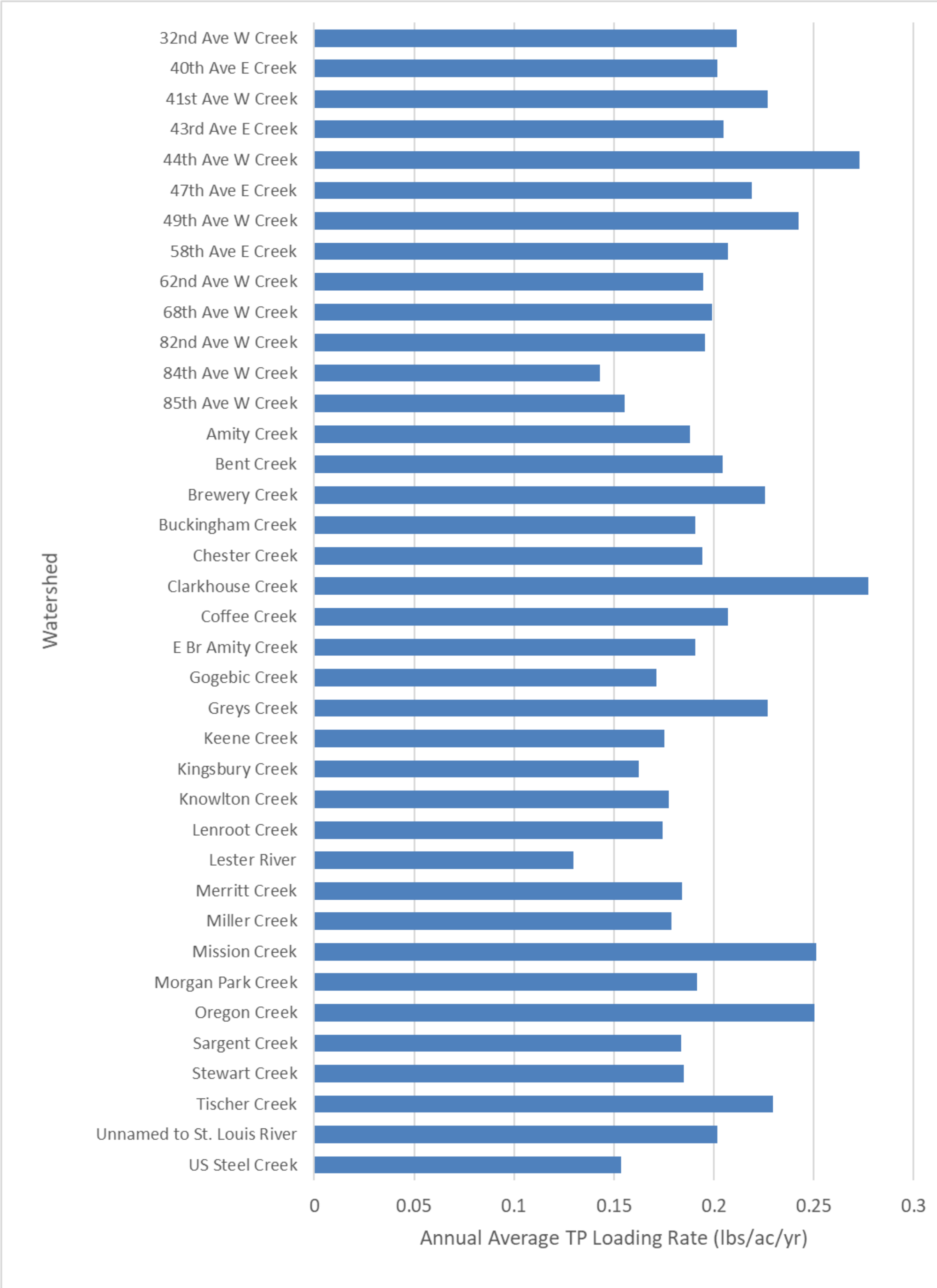

Figure 10-2. Watershed-scale Average Annual Loading Rates for TP

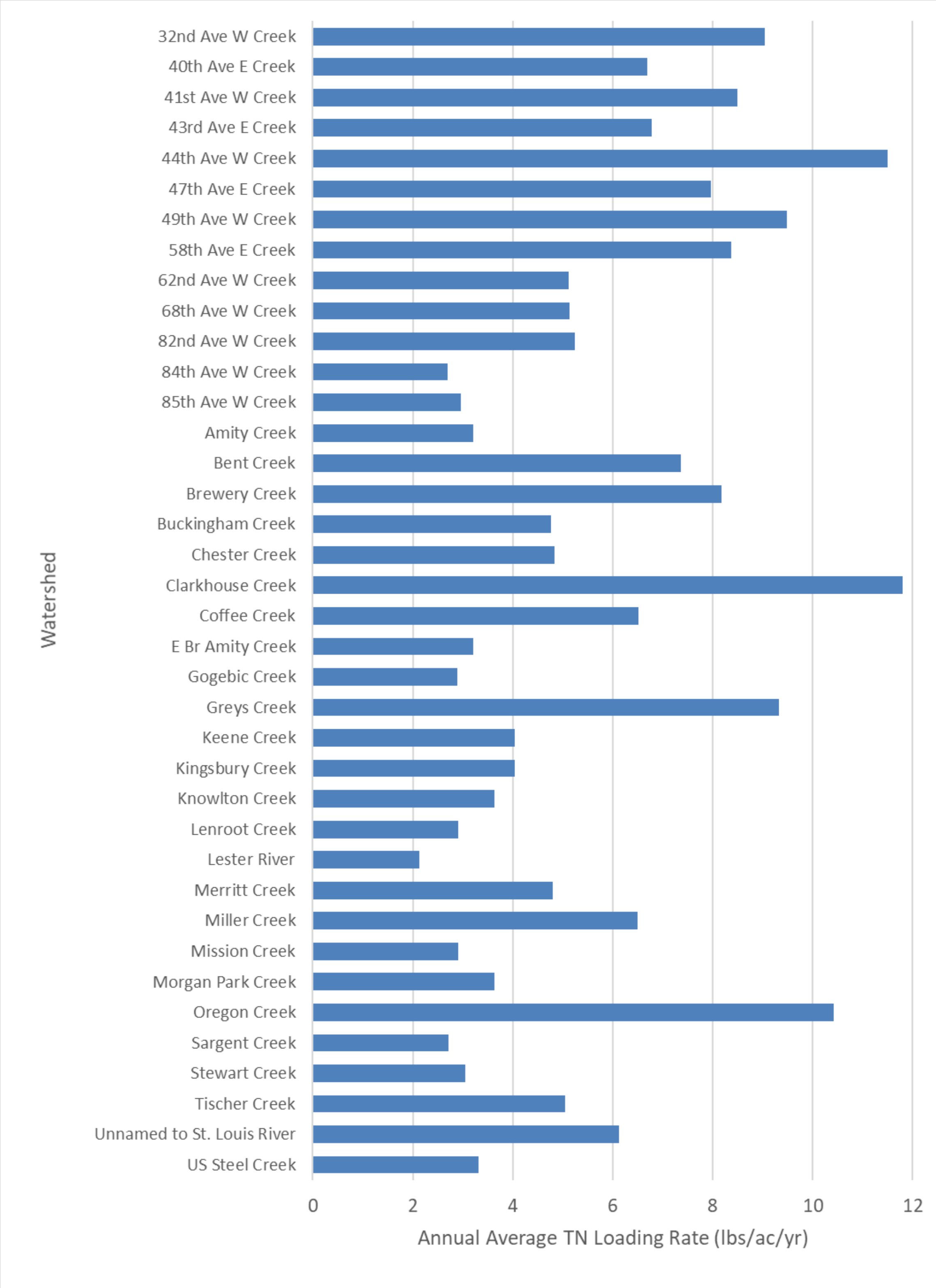

Figure 10-3. Watershed-scale Average Annual Loading Rates for TN

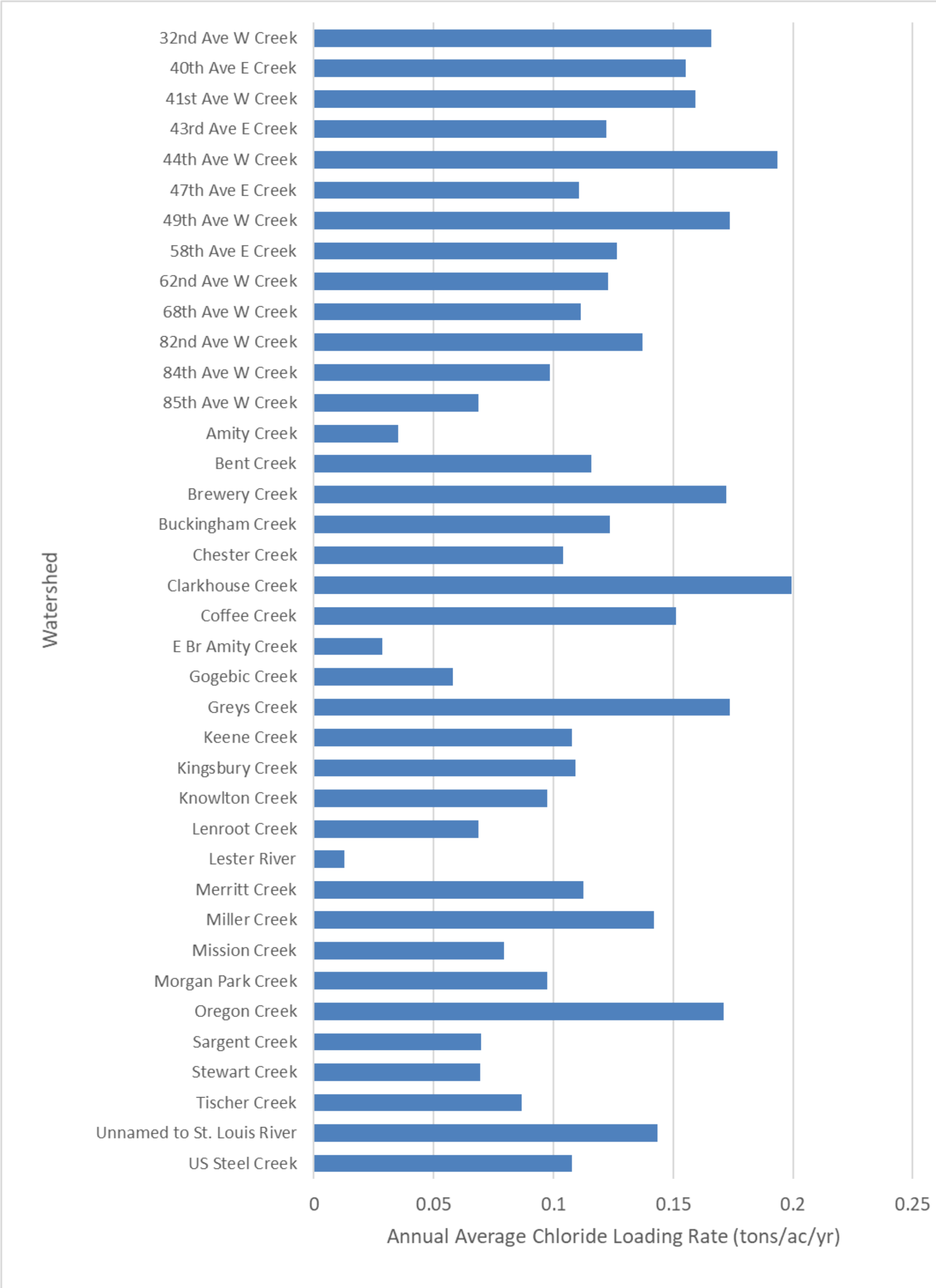

Figure 10-4. Watershed-scale Average Annual Loading Rates for Chloride

11 Potential Model Enhancements

The model calibration results presented in this report are based on available observed data available in 2019, and include new flow and water quality collected and reported following the first phase of the modeling in 2015, as well as new geomorphic information from several recently published studies. As more data and other information are collected in the study area, the model can be updated and adjusted to reflect new information.

Flow calibration and validation was successful, but there are areas in which the overall representation of the water balance could potentially be improved. One area in which additional attention may be needed is the representation of wetlands and bogs. Few monitoring or flow gaging data are available to directly evaluate the representation of these land forms. Bog and wetland hydrology simulation may need to be re-evaluated when further information is available. In addition, interaction with regional groundwater flow may need to be considered. The steep slope from the upper parts of the study area to Lake Superior may enhance groundwater discharges in some locations, some part of which may potentially be drawn from the adjacent St. Louis and Cloquet River basins. The simulation of Mission Creek may also benefit from further detailed study as the soils in this watershed have different characteristics from most of the remainder of the study area.

Another area for future enhancement of the model is greater use of detailed stream cross-section and culvert information for the development of stage-storage-discharge relationships (FTables) for modeled reaches. Incorporating such information to refine site-specific FTables would be expected to improve representation of the details of storm event hydrographs but would have only minor impacts on the overall flow balance. The storm hydrographs play an important role in determining channel scour and deposition process and improving these would also likely improve the model performance for suspended sediment and nutrient simulations.

The sediment simulation, while generally successful, is limited by knowledge about the behavior of bluffs and landslides in parts of the watershed, for which additional data are needed. The model could be enhanced through more extensive use of site-specific information about near-channel erosion throughout the study area. Further consideration of the responses of the different soils of the Mission Creek drainage may also be needed.

The model simulation for phosphorus presented challenges in some streams, and the validation tests were not entirely successful. There are significant differences in phosphorus concentrations observed at stations close to one another that are not fully explained by the model. Improvements to the phosphorus simulation might benefit through investigation of other potential sources, such as the phosphorus content of sediment eroded from bluffs and stream banks and phosphorus content of de-icing agents. As with any watershed model, detailed studies of nutrient loading from small areas of homogenous land use would help to further refine the nutrient simulation.

As currently constructed, the model is designed to provide a reasonable representation of water temperature and DO but is not calibrated to continuous hourly data. HSPF does have limitations for temperature and DO simulation. Continuous temperature and DO monitoring addresses conditions at a single, discrete location that is affected by local riparian cover, topographic shading, and the orientation or aspect of the stream segment relative to the position of the sun over the course of the day, all of which have strong impacts on energy inputs and exchanges. The HSPF model is best suited to produce daily averages over a whole model segment, not hourly patterns at a specific cross section. A detailed examination of temperature and dissolved oxygen in reaches of interest would best be served through the development of finer-scale models for reaches of interest, using a tool such as the QUAL2K model. The basin-scale HSPF model can be used to provide boundary conditions for a detailed model of this type.

Algae and macrophytes appear to play an important role in modifying nutrient concentrations and DO during the growing season in Duluth streams, particularly the balance between inorganic and organic nutrient species and the daily cycle of DO during low flow conditions. At present, there is only very limited information on planktonic chlorophyll a in these streams and little or no quantitative information on benthic (attached) algae and macrophytes. Collecting such information would help to refine both the DO and nutrient simulations.

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Appendix A. Detailed Snow Calibration Results

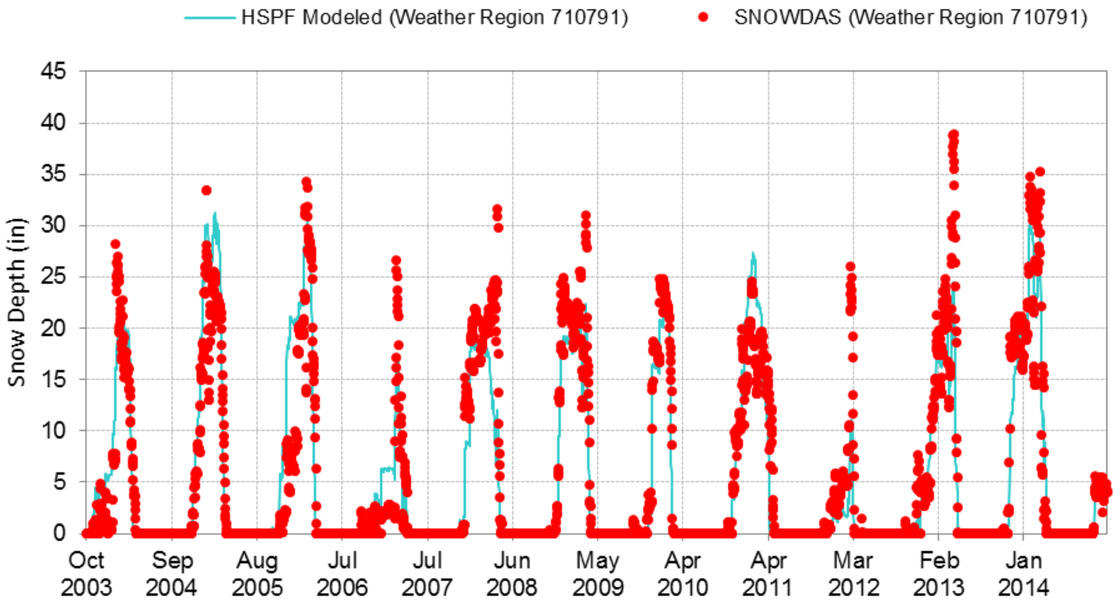


Figure A-1. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 710791

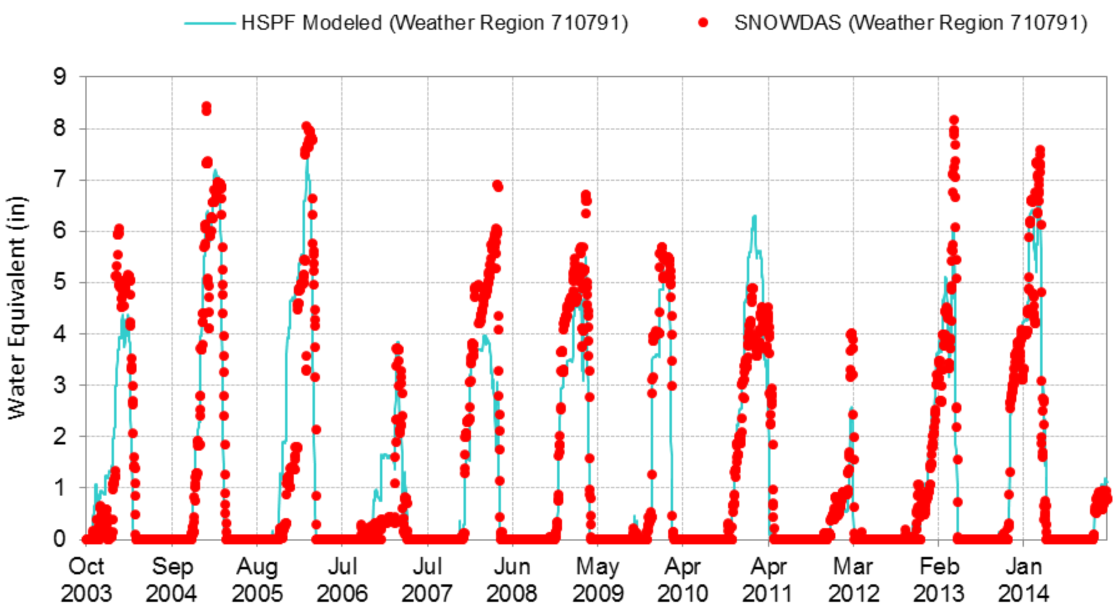


Figure A-2. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 710791

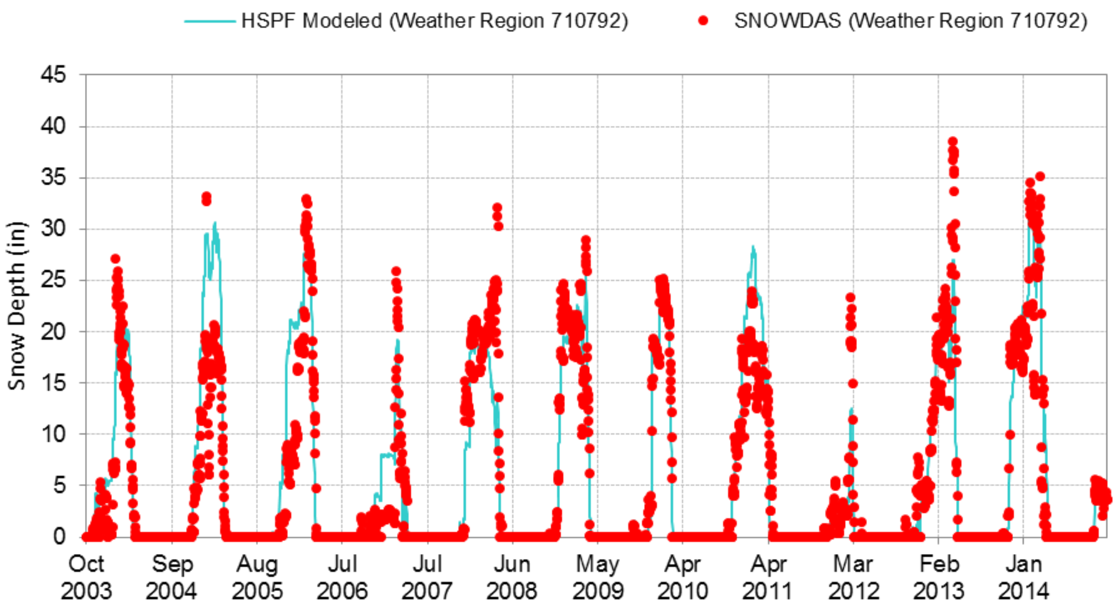


Figure A-3. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 710792

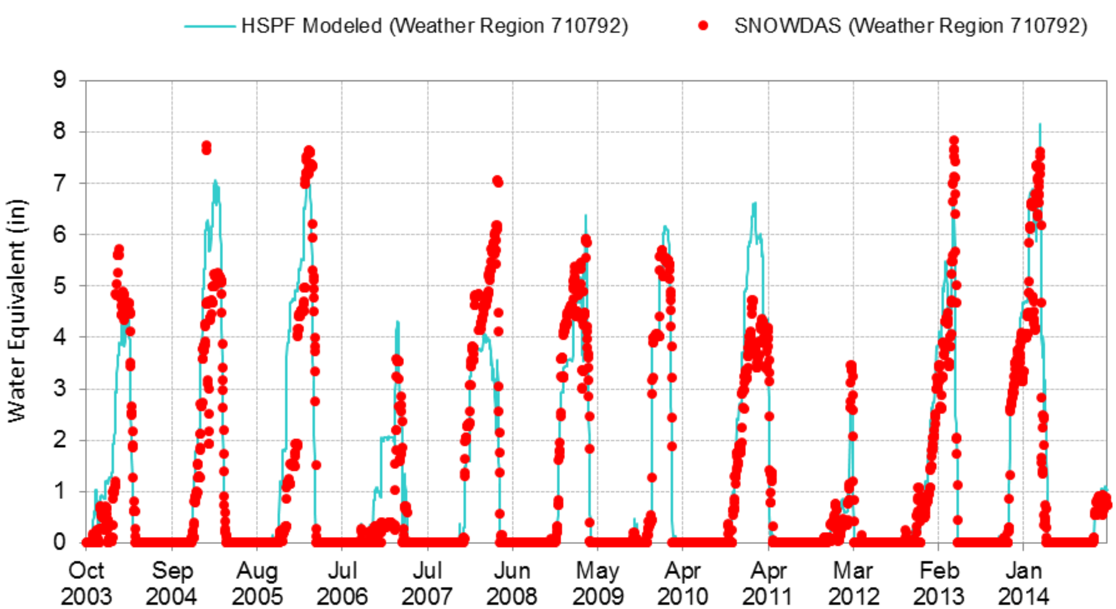


Figure A-4. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 710792

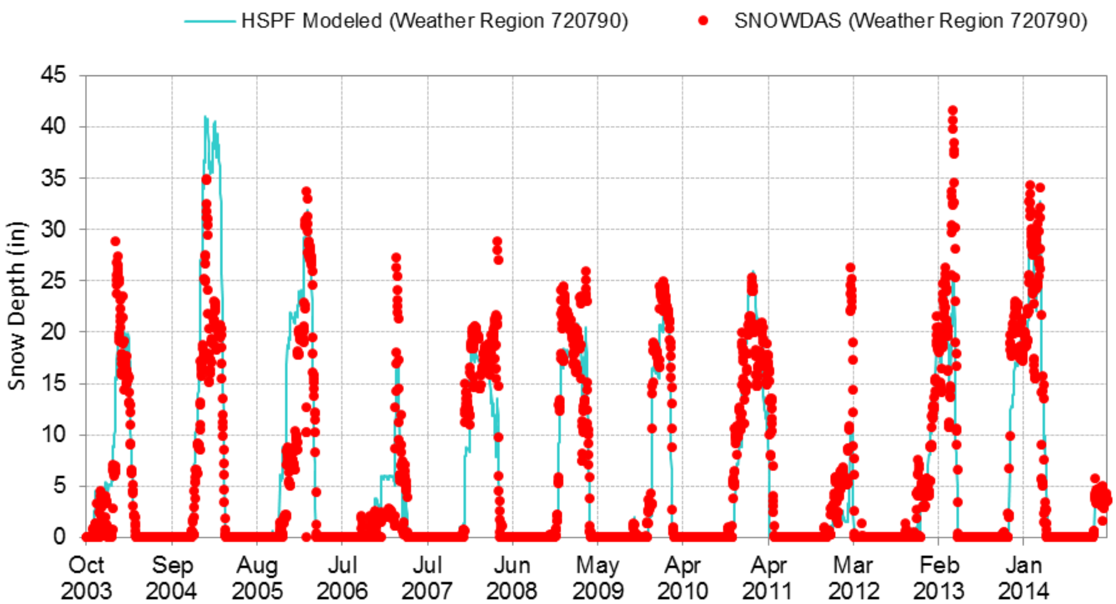
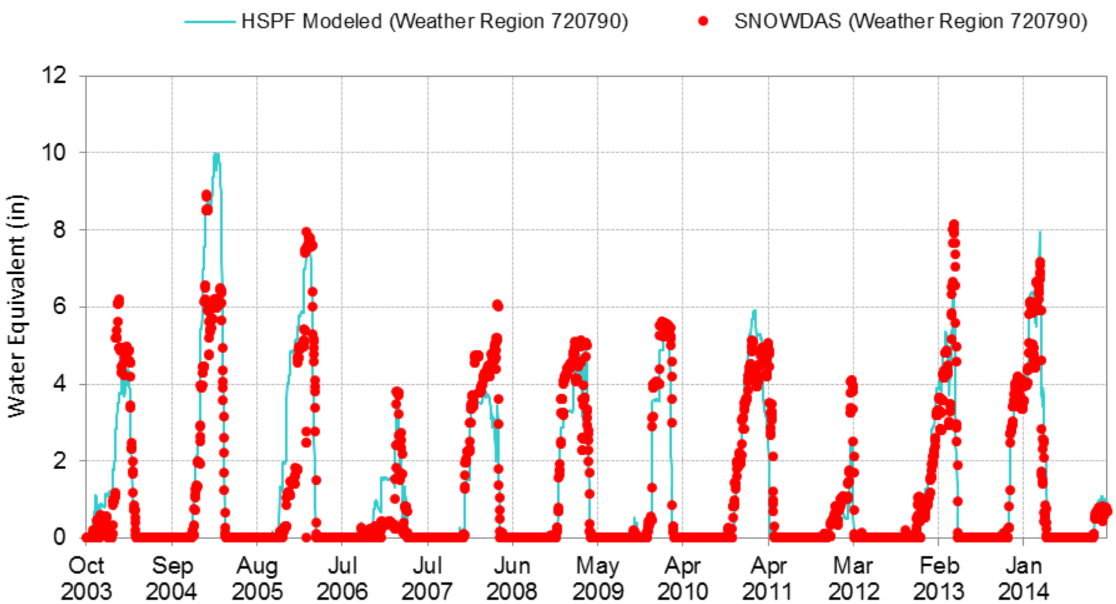


Figure A-5. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 720790



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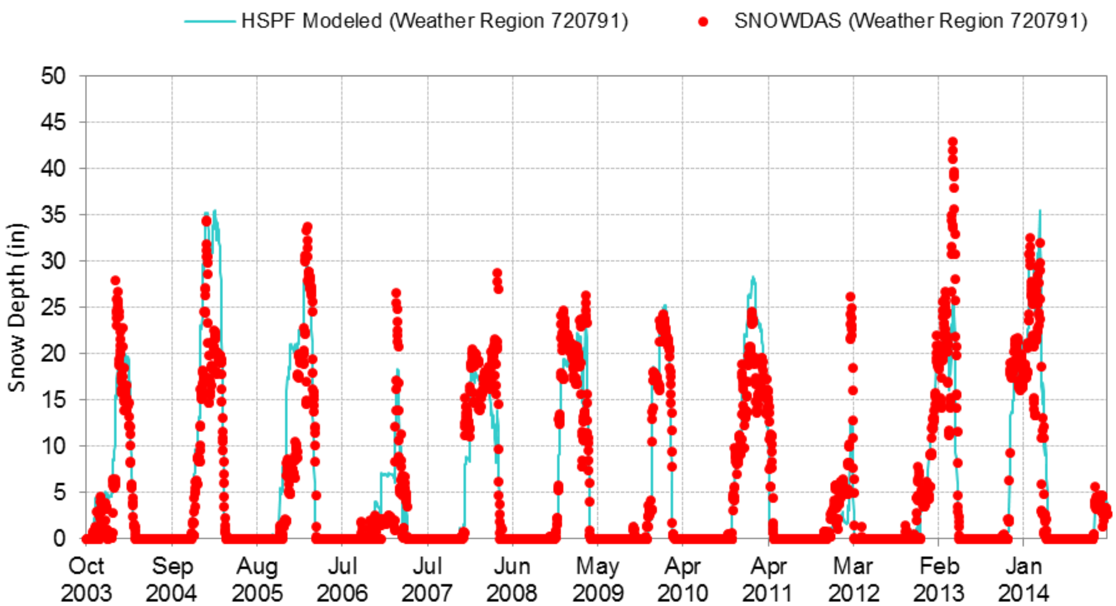


Figure A-7. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 720791

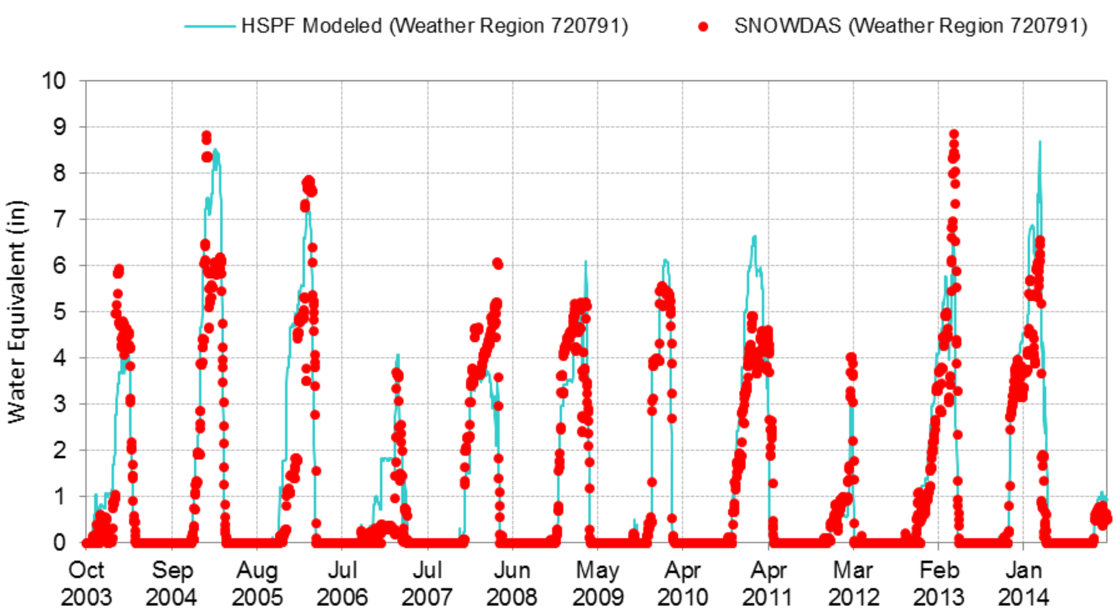


Figure A-8. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 720791

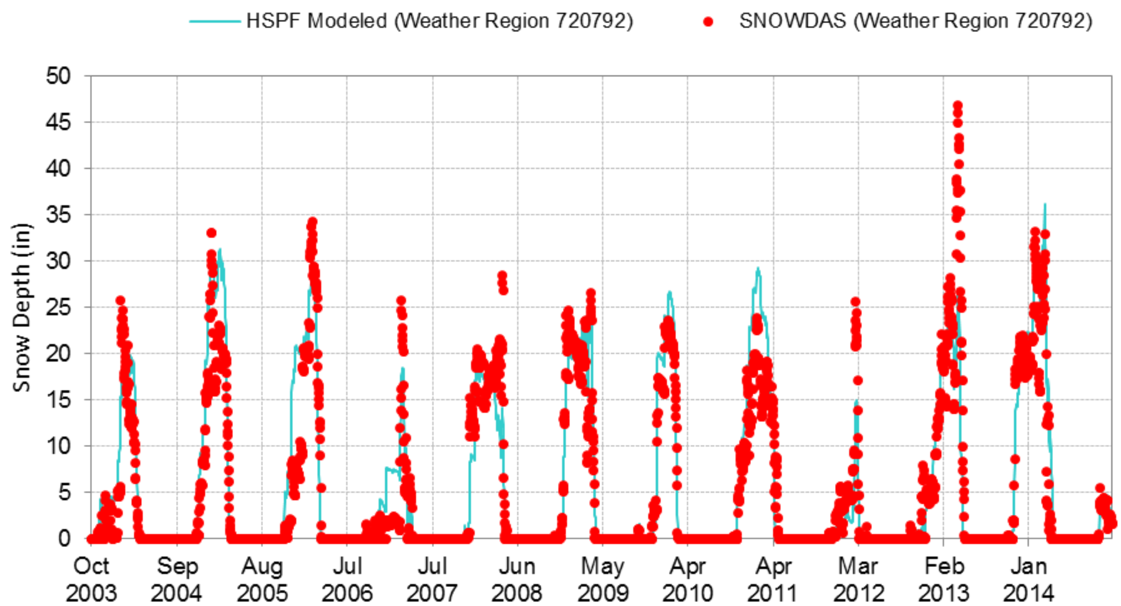


Figure A-9. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 720792

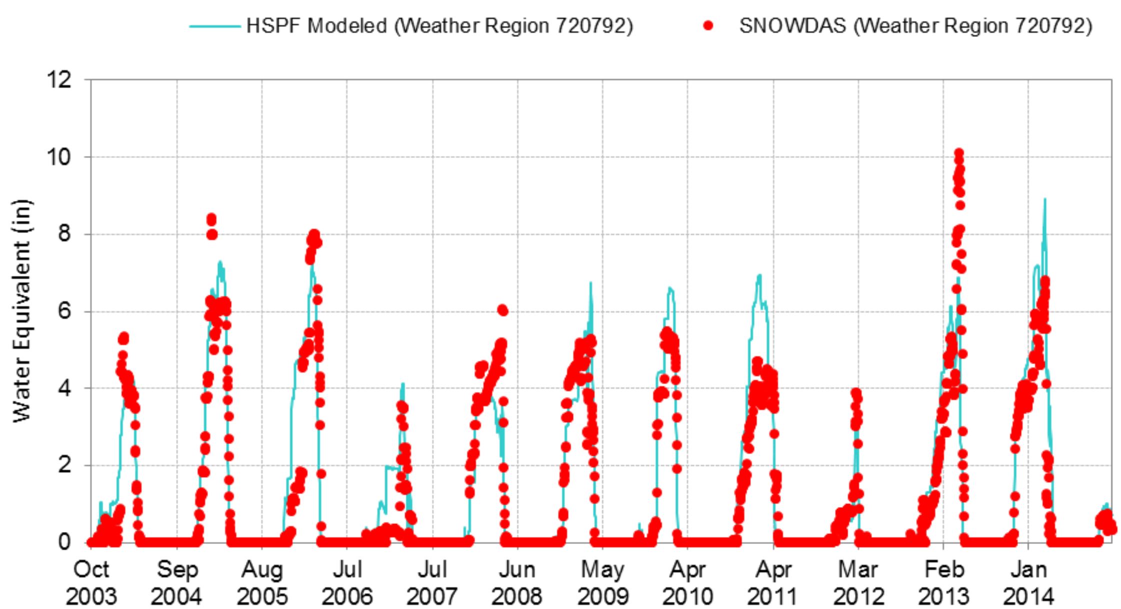


Figure A-10. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 720792

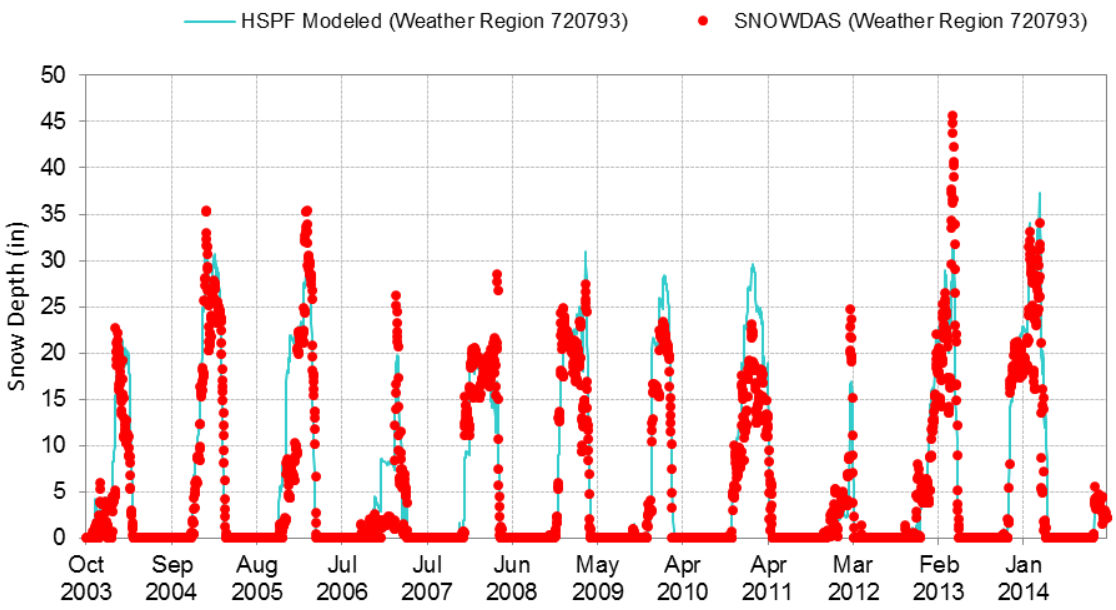
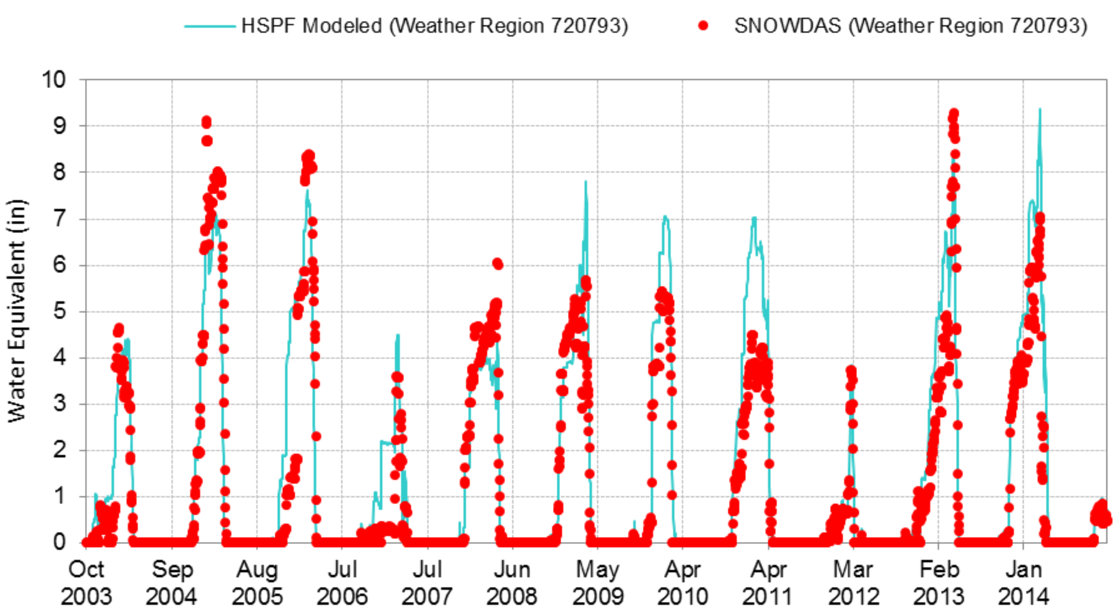


Figure A-11. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 720793



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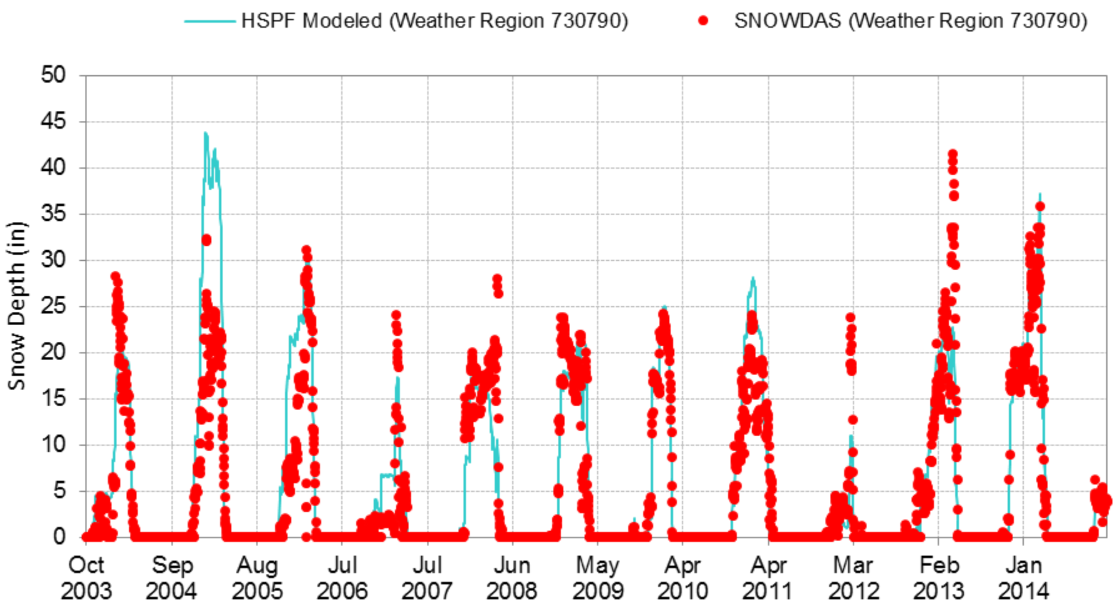

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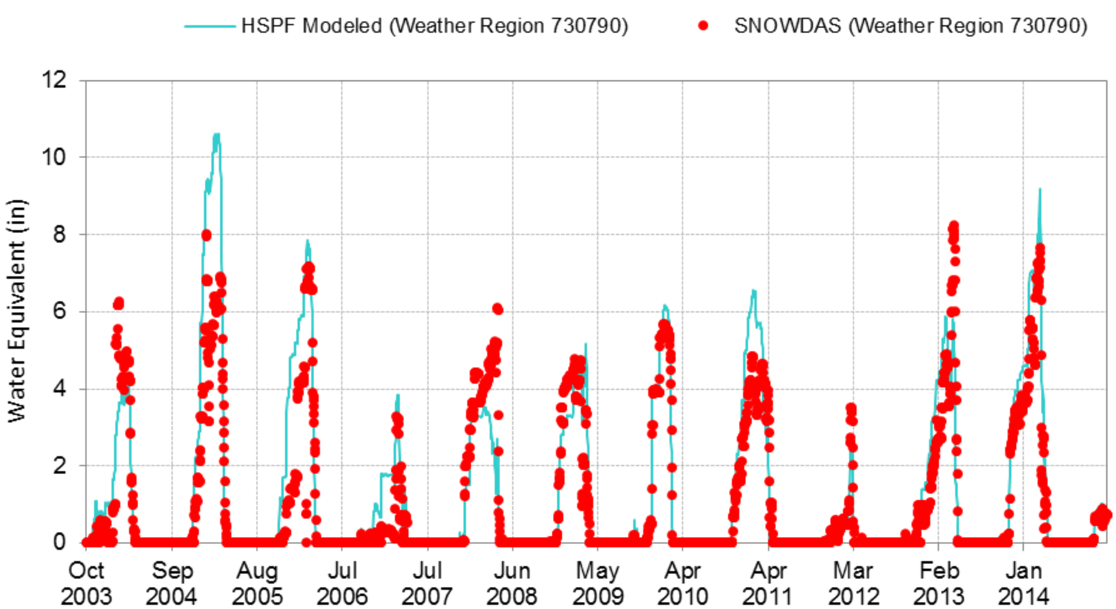


Figure A-14. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 730790

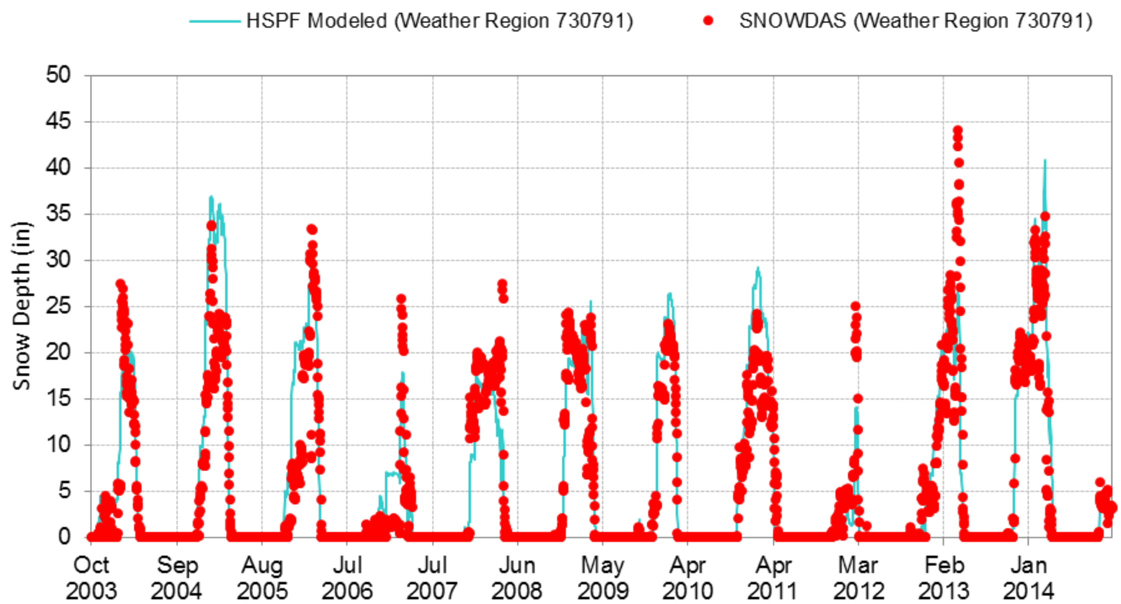


Figure A-15. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 730791

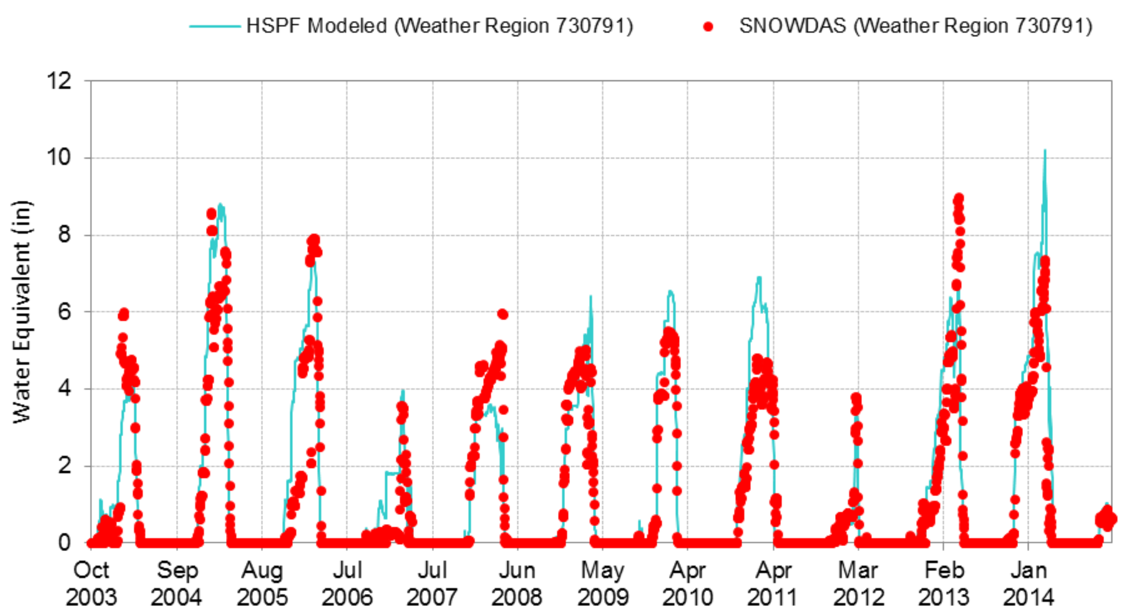


Figure A-16. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 730791

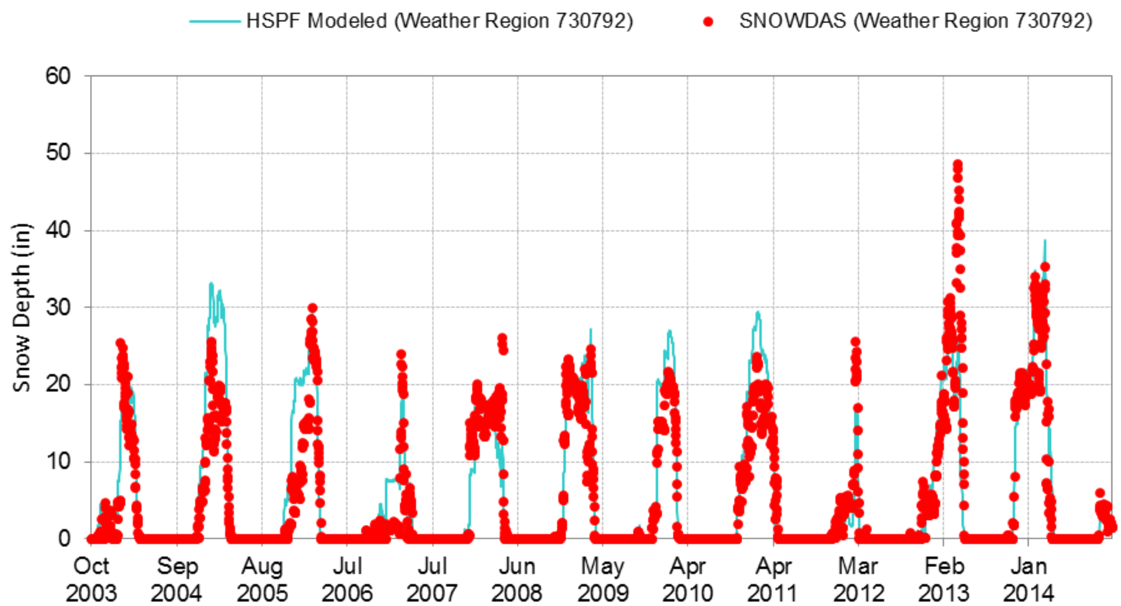


Figure A-17. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 730792

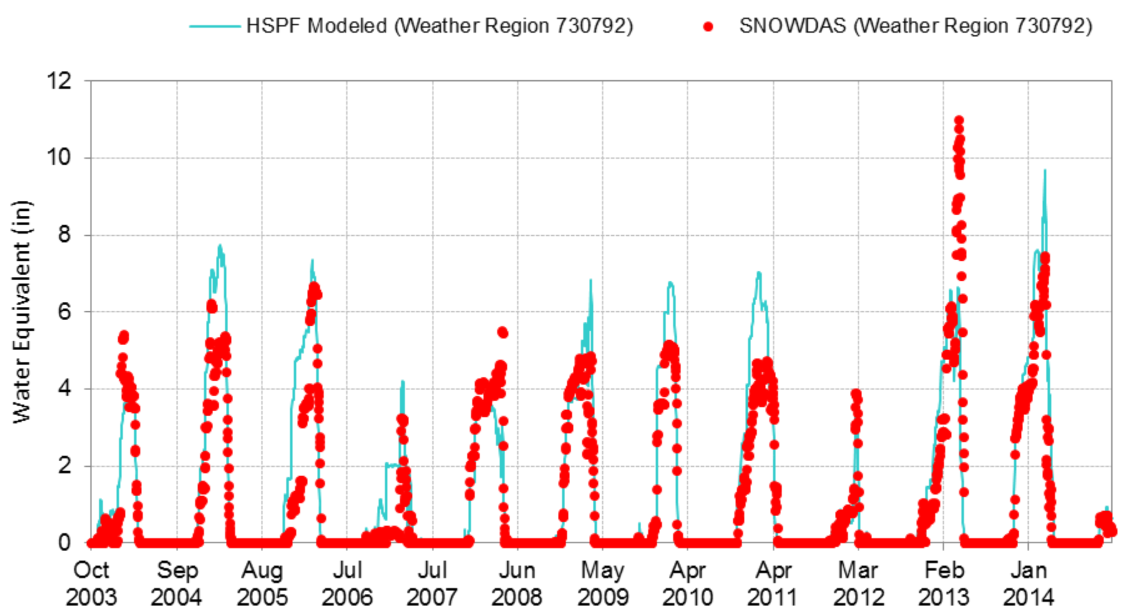


Figure A-18. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 730792

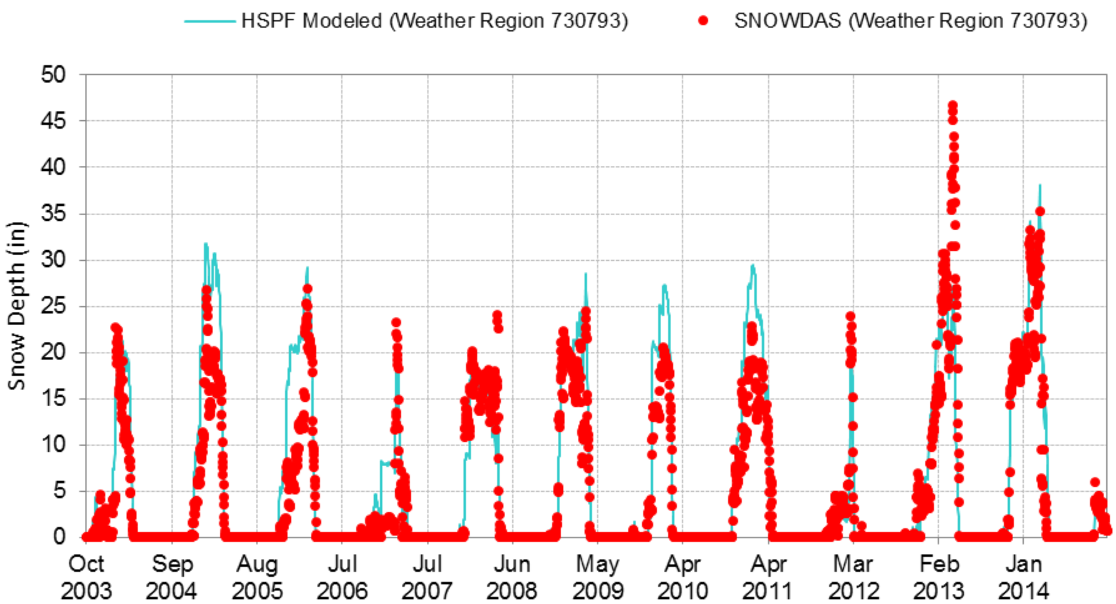


Figure A-19. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 730793

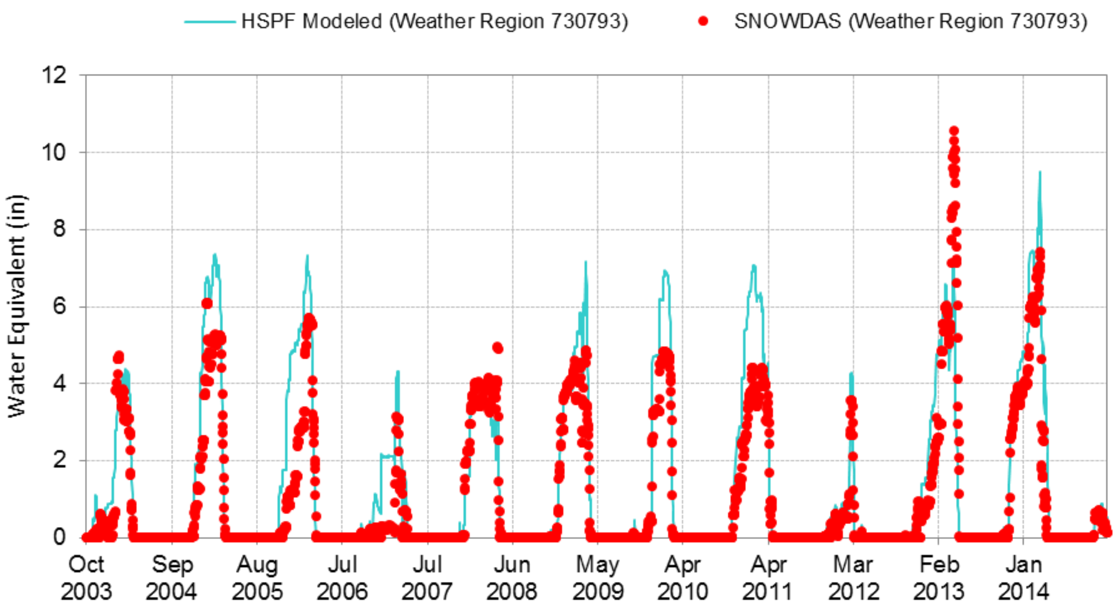


Figure A-20. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 730793

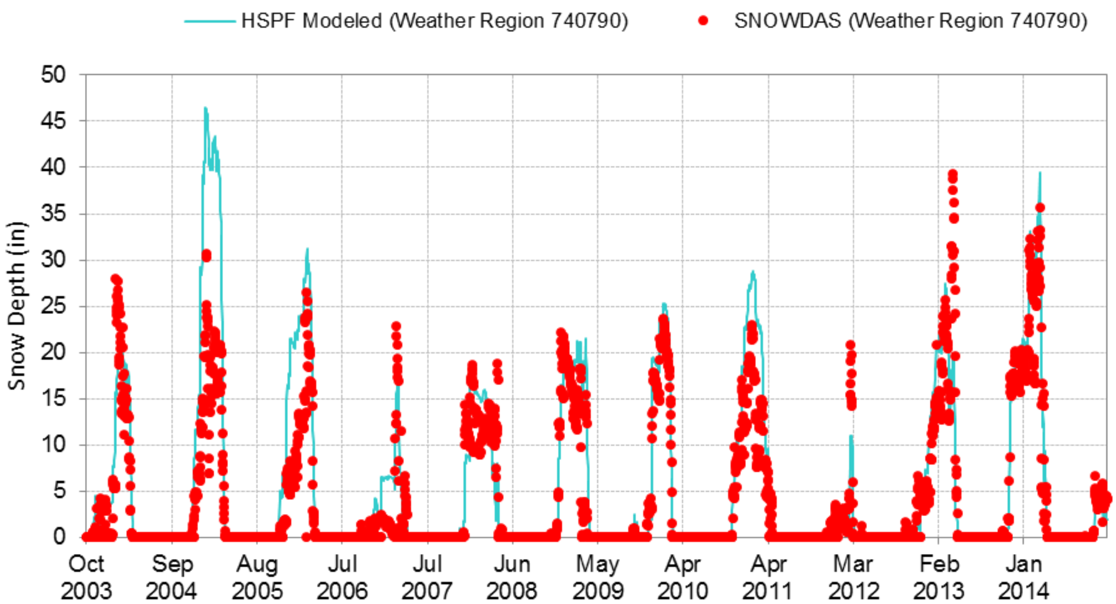


Figure A-21. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 740790

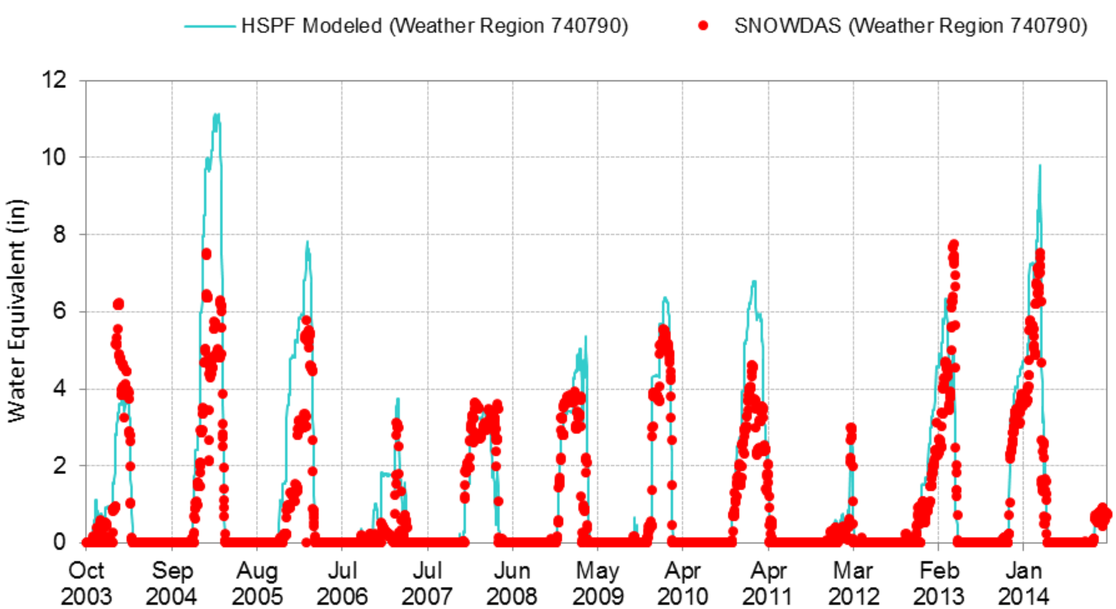


Figure A-22. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 740790

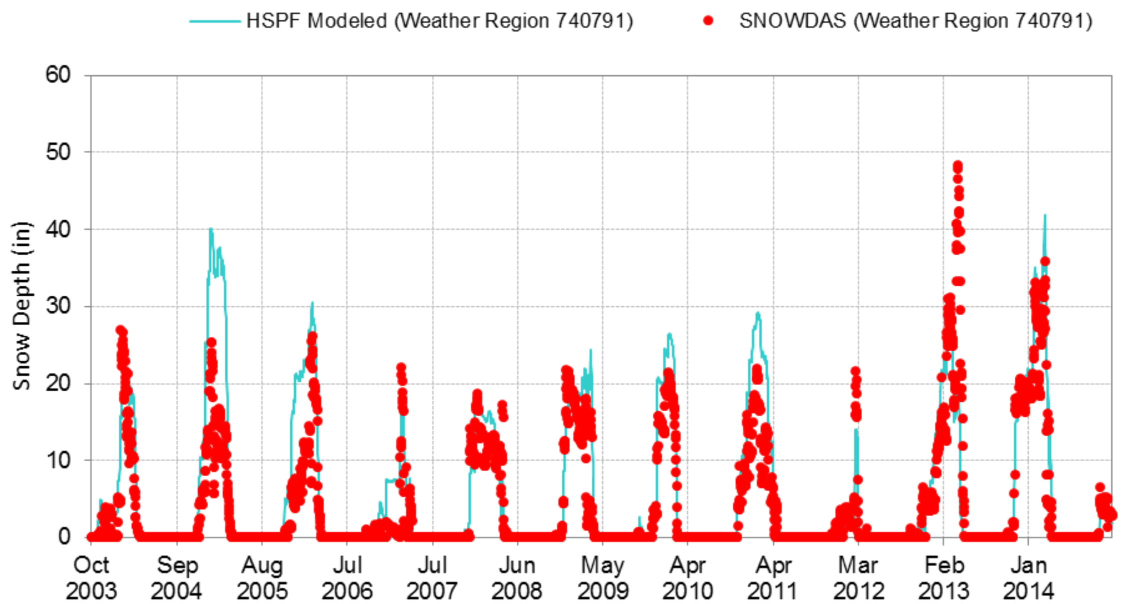


Figure A-23. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 740791

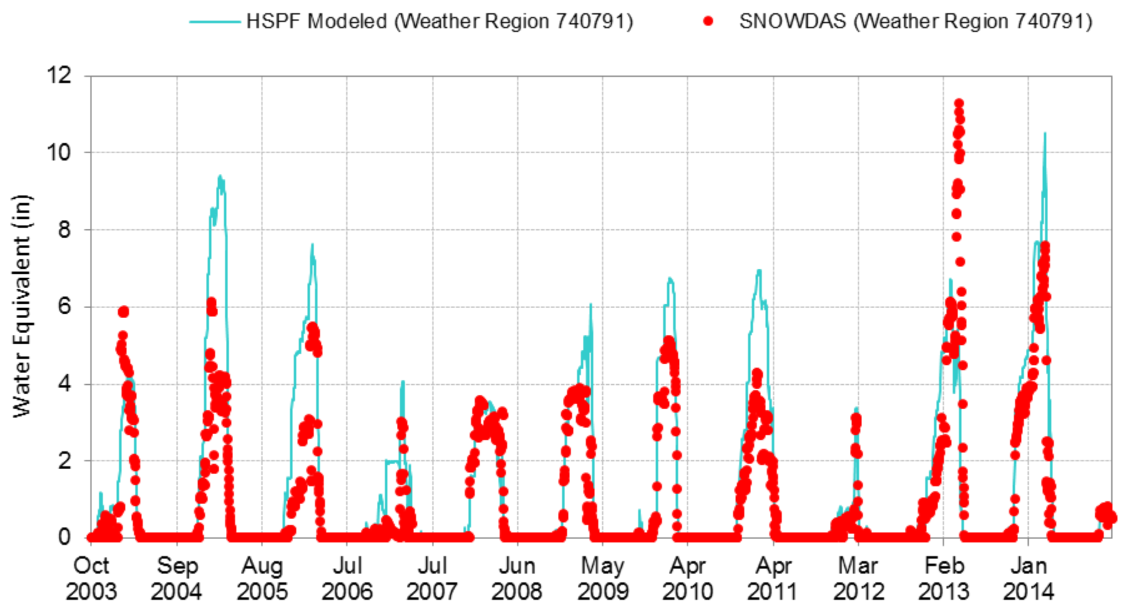


Figure A-24. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 740791

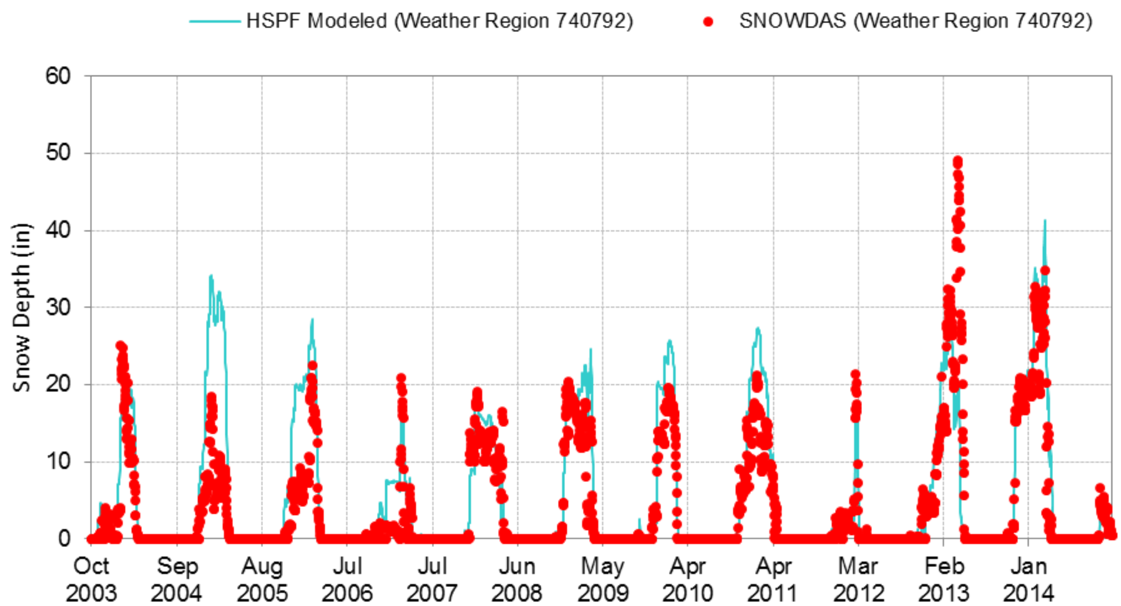


Figure A-25. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 740792

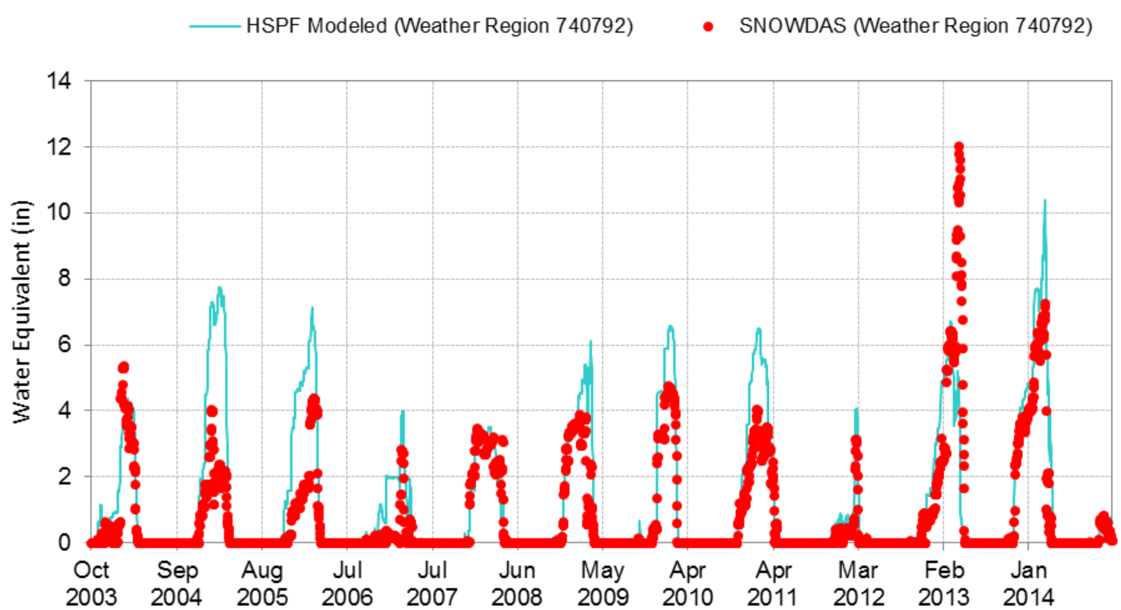


Figure A-26. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 740792

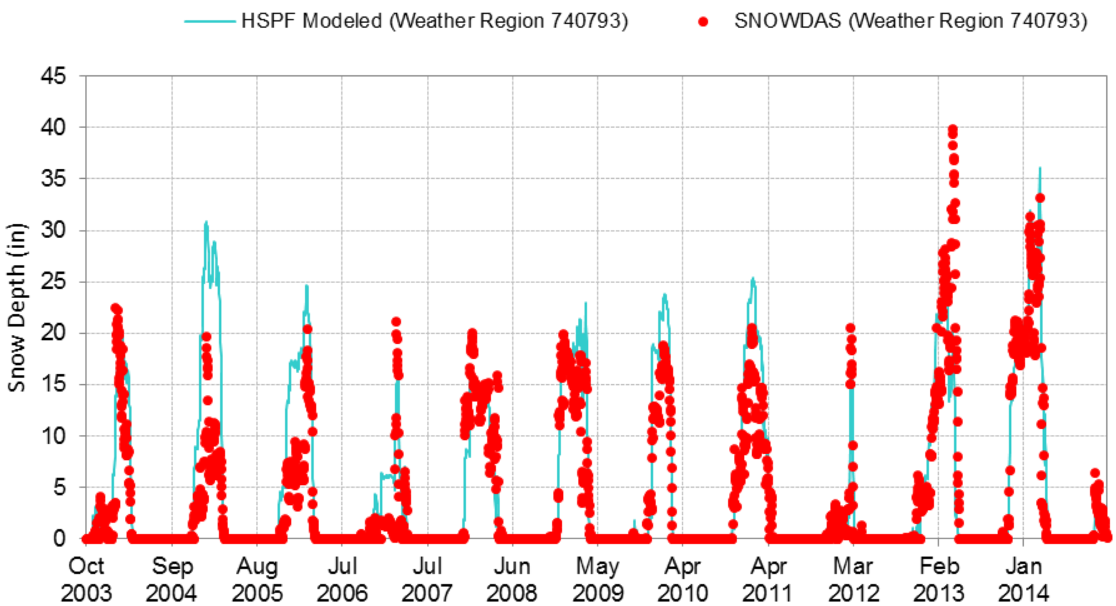


Figure A-27. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 740793

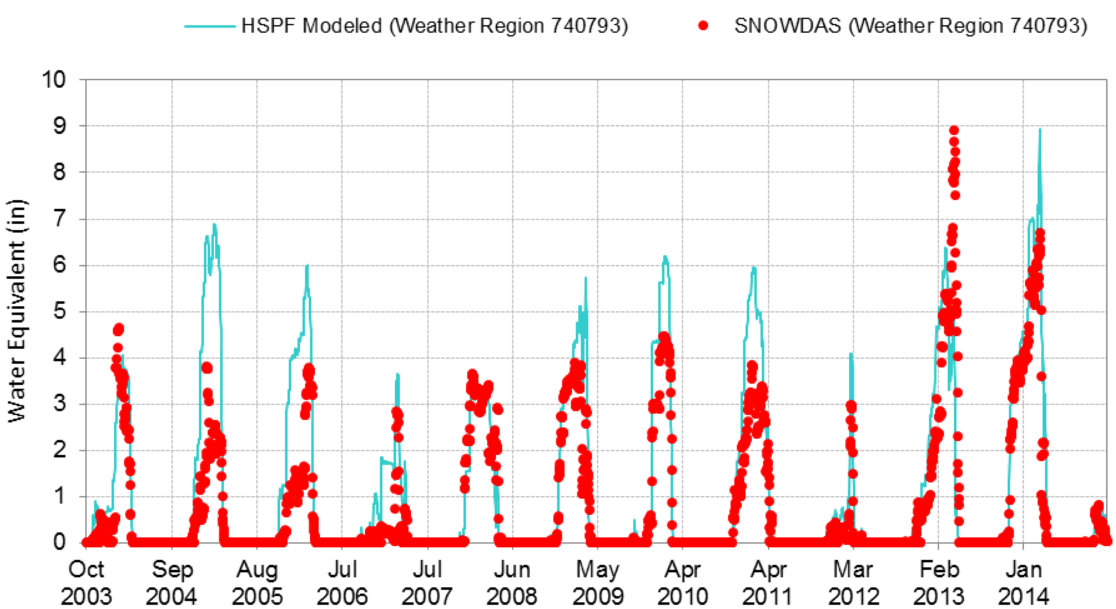


Figure A-28. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 740793

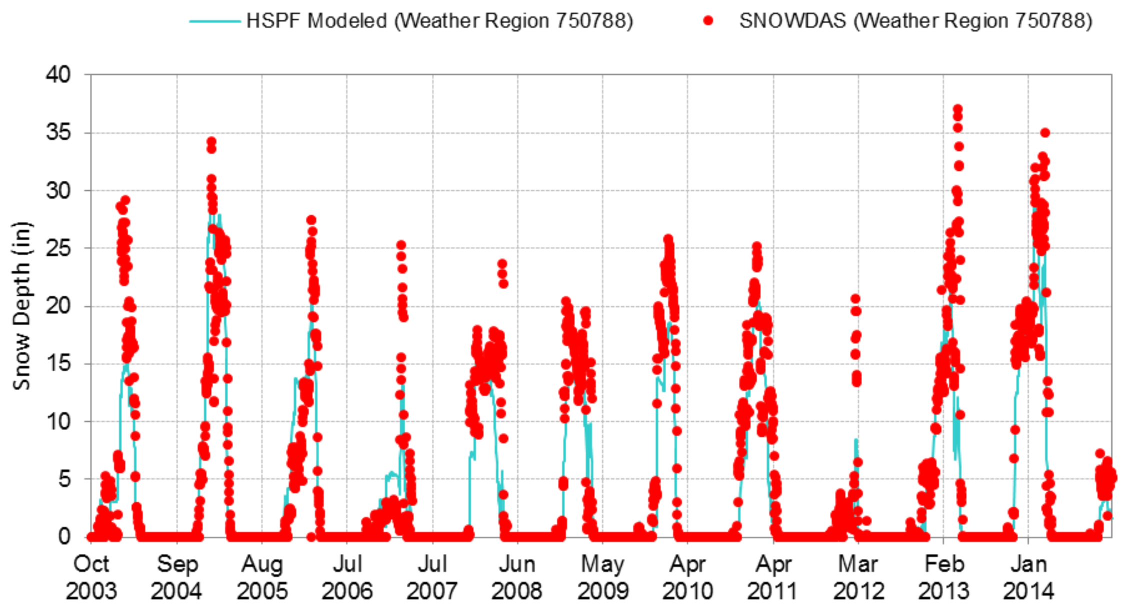


Figure A-29. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 750788

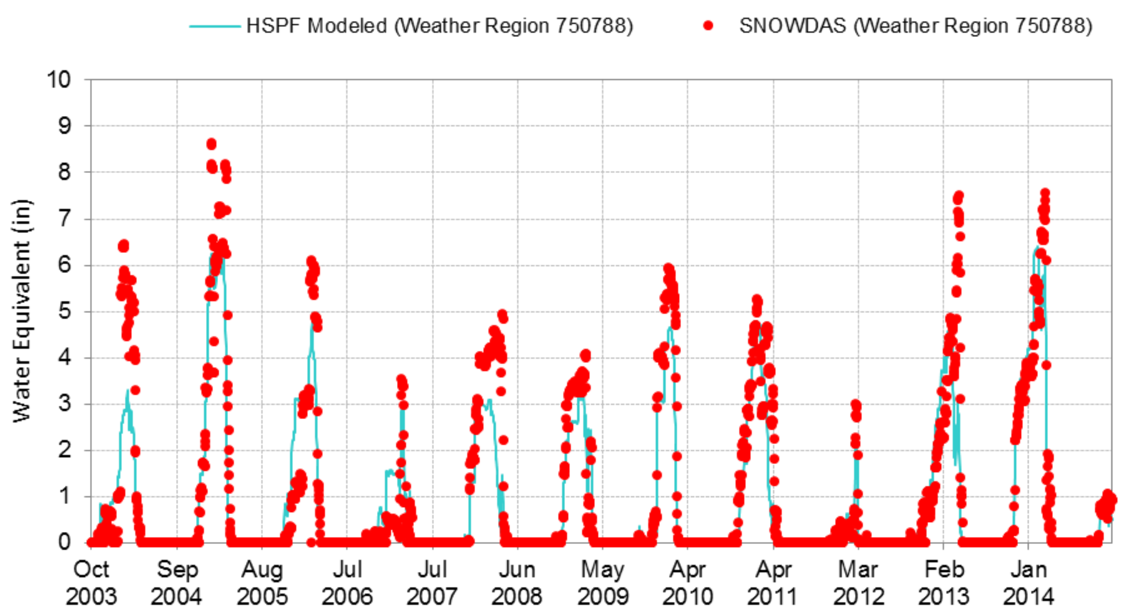


Figure A-30. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 750788

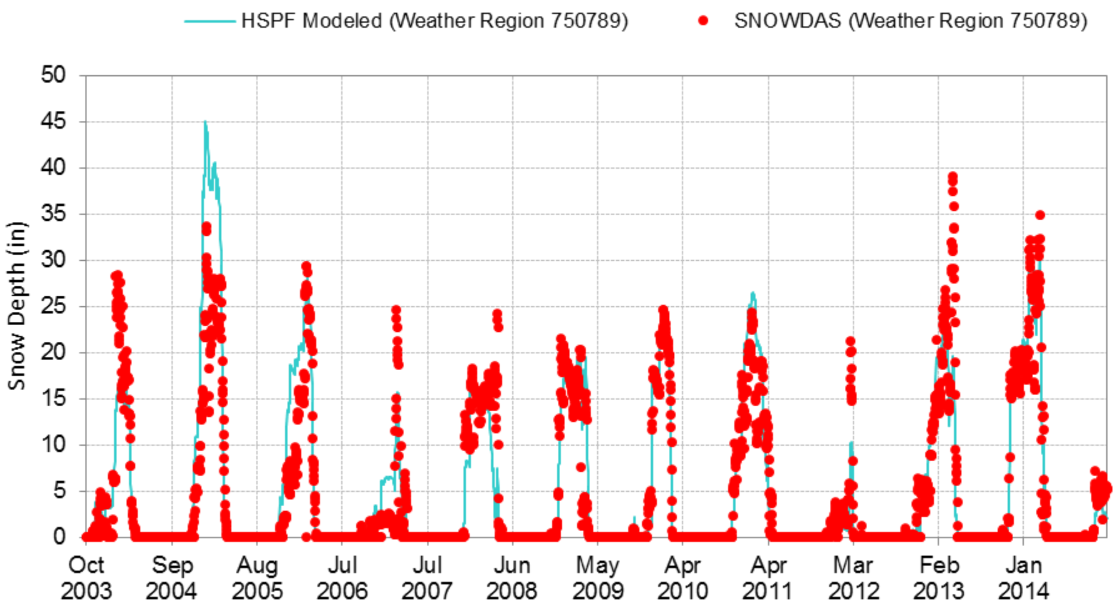


Figure A-31. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 750789

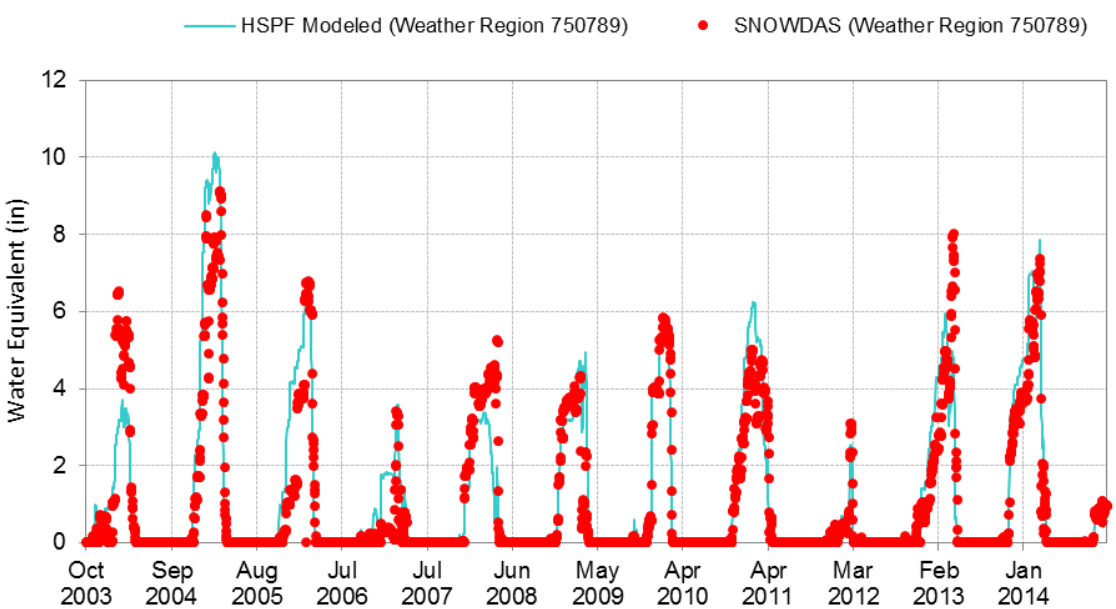


Figure A-32. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 750789

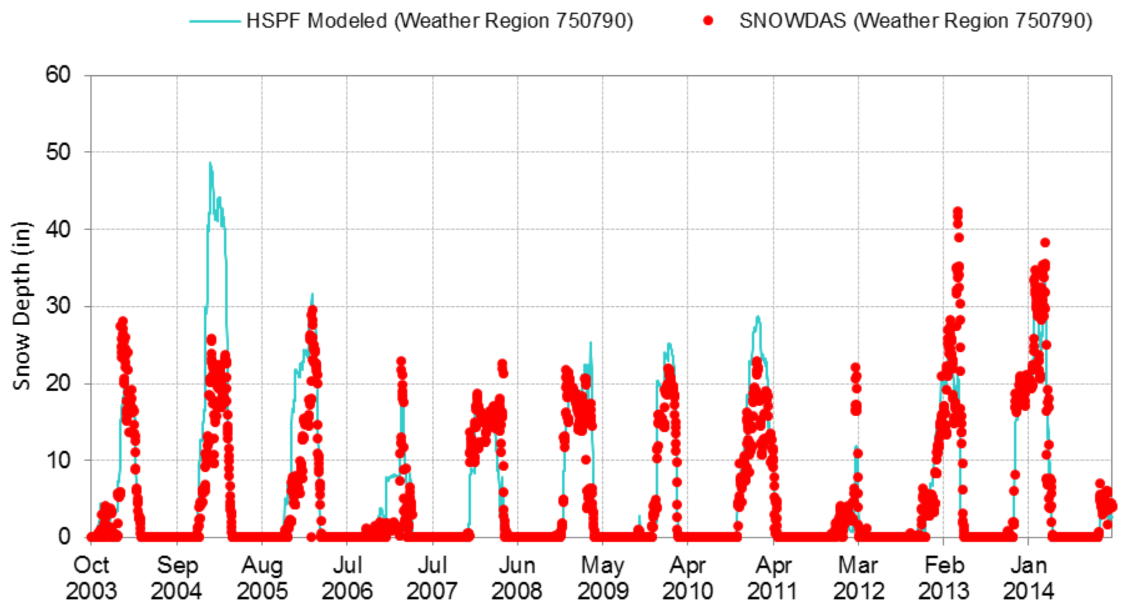


Figure A-33. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 750790

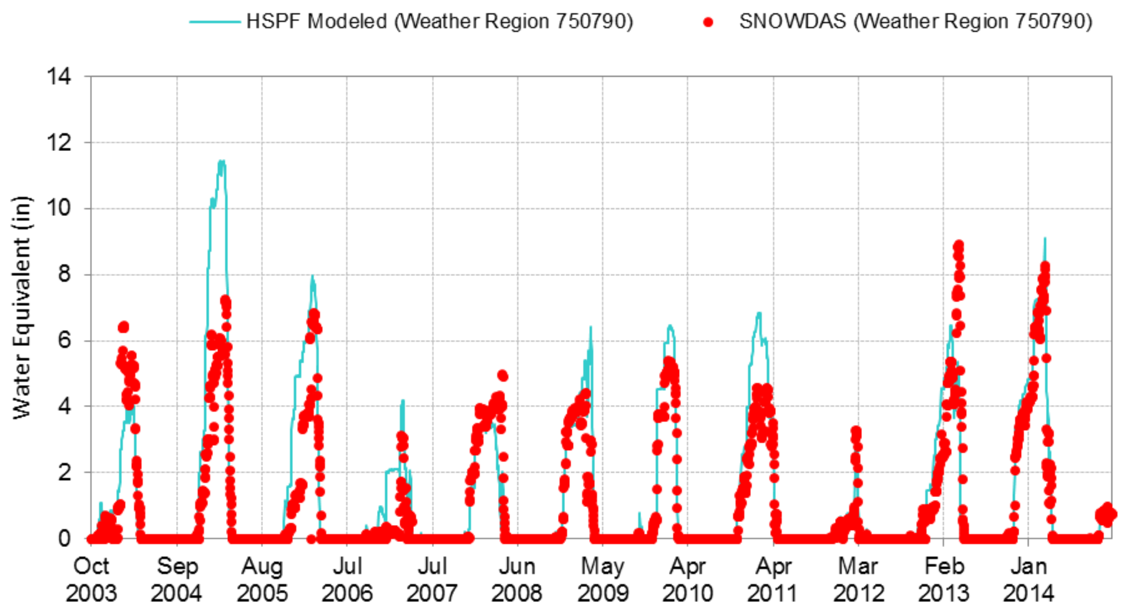


Figure A-34. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 750790

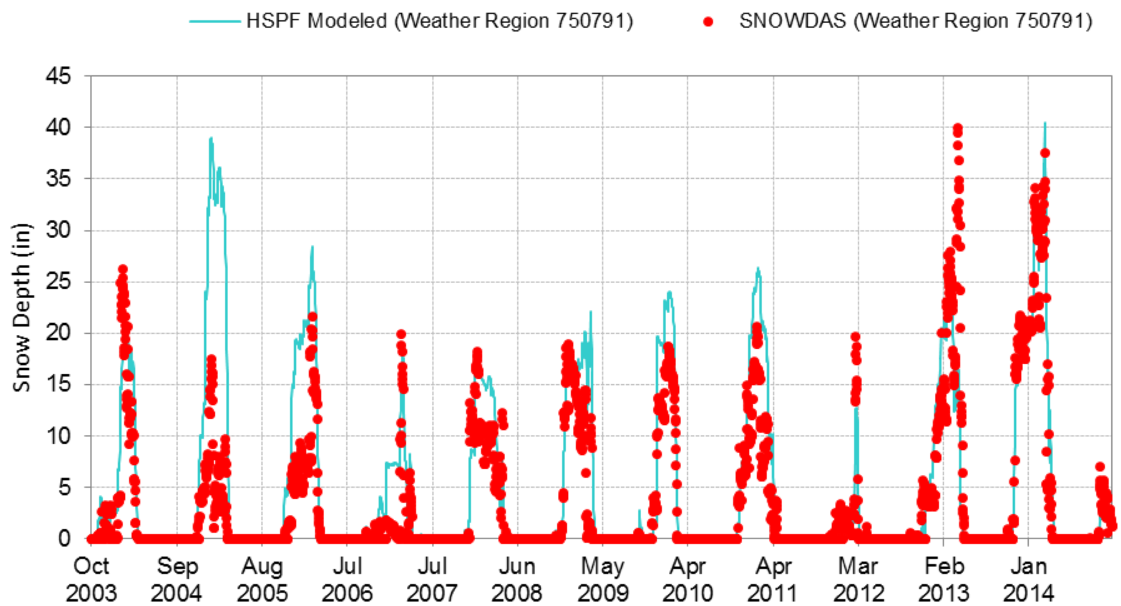


Figure A-35. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 750791

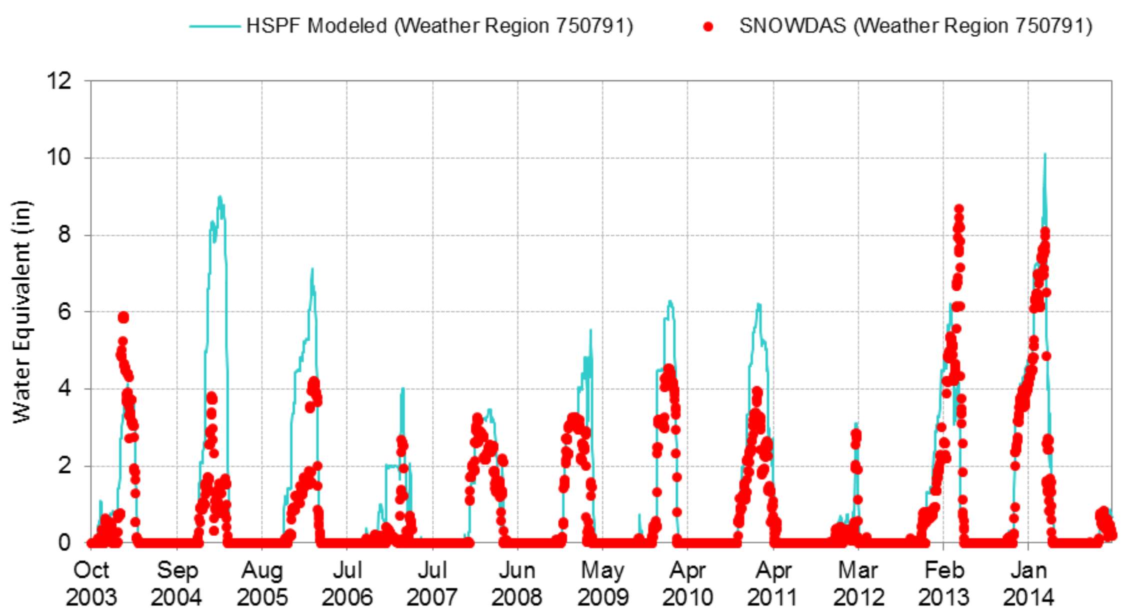


Figure A-36. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 750791

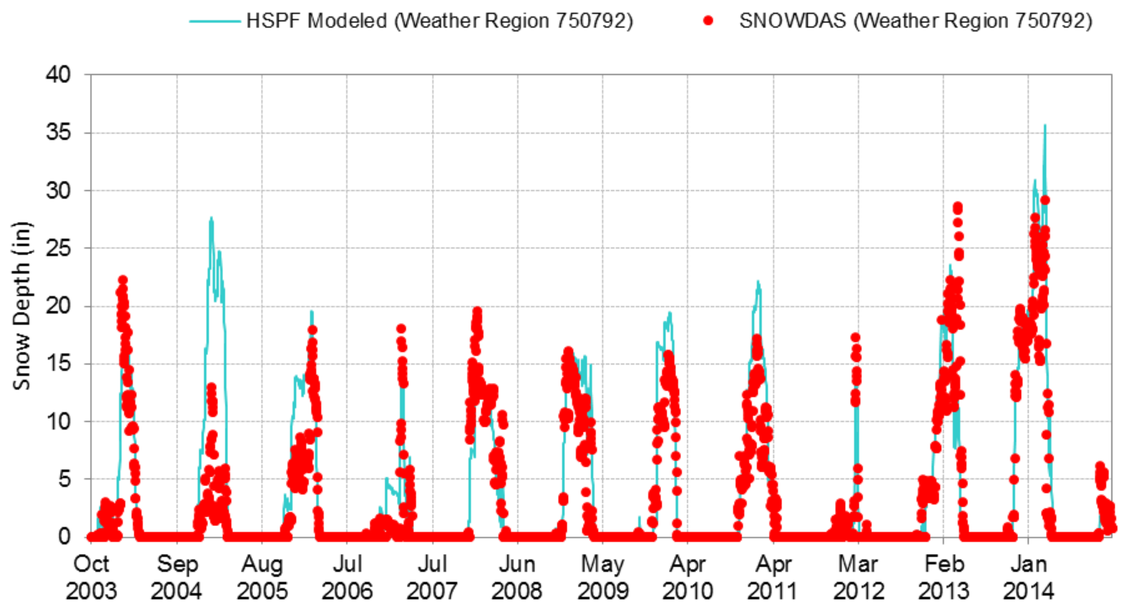


Figure A-37. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 750792

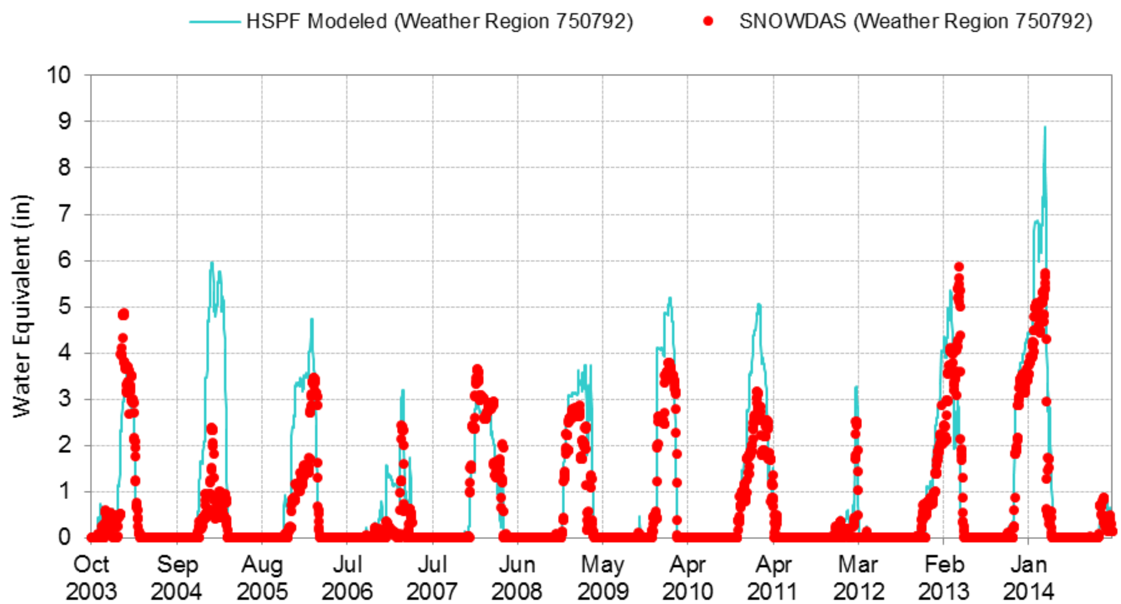


Figure A-38. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 750792

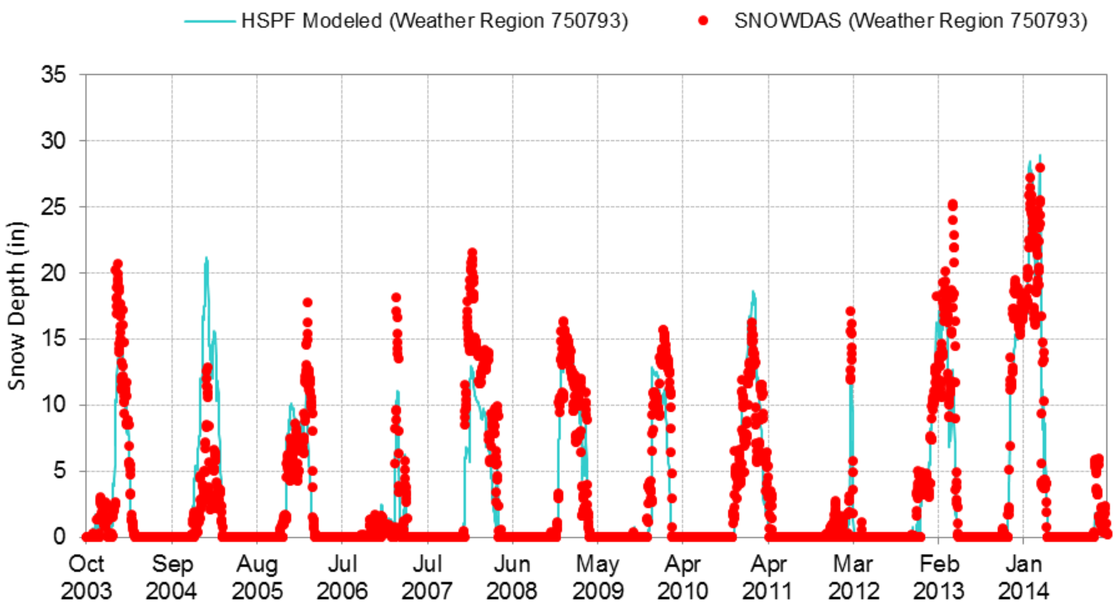


Figure A-39. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 750793

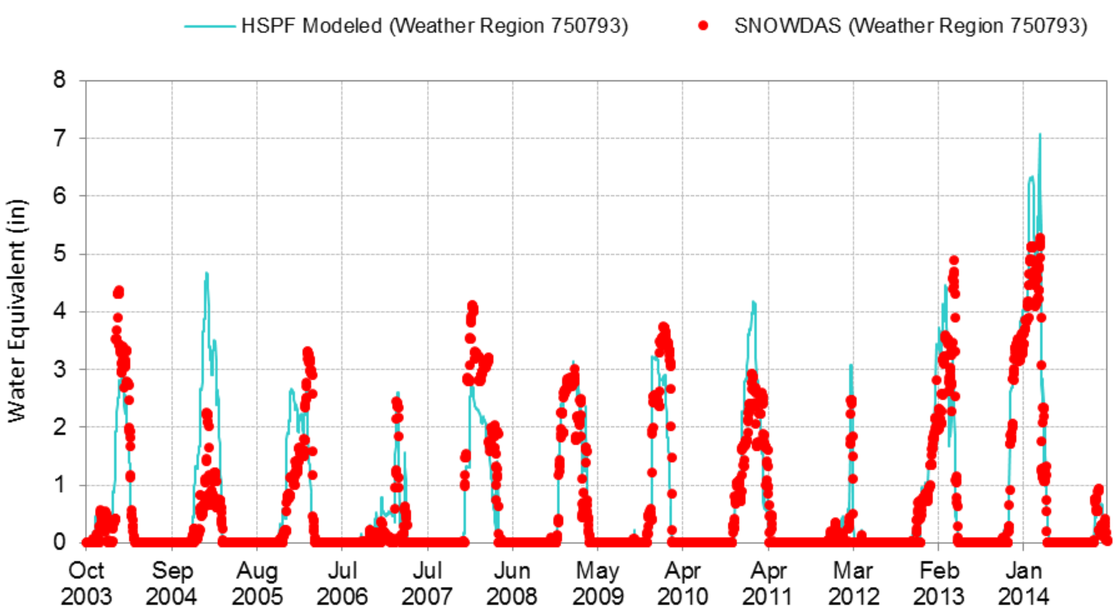


Figure A-40. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 750793

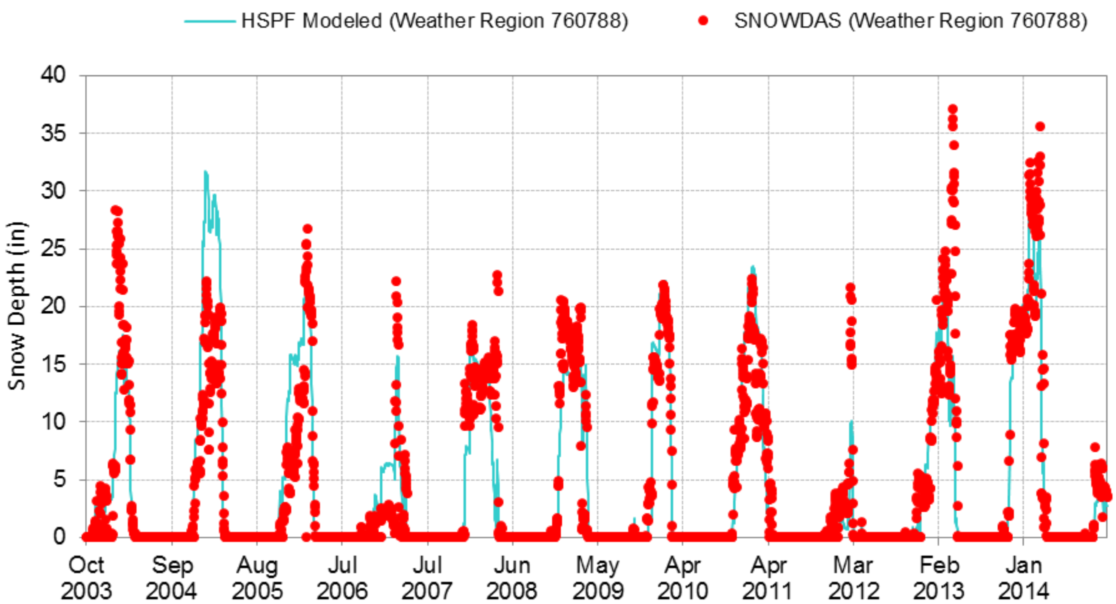


Figure A-41. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 760788

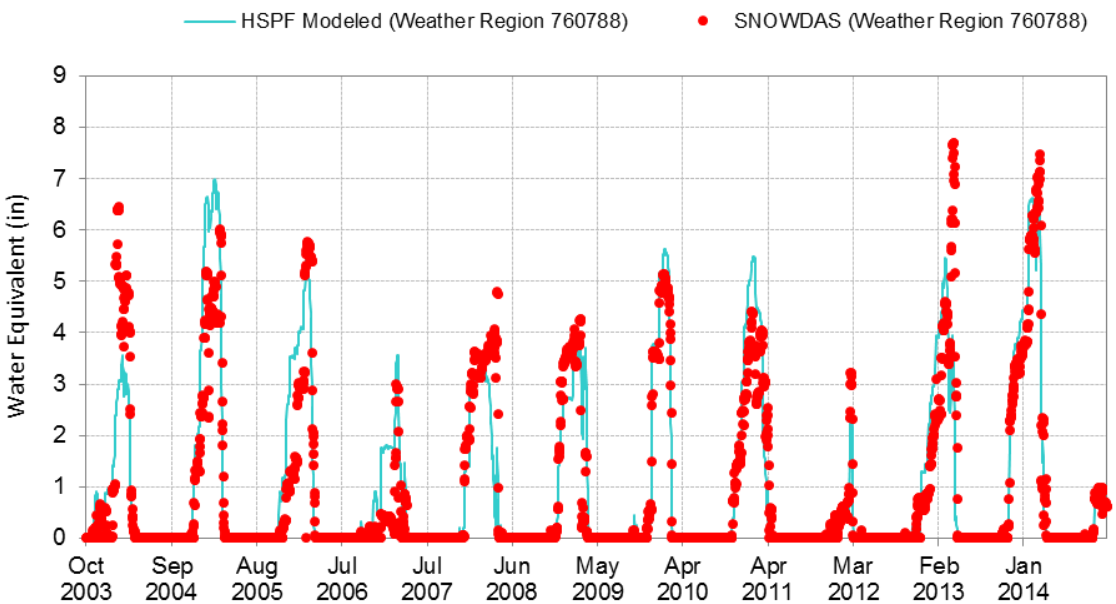


Figure A-42. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 760788

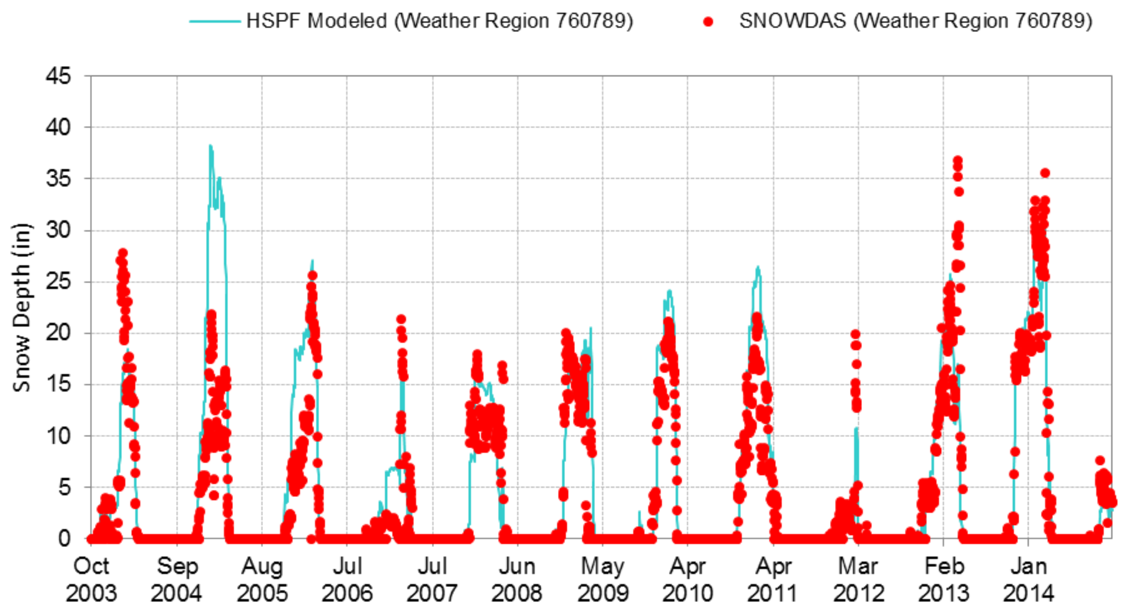


Figure A-43. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 760789

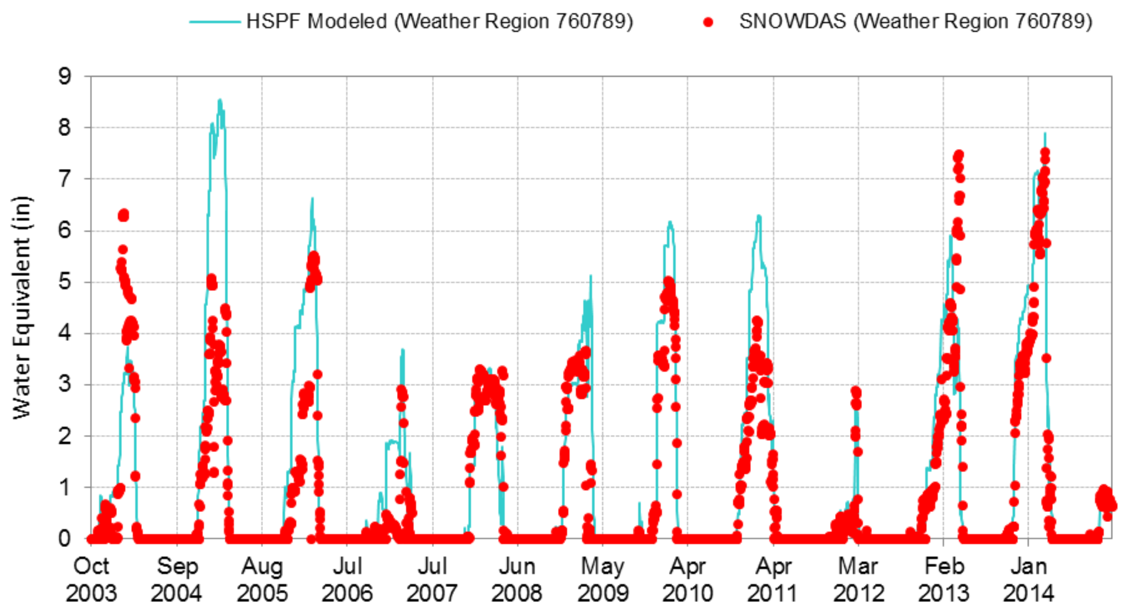


Figure A-44. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 760789

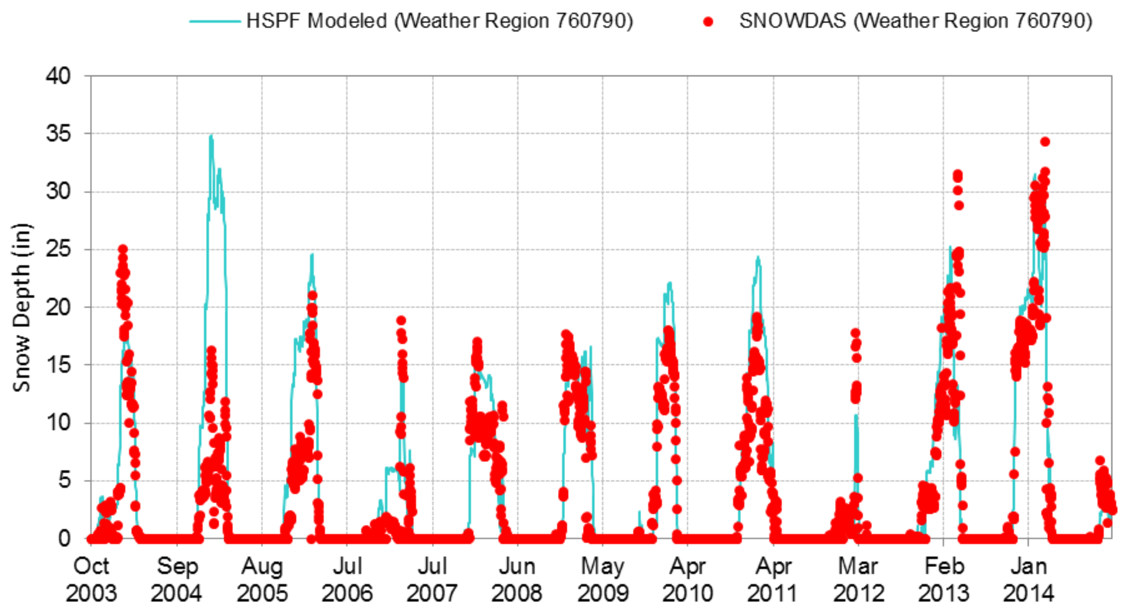


Figure A-45. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 760790

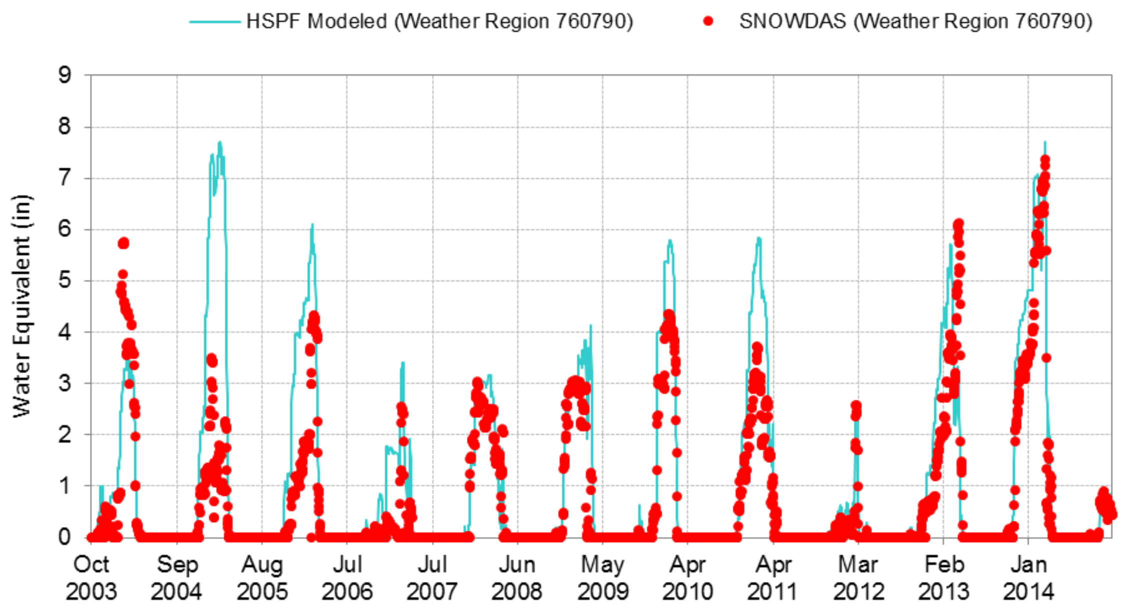


Figure A-46. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 760790

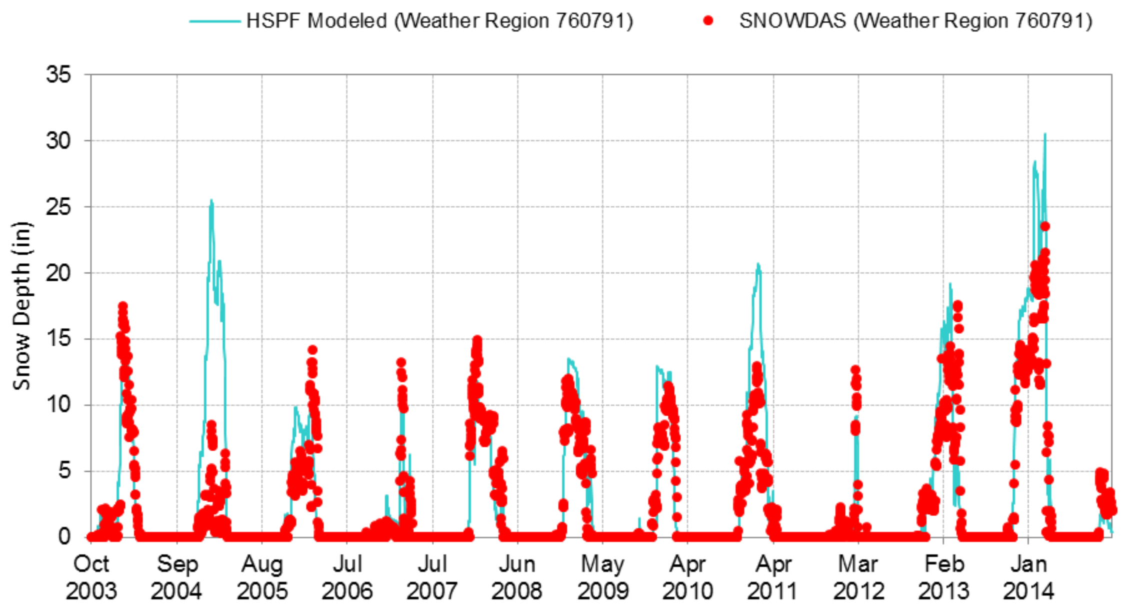


Figure A-47. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 760791

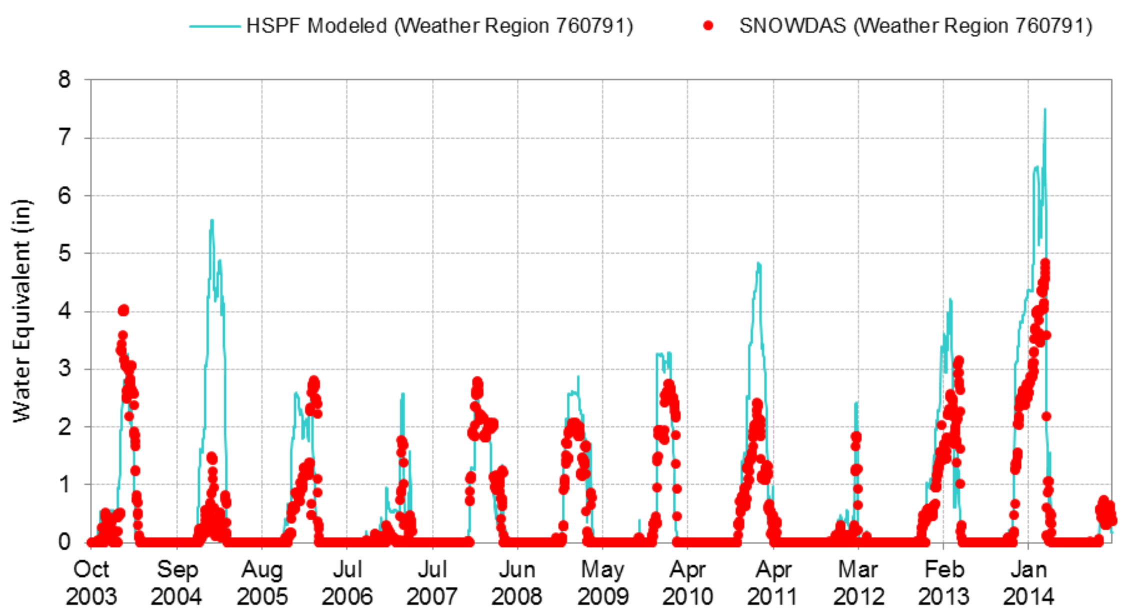


Figure A-48. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 760791

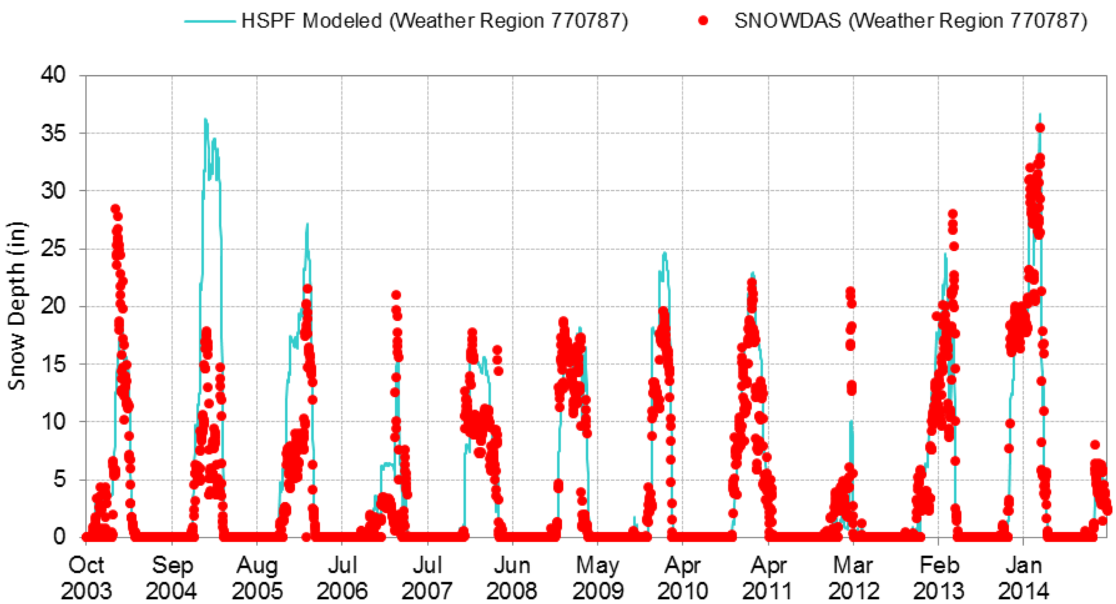


Figure A-49. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 770787

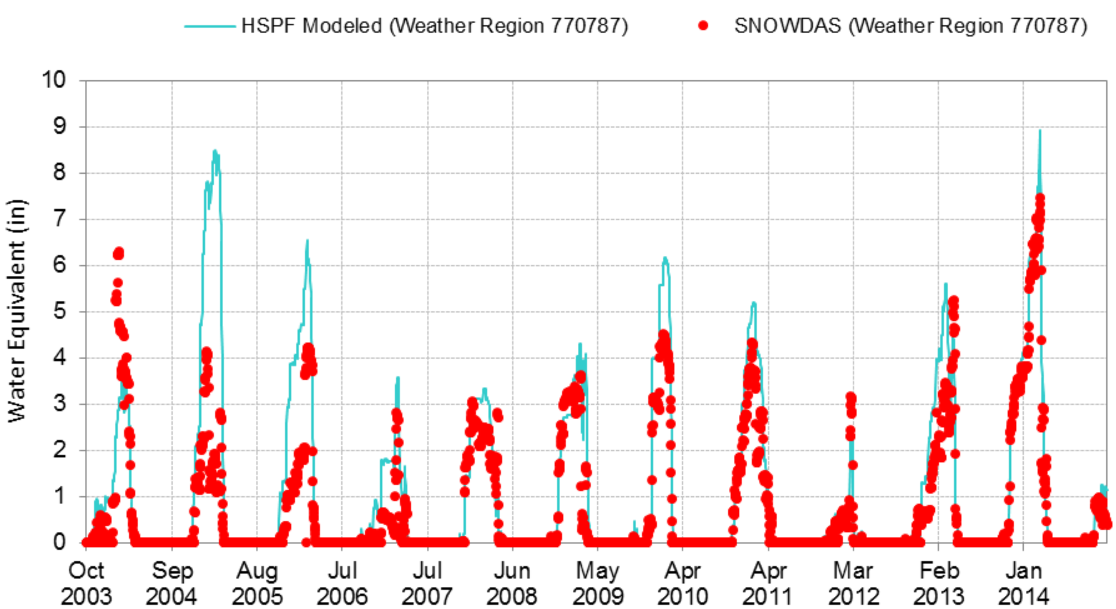


Figure A-50. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 770787

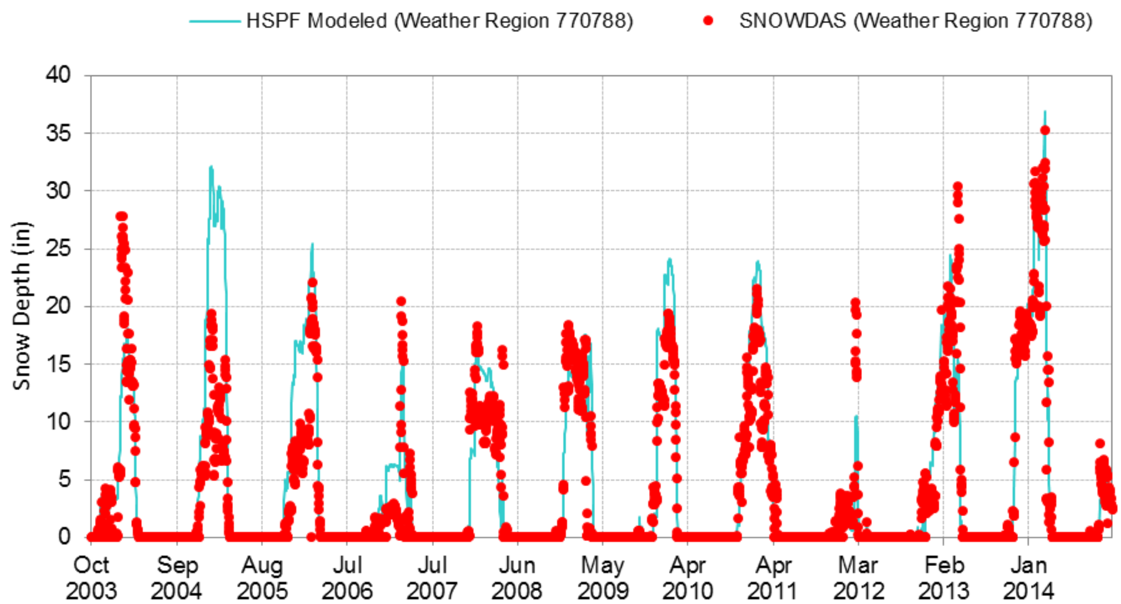


Figure A-51. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 770788

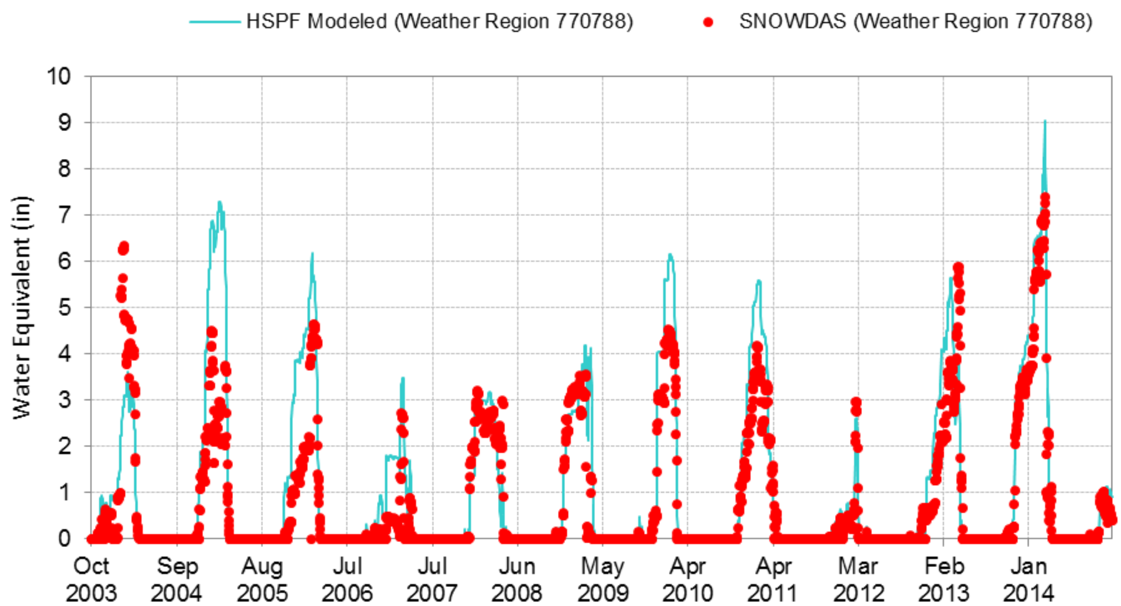


Figure A-52. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 770788

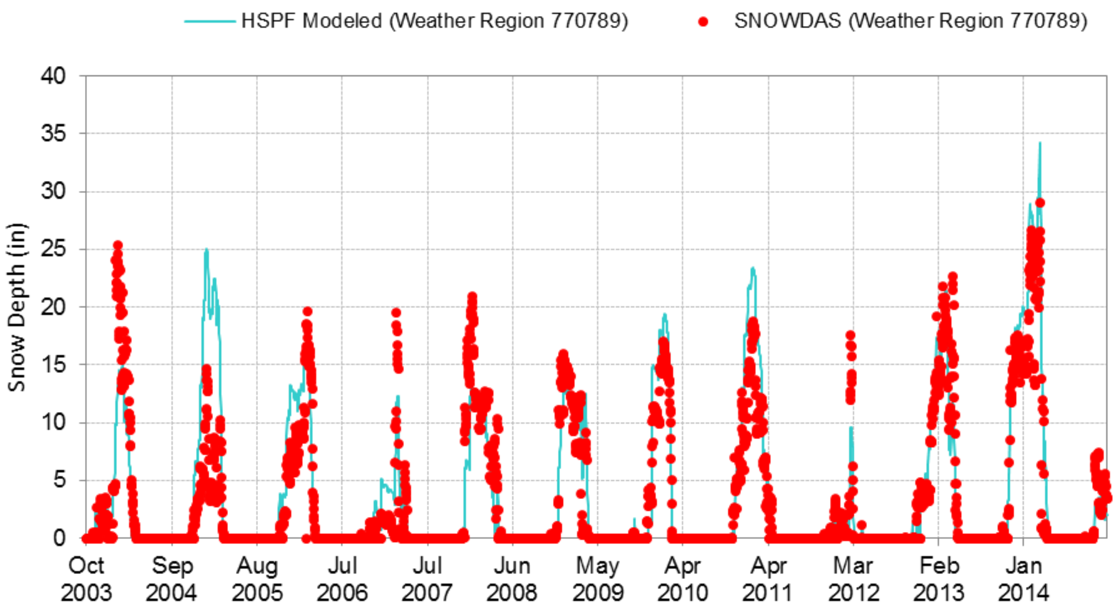


Figure A-53. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 770789

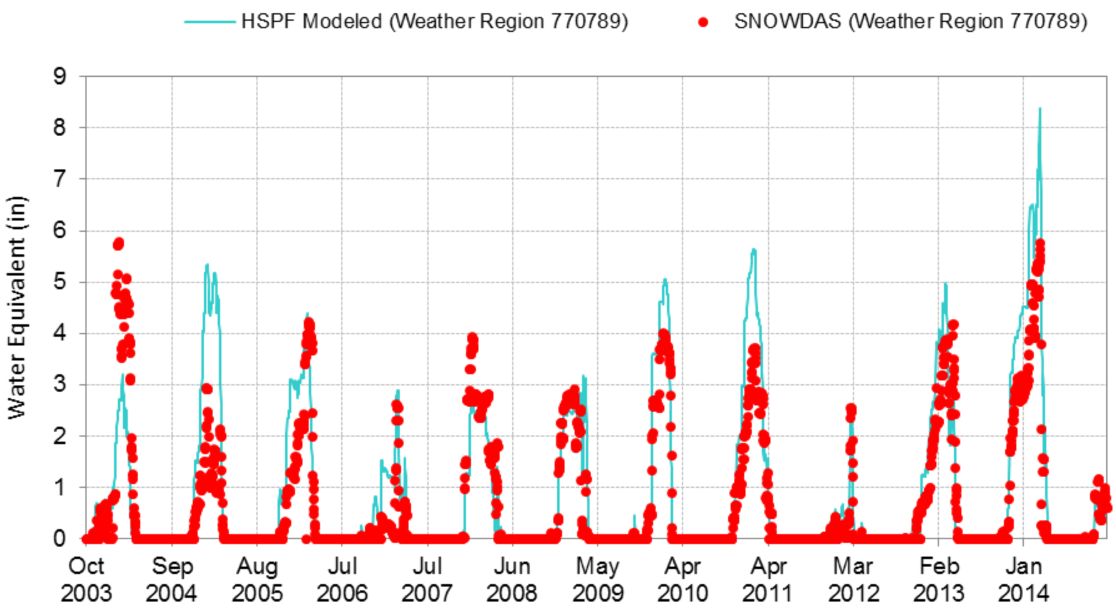


Figure A-54. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 770789

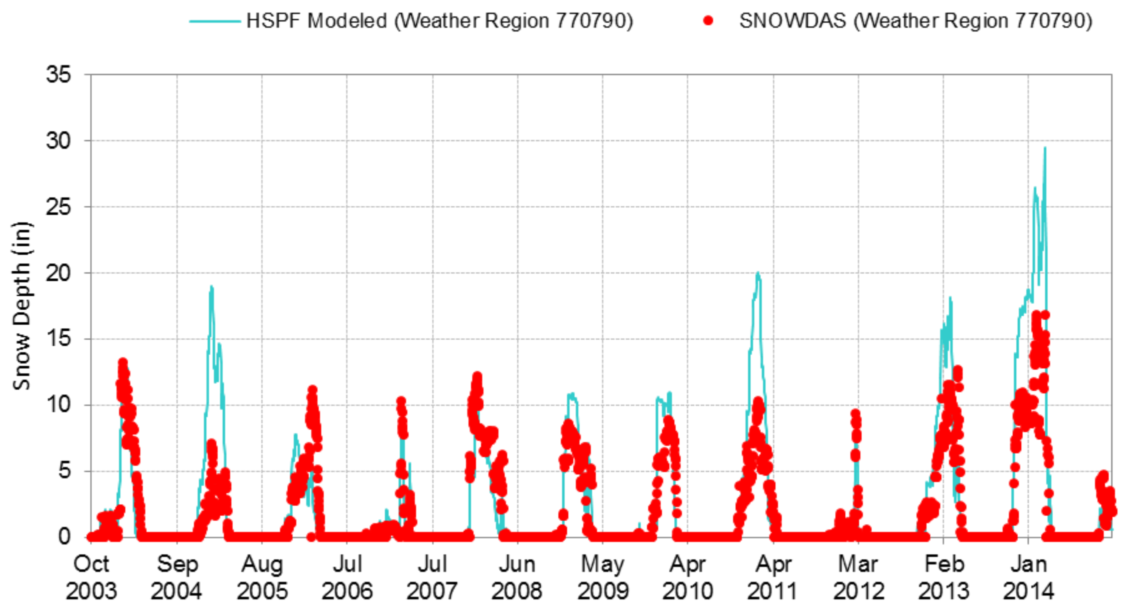


Figure A-55. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 770790

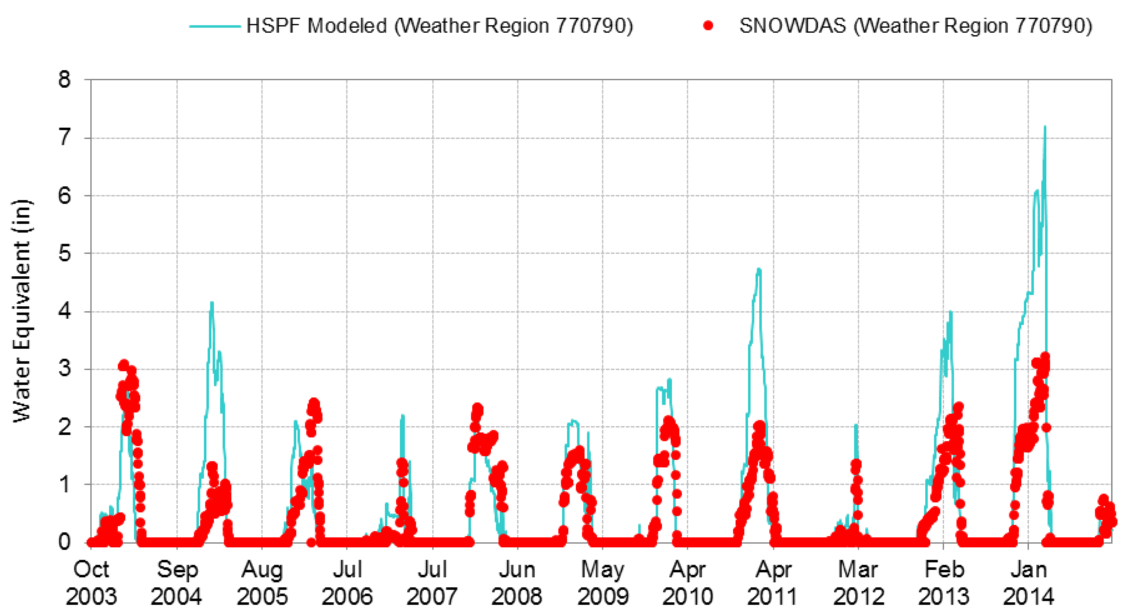


Figure A-56. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 770790

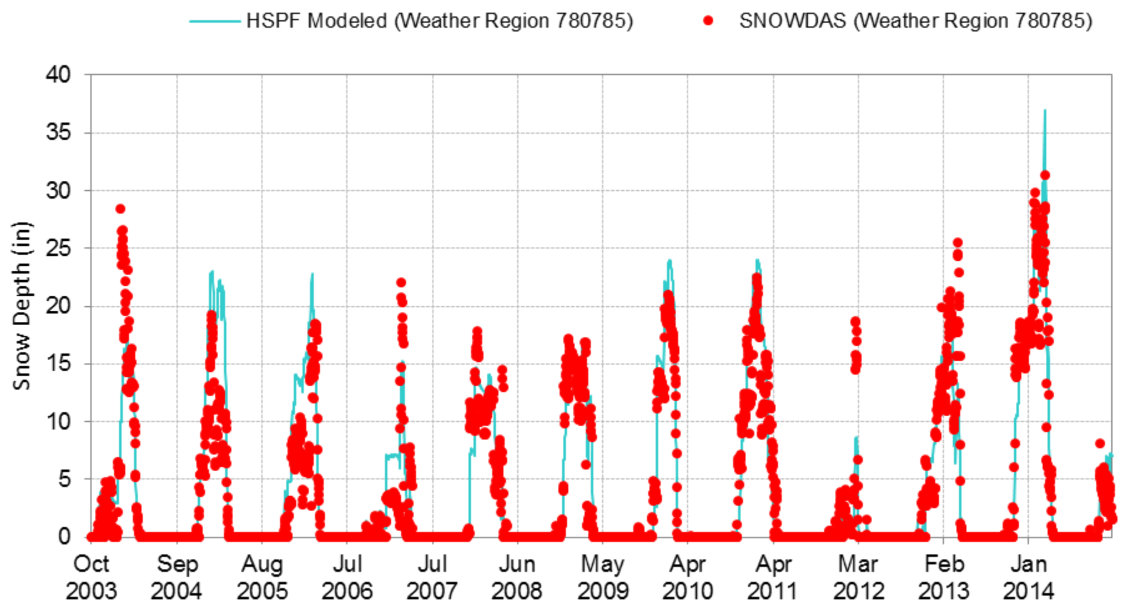


Figure A-57. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 780785

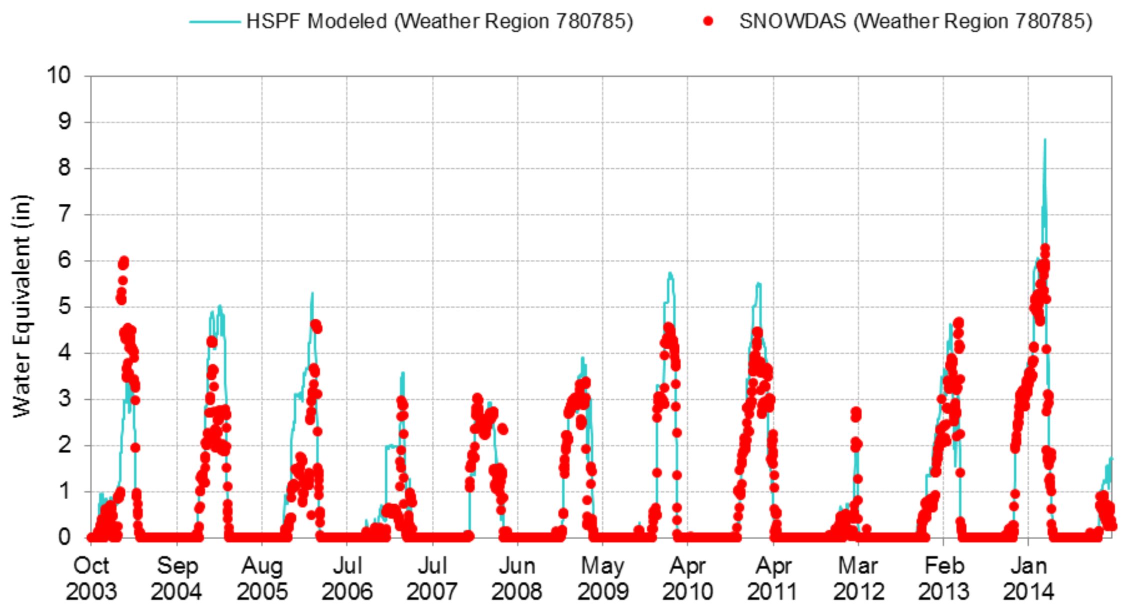


Figure A-58. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 780785

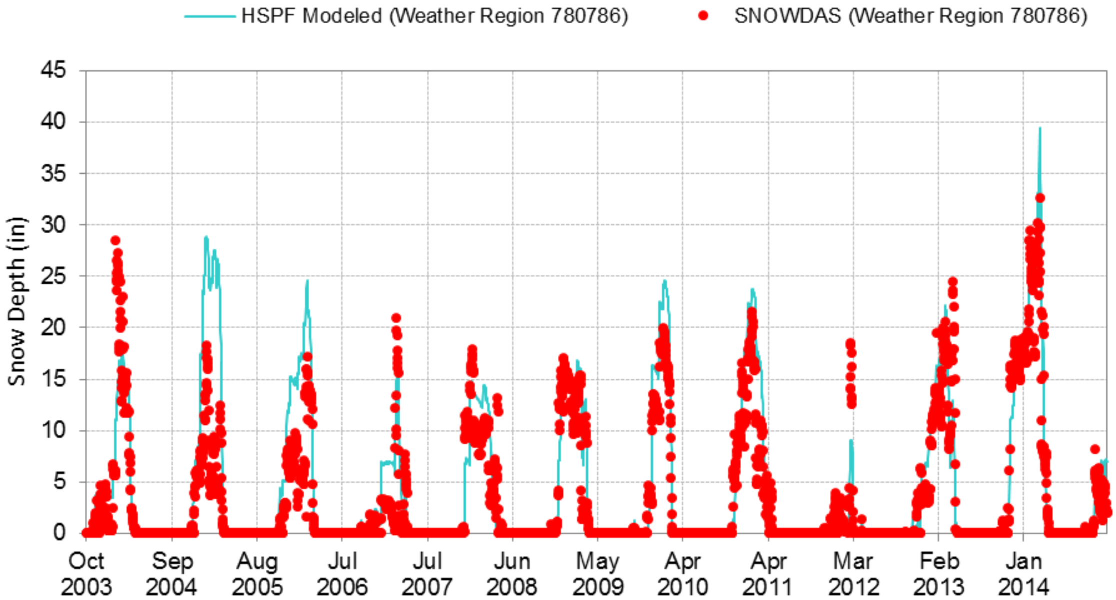


Figure A-59. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 780786

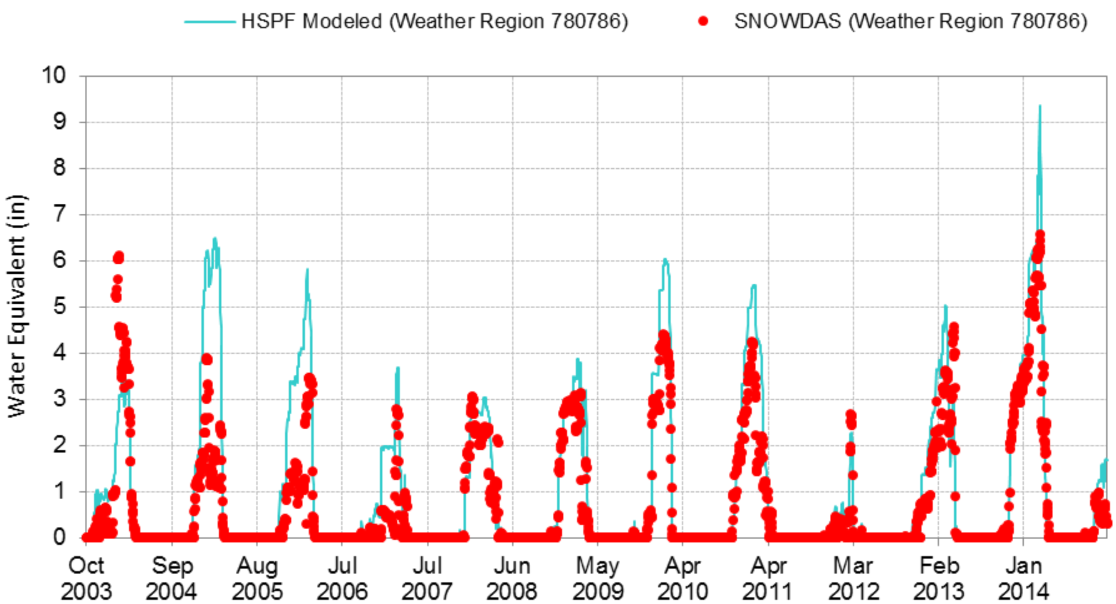


Figure A-60. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 780786

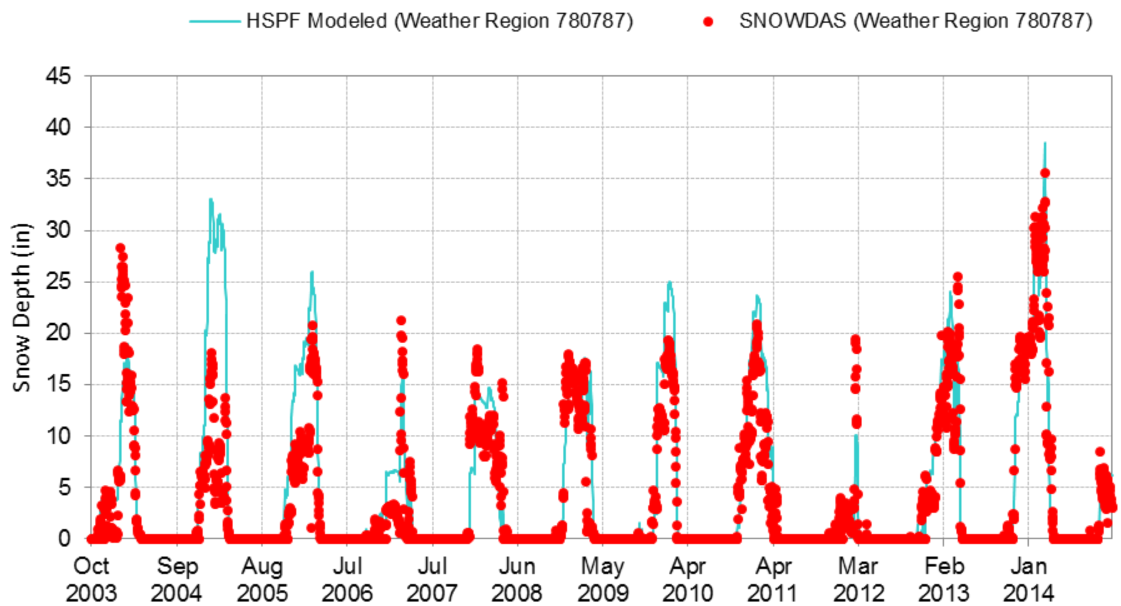


Figure A-61. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 780787

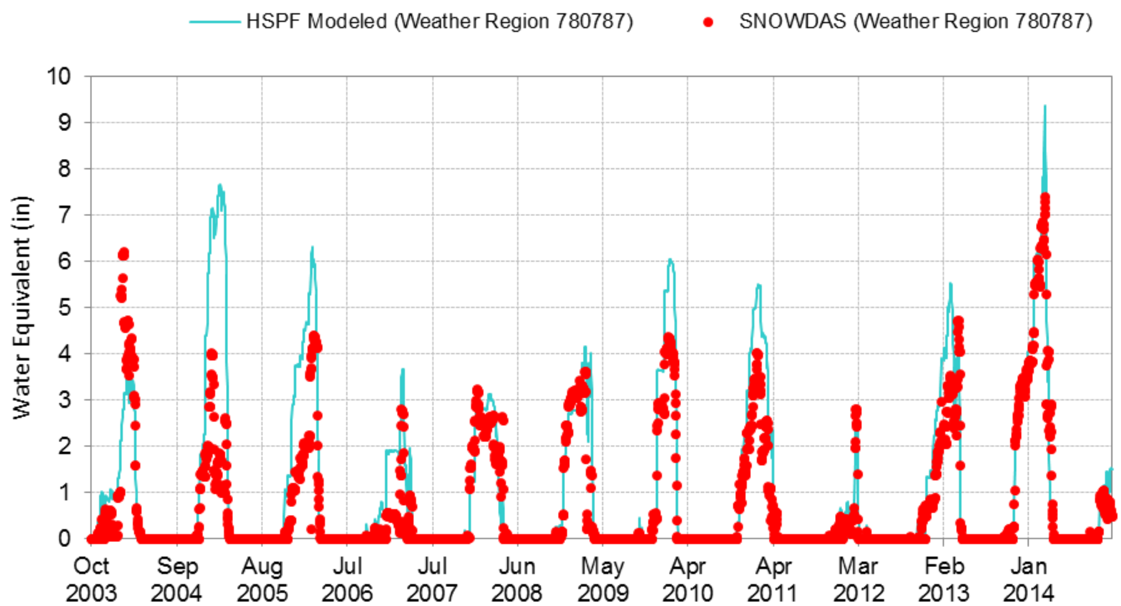


Figure A-62. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 780787

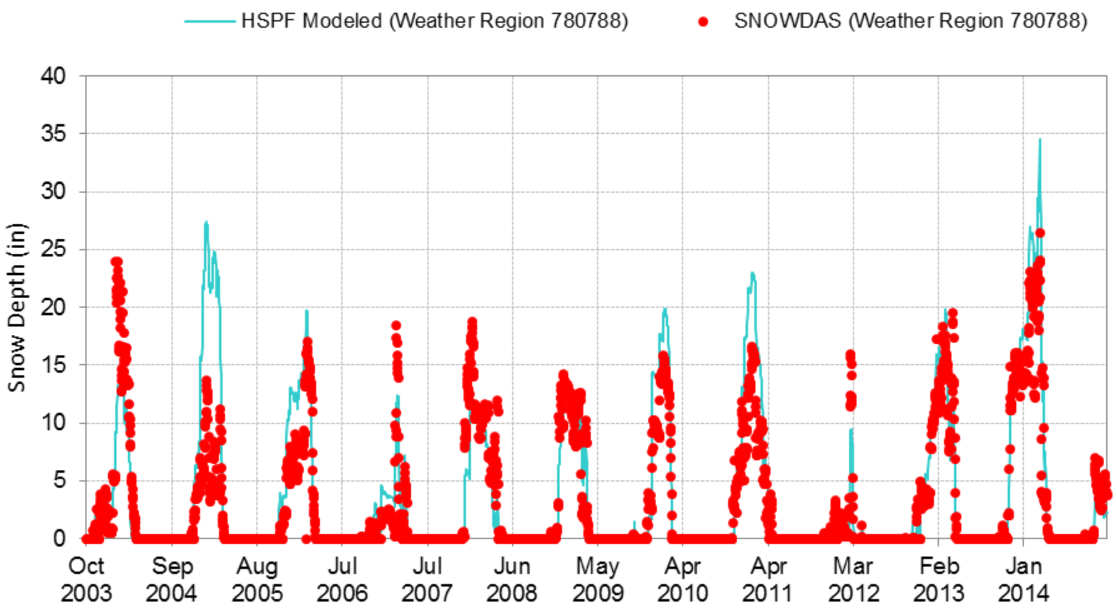


Figure A-63. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 780788

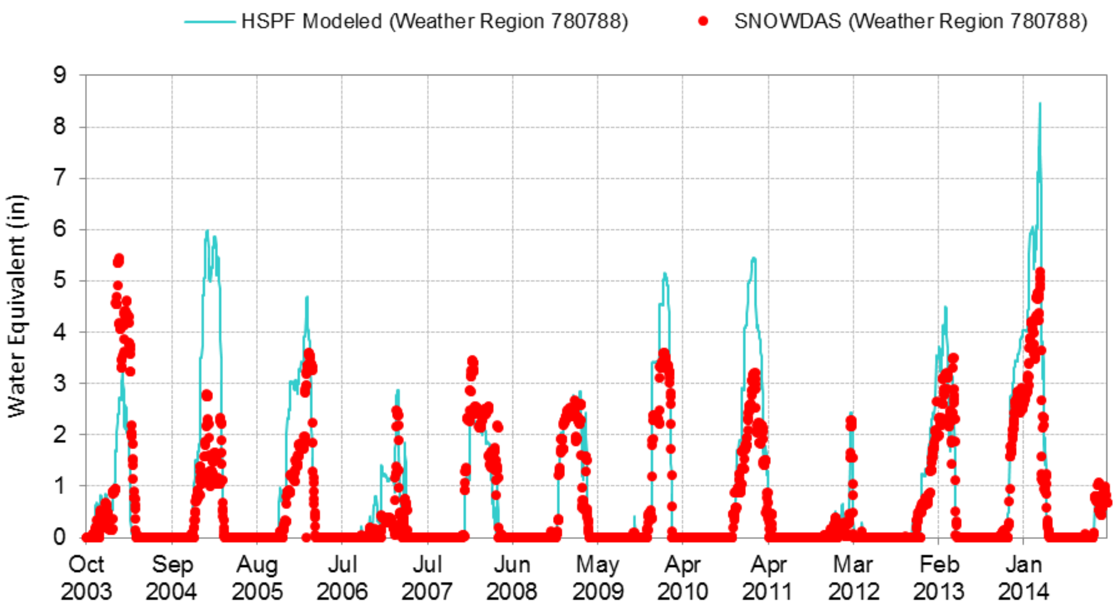


Figure A-64. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 780788

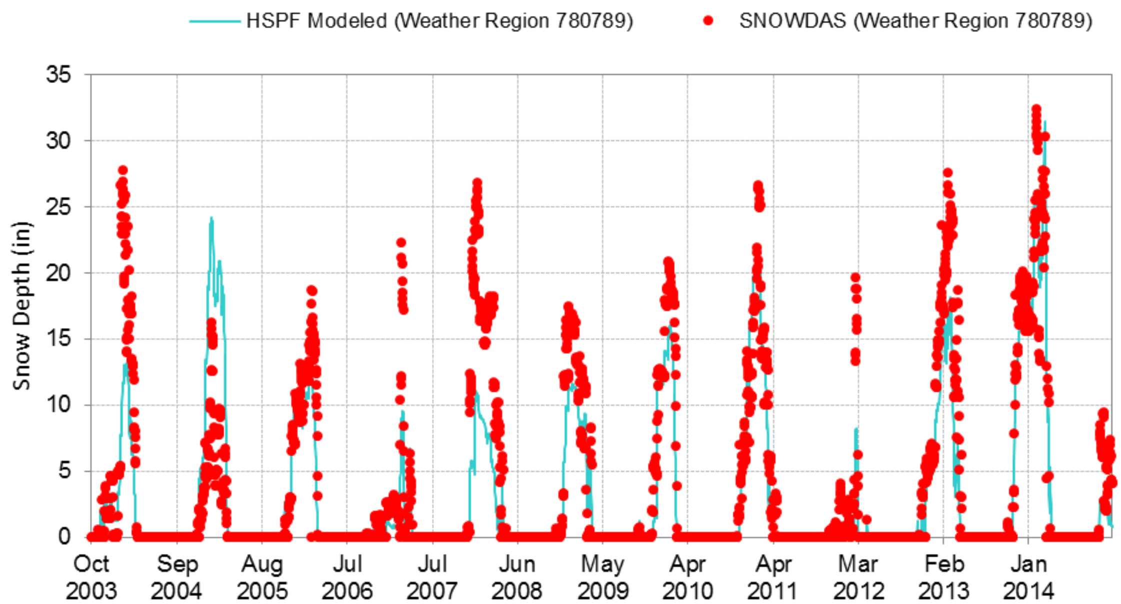


Figure A-65. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 780789

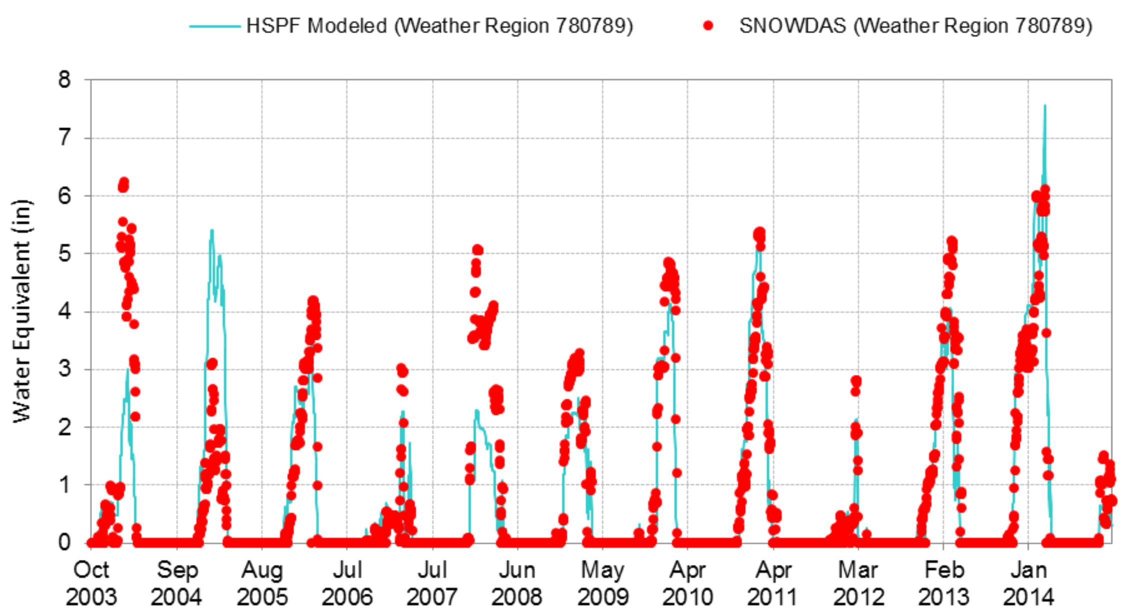


Figure A-66. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 780789

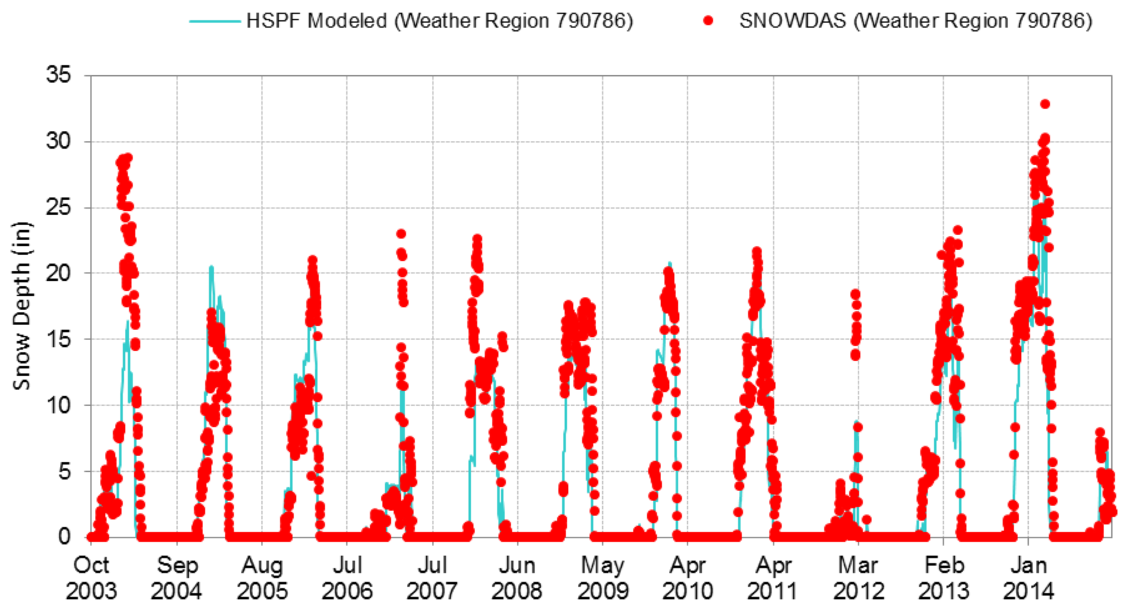


Figure A-67. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 790786

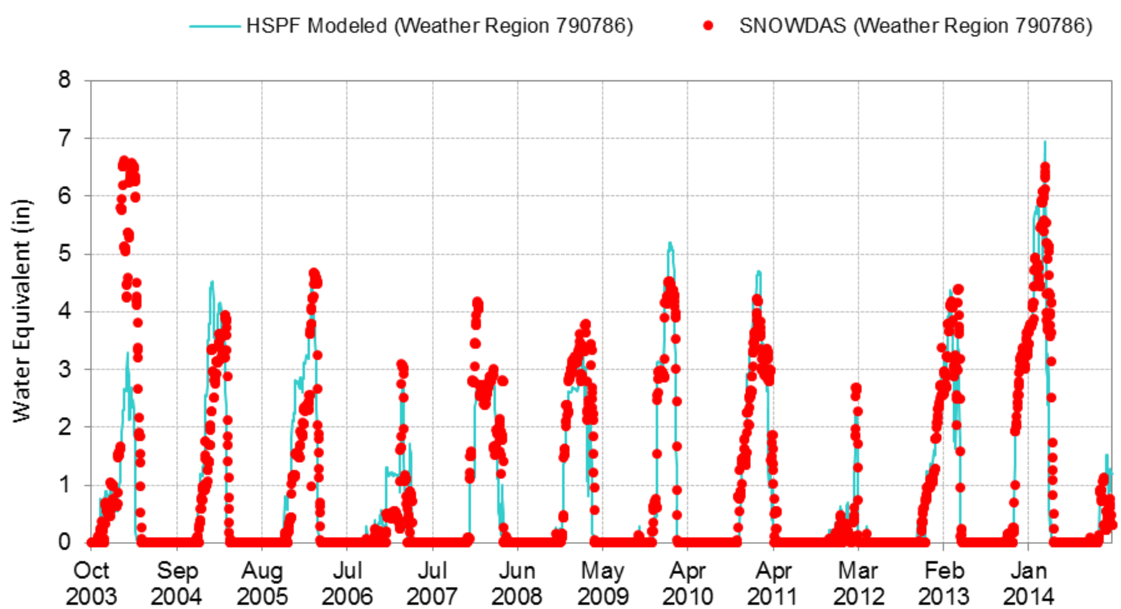


Figure A-68. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 790786

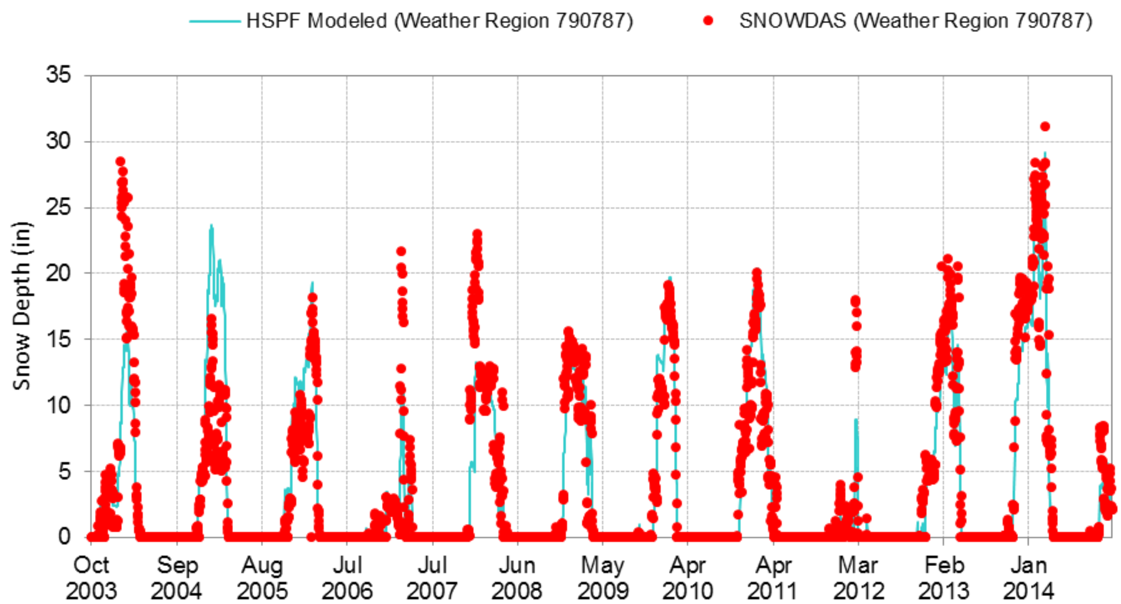


Figure A-69. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 790787

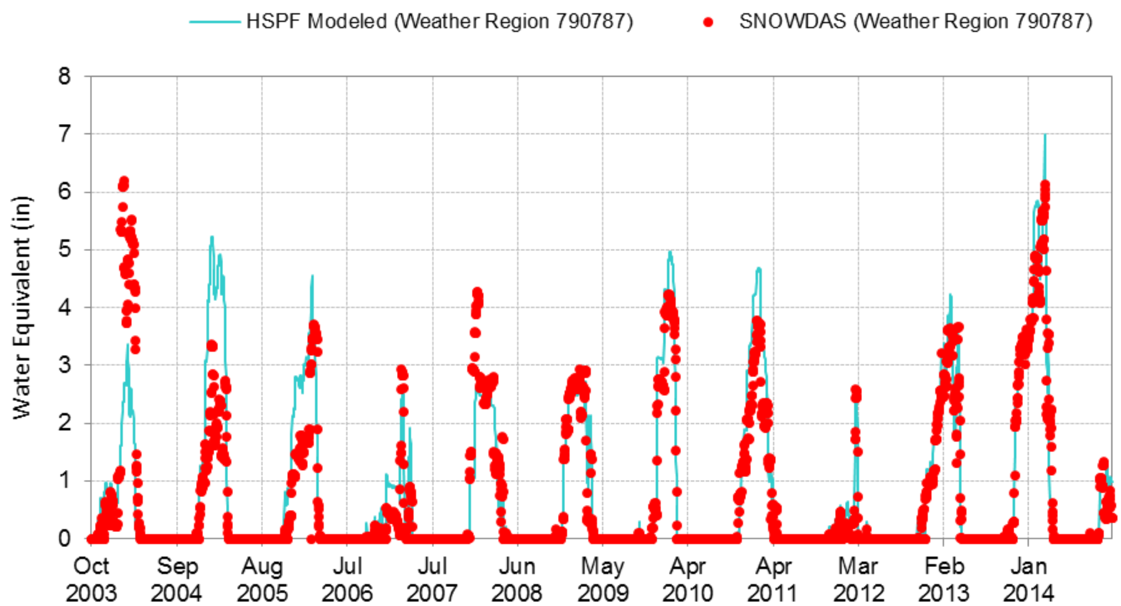


Figure A-70. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 790787

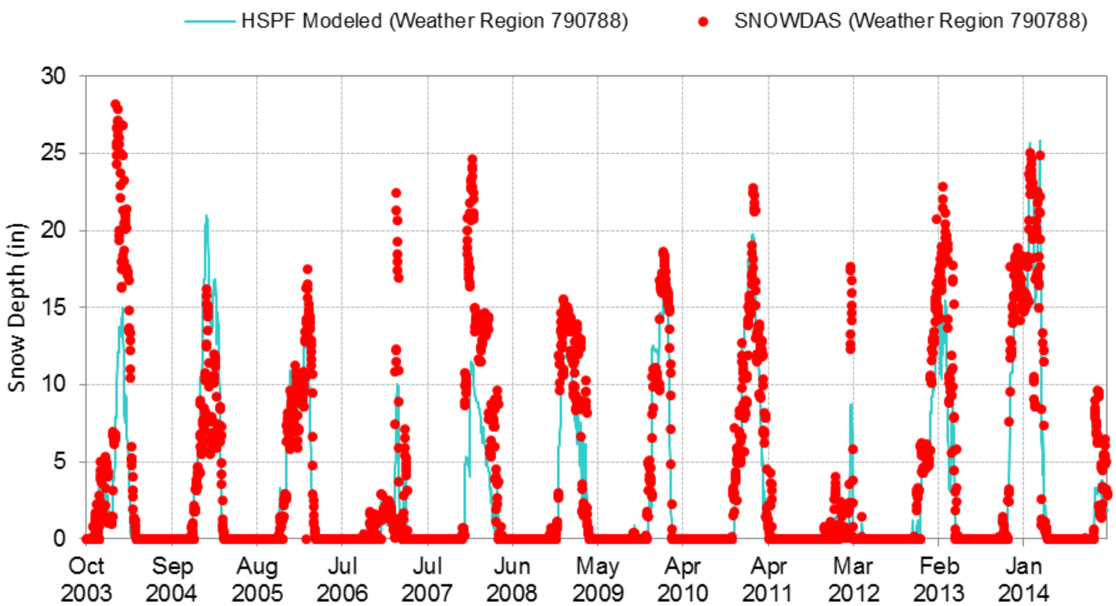


Figure A-71. Modeled (HSPF) and SNOWDAS Snow Depth in Weather Zone 790788

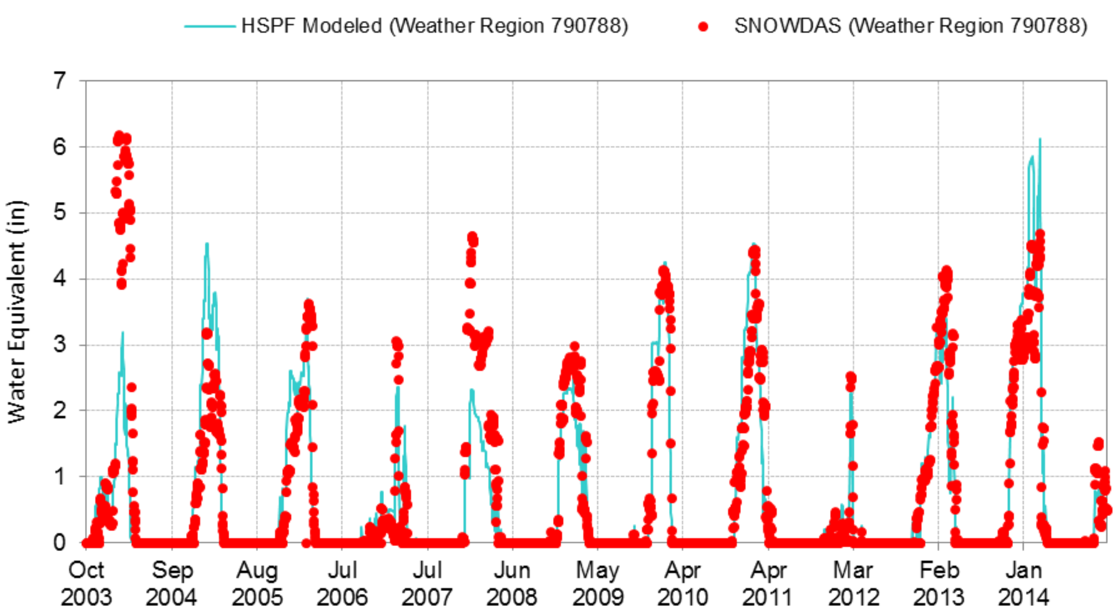


Figure A-72. Modeled (HSPF) and SNOWDAS Water Equivalent in Weather Zone 790788

Appendix B Detailed Flow Calibration Results

B.1 HYDSTRA 02036003 LESTER RIVER NEAR DULUTH, CSAH10

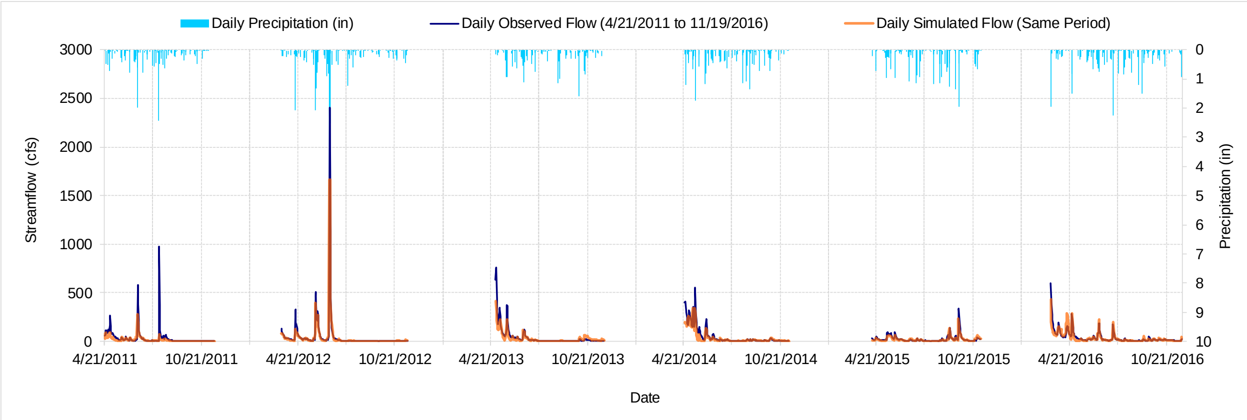


Figure B-1. Mean daily streamflow

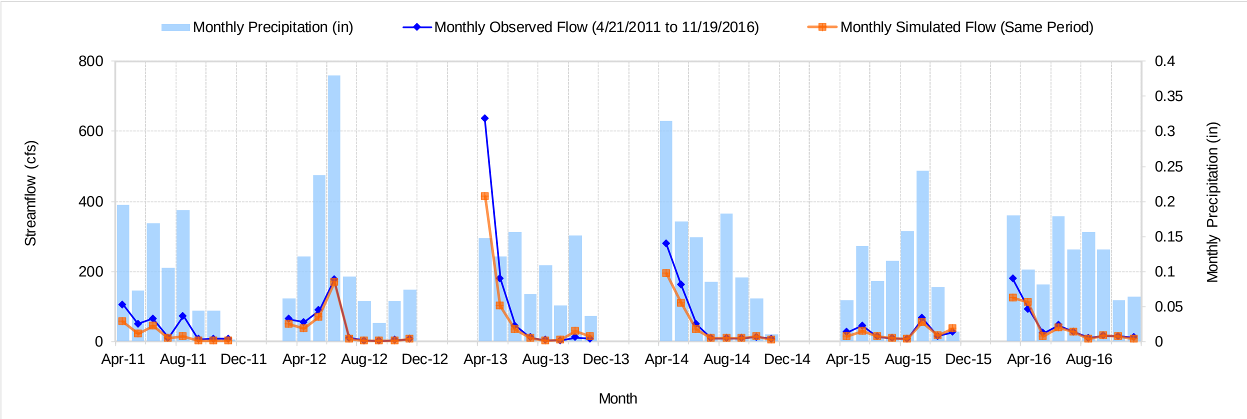


Figure B-2. Mean monthly streamflow

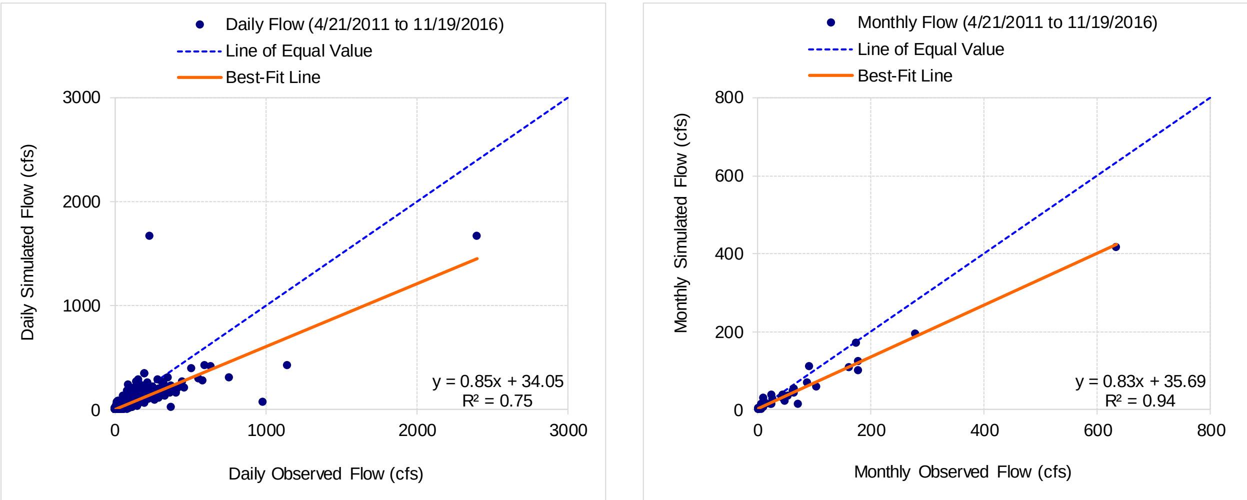


Figure B-3. Daily (left) and monthly (right) streamflow scatterplot

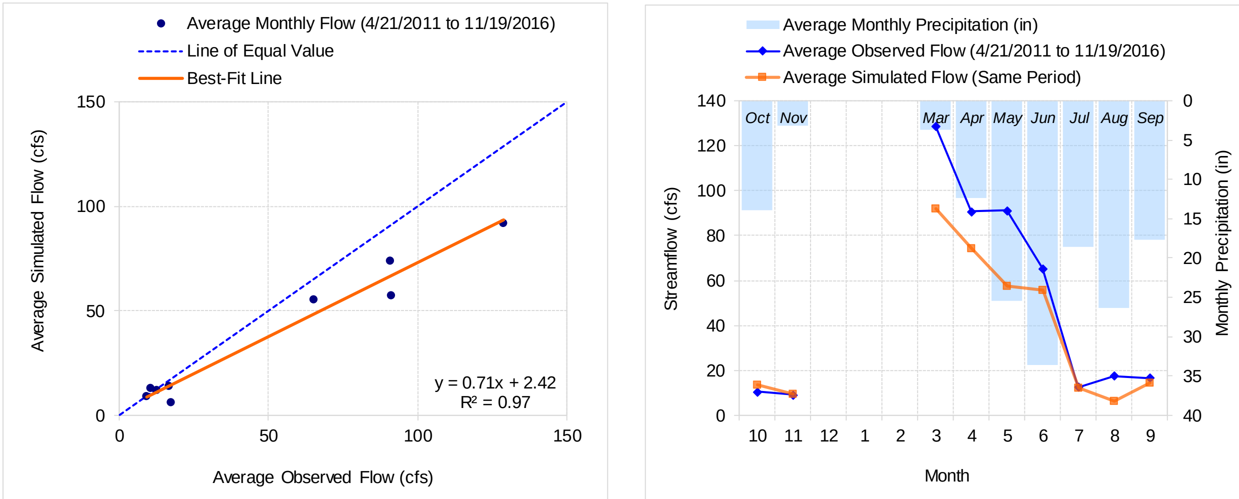


Figure B-4. Seasonal scatterplot (left) and temporal aggregate (right)

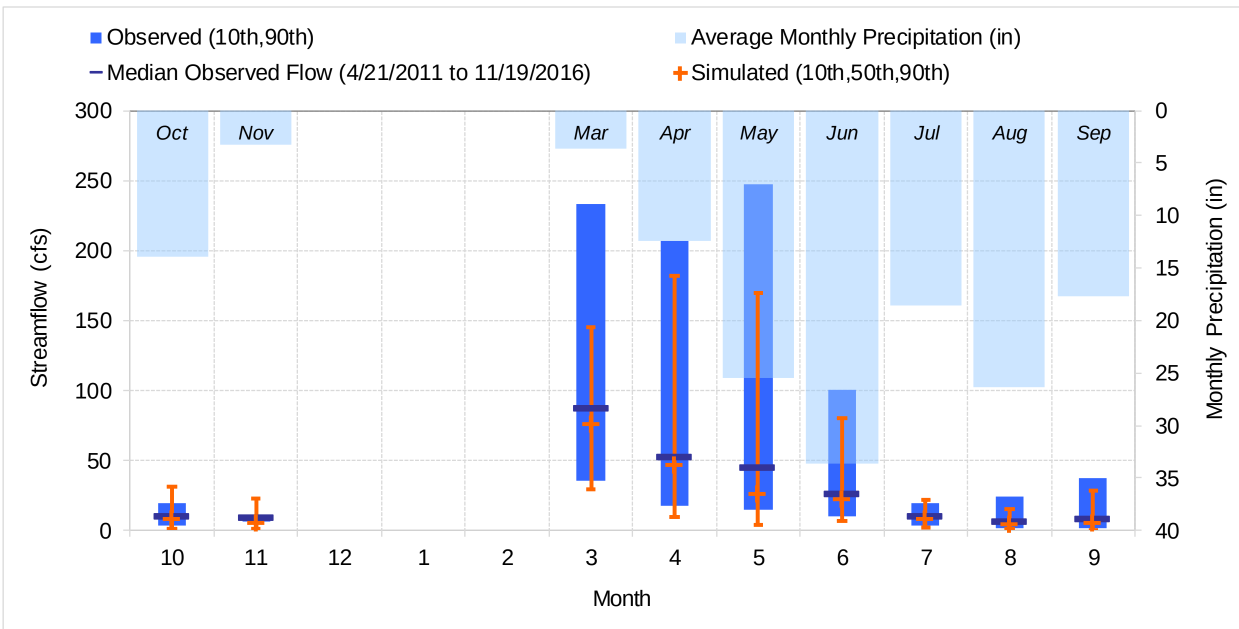


Figure B-5. Monthly medians and ranges

Table B-1. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	10.52	8.55	3.15	19.50	13.27	8.14	1.41	31.61
Nov	9.16	7.80	6.10	11.30	9.26	4.85	1.29	22.70
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	128.96	85.50	35.70	233.20	92.19	75.87	29.29	145.53
Apr	90.73	51.00	18.00	206.60	74.26	46.07	9.31	182.27
May	91.32	43.50	14.50	247.00	57.30	25.65	3.75	169.59
Jun	65.40	25.00	10.00	100.30	55.64	21.68	6.90	80.73
Jul	12.45	9.05	3.85	20.00	12.02	7.50	2.17	21.68
Aug	17.36	5.45	1.80	24.50	6.44	3.66	0.85	15.24
Sep	16.62	6.40	1.50	37.20	14.23	4.62	0.61	28.67

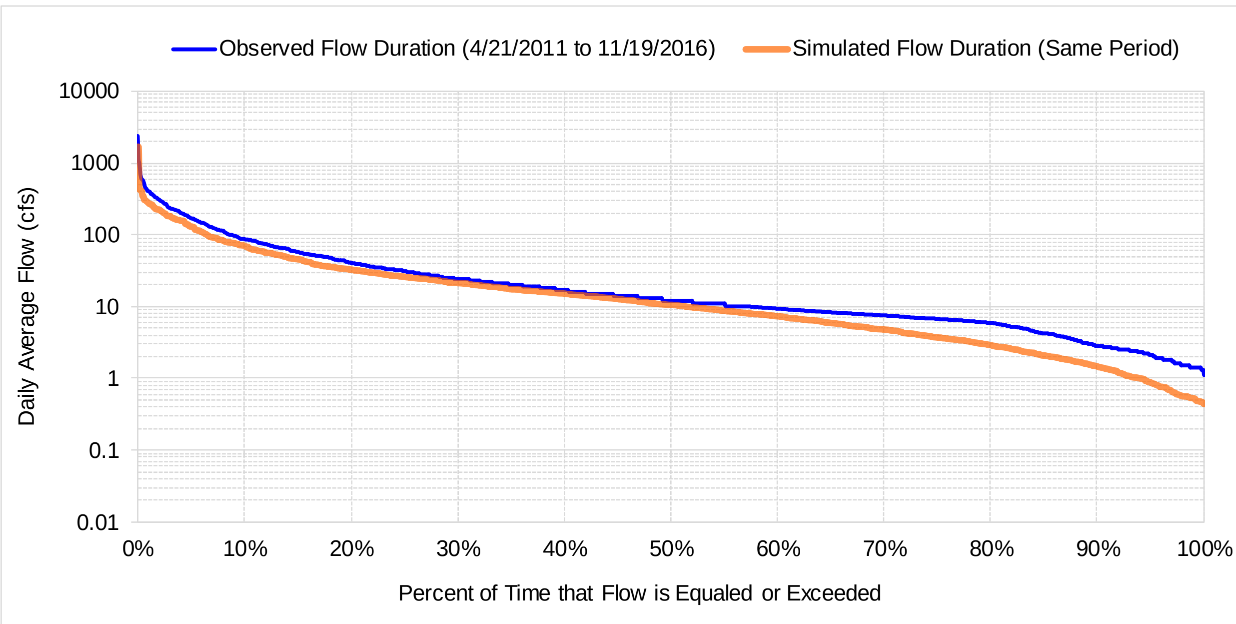


Figure B-6. Flow exceedance

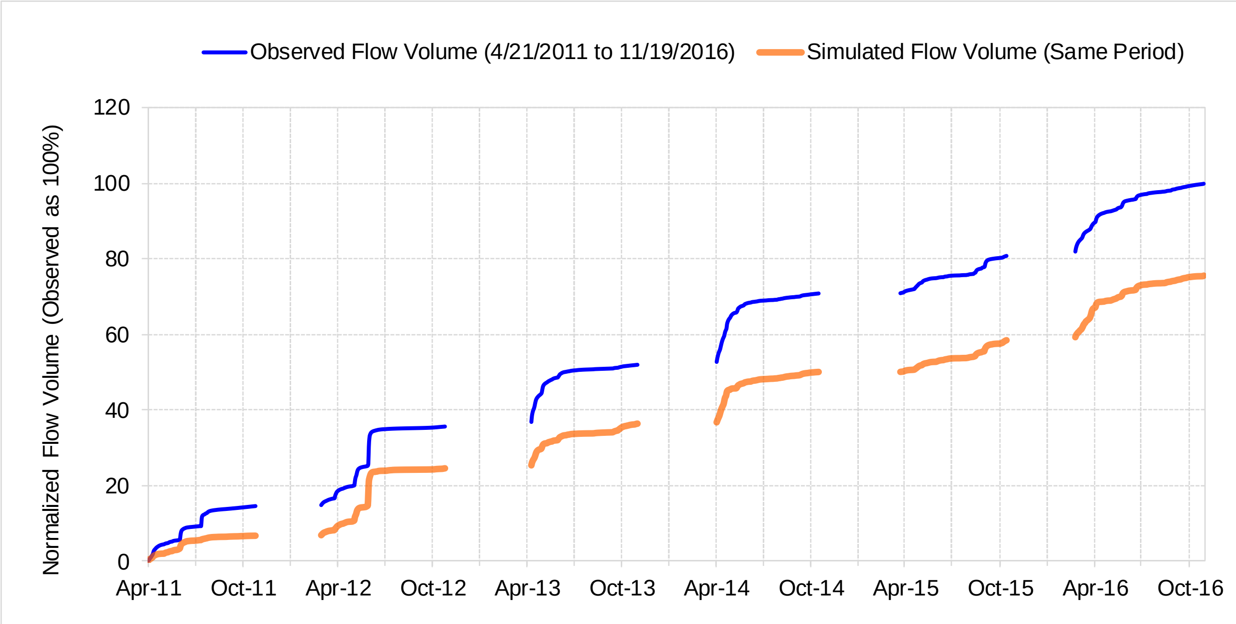


Figure B-7. Flow accumulation

Table B-2. Summary statistics

Lester River nr Duluth, CSAH10 (ID - 02036003)
Drainage Area (sq-mi): 35.26
Analysis Period: 4/21/2011 to 11/19/2016

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	9.90	7.49	-24.31	10
Total lowest 50% flows	0.79	0.54	-31.94	10
Total highest 10% flows	5.97	4.37	-26.76	15
Summer flow volume (months 7-9)	1.61	1.13	-29.76	30
Fall flow volume (months 10-12)	0.50	0.60	19.46	30
Winter flow volume (months 1-3)	0.68	0.49	-28.51 >>	30
Spring flow volume (months 4-6)	7.10	5.27	-25.78	30
Total storm volume	3.52	2.66	-24.43	20
Summer storm volume (7-9)	0.64	0.34	-46.10	50
Baseflow	6.38	4.83	-24.24	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.598	0.7
Baseline adjusted coefficient (Garrick), E'			0.595	0.5
Monthly NSE			0.810	0.85

B.2 HYDSTRA 02038001 AMITY CREEK AT DULUTH, OCCIDENTAL BLVD

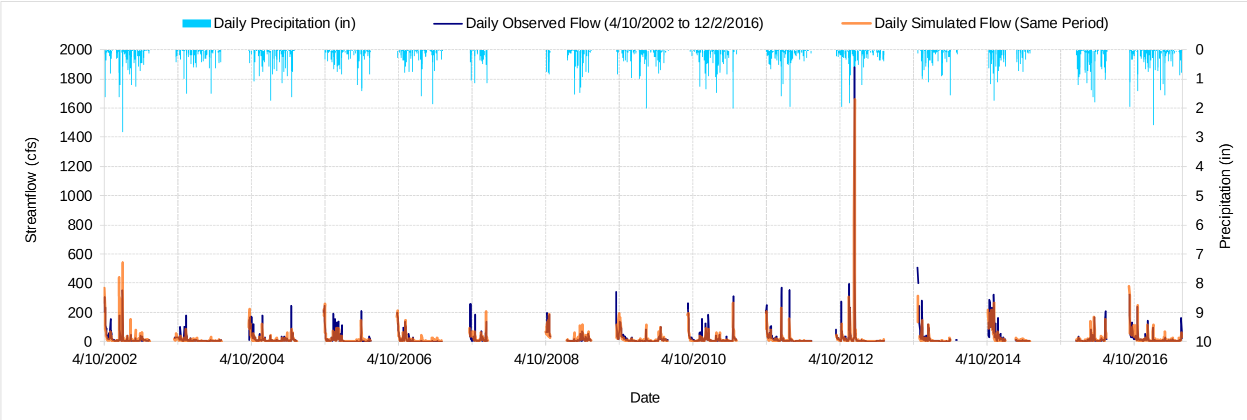


Figure B-8. Mean daily streamflow

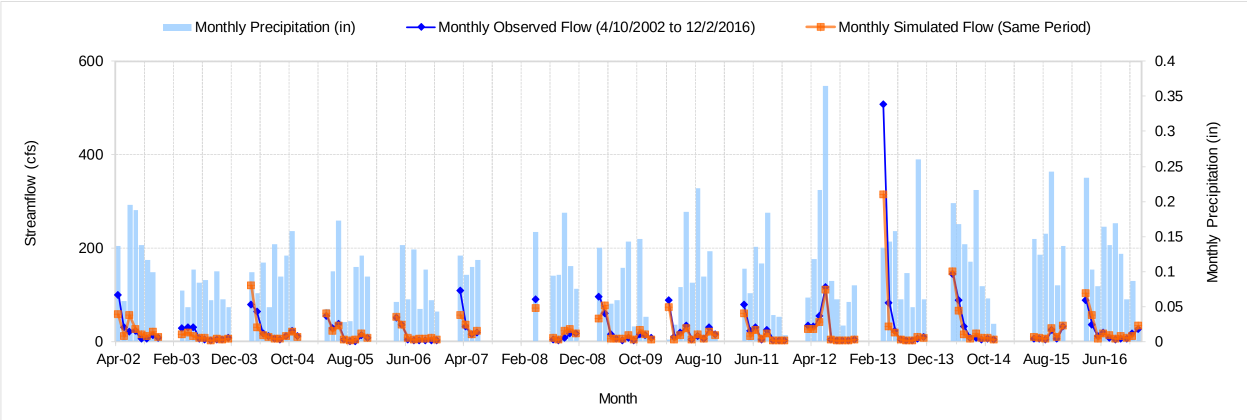


Figure B-9. Mean monthly streamflow

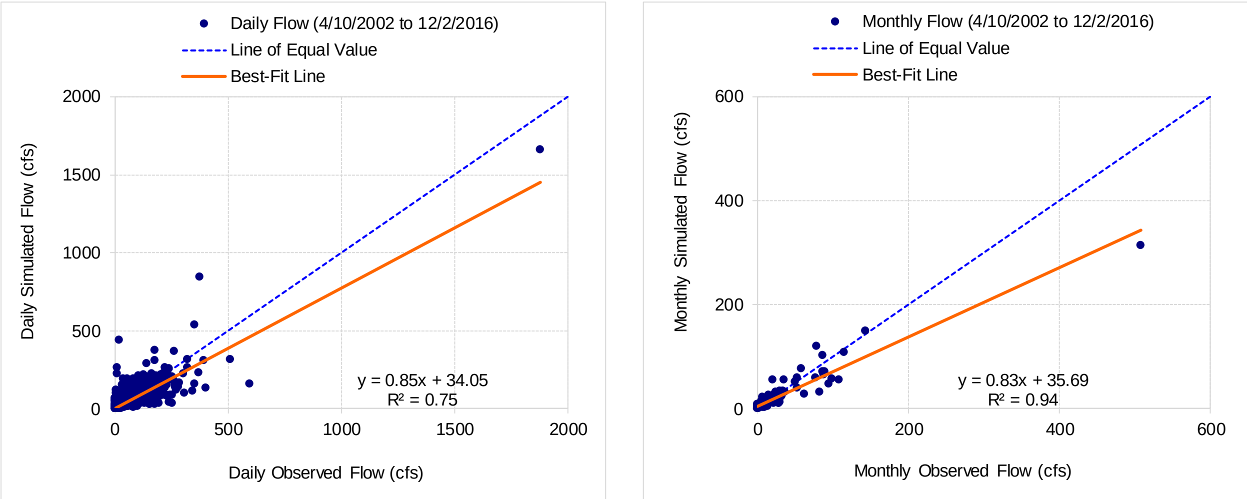
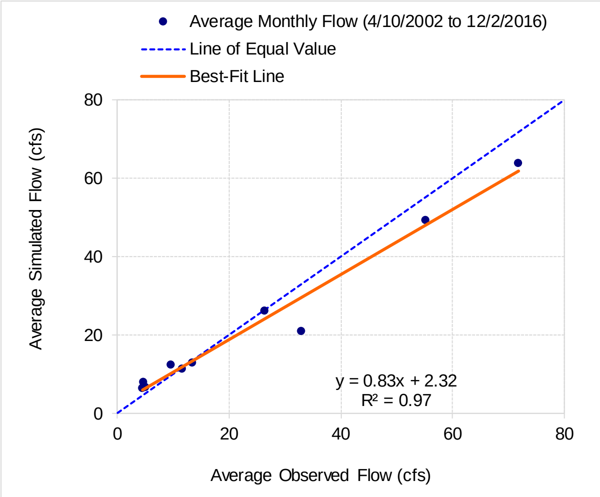


Figure B-10. Daily (left) and monthly (right) streamflow scatterplot



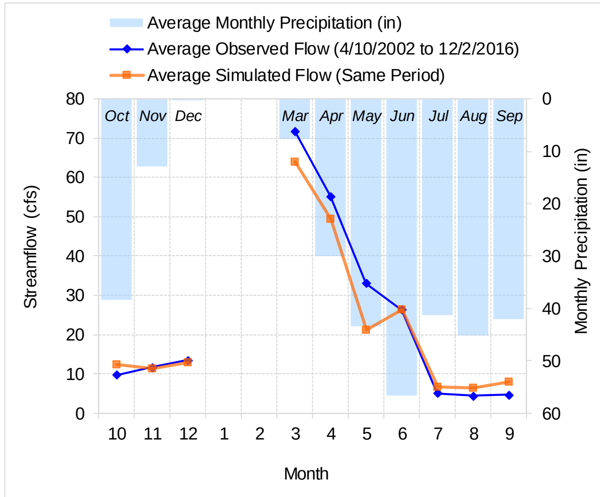


Figure B-11. Seasonal scatterplot (left) and temporal aggregate (right)

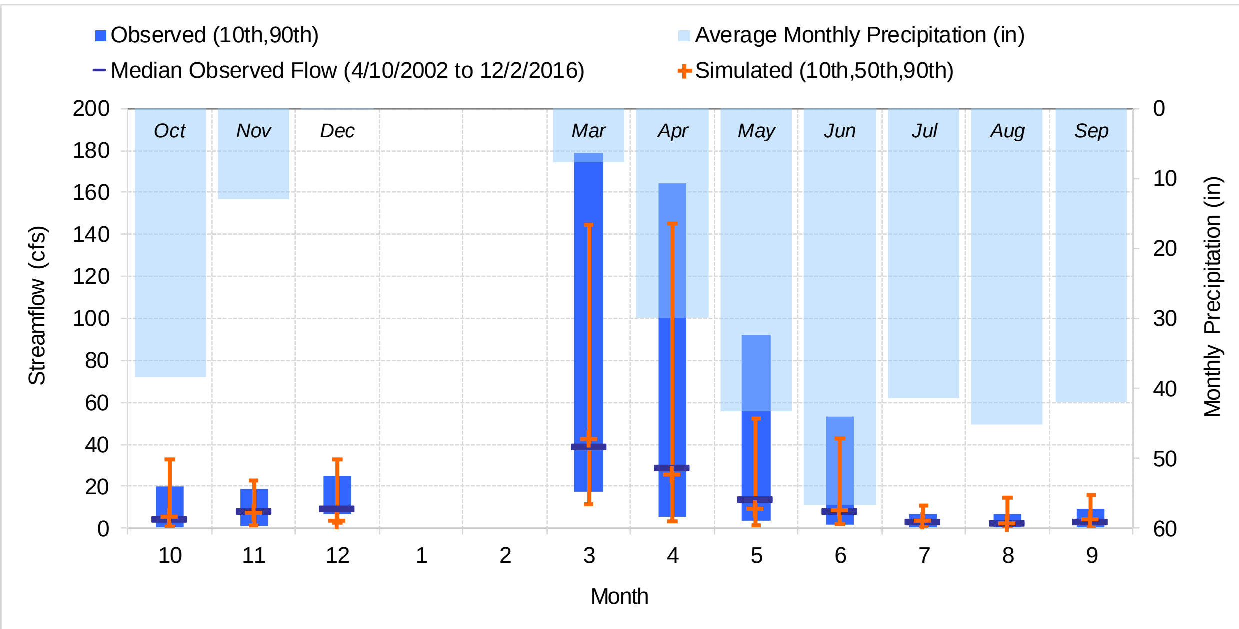


Figure B-12. Monthly medians and ranges

Table B-3. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	9.65	3.30	0.71	20.00	12.49	5.33	1.03	32.89
Nov	11.60	7.00	1.30	18.90	11.29	6.92	1.20	22.92
Dec	13.48	8.40	7.05	25.00	12.84	3.19	2.48	32.85
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	71.82	38.00	17.67	179.00	64.03	42.04	11.60	144.80
Apr	55.21	27.50	5.54	164.19	49.46	25.41	3.58	145.12
May	33.01	12.45	3.92	92.17	21.12	8.74	1.43	52.28
Jun	26.33	7.37	1.69	53.41	26.26	8.60	1.89	43.04
Jul	5.01	2.27	0.38	6.91	6.67	3.02	0.65	10.87
Aug	4.45	1.70	0.28	6.93	6.50	2.33	0.47	14.46
Sep	4.60	1.90	0.29	9.20	7.95	3.82	0.30	16.18

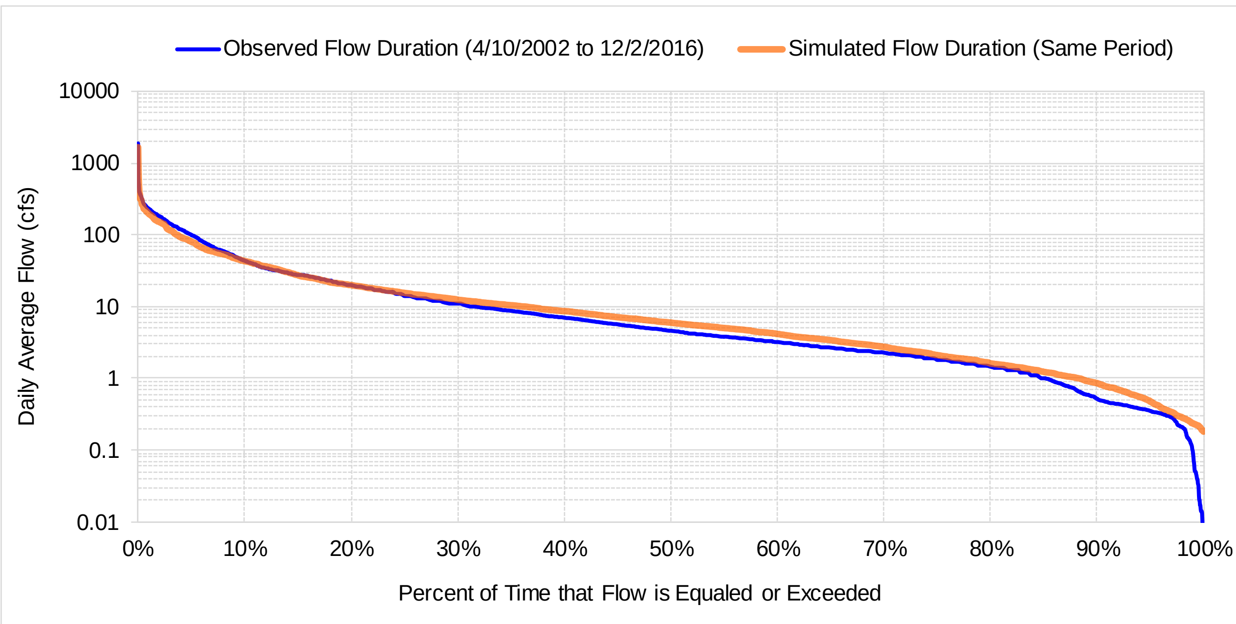


Figure B-13. Flow exceedance

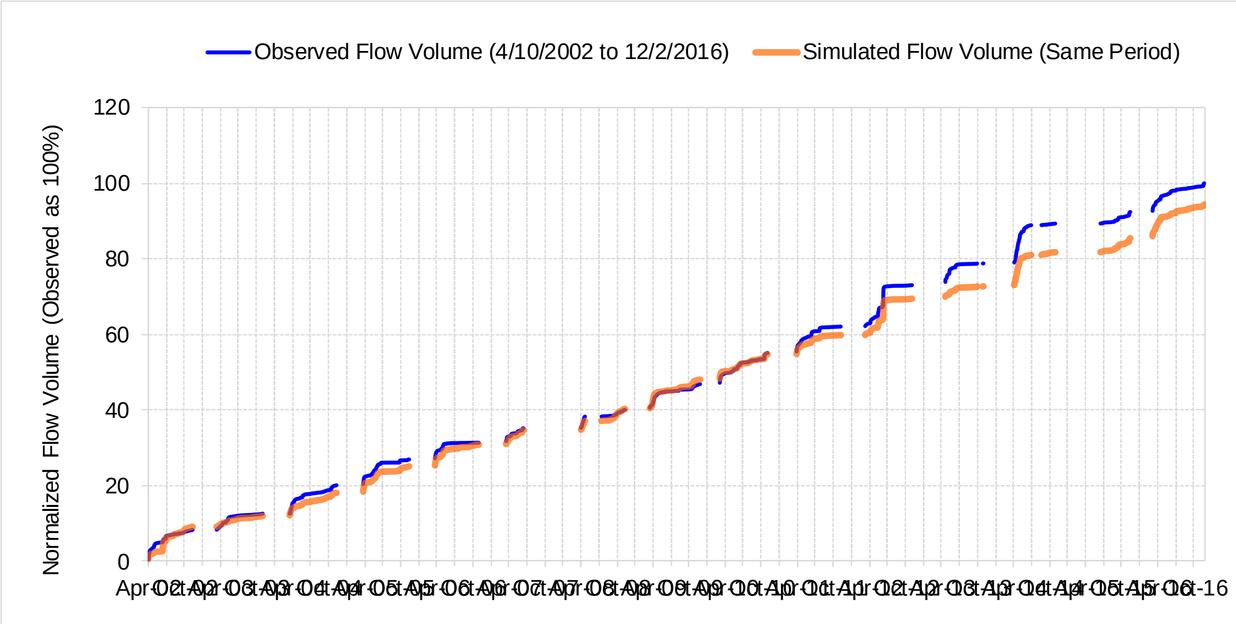


Figure B-14. Flow accumulation

Table B-4. Summary statistics

Amity Creek at Duluth, Occidential Blvd. (ID - 02038001)
Drainage Area (sq-mi): 16.7
Analysis Period: 4/10/2002 to 12/2/2016

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	9.22	8.70	-5.63	10
Total lowest 50% flows	0.45	0.57	26.94	10
Total highest 10% flows	6.07	5.22	-13.95	15
Summer flow volume (months 7-9)	0.86	1.29	50.85	30
Fall flow volume (months 10-12)	1.02	1.19	16.18	30
Winter flow volume (months 1-3)	0.82	0.73	-10.85 >>	30
Spring flow volume (months 4-6)	6.52	5.49	-15.82	30
Total storm volume	3.90	3.41	-12.63	20
Summer storm volume (7-9)	0.44	0.58	32.31	50
Baseflow	5.32	5.30	-0.49	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.734	0.7
Baseline adjusted coefficient (Garrick), E'			0.570	0.5
Monthly NSE			0.812	0.85

B.3 Duluth Streams S004-364 Tischer Creek at Wallace Ave "Mt. Royal"

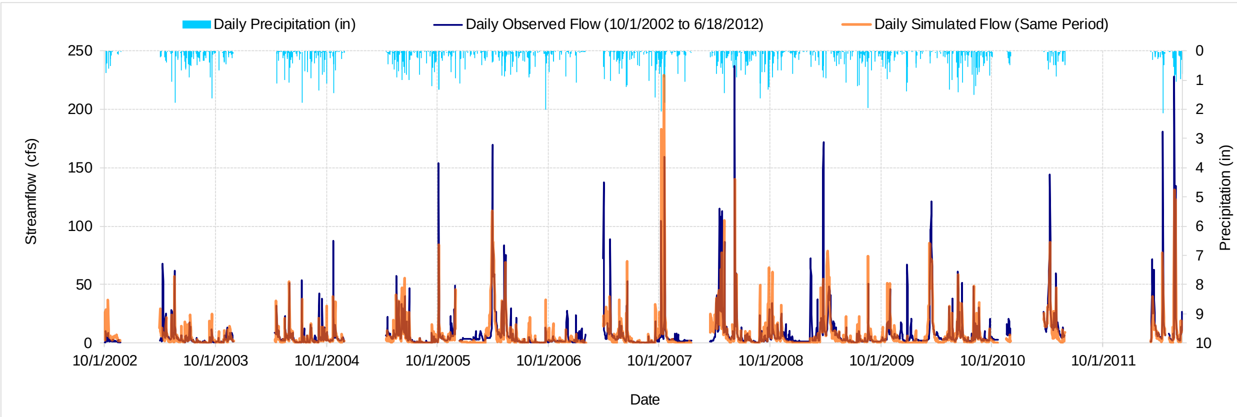


Figure B-15. Mean daily streamflow

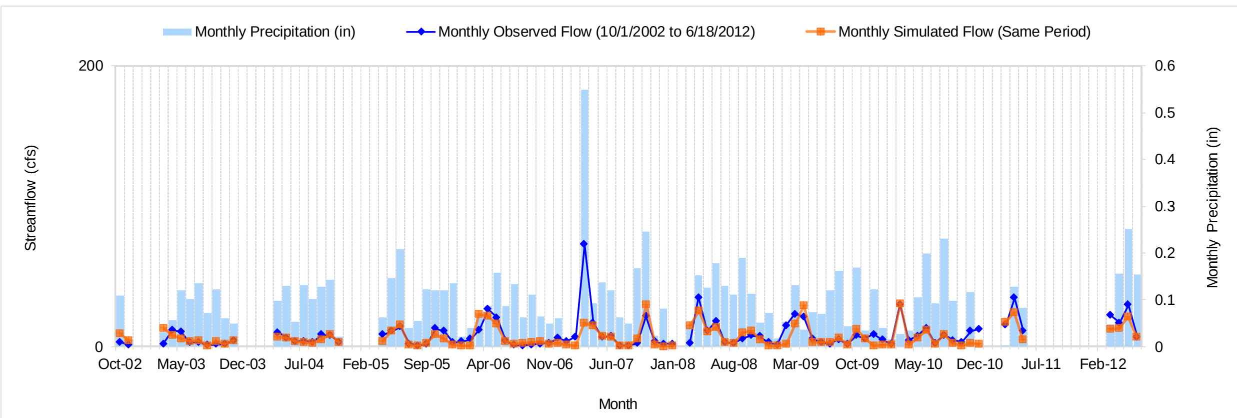


Figure B-16. Mean monthly streamflow

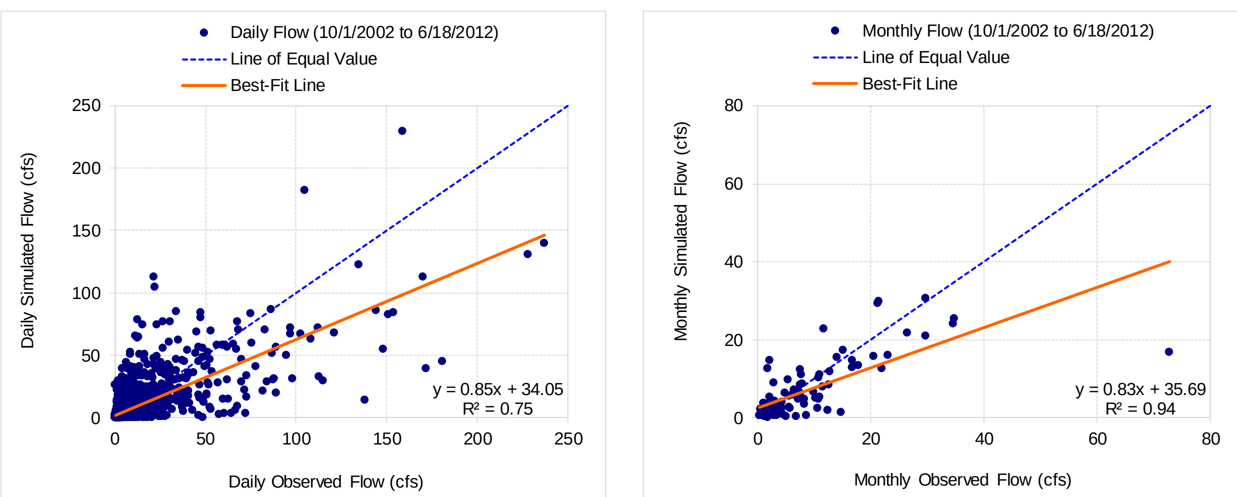


Figure B-17. Daily (left) and monthly (right) streamflow scatterplot

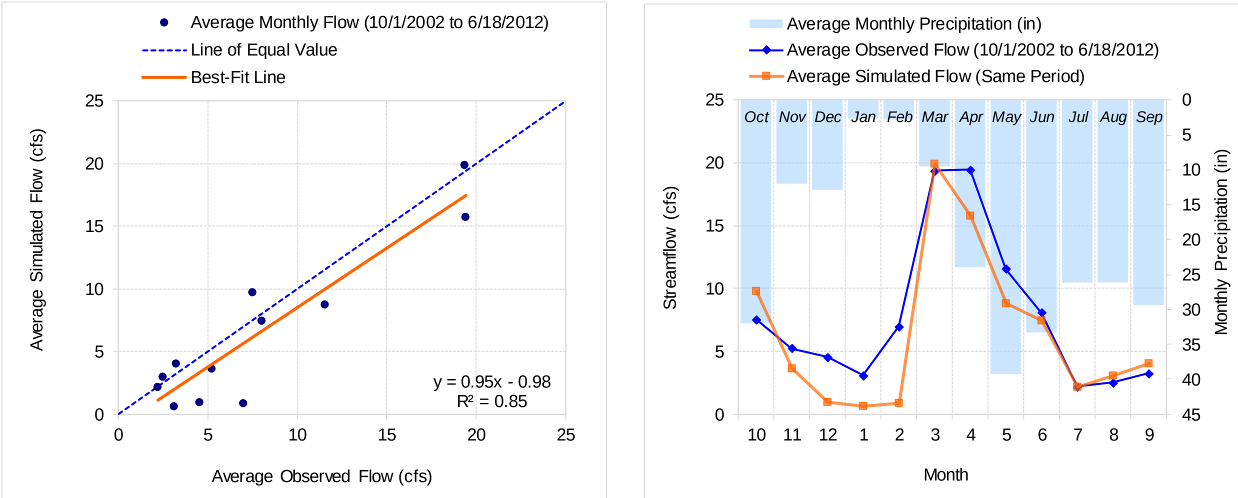


Figure B-18. Seasonal scatterplot (left) and temporal aggregate (right)

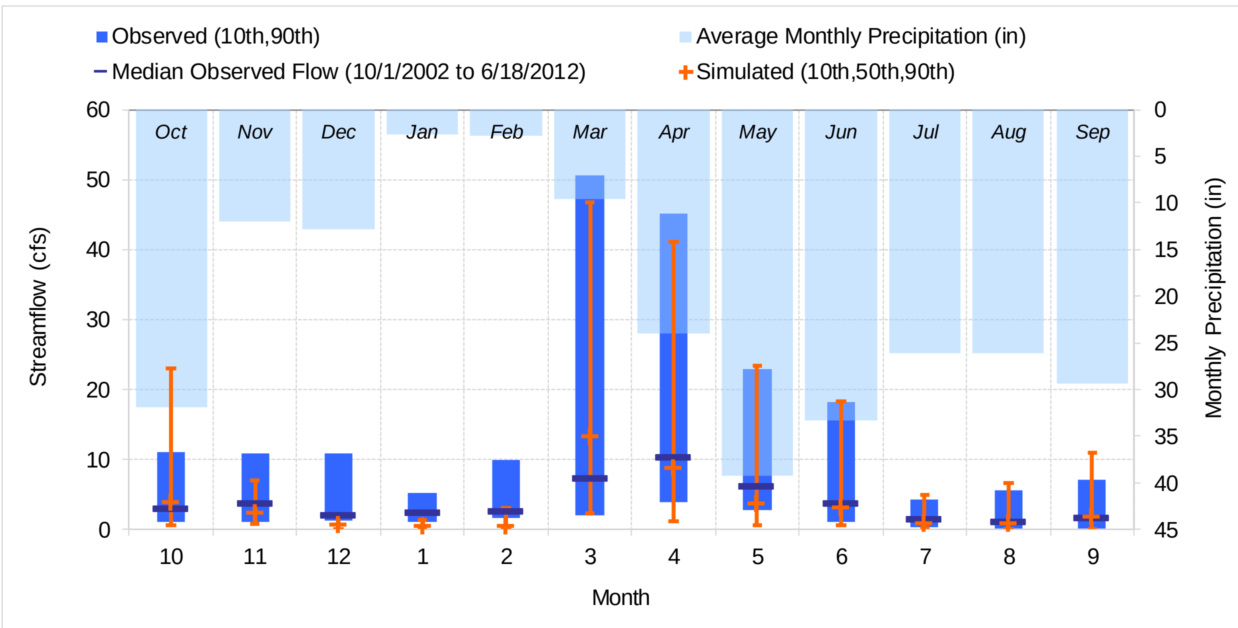


Figure B-19. Monthly medians and ranges

Table B-5. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	7.52	2.74	1.03	11.15	9.77	3.85	0.56	23.00
Nov	5.22	3.50	1.17	10.82	3.60	2.39	0.75	6.95
Dec	4.55	1.78	1.18	10.87	0.92	0.53	0.07	1.89
Jan	3.09	2.22	1.15	5.21	0.63	0.34	0.18	1.32
Feb	6.97	2.25	1.65	9.86	0.90	0.34	0.14	3.16
Mar	19.36	7.10	2.09	50.59	19.91	13.20	2.25	46.74
Apr	19.44	10.04	3.84	45.11	15.75	8.78	1.11	41.09
May	11.56	5.81	2.76	22.94	8.78	3.54	0.58	23.48
Jun	8.05	3.48	1.14	18.23	7.47	3.00	0.63	18.31
Jul	2.20	1.19	0.31	4.34	2.18	0.74	0.19	4.99
Aug	2.52	0.82	0.18	5.63	3.03	0.78	0.13	6.61
Sep	3.23	1.46	0.12	7.05	4.05	1.68	0.13	10.99

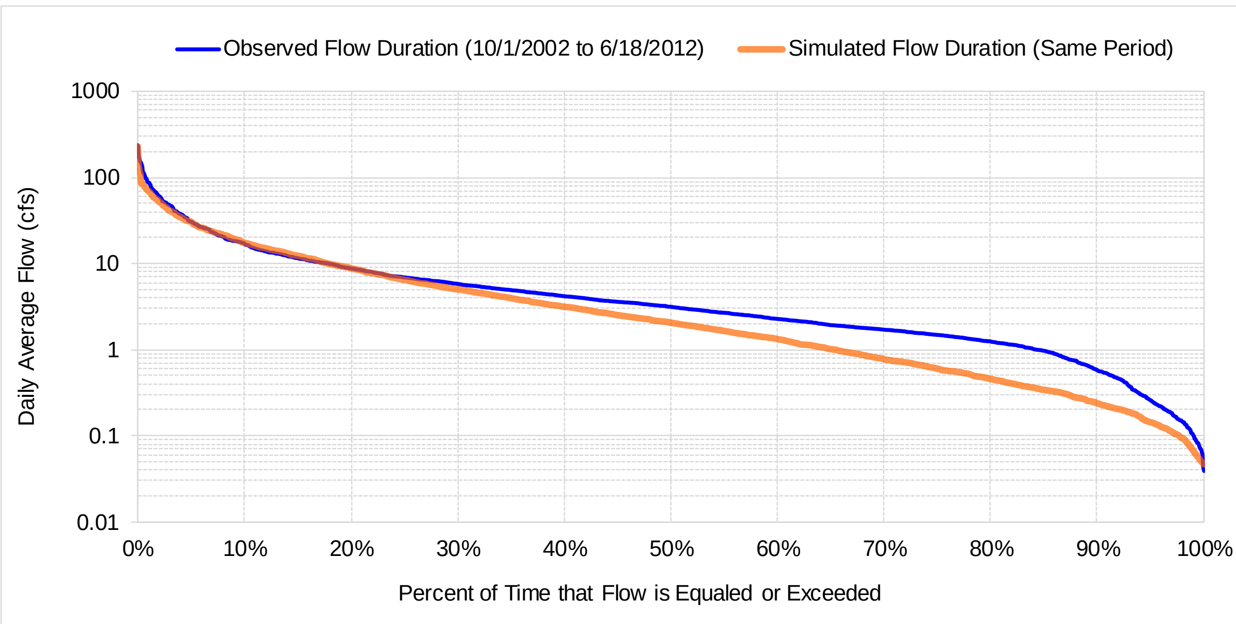


Figure B-20. Flow exceedance

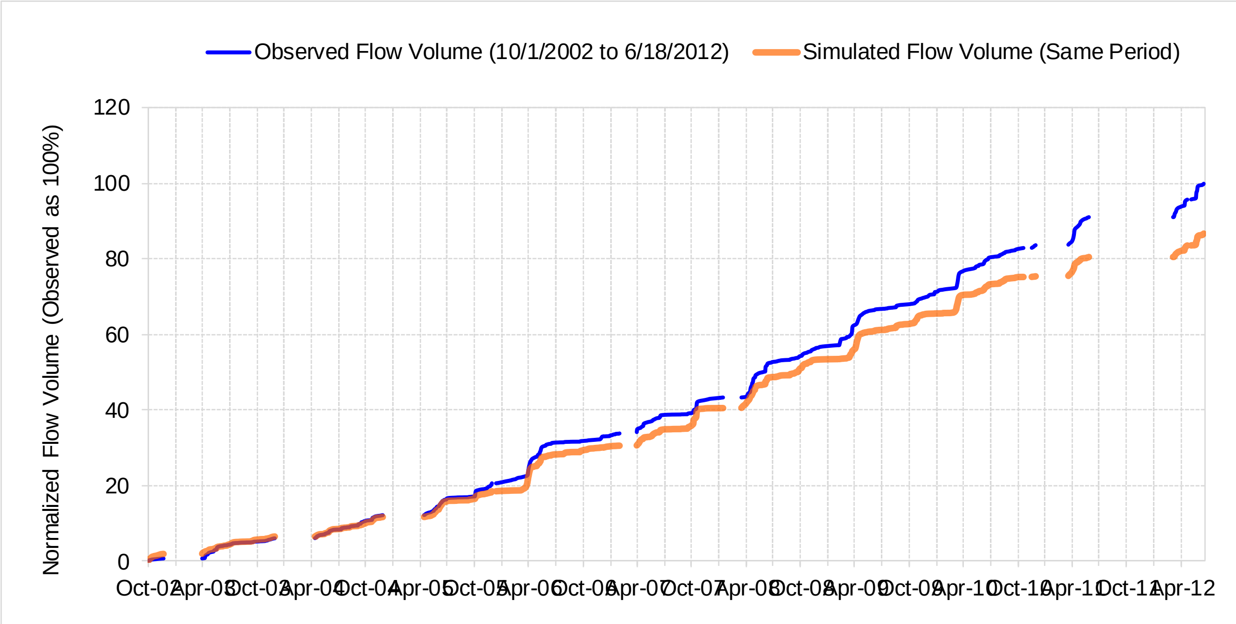


Figure B-21. Flow accumulation

Table B-6. Summary statistics

Tischer Creek at Wallace Ave. (ID -)
Drainage Area (sq-mi): 6.74
Analysis Period: 10/1/2002 to 6/18/2012

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	11.61	10.08	-13.24	10
Total lowest 50% flows	1.07	0.56	-47.76	10
Total highest 10% flows	6.53	5.73	-12.34	15
Summer flow volume (months 7-9)	1.11	1.29	16.29	30
Fall flow volume (months 10-12)	2.23	2.06	-7.59	30
Winter flow volume (months 1-3)	2.17	1.74	-19.78 >>	30
Spring flow volume (months 4-6)	6.11	4.99	-18.31	30
Total storm volume	4.74	4.16	-12.20	20
Summer storm volume (7-9)	0.54	0.68	25.41	50
Baseflow	6.87	5.91	-13.95	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.528	0.7
Baseline adjusted coefficient (Garrick), E'			0.405	0.5
Monthly NSE			0.756	0.85

B.4 SAFL 03-001-002 MILLER CREEK UPPER SITE AT MILLER HILL MALL

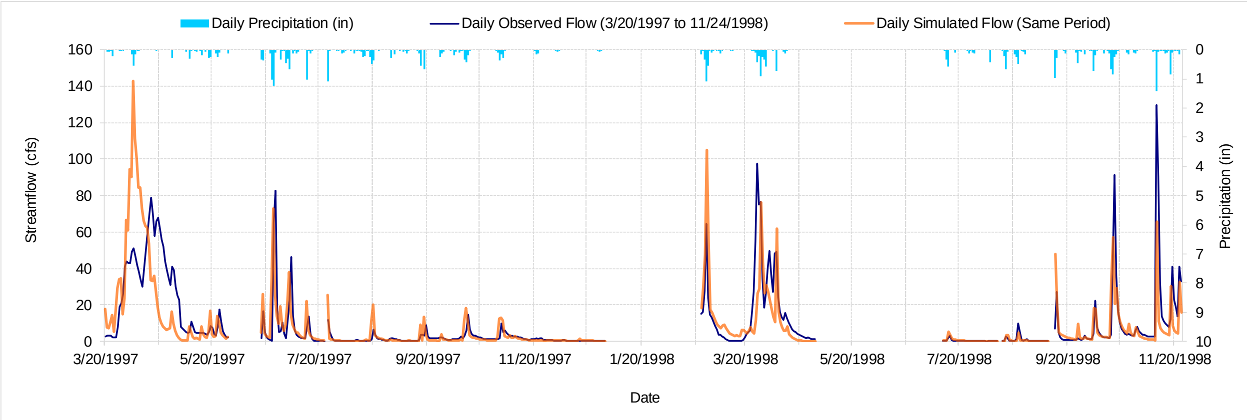


Figure B-22. Mean daily streamflow

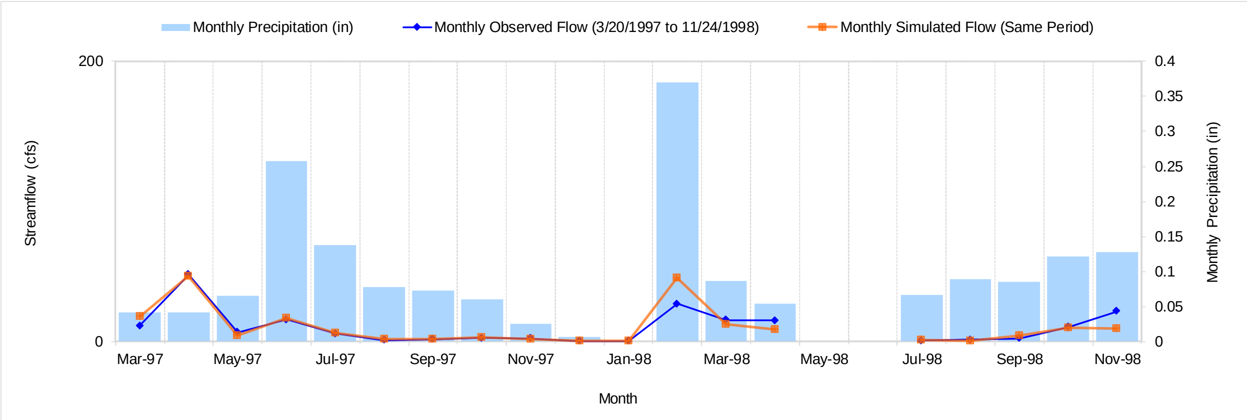


Figure B-23. Mean monthly streamflow

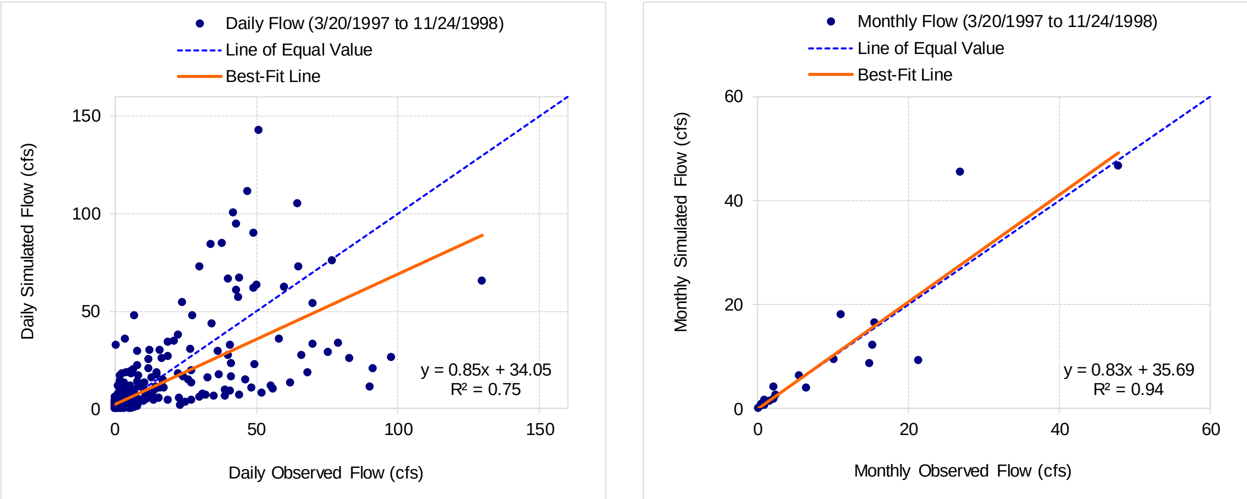


Figure B-24. Daily (left) and monthly (right) streamflow scatterplot

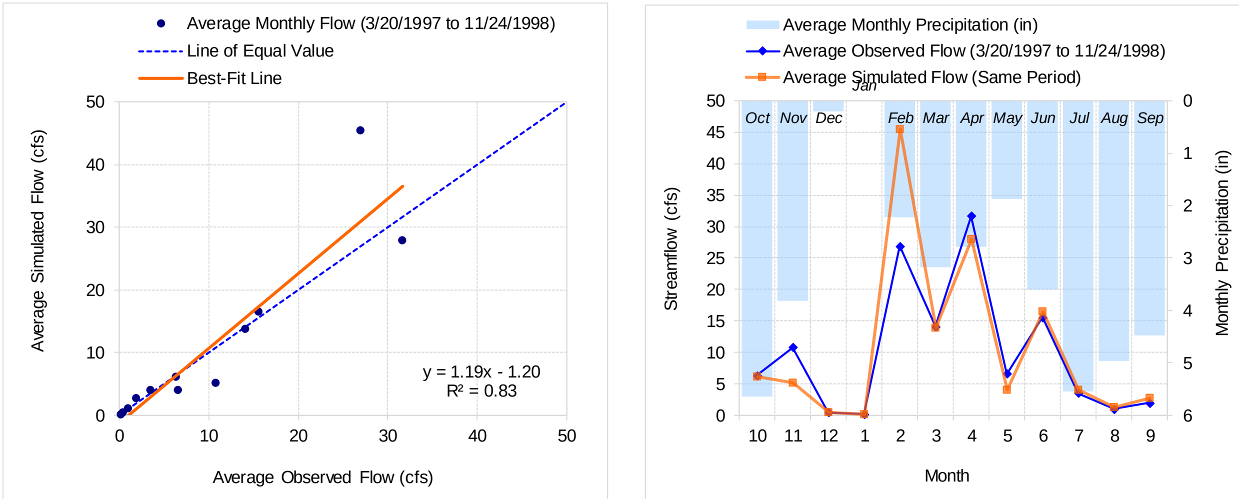


Figure B-25. Seasonal scatterplot (left) and temporal aggregate (right)

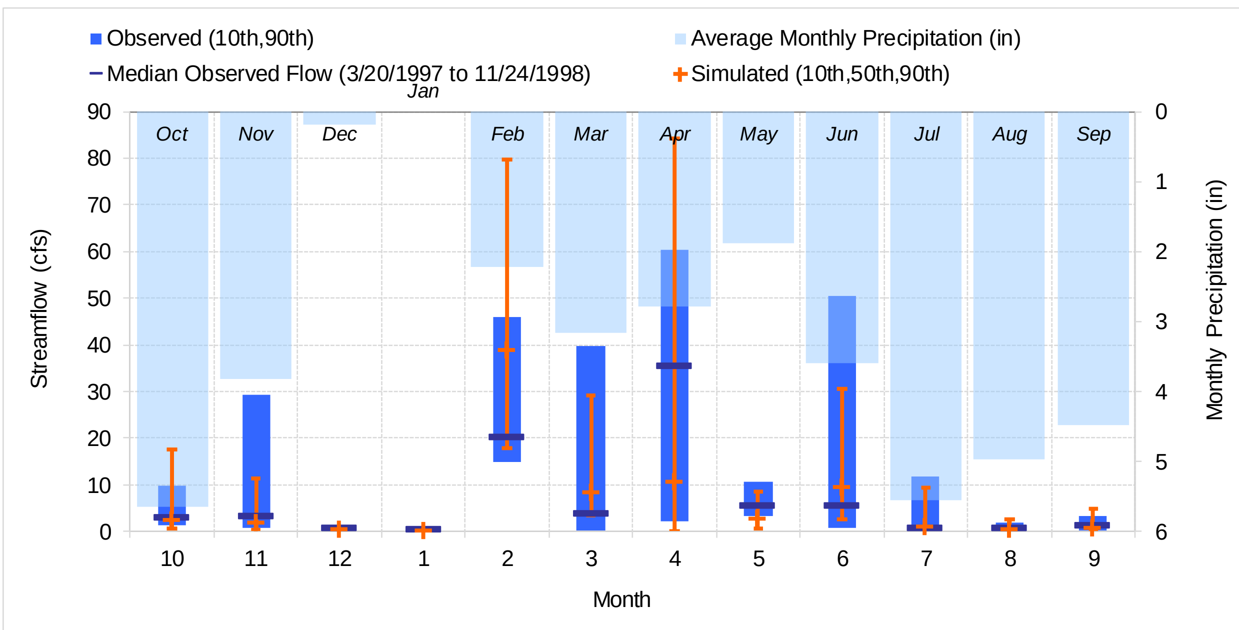


Figure B-26. Monthly medians and ranges

Table B-7. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	6.34	2.61	1.22	9.97	6.07	2.28	0.60	17.49
Nov	10.77	2.86	0.69	29.37	5.17	1.80	0.48	11.39
Dec	0.39	0.36	0.30	0.55	0.41	0.35	0.23	0.56
Jan	0.17	0.17	0.17	0.17	0.12	0.12	0.12	0.12
Feb	26.94	19.92	14.91	45.98	45.56	38.90	17.95	79.83
Mar	14.08	3.54	0.16	39.68	13.82	8.23	3.38	29.22
Apr	31.68	35.00	2.27	60.40	27.98	10.58	0.19	84.28
May	6.58	5.12	3.45	10.63	3.96	2.57	0.70	8.49
Jun	15.59	5.26	0.83	50.57	16.53	9.28	2.51	30.59
Jul	3.49	0.49	0.19	11.81	4.07	1.05	0.20	9.40
Aug	0.99	0.47	0.14	1.91	1.17	0.29	0.08	2.61
Sep	1.90	0.84	0.30	3.36	2.72	0.53	0.14	4.77

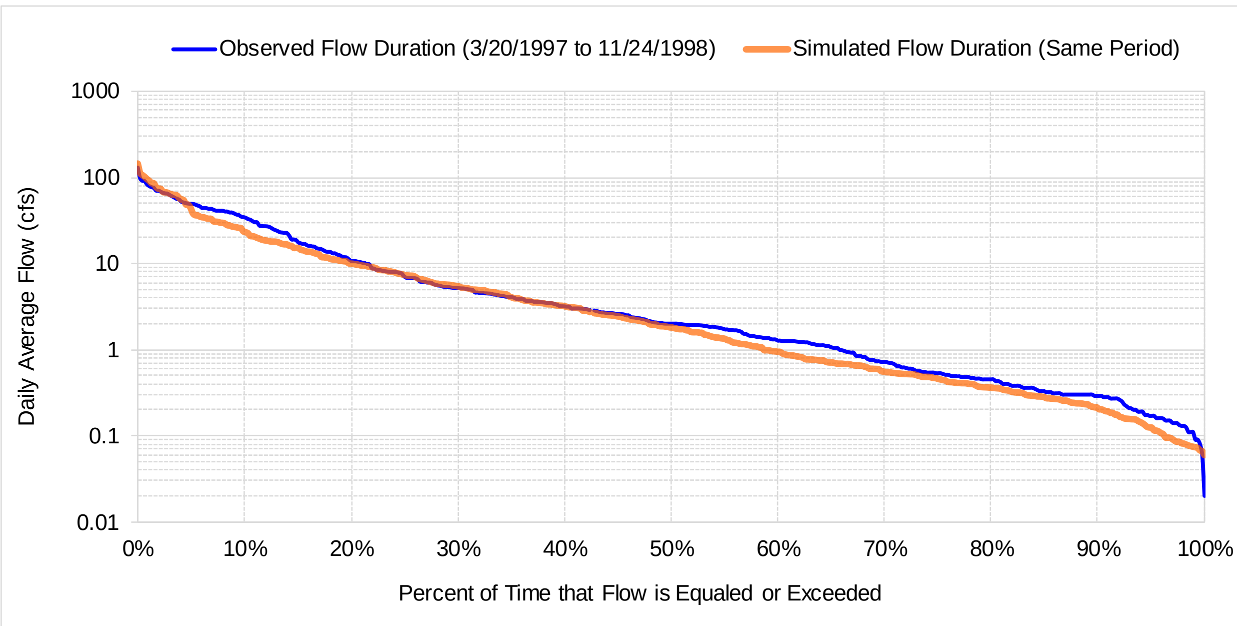


Figure B-27. Flow exceedance

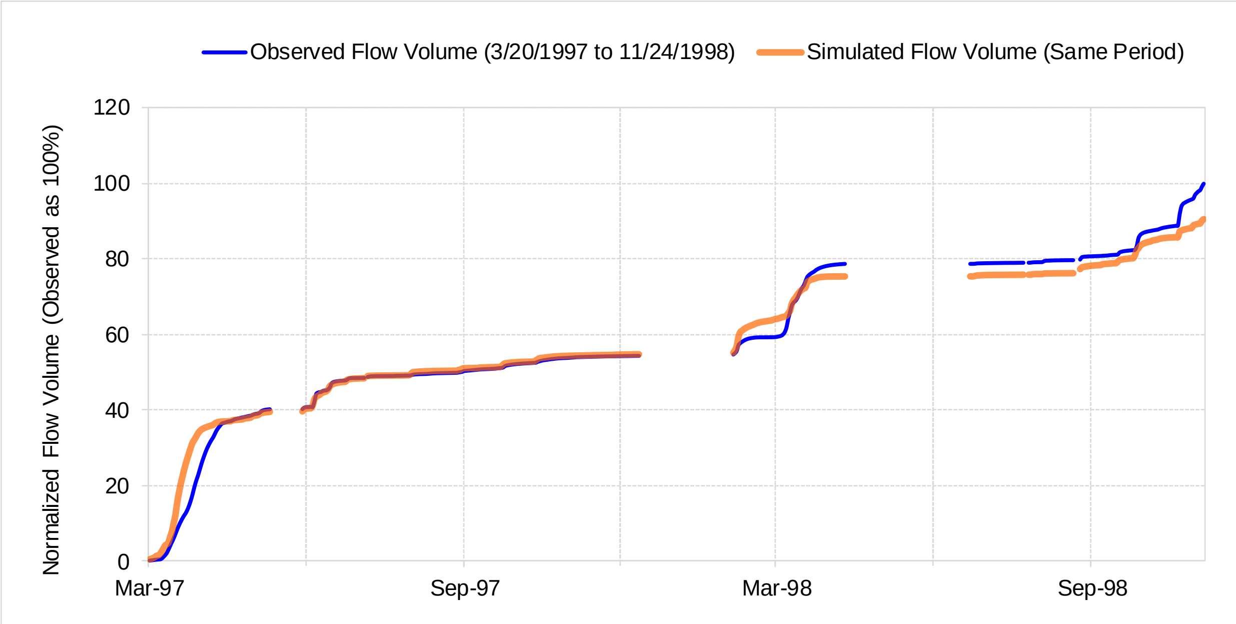


Figure B-28. Flow accumulation

Table B-8. Summary statistics

Miller Creek Upper Site, Miller Hill Mall (ID - 03-001-002)
Drainage Area (sq-mi): 6.26
Analysis Period: 3/20/1997 to 11/24/1998

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	15.47	14.01	-9.42	10
Total lowest 50% flows	0.62	0.47	-23.67	10
Total highest 10% flows	9.14	8.70	-4.90	15
Summer flow volume (months 7-9)	1.22	1.53	25.11	30
Fall flow volume (months 10-12)	3.49	2.36	-32.32	30
Winter flow volume (months 1-3)	2.71	3.07	13.12 >>	30
Spring flow volume (months 4-6)	8.05	7.06	-12.35	30
Total storm volume	5.21	5.23	0.38	20
Summer storm volume (7-9)	0.67	0.93	38.84	50
Baseflow	10.26	8.78	-14.41	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.331	0.7
Baseline adjusted coefficient (Garrick), E'			0.440	0.5
Monthly NSE			0.921	0.85

B.5 SAFL 03-001-003 Miller Creek Middle Site at Chambersburg Street

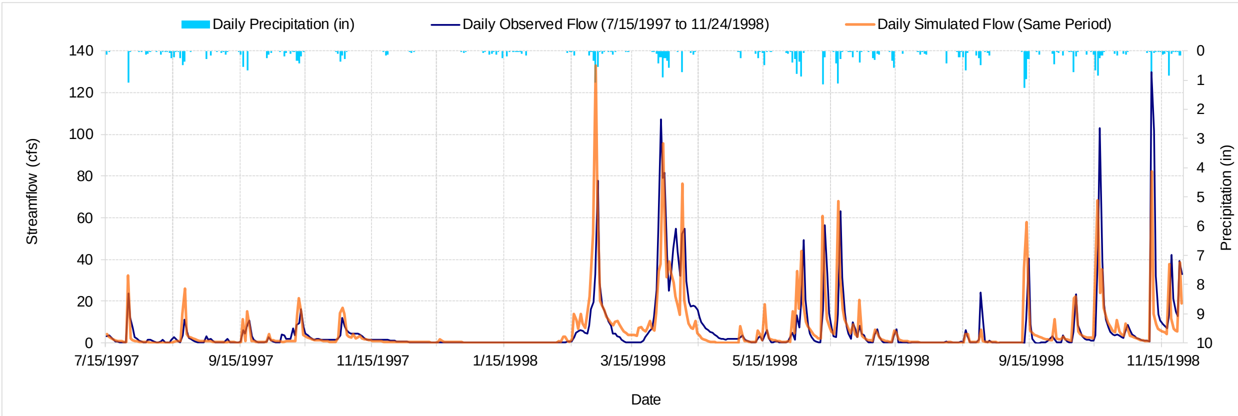


Figure B-29. Mean daily streamflow

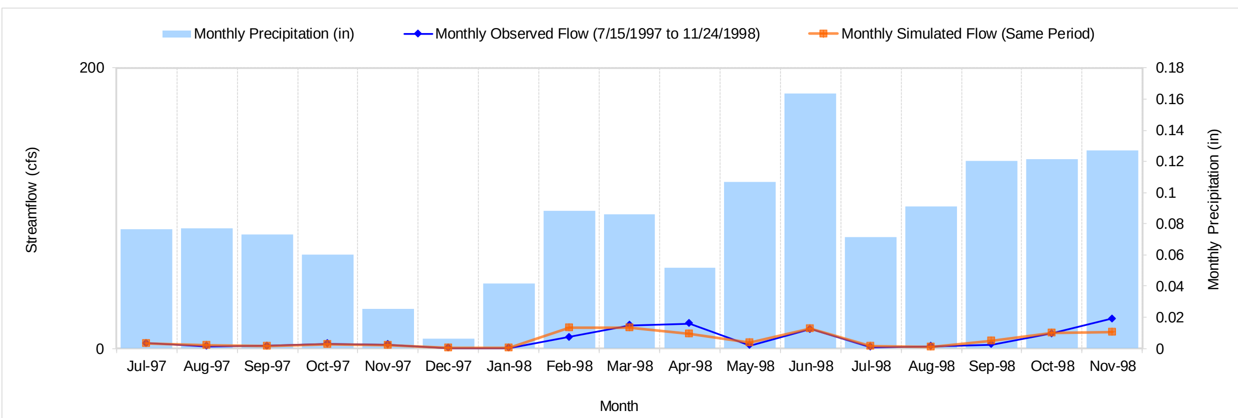


Figure B-30. Mean monthly streamflow

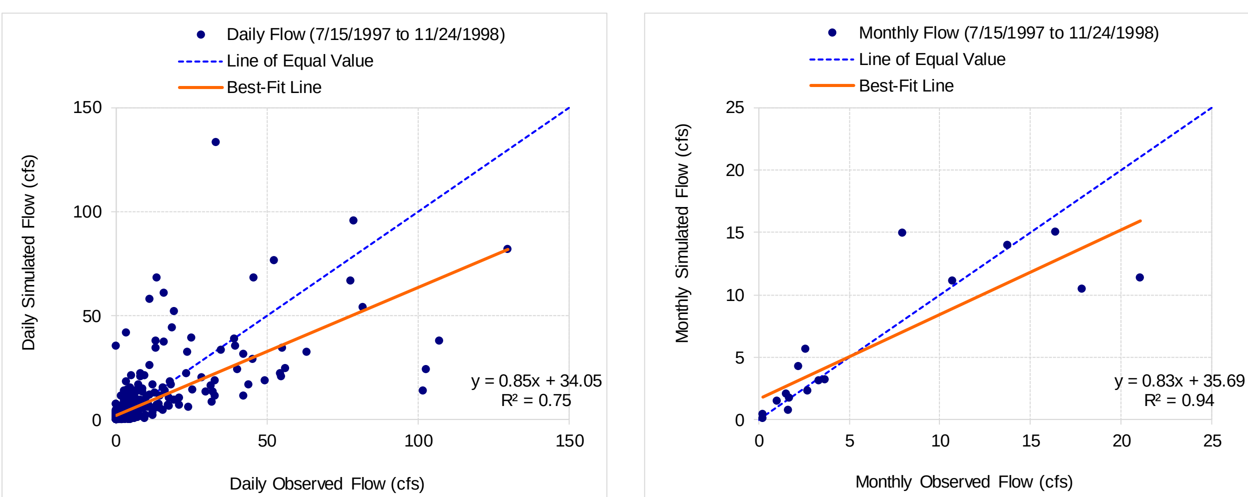
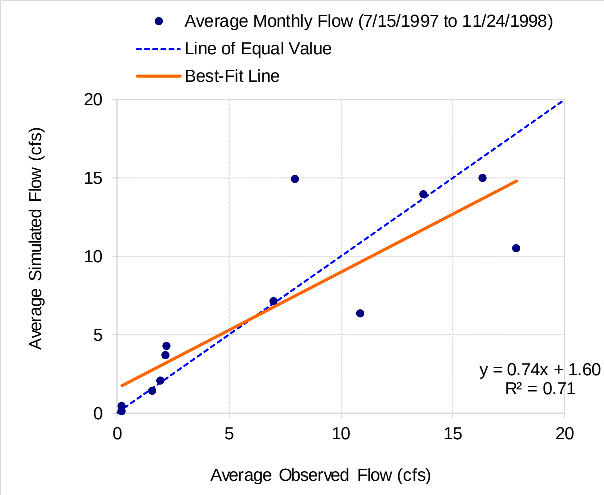


Figure B-31. Daily (left) and monthly (right) streamflow scatterplot



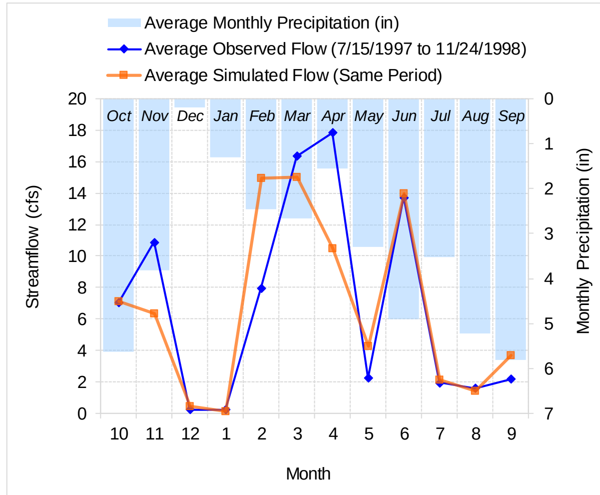


Figure B-32. Seasonal scatterplot (left) and temporal aggregate (right)

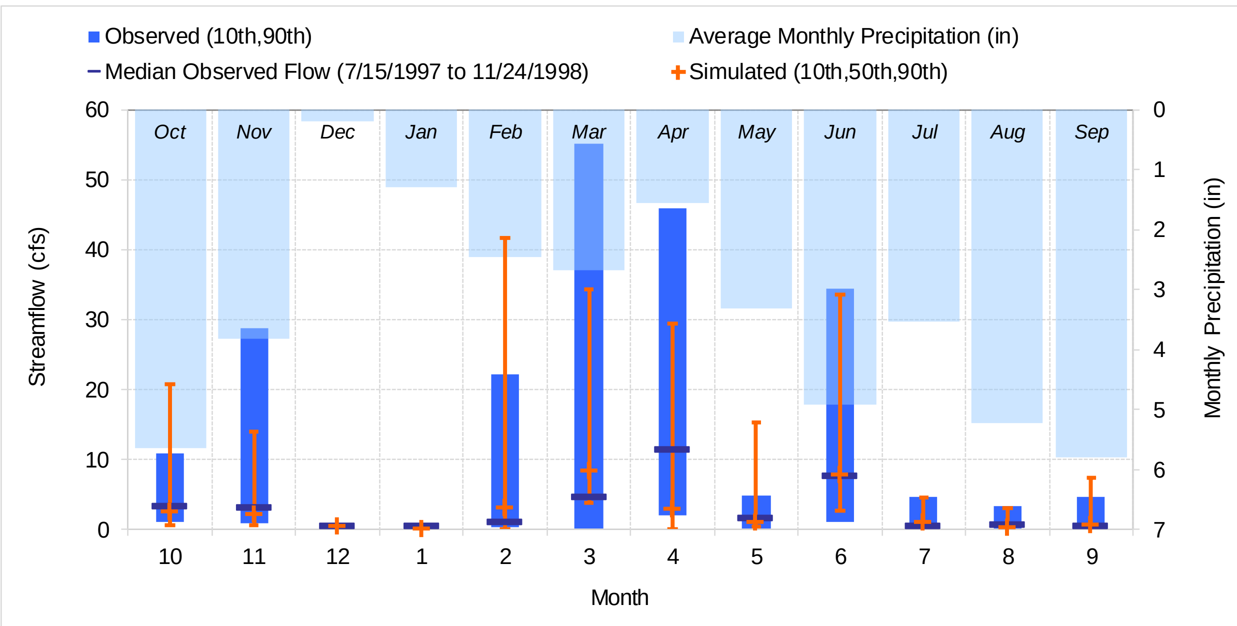


Figure B-33. Monthly medians and ranges

Table B-9. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	7.02	3.14	1.04	10.98	7.12	2.58	0.70	20.85
Nov	10.89	2.80	0.90	28.73	6.36	2.13	0.54	14.08
Dec	0.21	0.21	0.12	0.28	0.44	0.36	0.24	0.58
Jan	0.22	0.23	0.15	0.27	0.11	0.10	0.07	0.16
Feb	7.97	0.72	0.28	22.16	14.96	3.15	0.06	41.73
Mar	16.36	4.47	0.18	55.09	15.04	8.34	3.83	34.40
Apr	17.85	11.14	1.96	45.90	10.50	2.88	0.09	29.36
May	2.22	1.33	0.11	4.85	4.28	0.93	0.38	15.30
Jun	13.73	7.37	1.14	34.40	14.00	7.83	2.78	33.60
Jul	1.95	0.25	0.12	4.70	2.09	0.99	0.23	4.54
Aug	1.60	0.36	0.13	3.37	1.42	0.32	0.09	3.08
Sep	2.16	0.26	0.12	4.72	3.70	0.65	0.12	7.44

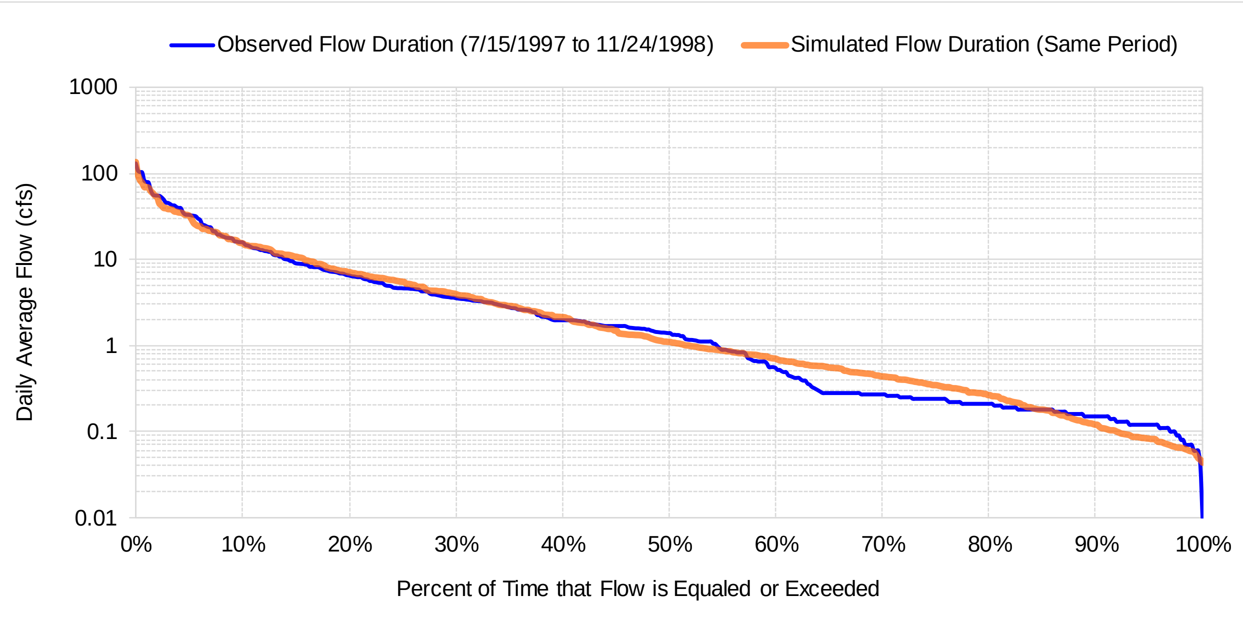


Figure B-34. Flow exceedance

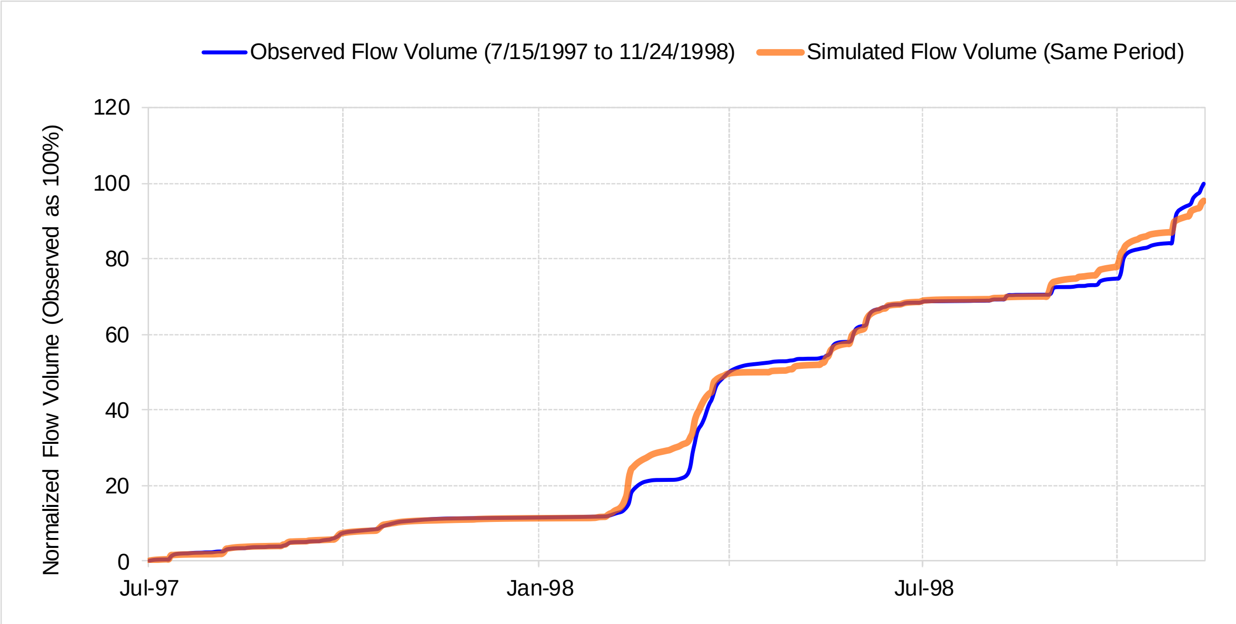


Figure B-35. Flow accumulation

Table B-10. Summary statistics

Miller Creek at Chambersburg St. Duluth (ID - 03-001-003)
Drainage Area (sq-mi): 7.61
Analysis Period: 7/15/1997 to 11/24/1998

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	11.15	10.65	-4.55	10
Total lowest 50% flows	0.32	0.36	12.44	10
Total highest 10% flows	7.36	6.59	-10.44	15
Summer flow volume (months 7-9)	1.16	1.47	27.20	30
Fall flow volume (months 10-12)	3.70	2.87	-22.49	30
Winter flow volume (months 1-3)	2.65	3.19	20.51 >>	30
Spring flow volume (months 4-6)	3.65	3.12	-14.63	30
Total storm volume	5.19	5.24	0.86	20
Summer storm volume (7-9)	0.81	0.92	13.88	50
Baseflow	5.96	5.41	-9.27	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.427	0.7
Baseline adjusted coefficient (Garrick), E'			0.459	0.5
Monthly NSE			0.739	0.85

B.6 SAFL 03-001-001 Miller Creek Lower Site at 26th Ave

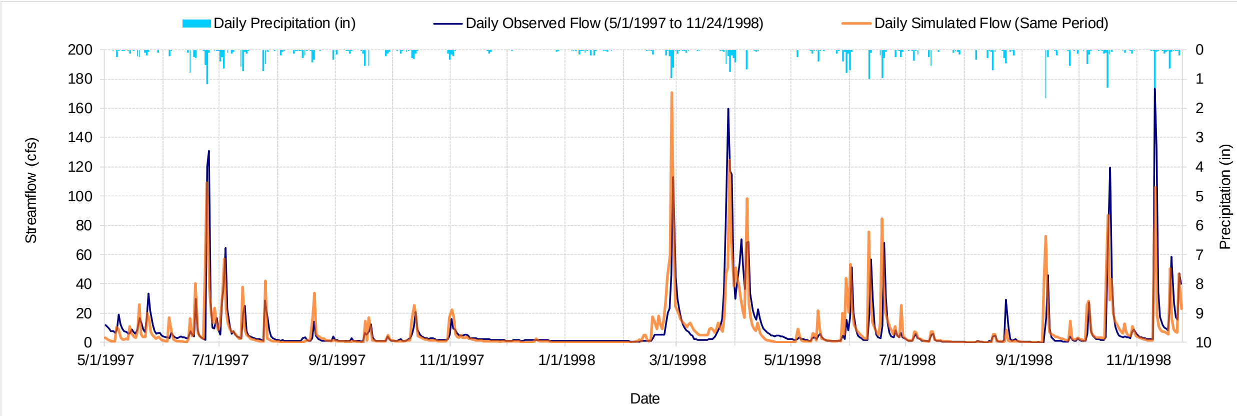


Figure B-36. Mean daily streamflow

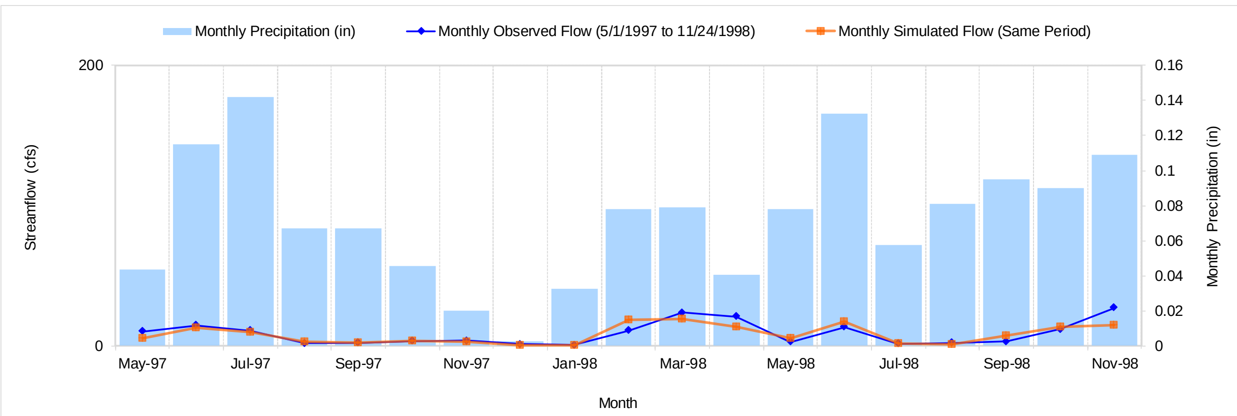


Figure B-37. Mean monthly streamflow

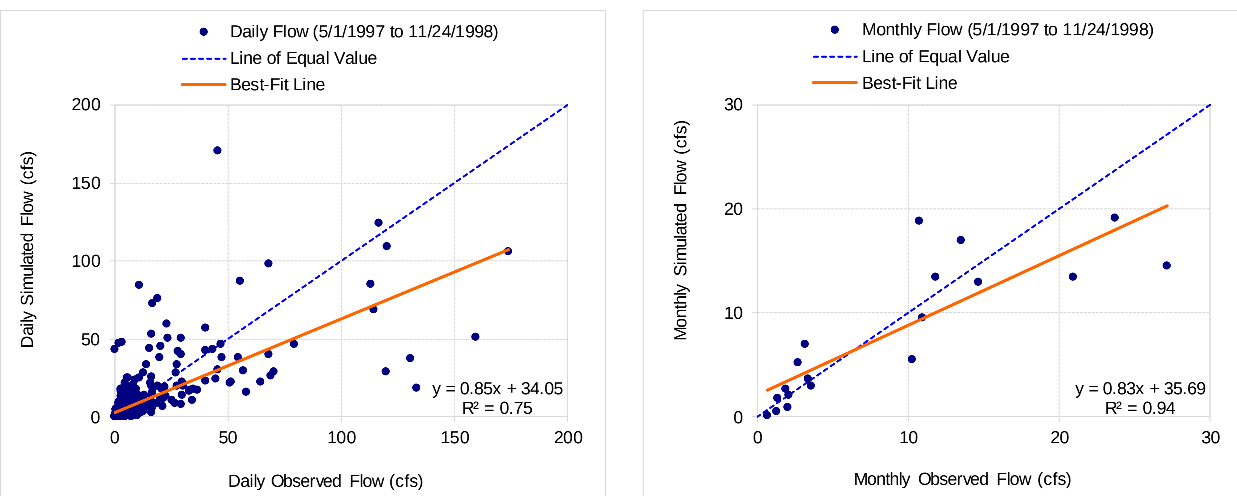


Figure B-38. Daily (left) and monthly (right) streamflow scatterplot

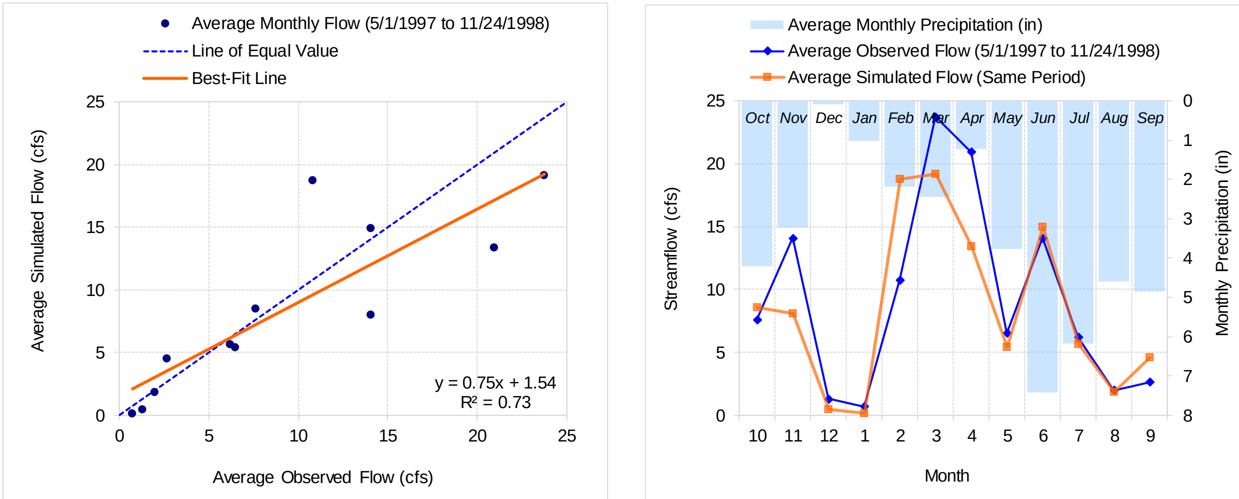


Figure B-39. Seasonal scatterplot (left) and temporal aggregate (right)

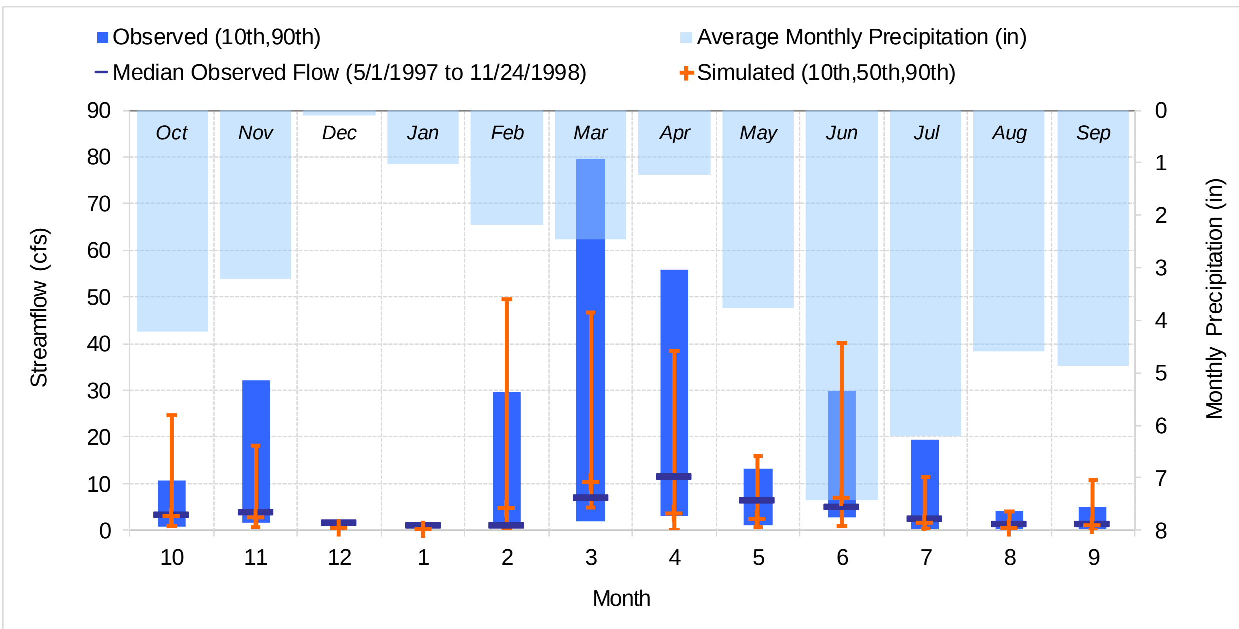


Figure B-40. Monthly medians and ranges

Table B-11. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	7.63	2.81	0.92	10.79	8.56	3.03	0.87	24.62
Nov	14.09	3.48	1.64	32.04	8.07	2.57	0.58	18.28
Dec	1.28	1.30	0.93	1.56	0.49	0.40	0.26	0.60
Jan	0.70	0.70	0.70	0.70	0.12	0.11	0.08	0.17
Feb	10.79	0.70	0.50	29.59	18.81	4.74	0.07	49.45
Mar	23.73	6.69	1.80	79.45	19.16	10.36	5.02	46.69
Apr	20.96	11.02	3.08	55.81	13.44	3.55	0.10	38.54
May	6.51	5.93	0.97	13.12	5.41	2.41	0.56	15.77
Jun	14.09	4.68	2.74	29.97	14.98	6.76	0.80	40.16
Jul	6.18	2.15	0.31	19.50	5.66	1.58	0.34	11.34
Aug	1.99	0.89	0.08	4.07	1.83	0.41	0.11	4.00
Sep	2.65	0.87	0.11	5.04	4.56	0.82	0.15	10.90

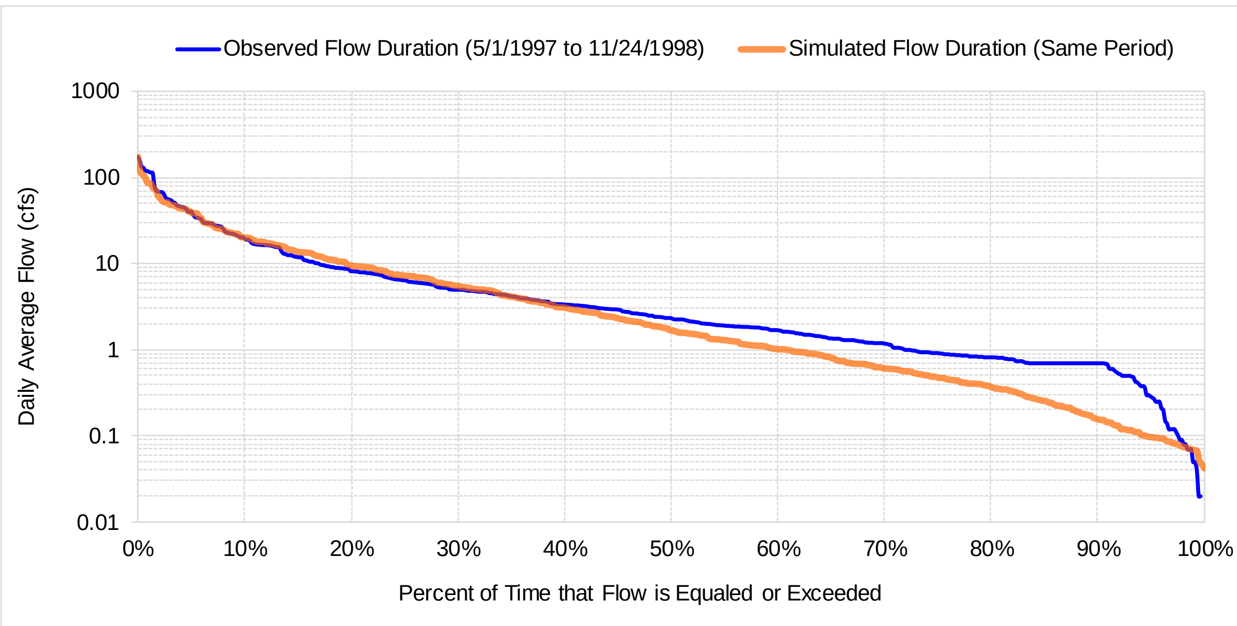


Figure B-41. Flow exceedance

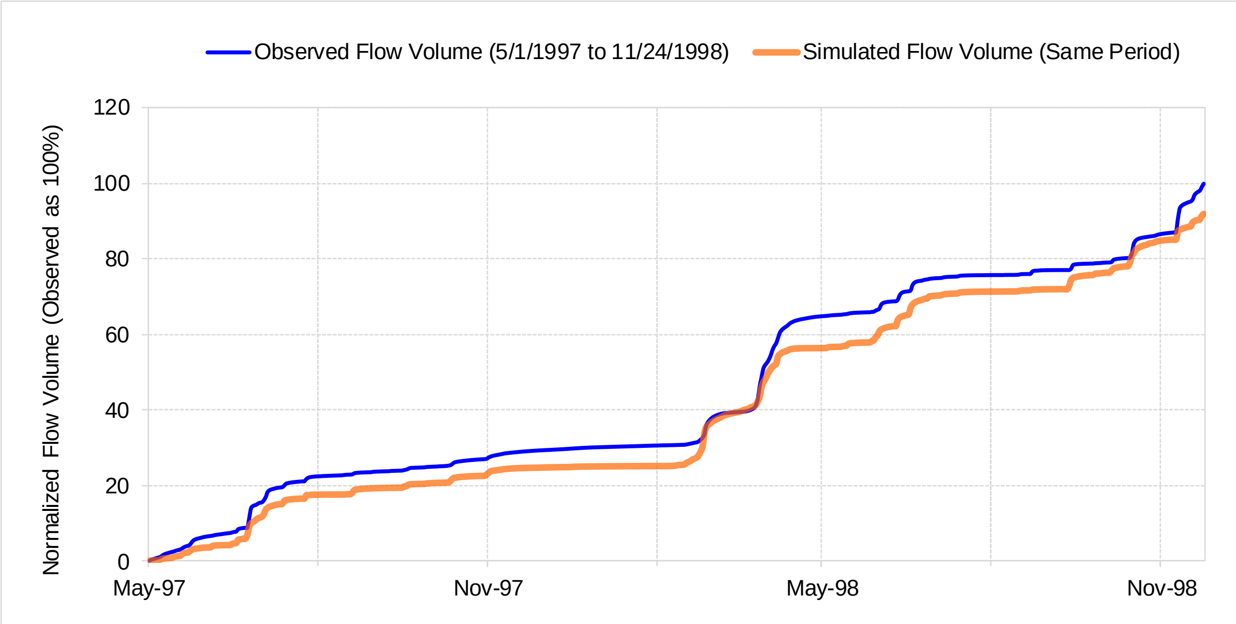


Figure B-42. Flow accumulation

Table B-12. Summary statistics

Miller Creek Lower Site at 26th St. Duluth (ID - 03-001-001)
Drainage Area (sq-mi): 9.9
Analysis Period: 5/1/1997 to 11/24/1998

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	11.69	10.75	-8.08	10
Total lowest 50% flows	0.73	0.40	-45.17	10
Total highest 10% flows	7.33	6.47	-11.64	15
Summer flow volume (months 7-9)	1.60	1.77	11.00	30
Fall flow volume (months 10-12)	3.05	2.35	-22.91	30
Winter flow volume (months 1-3)	2.54	2.70	6.13 >>	30
Spring flow volume (months 4-6)	4.50	3.93	-12.81	30
Total storm volume	5.44	5.50	1.11	20
Summer storm volume (7-9)	0.90	1.06	18.34	50
Baseflow	6.25	5.24	-16.09	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.469	0.7
Baseline adjusted coefficient (Garrick), E'			0.447	0.5
Monthly NSE			0.714	0.85

B.7 Duluth Streams S004-952 Kingsbury Creek at Lake Superior Zoo

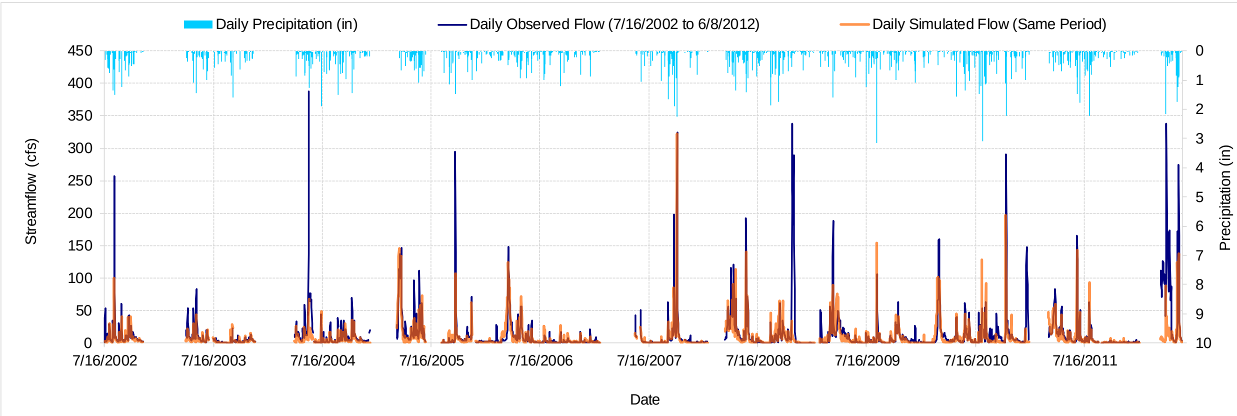


Figure B-43. Mean daily streamflow

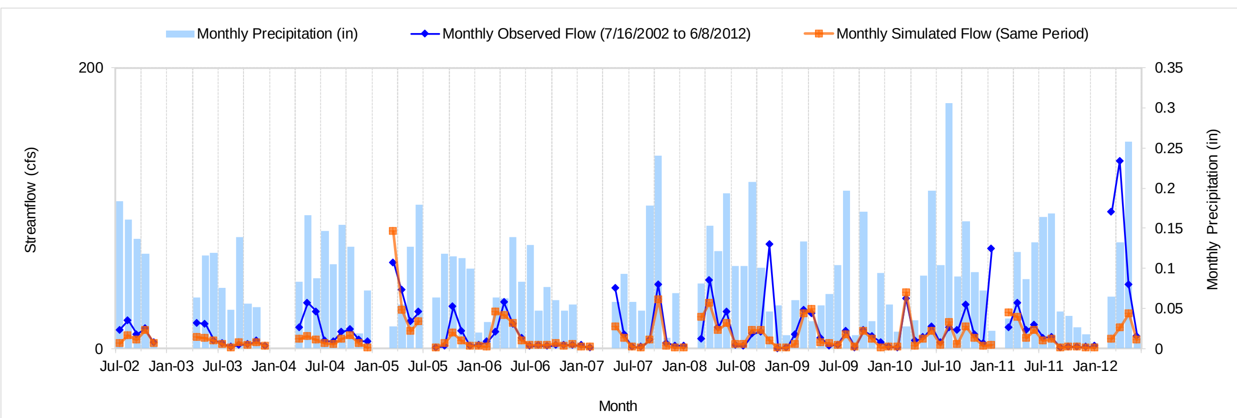


Figure B-44. Mean monthly streamflow

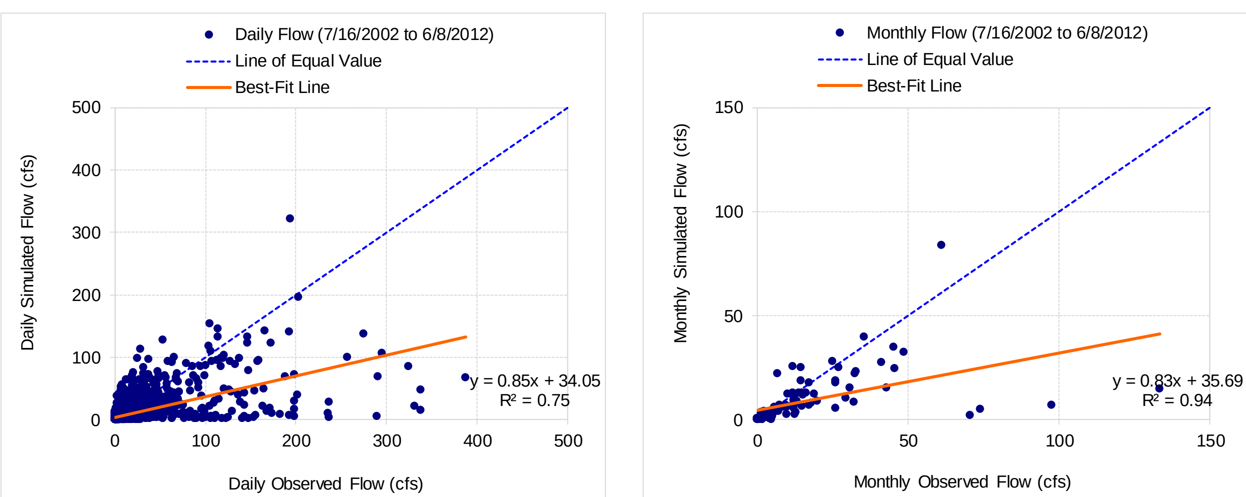
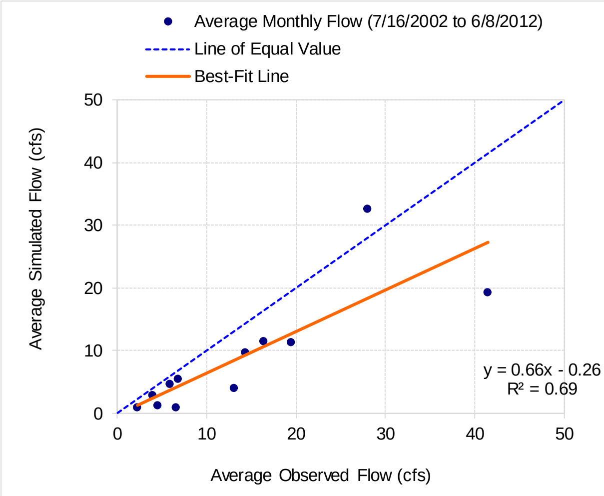


Figure B-45. Daily (left) and monthly (right) streamflow scatterplot



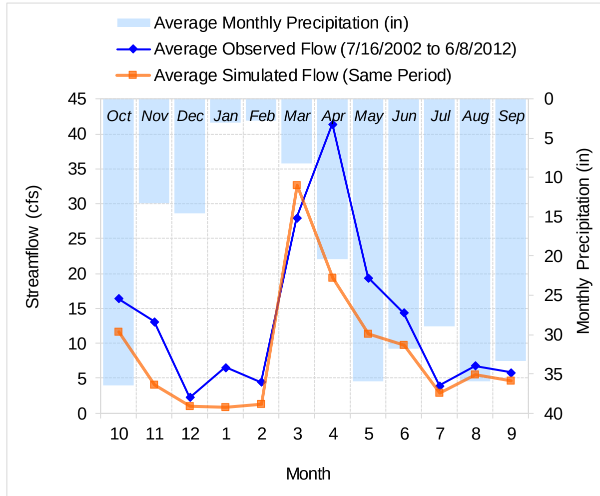


Figure B-46. Seasonal scatterplot (left) and temporal aggregate (right)

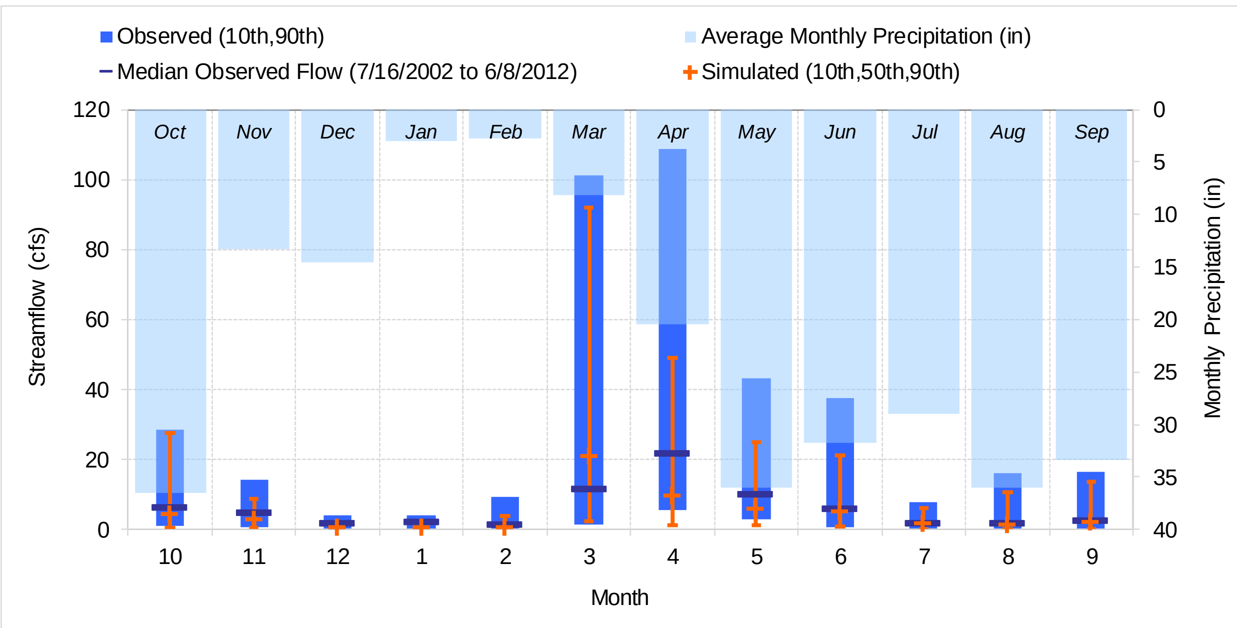


Figure B-47. Monthly medians and ranges

Table B-13. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	16.44	5.66	0.88	28.58	11.57	4.16	0.55	27.64
Nov	13.10	4.43	0.70	14.17	4.11	2.58	0.62	8.84
Dec	2.26	1.34	0.06	4.10	0.99	0.57	0.12	1.93
Jan	6.56	1.58	0.23	4.25	0.89	0.53	0.10	1.96
Feb	4.48	0.72	0.27	9.41	1.25	0.61	0.13	4.05
Mar	28.04	11.09	1.32	101.11	32.58	20.80	2.38	92.15
Apr	41.41	21.03	5.64	108.86	19.35	9.63	1.39	49.24
May	19.41	9.53	2.87	43.27	11.33	5.70	1.09	25.14
Jun	14.34	5.20	0.75	37.51	9.74	4.93	0.95	21.32
Jul	3.93	1.29	0.21	8.01	2.90	1.45	0.25	6.22
Aug	6.81	1.08	0.13	16.06	5.53	1.21	0.11	10.60
Sep	5.86	1.89	0.15	16.61	4.66	1.98	0.13	13.50

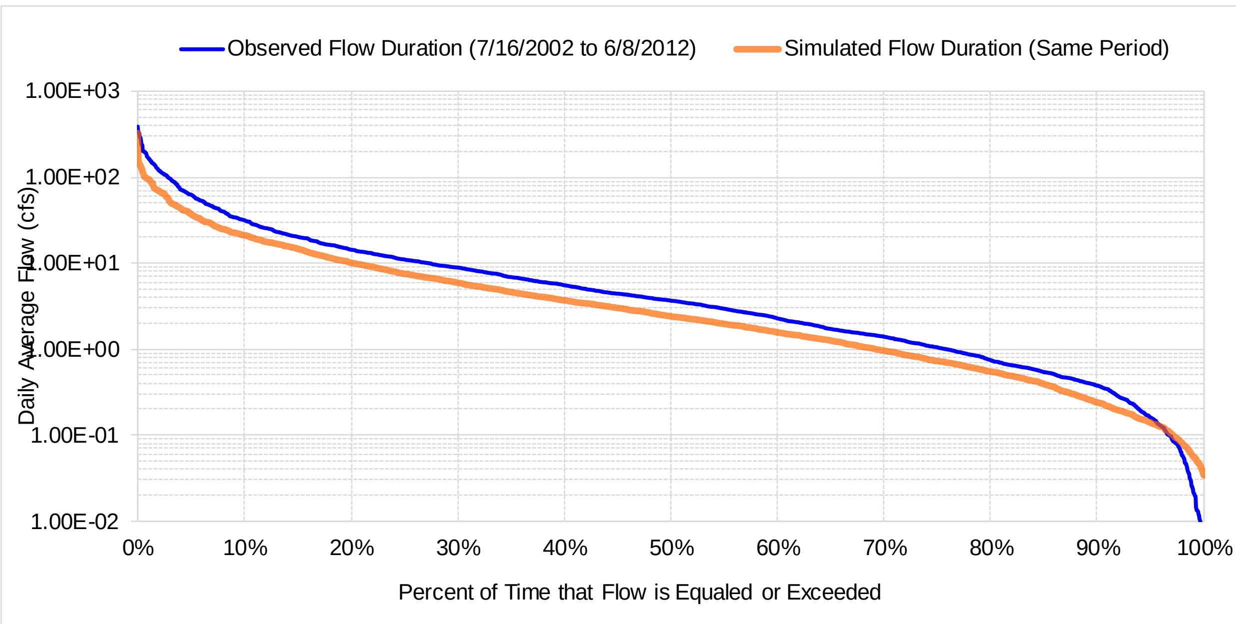


Figure B-48. Flow exceedance

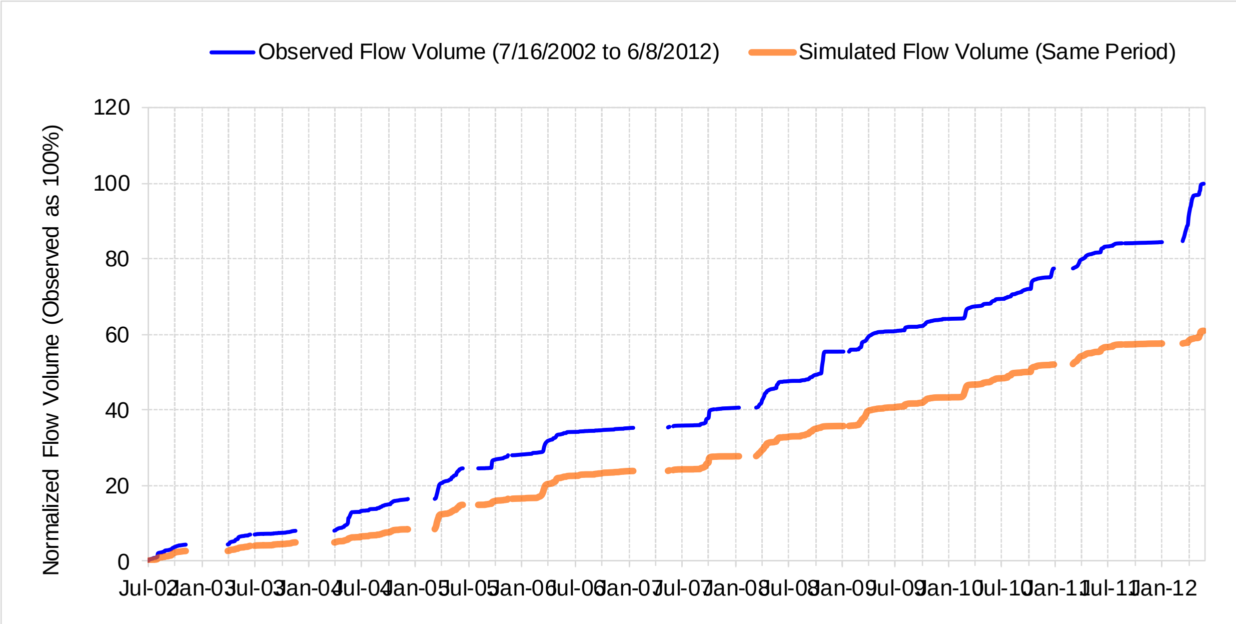


Figure B-49. Flow accumulation

Table B-14. Summary statistics

Kingsbury Creek at Lake Superior Zoo in Duluth (ID - S004-952)
Drainage Area (sq-mi): 9.39
Analysis Period: 7/16/2002 to 6/8/2012

Constituent	***Observed (in/yr)***	***Simulated (in/yr)***	***Error (Sim-Obs)***	***Recommended***
Total flow	15.18	9.28	-38.89	10
Total lowest 50% flows	0.72	0.50	-31.61	10
Total highest 10% flows	9.57	5.44	-43.20	15
Summer flow volume (months 7-9)	1.83	1.45	-20.97	30
Fall flow volume (months 10-12)	3.70	1.97	-46.73	30
Winter flow volume (months 1-3)	1.96	1.70	-13.00 >>	30
Spring flow volume (months 4-6)	7.69	4.15	-45.97	30
Total storm volume	5.68	3.61	-36.42	20
Summer storm volume (7-9)	1.03	0.78	-24.04	50
Baseflow	9.50	5.66	-40.37	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.334	0.7
Baseline adjusted coefficient (Garrick), E'			0.469	0.5
Monthly NSE			0.274	0.85

Appendix C Detailed Flow Validation Results

C.1 HYDSTRA 02037005 EAST BRANCH AMITY CREEK, 1.8 MI D/S OF CSAH37

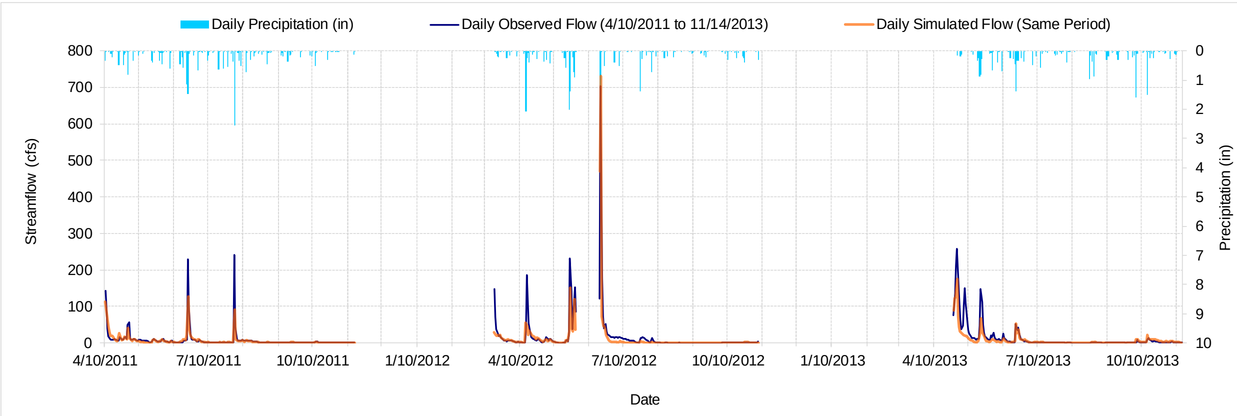


Figure C-1. Mean daily streamflow

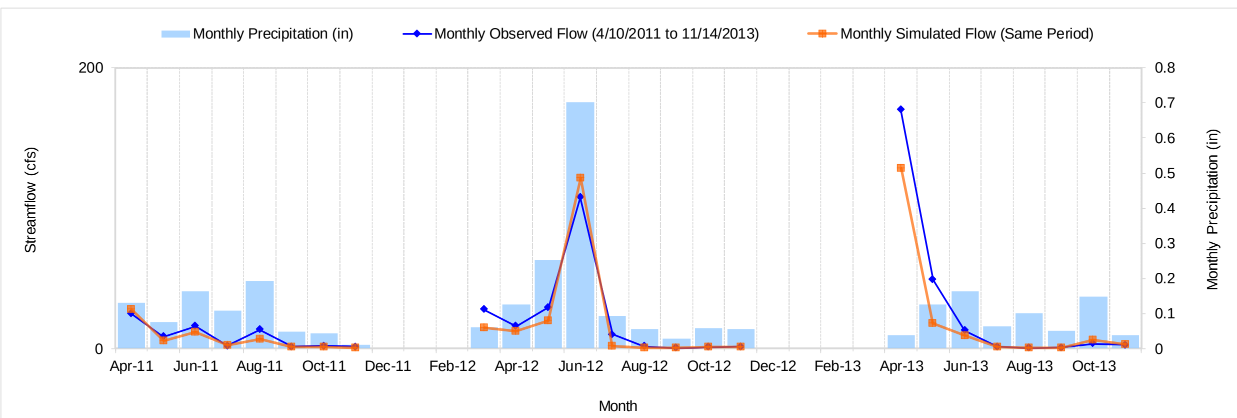


Figure C-2. Mean monthly streamflow

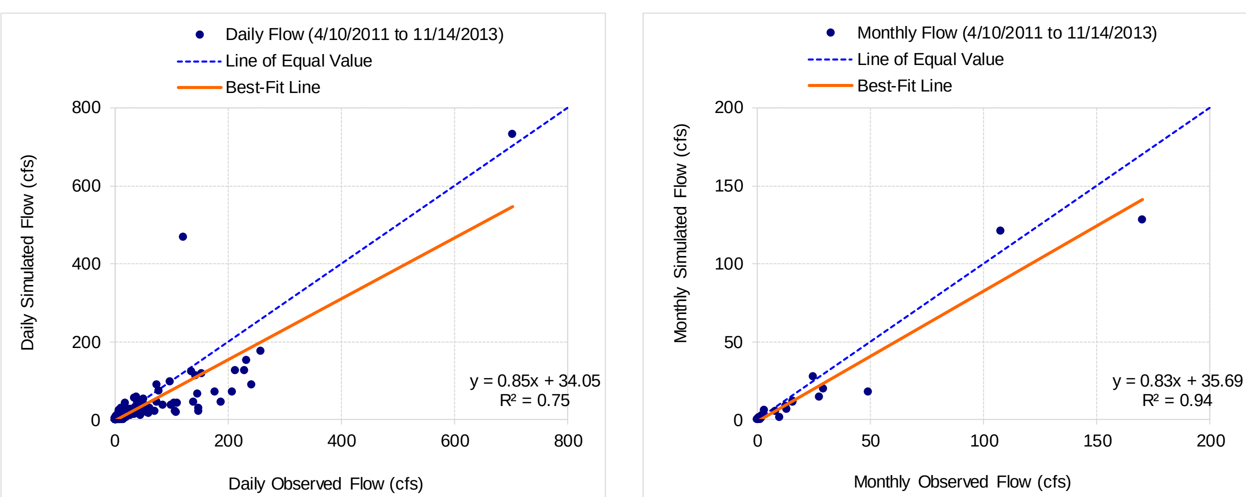


Figure C-3. Daily (left) and monthly (right) streamflow scatterplot

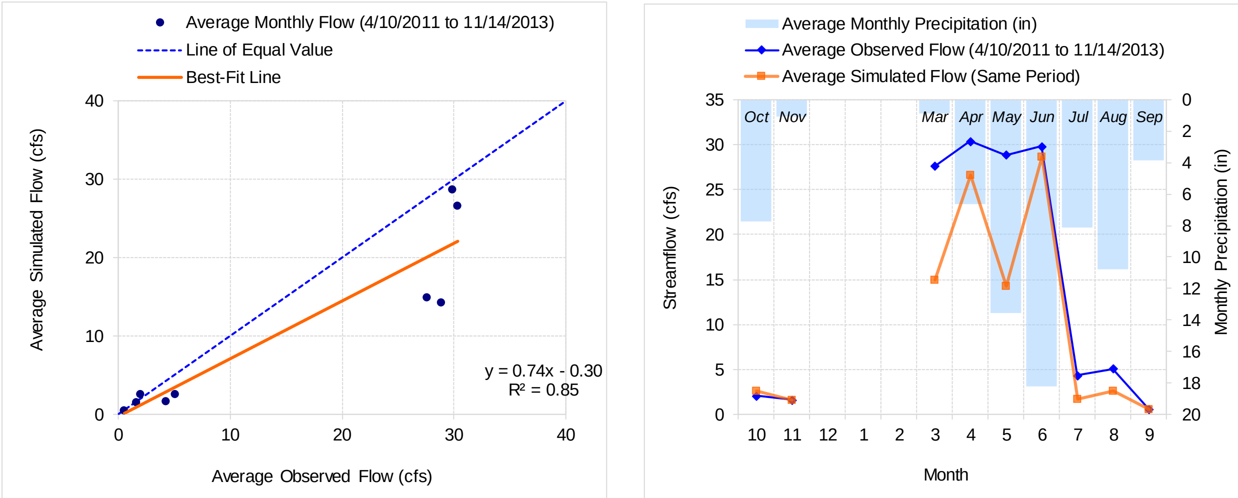


Figure C-4. Seasonal scatterplot (left) and temporal aggregate (right)

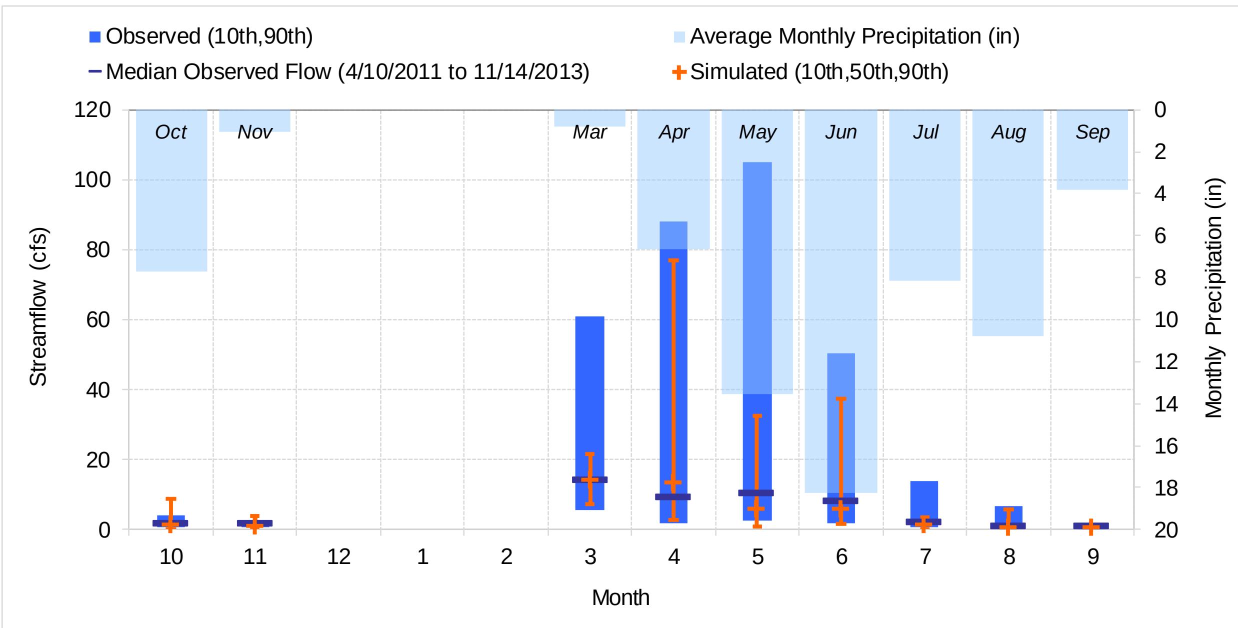


Figure C-5. Monthly medians and ranges

Table C-1. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	2.03	1.40	0.76	4.10	2.59	1.06	0.27	8.61
Nov	1.58	1.20	0.71	2.60	1.53	0.75	0.25	3.96
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	27.61	13.50	5.70	60.80	14.89	14.20	7.08	21.69
Apr	30.38	8.60	1.70	88.20	26.61	13.19	2.86	76.89
May	28.89	9.80	2.60	105.00	14.23	5.65	0.78	32.50
Jun	29.86	7.70	1.91	50.20	28.69	5.94	1.53	37.56
Jul	4.30	1.50	0.59	14.00	1.70	1.31	0.29	3.35
Aug	5.06	0.56	0.19	6.60	2.61	0.61	0.14	5.93
Sep	0.55	0.41	0.06	1.30	0.55	0.46	0.09	1.17

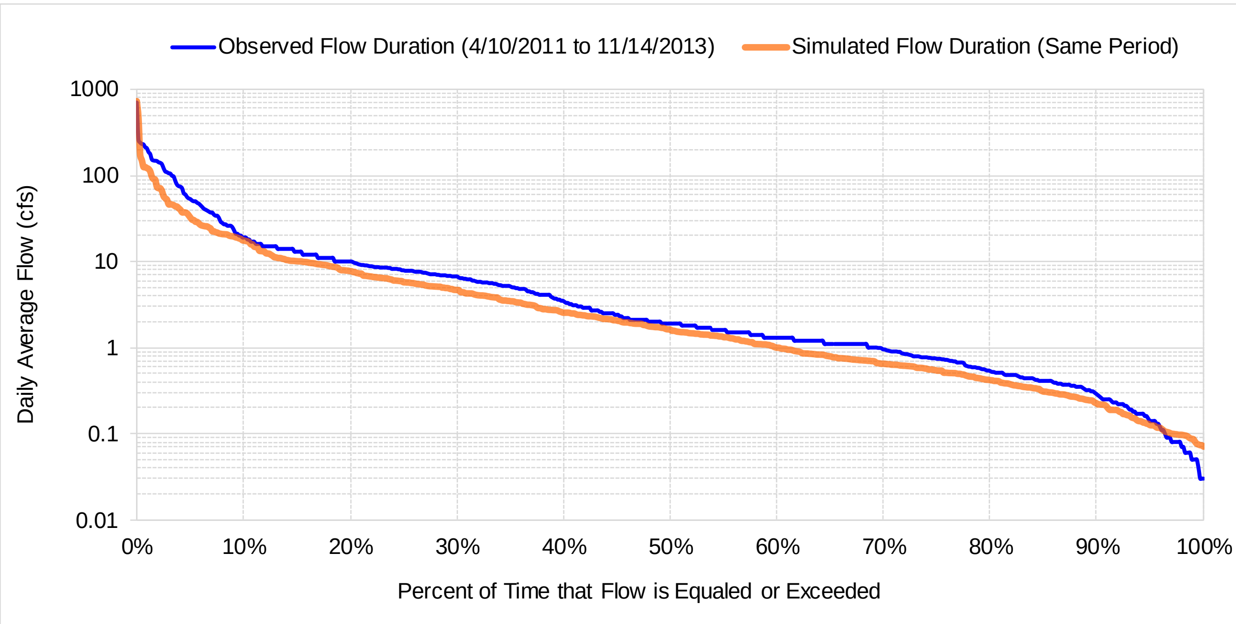


Figure C-6. Flow exceedance

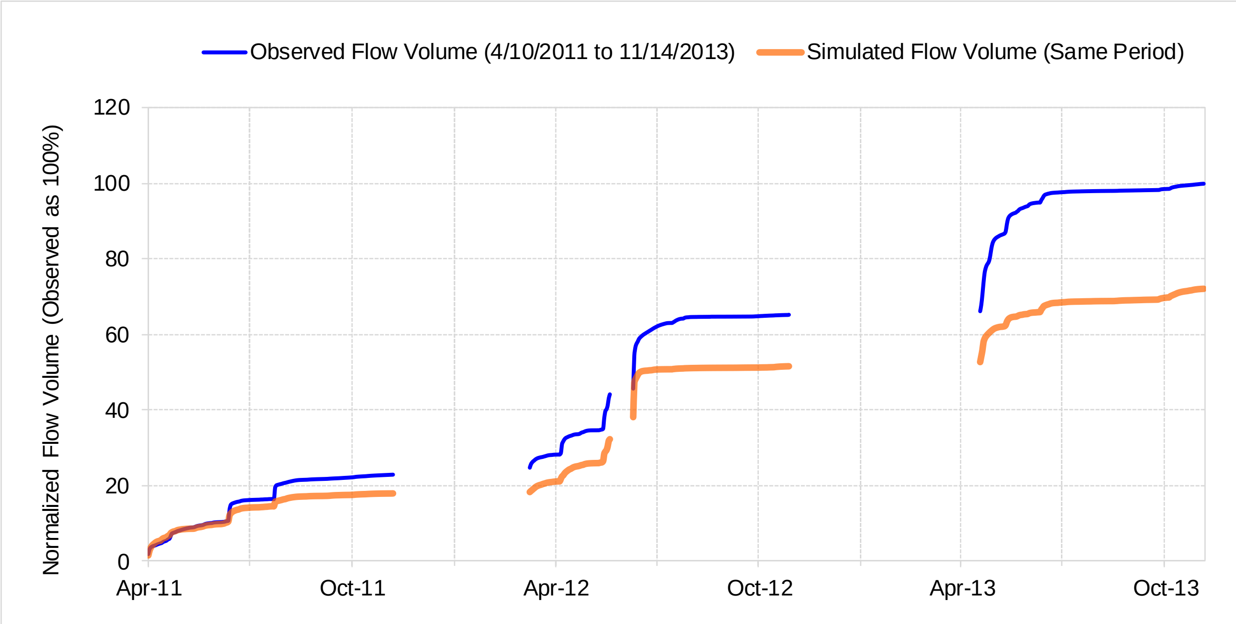


Figure C-7. Flow accumulation

Table C-2. Summary statistics

East Branch Amity Creek at Duluth (ID - 02038001)
Drainage Area (sq-mi): 8.18
Analysis Period: 4/10/2011 to 11/14/2013

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	14.00	10.11	-27.77	10
Total lowest 50% flows	0.45	0.35	-22.24	10
Total highest 10% flows	10.32	7.22	-30.02	15
Summer flow volume (months 7-9)	1.61	0.79	-51.03	30
Fall flow volume (months 10-12)	0.43	0.52	20.73	30
Winter flow volume (months 1-3)	0.68	0.36	-46.08 >>	30
Spring flow volume (months 4-6)	11.29	8.44	-25.20	30
Total storm volume	6.76	5.00	-26.07	20
Summer storm volume (7-9)	0.69	0.32	-54.19	50
Baseflow	7.24	5.11	-29.36	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.706	0.7
Baseline adjusted coefficient (Garrick), E'			0.626	0.5
Monthly NSE			0.683	0.85

C.2 HYDSTRA 02040008 Chester Creek at Duluth, W College St

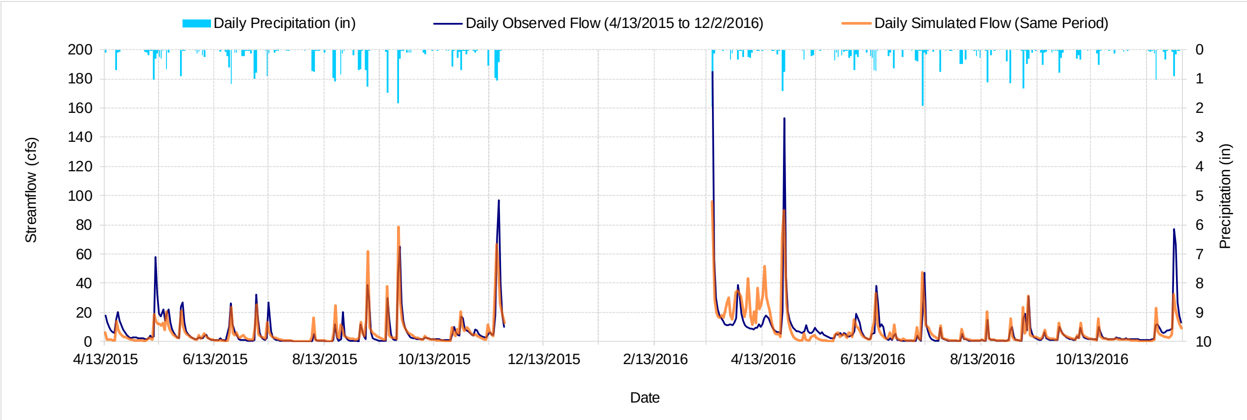


Figure C-8. Mean daily streamflow

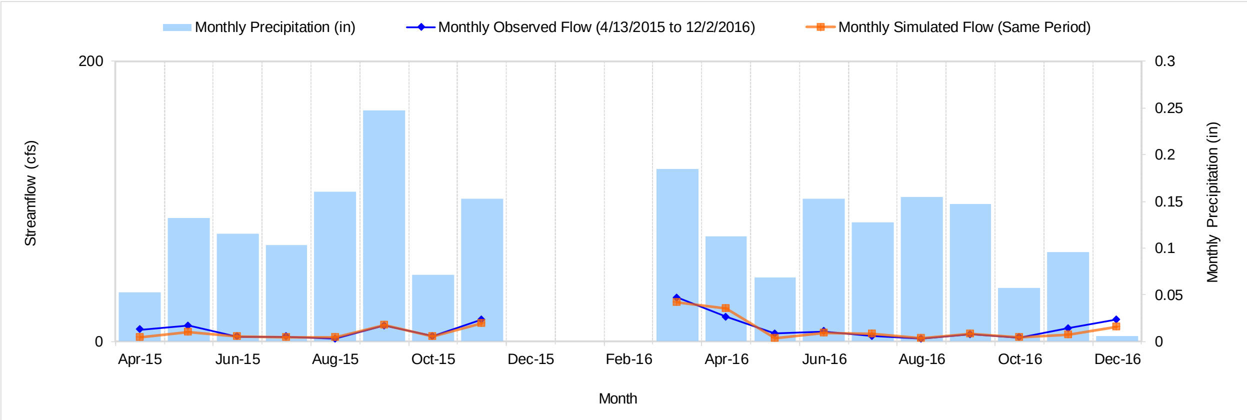


Figure C-9. Mean monthly streamflow

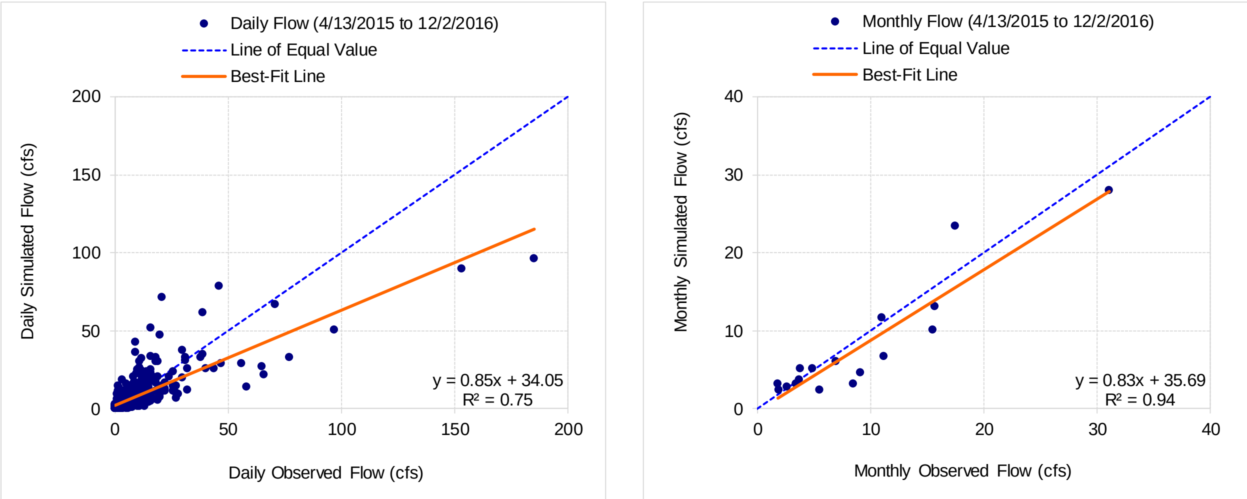


Figure C-10. Daily (left) and monthly (right) streamflow scatterplot

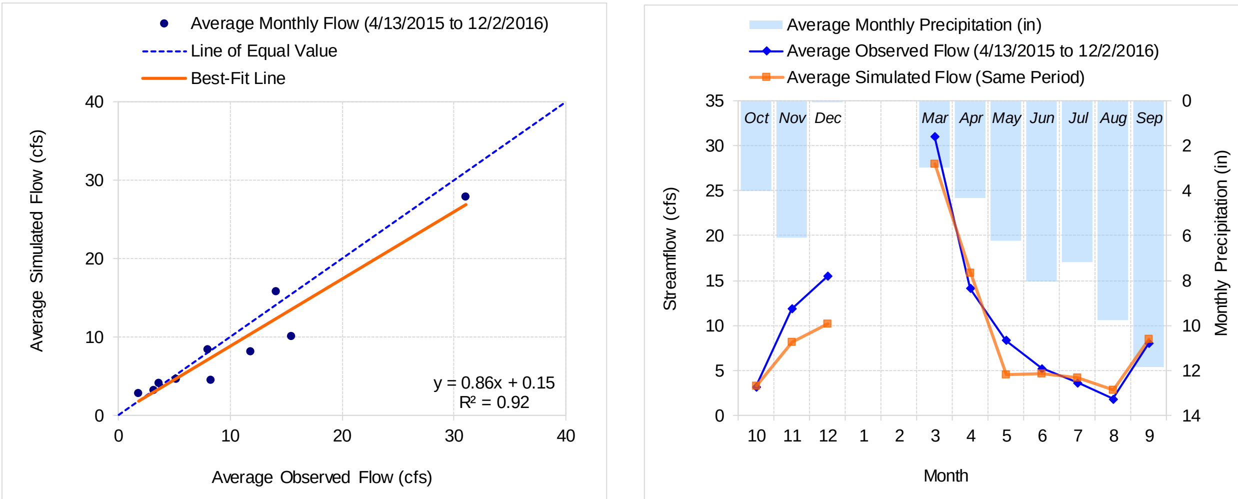


Figure C-11. Seasonal scatterplot (left) and temporal aggregate (right)

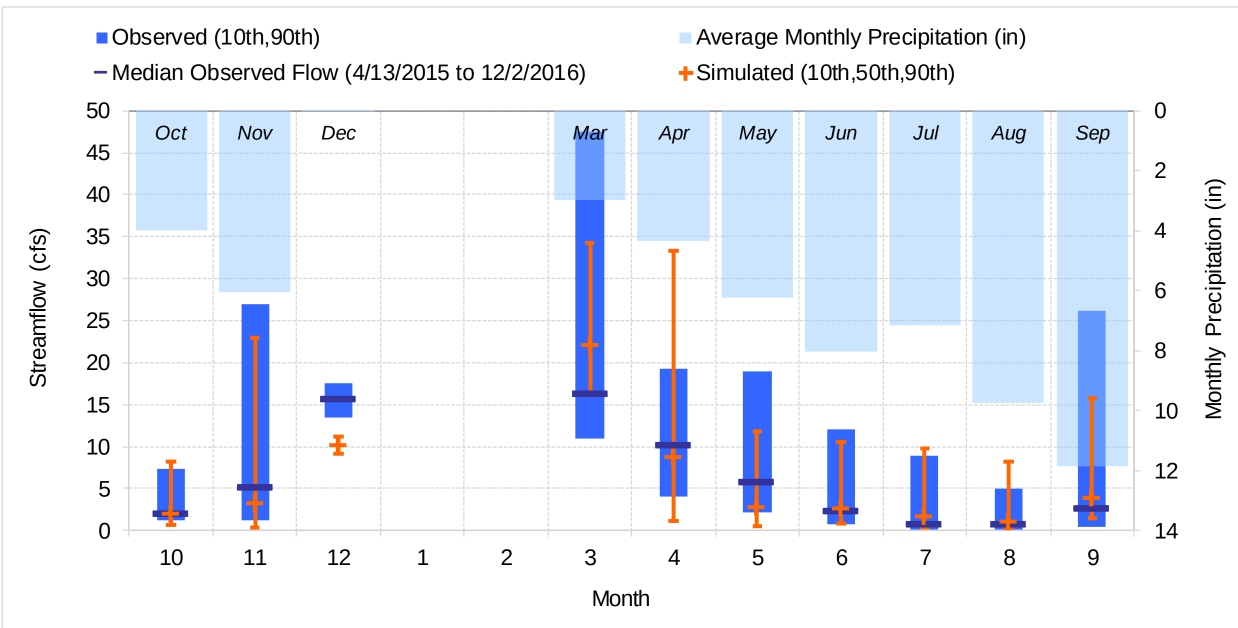


Figure C-12. Monthly medians and ranges

Table C-3. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	3.16	1.80	1.20	7.36	3.25	1.92	0.62	8.17
Nov	11.84	4.90	1.20	27.00	8.10	3.17	0.37	23.00
Dec	15.50	15.50	13.50	17.50	10.16	10.16	9.16	11.17
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	31.06	16.00	11.00	47.50	27.97	21.95	16.29	34.30
Apr	14.10	9.90	4.02	19.30	15.83	8.72	1.17	33.35
May	8.31	5.50	2.21	19.00	4.55	2.77	0.48	11.75
Jun	5.19	2.15	0.81	12.10	4.62	2.59	0.77	10.52
Jul	3.63	0.58	0.12	8.88	4.13	1.56	0.34	9.72
Aug	1.83	0.48	0.07	4.93	2.79	1.04	0.26	8.14
Sep	7.98	2.45	0.49	26.20	8.45	3.85	1.47	15.77

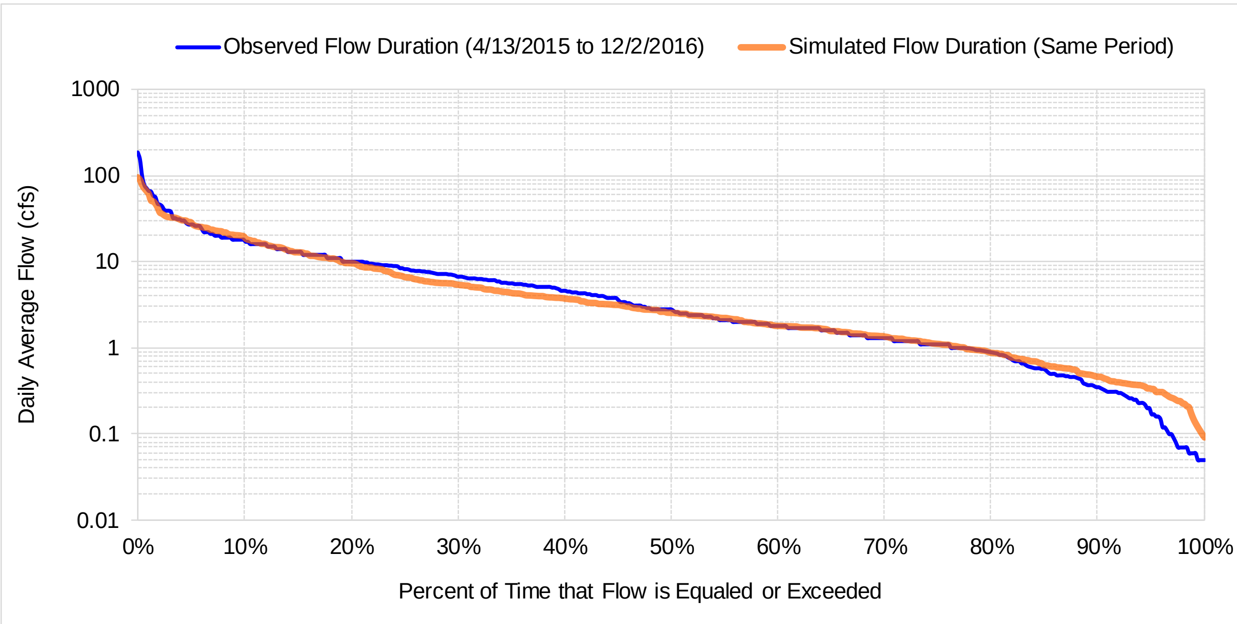


Figure C-13. Flow exceedance

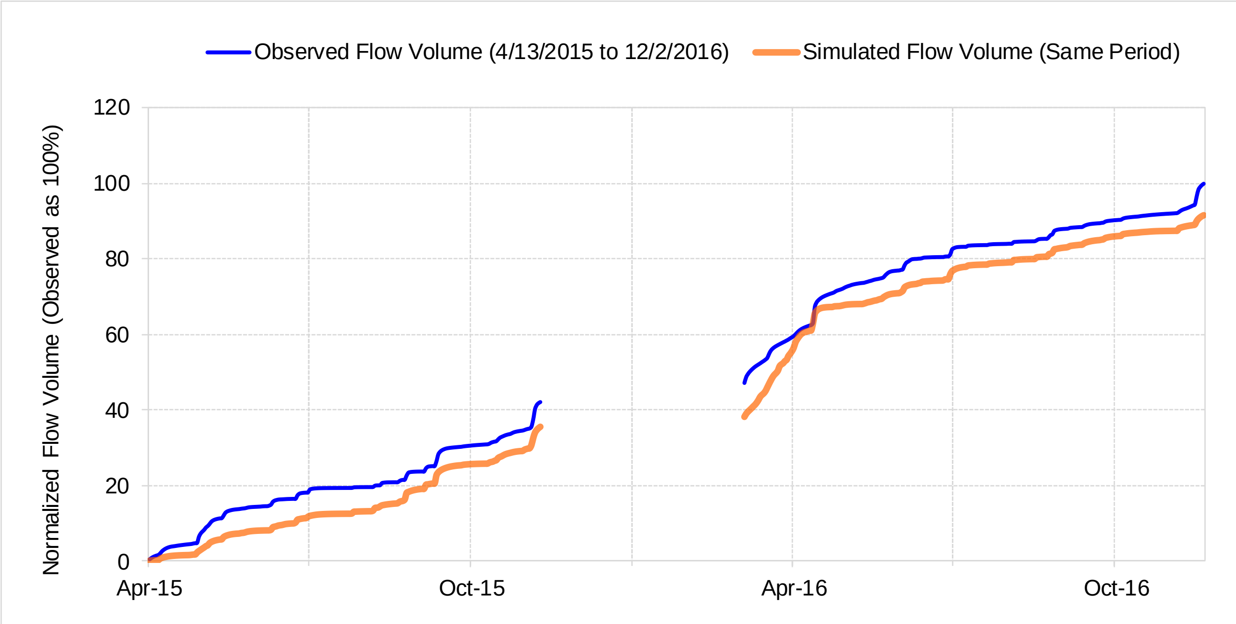


Figure C-14. Flow accumulation

Table C-4. Summary statistics

Chester Creek at W. College St. (ID - 02040008)
Drainage Area (sq-mi): 6.45
Analysis Period: 4/13/2015 to 12/2/2016

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	12.83	11.73	-8.53	10
Total lowest 50% flows	0.94	1.00	5.95	10
Total highest 10% flows	6.58	5.89	-10.42	15
Summer flow volume (months 7-9)	2.87	3.29	14.48	30
Fall flow volume (months 10-12)	2.92	2.23	-23.56	30
Winter flow volume (months 1-3)	1.75	1.57	-9.96 >>	30
Spring flow volume (months 4-6)	5.29	4.64	-12.25	30
Total storm volume	6.29	5.40	-14.19	20
Summer storm volume (7-9)	1.98	1.97	-0.14	50
Baseflow	6.54	6.34	-3.08	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.628	0.7
Baseline adjusted coefficient (Garrick), E'			0.458	0.5
Monthly NSE			0.736	0.85

C.3 HYDSTRA 03189016 KEENE CREEK AT DULUTH, S 57TH AVE W

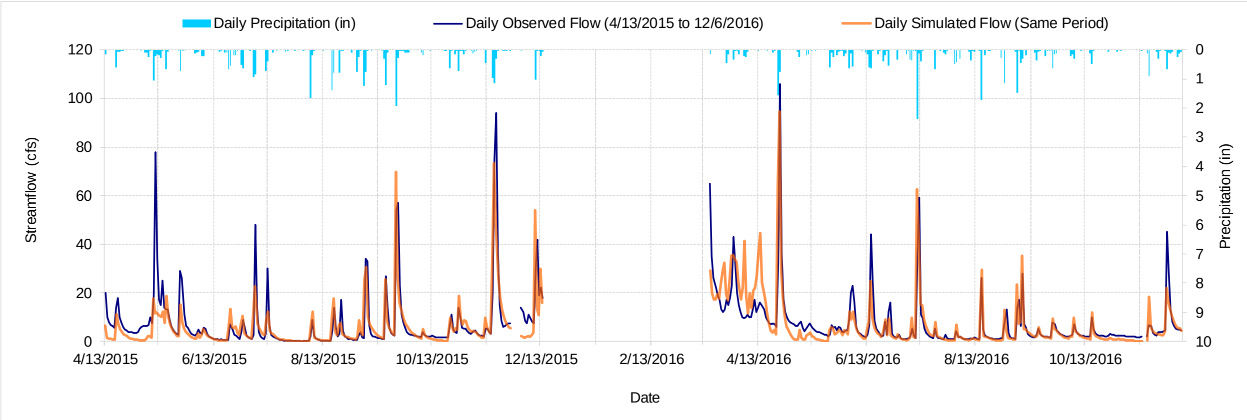


Figure C-15. Mean daily streamflow

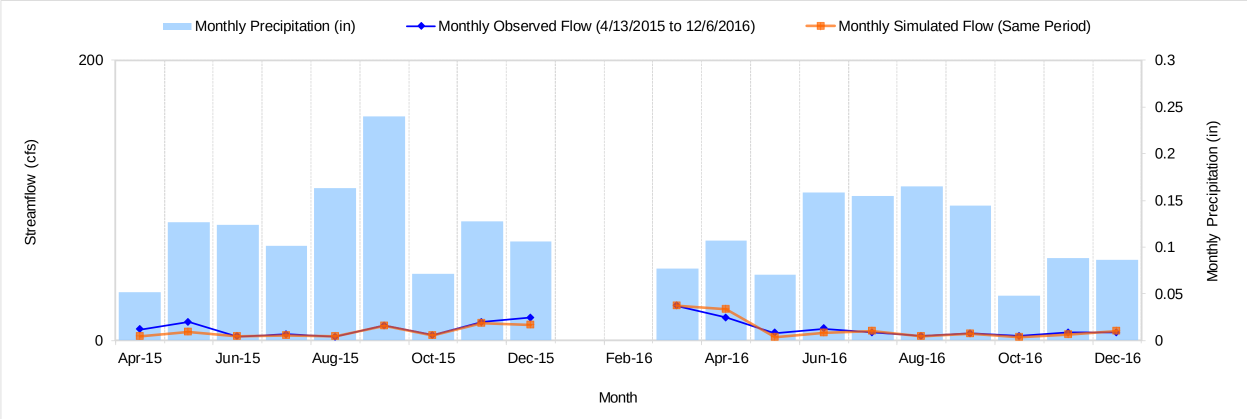
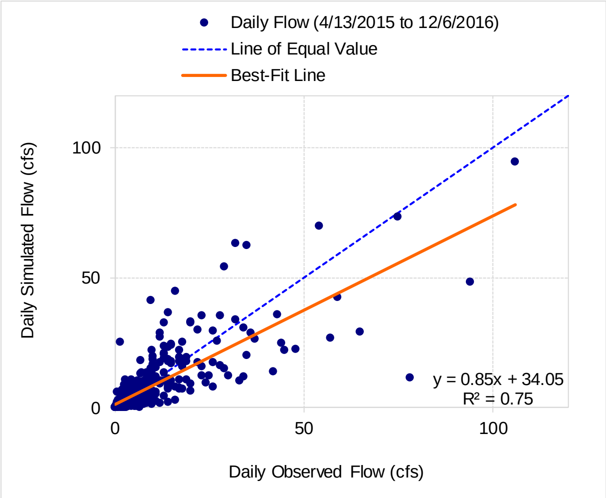


Figure C-16. Mean monthly streamflow



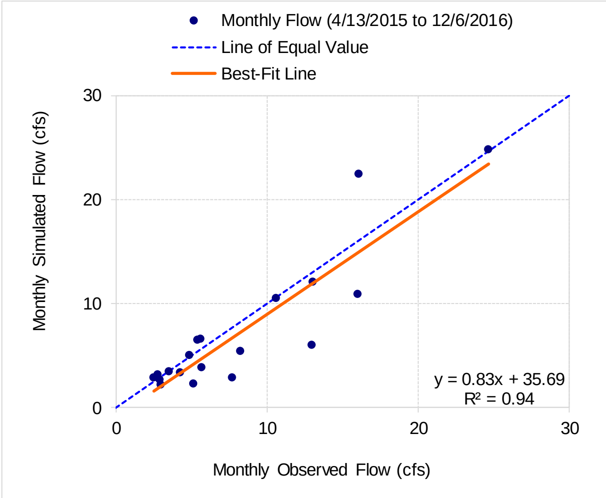


Figure C-17. Daily (left) and monthly (right) streamflow scatterplot

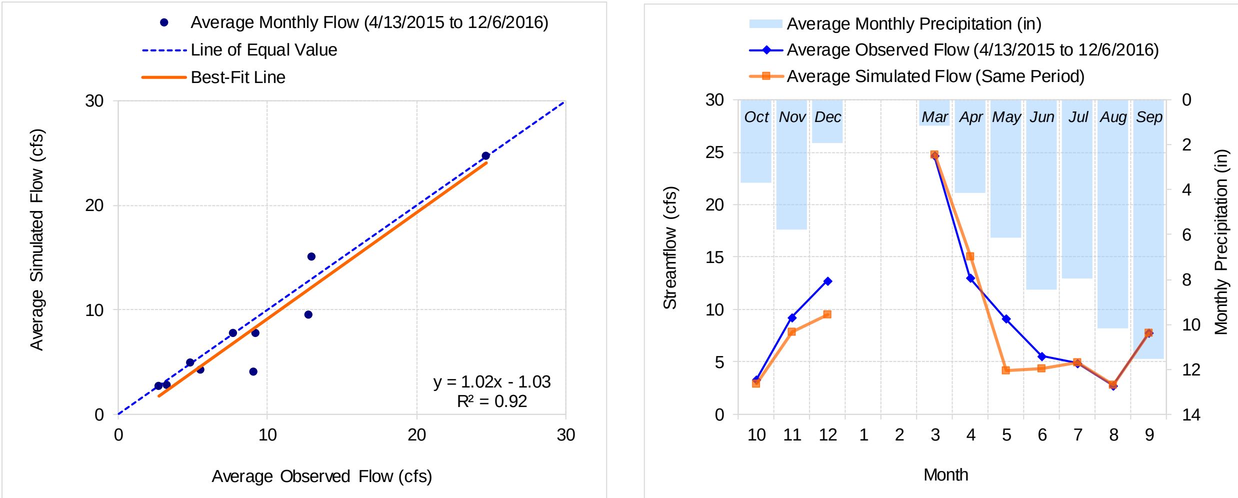


Figure C-18. Seasonal scatterplot (left) and temporal aggregate (right)

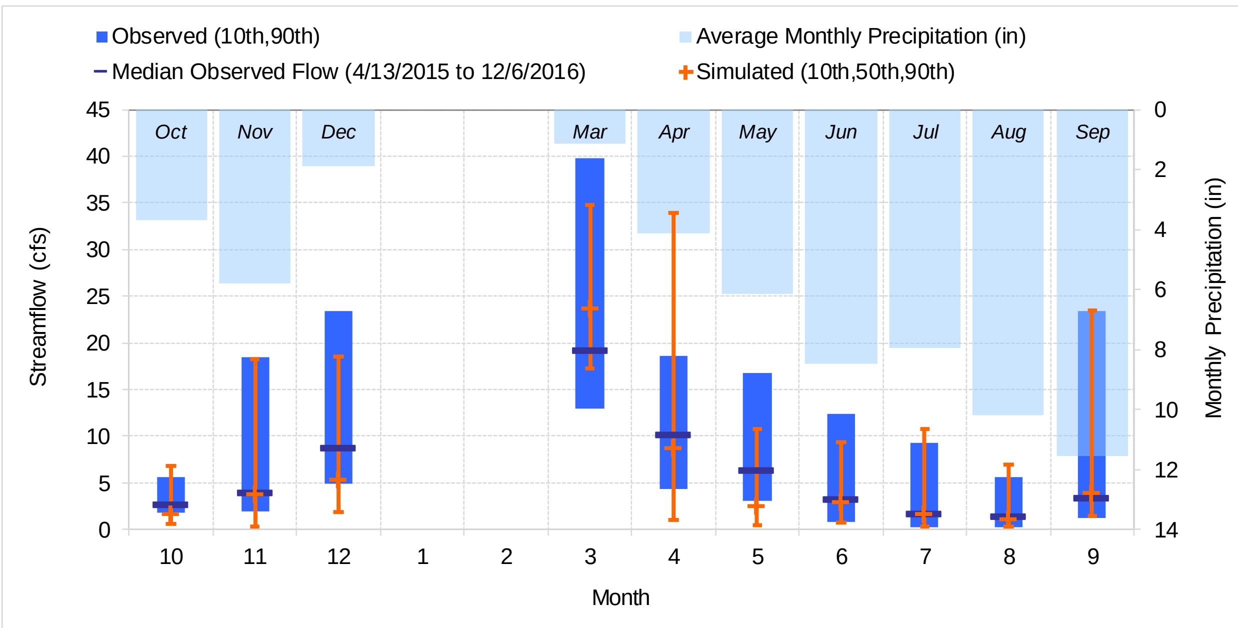


Figure C-19. Monthly medians and ranges

Table C-5. Monthly summary

Month	OBSERVED FLOW (cfs) Mean	Median	Lower	Upper	MODELED FLOW (cfs) Mean	Median	Lower	Upper
Oct	3.27	2.40	1.80	5.57	2.85	1.60	0.57	6.83
Nov	9.22	3.70	1.93	18.50	7.83	3.73	0.28	18.23
Dec	12.75	8.50	4.96	23.40	9.54	5.31	1.83	18.56
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	24.67	19.00	13.00	39.80	24.81	23.67	17.23	34.73
Apr	12.98	9.95	4.28	18.60	15.09	8.67	1.05	33.98
May	9.07	6.15	3.11	16.80	4.11	2.40	0.41	10.75
Jun	5.52	3.00	0.82	12.40	4.32	2.91	0.75	9.36
Jul	4.85	1.40	0.32	9.34	4.92	1.60	0.29	10.77
Aug	2.70	1.20	0.24	5.63	2.76	1.08	0.25	6.95
Sep	7.74	3.10	1.29	23.40	7.79	3.85	1.39	23.45

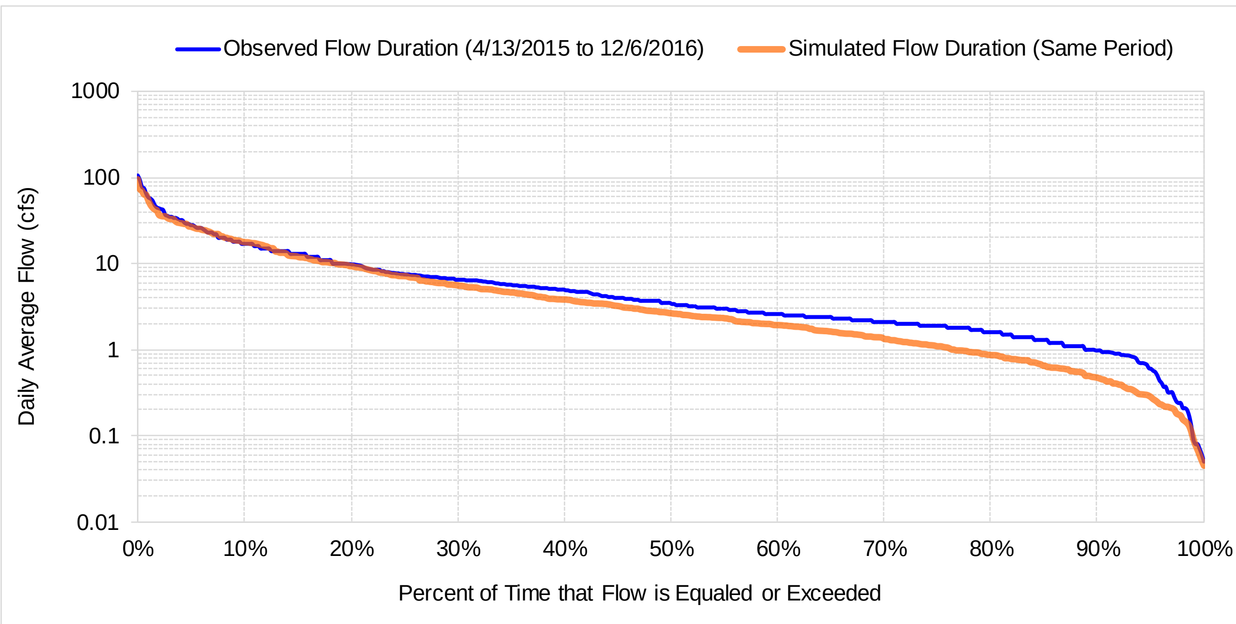


Figure C-20. Flow exceedance

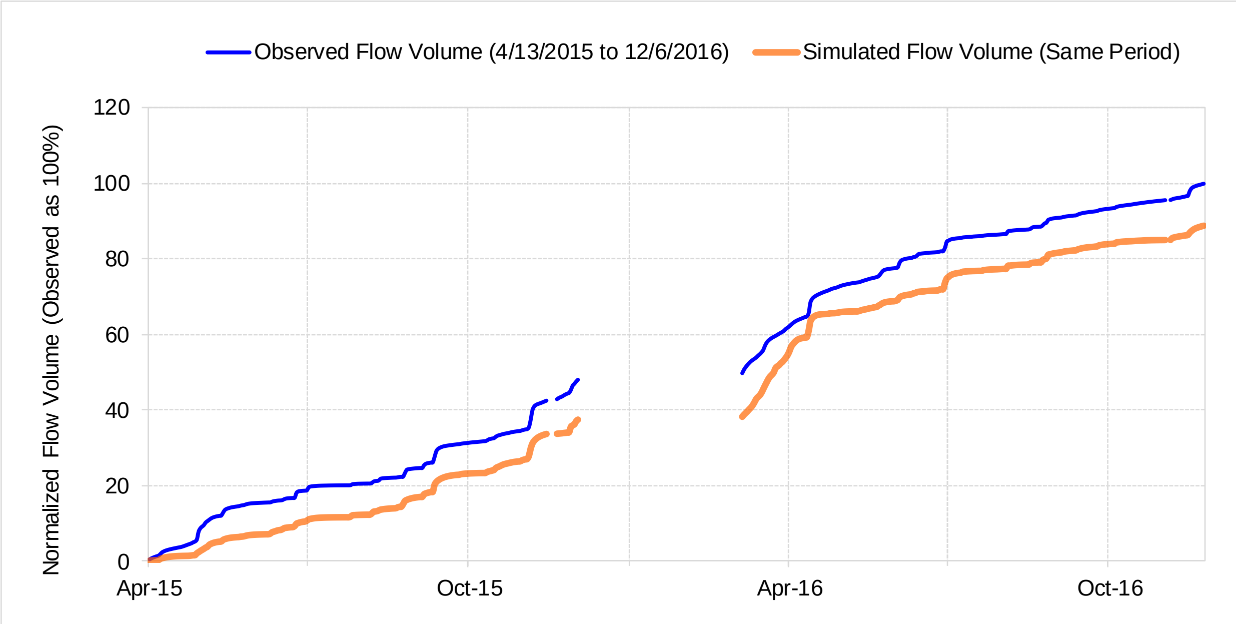


Figure C-21. Flow accumulation

Table C-6. Summary statistics

Keene Creek at S. 57th Ave. W (ID - 03189016)
Drainage Area (sq-mi): 6.28
Analysis Period: 4/13/2015 to 12/6/2016

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	13.49	11.96	-11.36	10
Total lowest 50% flows	1.63	1.07	-33.89	10
Total highest 10% flows	6.30	5.82	-7.51	15
Summer flow volume (months 7-9)	3.34	3.38	1.22	30
Fall flow volume (months 10-12)	3.38	2.80	-17.23	30
Winter flow volume (months 1-3)	1.33	1.34	0.59 >>	30
Spring flow volume (months 4-6)	5.44	4.44	-18.36	30
Total storm volume	5.80	5.14	-11.35	20
Summer storm volume (7-9)	2.09	1.92	-7.75	50
Baseflow	7.69	6.82	-11.37	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.613	0.7
Baseline adjusted coefficient (Garrick), E'			0.470	0.5
Monthly NSE			0.599	0.85

C.4 HYDSTRA 03163011 MERRITT CREEK AT DULUTH, GRAND AVE

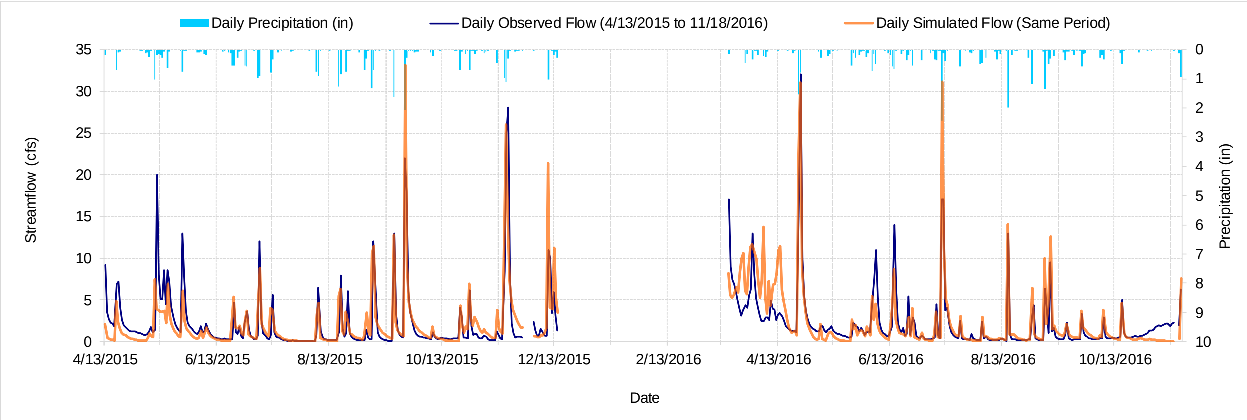


Figure C-22. Mean daily streamflow

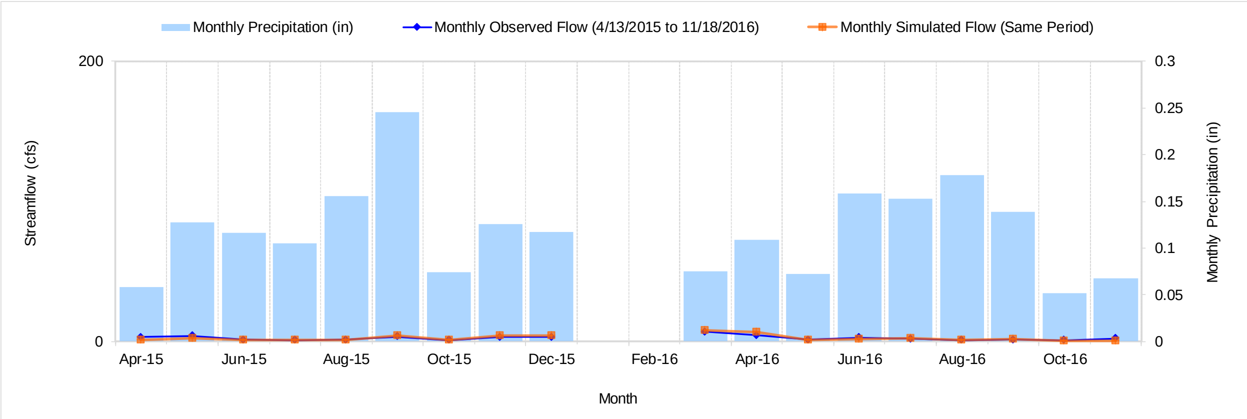


Figure C-23. Mean monthly streamflow

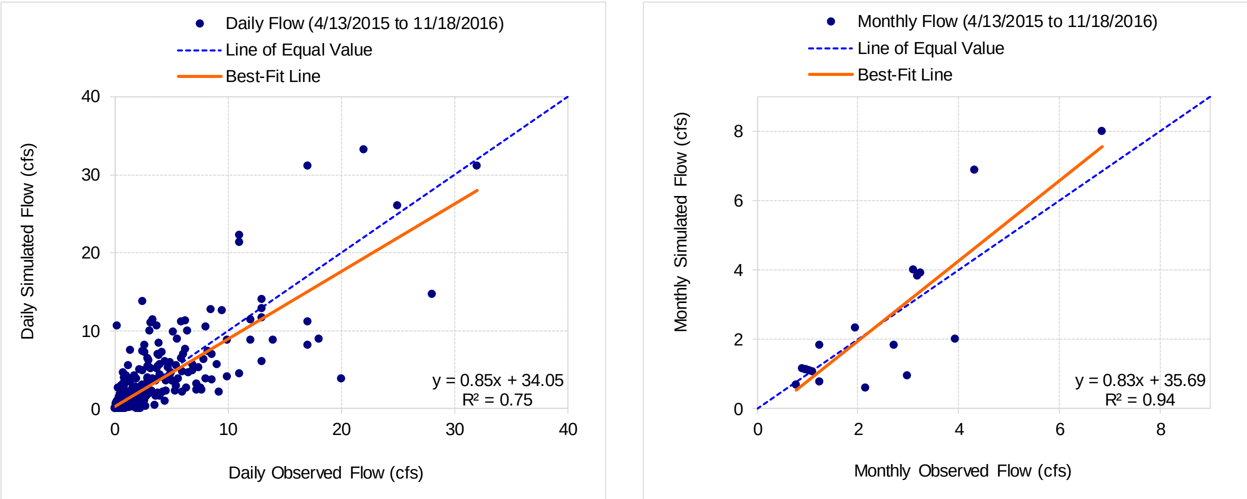


Figure C-24. Daily (left) and monthly (right) streamflow scatterplot

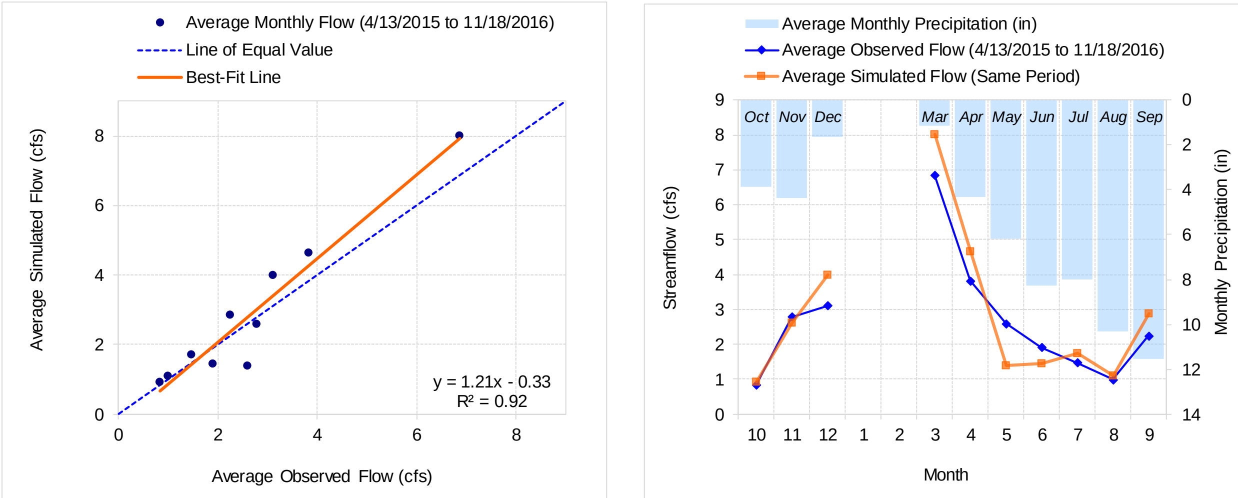


Figure C-25. Seasonal scatterplot (left) and temporal aggregate (right)

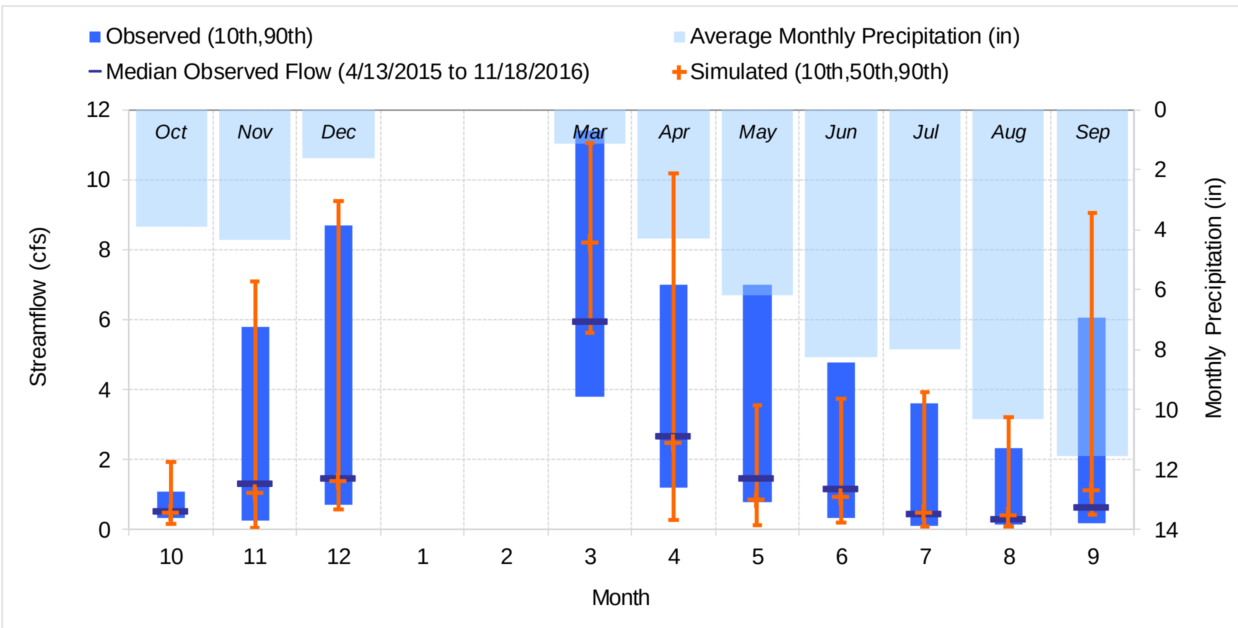


Figure C-26. Monthly medians and ranges

Table C-7. Monthly summary

Month	OBSERVED FLOW (cfs) Mean	Median	Lower	Upper	MODELED FLOW (cfs) Mean	Median	Lower	Upper
Oct	0.83	0.48	0.33	1.10	0.92	0.45	0.16	1.92
Nov	2.79	1.25	0.25	5.81	2.61	1.03	0.06	7.09
Dec	3.11	1.40	0.70	8.70	4.00	1.36	0.57	9.40
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	6.86	5.90	3.78	11.40	8.01	8.19	5.62	11.04
Apr	3.82	2.60	1.20	6.99	4.65	2.47	0.28	10.18
May	2.59	1.40	0.78	6.99	1.39	0.84	0.12	3.57
Jun	1.91	1.10	0.34	4.76	1.45	0.92	0.20	3.75
Jul	1.47	0.40	0.11	3.61	1.73	0.46	0.08	3.94
Aug	0.99	0.23	0.14	2.31	1.11	0.37	0.08	3.20
Sep	2.24	0.57	0.17	6.04	2.87	1.12	0.43	9.04

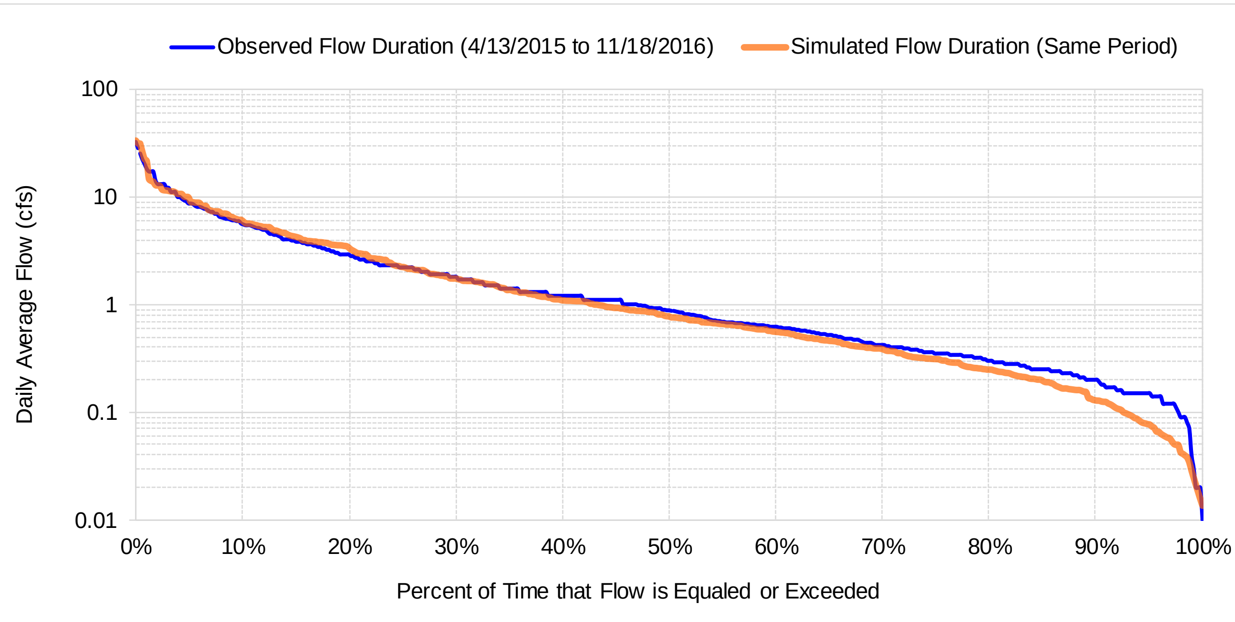


Figure C-27. Flow exceedance

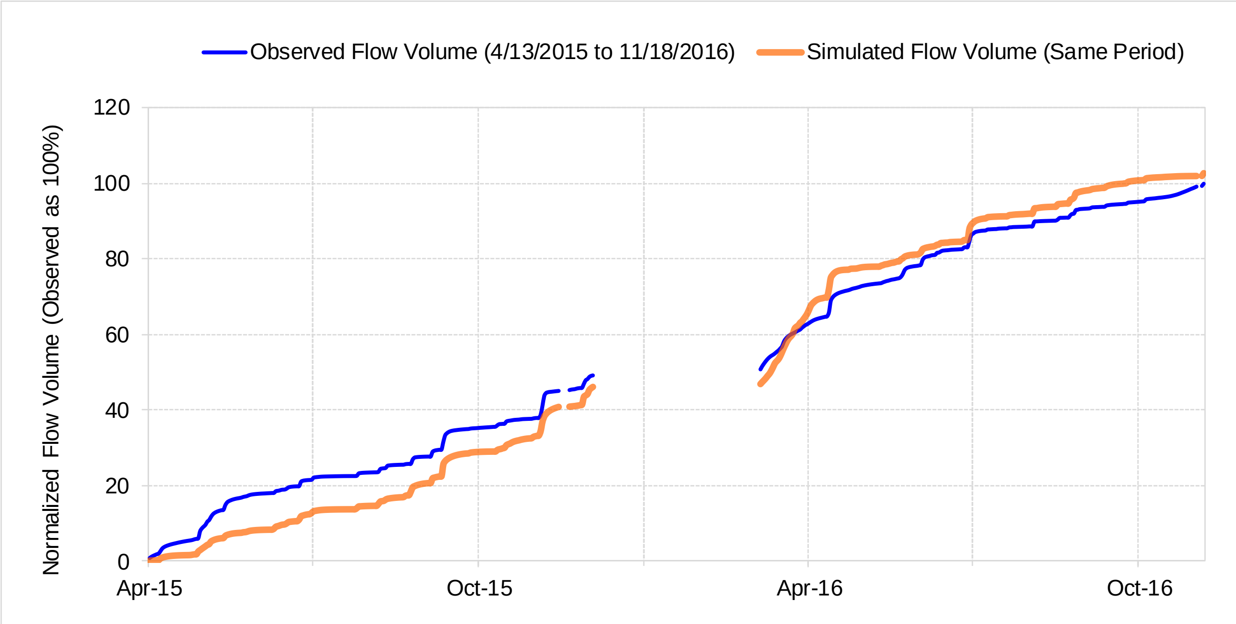


Figure C-28. Flow accumulation

Table C-8. Summary statistics

Merritt Creek at Grand Ave. (ID - 03163011)
Drainage Area (sq-mi): 2.04
Analysis Period: 4/13/2015 to 11/18/2016

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	12.08	12.38	2.53	10
Total lowest 50% flows	1.09	0.93	-14.19	10
Total highest 10% flows	6.11	6.36	4.08	15
Summer flow volume (months 7-9)	3.27	3.97	21.29	30
Fall flow volume (months 10-12)	2.41	2.53	4.98	30
Winter flow volume (months 1-3)	1.17	1.37	16.76 >>	30
Spring flow volume (months 4-6)	5.22	4.51	-13.55	30
Total storm volume	6.20	6.14	-1.01	20
Summer storm volume (7-9)	2.36	2.58	9.10	50
Baseflow	5.87	6.24	6.26	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.583	0.7
Baseline adjusted coefficient (Garrick), E'			0.437	0.5
Monthly NSE			0.315	0.85

C.5 HYDSTRA 03001001 MILLER CREEK AT DULUTH, 26TH AVE W & W MICHIGAN

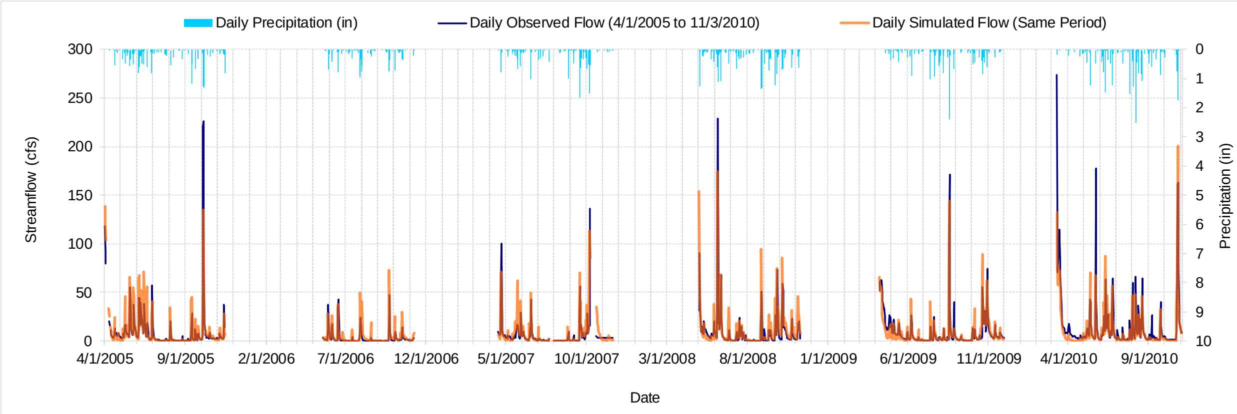


Figure C-29. Mean daily streamflow

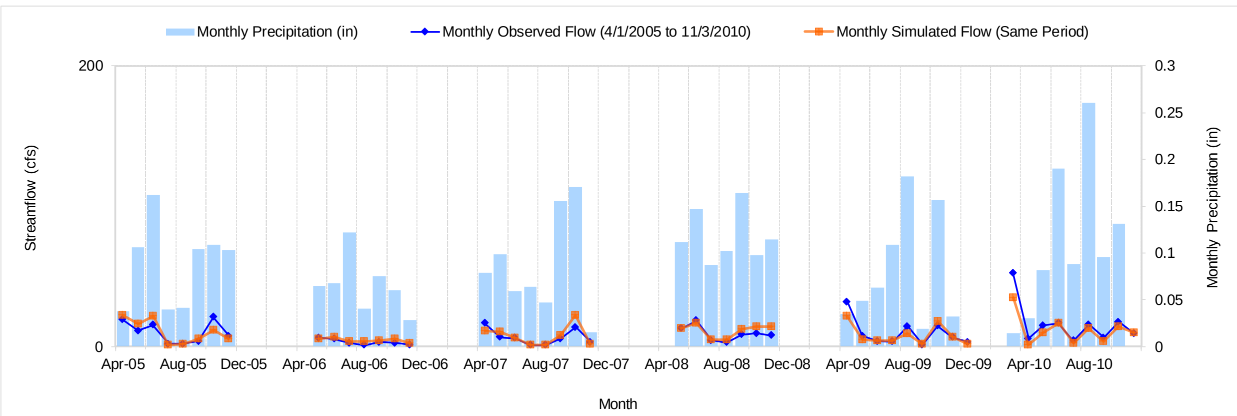


Figure C-30. Mean monthly streamflow

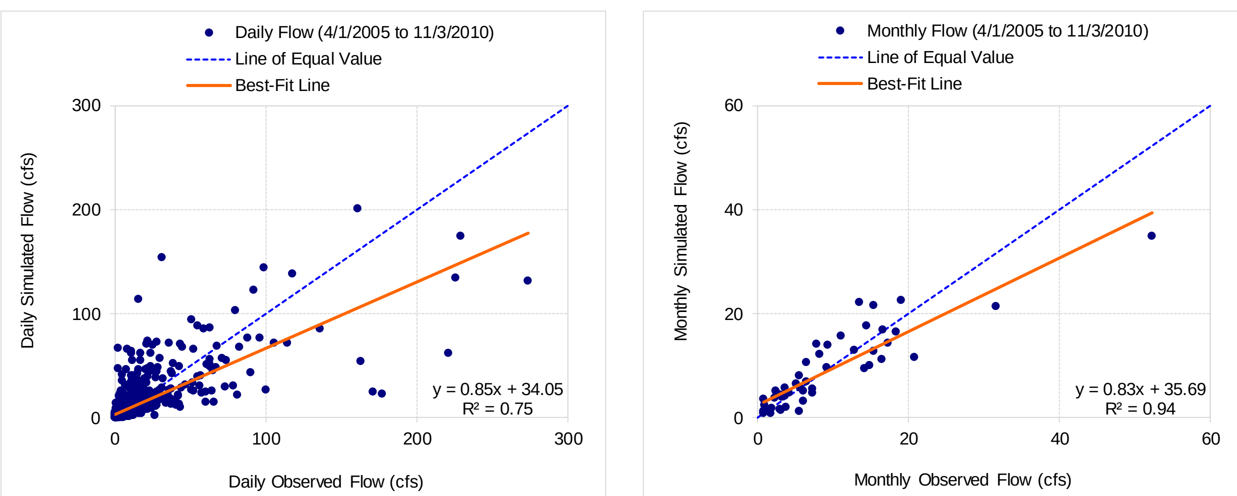


Figure C-31. Daily (left) and monthly (right) streamflow scatterplot

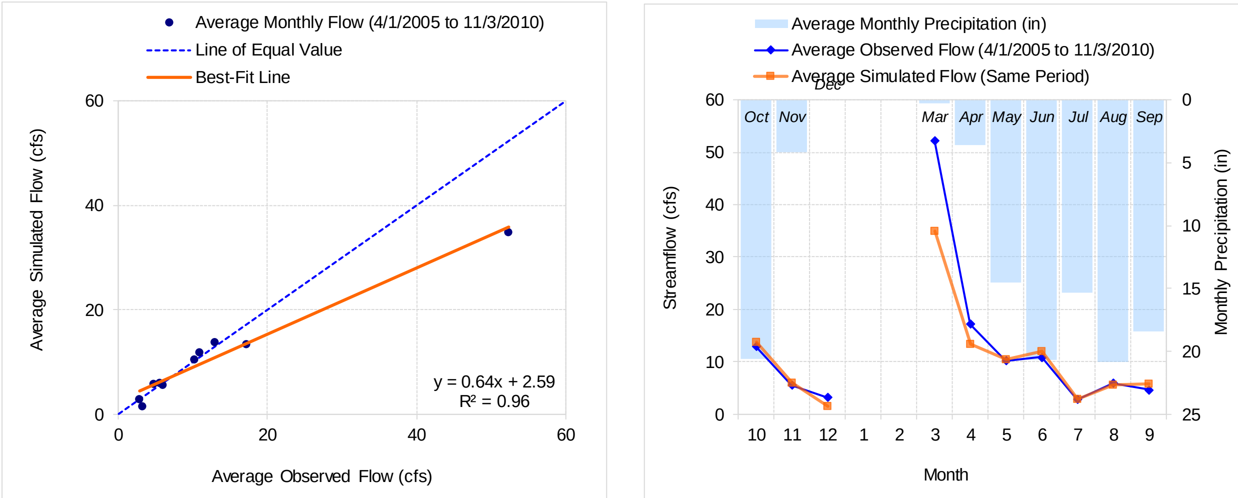


Figure C-32. Seasonal scatterplot (left) and temporal aggregate (right)

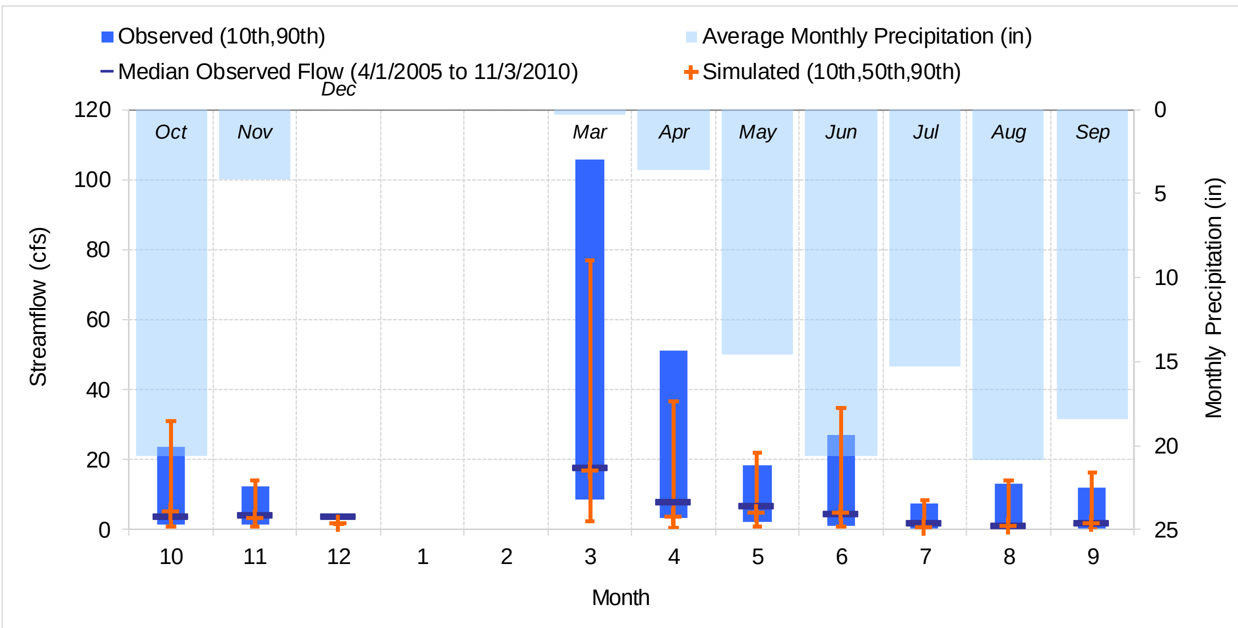


Figure C-33. Monthly medians and ranges

Table C-9. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	12.95	3.10	1.30	23.60	13.72	4.88	0.80	31.12
Nov	5.58	3.40	1.55	12.24	5.96	3.14	0.71	13.99
Dec	3.20	3.20	3.20	3.20	1.55	1.55	1.55	1.55
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	52.33	16.97	8.48	105.72	34.86	16.78	2.33	76.97
Apr	17.21	7.30	3.16	51.20	13.34	3.41	0.33	36.75
May	10.22	6.30	2.30	18.32	10.43	4.45	0.90	21.80
Jun	10.85	3.80	0.89	27.06	11.93	4.63	0.89	34.69
Jul	2.82	1.10	0.13	7.31	2.82	0.63	0.13	8.25
Aug	5.96	0.55	0.13	13.19	5.56	0.86	0.07	13.87
Sep	4.69	1.30	0.16	11.86	5.83	1.55	0.11	16.28

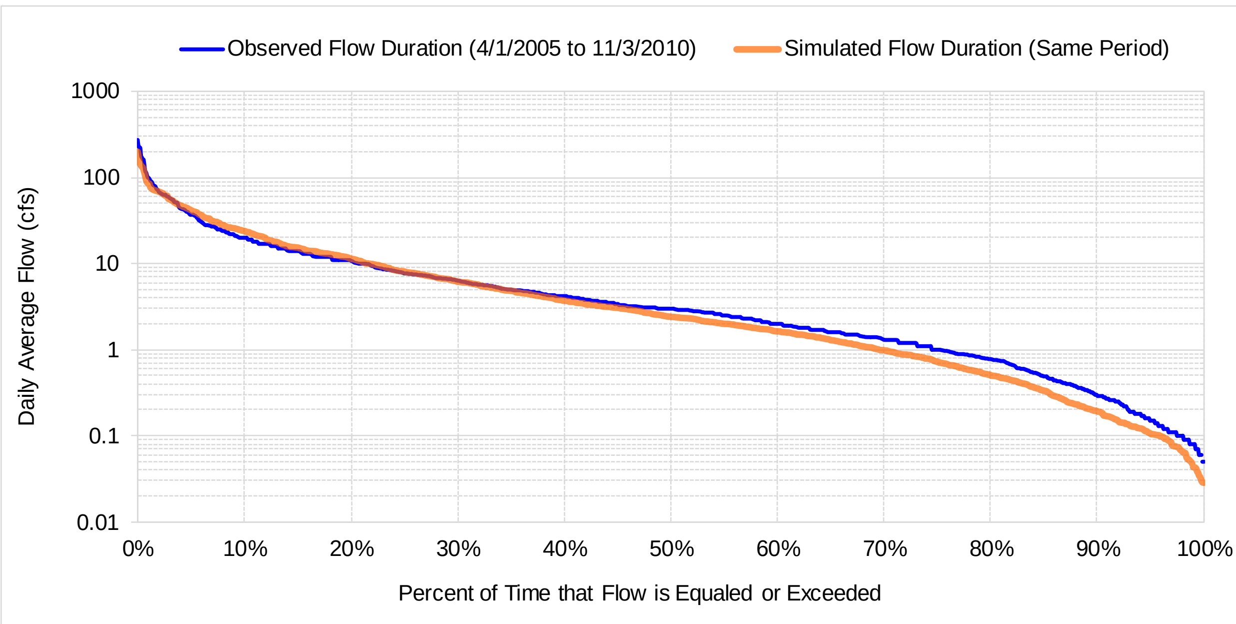


Figure C-34. Flow exceedance

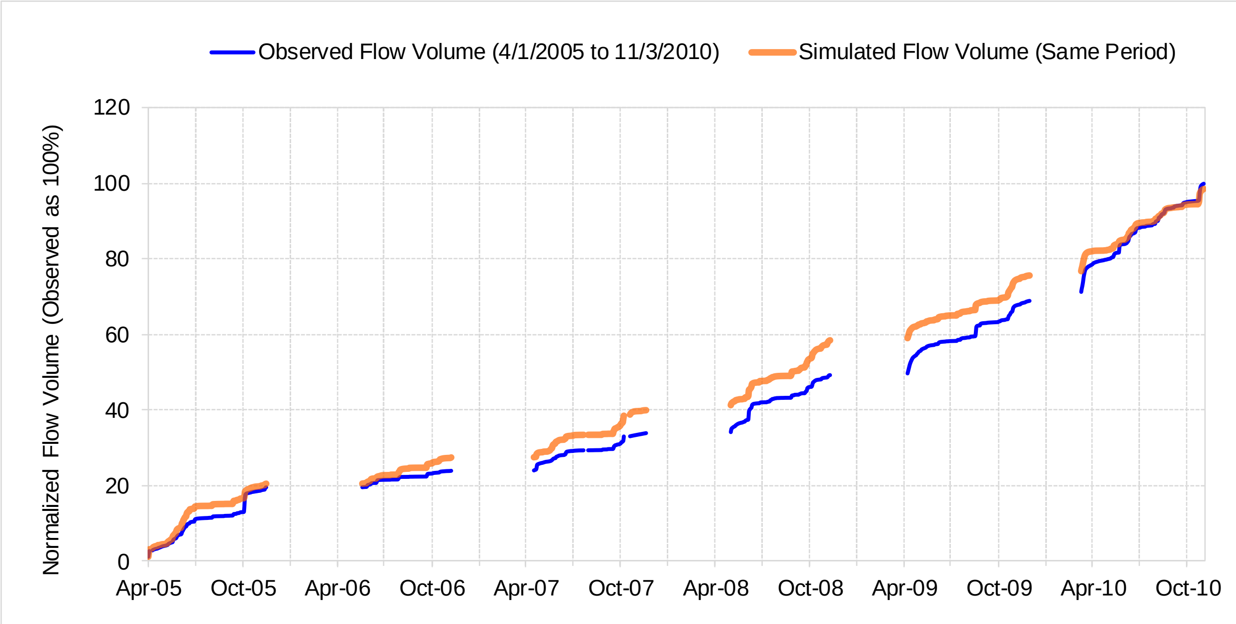


Figure C-35. Flow accumulation

Table C-10. Summary statistics

Miller Creek at Duluth, 26th Ave W & W Michigan (ID - 03001001)
Drainage Area (sq-mi): 9.9
Analysis Period: 4/1/2005 to 11/3/2010

Constituent	***Observed (in/yr)***	***Simulated (in/yr)***	***Error (Sim-Obs)***	***Recommended***
Total flow	7.72	7.59	-1.63	10
Total lowest 50% flows	0.50	0.38	-22.38	10
Total highest 10% flows	4.60	4.43	-3.73	15
Summer flow volume (months 7-9)	1.65	1.74	5.32	30
Fall flow volume (months 10-12)	1.85	1.96	6.00	30
Winter flow volume (months 1-3)	0.74	0.49	-33.38 >>	30
Spring flow volume (months 4-6)	3.48	3.40	-2.25	30
Total storm volume	4.01	4.14	3.15	20
Summer storm volume (7-9)	1.09	1.10	0.43	50
Baseflow	3.71	3.46	-6.80	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.548	0.7
Baseline adjusted coefficient (Garrick), E'			0.460	0.5
Monthly NSE			0.766	0.85

C.6 HYDSTRA 03001012 MILLER CREEK AT DULUTH, S 24TH AVE W

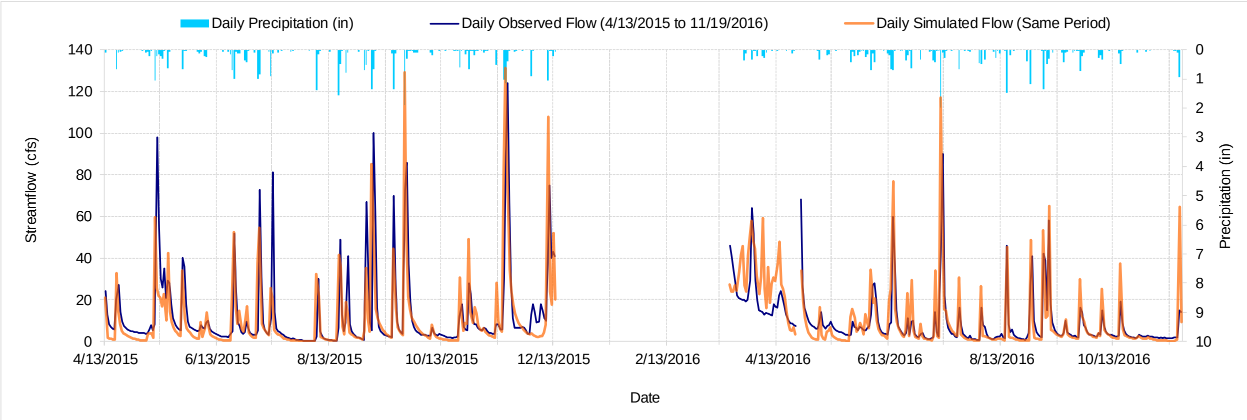


Figure C-36. Mean daily streamflow

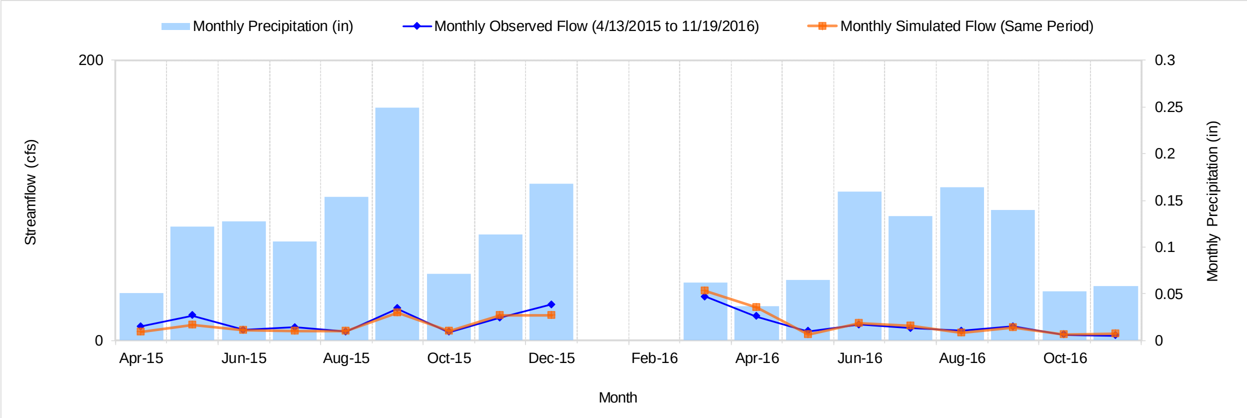


Figure C-37. Mean monthly streamflow

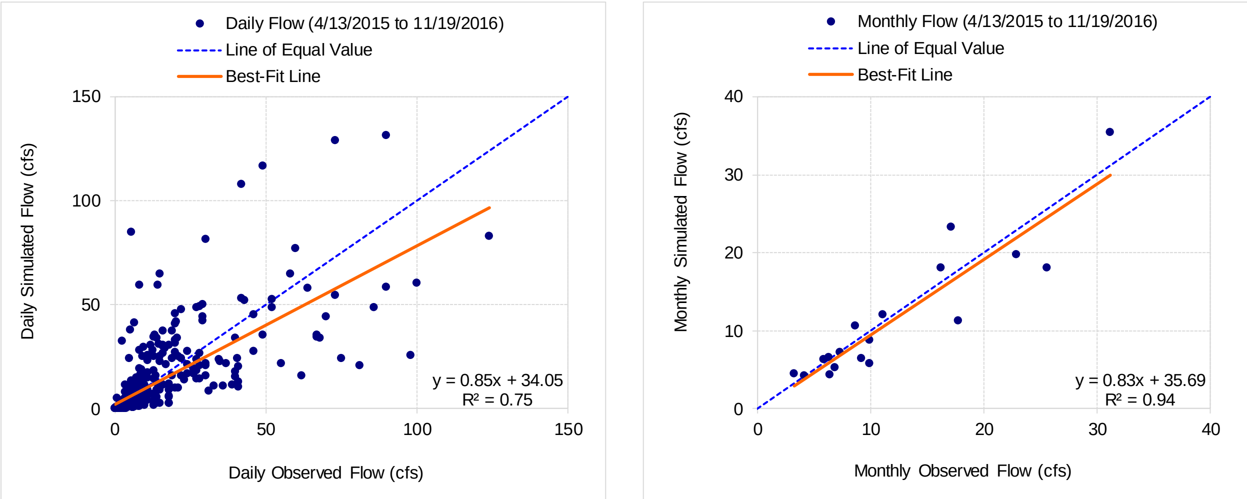
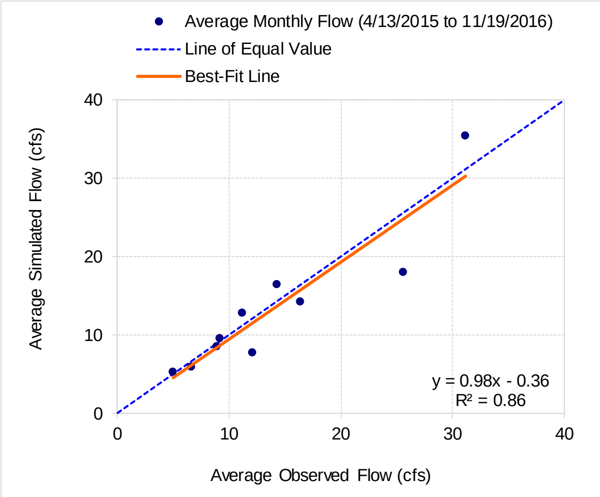


Figure C-38. Daily (left) and monthly (right) streamflow scatterplot



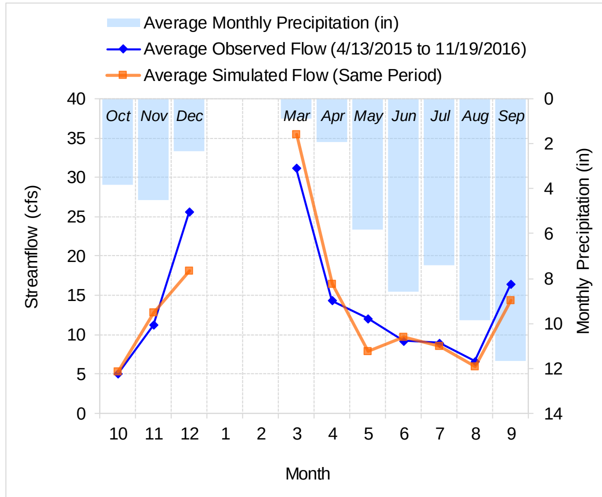


Figure C-39. Seasonal scatterplot (left) and temporal aggregate (right)

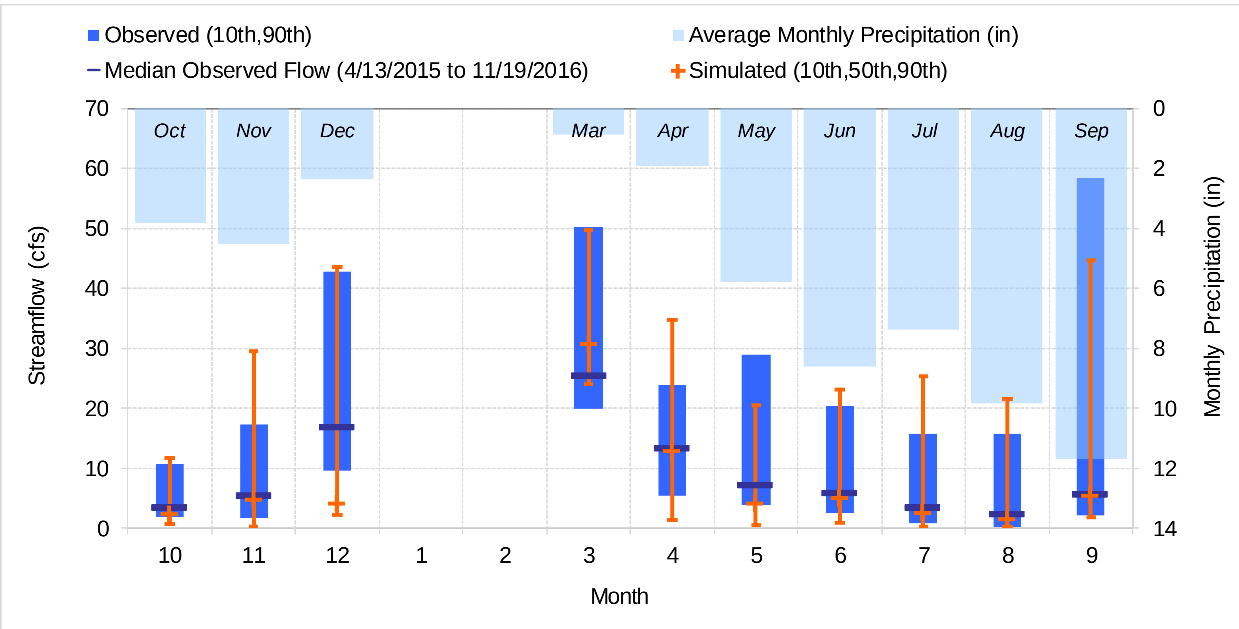


Figure C-40. Monthly medians and ranges

Table C-11. Monthly summary

Month	OBSERVED FLOW (cfs) Mean	Median	Lower	Upper	MODELED FLOW (cfs) Mean	Median	Lower	Upper
Oct	5.02	3.05	1.91	10.79	5.30	2.26	0.72	11.76
Nov	11.20	5.20	1.70	17.40	12.80	4.66	0.31	29.40
Dec	25.59	16.50	9.51	42.70	18.06	4.00	2.32	43.57
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	31.19	25.06	20.00	50.20	35.43	30.64	24.01	49.61
Apr	14.32	13.00	5.55	24.00	16.45	12.88	1.32	34.72
May	12.08	6.80	3.91	28.90	7.82	3.96	0.56	20.54
Jun	9.21	5.50	2.50	20.40	9.64	4.87	1.03	23.13
Jul	8.94	3.15	0.90	15.80	8.55	2.40	0.39	25.23
Aug	6.60	2.15	0.28	15.70	5.89	1.33	0.34	21.54
Sep	16.40	5.25	2.20	58.40	14.32	5.30	1.74	44.75

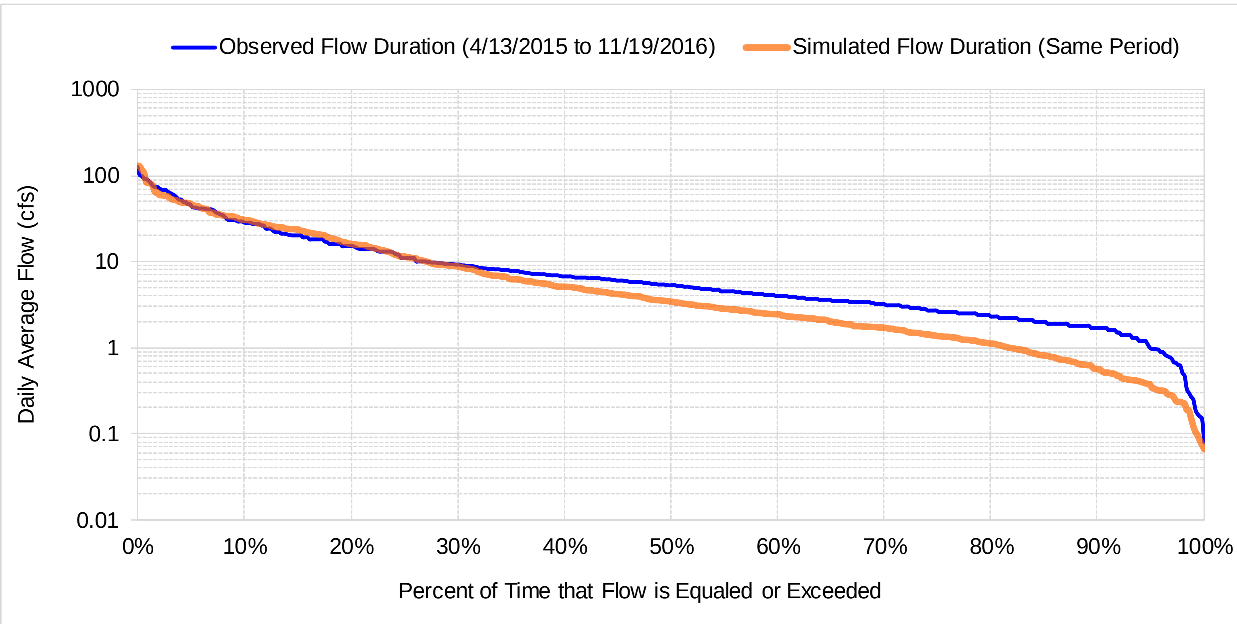


Figure C-41. Flow exceedance

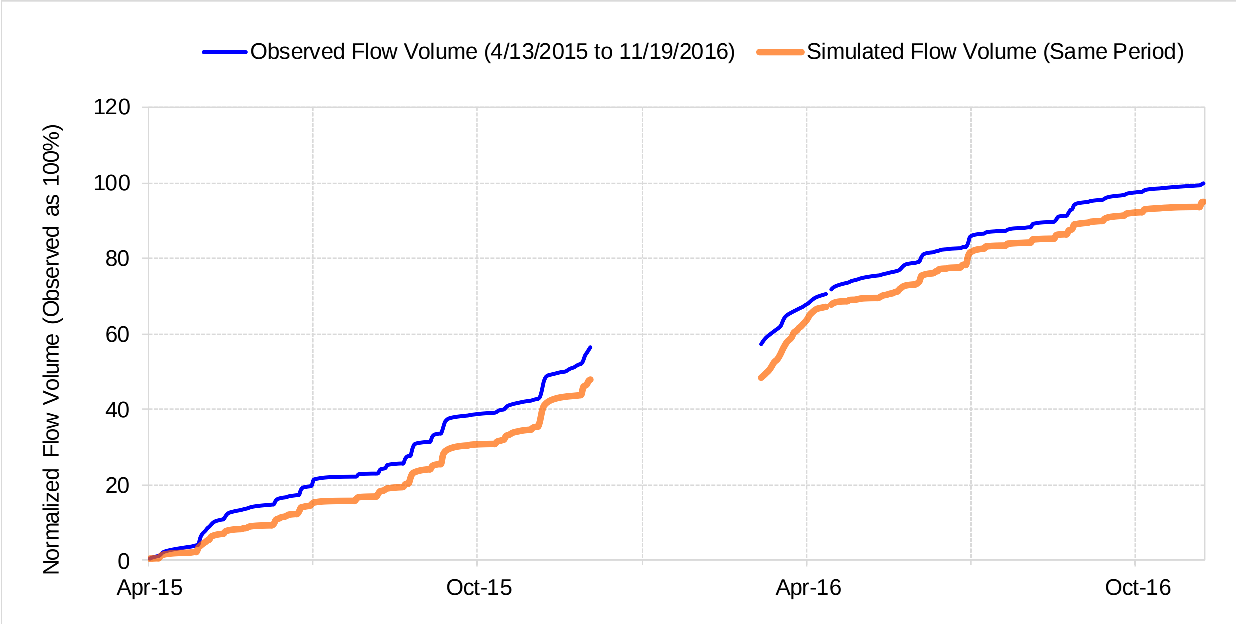


Figure C-42. Flow accumulation

Table C-12. Summary statistics

Miller Creek at S. 24th Ave. W (ID - 03001012)
Drainage Area (sq-mi): 9.71
Analysis Period: 4/13/2015 to 11/19/2016

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	13.28	12.60	-5.11	10
Total lowest 50% flows	1.62	0.87	-46.26	10
Total highest 10% flows	6.25	6.30	0.80	15
Summer flow volume (months 7-9)	4.65	4.19	-9.91	30
Fall flow volume (months 10-12)	2.91	2.88	-0.82	30
Winter flow volume (months 1-3)	1.04	1.18	13.60 >>	30
Spring flow volume (months 4-6)	4.68	4.34	-7.19	30
Total storm volume	6.10	6.70	9.97	20
Summer storm volume (7-9)	3.10	2.93	-5.30	50
Baseflow	7.18	5.90	-17.92	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.403	0.7
Baseline adjusted coefficient (Garrick), E'			0.384	0.5
Monthly NSE			0.731	0.85

C.7 HYDSTRA 03010003 MISSION CREEK NR FOND DU LAC, 1 MI U/S OF MN23

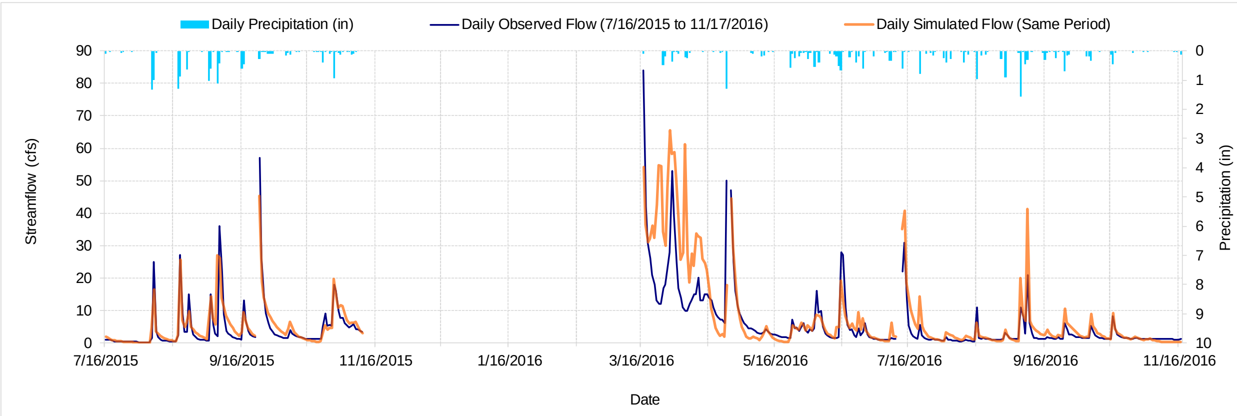


Figure C-43. Mean daily streamflow

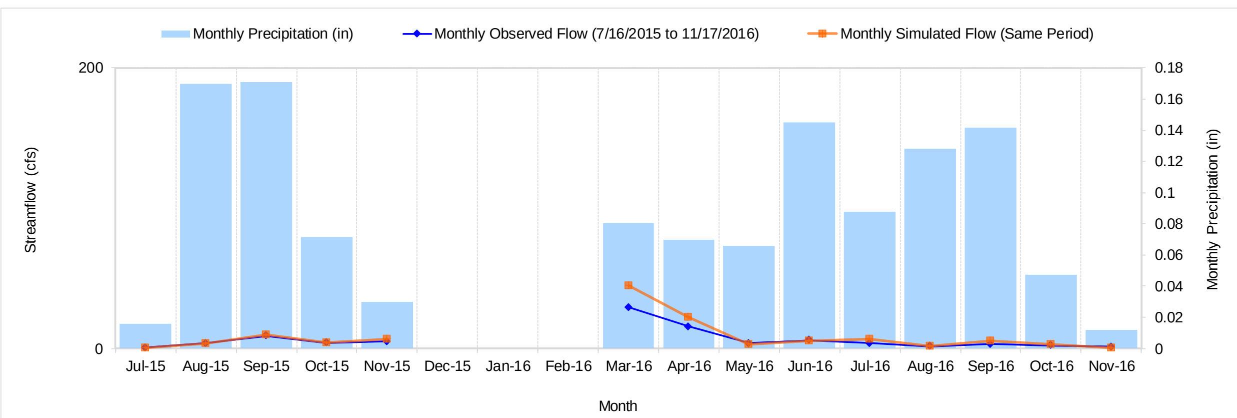


Figure C-44. Mean monthly streamflow

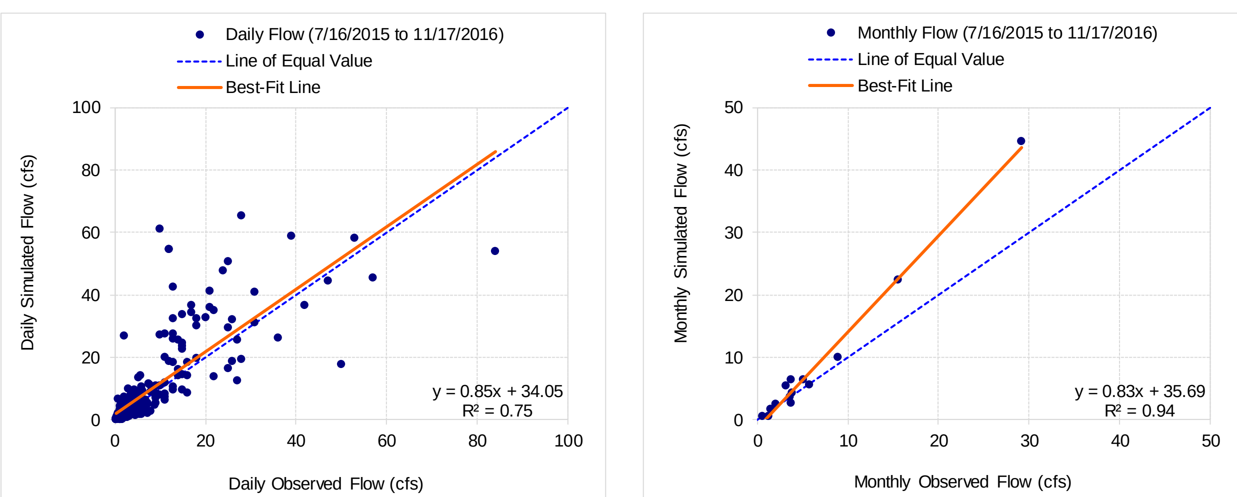
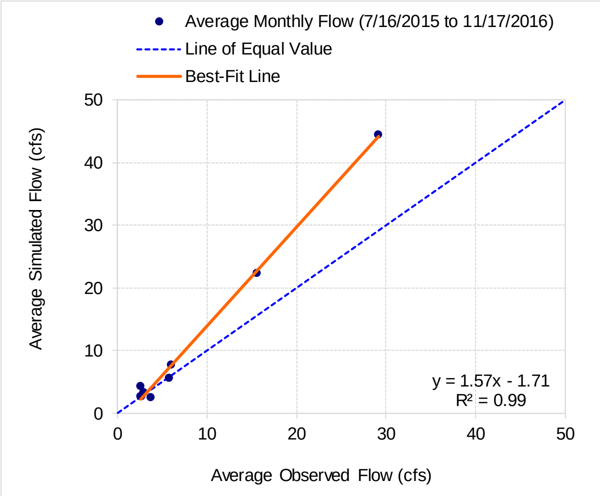


Figure C-45. Daily (left) and monthly (right) streamflow scatterplot



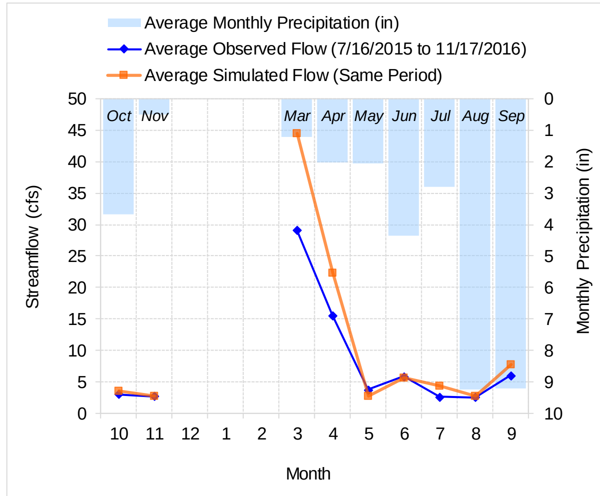


Figure C-46. Seasonal scatterplot (left) and temporal aggregate (right)

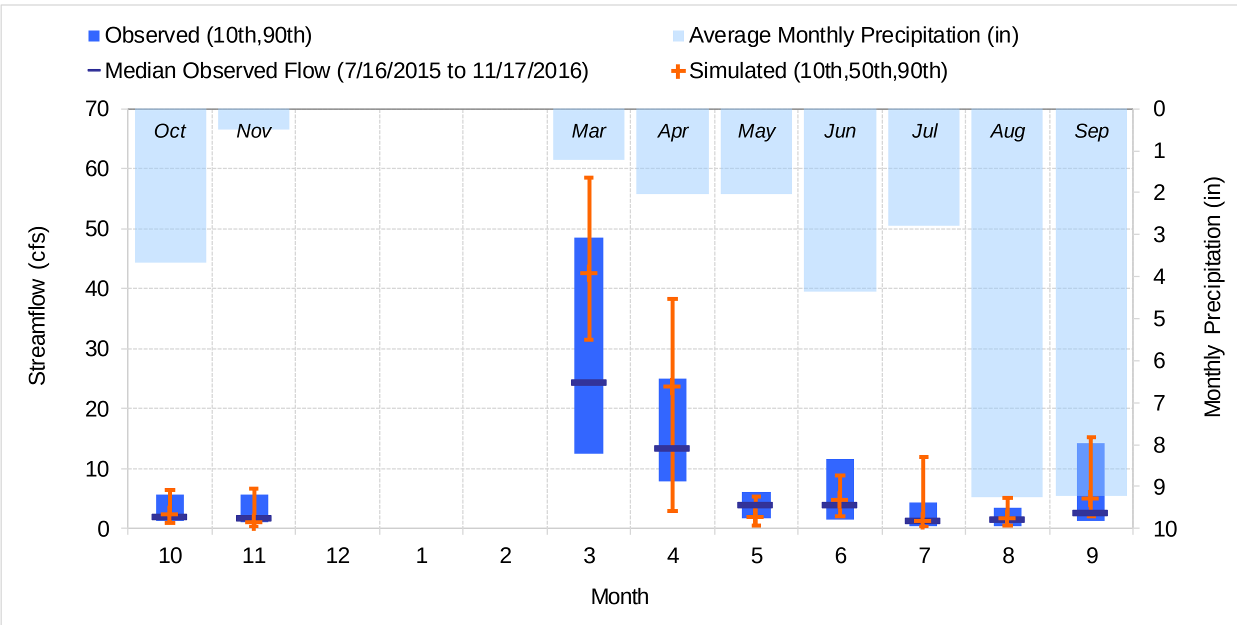


Figure C-47. Monthly medians and ranges

Table C-13. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	2.96	1.60	1.21	5.65	3.45	2.29	0.96	6.44
Nov	2.66	1.30	1.16	5.56	2.70	0.91	0.27	6.70
Dec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	29.20	24.00	12.40	48.60	44.60	42.56	31.53	58.53
Apr	15.56	13.00	7.78	25.00	22.37	23.63	2.86	38.21
May	3.69	3.50	1.80	6.00	2.63	1.87	0.50	5.40
Jun	5.80	3.60	1.50	11.50	5.60	4.70	1.94	8.79
Jul	2.60	1.00	0.39	4.38	4.35	1.22	0.24	12.01
Aug	2.54	1.10	0.44	3.50	2.72	1.63	0.53	5.01
Sep	6.01	2.20	1.20	14.20	7.74	4.99	1.96	15.33

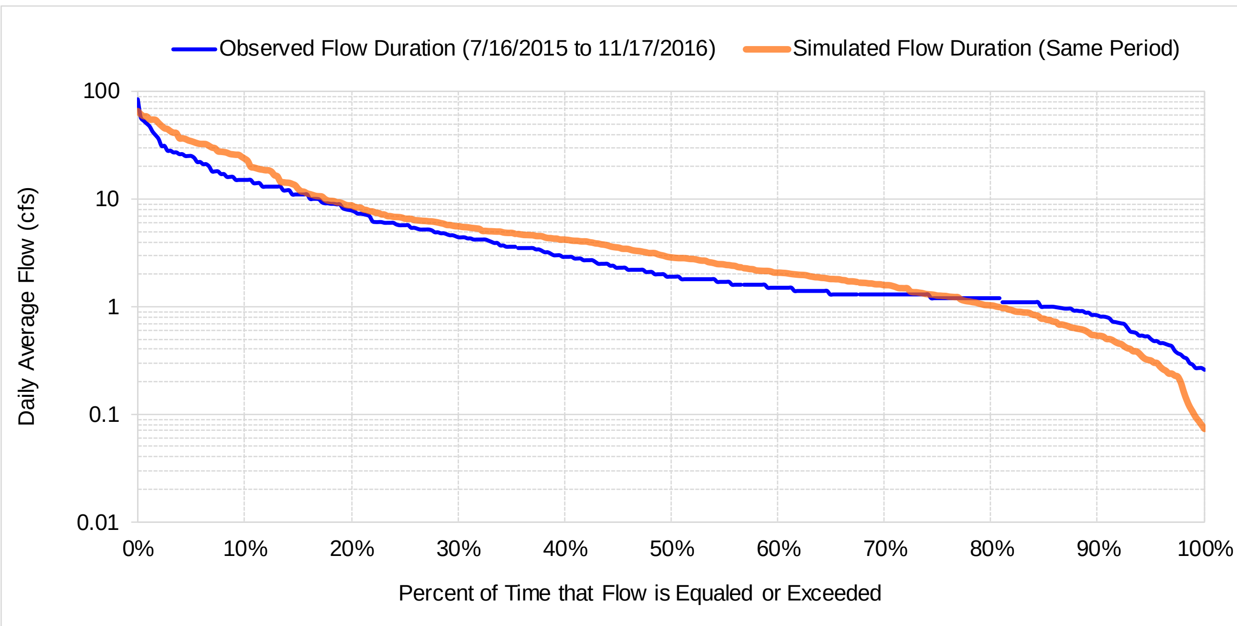


Figure C-48. Flow exceedance

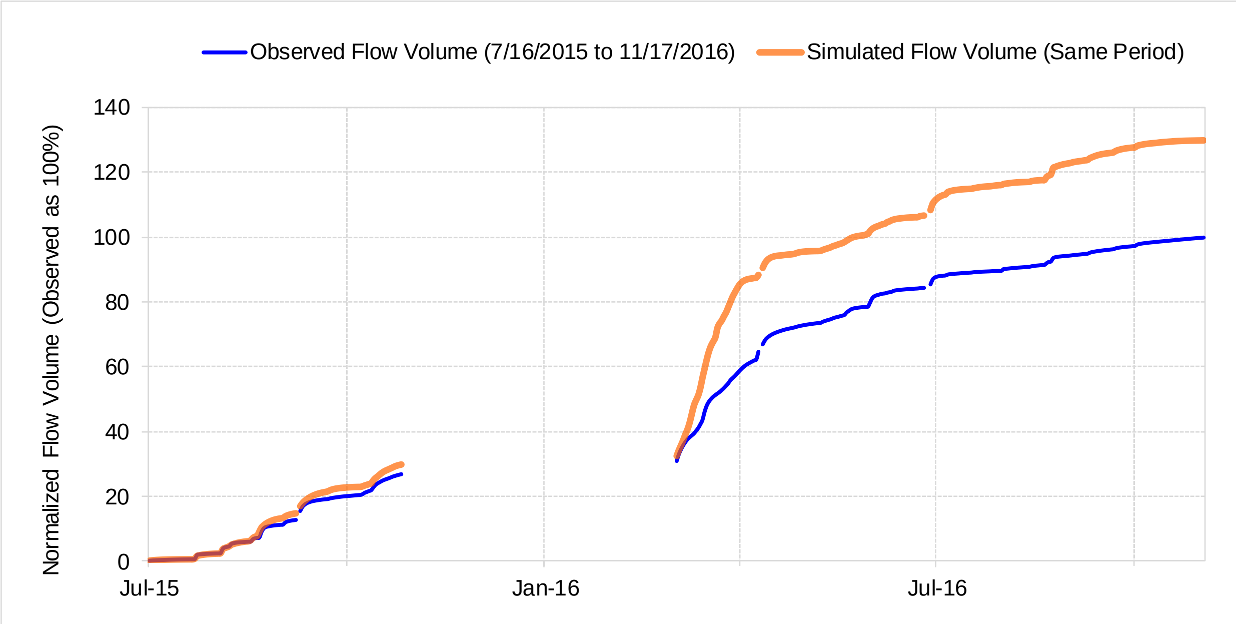


Figure C-49. Flow accumulation

Table C-14. Summary statistics

Mission Creek 1 mi u/s MN23 (ID - 03010003)
Drainage Area (sq-mi): 10.69
Analysis Period: 7/16/2015 to 11/17/2016

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	5.35	6.94	29.72	10
Total lowest 50% flows	0.54	0.62	13.78	10
Total highest 10% flows	2.64	3.61	36.57	15
Summer flow volume (months 7-9)	1.63	2.13	30.44	30
Fall flow volume (months 10-12)	0.66	0.74	12.36	30
Winter flow volume (months 1-3)	1.14	1.73	52.73 >>	30
Spring flow volume (months 4-6)	1.92	2.33	21.46	30
Total storm volume	2.11	2.24	6.16	20
Summer storm volume (7-9)	0.95	0.97	2.16	50
Baseflow	3.24	4.70	45.02	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.397	0.7
Baseline adjusted coefficient (Garrick), E'			0.432	0.5
Monthly NSE			0.590	0.85

C.8 HYDSTRA 02039008 TISCHER CREEK AT DULUTH, WALLACE AVE

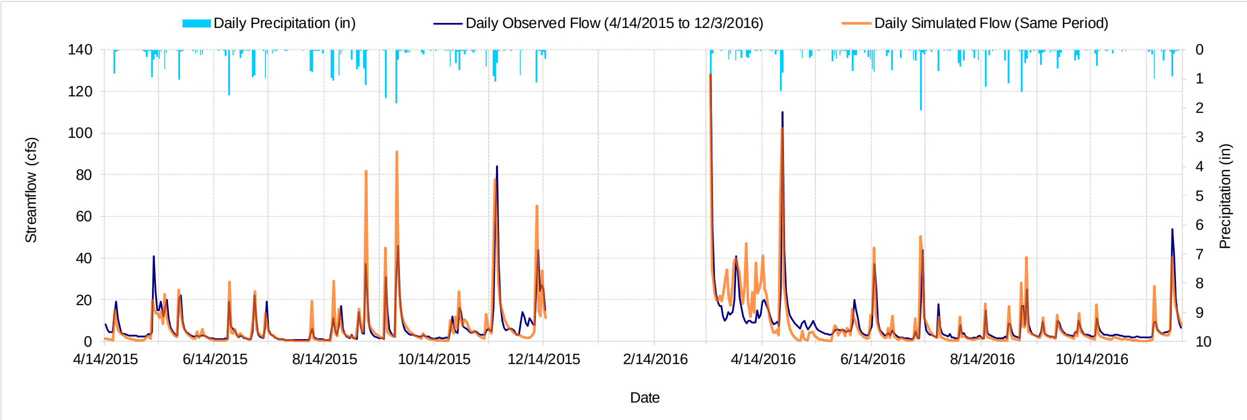


Figure C-50. Mean daily streamflow

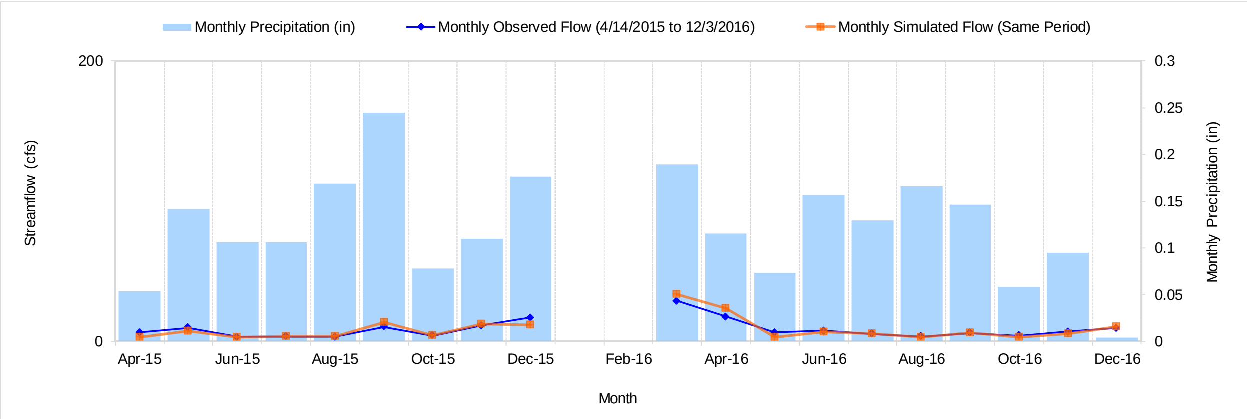


Figure C-51. Mean monthly streamflow

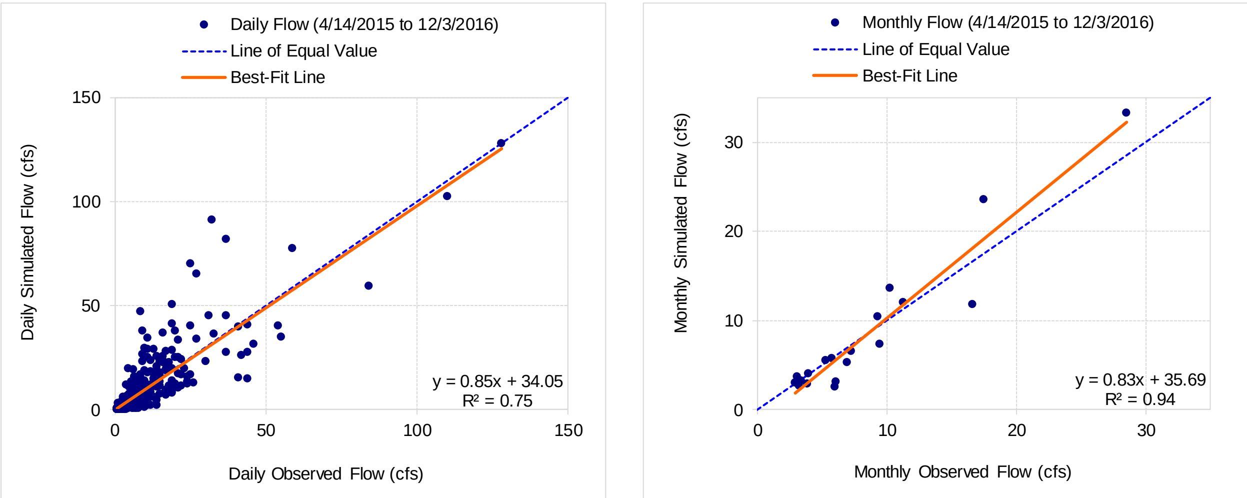


Figure C-52. Daily (left) and monthly (right) streamflow scatterplot

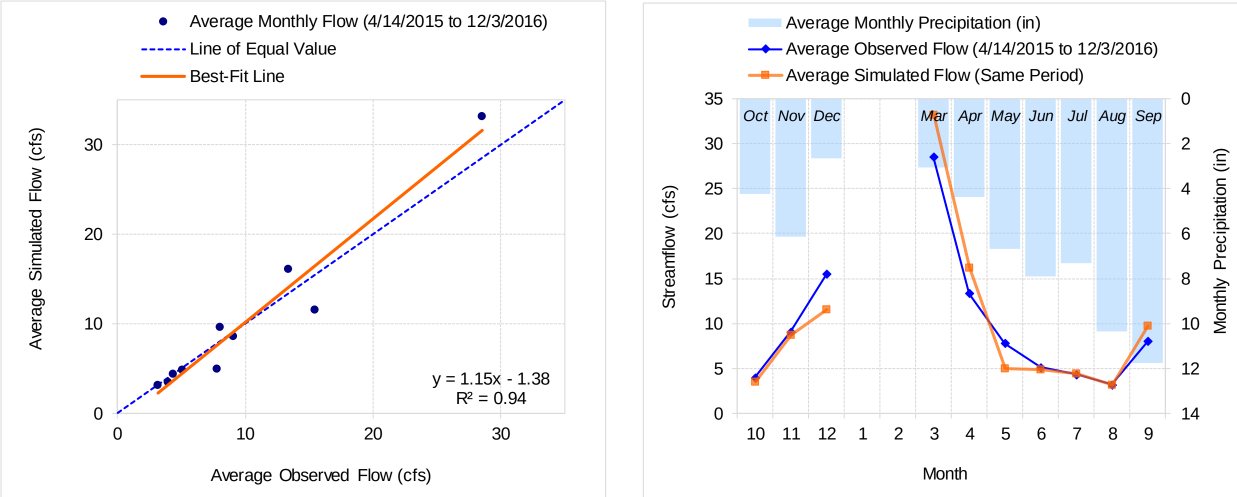


Figure C-53. Seasonal scatterplot (left) and temporal aggregate (right)

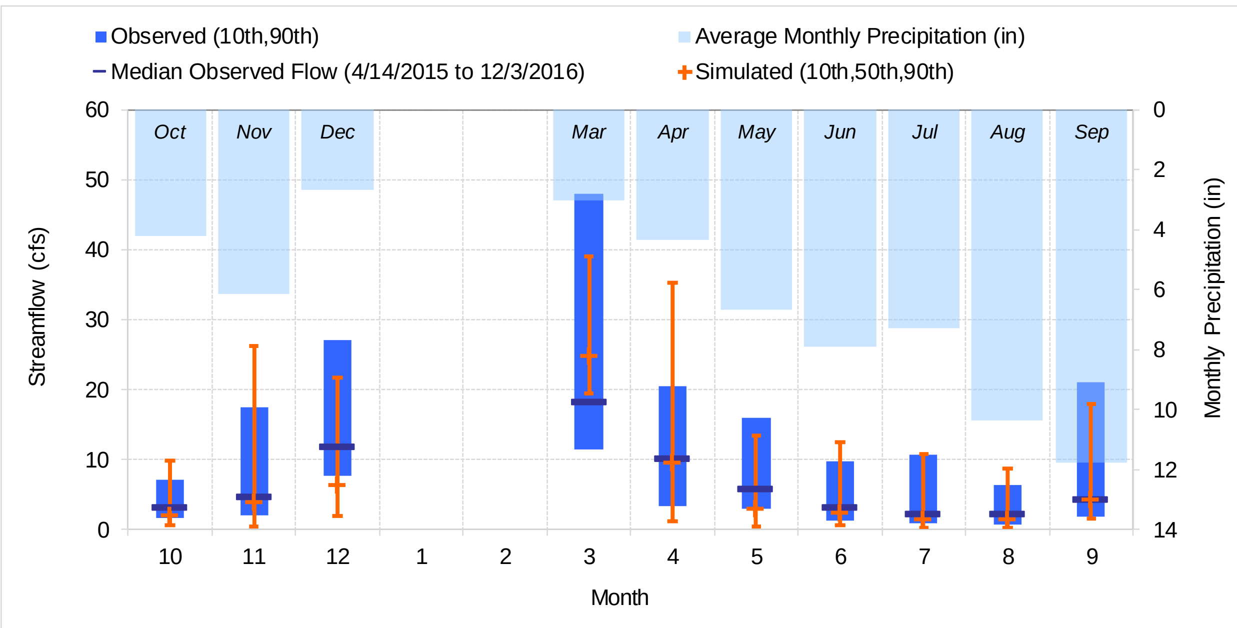


Figure C-54. Monthly medians and ranges

Table C-15. Monthly summary

Month	OBSERVED FLOW (cfs)				MODELED FLOW (cfs)			
	Mean	Median	Lower	Upper	Mean	Median	Lower	Upper
Oct	3.94	2.95	1.70	7.09	3.49	1.89	0.57	9.93
Nov	9.10	4.35	1.99	17.40	8.66	3.86	0.36	26.32
Dec	15.46	11.50	7.64	27.00	11.56	6.36	1.92	21.79
Jan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mar	28.56	18.00	11.50	48.00	33.25	24.65	19.42	38.98
Apr	13.35	9.80	3.38	20.40	16.18	9.44	1.09	35.20
May	7.76	5.45	2.90	15.90	4.97	2.90	0.45	13.38
Jun	5.12	2.90	1.29	9.74	4.82	2.30	0.68	12.42
Jul	4.33	2.00	0.85	10.60	4.40	1.32	0.33	10.88
Aug	3.15	1.95	0.80	6.39	3.20	1.41	0.30	8.74
Sep	8.02	4.05	1.88	21.10	9.70	4.16	1.56	17.86

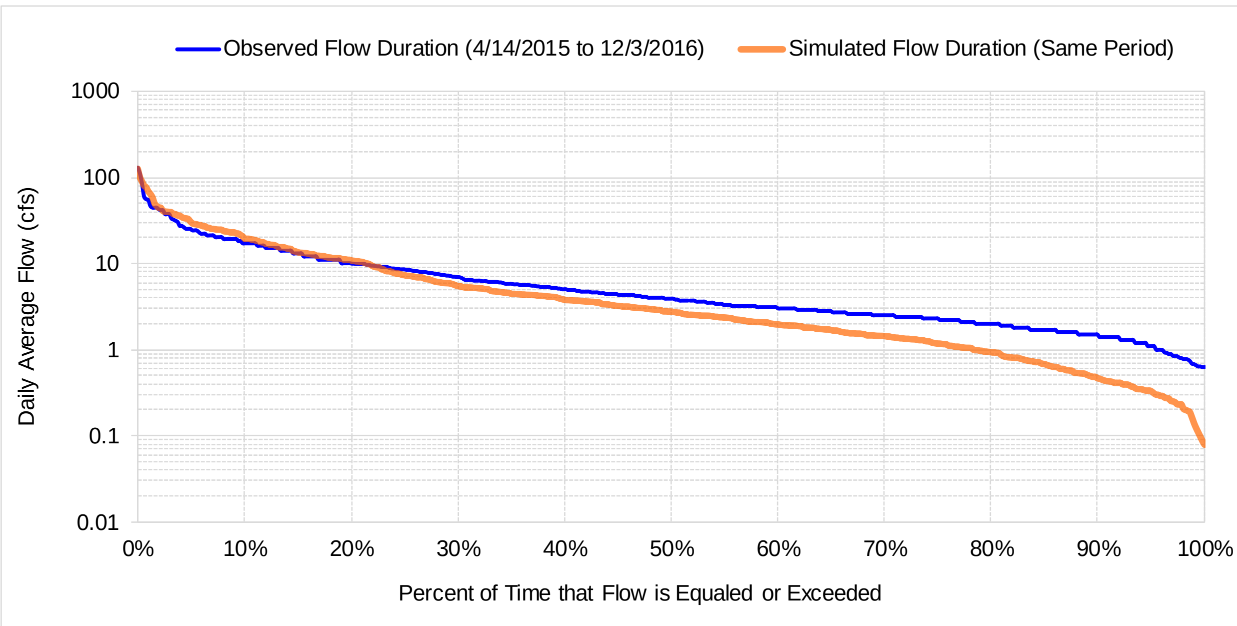


Figure C-55. Flow exceedance

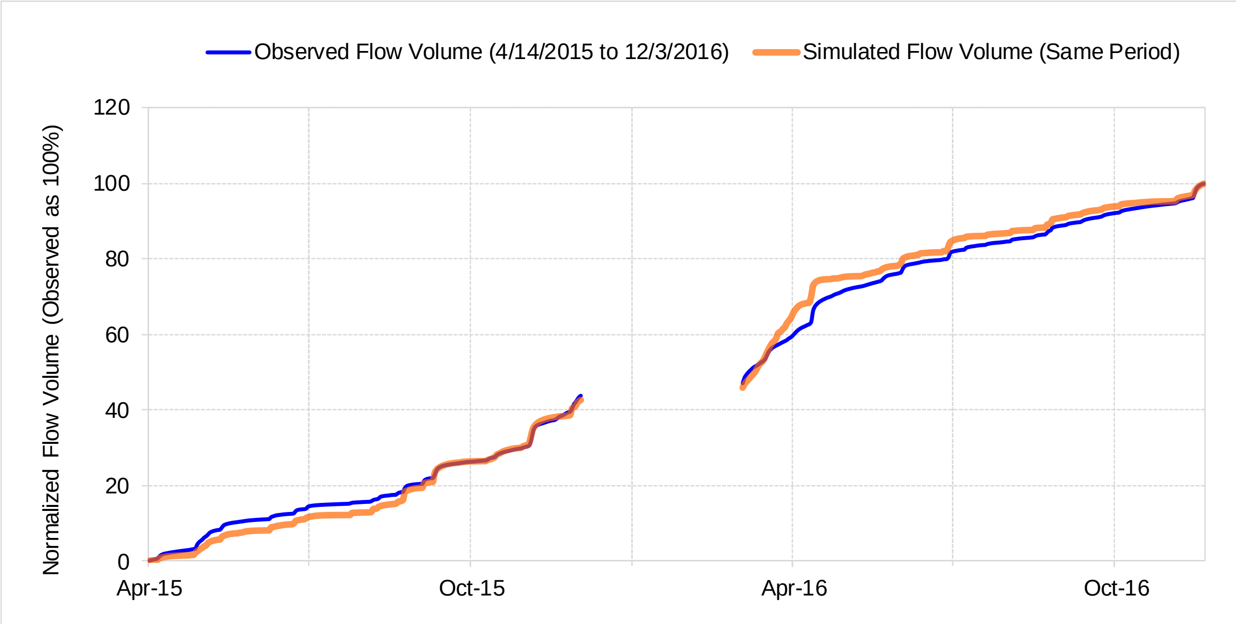


Figure C-56. Flow accumulation

Table C-16. Summary statistics

Tischer Creek at Wallace Ave. (ID - 03029008)
Drainage Area (sq-mi): 6.74
Analysis Period: 4/14/2015 to 12/3/2016

Constituent	*Observed (in/yr)*	*Simulated (in/yr)*	*Error (Sim-Obs)*	*Recommended*
Total flow	13.07	13.08	0.01	10
Total lowest 50% flows	1.90	1.07	-43.99	10
Total highest 10% flows	5.65	6.71	18.92	15
Summer flow volume (months 7-9)	3.18	3.54	11.40	30
Fall flow volume (months 10-12)	3.59	3.18	-11.63	30
Winter flow volume (months 1-3)	1.54	1.79	16.44 >>	30
Spring flow volume (months 4-6)	4.76	4.57	-4.11	30
Total storm volume	5.15	6.25	21.50	20
Summer storm volume (7-9)	1.61	2.18	35.26	50
Baseflow	7.93	6.82	-13.95	20
Nash-Sutcliffe Coefficient of Efficiency, E			0.607	0.7
Baseline adjusted coefficient (Garrick), E'			0.433	0.5
Monthly NSE			0.747	0.85

Appendix D Suspended Sediment Calibration and Validation

D.1 LESTER RIVER AT STRAND RD

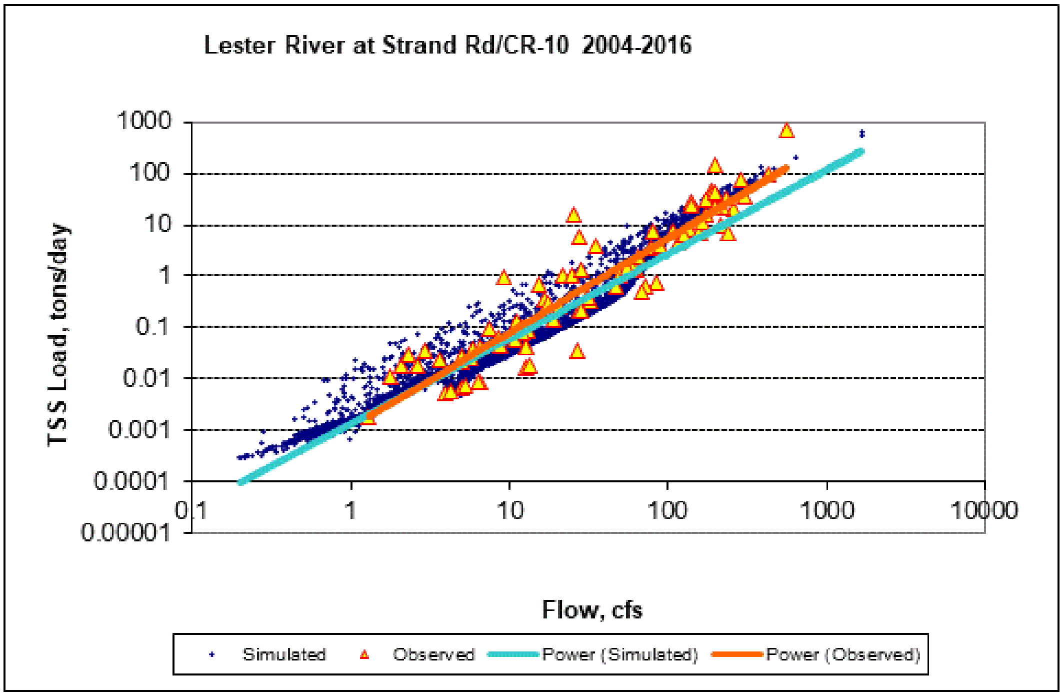


Figure D-1 Power Plot of Simulated and Observed TSS Load vs Flow at the Lester River at Strand Rd/CR-10 (Calibration Period)

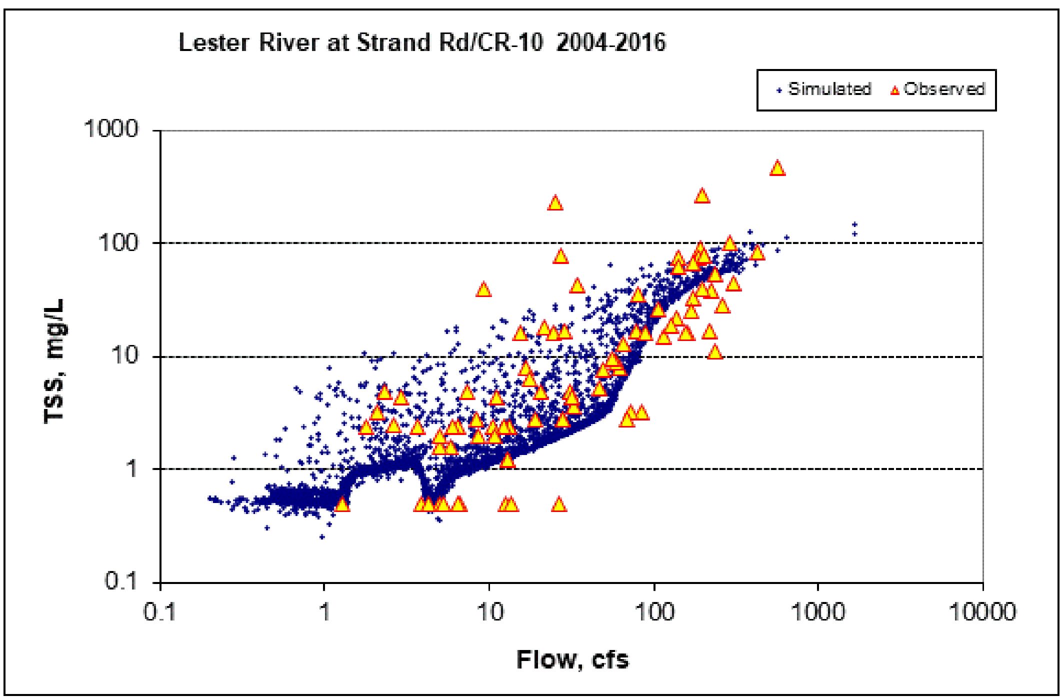


Figure D-2. Simulated and Observed TSS Concentration vs Flow Plot at the Lester River at Strand Rd/CR-10 (Calibration Period)

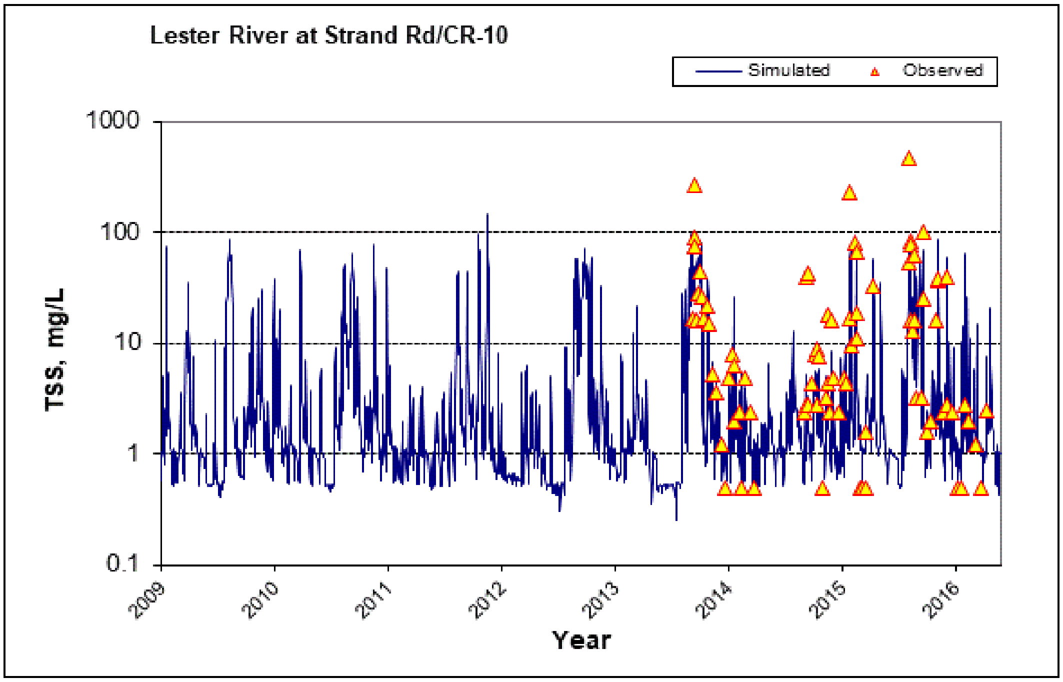


Figure D-3. TSS Concentration Time Series at the Lester River at Strand Rd/CR-10 (2008-2015)

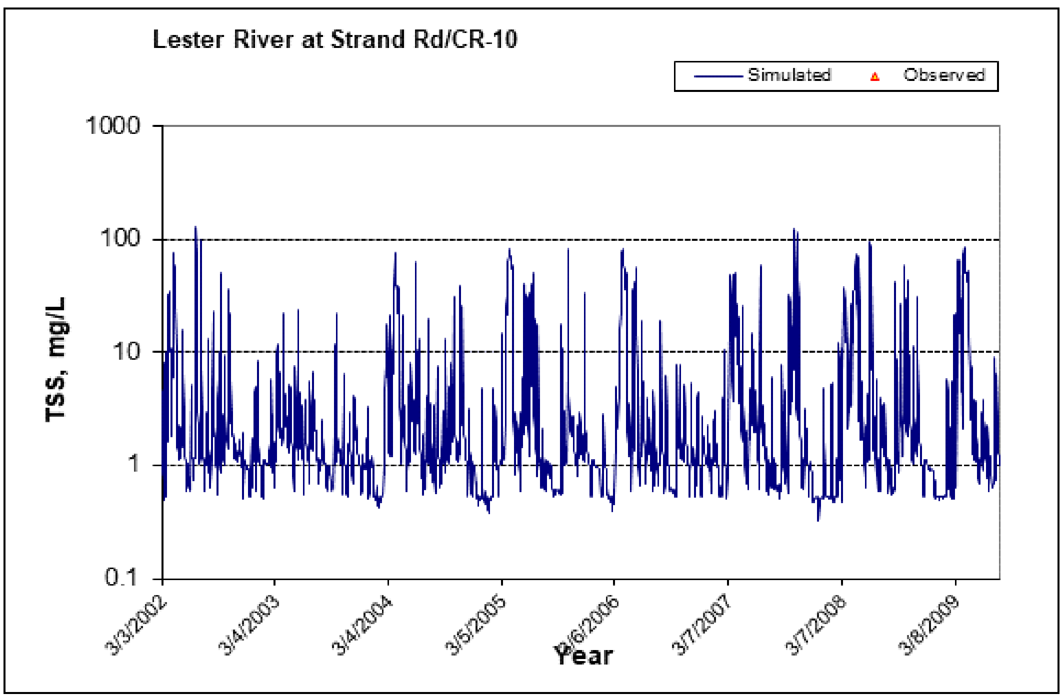


Figure D-4. TSS Concentration Time Series at the Lester River at Strand Rd/CR-10 (2001-2008)

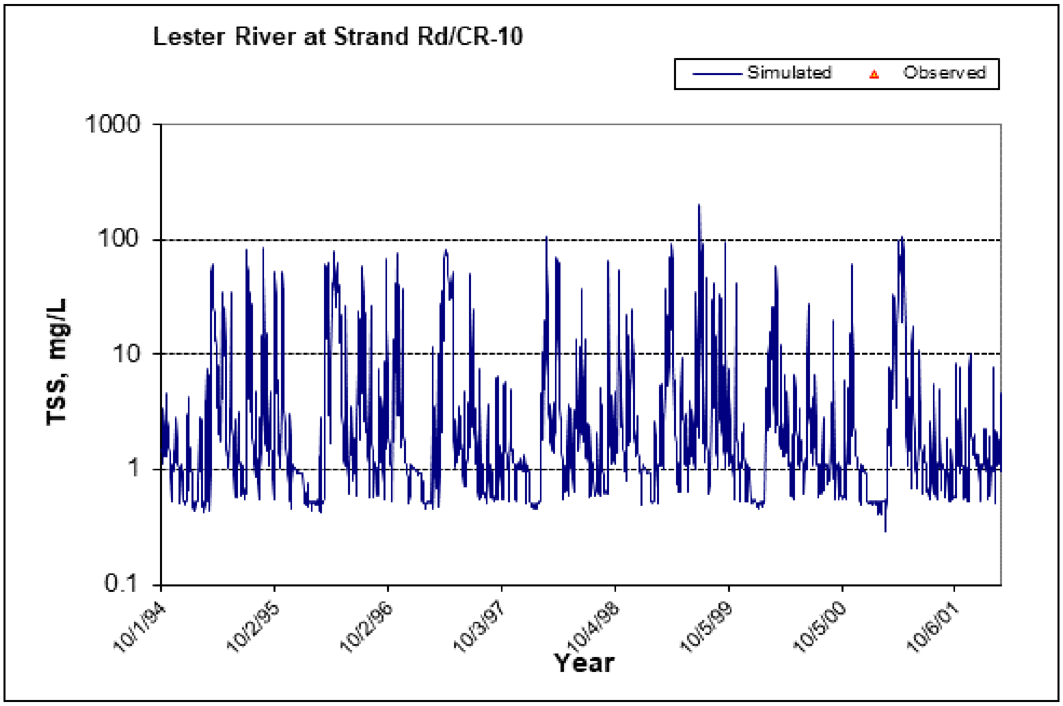


Figure D-5. TSS Concentration Time Series at the Lester River at Strand Rd/CR-10 (1994-2001)

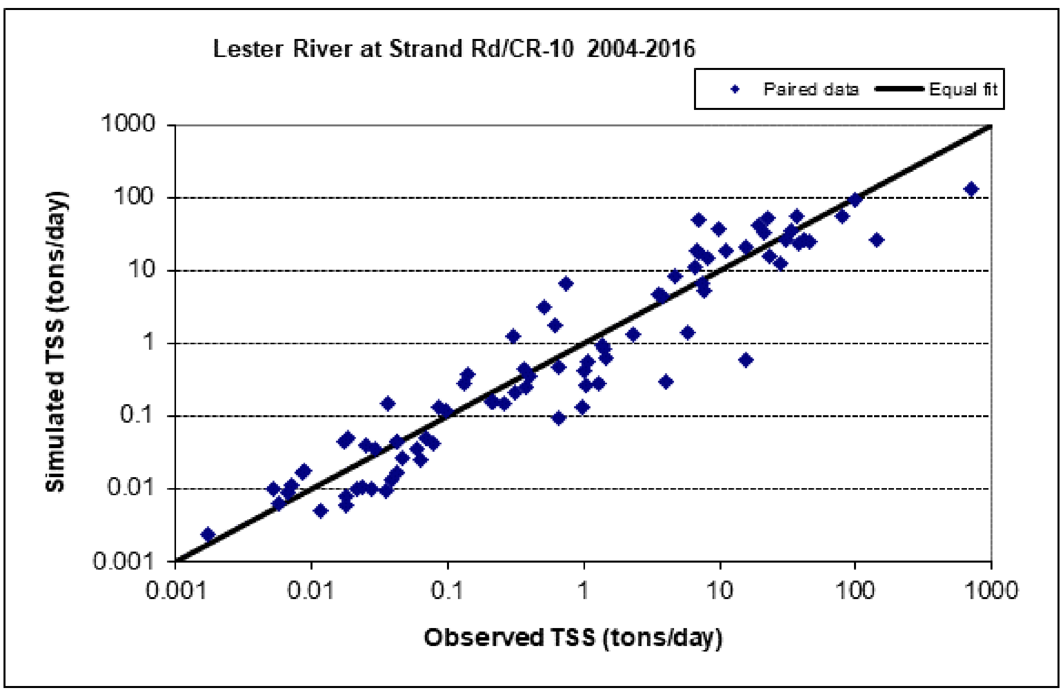


Figure D-6. Paired Simulated vs Observed TSS Load at the Lester River at Strand Rd/CR-10 (Calibration Period)

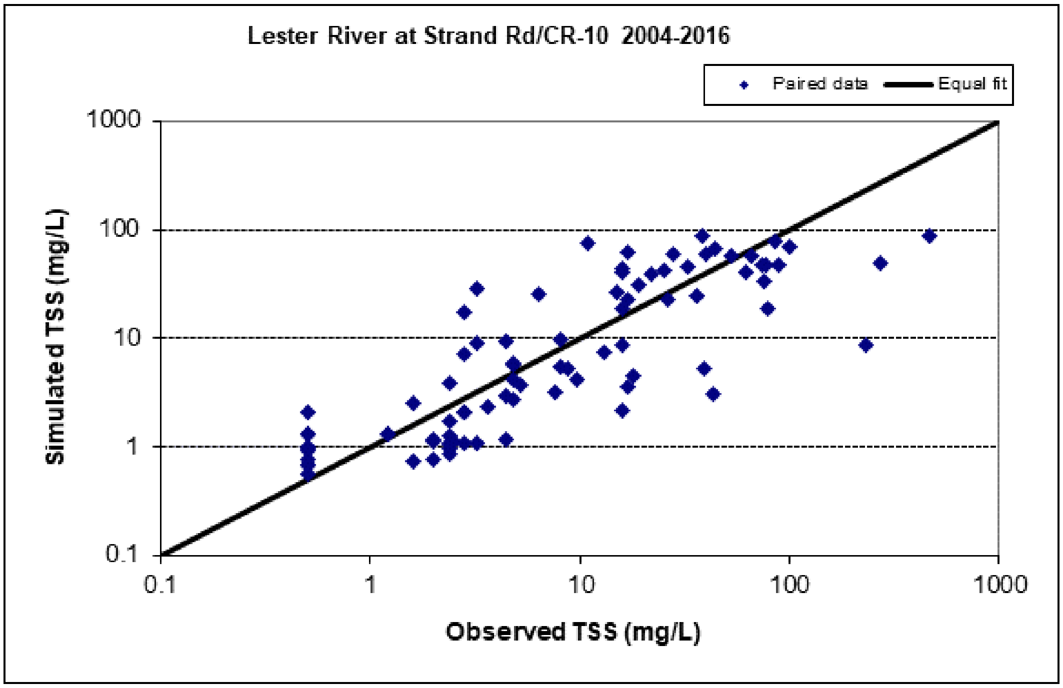


Figure D-7. Paired Simulated vs Observed TSS Concentration at the Lester River at Strand Rd/CR-10 (Calibration Period)

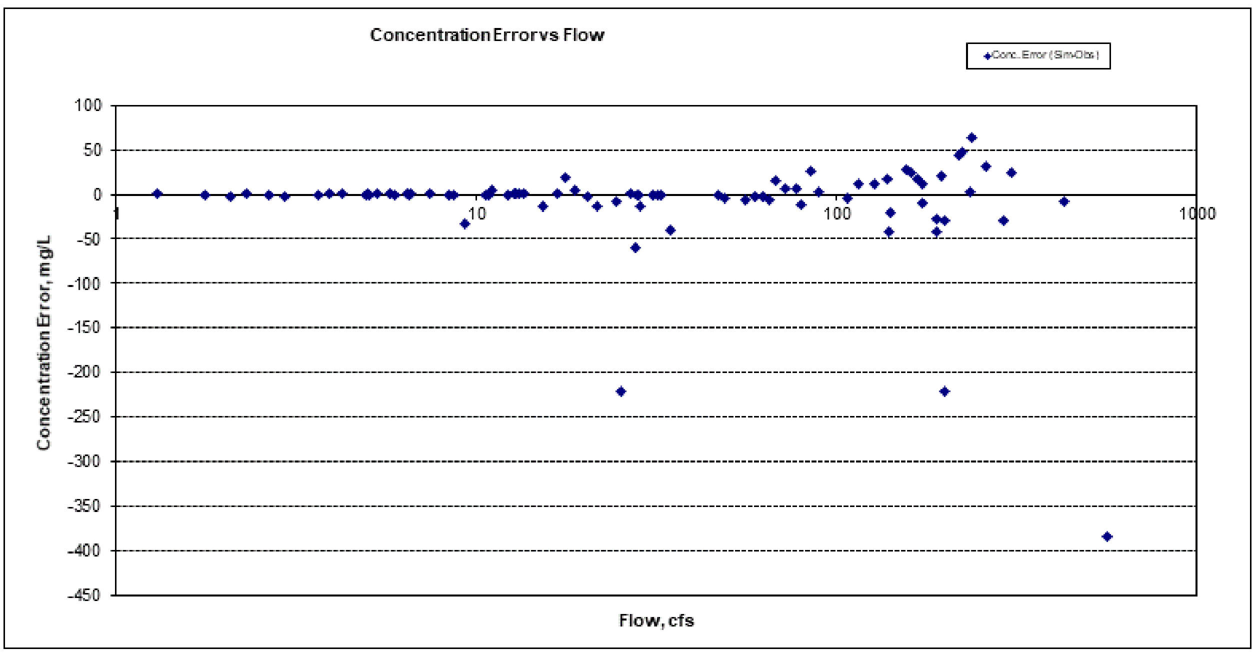


Figure D-8. TSS Concentration Error vs Flow at the Lester River at Strand Rd/CR-10

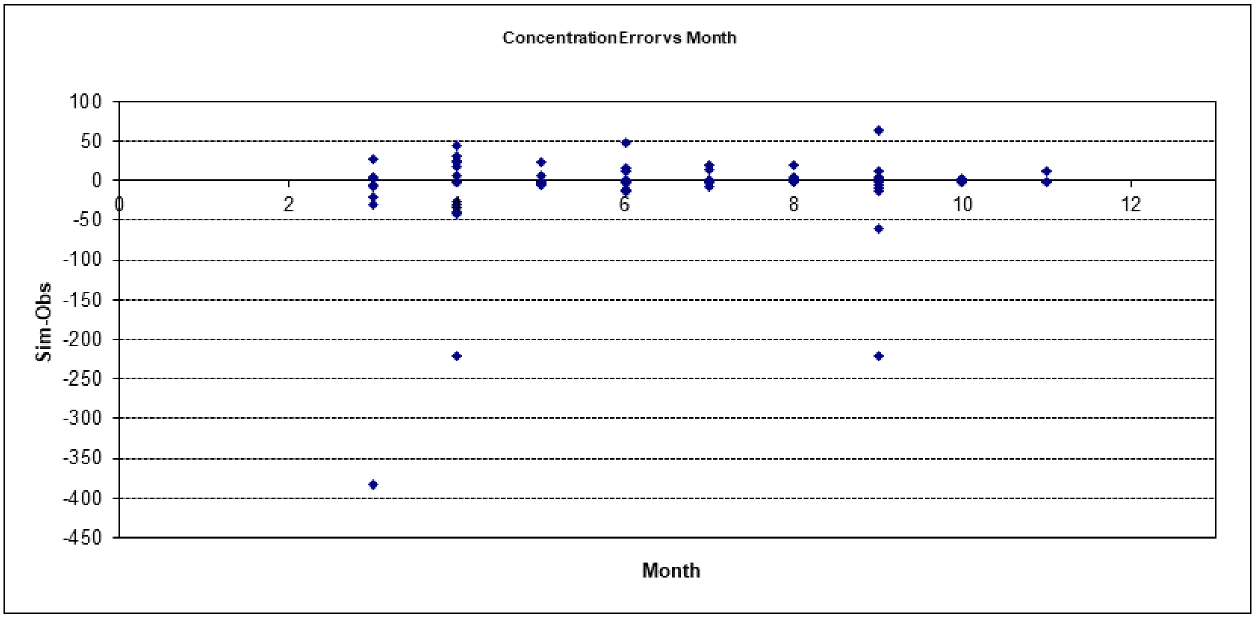


Figure D-9. TSS Concentration Error vs Month at the Lester River at Strand Rd/CR-10

D.2 LESTER RIVER UPSTREAM OF TISCHER RD

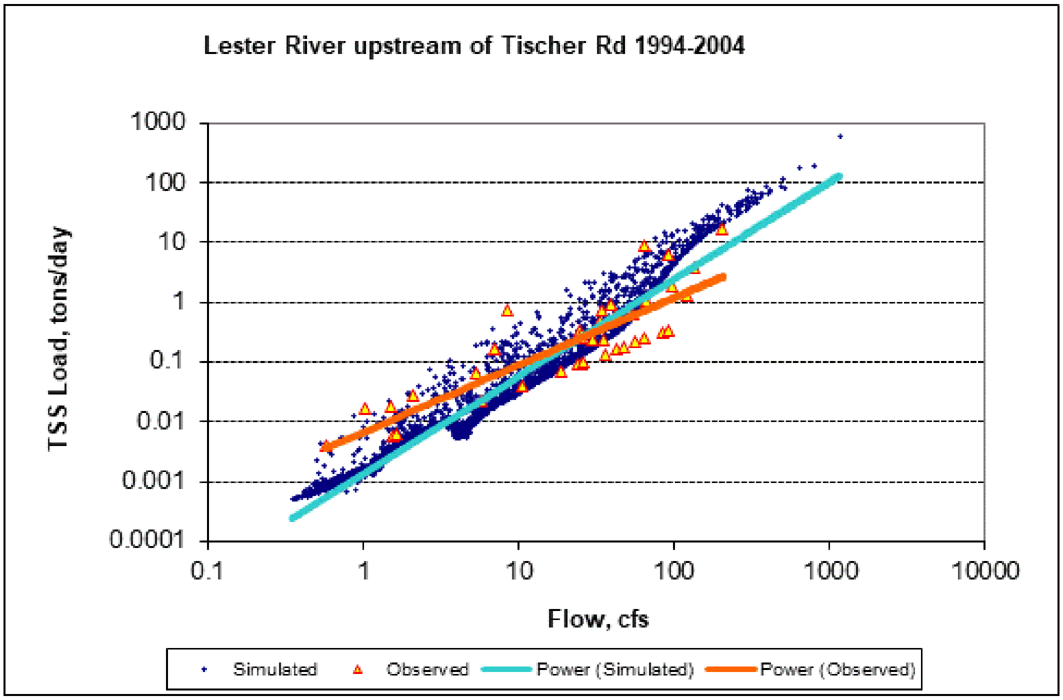


Figure D-10. Power Plot of Simulated and Observed TSS Load vs Flow at the Lester River upstream of Tischer Rd (Validation Period)

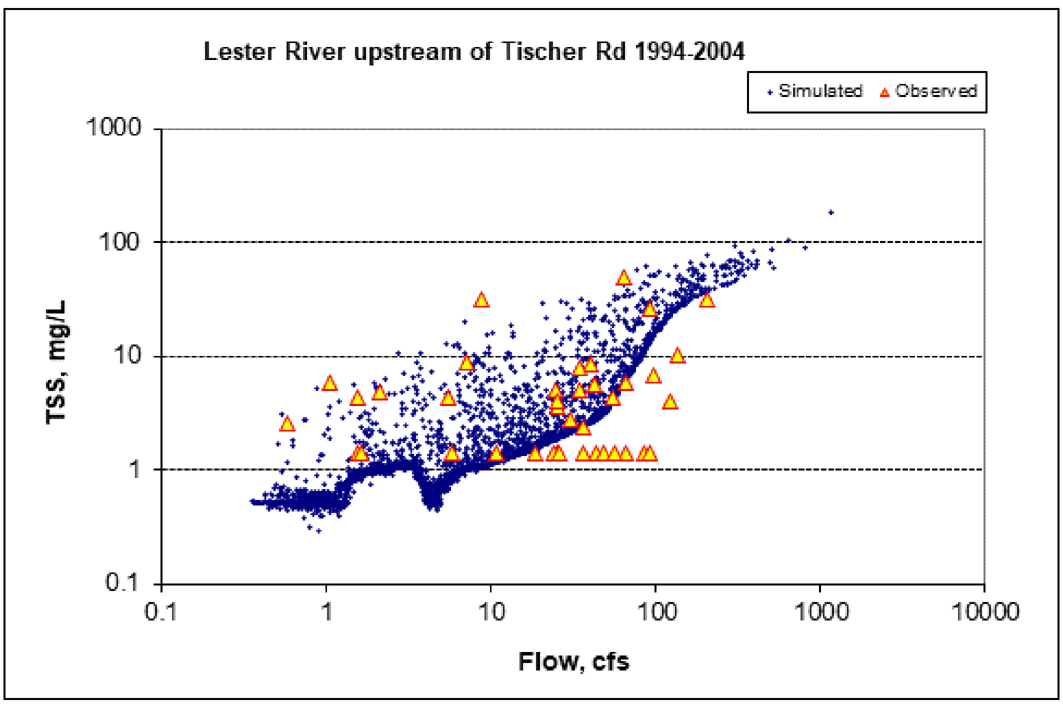


Figure D-11. Simulated and Observed TSS Concentration vs Flow Plot at the Lester River upstream of Tischer Rd (Validation Period)

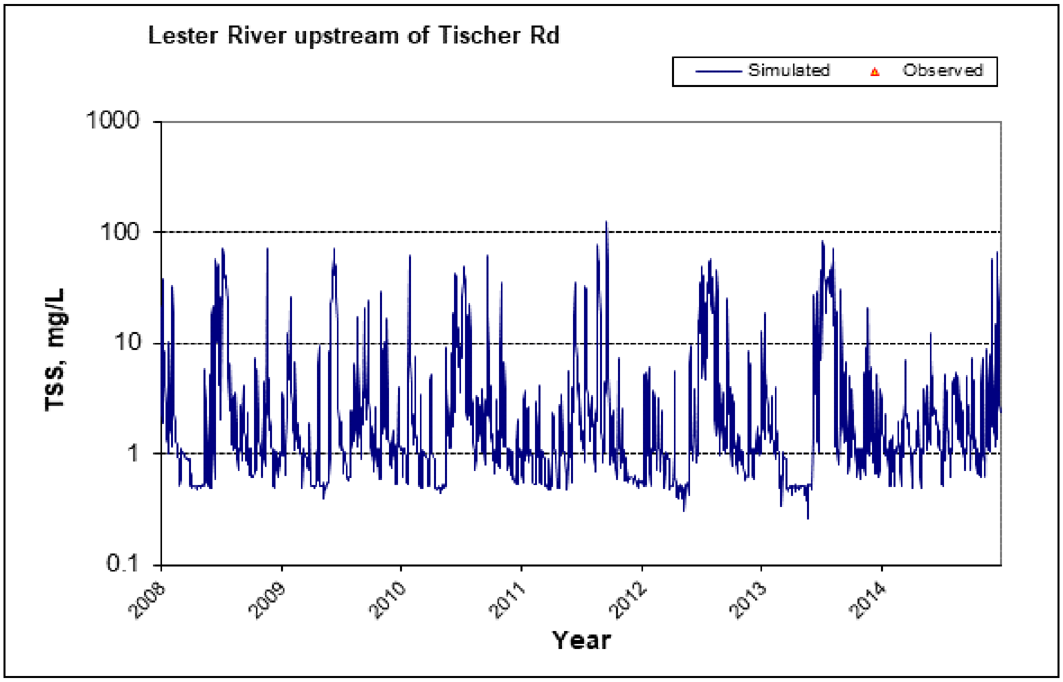


Figure D-12. TSS Concentration Time Series at the Lester River upstream of Tischer Rd (2008-2015)

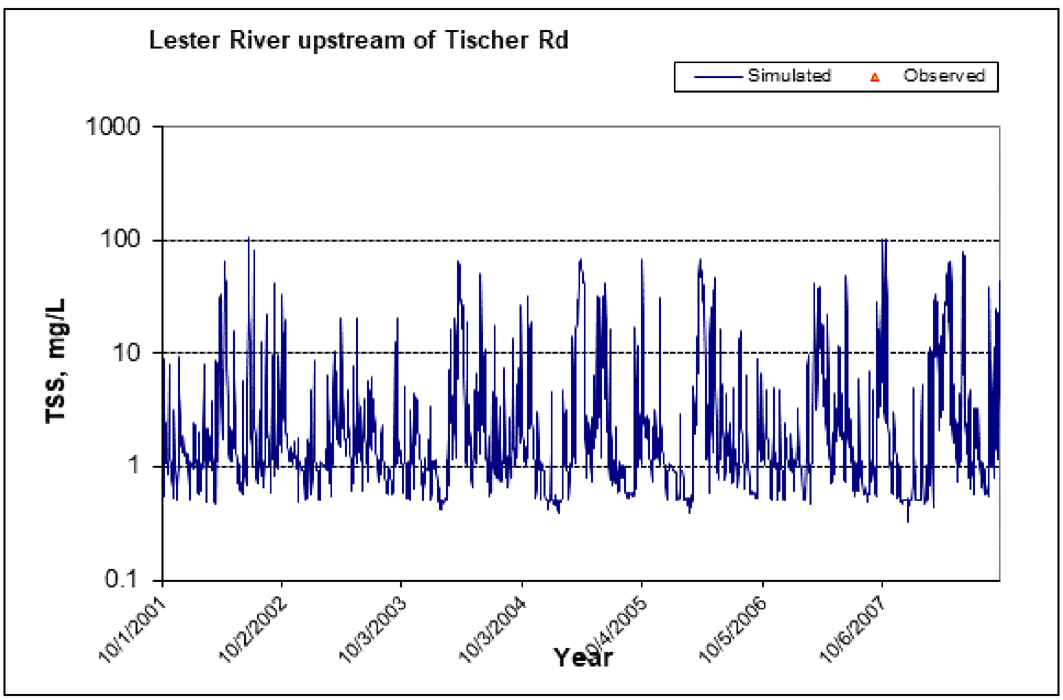


Figure D-13. TSS Concentration Time Series at the Lester River upstream of Tischer Rd (2001-2008)

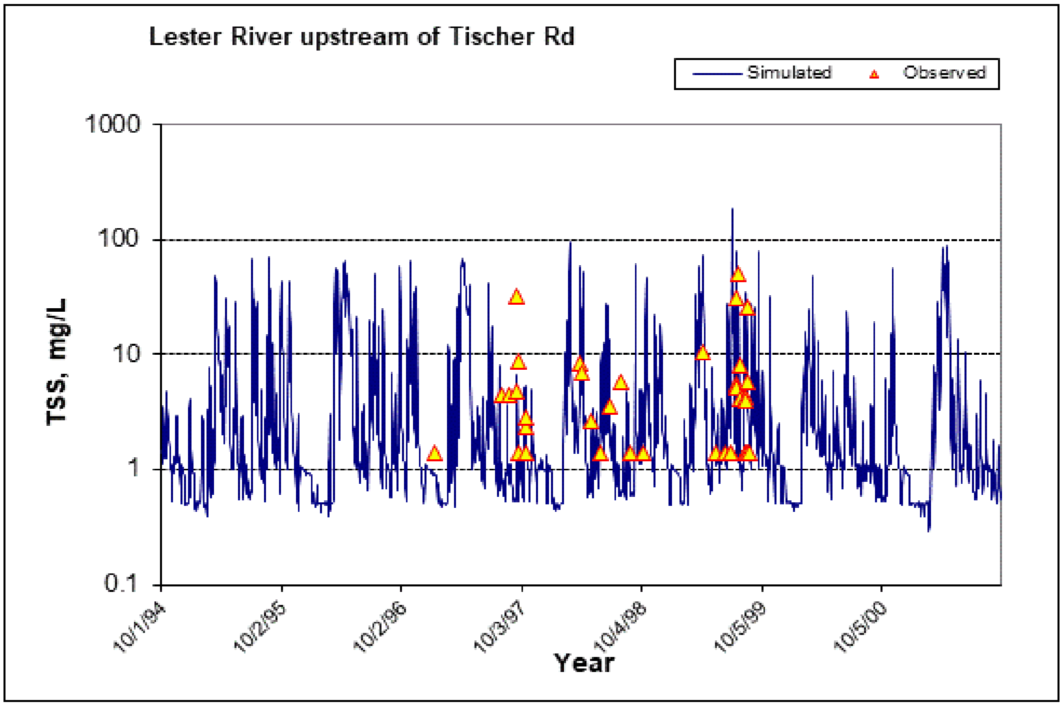


Figure D-14. TSS Concentration Time Series at the Lester River upstream of Tischer Rd (1994-2001)

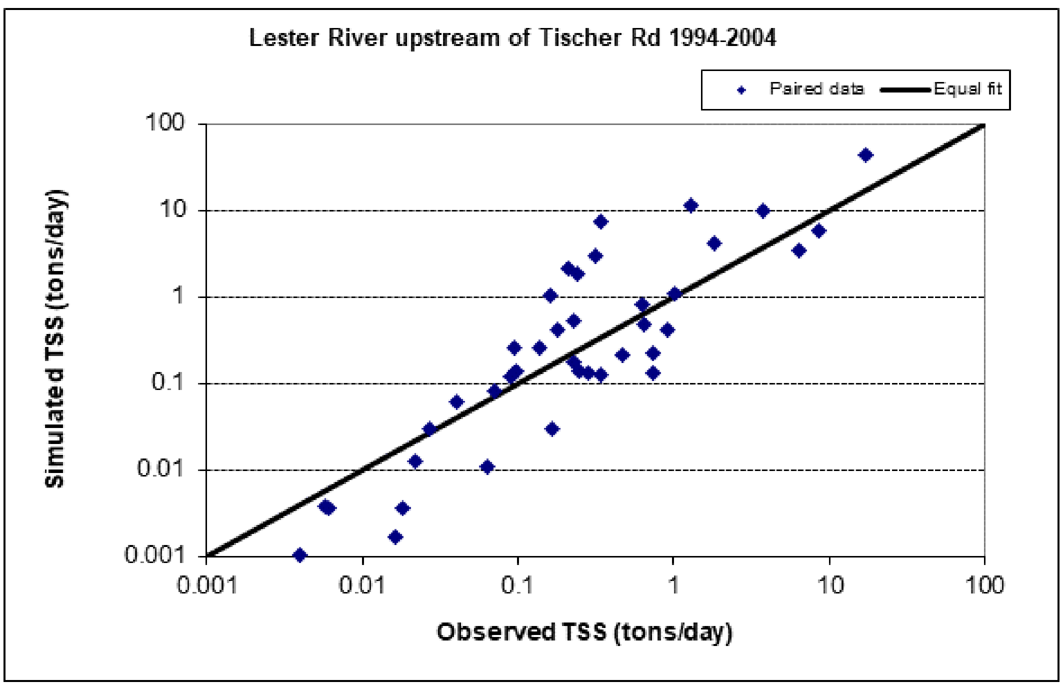


Figure D-15. Paired Simulated vs Observed TSS Load at the Lester River upstream of Tischer Rd (Validation Period)

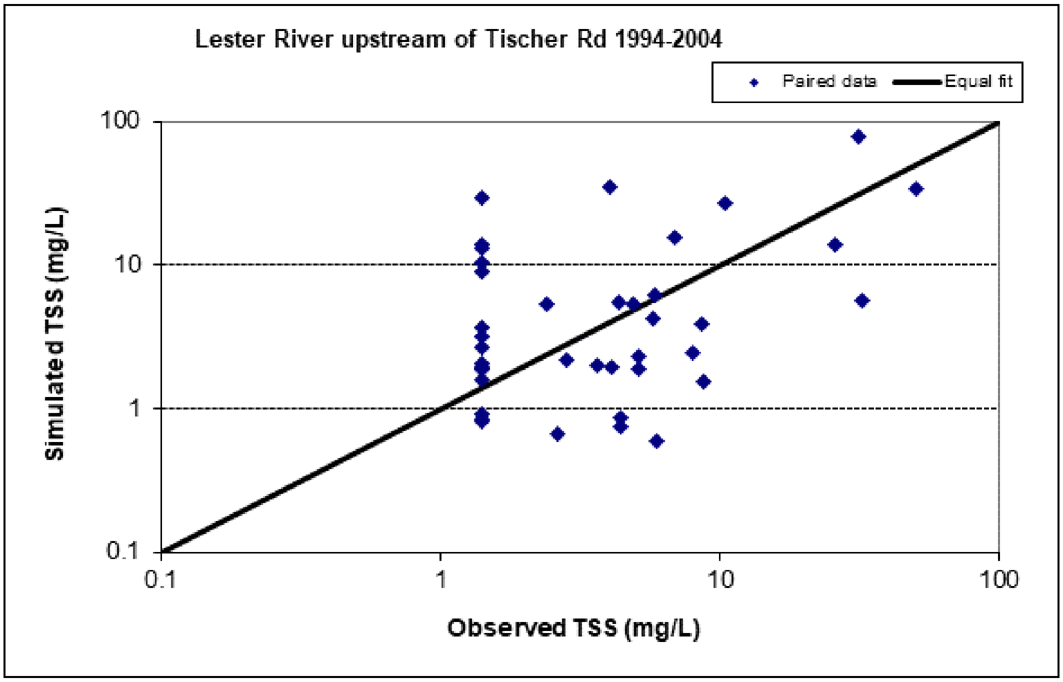


Figure D-16. Paired Simulated vs Observed TSS Concentration at the Lester River upstream of Tischer Rd (Validation Period)

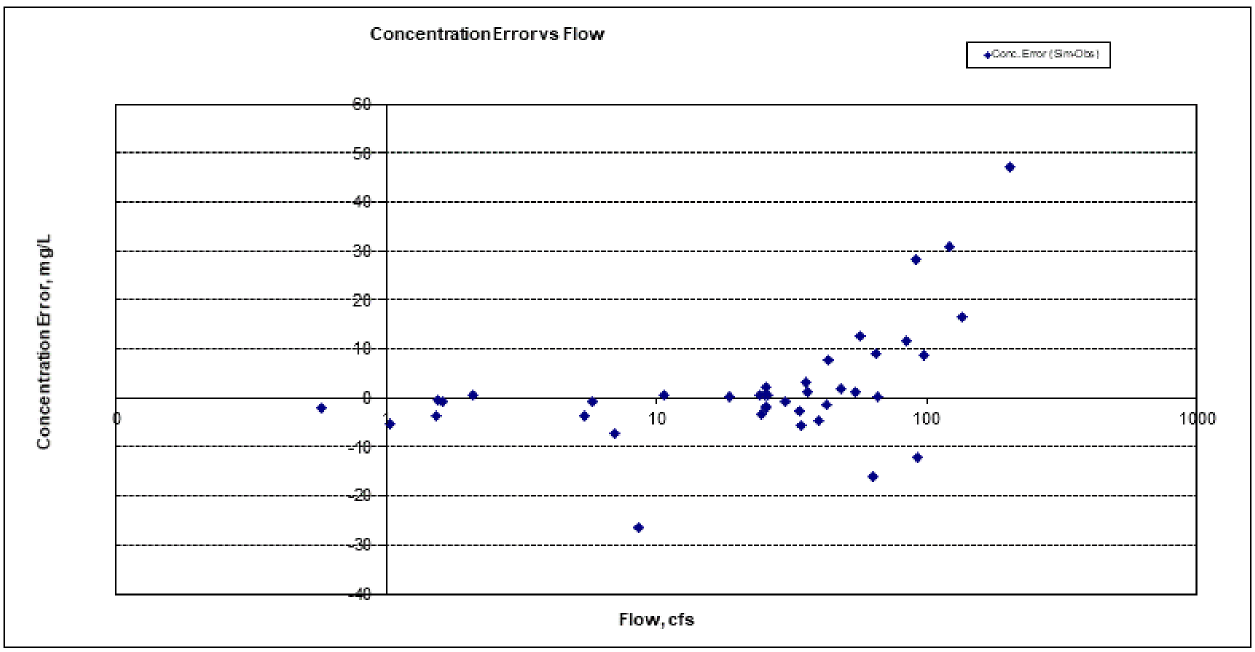


Figure D-17. TSS Concentration Error vs Flow at the Lester River upstream of Tischer Rd

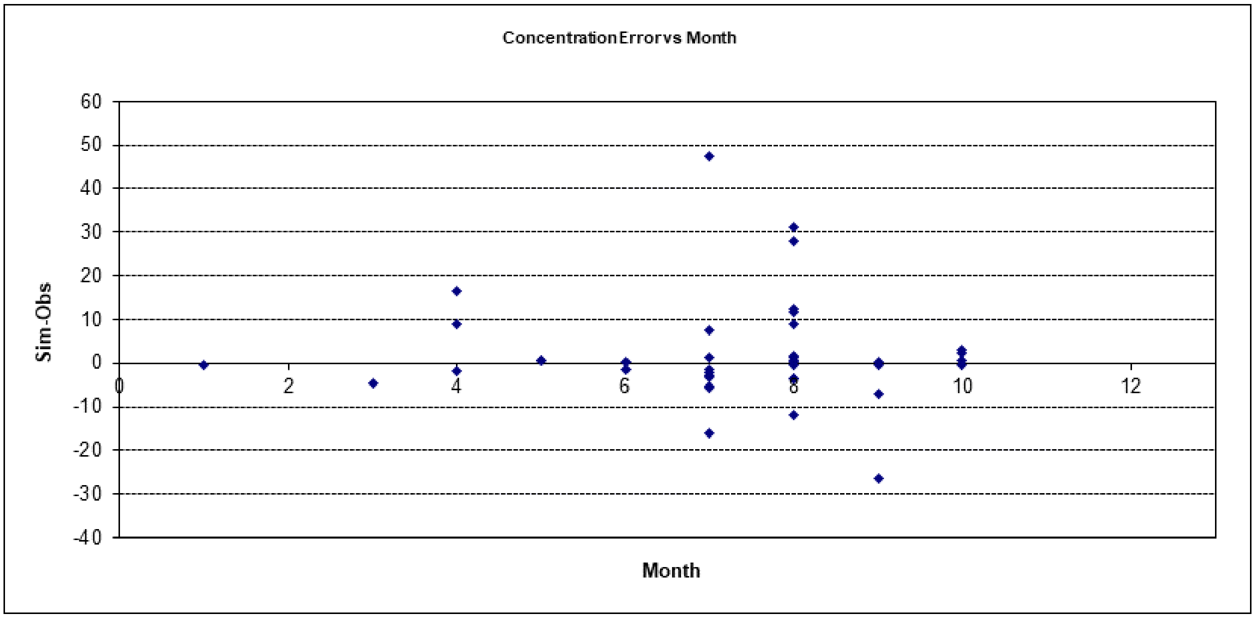


Figure D-18. TSS Concentration Error vs Month at the Lester River upstream of Tischer Rd

D.3 LESTER RIVER ABOVE SUPERIOR STREET

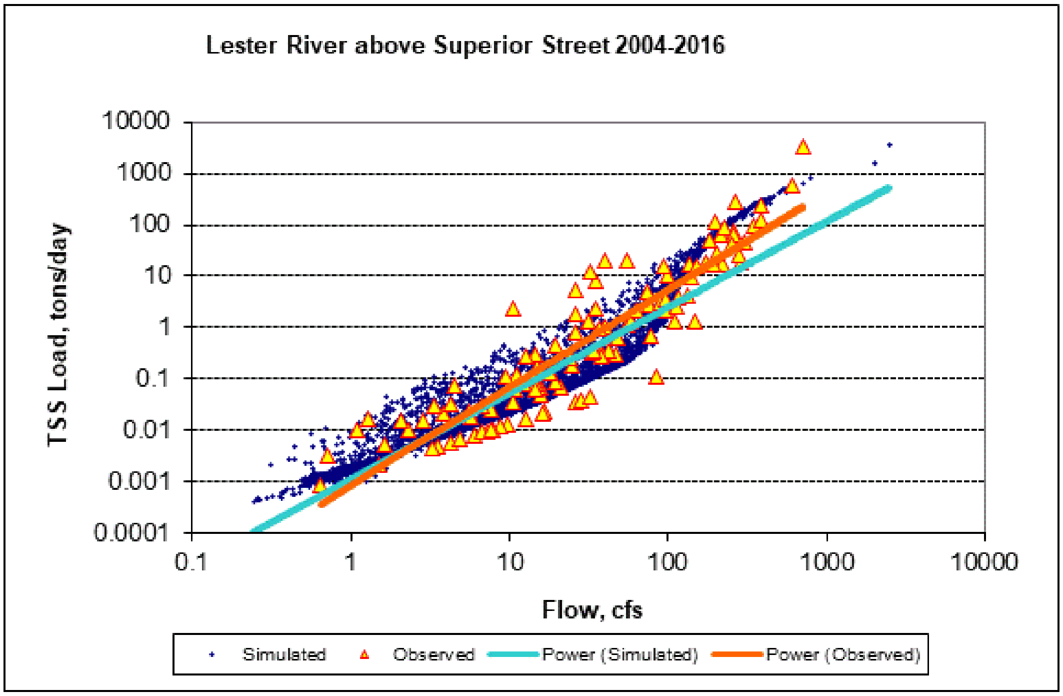


Figure D-19. Power Plot of Simulated and Observed TSS Load vs Flow at the Lester River above Superior Street (Calibration Period)

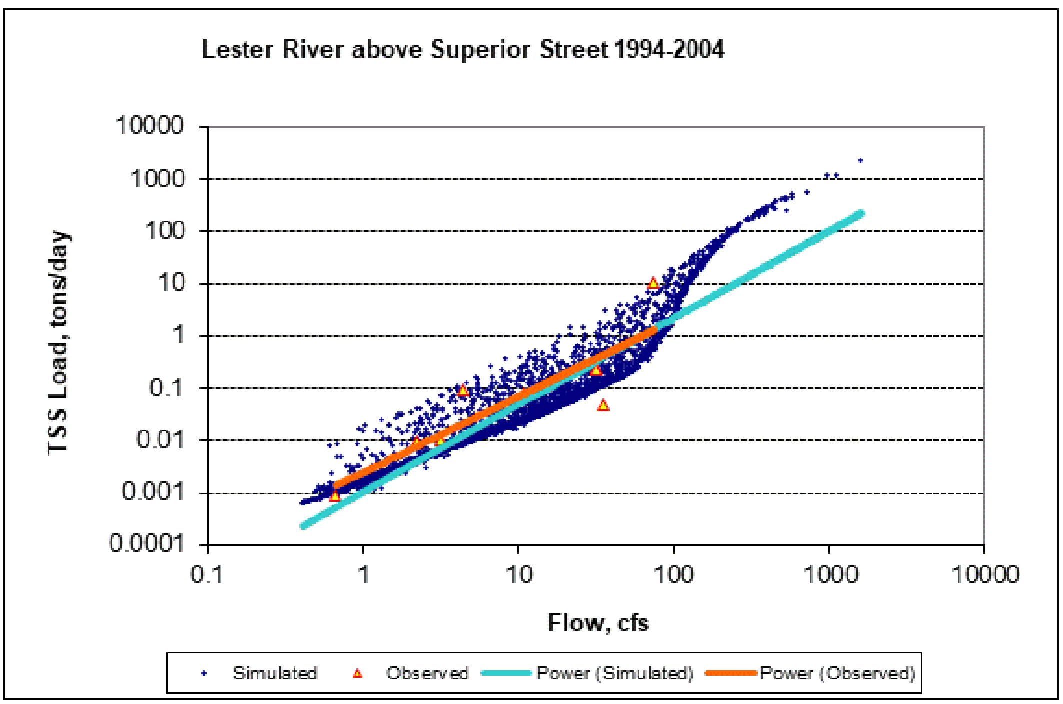


Figure D-20. Power Plot of Simulated and Observed TSS Load vs Flow at the Lester River above Superior Street (Validation Period)

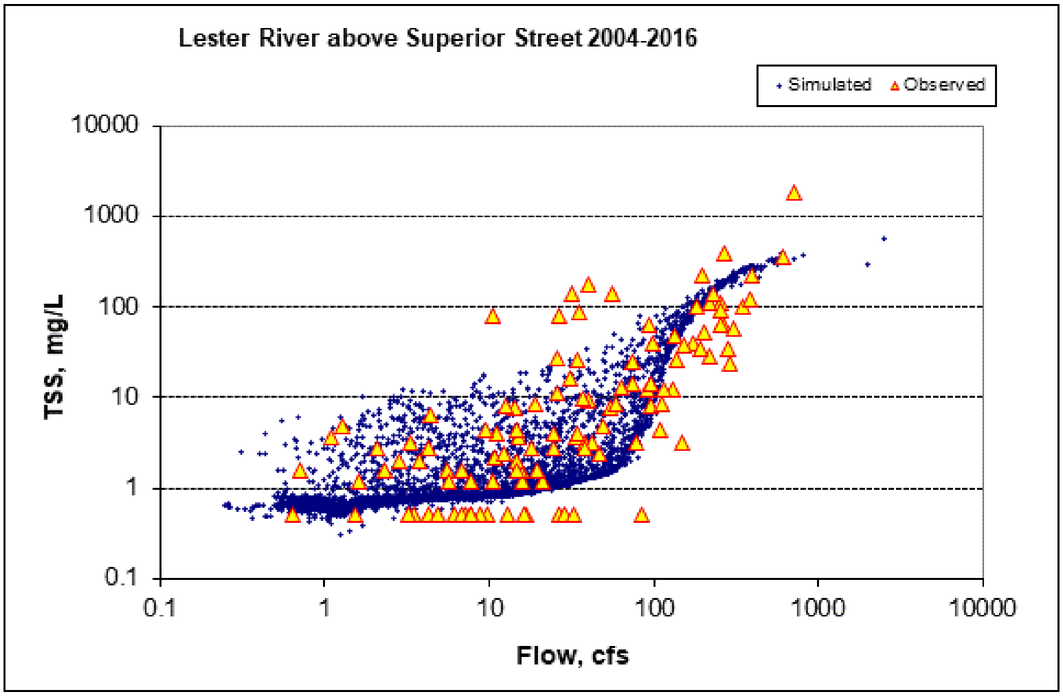


Figure D-21. Simulated and Observed TSS Concentration vs Flow Plot at the Lester River above Superior Street (Calibration Period)

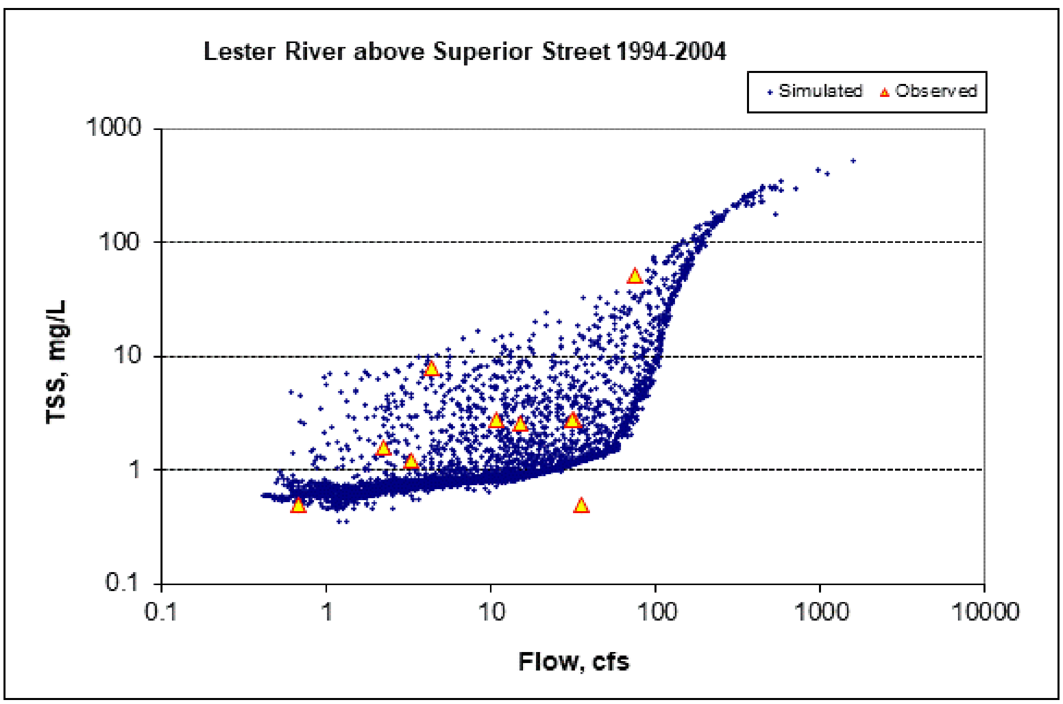


Figure D-22. Simulated and Observed TSS Concentration vs Flow Plot at the Lester River above Superior Street (Validation Period)

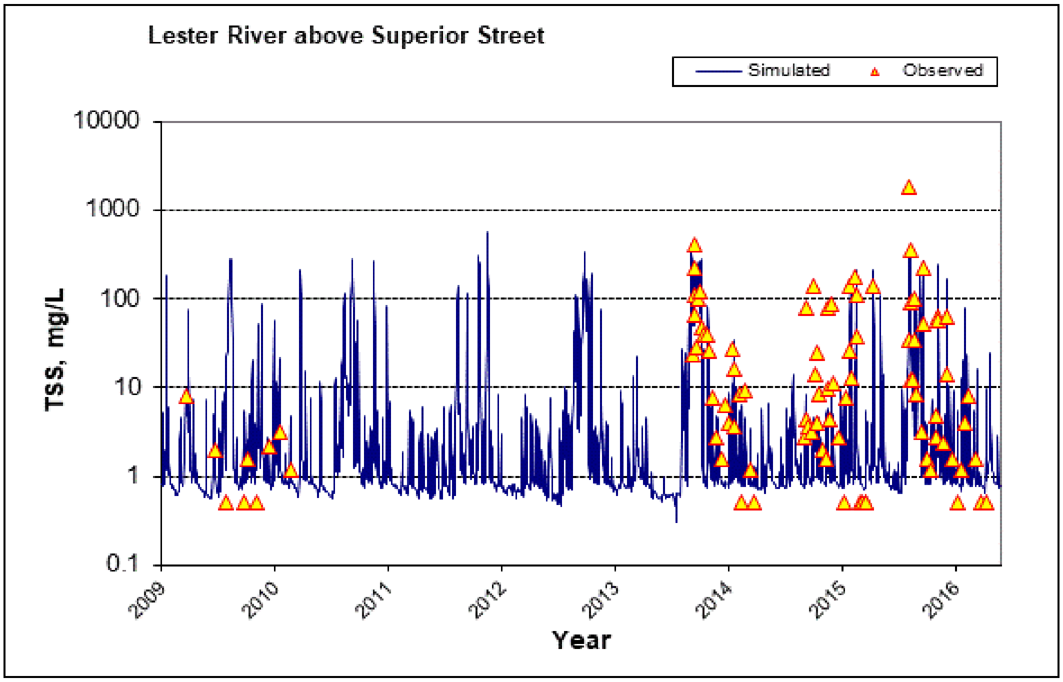


Figure D-23. TSS Concentration Time Series at the Lester River above Superior Street (2008-2015)

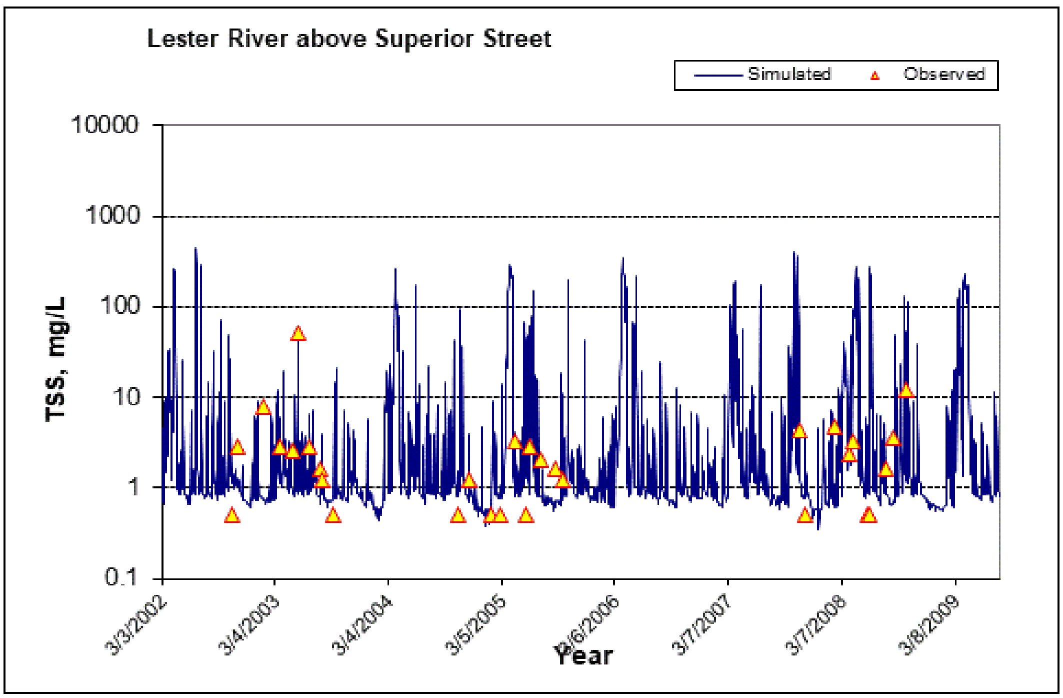


Figure D-24. TSS Concentration Time Series at the Lester River above Superior Street (2001-2008)

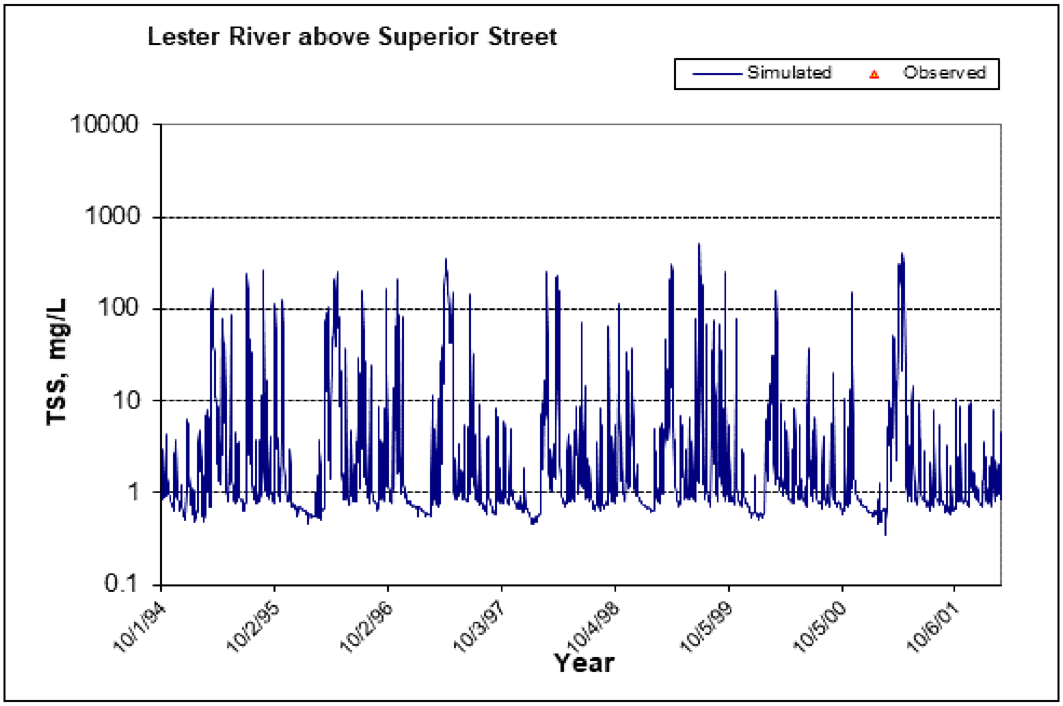


Figure D-25. TSS Concentration Time Series at the Lester River above Superior Street (1994-2001)

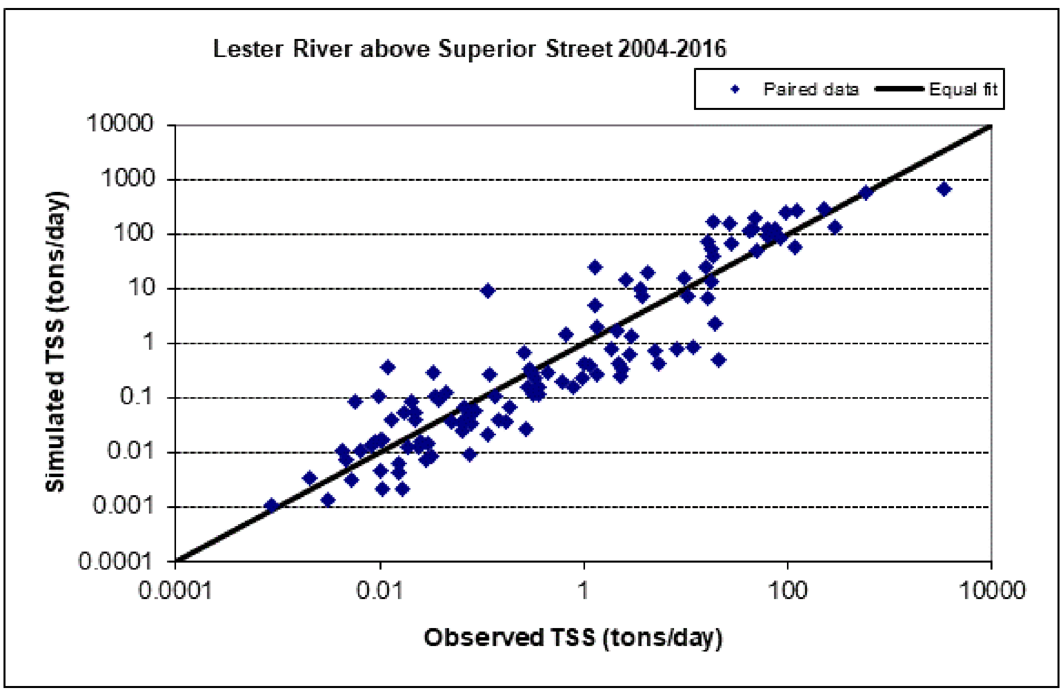


Figure D-26. Paired Simulated vs Observed TSS Load at the Lester River above Superior Street (Calibration Period)

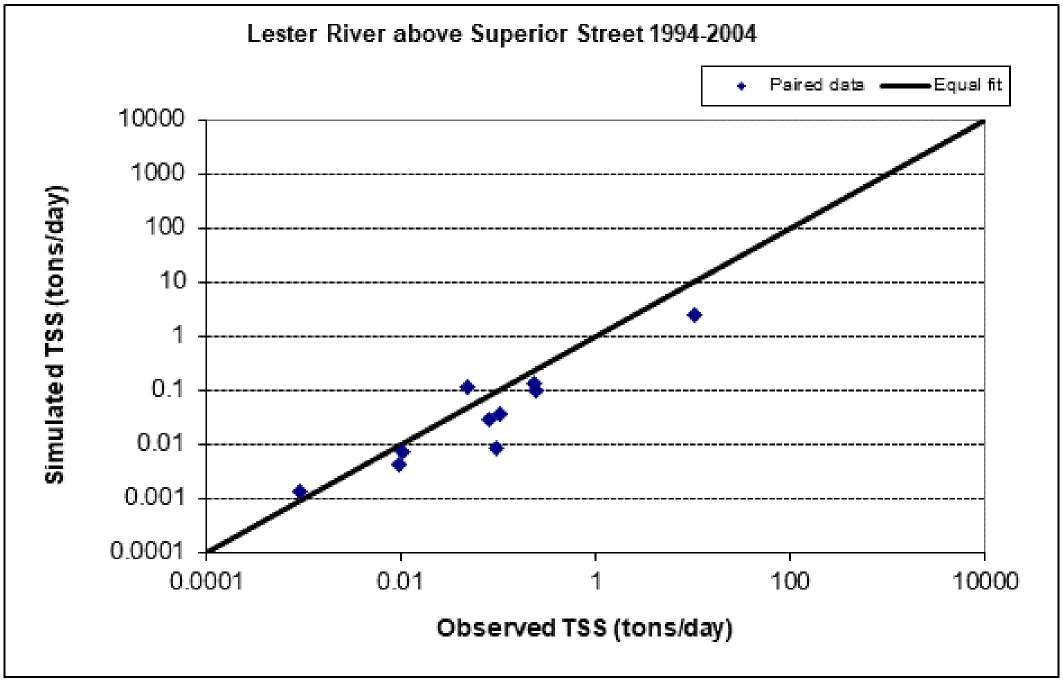


Figure D-27. Paired Simulated vs Observed TSS Load at the Lester River above Superior Street (Validation Period)

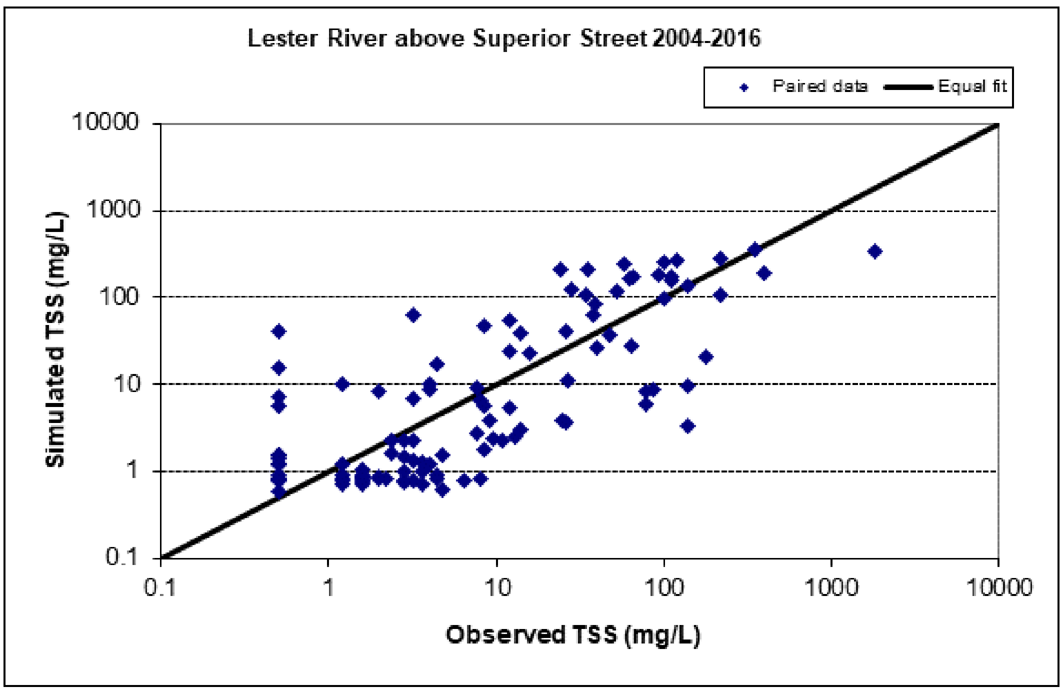


Figure D-28. Paired Simulated vs Observed TSS Concentration at the Lester River above Superior Street (Calibration Period)

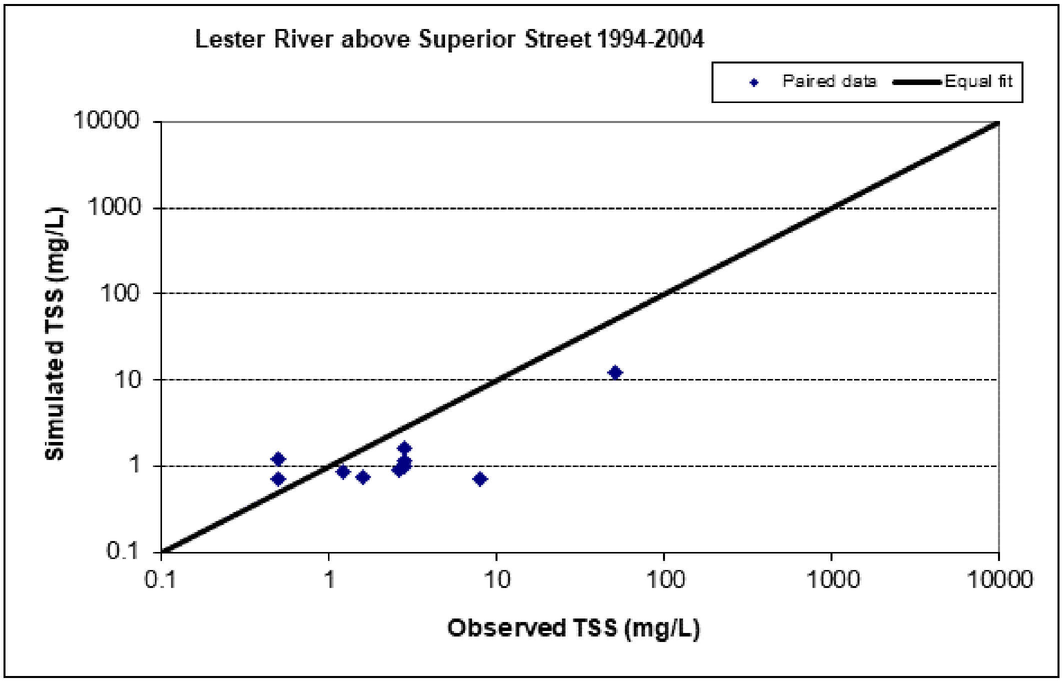


Figure D-29. Paired Simulated vs Observed TSS Concentration at the Lester River above Superior Street (Validation Period)

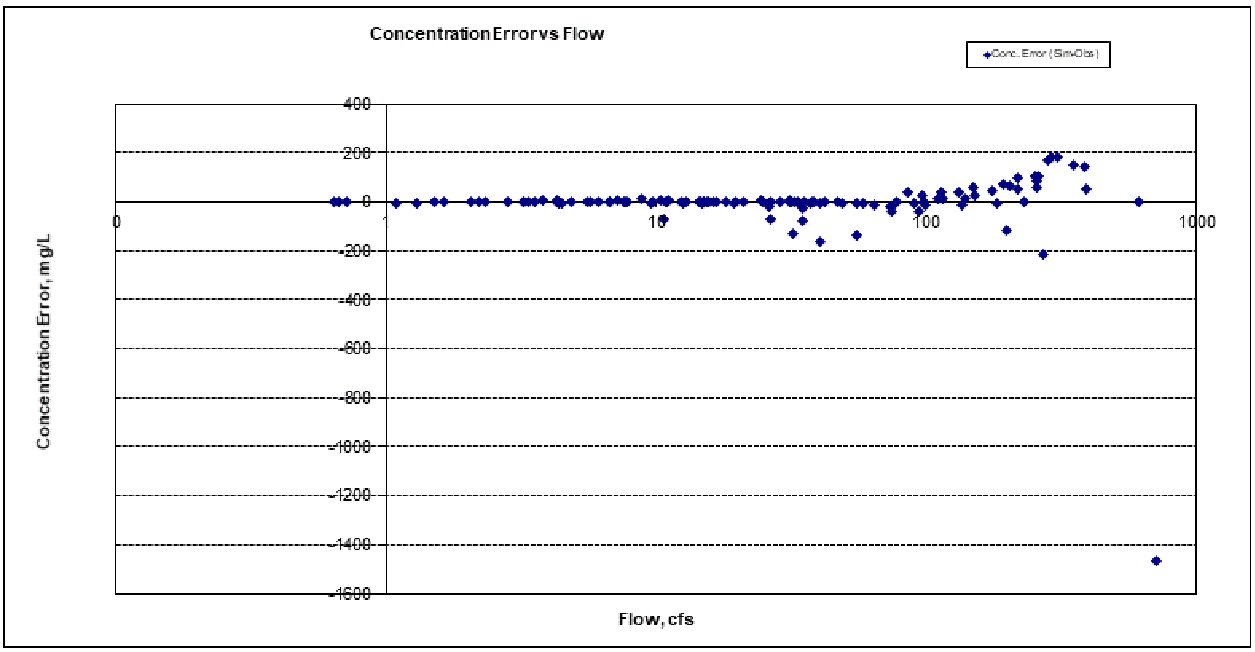


Figure D-30. TSS Concentration Error vs Flow at the Lester River above Superior Street

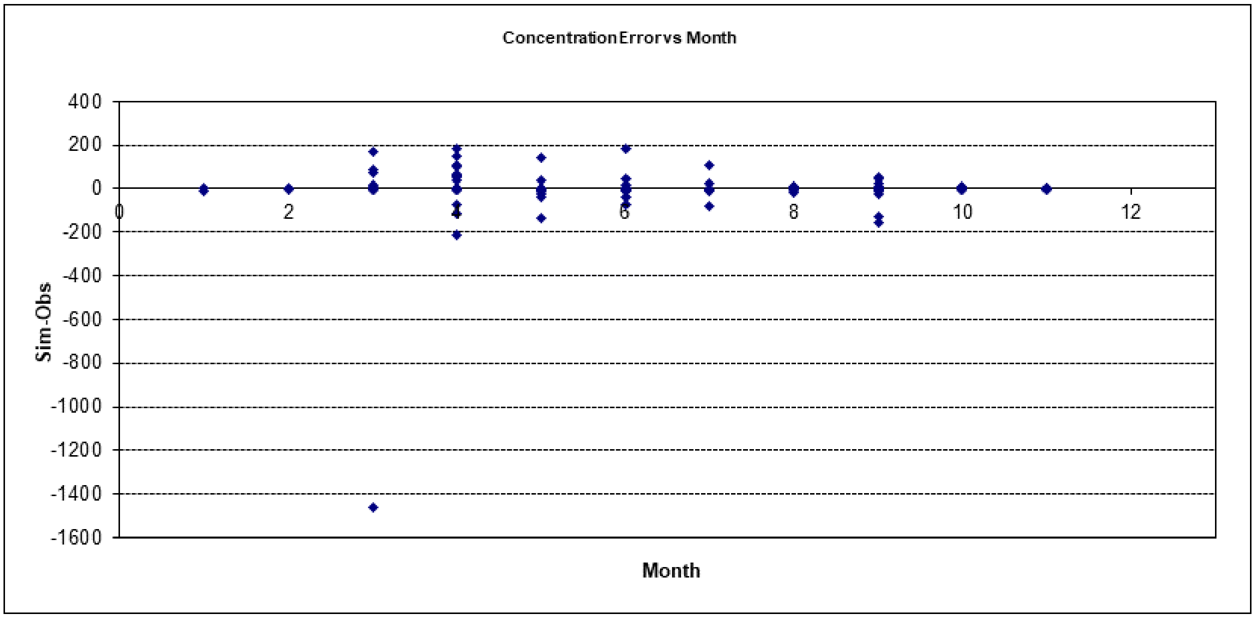


Figure D-31. TSS Concentration Error vs Month at the Lester River above Superior Street

D.4 East Br Amity Cr above Confluence with Amity Cr

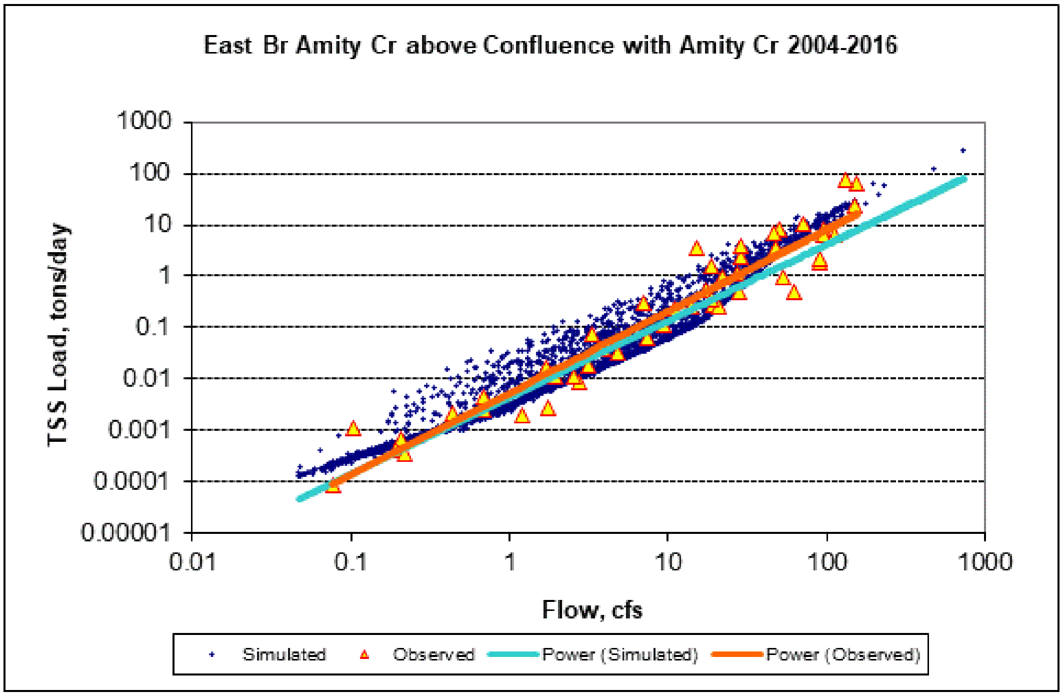


Figure D-32. Power Plot of Simulated and Observed TSS Load vs Flow at the East Br Amity Cr above Confluence with Amity Cr (Calibration Period)

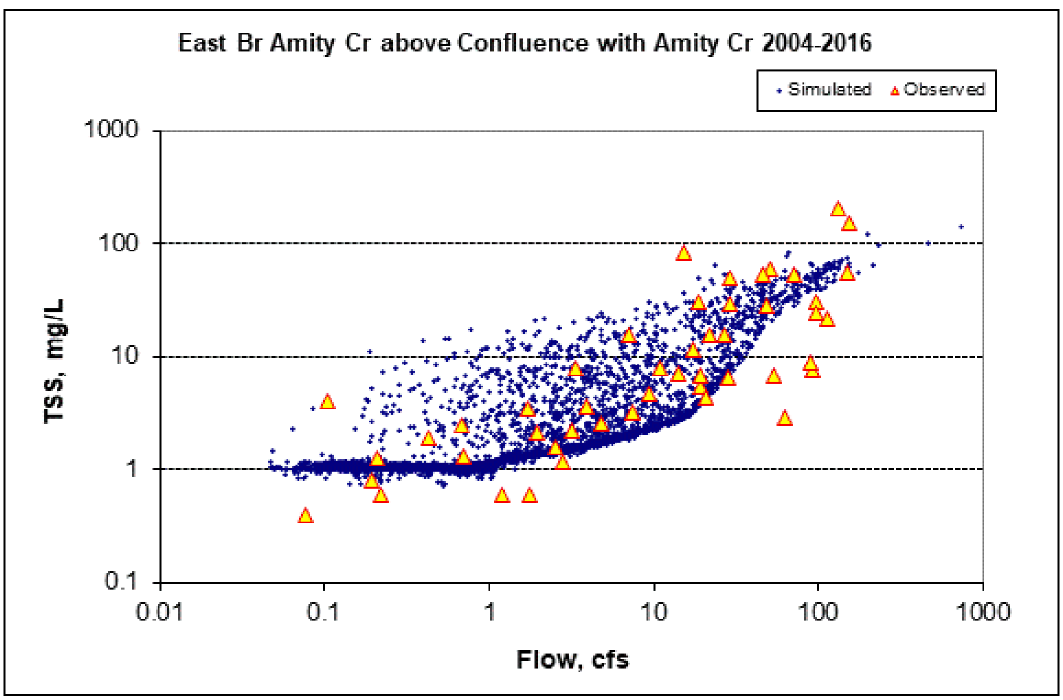


Figure D-33. Simulated and Observed TSS Concentration vs Flow Plot at the East Br Amity Cr above Confluence with Amity Cr (Calibration Period)

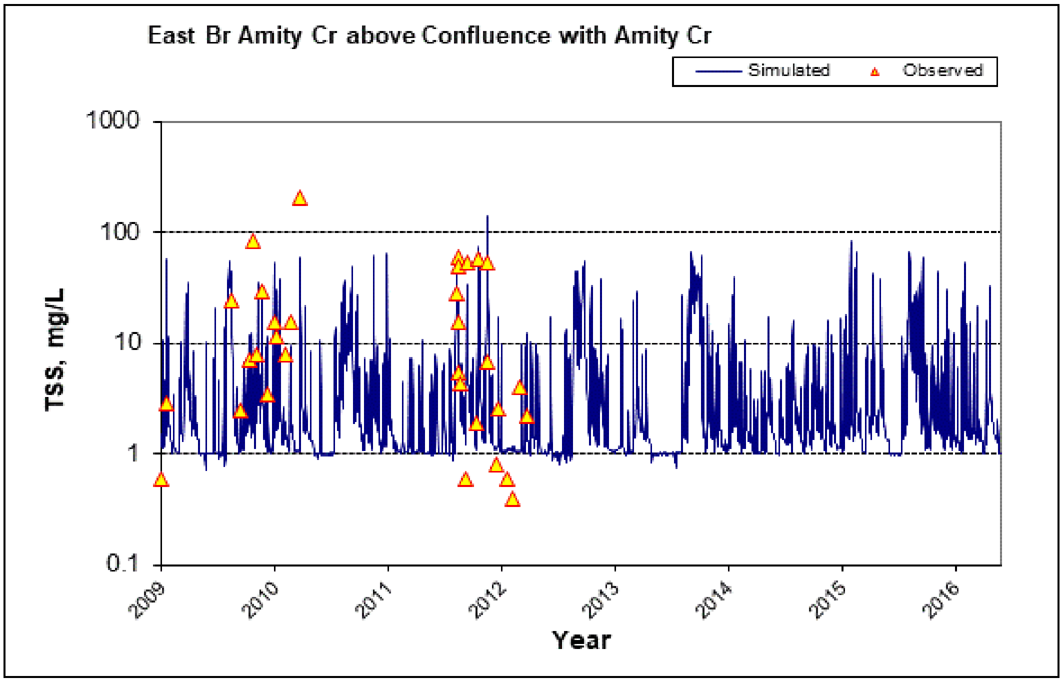


Figure D-34. TSS Concentration Time Series at the East Br Amity Cr above Confluence with Amity Cr (2008-2015)

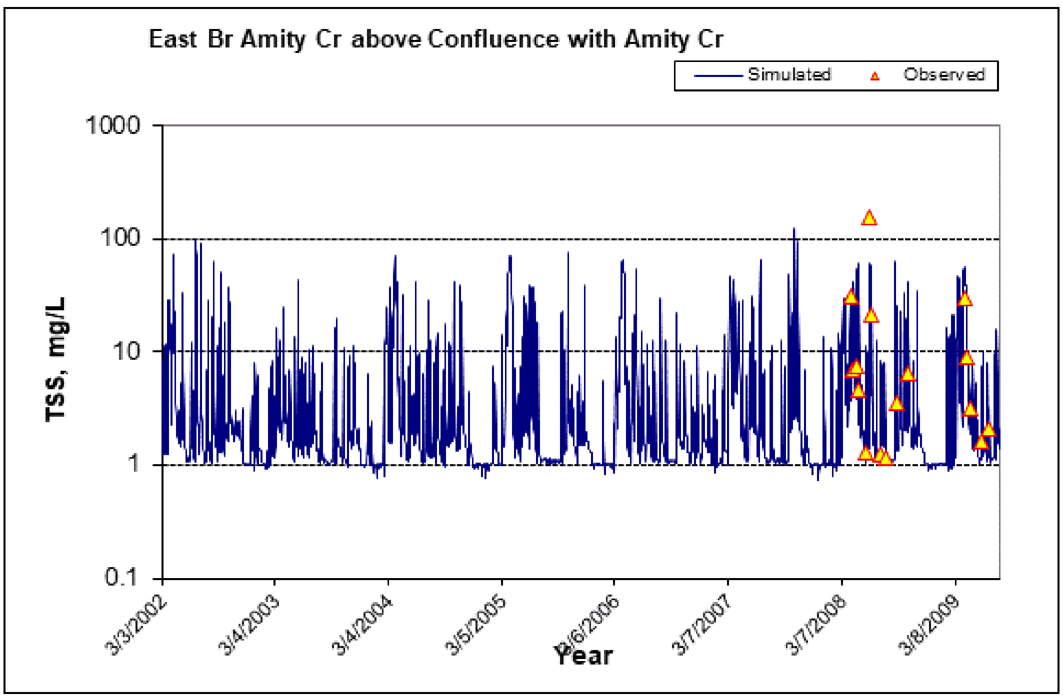


Figure D-35. TSS Concentration Time Series at the East Br Amity Cr above Confluence with Amity Cr (2001-2008)

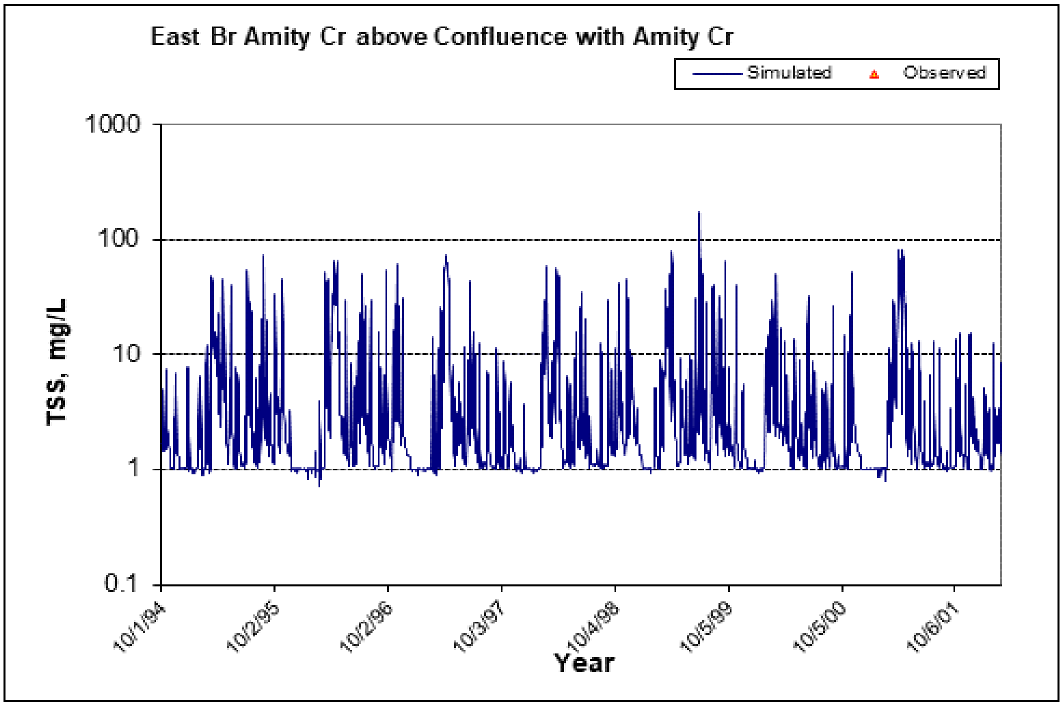


Figure D-36. TSS Concentration Time Series at the East Br Amity Cr above Confluence with Amity Cr (1994-2001)

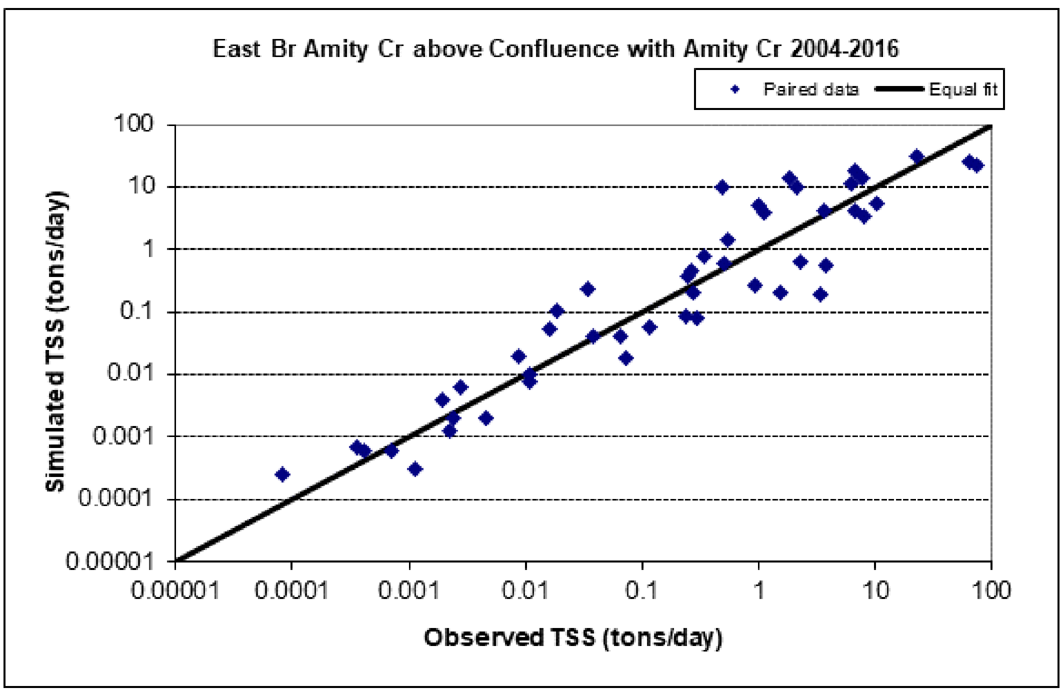


Figure D-37. Paired Simulated vs Observed TSS Load at the East Br Amity Cr above Confluence with Amity Cr (Calibration Period)

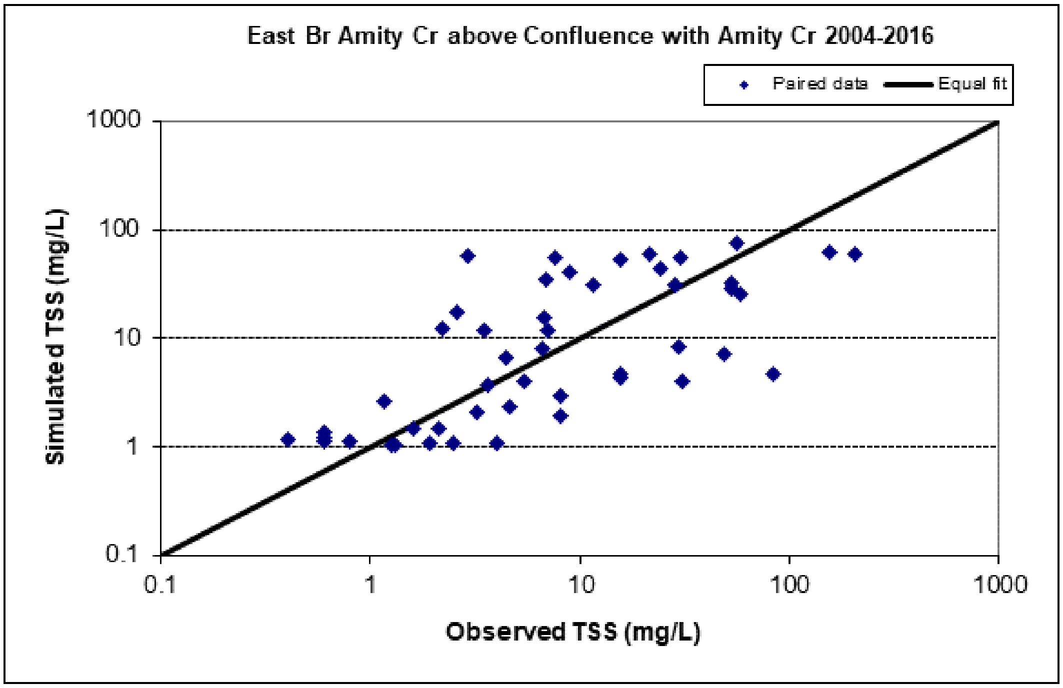


Figure D-38. Paired Simulated vs Observed TSS Concentration at the East Br Amity Cr above Confluence with Amity Cr (Calibration Period)

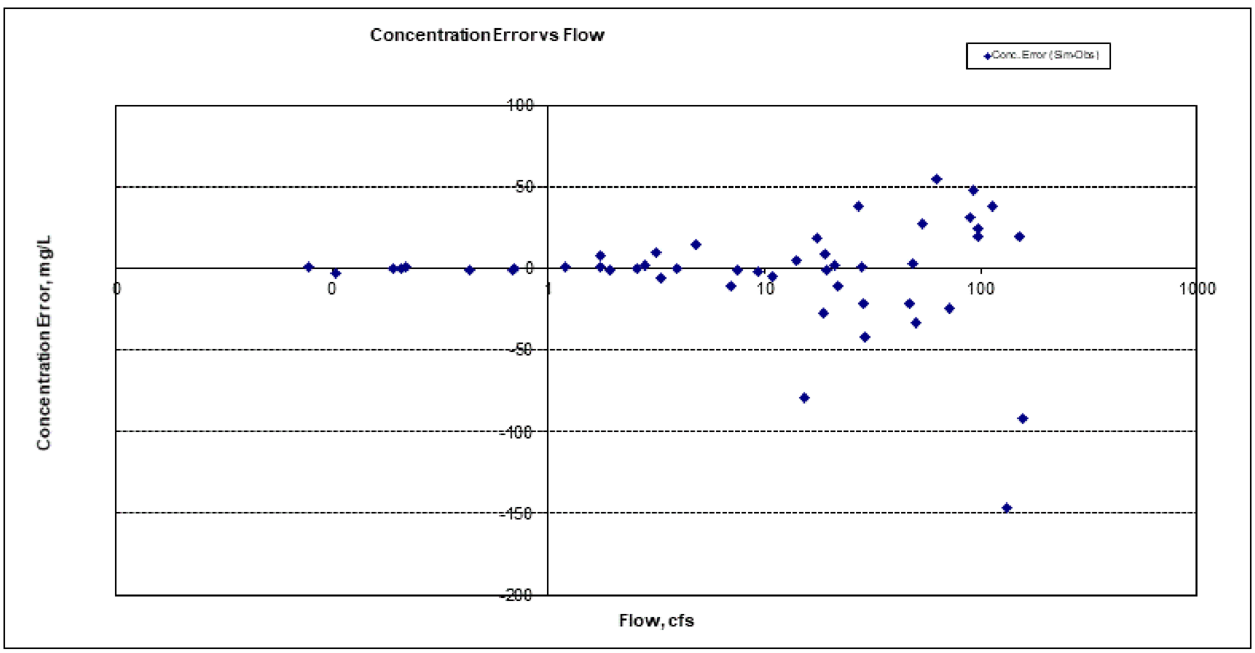


Figure D-39. TSS Concentration Error vs Flow at the East Br Amity Cr above Confluence with Amity Cr

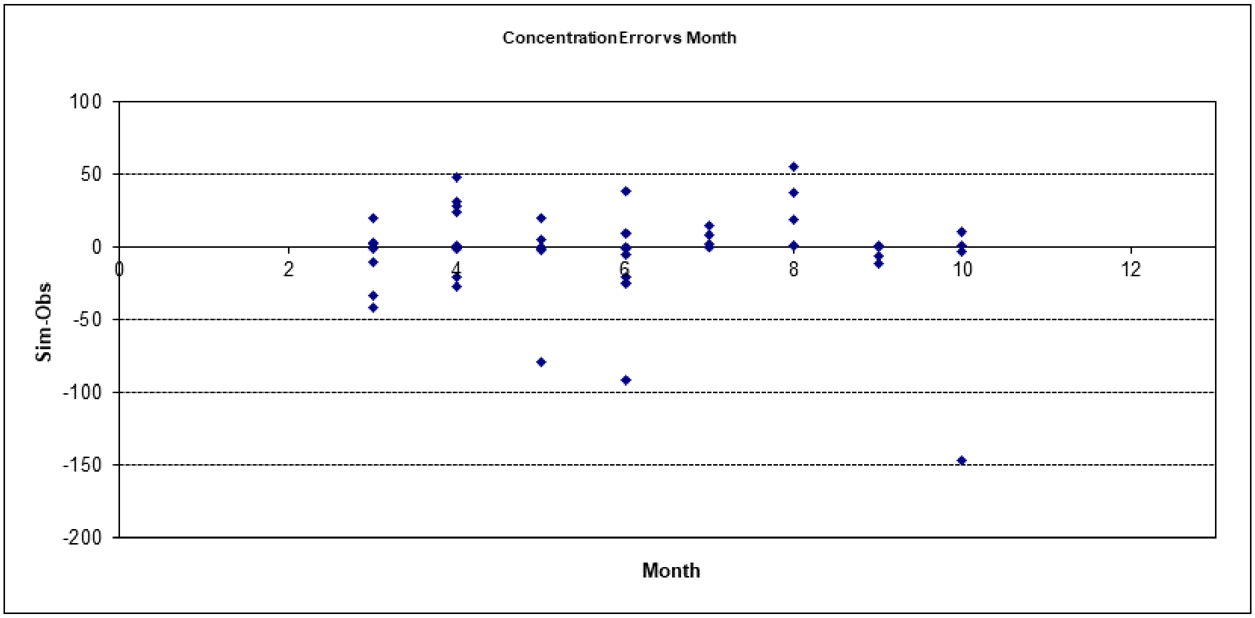


Figure D-40. TSS Concentration Error vs Month at the East Br Amity Cr above Confluence with Amity Cr

D.5 UNNAMED STREAM TO AMITY CREEK

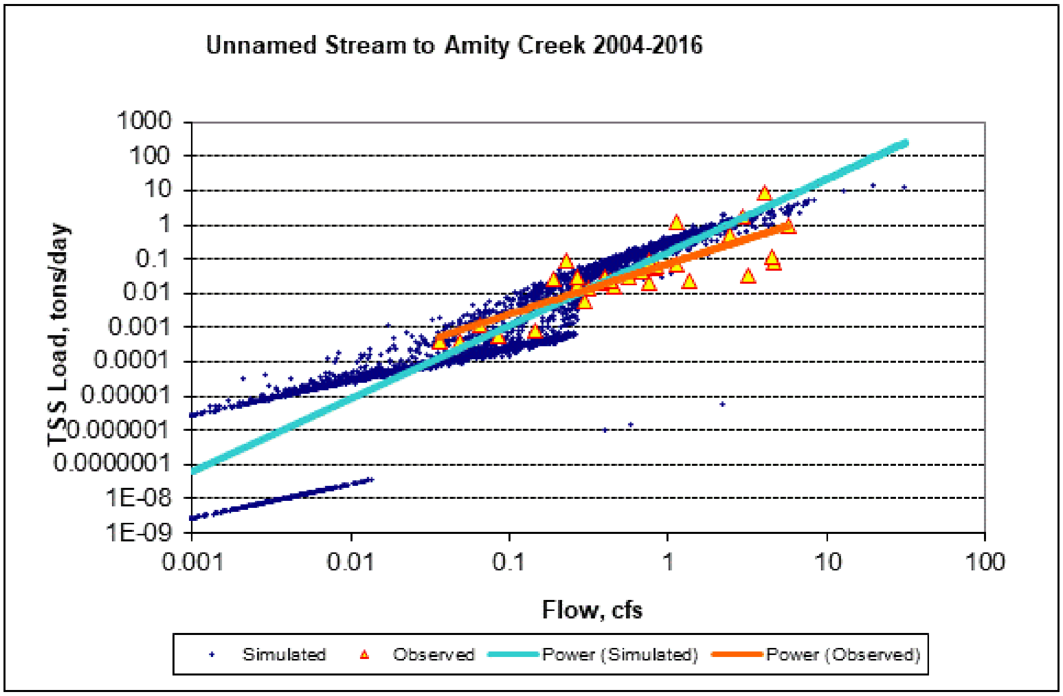


Figure D-41. Power Plot of Simulated and Observed TSS Load vs Flow at the Unnamed Stream to Amity Creek (Calibration Period)

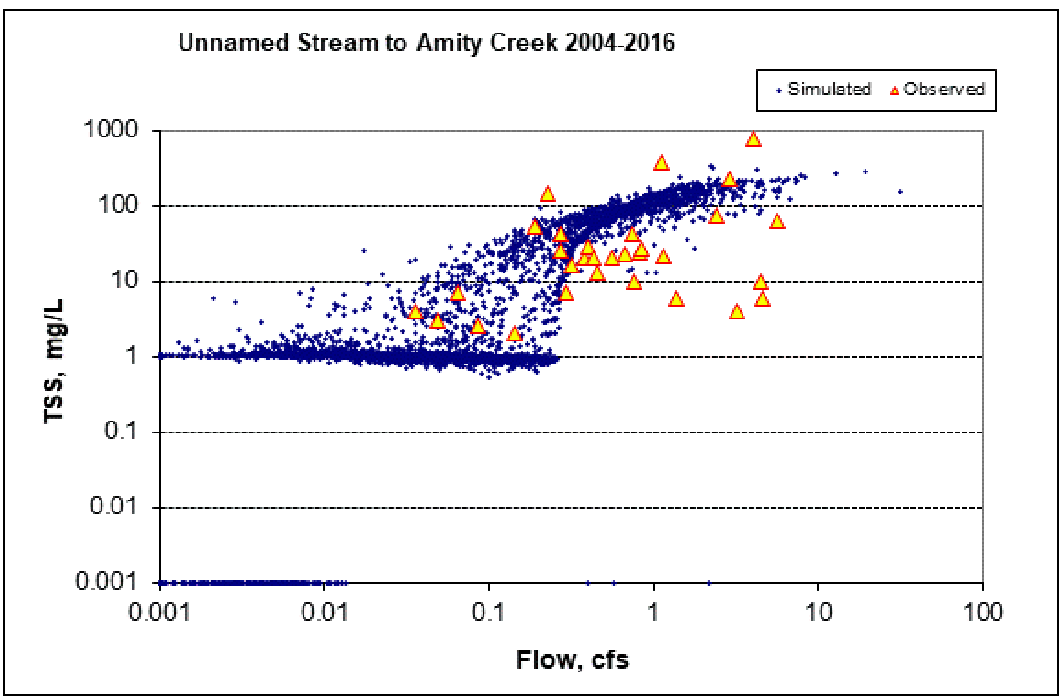


Figure D-42. Simulated and Observed TSS Concentration vs Flow Plot at the Unnamed Stream to Amity Creek (Calibration Period)

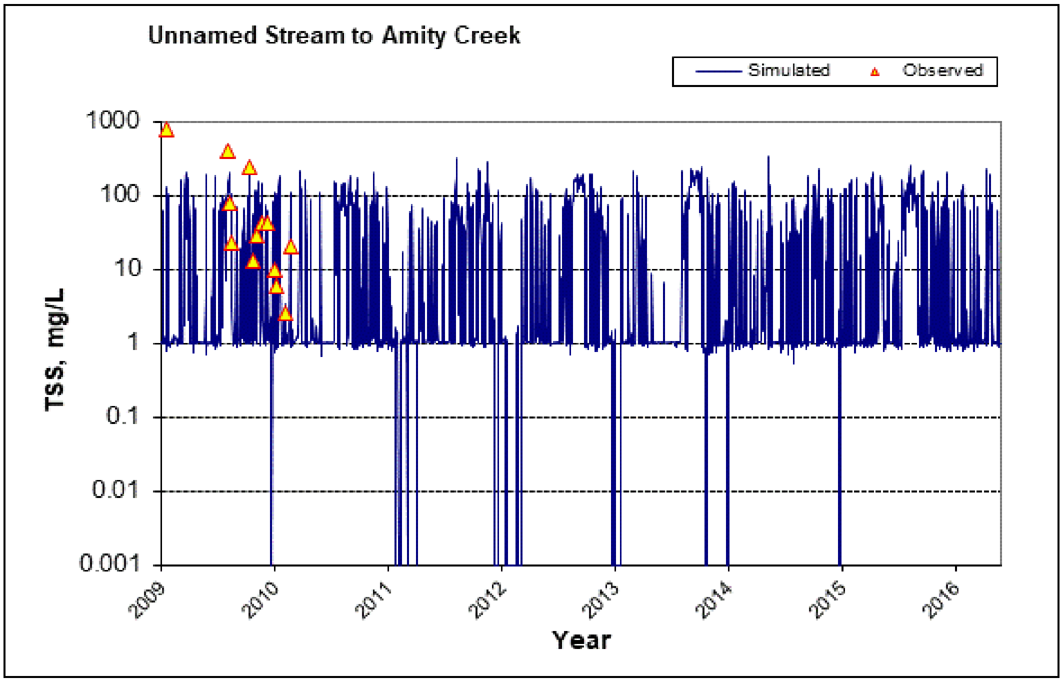


Figure D-43. TSS Concentration Time Series at the Unnamed Stream to Amity Creek (2008-2015)

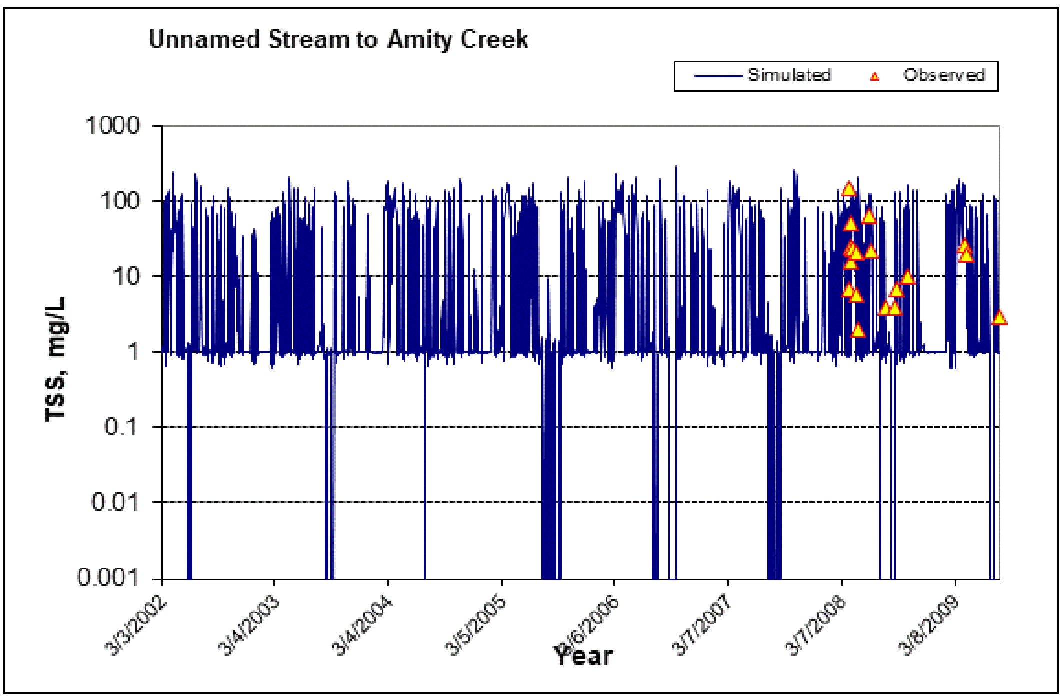


Figure D-44. TSS Concentration Time Series at the Unnamed Stream to Amity Creek (2001-2008)

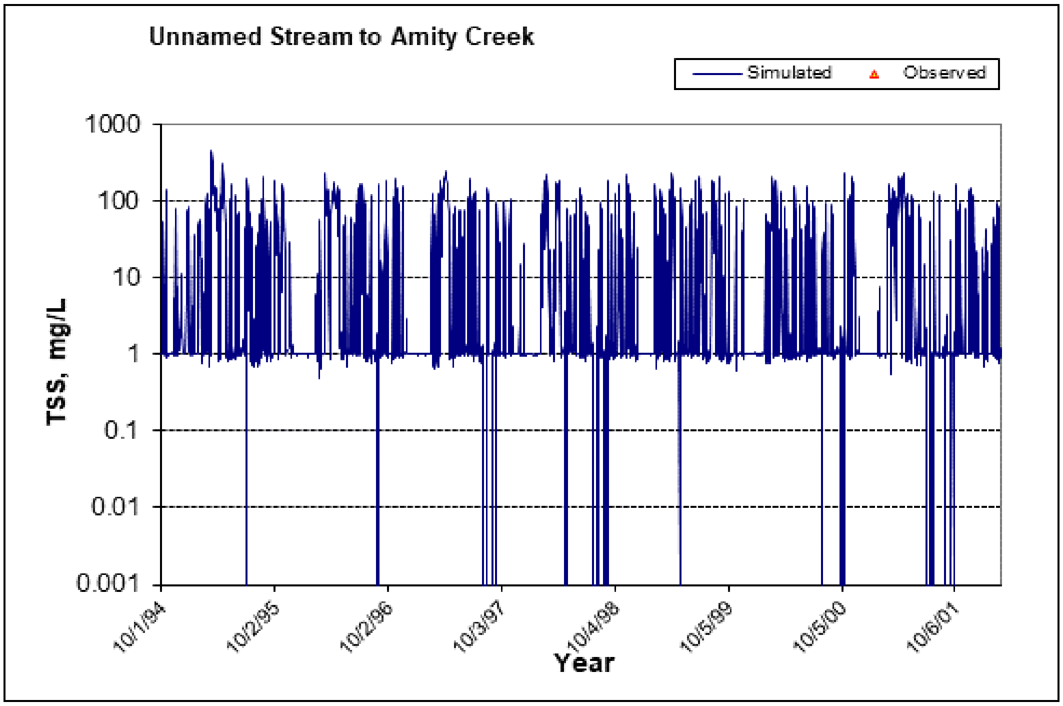


Figure D-45. TSS Concentration Time Series at the Unnamed Stream to Amity Creek (1994-2001)

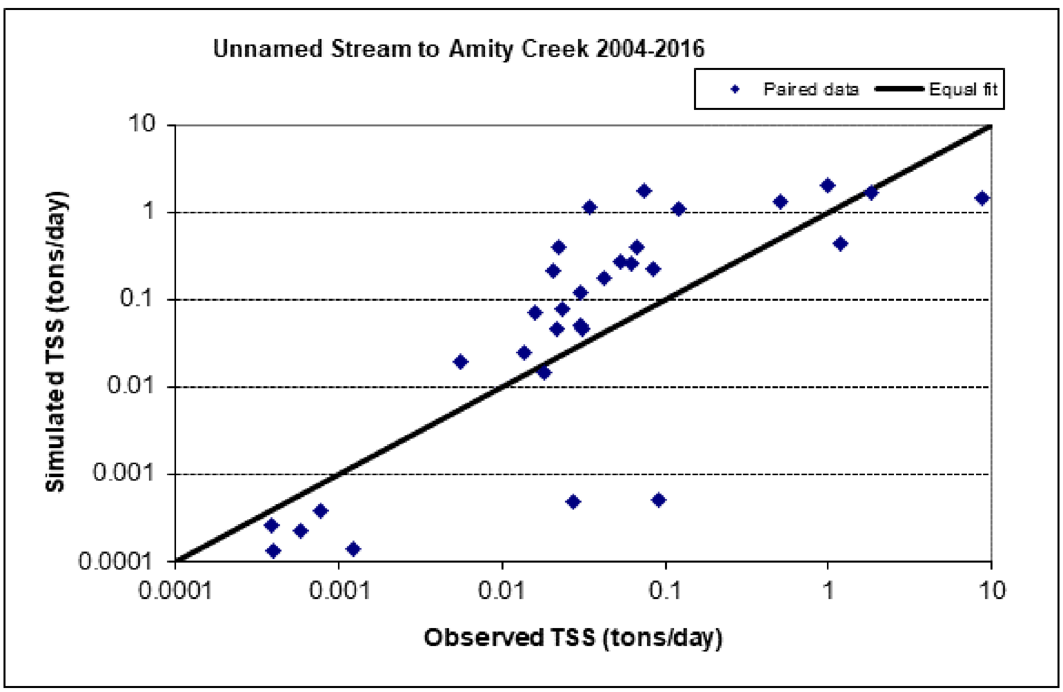


Figure D-46. Paired Simulated vs Observed TSS Load at the Unnamed Stream to Amity Creek (Calibration Period)

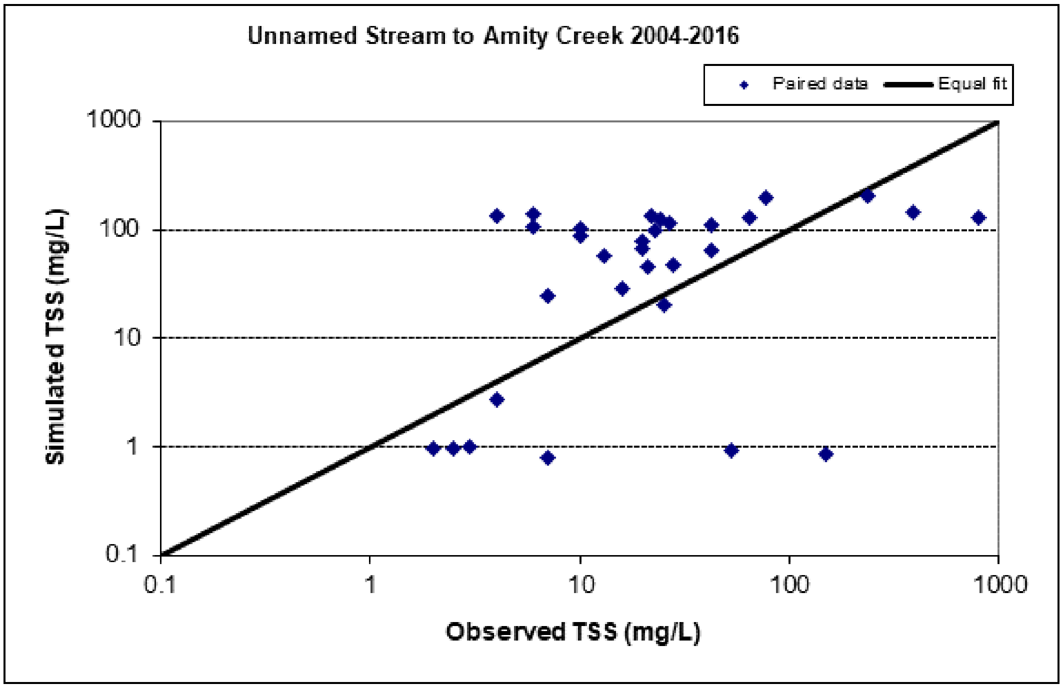


Figure D-47. Paired Simulated vs Observed TSS Concentration at the Unnamed Stream to Amity Creek (Calibration Period)

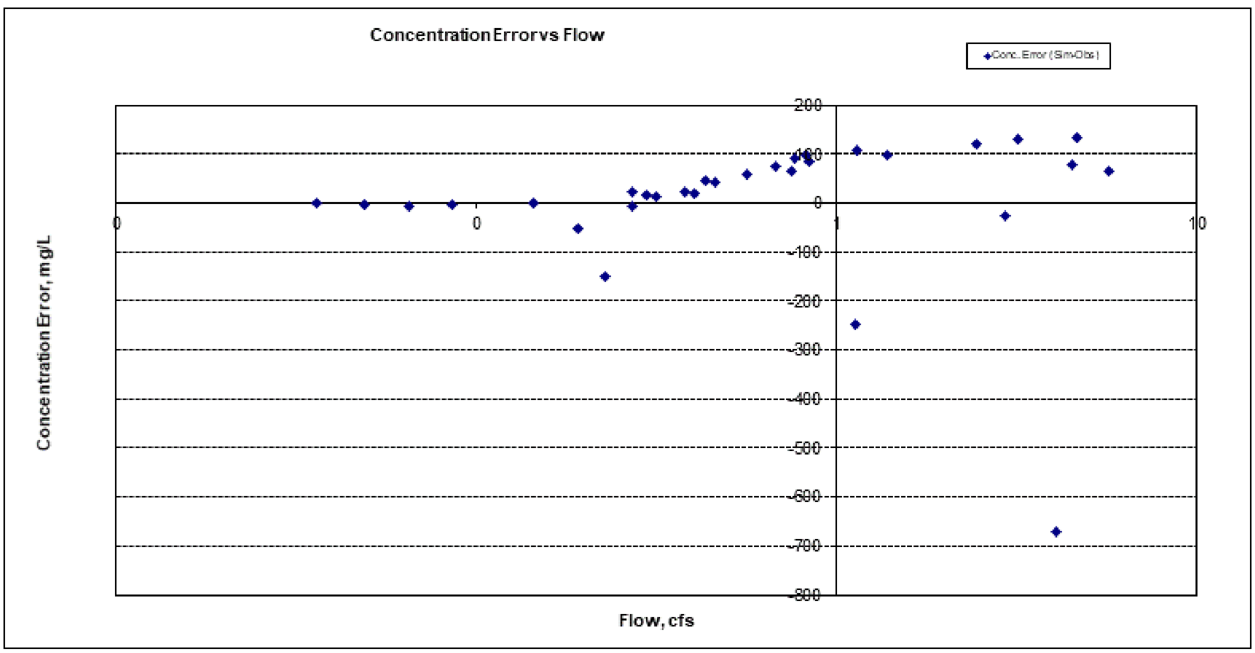


Figure D-48. TSS Concentration Error vs Flow at the Unnamed Stream to Amity Creek

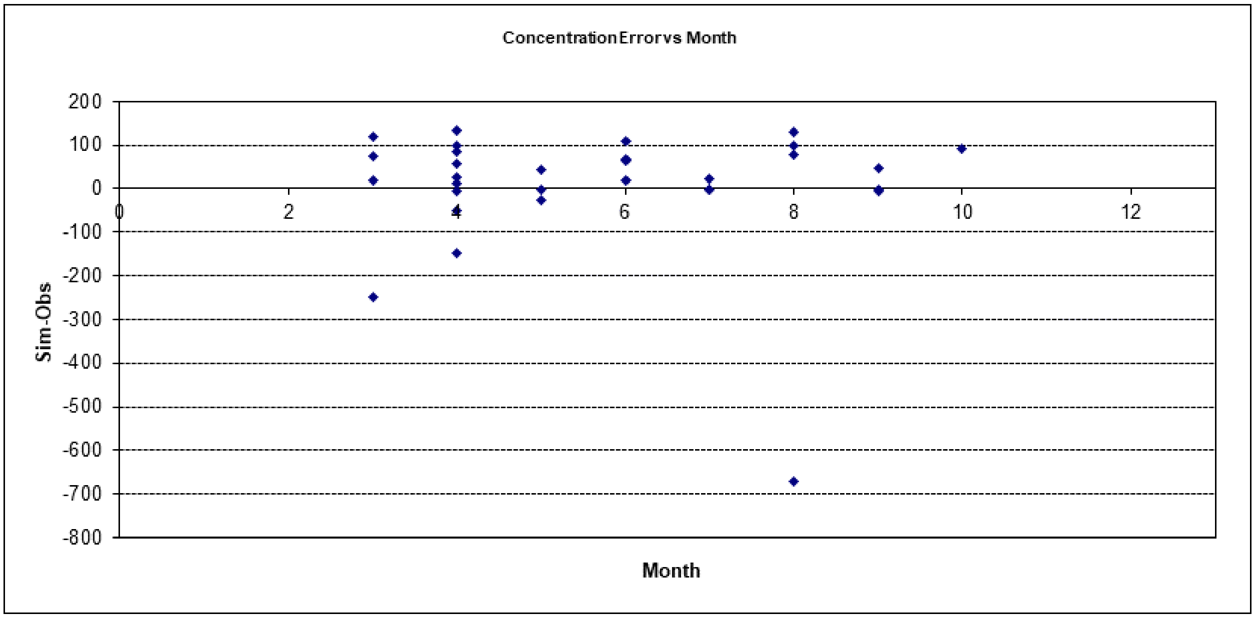


Figure D-49. TSS Concentration Error vs Month at the Unnamed Stream to Amity Creek

D.6 AMITY CREEK AT OCCIDENTAL BLVD, DULUTH

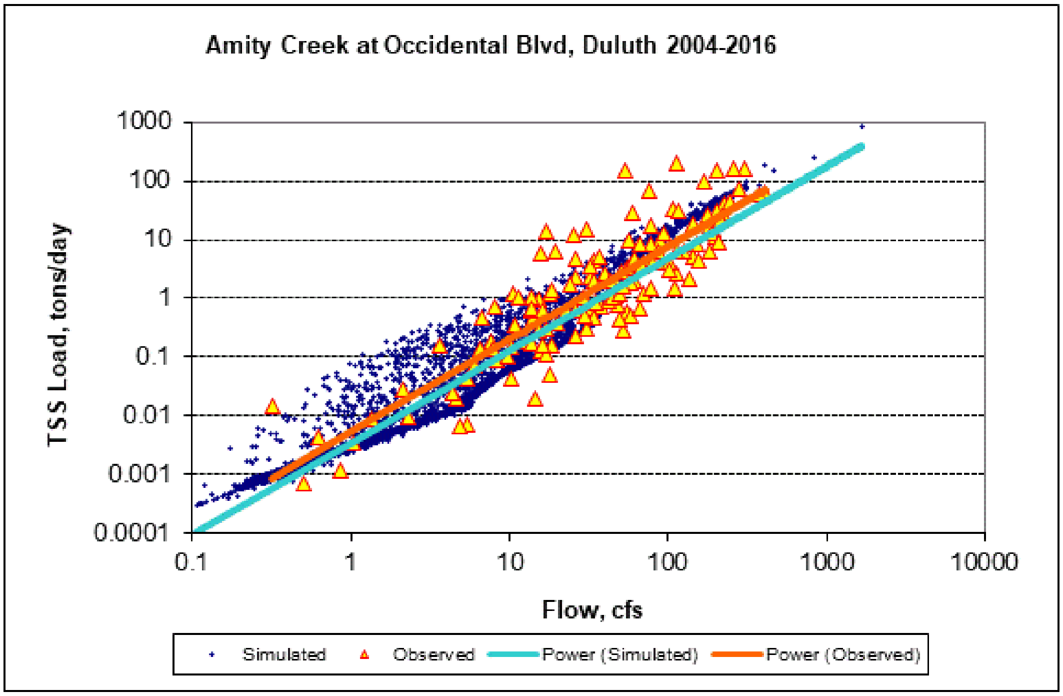


Figure D-50. Power Plot of Simulated and Observed TSS Load vs Flow at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

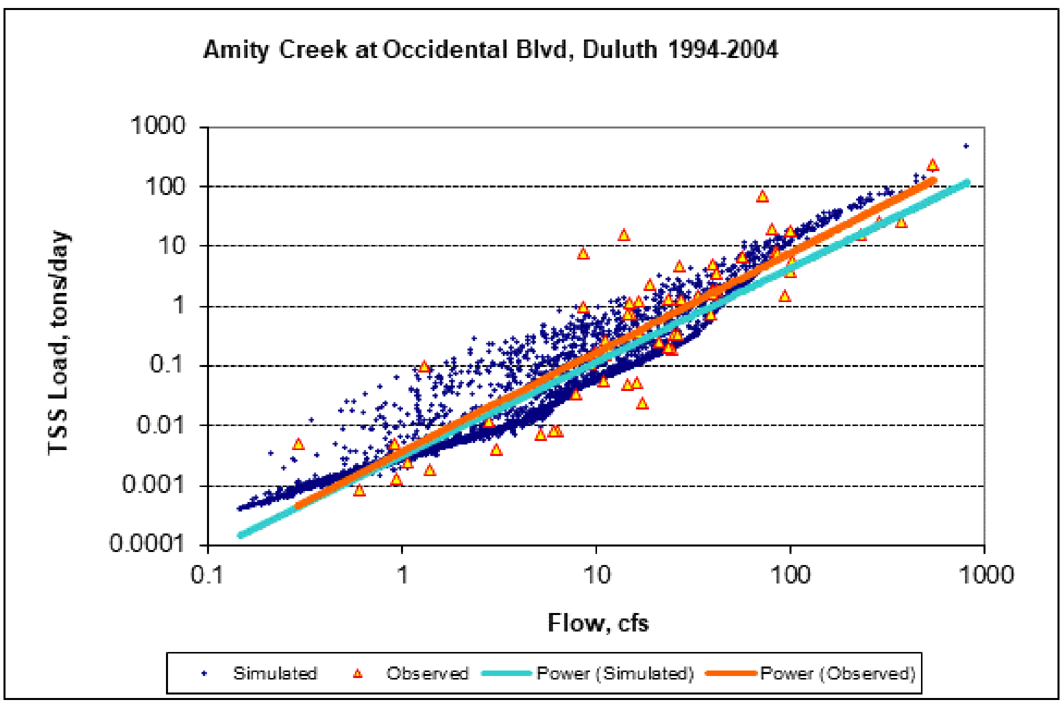


Figure D-51. Power Plot of Simulated and Observed TSS Load vs Flow at the Amity Creek at Occidental Blvd, Duluth (Validation Period)

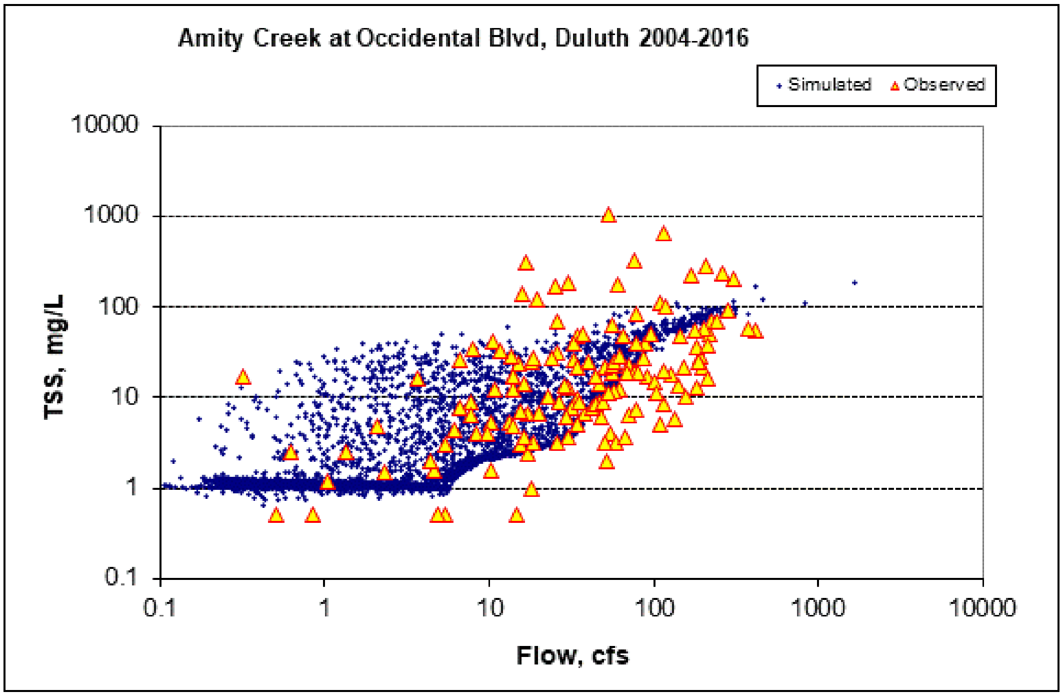


Figure D-52. Simulated and Observed TSS Concentration vs Flow Plot at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

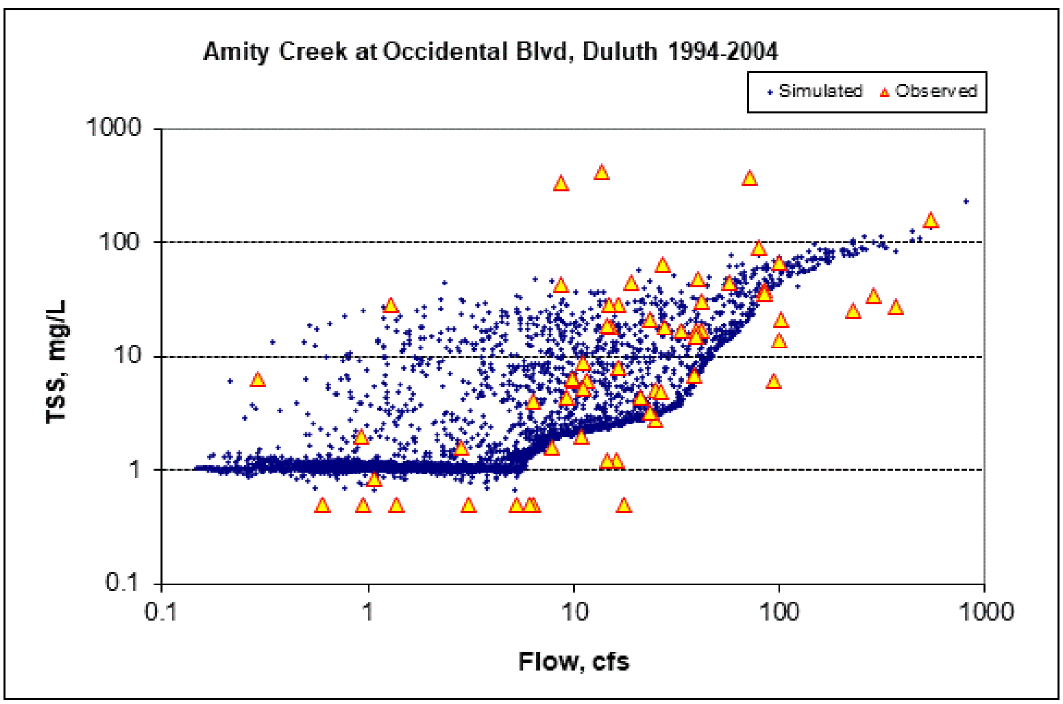


Figure D-53. Simulated and Observed TSS Concentration vs Flow Plot at the Amity Creek at Occidental Blvd, Duluth (Validation Period)

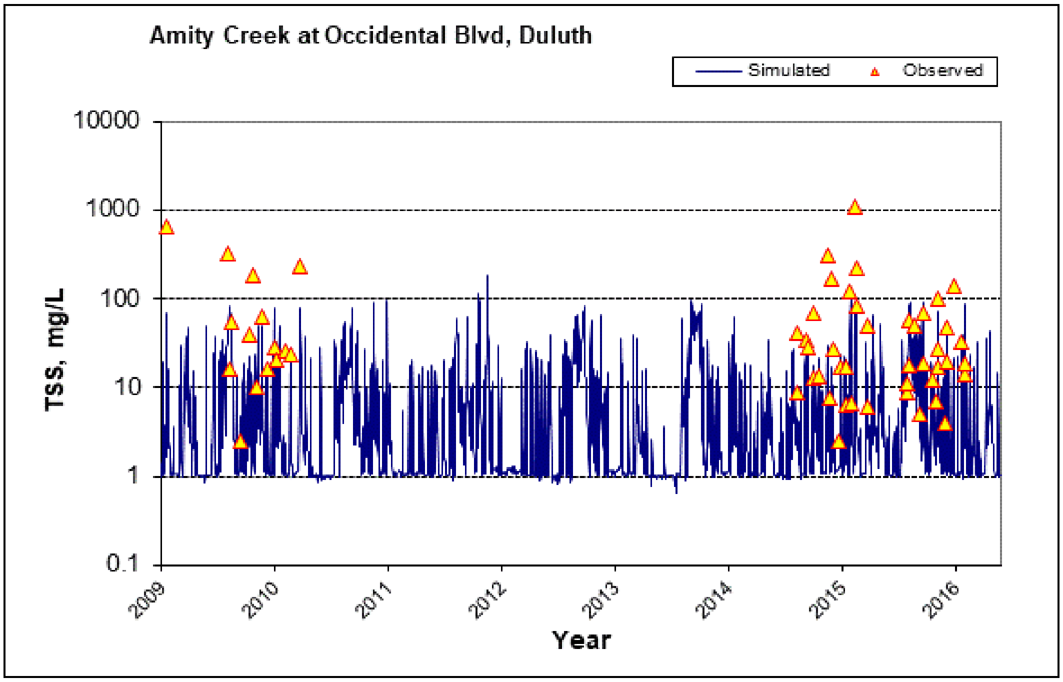


Figure D-54. TSS Concentration Time Series at the Amity Creek at Occidental Blvd, Duluth (2008-2015)

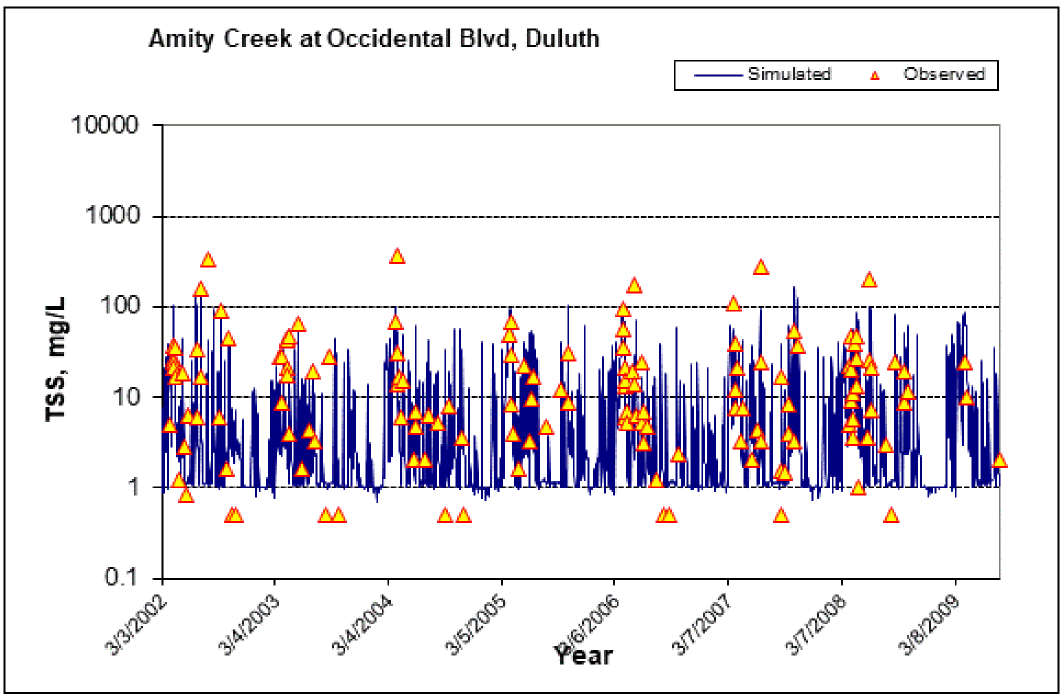


Figure D-55. TSS Concentration Time Series at the Amity Creek at Occidental Blvd, Duluth (2001-2008)

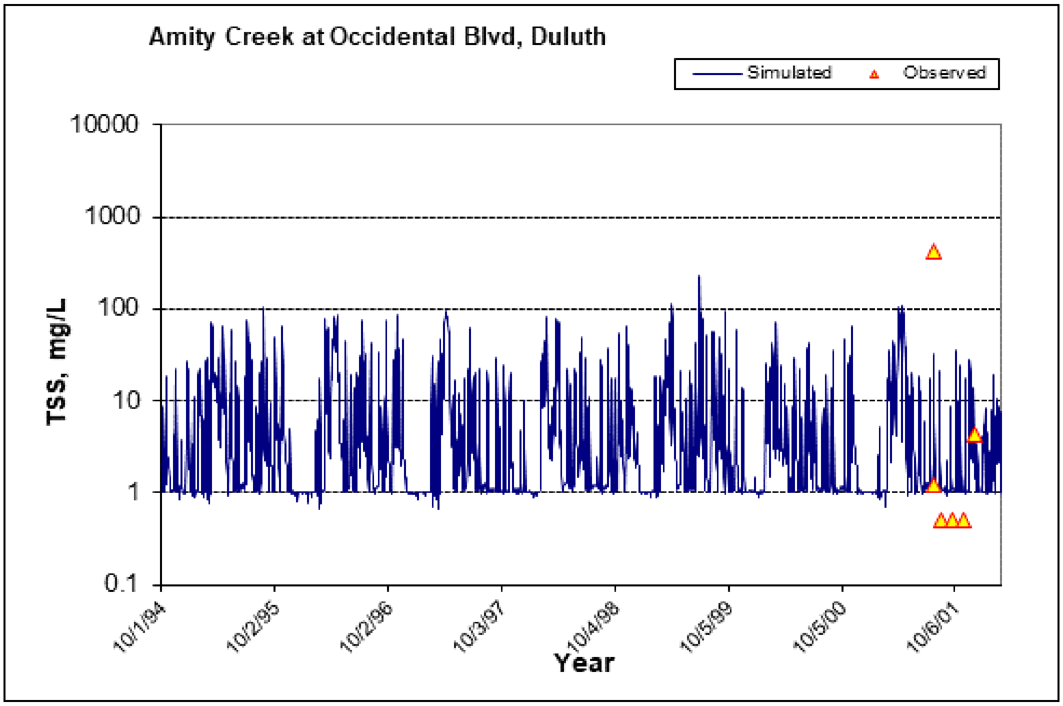


Figure D-56. TSS Concentration Time Series at the Amity Creek at Occidental Blvd, Duluth (1994-2001)

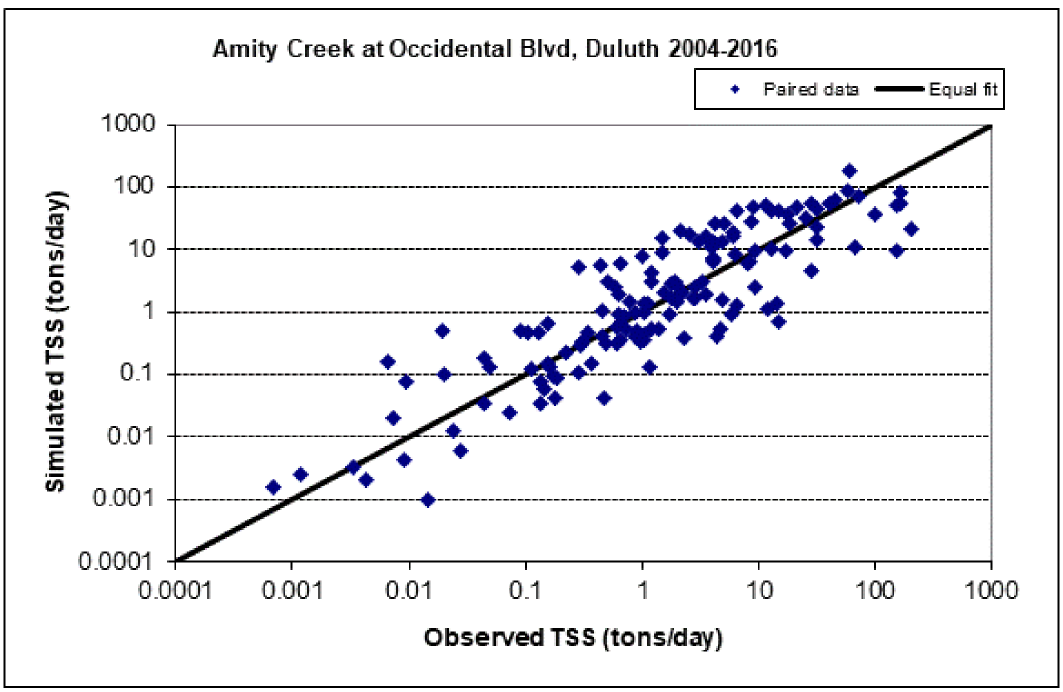


Figure D-57. Paired Simulated vs Observed TSS Load at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

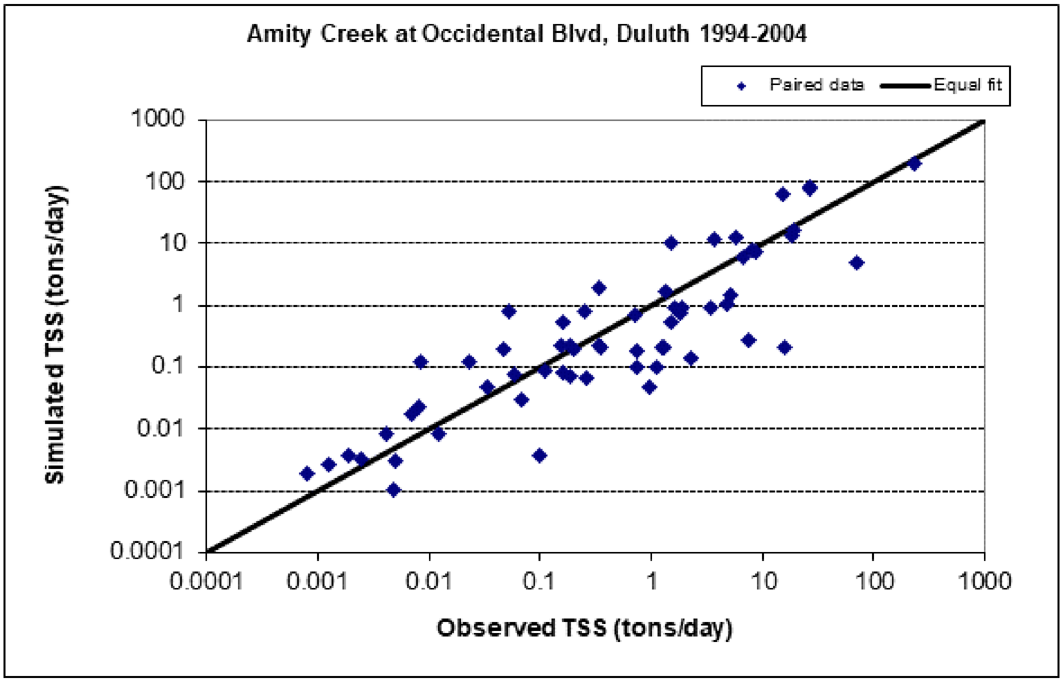


Figure D-58. Paired Simulated vs Observed TSS Load at the Amity Creek at Occidental Blvd, Duluth (Validation Period)

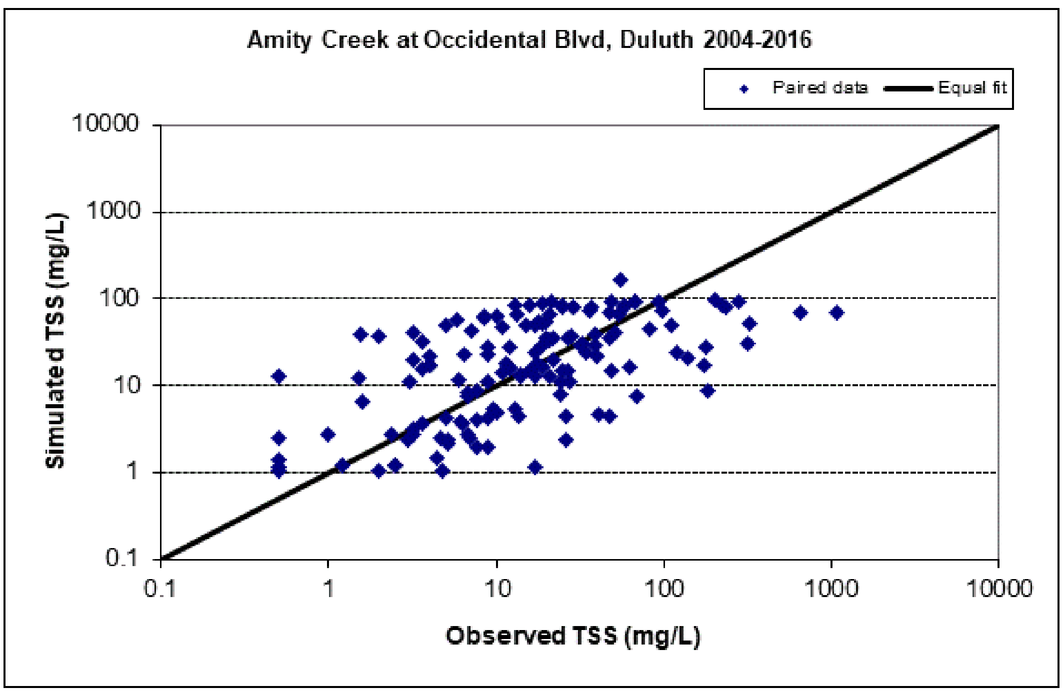


Figure D-59. Paired Simulated vs Observed TSS Concentration at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

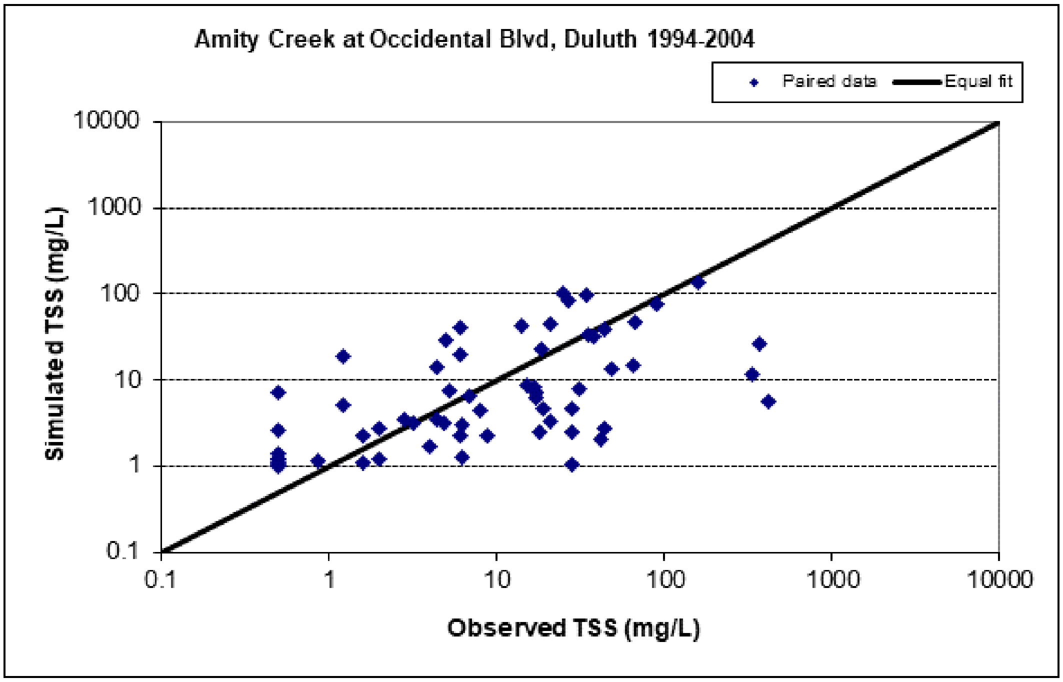


Figure D-60. Paired Simulated vs Observed TSS Concentration at the Amity Creek at Occidental Blvd, Duluth (Validation Period)

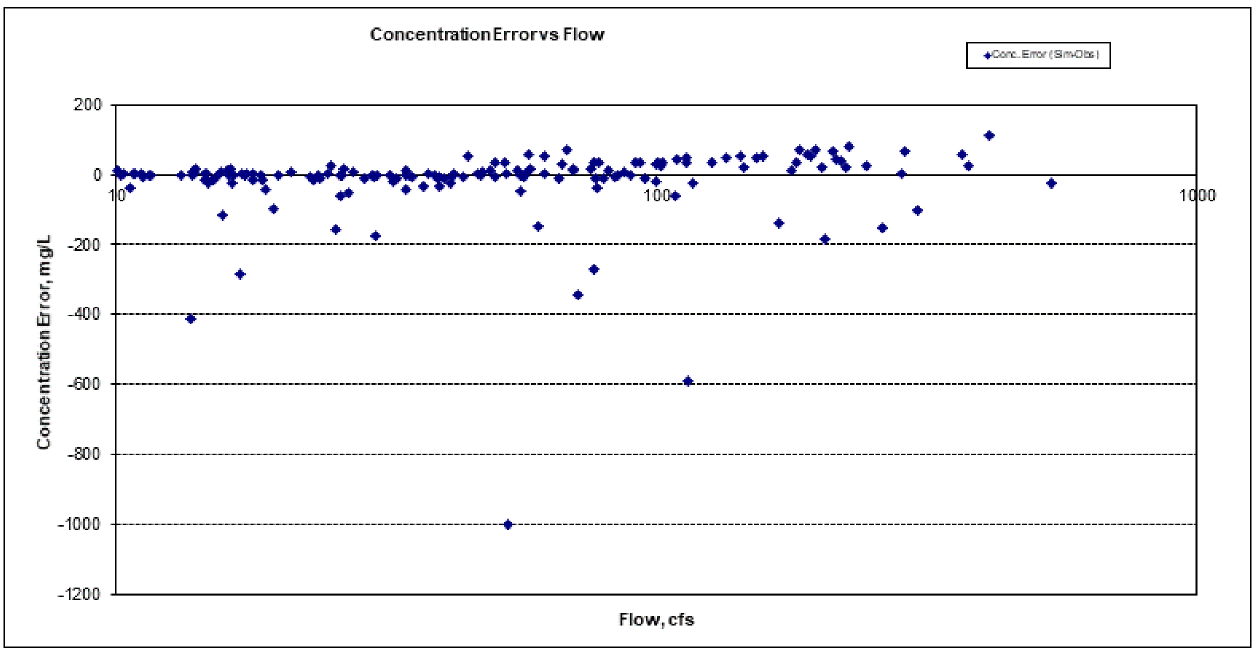


Figure D-61. TSS Concentration Error vs Flow at the Amity Creek at Occidental Blvd, Duluth

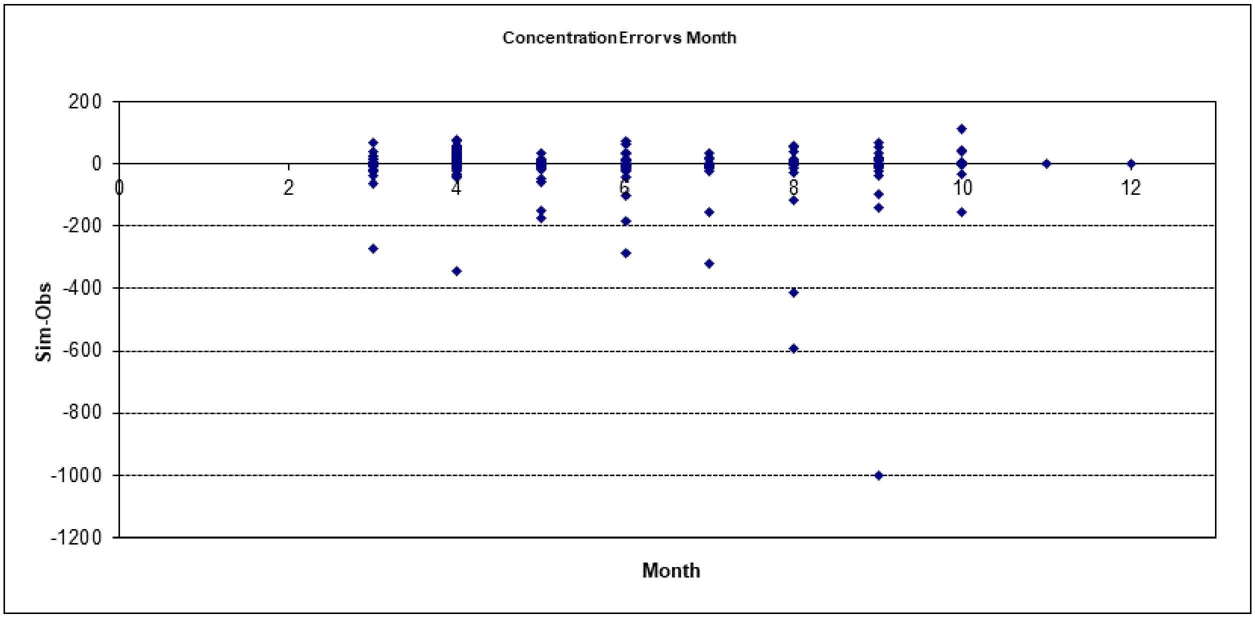


Figure D-62. TSS Concentration Error vs Month at the Amity Creek at Occidental Blvd, Duluth

D.7 AMITY CREEK NEAR SKYLINE PKWY

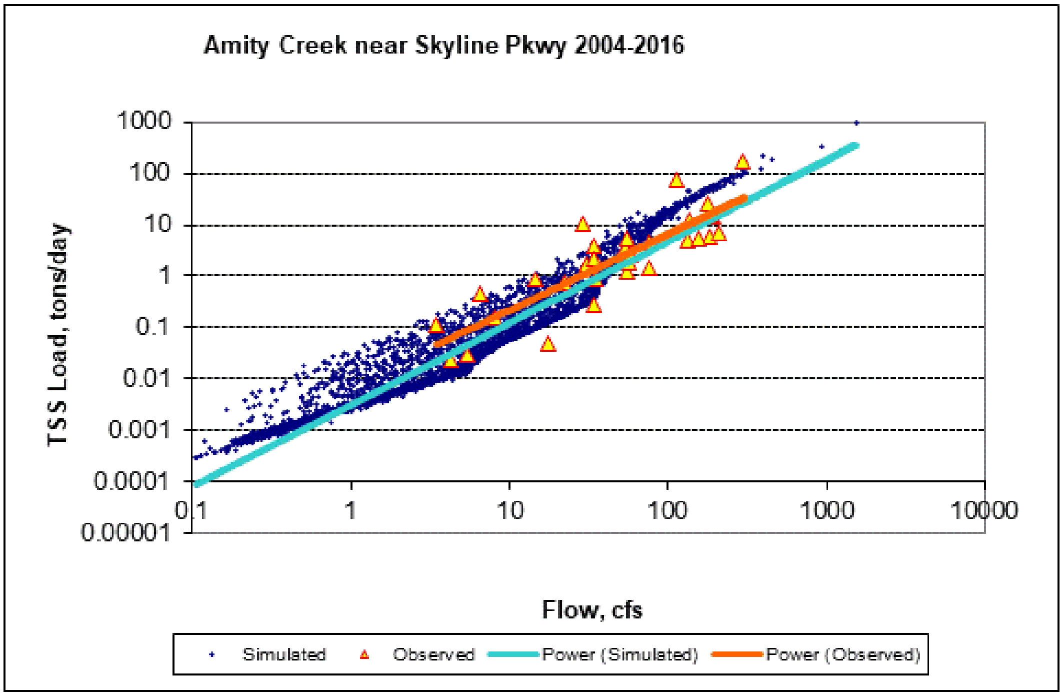


Figure D-63. Power Plot of Simulated and Observed TSS Load vs Flow at the Amity Creek near Skyline Pkwy (Calibration Period)

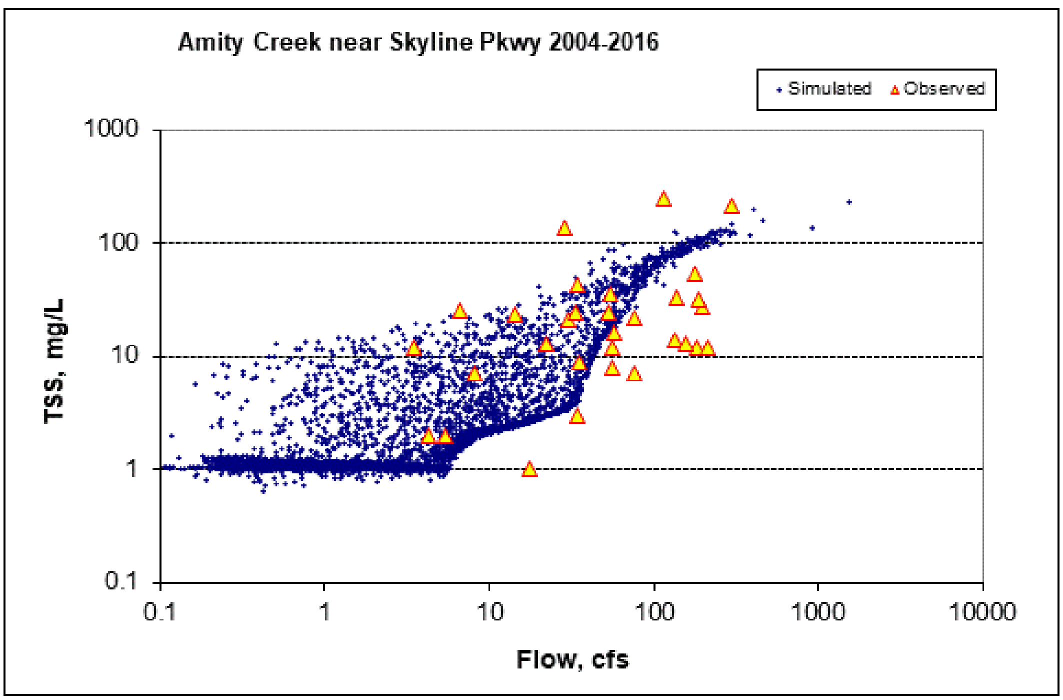


Figure D-64. Simulated and Observed TSS Concentration vs Flow Plot at the Amity Creek near Skyline Pkwy (Calibration Period)

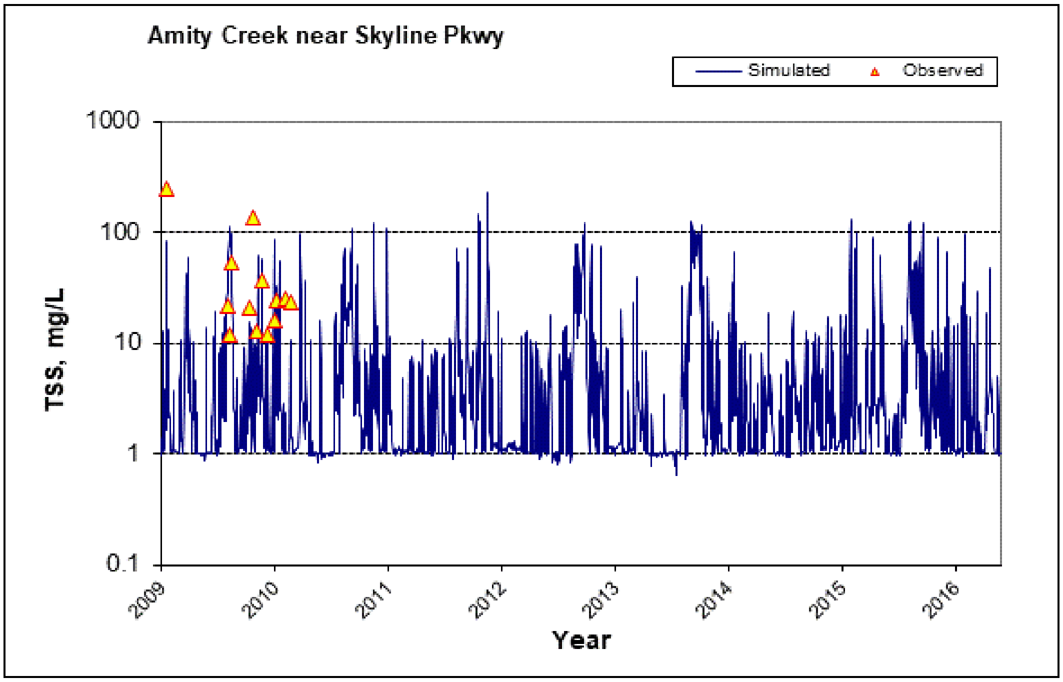


Figure D-65. TSS Concentration Time Series at the Amity Creek near Skyline Pkwy (2008-2015)

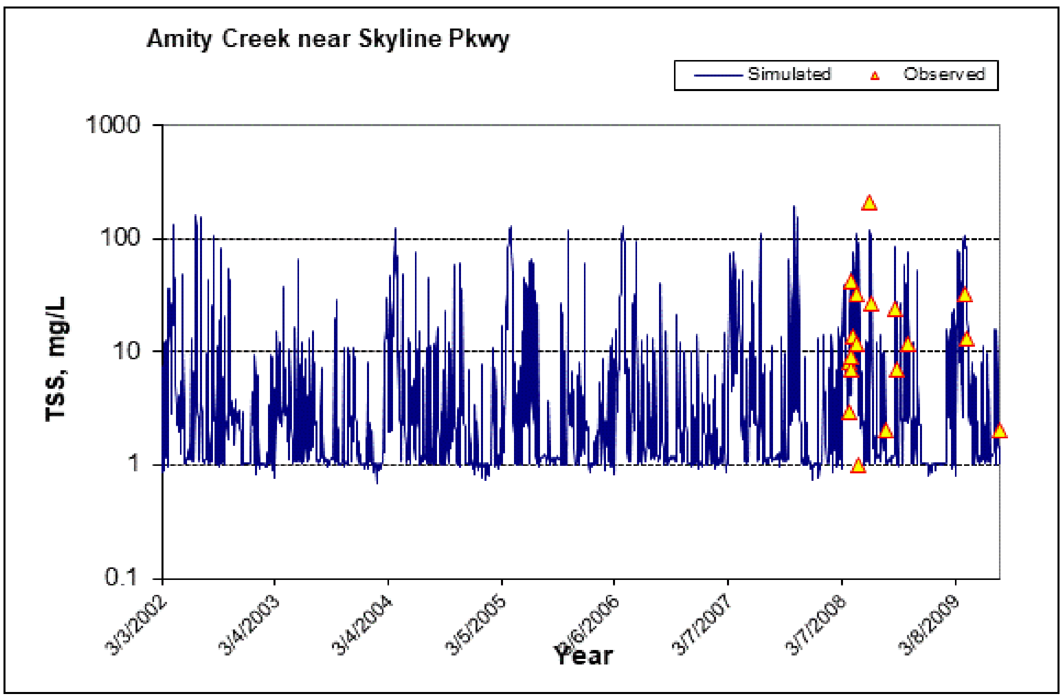


Figure D-66. TSS Concentration Time Series at the Amity Creek near Skyline Pkwy (2001-2008)

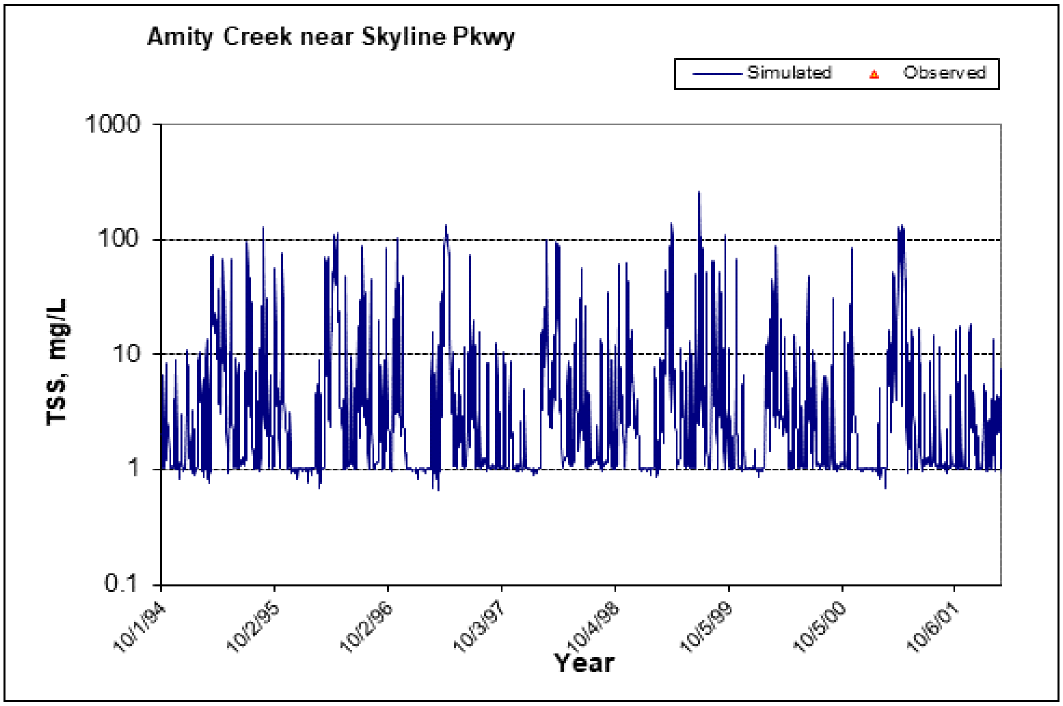


Figure D-67. TSS Concentration Time Series at the Amity Creek near Skyline Pkwy (1994-2001)

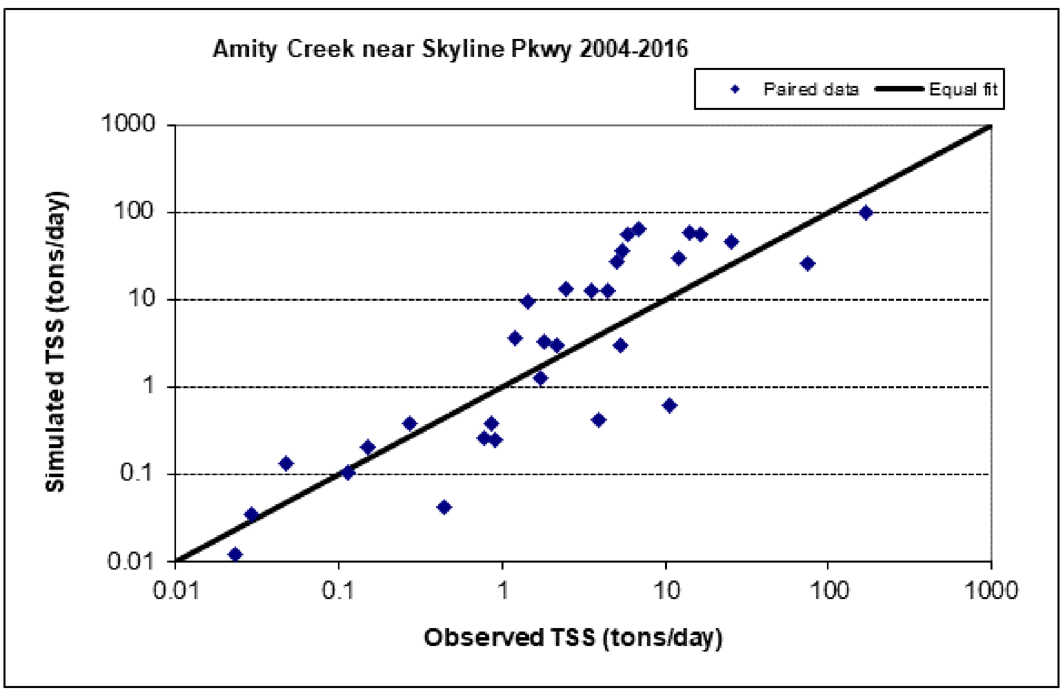


Figure D-68. Paired Simulated vs Observed TSS Load at the Amity Creek near Skyline Pkwy (Calibration Period)

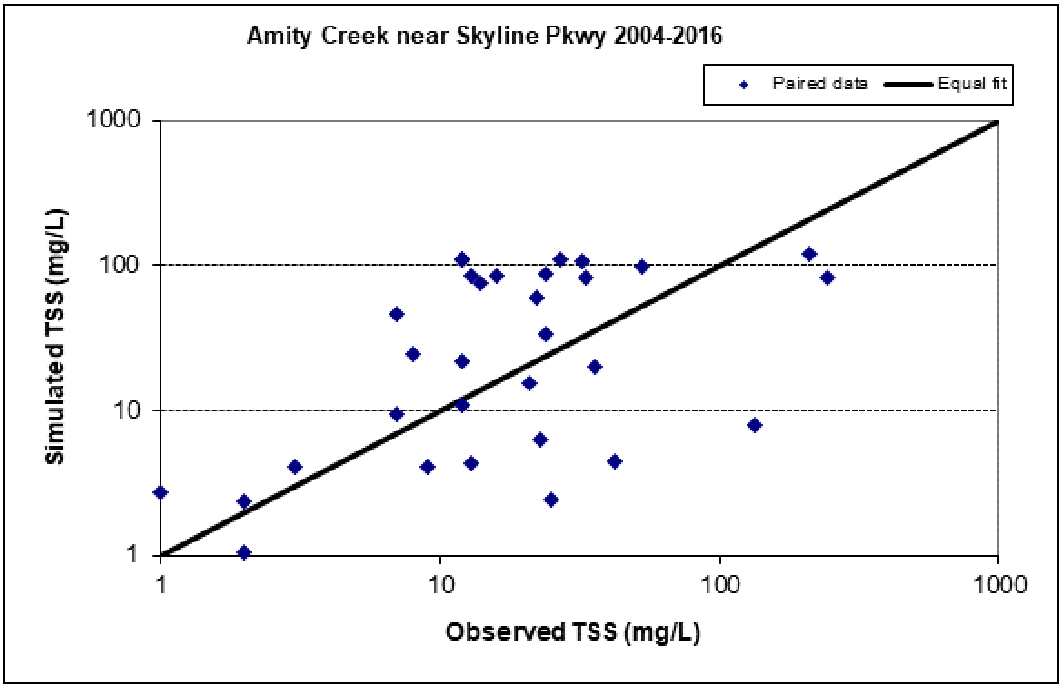


Figure D-69. Paired Simulated vs Observed TSS Concentration at the Amity Creek near Skyline Pkwy (Calibration Period)

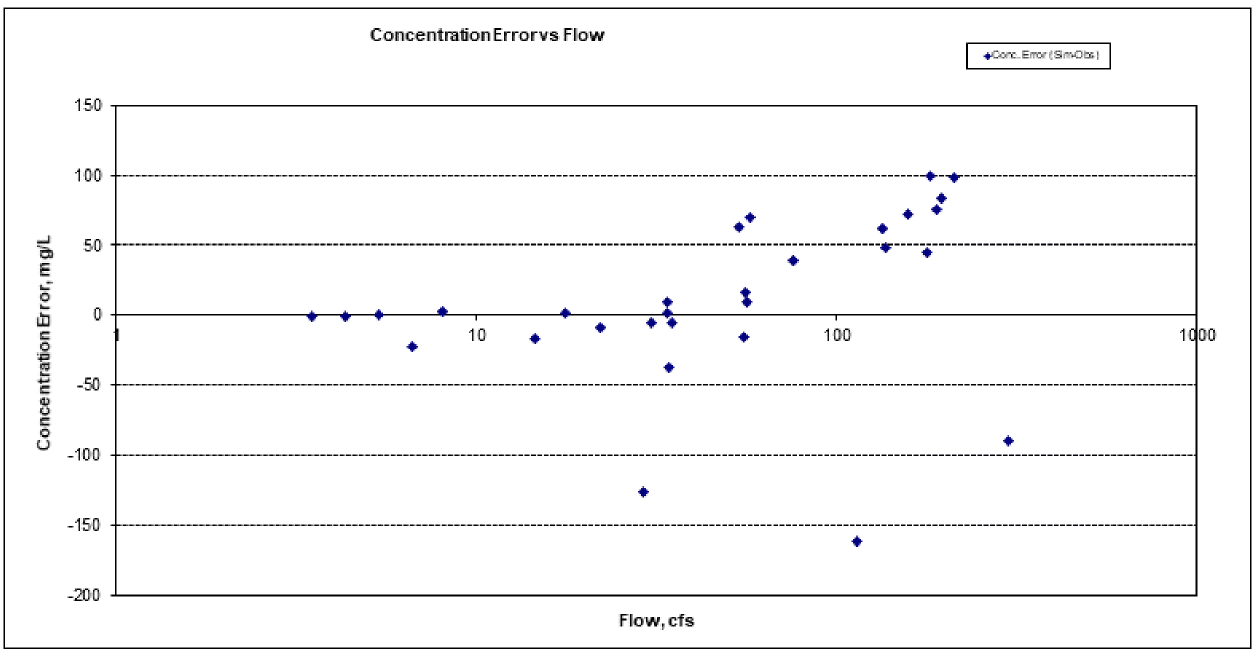


Figure D-70. TSS Concentration Error vs Flow at the Amity Creek near Skyline Pkwy

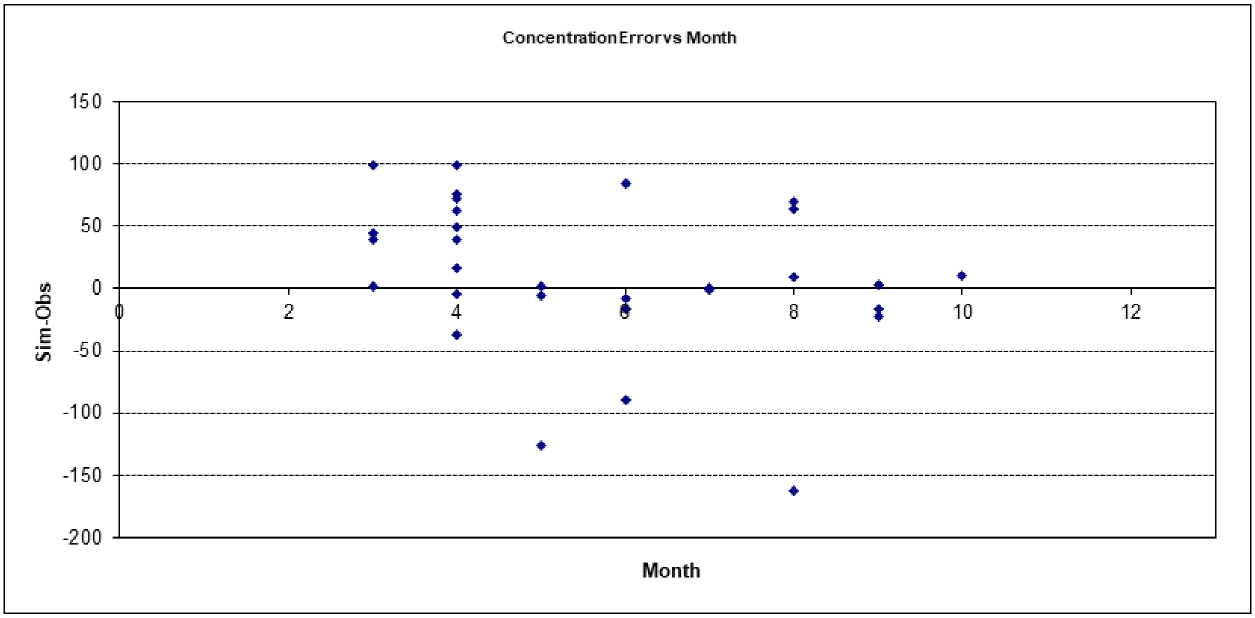


Figure D-71. TSS Concentration Error vs Month at the Amity Creek near Skyline Pkwy

D.8 AMITY CREEK WEST OF SKYLINE PKWAY

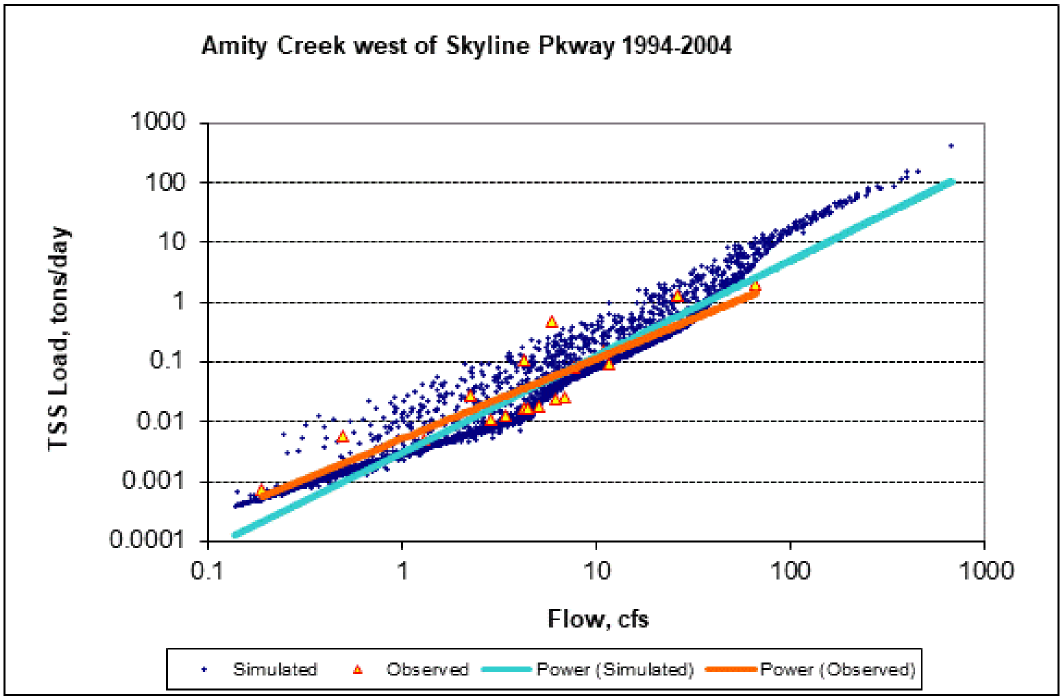


Figure D-72. Power Plot of Simulated and Observed TSS Load vs Flow at the Amity Creek west of Skyline Pkway (Validation Period)

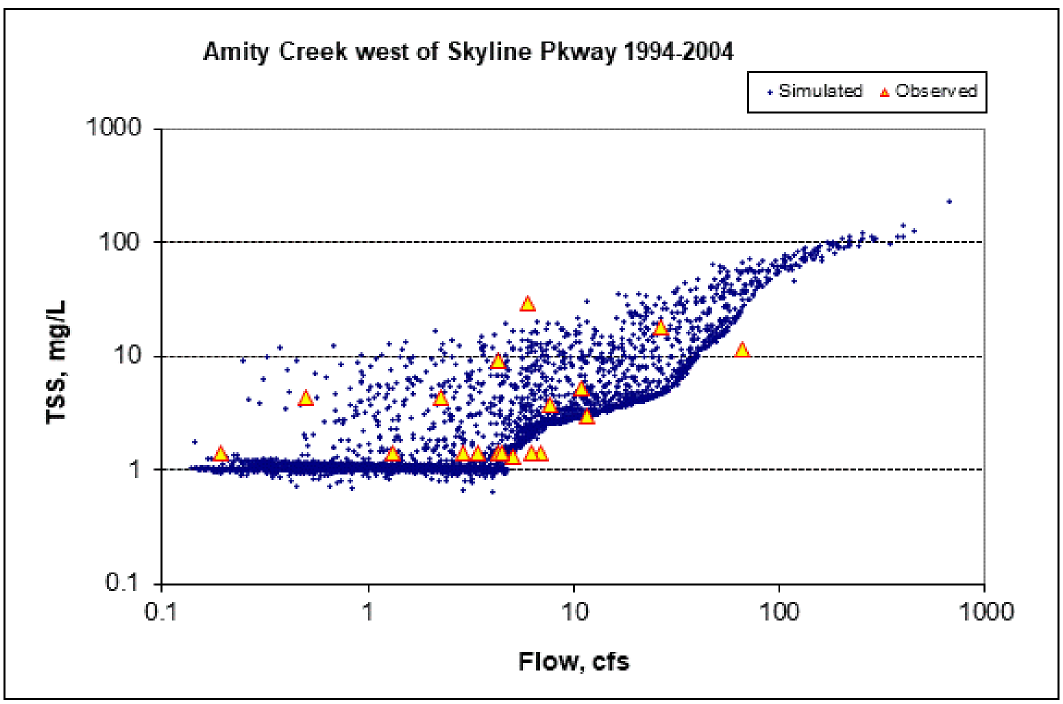


Figure D-73. Simulated and Observed TSS Concentration vs Flow Plot at the Amity Creek west of Skyline Pkway (Validation Period)

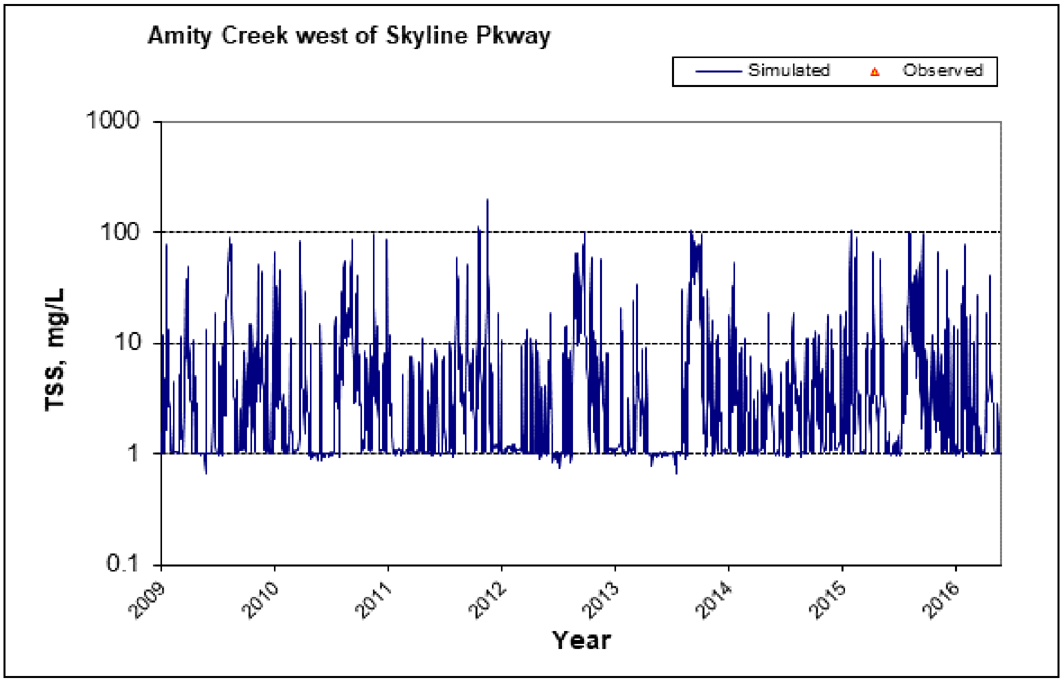


Figure D-74. TSS Concentration Time Series at the Amity Creek west of Skyline Pkway (2008-2015)

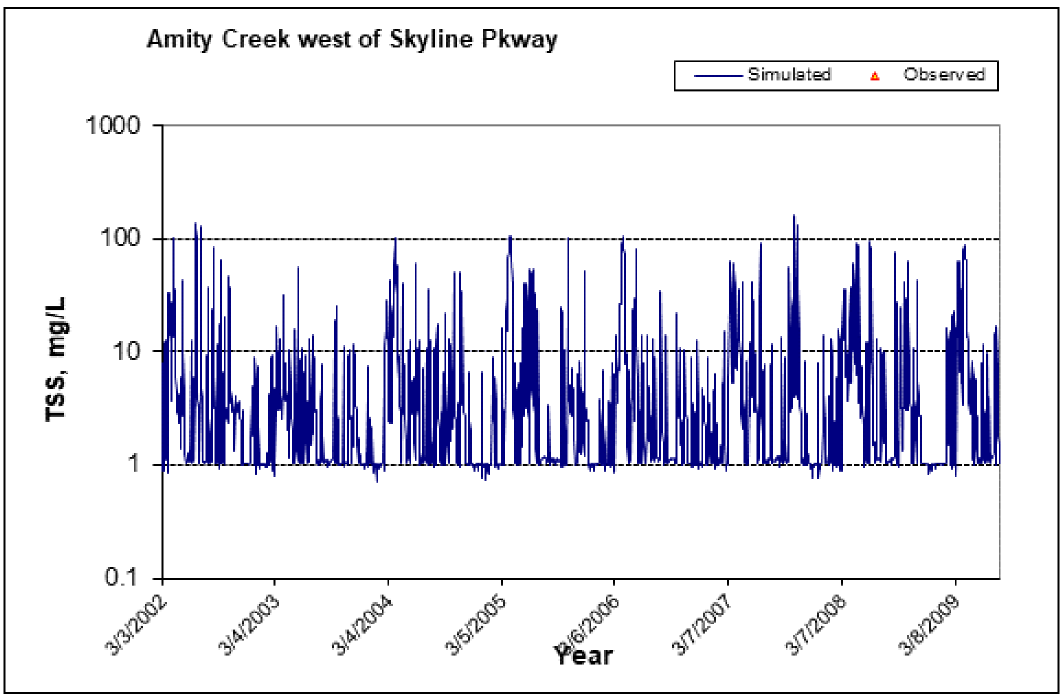


Figure D-75. TSS Concentration Time Series at the Amity Creek west of Skyline Pkway (2001-2008)

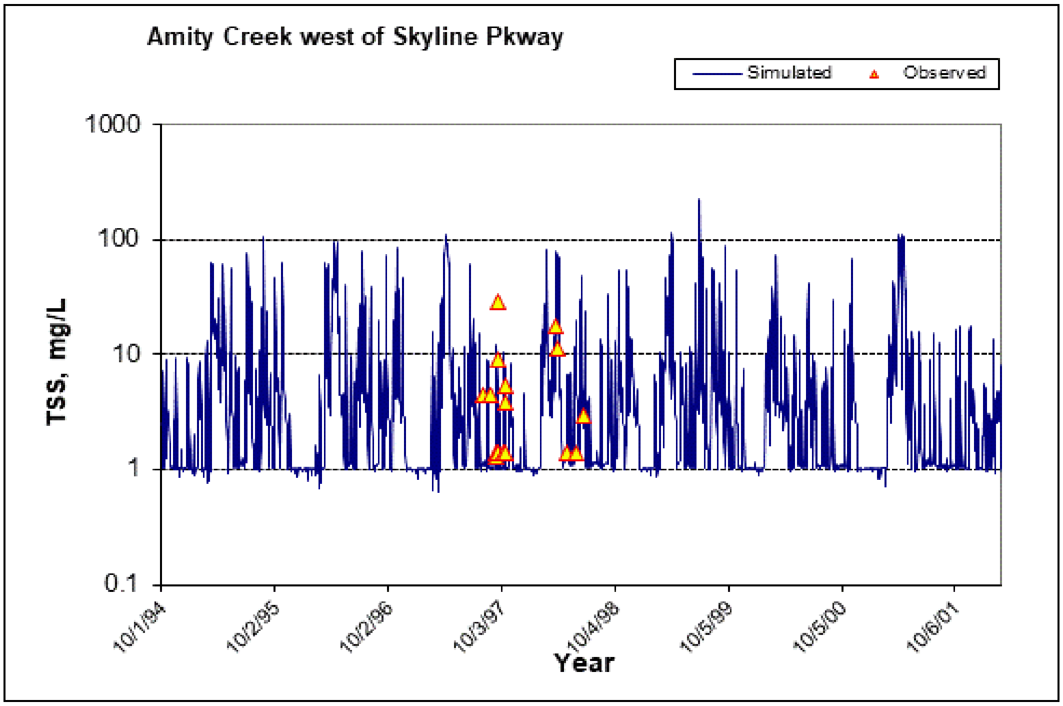


Figure D-76. TSS Concentration Time Series at the Amity Creek west of Skyline Pkway (1994-2001)

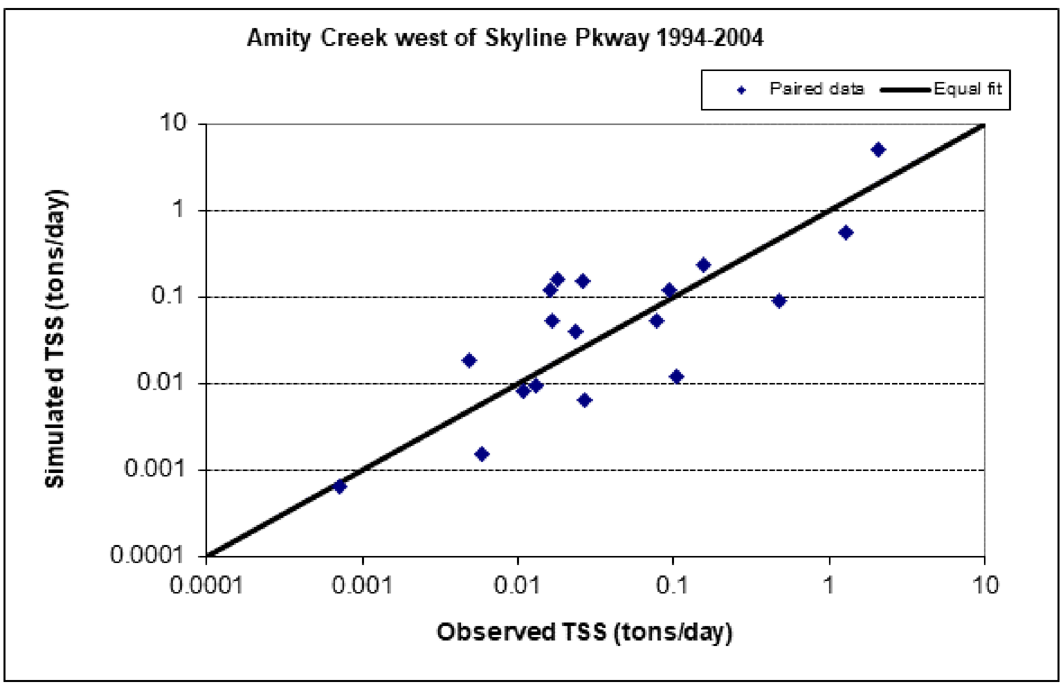


Figure D-77. Paired Simulated vs Observed TSS Load at the Amity Creek west of Skyline Pkway (Validation Period)

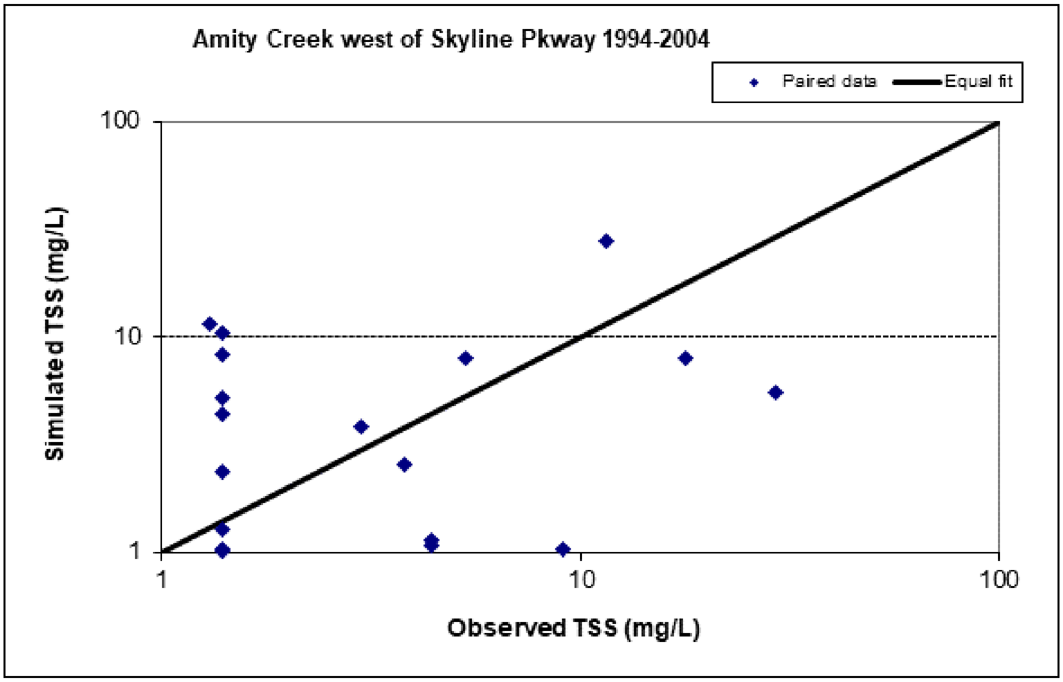


Figure D-78. Paired Simulated vs Observed TSS Concentration at the Amity Creek west of Skyline Pkway (Validation Period)

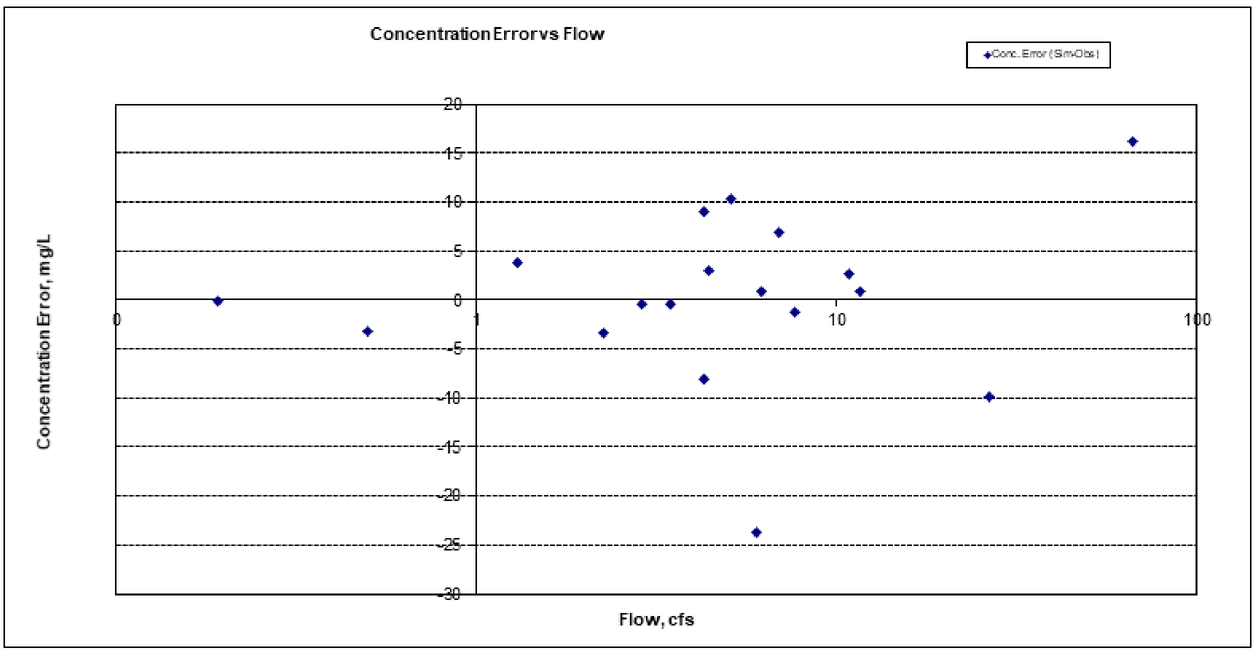


Figure D-79. TSS Concentration Error vs Flow at the Amity Creek west of Skyline Pkway

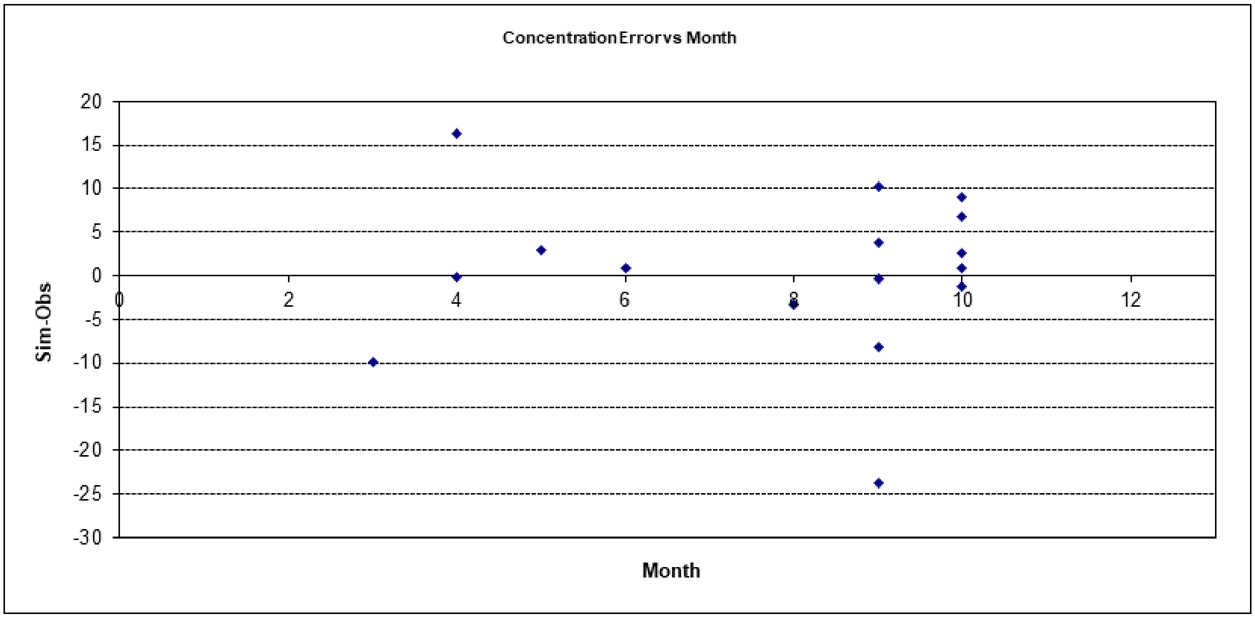


Figure D-80. TSS Concentration Error vs Month at the Amity Creek west of Skyline Pkway

D.9 TISCHER CREEK (MULTIPLE STATIONS)

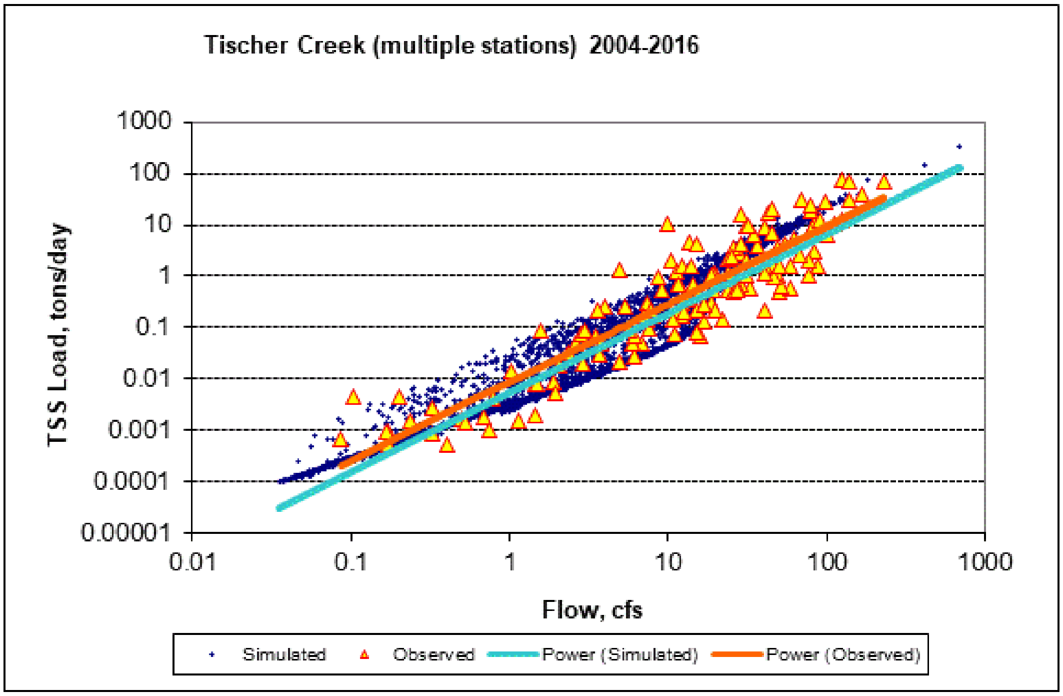


Figure D-81. Power Plot of Simulated and Observed TSS Load vs Flow at the Tischer Creek (multiple stations) (Calibration Period)

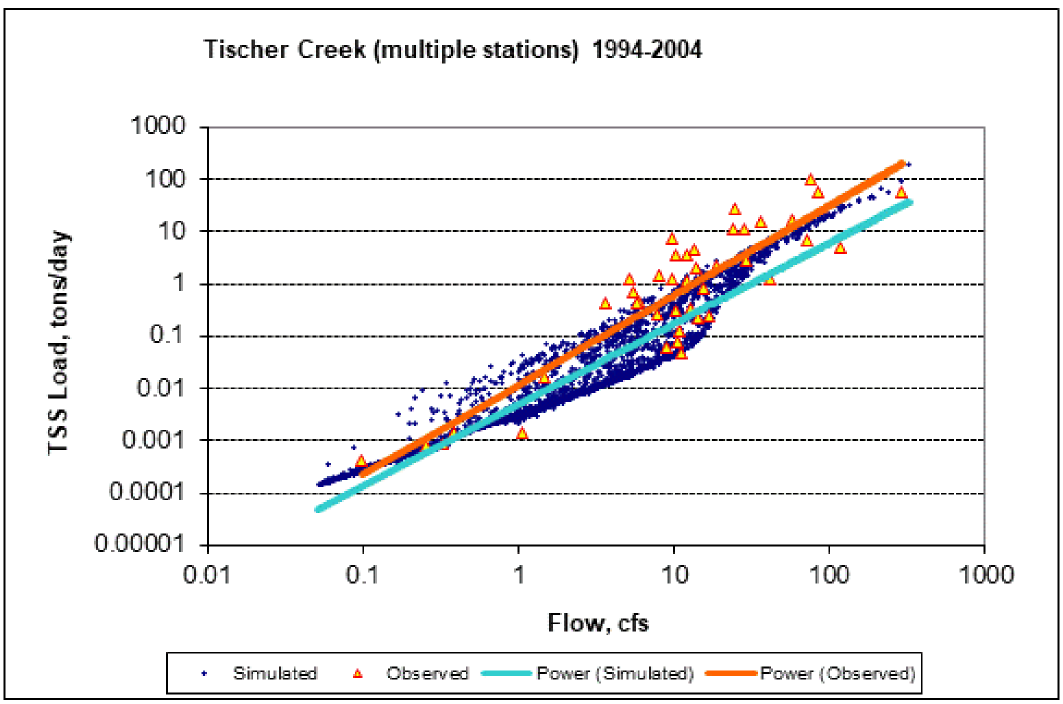


Figure D-82. Power Plot of Simulated and Observed TSS Load vs Flow at the Tischer Creek (multiple stations) (Validation Period)

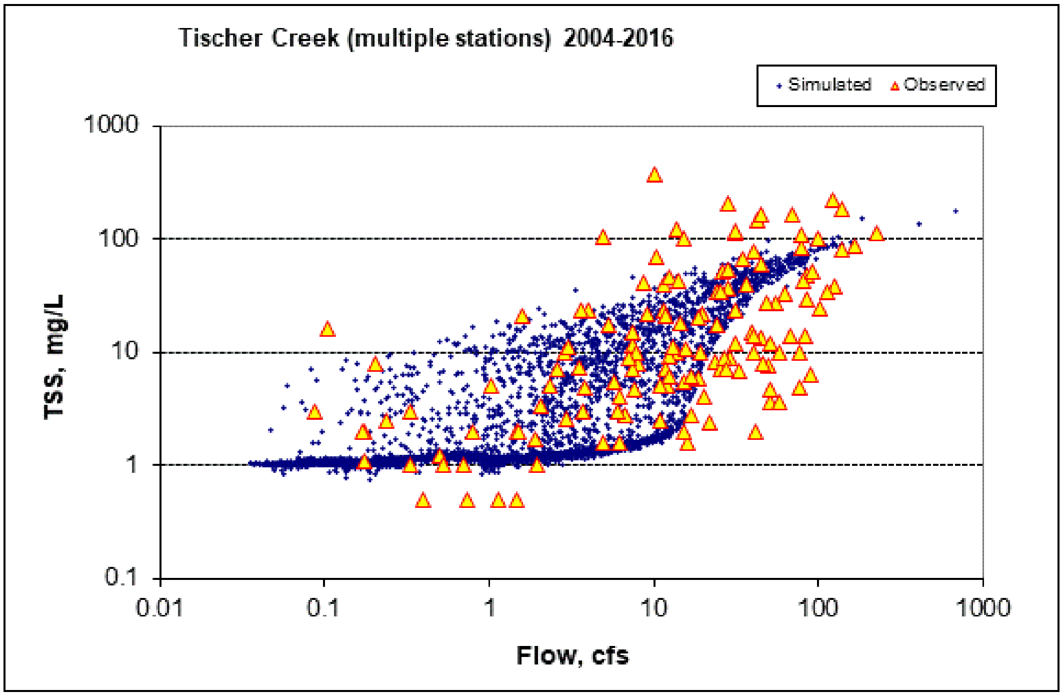


Figure D-83. Simulated and Observed TSS Concentration vs Flow Plot at the Tischer Creek (multiple stations) (Calibration Period)

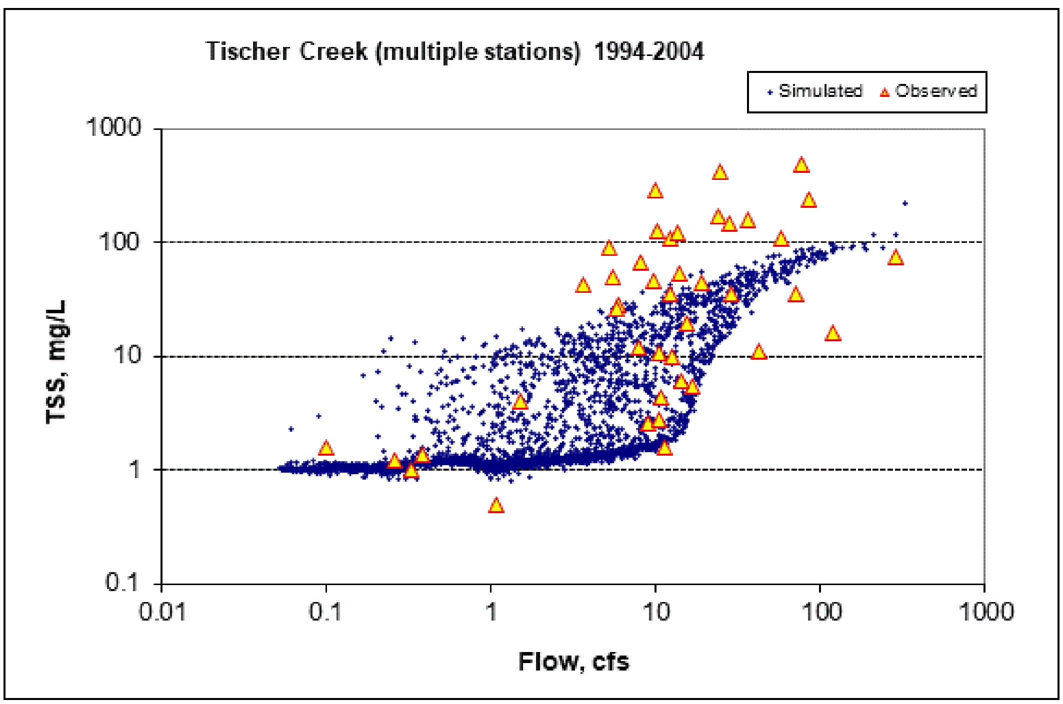


Figure D-84. Simulated and Observed TSS Concentration vs Flow Plot at the Tischer Creek (multiple stations) (Validation Period)

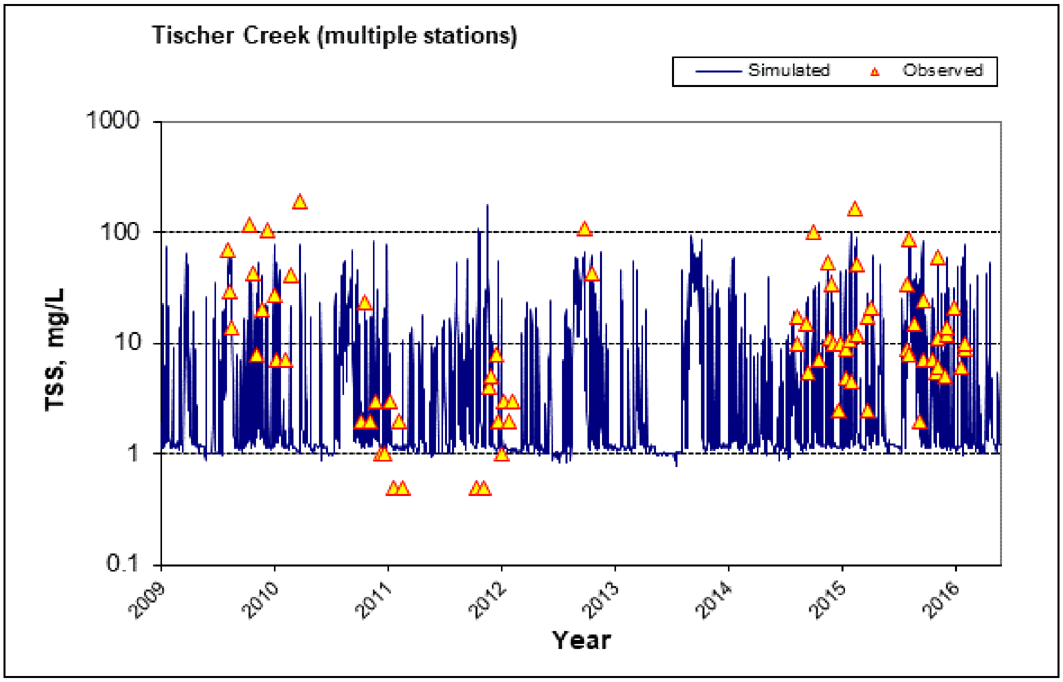


Figure D-85. TSS Concentration Time Series at the Tischer Creek (multiple stations) (2008-2015)

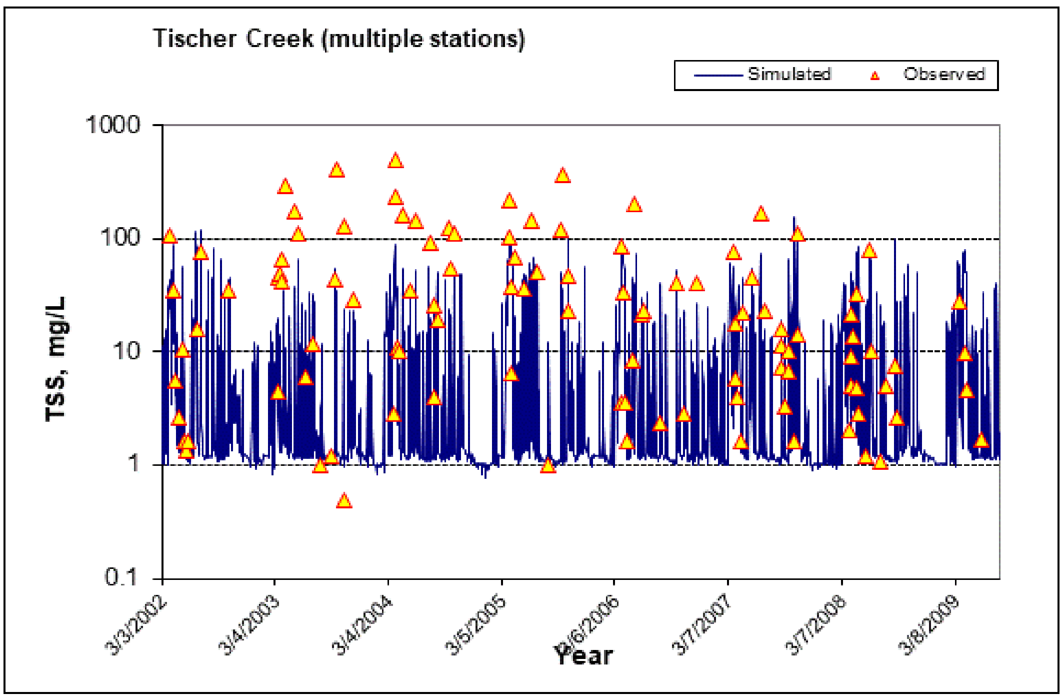


Figure D-86. TSS Concentration Time Series at the Tischer Creek (multiple stations) (2001-2008)

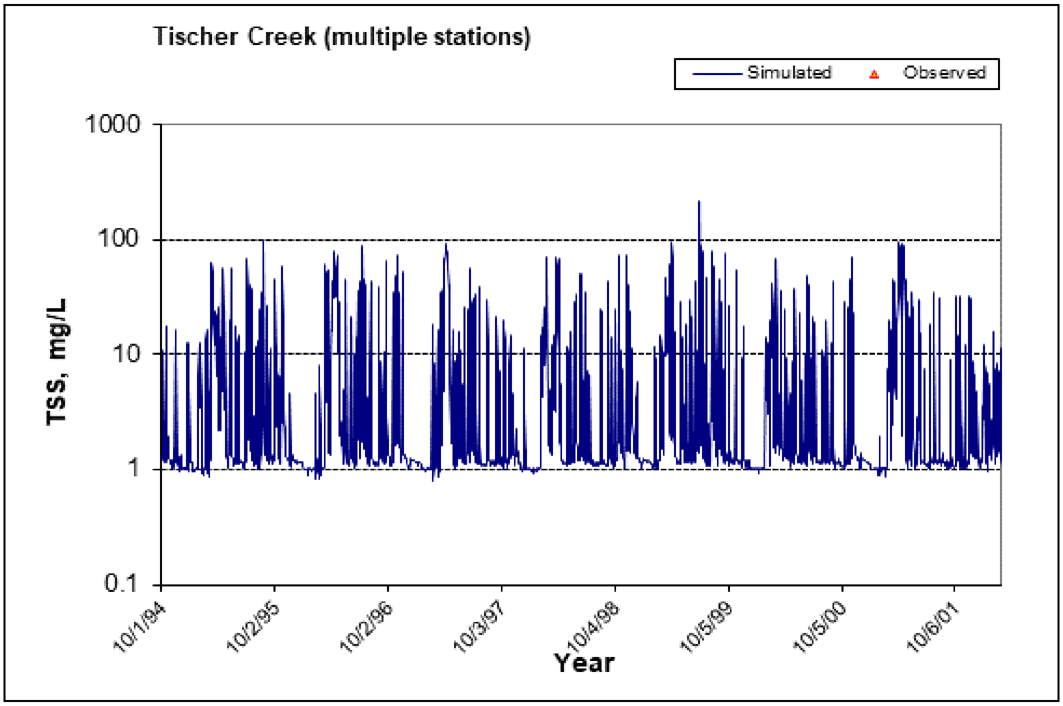


Figure D-87. TSS Concentration Time Series at the Tischer Creek (multiple stations) (1994-2001)

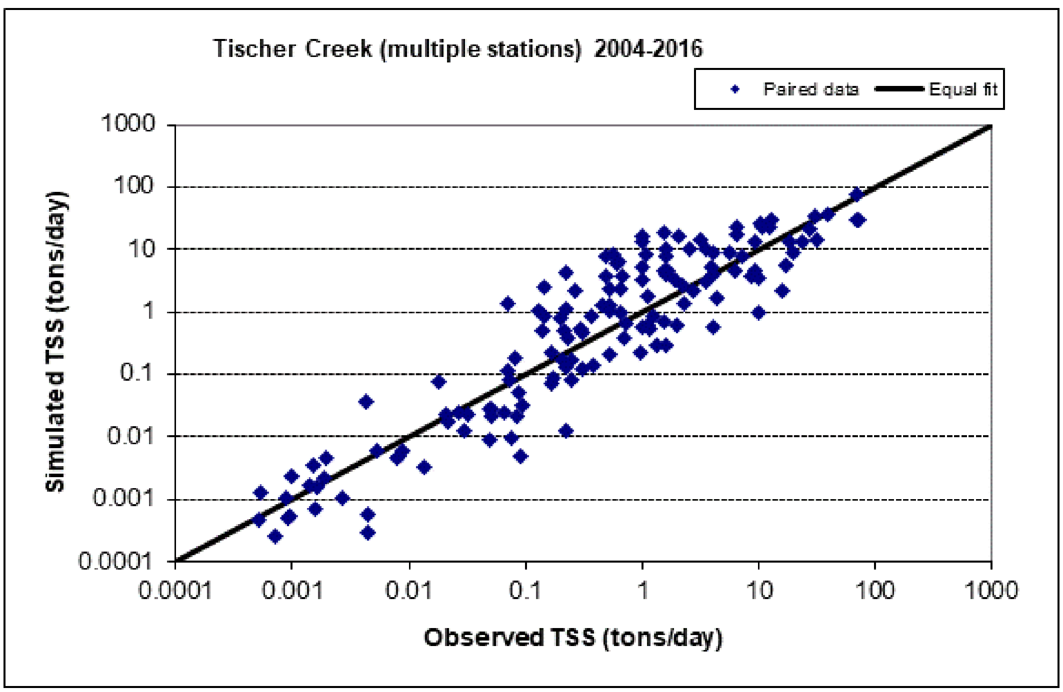


Figure D-88. Paired Simulated vs Observed TSS Load at the Tischer Creek (multiple stations) (Calibration Period)

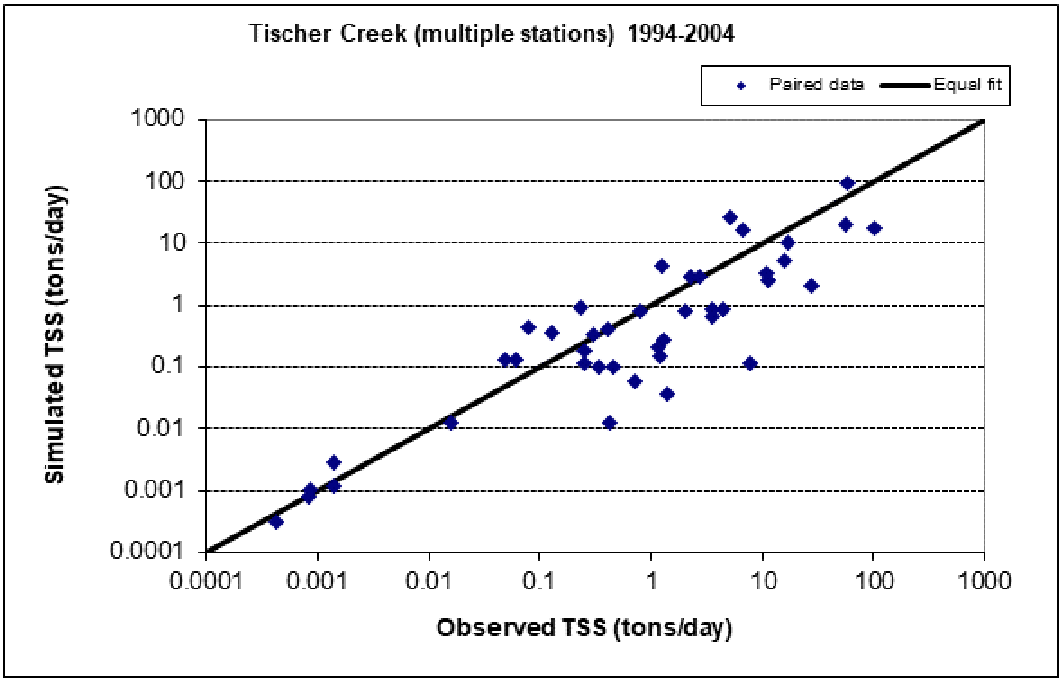


Figure D-89. Paired Simulated vs Observed TSS Load at the Tischer Creek (multiple stations) (Validation Period)

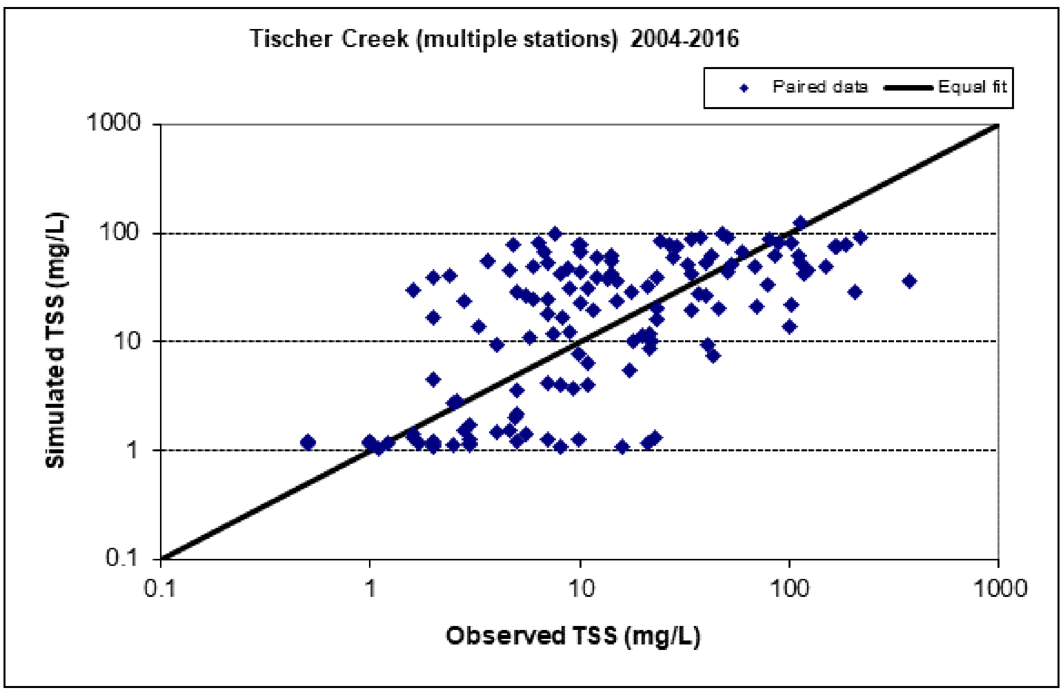


Figure D-90. Paired Simulated vs Observed TSS Concentration at the Tischer Creek (multiple stations) (Calibration Period)

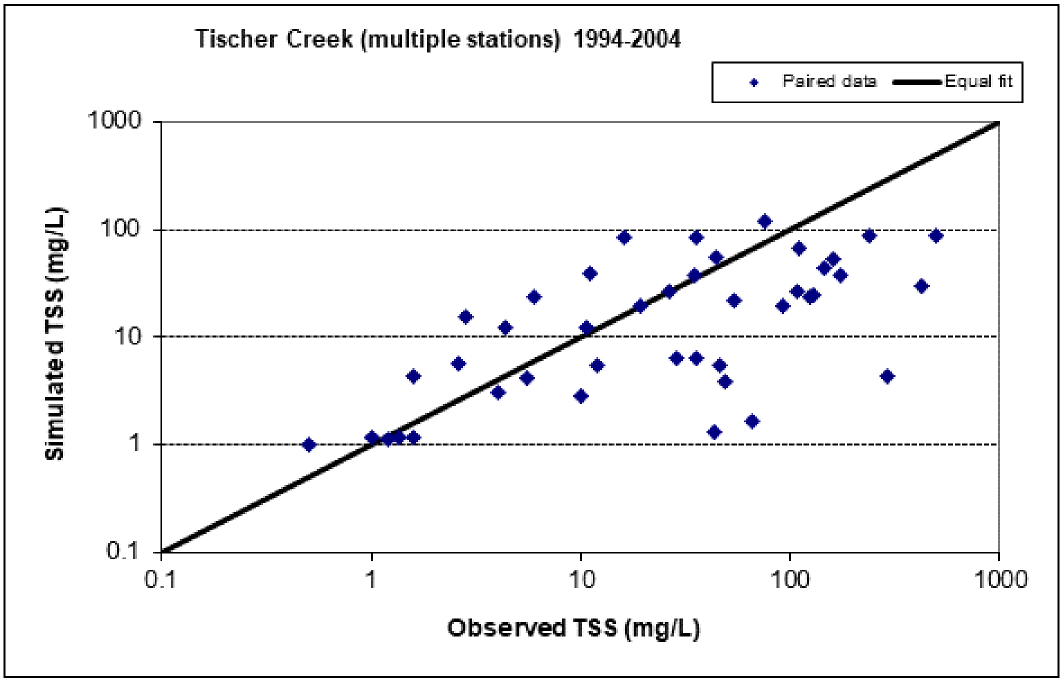


Figure D-91. Paired Simulated vs Observed TSS Concentration at the Tischer Creek (multiple stations) (Validation Period)

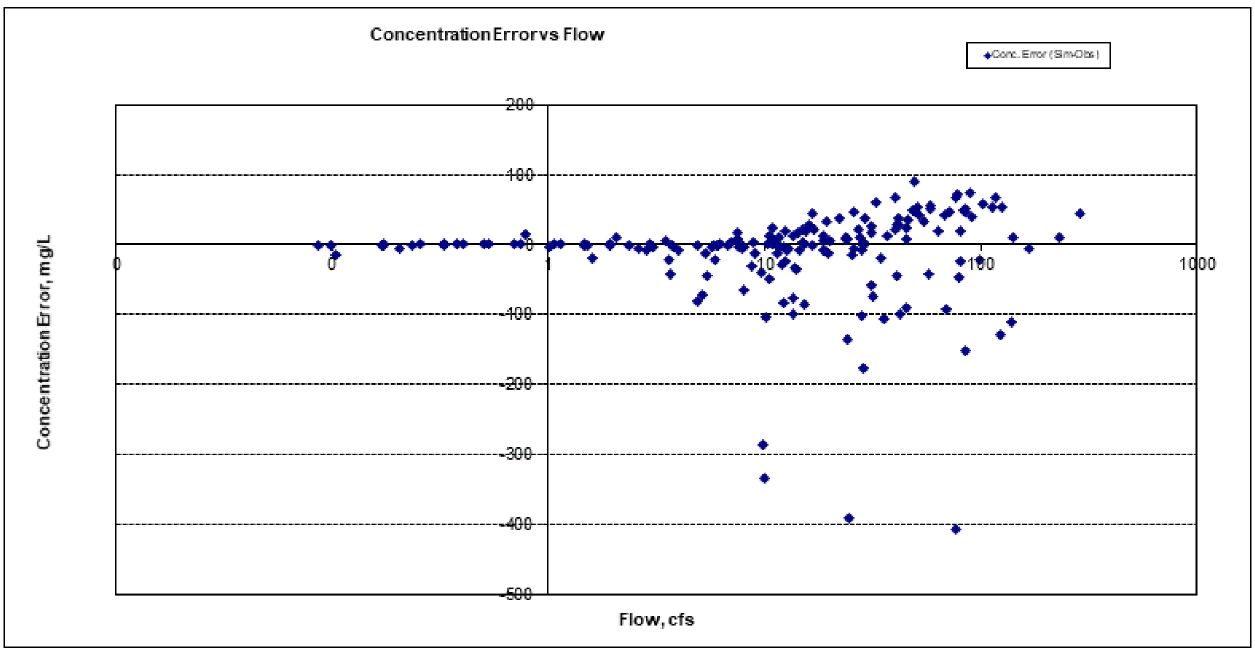


Figure D-92. TSS Concentration Error vs Flow at the Tischer Creek (multiple stations)

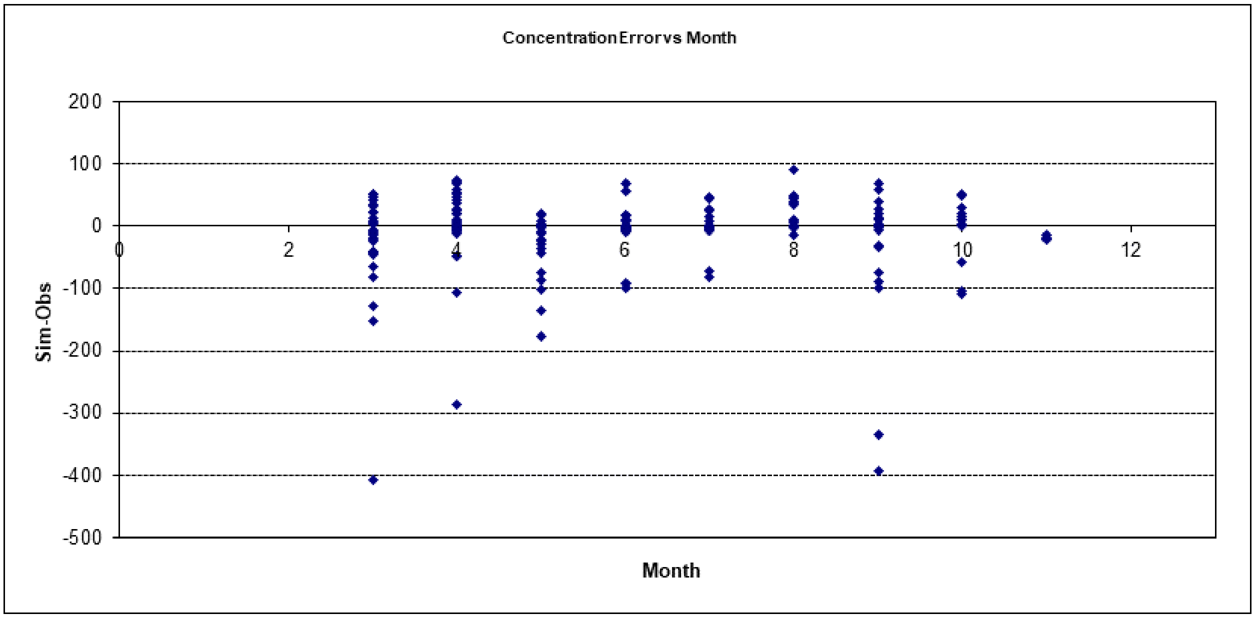


Figure D-93. TSS Concentration Error vs Month at the Tischer Creek (multiple stations)

D.10 CHESTER CREEK (MULTIPLE STATIONS)

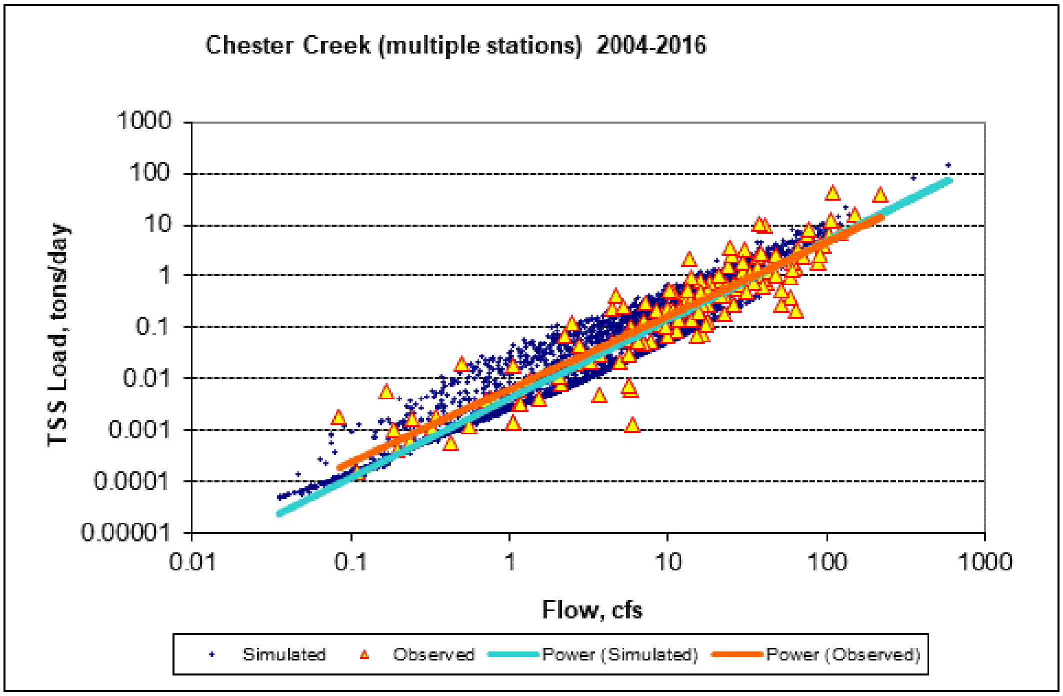


Figure D-94. Power Plot of Simulated and Observed TSS Load vs Flow at the Chester Creek (multiple stations) (Calibration Period)

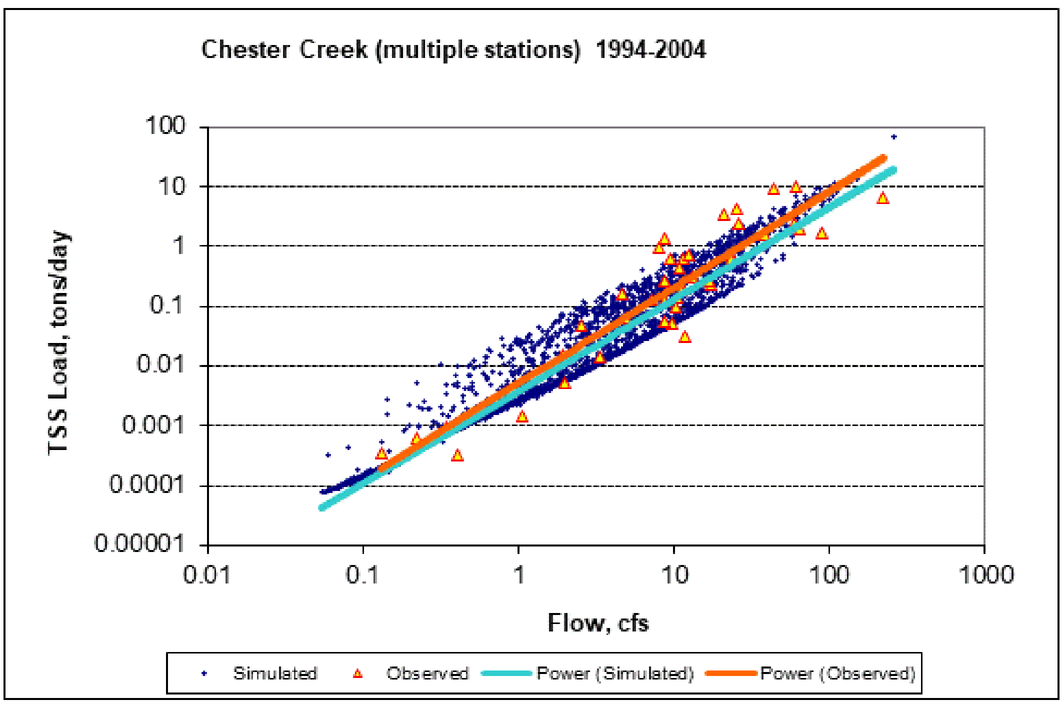


Figure D-95. Power Plot of Simulated and Observed TSS Load vs Flow at the Chester Creek (multiple stations) (Validation Period)

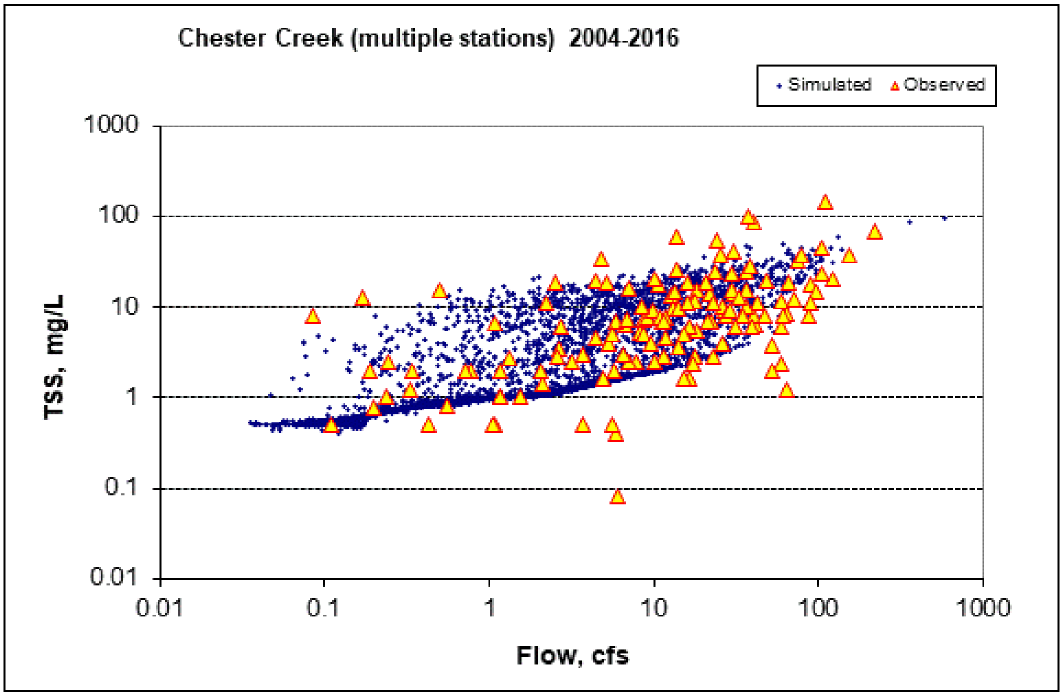


Figure D-96. Simulated and Observed TSS Concentration vs Flow Plot at the Chester Creek (multiple stations) (Calibration Period)

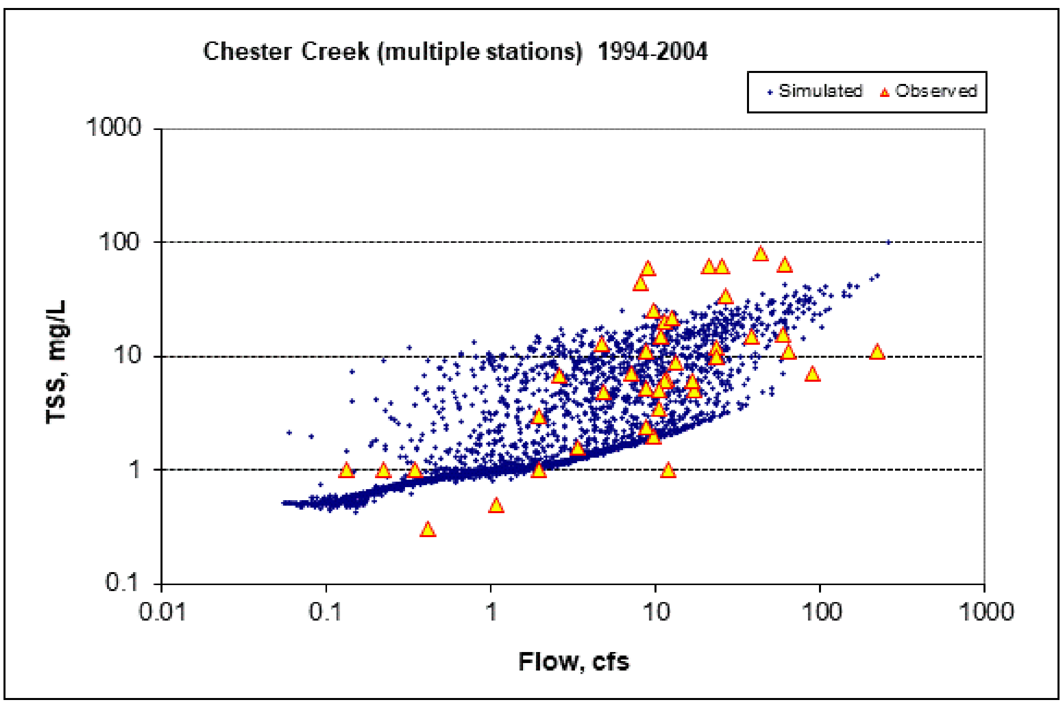


Figure D-97. Simulated and Observed TSS Concentration vs Flow Plot at the Chester Creek (multiple stations) (Validation Period)

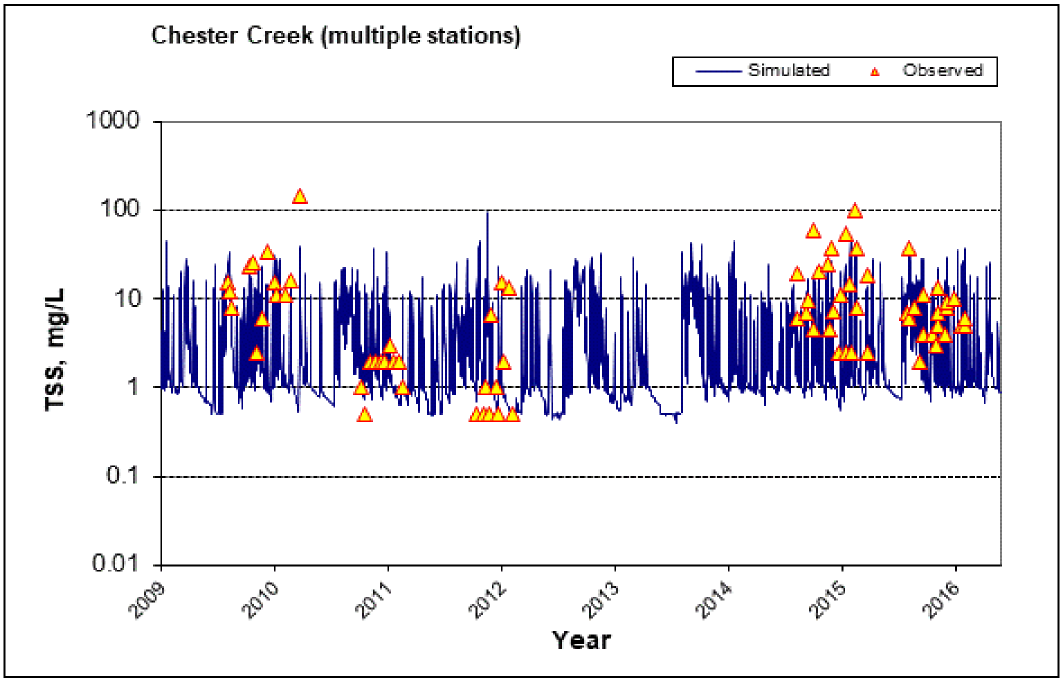


Figure D-98. TSS Concentration Time Series at the Chester Creek (multiple stations) (2008-2015)

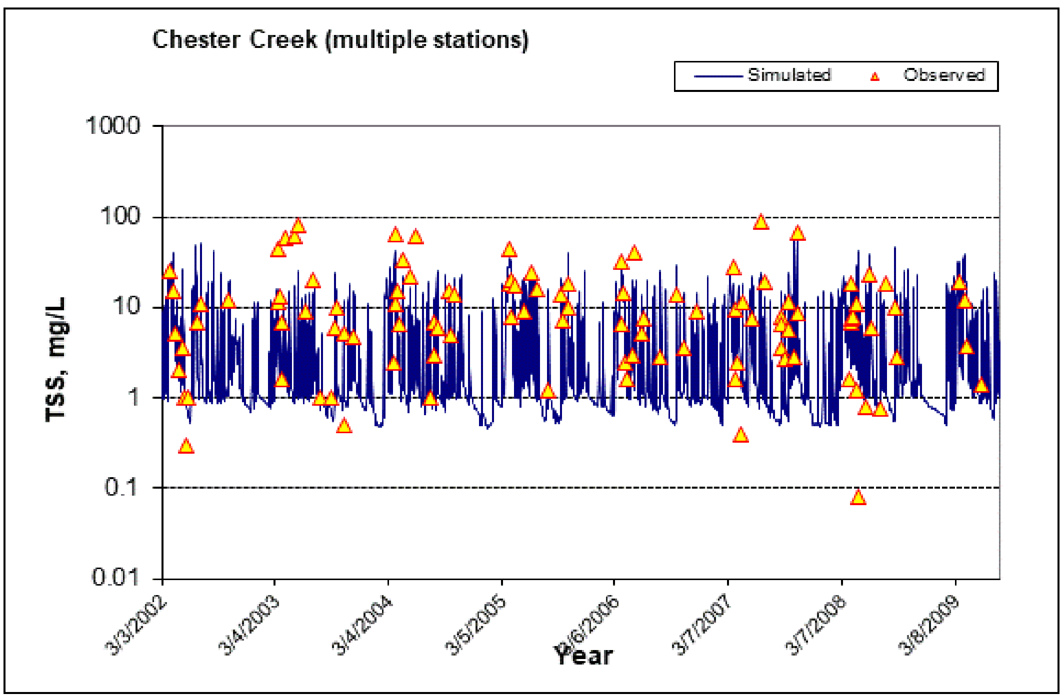


Figure D-99. TSS Concentration Time Series at the Chester Creek (multiple stations) (2001-2008)

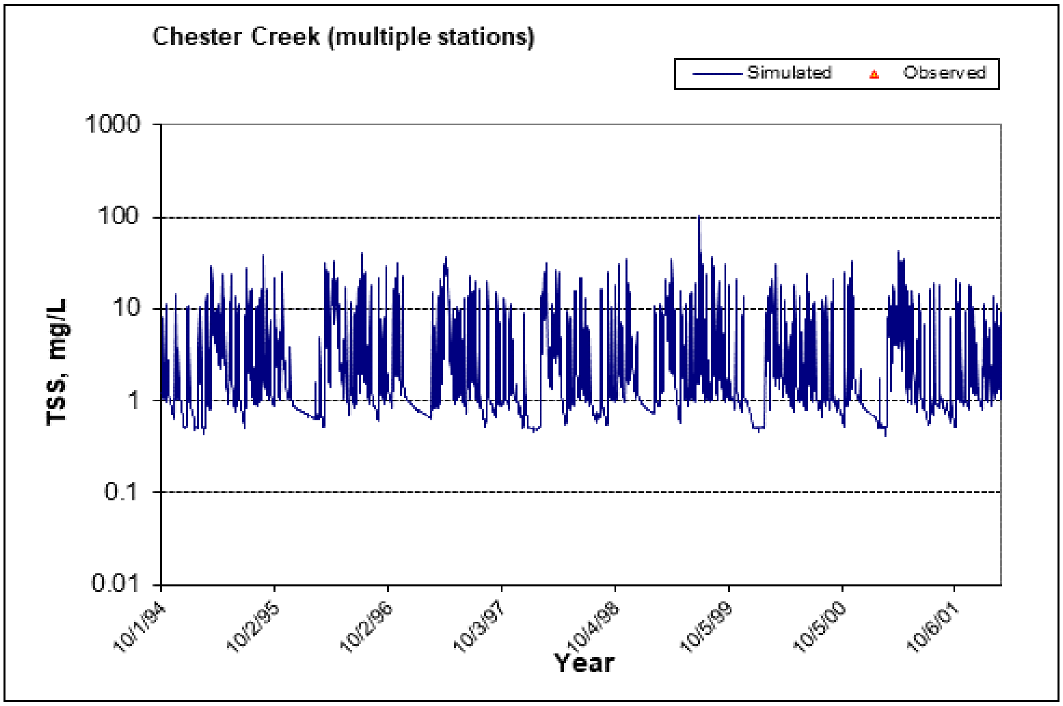


Figure D-100. TSS Concentration Time Series at the Chester Creek (multiple stations) (1994-2001)

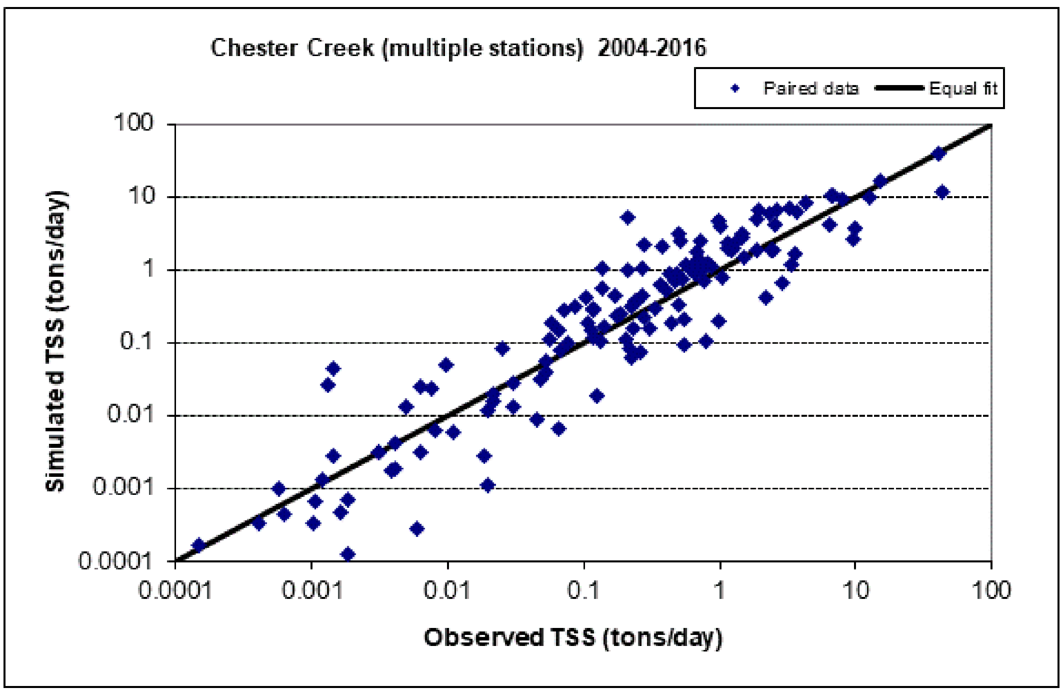


Figure D-101. Paired Simulated vs Observed TSS Load at the Chester Creek (multiple stations) (Calibration Period)

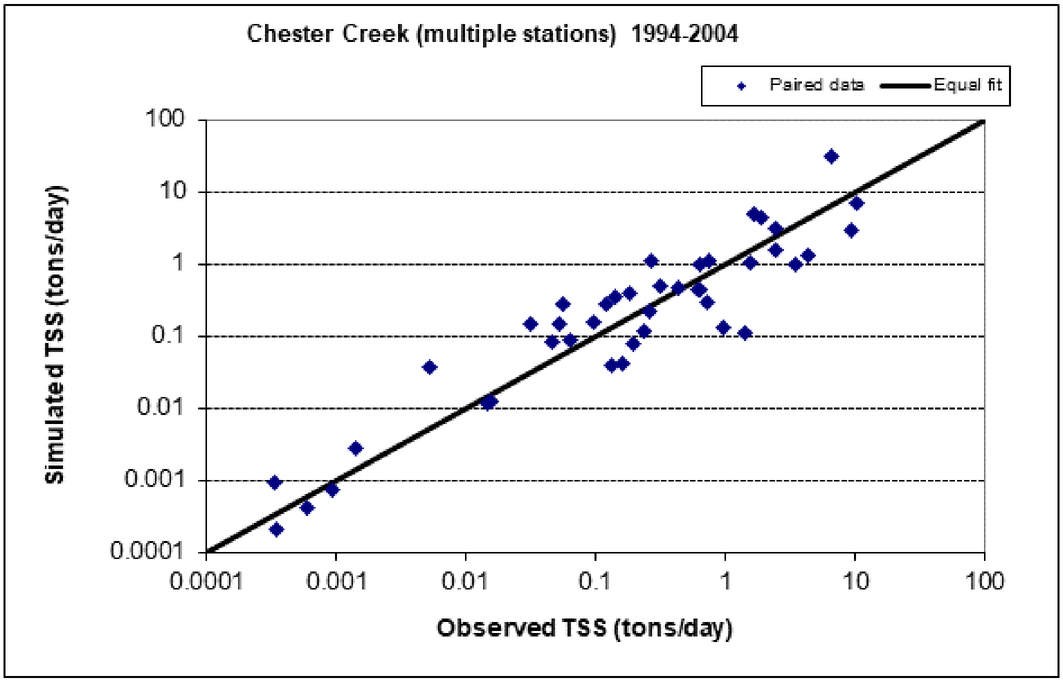


Figure D-102. Paired Simulated vs Observed TSS Load at the Chester Creek (multiple stations) (Validation Period)

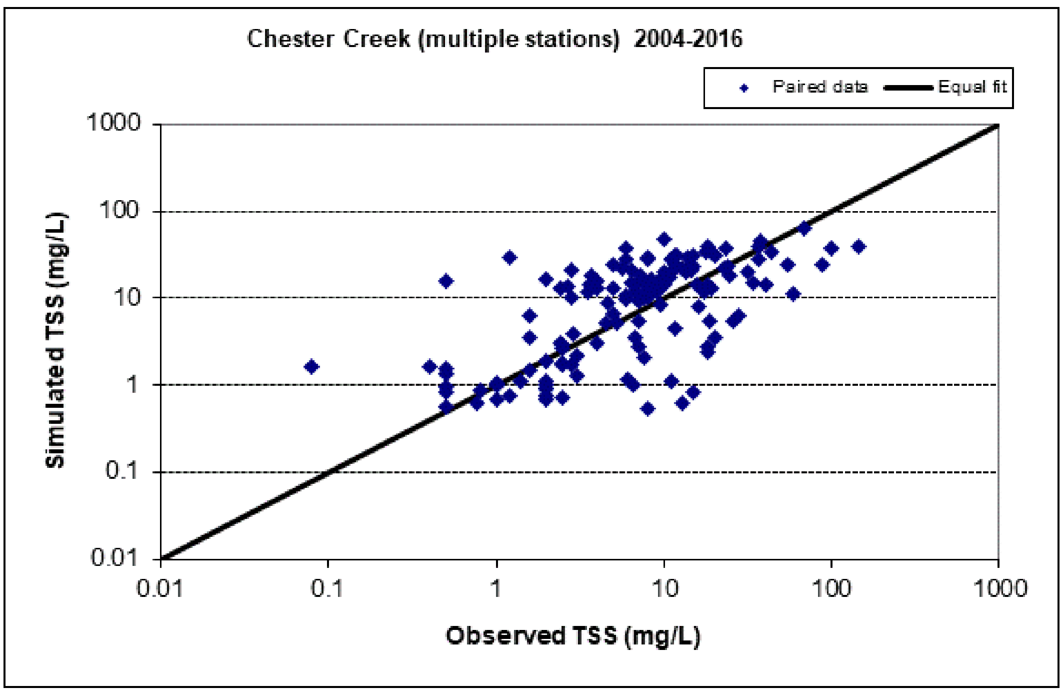


Figure D-103. Paired Simulated vs Observed TSS Concentration at the Chester Creek (multiple stations) (Calibration Period)

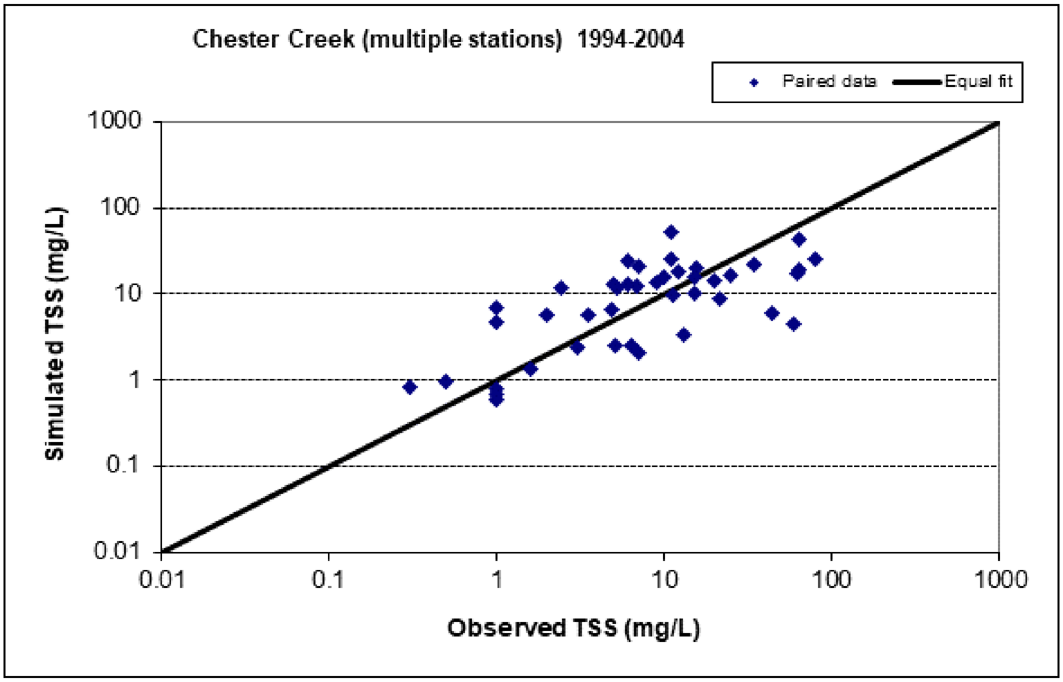


Figure D-104. Paired Simulated vs Observed TSS Concentration at the Chester Creek (multiple stations) (Validation Period)

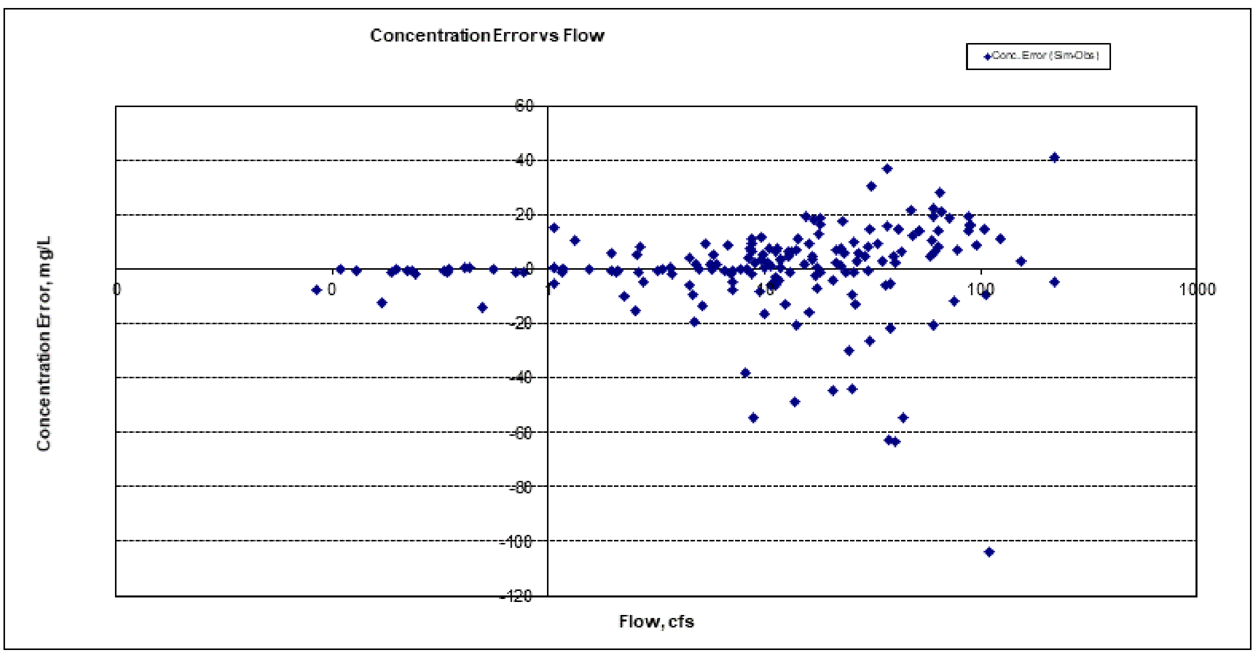


Figure D-105. TSS Concentration Error vs Flow at the Chester Creek (multiple stations)

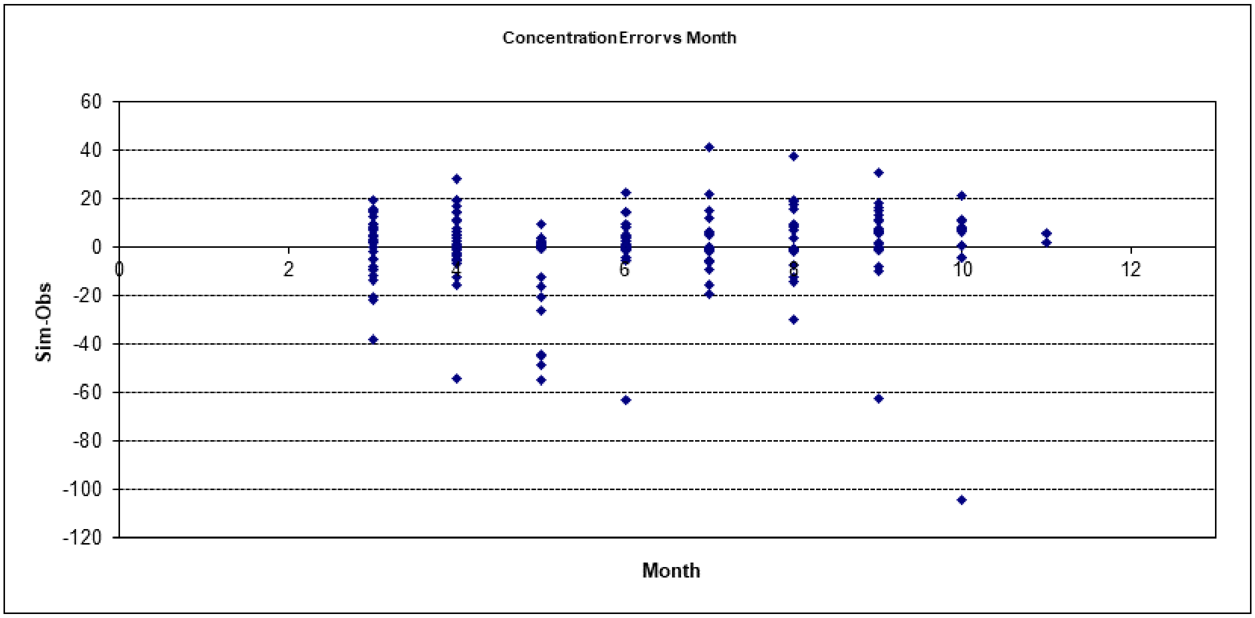


Figure D-106. TSS Concentration Error vs Month at the Chester Creek (multiple stations)

D.11 Buckingham Creek at W 3rd St

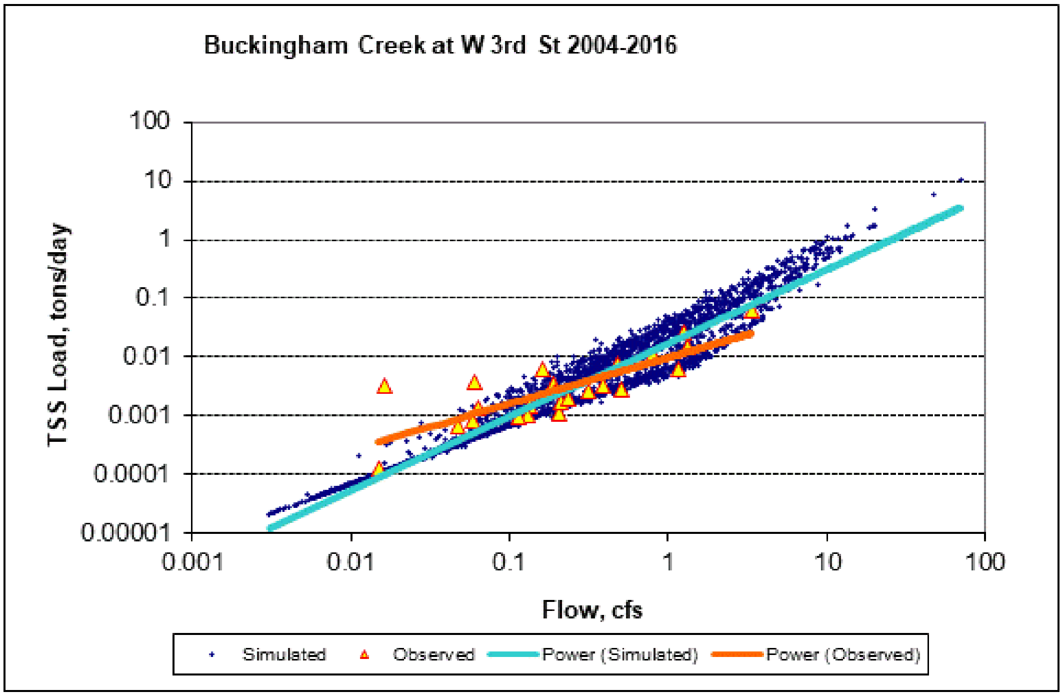


Figure D-107. Power Plot of Simulated and Observed TSS Load vs Flow at the Buckingham Creek at W 3rd St (Calibration Period)

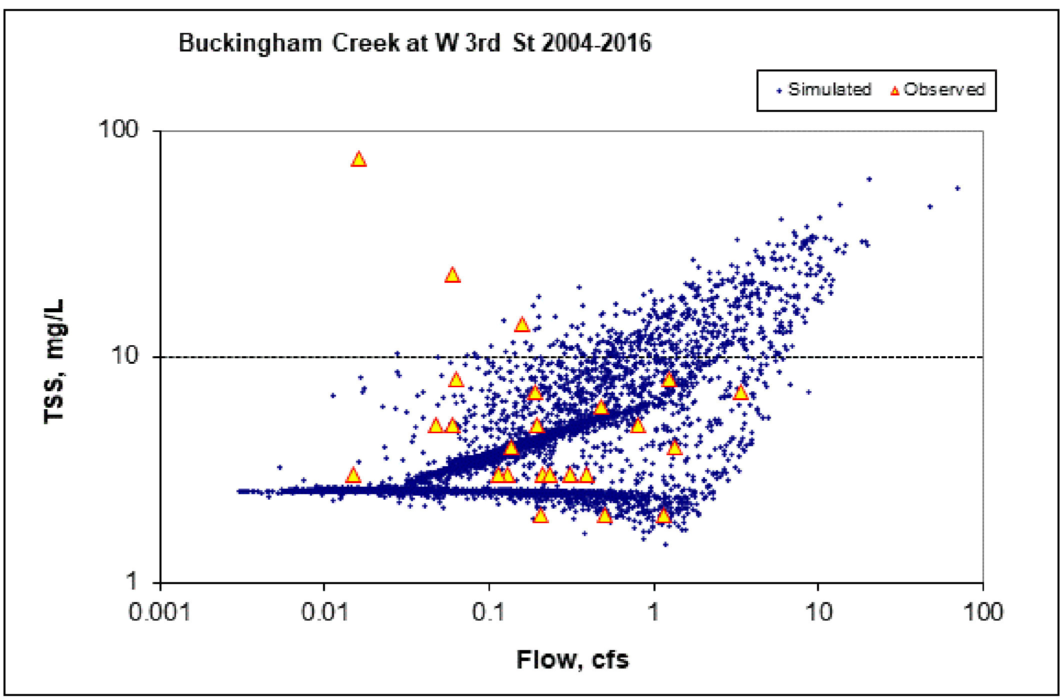


Figure D-108. Simulated and Observed TSS Concentration vs Flow Plot at the Buckingham Creek at W 3rd St (Calibration Period)

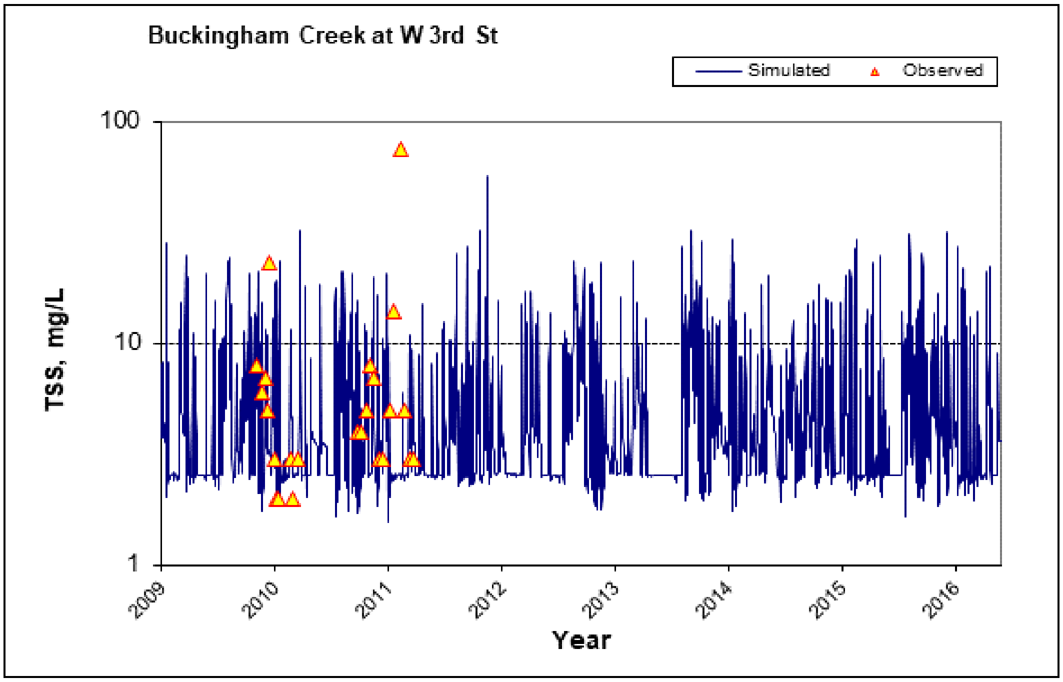


Figure D-109. TSS Concentration Time Series at the Buckingham Creek at W 3rd St (2008-2015)

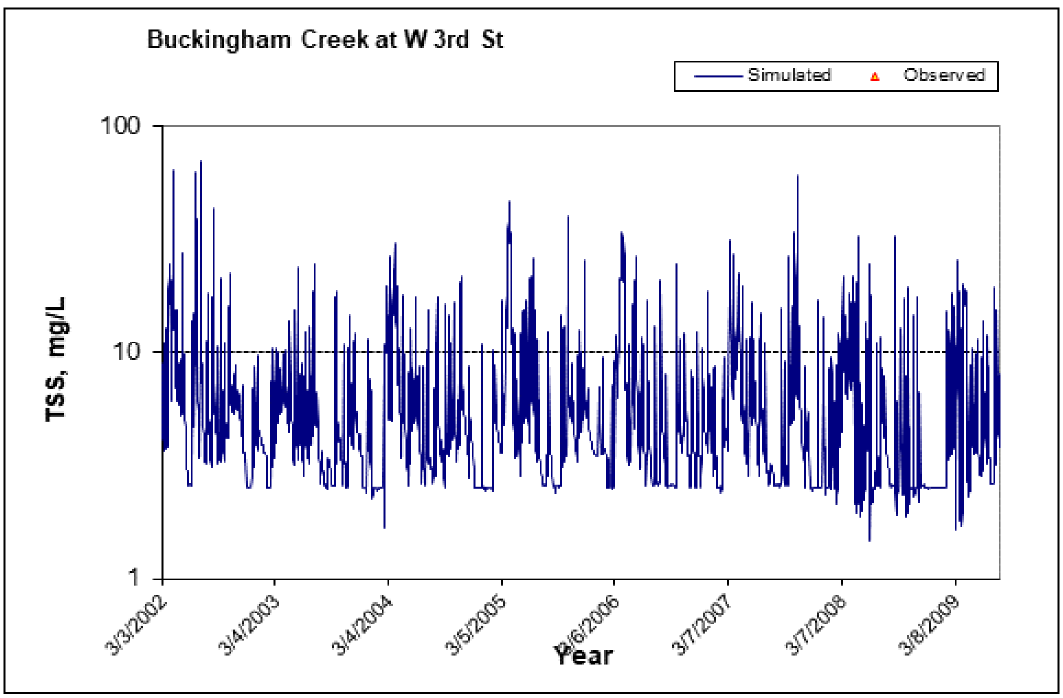


Figure D-110. TSS Concentration Time Series at the Buckingham Creek at W 3rd St (2001-2008)

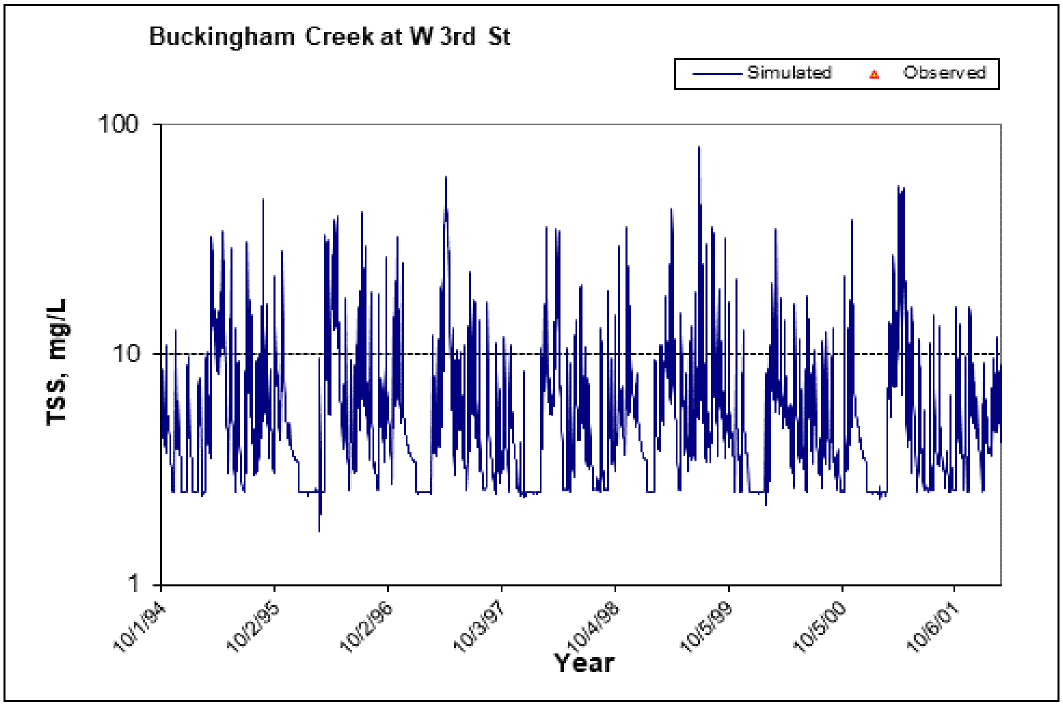


Figure D-111. TSS Concentration Time Series at the Buckingham Creek at W 3rd St (1994-2001)

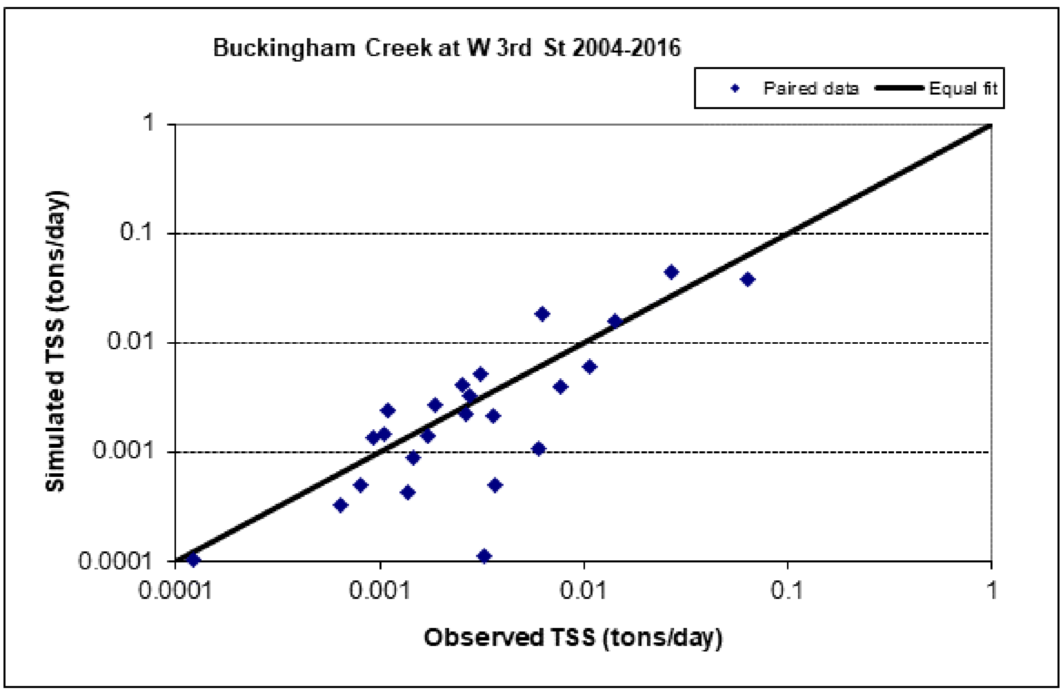


Figure D-112. Paired Simulated vs Observed TSS Load at the Buckingham Creek at W 3rd St (Calibration Period)

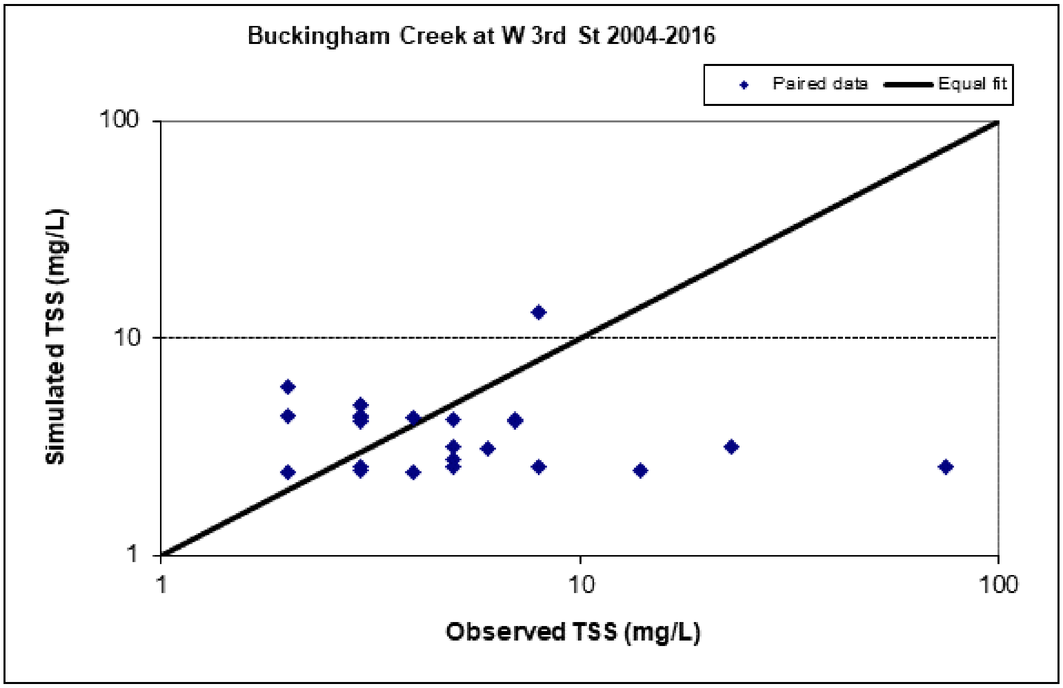


Figure D-113. Paired Simulated vs Observed TSS Concentration at the Buckingham Creek at W 3rd St (Calibration Period)

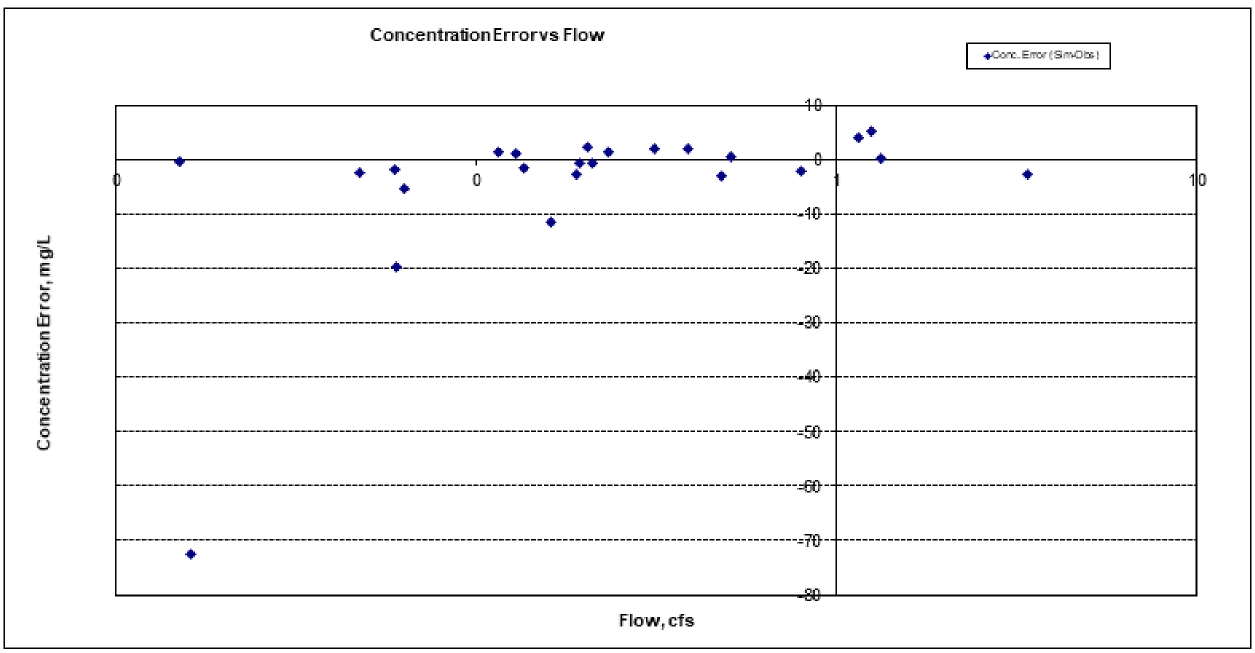


Figure D-114. TSS Concentration Error vs Flow at the Buckingham Creek at W 3rd St

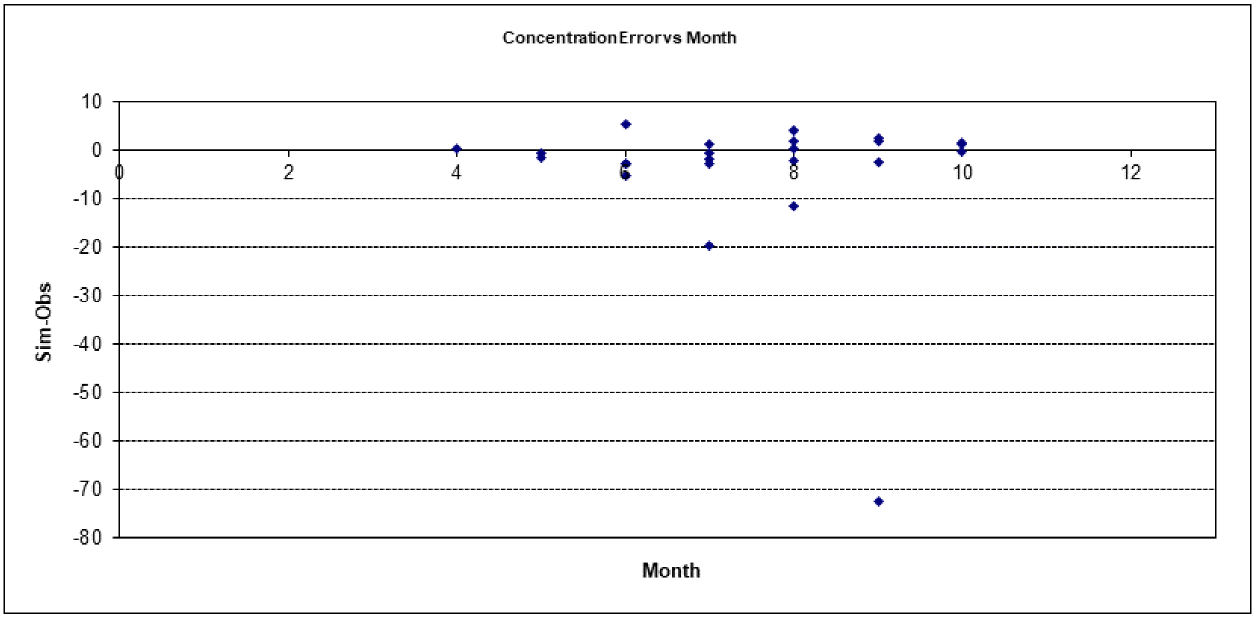


Figure D-115. TSS Concentration Error vs Month at the Buckingham Creek at W 3rd St

D.12 COFFEE CREEK EAST OF MILLER CREEK

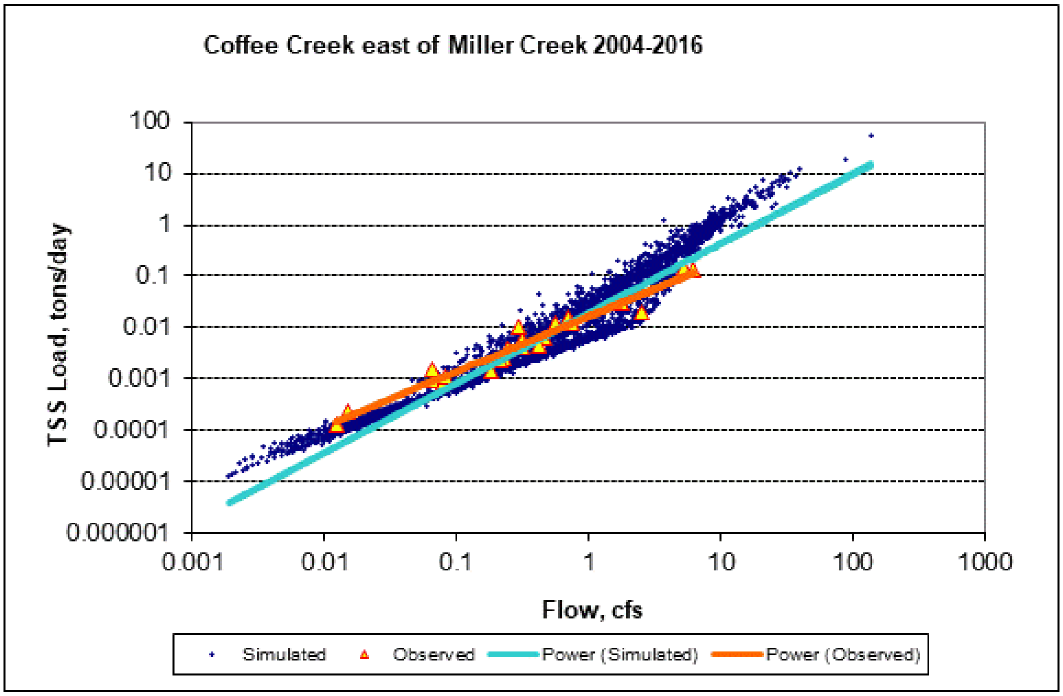


Figure D-116. Power Plot of Simulated and Observed TSS Load vs Flow at the Coffee Creek east of Miller Creek (Calibration Period)

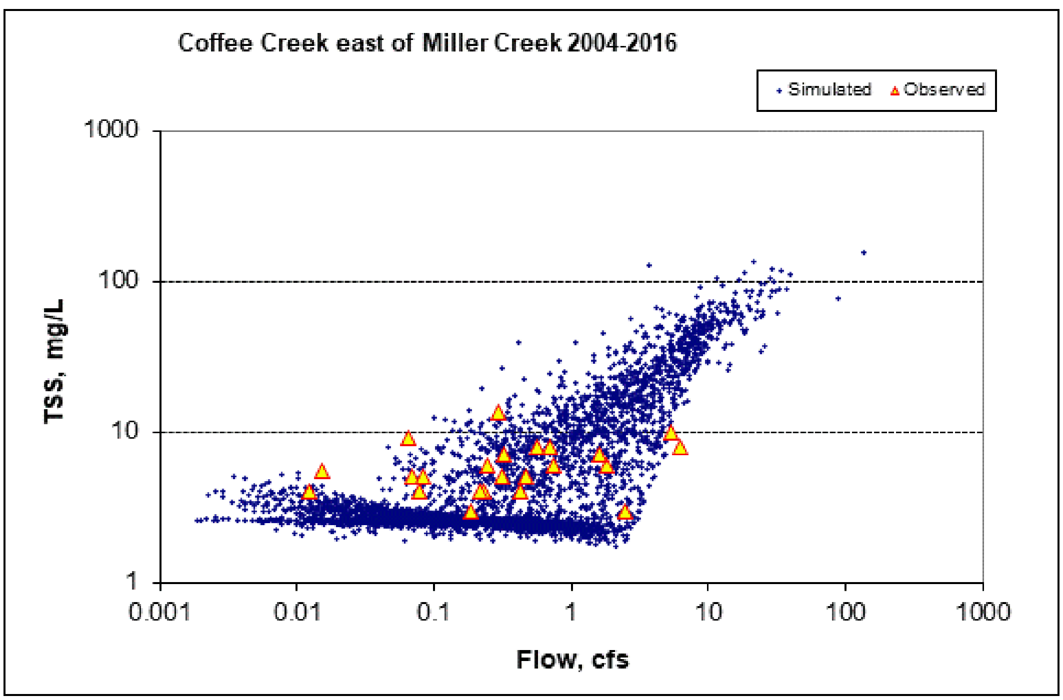


Figure D-117. Simulated and Observed TSS Concentration vs Flow Plot at the Coffee Creek east of Miller Creek (Calibration Period)

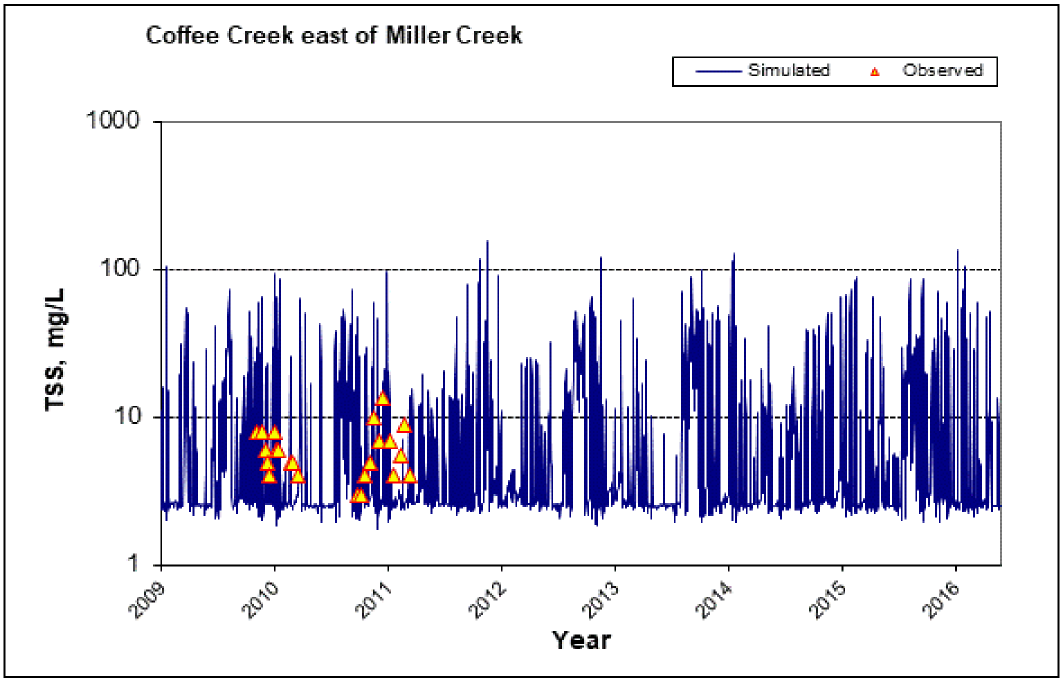


Figure D-118. TSS Concentration Time Series at the Coffee Creek east of Miller Creek (2008-2015)

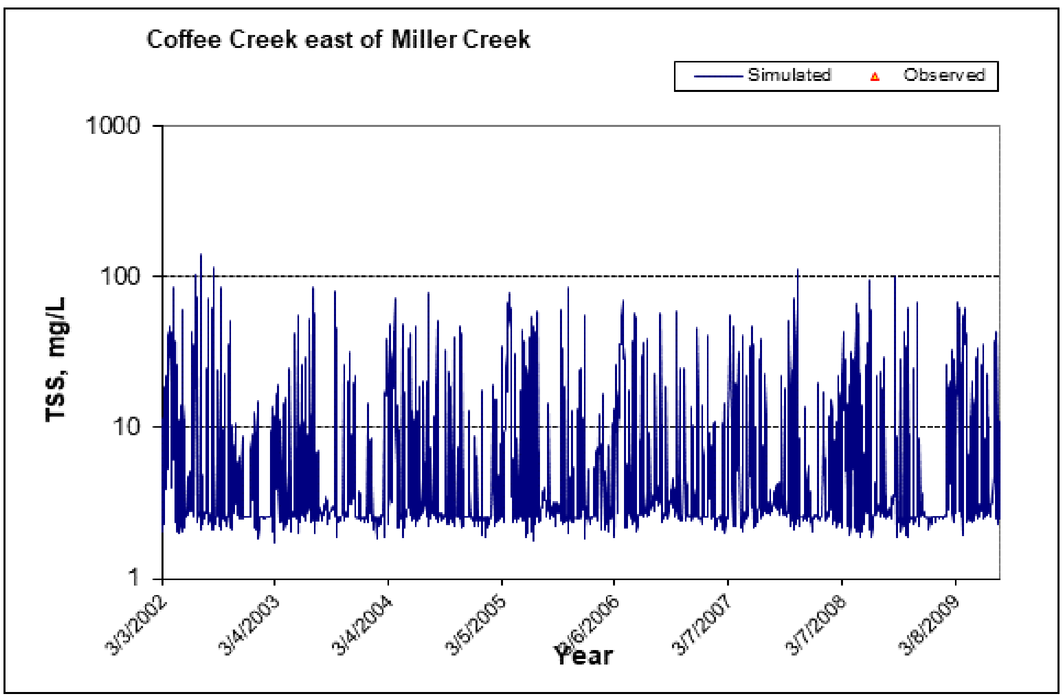


Figure D-119. TSS Concentration Time Series at the Coffee Creek east of Miller Creek (2001-2008)

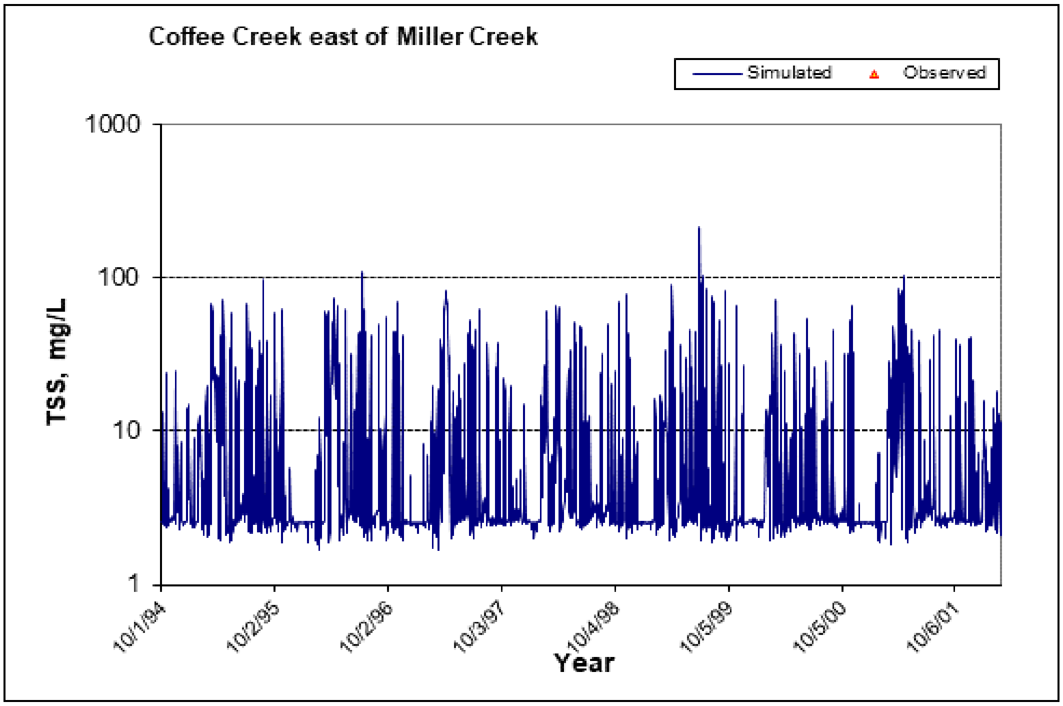


Figure D-120. TSS Concentration Time Series at the Coffee Creek east of Miller Creek (1994-2001)

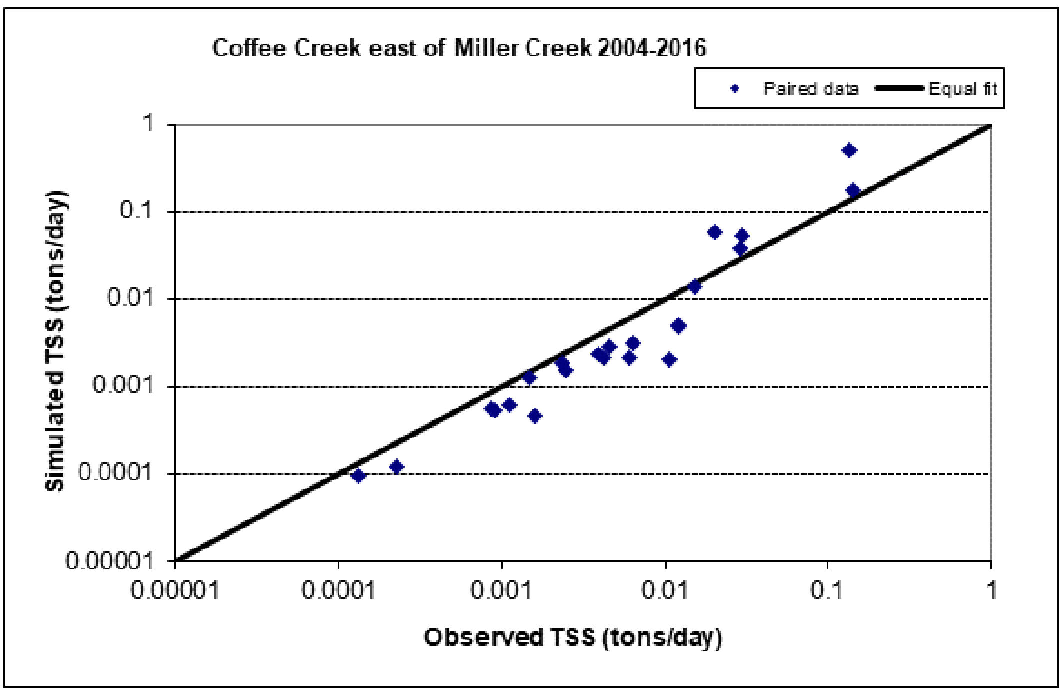


Figure D-121. Paired Simulated vs Observed TSS Load at the Coffee Creek east of Miller Creek (Calibration Period)

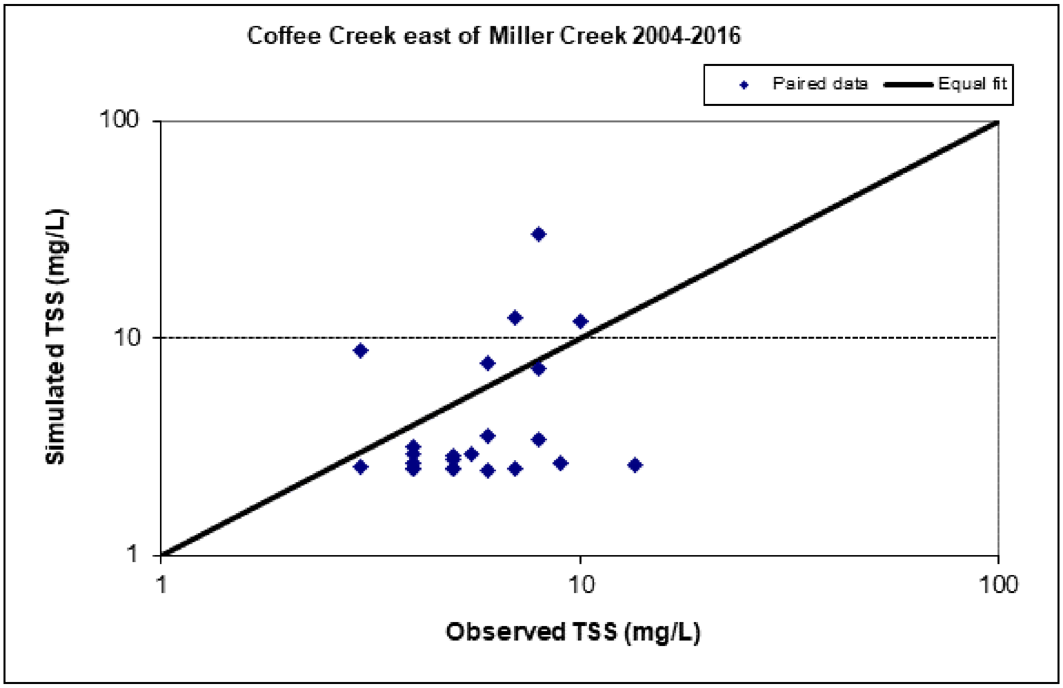


Figure D-122. Paired Simulated vs Observed TSS Concentration at the Coffee Creek east of Miller Creek (Calibration Period)

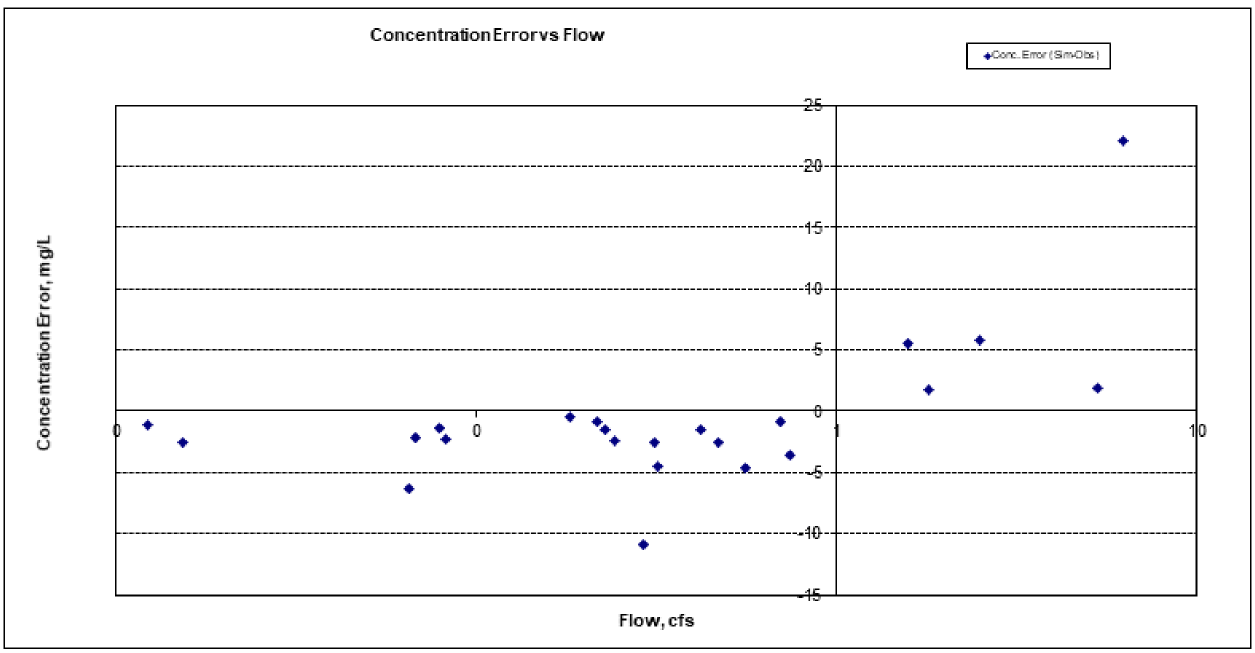


Figure D-123. TSS Concentration Error vs Flow at the Coffee Creek east of Miller Creek

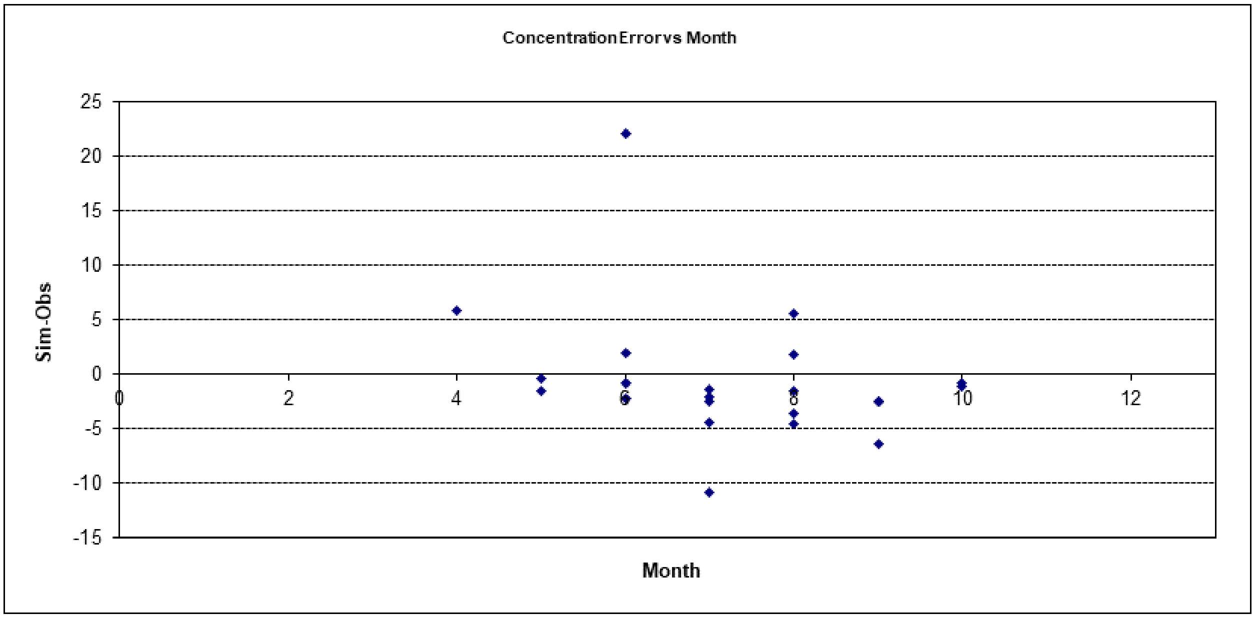


Figure D-124. TSS Concentration Error vs Month at the Coffee Creek east of Miller Creek

D.13 Miller Creek at Chambersburg Rd

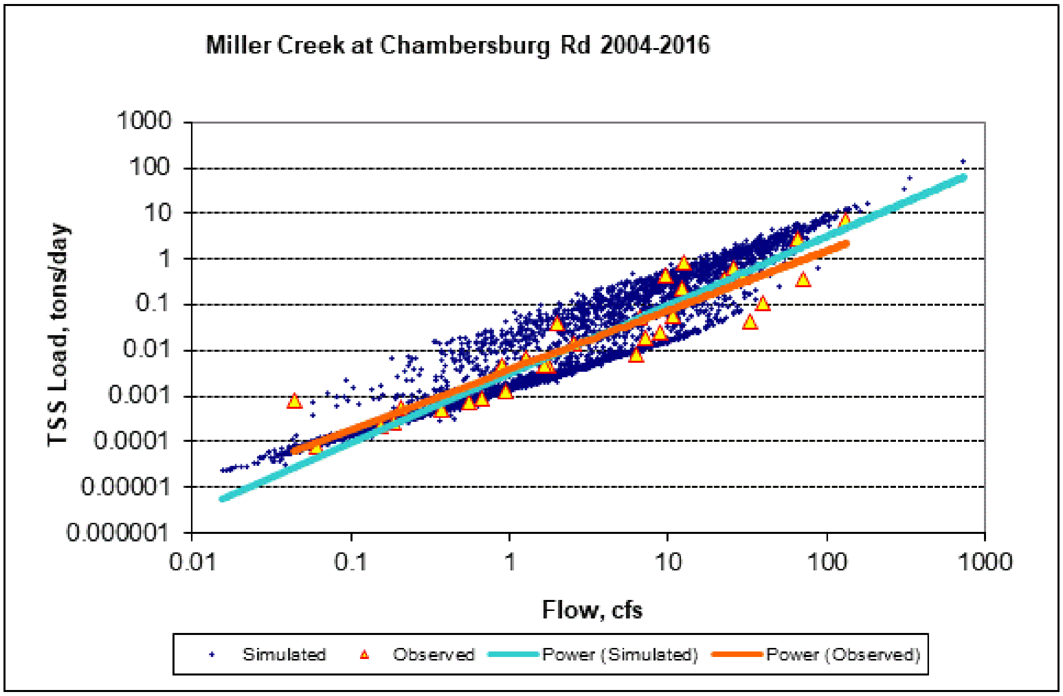


Figure D-125. Power Plot of Simulated and Observed TSS Load vs Flow at the Miller Creek at Chambersburg Rd (Calibration Period)

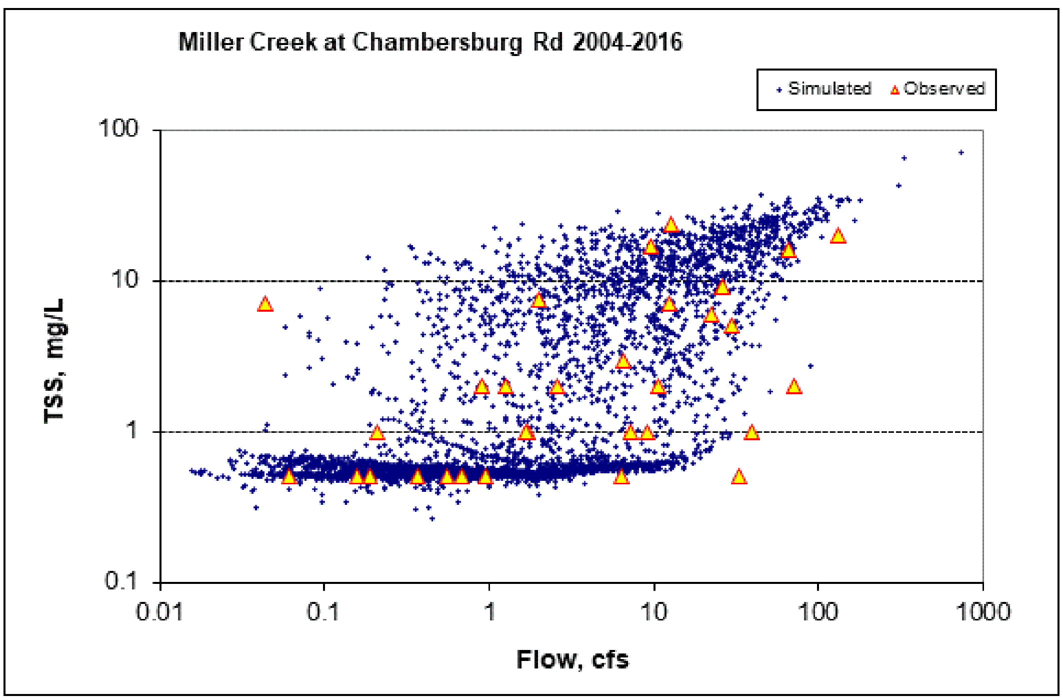


Figure D-126. Simulated and Observed TSS Concentration vs Flow Plot at the Miller Creek at Chambersburg Rd (Calibration Period)

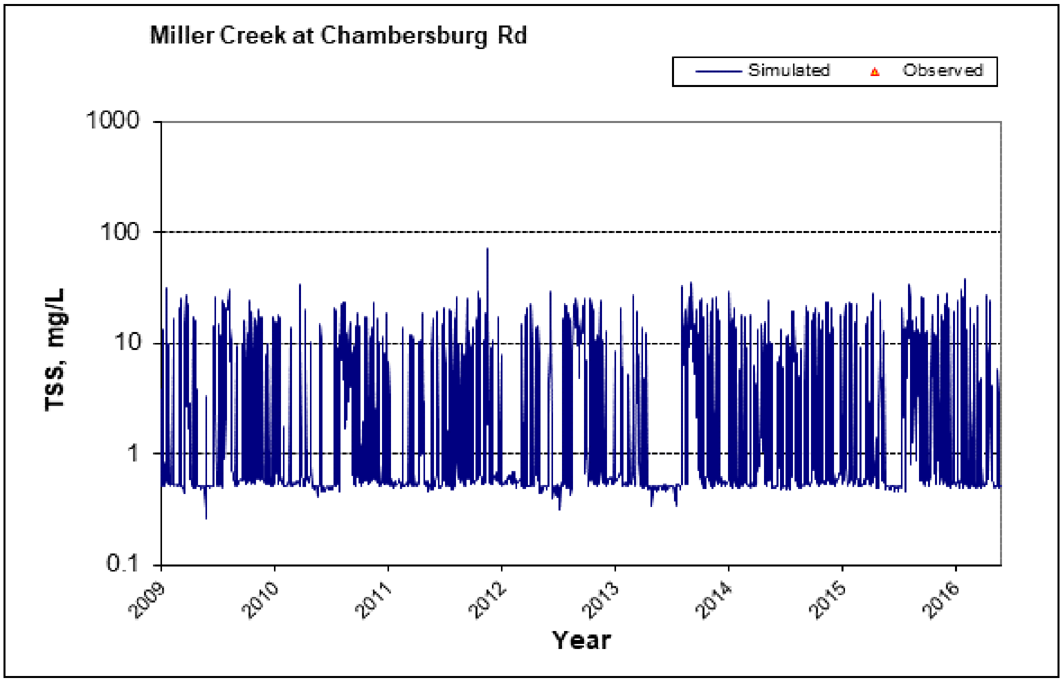


Figure D-127. TSS Concentration Time Series at the Miller Creek at Chambersburg Rd (2008-2015)

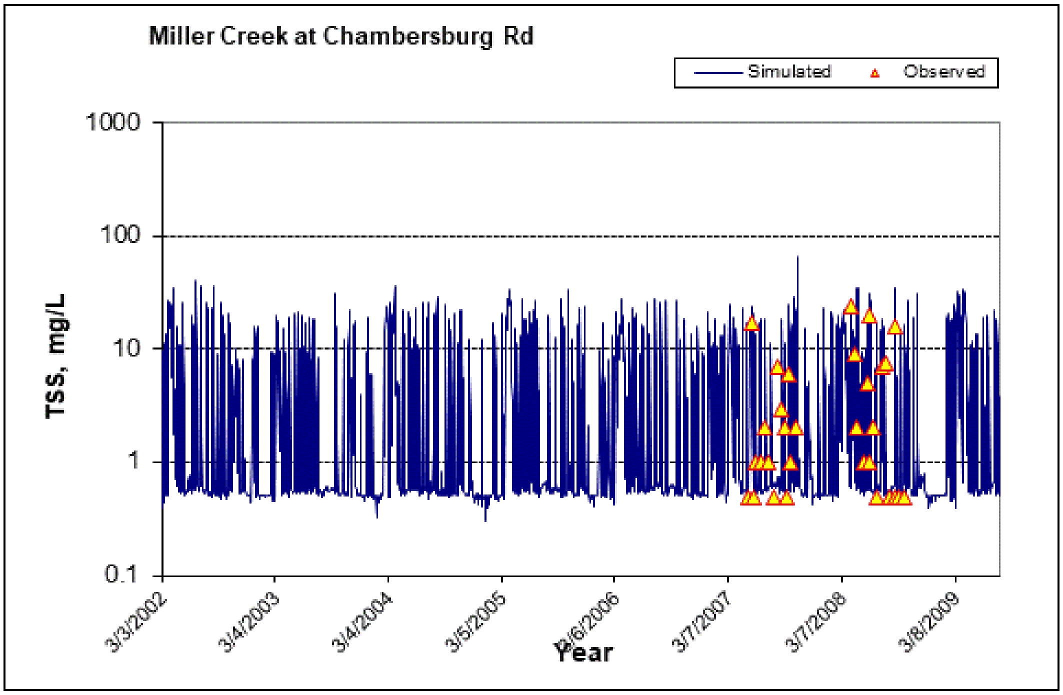


Figure D-128. TSS Concentration Time Series at the Miller Creek at Chambersburg Rd (2001-2008)

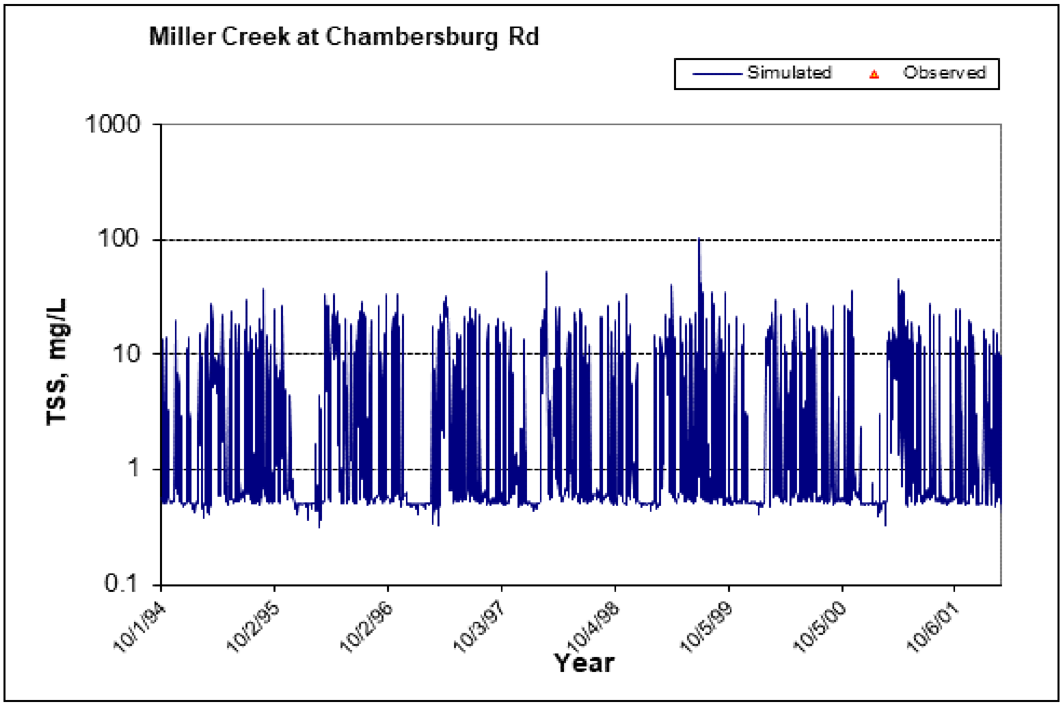


Figure D-129. TSS Concentration Time Series at the Miller Creek at Chambersburg Rd (1994-2001)

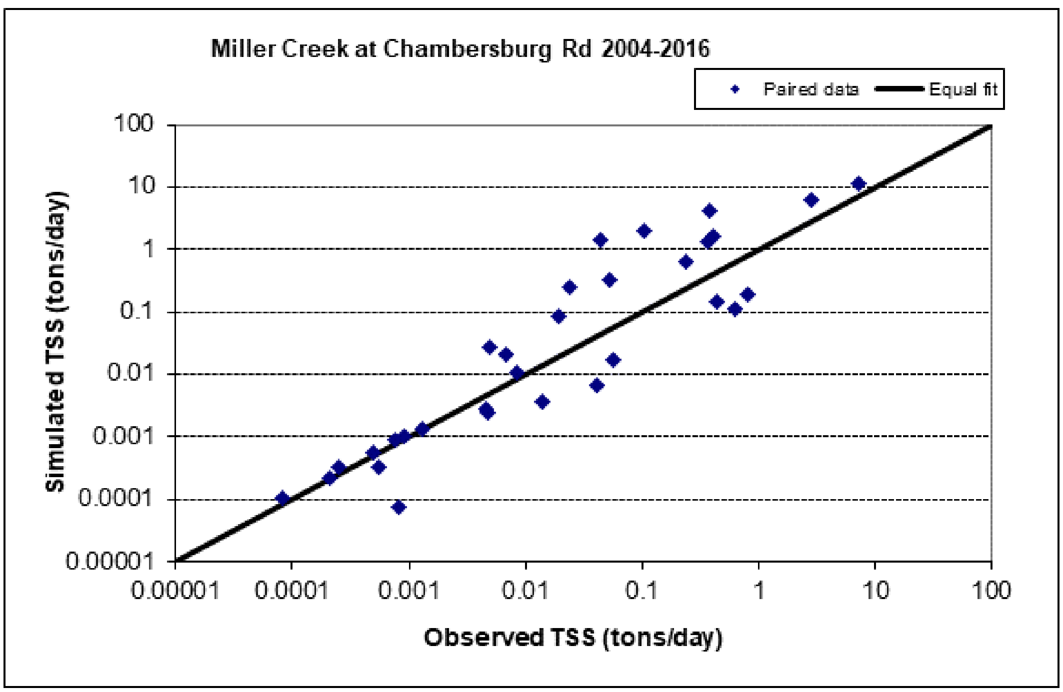


Figure D-130. Paired Simulated vs Observed TSS Load at the Miller Creek at Chambersburg Rd (Calibration Period)

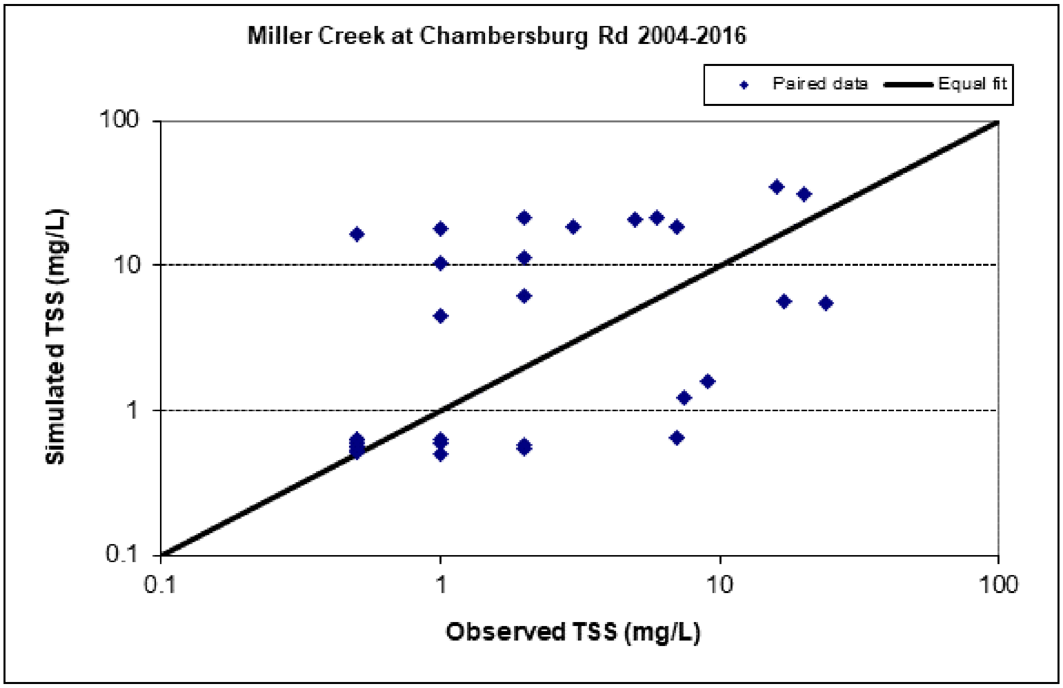


Figure D-131. Paired Simulated vs Observed TSS Concentration at the Miller Creek at Chambersburg Rd (Calibration Period)

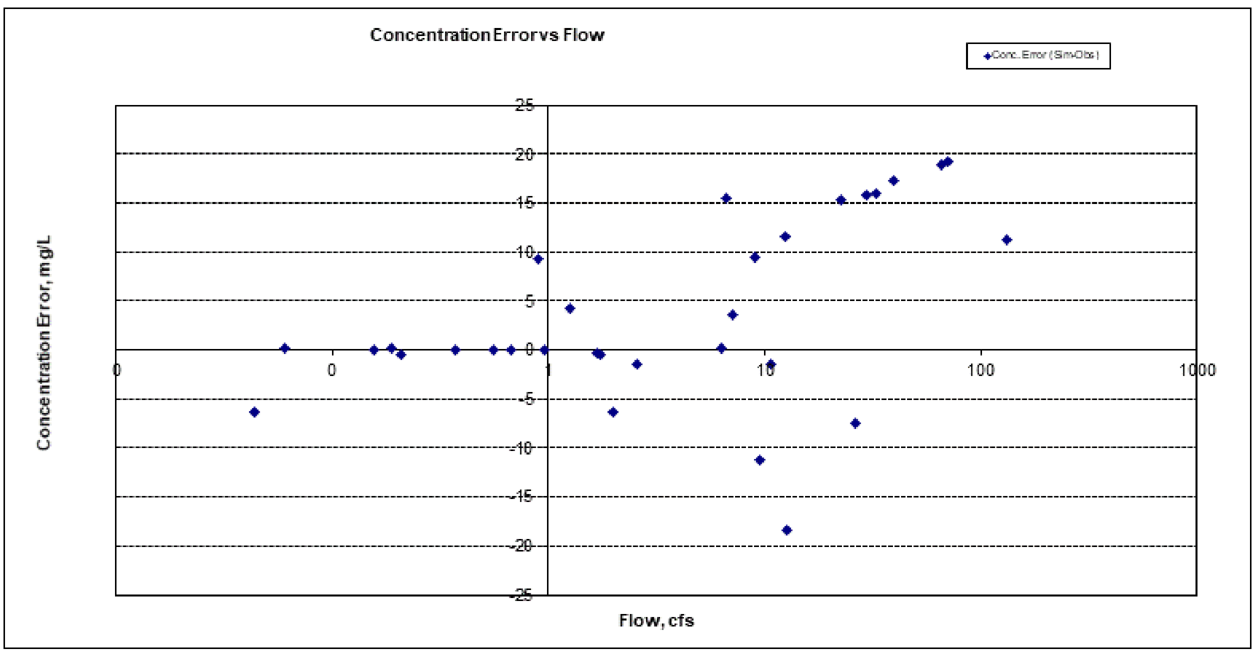


Figure D-132. TSS Concentration Error vs Flow at the Miller Creek at Chambersburg Rd

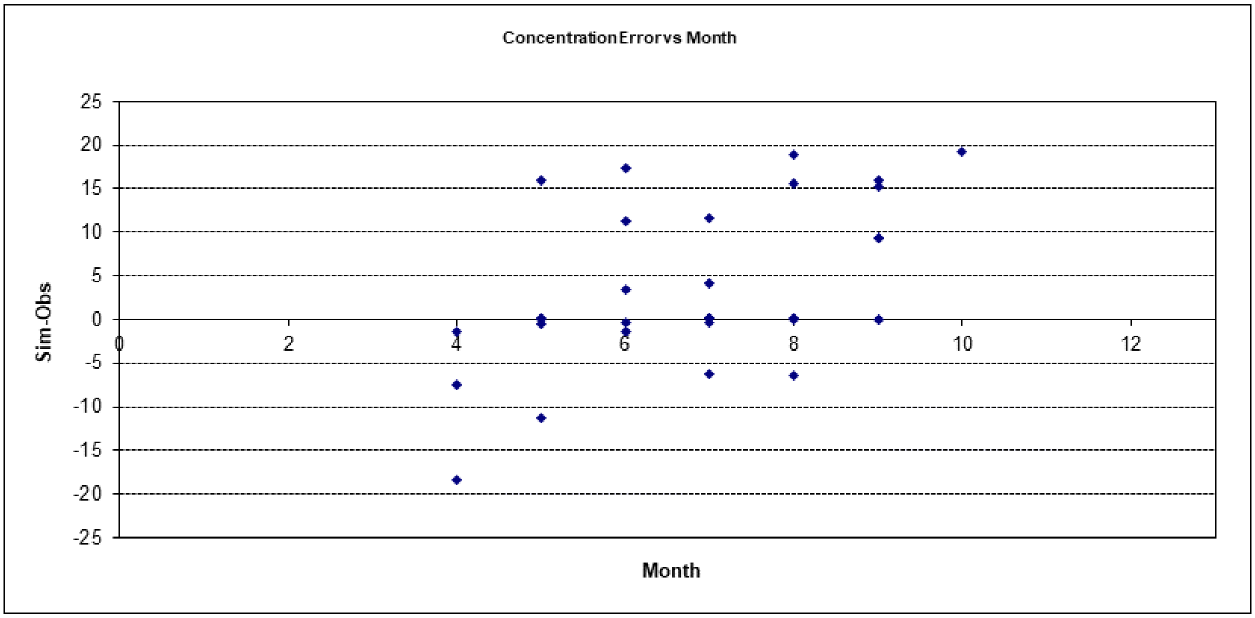


Figure D-133. TSS Concentration Error vs Month at the Miller Creek at Chambersburg Rd

D.14 MILLER CREEK NR LOWER GAGE (MULTIPLE STATIONS)

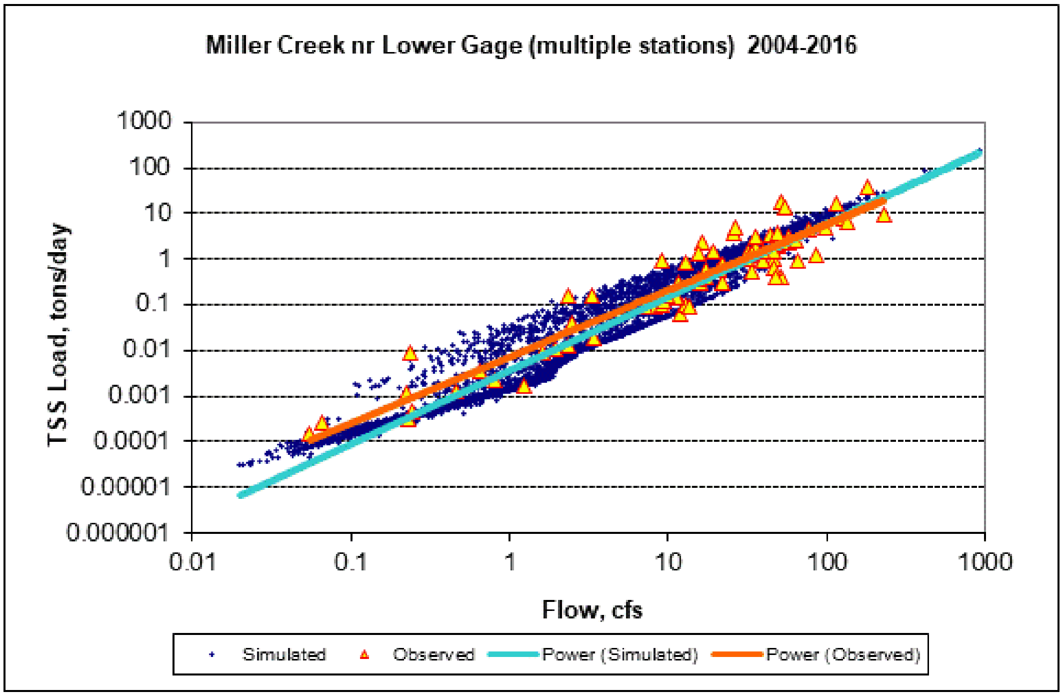


Figure D-134. Power Plot of Simulated and Observed TSS Load vs Flow at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

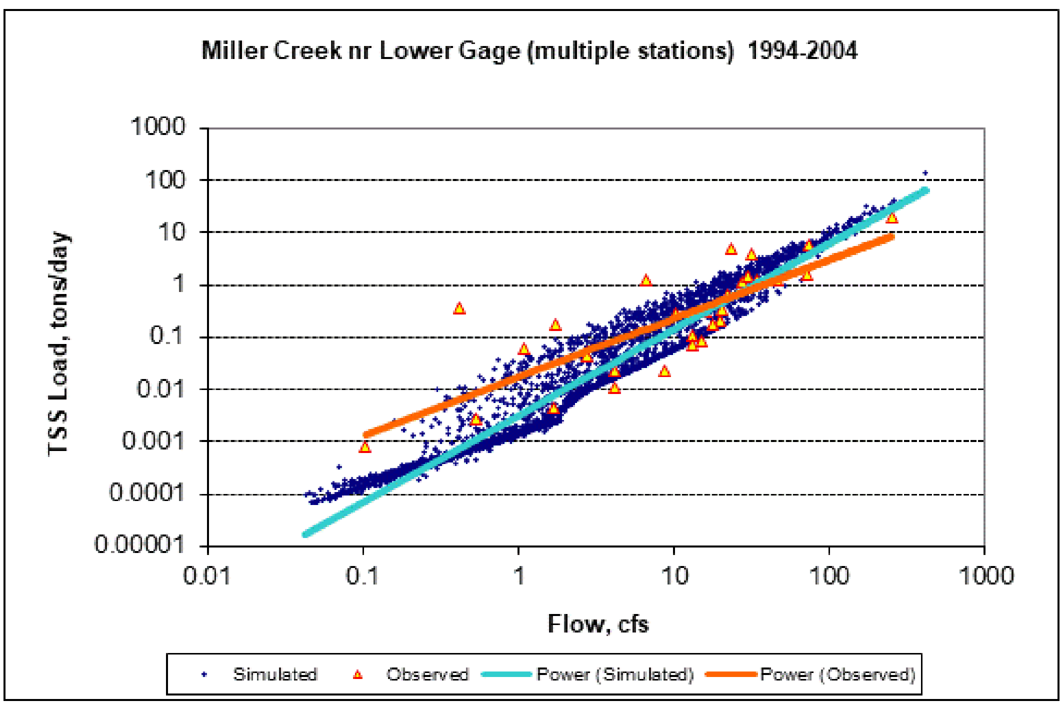


Figure D-135. Power Plot of Simulated and Observed TSS Load vs Flow at the Miller Creek nr Lower Gage (multiple stations) (Validation Period)

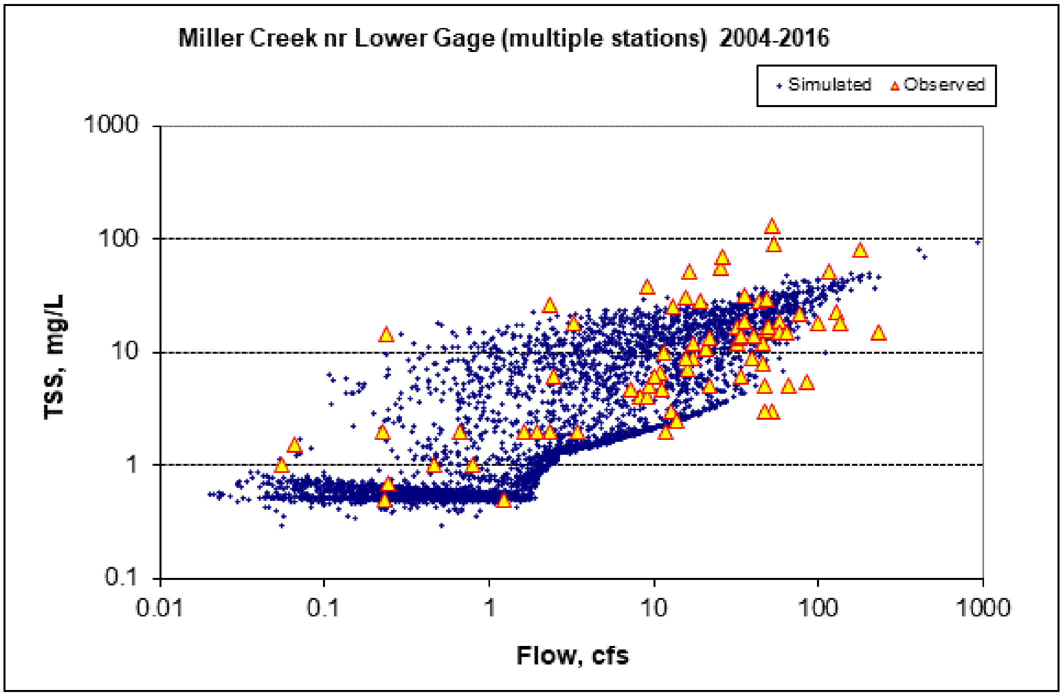


Figure D-136. Simulated and Observed TSS Concentration vs Flow Plot at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

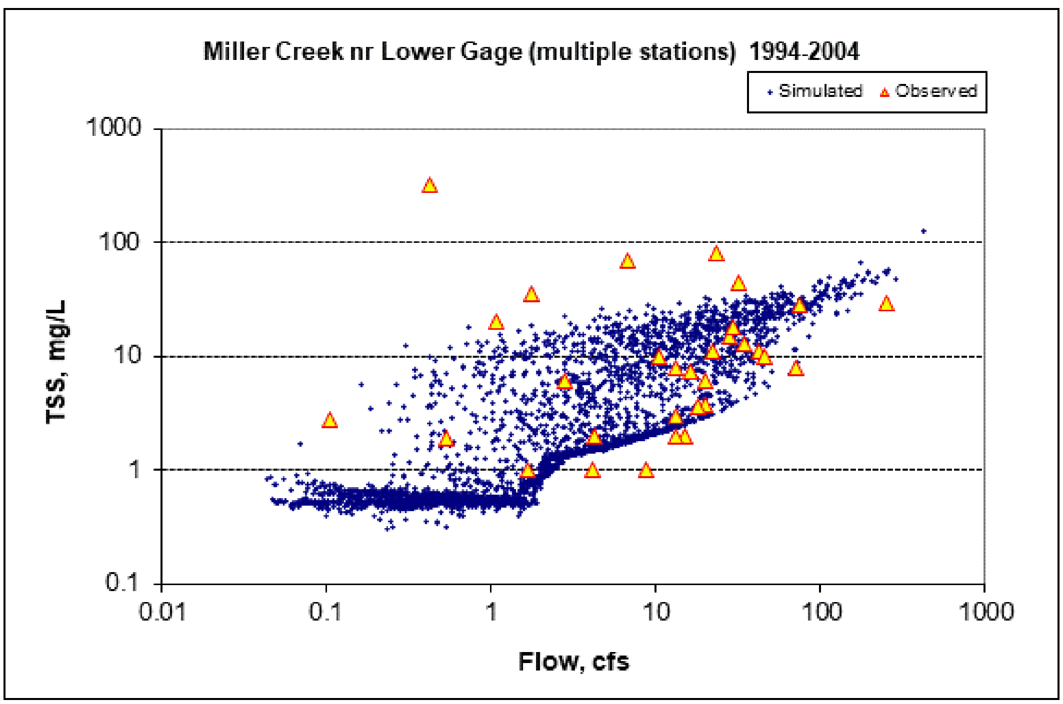


Figure D-137. Simulated and Observed TSS Concentration vs Flow Plot at the Miller Creek nr Lower Gage (multiple stations) (Validation Period)

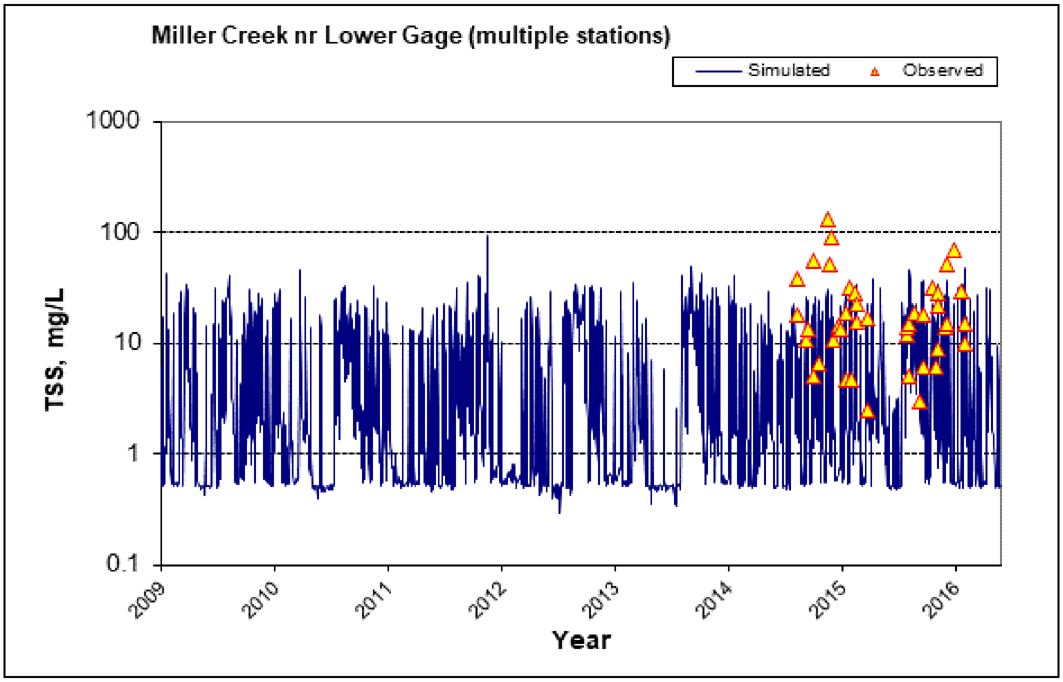


Figure D-138. TSS Concentration Time Series at the Miller Creek nr Lower Gage (multiple stations) (2008-2015)

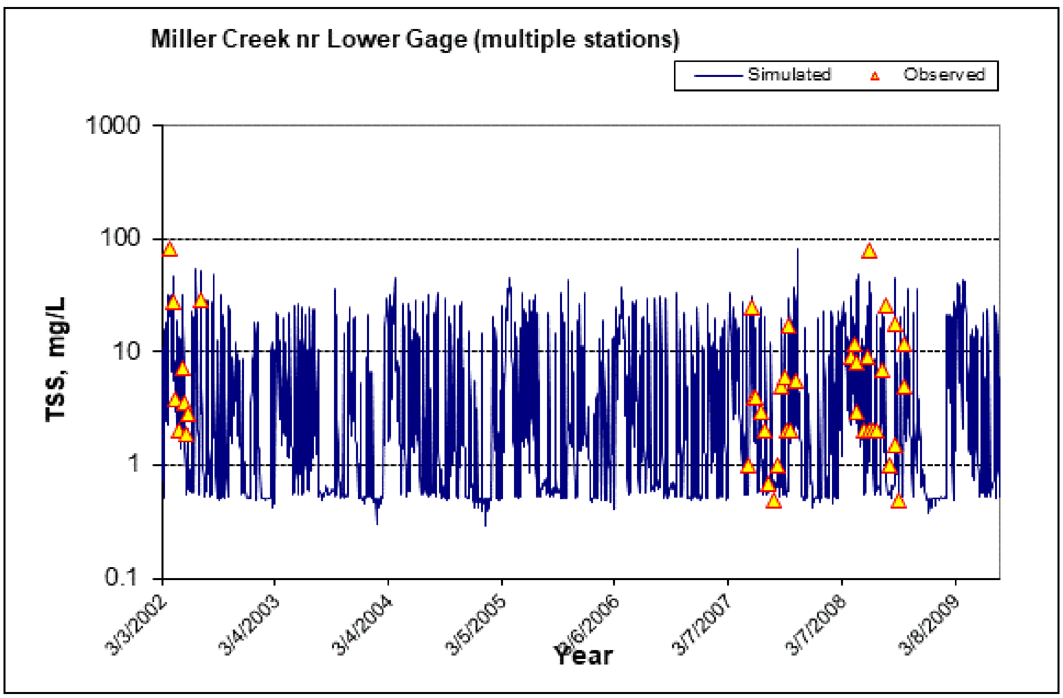


Figure D-139. TSS Concentration Time Series at the Miller Creek nr Lower Gage (multiple stations) (2001-2008)

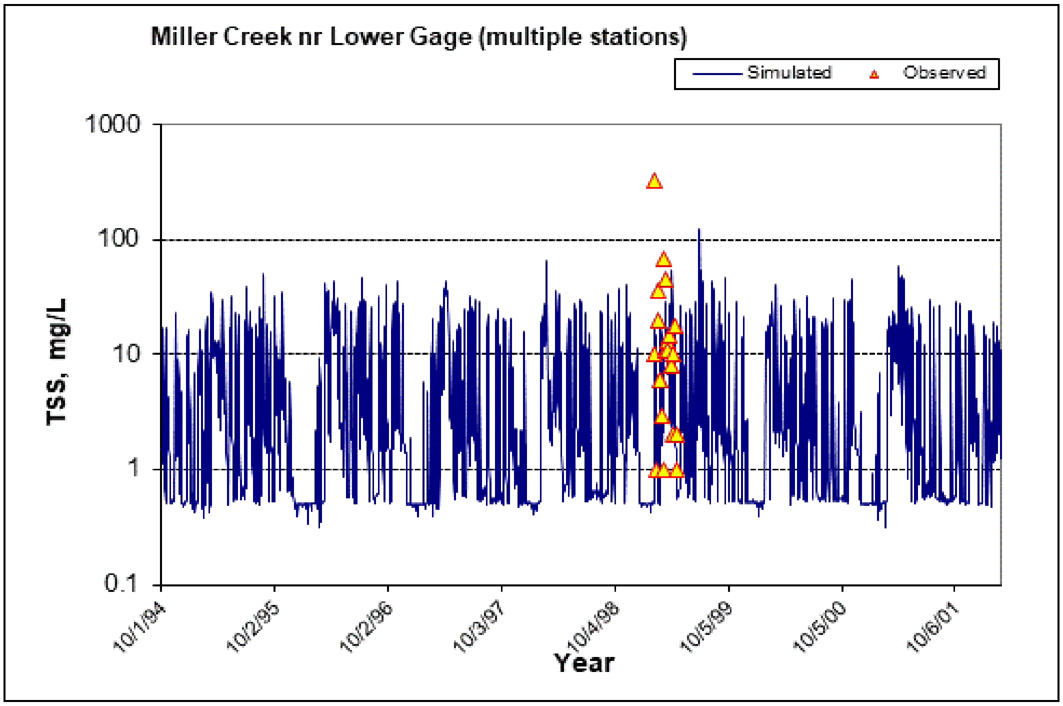


Figure D-140. TSS Concentration Time Series at the Miller Creek nr Lower Gage (multiple stations) (1994-2001)

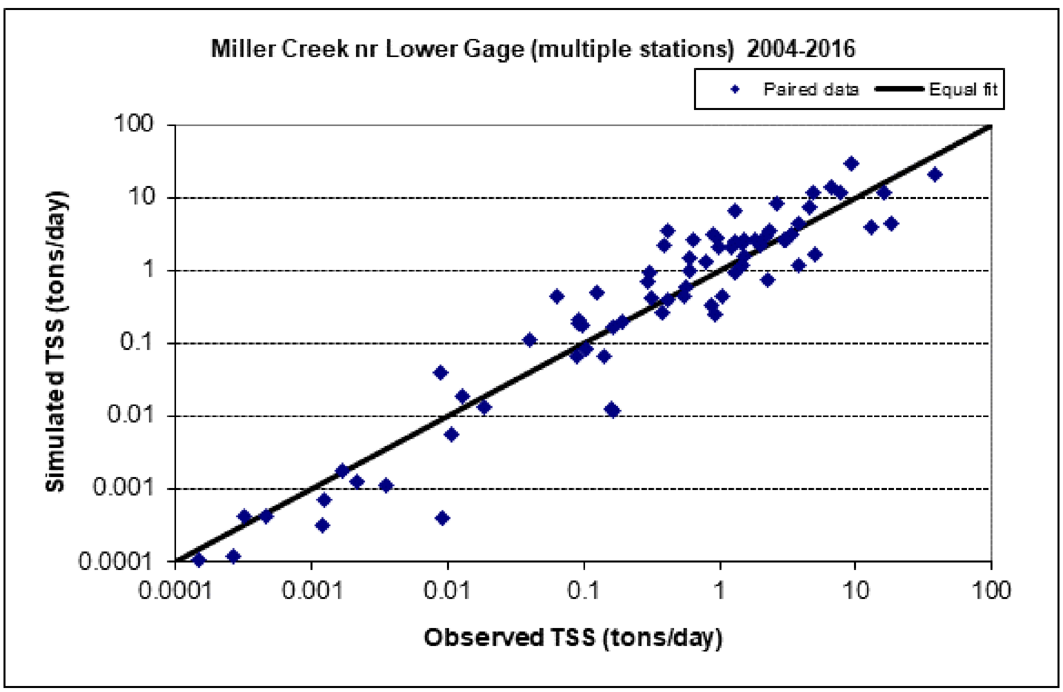


Figure D-141. Paired Simulated vs Observed TSS Load at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

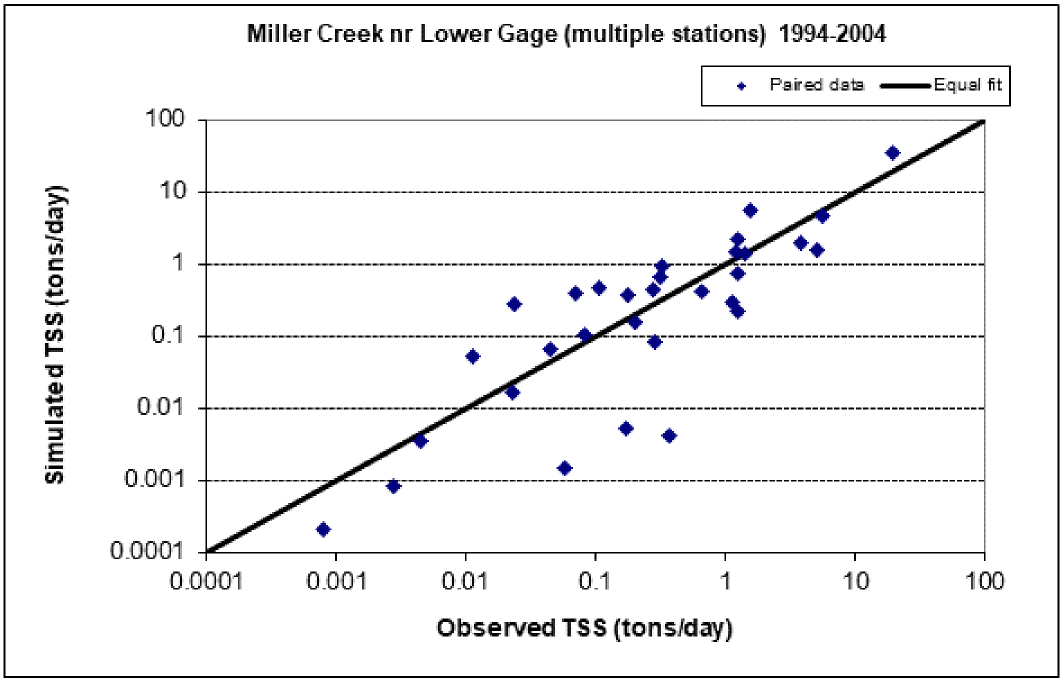


Figure D-142. Paired Simulated vs Observed TSS Load at the Miller Creek nr Lower Gage (multiple stations) (Validation Period)

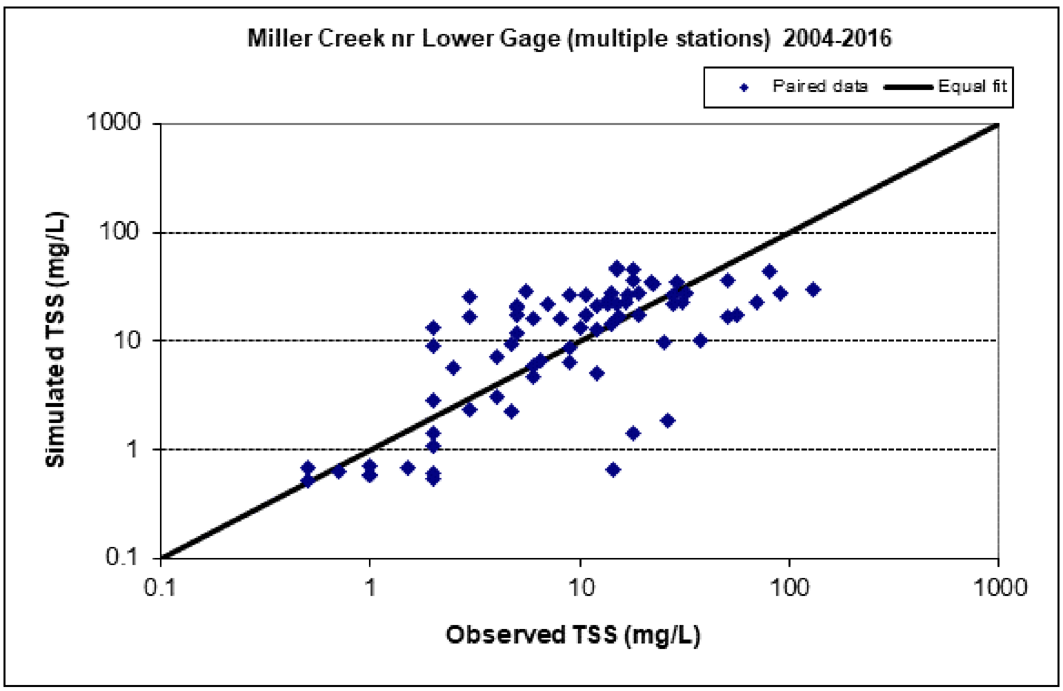


Figure D-143. Paired Simulated vs Observed TSS Concentration at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

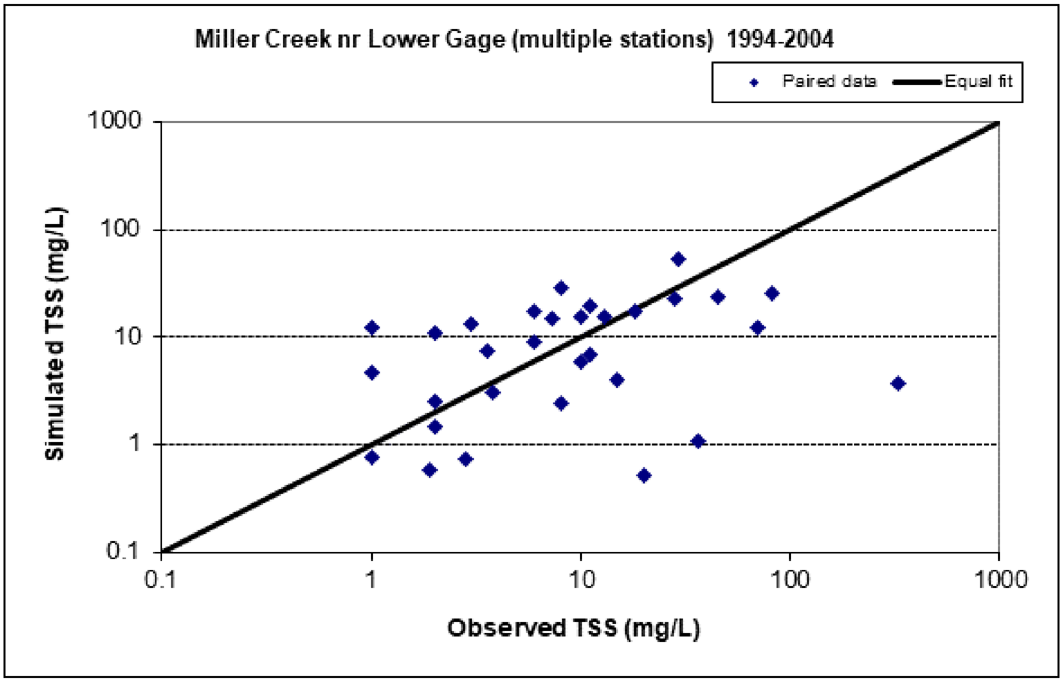


Figure D-144. Paired Simulated vs Observed TSS Concentration at the Miller Creek nr Lower Gage (multiple stations) (Validation Period)

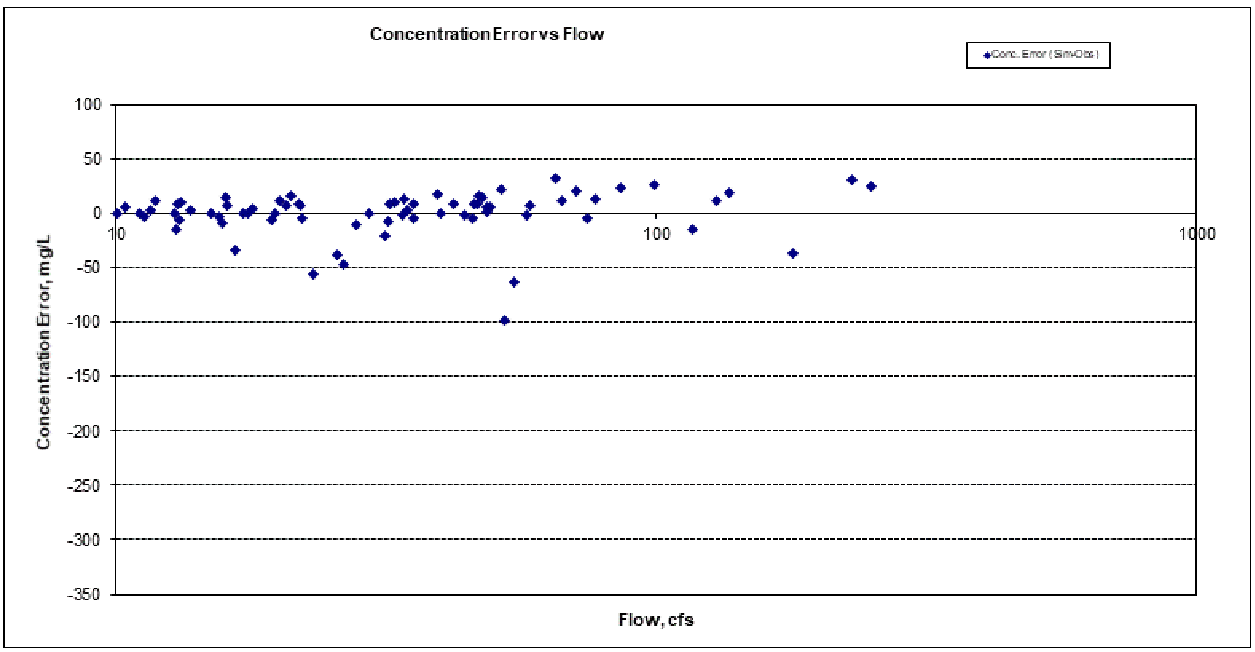


Figure D-145. TSS Concentration Error vs Flow at the Miller Creek nr Lower Gage (multiple stations)

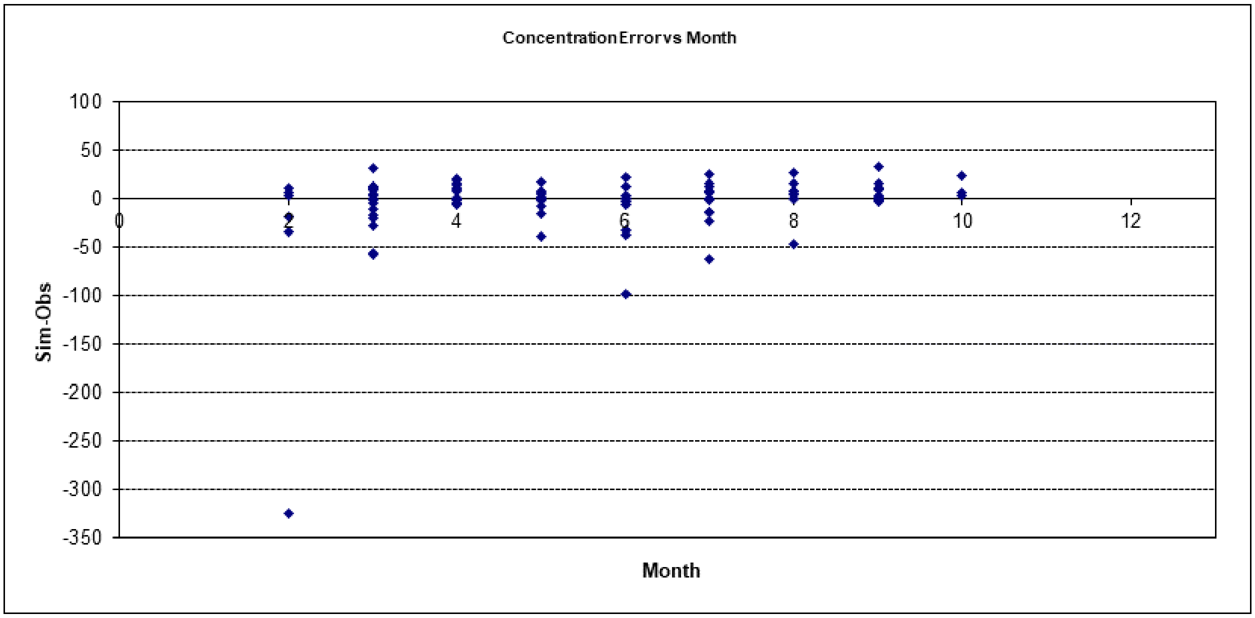


Figure D-146. TSS Concentration Error vs Month at the Miller Creek nr Lower Gage (multiple stations)

D.15 MILLER CREEK, UPPER GAGE AT HWY 53

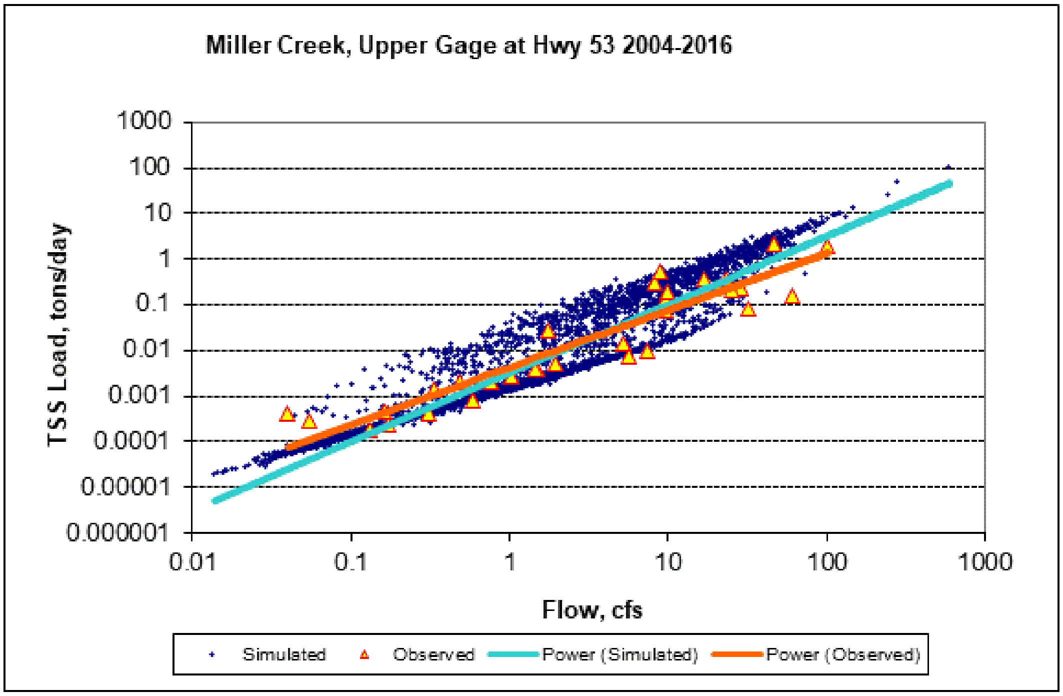


Figure D-147. Power Plot of Simulated and Observed TSS Load vs Flow at the Miller Creek, Upper Gage at Hwy 53 (Calibration Period)

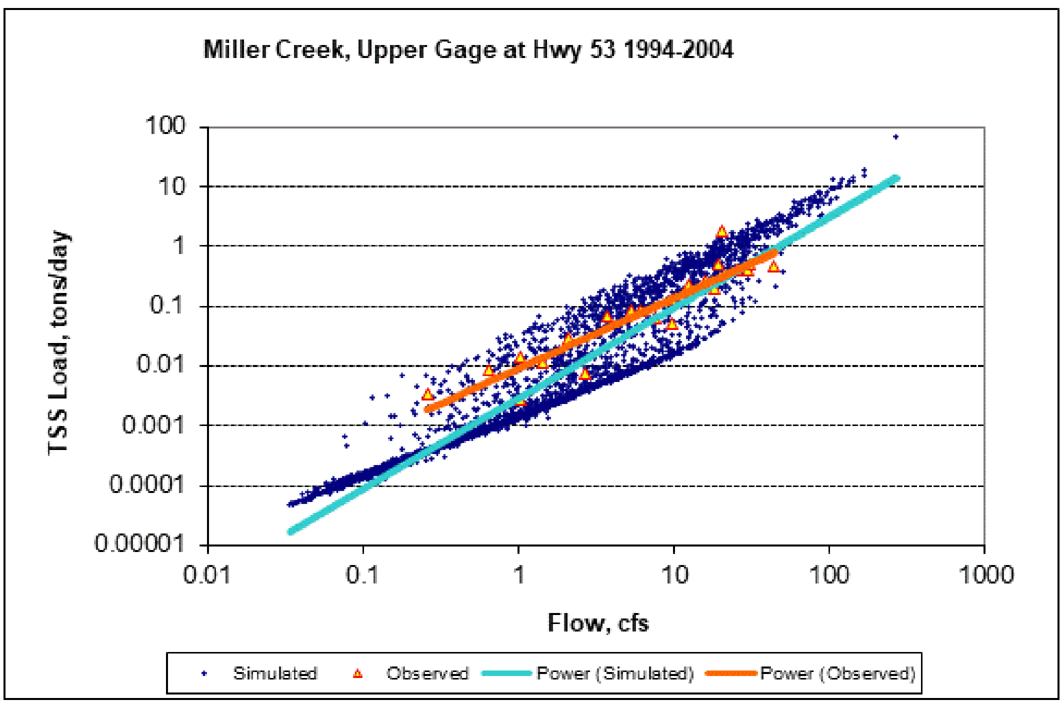


Figure D-148. Power Plot of Simulated and Observed TSS Load vs Flow at the Miller Creek, Upper Gage at Hwy 53 (Validation Period)

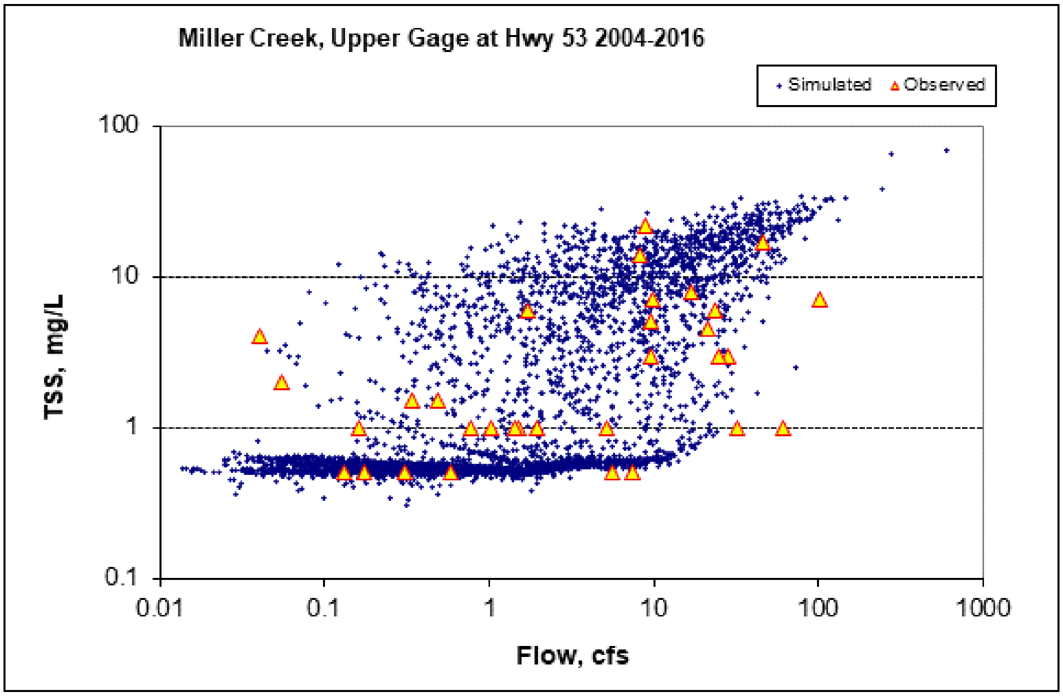


Figure D-149. Simulated and Observed TSS Concentration vs Flow Plot at the Miller Creek, Upper Gage at Hwy 53 (Calibration Period)

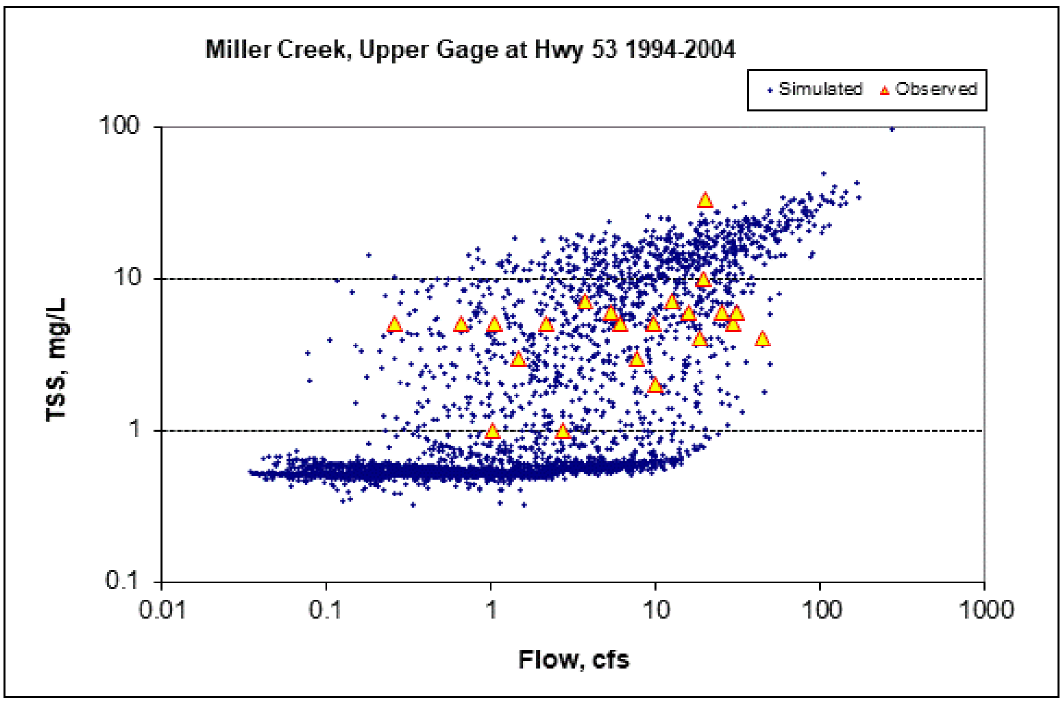


Figure D-150. Simulated and Observed TSS Concentration vs Flow Plot at the Miller Creek, Upper Gage at Hwy 53 (Validation Period)

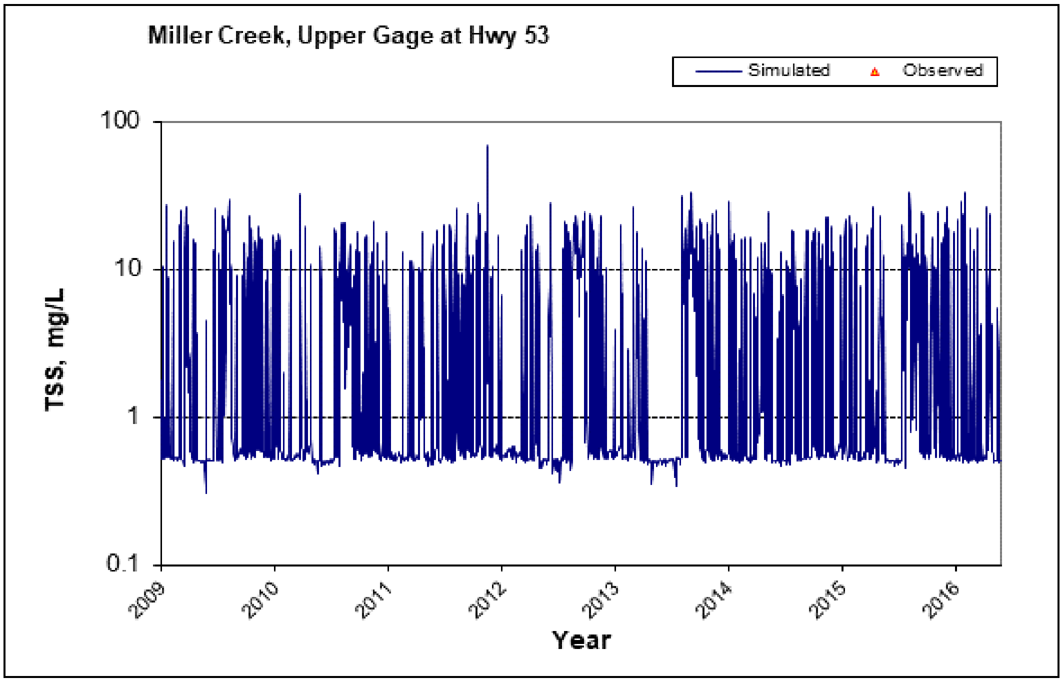


Figure D-151. TSS Concentration Time Series at the Miller Creek, Upper Gage at Hwy 53 (2008-2015)

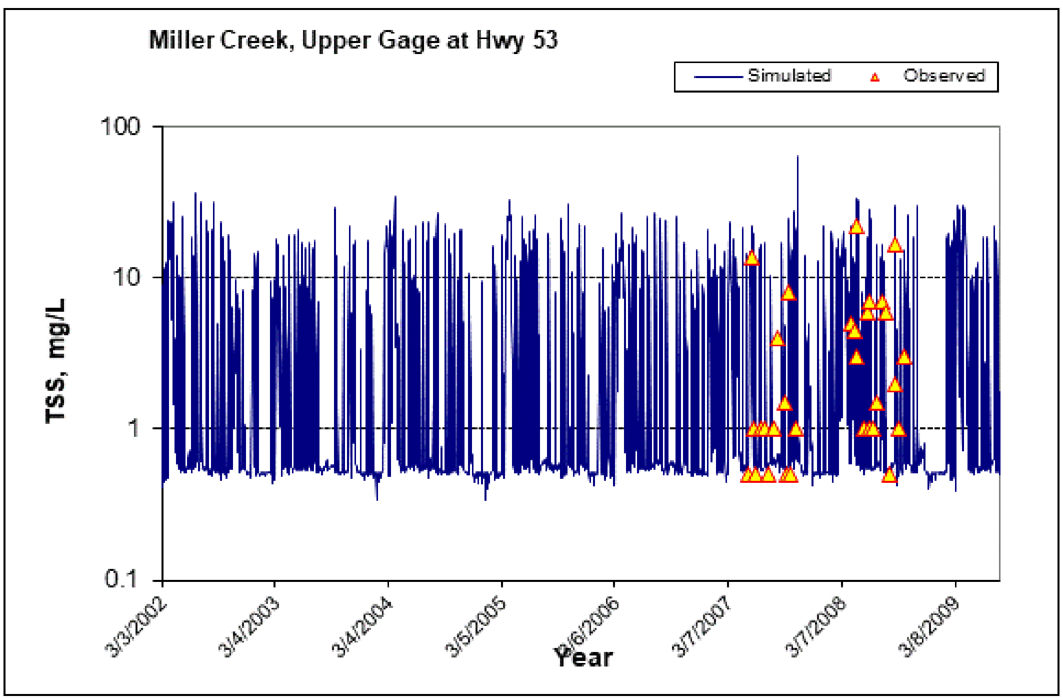


Figure D-152. TSS Concentration Time Series at the Miller Creek, Upper Gage at Hwy 53 (2001-2008)

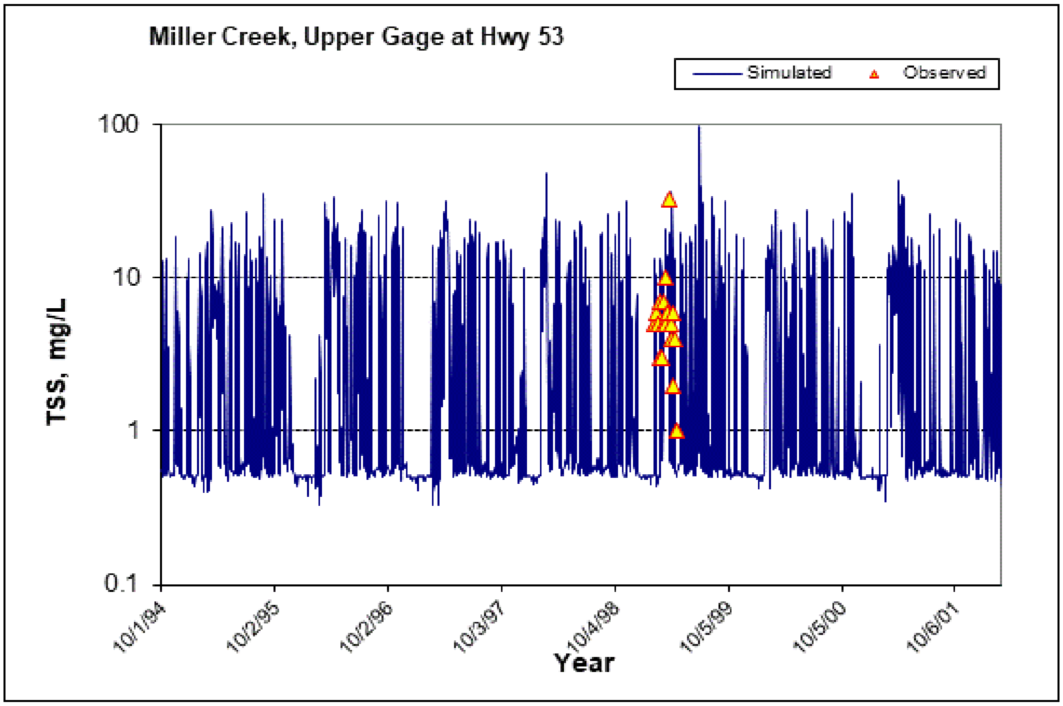


Figure D-153. TSS Concentration Time Series at the Miller Creek, Upper Gage at Hwy 53 (1994-2001)

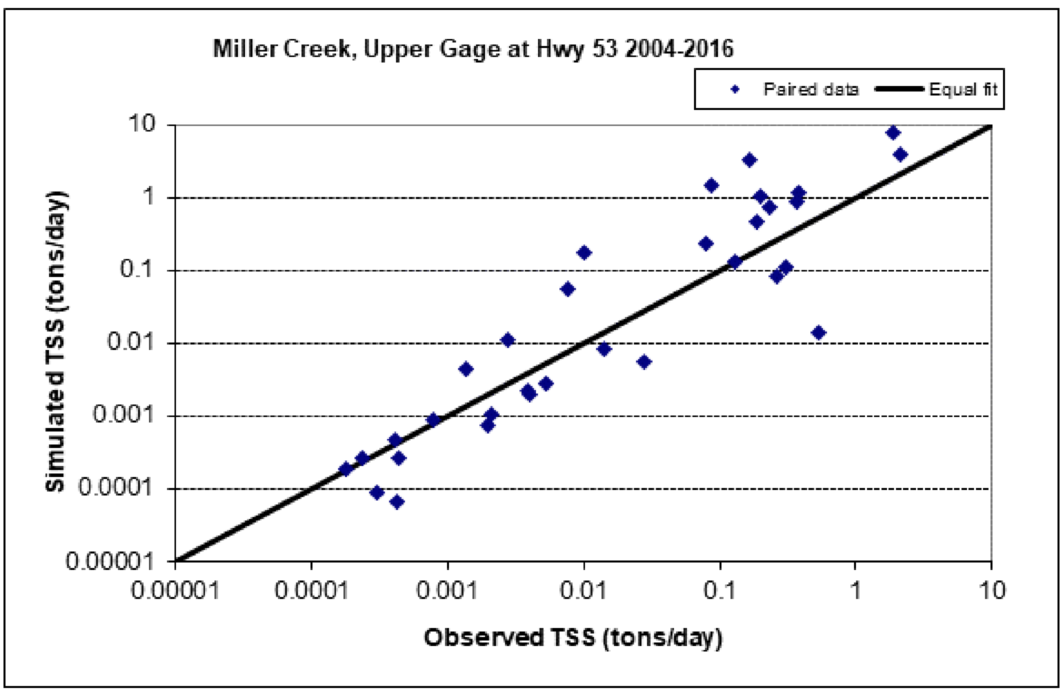


Figure D-154. Paired Simulated vs Observed TSS Load at the Miller Creek, Upper Gage at Hwy 53 (Calibration Period)

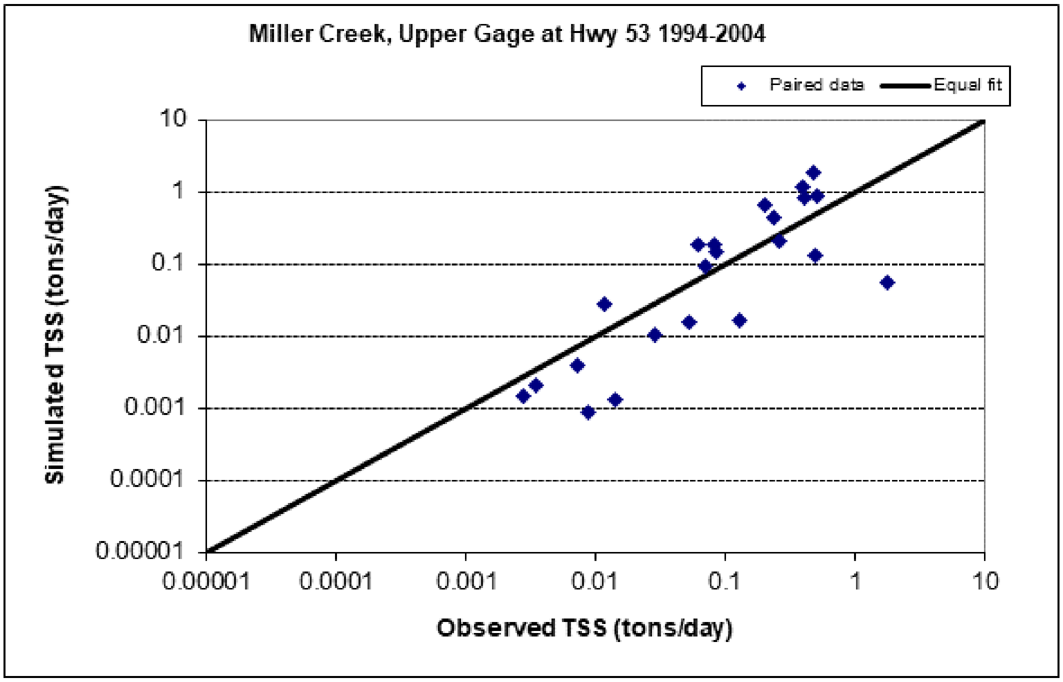


Figure D-155. Paired Simulated vs Observed TSS Load at the Miller Creek, Upper Gage at Hwy 53 (Validation Period)

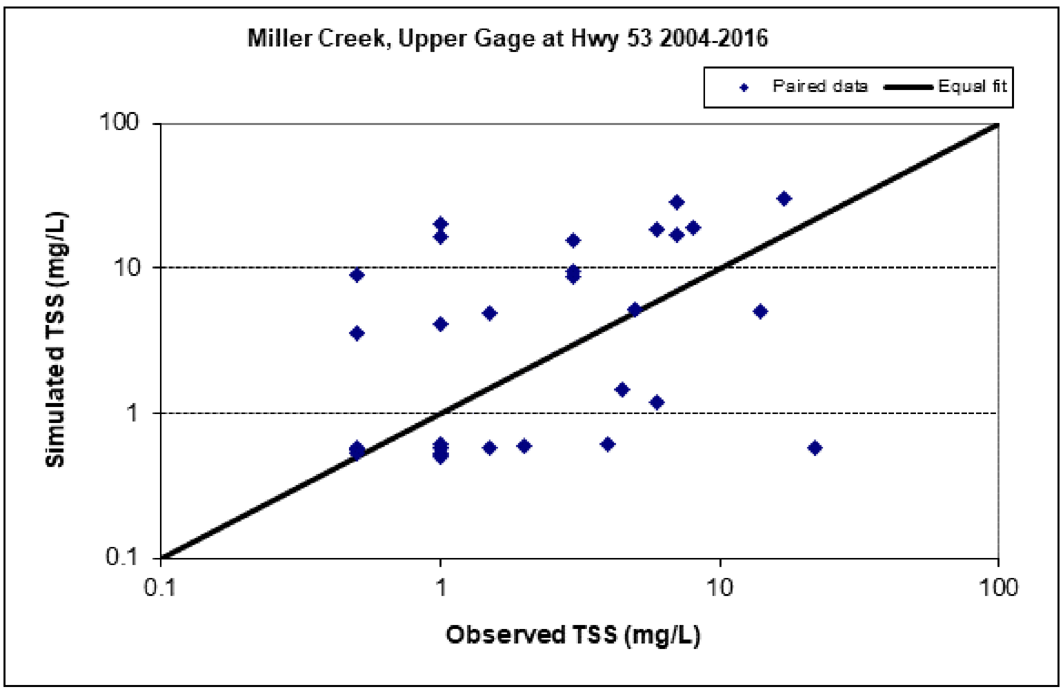


Figure D-156. Paired Simulated vs Observed TSS Concentration at the Miller Creek, Upper Gage at Hwy 53 (Calibration Period)

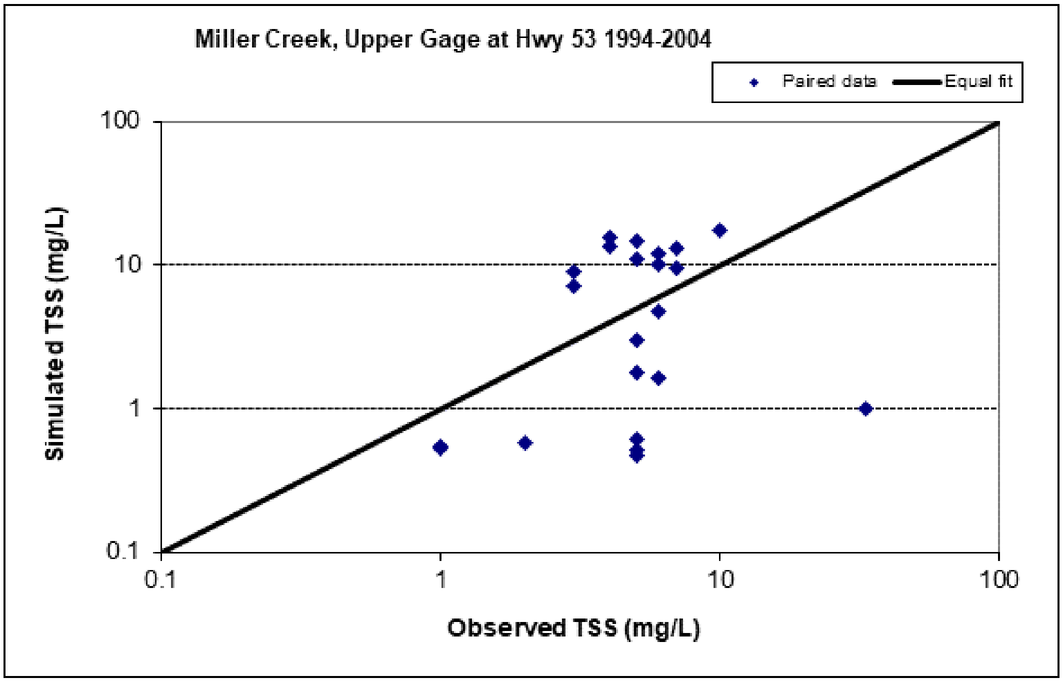


Figure D-157. Paired Simulated vs Observed TSS Concentration at the Miller Creek, Upper Gage at Hwy 53 (Validation Period)

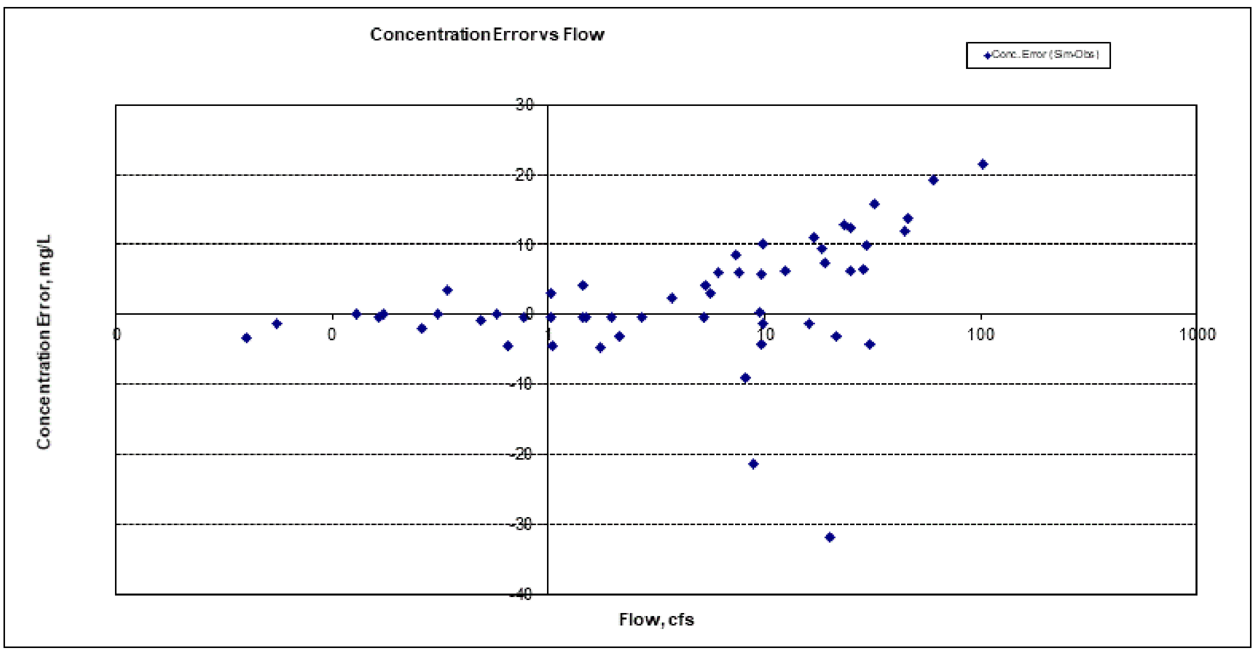


Figure D-158. TSS Concentration Error vs Flow at the Miller Creek, Upper Gage at Hwy 53

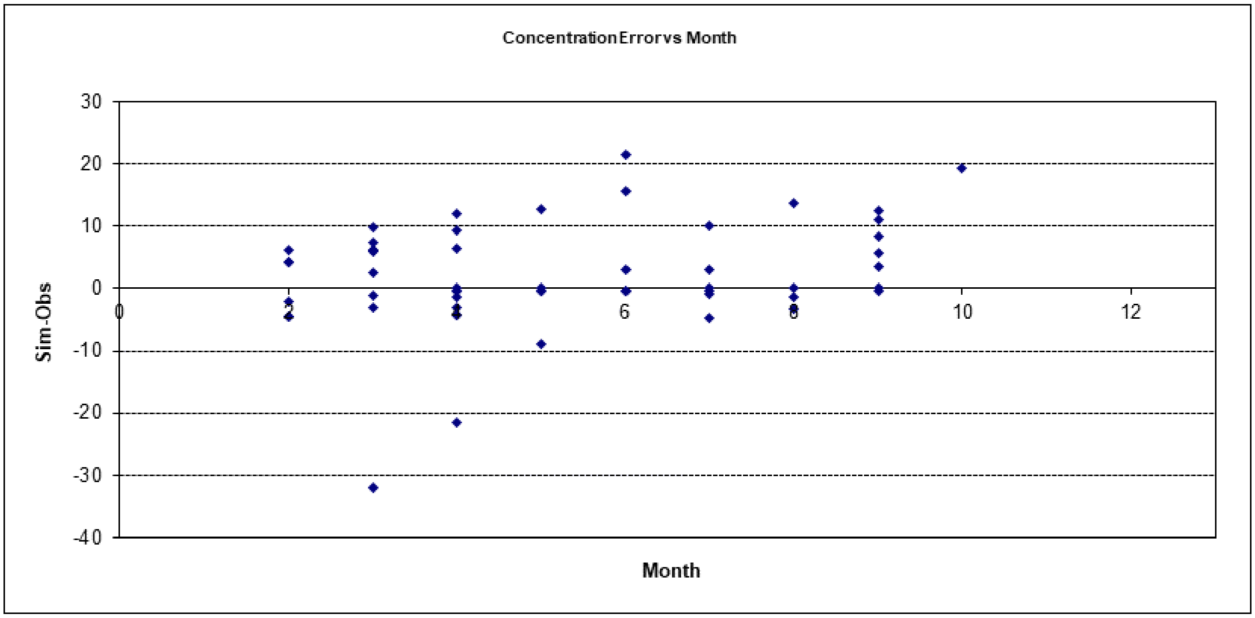


Figure D-159. TSS Concentration Error vs Month at the Miller Creek, Upper Gage at Hwy 53

D.16 Merritt Creek at Grand Ave

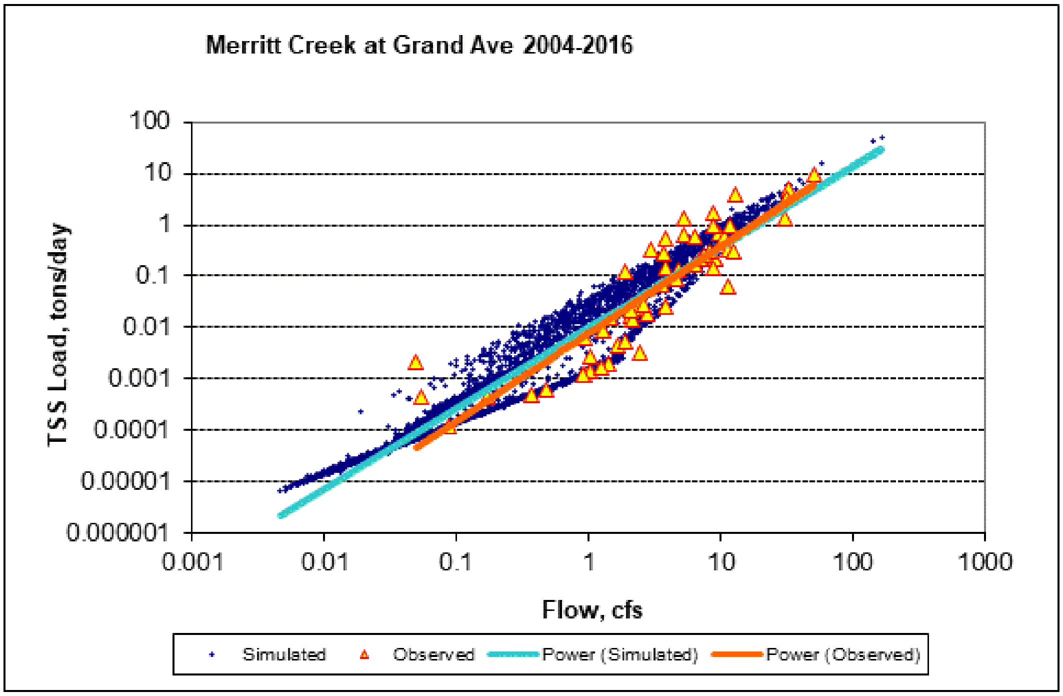


Figure D-160. Power Plot of Simulated and Observed TSS Load vs Flow at the Merritt Creek at Grand Ave (Calibration Period)

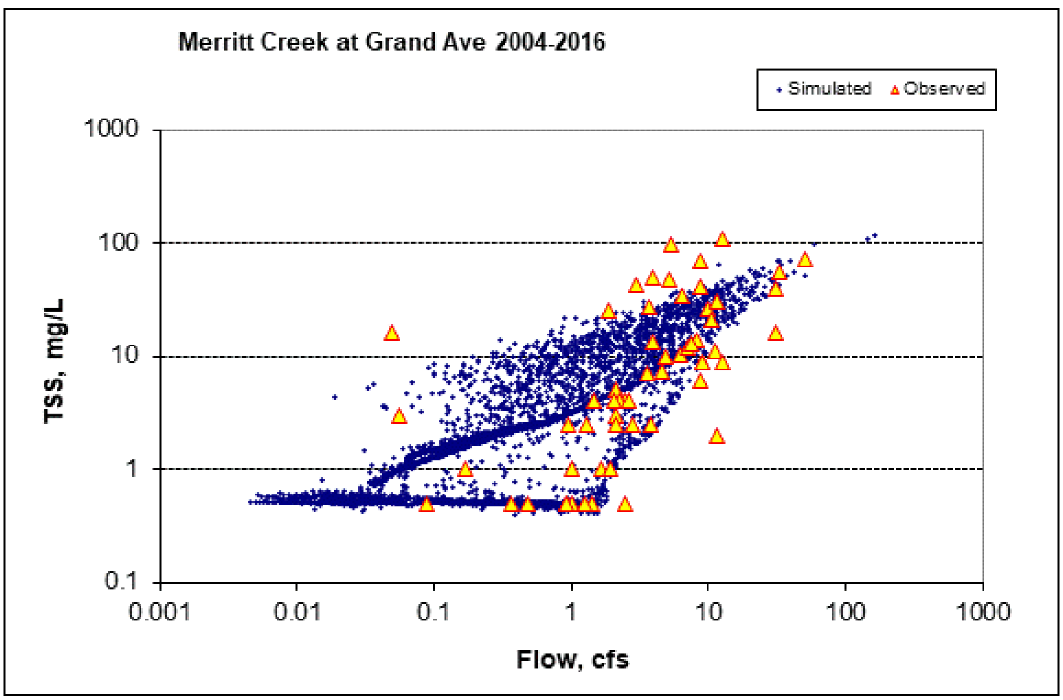


Figure D-161. Simulated and Observed TSS Concentration vs Flow Plot at the Merritt Creek at Grand Ave (Calibration Period)

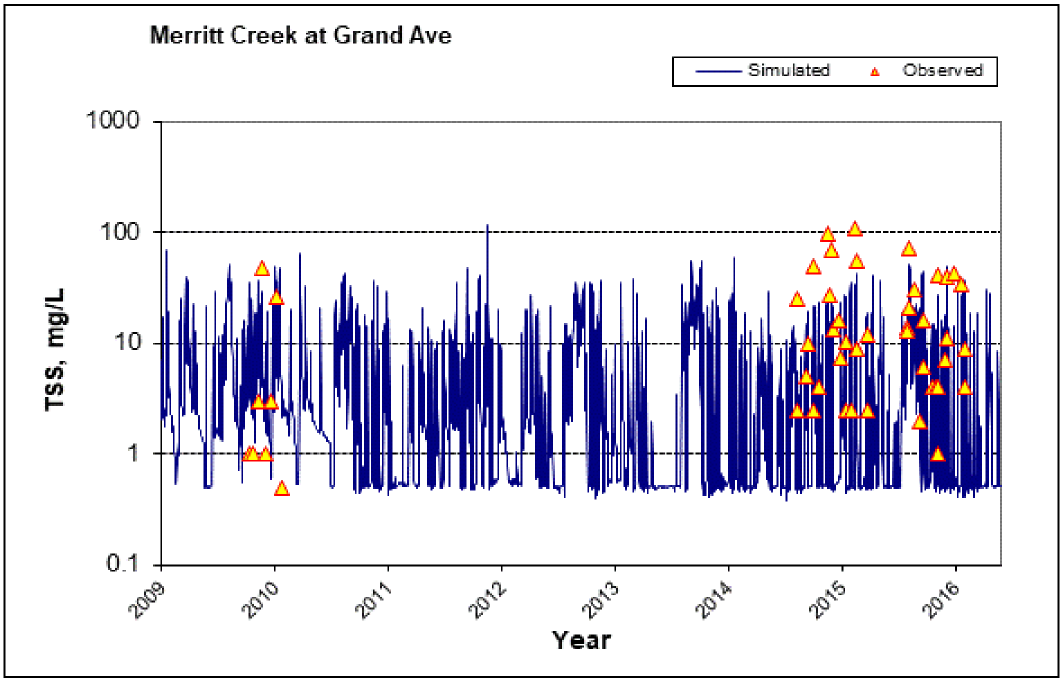


Figure D-162. TSS Concentration Time Series at the Merritt Creek at Grand Ave (2008-2015)

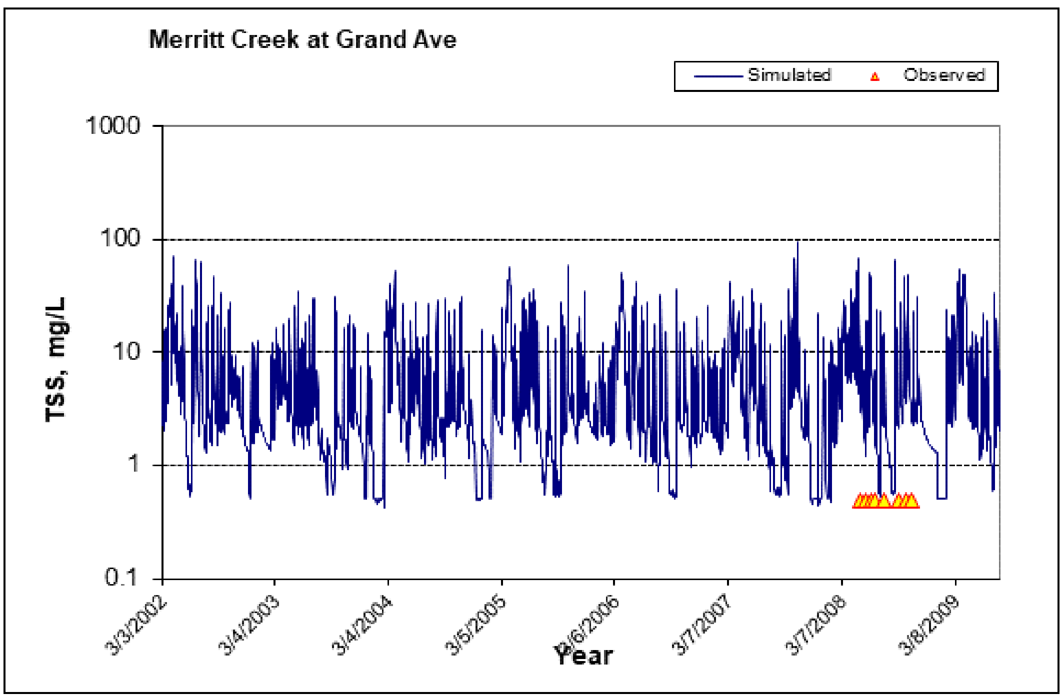


Figure D-163. TSS Concentration Time Series at the Merritt Creek at Grand Ave (2001-2008)

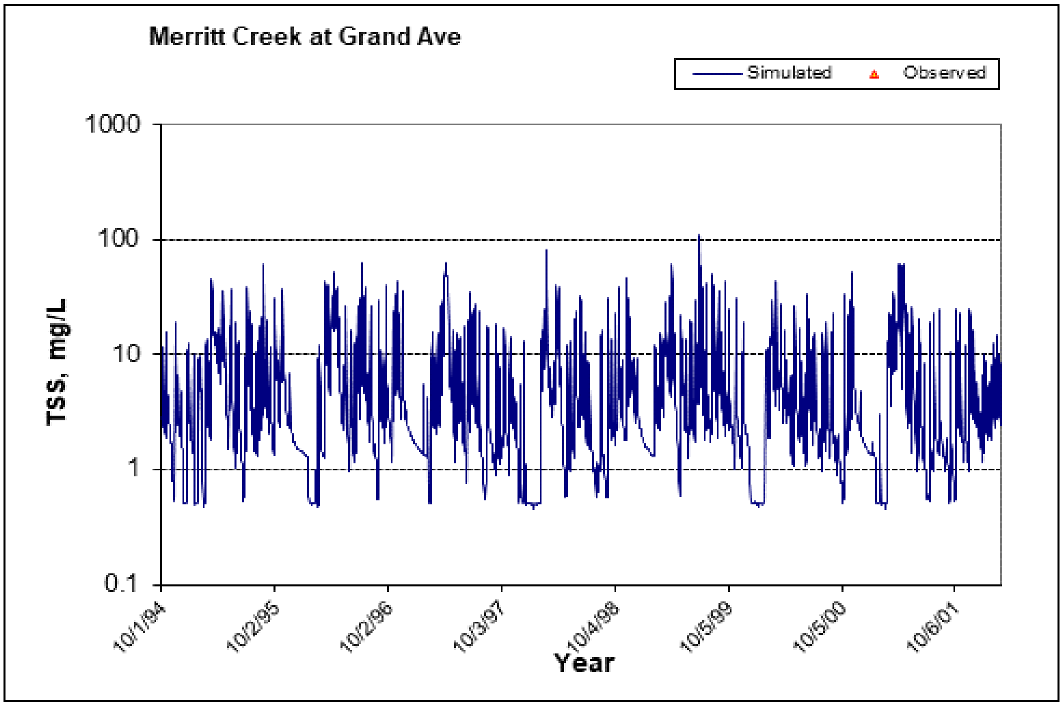


Figure D-164. TSS Concentration Time Series at the Merritt Creek at Grand Ave (1994-2001)

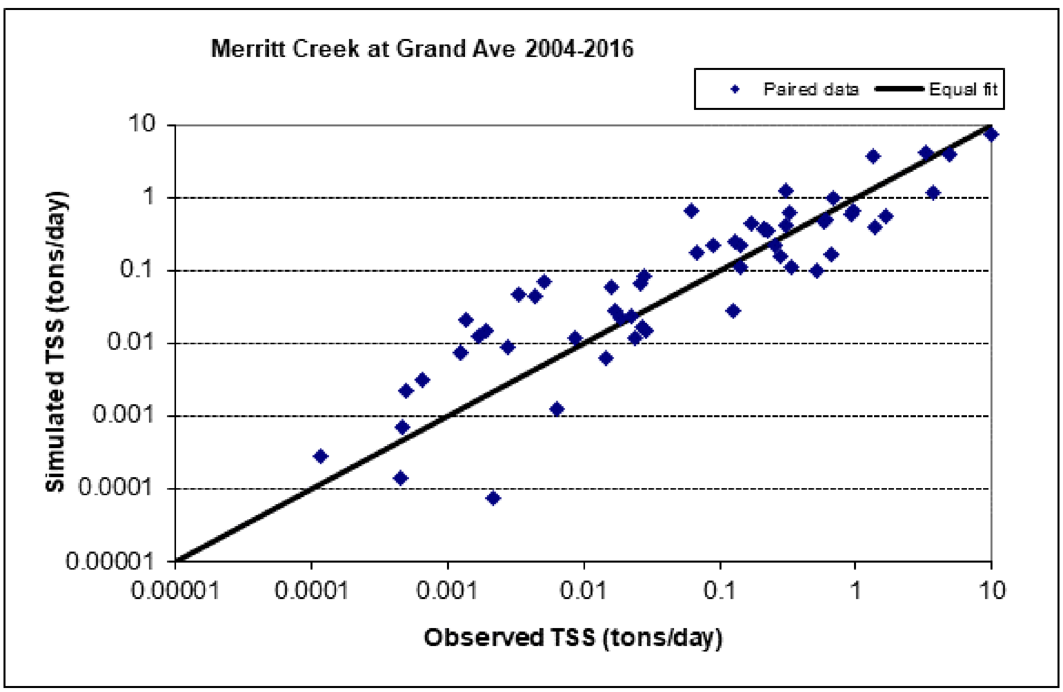


Figure D-165. Paired Simulated vs Observed TSS Load at the Merritt Creek at Grand Ave (Calibration Period)

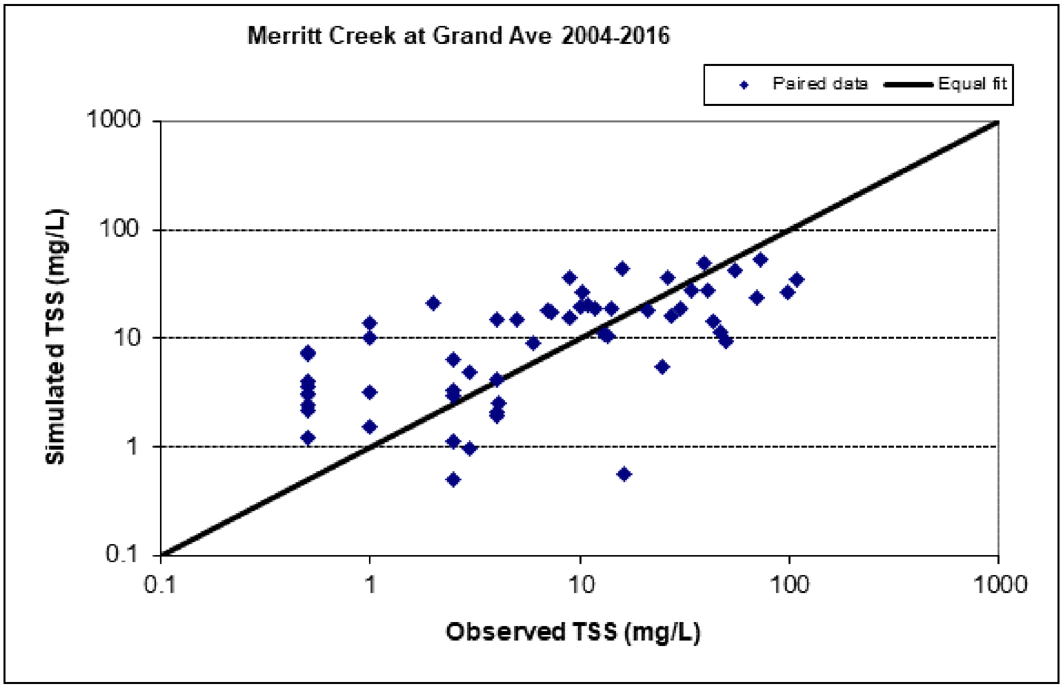


Figure D-166. Paired Simulated vs Observed TSS Concentration at the Merritt Creek at Grand Ave (Calibration Period)

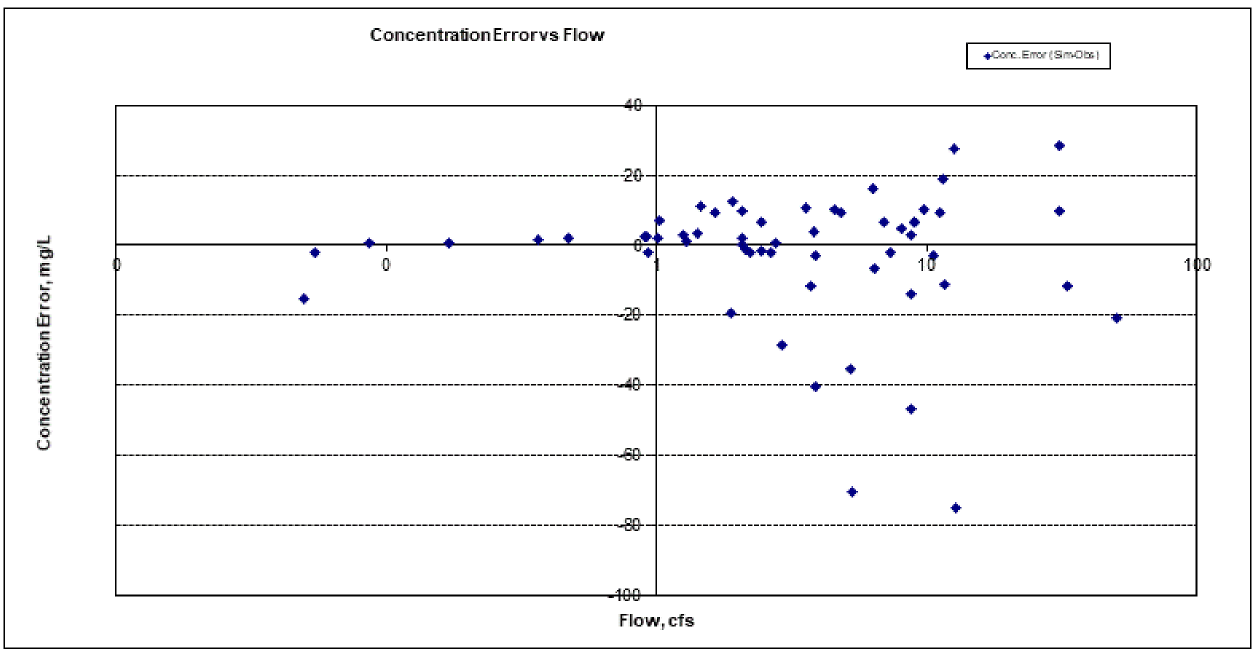


Figure D-167. TSS Concentration Error vs Flow at the Merritt Creek at Grand Ave

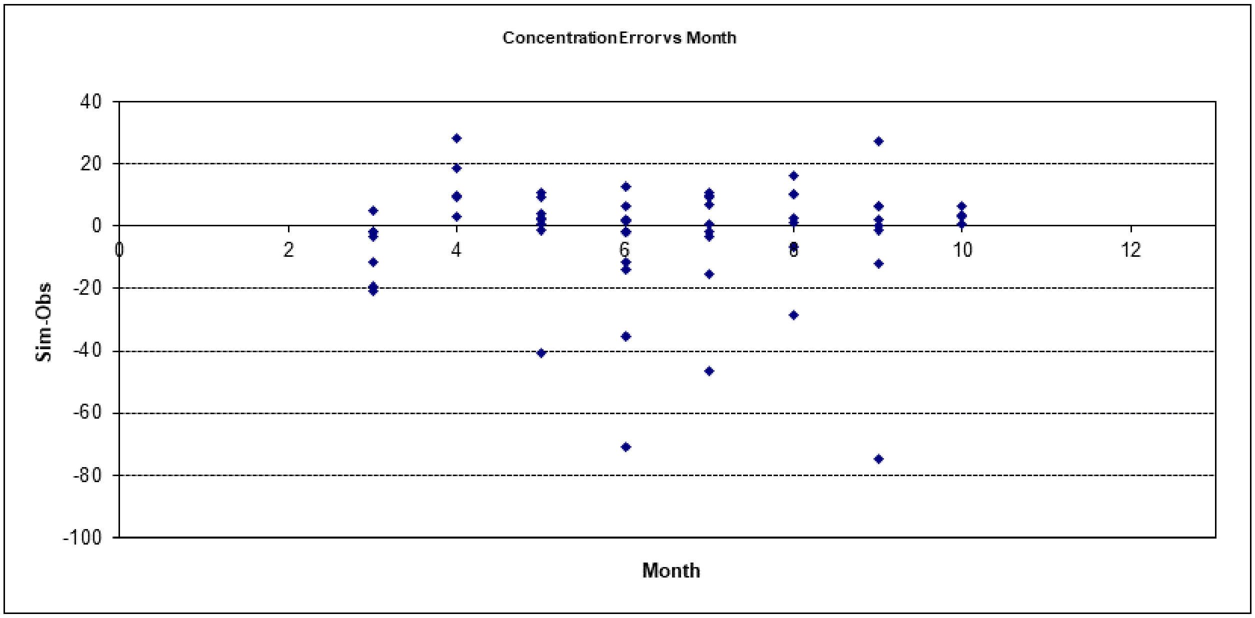


Figure D-168. TSS Concentration Error vs Month at the Merritt Creek at Grand Ave

D.17 Keene Creek at 57th Ave W

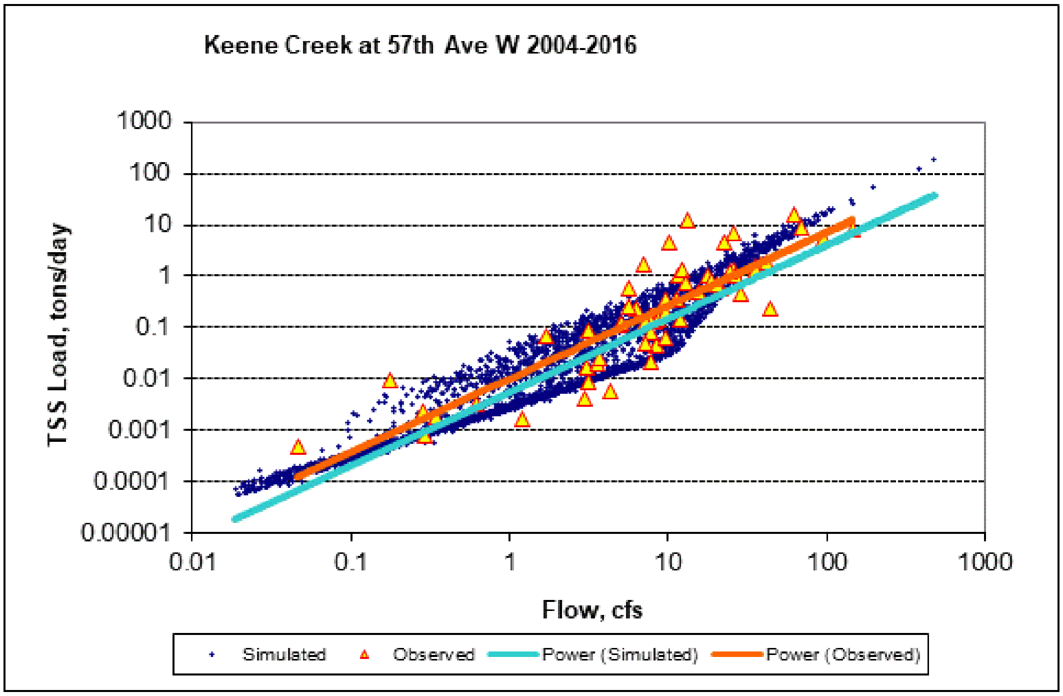


Figure D-169. Power Plot of Simulated and Observed TSS Load vs Flow at the Keene Creek at 57th Ave W (Calibration Period)

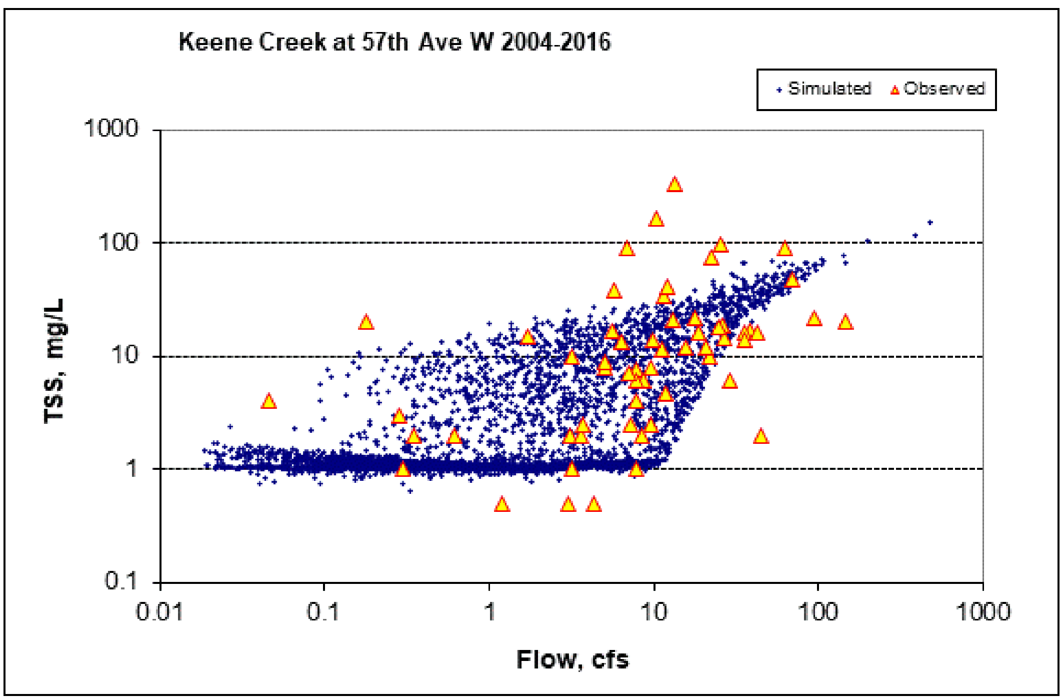


Figure D-170. Simulated and Observed TSS Concentration vs Flow Plot at the Keene Creek at 57th Ave W (Calibration Period)

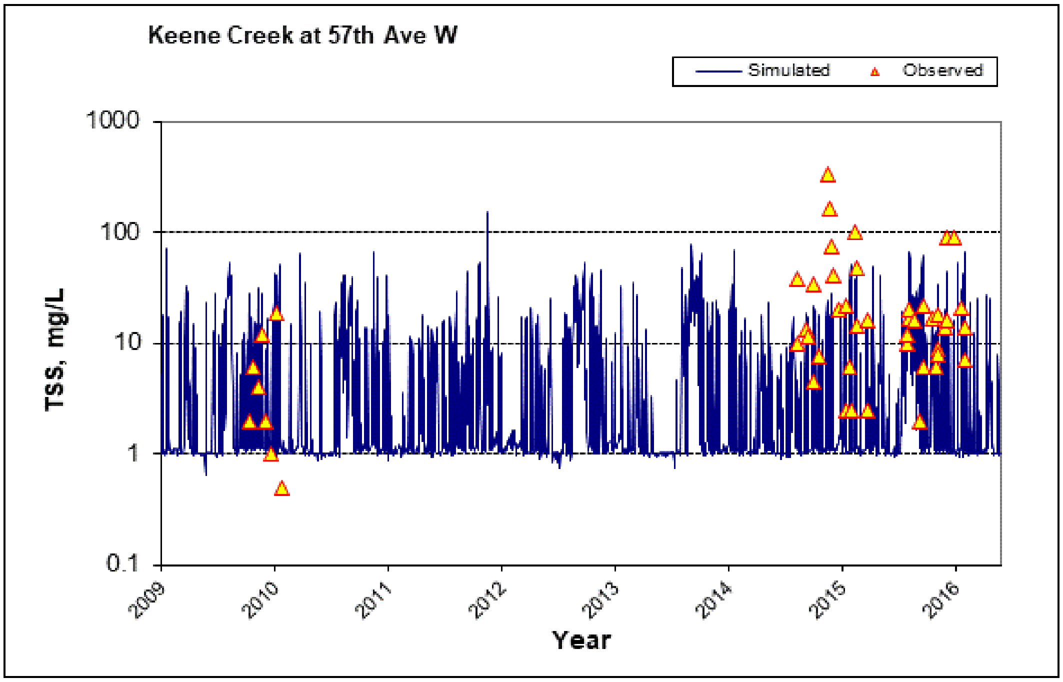


Figure D-171. TSS Concentration Time Series at the Keene Creek at 57th Ave W (2008-2015)

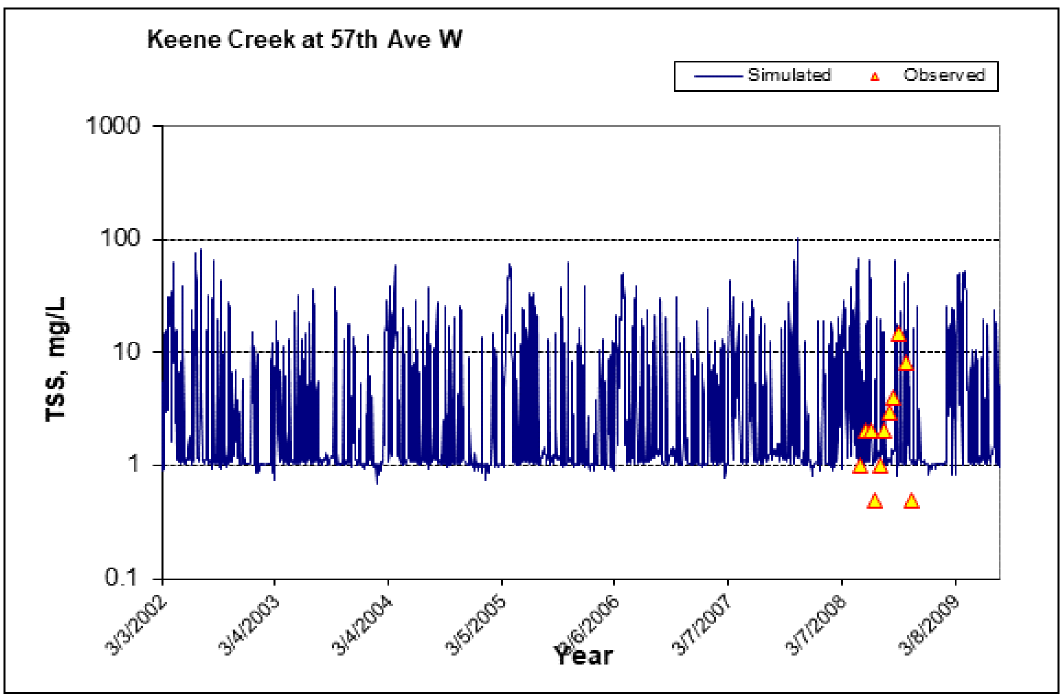


Figure D-172. TSS Concentration Time Series at the Keene Creek at 57th Ave W (2001-2008)

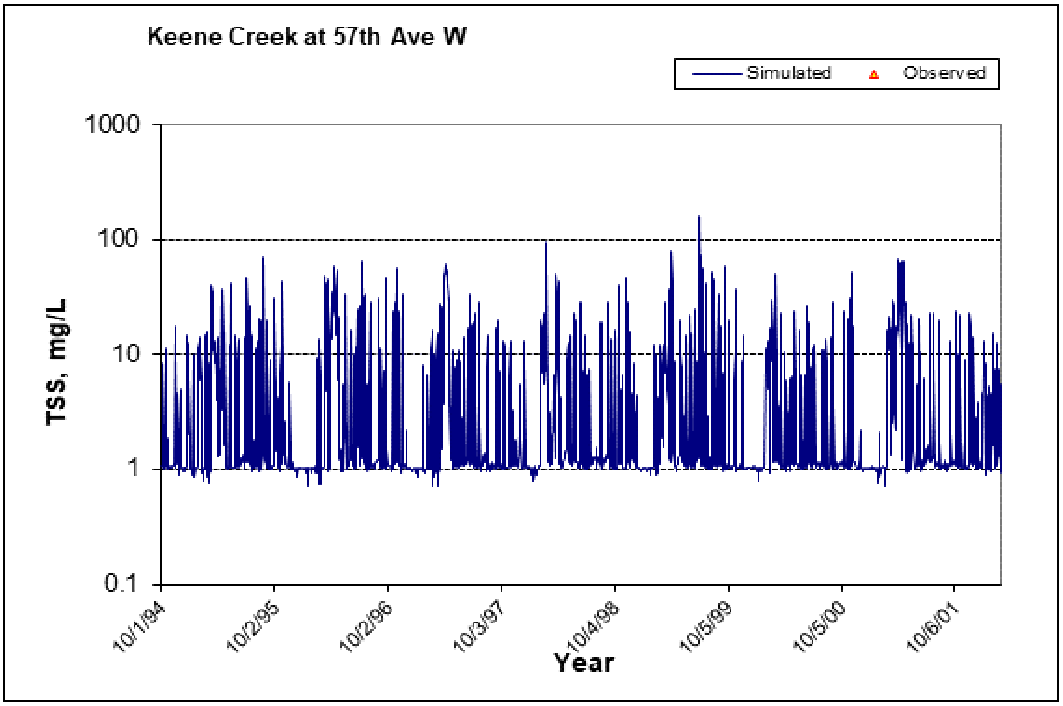


Figure D-173. TSS Concentration Time Series at the Keene Creek at 57th Ave W (1994-2001)

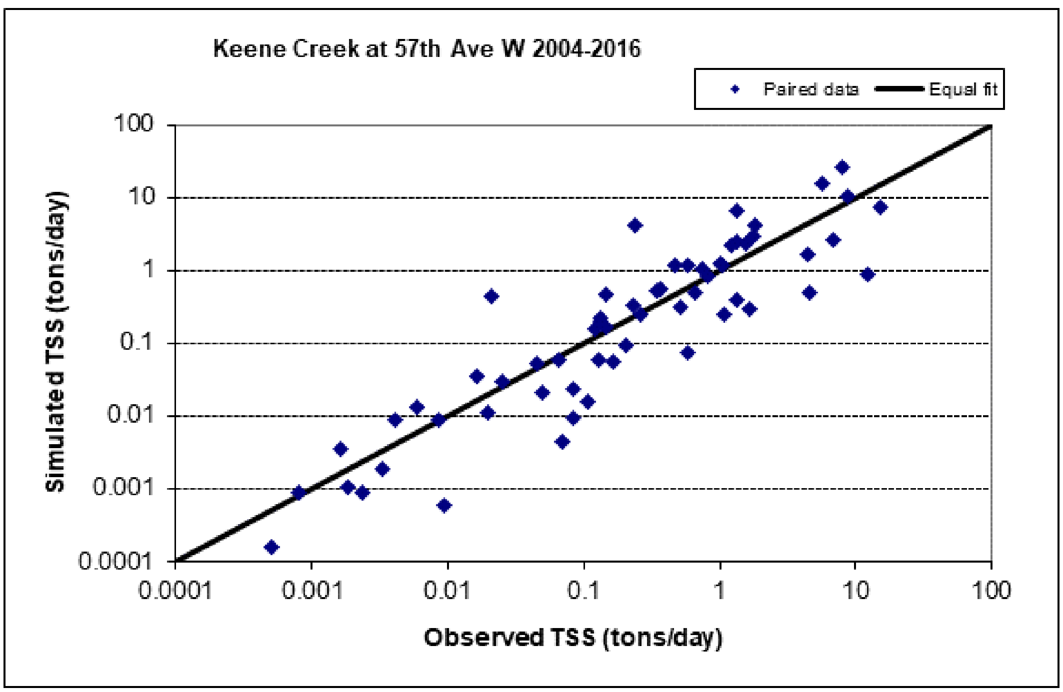


Figure D-174. Paired Simulated vs Observed TSS Load at the Keene Creek at 57th Ave W (Calibration Period)

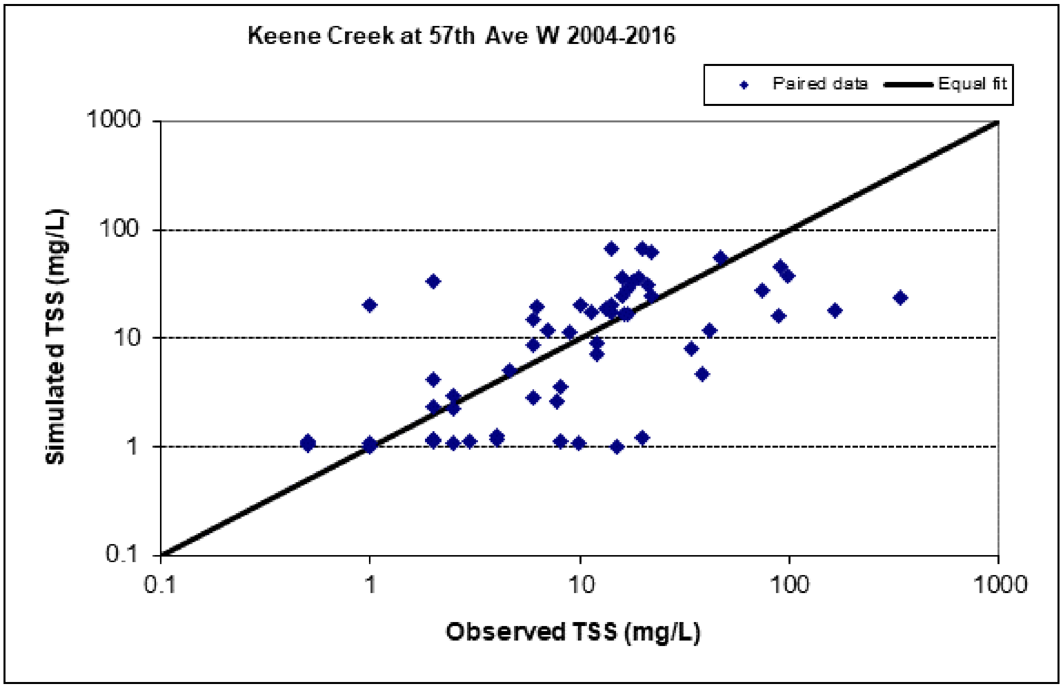


Figure D-175. Paired Simulated vs Observed TSS Concentration at the Keene Creek at 57th Ave W (Calibration Period)

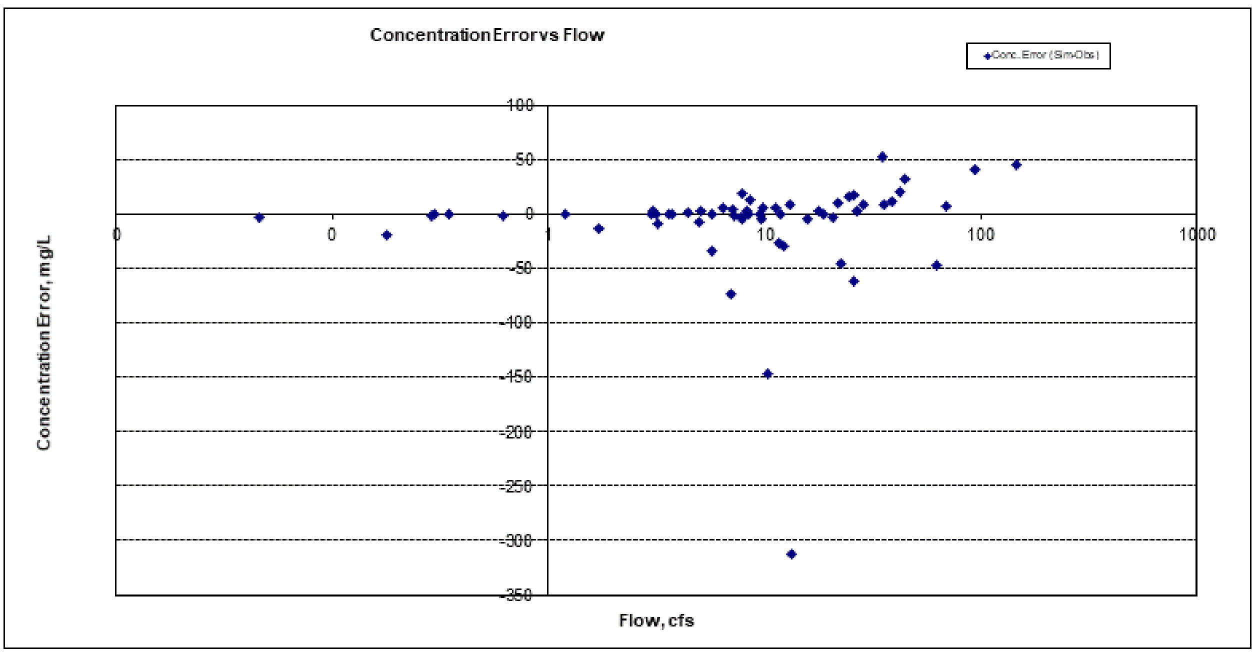


Figure D-176. TSS Concentration Error vs Flow at the Keene Creek at 57th Ave W

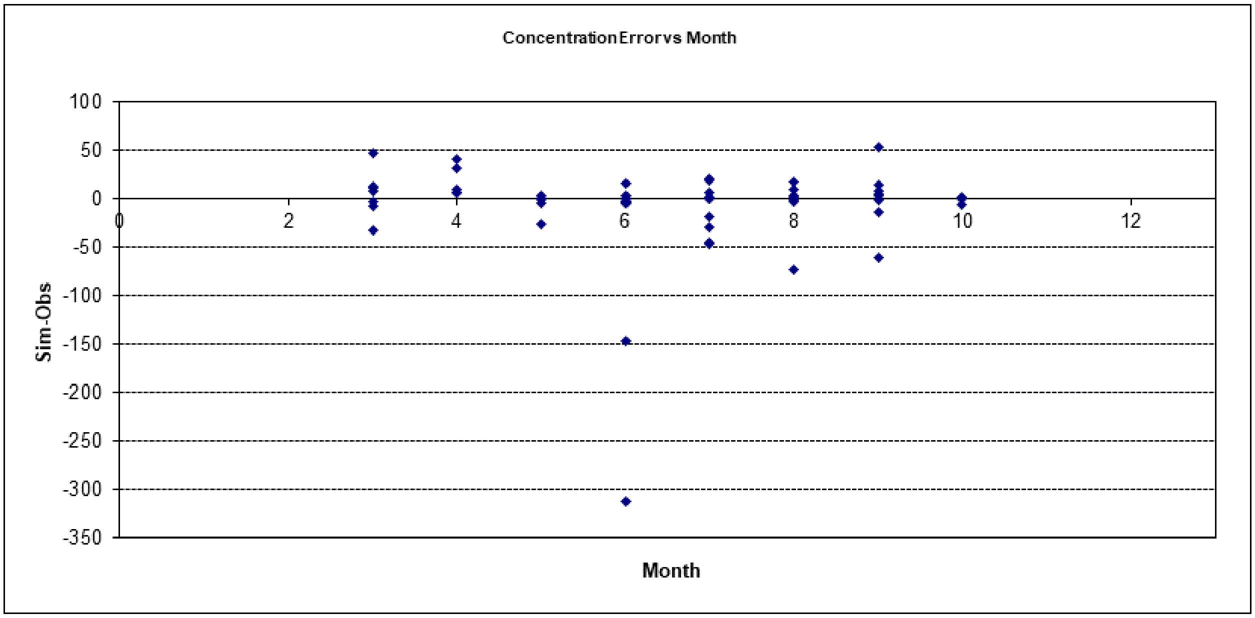


Figure D-177. TSS Concentration Error vs Month at the Keene Creek at 57th Ave W

D.18 Kingsbury Creek (Multiple Stations)

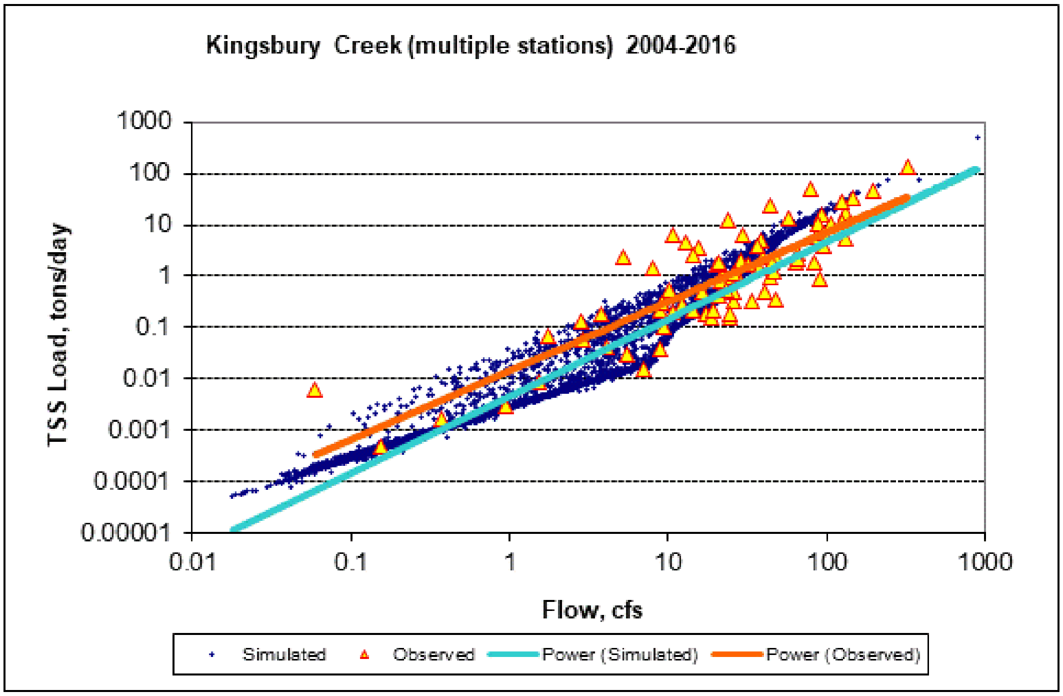


Figure D-178. Power Plot of Simulated and Observed TSS Load vs Flow at the Kingsbury Creek (multiple stations) (Calibration Period)

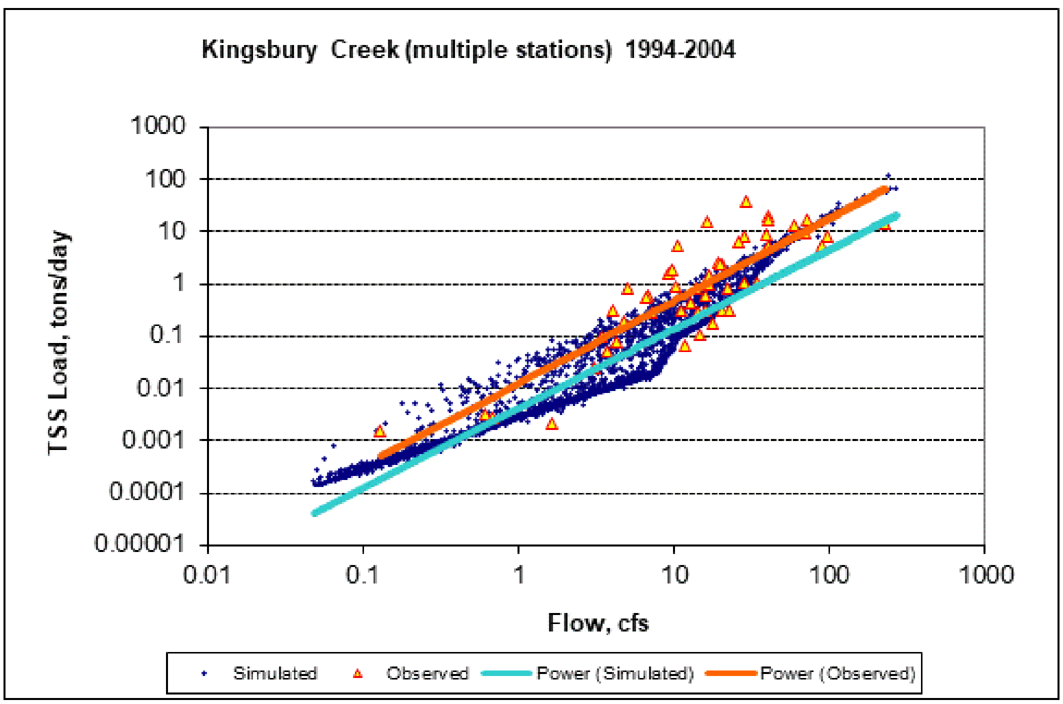


Figure D-179. Power Plot of Simulated and Observed TSS Load vs Flow at the Kingsbury Creek (multiple stations) (Validation Period)

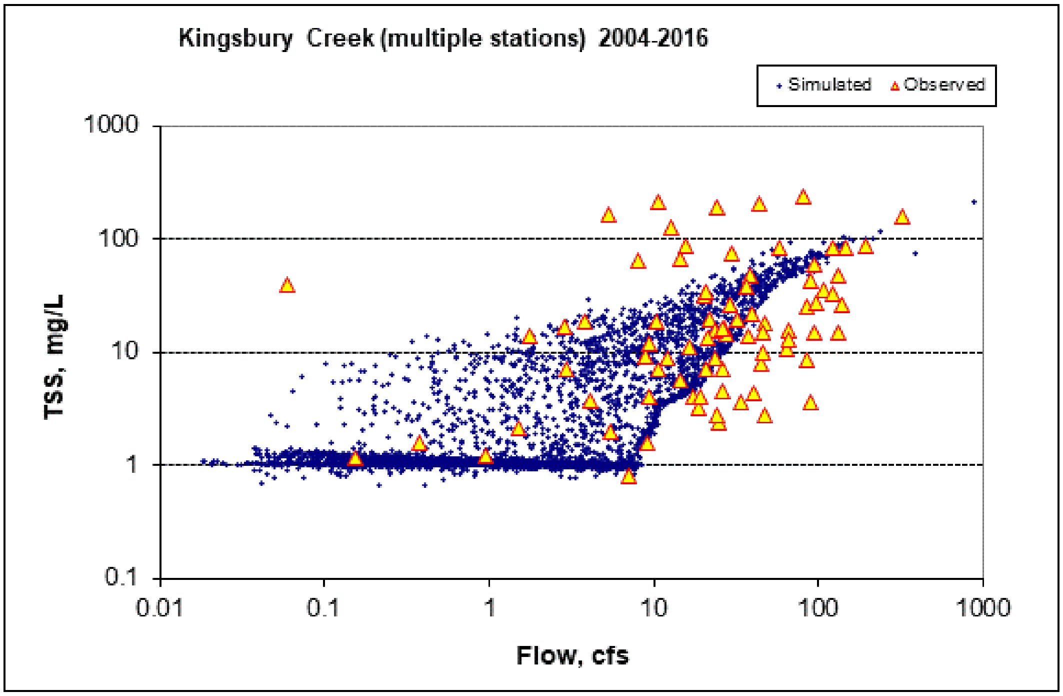


Figure D-180. Simulated and Observed TSS Concentration vs Flow Plot at the Kingsbury Creek (multiple stations) (Calibration Period)

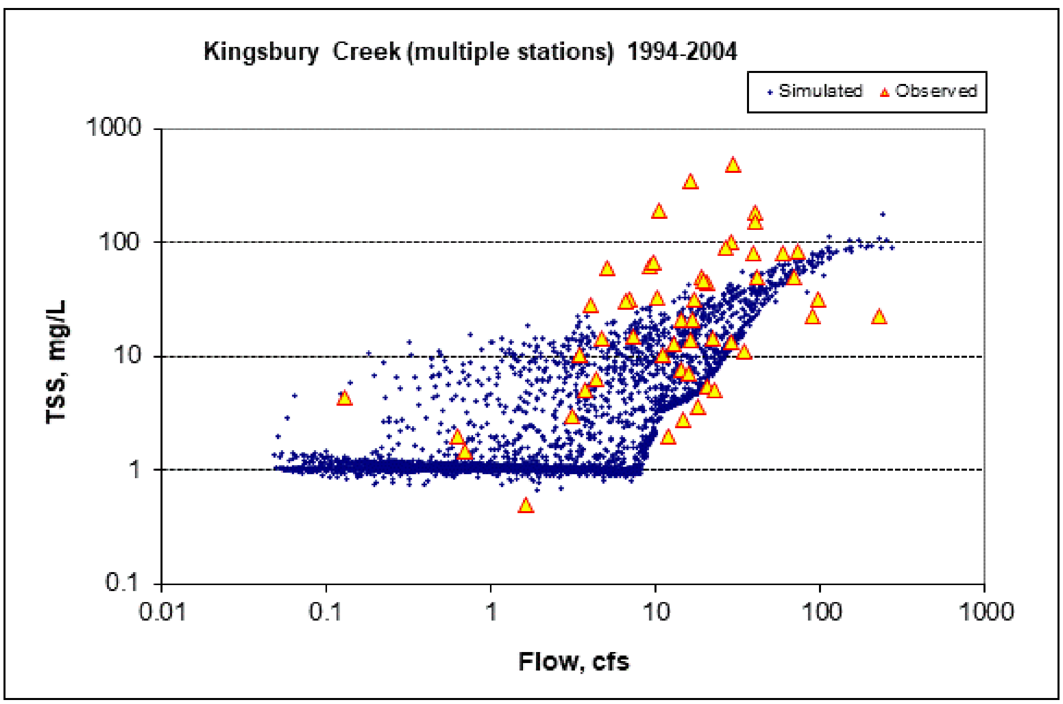


Figure D-181. Simulated and Observed TSS Concentration vs Flow Plot at the Kingsbury Creek (multiple stations) (Validation Period)

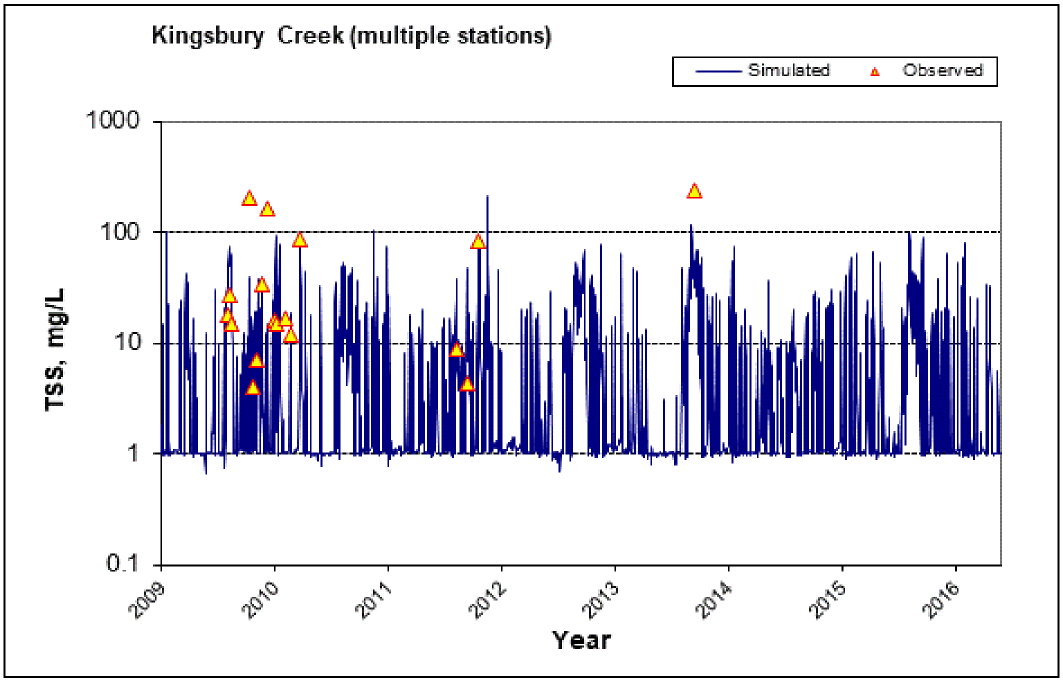


Figure D-182. TSS Concentration Time Series at the Kingsbury Creek (multiple stations) (2008-2015)

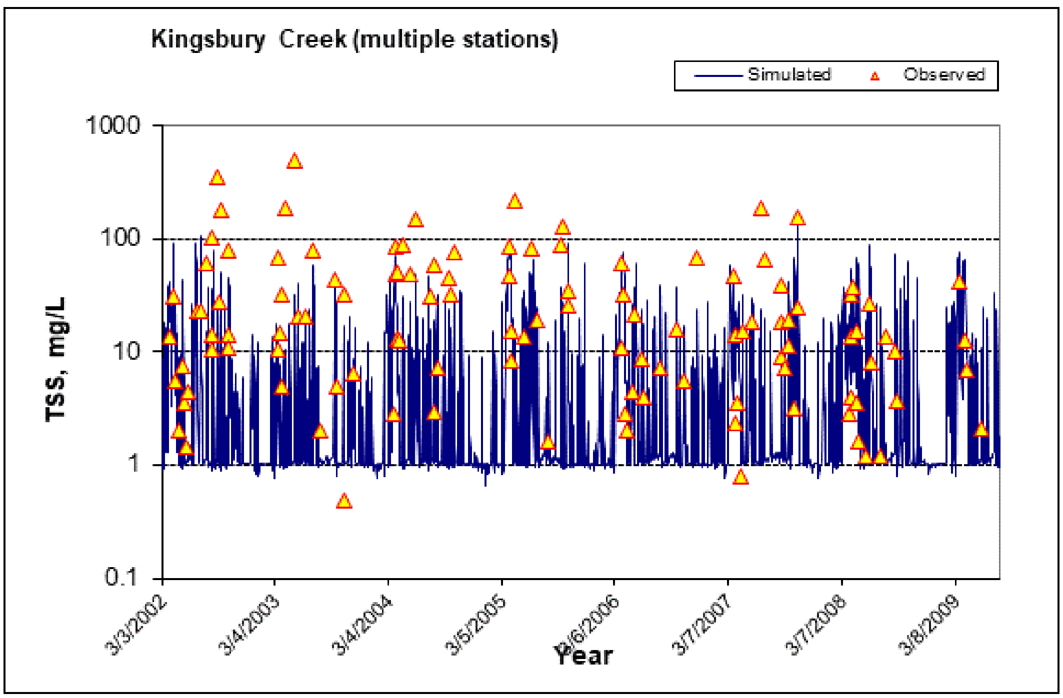


Figure D-183. TSS Concentration Time Series at the Kingsbury Creek (multiple stations) (2001-2008)

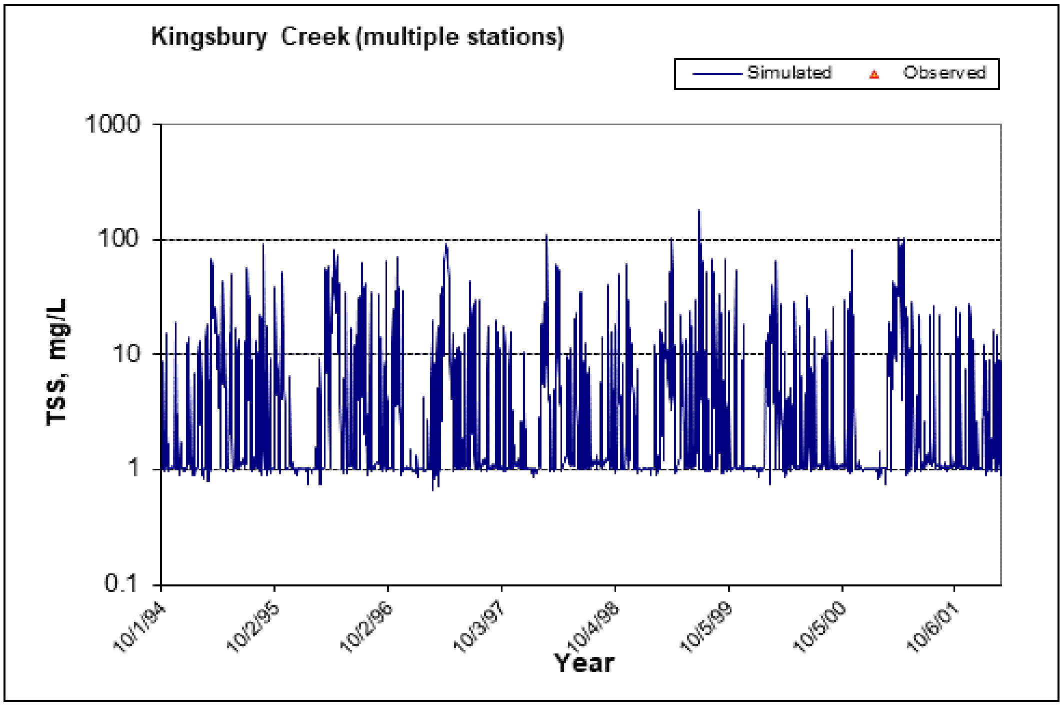


Figure D-184. TSS Concentration Time Series at the Kingsbury Creek (multiple stations) (1994-2001)

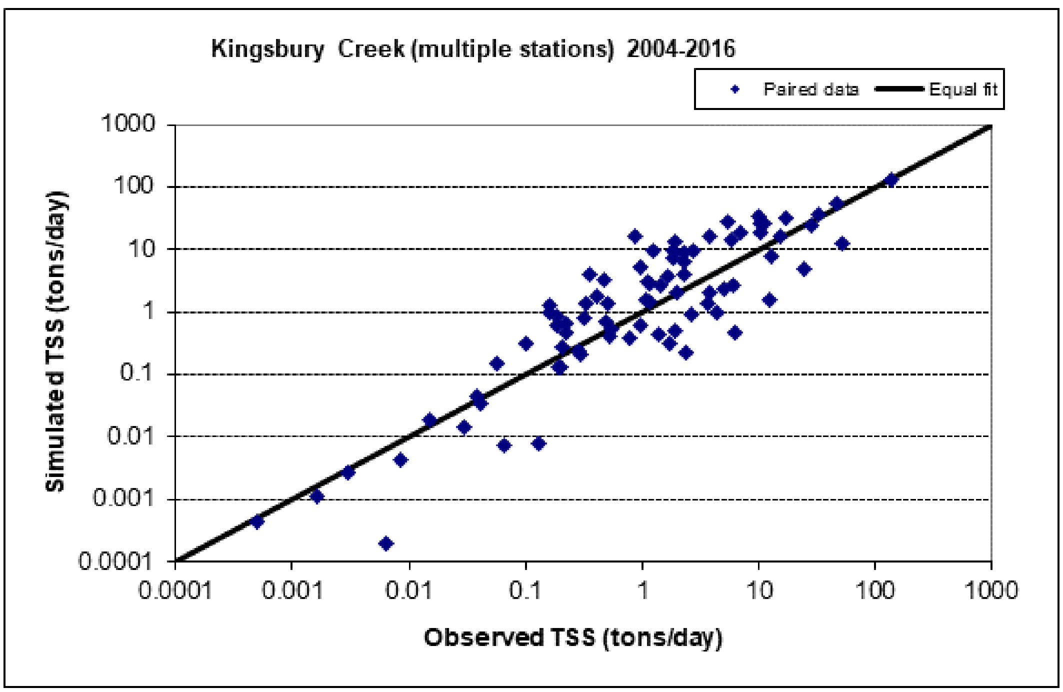


Figure D-185. Paired Simulated vs Observed TSS Load at the Kingsbury Creek (multiple stations) (Calibration Period)

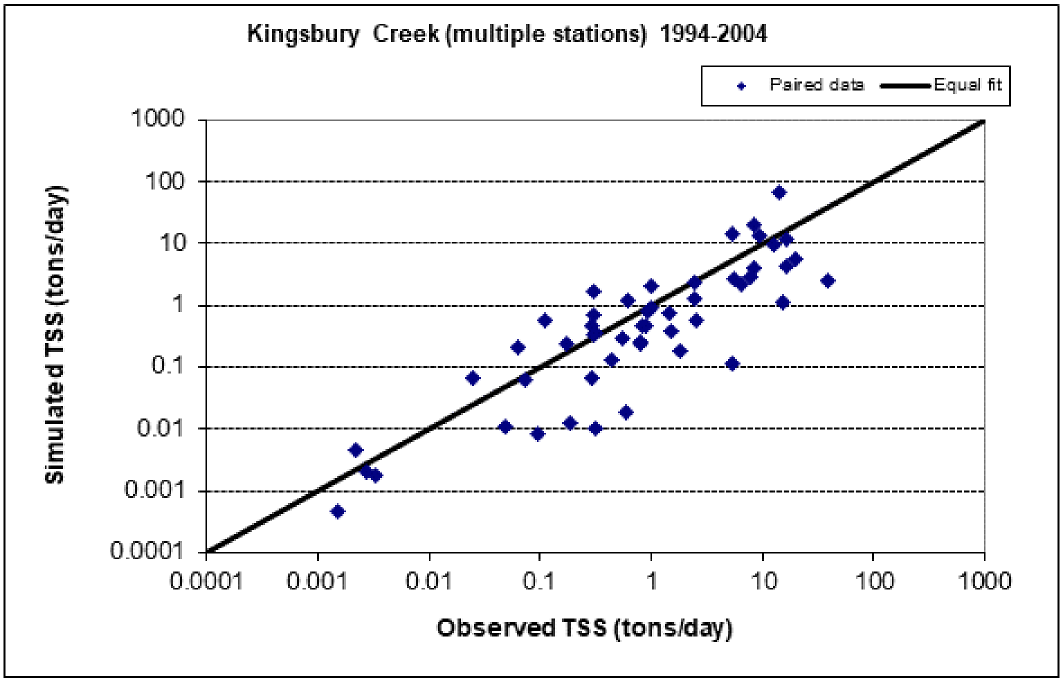


Figure D-186. Paired Simulated vs Observed TSS Load at the Kingsbury Creek (multiple stations) (Validation Period)

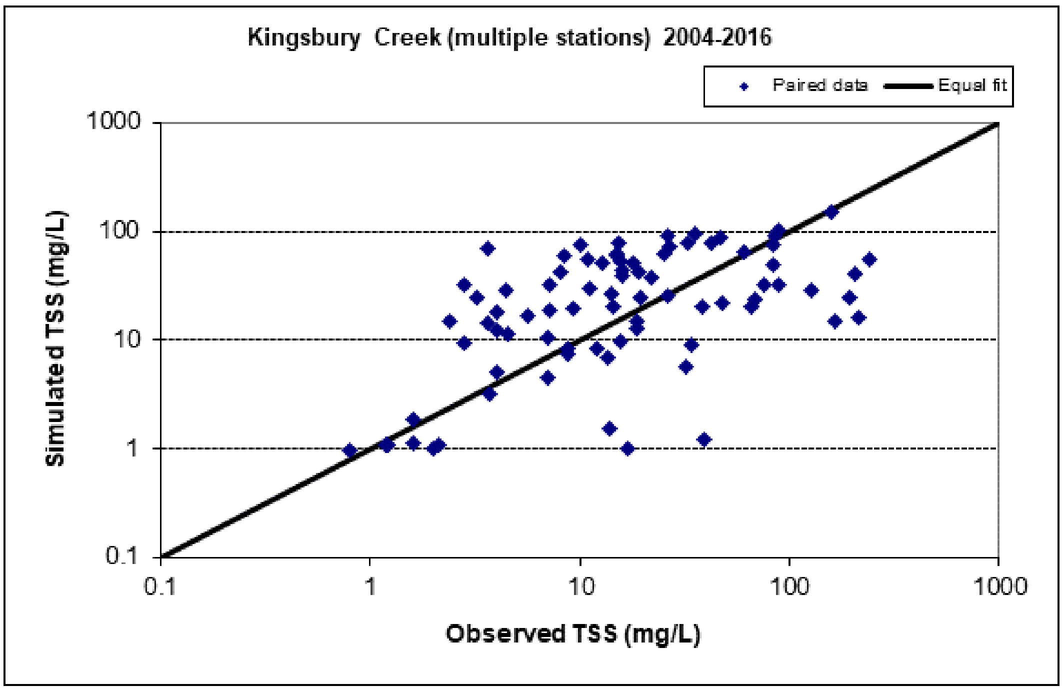


Figure D-187. Paired Simulated vs Observed TSS Concentration at the Kingsbury Creek (multiple stations) (Calibration Period)

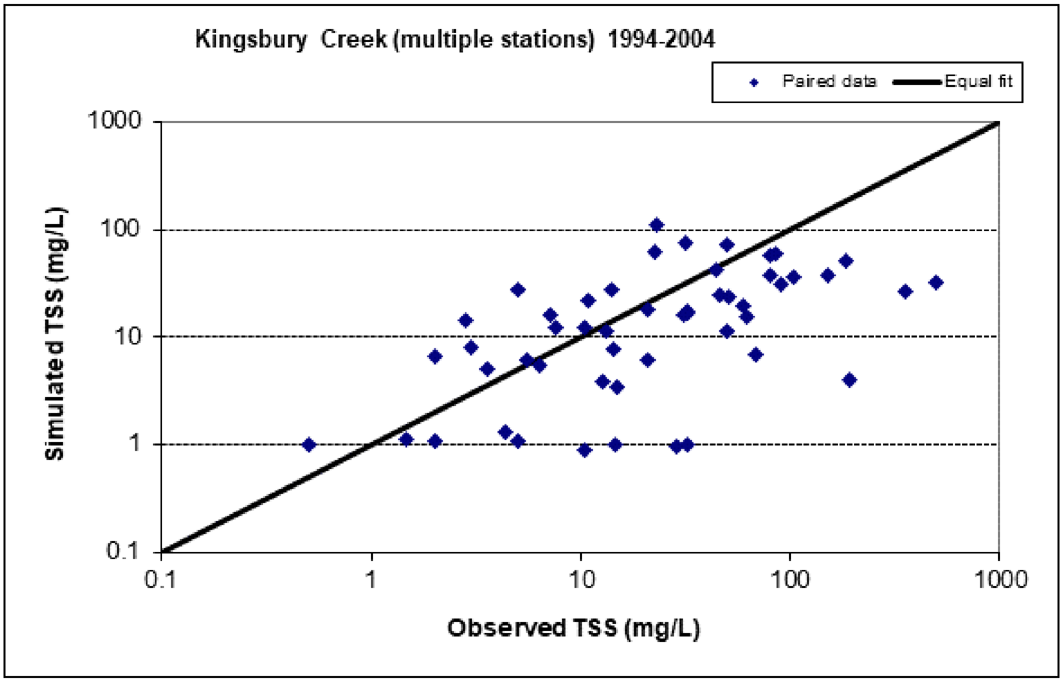


Figure D-188. Paired Simulated vs Observed TSS Concentration at the Kingsbury Creek (multiple stations) (Validation Period)

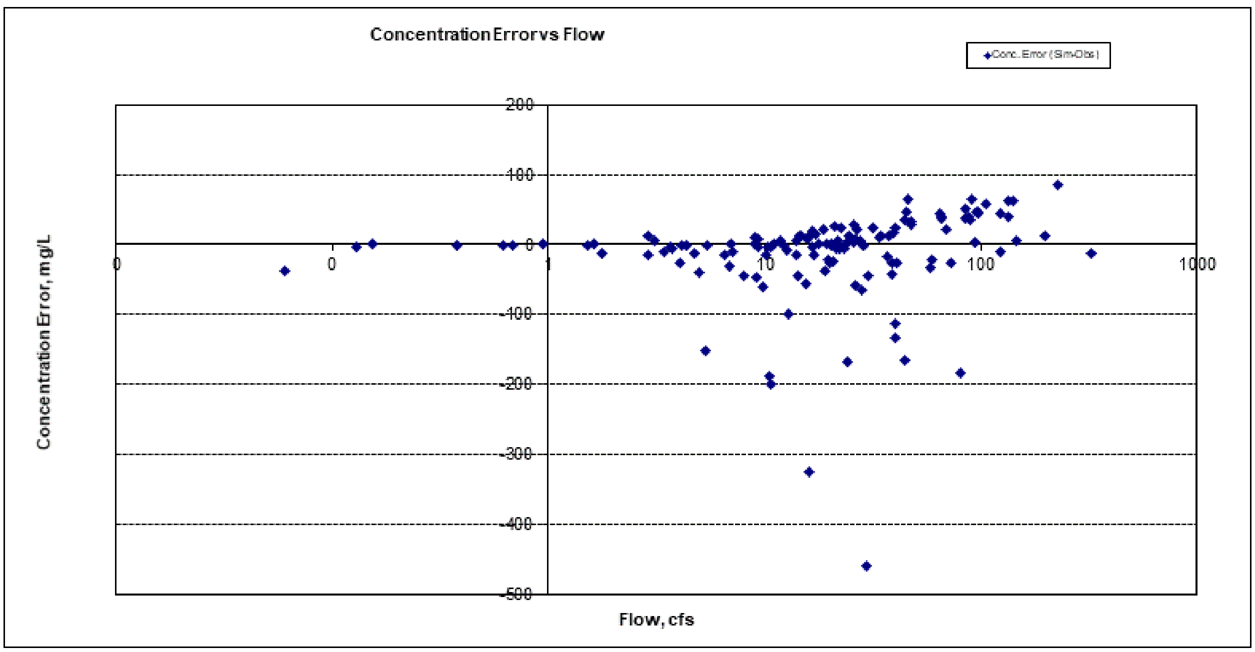


Figure D-189. TSS Concentration Error vs Flow at the Kingsbury Creek (multiple stations)

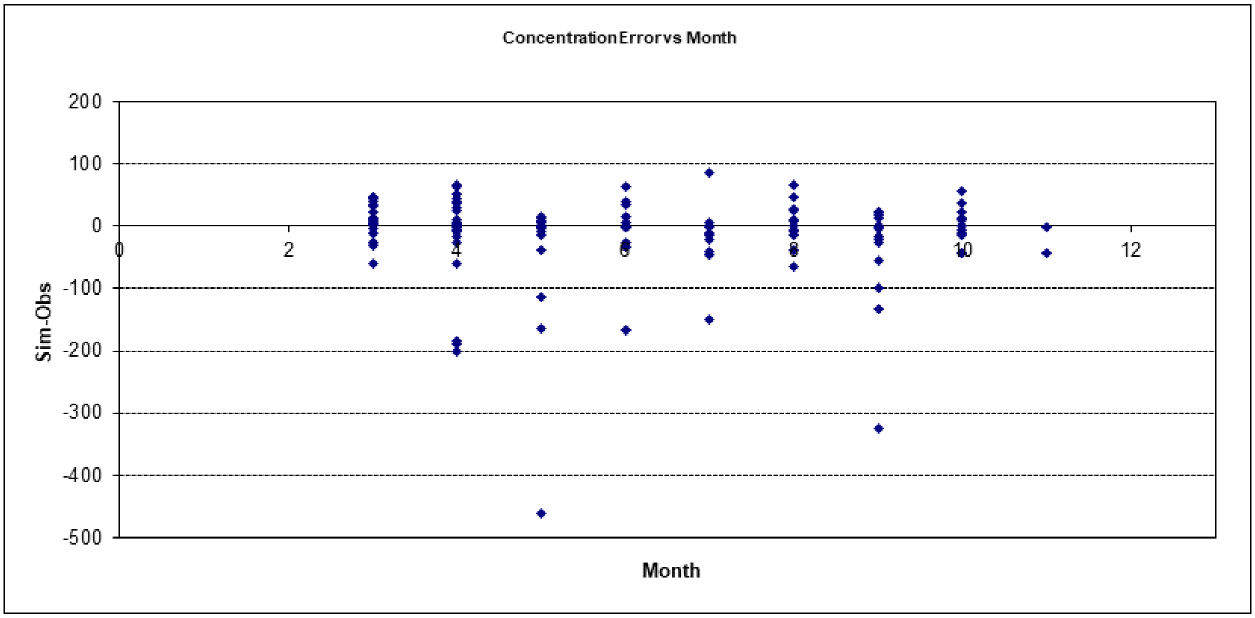


Figure D-190. TSS Concentration Error vs Month at the Kingsbury Creek (multiple stations)

D.19 SARGENT CREEK AT HUDSON BLVD

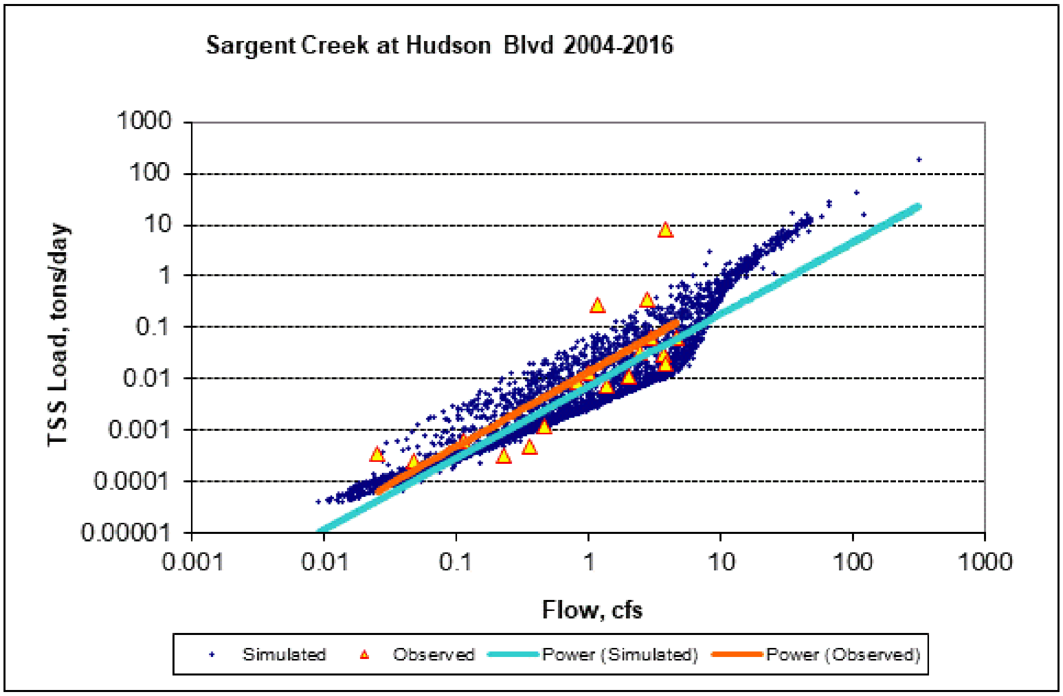


Figure D-191. Power Plot of Simulated and Observed TSS Load vs Flow at the Sargent Creek at Hudson Blvd (Calibration Period)

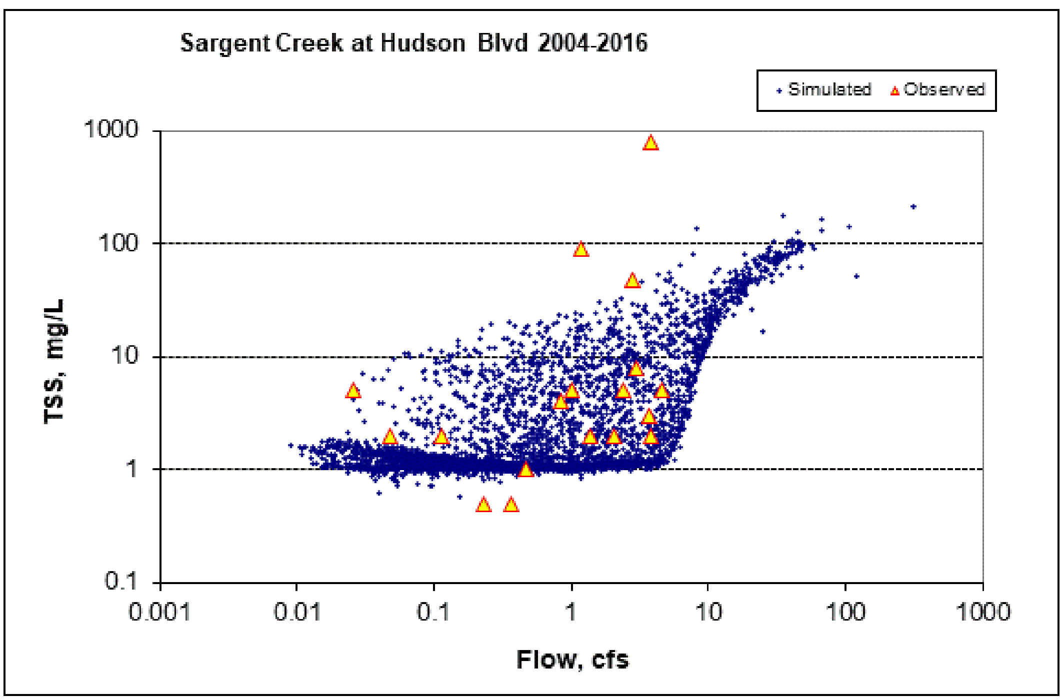


Figure D-192. Simulated and Observed TSS Concentration vs Flow Plot at the Sargent Creek at Hudson Blvd (Calibration Period)

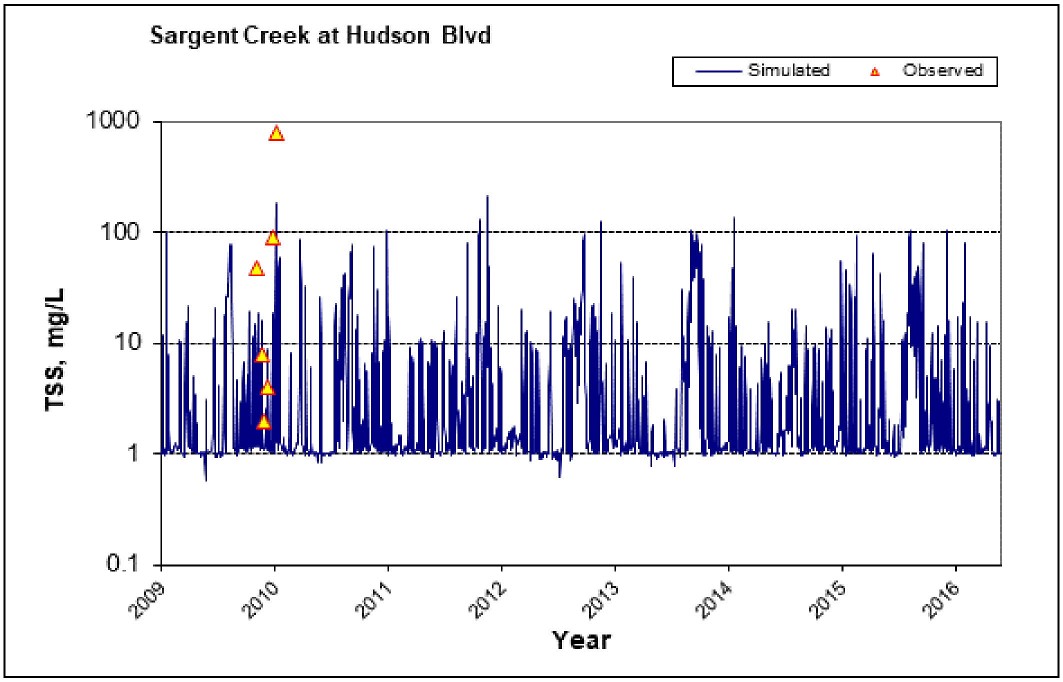


Figure D-193. TSS Concentration Time Series at the Sargent Creek at Hudson Blvd (2008-2015)

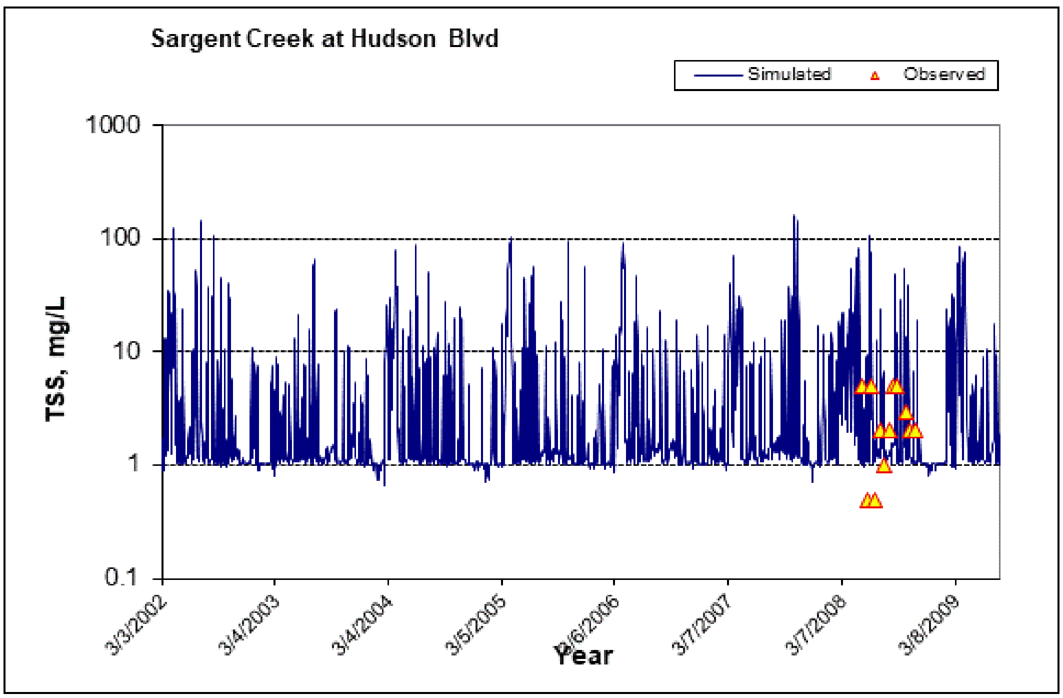


Figure D-194. TSS Concentration Time Series at the Sargent Creek at Hudson Blvd (2001-2008)

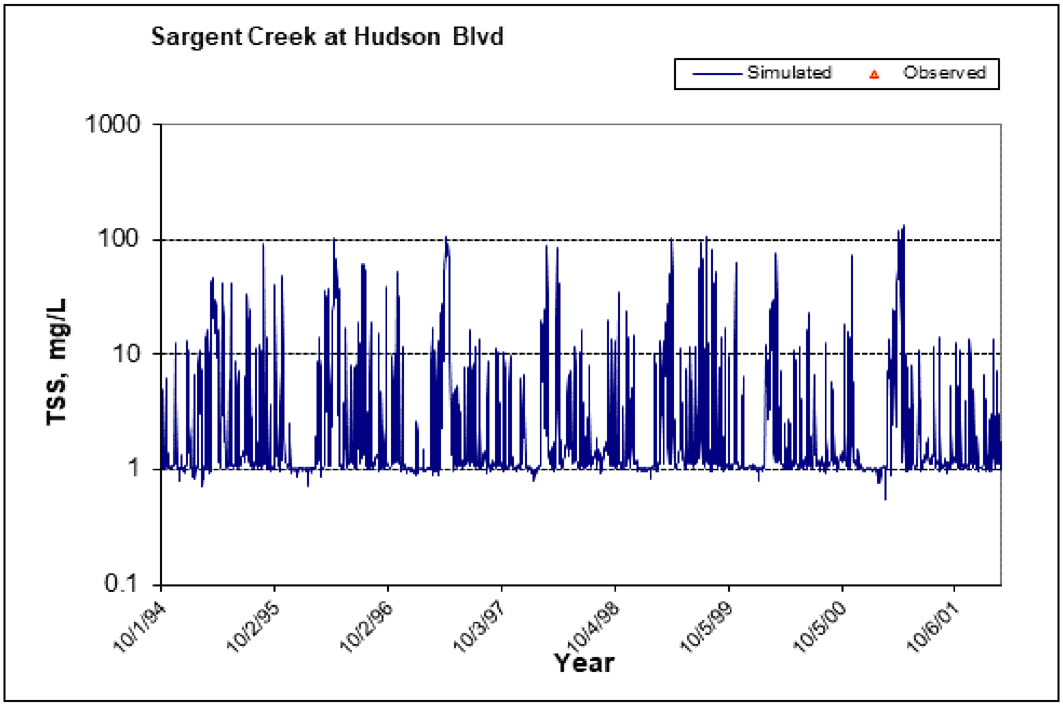


Figure D-195. TSS Concentration Time Series at the Sargent Creek at Hudson Blvd (1994-2001)

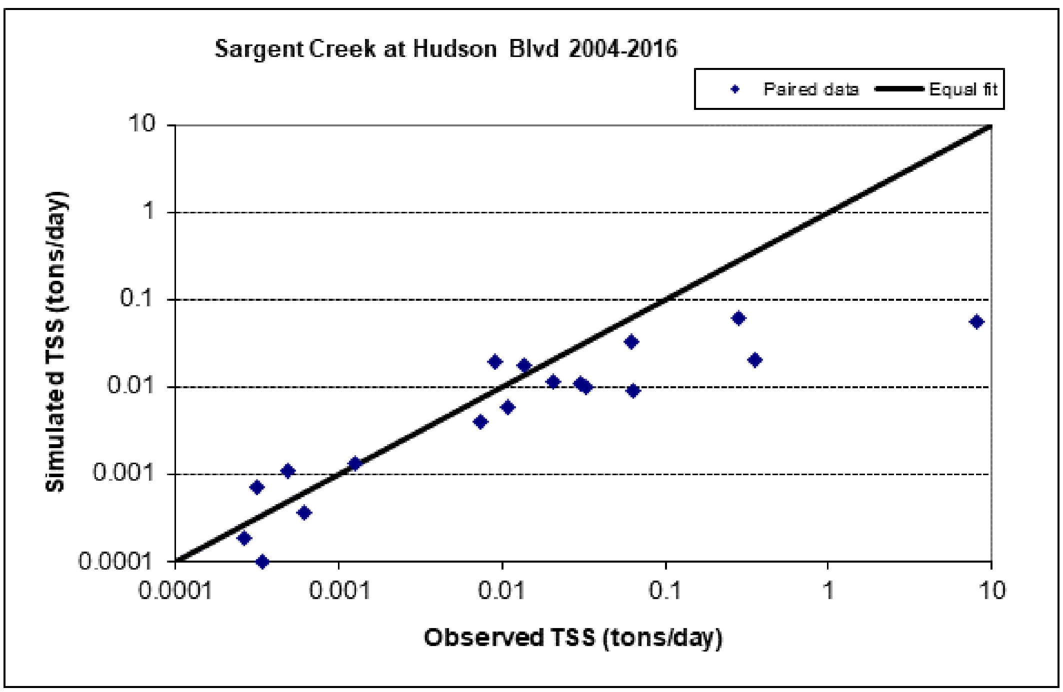


Figure D-196. Paired Simulated vs Observed TSS Load at the Sargent Creek at Hudson Blvd (Calibration Period)

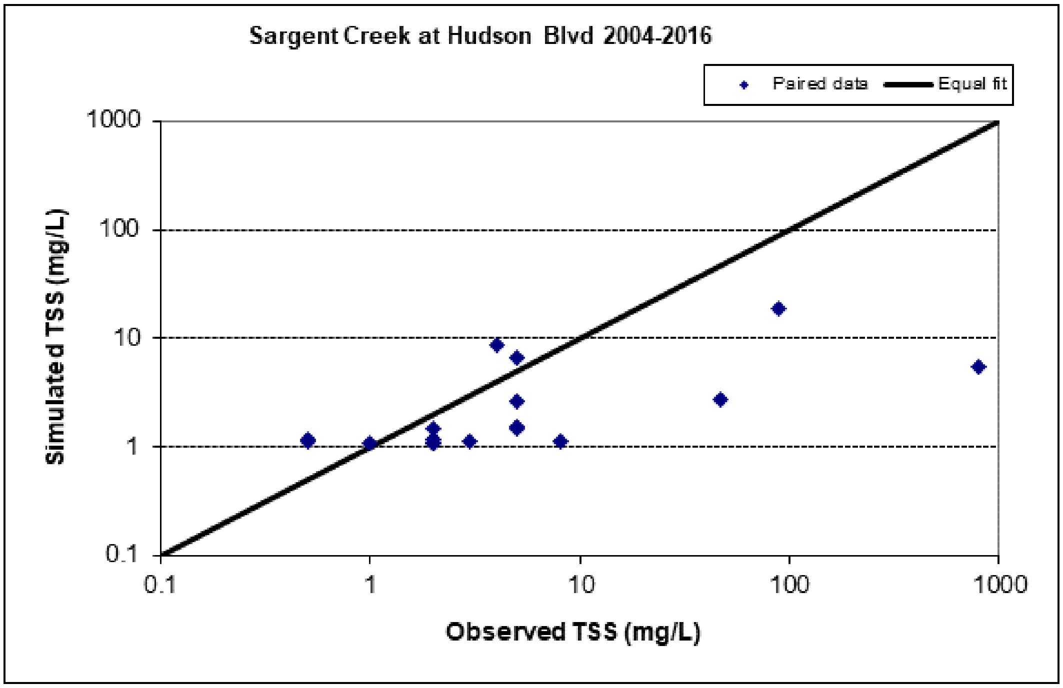


Figure D-197. Paired Simulated vs Observed TSS Concentration at the Sargent Creek at Hudson Blvd (Calibration Period)

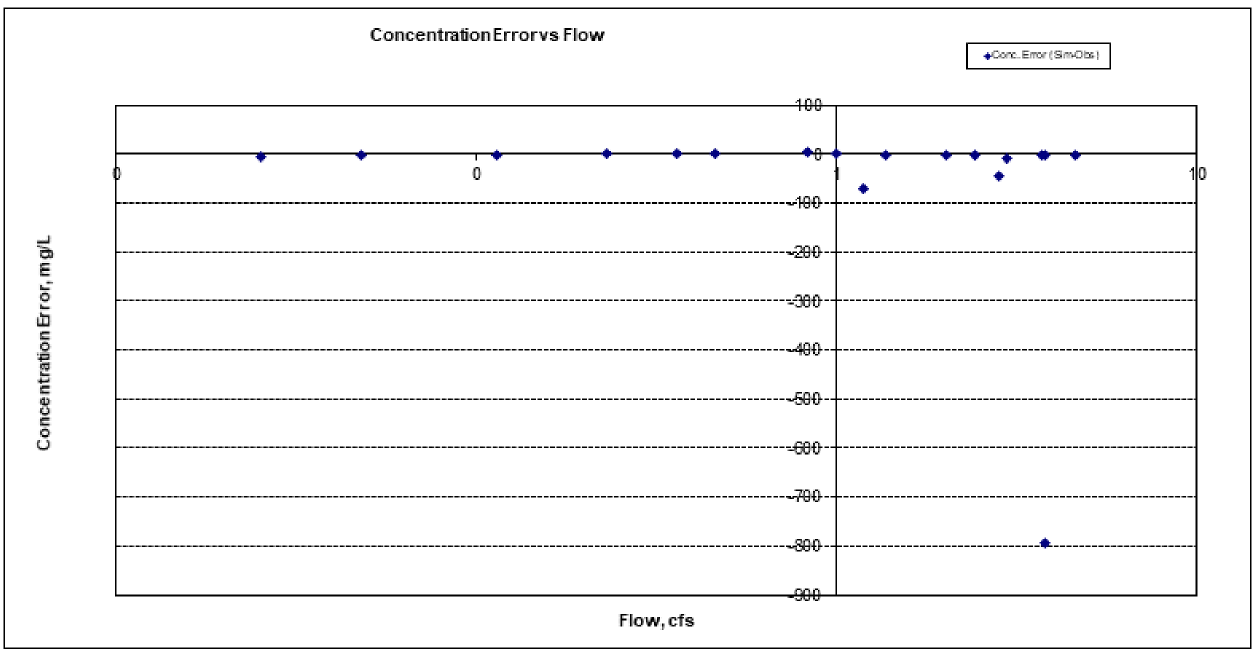


Figure D-198. TSS Concentration Error vs Flow at the Sargent Creek at Hudson Blvd

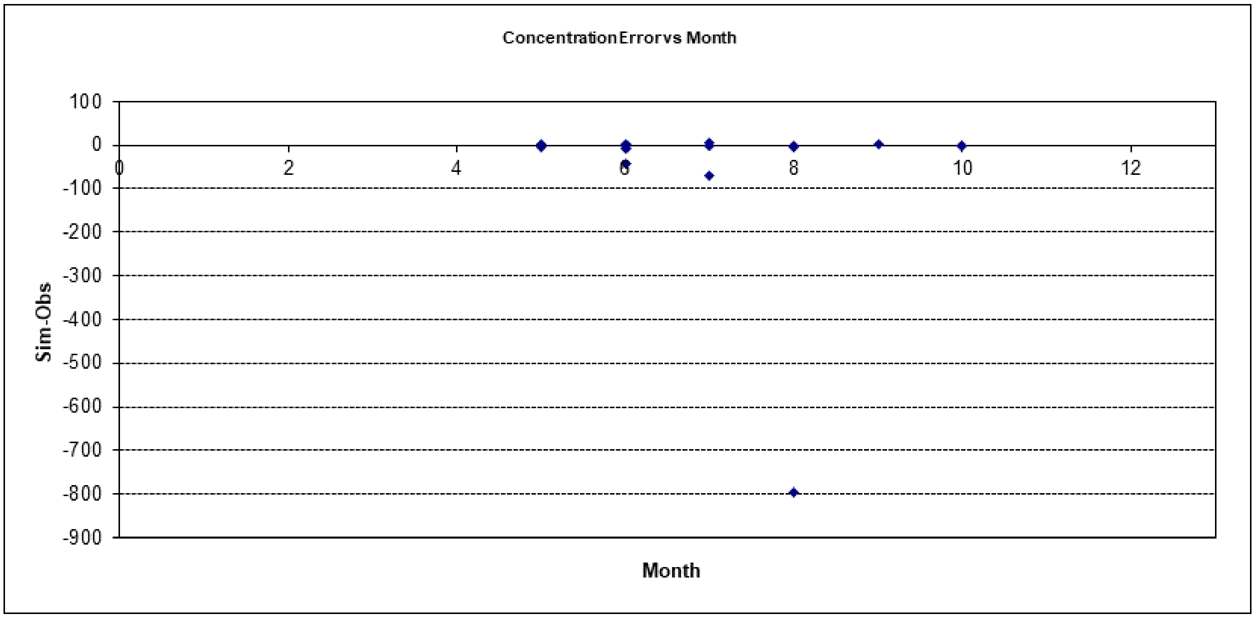


Figure D-199. TSS Concentration Error vs Month at the Sargent Creek at Hudson Blvd

D.20 Mission Creek above 131st Ave W

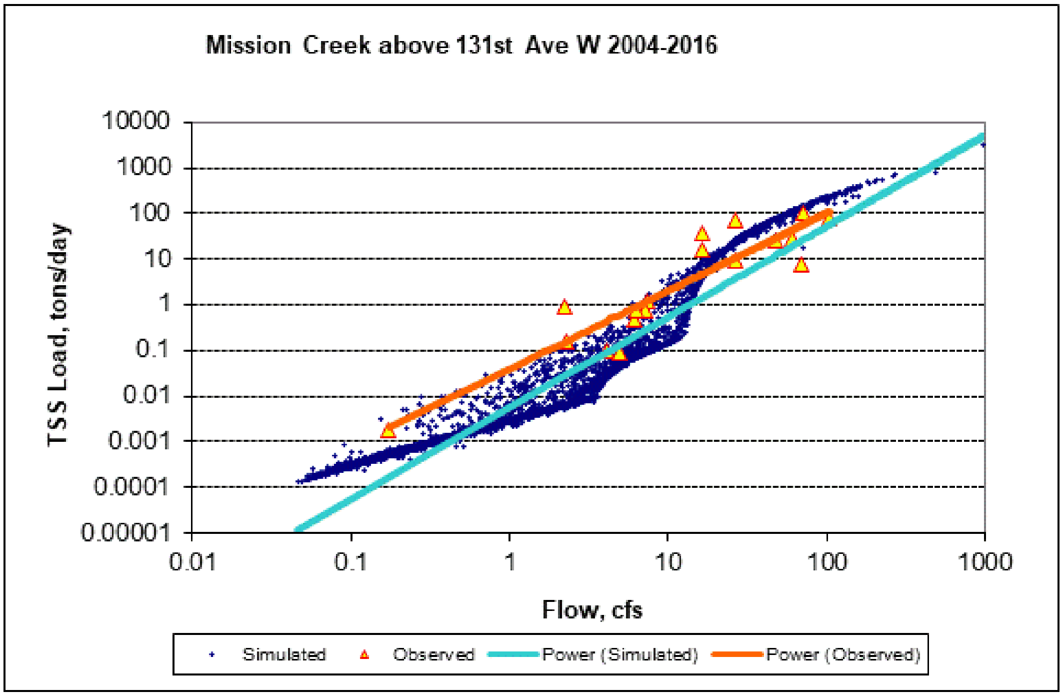


Figure D-200. Power Plot of Simulated and Observed TSS Load vs Flow at the Mission Creek above 131st Ave W (Calibration Period)

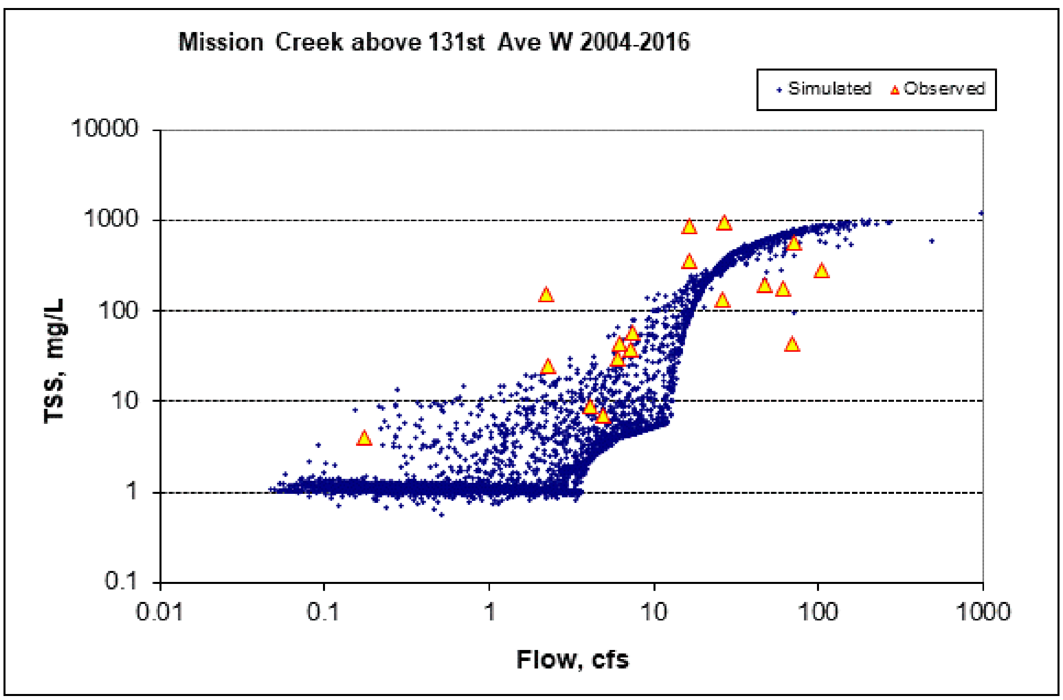


Figure D-201. Simulated and Observed TSS Concentration vs Flow Plot at the Mission Creek above 131st Ave W (Calibration Period)

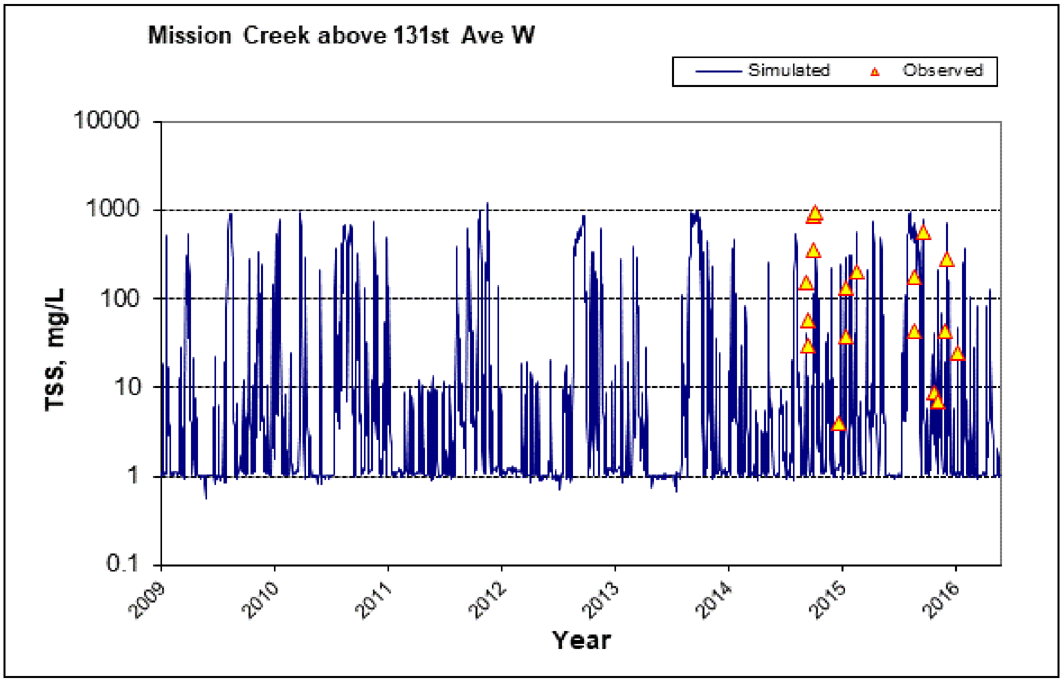


Figure D-202. TSS Concentration Time Series at the Mission Creek above 131st Ave W (2008-2015)

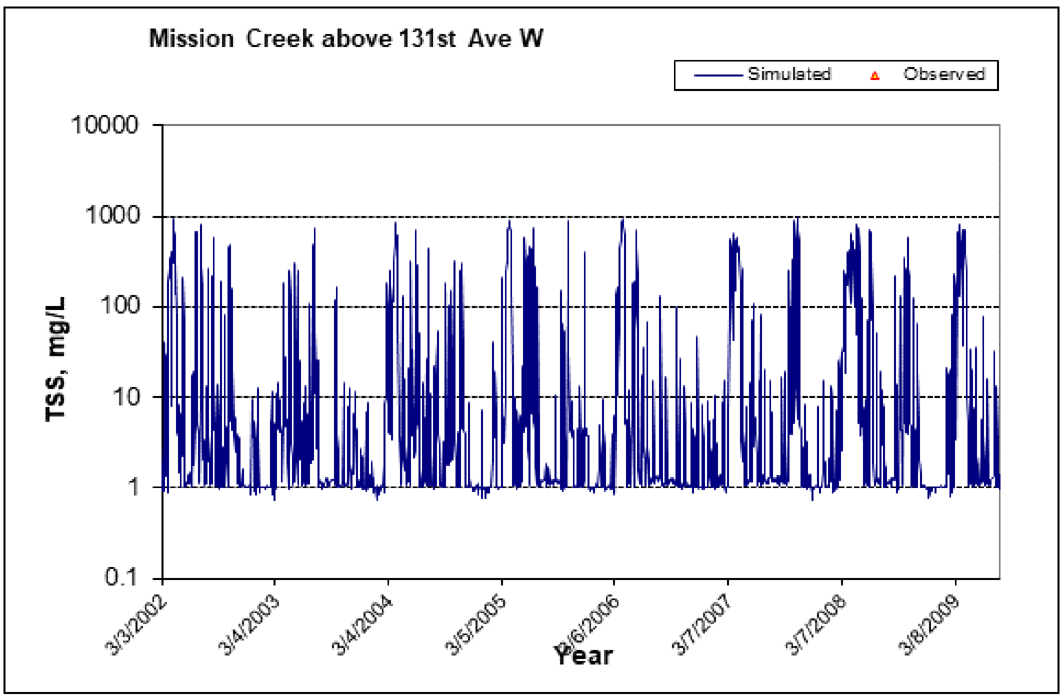


Figure D-203. TSS Concentration Time Series at the Mission Creek above 131st Ave W (2001-2008)

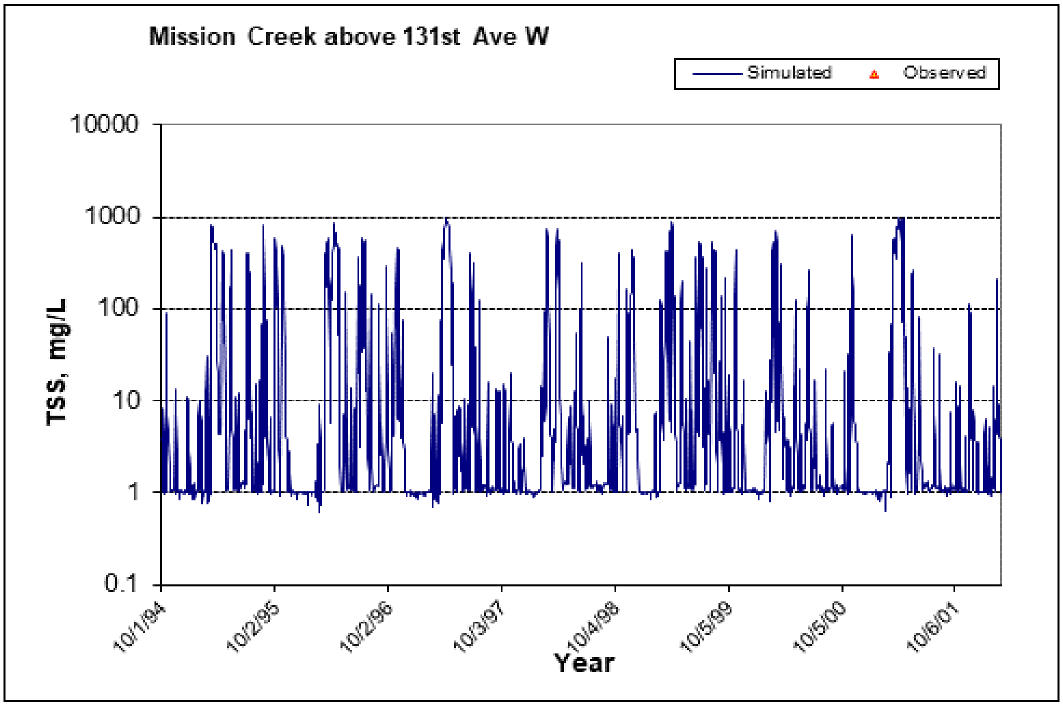


Figure D-204. TSS Concentration Time Series at the Mission Creek above 131st Ave W (1994-2001)

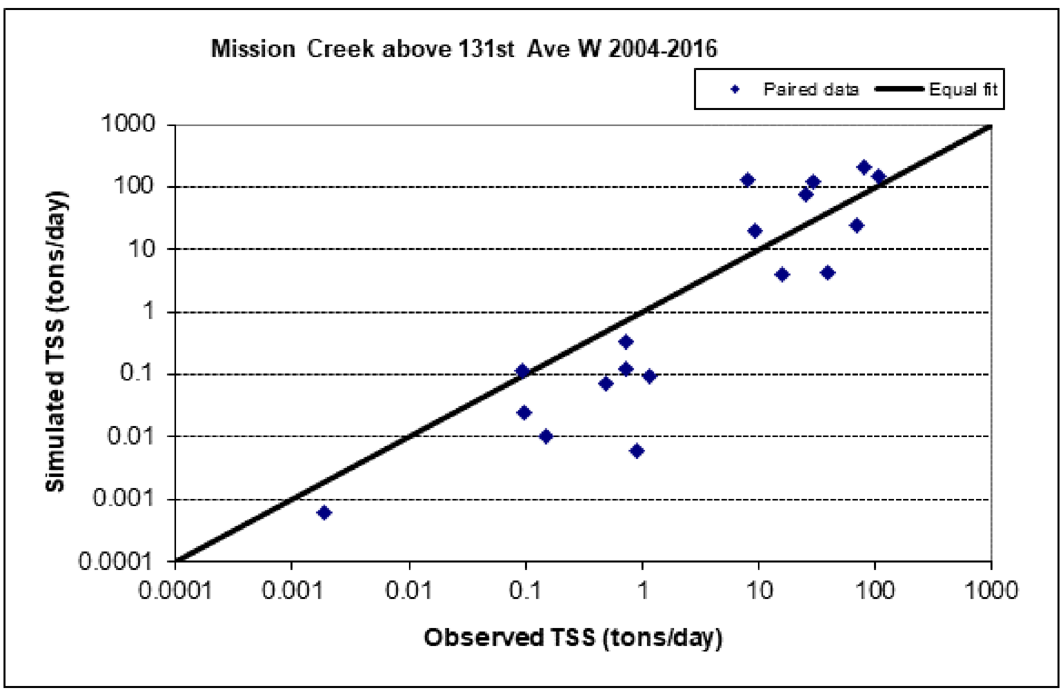


Figure D-205. Paired Simulated vs Observed TSS Load at the Mission Creek above 131st Ave W (Calibration Period)

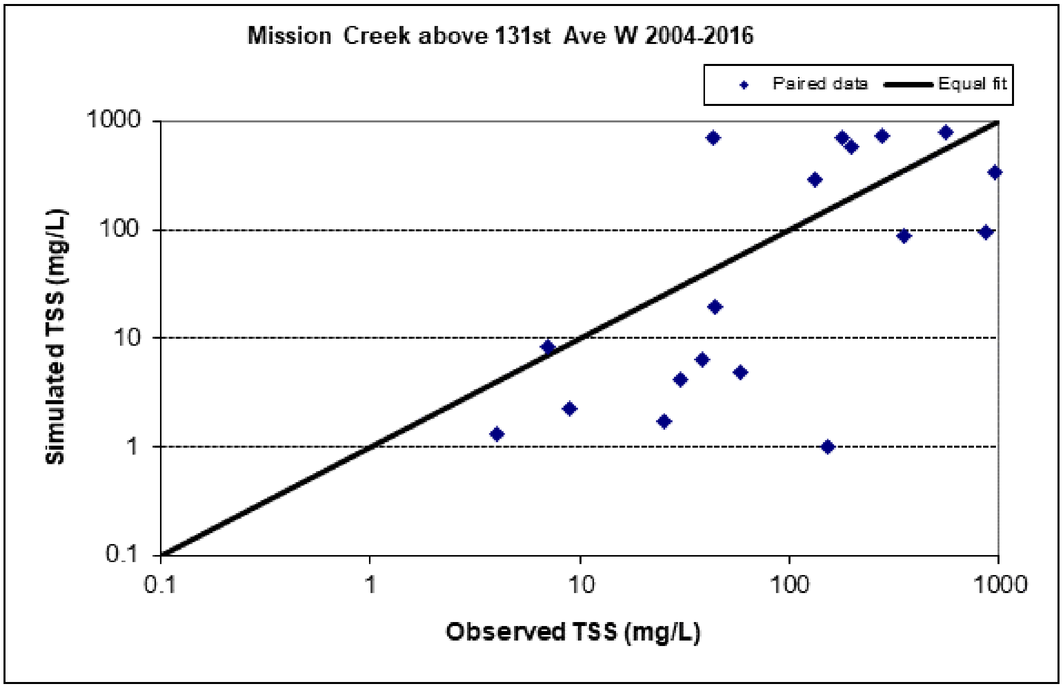


Figure D-206. Paired Simulated vs Observed TSS Concentration at the Mission Creek above 131st Ave W (Calibration Period)

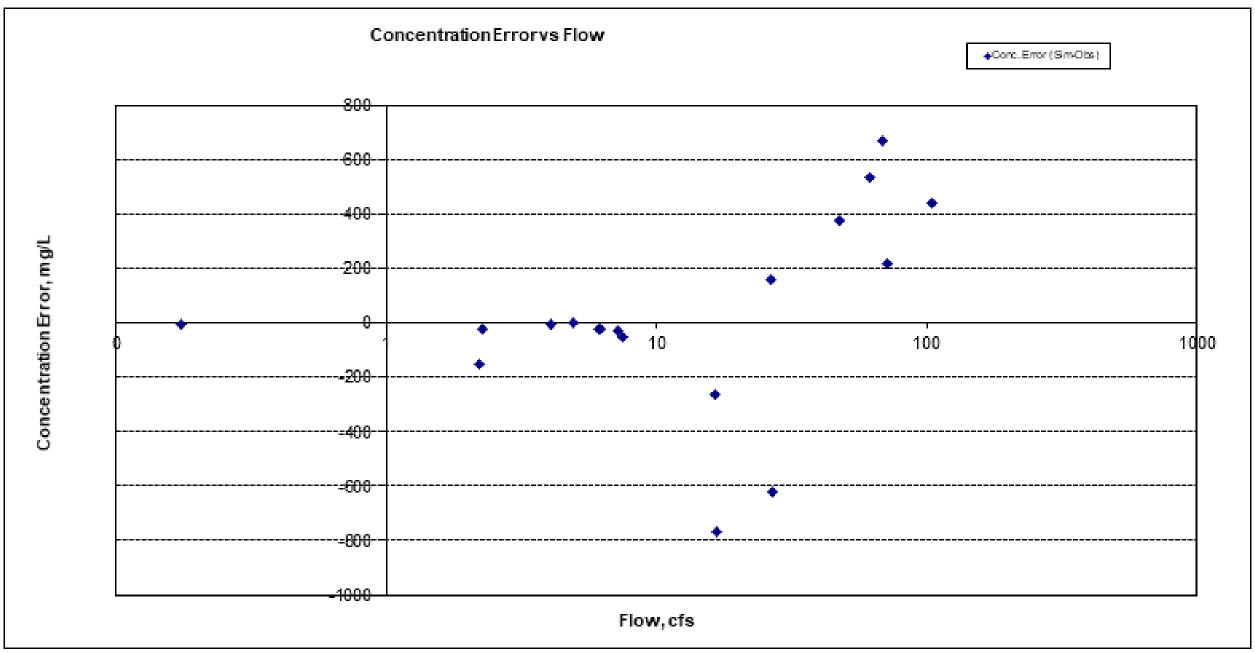


Figure D-207. TSS Concentration Error vs Flow at the Mission Creek above 131st Ave W

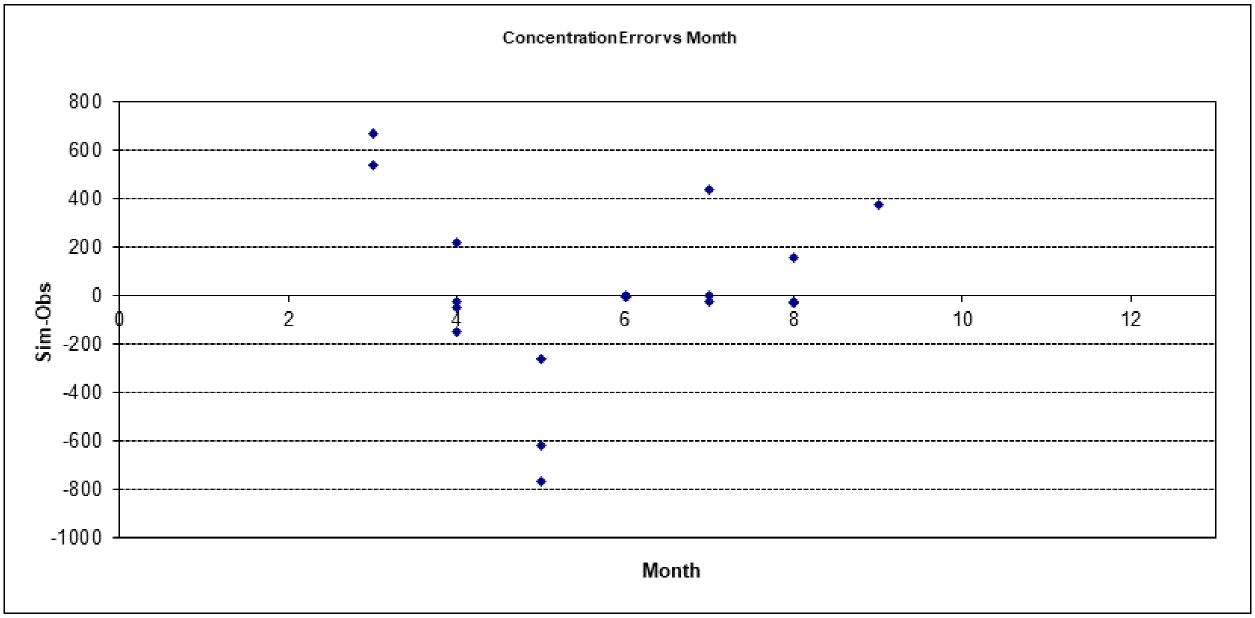


Figure D-208. TSS Concentration Error vs Month at the Mission Creek above 131st Ave W

D.21 Mission Creek at MN-23

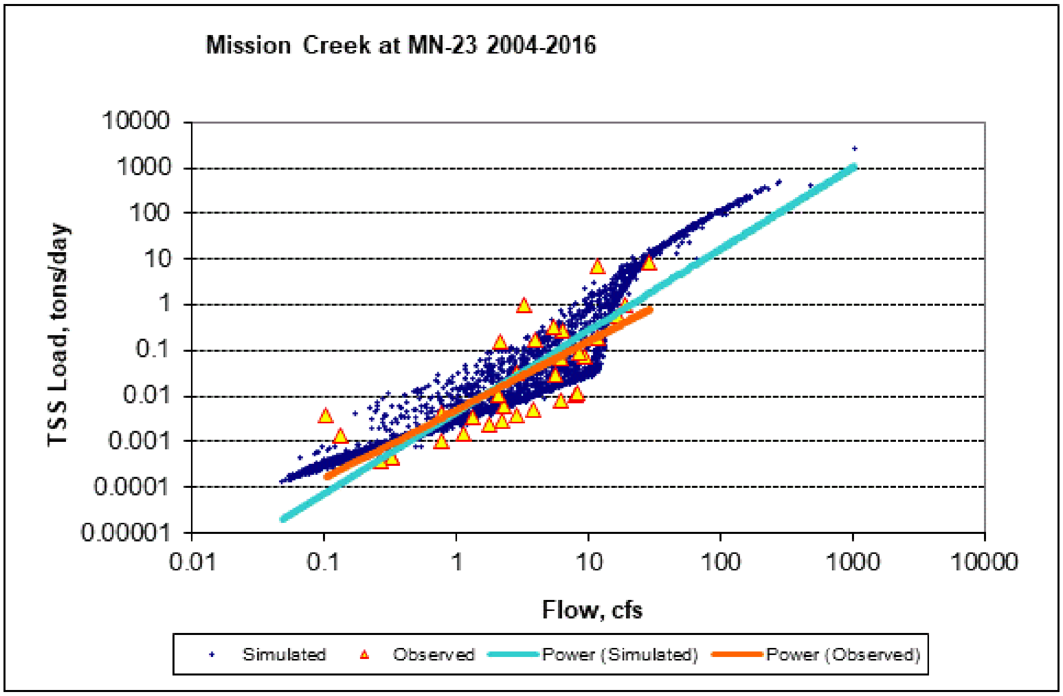


Figure D-209. Power Plot of Simulated and Observed TSS Load vs Flow at the Mission Creek at MN-23 (Calibration Period)

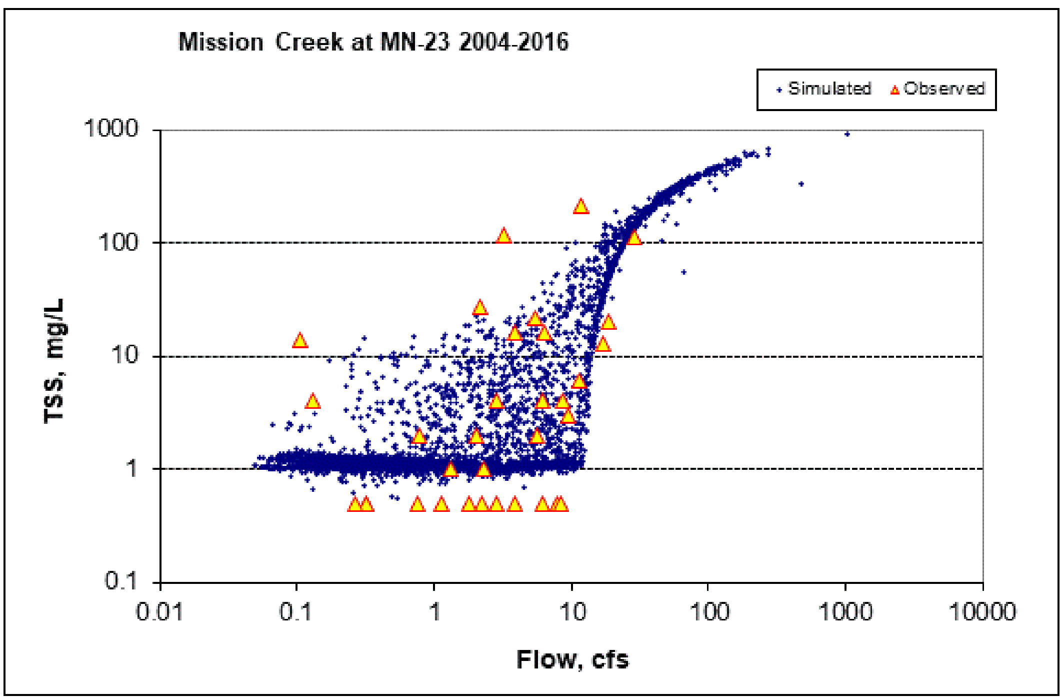


Figure D-210. Simulated and Observed TSS Concentration vs Flow Plot at the Mission Creek at MN-23 (Calibration Period)

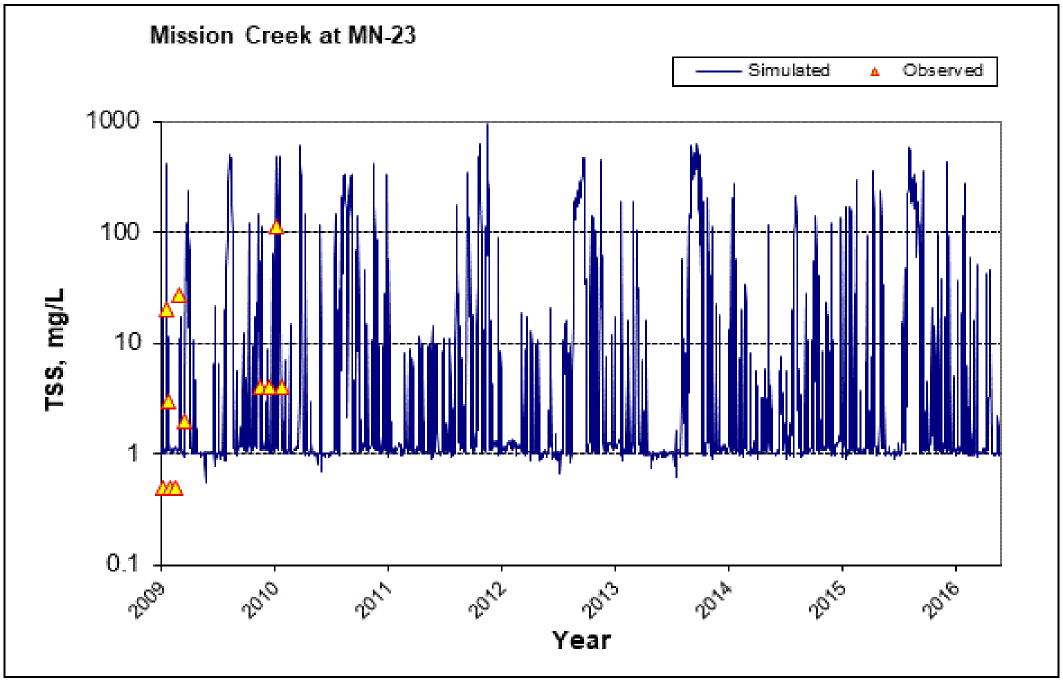


Figure D-211. TSS Concentration Time Series at the Mission Creek at MN-23 (2008-2015)

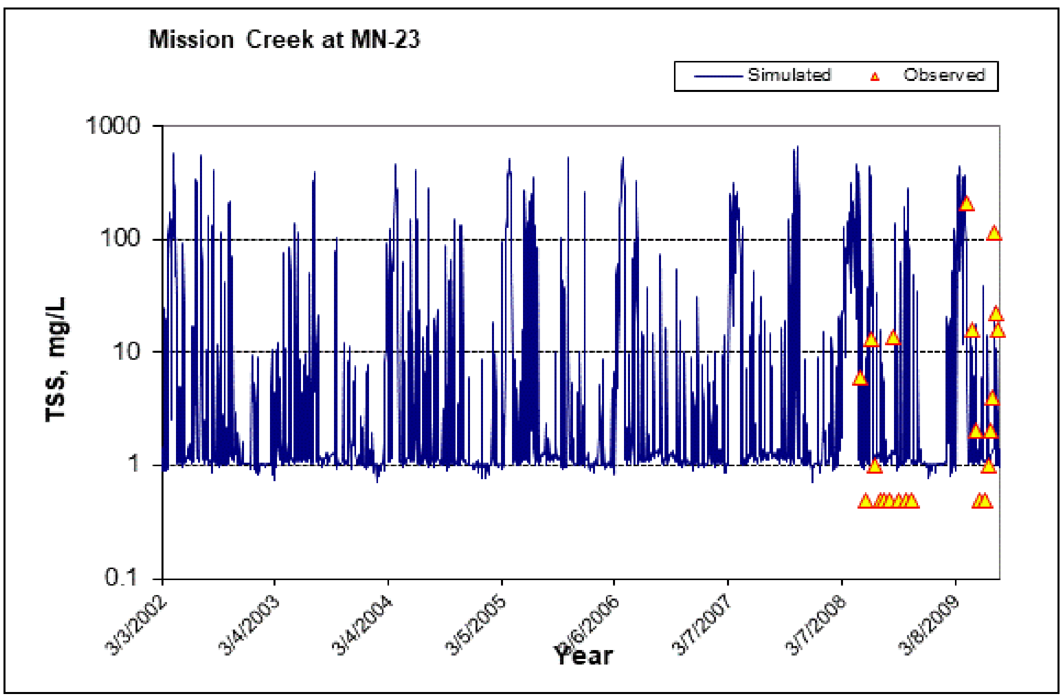


Figure D-212. TSS Concentration Time Series at the Mission Creek at MN-23 (2001-2008)

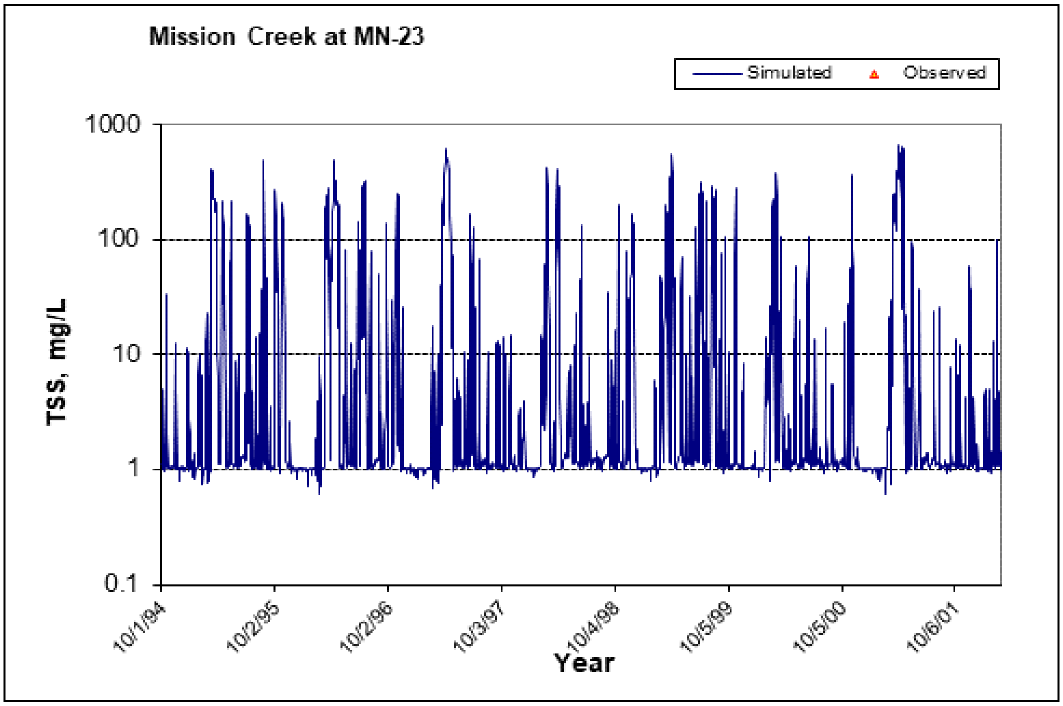


Figure D-213. TSS Concentration Time Series at the Mission Creek at MN-23 (1994-2001)

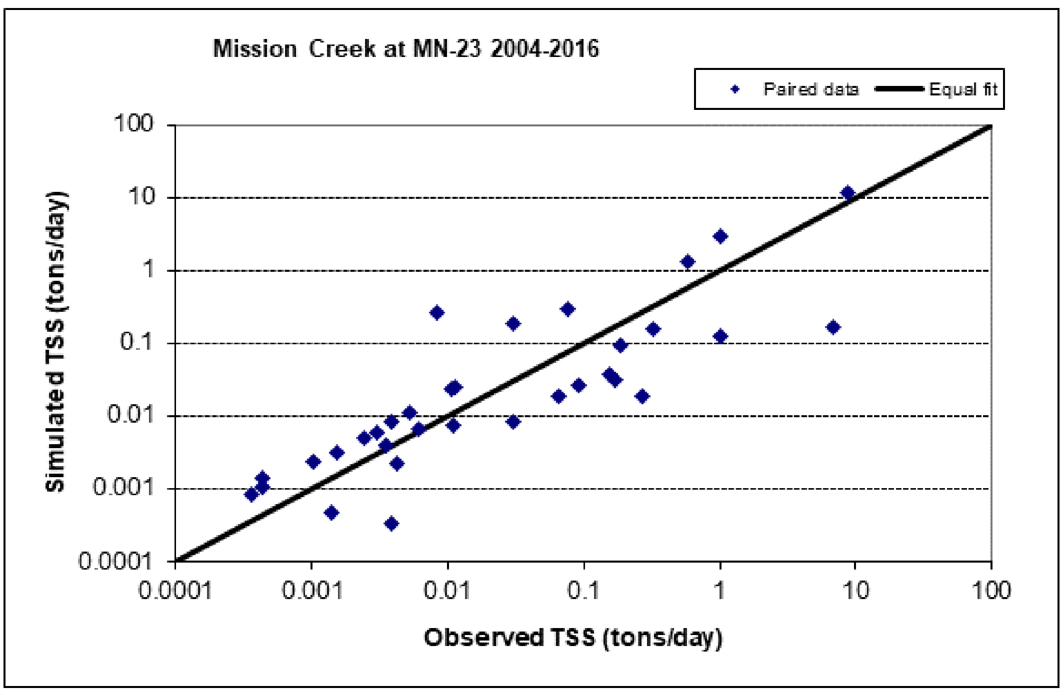


Figure D-214. Paired Simulated vs Observed TSS Load at the Mission Creek at MN-23 (Calibration Period)

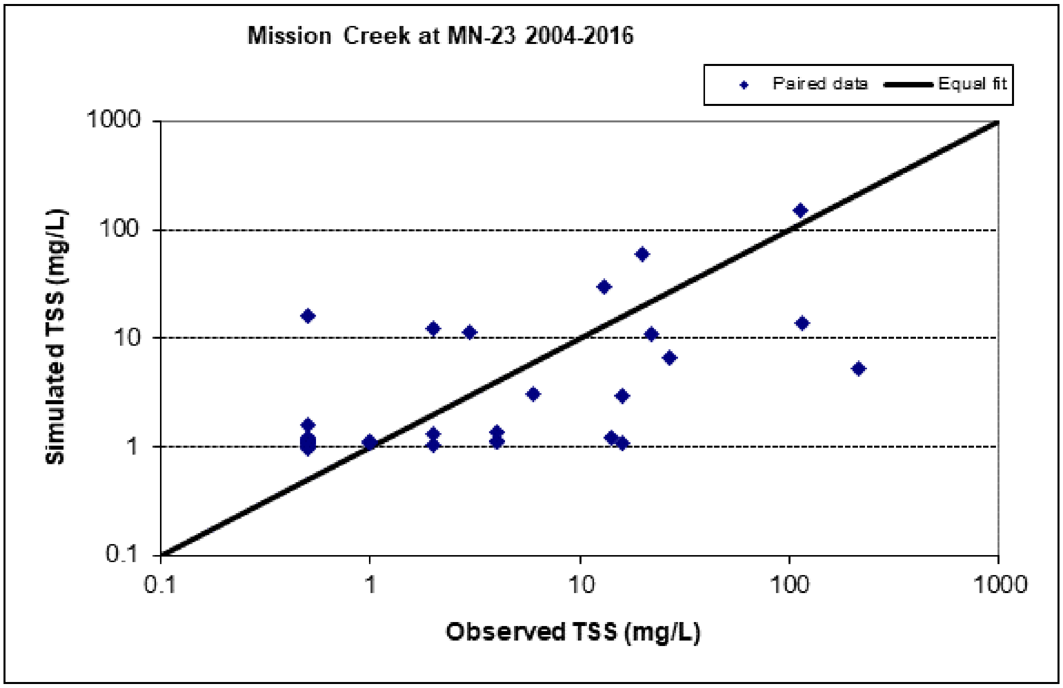


Figure D-215. Paired Simulated vs Observed TSS Concentration at the Mission Creek at MN-23 (Calibration Period)

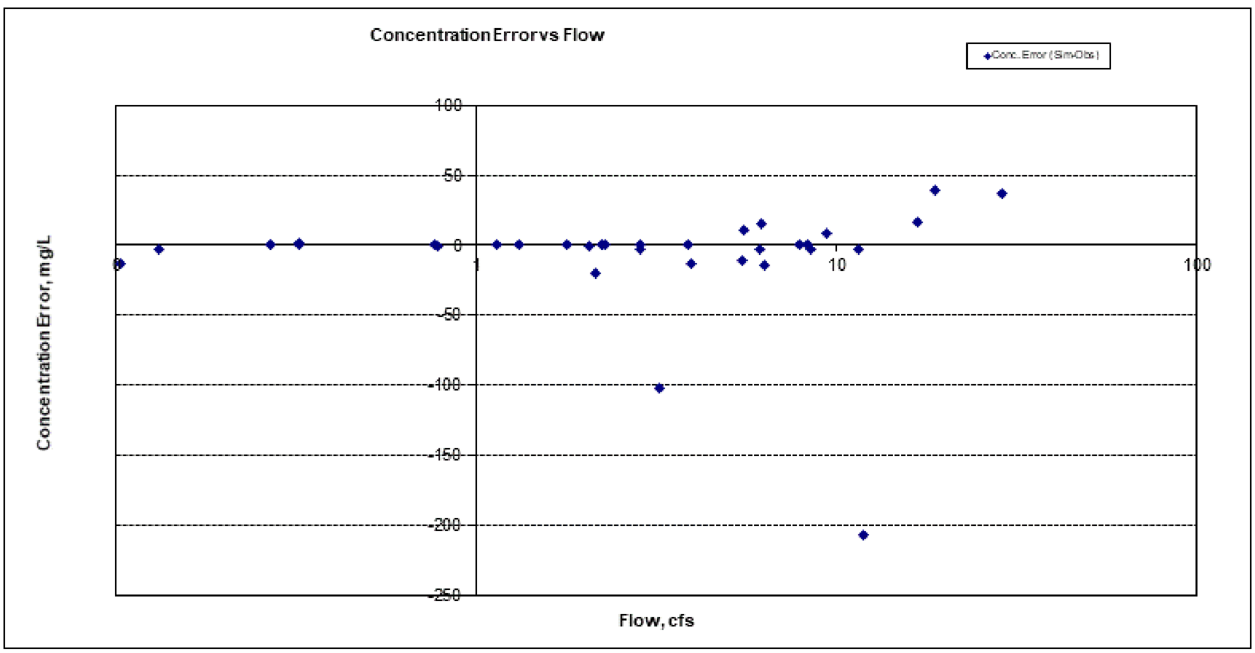


Figure D-216. TSS Concentration Error vs Flow at the Mission Creek at MN-23

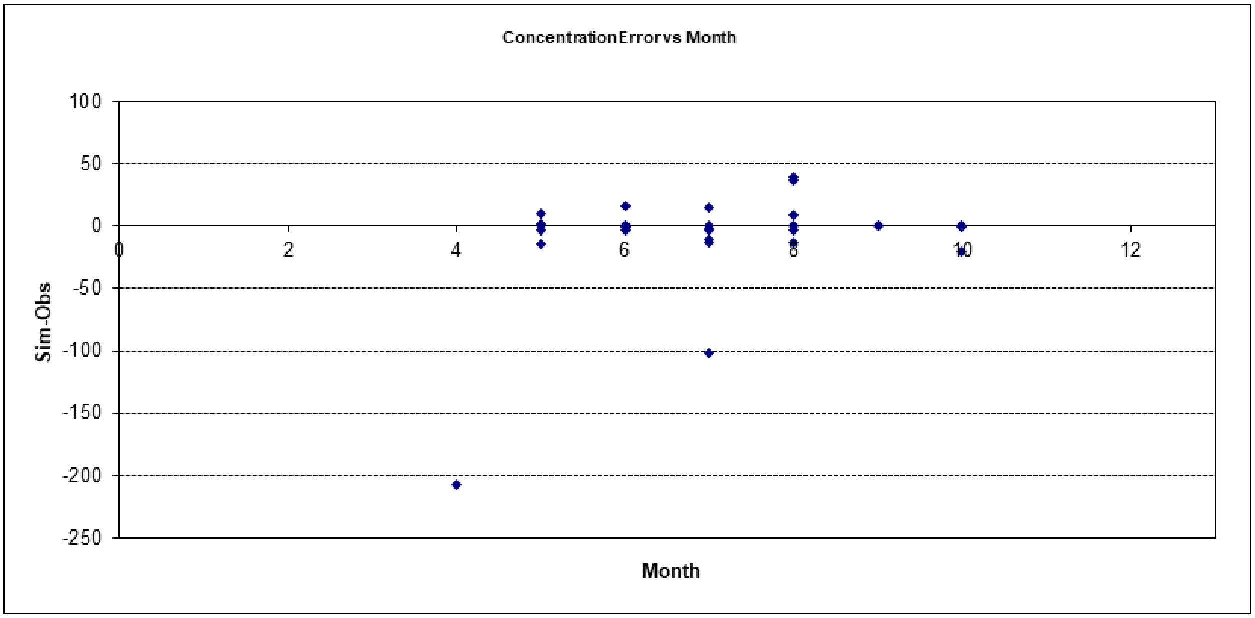


Figure D-217. TSS Concentration Error vs Month at the Mission Creek at MN-23

Appendix E Nutrients and DO Calibration and Validation

E.1 Lester River upstream of Tischer Rd

E.1.1 Ammonia Nitrogen (NH3)

Table E-1. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	42	ND
Concentration Average Error	174.35%	
Concentration Median Error	108.59%	
Load Average Error	138.30%	
Load Median Error	56.07%	
Paired t conc	0.00	
Paired t load	0.04	

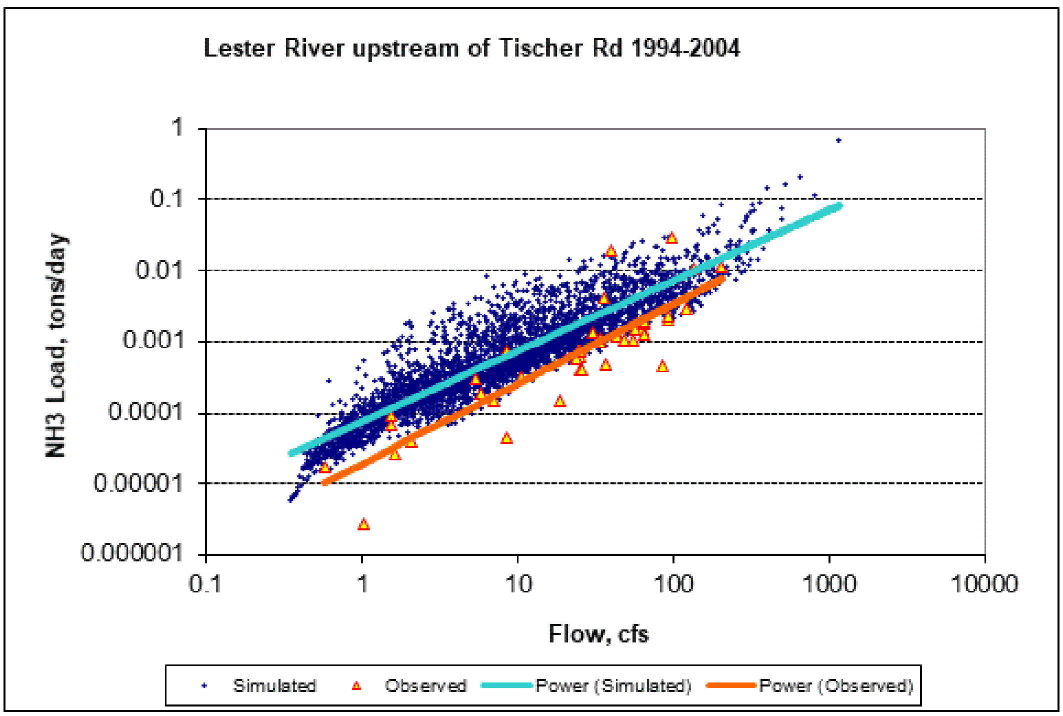


Figure E-1. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Lester River upstream of Tischer Rd (validation period)

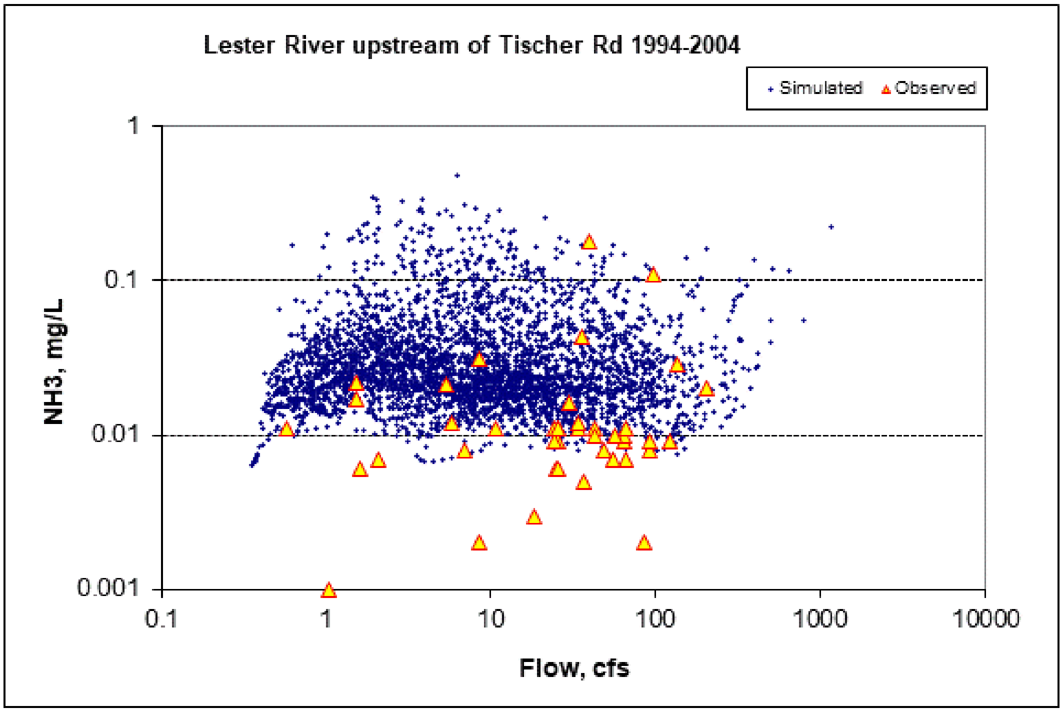
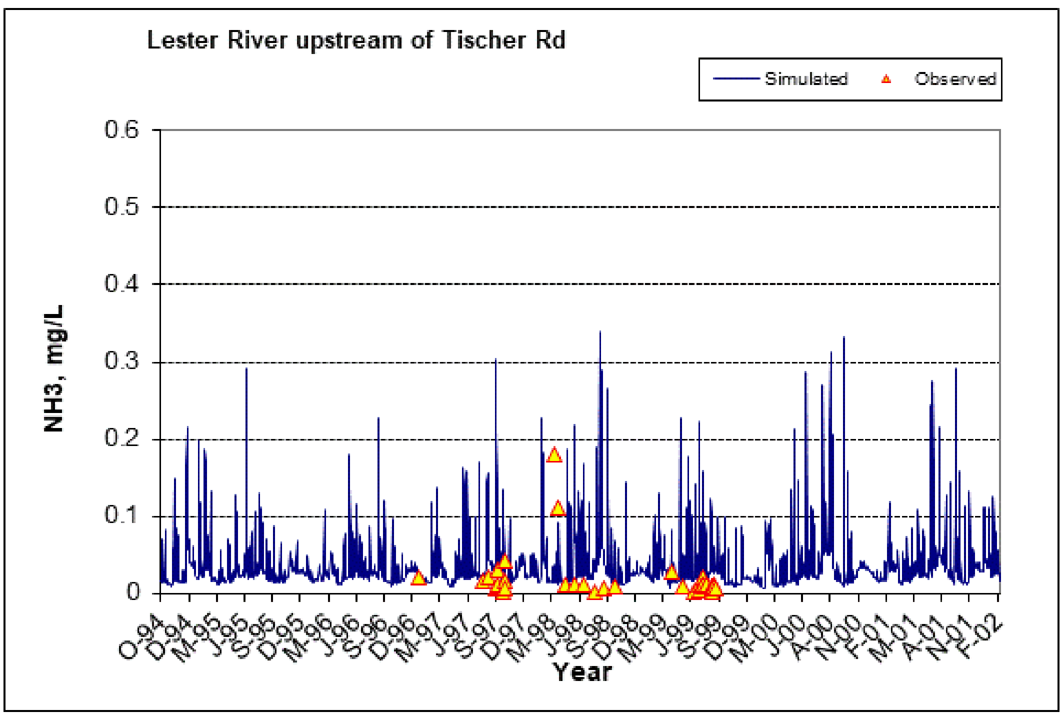


Figure E-2. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Lester River upstream of Tischer Rd (validation period)



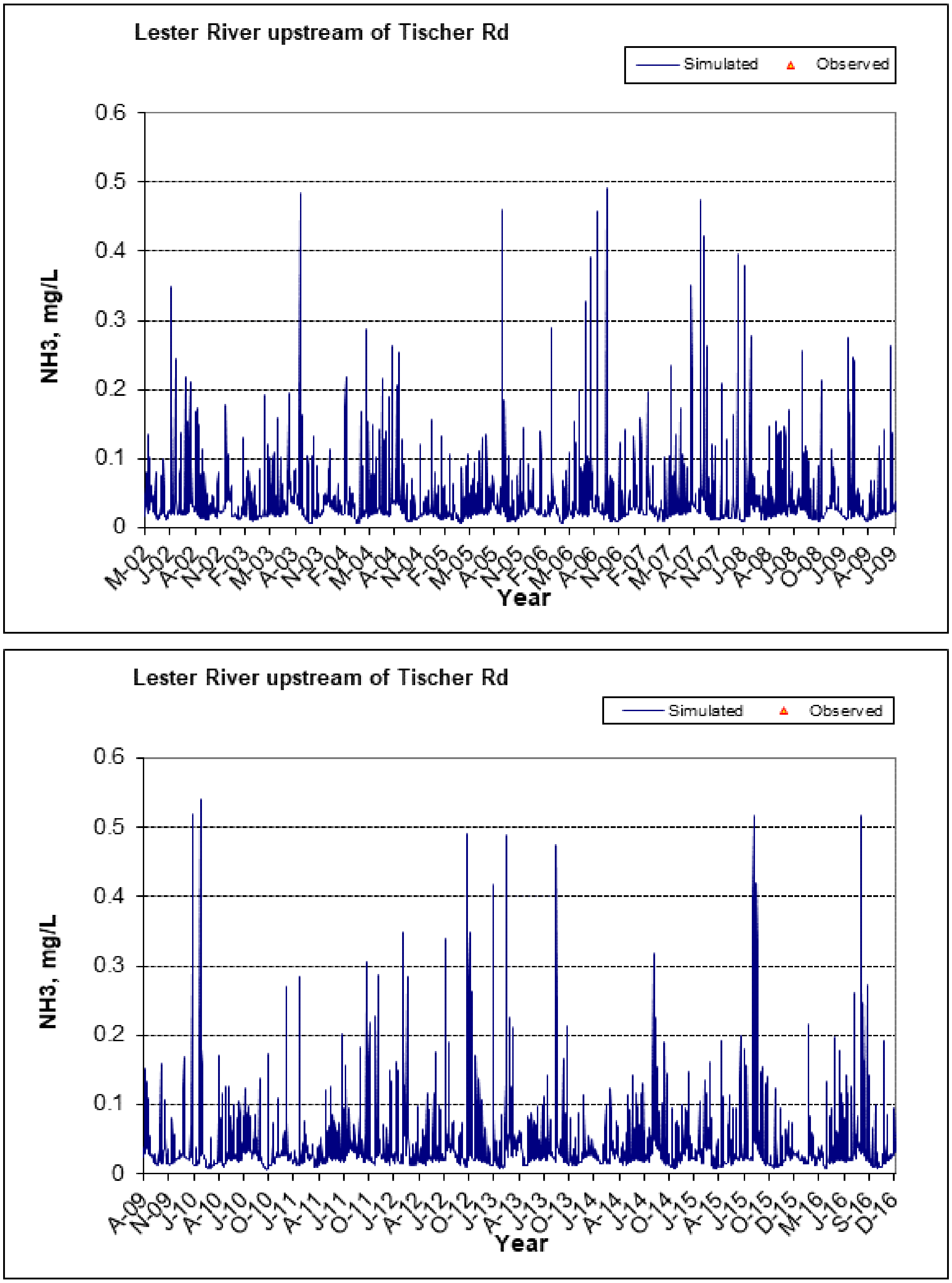


Figure E-3. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Lester River upstream of Tischer Rd

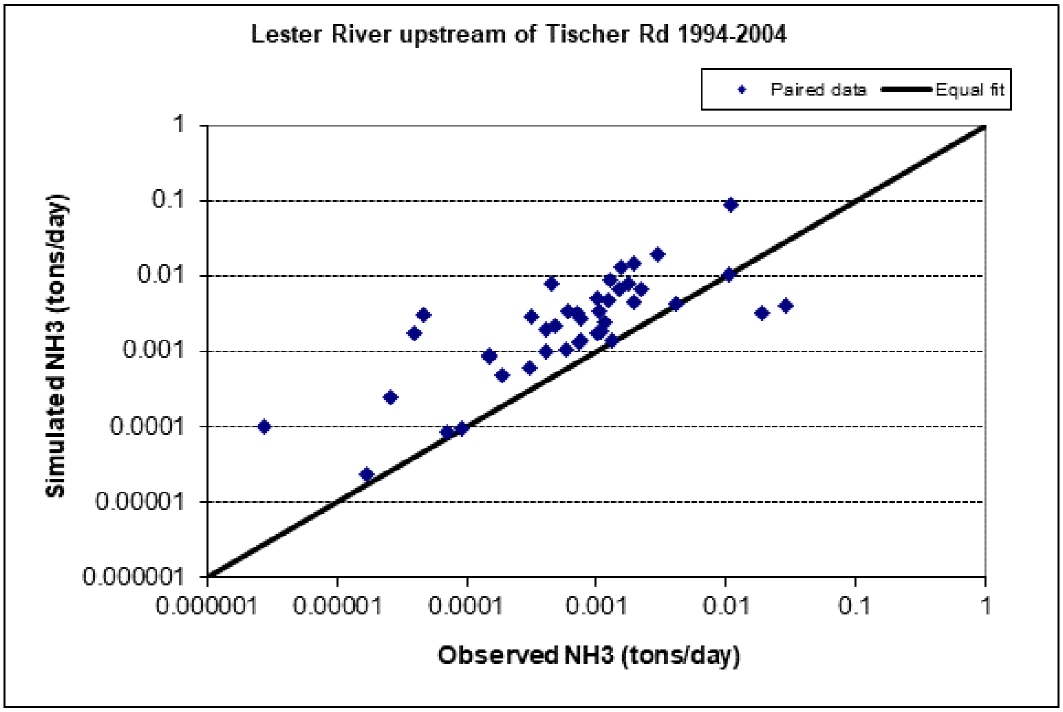


Figure E-4. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Lester River upstream of Tischer Rd (validation period)

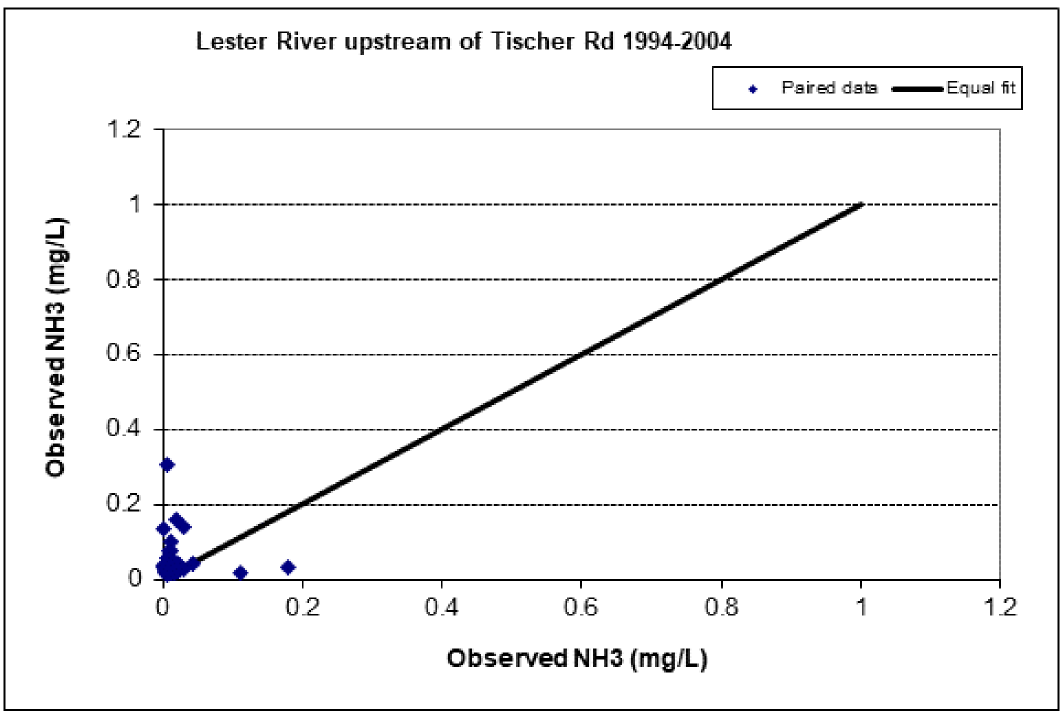


Figure E-5. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Lester River upstream of Tischer Rd (validation period)

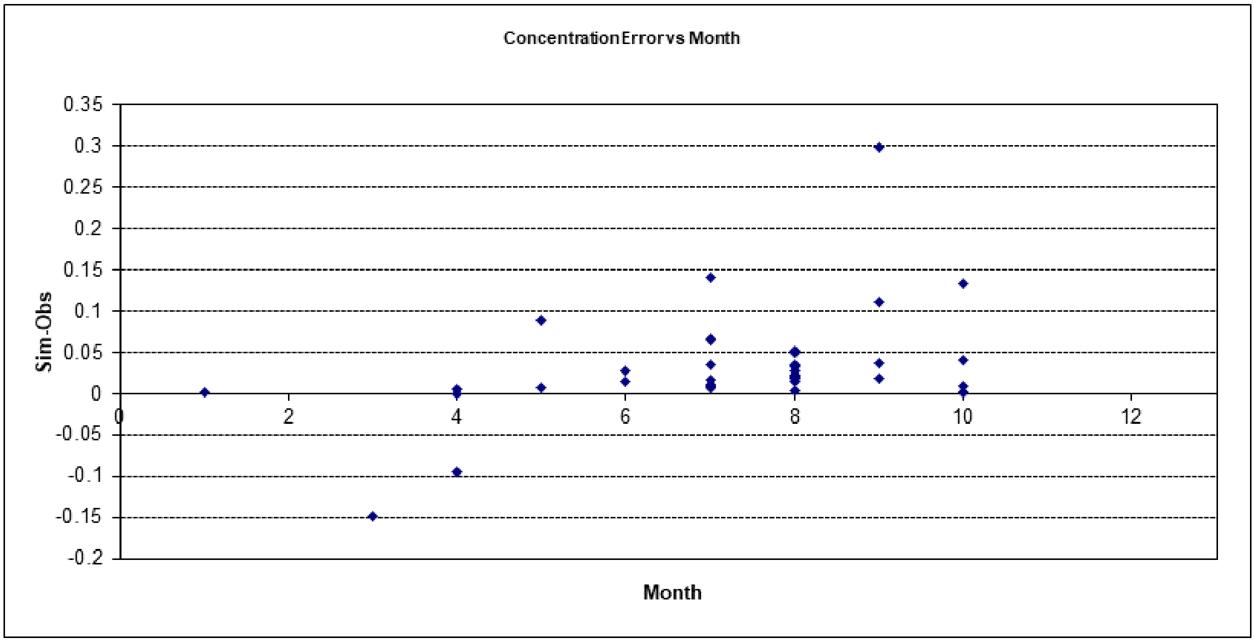


Figure E-6. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Lester River upstream of Tischer Rd

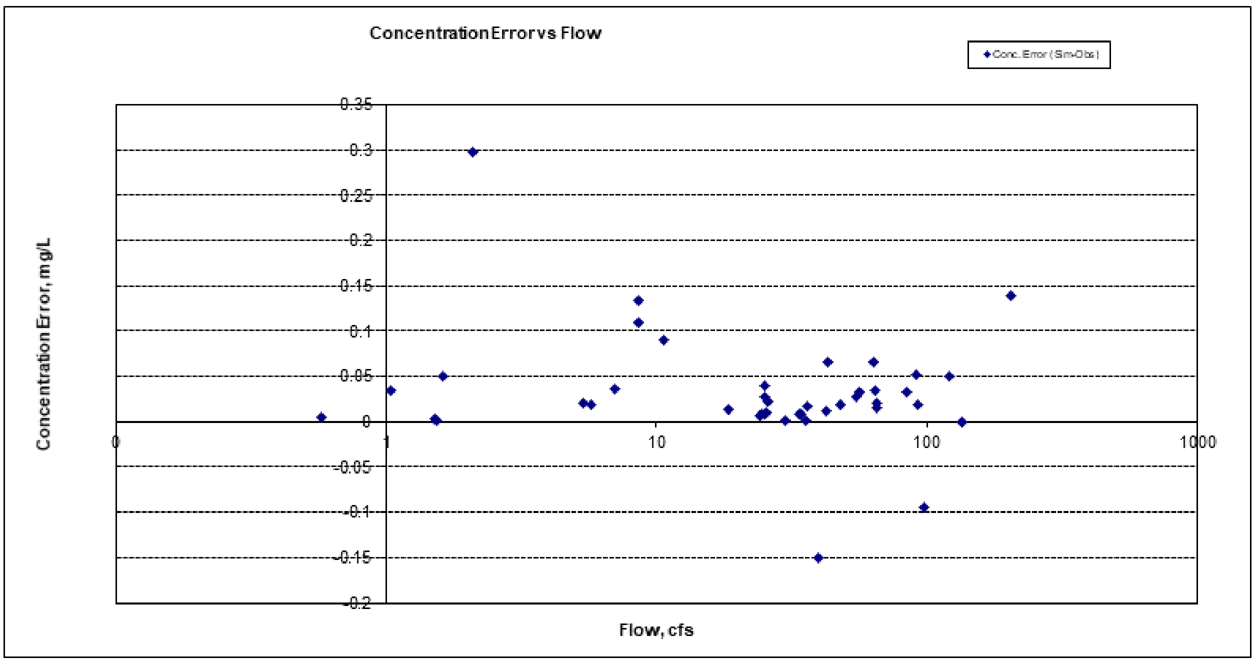


Figure E-7. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Lester River upstream of Tischer Rd

E.1.2 Organic Nitrogen (OrgN)

Table E-2. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	41	ND
Concentration Average Error	-42.98%	
Concentration Median Error	-49.10%	
Load Average Error	-37.39%	
Load Median Error	-33.59%	
Paired t conc	0.00	
Paired t load	0.17	

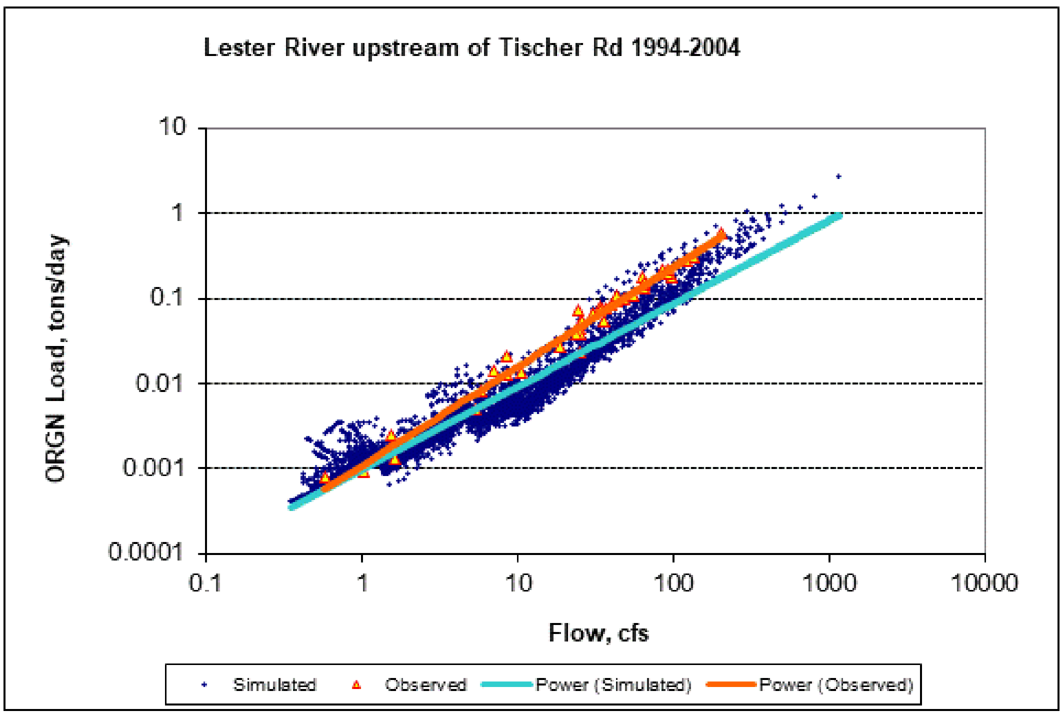


Figure E-8. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Lester River upstream of Tischer Rd (validation period)

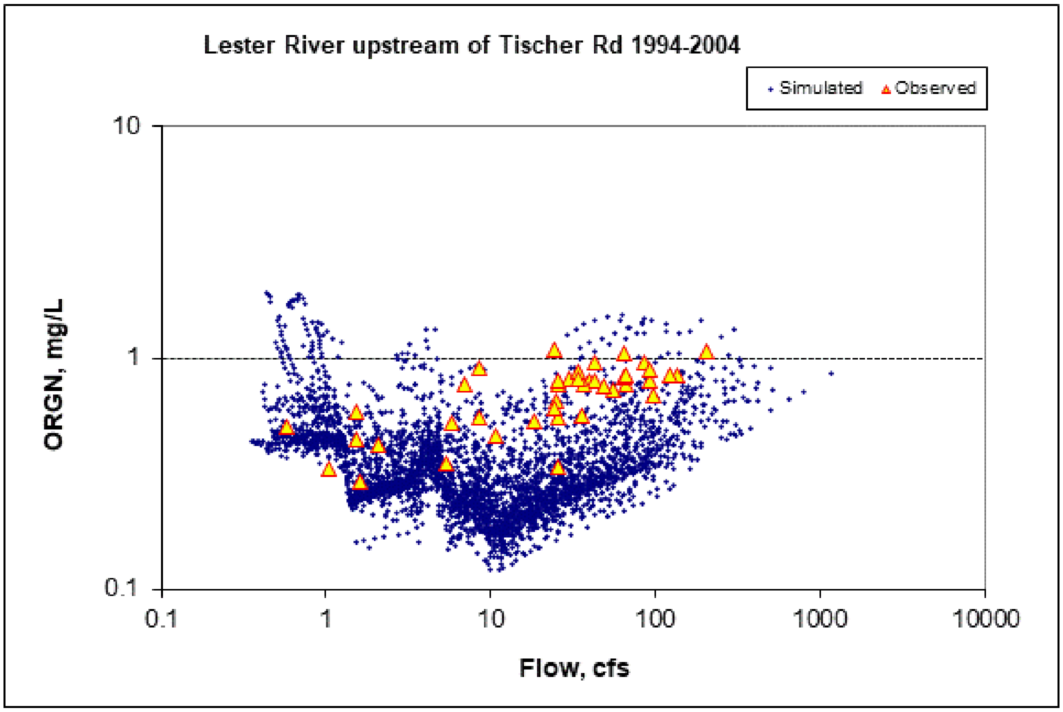
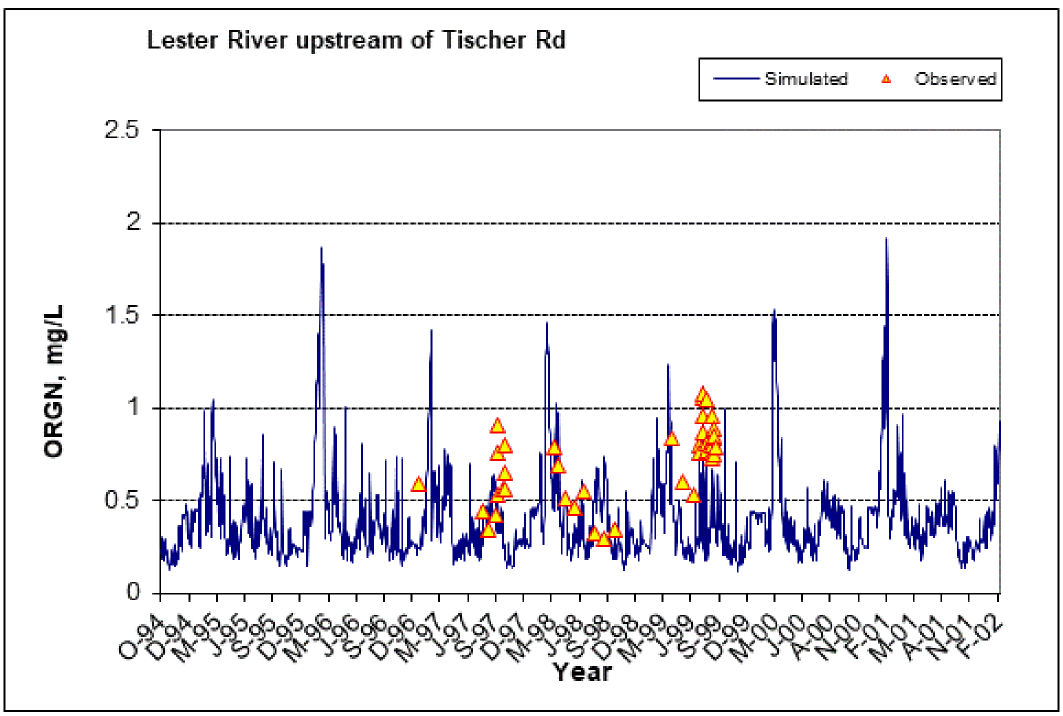


Figure E-9. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Lester River upstream of Tischer Rd (validation period)



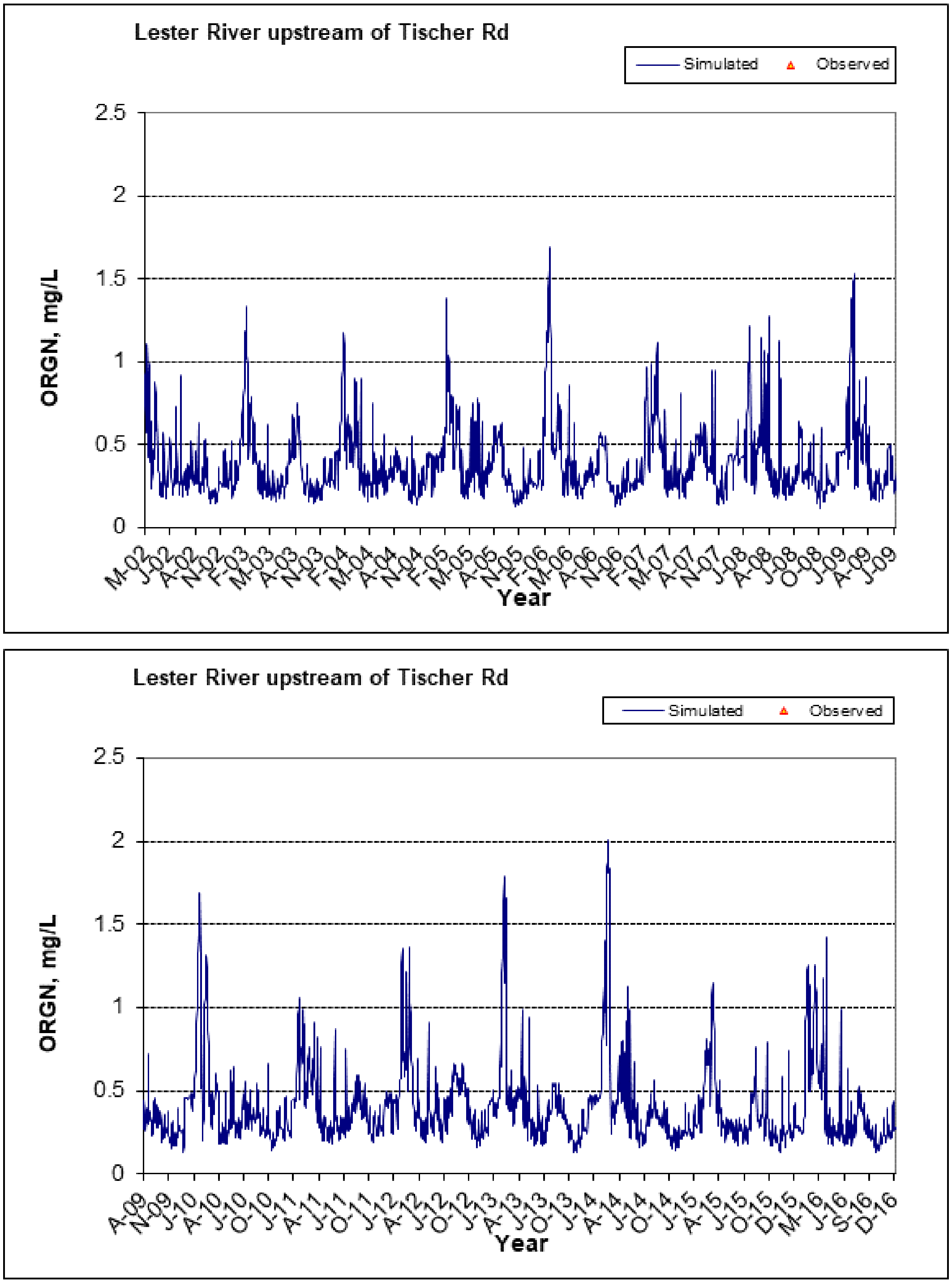


Figure E-10. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Lester River upstream of Tischer Rd

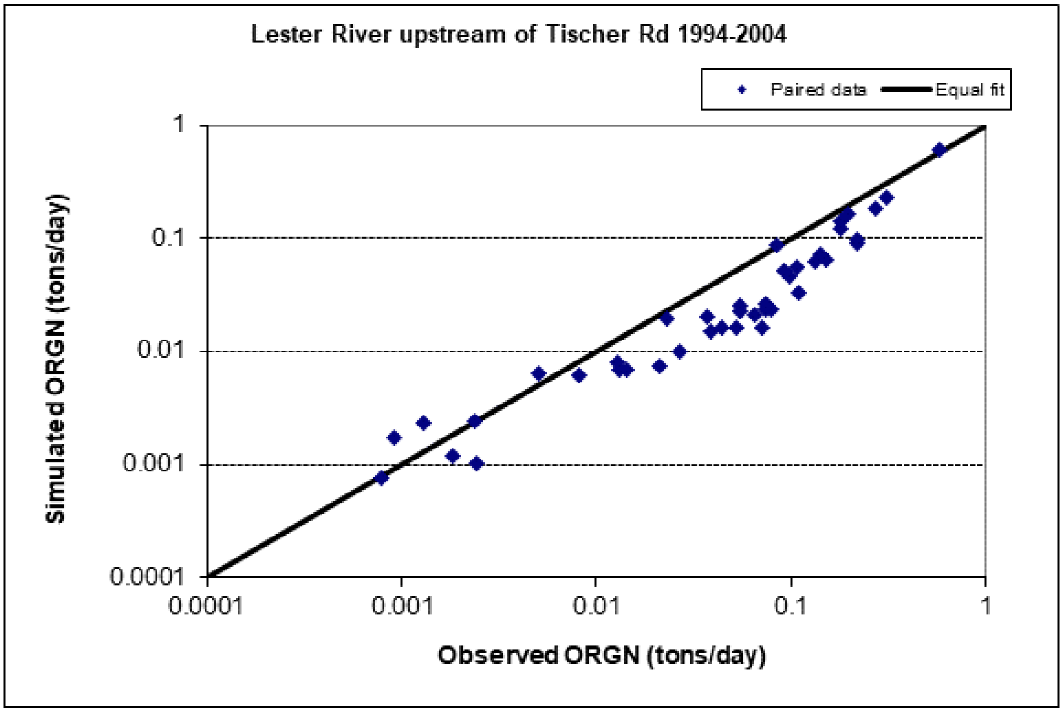


Figure E-11. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Lester River upstream of Tischer Rd (validation period)

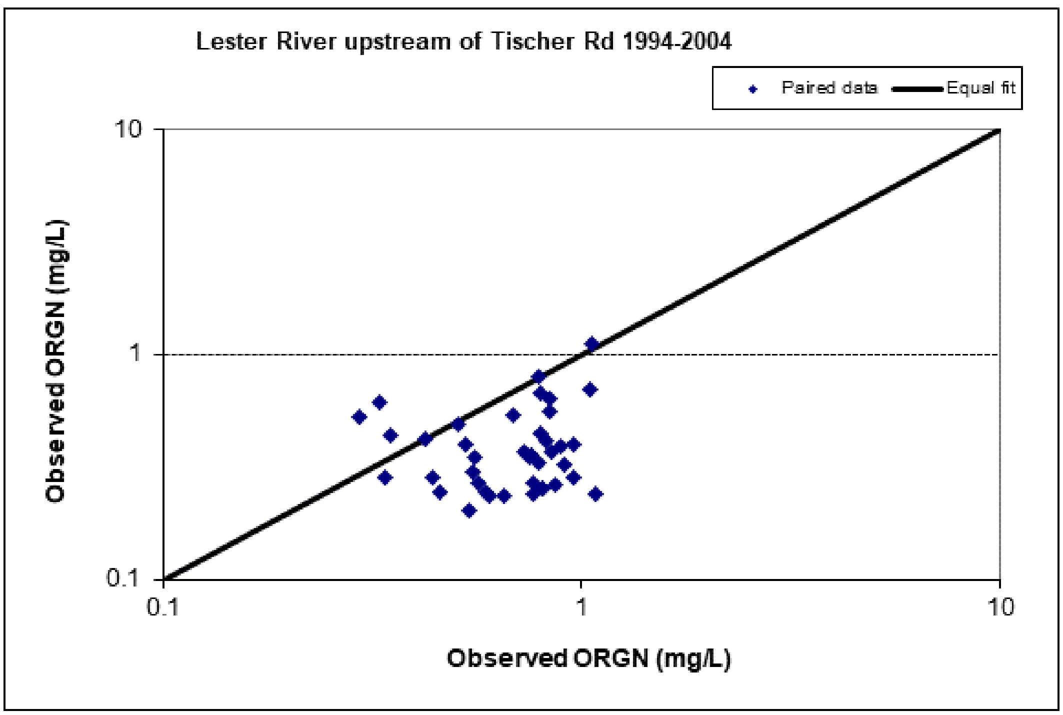


Figure E-12. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Lester River upstream of Tischer Rd (validation period)

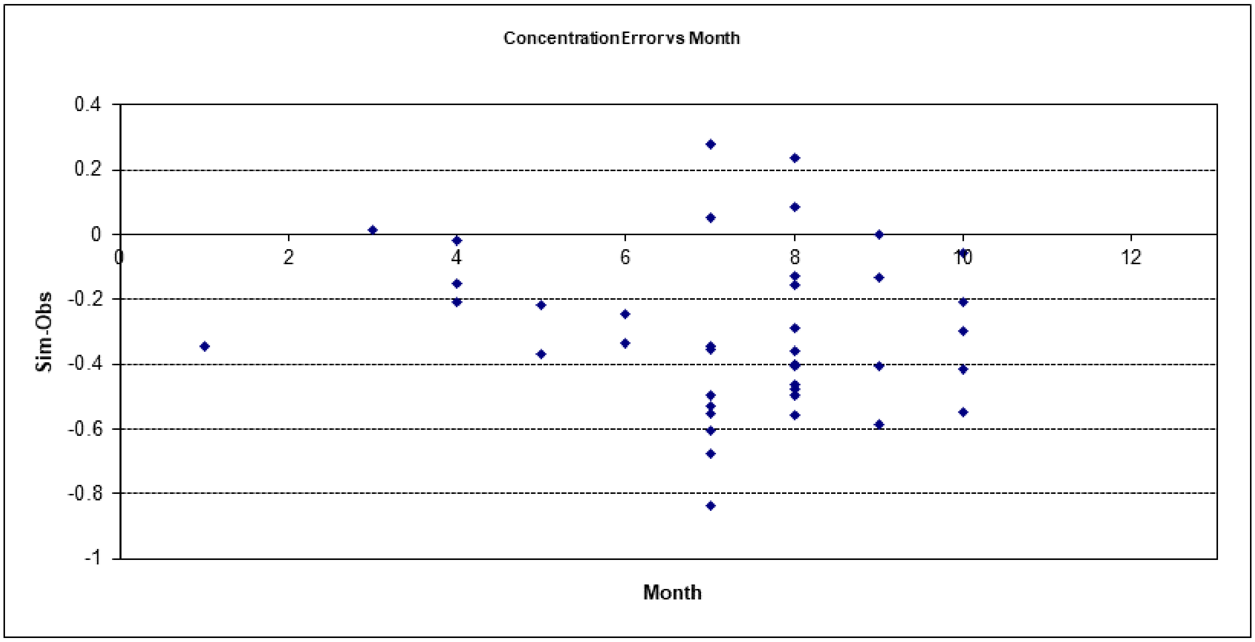


Figure E-13. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at Lester River upstream of Tischer Rd

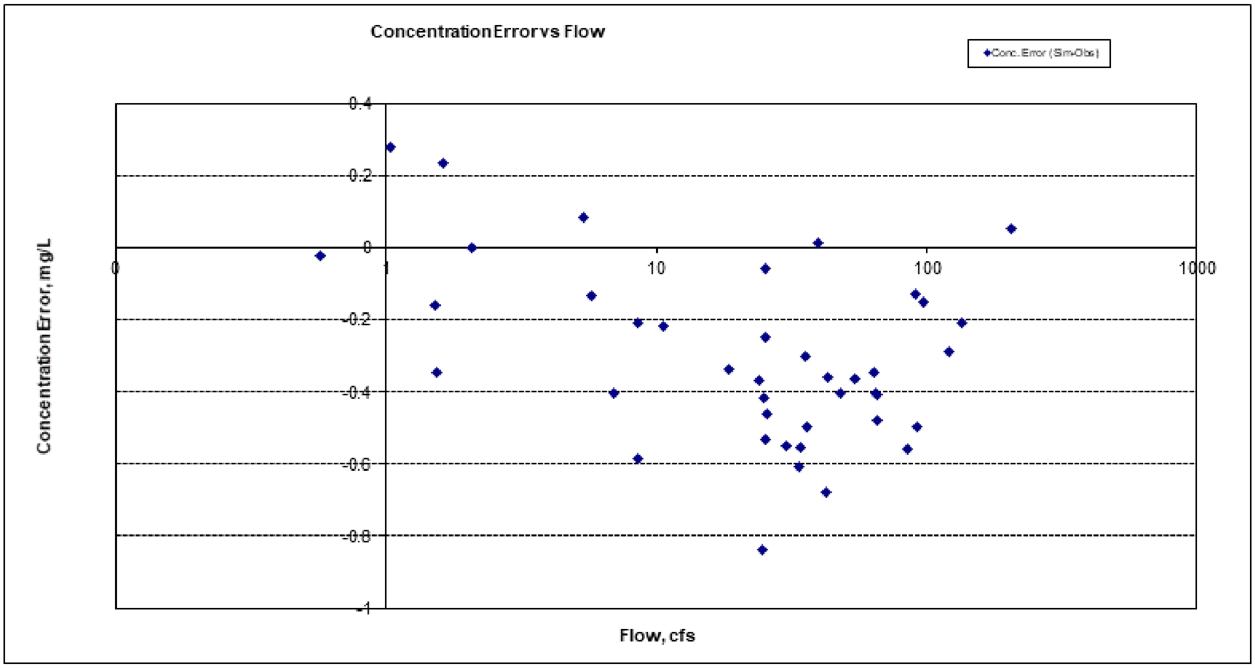


Figure E-14. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at Lester River upstream of Tischer Rd

E.1.3 Total Kjeldahl Nitrogen (TKN)

Table E-3. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	41	ND
Concentration Average Error	-37.59%	
Concentration Median Error	-44.30%	
Load Average Error	-32.90%	
Load Median Error	-29.63%	
Paired t conc	0.00	
Paired t load	0.25	

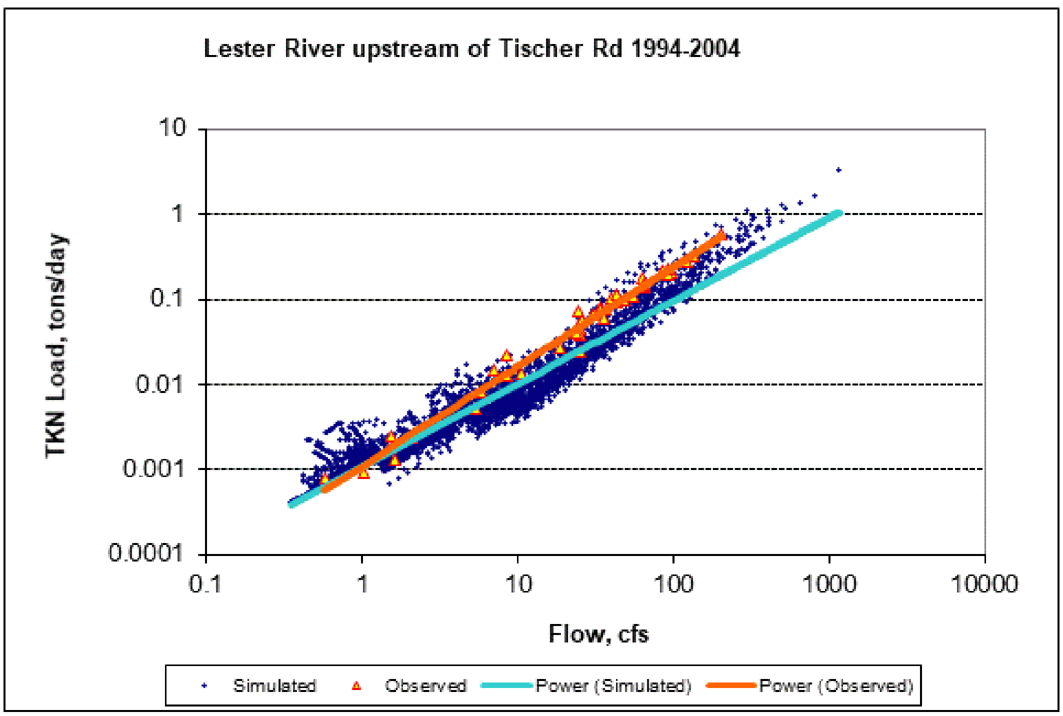


Figure E-15. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Lester River upstream of Tischer Rd (validation period)

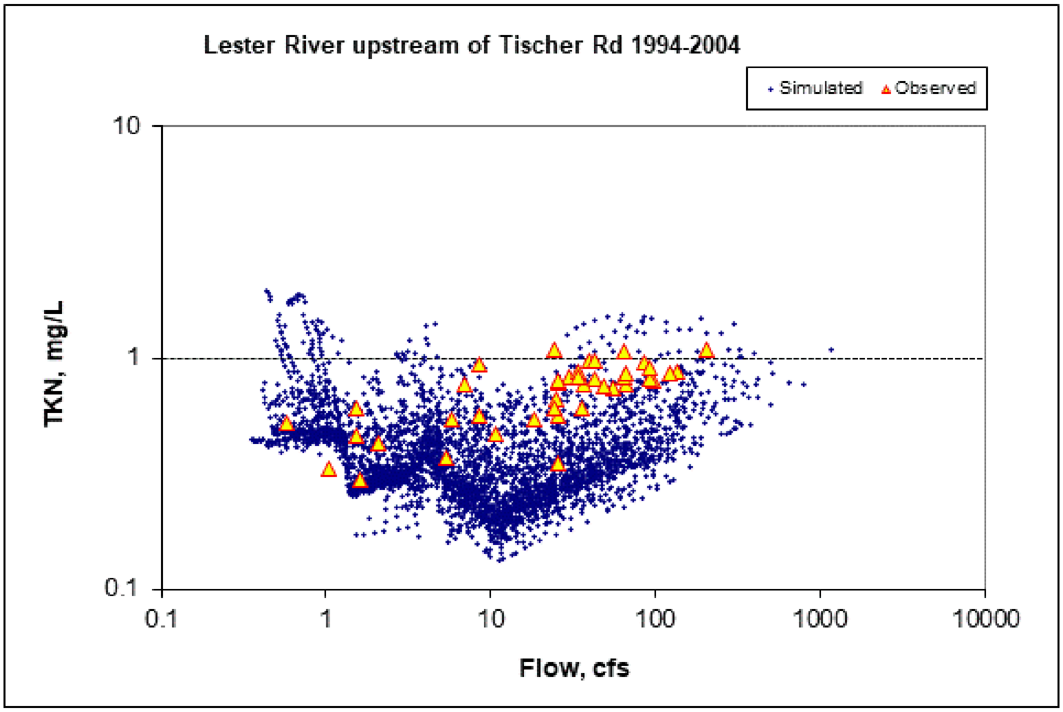
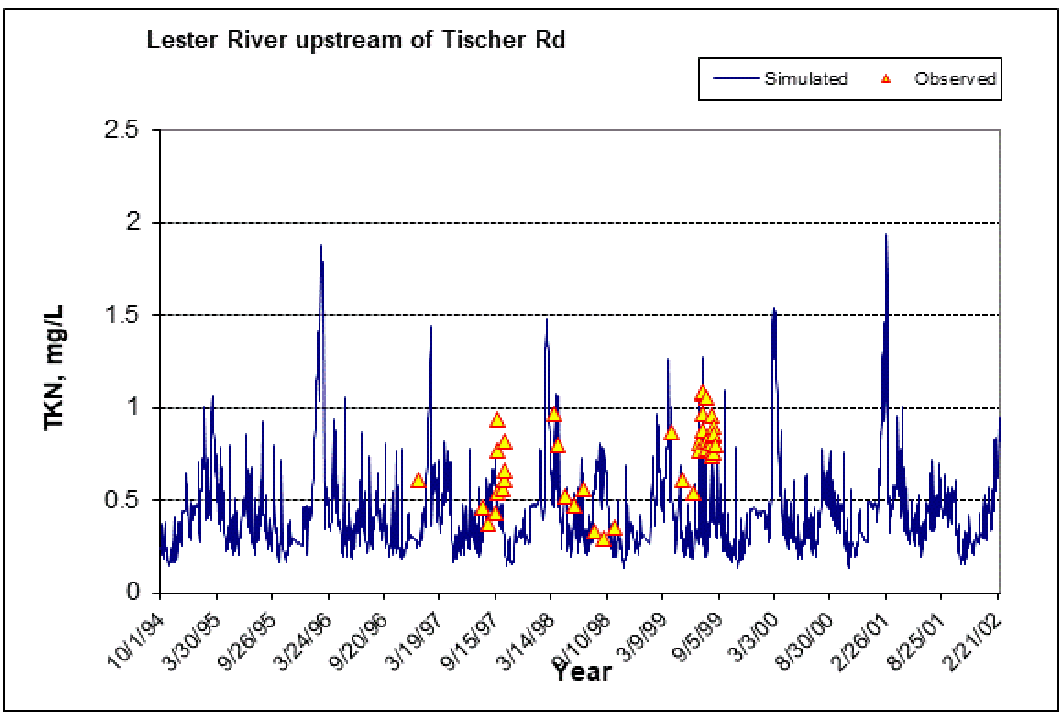
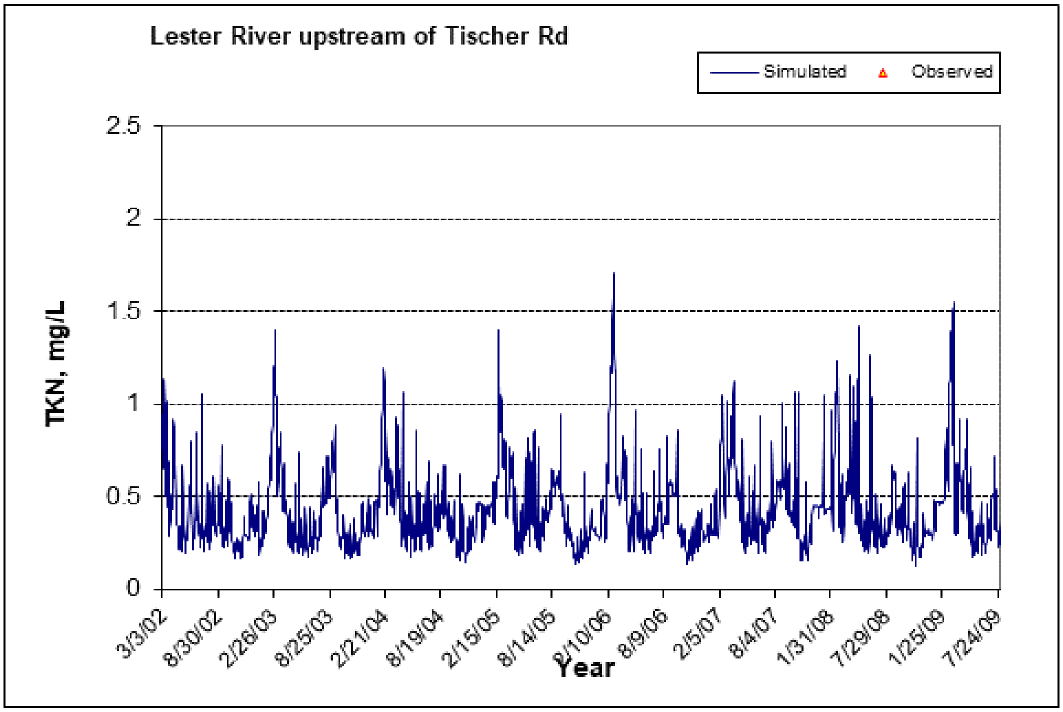


Figure E-16. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Lester River upstream of Tischer Rd (validation period)





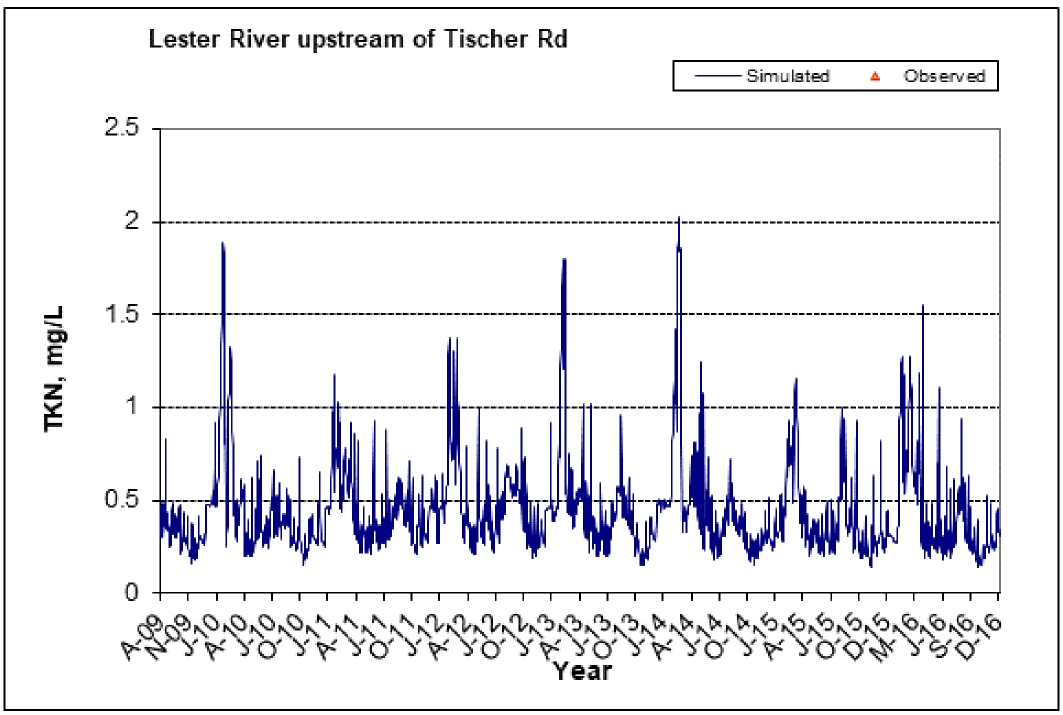


Figure E-17. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Lester River upstream of Tischer Rd

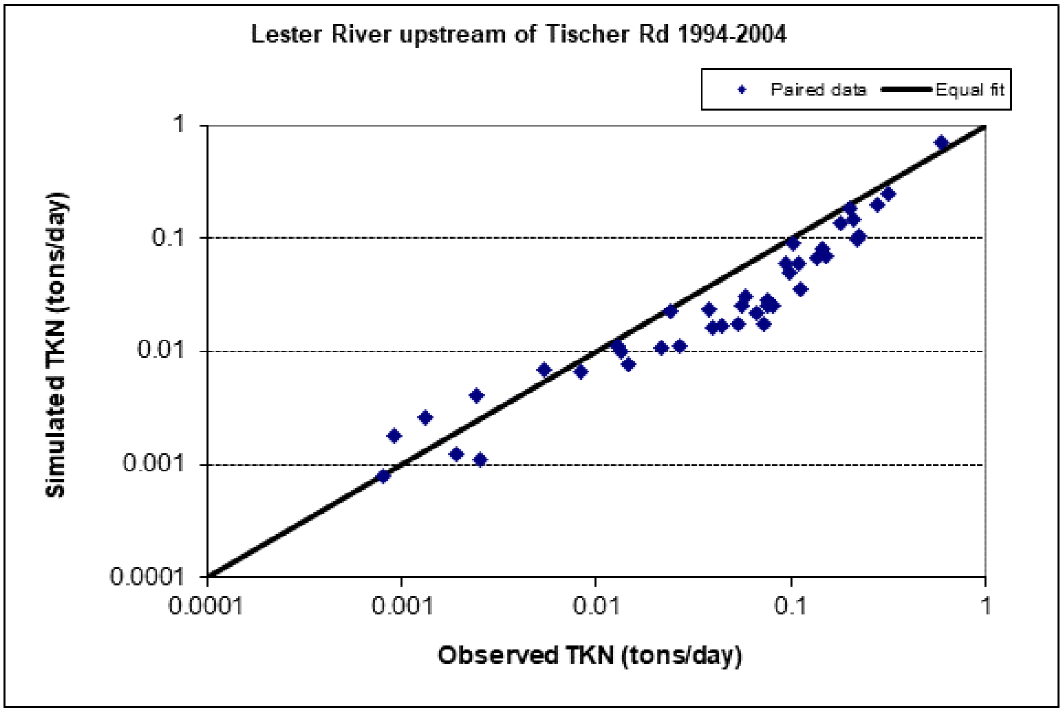


Figure E-18. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Lester River upstream of Tischer Rd (validation period)

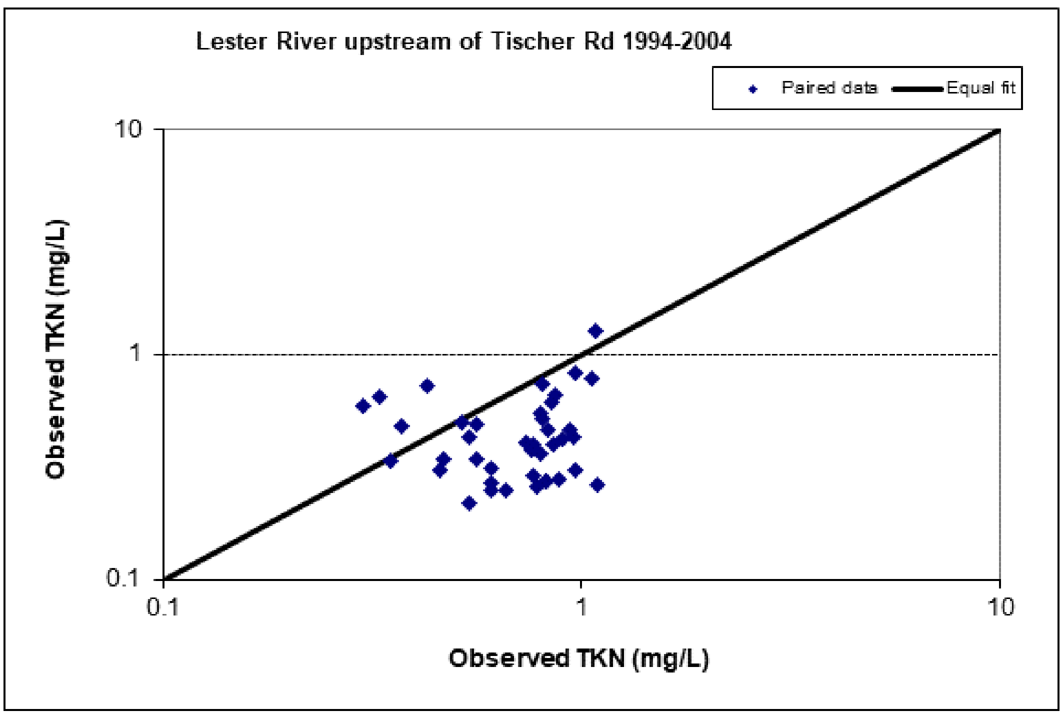


Figure E-19. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Lester River upstream of Tischer Rd (validation period)

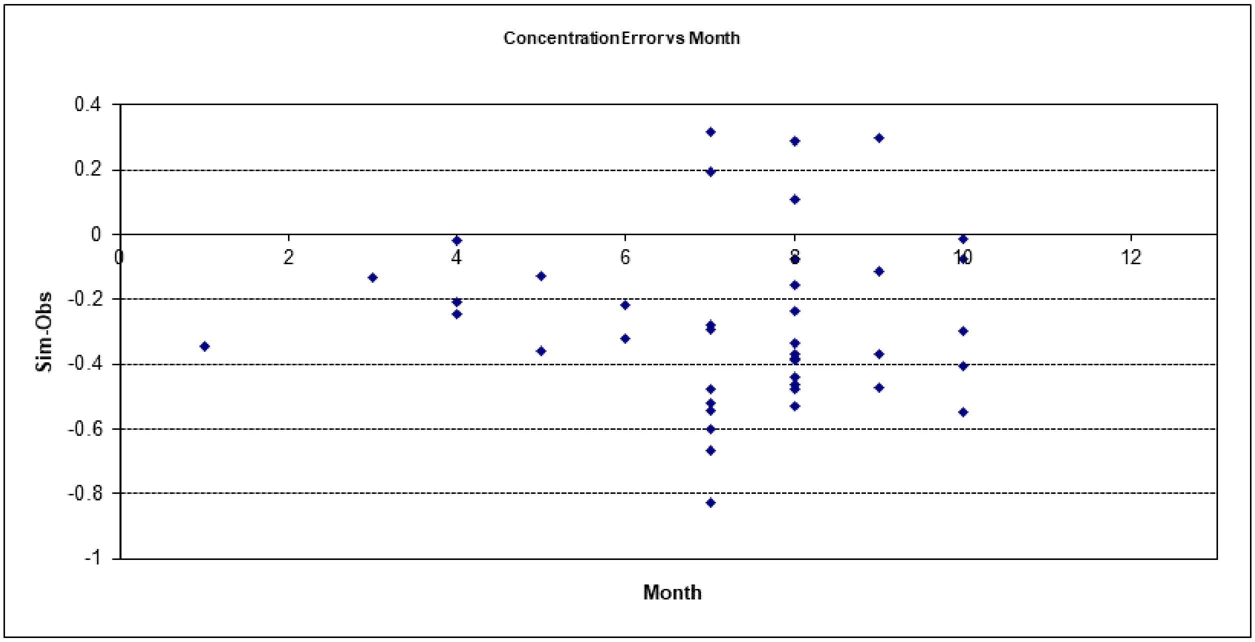


Figure E-20. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at Lester River upstream of Tischer Rd

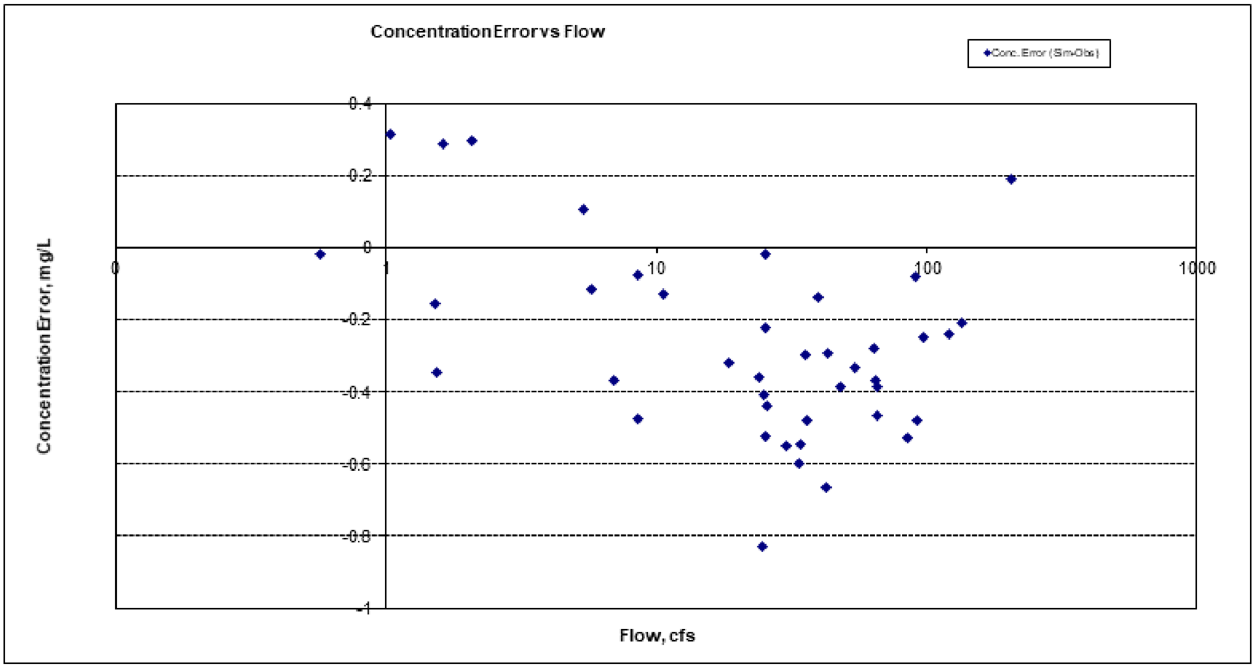


Figure E-21. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at Lester River upstream of Tischer Rd

E.1.4 Nitrite+ Nitrate Nitrogen (NOx)

Table E-4. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	42	ND
Concentration Average Error	93.85%	
Concentration Median Error	26.83%	
Load Average Error	34.74%	
Load Median Error	3.20%	
Paired t conc	0.02	
Paired t load	0.36	

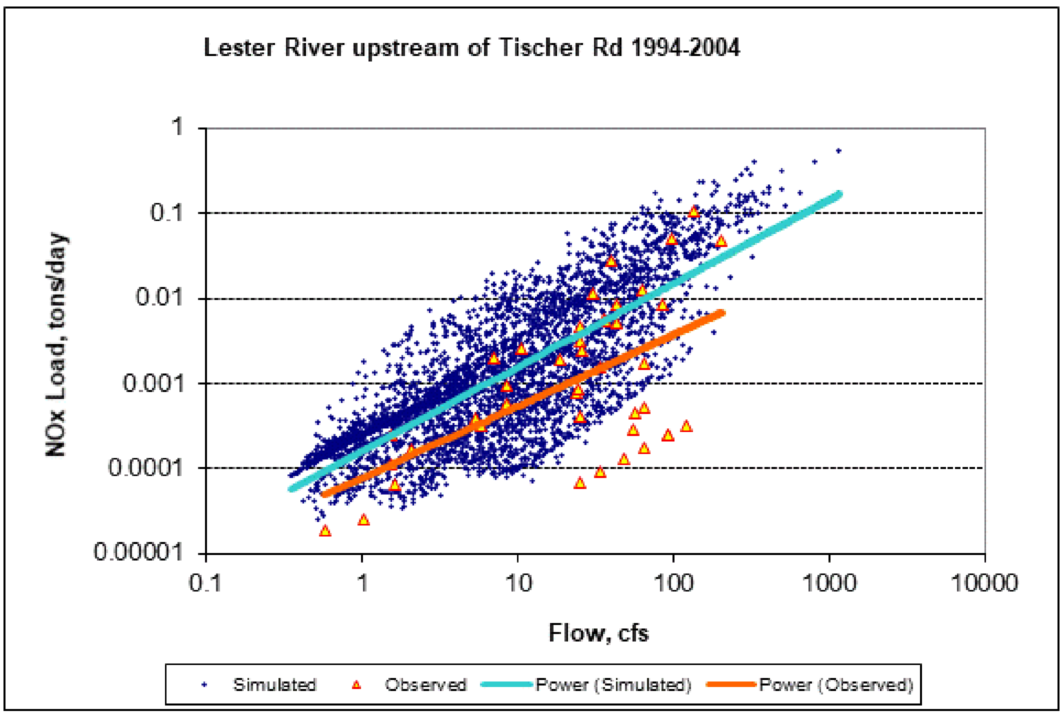


Figure E-22. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Lester River upstream of Tischer Rd (validation period)

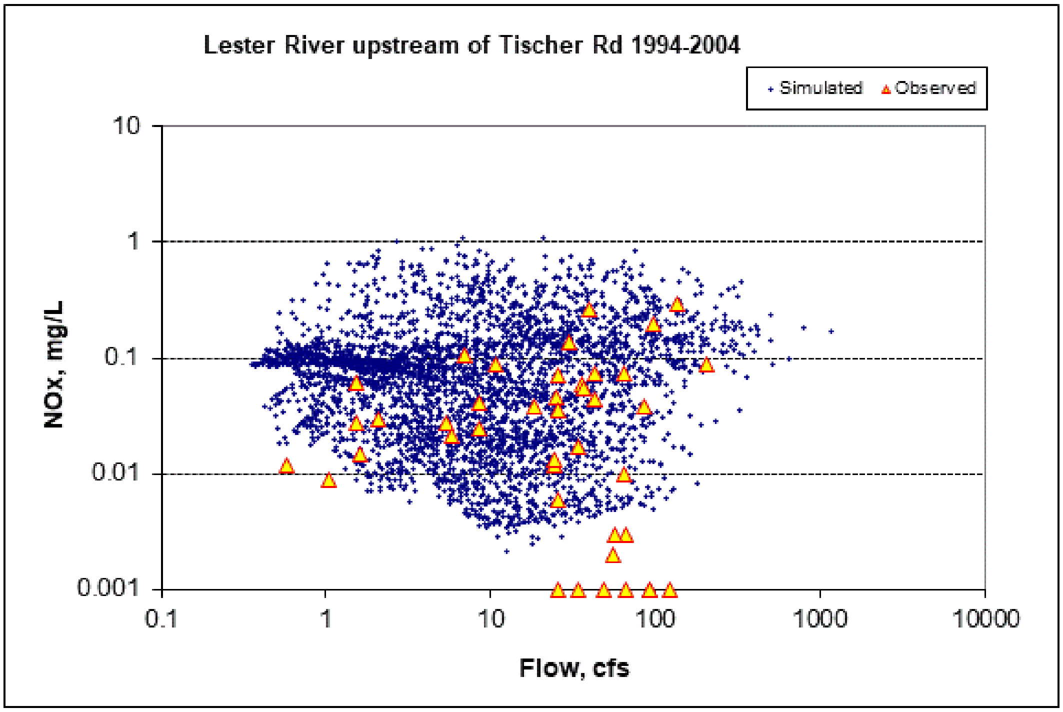
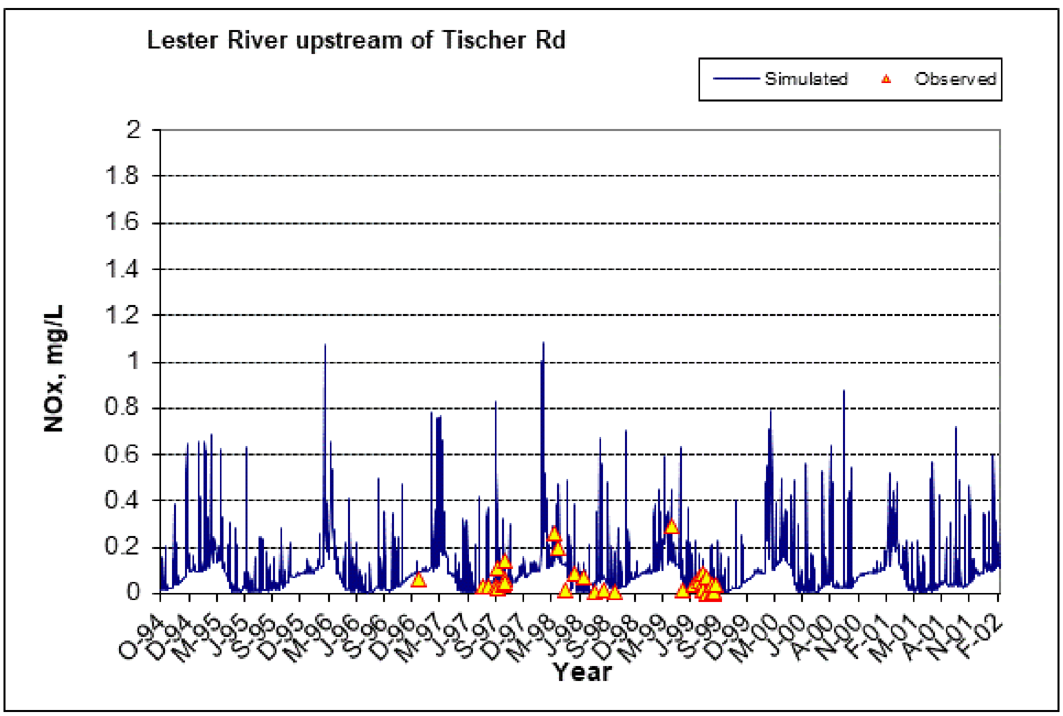
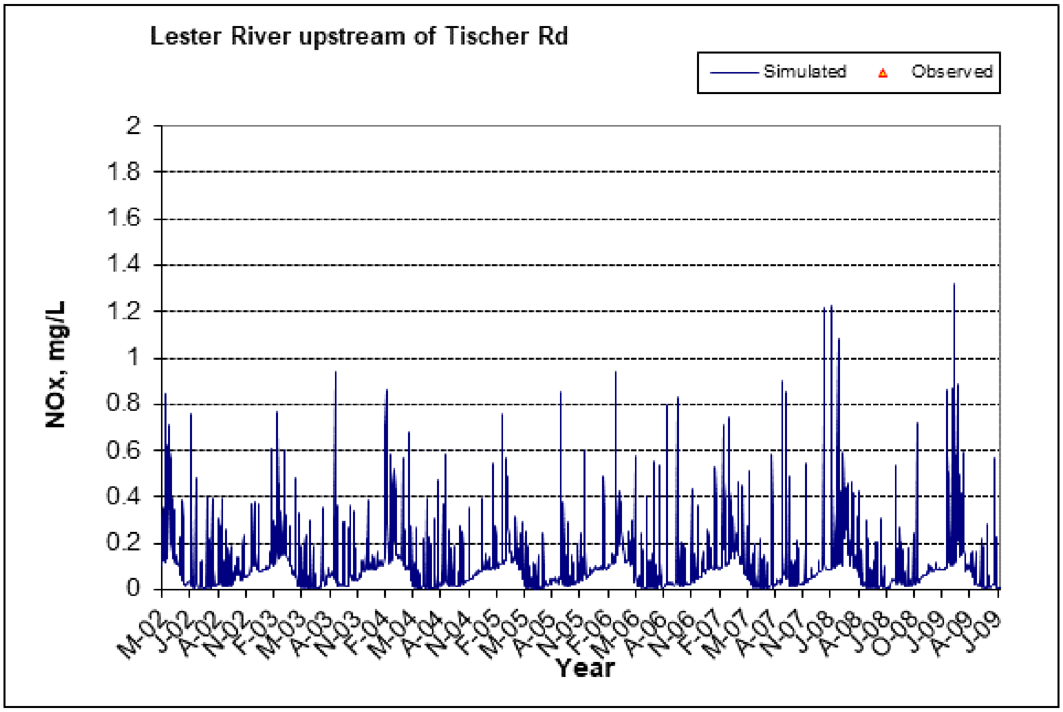


Figure E-23. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Lester River upstream of Tischer Rd (validation period)





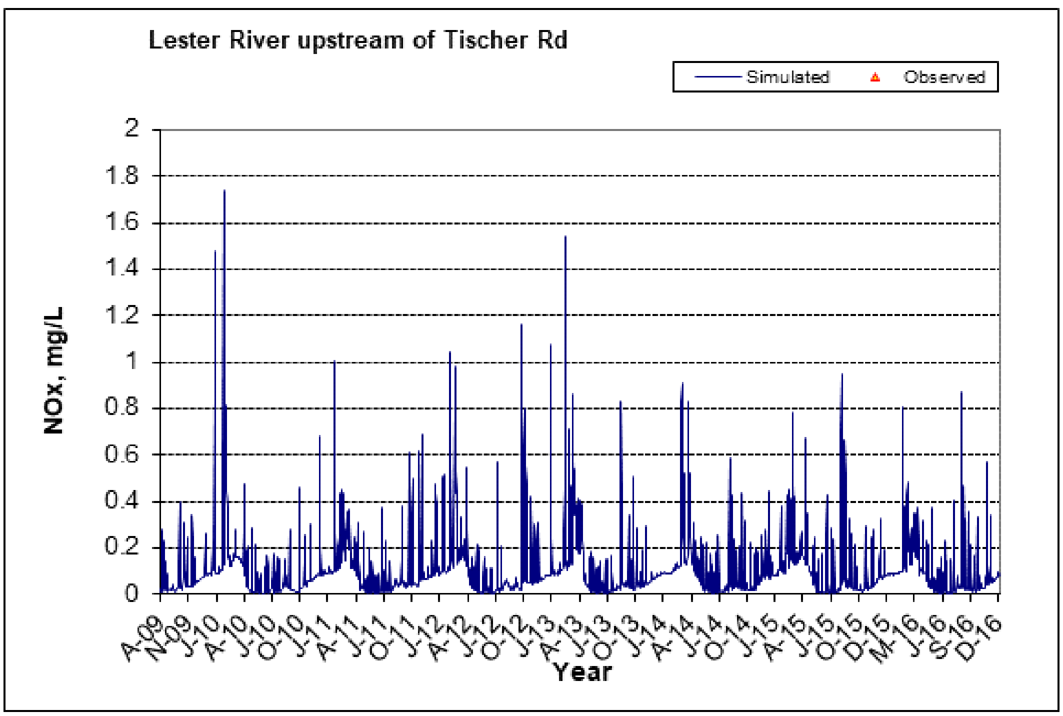


Figure E-24. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Lester River upstream of Tischer Rd

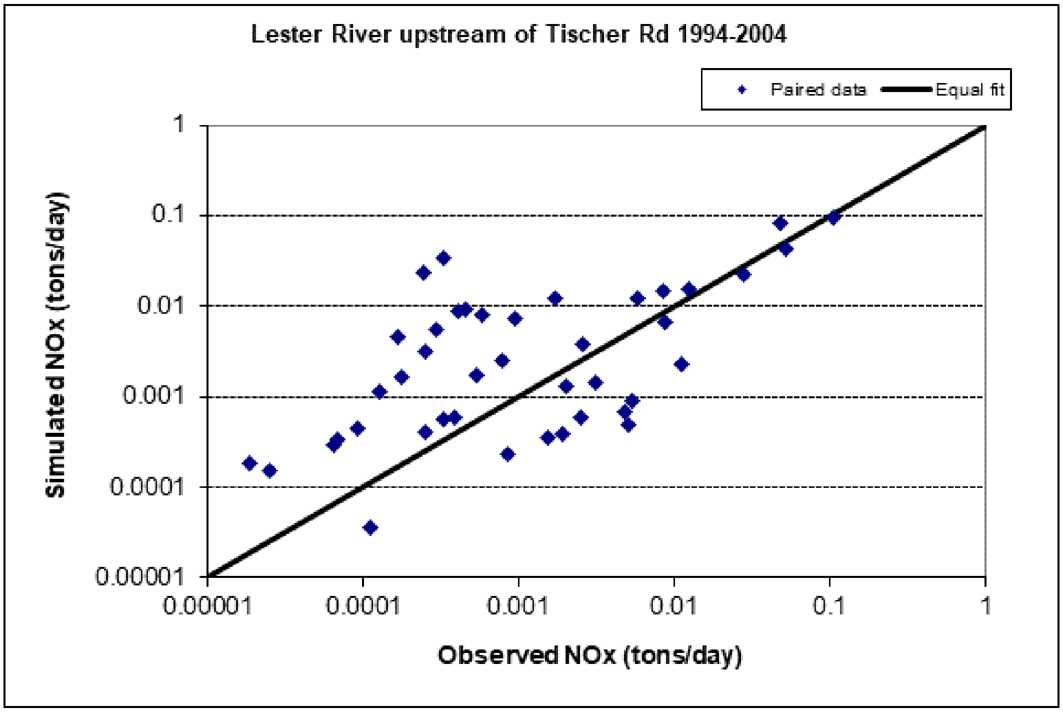


Figure E-25. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Lester River upstream of Tischer Rd (validation period)

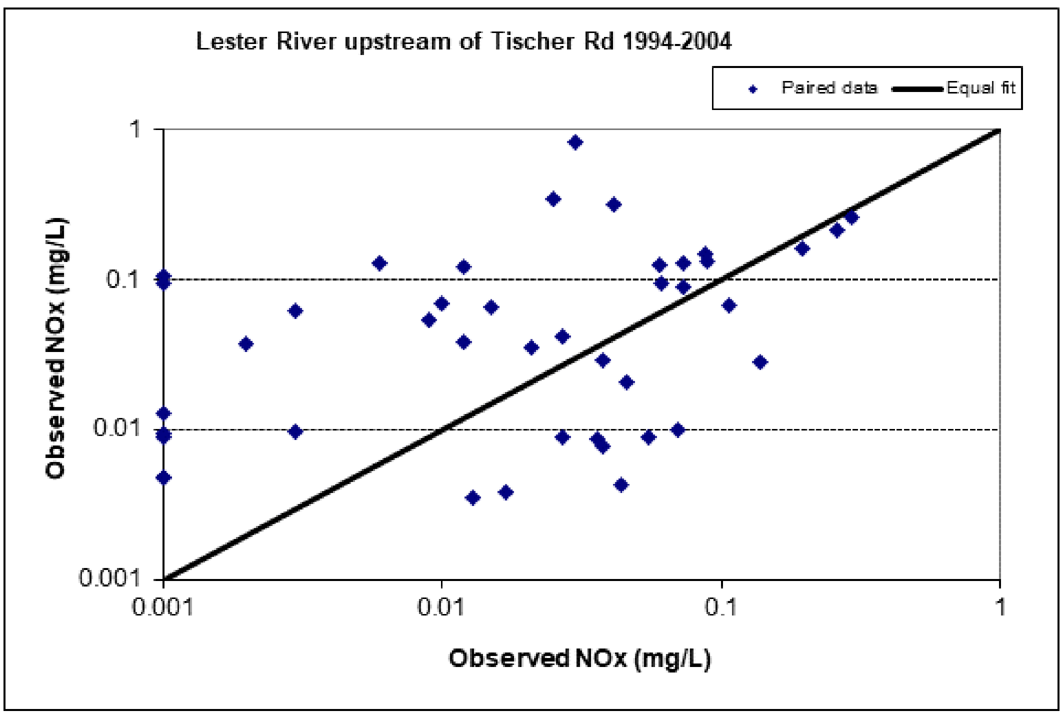


Figure E-26. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Lester River upstream of Tischer Rd (validation period)

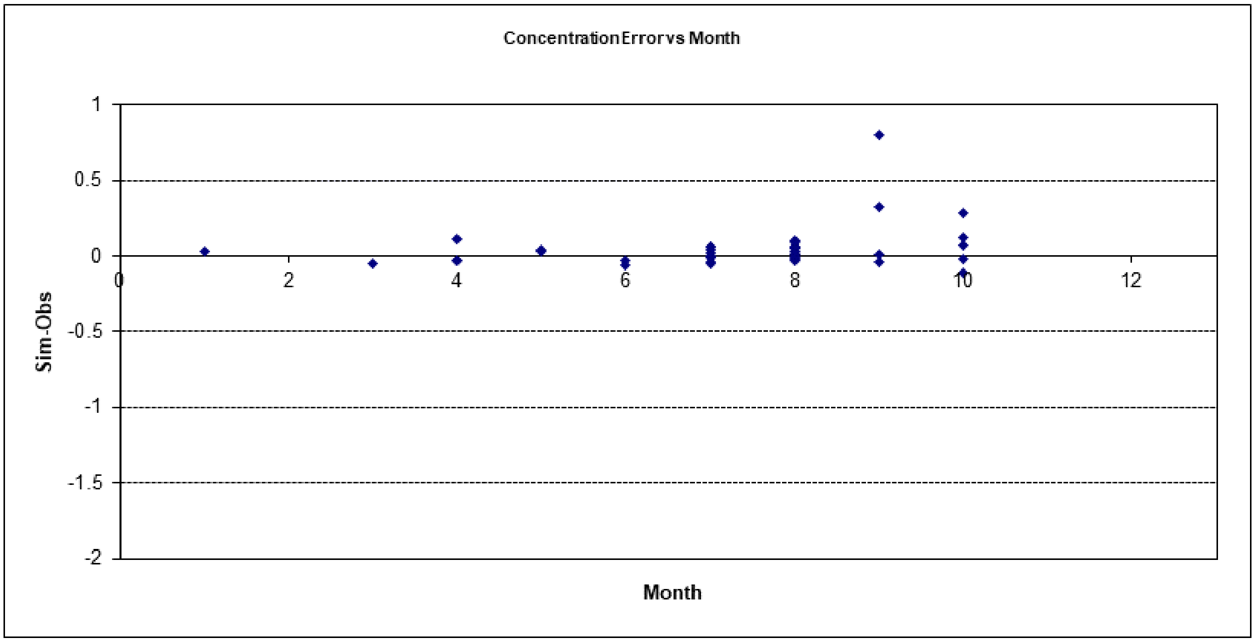


Figure E-27. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Lester River upstream of Tischer Rd

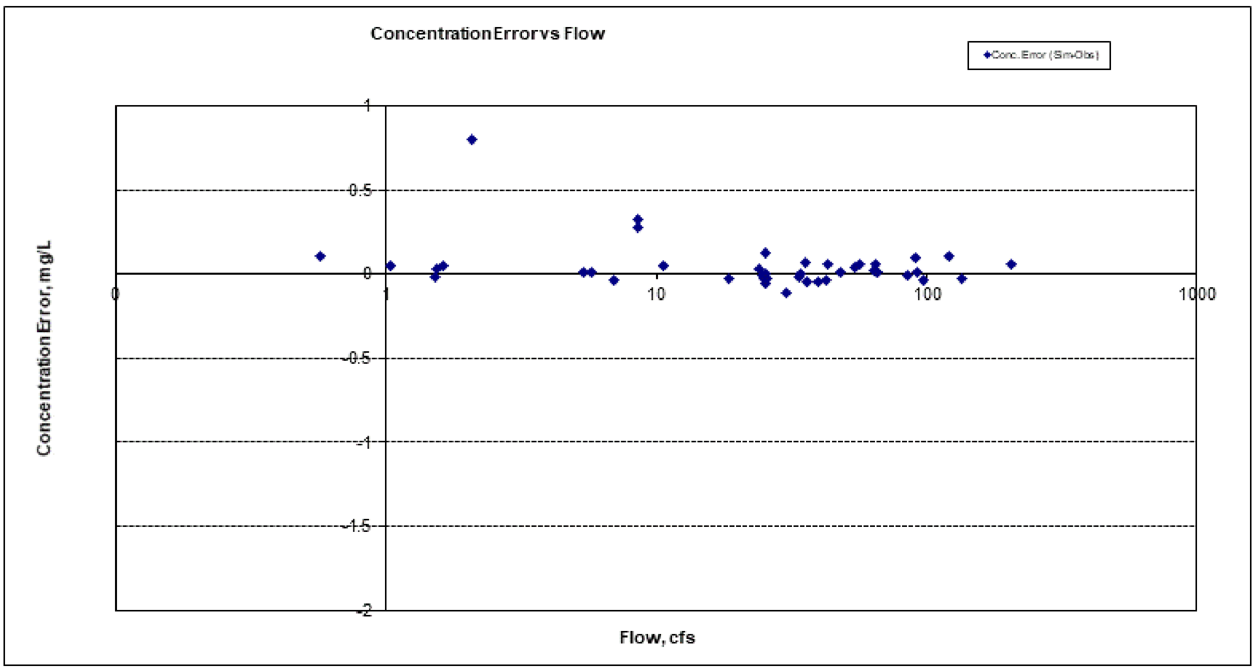


Figure E-28. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Lester River upstream of Tischer Rd

E.1.5 Total Nitrogen (TN)

Table E-5. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	41	ND
Concentration Average Error	-29.30%	
Concentration Median Error	-36.43%	
Load Average Error	-28.08%	
Load Median Error	-26.08%	
Paired t conc	0.05	
Paired t load	0.34	

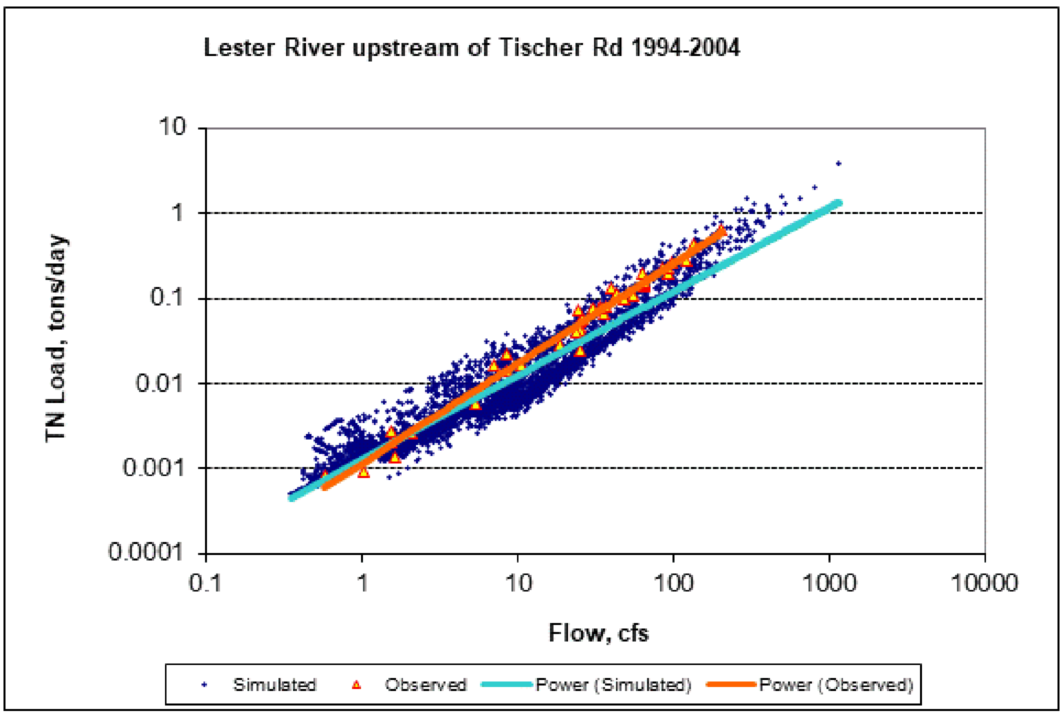


Figure E-29. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Lester River upstream of Tischer Rd (validation period)

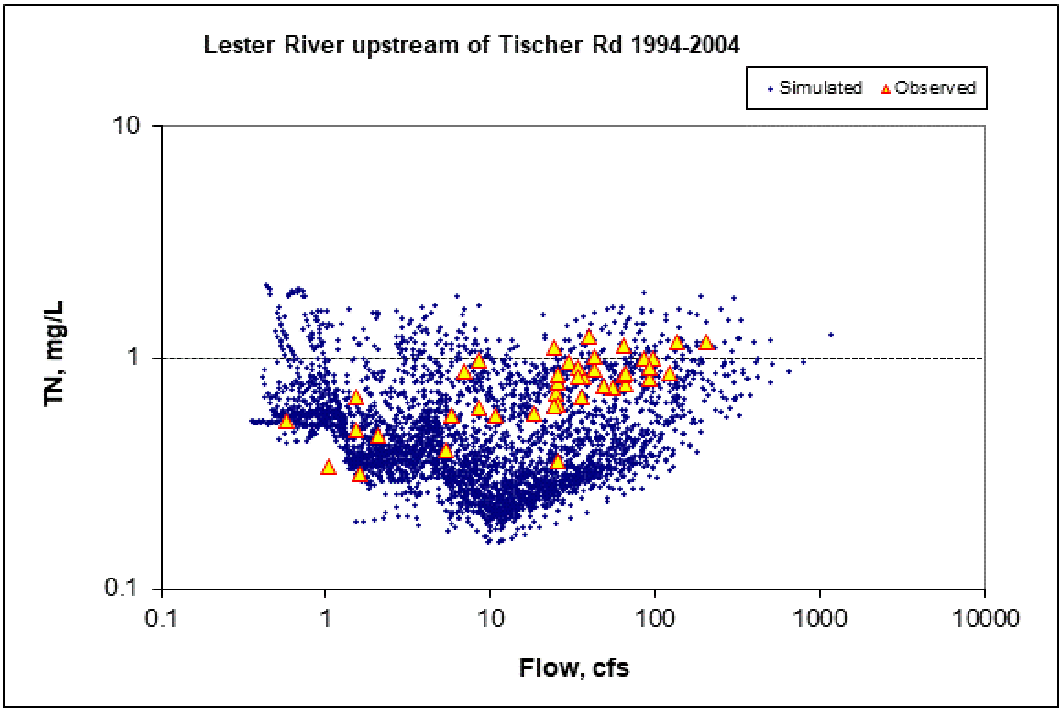
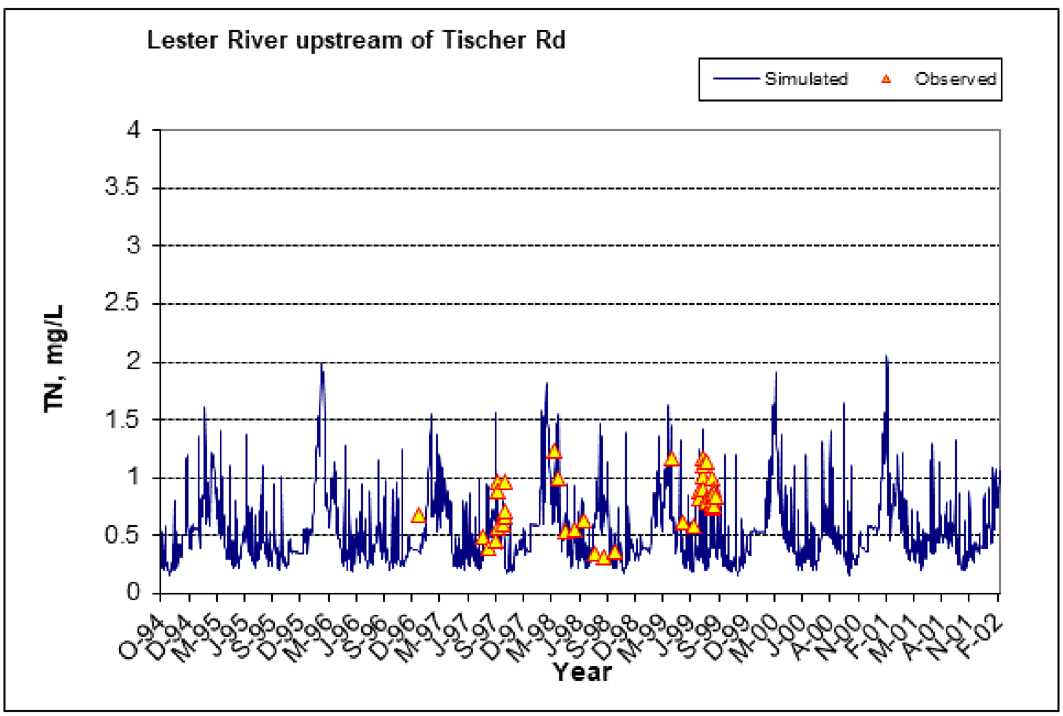
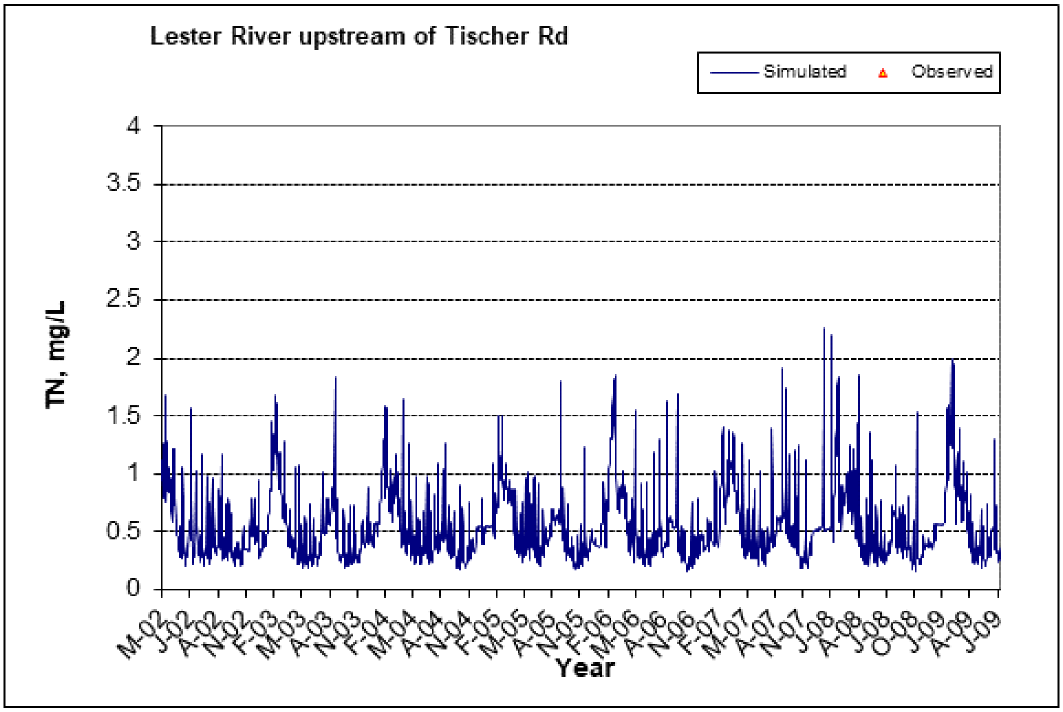


Figure E-30. Simulated and observed Total Nitrogen (TN) concentration vs flow at Lester River upstream of Tischer Rd (validation period)





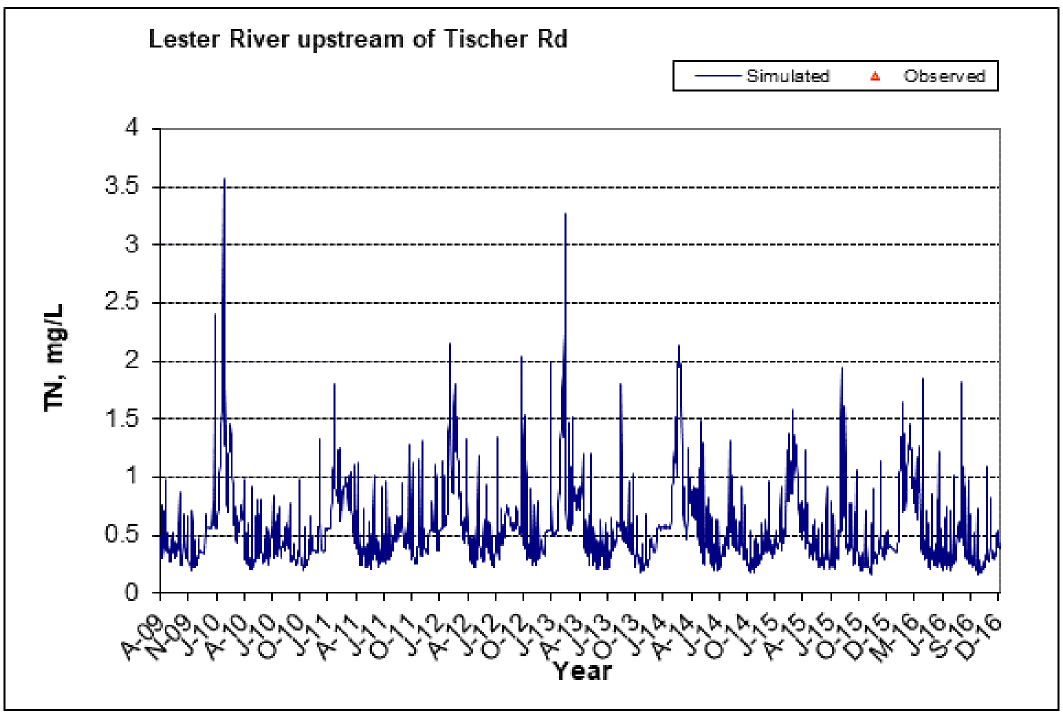


Figure E-31. Time series of observed and simulated Total Nitrogen (TN) concentration at Lester River upstream of Tischer Rd

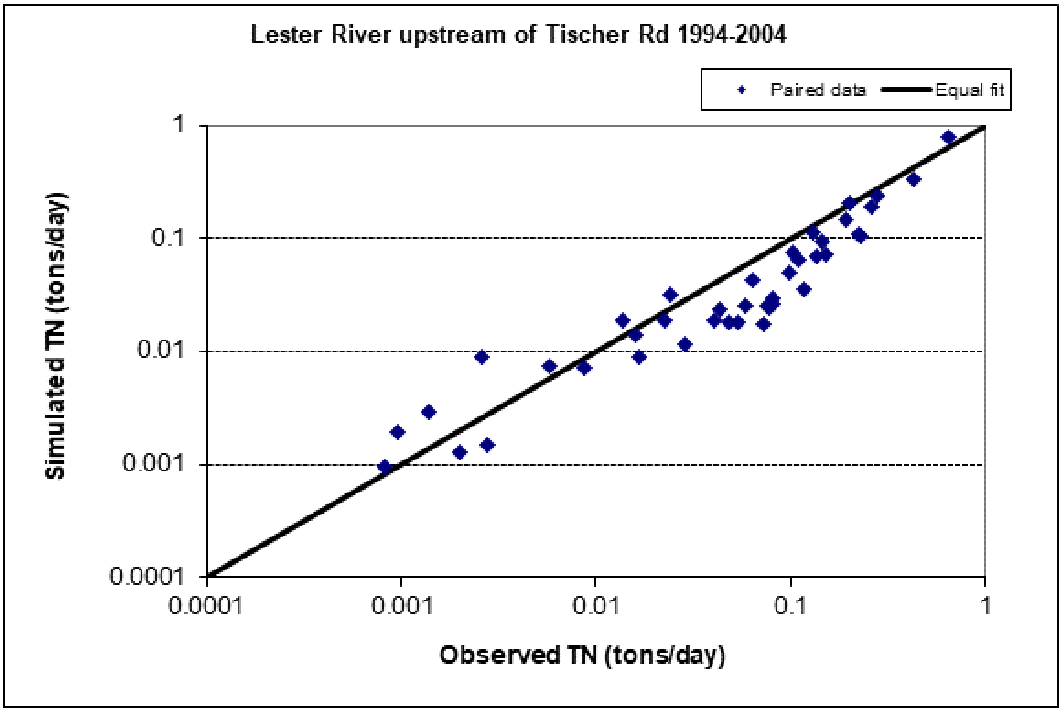


Figure E-32. Paired simulated vs. observed Total Nitrogen (TN) load at Lester River upstream of Tischer Rd (validation period)

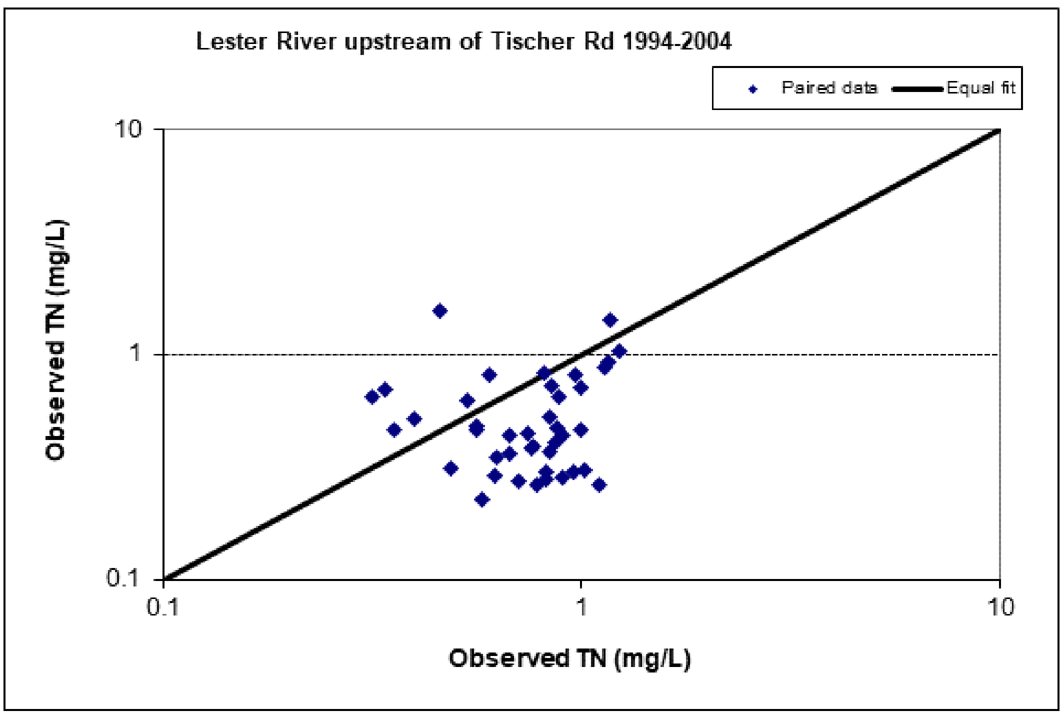


Figure E-33. Paired simulated vs. observed Total Nitrogen (TN) concentration at Lester River upstream of Tischer Rd (validation period)

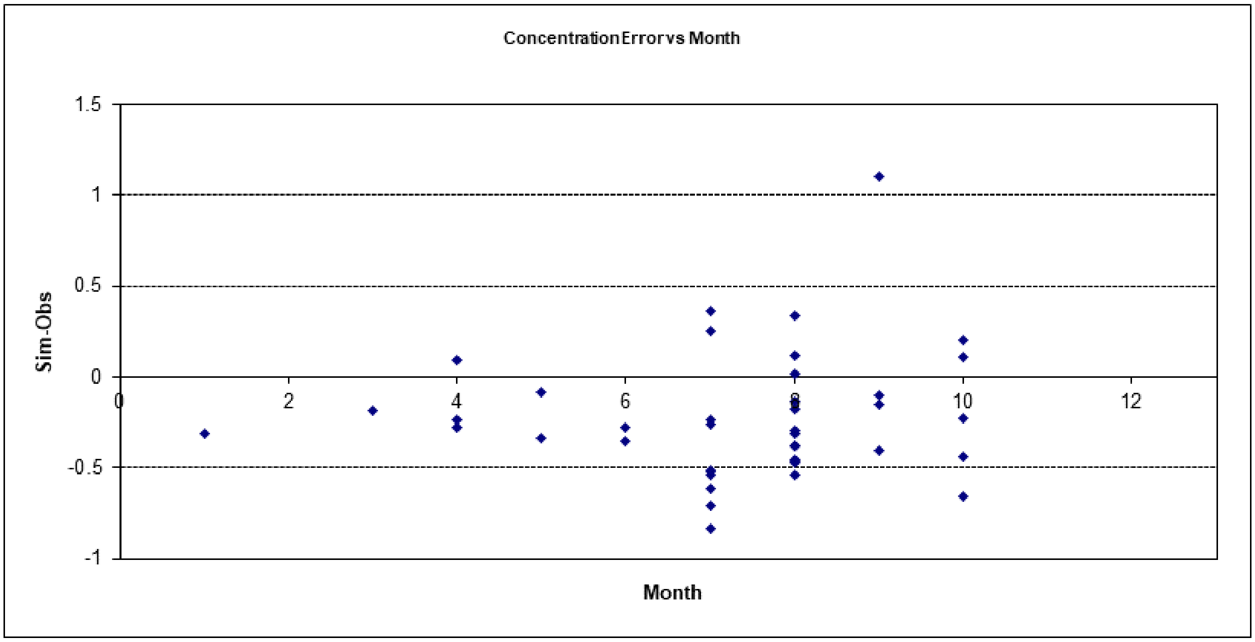


Figure E-34. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at Lester River upstream of Tischer Rd

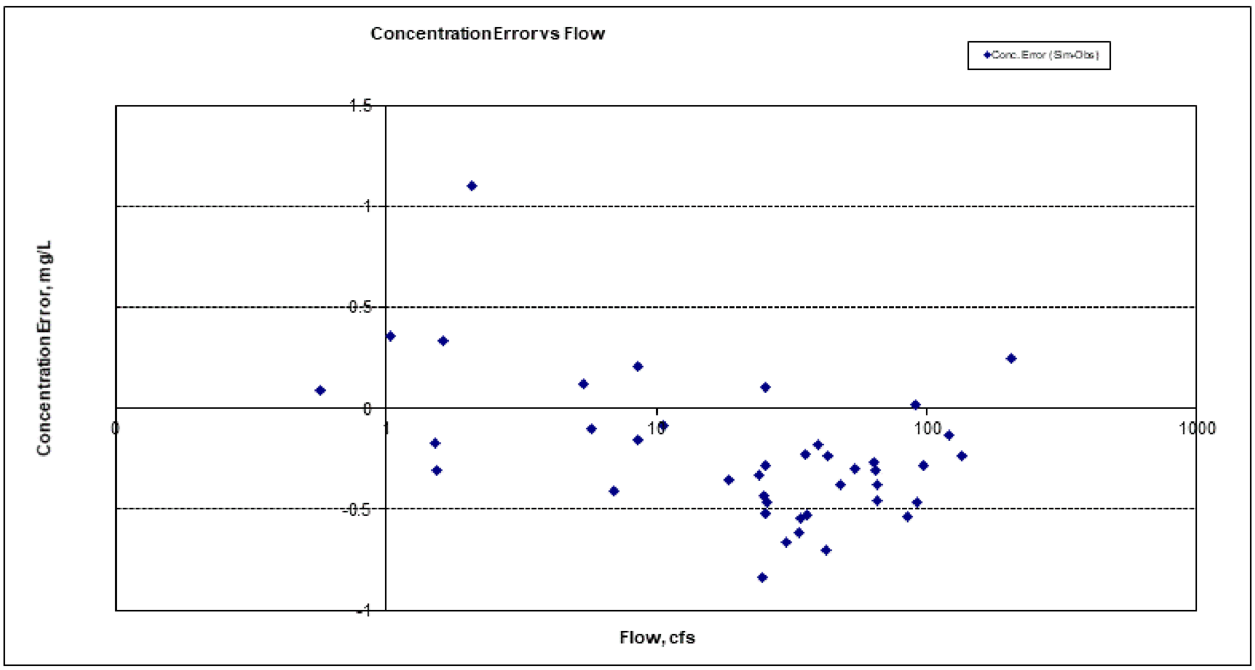


Figure E-35. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at Lester River upstream of Tischer Rd

E.1.6 Soluble Reactive Phosphorus (SRP)

Table E-6. Soluble Reactive Phosphorus (SRP) statistics

Period	1994-2004	2004-2016
Count	42	ND
Concentration Average Error	1.69%	
Concentration Median Error	0.04%	
Load Average Error	46.68%	
Load Median Error	0.21%	
Paired t conc	0.99	
Paired t load	0.19	

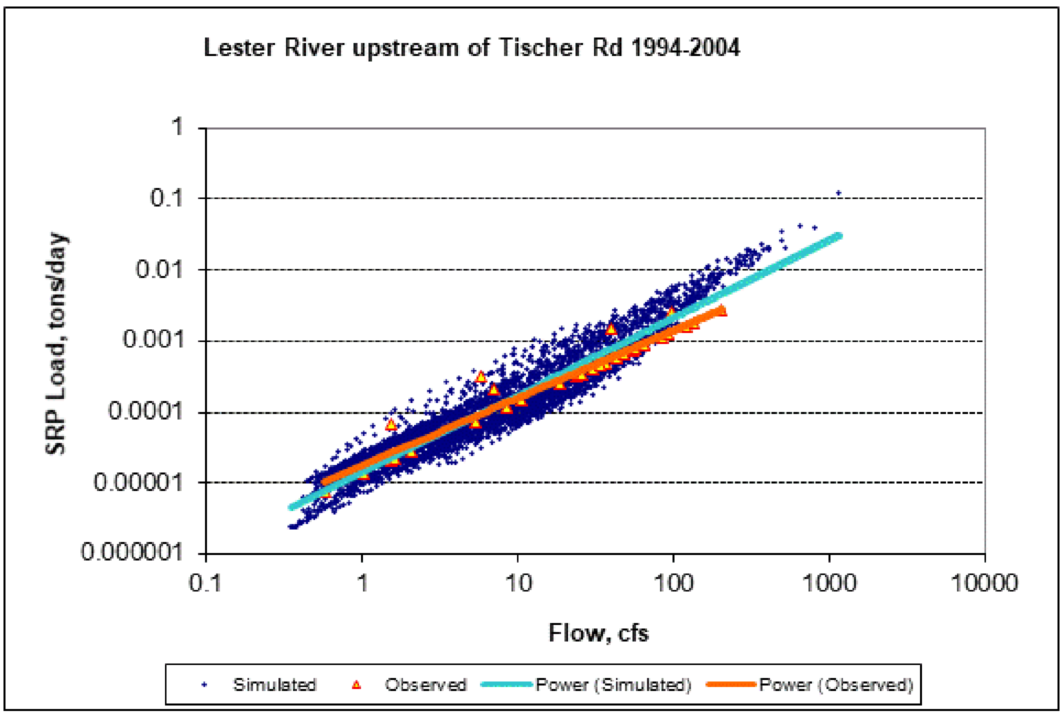


Figure E-36. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Lester River upstream of Tischer Rd (validation period)

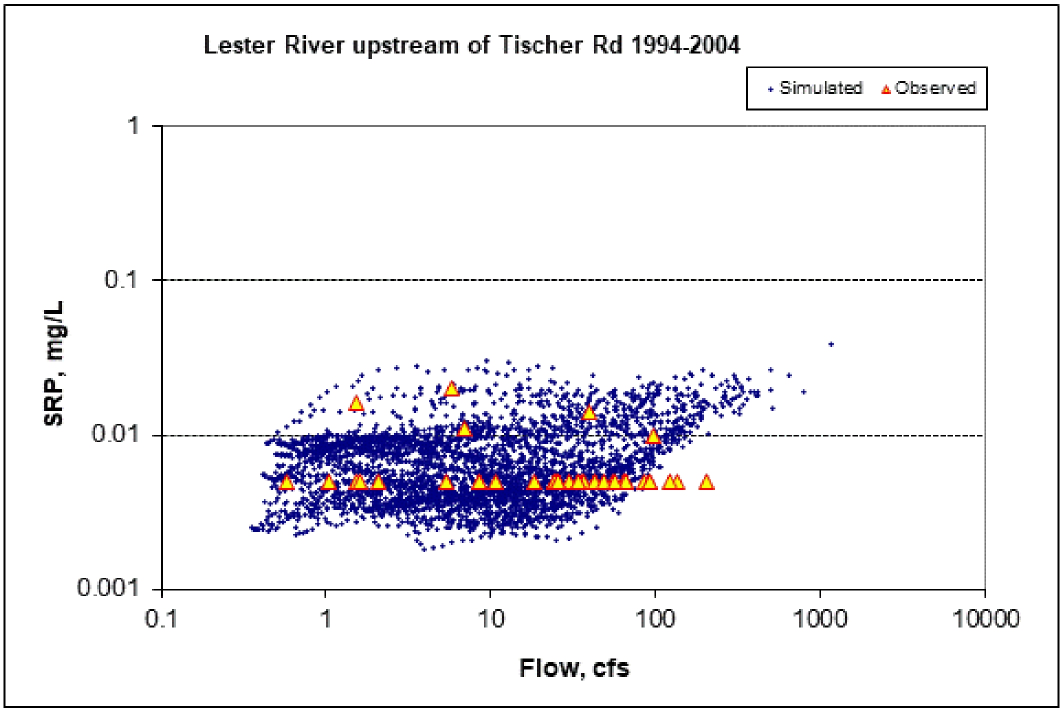
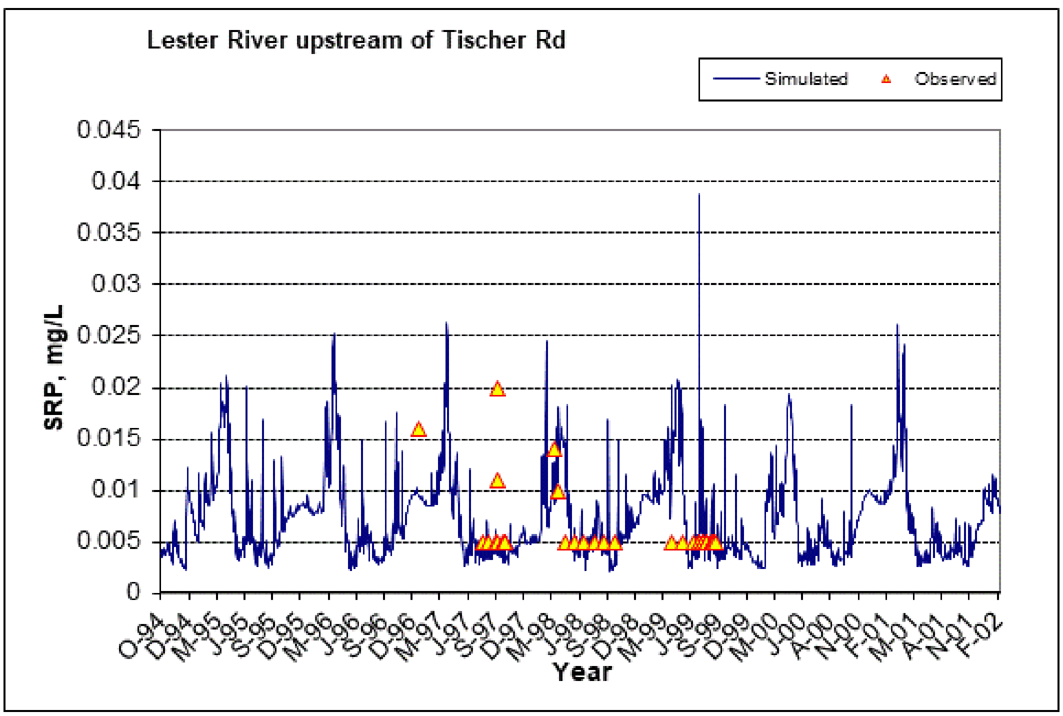


Figure E-37. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at Lester River upstream of Tischer Rd (validation period)



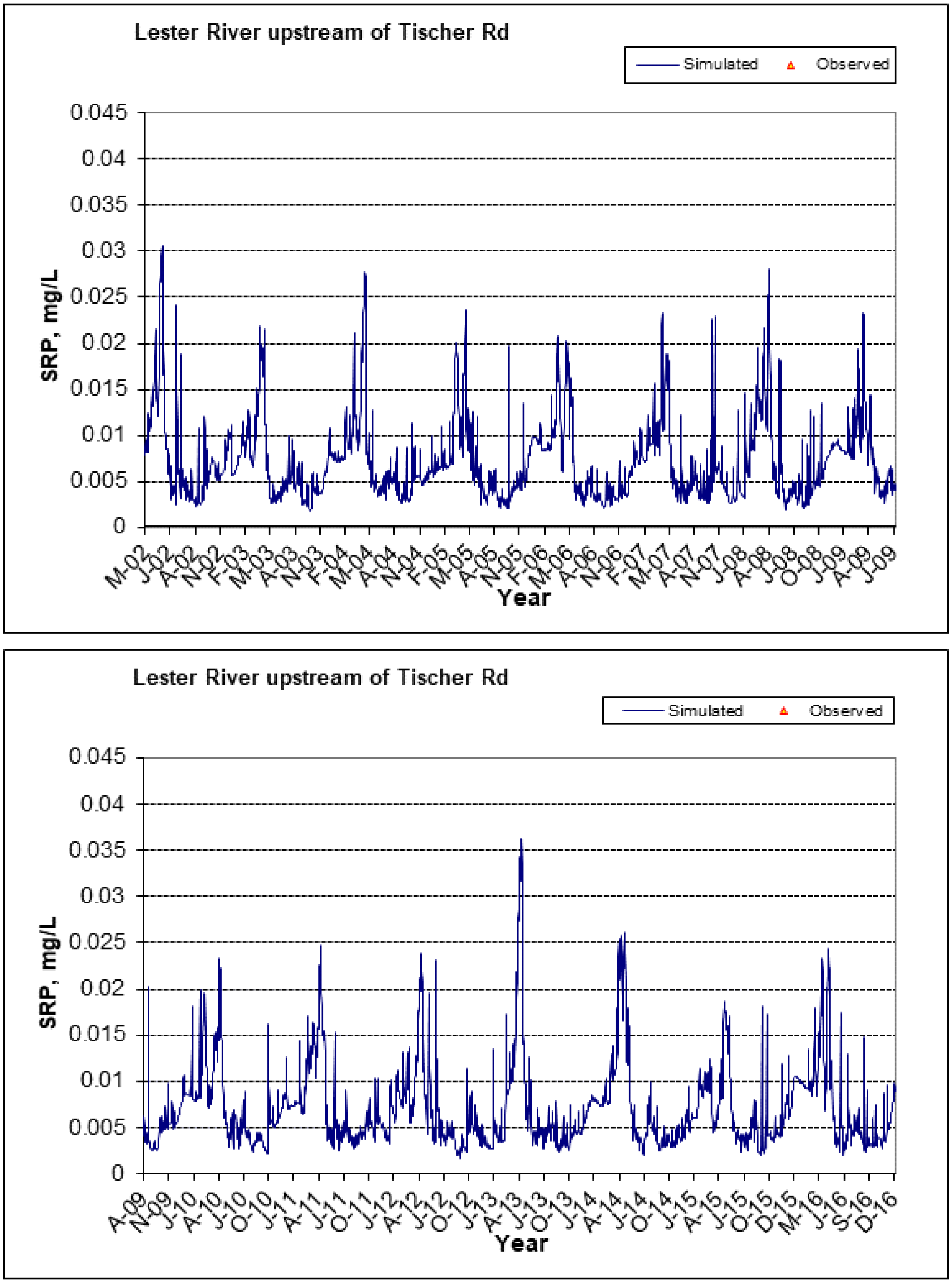


Figure E-38. Time series of observed and simulated Soluble Reactive Phosphorus (SRP) concentration at Lester River upstream of Tischer Rd

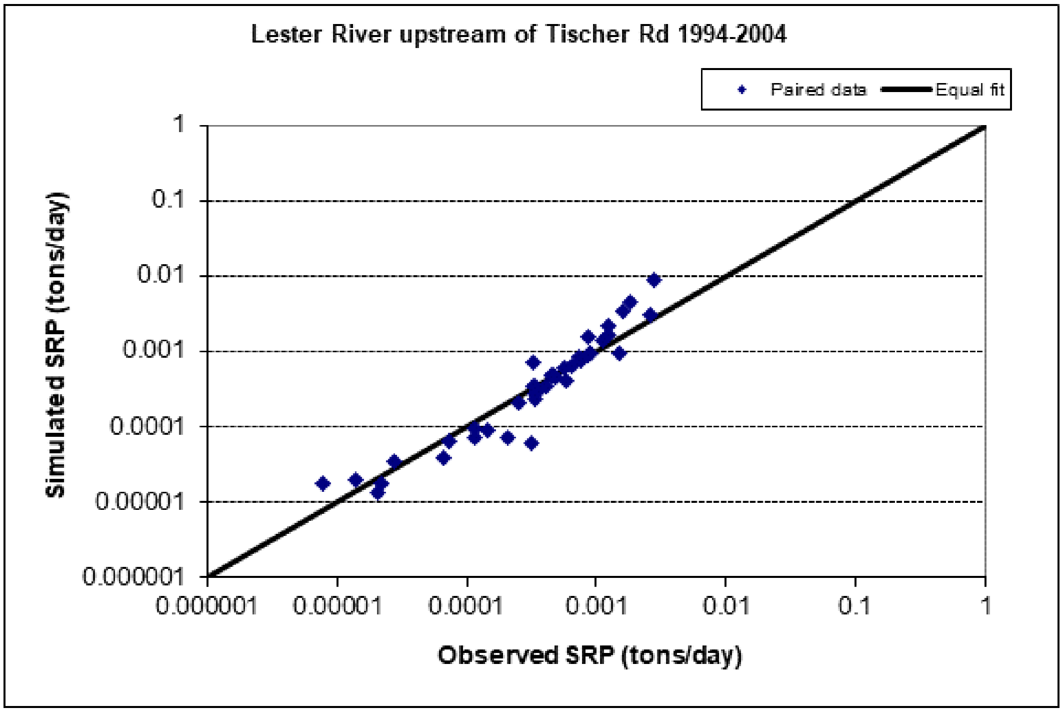


Figure E-39. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at Lester River upstream of Tischer Rd (validation period)

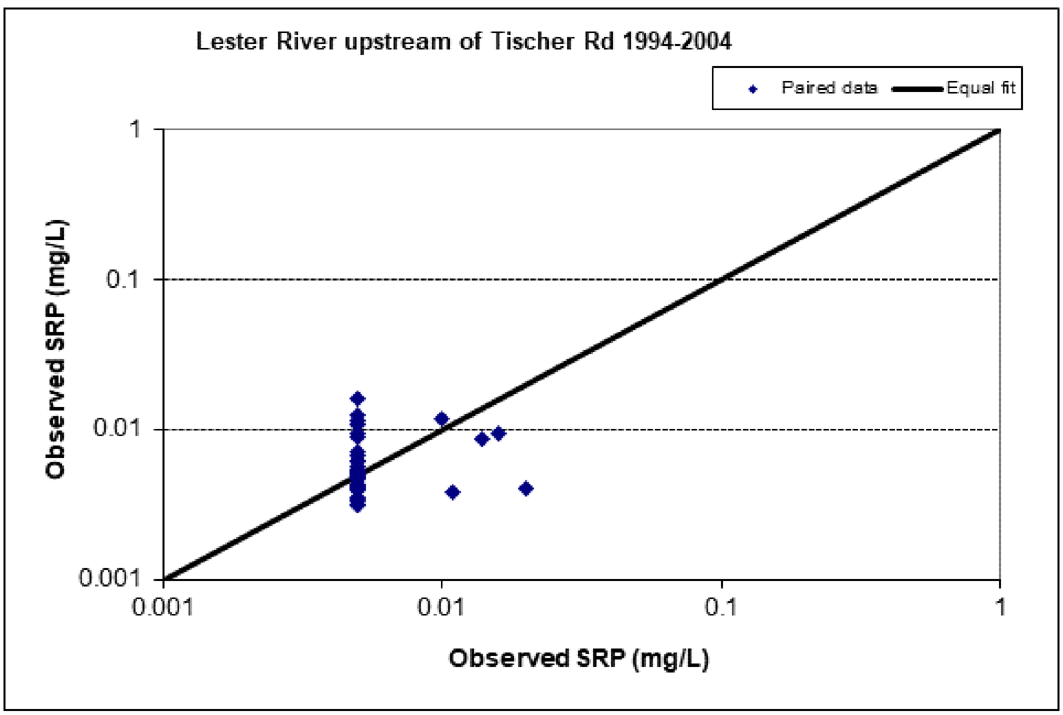


Figure E-40. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at Lester River upstream of Tischer Rd (validation period)

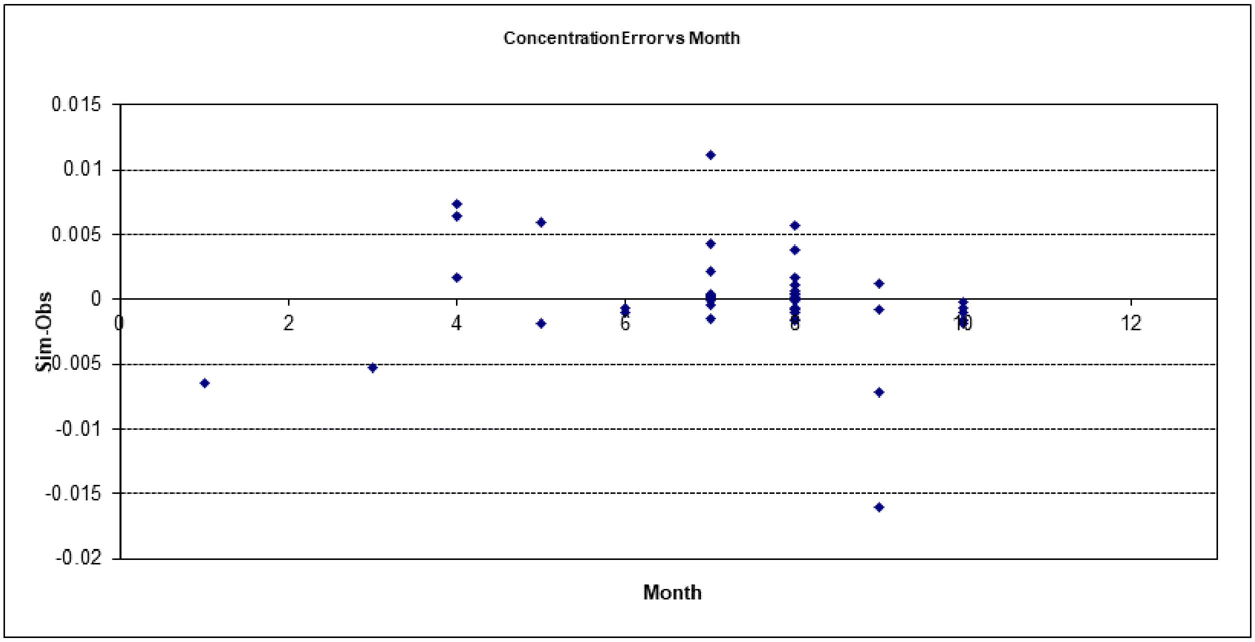


Figure E-41. Residual (Simulated - Observed) vs. Month, Soluble Reactive Phosphorus (SRP) at Lester River upstream of Tischer Rd

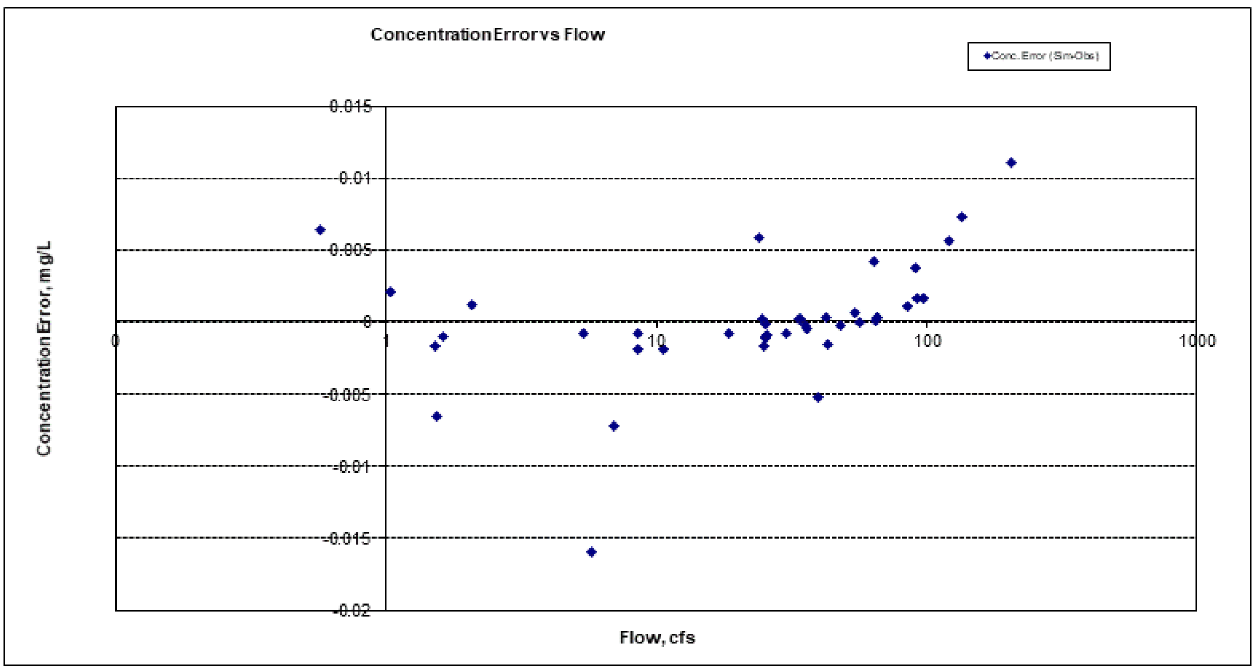


Figure E-42. Residual (Simulated - Observed) vs. Flow, Soluble Reactive Phosphorus (SRP) at Lester River upstream of Tischer Rd

E.1.7 Organic Phosphorus (OrgP)

Table E-7. Organic Phosphorus (OrgP) statistics

Period	1994-2004	2004-2016
Count	38	ND
Concentration Average Error	-61.59%	
Concentration Median Error	-50.98%	
Load Average Error	-40.71%	
Load Median Error	-19.07%	
Paired t conc	0.00	
Paired t load	0.23	

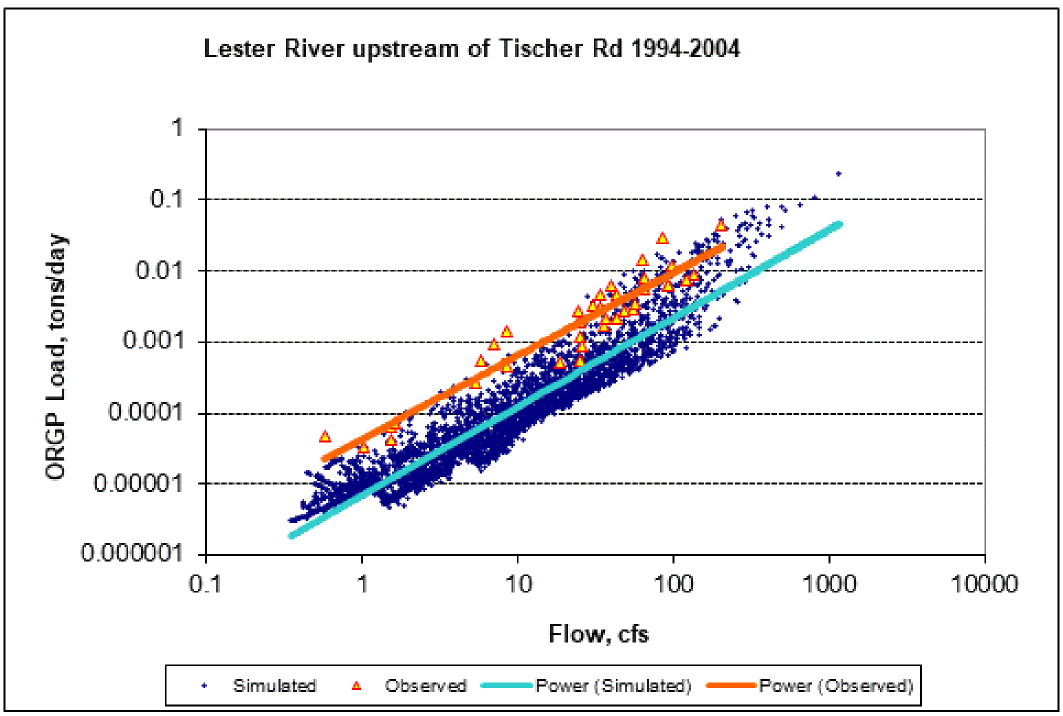


Figure E-43. Power plot of simulated and observed Organic Phosphorus (OrgP) load vs flow at Lester River upstream of Tischer Rd (validation period)

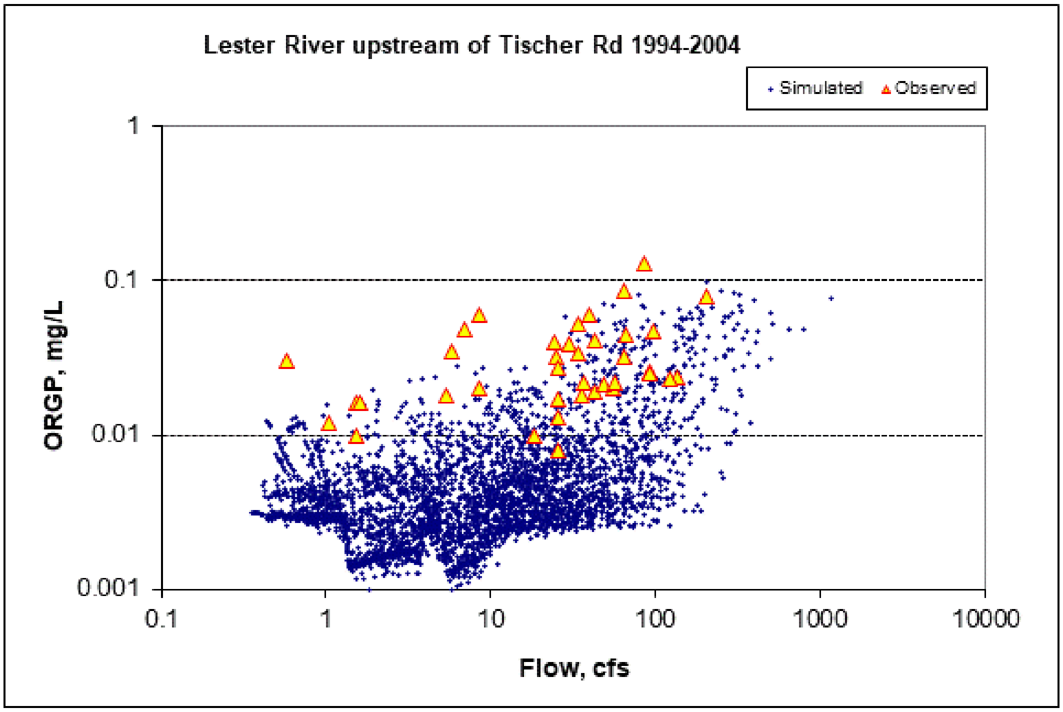
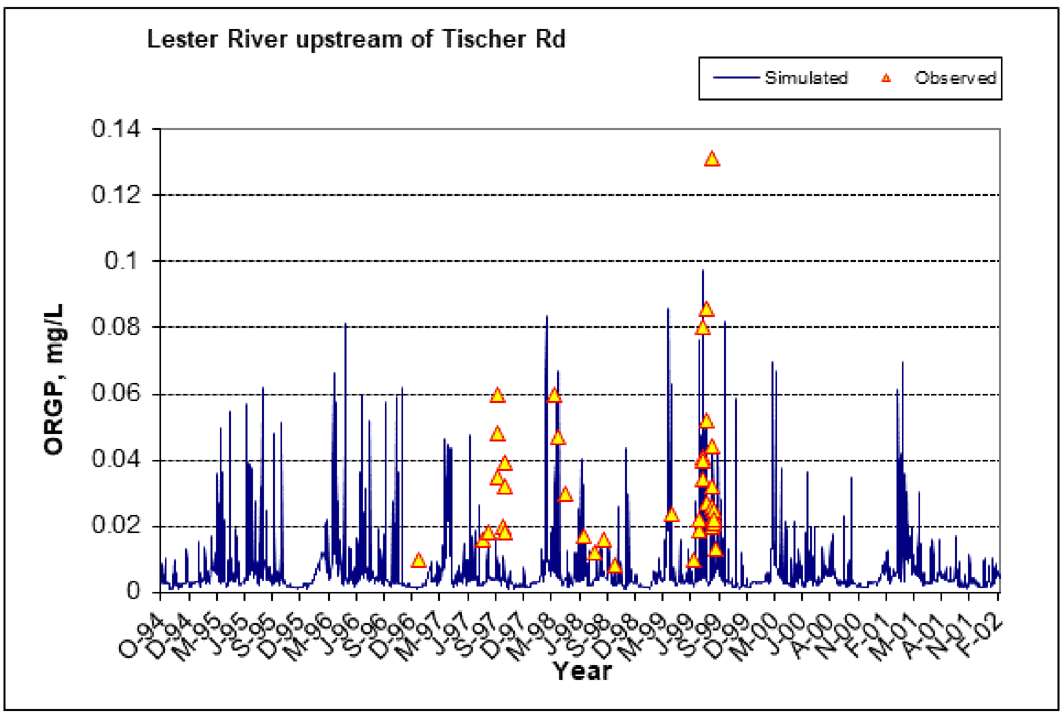
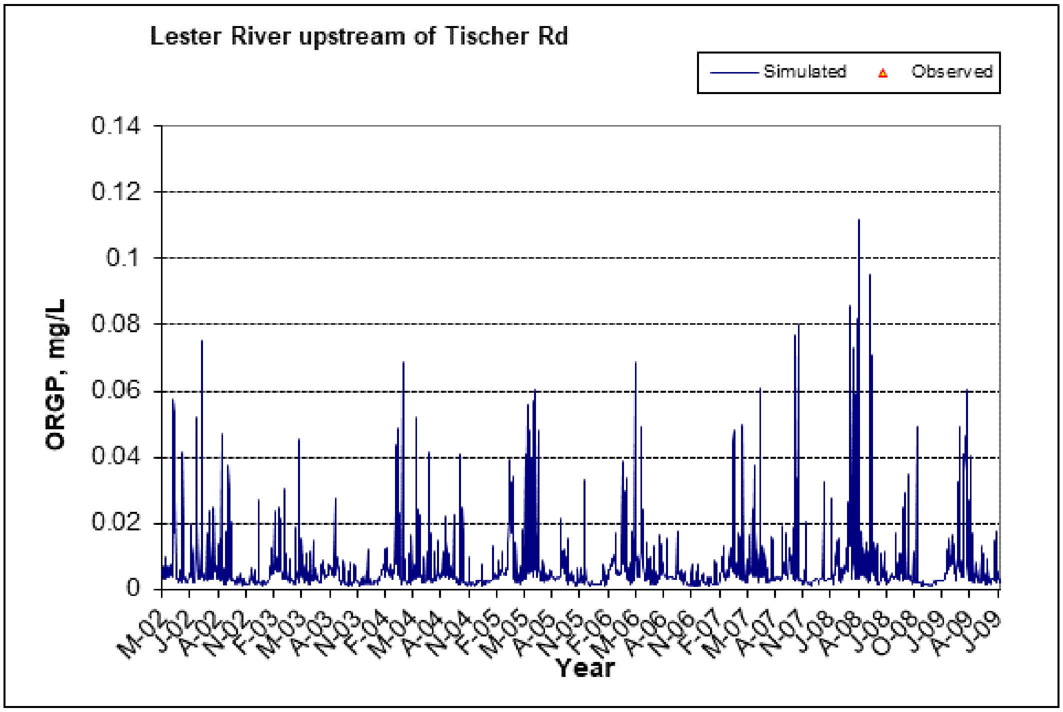


Figure E-44. Simulated and observed Organic Phosphorus (OrgP) concentration vs flow at Lester River upstream of Tischer Rd (validation period)





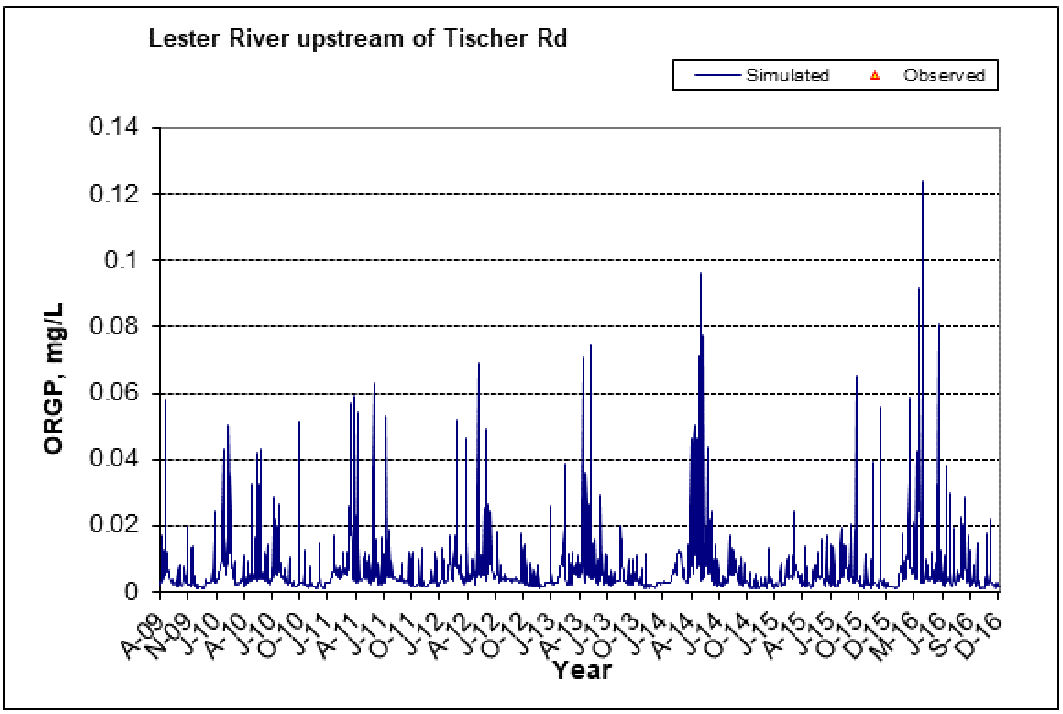


Figure E-45. Time series of observed and simulated Organic Phosphorus (OrgP) concentration at Lester River upstream of Tischer Rd

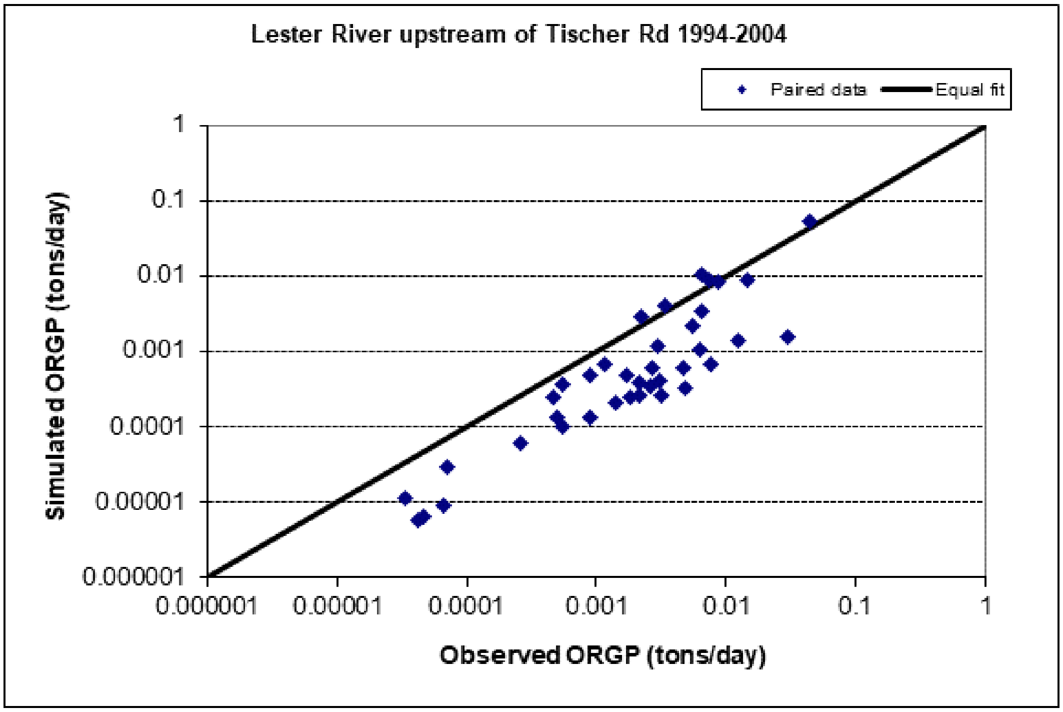


Figure E-46. Paired simulated vs. observed Organic Phosphorus (OrgP) load at Lester River upstream of Tischer Rd (validation period)

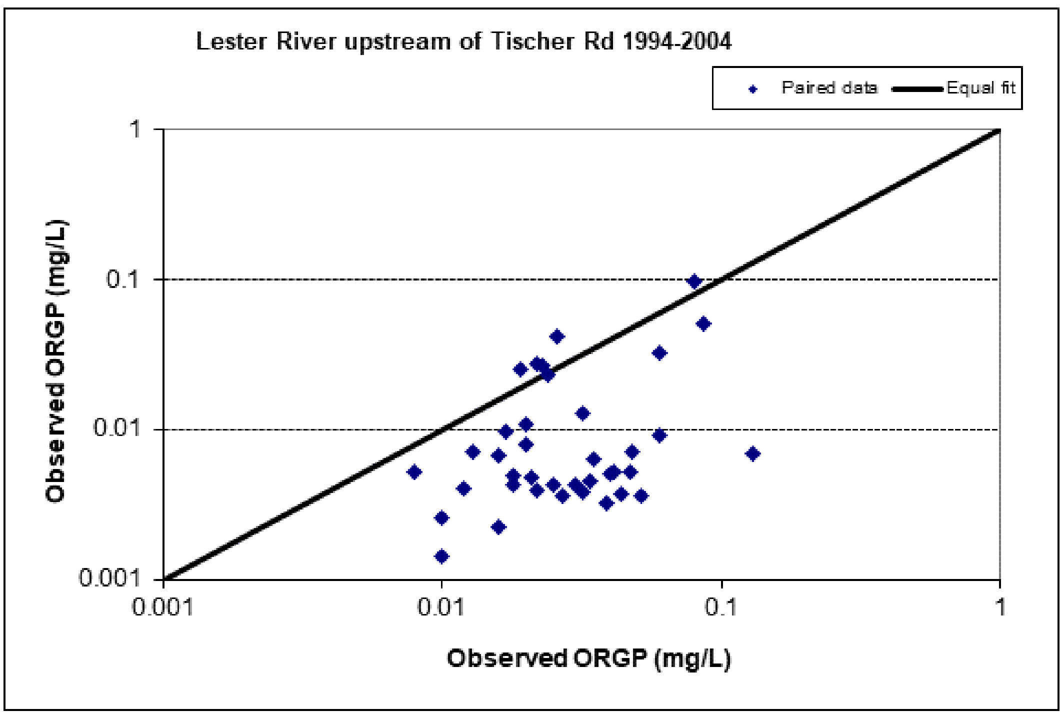


Figure E-47. Paired simulated vs. observed Organic Phosphorus (OrgP) concentration at Lester River upstream of Tischer Rd (validation period)

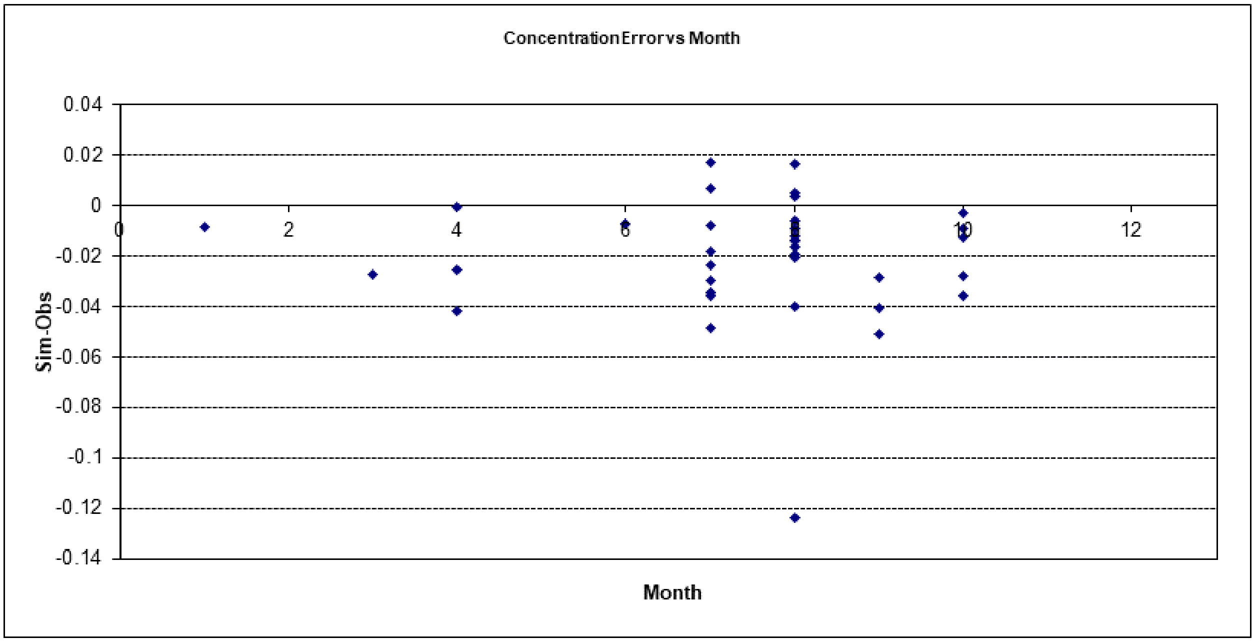


Figure E-48. Residual (Simulated - Observed) vs. Month, Organic Phosphorus (OrgP) at Lester River upstream of Tischer Rd

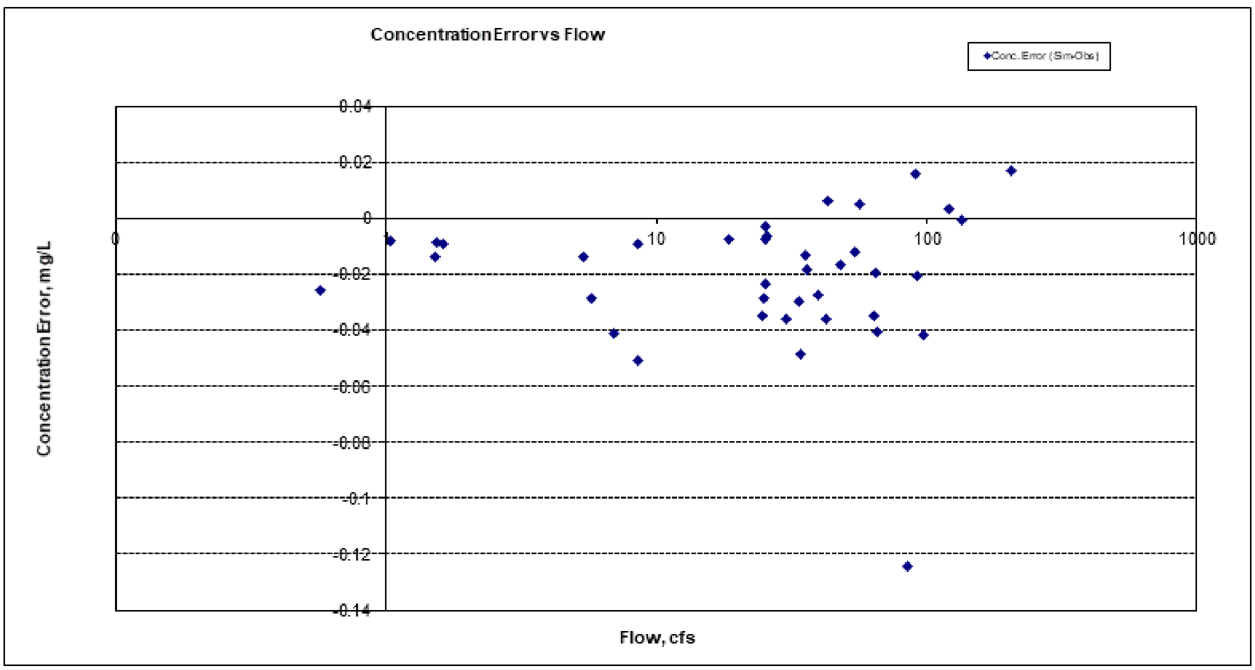


Figure E-49. Residual (Simulated - Observed) vs. Flow, Organic Phosphorus (OrgP) at Lester River upstream of Tischer Rd

E.1.8 Total Phosphorus (TP)

Table E-8. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	42	ND
Concentration Average Error	-49.11%	
Concentration Median Error	-41.75%	
Load Average Error	-29.57%	
Load Median Error	-11.99%	
Paired t conc	0.00	
Paired t load	0.36	

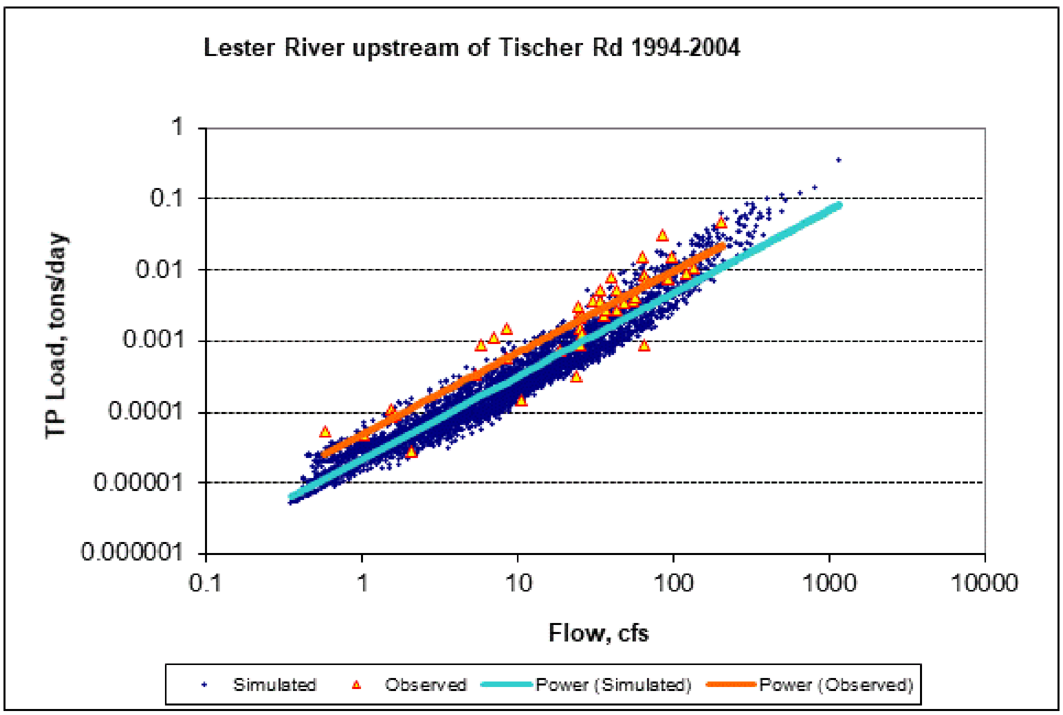


Figure E-50. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Lester River upstream of Tischer Rd (validation period)

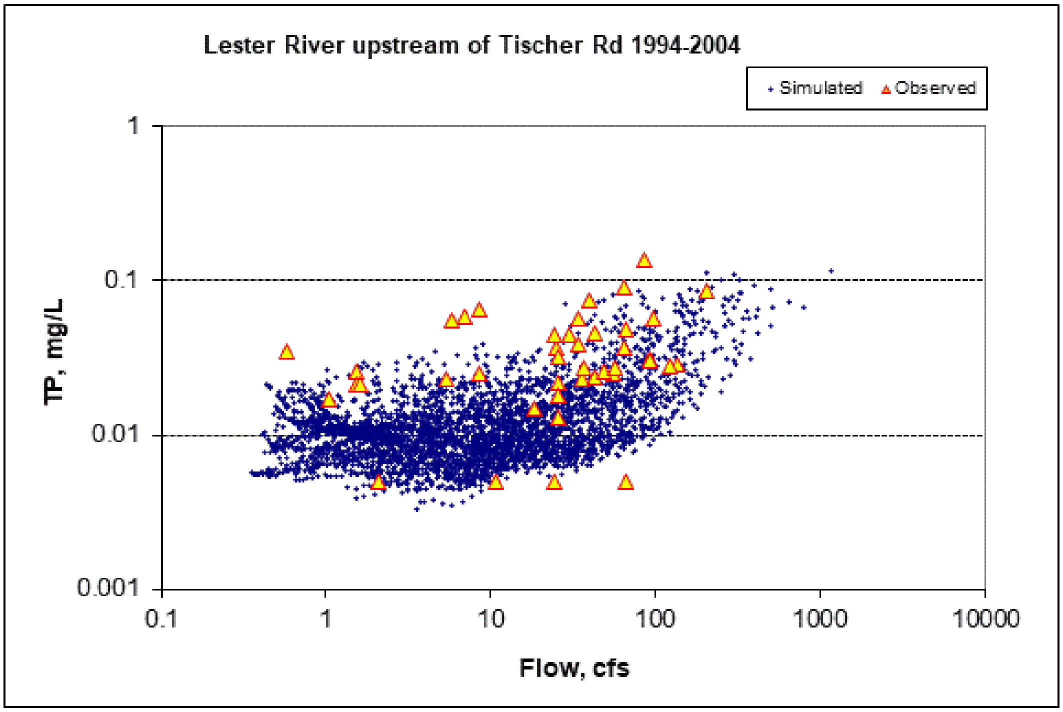
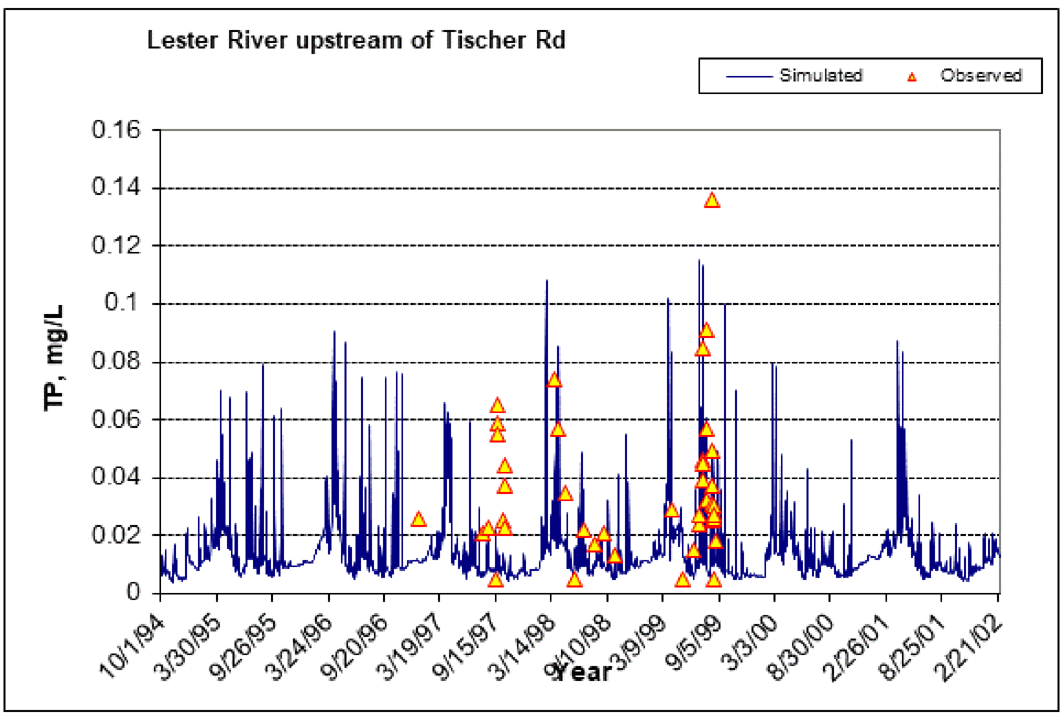


Figure E-51. Simulated and observed Total Phosphorus (TP) concentration vs flow at Lester River upstream of Tischer Rd (validation period)



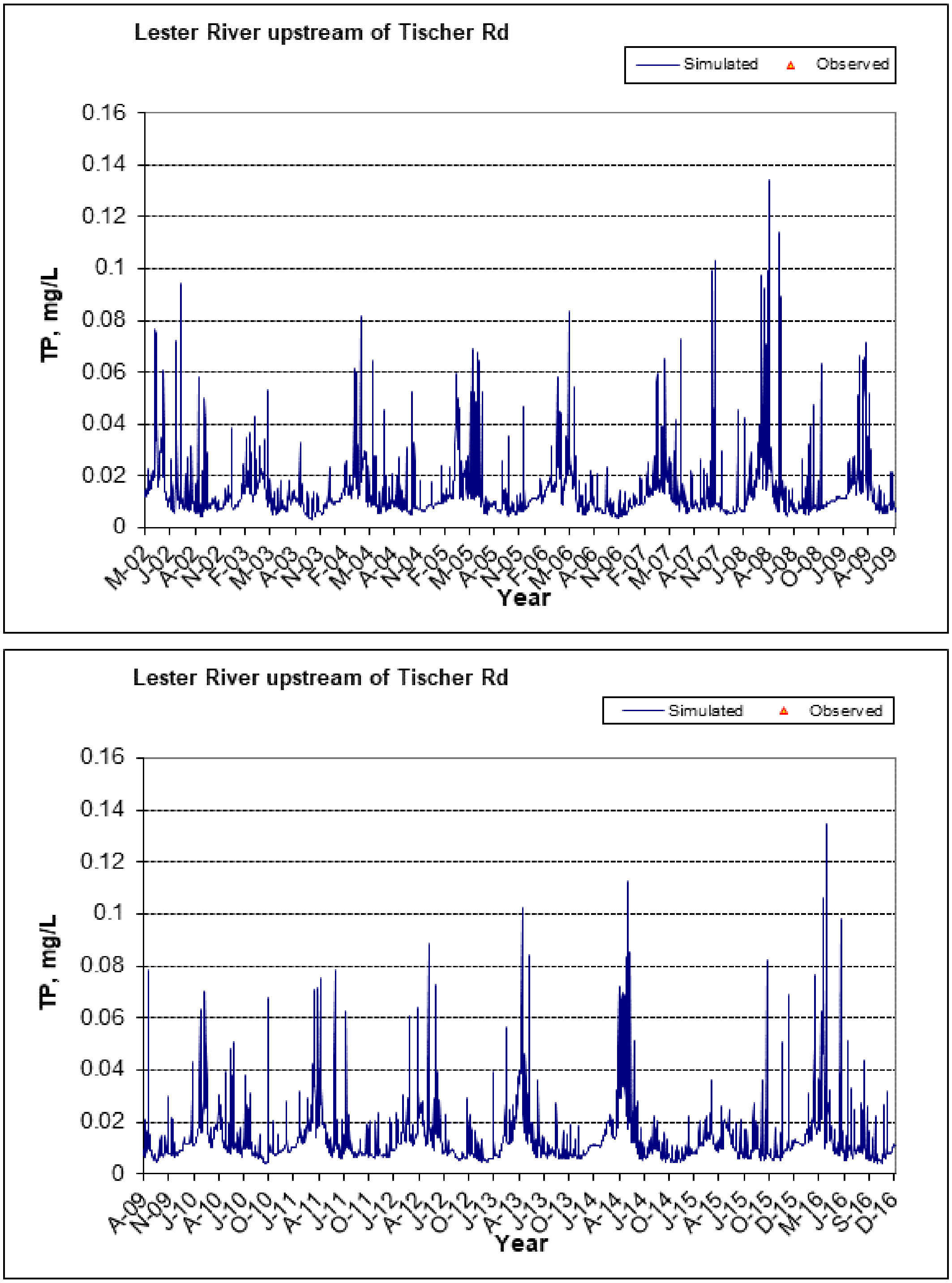


Figure E-52. Time series of observed and simulated Total Phosphorus (TP) concentration at Lester River upstream of Tischer Rd

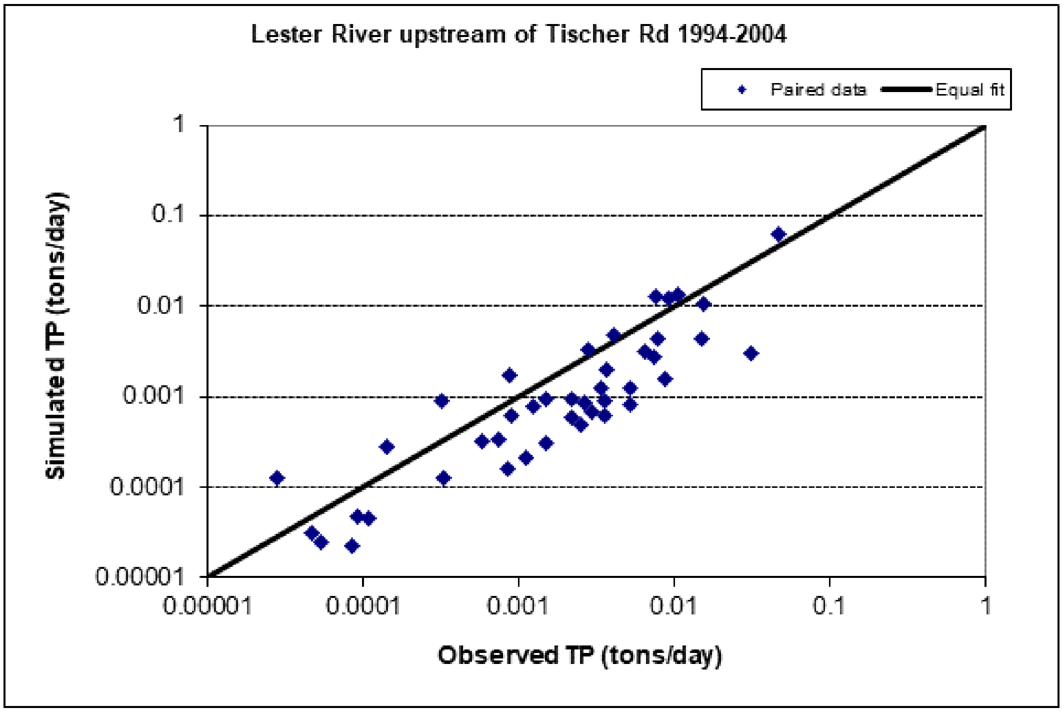


Figure E-53. Paired simulated vs. observed Total Phosphorus (TP) load at Lester River upstream of Tischer Rd (validation period)

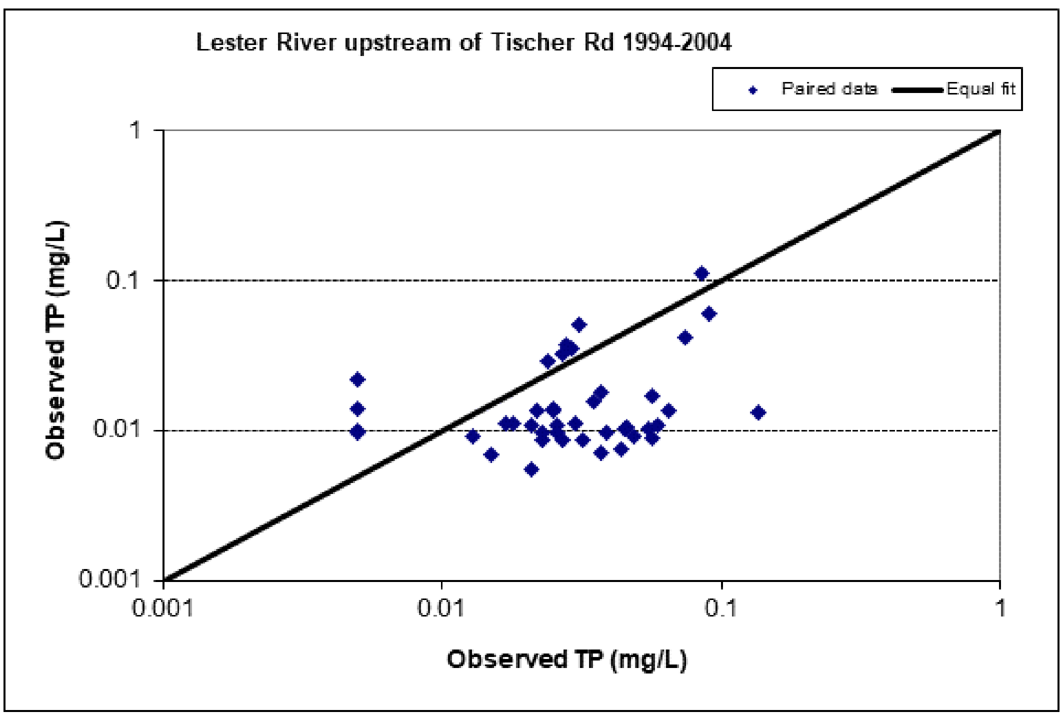


Figure E-54. Paired simulated vs. observed Total Phosphorus (TP) concentration at Lester River upstream of Tischer Rd (validation period)

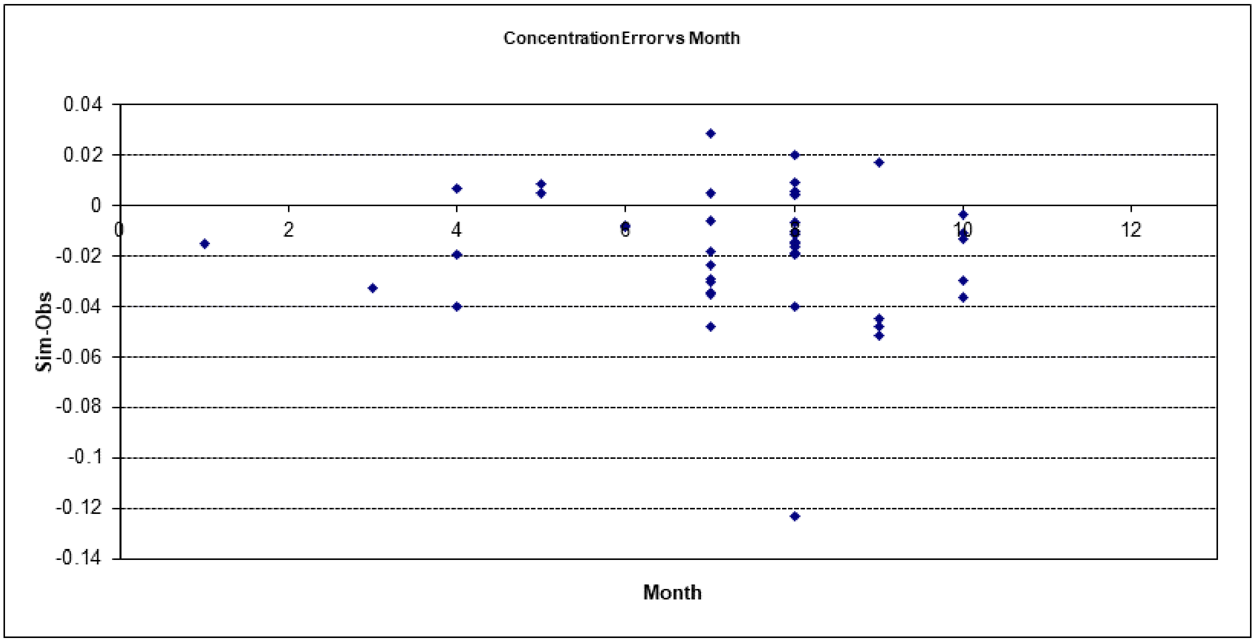


Figure E-55. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Lester River upstream of Tischer Rd

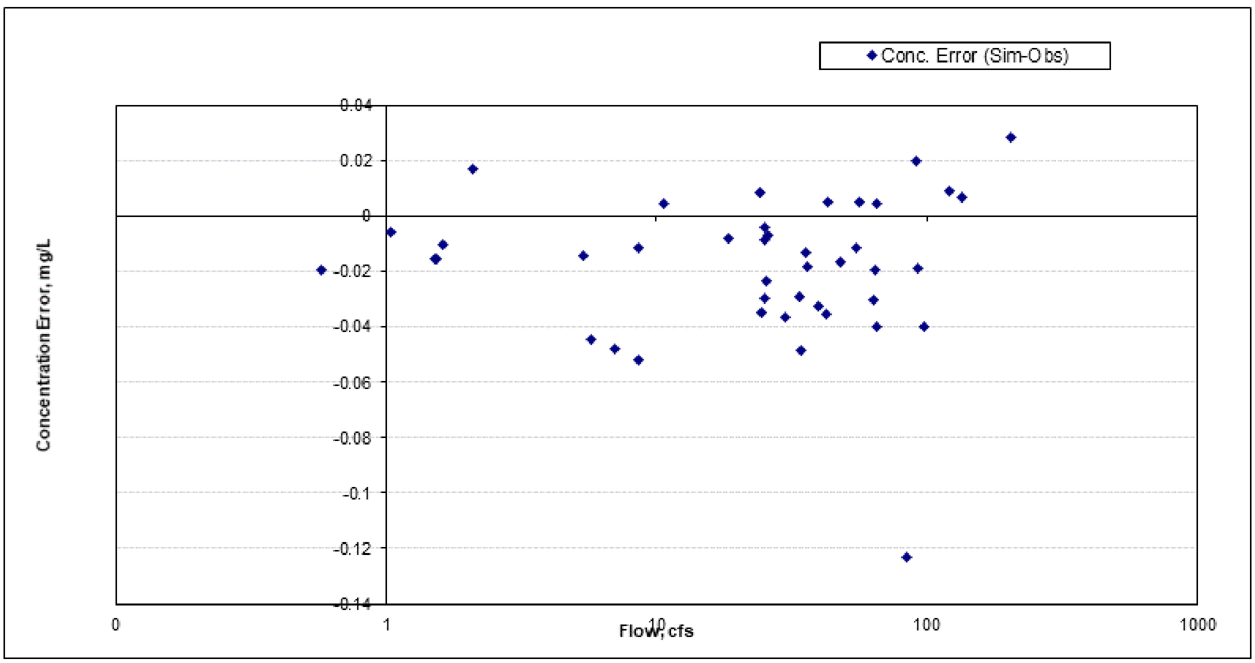


Figure E-56. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Lester River upstream of Tischer Rd

E.2 Lester River above Superior Street

E.2.1 Dissolved Oxygen (DO)

Table E-9. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	37	85
Concentration Average Error	2.35%	1.57%
Concentration Median Error	2.19%	1.75%
Load Average Error	-2.33%	-3.80%
Load Median Error	0.51%	0.21%
Paired t conc	1.00	1.00
Paired t load	0.72	0.82

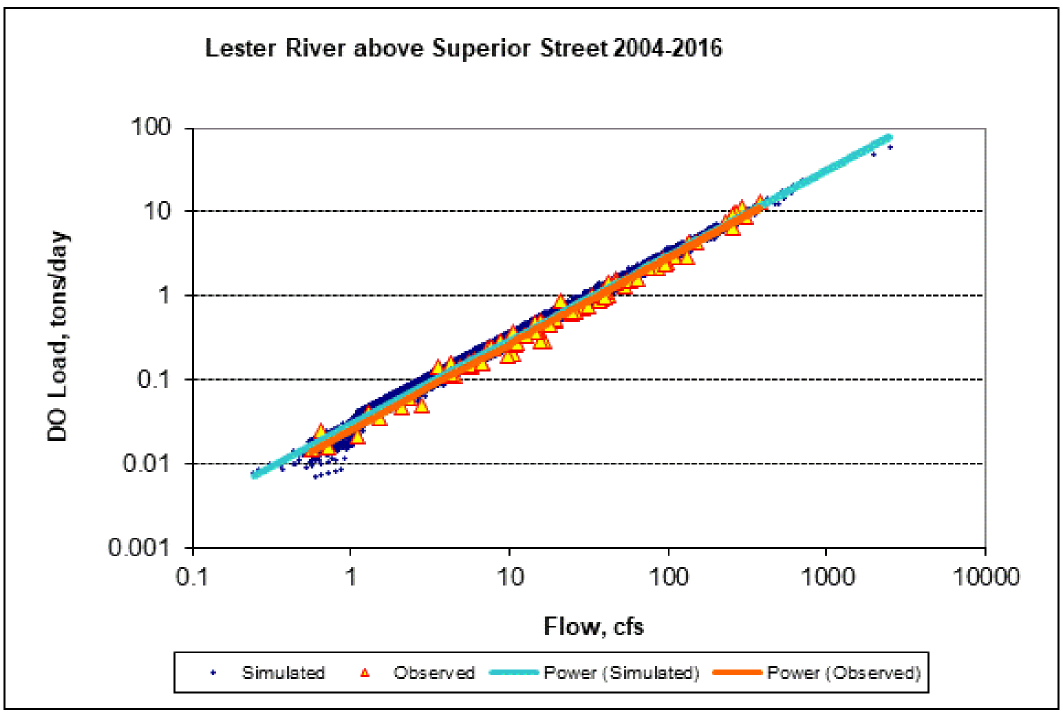


Figure E-57. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Lester River above Superior Street (calibration period)

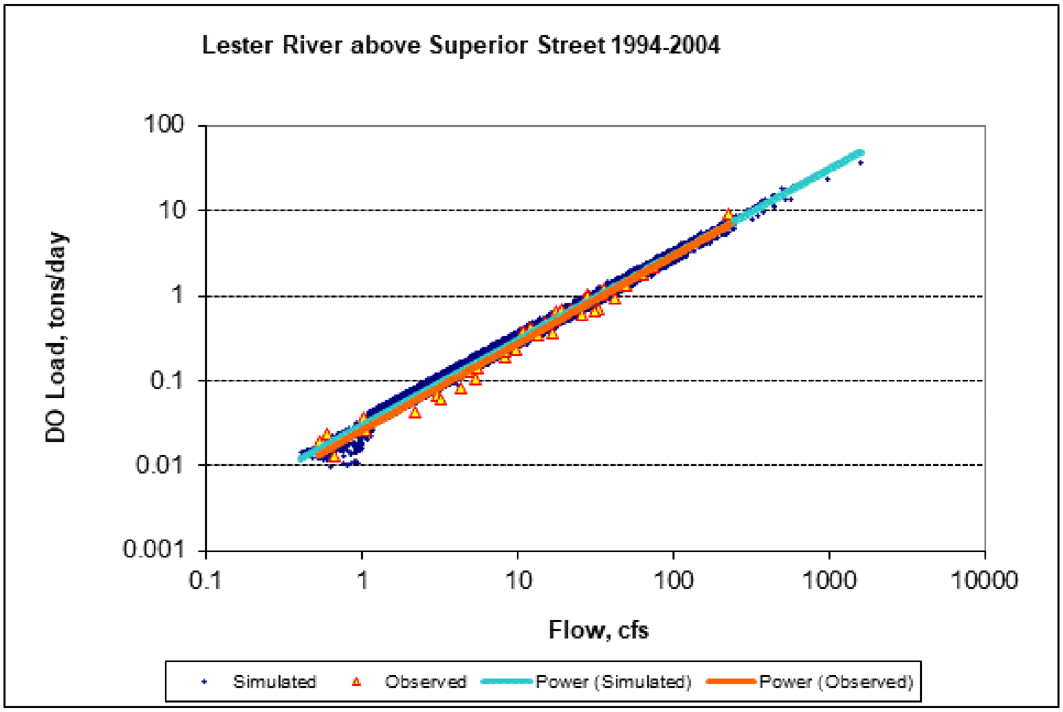


Figure E-58. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Lester River above Superior Street (validation period)

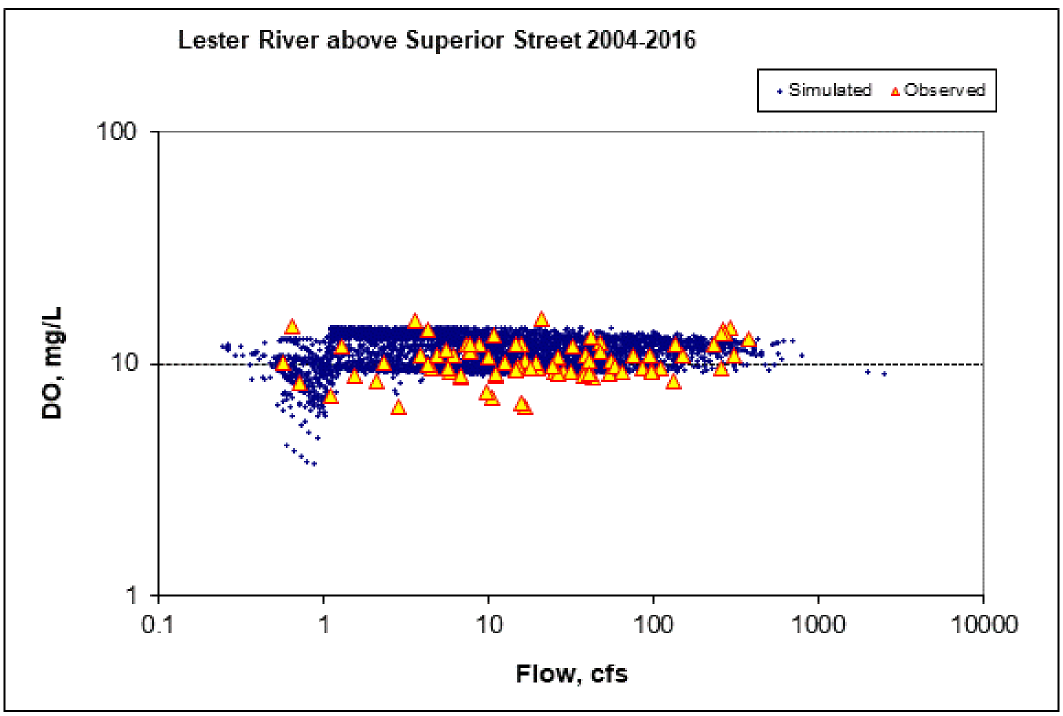


Figure E-59. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Lester River above Superior Street (calibration period)

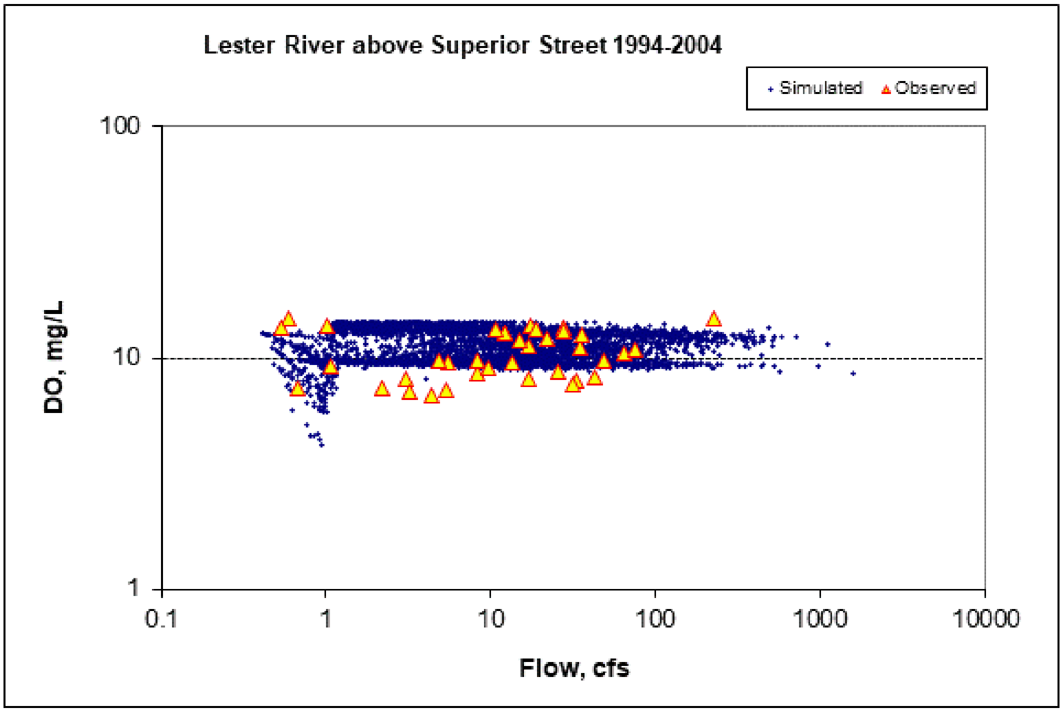
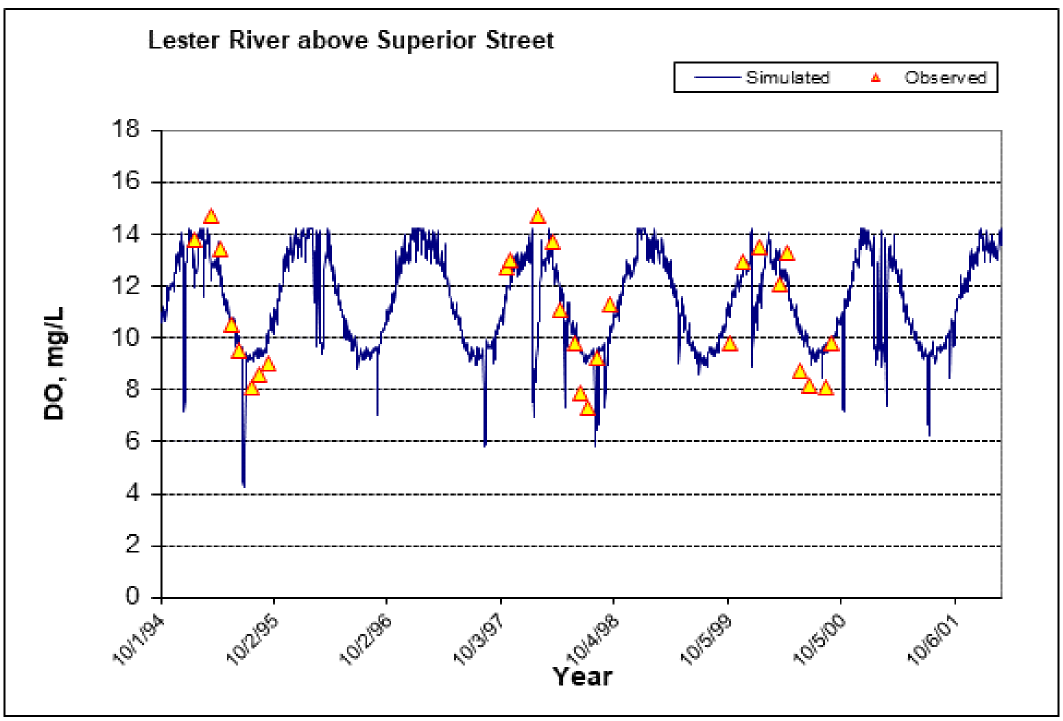


Figure E-60. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Lester River above Superior Street (validation period)



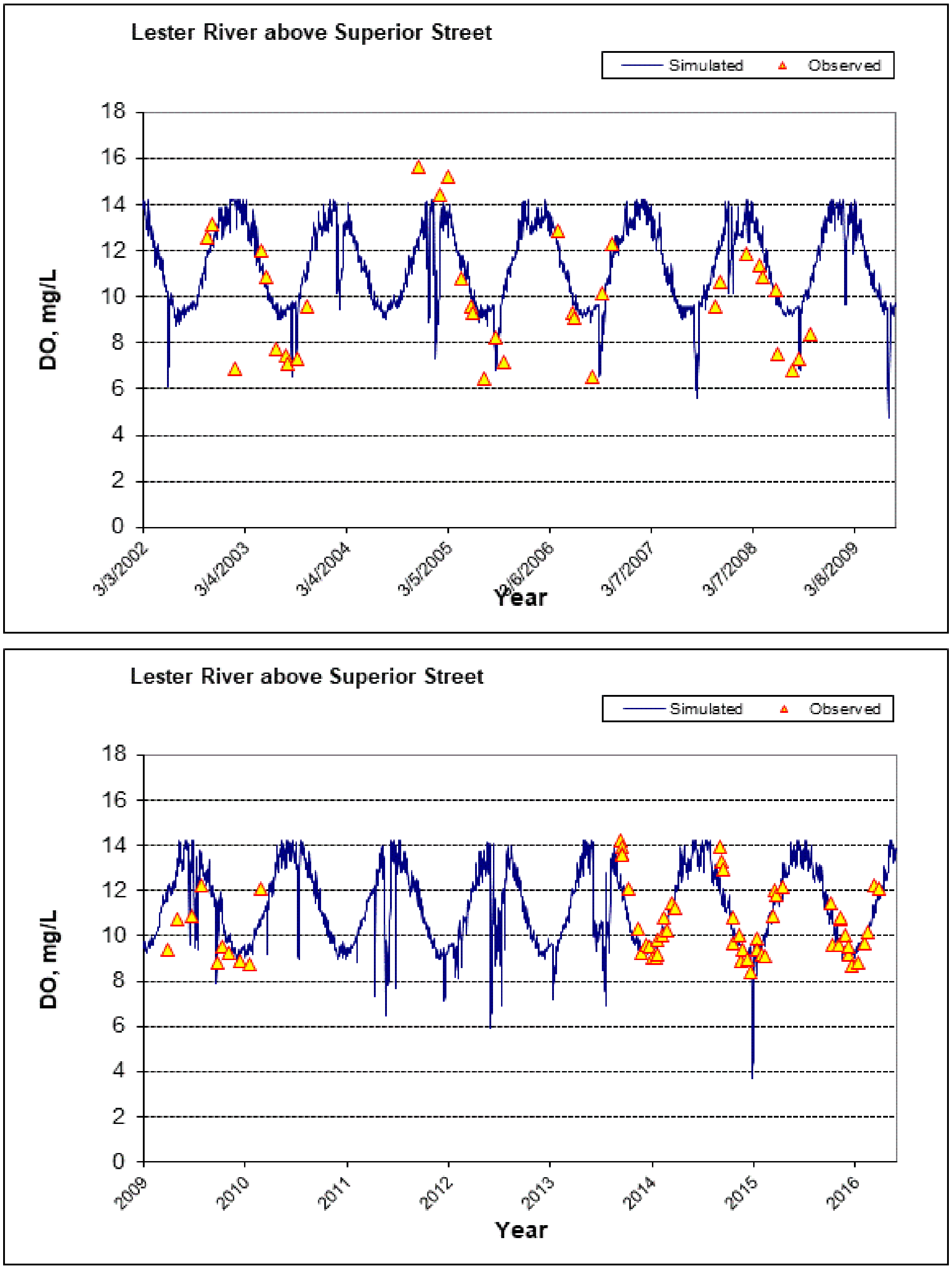


Figure E-61. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Lester River above Superior Street

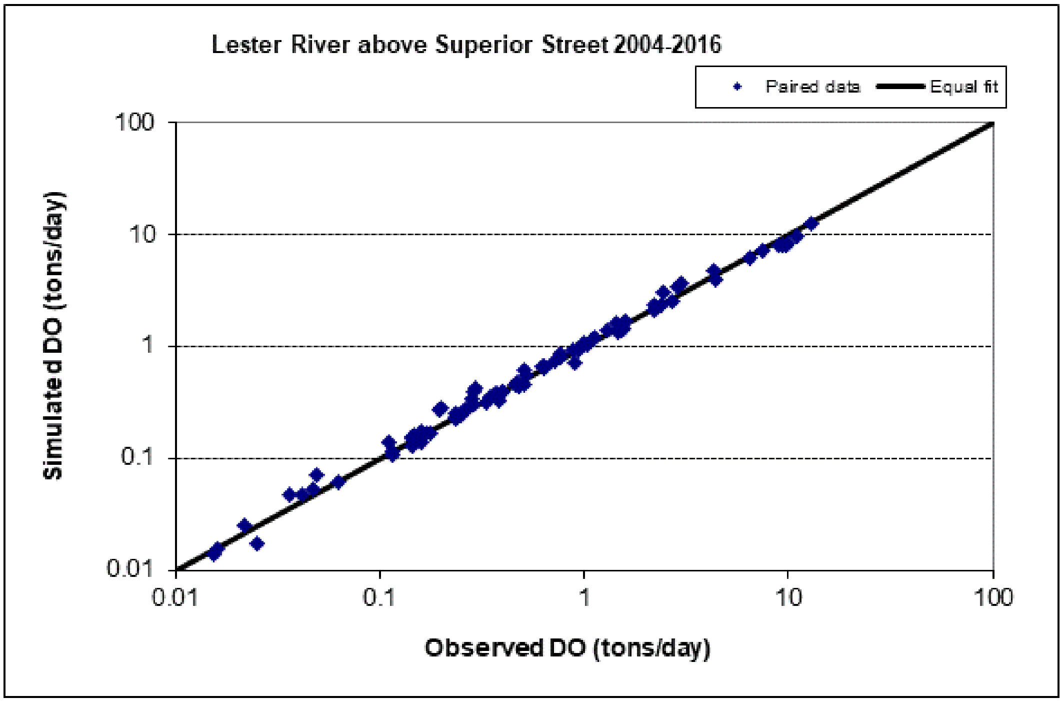


Figure E-62. Paired simulated vs. observed Dissolved Oxygen (DO) load at Lester River above Superior Street (calibration period)

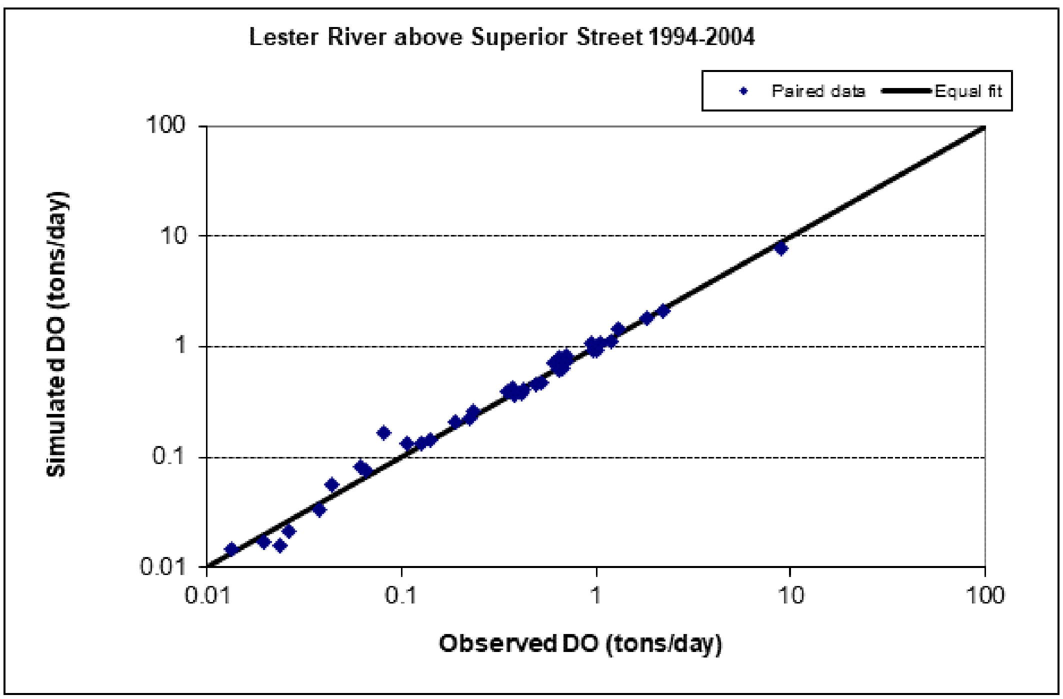


Figure E-63. Paired simulated vs. observed Dissolved Oxygen (DO) load at Lester River above Superior Street (validation period)

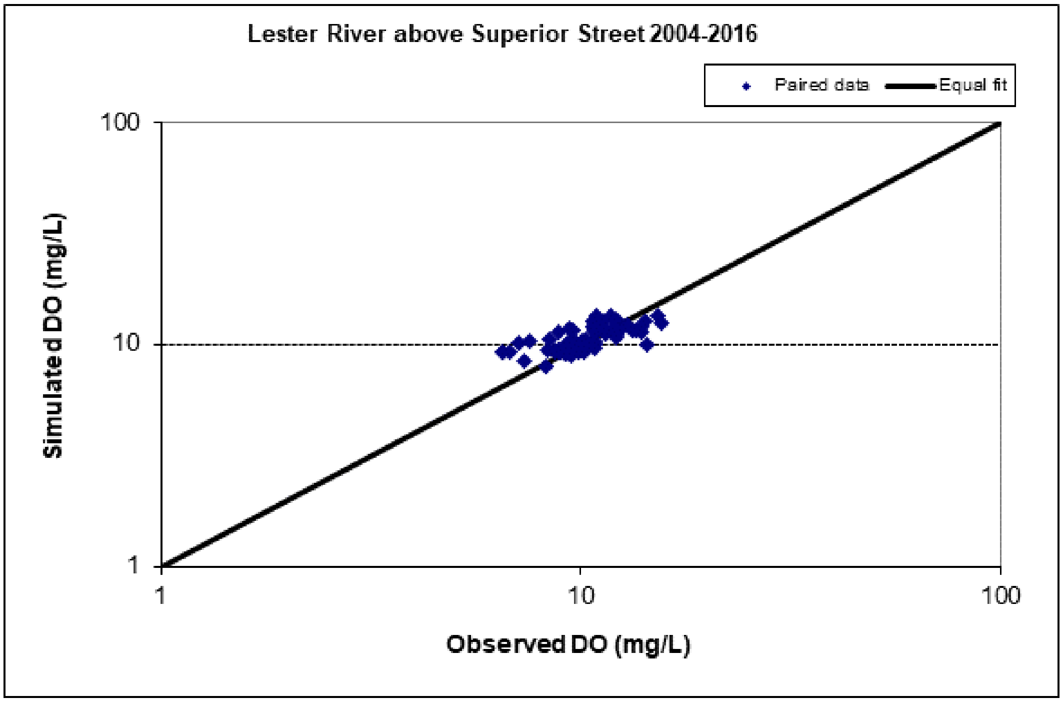


Figure E-64. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Lester River above Superior Street (calibration period)

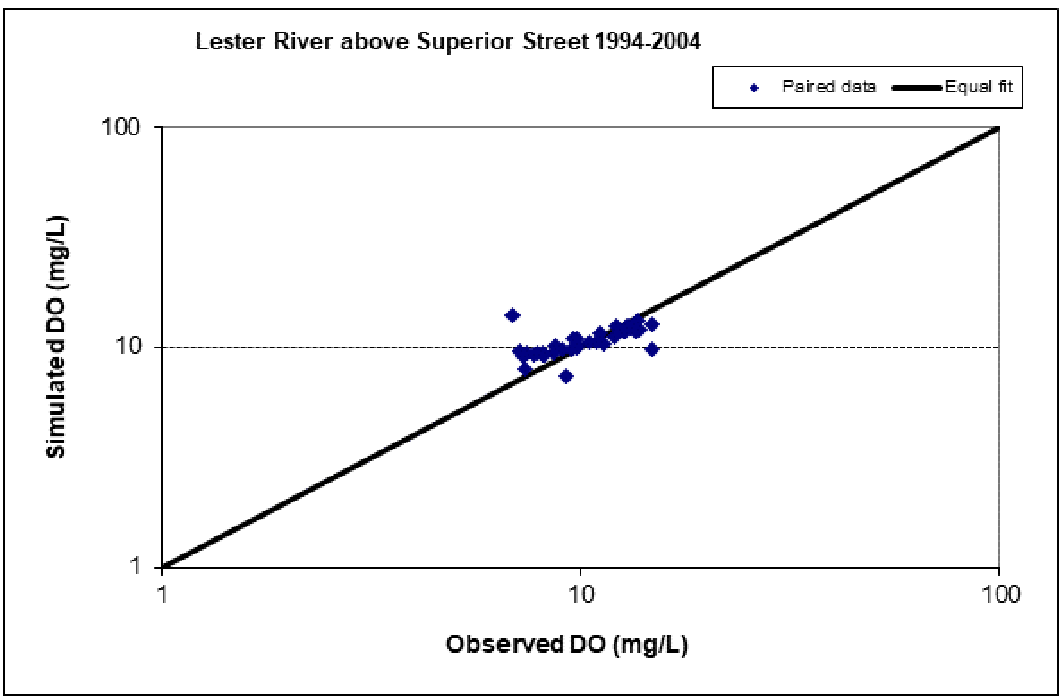


Figure E-65. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Lester River above Superior Street (validation period)

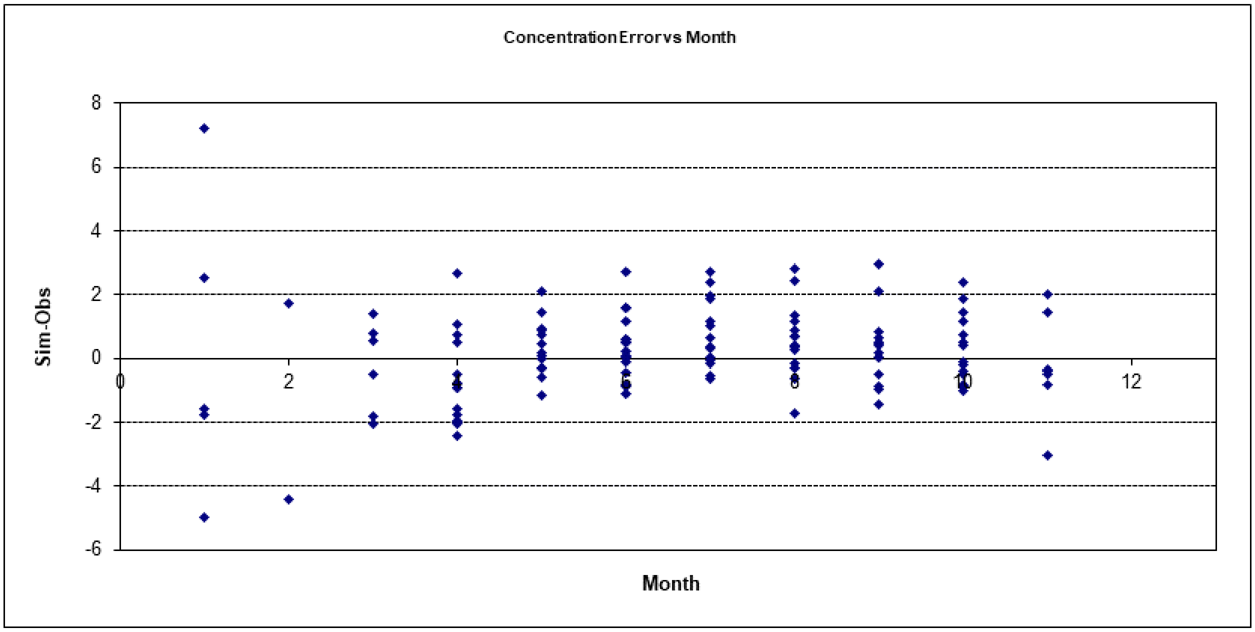


Figure E-66. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Lester River above Superior Street

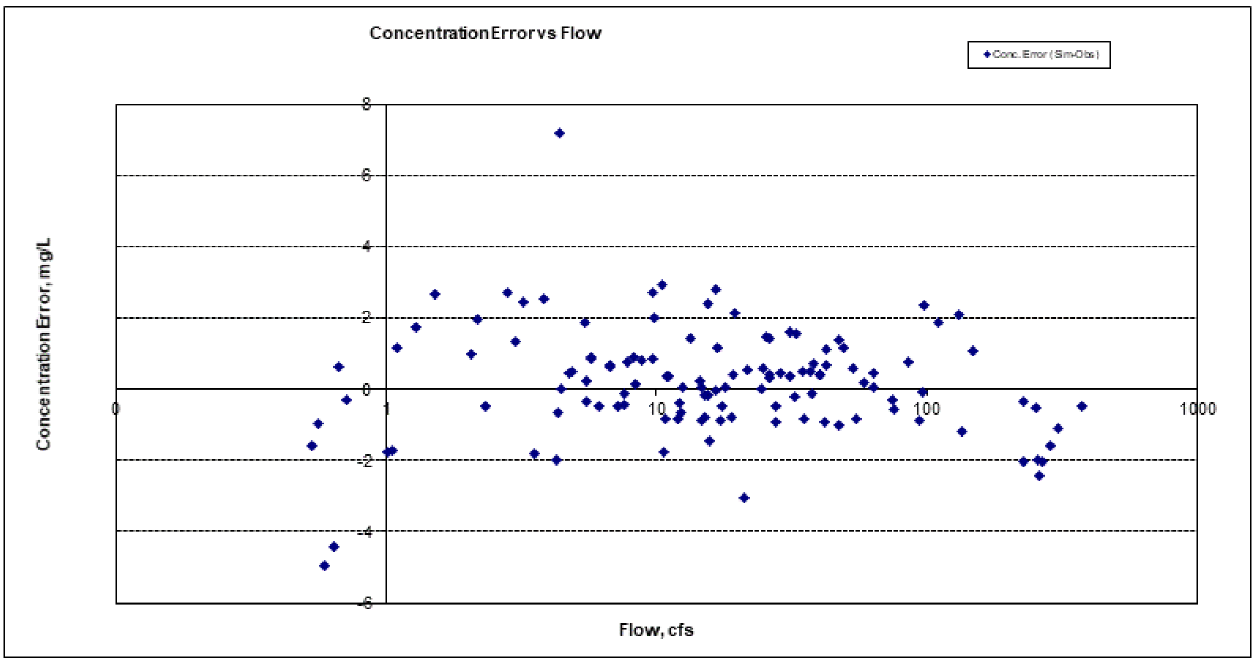


Figure E-67. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Lester River above Superior Street

E.2.2 Ammonia Nitrogen (NH3)

Table E-10. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	37	30
Concentration Average Error	-9.45%	22.56%
Concentration Median Error	20.65%	6.62%
Load Average Error	-49.91%	34.45%
Load Median Error	8.75%	9.42%
Paired t conc	0.68	0.47
Paired t load	0.24	0.31

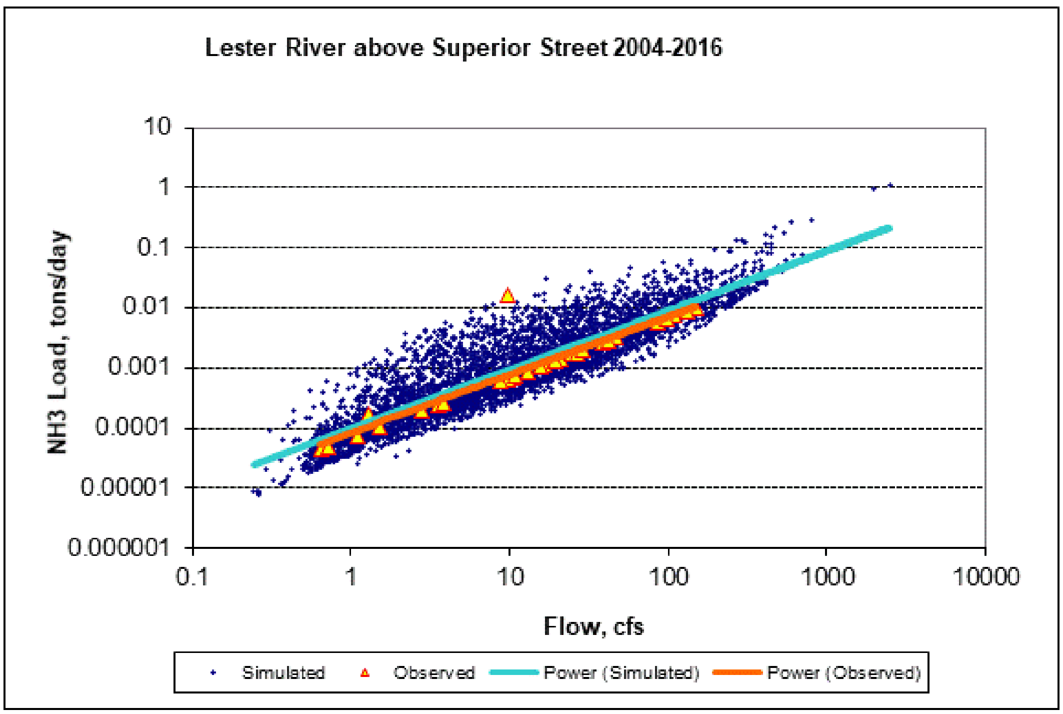


Figure E-68. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Lester River above Superior Street (calibration period)

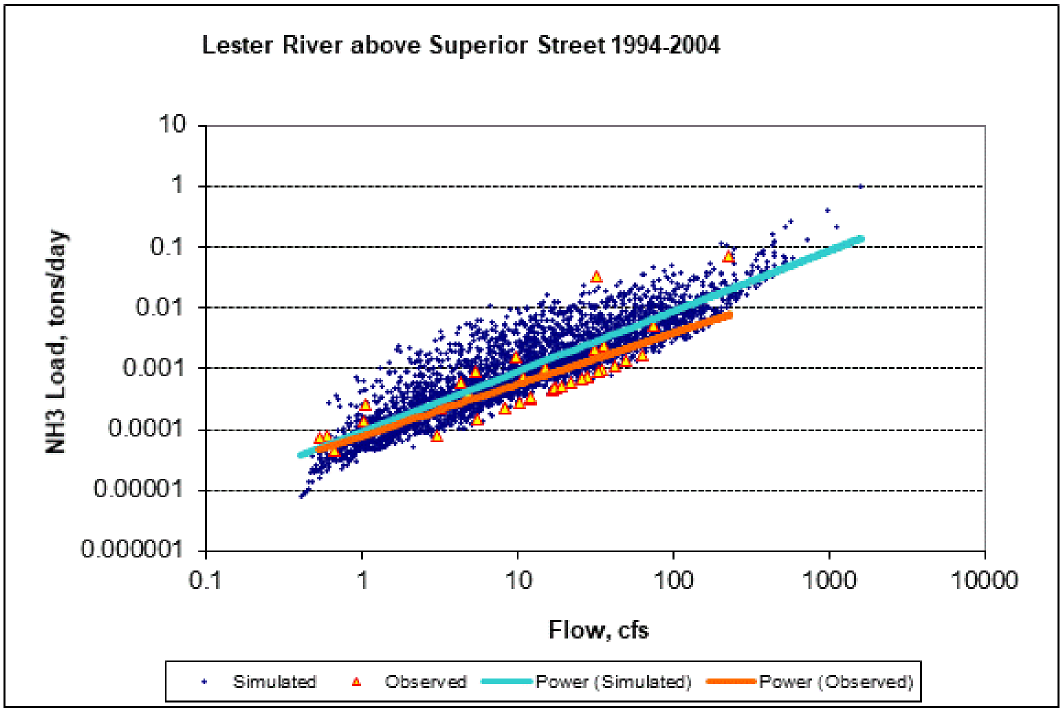


Figure E-69. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Lester River above Superior Street (validation period)

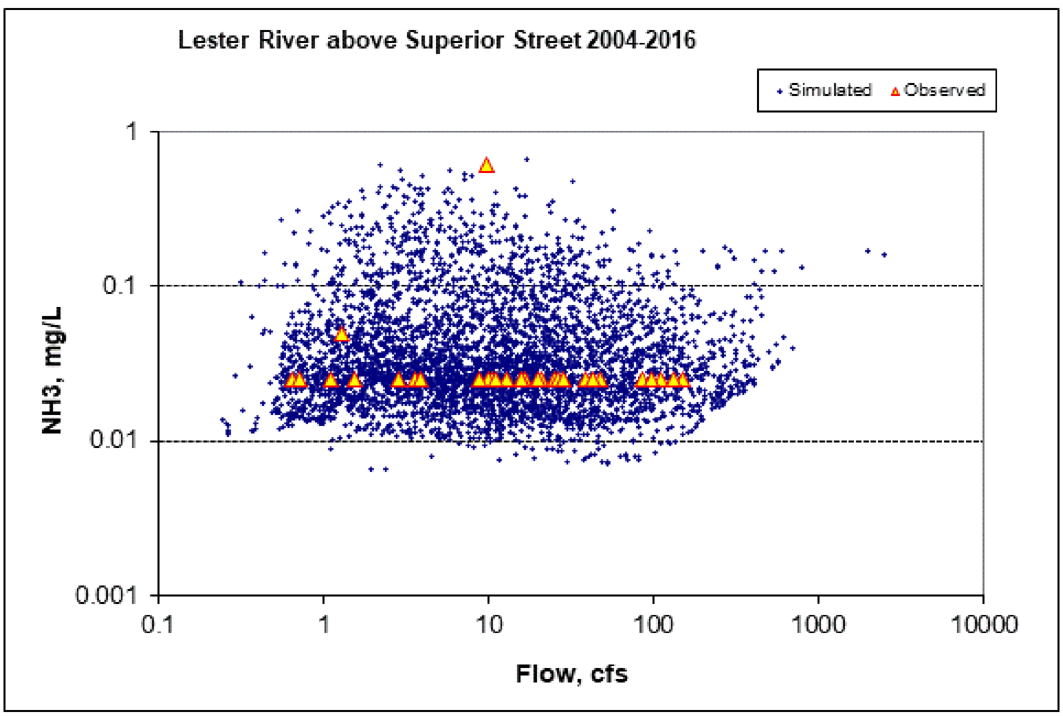


Figure E-70. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Lester River above Superior Street (calibration period)

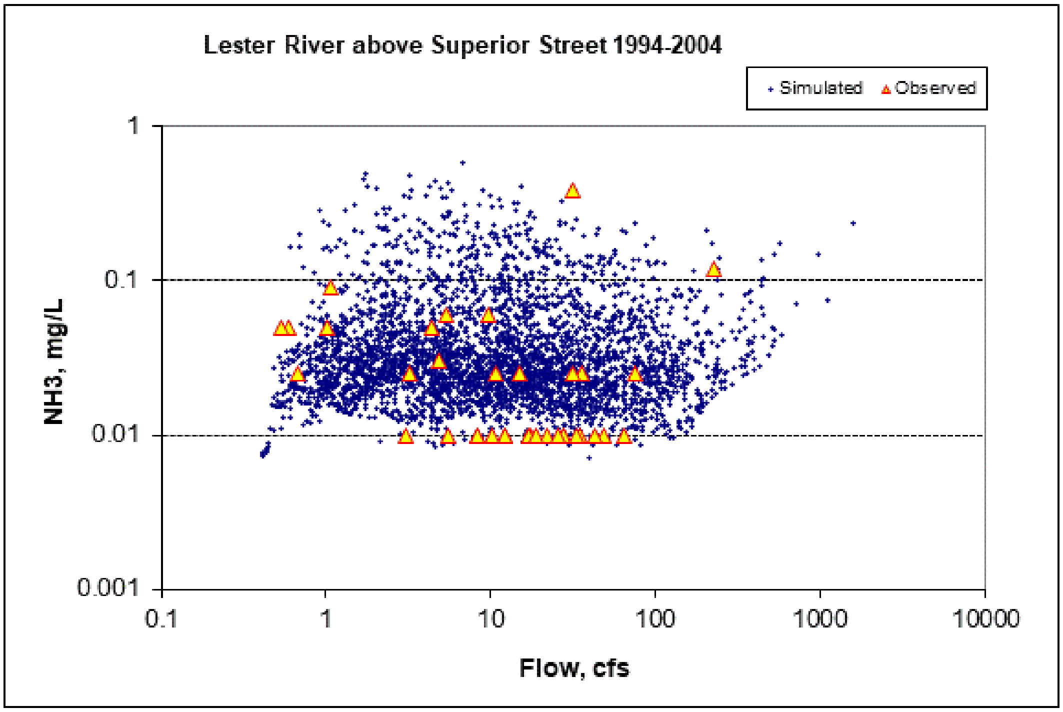
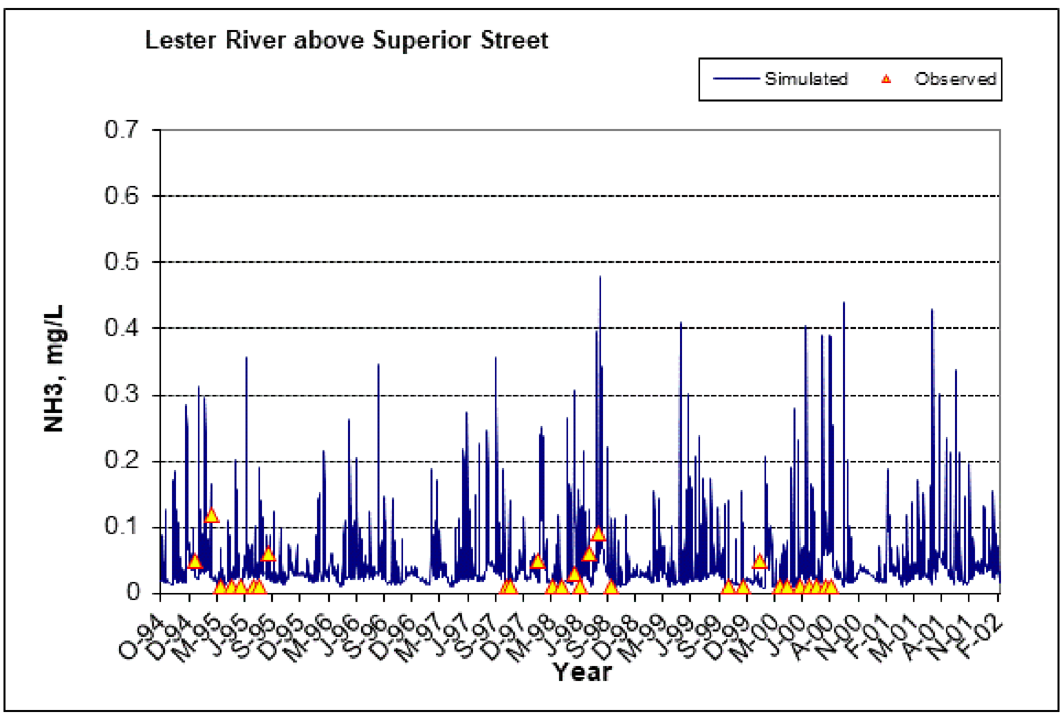


Figure E-71. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Lester River above Superior Street (validation period)



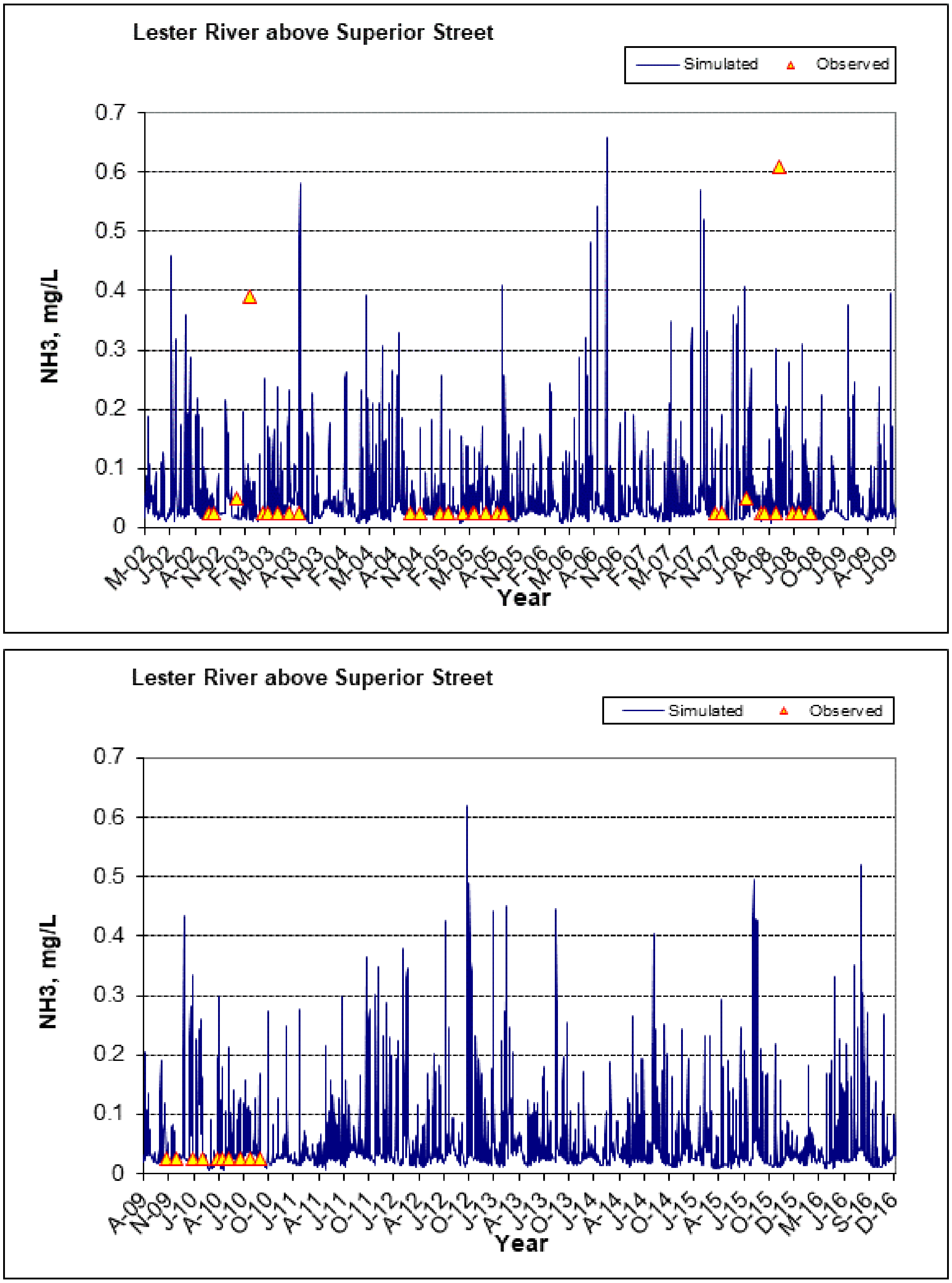


Figure E-72. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Lester River above Superior Street

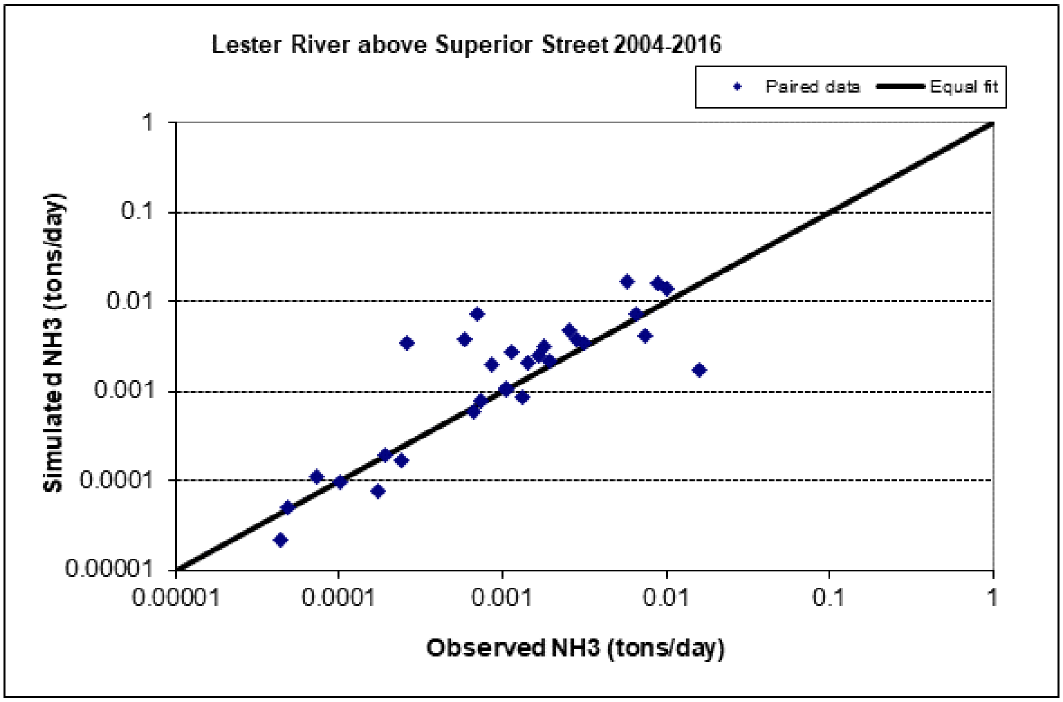


Figure E-73. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Lester River above Superior Street (calibration period)

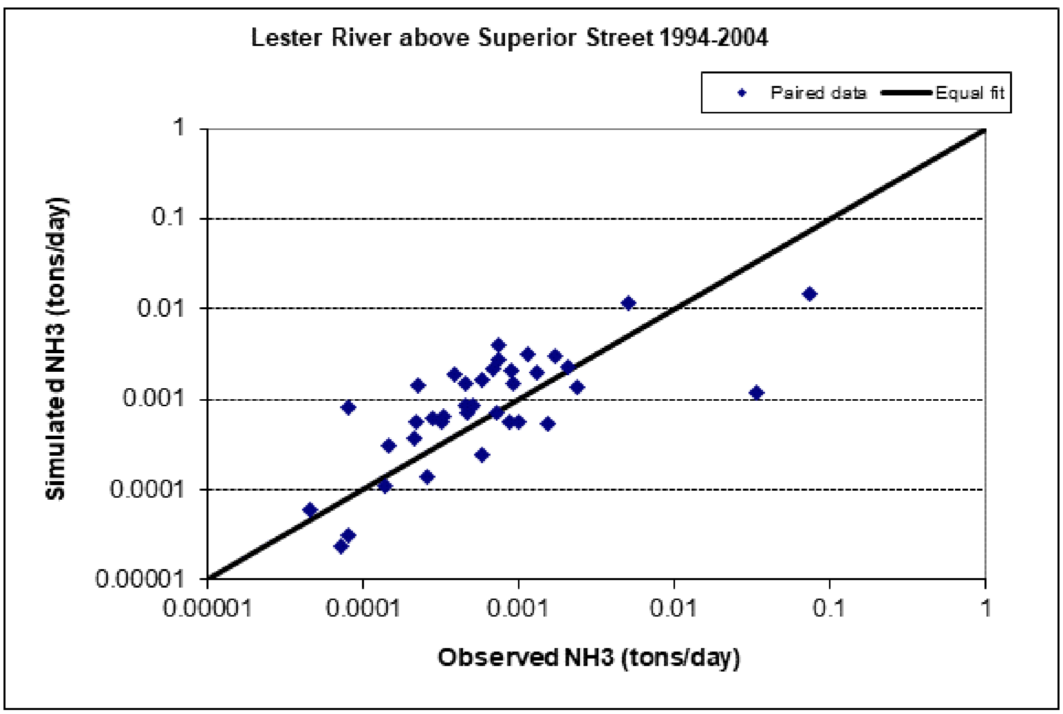


Figure E-74. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Lester River above Superior Street (validation period)

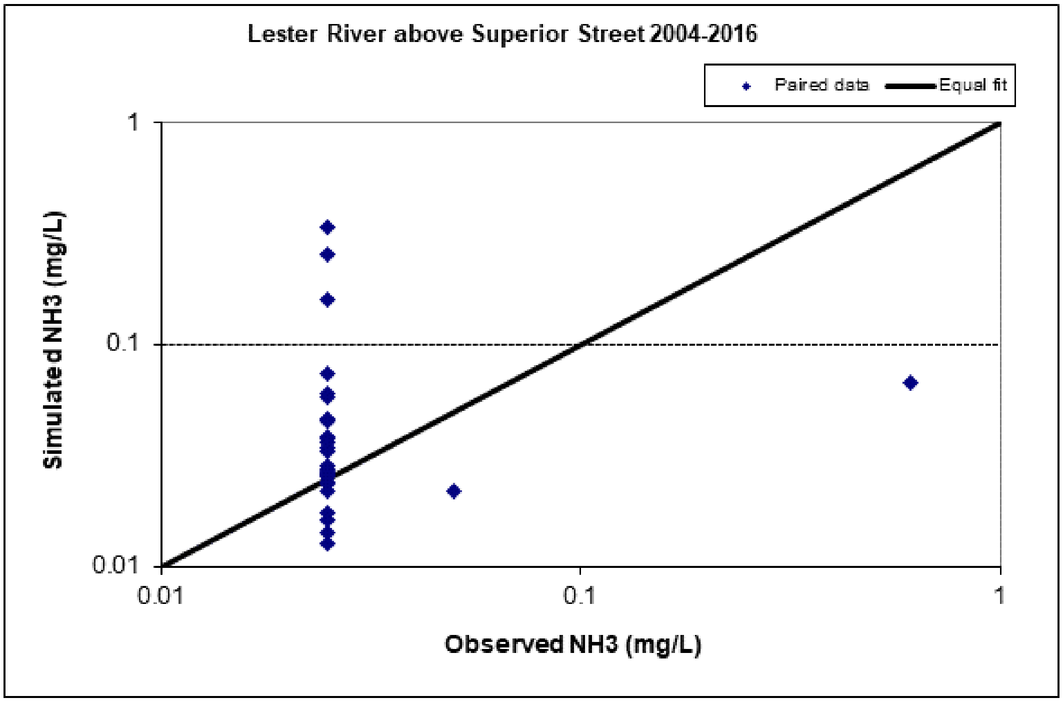


Figure E-75. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Lester River above Superior Street (calibration period)

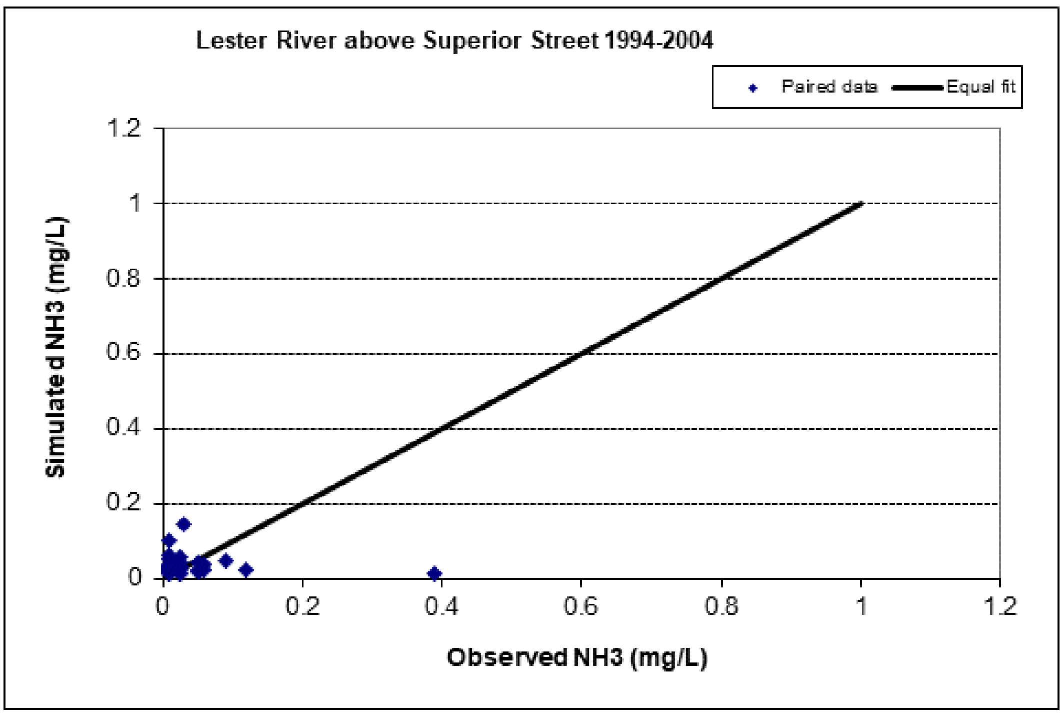


Figure E-76. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Lester River above Superior Street (validation period)

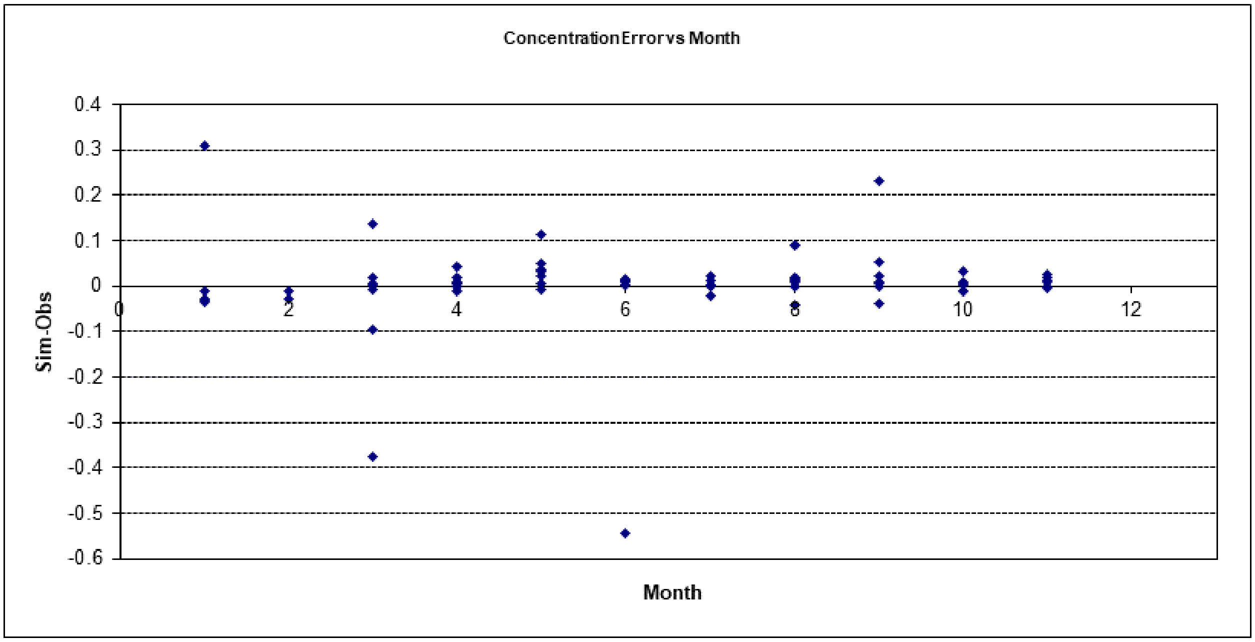


Figure E-77. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Lester River above Superior Street

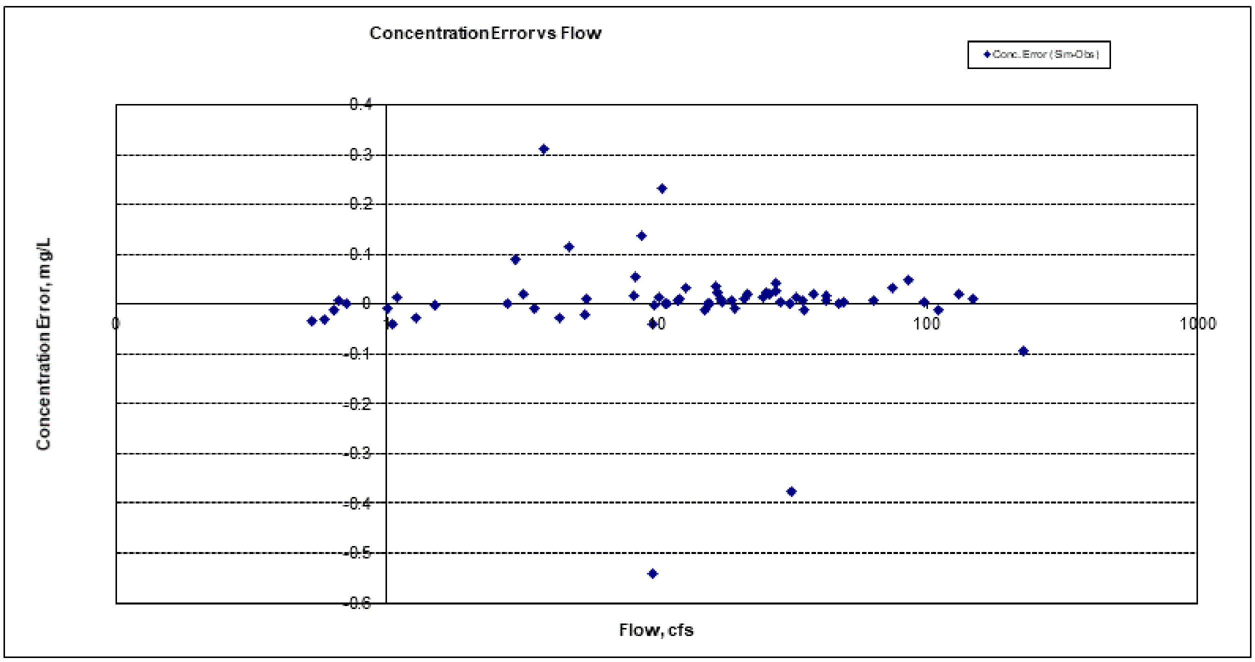


Figure E-78. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Lester River above Superior Street

E.2.3 Organic Nitrogen (OrgN)

Table E-11. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	ND	6
Concentration Average Error		-65.13%
Concentration Median Error		-67.81%
Load Average Error		-70.34%
Load Median Error		-51.88%
Paired t conc		0.00
Paired t load		0.07

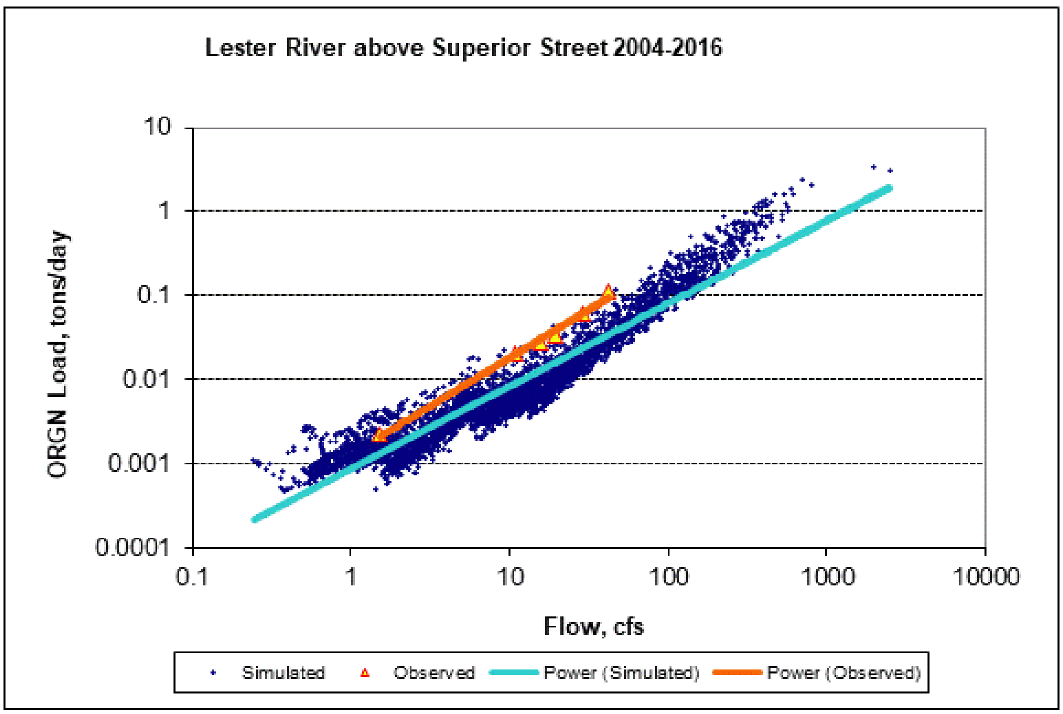


Figure E-79. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Lester River above Superior Street (calibration period)

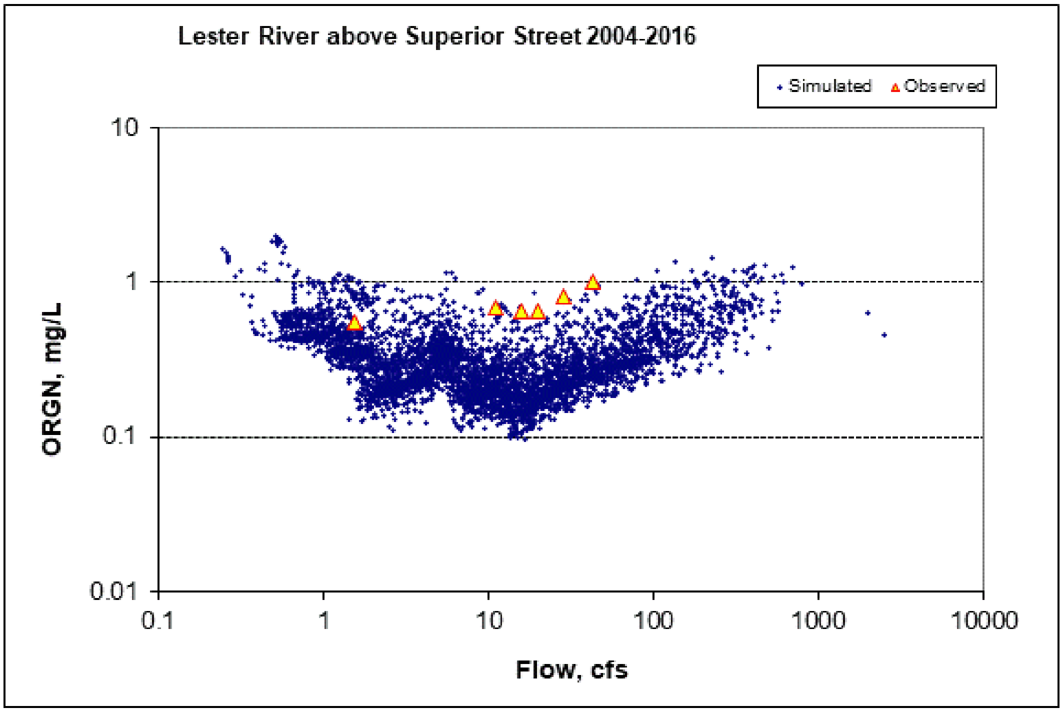
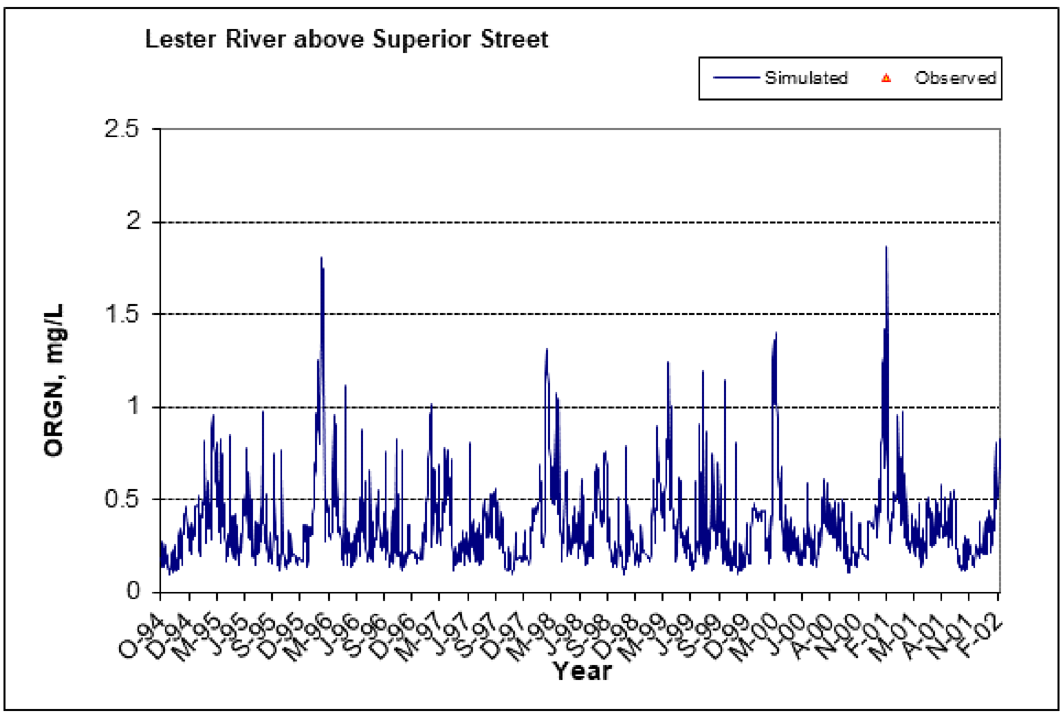


Figure E-80. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Lester River above Superior Street (calibration period)



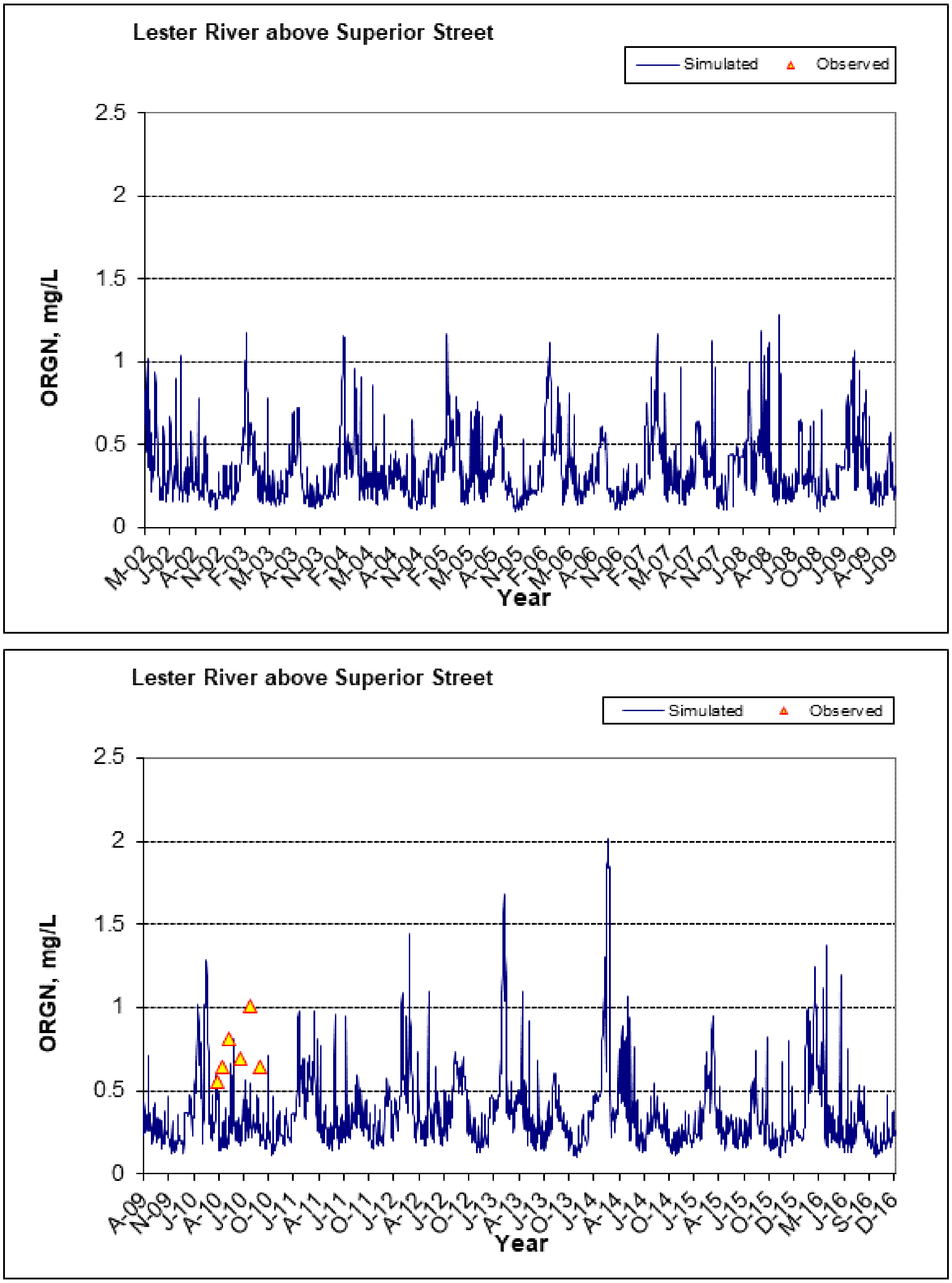


Figure E-81. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Lester River above Superior Street

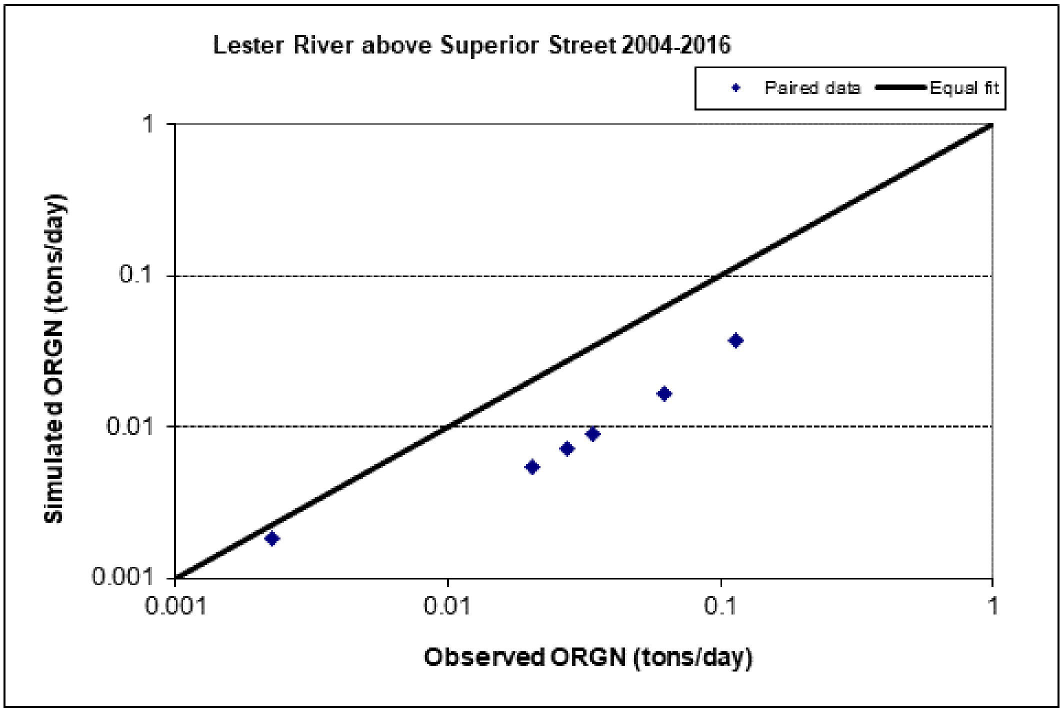


Figure E-82. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Lester River above Superior Street (calibration period)

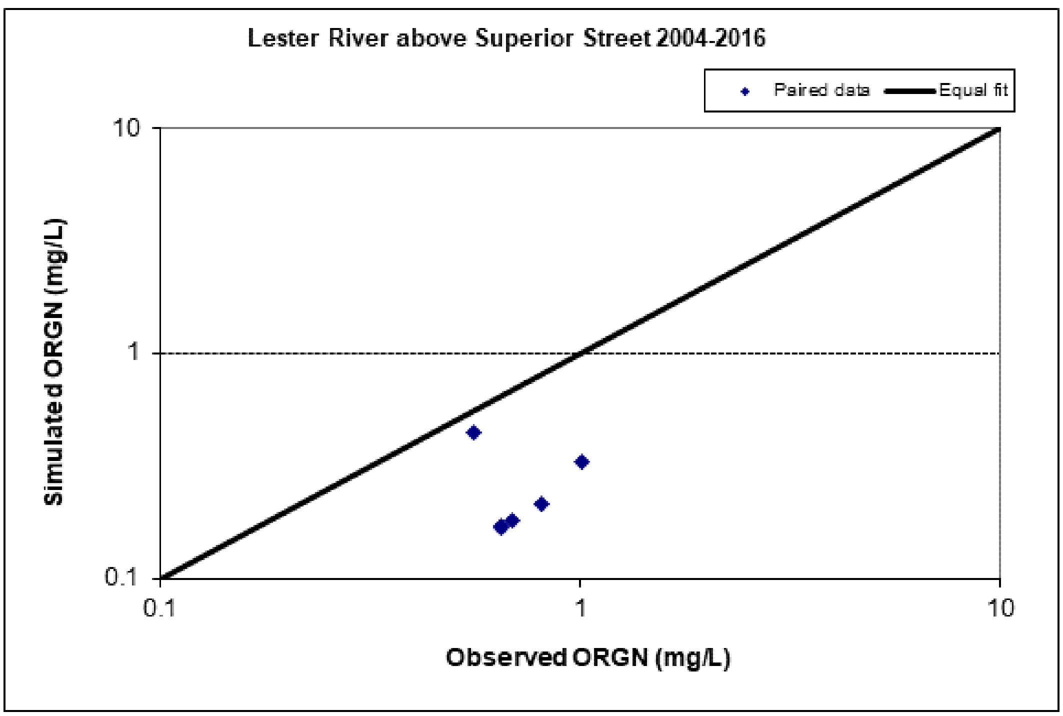


Figure E-83. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Lester River above Superior Street (calibration period)

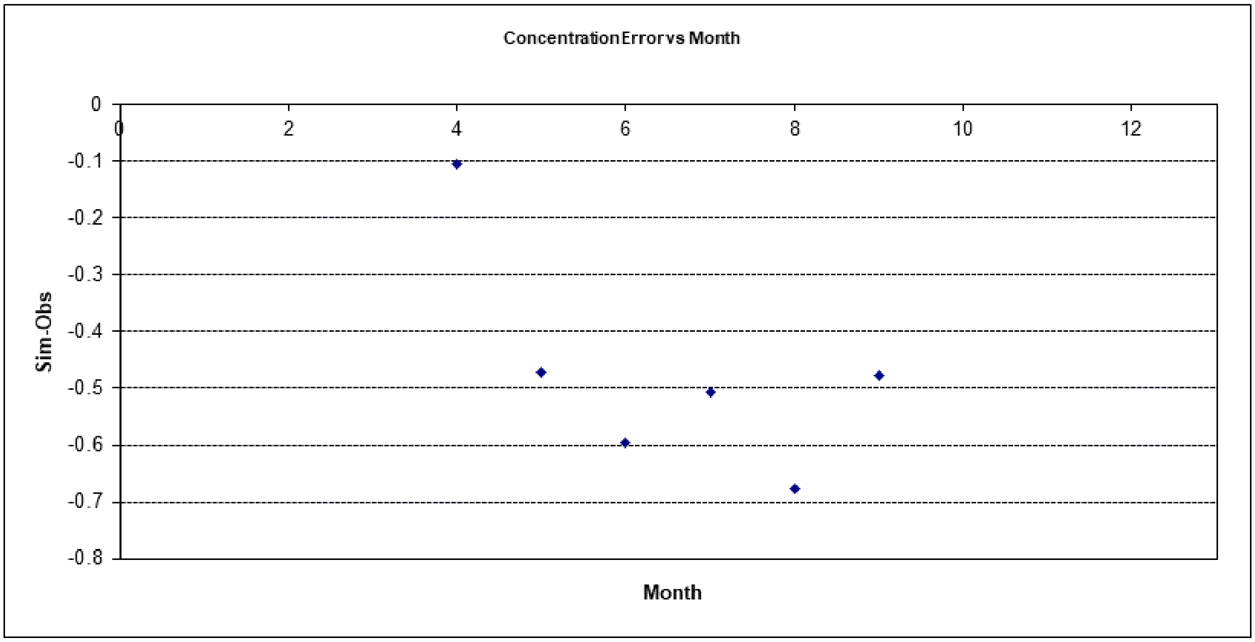


Figure E-84. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at Lester River above Superior Street

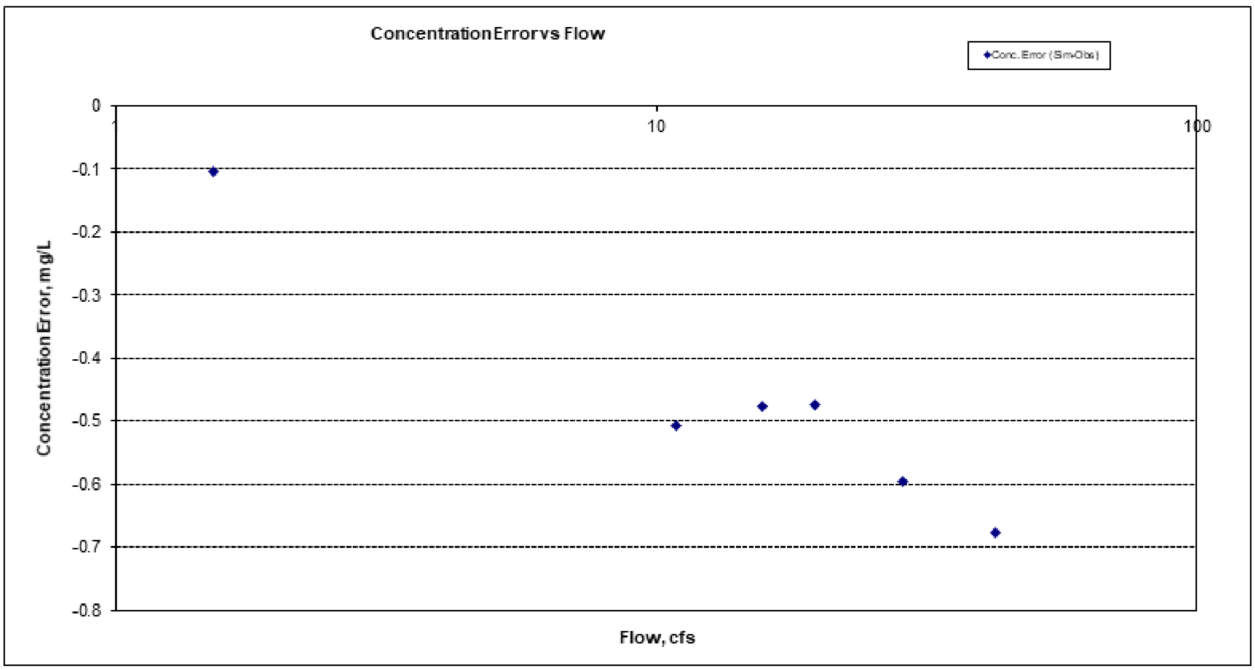


Figure E-85. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at Lester River above Superior Street

E.2.4 Total Kjeldahl Nitrogen (TKN)

Table E-12. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	ND	6
Concentration Average Error		-62.90%
Concentration Median Error		-65.81%
Load Average Error		-67.96%
Load Median Error		-50.88%
Paired t conc		0.00
Paired t load		0.07

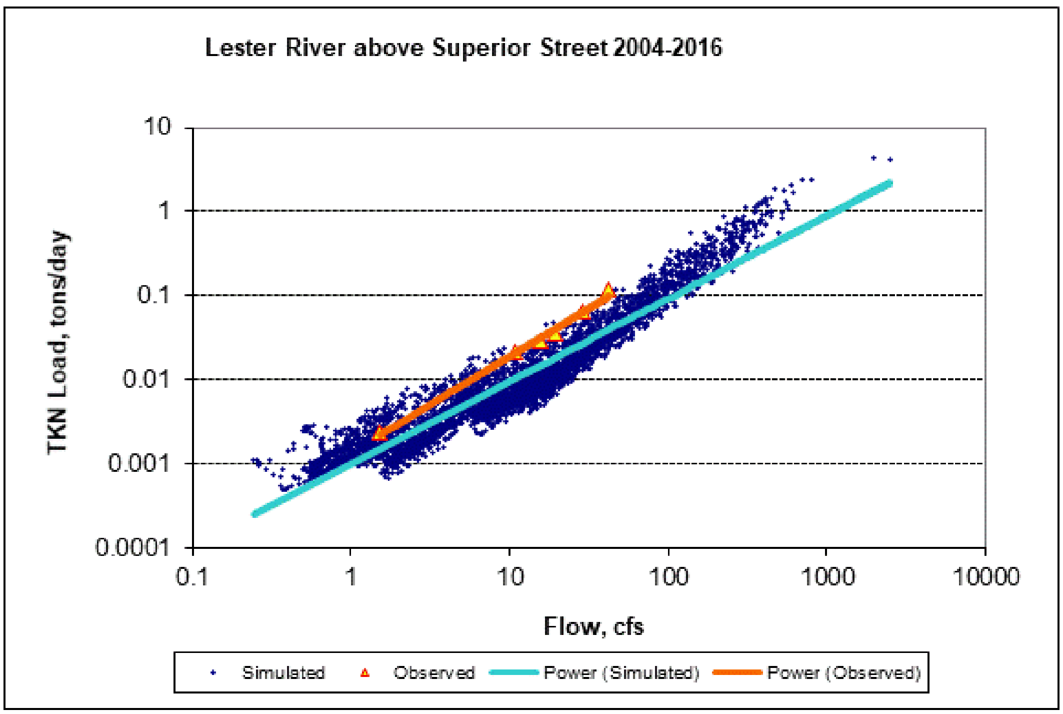


Figure E-86. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Lester River above Superior Street (calibration period)

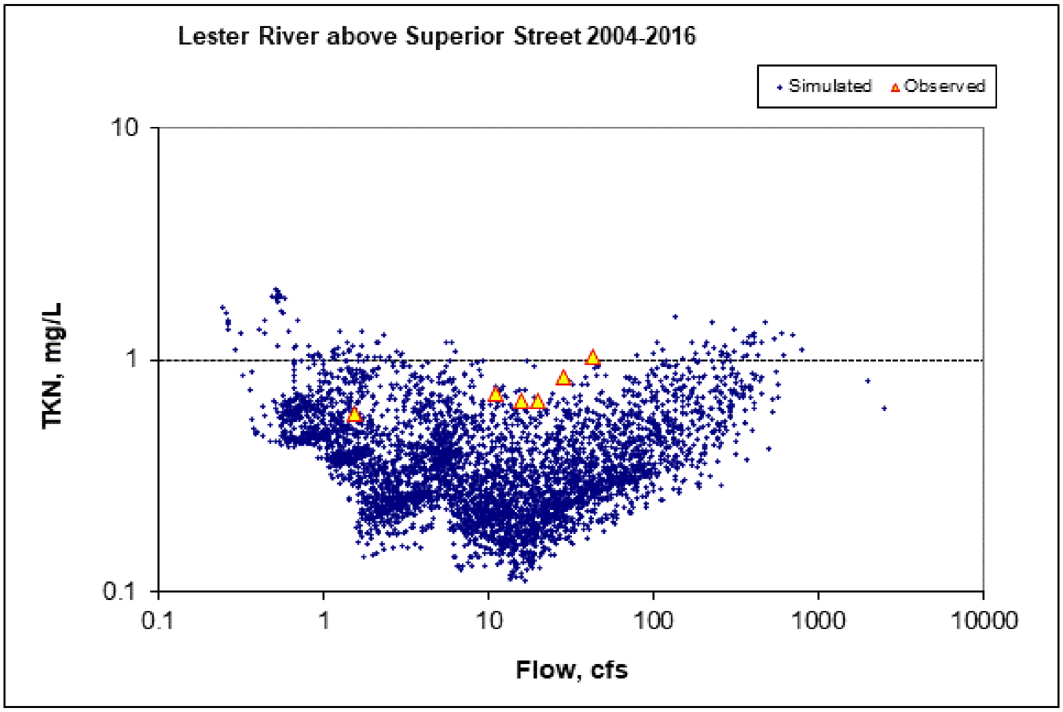
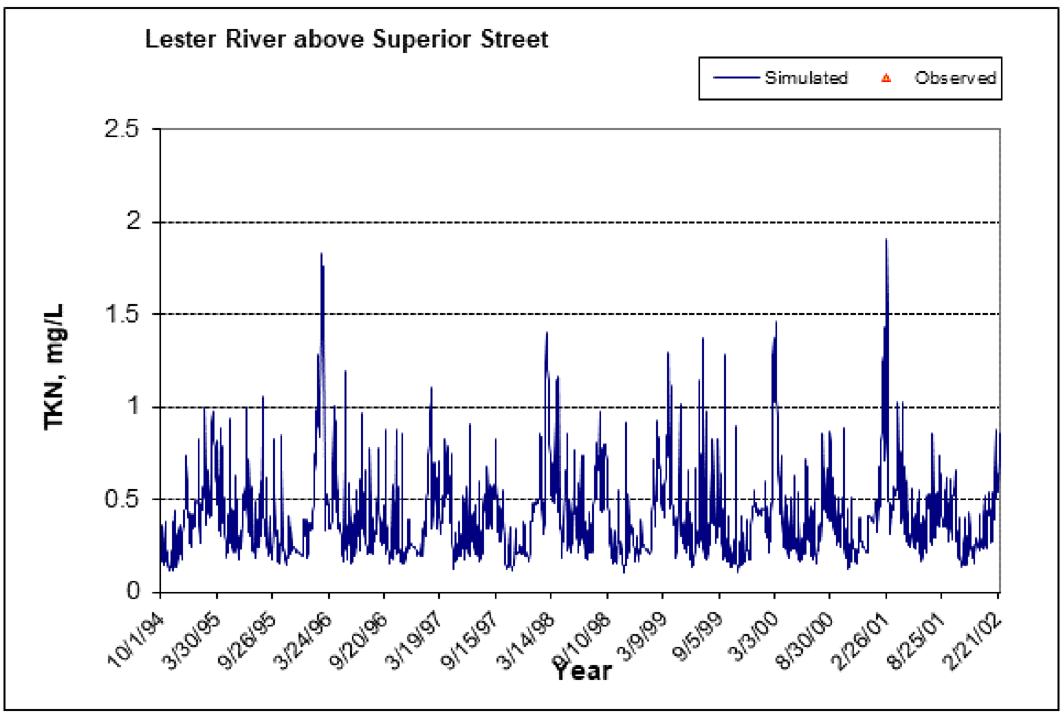


Figure E-87. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Lester River above Superior Street (calibration period)



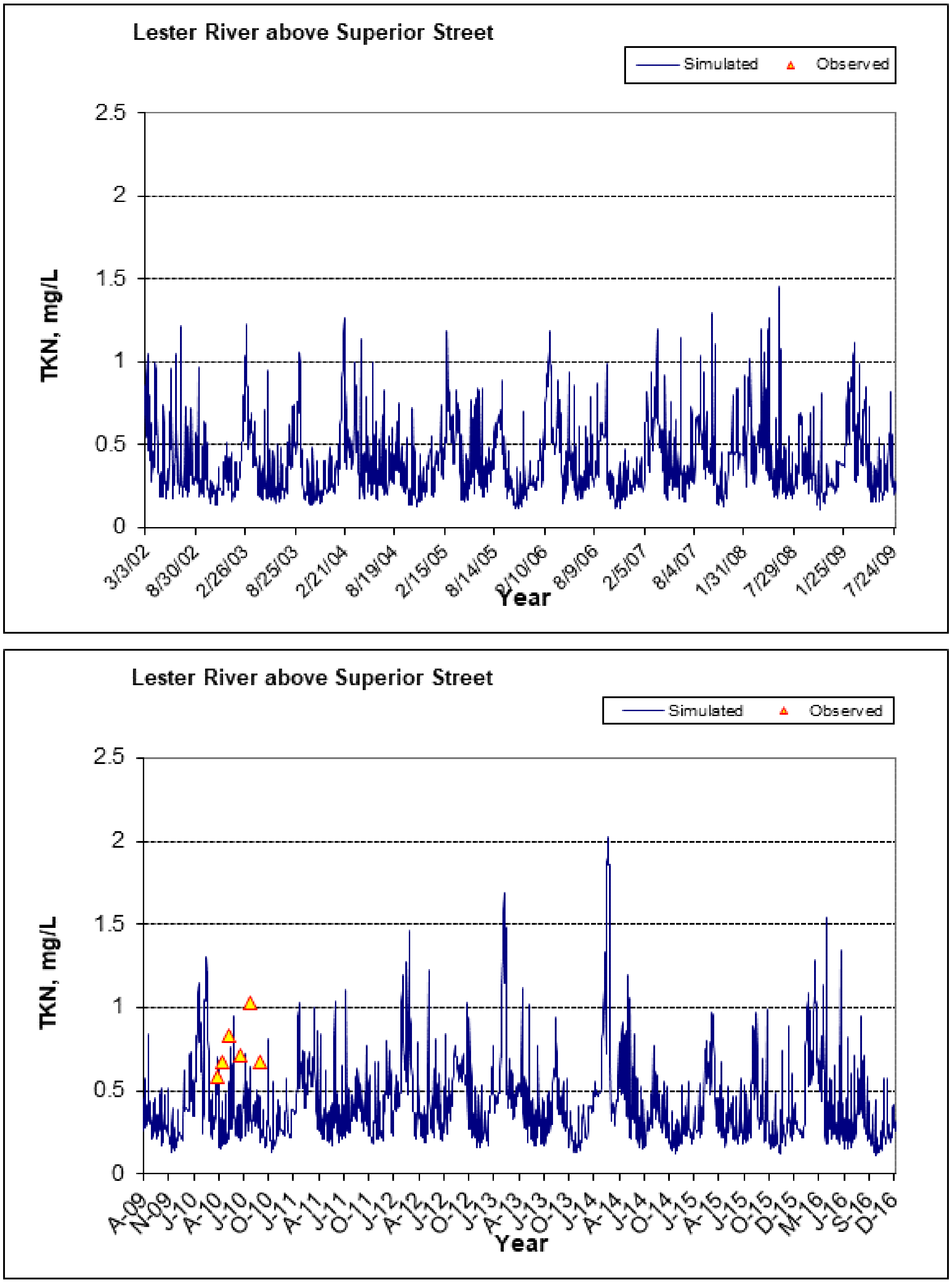


Figure E-88. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Lester River above Superior Street

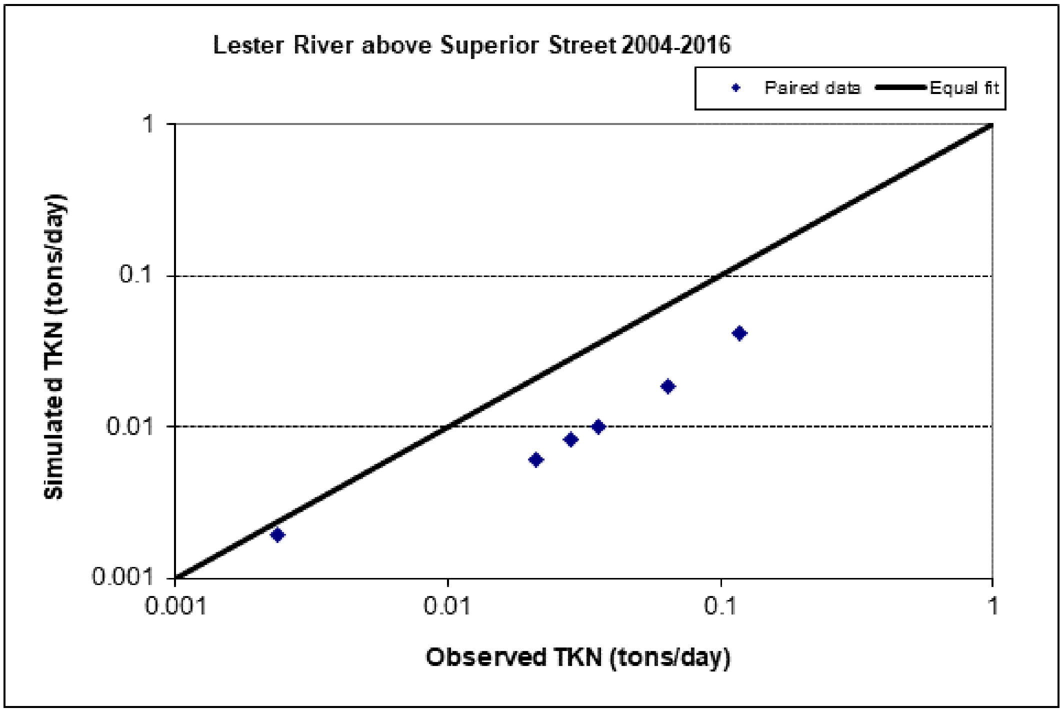


Figure E-89. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Lester River above Superior Street (calibration period)

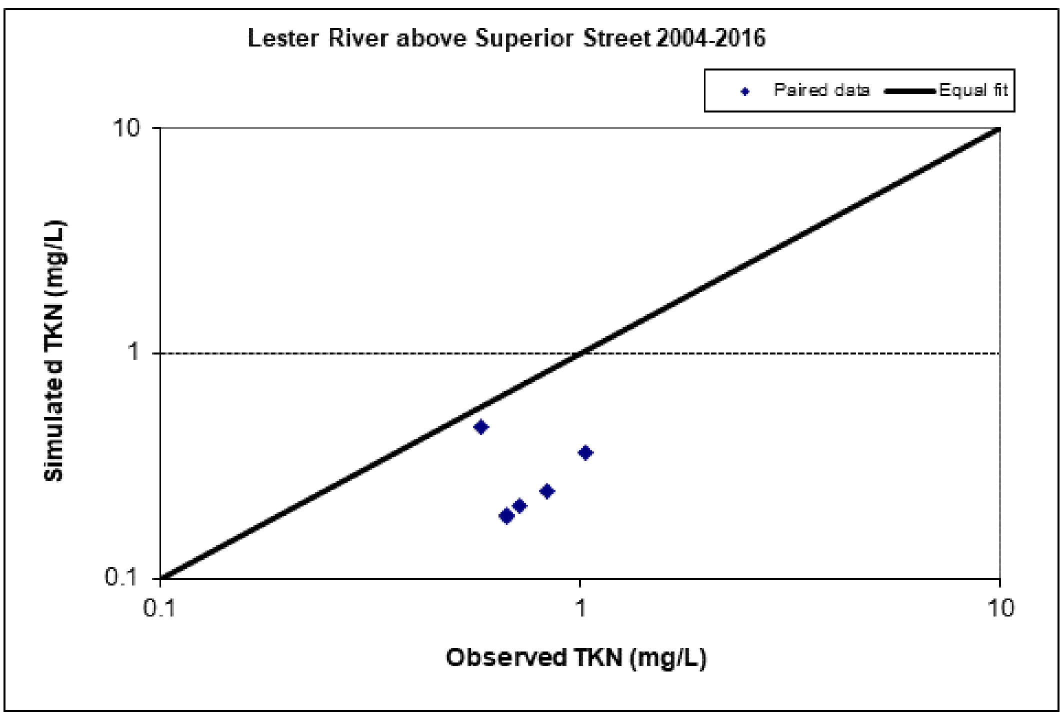


Figure E-90. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Lester River above Superior Street (calibration period)

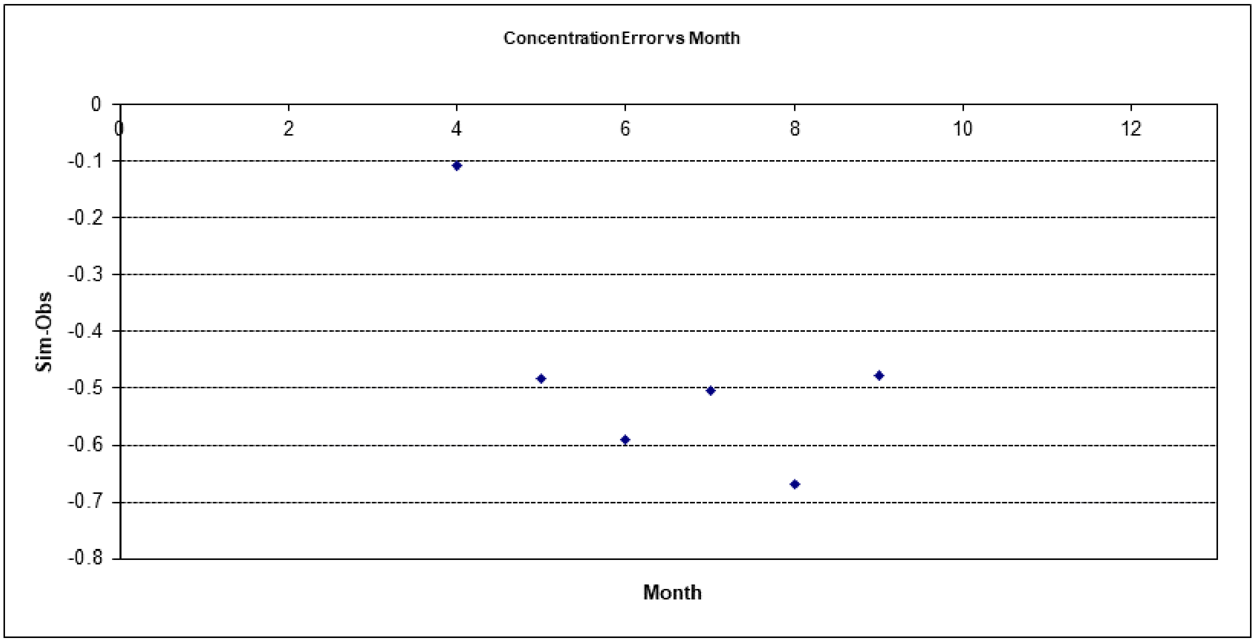


Figure E-91. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at Lester River above Superior Street

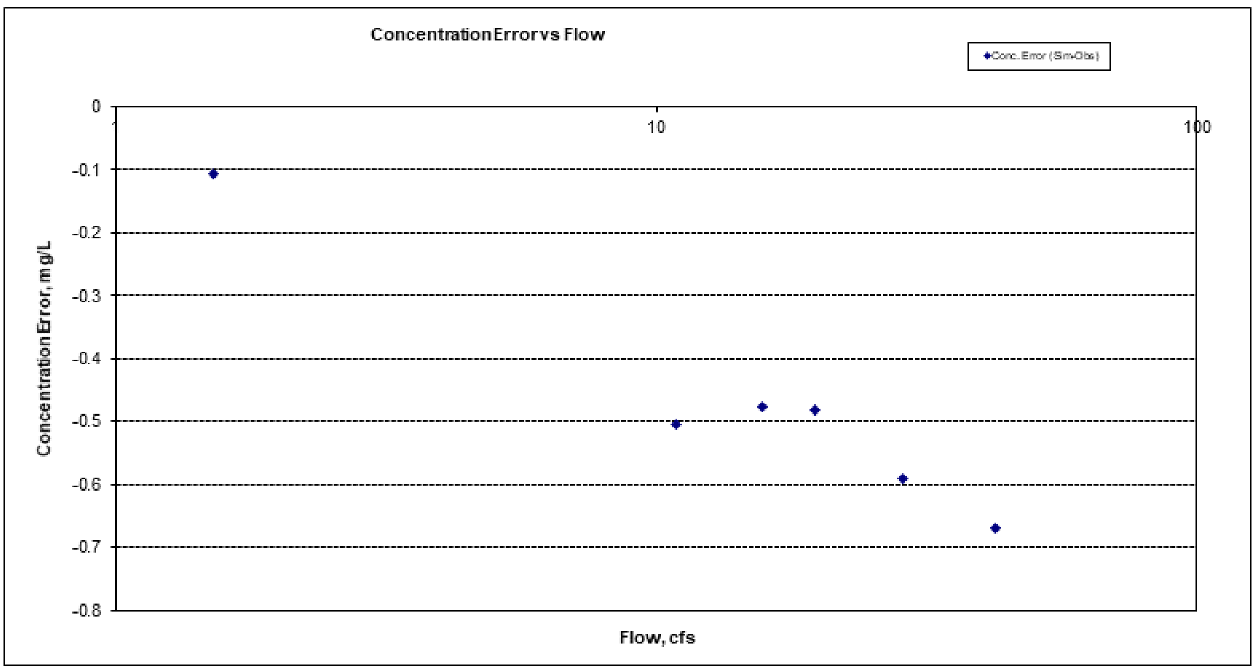


Figure E-92. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at Lester River above Superior Street

E.2.5 Nitrite+ Nitrate Nitrogen (NOx)

Table E-13. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	37	30
Concentration Average Error	-43.40%	85.97%
Concentration Median Error	-13.42%	19.41%
Load Average Error	-57.18%	38.73%
Load Median Error	-2.79%	3.01%
Paired t conc	0.08	0.06
Paired t load	0.23	0.36

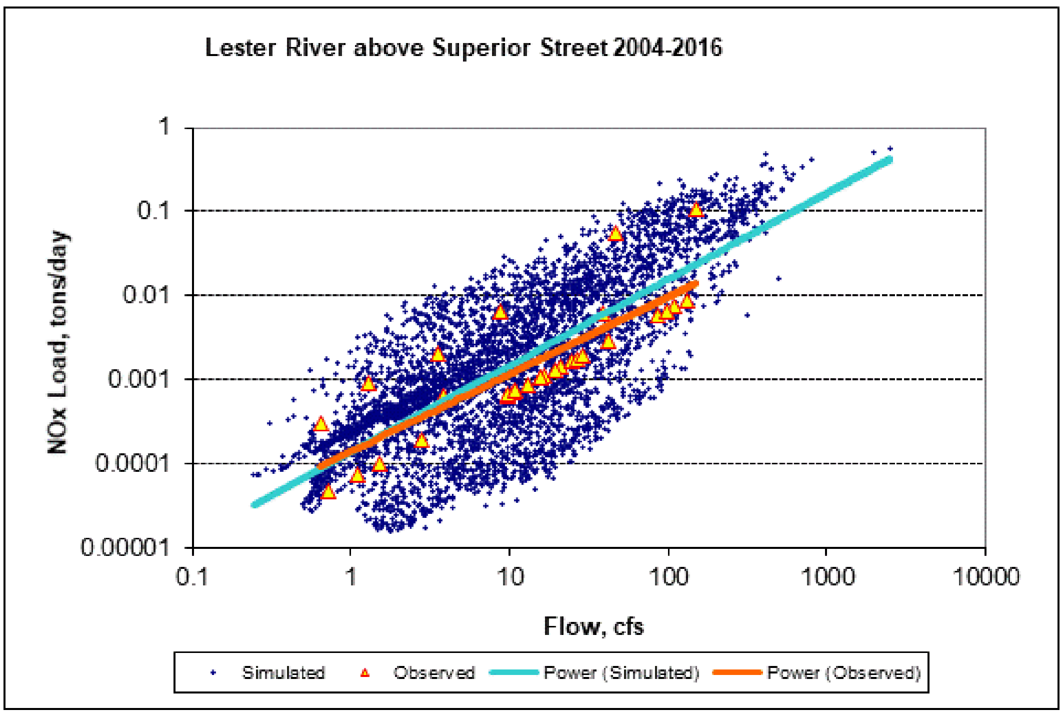


Figure E-93. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Lester River above Superior Street (calibration period)

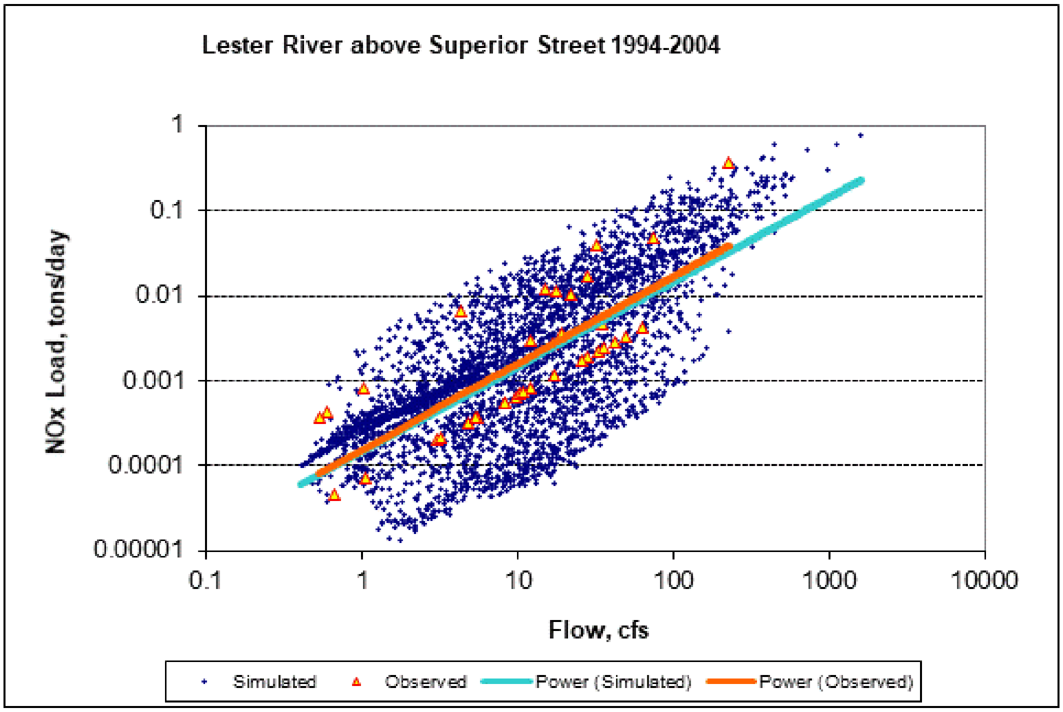


Figure E-94. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Lester River above Superior Street (validation period)

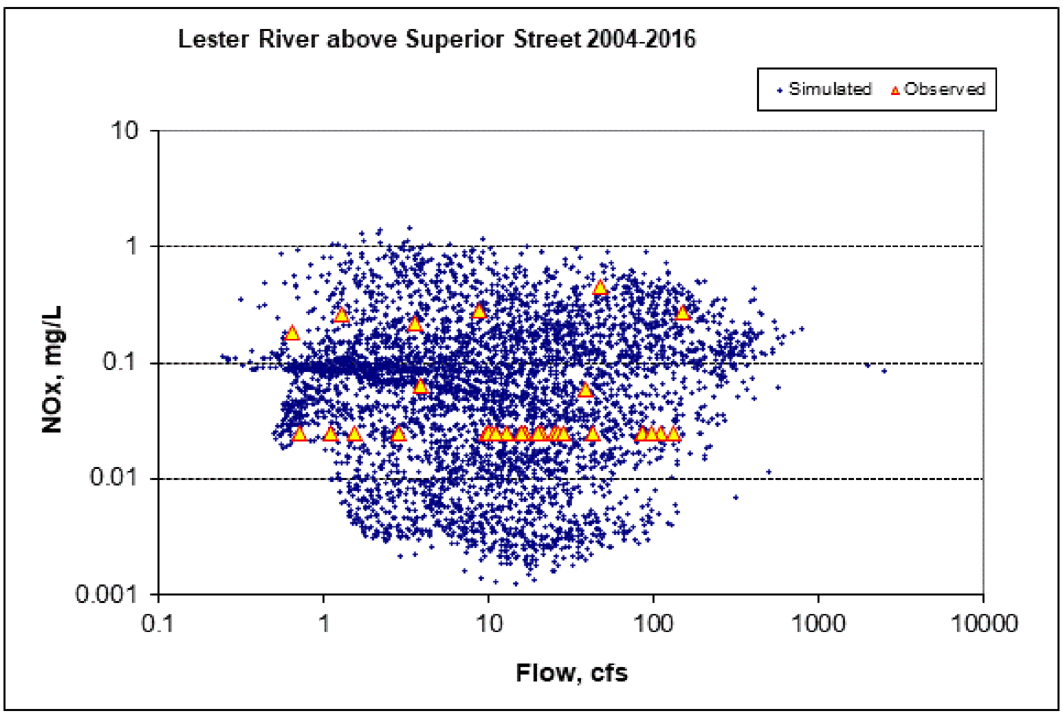


Figure E-95. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Lester River above Superior Street (calibration period)

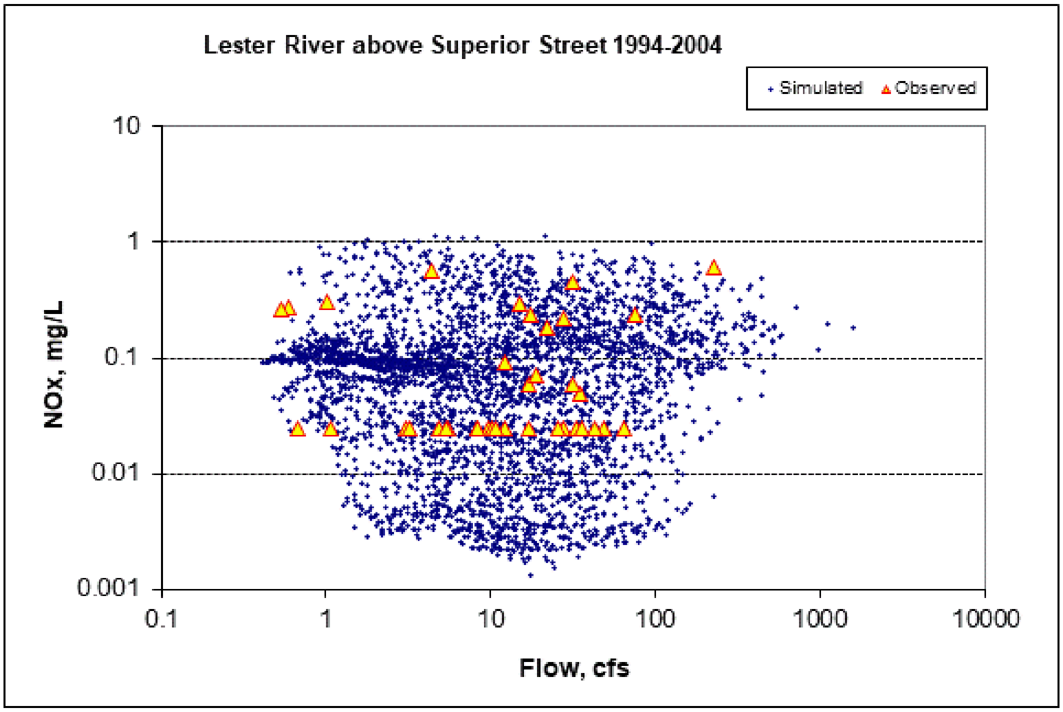
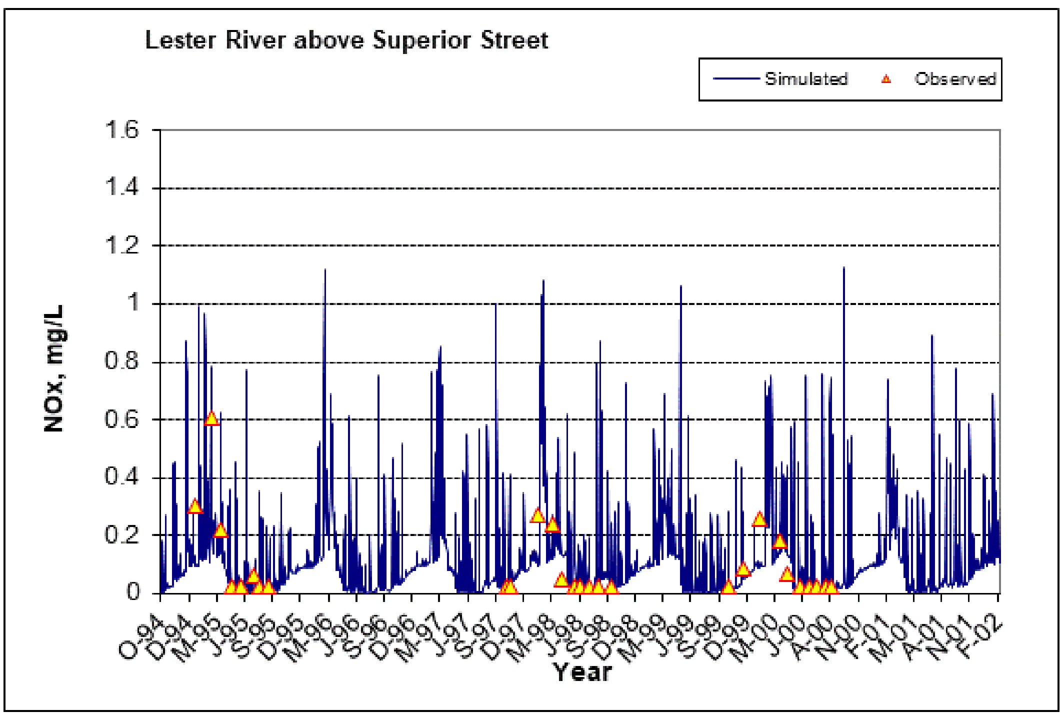


Figure E-96. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Lester River above Superior Street (validation period)



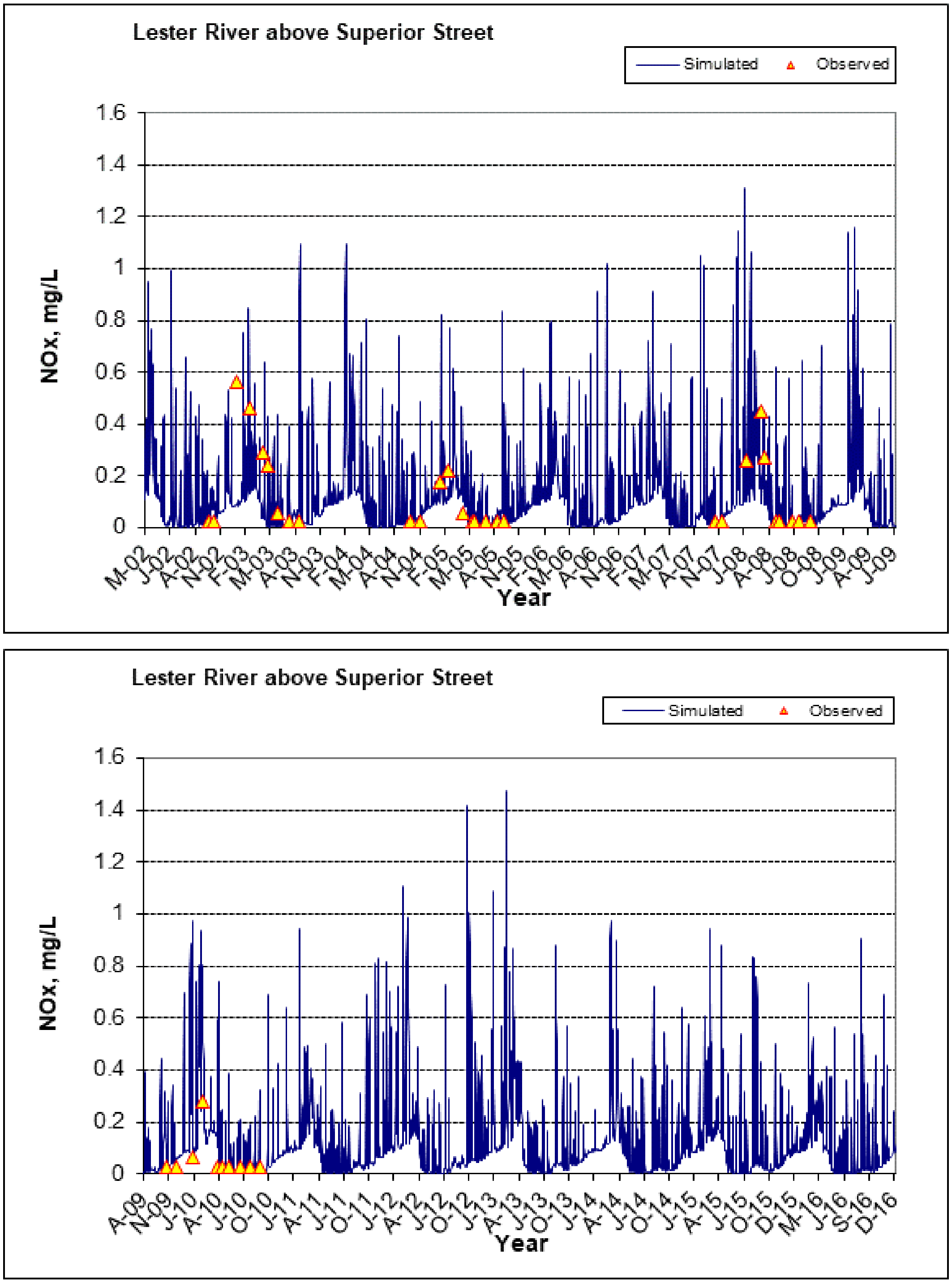


Figure E-97. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Lester River above Superior Street

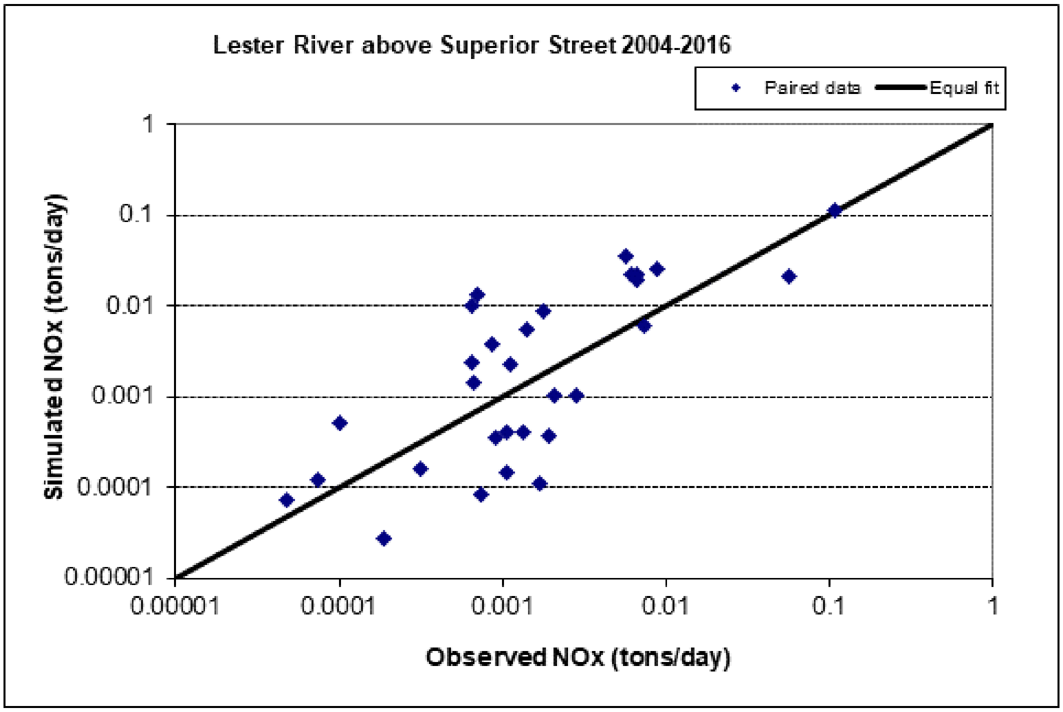


Figure E-98. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Lester River above Superior Street (calibration period)

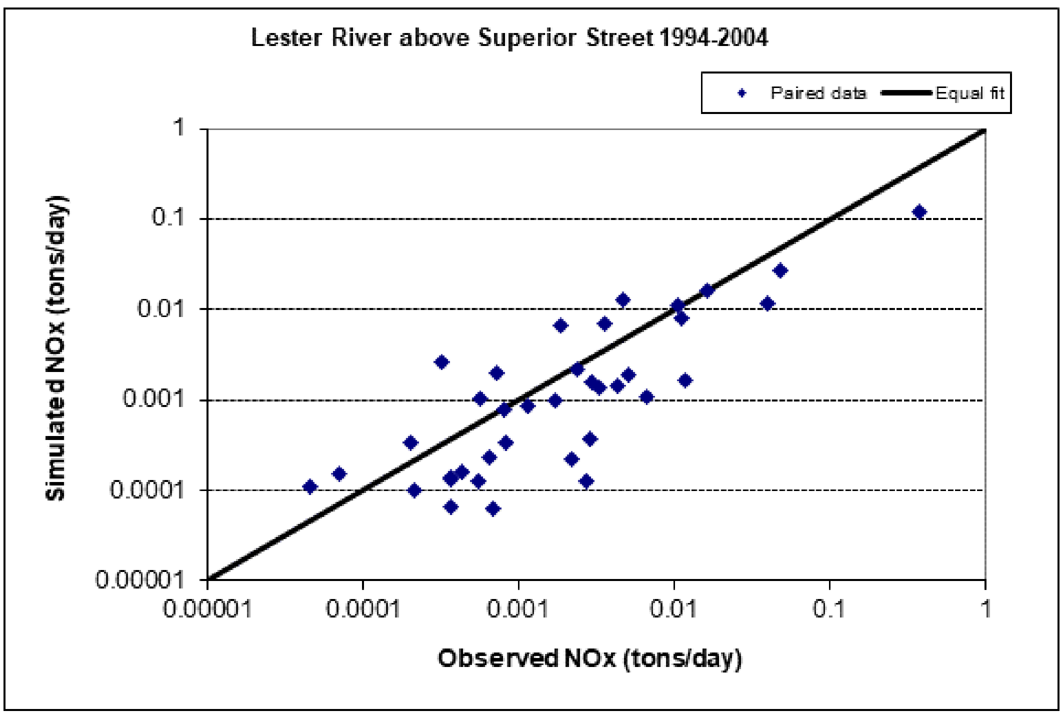


Figure E-99. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Lester River above Superior Street (validation period)

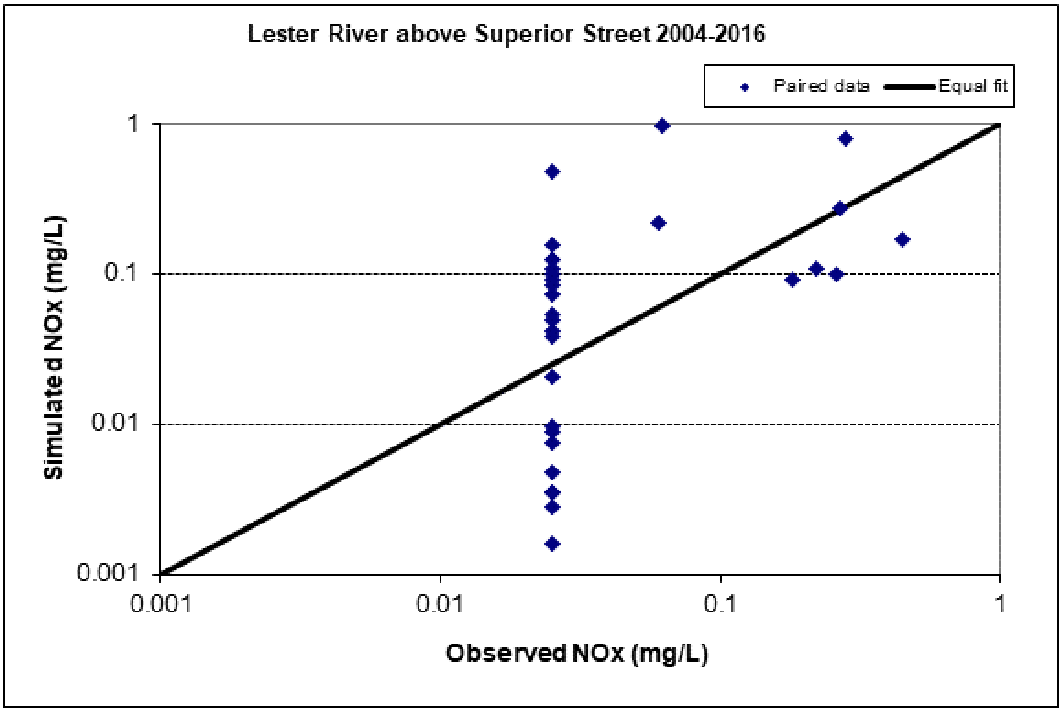


Figure E-100. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Lester River above Superior Street (calibration period)

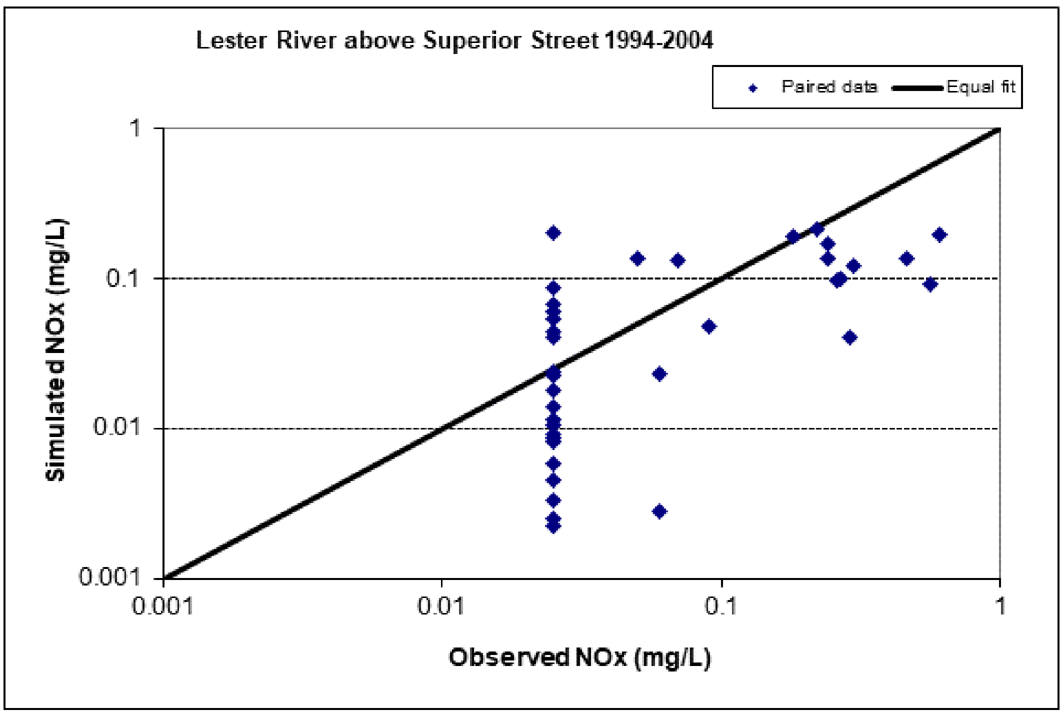


Figure E-101. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Lester River above Superior Street (validation period)

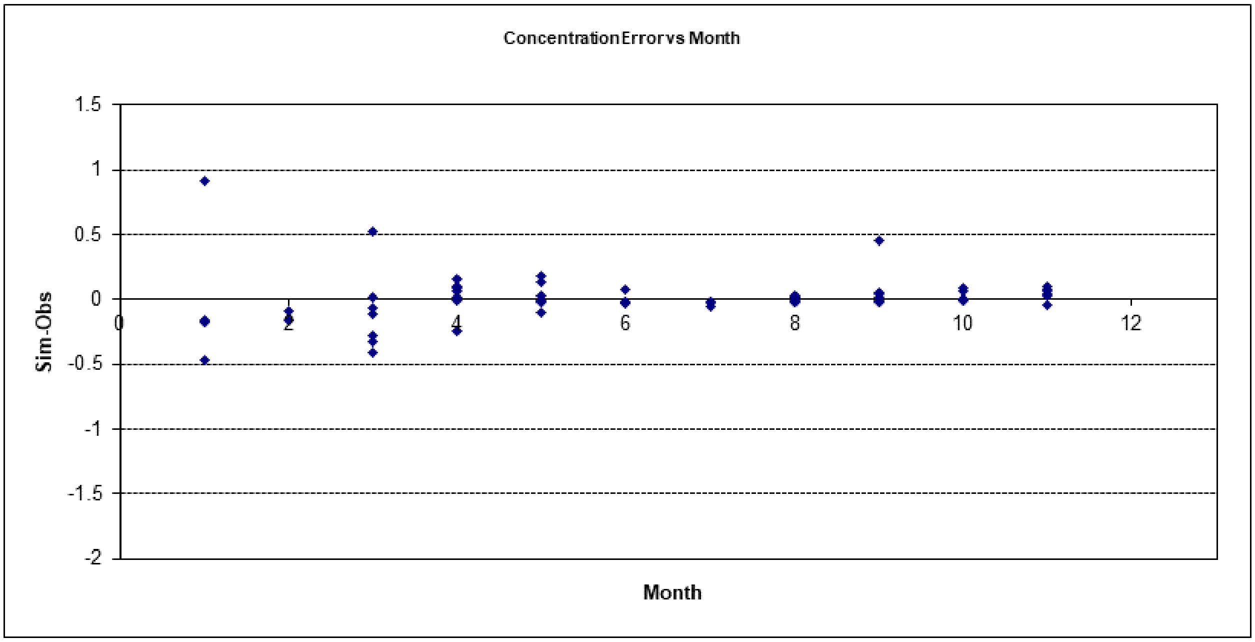


Figure E-102. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Lester River above Superior Street

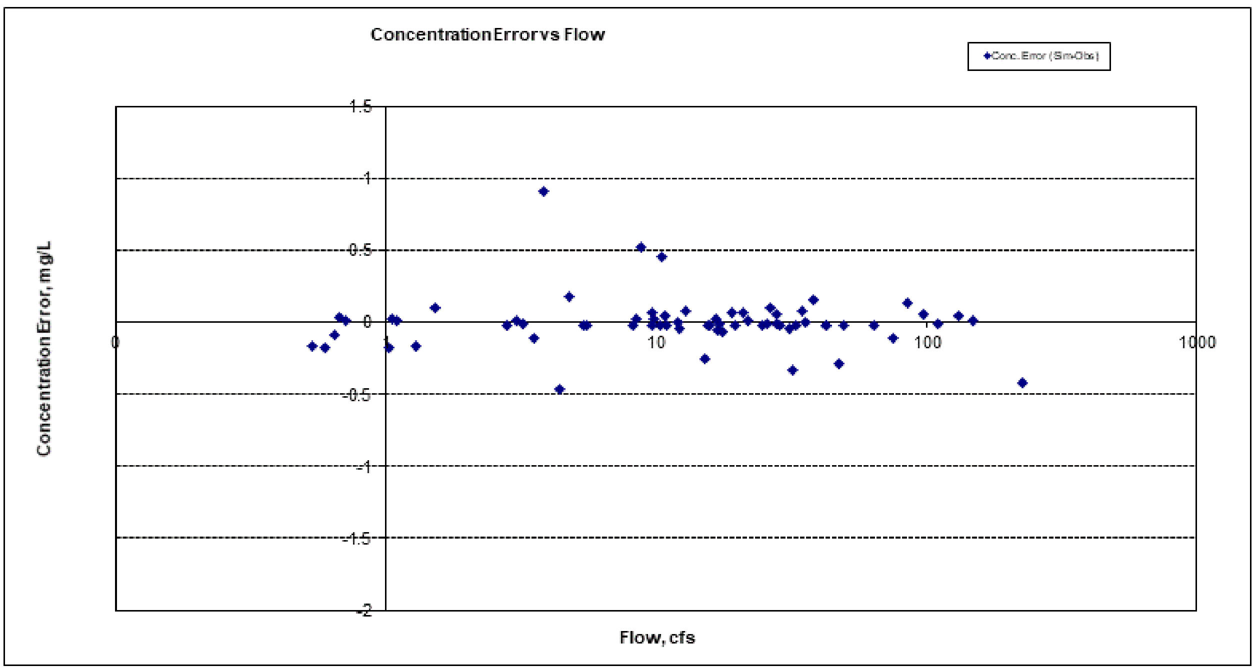


Figure E-103. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Lester River above Superior Street

E.2.6 Total Nitrogen (TN)

Table E-14. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	ND	6
Concentration Average Error		-60.68%
Concentration Median Error		-66.24%
Load Average Error		-67.87%
Load Median Error		-51.11%
Paired t conc		0.00
Paired t load		0.07

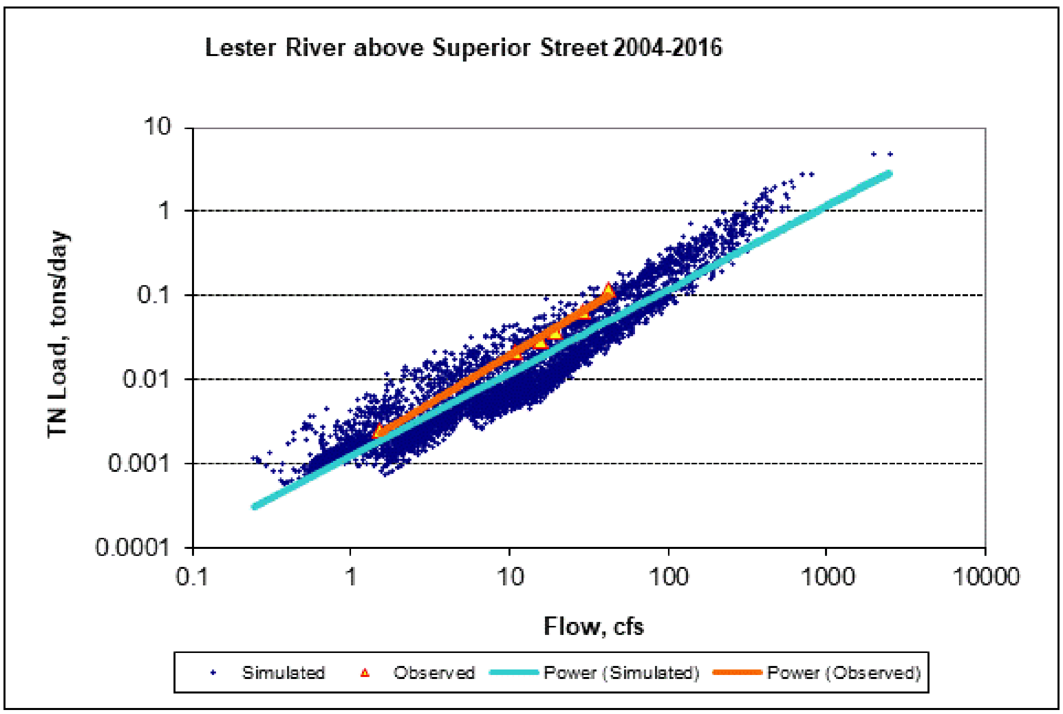


Figure E-104. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Lester River above Superior Street (calibration period)

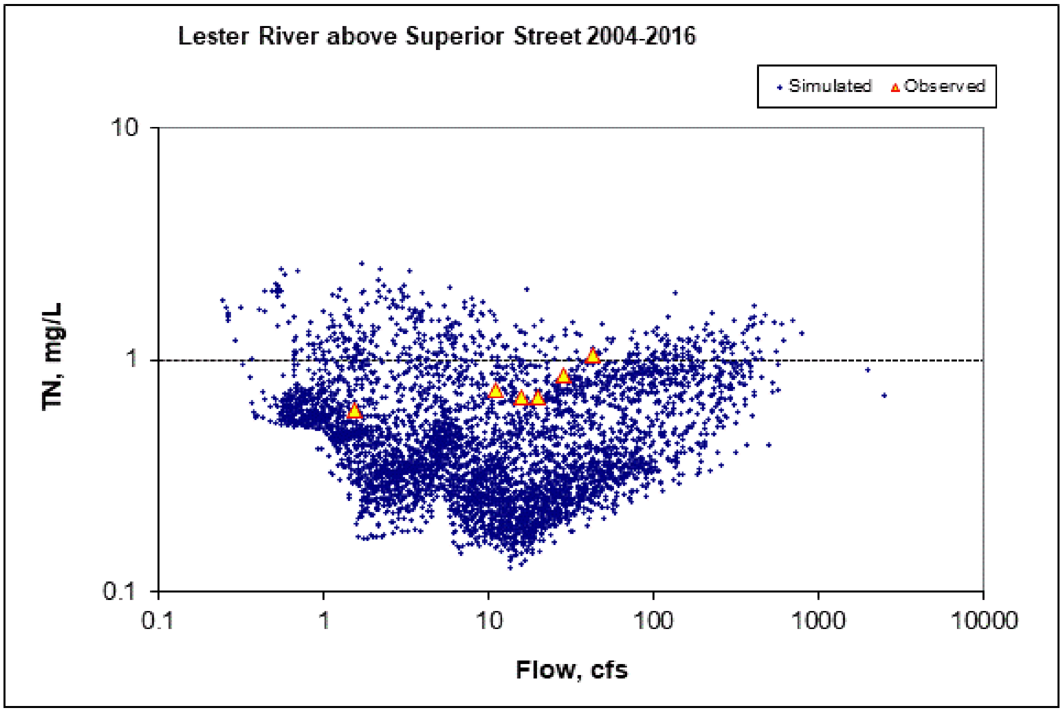
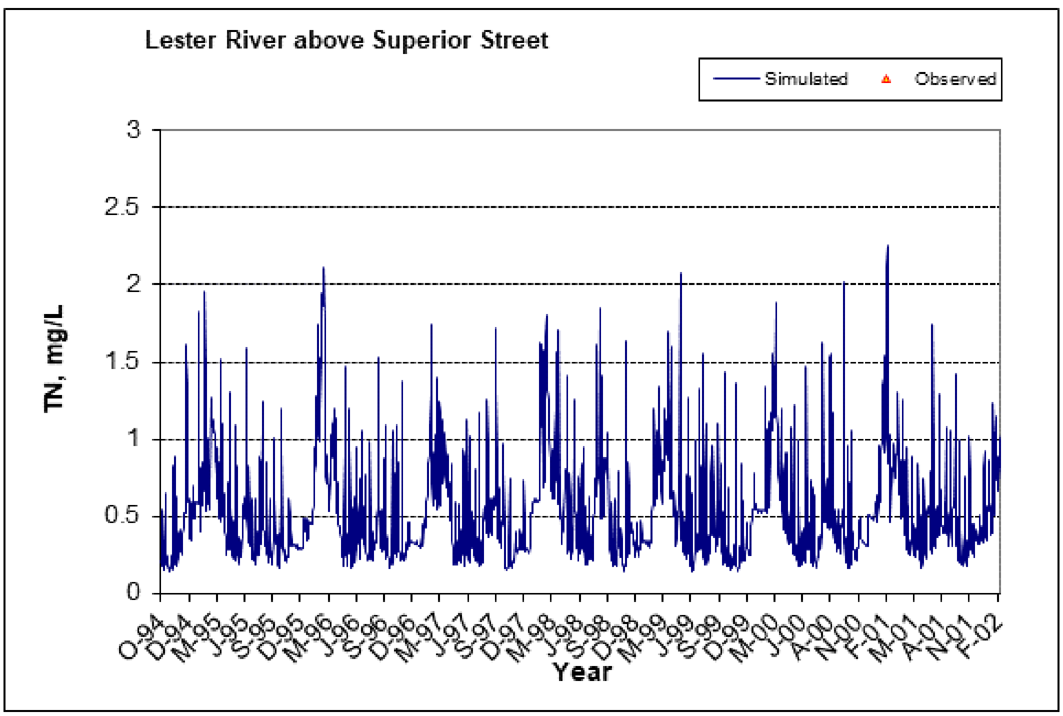
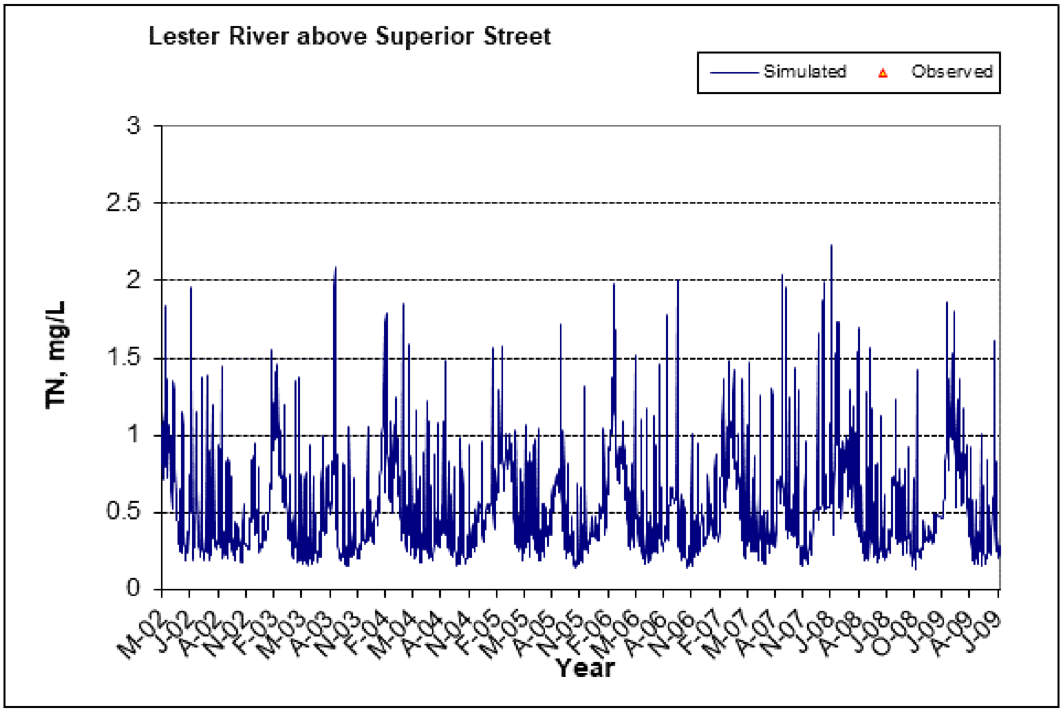


Figure E-105. Simulated and observed Total Nitrogen (TN) concentration vs flow at Lester River above Superior Street (calibration period)





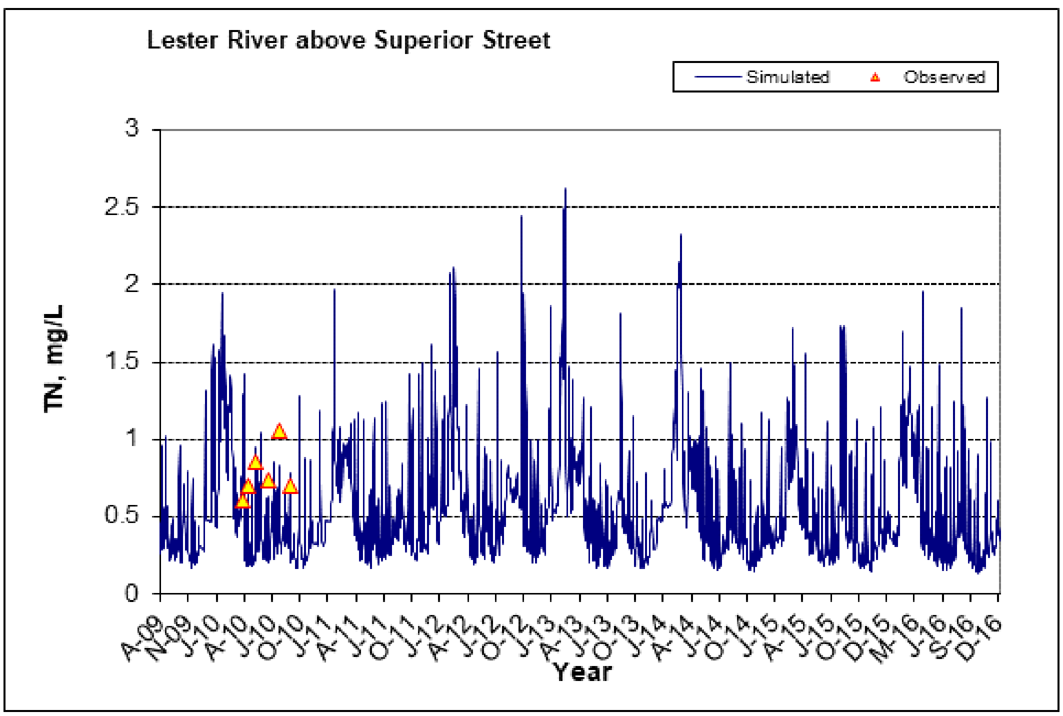


Figure E-106. Time series of observed and simulated Total Nitrogen (TN) concentration at Lester River above Superior Street

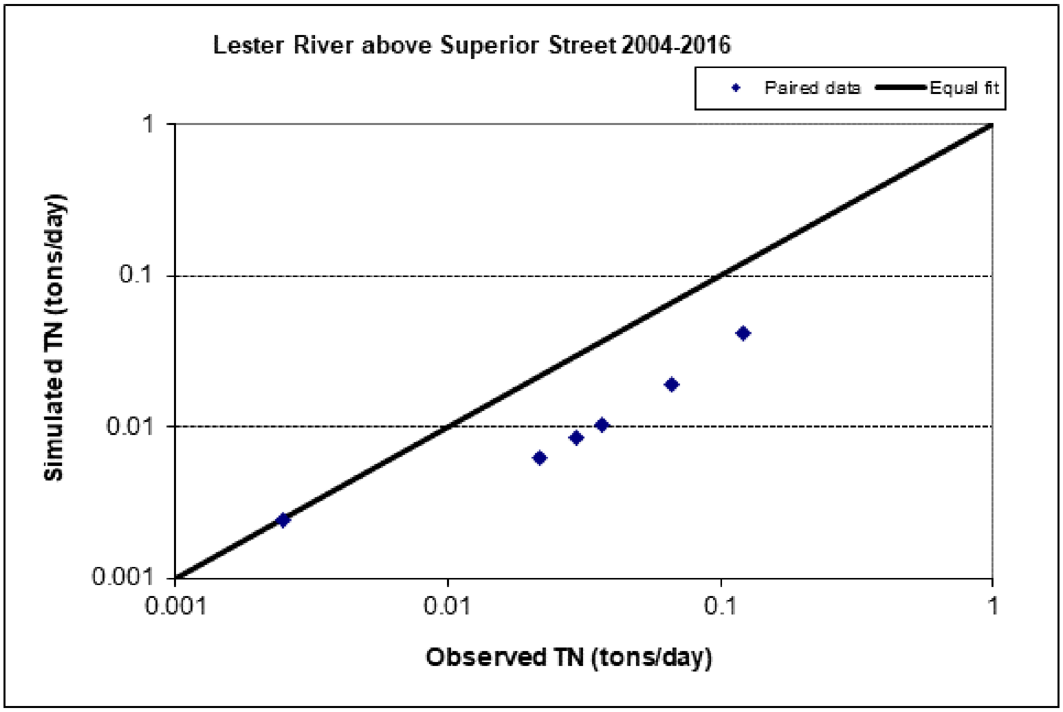


Figure E-107. Paired simulated vs. observed Total Nitrogen (TN) load at Lester River above Superior Street (calibration period)

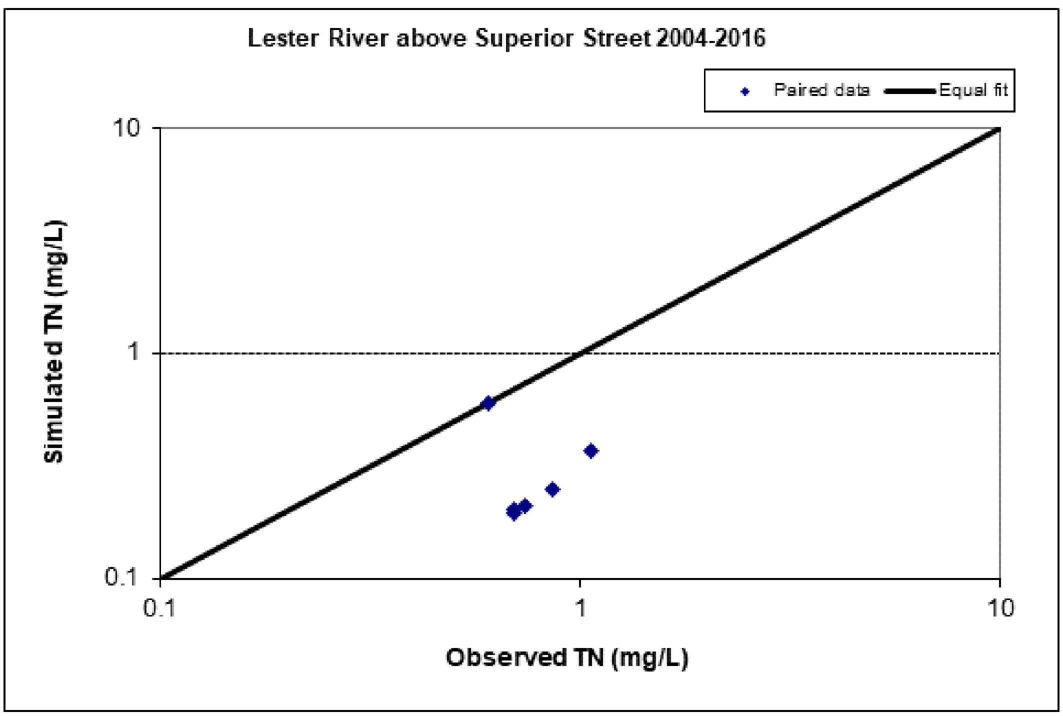


Figure E-108. Paired simulated vs. observed Total Nitrogen (TN) concentration at Lester River above Superior Street (calibration period)

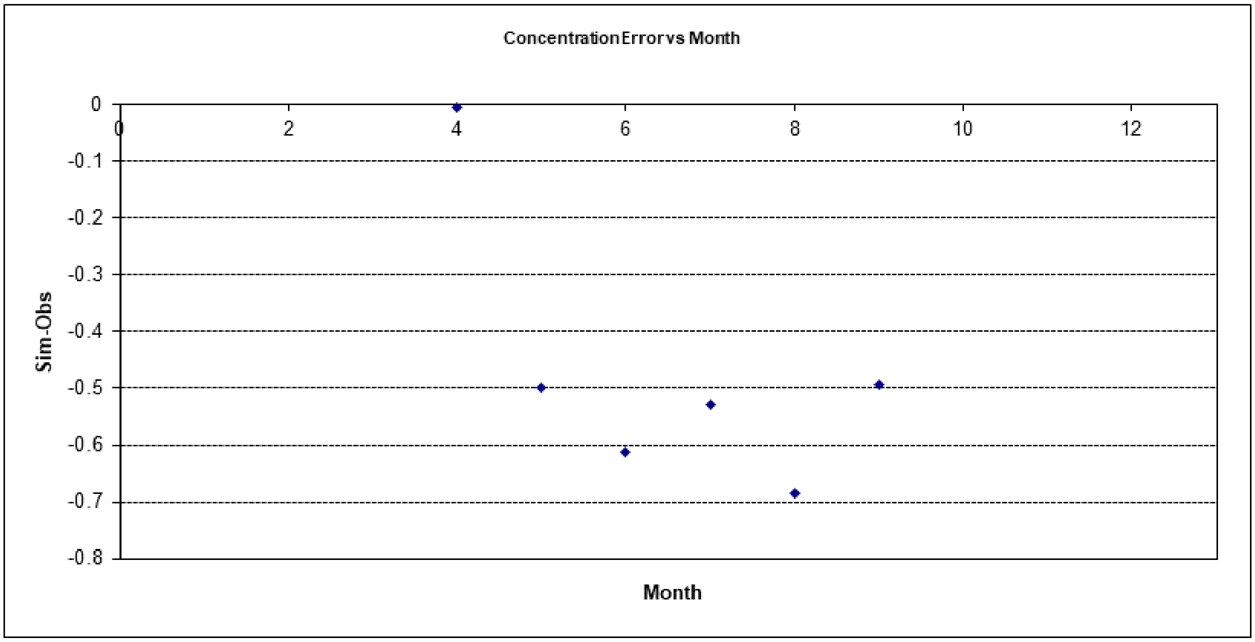


Figure E-109. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at Lester River above Superior Street

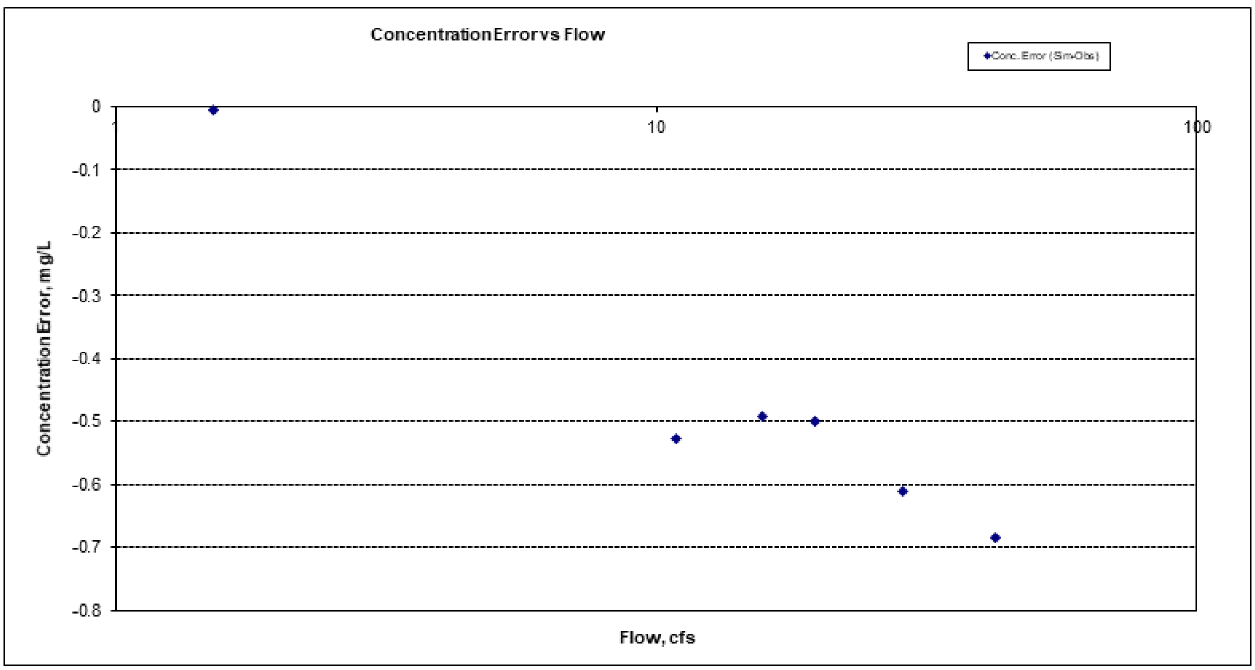


Figure E-110. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at Lester River above Superior Street

E.2.7 Total Phosphorus (TP)

Table E-15. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	10	30
Concentration Average Error	-75.22%	-20.18%
Concentration Median Error	-17.19%	-28.37%
Load Average Error	-80.11%	7.12%
Load Median Error	-7.21%	-7.43%
Paired t conc	0.08	0.49
Paired t load	0.09	0.63

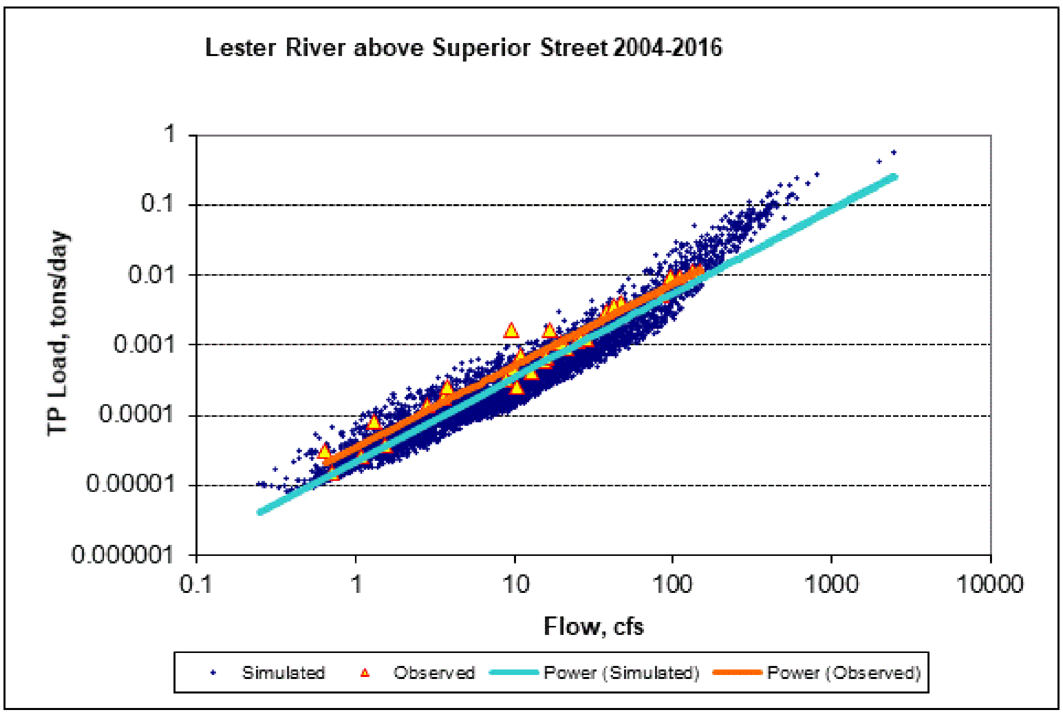


Figure E-111. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Lester River above Superior Street (calibration period)

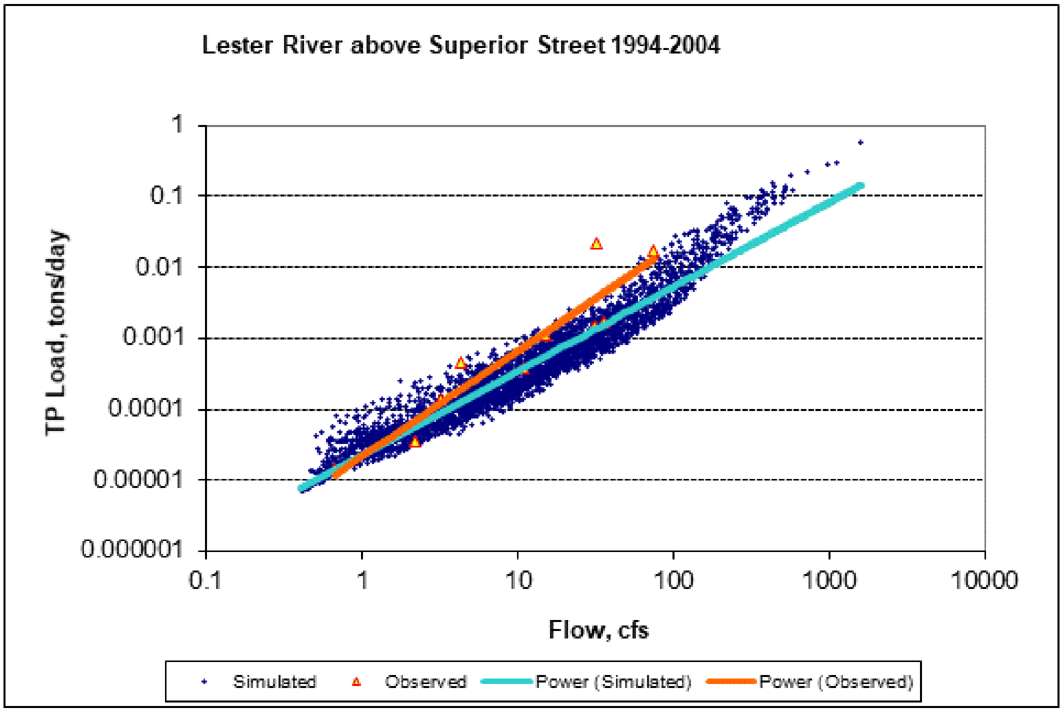


Figure E-112. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Lester River above Superior Street (validation period)

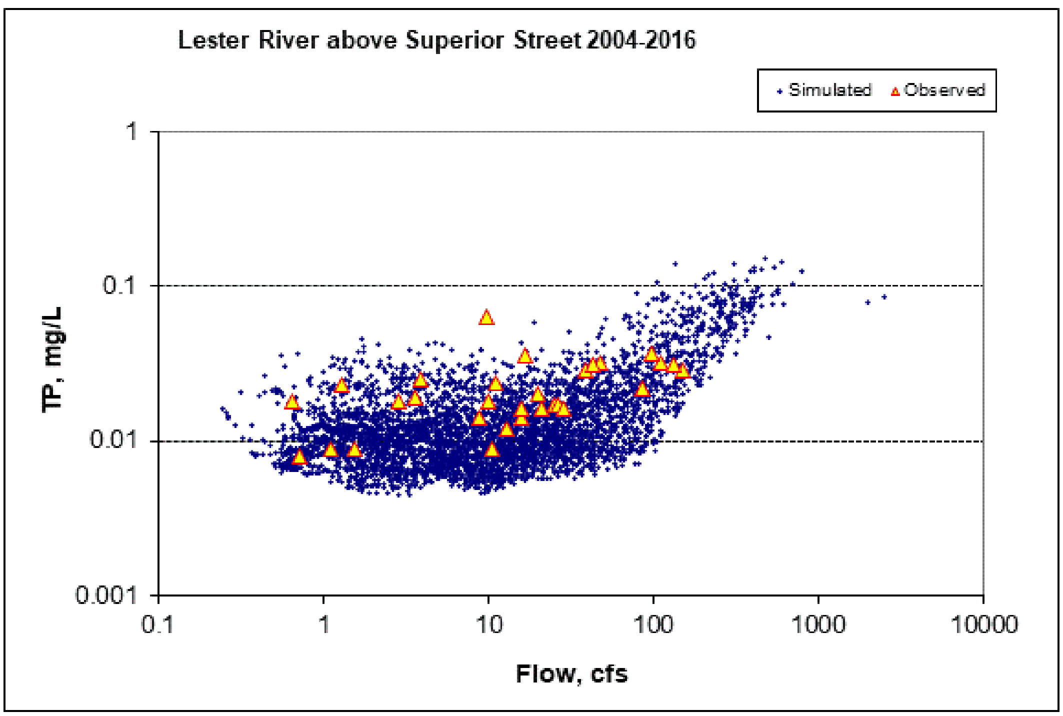


Figure E-113. Simulated and observed Total Phosphorus (TP) concentration vs flow at Lester River above Superior Street (calibration period)

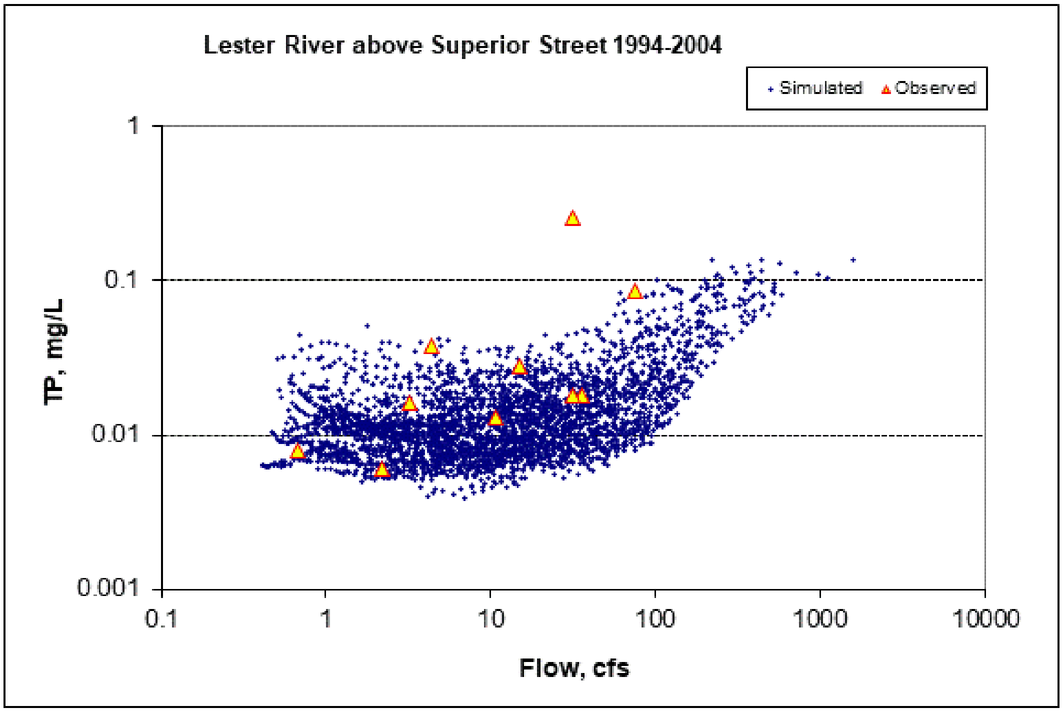
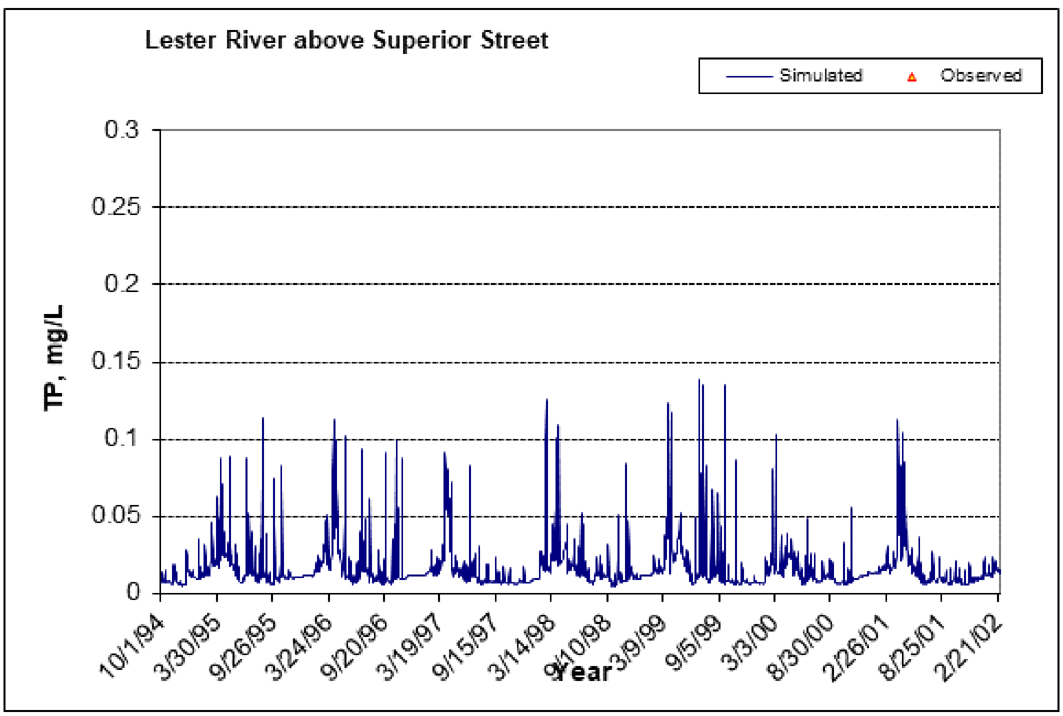
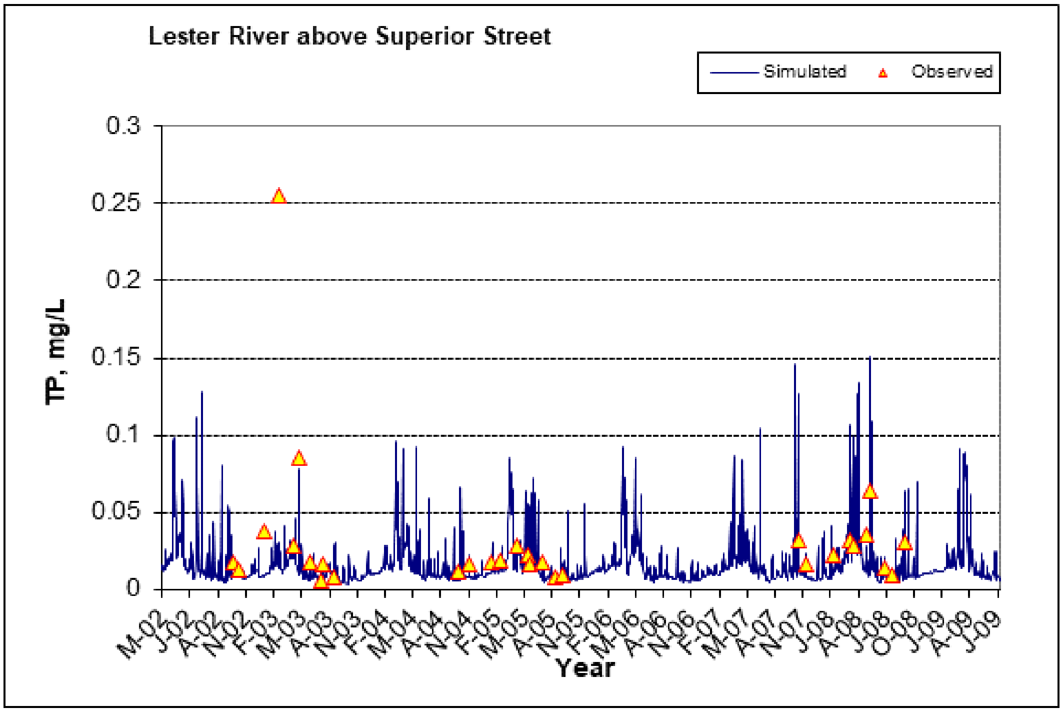


Figure E-114. Simulated and observed Total Phosphorus (TP) concentration vs flow at Lester River above Superior Street (validation period)





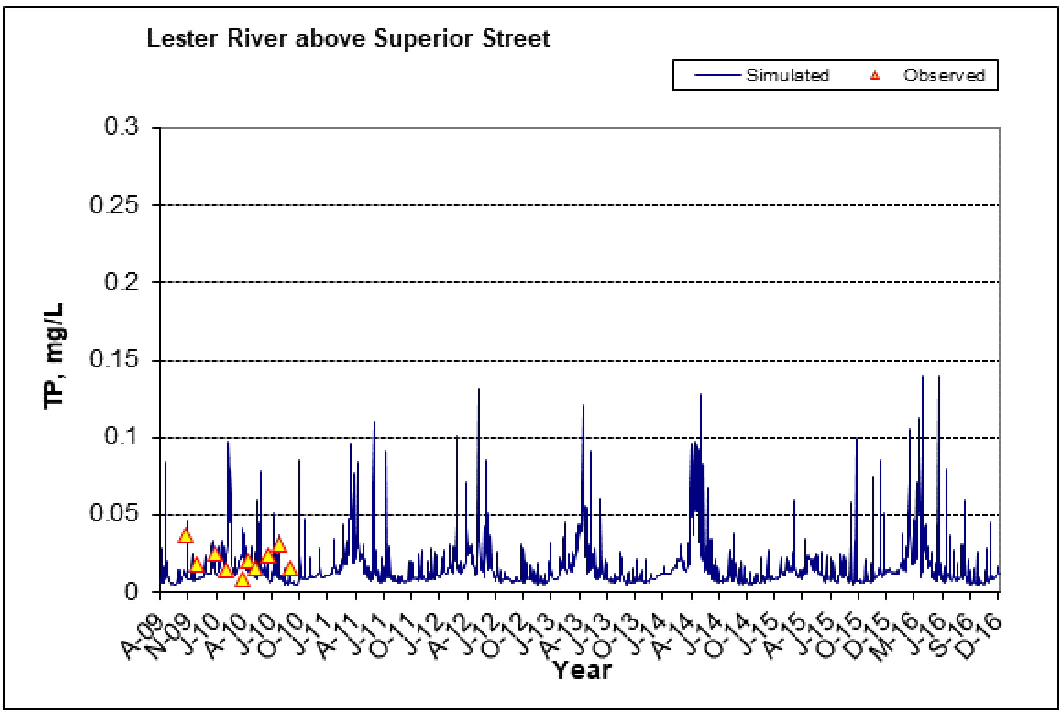


Figure E-115. Time series of observed and simulated Total Phosphorus (TP) concentration at Lester River above Superior Street

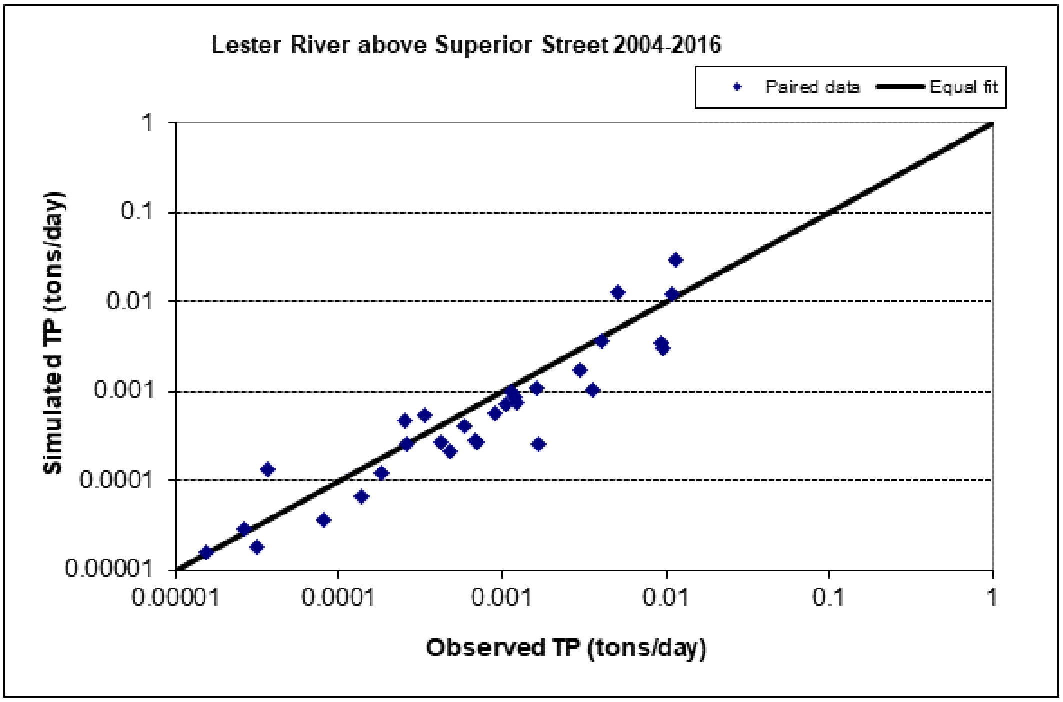


Figure E-116. Paired simulated vs. observed Total Phosphorus (TP) load at Lester River above Superior Street (calibration period)

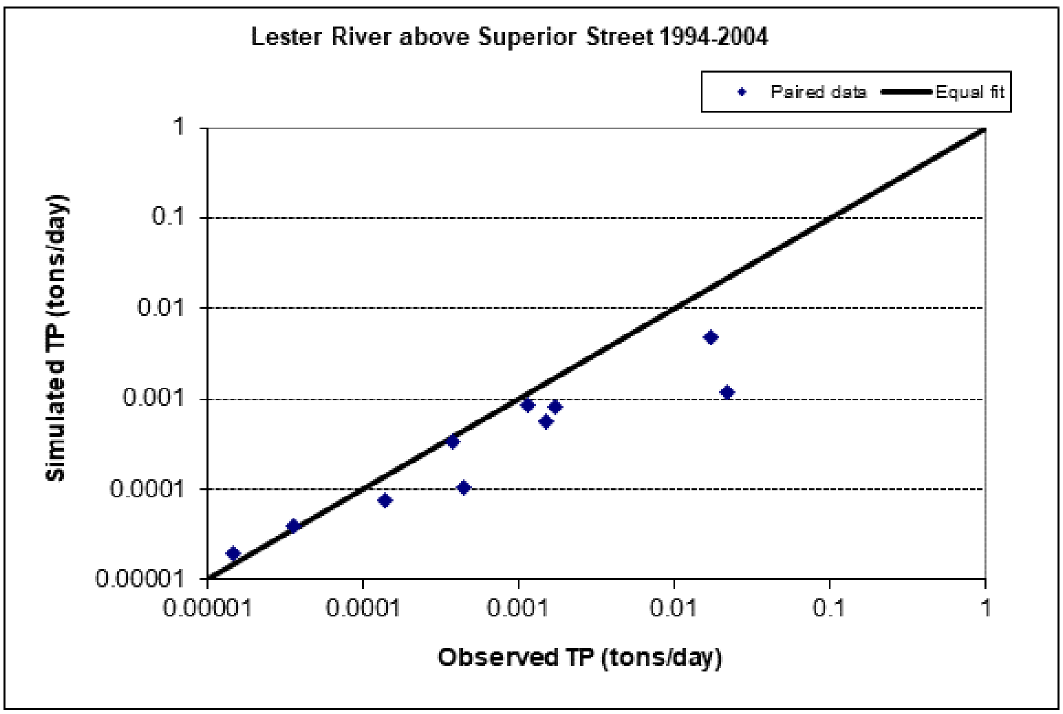


Figure E-117. Paired simulated vs. observed Total Phosphorus (TP) load at Lester River above Superior Street (validation period)

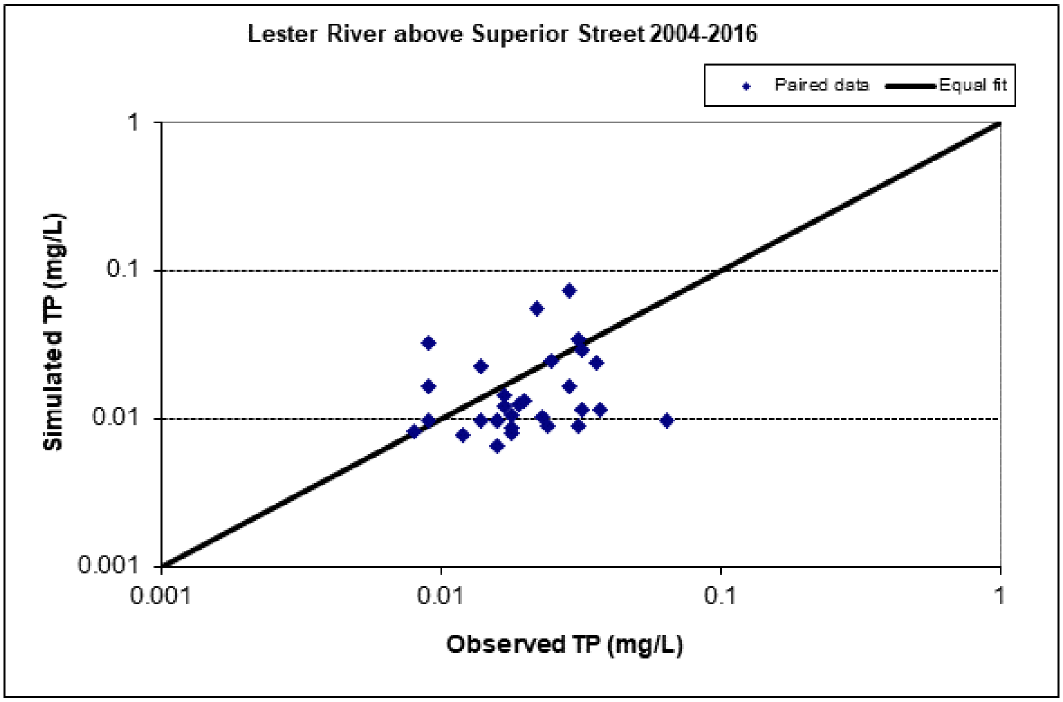


Figure E-118. Paired simulated vs. observed Total Phosphorus (TP) concentration at Lester River above Superior Street (calibration period)

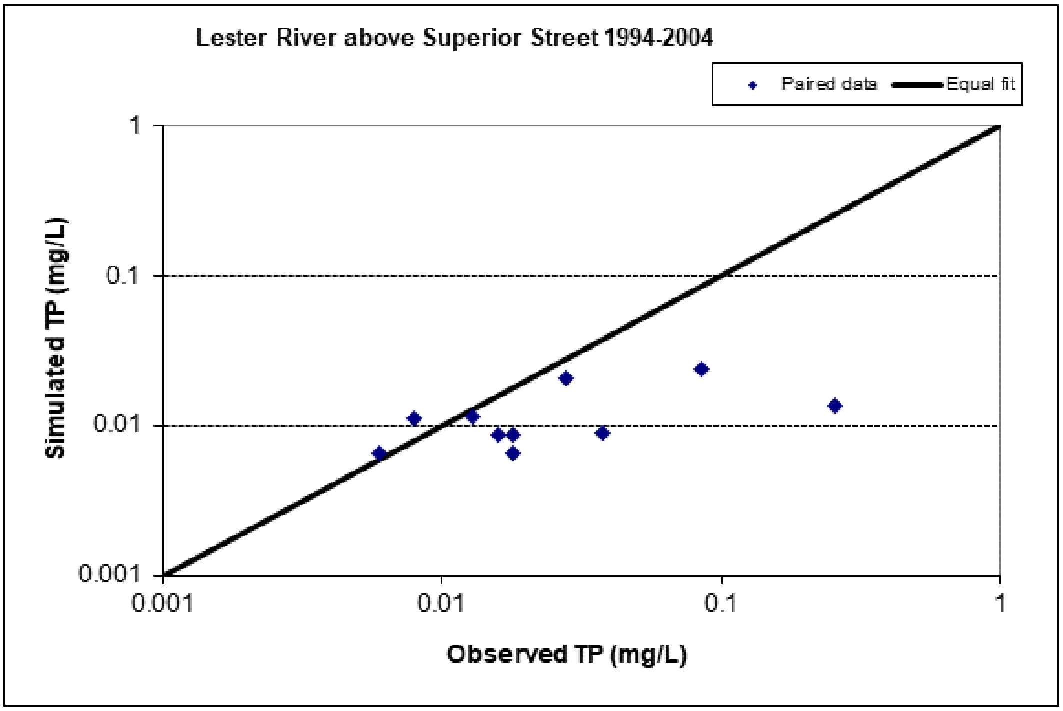


Figure E-119. Paired simulated vs. observed Total Phosphorus (TP) concentration at Lester River above Superior Street (validation period)

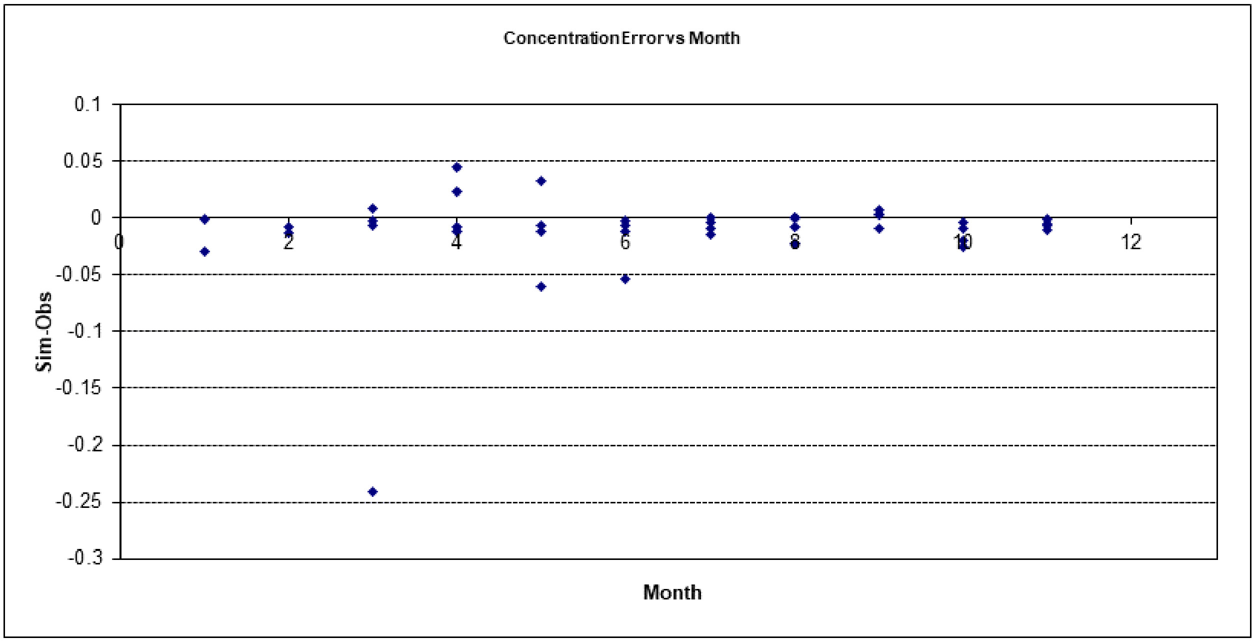


Figure E-120. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Lester River above Superior Street

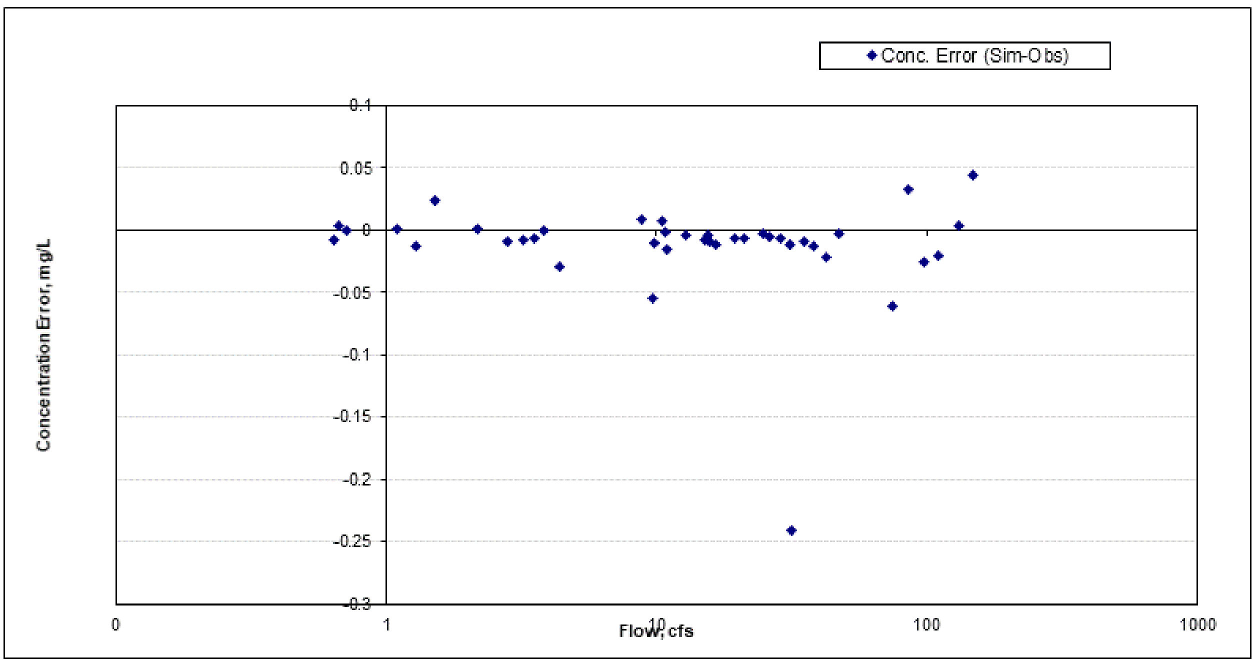


Figure E-121. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Lester River above Superior Street

E.2.8 Biochemical Oxygen Demand (BOD5)

Table E-16. Biochemical Oxygen Demand (BOD5) statistics

Period	1994-2004	2004-2016
Count	4	12
Concentration Average Error	-38.48%	-68.54%
Concentration Median Error	-19.97%	-59.70%
Load Average Error	-17.50%	-71.57%
Load Median Error	-11.98%	-35.91%
Paired t conc	0.29	0.00
Paired t load	0.51	0.10

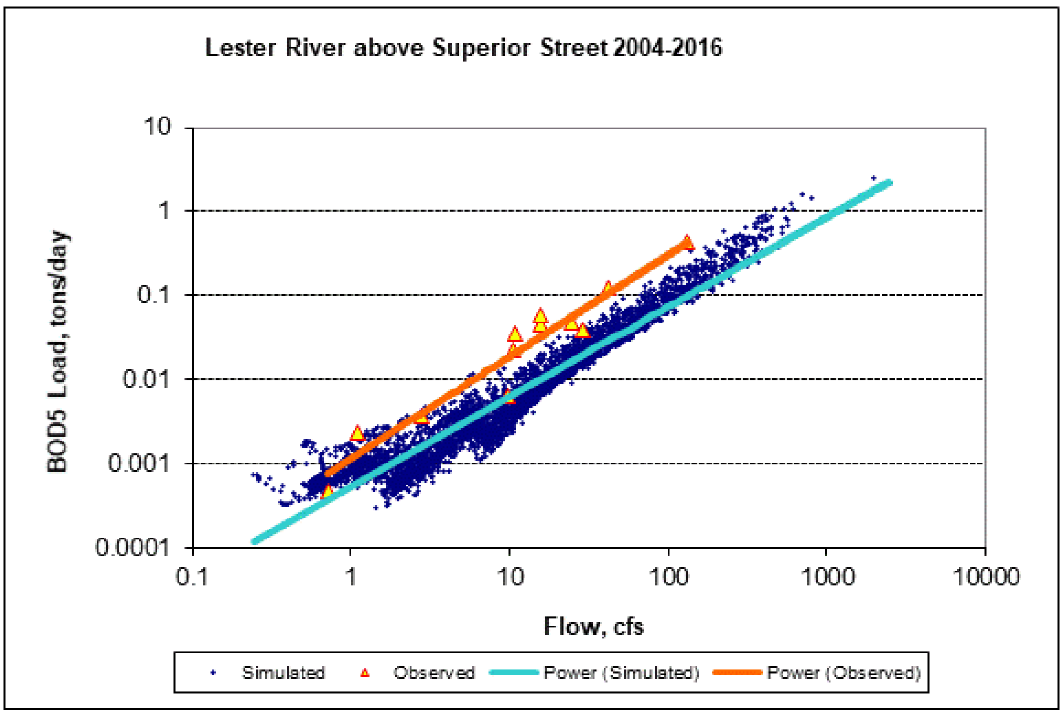


Figure E-122. Power plot of simulated and observed Biochemical Oxygen Demand (BOD5) load vs flow at Lester River above Superior Street (calibration period)

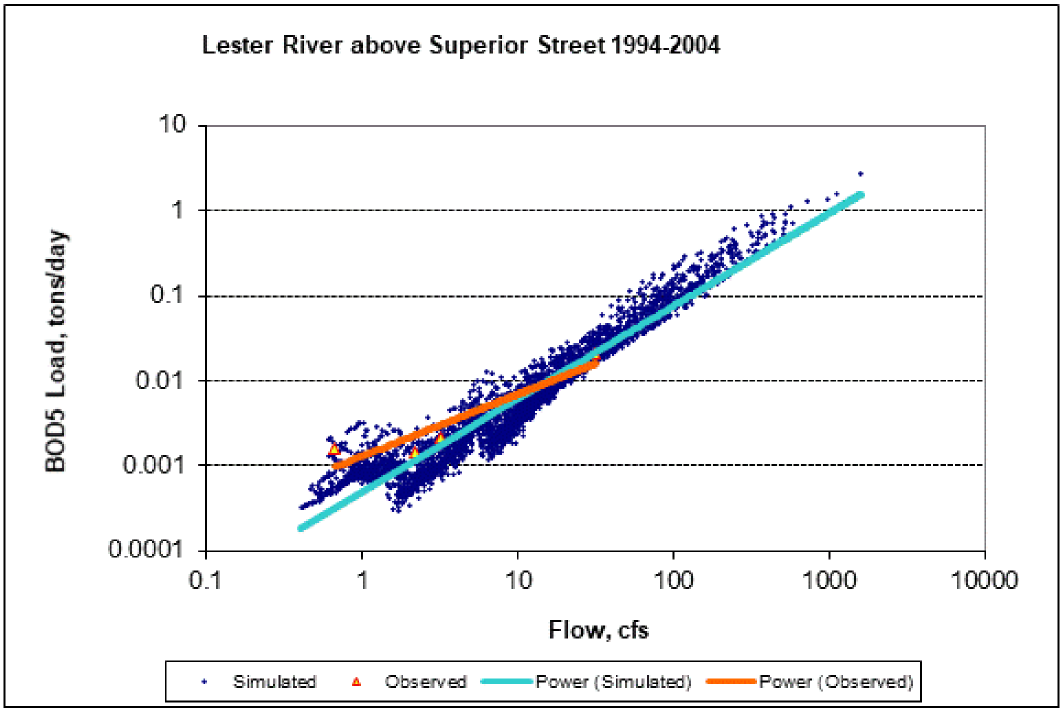


Figure E-123. Power plot of simulated and observed Biochemical Oxygen Demand (BOD5) load vs flow at Lester River above Superior Street (validation period)

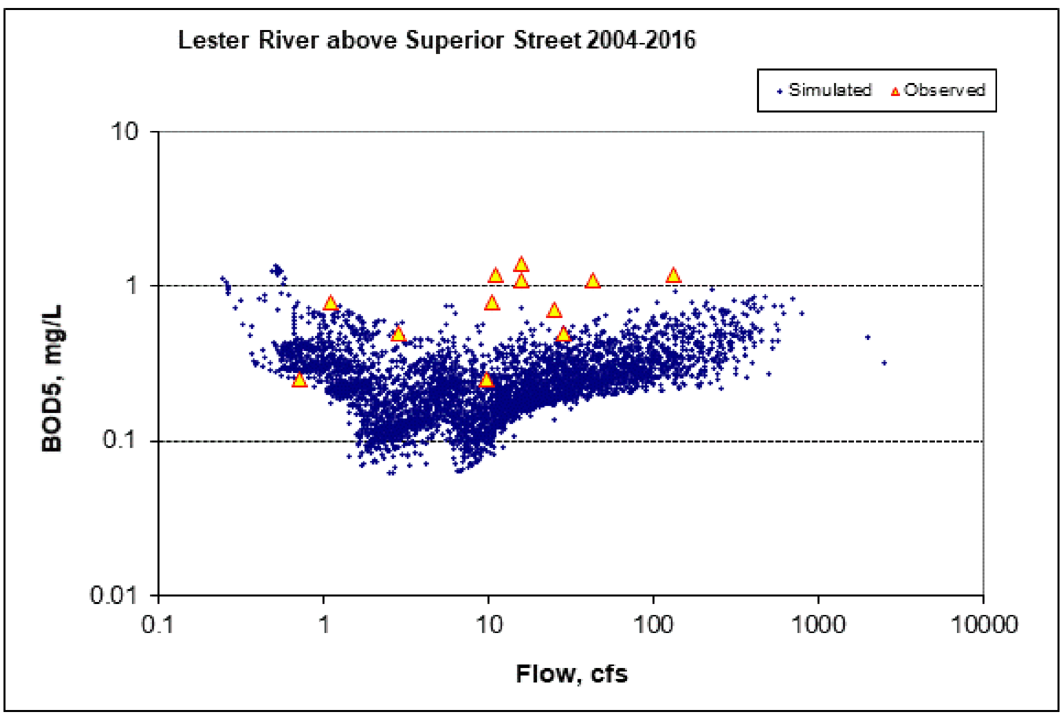


Figure E-124. Simulated and observed Biochemical Oxygen Demand (BOD5) concentration vs flow at Lester River above Superior Street (calibration period)

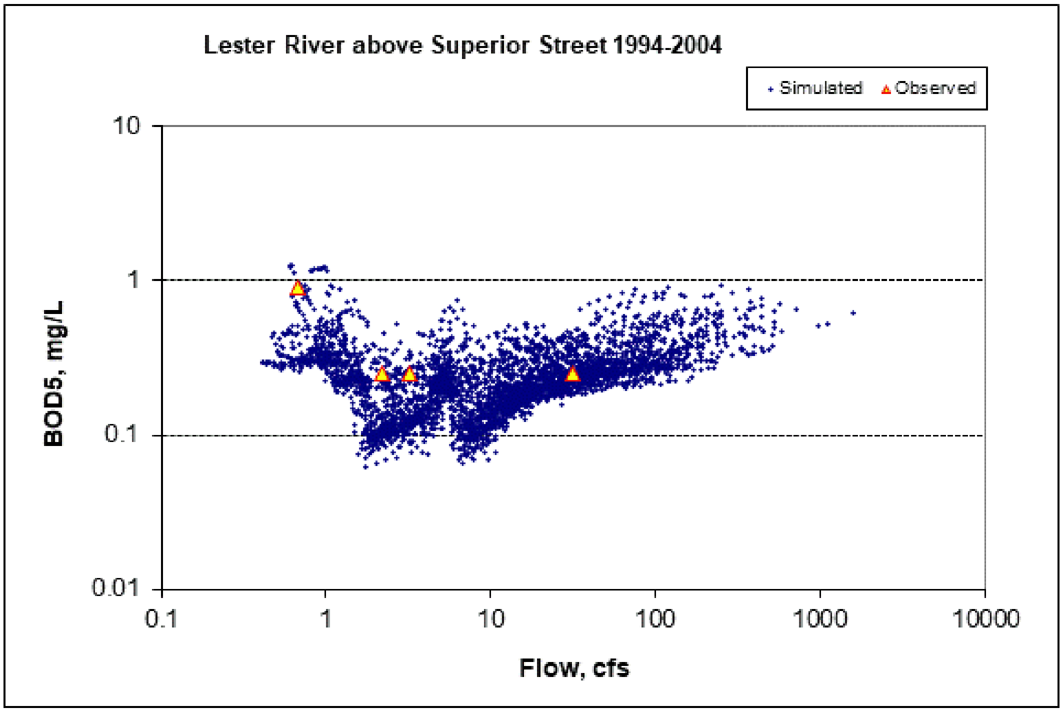
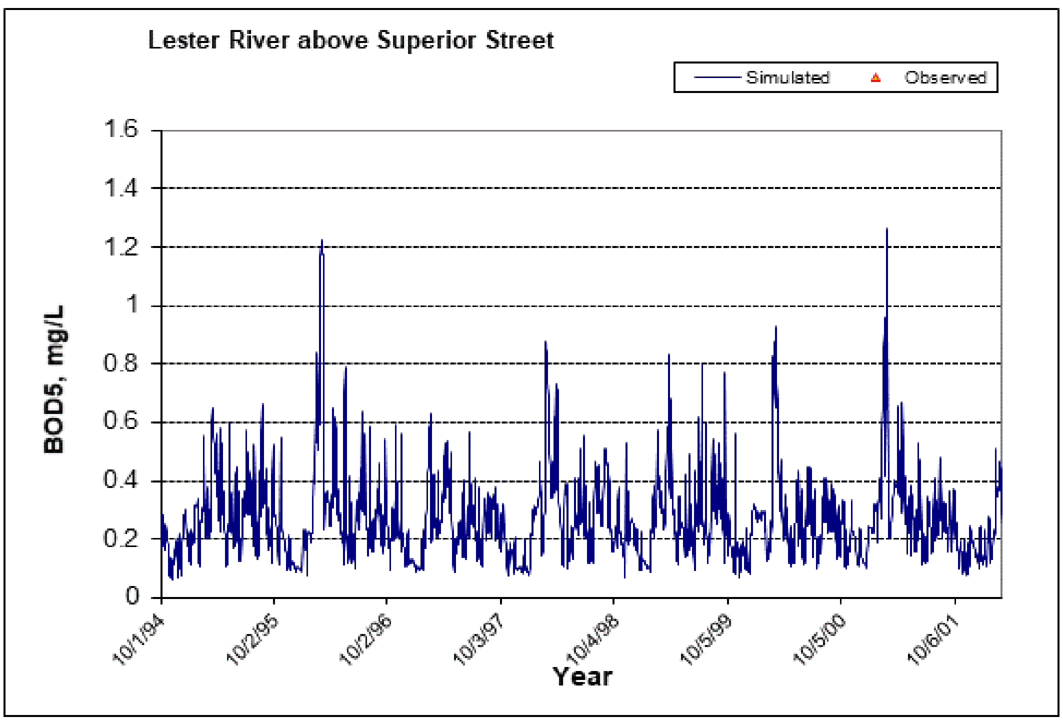
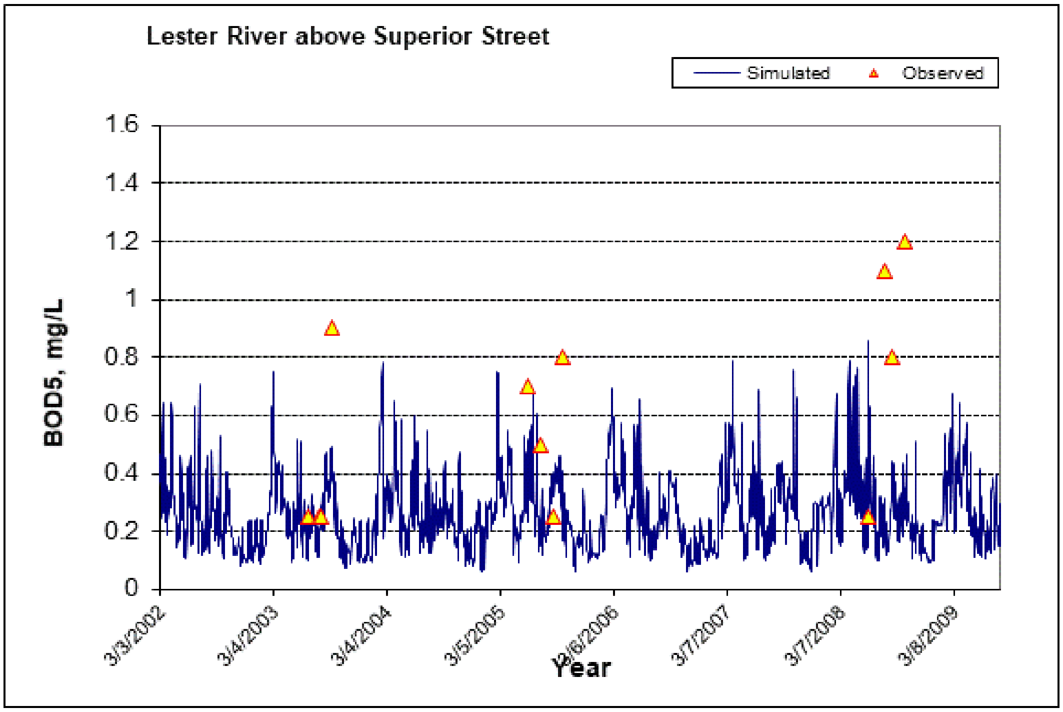


Figure E-125. Simulated and observed Biochemical Oxygen Demand (BOD5) concentration vs flow at Lester River above Superior Street (validation period)





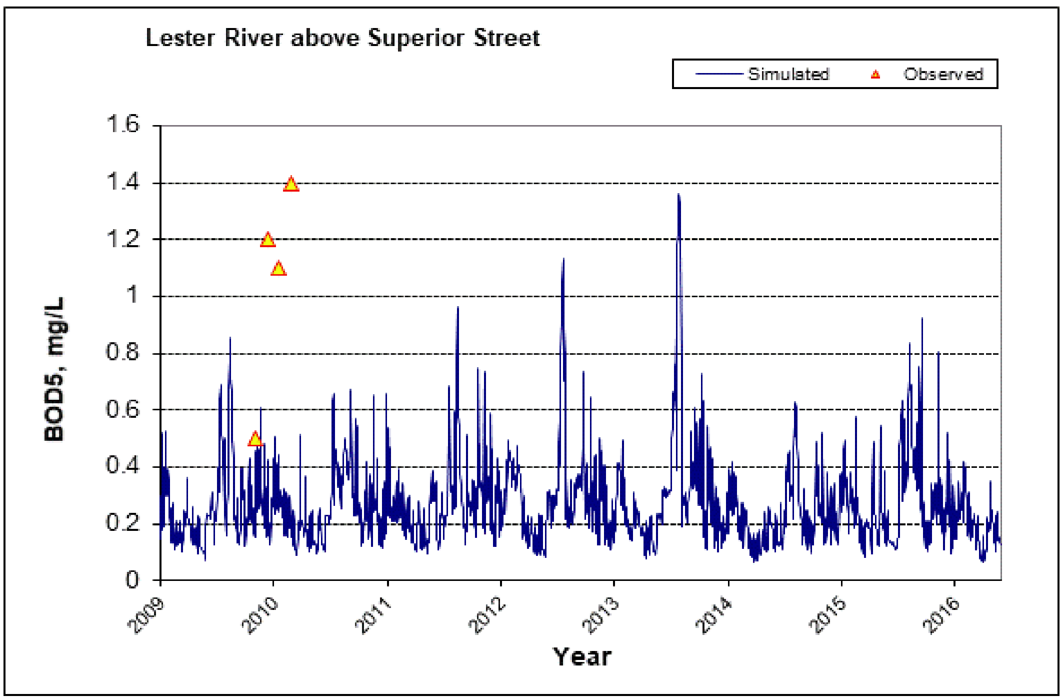


Figure E-126. Time series of observed and simulated Biochemical Oxygen Demand (BOD5) concentration at Lester River above Superior Street

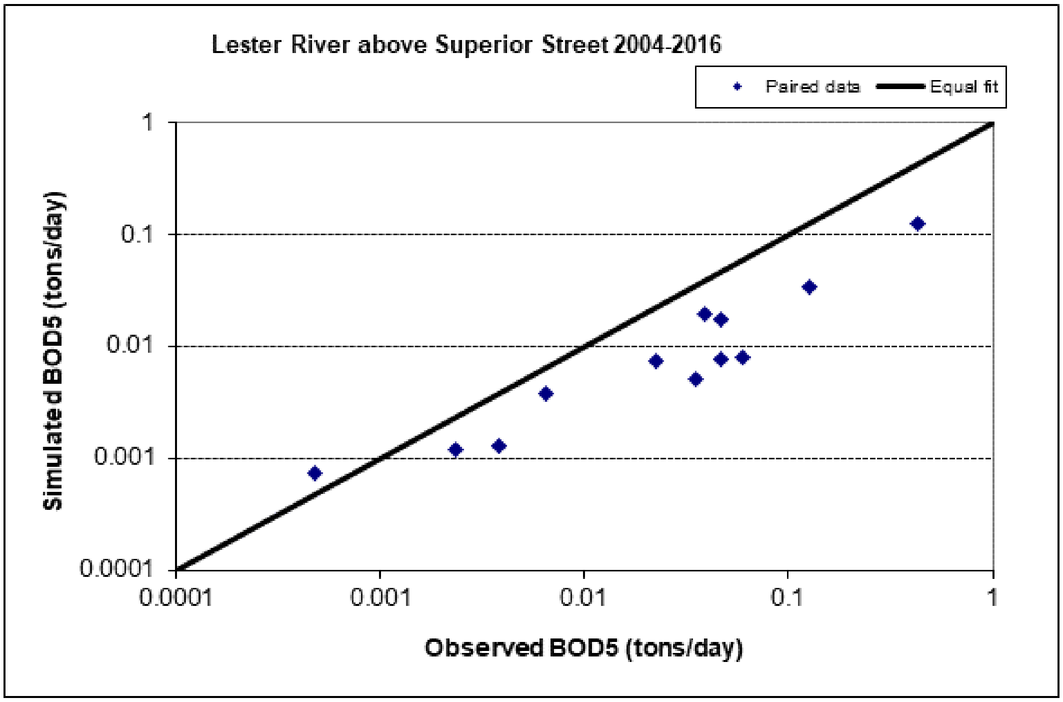


Figure E-127. Paired simulated vs. observed Biochemical Oxygen Demand (BOD5) load at Lester River above Superior Street (calibration period)

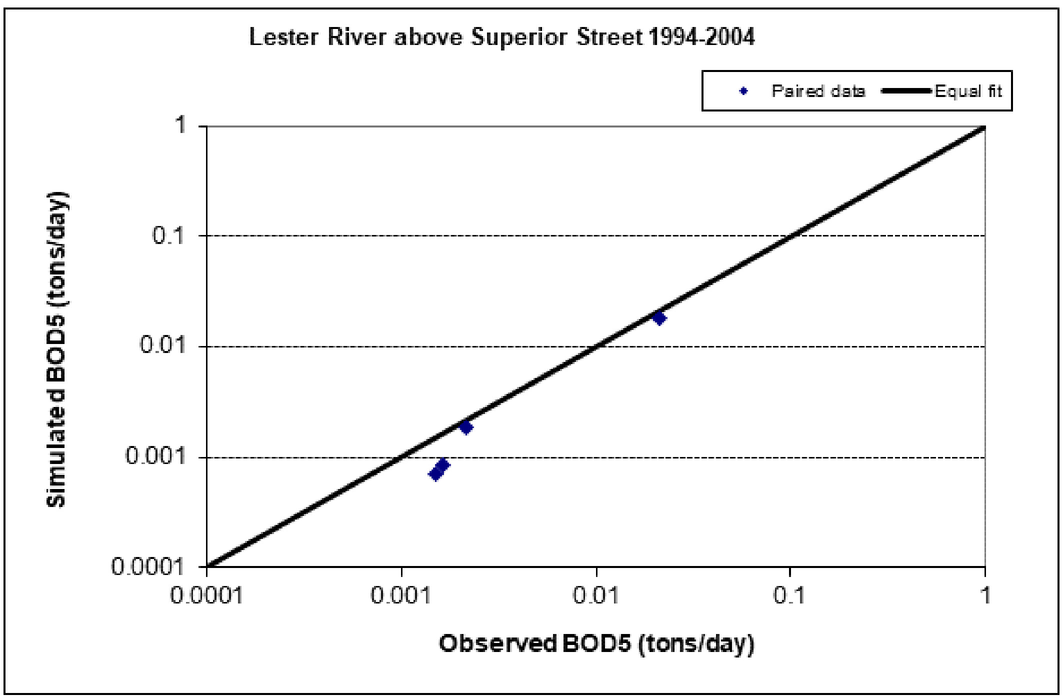


Figure E-128. Paired simulated vs. observed Biochemical Oxygen Demand (BOD5) load at Lester River above Superior Street (validation period)

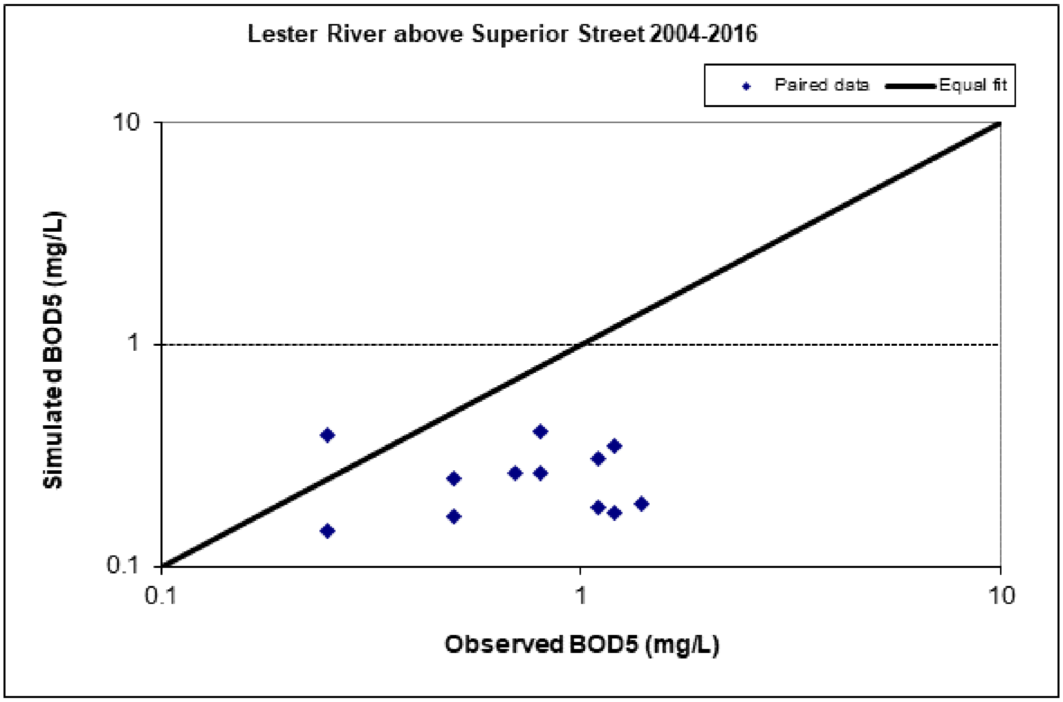


Figure E-129. Paired simulated vs. observed Biochemical Oxygen Demand (BOD5) concentration at Lester River above Superior Street (calibration period)

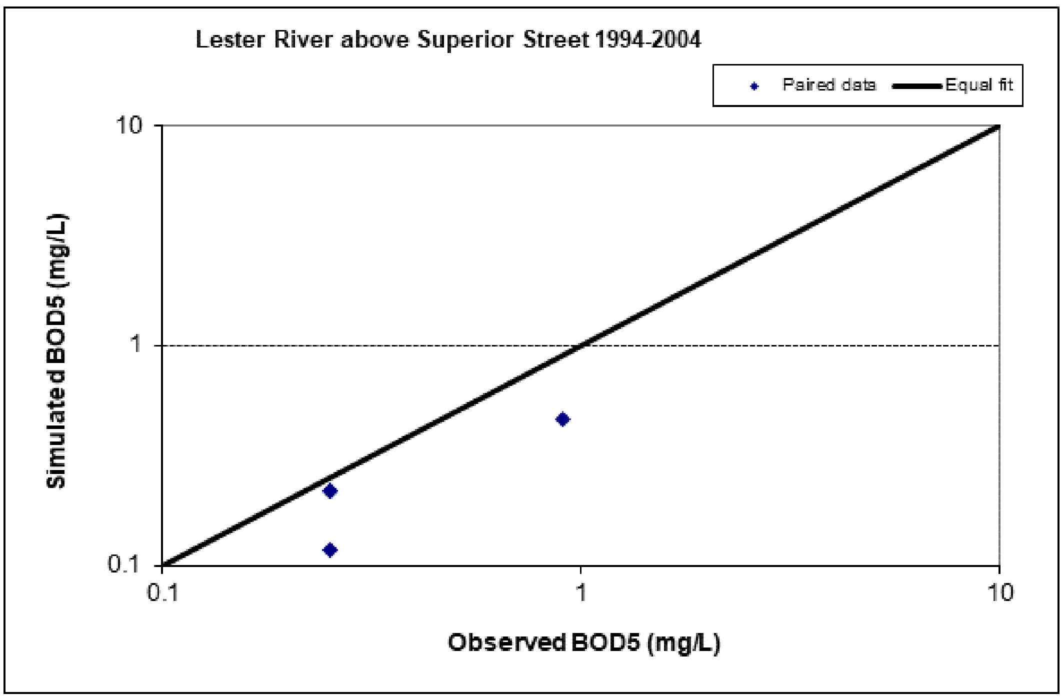


Figure E-130. Paired simulated vs. observed Biochemical Oxygen Demand (BOD5) concentration at Lester River above Superior Street (validation period)

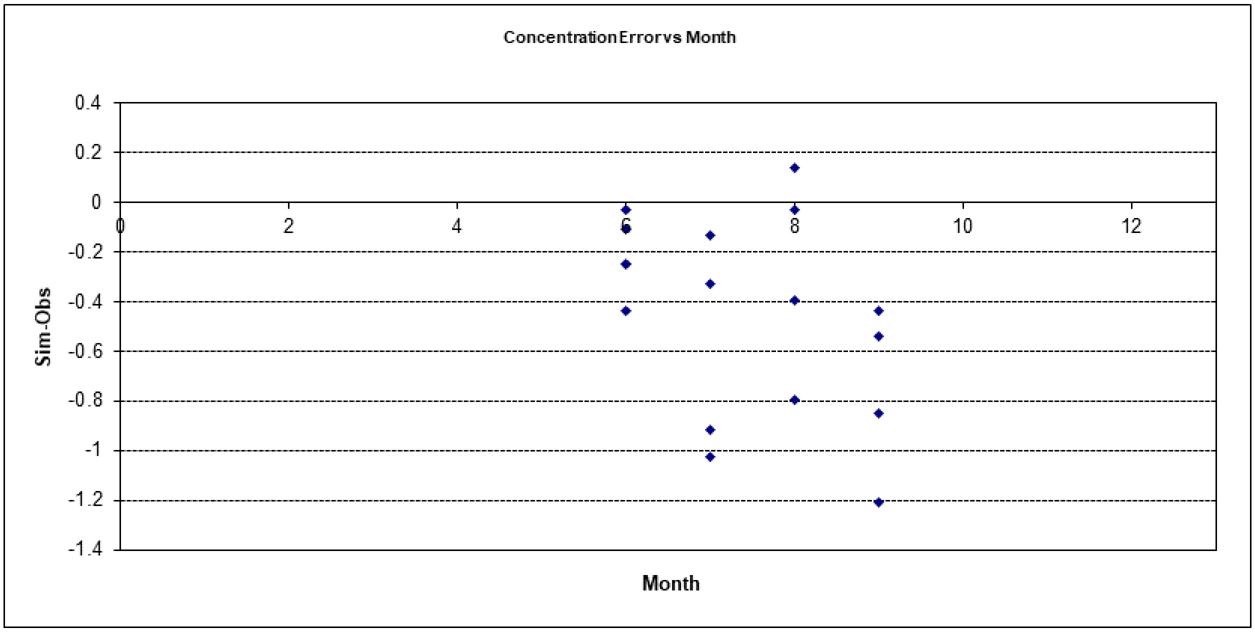


Figure E-131. Residual (Simulated - Observed) vs. Month, Biochemical Oxygen Demand (BOD5) at Lester River above Superior Street

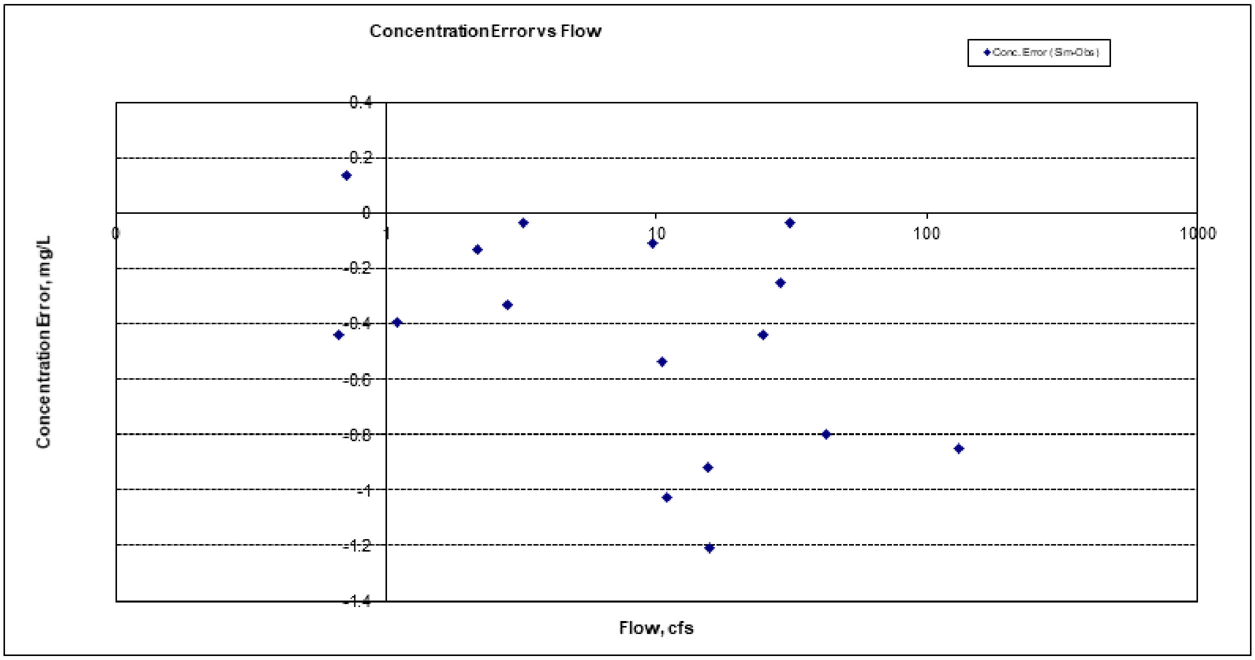


Figure E-132. Residual (Simulated - Observed) vs. Flow, Biochemical Oxygen Demand (BOD5) at Lester River above Superior Street

E.2.9 Chlorophyll-a (CHLa)

Table E-17. Chlorophyll-a (CHLa) statistics

Period	1994-2004	2004-2016
Count	4	12
Concentration Average Error	-80.37%	-86.86%
Concentration Median Error	-64.93%	-62.12%
Load Average Error	-93.74%	-85.38%
Load Median Error	-9.55%	-35.56%
Paired t conc	0.02	0.00
Paired t load	0.16	0.03

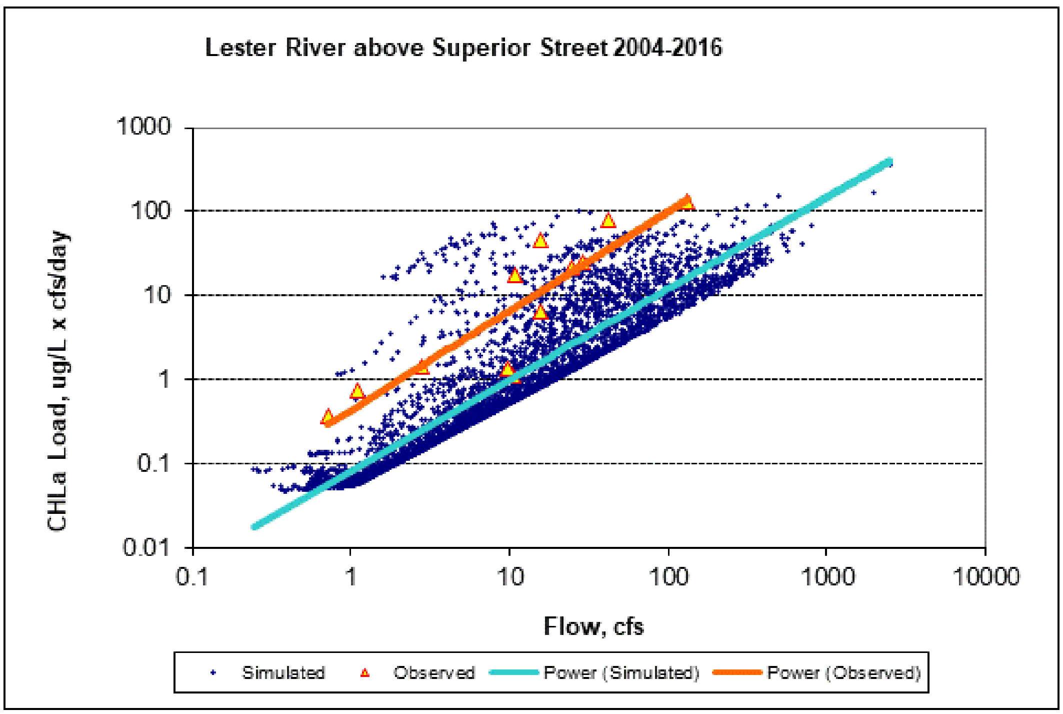


Figure E-133. Power plot of simulated and observed Chlorophyll-a (CHLa) load vs flow at Lester River above Superior Street (calibration period)

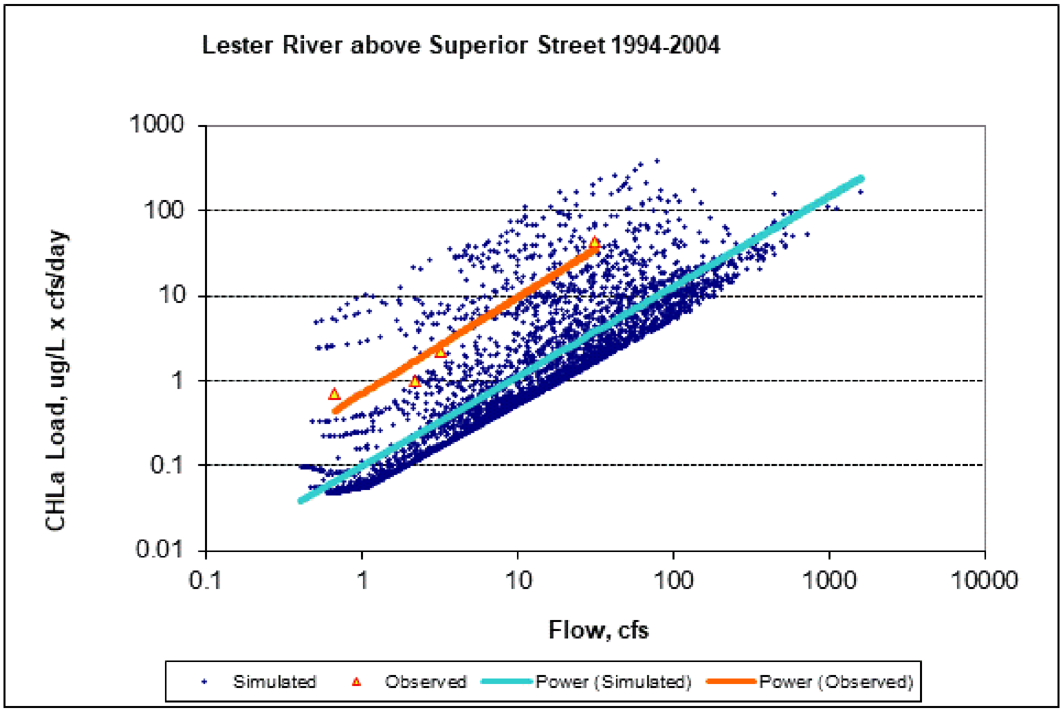


Figure E-134. Power plot of simulated and observed Chlorophyll-a (CHLa) load vs flow at Lester River above Superior Street (validation period)

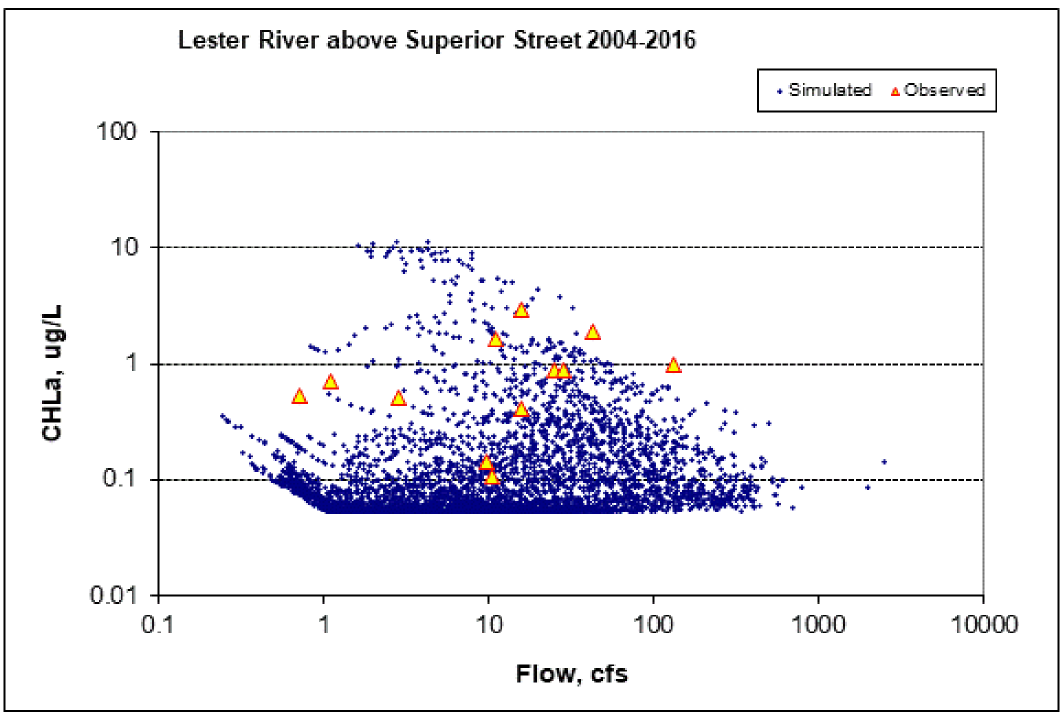


Figure E-135. Simulated and observed Chlorophyll-a (CHLa) concentration vs flow at Lester River above Superior Street (calibration period)

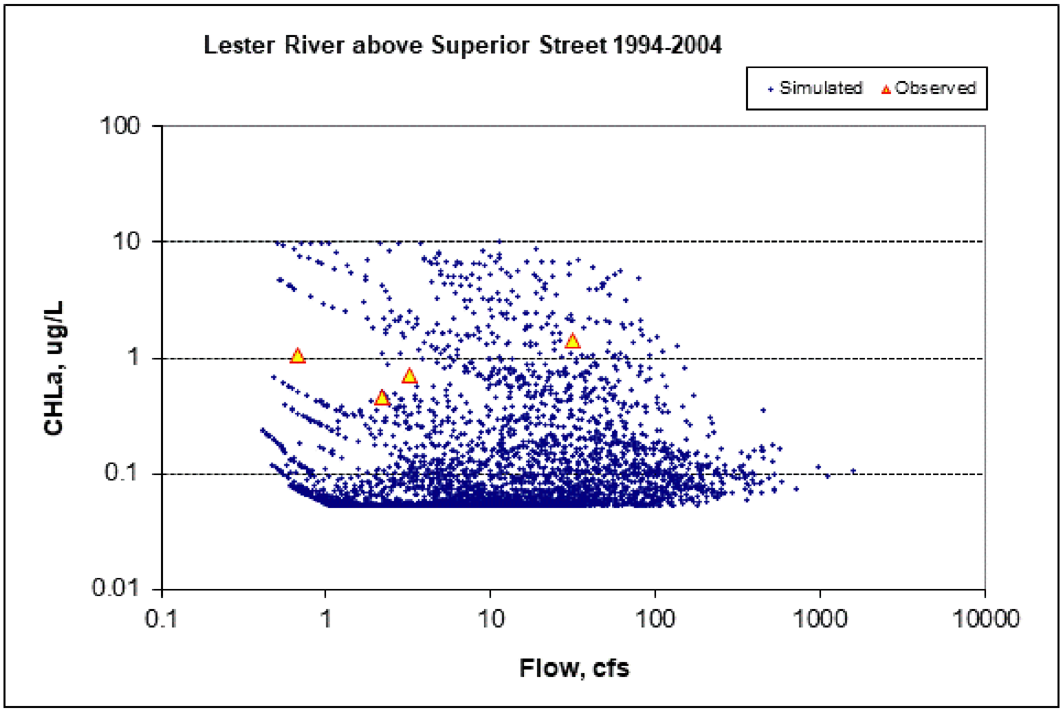
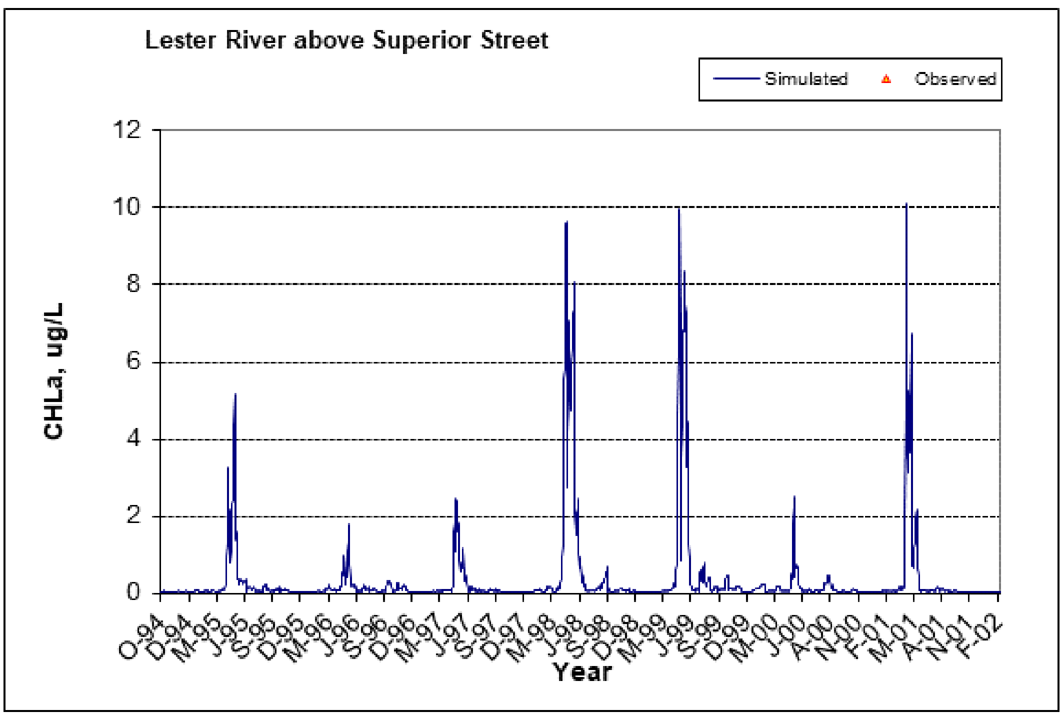
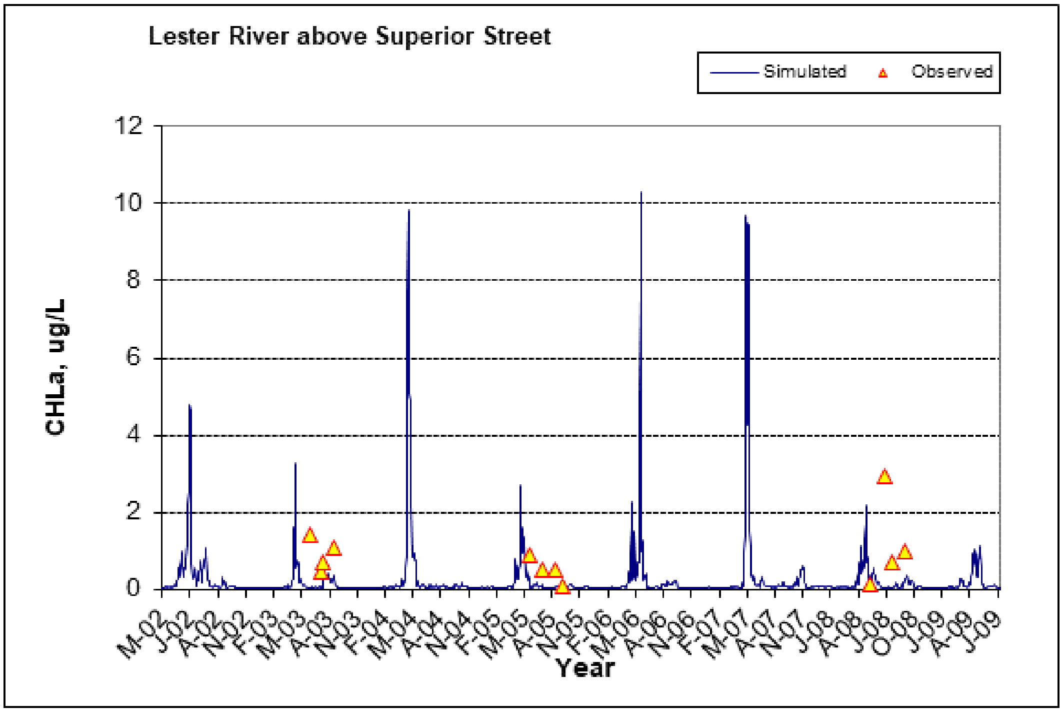


Figure E-136. Simulated and observed Chlorophyll-a (CHLa) concentration vs flow at Lester River above Superior Street (validation period)





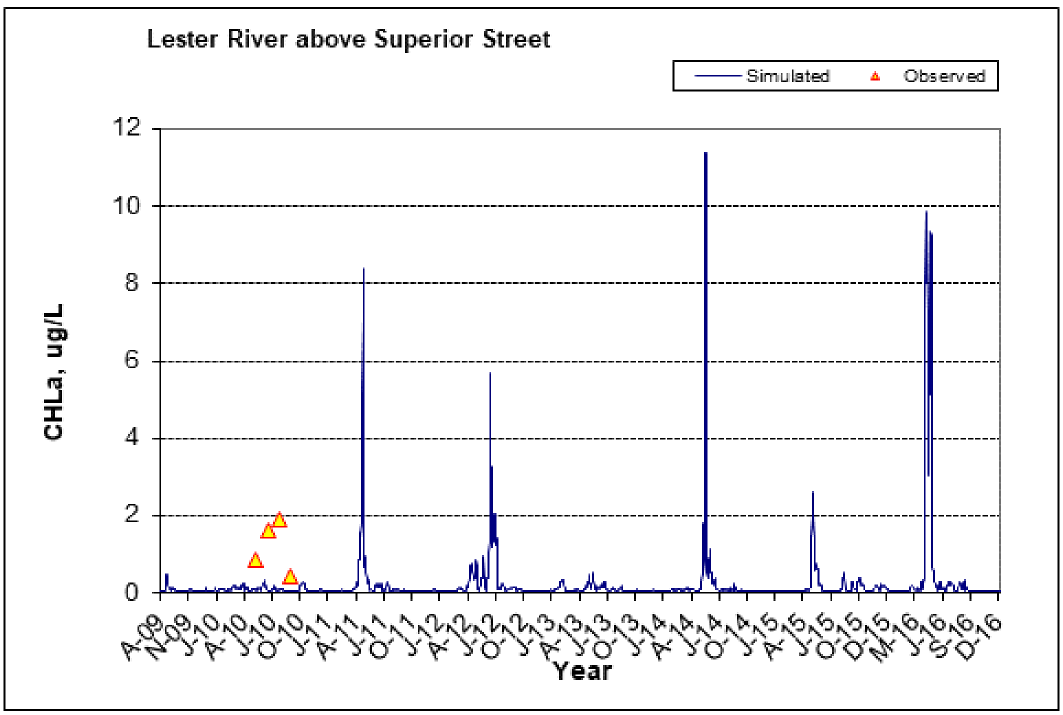


Figure E-137. Time series of observed and simulated Chlorophyll-a (CHLa) concentration at Lester River above Superior Street

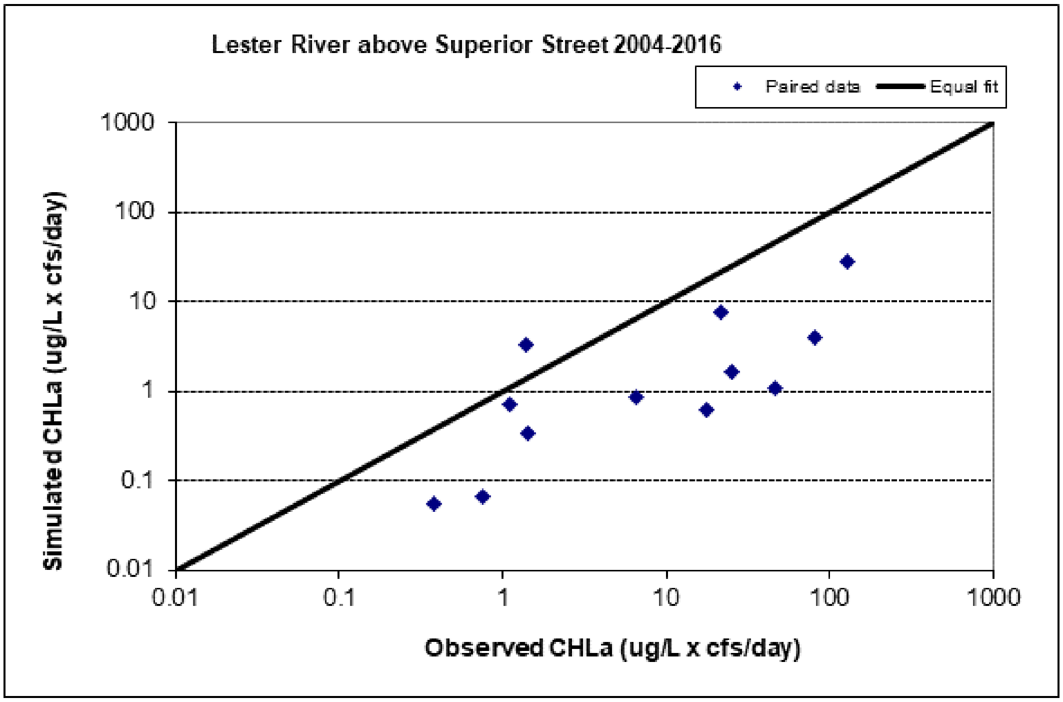


Figure E-138. Paired simulated vs. observed Chlorophyll-a (CHLa) load at Lester River above Superior Street (calibration period)

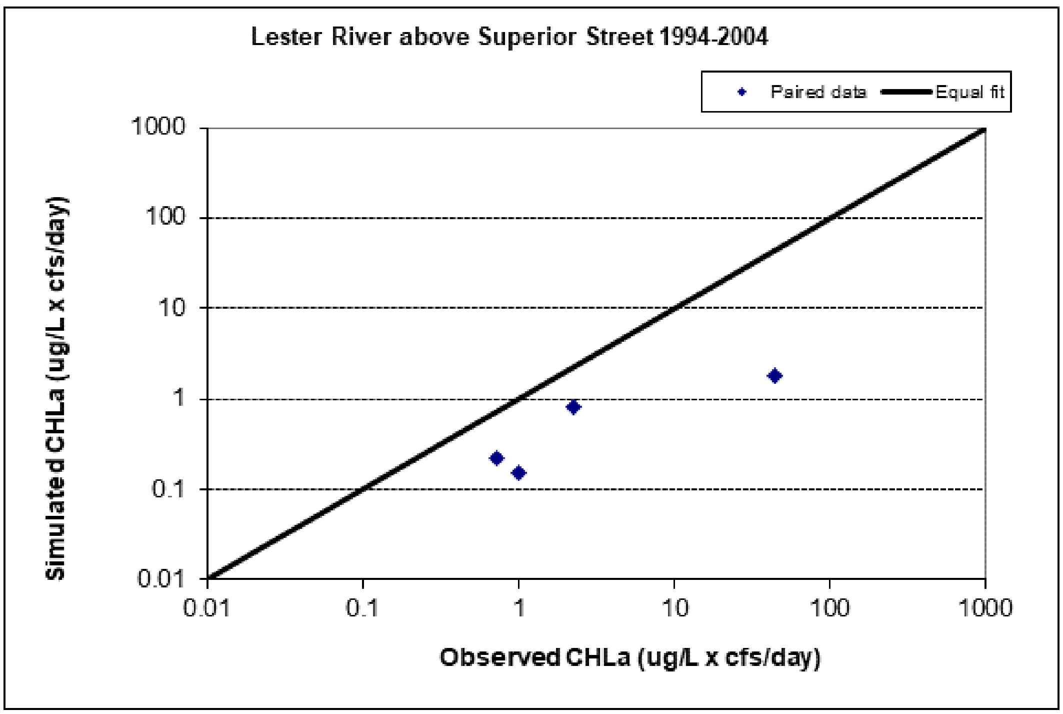


Figure E-139. Paired simulated vs. observed Chlorophyll-a (CHLa) load at Lester River above Superior Street (validation period)

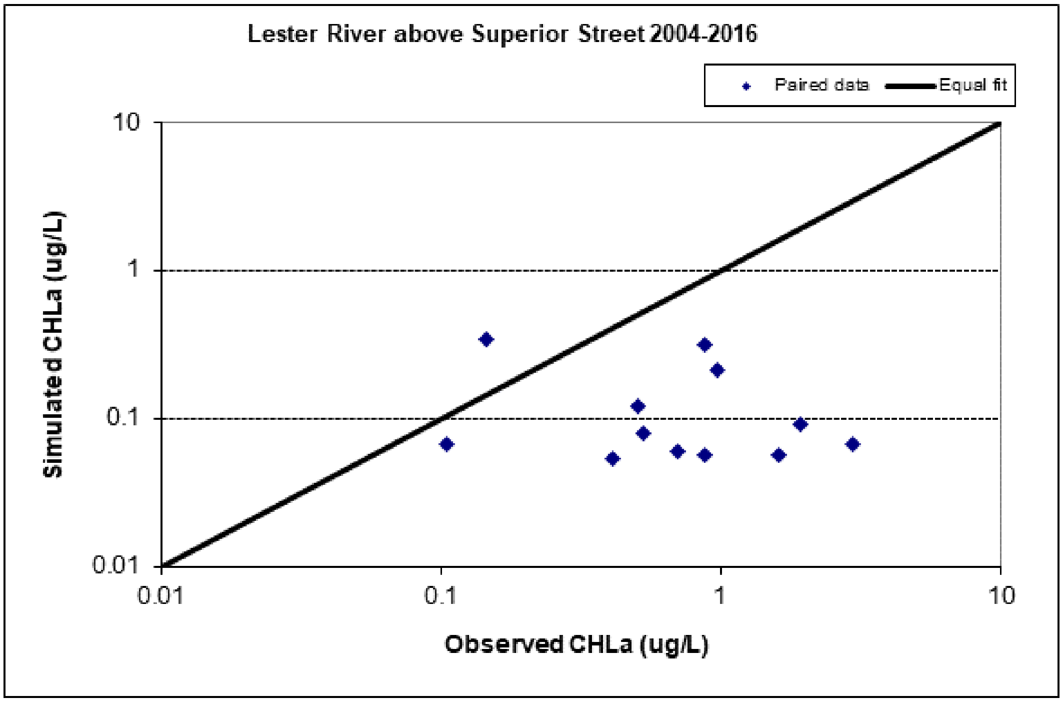


Figure E-140. Paired simulated vs. observed Chlorophyll-a (CHLa) concentration at Lester River above Superior Street (calibration period)

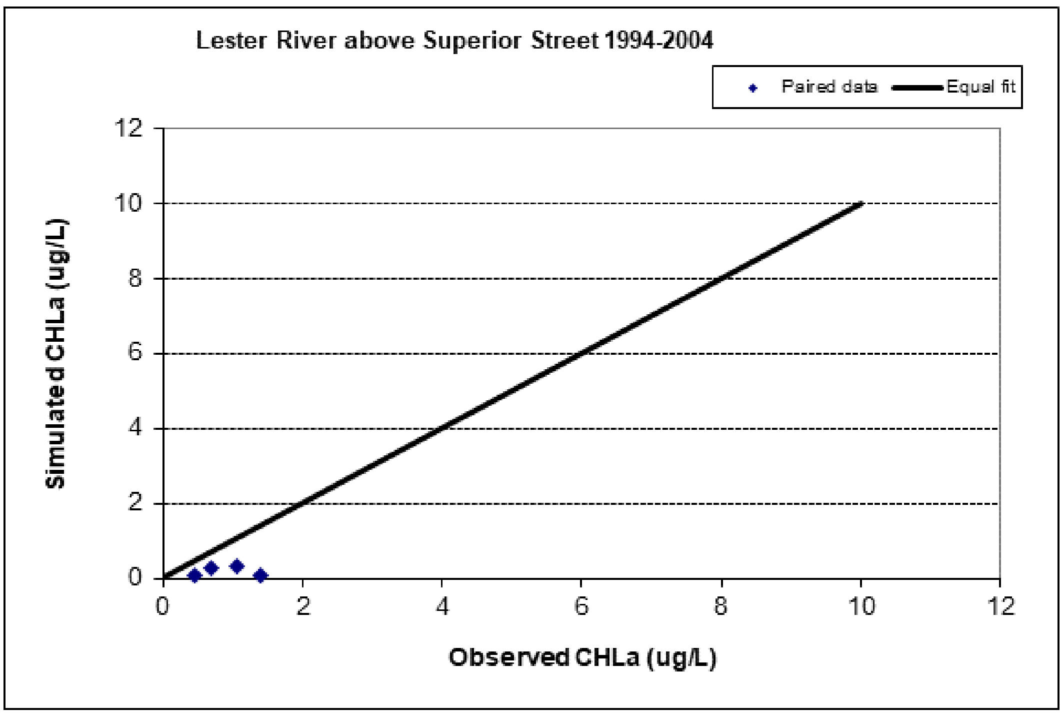


Figure E-141. Paired simulated vs. observed Chlorophyll-a (CHLa) concentration at Lester River above Superior Street (validation period)

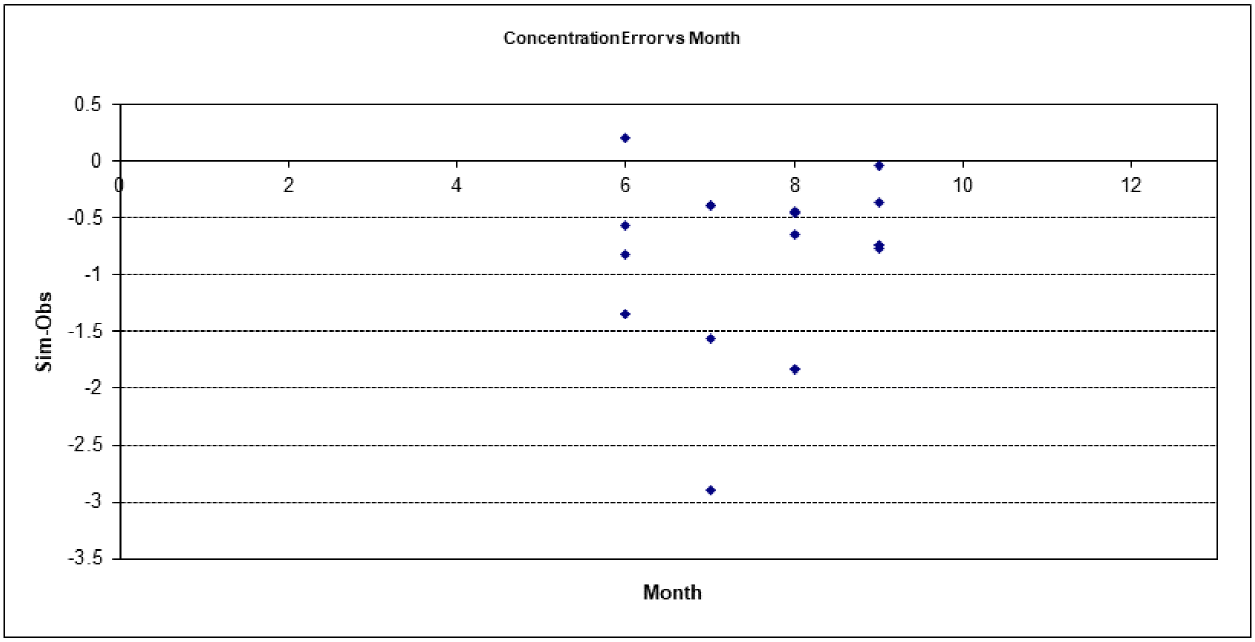


Figure E-142. Residual (Simulated - Observed) vs. Month, Chlorophyll-a (CHLa) at Lester River above Superior Street

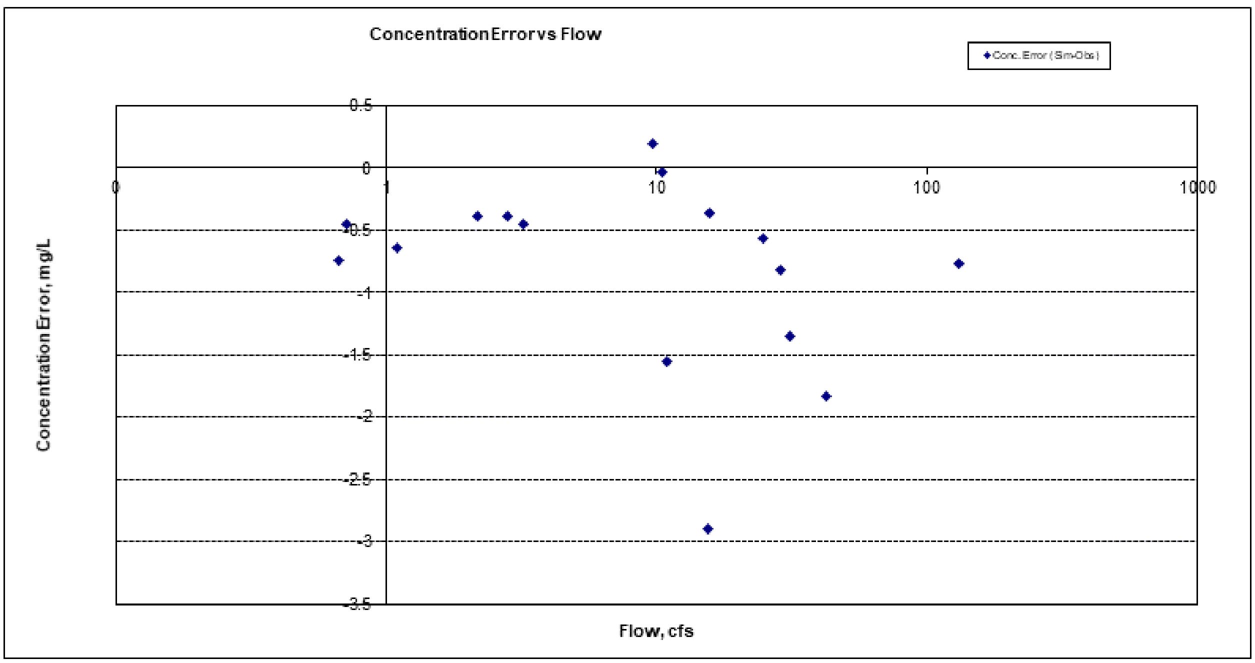


Figure E-143. Residual (Simulated - Observed) vs. Flow, Chlorophyll-a (CHLa) at Lester River above Superior Street

E.2.10 Organic Carbon (OrgC)

Table E-18. Organic Carbon (OrgC) statistics

Period	1994-2004	2004-2016
Count	ND	5
Concentration Average Error		-79.13%
Concentration Median Error		-79.97%
Load Average Error		-67.17%
Load Median Error		-55.37%
Paired t conc		0.00
Paired t load		0.10

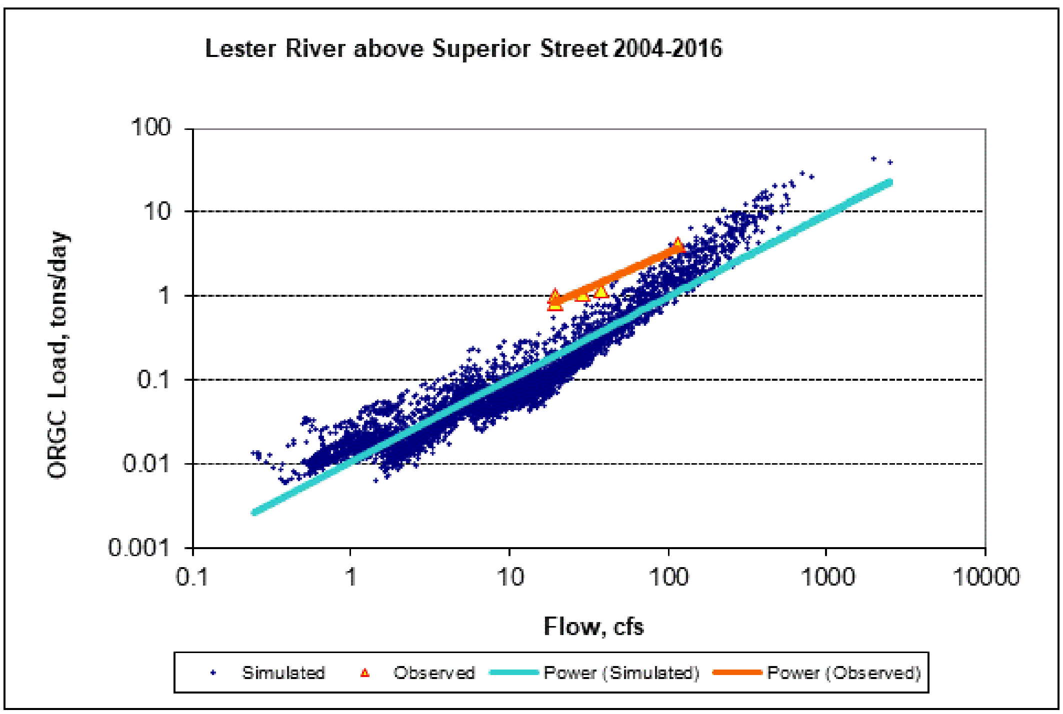


Figure E-144. Power plot of simulated and observed Organic Carbon (OrgC) load vs flow at Lester River above Superior Street (calibration period)

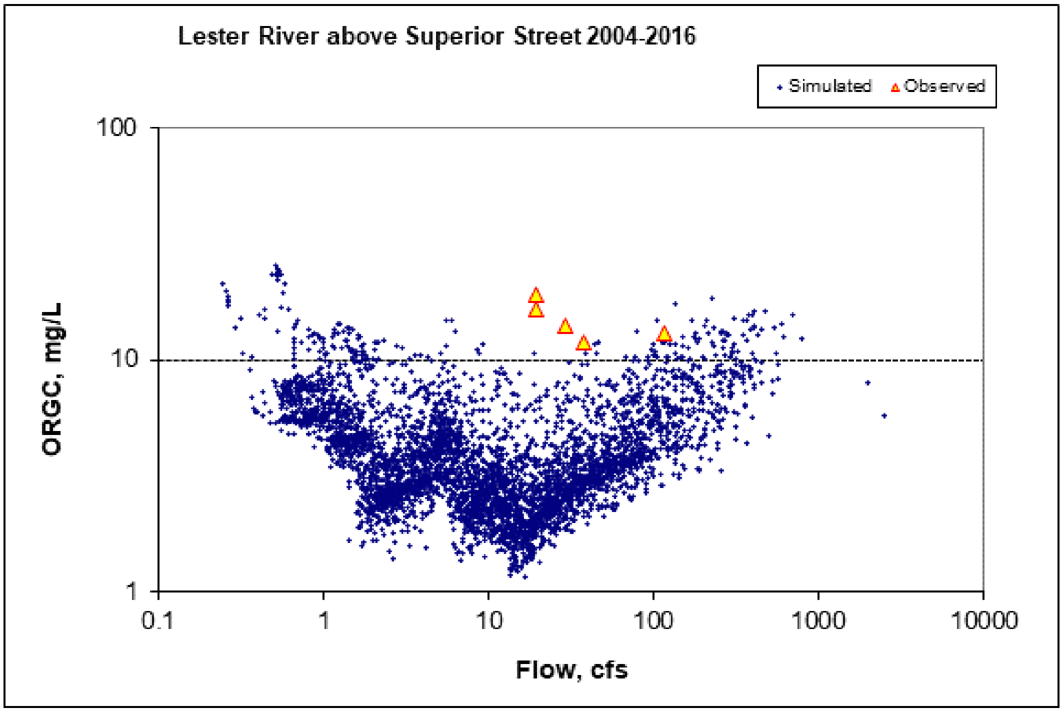
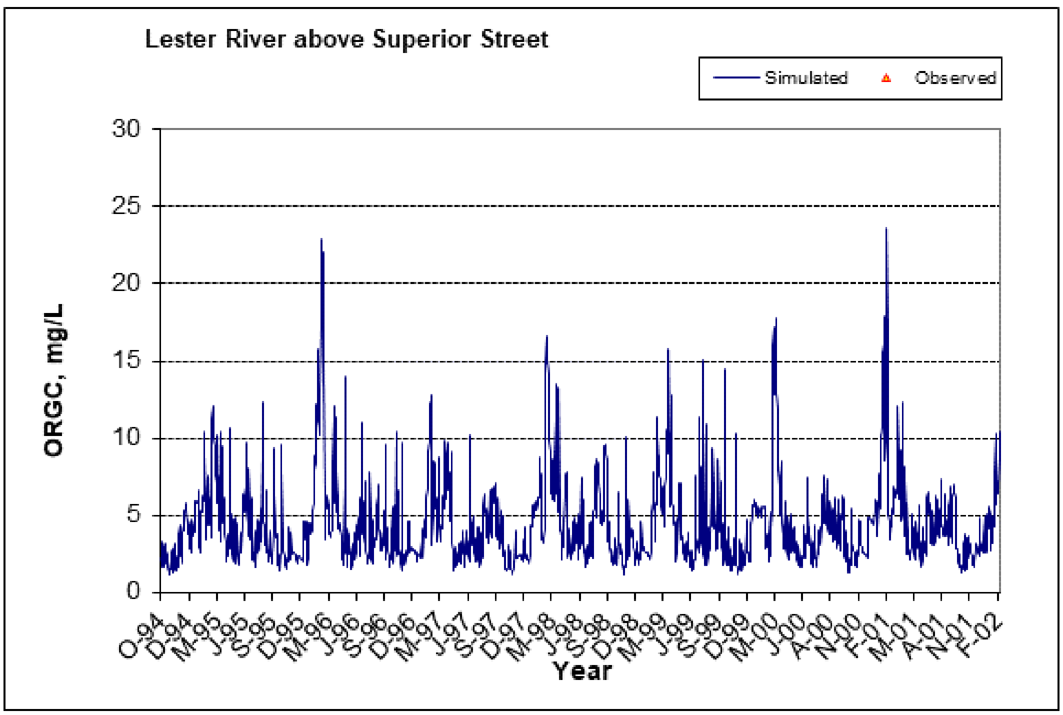


Figure E-145. Simulated and observed Organic Carbon (OrgC) concentration vs flow at Lester River above Superior Street (calibration period)



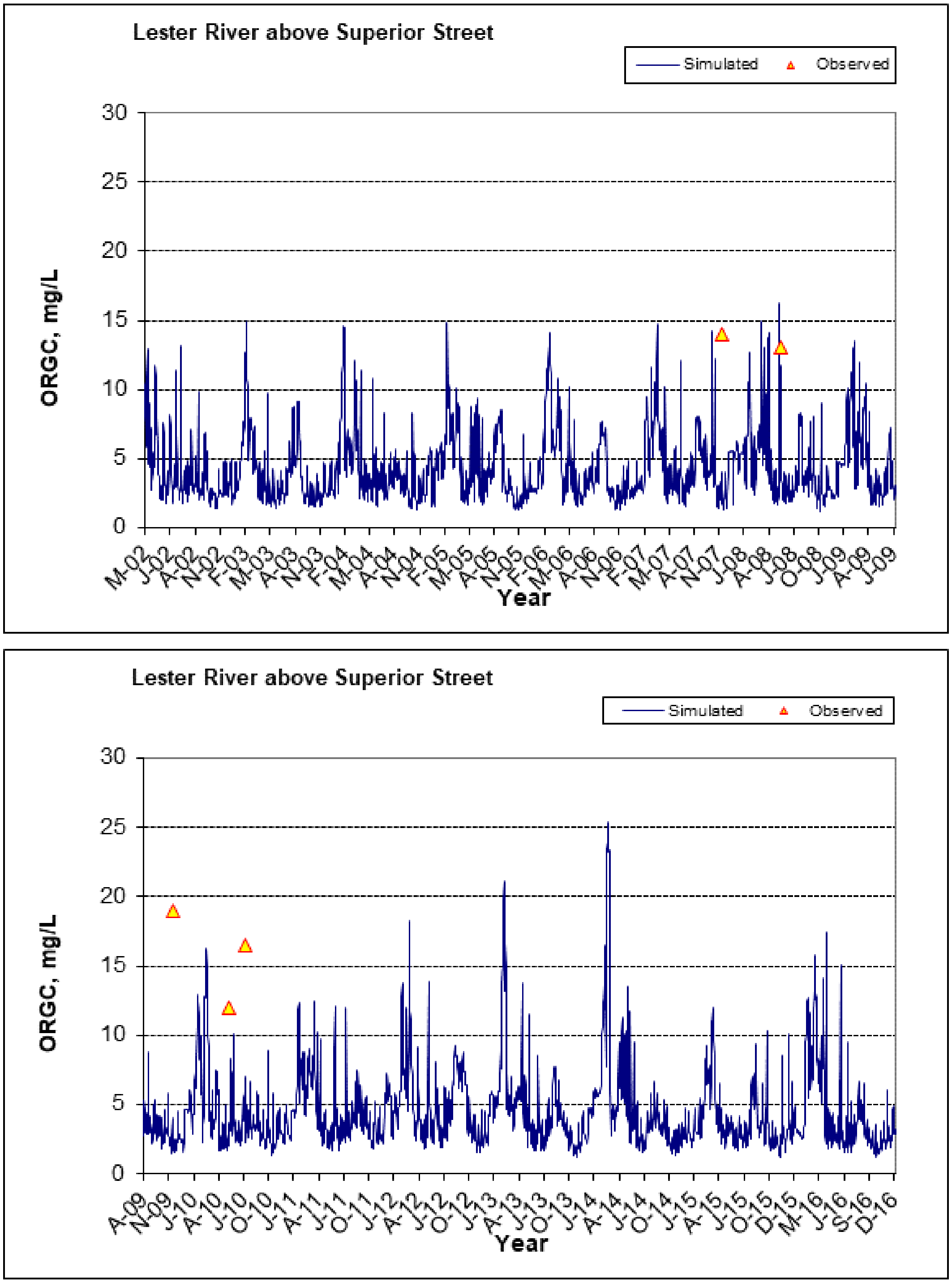


Figure E-146. Time series of observed and simulated Organic Carbon (OrgC) concentration at Lester River above Superior Street

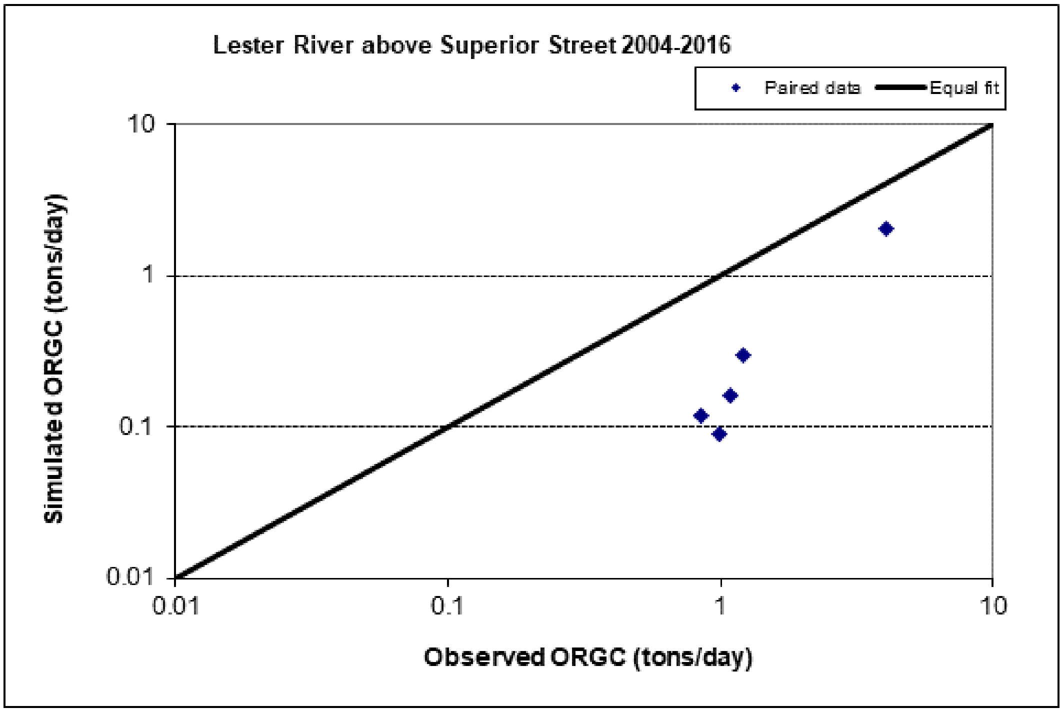


Figure E-147. Paired simulated vs. observed Organic Carbon (OrgC) load at Lester River above Superior Street (calibration period)

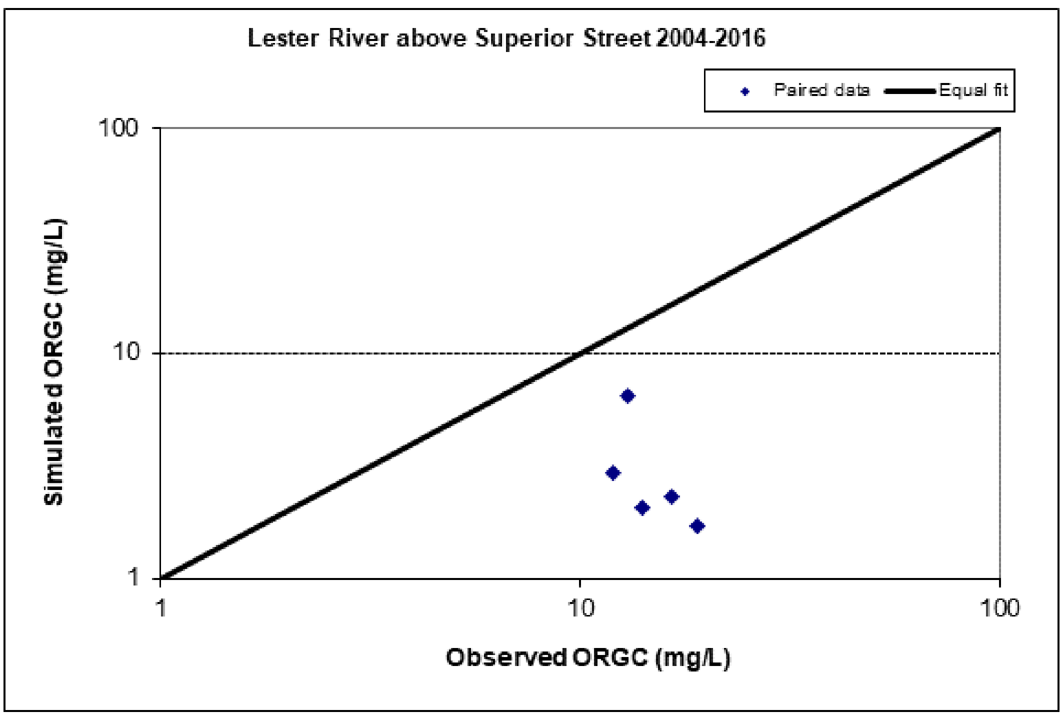


Figure E-148. Paired simulated vs. observed Organic Carbon (OrgC) concentration at Lester River above Superior Street (calibration period)

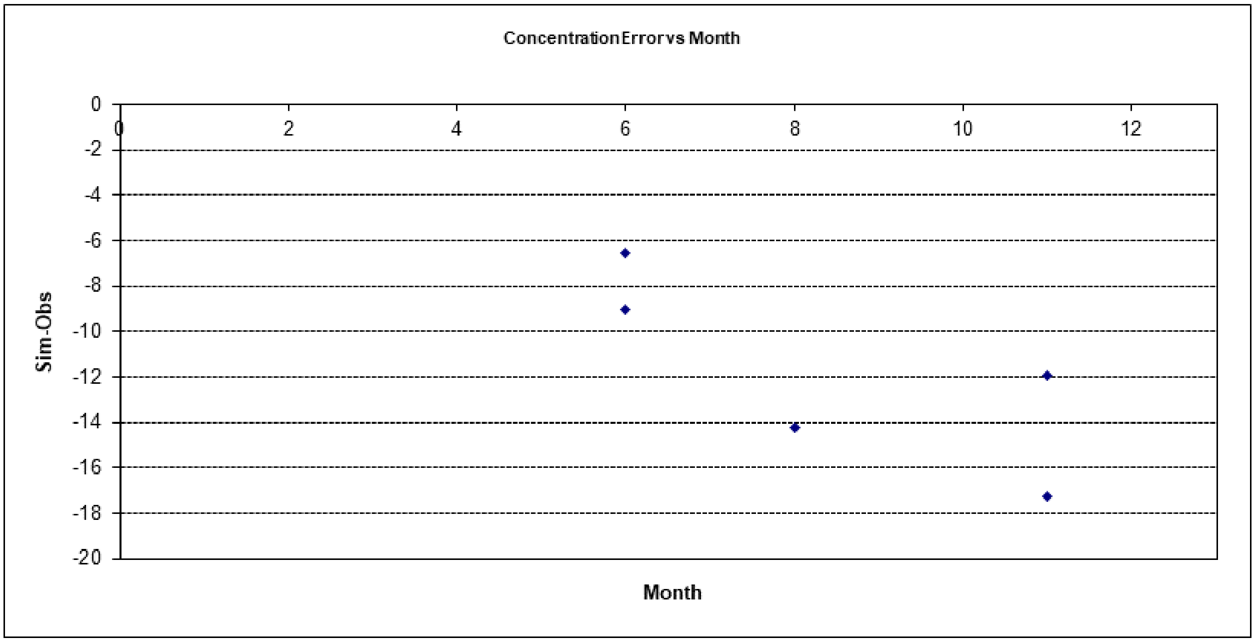


Figure E-149. Residual (Simulated - Observed) vs. Month, Organic Carbon (OrgC) at Lester River above Superior Street

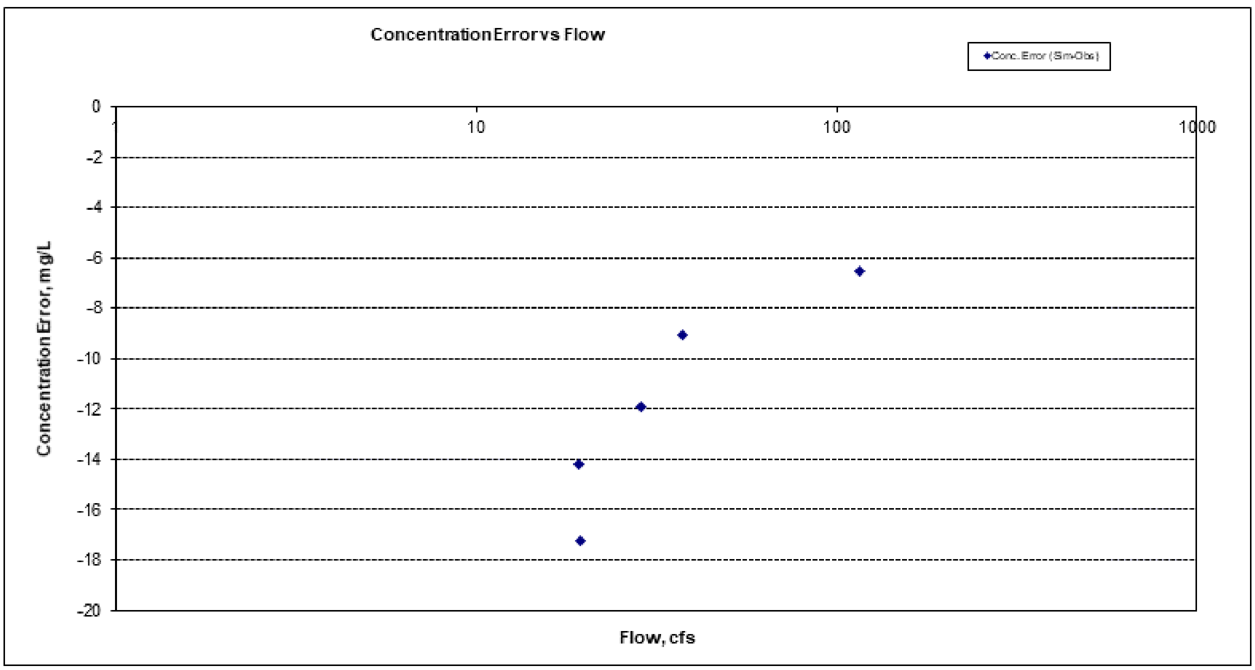


Figure E-150. Residual (Simulated - Observed) vs. Flow, Organic Carbon (OrgC) at Lester River above Superior Street

E.3 East Br Amity Cr above Confluence with Amity Cr

E.3.1 Dissolved Oxygen (DO)

Table E-19. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	49
Concentration Average Error		-8.86%
Concentration Median Error		-5.90%
Load Average Error		-9.69%
Load Median Error		-0.95%
Paired t conc		1.00
Paired t load		0.72

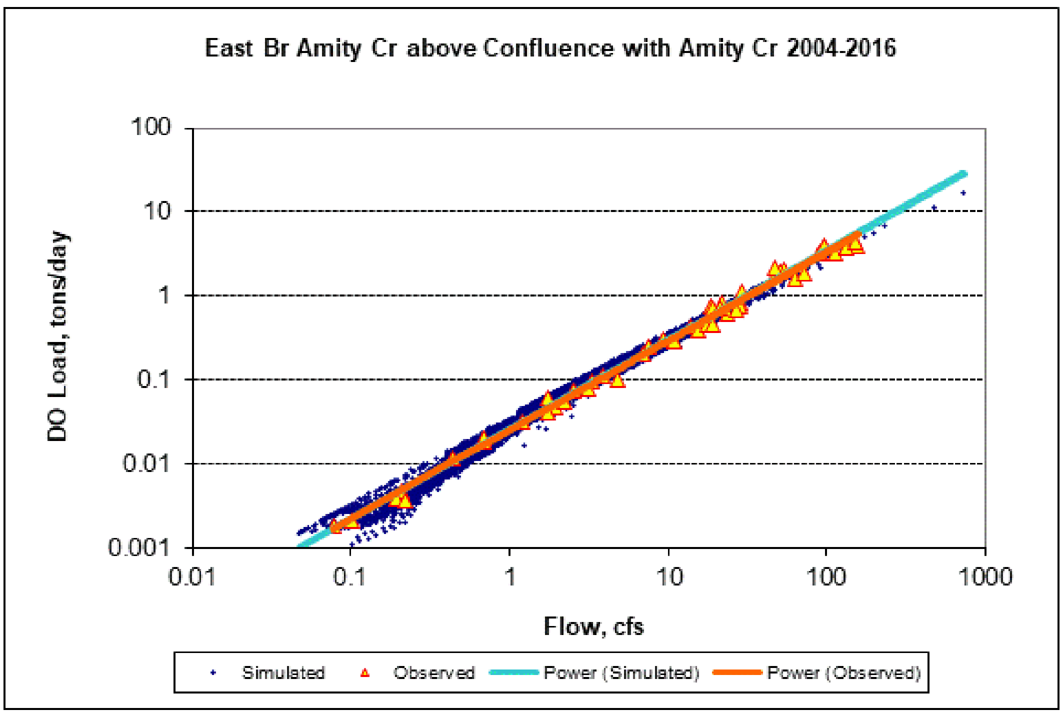


Figure E-151. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

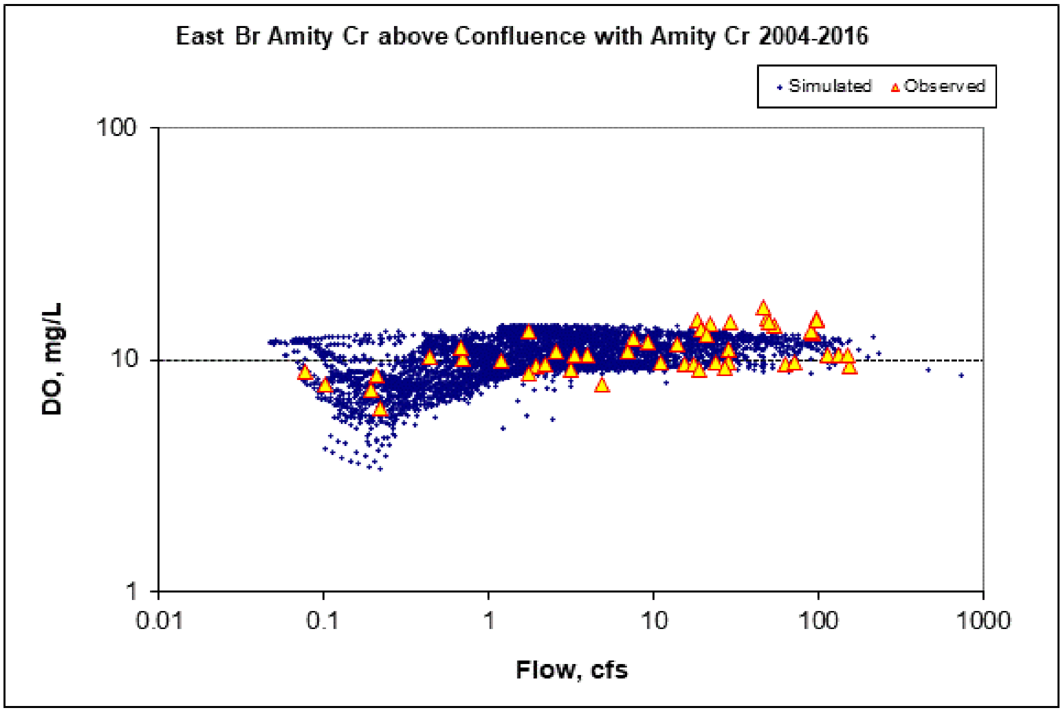
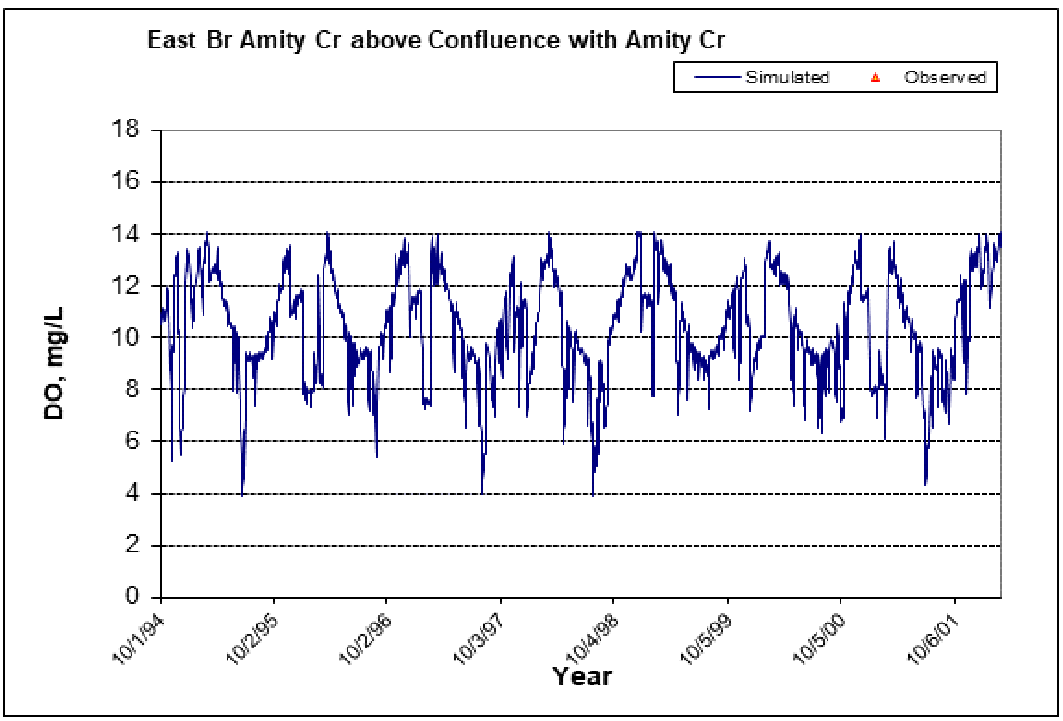


Figure E-152. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)



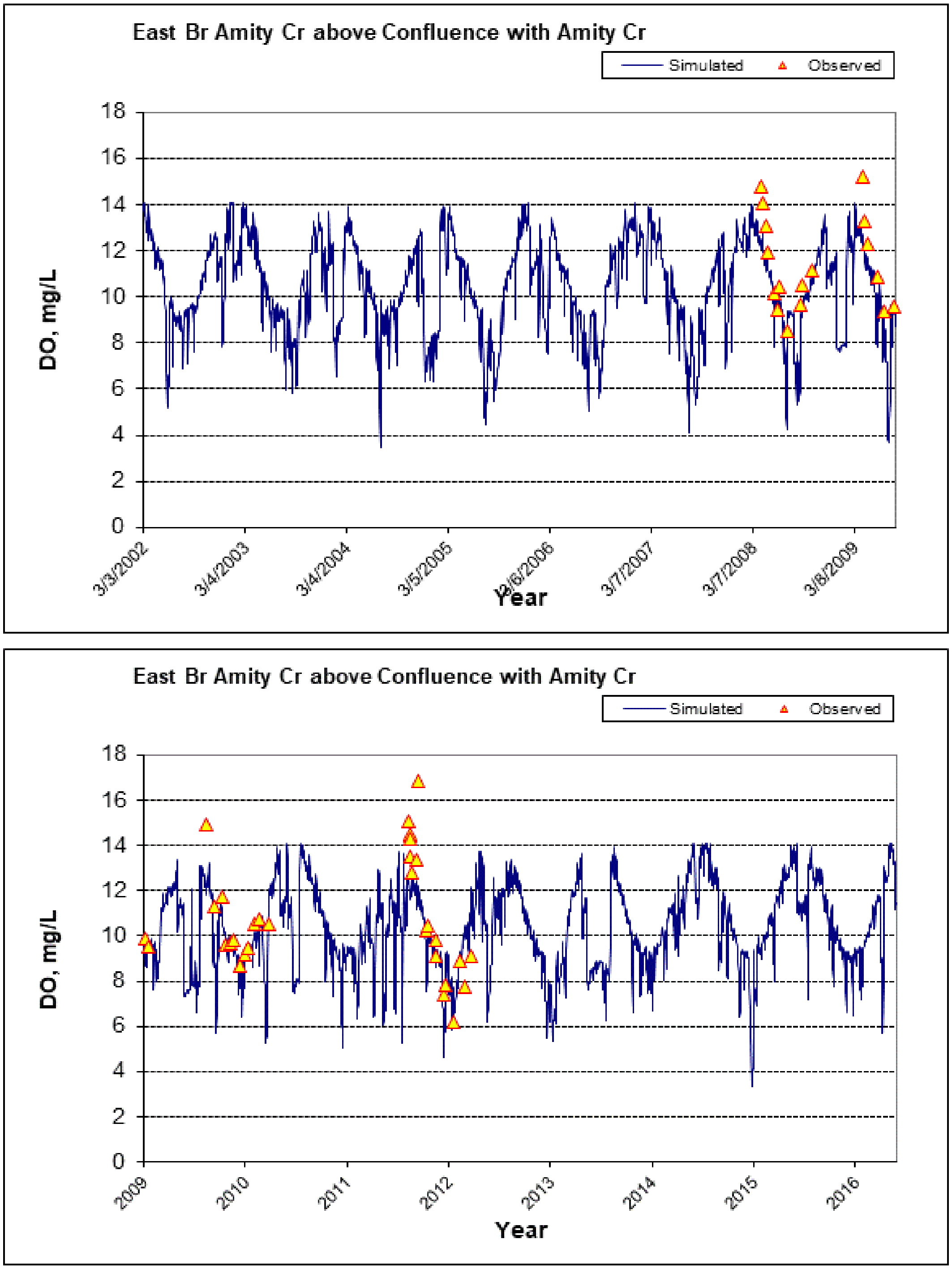


Figure E-153. Time series of observed and simulated Dissolved Oxygen (DO) concentration at East Br Amity Cr above Confluence with Amity Cr

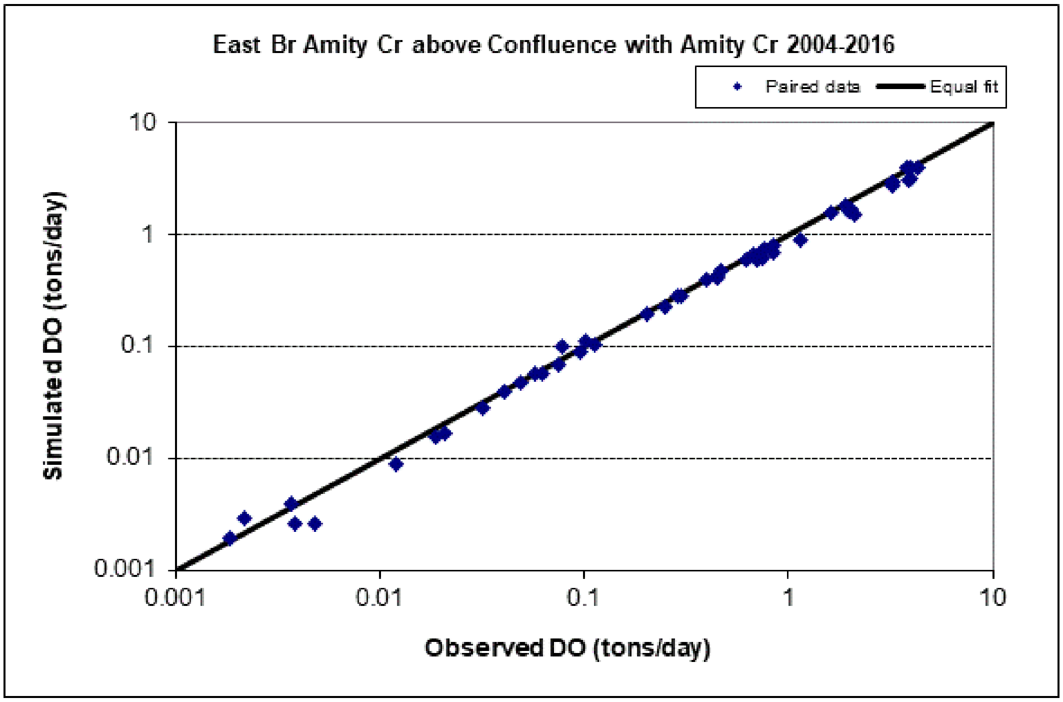


Figure E-154. Paired simulated vs. observed Dissolved Oxygen (DO) load at East Br Amity Cr above Confluence with Amity Cr (calibration period)

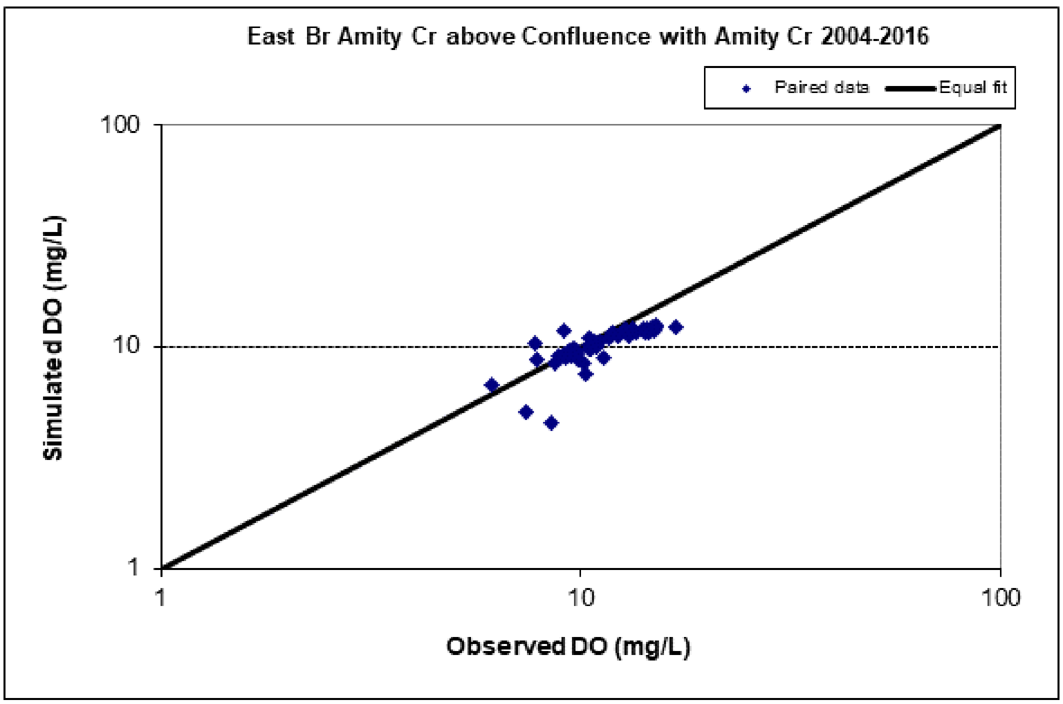


Figure E-155. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at East Br Amity Cr above Confluence with Amity Cr (calibration period)

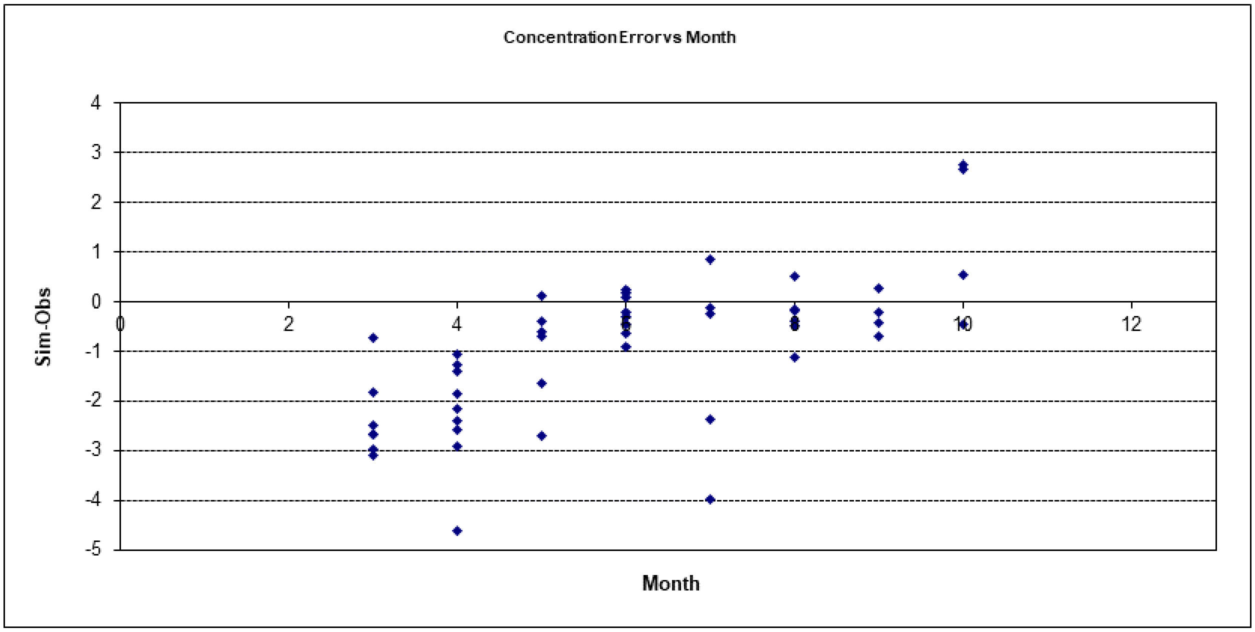


Figure E-156. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at East Br Amity Cr above Confluence with Amity Cr

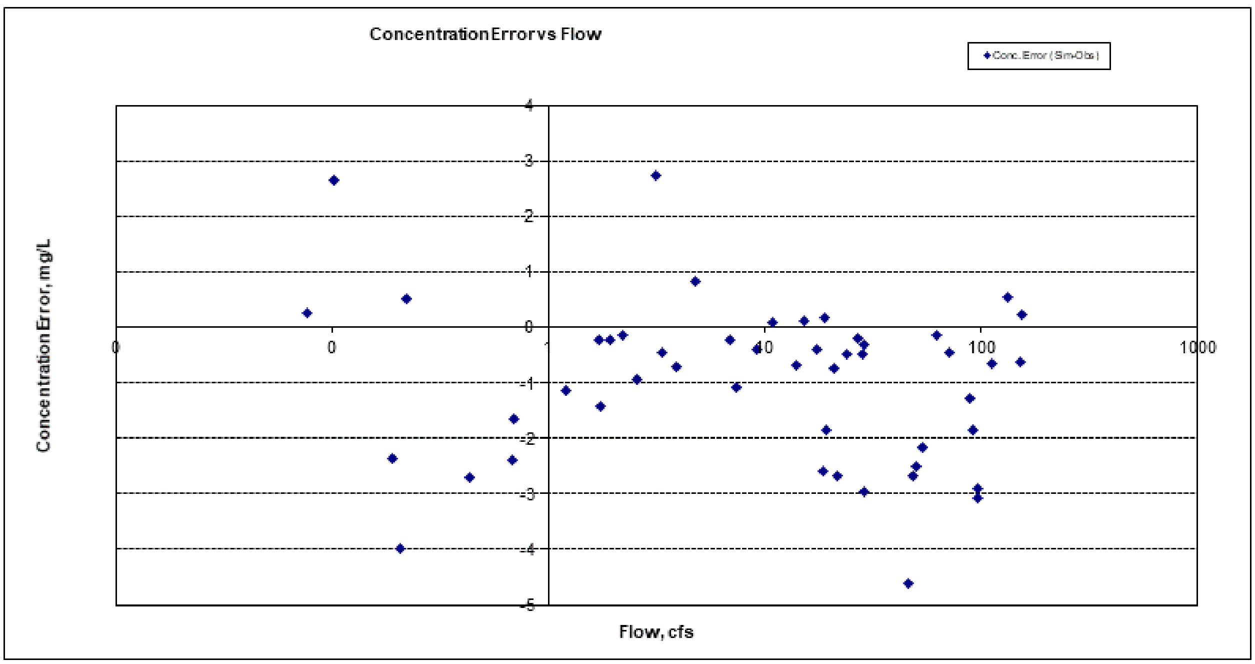


Figure E-157. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at East Br Amity Cr above Confluence with Amity Cr

E.3.2 Ammonia Nitrogen (NH3)

Table E-20. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	18	19
Concentration Average Error	-5.67%	498.13%
Concentration Median Error	5.53%	190.94%
Load Average Error	-49.76%	547.63%
Load Median Error	0.20%	47.79%
Paired t conc	0.71	0.00
Paired t load	0.31	0.00

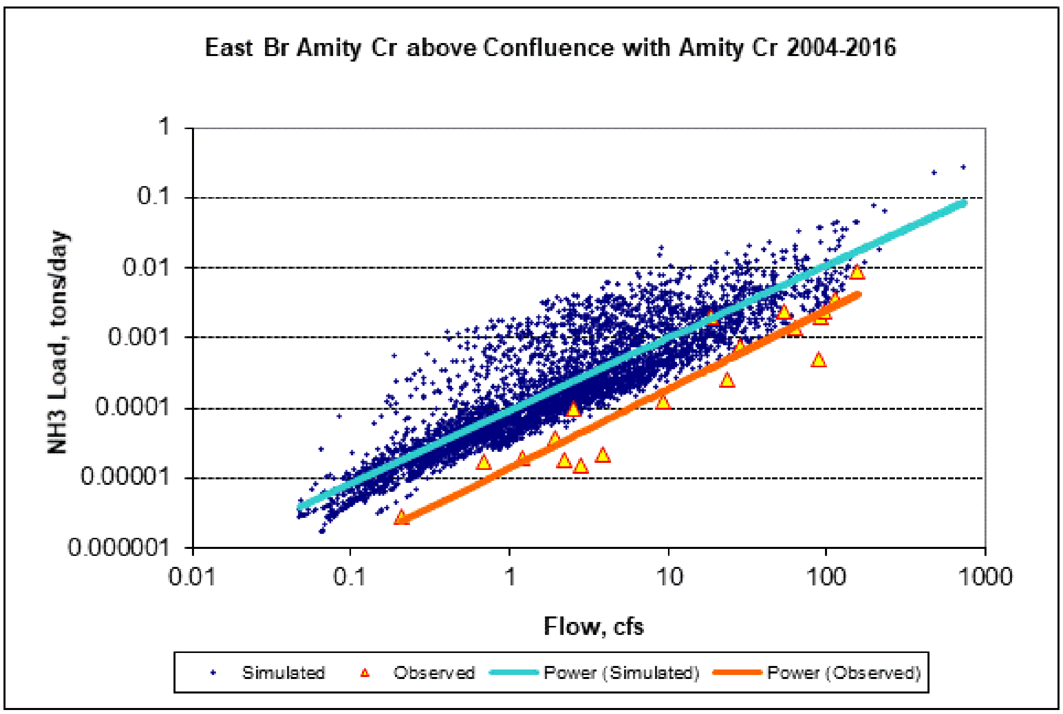


Figure E-158. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

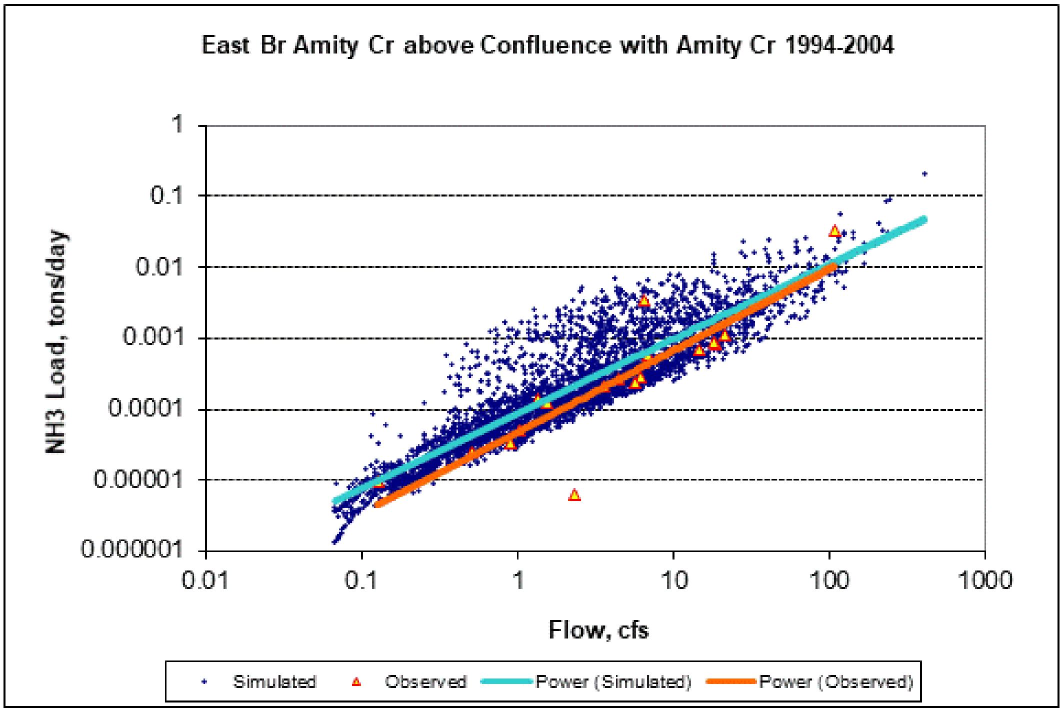


Figure E-159. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)

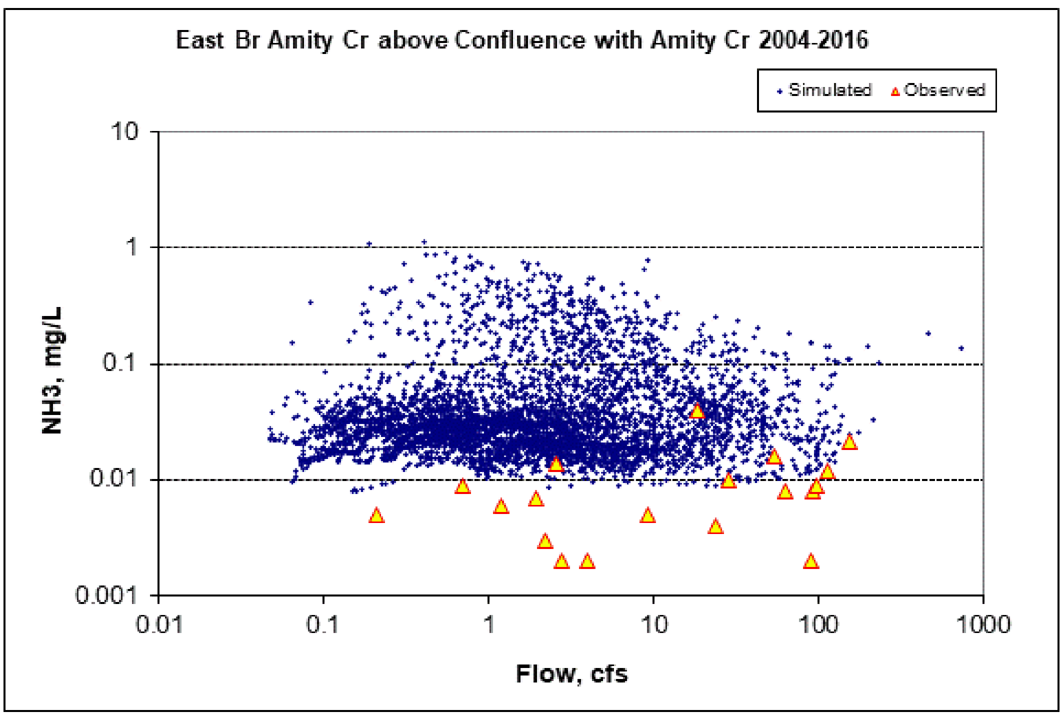


Figure E-160. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

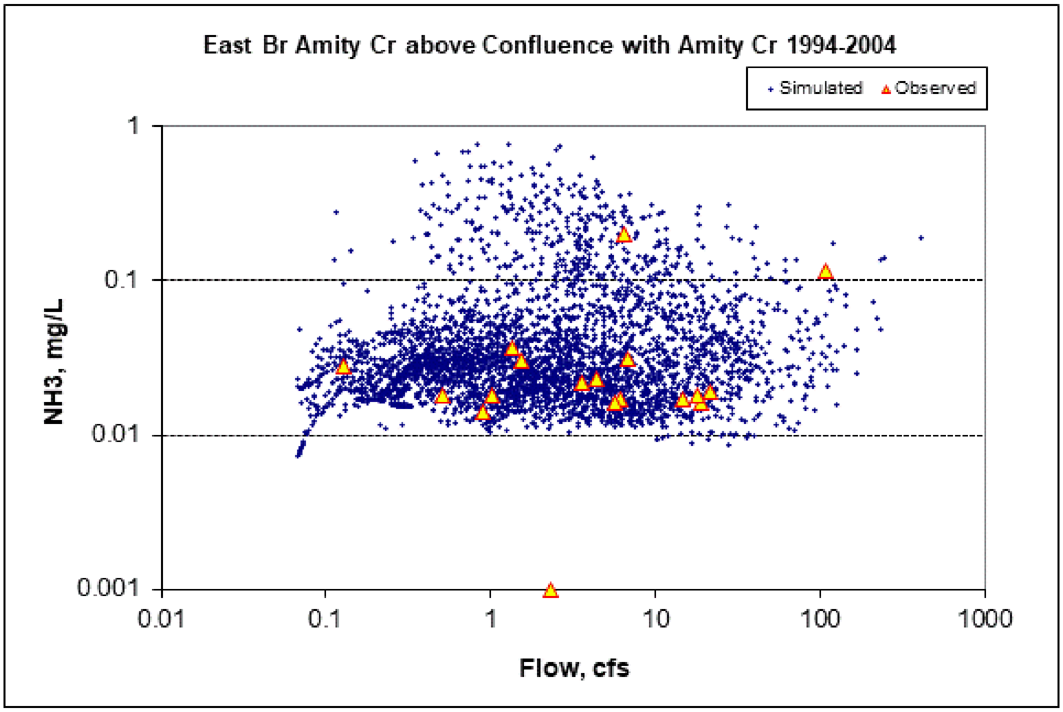
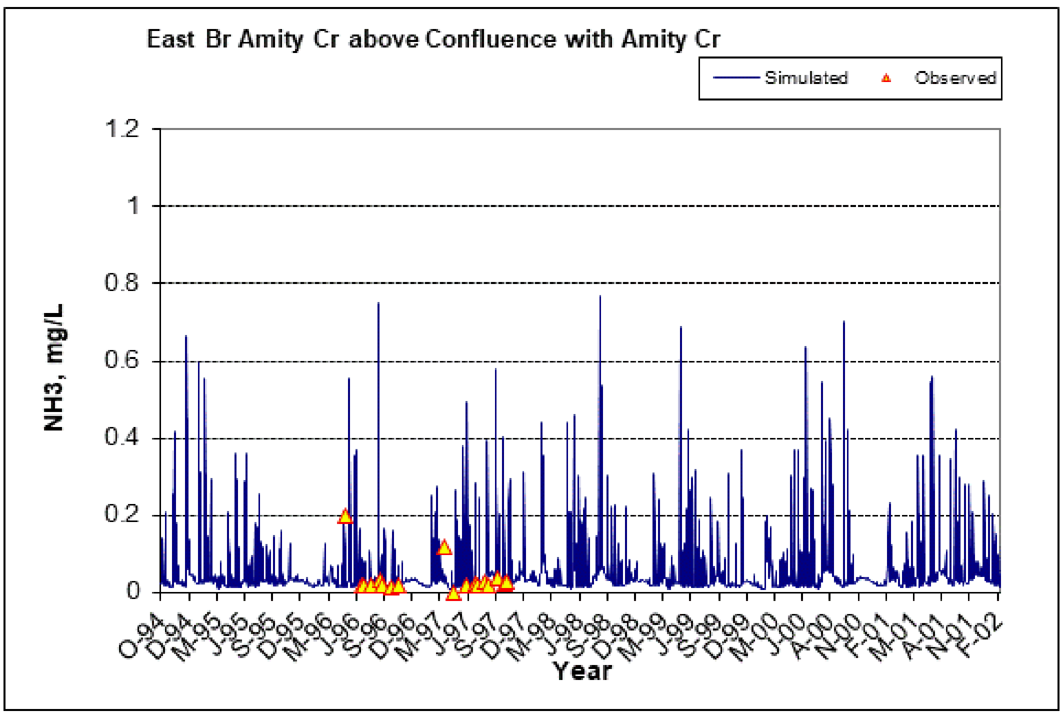
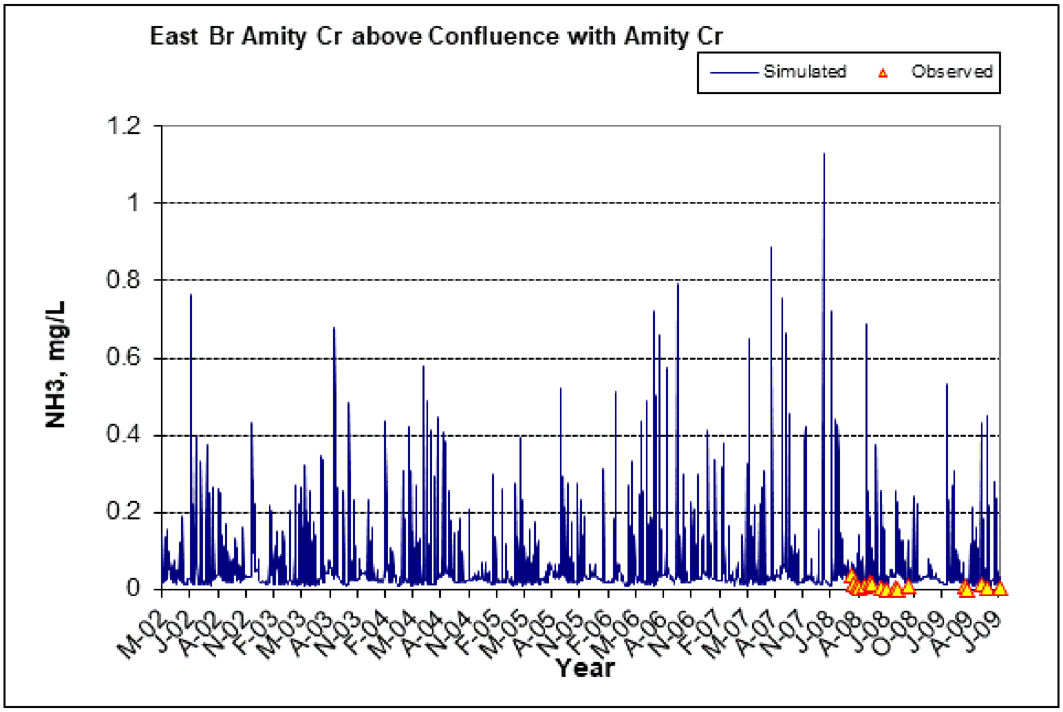


Figure E-161. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)





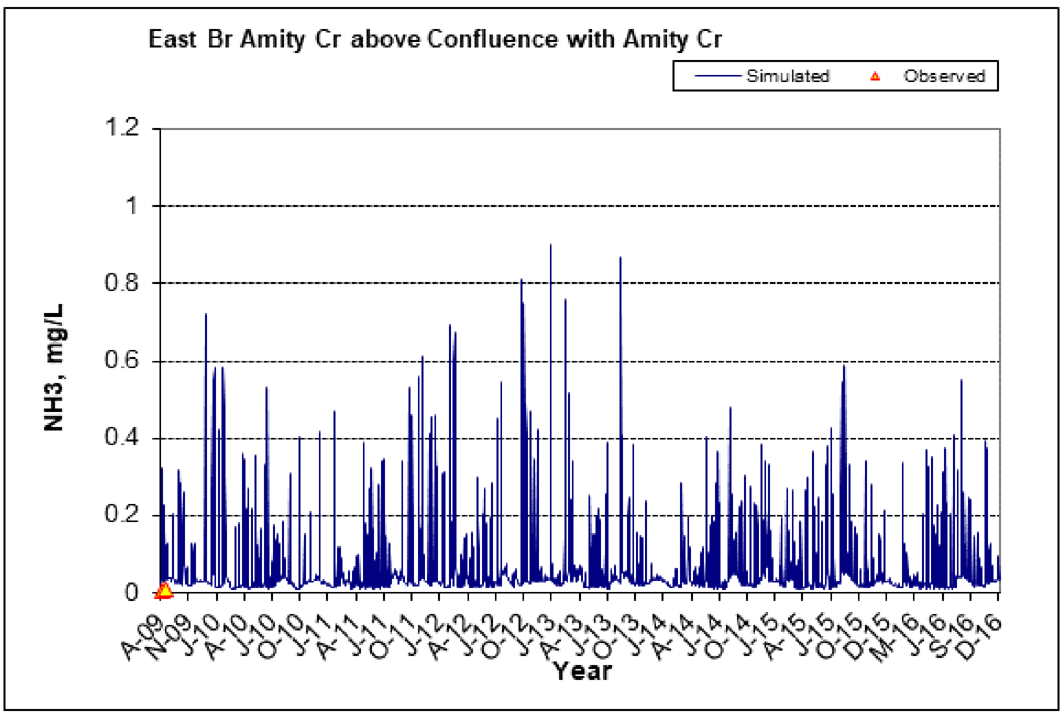


Figure E-162. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at East Br Amity Cr above Confluence with Amity Cr

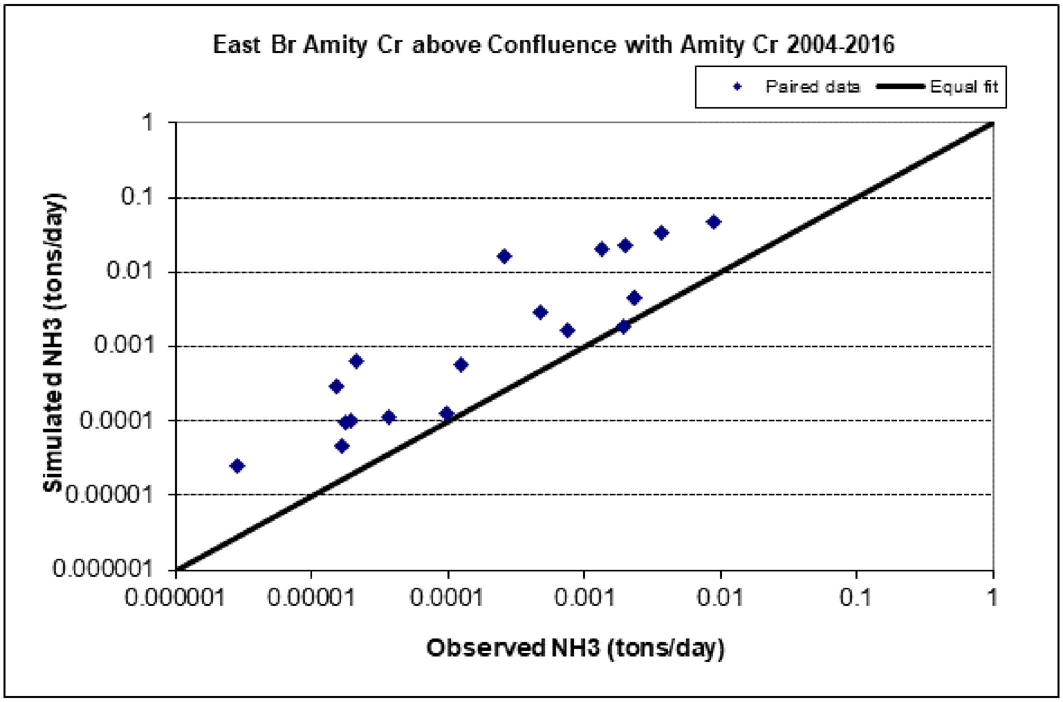


Figure E-163. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at East Br Amity Cr above Confluence with Amity Cr (calibration period)

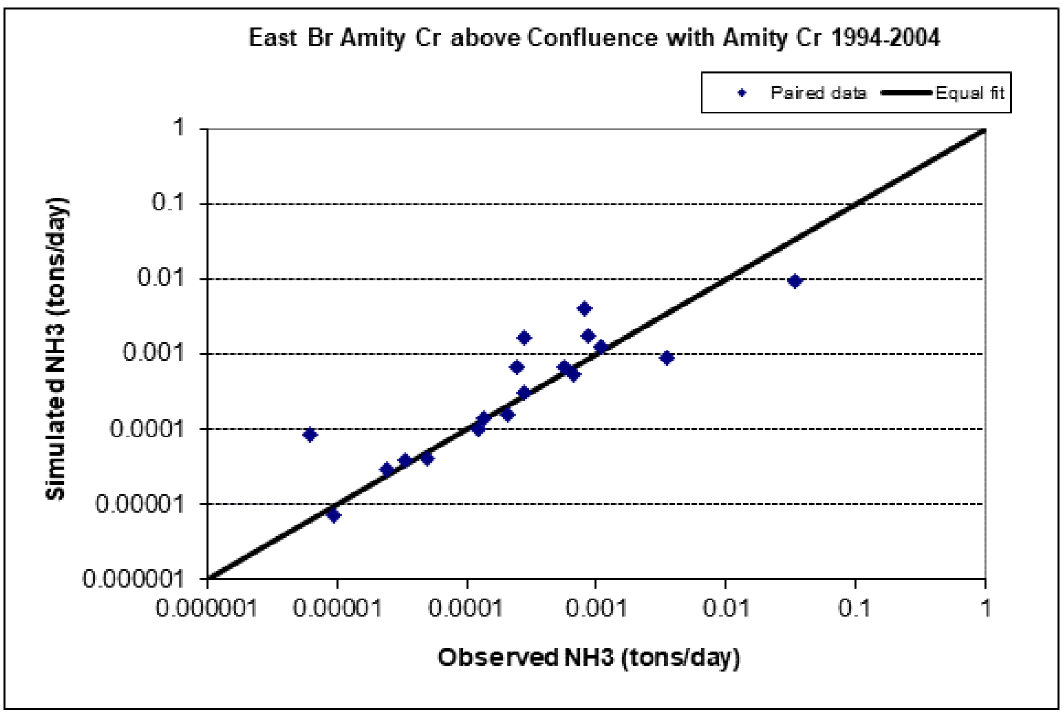


Figure E-164. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at East Br Amity Cr above Confluence with Amity Cr (validation period)

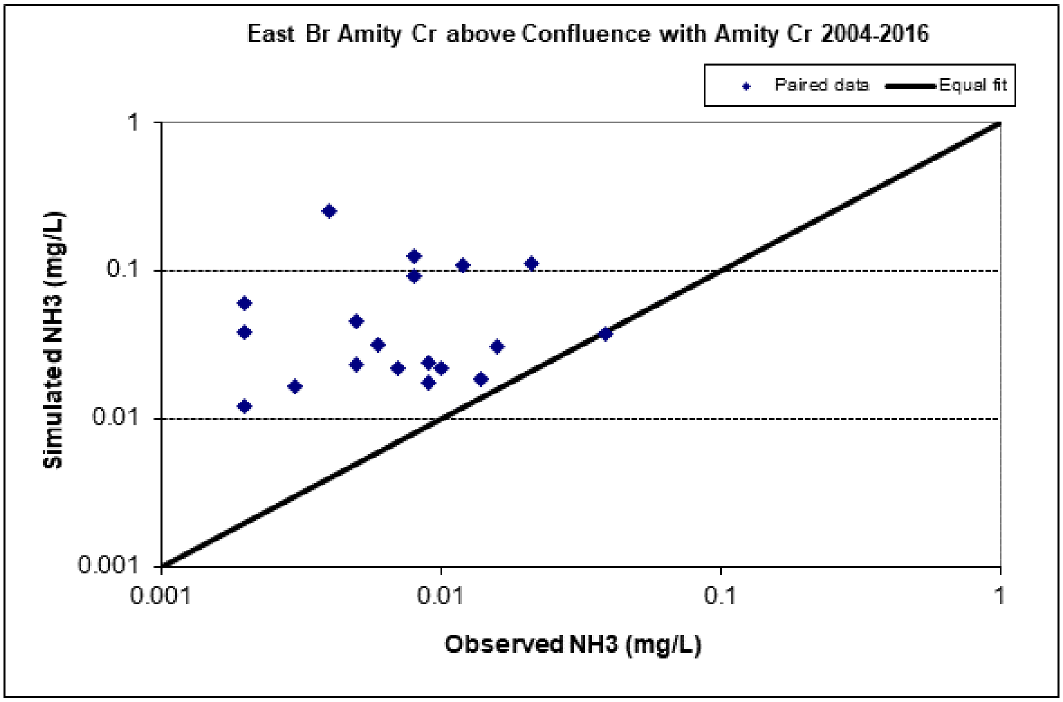


Figure E-165. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at East Br Amity Cr above Confluence with Amity Cr (calibration period)

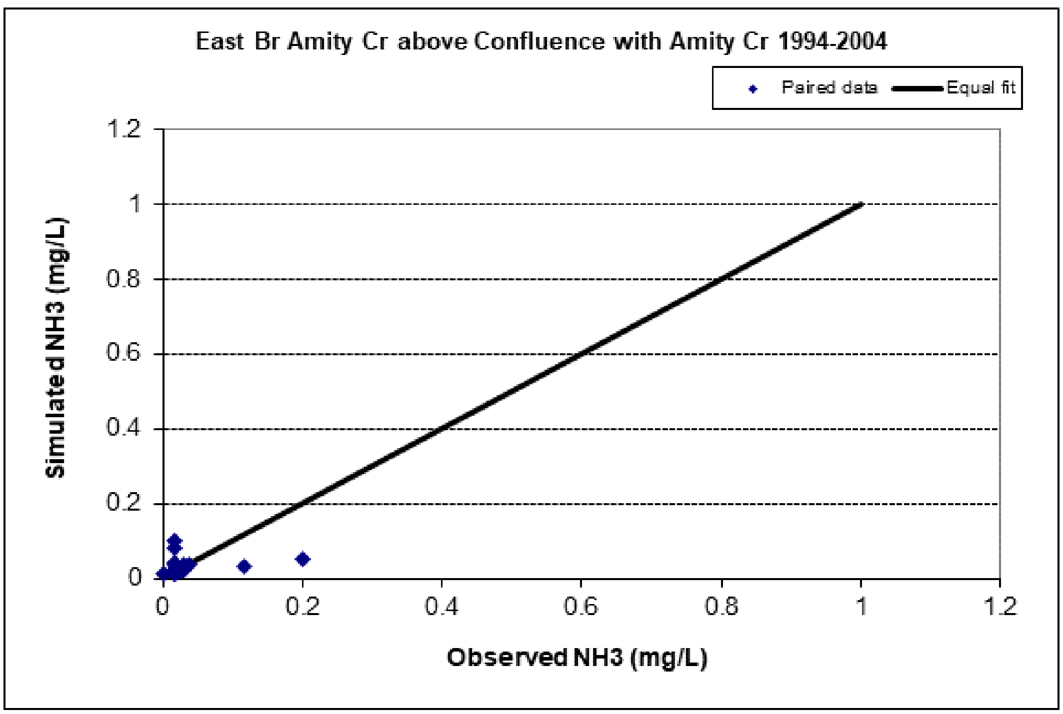


Figure E-166. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at East Br Amity Cr above Confluence with Amity Cr (validation period)

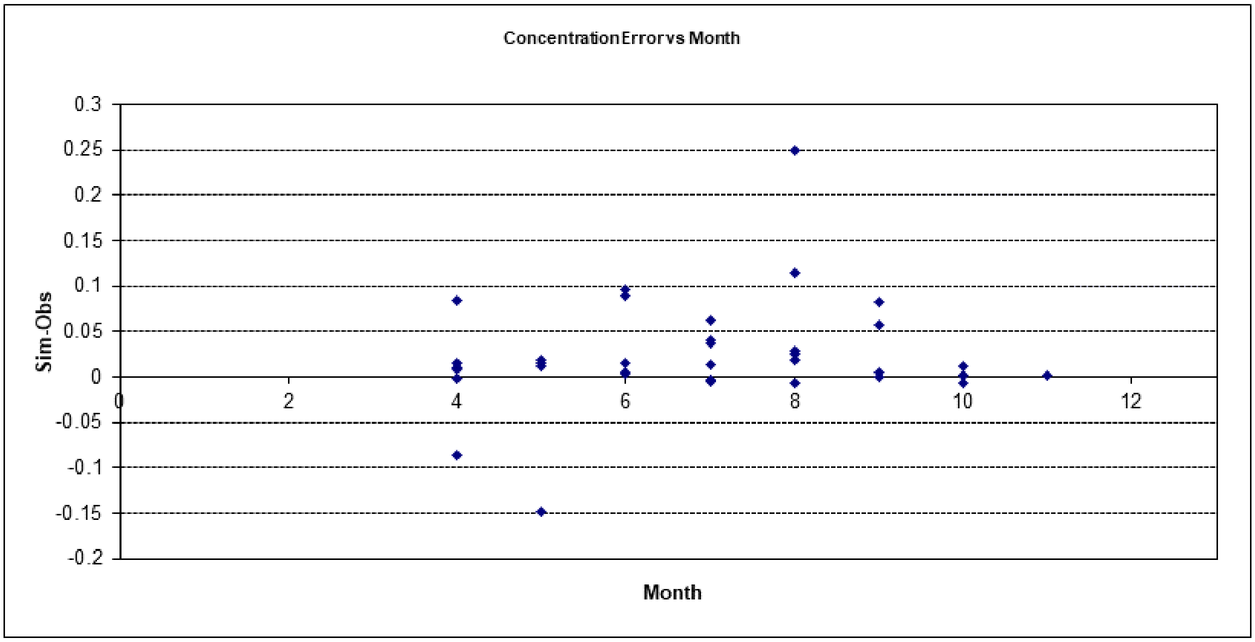


Figure E-167. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at East Br Amity Cr above Confluence with Amity Cr

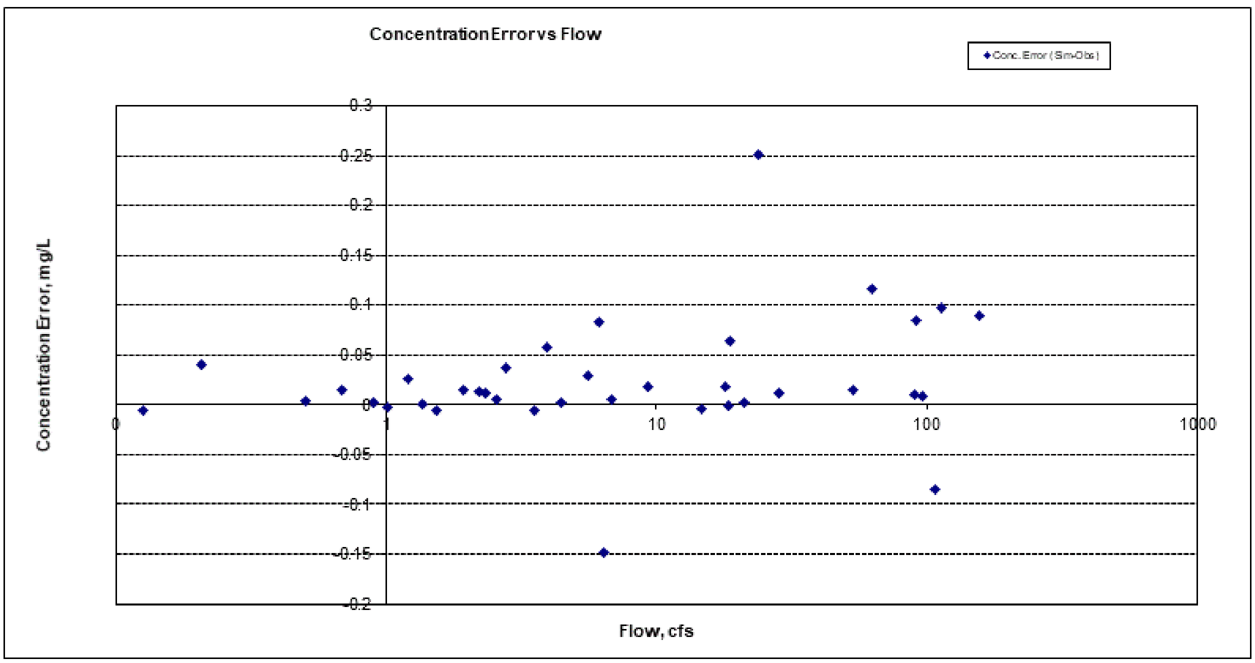


Figure E-168. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at East Br Amity Cr above Confluence with Amity Cr

E.3.3 Organic Nitrogen (OrgN)

Table E-21. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	5	18
Concentration Average Error	-40.80%	28.76%
Concentration Median Error	-29.56%	36.36%
Load Average Error	-43.85%	35.69%
Load Median Error	-1.39%	1.42%
Paired t conc	0.20	0.25
Paired t load	0.39	0.35

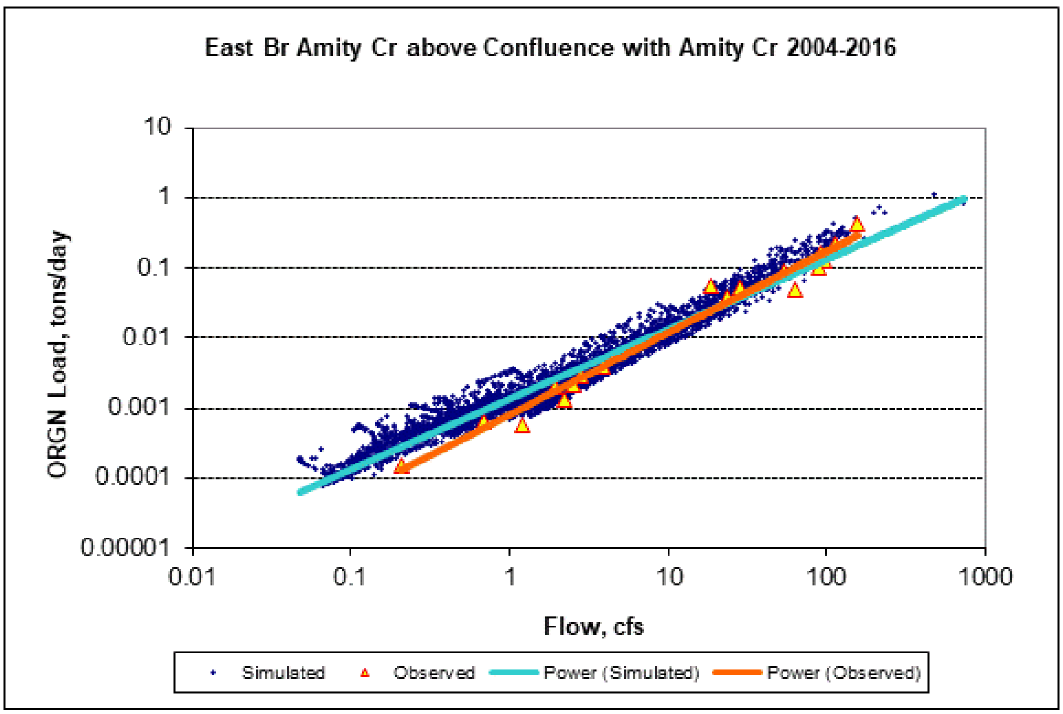


Figure E-169. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

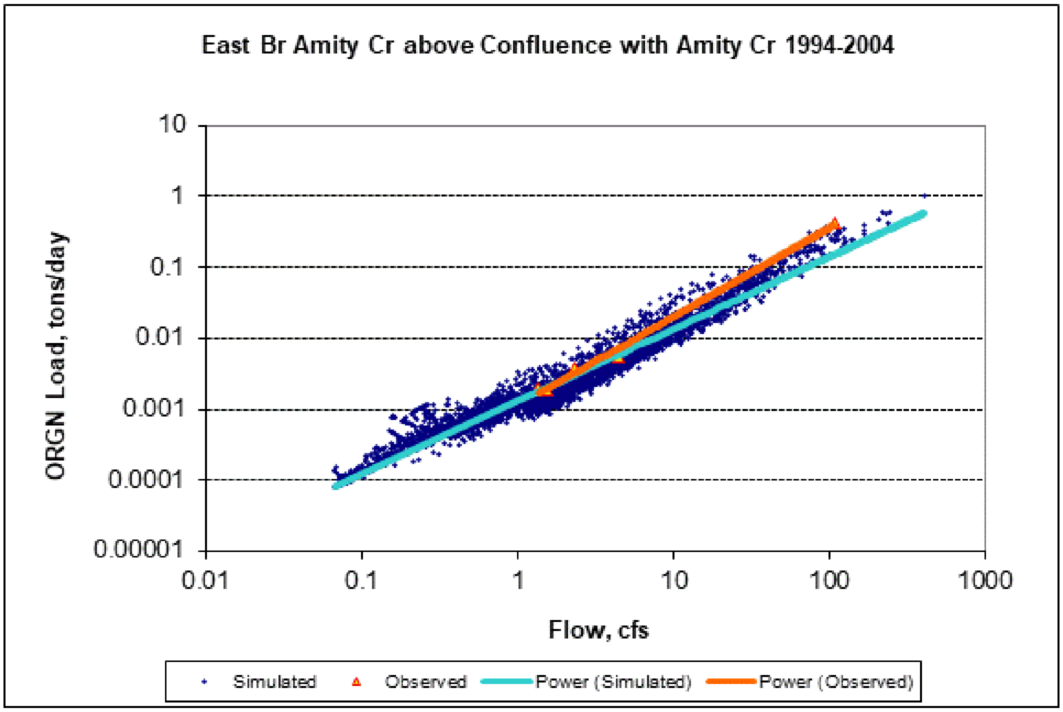


Figure E-170. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)

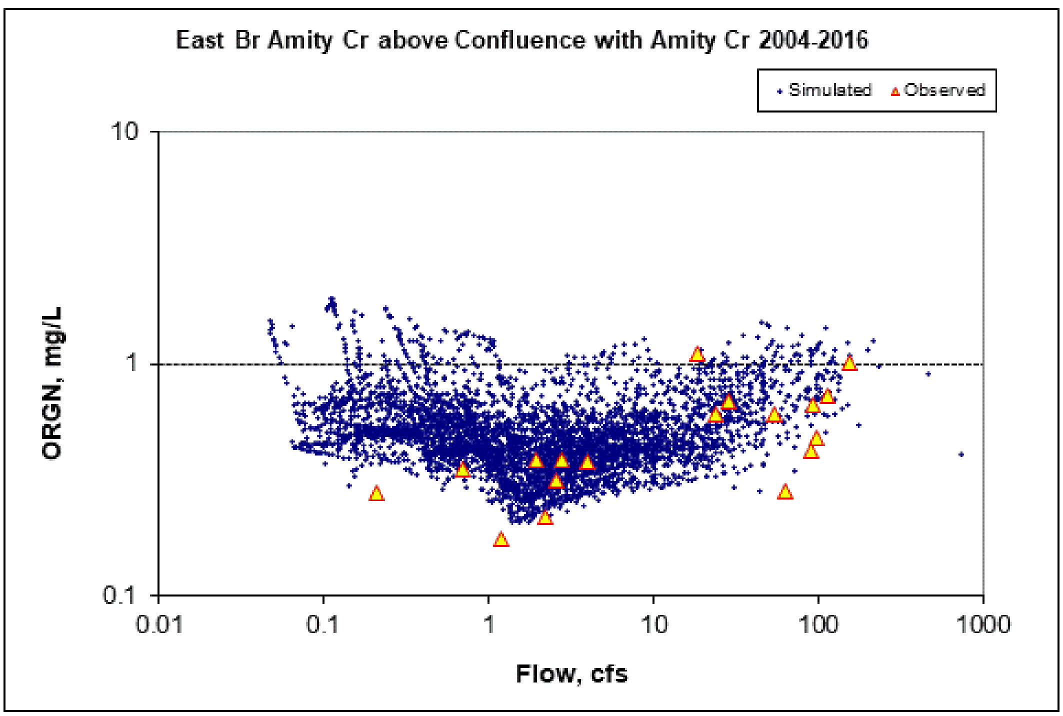


Figure E-171. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

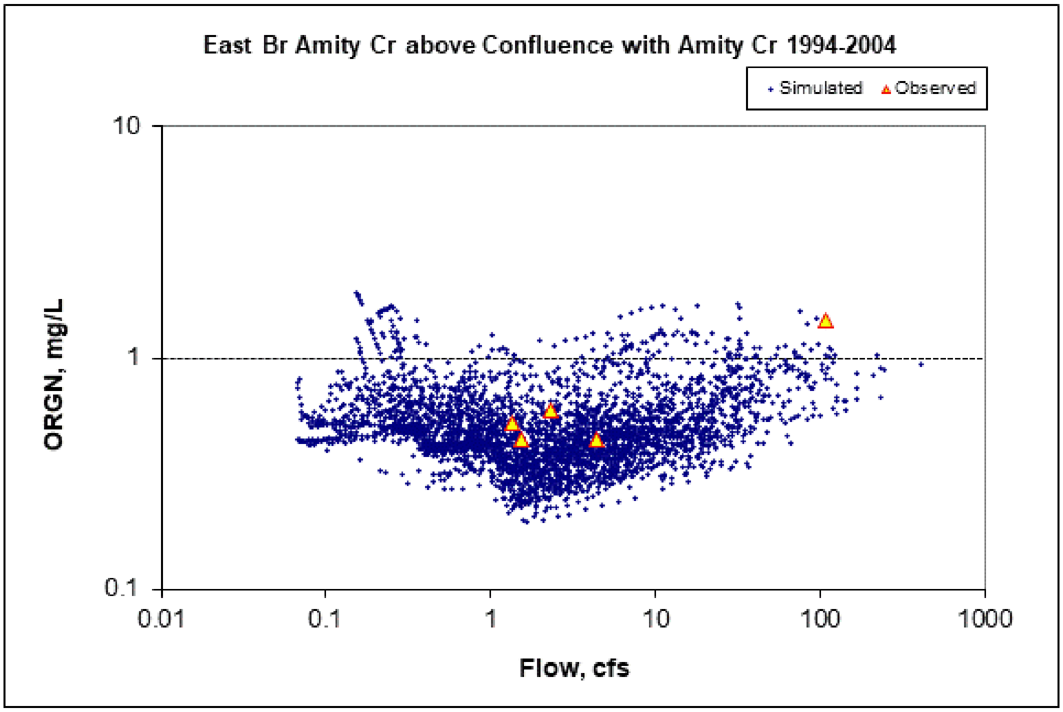
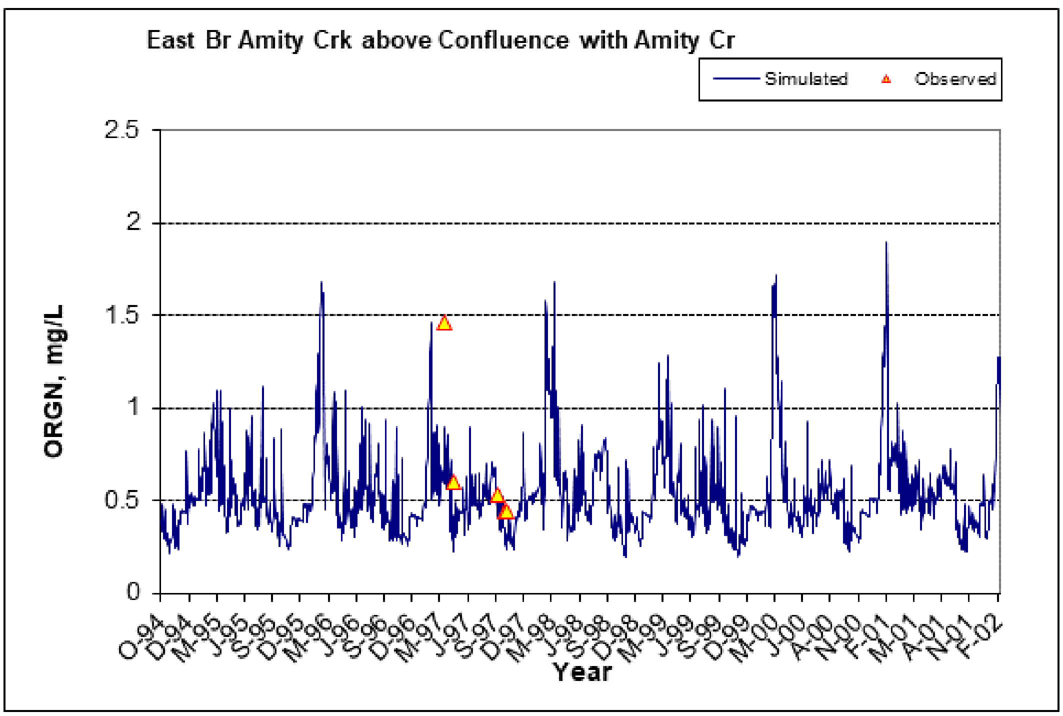
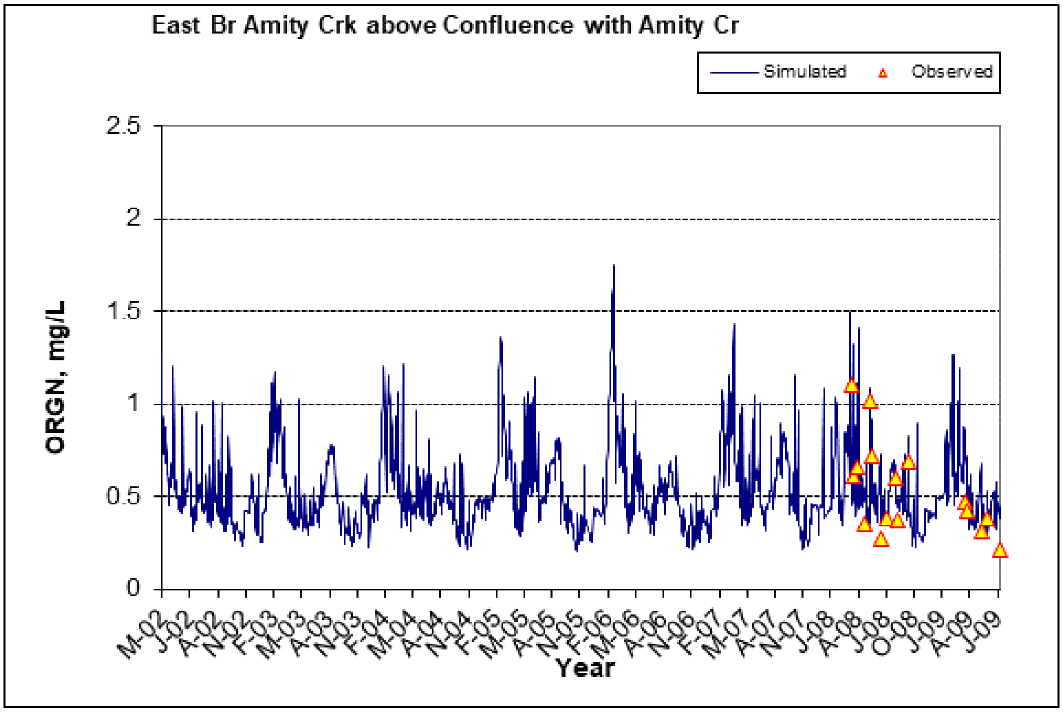


Figure E-172. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)





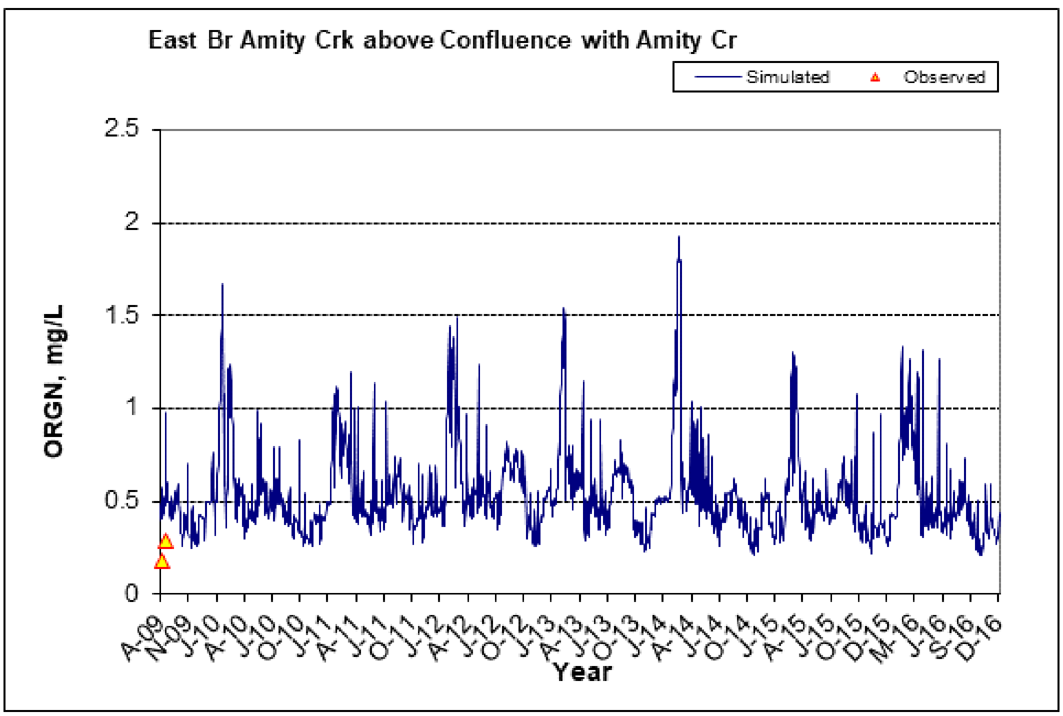


Figure E-173. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at East Br Amity Cr above Confluence with Amity Cr

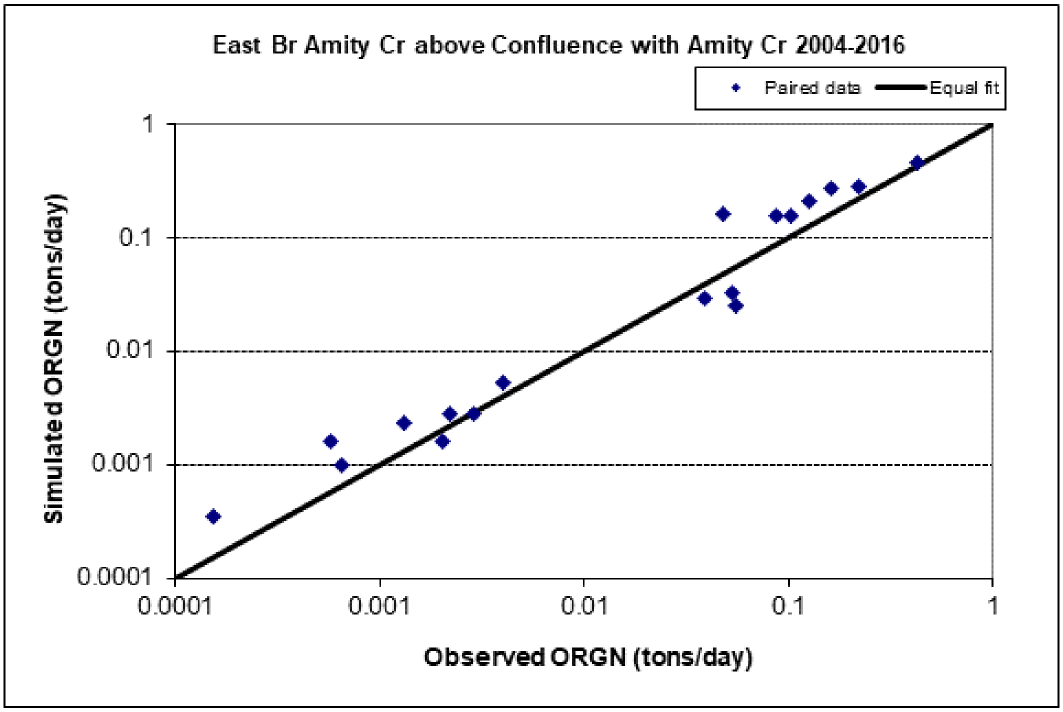


Figure E-174. Paired simulated vs. observed Organic Nitrogen (OrgN) load at East Br Amity Cr above Confluence with Amity Cr (calibration period)

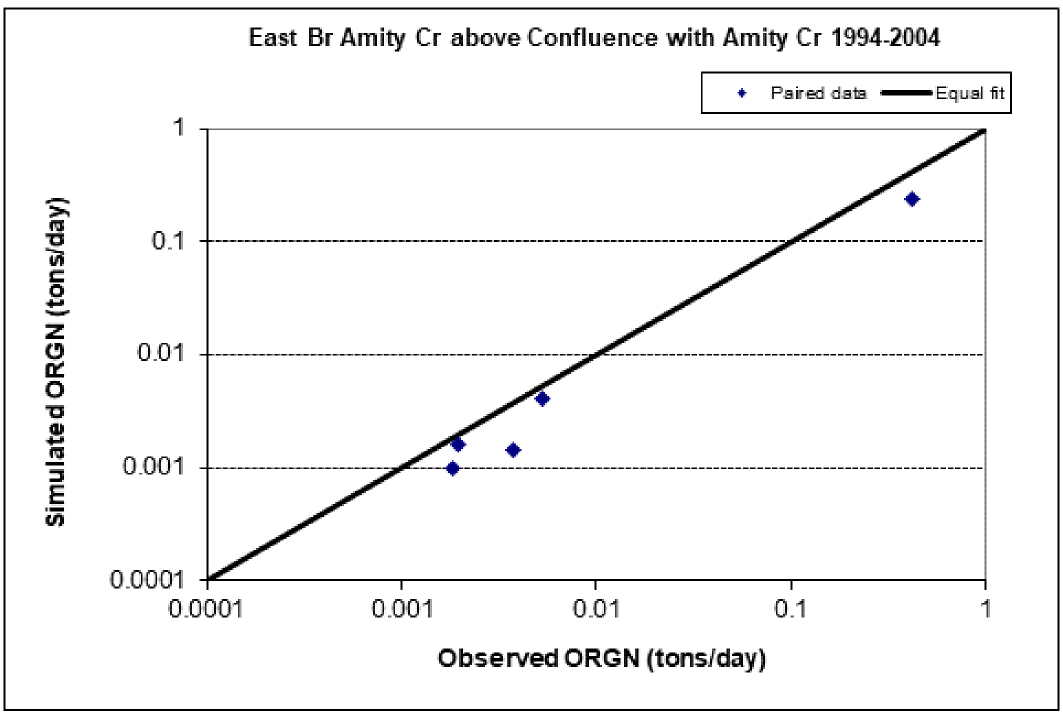


Figure E-175. Paired simulated vs. observed Organic Nitrogen (OrgN) load at East Br Amity Cr above Confluence with Amity Cr (validation period)

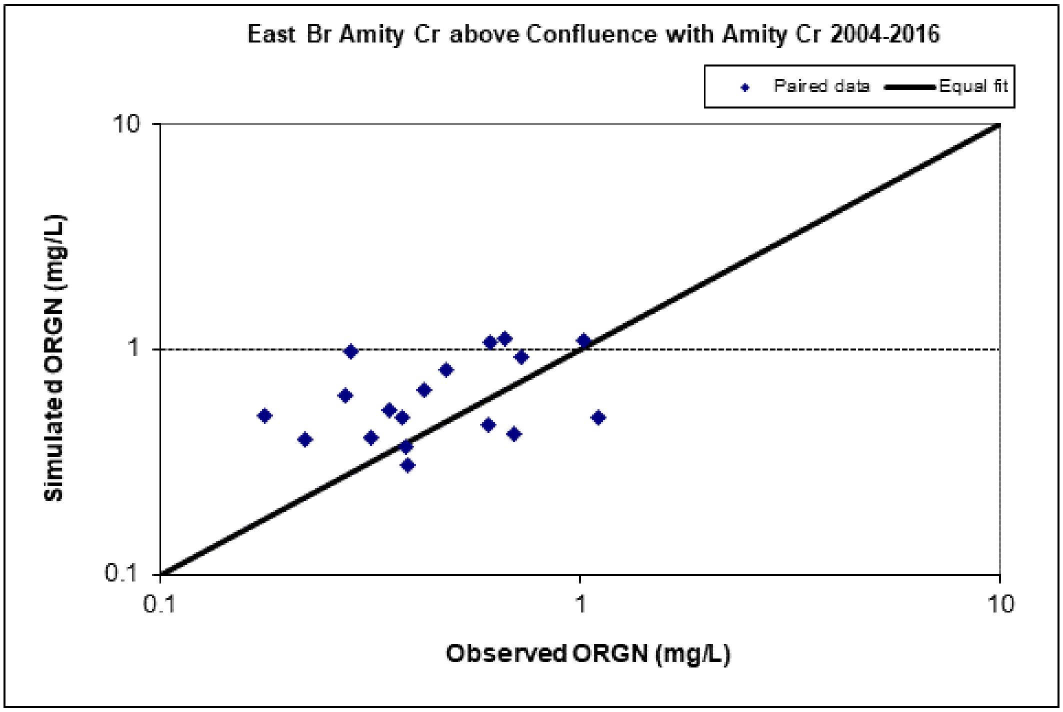


Figure E-176. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at East Br Amity Cr above Confluence with Amity Cr (calibration period)

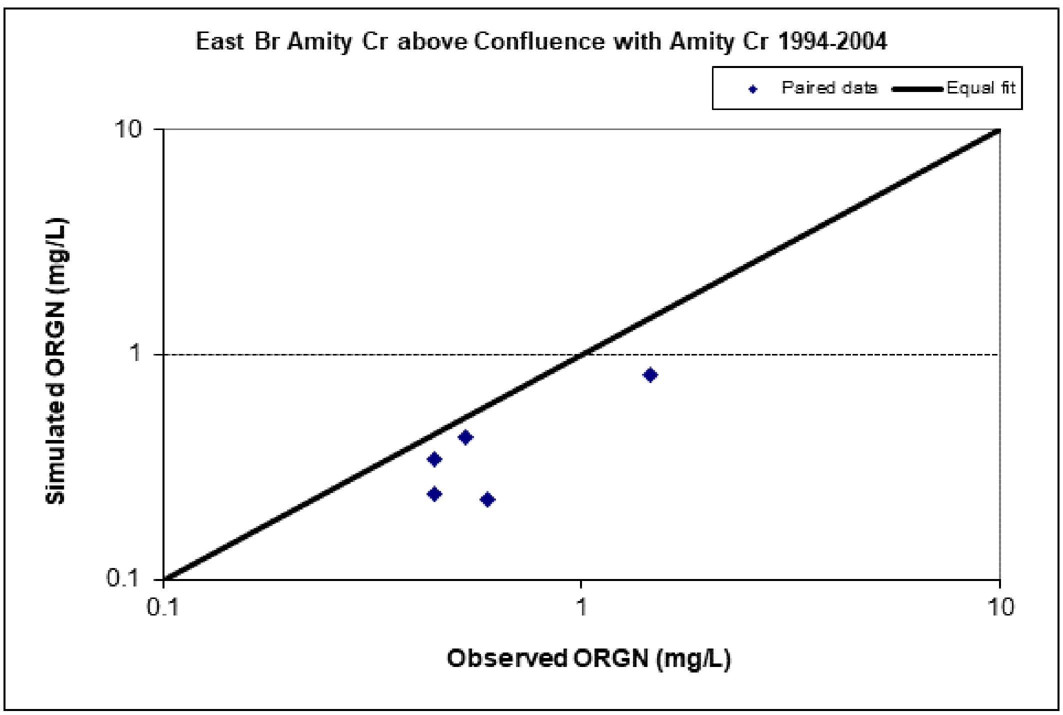


Figure E-177. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at East Br Amity Cr above Confluence with Amity Cr (validation period)

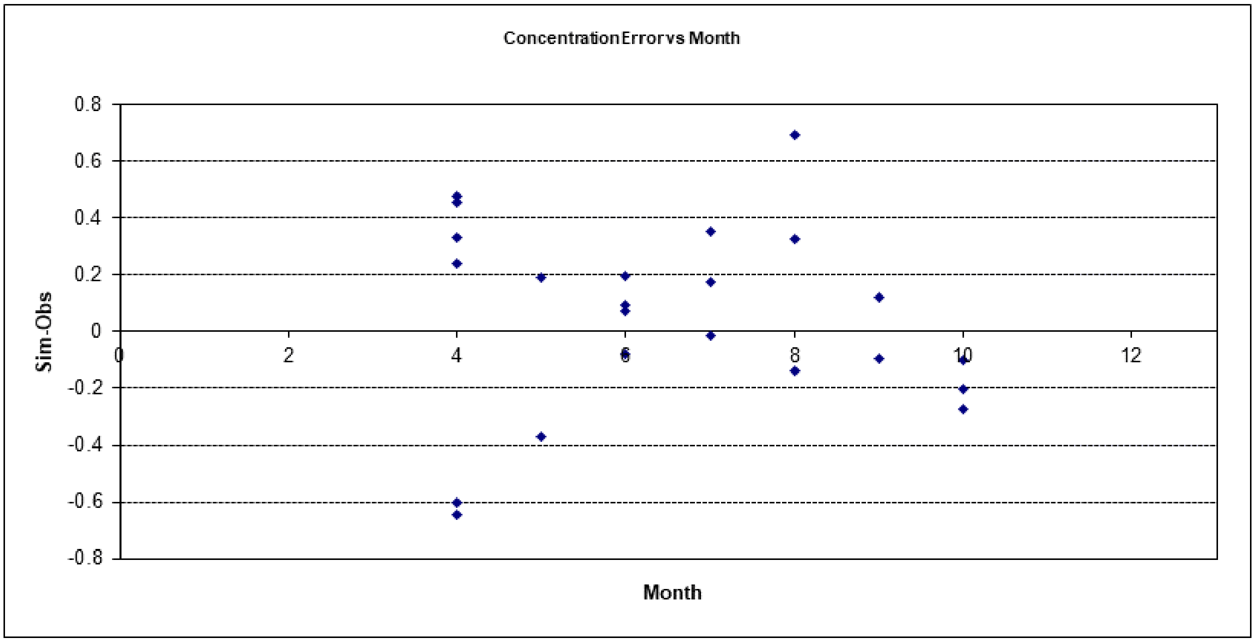


Figure E-178. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at East Br Amity Cr above Confluence with Amity Cr

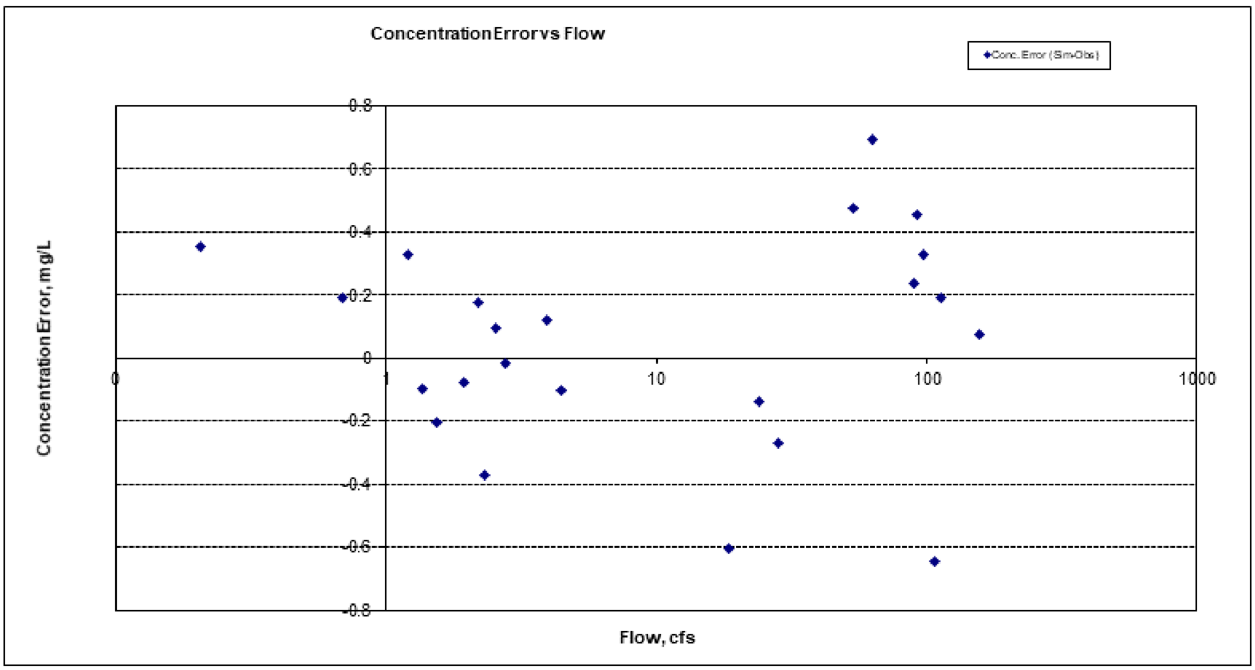


Figure E-179. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at East Br Amity Cr above Confluence with Amity Cr

E.3.4 Total Kjeldahl Nitrogen (TKN)

Table E-22. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	10	37
Concentration Average Error	-37.22%	33.43%
Concentration Median Error	-29.25%	32.50%
Load Average Error	-45.22%	33.04%
Load Median Error	-3.06%	1.62%
Paired t conc	0.09	0.08
Paired t load	0.37	0.32

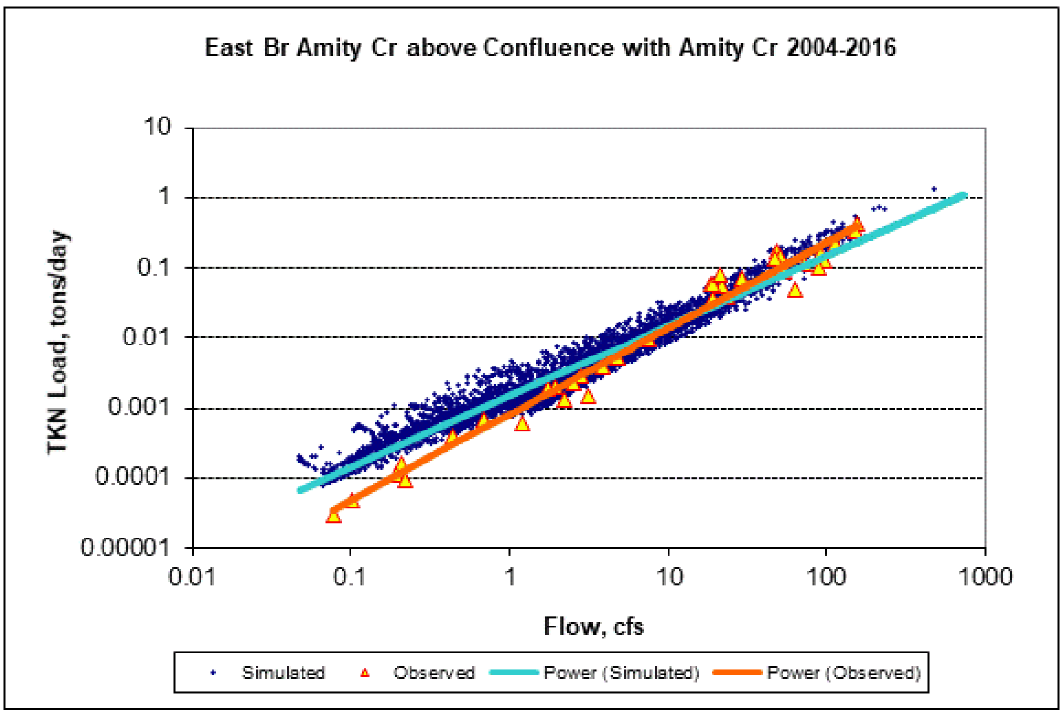


Figure E-180. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

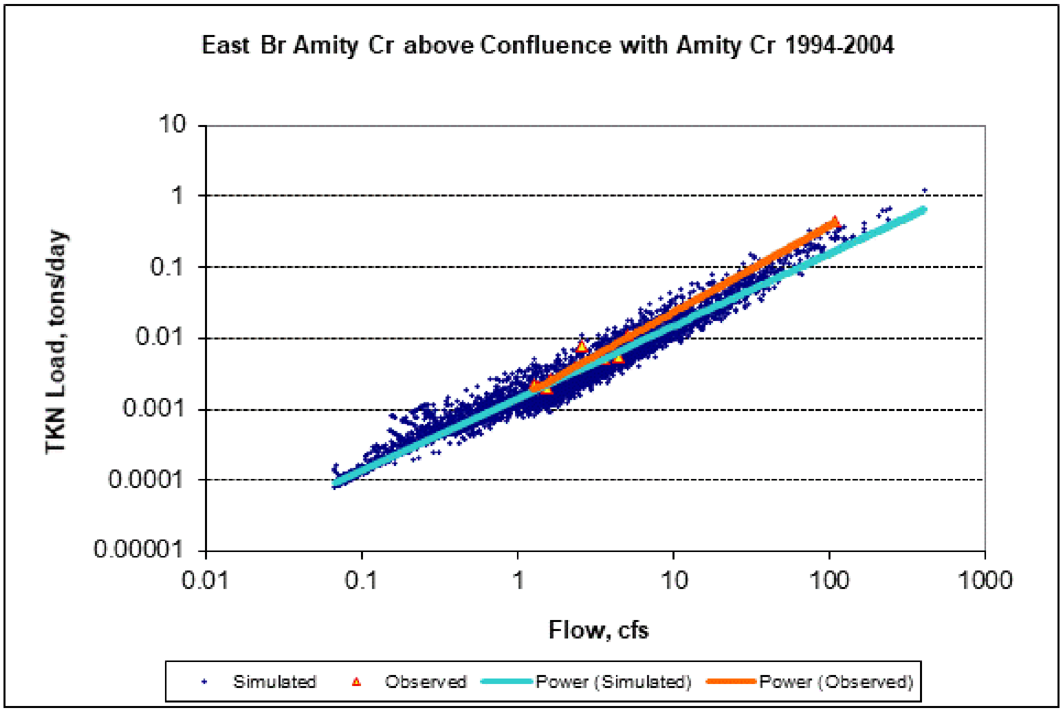


Figure E-181. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)

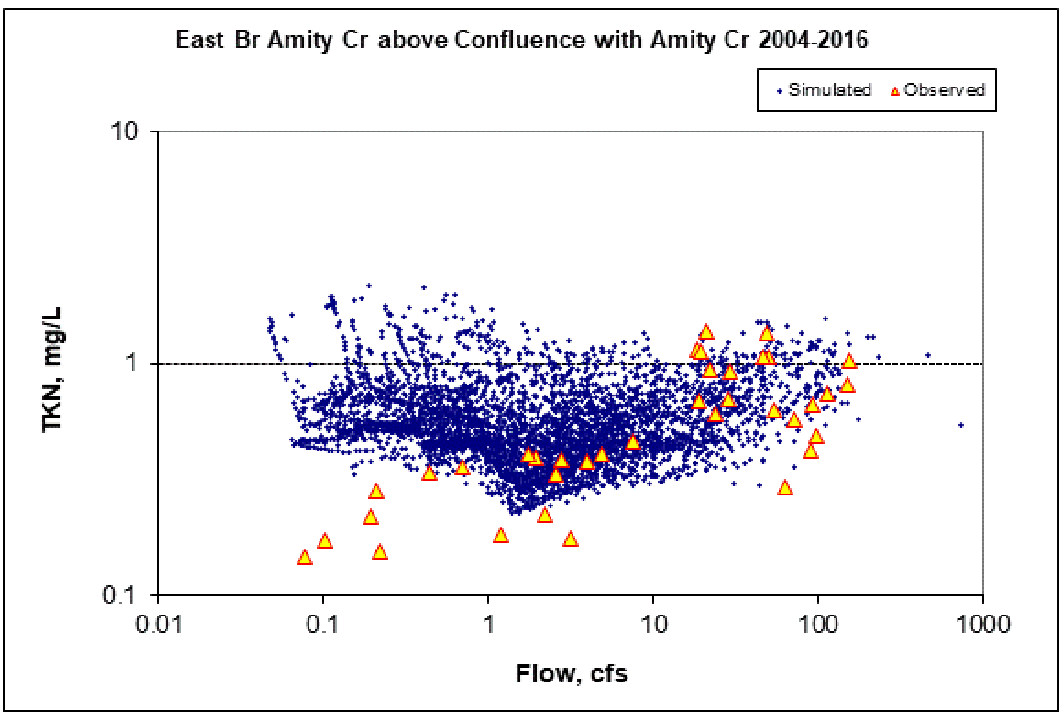


Figure E-182. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

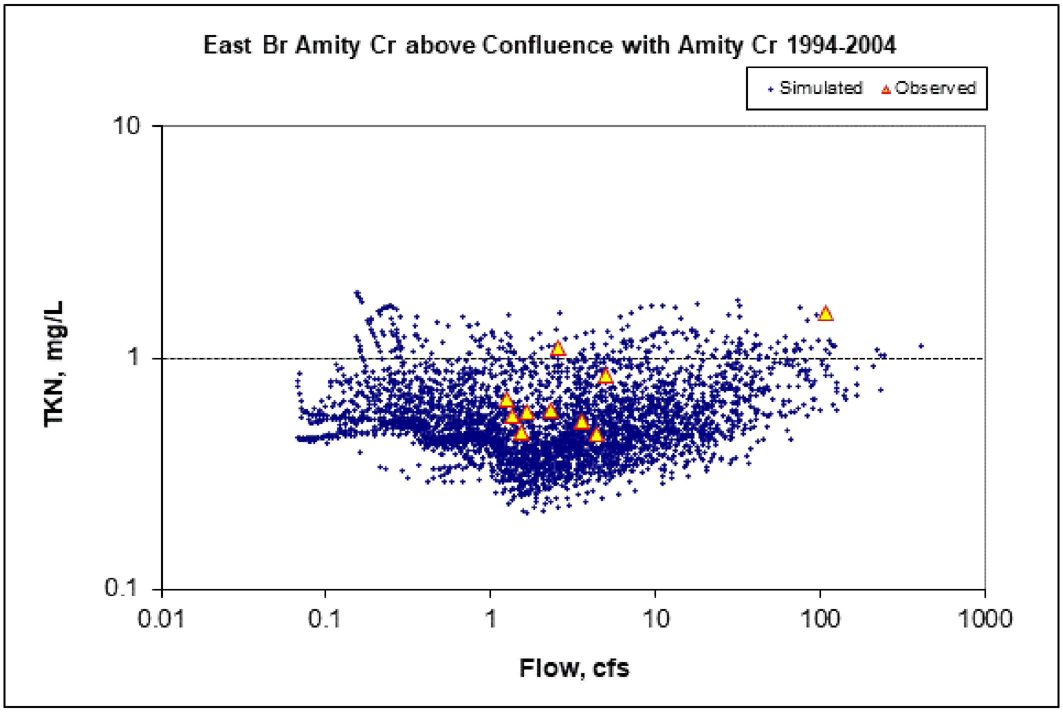
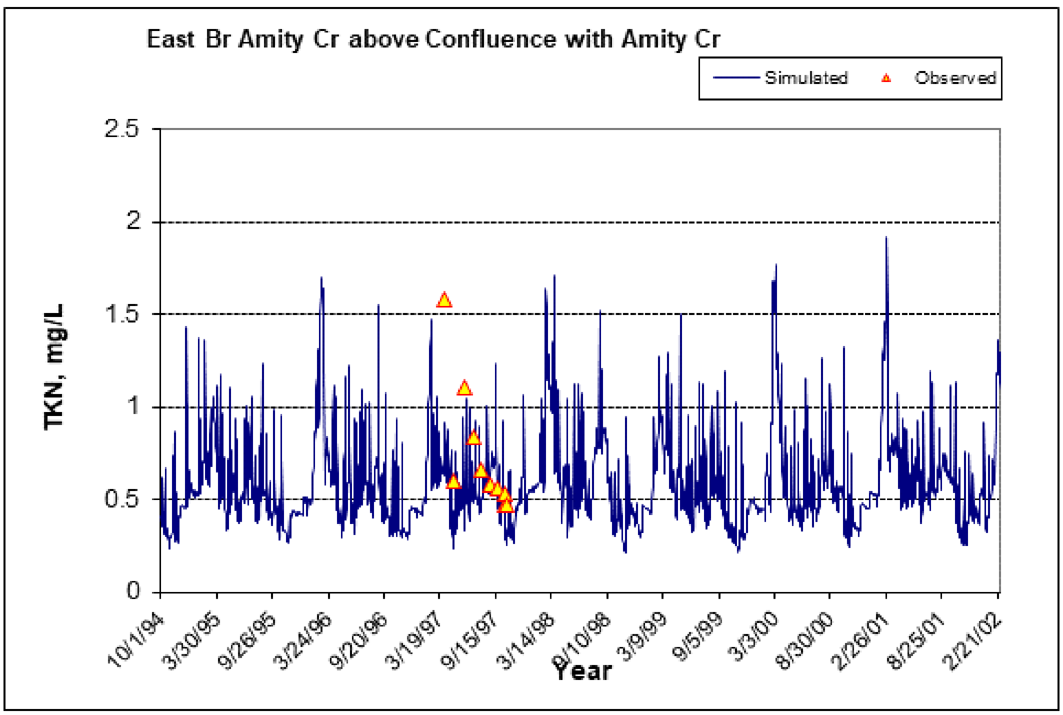


Figure E-183. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)



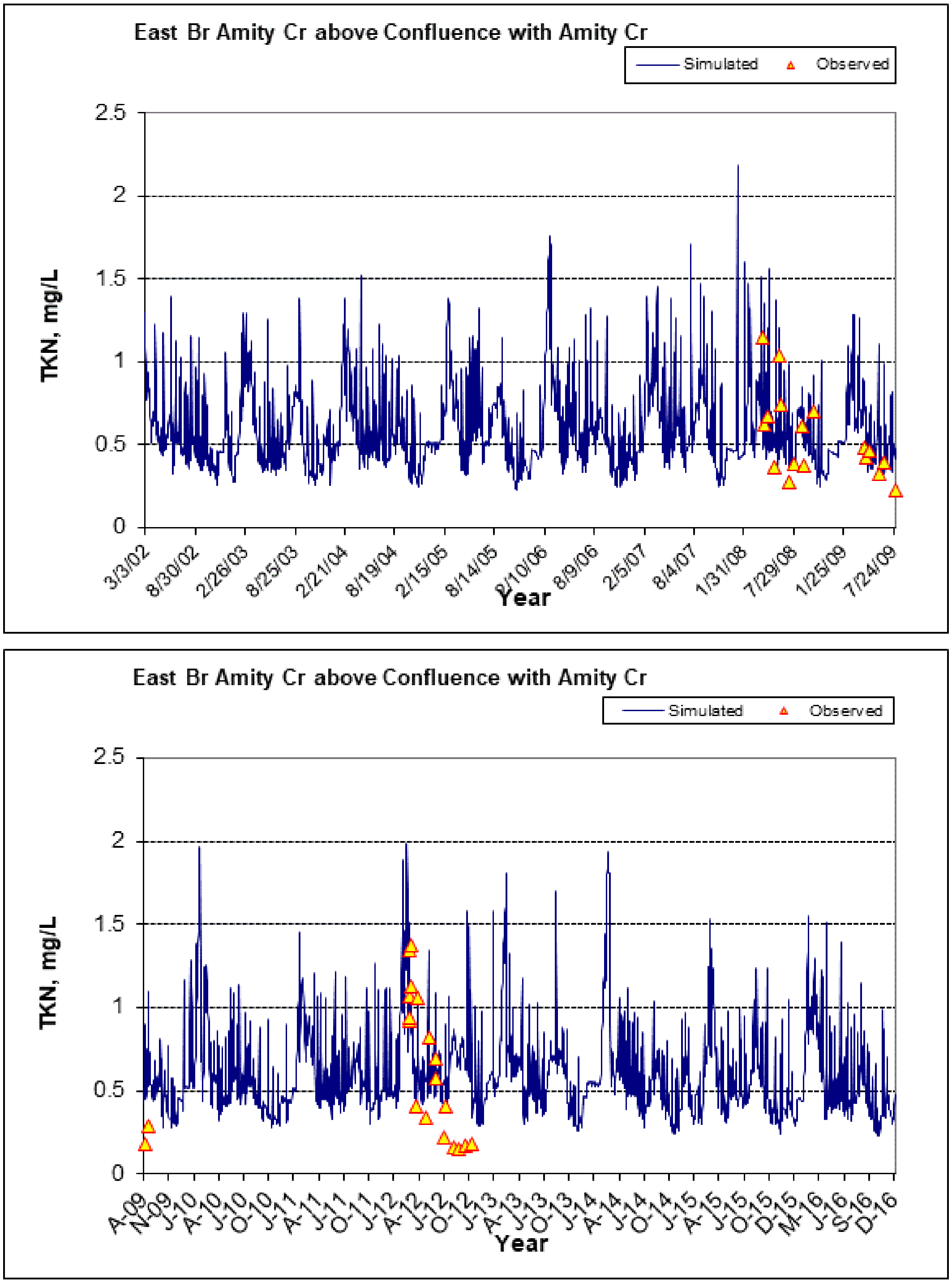


Figure E-184. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at East Br Amity Cr above Confluence with Amity Cr

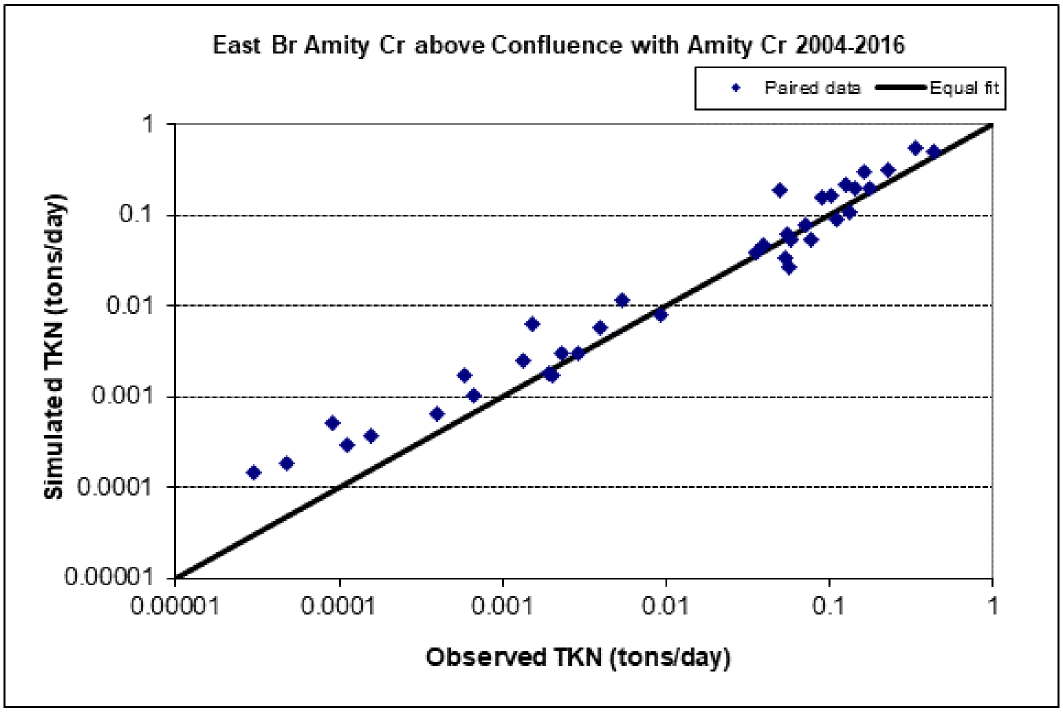


Figure E-185. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at East Br Amity Cr above Confluence with Amity Cr (calibration period)

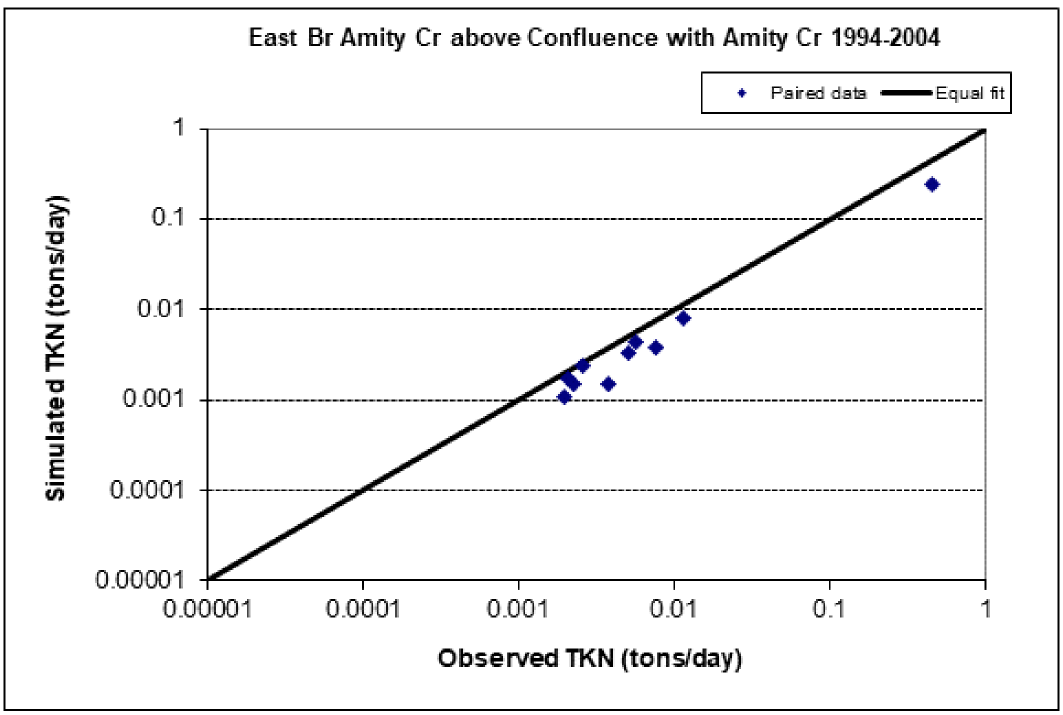


Figure E-186. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at East Br Amity Cr above Confluence with Amity Cr (validation period)

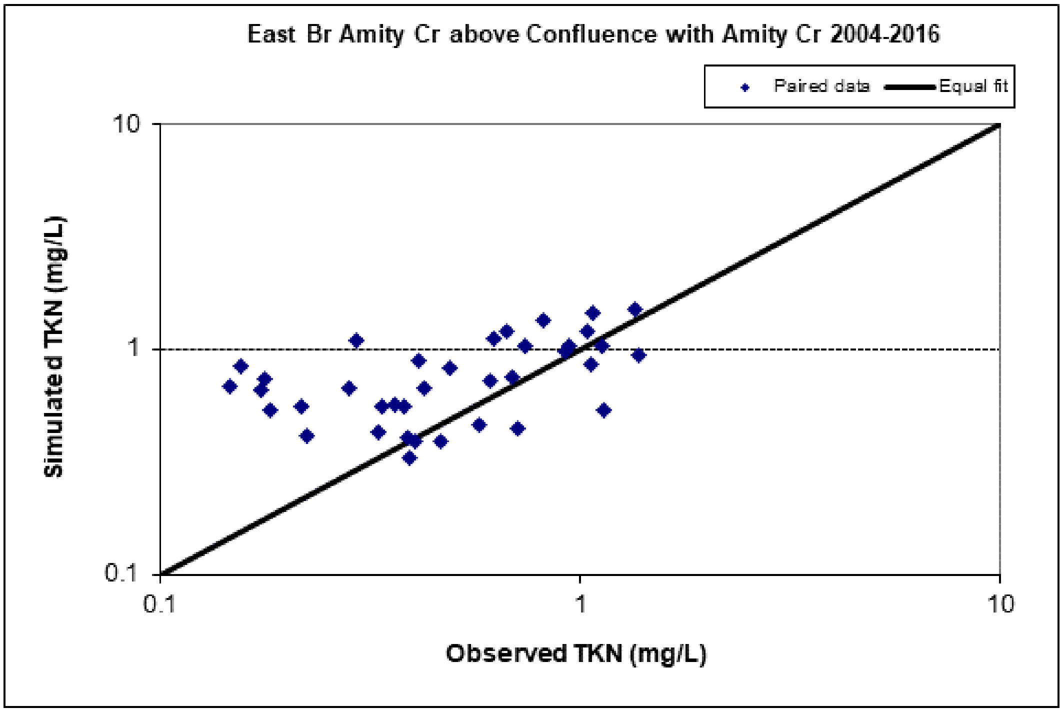


Figure E-187. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at East Br Amity Cr above Confluence with Amity Cr (calibration period)

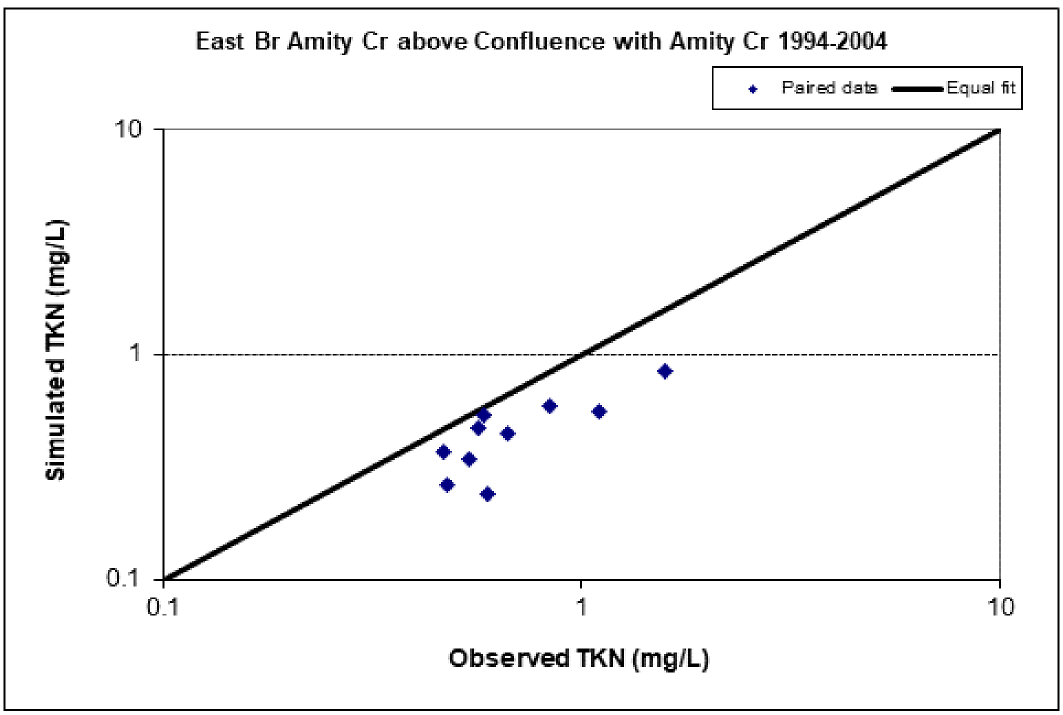


Figure E-188. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at East Br Amity Cr above Confluence with Amity Cr (validation period)

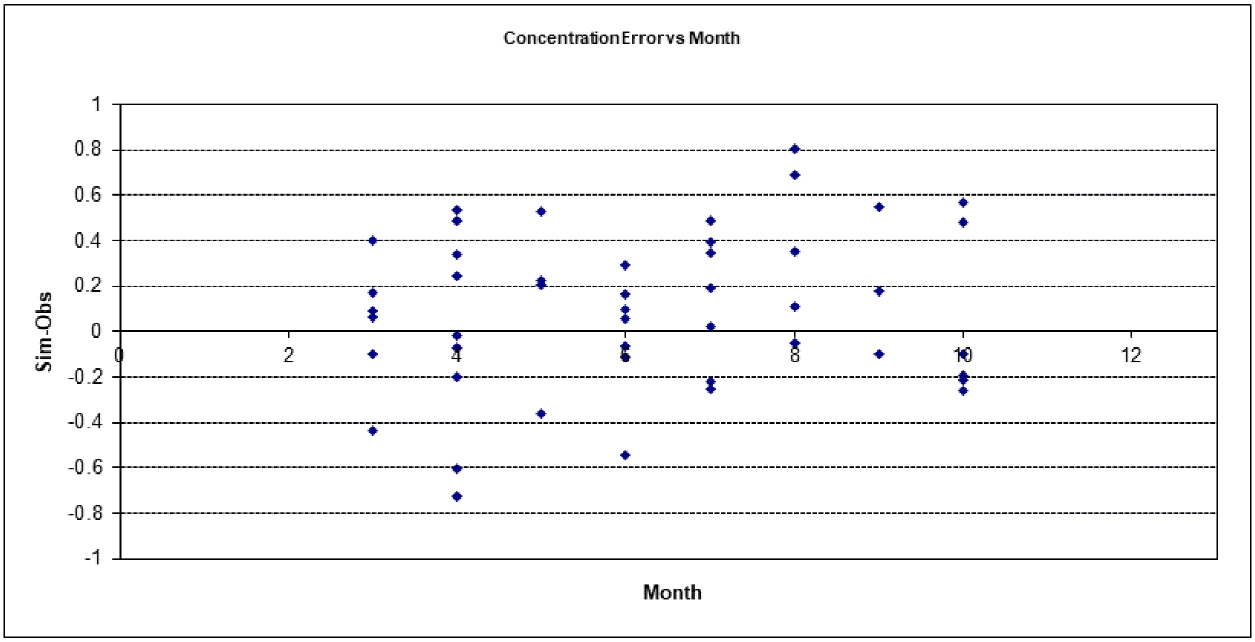


Figure E-189. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at East Br Amity Cr above Confluence with Amity Cr

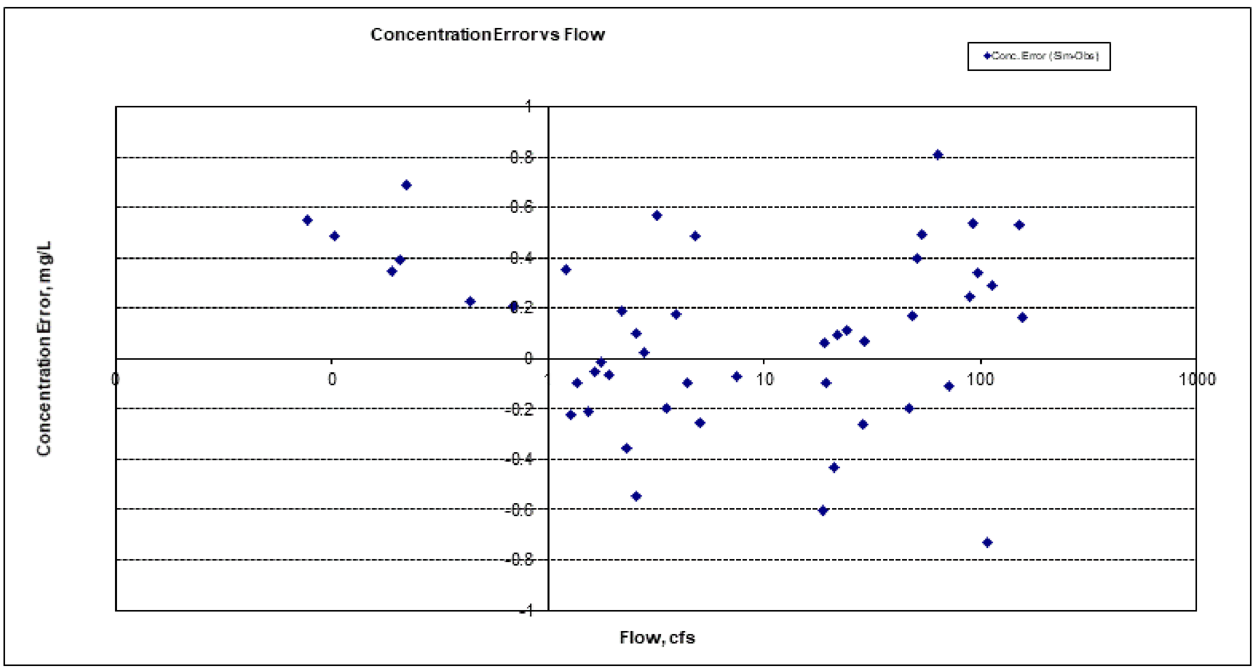


Figure E-190. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at East Br Amity Cr above Confluence with Amity Cr

E.3.5 Nitrite+ Nitrate Nitrogen (NOx)

Table E-23. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	18	38
Concentration Average Error	-70.48%	5.43%
Concentration Median Error	-51.51%	1.01%
Load Average Error	-65.42%	-1.46%
Load Median Error	-3.47%	0.02%
Paired t conc	0.00	0.76
Paired t load	0.25	0.78

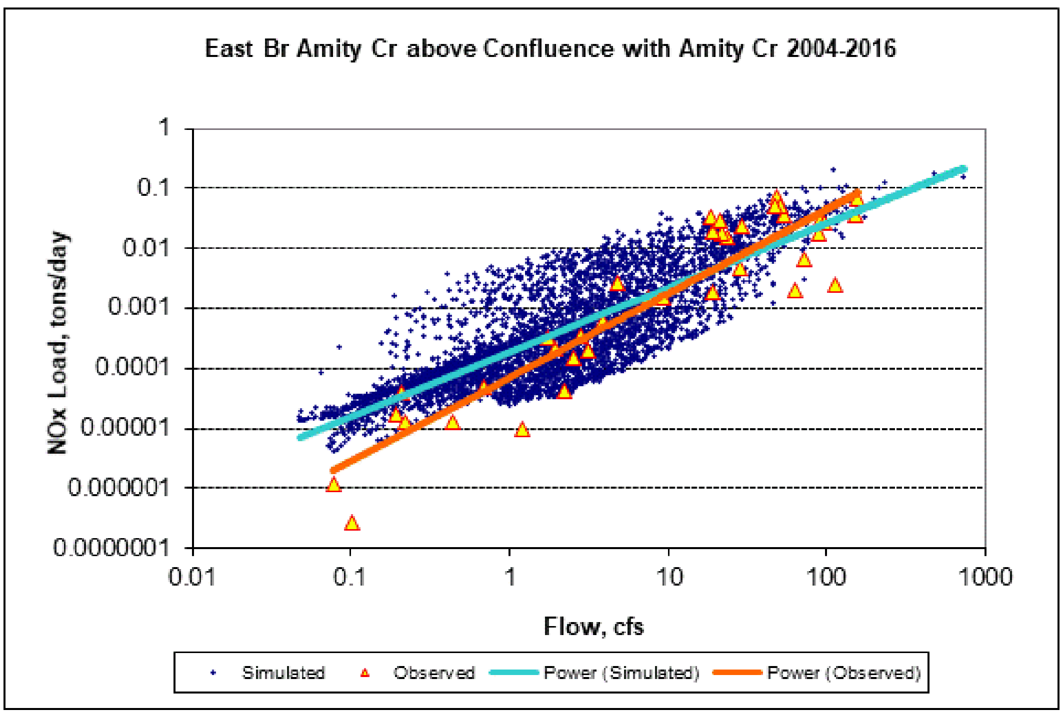


Figure E-191. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

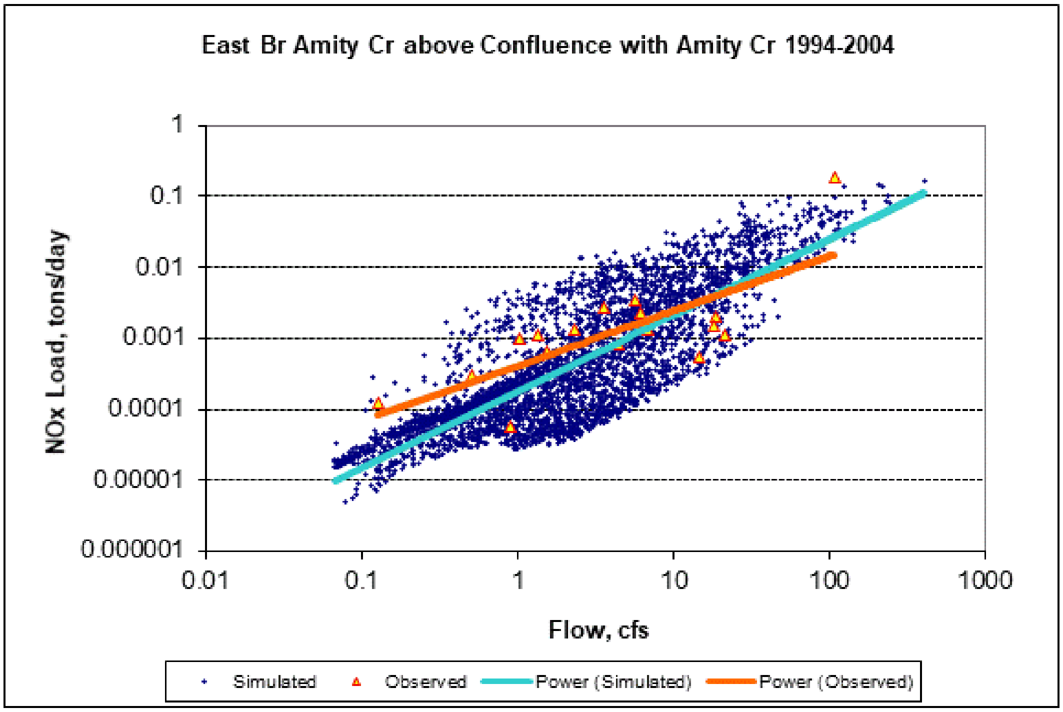


Figure E-192. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)

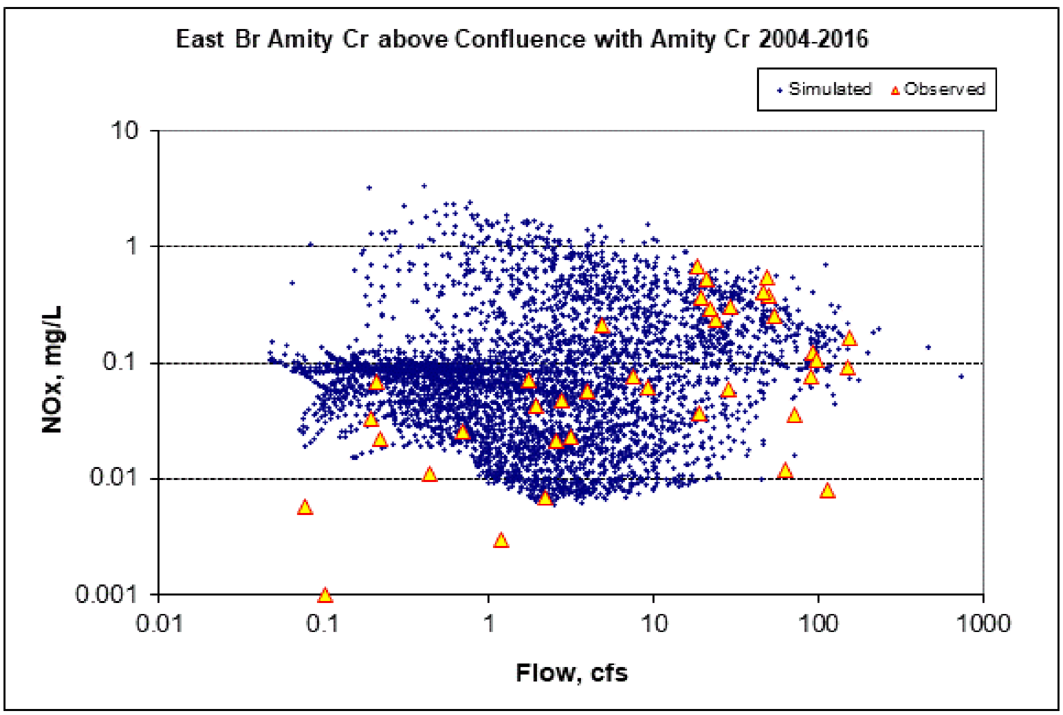


Figure E-193. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

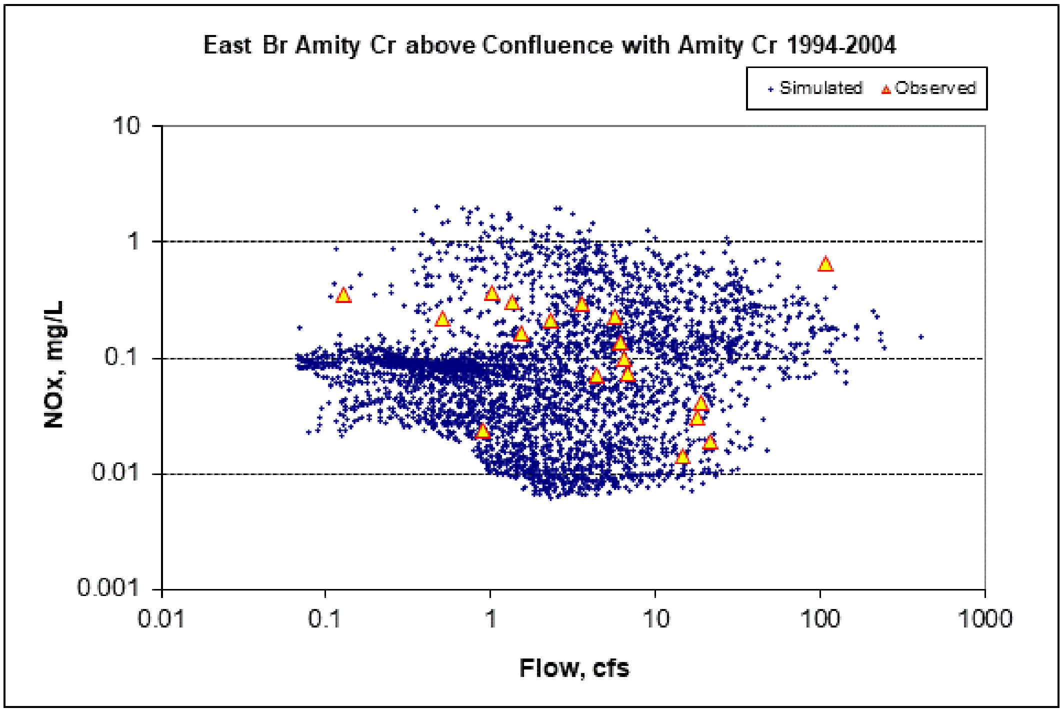
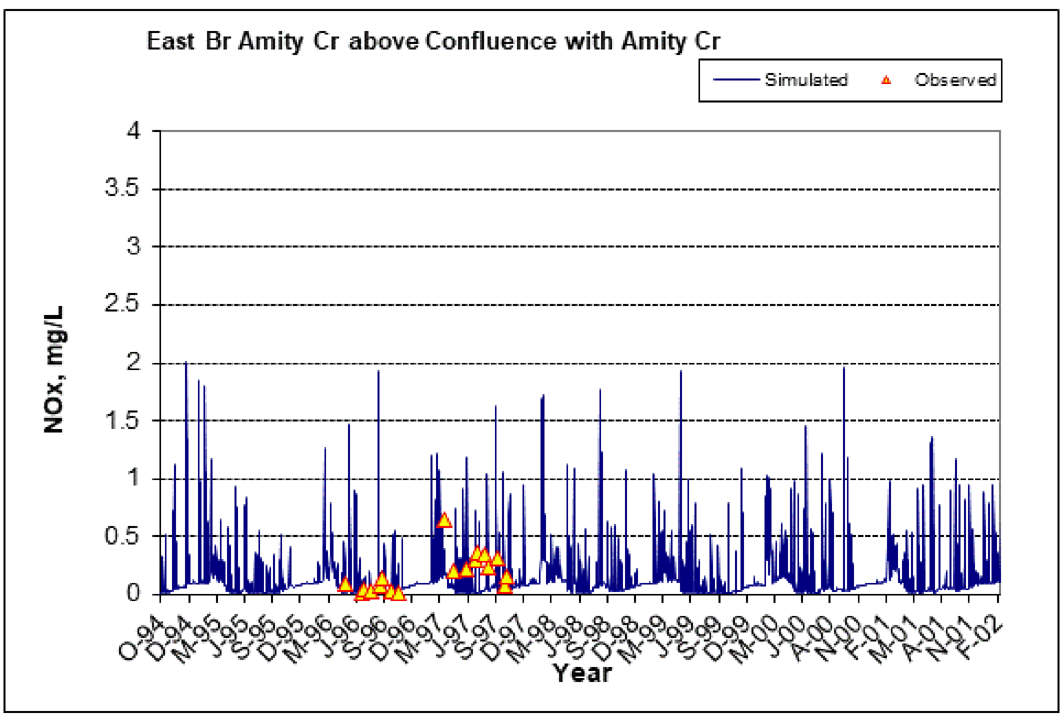
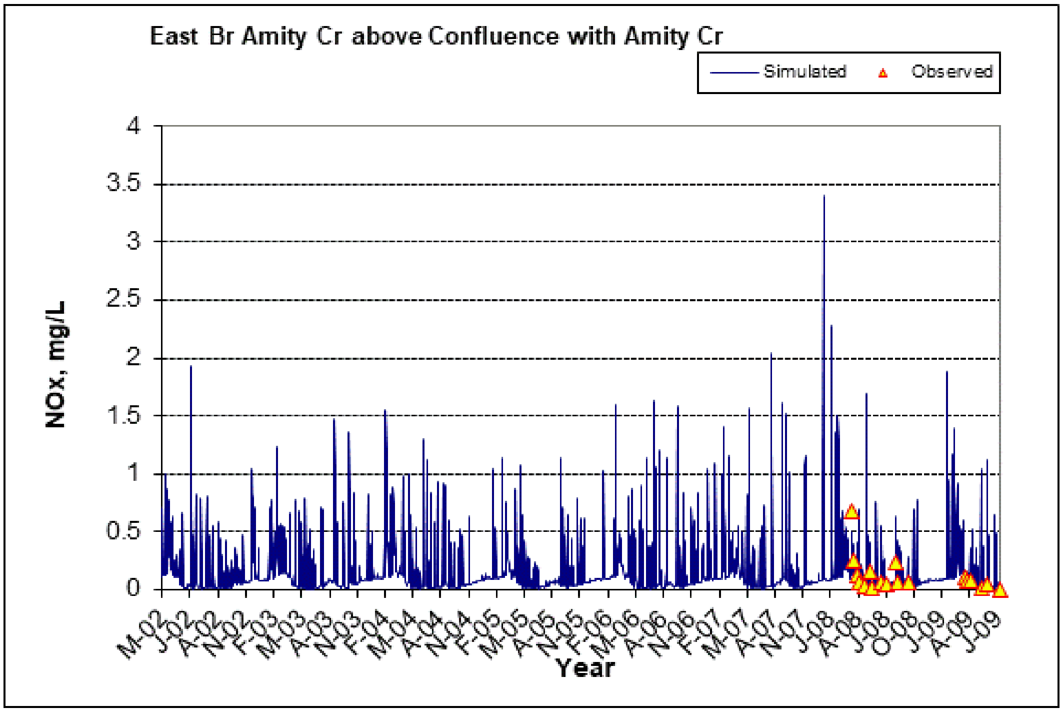


Figure E-194. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)





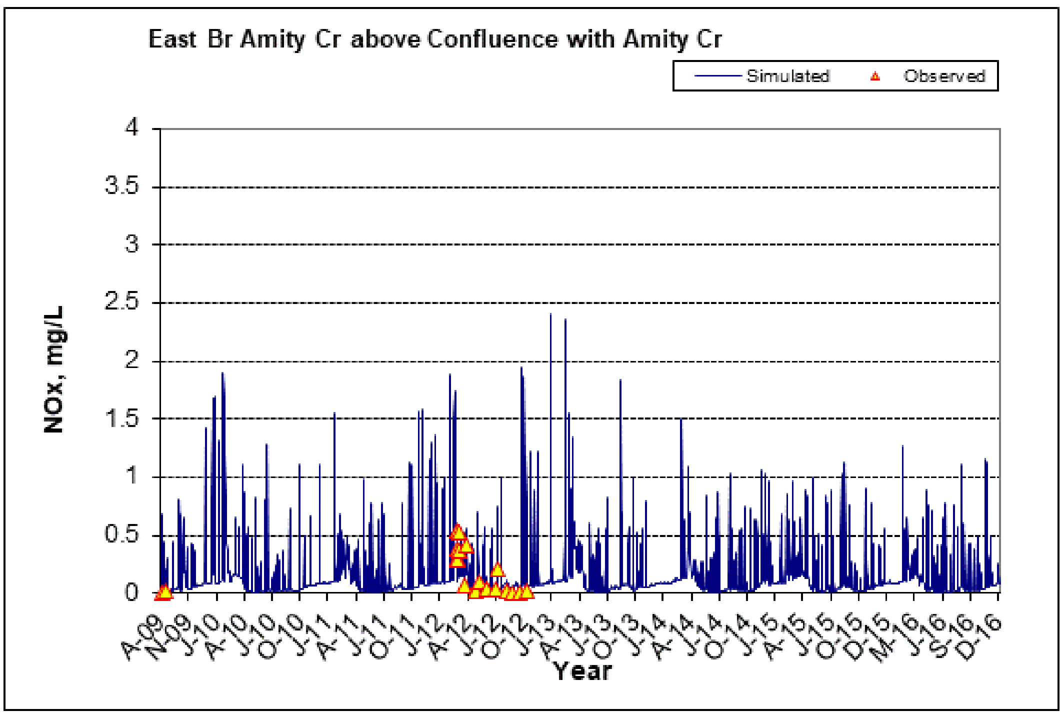


Figure E-195. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at East Br Amity Cr above Confluence with Amity Cr

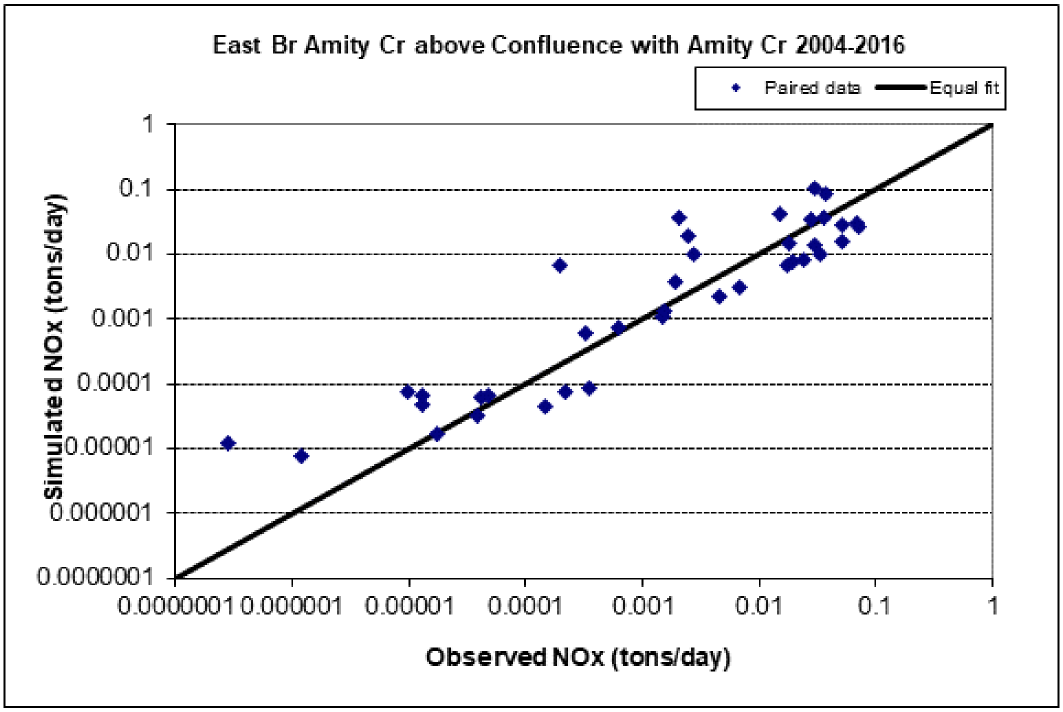


Figure E-196. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at East Br Amity Cr above Confluence with Amity Cr (calibration period)

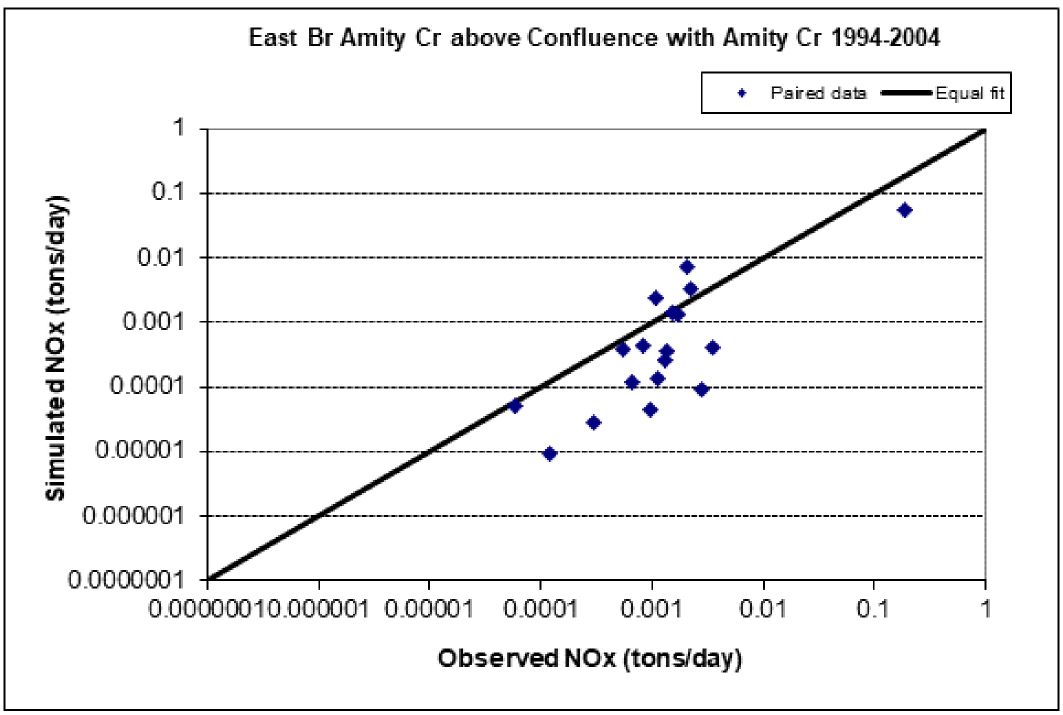


Figure E-197. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at East Br Amity Cr above Confluence with Amity Cr (validation period)

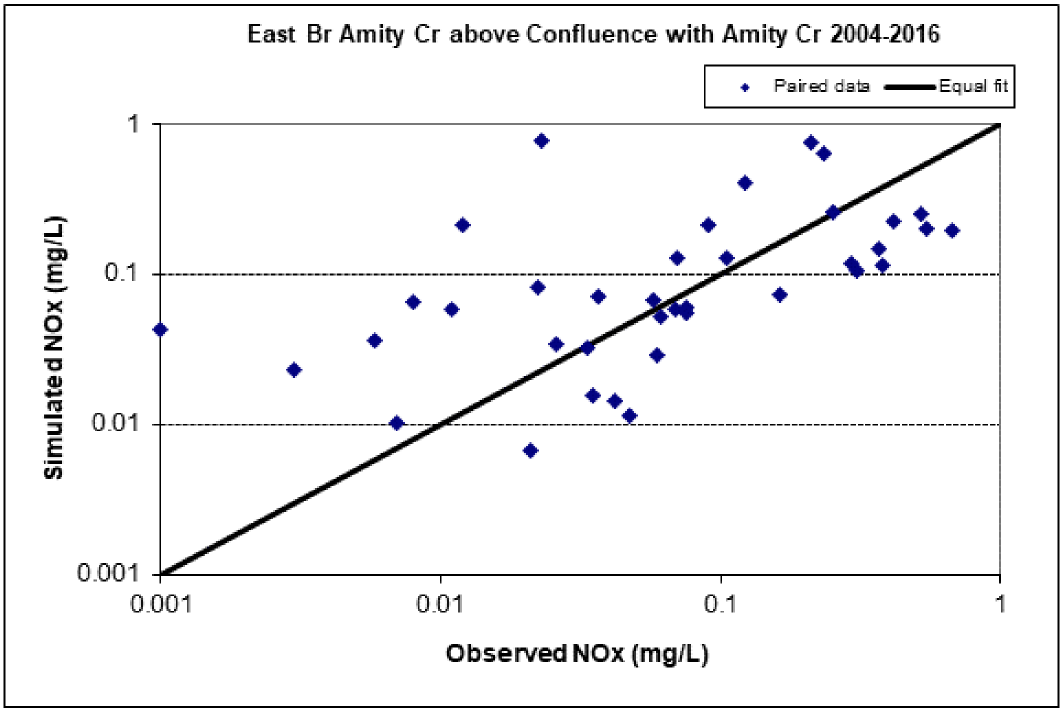


Figure E-198. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at East Br Amity Cr above Confluence with Amity Cr (calibration period)

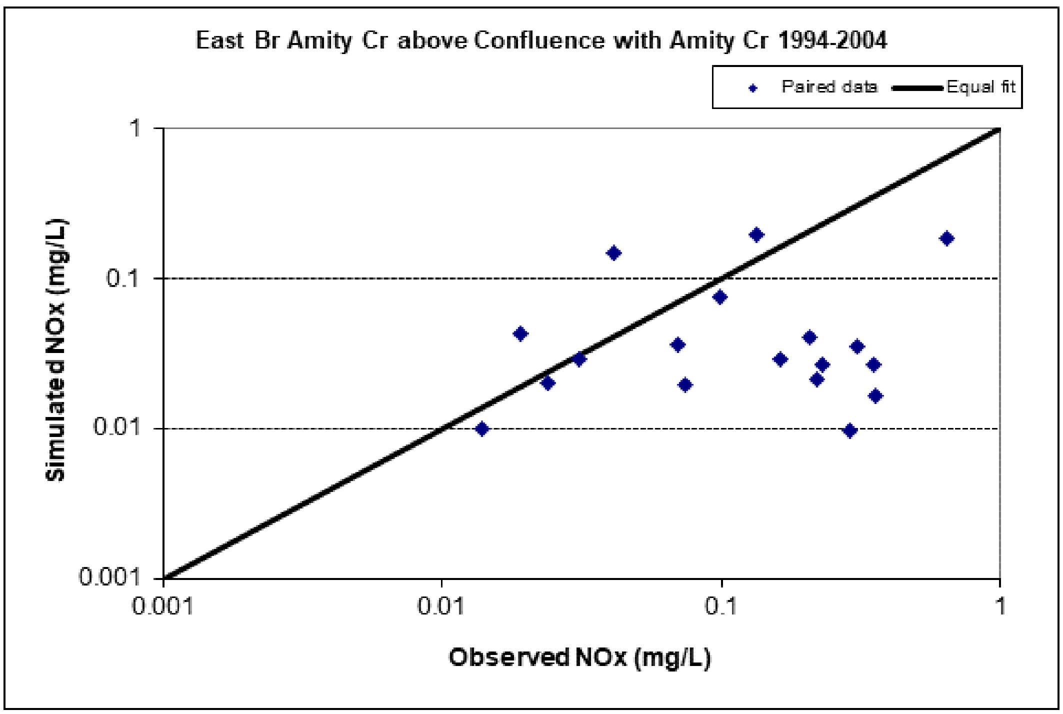


Figure E-199. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at East Br Amity Cr above Confluence with Amity Cr (validation period)

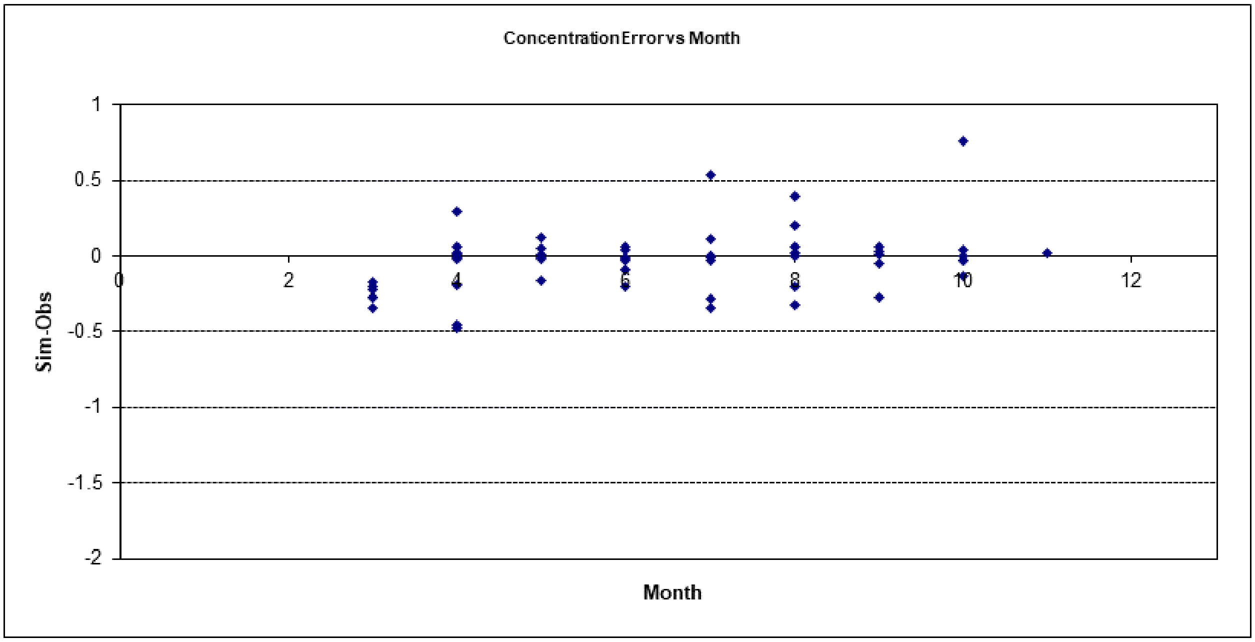


Figure E-200. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at East Br Amity Cr above Confluence with Amity Cr

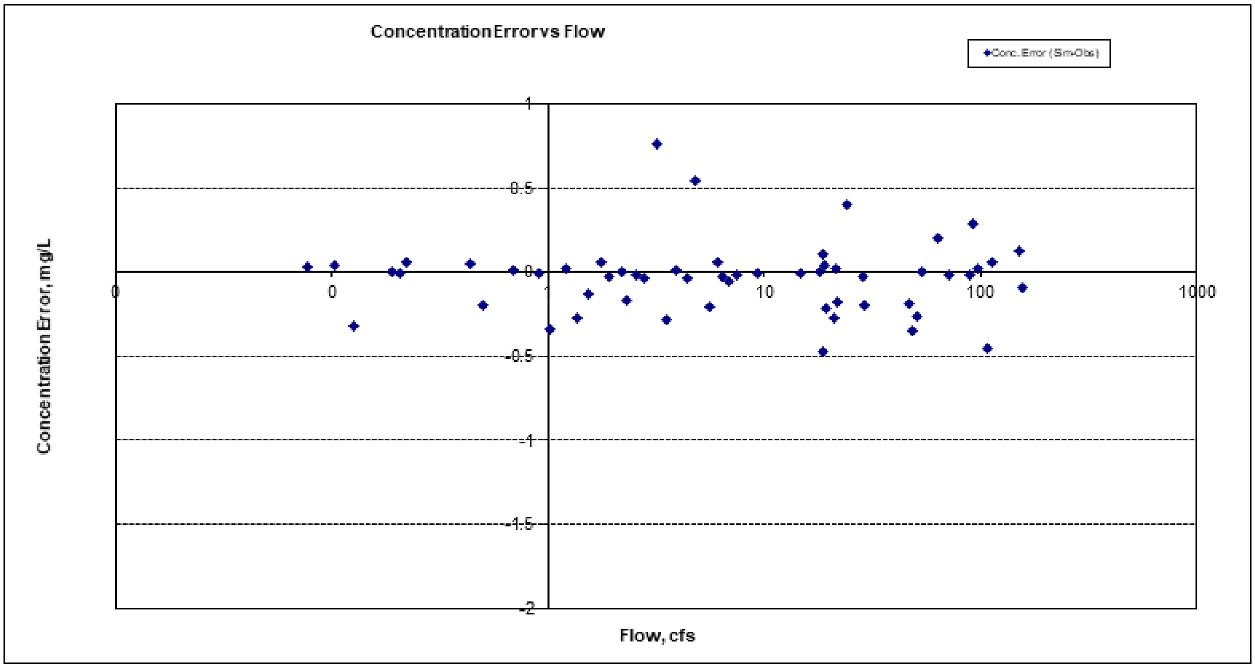


Figure E-201. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at East Br Amity Cr above Confluence with Amity Cr

E.3.6 Total Nitrogen (TN)

Table E-24. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	5	37
Concentration Average Error	-50.40%	27.86%
Concentration Median Error	-36.46%	26.45%
Load Average Error	-53.15%	26.92%
Load Median Error	-1.20%	0.47%
Paired t conc	0.13	0.23
Paired t load	0.34	0.40

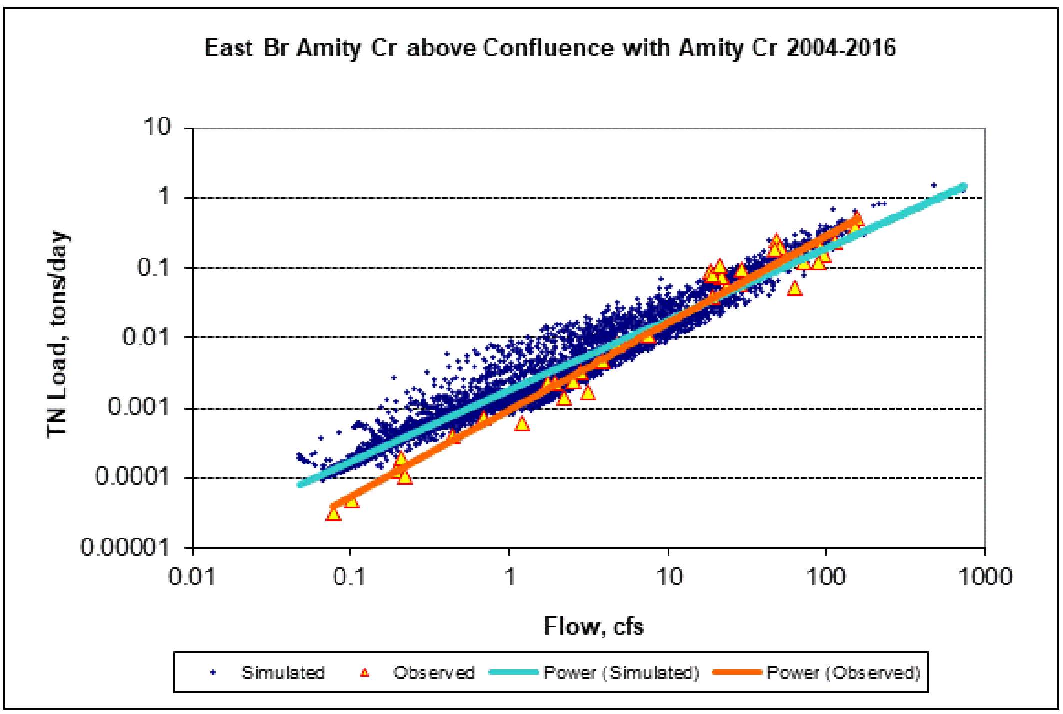


Figure E-202. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

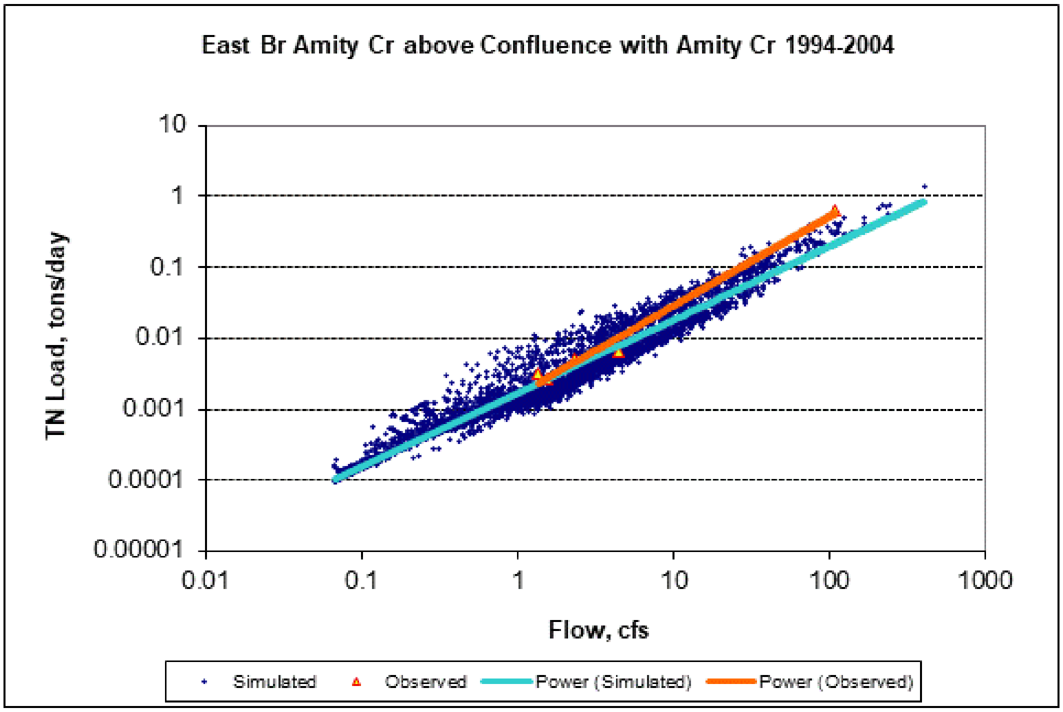


Figure E-203. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)

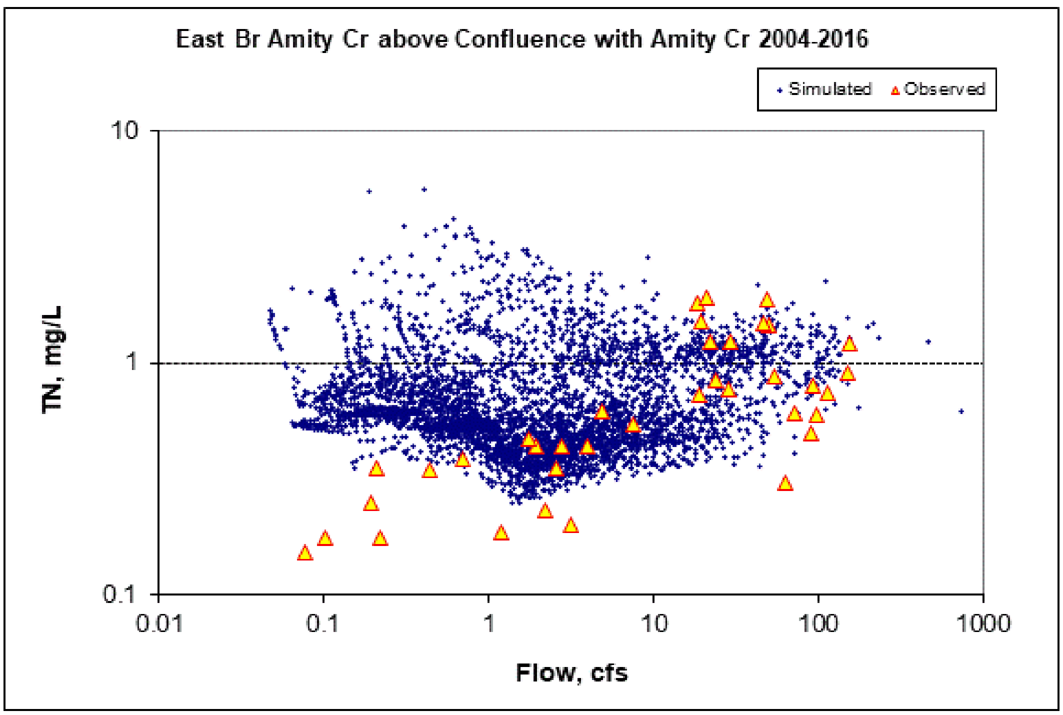


Figure E-204. Simulated and observed Total Nitrogen (TN) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

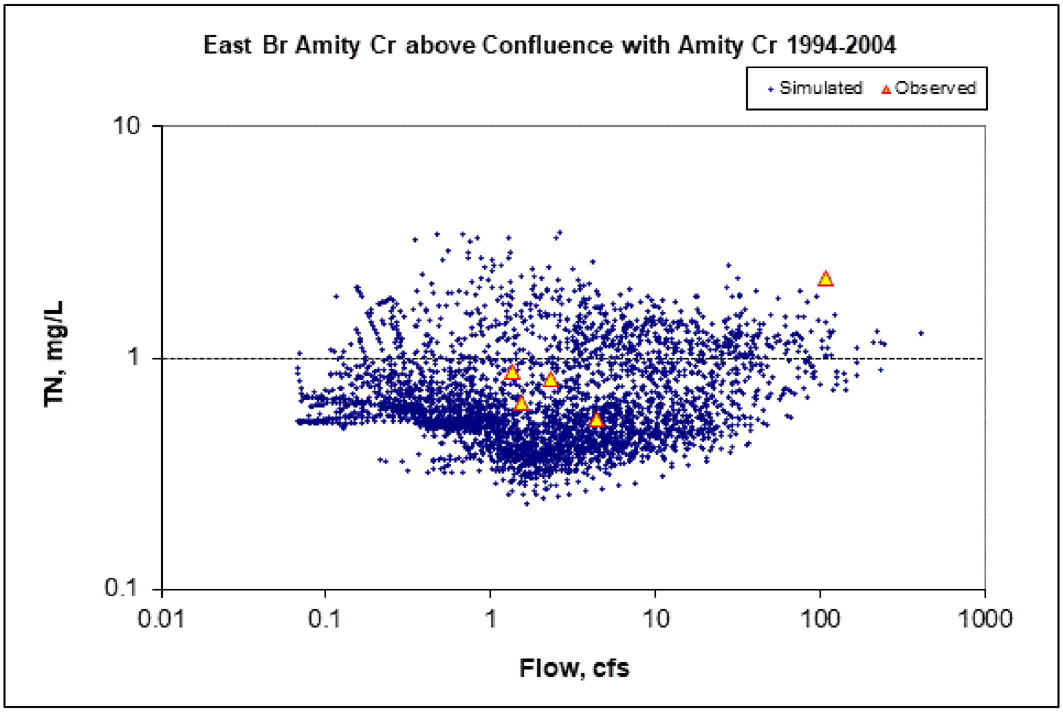
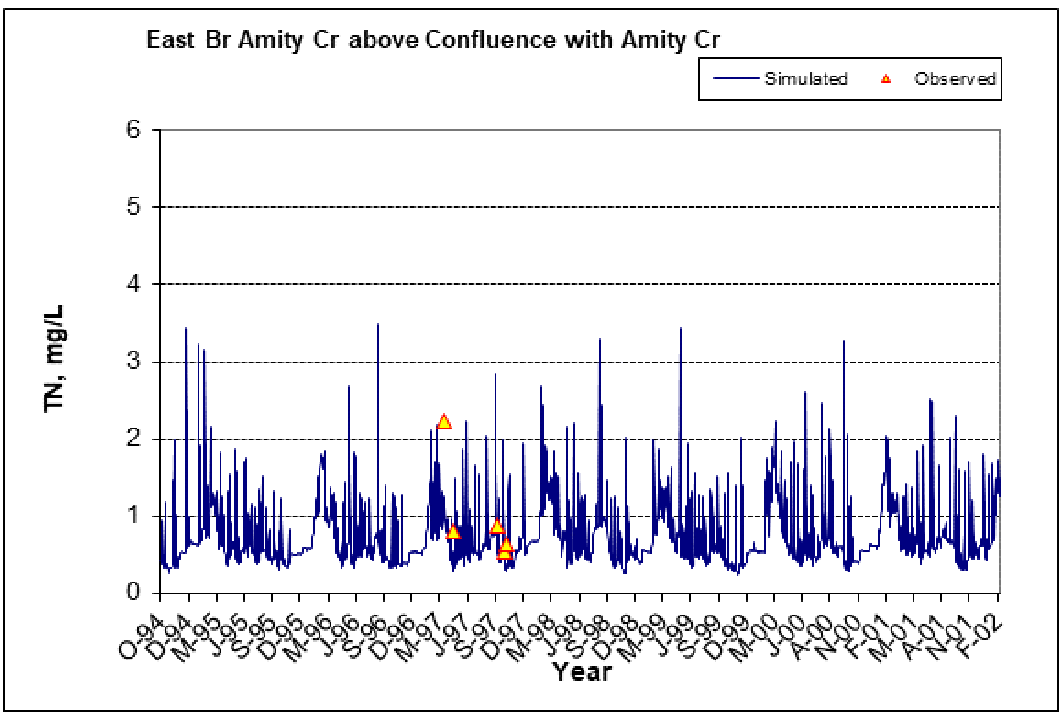
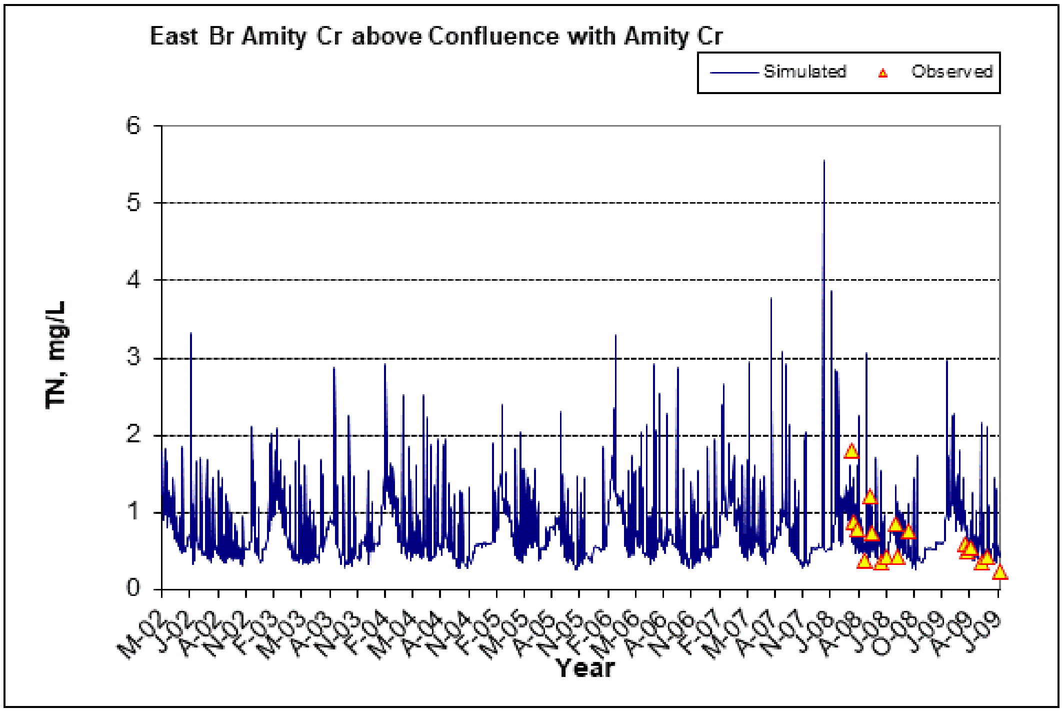


Figure E-205. Simulated and observed Total Nitrogen (TN) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)





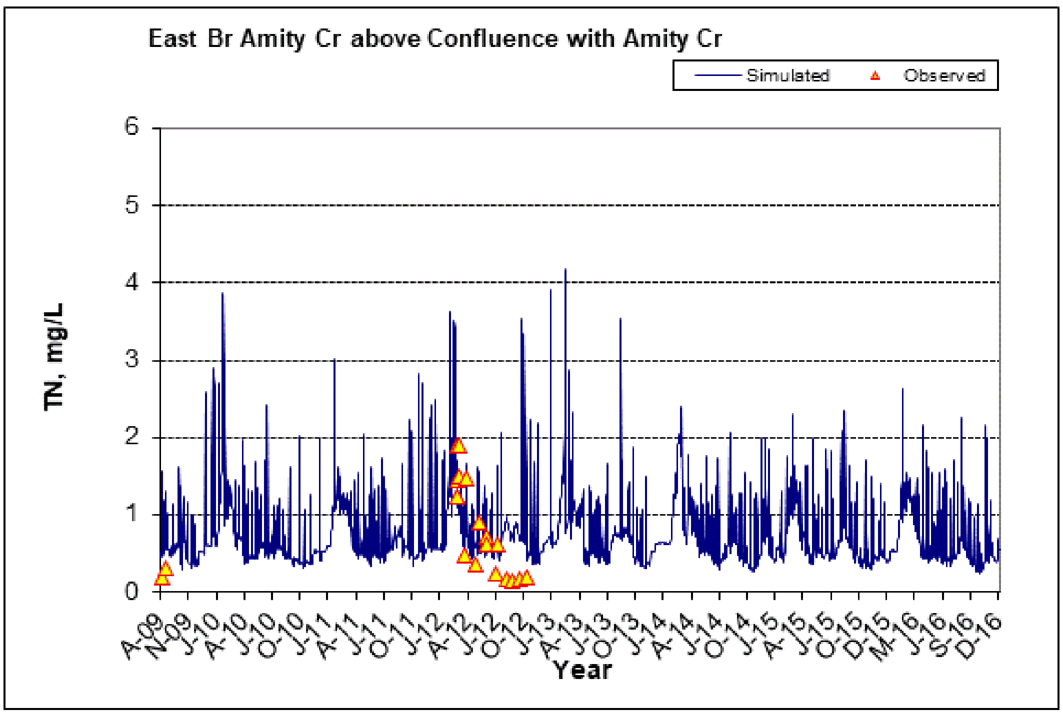


Figure E-206. Time series of observed and simulated Total Nitrogen (TN) concentration at East Br Amity Cr above Confluence with Amity Cr

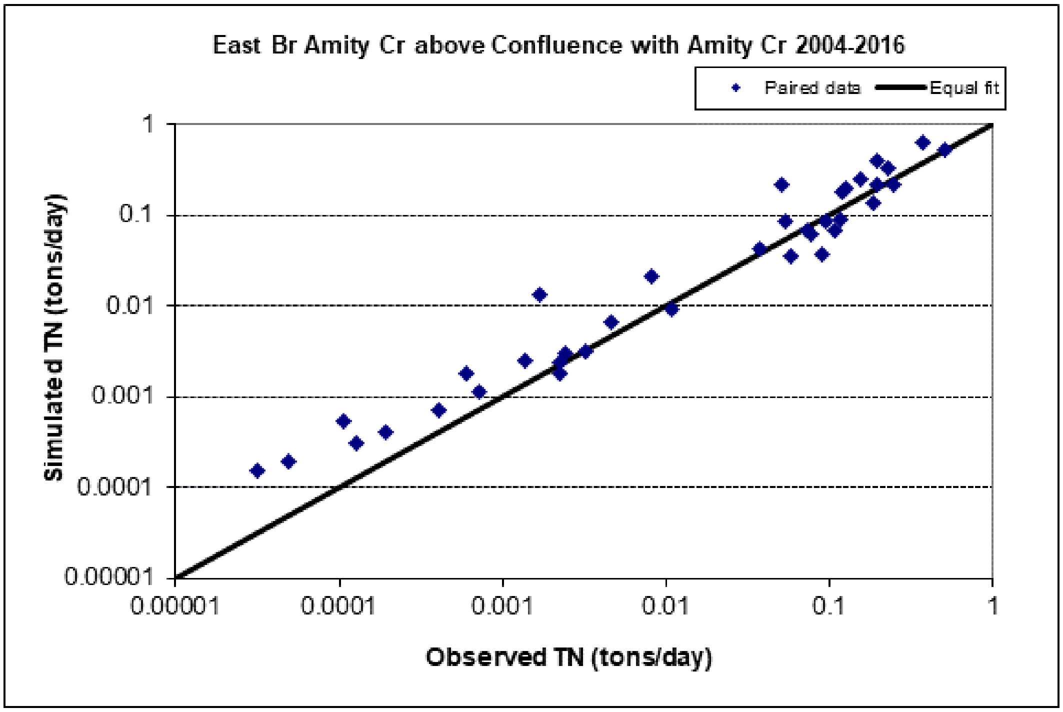


Figure E-207. Paired simulated vs. observed Total Nitrogen (TN) load at East Br Amity Cr above Confluence with Amity Cr (calibration period)

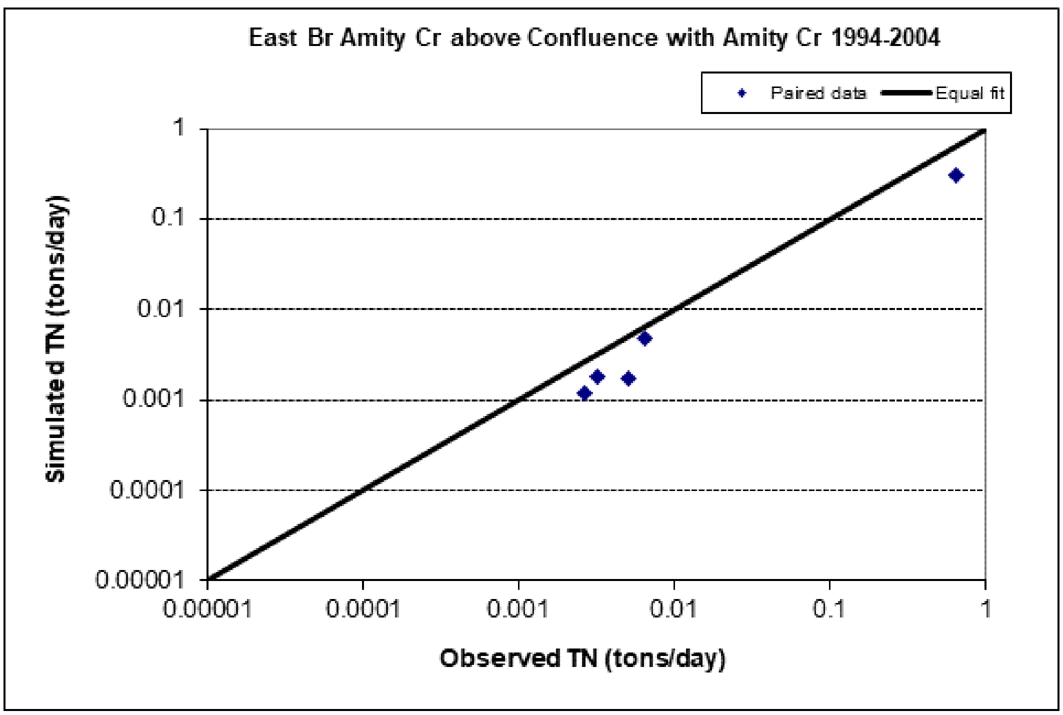


Figure E-208. Paired simulated vs. observed Total Nitrogen (TN) load at East Br Amity Cr above Confluence with Amity Cr (validation period)

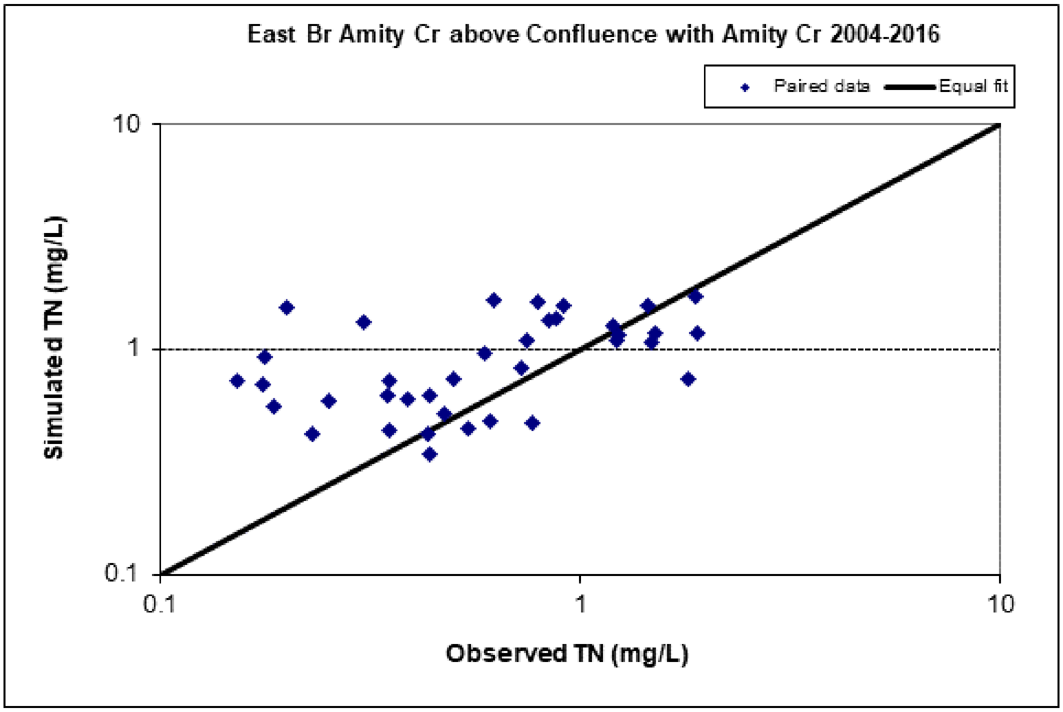


Figure E-209. Paired simulated vs. observed Total Nitrogen (TN) concentration at East Br Amity Cr above Confluence with Amity Cr (calibration period)

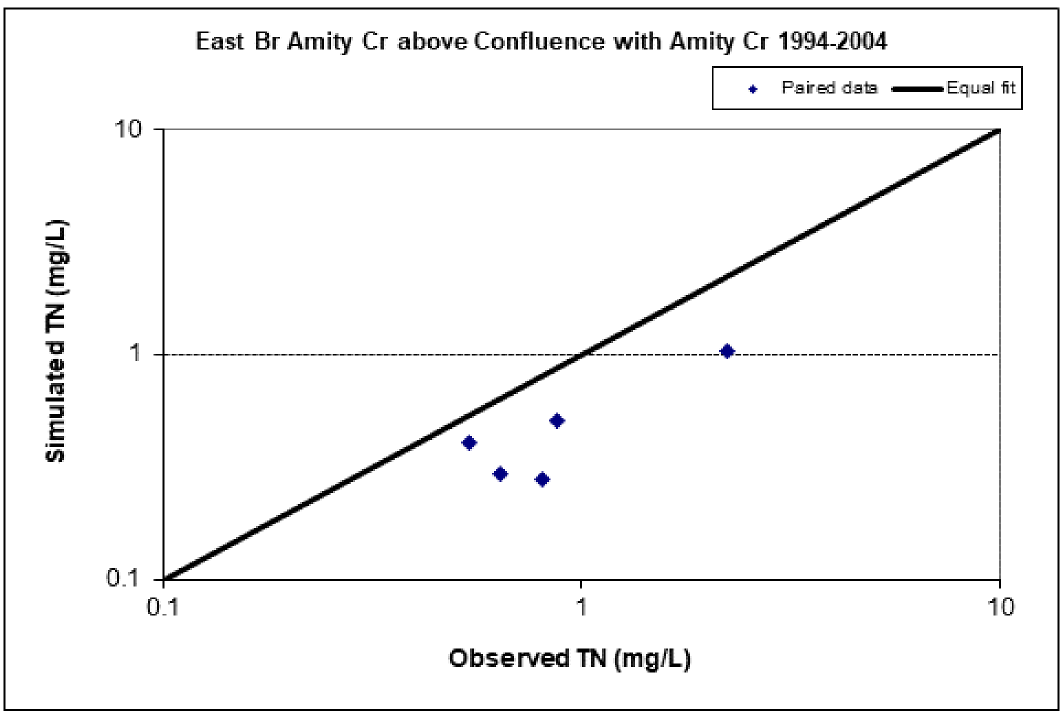


Figure E-210. Paired simulated vs. observed Total Nitrogen (TN) concentration at East Br Amity Cr above Confluence with Amity Cr (validation period)

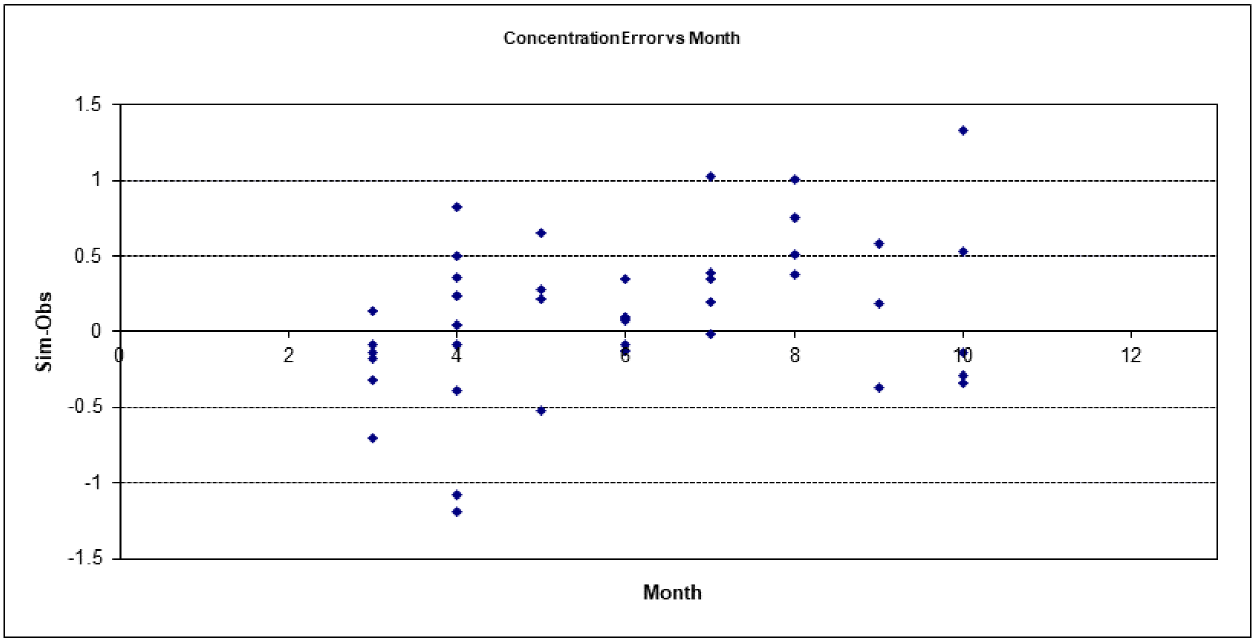


Figure E-211. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at East Br Amity Cr above Confluence with Amity Cr

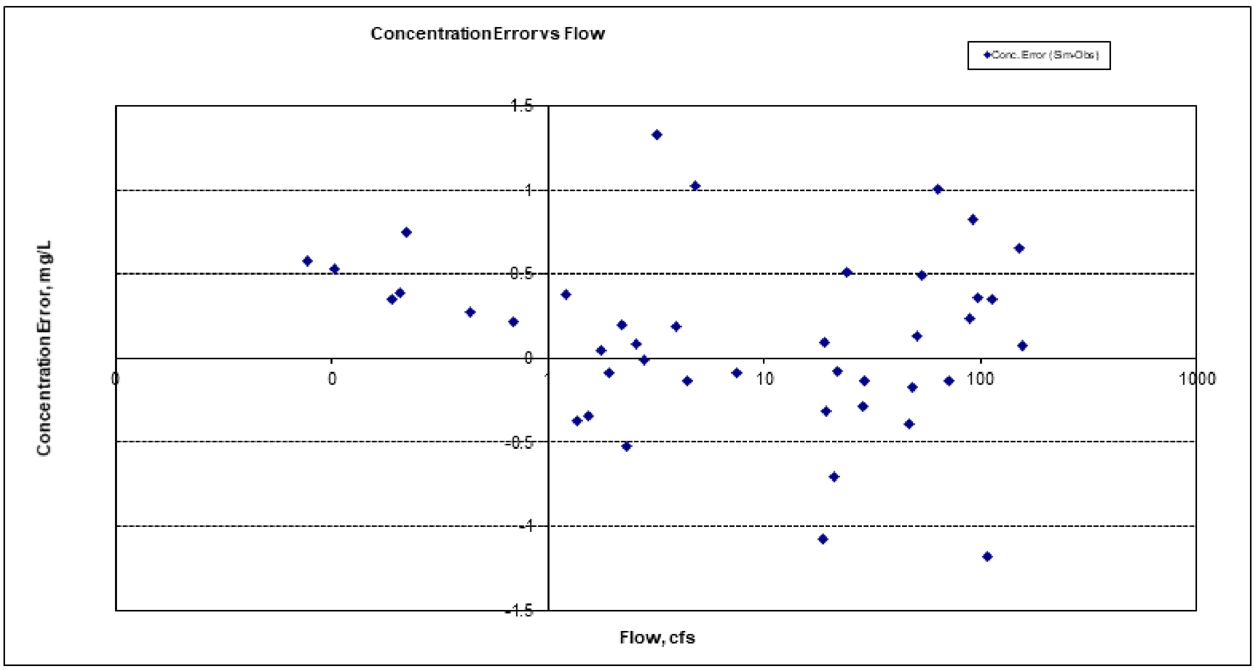


Figure E-212. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at East Br Amity Cr above Confluence with Amity Cr

E.3.7 Soluble Reactive Phosphorus (SRP)

Table E-25. Soluble Reactive Phosphorus (SRP) statistics

Period	1994-2004	2004-2016
Count	18	18
Concentration Average Error	-33.90%	16.99%
Concentration Median Error	-34.95%	9.78%
Load Average Error	-3.54%	6.92%
Load Median Error	-2.21%	0.66%
Paired t conc	0.17	0.56
Paired t load	0.60	0.63

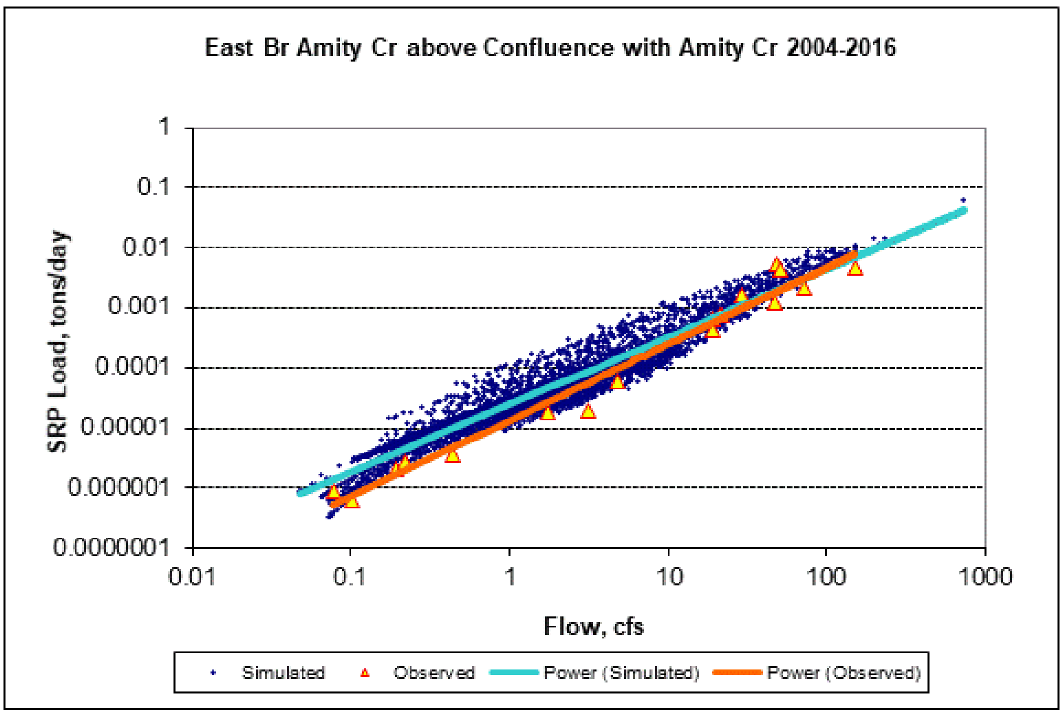


Figure E-213. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

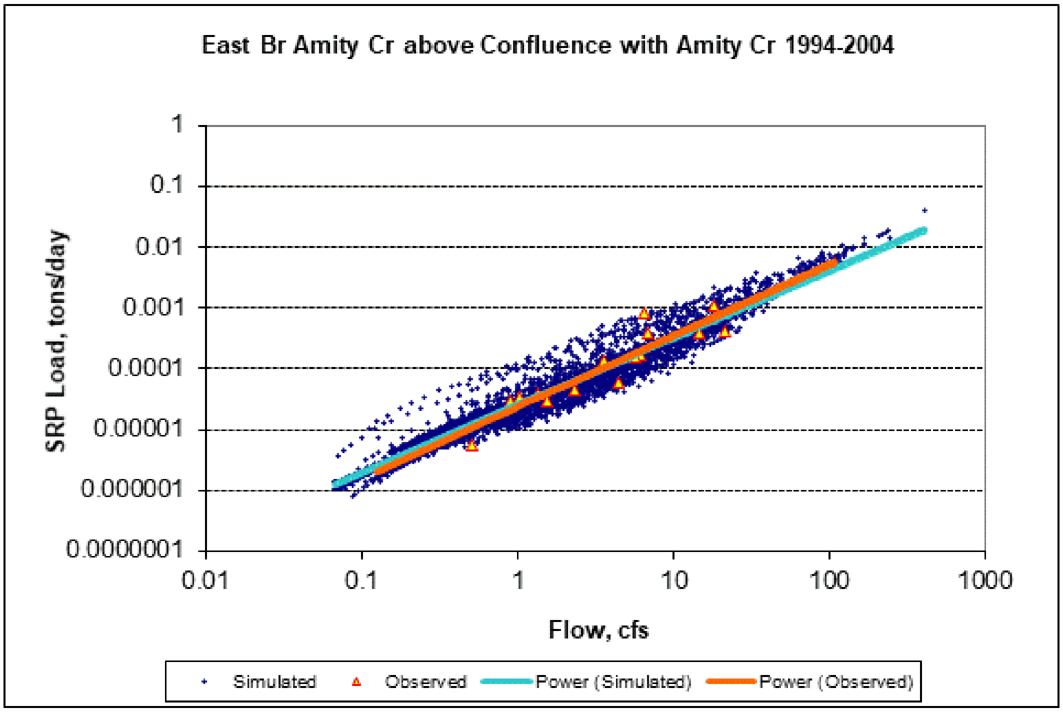


Figure E-214. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)

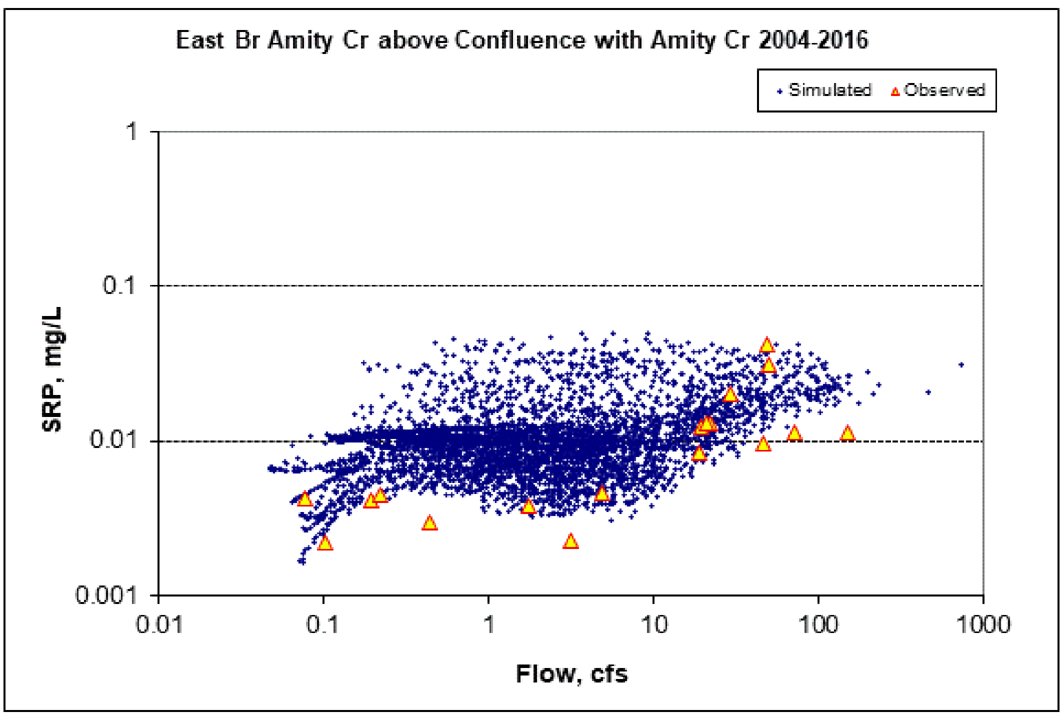


Figure E-215. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

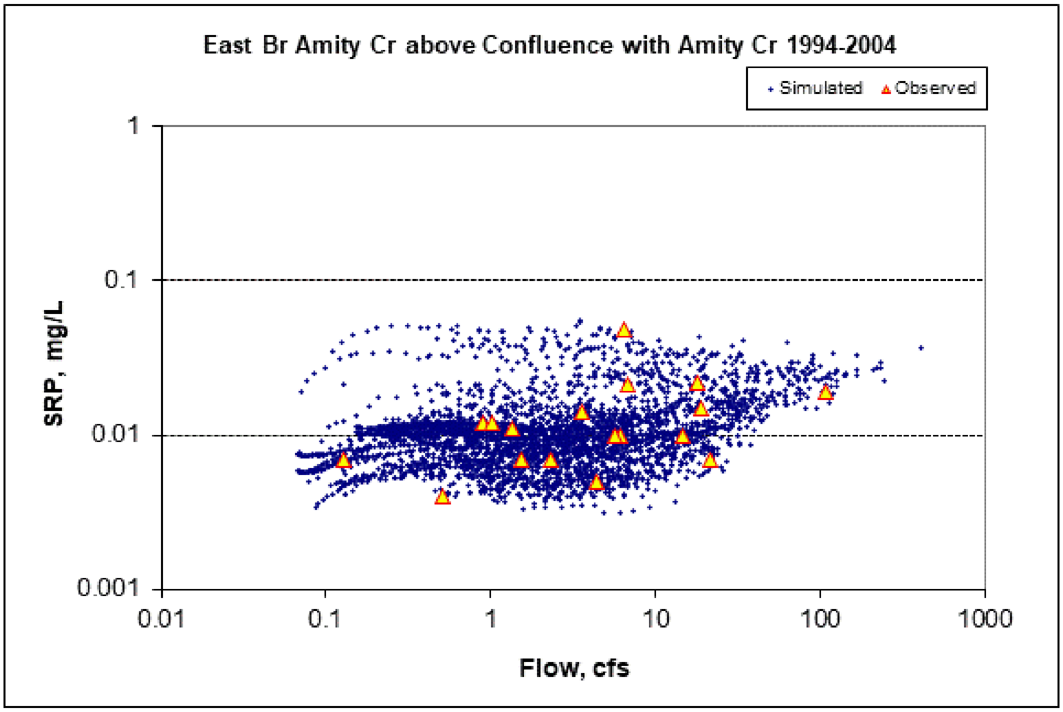
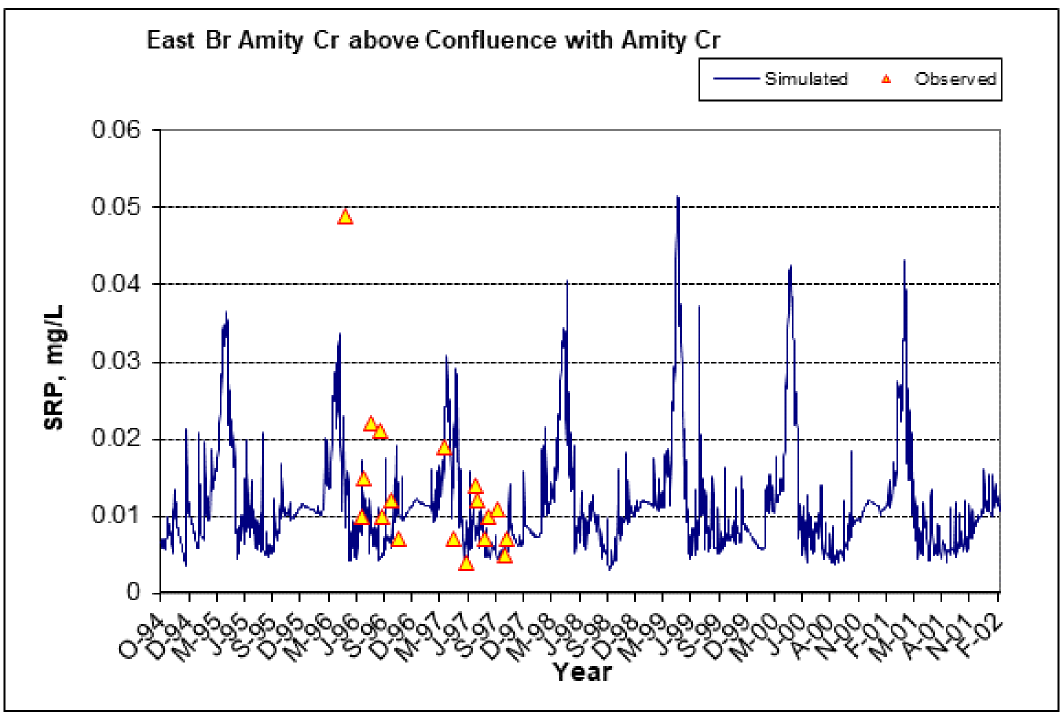


Figure E-216. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)



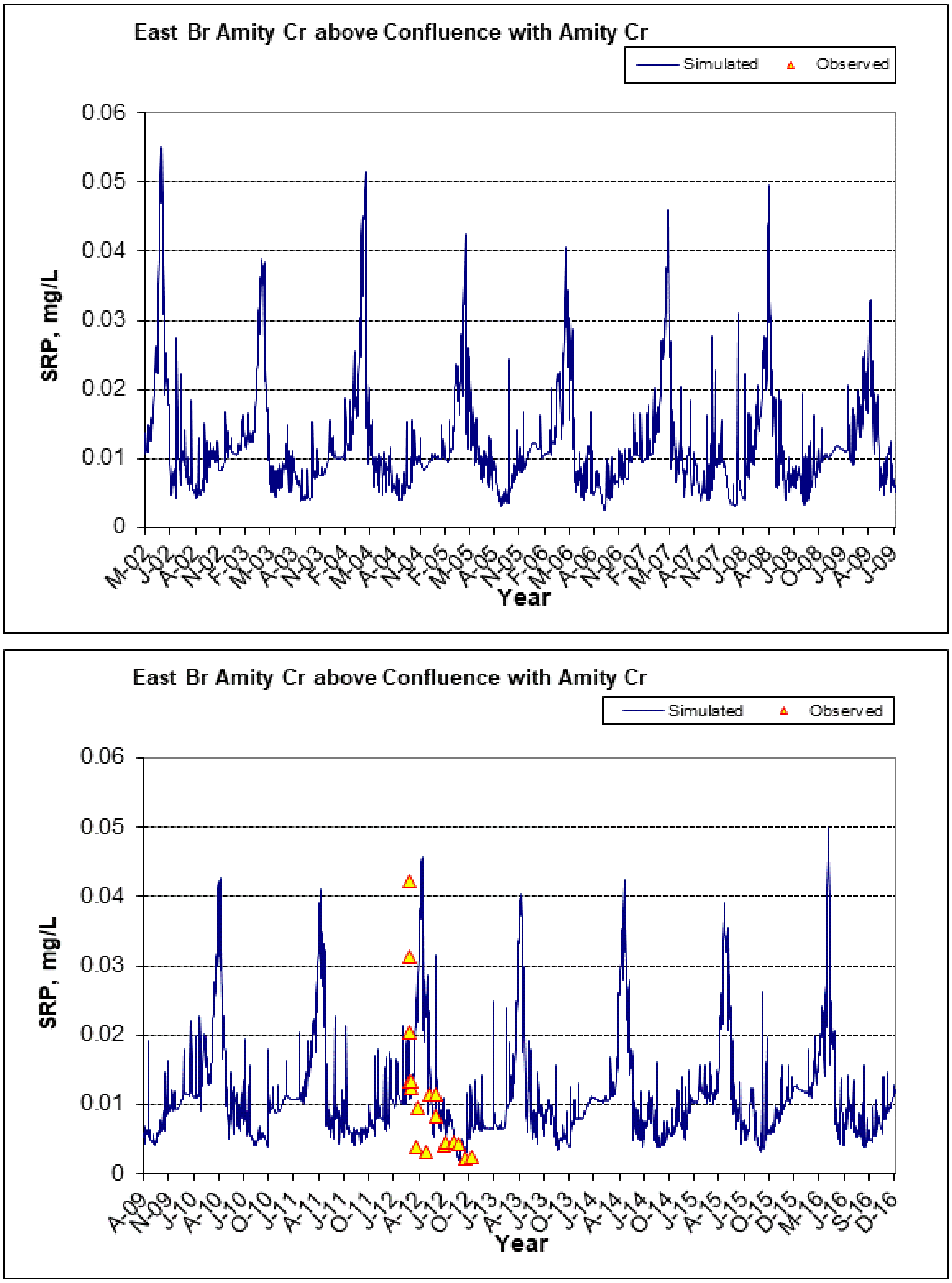


Figure E-217. Time series of observed and simulated Soluble Reactive Phosphorus (SRP) concentration at East Br Amity Cr above Confluence with Amity Cr

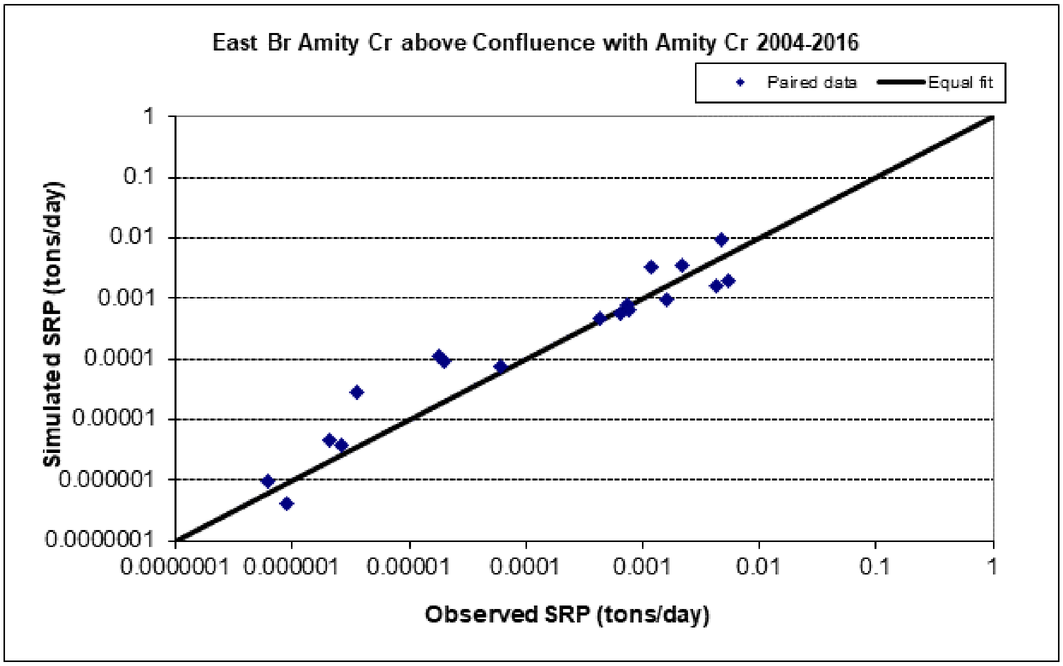


Figure E-218. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at East Br Amity Cr above Confluence with Amity Cr (calibration period)

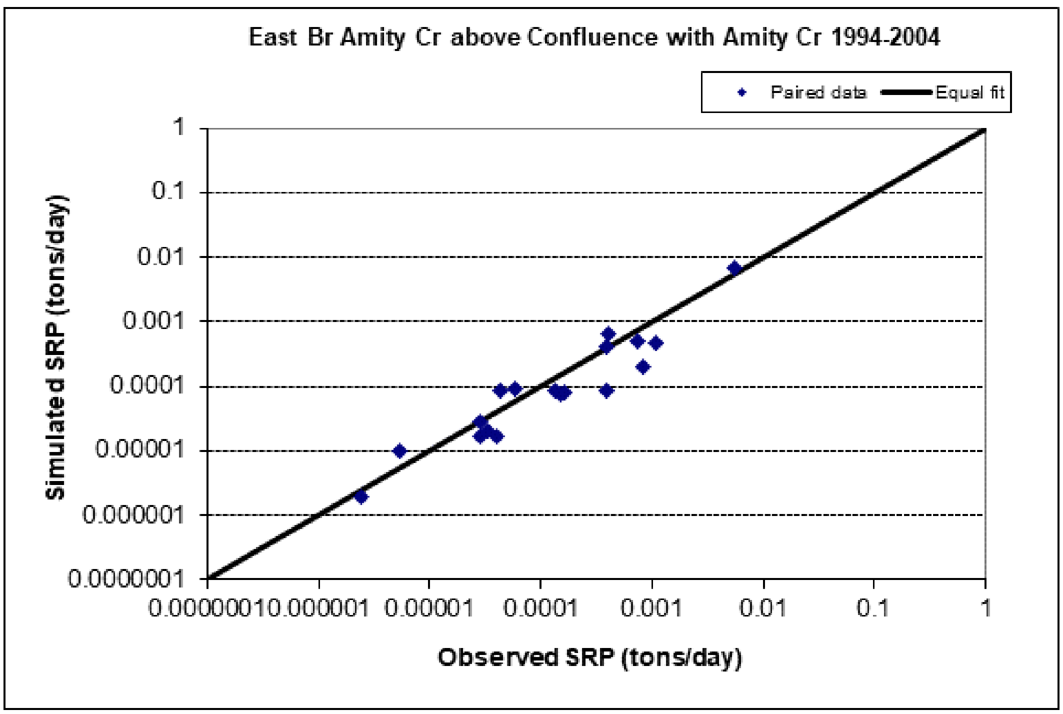


Figure E-219. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at East Br Amity Cr above Confluence with Amity Cr (validation period)

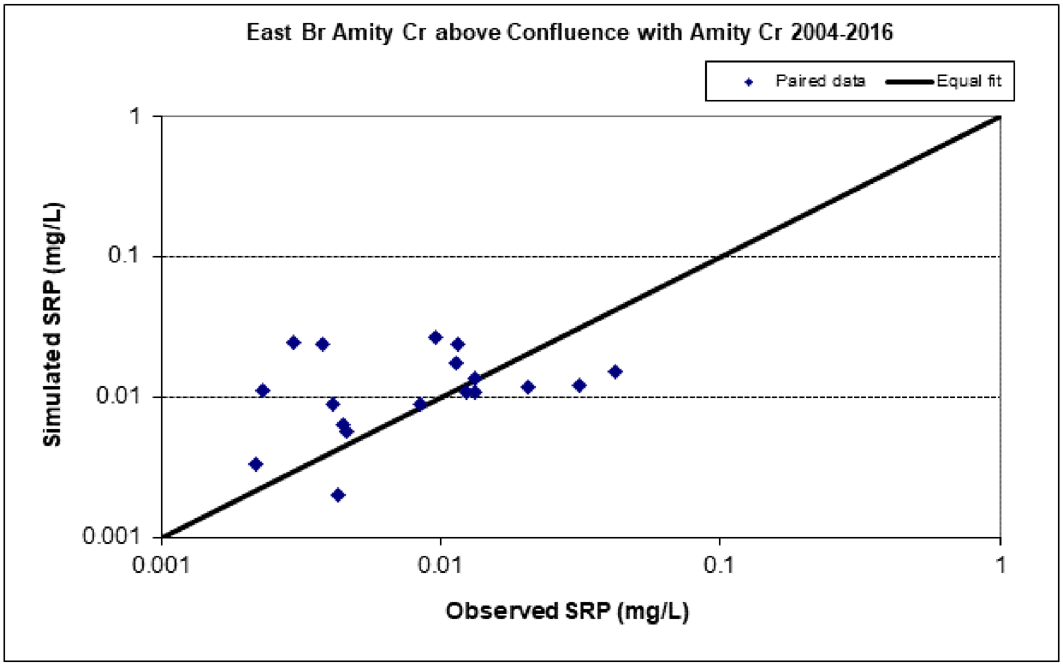


Figure E-220. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at East Br Amity Cr above Confluence with Amity Cr (calibration period)

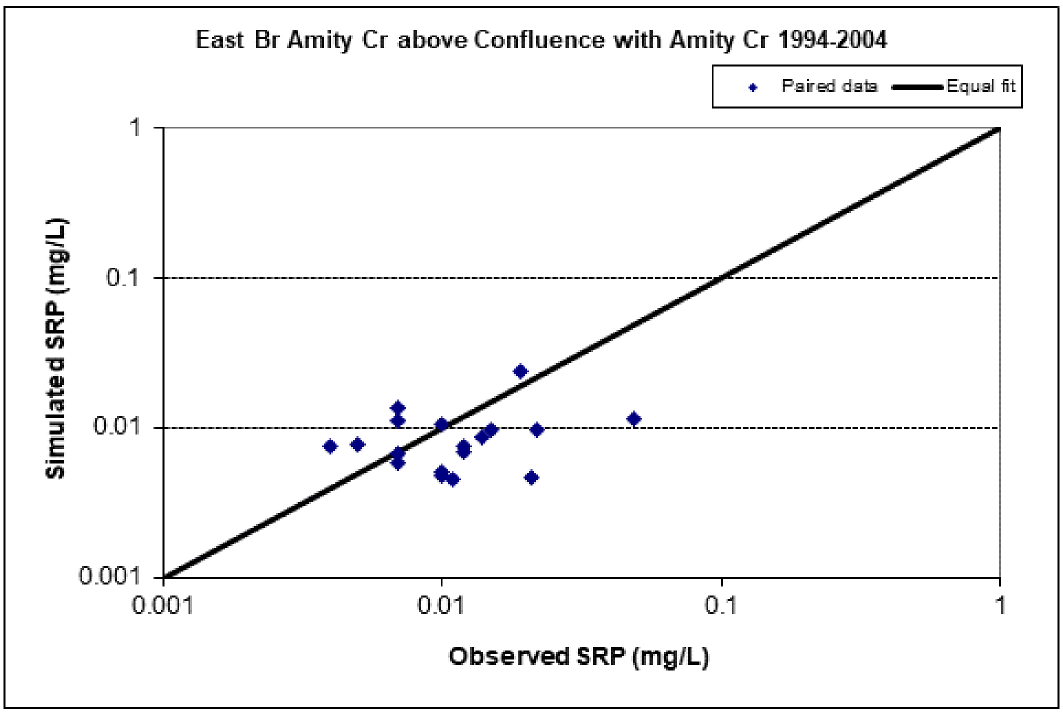


Figure E-221. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at East Br Amity Cr above Confluence with Amity Cr (validation period)

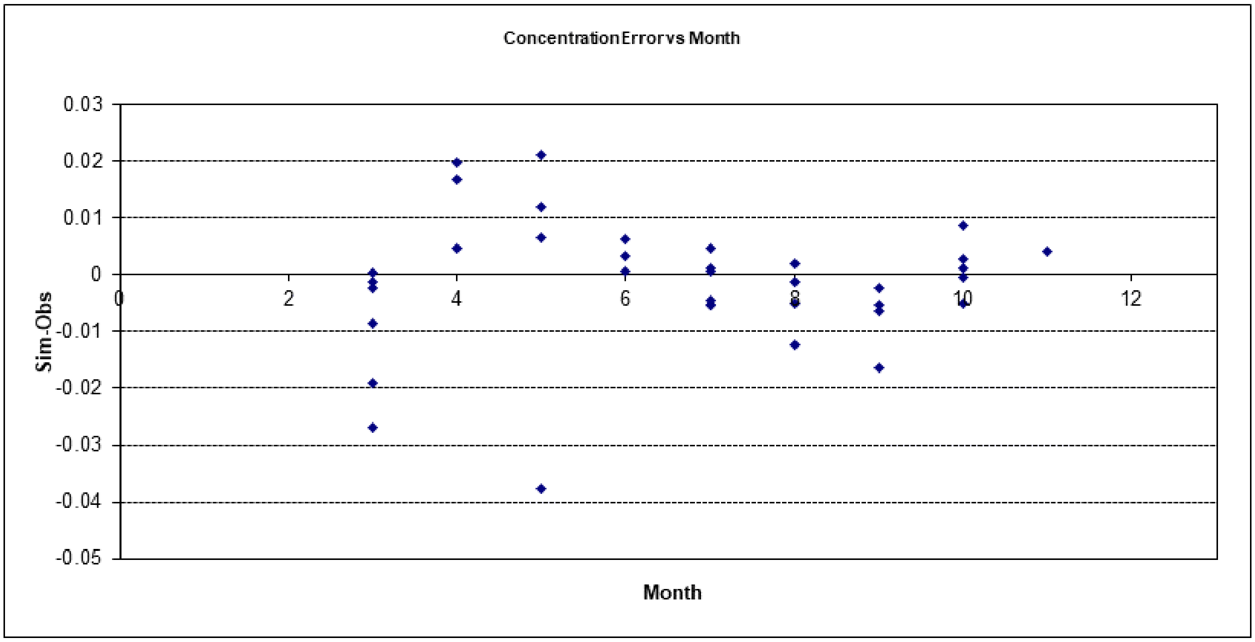


Figure E-222. Residual (Simulated - Observed) vs. Month, Soluble Reactive Phosphorus (SRP) at East Br Amity Cr above Confluence with Amity Cr

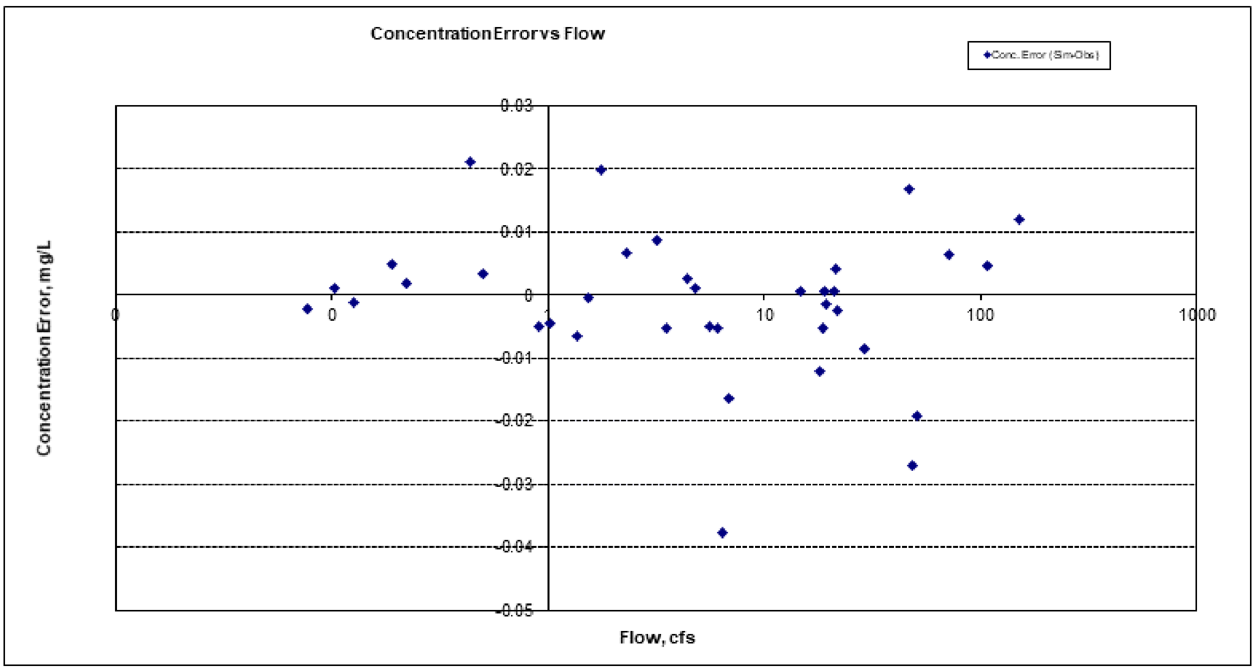


Figure E-223. Residual (Simulated - Observed) vs. Flow, Soluble Reactive Phosphorus (SRP) at East Br Amity Cr above Confluence with Amity Cr

E.3.8 Organic Phosphorus (OrgP)

Table E-26. Organic Phosphorus (OrgP) statistics

Period	1994-2004	2004-2016
Count	8	18
Concentration Average Error	8.05%	-19.93%
Concentration Median Error	-0.68%	13.51%
Load Average Error	61.41%	-15.88%
Load Median Error	-0.76%	0.04%
Paired t conc	0.60	0.50
Paired t load	0.36	0.54

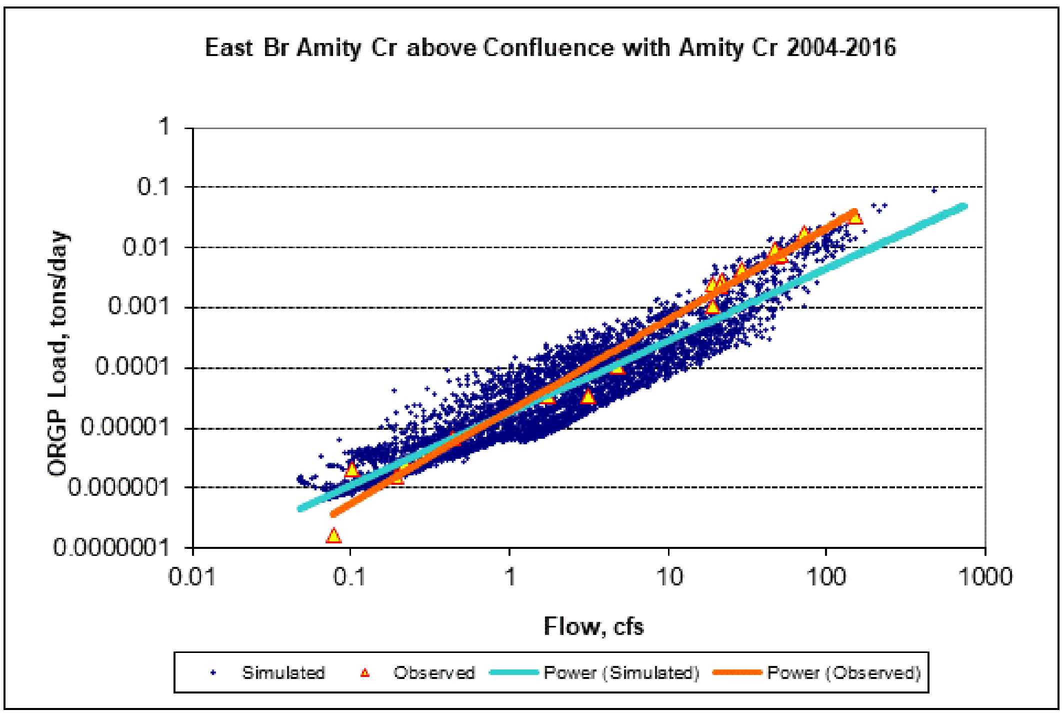


Figure E-224. Power plot of simulated and observed Organic Phosphorus (OrgP) load vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

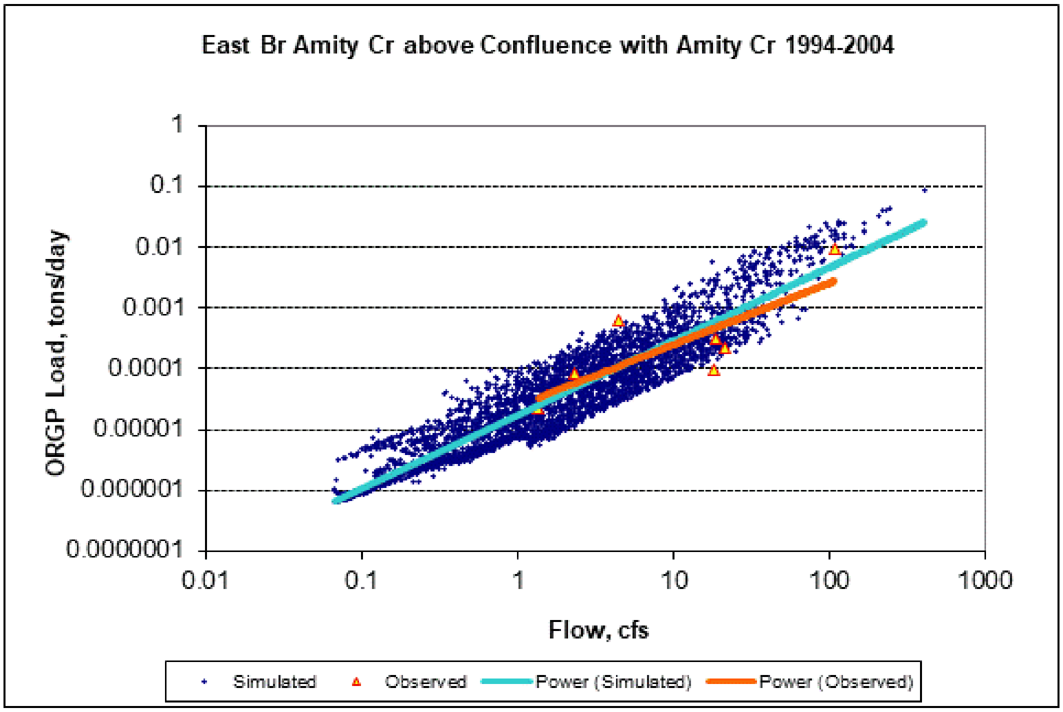


Figure E-225. Power plot of simulated and observed Organic Phosphorus (OrgP) load vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)

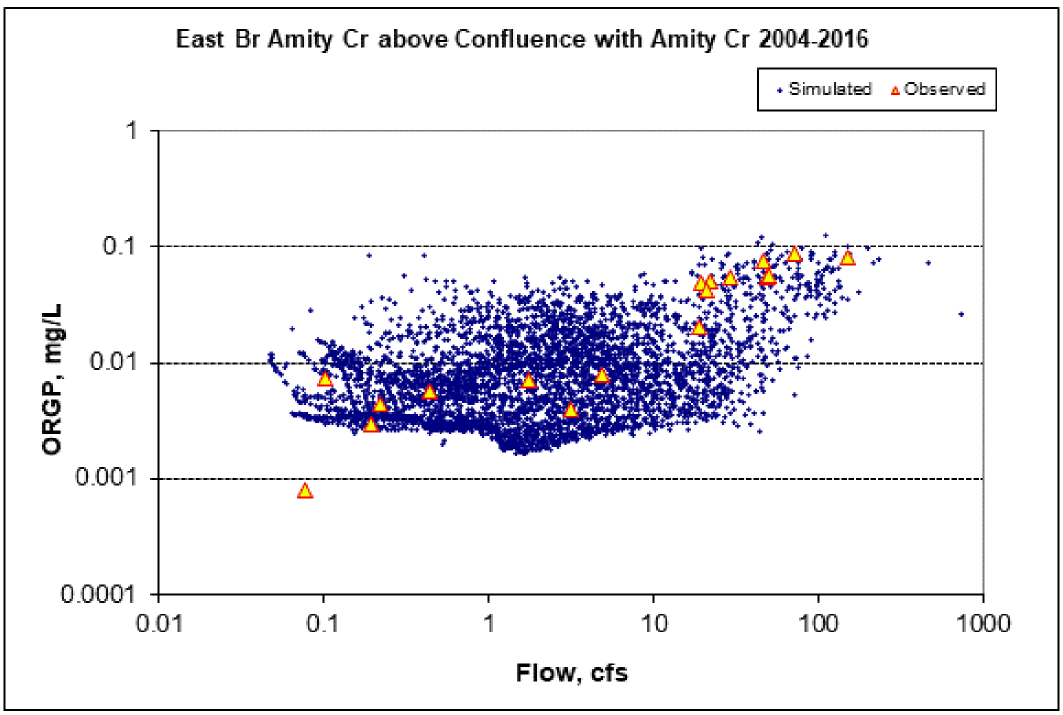


Figure E-226. Simulated and observed Organic Phosphorus (OrgP) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

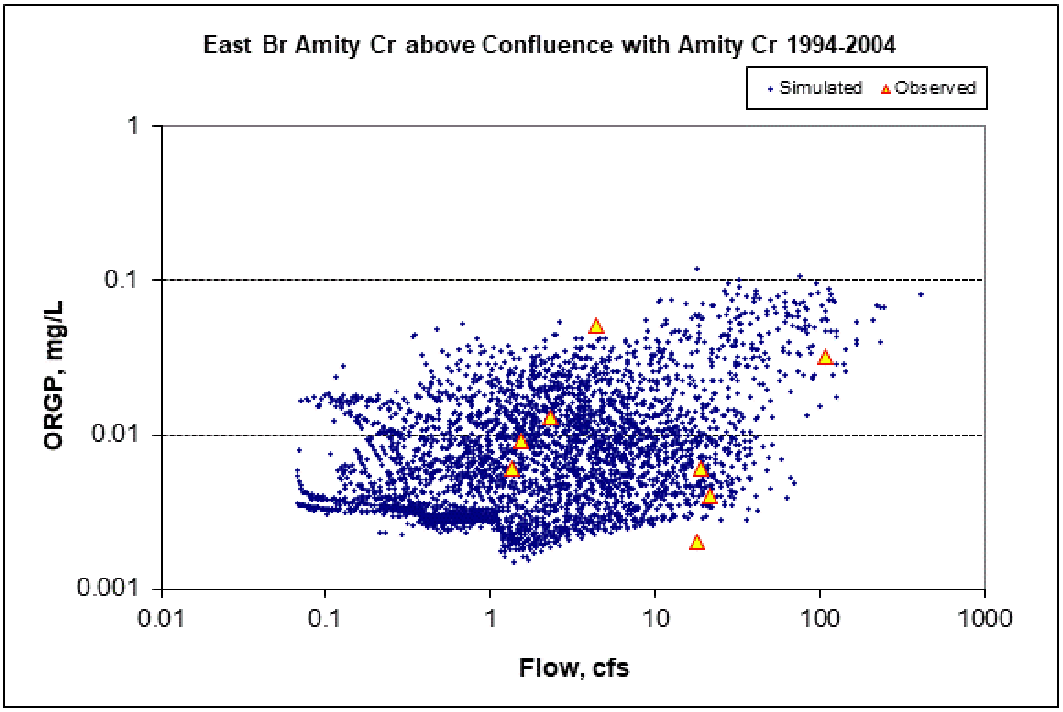
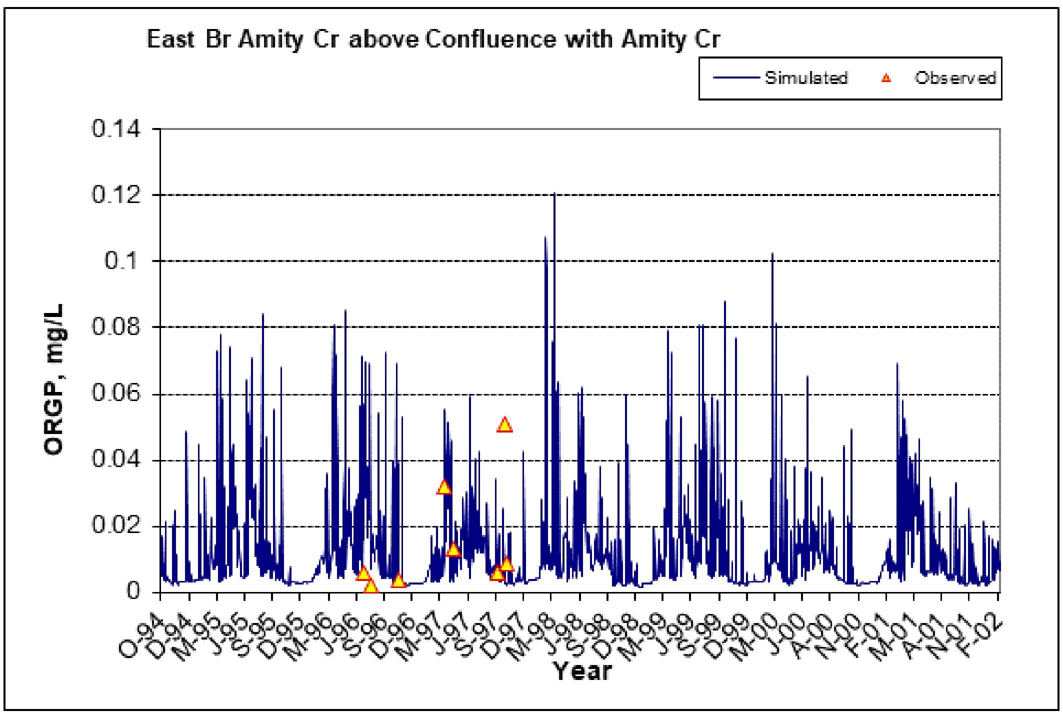
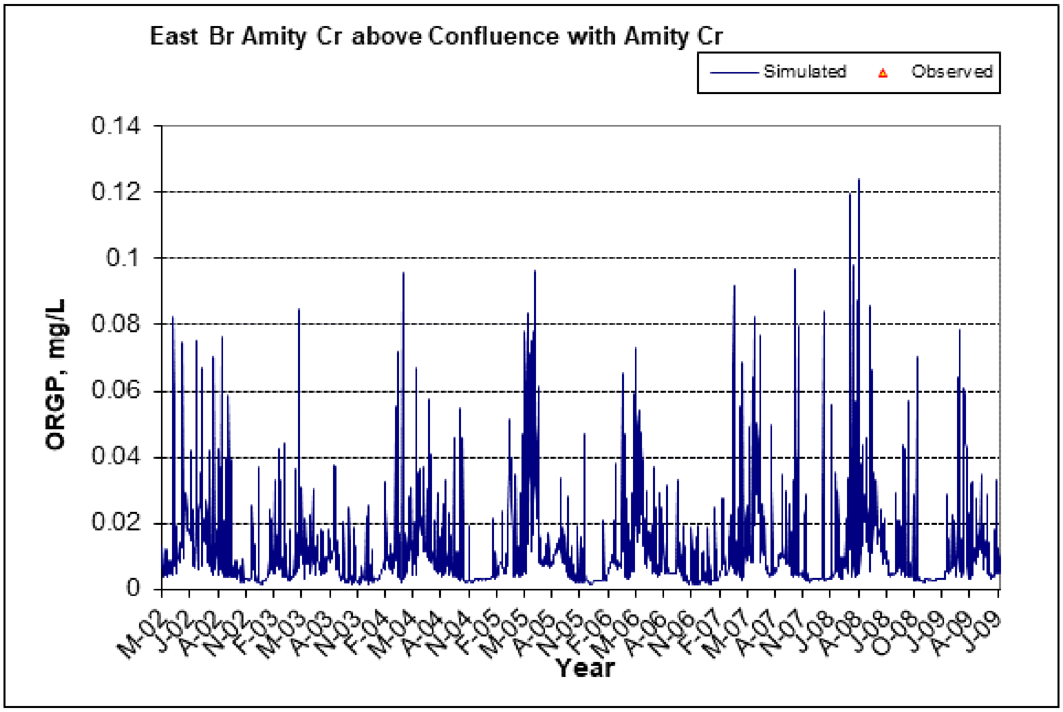


Figure E-227. Simulated and observed Organic Phosphorus (OrgP) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)





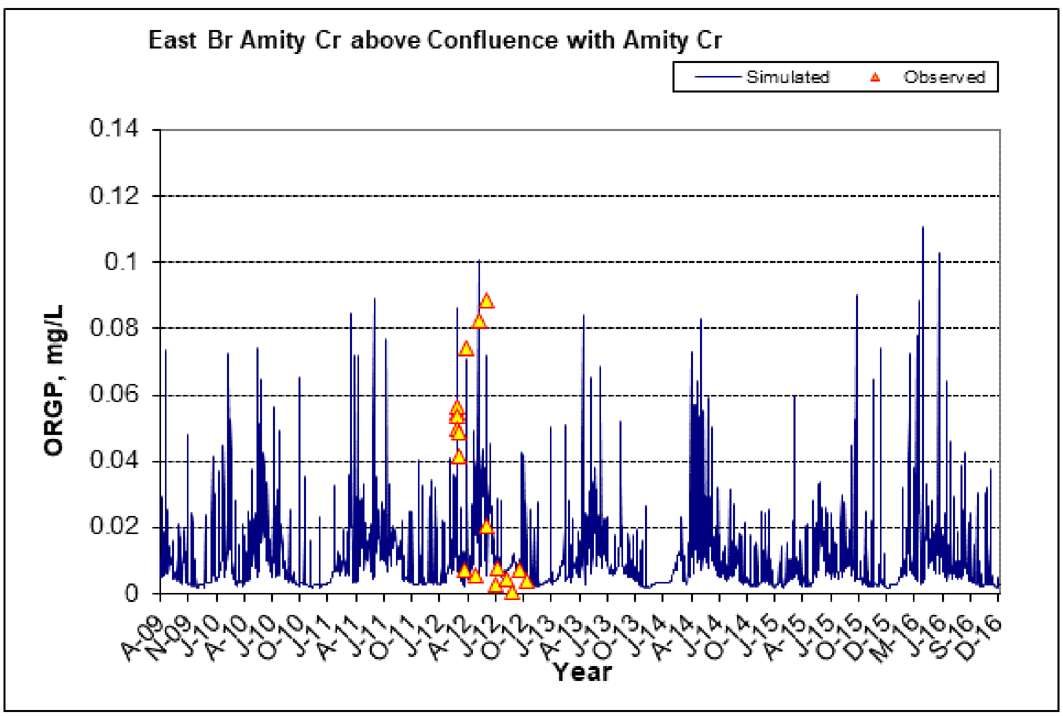


Figure E-228. Time series of observed and simulated Organic Phosphorus (OrgP) concentration at East Br Amity Cr above Confluence with Amity Cr

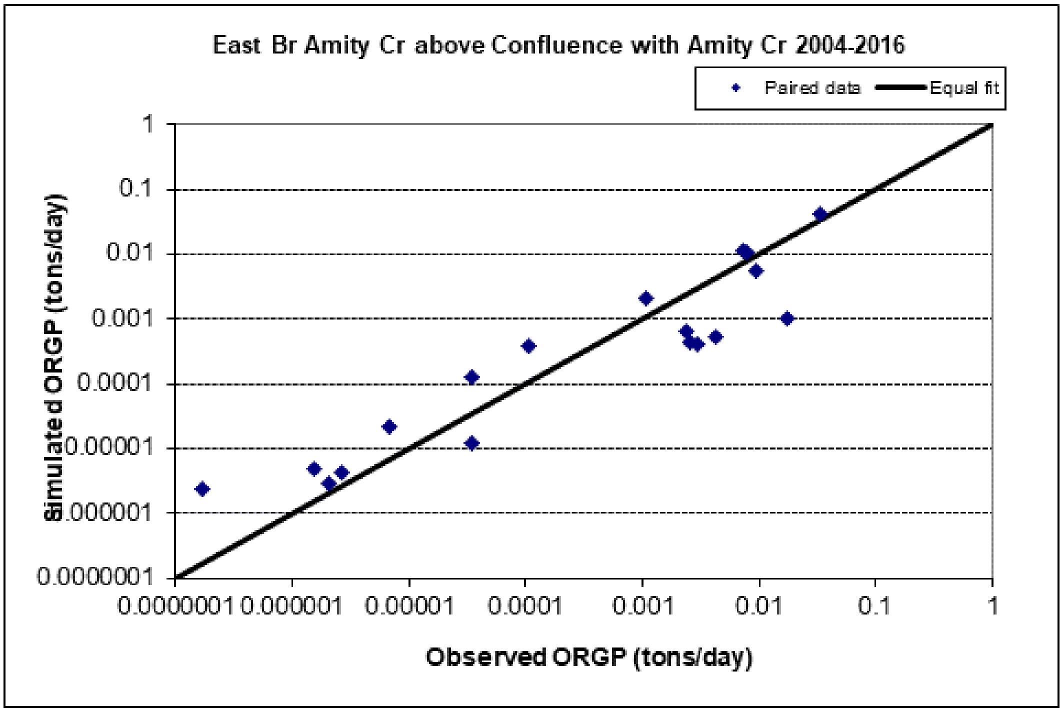


Figure E-229. Paired simulated vs. observed Organic Phosphorus (OrgP) load at East Br Amity Cr above Confluence with Amity Cr (calibration period)

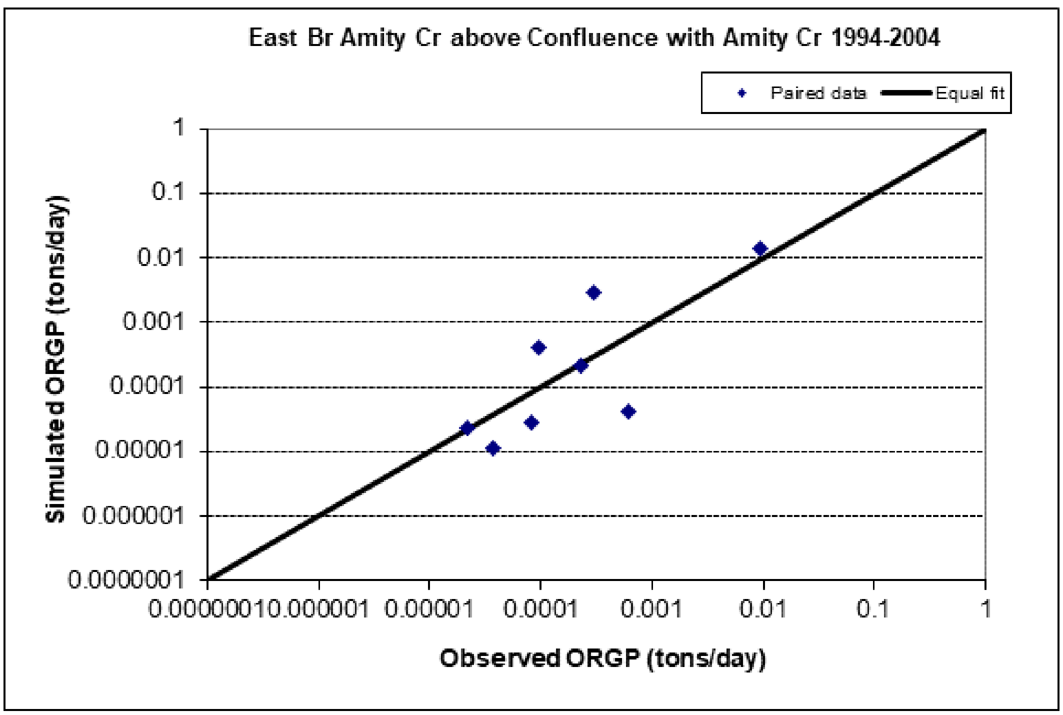


Figure E-230. Paired simulated vs. observed Organic Phosphorus (OrgP) load at East Br Amity Cr above Confluence with Amity Cr (validation period)

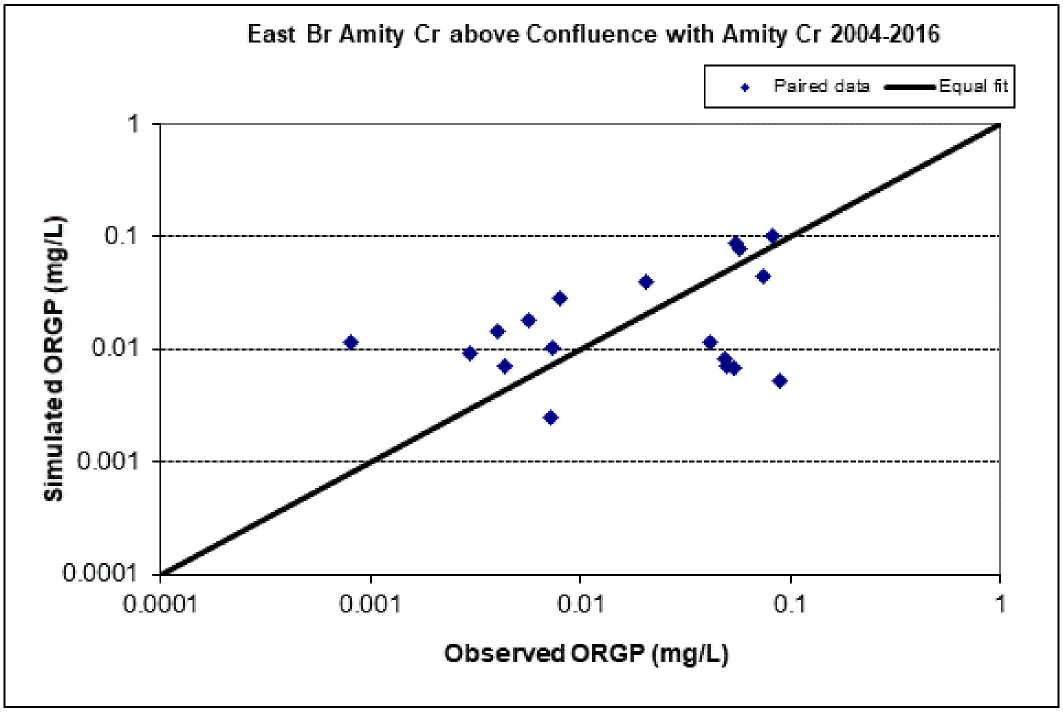


Figure E-231. Paired simulated vs. observed Organic Phosphorus (OrgP) concentration at East Br Amity Cr above Confluence with Amity Cr (calibration period)

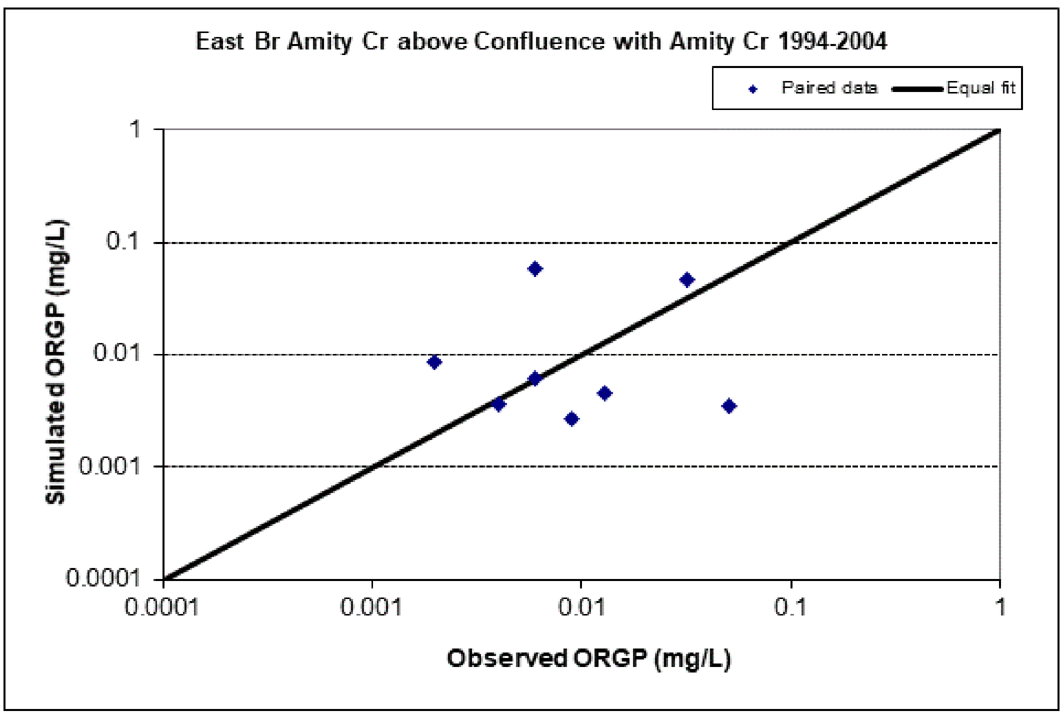


Figure E-232. Paired simulated vs. observed Organic Phosphorus (OrgP) concentration at East Br Amity Cr above Confluence with Amity Cr (validation period)

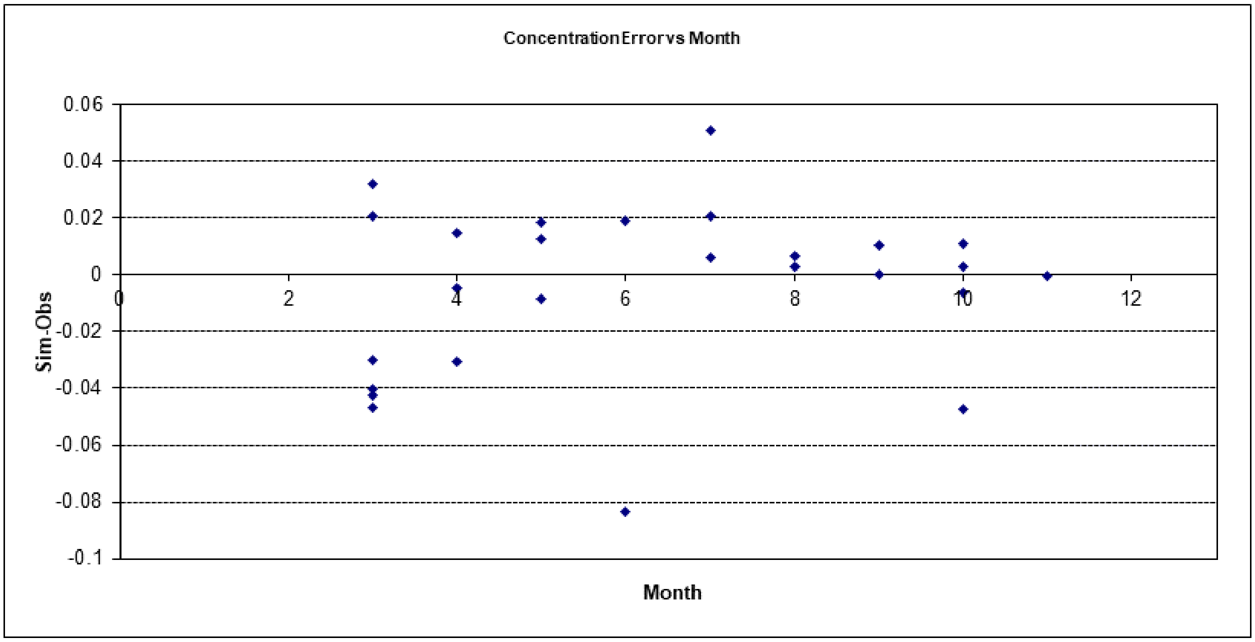


Figure E-233. Residual (Simulated - Observed) vs. Month, Organic Phosphorus (OrgP) at East Br Amity Cr above Confluence with Amity Cr

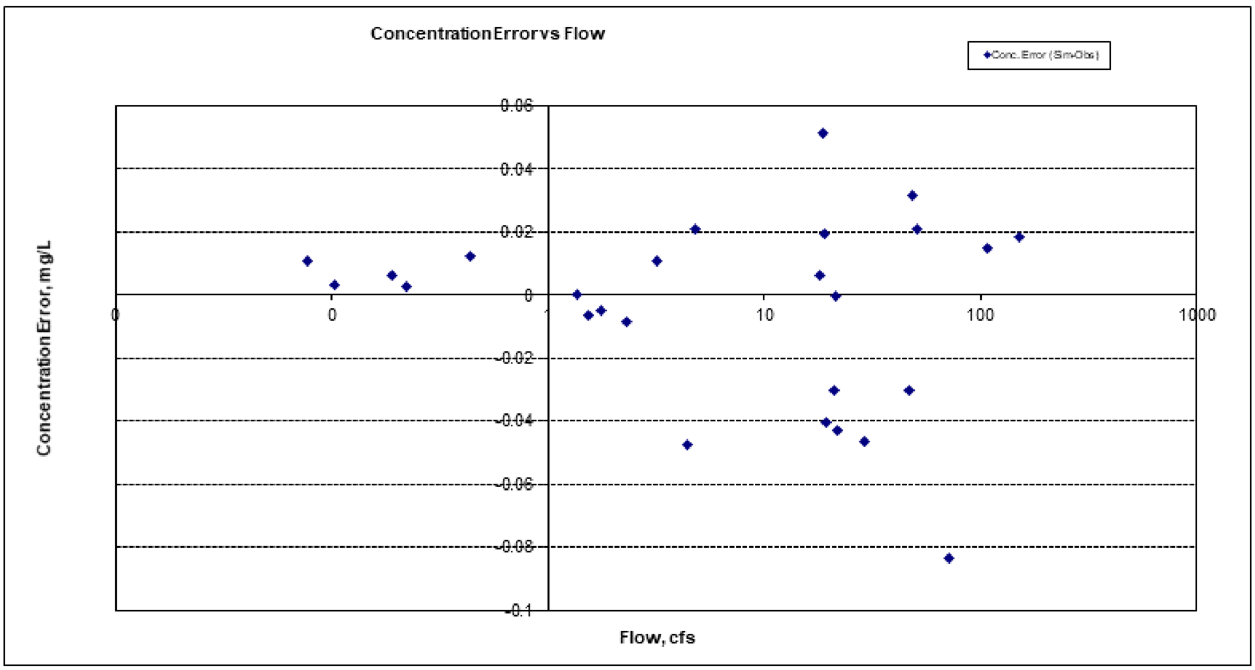


Figure E-234. Residual (Simulated - Observed) vs. Flow, Organic Phosphorus (OrgP) at East Br Amity Cr above Confluence with Amity Cr

E.3.9 Total Phosphorus (TP)

Table E-27. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	12	38
Concentration Average Error	-25.67%	28.45%
Concentration Median Error	-10.68%	39.79%
Load Average Error	32.52%	33.63%
Load Median Error	-1.03%	1.29%
Paired t conc	0.41	0.29
Paired t load	0.44	0.34

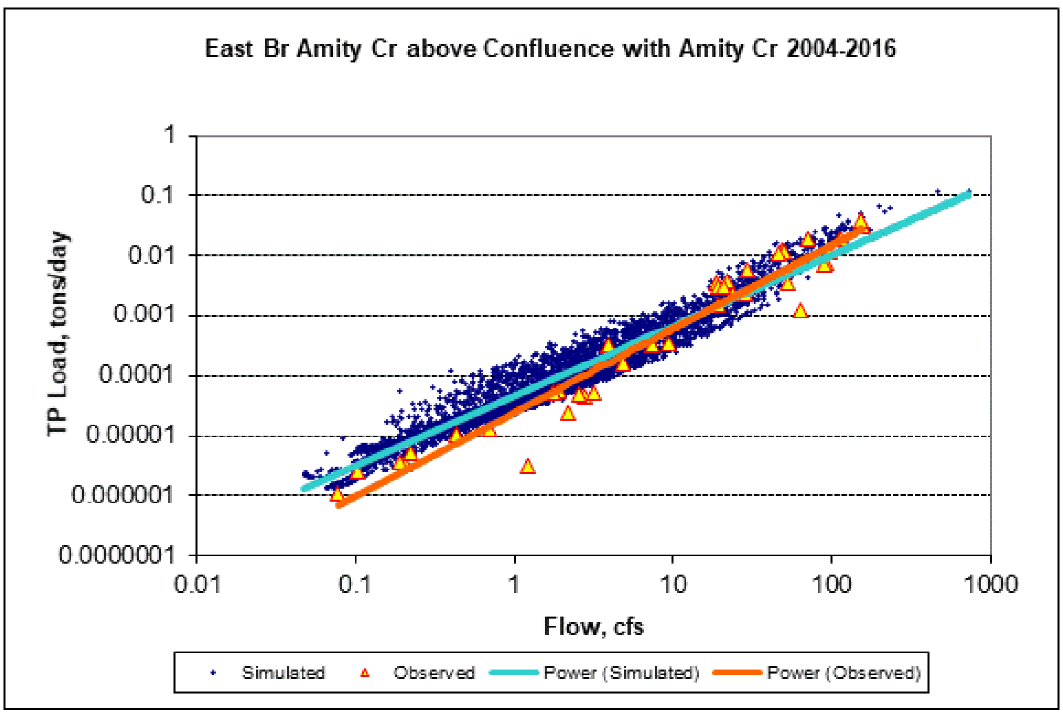


Figure E-235. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

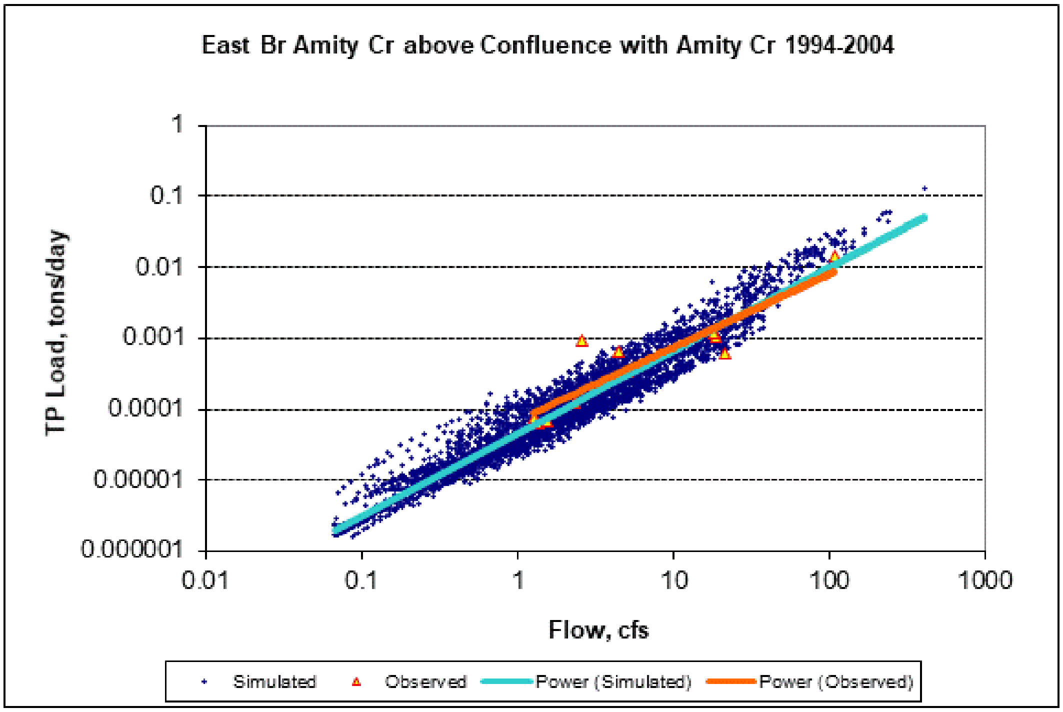


Figure E-236. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)

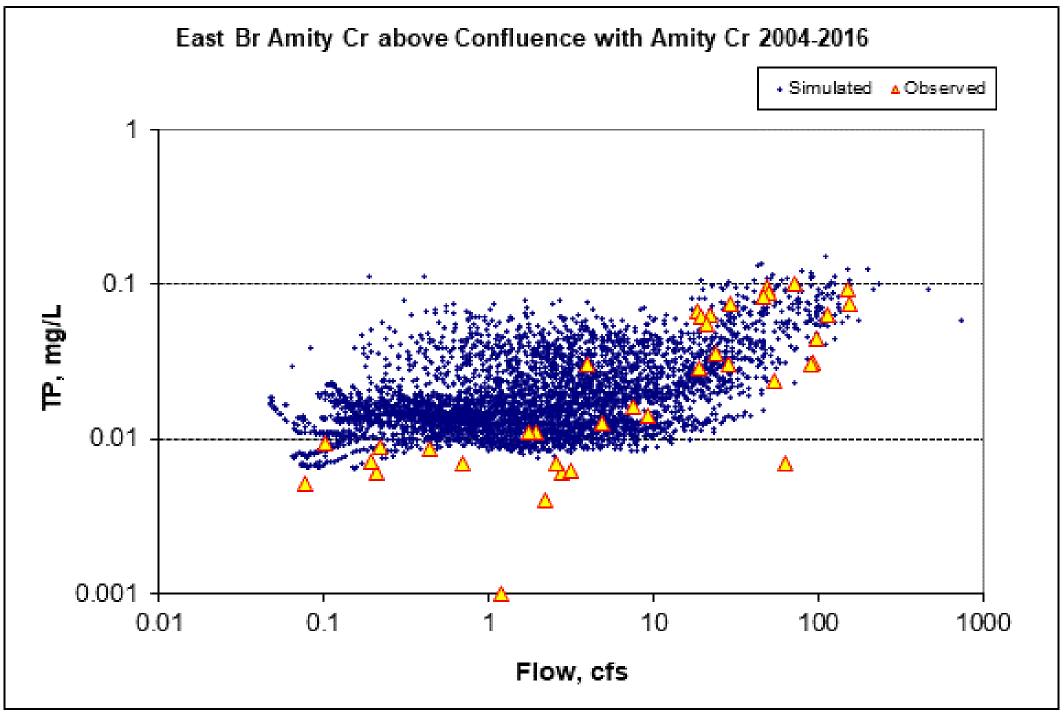


Figure E-237. Simulated and observed Total Phosphorus (TP) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (calibration period)

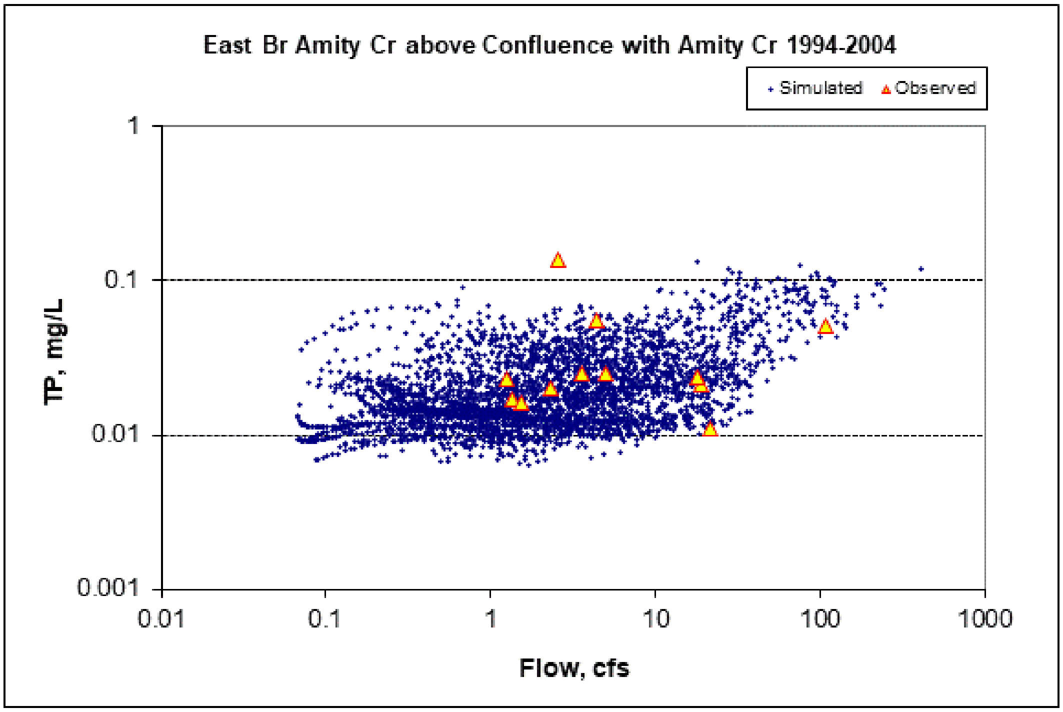
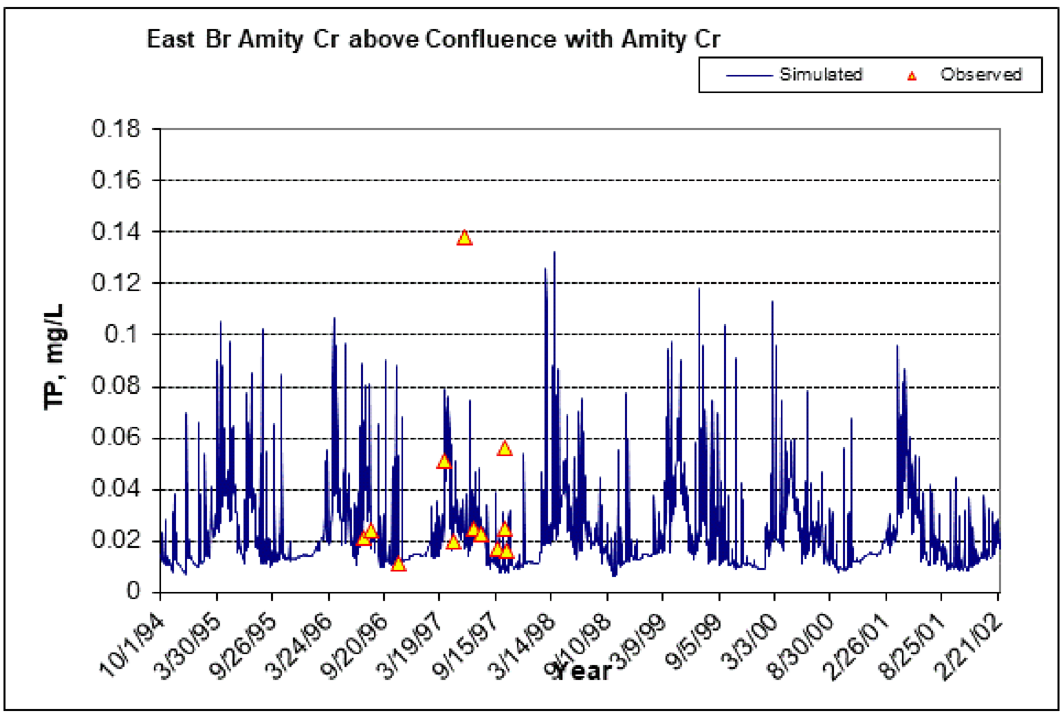


Figure E-238. Simulated and observed Total Phosphorus (TP) concentration vs flow at East Br Amity Cr above Confluence with Amity Cr (validation period)



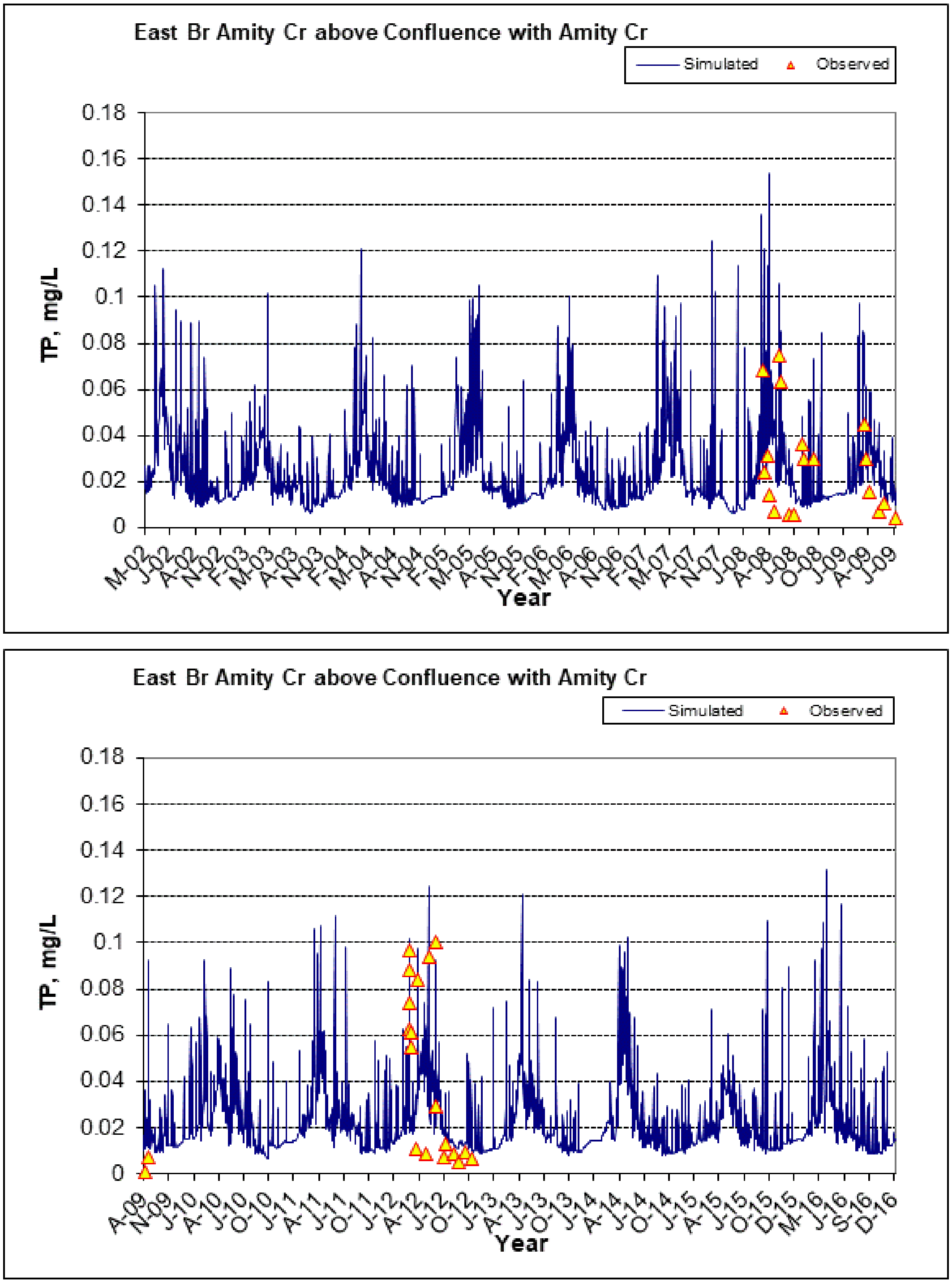


Figure E-239. Time series of observed and simulated Total Phosphorus (TP) concentration at East Br Amity Cr above Confluence with Amity Cr

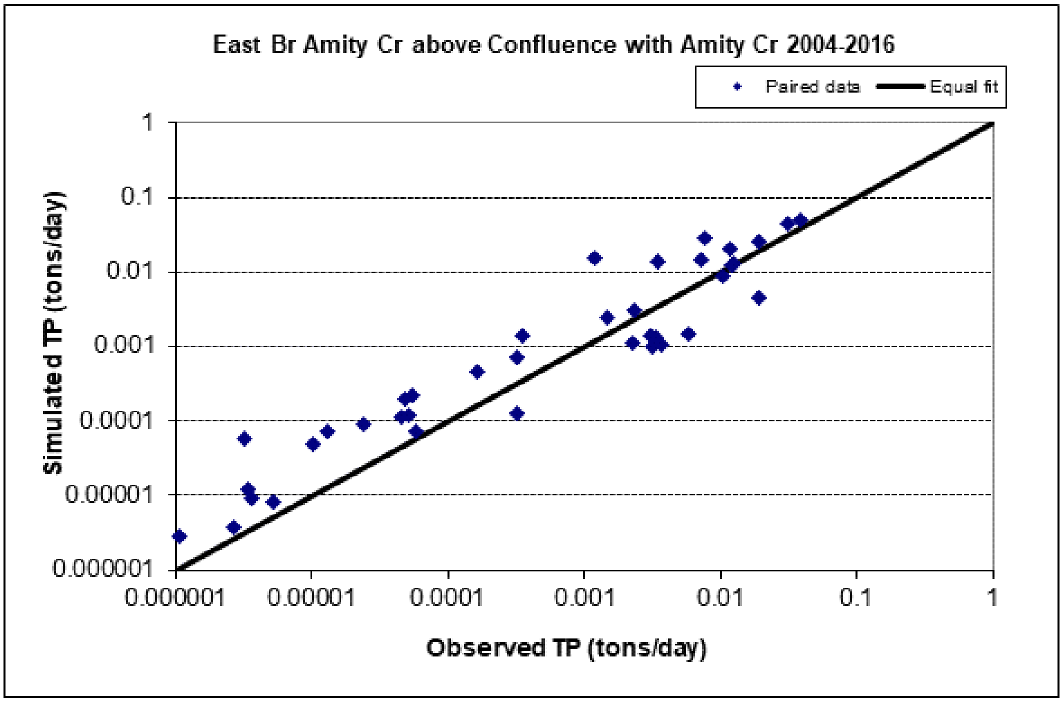


Figure E-240. Paired simulated vs. observed Total Phosphorus (TP) load at East Br Amity Cr above Confluence with Amity Cr (calibration period)

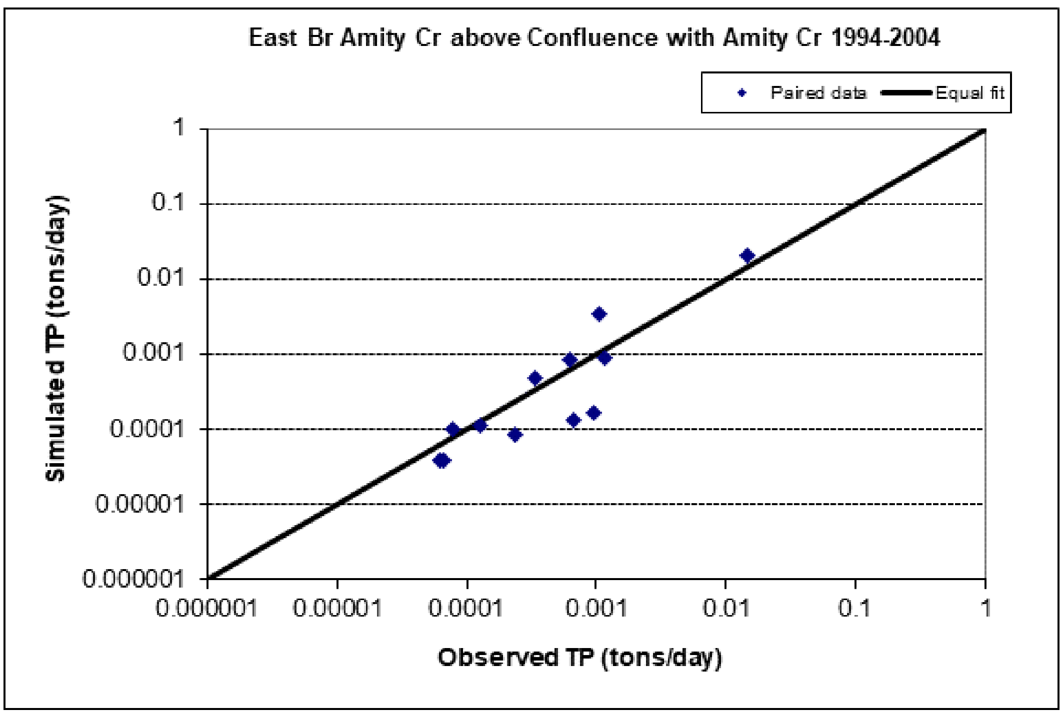


Figure E-241. Paired simulated vs. observed Total Phosphorus (TP) load at East Br Amity Cr above Confluence with Amity Cr (validation period)

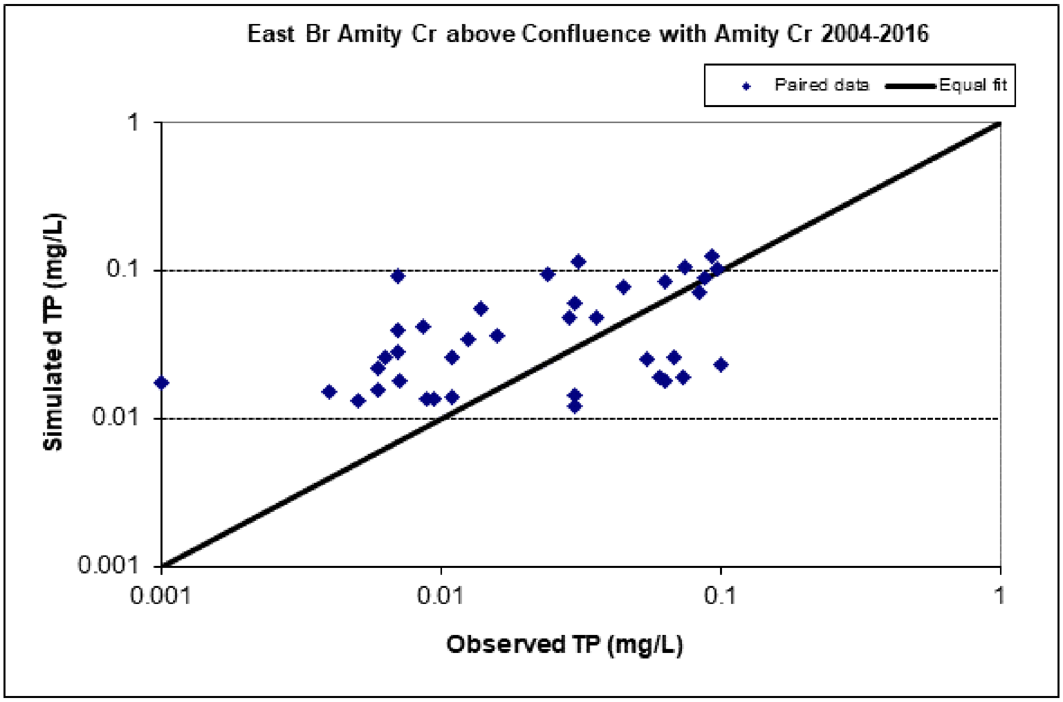


Figure E-242. Paired simulated vs. observed Total Phosphorus (TP) concentration at East Br Amity Cr above Confluence with Amity Cr (calibration period)

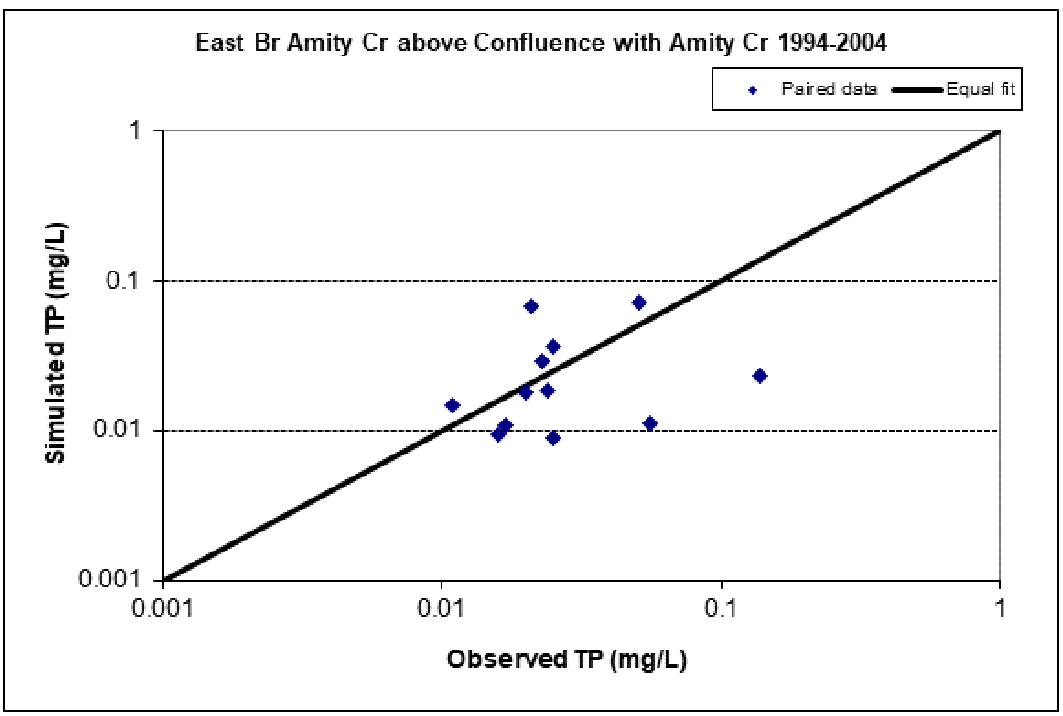


Figure E-243. Paired simulated vs. observed Total Phosphorus (TP) concentration at East Br Amity Cr above Confluence with Amity Cr (validation period)

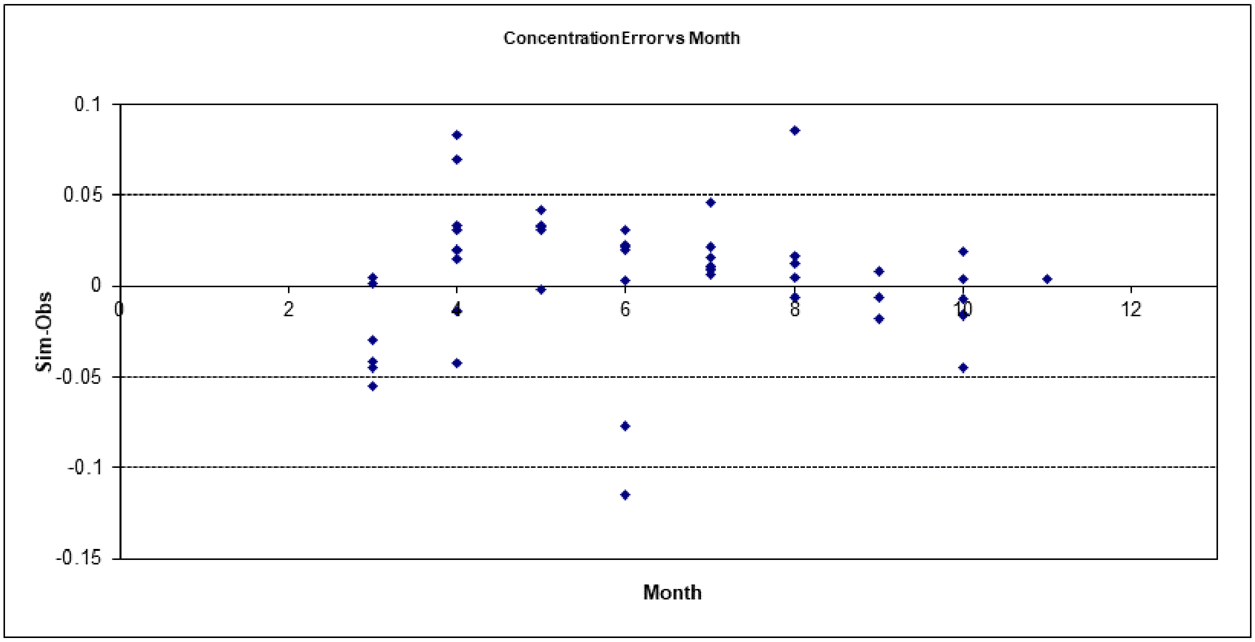


Figure E-244. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at East Br Amity Cr above Confluence with Amity Cr

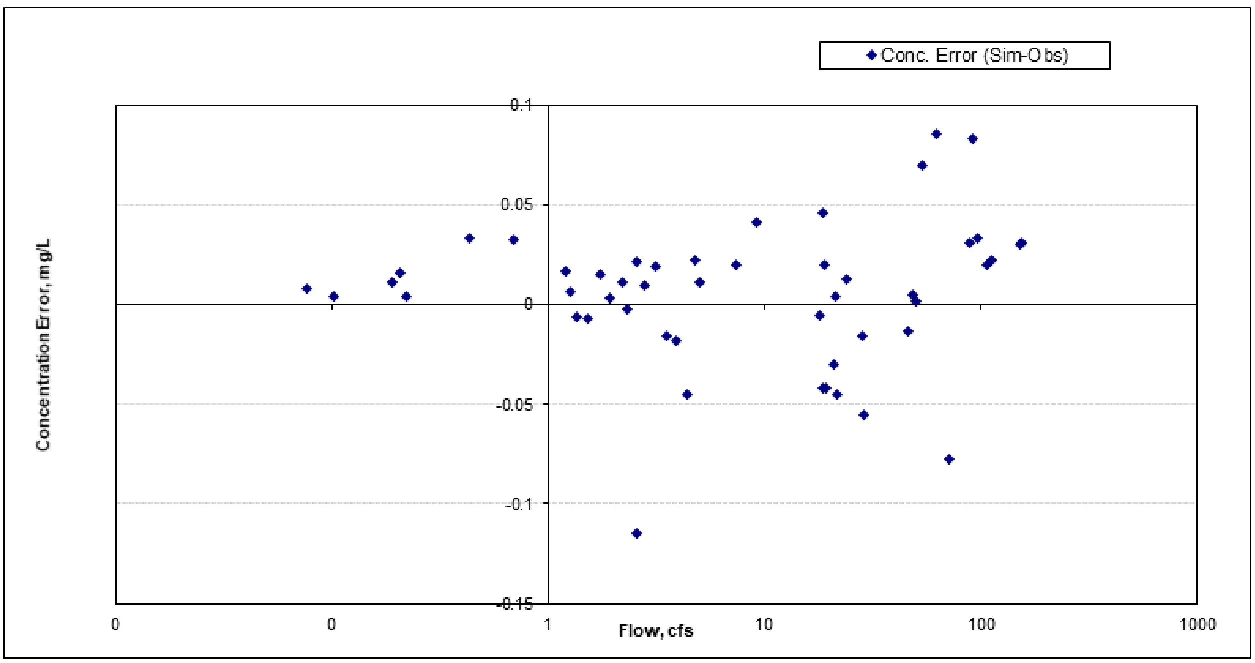


Figure E-245. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at East Br Amity Cr above Confluence with Amity Cr

E.4 AMITY CREEK WEST OF SKYLINE PKWAY

E.4.1 Ammonia Nitrogen (NH3)

Table E-28. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	18	ND
Concentration Average Error	604.18%	
Concentration Median Error	215.49%	
Load Average Error	127.19%	
Load Median Error	43.34%	
Paired t conc	0.00	
Paired t load	0.04	

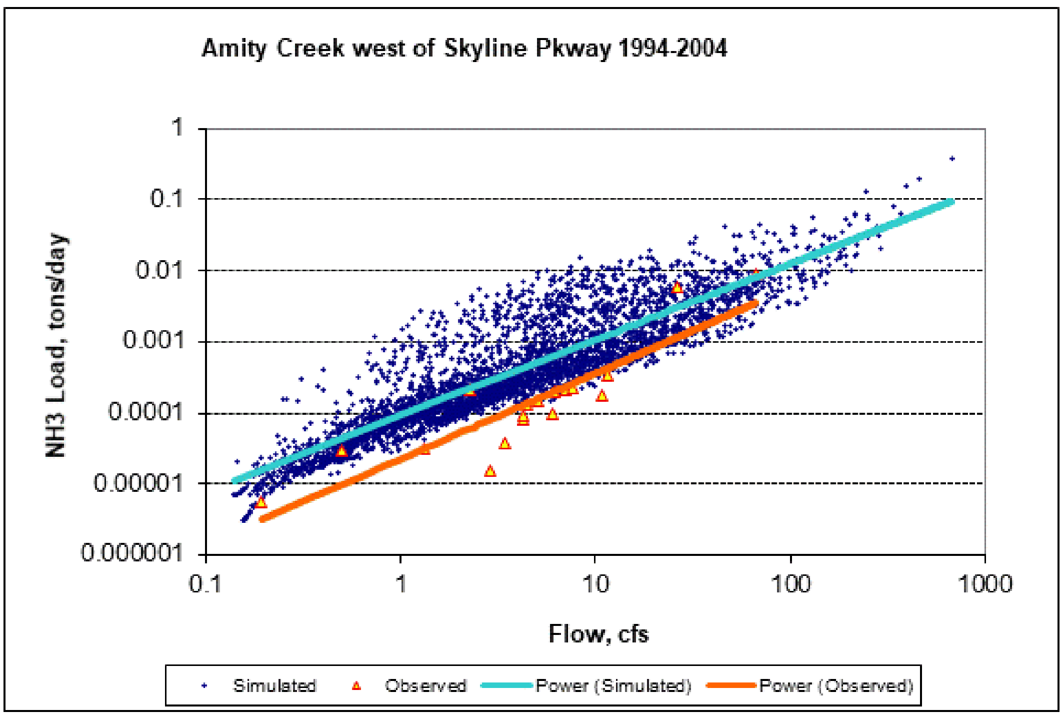


Figure E-246. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Amity Creek west of Skyline Pkway (validation period)

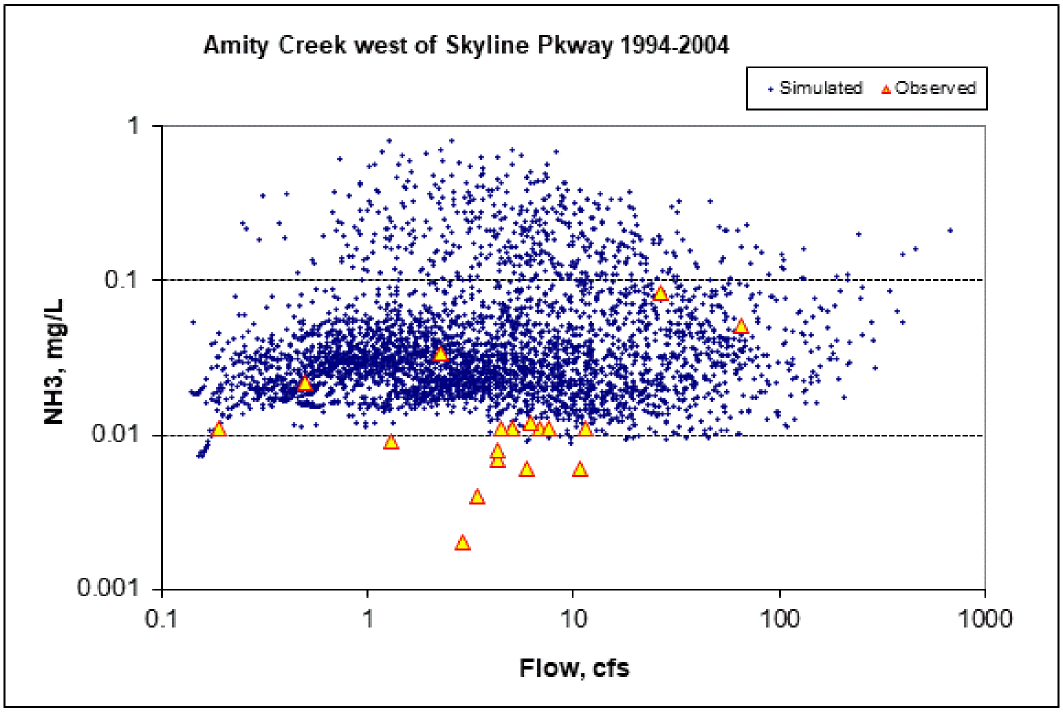
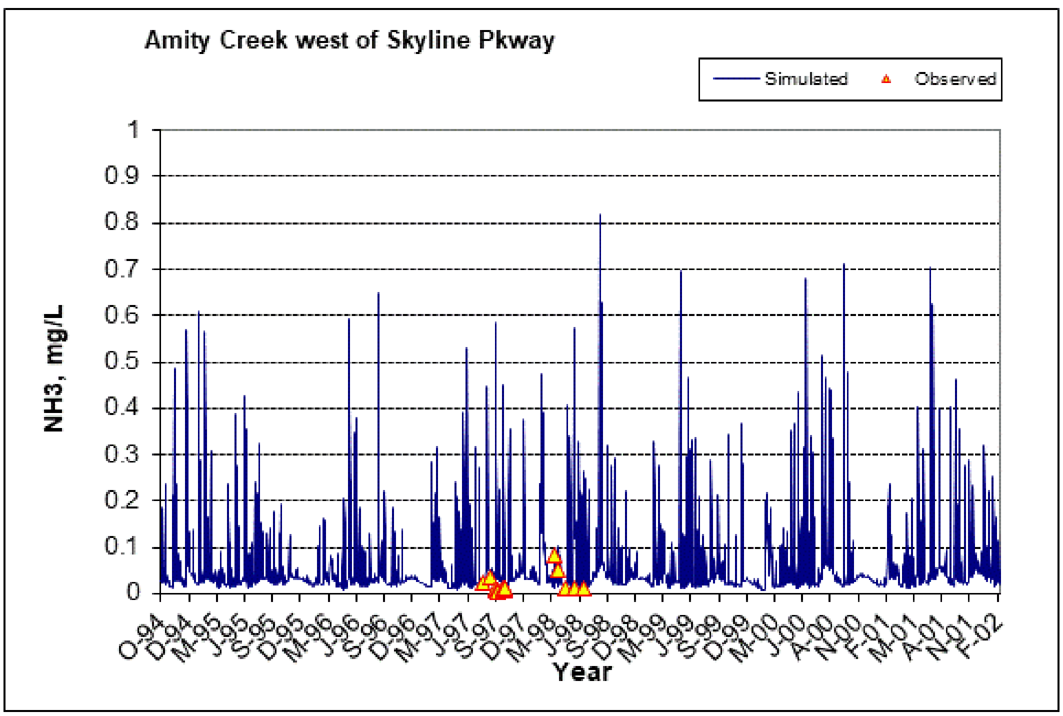
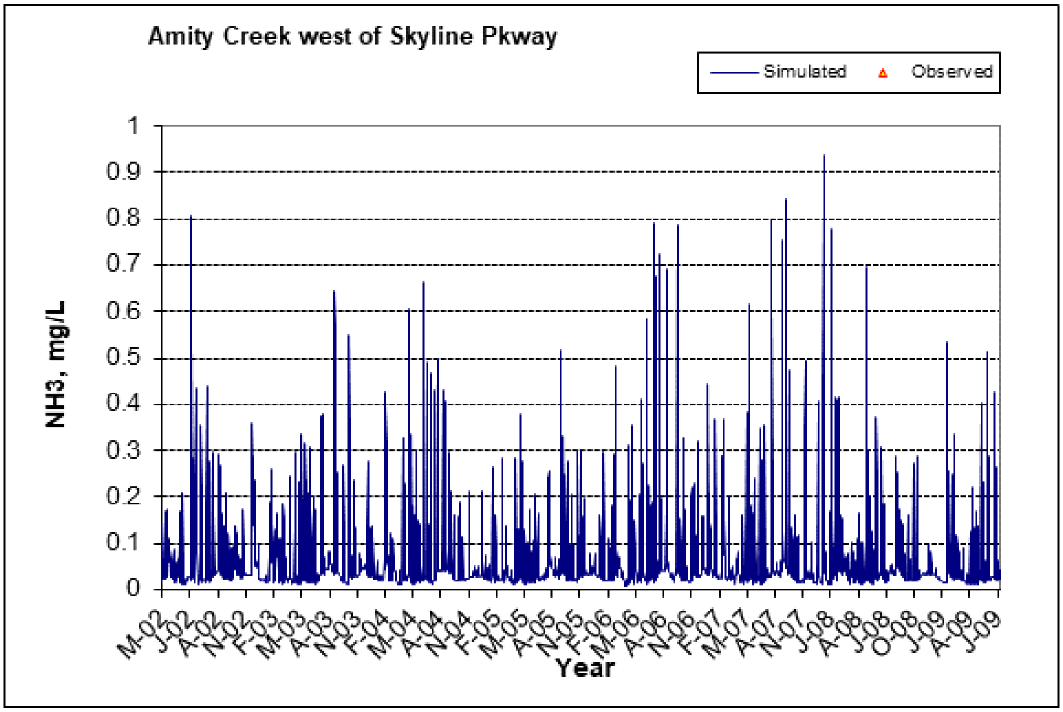


Figure E-247. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Amity Creek west of Skyline Pkway (validation period)





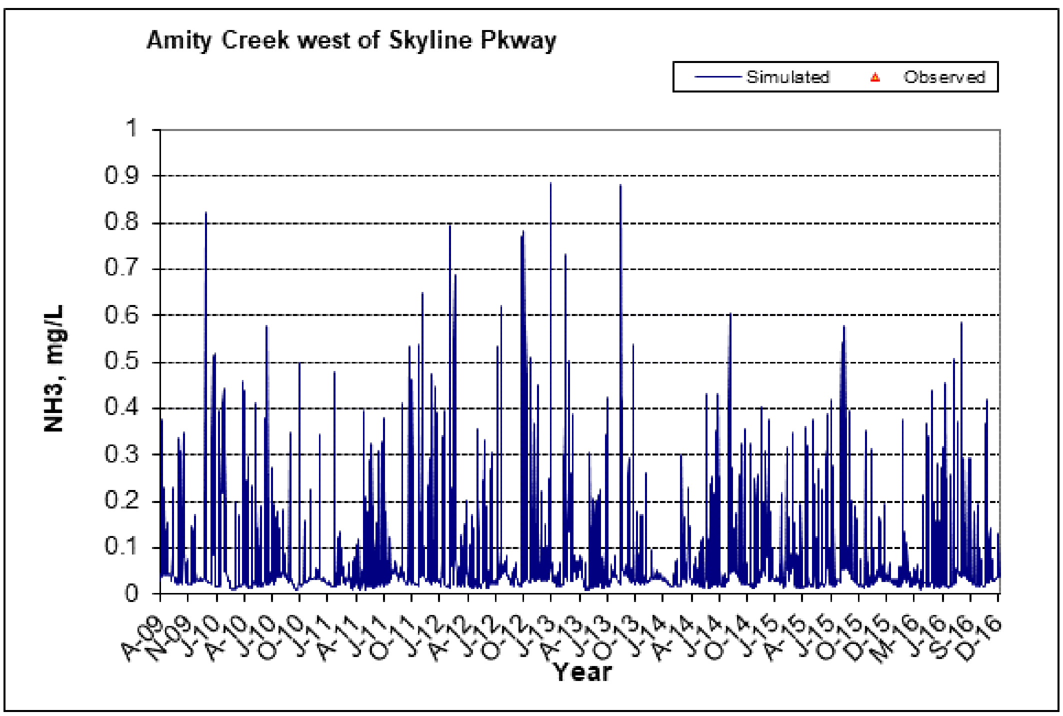


Figure E-248. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Amity Creek west of Skyline Pkway

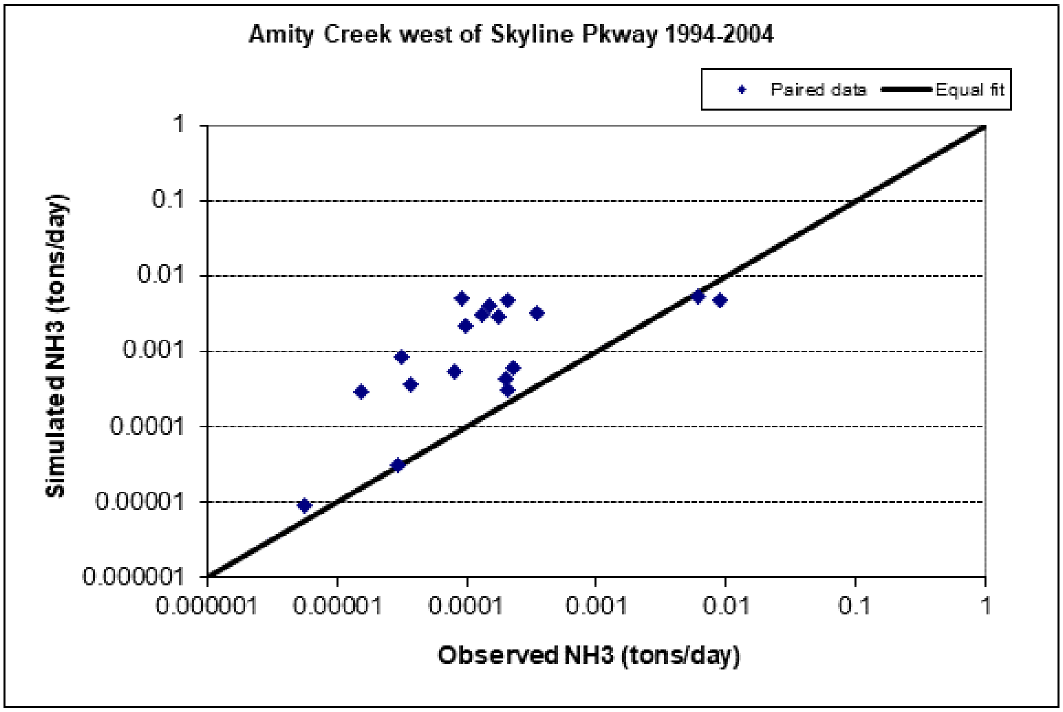


Figure E-249. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Amity Creek west of Skyline Pkway (validation period)

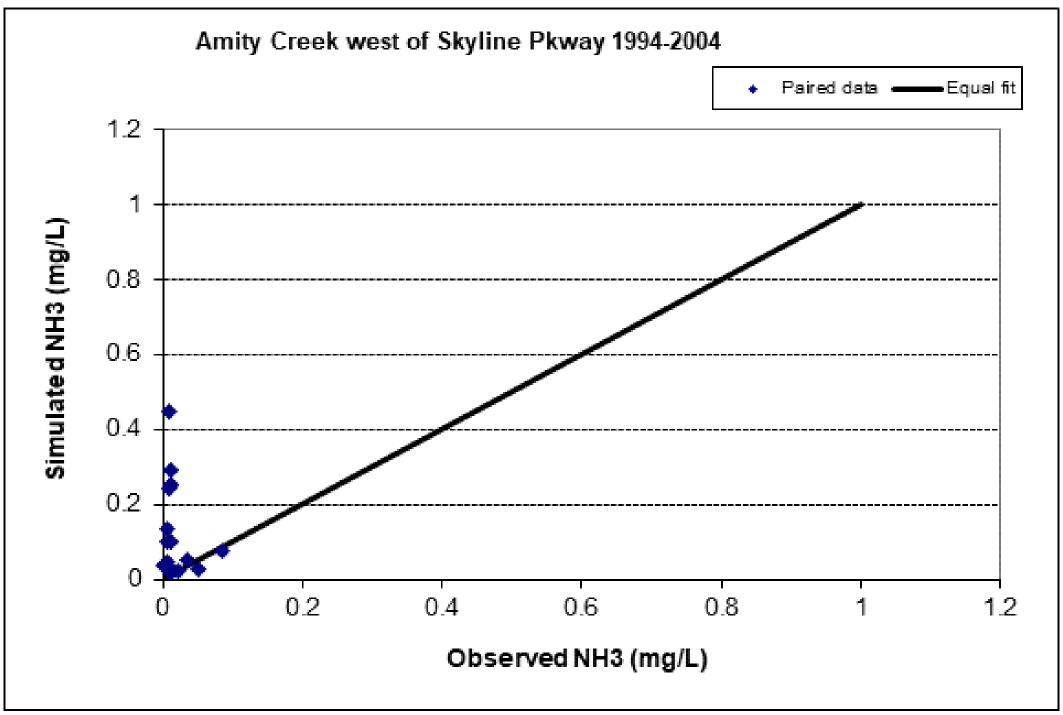


Figure E-250. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Amity Creek west of Skyline Pkway (validation period)

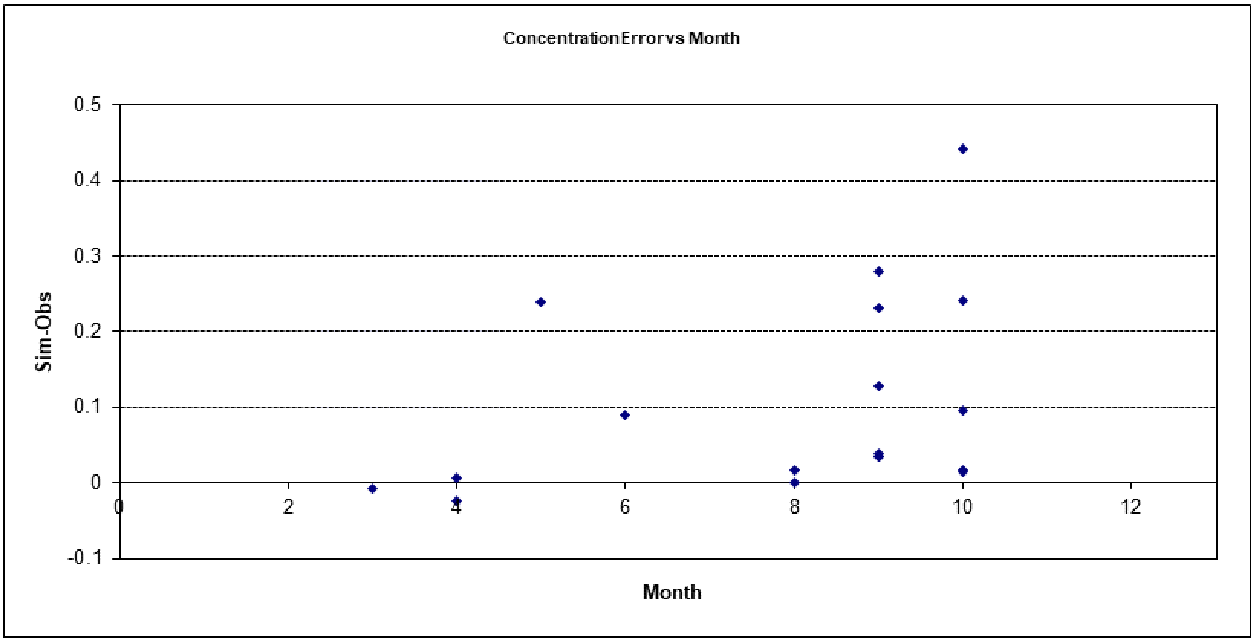


Figure E-251. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Amity Creek west of Skyline Pkway

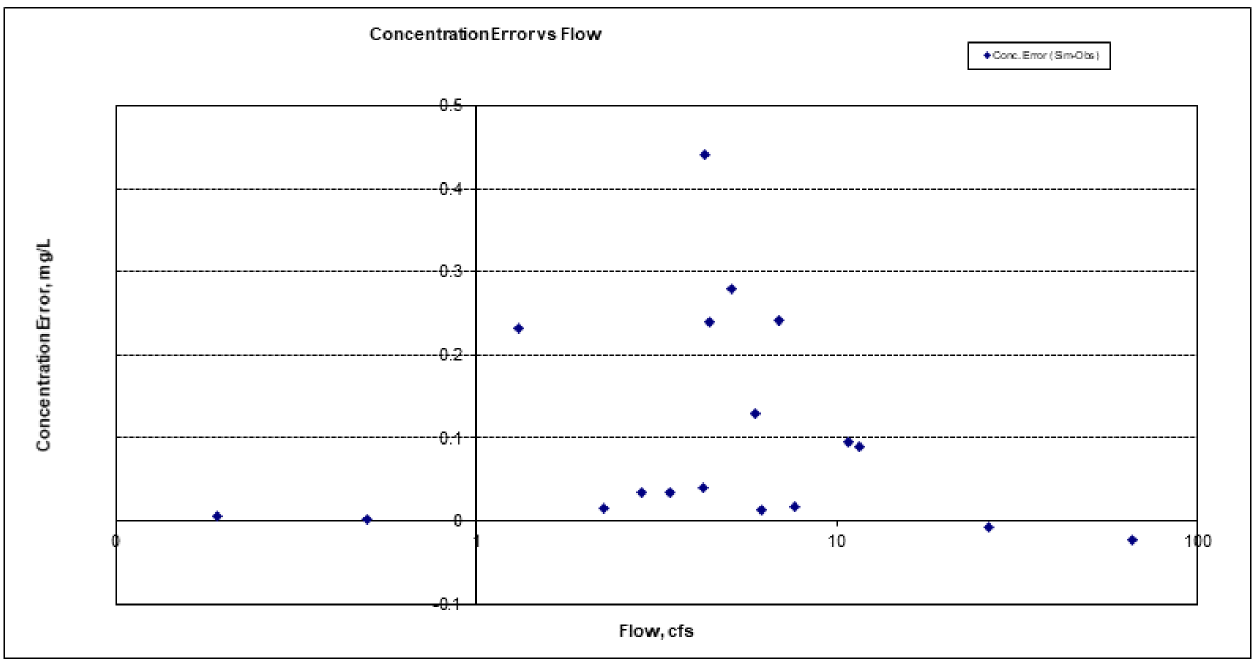


Figure E-252. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Amity Creek west of Skyline Pkway

E.4.2 Organic Nitrogen (OrgN)

Table E-29. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	18	ND
Concentration Average Error	16.67%	
Concentration Median Error	32.26%	
Load Average Error	-14.67%	
Load Median Error	3.45%	
Paired t conc	0.62	
Paired t load	0.55	

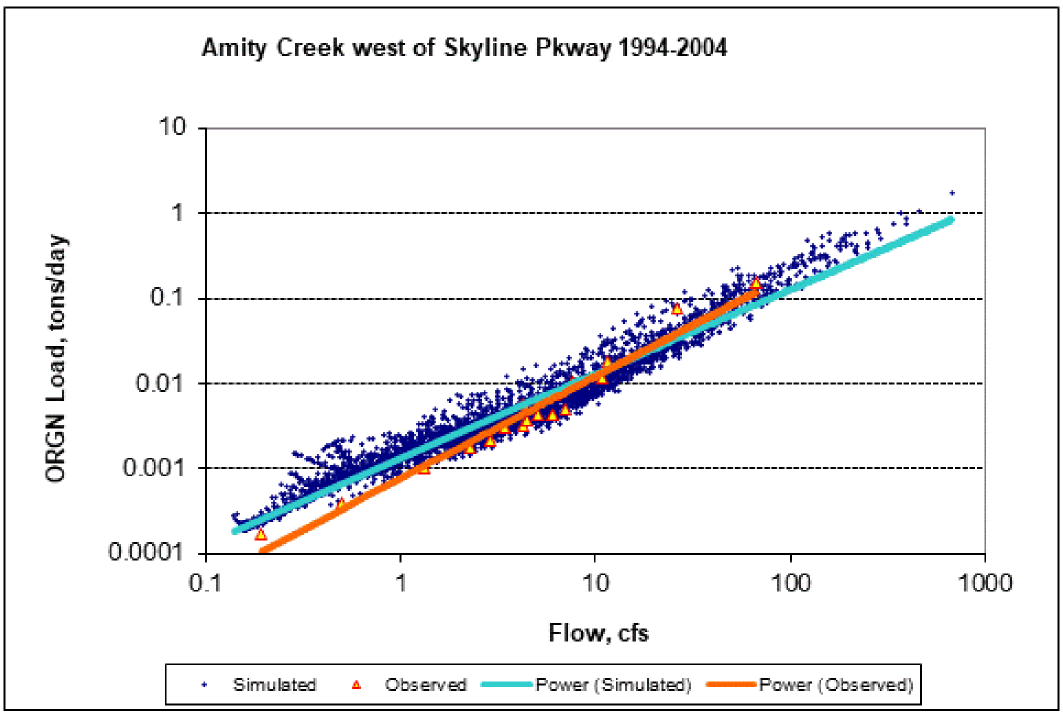


Figure E-253. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Amity Creek west of Skyline Pkway (validation period)

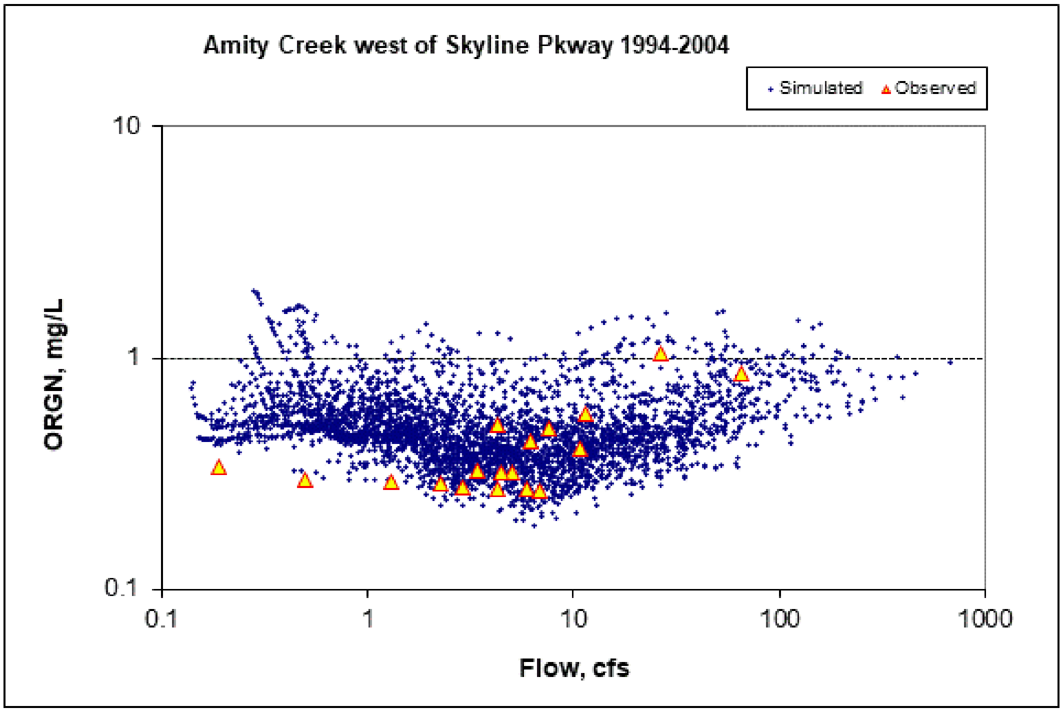
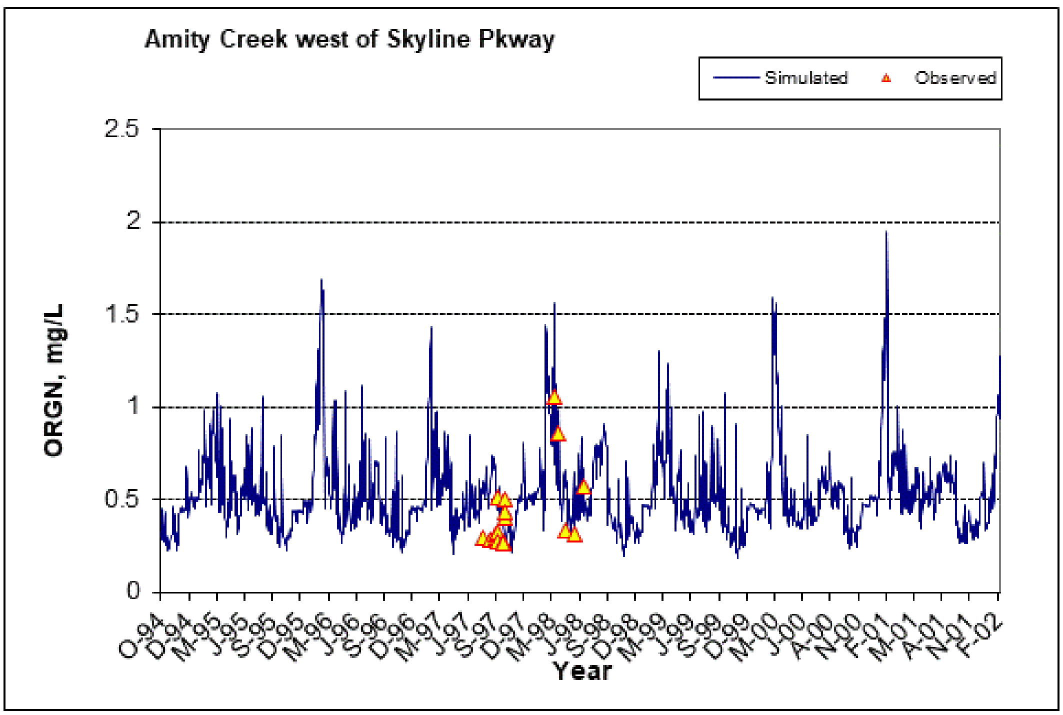
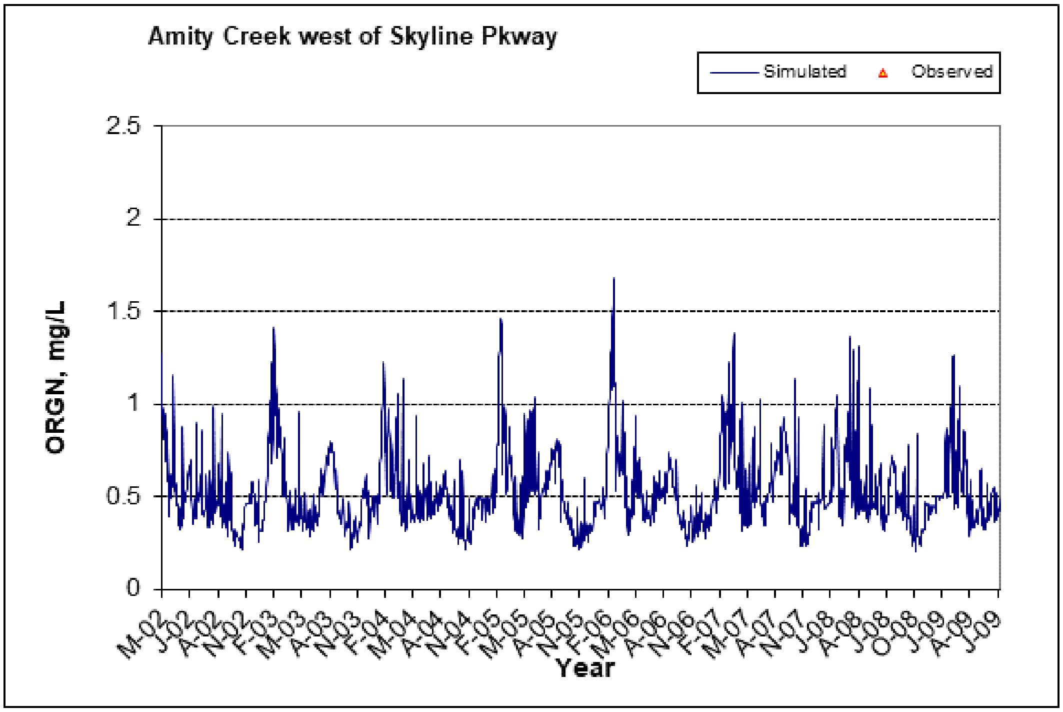


Figure E-254. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Amity Creek west of Skyline Pkway (validation period)





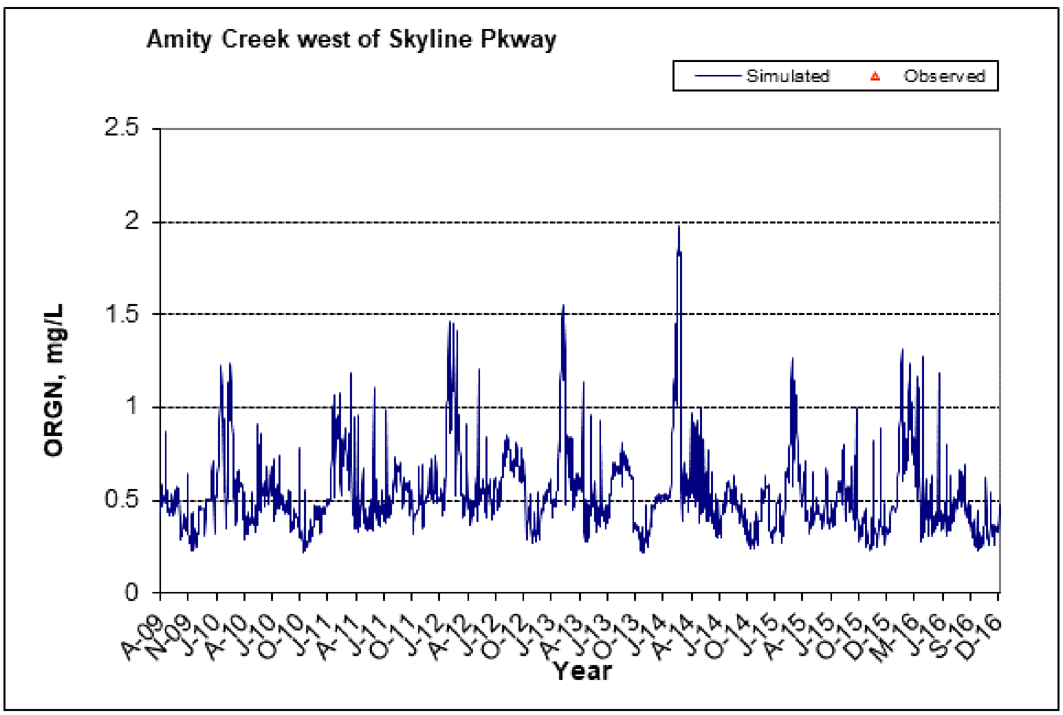


Figure E-255. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Amity Creek west of Skyline Pkway

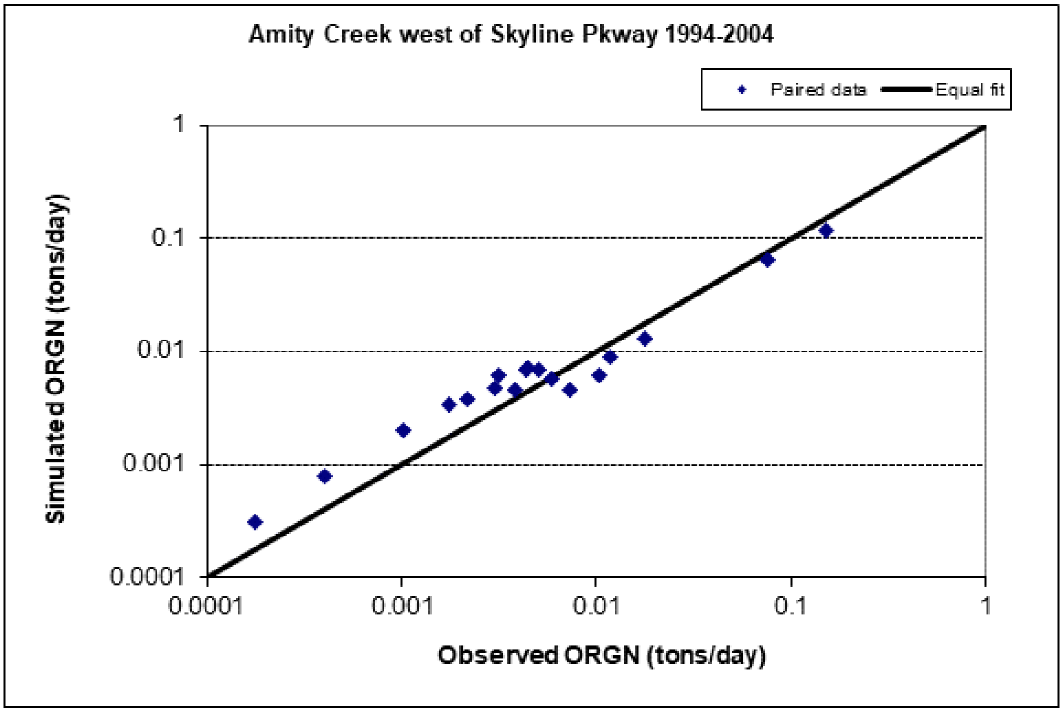


Figure E-256. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Amity Creek west of Skyline Pkway (validation period)

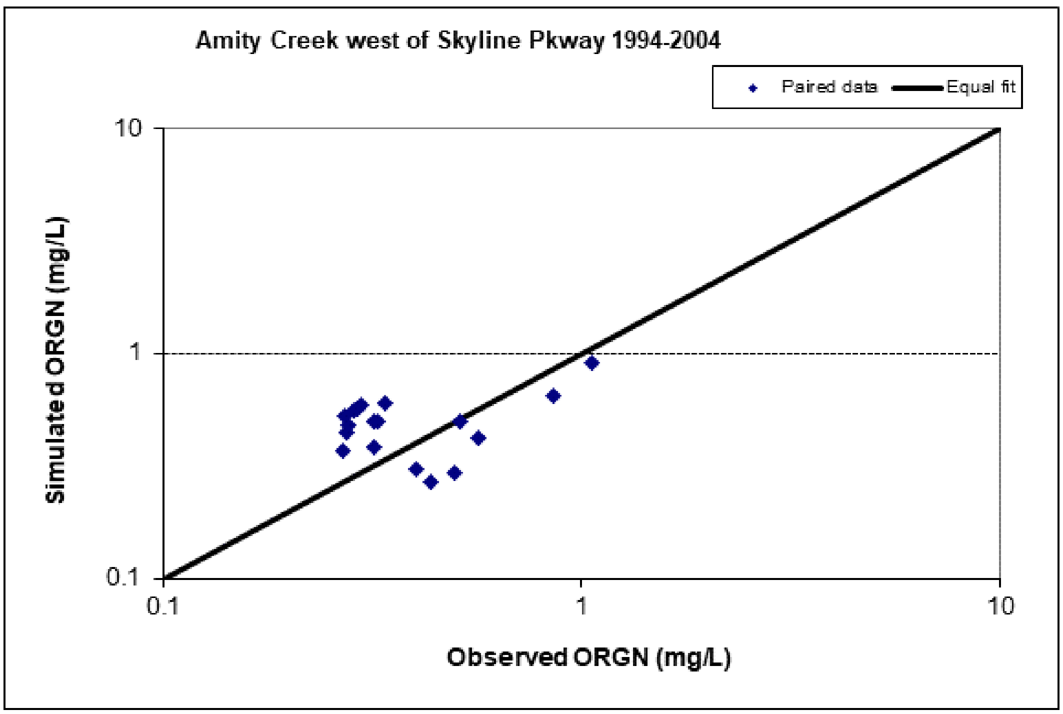


Figure E-257. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Amity Creek west of Skyline Pkway (validation period)

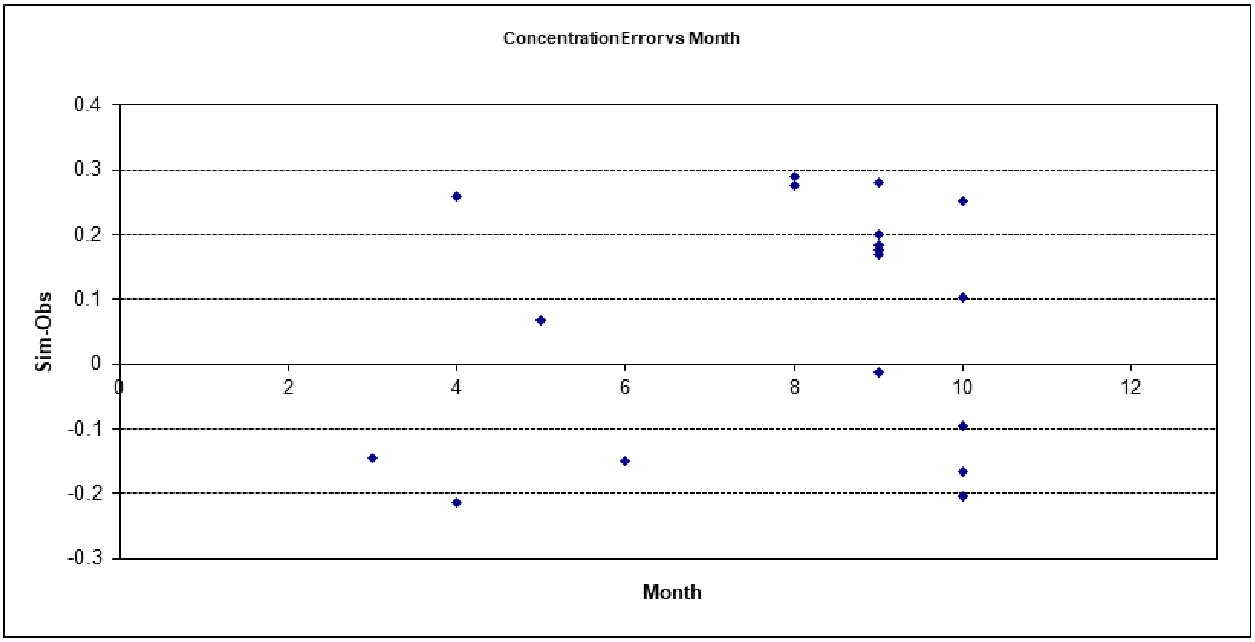


Figure E-258. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at Amity Creek west of Skyline Pkway

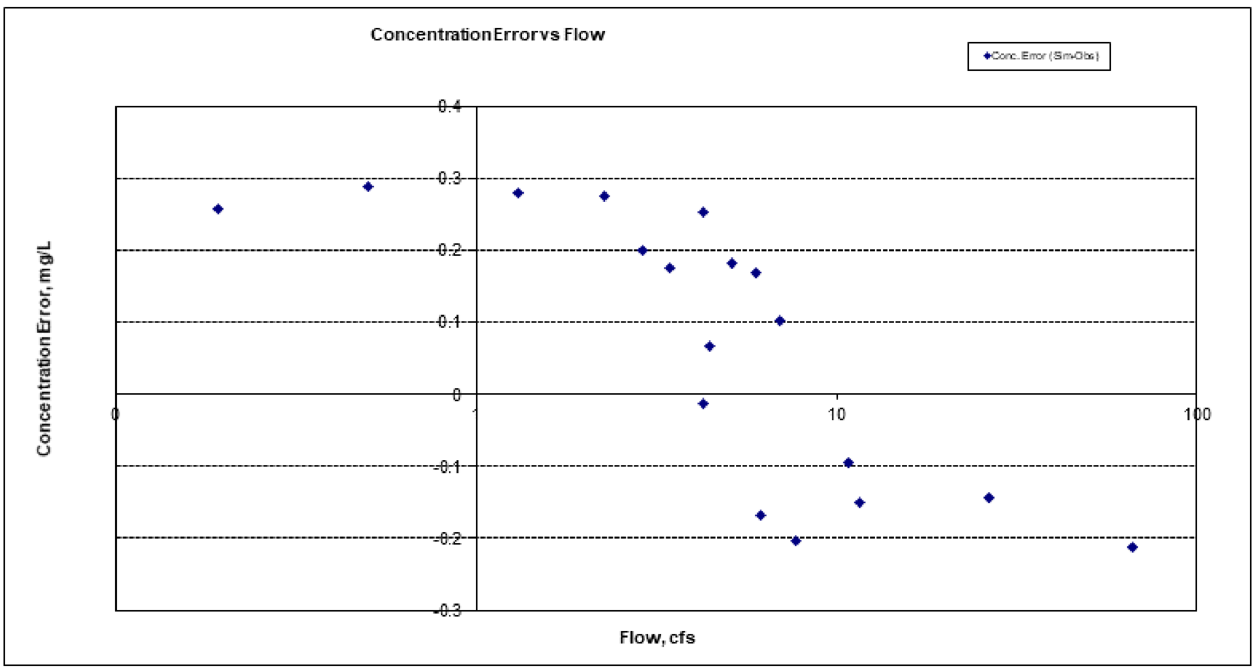


Figure E-259. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at Amity Creek west of Skyline Pkway

E.4.3 Total Kjeldahl Nitrogen (TKN)

Table E-30. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	18	ND
Concentration Average Error	39.74%	
Concentration Median Error	56.79%	
Load Average Error	-7.27%	
Load Median Error	5.95%	
Paired t conc	0.05	
Paired t load	0.61	

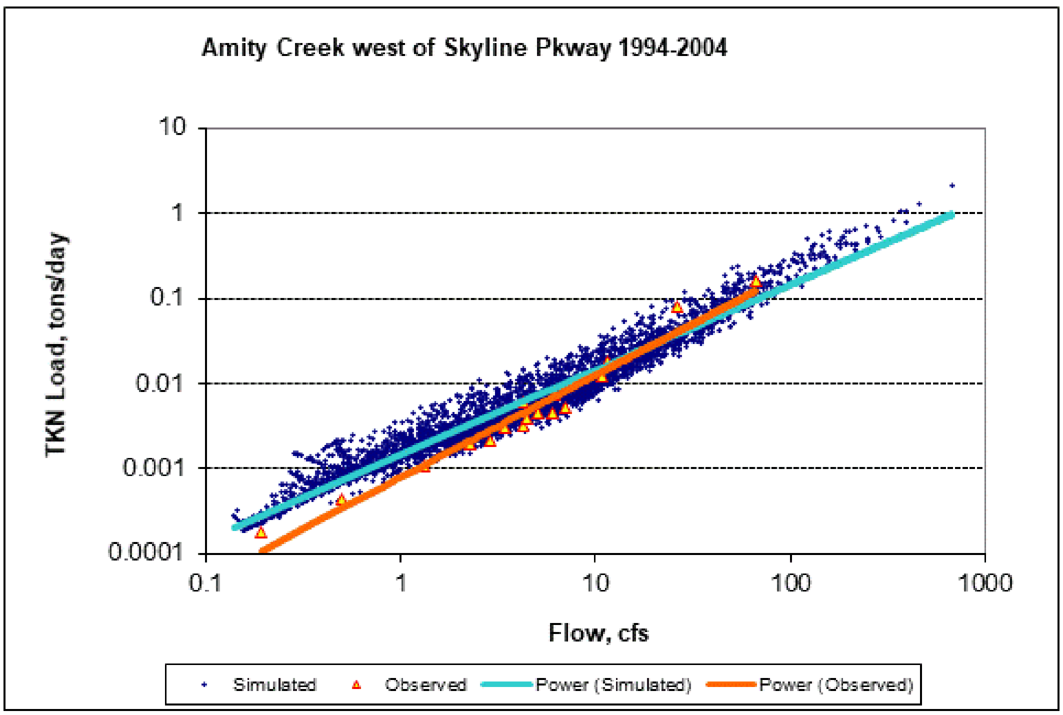


Figure E-260. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Amity Creek west of Skyline Pkway (validation period)

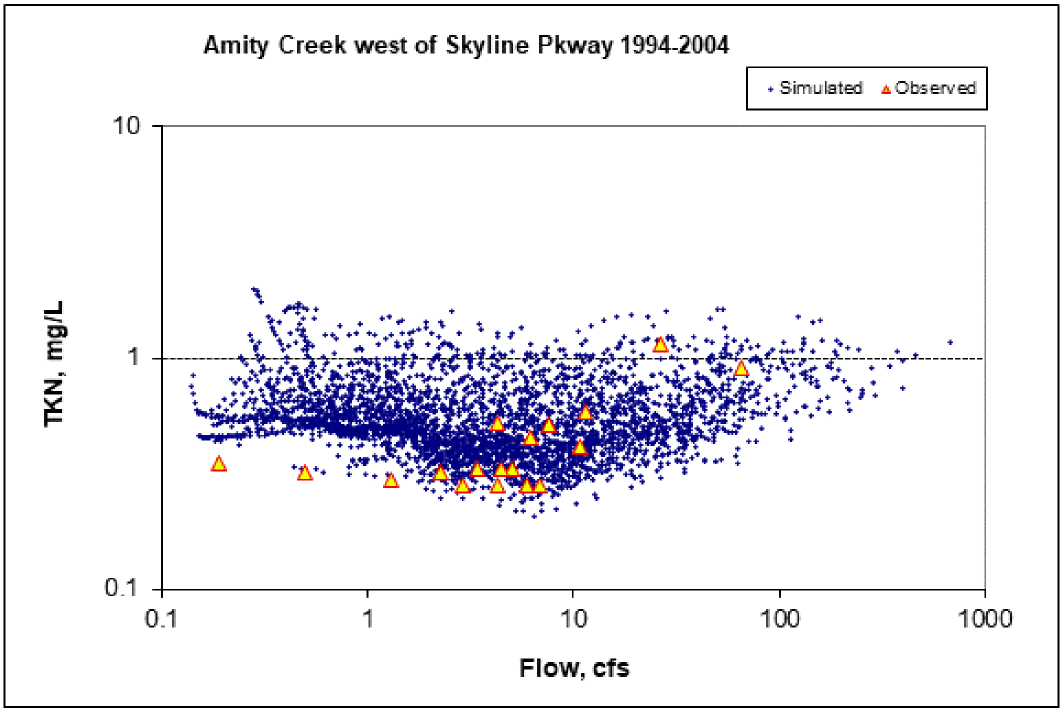
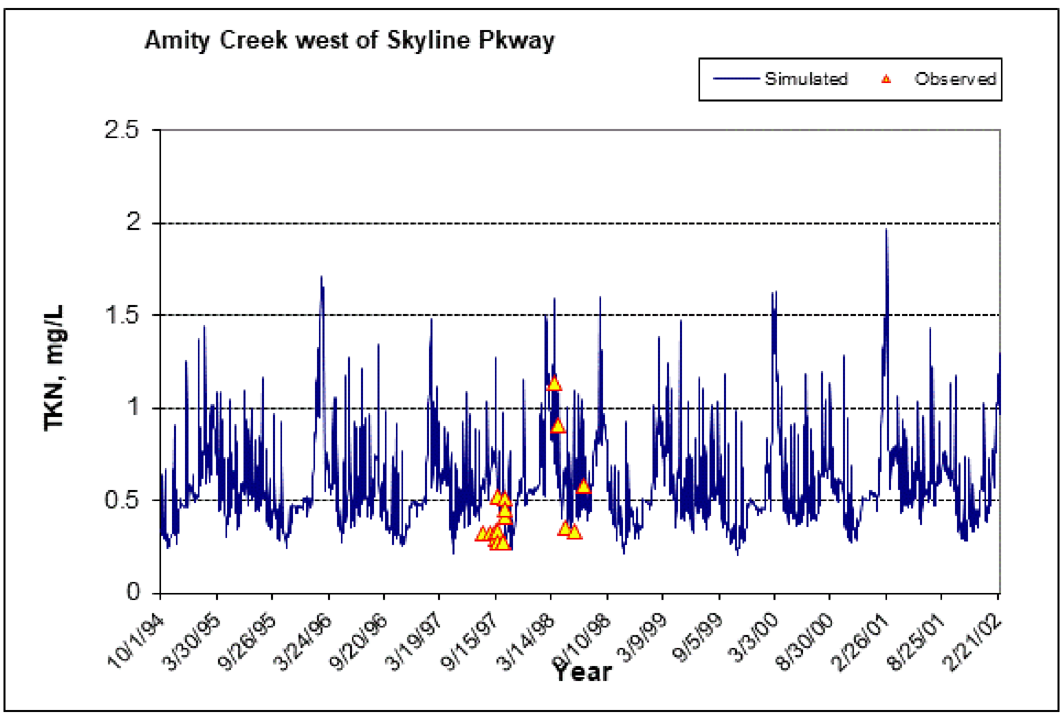
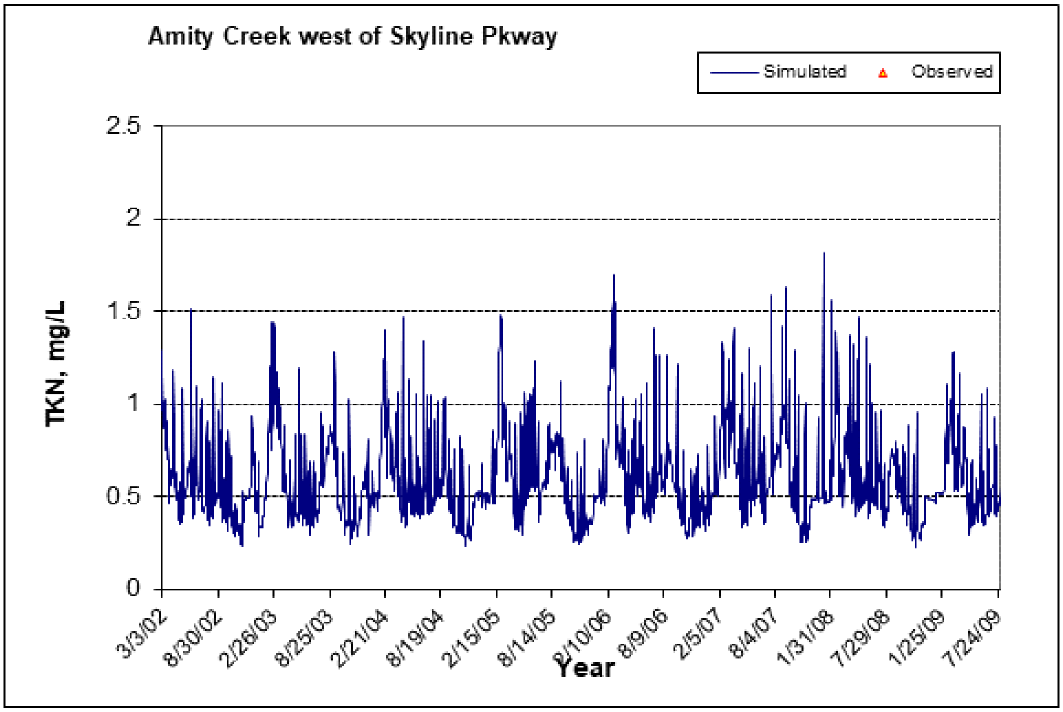


Figure E-261. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Amity Creek west of Skyline Pkway (validation period)





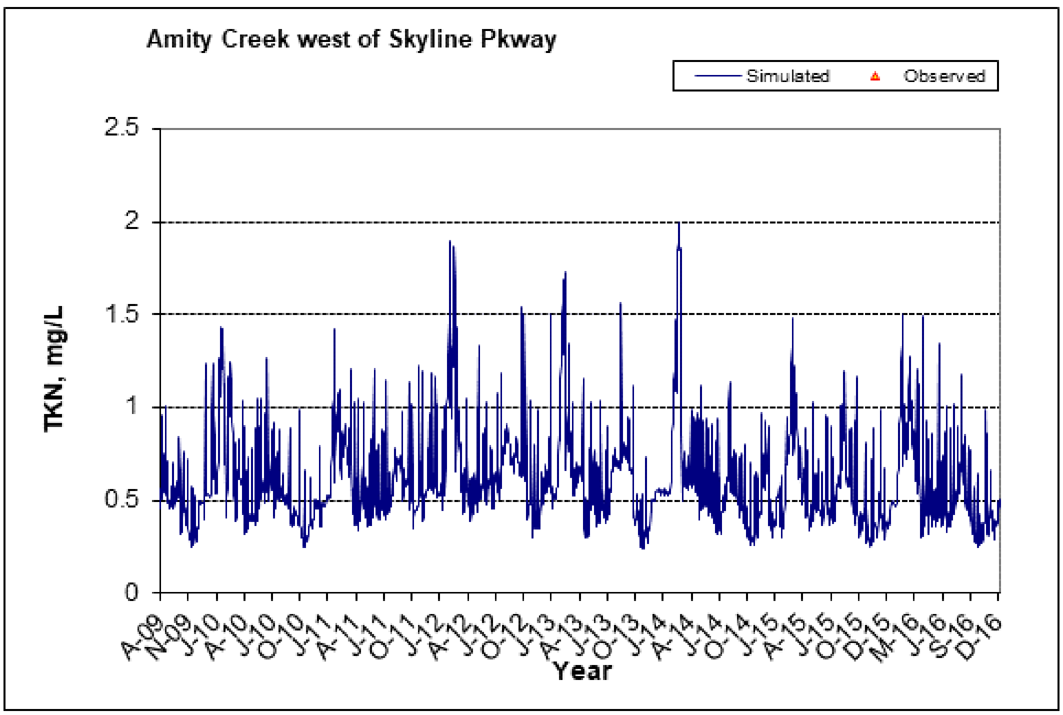


Figure E-262. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Amity Creek west of Skyline Pkway

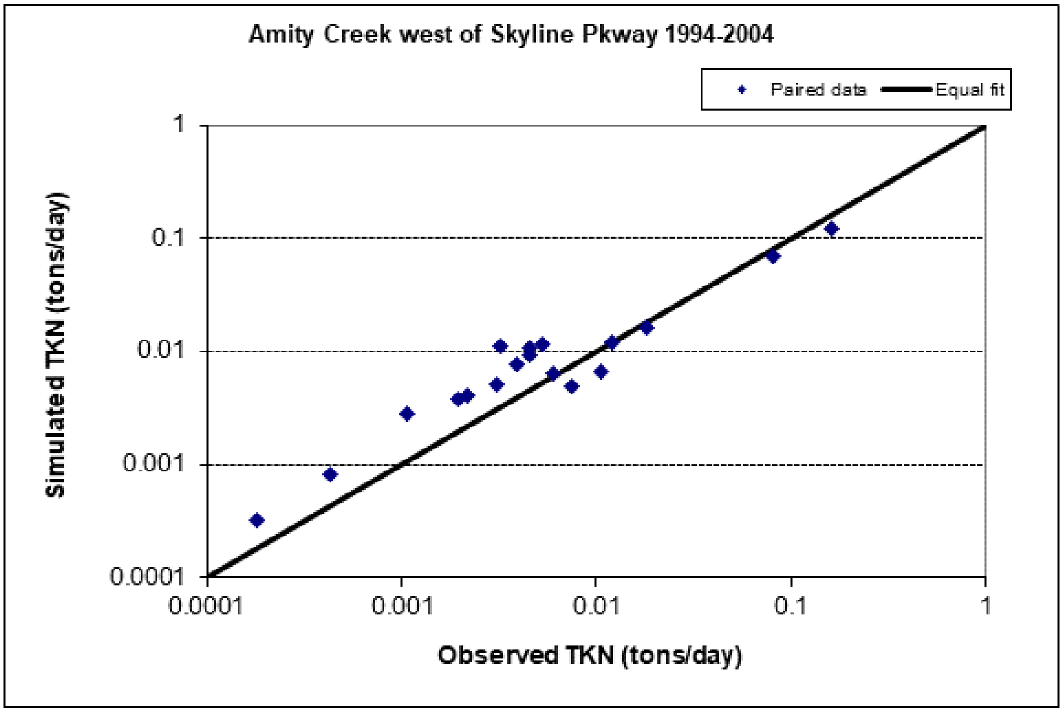


Figure E-263. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Amity Creek west of Skyline Pkway (validation period)

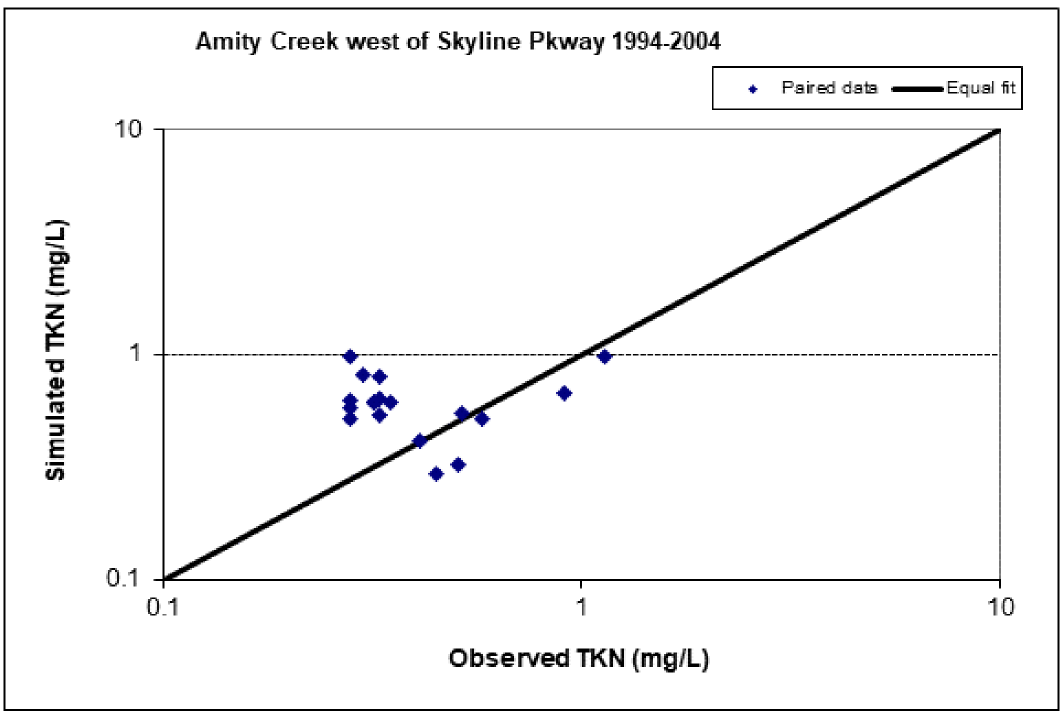


Figure E-264. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Amity Creek west of Skyline Pkway (validation period)

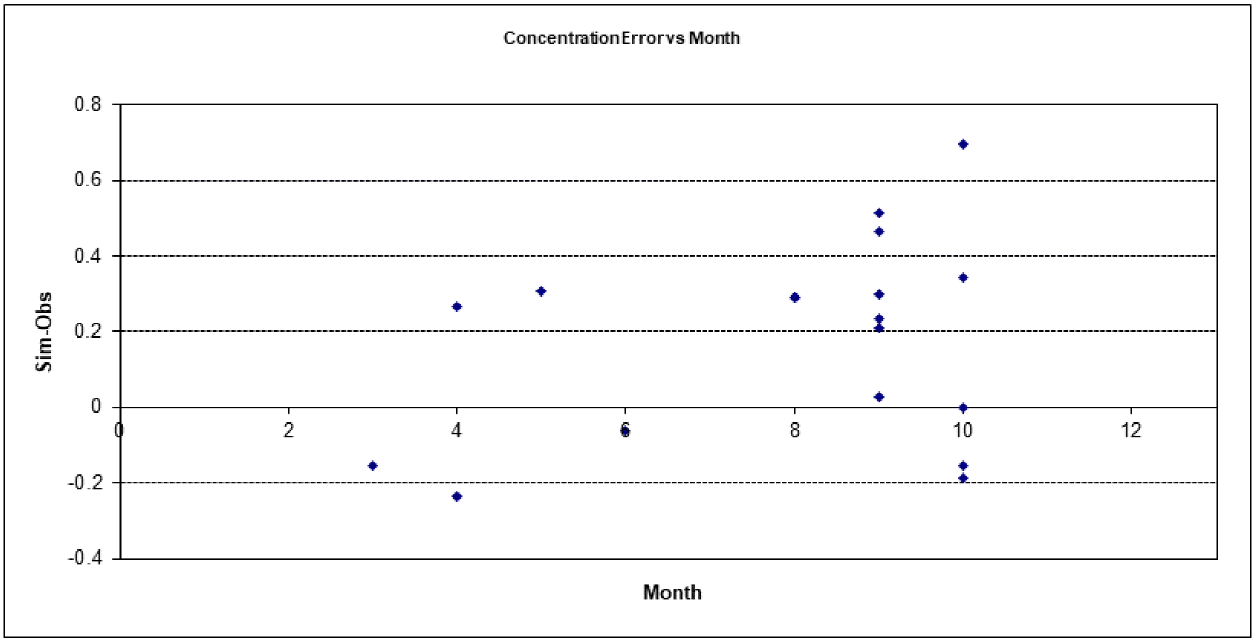


Figure E-265. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at Amity Creek west of Skyline Pkway

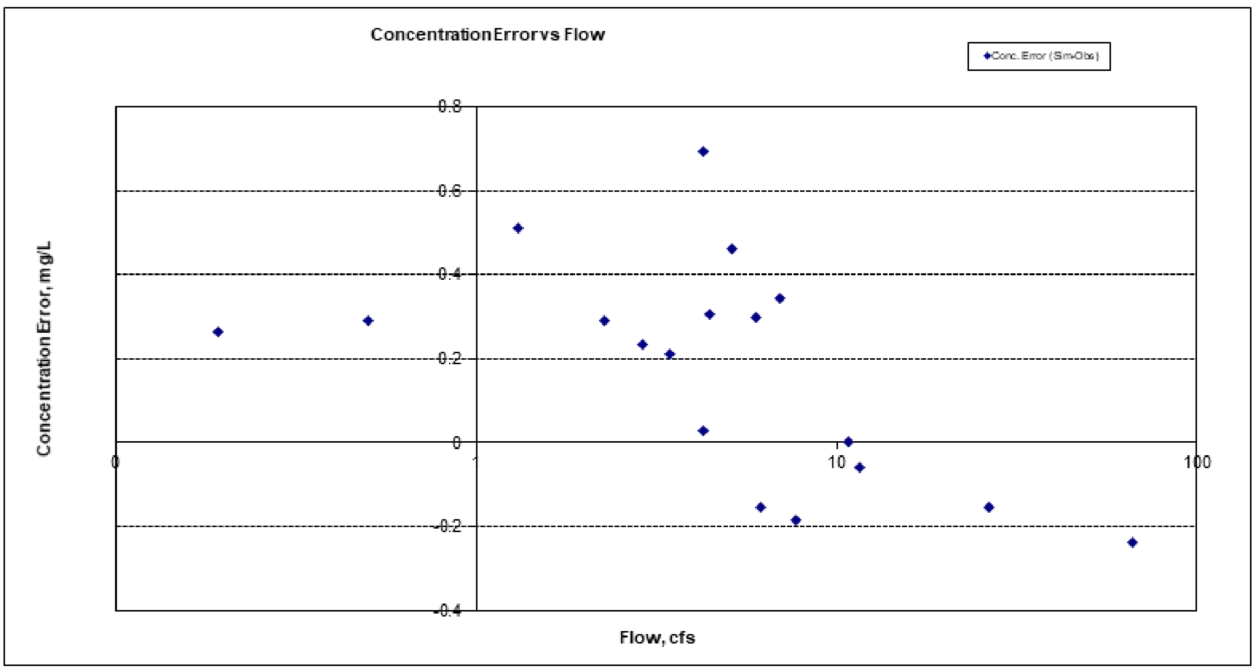


Figure E-266. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at Amity Creek west of Skyline Pkway

E.4.4 Nitrite+ Nitrate Nitrogen (NOx)

Table E-31. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	16	ND
Concentration Average Error	114.42%	
Concentration Median Error	10.67%	
Load Average Error	-6.87%	
Load Median Error	0.36%	
Paired t conc	0.02	
Paired t load	0.60	

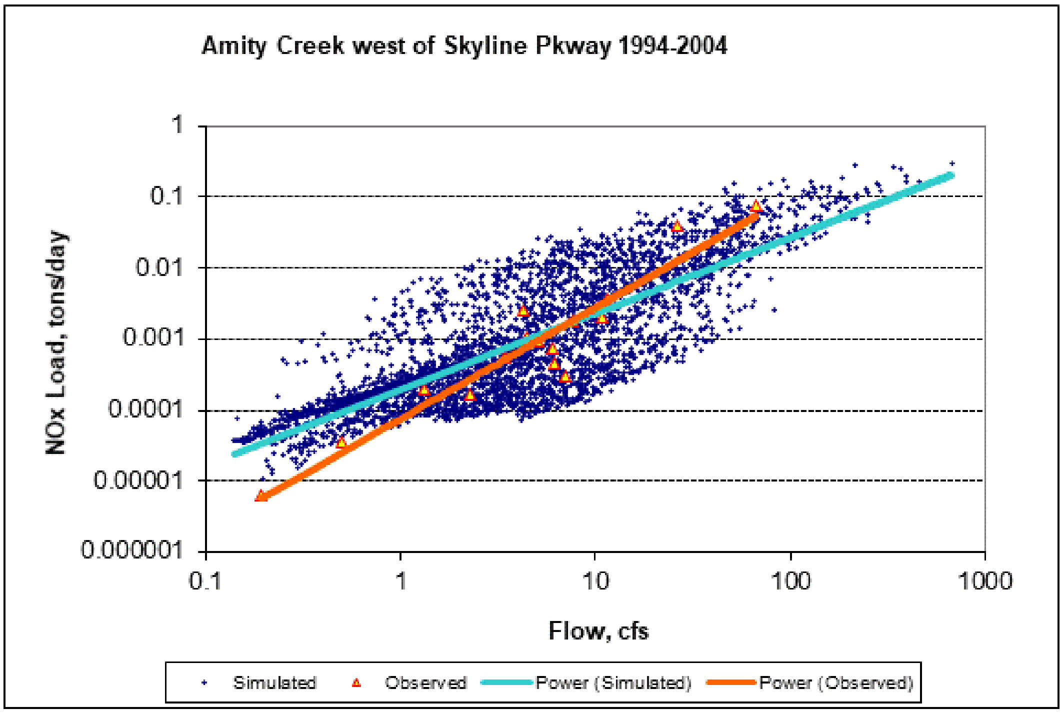


Figure E-267. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Amity Creek west of Skyline Pkway (validation period)

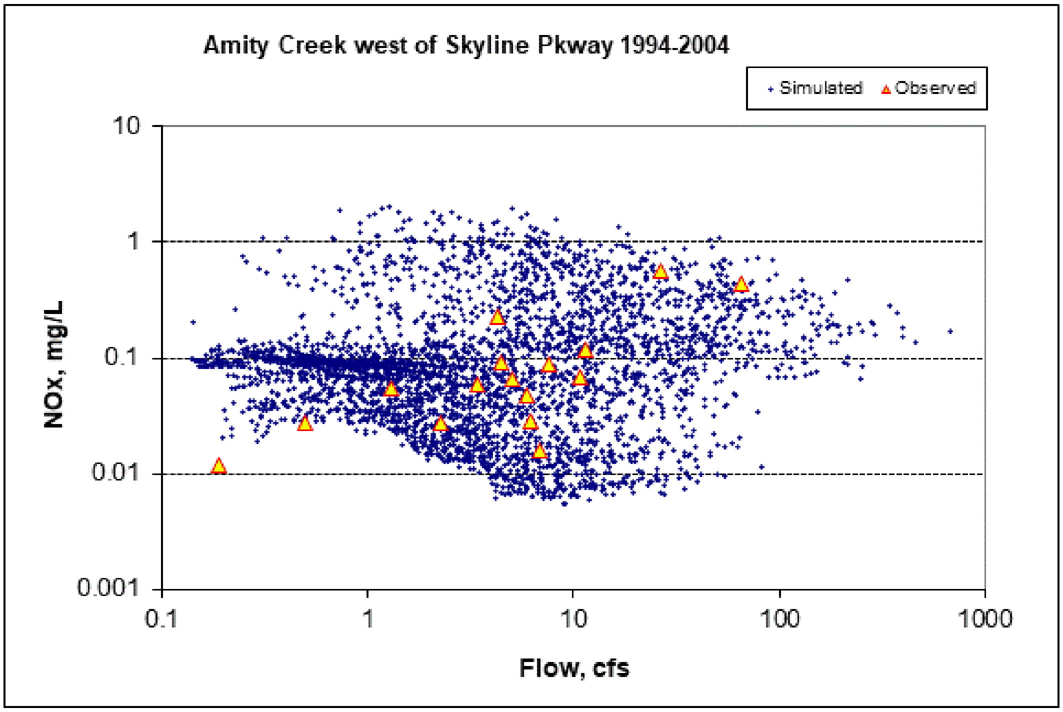
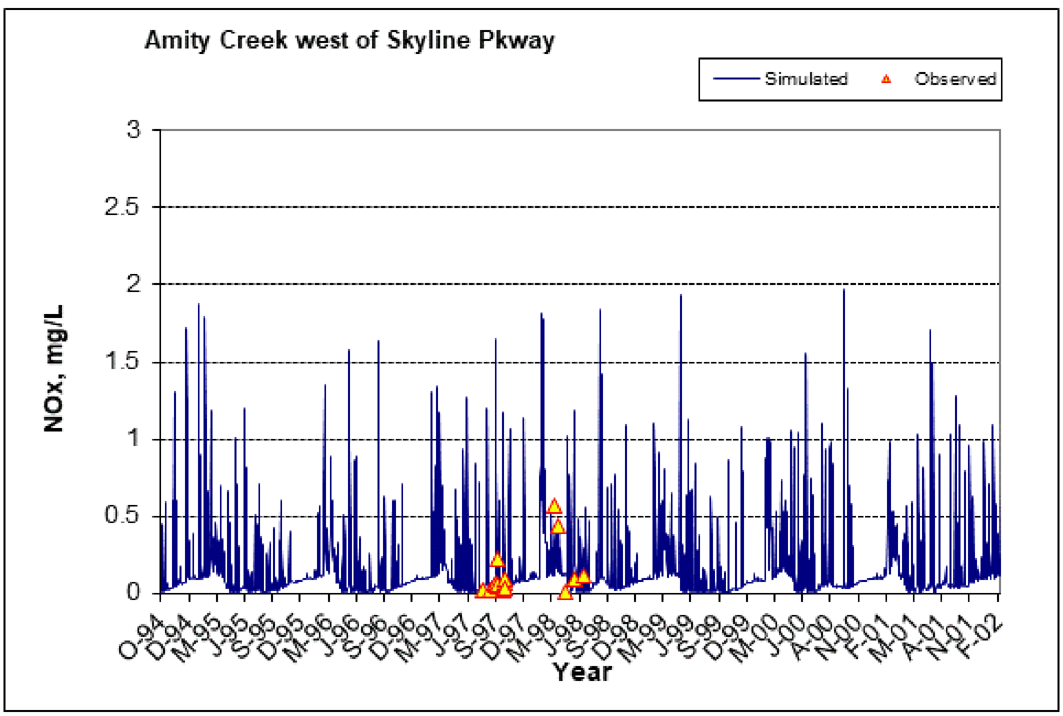
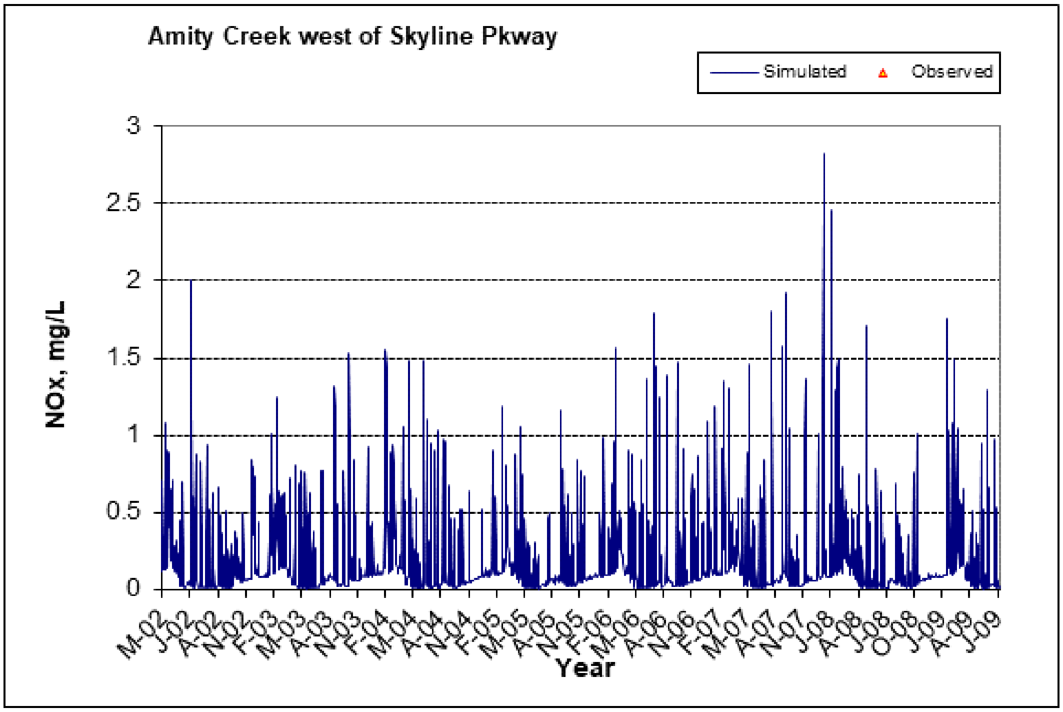


Figure E-268. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Amity Creek west of Skyline Pkway (validation period)





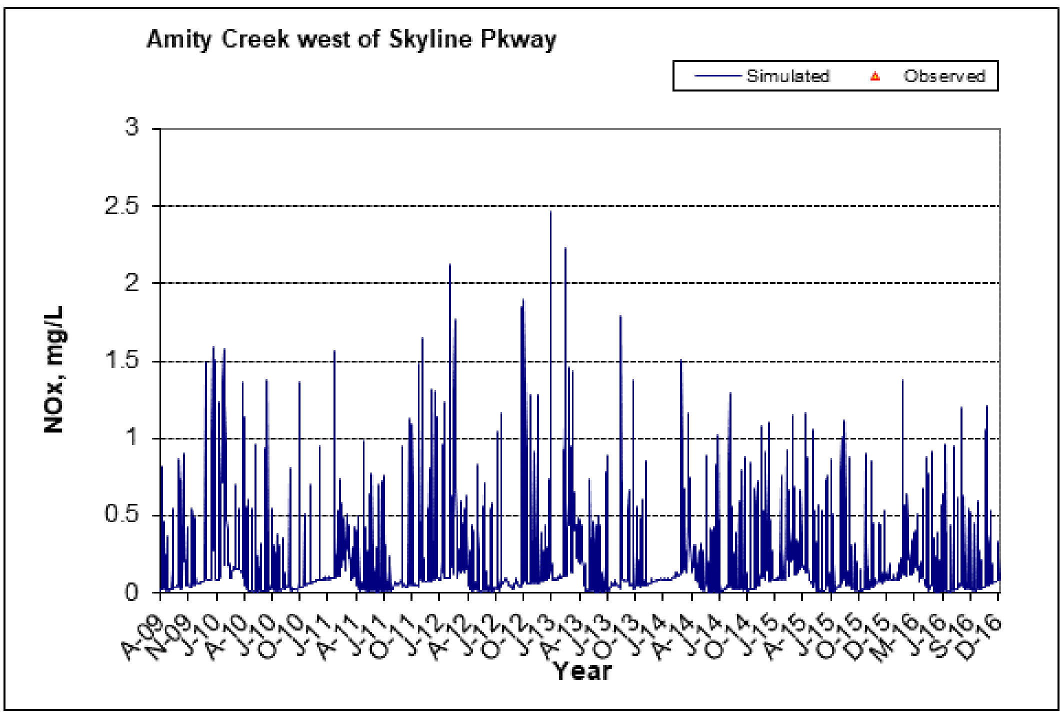


Figure E-269. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Amity Creek west of Skyline Pkway

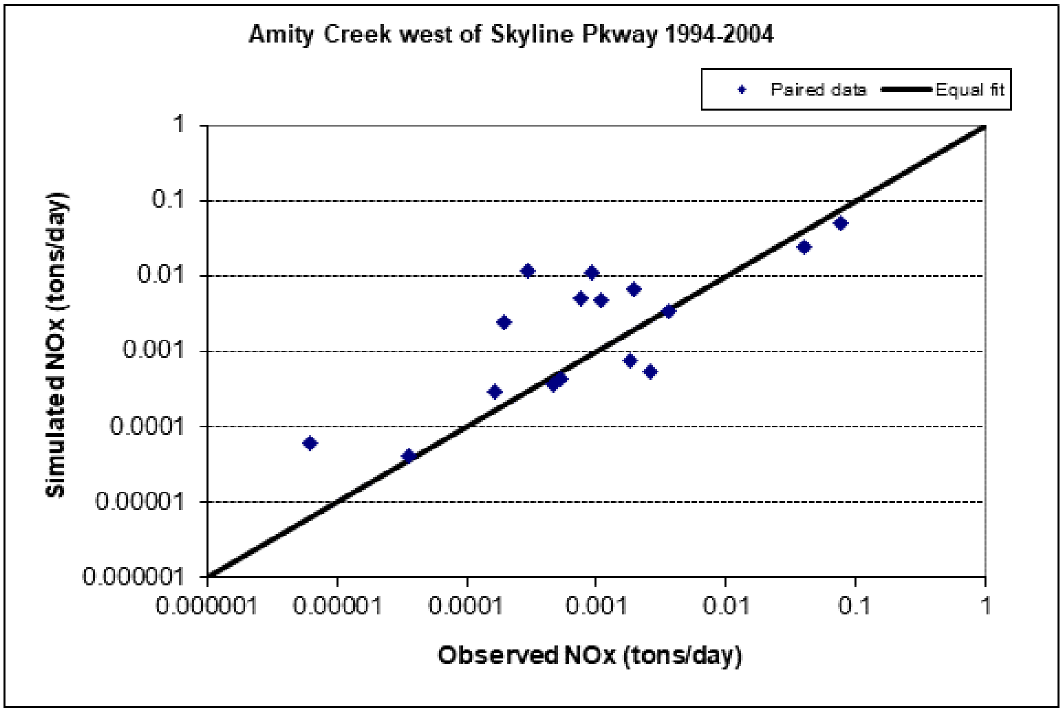


Figure E-270. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Amity Creek west of Skyline Pkway (validation period)

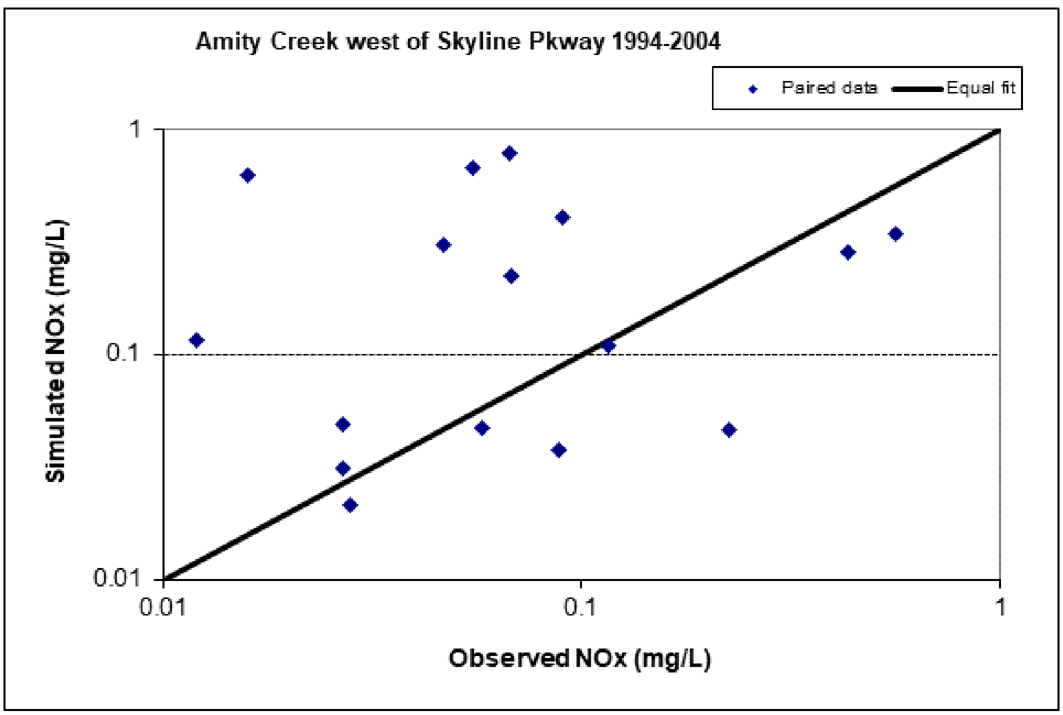


Figure E-271. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Amity Creek west of Skyline Pkway (validation period)

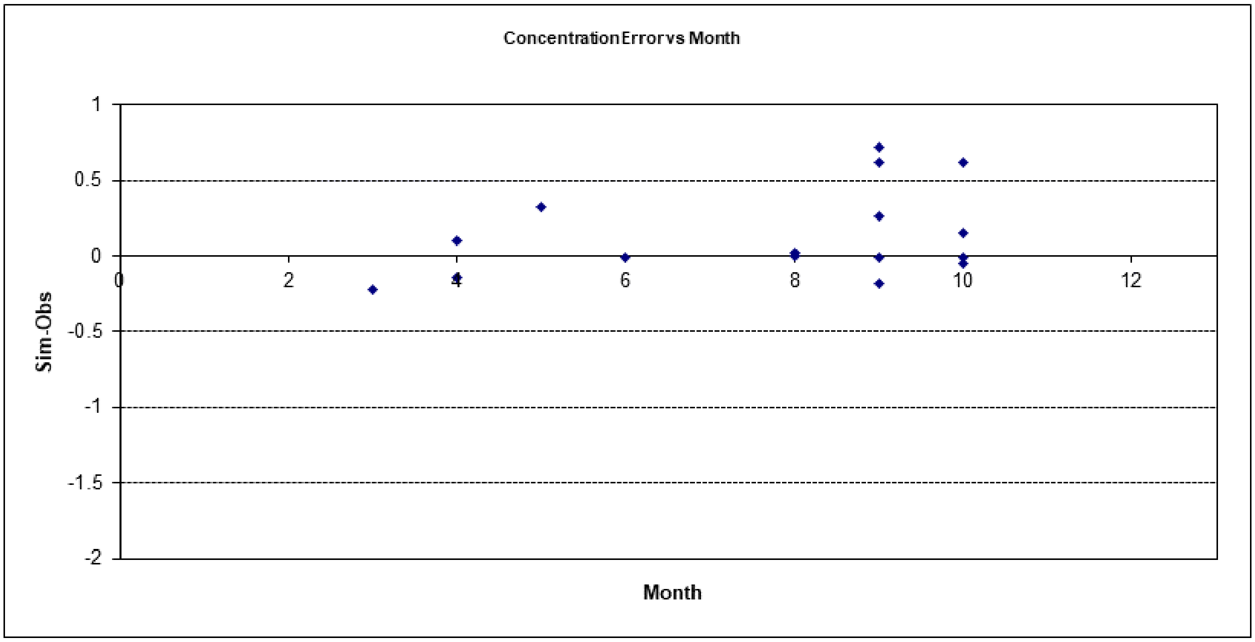


Figure E-272. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Amity Creek west of Skyline Pkway

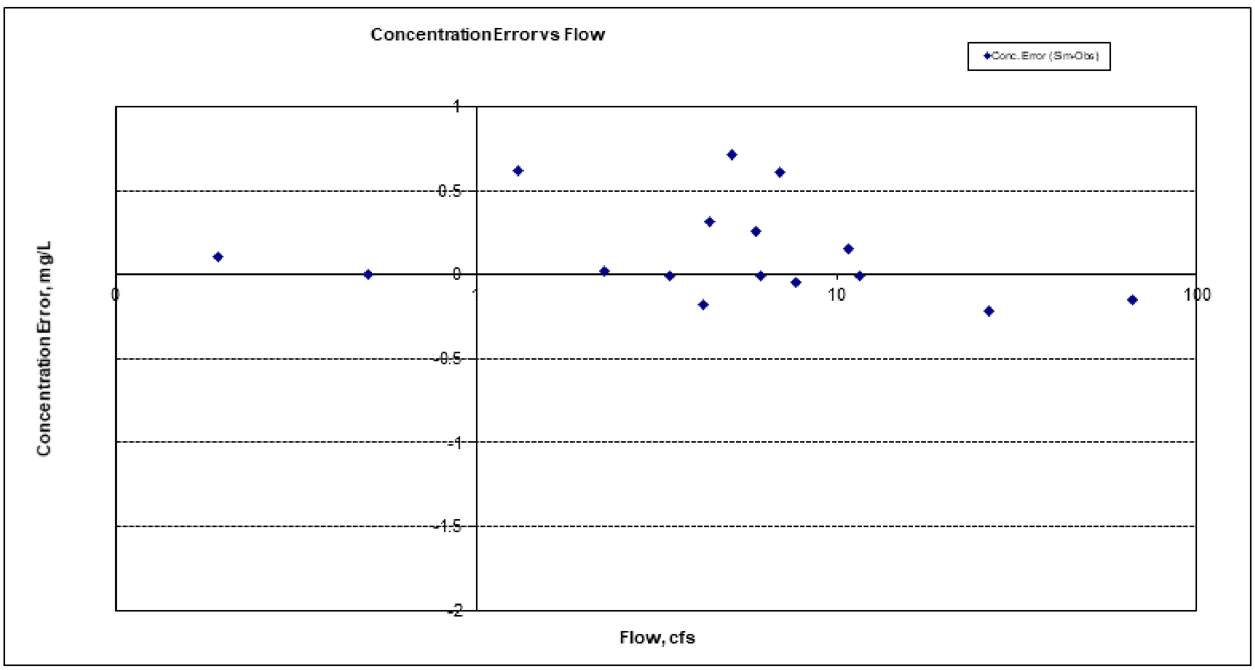


Figure E-273. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Amity Creek west of Skyline Pkway

E.4.5 Total Nitrogen (TN)

Table E-32. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	16	ND
Concentration Average Error	47.59%	
Concentration Median Error	42.54%	
Load Average Error	-9.41%	
Load Median Error	3.97%	
Paired t conc	0.06	
Paired t load	0.59	

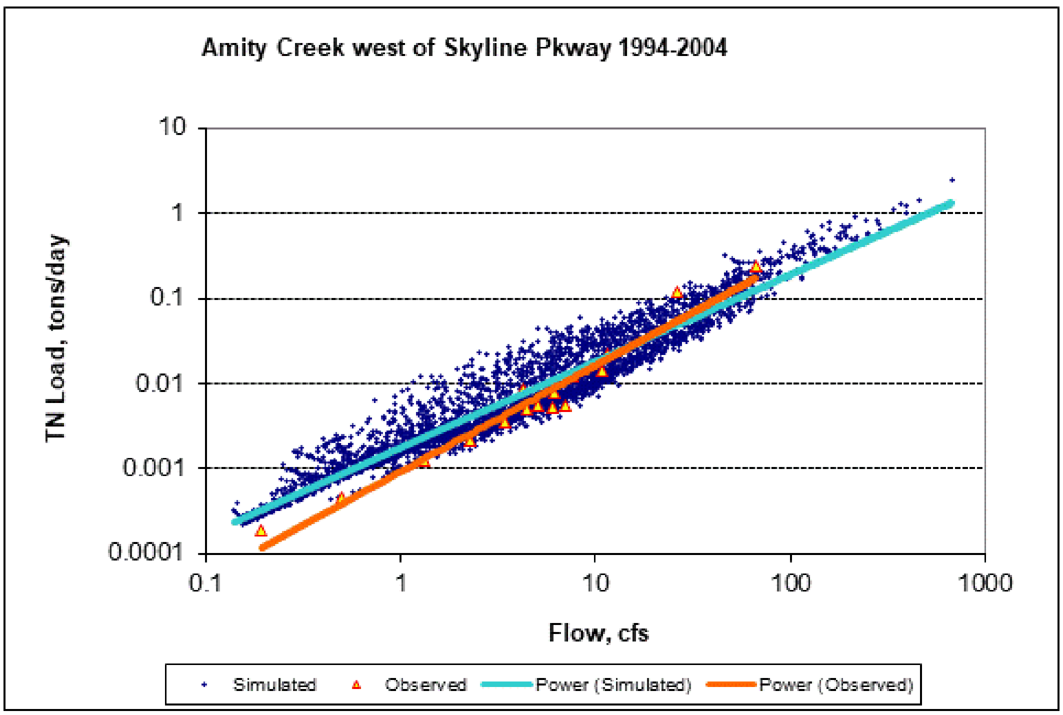


Figure E-274. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Amity Creek west of Skyline Pkway (validation period)

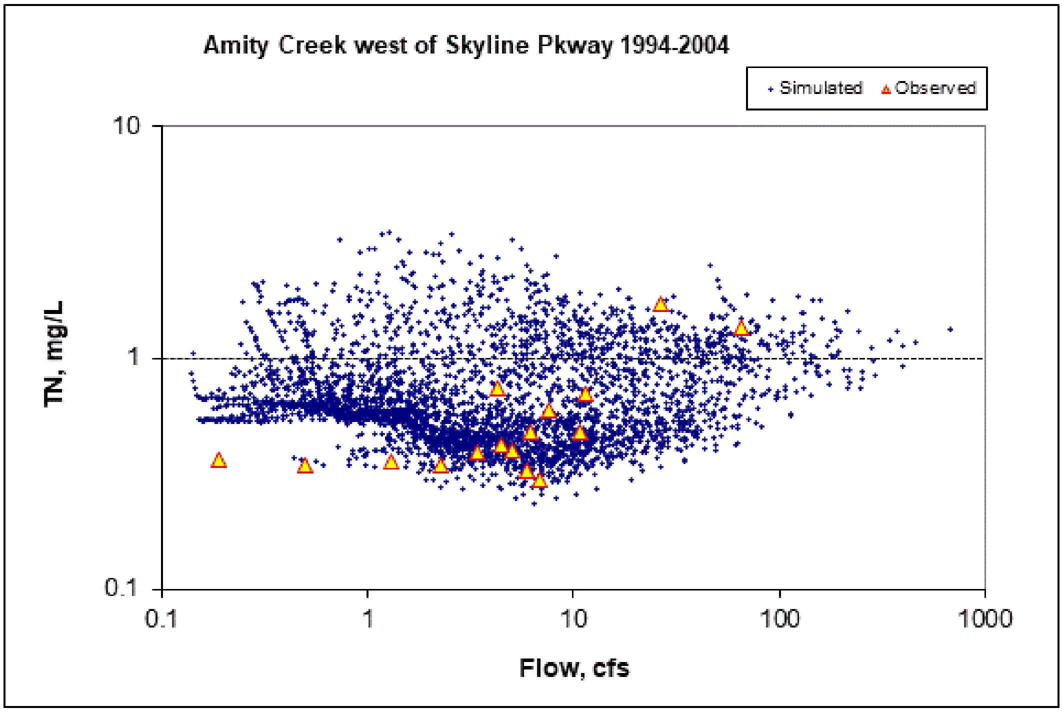
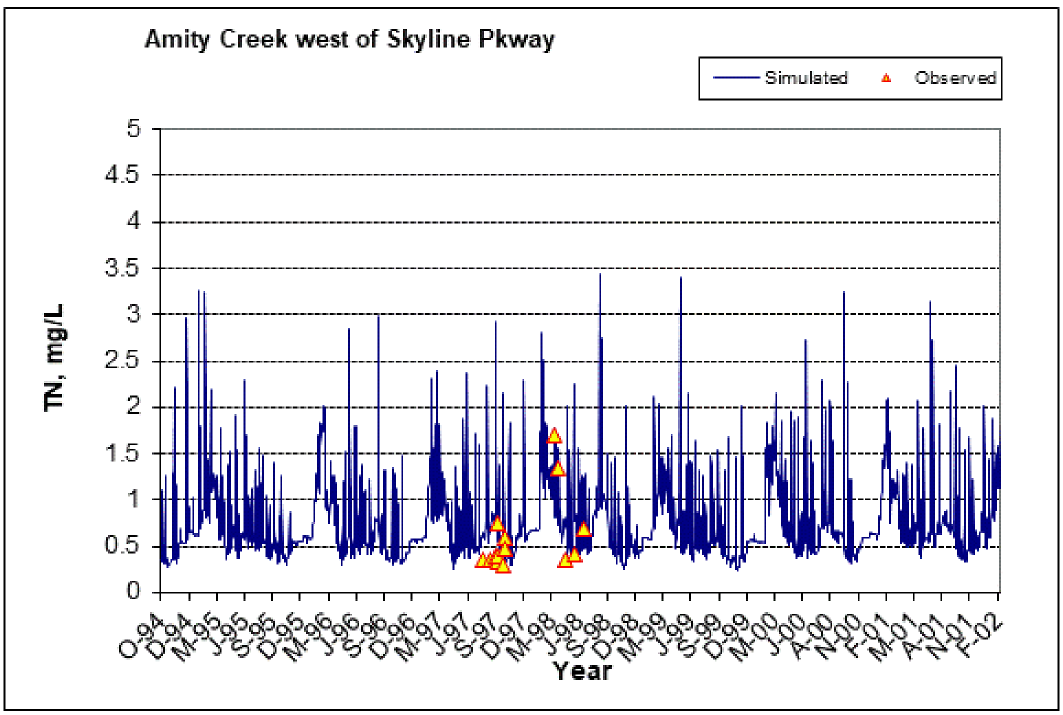
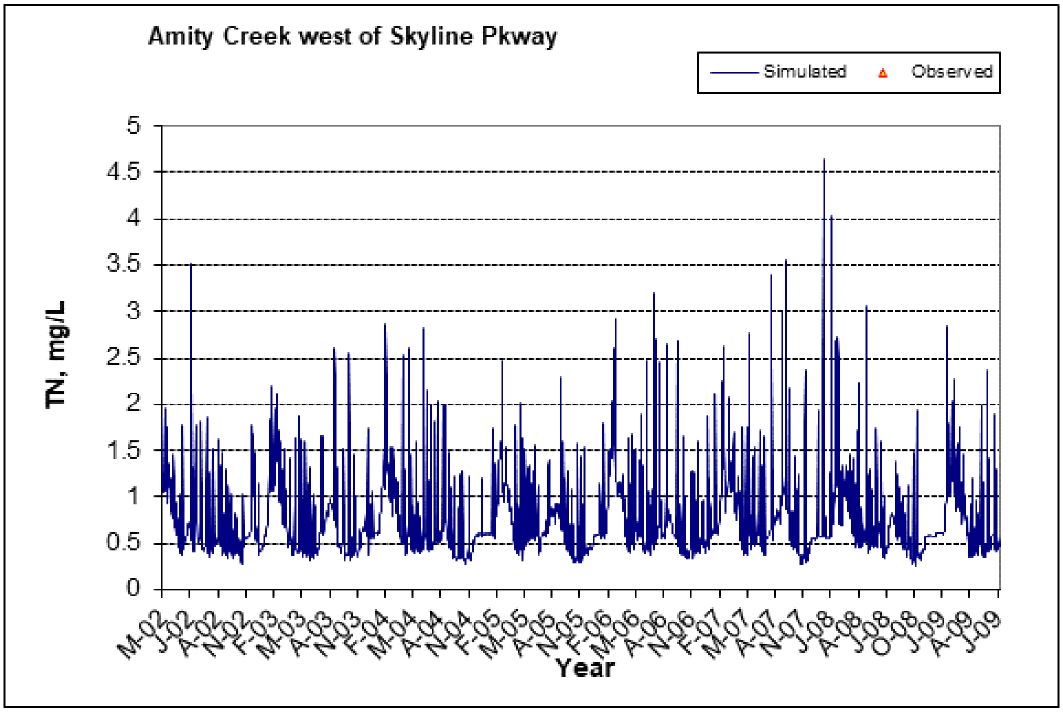


Figure E-275. Simulated and observed Total Nitrogen (TN) concentration vs flow at Amity Creek west of Skyline Pkway (validation period)





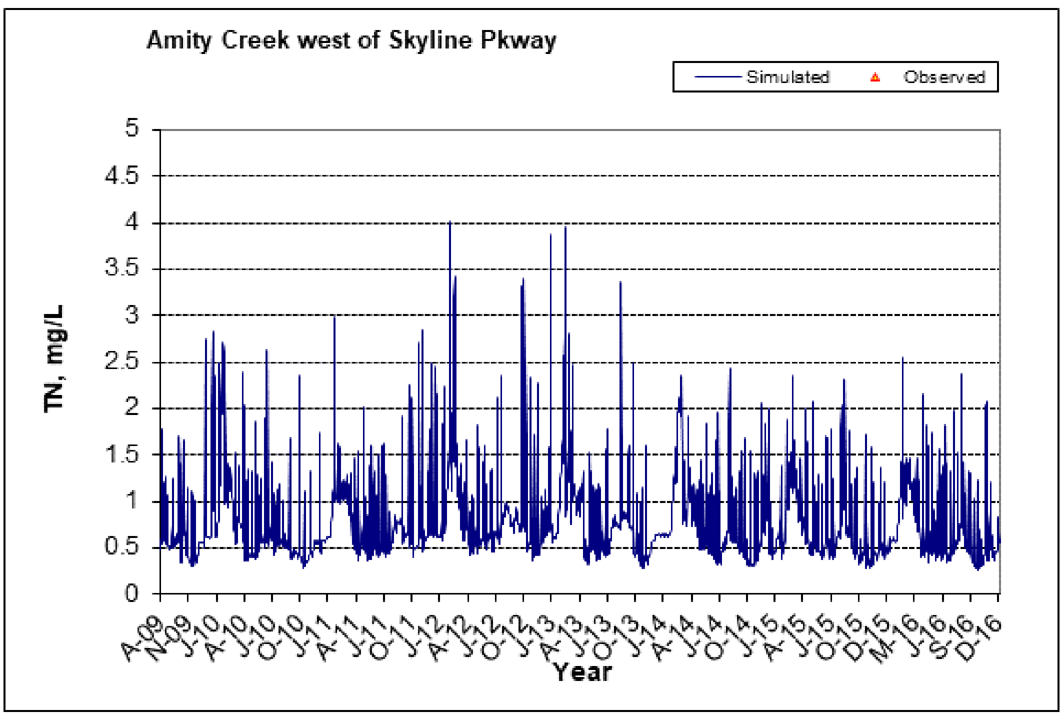


Figure E-276. Time series of observed and simulated Total Nitrogen (TN) concentration at Amity Creek west of Skyline Pkway

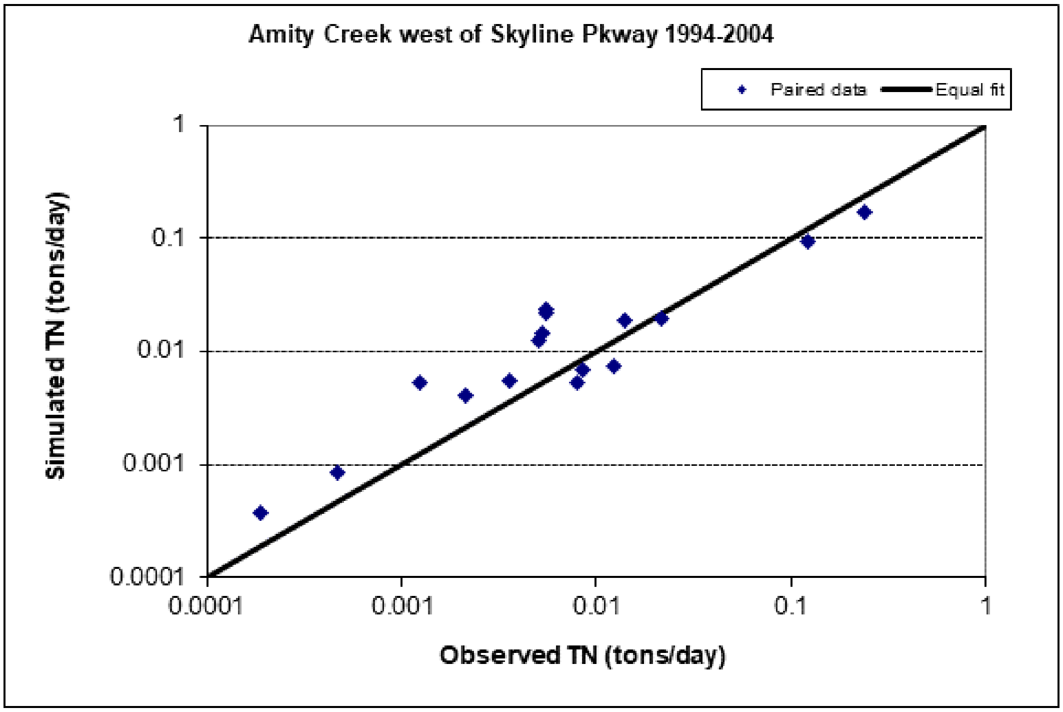


Figure E-277. Paired simulated vs. observed Total Nitrogen (TN) load at Amity Creek west of Skyline Pkway (validation period)

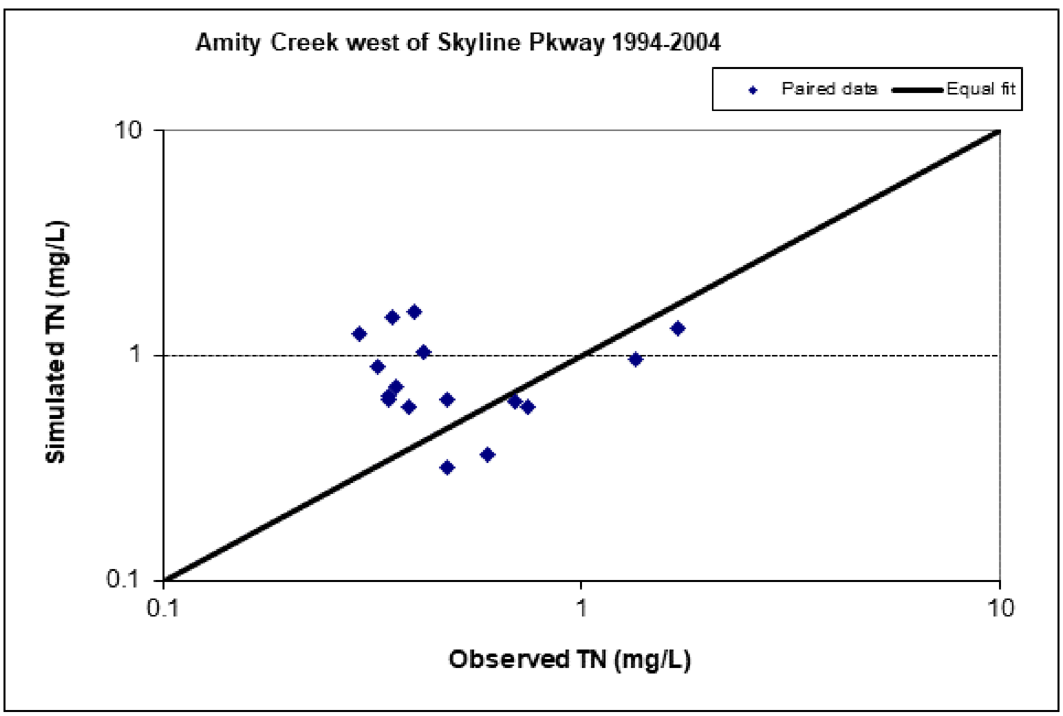


Figure E-278. Paired simulated vs. observed Total Nitrogen (TN) concentration at Amity Creek west of Skyline Pkway (validation period)

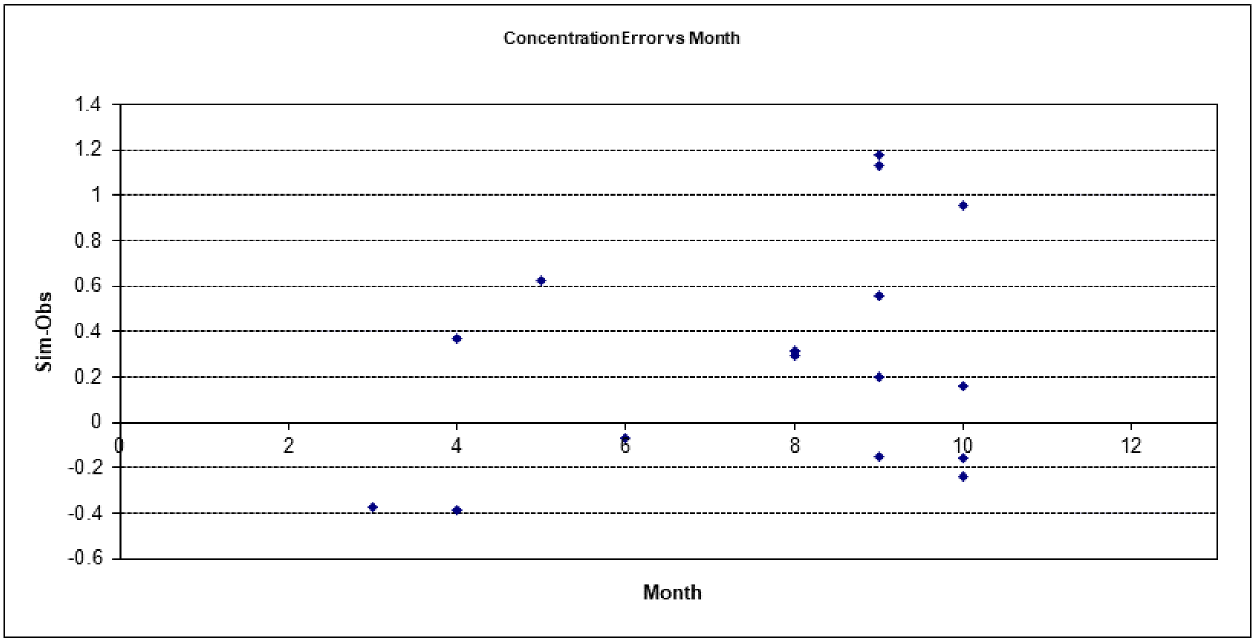


Figure E-279. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at Amity Creek west of Skyline Pkway

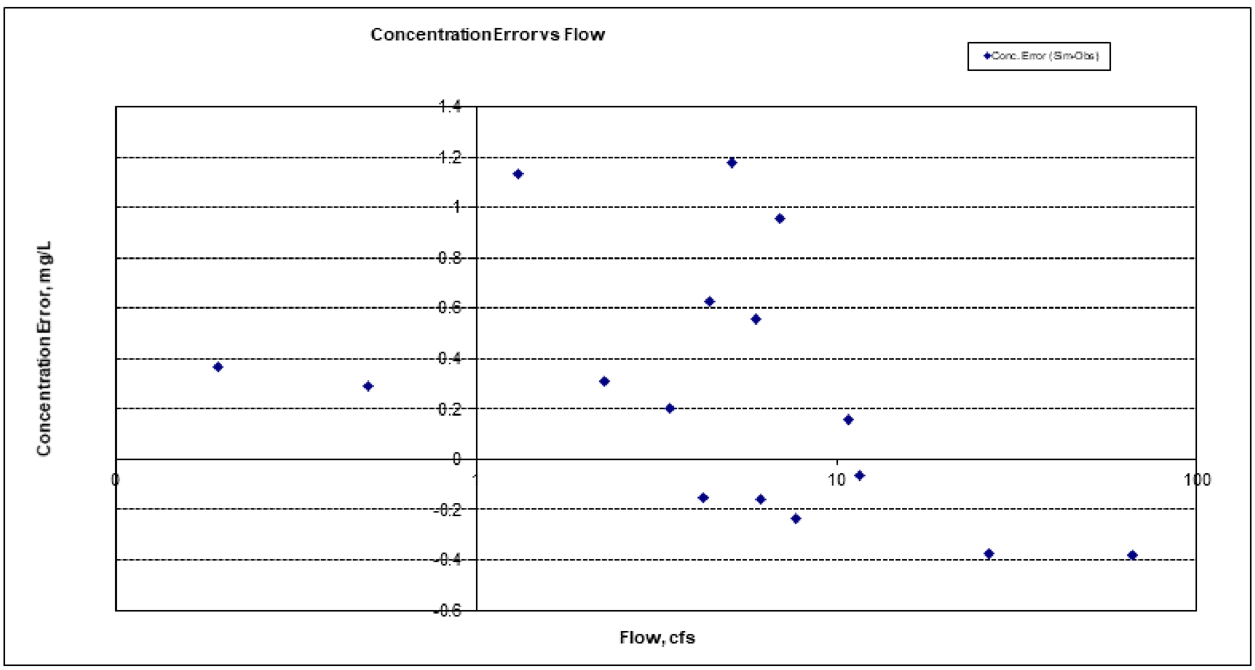


Figure E-280. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at Amity Creek west of Skyline Pkway

E.4.6 Soluble Reactive Phosphorus (SRP)

Table E-33. Soluble Reactive Phosphorus (SRP) statistics

Period	1994-2004	2004-2016
Count	18	ND
Concentration Average Error	10.01%	
Concentration Median Error	1.29%	
Load Average Error	110.59%	
Load Median Error	1.08%	
Paired t conc	0.71	
Paired t load	0.17	

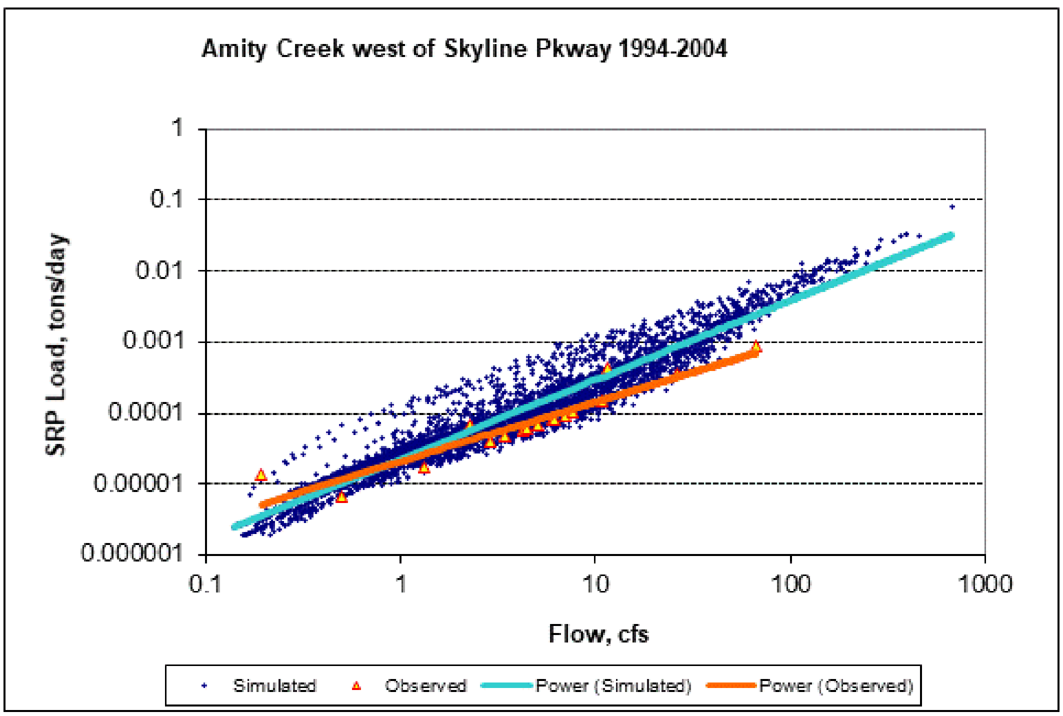


Figure E-281. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Amity Creek west of Skyline Pkway (validation period)

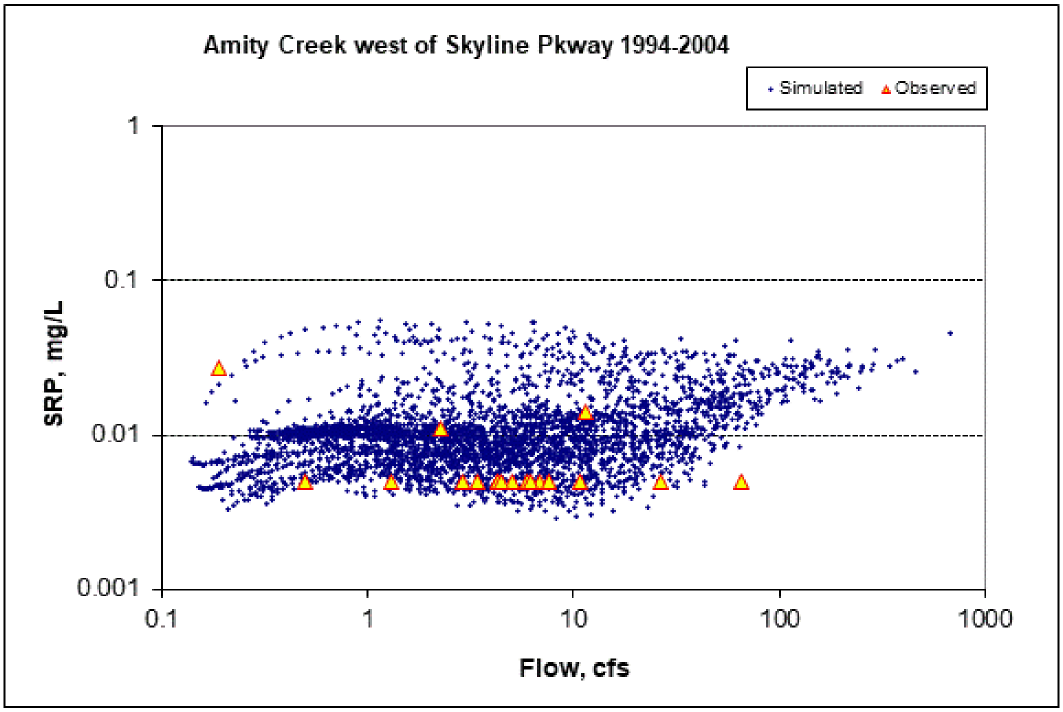
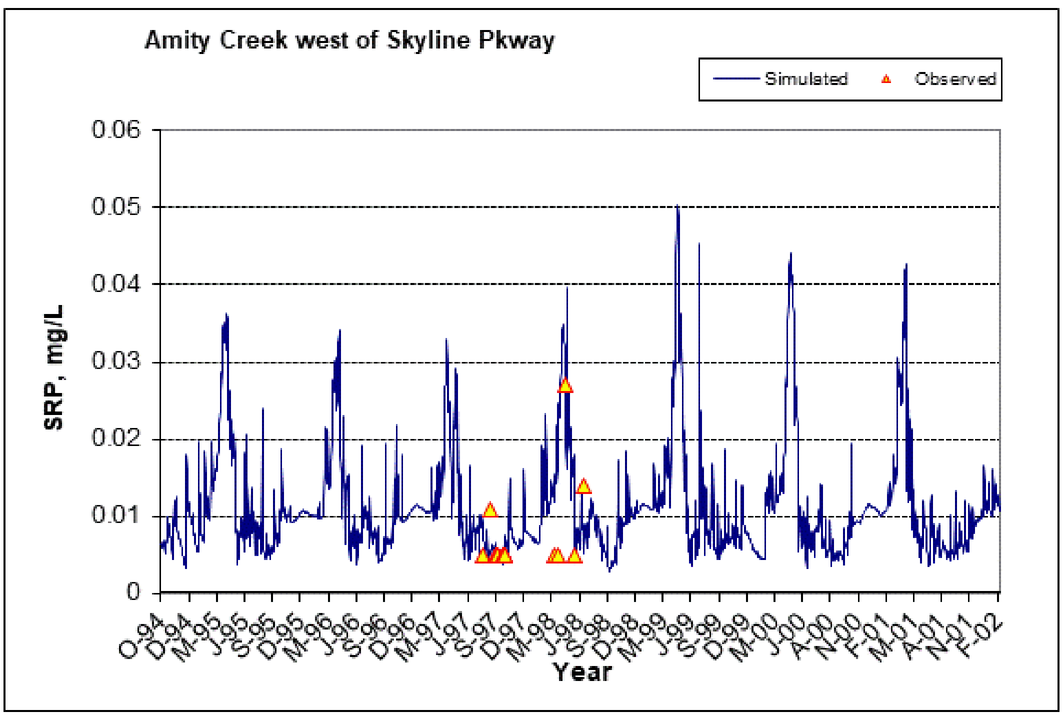
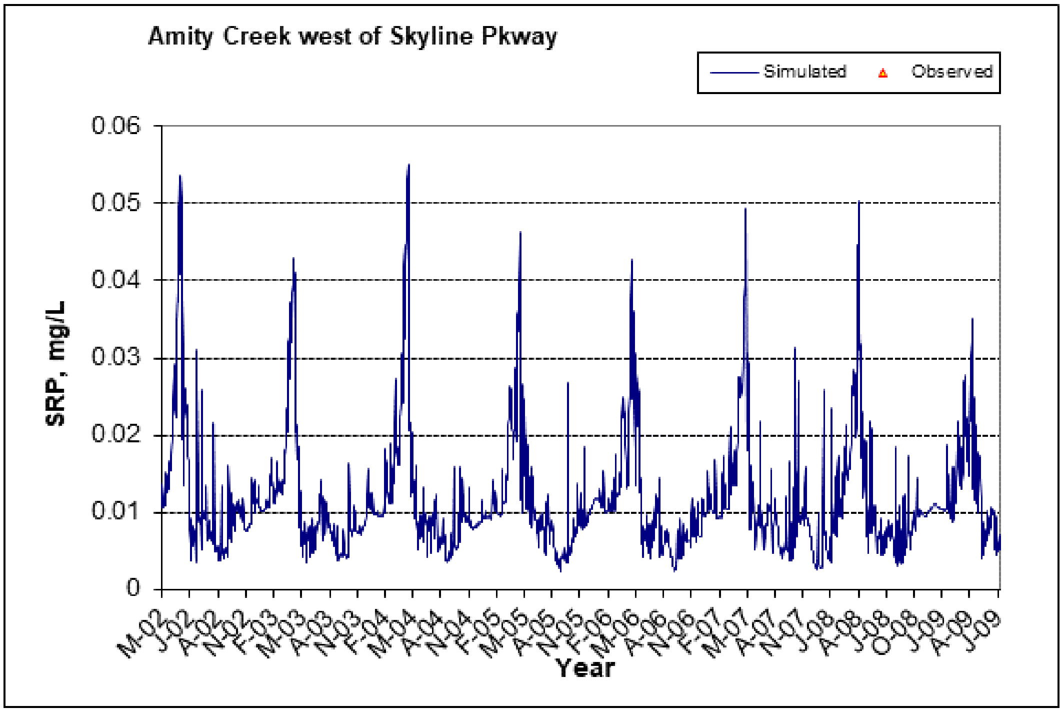


Figure E-282. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at Amity Creek west of Skyline Pkway (validation period)





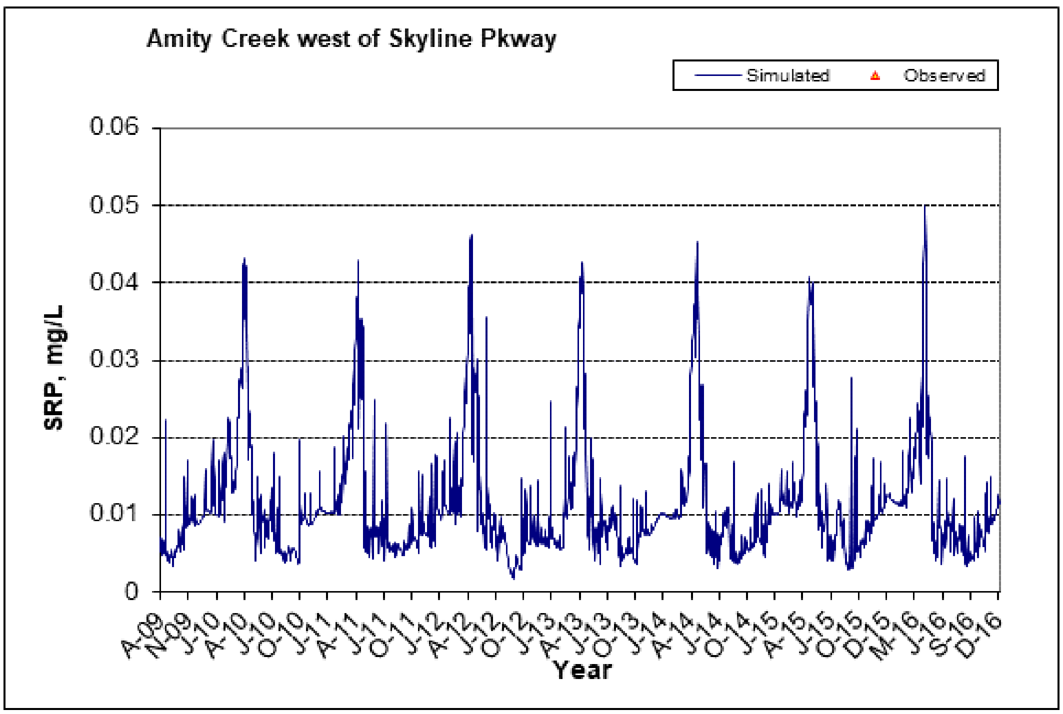


Figure E-283. Time series of observed and simulated Soluble Reactive Phosphorus (SRP) concentration at Amity Creek west of Skyline Pkway

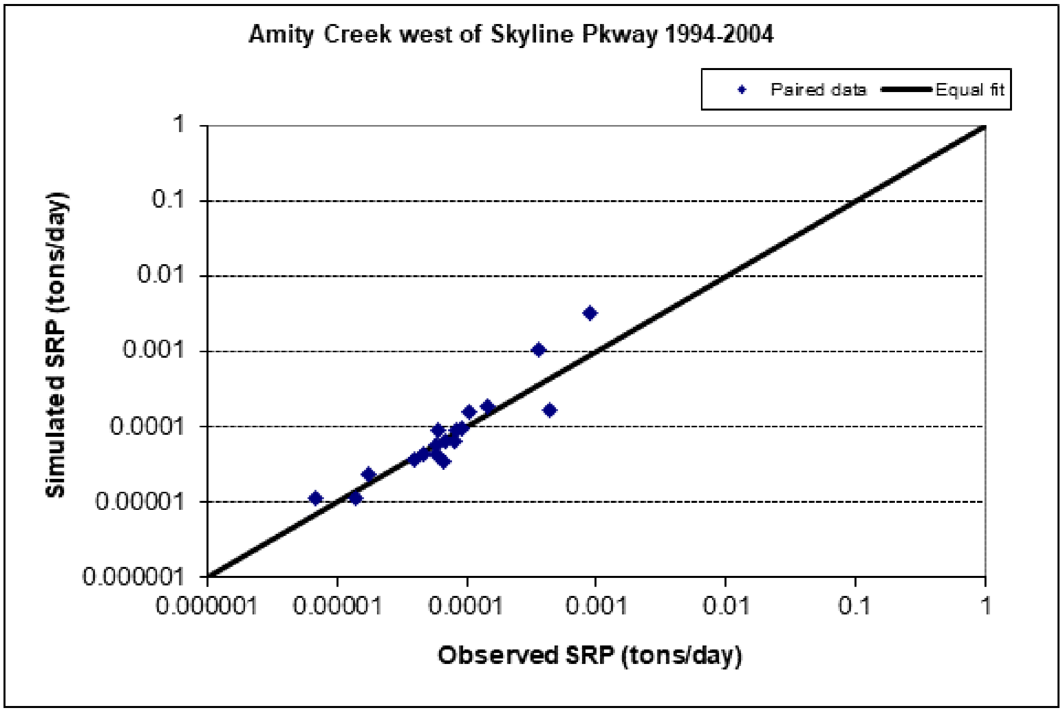


Figure E-284. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at Amity Creek west of Skyline Pkway (validation period)

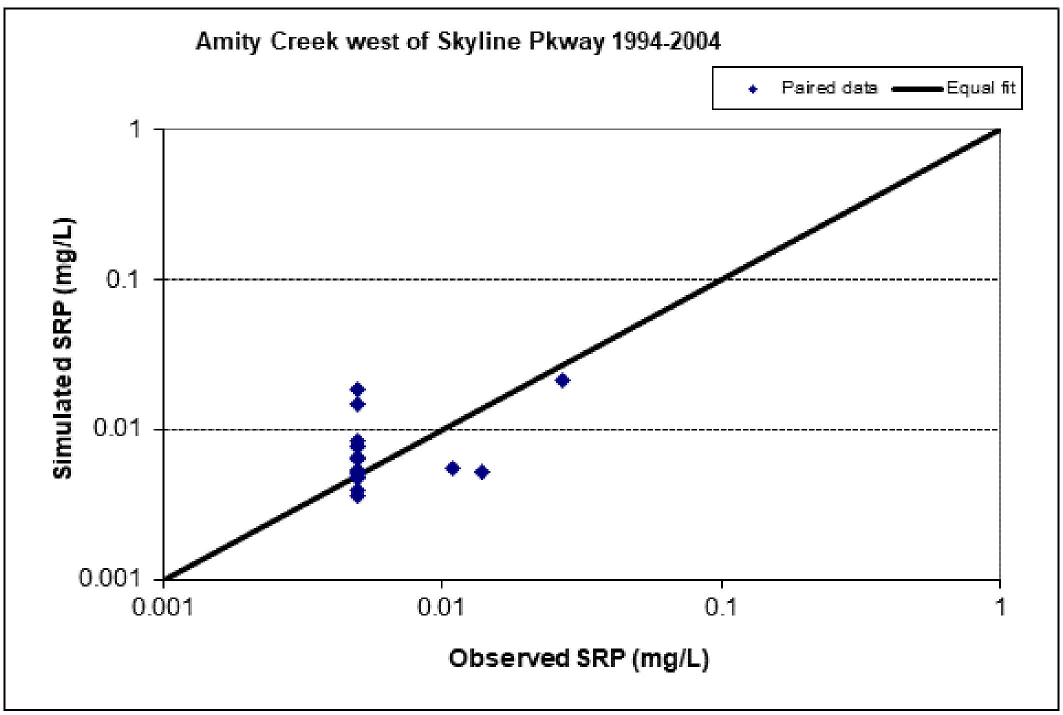


Figure E-285. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at Amity Creek west of Skyline Pkway (validation period)

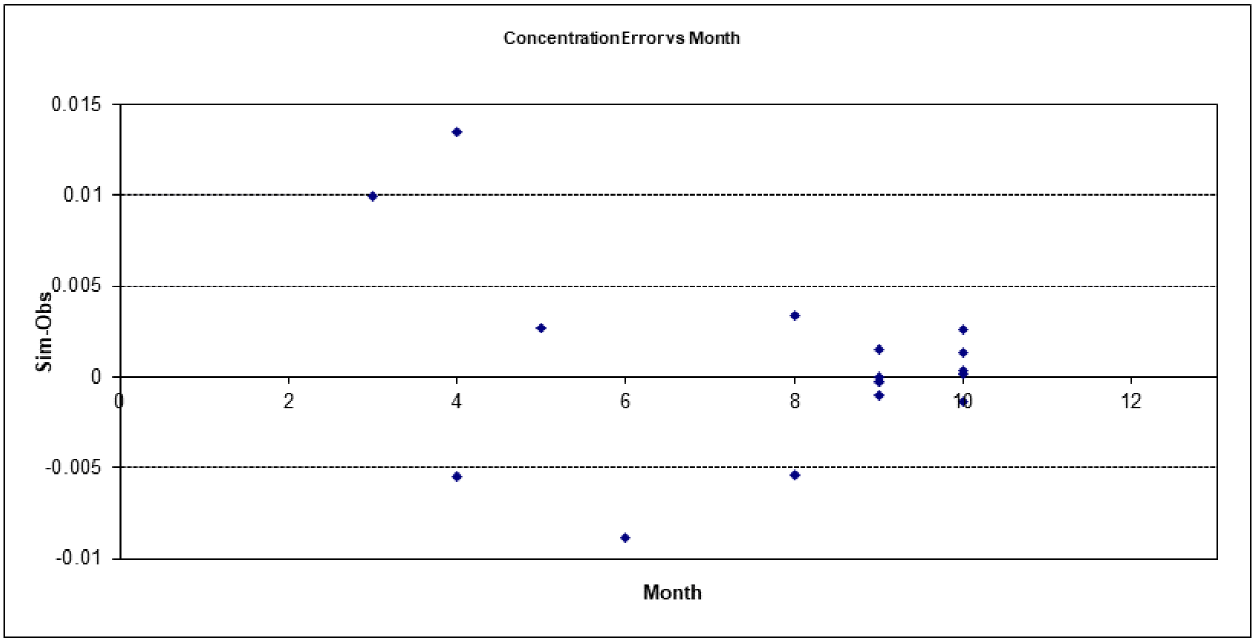


Figure E-286. Residual (Simulated - Observed) vs. Month, Soluble Reactive Phosphorus (SRP) at Amity Creek west of Skyline Pkway

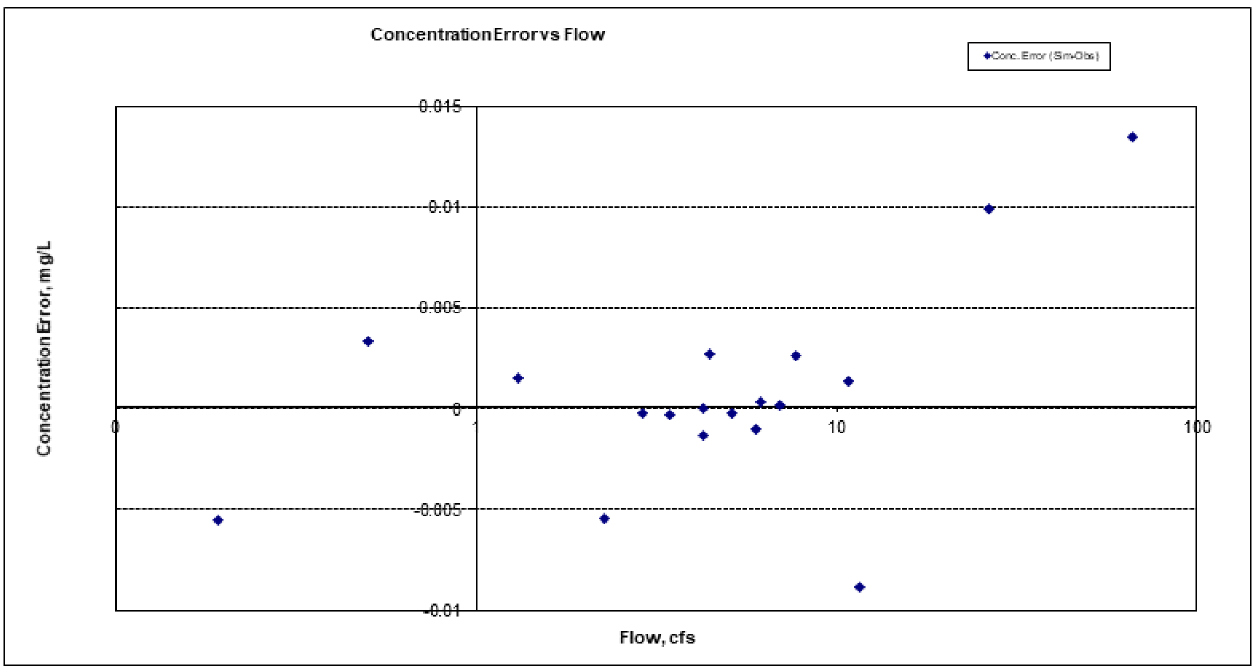


Figure E-287. Residual (Simulated - Observed) vs. Flow, Soluble Reactive Phosphorus (SRP) at Amity Creek west of Skyline Pkway

E.4.7 Organic Phosphorus (OrgP)

Table E-34. Organic Phosphorus (OrgP) statistics

Period	1994-2004	2004-2016
Count	11	ND
Concentration Average Error	-54.56%	
Concentration Median Error	-46.44%	
Load Average Error	-66.18%	
Load Median Error	-21.27%	
Paired t conc	0.04	
Paired t load	0.14	

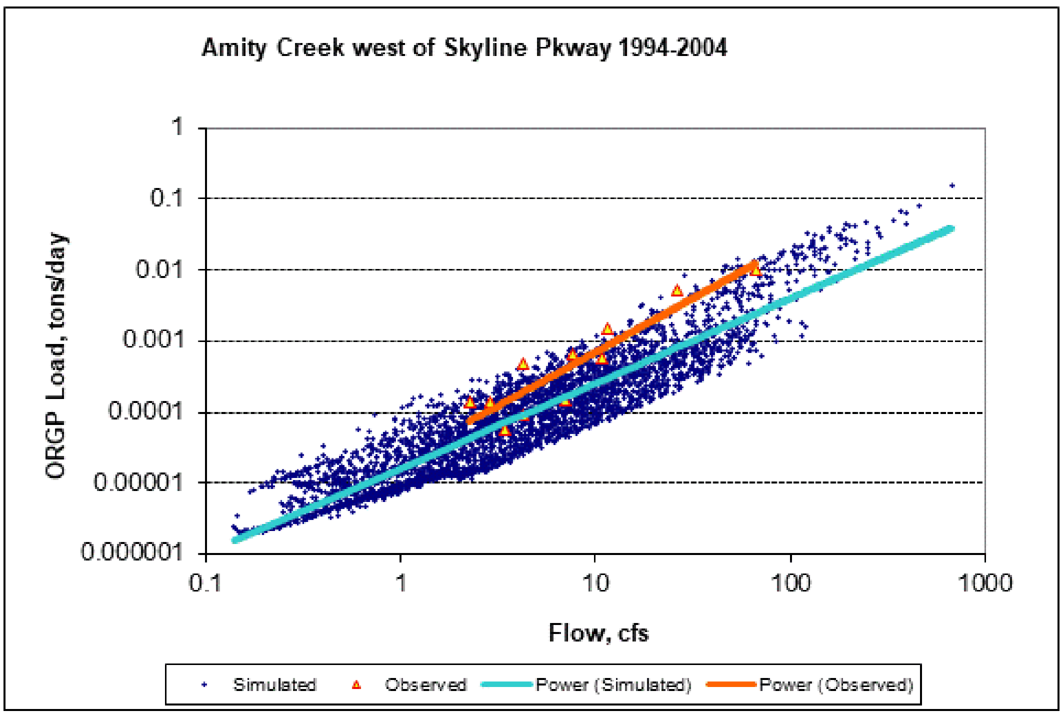


Figure E-288. Power plot of simulated and observed Organic Phosphorus (OrgP) load vs flow at Amity Creek west of Skyline Pkway (validation period)

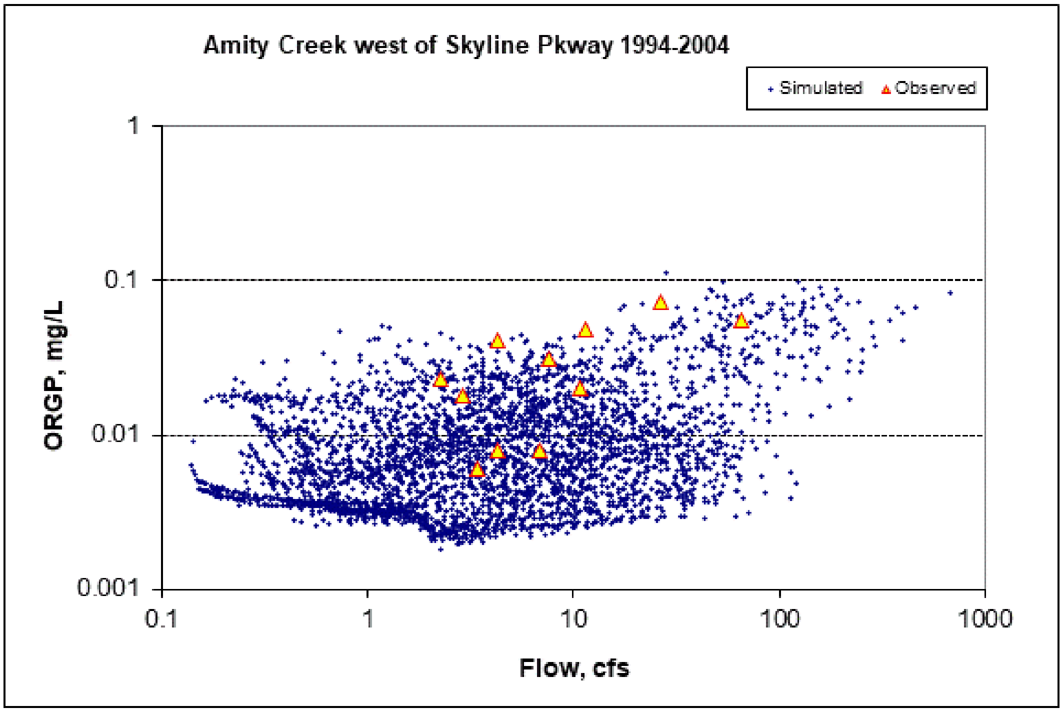
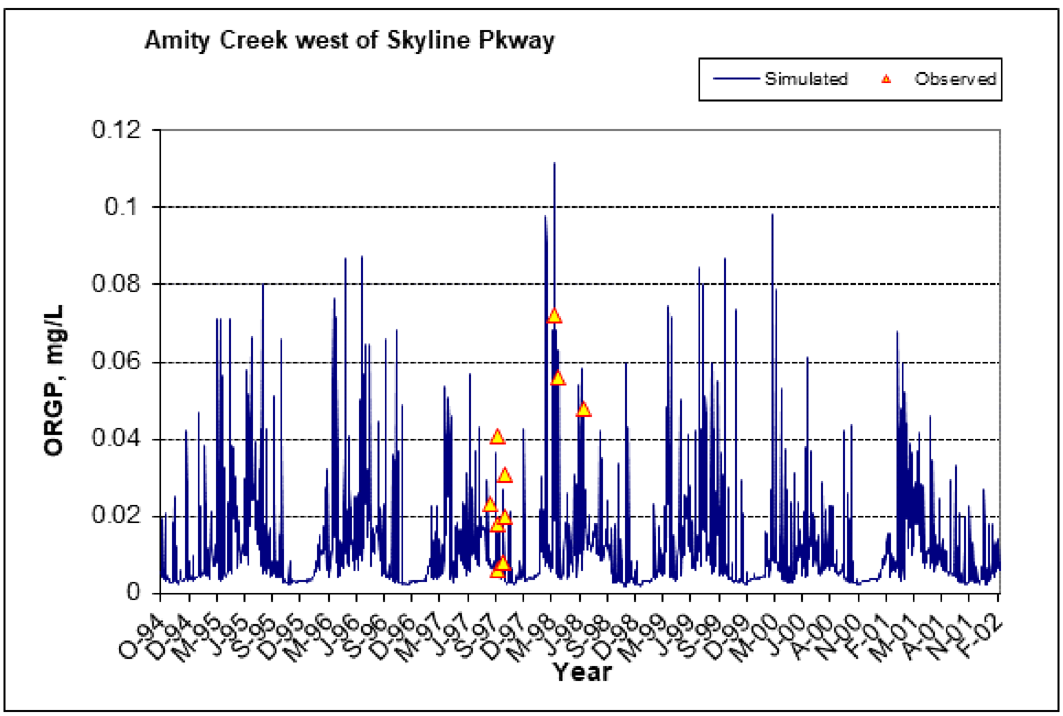
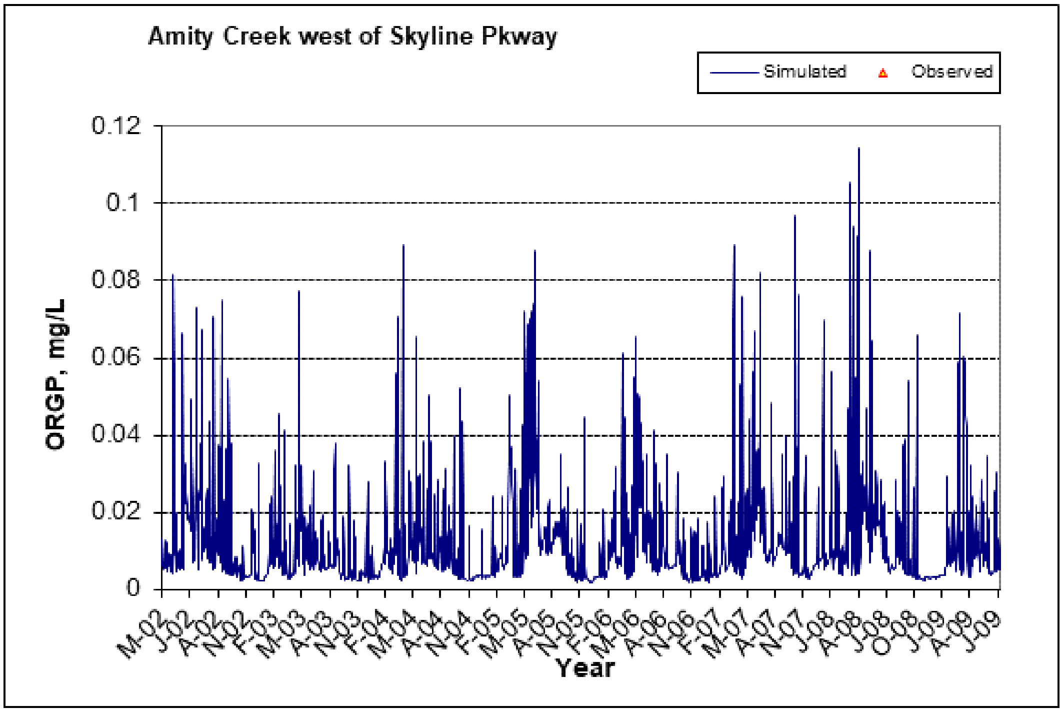


Figure E-289. Simulated and observed Organic Phosphorus (OrgP) concentration vs flow at Amity Creek west of Skyline Pkway (validation period)





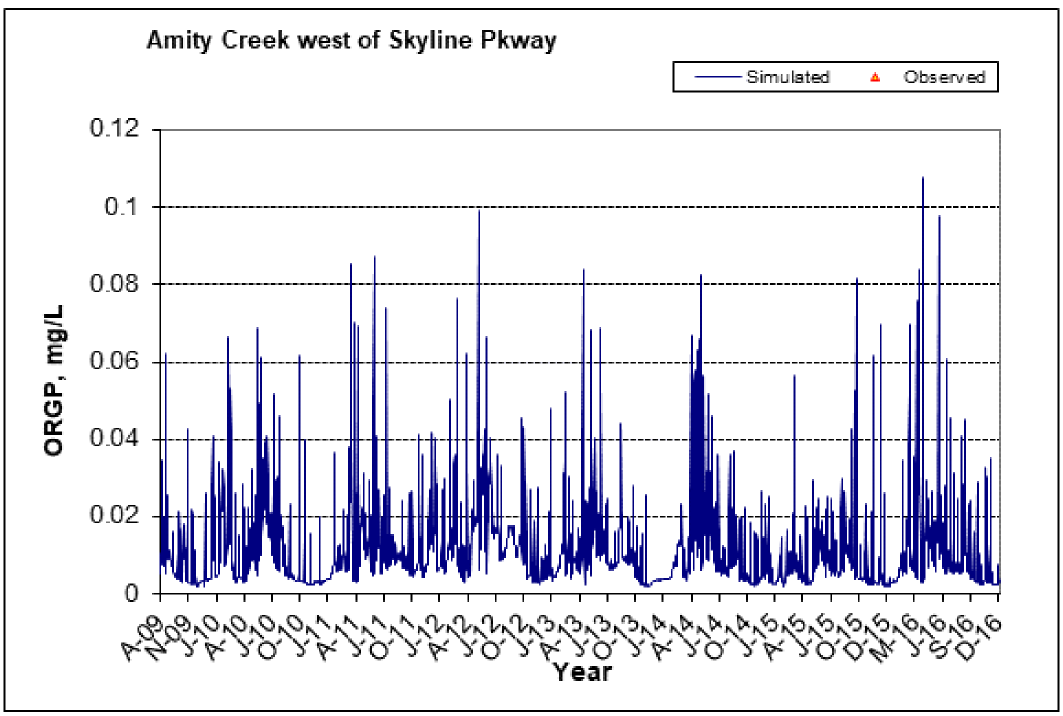


Figure E-290. Time series of observed and simulated Organic Phosphorus (OrgP) concentration at Amity Creek west of Skyline Pkway

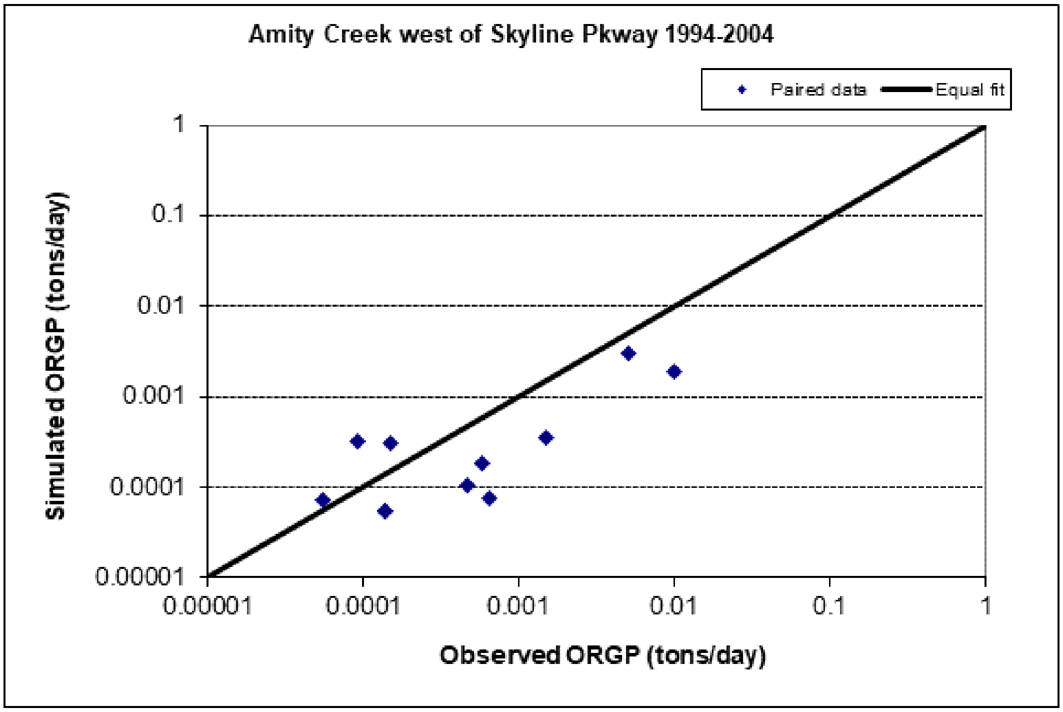


Figure E-291. Paired simulated vs. observed Organic Phosphorus (OrgP) load at Amity Creek west of Skyline Pkway (validation period)

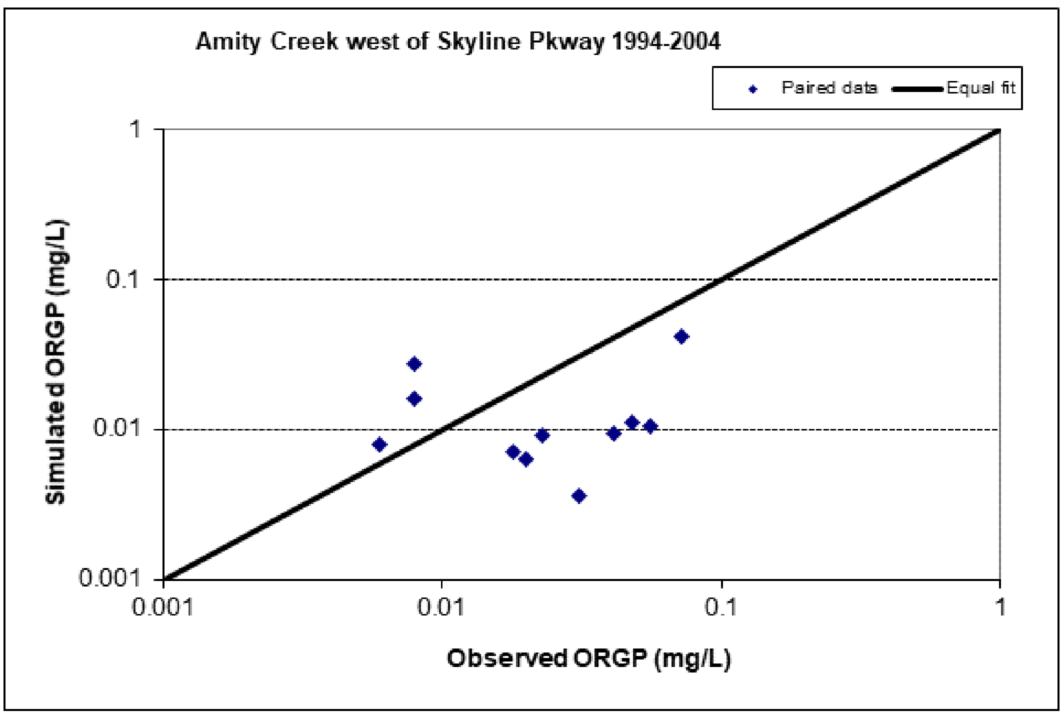


Figure E-292. Paired simulated vs. observed Organic Phosphorus (OrgP) concentration at Amity Creek west of Skyline Pkway (validation period)

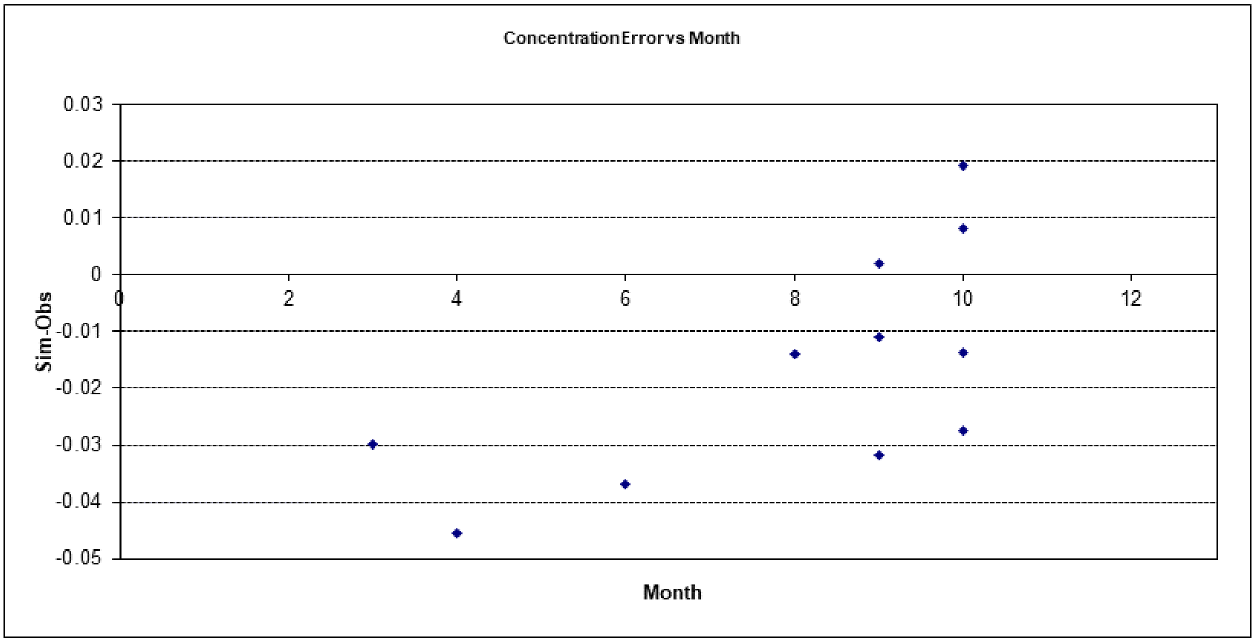


Figure E-293. Residual (Simulated - Observed) vs. Month, Organic Phosphorus (OrgP) at Amity Creek west of Skyline Pkway

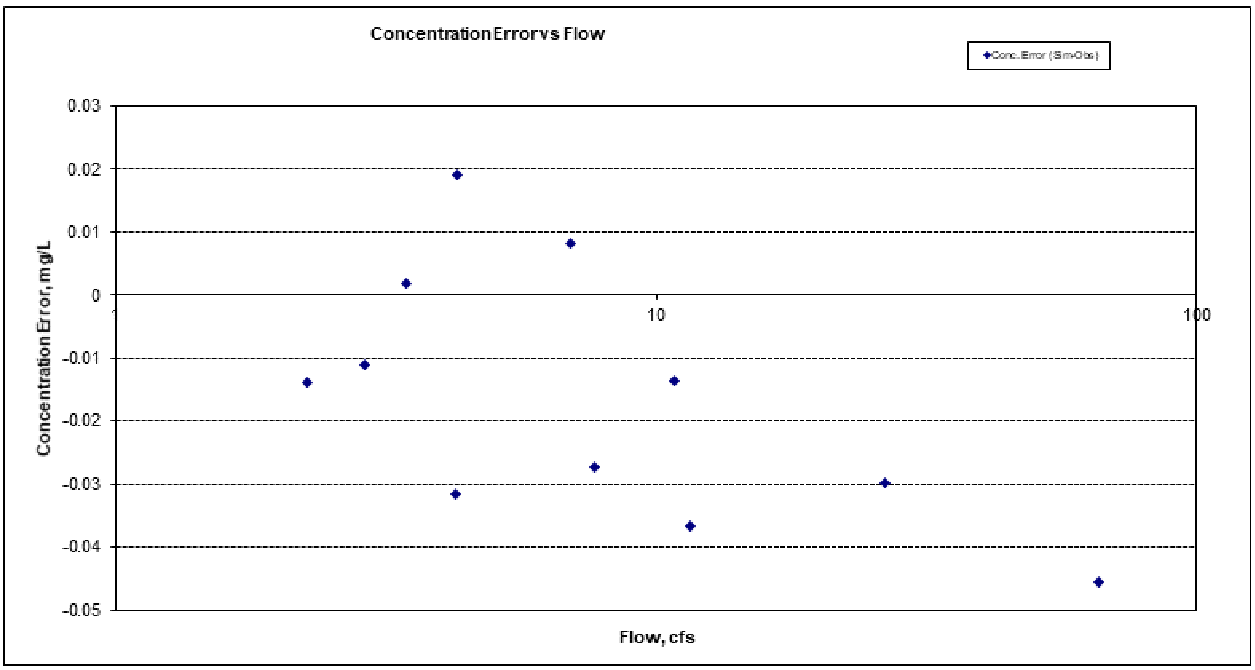


Figure E-294. Residual (Simulated - Observed) vs. Flow, Organic Phosphorus (OrgP) at Amity Creek west of Skyline Pkway

E.4.8 Total Phosphorus (TP)

Table E-35. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	18	ND
Concentration Average Error	-13.91%	
Concentration Median Error	12.46%	
Load Average Error	-40.76%	
Load Median Error	0.98%	
Paired t conc	0.64	
Paired t load	0.32	

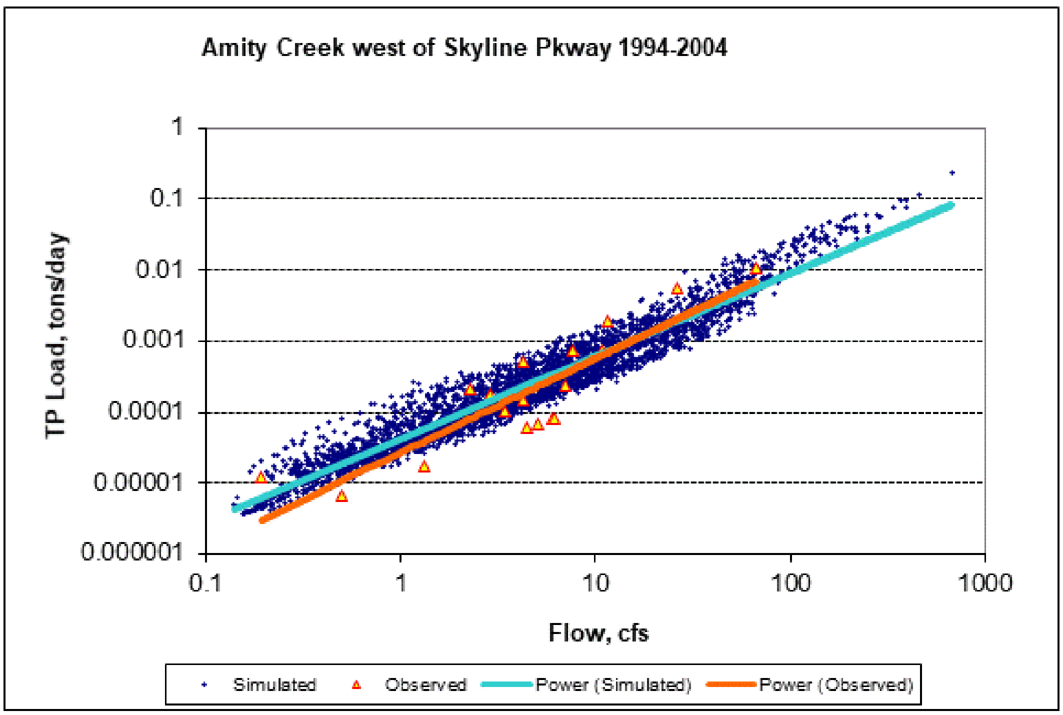


Figure E-295. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Amity Creek west of Skyline Pkway (validation period)

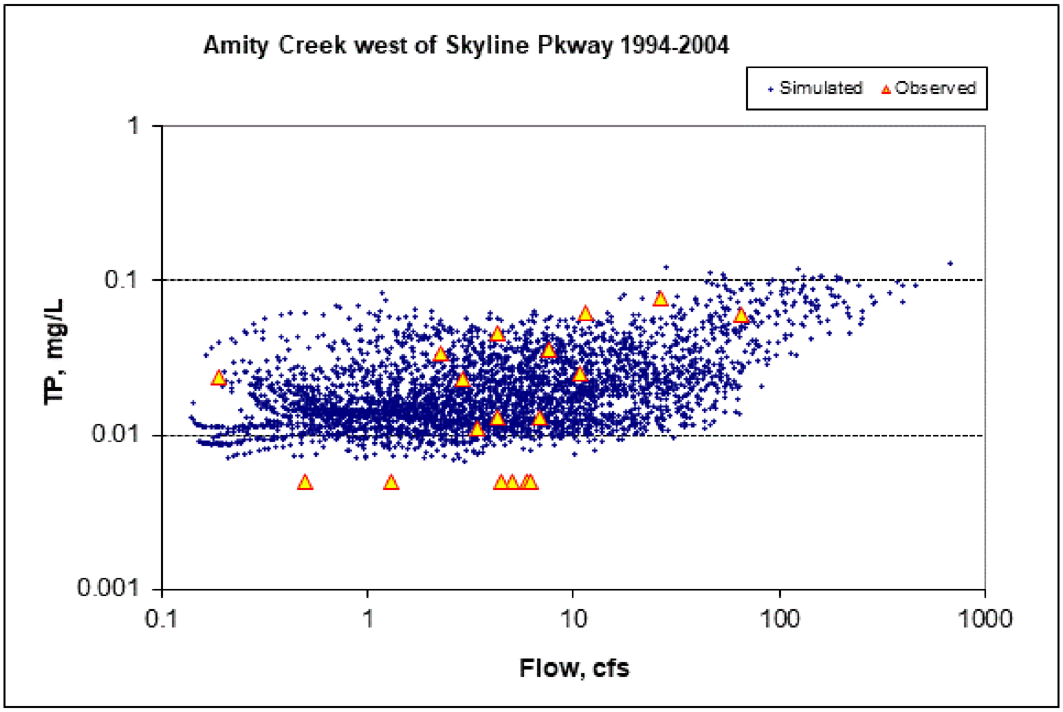
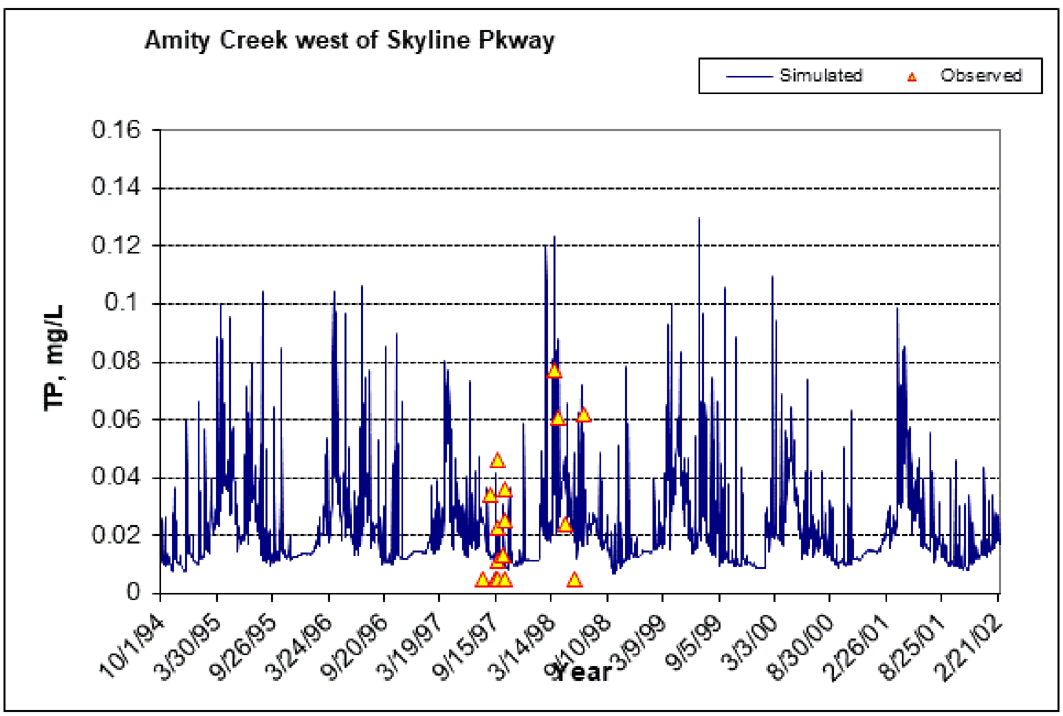
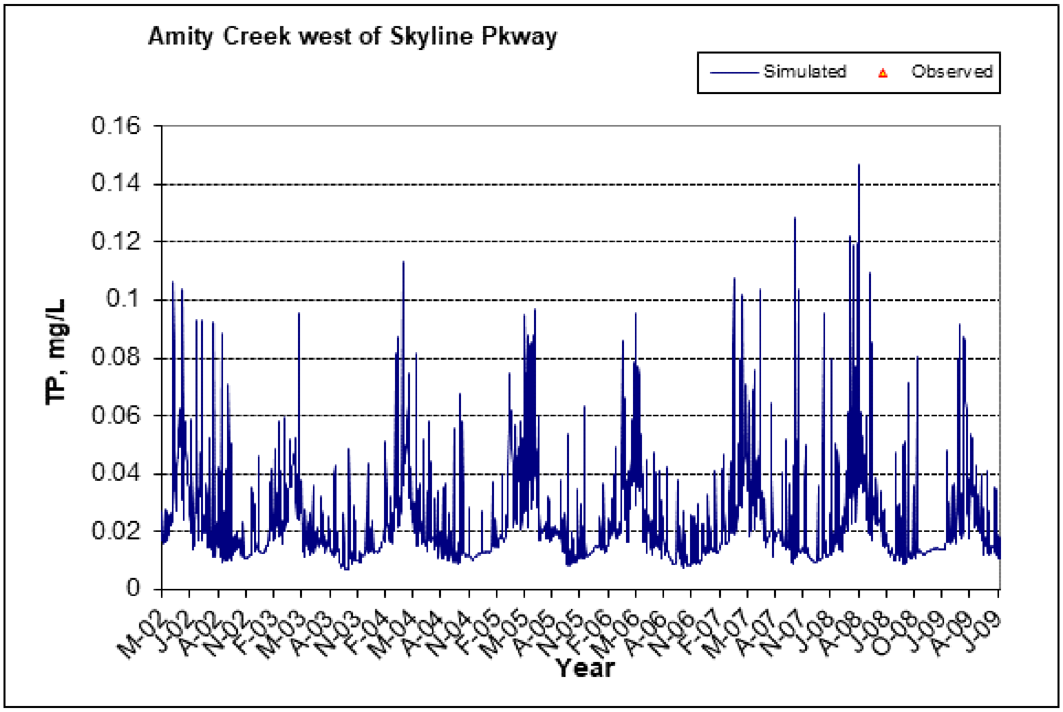


Figure E-296. Simulated and observed Total Phosphorus (TP) concentration vs flow at Amity Creek west of Skyline Pkway (validation period)





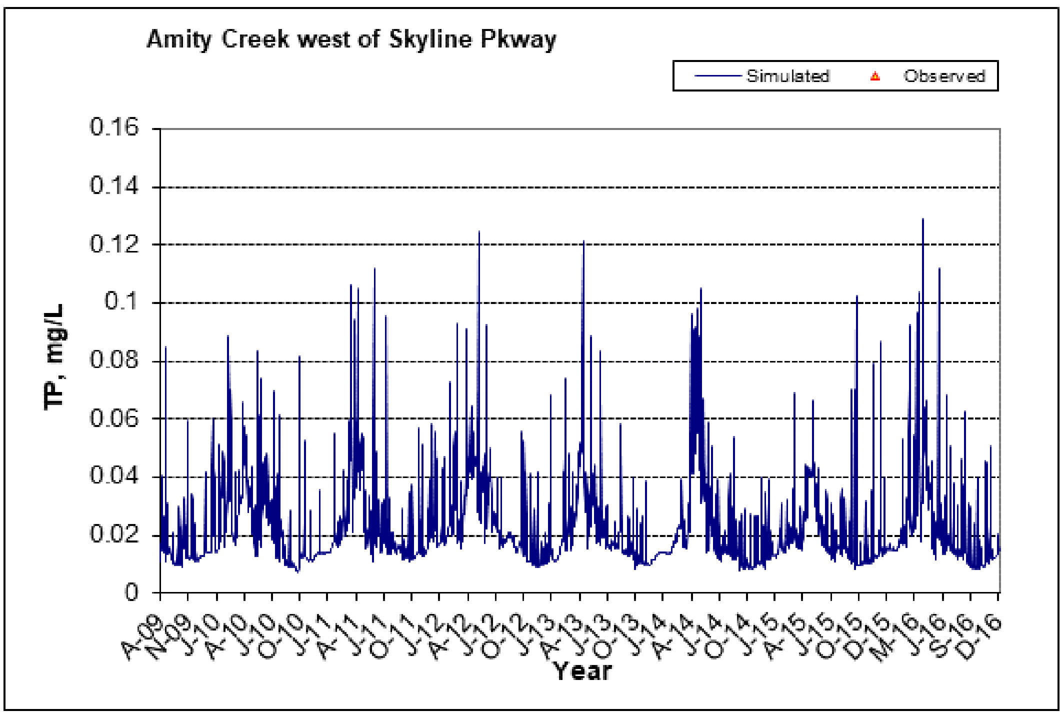


Figure E-297. Time series of observed and simulated Total Phosphorus (TP) concentration at Amity Creek west of Skyline Pkway

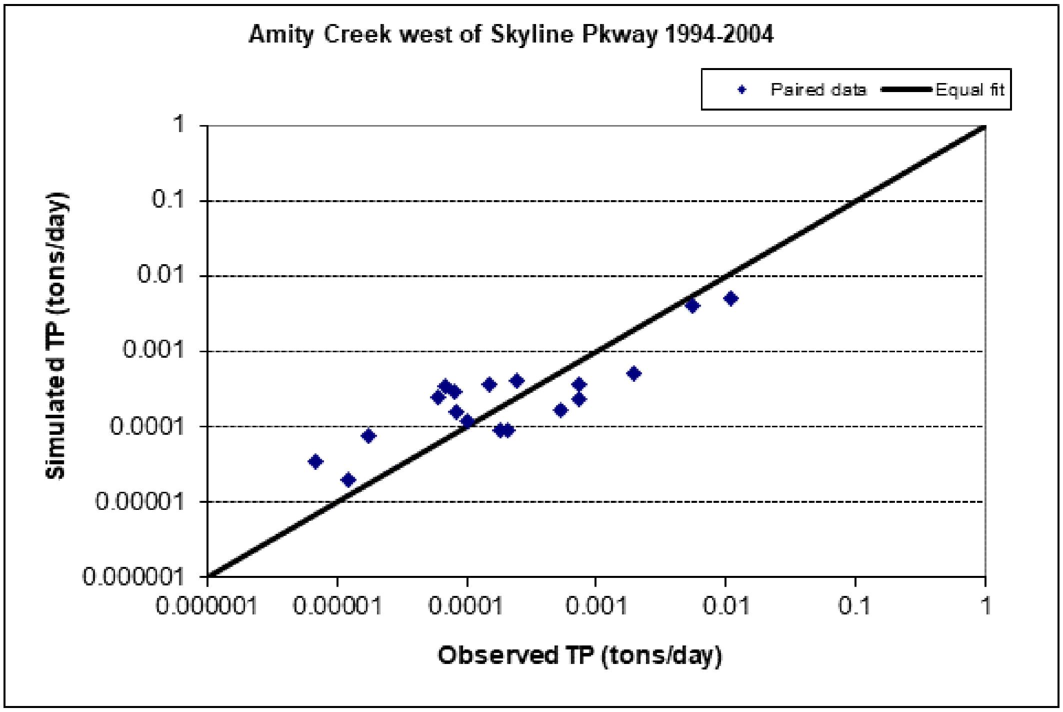


Figure E-298. Paired simulated vs. observed Total Phosphorus (TP) load at Amity Creek west of Skyline Pkway (validation period)

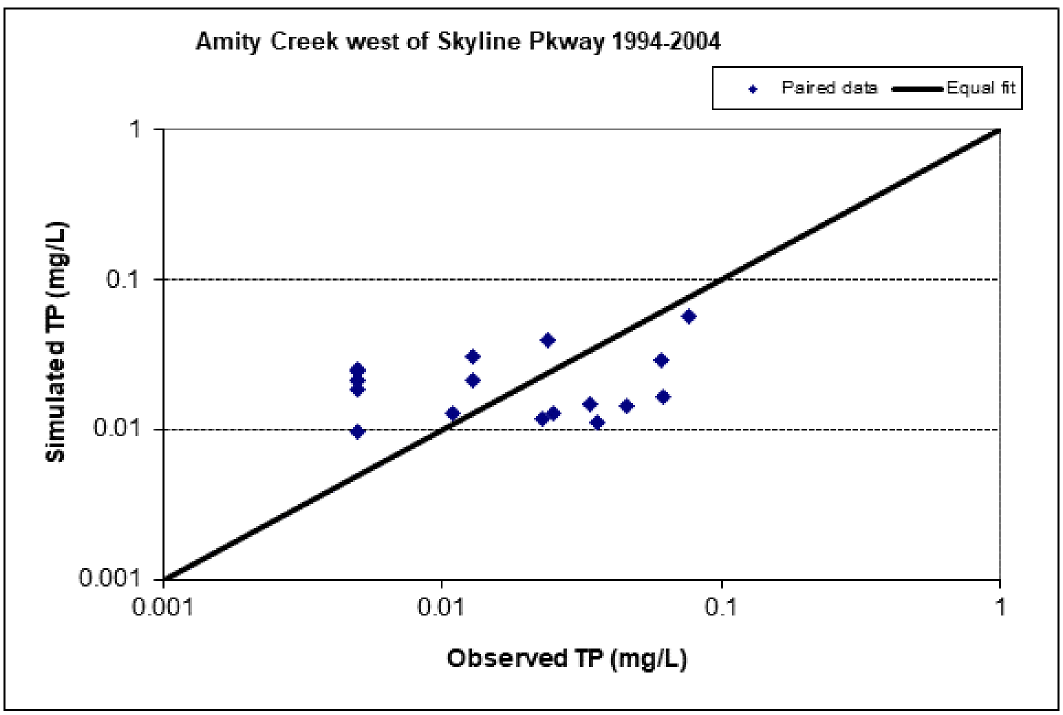


Figure E-299. Paired simulated vs. observed Total Phosphorus (TP) concentration at Amity Creek west of Skyline Pkway (validation period)

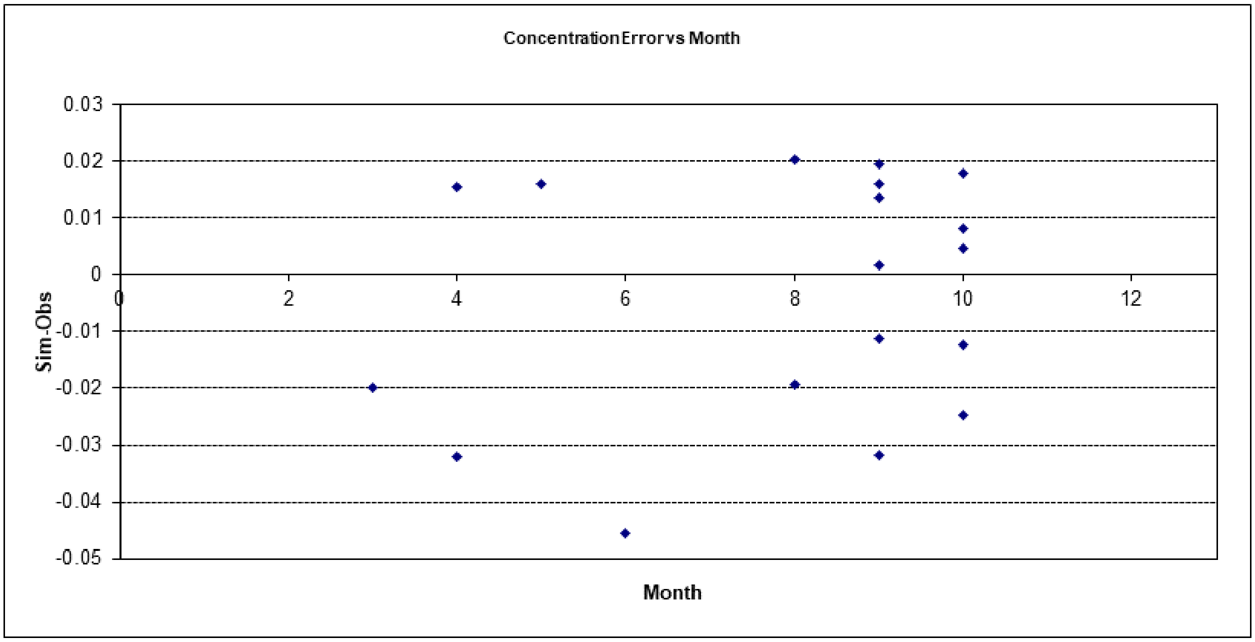


Figure E-300. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Amity Creek west of Skyline Pkway

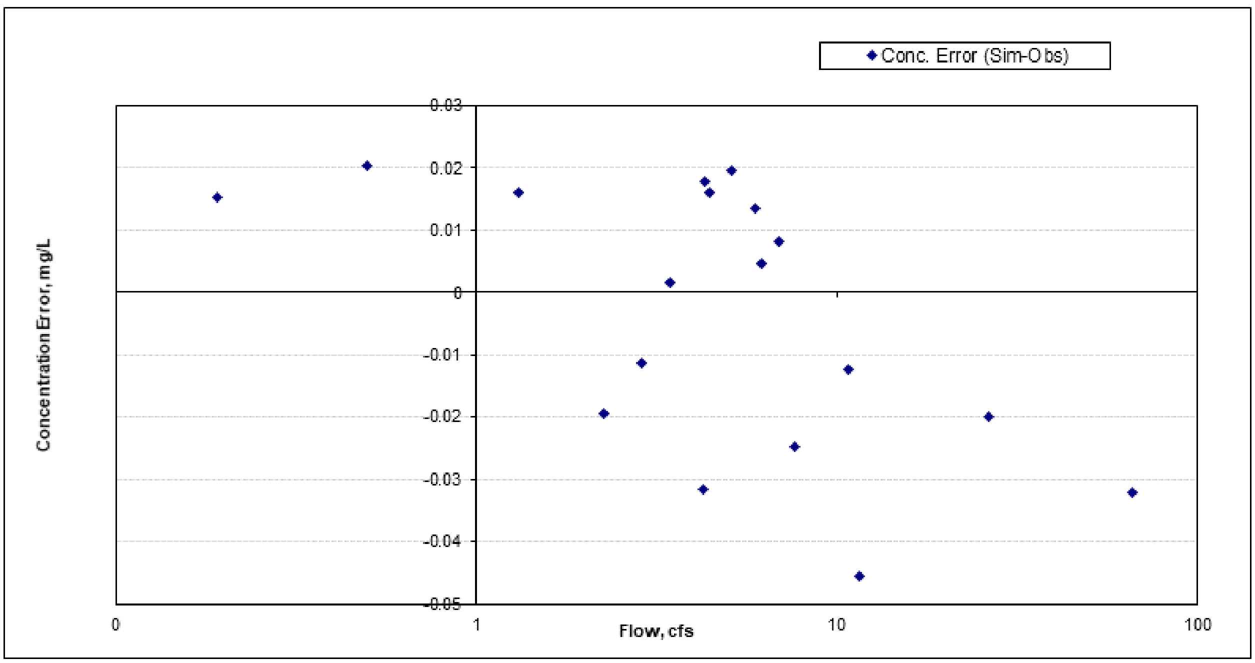


Figure E-301. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Amity Creek west of Skyline Pkway

E.5 Amity Creek near Skyline Pkwy

E.5.1 Dissolved Oxygen (DO)

Table E-36. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	27
Concentration Average Error		-11.37%
Concentration Median Error		-7.89%
Load Average Error		-11.26%
Load Median Error		-3.42%
Paired t conc		0.99
Paired t load		0.68

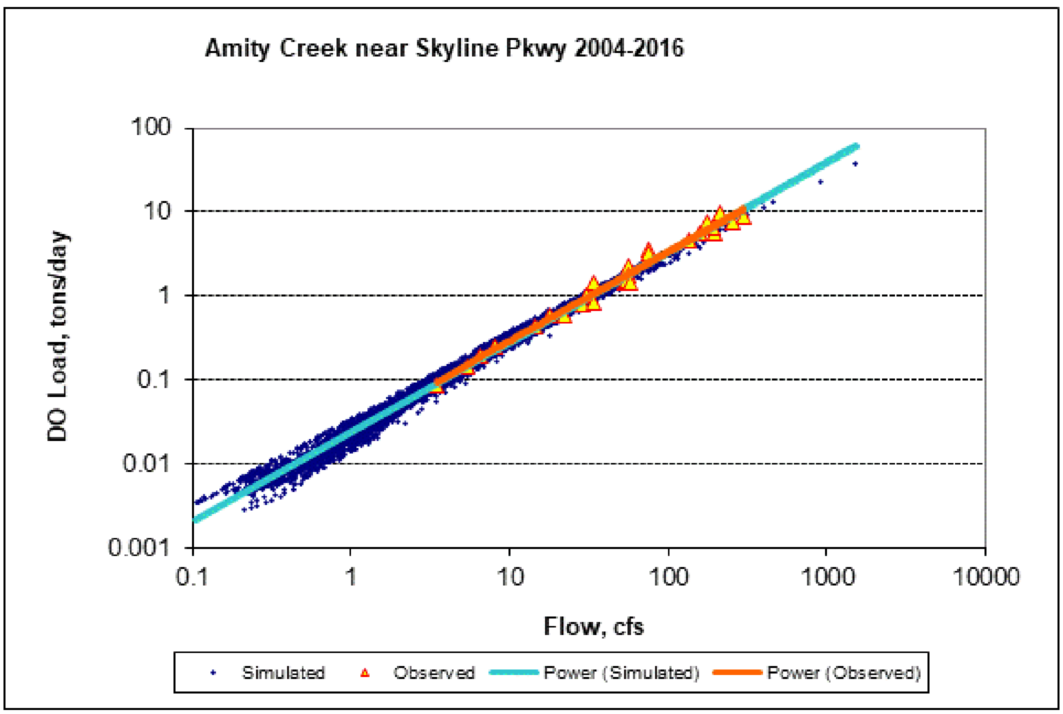


Figure E-302. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Amity Creek near Skyline Pkwy (calibration period)

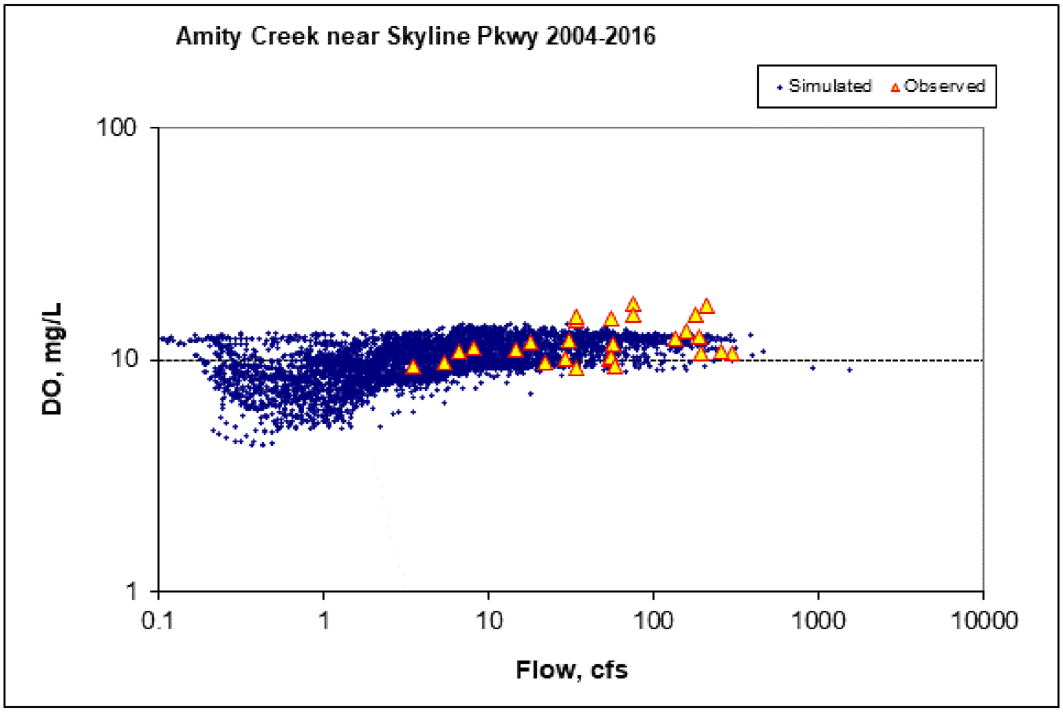
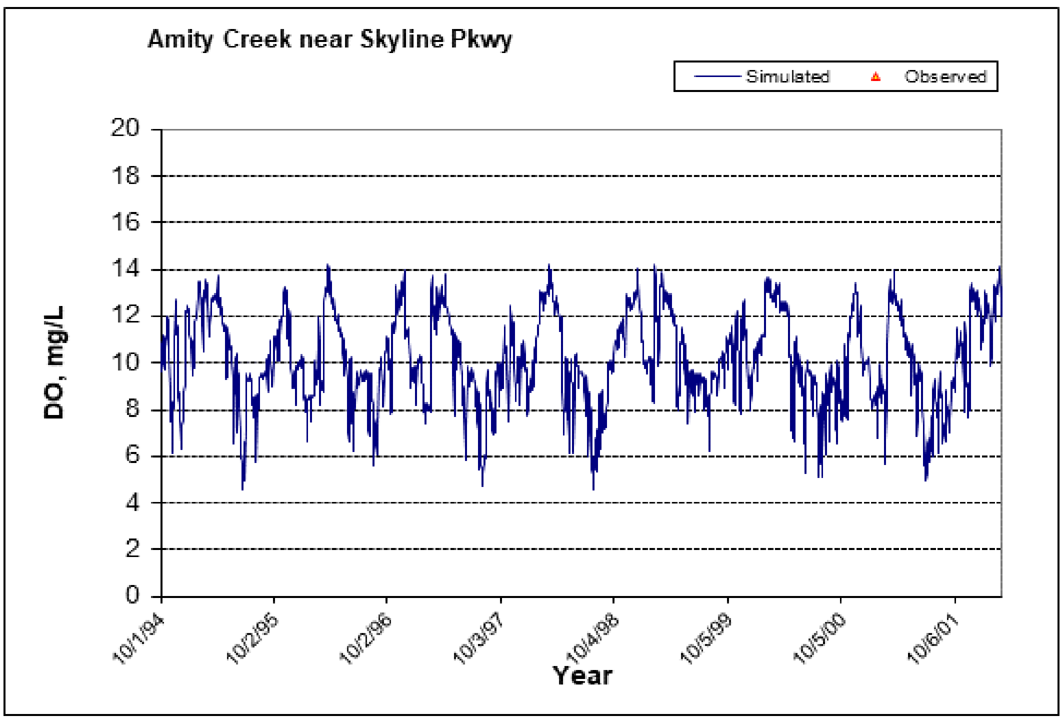
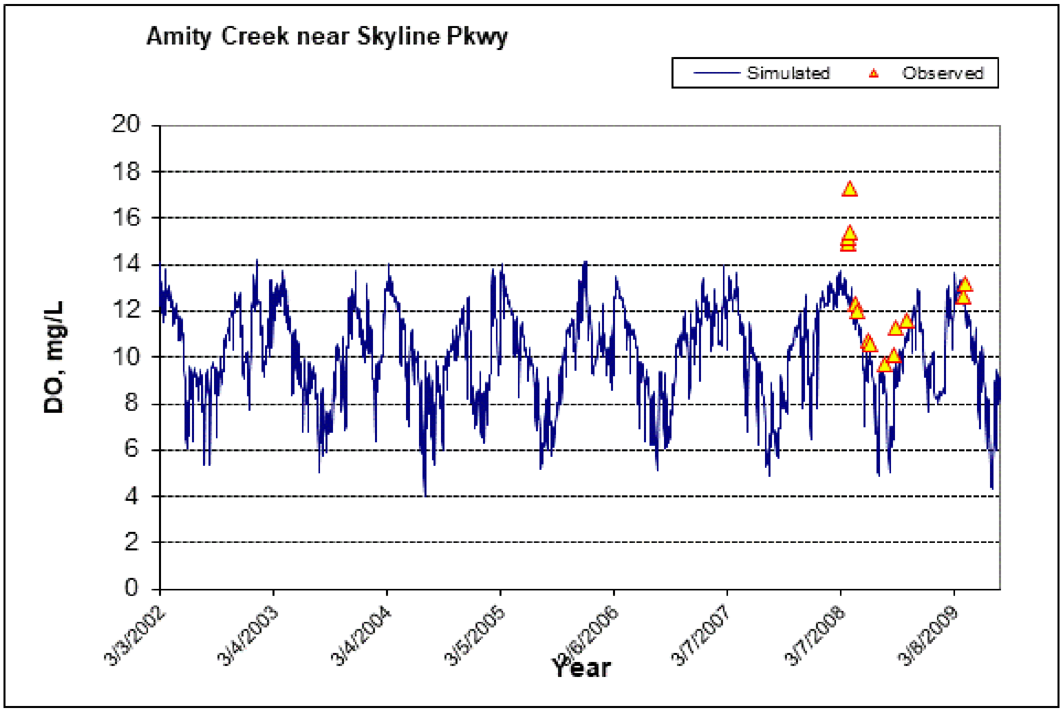


Figure E-303. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Amity Creek near Skyline Pkwy (calibration period)





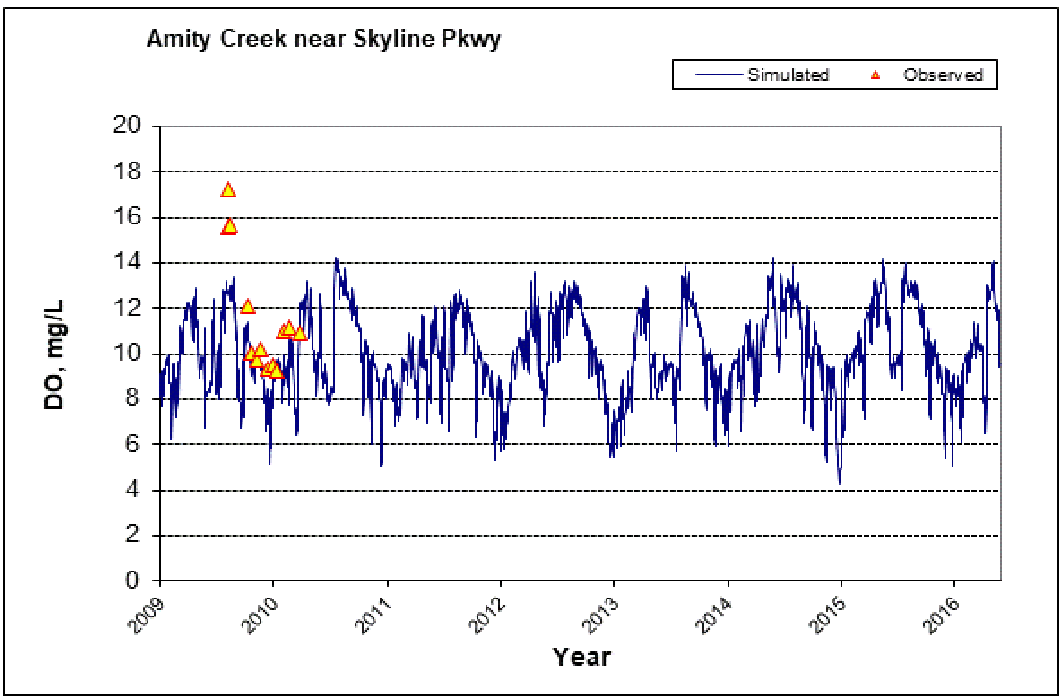


Figure E-304. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Amity Creek near Skyline Pkwy

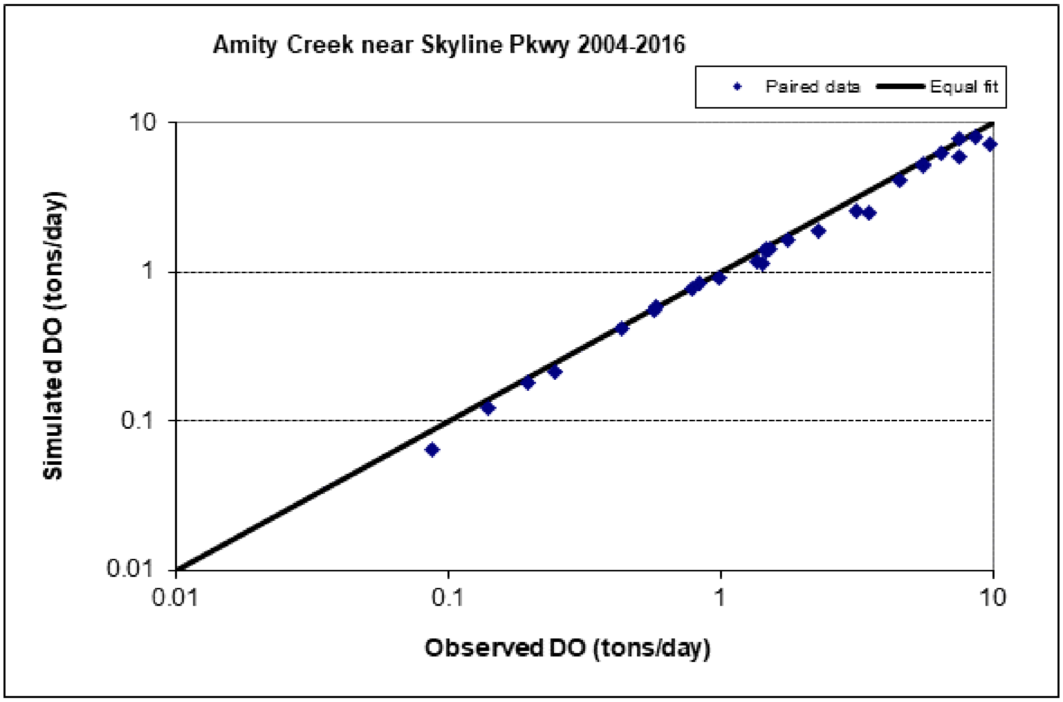


Figure E-305. Paired simulated vs. observed Dissolved Oxygen (DO) load at Amity Creek near Skyline Pkwy (calibration period)

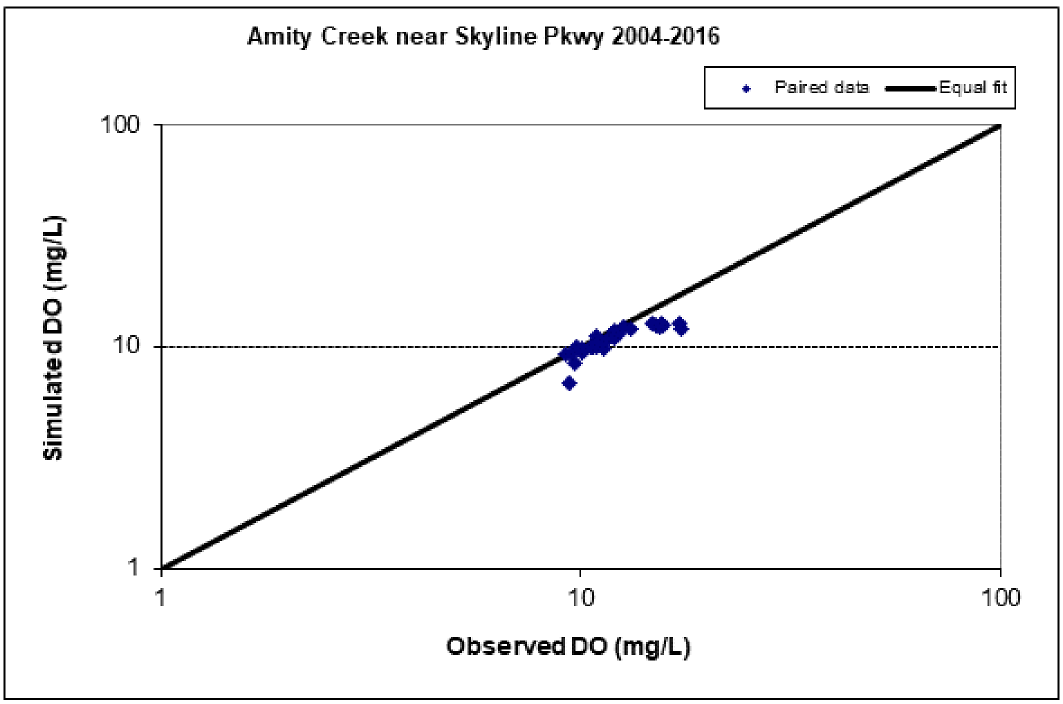


Figure E-306. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Amity Creek near Skyline Pkwy (calibration period)

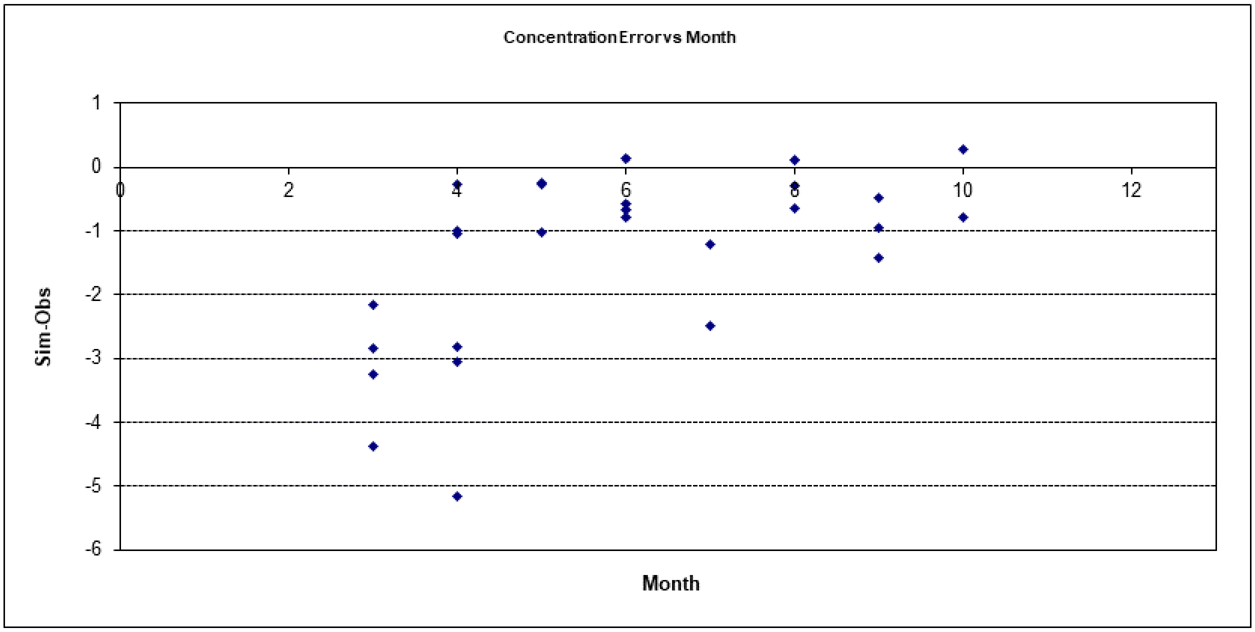


Figure E-307. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Amity Creek near Skyline Pkwy

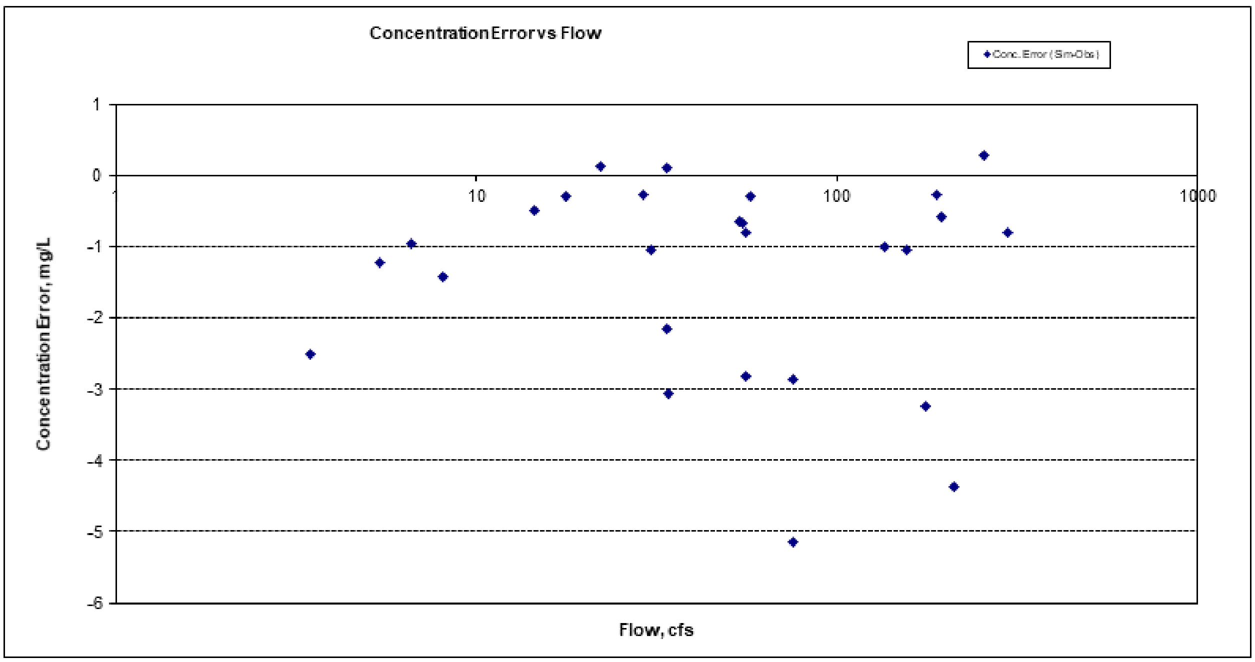


Figure E-308. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Amity Creek near Skyline Pkwy

E.6 Unnamed Stream to Amity Creek

E.6.1 Dissolved Oxygen (DO)

Table E-37. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	27
Concentration Average Error		-20.23%
Concentration Median Error		-12.94%
Load Average Error		-8.88%
Load Median Error		-4.37%
Paired t conc		0.48
Paired t load		0.67

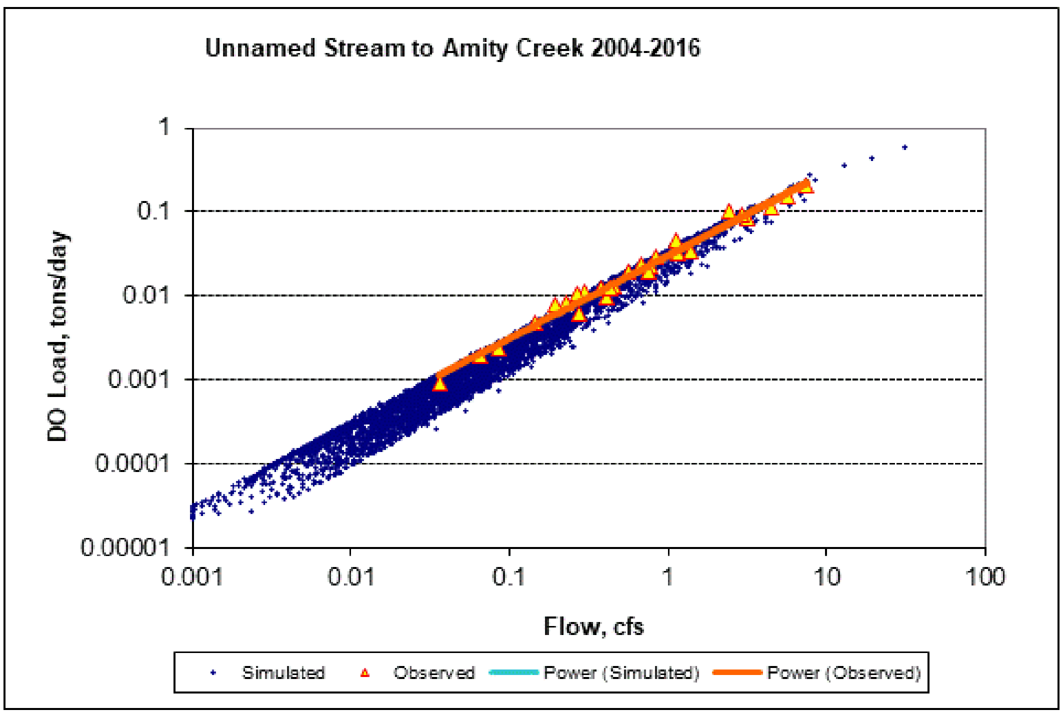


Figure E-309. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Unnamed Stream to Amity Creek (calibration period)

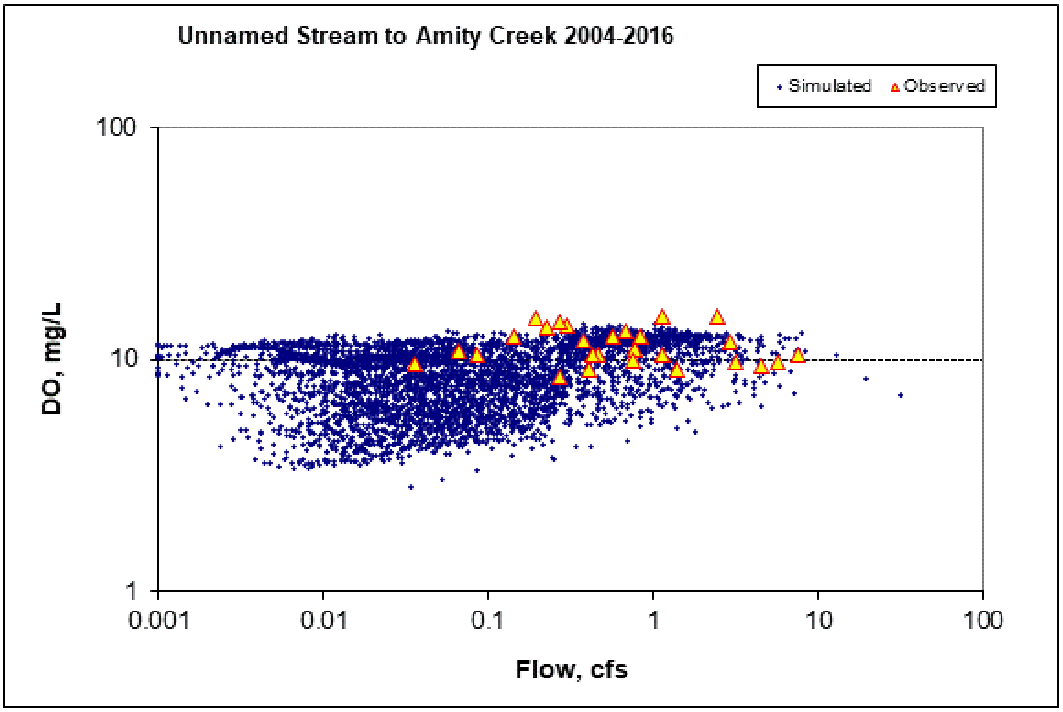
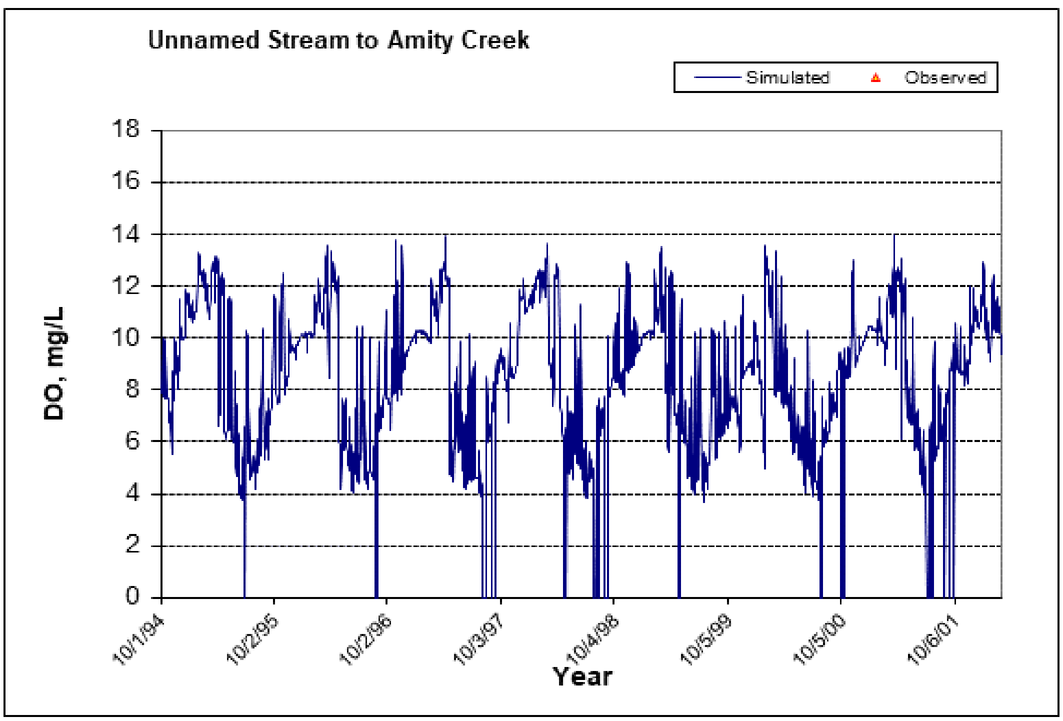
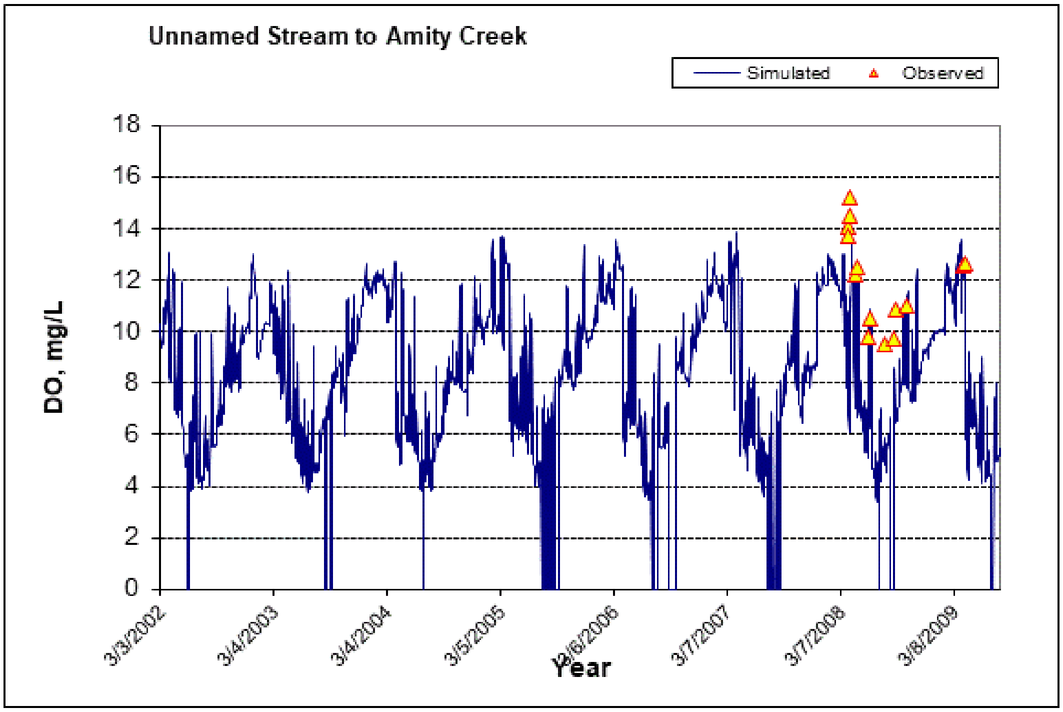


Figure E-310. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Unnamed Stream to Amity Creek (calibration period)





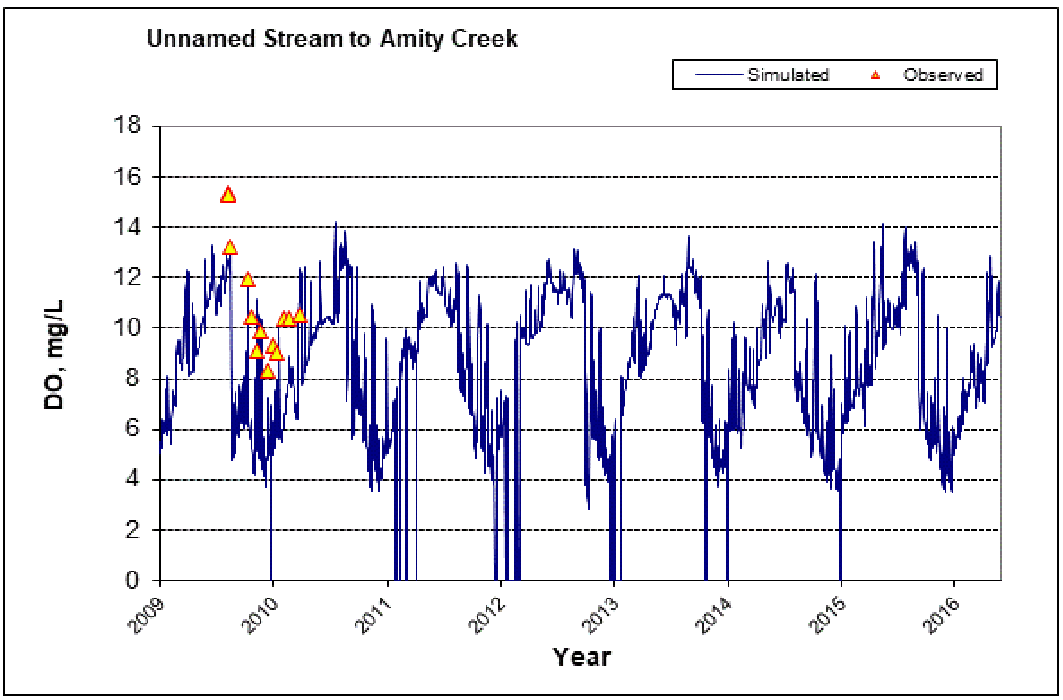


Figure E-311. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Unnamed Stream to Amity Creek

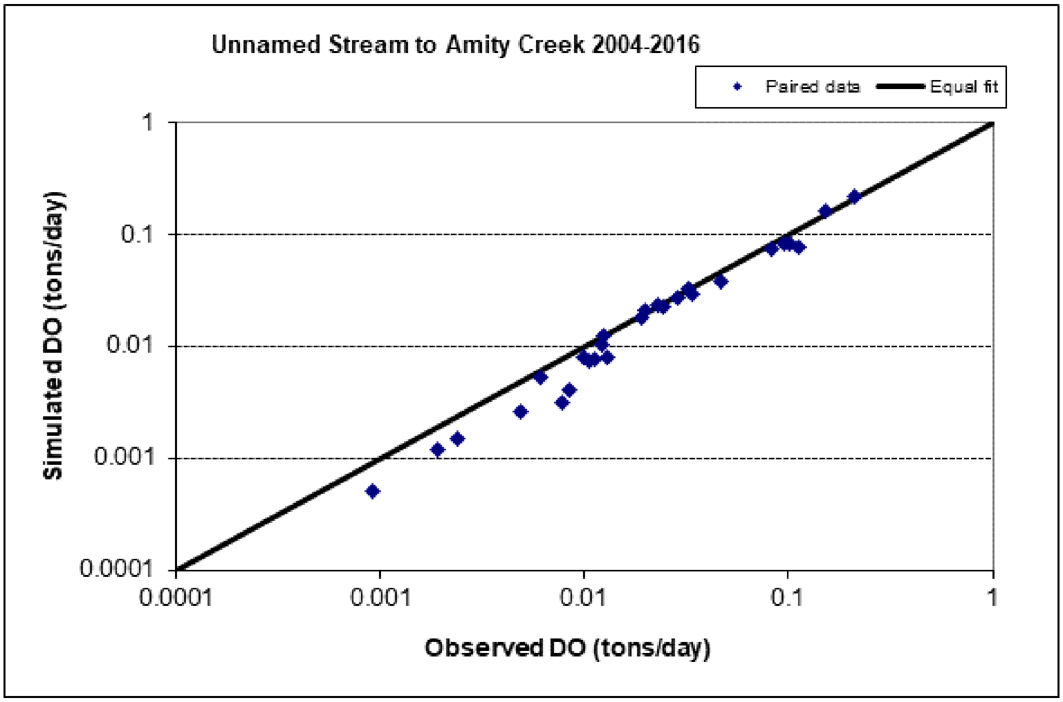


Figure E-312. Paired simulated vs. observed Dissolved Oxygen (DO) load at Unnamed Stream to Amity Creek (calibration period)

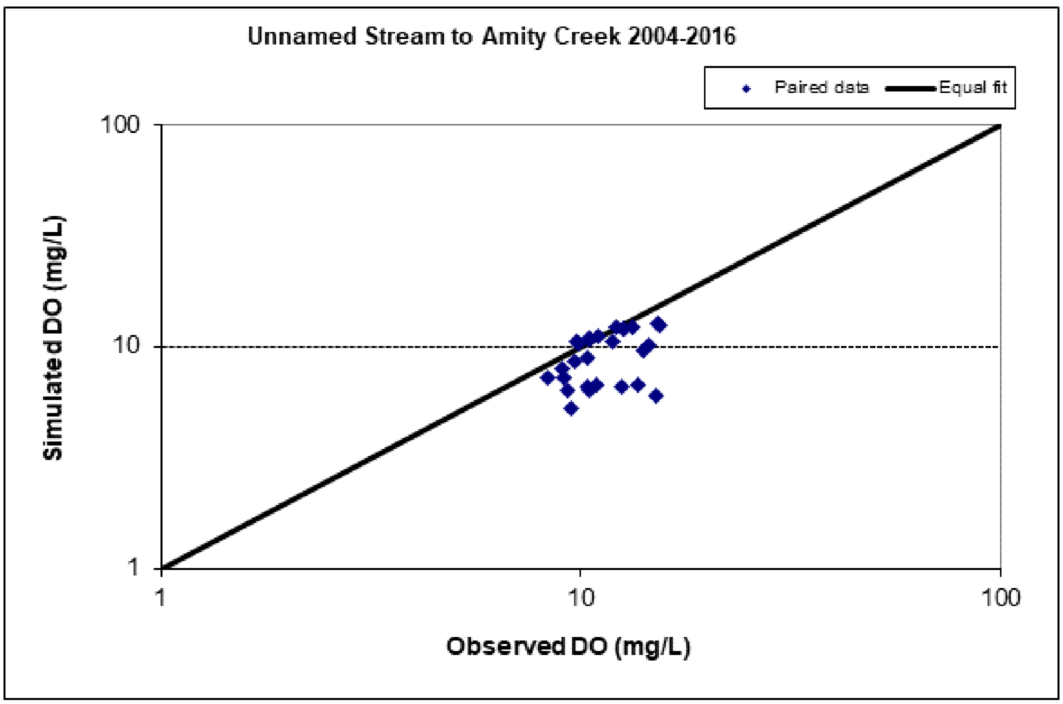


Figure E-313. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Unnamed Stream to Amity Creek (calibration period)

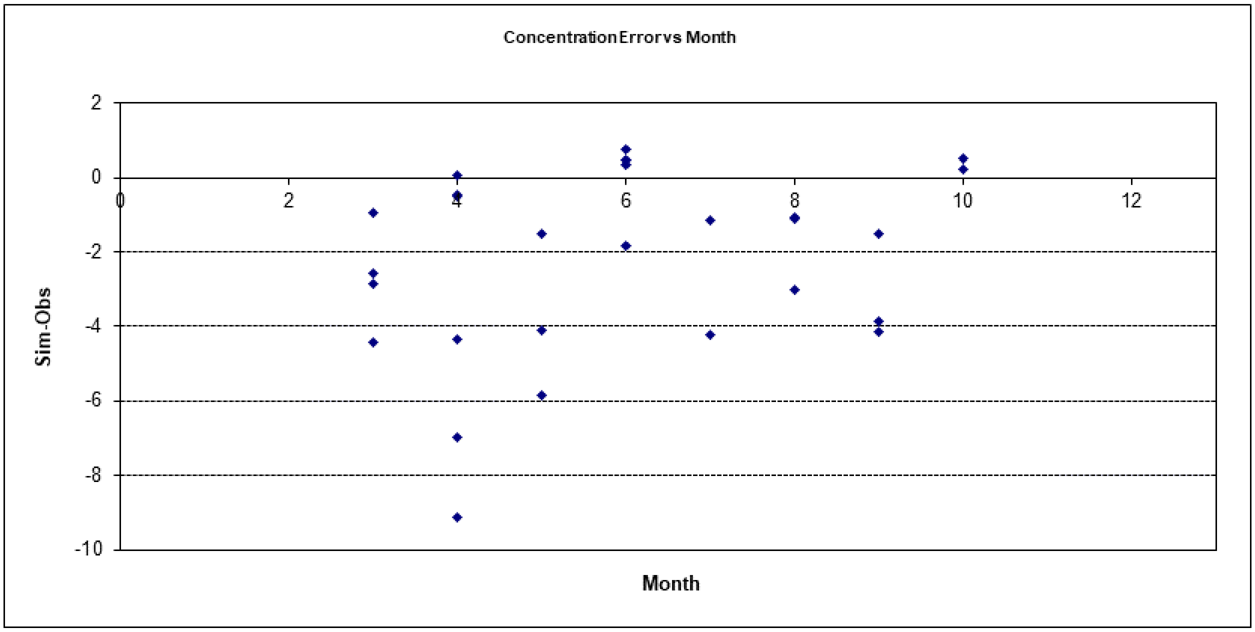


Figure E-314. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Unnamed Stream to Amity Creek

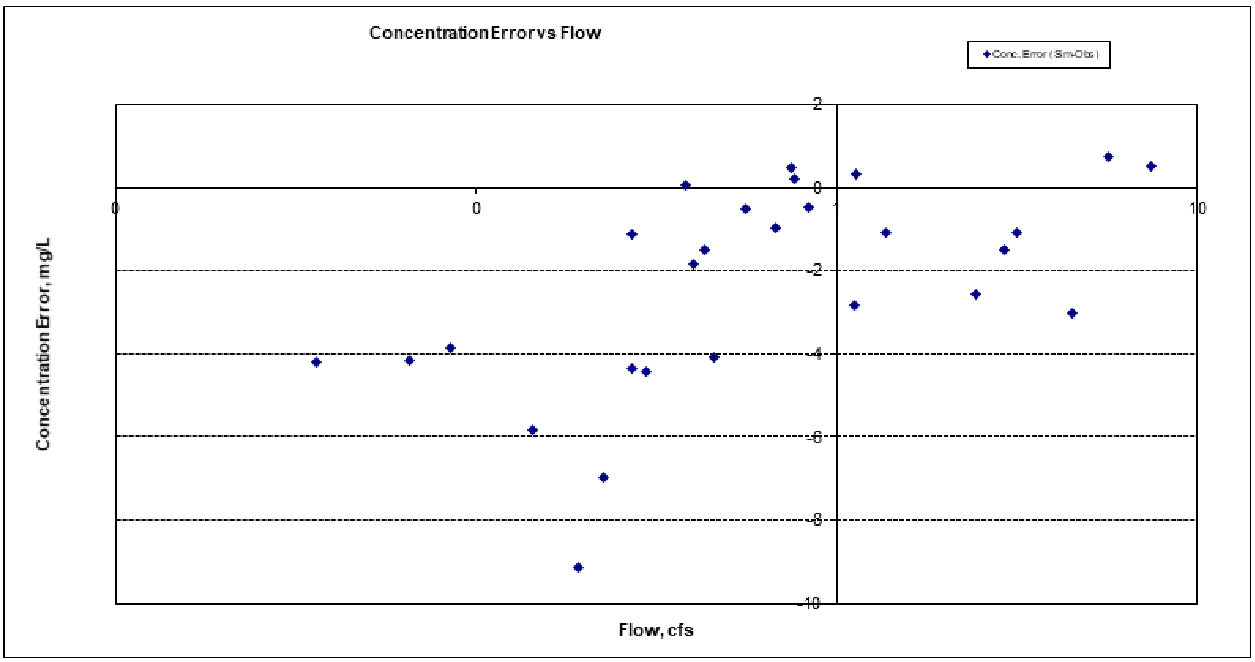


Figure E-315. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Unnamed Stream to Amity Creek

E.7 Amity Creek at Occidental Blvd, Duluth

E.7.1 Dissolved Oxygen (DO)

Table E-38. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	35	113
Concentration Average Error	-13.20%	-10.64%
Concentration Median Error	-10.25%	-9.88%
Load Average Error	-9.23%	-6.97%
Load Median Error	-4.06%	-2.09%
Paired t conc	0.99	1.00
Paired t load	0.64	0.86

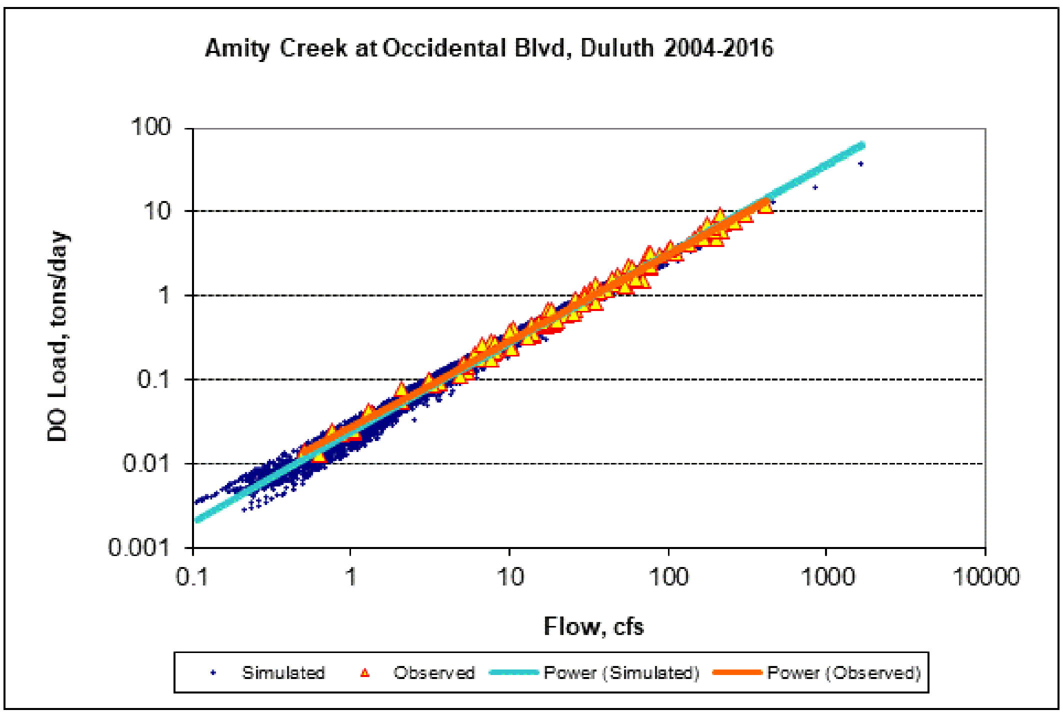


Figure E-316. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

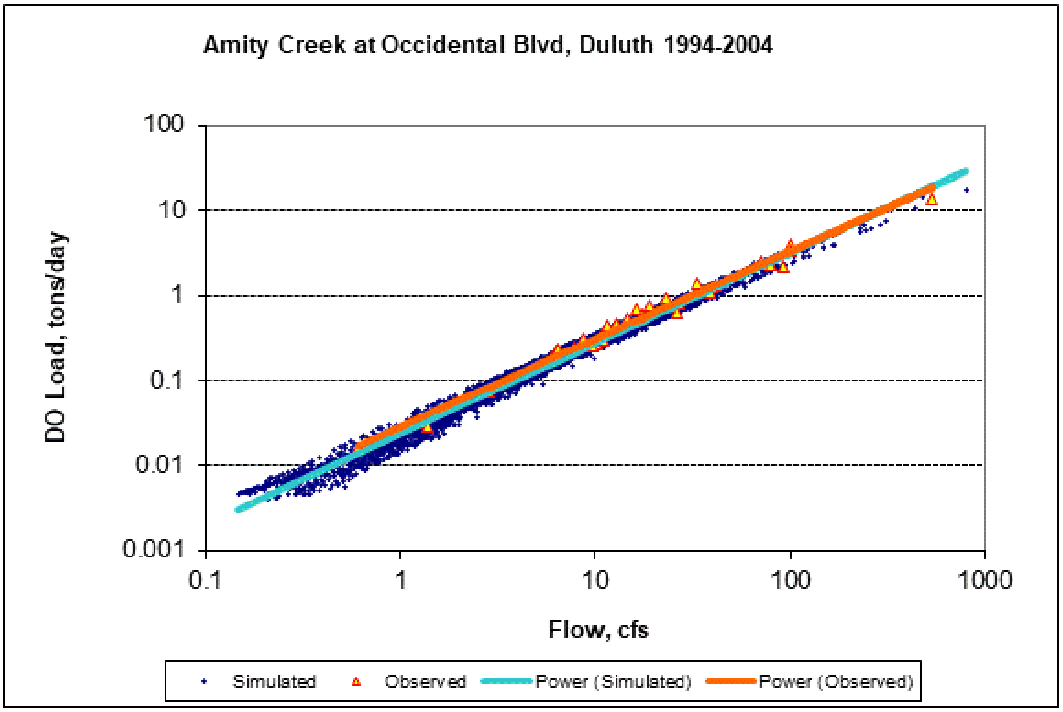


Figure E-317. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)

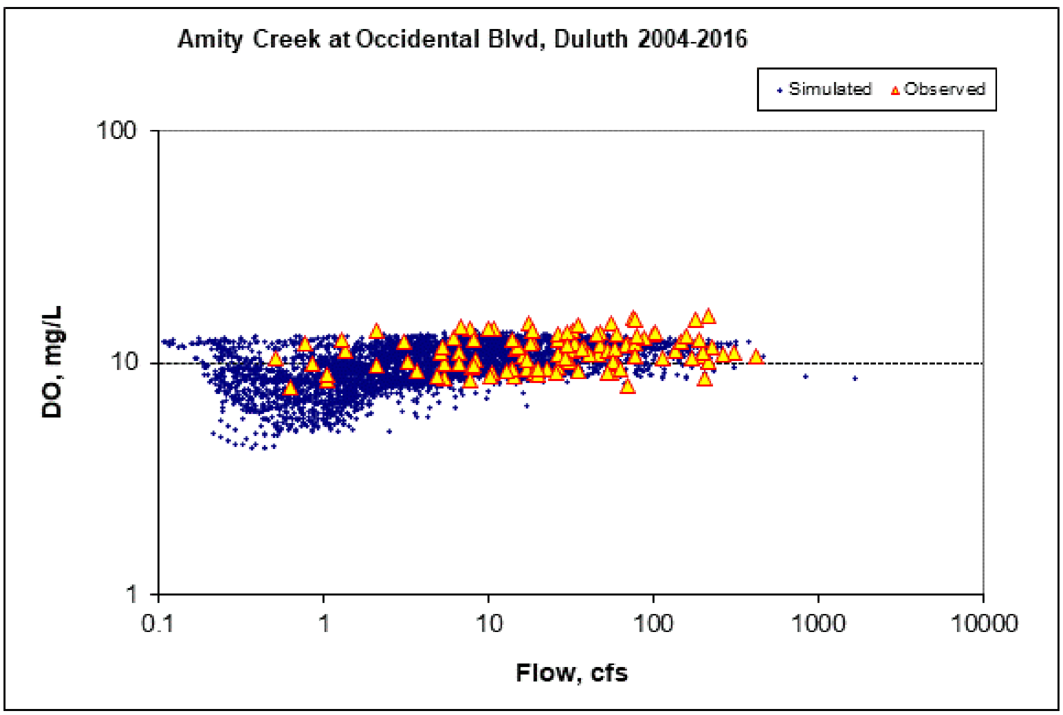


Figure E-318. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

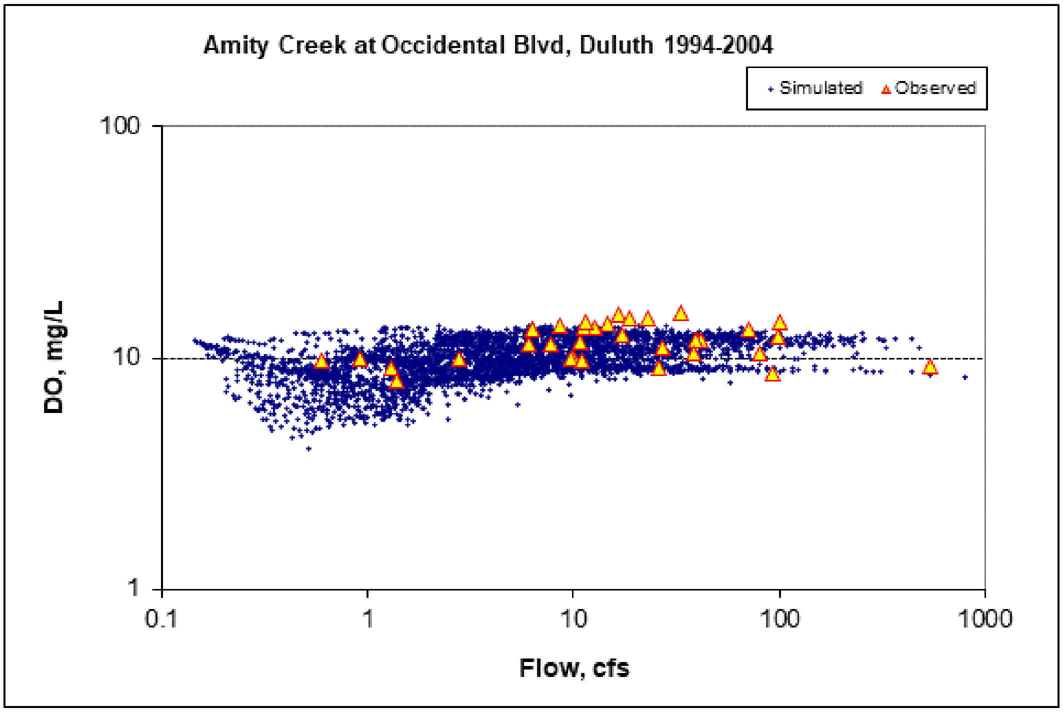
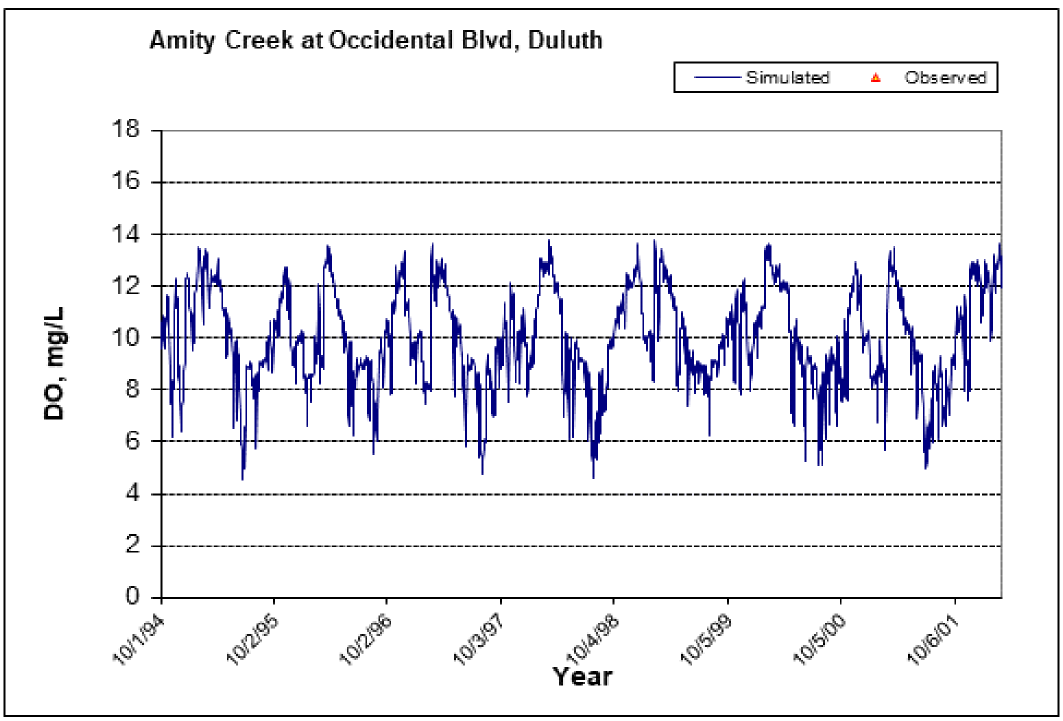


Figure E-319. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)



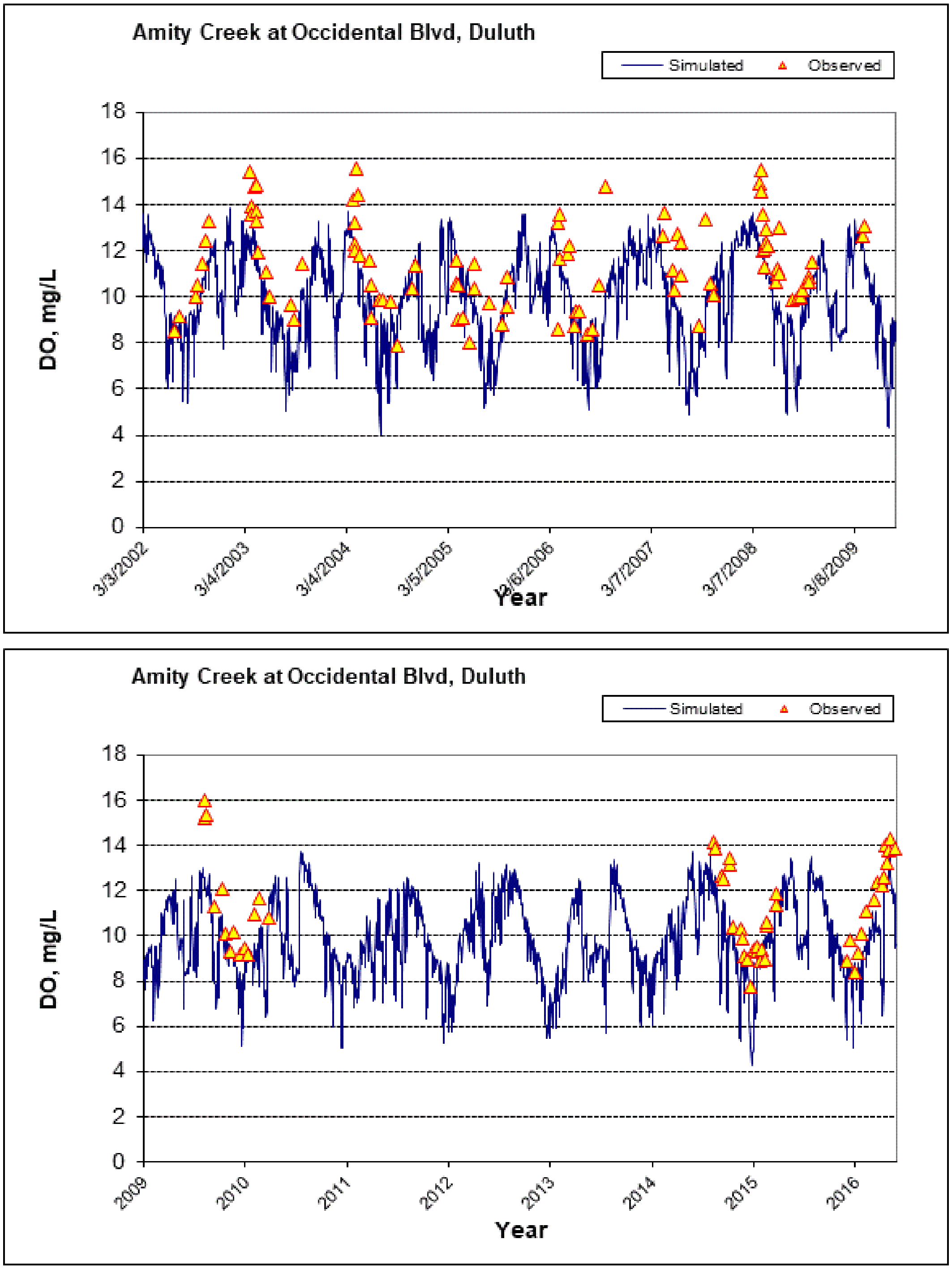


Figure E-320. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Amity Creek at Occidental Blvd, Duluth

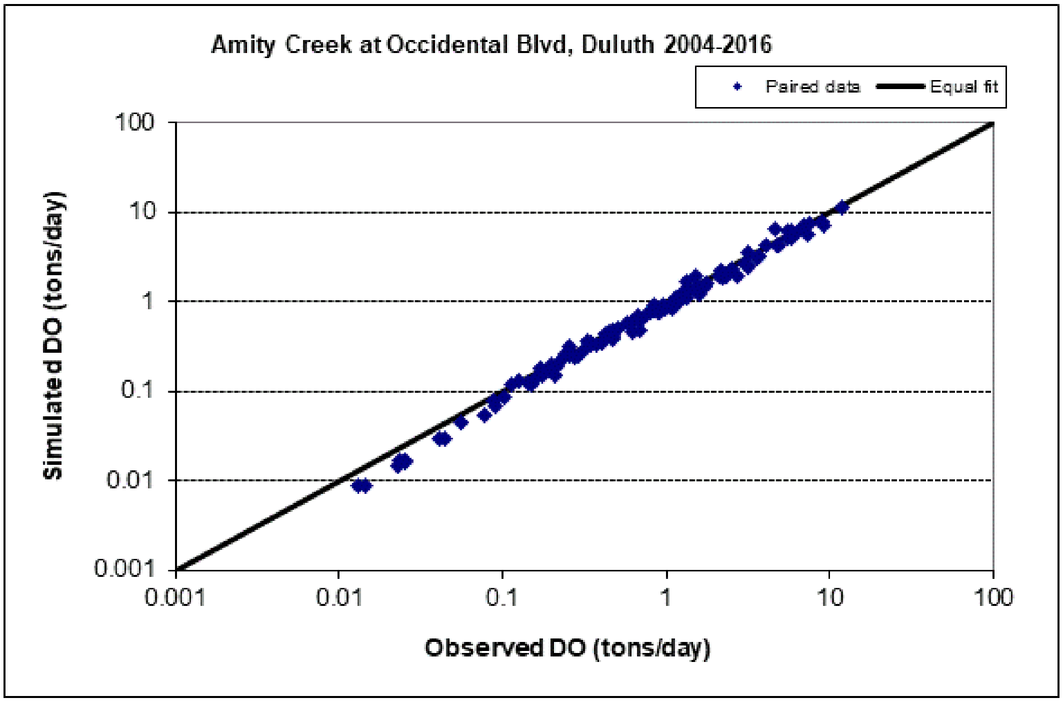


Figure E-321. Paired simulated vs. observed Dissolved Oxygen (DO) load at Amity Creek at Occidental Blvd, Duluth (calibration period)

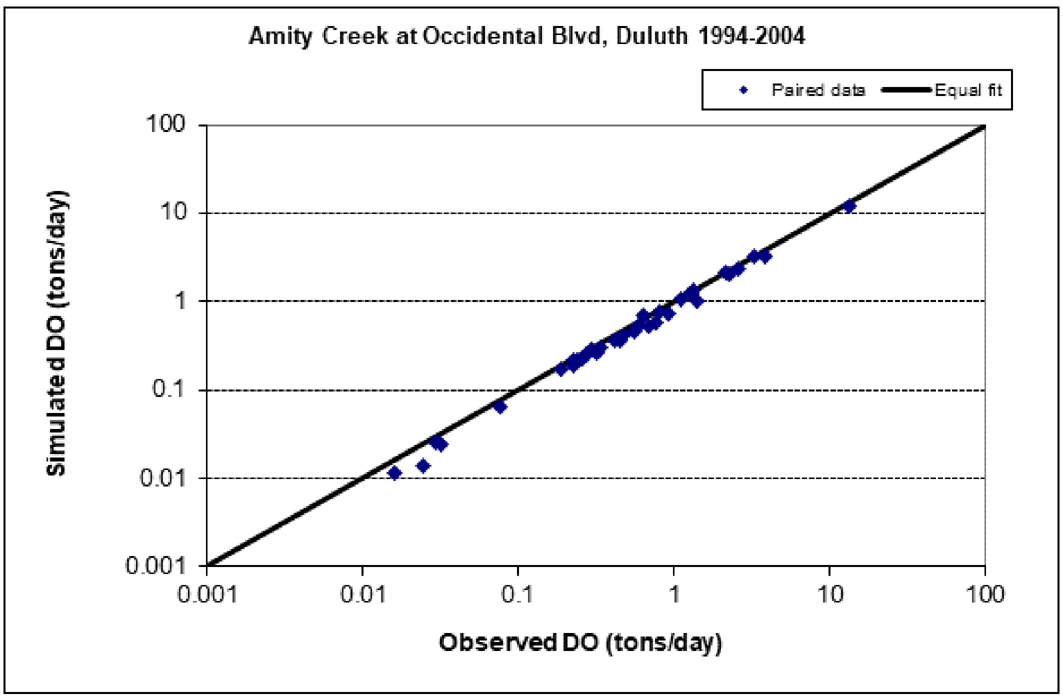


Figure E-322. Paired simulated vs. observed Dissolved Oxygen (DO) load at Amity Creek at Occidental Blvd, Duluth (validation period)

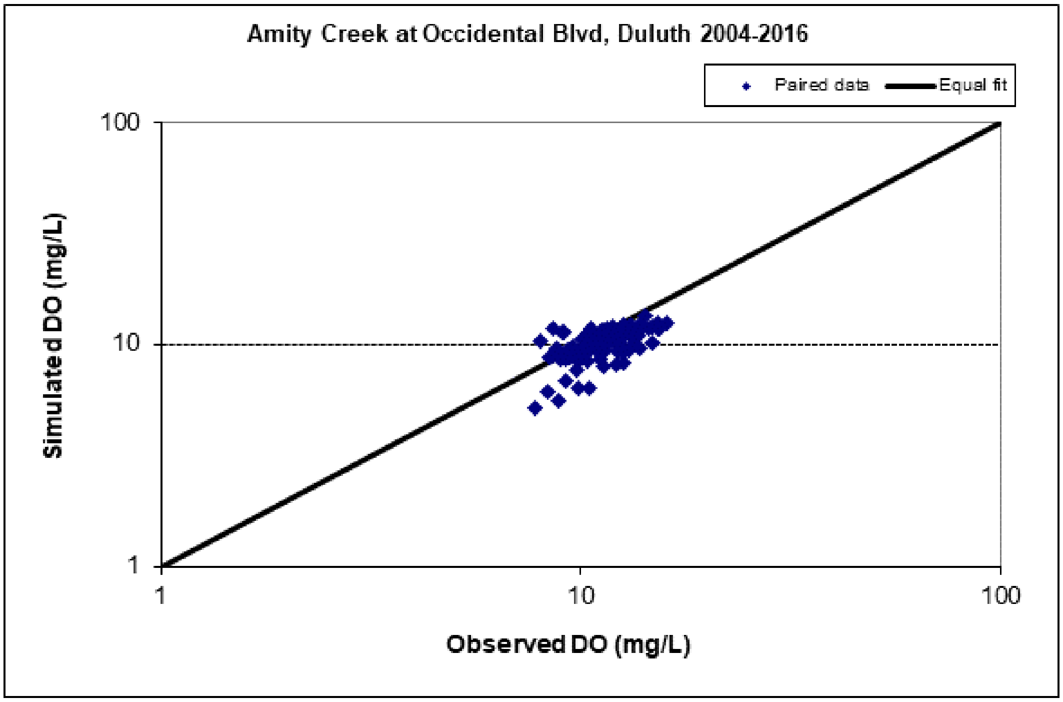


Figure E-323. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Amity Creek at Occidental Blvd, Duluth (calibration period)

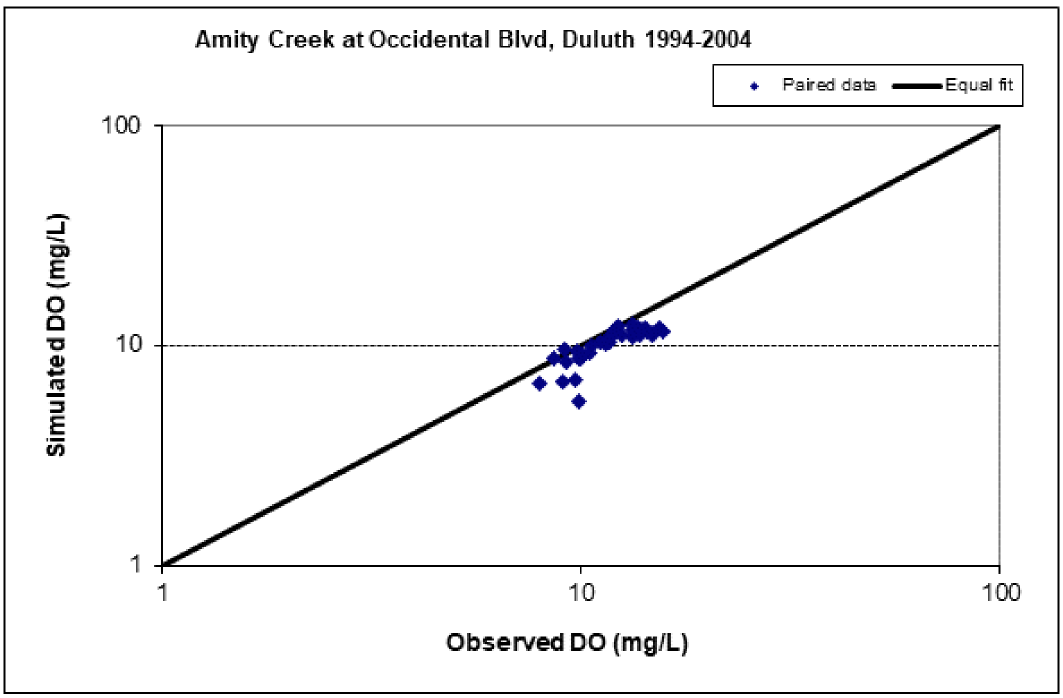


Figure E-324. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Amity Creek at Occidental Blvd, Duluth (validation period)

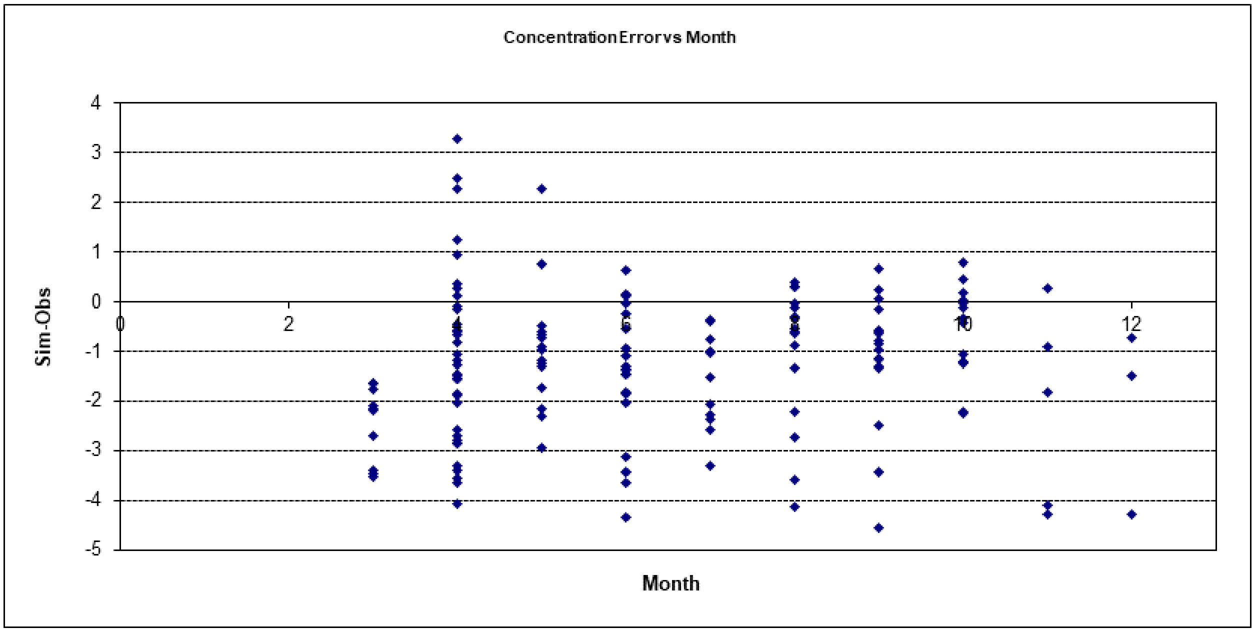


Figure E-325. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Amity Creek at Occidental Blvd, Duluth

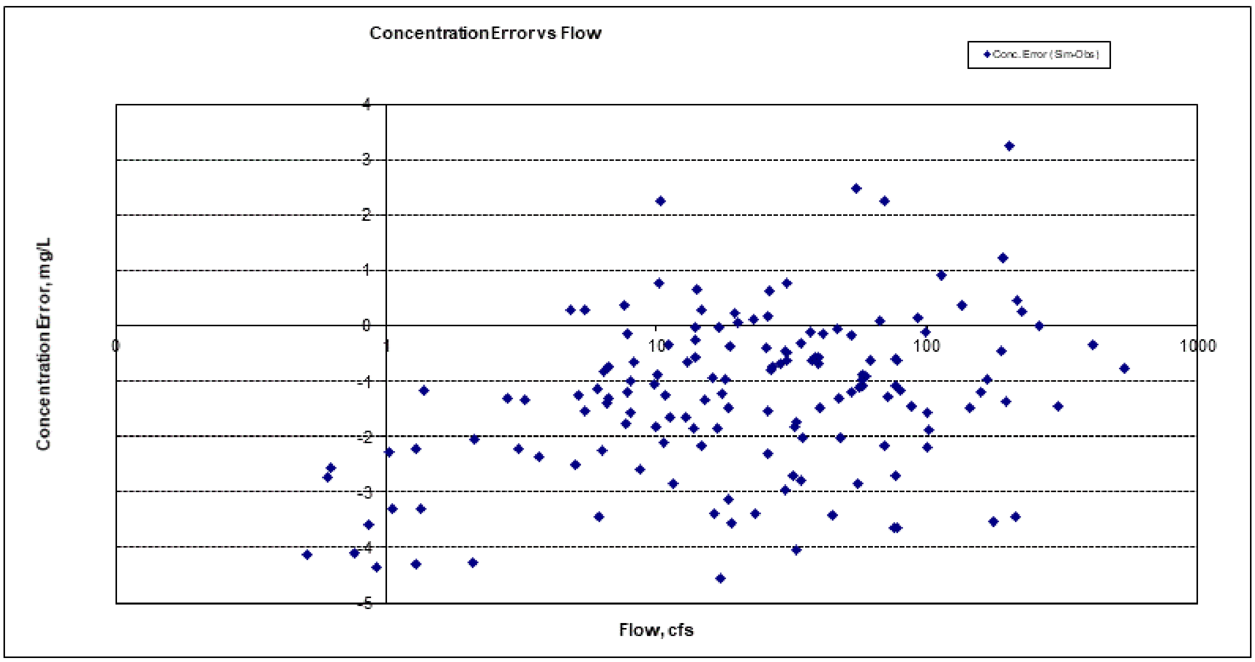


Figure E-326. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Amity Creek at Occidental Blvd, Duluth

E.7.2 Ammonia Nitrogen (NH3)

Table E-39. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	12
Concentration Average Error		121.65%
Concentration Median Error		129.64%
Load Average Error		-11.05%
Load Median Error		26.58%
Paired t conc		0.07
Paired t load		0.58

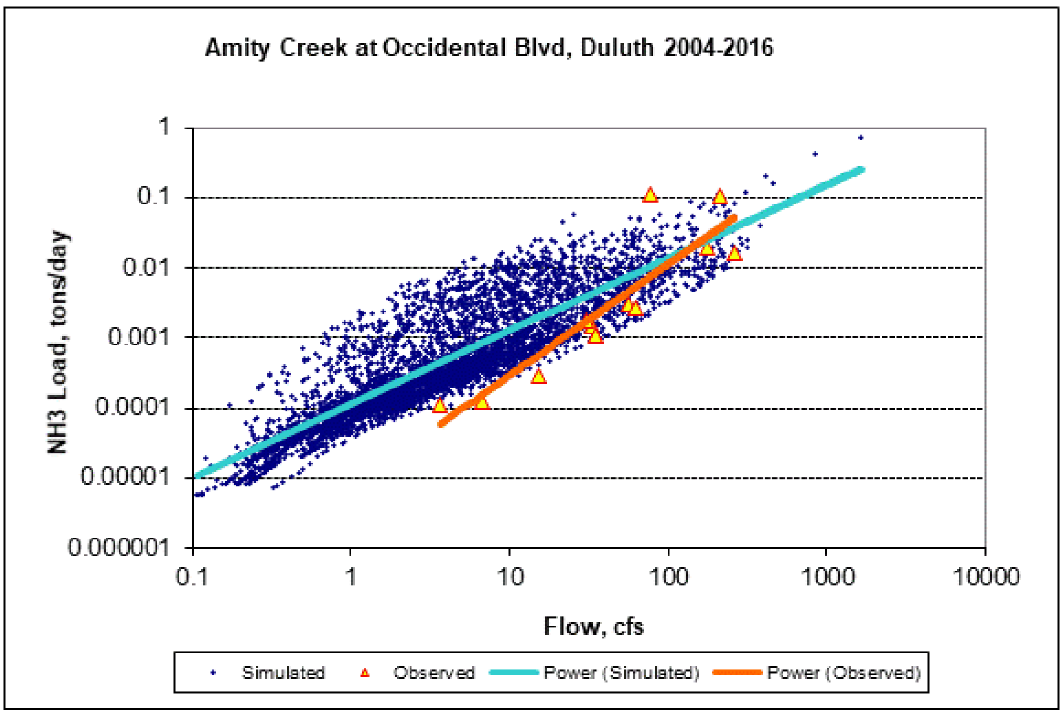


Figure E-327. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

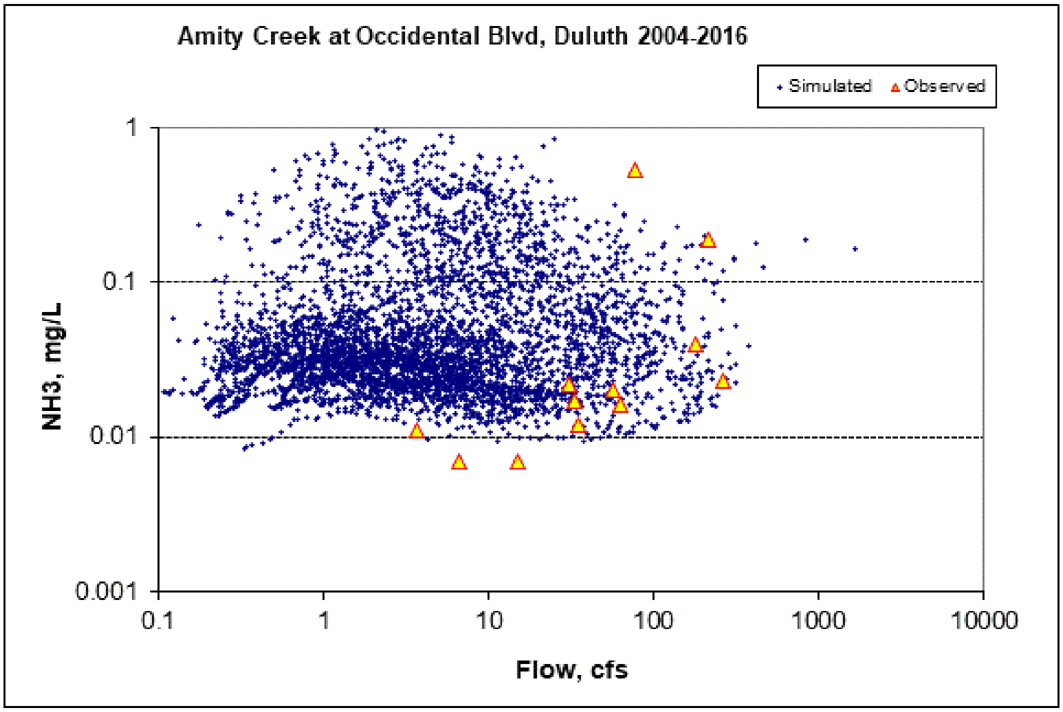
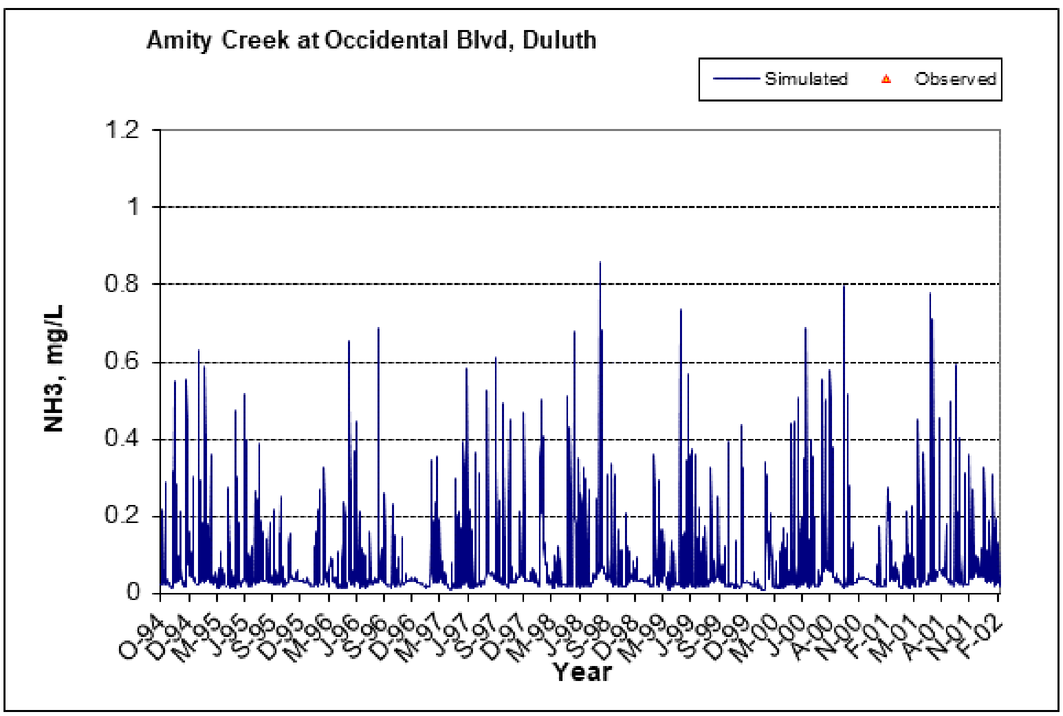


Figure E-328. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)



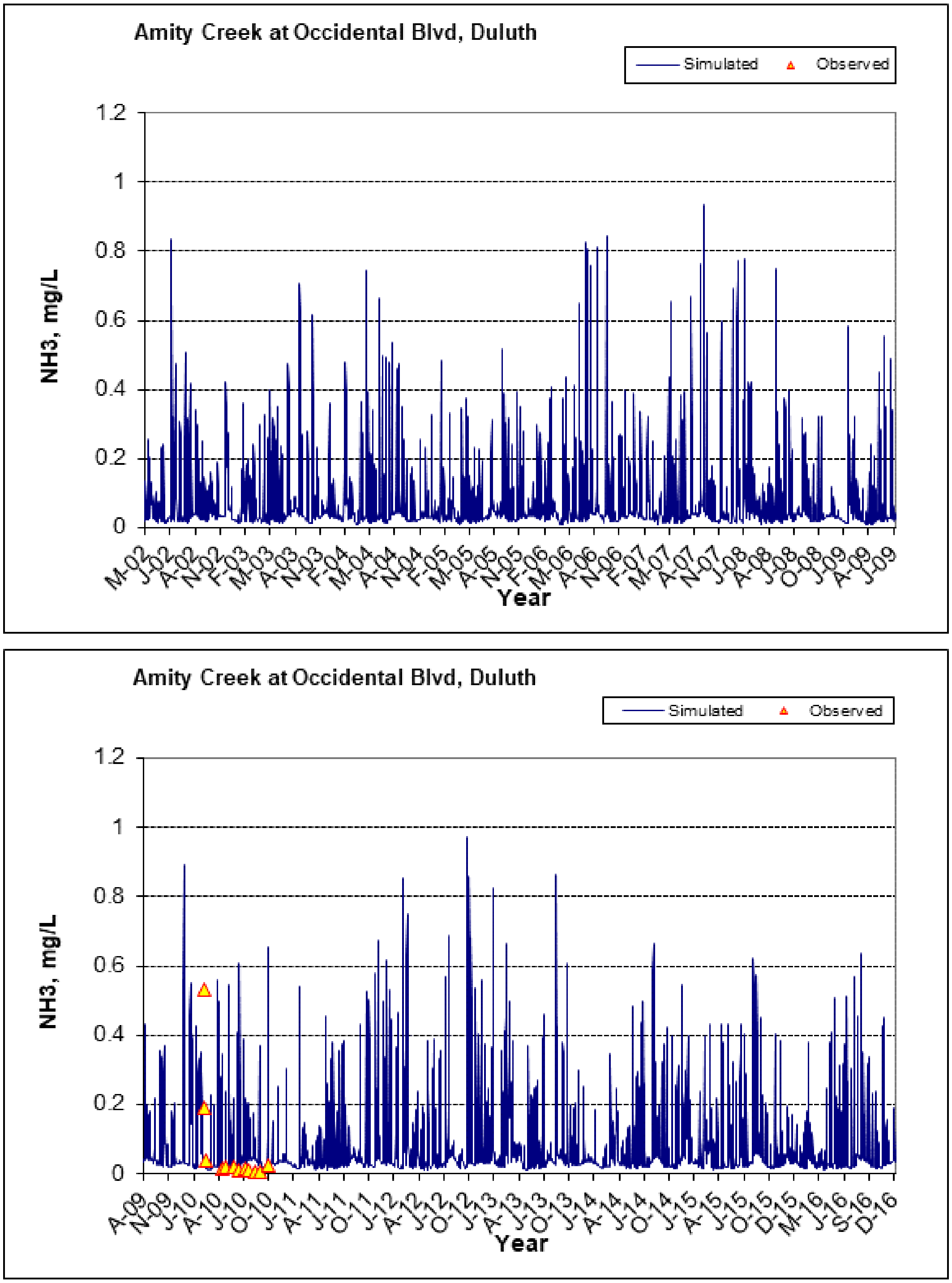


Figure E-329. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Amity Creek at Occidental Blvd, Duluth

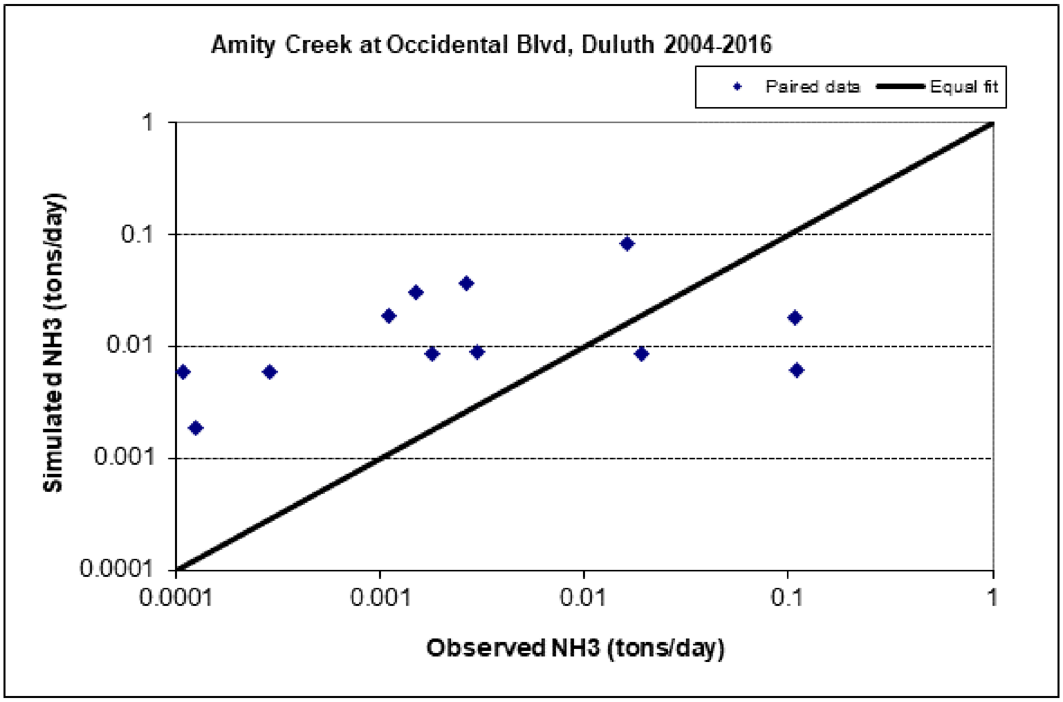


Figure E-330. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Amity Creek at Occidental Blvd, Duluth (calibration period)

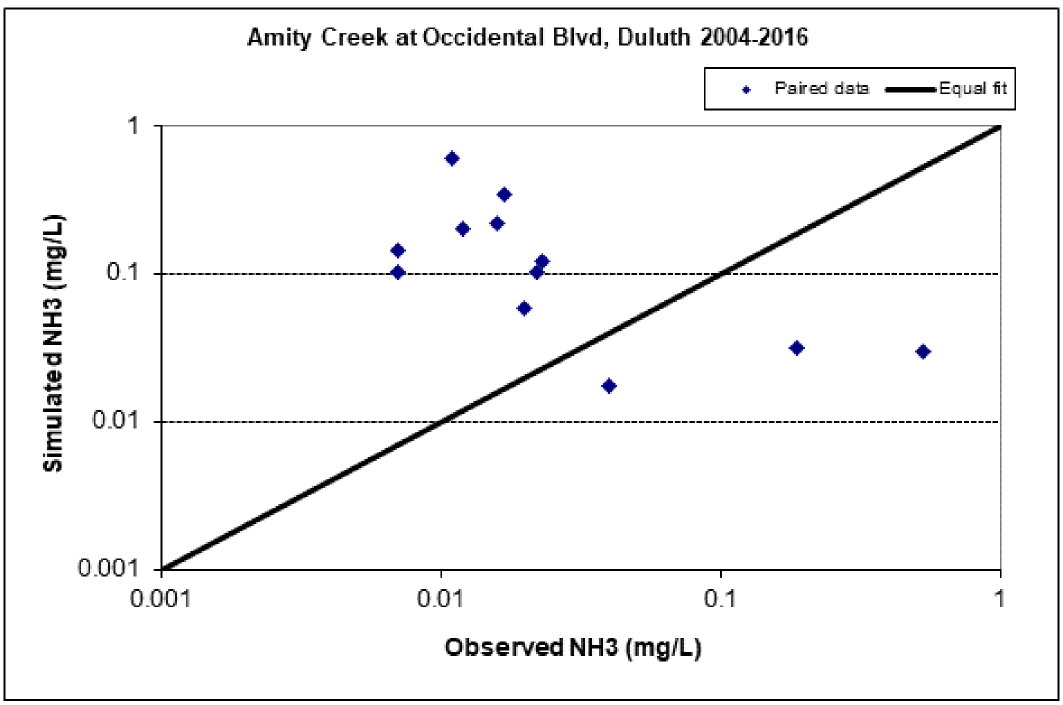


Figure E-331. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Amity Creek at Occidental Blvd, Duluth (calibration period)

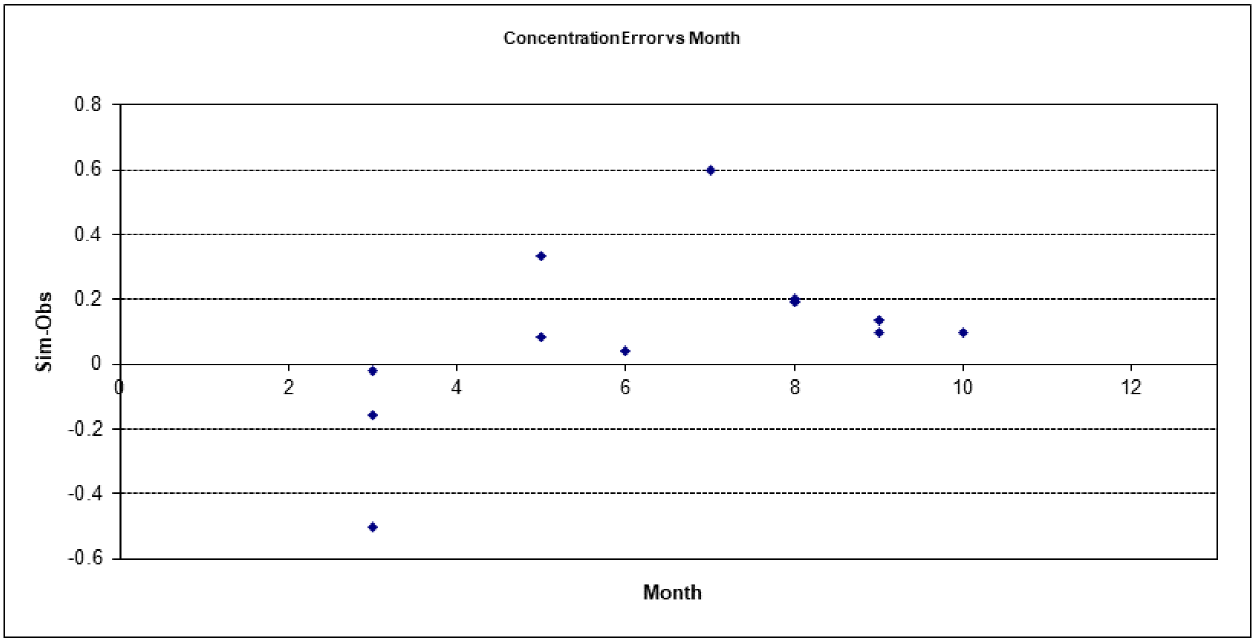


Figure E-332. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Amity Creek at Occidental Blvd, Duluth

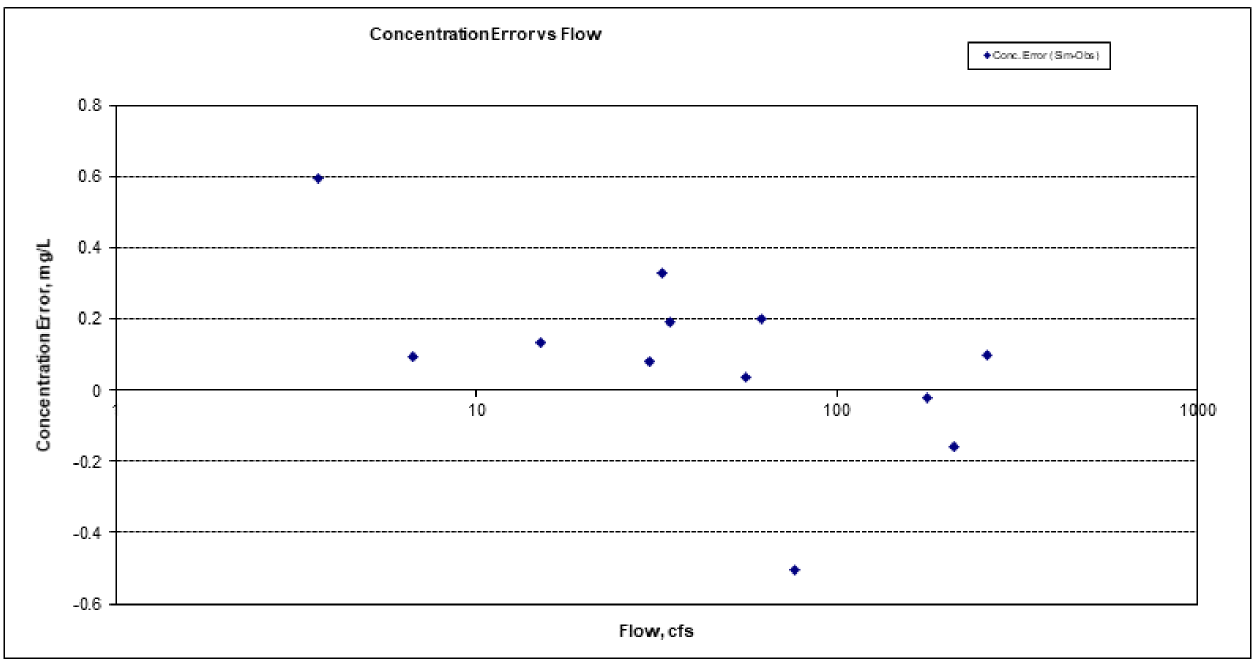


Figure E-333. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Amity Creek at Occidental Blvd, Duluth

E.7.3 Organic Nitrogen (OrgN)

Table E-40. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	ND	12
Concentration Average Error		-24.92%
Concentration Median Error		-22.77%
Load Average Error		-20.79%
Load Median Error		-7.02%
Paired t conc		0.32
Paired t load		0.49

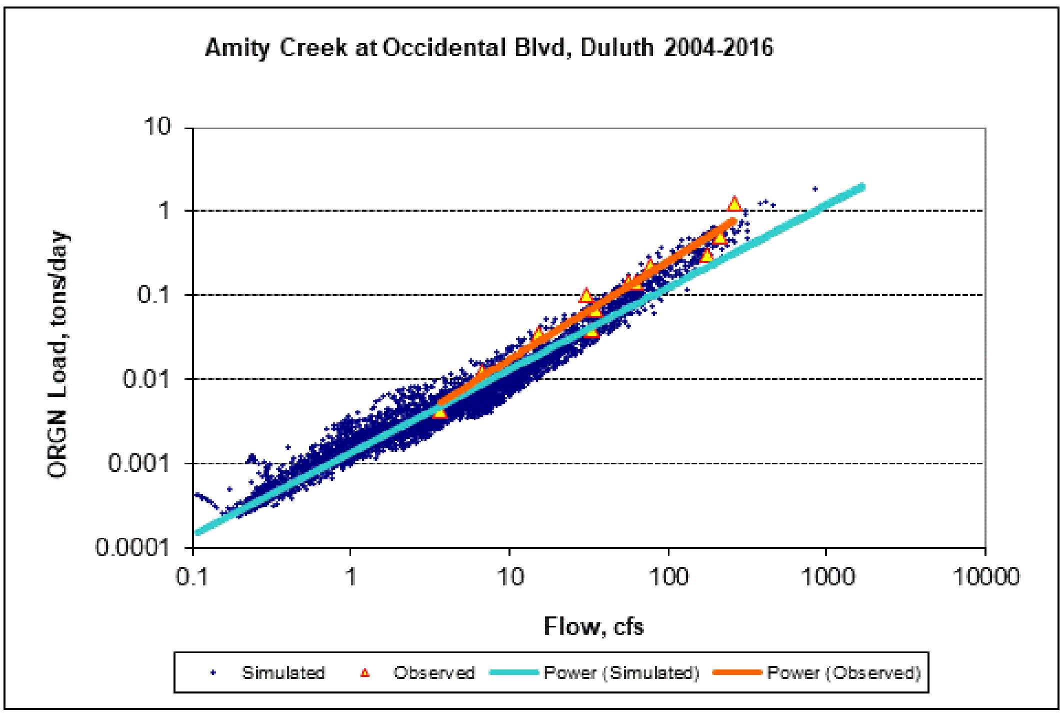


Figure E-334. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

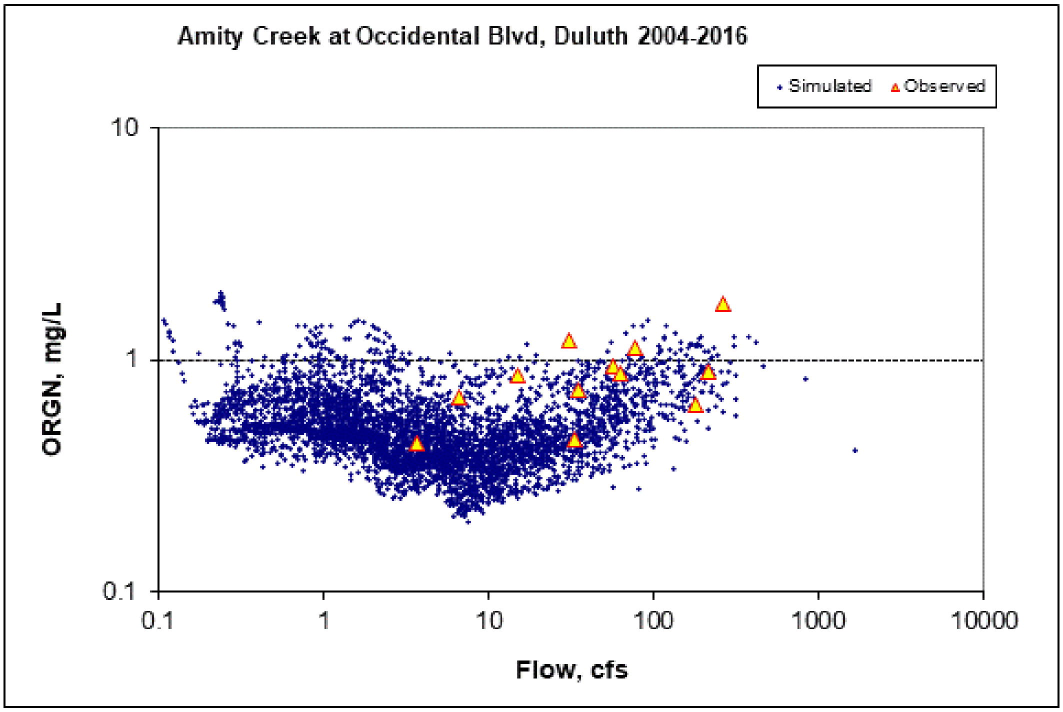
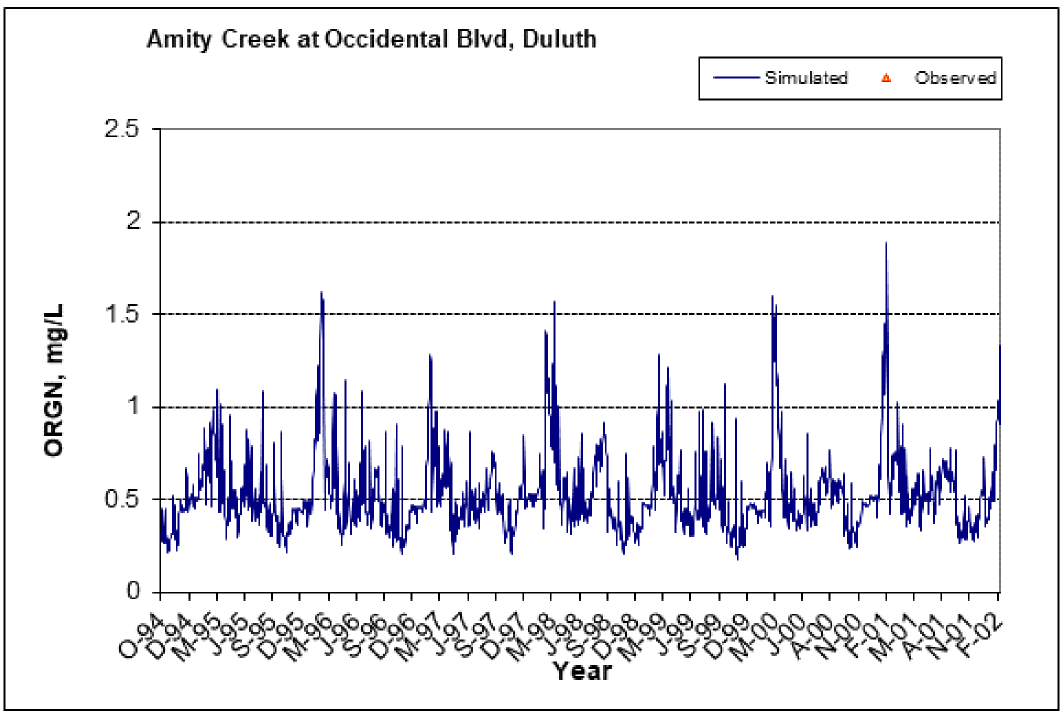


Figure E-335. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)



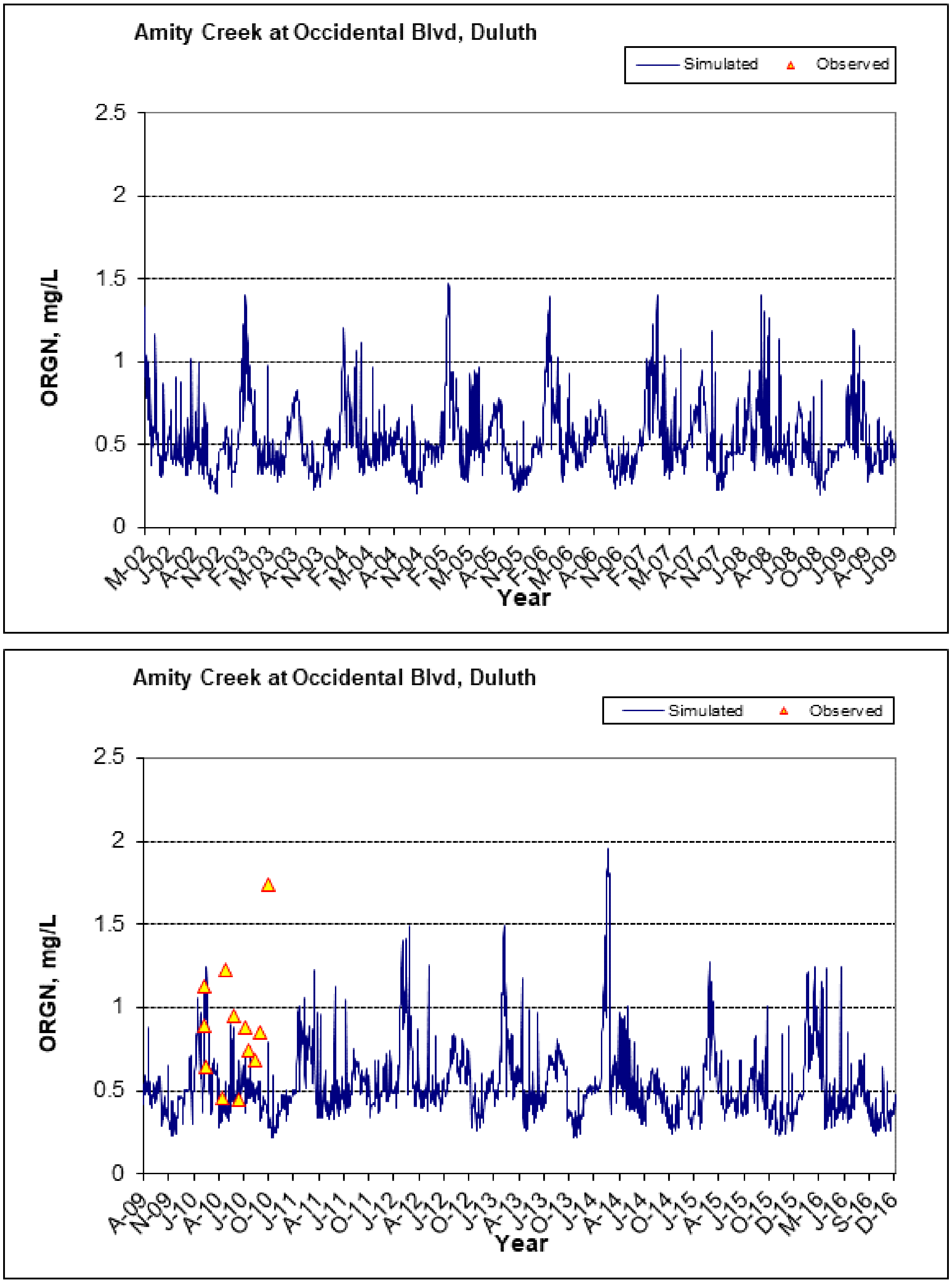


Figure E-336. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Amity Creek at Occidental Blvd, Duluth

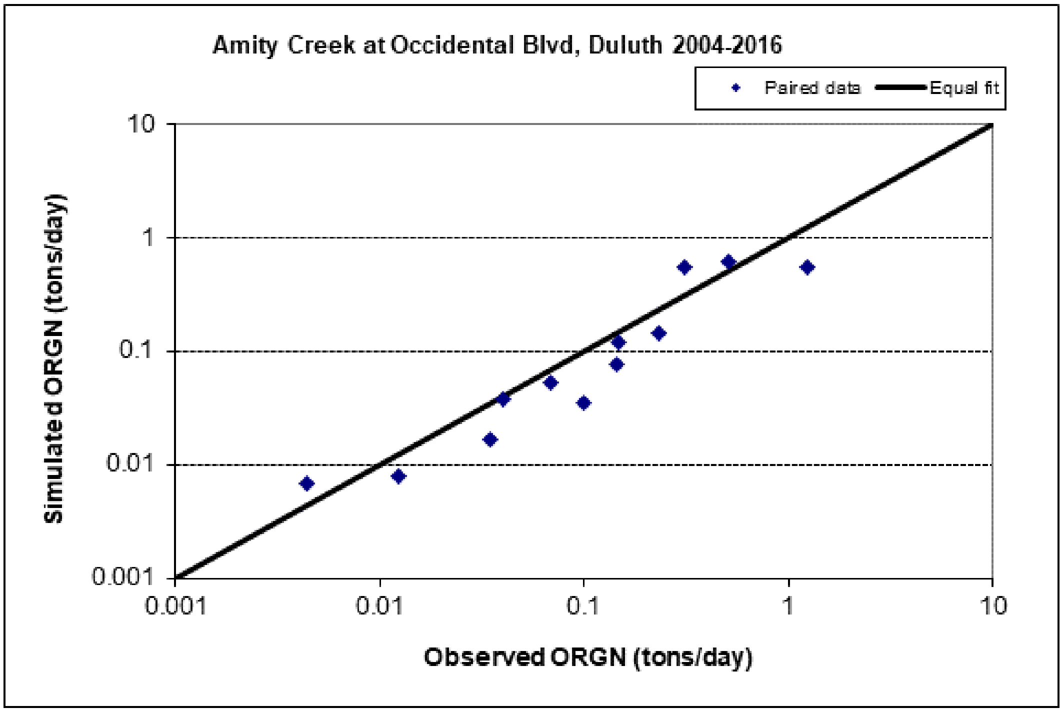


Figure E-337. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Amity Creek at Occidental Blvd, Duluth (calibration period)

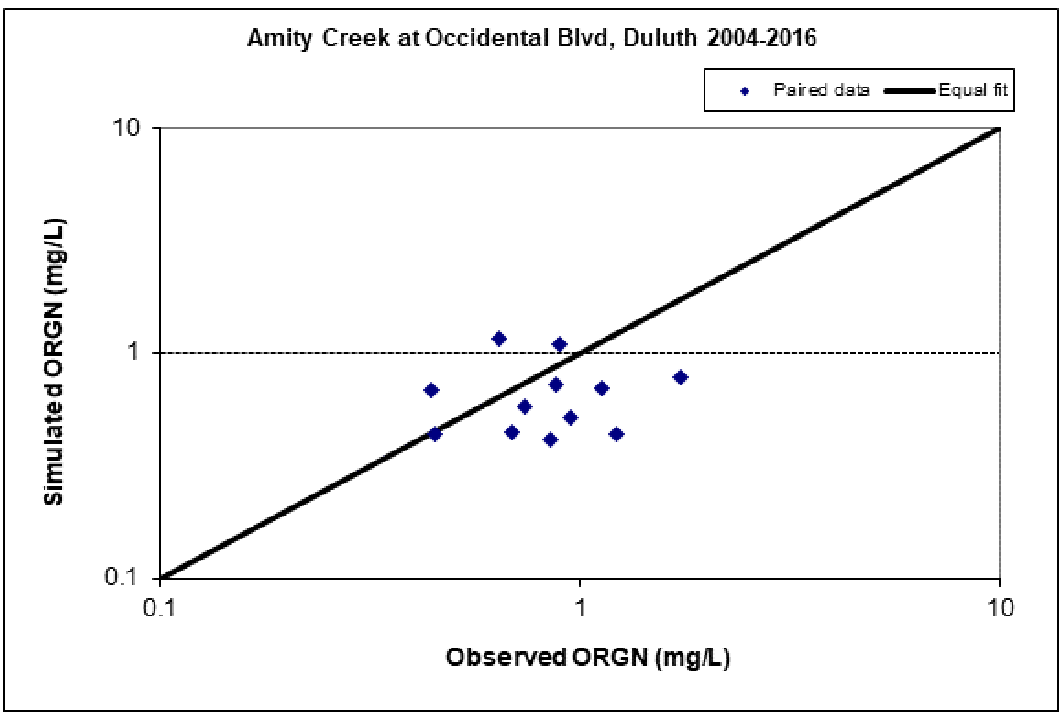


Figure E-338. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Amity Creek at Occidental Blvd, Duluth (calibration period)

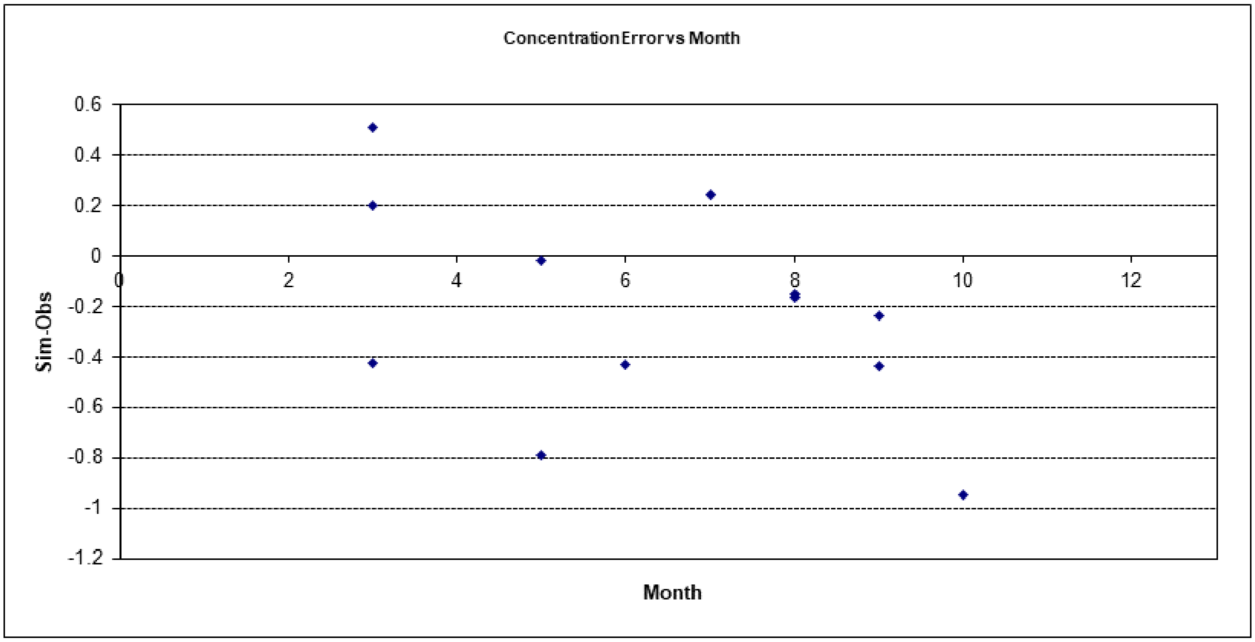


Figure E-339. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at Amity Creek at Occidental Blvd, Duluth

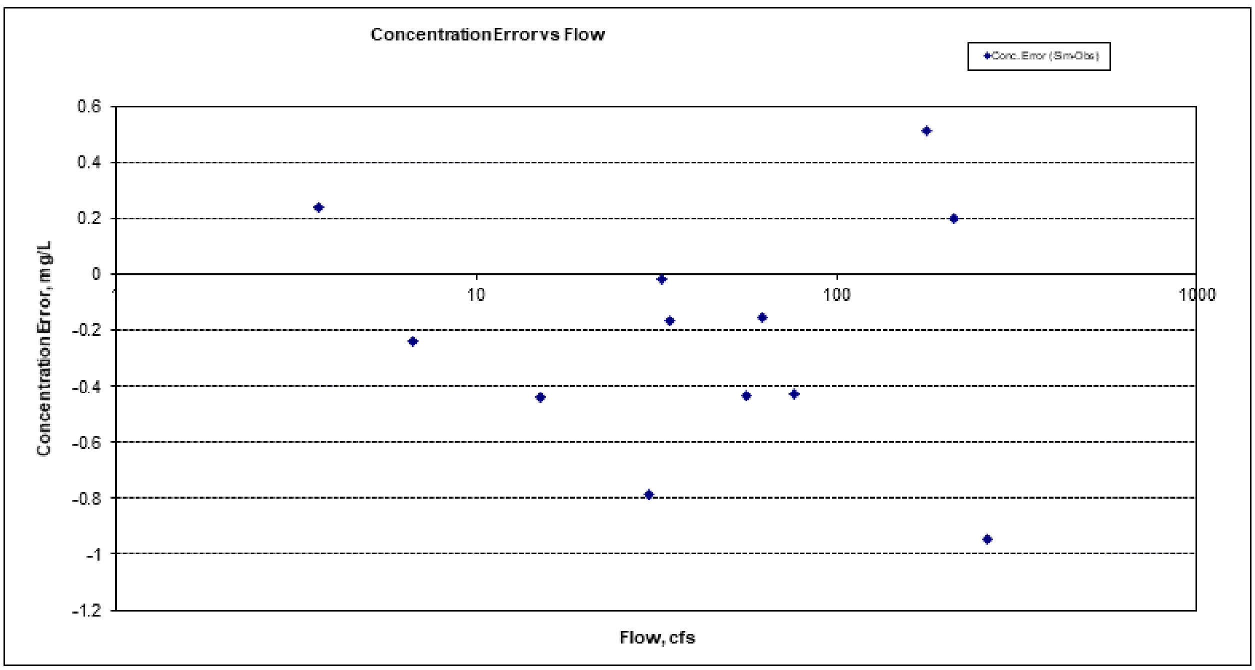


Figure E-340. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at Amity Creek at Occidental Blvd, Duluth

E.7.4 Total Kjeldahl Nitrogen (TKN)

Table E-41. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	57	20
Concentration Average Error	-27.93%	-4.38%
Concentration Median Error	-20.17%	6.31%
Load Average Error	-25.38%	-0.23%
Load Median Error	-7.73%	2.67%
Paired t conc	0.09	0.93
Paired t load	0.42	0.75

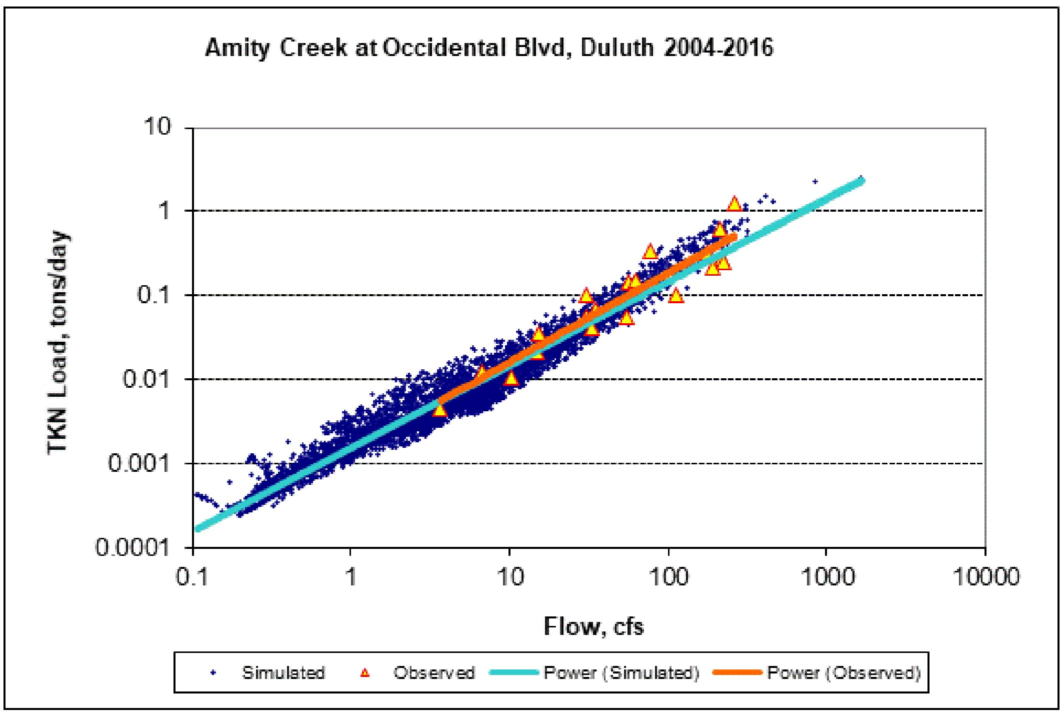


Figure E-341. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

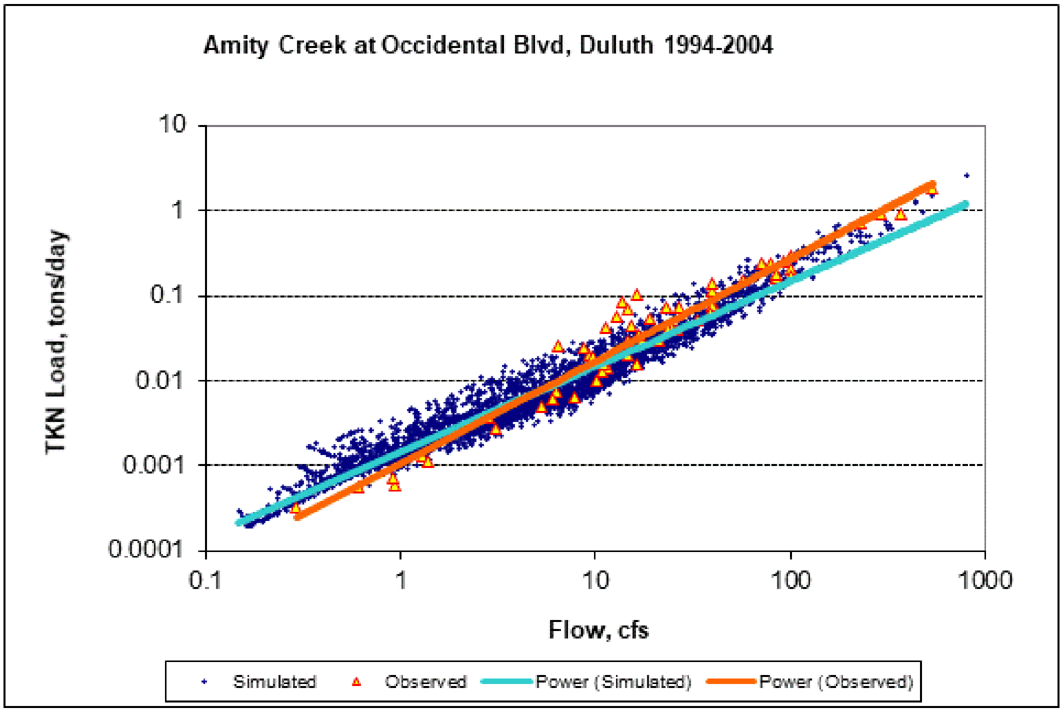


Figure E-342. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)

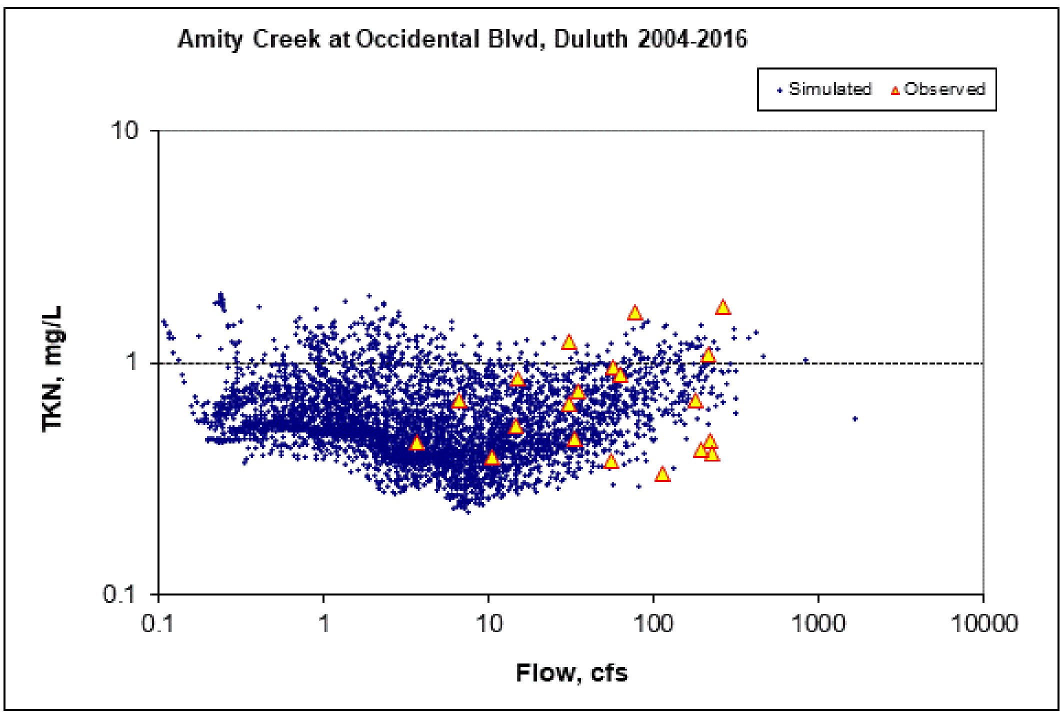


Figure E-343. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

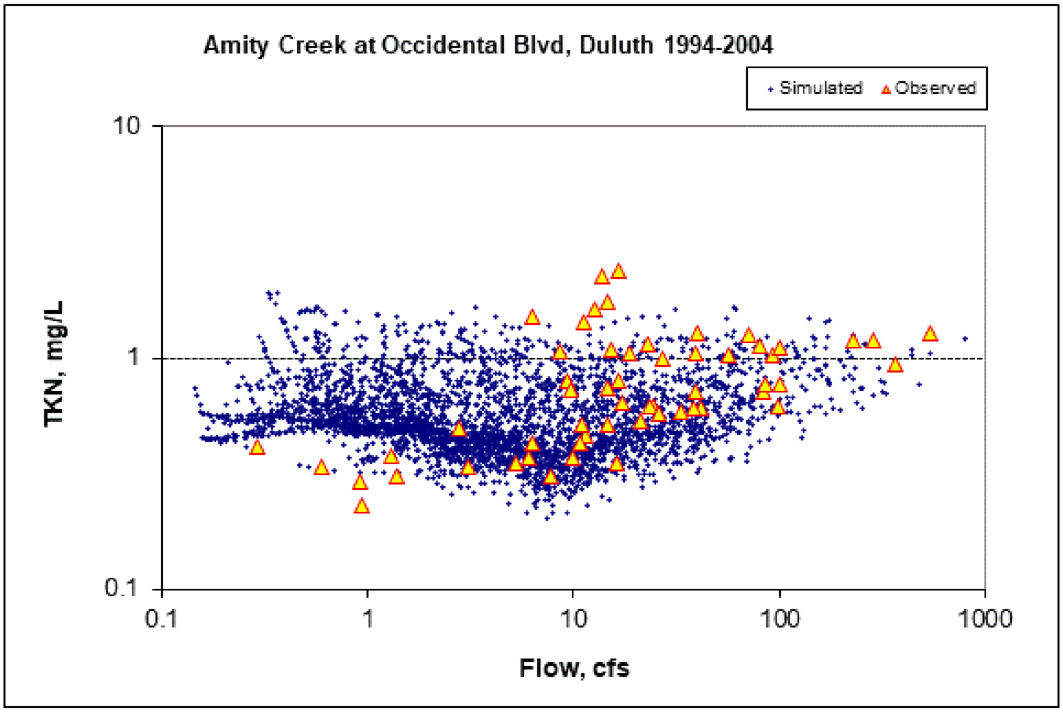
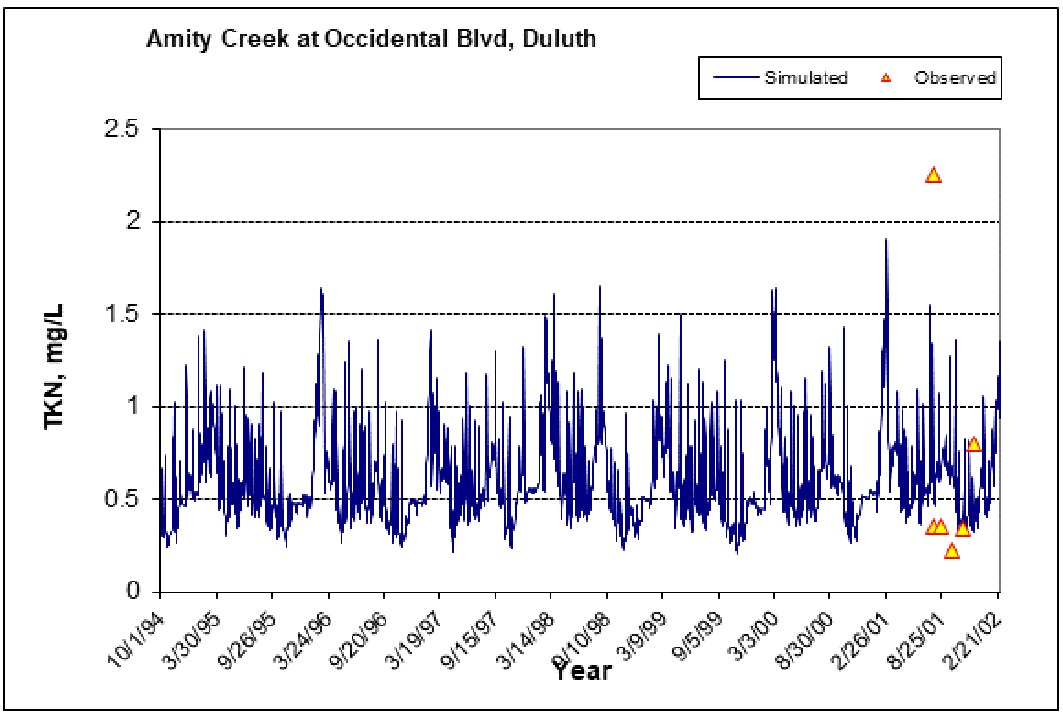
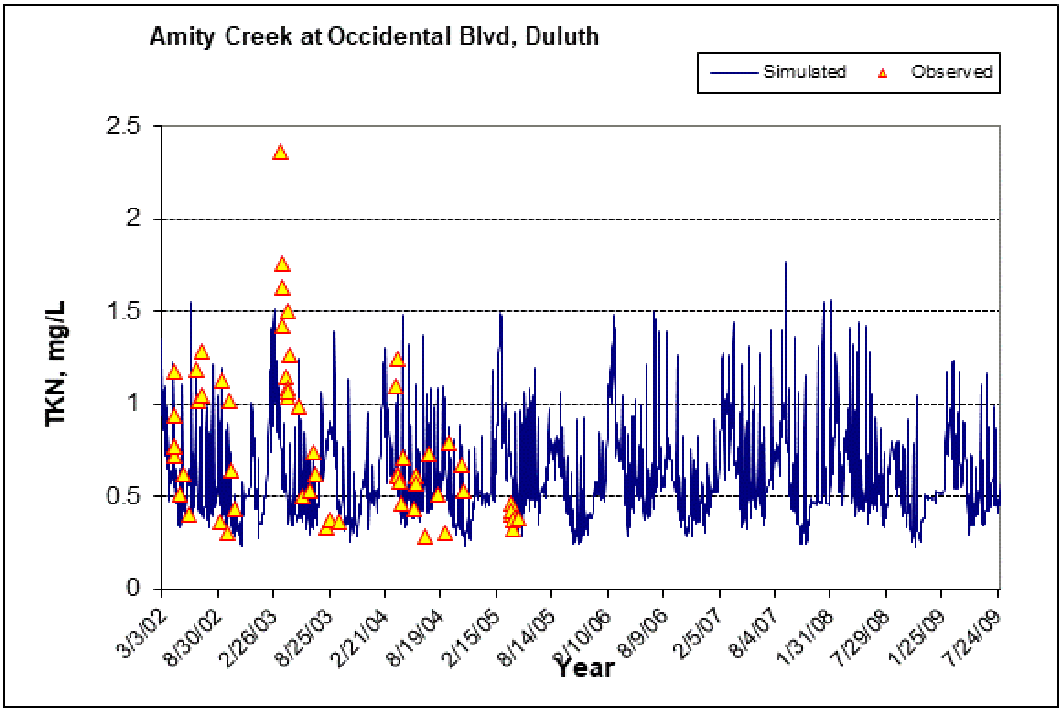


Figure E-344. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)





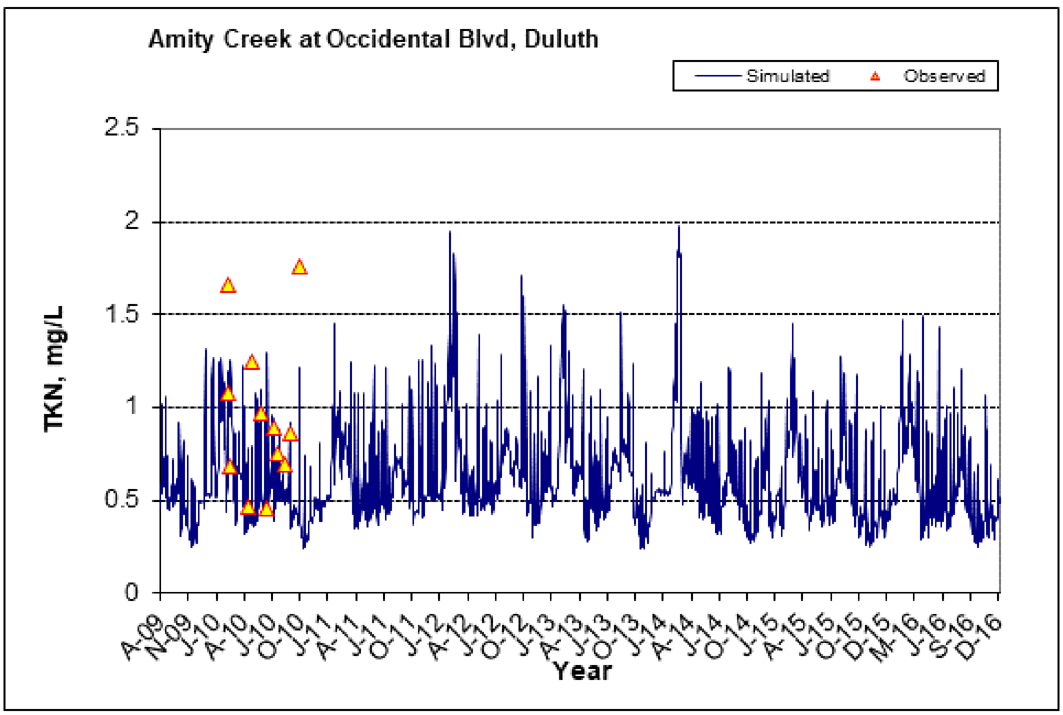


Figure E-345. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Amity Creek at Occidental Blvd, Duluth

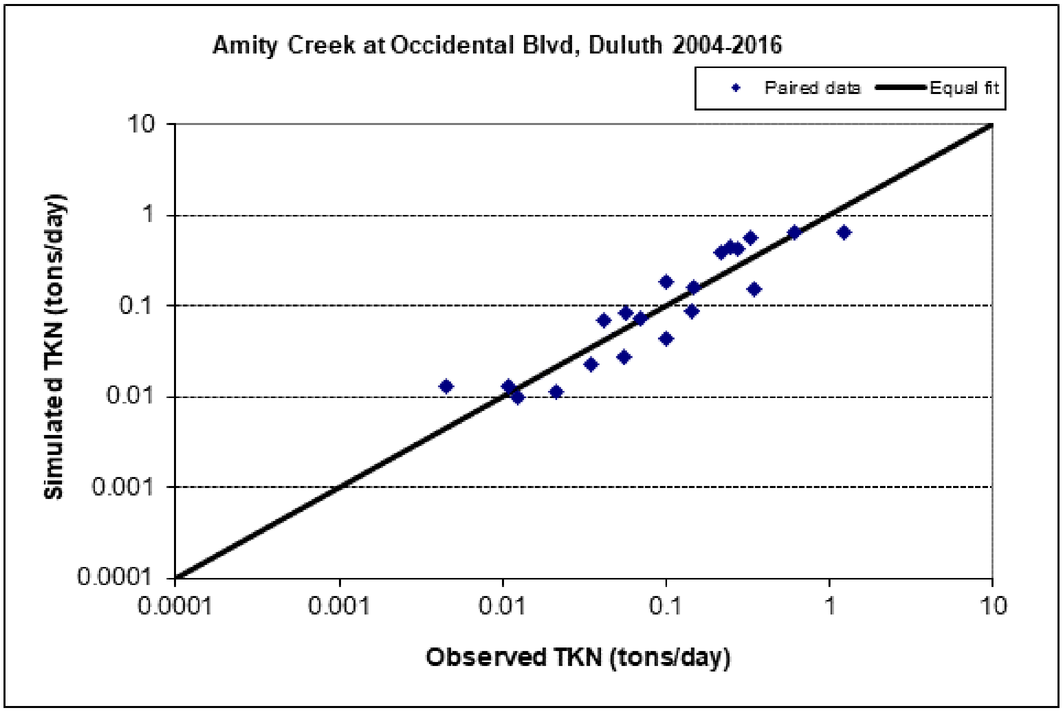


Figure E-346. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Amity Creek at Occidental Blvd, Duluth (calibration period)

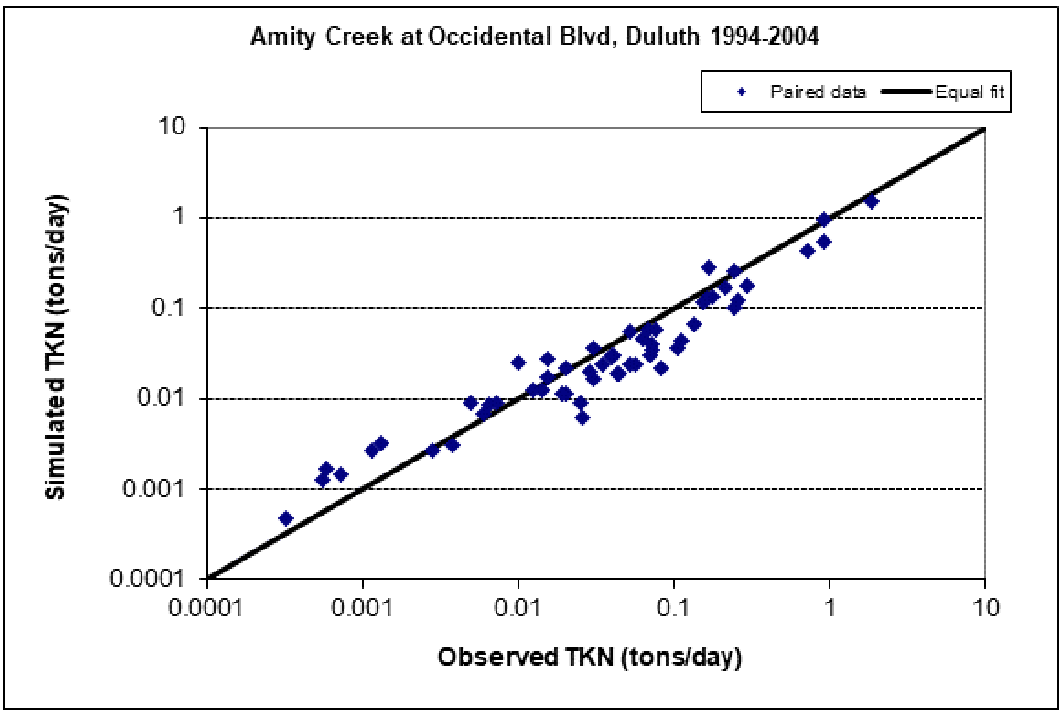


Figure E-347. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Amity Creek at Occidental Blvd, Duluth (validation period)

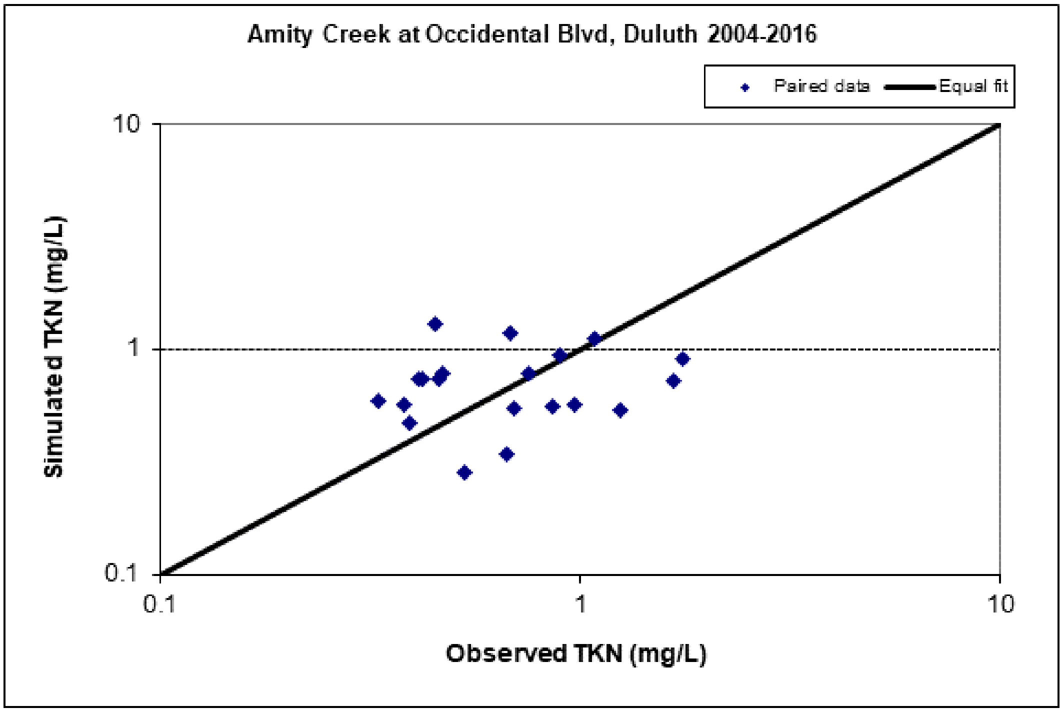


Figure E-348. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Amity Creek at Occidental Blvd, Duluth (calibration period)

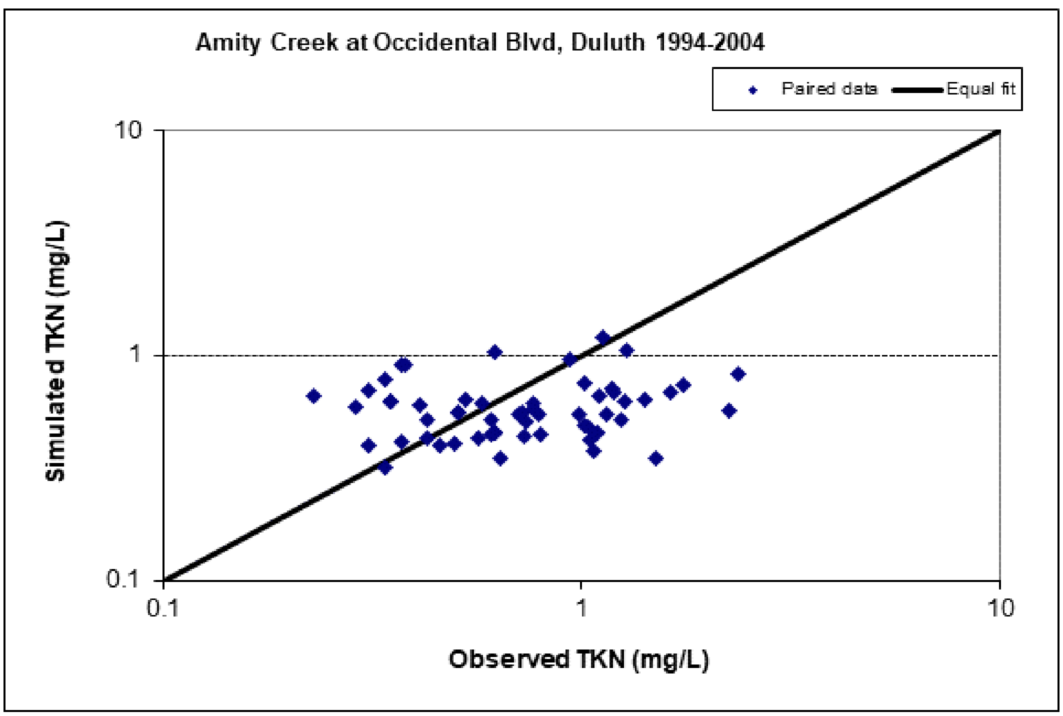


Figure E-349. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Amity Creek at Occidental Blvd, Duluth (validation period)

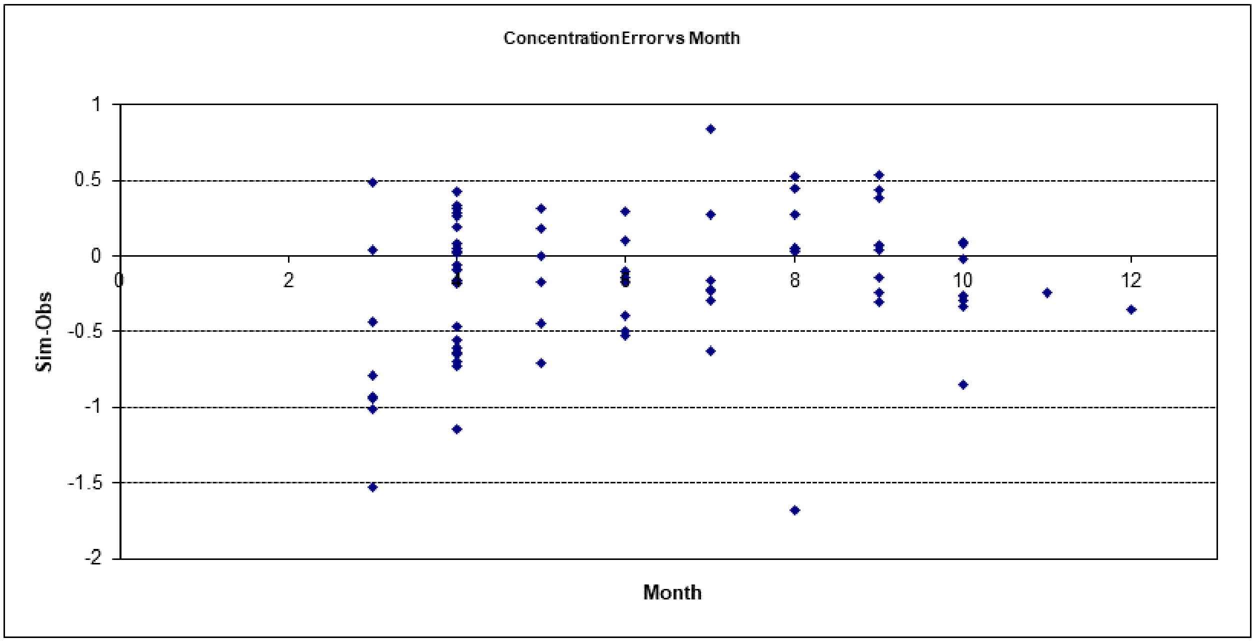


Figure E-350. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at Amity Creek at Occidental Blvd, Duluth

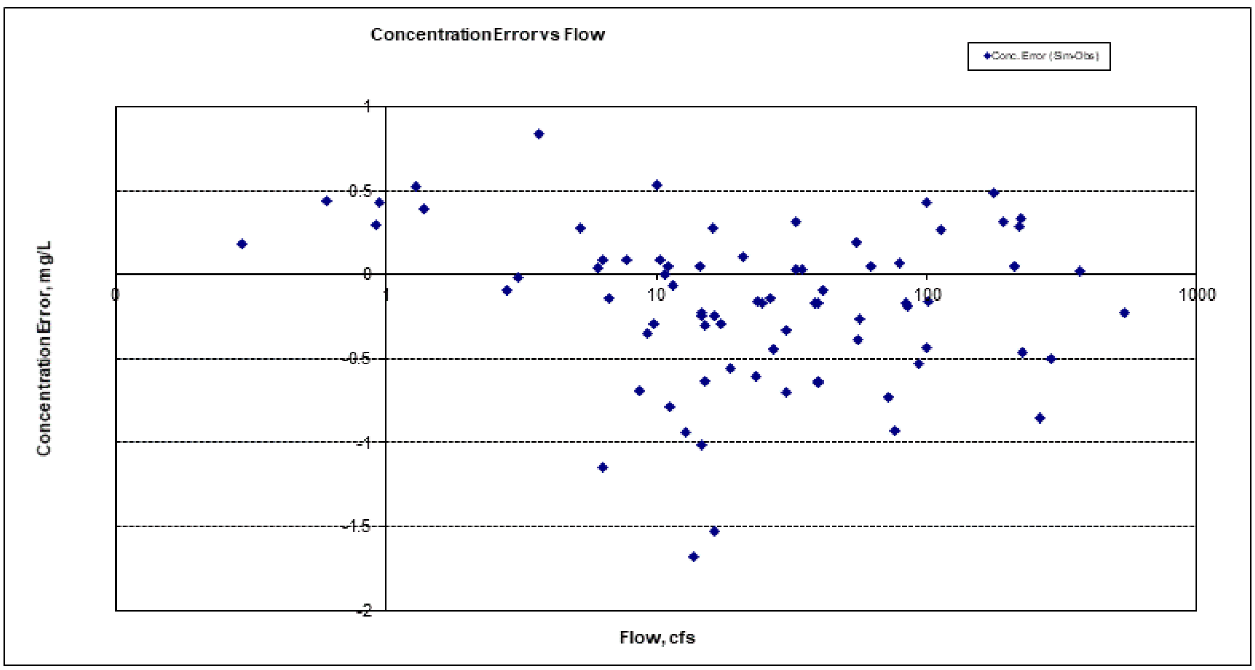


Figure E-351. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at Amity Creek at Occidental Blvd, Duluth

E.7.5 Nitrite+ Nitrate Nitrogen (NOx)

Table E-42. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	57	34
Concentration Average Error	-8.11%	-22.24%
Concentration Median Error	-3.55%	-12.83%
Load Average Error	-33.86%	-37.91%
Load Median Error	-0.54%	-11.04%
Paired t conc	0.84	0.44
Paired t load	0.29	0.19

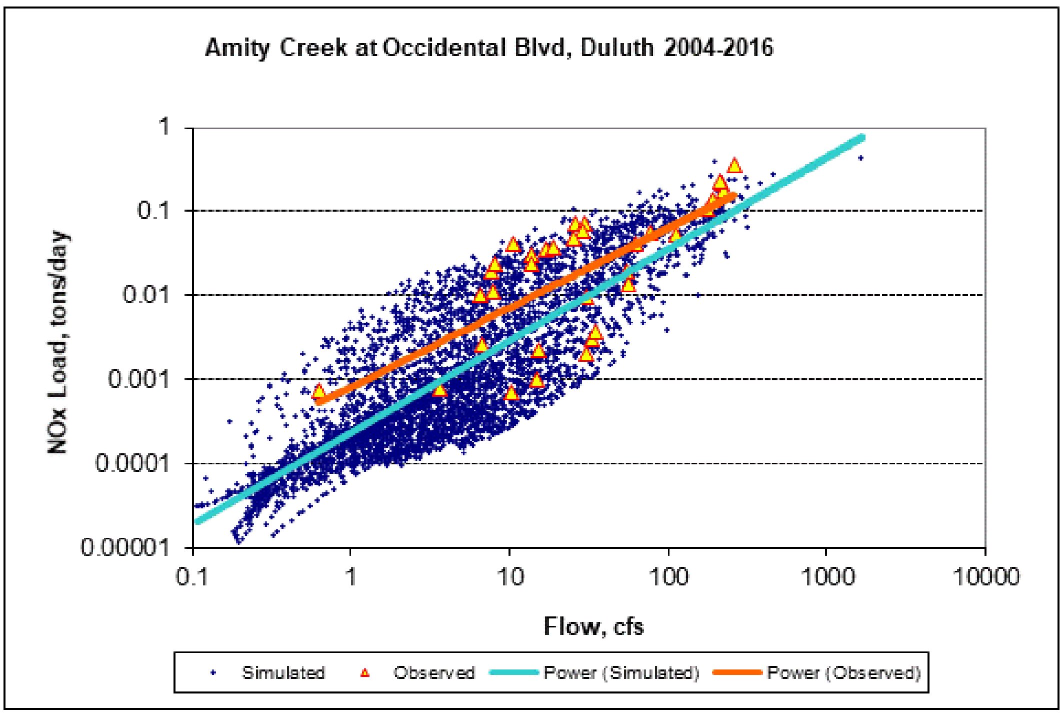


Figure E-352. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

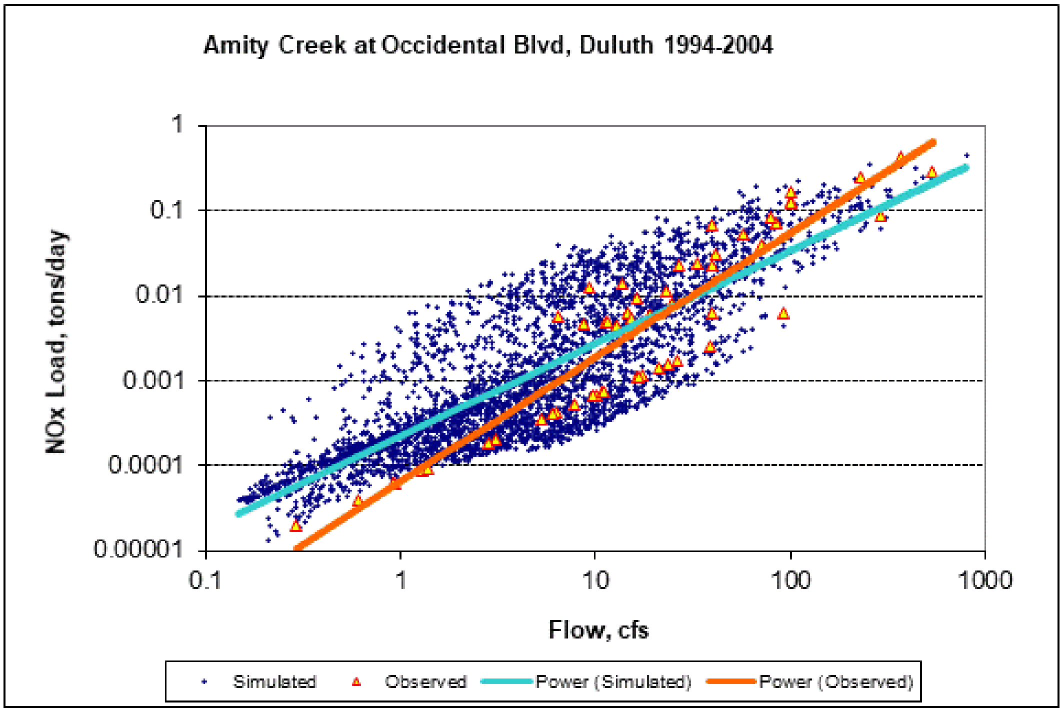


Figure E-353. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)

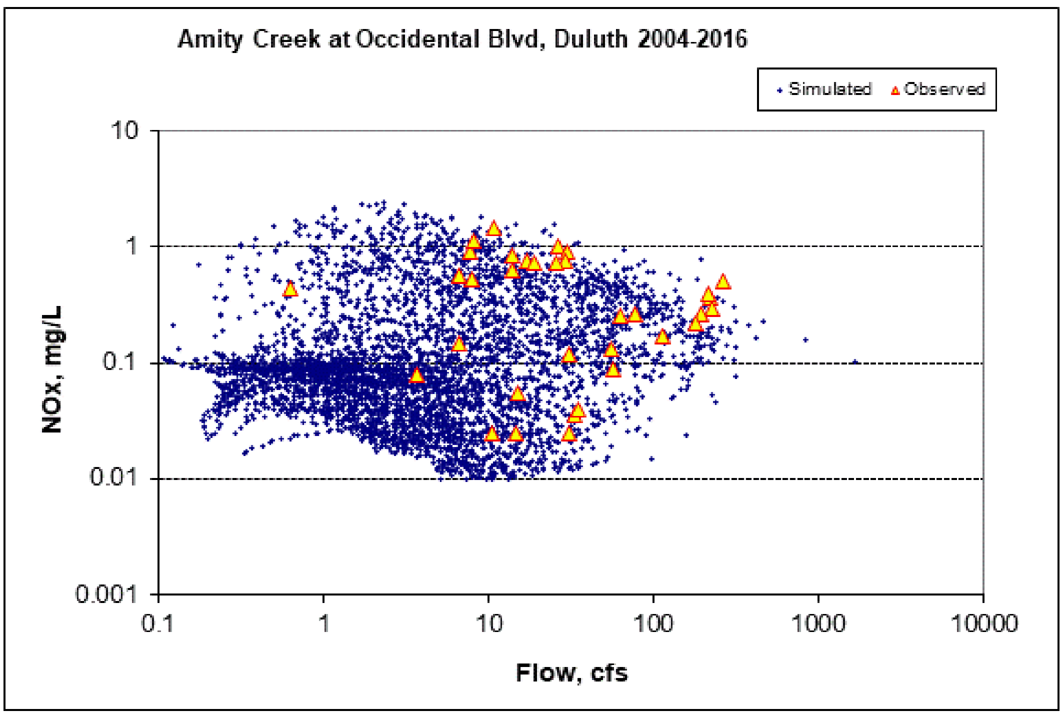


Figure E-354. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

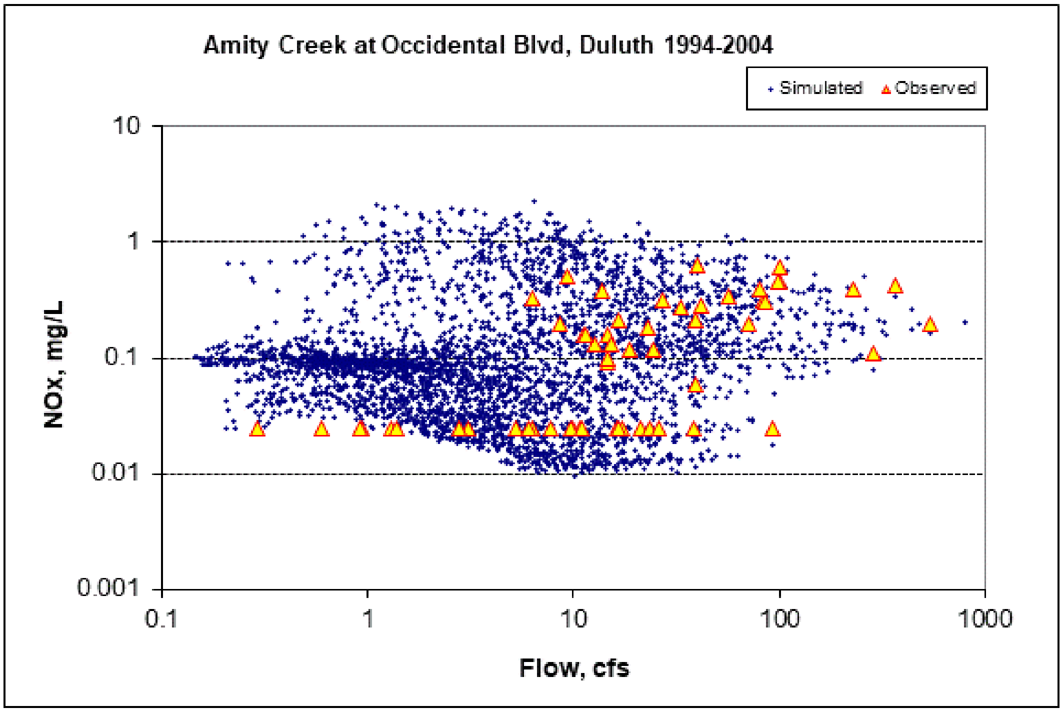
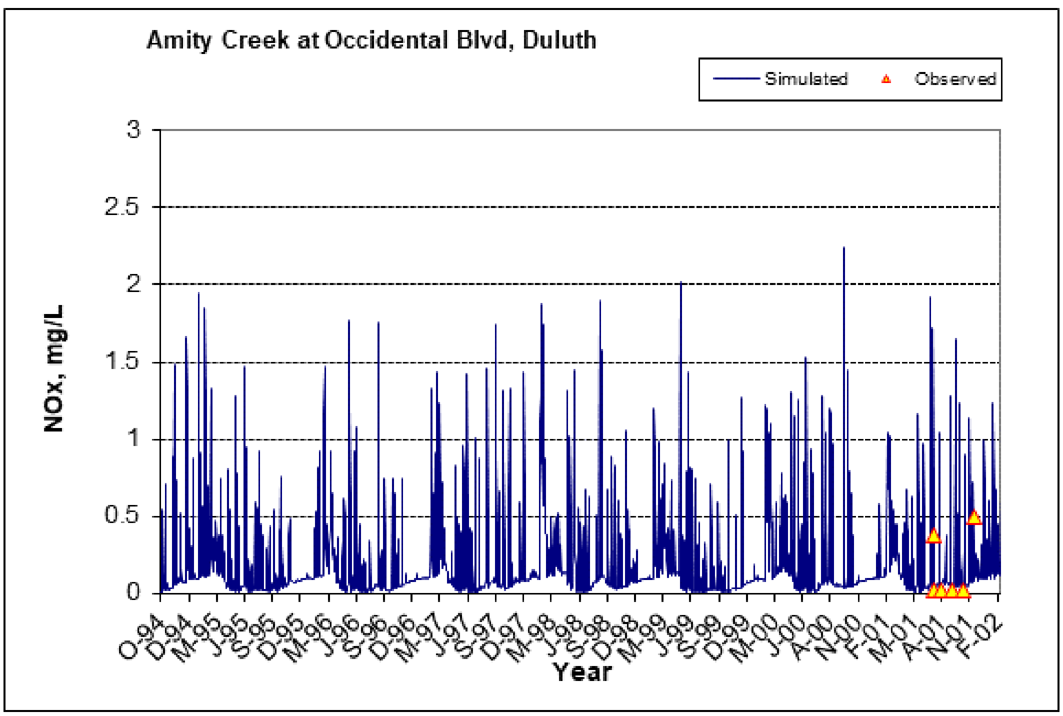


Figure E-355. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)



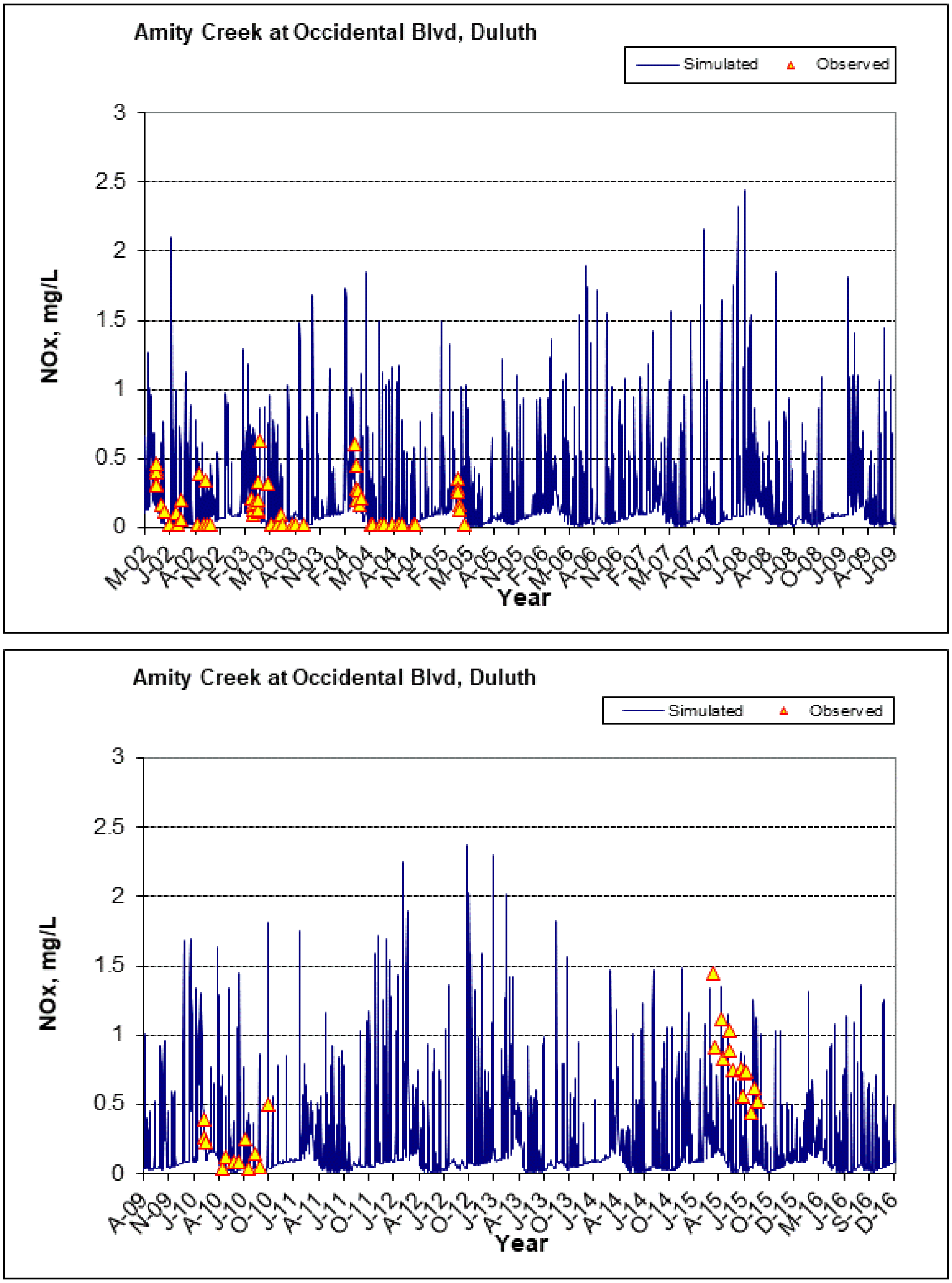


Figure E-356. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Amity Creek at Occidental Blvd, Duluth

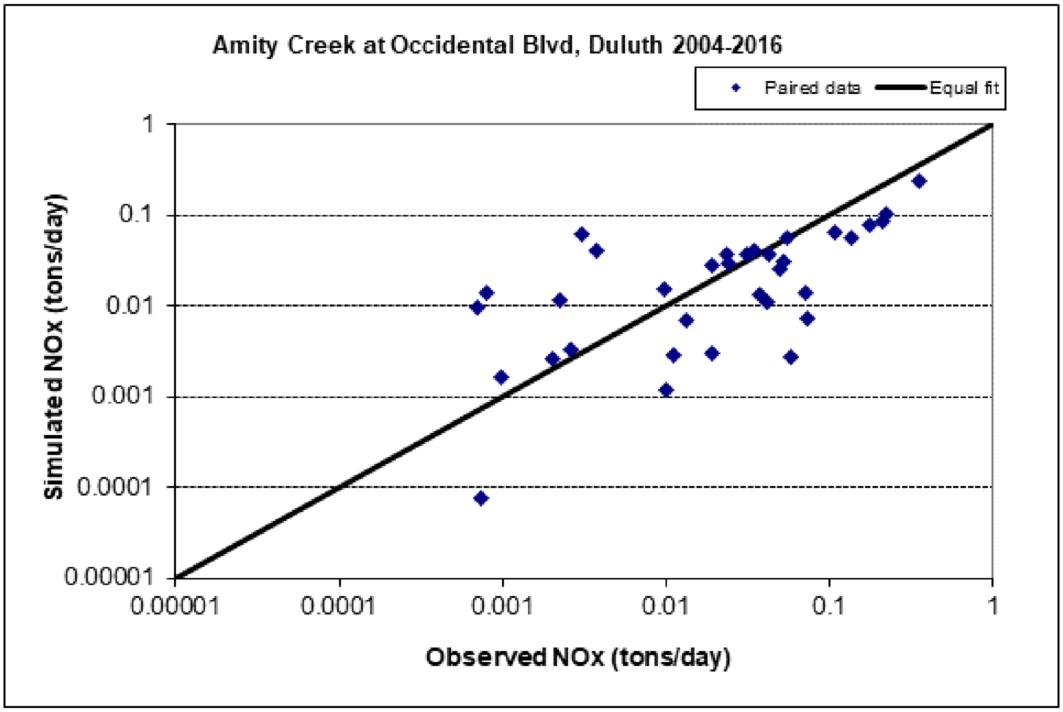


Figure E-357. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Amity Creek at Occidental Blvd, Duluth (calibration period)

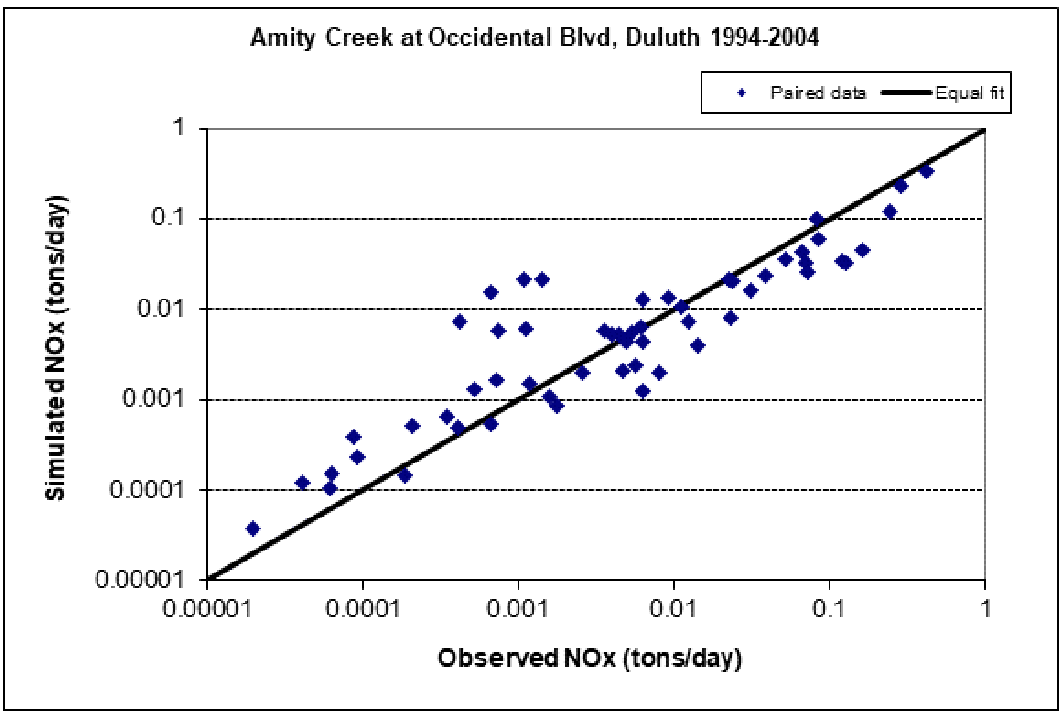


Figure E-358. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Amity Creek at Occidental Blvd, Duluth (validation period)

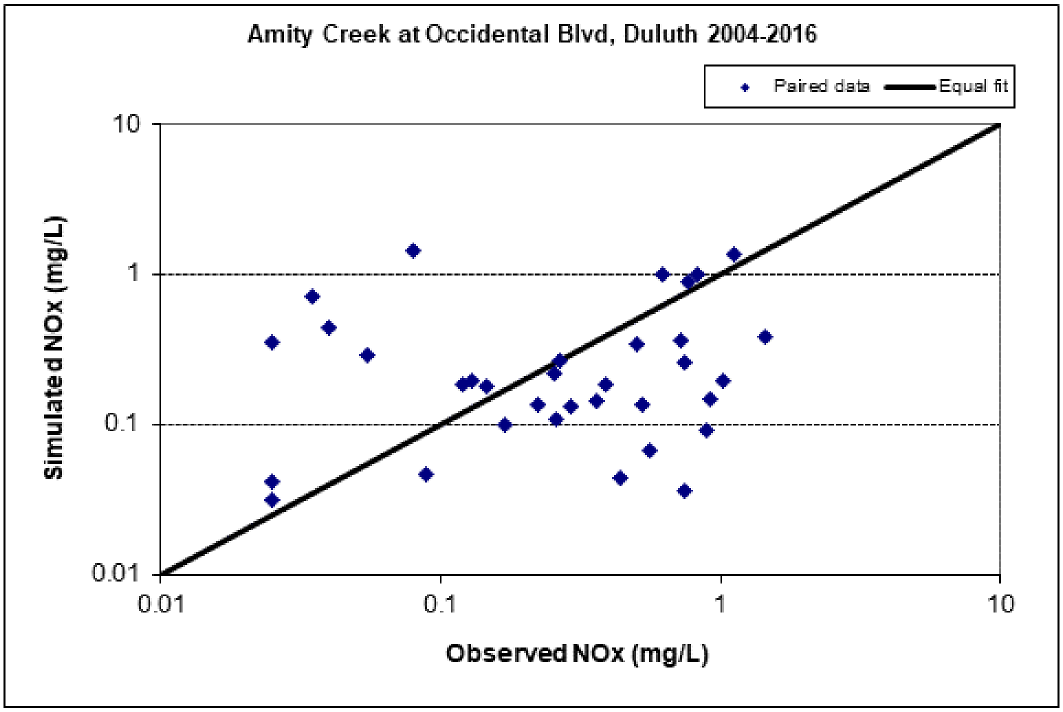


Figure E-359. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Amity Creek at Occidental Blvd, Duluth (calibration period)

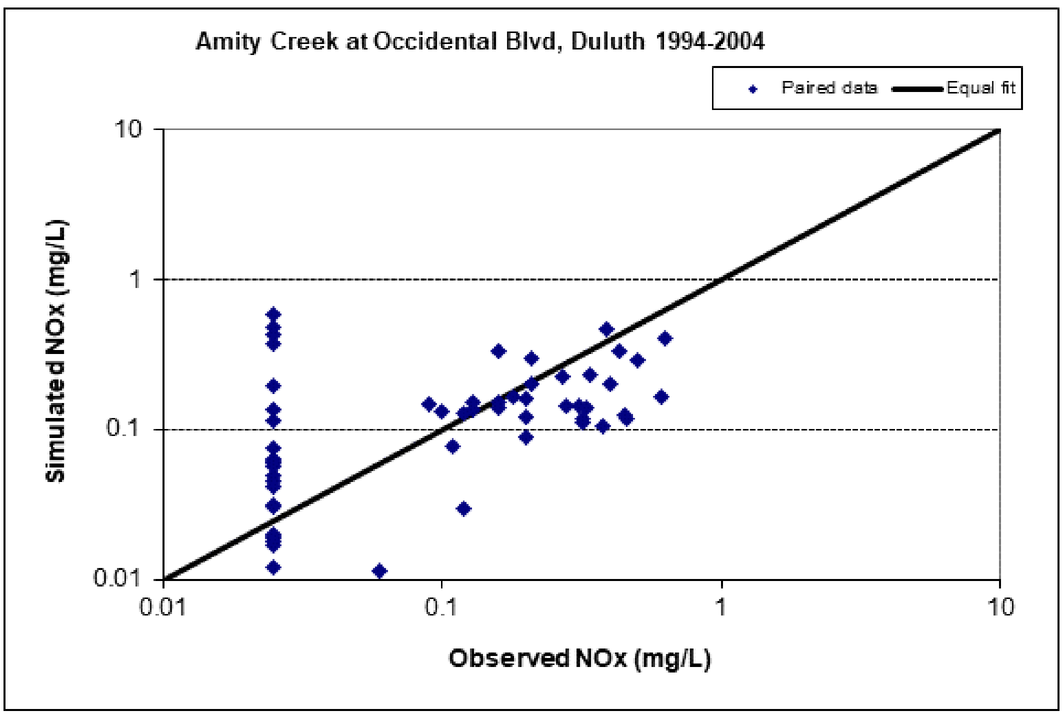


Figure E-360. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Amity Creek at Occidental Blvd, Duluth (validation period)

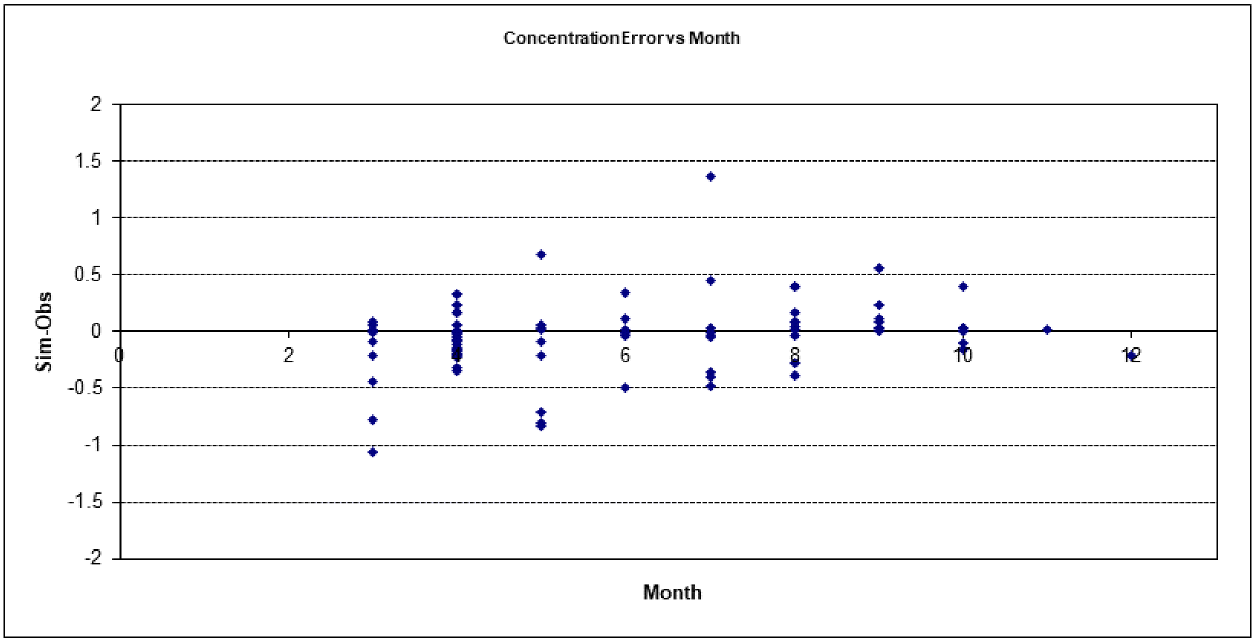


Figure E-361. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Amity Creek at Occidental Blvd, Duluth

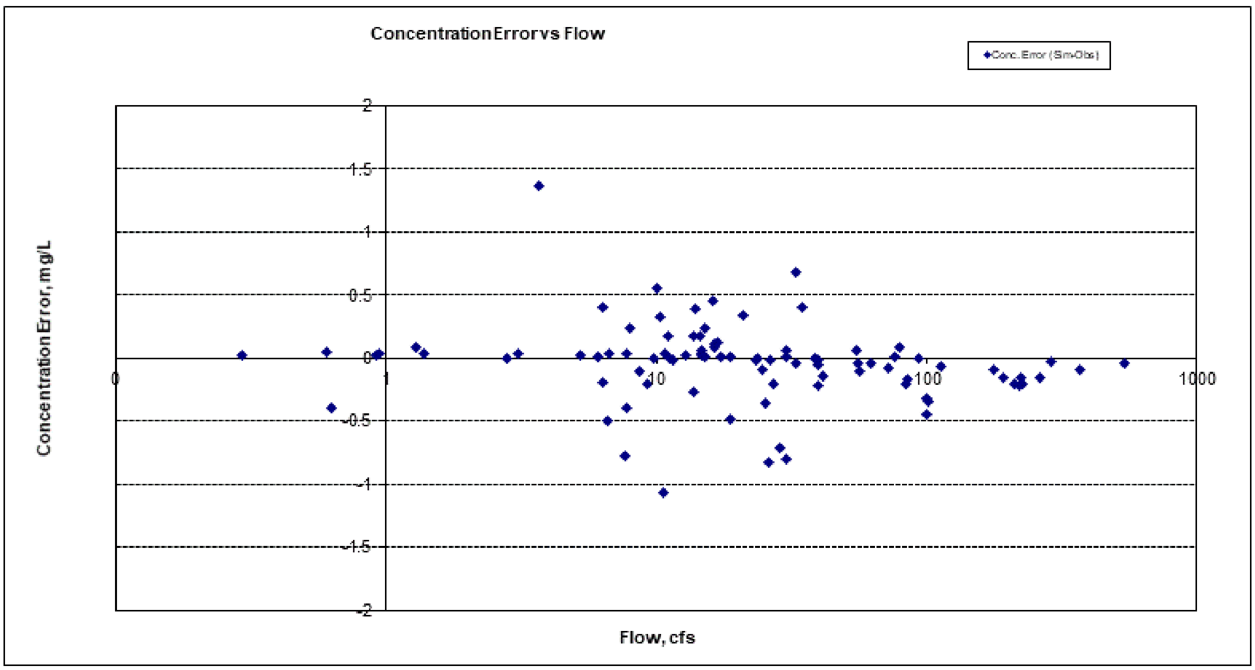


Figure E-362. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Amity Creek at Occidental Blvd, Duluth

E.7.6 Total Nitrogen (TN)

Table E-43. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	57	20
Concentration Average Error	-24.58%	7.60%
Concentration Median Error	-19.88%	4.33%
Load Average Error	-27.15%	-8.58%
Load Median Error	-8.04%	2.51%
Paired t conc	0.22	0.84
Paired t load	0.39	0.66

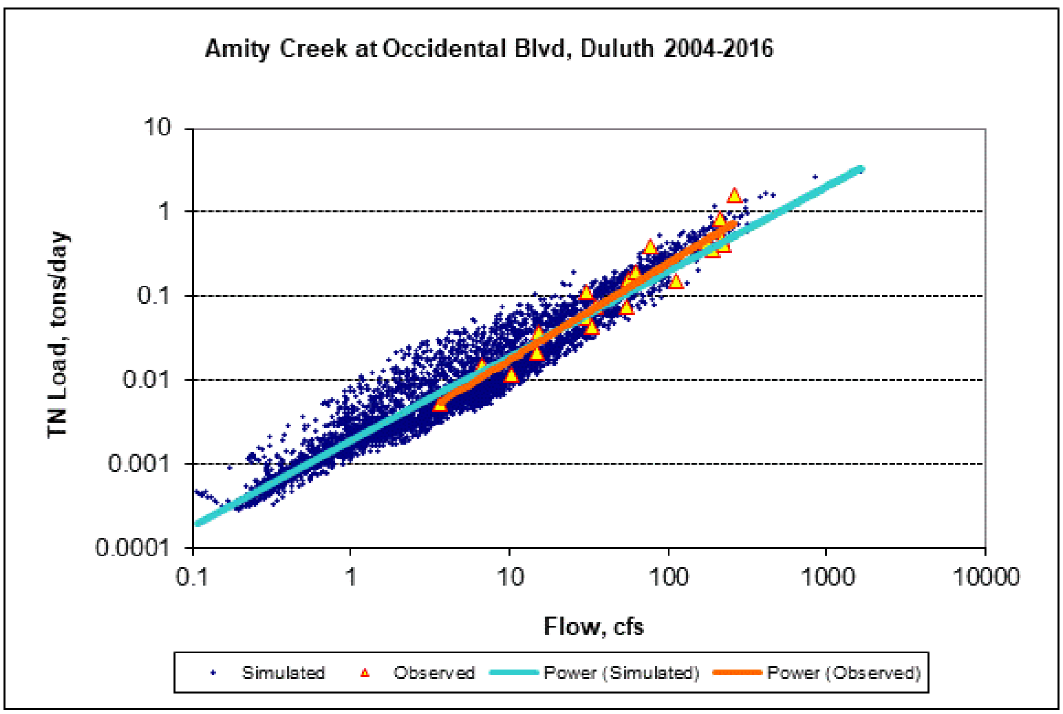


Figure E-363. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

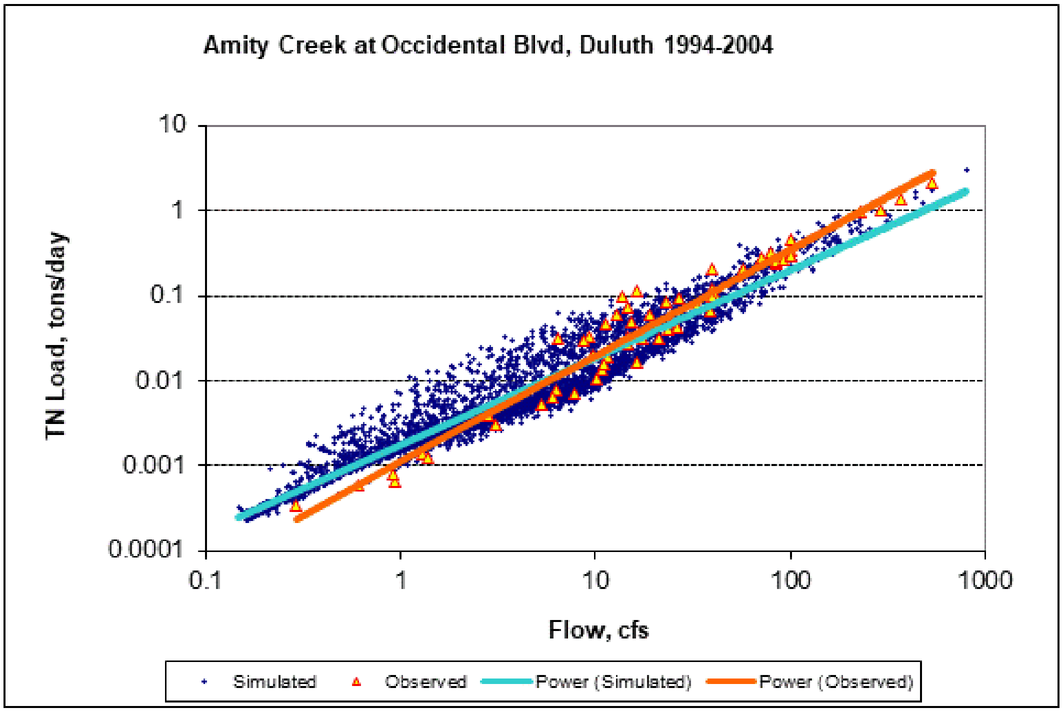


Figure E-364. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)

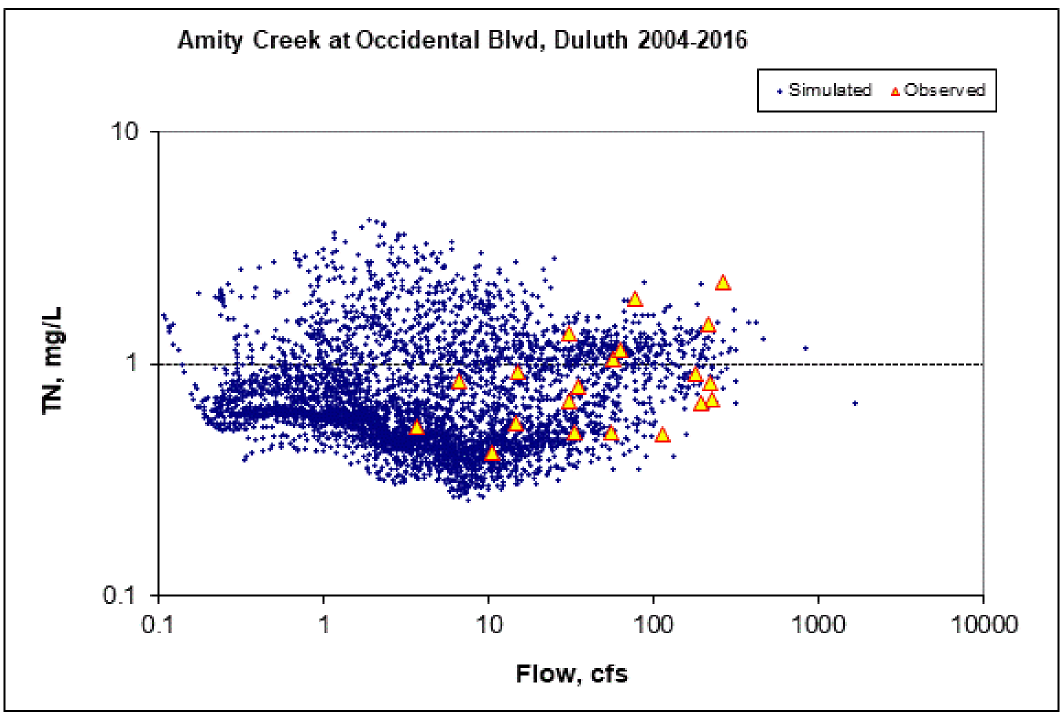


Figure E-365. Simulated and observed Total Nitrogen (TN) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

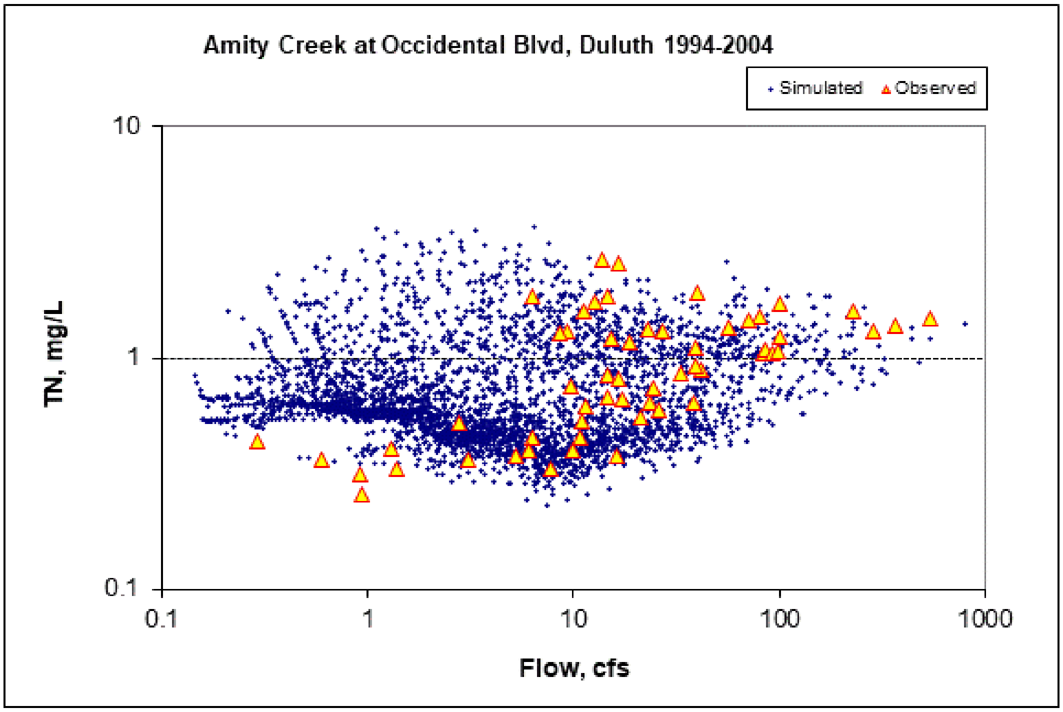
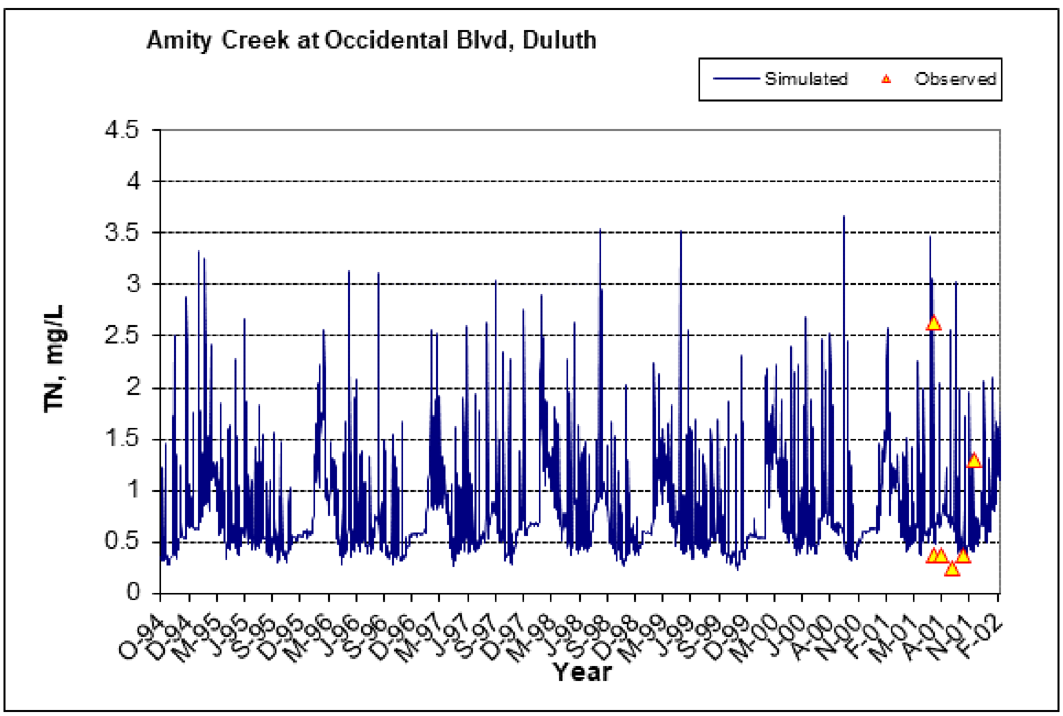
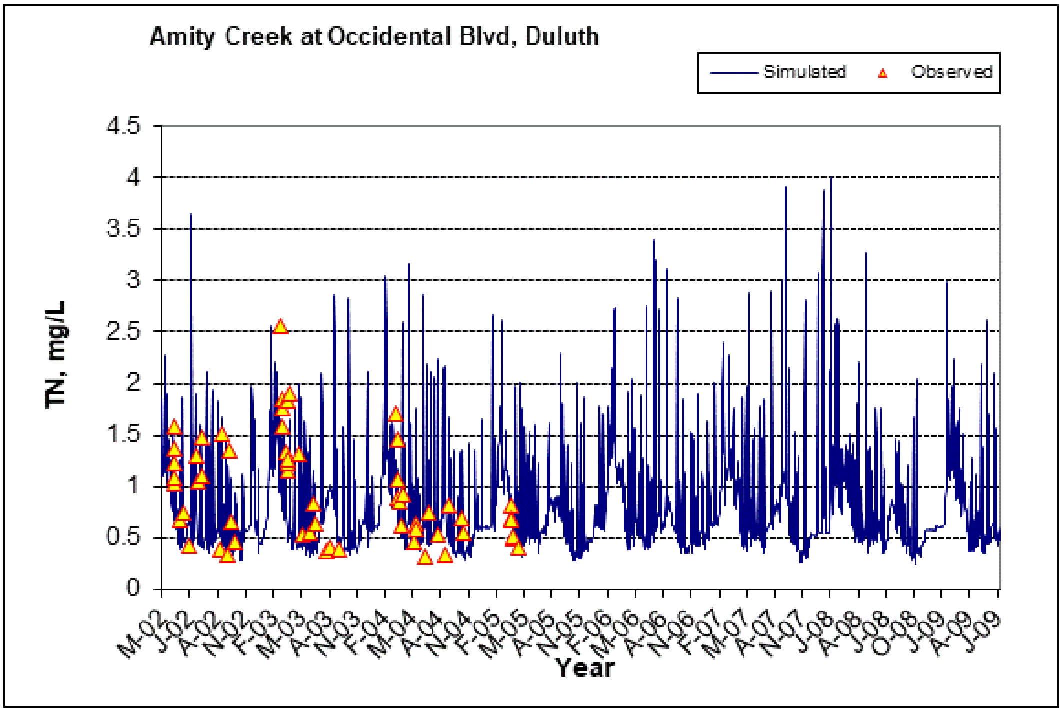


Figure E-366. Simulated and observed Total Nitrogen (TN) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)





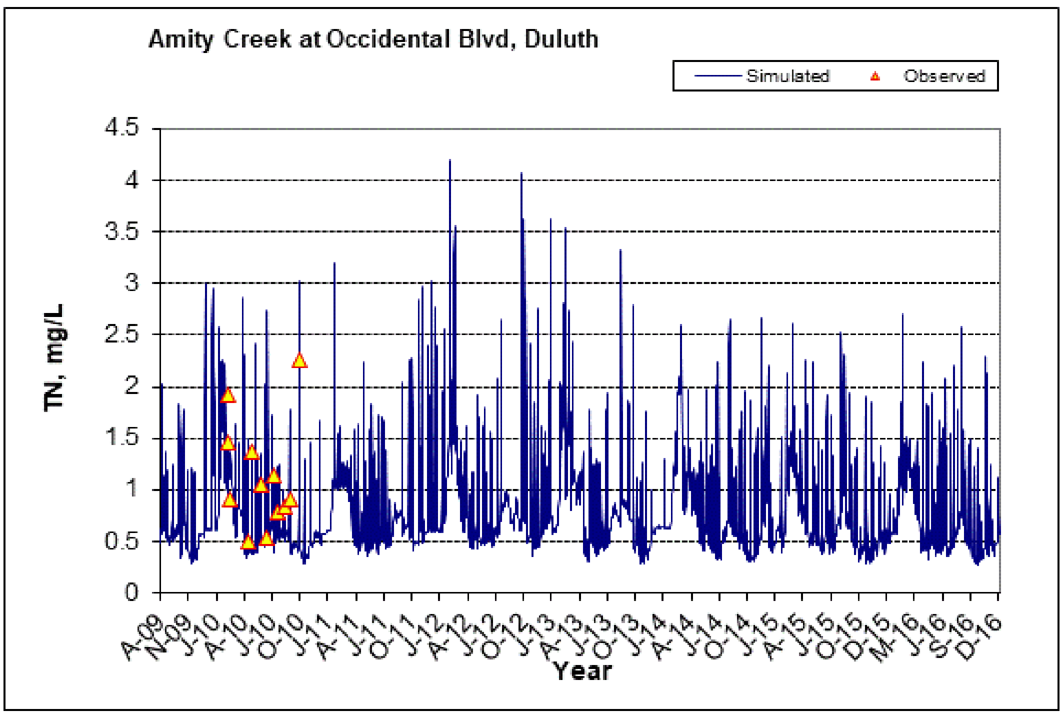


Figure E-367. Time series of observed and simulated Total Nitrogen (TN) concentration at Amity Creek at Occidental Blvd, Duluth

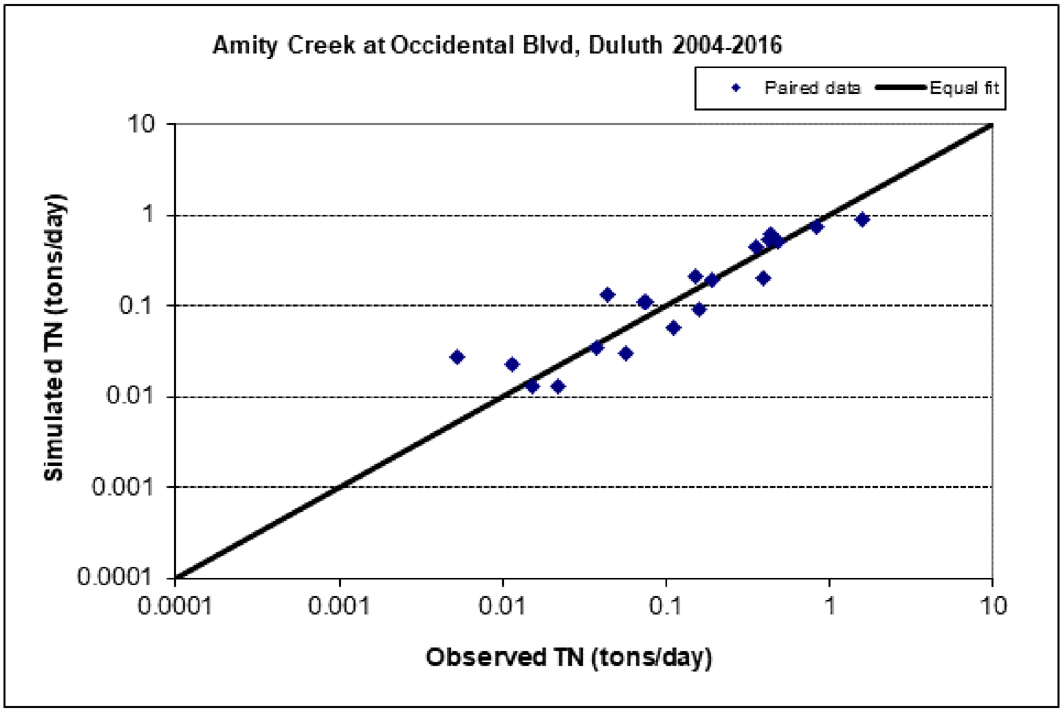


Figure E-368. Paired simulated vs. observed Total Nitrogen (TN) load at Amity Creek at Occidental Blvd, Duluth (calibration period)

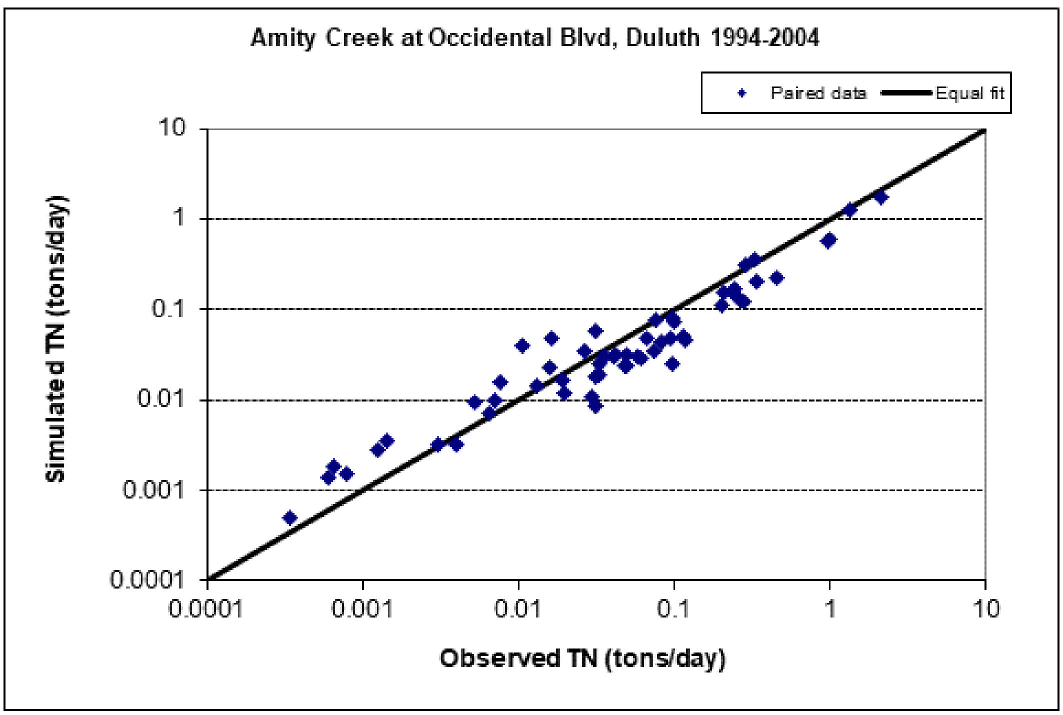


Figure E-369. Paired simulated vs. observed Total Nitrogen (TN) load at Amity Creek at Occidental Blvd, Duluth (validation period)

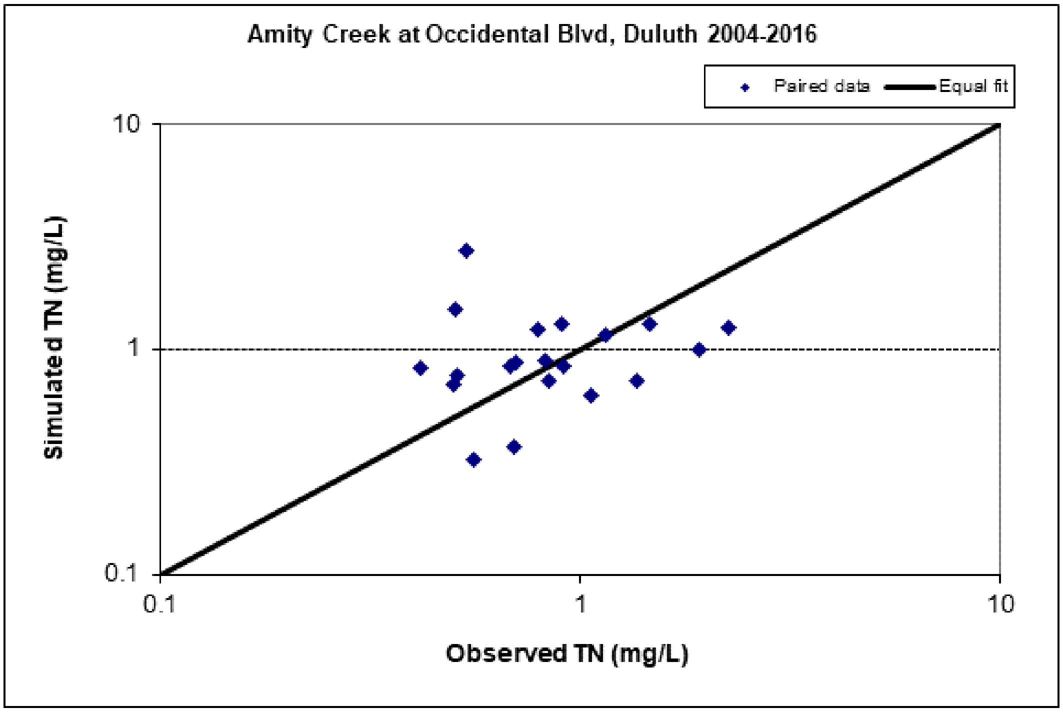


Figure E-370. Paired simulated vs. observed Total Nitrogen (TN) concentration at Amity Creek at Occidental Blvd, Duluth (calibration period)

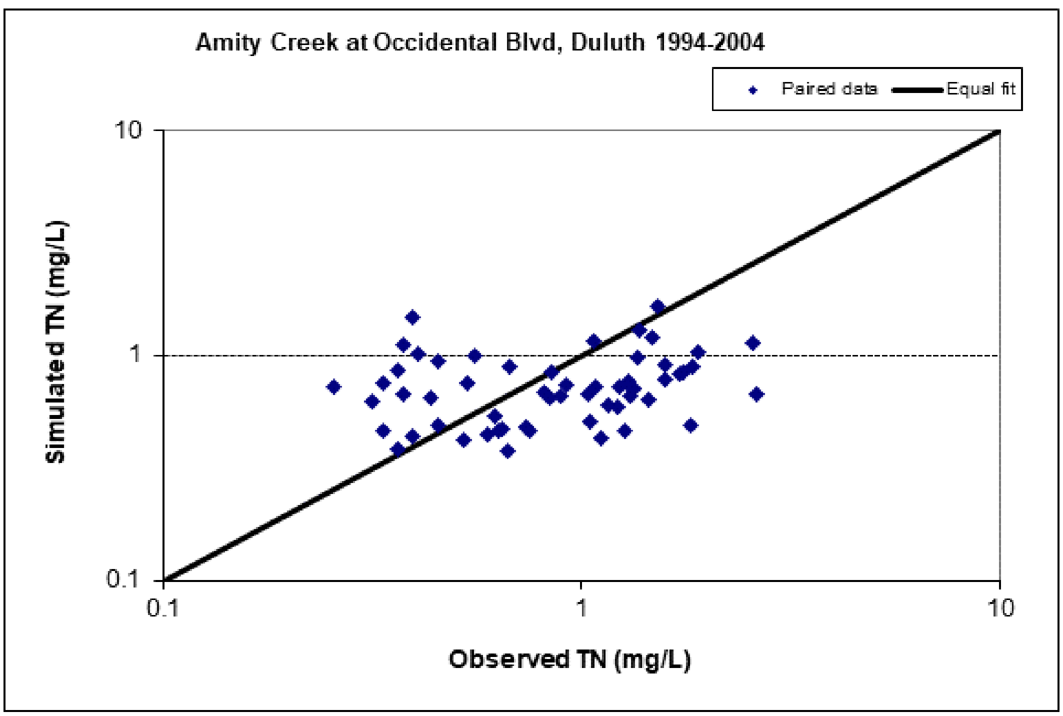


Figure E-371. Paired simulated vs. observed Total Nitrogen (TN) concentration at Amity Creek at Occidental Blvd, Duluth (validation period)

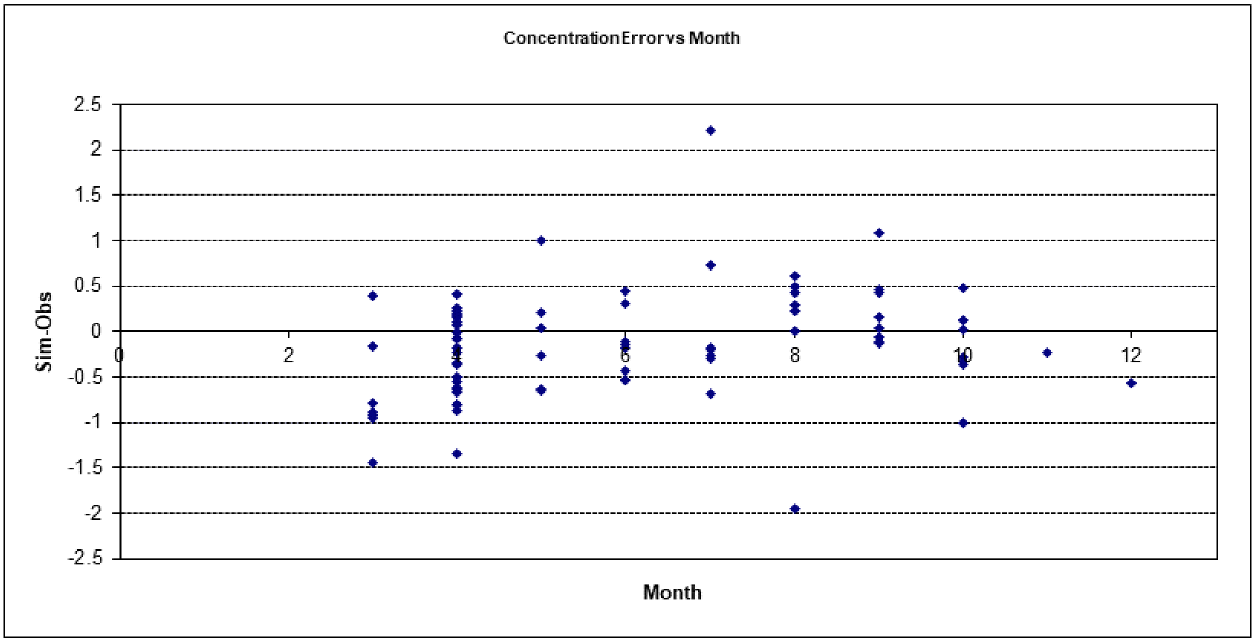


Figure E-372. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at Amity Creek at Occidental Blvd, Duluth

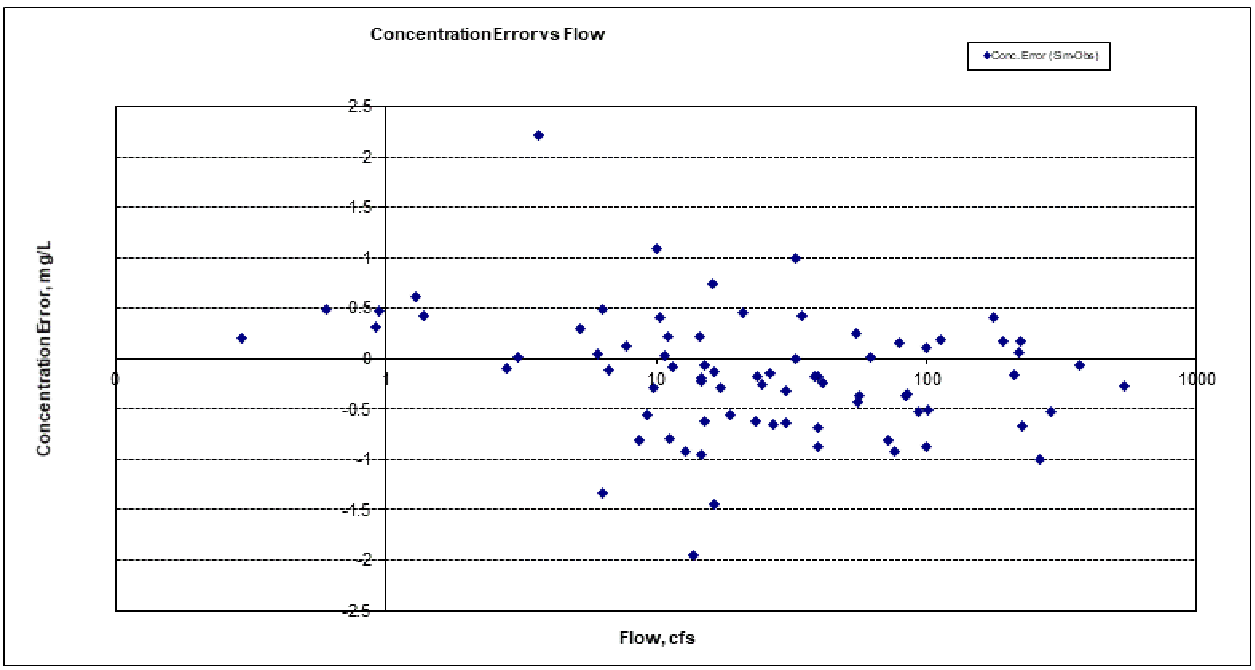


Figure E-373. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at Amity Creek at Occidental Blvd, Duluth

E.7.7 Soluble Reactive Phosphorus (SRP)

Table E-44. Soluble Reactive Phosphorus (SRP) statistics

Period	1994-2004	2004-2016
Count	57	2
Concentration Average Error	28.70%	9.74%
Concentration Median Error	33.17%	9.74%
Load Average Error	15.43%	5.71%
Load Median Error	2.96%	5.71%
Paired t conc	0.24	0.84
Paired t load	0.55	0.62

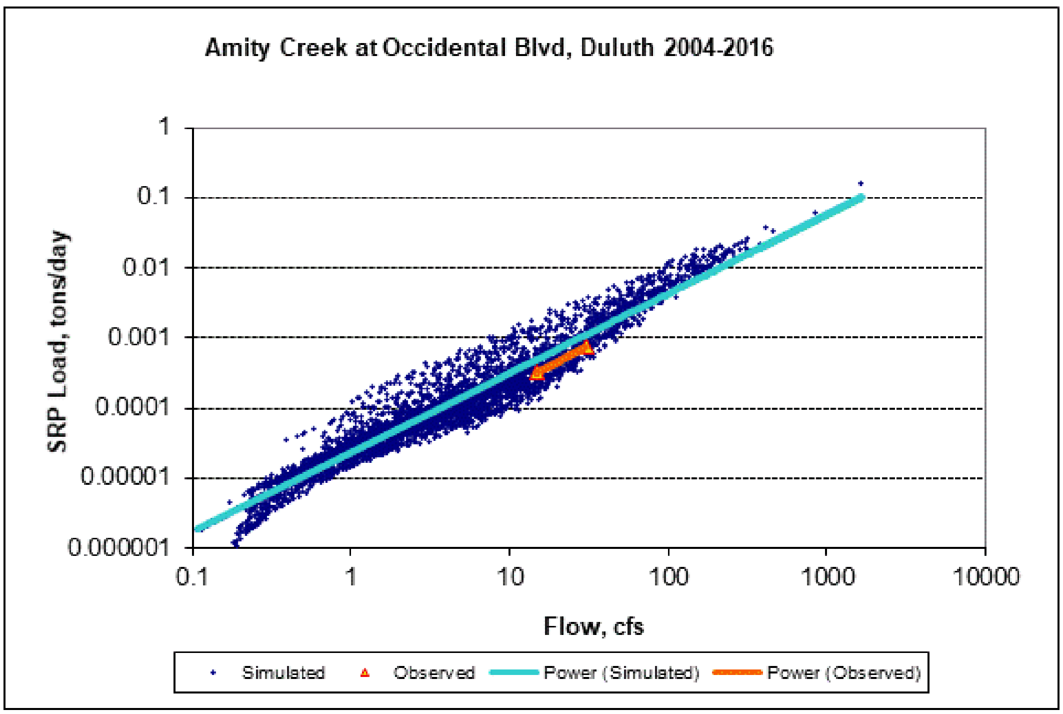


Figure E-374. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

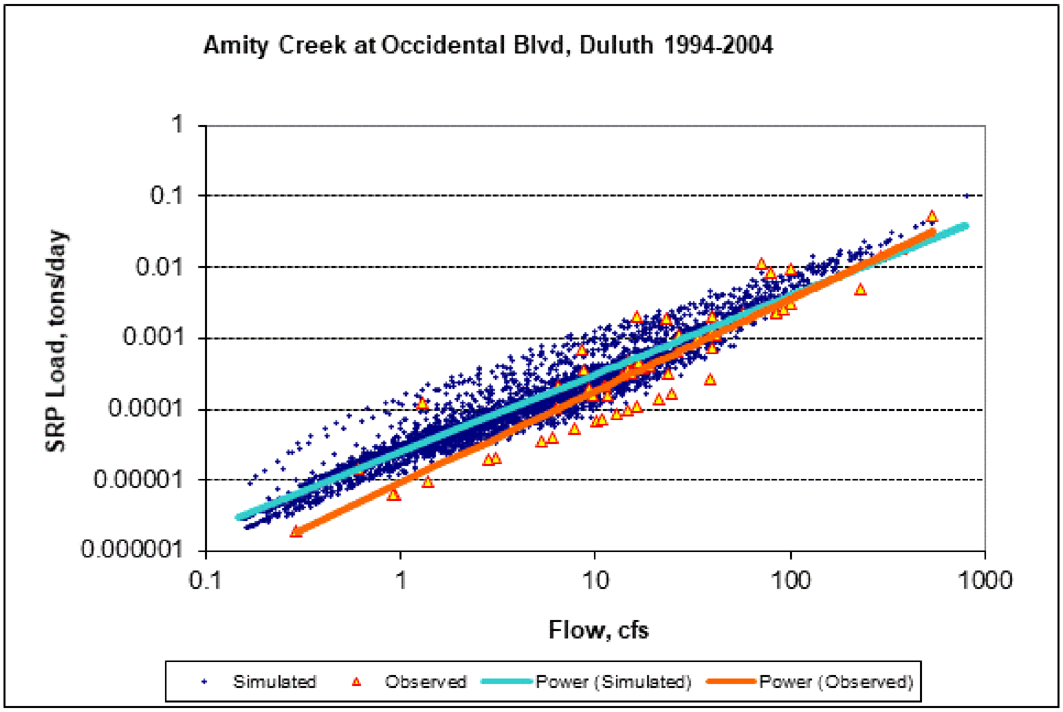


Figure E-375. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)

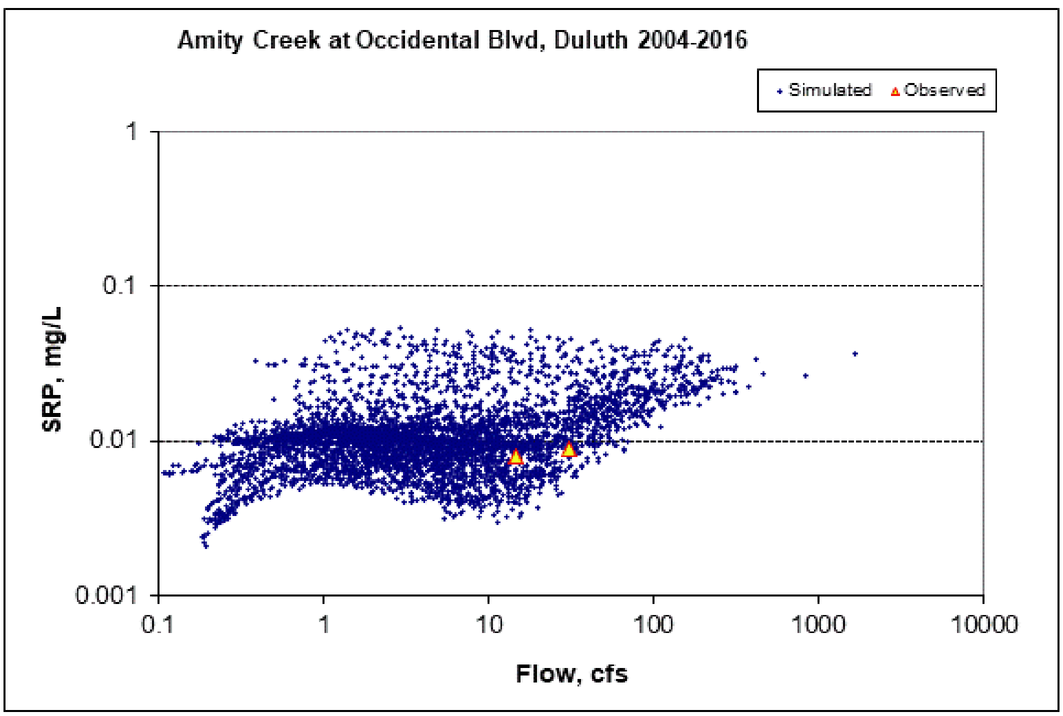


Figure E-376. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

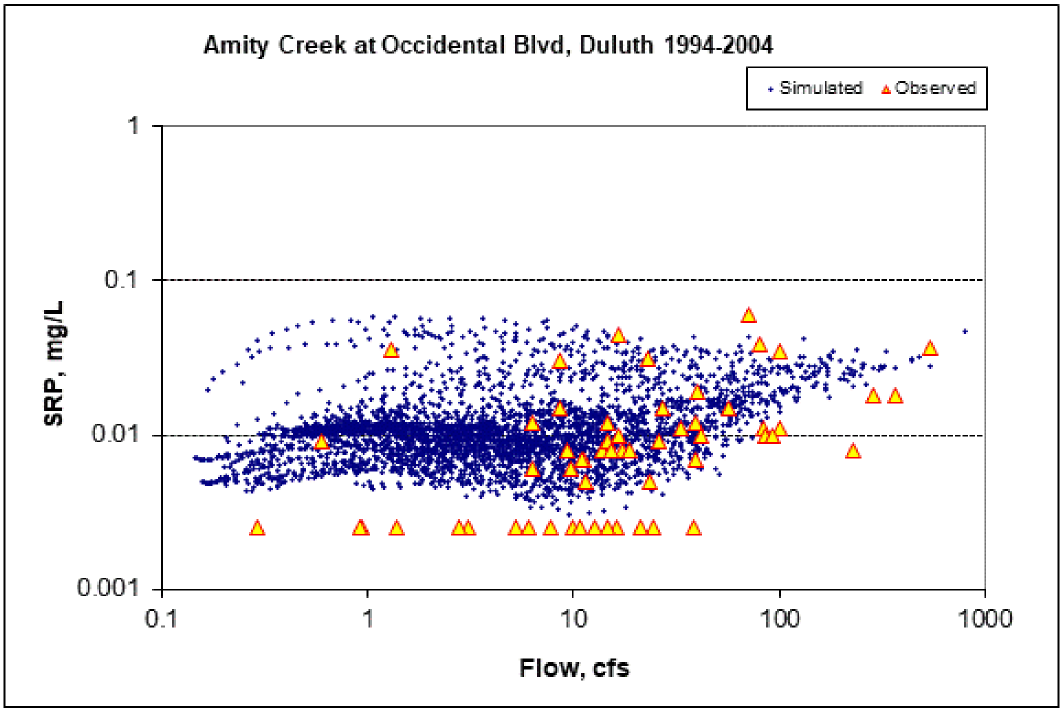
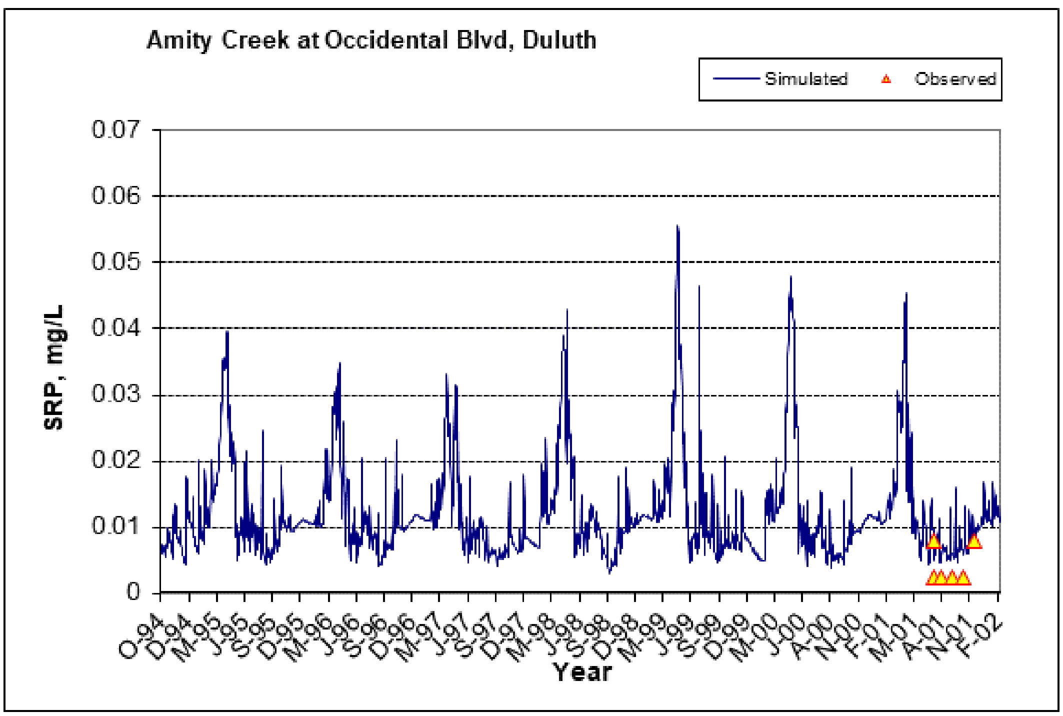
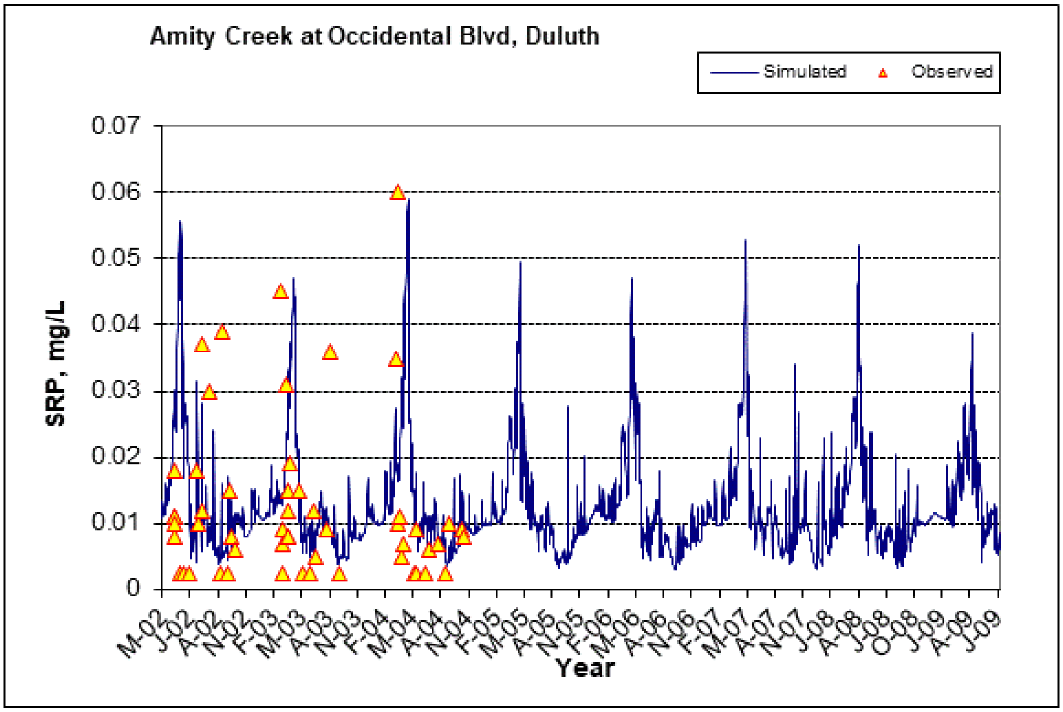


Figure E-377. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)





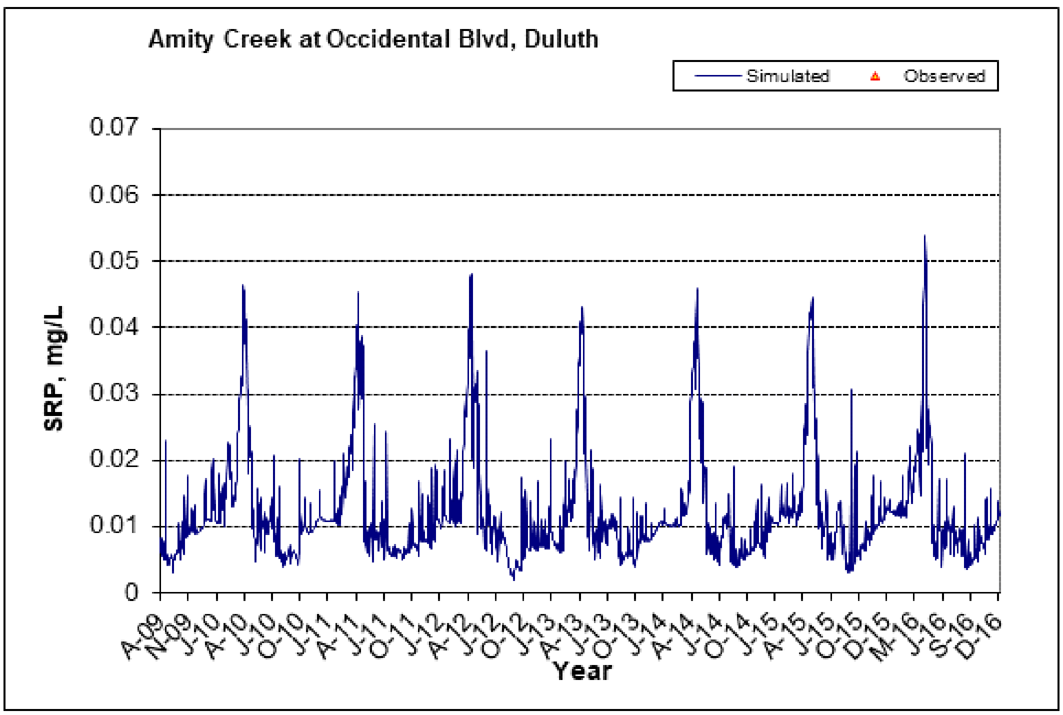


Figure E-378. Time series of observed and simulated Soluble Reactive Phosphorus (SRP) concentration at Amity Creek at Occidental Blvd, Duluth

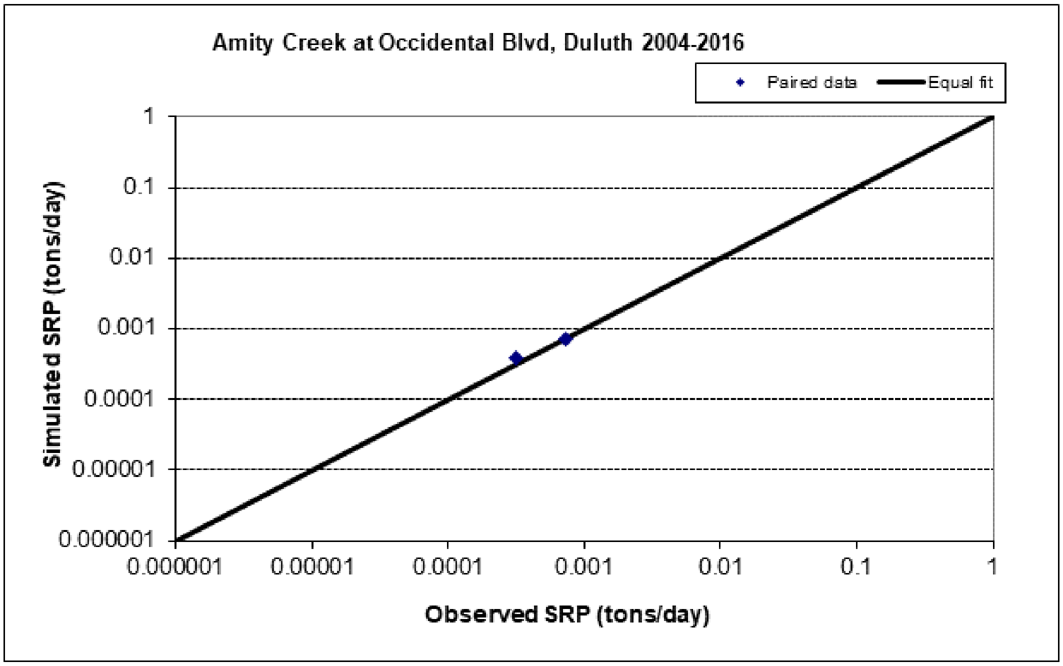


Figure E-379. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at Amity Creek at Occidental Blvd, Duluth (calibration period)

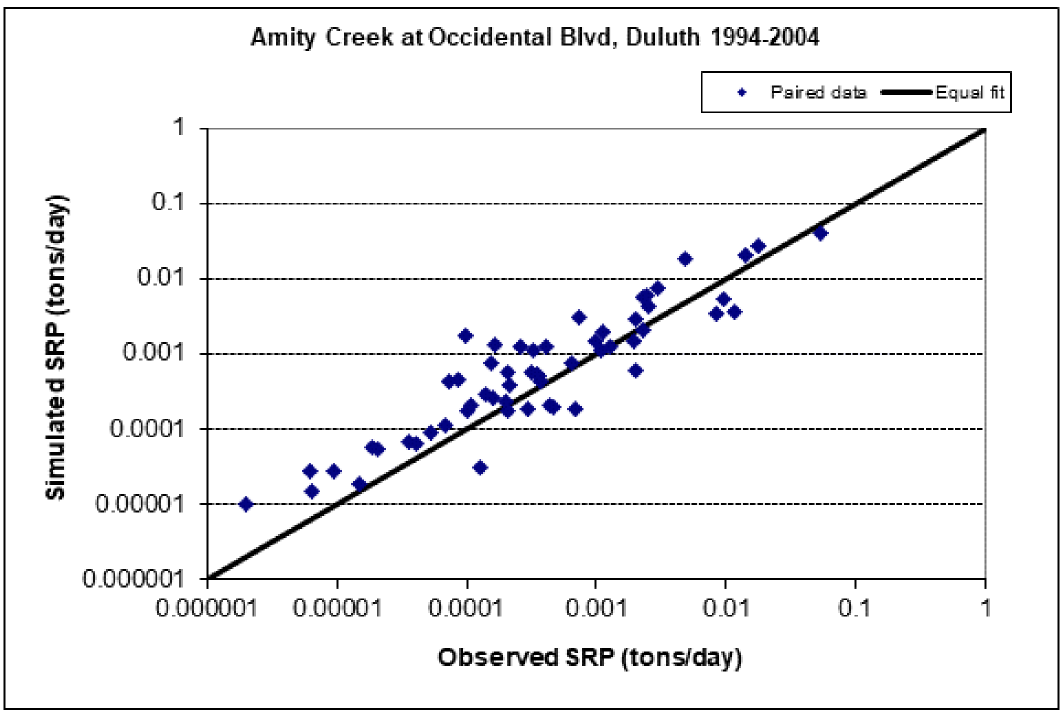


Figure E-380. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at Amity Creek at Occidental Blvd, Duluth (validation period)

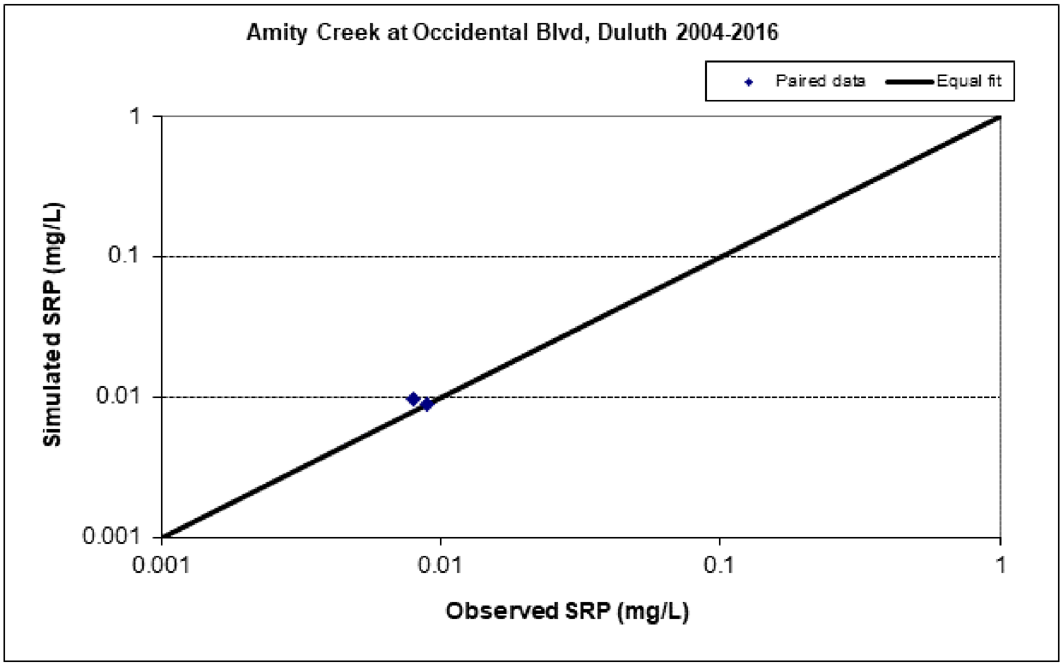


Figure E-381. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at Amity Creek at Occidental Blvd, Duluth (calibration period)

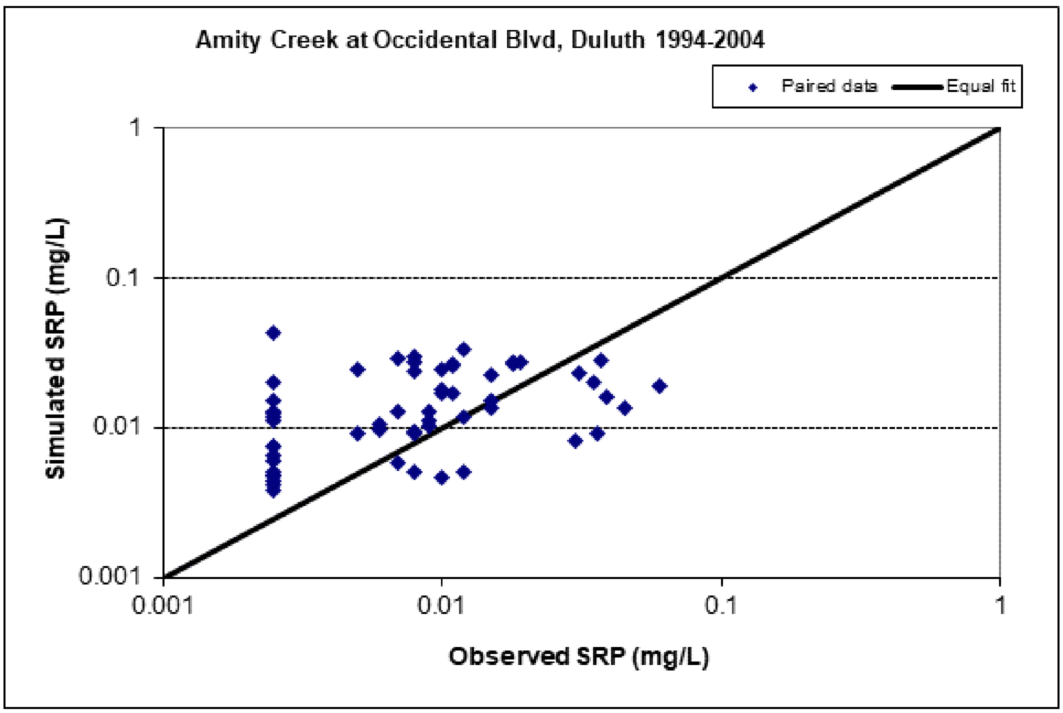


Figure E-382. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at Amity Creek at Occidental Blvd, Duluth (validation period)

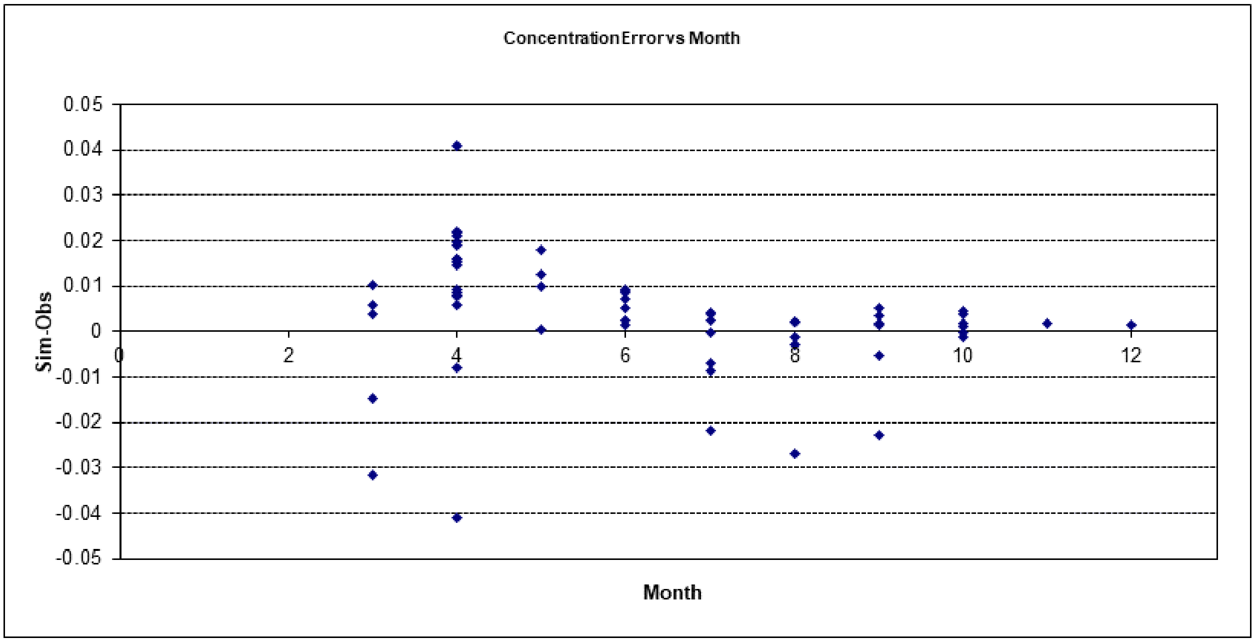


Figure E-383. Residual (Simulated - Observed) vs. Month, Soluble Reactive Phosphorus (SRP) at Amity Creek at Occidental Blvd, Duluth

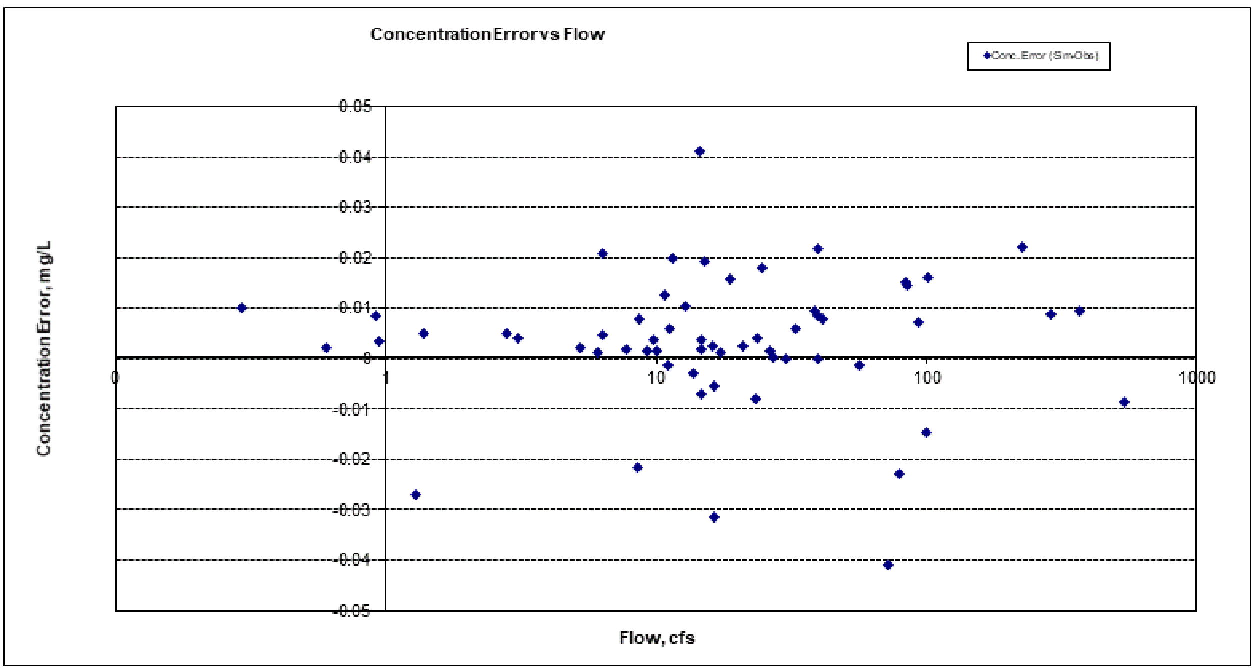


Figure E-384. Residual (Simulated - Observed) vs. Flow, Soluble Reactive Phosphorus (SRP) at Amity Creek at Occidental Blvd, Duluth

E.7.8 Organic Phosphorus (OrgP)

Table E-45. Organic Phosphorus (OrgP) statistics

Period	1994-2004	2004-2016
Count	55	2
Concentration Average Error	-80.84%	-81.00%
Concentration Median Error	-41.48%	-81.00%
Load Average Error	-70.11%	-82.72%
Load Median Error	-12.44%	-82.72%
Paired t conc	0.00	0.13
Paired t load	0.05	0.20

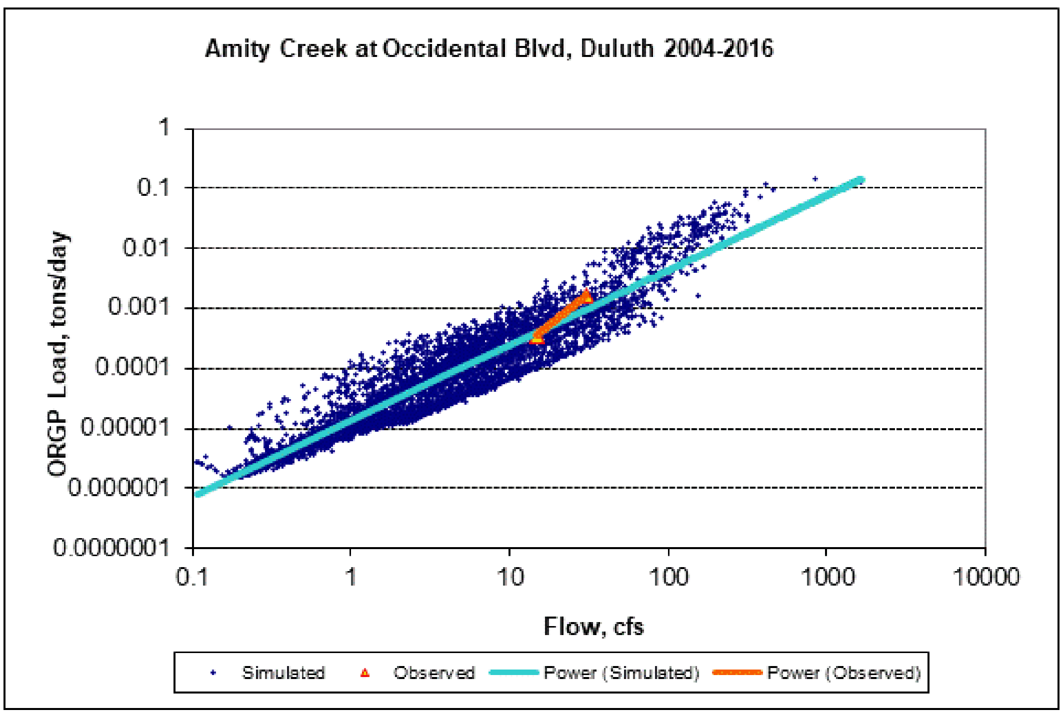


Figure E-385. Power plot of simulated and observed Organic Phosphorus (OrgP) load vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

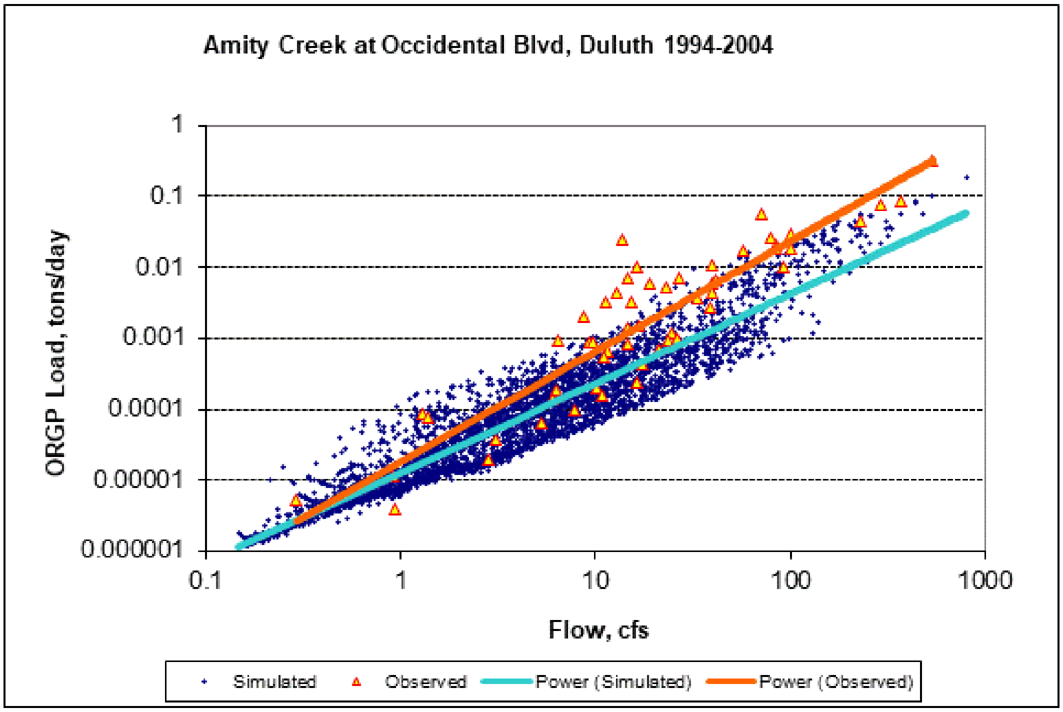


Figure E-386. Power plot of simulated and observed Organic Phosphorus (OrgP) load vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)

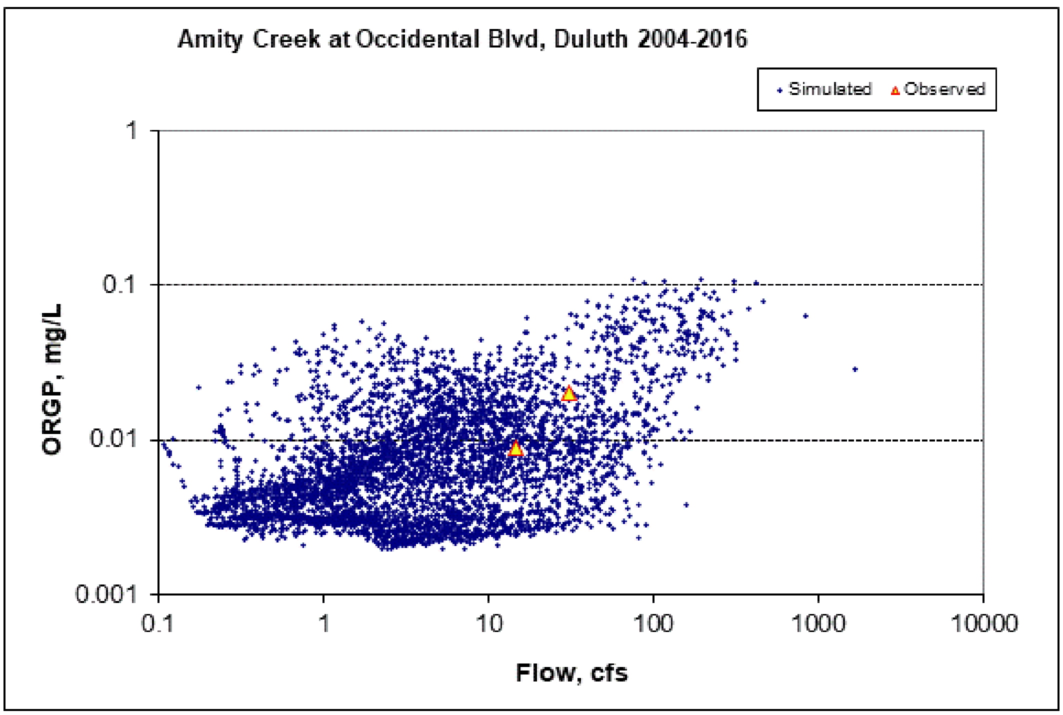


Figure E-387. Simulated and observed Organic Phosphorus (OrgP) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

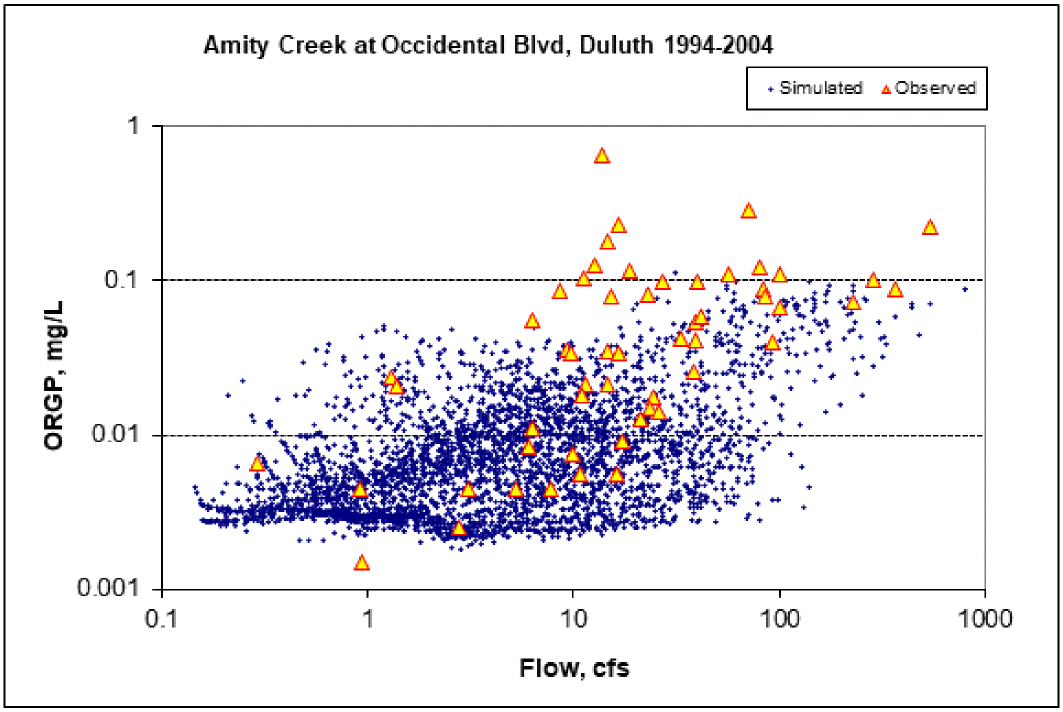
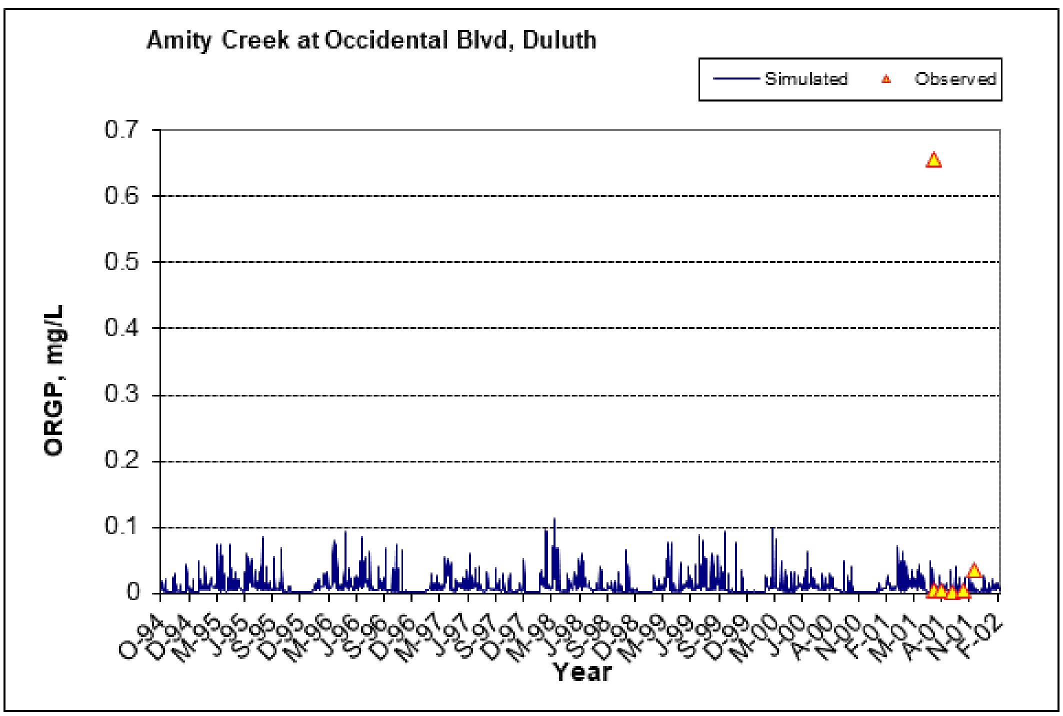
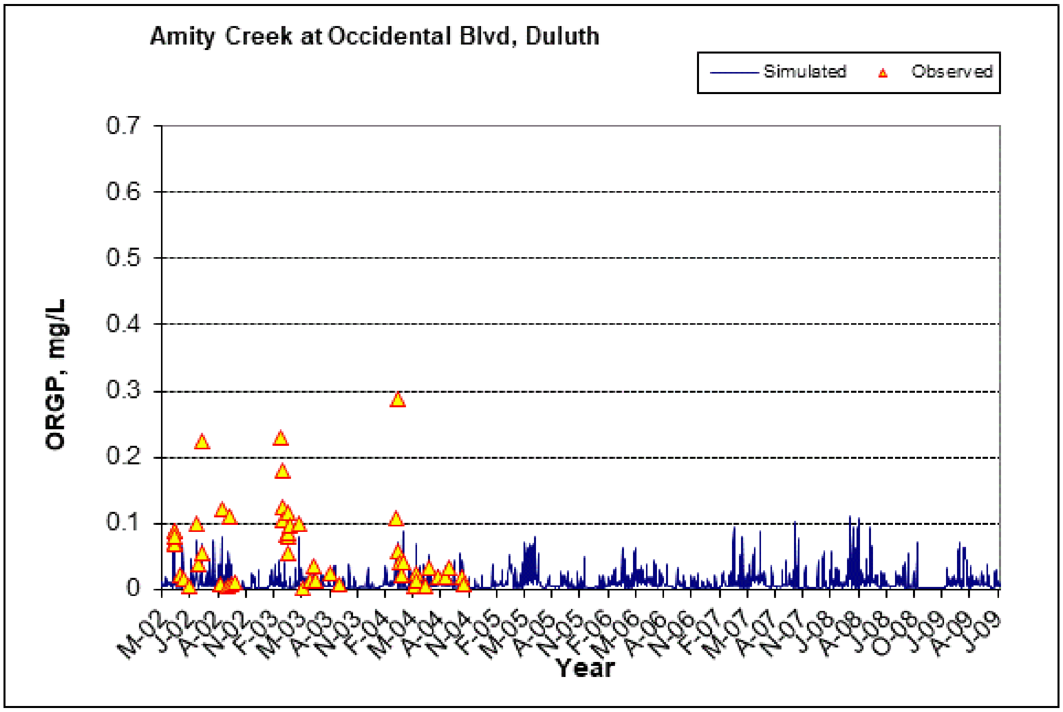


Figure E-388. Simulated and observed Organic Phosphorus (OrgP) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)





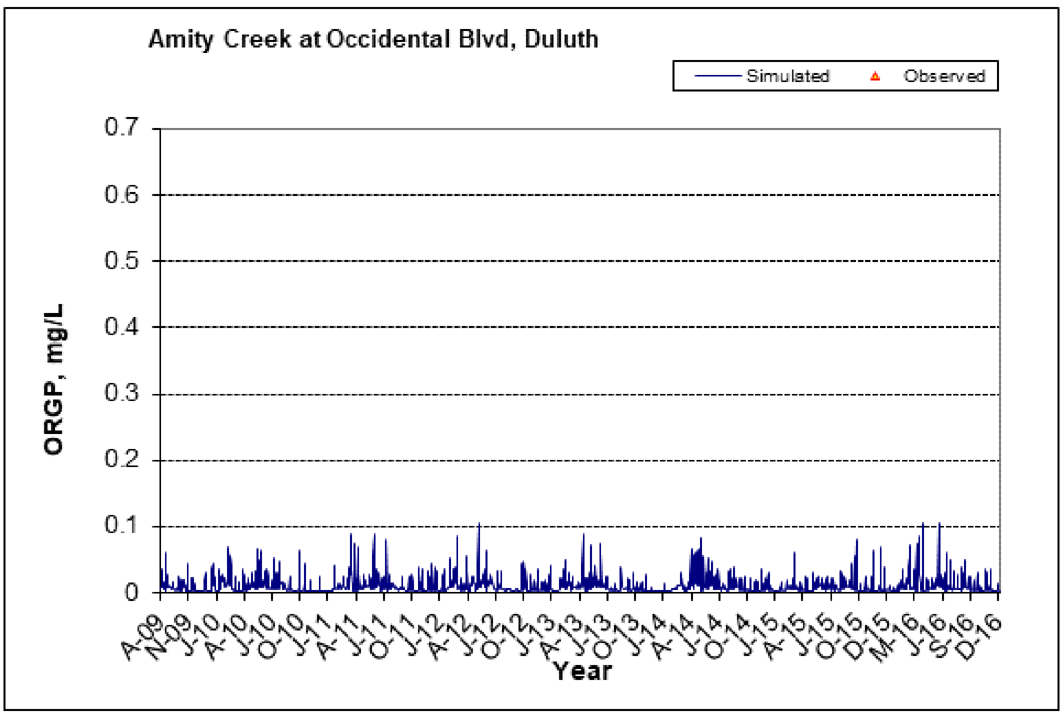


Figure E-389. Time series of observed and simulated Organic Phosphorus (OrgP) concentration at Amity Creek at Occidental Blvd, Duluth

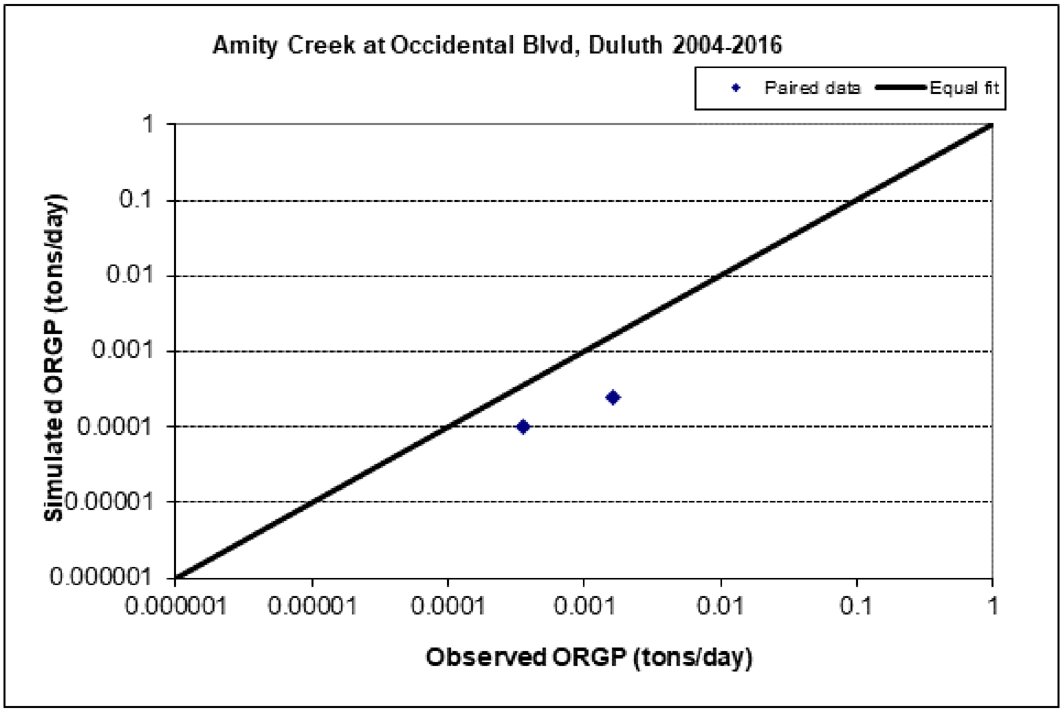


Figure E-390. Paired simulated vs. observed Organic Phosphorus (OrgP) load at Amity Creek at Occidental Blvd, Duluth (calibration period)

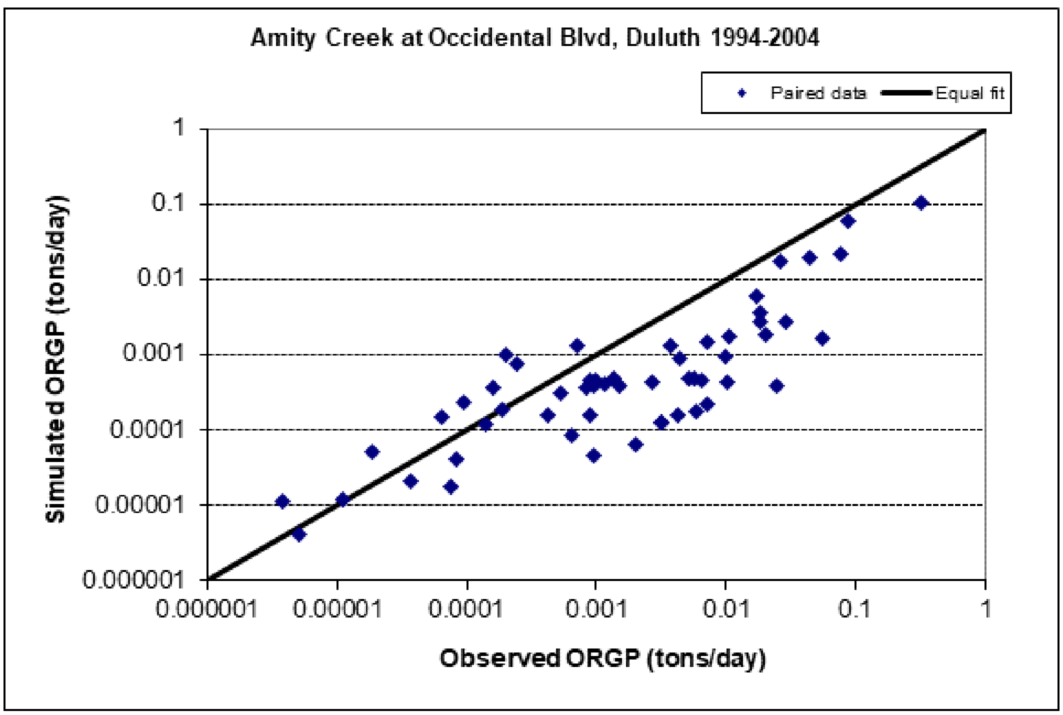


Figure E-391. Paired simulated vs. observed Organic Phosphorus (OrgP) load at Amity Creek at Occidental Blvd, Duluth (validation period)

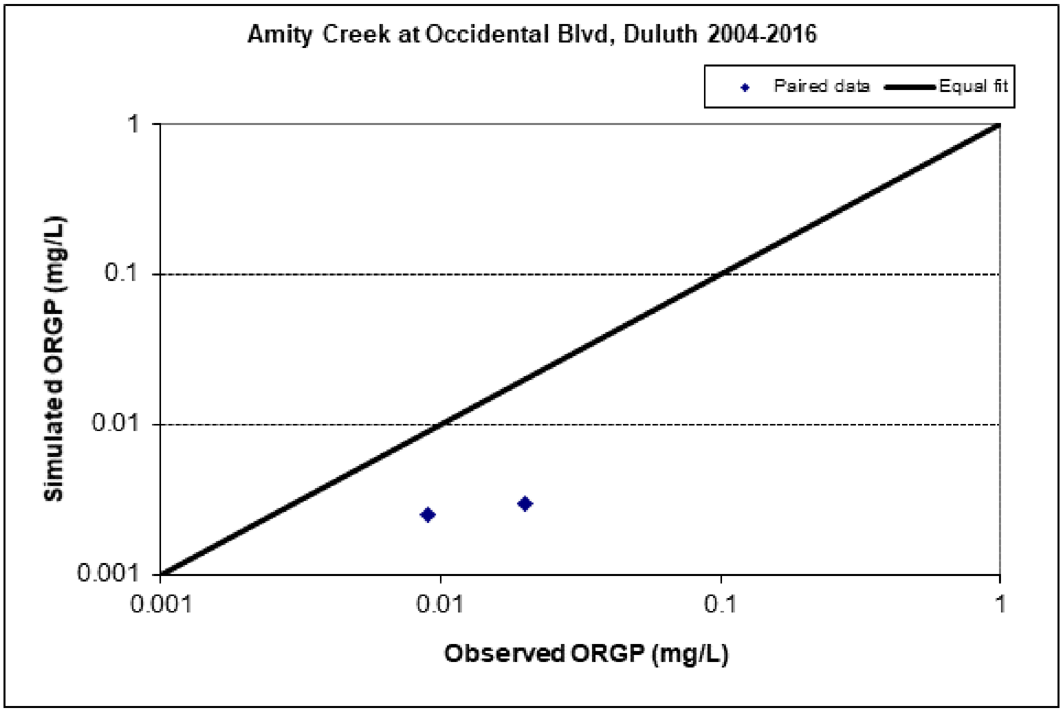


Figure E-392. Paired simulated vs. observed Organic Phosphorus (OrgP) concentration at Amity Creek at Occidental Blvd, Duluth (calibration period)

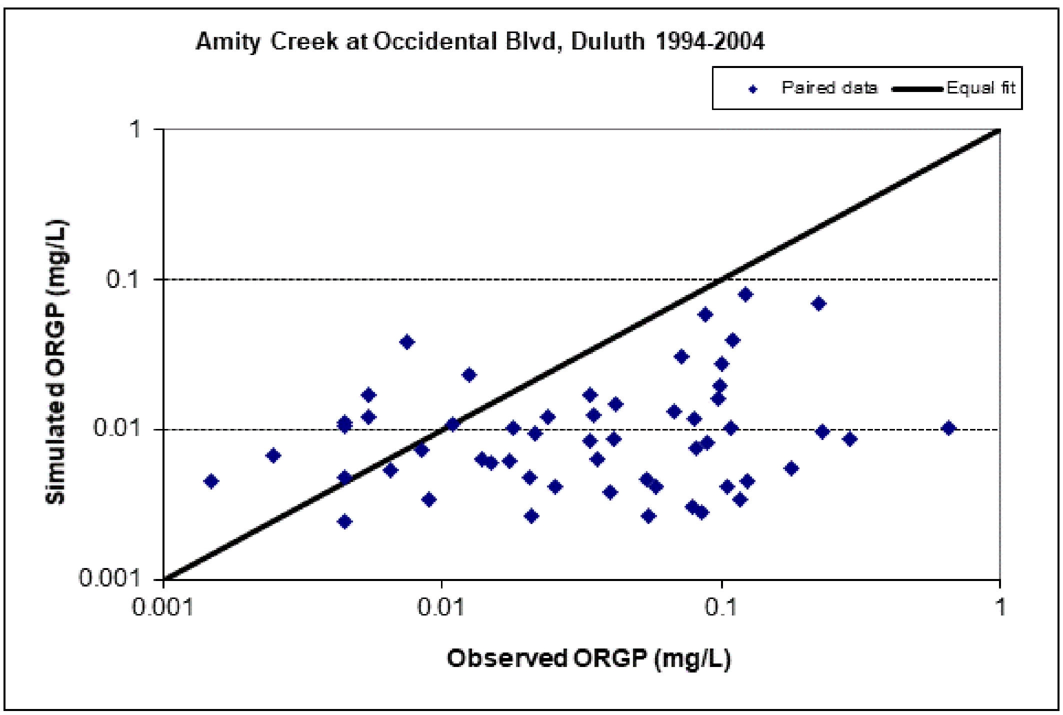


Figure E-393. Paired simulated vs. observed Organic Phosphorus (OrgP) concentration at Amity Creek at Occidental Blvd, Duluth (validation period)

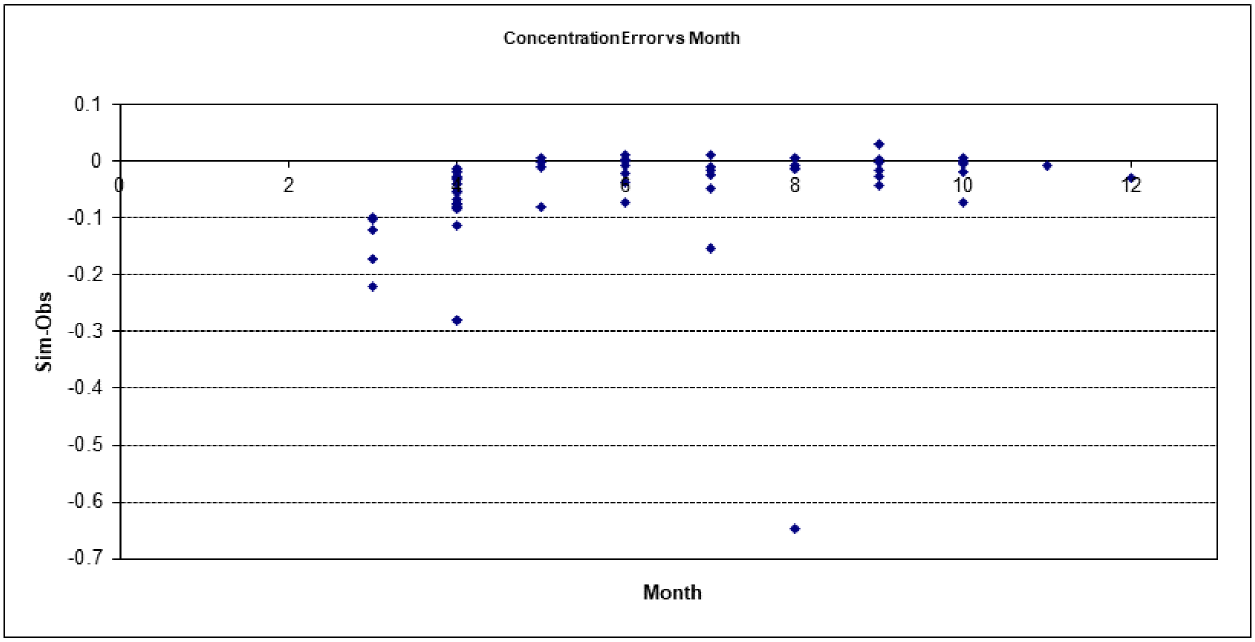


Figure E-394. Residual (Simulated - Observed) vs. Month, Organic Phosphorus (OrgP) at Amity Creek at Occidental Blvd, Duluth

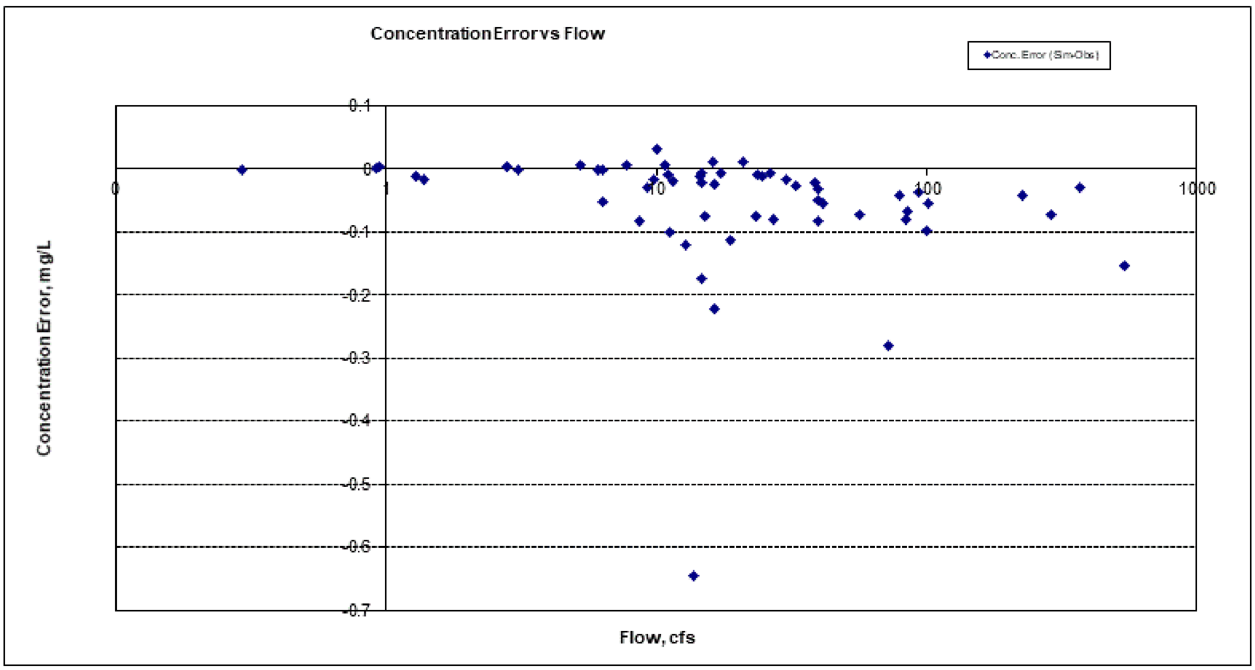


Figure E-395. Residual (Simulated - Observed) vs. Flow, Organic Phosphorus (OrgP) at Amity Creek at Occidental Blvd, Duluth

E.7.9 Total Phosphorus (TP)

Table E-46. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	56	115
Concentration Average Error	-64.36%	-38.23%
Concentration Median Error	-30.49%	-16.30%
Load Average Error	-57.19%	-36.38%
Load Median Error	-6.82%	-3.87%
Paired t conc	0.00	0.00
Paired t load	0.12	0.14

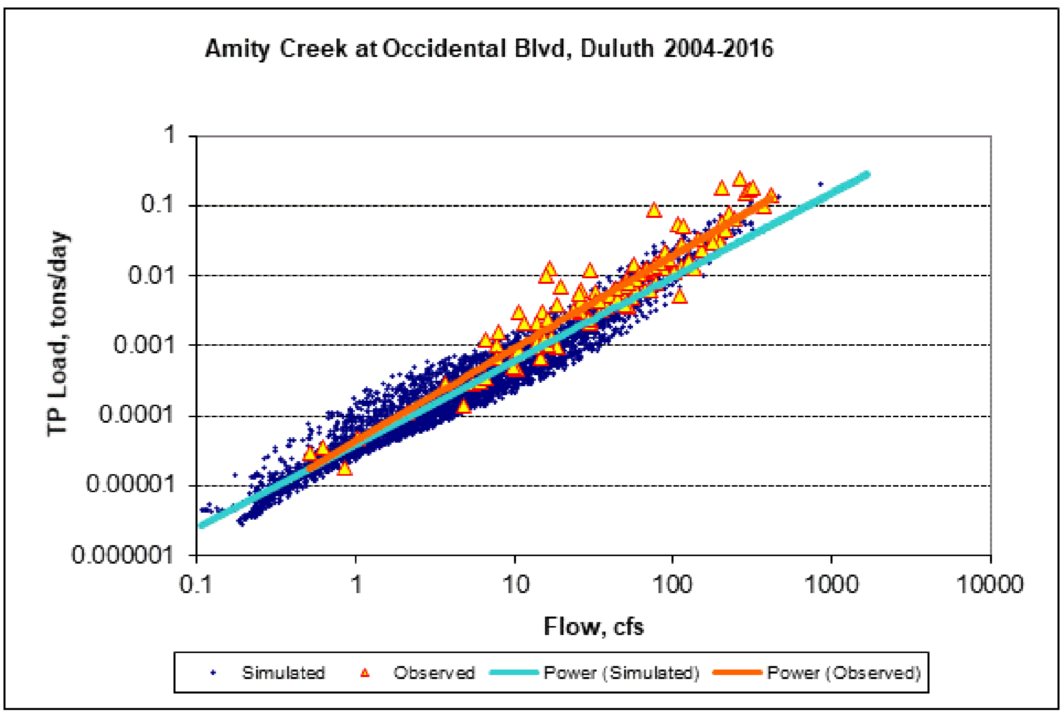


Figure E-396. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

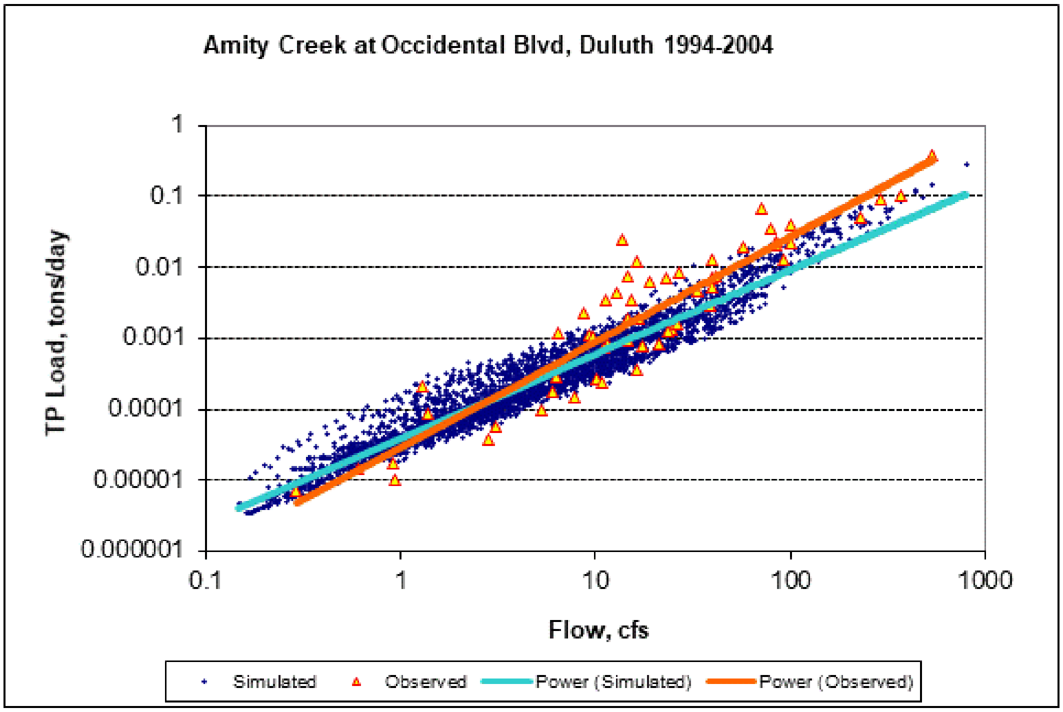


Figure E-397. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)

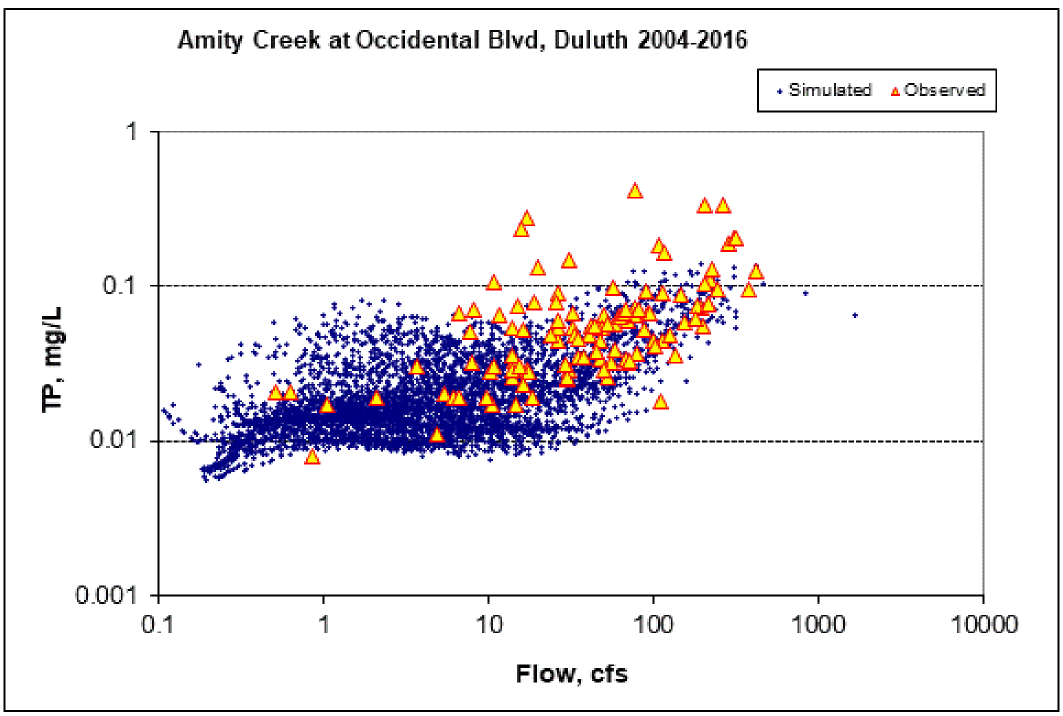


Figure E-398. Simulated and observed Total Phosphorus (TP) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (calibration period)

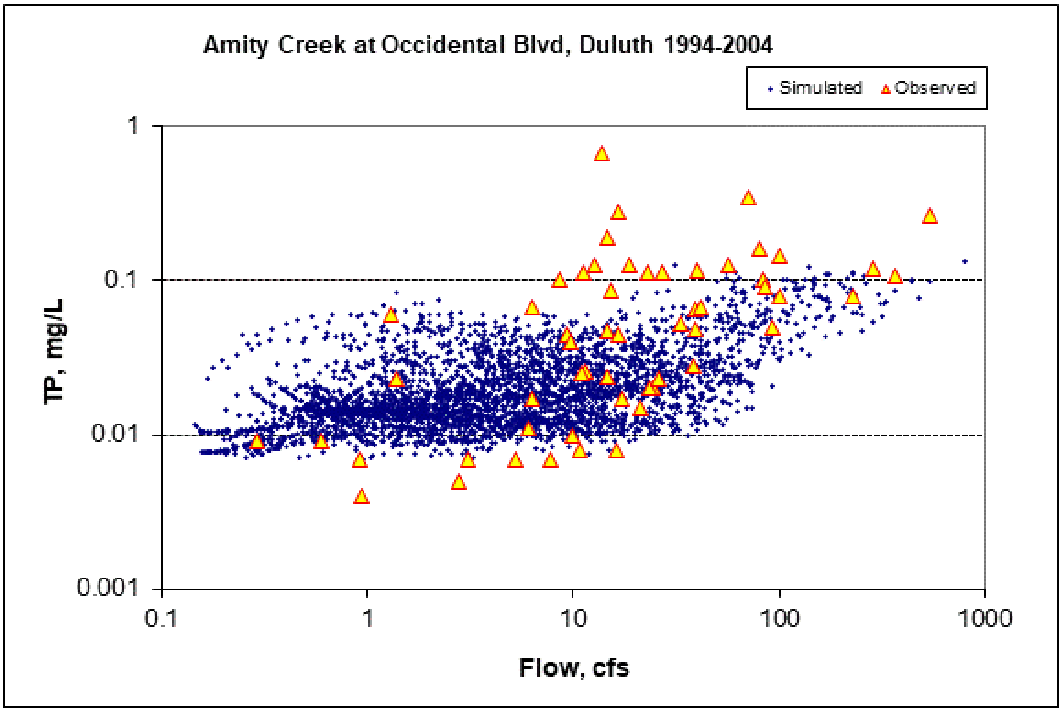
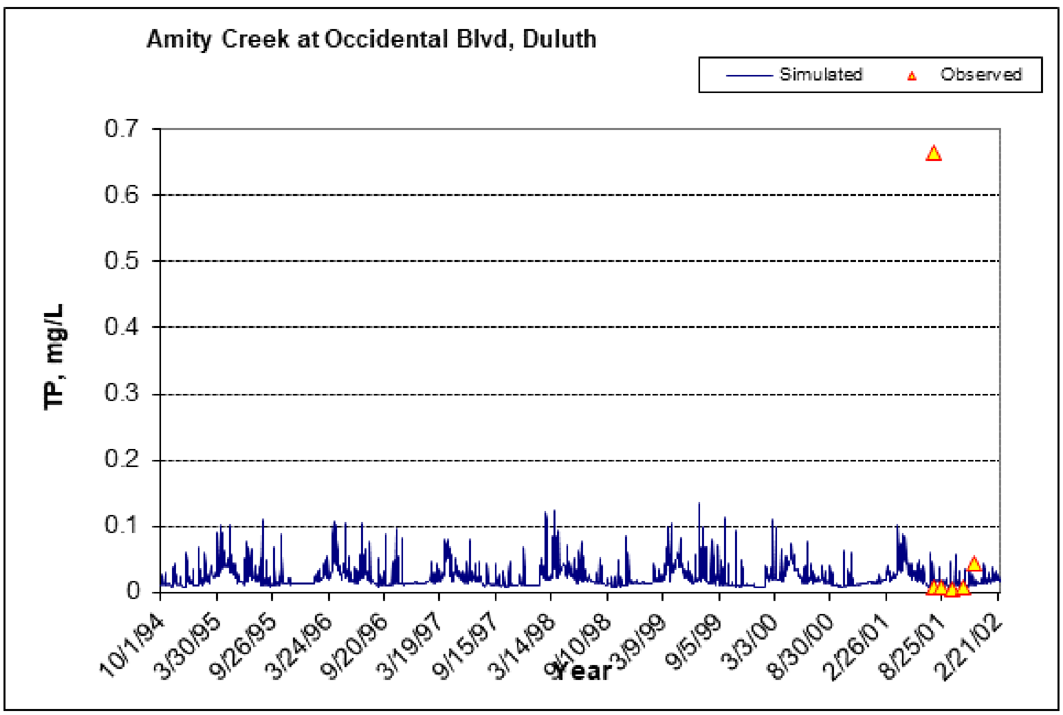
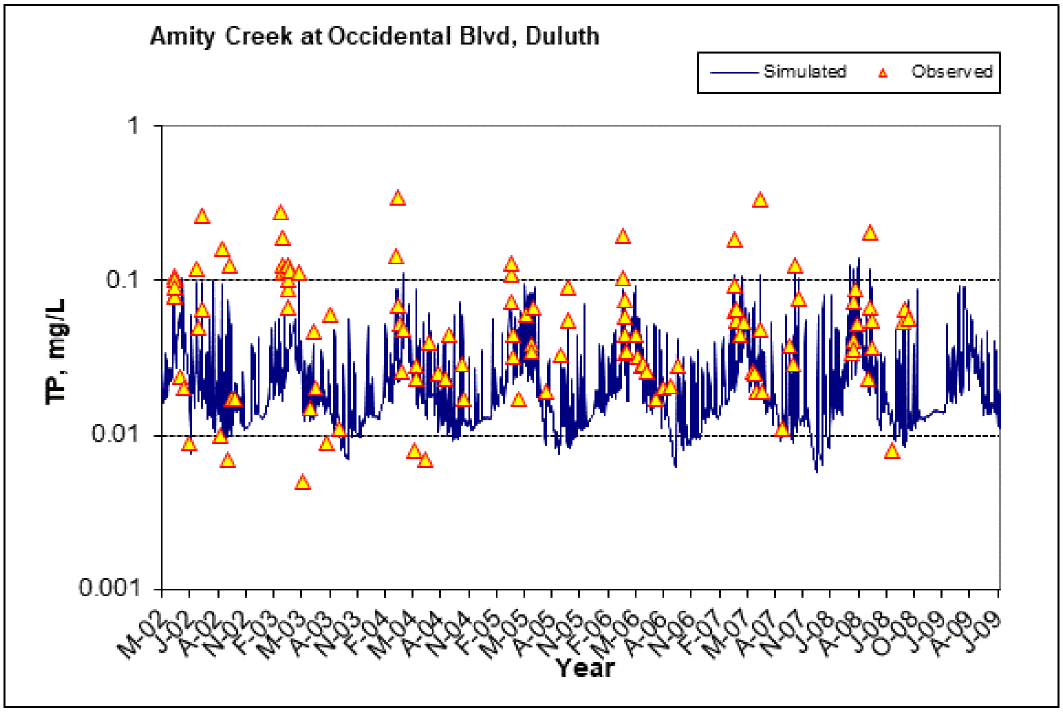


Figure E-399. Simulated and observed Total Phosphorus (TP) concentration vs flow at Amity Creek at Occidental Blvd, Duluth (validation period)





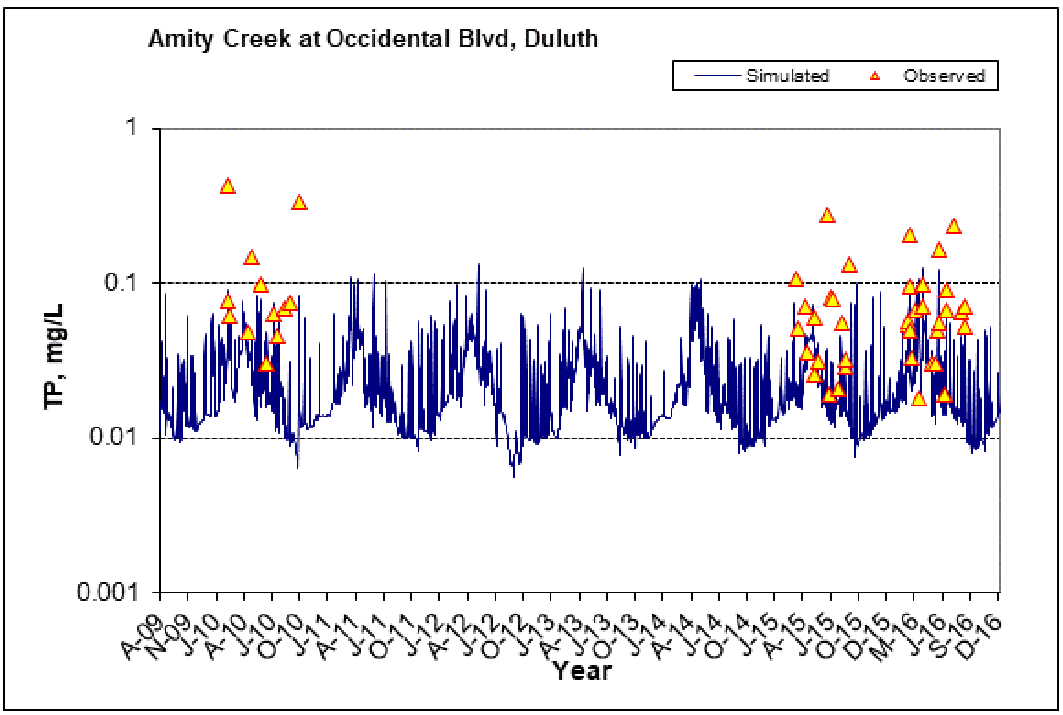


Figure E-400. Time series of observed and simulated Total Phosphorus (TP) concentration at Amity Creek at Occidental Blvd, Duluth

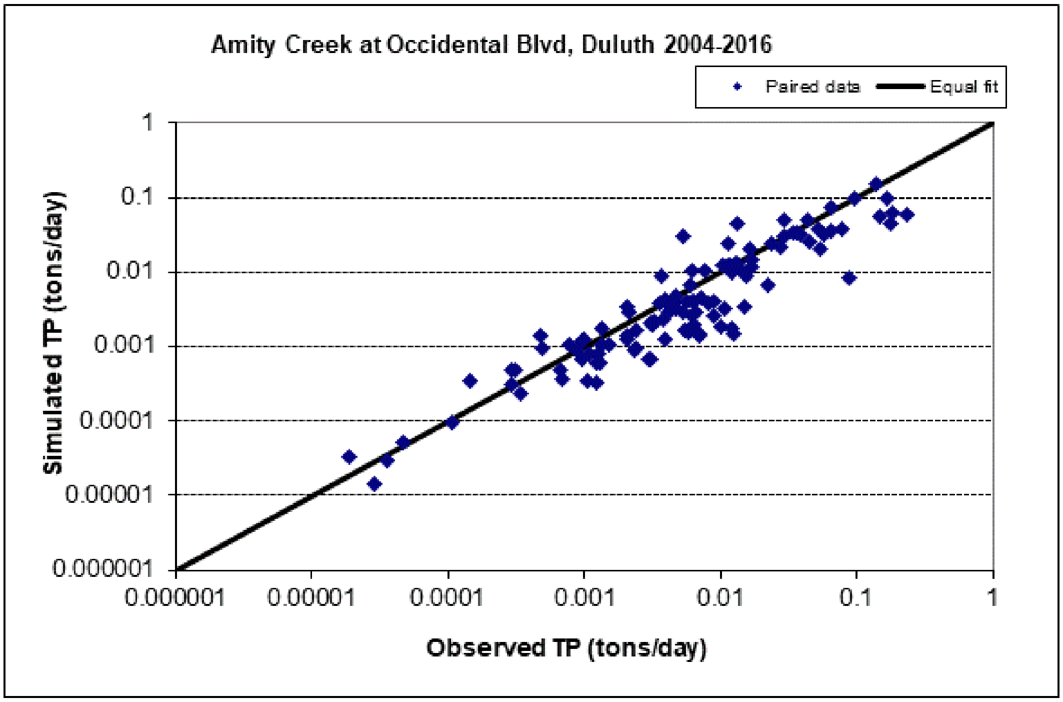


Figure E-401. Paired simulated vs. observed Total Phosphorus (TP) load at Amity Creek at Occidental Blvd, Duluth (calibration period)

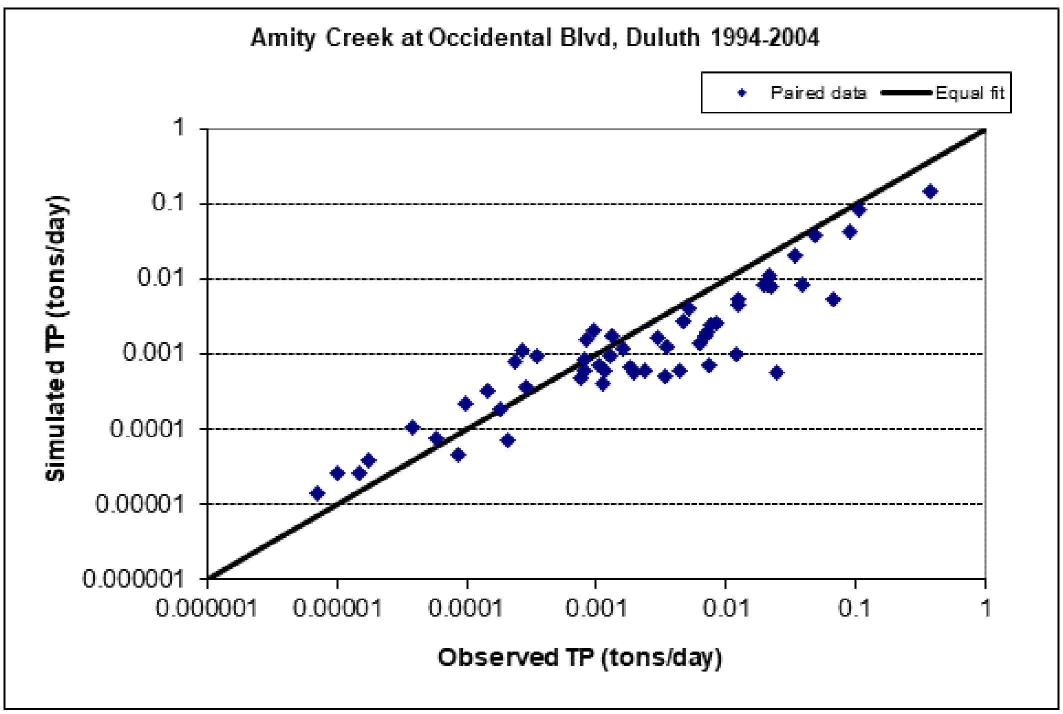


Figure E-402. Paired simulated vs. observed Total Phosphorus (TP) load at Amity Creek at Occidental Blvd, Duluth (validation period)

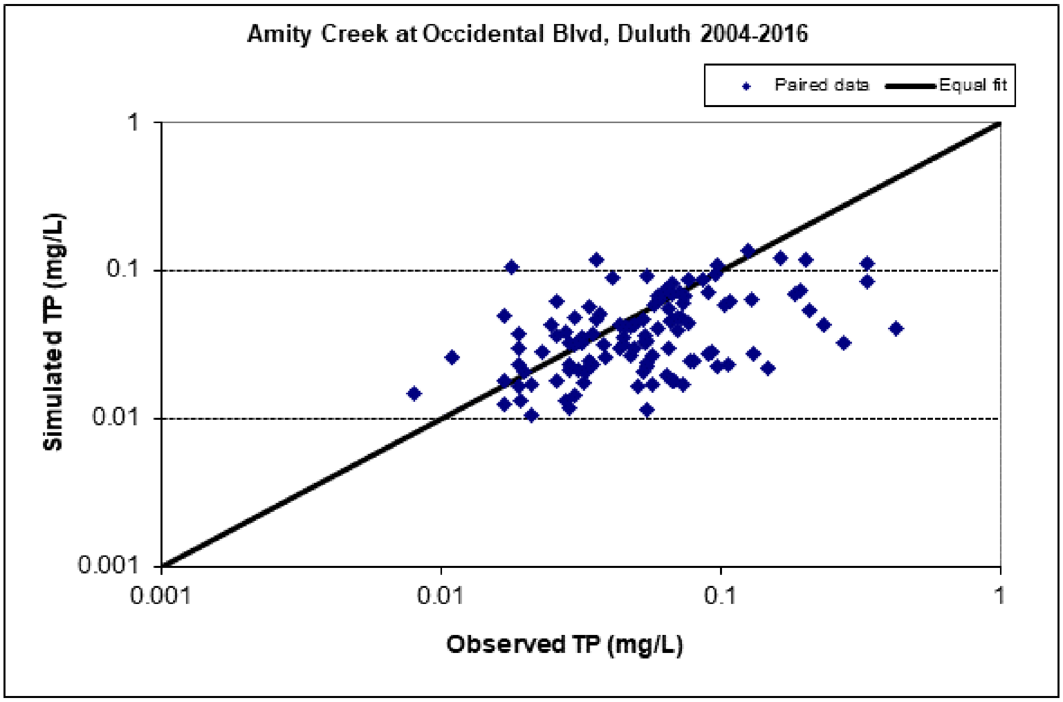


Figure E-403. Paired simulated vs. observed Total Phosphorus (TP) concentration at Amity Creek at Occidental Blvd, Duluth (calibration period)

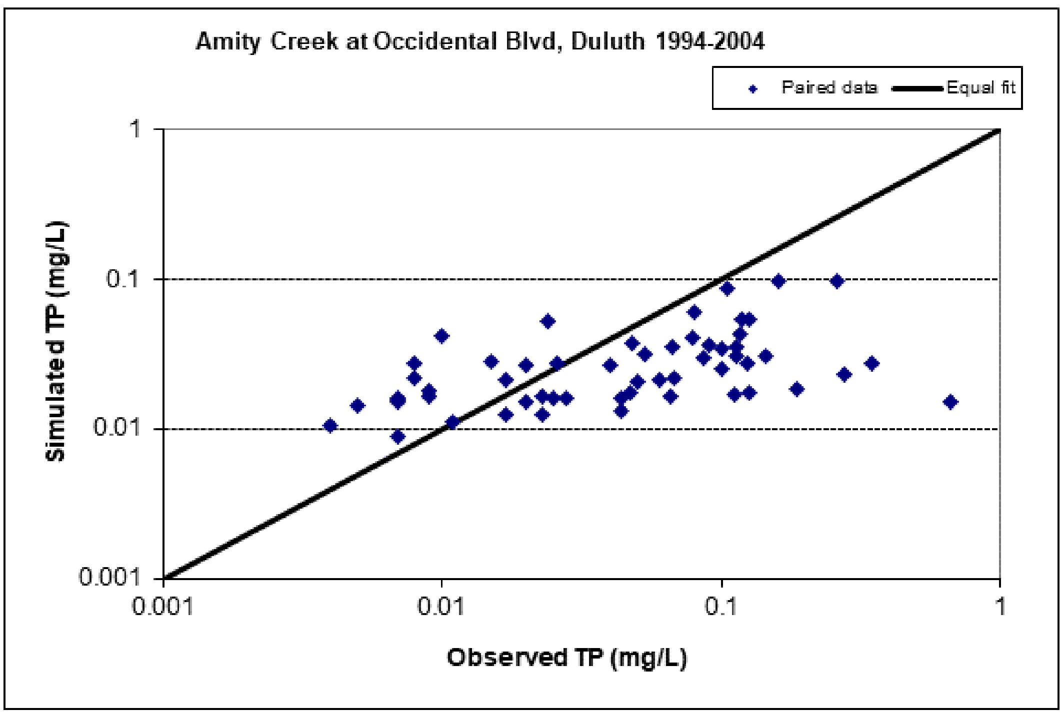


Figure E-404. Paired simulated vs. observed Total Phosphorus (TP) concentration at Amity Creek at Occidental Blvd, Duluth (validation period)

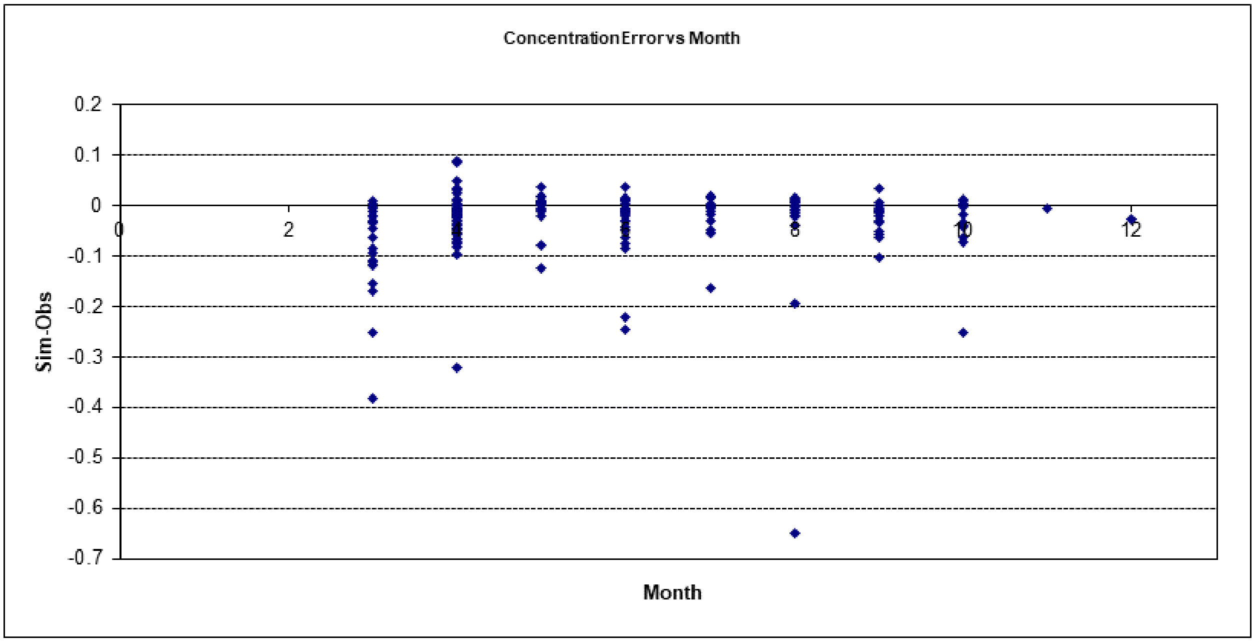


Figure E-405. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Amity Creek at Occidental Blvd, Duluth

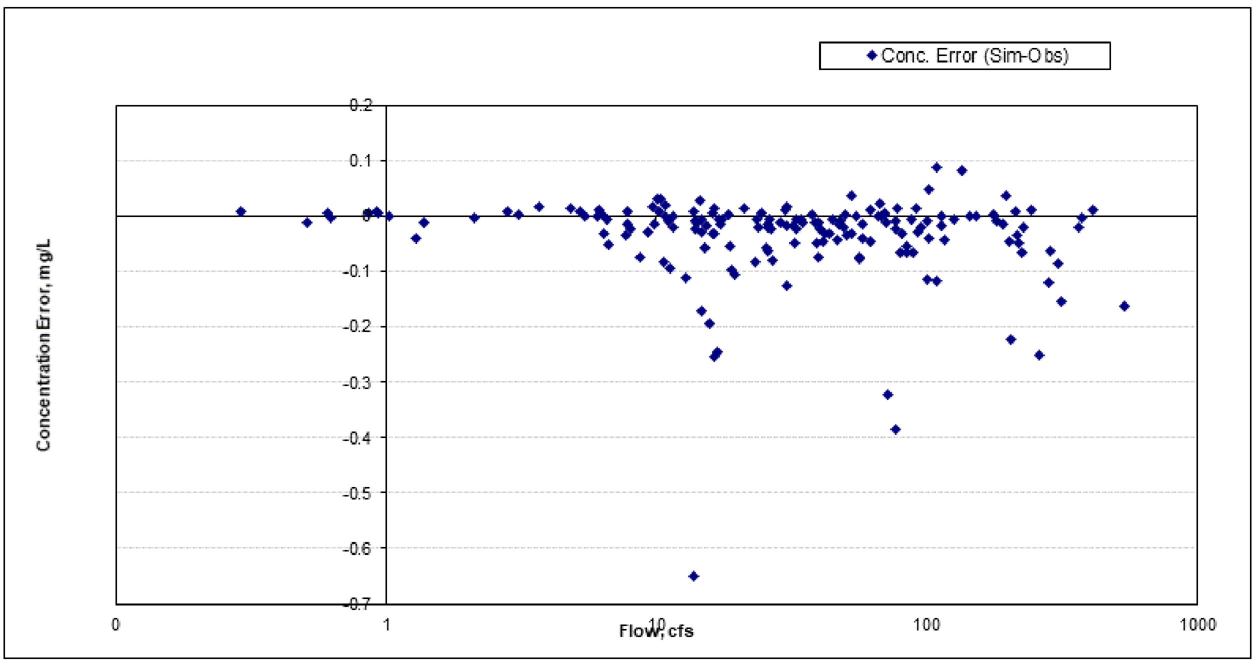


Figure E-406. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Amity Creek at Occidental Blvd, Duluth

E.8 Tischer Creek (Multiple Stations)

E.8.1 Dissolved Oxygen (DO)

Table E-47. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	76
Concentration Average Error		-16.51%
Concentration Median Error		-15.44%
Load Average Error		-12.90%
Load Median Error		-3.29%
Paired t conc		0.94
Paired t load		0.67

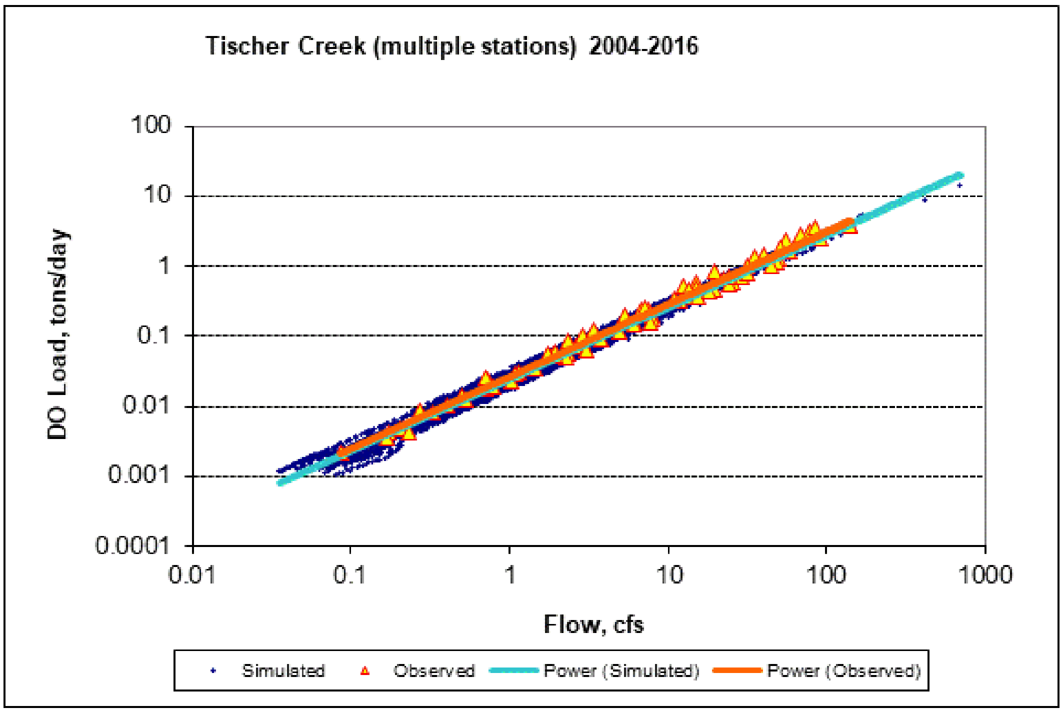


Figure E-407. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Tischer Creek (multiple stations) (calibration period)

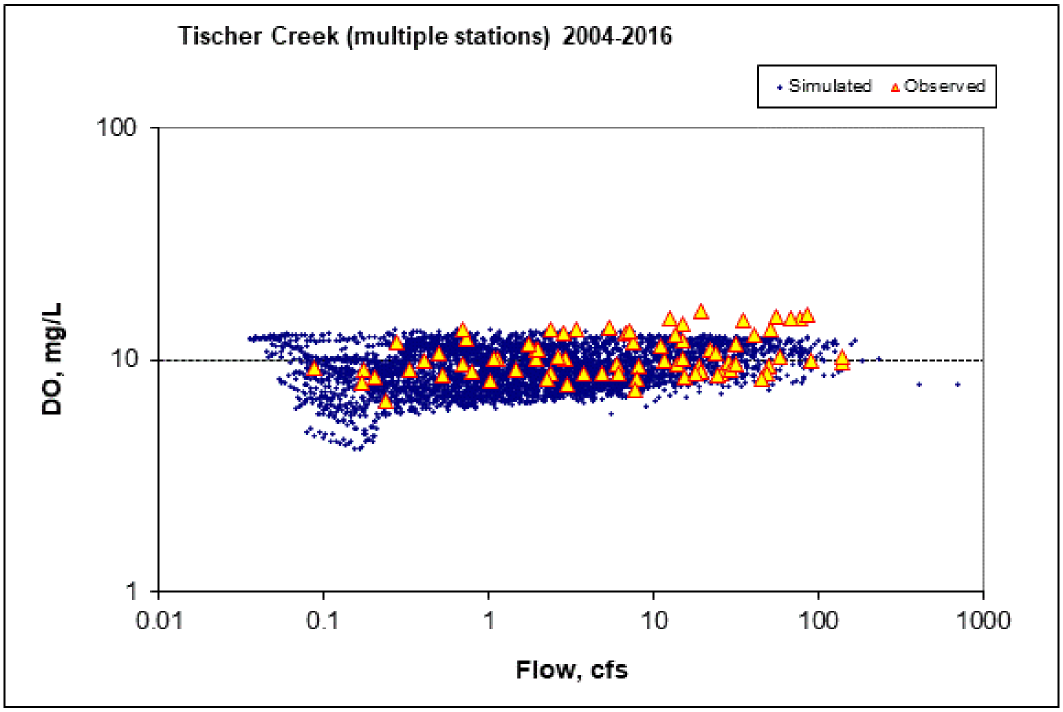
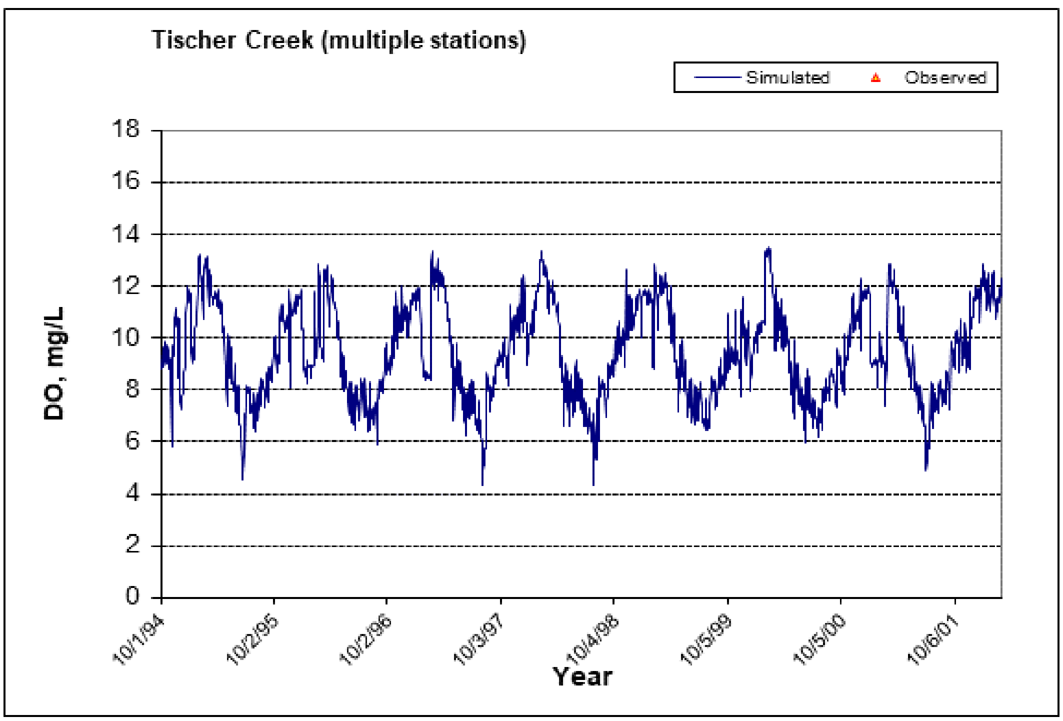
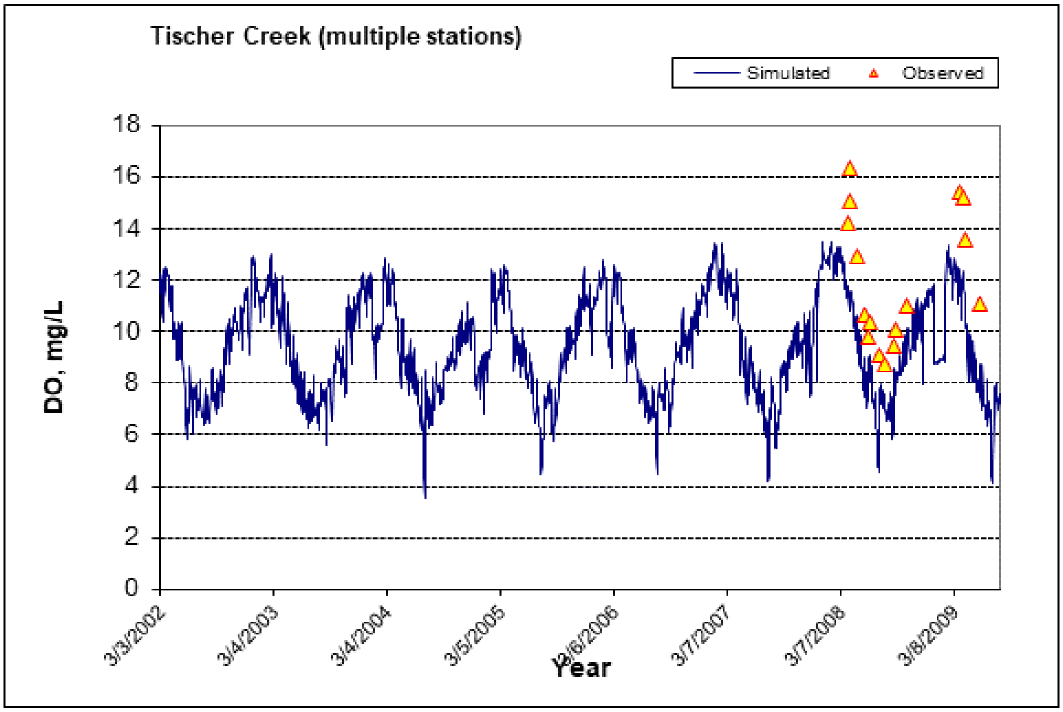


Figure E-408. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Tischer Creek (multiple stations) (calibration period)





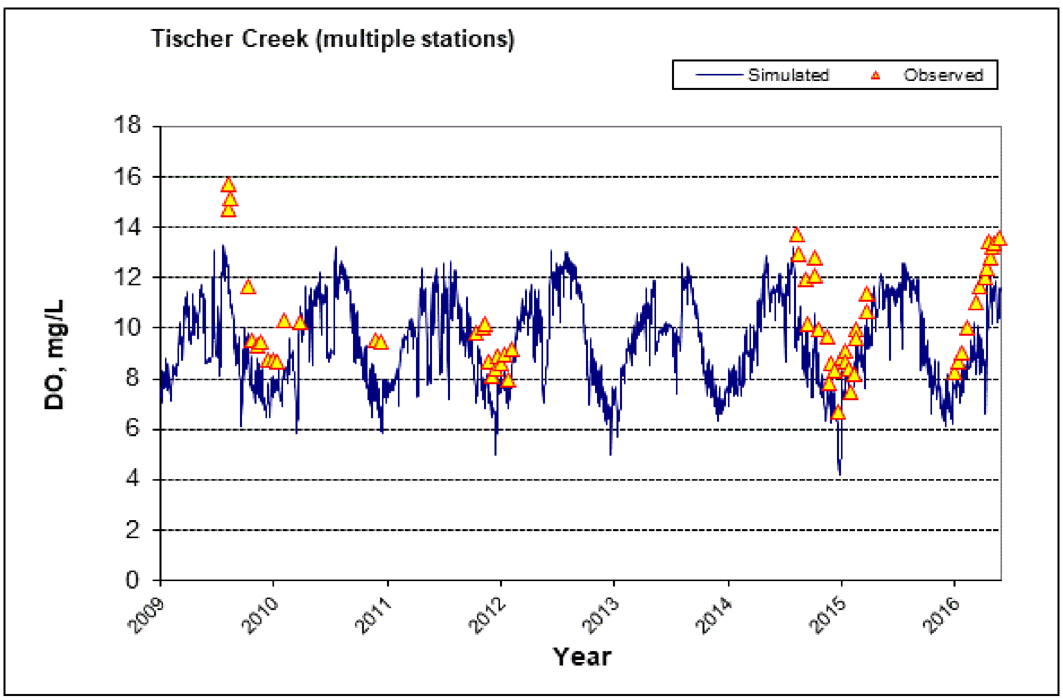


Figure E-409. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Tischer Creek (multiple stations)

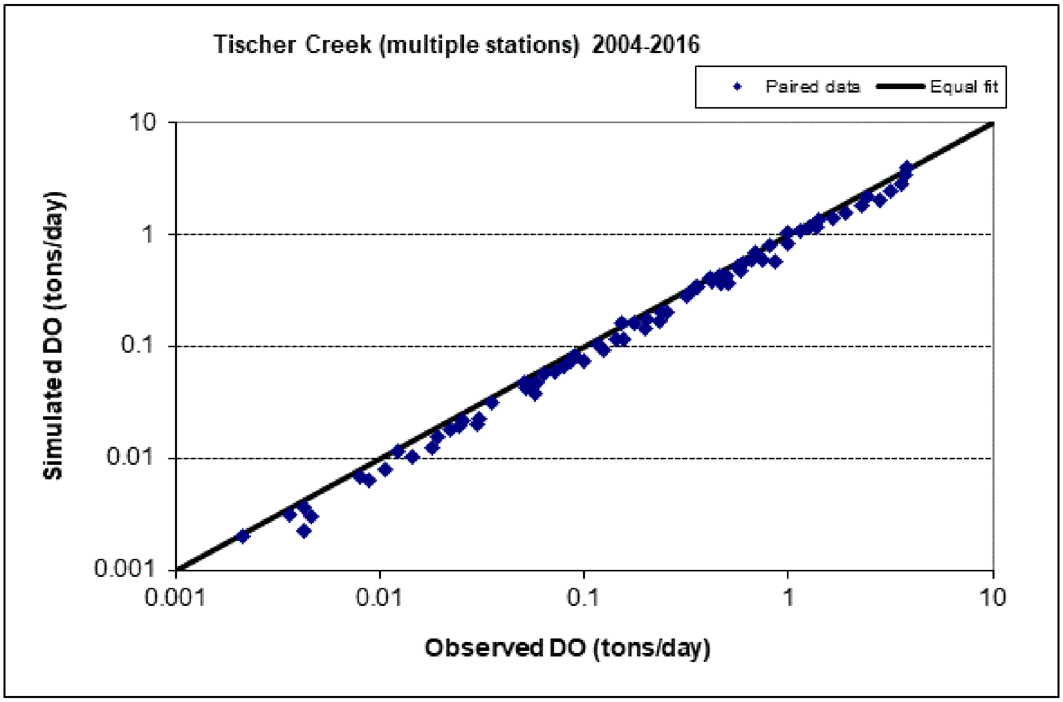


Figure E-410. Paired simulated vs. observed Dissolved Oxygen (DO) load at Tischer Creek (multiple stations) (calibration period)

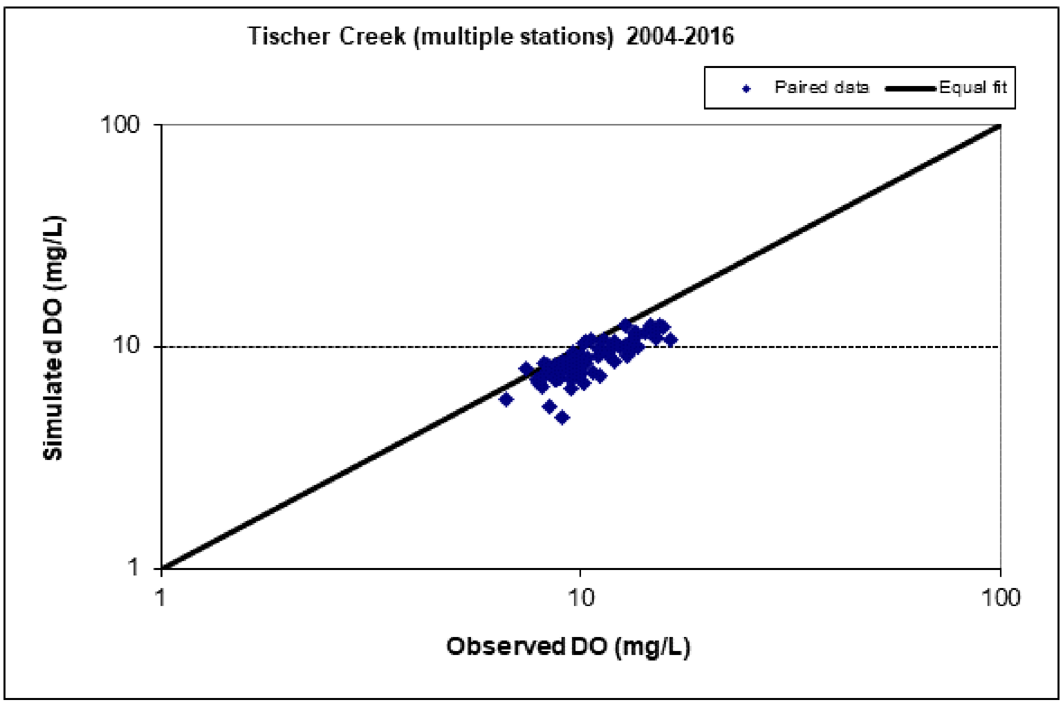


Figure E-411. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Tischer Creek (multiple stations) (calibration period)

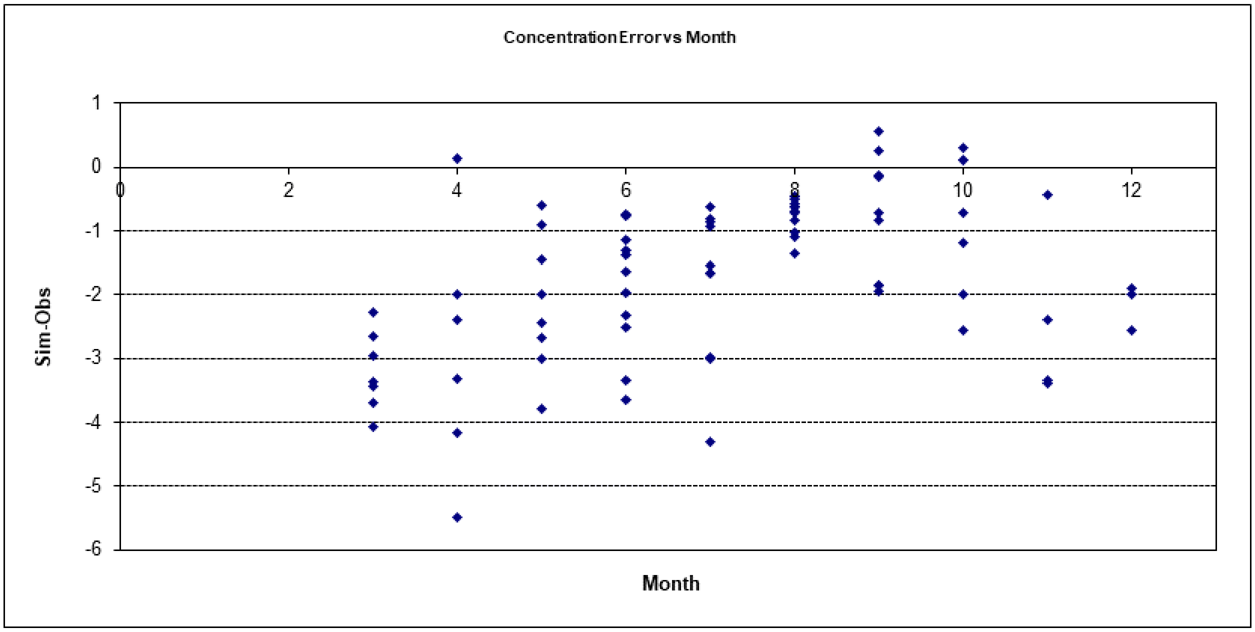


Figure E-412. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Tischer Creek (multiple stations)

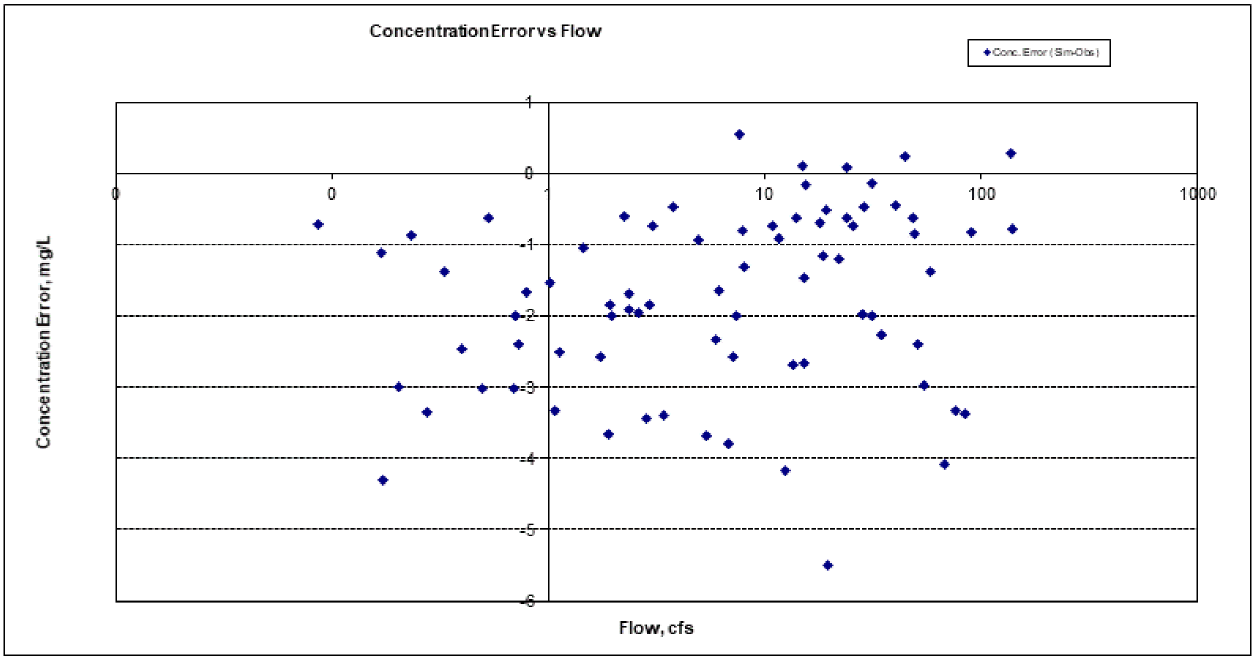


Figure E-413. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Tischer Creek (multiple stations)

E.8.2 Ammonia Nitrogen (NH3)

Table E-48. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	53
Concentration Average Error		142.45%
Concentration Median Error		63.93%
Load Average Error		89.85%
Load Median Error		2.84%
Paired t conc		0.00
Paired t load		0.05

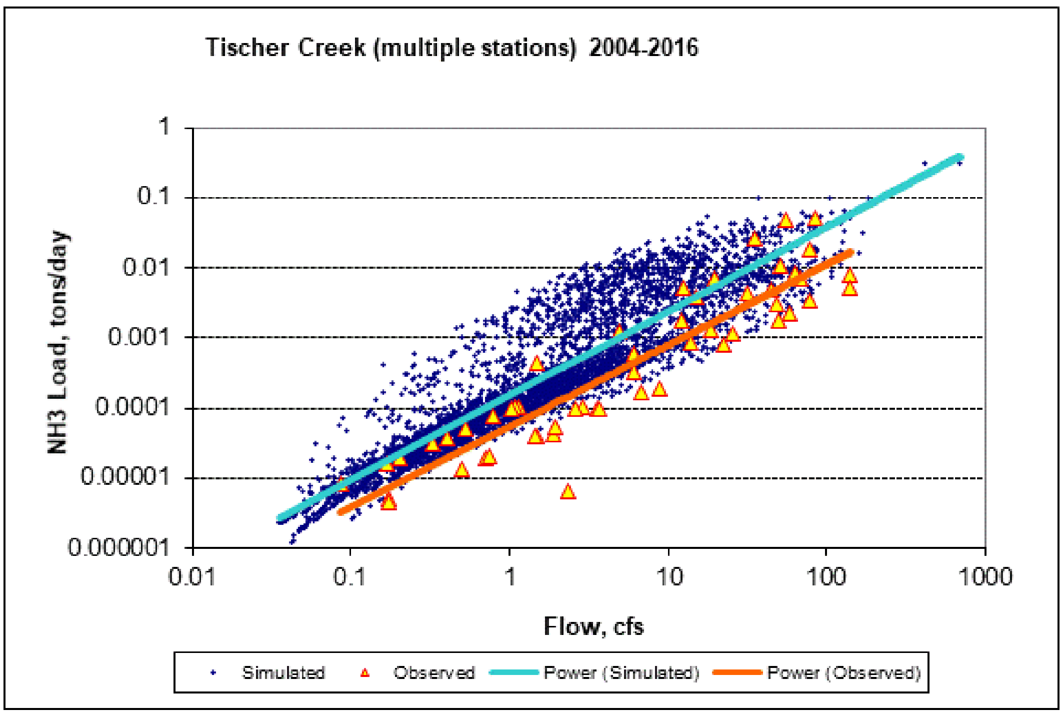


Figure E-414. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Tischer Creek (multiple stations) (calibration period)

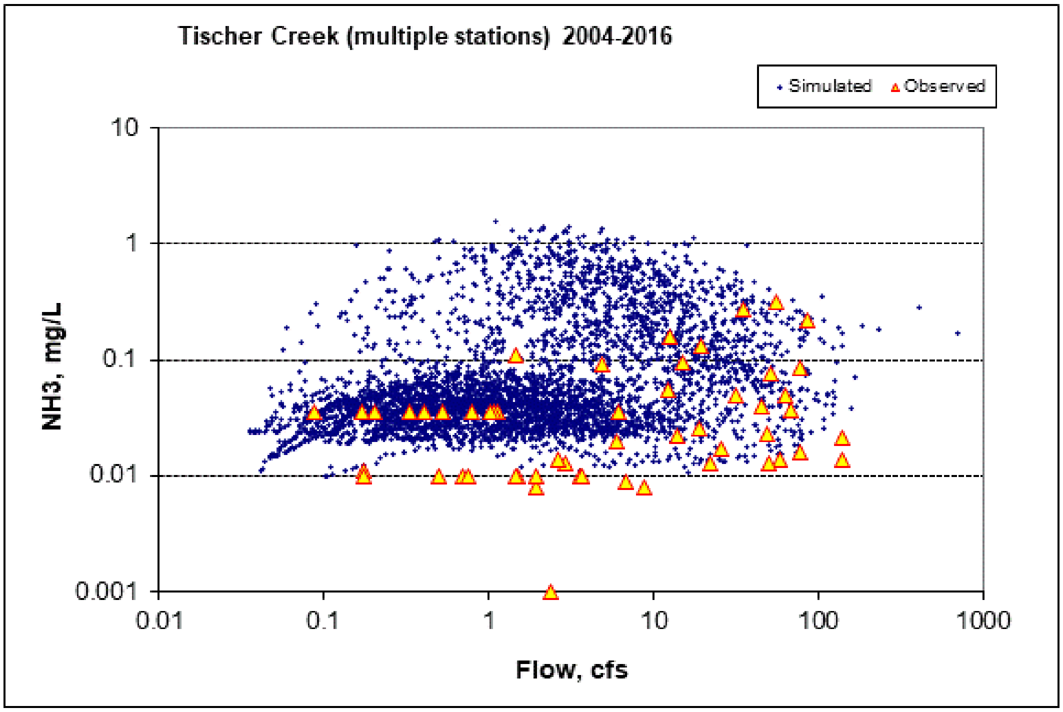
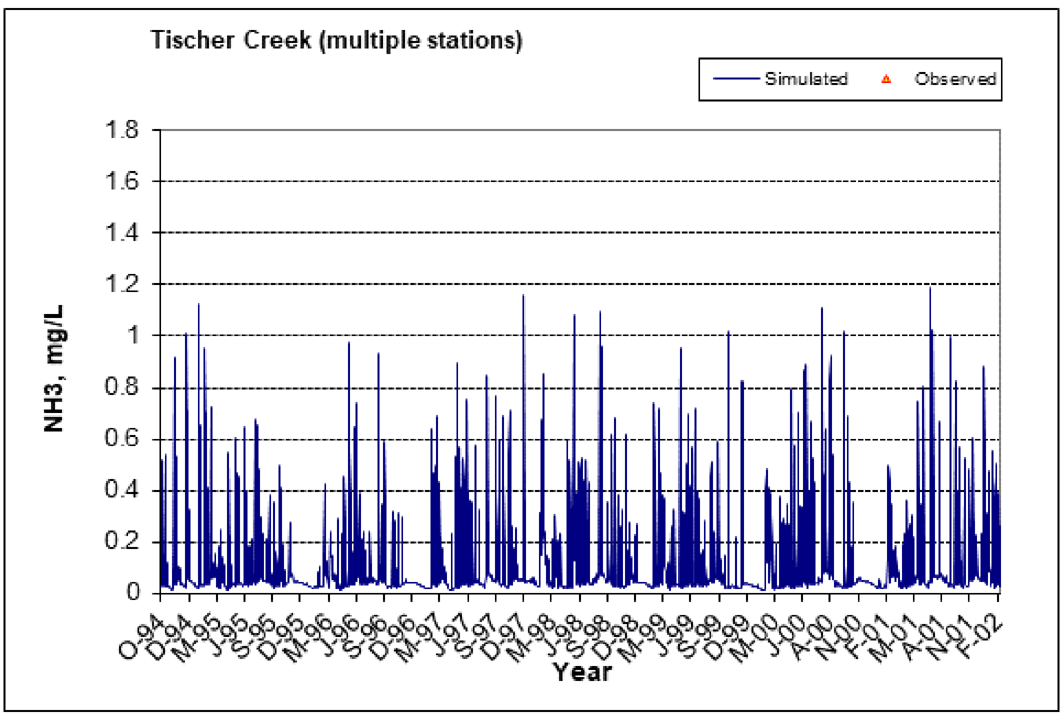
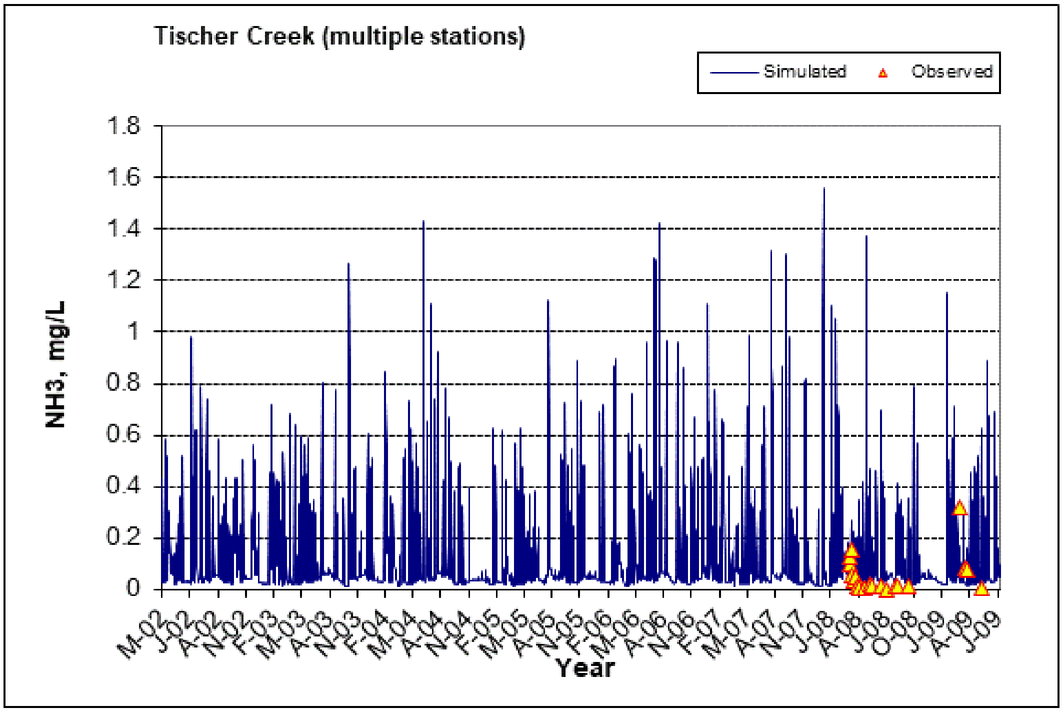


Figure E-415. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Tischer Creek (multiple stations) (calibration period)





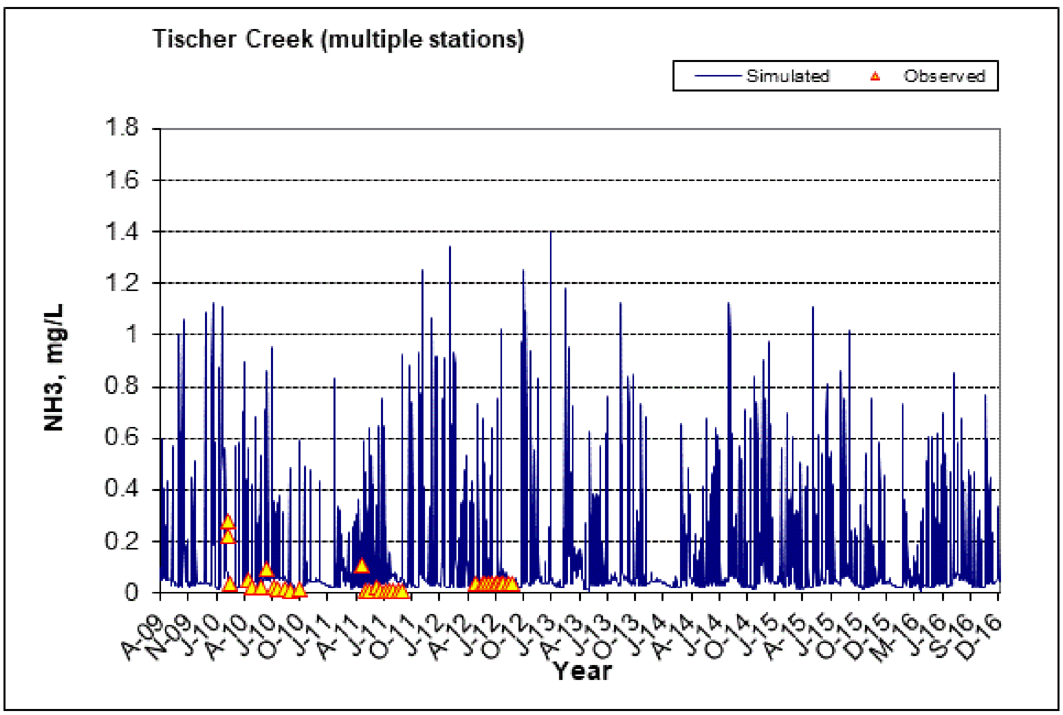


Figure E-416. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Tischer Creek (multiple stations)

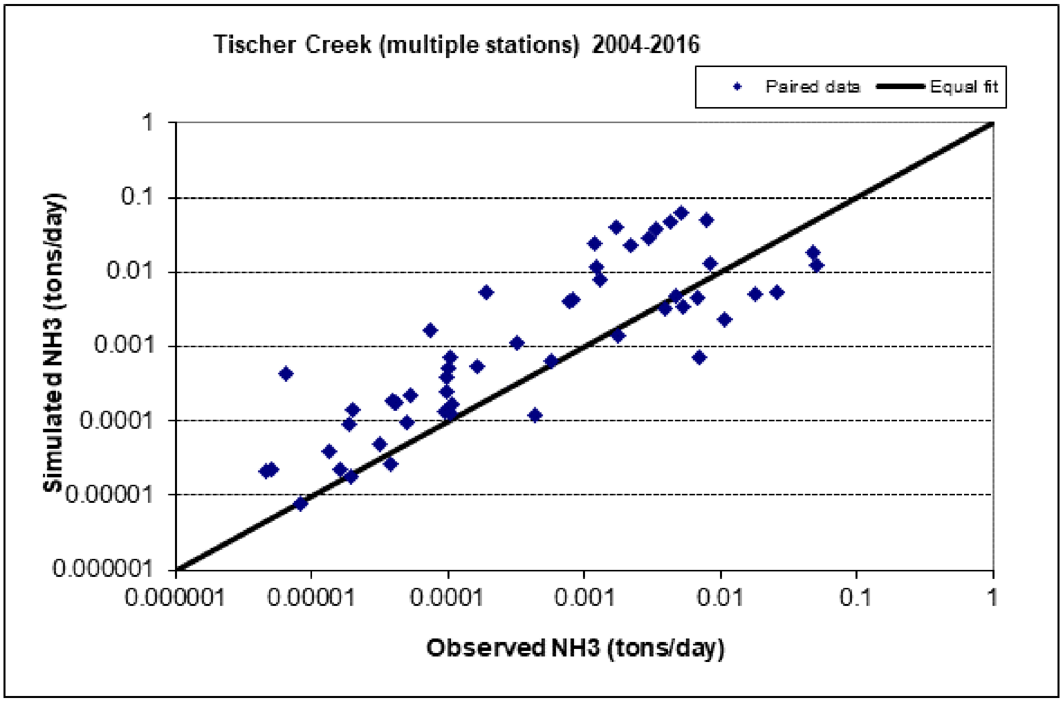


Figure E-417. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Tischer Creek (multiple stations) (calibration period)

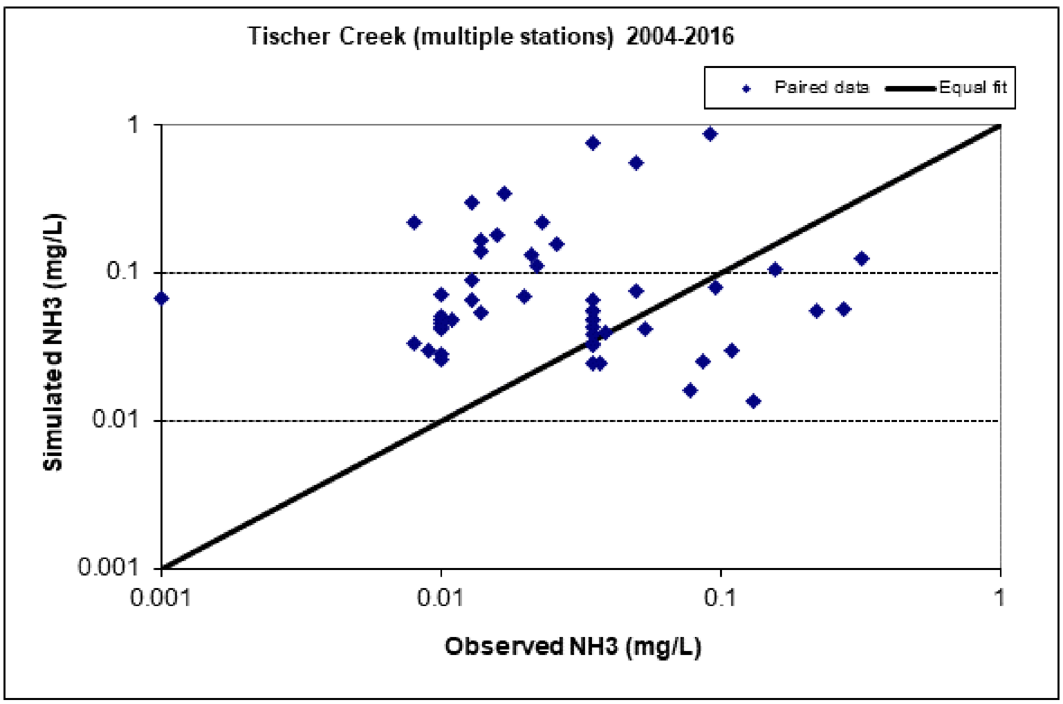


Figure E-418. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Tischer Creek (multiple stations) (calibration period)

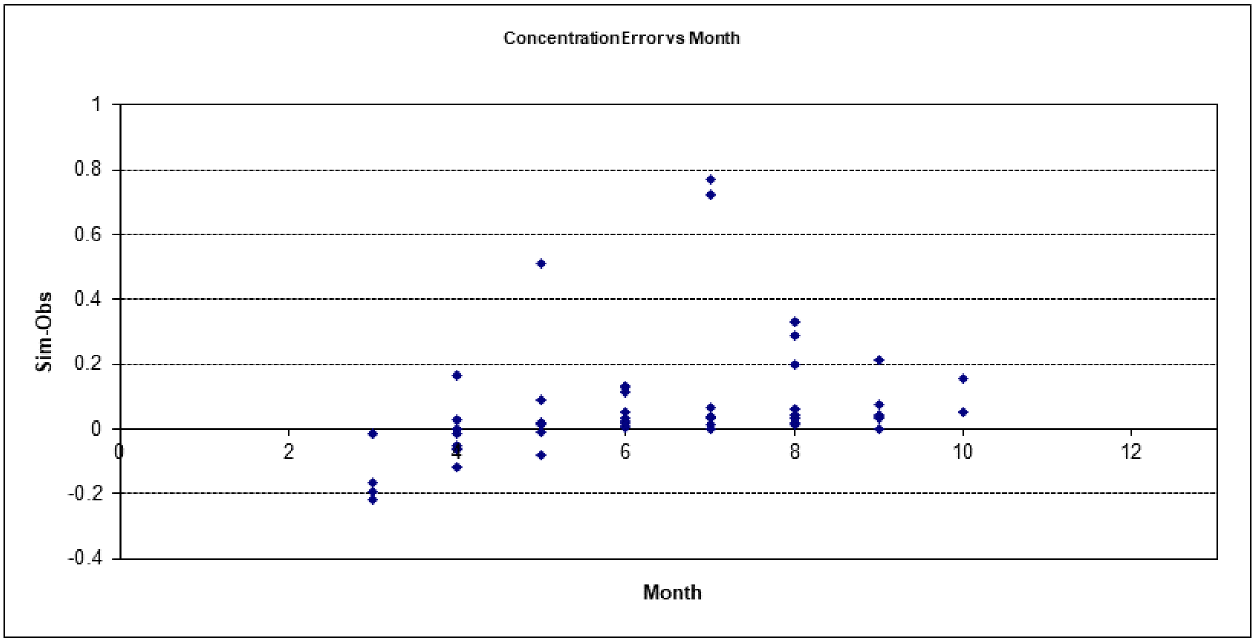


Figure E-419. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Tischer Creek (multiple stations)

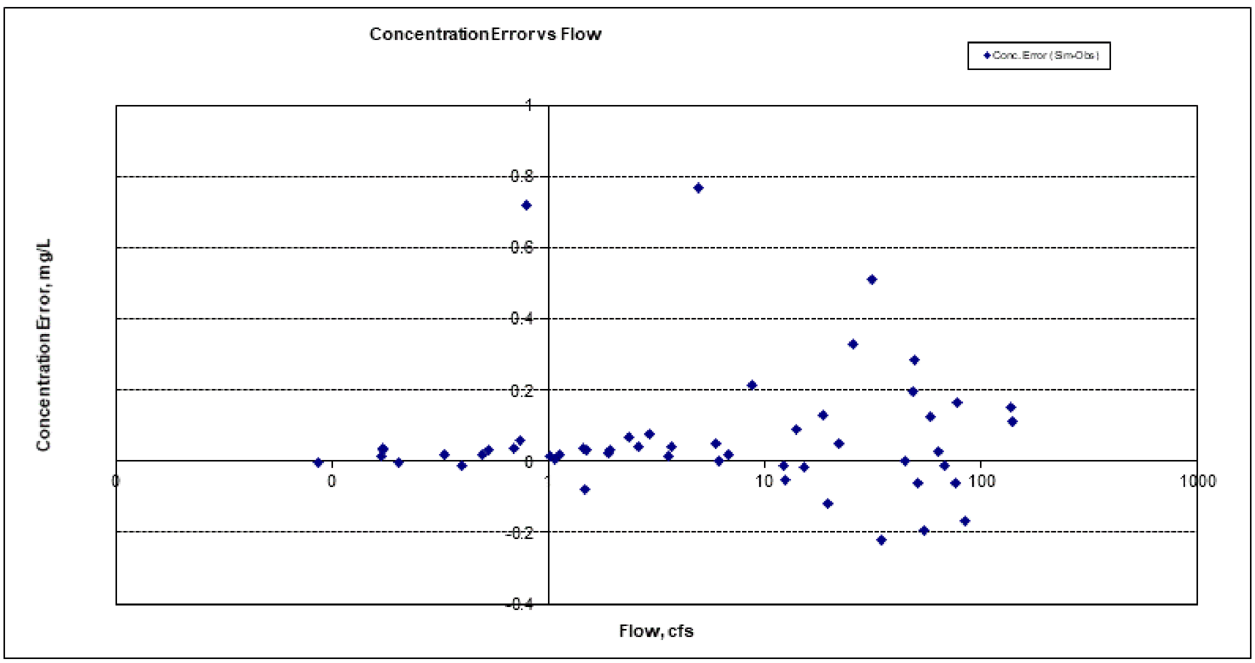


Figure E-420. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Tischer Creek (multiple stations)

E.8.3 Organic Nitrogen (OrgN)

Table E-49. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	ND	53
Concentration Average Error		10.90%
Concentration Median Error		10.09%
Load Average Error		-10.55%
Load Median Error		0.41%
Paired t conc		0.95
Paired t load		0.67

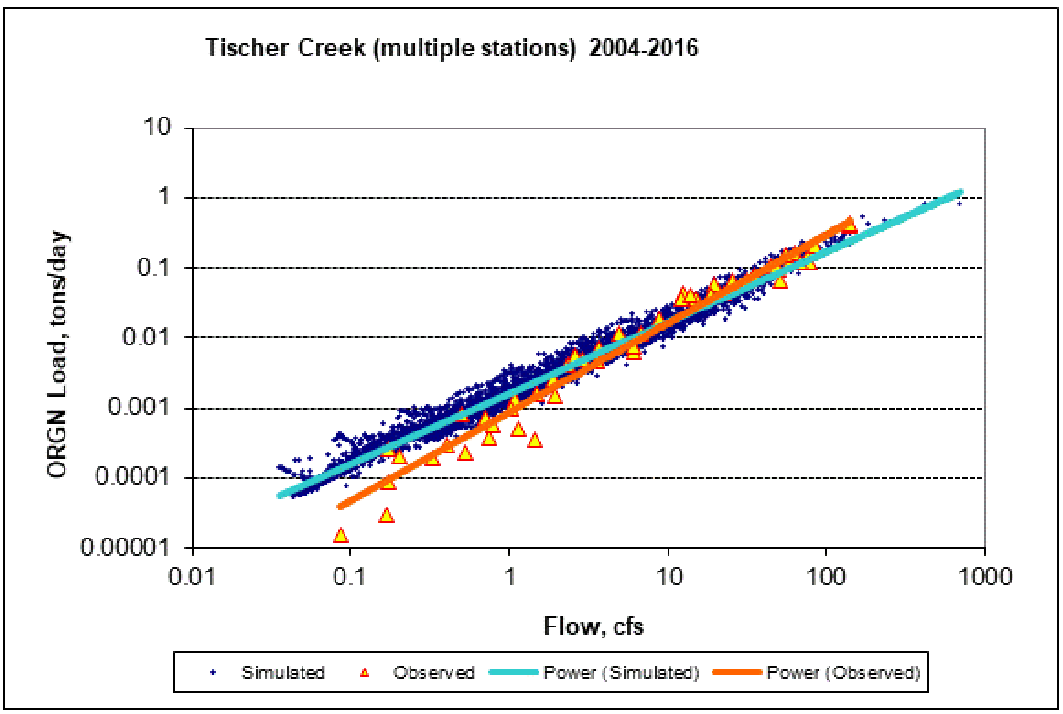


Figure E-421. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Tischer Creek (multiple stations) (calibration period)

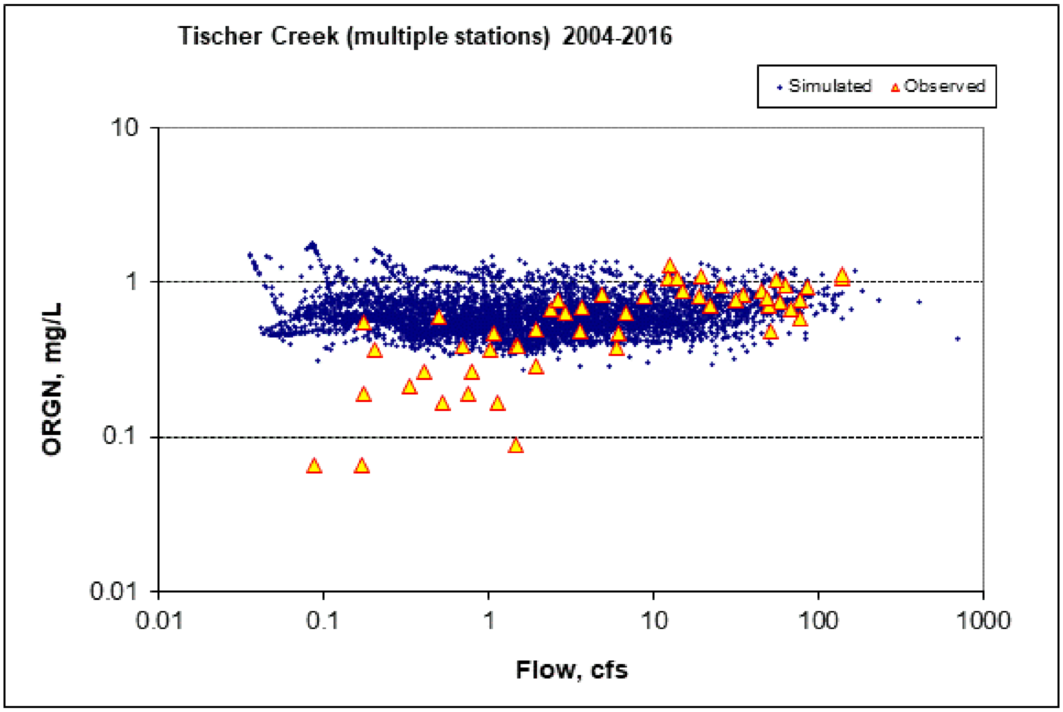
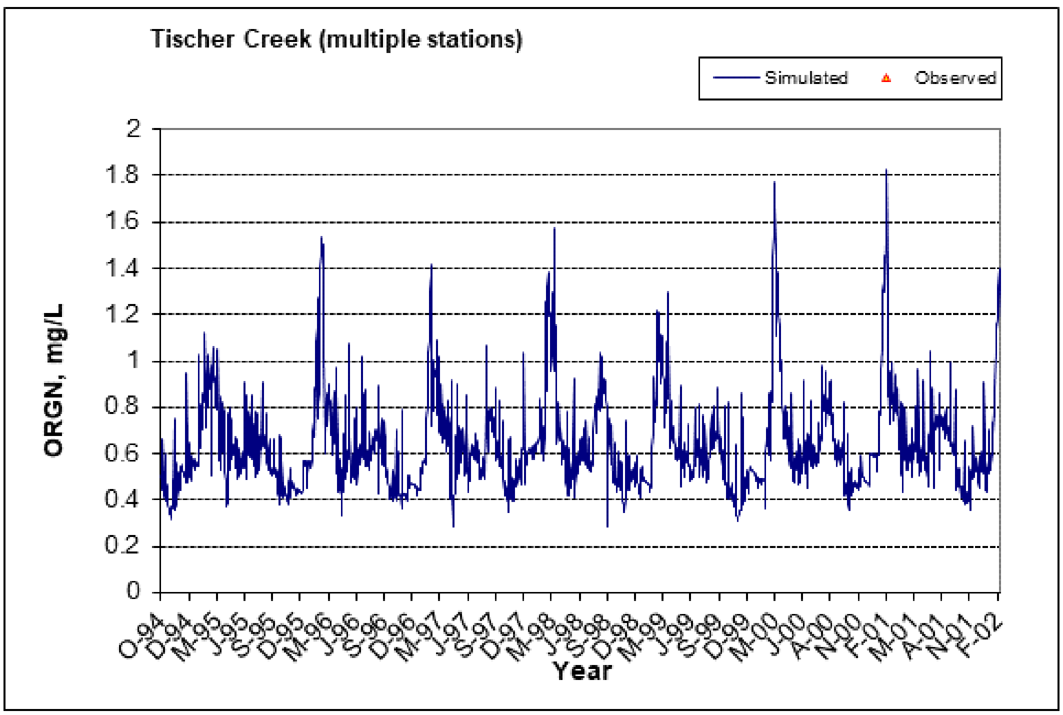


Figure E-422. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Tischer Creek (multiple stations) (calibration period)



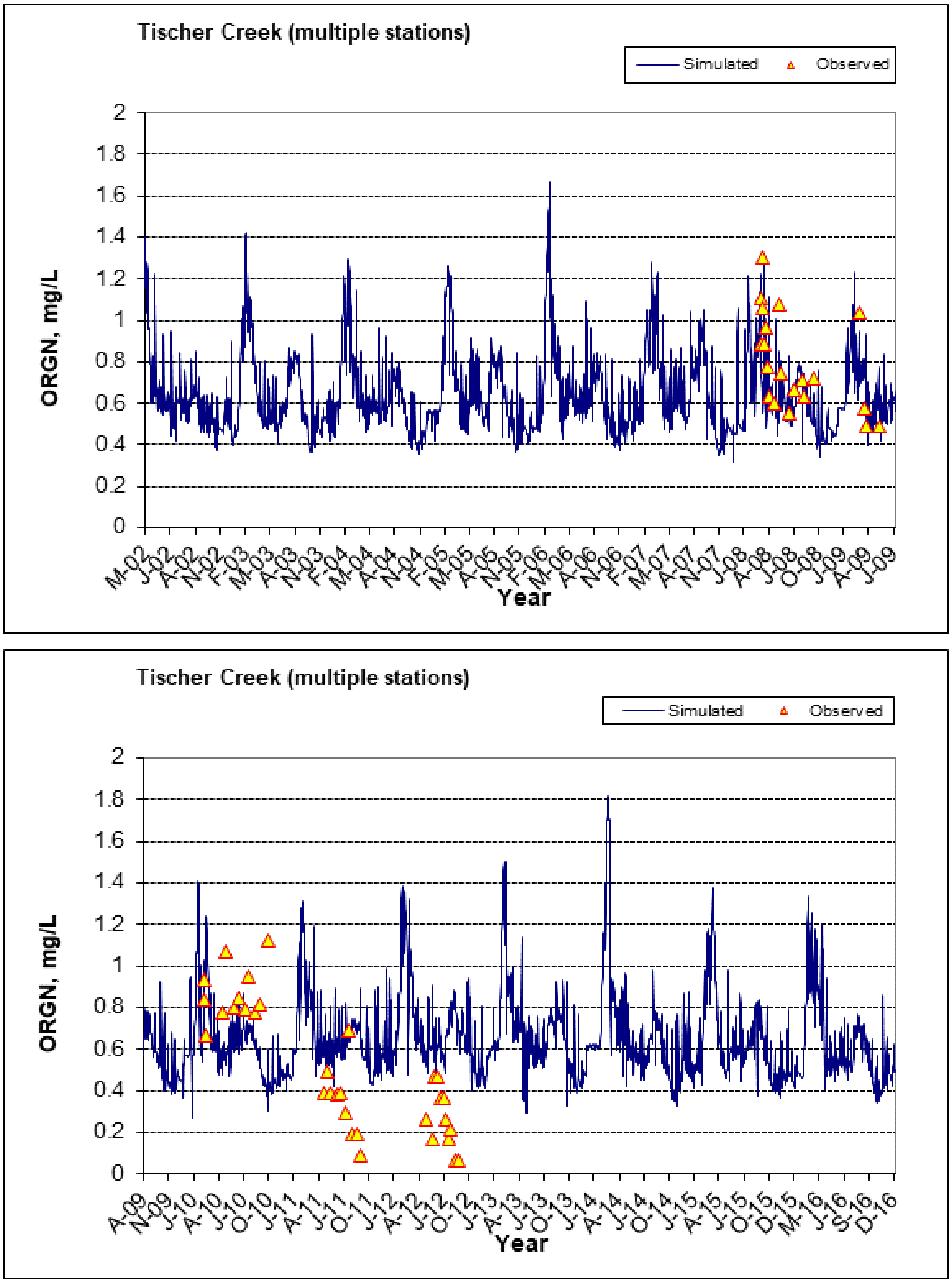


Figure E-423. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Tischer Creek (multiple stations)

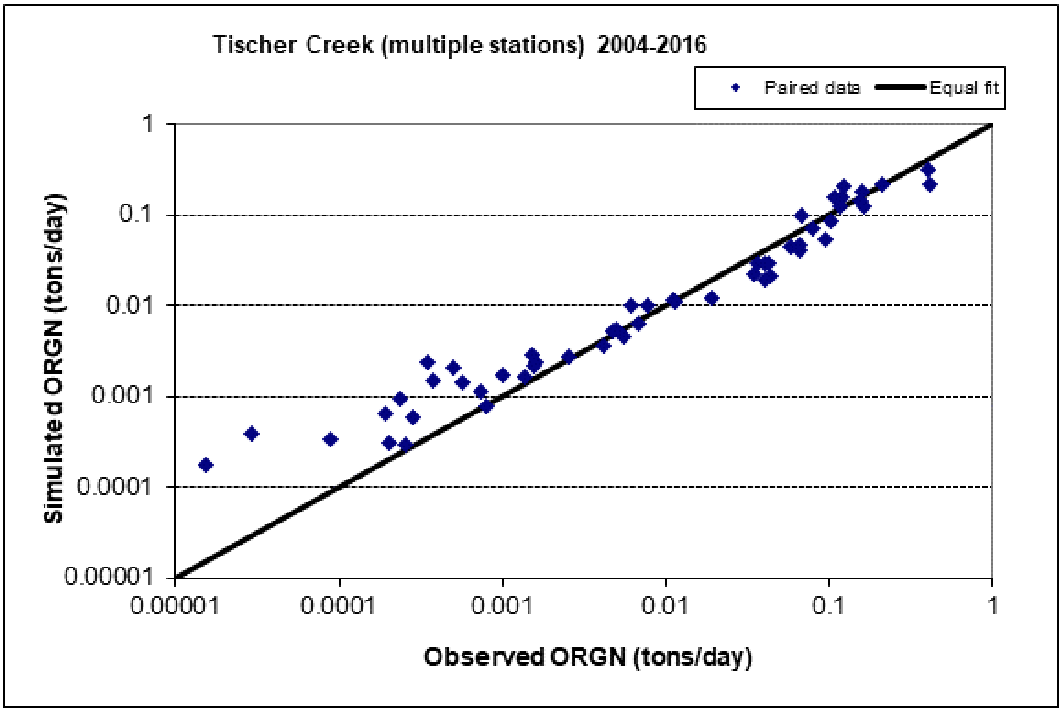


Figure E-424. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Tischer Creek (multiple stations) (calibration period)

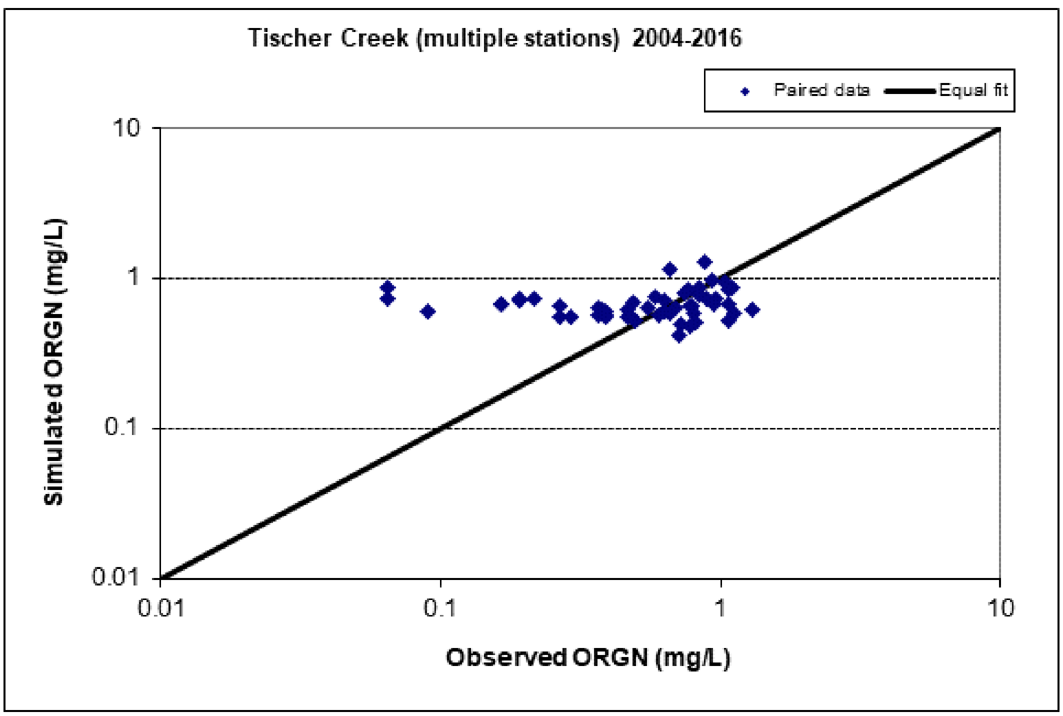


Figure E-425. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Tischer Creek (multiple stations) (calibration period)

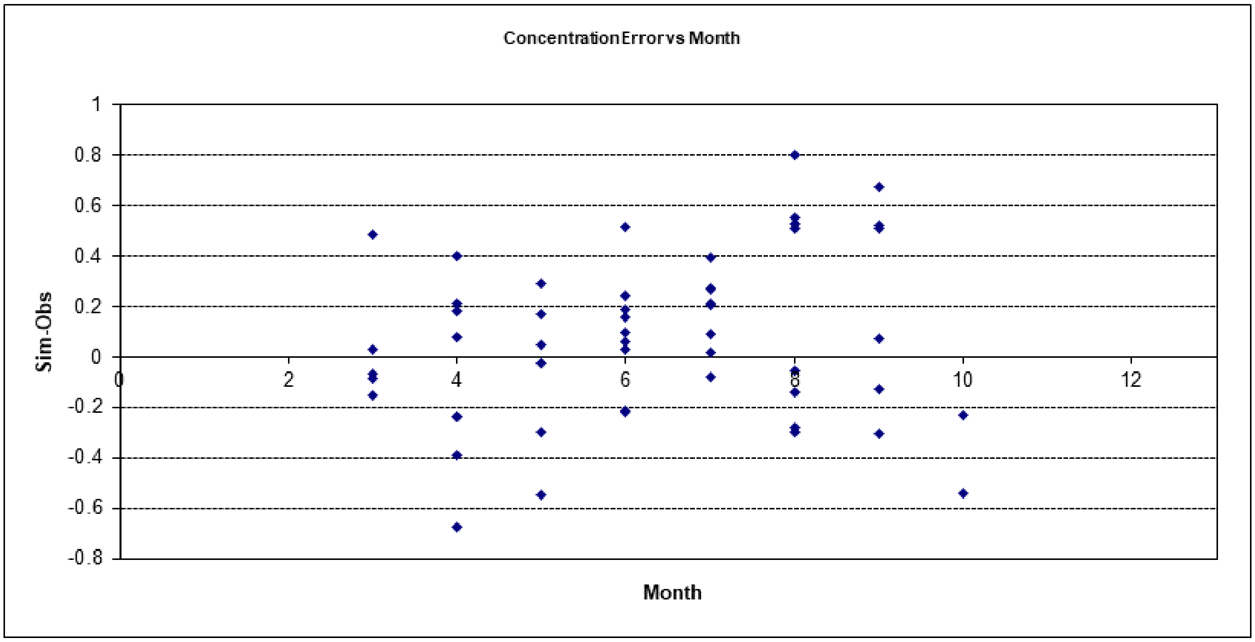


Figure E-426. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at Tischer Creek (multiple stations)

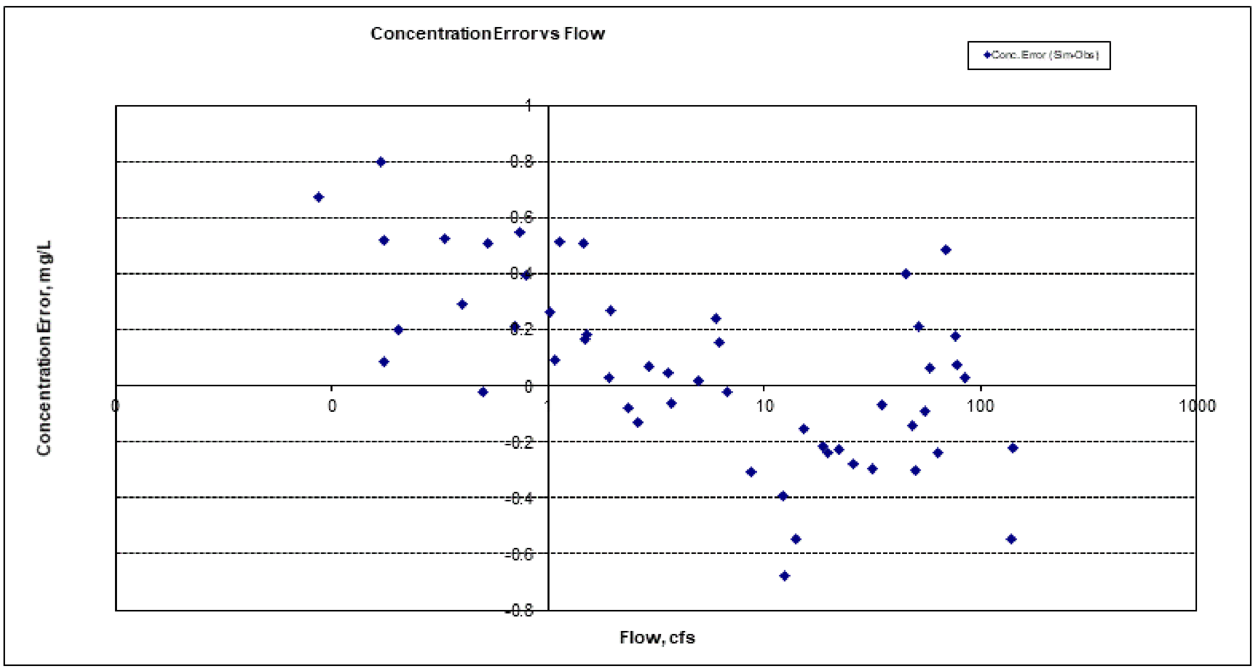


Figure E-427. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at Tischer Creek (multiple stations)

E.8.4 Total Kjeldahl Nitrogen (TKN)

Table E-50. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	ND	53
Concentration Average Error		20.38%
Concentration Median Error		17.89%
Load Average Error		-3.19%
Load Median Error		0.52%
Paired t conc		0.48
Paired t load		0.78

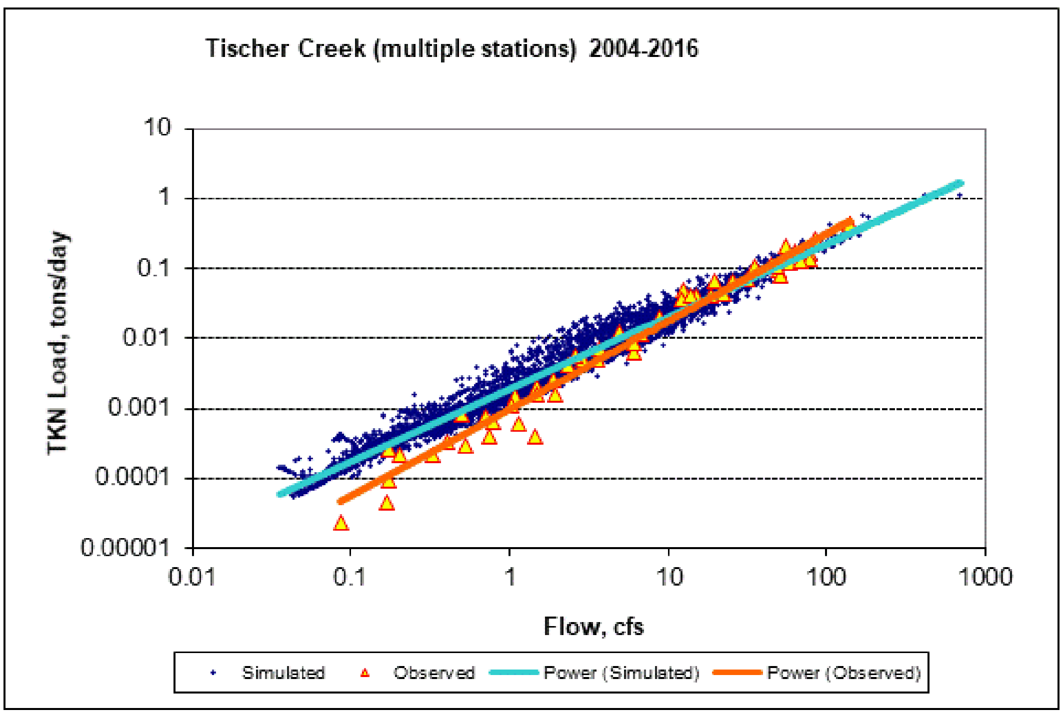


Figure E-428. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Tischer Creek (multiple stations) (calibration period)

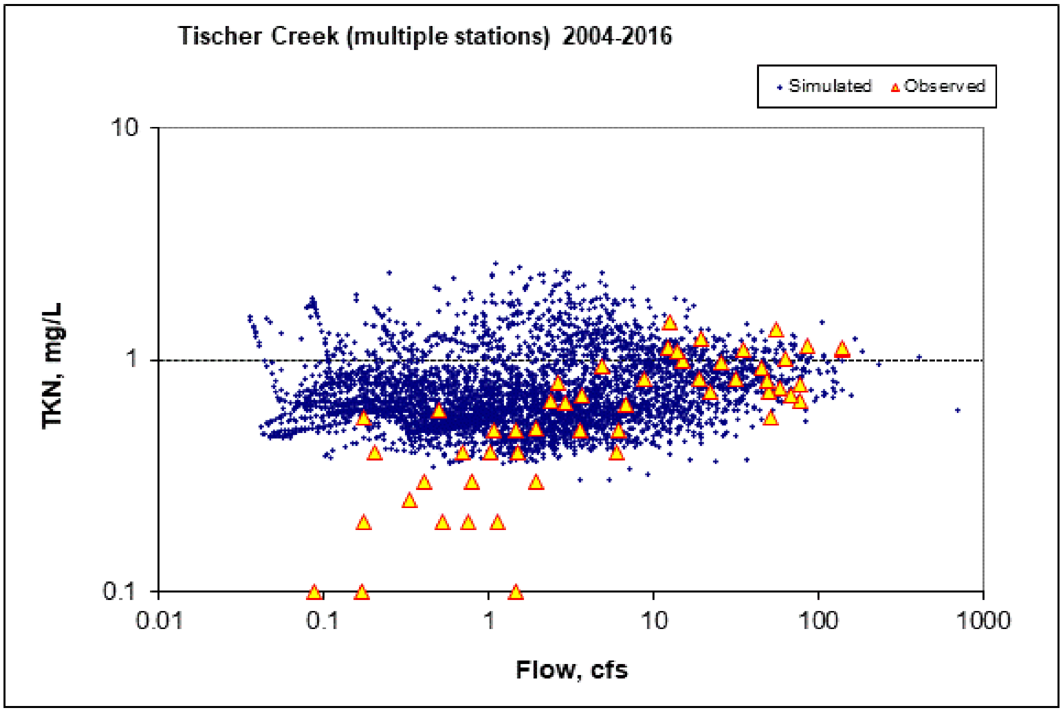
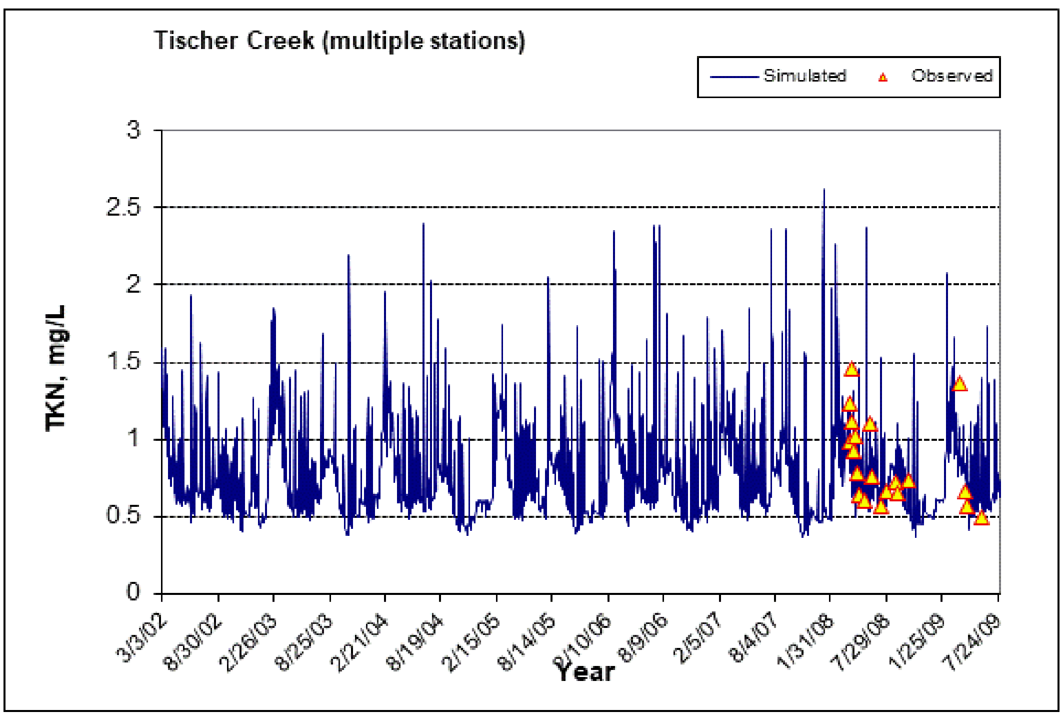


Figure E-429. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Tischer Creek (multiple stations) (calibration period)



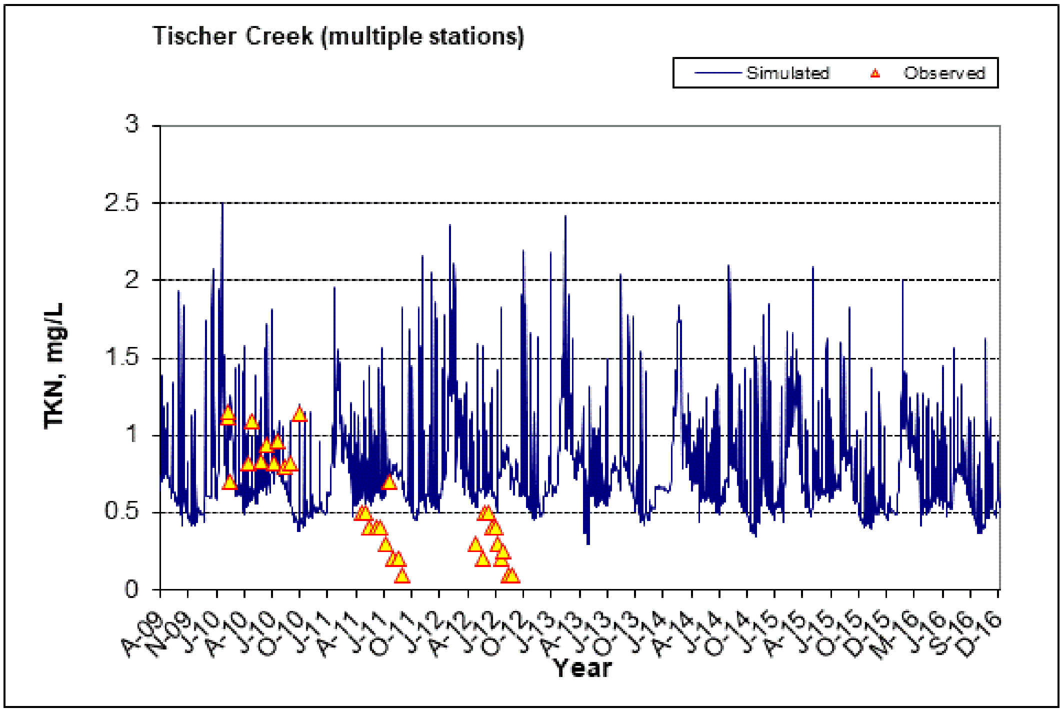


Figure E-430. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Tischer Creek (multiple stations)

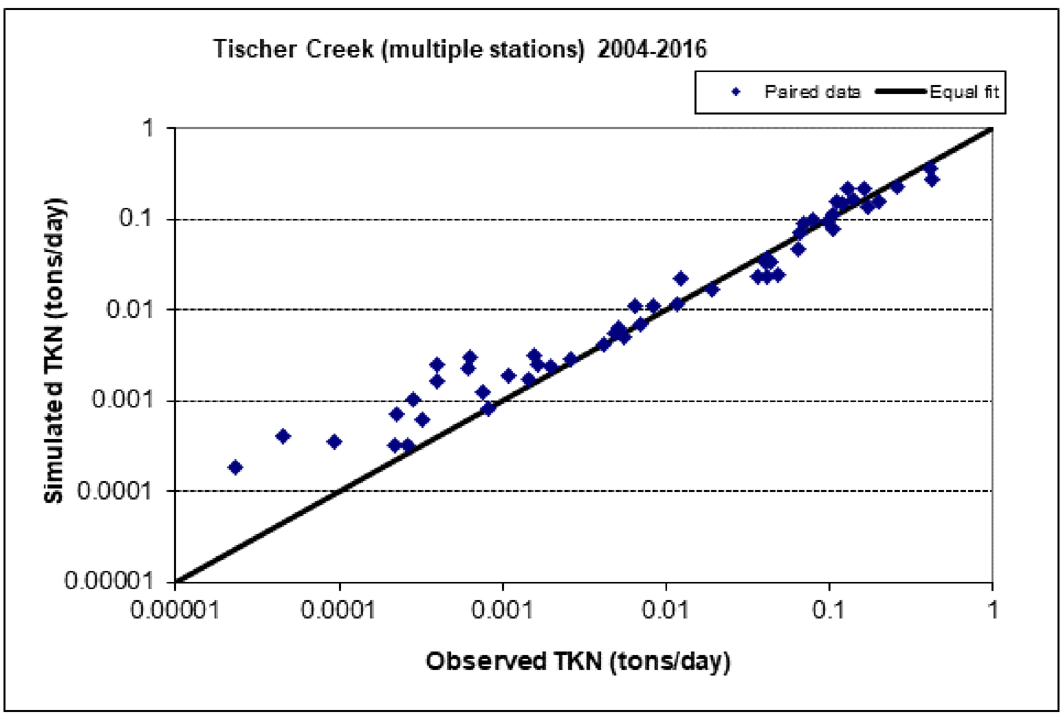


Figure E-431. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Tischer Creek (multiple stations) (calibration period)

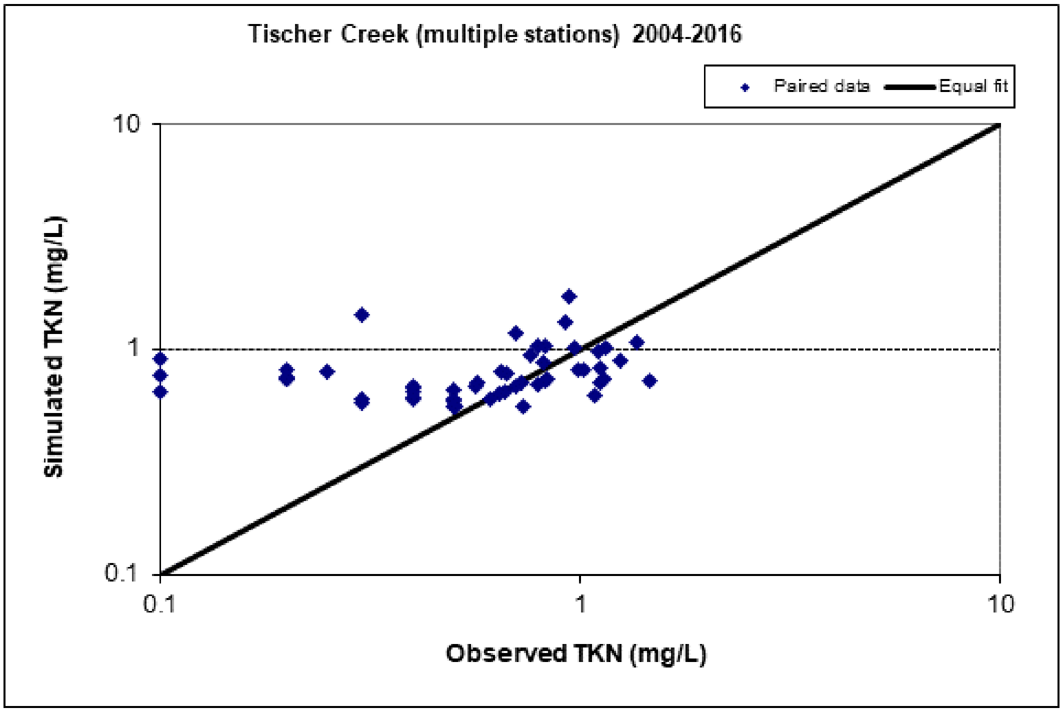


Figure E-432. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Tischer Creek (multiple stations) (calibration period)

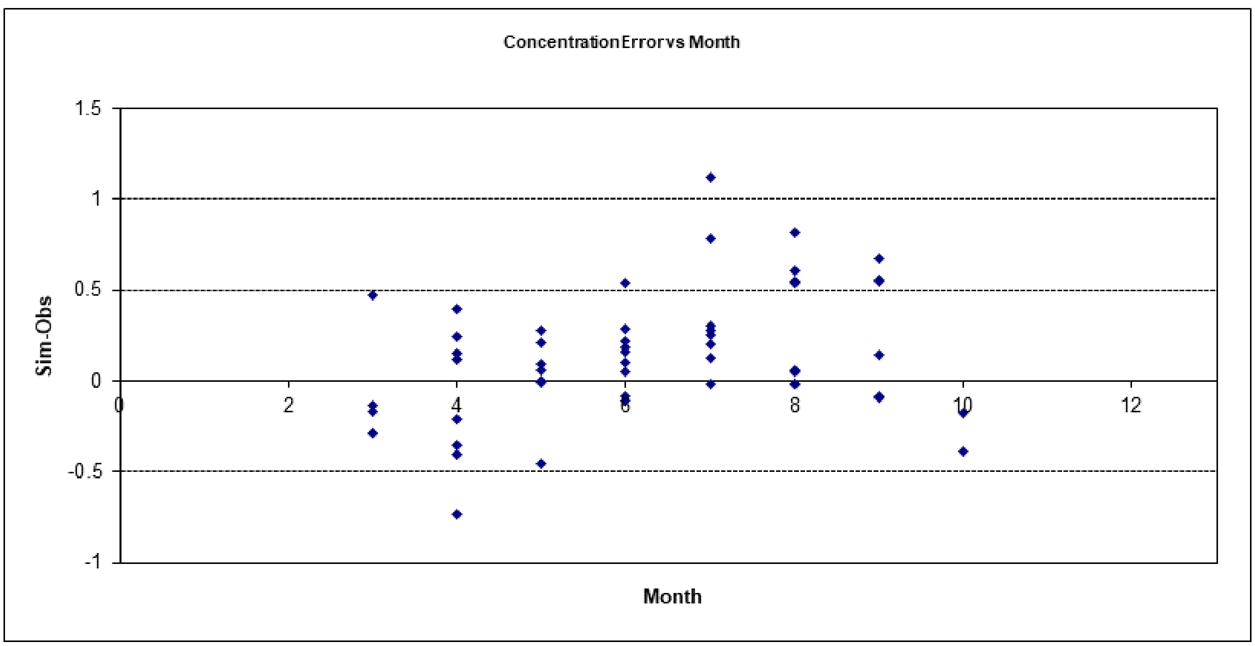


Figure E-433. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at Tischer Creek (multiple stations)

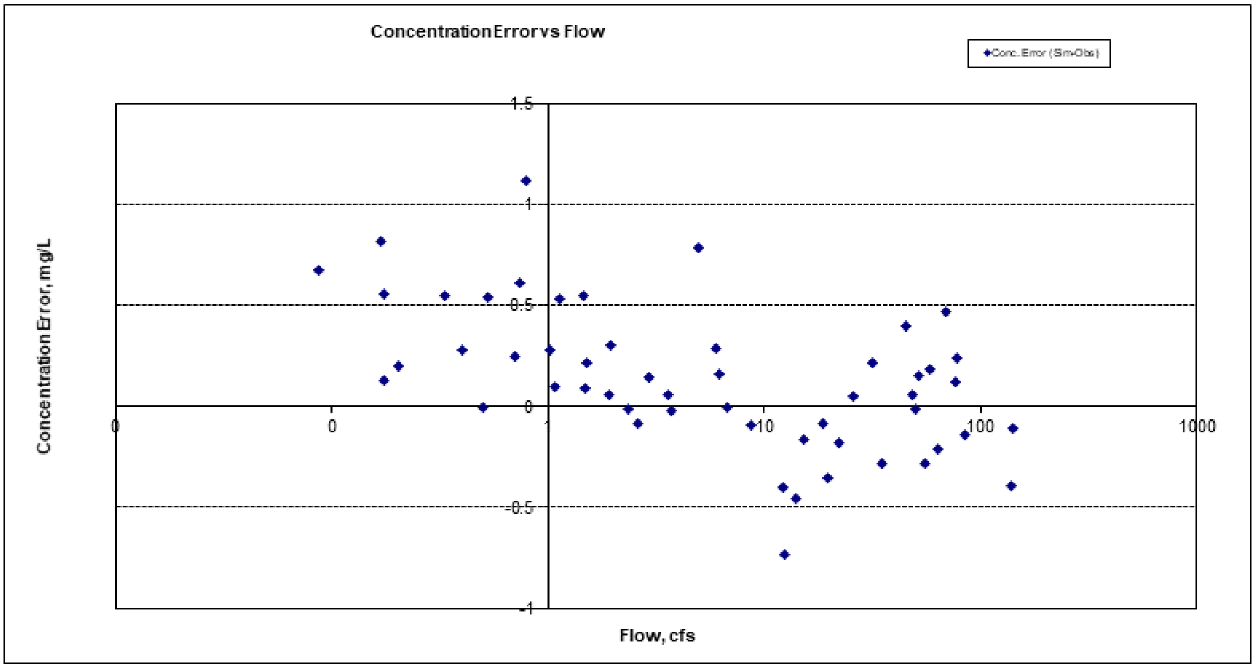


Figure E-434. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at Tischer Creek (multiple stations)

E.8.5 Nitrite+ Nitrate Nitrogen (NOx)

Table E-51. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	66
Concentration Average Error		-18.32%
Concentration Median Error		-35.33%
Load Average Error		4.52%
Load Median Error		-2.18%
Paired t conc		0.56
Paired t load		0.79

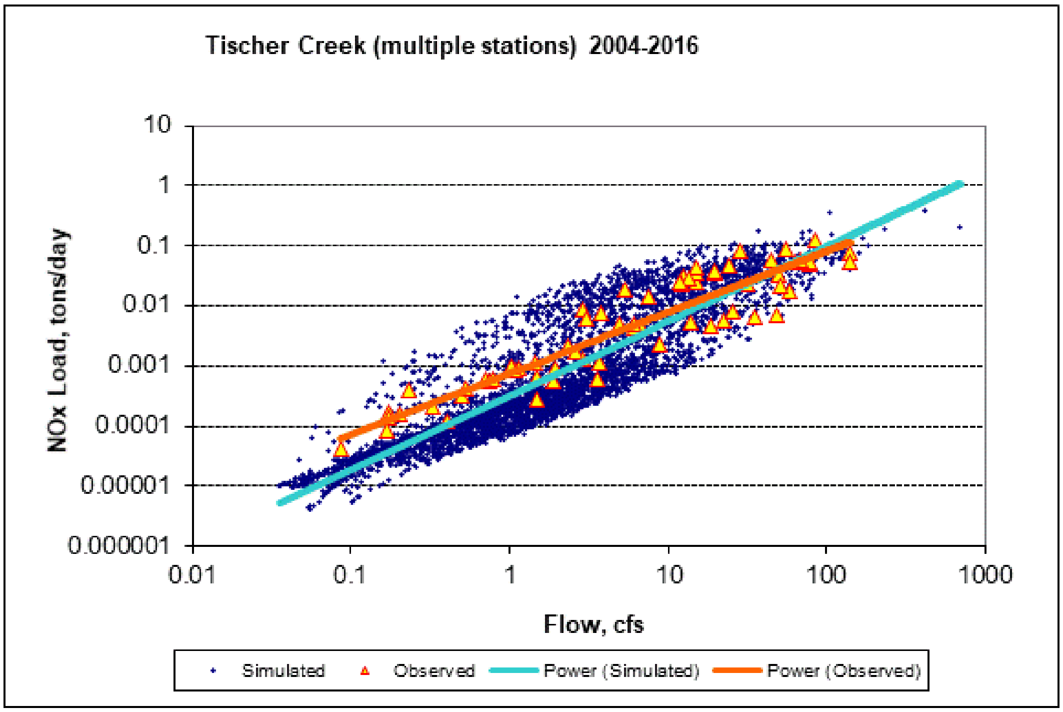


Figure E-435. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Tischer Creek (multiple stations) (calibration period)

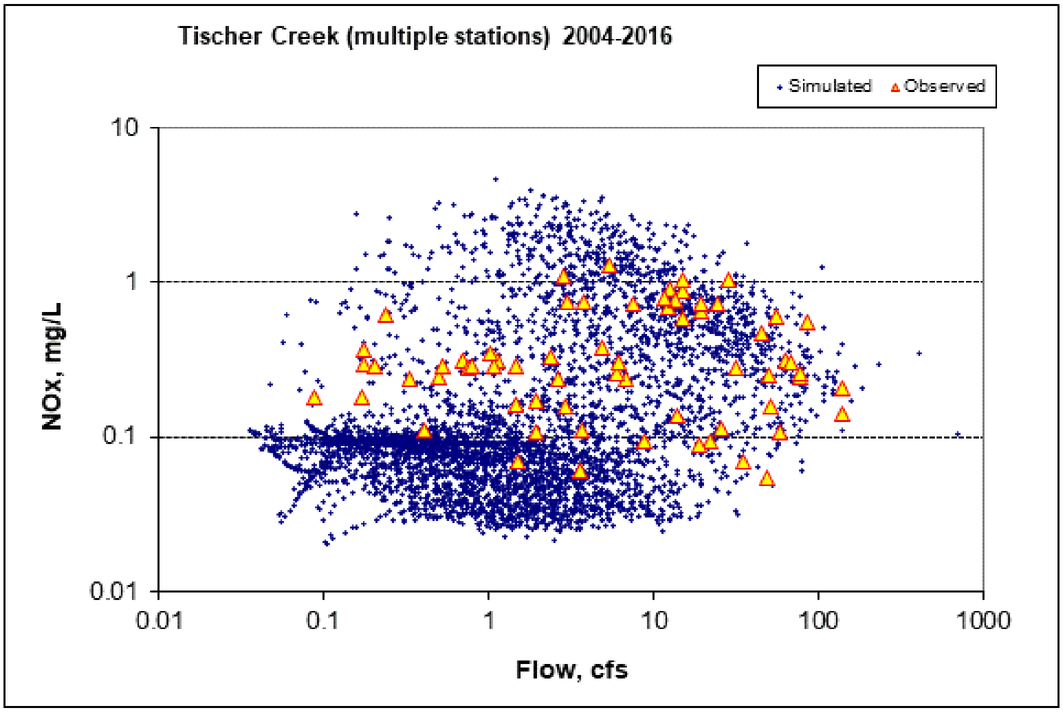
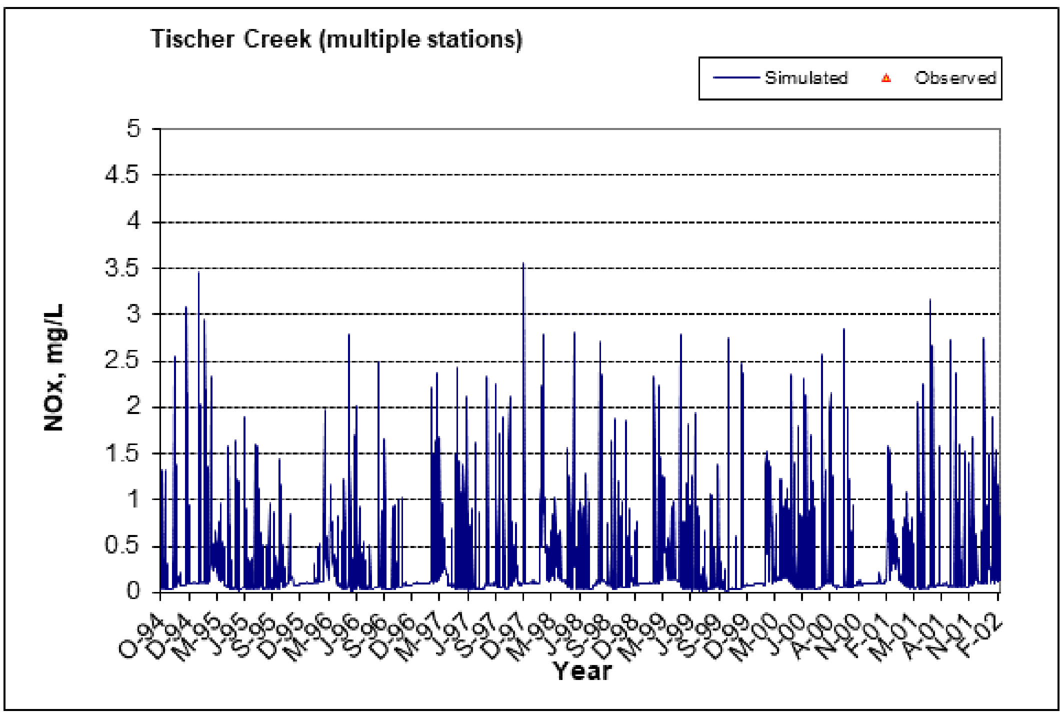
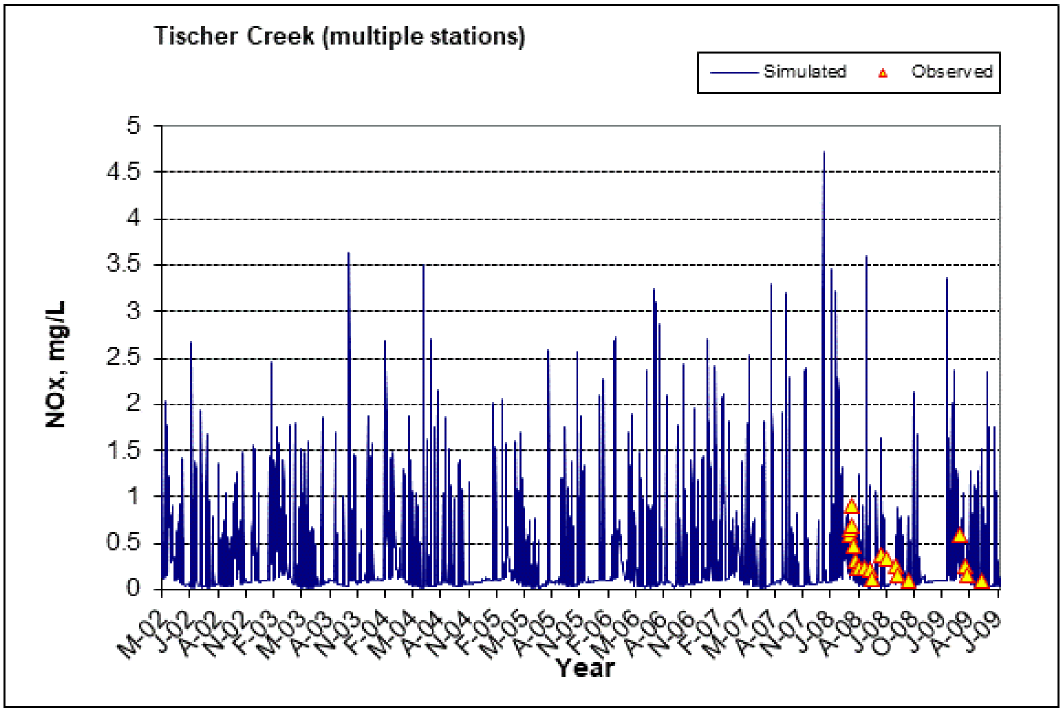


Figure E-436. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Tischer Creek (multiple stations) (calibration period)





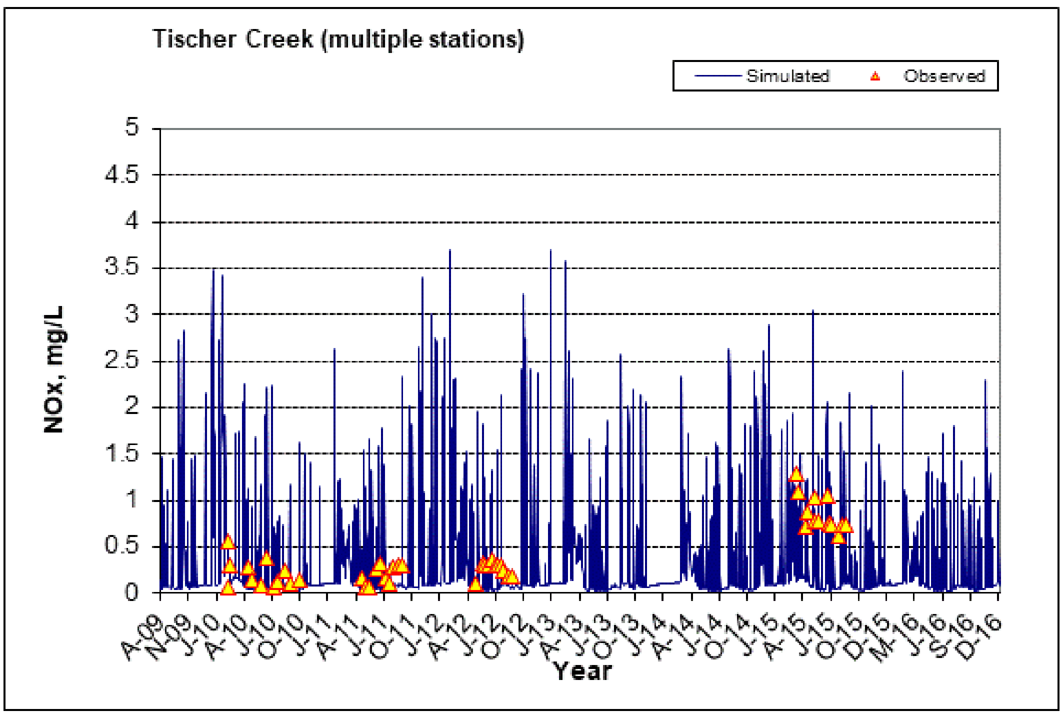


Figure E-437. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Tischer Creek (multiple stations)

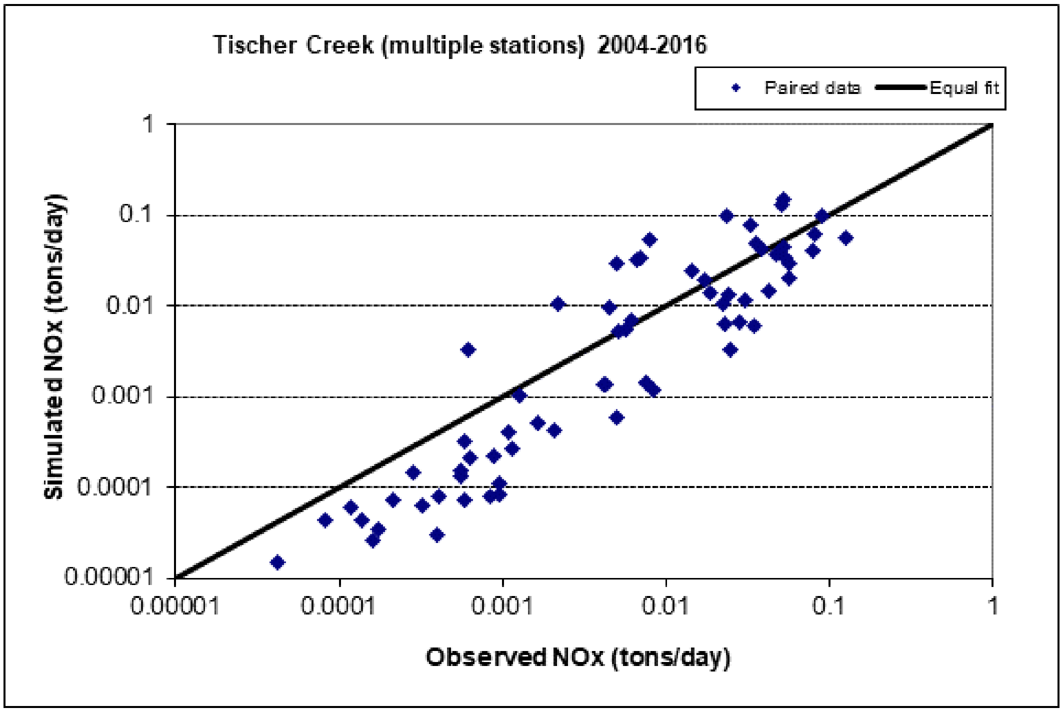


Figure E-438. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Tischer Creek (multiple stations) (calibration period)

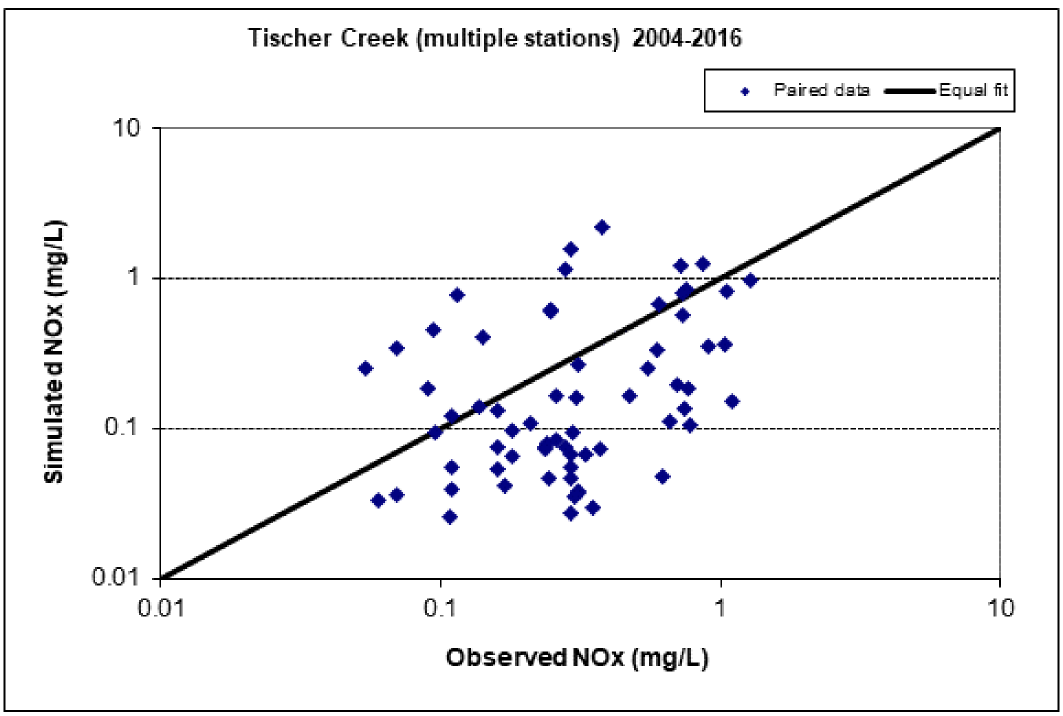


Figure E-439. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Tischer Creek (multiple stations) (calibration period)

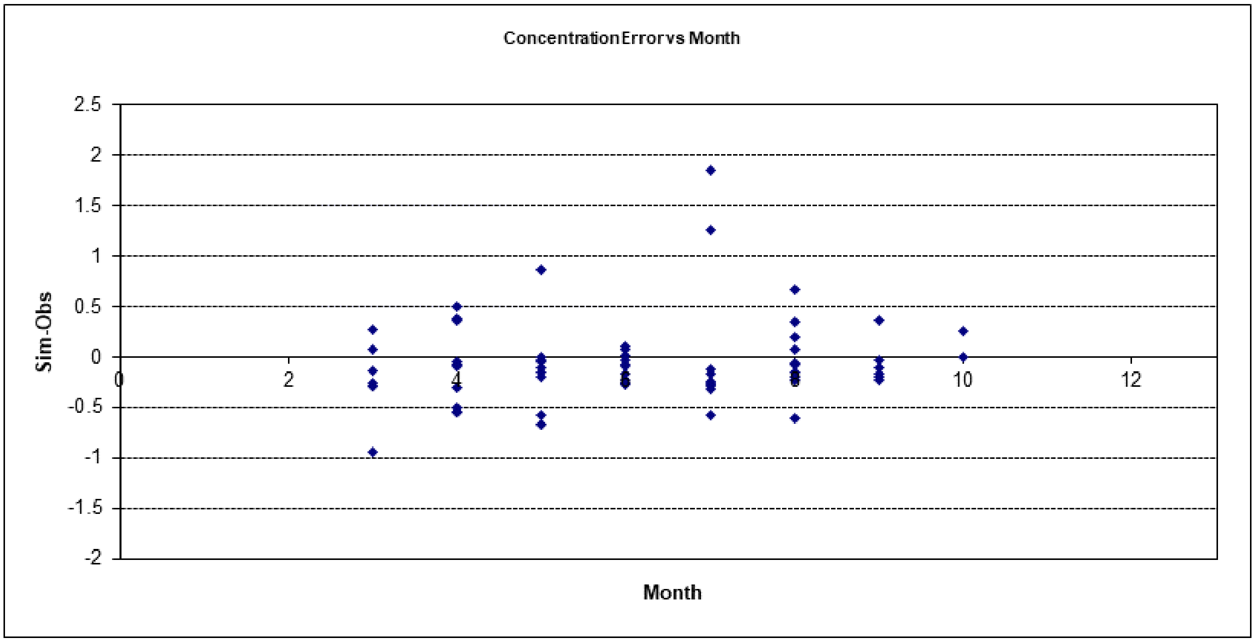


Figure E-440. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Tischer Creek (multiple stations)

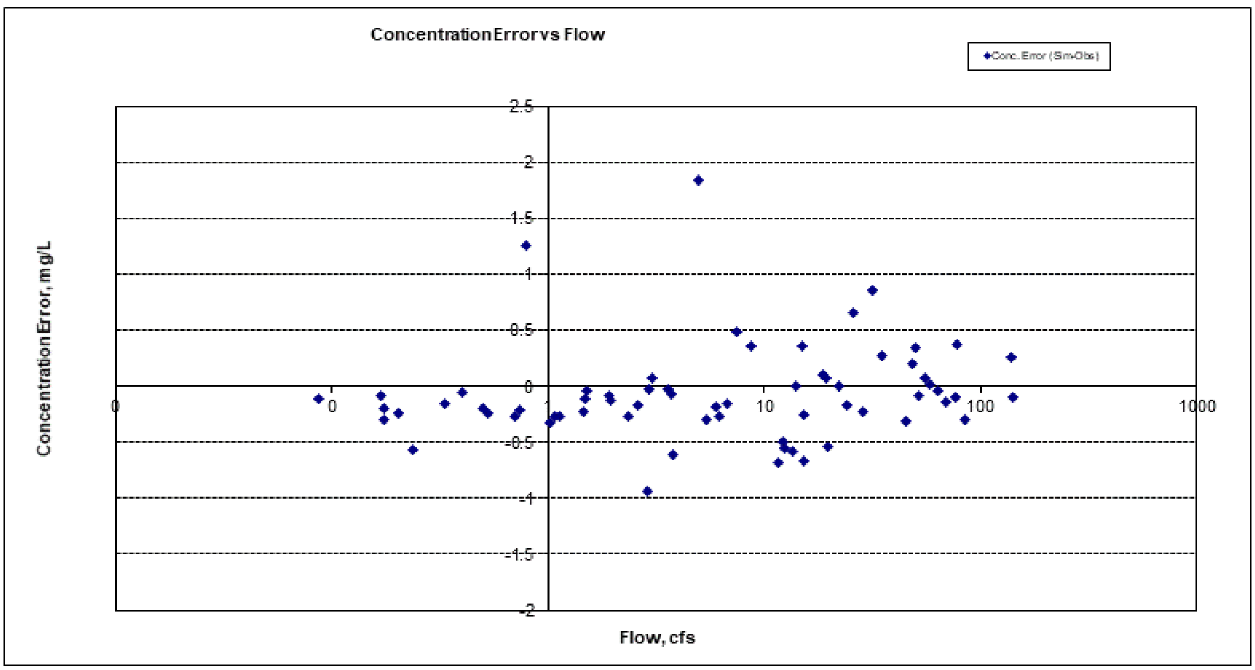


Figure E-441. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Tischer Creek (multiple stations)

E.8.6 Total Nitrogen (TN)

Table E-52. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	ND	53
Concentration Average Error		12.59%
Concentration Median Error		2.98%
Load Average Error		1.14%
Load Median Error		0.22%
Paired t conc		0.83
Paired t load		0.81

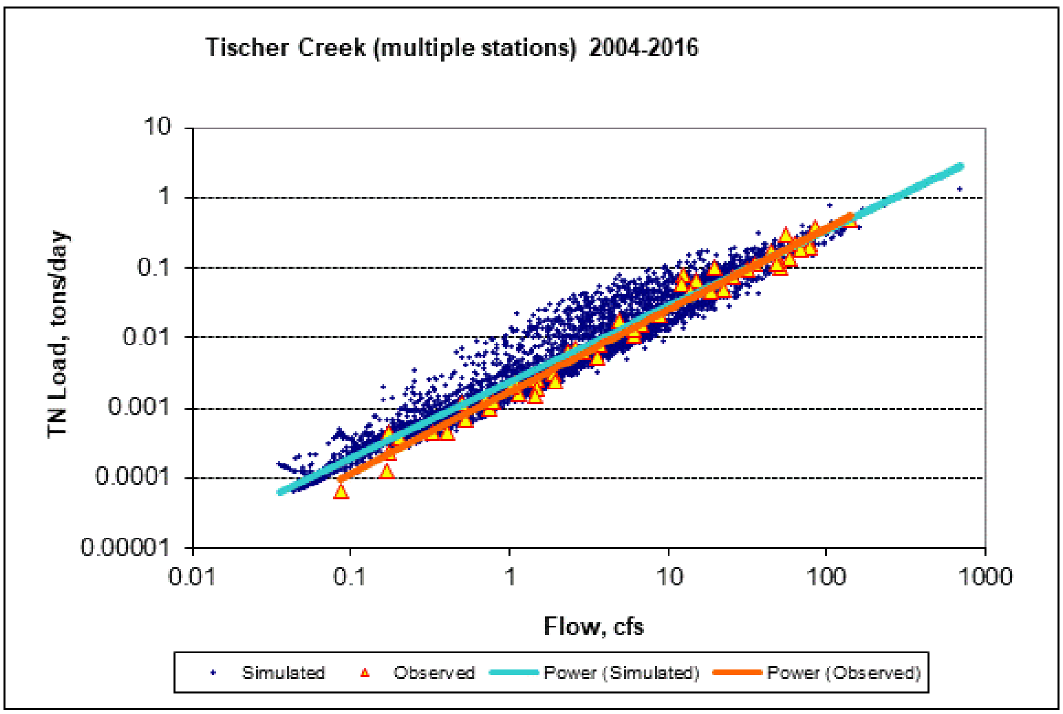


Figure E-442. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Tischer Creek (multiple stations) (calibration period)

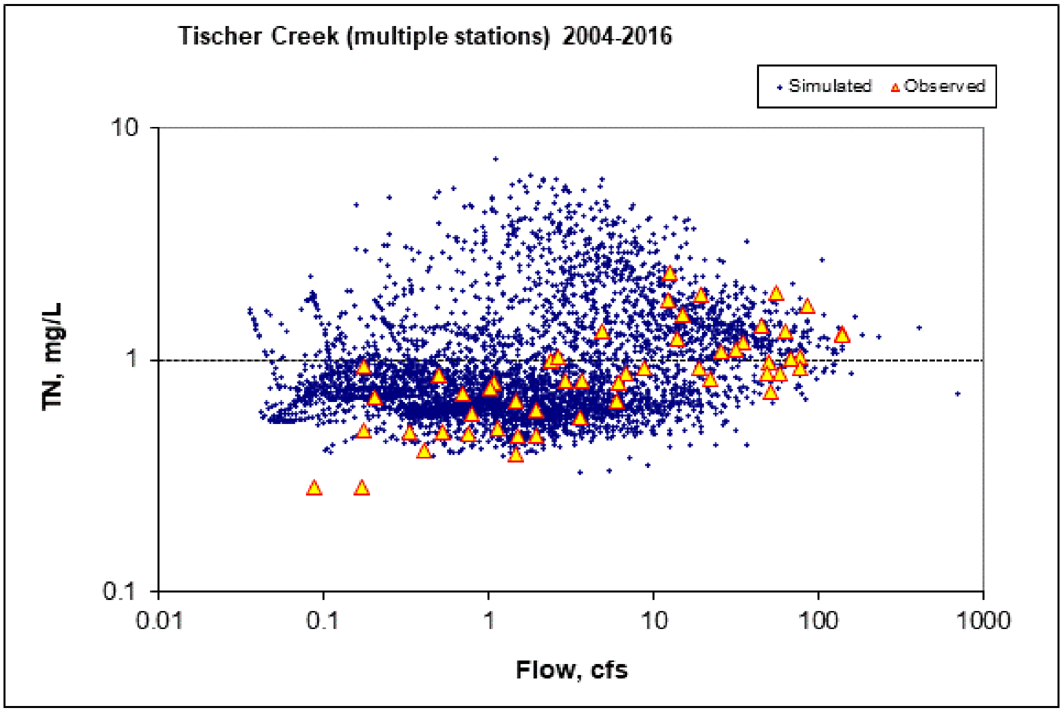
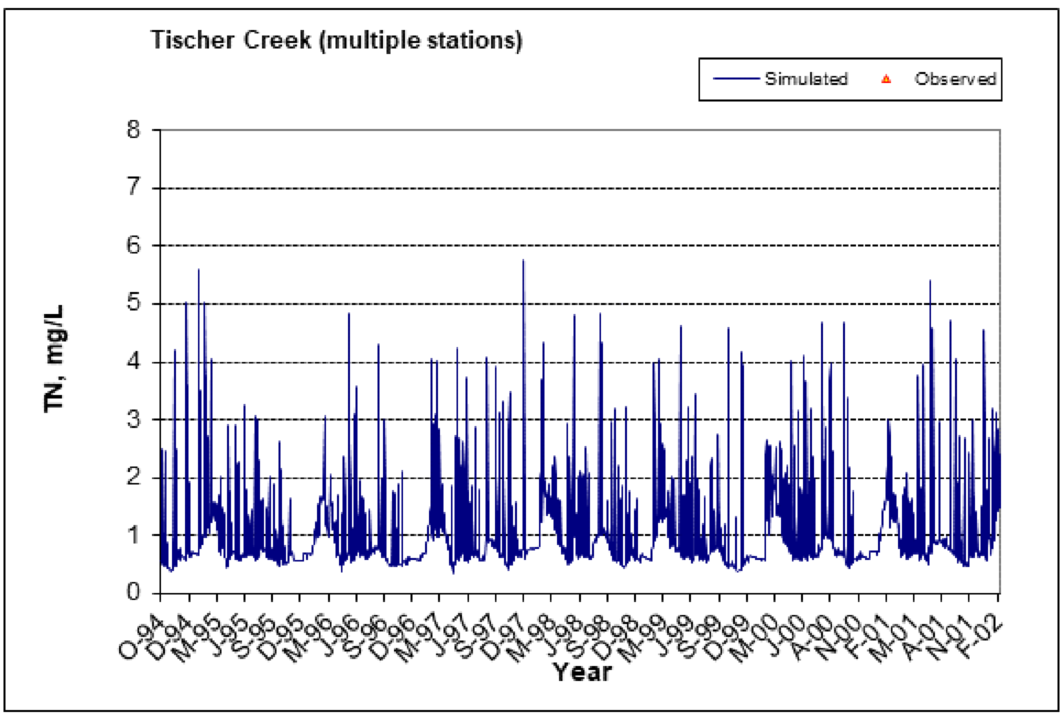


Figure E-443. Simulated and observed Total Nitrogen (TN) concentration vs flow at Tischer Creek (multiple stations) (calibration period)



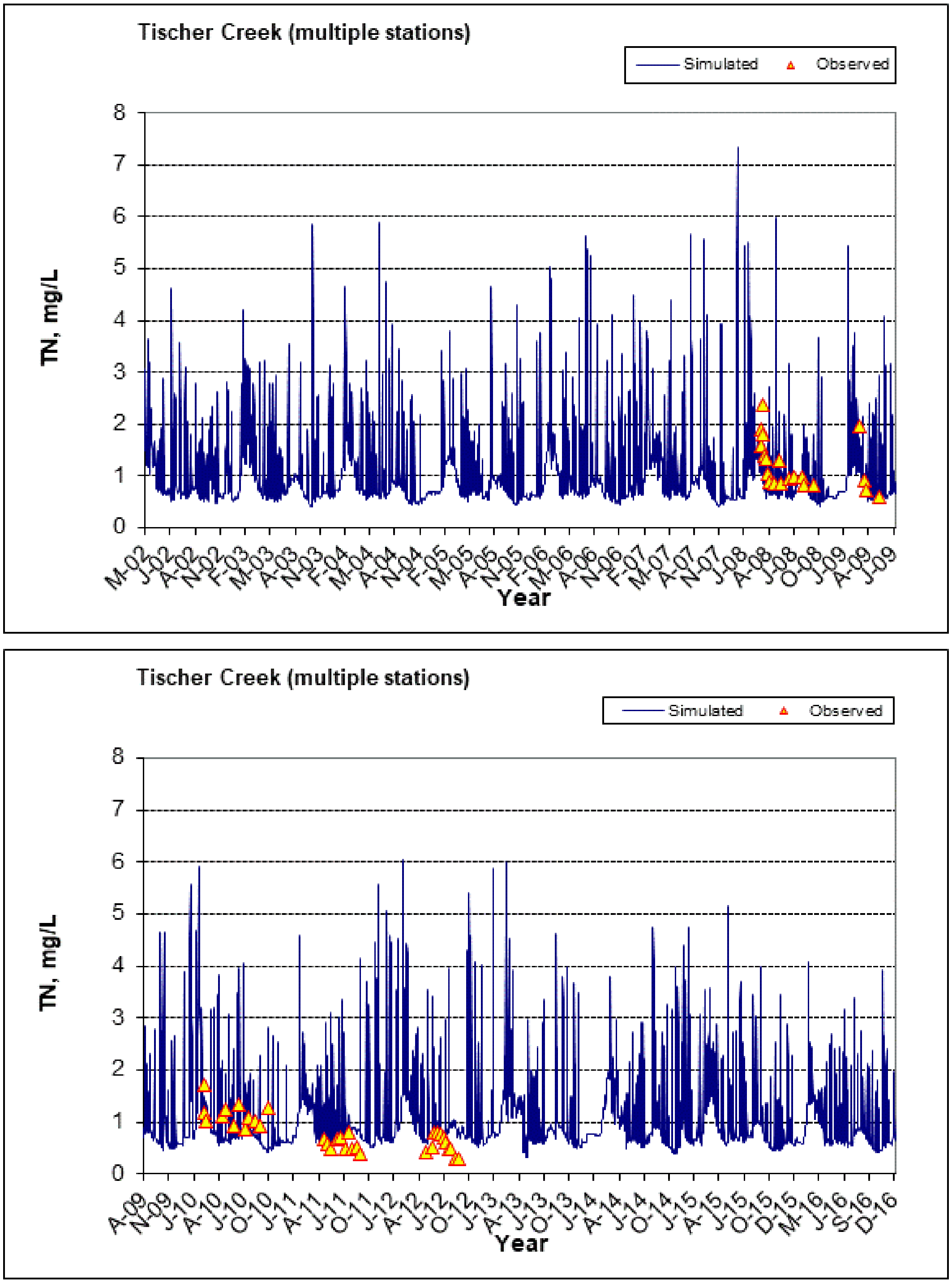


Figure E-444. Time series of observed and simulated Total Nitrogen (TN) concentration at Tischer Creek (multiple stations)

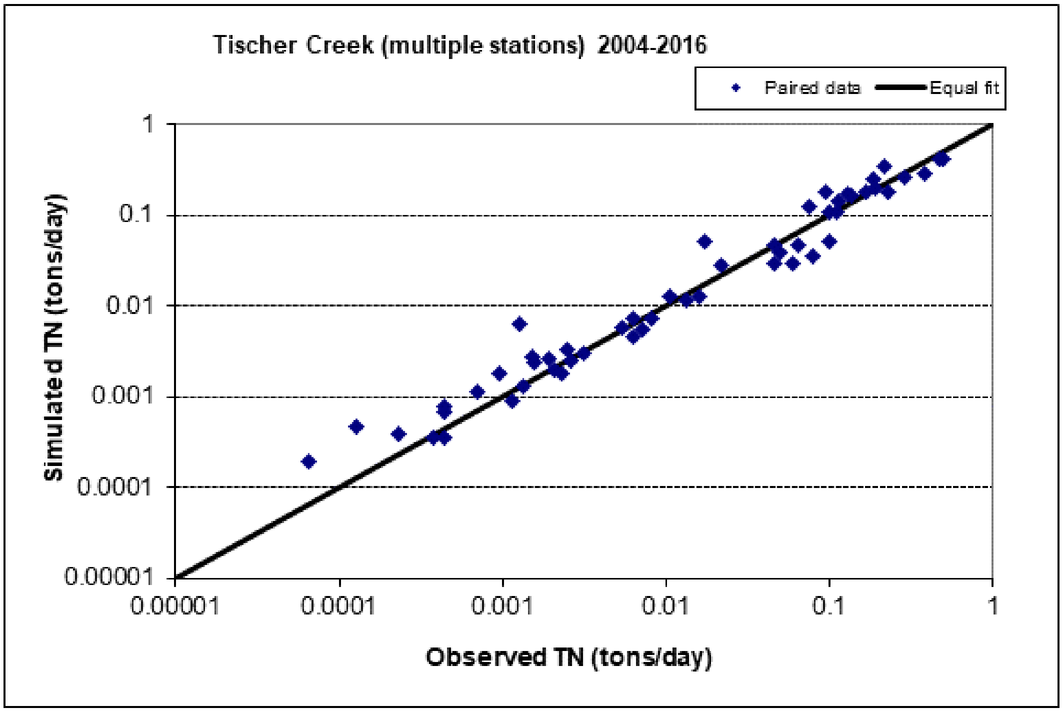


Figure E-445. Paired simulated vs. observed Total Nitrogen (TN) load at Tischer Creek (multiple stations) (calibration period)

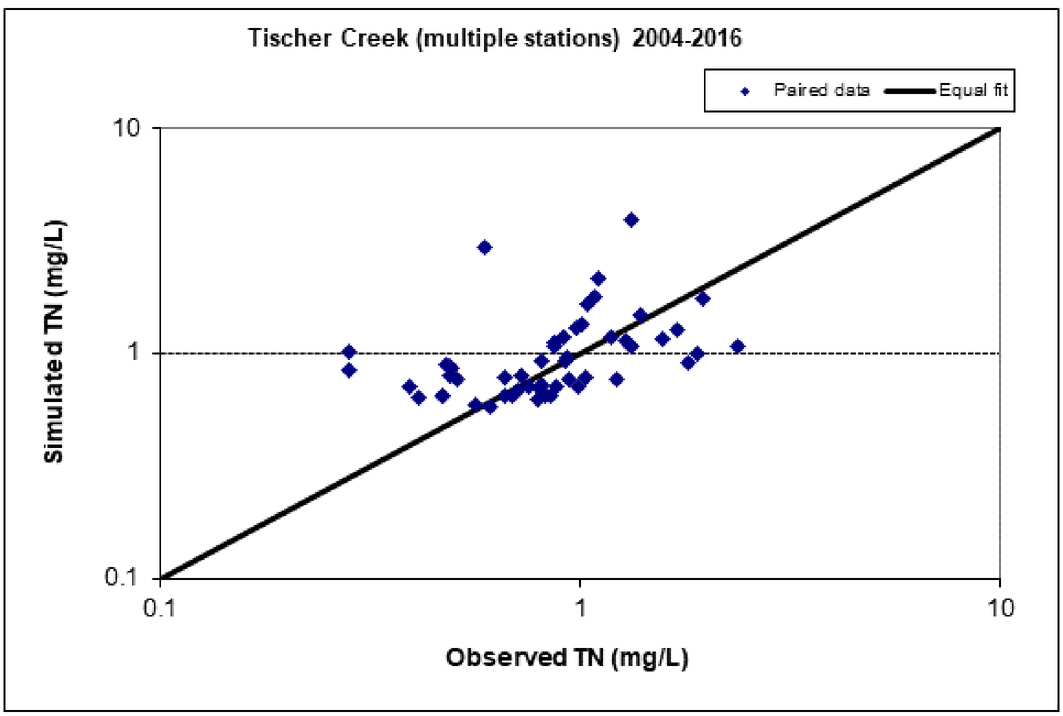


Figure E-446. Paired simulated vs. observed Total Nitrogen (TN) concentration at Tischer Creek (multiple stations) (calibration period)

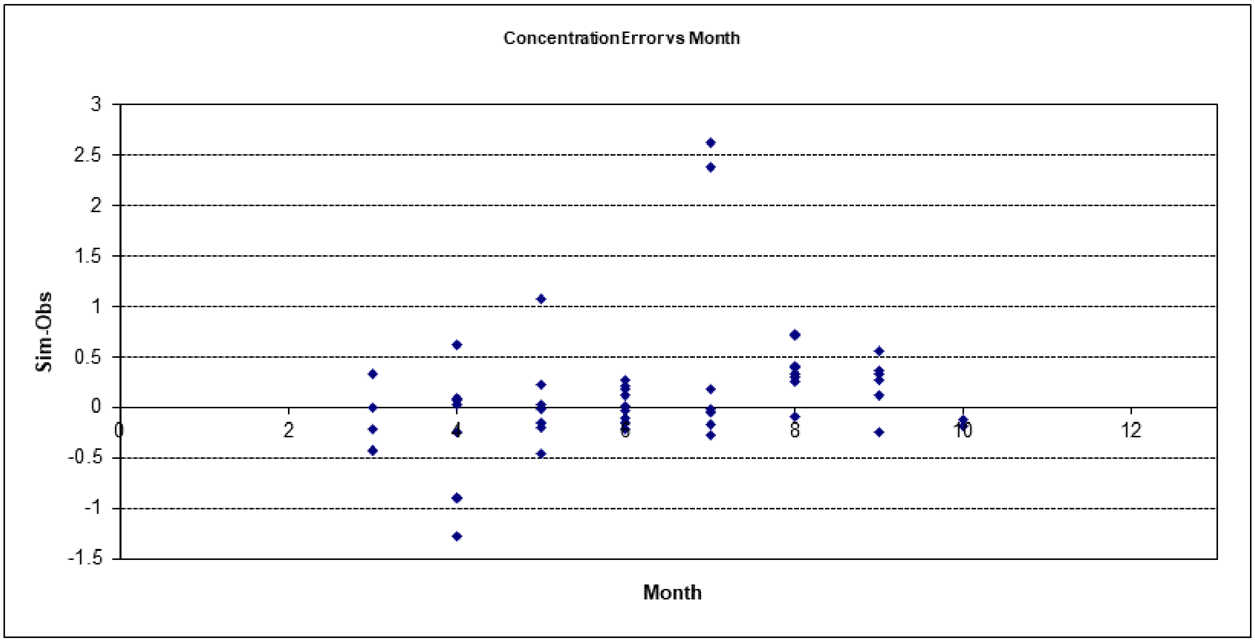


Figure E-447. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at Tischer Creek (multiple stations)

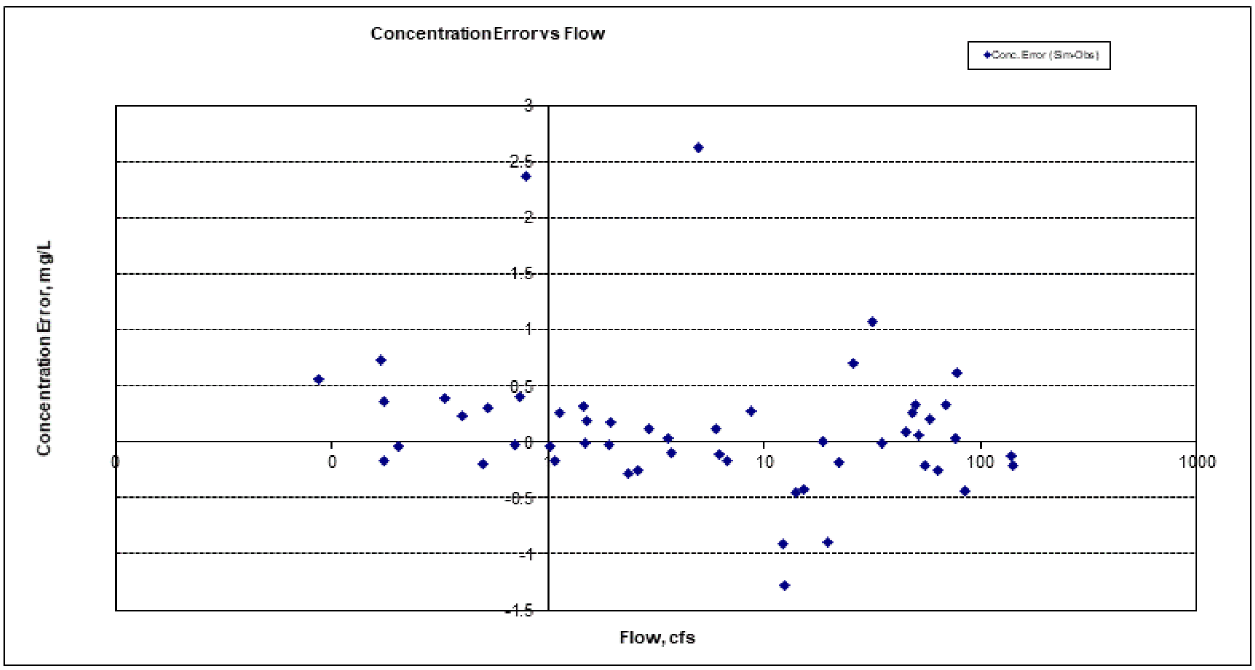


Figure E-448. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at Tischer Creek (multiple stations)

E.8.7 Total Phosphorus (TP)

Table E-53. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	90
Concentration Average Error		-25.23%
Concentration Median Error		-9.36%
Load Average Error		-33.53%
Load Median Error		-1.13%
Paired t conc		0.23
Paired t load		0.26

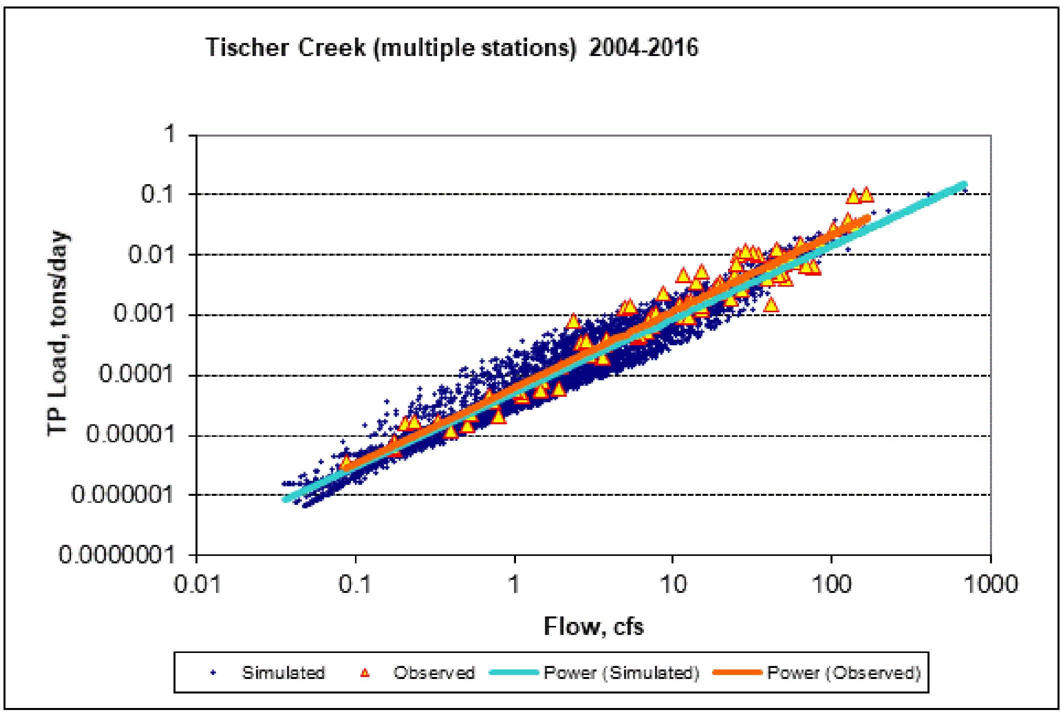


Figure E-449. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Tischer Creek (multiple stations) (calibration period)

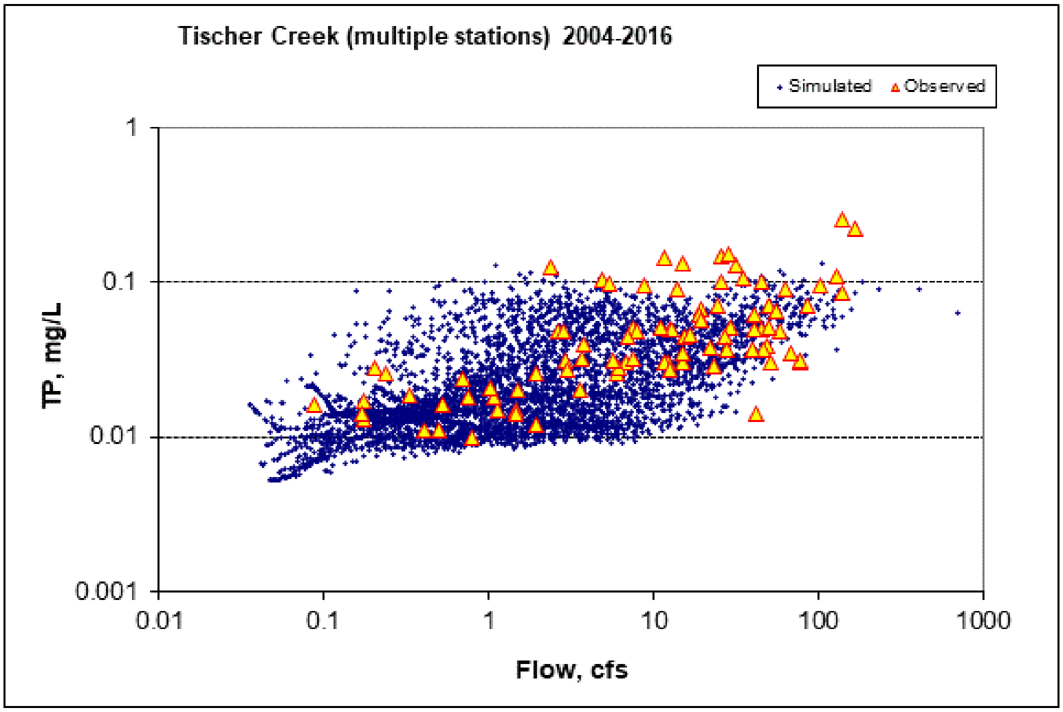
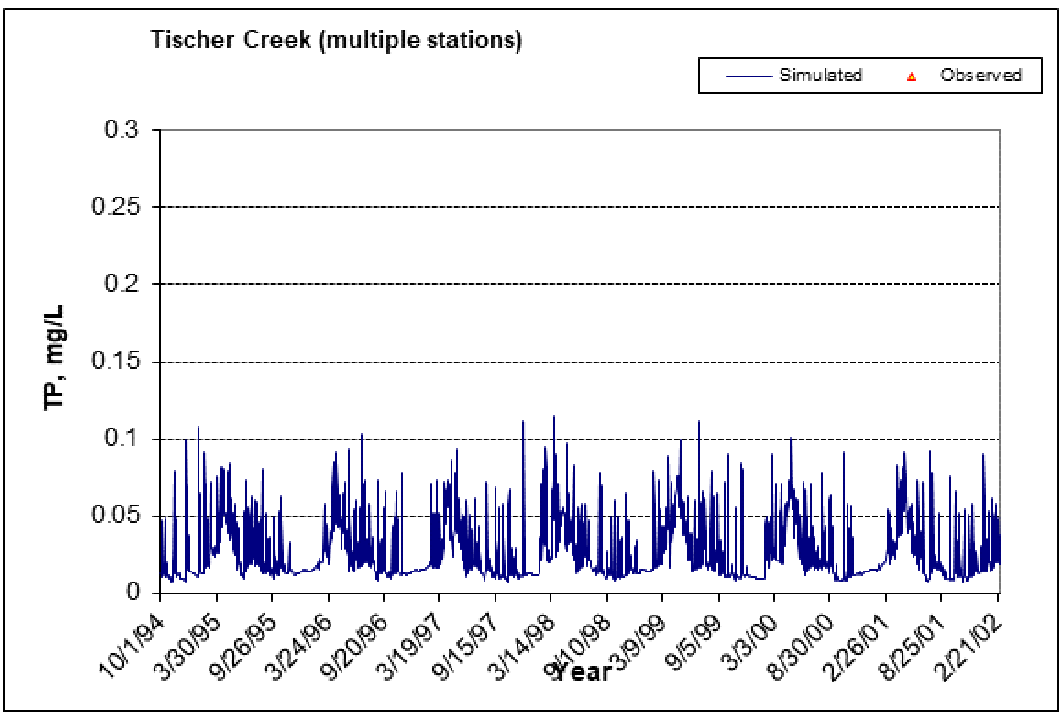
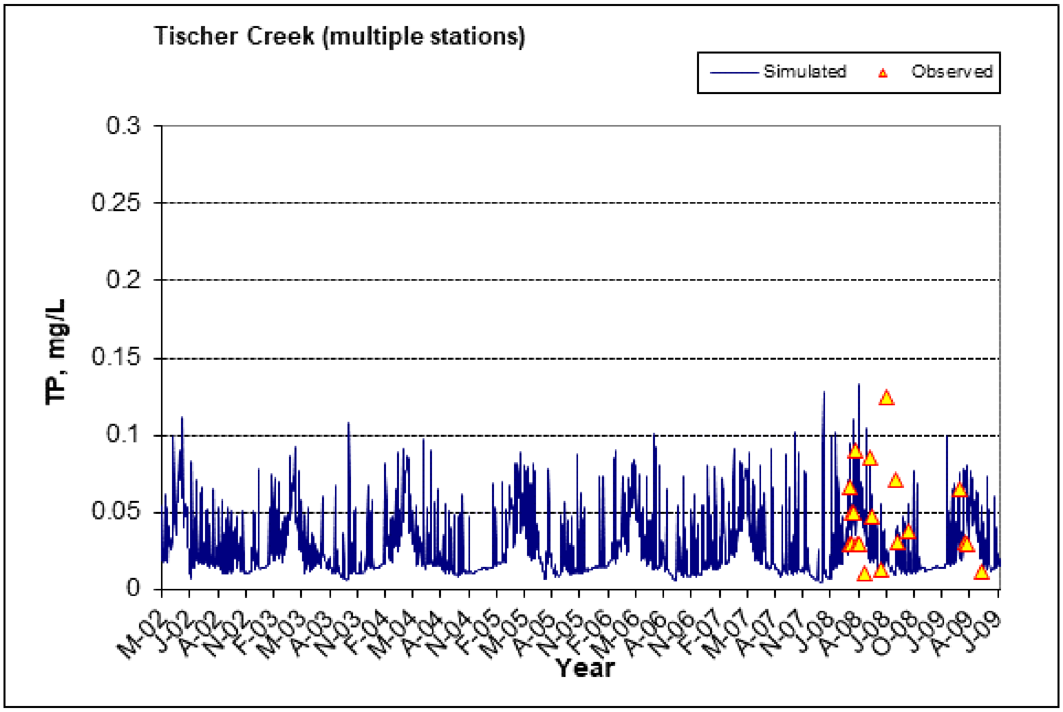


Figure E-450. Simulated and observed Total Phosphorus (TP) concentration vs flow at Tischer Creek (multiple stations) (calibration period)





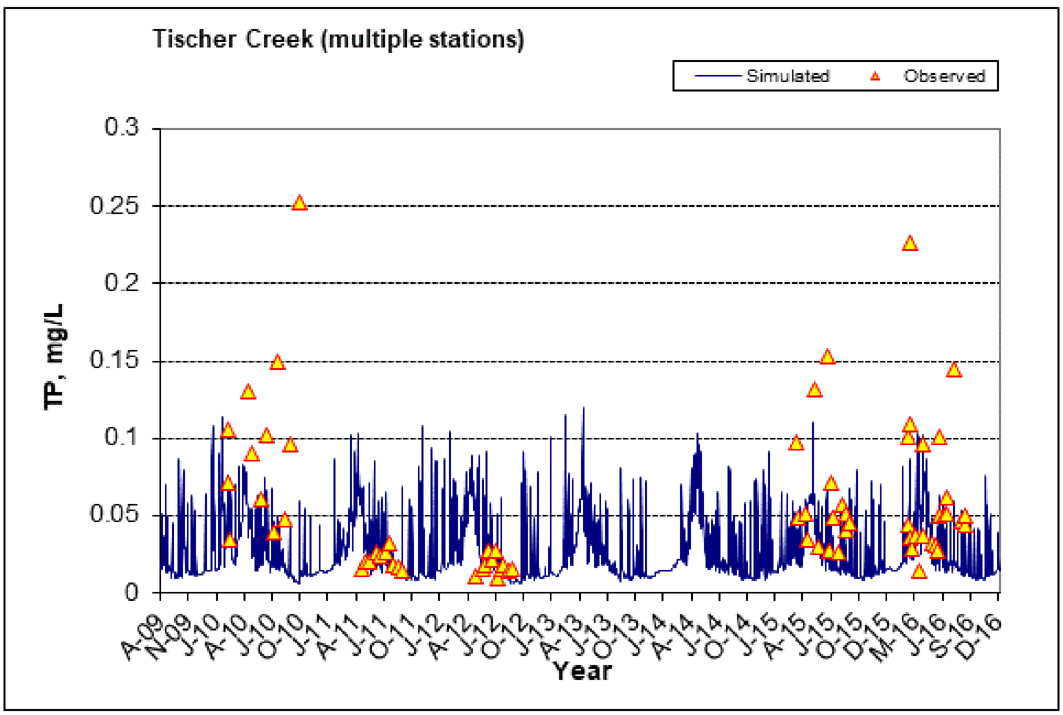


Figure E-451. Time series of observed and simulated Total Phosphorus (TP) concentration at Tischer Creek (multiple stations)

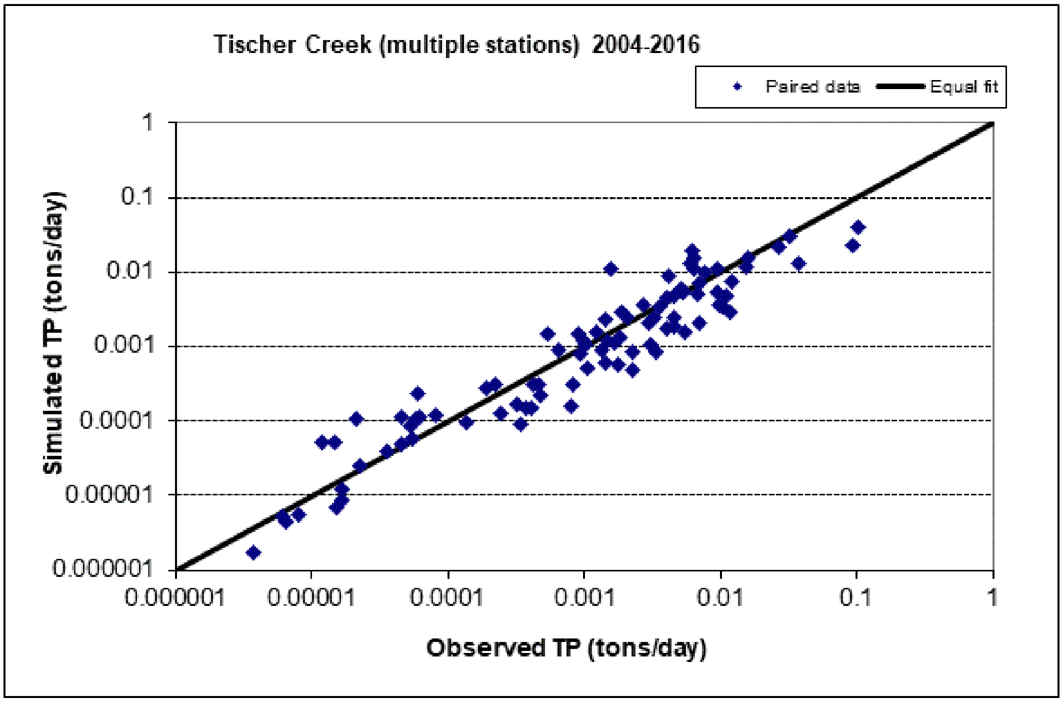


Figure E-452. Paired simulated vs. observed Total Phosphorus (TP) load at Tischer Creek (multiple stations) (calibration period)

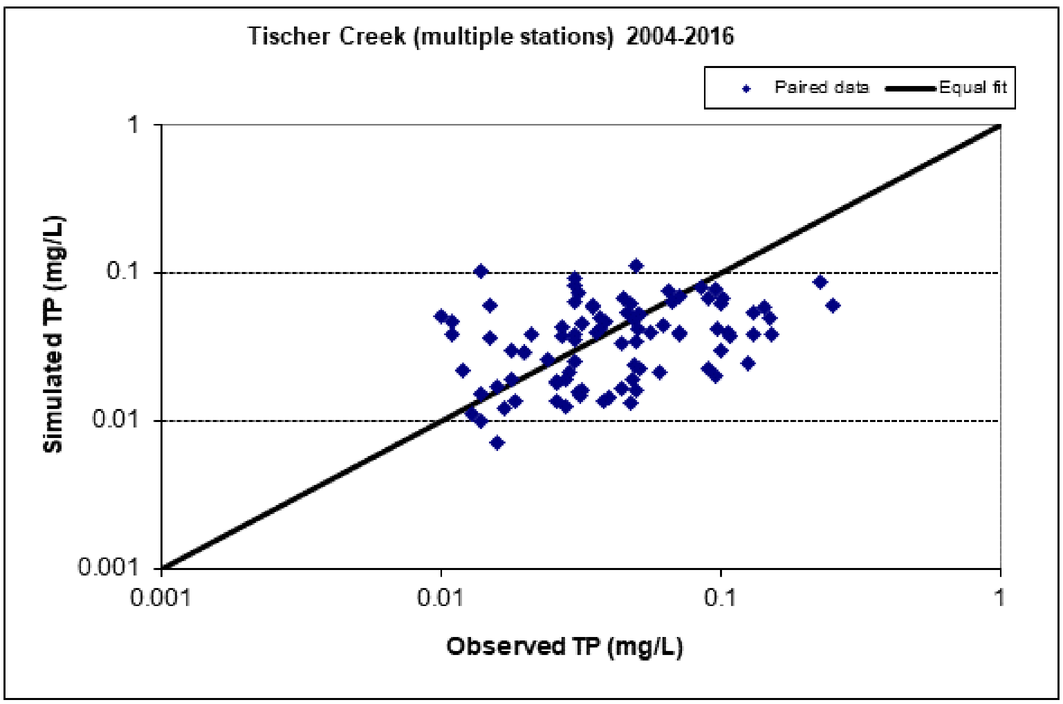


Figure E-453. Paired simulated vs. observed Total Phosphorus (TP) concentration at Tischer Creek (multiple stations) (calibration period)

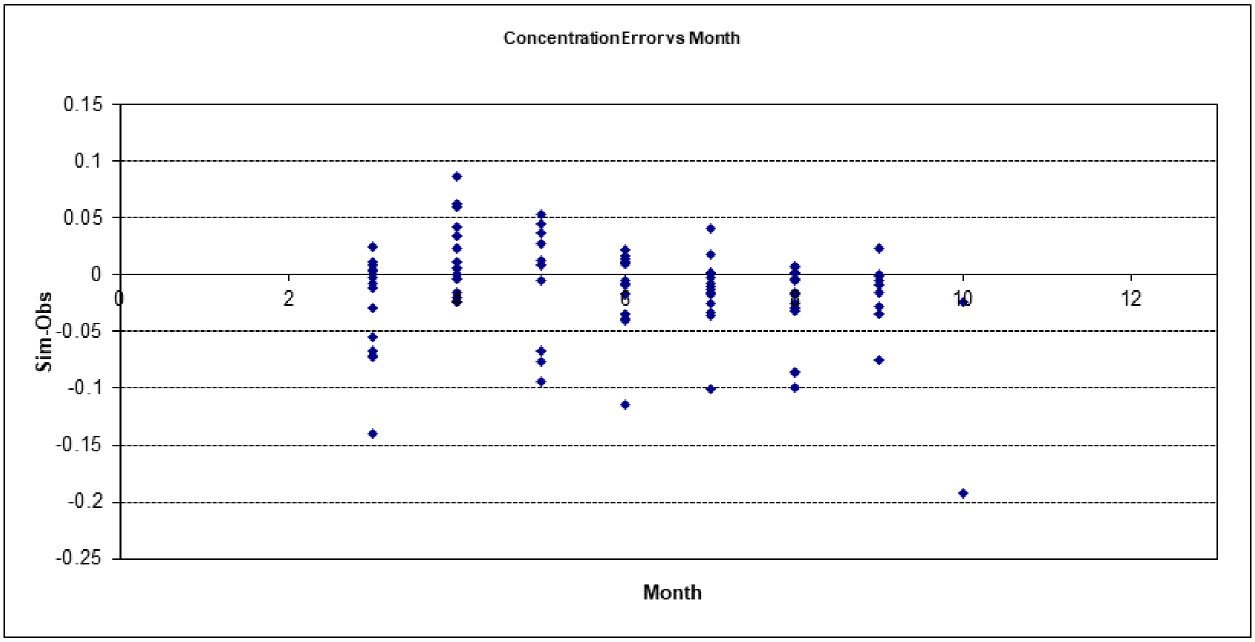


Figure E-454. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Tischer Creek (multiple stations)

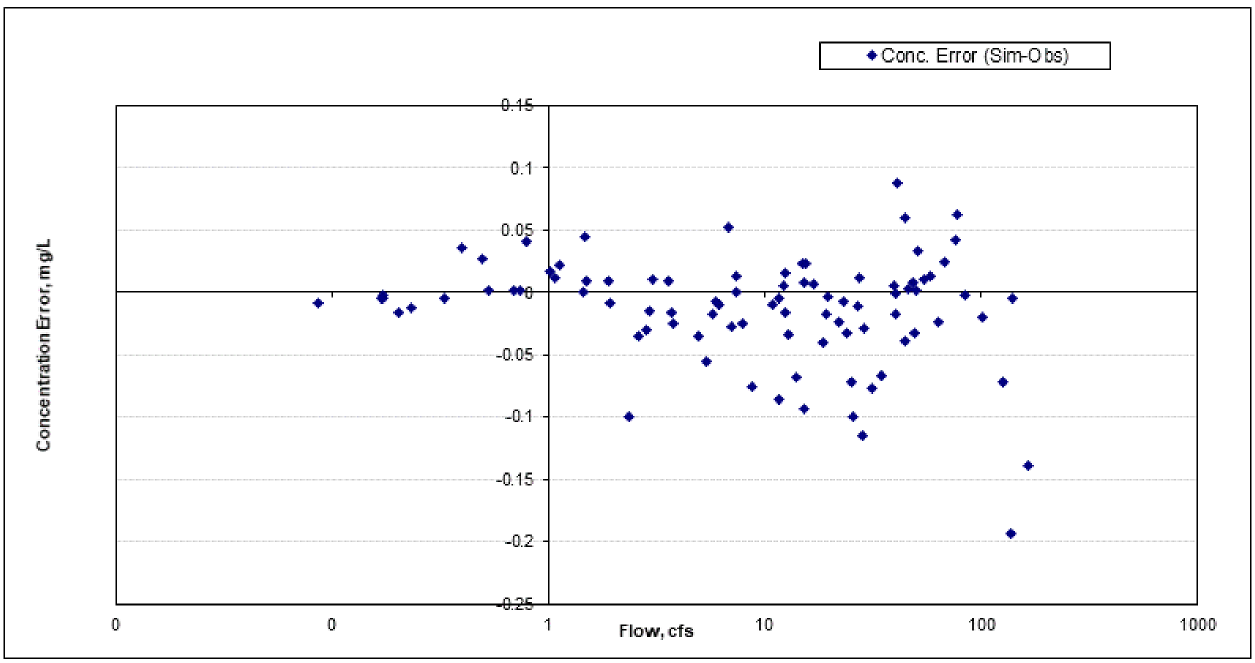


Figure E-455. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Tischer Creek (multiple stations)

E.9 CHESTER CREEK (MULTIPLE STATIONS)

E.9.1 Dissolved Oxygen (DO)

Table E-54. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	80
Concentration Average Error		-0.55%
Concentration Median Error		1.05%
Load Average Error		-2.78%
Load Median Error		0.12%
Paired t conc		1.00
Paired t load		0.85

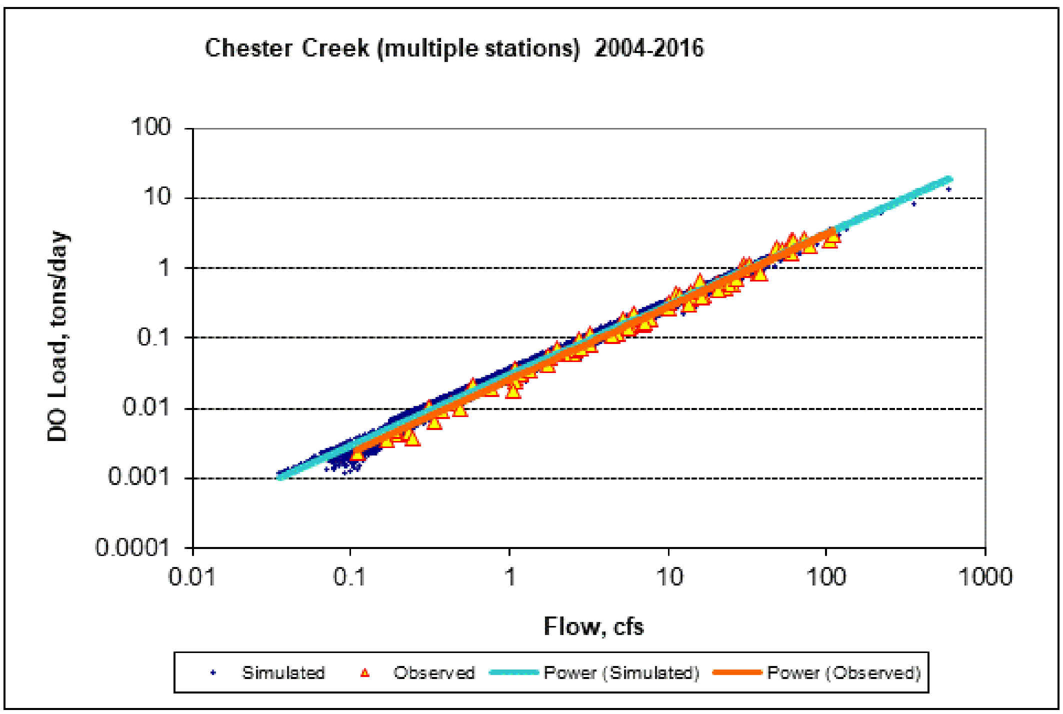


Figure E-456. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Chester Creek (multiple stations) (calibration period)

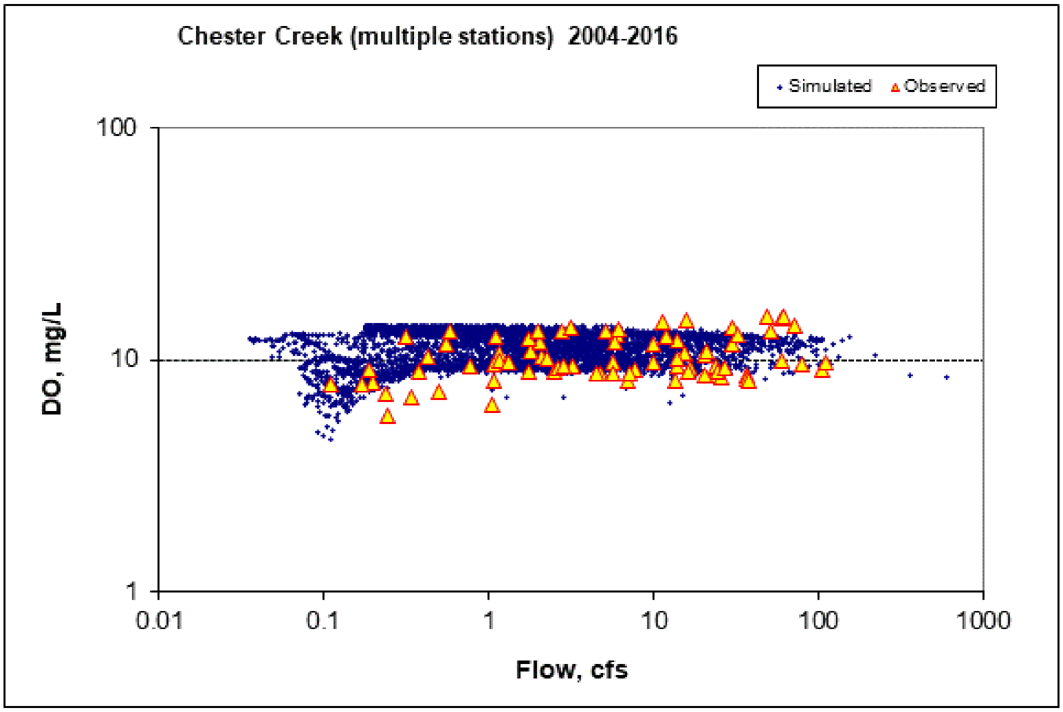
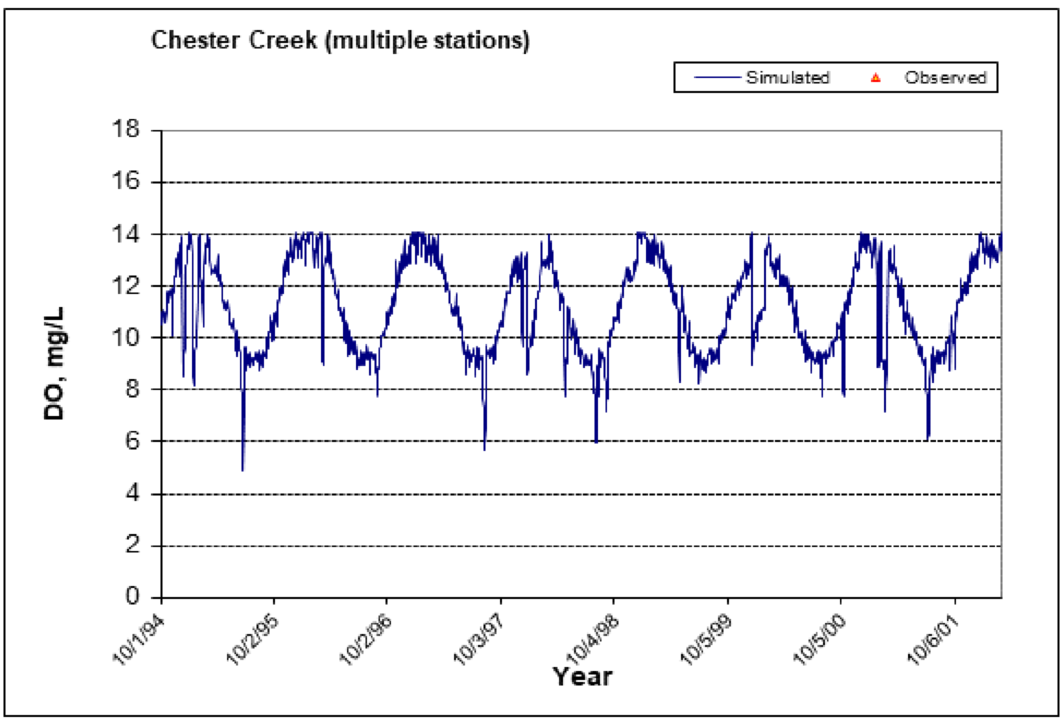
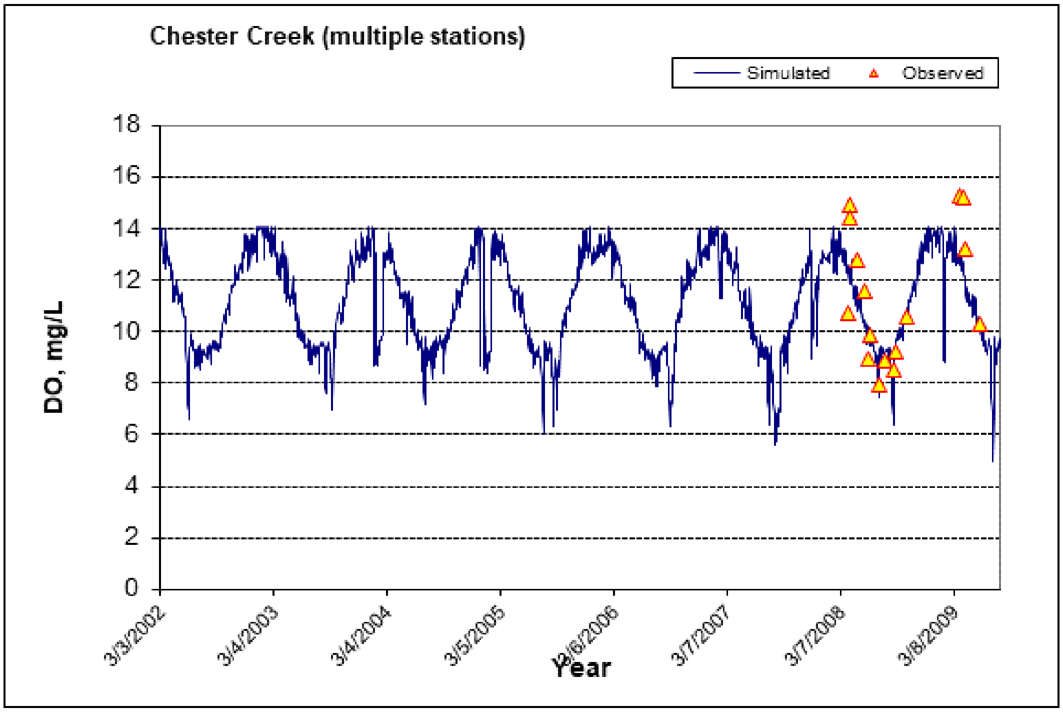


Figure E-457. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Chester Creek (multiple stations) (calibration period)





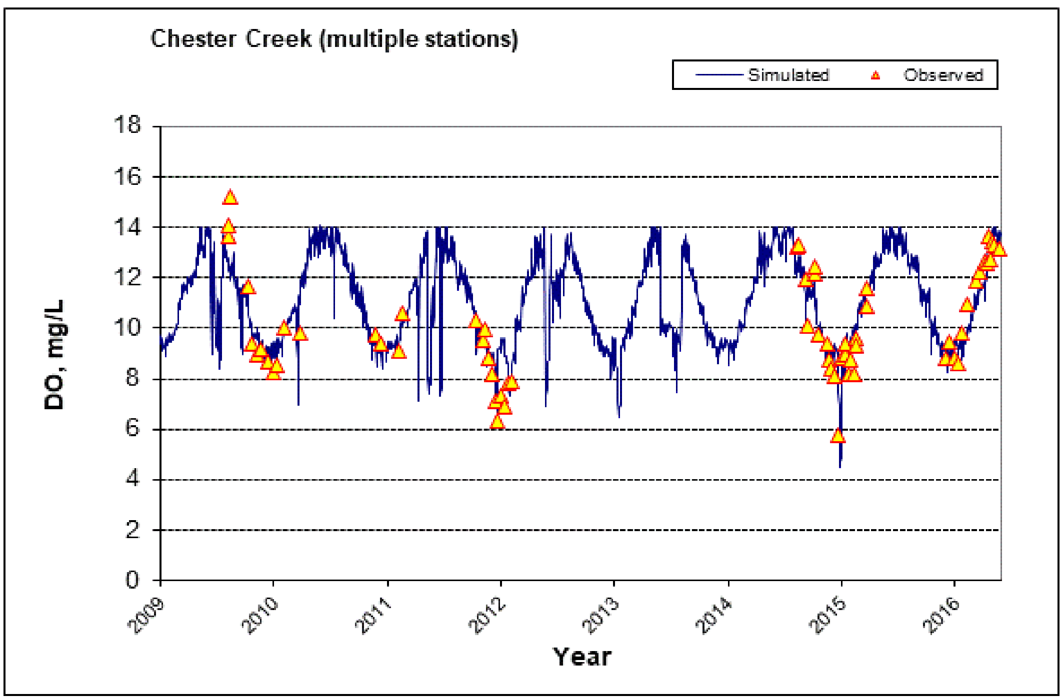


Figure E-458. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Chester Creek (multiple stations)

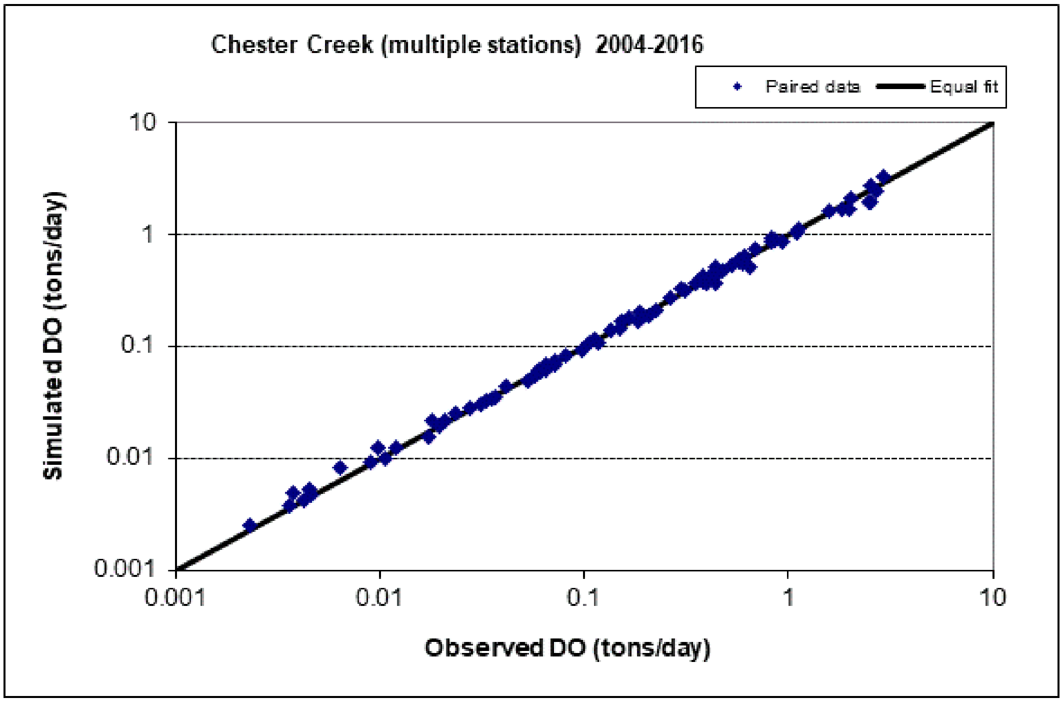


Figure E-459. Paired simulated vs. observed Dissolved Oxygen (DO) load at Chester Creek (multiple stations) (calibration period)

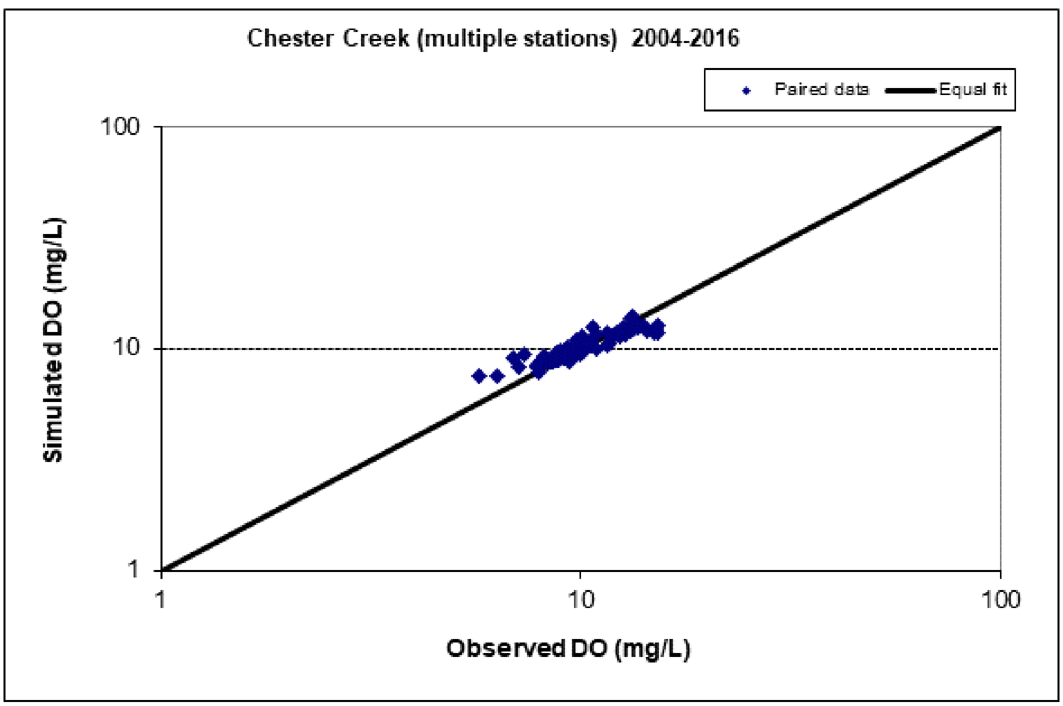


Figure E-460. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Chester Creek (multiple stations) (calibration period)

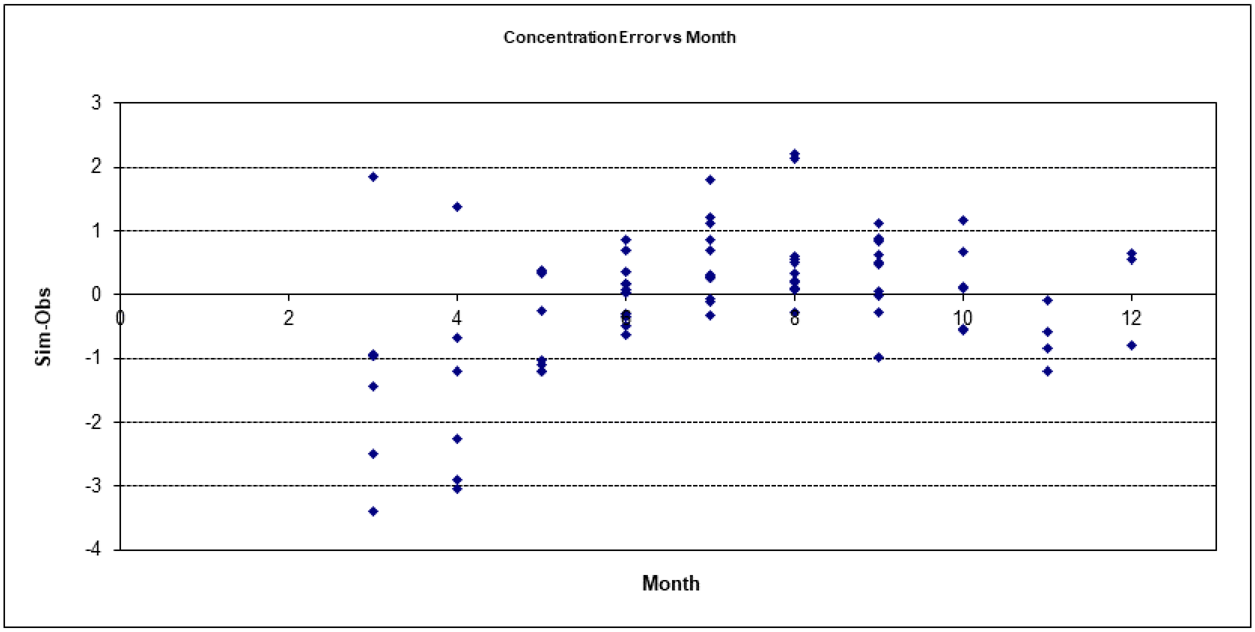


Figure E-461. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Chester Creek (multiple stations)

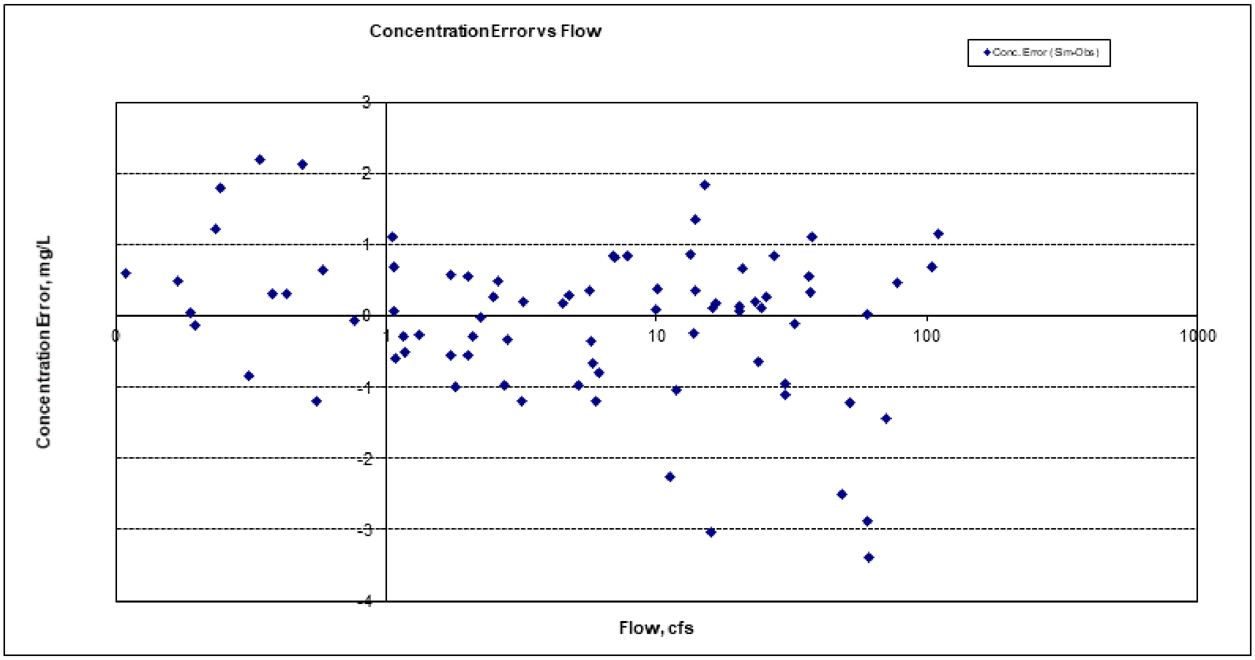


Figure E-462. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Chester Creek (multiple stations)

E.9.2 Ammonia Nitrogen (NH3)

Table E-55. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	53
Concentration Average Error		114.20%
Concentration Median Error		22.45%
Load Average Error		122.41%
Load Median Error		1.61%
Paired t conc		0.00
Paired t load		0.01

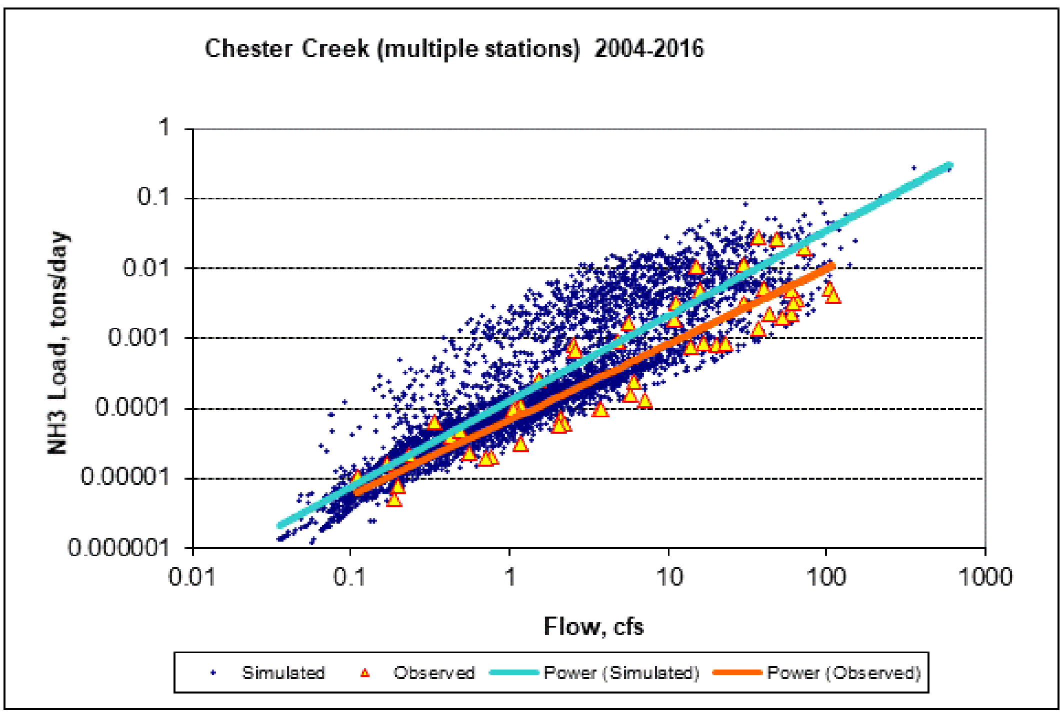


Figure E-463. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Chester Creek (multiple stations) (calibration period)

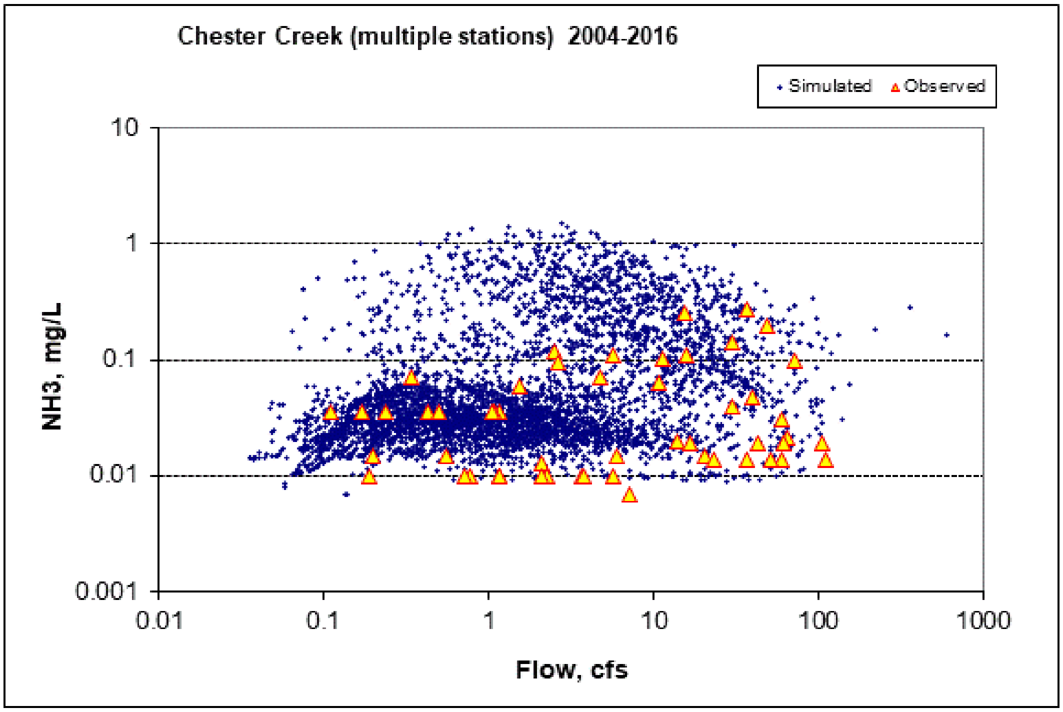
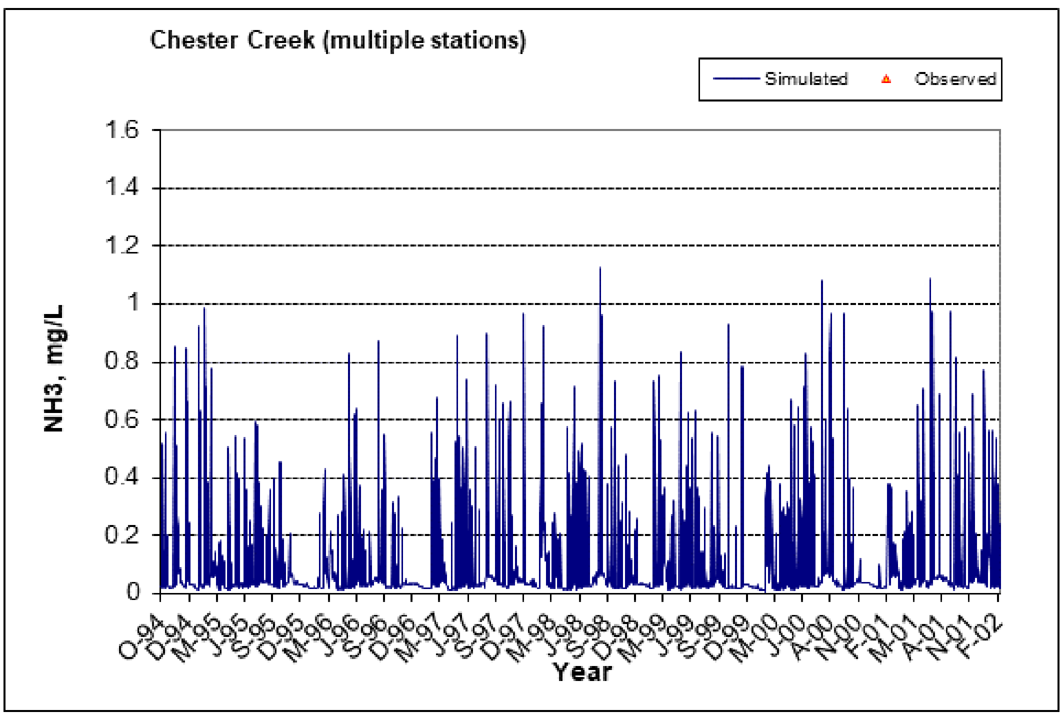


Figure E-464. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Chester Creek (multiple stations) (calibration period)



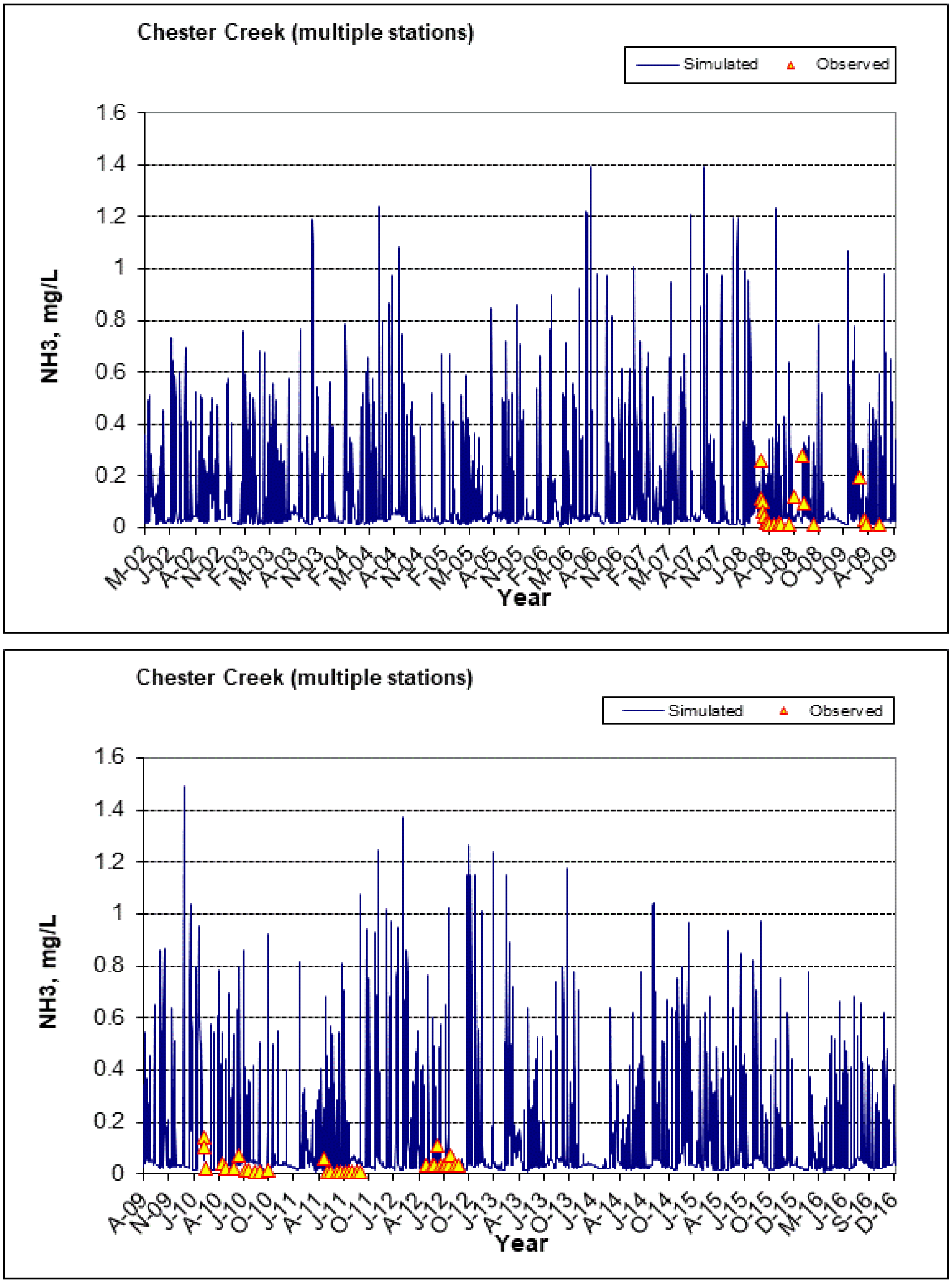


Figure E-465. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Chester Creek (multiple stations)

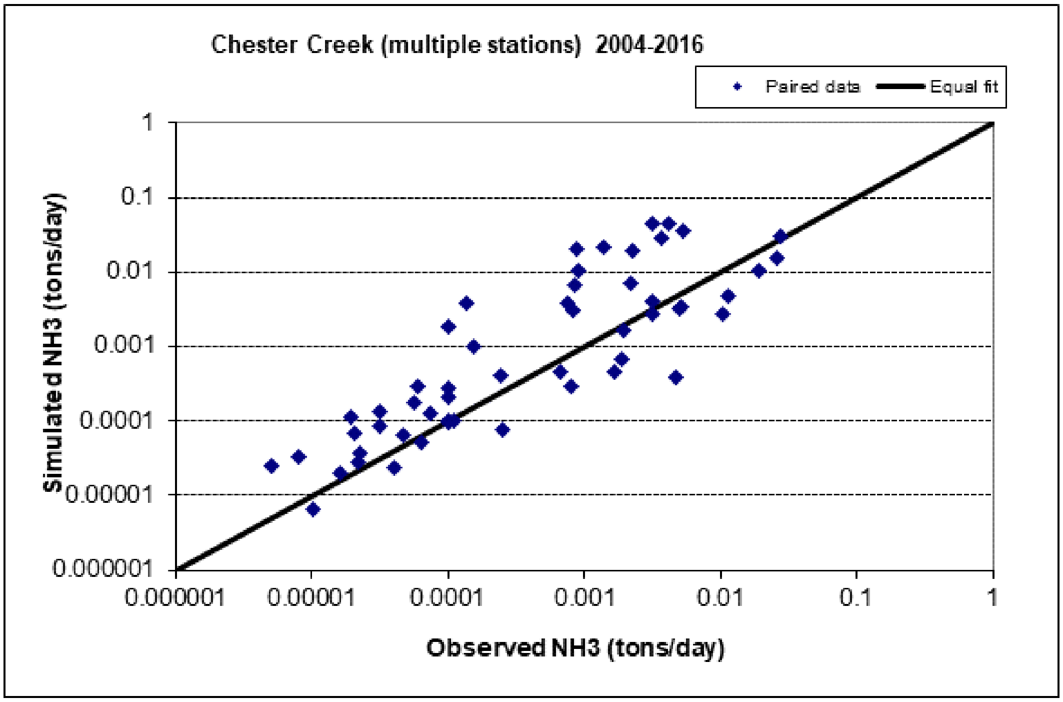


Figure E-466. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Chester Creek (multiple stations) (calibration period)

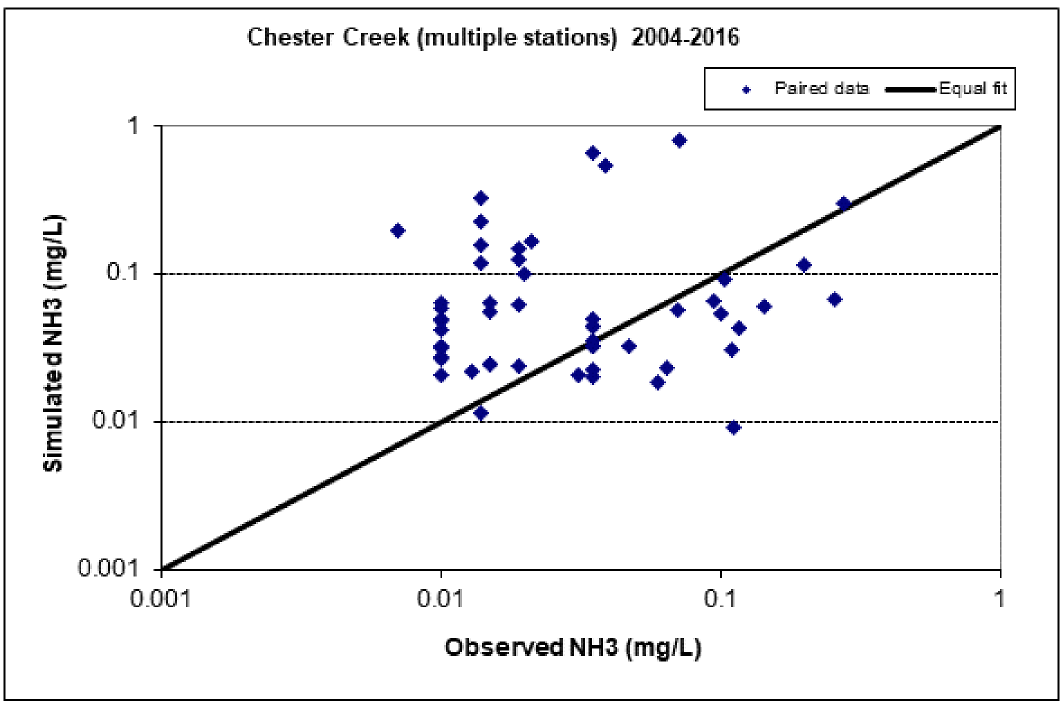


Figure E-467. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Chester Creek (multiple stations) (calibration period)

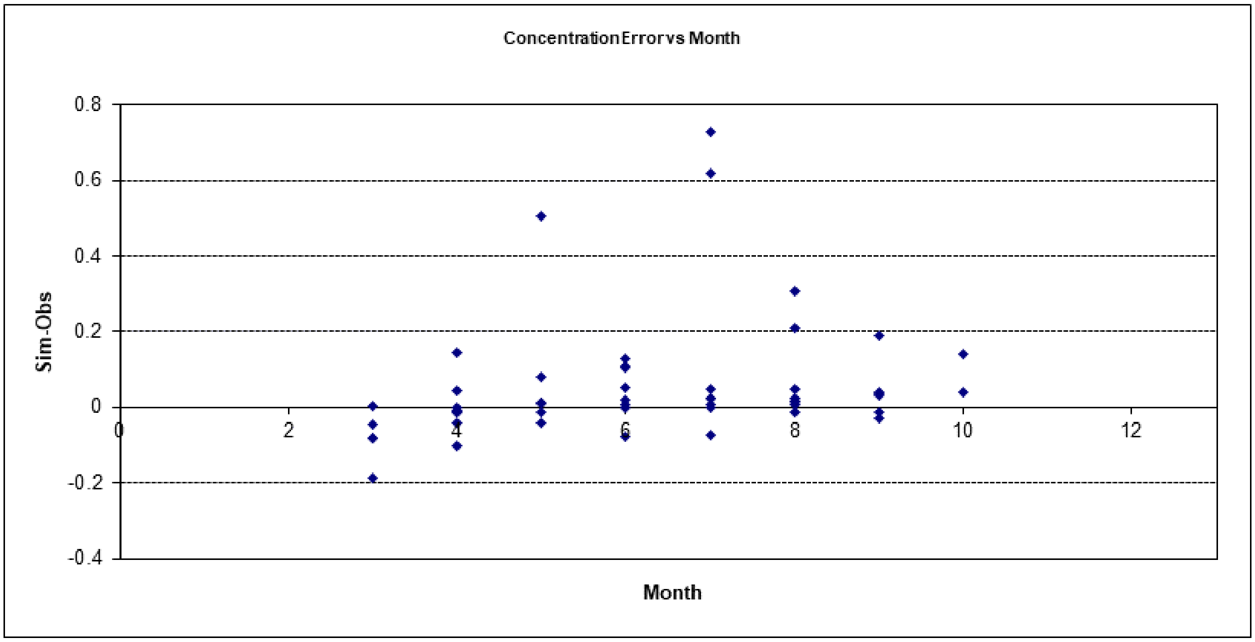


Figure E-468. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Chester Creek (multiple stations)

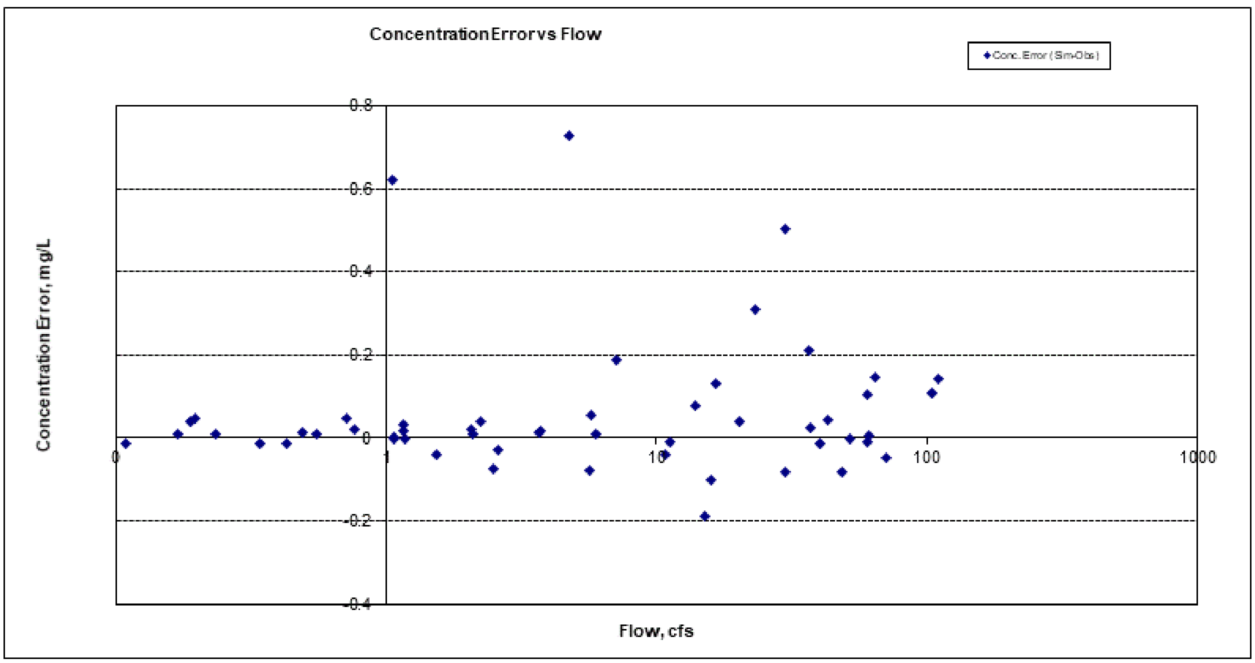


Figure E-469. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Chester Creek (multiple stations)

E.9.3 Organic Nitrogen (OrgN)

Table E-56. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	ND	53
Concentration Average Error		4.42%
Concentration Median Error		7.34%
Load Average Error		-3.30%
Load Median Error		0.44%
Paired t conc		1.00
Paired t load		0.78

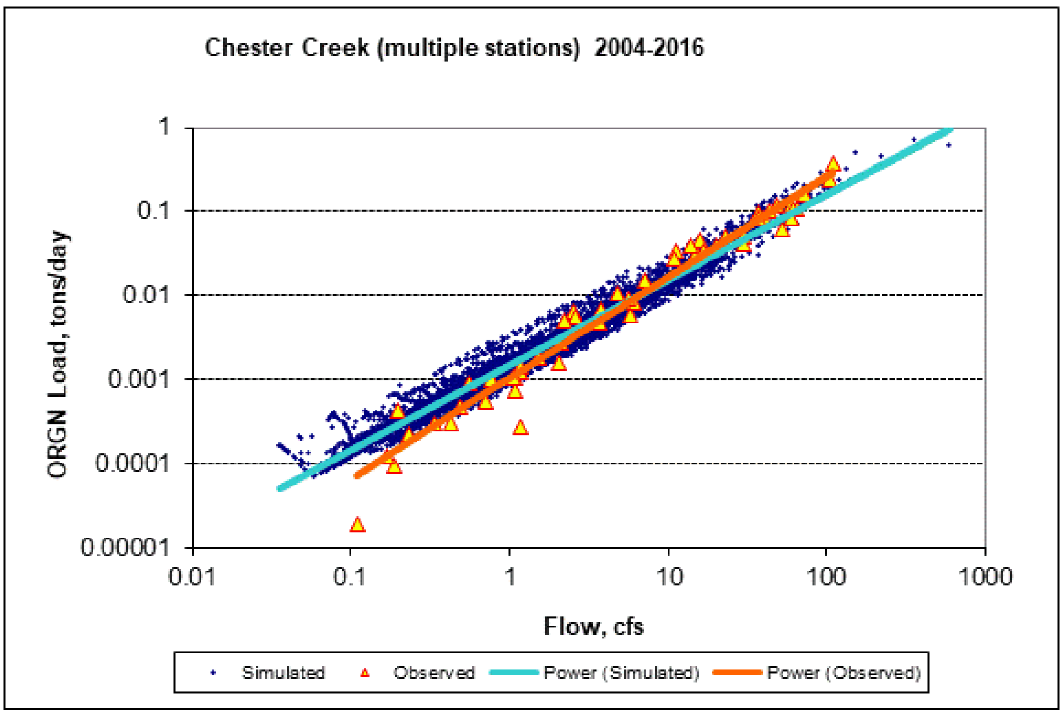


Figure E-470. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Chester Creek (multiple stations) (calibration period)

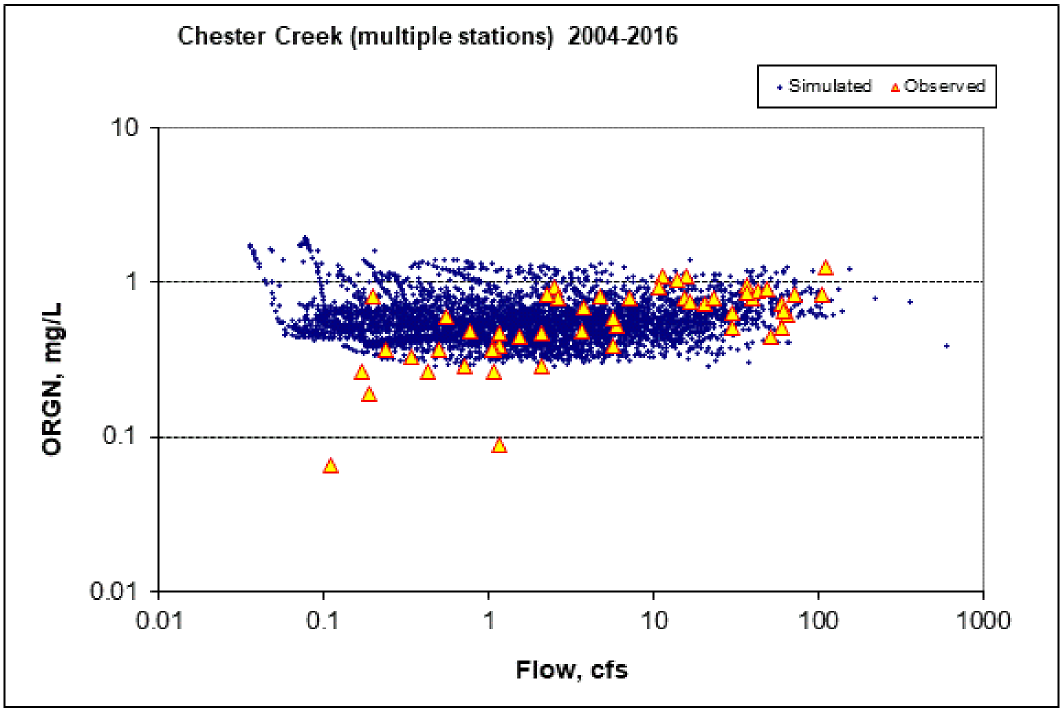
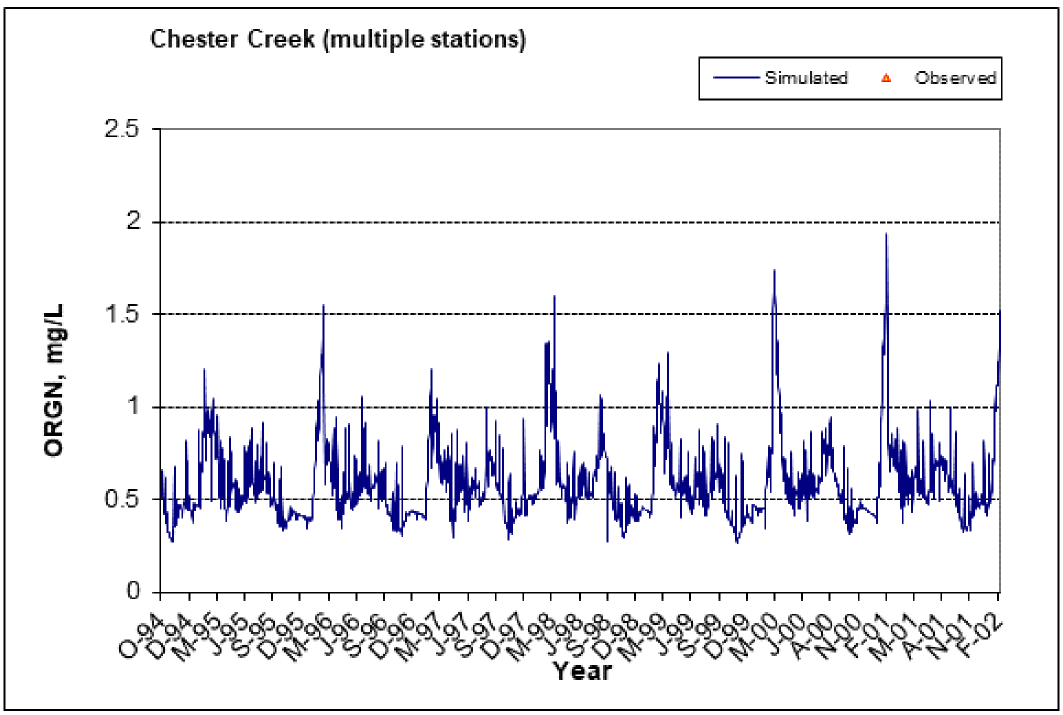


Figure E-471. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Chester Creek (multiple stations) (calibration period)



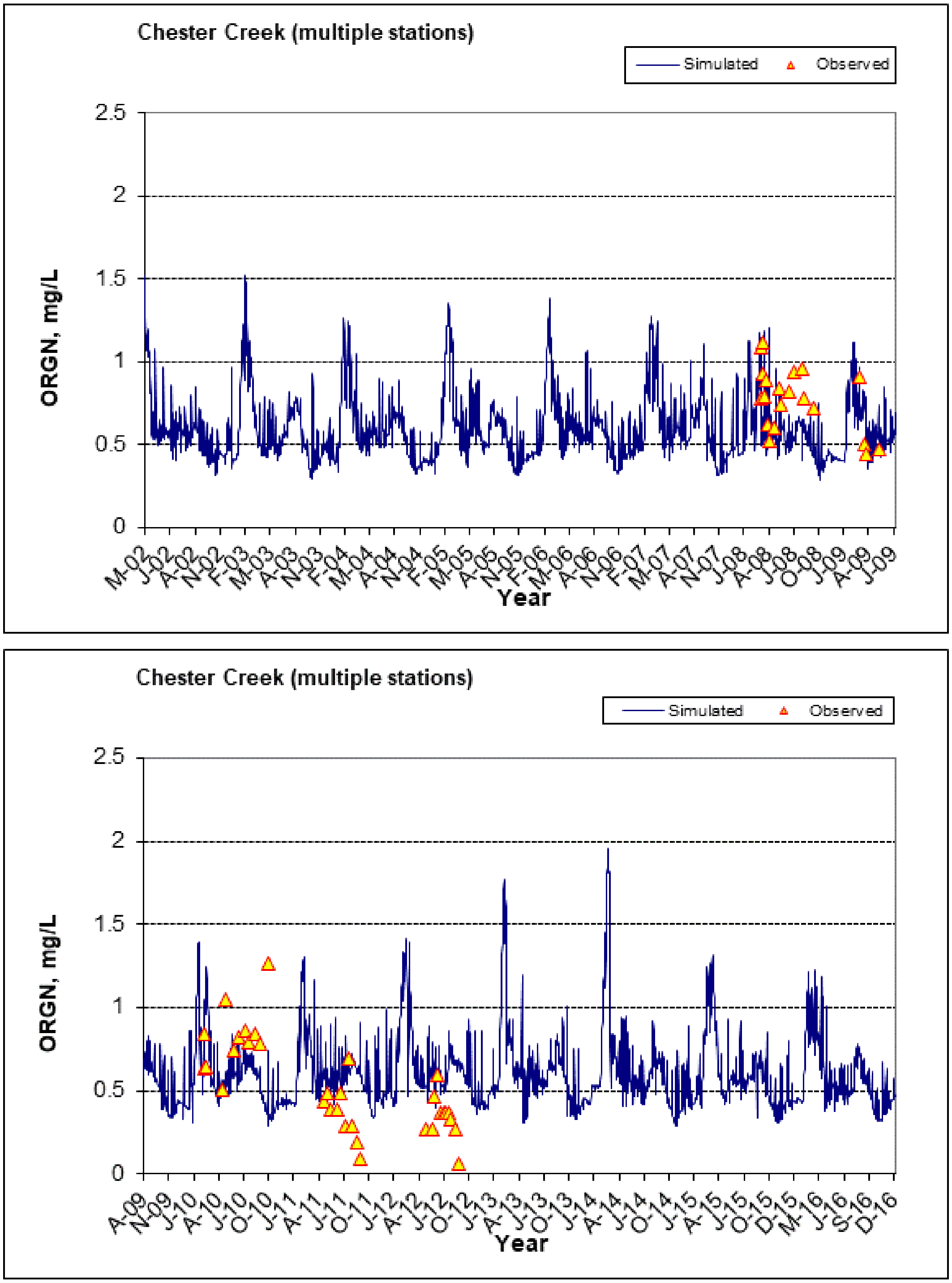


Figure E-472. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Chester Creek (multiple stations)

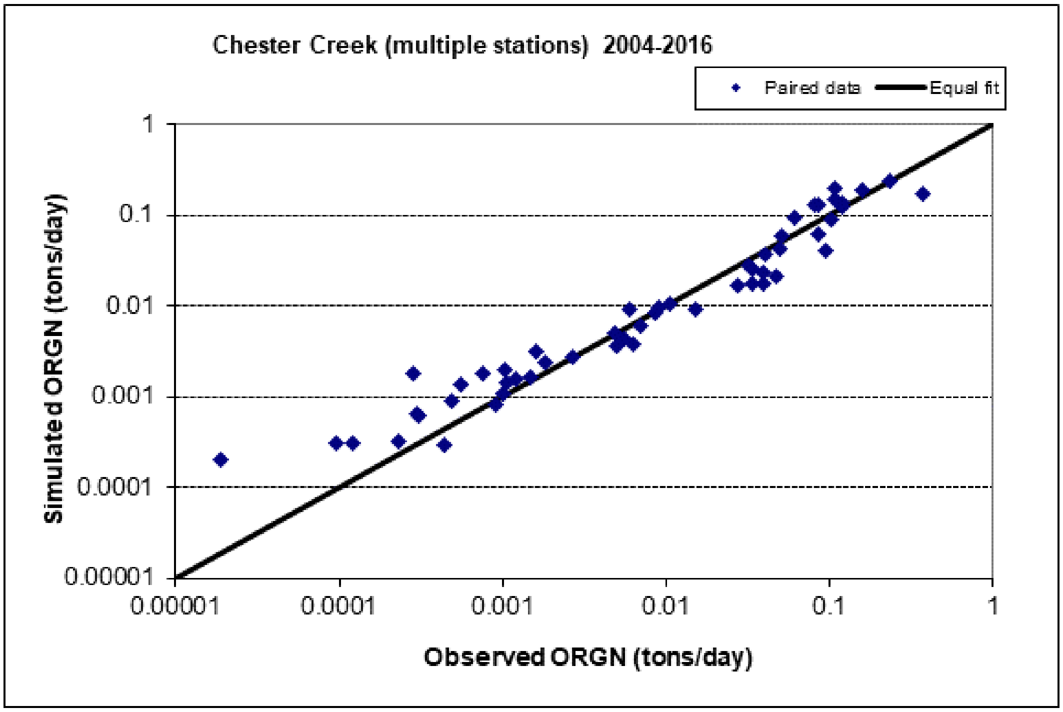


Figure E-473. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Chester Creek (multiple stations) (calibration period)

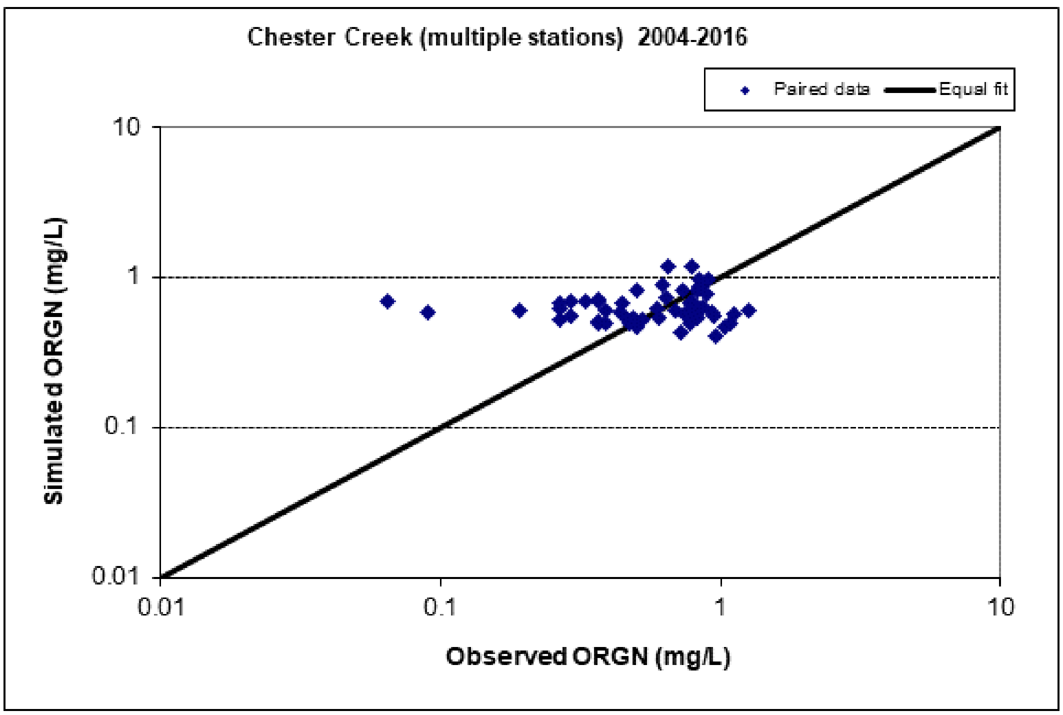


Figure E-474. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Chester Creek (multiple stations) (calibration period)

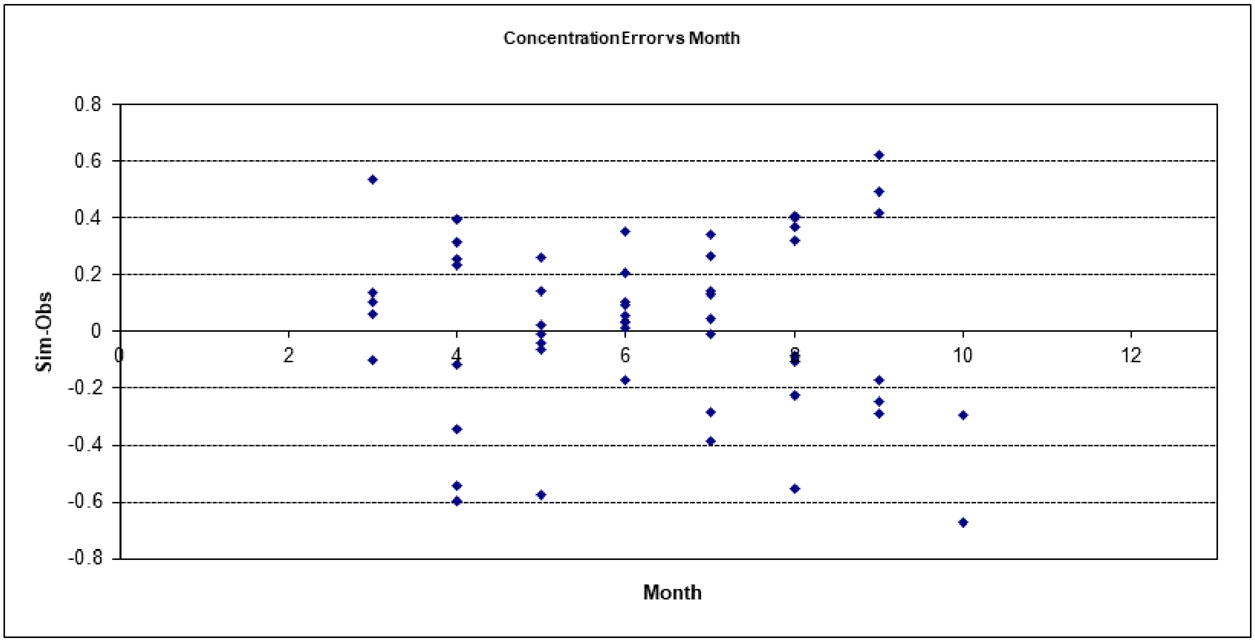


Figure E-475. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at Chester Creek (multiple stations)

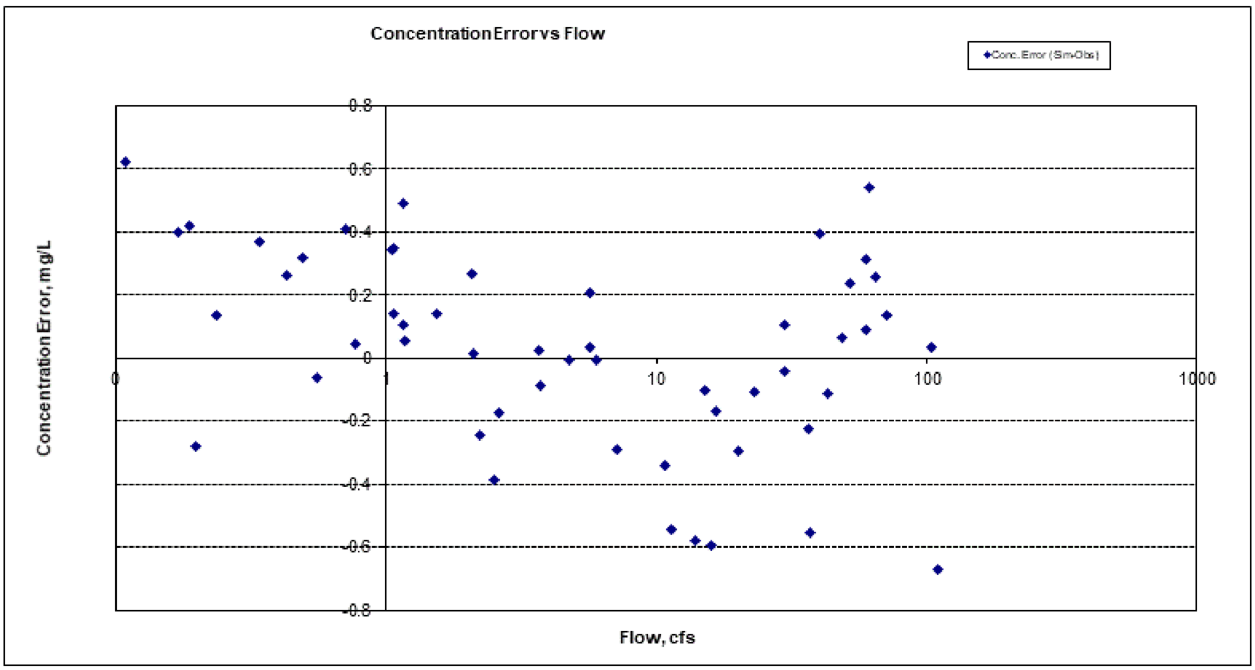


Figure E-476. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at Chester Creek (multiple stations)

E.9.4 Total Kjeldahl Nitrogen (TKN)

Table E-57. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	ND	53
Concentration Average Error		12.43%
Concentration Median Error		13.49%
Load Average Error		4.68%
Load Median Error		0.42%
Paired t conc		0.91
Paired t load		0.76

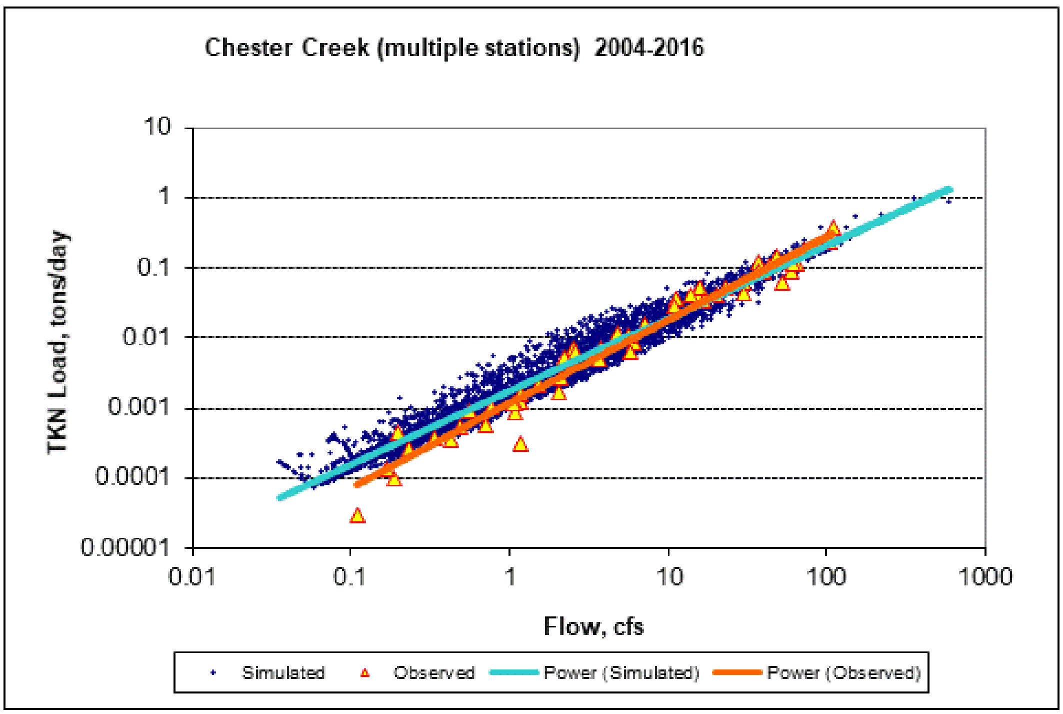


Figure E-477. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Chester Creek (multiple stations) (calibration period)

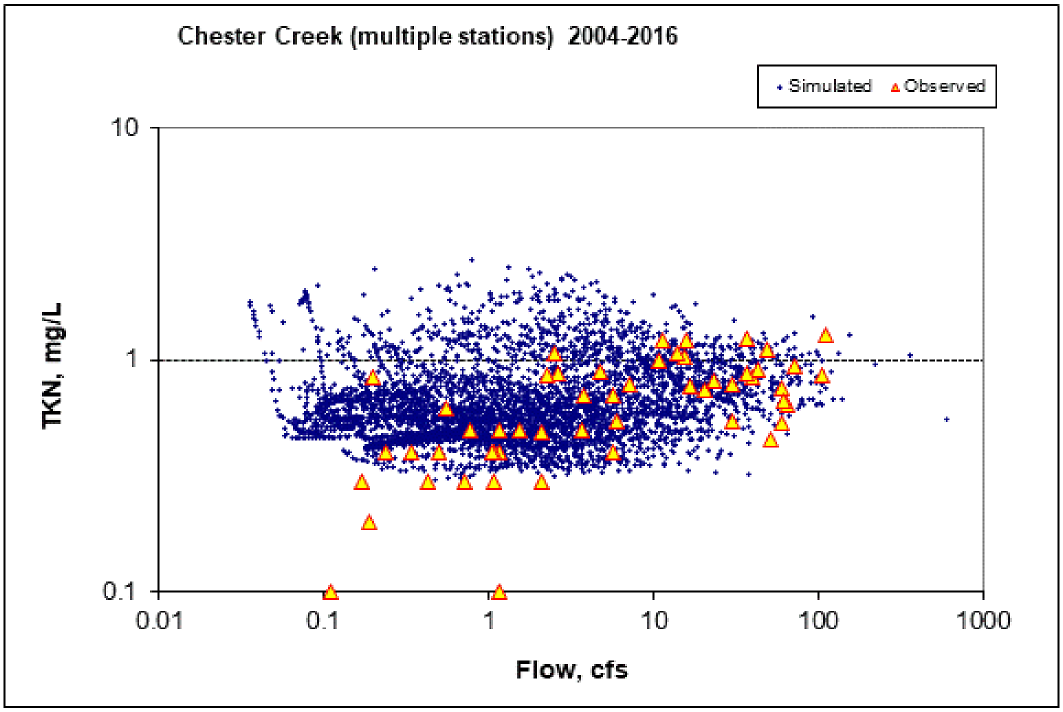
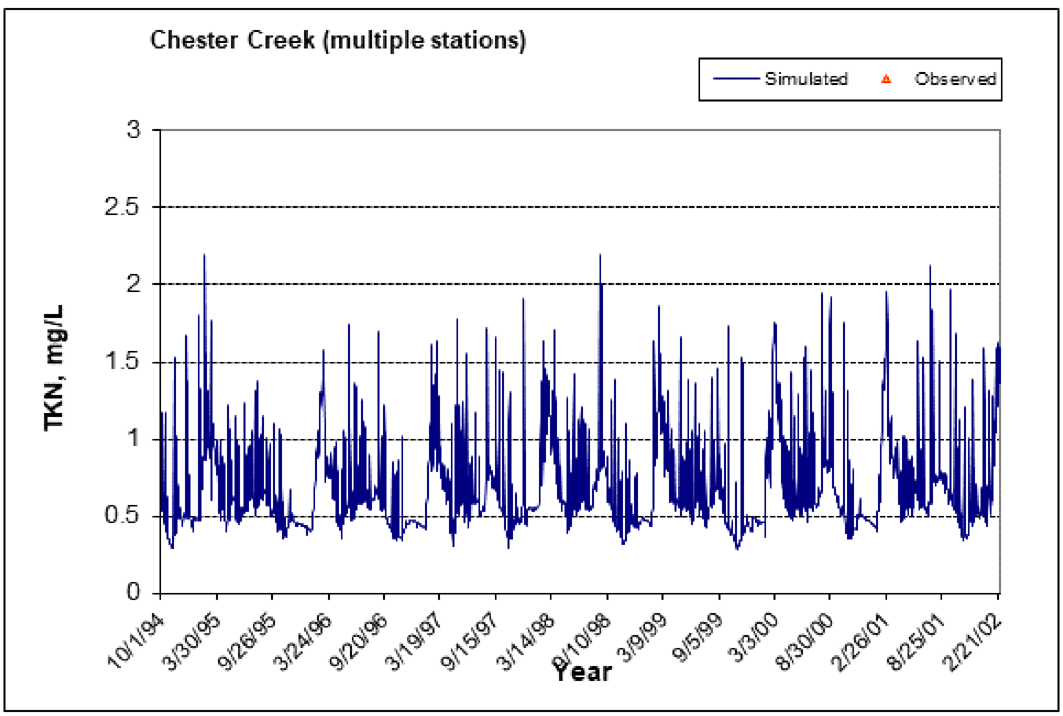


Figure E-478. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Chester Creek (multiple stations) (calibration period)



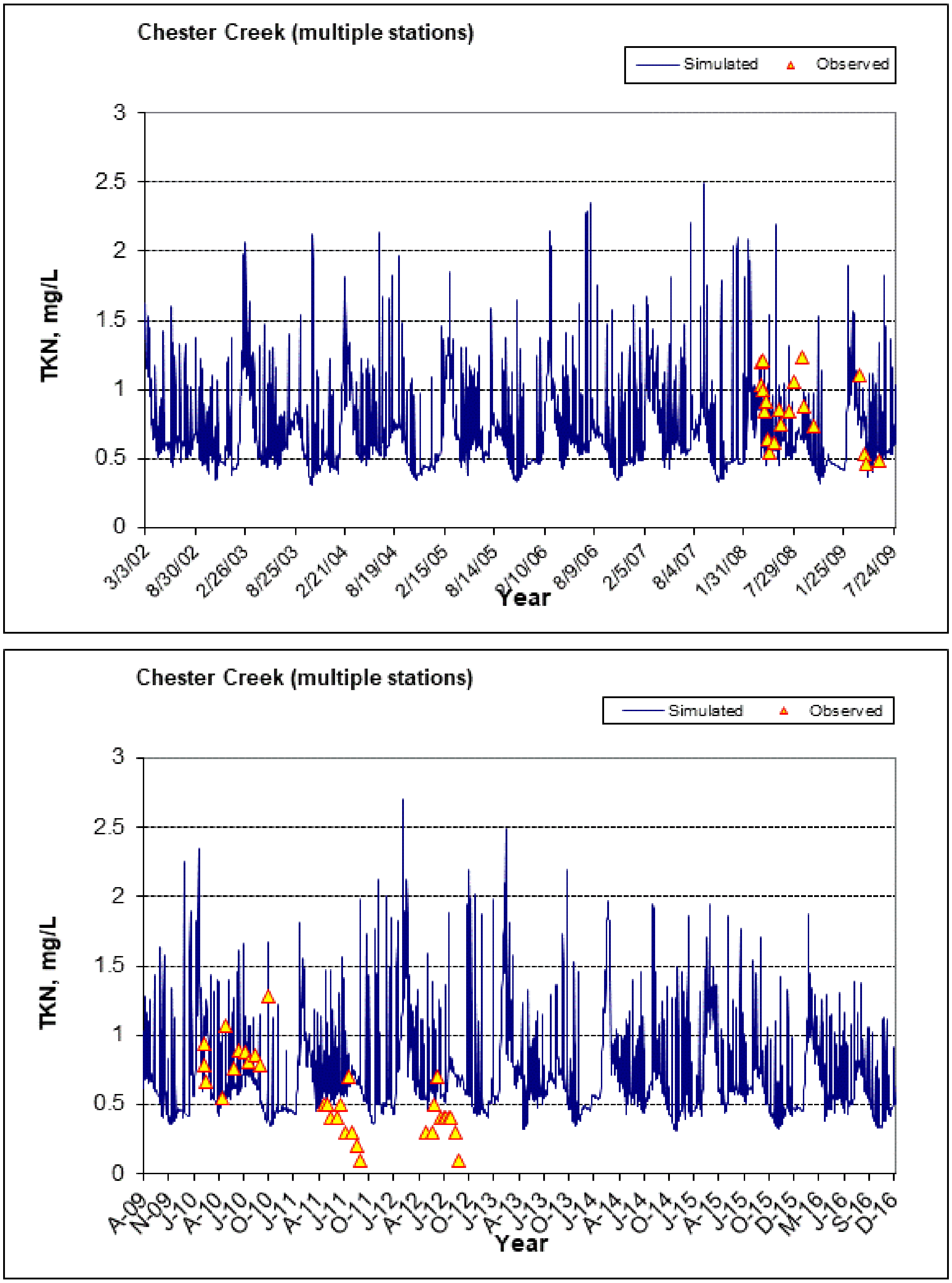


Figure E-479. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Chester Creek (multiple stations)

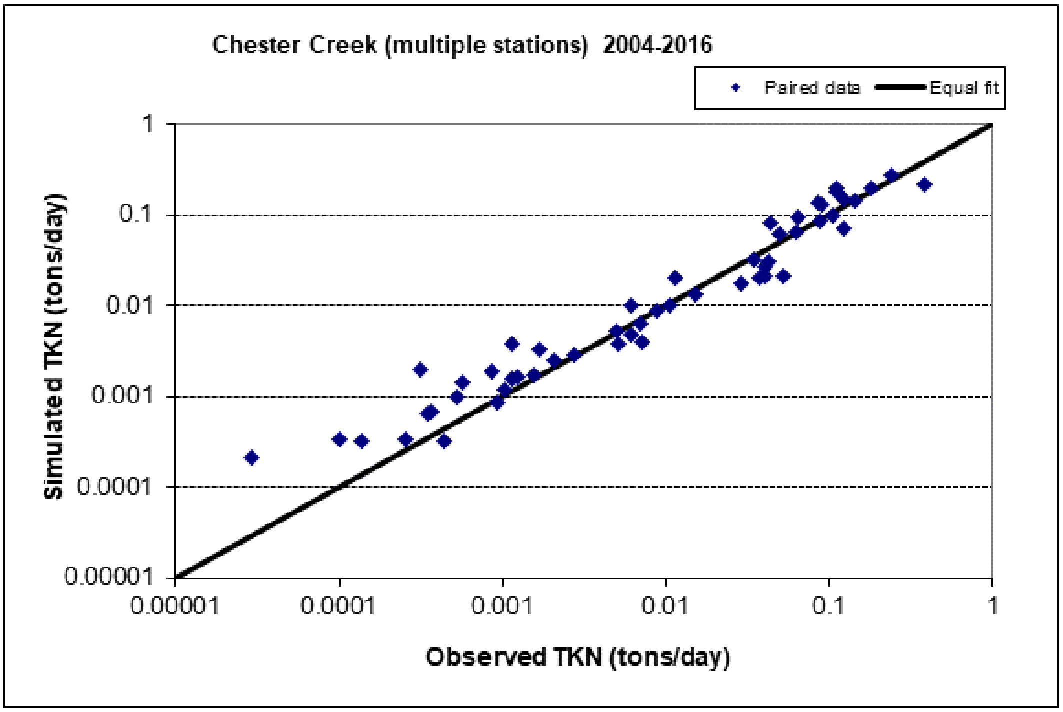


Figure E-480. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Chester Creek (multiple stations) (calibration period)

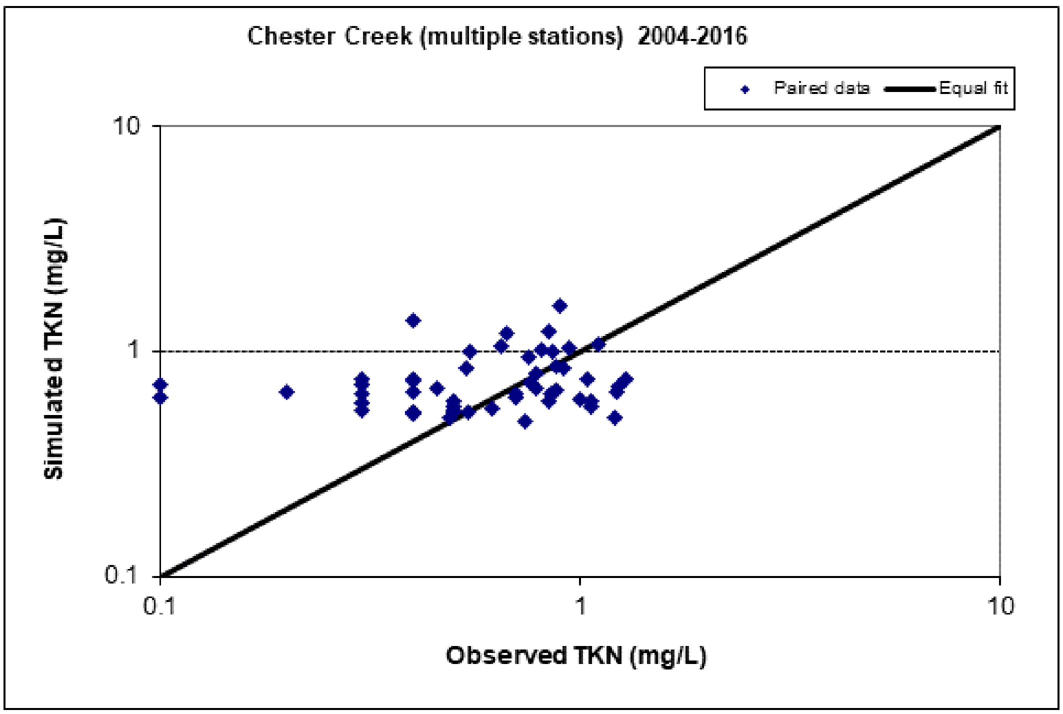


Figure E-481. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Chester Creek (multiple stations) (calibration period)

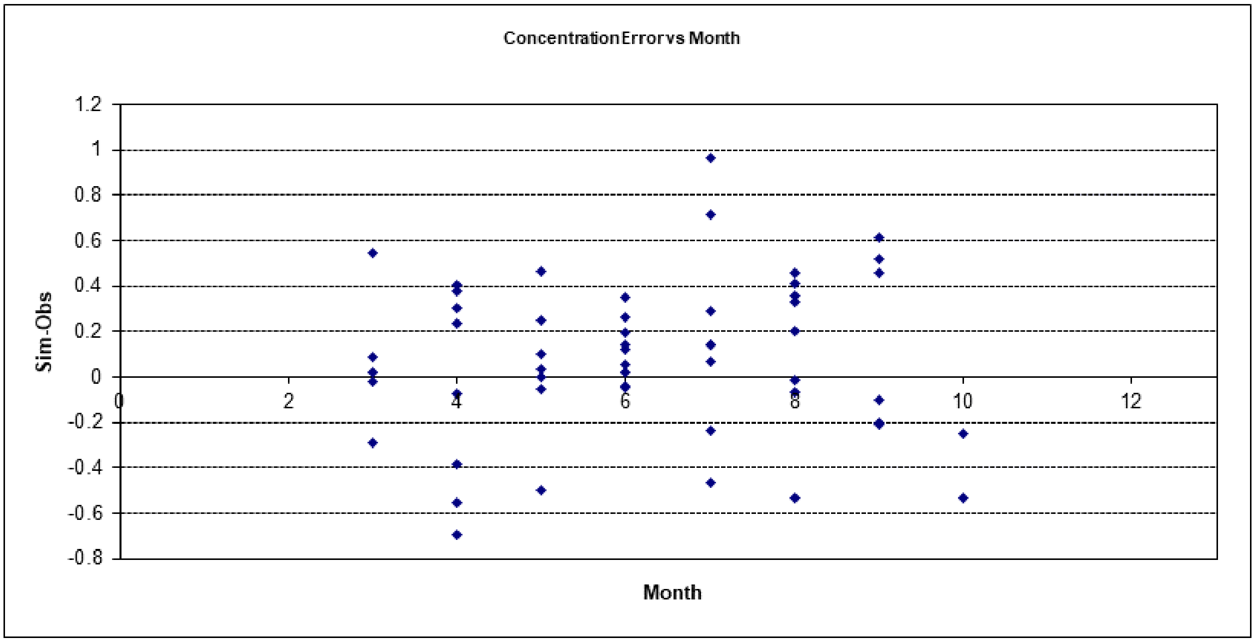


Figure E-482. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at Chester Creek (multiple stations)

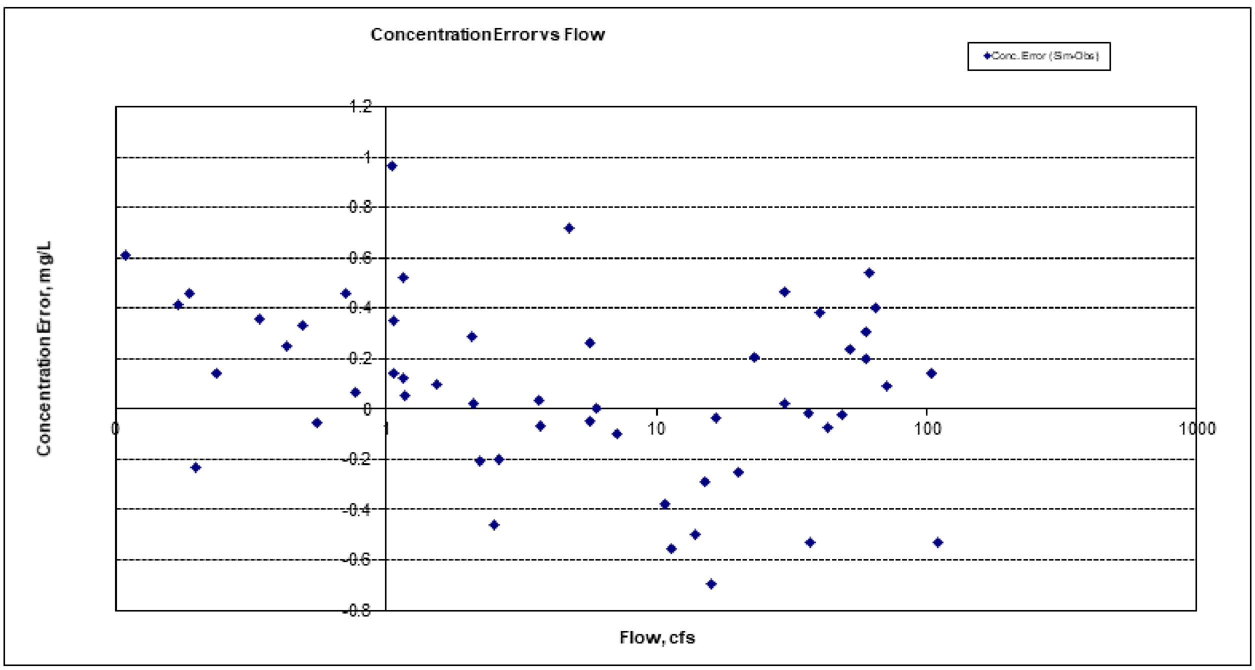


Figure E-483. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at Chester Creek (multiple stations)

E.9.5 Nitrite+ Nitrate Nitrogen (NOx)

Table E-58. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	67
Concentration Average Error		-35.22%
Concentration Median Error		-27.48%
Load Average Error		10.51%
Load Median Error		-4.64%
Paired t conc		0.07
Paired t load		0.69

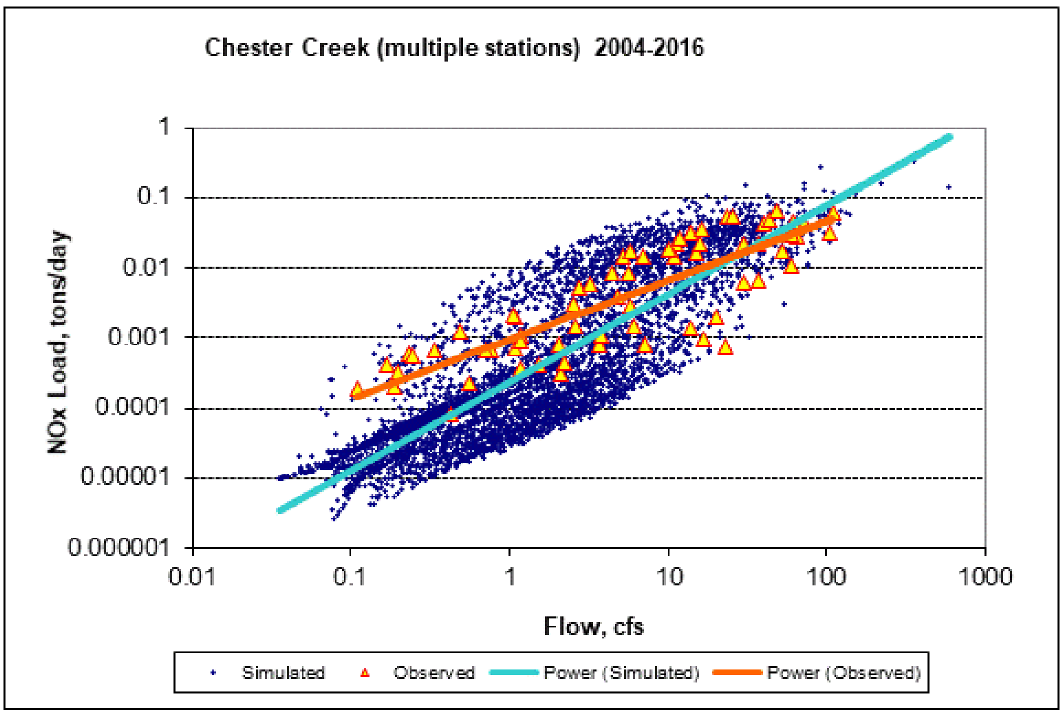


Figure E-484. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Chester Creek (multiple stations) (calibration period)

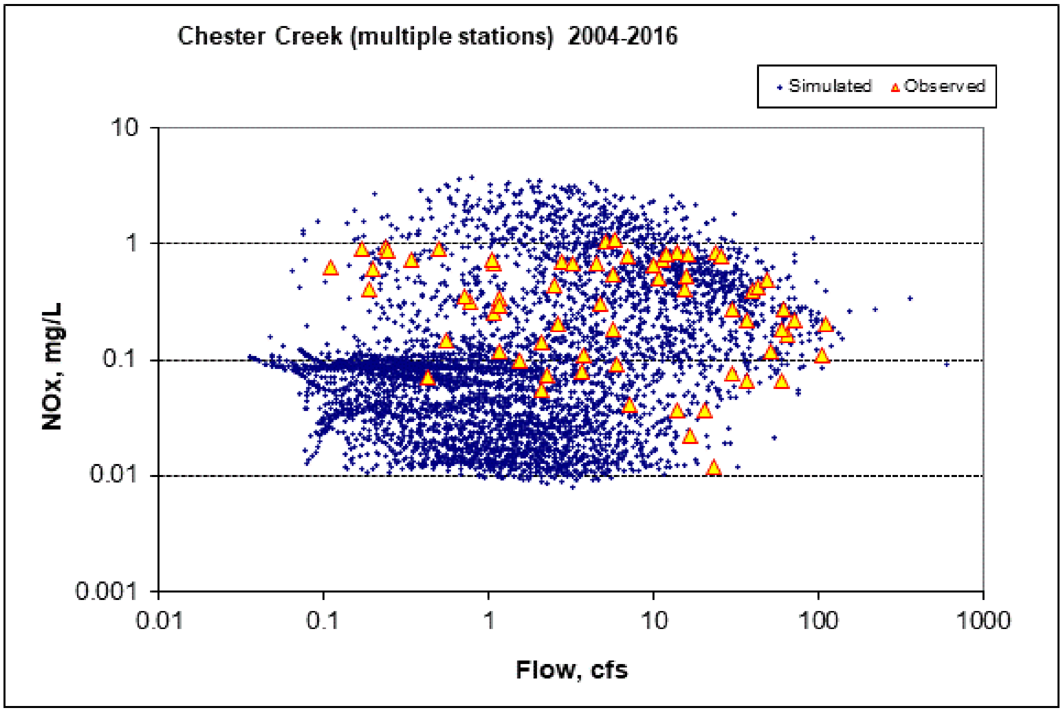
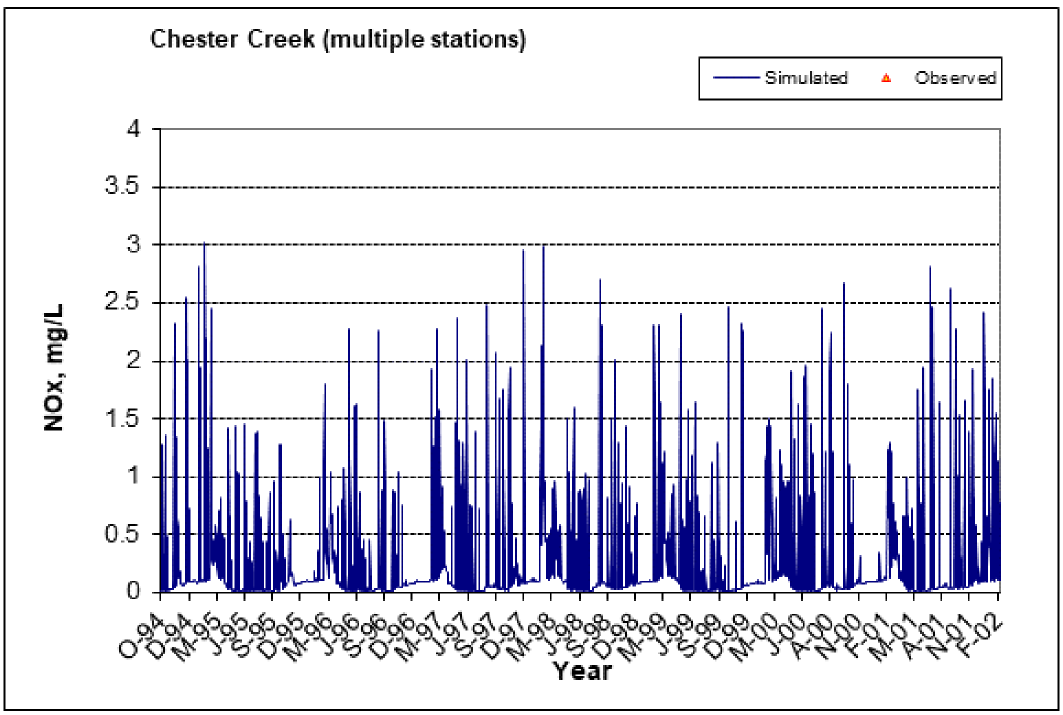


Figure E-485. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Chester Creek (multiple stations) (calibration period)



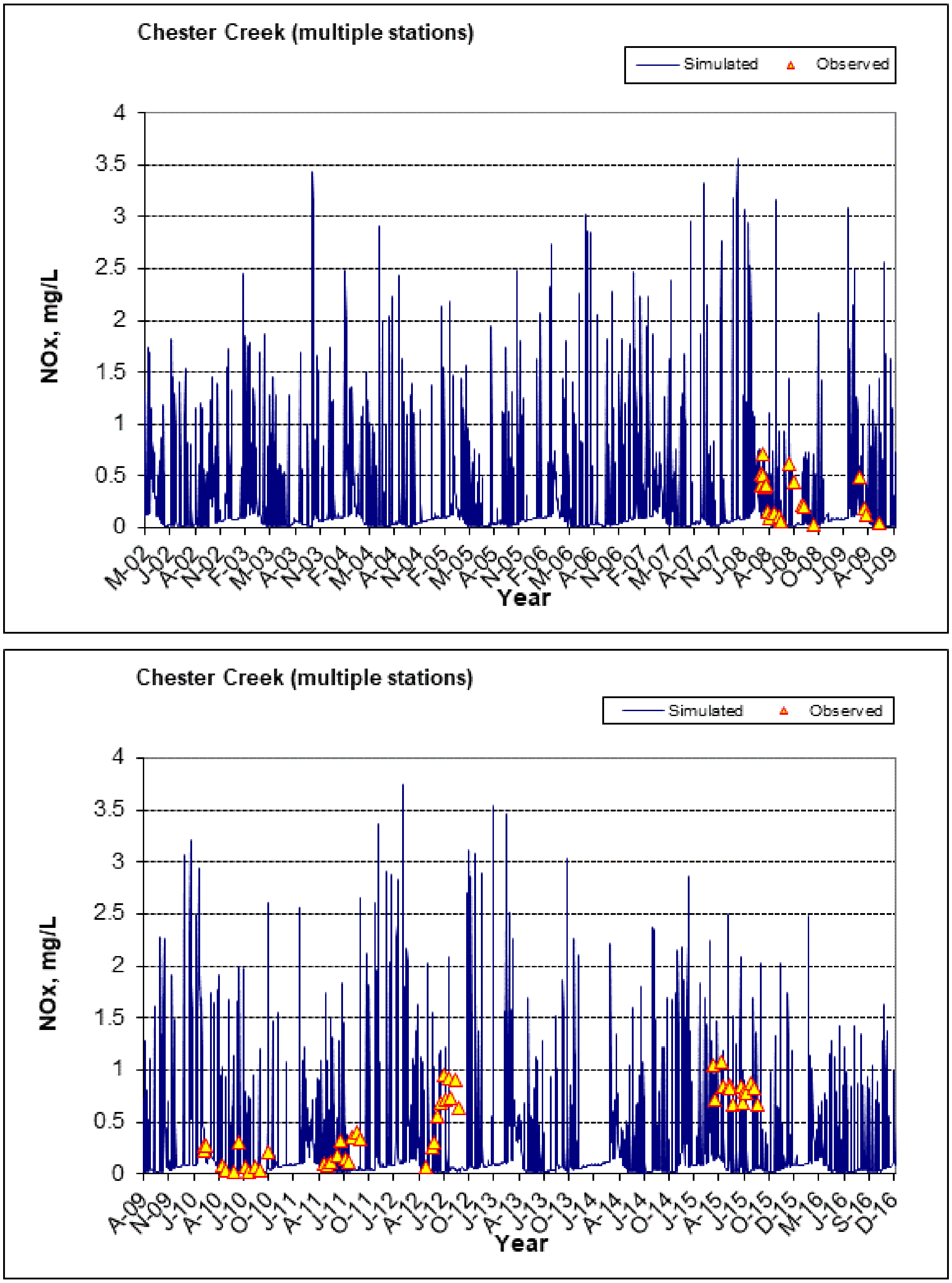


Figure E-486. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Chester Creek (multiple stations)

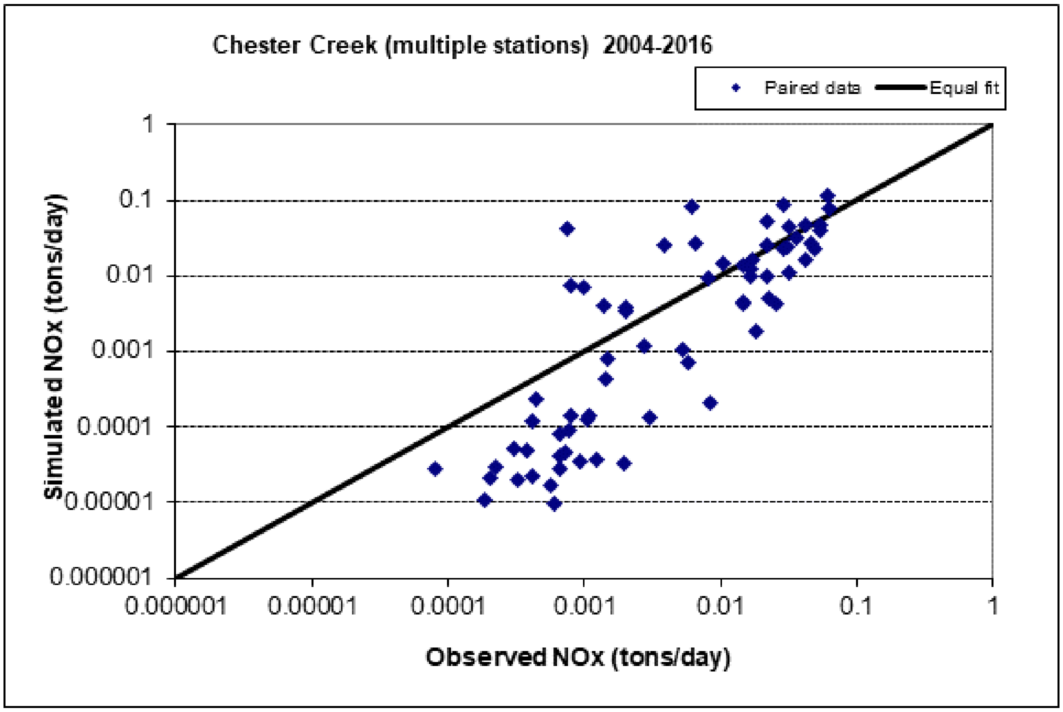


Figure E-487. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Chester Creek (multiple stations) (calibration period)

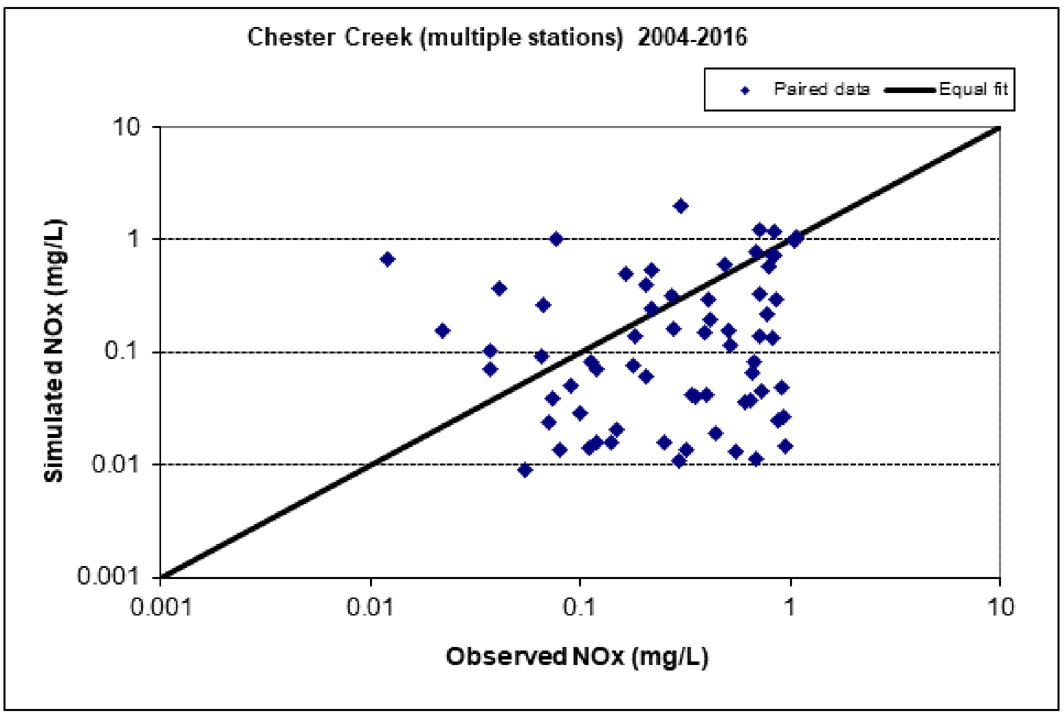


Figure E-488. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Chester Creek (multiple stations) (calibration period)

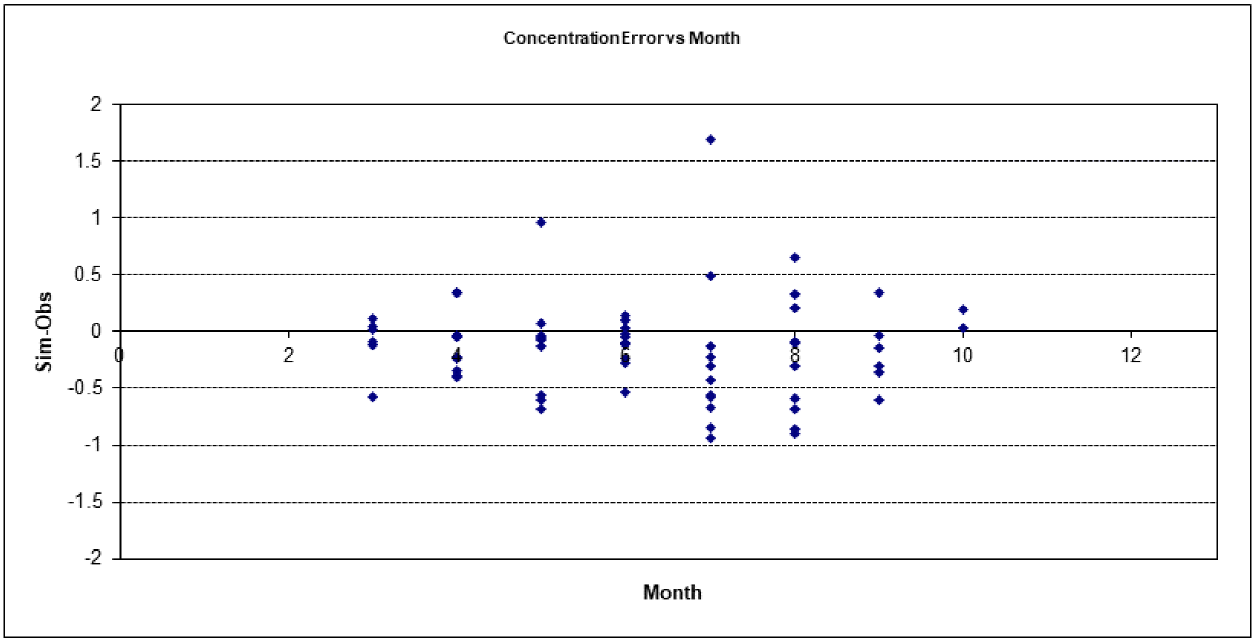


Figure E-489. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Chester Creek (multiple stations)

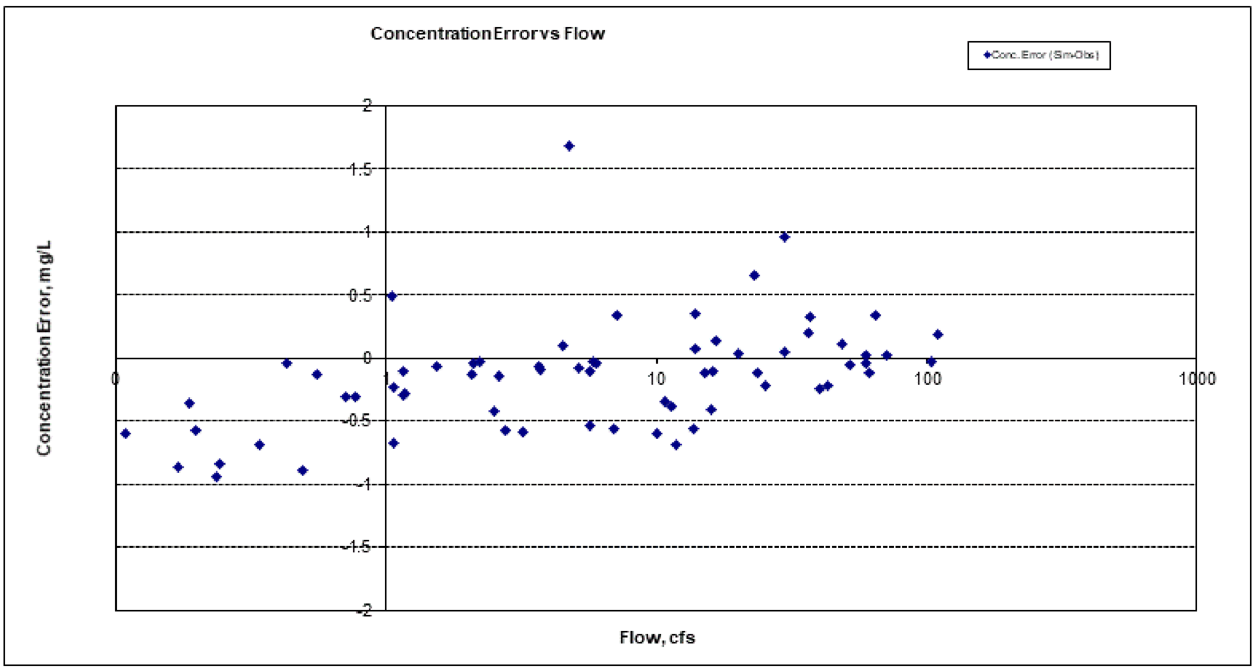


Figure E-490. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Chester Creek (multiple stations)

E.9.6 Total Nitrogen (TN)

Table E-59. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	ND	53
Concentration Average Error		-1.77%
Concentration Median Error		1.04%
Load Average Error		10.11%
Load Median Error		0.01%
Paired t conc		1.00
Paired t load		0.68

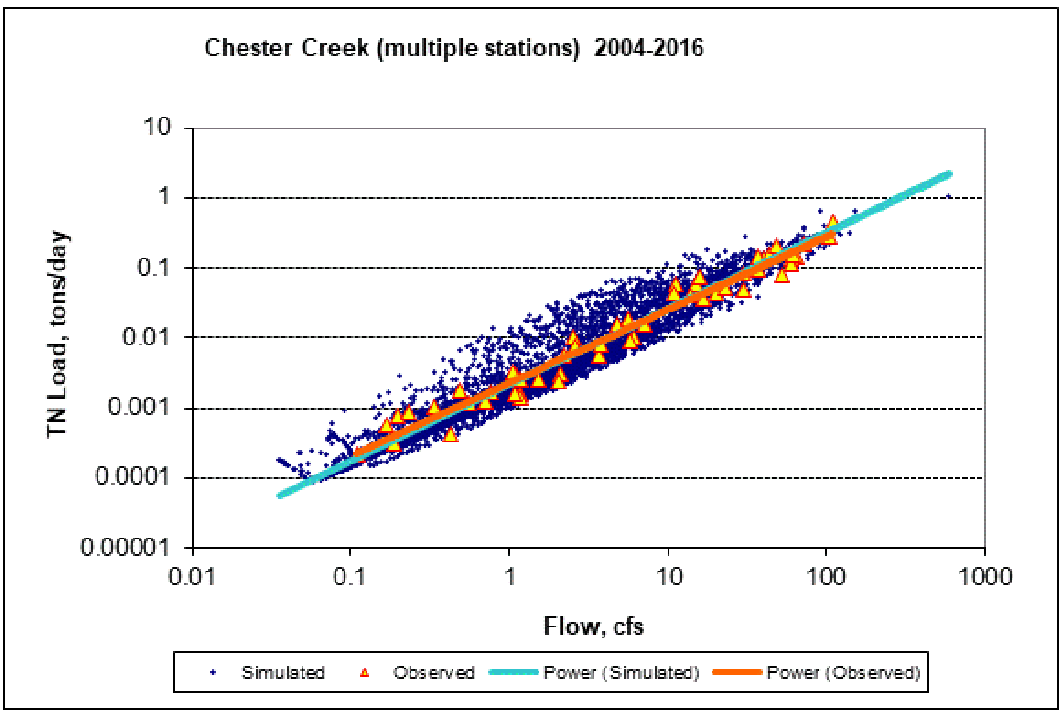


Figure E-491. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Chester Creek (multiple stations) (calibration period)

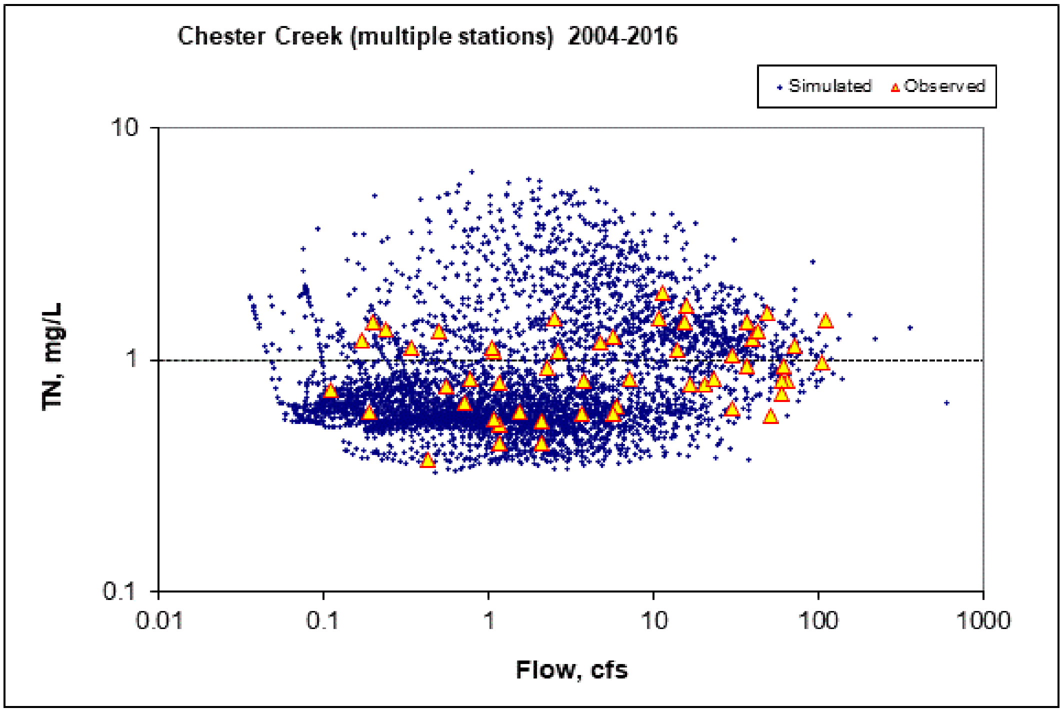
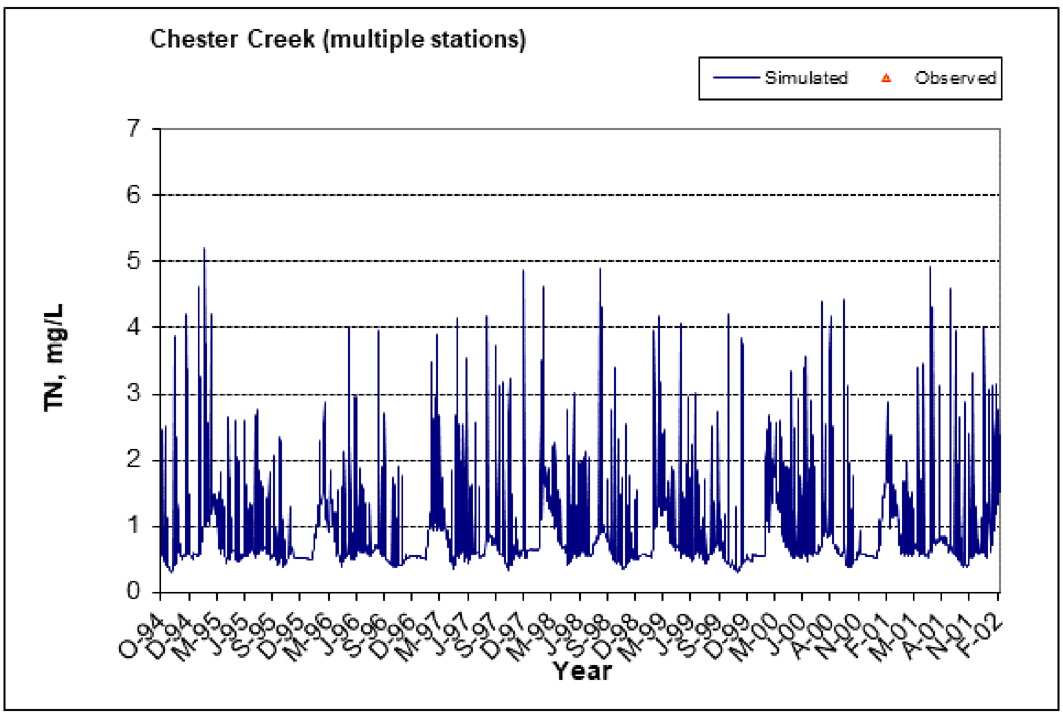


Figure E-492. Simulated and observed Total Nitrogen (TN) concentration vs flow at Chester Creek (multiple stations) (calibration period)



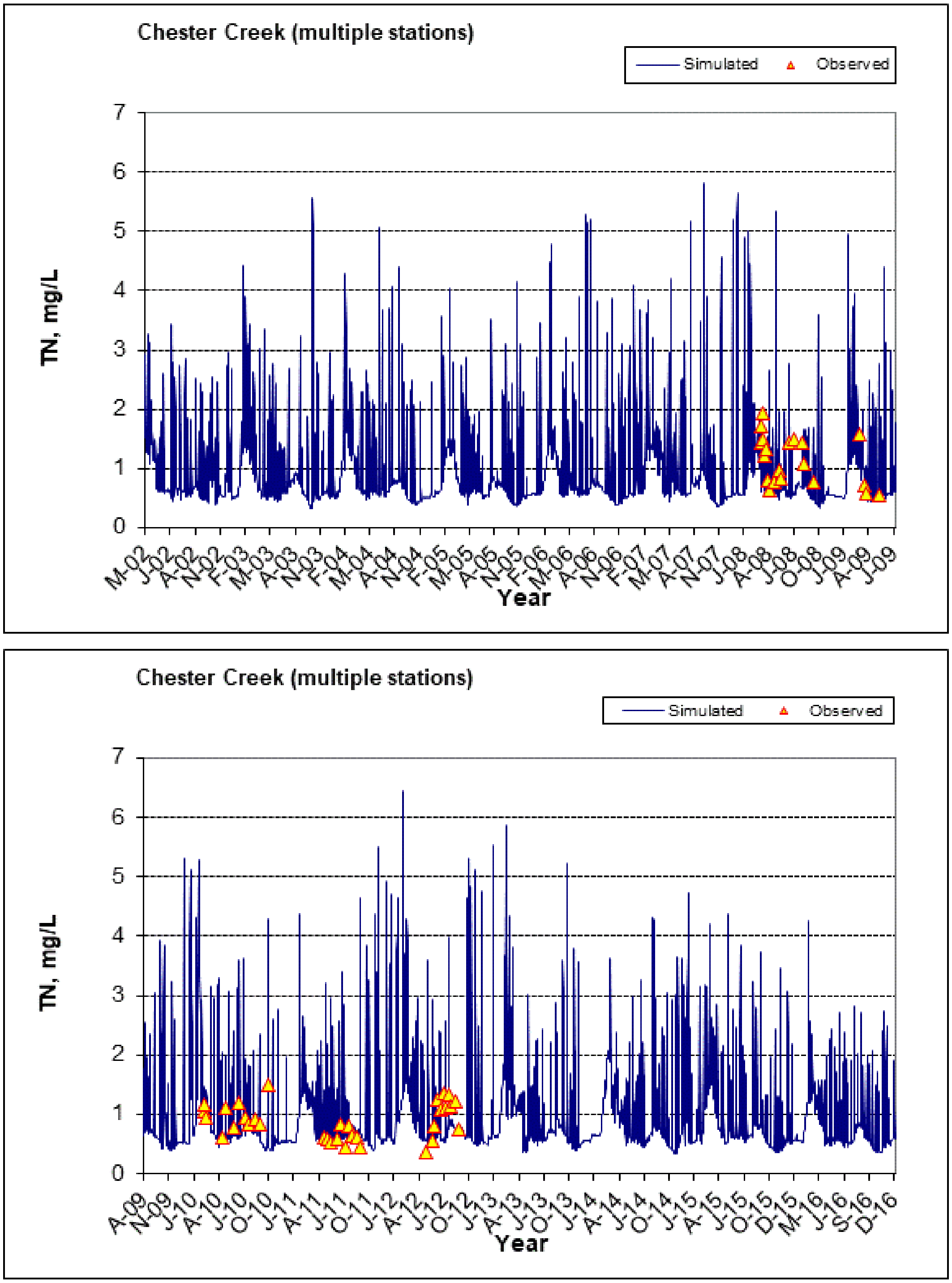


Figure E-493. Time series of observed and simulated Total Nitrogen (TN) concentration at Chester Creek (multiple stations)

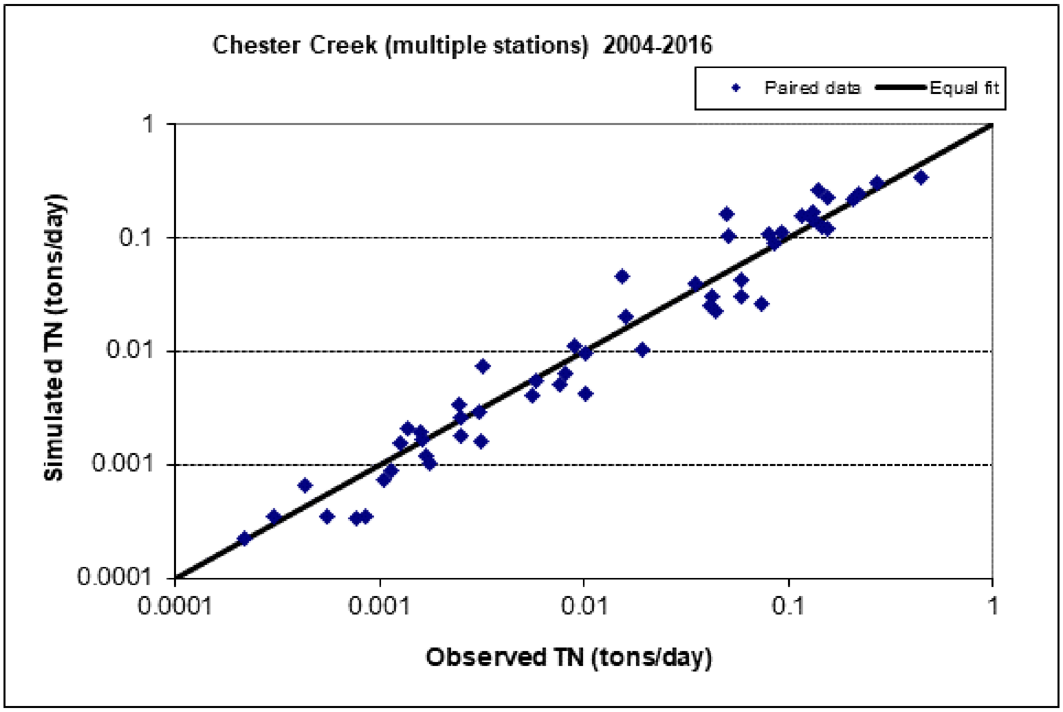


Figure E-494. Paired simulated vs. observed Total Nitrogen (TN) load at Chester Creek (multiple stations) (calibration period)

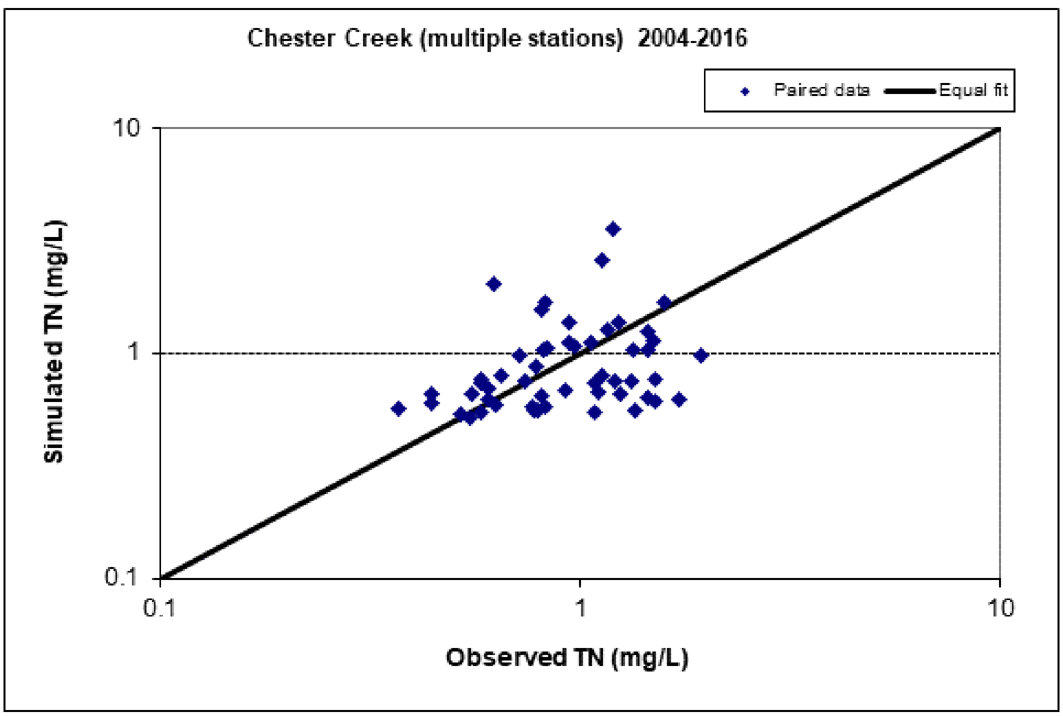


Figure E-495. Paired simulated vs. observed Total Nitrogen (TN) concentration at Chester Creek (multiple stations) (calibration period)

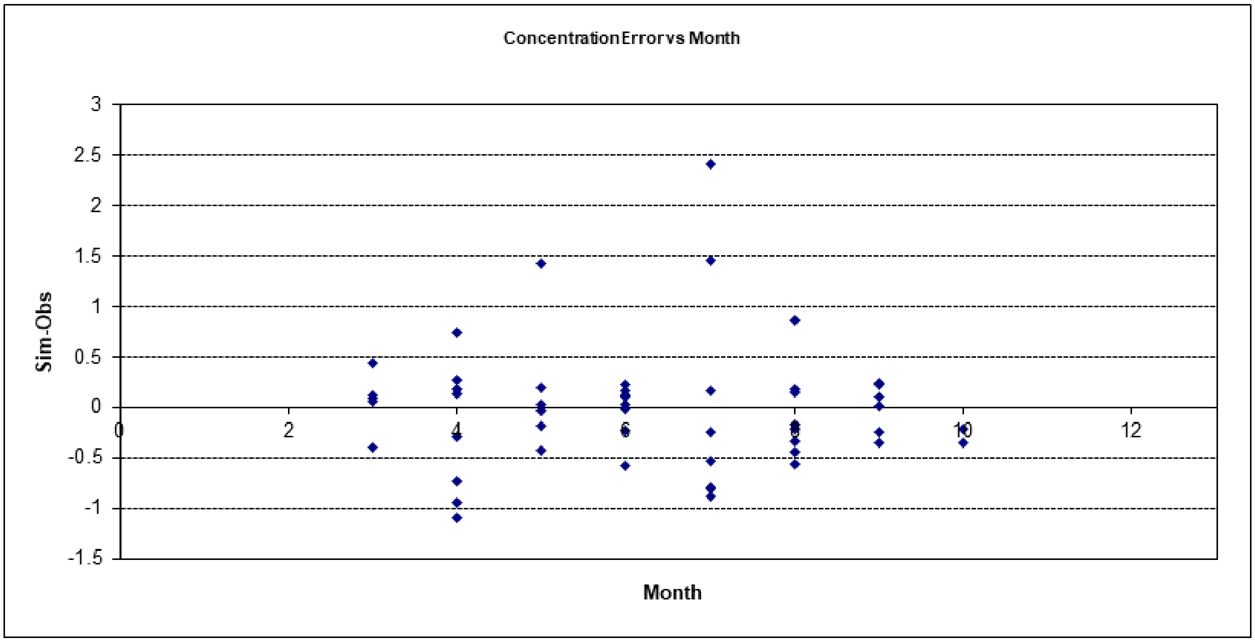


Figure E-496. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at Chester Creek (multiple stations)

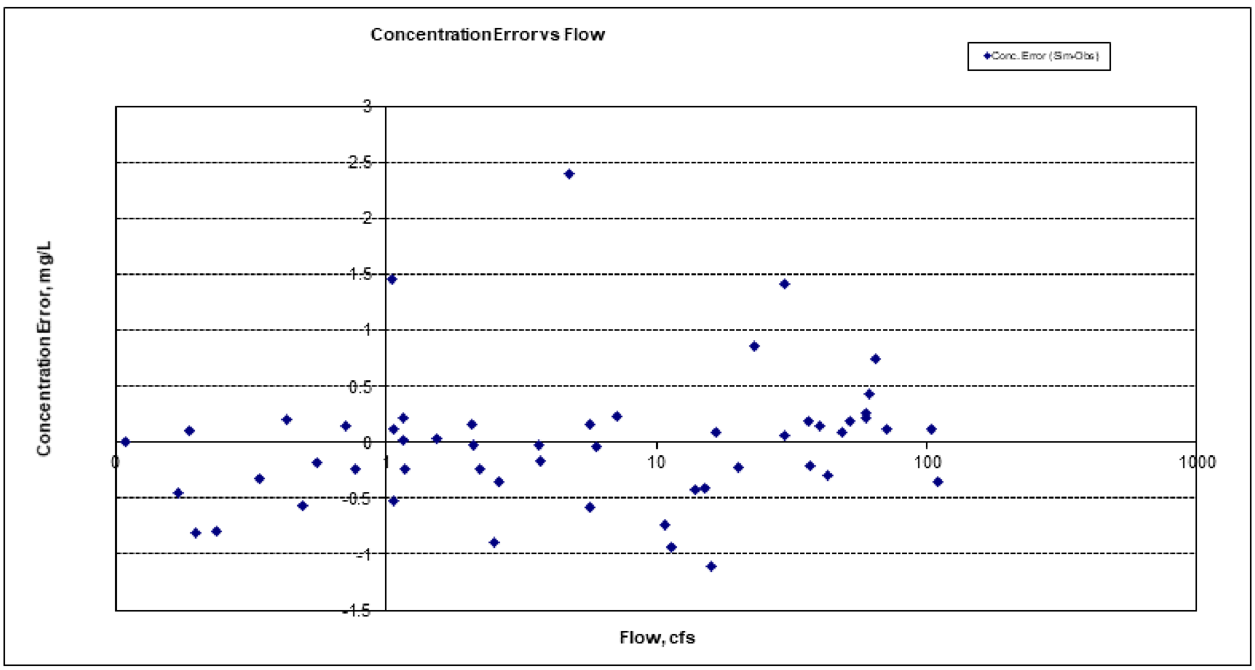


Figure E-497. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at Chester Creek (multiple stations)

E.9.7 Total Phosphorus (TP)

Table E-60. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	91
Concentration Average Error		-19.95%
Concentration Median Error		-8.84%
Load Average Error		-17.15%
Load Median Error		-0.37%
Paired t conc		0.50
Paired t load		0.55

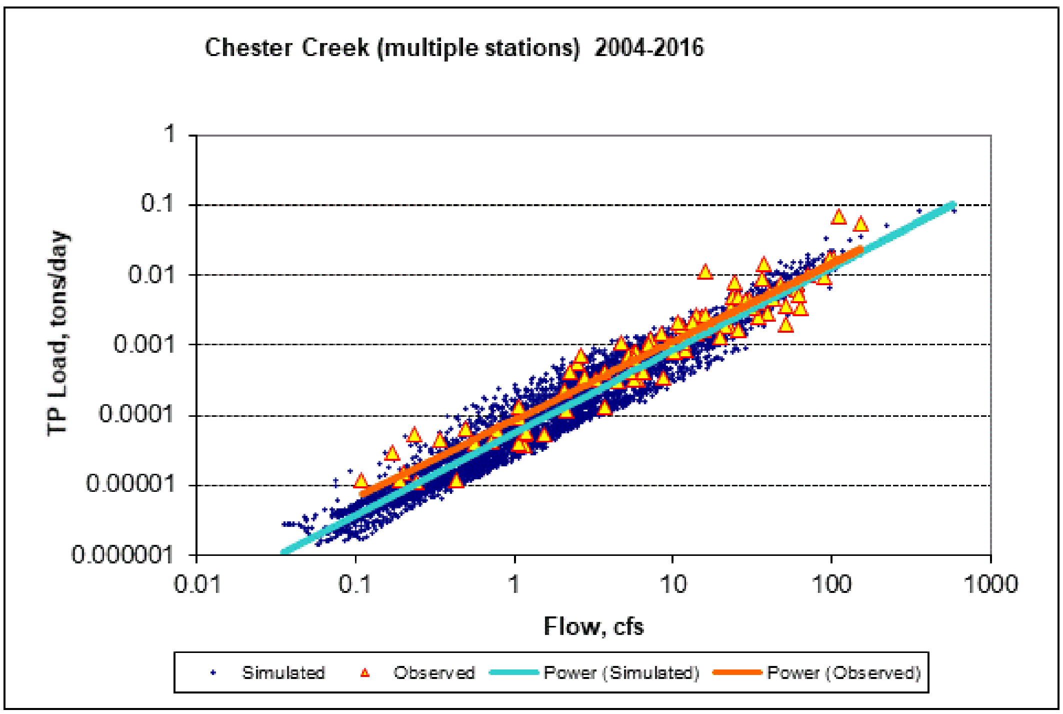


Figure E-498. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Chester Creek (multiple stations) (calibration period)

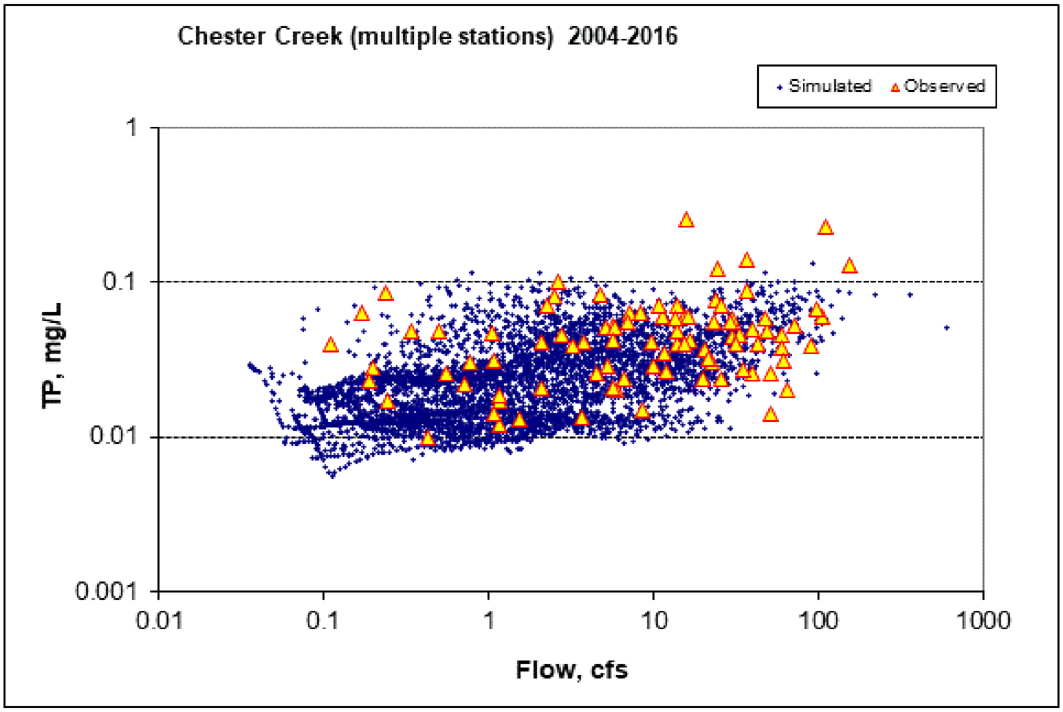
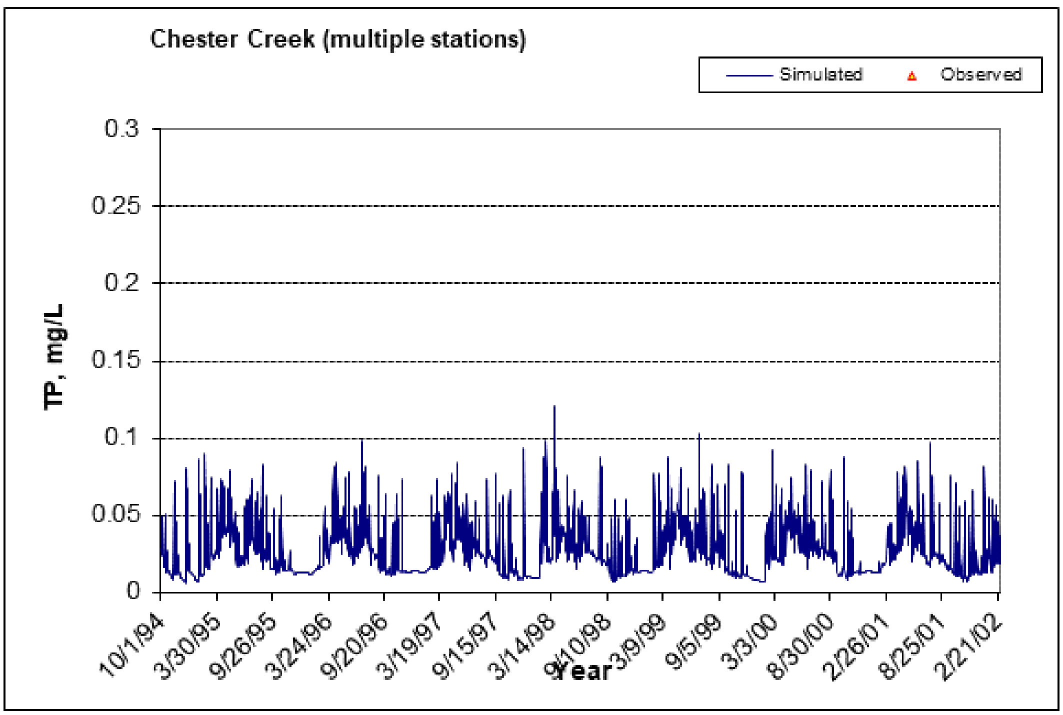
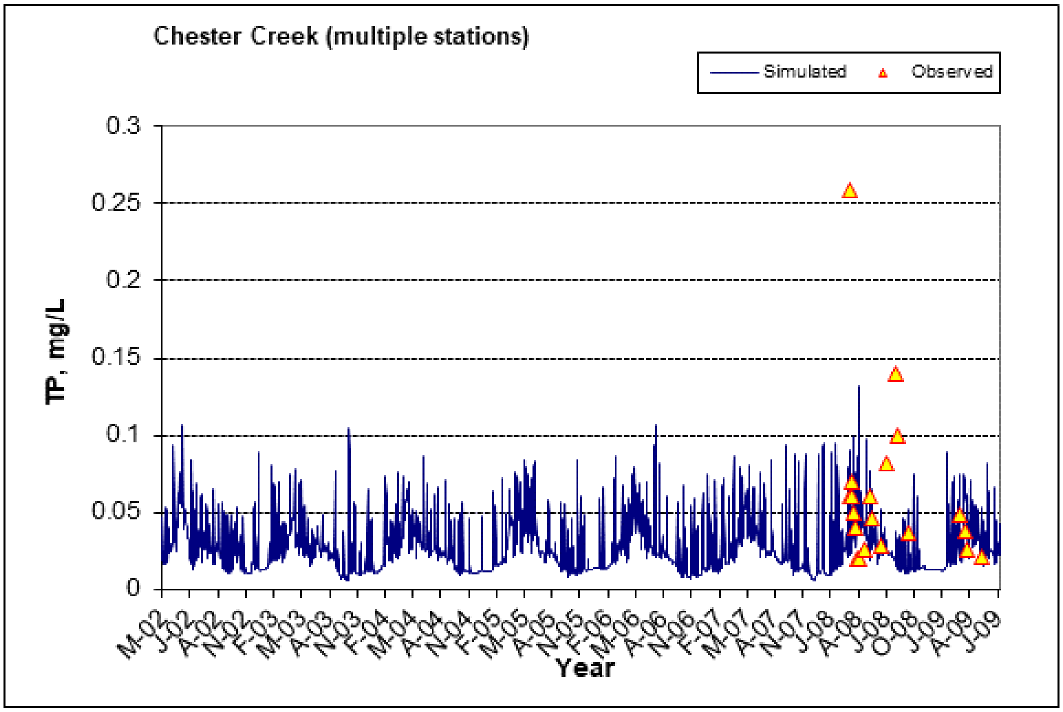


Figure E-499. Simulated and observed Total Phosphorus (TP) concentration vs flow at Chester Creek (multiple stations) (calibration period)





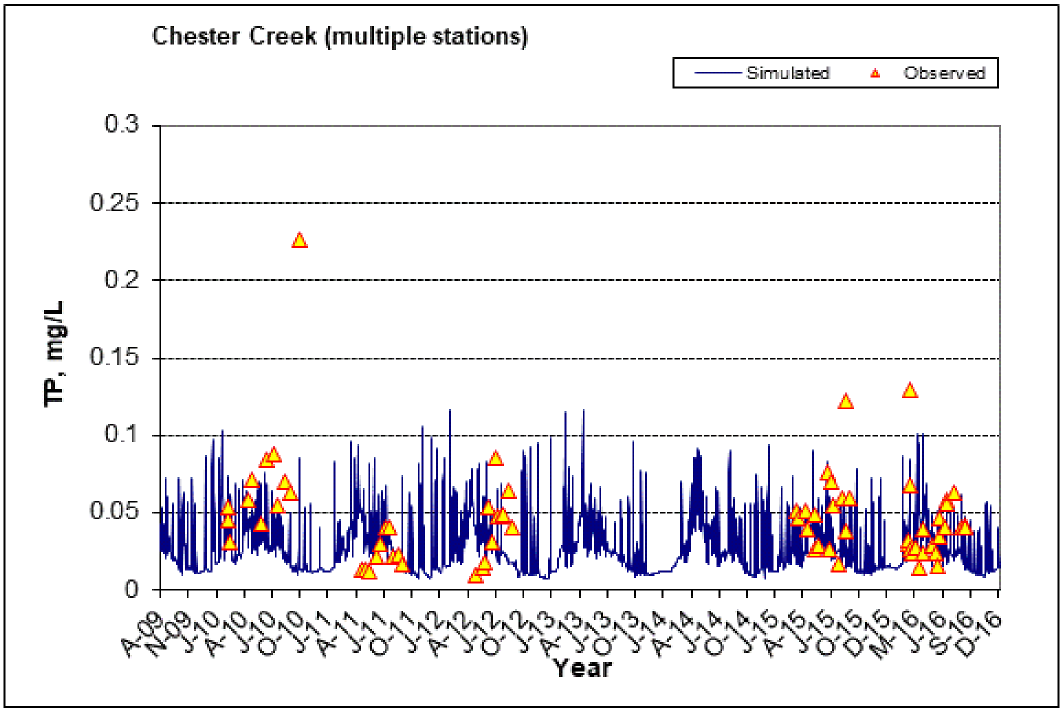


Figure E-500. Time series of observed and simulated Total Phosphorus (TP) concentration at Chester Creek (multiple stations)

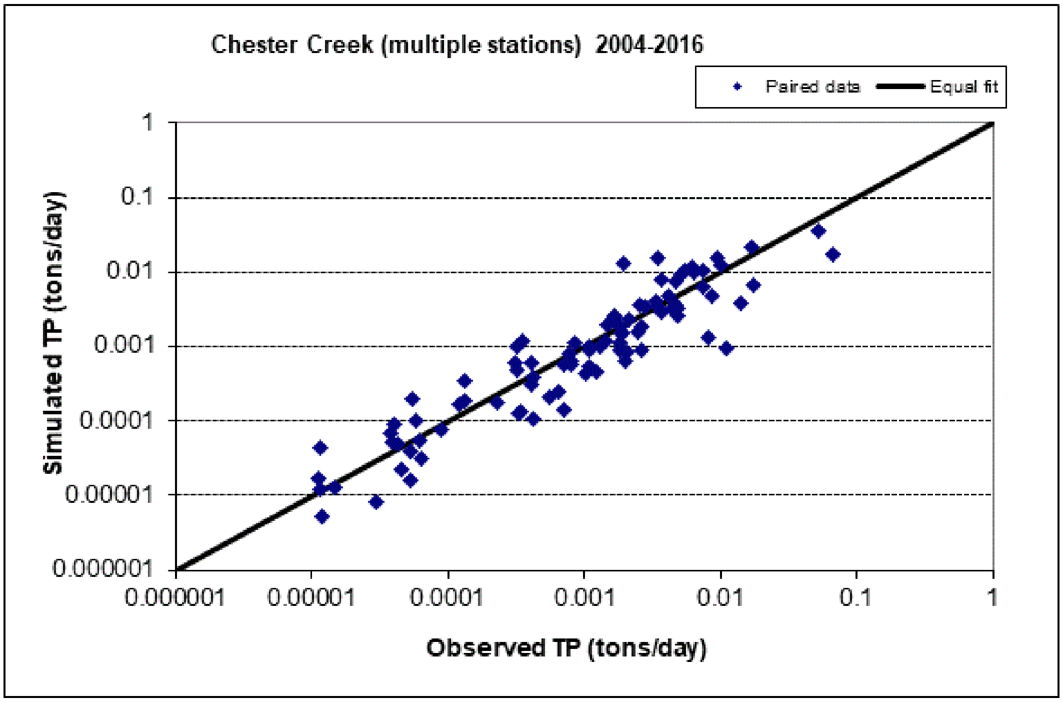


Figure E-501. Paired simulated vs. observed Total Phosphorus (TP) load at Chester Creek (multiple stations) (calibration period)

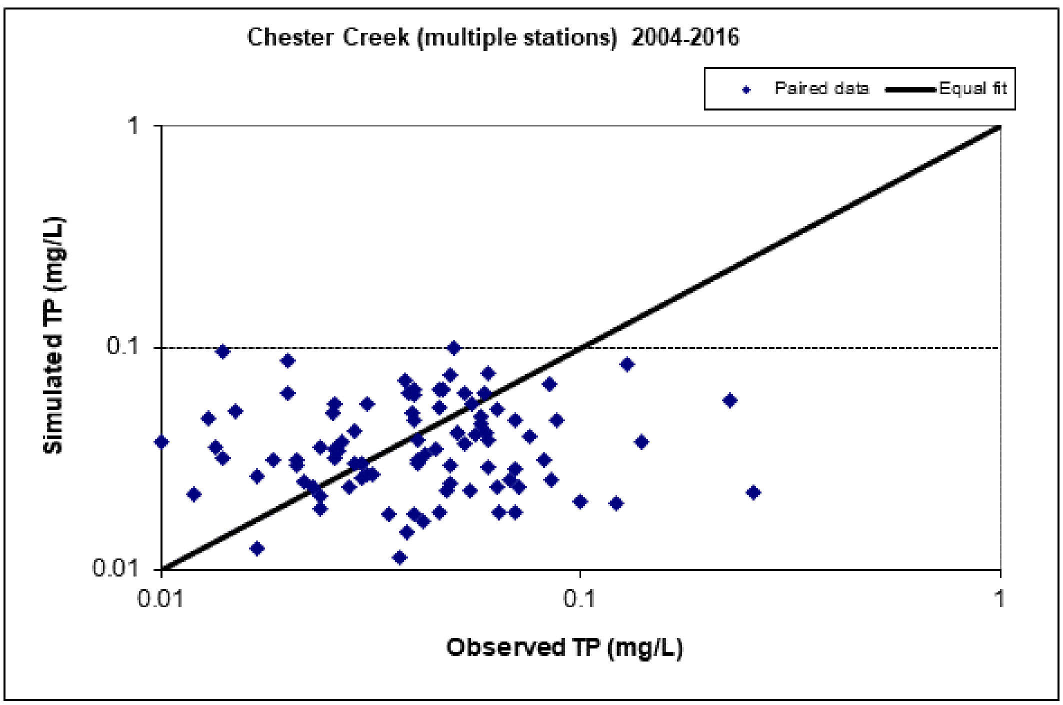


Figure E-502. Paired simulated vs. observed Total Phosphorus (TP) concentration at Chester Creek (multiple stations) (calibration period)

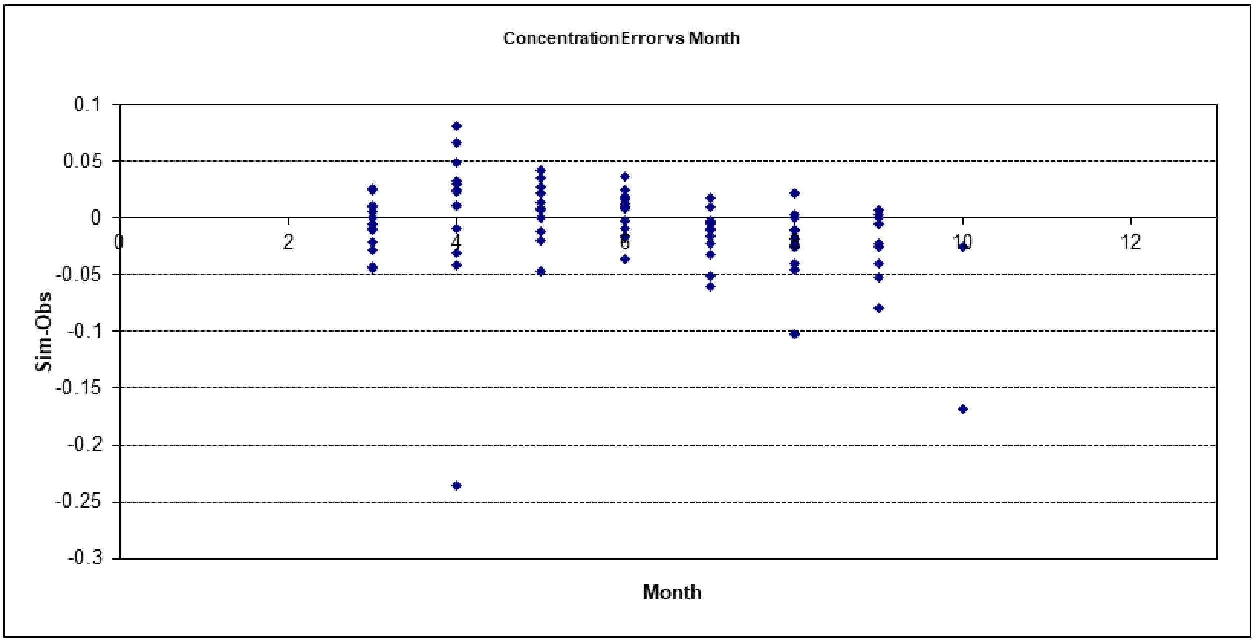


Figure E-503. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Chester Creek (multiple stations)

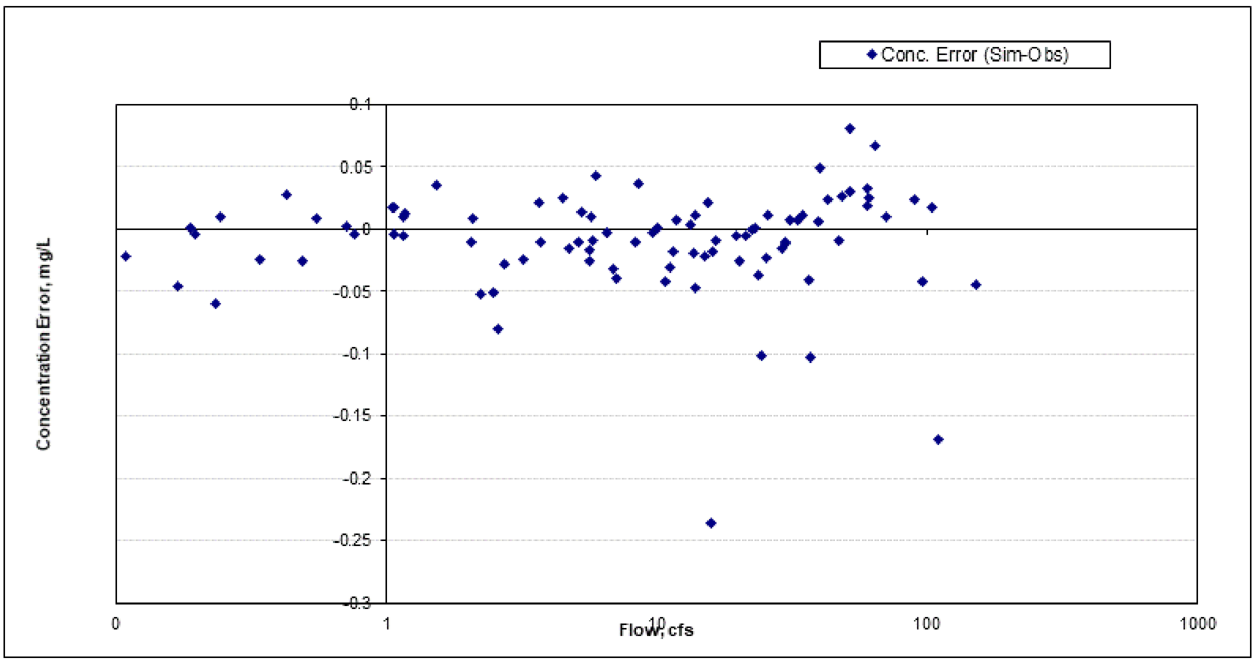


Figure E-504. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Chester Creek (multiple stations)

E.10 Buckingham Creek at W 3rd St

E.10.1 Dissolved Oxygen (DO)

Table E-61. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	26
Concentration Average Error		-0.81%
Concentration Median Error		2.73%
Load Average Error		-0.87%
Load Median Error		0.94%
Paired t conc		1.00
Paired t load		0.74

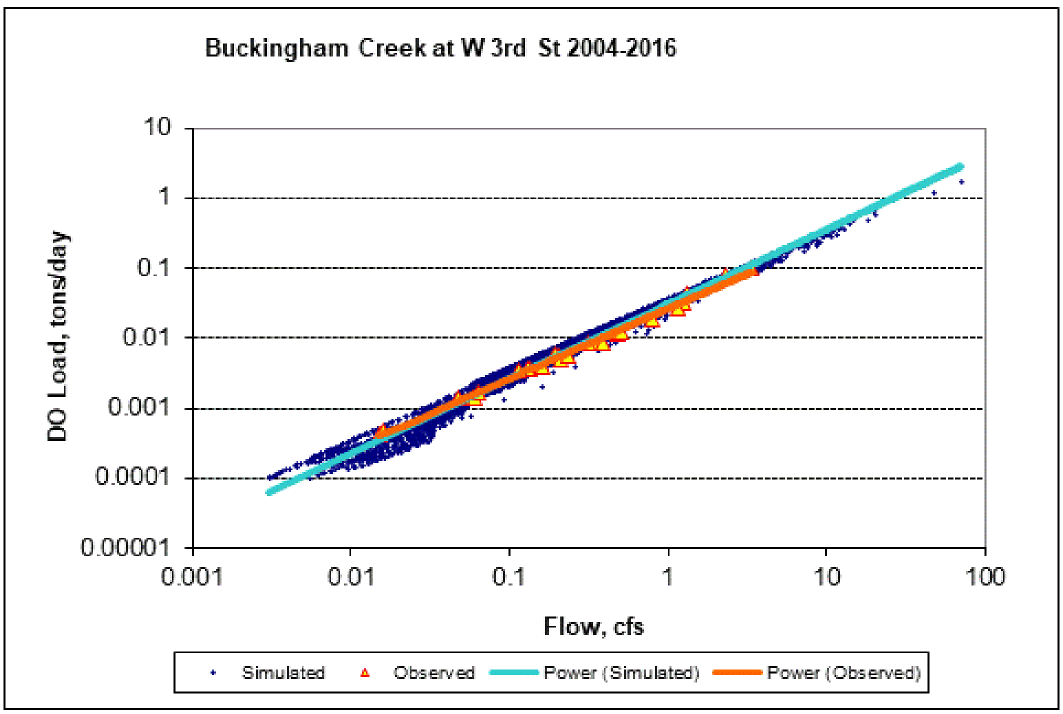


Figure E-505. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Buckingham Creek at W 3rd St (calibration period)

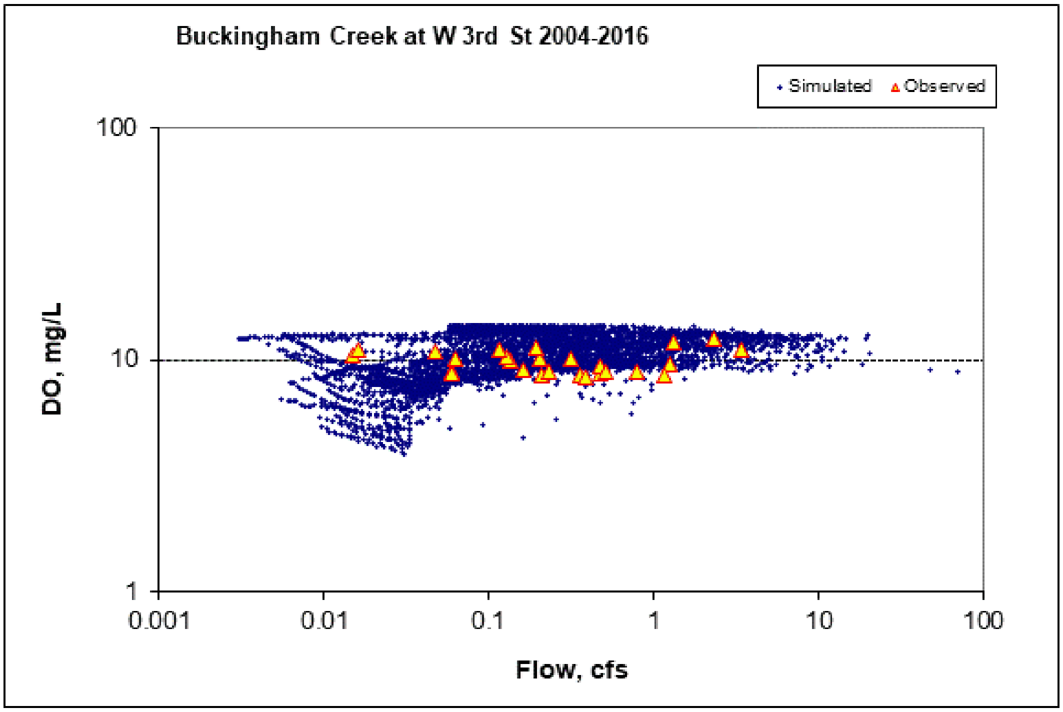
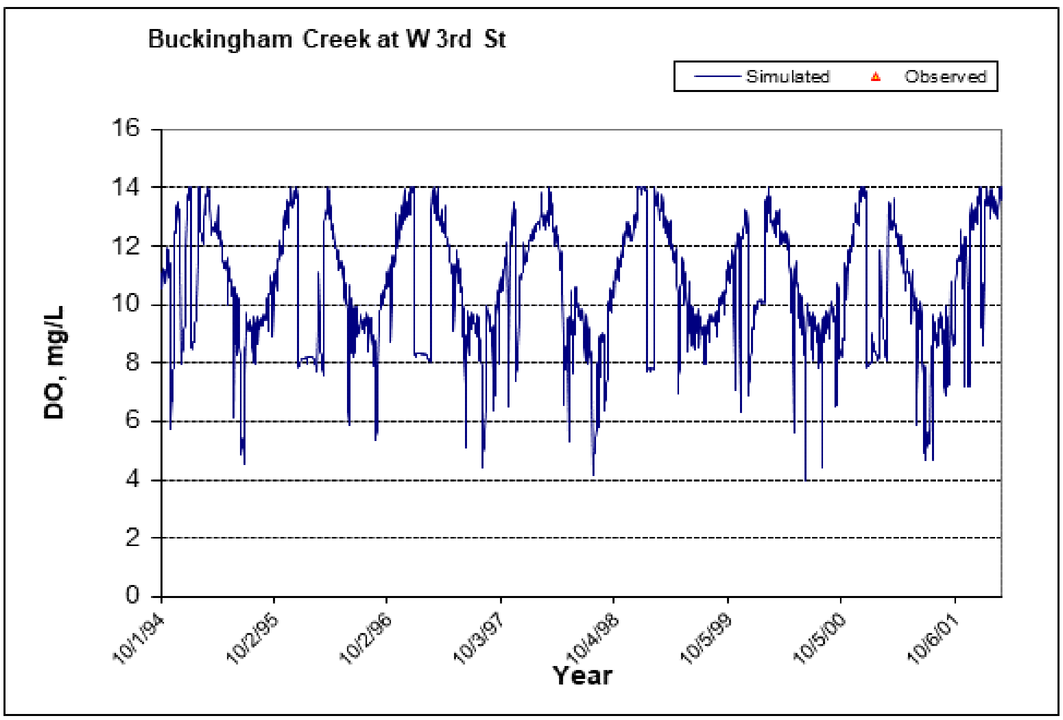
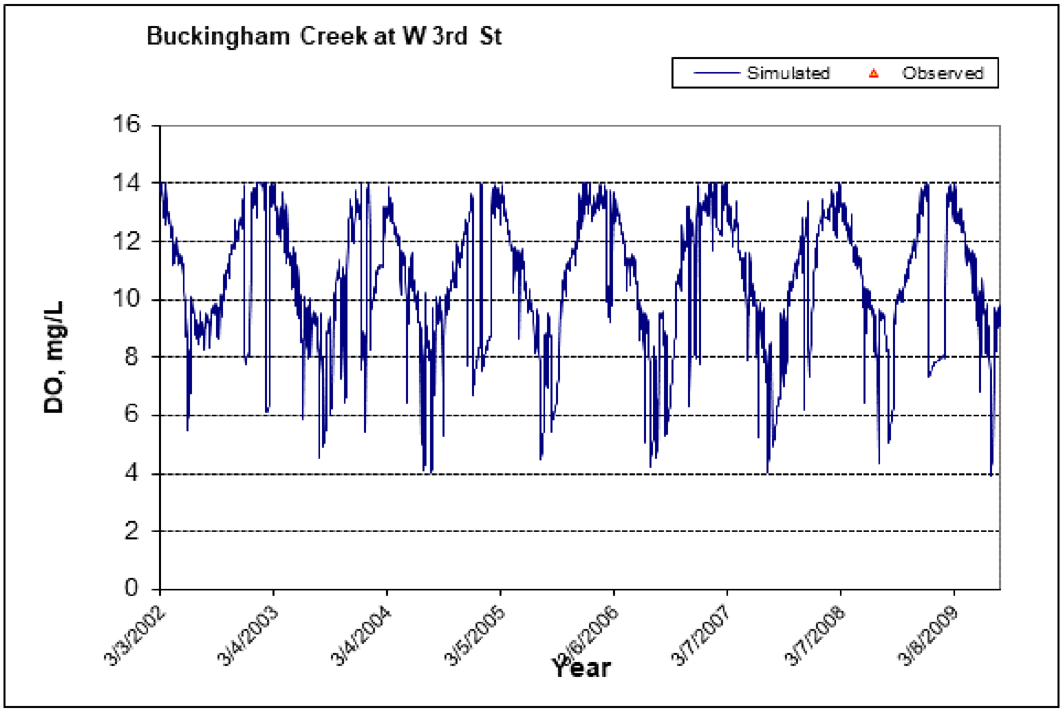


Figure E-506. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Buckingham Creek at W 3rd St (calibration period)





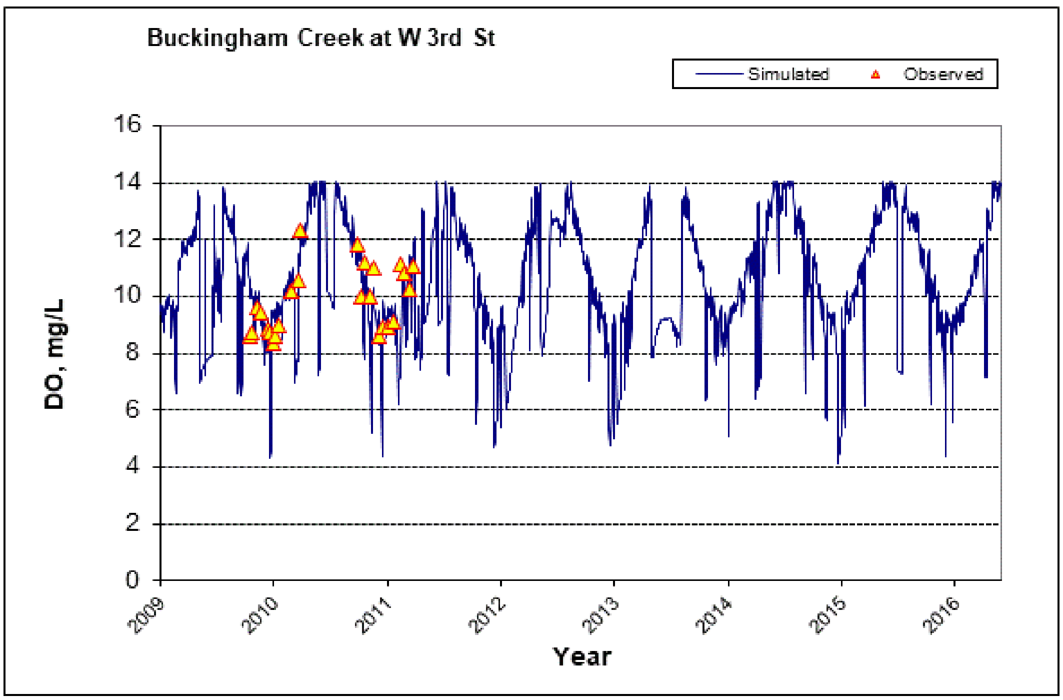


Figure E-507. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Buckingham Creek at W 3rd St

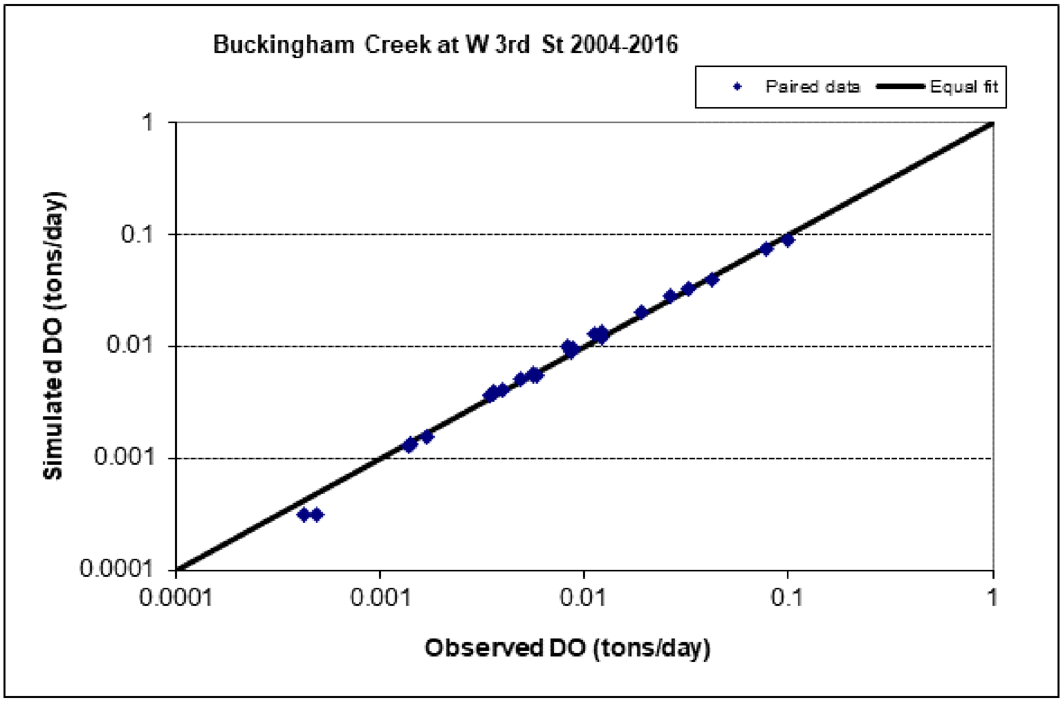


Figure E-508. Paired simulated vs. observed Dissolved Oxygen (DO) load at Buckingham Creek at W 3rd St (calibration period)

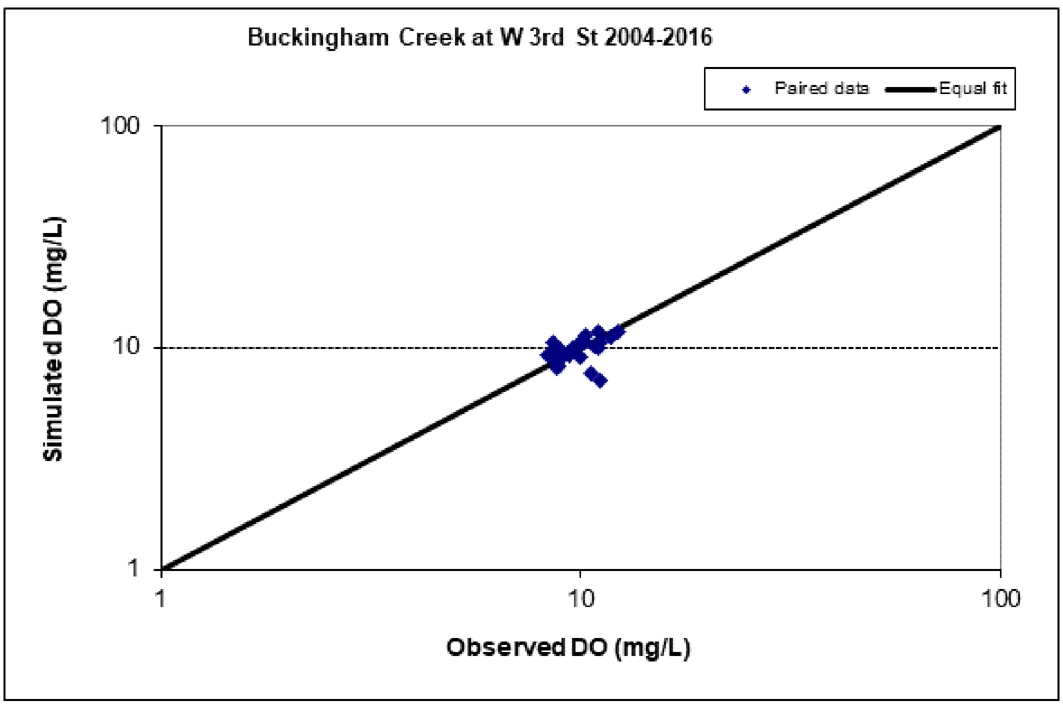


Figure E-509. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Buckingham Creek at W 3rd St (calibration period)

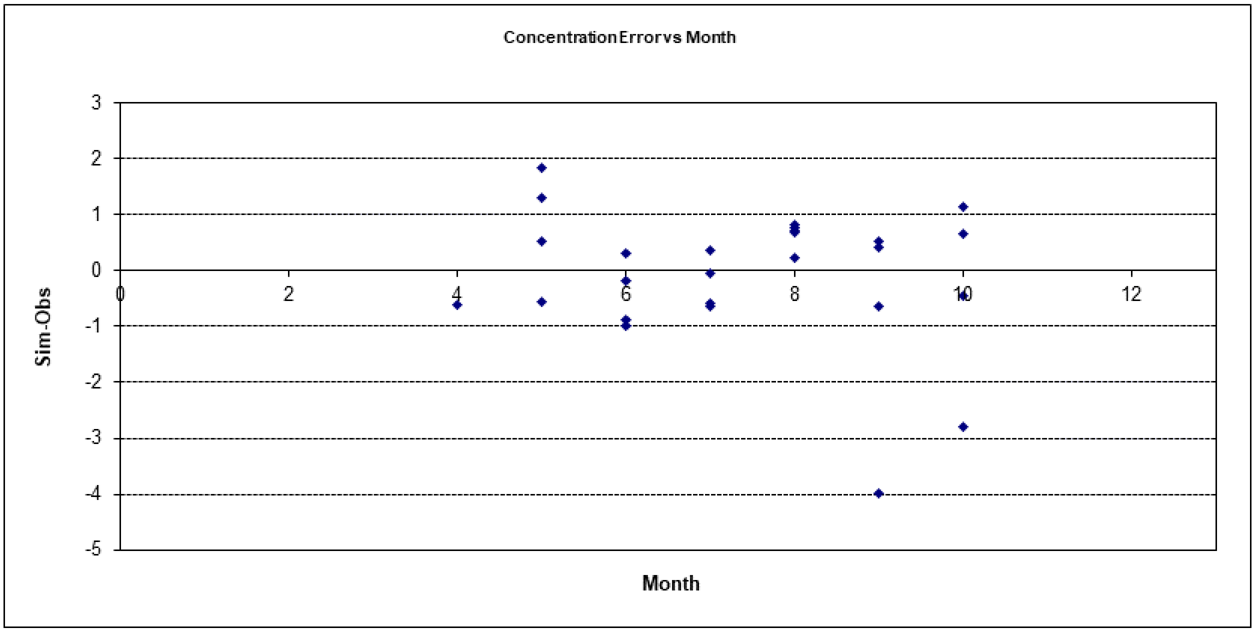


Figure E-510. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Buckingham Creek at W 3rd St

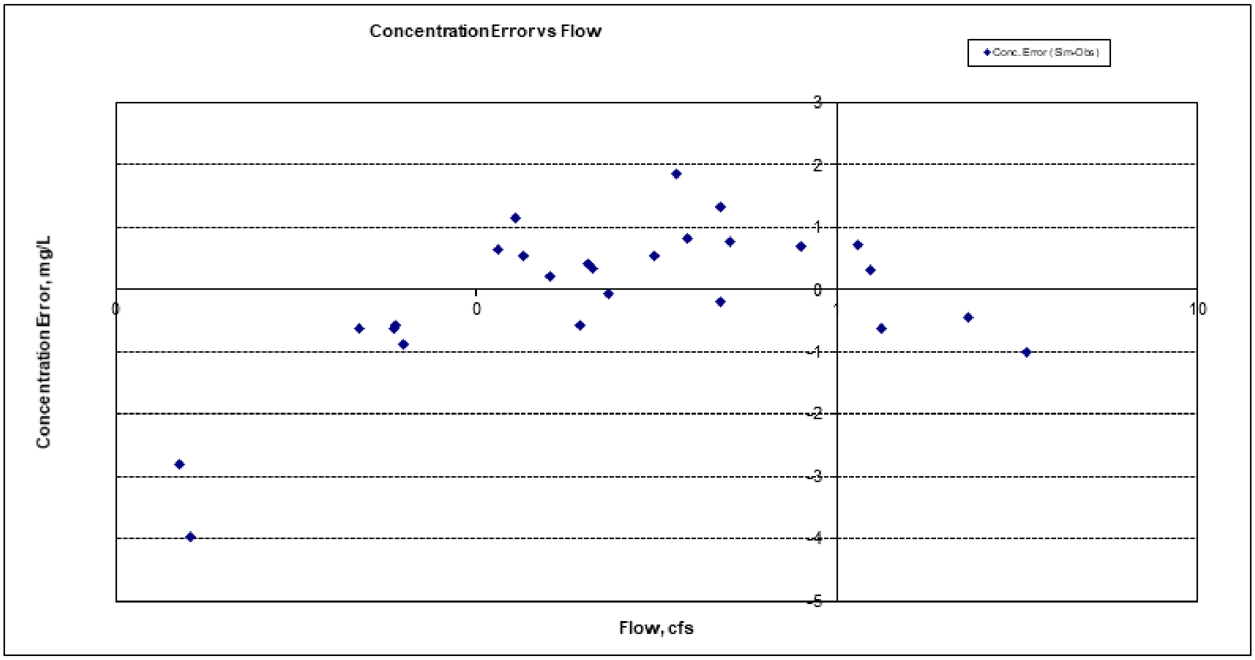


Figure E-511. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Buckingham Creek at W 3rd St

E.10.2 Ammonia Nitrogen (NH3)

Table E-62. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	22
Concentration Average Error		-30.01%
Concentration Median Error		-35.87%
Load Average Error		-4.09%
Load Median Error		-14.86%
Paired t conc		0.27
Paired t load		0.63

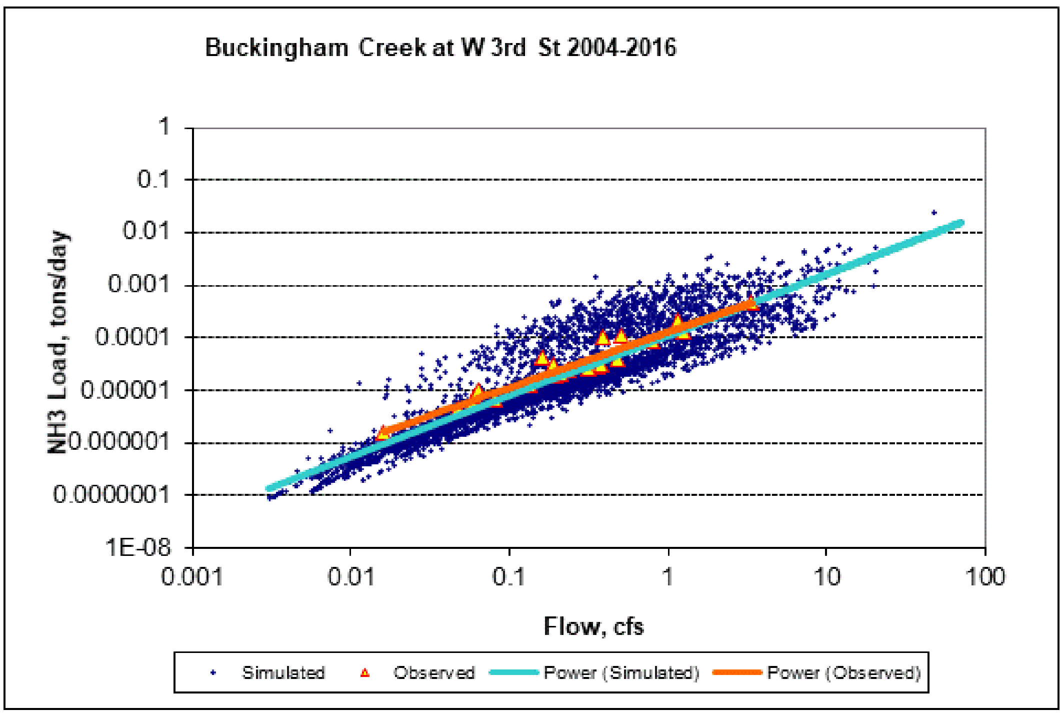


Figure E-512. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Buckingham Creek at W 3rd St (calibration period)

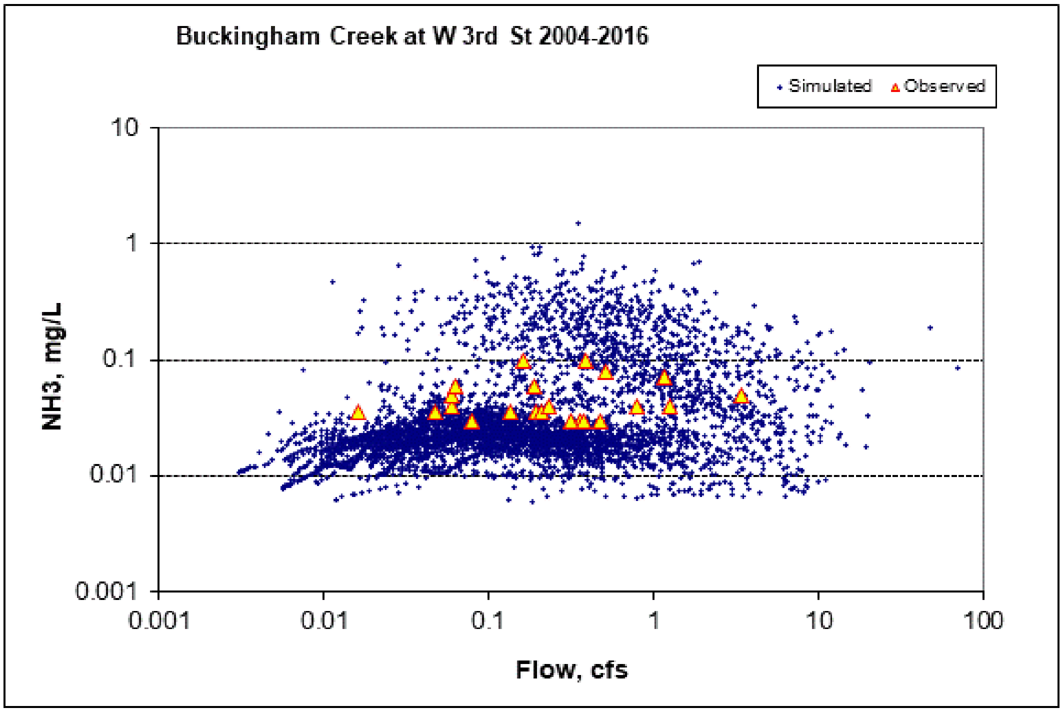
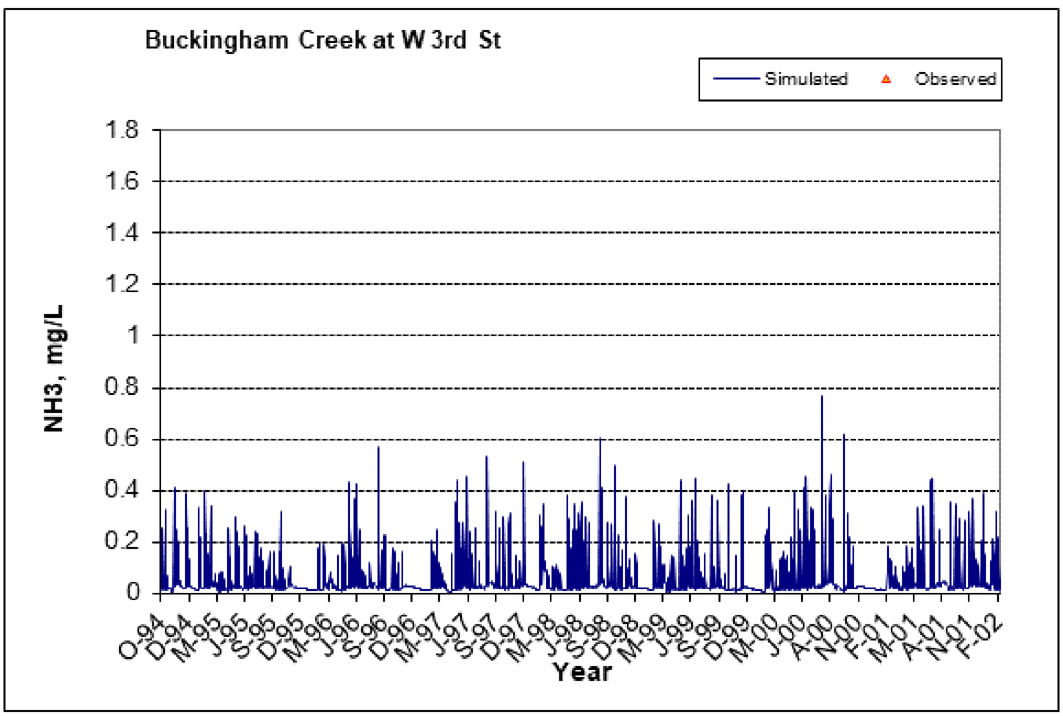
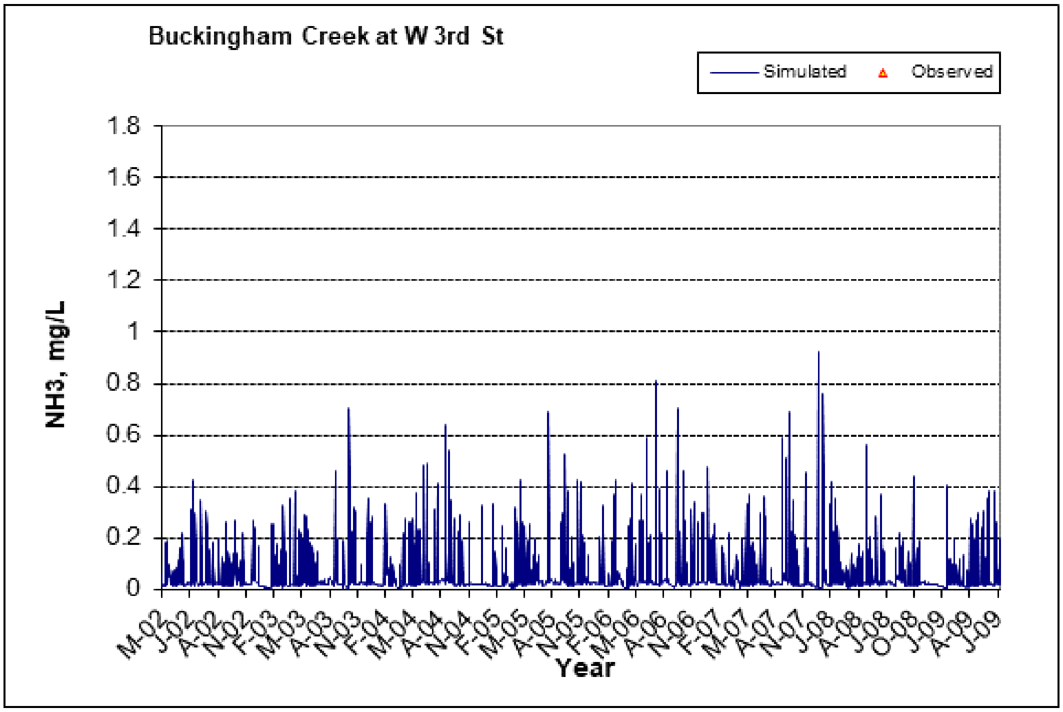


Figure E-513. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Buckingham Creek at W 3rd St (calibration period)





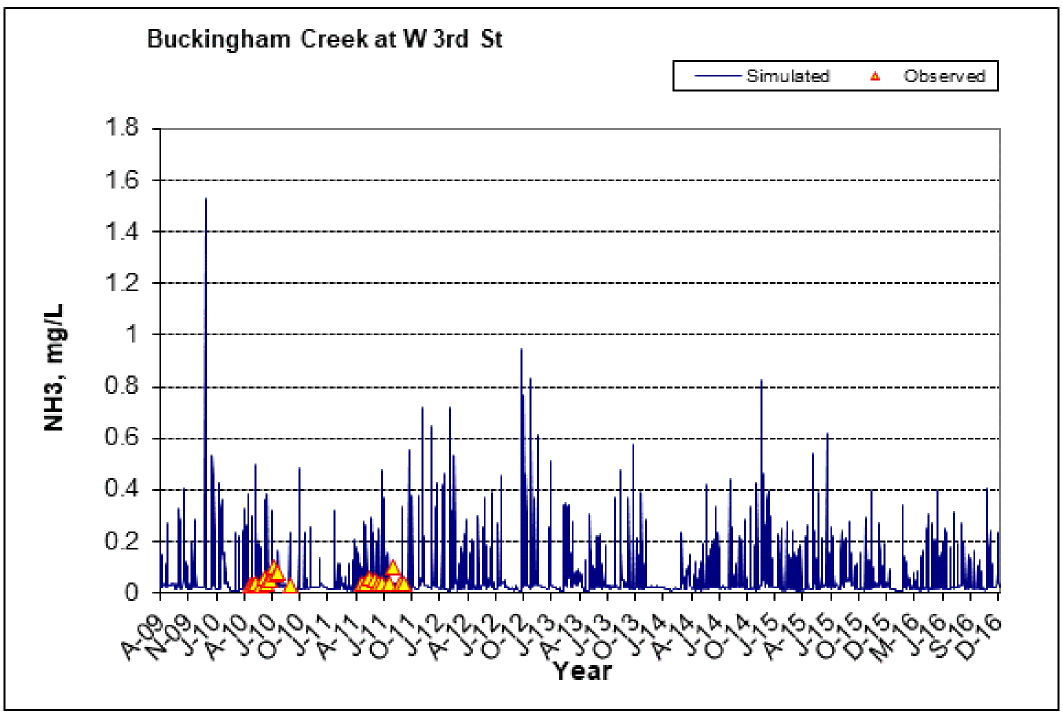


Figure E-514. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Buckingham Creek at W 3rd St

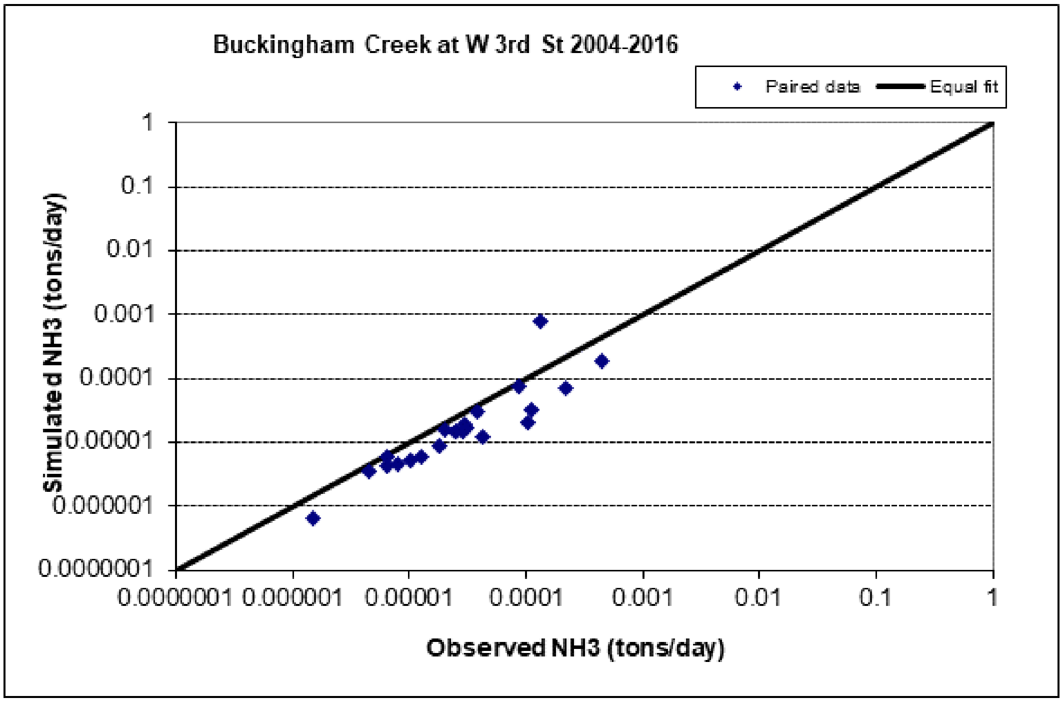


Figure E-515. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Buckingham Creek at W 3rd St (calibration period)

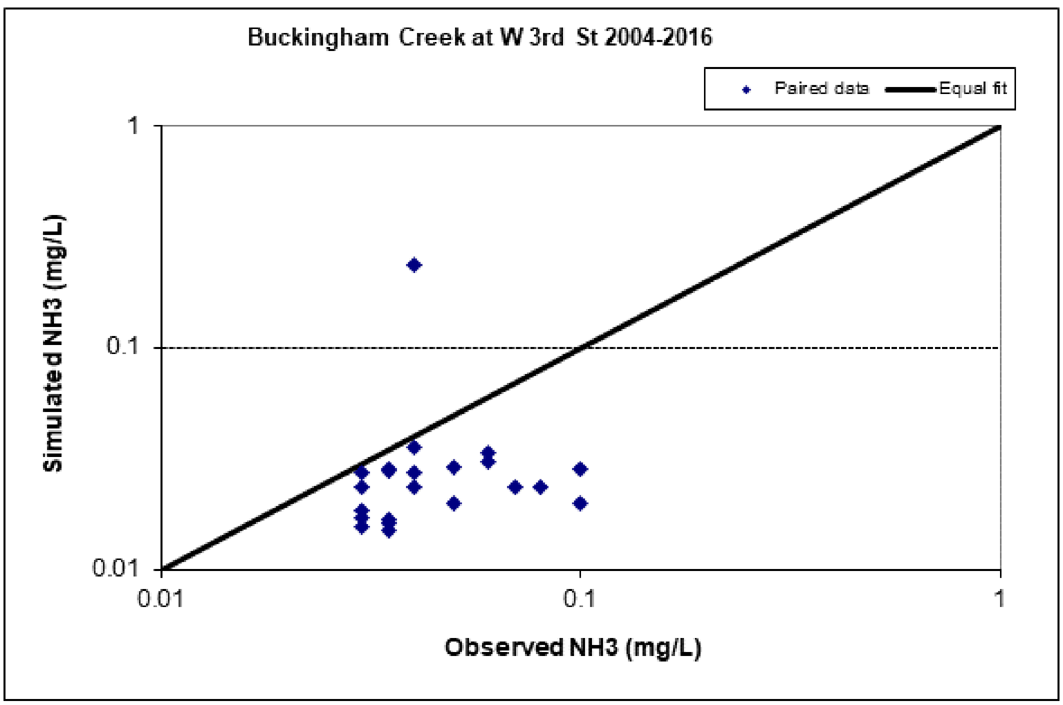


Figure E-516. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Buckingham Creek at W 3rd St (calibration period)

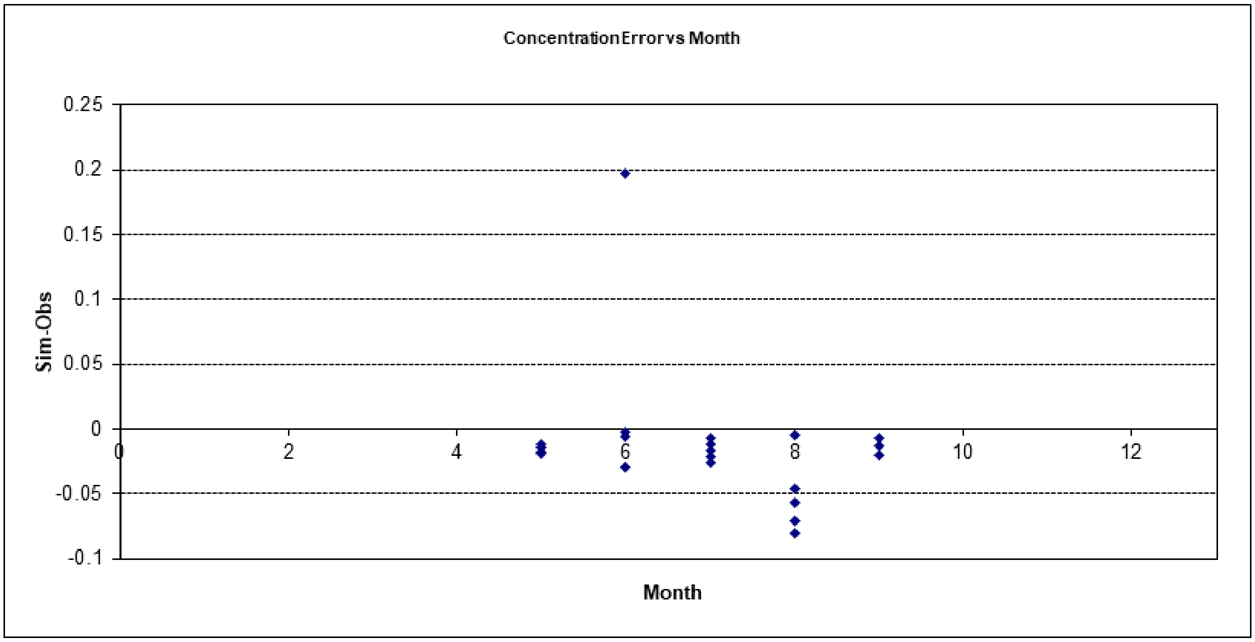


Figure E-517. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Buckingham Creek at W 3rd St

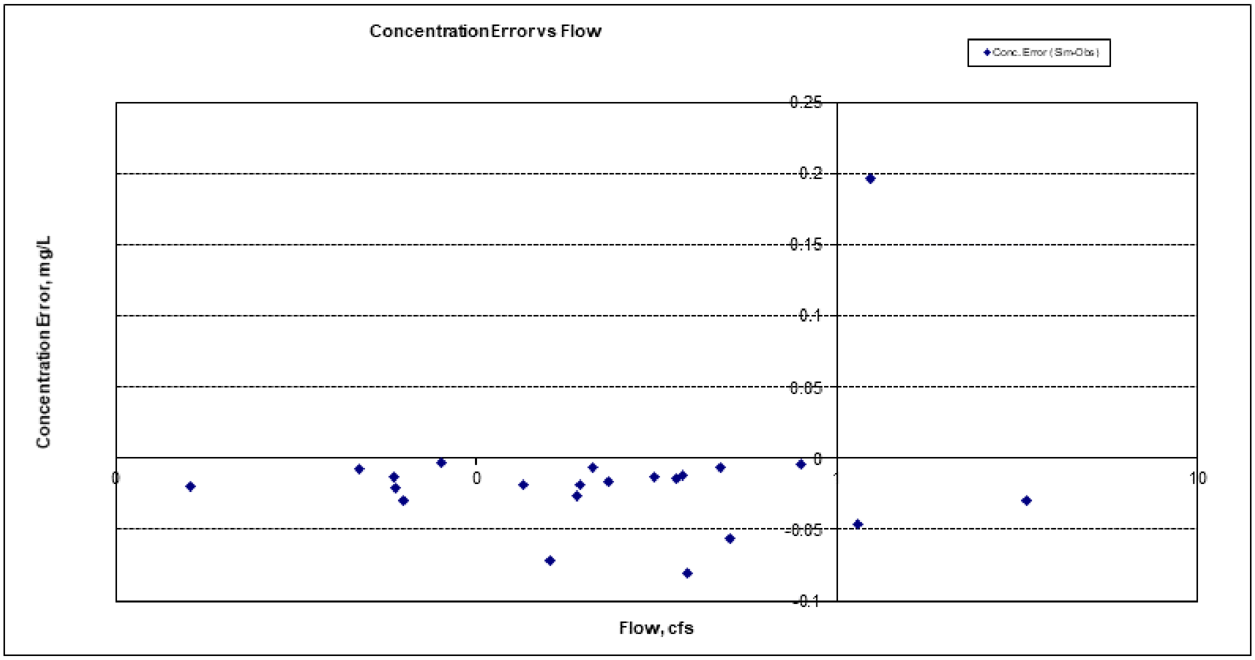


Figure E-518. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Buckingham Creek at W 3rd St

E.10.3 Nitrite+ Nitrate Nitrogen (NOx)

Table E-63. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	21
Concentration Average Error		-50.26%
Concentration Median Error		-55.87%
Load Average Error		-0.31%
Load Median Error		-27.54%
Paired t conc		0.09
Paired t load		0.64

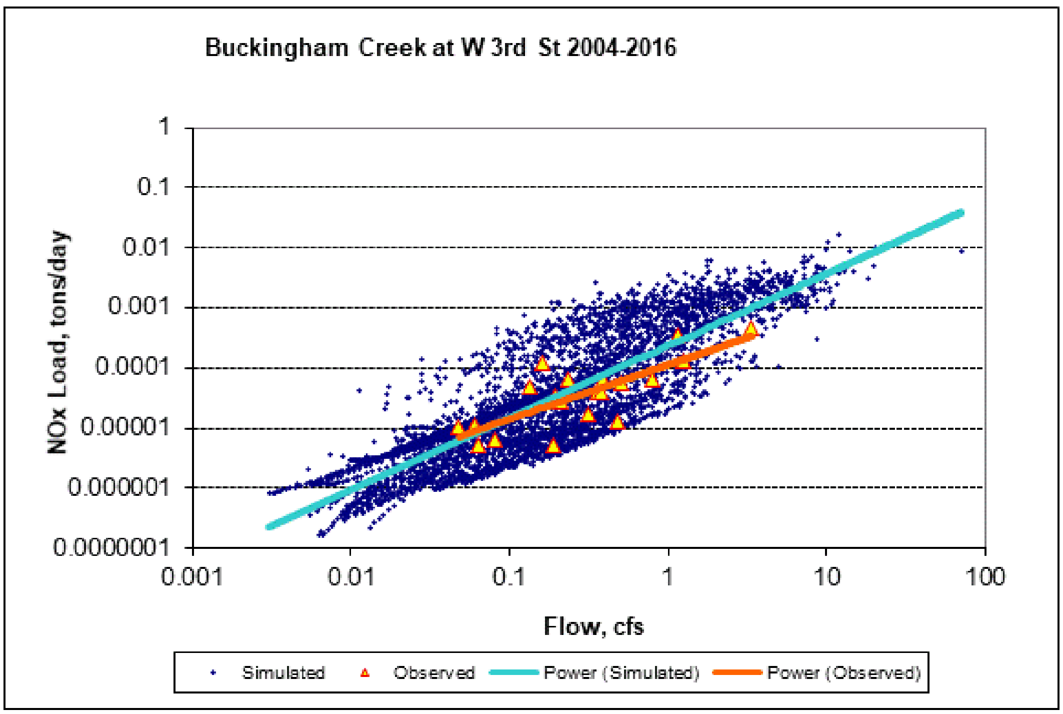


Figure E-519. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Buckingham Creek at W 3rd St (calibration period)

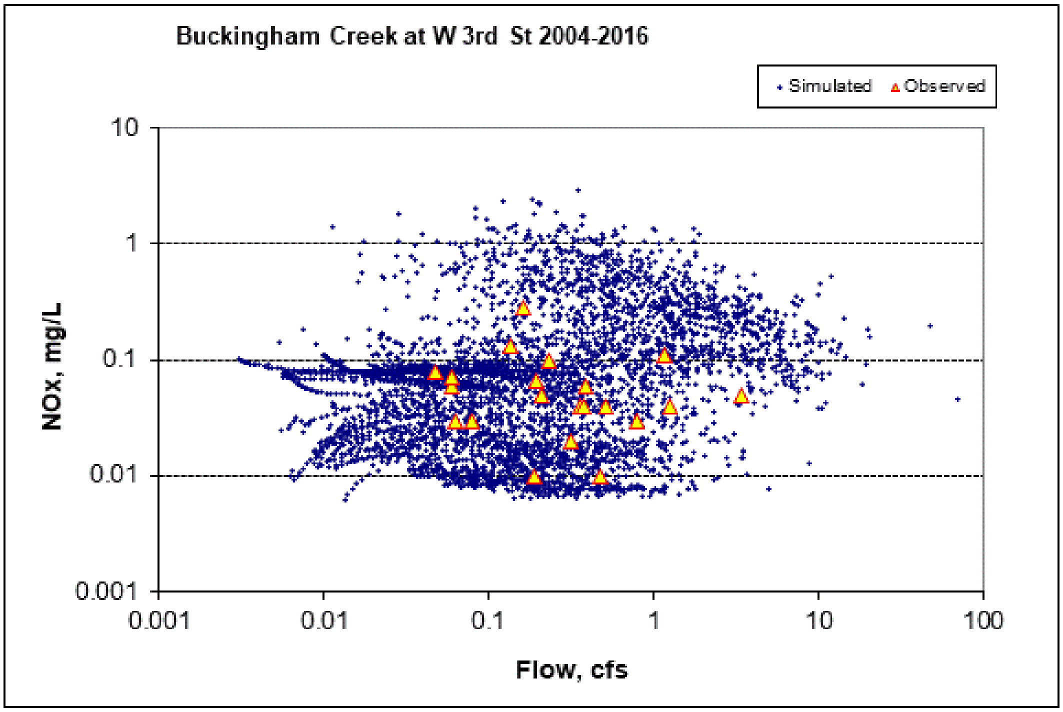
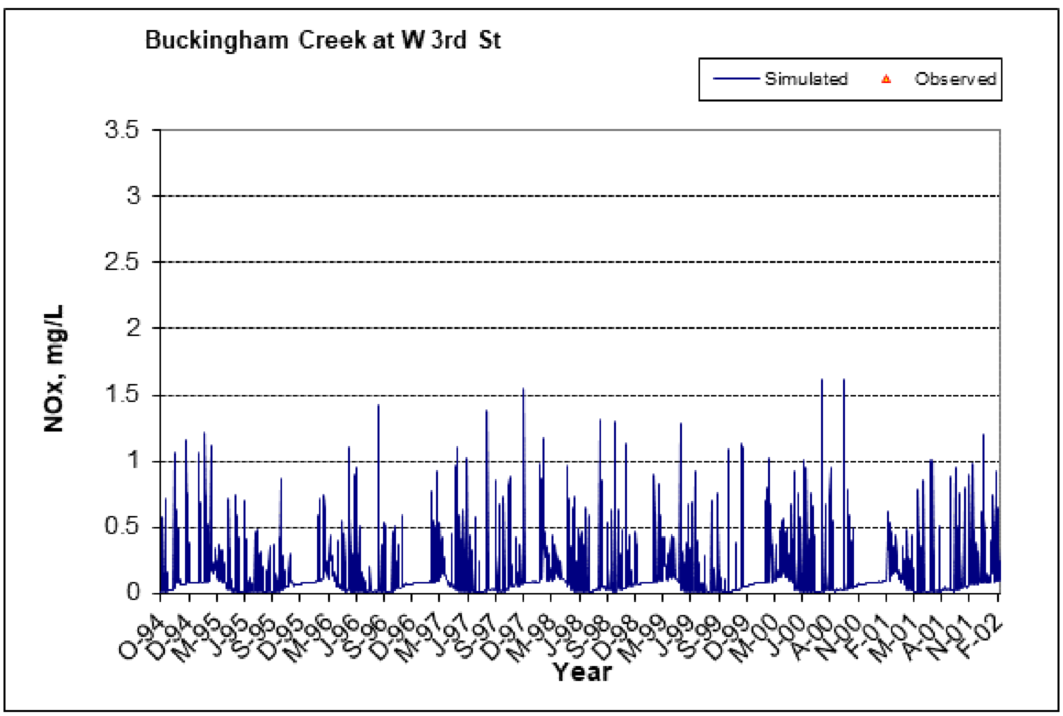
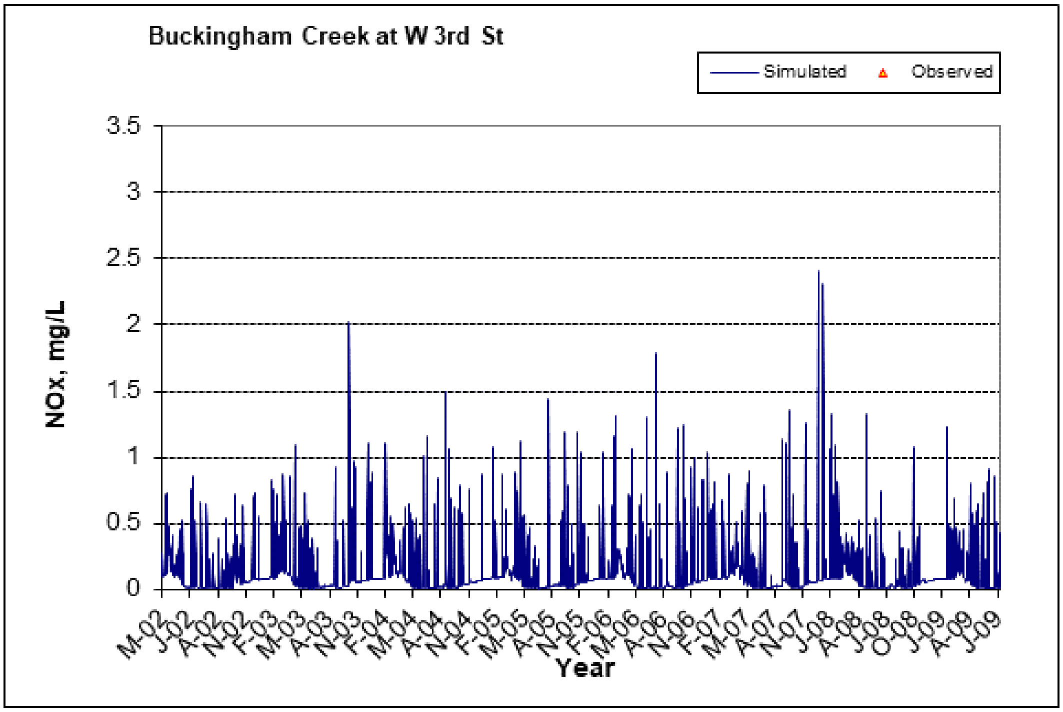


Figure E-520. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Buckingham Creek at W 3rd St (calibration period)





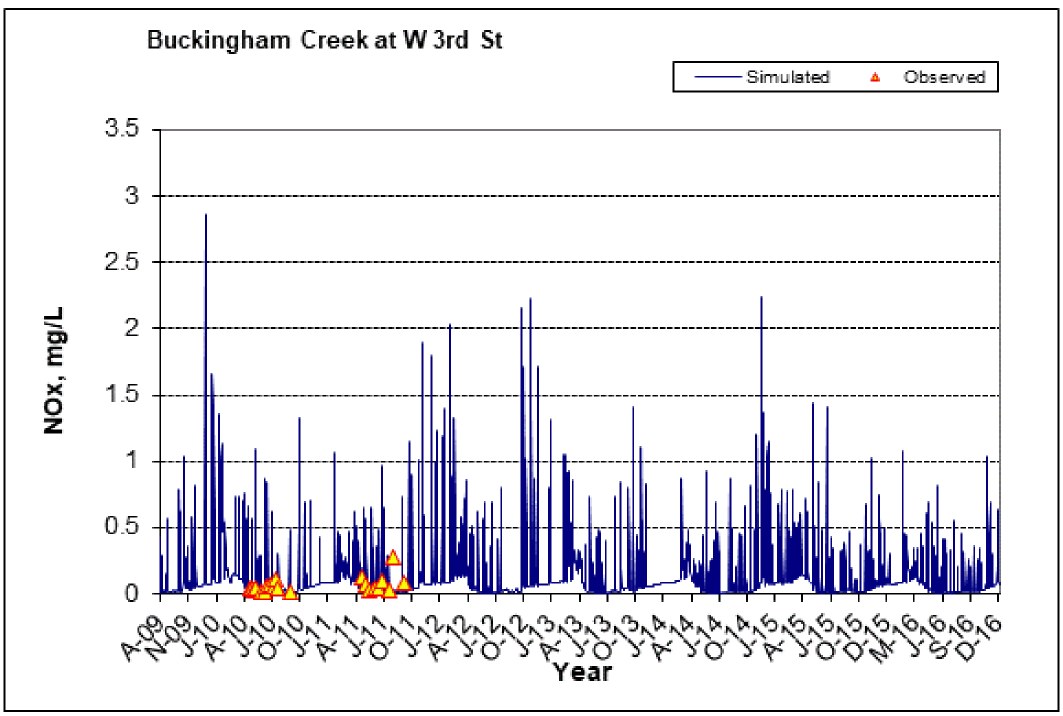


Figure E-521. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Buckingham Creek at W 3rd St

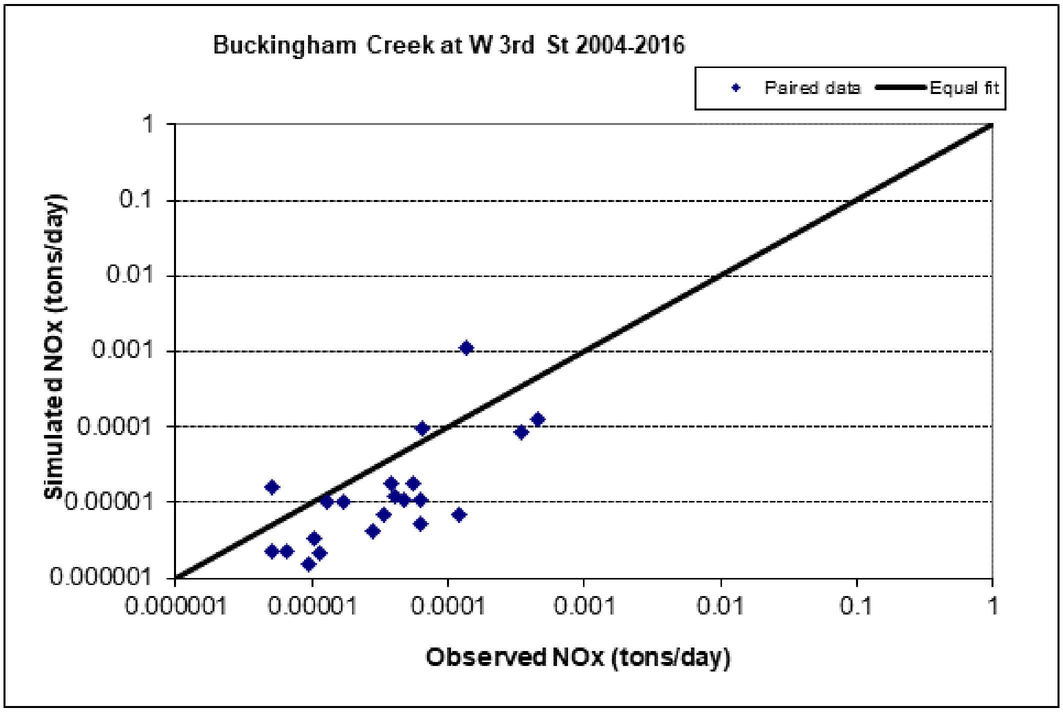


Figure E-522. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Buckingham Creek at W 3rd St (calibration period)

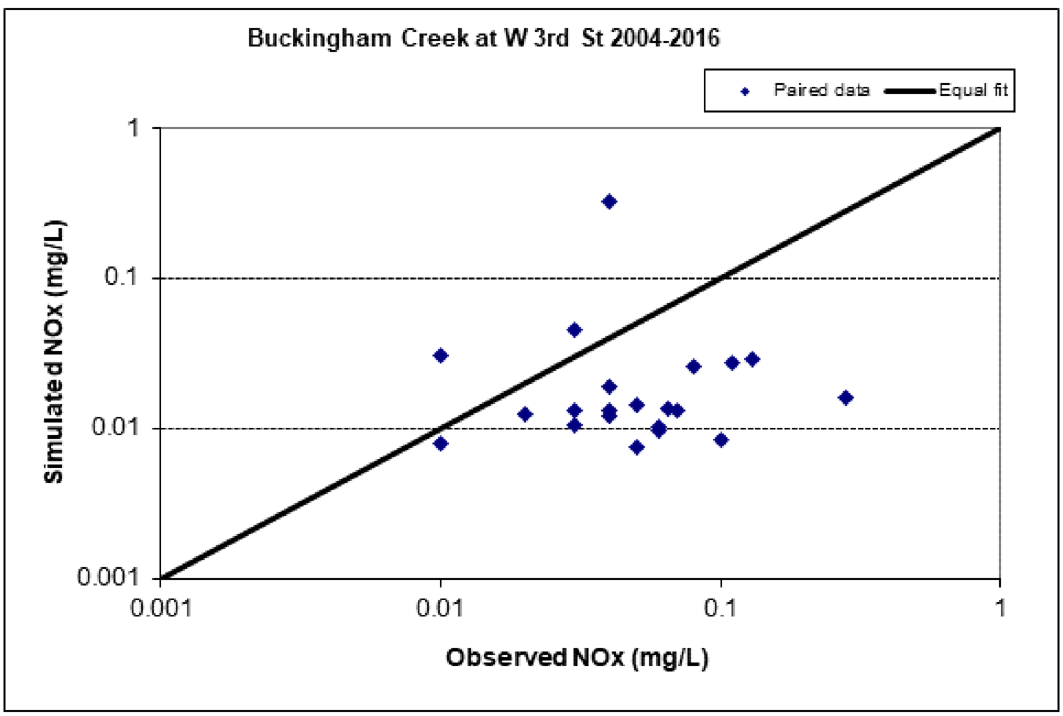


Figure E-523. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Buckingham Creek at W 3rd St (calibration period)

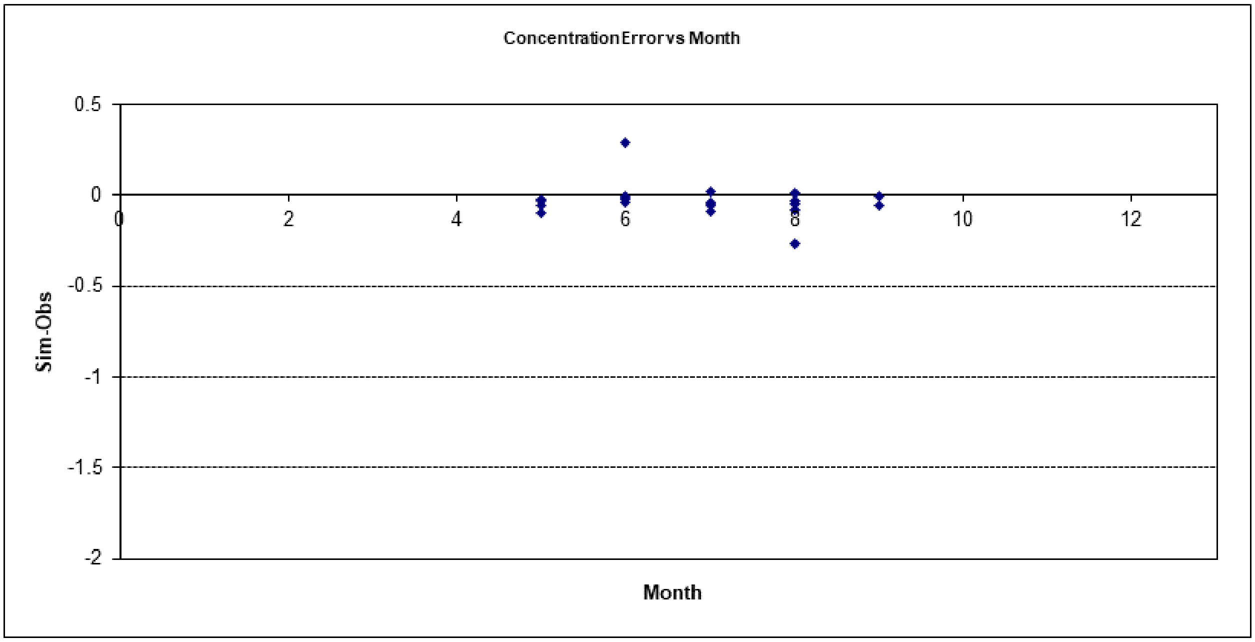


Figure E-524. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Buckingham Creek at W 3rd St

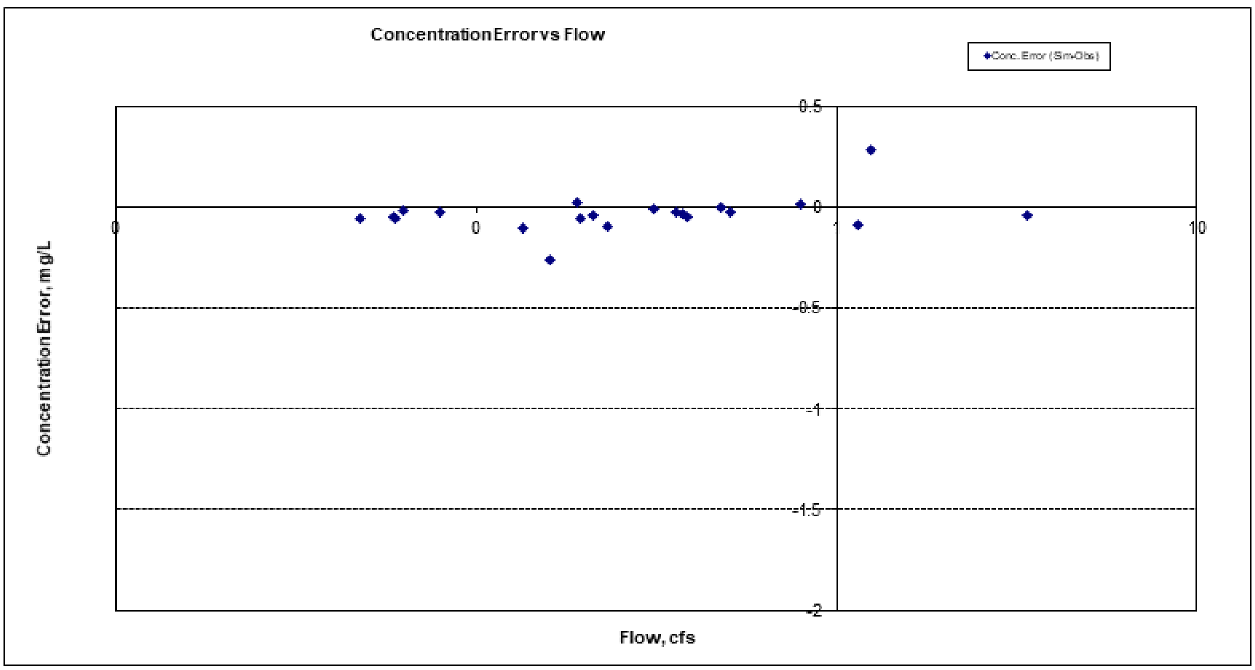


Figure E-525. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Buckingham Creek at W 3rd St

E.10.4 Total Phosphorus (TP)

Table E-64. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	22
Concentration Average Error		-36.14%
Concentration Median Error		-25.79%
Load Average Error		-31.19%
Load Median Error		-8.57%
Paired t conc		0.10
Paired t load		0.36

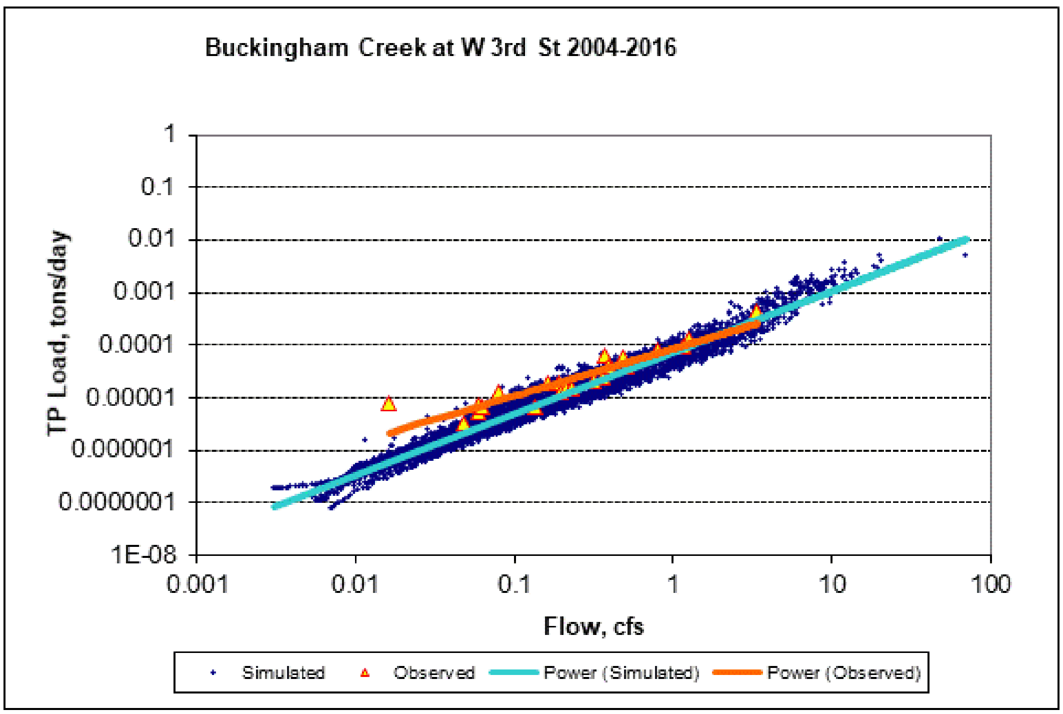


Figure E-526. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Buckingham Creek at W 3rd St (calibration period)

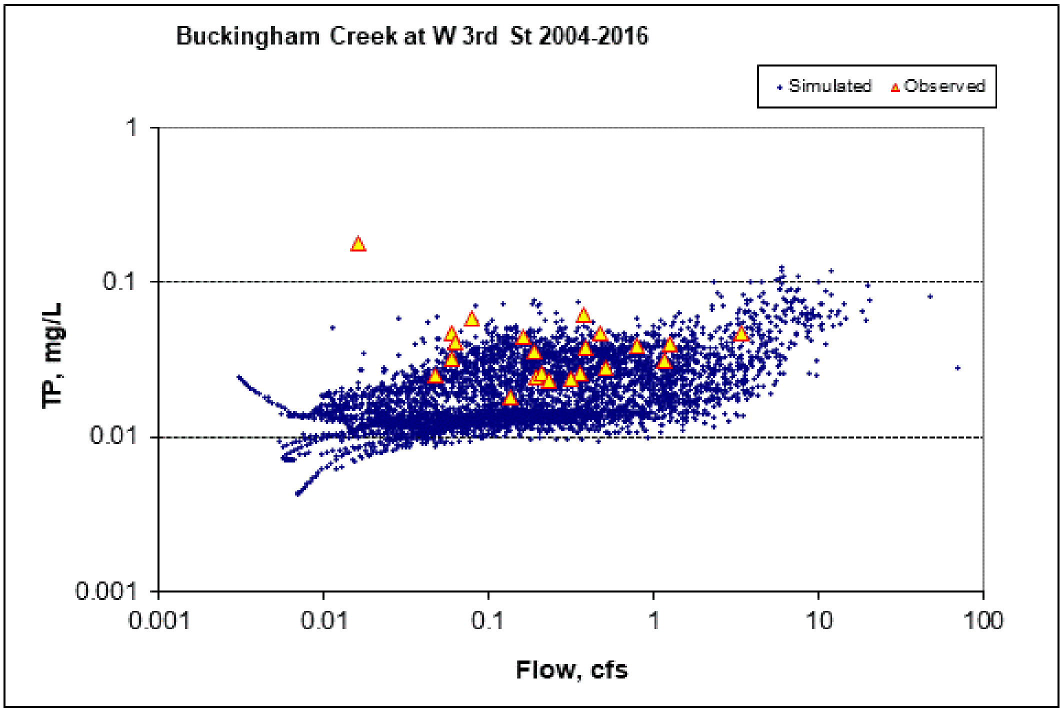
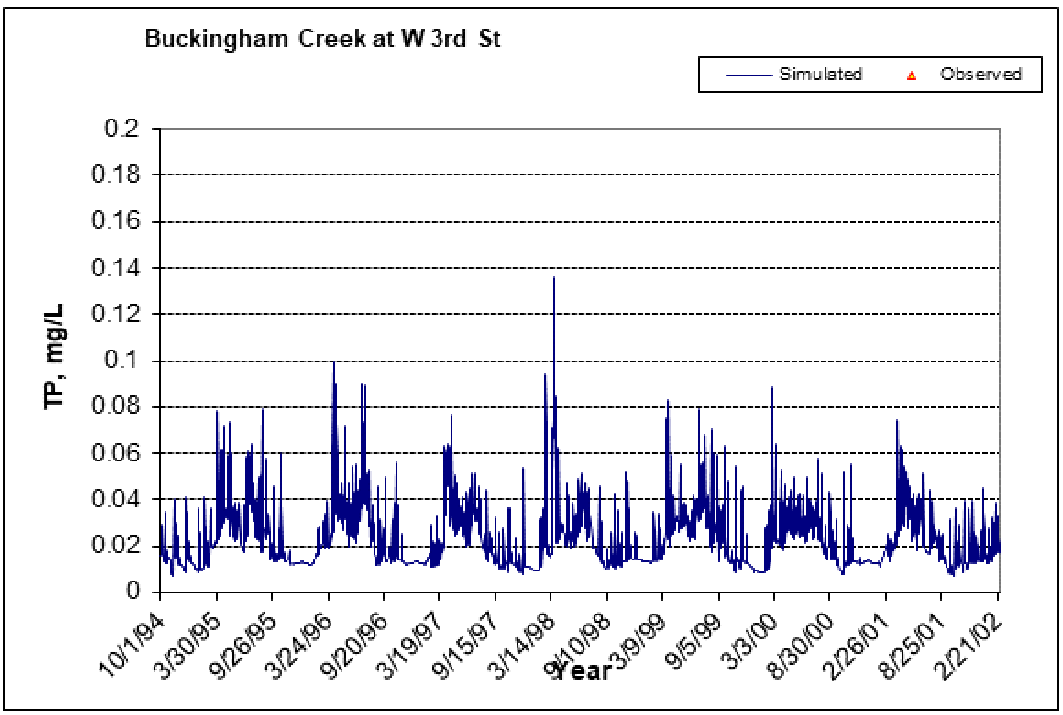


Figure E-527. Simulated and observed Total Phosphorus (TP) concentration vs flow at Buckingham Creek at W 3rd St (calibration period)



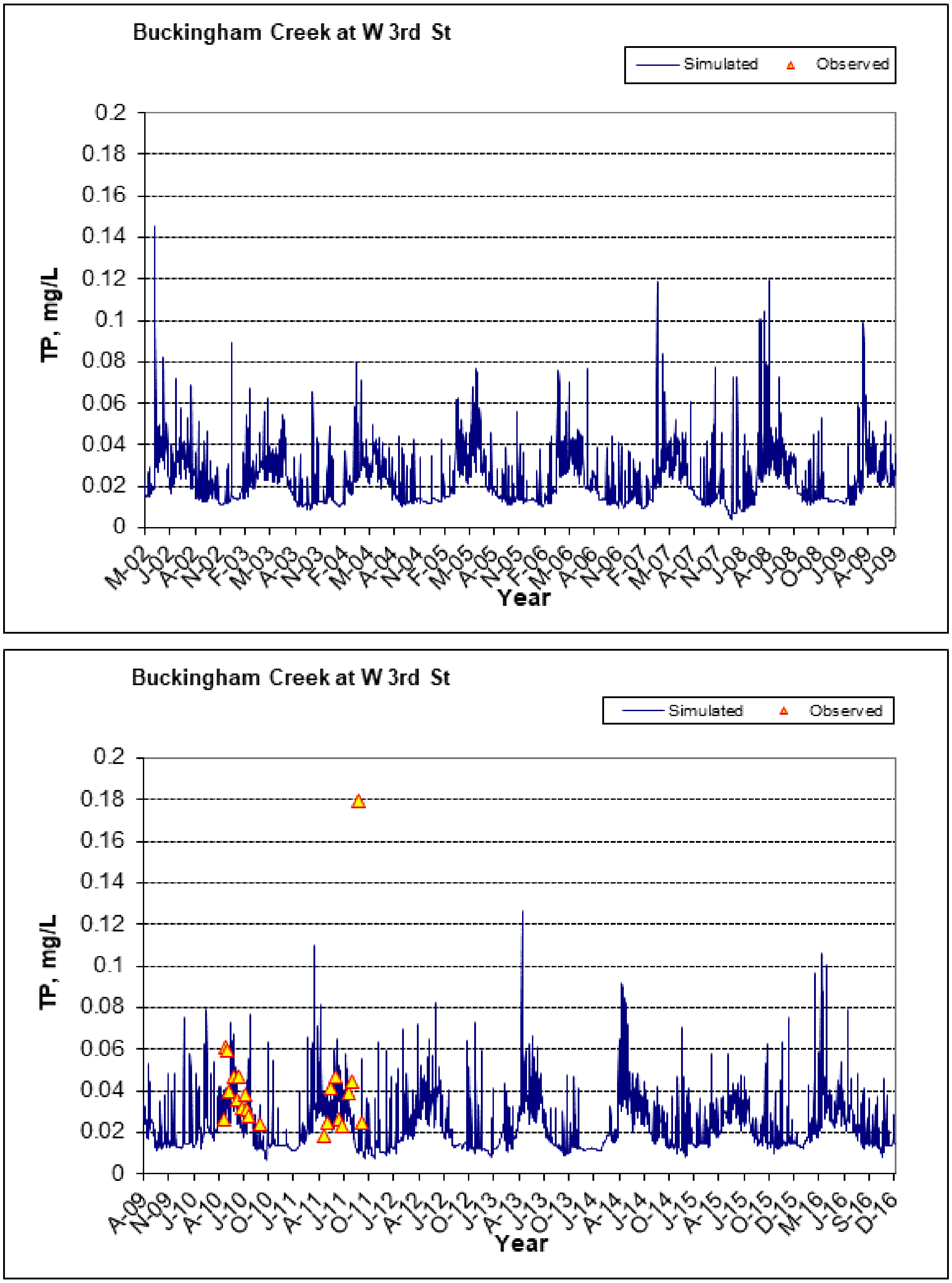


Figure E-528. Time series of observed and simulated Total Phosphorus (TP) concentration at Buckingham Creek at W 3rd St

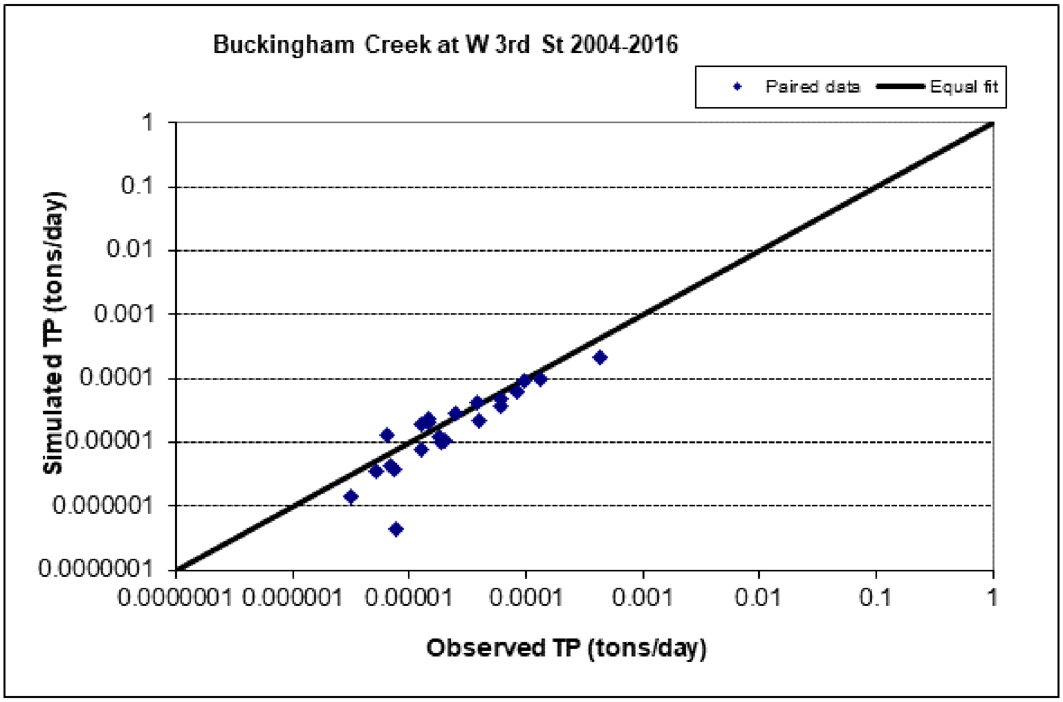


Figure E-529. Paired simulated vs. observed Total Phosphorus (TP) load at Buckingham Creek at W 3rd St (calibration period)

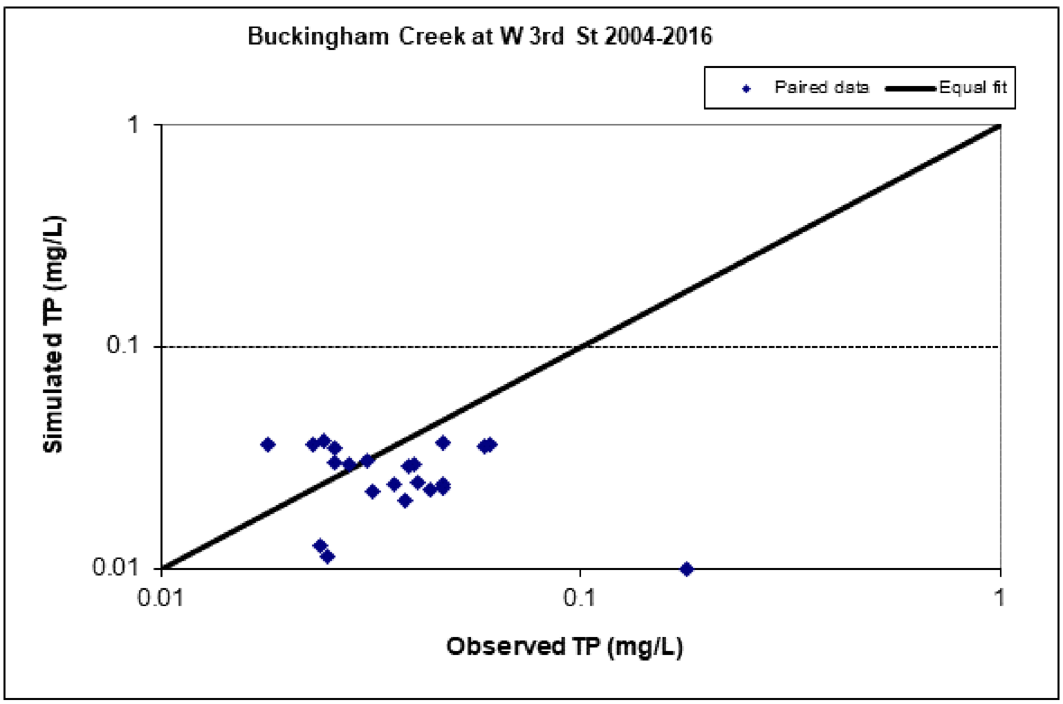


Figure E-530. Paired simulated vs. observed Total Phosphorus (TP) concentration at Buckingham Creek at W 3rd St (calibration period)

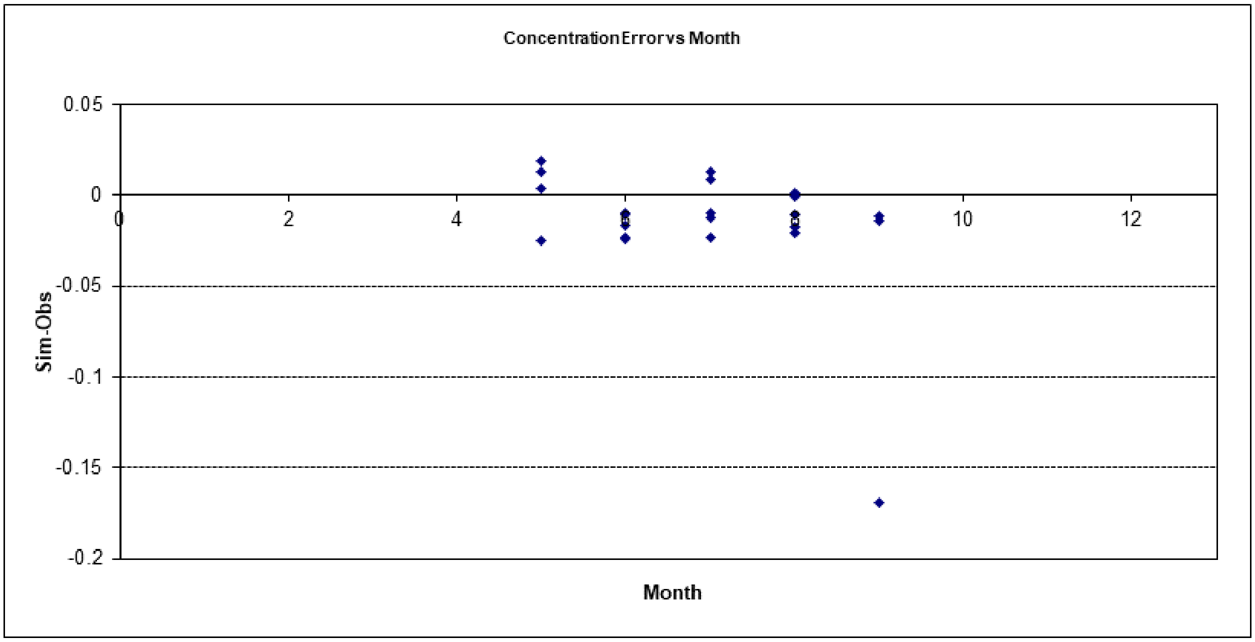


Figure E-531. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Buckingham Creek at W 3rd St

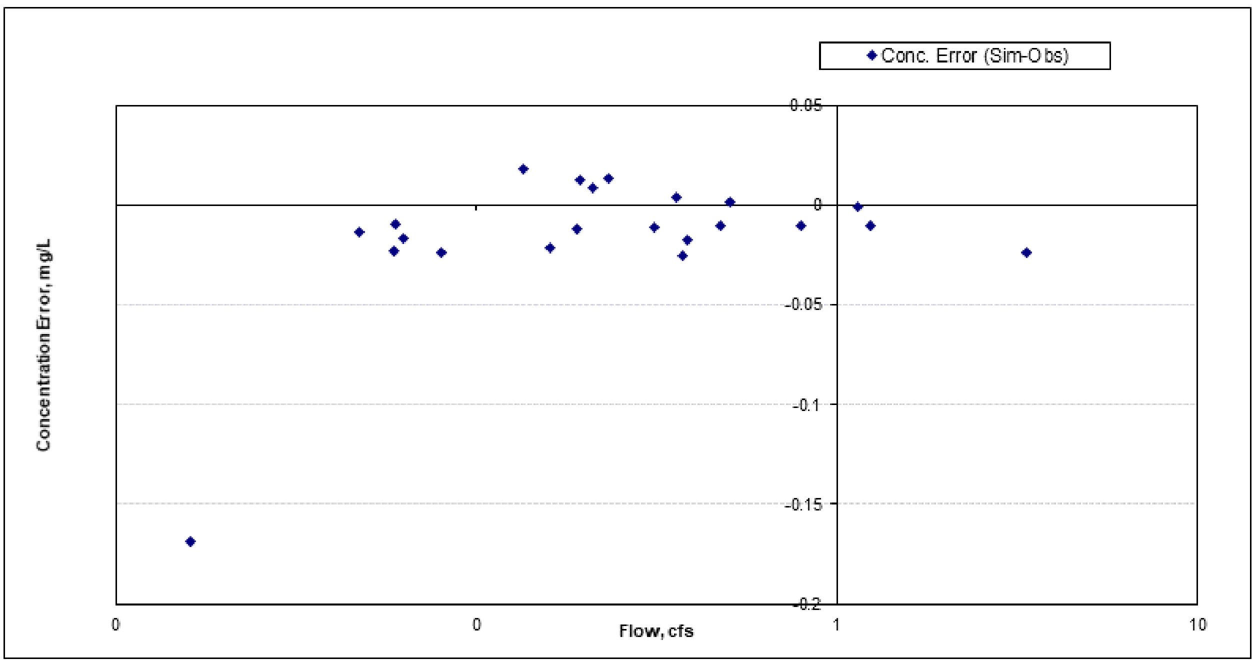


Figure E-532. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Buckingham Creek at W 3rd St

E.11 Coffee Creek east of Miller Creek

E.11.1 Dissolved Oxygen (DO)

Table E-65. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	26
Concentration Average Error		-30.42%
Concentration Median Error		-28.69%
Load Average Error		-20.89%
Load Median Error		-13.00%
Paired t conc		0.00
Paired t load		0.49

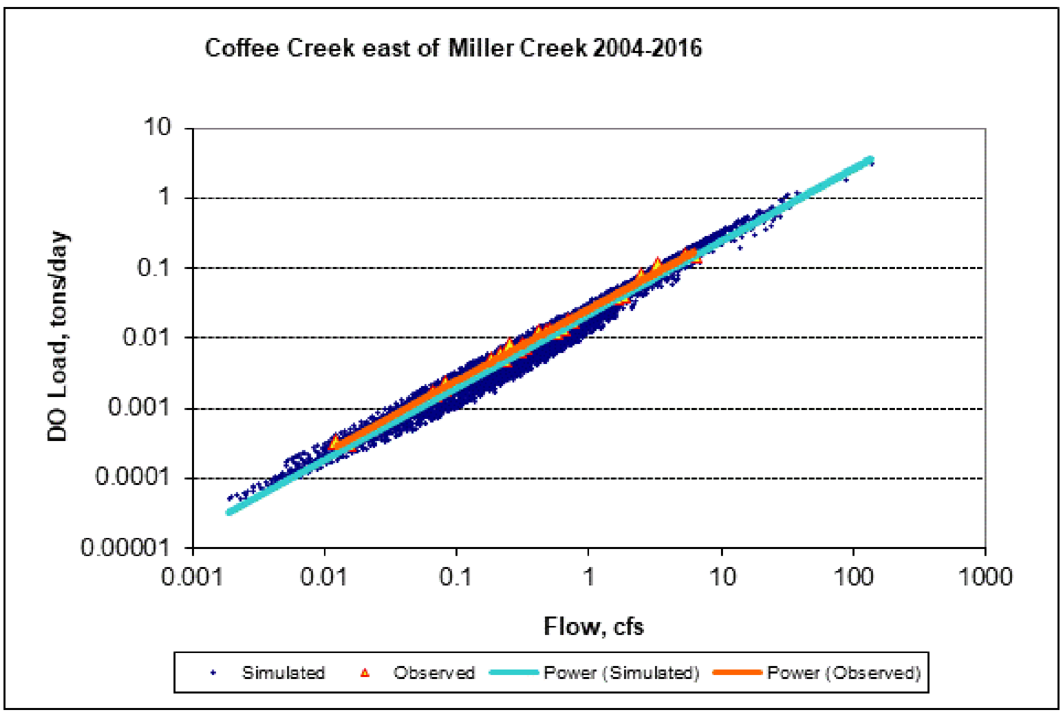


Figure E-533. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Coffee Creek east of Miller Creek (calibration period)

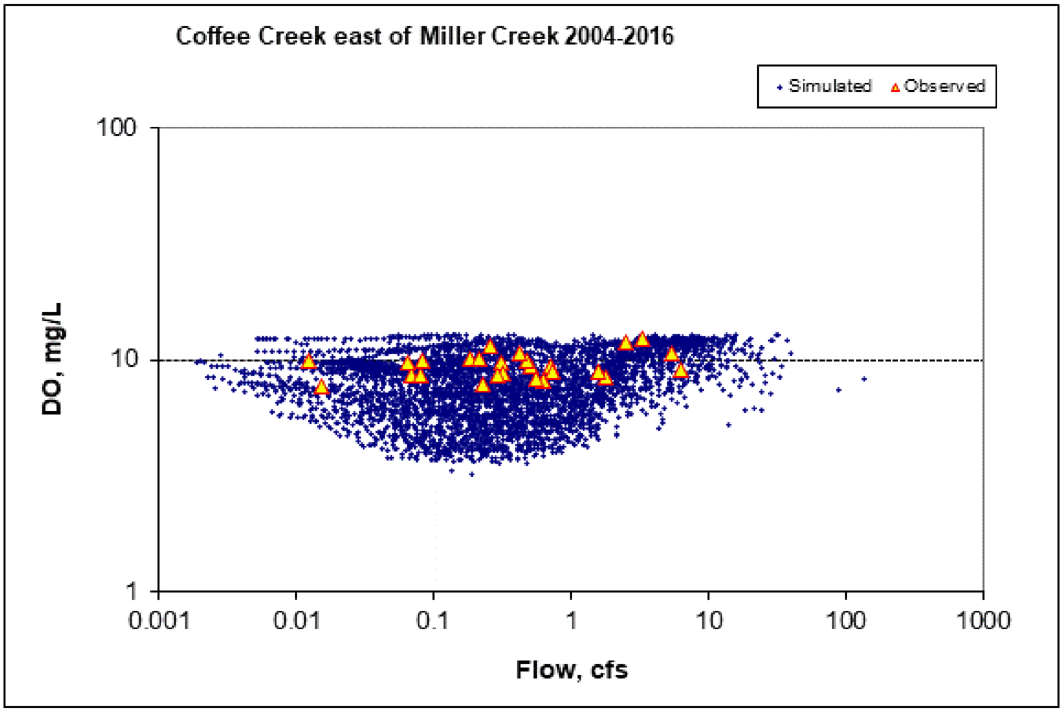
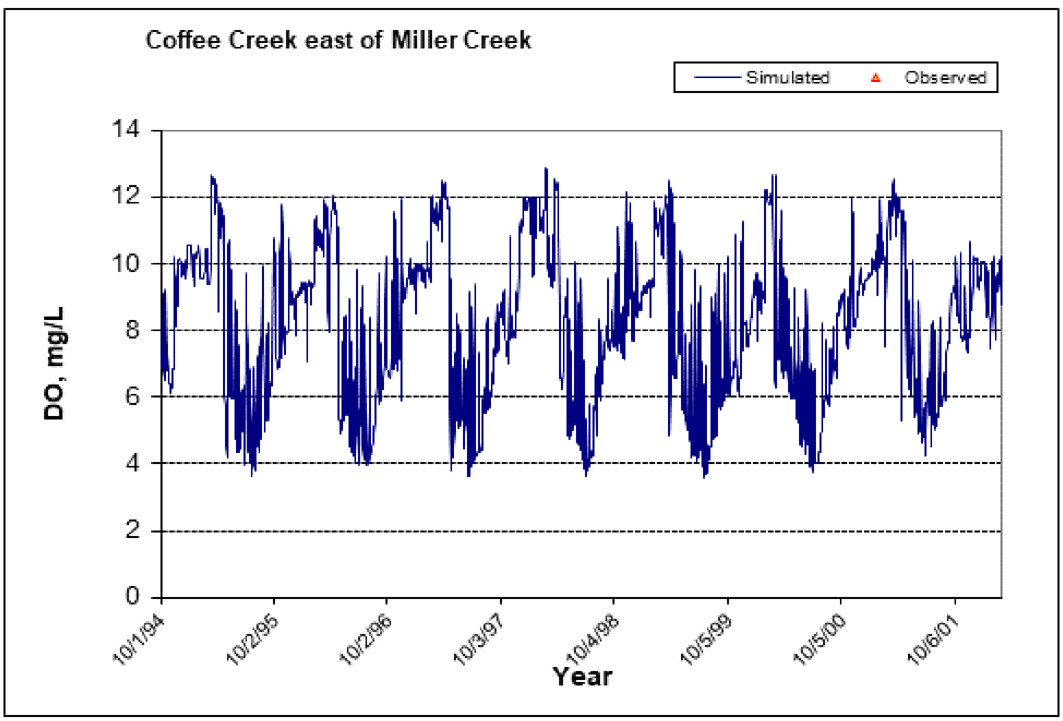


Figure E-534. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Coffee Creek east of Miller Creek (calibration period)



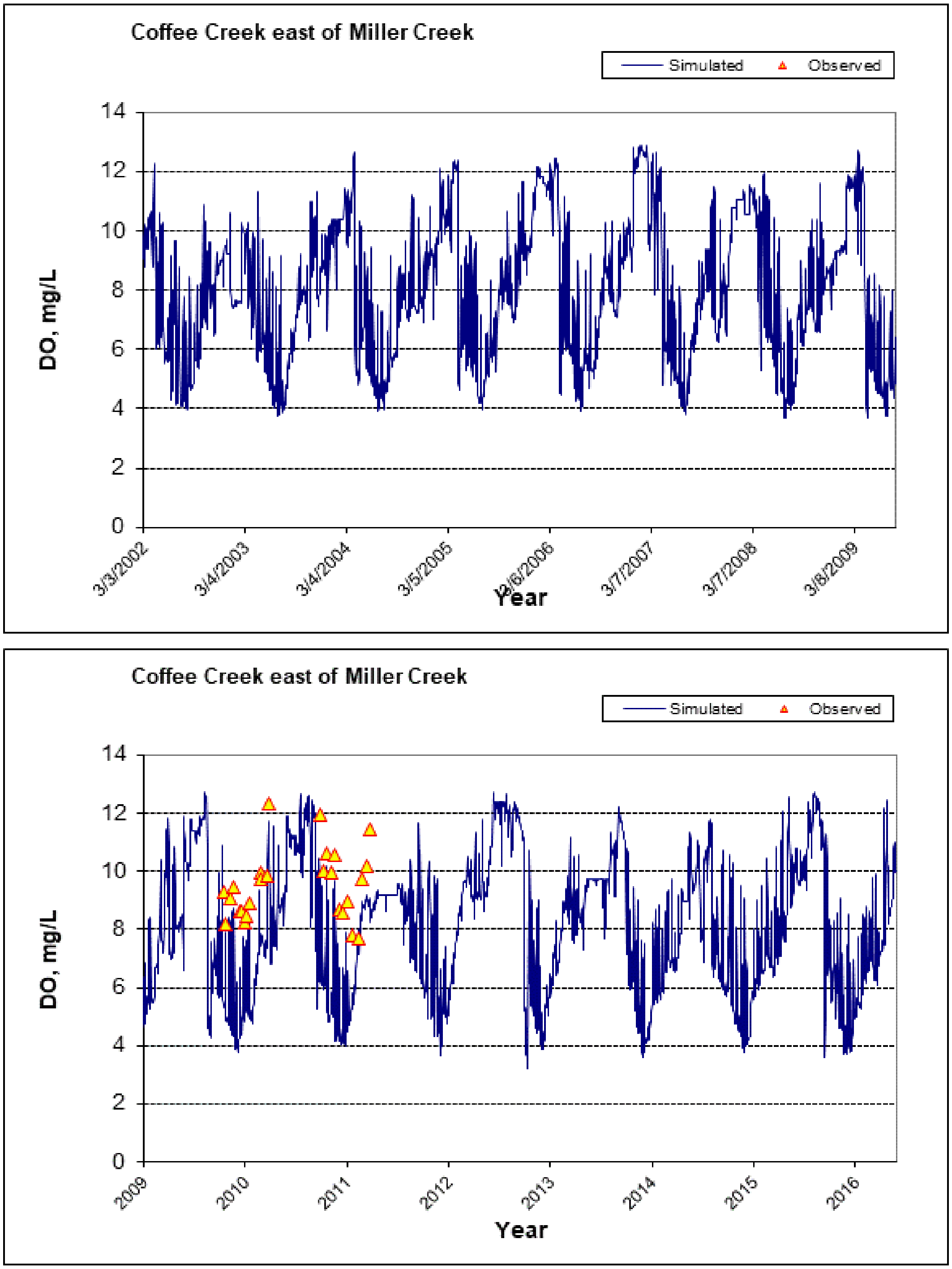


Figure E-535. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Coffee Creek east of Miller Creek

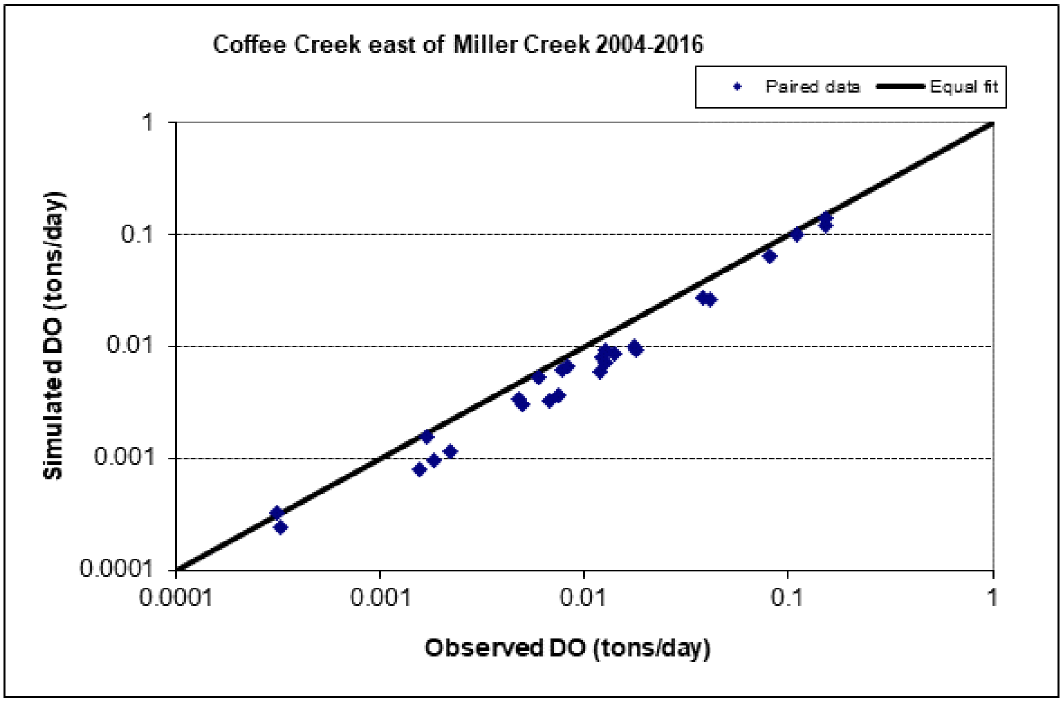


Figure E-536. Paired simulated vs. observed Dissolved Oxygen (DO) load at Coffee Creek east of Miller Creek (calibration period)

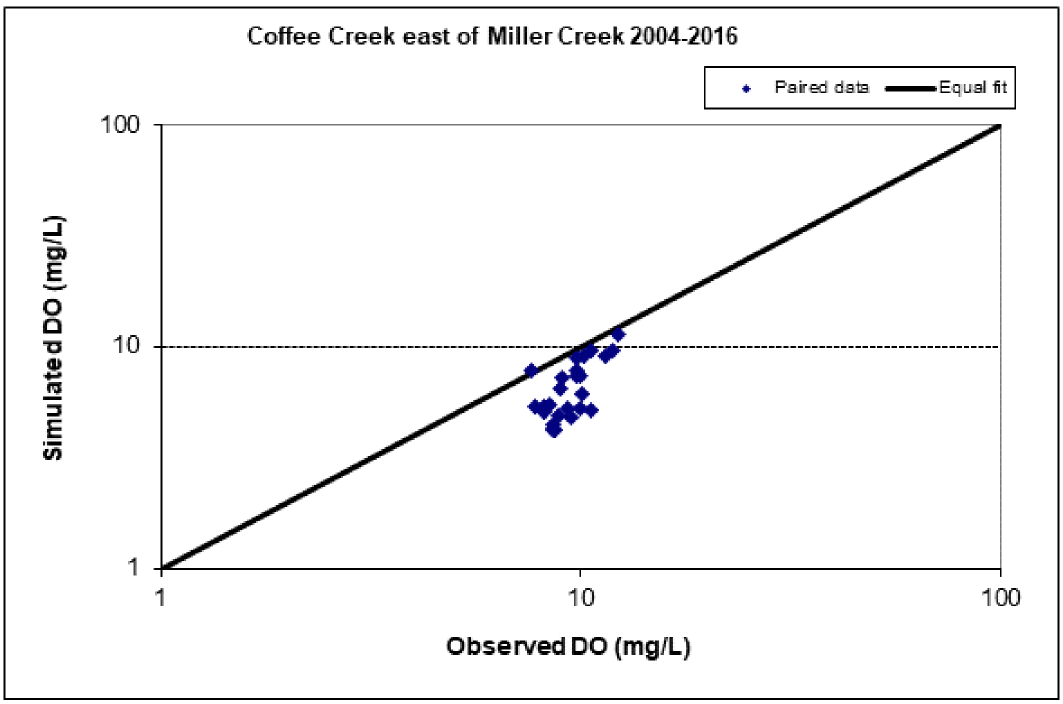


Figure E-537. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Coffee Creek east of Miller Creek (calibration period)

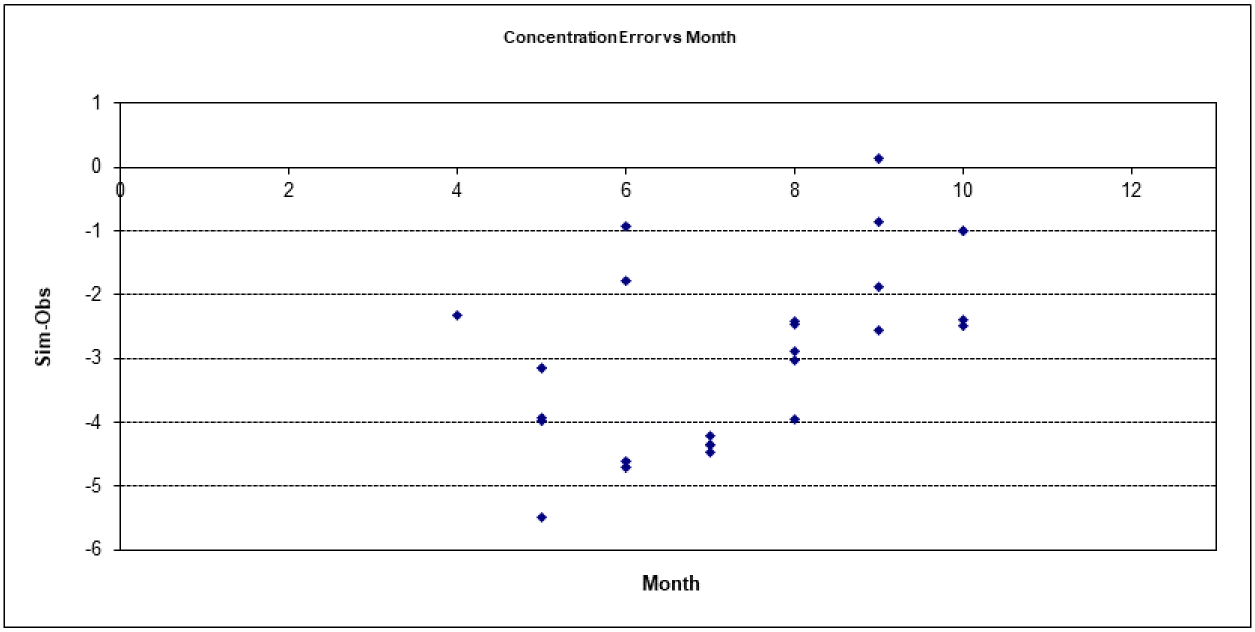


Figure E-538. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Coffee Creek east of Miller Creek

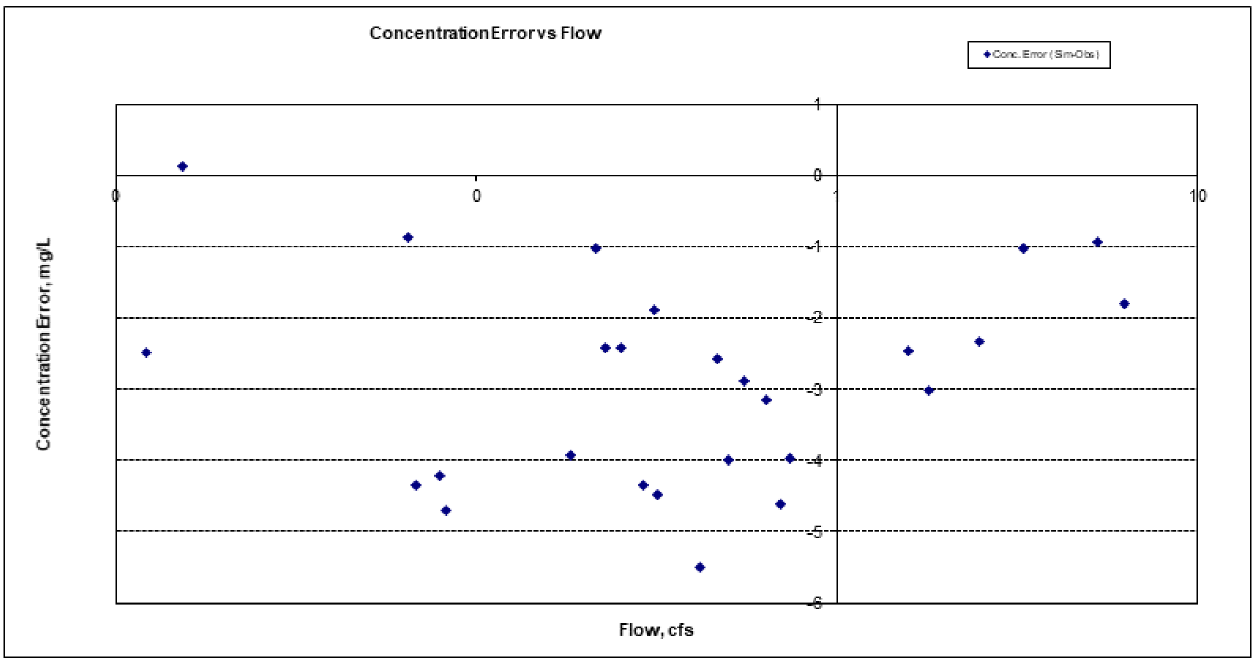


Figure E-539. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Coffee Creek east of Miller Creek

E.11.2 Ammonia Nitrogen (NH3)

Table E-66. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	22
Concentration Average Error		88.83%
Concentration Median Error		23.89%
Load Average Error		308.71%
Load Median Error		2.62%
Paired t conc		0.02
Paired t load		0.07

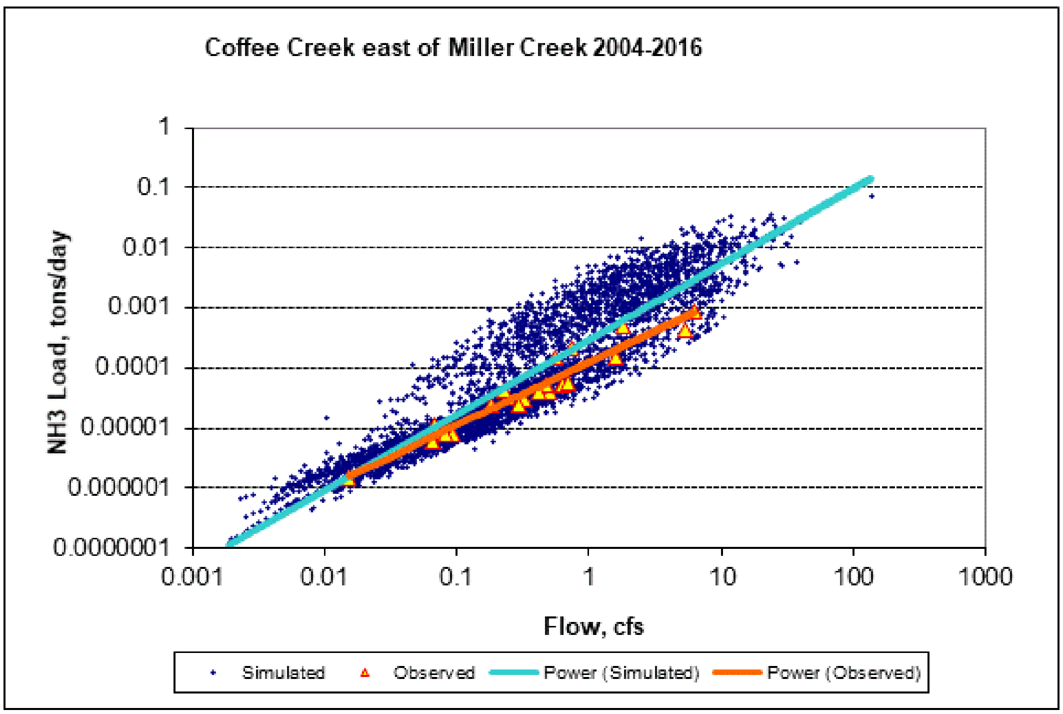


Figure E-540. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Coffee Creek east of Miller Creek (calibration period)

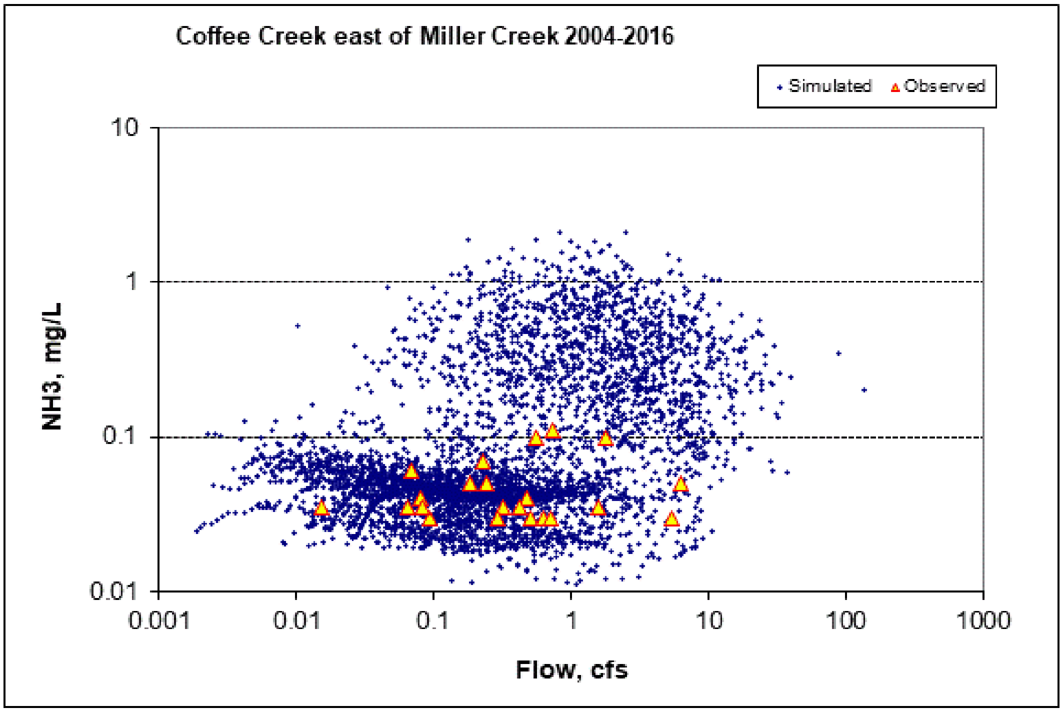
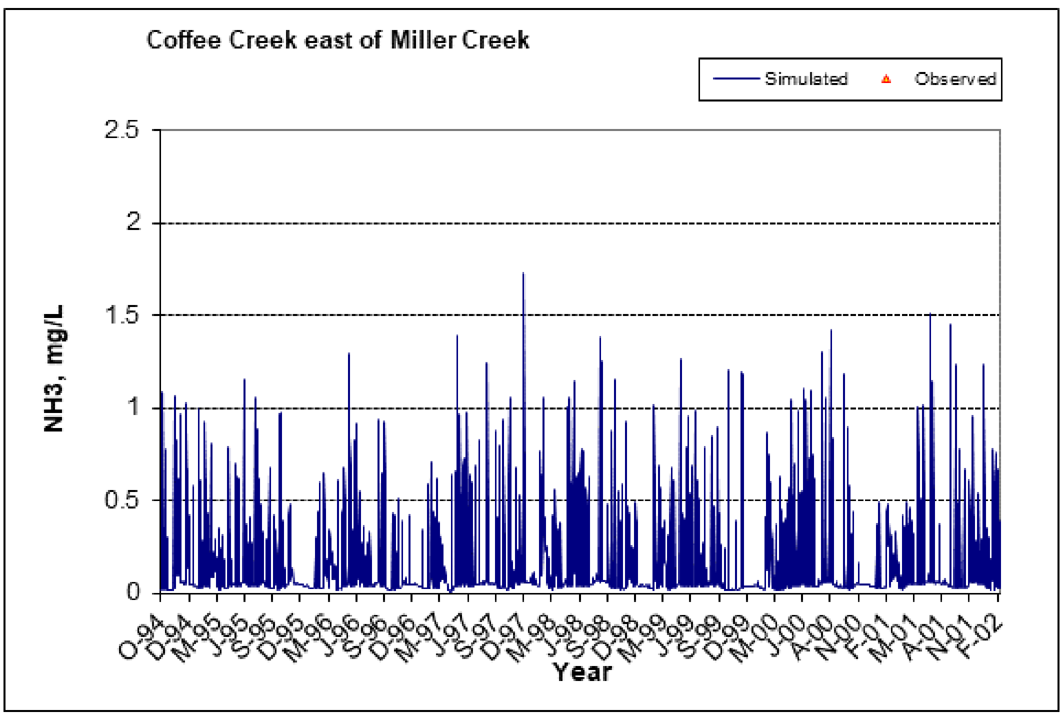
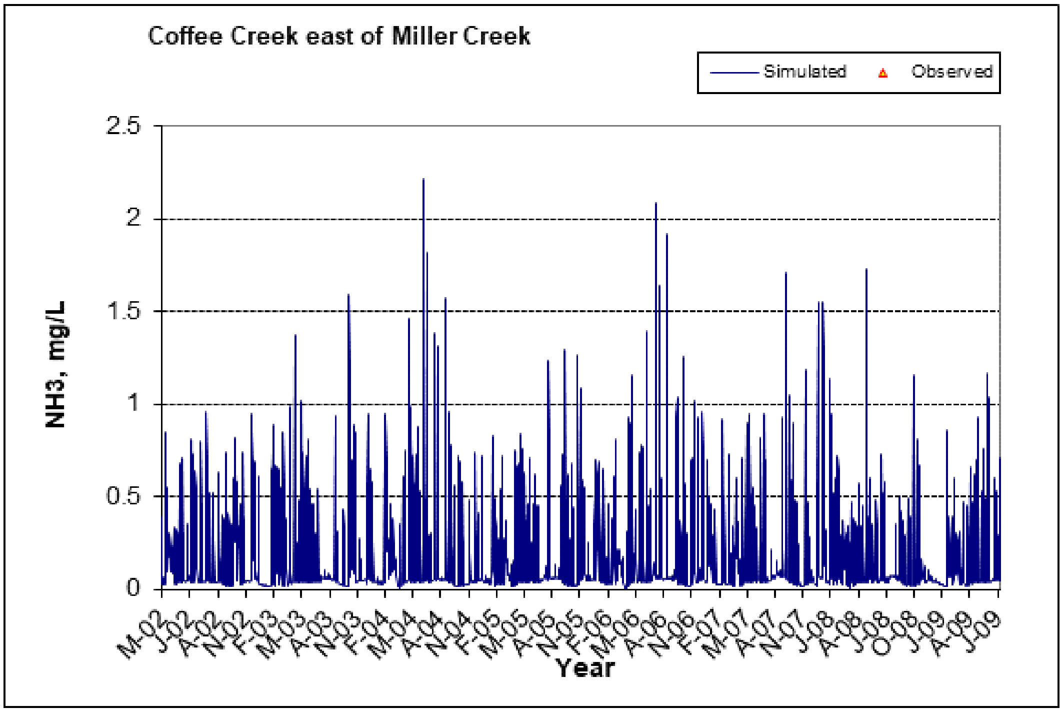


Figure E-541. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Coffee Creek east of Miller Creek (calibration period)





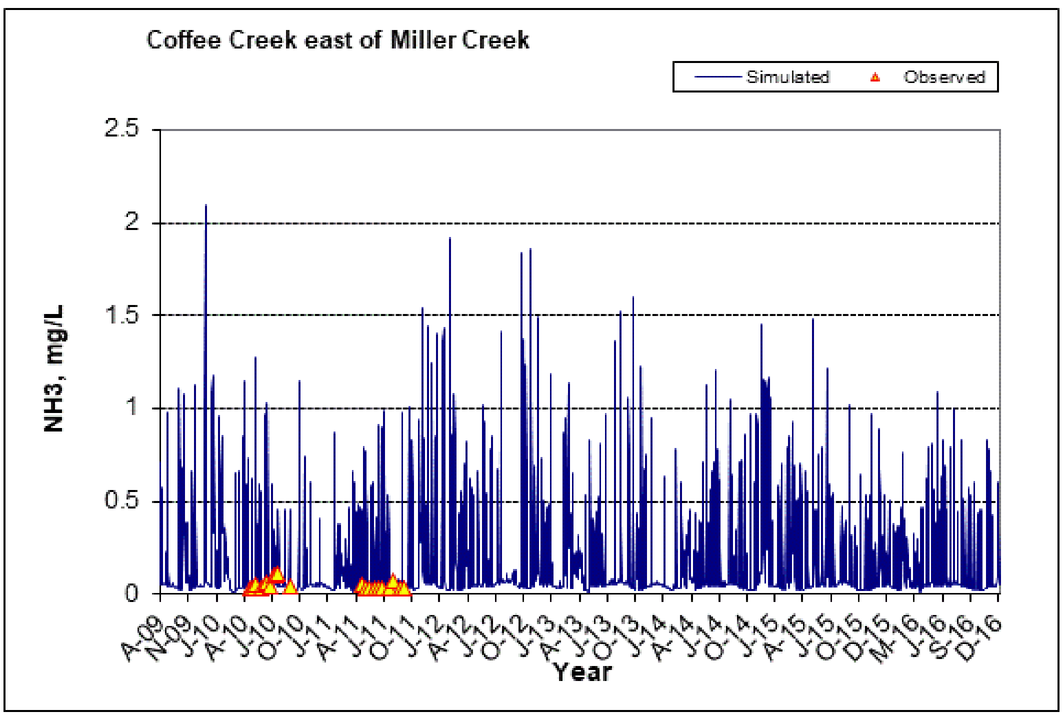


Figure E-542. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Coffee Creek east of Miller Creek

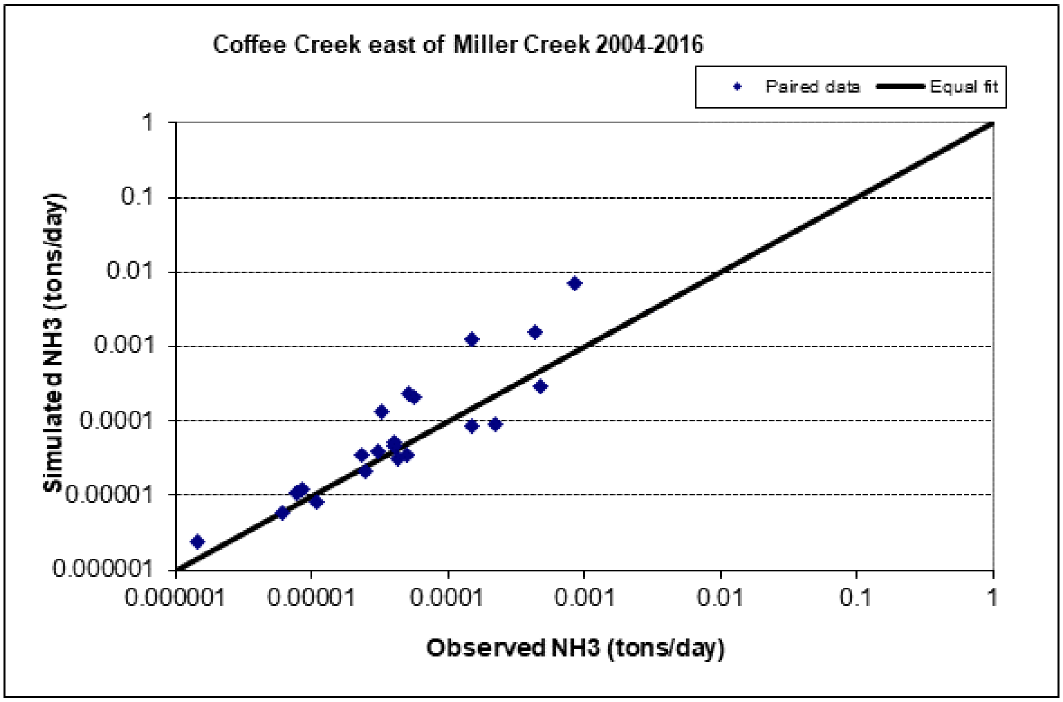


Figure E-543. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Coffee Creek east of Miller Creek (calibration period)

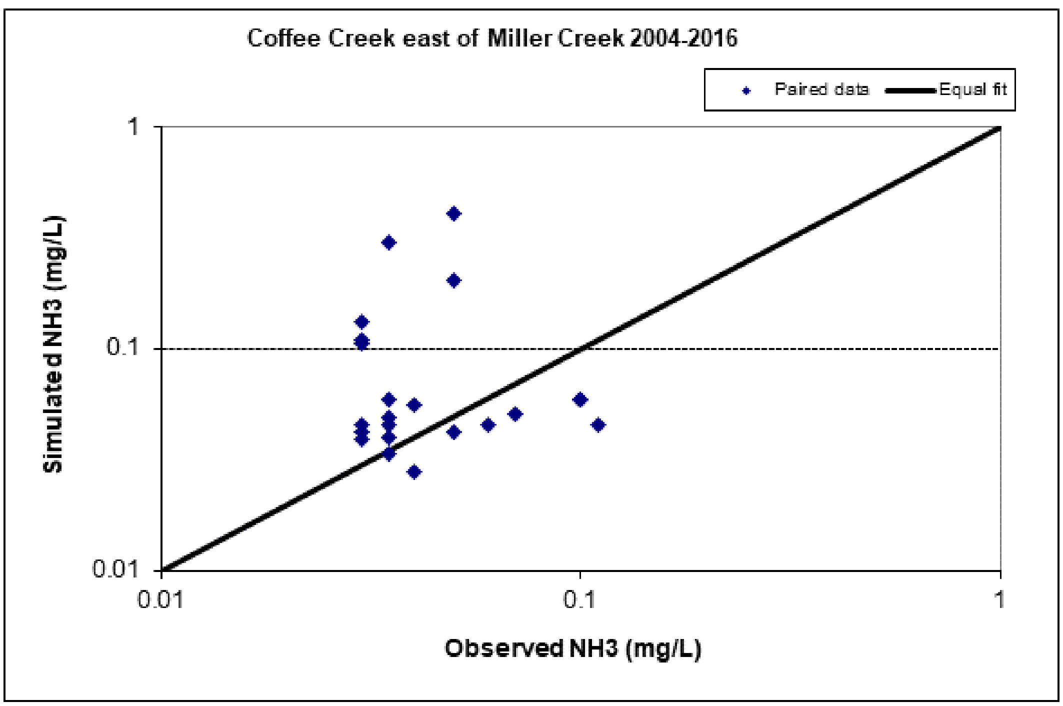


Figure E-544. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Coffee Creek east of Miller Creek (calibration period)

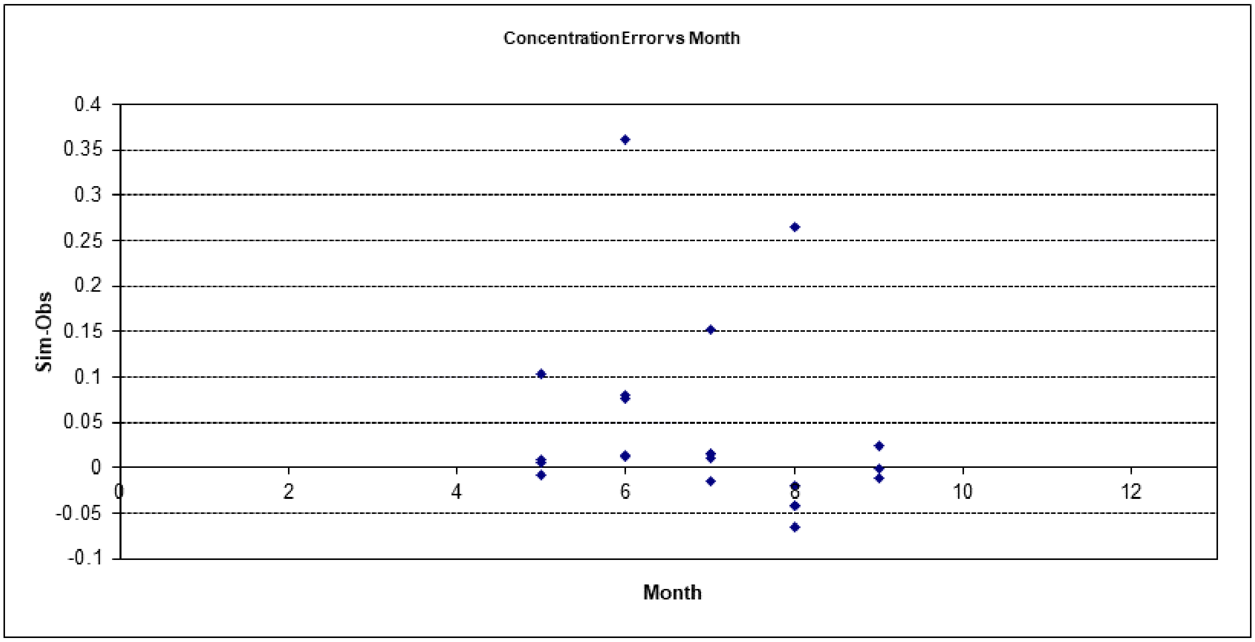


Figure E-545. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Coffee Creek east of Miller Creek

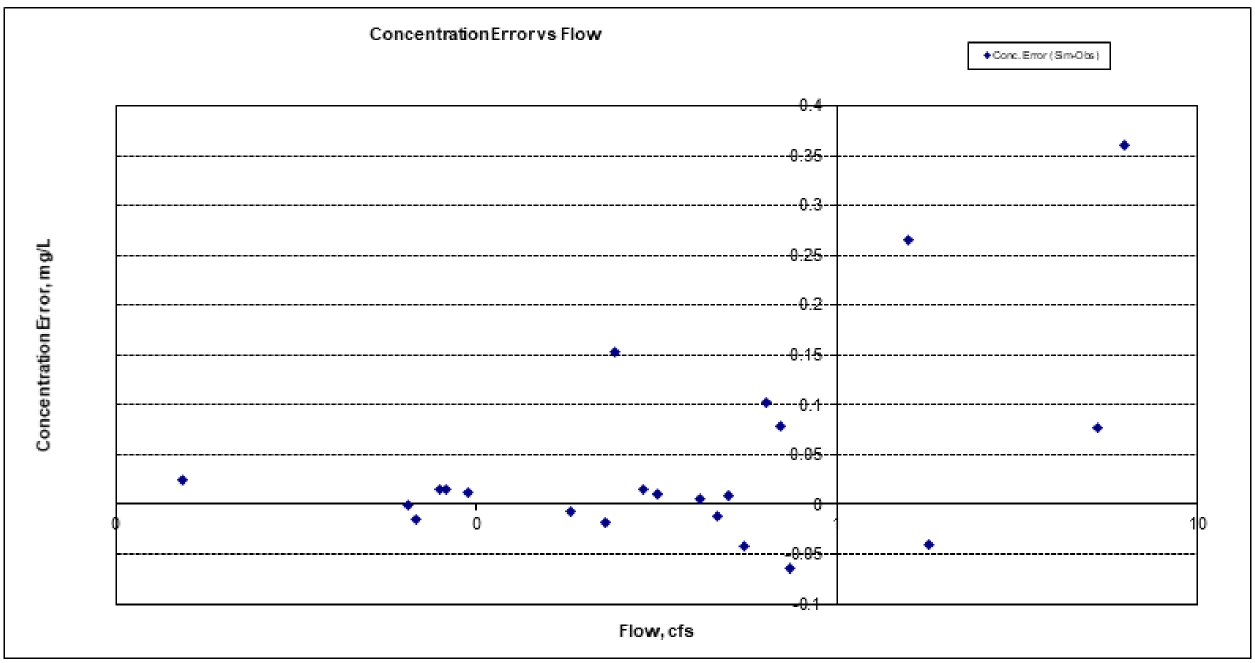


Figure E-546. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Coffee Creek east of Miller Creek

E.11.3 Nitrite+ Nitrate Nitrogen (NOx)

Table E-67. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	22
Concentration Average Error		-51.26%
Concentration Median Error		-58.66%
Load Average Error		16.45%
Load Median Error		-15.89%
Paired t conc		0.00
Paired t load		0.52

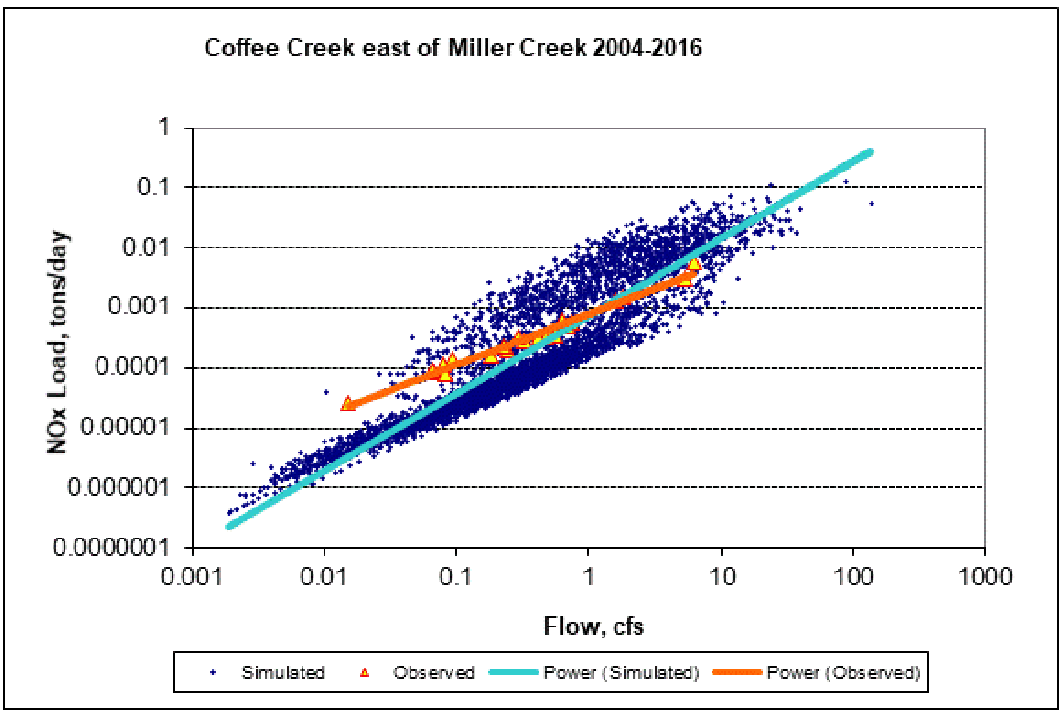


Figure E-547. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Coffee Creek east of Miller Creek (calibration period)

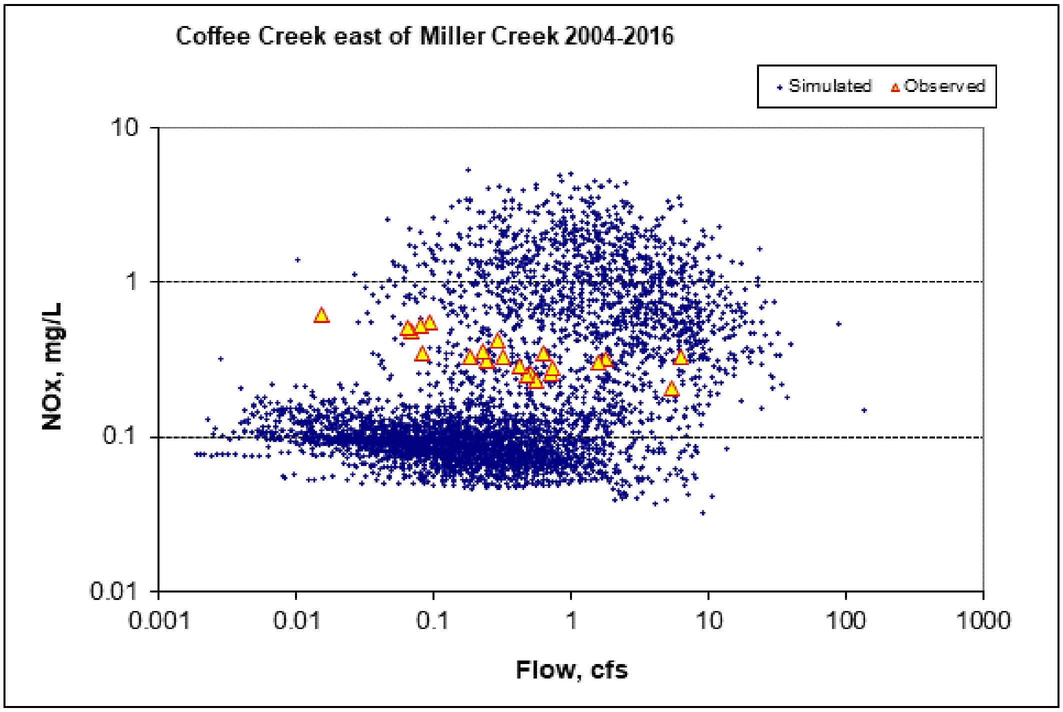
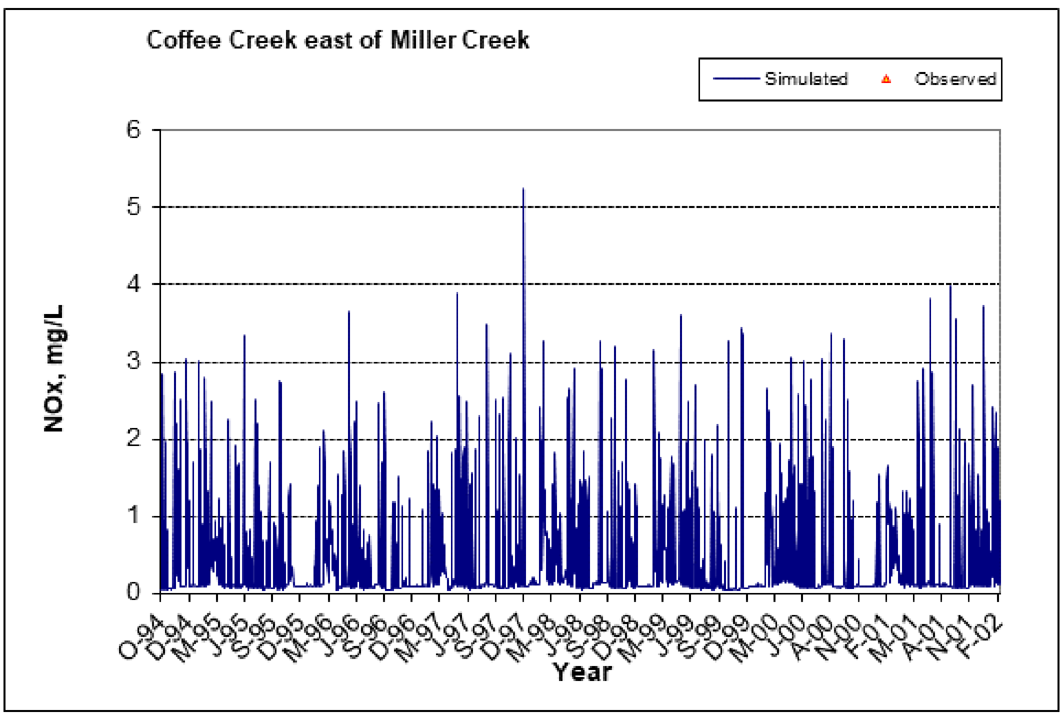
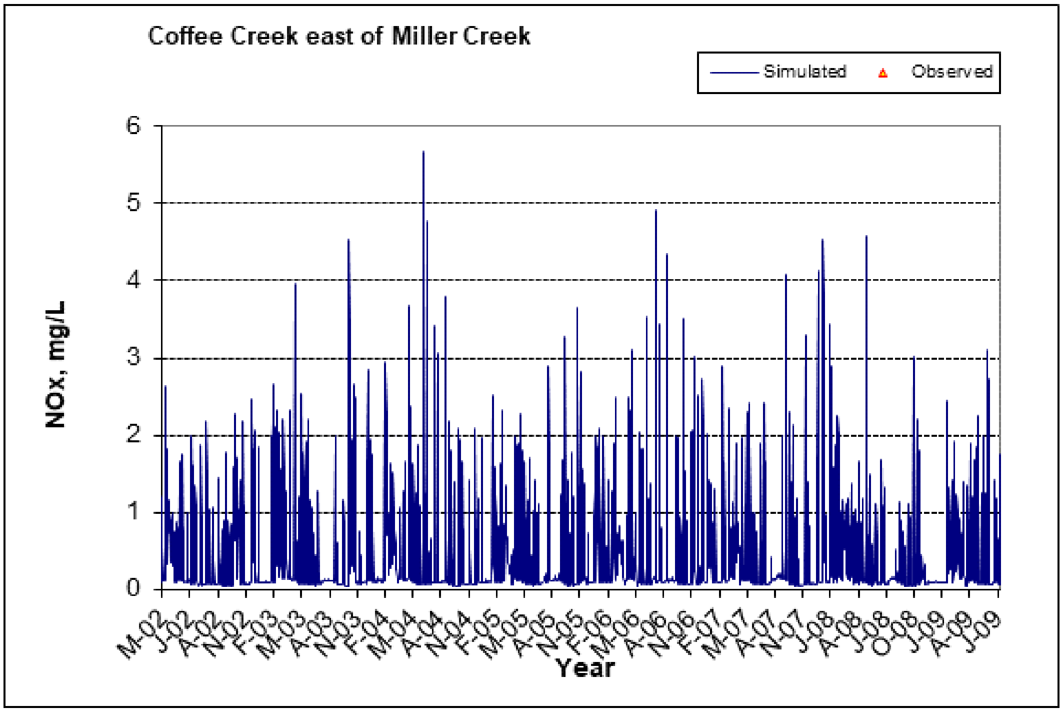


Figure E-548. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Coffee Creek east of Miller Creek (calibration period)





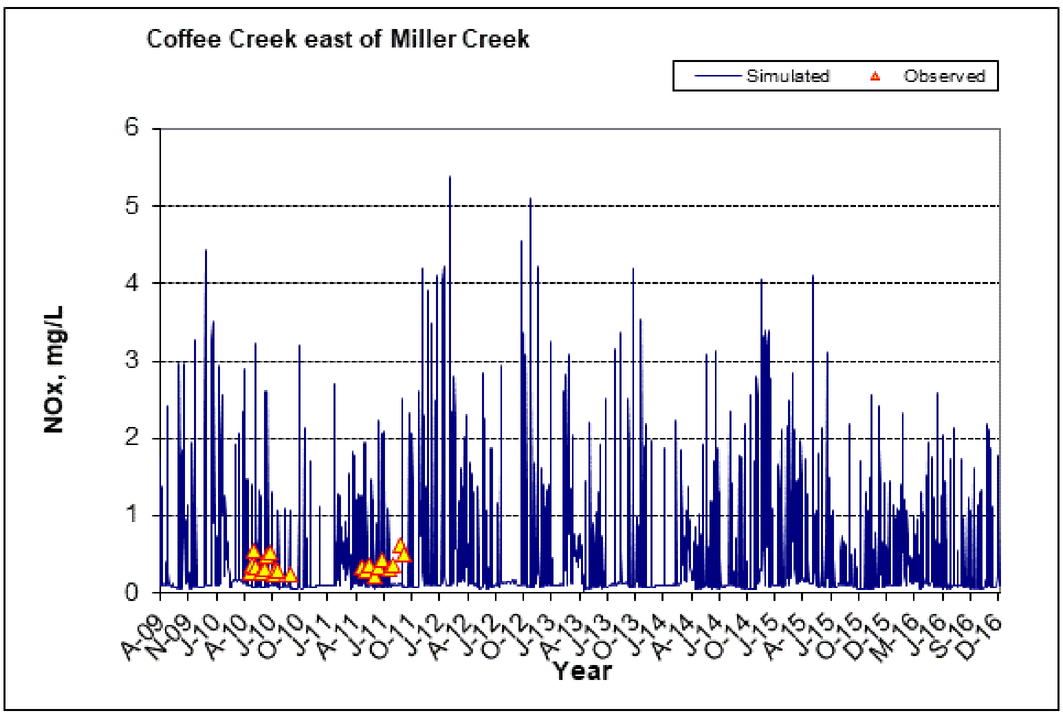


Figure E-549. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Coffee Creek east of Miller Creek

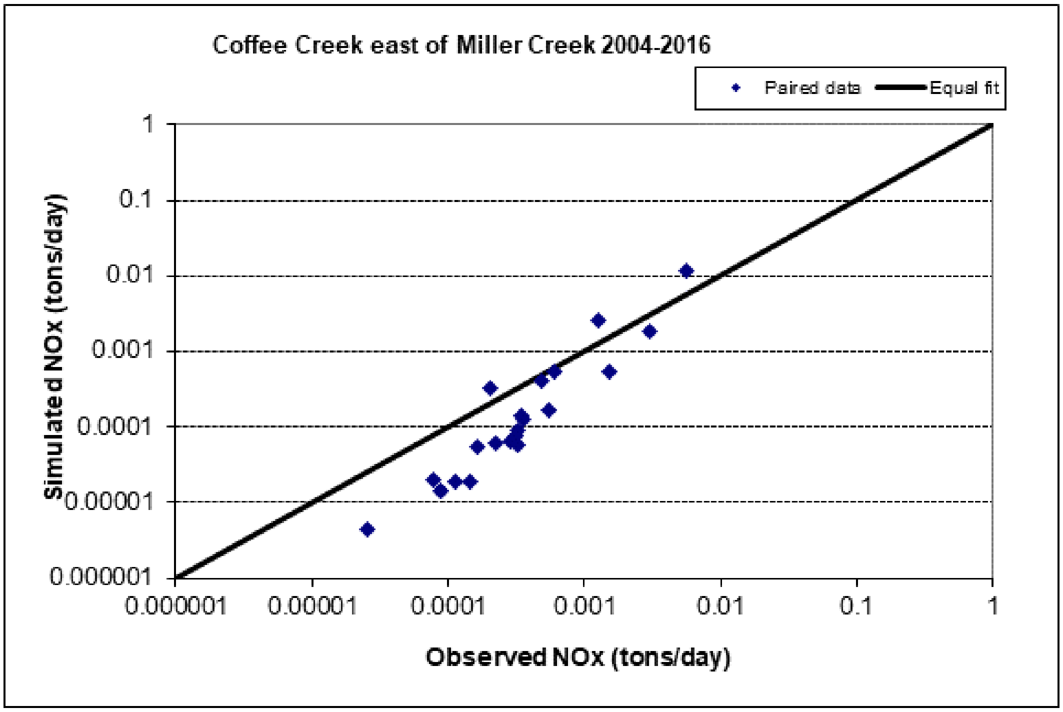


Figure E-550. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Coffee Creek east of Miller Creek (calibration period)

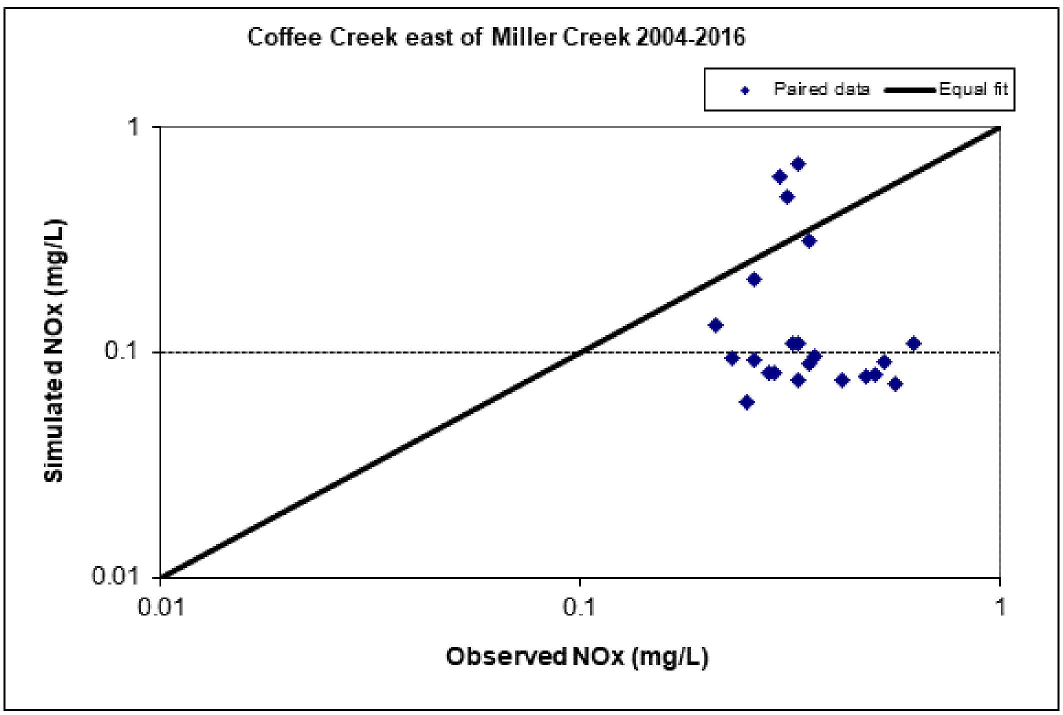


Figure E-551. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Coffee Creek east of Miller Creek (calibration period)

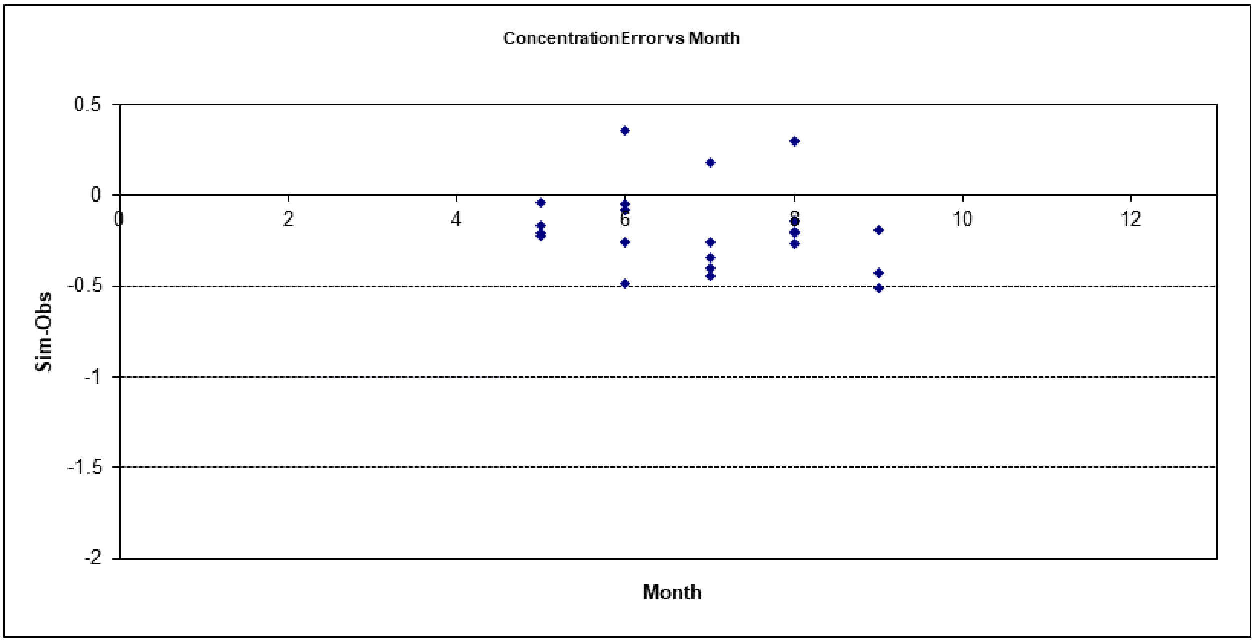


Figure E-552. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Coffee Creek east of Miller Creek

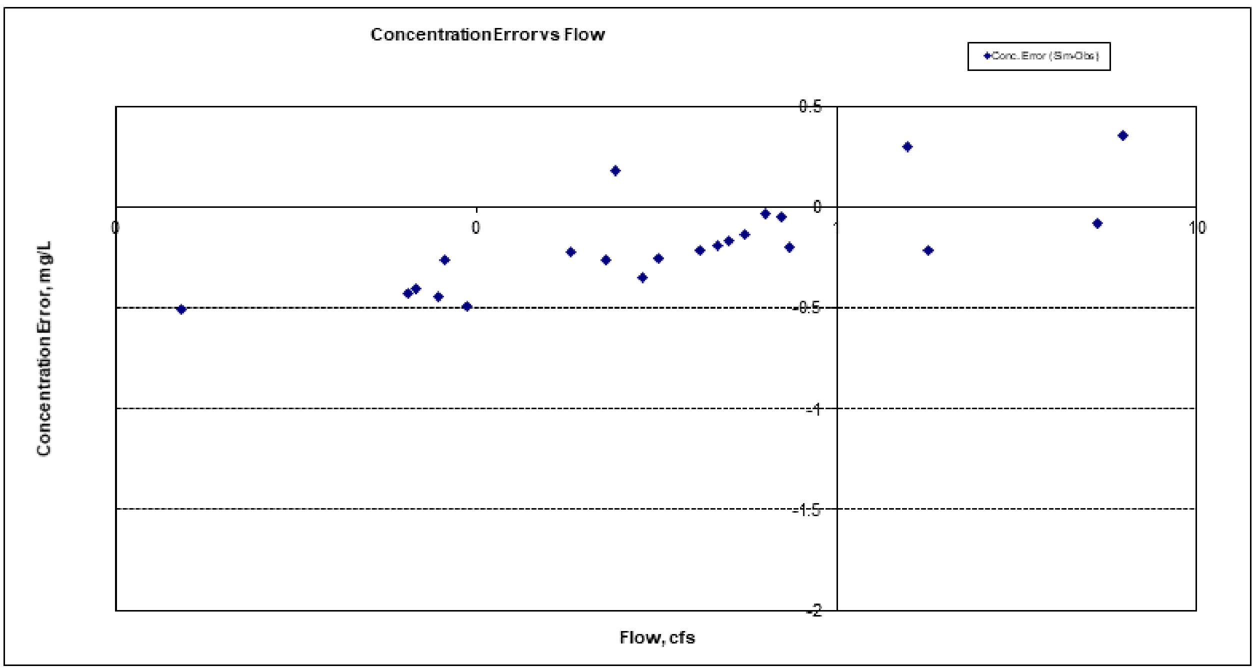


Figure E-553. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Coffee Creek east of Miller Creek

E.11.4 Total Phosphorus (TP)

Table E-68. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	22
Concentration Average Error		-14.26%
Concentration Median Error		-20.11%
Load Average Error		-32.73%
Load Median Error		-3.37%
Paired t conc		0.73
Paired t load		0.36

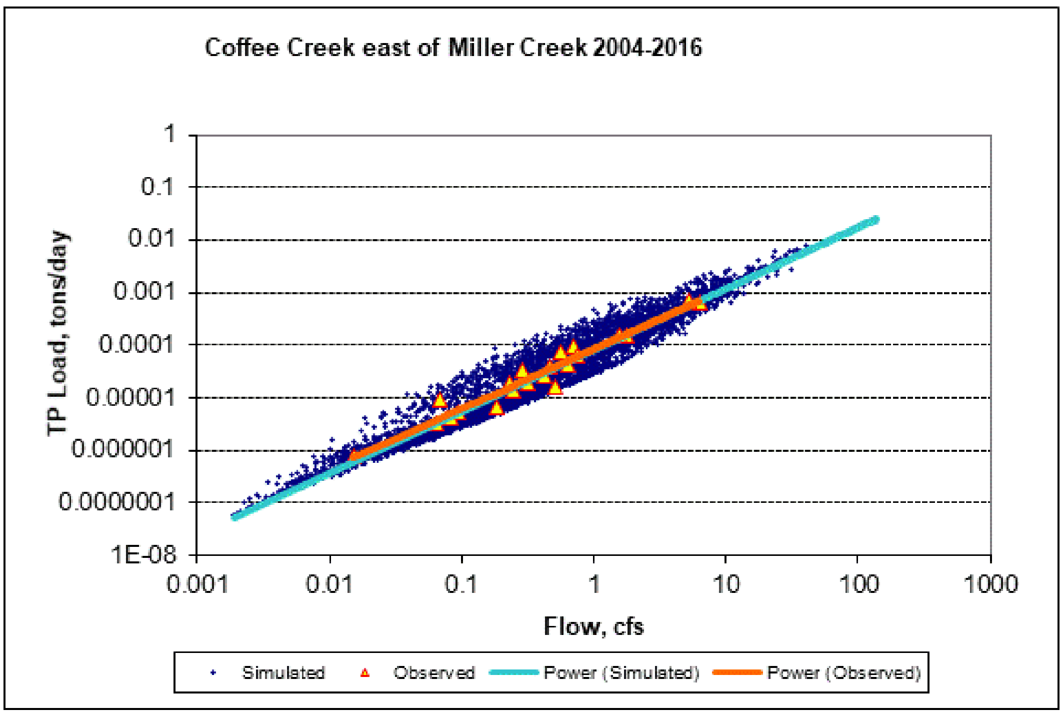


Figure E-554. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Coffee Creek east of Miller Creek (calibration period)

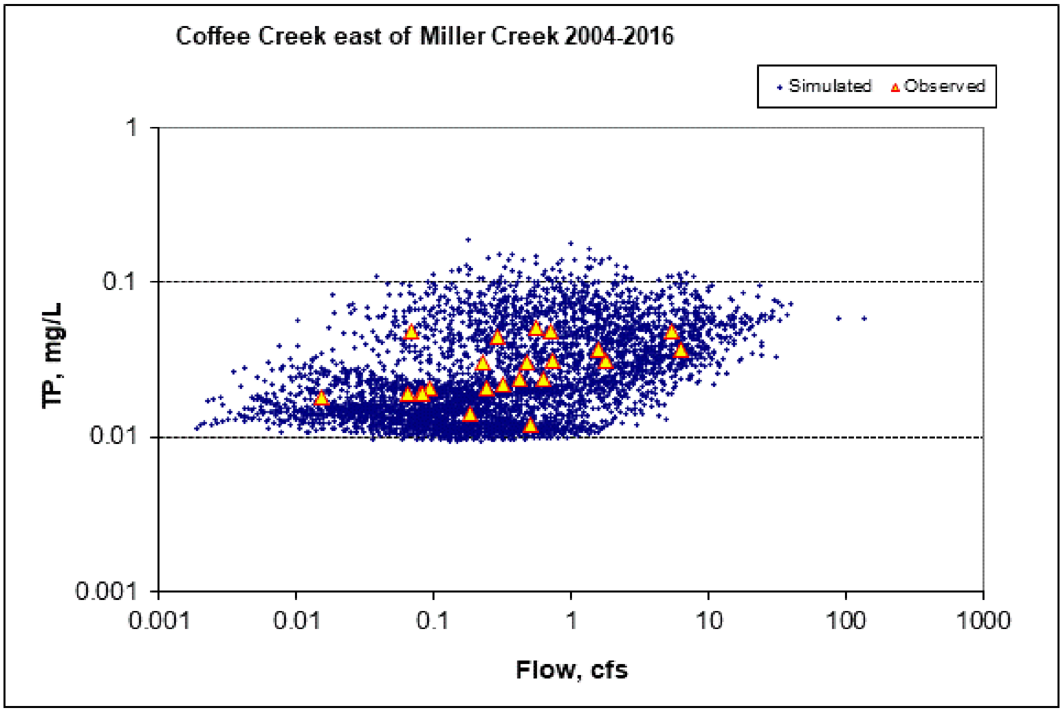
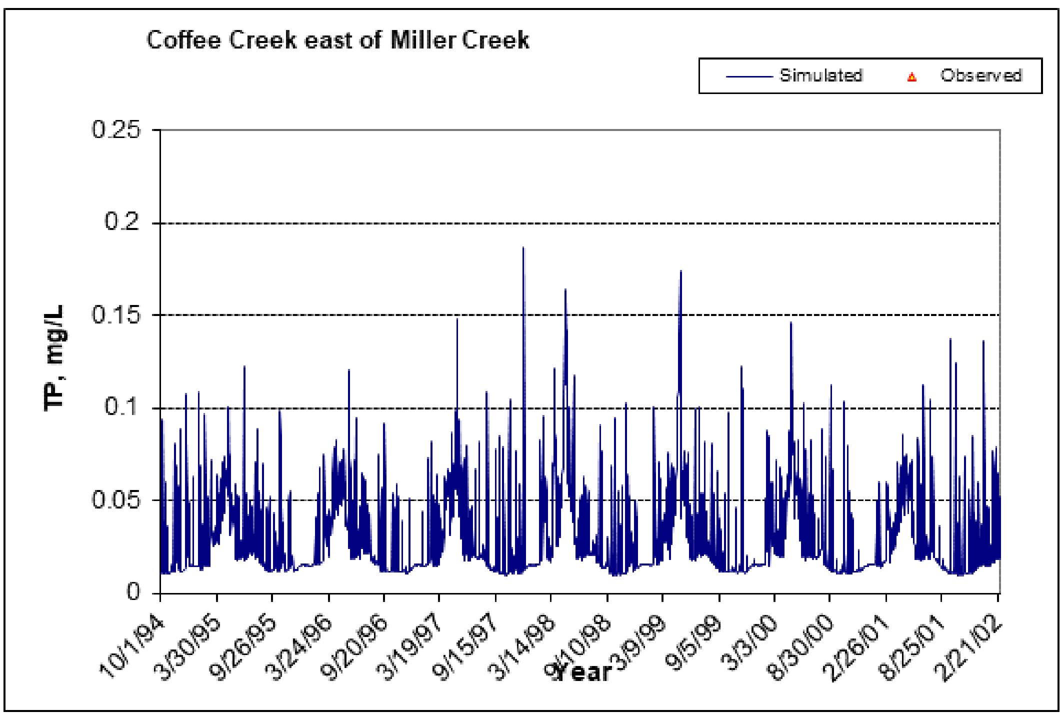
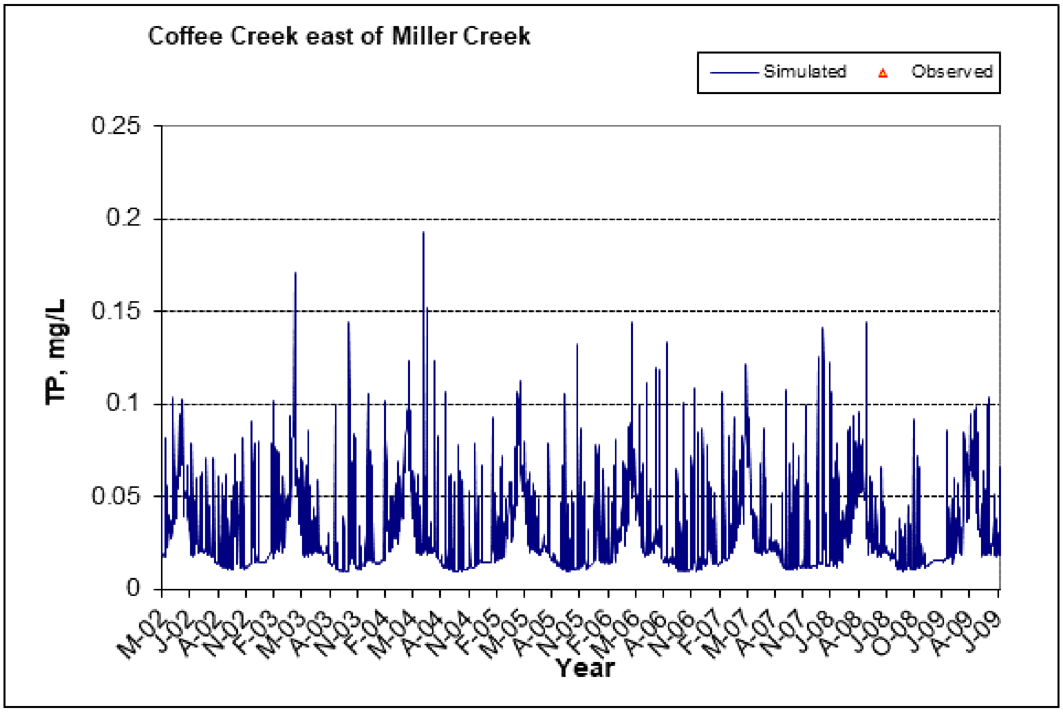


Figure E-555. Simulated and observed Total Phosphorus (TP) concentration vs flow at Coffee Creek east of Miller Creek (calibration period)





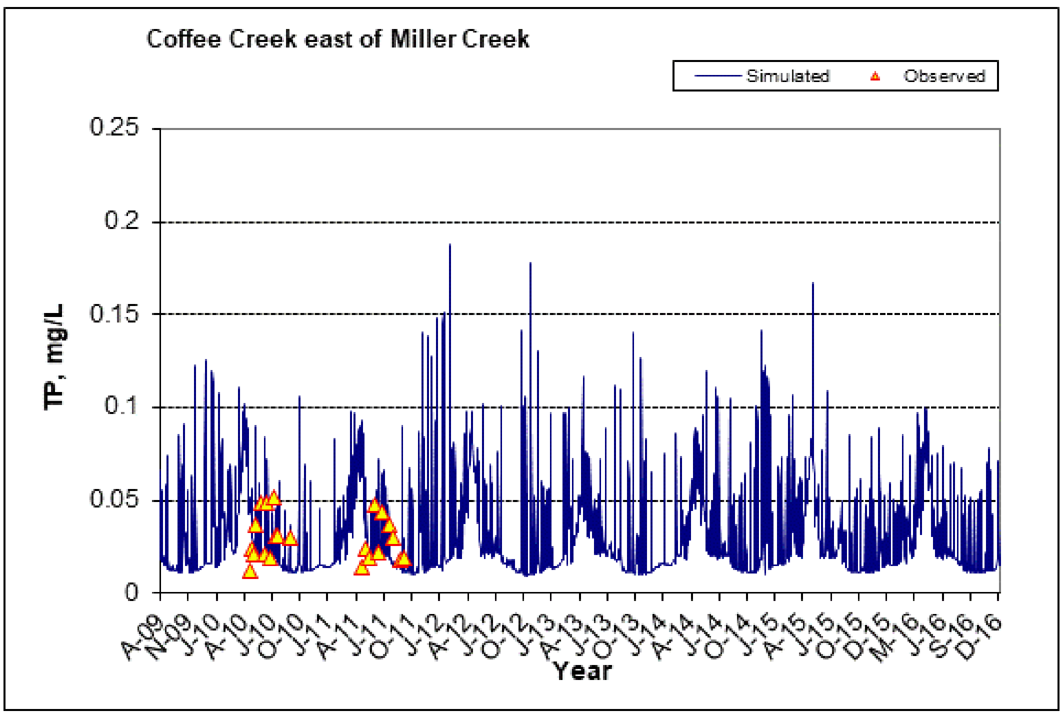


Figure E-556. Time series of observed and simulated Total Phosphorus (TP) concentration at Coffee Creek east of Miller Creek

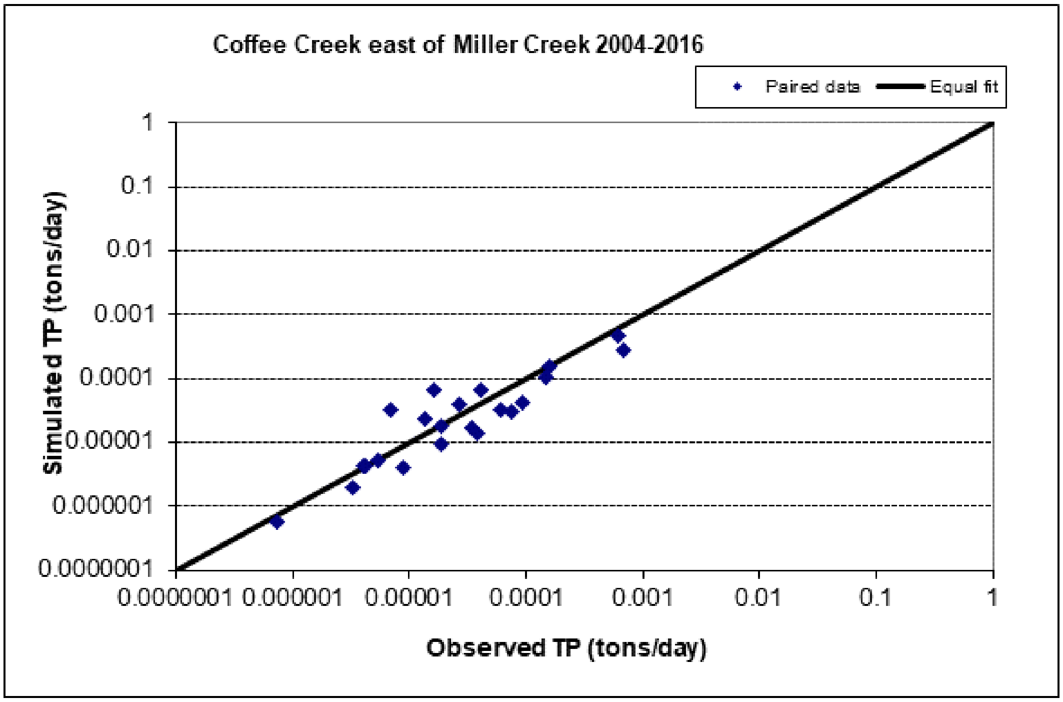


Figure E-557. Paired simulated vs. observed Total Phosphorus (TP) load at Coffee Creek east of Miller Creek (calibration period)

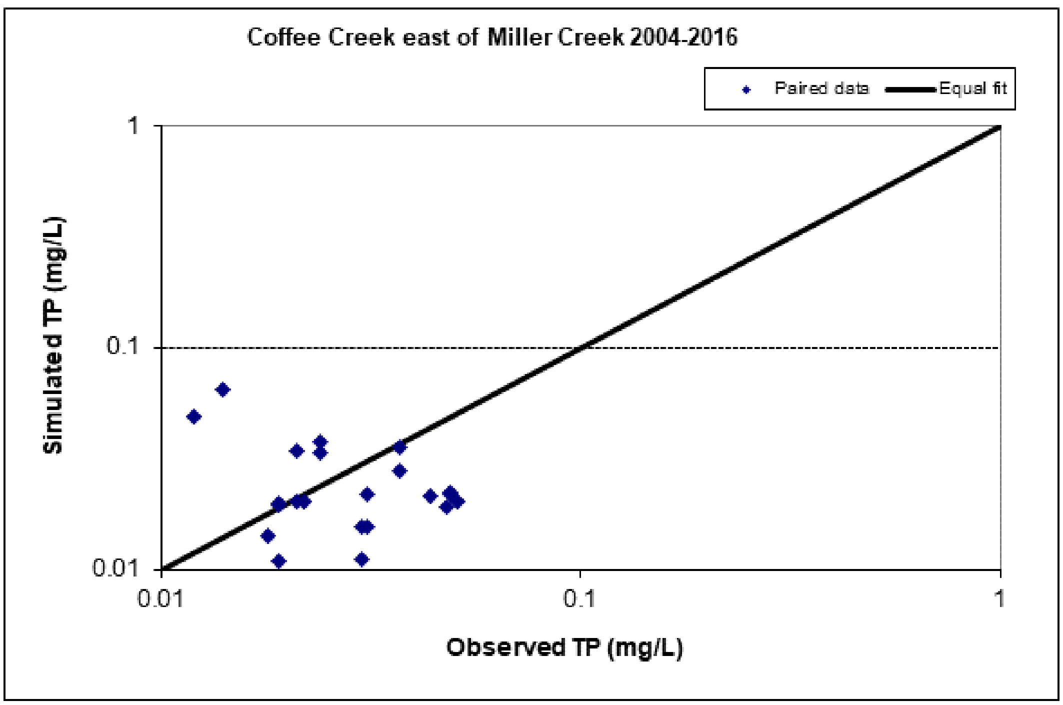


Figure E-558. Paired simulated vs. observed Total Phosphorus (TP) concentration at Coffee Creek east of Miller Creek (calibration period)

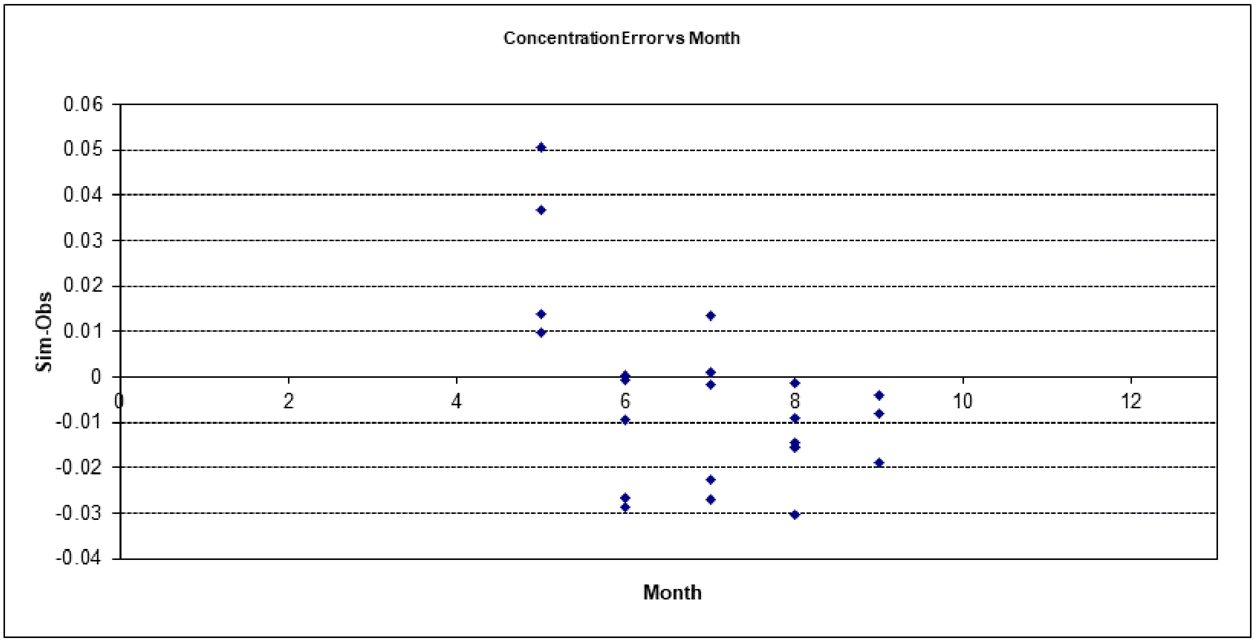


Figure E-559. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Coffee Creek east of Miller Creek

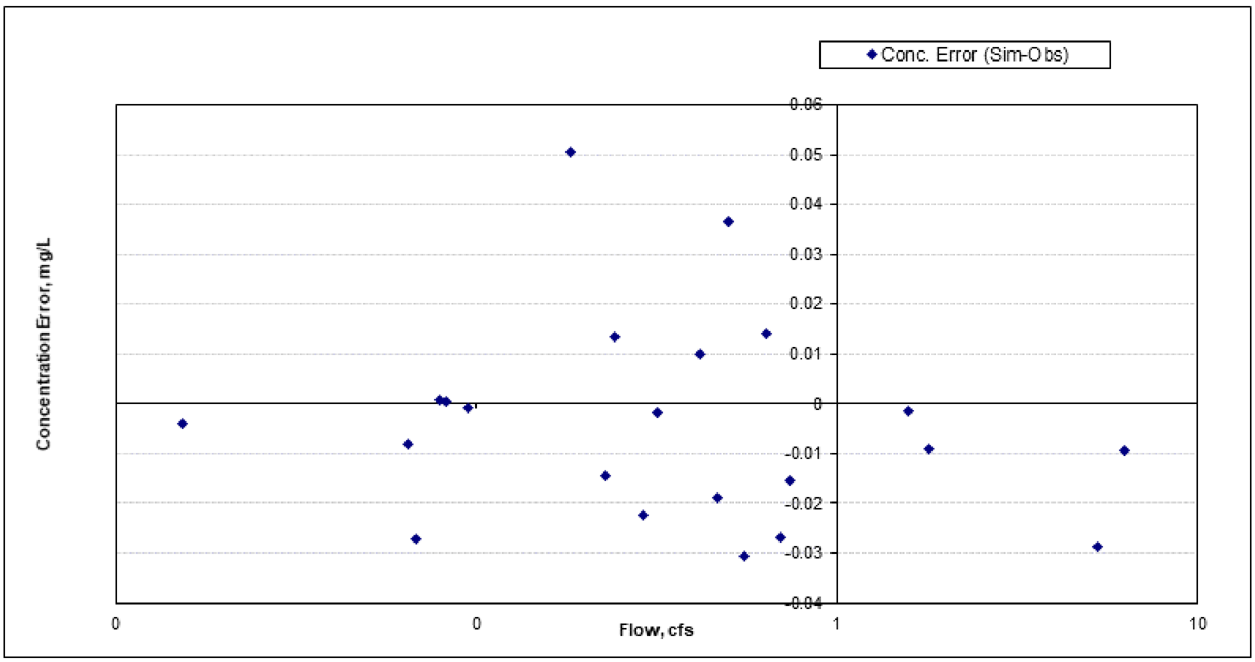


Figure E-560. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Coffee Creek east of Miller Creek

E.12 Miller Creek, Upper Gage at Hwy 53

E.12.1 Dissolved Oxygen (DO)

Table E-69. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	29
Concentration Average Error		-14.45%
Concentration Median Error		-20.09%
Load Average Error		5.81%
Load Median Error		-3.87%
Paired t conc		0.83
Paired t load		0.69

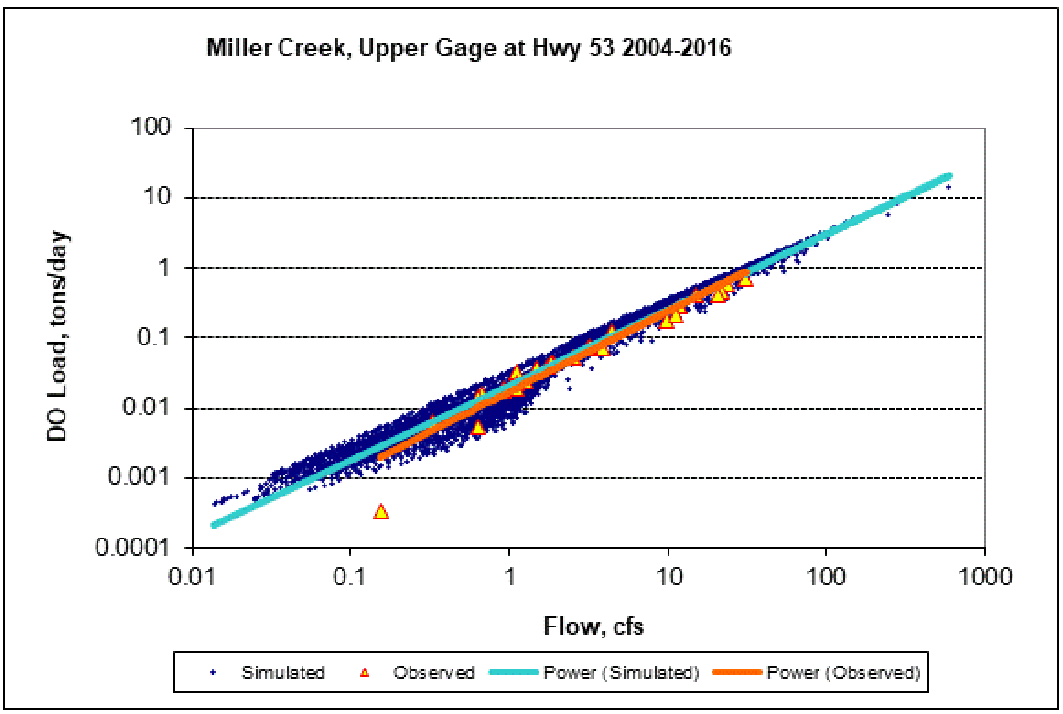


Figure E-561. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Miller Creek, Upper Gage at Hwy 53 (calibration period)

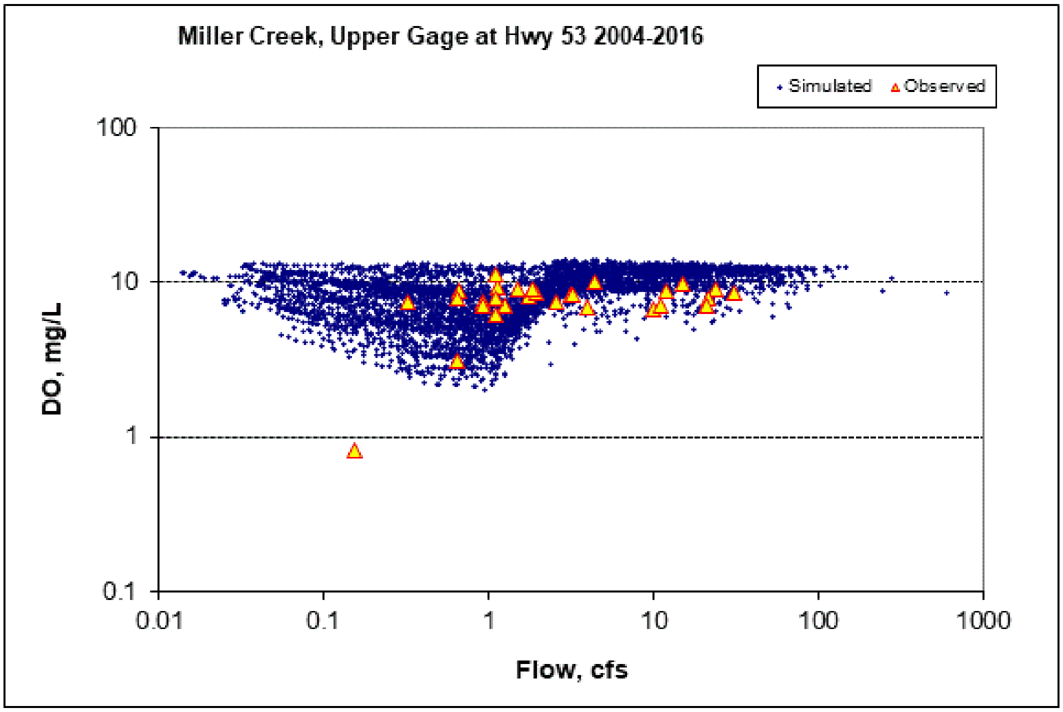
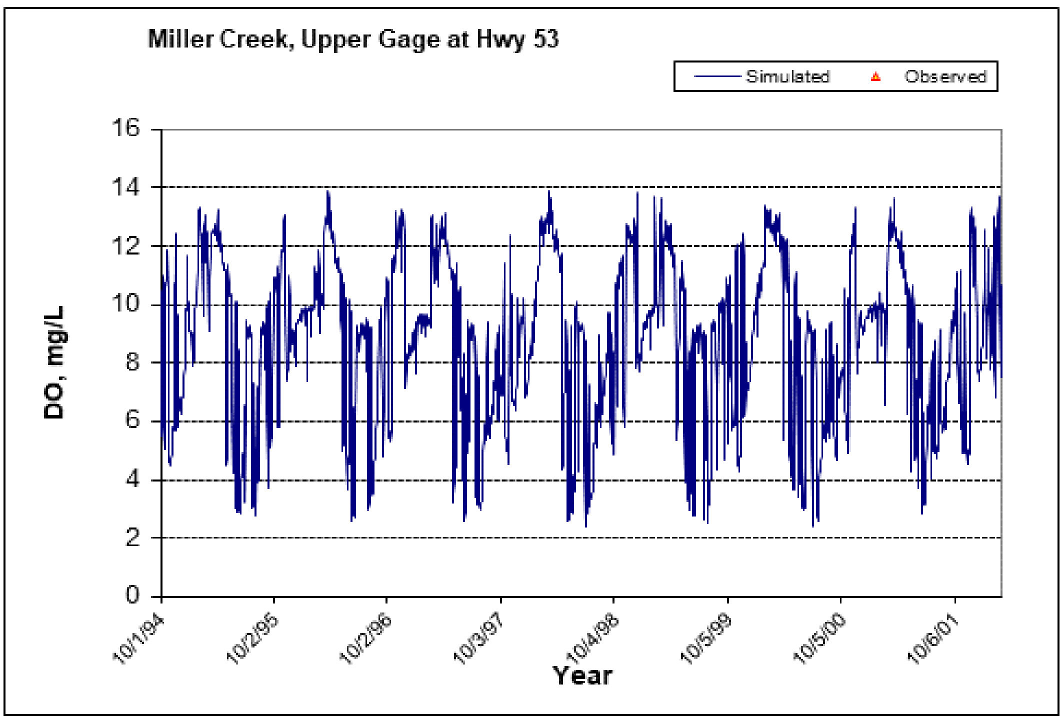
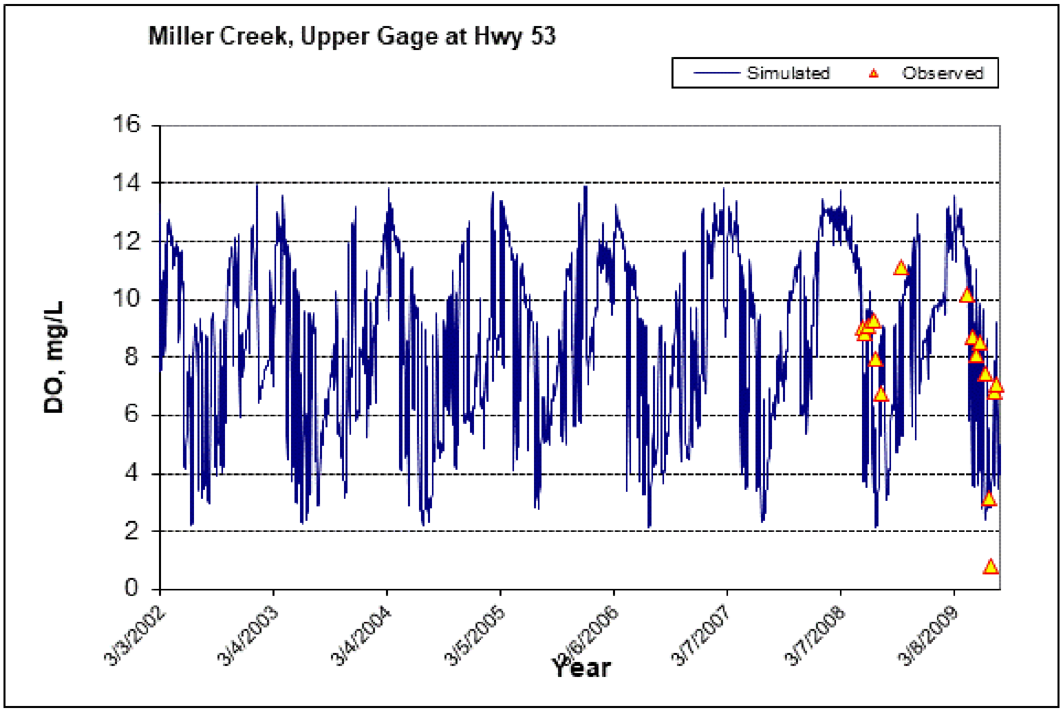


Figure E-562. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Miller Creek, Upper Gage at Hwy 53 (calibration period)





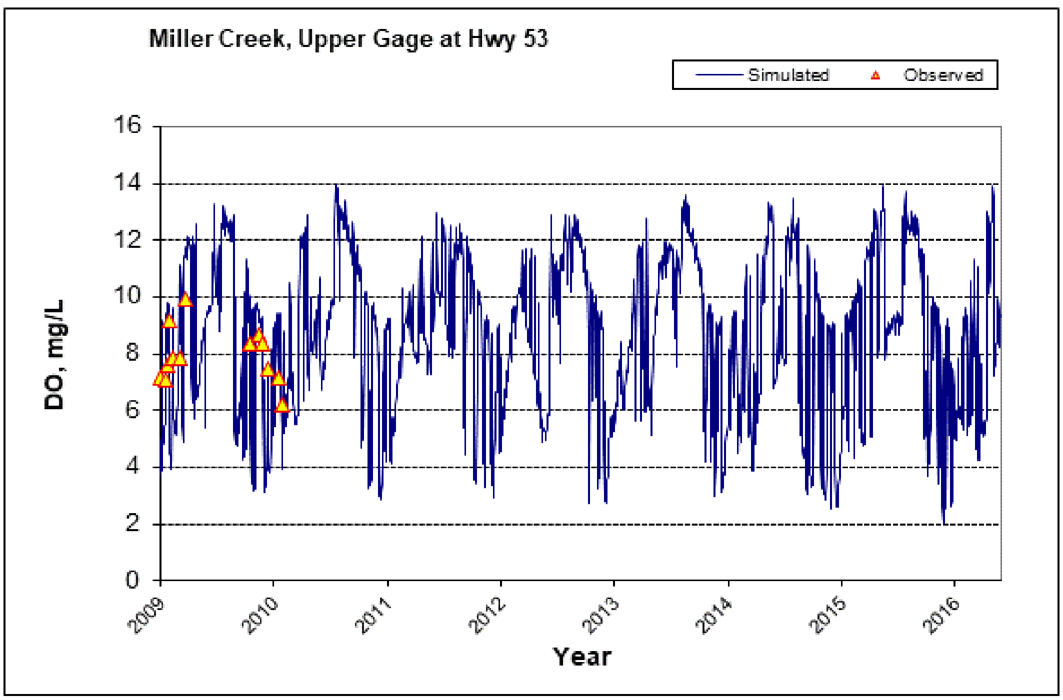


Figure E-563. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Miller Creek, Upper Gage at Hwy 53

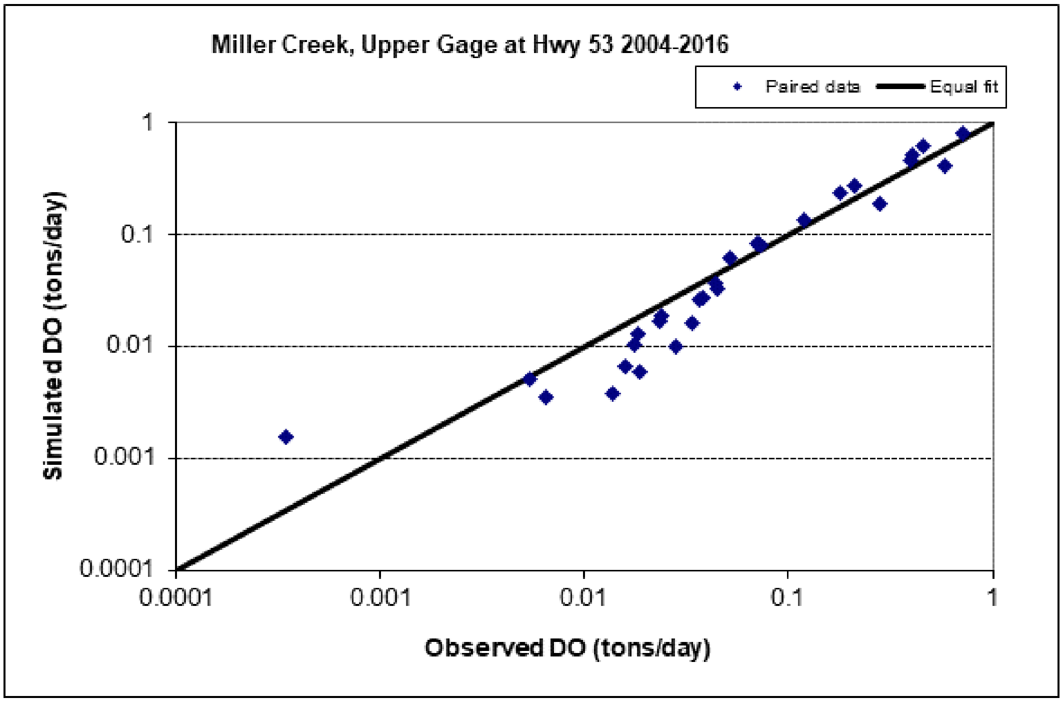


Figure E-564. Paired simulated vs. observed Dissolved Oxygen (DO) load at Miller Creek, Upper Gage at Hwy 53 (calibration period)

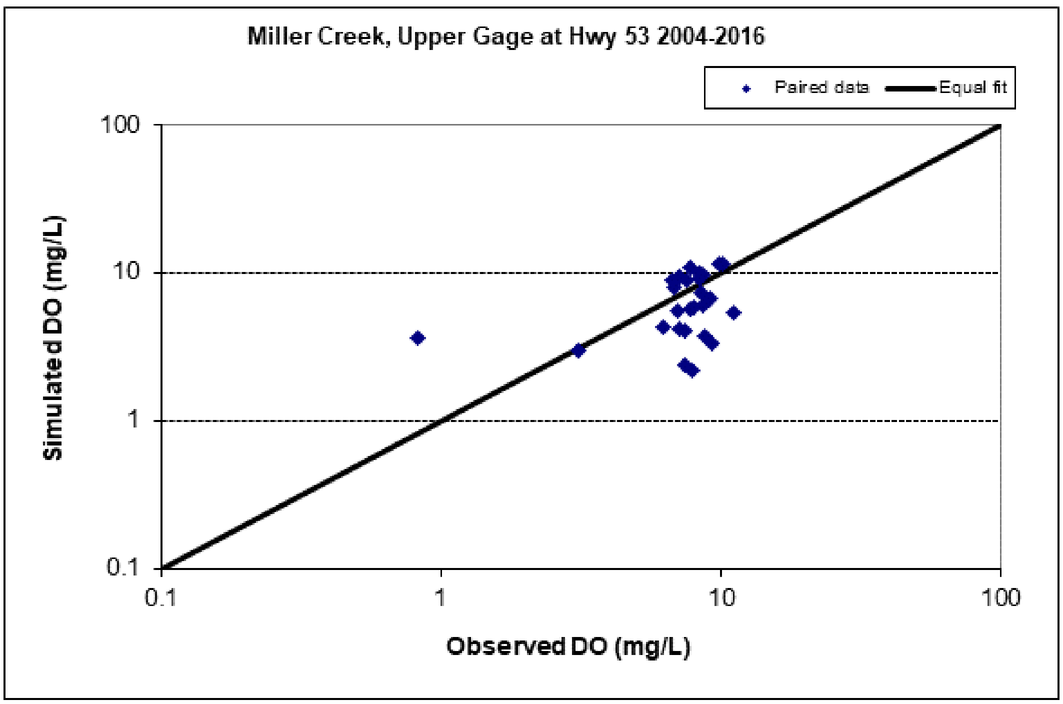


Figure E-565. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Miller Creek, Upper Gage at Hwy 53 (calibration period)

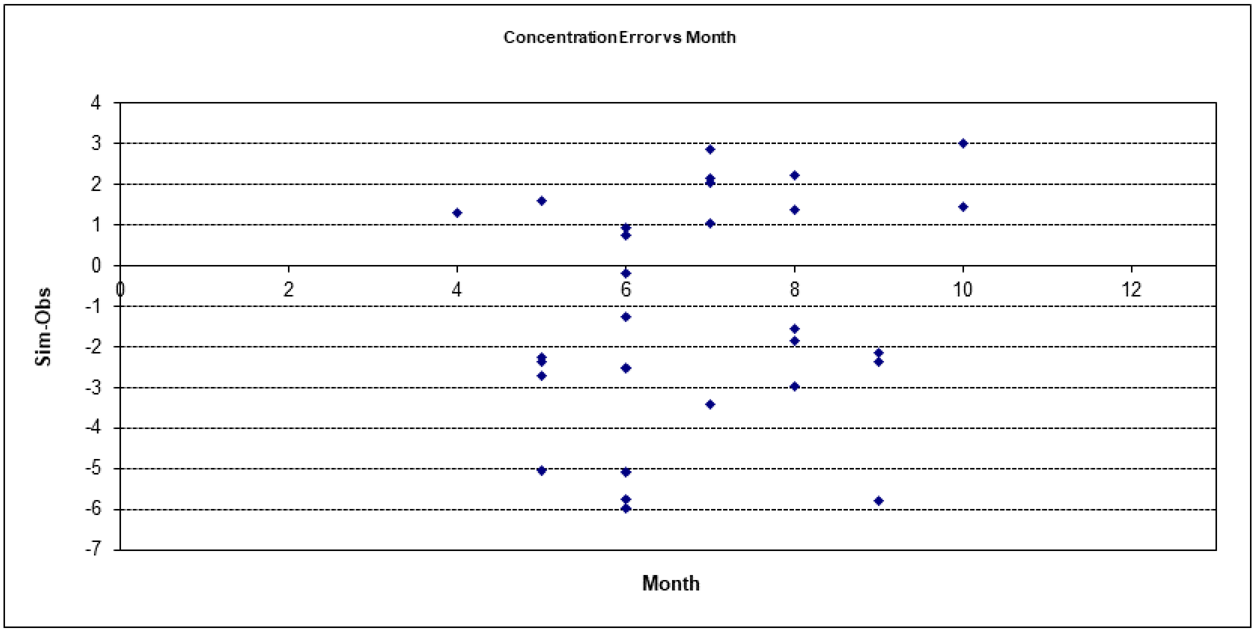


Figure E-566. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Miller Creek, Upper Gage at Hwy 53

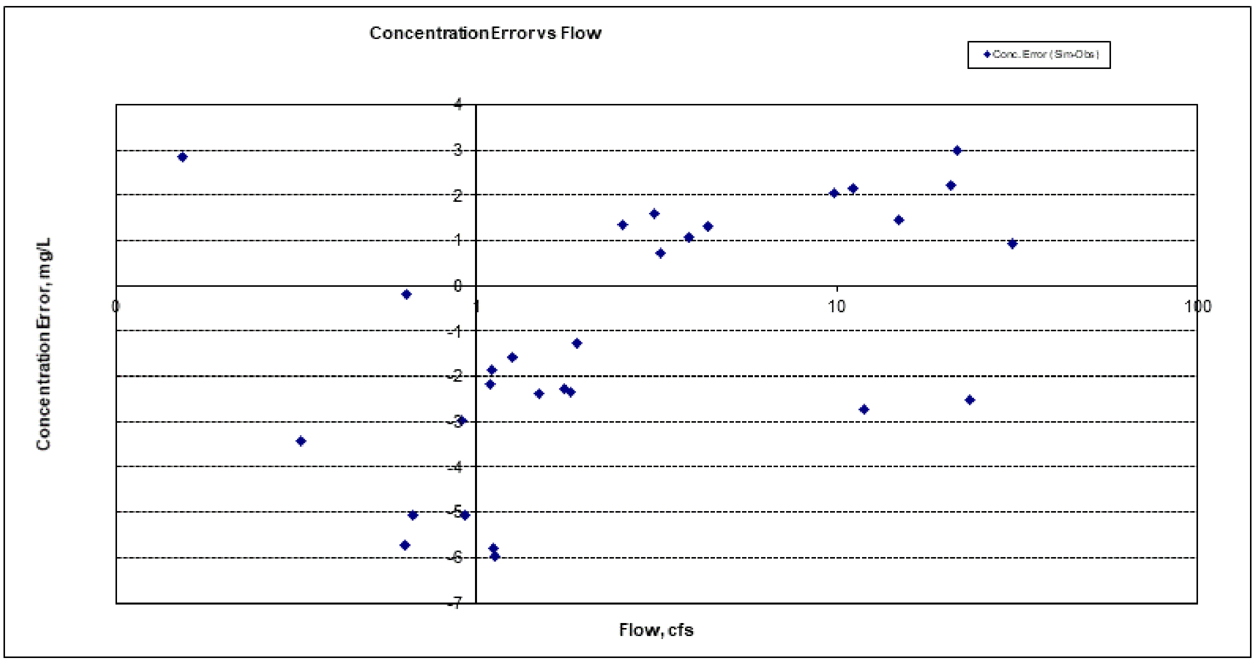


Figure E-567. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Miller Creek, Upper Gage at Hwy 53

E.12.2 Ammonia Nitrogen (NH3)

Table E-70. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	31
Concentration Average Error		103.38%
Concentration Median Error		0.78%
Load Average Error		300.41%
Load Median Error		0.11%
Paired t conc		0.03
Paired t load		0.00

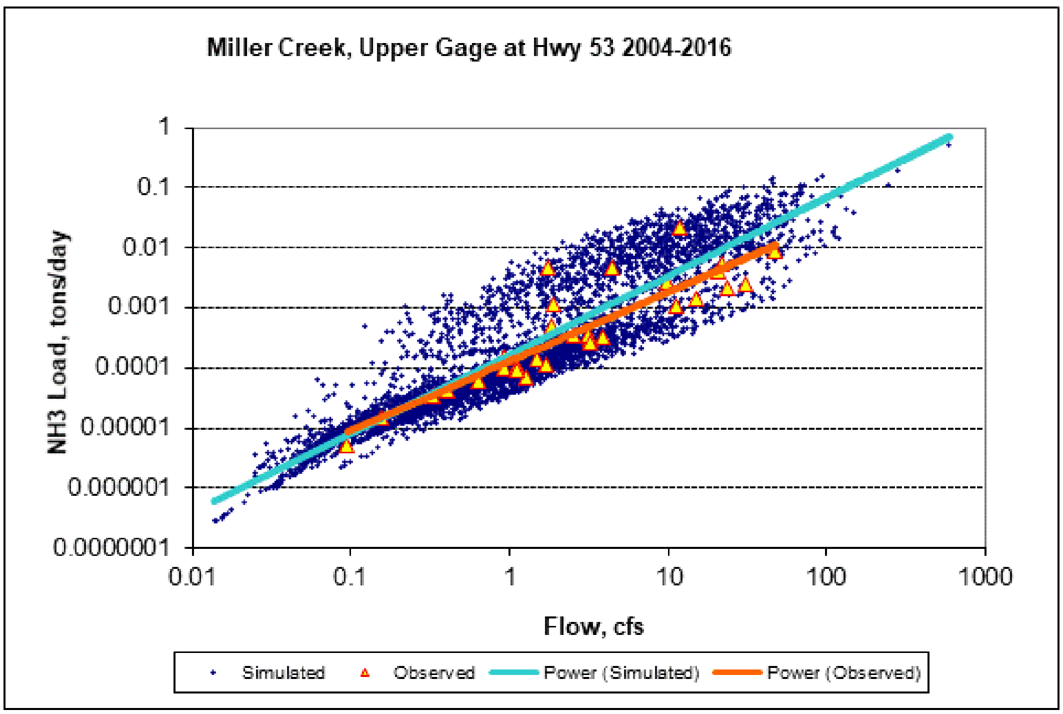


Figure E-568. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Miller Creek, Upper Gage at Hwy 53 (calibration period)

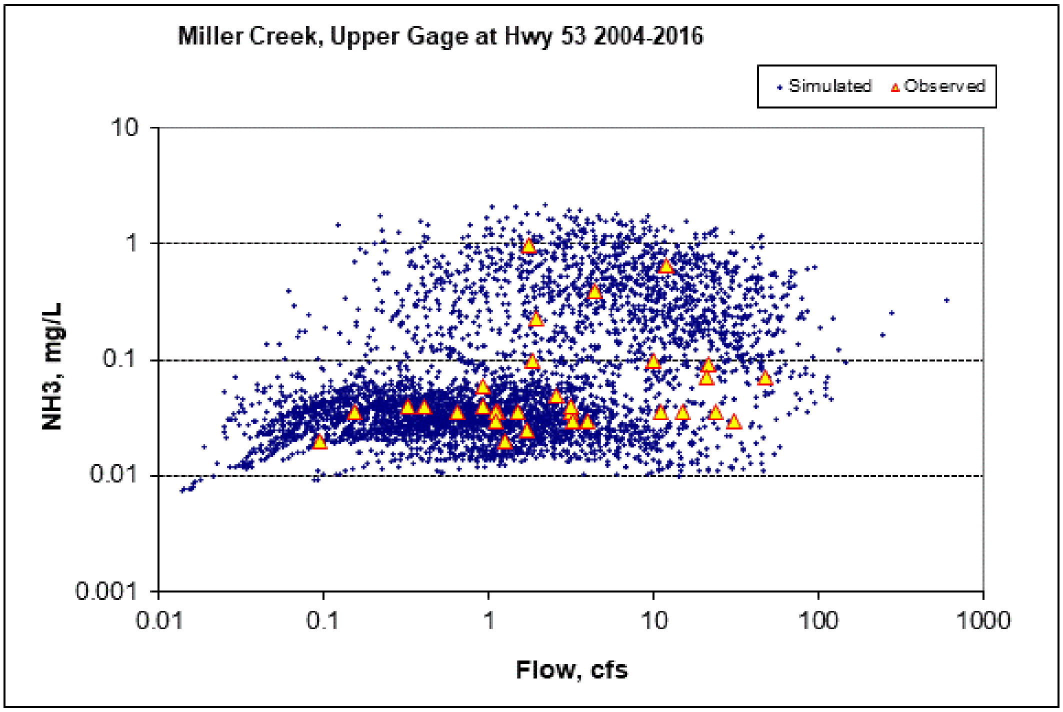
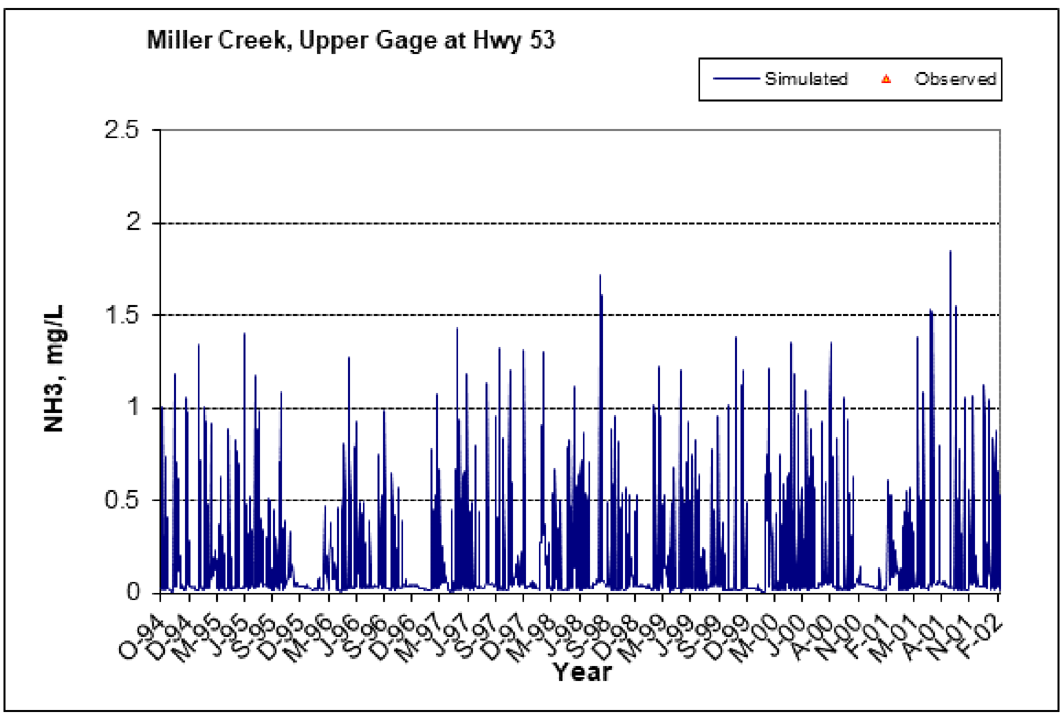


Figure E-569. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Miller Creek, Upper Gage at Hwy 53 (calibration period)



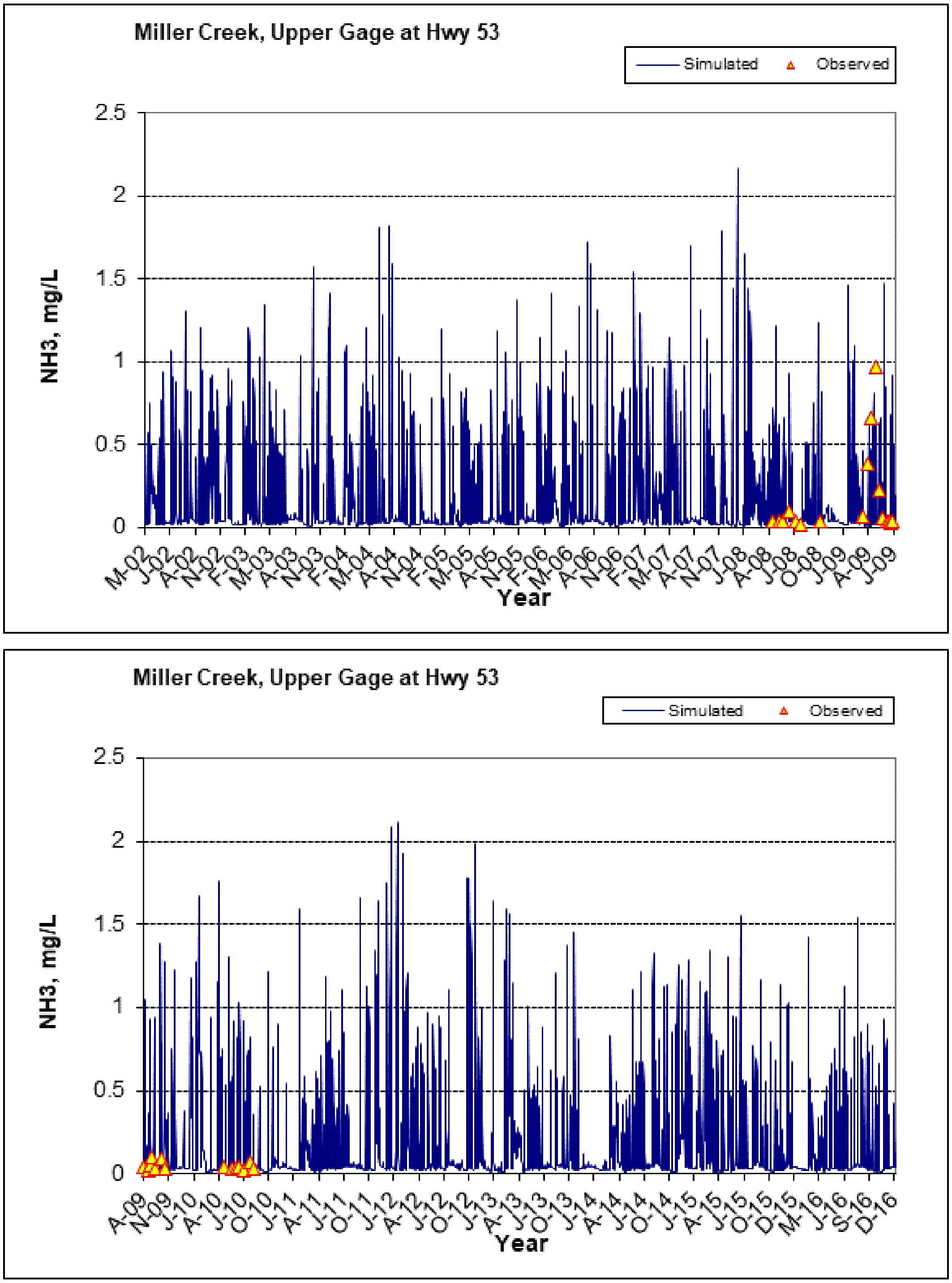


Figure E-570. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Miller Creek, Upper Gage at Hwy 53

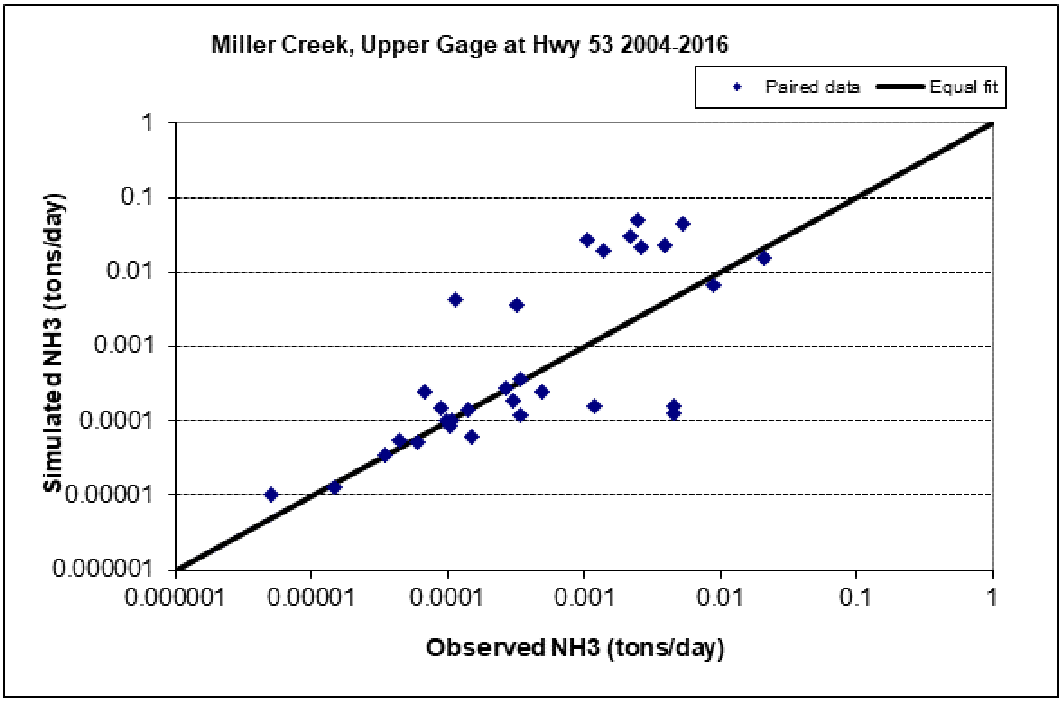


Figure E-571. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Miller Creek, Upper Gage at Hwy 53 (calibration period)

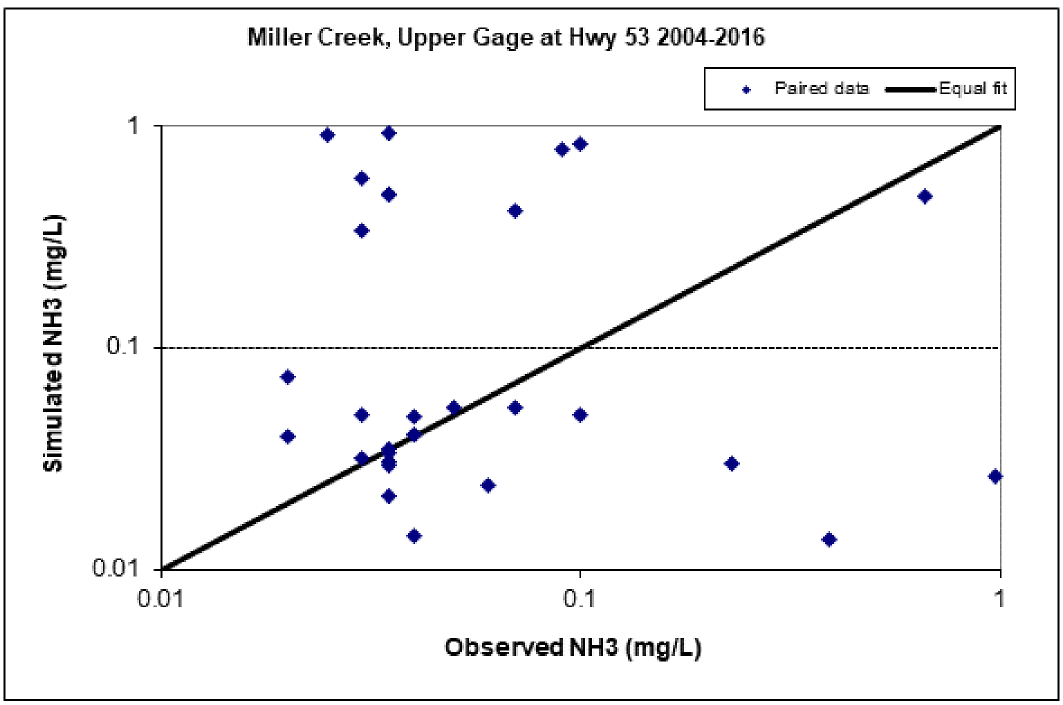


Figure E-572. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Miller Creek, Upper Gage at Hwy 53 (calibration period)

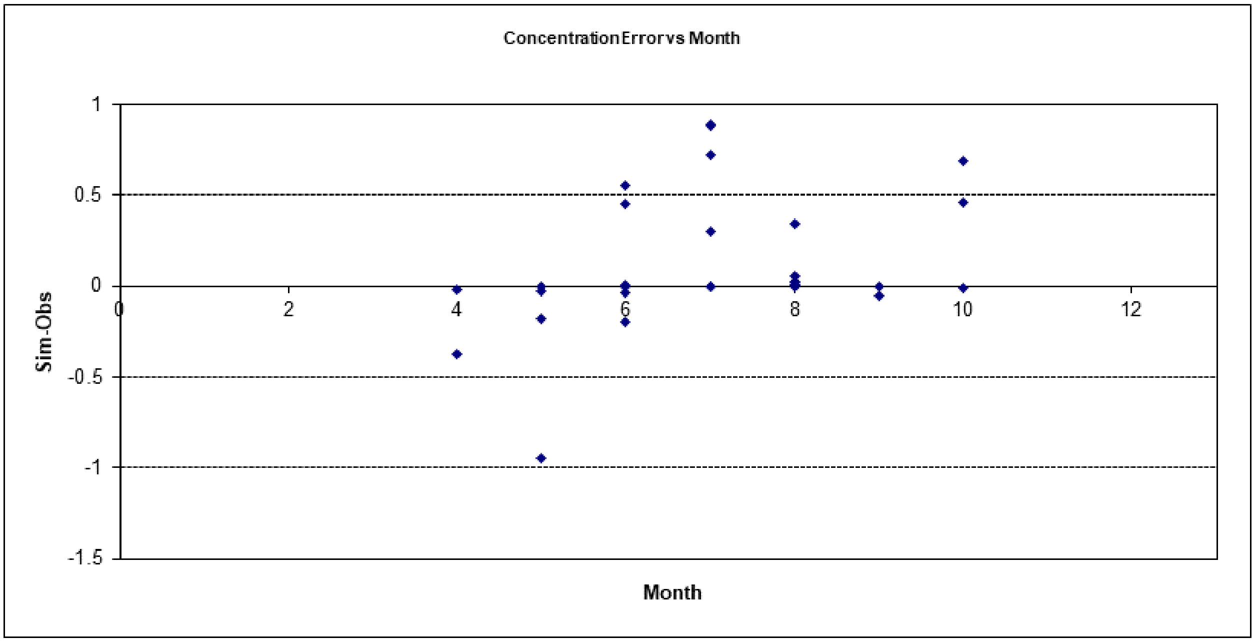


Figure E-573. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Miller Creek, Upper Gage at Hwy 53

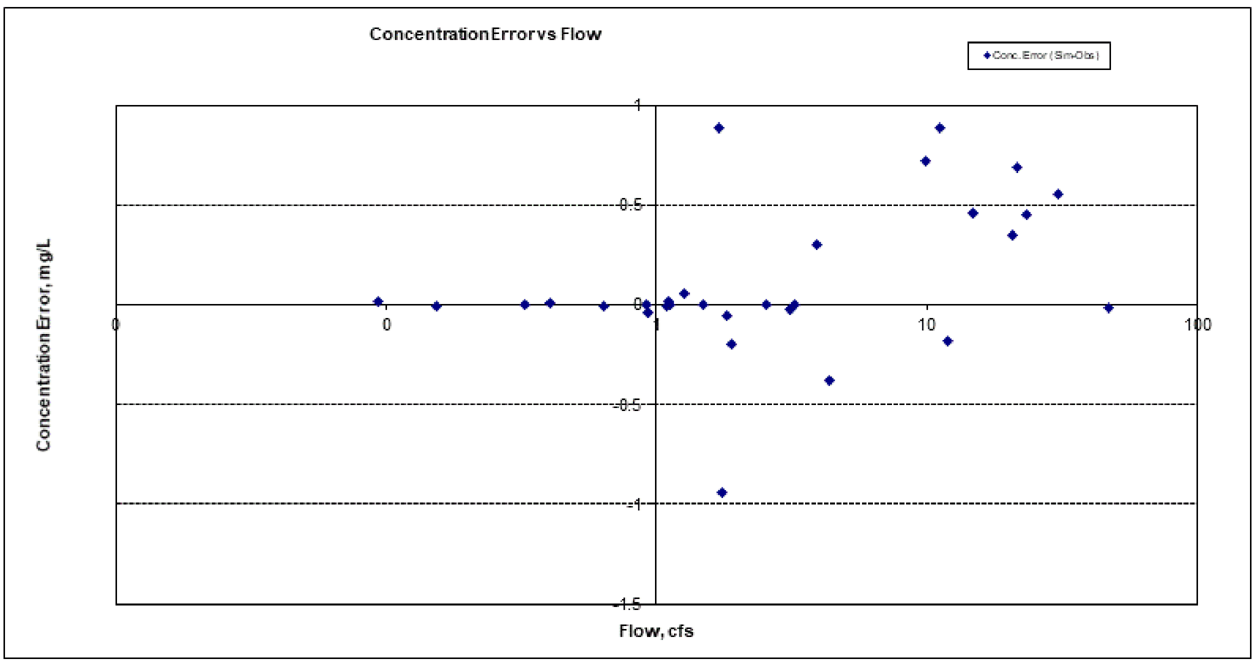


Figure E-574. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Miller Creek, Upper Gage at Hwy 53

E.12.3 Nitrite+ Nitrate Nitrogen (NOx)

Table E-71. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	26
Concentration Average Error		570.65%
Concentration Median Error		48.39%
Load Average Error		1283.08%
Load Median Error		6.75%
Paired t conc		0.00
Paired t load		0.00

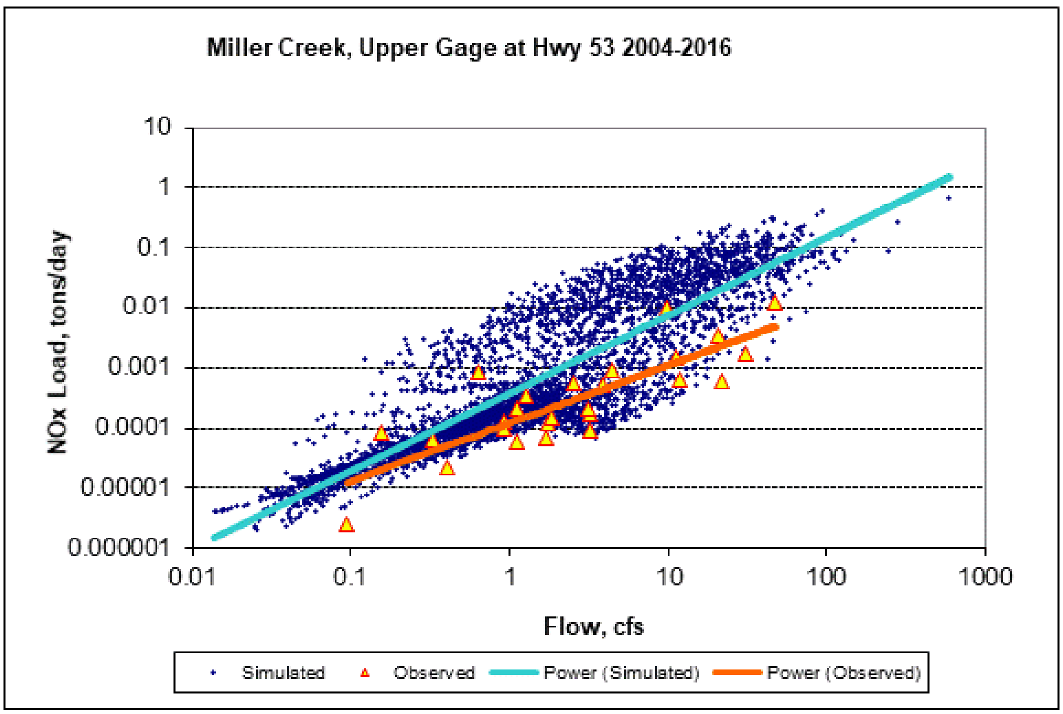


Figure E-575. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Miller Creek, Upper Gage at Hwy 53 (calibration period)

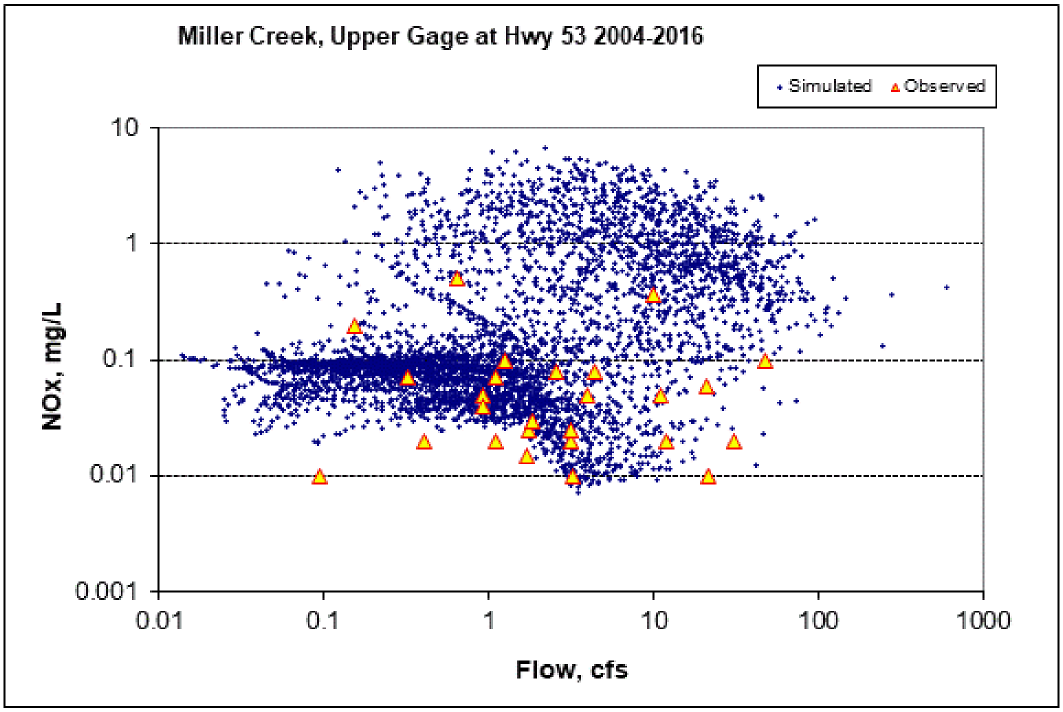
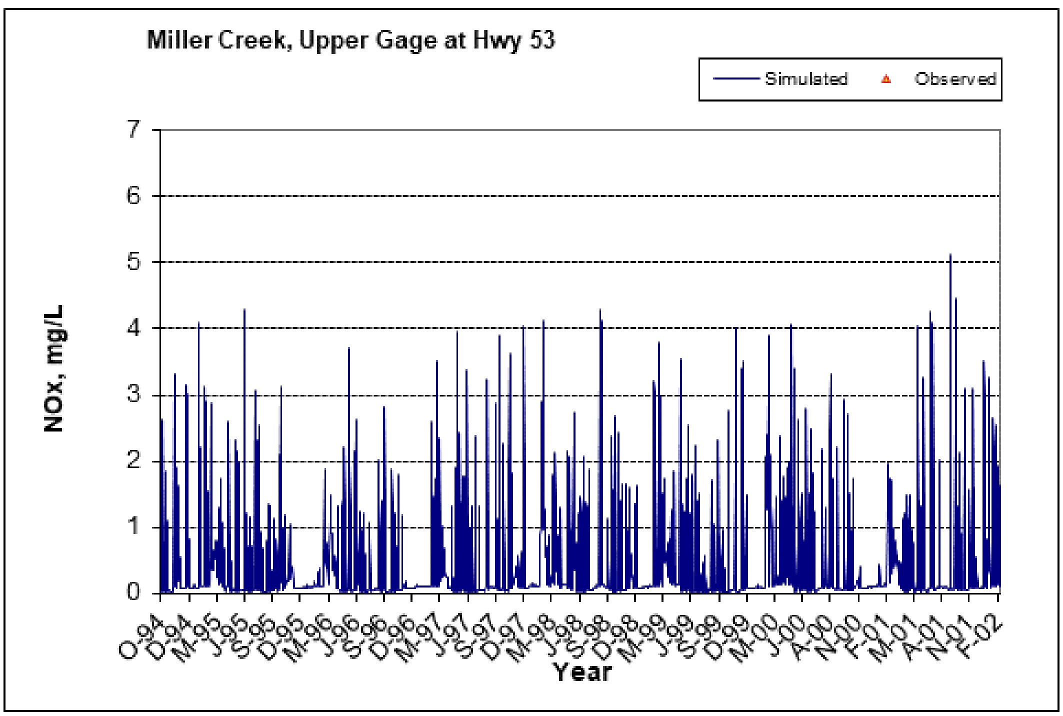
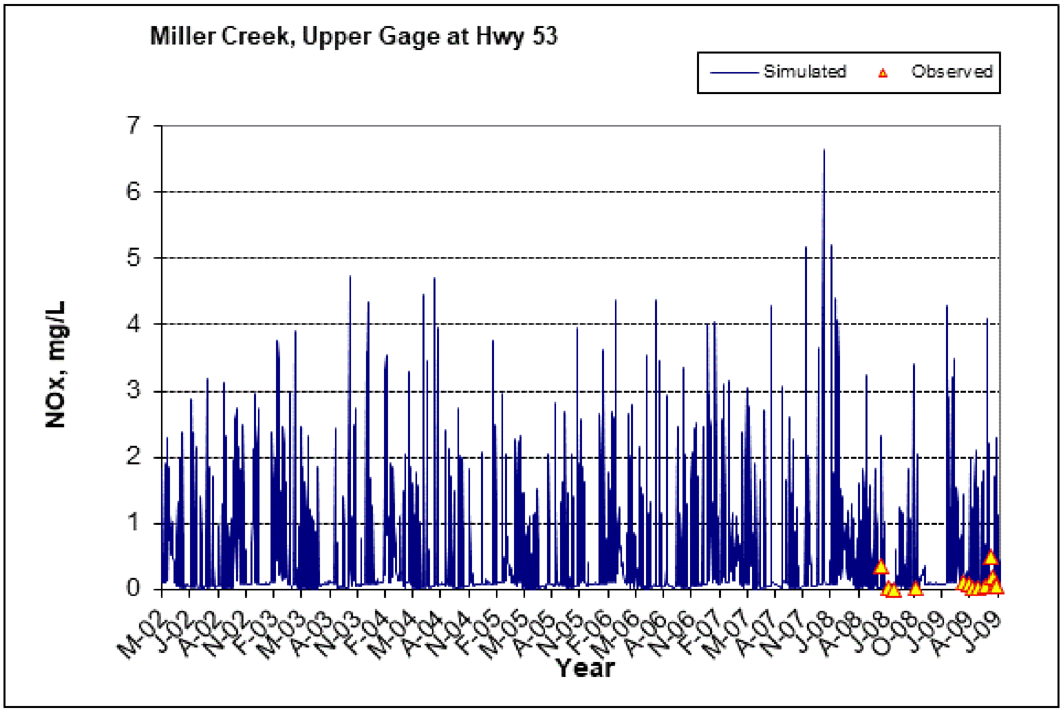


Figure E-576. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Miller Creek, Upper Gage at Hwy 53 (calibration period)





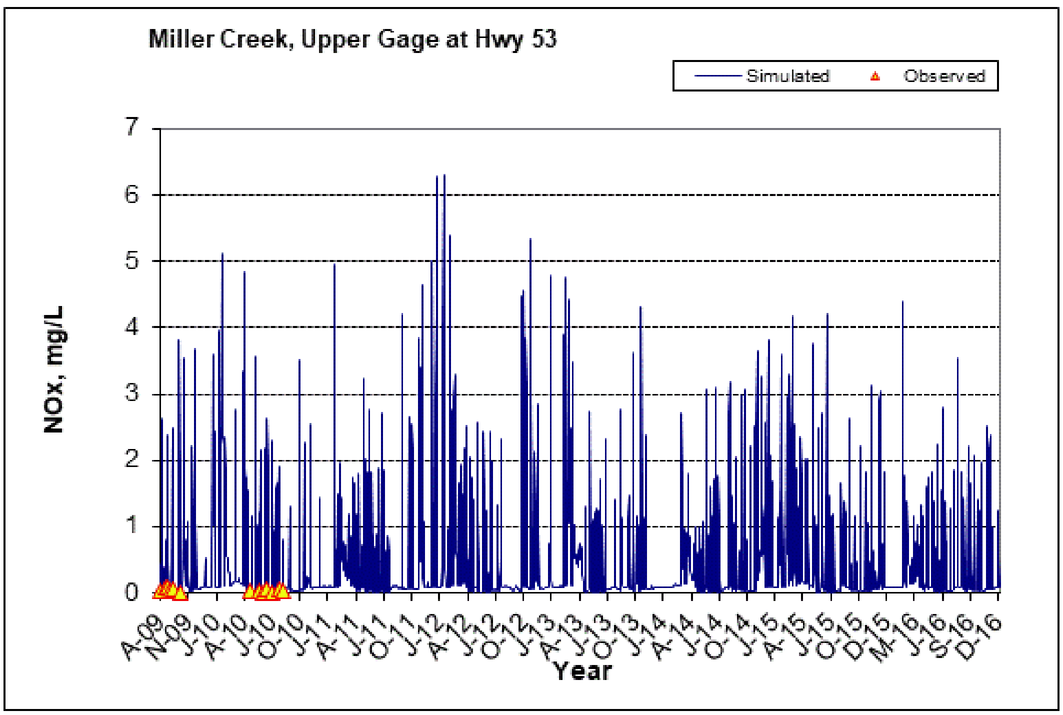


Figure E-577. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Miller Creek, Upper Gage at Hwy 53

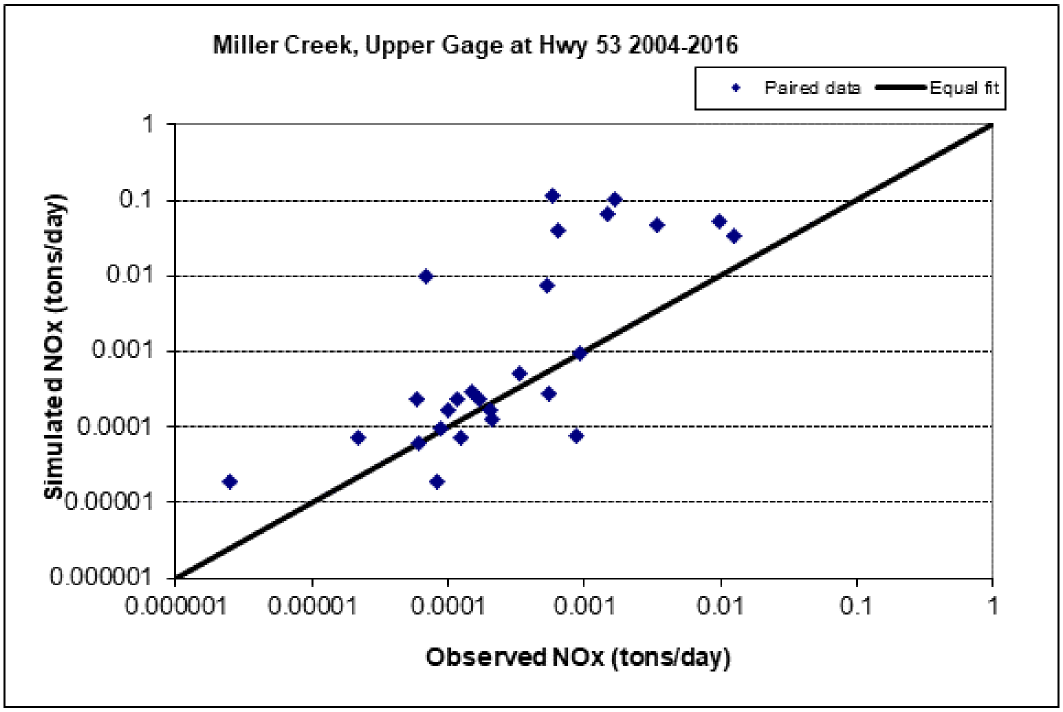


Figure E-578. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Miller Creek, Upper Gage at Hwy 53 (calibration period)

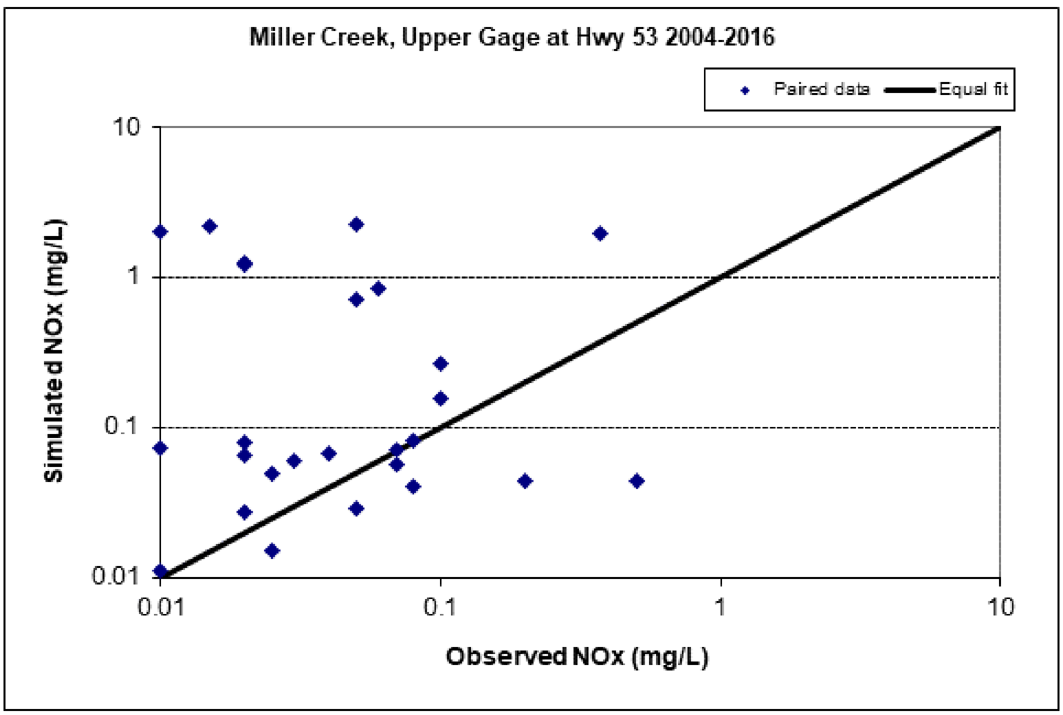


Figure E-579. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Miller Creek, Upper Gage at Hwy 53 (calibration period)

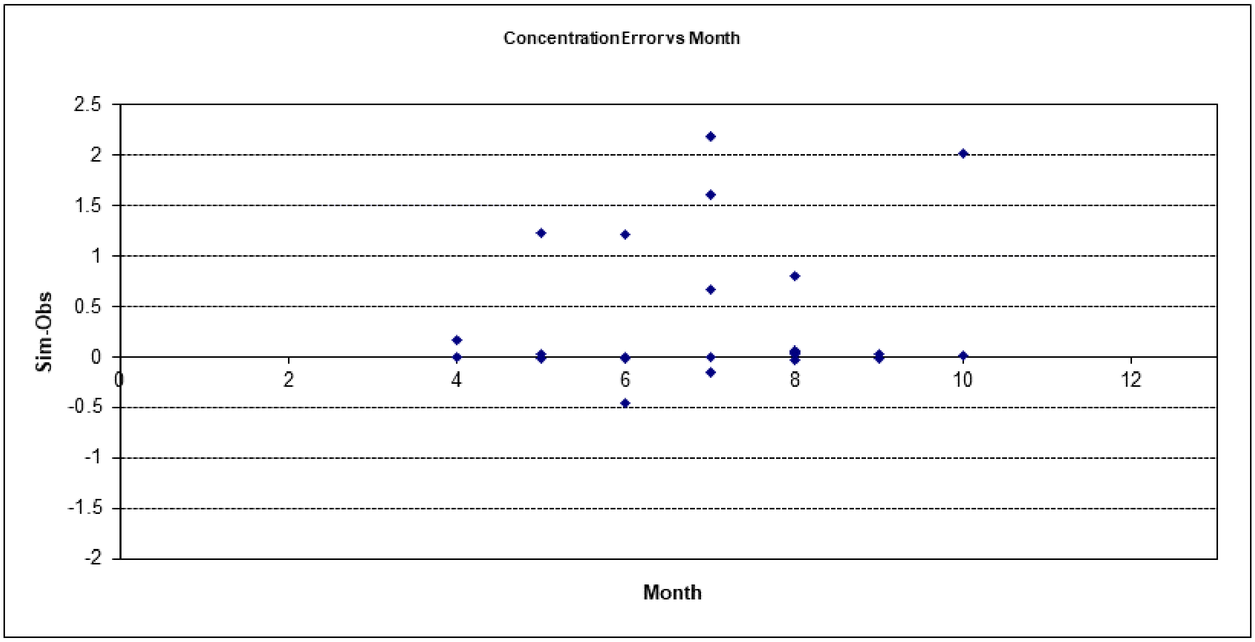


Figure E-580. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Miller Creek, Upper Gage at Hwy 53

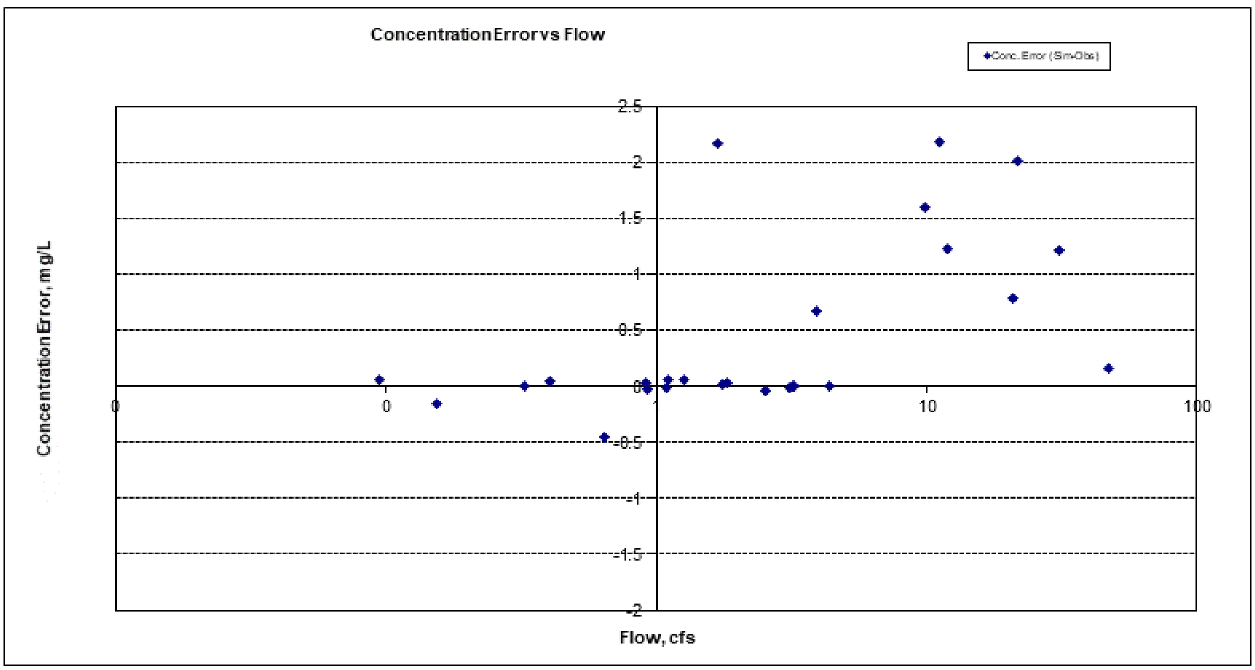


Figure E-581. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Miller Creek, Upper Gage at Hwy 53

E.12.4 Total Phosphorus (TP)

Table E-72. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	31
Concentration Average Error		-7.70%
Concentration Median Error		-19.31%
Load Average Error		50.40%
Load Median Error		-0.93%
Paired t conc		0.88
Paired t load		0.22

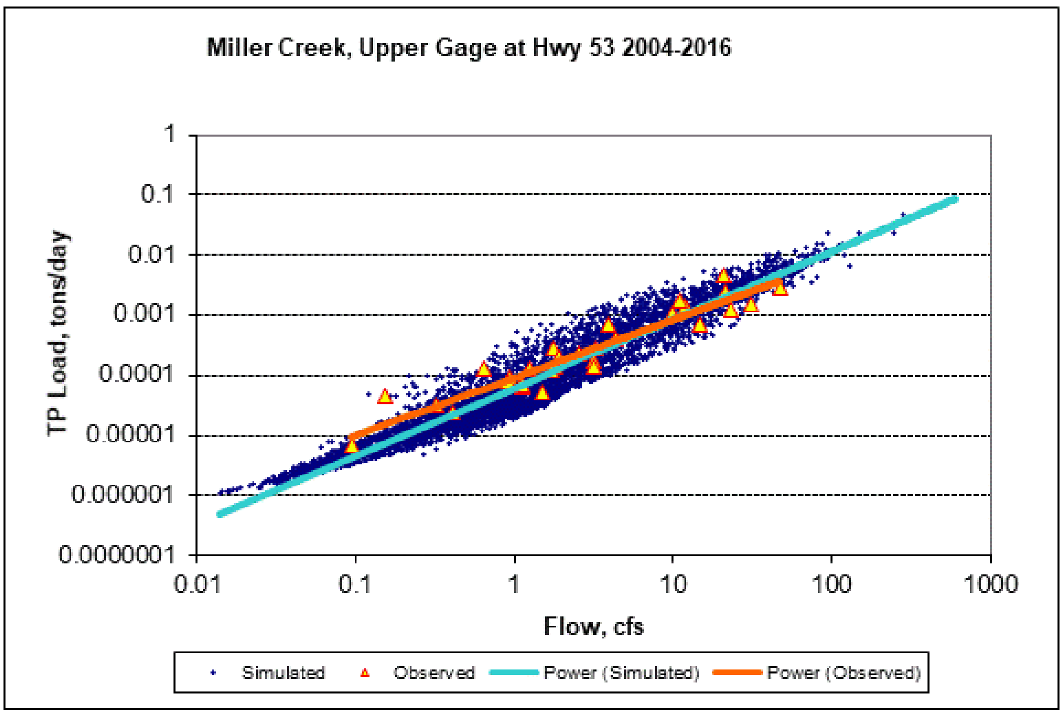


Figure E-582. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Miller Creek, Upper Gage at Hwy 53 (calibration period)

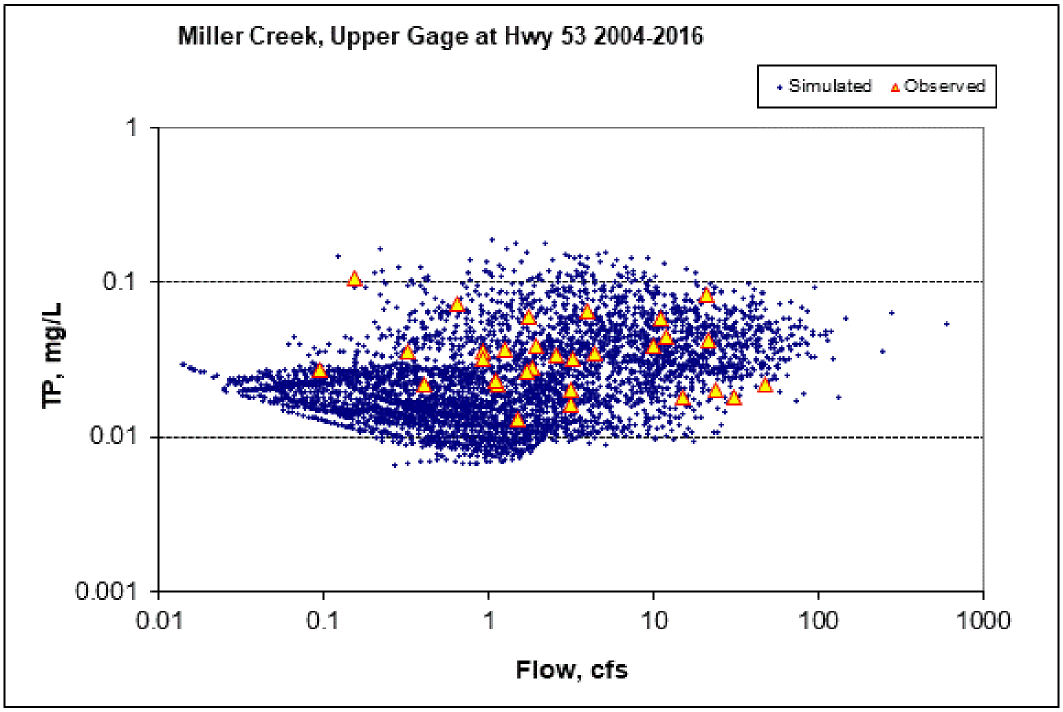
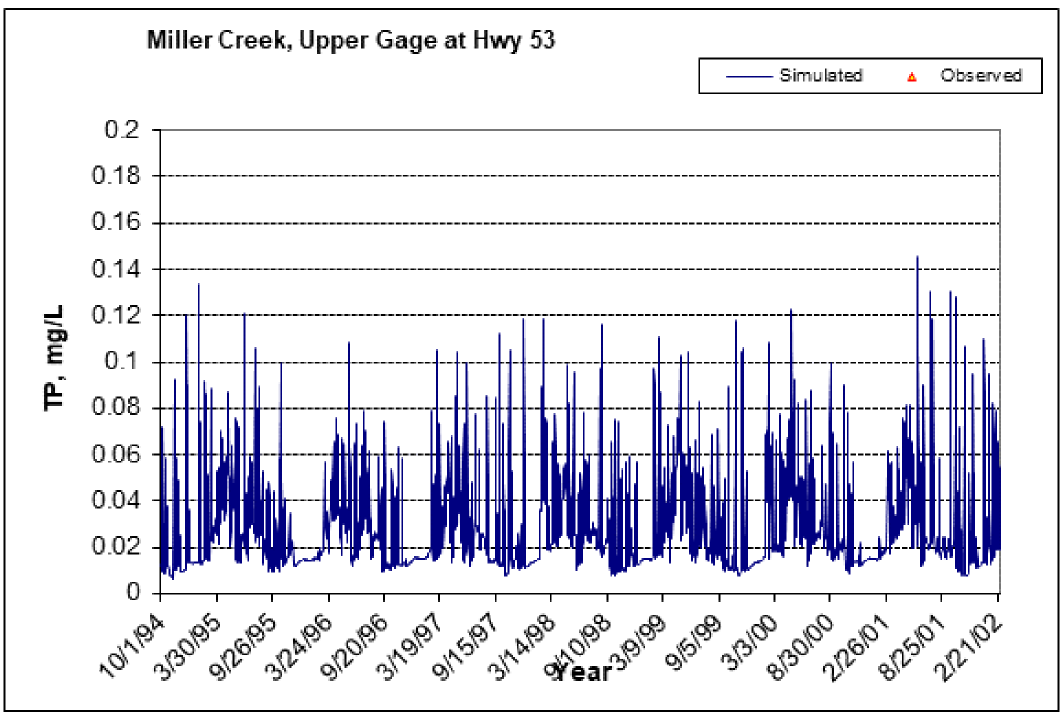
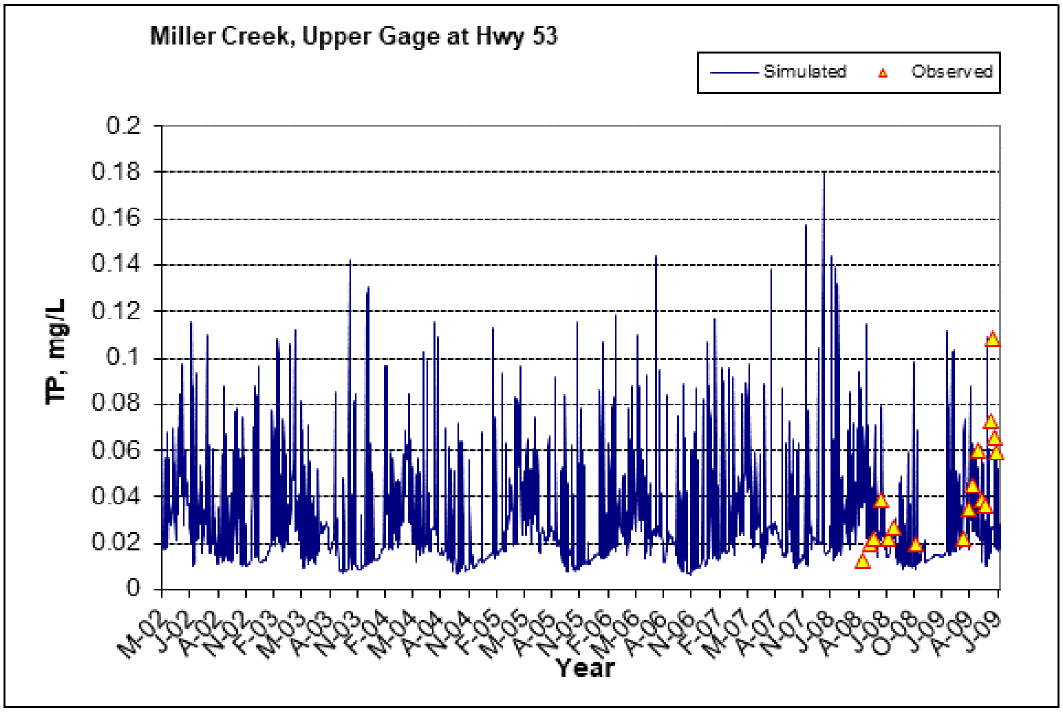


Figure E-583. Simulated and observed Total Phosphorus (TP) concentration vs flow at Miller Creek, Upper Gage at Hwy 53 (calibration period)





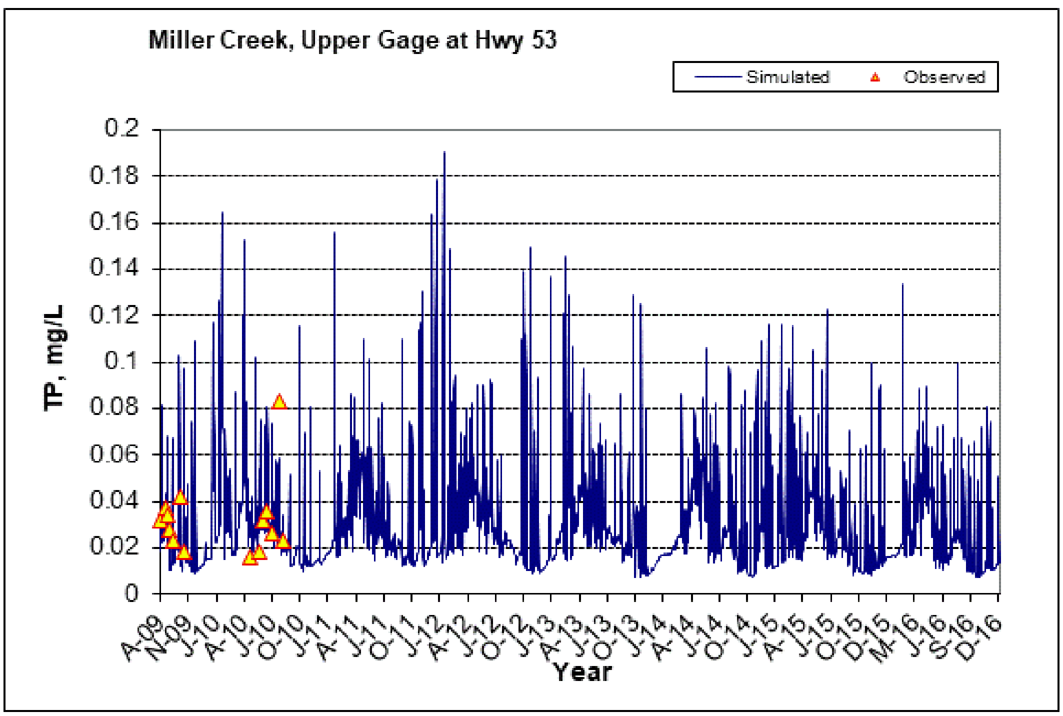


Figure E-584. Time series of observed and simulated Total Phosphorus (TP) concentration at Miller Creek, Upper Gage at Hwy 53

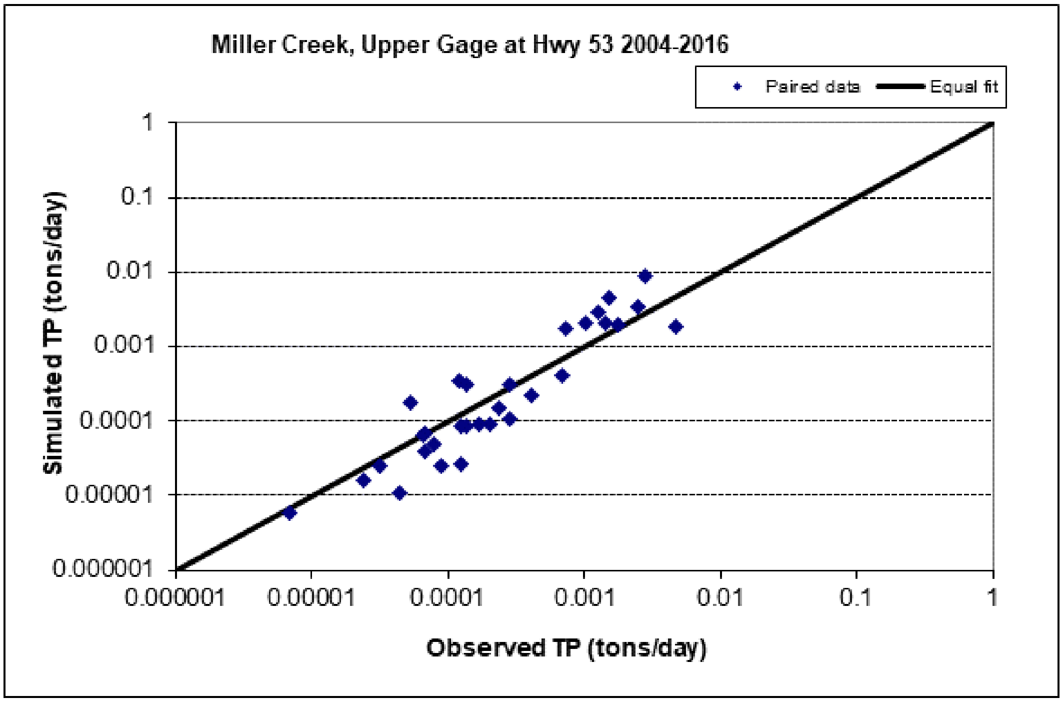


Figure E-585. Paired simulated vs. observed Total Phosphorus (TP) load at Miller Creek, Upper Gage at Hwy 53 (calibration period)

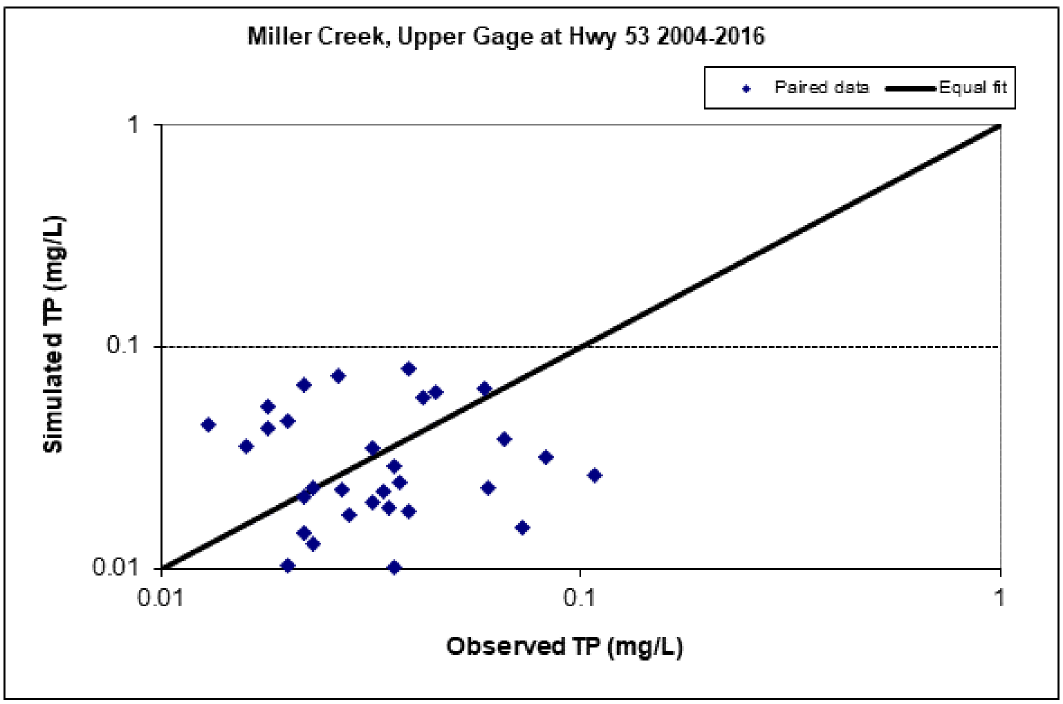


Figure E-586. Paired simulated vs. observed Total Phosphorus (TP) concentration at Miller Creek, Upper Gage at Hwy 53 (calibration period)

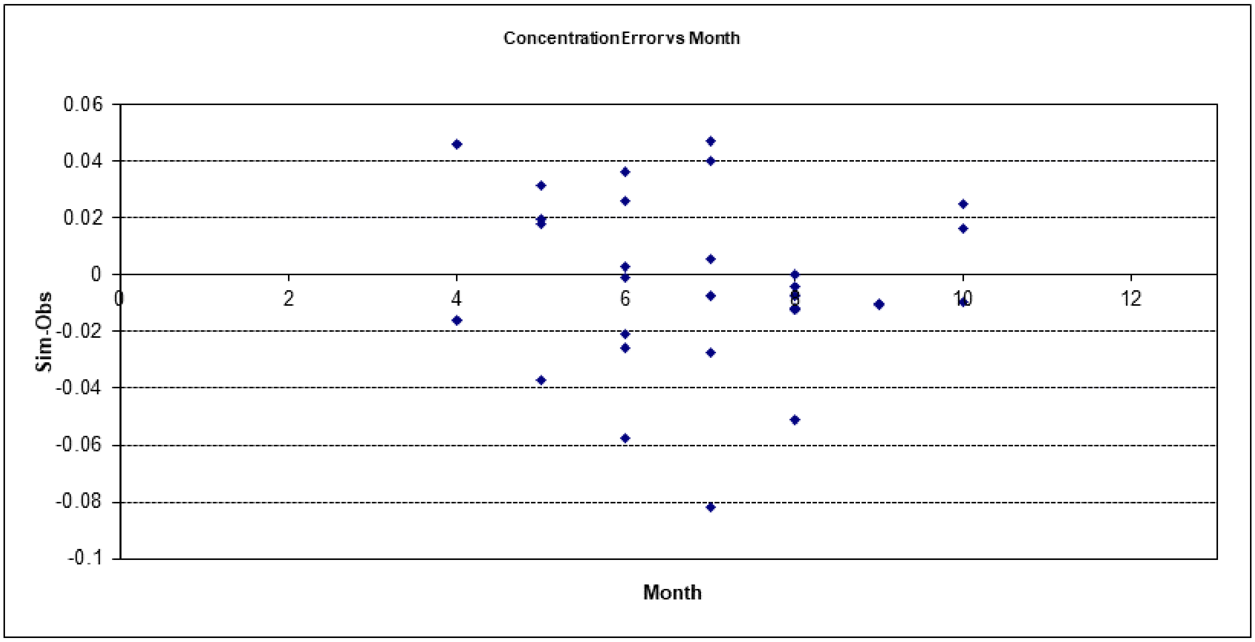


Figure E-587. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Miller Creek, Upper Gage at Hwy 53

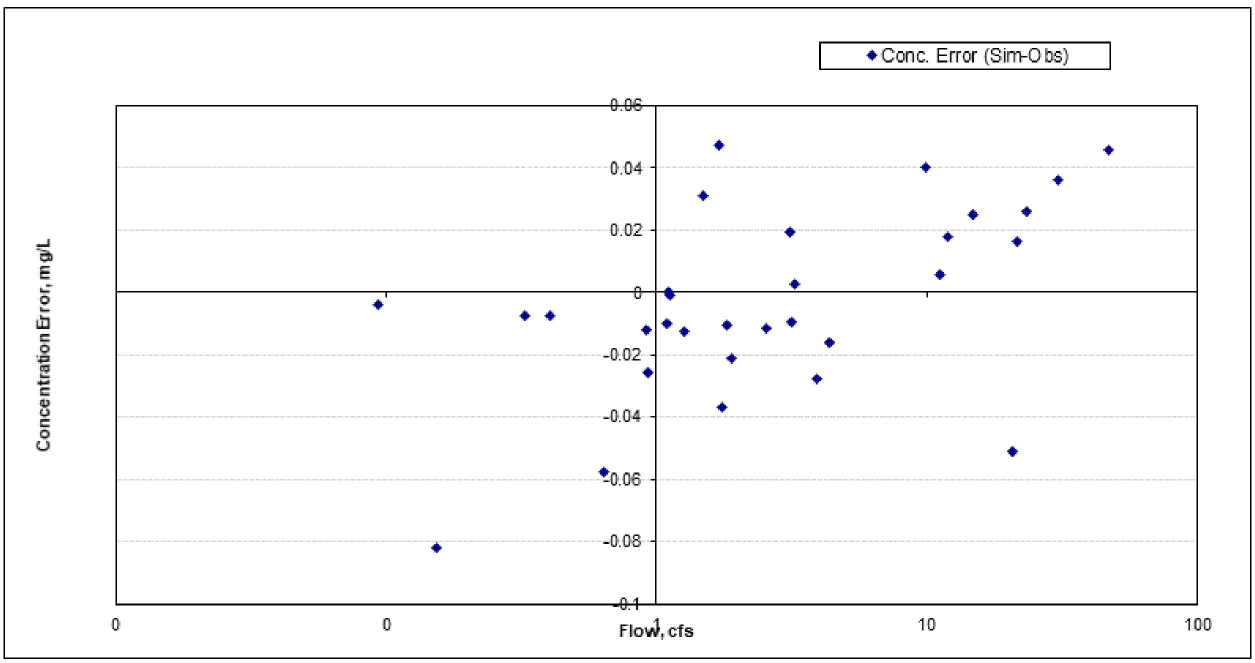


Figure E-588. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Miller Creek, Upper Gage at Hwy 53

E.13 Miller Creek at Chambersburg Rd

E.13.1 Dissolved Oxygen (DO)

Table E-73. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	18
Concentration Average Error		-20.15%
Concentration Median Error		-7.15%
Load Average Error		-18.32%
Load Median Error		-1.36%
Paired t conc		0.49
Paired t load		0.52

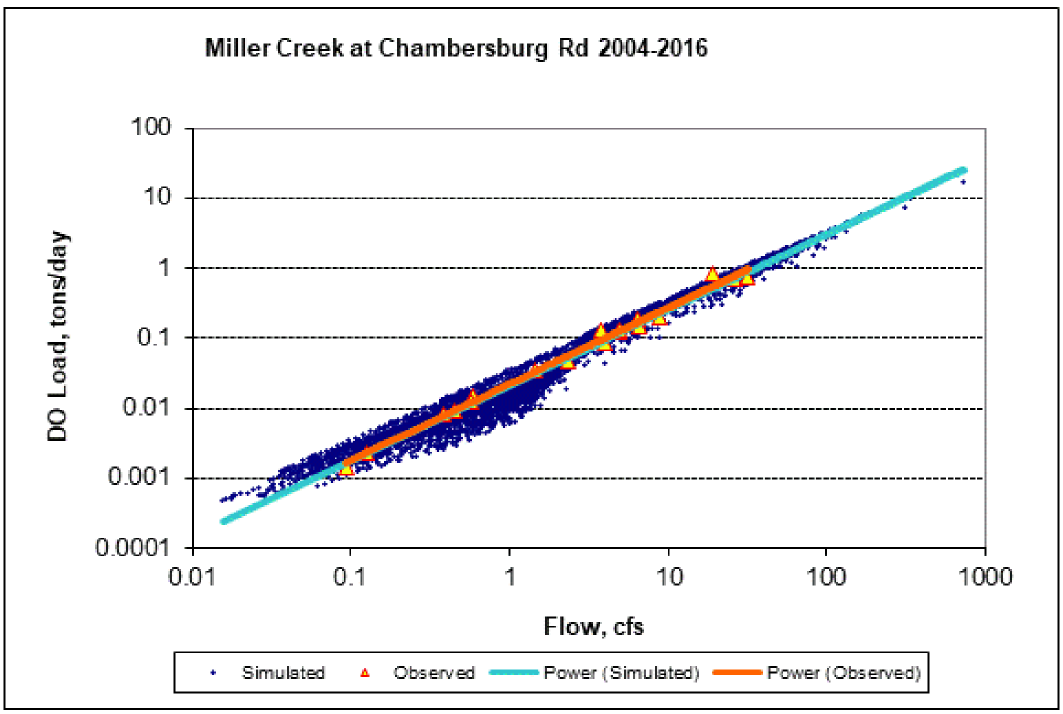


Figure E-589. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Miller Creek at Chambersburg Rd (calibration period)

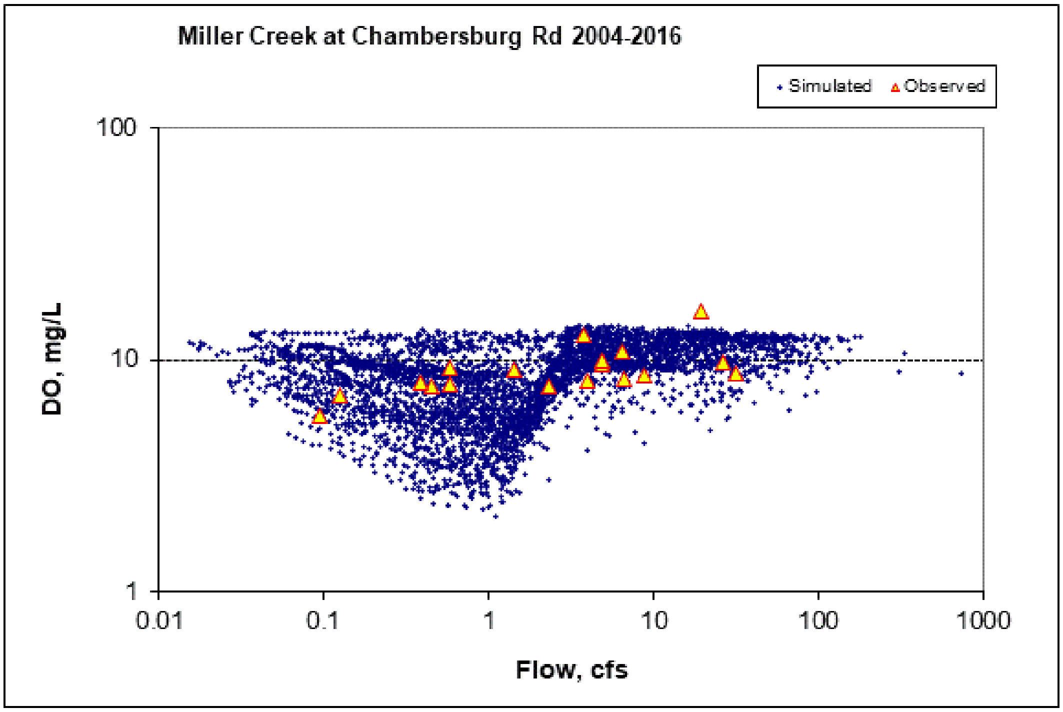
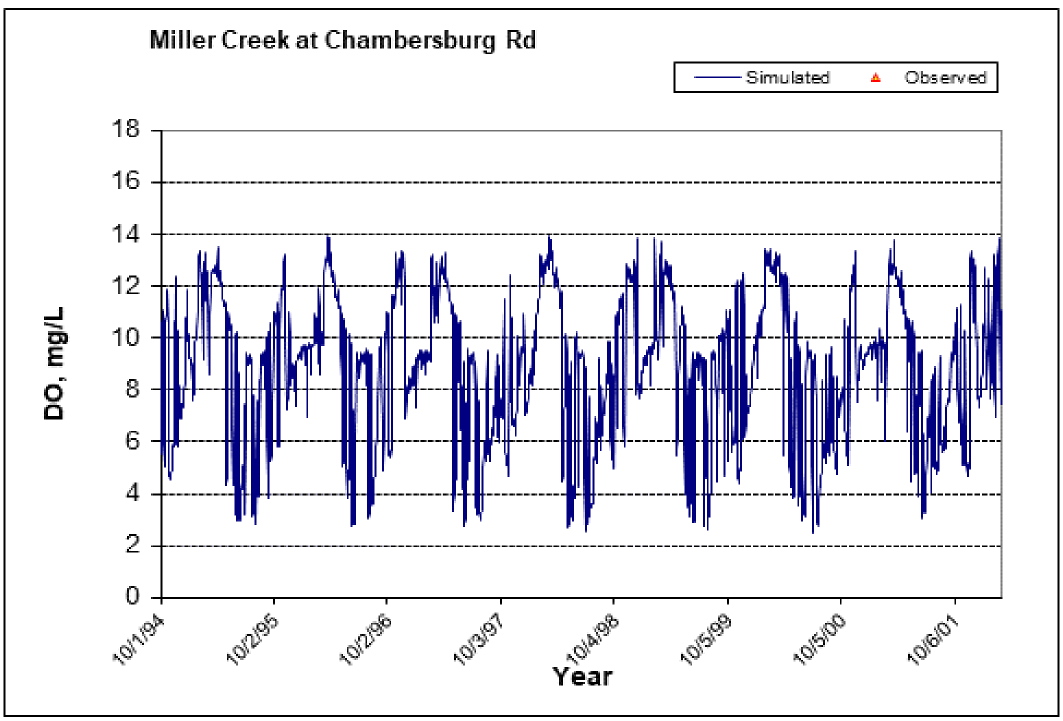
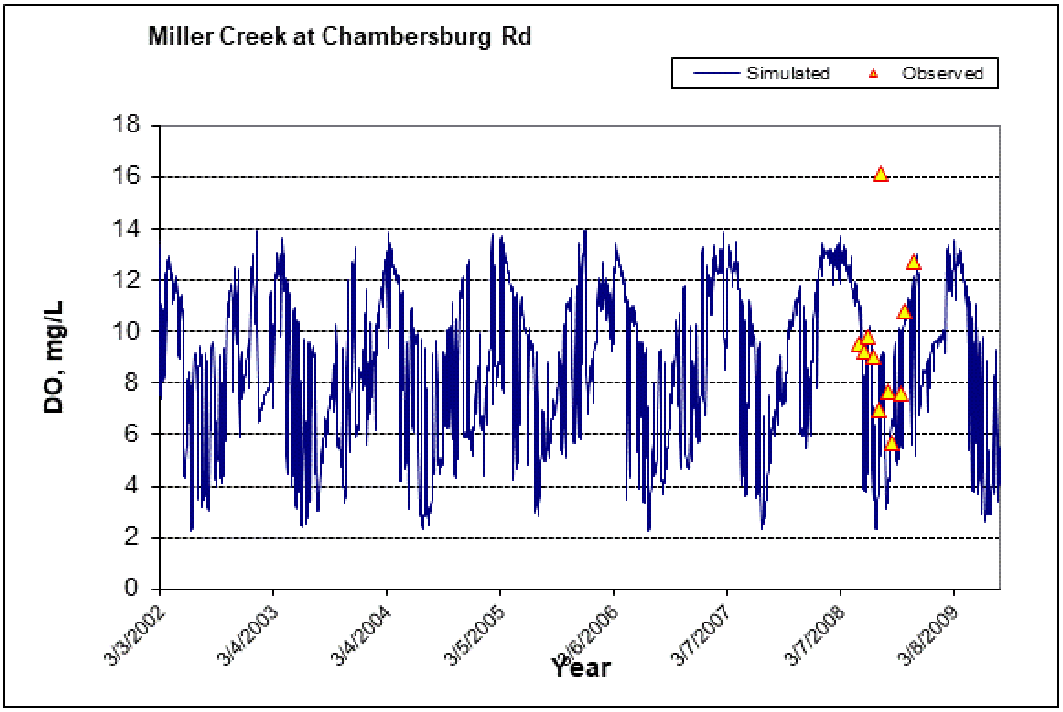


Figure E-590. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Miller Creek at Chambersburg Rd (calibration period)





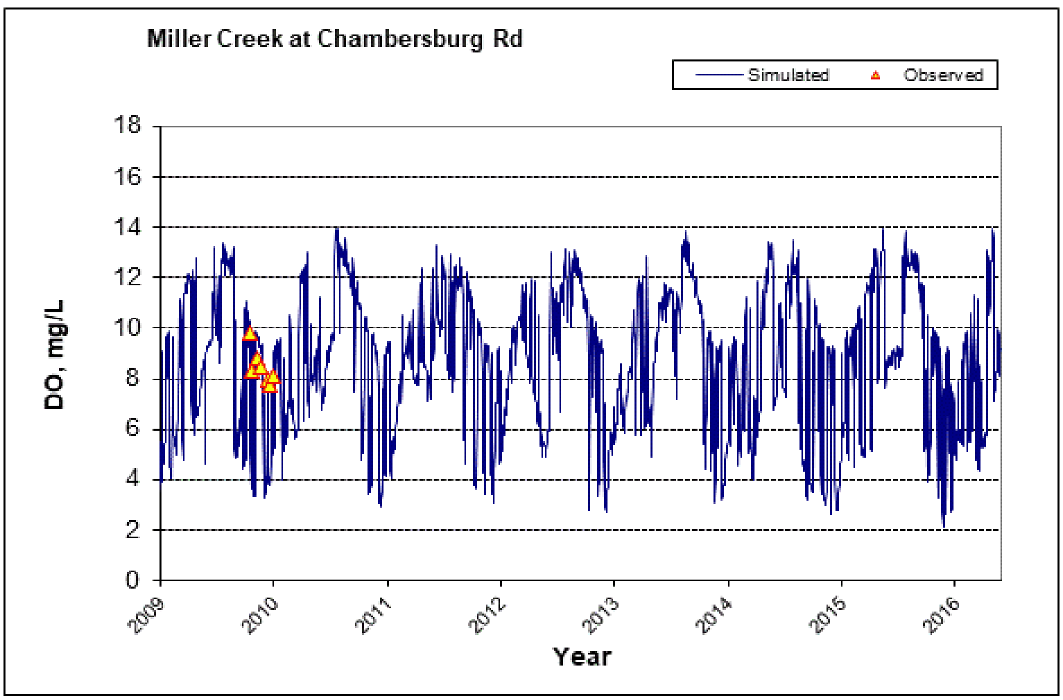


Figure E-591. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Miller Creek at Chambersburg Rd

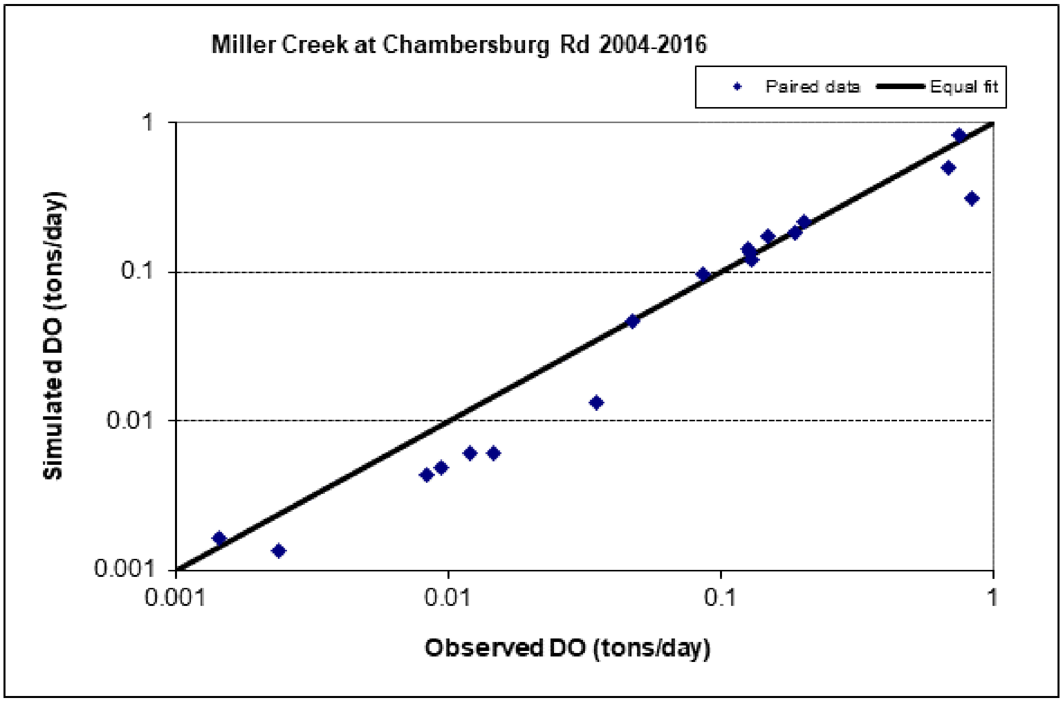


Figure E-592. Paired simulated vs. observed Dissolved Oxygen (DO) load at Miller Creek at Chambersburg Rd (calibration period)

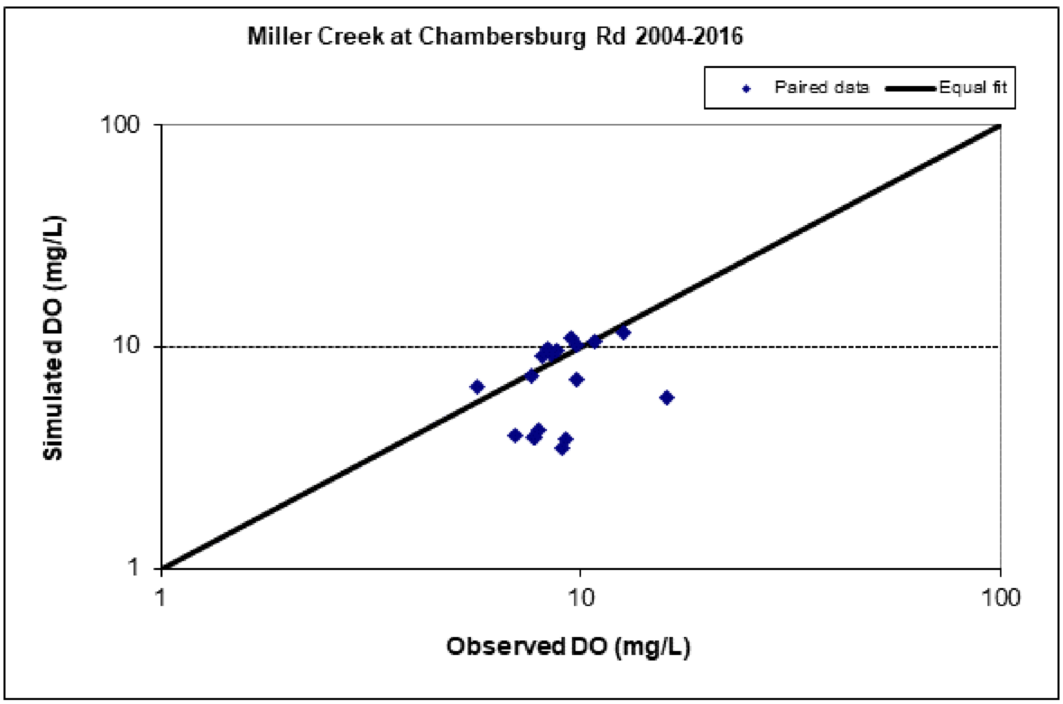


Figure E-593. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Miller Creek at Chambersburg Rd (calibration period)

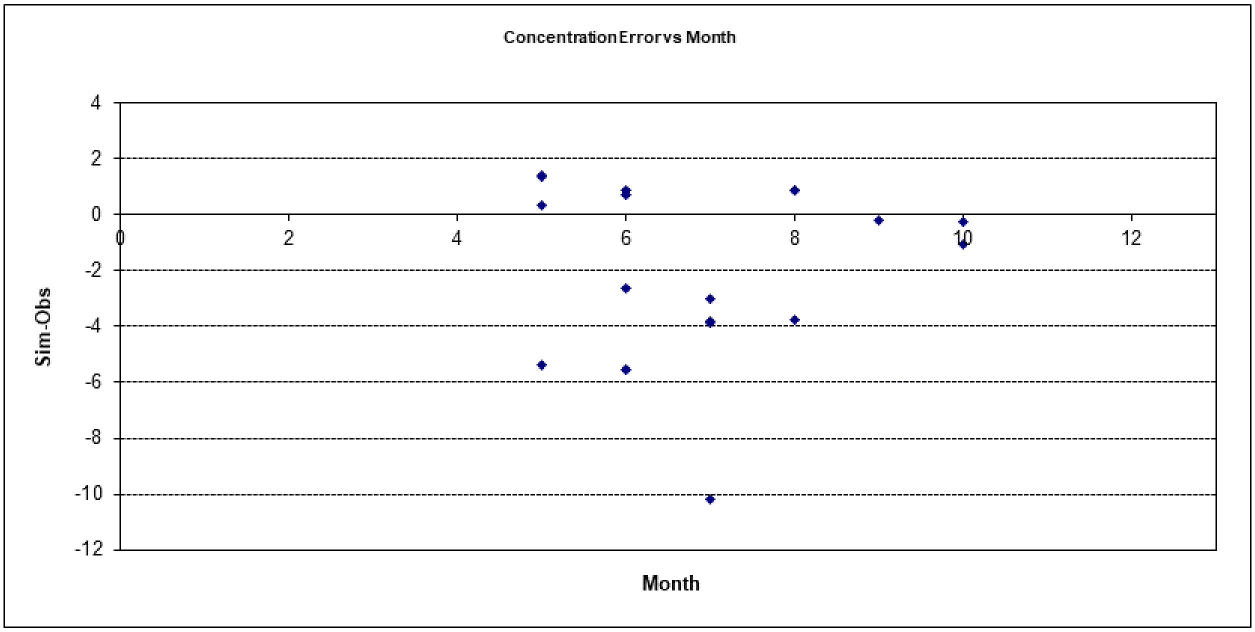


Figure E-594. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Miller Creek at Chambersburg Rd

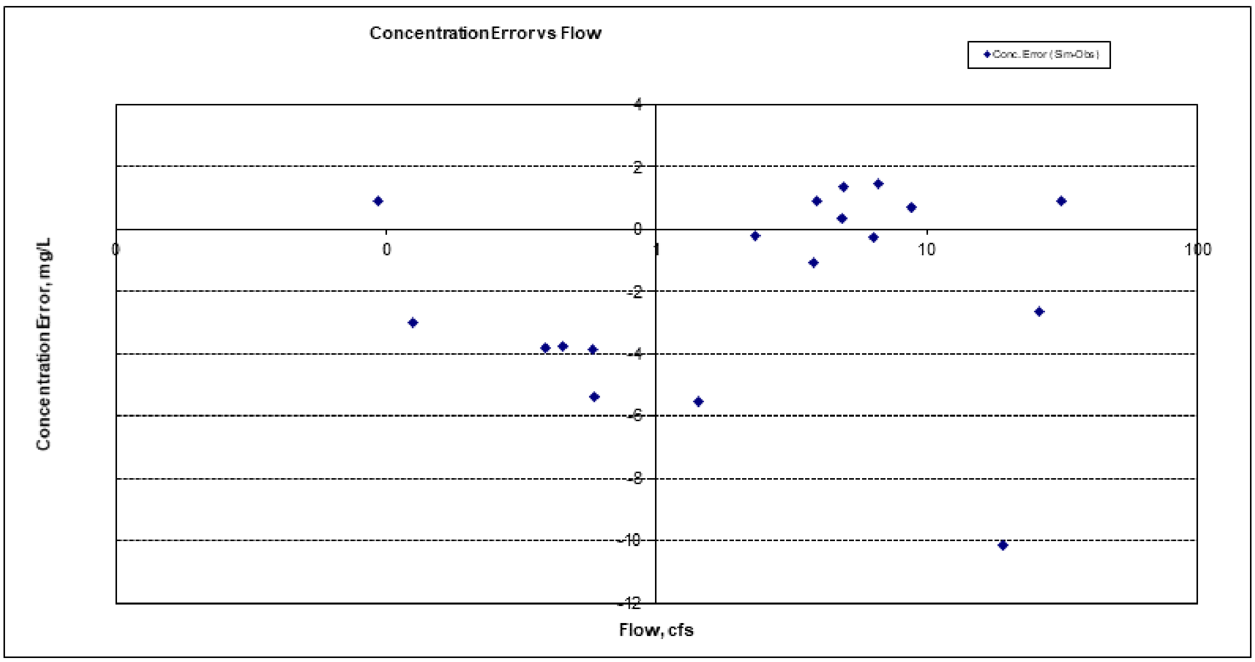


Figure E-595. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Miller Creek at Chambersburg Rd

E.13.2 Ammonia Nitrogen (NH3)

Table E-74. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	18	32
Concentration Average Error	673.52%	148.70%
Concentration Median Error	125.05%	6.06%
Load Average Error	779.08%	247.62%
Load Median Error	110.35%	0.13%
Paired t conc	0.00	0.00
Paired t load	0.00	0.00

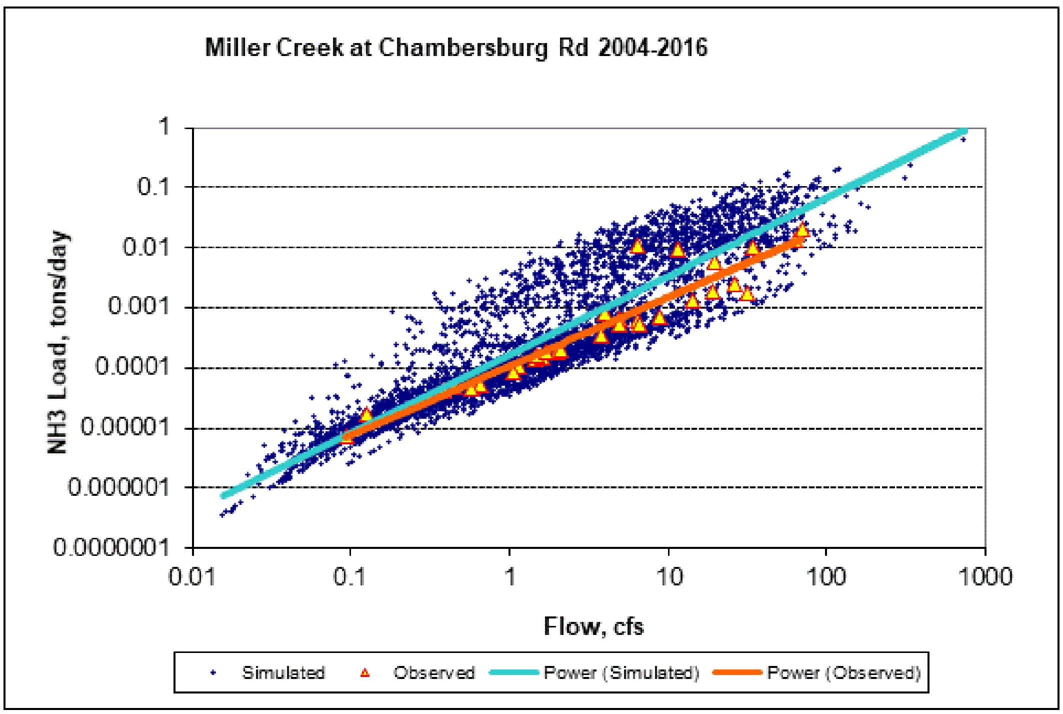


Figure E-596. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Miller Creek at Chambersburg Rd (calibration period)

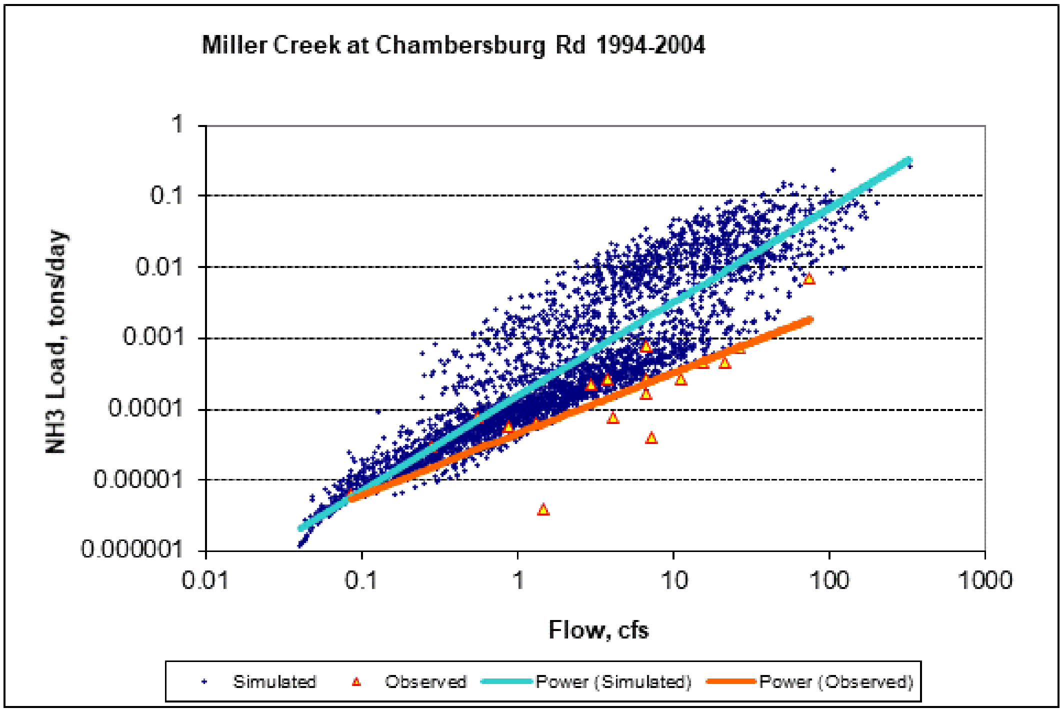


Figure E-597. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Miller Creek at Chambersburg Rd (validation period)

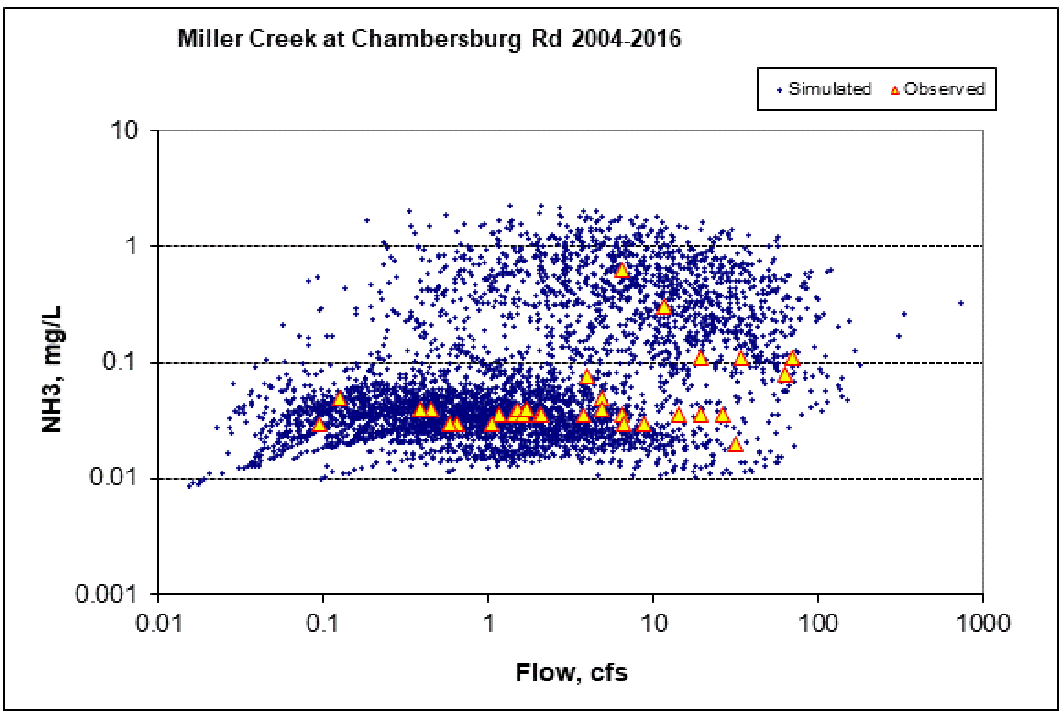


Figure E-598. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Miller Creek at Chambersburg Rd (calibration period)

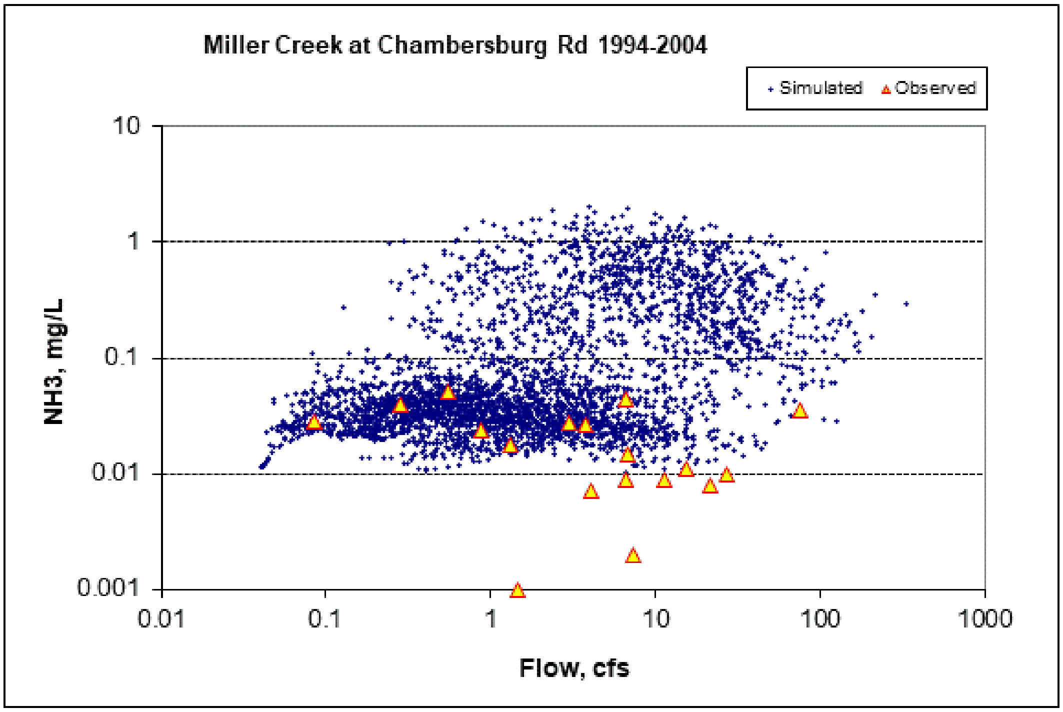
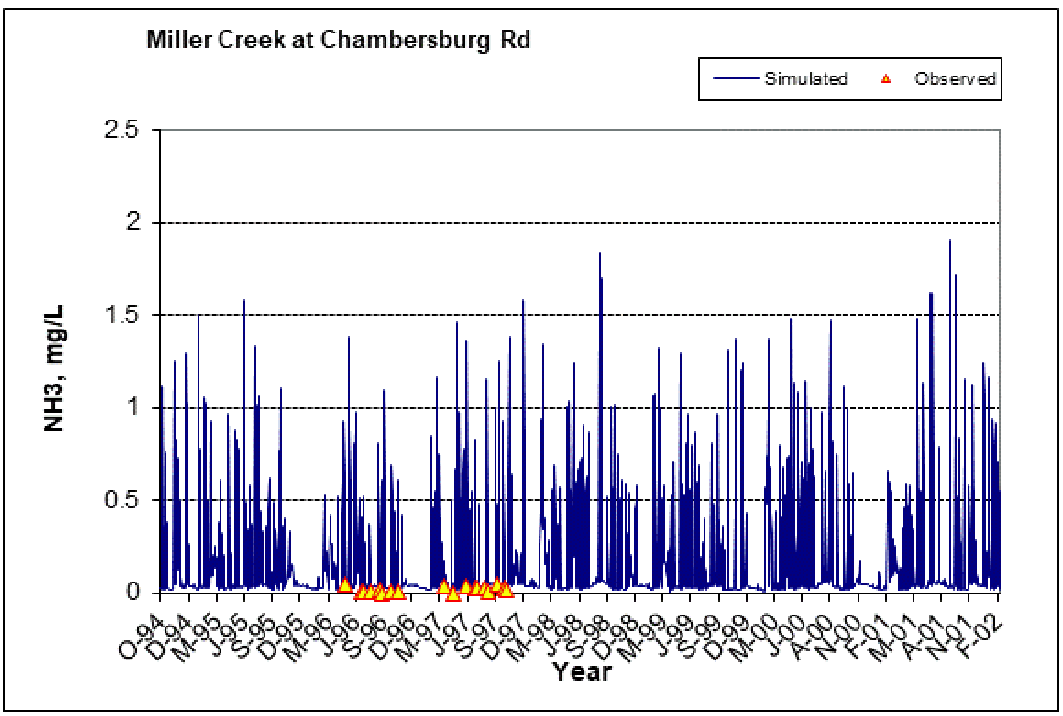


Figure E-599. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Miller Creek at Chambersburg Rd (validation period)



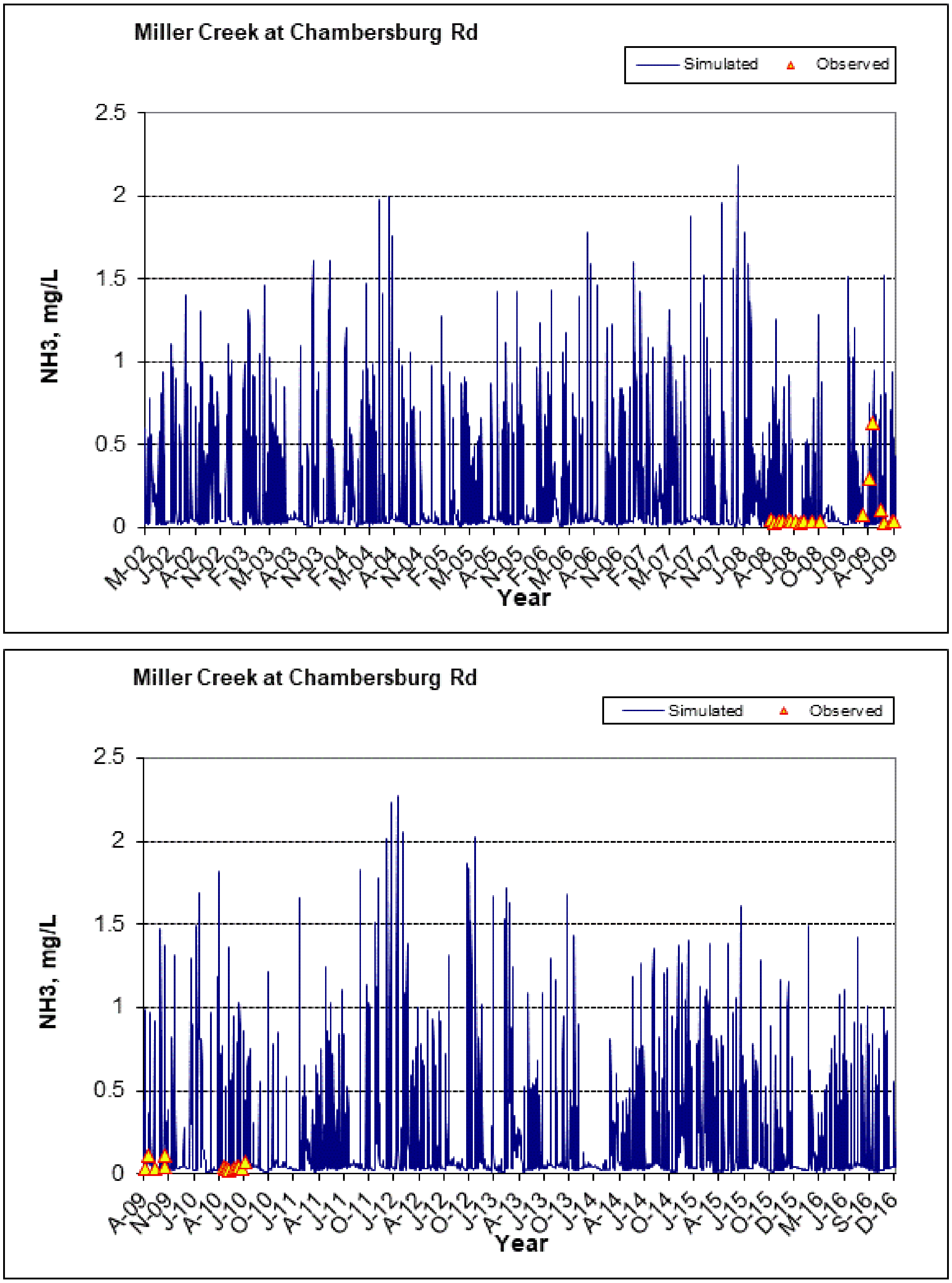


Figure E-600. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Miller Creek at Chambersburg Rd

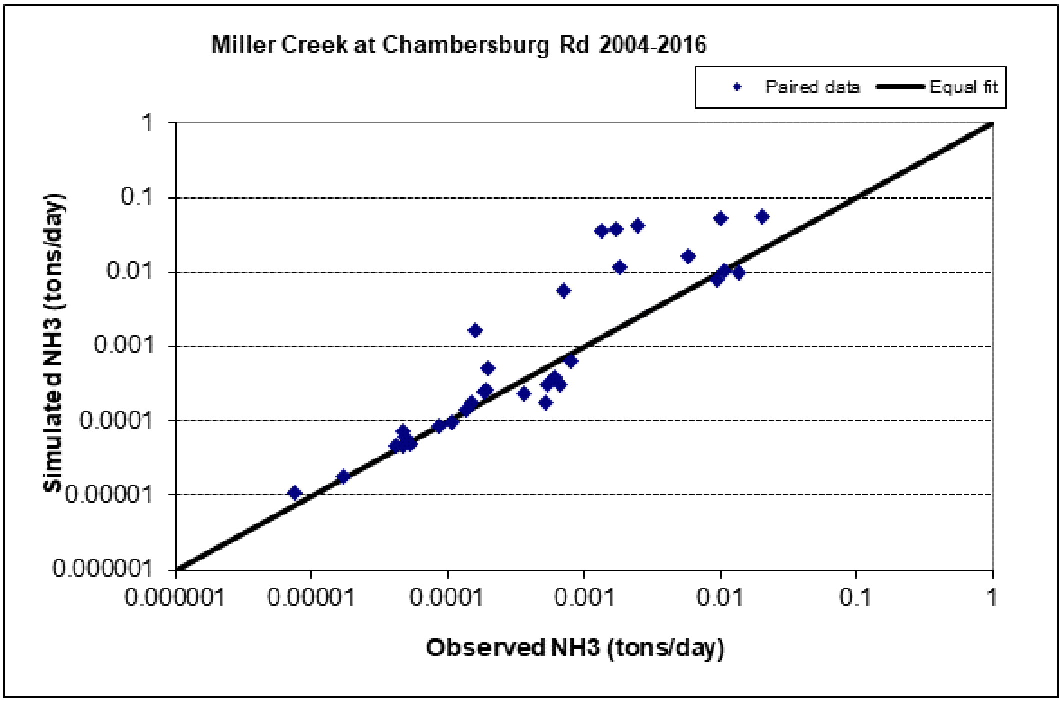


Figure E-601. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Miller Creek at Chambersburg Rd (calibration period)

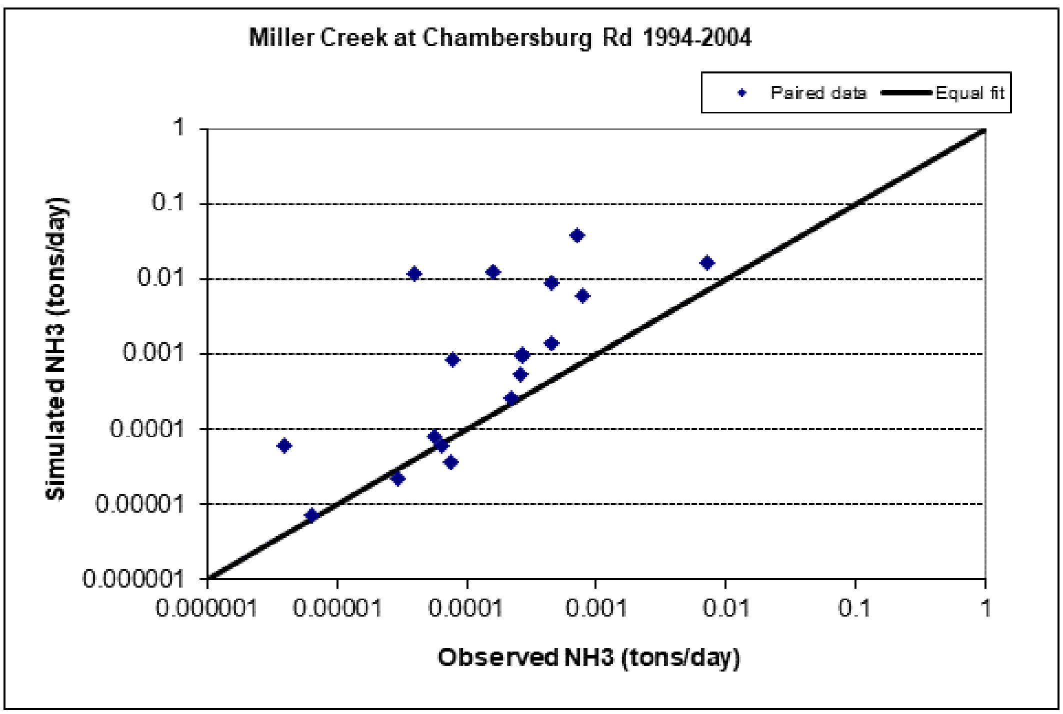


Figure E-602. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Miller Creek at Chambersburg Rd (validation period)

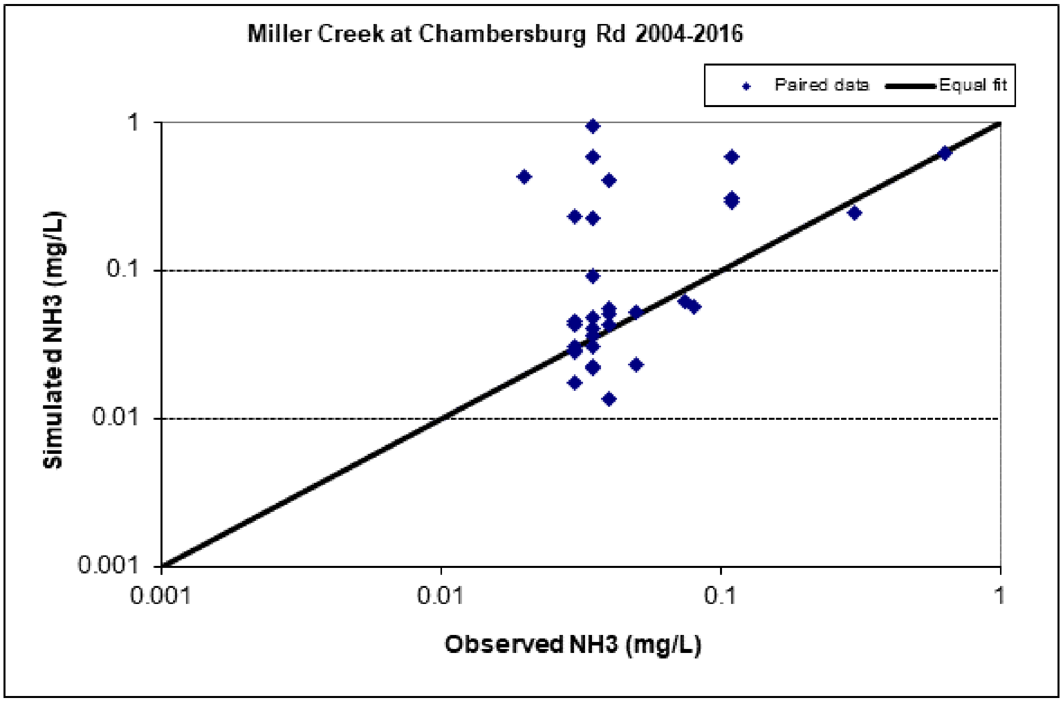


Figure E-603. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Miller Creek at Chambersburg Rd (calibration period)

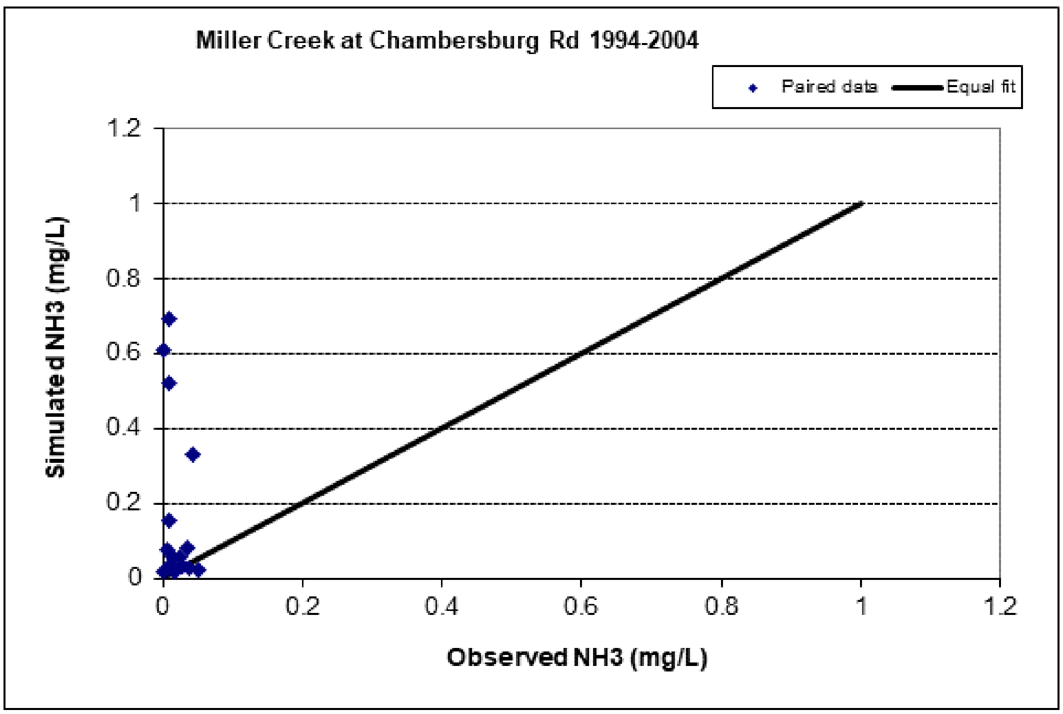


Figure E-604. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Miller Creek at Chambersburg Rd (validation period)

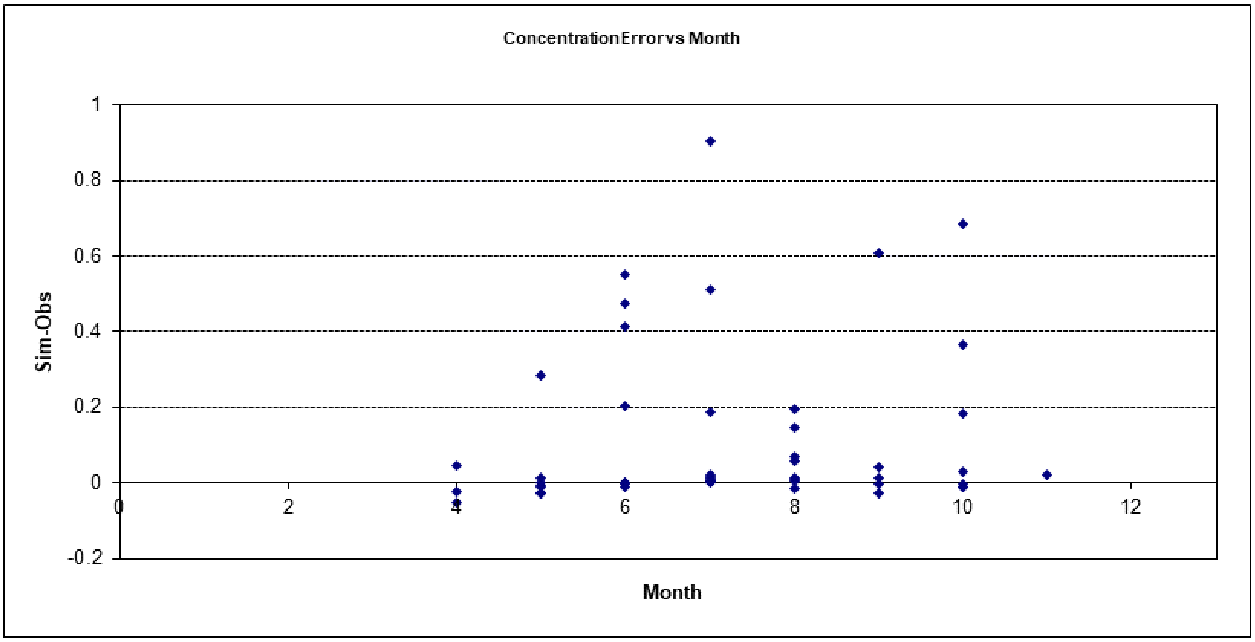


Figure E-605. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Miller Creek at Chambersburg Rd

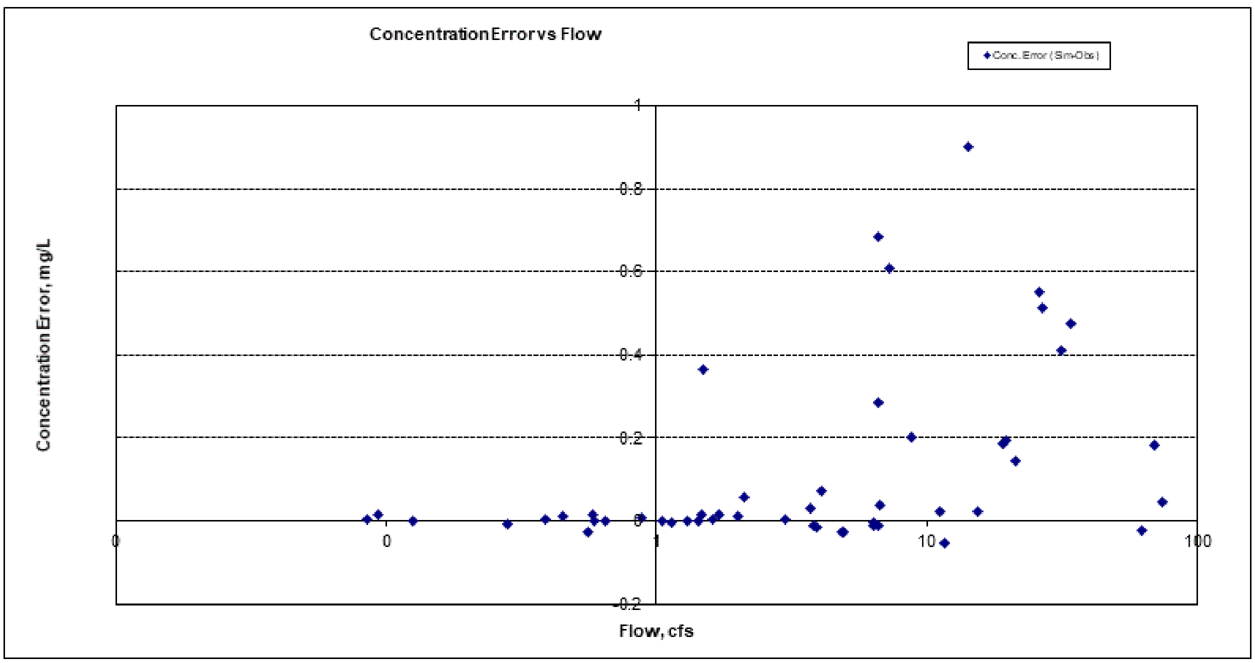


Figure E-606. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Miller Creek at Chambersburg Rd

E.13.3 Organic Nitrogen (OrgN)

Table E-75. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	5	ND
Concentration Average Error	-31.99%	
Concentration Median Error	-35.30%	
Load Average Error	-51.99%	
Load Median Error	-2.08%	
Paired t conc	0.19	
Paired t load	0.34	

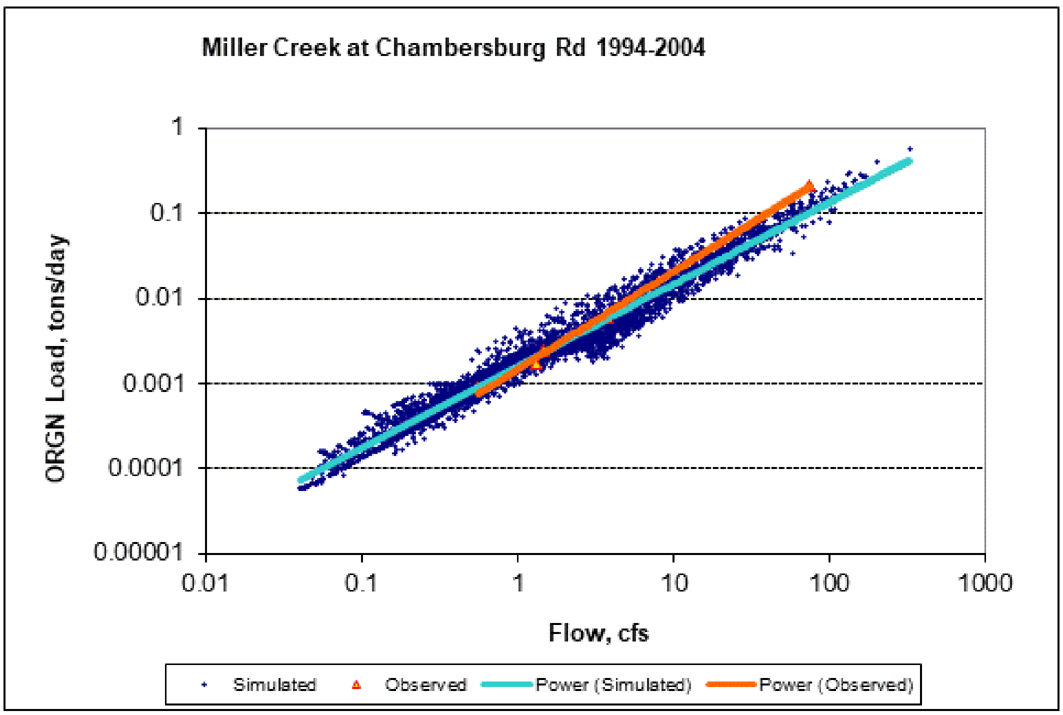


Figure E-607. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Miller Creek at Chambersburg Rd (validation period)

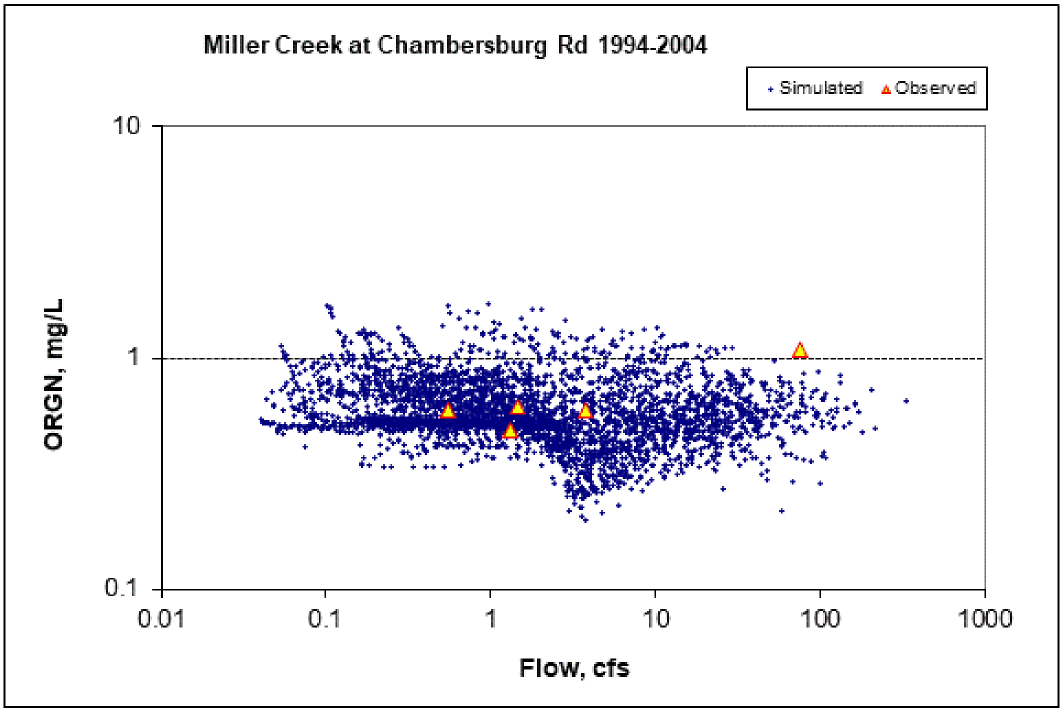
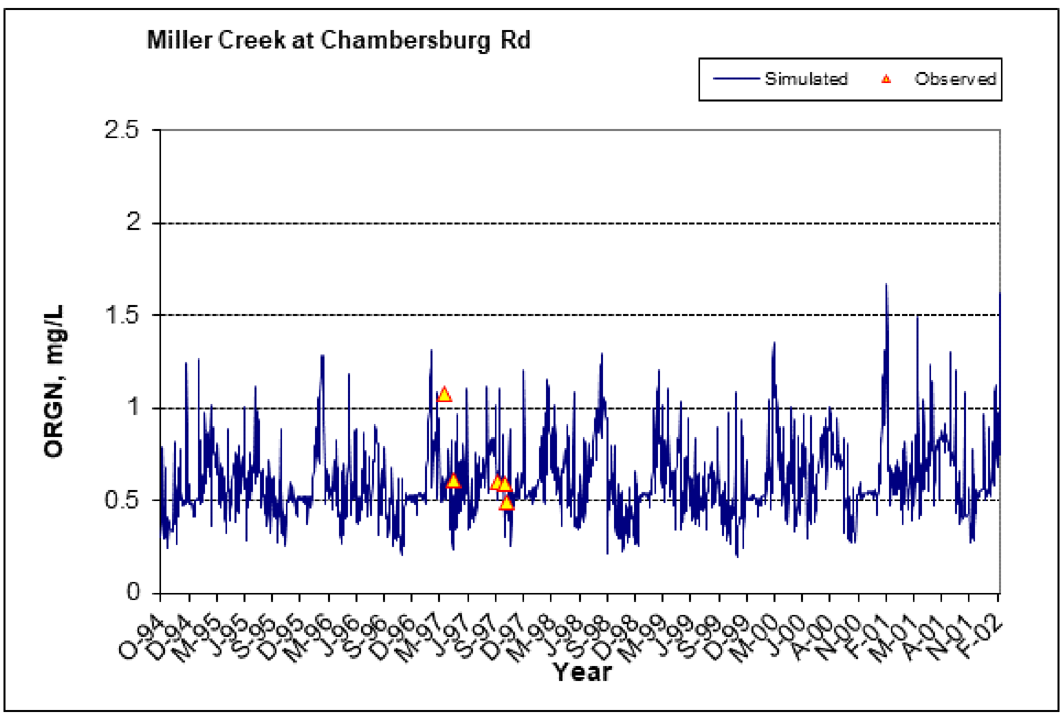
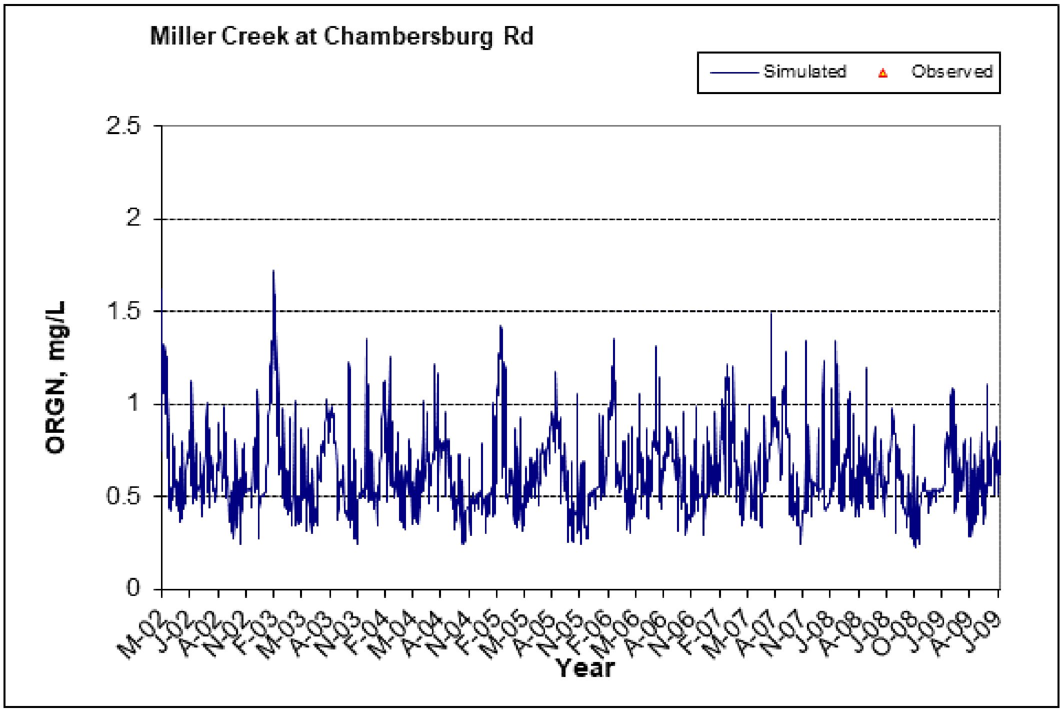


Figure E-608. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Miller Creek at Chambersburg Rd (validation period)





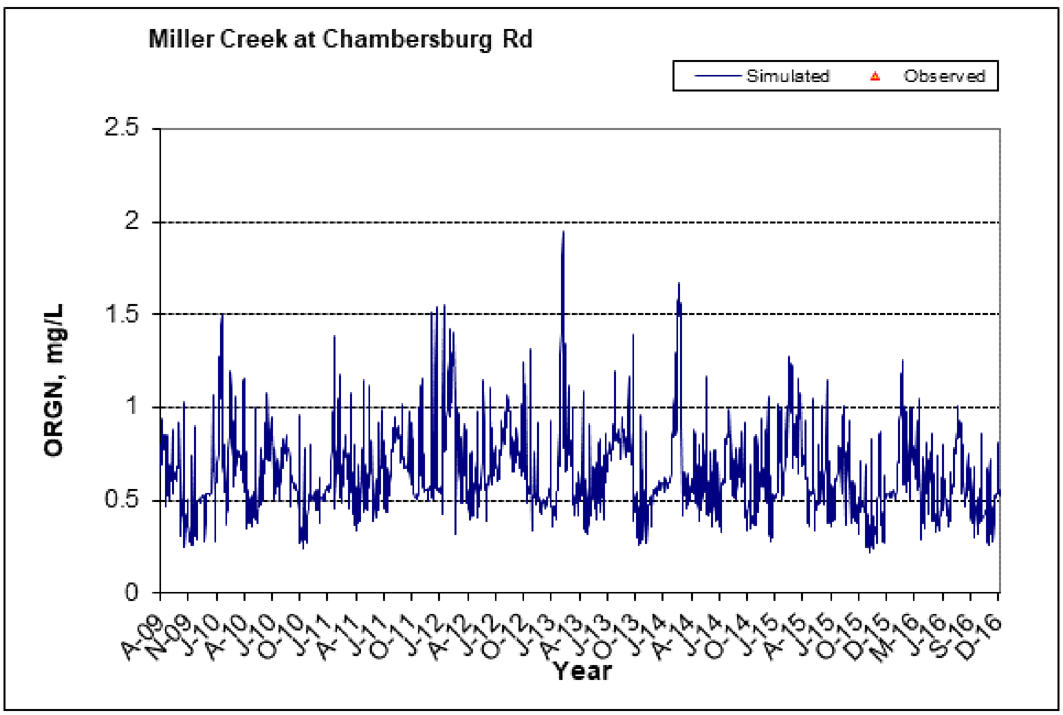


Figure E-609. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Miller Creek at Chambersburg Rd

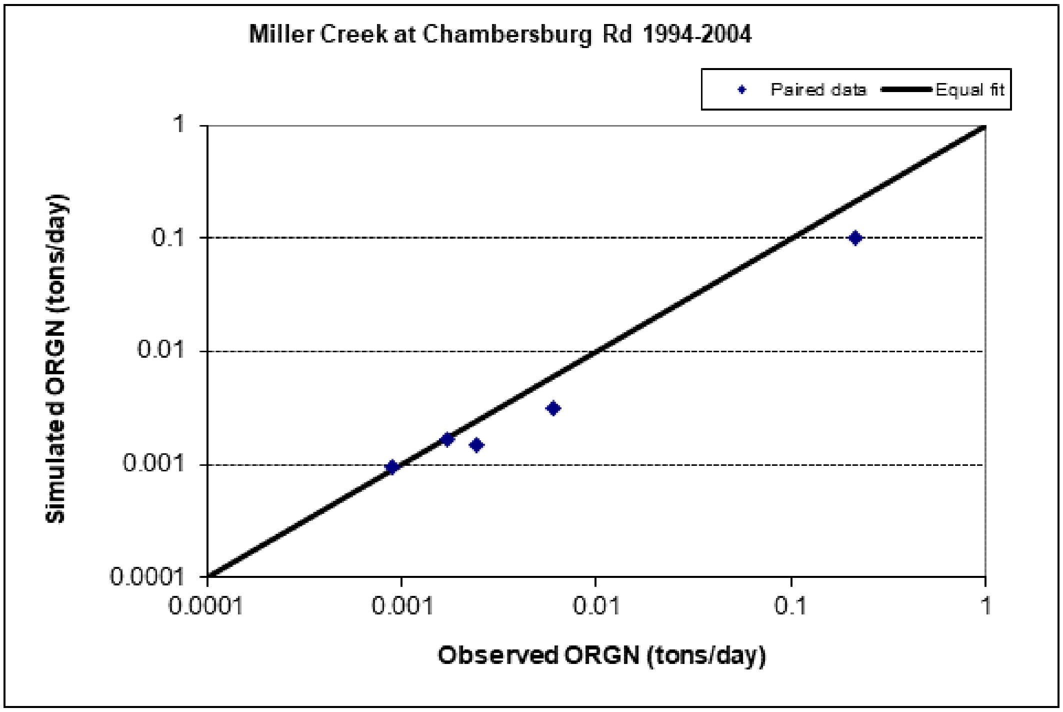


Figure E-610. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Miller Creek at Chambersburg Rd (validation period)

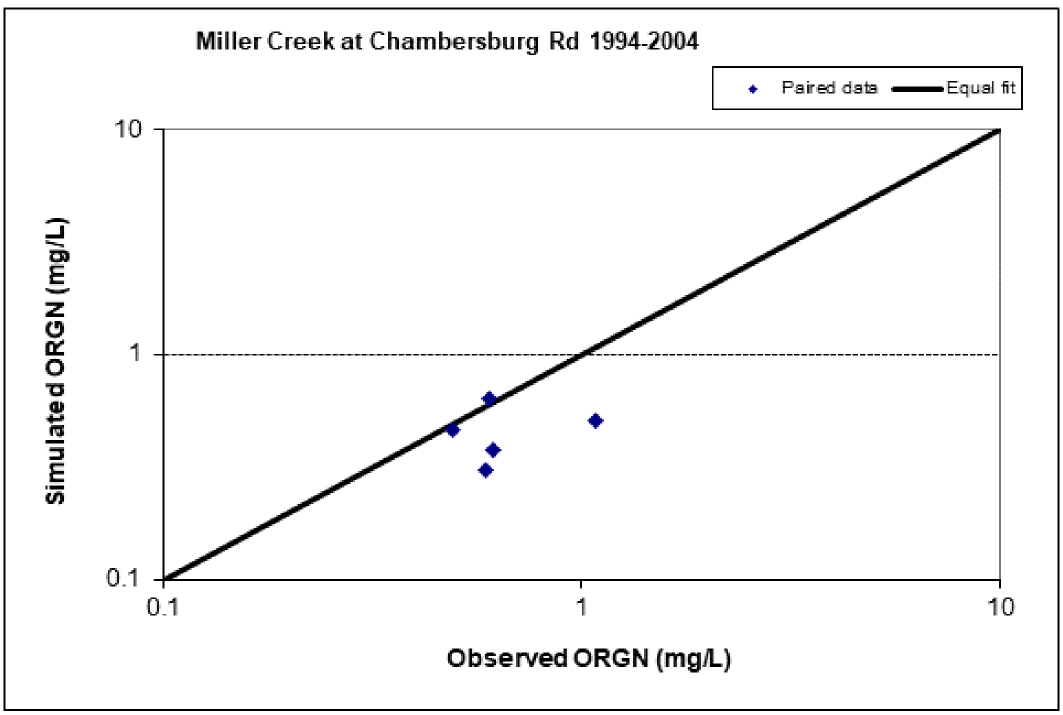


Figure E-611. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Miller Creek at Chambersburg Rd (validation period)

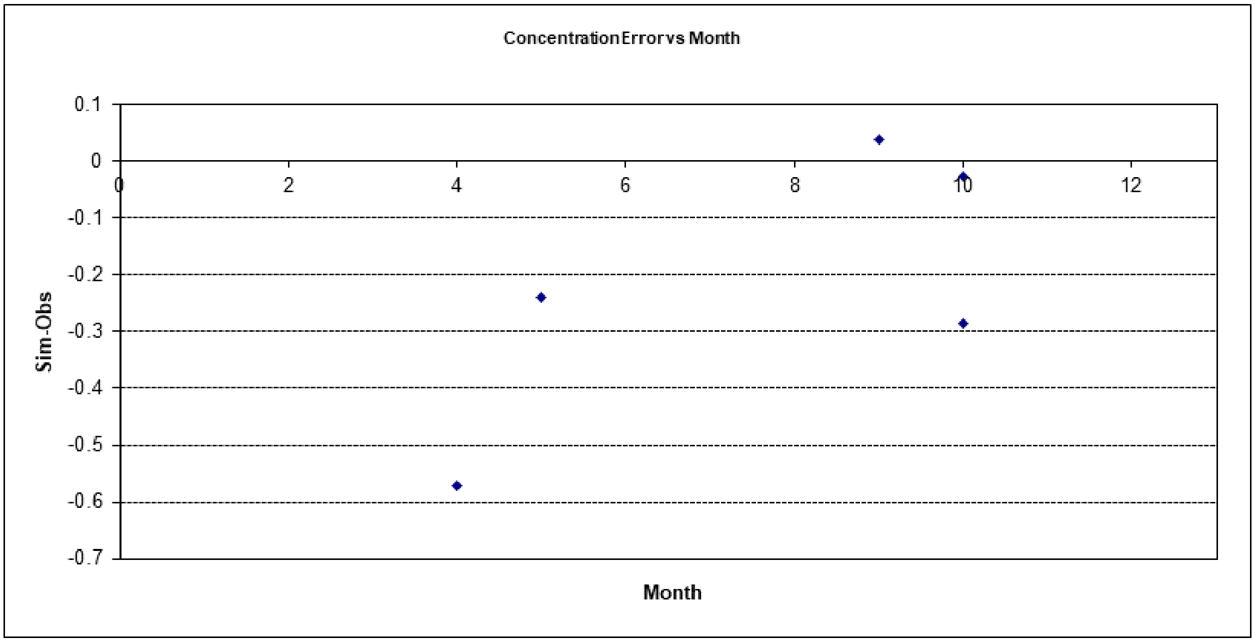


Figure E-612. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at Miller Creek at Chambersburg Rd

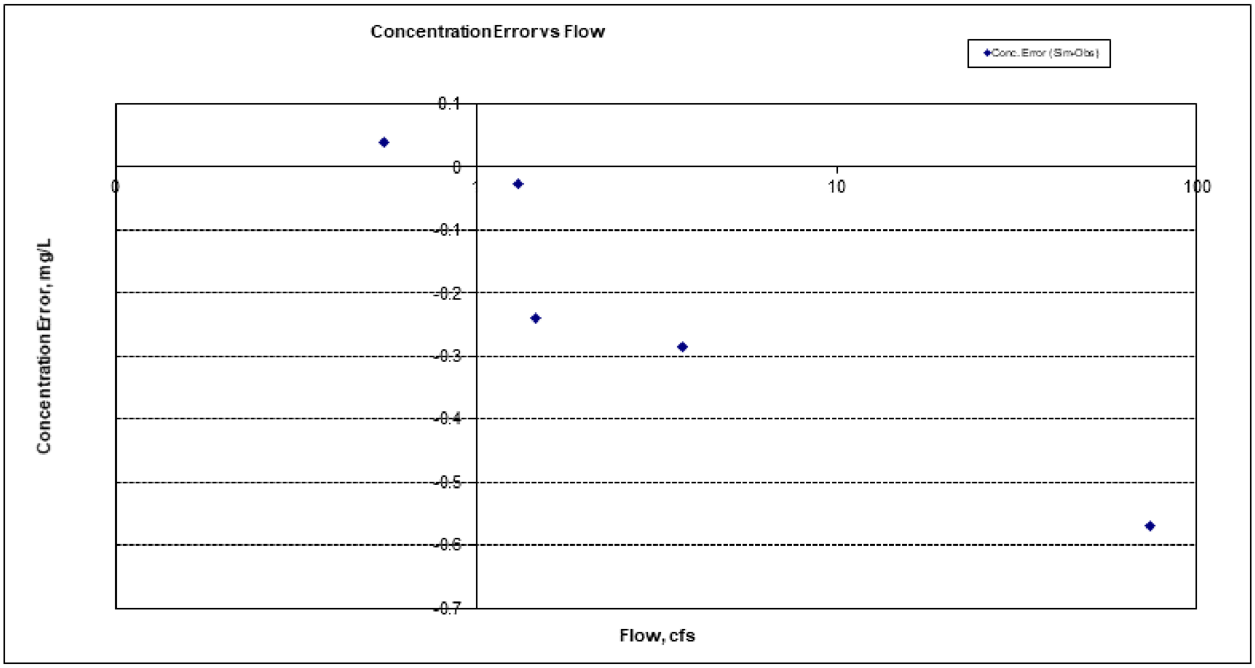


Figure E-613. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at Miller Creek at Chambersburg Rd

E.13.4 Total Kjeldahl Nitrogen (TKN)

Table E-76. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	10	ND
Concentration Average Error	-10.07%	
Concentration Median Error	-15.55%	
Load Average Error	-38.62%	
Load Median Error	-1.86%	
Paired t conc	0.79	
Paired t load	0.39	

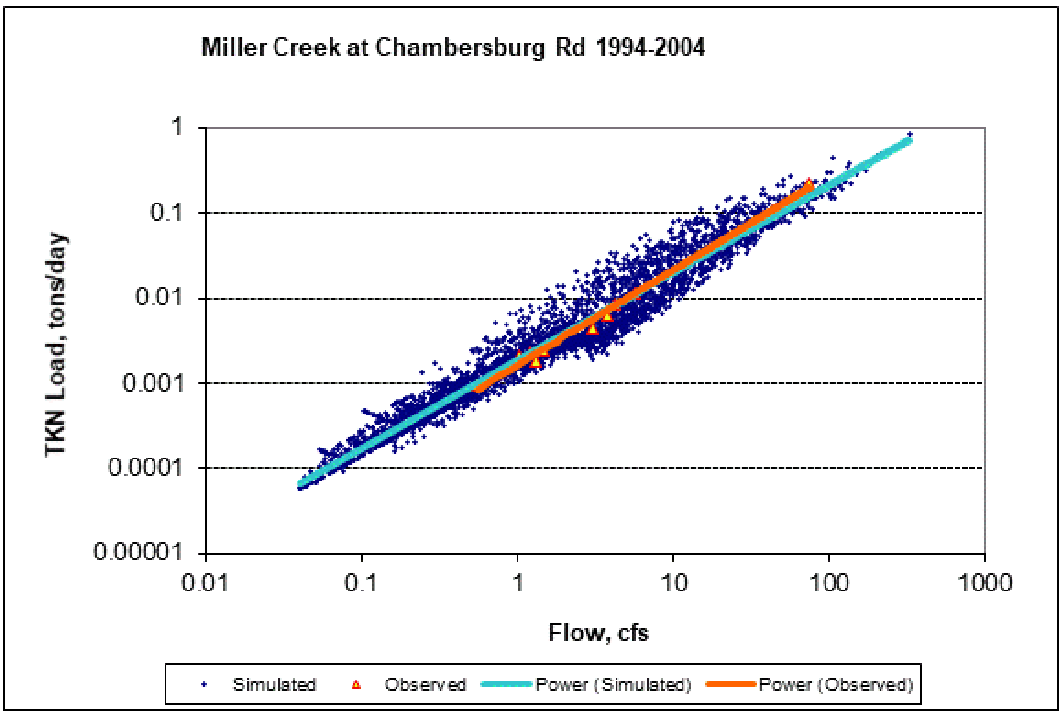


Figure E-614. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Miller Creek at Chambersburg Rd (validation period)

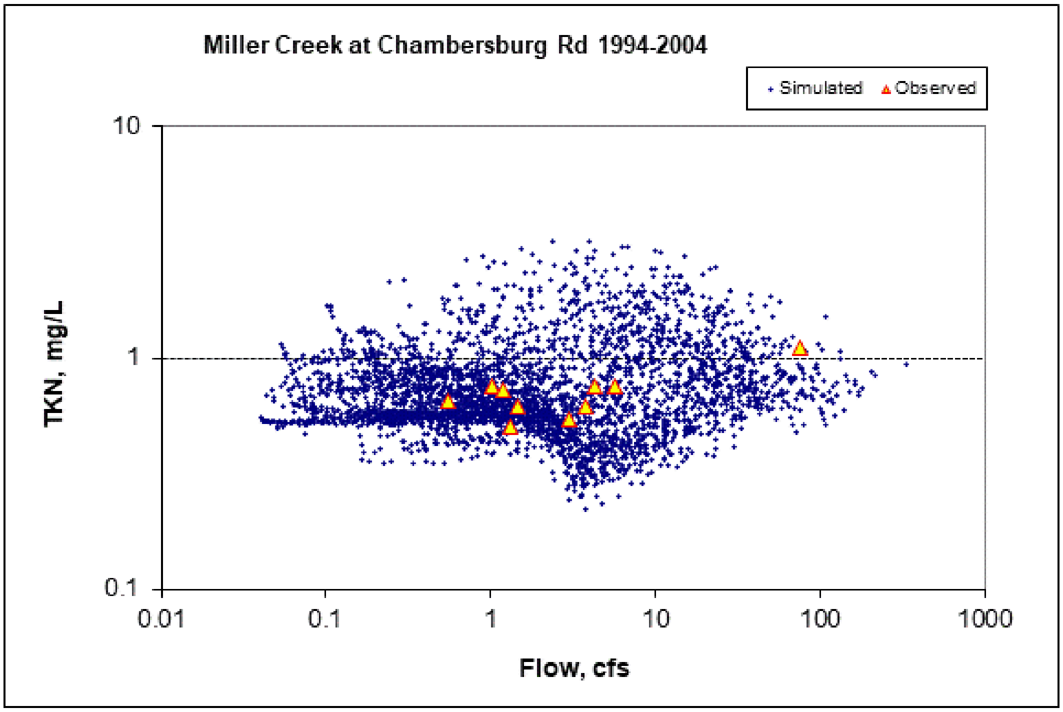
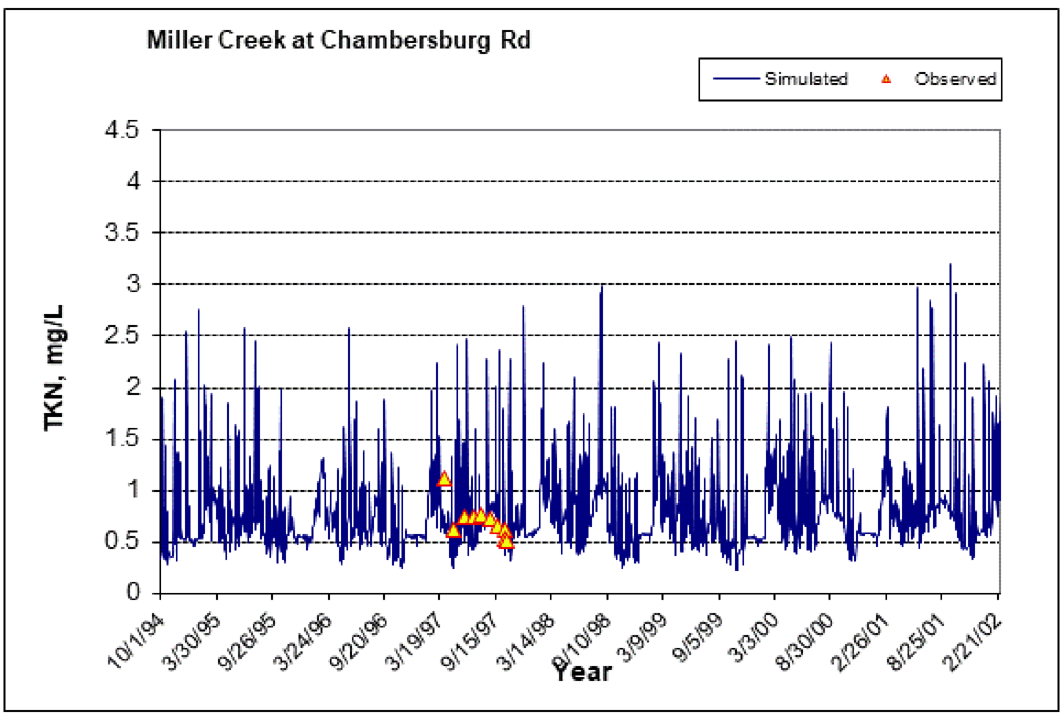
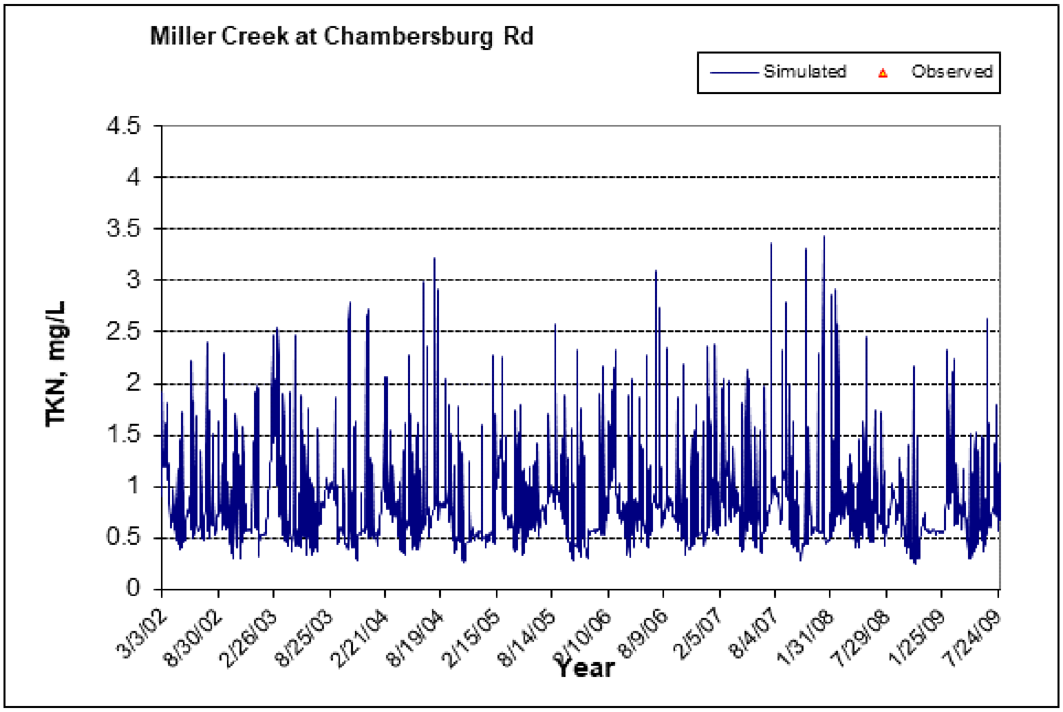


Figure E-615. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Miller Creek at Chambersburg Rd (validation period)





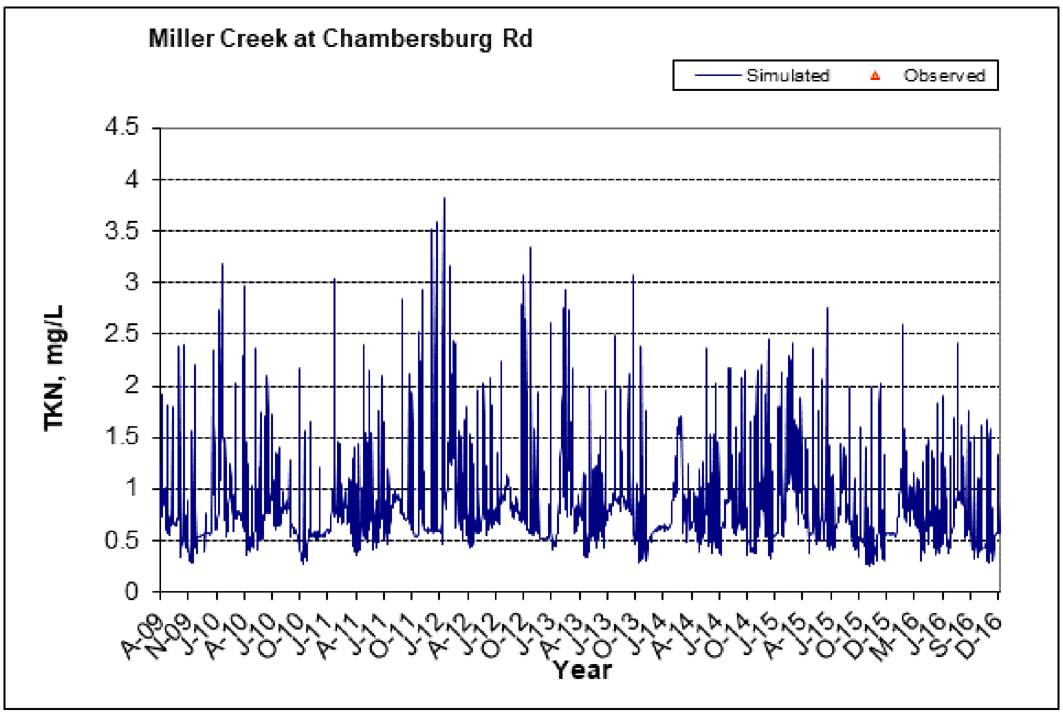


Figure E-616. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Miller Creek at Chambersburg Rd

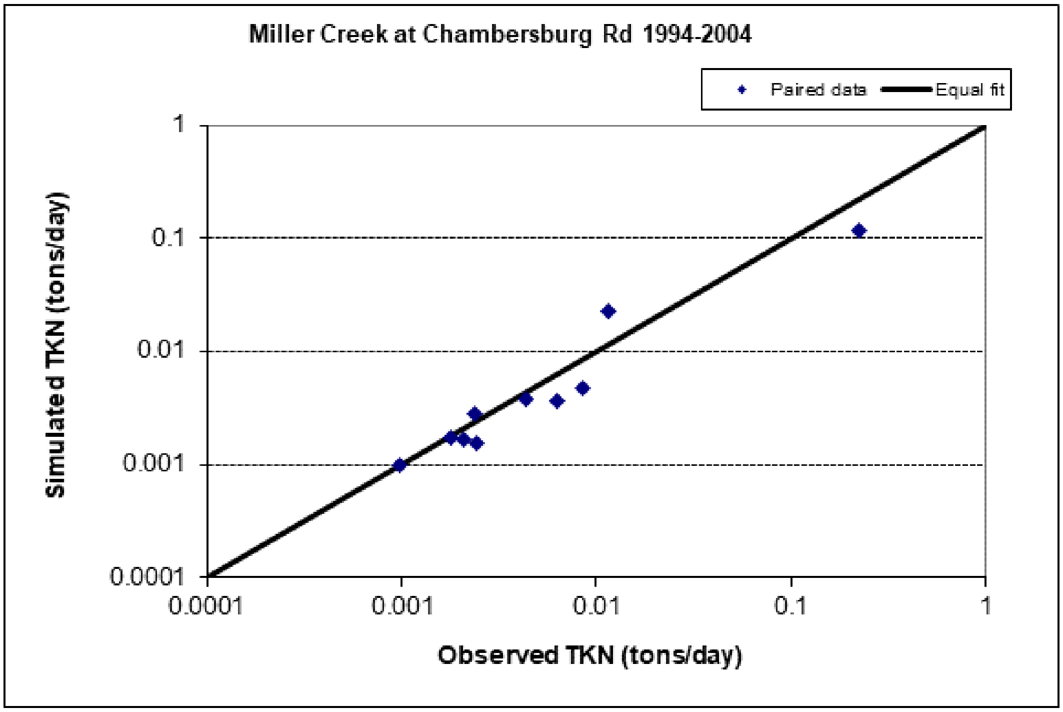


Figure E-617. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Miller Creek at Chambersburg Rd (validation period)

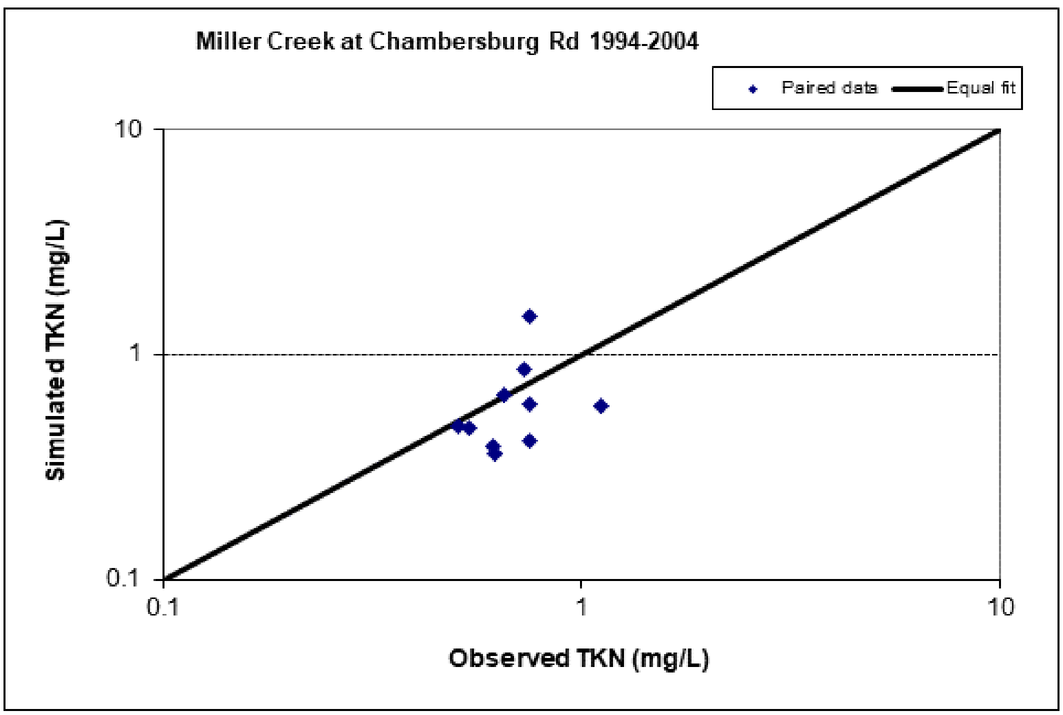


Figure E-618. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Miller Creek at Chambersburg Rd (validation period)

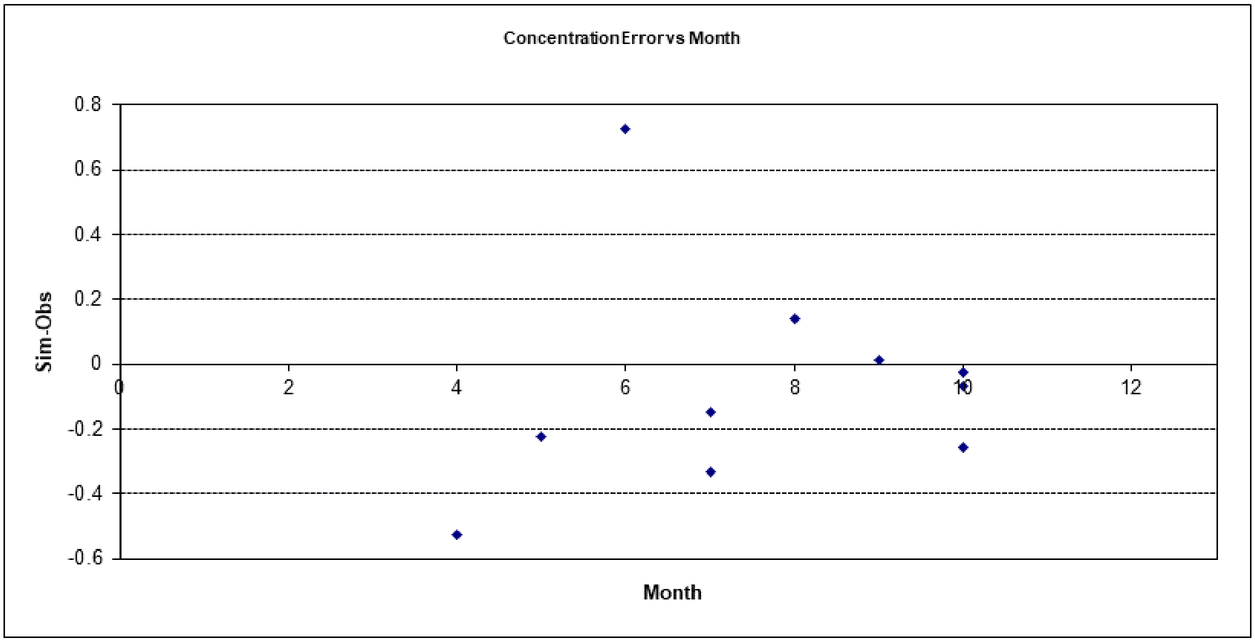


Figure E-619. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at Miller Creek at Chambersburg Rd

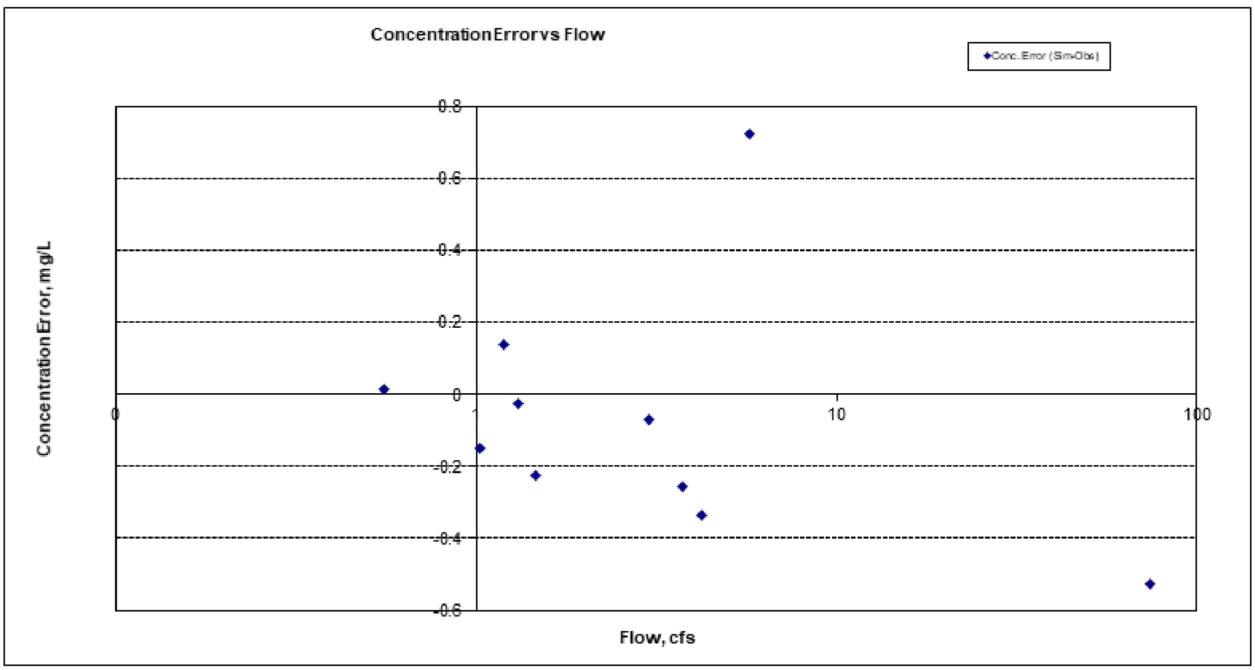


Figure E-620. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at Miller Creek at Chambersburg Rd

E.13.5 Nitrite+ Nitrate Nitrogen (NOx)

Table E-77. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	18	32
Concentration Average Error	185.05%	276.02%
Concentration Median Error	-13.99%	5.25%
Load Average Error	132.97%	529.54%
Load Median Error	-1.69%	2.33%
Paired t conc	0.03	0.00
Paired t load	0.12	0.00

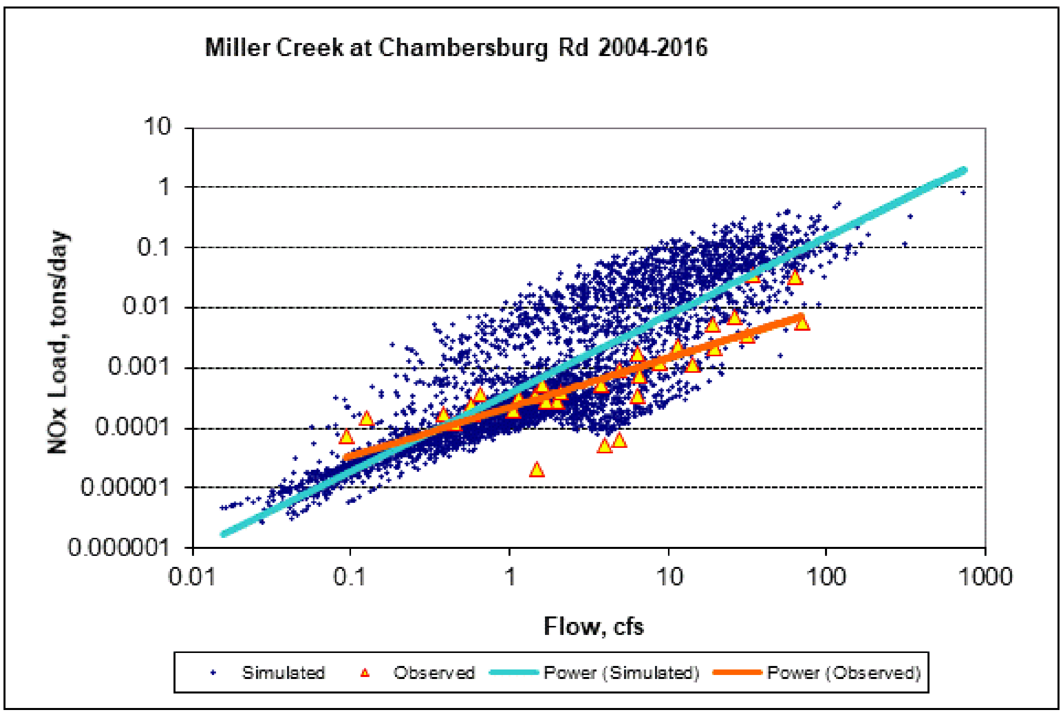


Figure E-621. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Miller Creek at Chambersburg Rd (calibration period)

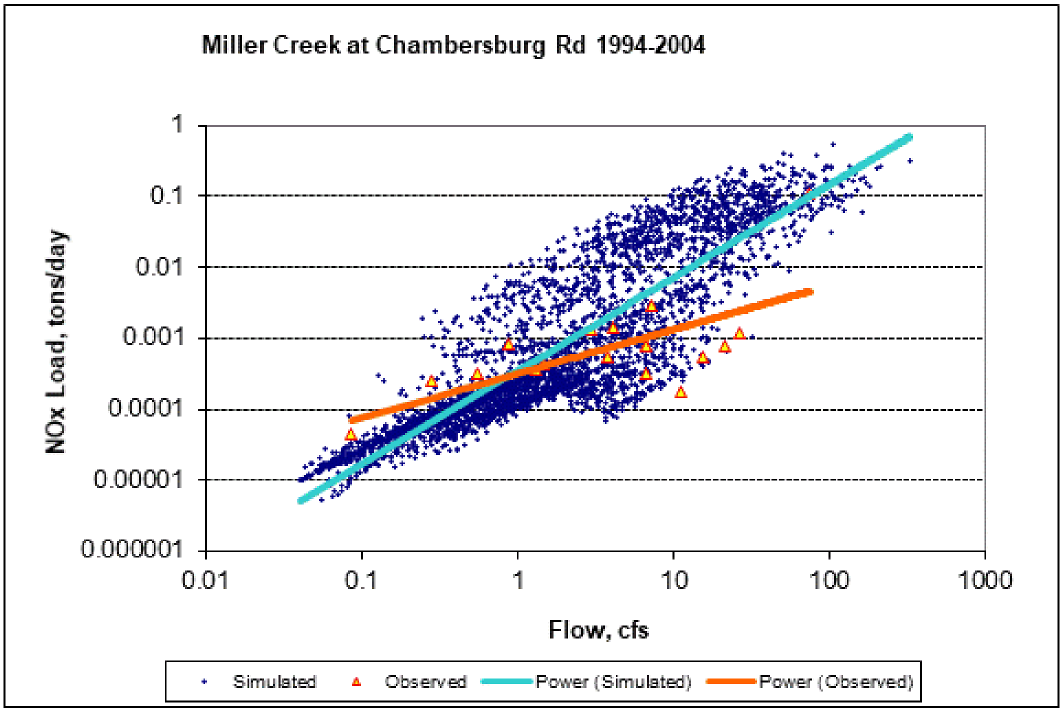


Figure E-622. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Miller Creek at Chambersburg Rd (validation period)

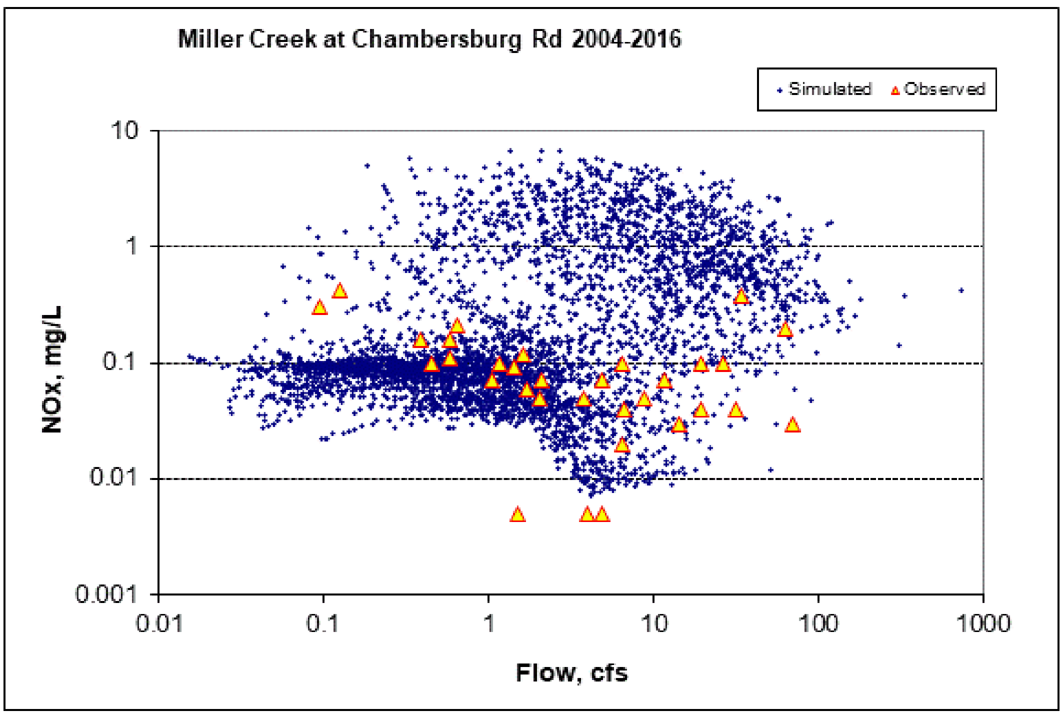


Figure E-623. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Miller Creek at Chambersburg Rd (calibration period)

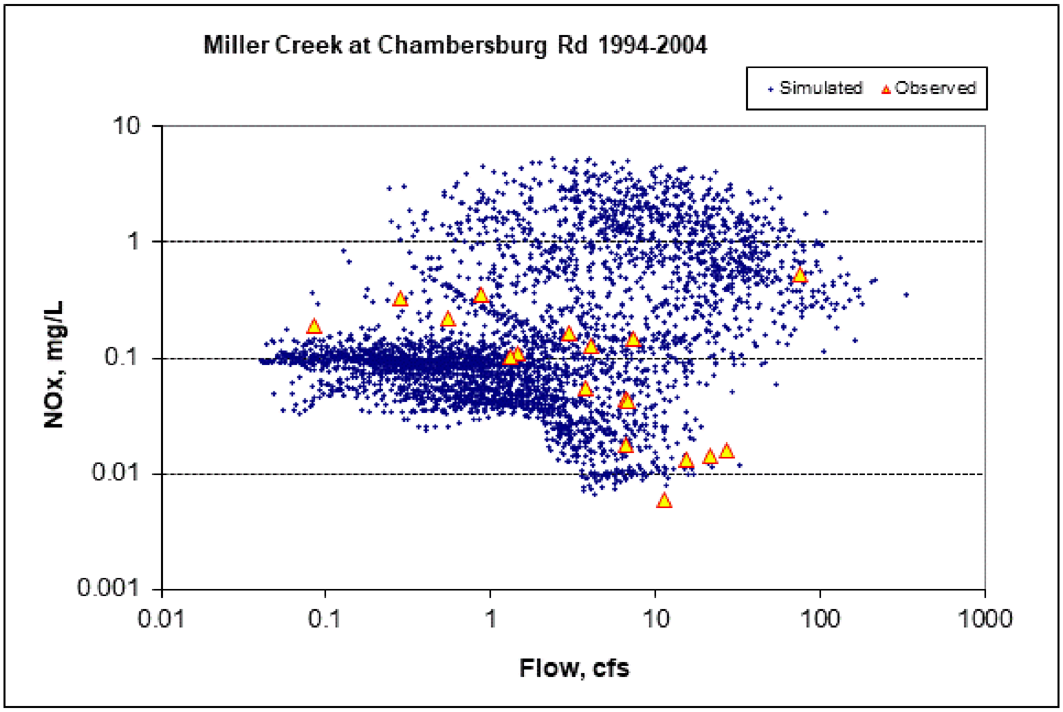
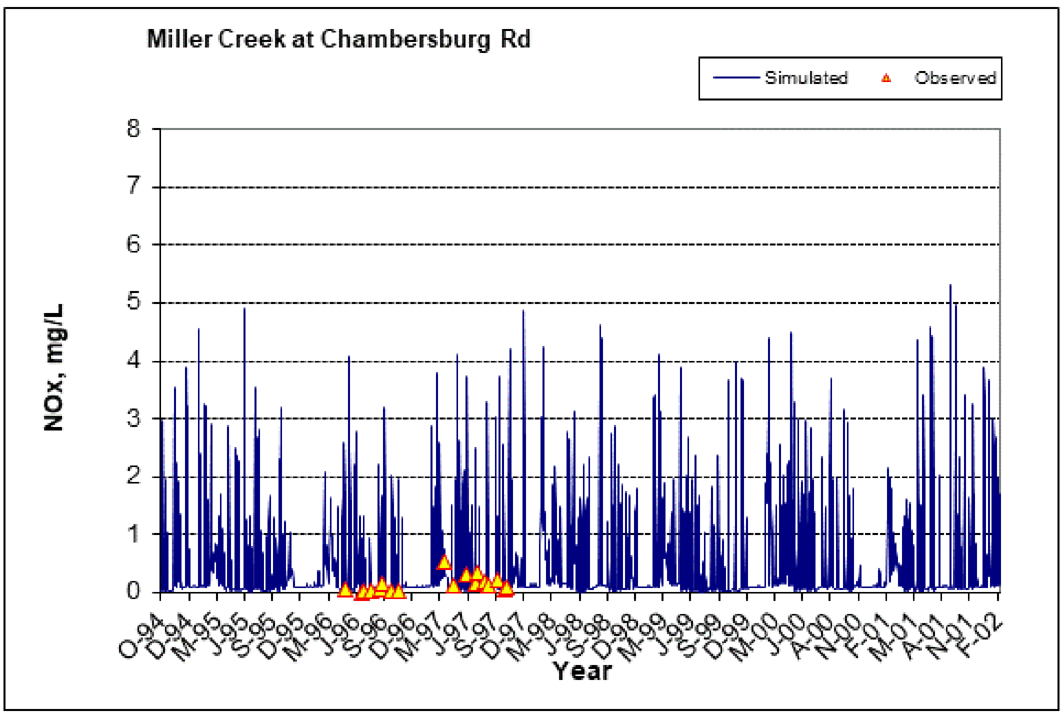


Figure E-624. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Miller Creek at Chambersburg Rd (validation period)



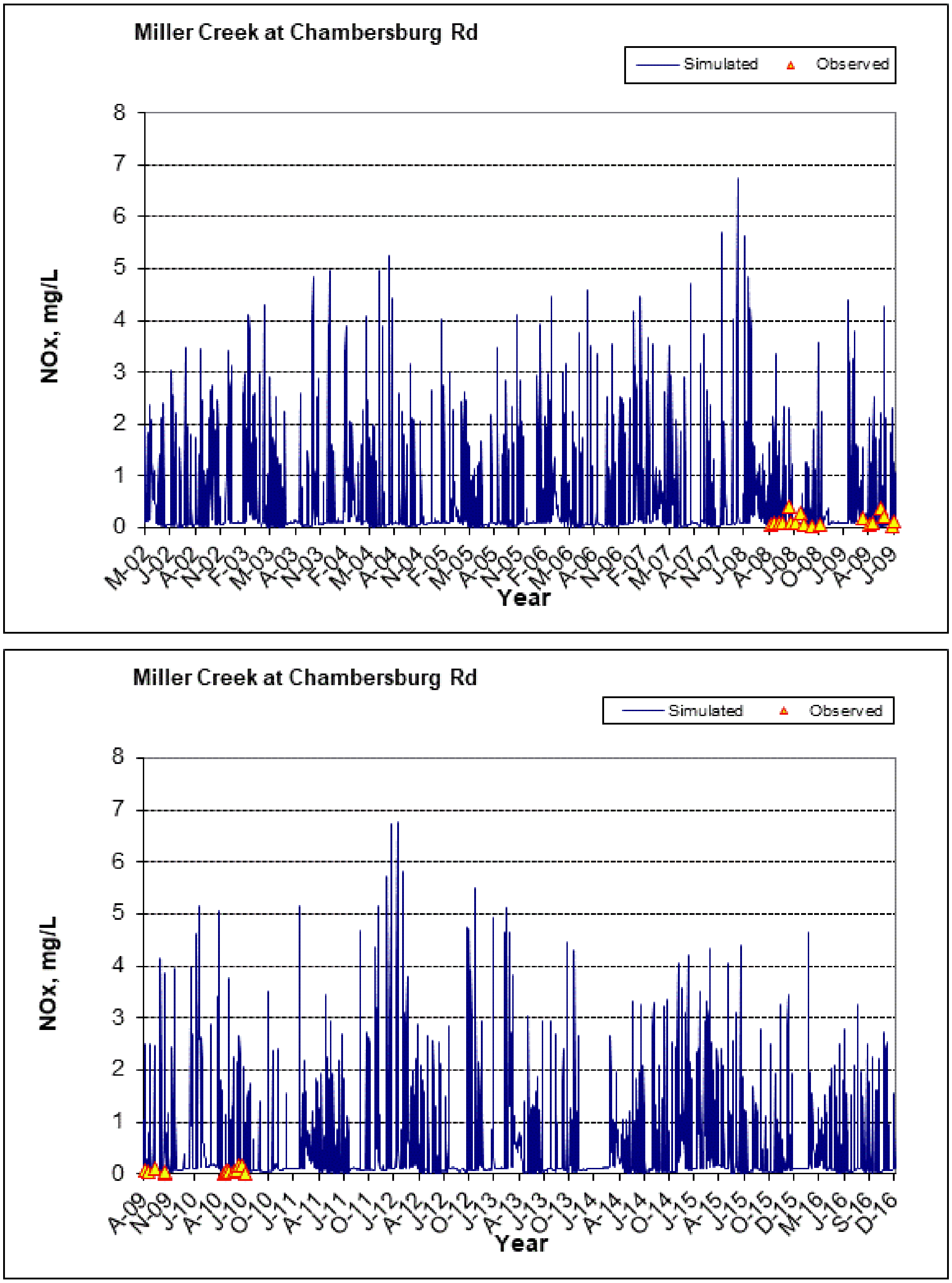


Figure E-625. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Miller Creek at Chambersburg Rd

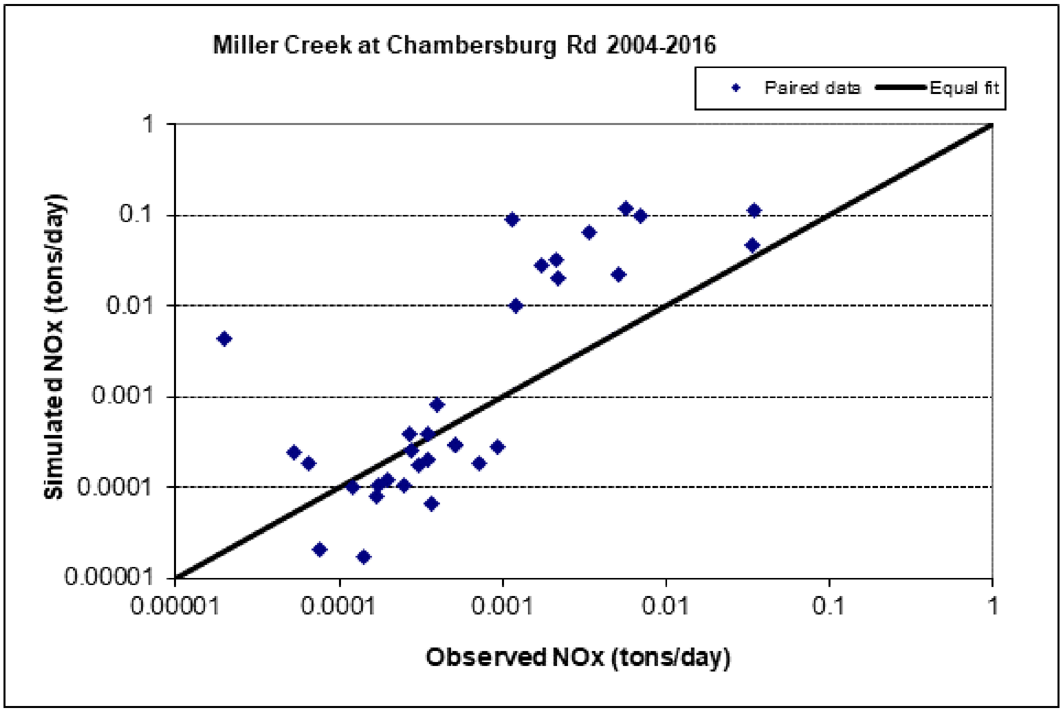


Figure E-626. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Miller Creek at Chambersburg Rd (calibration period)

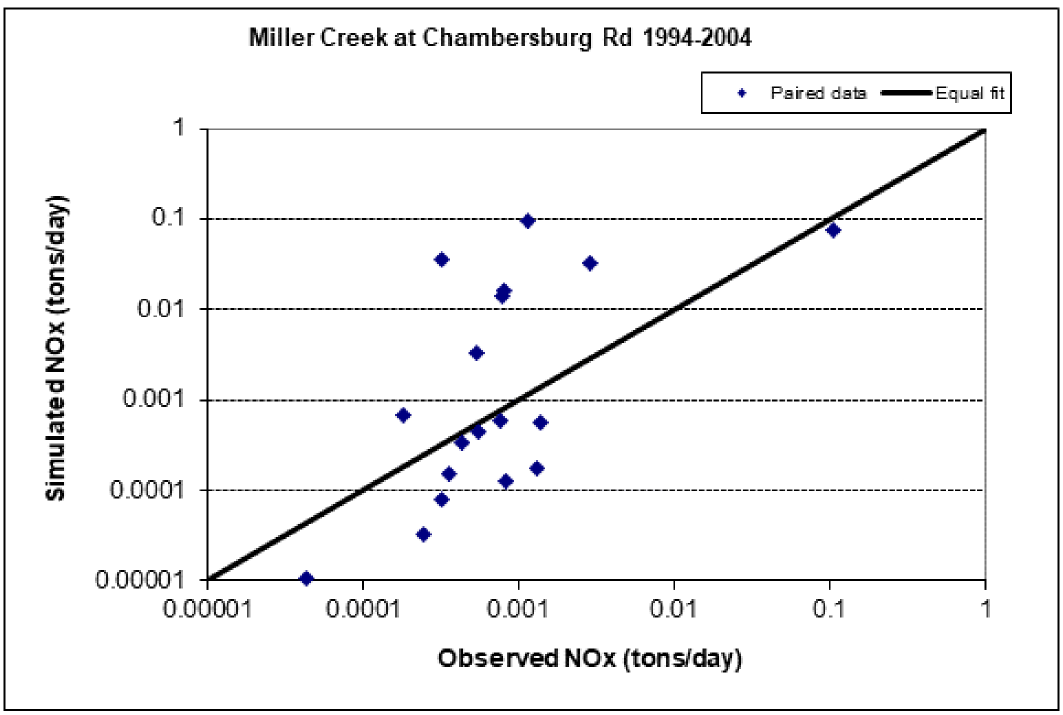


Figure E-627. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Miller Creek at Chambersburg Rd (validation period)

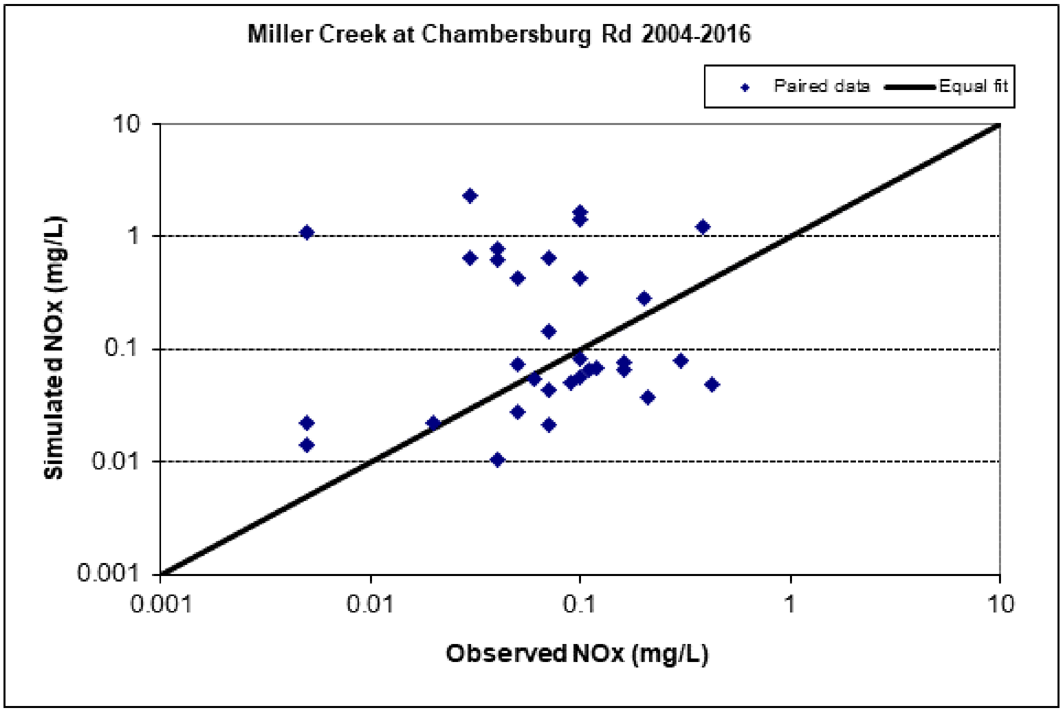


Figure E-628. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Miller Creek at Chambersburg Rd (calibration period)

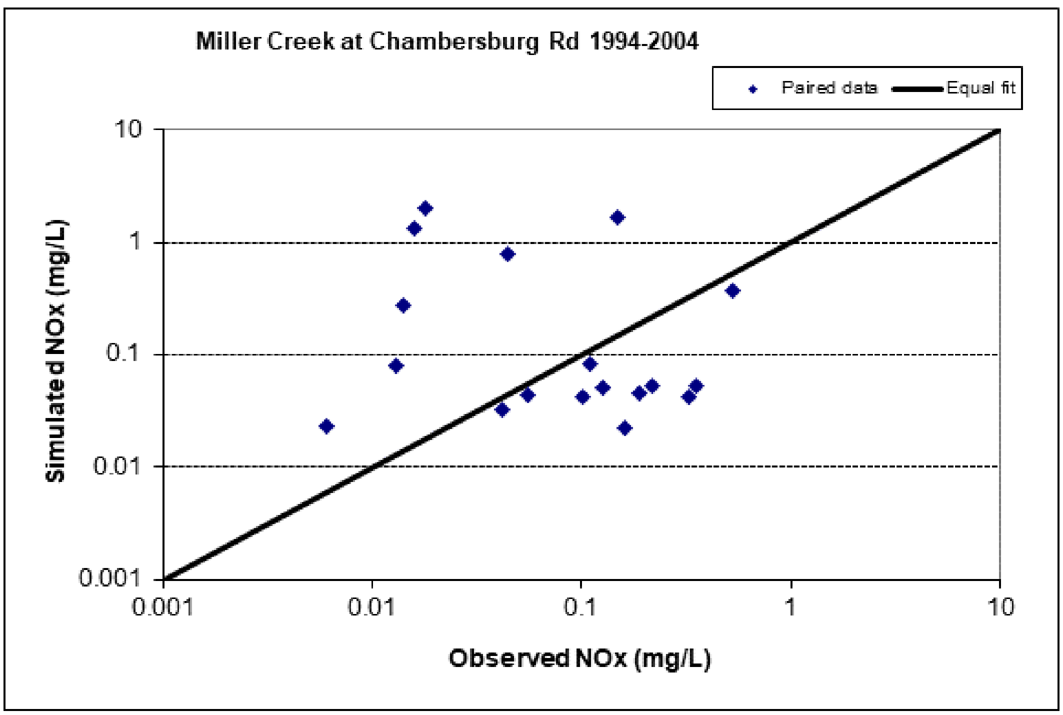


Figure E-629. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Miller Creek at Chambersburg Rd (validation period)

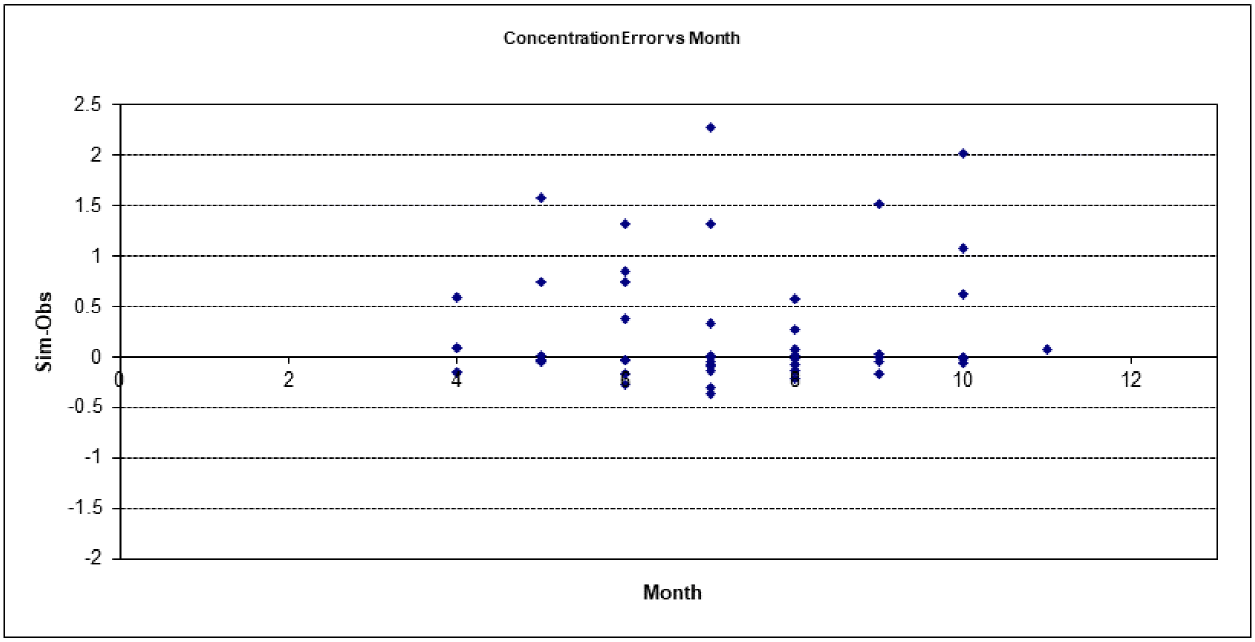


Figure E-630. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Miller Creek at Chambersburg Rd

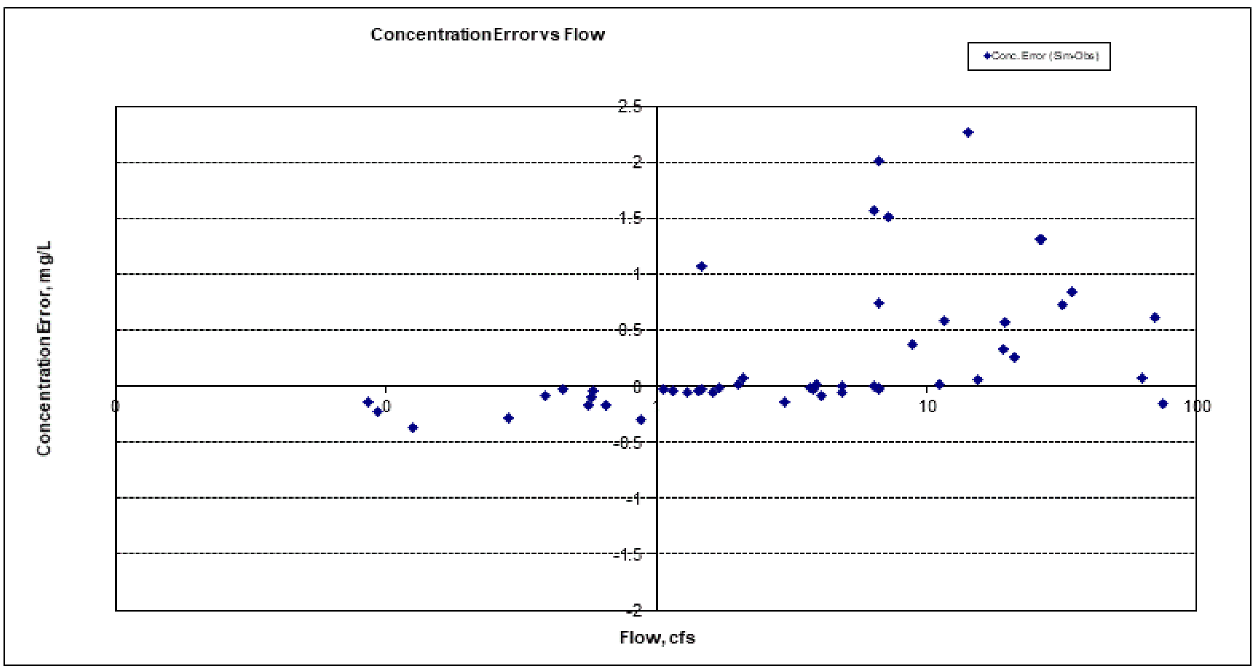


Figure E-631. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Miller Creek at Chambersburg Rd

E.13.6 Total Nitrogen (TN)

Table E-78. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	5	ND
Concentration Average Error	-31.69%	
Concentration Median Error	-27.69%	
Load Average Error	-40.88%	
Load Median Error	-1.45%	
Paired t conc	0.26	
Paired t load	0.40	

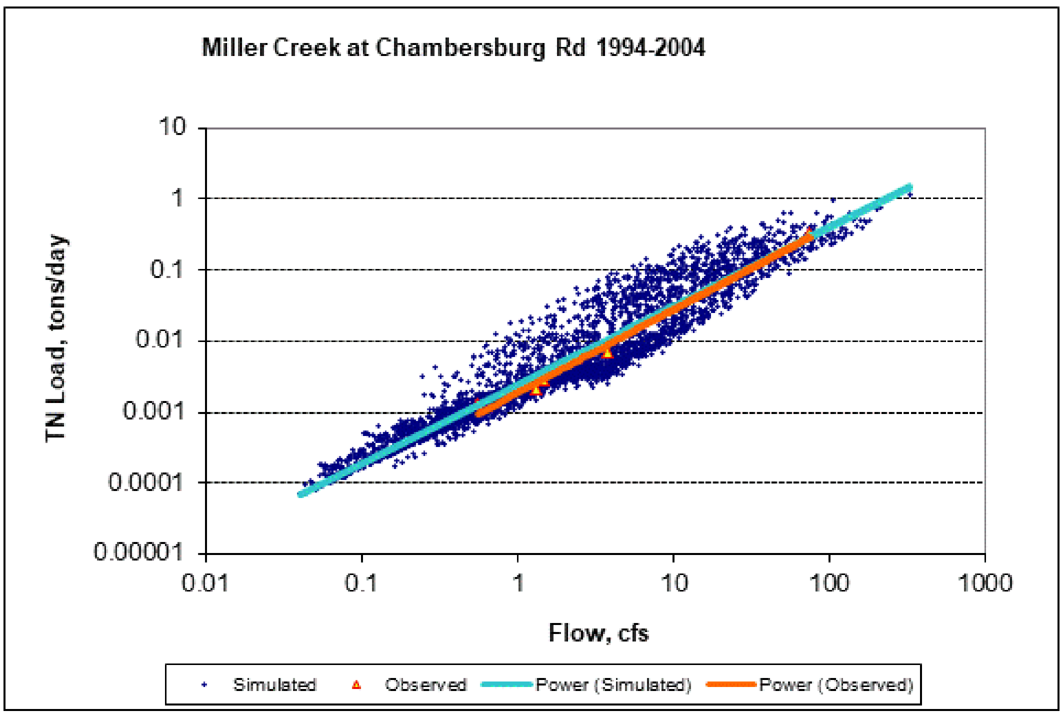


Figure E-632. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Miller Creek at Chambersburg Rd (validation period)

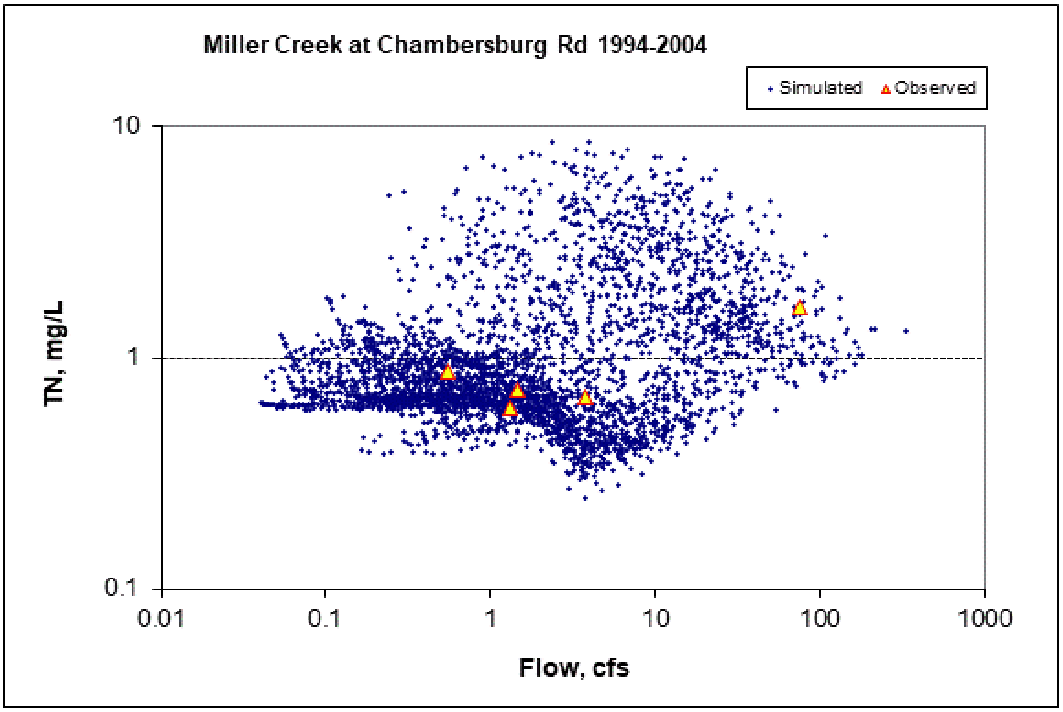
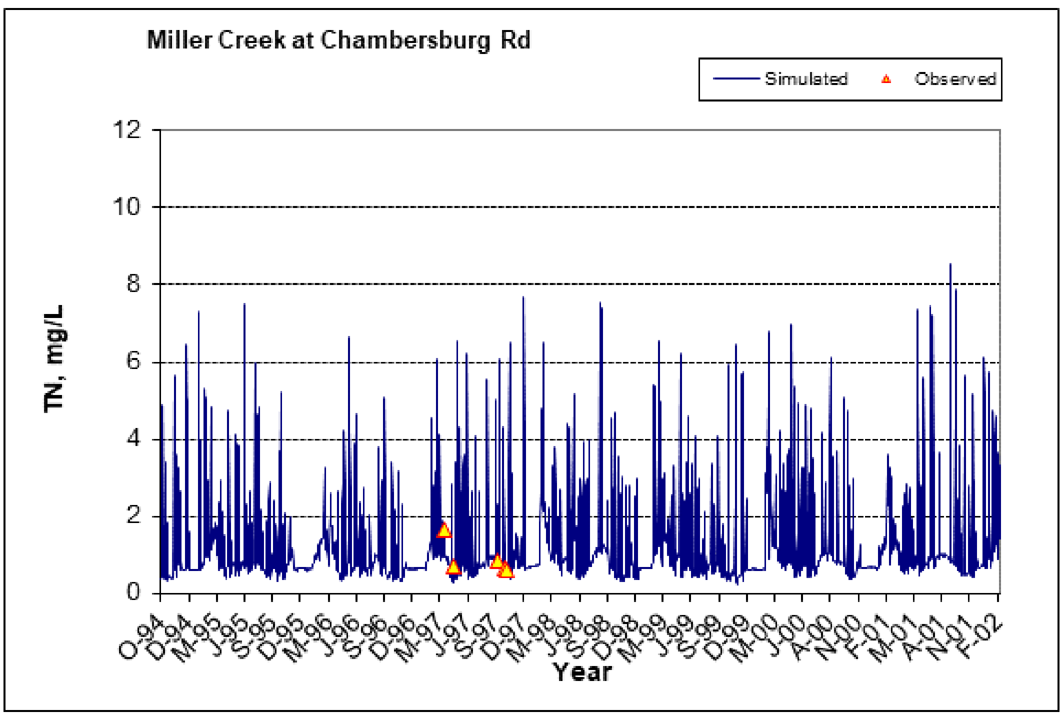
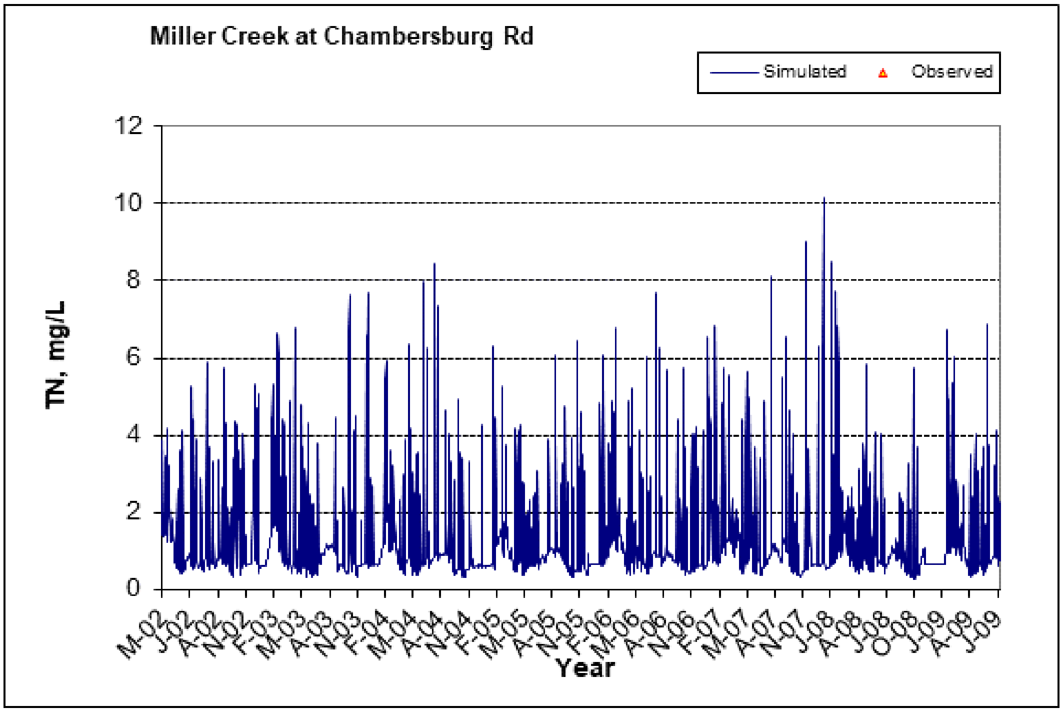


Figure E-633. Simulated and observed Total Nitrogen (TN) concentration vs flow at Miller Creek at Chambersburg Rd (validation period)





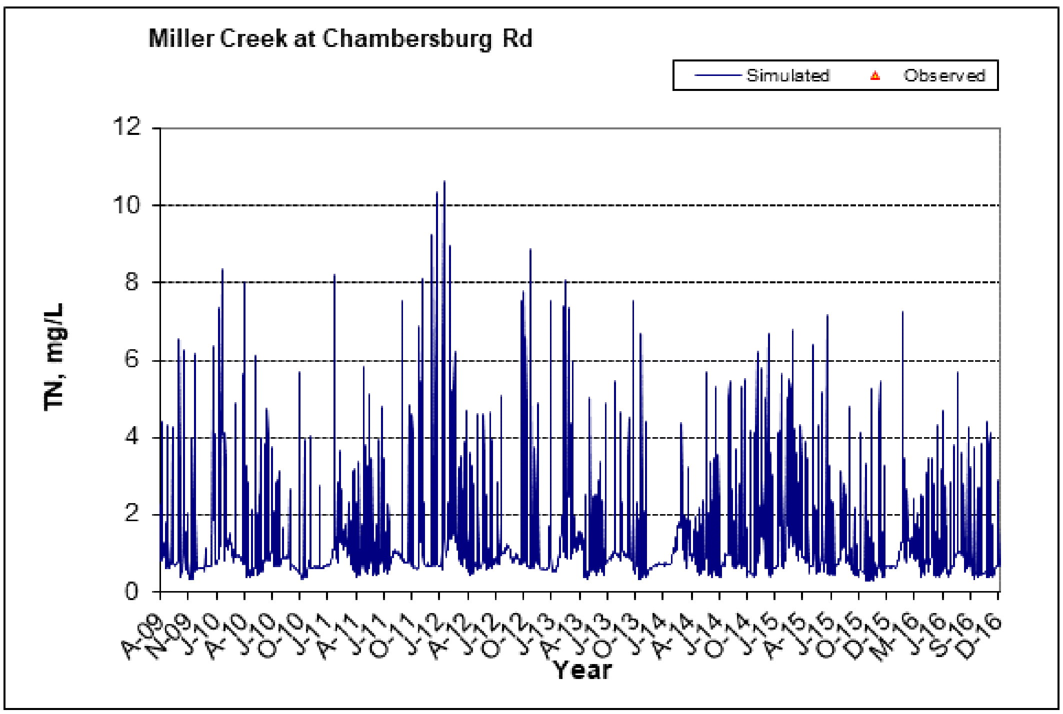


Figure E-634. Time series of observed and simulated Total Nitrogen (TN) concentration at Miller Creek at Chambersburg Rd

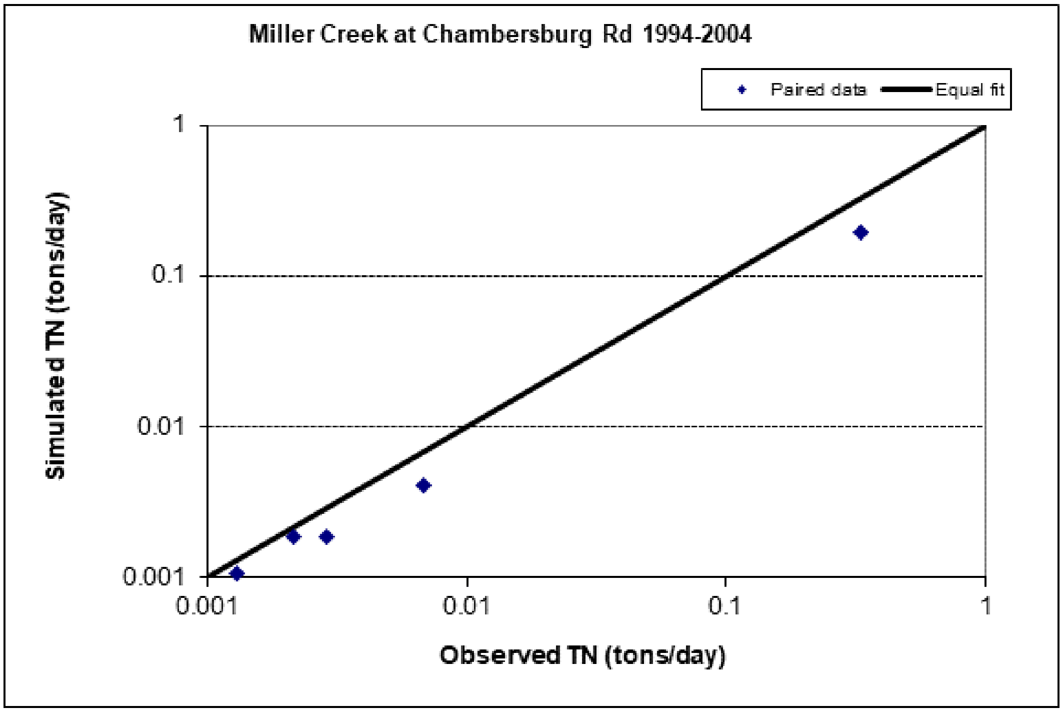


Figure E-635. Paired simulated vs. observed Total Nitrogen (TN) load at Miller Creek at Chambersburg Rd (validation period)

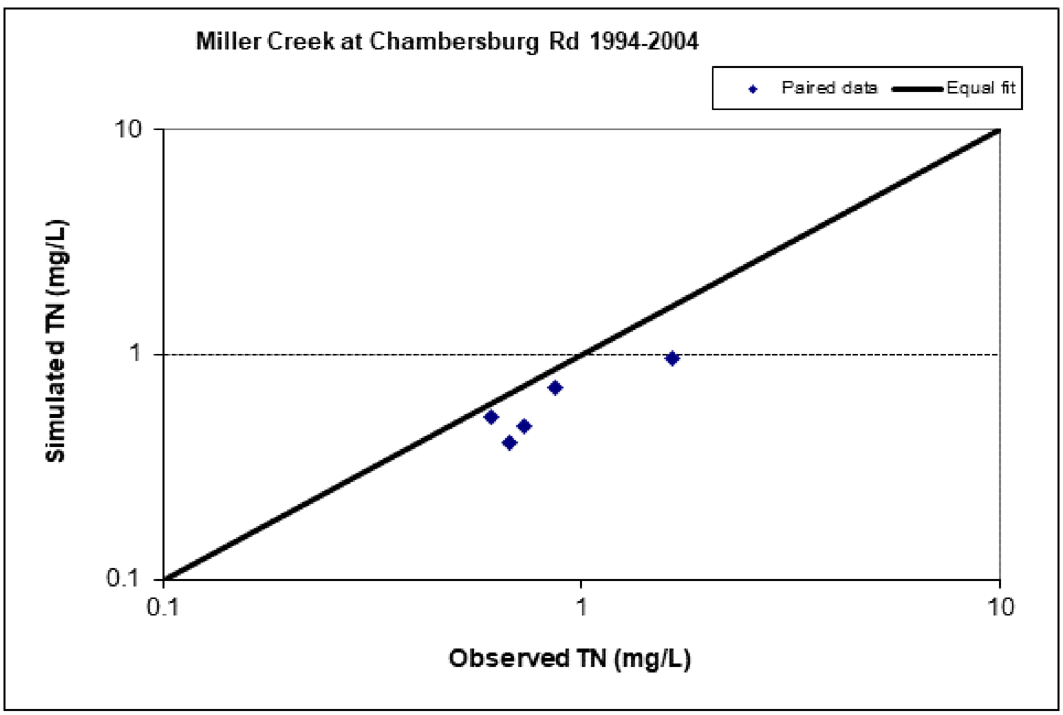


Figure E-636. Paired simulated vs. observed Total Nitrogen (TN) concentration at Miller Creek at Chambersburg Rd (validation period)

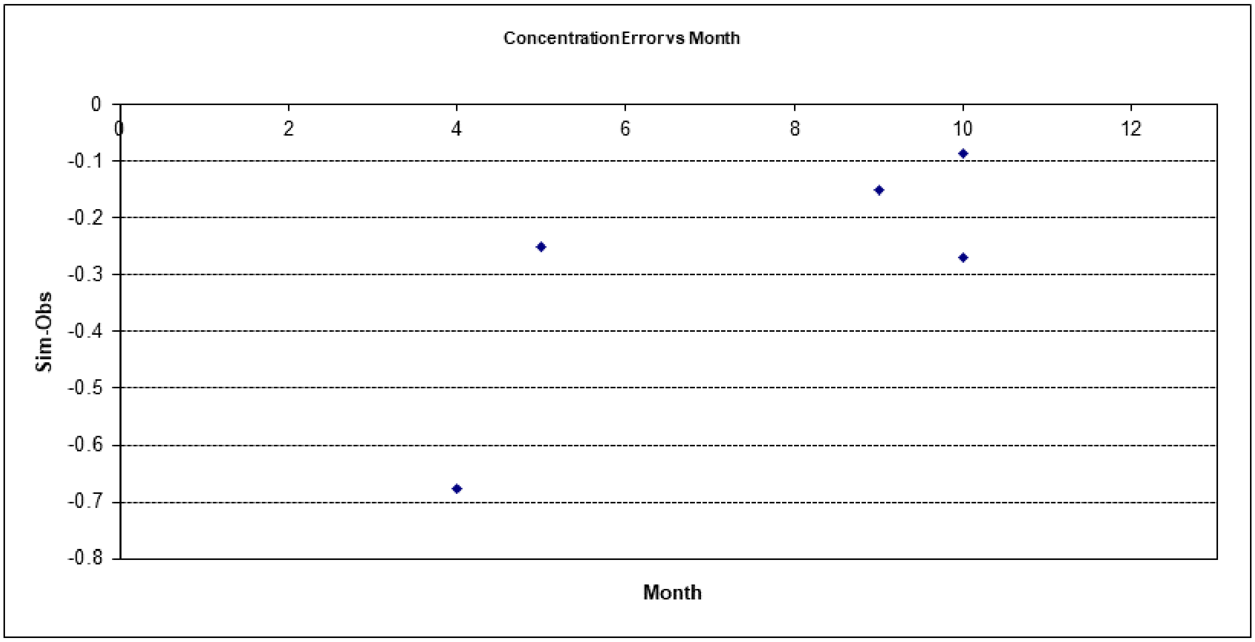


Figure E-637. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at Miller Creek at Chambersburg Rd

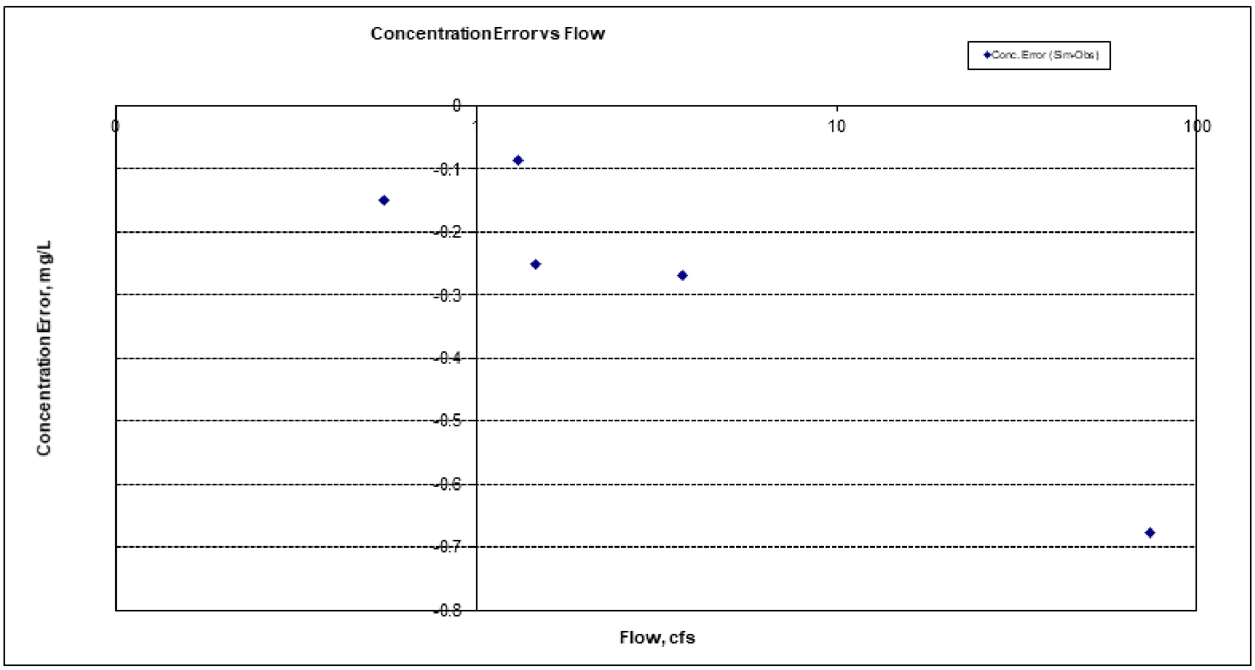


Figure E-638. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at Miller Creek at Chambersburg Rd

E.13.7 Soluble Reactive Phosphorus (SRP)

Table E-79. Soluble Reactive Phosphorus (SRP) statistics

Period	1994-2004	2004-2016
Count	18	ND
Concentration Average Error	-12.07%	
Concentration Median Error	-29.17%	
Load Average Error	19.23%	
Load Median Error	-0.73%	
Paired t conc	0.77	
Paired t load	0.51	

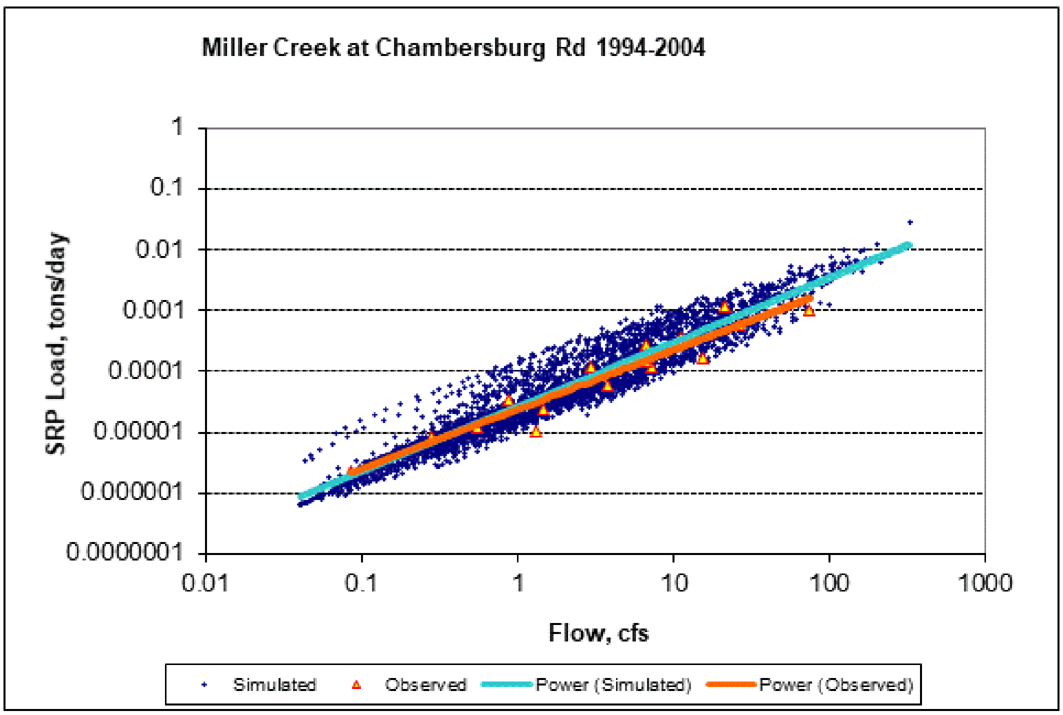


Figure E-639. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Miller Creek at Chambersburg Rd (validation period)

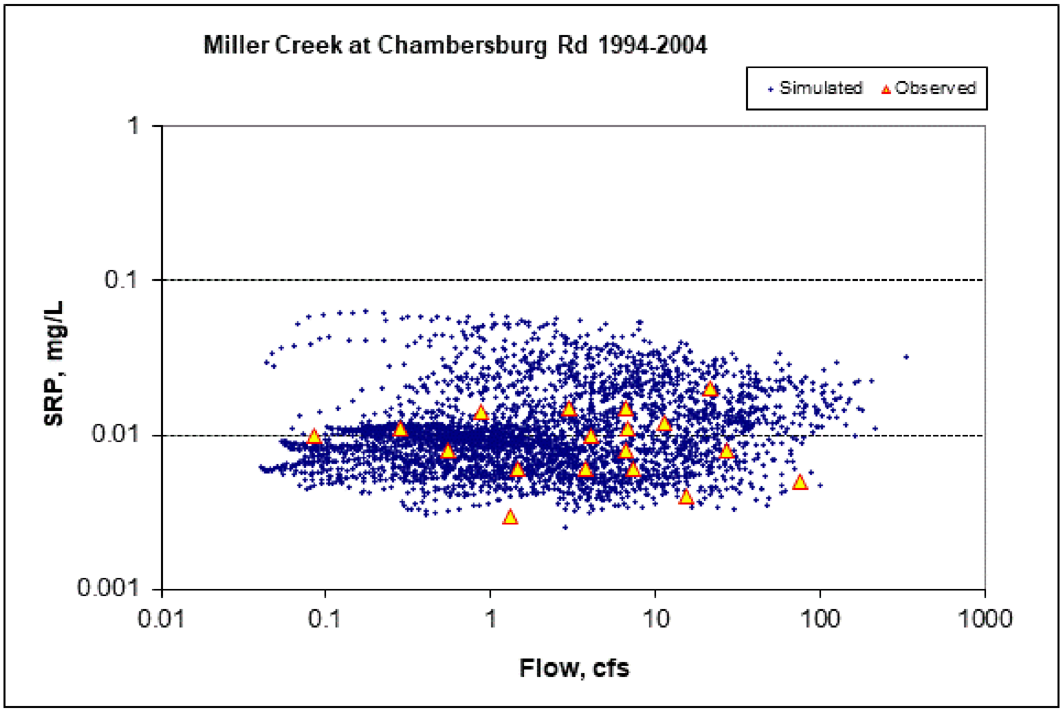
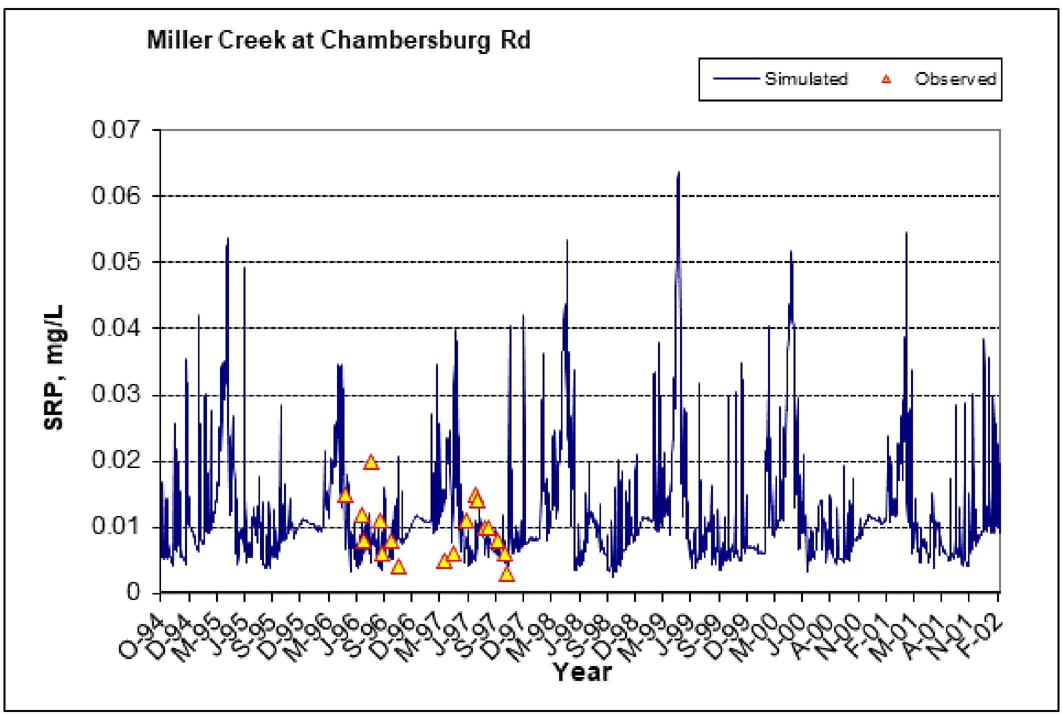


Figure E-640. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at Miller Creek at Chambersburg Rd (validation period)



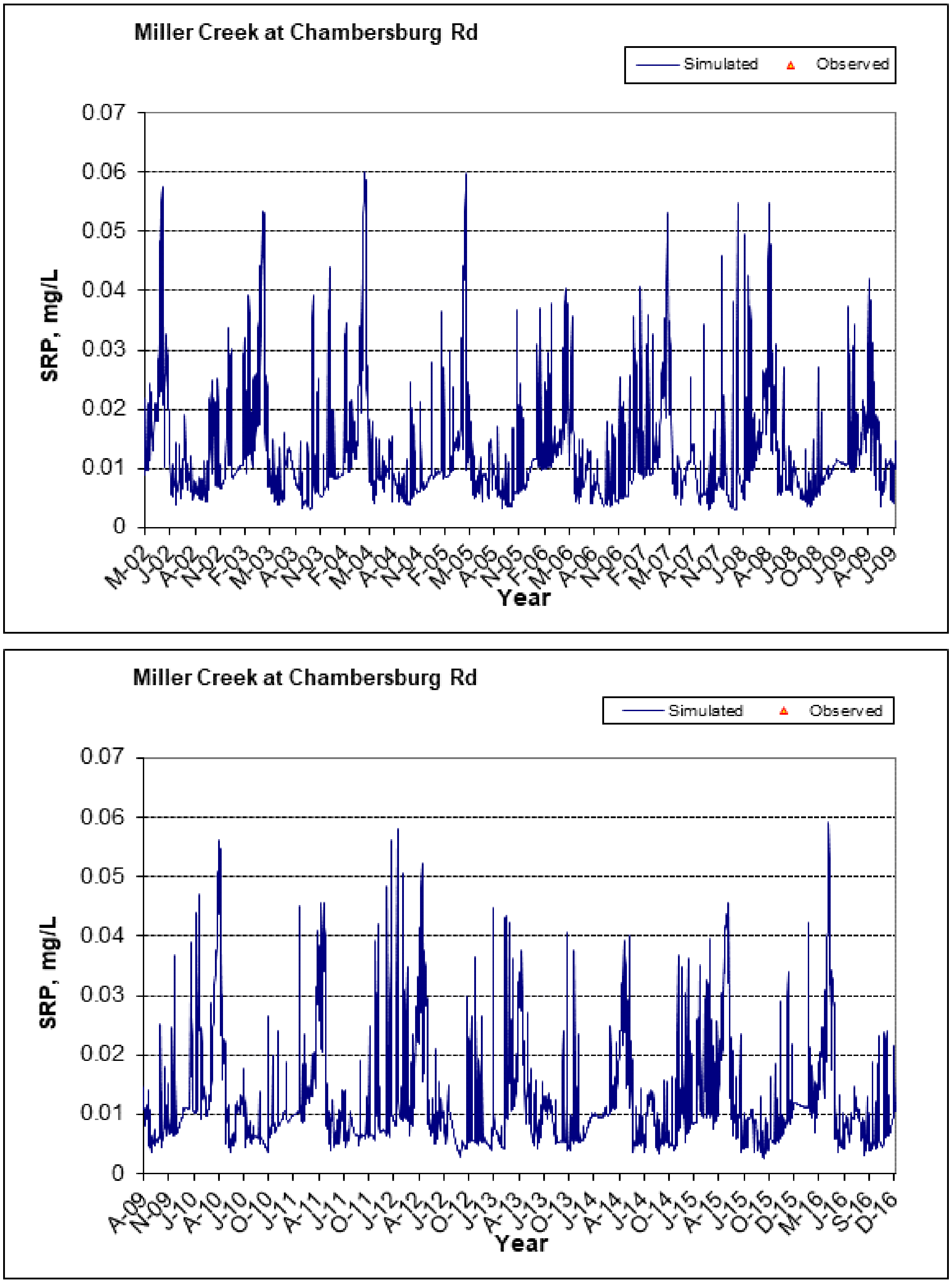


Figure E-641. Time series of observed and simulated Soluble Reactive Phosphorus (SRP) concentration at Miller Creek at Chambersburg Rd

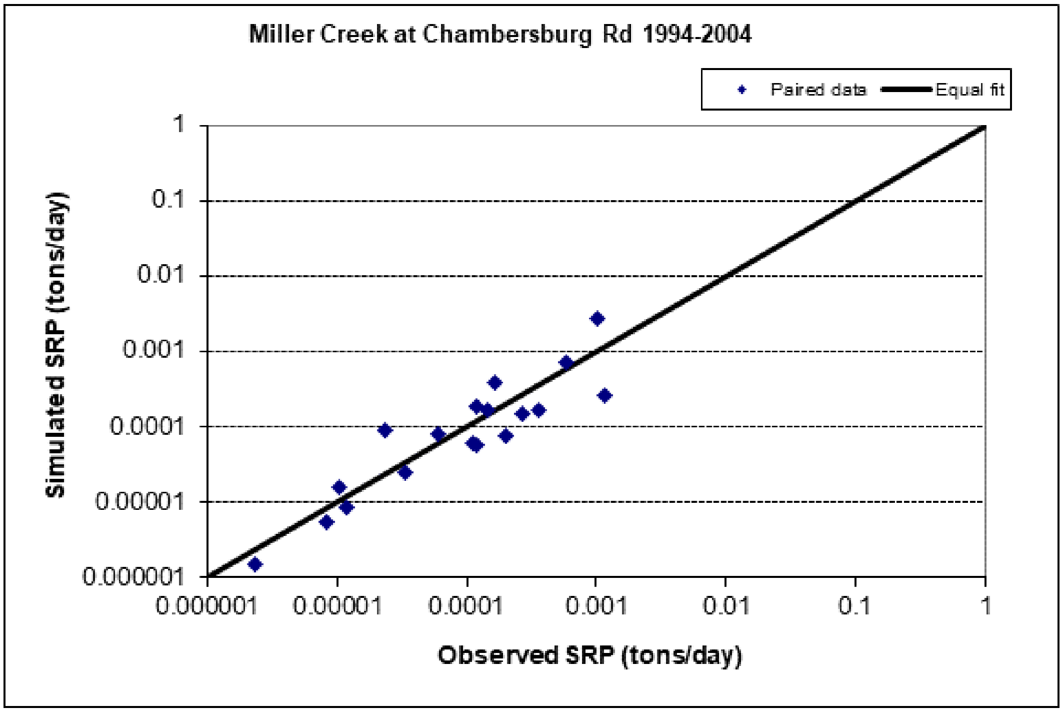


Figure E-642. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at Miller Creek at Chambersburg Rd (validation period)

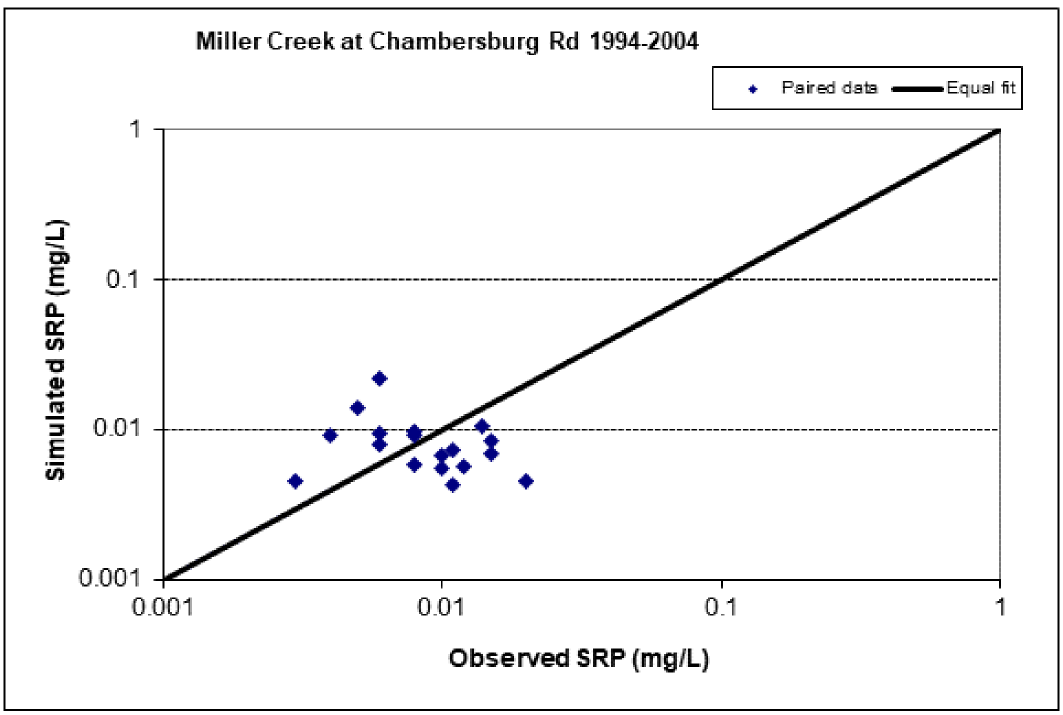


Figure E-643. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at Miller Creek at Chambersburg Rd (validation period)

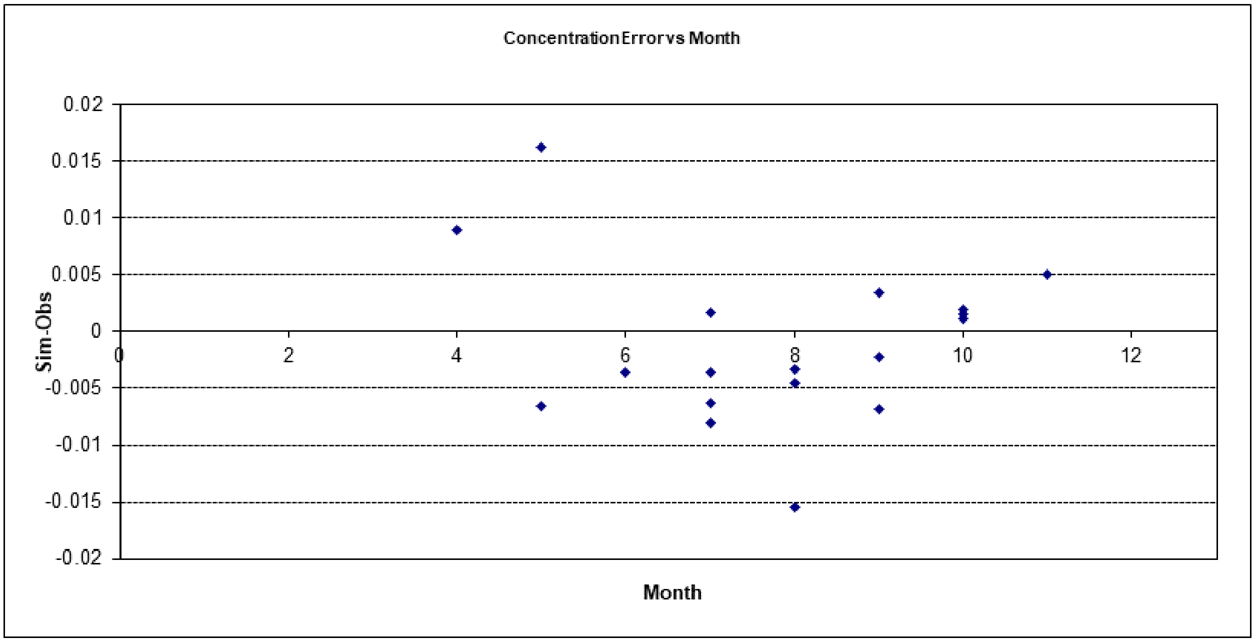


Figure E-644. Residual (Simulated - Observed) vs. Month, Soluble Reactive Phosphorus (SRP) at Miller Creek at Chambersburg Rd

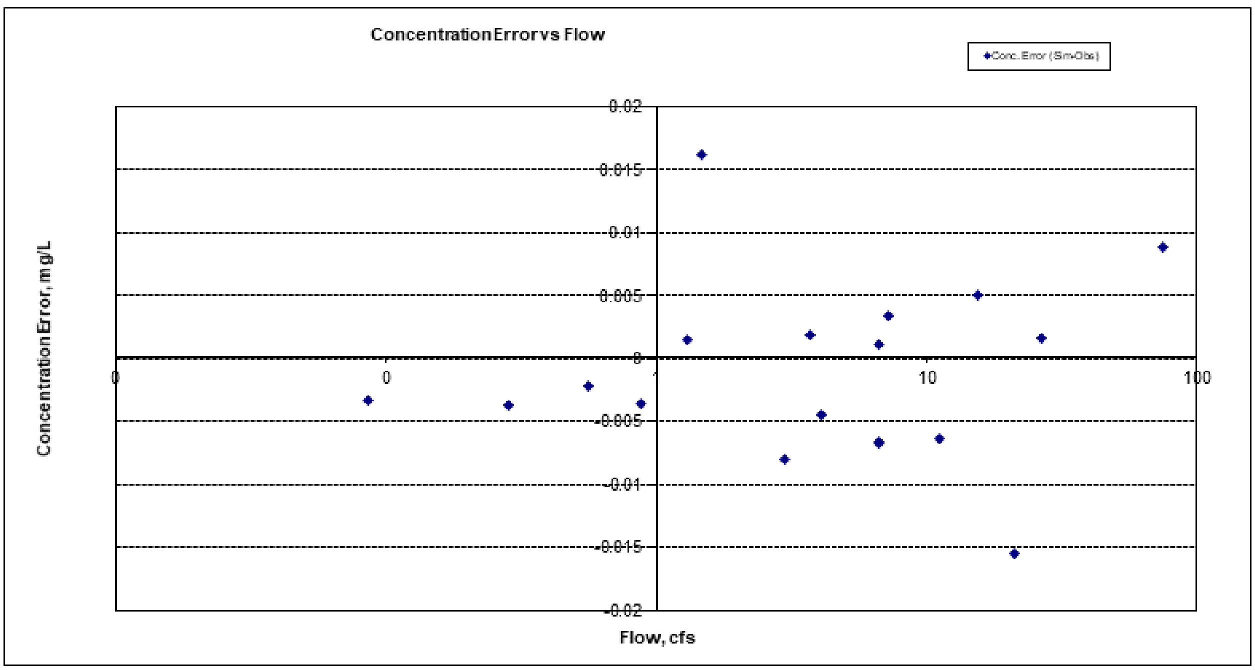


Figure E-645. Residual (Simulated - Observed) vs. Flow, Soluble Reactive Phosphorus (SRP) at Miller Creek at Chambersburg Rd

E.13.8 Organic Phosphorus (OrgP)

Table E-80. Organic Phosphorus (OrgP) statistics

Period	1994-2004	2004-2016
Count	7	ND
Concentration Average Error	26.35%	
Concentration Median Error	-28.34%	
Load Average Error	20.76%	
Load Median Error	-2.83%	
Paired t conc	0.45	
Paired t load	0.50	

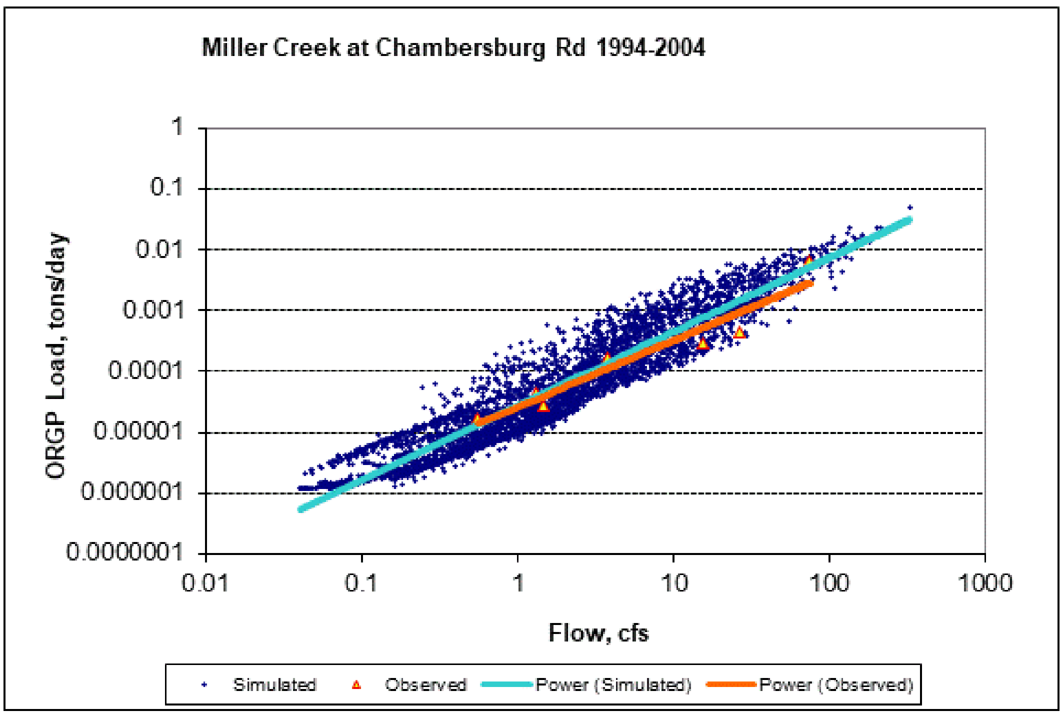


Figure E-646. Power plot of simulated and observed Organic Phosphorus (OrgP) load vs flow at Miller Creek at Chambersburg Rd (validation period)

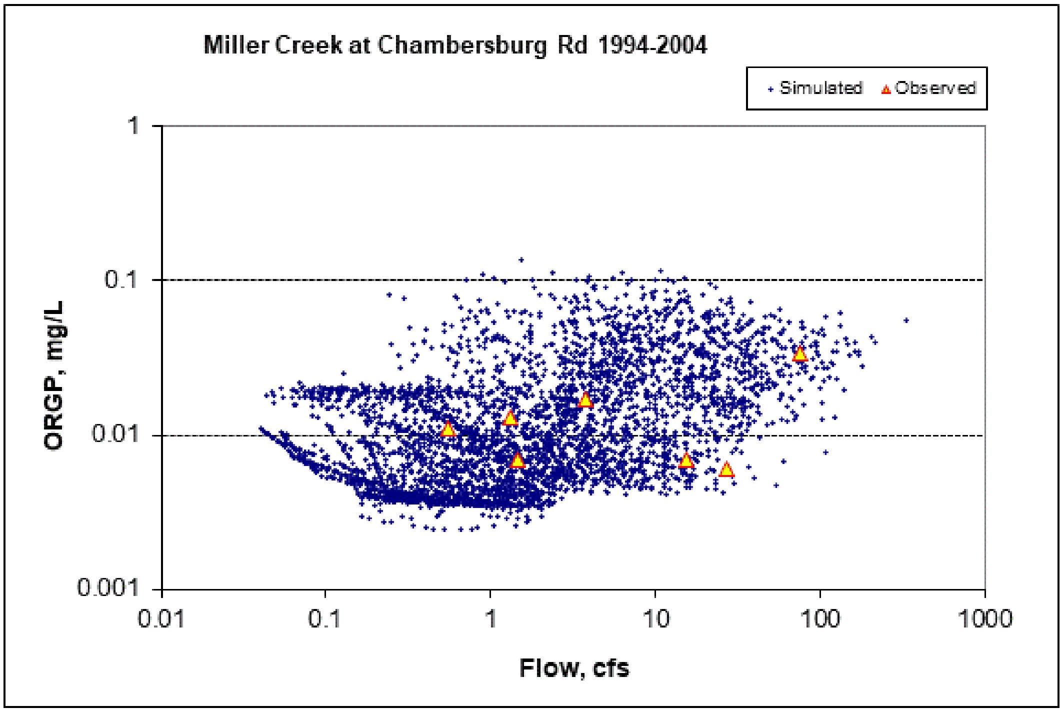
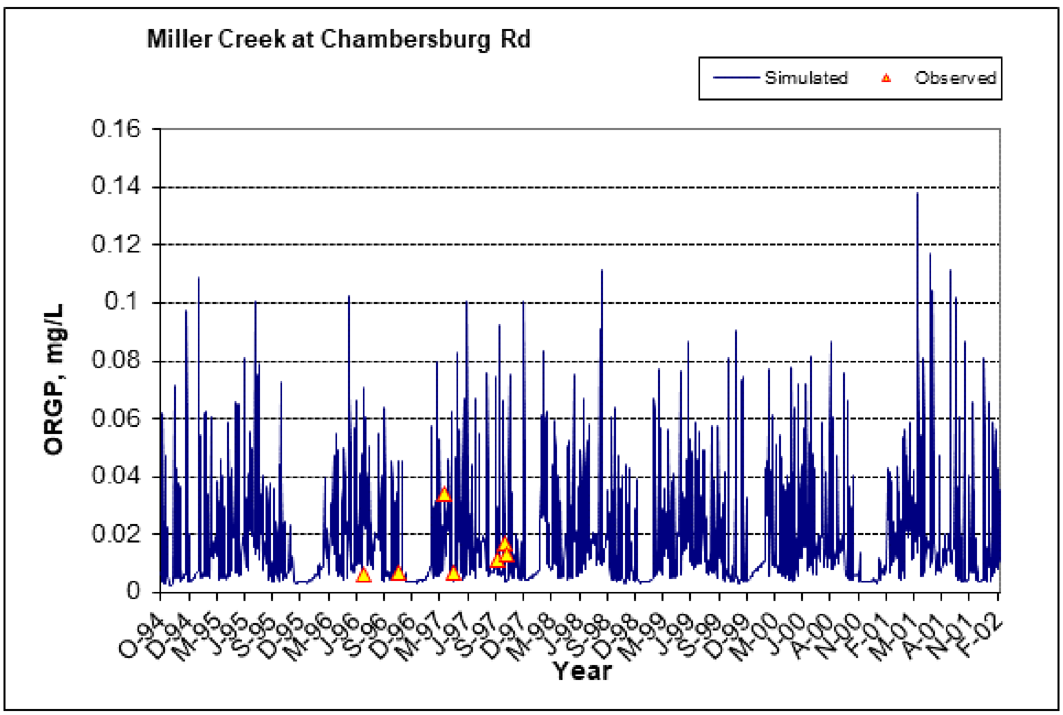


Figure E-647. Simulated and observed Organic Phosphorus (OrgP) concentration vs flow at Miller Creek at Chambersburg Rd (validation period)



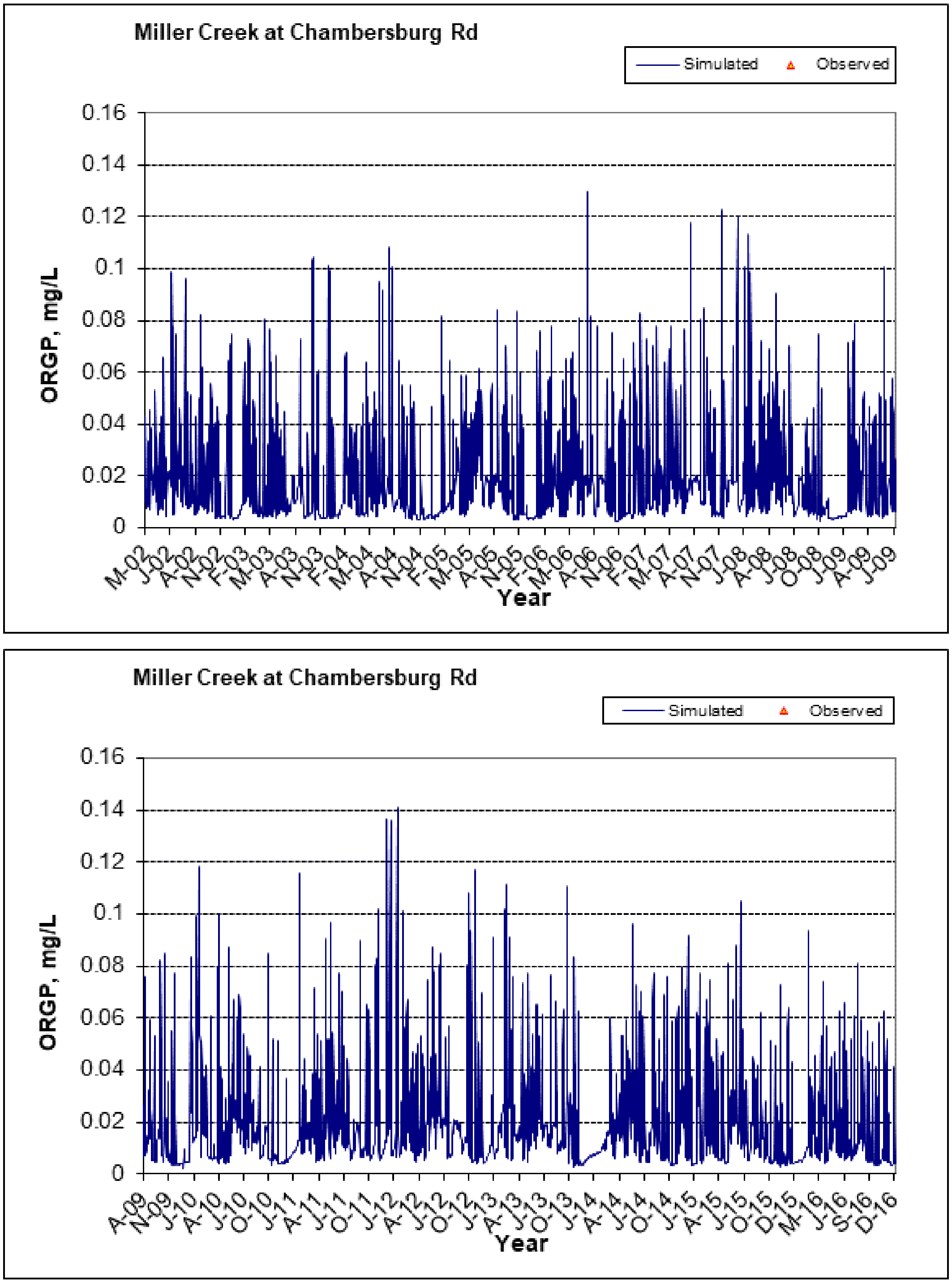


Figure E-648. Time series of observed and simulated Organic Phosphorus (OrgP) concentration at Miller Creek at Chambersburg Rd

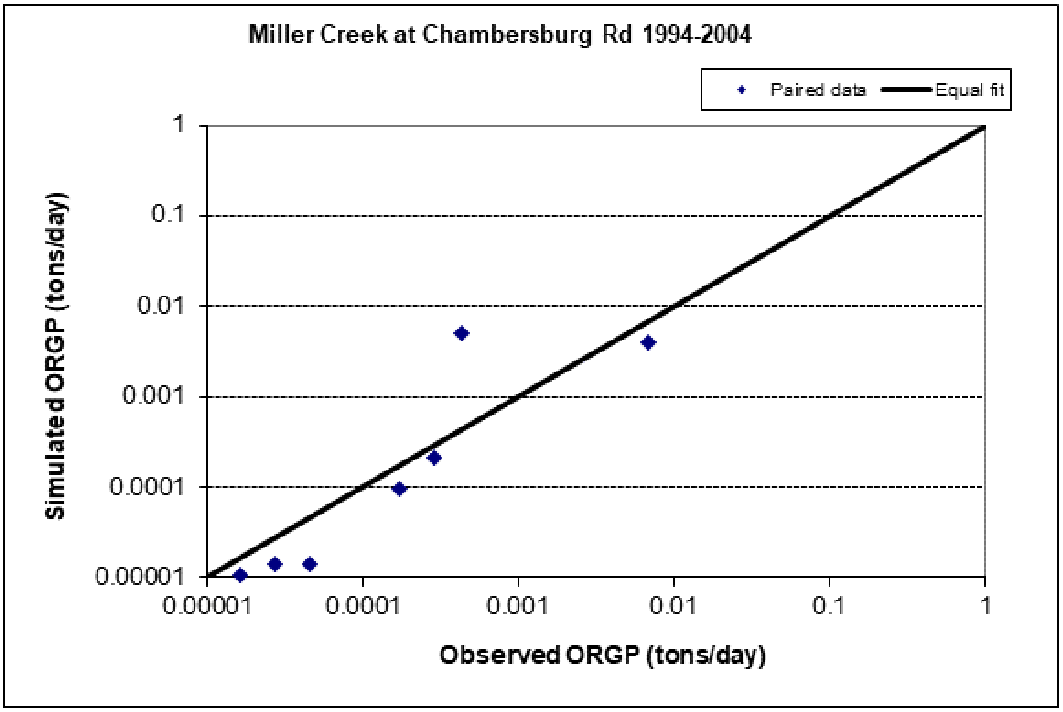


Figure E-649. Paired simulated vs. observed Organic Phosphorus (OrgP) load at Miller Creek at Chambersburg Rd (validation period)

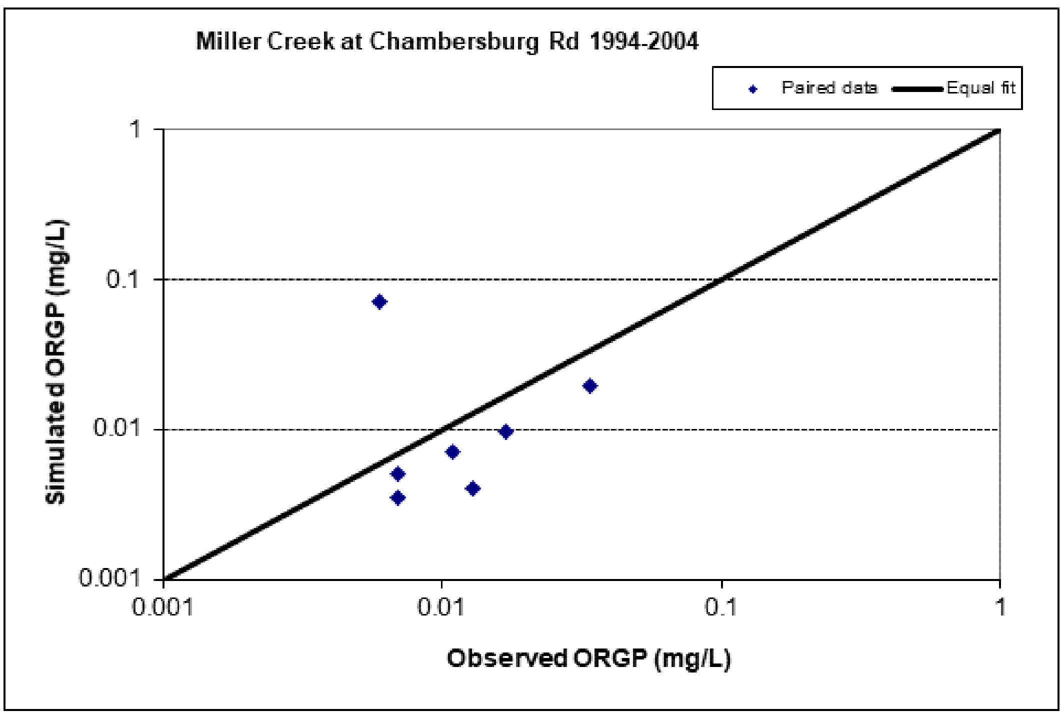


Figure E-650. Paired simulated vs. observed Organic Phosphorus (OrgP) concentration at Miller Creek at Chambersburg Rd (validation period)

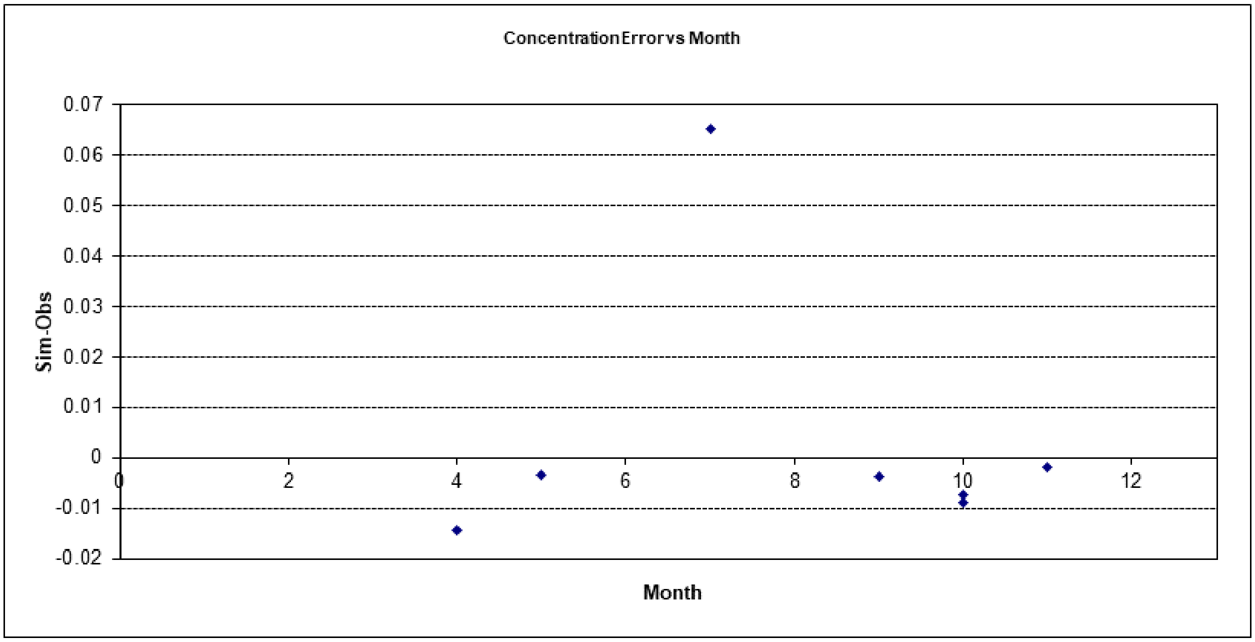


Figure E-651. Residual (Simulated - Observed) vs. Month, Organic Phosphorus (OrgP) at Miller Creek at Chambersburg Rd

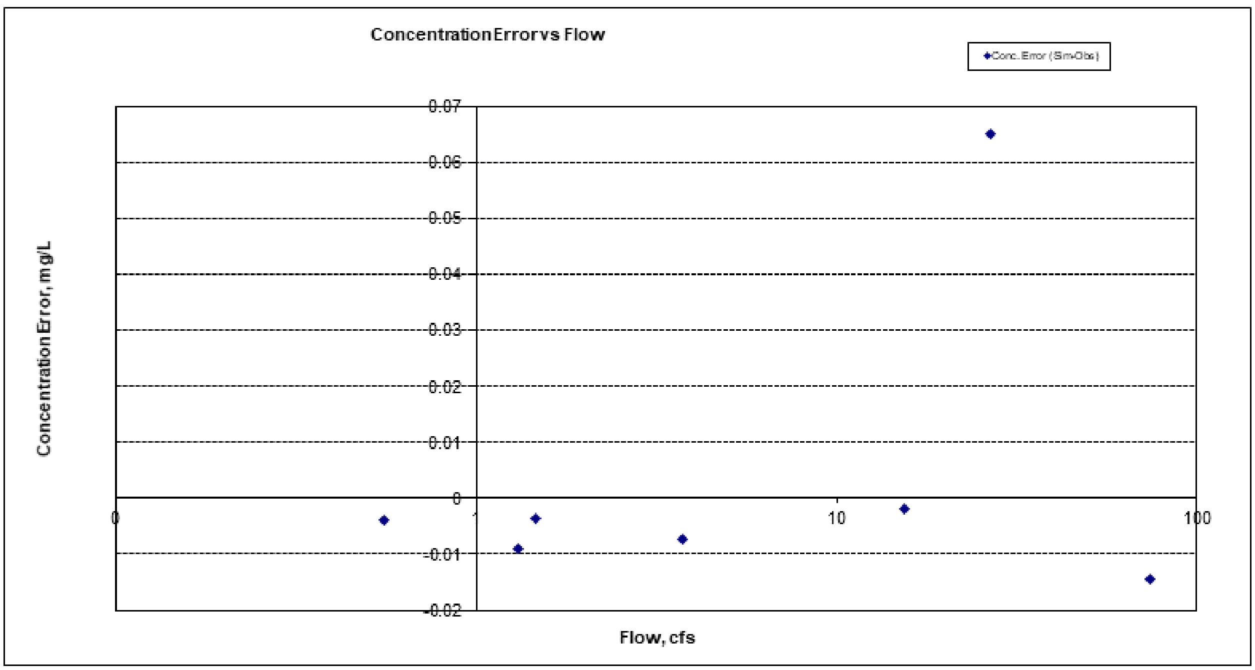


Figure E-652. Residual (Simulated - Observed) vs. Flow, Organic Phosphorus (OrgP) at Miller Creek at Chambersburg Rd

E.13.9 Total Phosphorus (TP)

Table E-81. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	12	32
Concentration Average Error	14.78%	-30.58%
Concentration Median Error	-21.76%	3.05%
Load Average Error	34.61%	-36.56%
Load Median Error	-1.82%	0.10%
Paired t conc	0.59	0.30
Paired t load	0.42	0.32

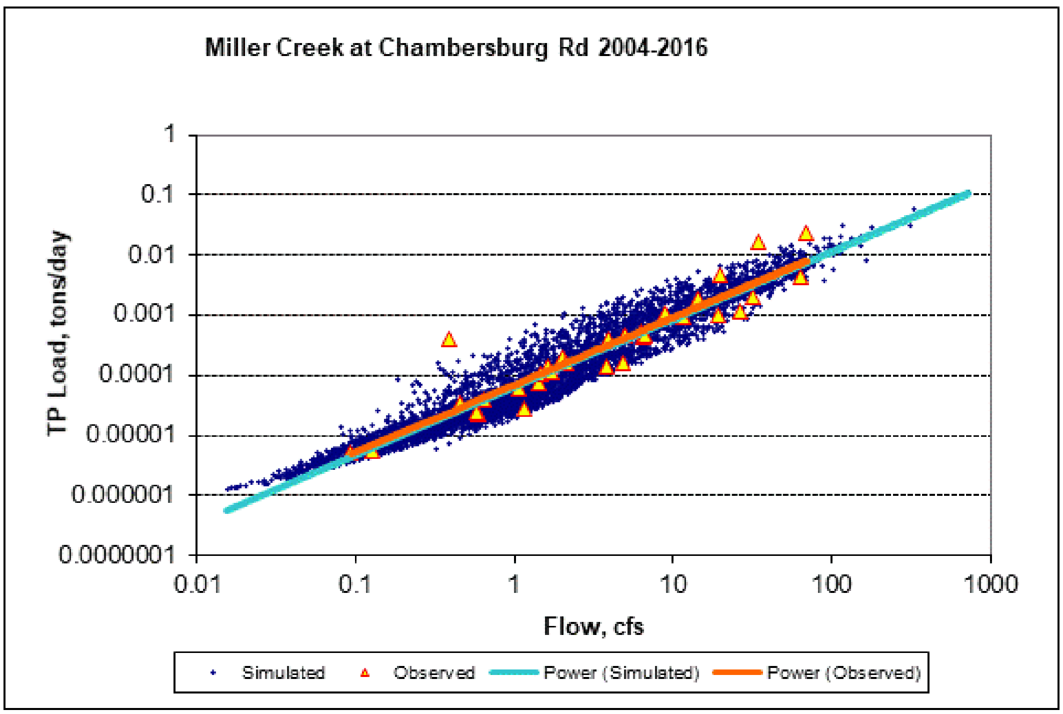


Figure E-653. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Miller Creek at Chambersburg Rd (calibration period)

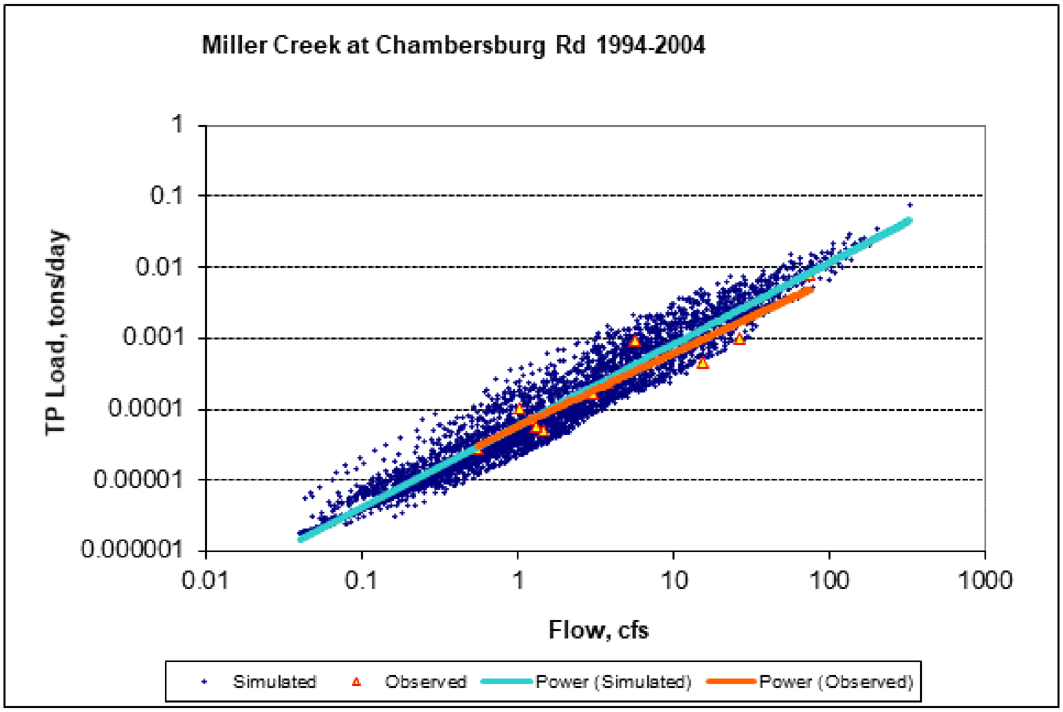


Figure E-654. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Miller Creek at Chambersburg Rd (validation period)

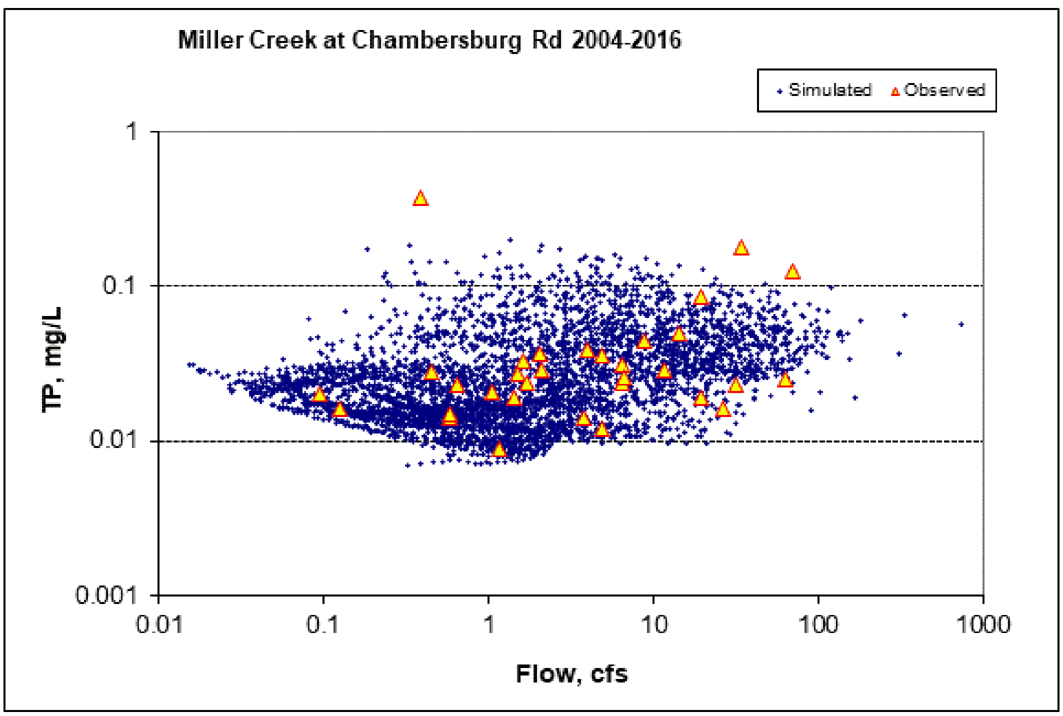


Figure E-655. Simulated and observed Total Phosphorus (TP) concentration vs flow at Miller Creek at Chambersburg Rd (calibration period)

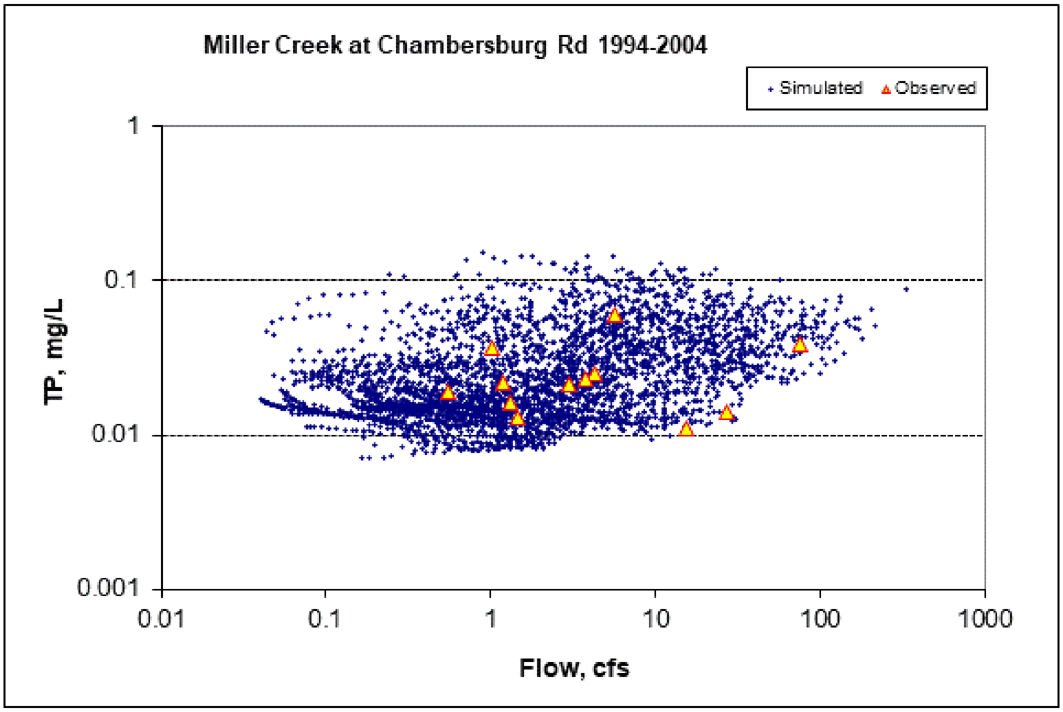
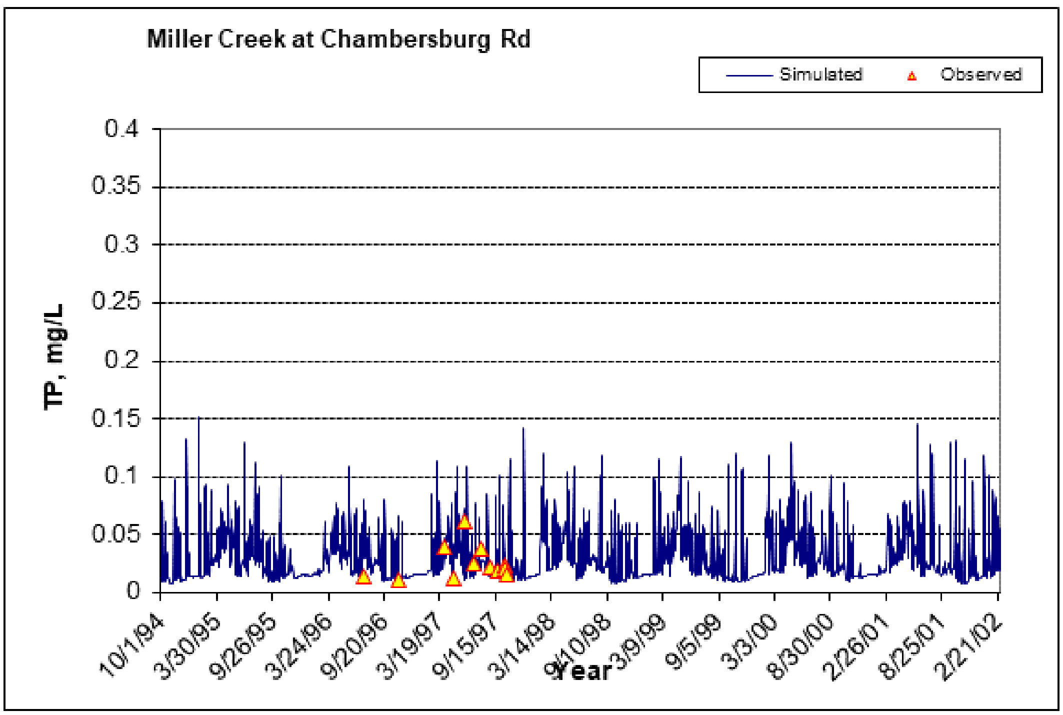
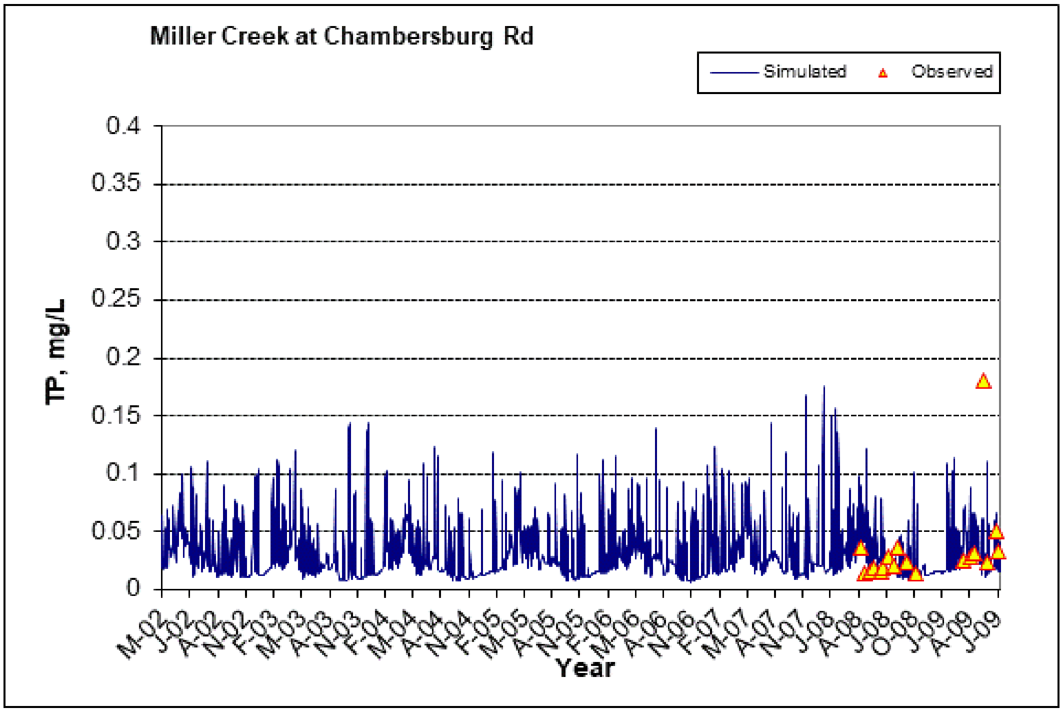


Figure E-656. Simulated and observed Total Phosphorus (TP) concentration vs flow at Miller Creek at Chambersburg Rd (validation period)





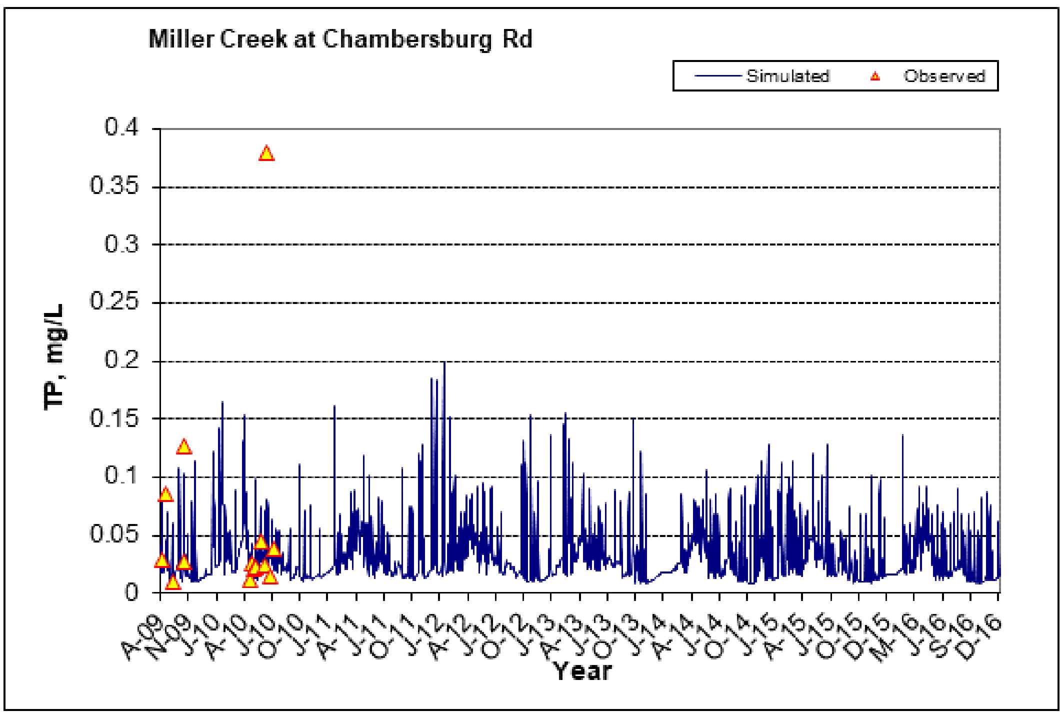


Figure E-657. Time series of observed and simulated Total Phosphorus (TP) concentration at Miller Creek at Chambersburg Rd

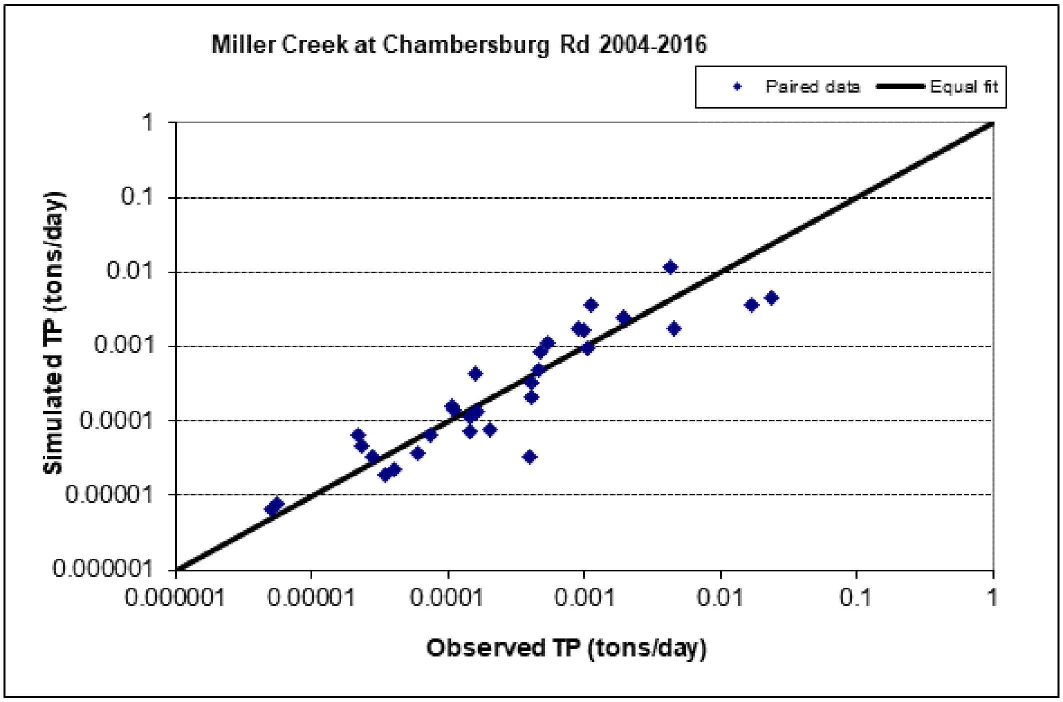


Figure E-658. Paired simulated vs. observed Total Phosphorus (TP) load at Miller Creek at Chambersburg Rd (calibration period)

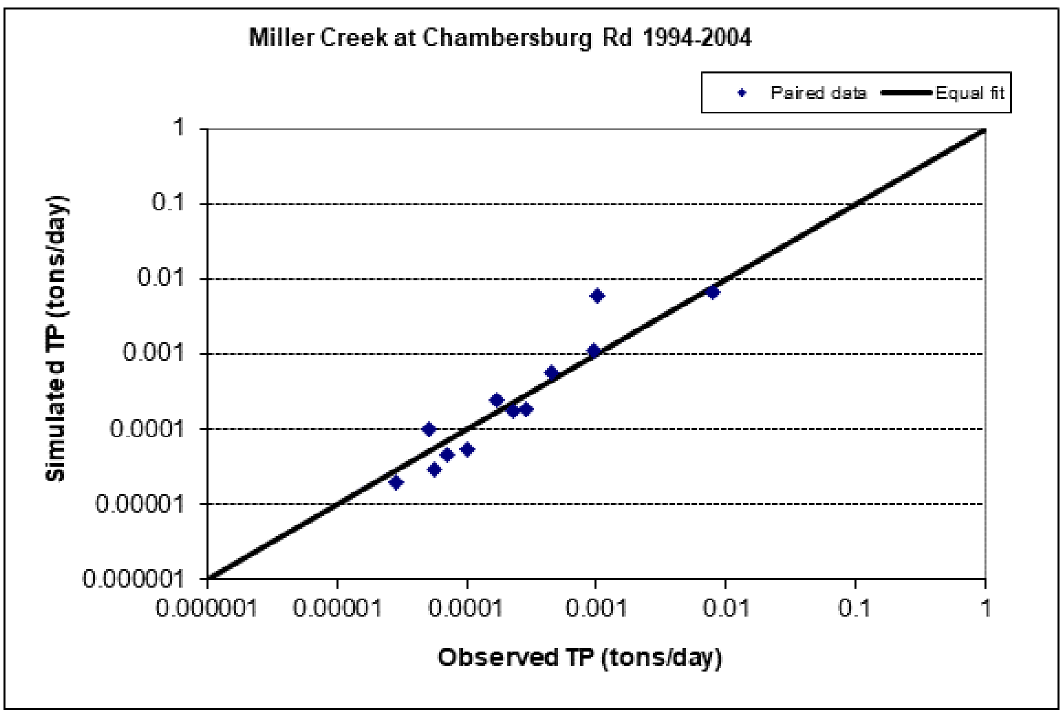


Figure E-659. Paired simulated vs. observed Total Phosphorus (TP) load at Miller Creek at Chambersburg Rd (validation period)

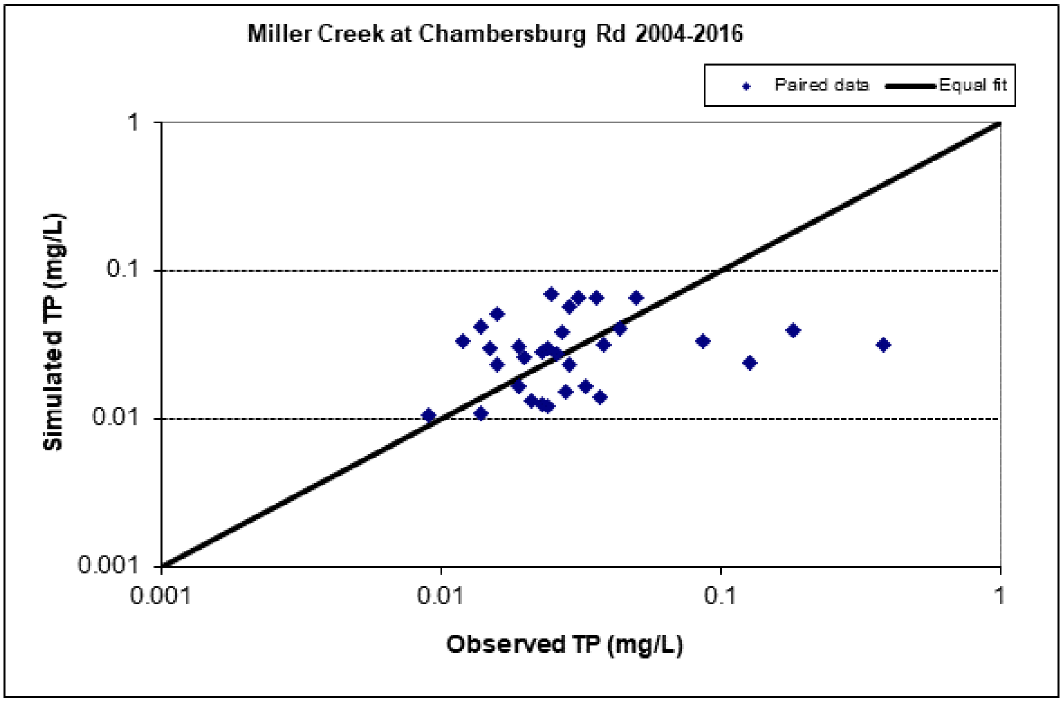


Figure E-660. Paired simulated vs. observed Total Phosphorus (TP) concentration at Miller Creek at Chambersburg Rd (calibration period)

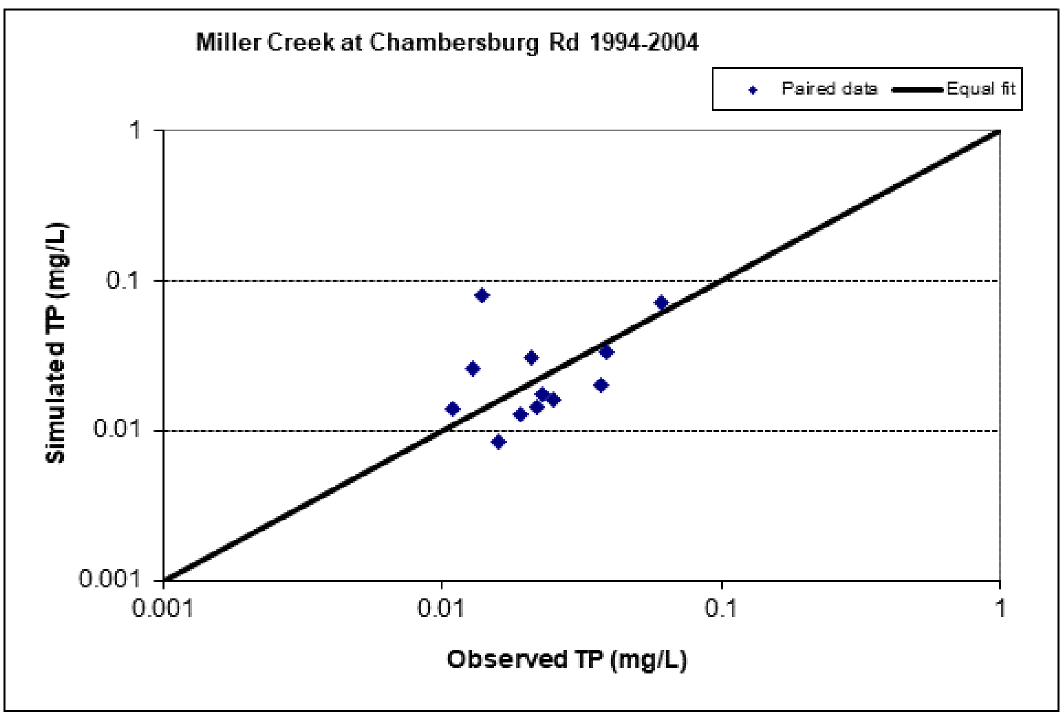


Figure E-661. Paired simulated vs. observed Total Phosphorus (TP) concentration at Miller Creek at Chambersburg Rd (validation period)

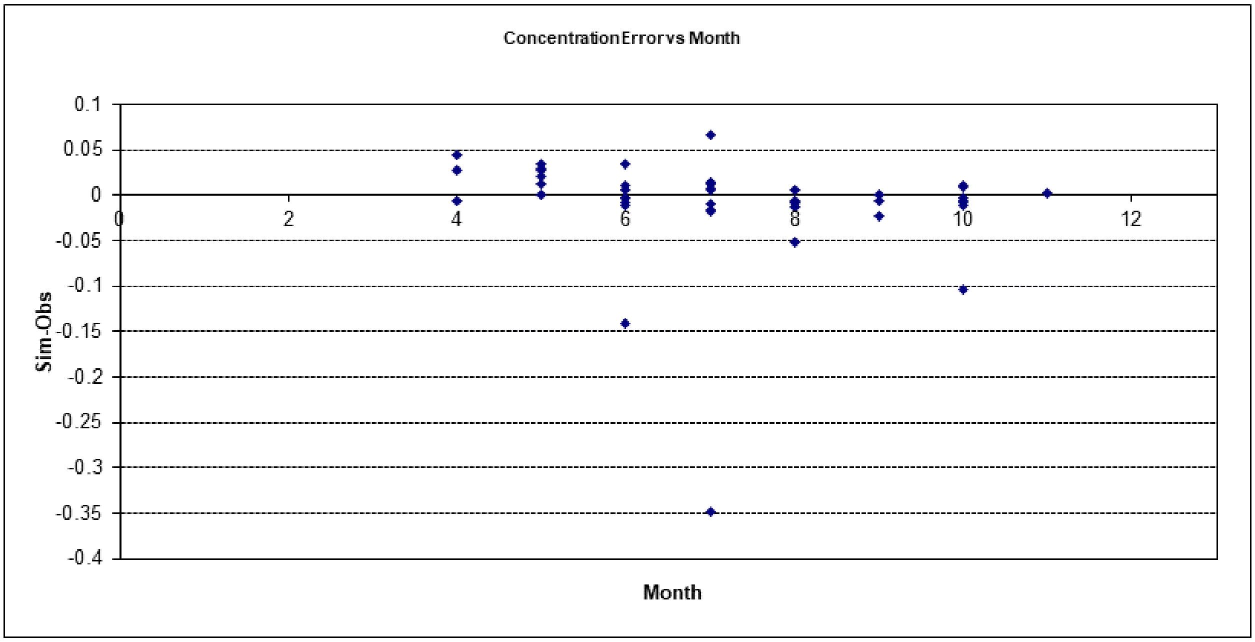


Figure E-662. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Miller Creek at Chambersburg Rd

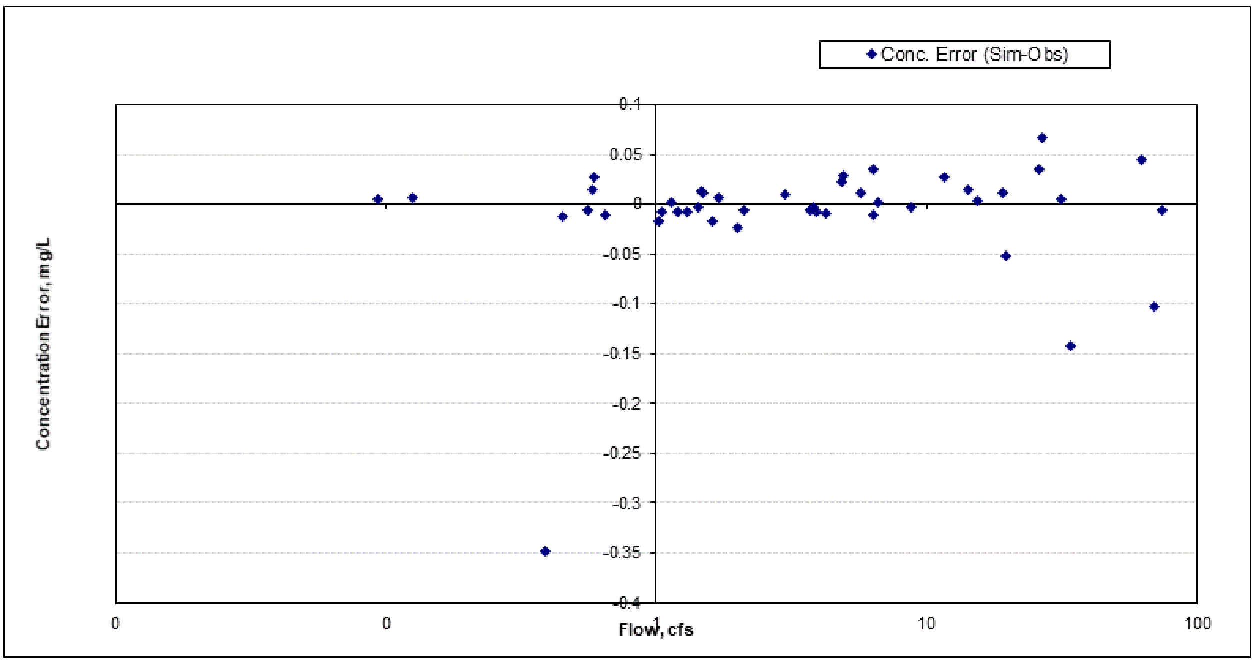


Figure E-663. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Miller Creek at Chambersburg Rd

E.14 Miller Creek at Lake Superior College

E.14.1 Dissolved Oxygen (DO)

Table E-82. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	41
Concentration Average Error		-8.09%
Concentration Median Error		-5.01%
Load Average Error		-9.77%
Load Median Error		-0.85%
Paired t conc		1.00
Paired t load		0.65

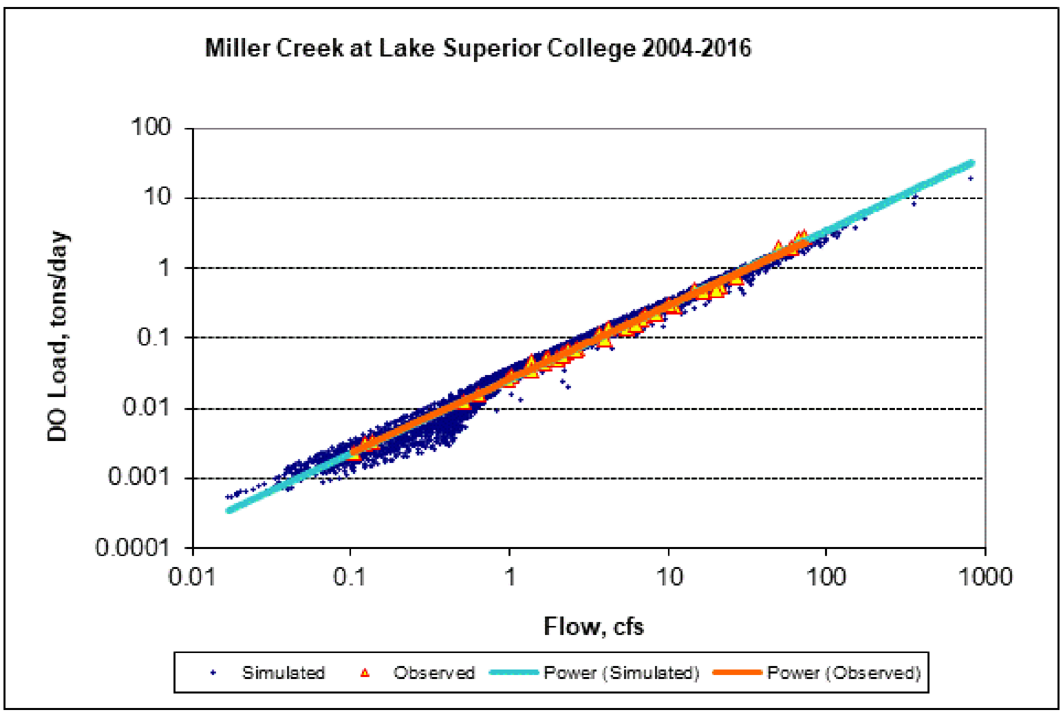


Figure E-664. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Miller Creek at Lake Superior College (calibration period)

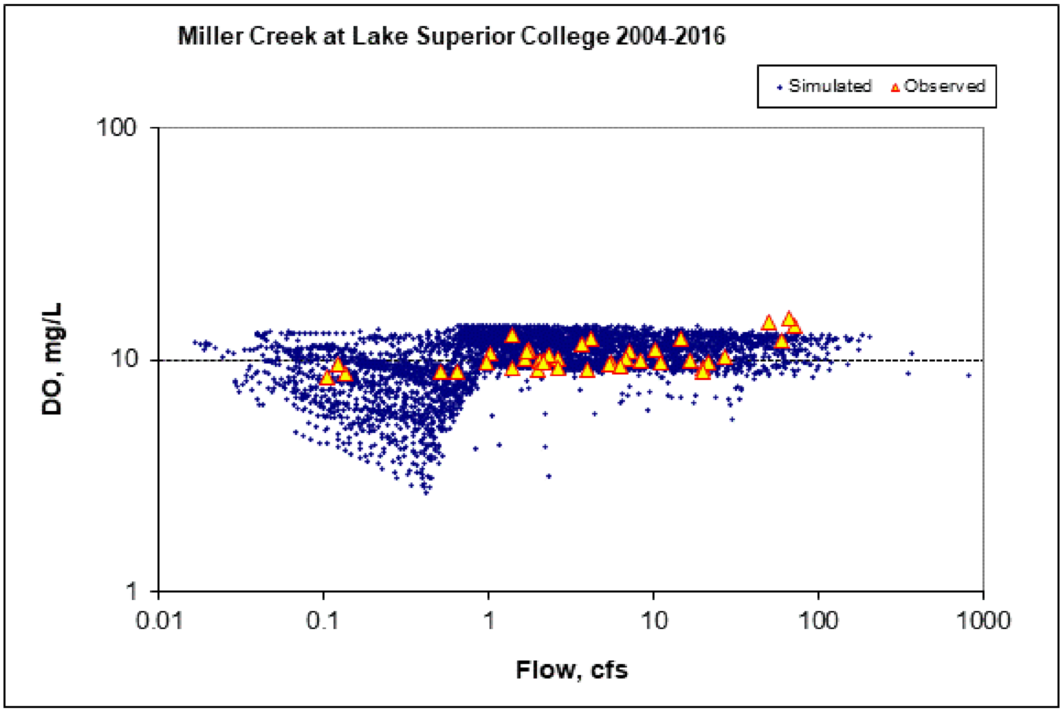
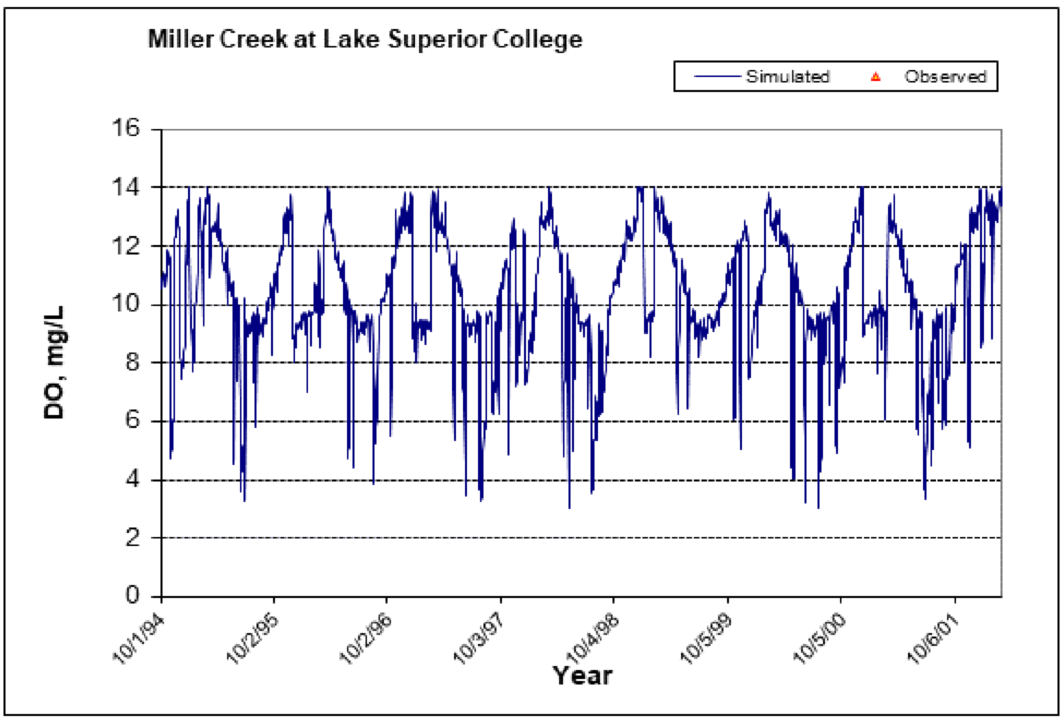
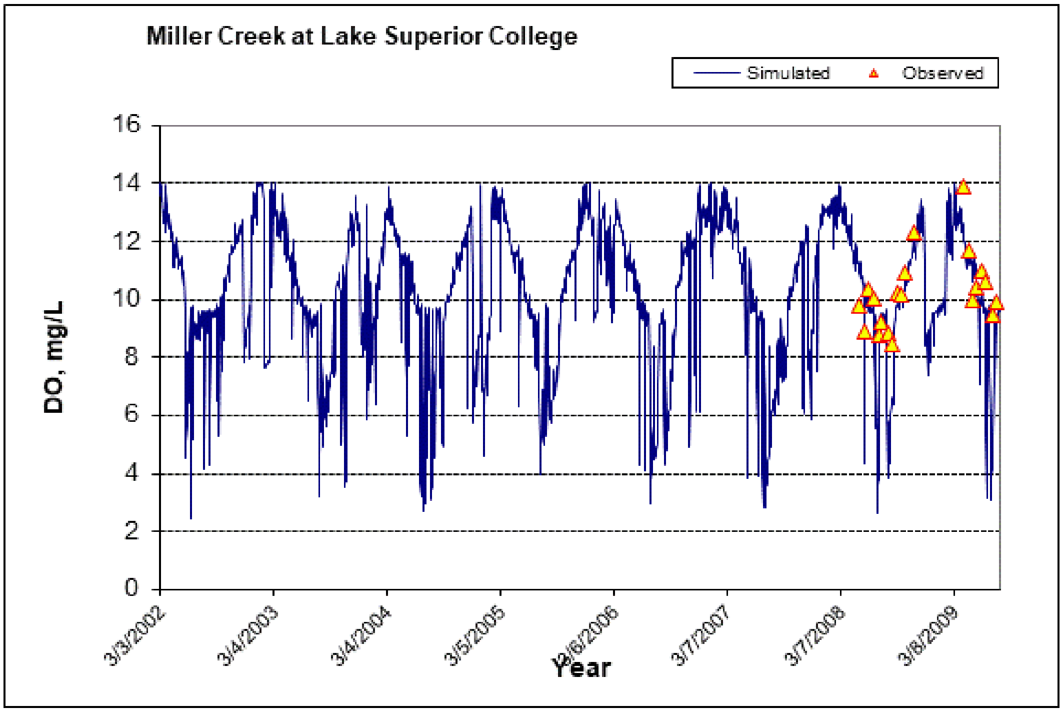


Figure E-665. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Miller Creek at Lake Superior College (calibration period)





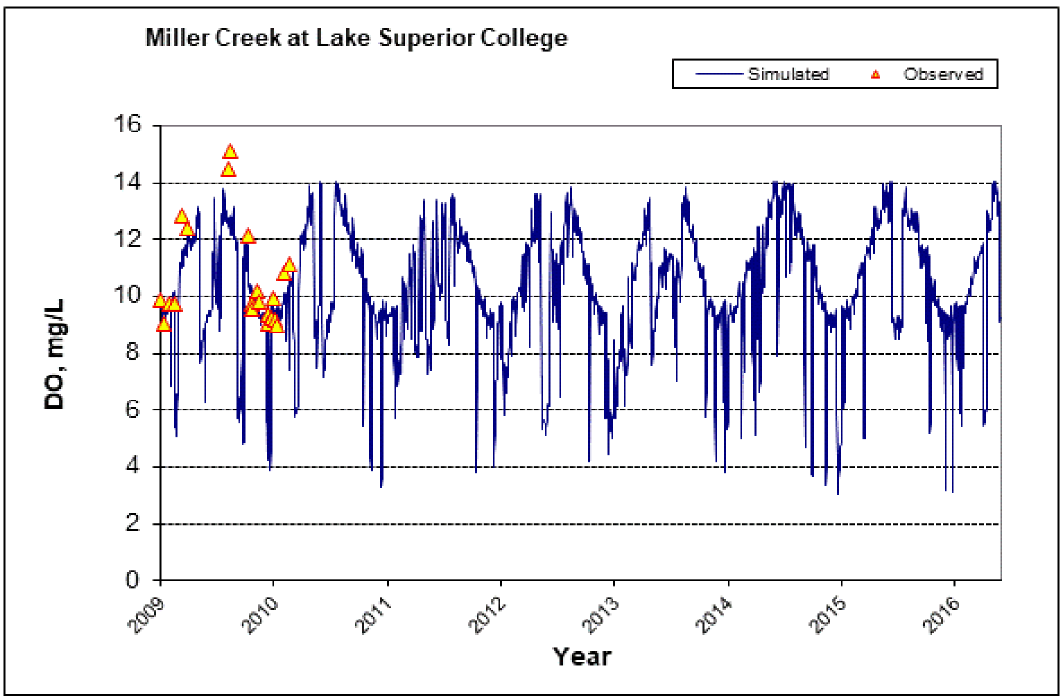


Figure E-666. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Miller Creek at Lake Superior College

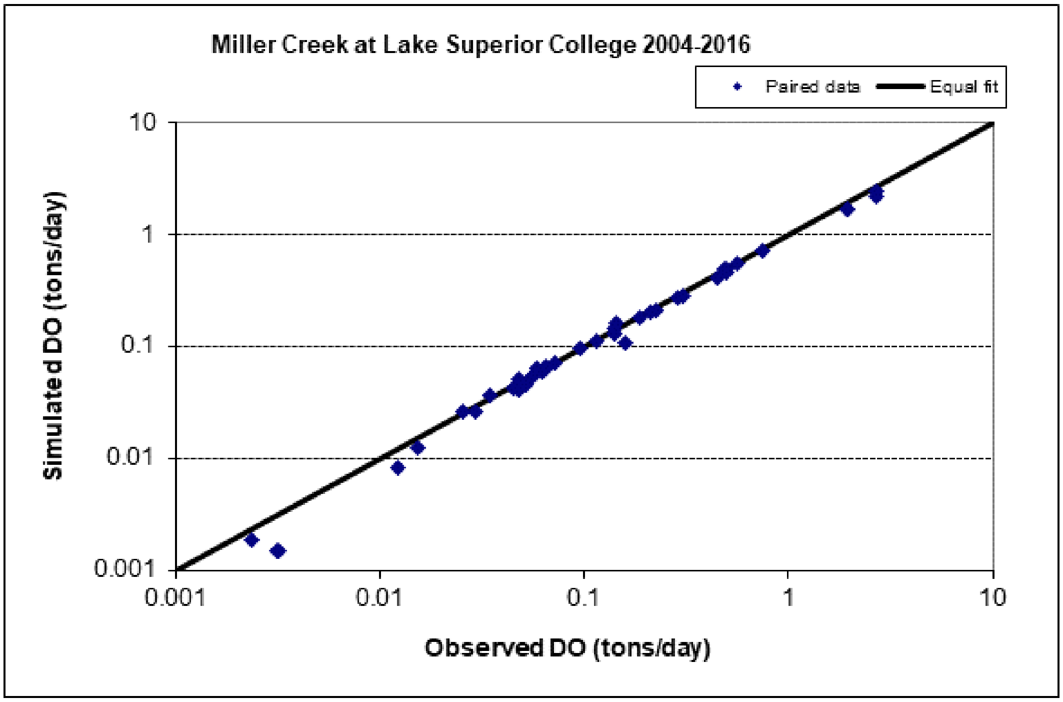


Figure E-667. Paired simulated vs. observed Dissolved Oxygen (DO) load at Miller Creek at Lake Superior College (calibration period)

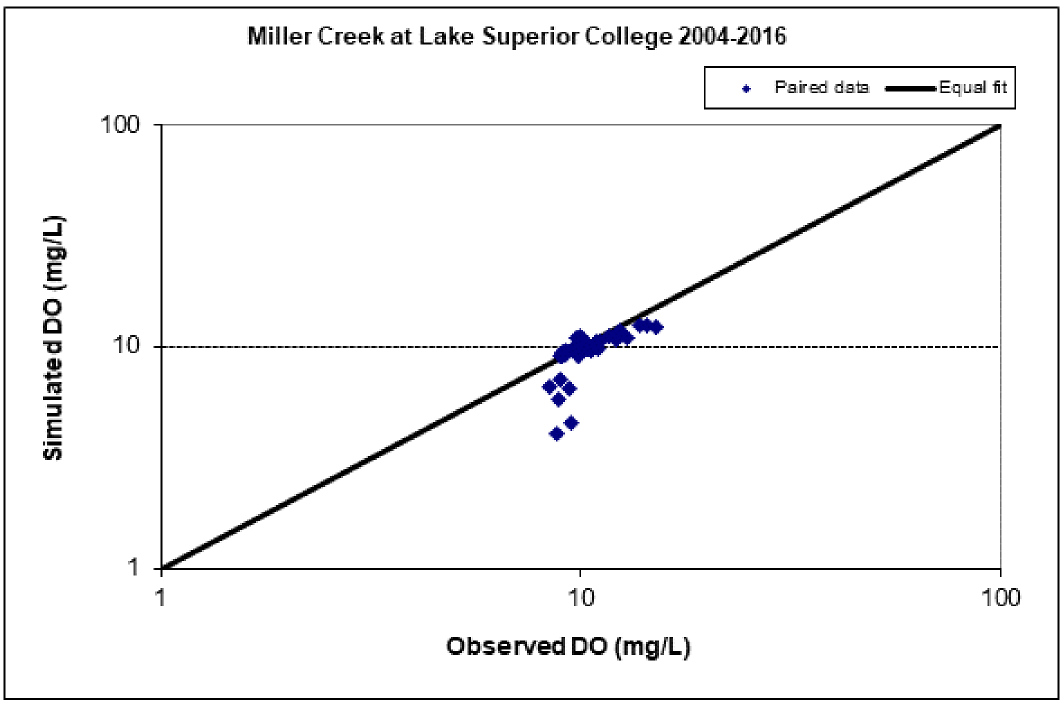


Figure E-668. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Miller Creek at Lake Superior College (calibration period)

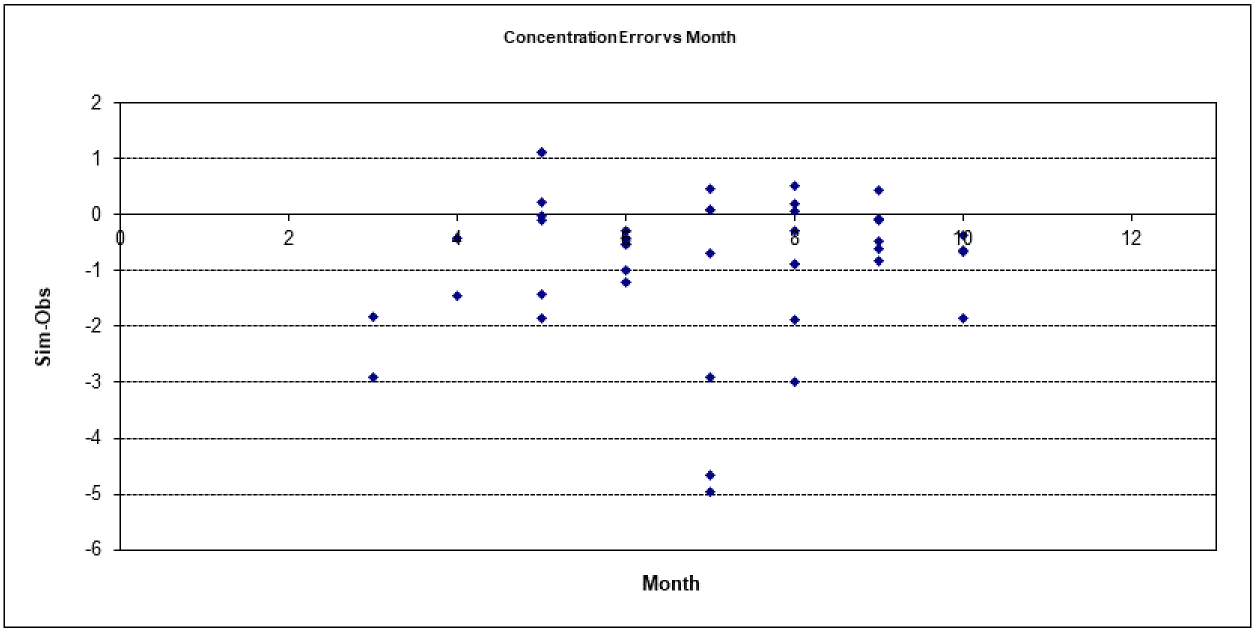


Figure E-669. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Miller Creek at Lake Superior College

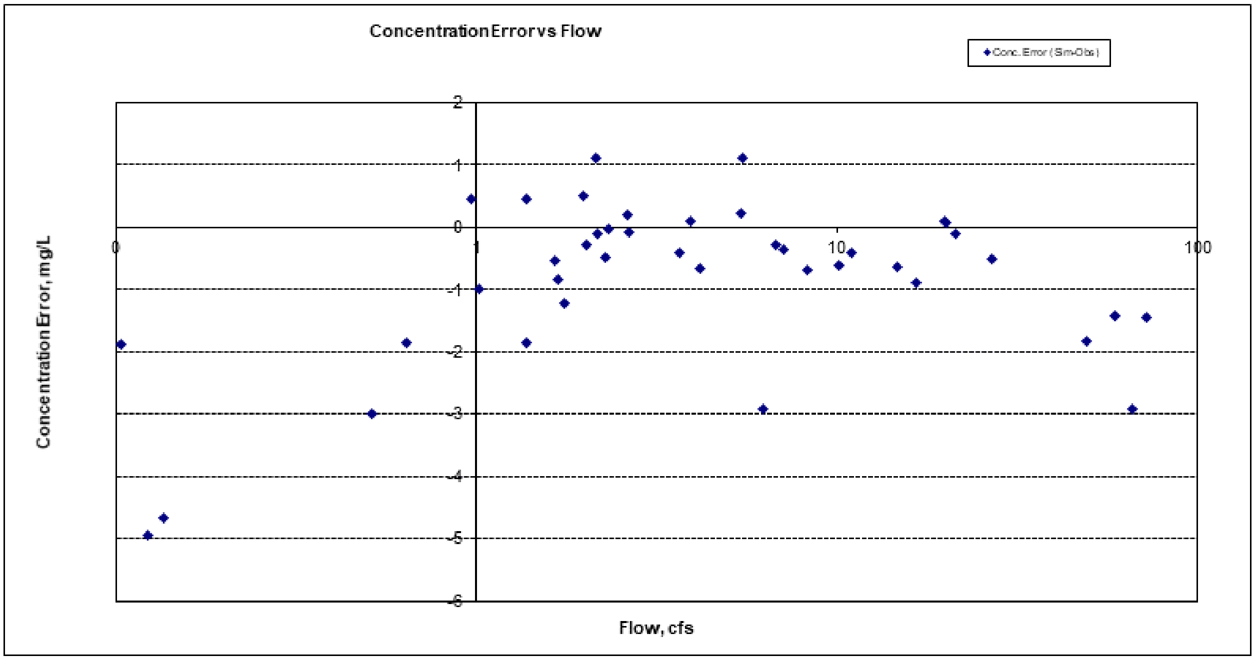


Figure E-670. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Miller Creek at Lake Superior College

E.14.2 Ammonia Nitrogen (NH3)

Table E-83. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	41
Concentration Average Error		225.96%
Concentration Median Error		21.02%
Load Average Error		577.62%
Load Median Error		4.62%
Paired t conc		0.00
Paired t load		0.00

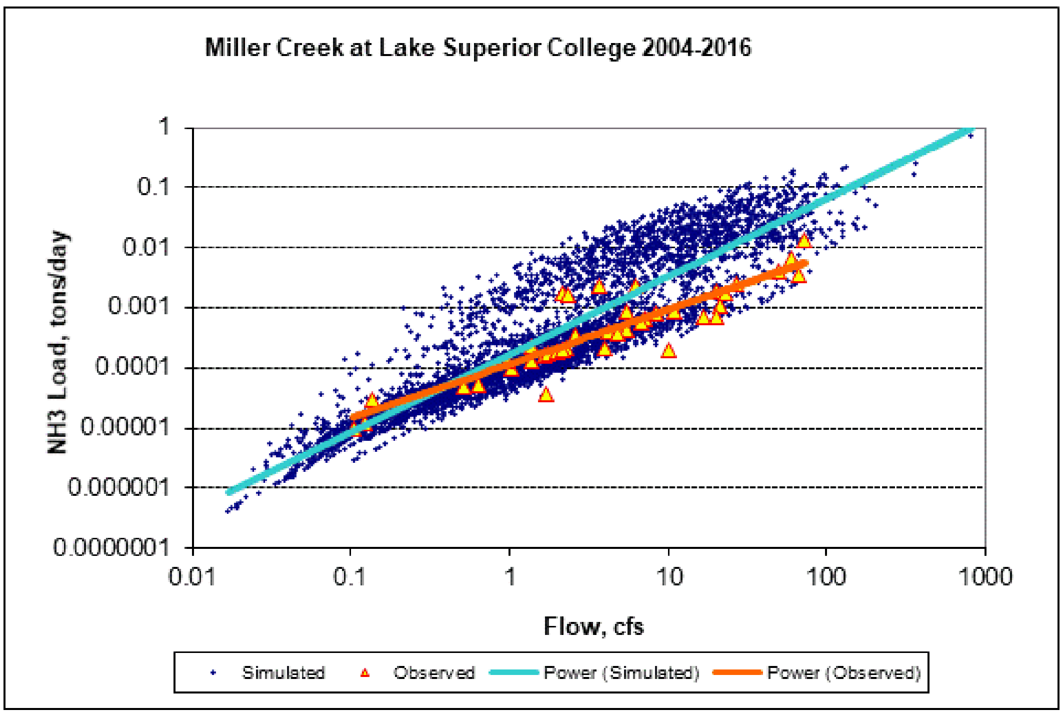


Figure E-671. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Miller Creek at Lake Superior College (calibration period)

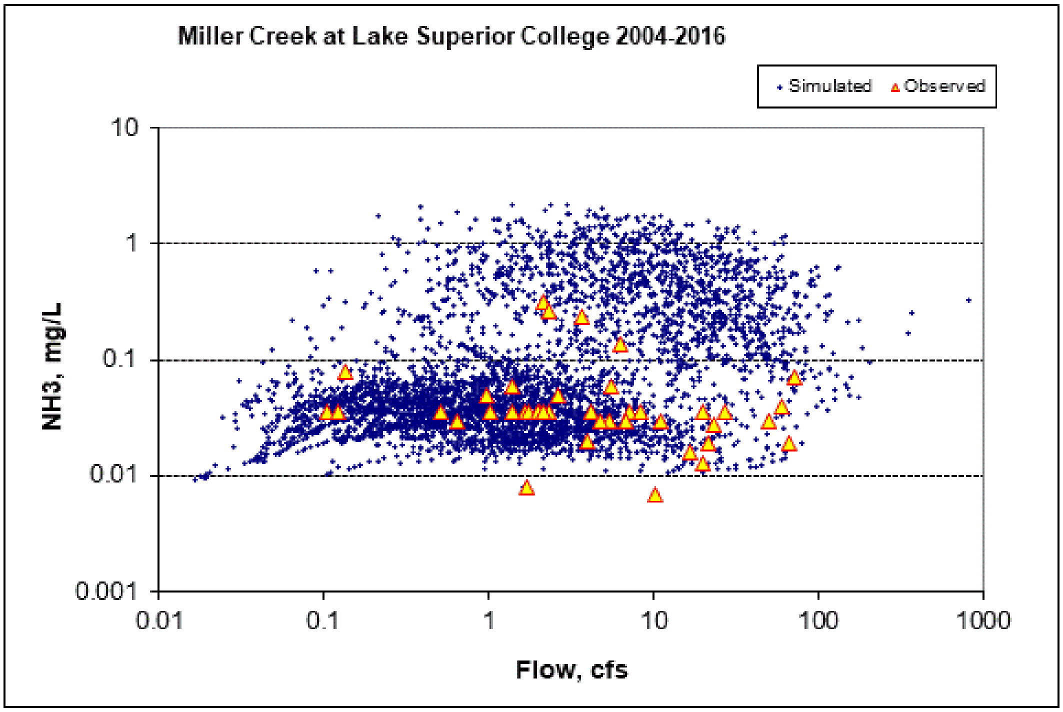
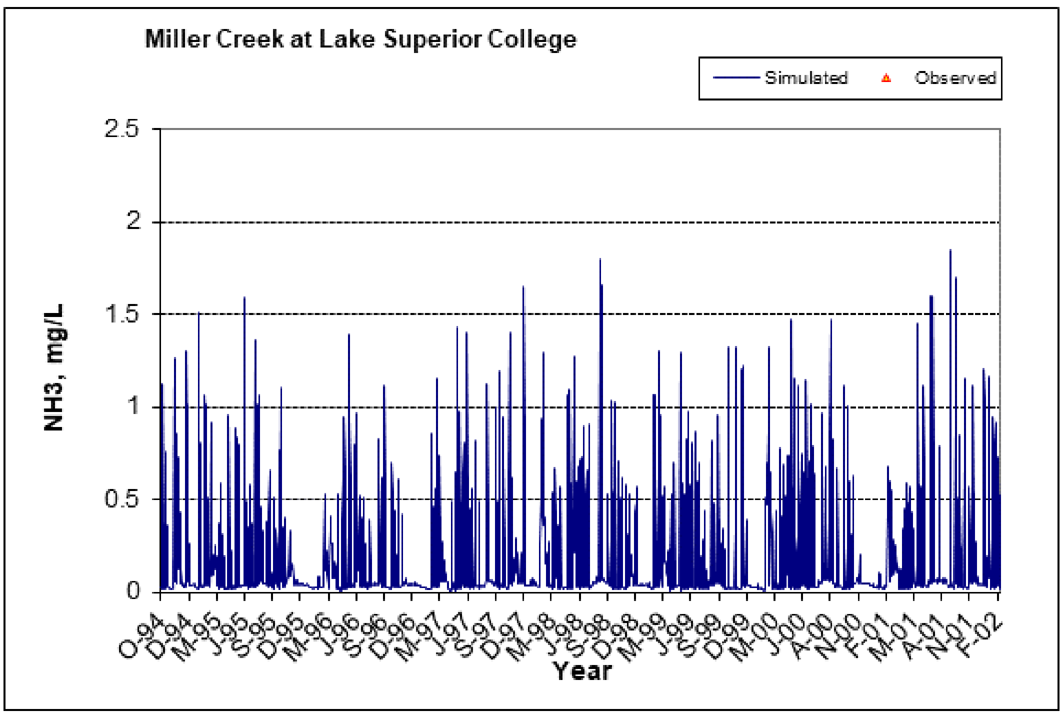
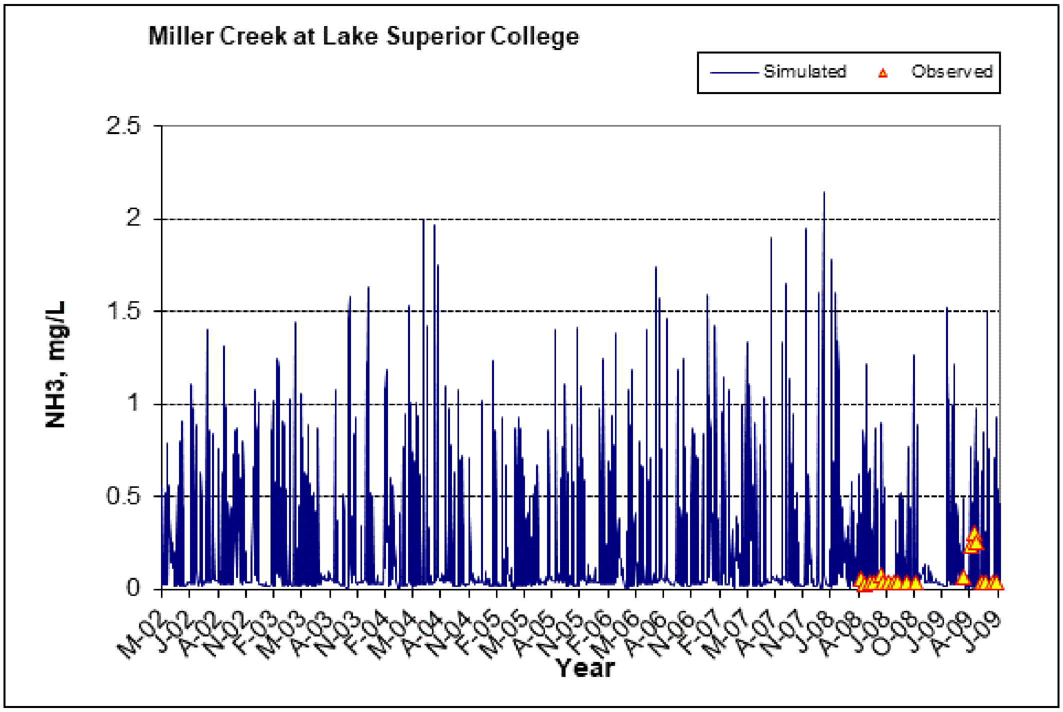


Figure E-672. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Miller Creek at Lake Superior College (calibration period)





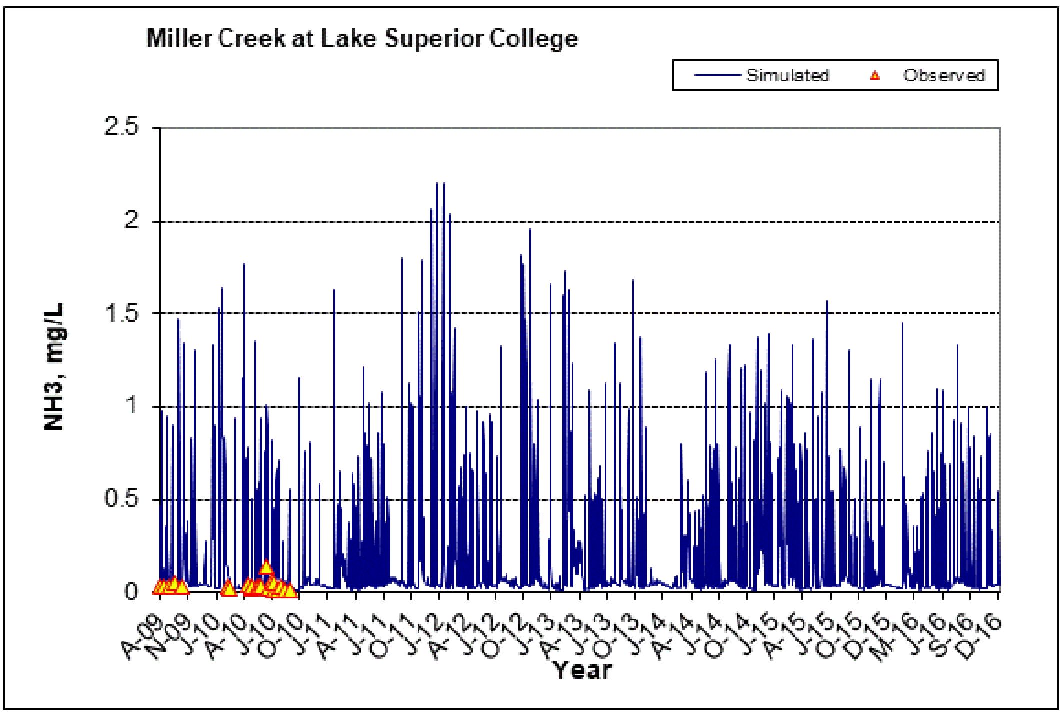


Figure E-673. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Miller Creek at Lake Superior College

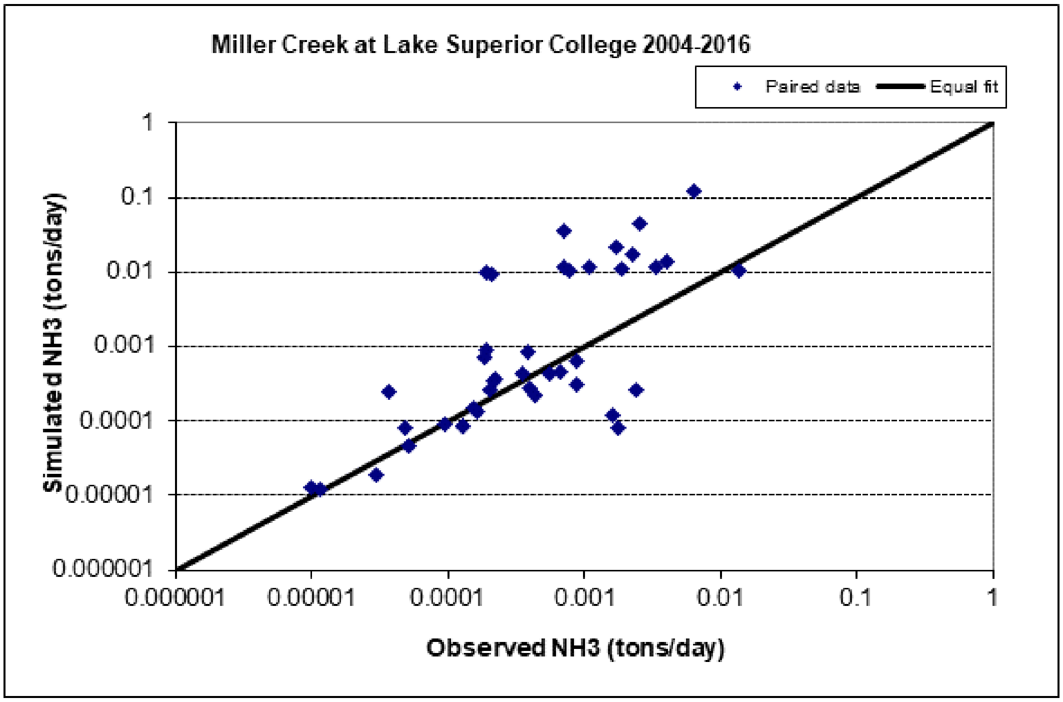


Figure E-674. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Miller Creek at Lake Superior College (calibration period)

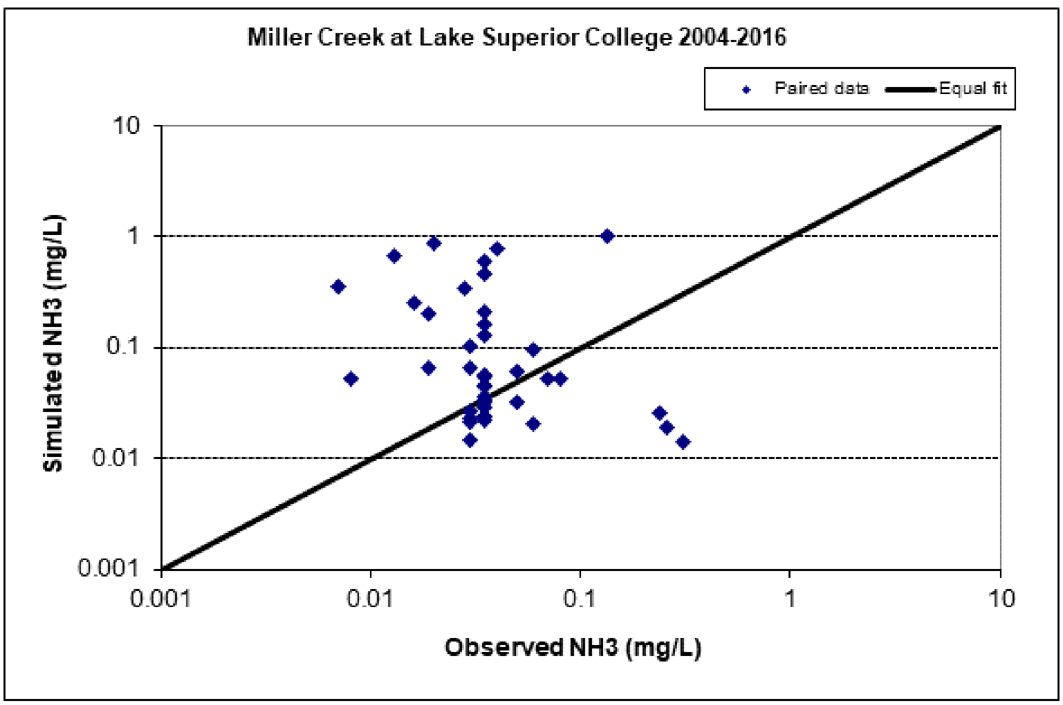


Figure E-675. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Miller Creek at Lake Superior College (calibration period)

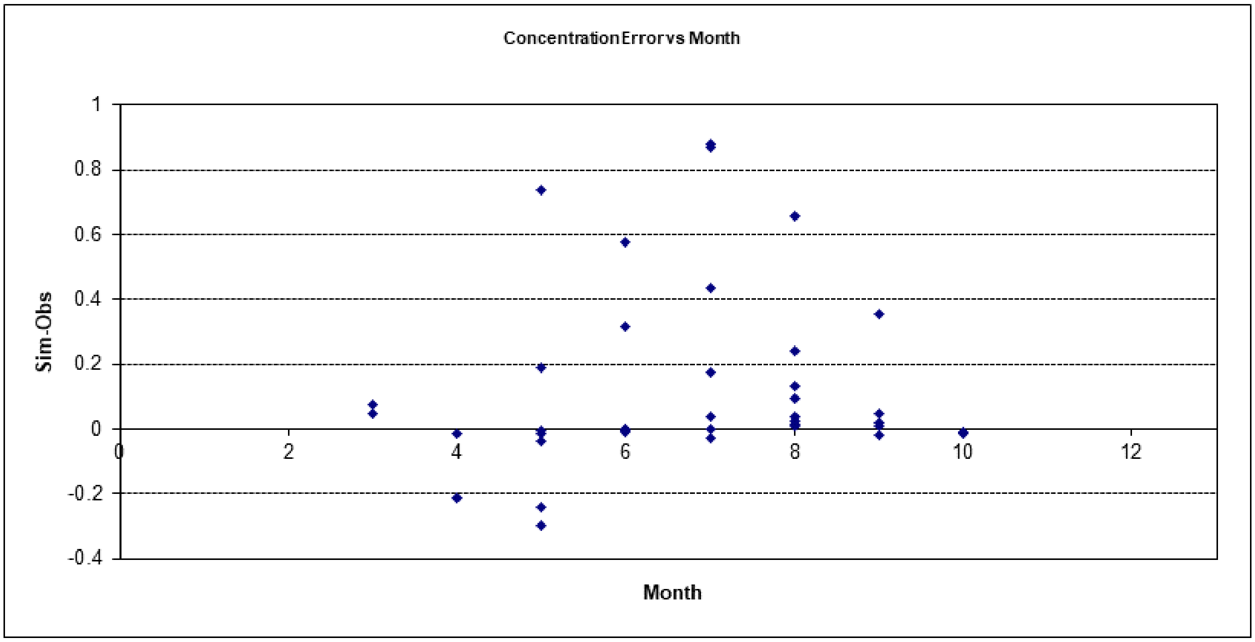


Figure E-676. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Miller Creek at Lake Superior College

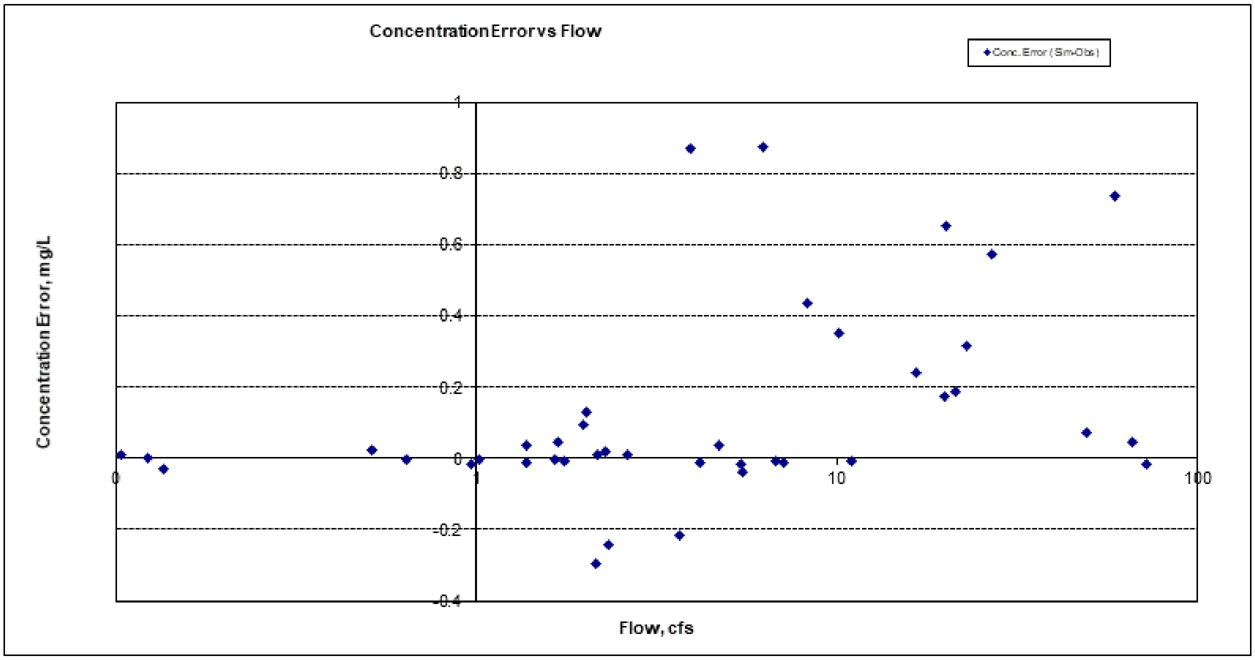


Figure E-677. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Miller Creek at Lake Superior College

E.14.3 Organic Nitrogen (OrgN)

Table E-84. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	ND	10
Concentration Average Error		-8.08%
Concentration Median Error		-13.57%
Load Average Error		1.73%
Load Median Error		-7.21%
Paired t conc		0.89
Paired t load		0.71

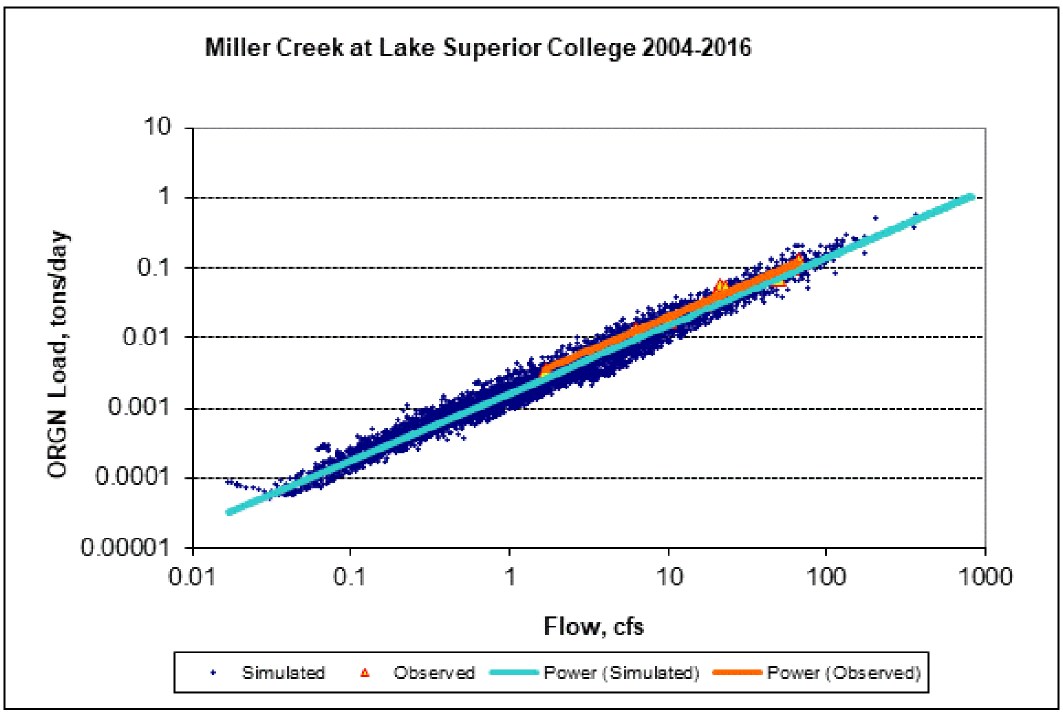


Figure E-678. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Miller Creek at Lake Superior College (calibration period)

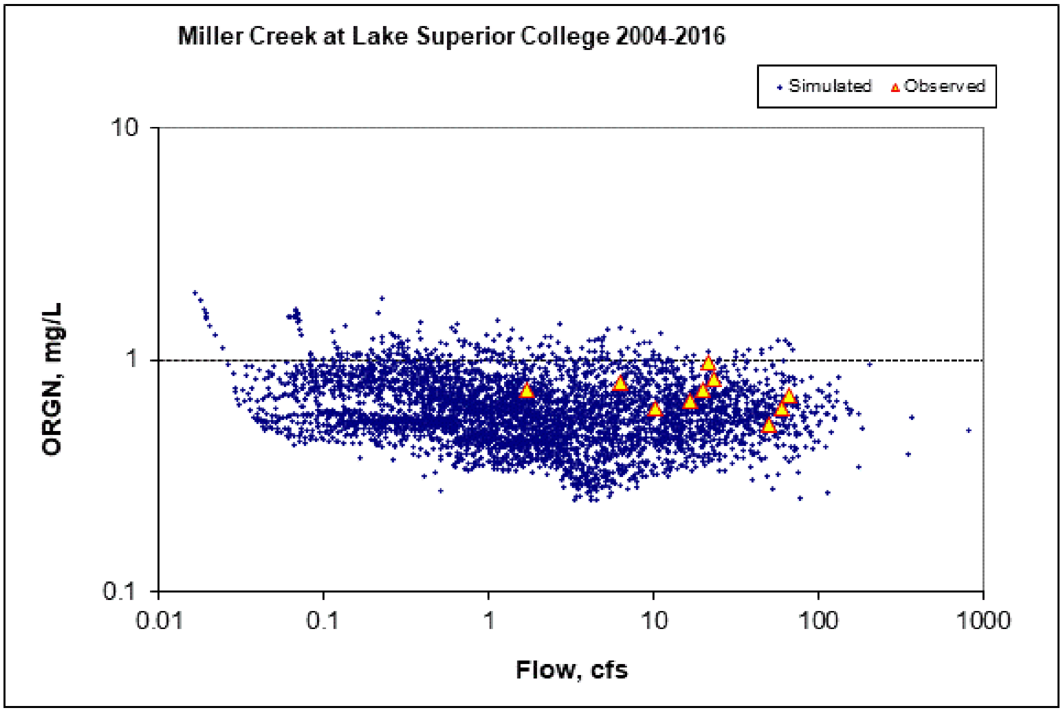
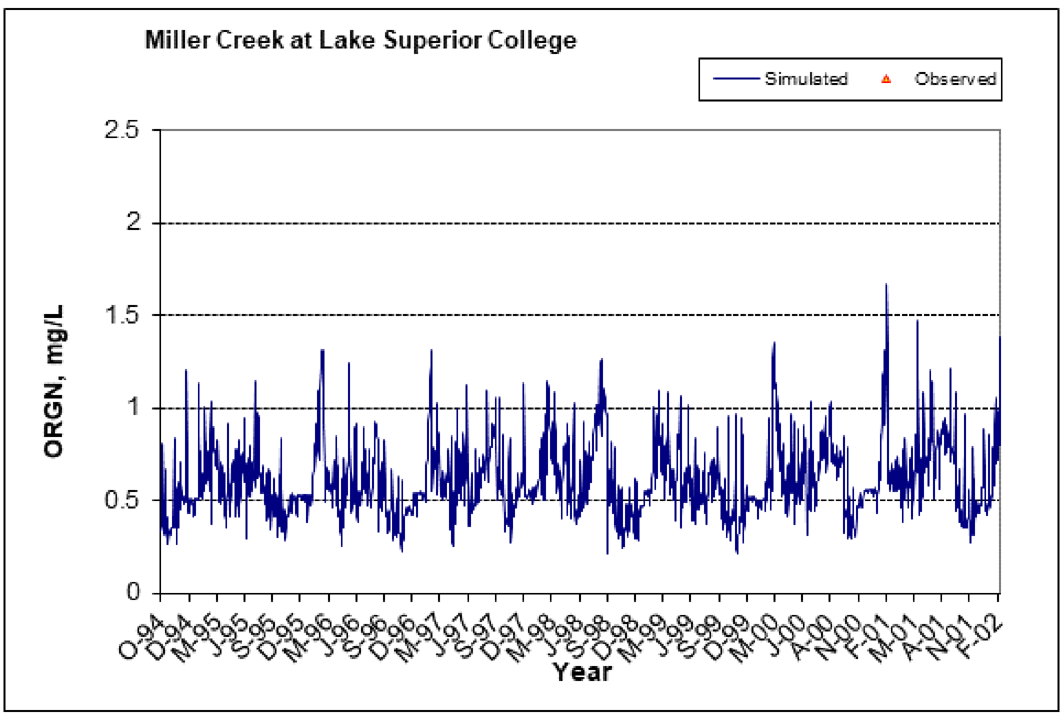
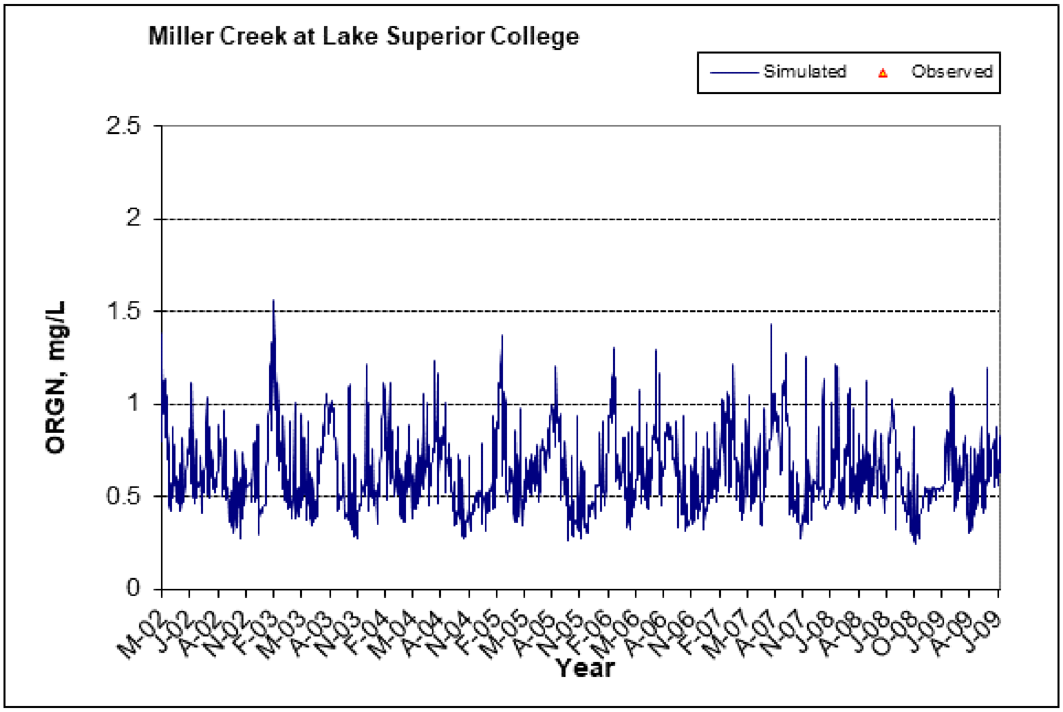


Figure E-679. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Miller Creek at Lake Superior College (calibration period)





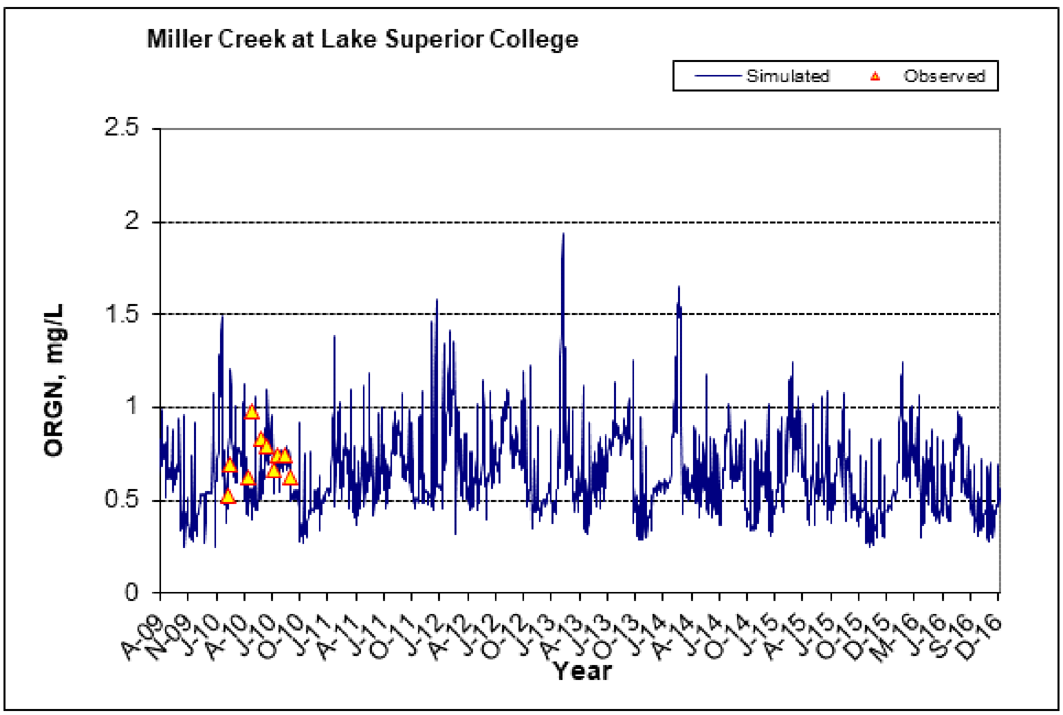


Figure E-680. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Miller Creek at Lake Superior College

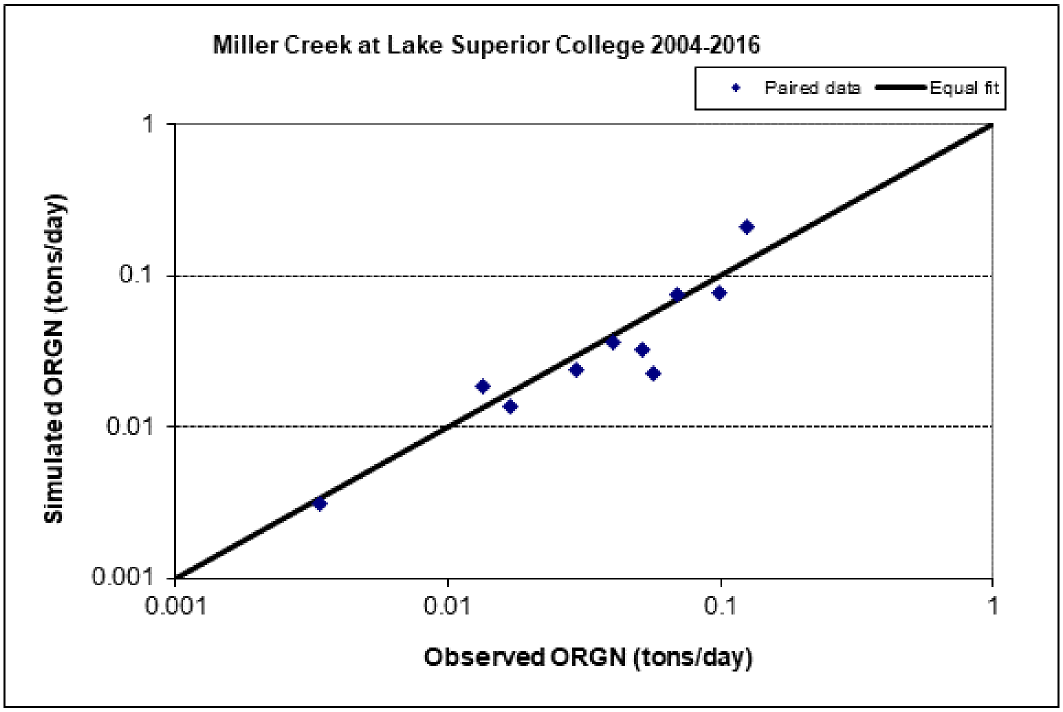


Figure E-681. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Miller Creek at Lake Superior College (calibration period)

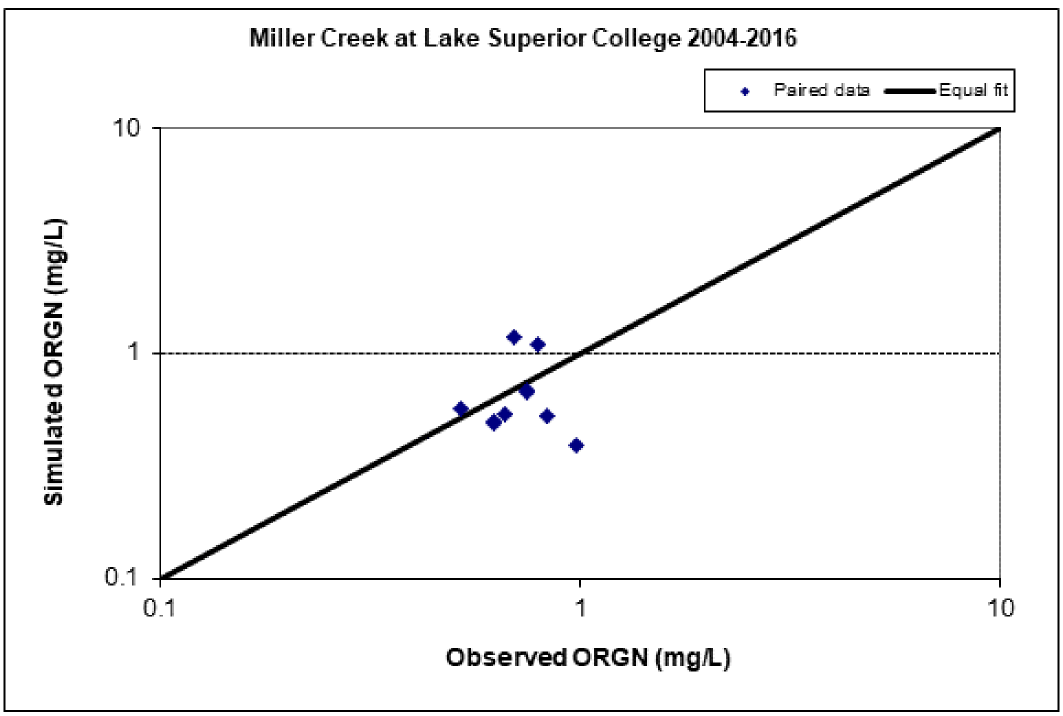


Figure E-682. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Miller Creek at Lake Superior College (calibration period)

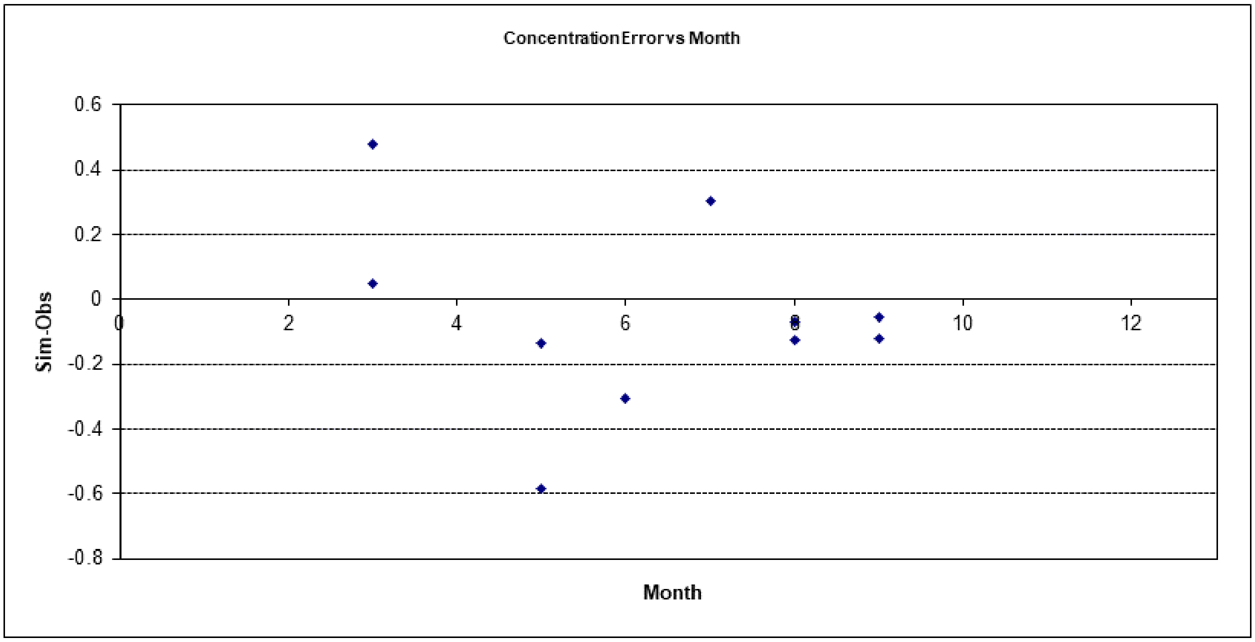


Figure E-683. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at Miller Creek at Lake Superior College

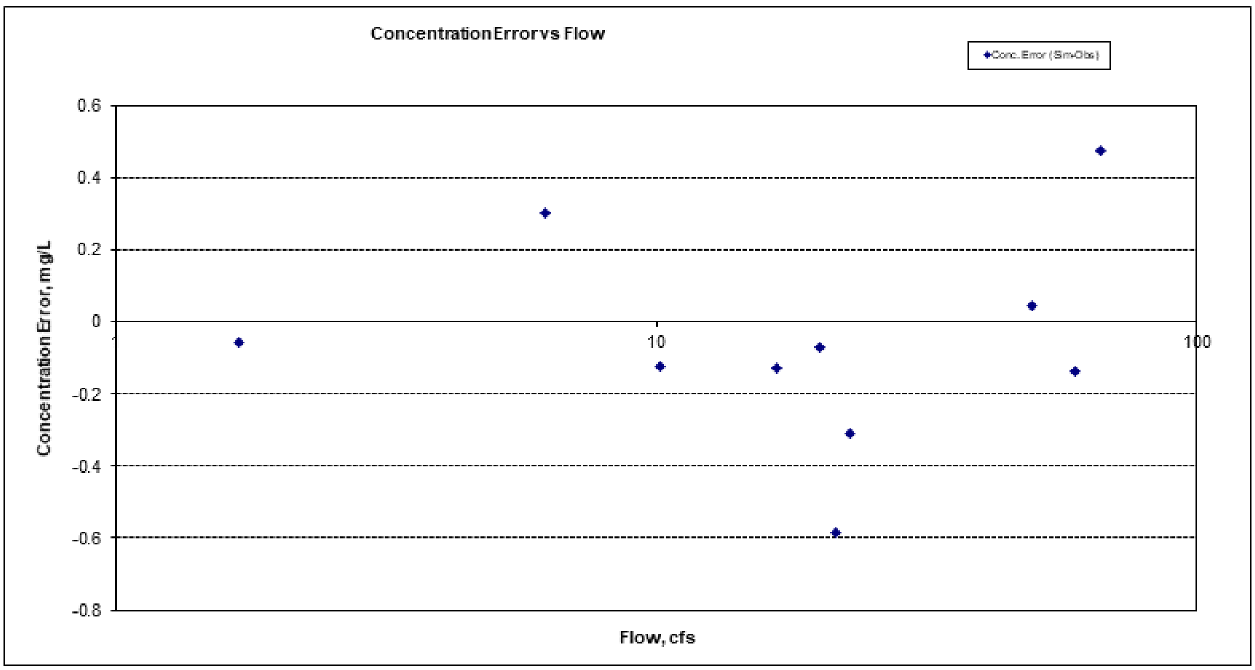


Figure E-684. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at Miller Creek at Lake Superior College

E.14.4 Total Kjeldahl Nitrogen (TKN)

Table E-85. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	ND	10
Concentration Average Error		39.09%
Concentration Median Error		23.25%
Load Average Error		46.76%
Load Median Error		21.30%
Paired t conc		0.10
Paired t load		0.24

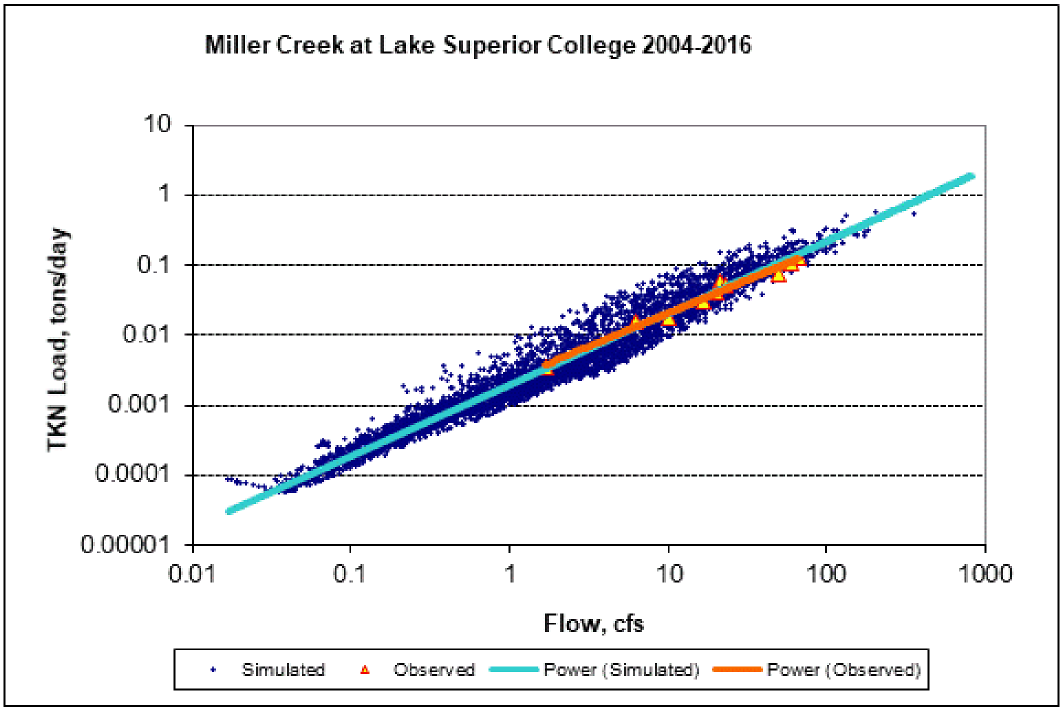


Figure E-685. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Miller Creek at Lake Superior College (calibration period)

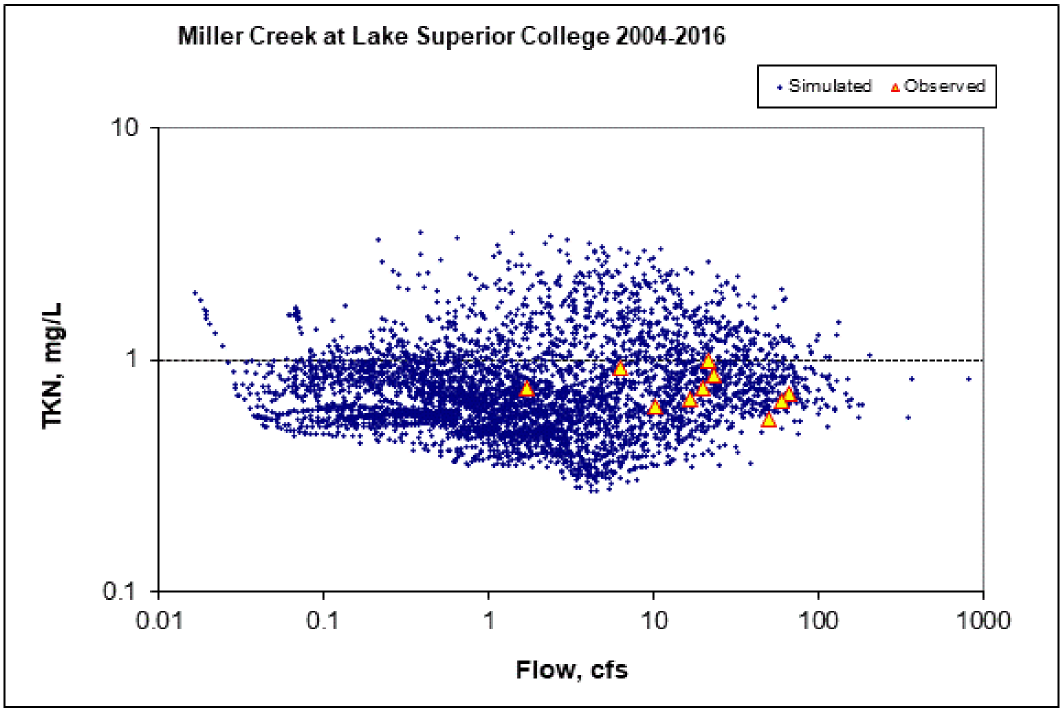
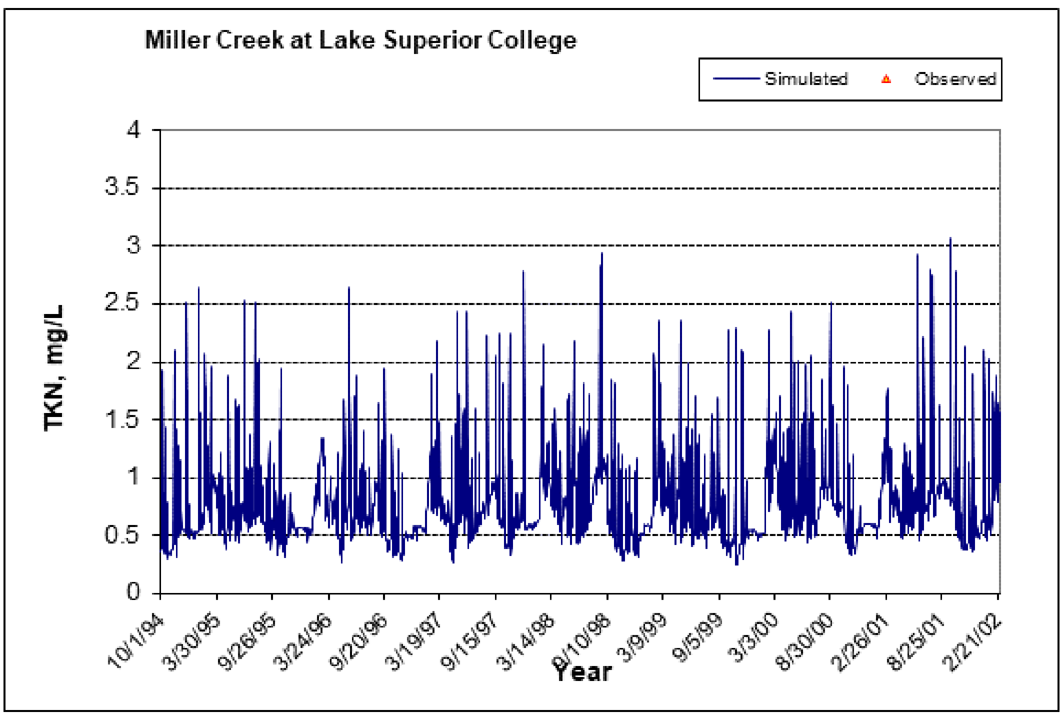
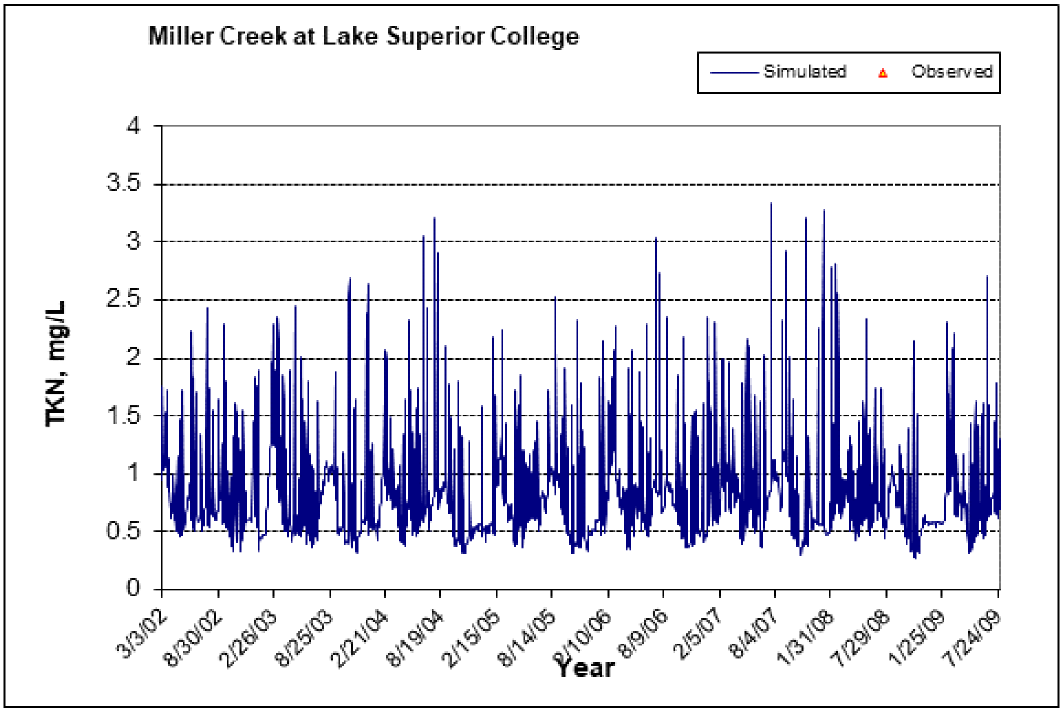


Figure E-686. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Miller Creek at Lake Superior College (calibration period)





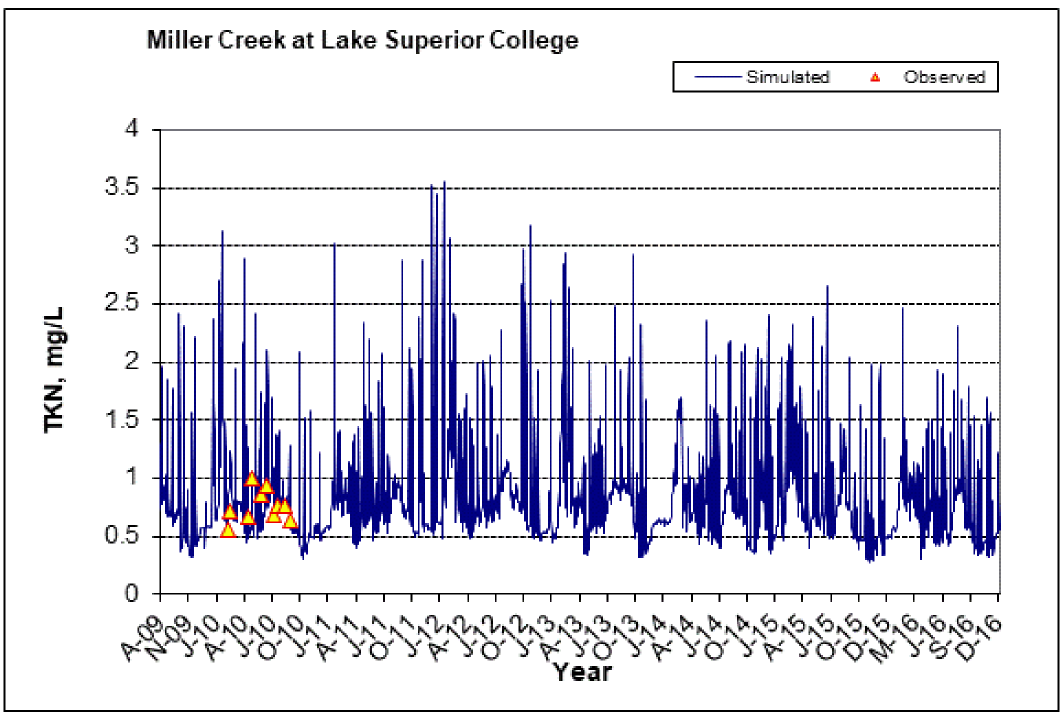


Figure E-687. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Miller Creek at Lake Superior College

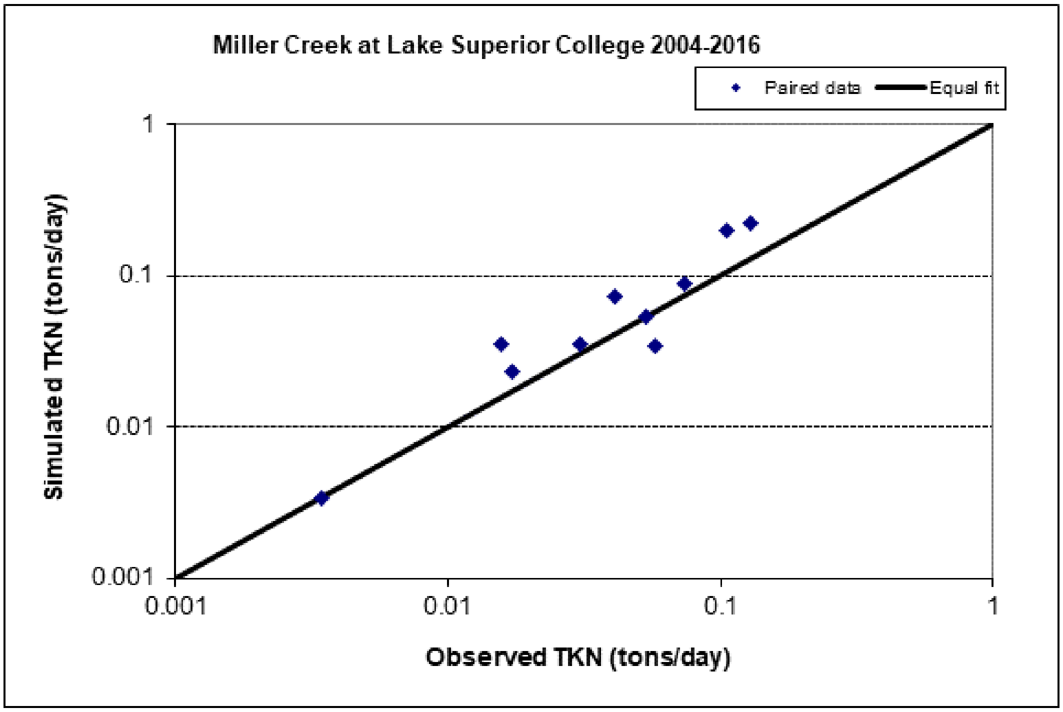


Figure E-688. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Miller Creek at Lake Superior College (calibration period)

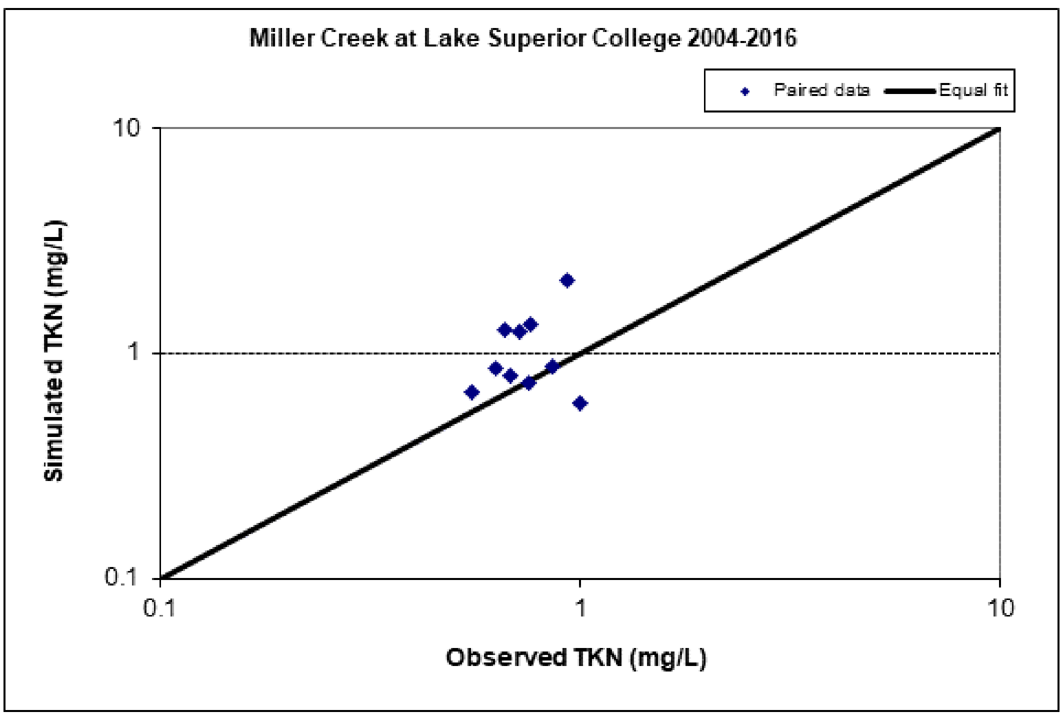


Figure E-689. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Miller Creek at Lake Superior College (calibration period)

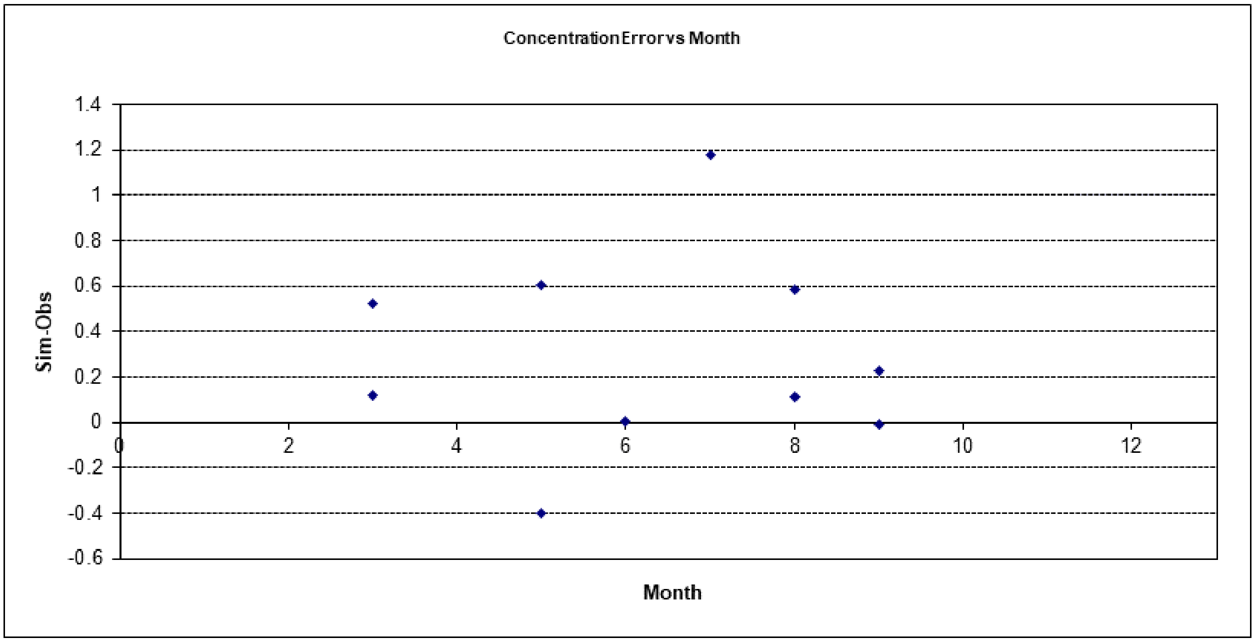


Figure E-690. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at Miller Creek at Lake Superior College

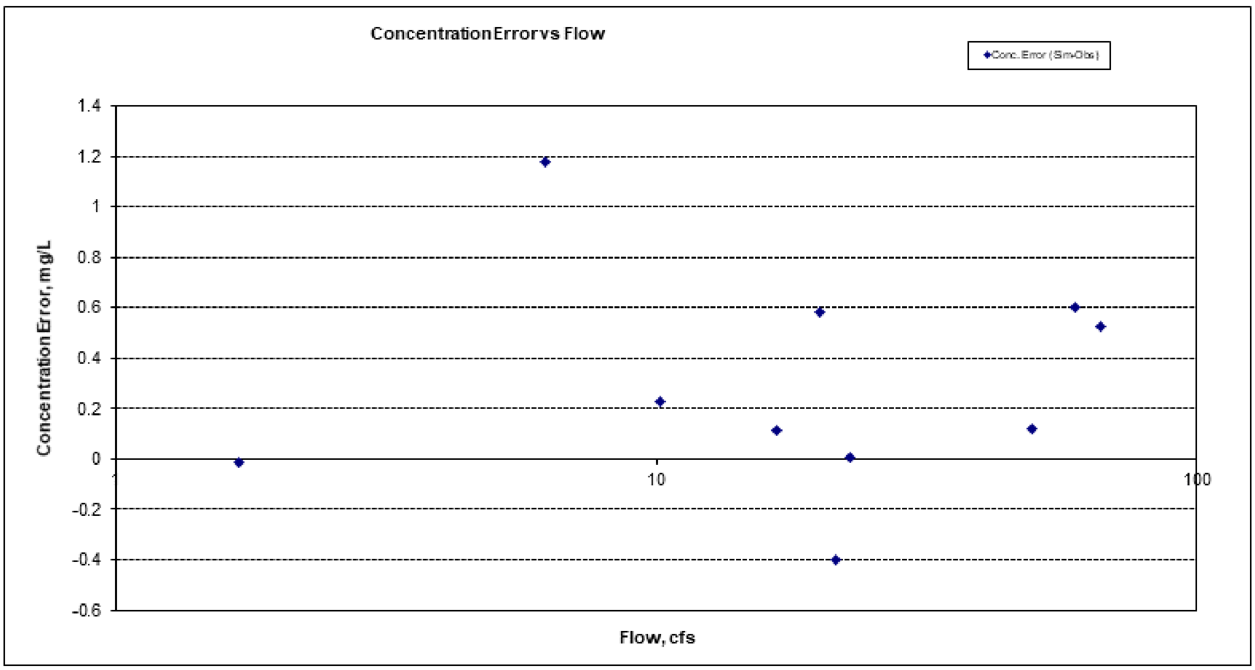


Figure E-691. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at Miller Creek at Lake Superior College

E.14.5 Nitrite+ Nitrate Nitrogen (NOx)

Table E-86. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	41
Concentration Average Error		99.73%
Concentration Median Error		-25.14%
Load Average Error		305.67%
Load Median Error		-6.37%
Paired t conc		0.02
Paired t load		0.00

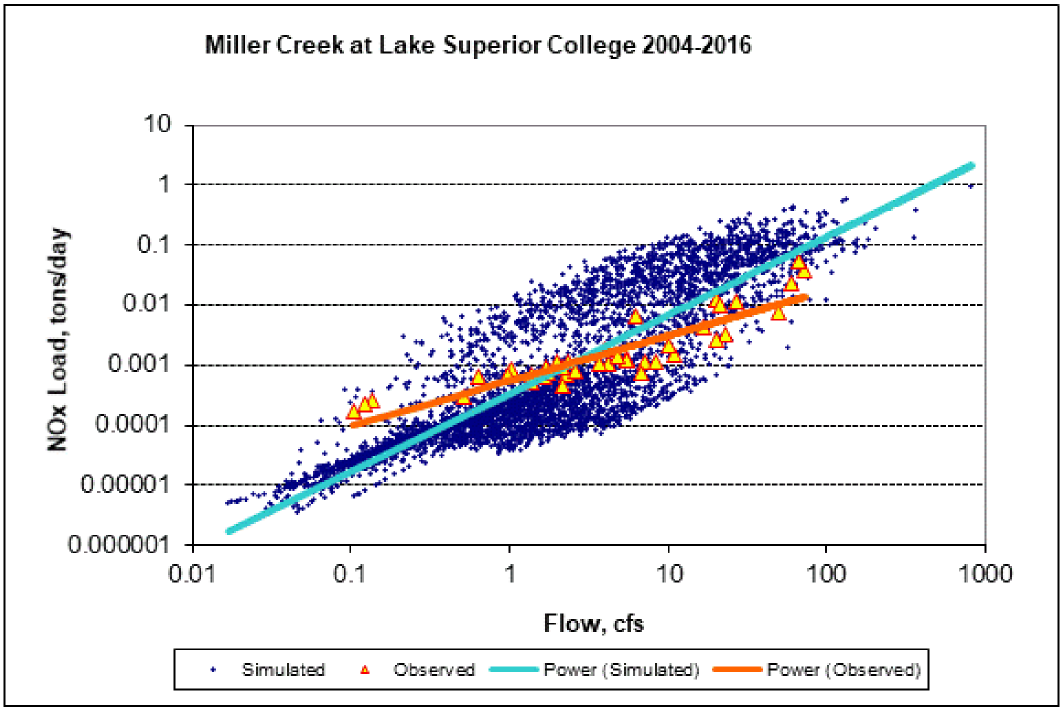


Figure E-692. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Miller Creek at Lake Superior College (calibration period)

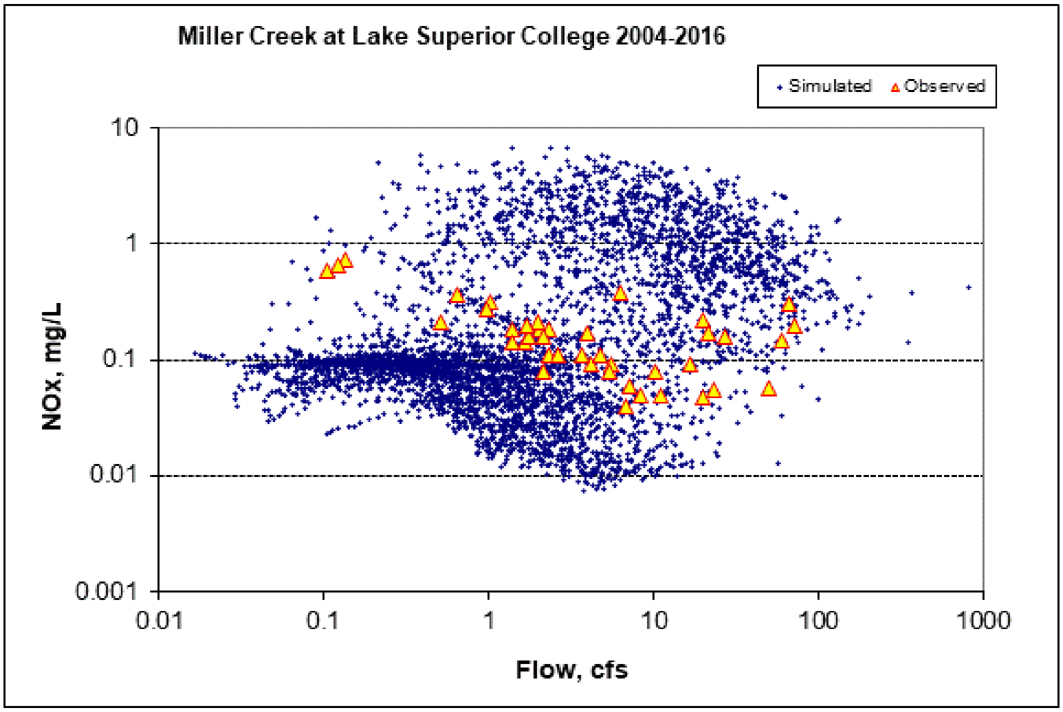
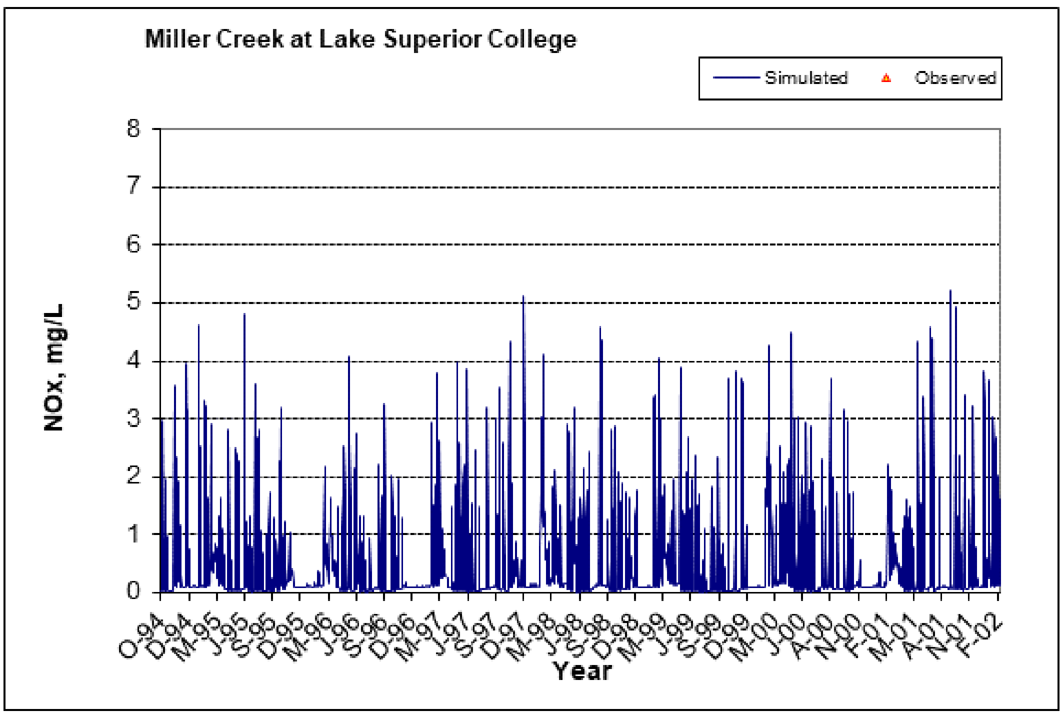
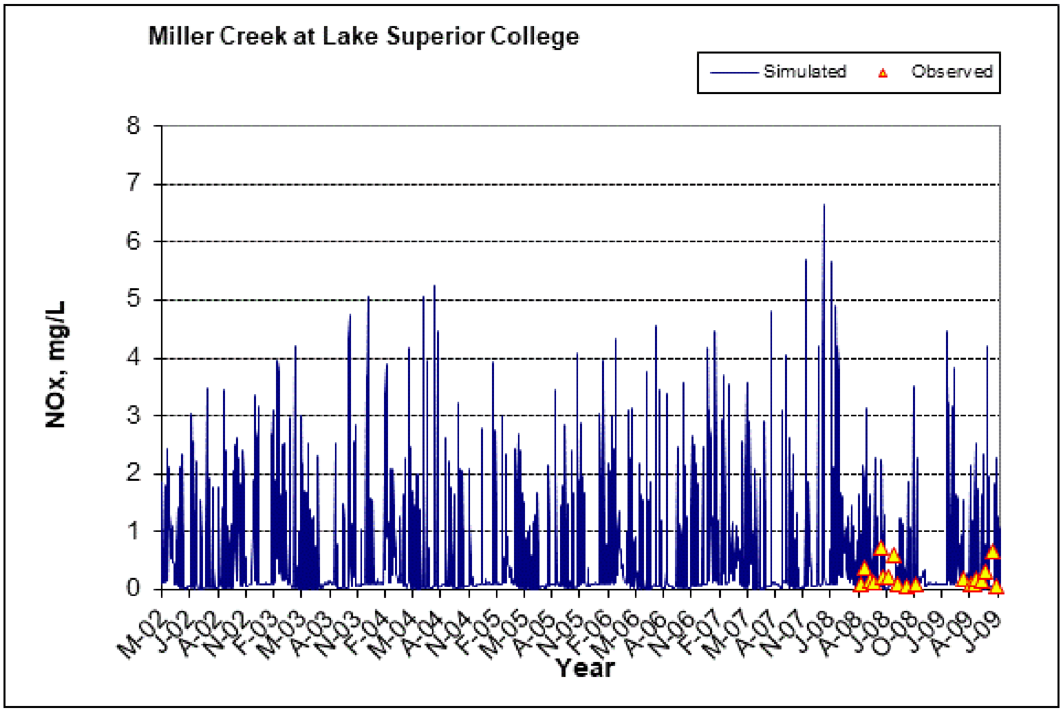


Figure E-693. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Miller Creek at Lake Superior College (calibration period)





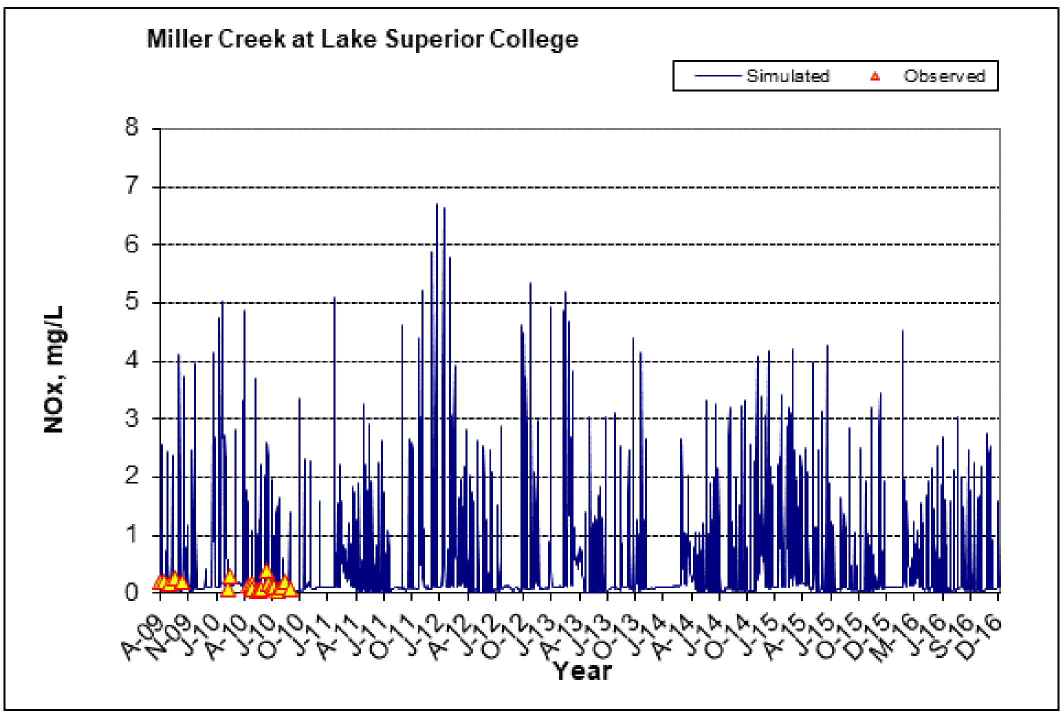


Figure E-694. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Miller Creek at Lake Superior College

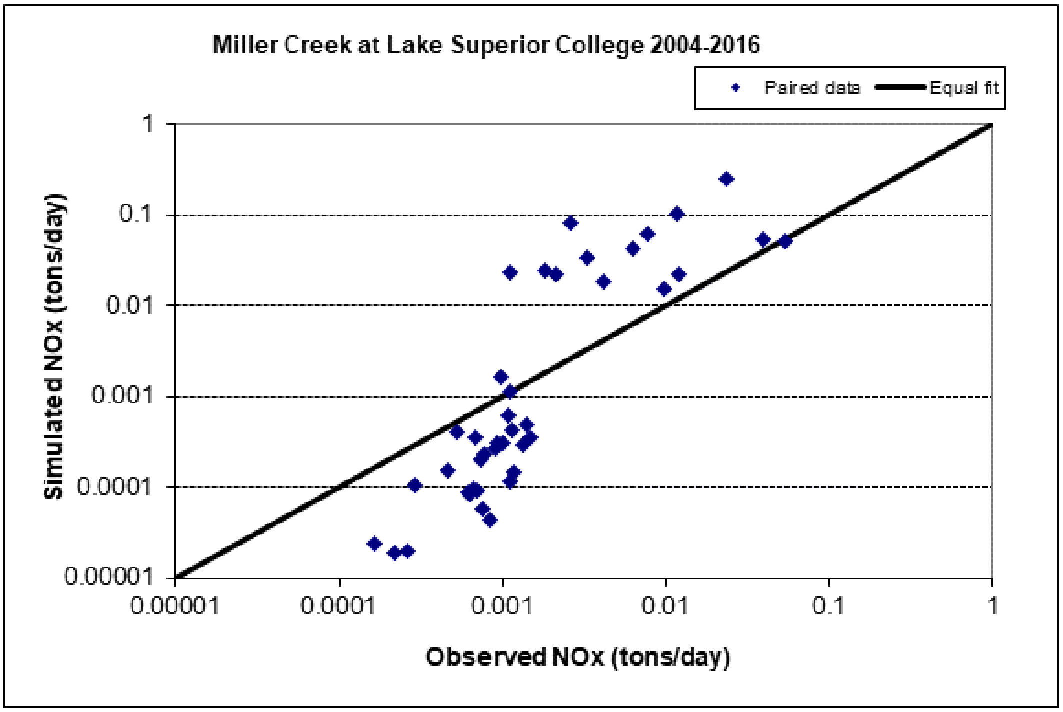


Figure E-695. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Miller Creek at Lake Superior College (calibration period)

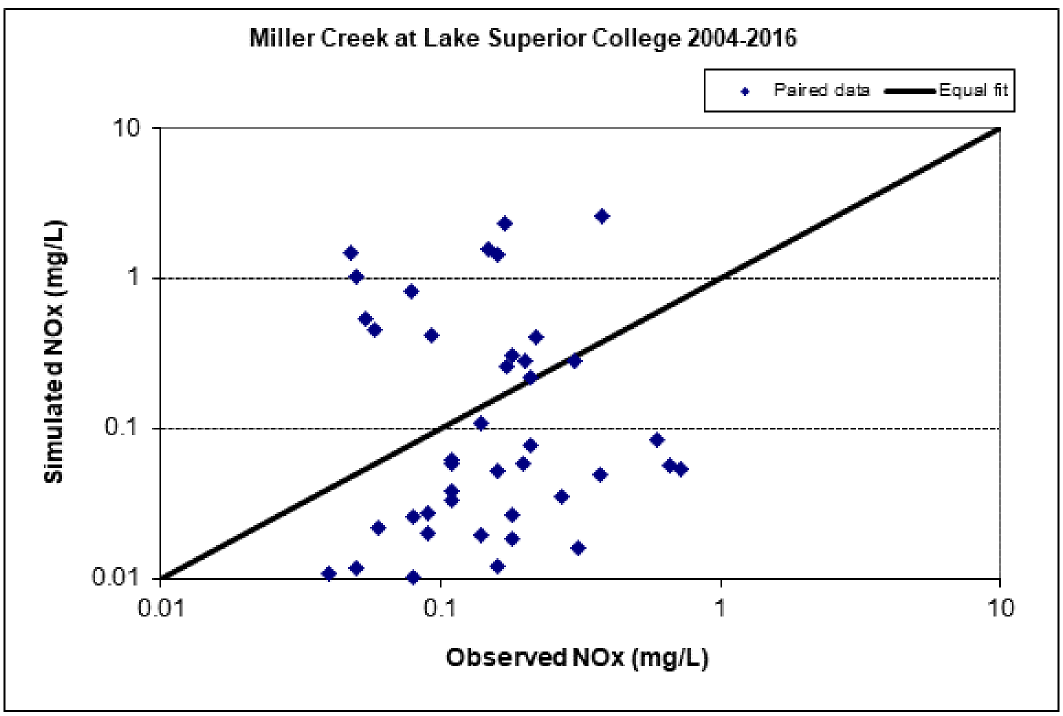


Figure E-696. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Miller Creek at Lake Superior College (calibration period)

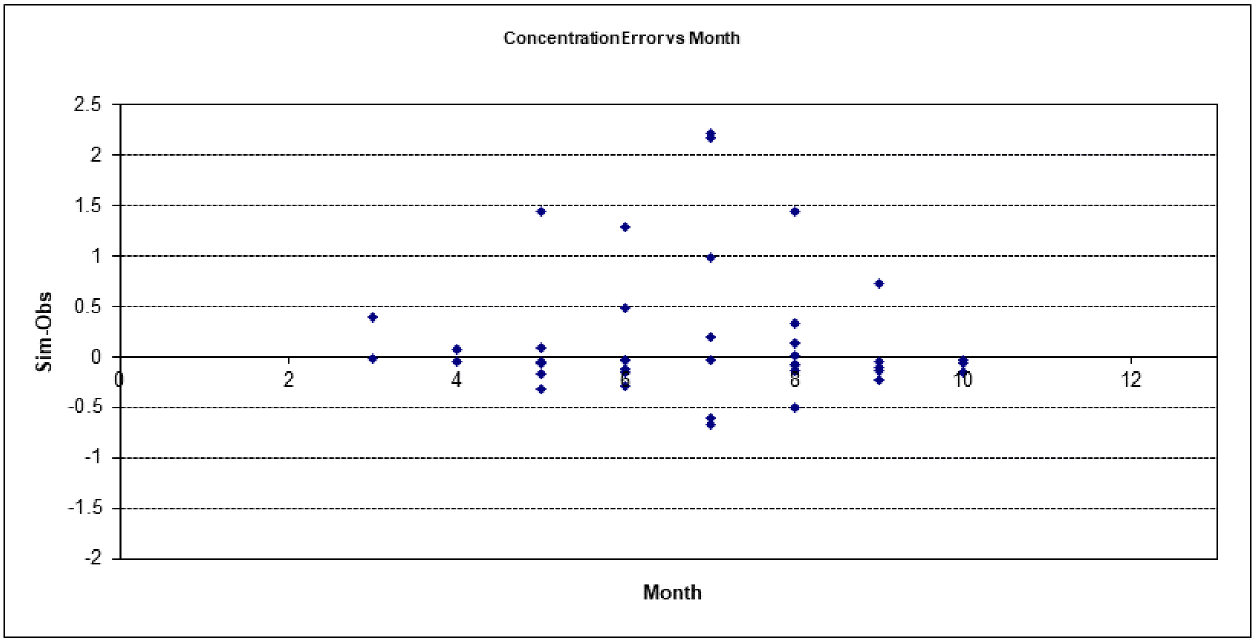


Figure E-697. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Miller Creek at Lake Superior College

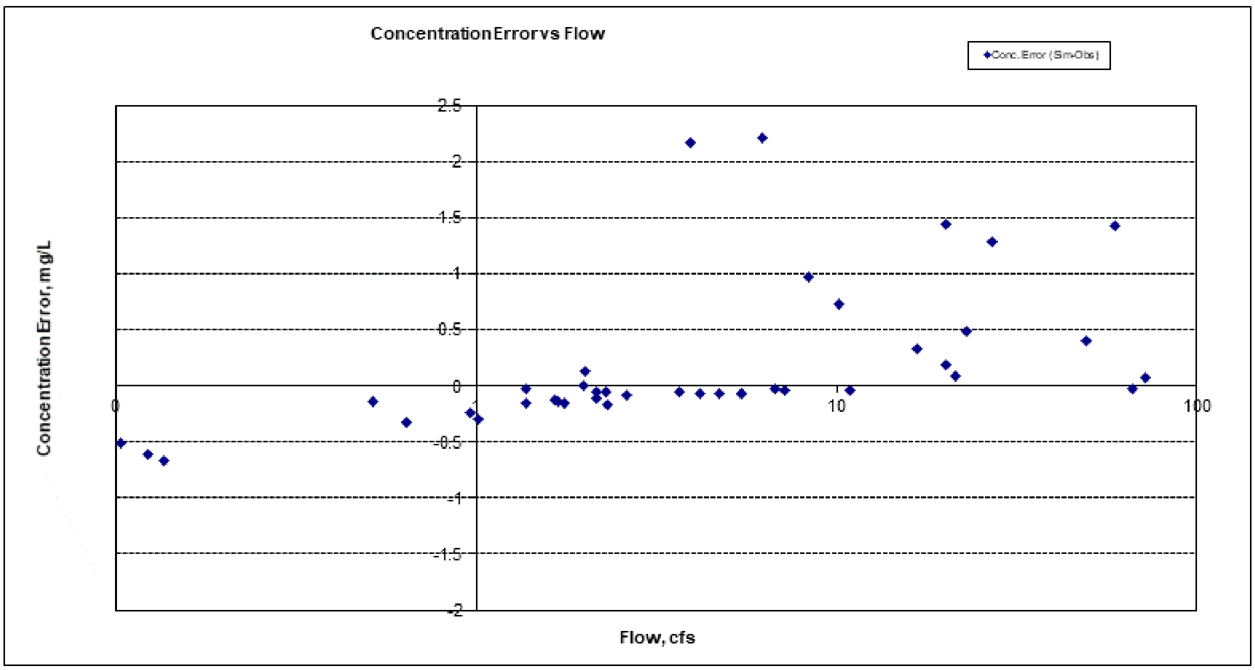


Figure E-698. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Miller Creek at Lake Superior College

E.14.6 Total Nitrogen (TN)

Table E-87. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	ND	10
Concentration Average Error		109.41%
Concentration Median Error		56.55%
Load Average Error		110.82%
Load Median Error		68.18%
Paired t conc		0.01
Paired t load		0.05

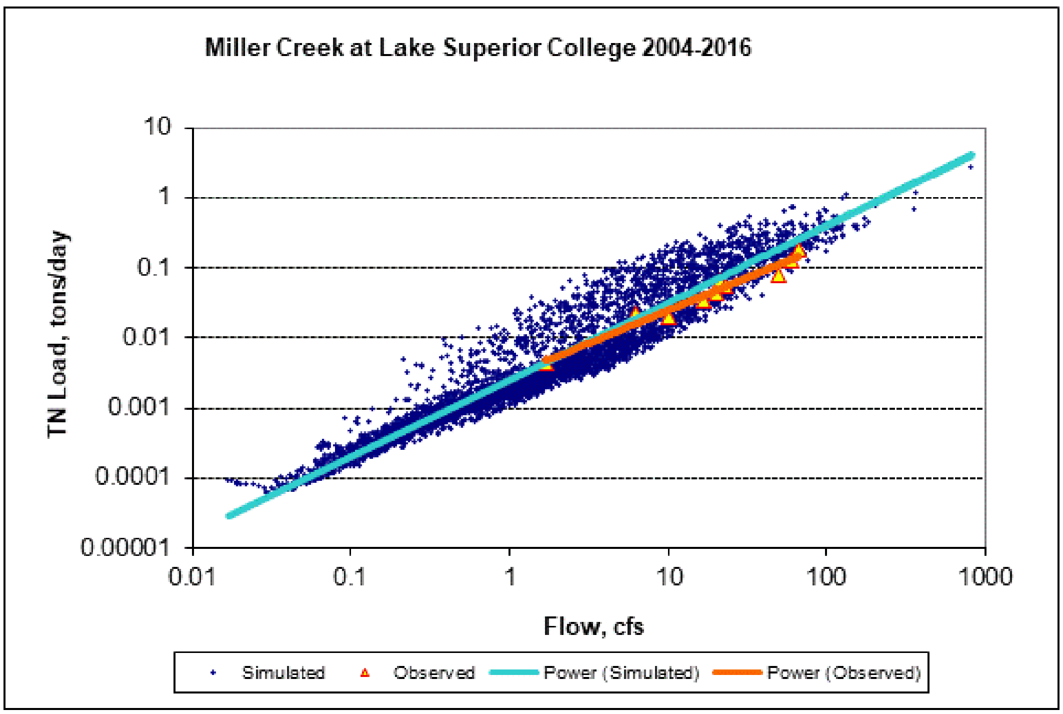


Figure E-699. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Miller Creek at Lake Superior College (calibration period)

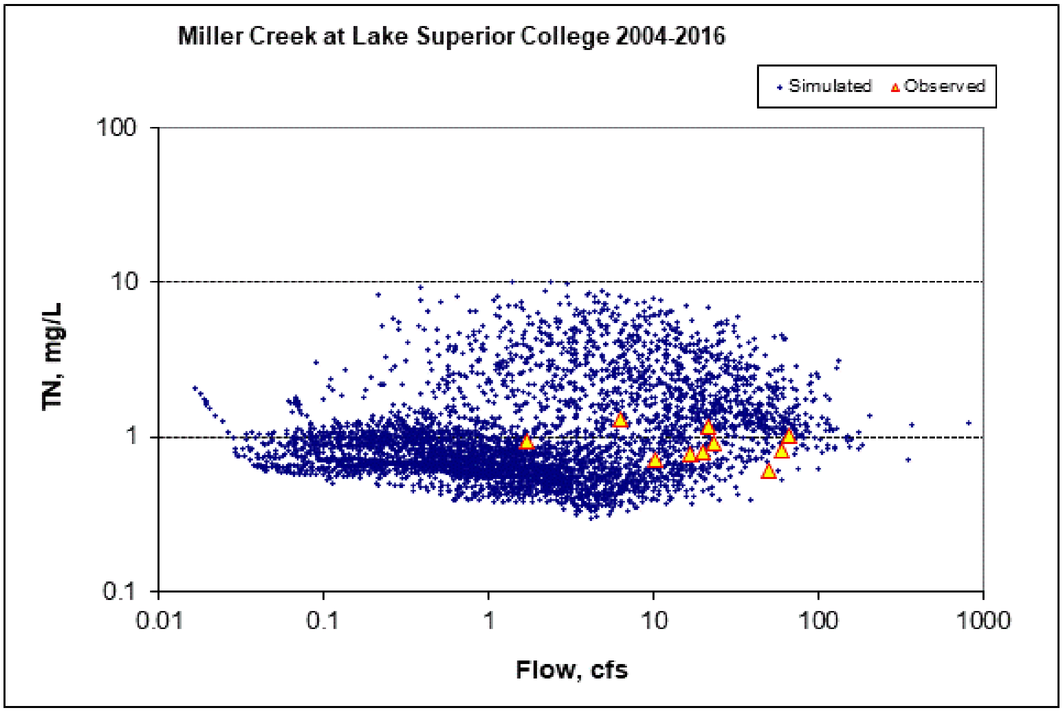
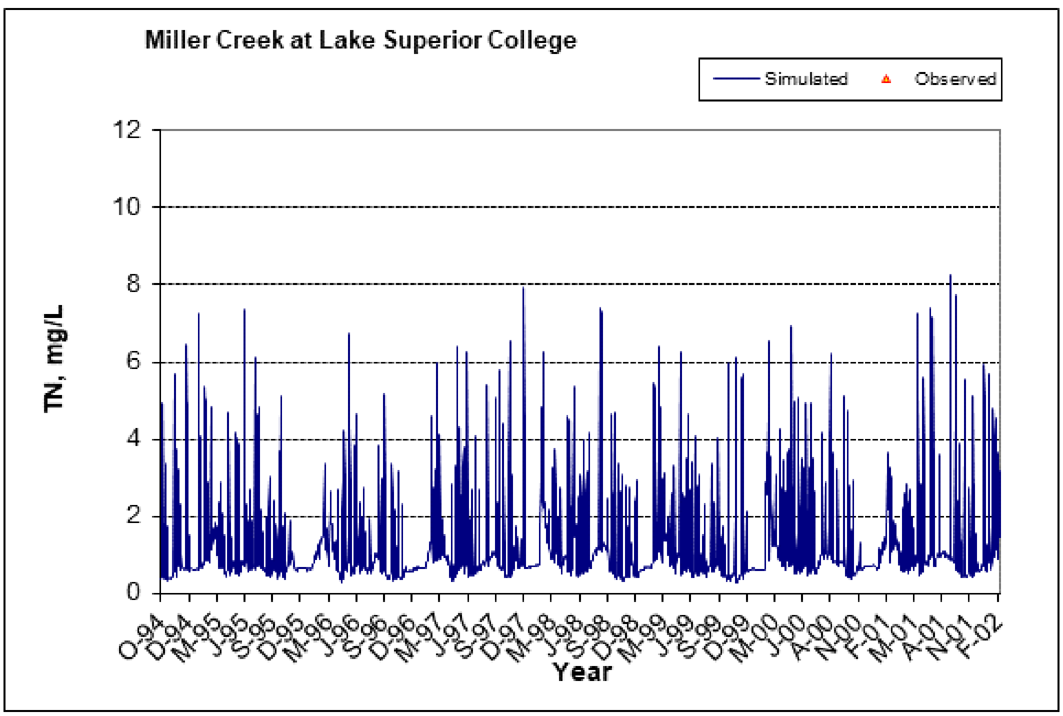


Figure E-700. Simulated and observed Total Nitrogen (TN) concentration vs flow at Miller Creek at Lake Superior College (calibration period)



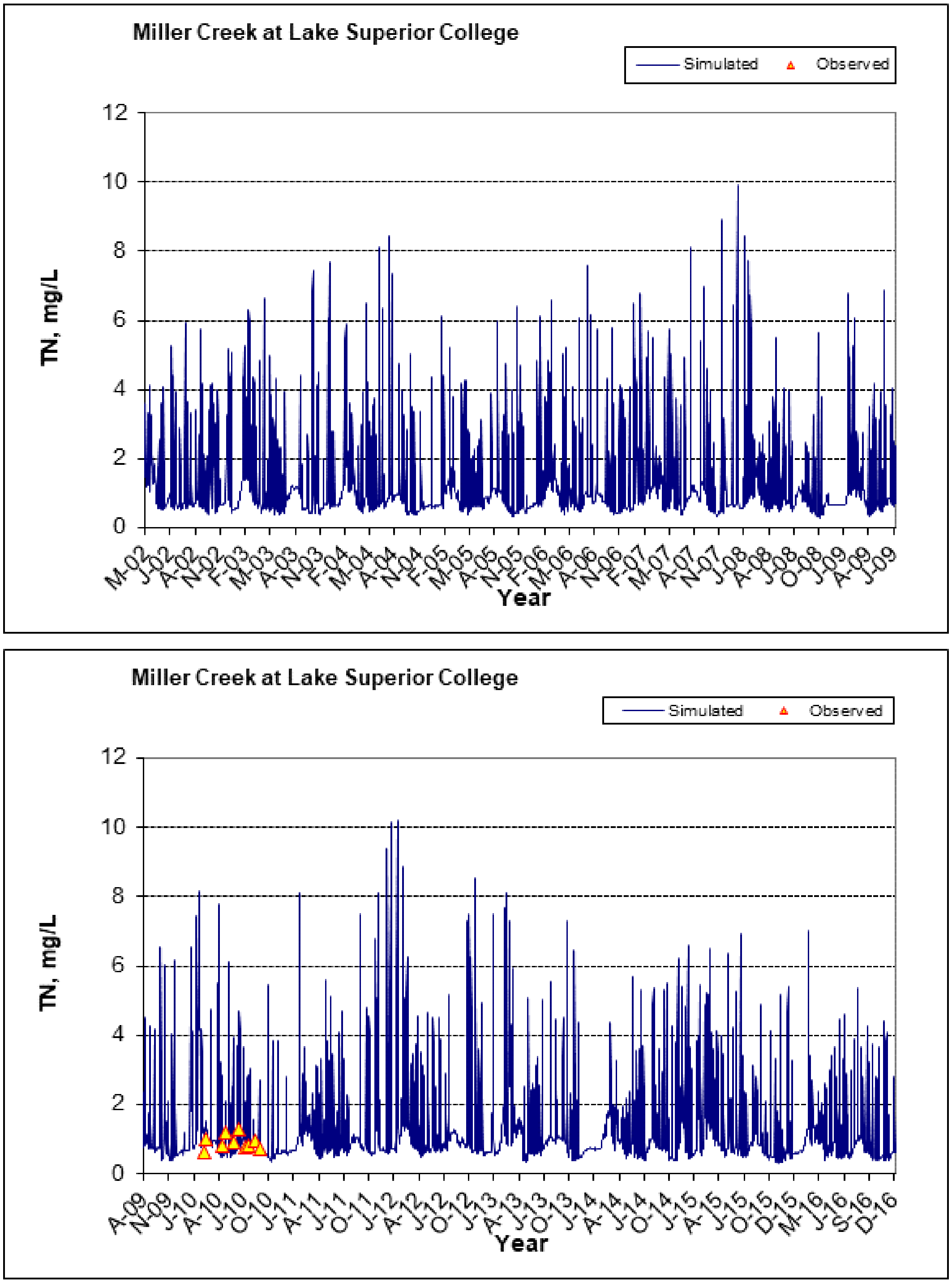


Figure E-701. Time series of observed and simulated Total Nitrogen (TN) concentration at Miller Creek at Lake Superior College

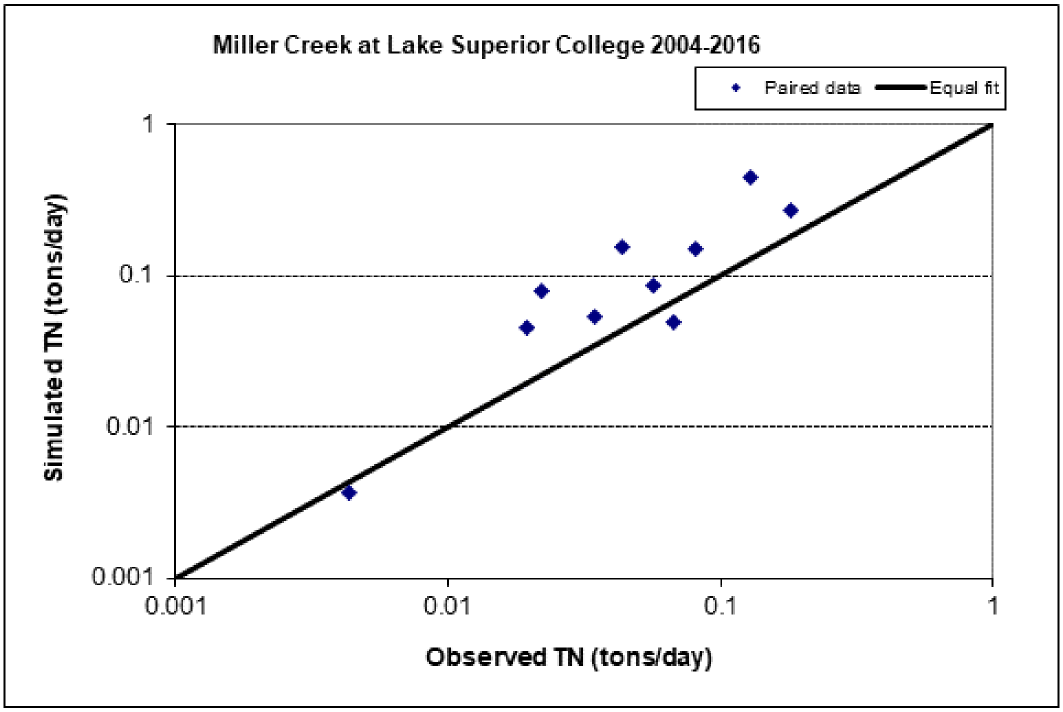


Figure E-702. Paired simulated vs. observed Total Nitrogen (TN) load at Miller Creek at Lake Superior College (calibration period)

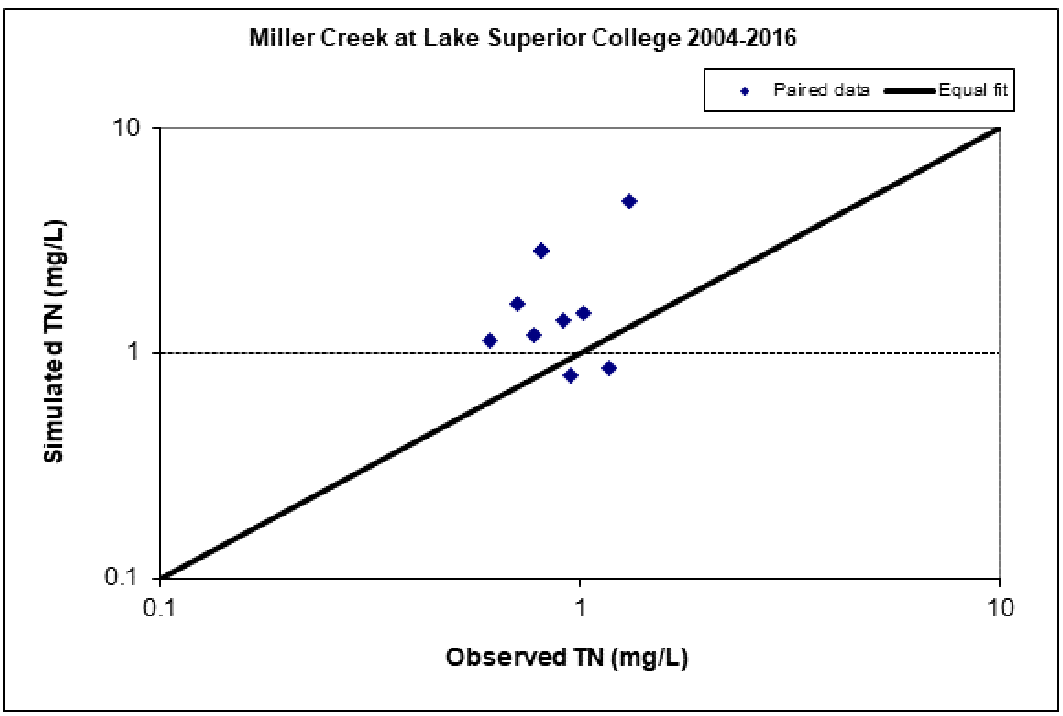


Figure E-703. Paired simulated vs. observed Total Nitrogen (TN) concentration at Miller Creek at Lake Superior College (calibration period)

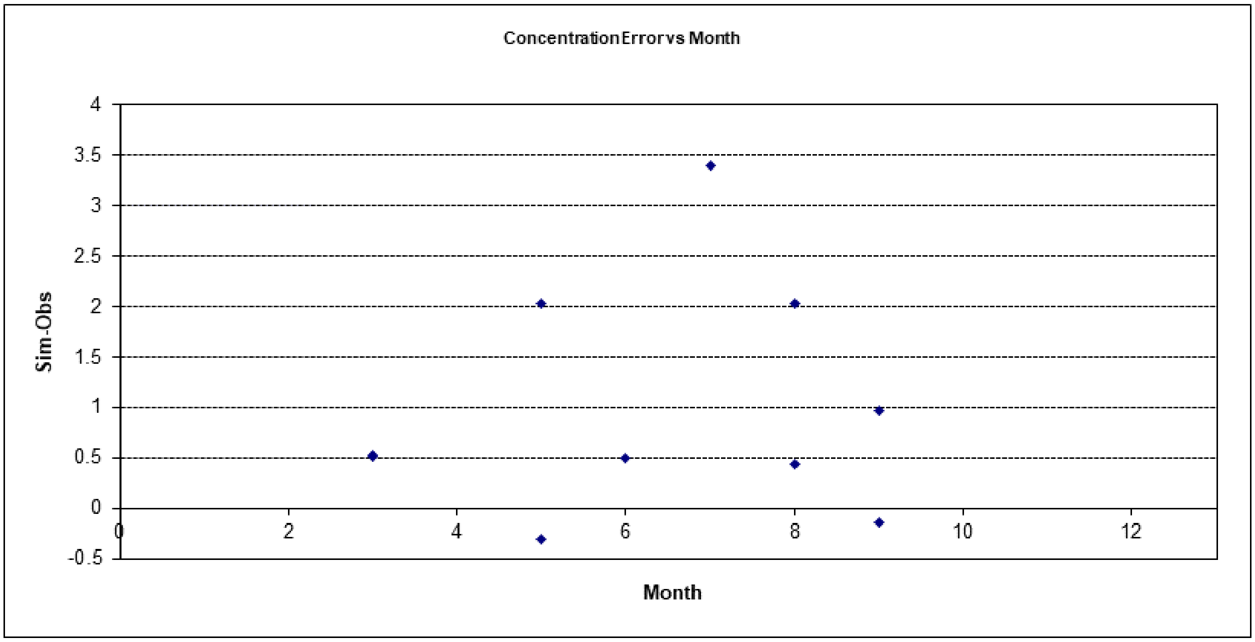


Figure E-704. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at Miller Creek at Lake Superior College

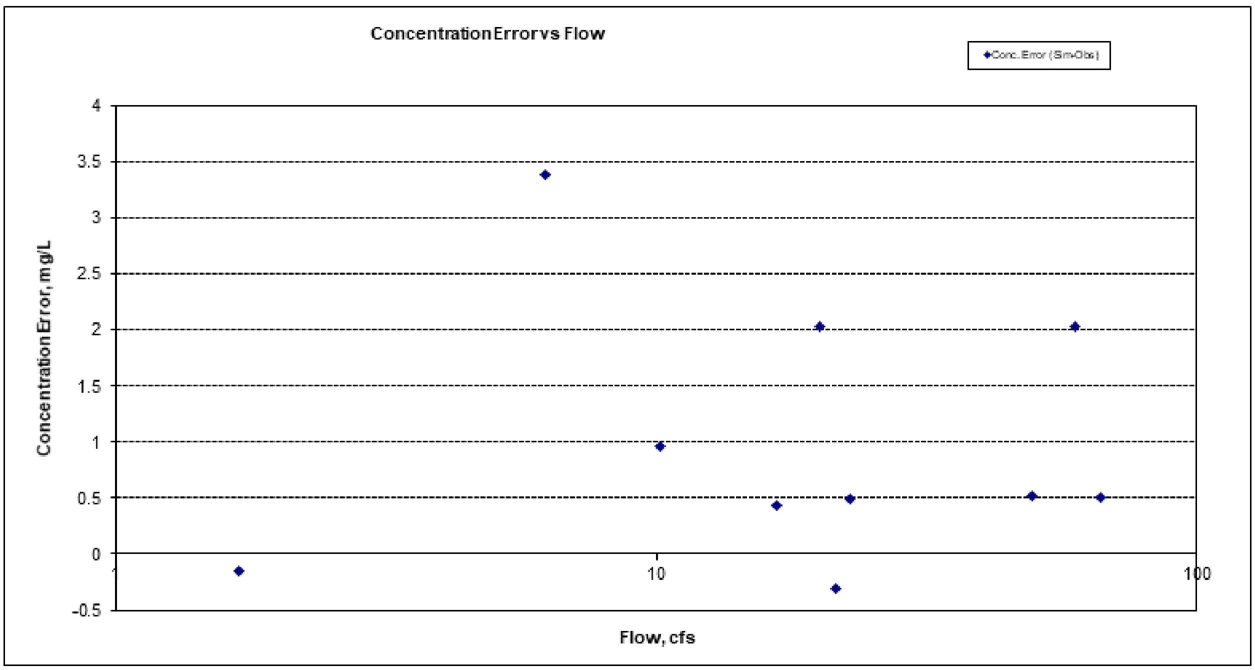


Figure E-705. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at Miller Creek at Lake Superior College

E.14.7 Total Phosphorus (TP)

Table E-88. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	41
Concentration Average Error		19.03%
Concentration Median Error		28.51%
Load Average Error		17.90%
Load Median Error		0.57%
Paired t conc		0.54
Paired t load		0.52

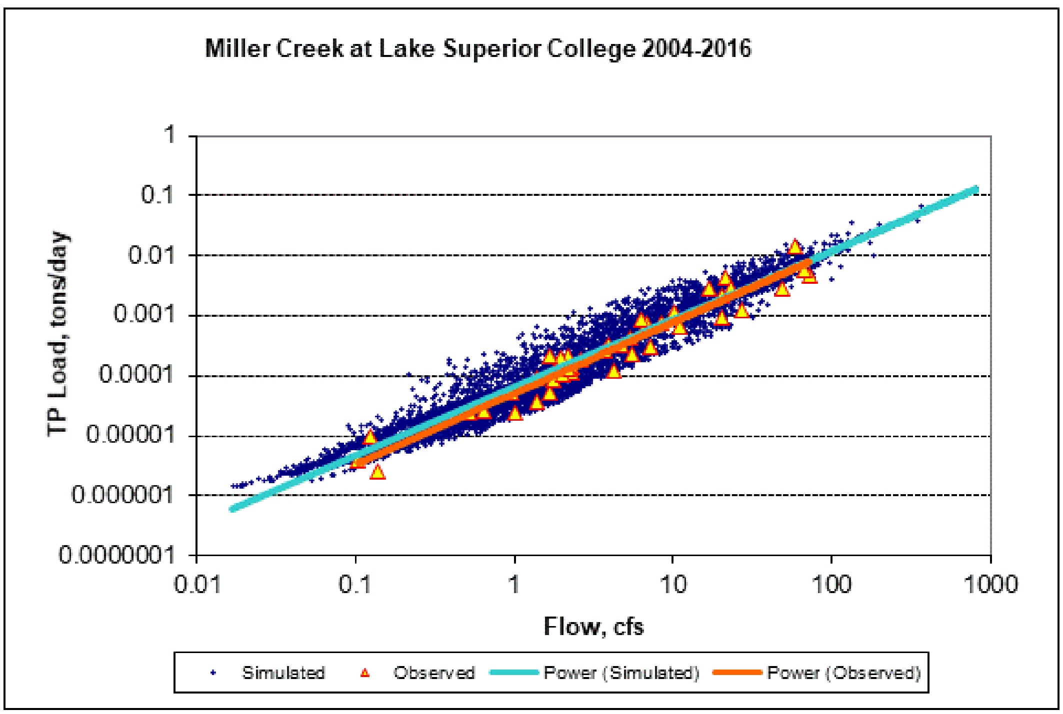


Figure E-706. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Miller Creek at Lake Superior College (calibration period)

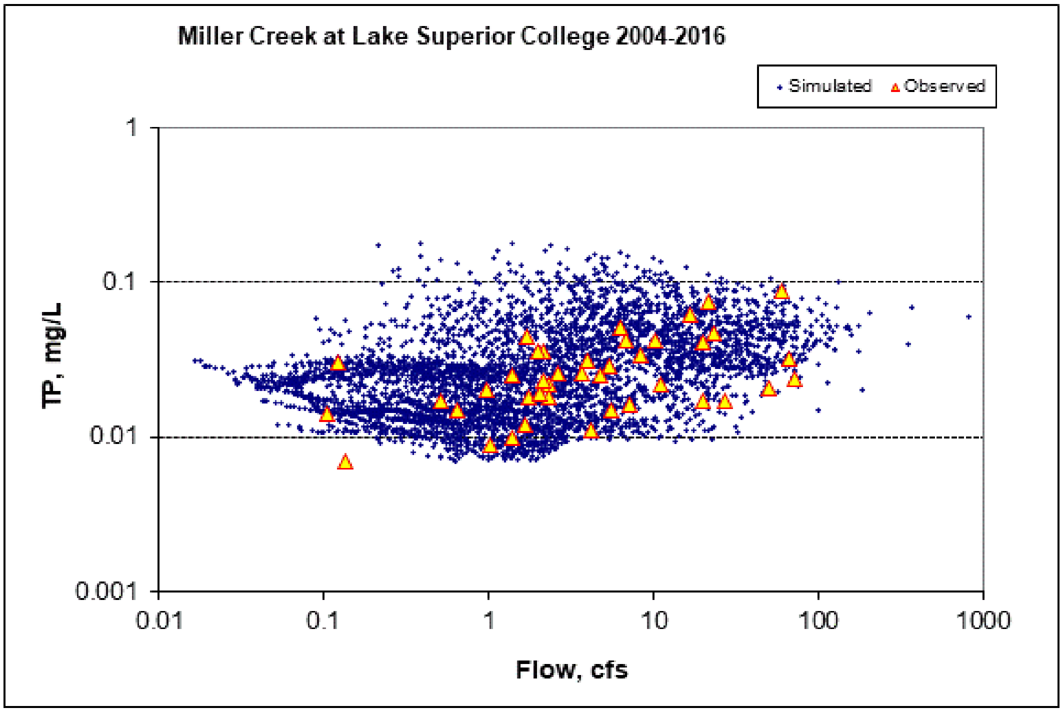
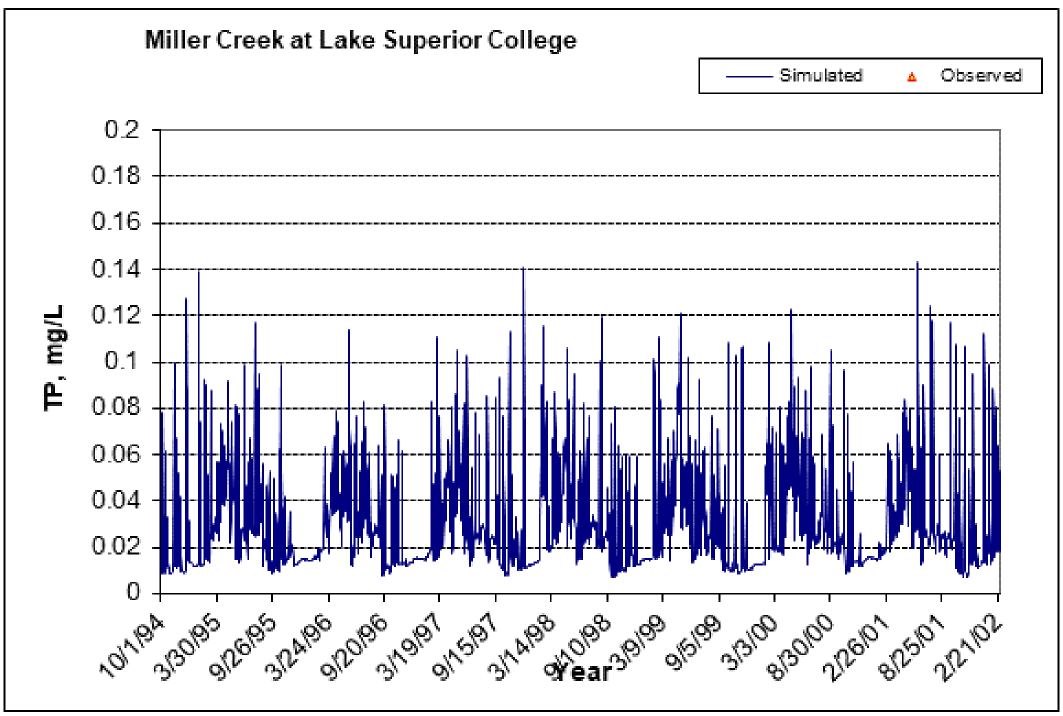


Figure E-707. Simulated and observed Total Phosphorus (TP) concentration vs flow at Miller Creek at Lake Superior College (calibration period)



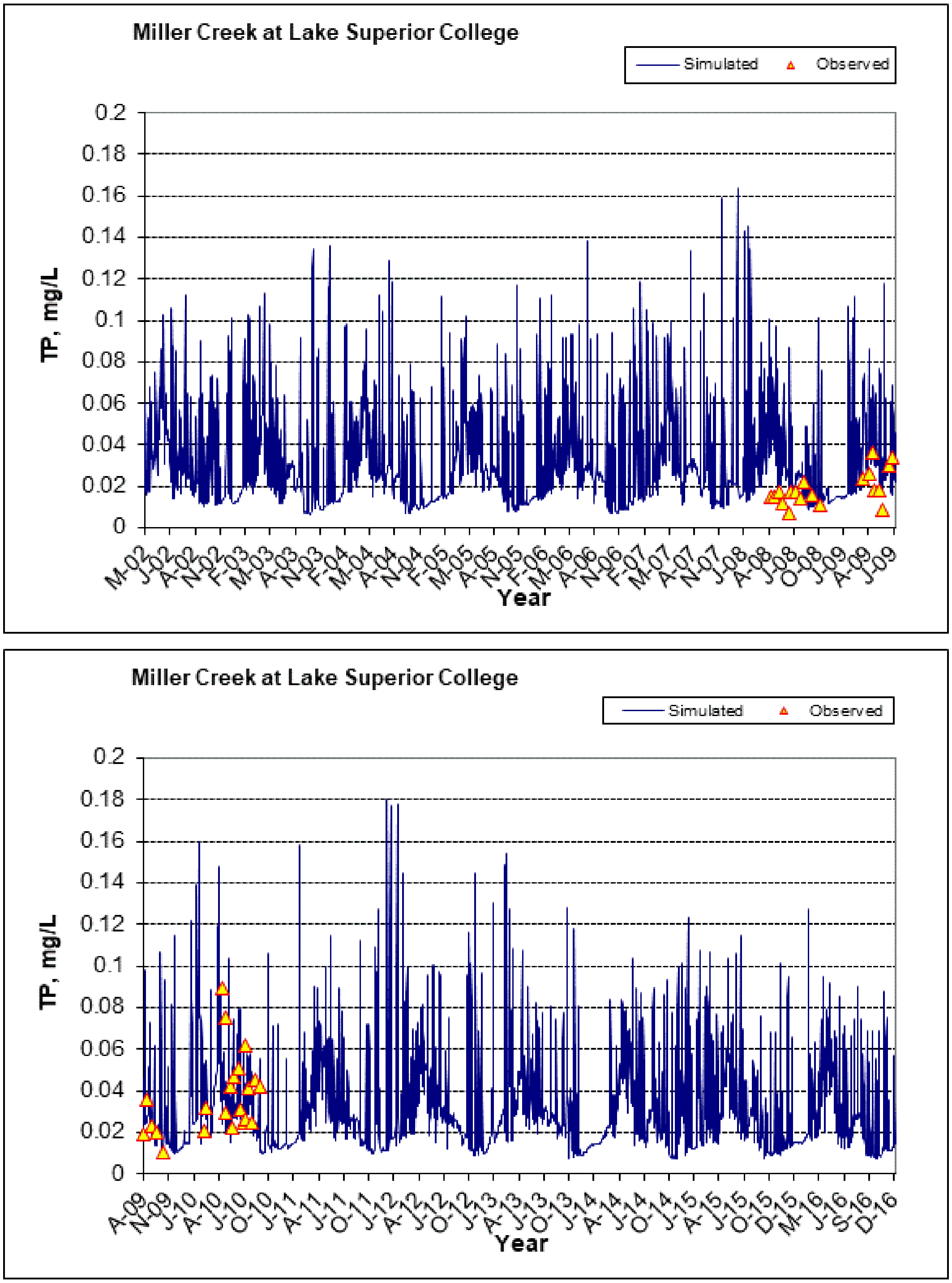


Figure E-708. Time series of observed and simulated Total Phosphorus (TP) concentration at Miller Creek at Lake Superior College

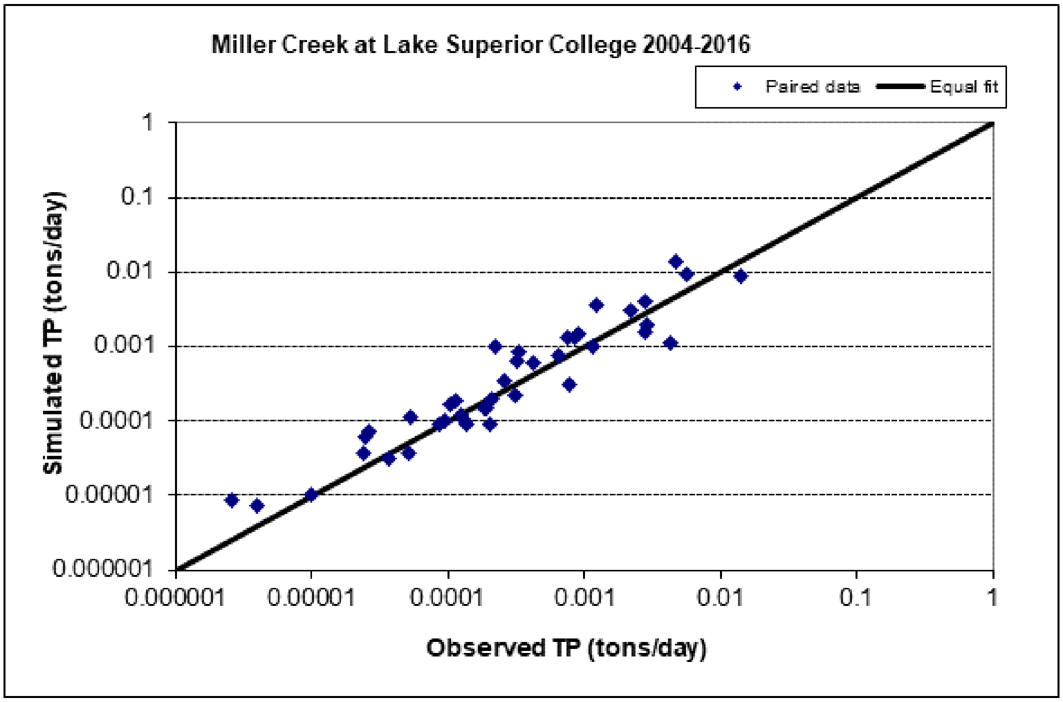


Figure E-709. Paired simulated vs. observed Total Phosphorus (TP) load at Miller Creek at Lake Superior College (calibration period)

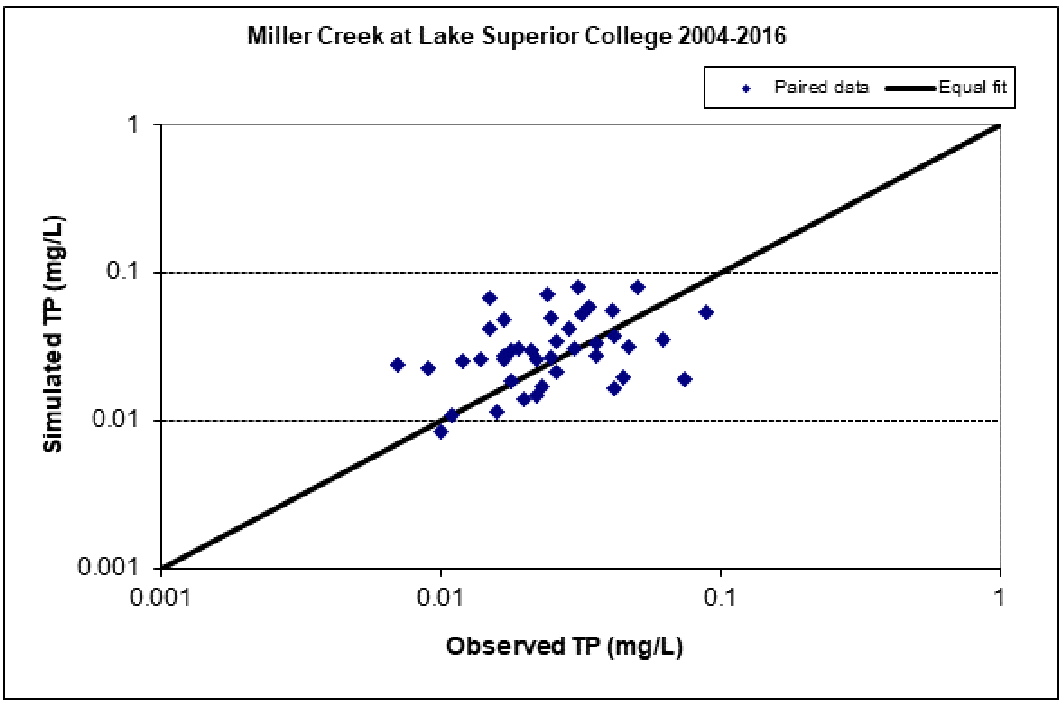


Figure E-710. Paired simulated vs. observed Total Phosphorus (TP) concentration at Miller Creek at Lake Superior College (calibration period)

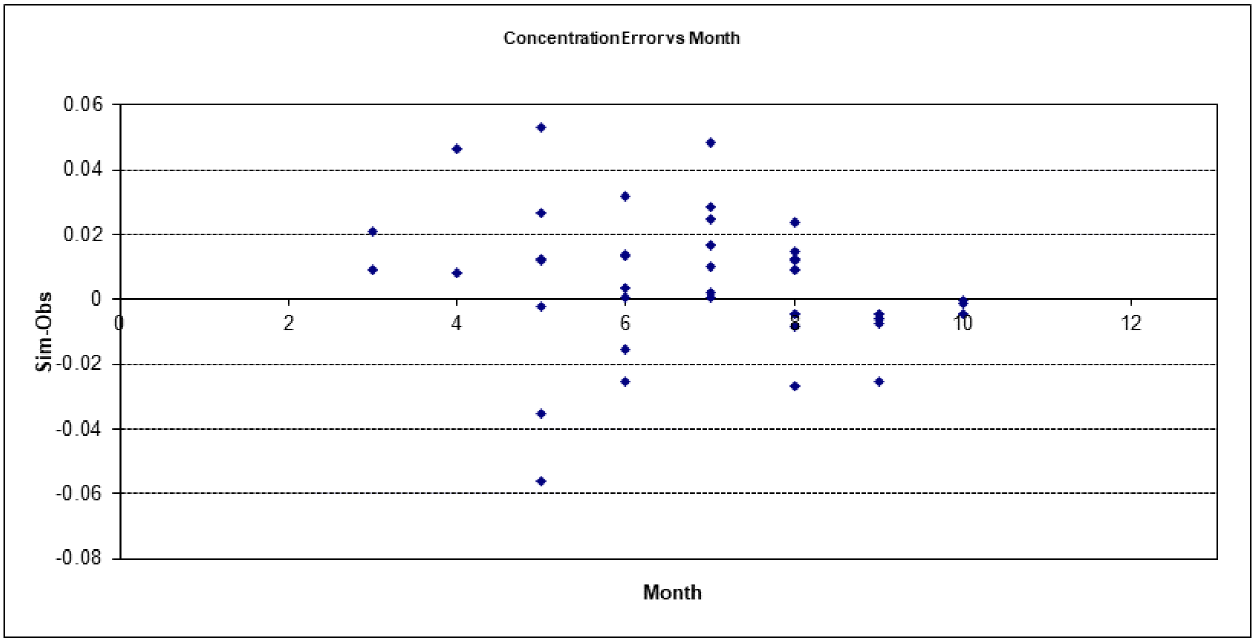


Figure E-711. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Miller Creek at Lake Superior College

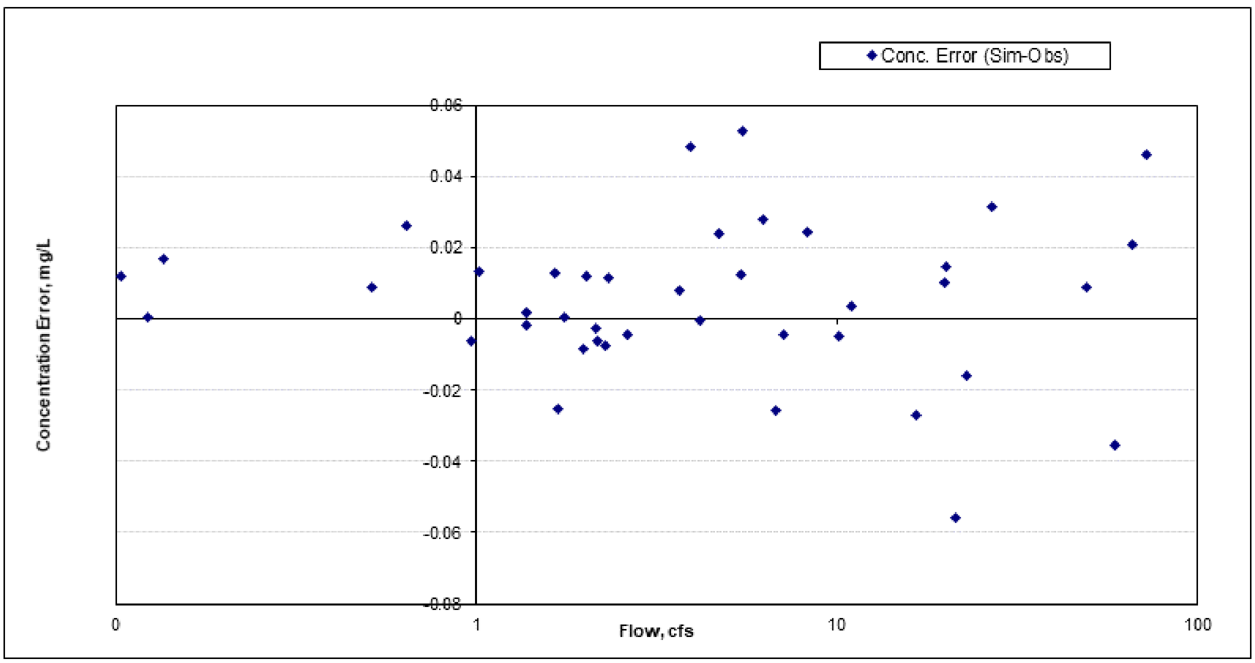


Figure E-712. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Miller Creek at Lake Superior College

E.15 Miller Creek nr Lower Gage (multiple stations)

E.15.1 Dissolved Oxygen (DO)

Table E-89. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	65
Concentration Average Error		-13.45%
Concentration Median Error		-9.19%
Load Average Error		-8.11%
Load Median Error		-2.51%
Paired t conc		1.00
Paired t load		0.74

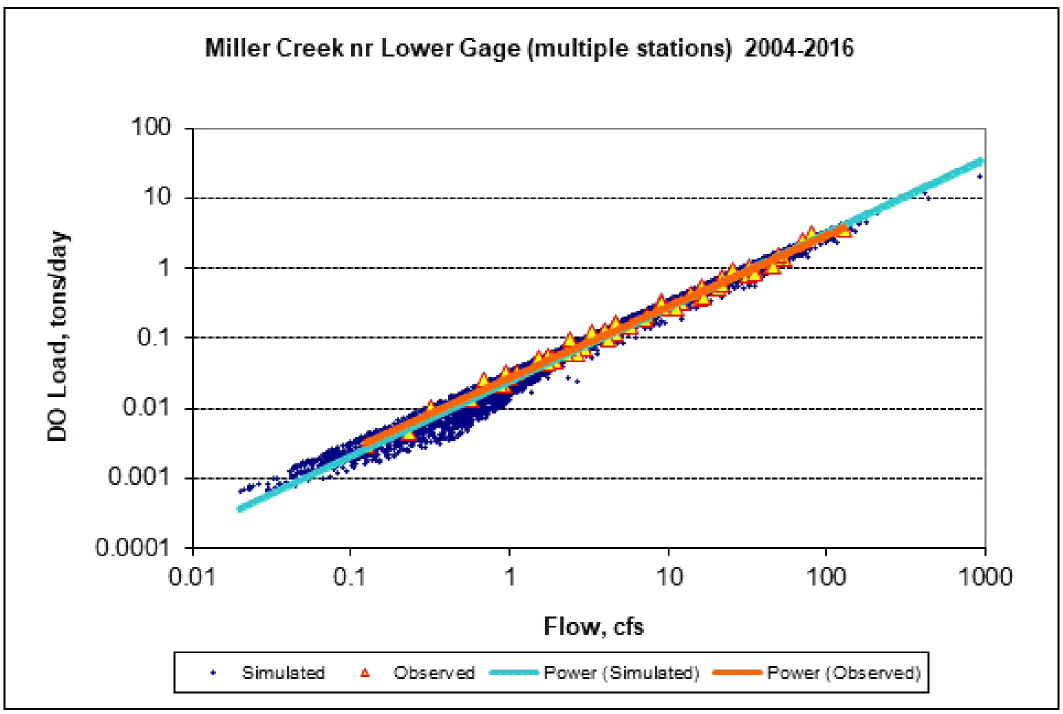


Figure E-713. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Miller Creek nr Lower Gage (multiple stations) (calibration period)

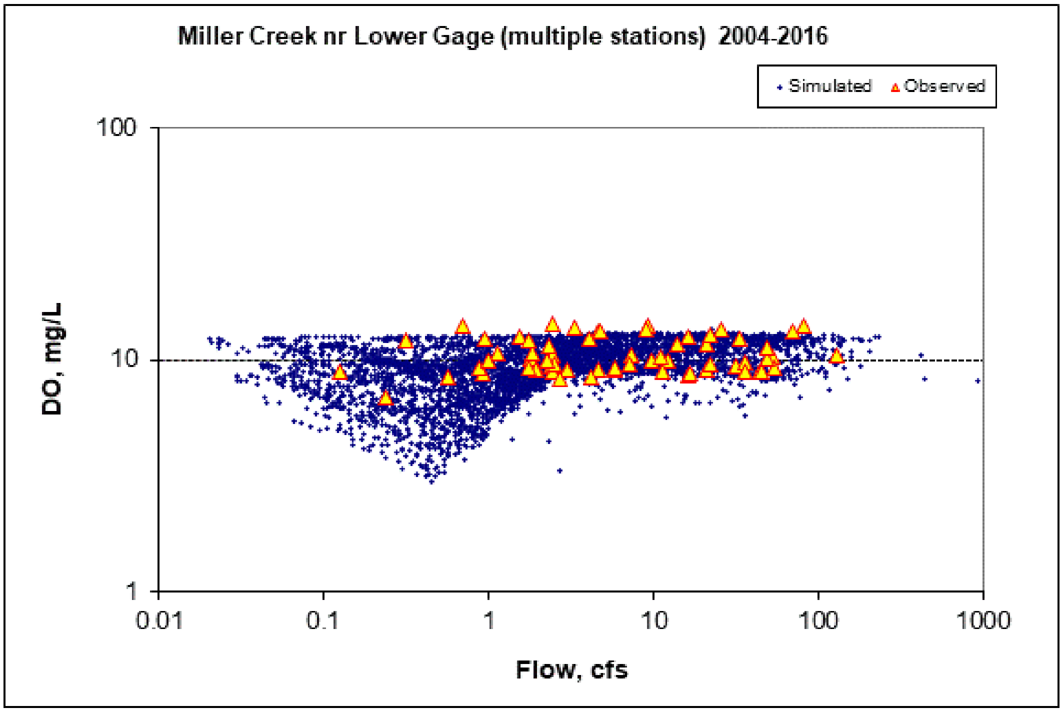
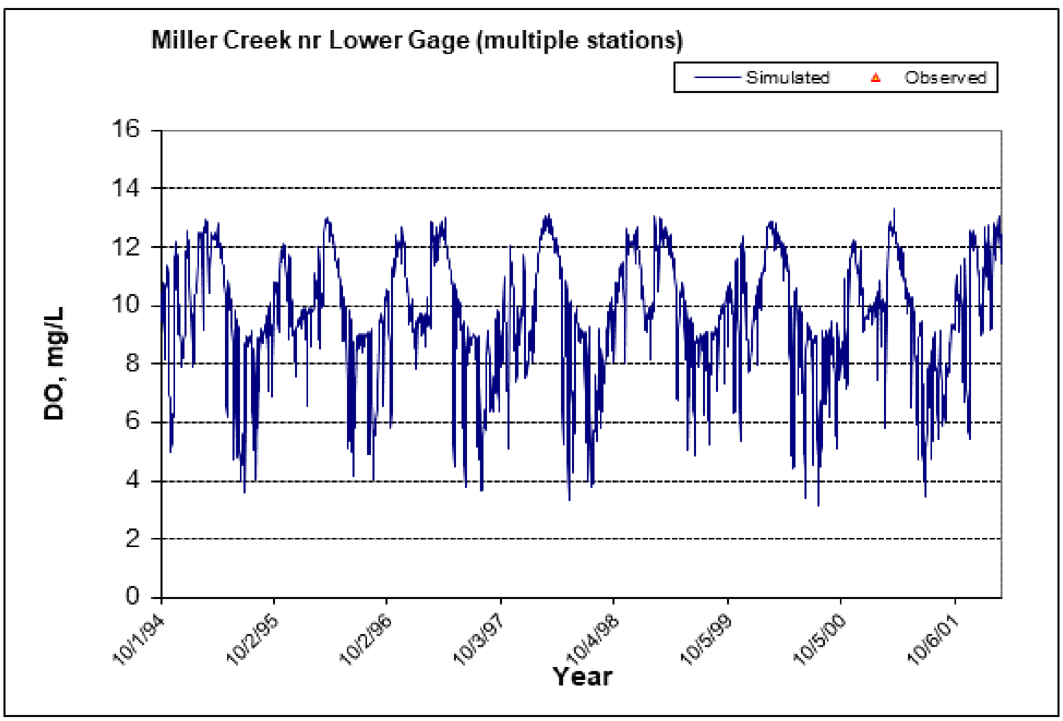
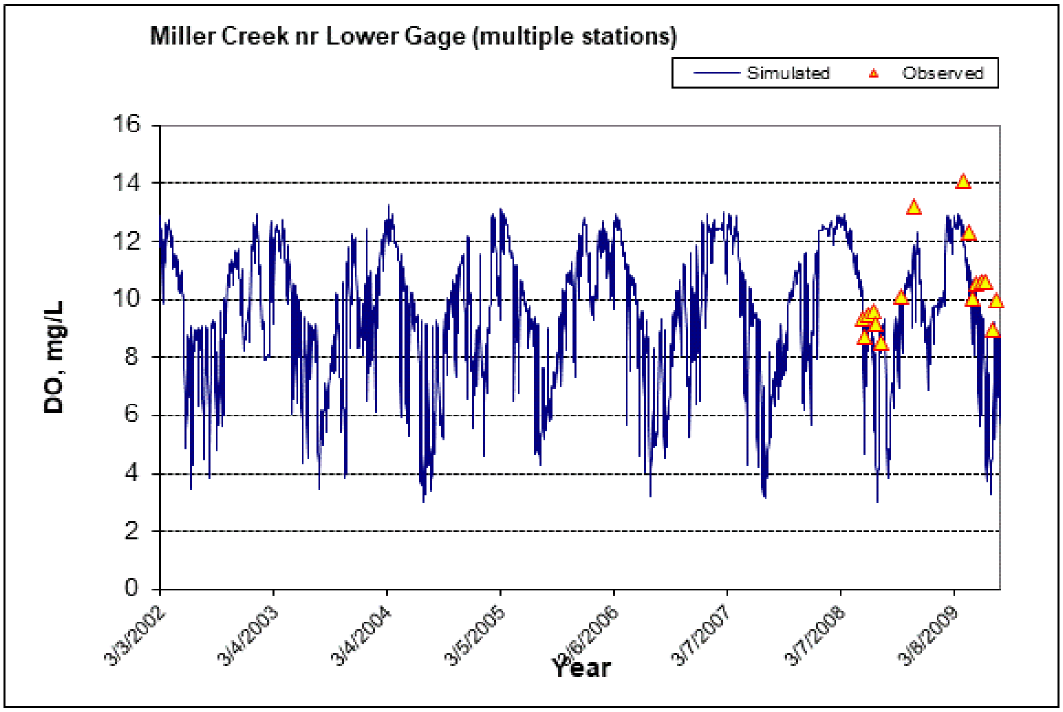


Figure E-714. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Miller Creek nr Lower Gage (multiple stations) (calibration period)





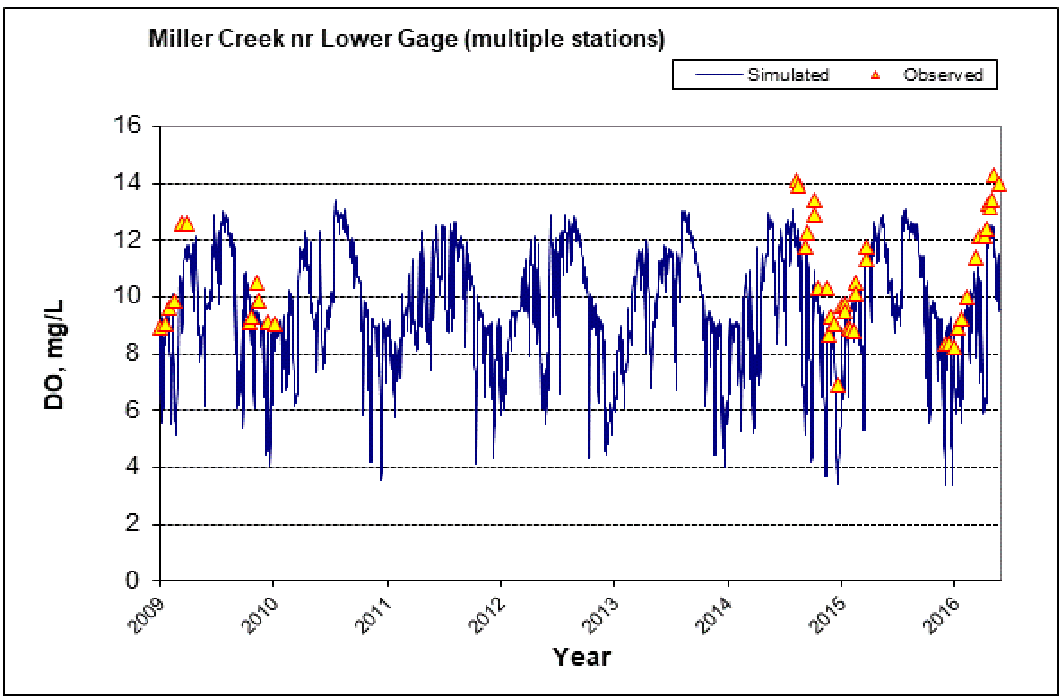


Figure E-715. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Miller Creek nr Lower Gage (multiple stations)

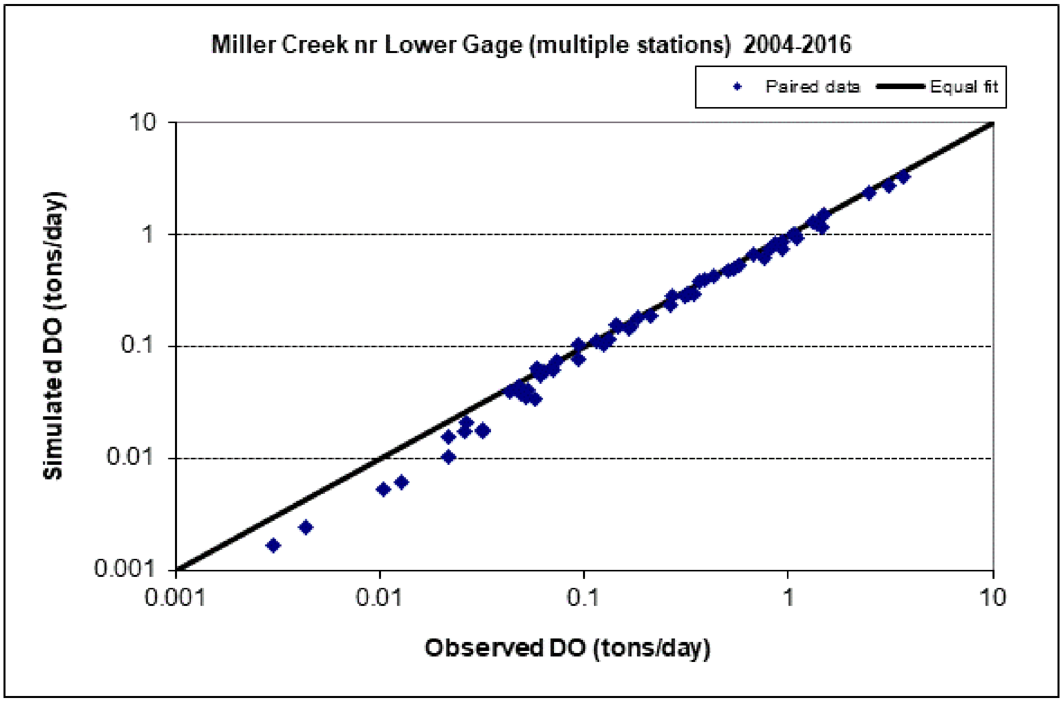


Figure E-716. Paired simulated vs. observed Dissolved Oxygen (DO) load at Miller Creek nr Lower Gage (multiple stations) (calibration period)

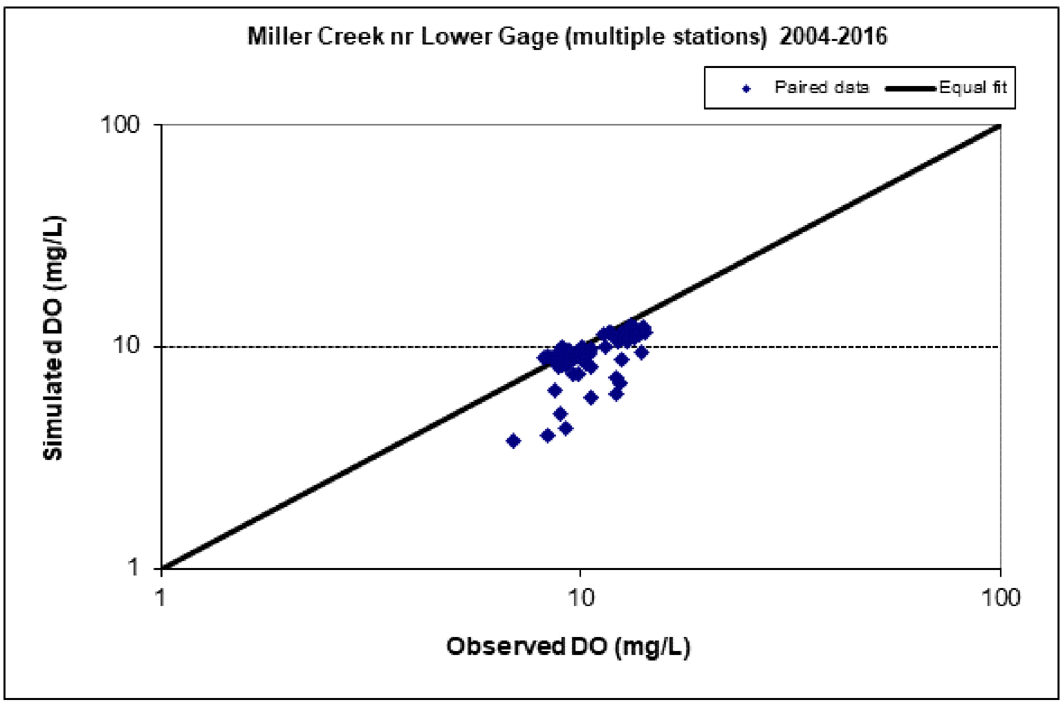


Figure E-717. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Miller Creek nr Lower Gage (multiple stations) (calibration period)

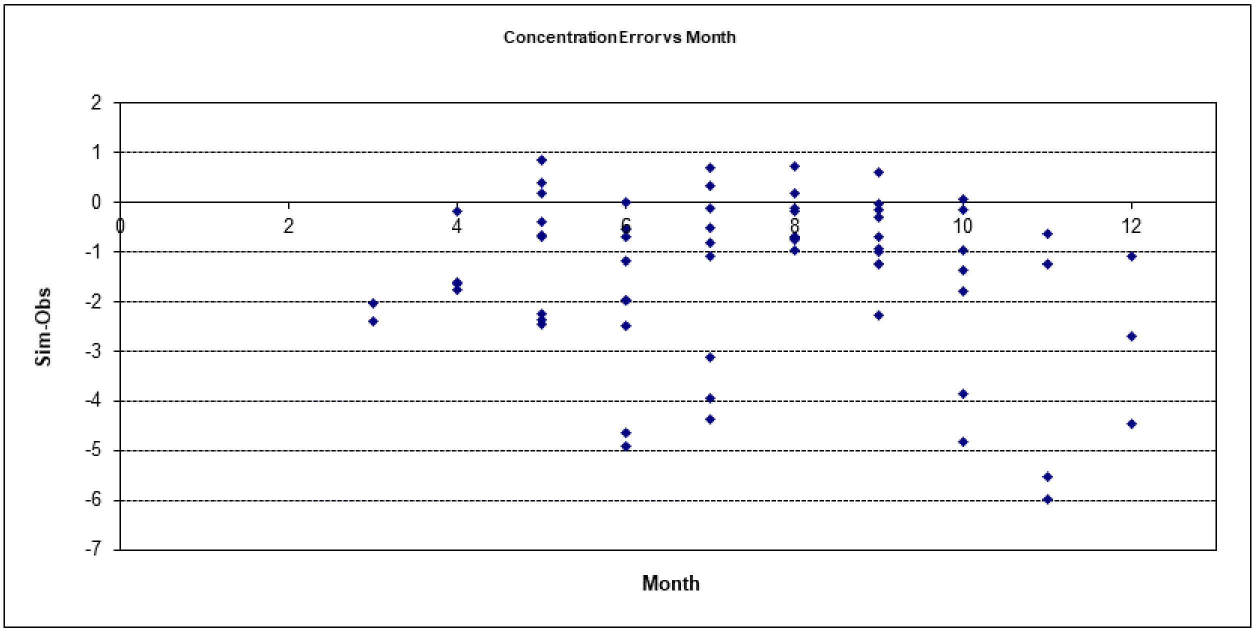


Figure E-718. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Miller Creek nr Lower Gage (multiple stations)

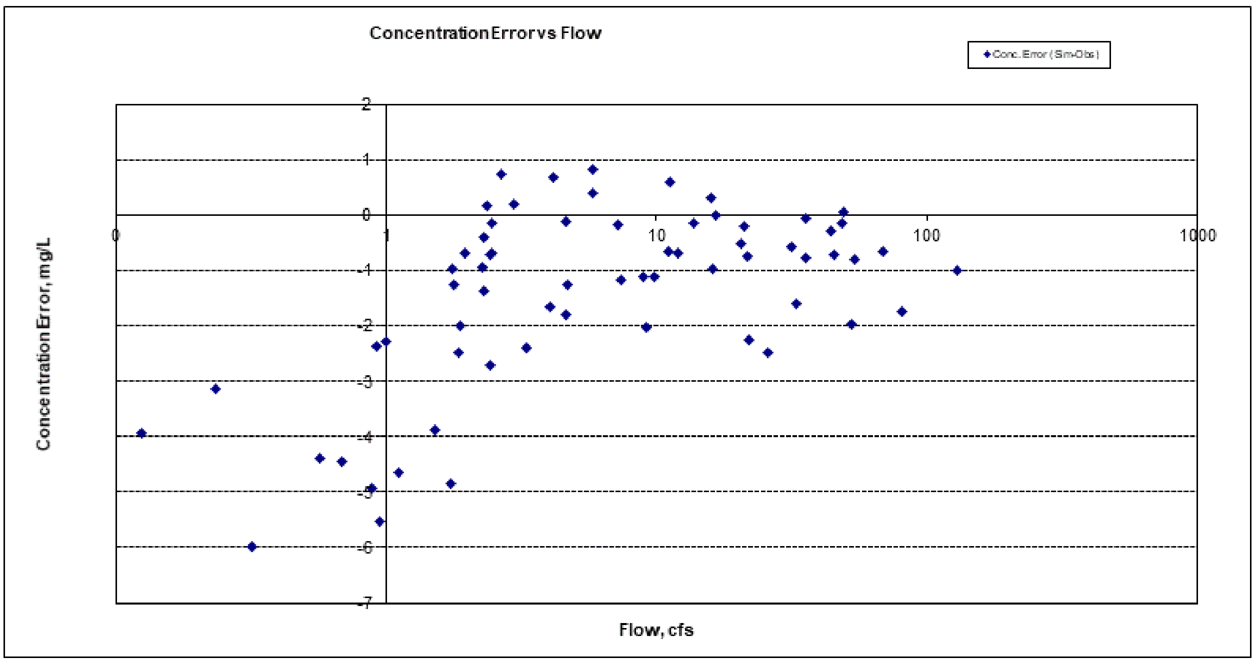


Figure E-719. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Miller Creek nr Lower Gage (multiple stations)

E.15.2 Ammonia Nitrogen (NH3)

Table E-90. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	28
Concentration Average Error		-79.26%
Concentration Median Error		-45.18%
Load Average Error		-71.17%
Load Median Error		-27.66%
Paired t conc		0.00
Paired t load		0.08

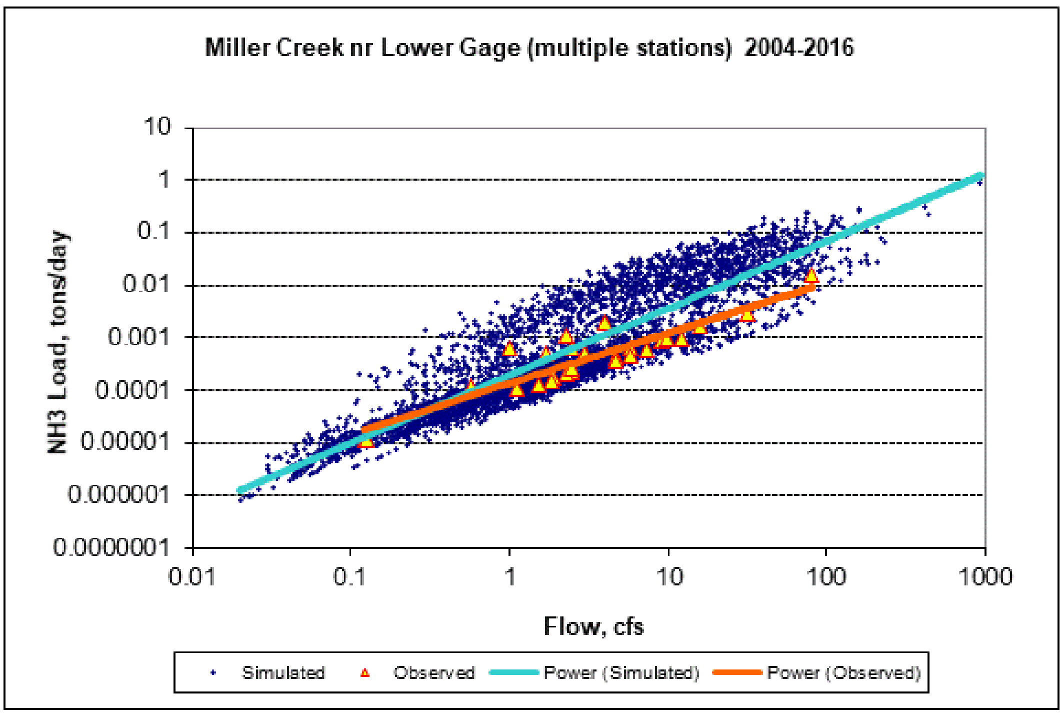


Figure E-720. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Miller Creek nr Lower Gage (multiple stations) (calibration period)

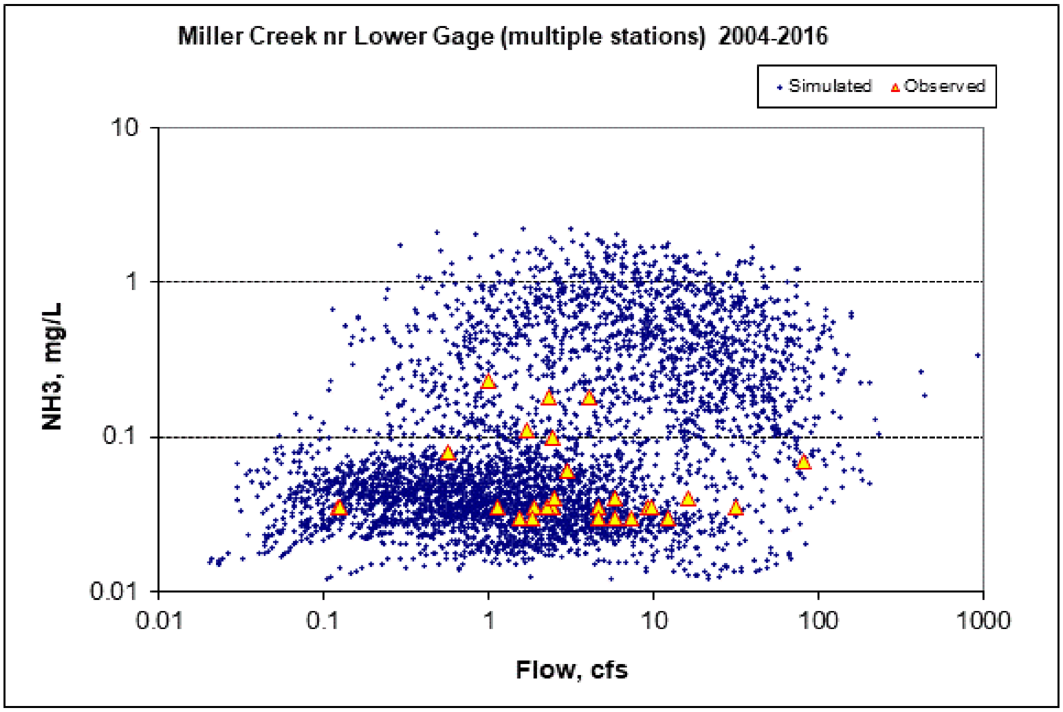
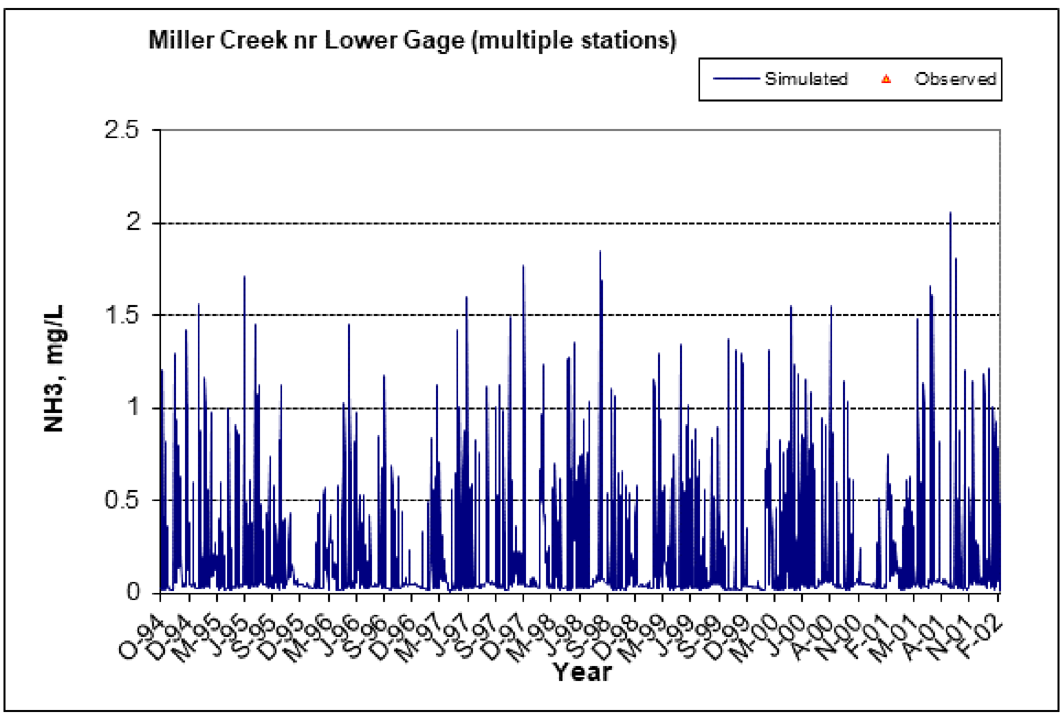
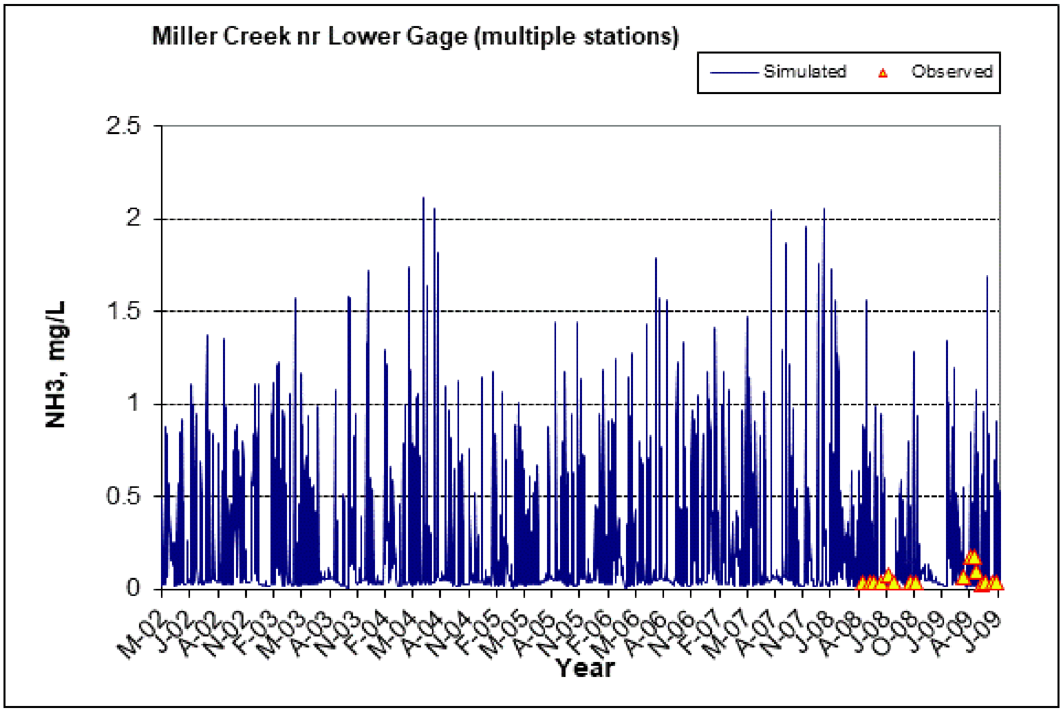


Figure E-721. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Miller Creek nr Lower Gage (multiple stations) (calibration period)





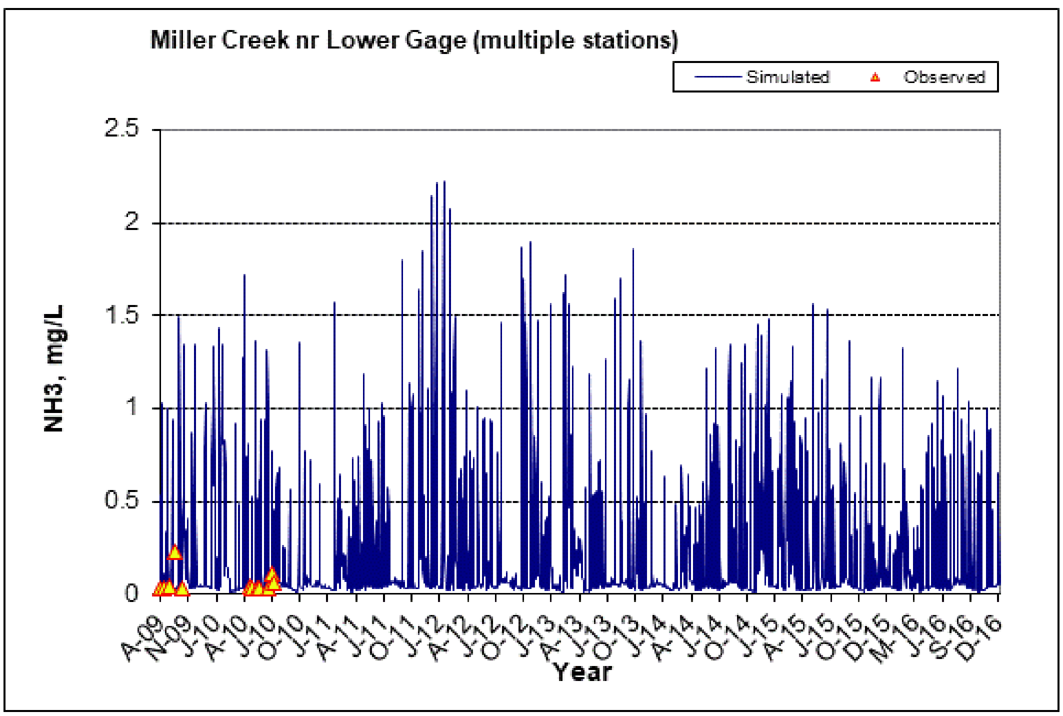


Figure E-722. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Miller Creek nr Lower Gage (multiple stations)

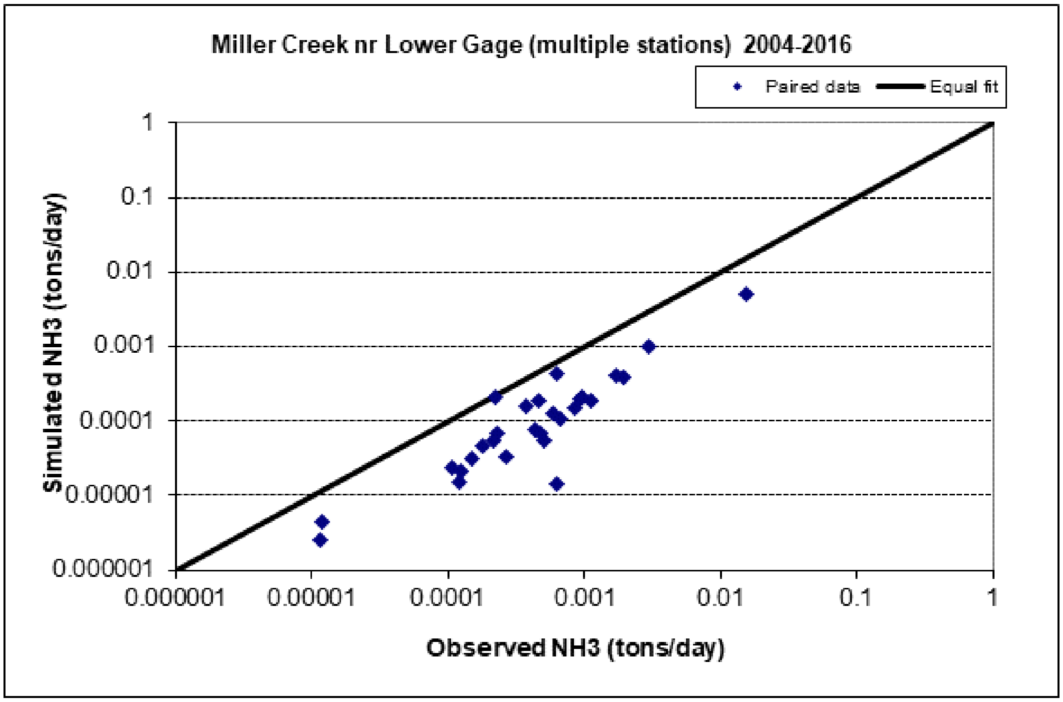


Figure E-723. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Miller Creek nr Lower Gage (multiple stations) (calibration period)

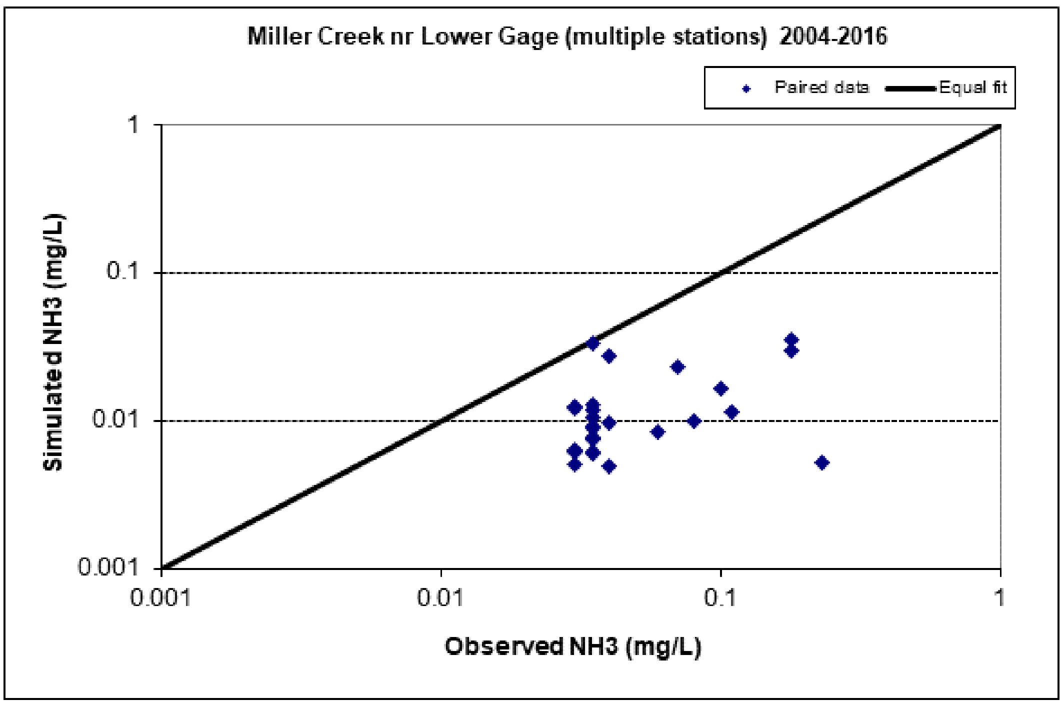


Figure E-724. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Miller Creek nr Lower Gage (multiple stations) (calibration period)

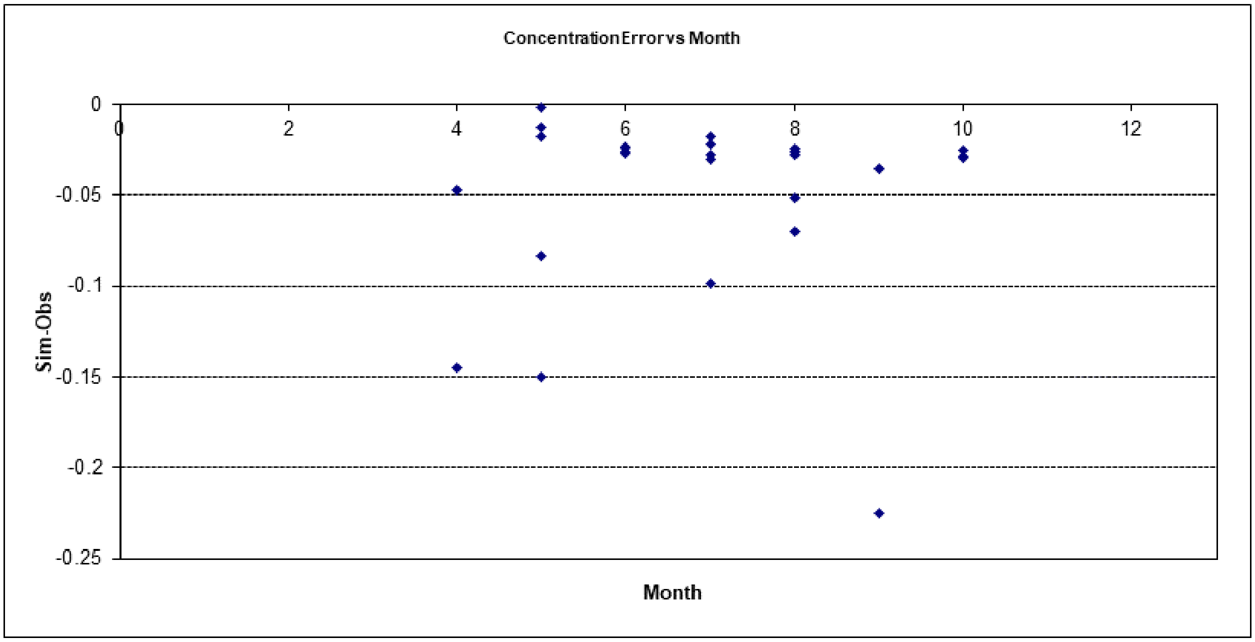


Figure E-725. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Miller Creek nr Lower Gage (multiple stations)

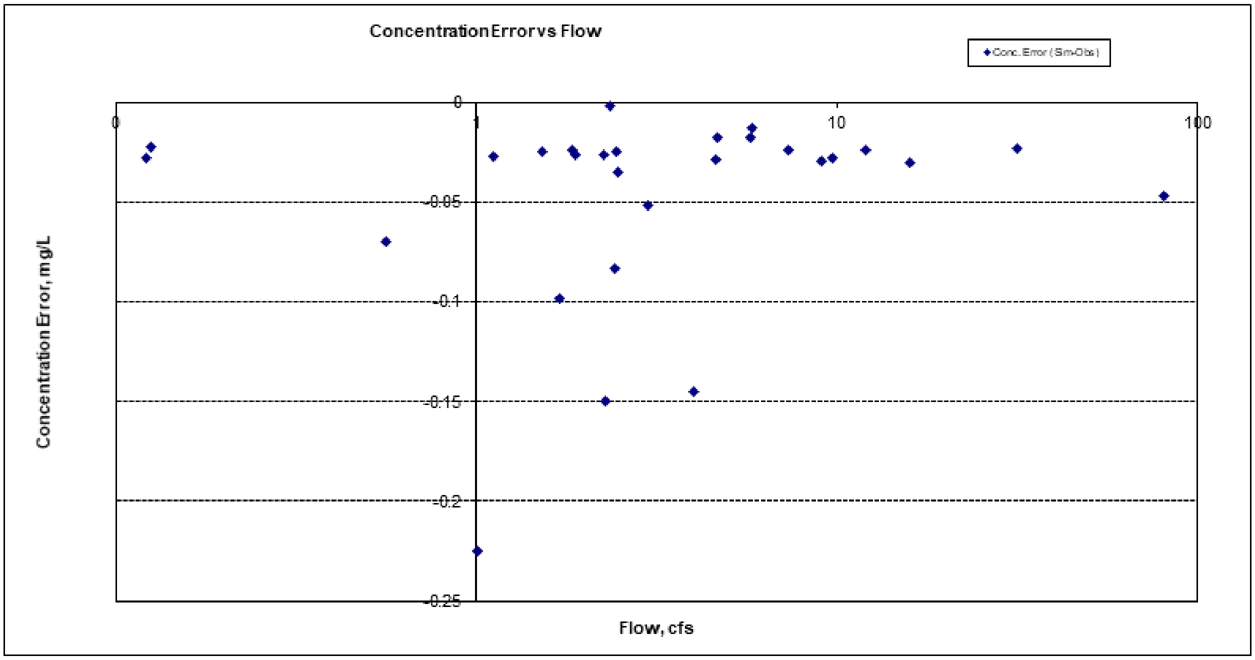


Figure E-726. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Miller Creek nr Lower Gage (multiple stations)

E.15.3 Nitrite+ Nitrate Nitrogen (NOx)

Table E-91. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	41
Concentration Average Error		73.39%
Concentration Median Error		-1.31%
Load Average Error		65.81%
Load Median Error		-0.08%
Paired t conc		0.03
Paired t load		0.10

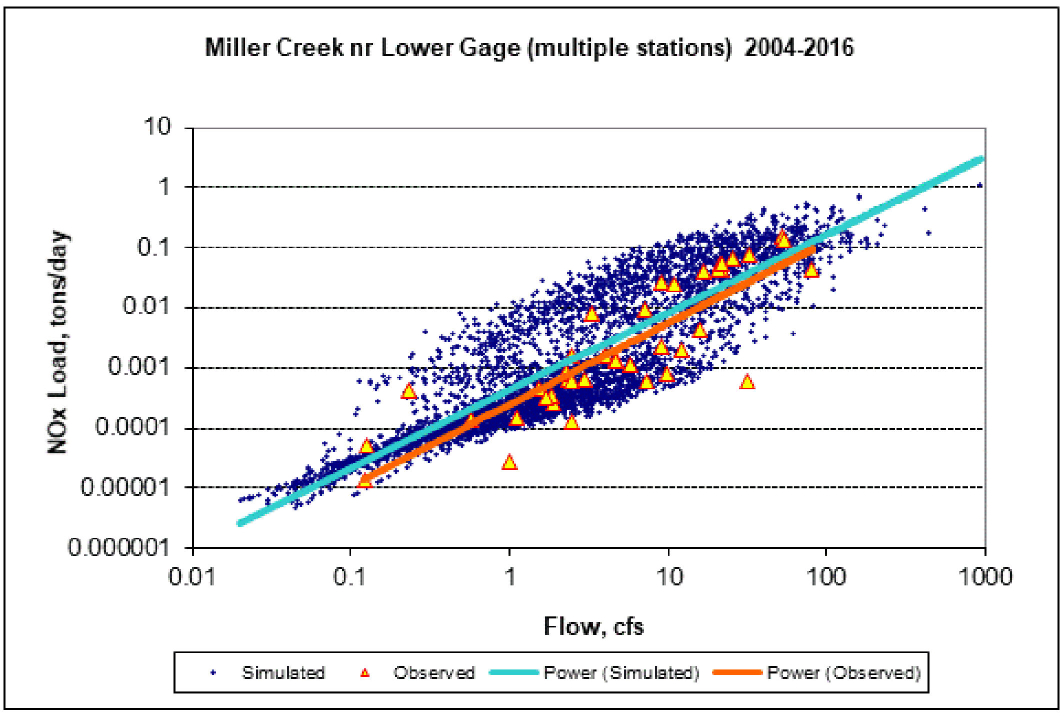


Figure E-727. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Miller Creek nr Lower Gage (multiple stations) (calibration period)

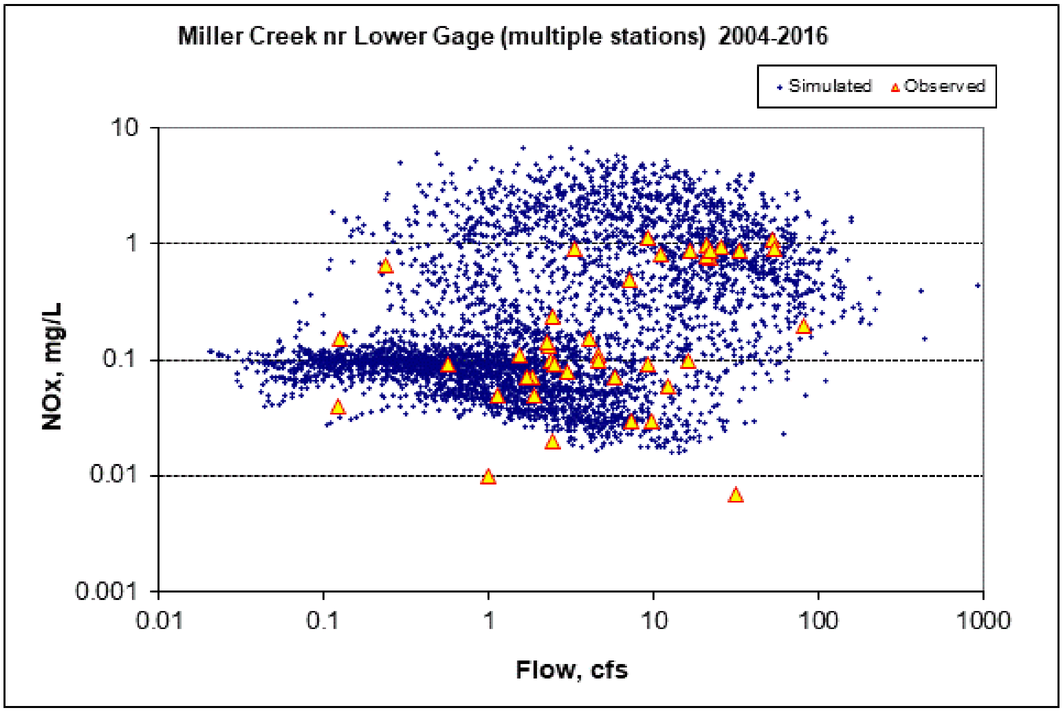
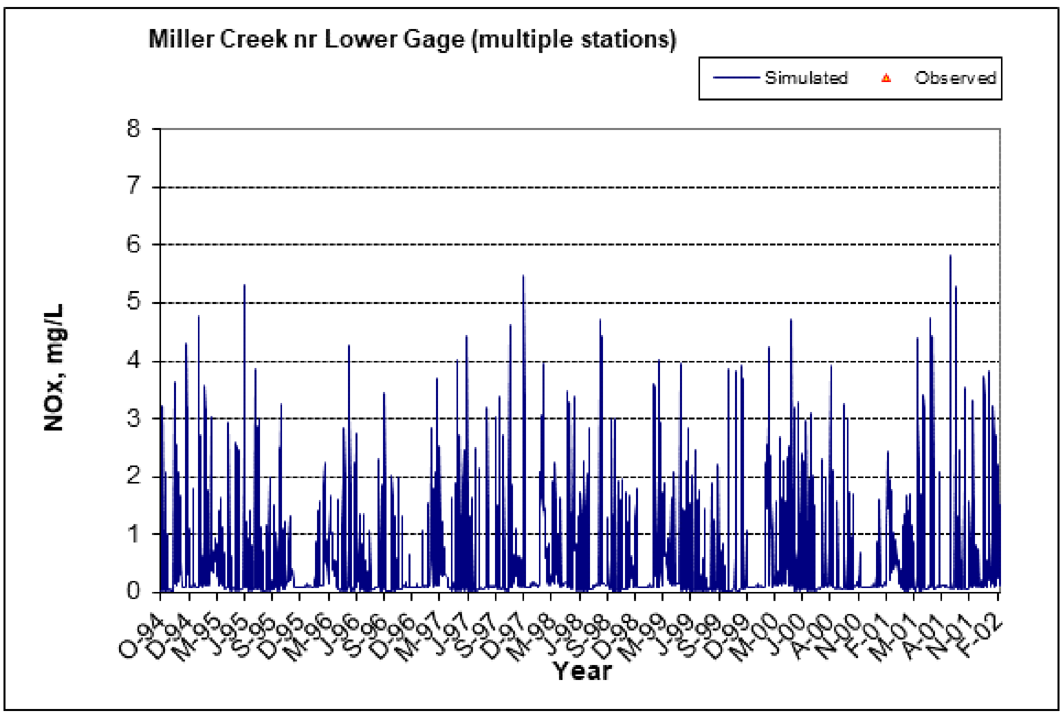


Figure E-728. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Miller Creek nr Lower Gage (multiple stations) (calibration period)



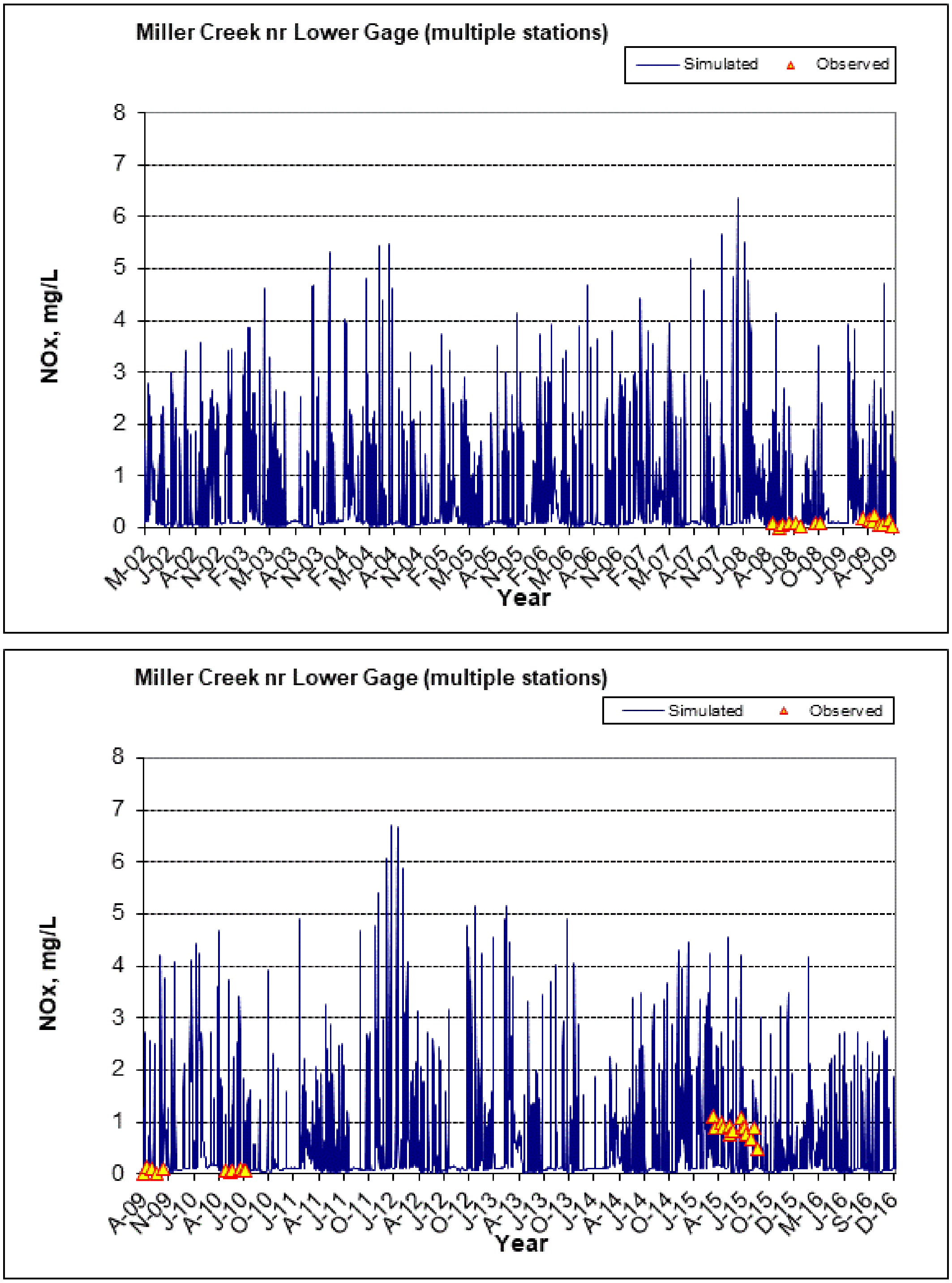


Figure E-729. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Miller Creek nr Lower Gage (multiple stations)

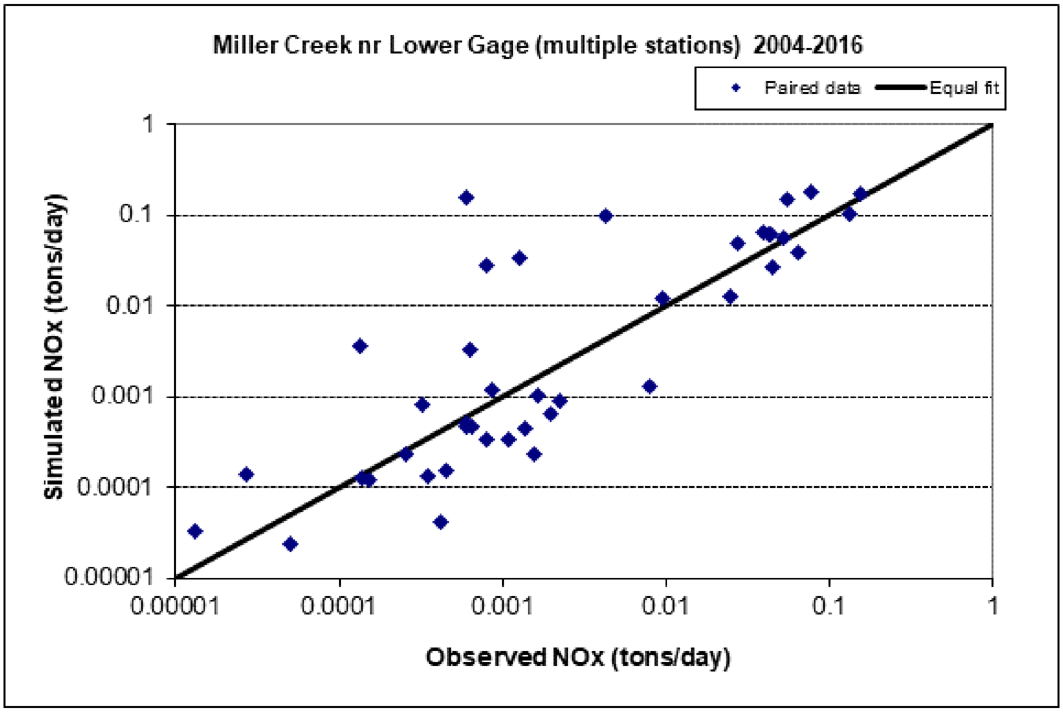


Figure E-730. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Miller Creek nr Lower Gage (multiple stations) (calibration period)

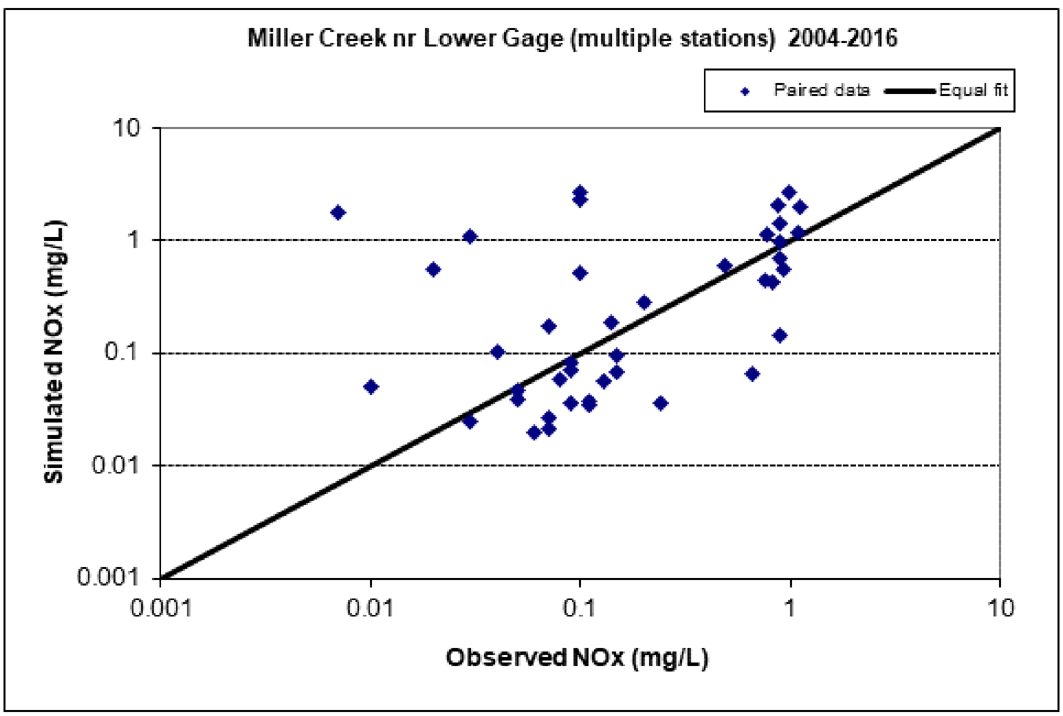


Figure E-731. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Miller Creek nr Lower Gage (multiple stations) (calibration period)

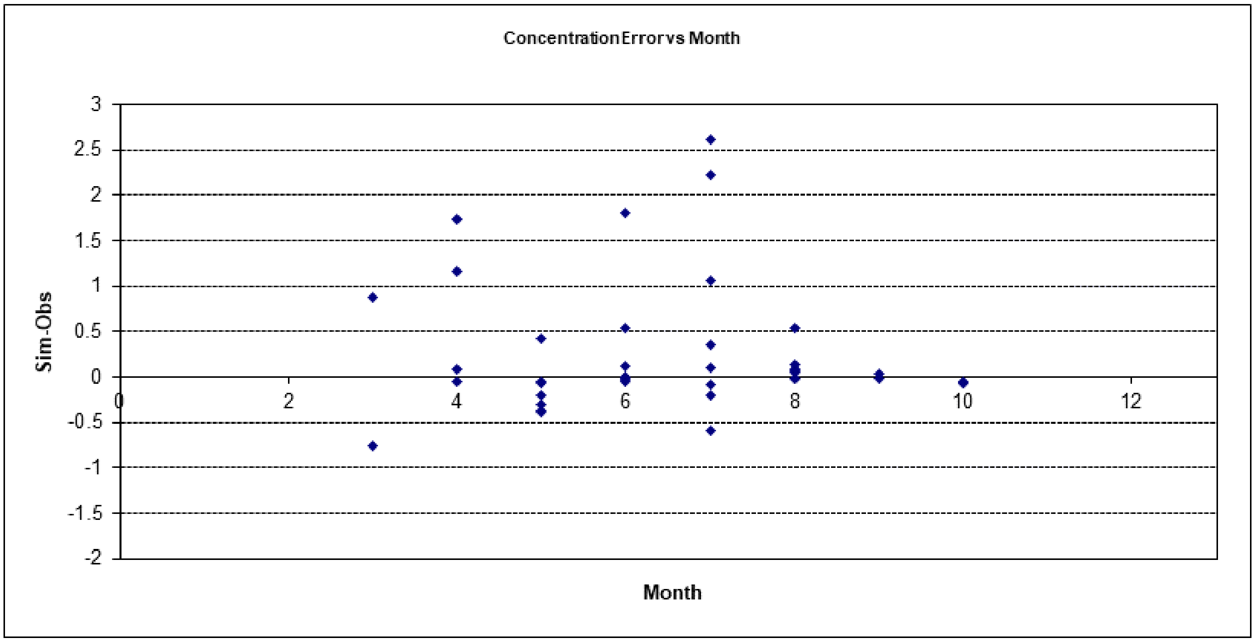


Figure E-732. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Miller Creek nr Lower Gage (multiple stations)

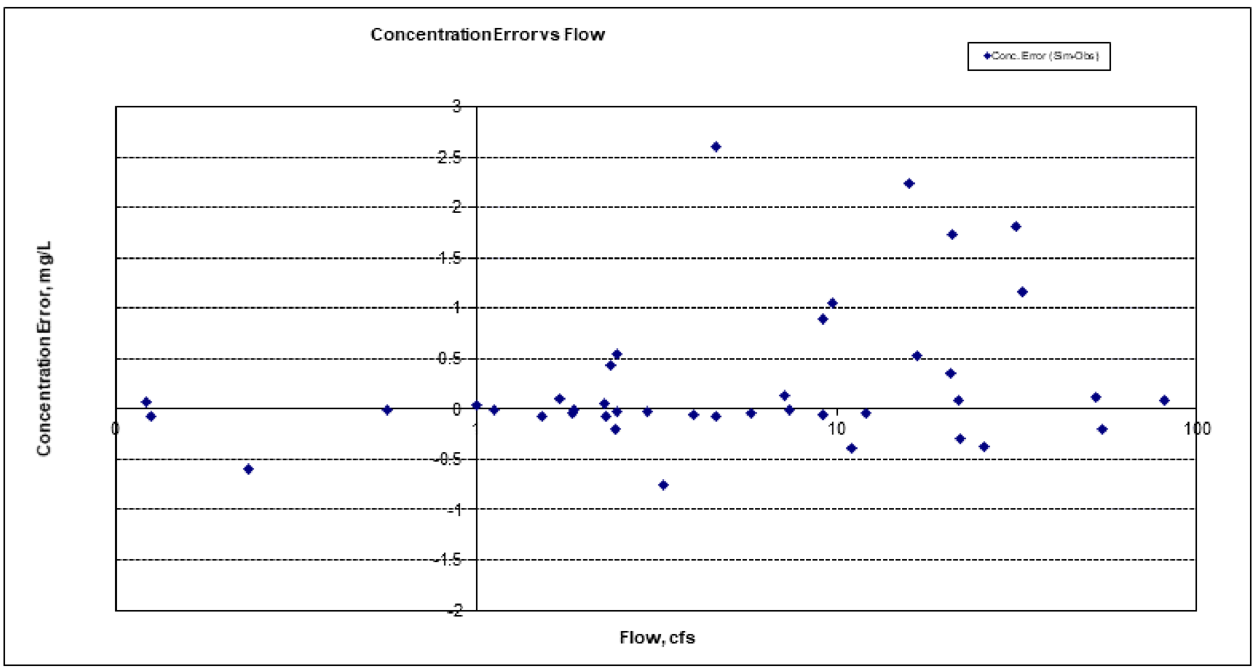


Figure E-733. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Miller Creek nr Lower Gage (multiple stations)

E.15.4 Total Phosphorus (TP)

Table E-92. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	65
Concentration Average Error		-8.35%
Concentration Median Error		-5.53%
Load Average Error		-22.21%
Load Median Error		-0.26%
Paired t conc		0.91
Paired t load		0.46

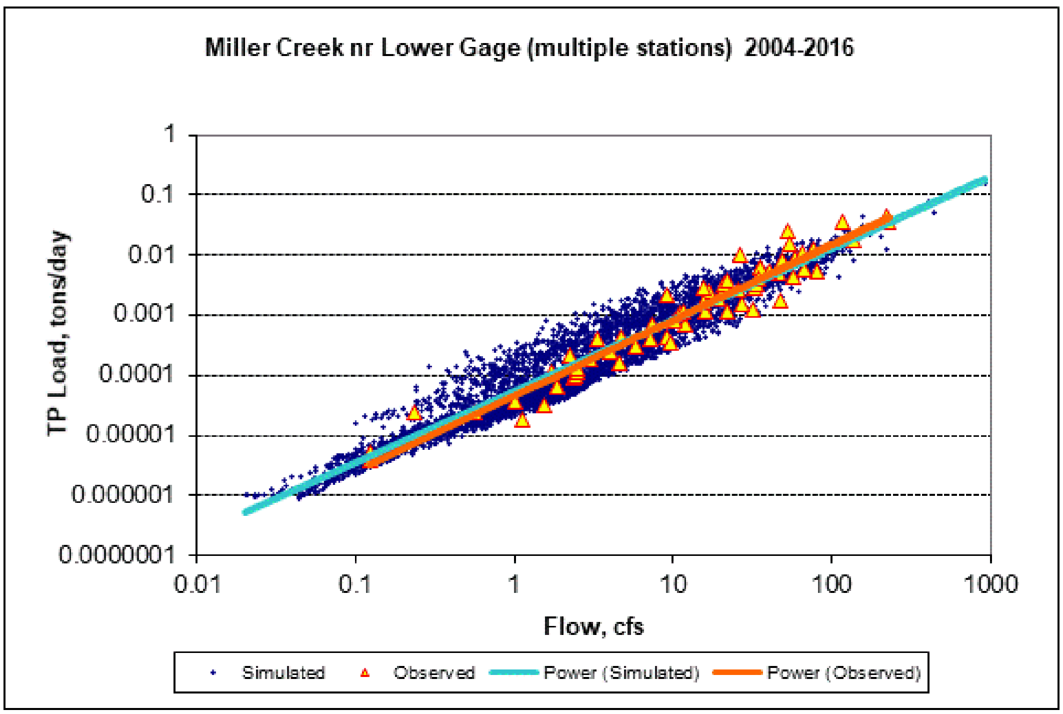


Figure E-734. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Miller Creek nr Lower Gage (multiple stations) (calibration period)

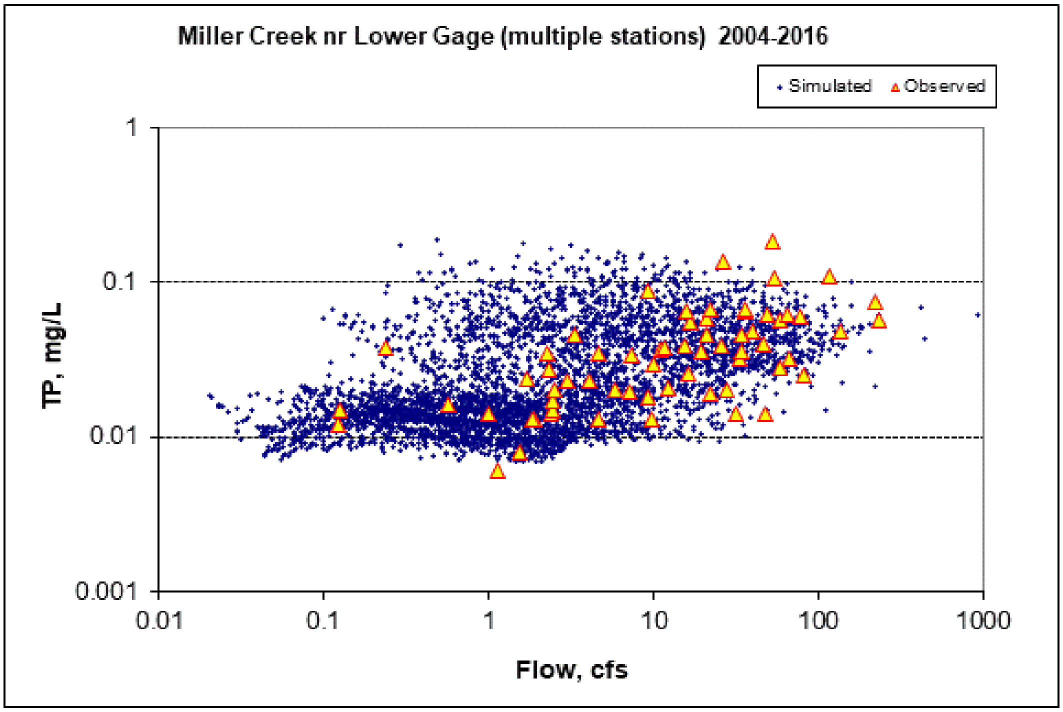
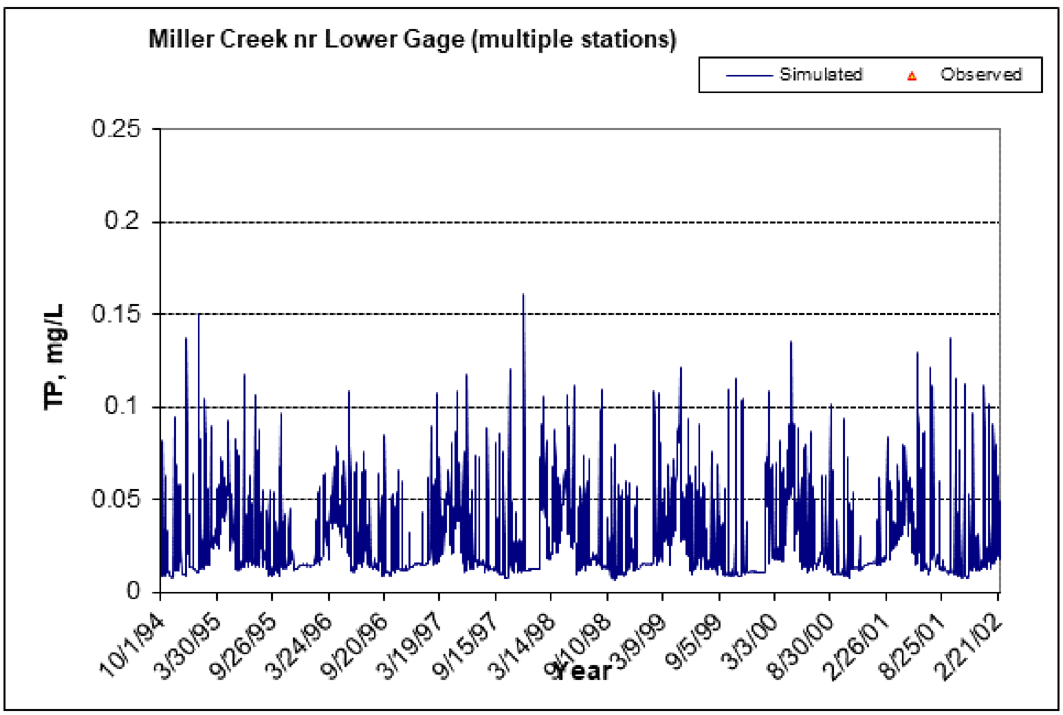


Figure E-735. Simulated and observed Total Phosphorus (TP) concentration vs flow at Miller Creek nr Lower Gage (multiple stations) (calibration period)



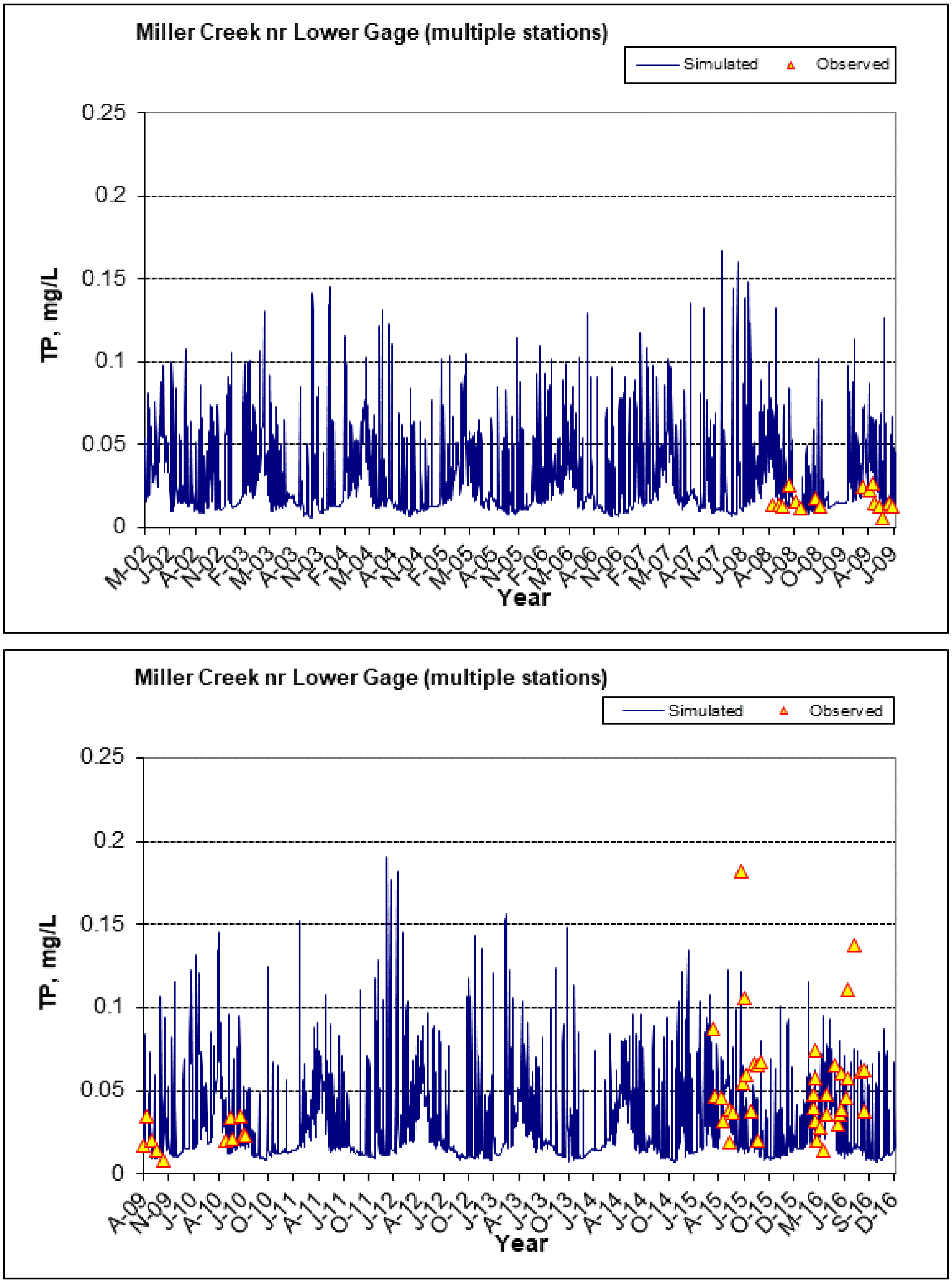


Figure E-736. Time series of observed and simulated Total Phosphorus (TP) concentration at Miller Creek nr Lower Gage (multiple stations)

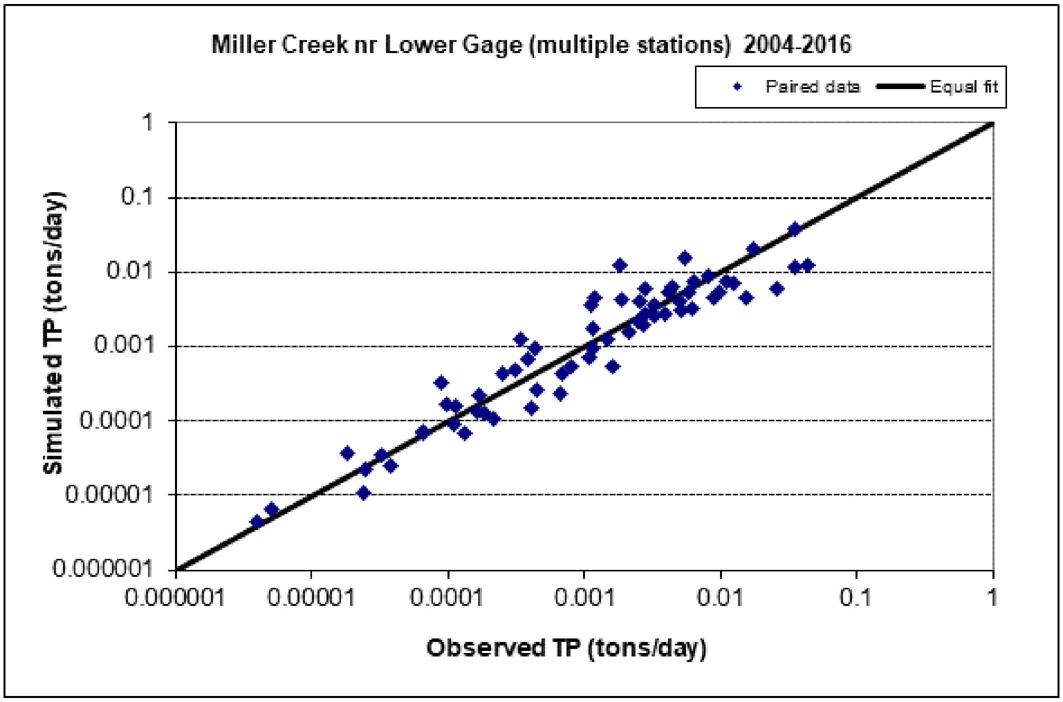


Figure E-737. Paired simulated vs. observed Total Phosphorus (TP) load at Miller Creek nr Lower Gage (multiple stations) (calibration period)

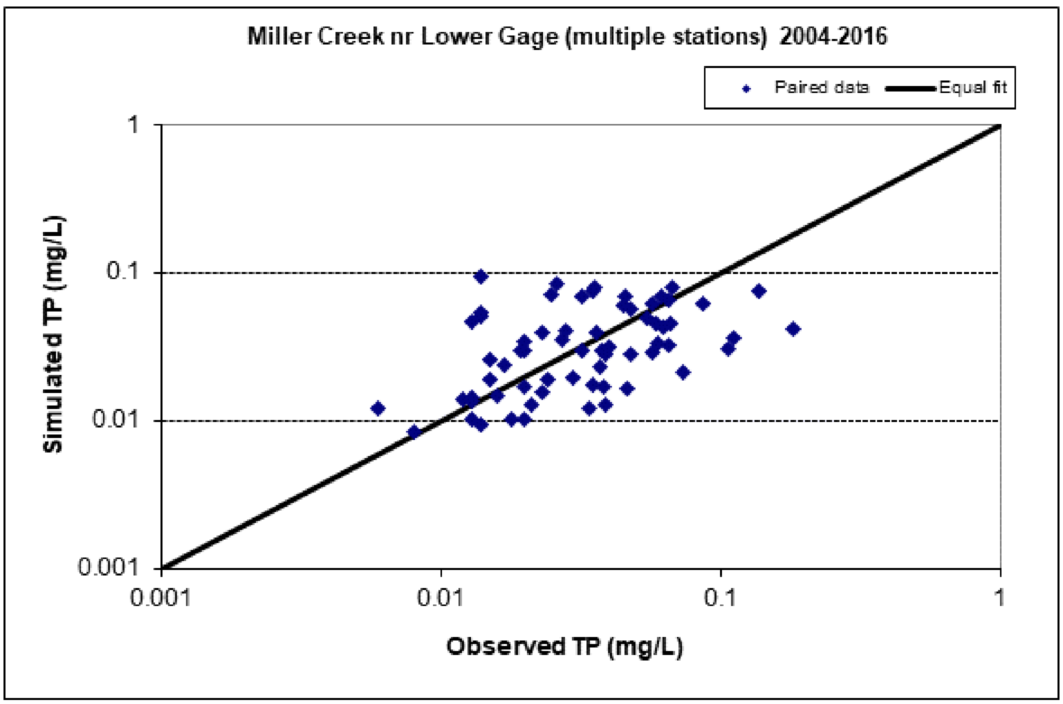


Figure E-738. Paired simulated vs. observed Total Phosphorus (TP) concentration at Miller Creek nr Lower Gage (multiple stations) (calibration period)

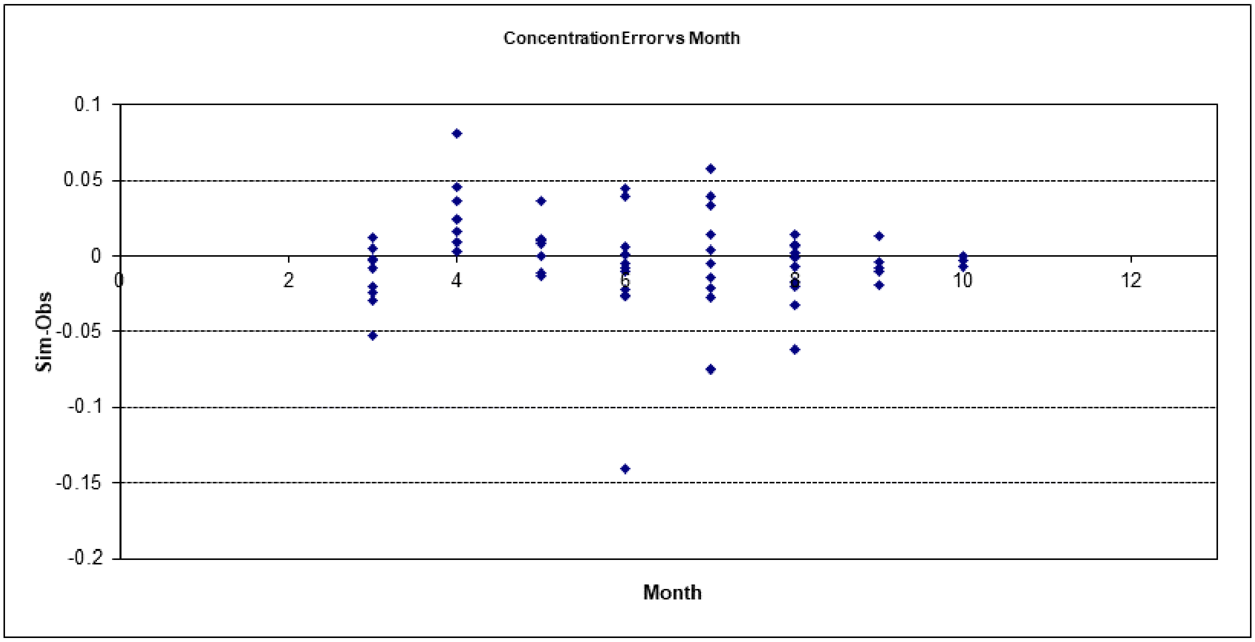


Figure E-739. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Miller Creek nr Lower Gage (multiple stations)

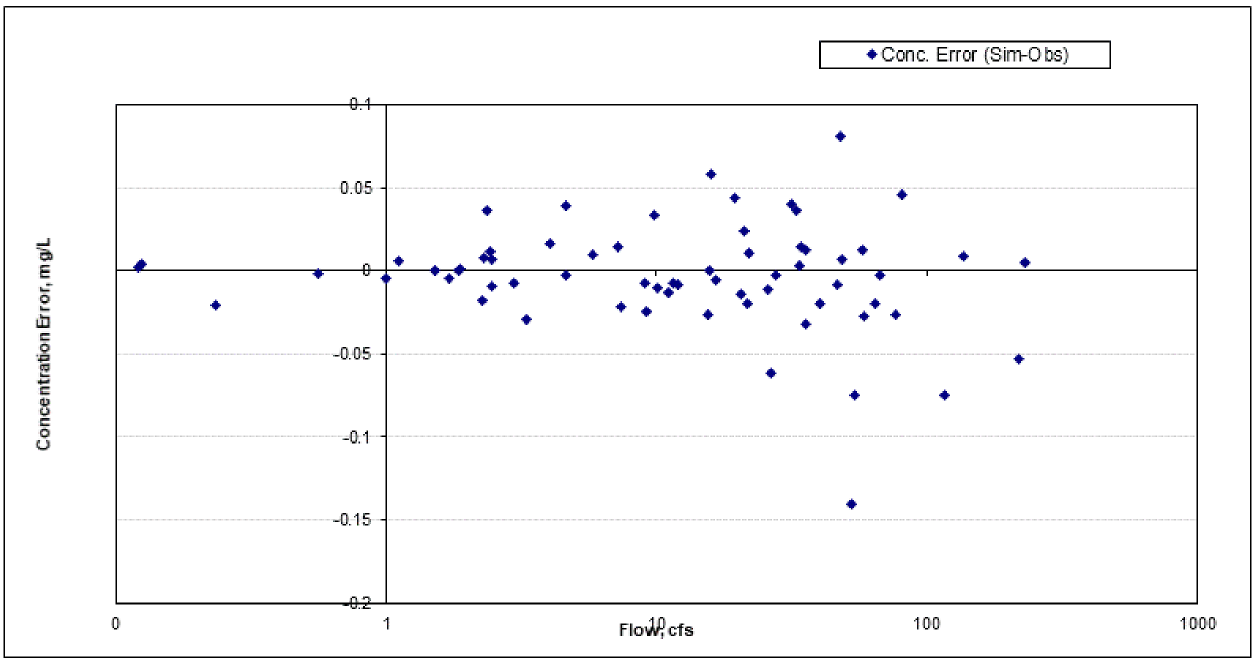


Figure E-740. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Miller Creek nr Lower Gage (multiple stations)

E.16 Merritt Creek at Grand Ave

E.16.1 Dissolved Oxygen (DO)

Table E-93. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	59
Concentration Average Error		5.17%
Concentration Median Error		4.08%
Load Average Error		1.18%
Load Median Error		1.03%
Paired t conc		1.00
Paired t load		0.82

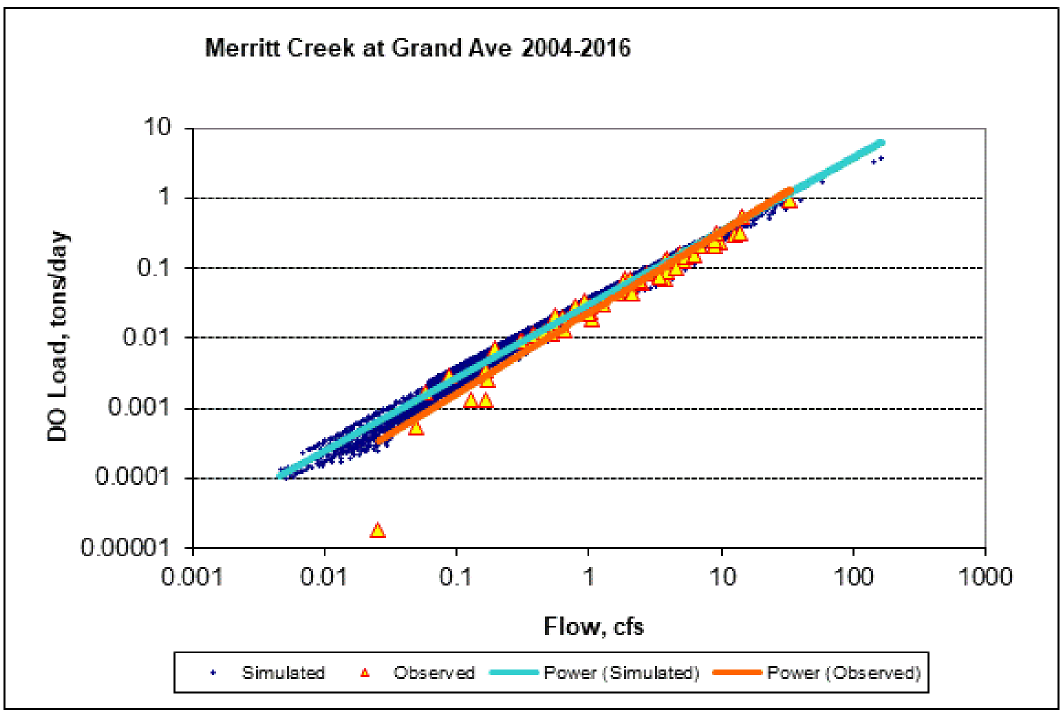


Figure E-741. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Merritt Creek at Grand Ave (calibration period)

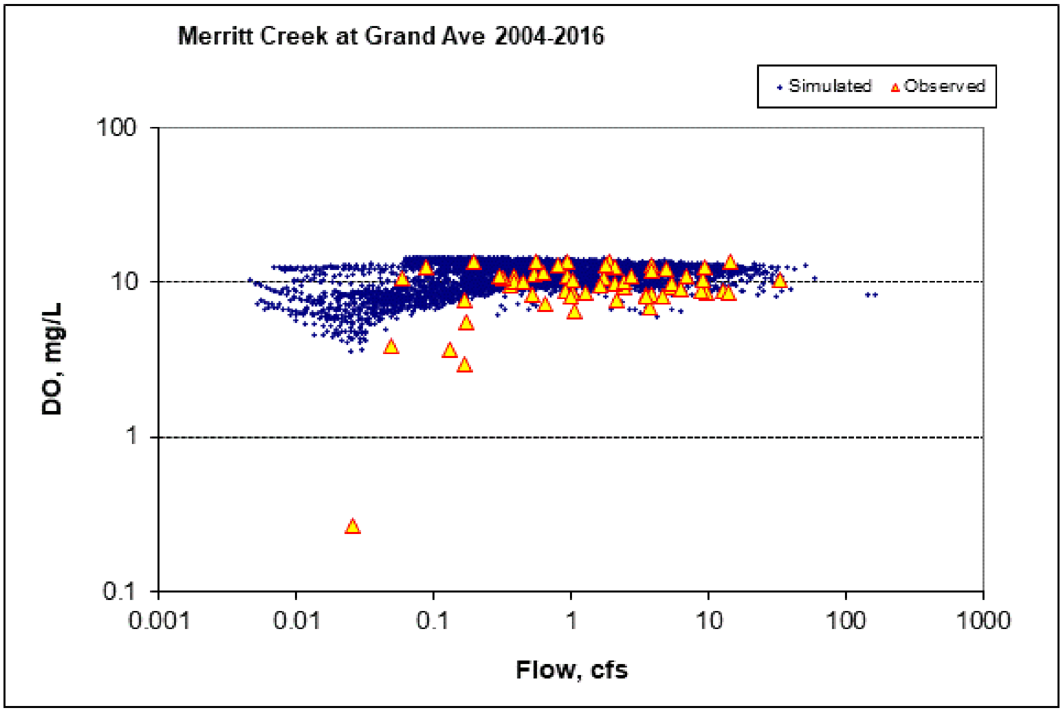
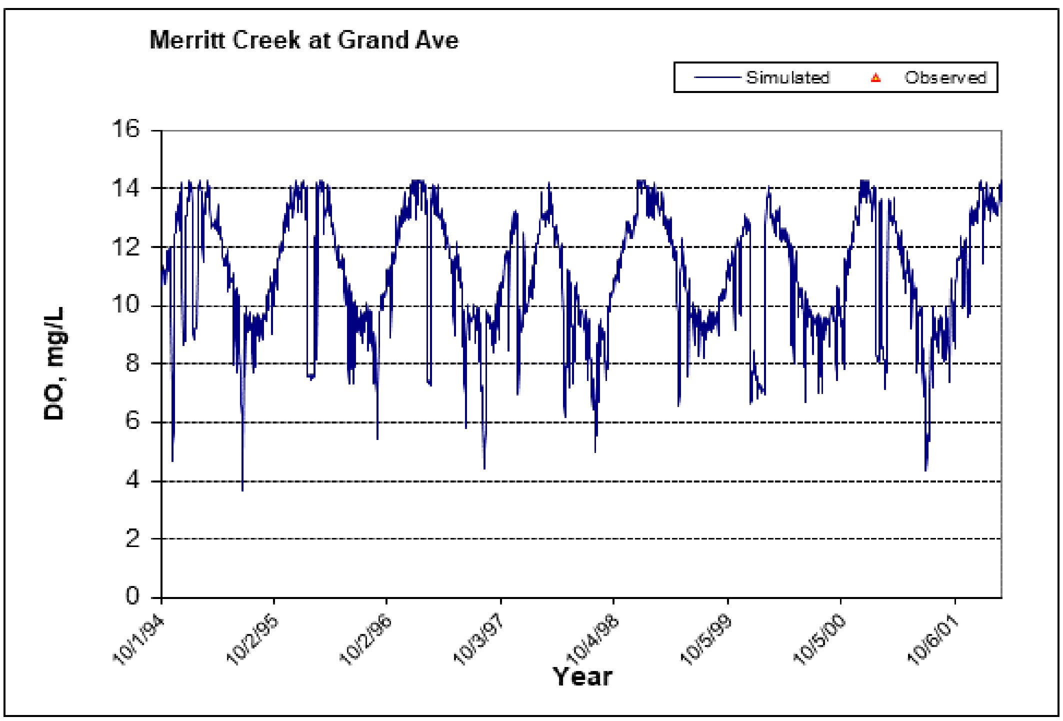
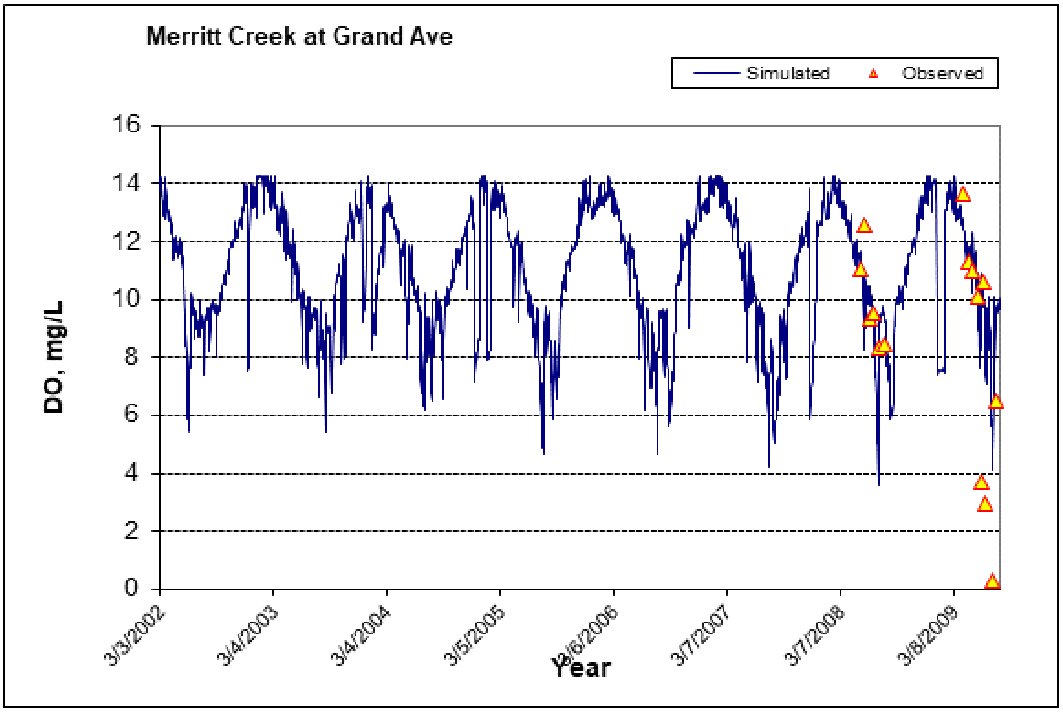


Figure E-742. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Merritt Creek at Grand Ave (calibration period)





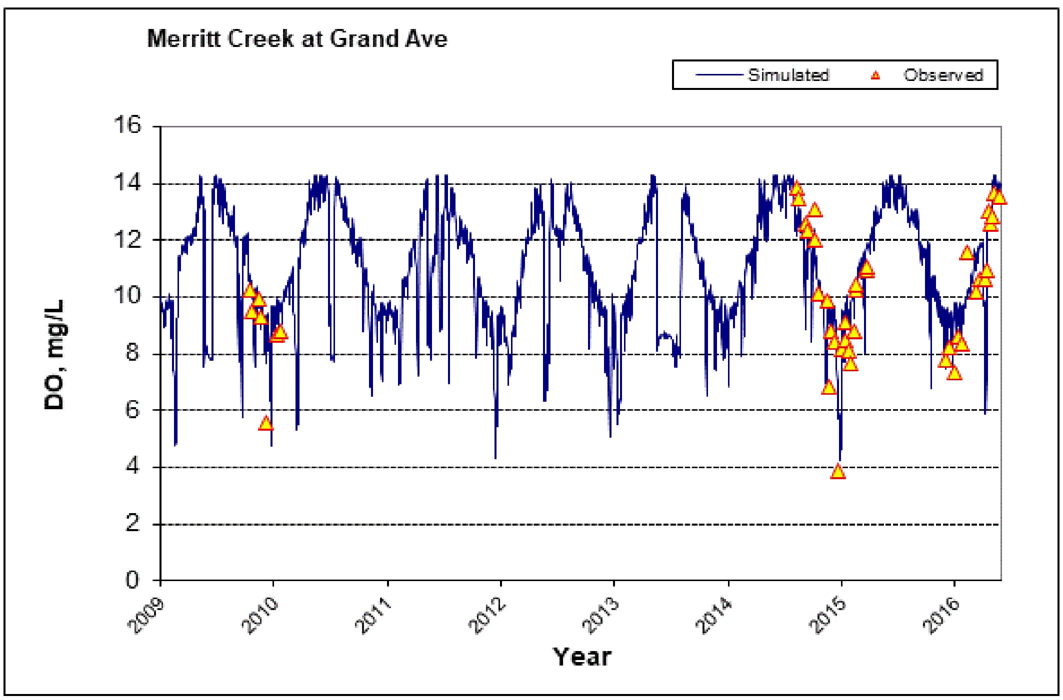


Figure E-743. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Merritt Creek at Grand Ave

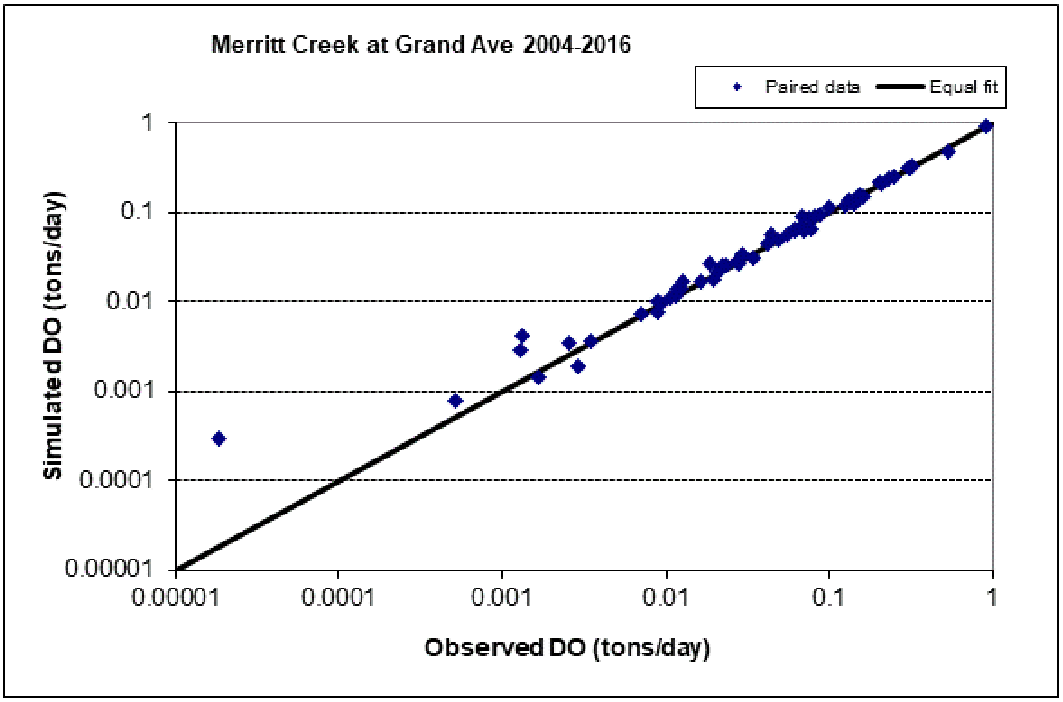


Figure E-744. Paired simulated vs. observed Dissolved Oxygen (DO) load at Merritt Creek at Grand Ave (calibration period)

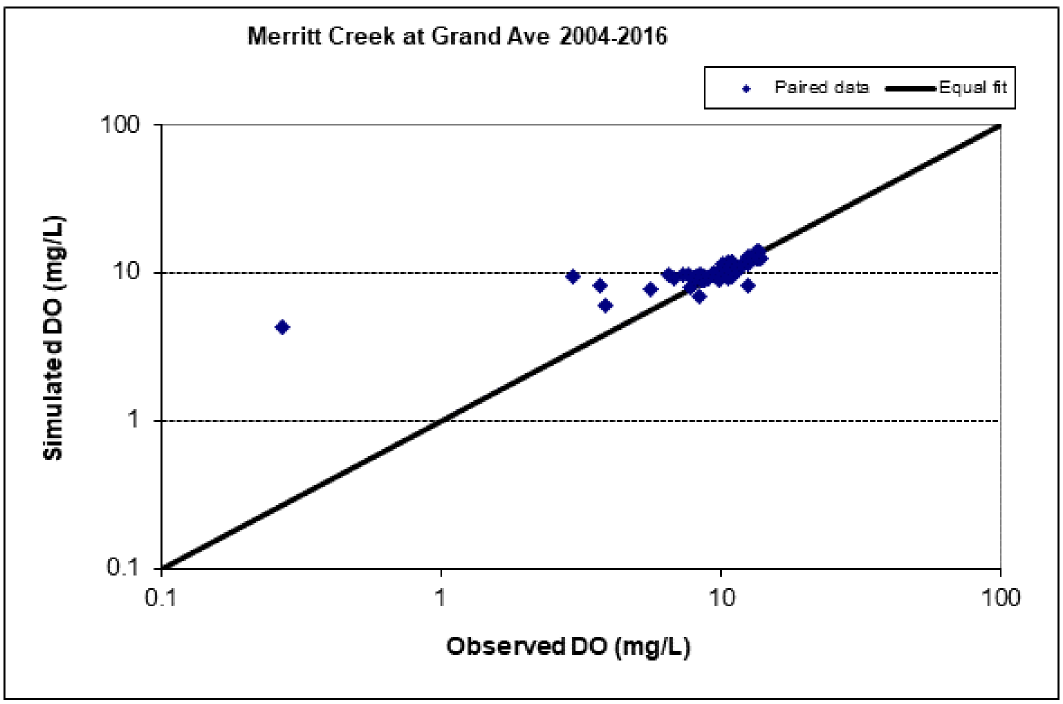


Figure E-745. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Merritt Creek at Grand Ave (calibration period)

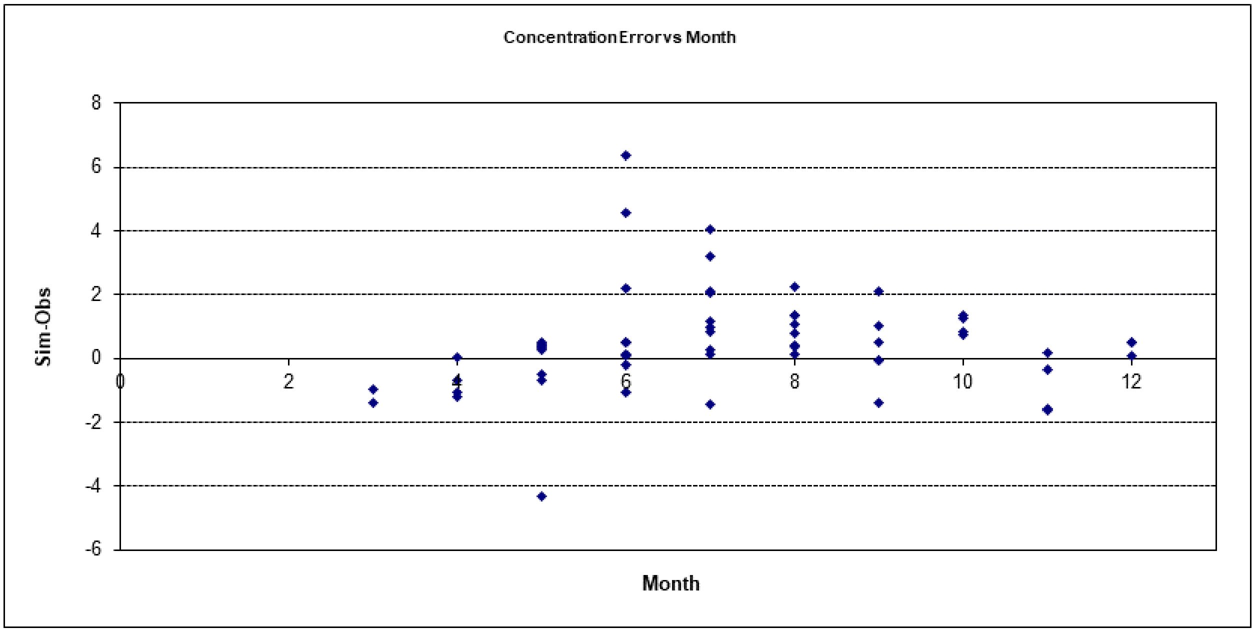


Figure E-746. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Merritt Creek at Grand Ave

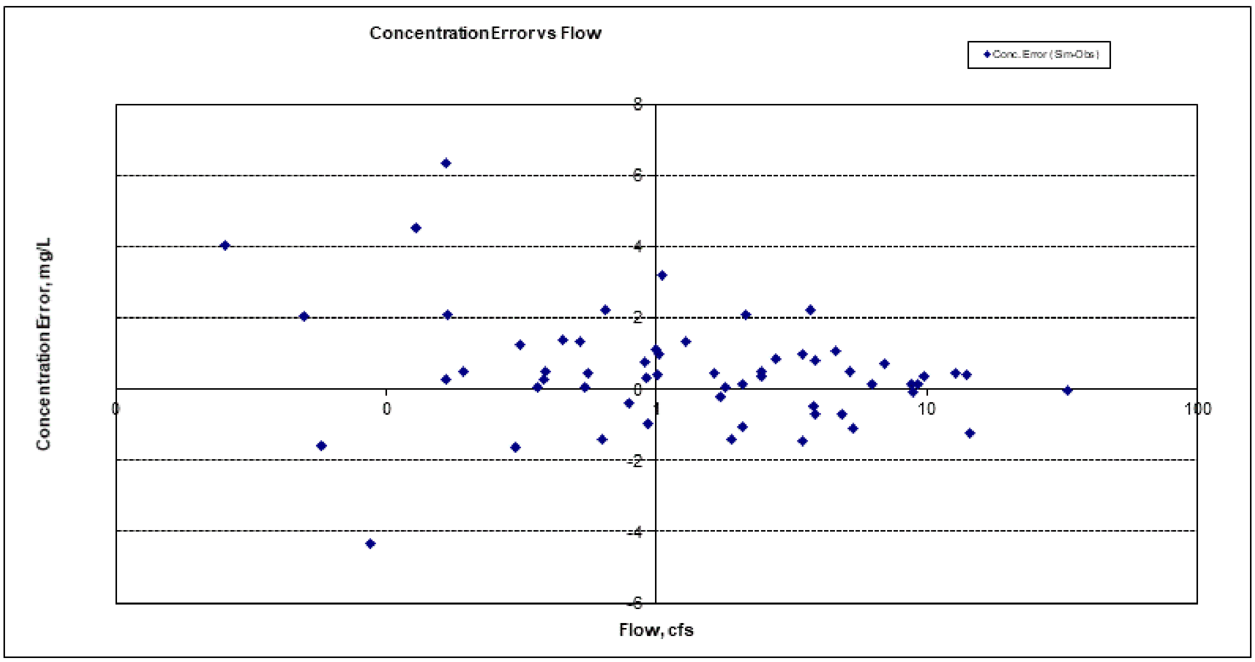


Figure E-747. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Merritt Creek at Grand Ave

E.16.2 Ammonia Nitrogen (NH3)

Table E-94. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	34
Concentration Average Error		-59.91%
Concentration Median Error		-17.16%
Load Average Error		-22.90%
Load Median Error		-3.71%
Paired t conc		0.05
Paired t load		0.48

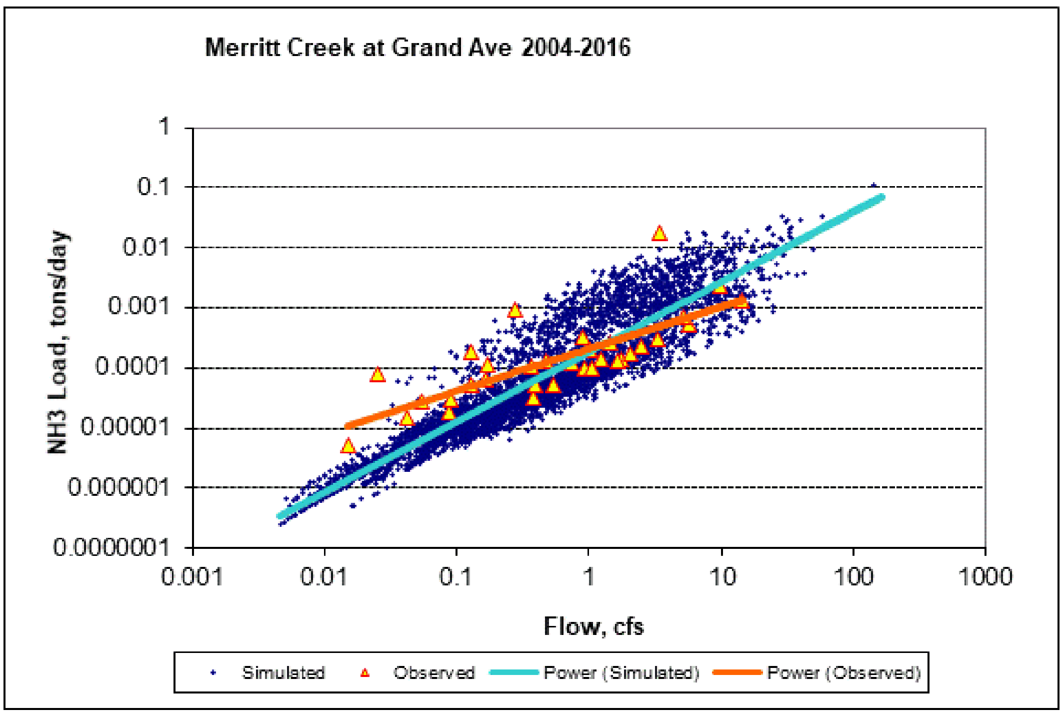


Figure E-748. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Merritt Creek at Grand Ave (calibration period)

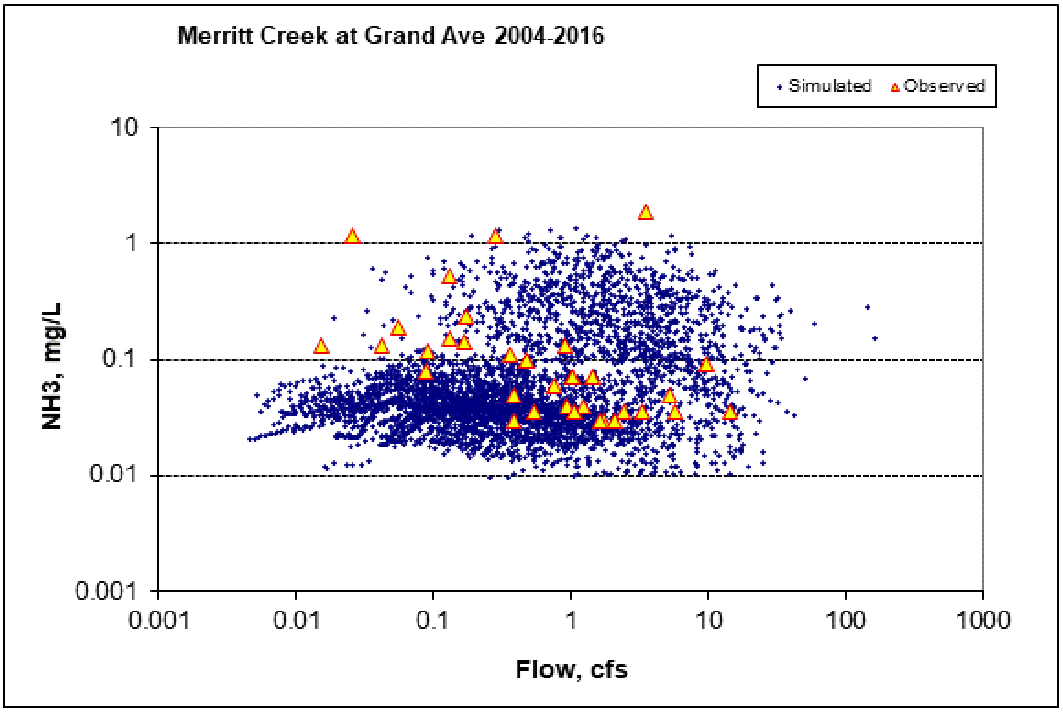
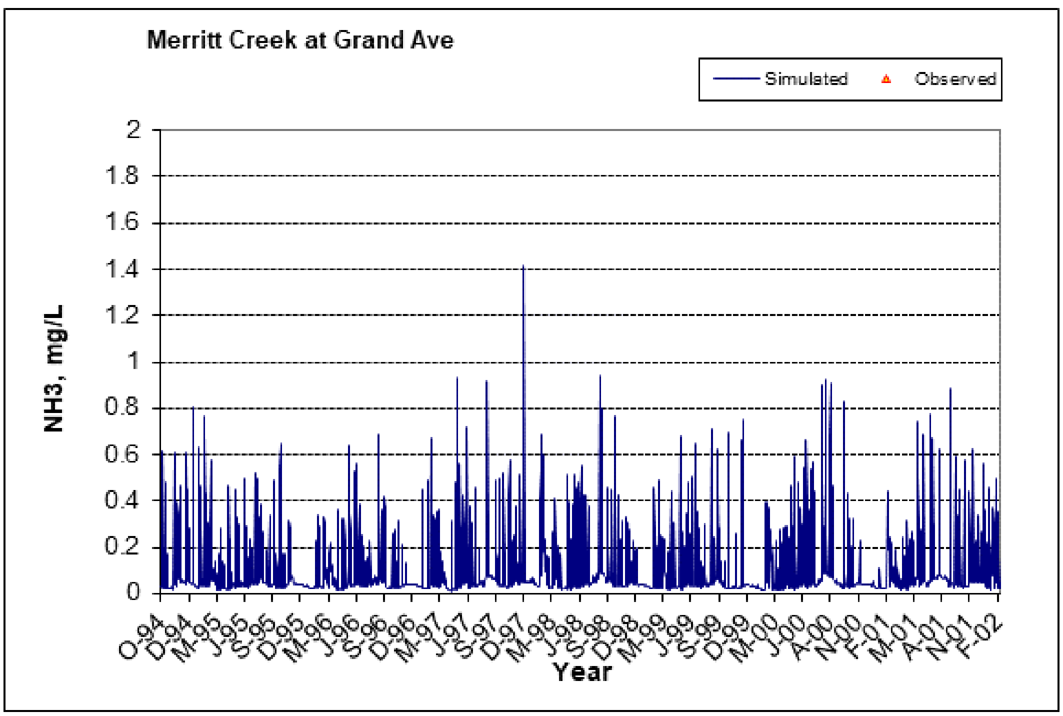


Figure E-749. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Merritt Creek at Grand Ave (calibration period)



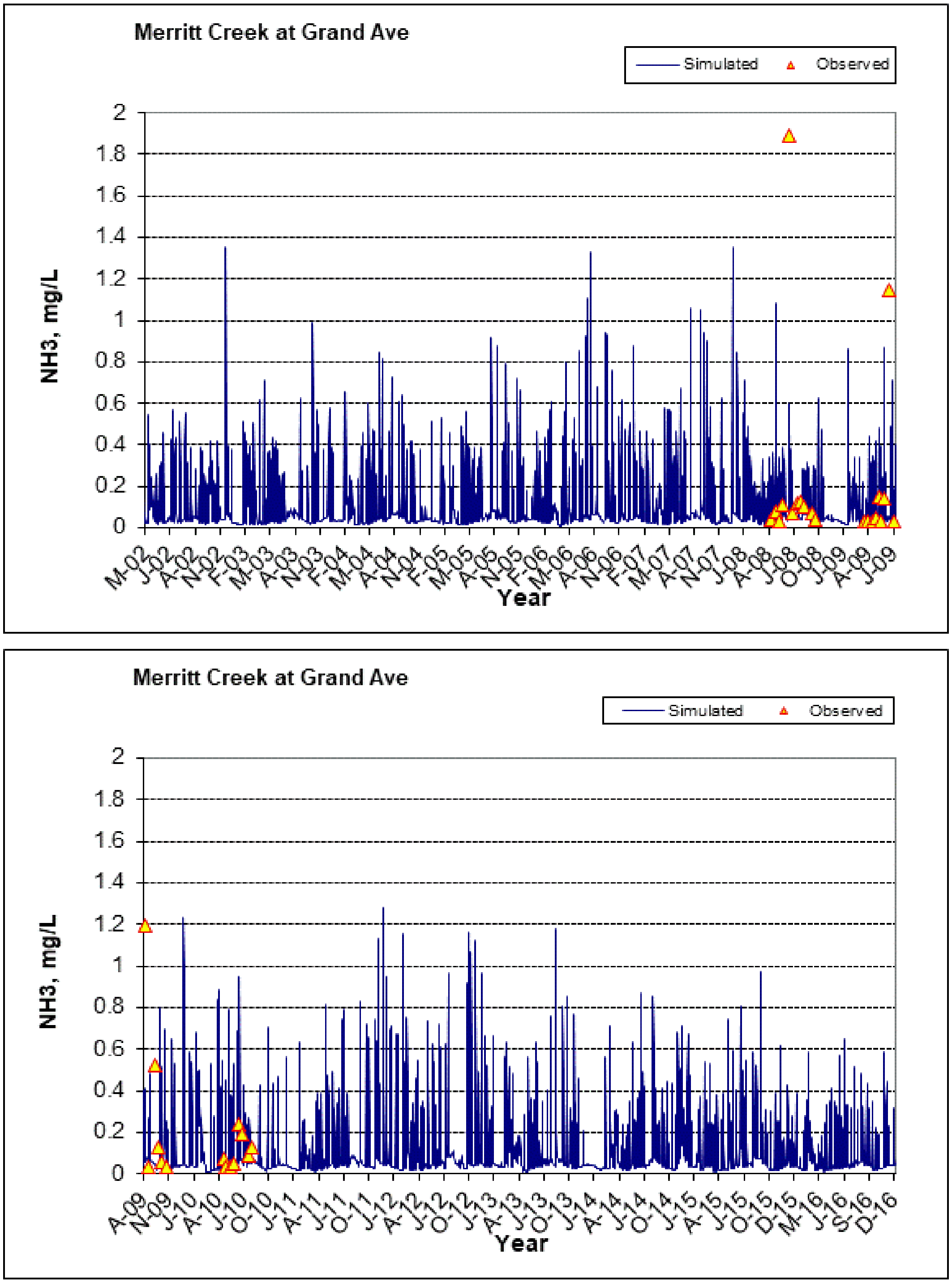


Figure E-750. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Merritt Creek at Grand Ave

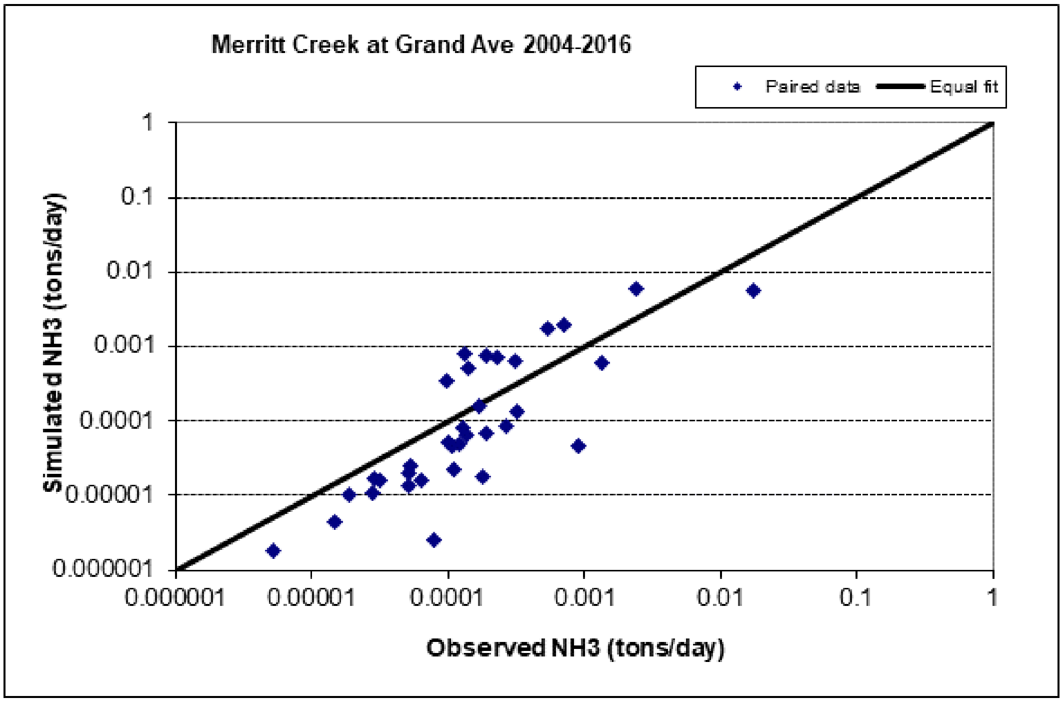


Figure E-751. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Merritt Creek at Grand Ave (calibration period)

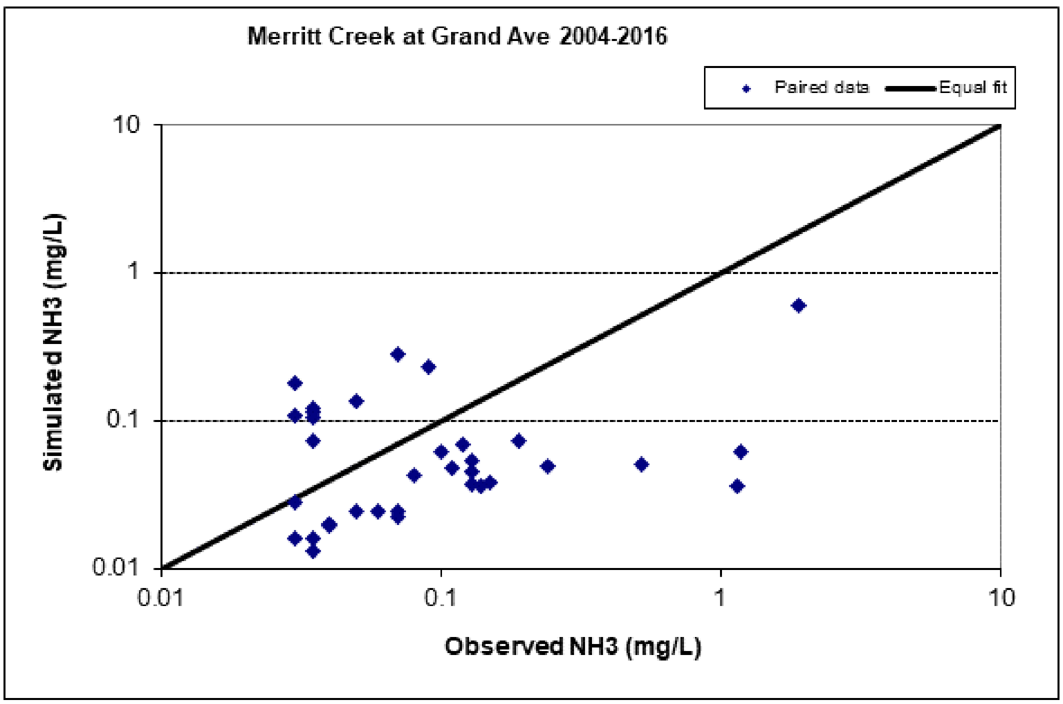


Figure E-752. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Merritt Creek at Grand Ave (calibration period)

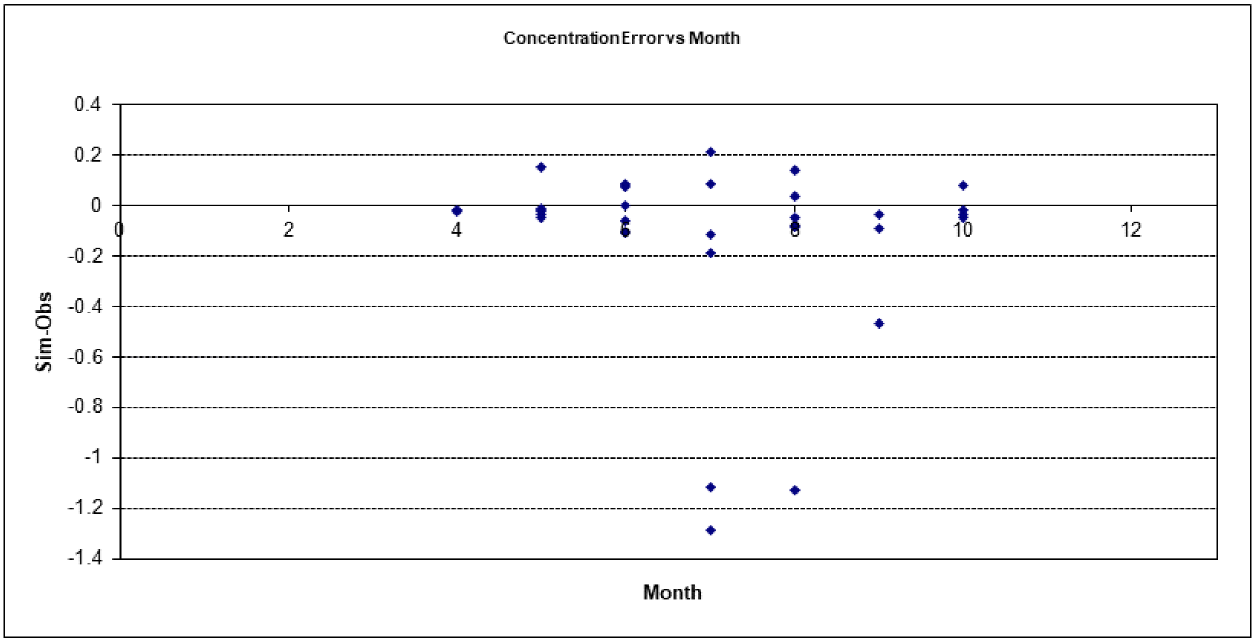


Figure E-753. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Merritt Creek at Grand Ave

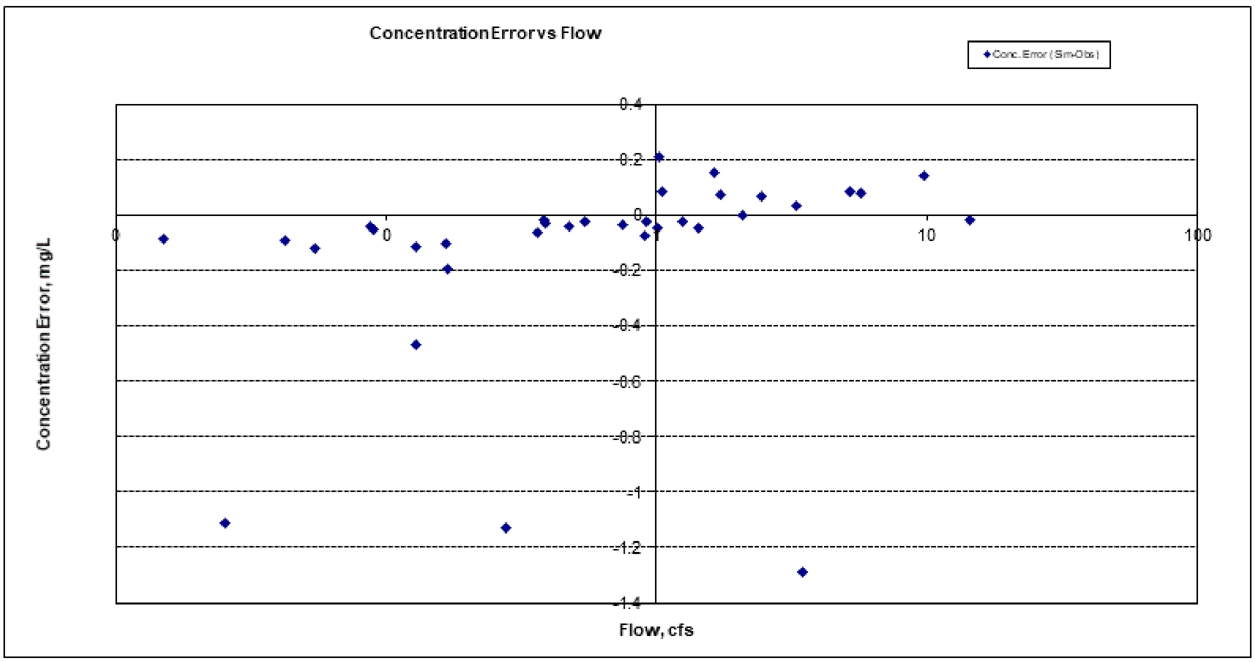


Figure E-754. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Merritt Creek at Grand Ave

E.16.3 Nitrite+ Nitrate Nitrogen (NOx)

Table E-95. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	48
Concentration Average Error		-25.62%
Concentration Median Error		-12.78%
Load Average Error		-18.03%
Load Median Error		-1.50%
Paired t conc		0.37
Paired t load		0.54

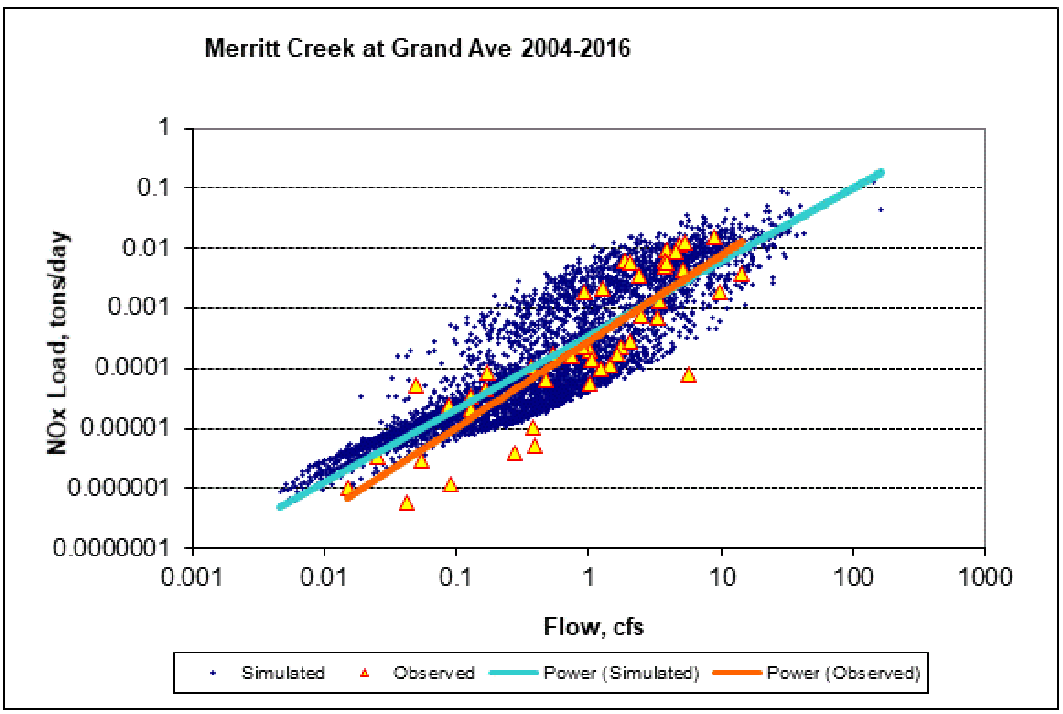


Figure E-755. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Merritt Creek at Grand Ave (calibration period)

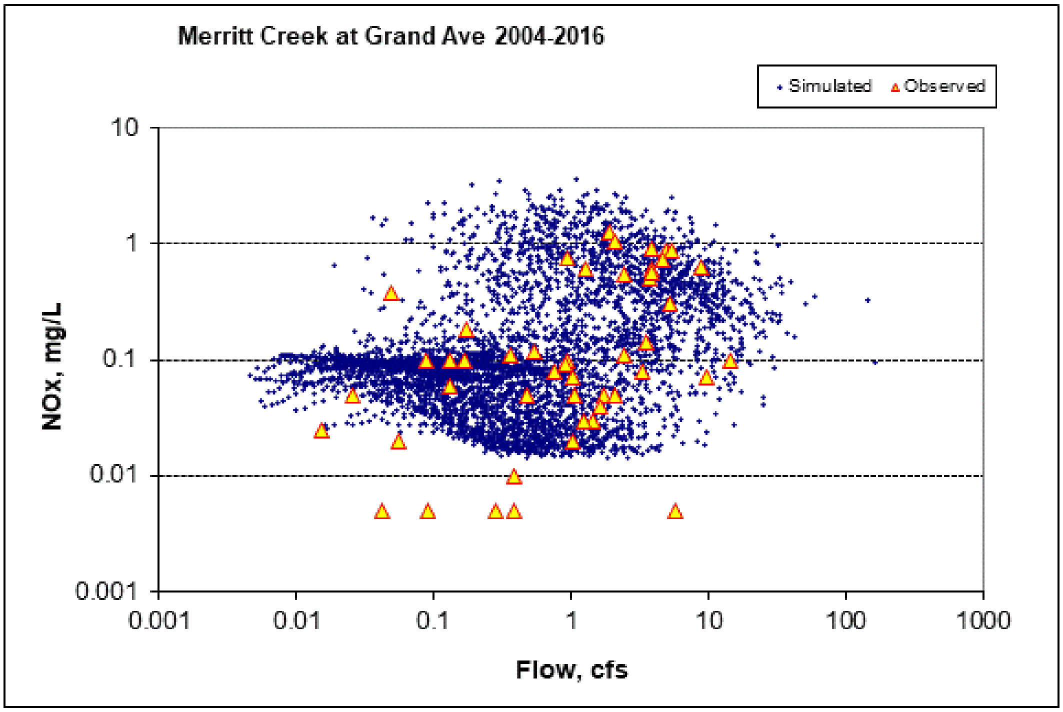
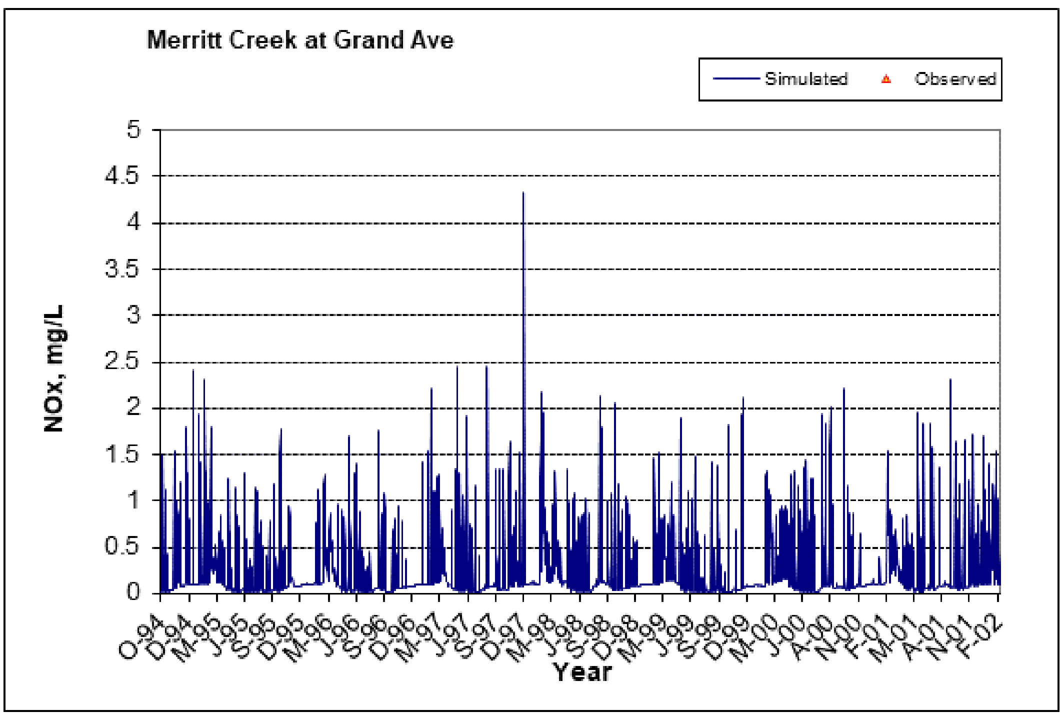
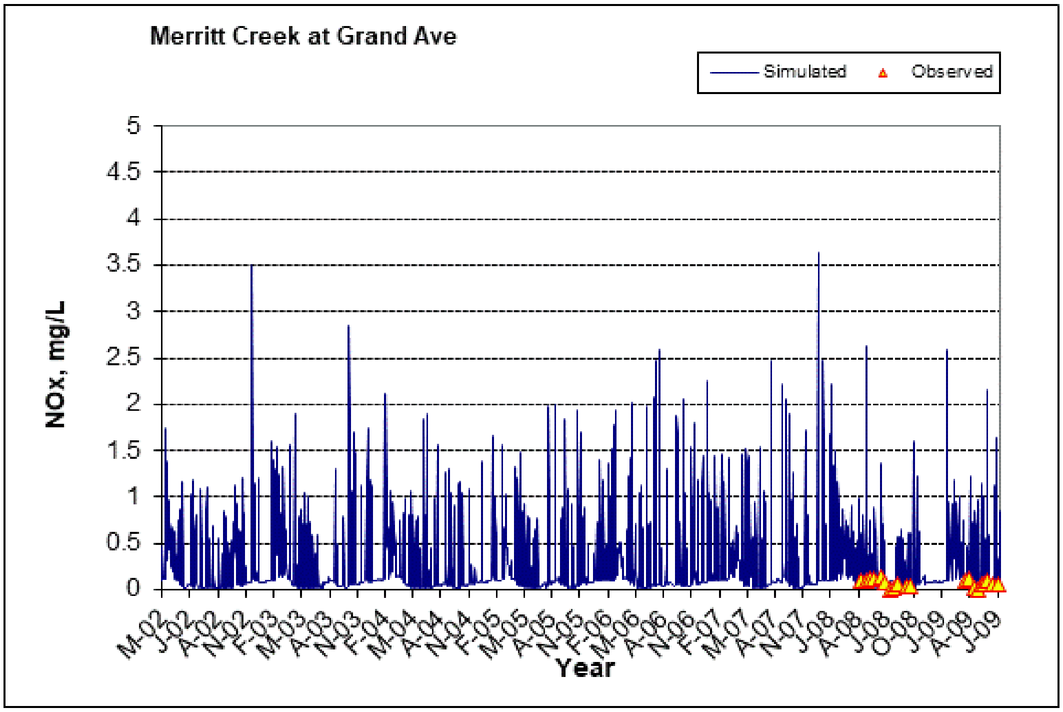


Figure E-756. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Merritt Creek at Grand Ave (calibration period)





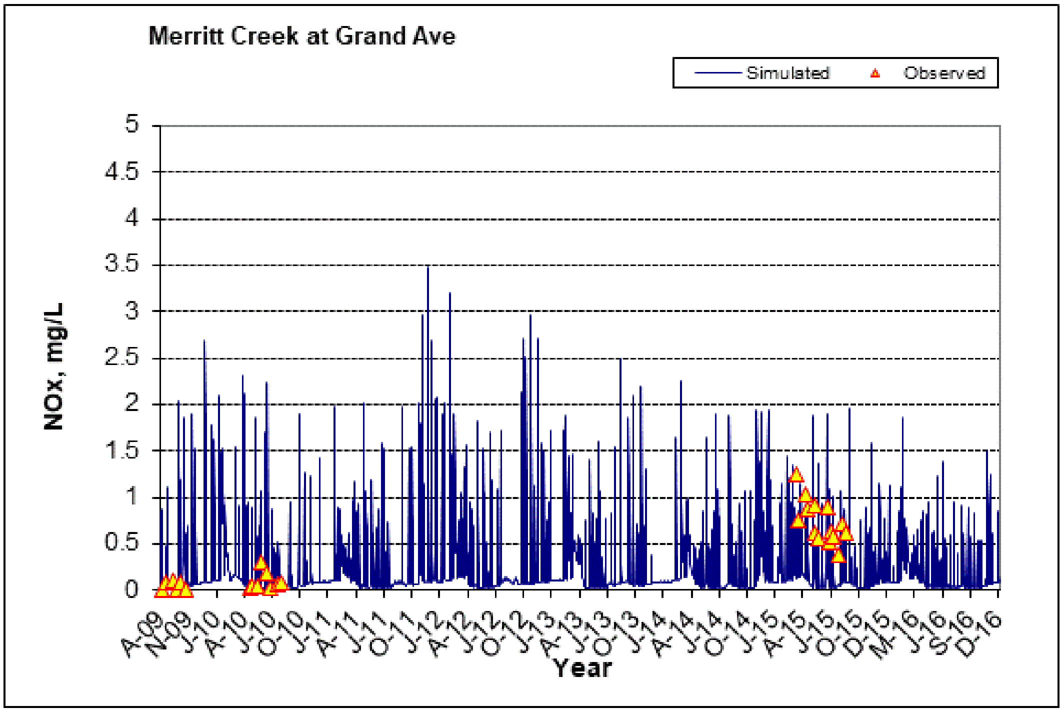


Figure E-757. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Merritt Creek at Grand Ave

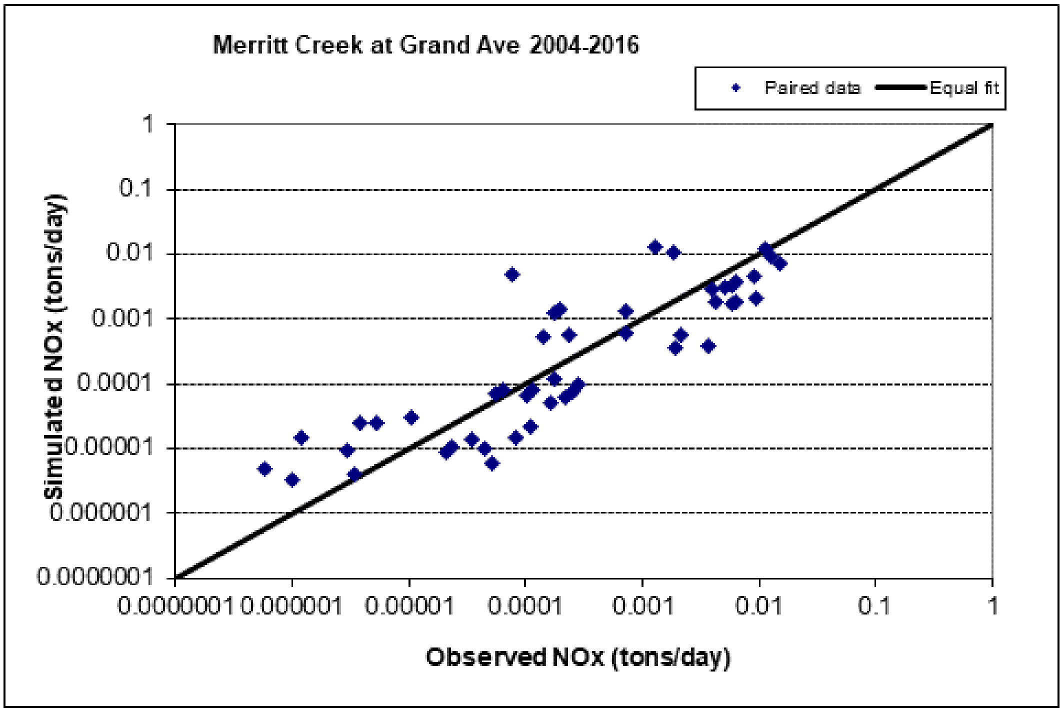


Figure E-758. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Merritt Creek at Grand Ave (calibration period)

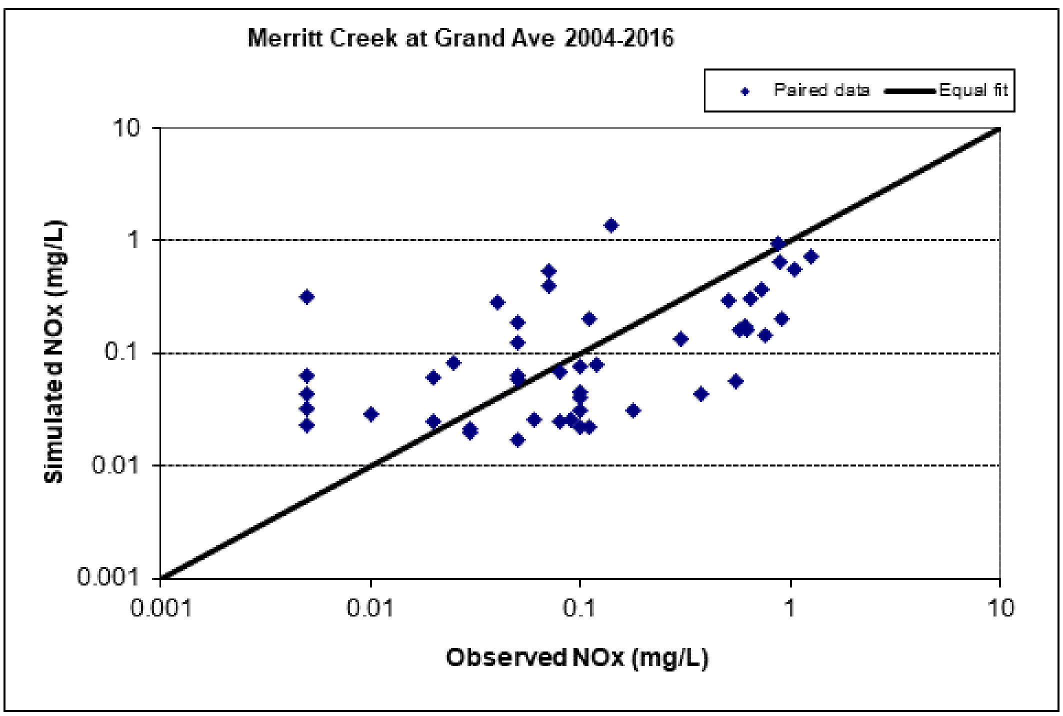


Figure E-759. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Merritt Creek at Grand Ave (calibration period)

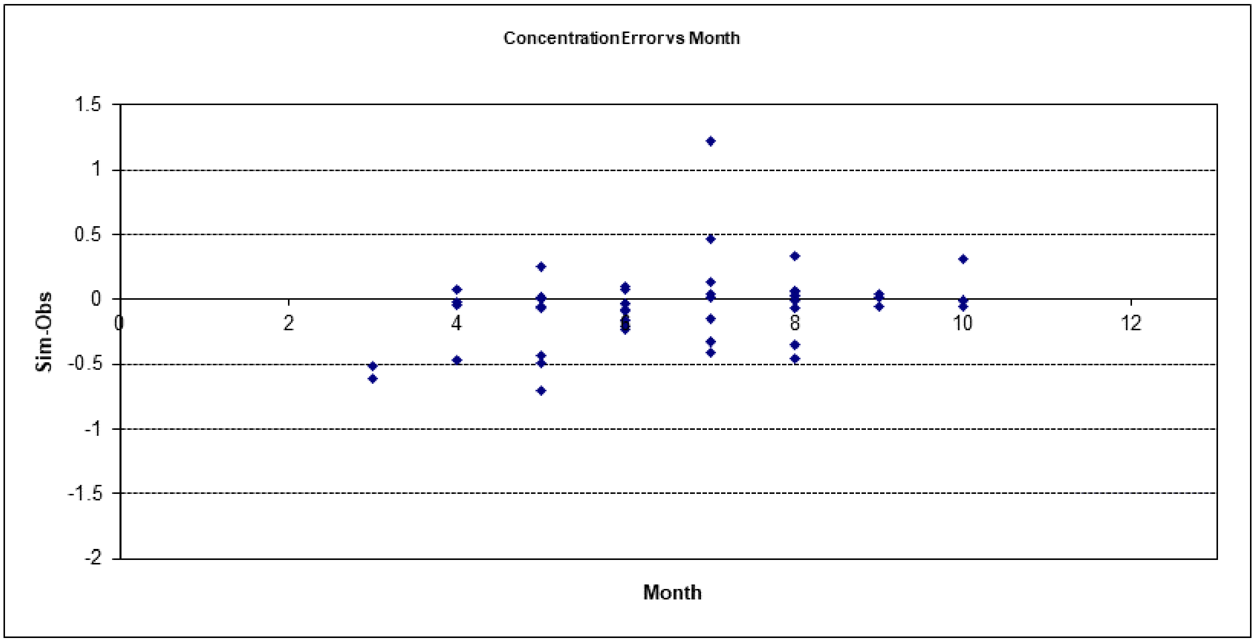


Figure E-760. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Merritt Creek at Grand Ave

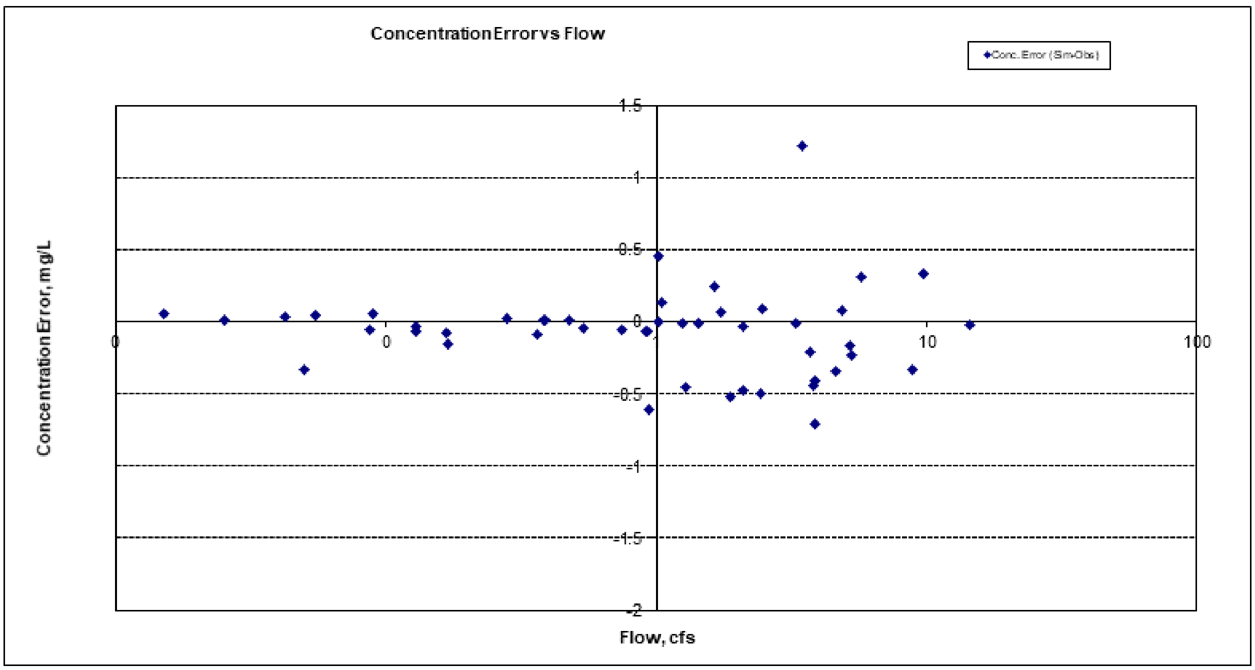


Figure E-761. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Merritt Creek at Grand Ave

E.16.4 Total Phosphorus (TP)

Table E-96. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	72
Concentration Average Error		-16.79%
Concentration Median Error		1.32%
Load Average Error		-17.87%
Load Median Error		0.03%
Paired t conc		0.64
Paired t load		0.53

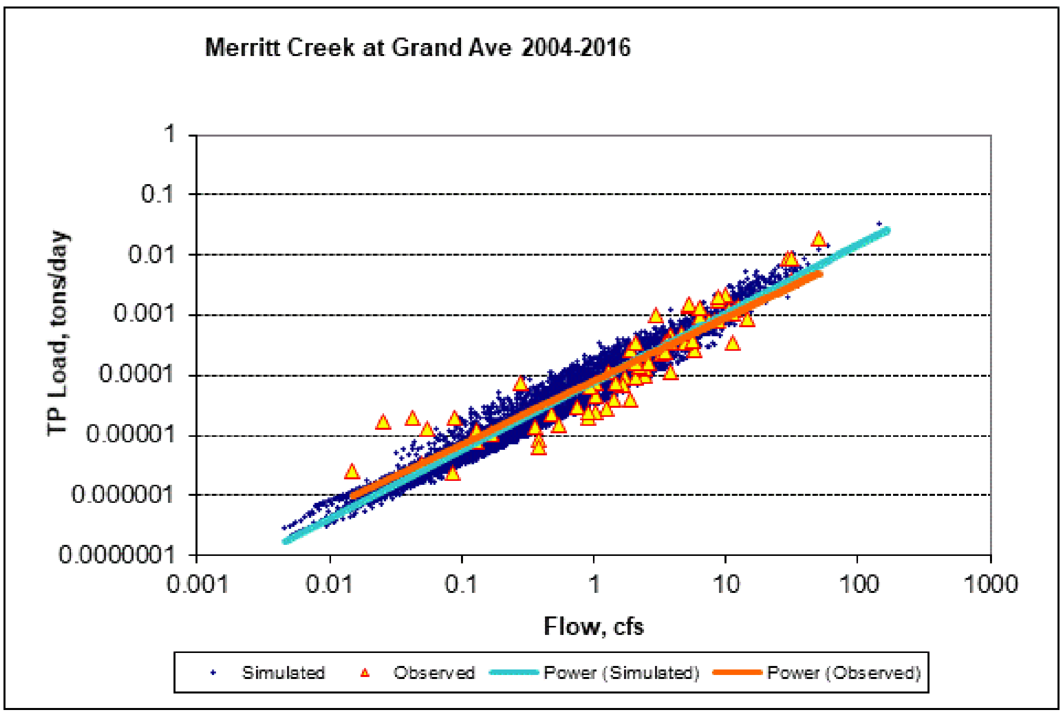


Figure E-762. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Merritt Creek at Grand Ave (calibration period)

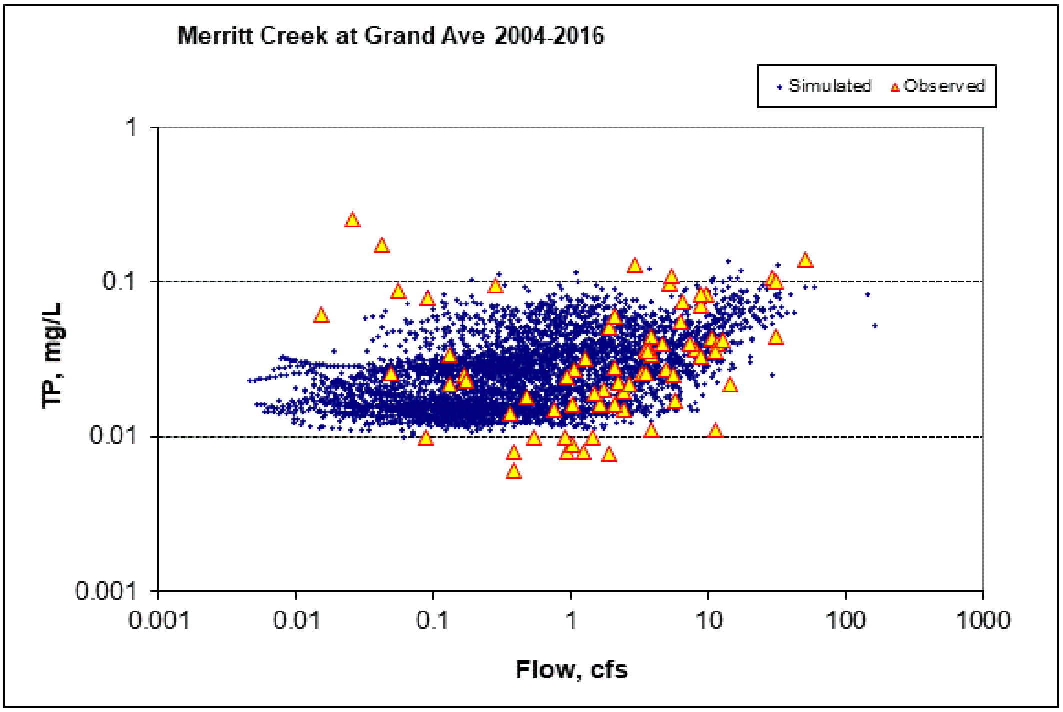
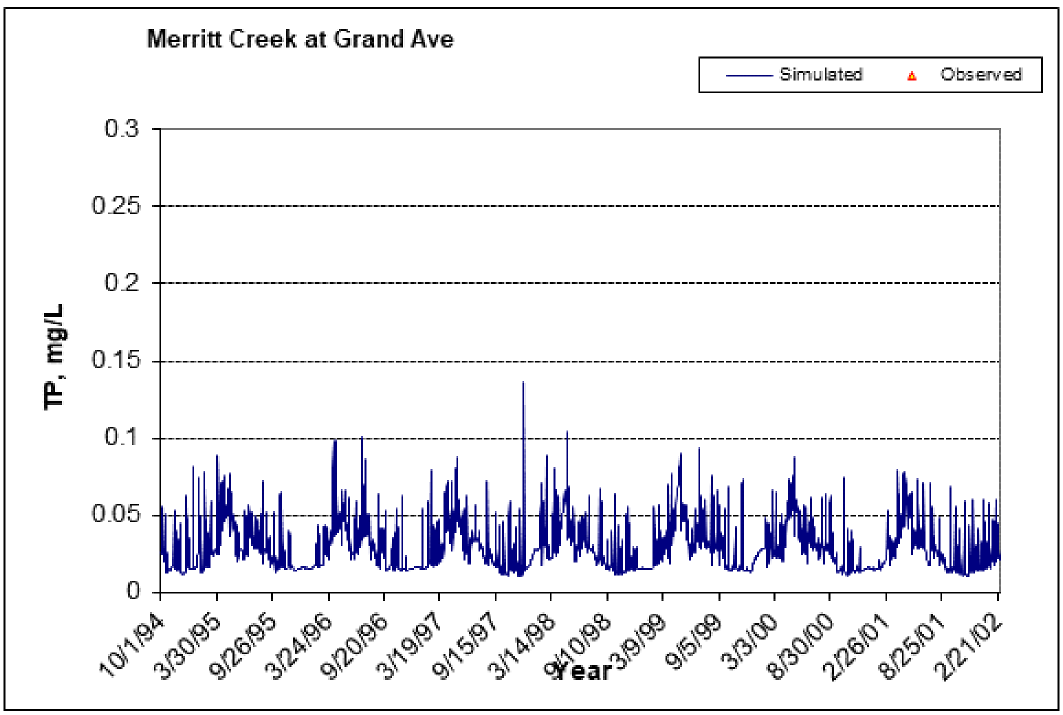
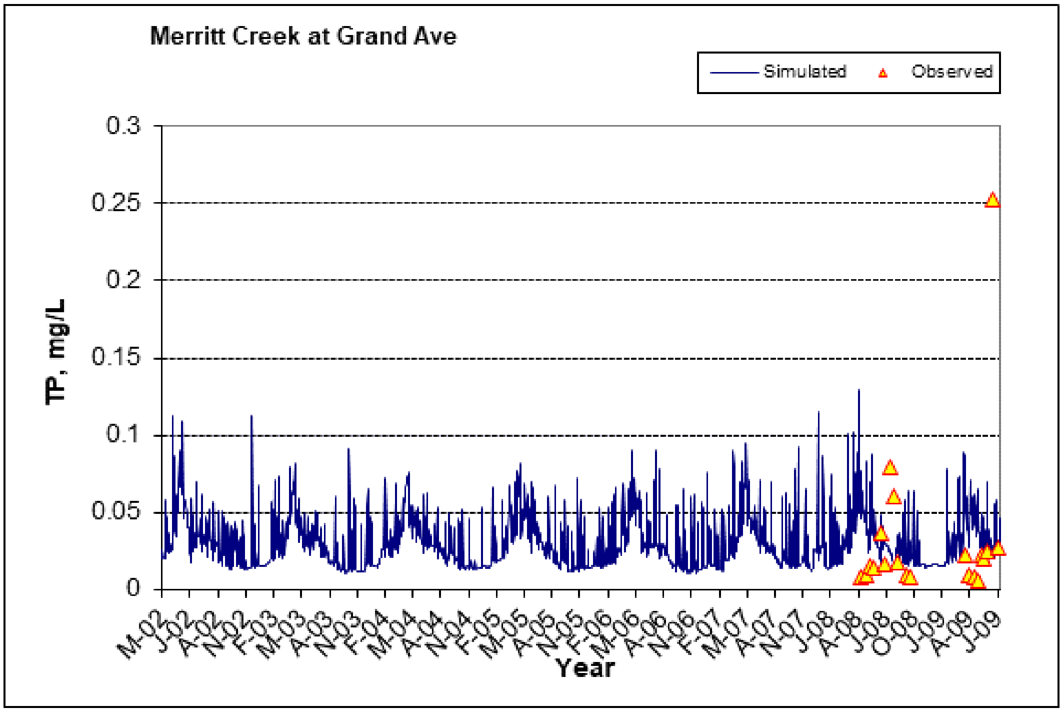


Figure E-763. Simulated and observed Total Phosphorus (TP) concentration vs flow at Merritt Creek at Grand Ave (calibration period)





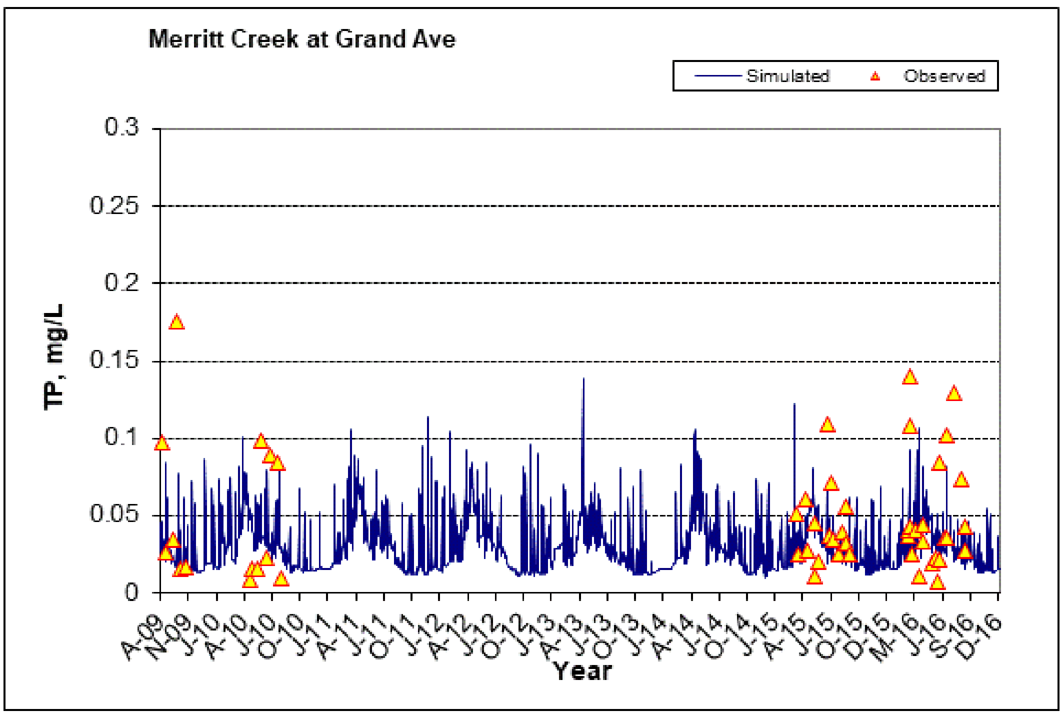


Figure E-764. Time series of observed and simulated Total Phosphorus (TP) concentration at Merritt Creek at Grand Ave

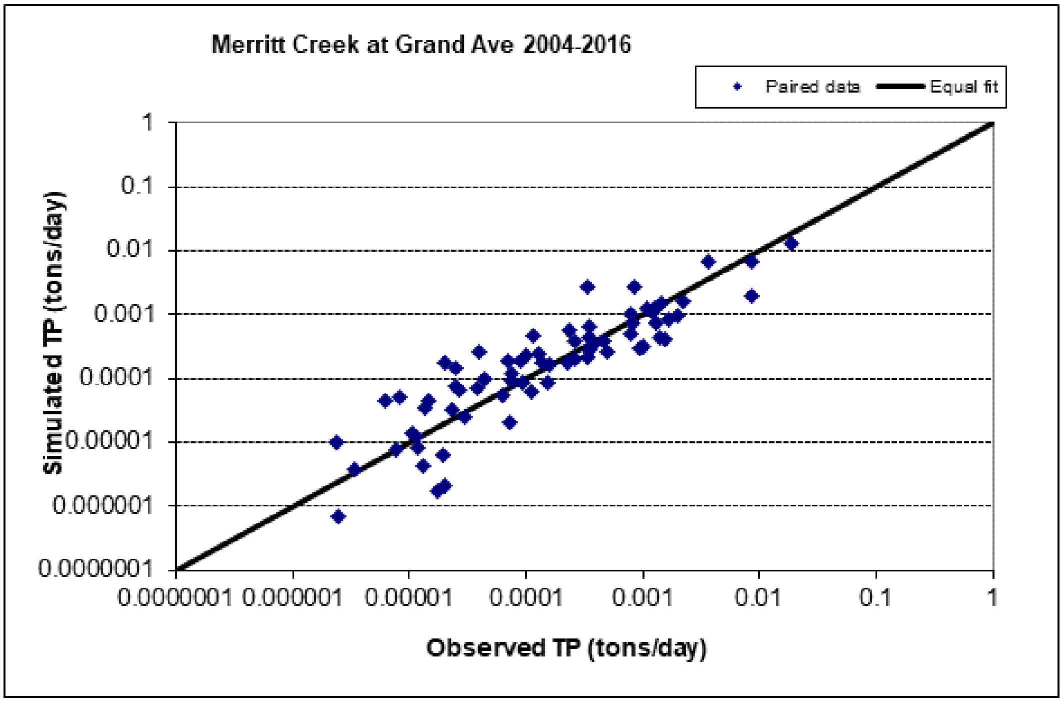


Figure E-765. Paired simulated vs. observed Total Phosphorus (TP) load at Merritt Creek at Grand Ave (calibration period)

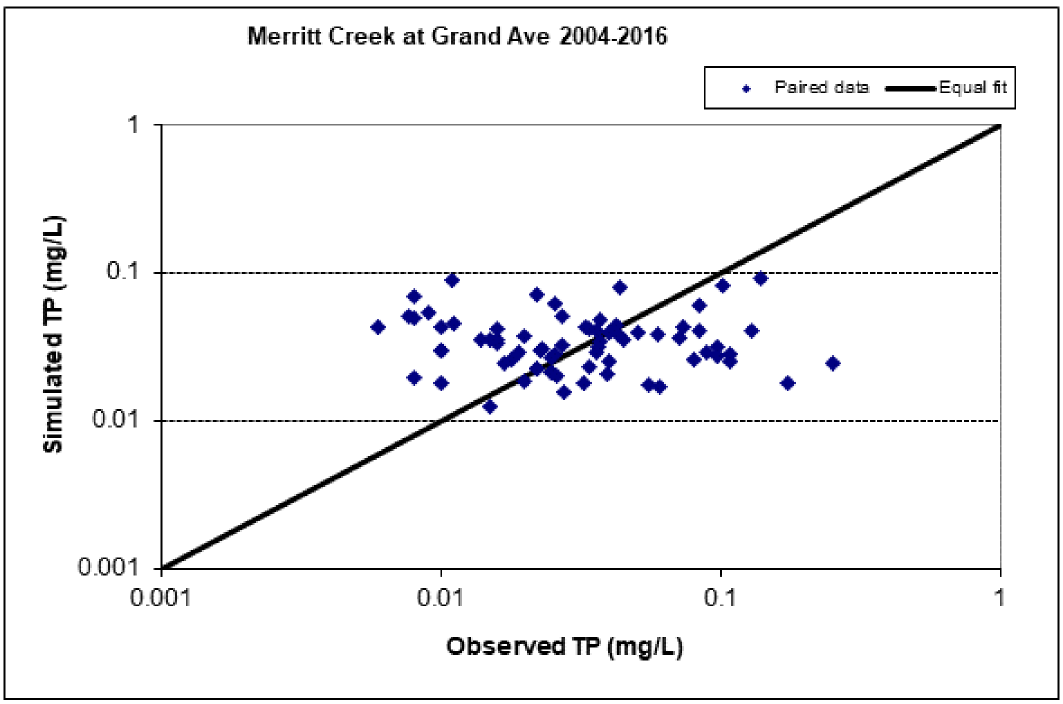


Figure E-766. Paired simulated vs. observed Total Phosphorus (TP) concentration at Merritt Creek at Grand Ave (calibration period)

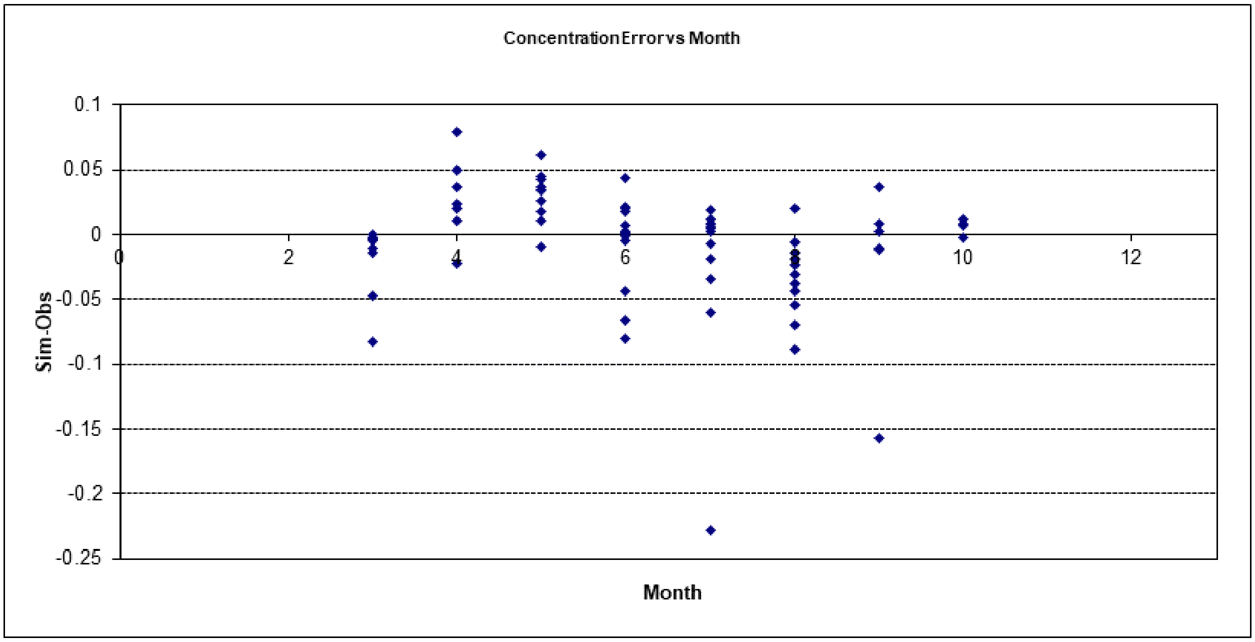


Figure E-767. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Merritt Creek at Grand Ave

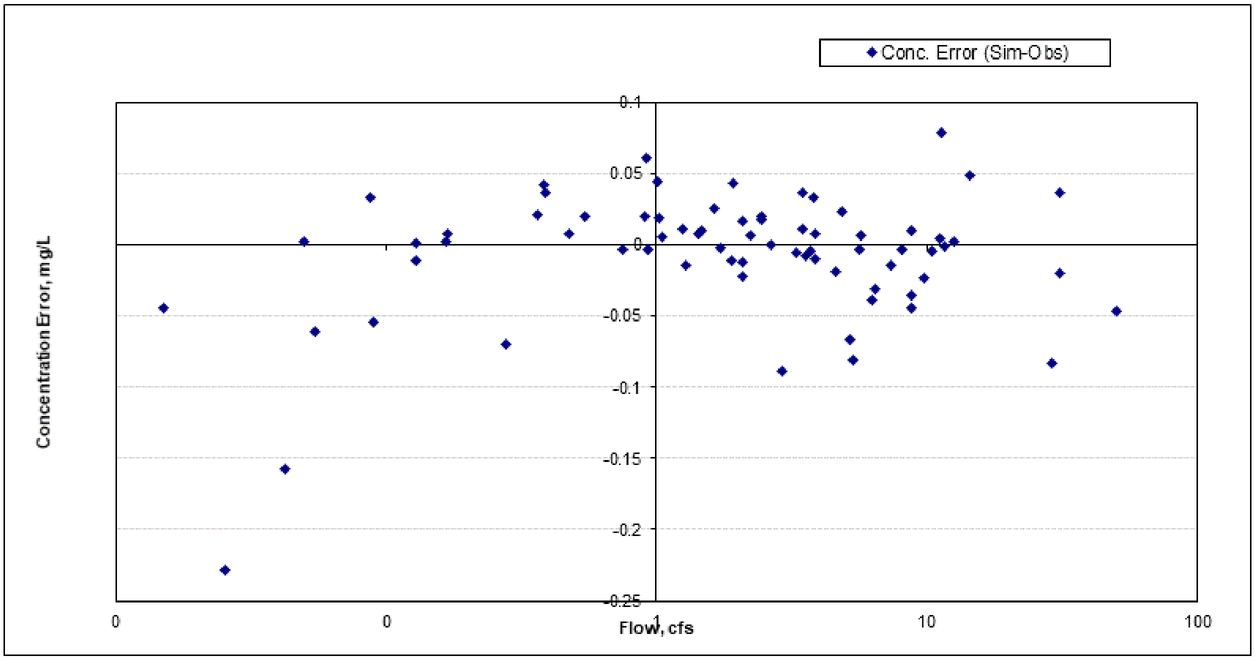


Figure E-768. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Merritt Creek at Grand Ave

E.17 KEENE CREEK AT 57TH AVE W

E.17.1 Dissolved Oxygen (DO)

Table E-97. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	58
Concentration Average Error		-12.52%
Concentration Median Error		-9.58%
Load Average Error		-4.87%
Load Median Error		-3.02%
Paired t conc		1.00
Paired t load		0.80

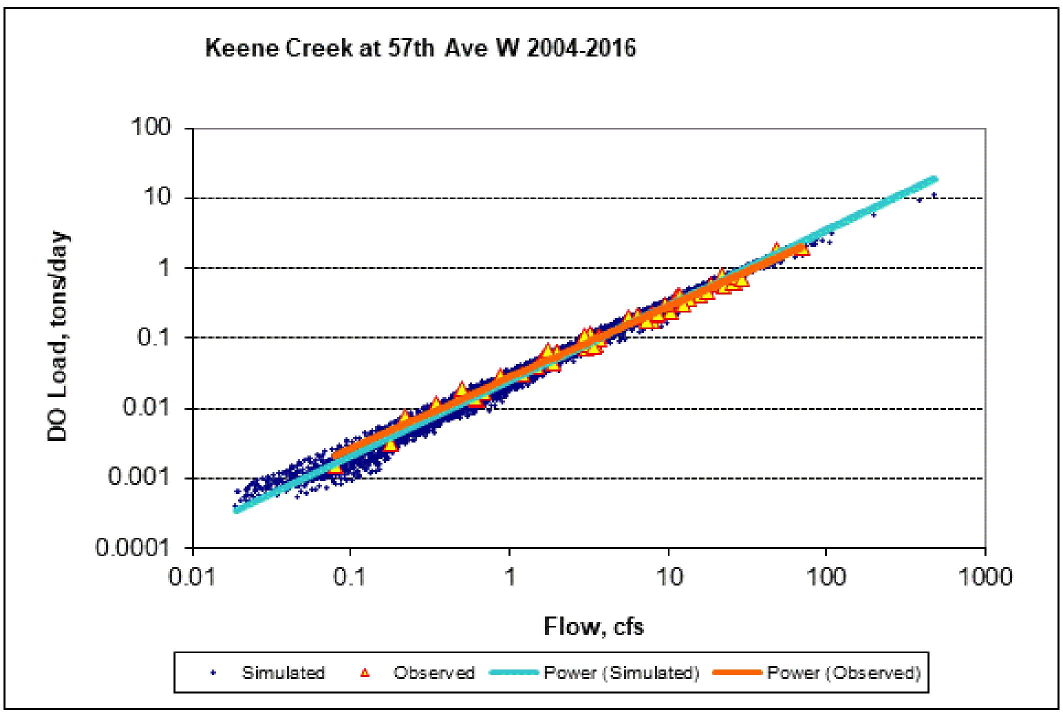


Figure E-769. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Keene Creek at 57th Ave W (calibration period)

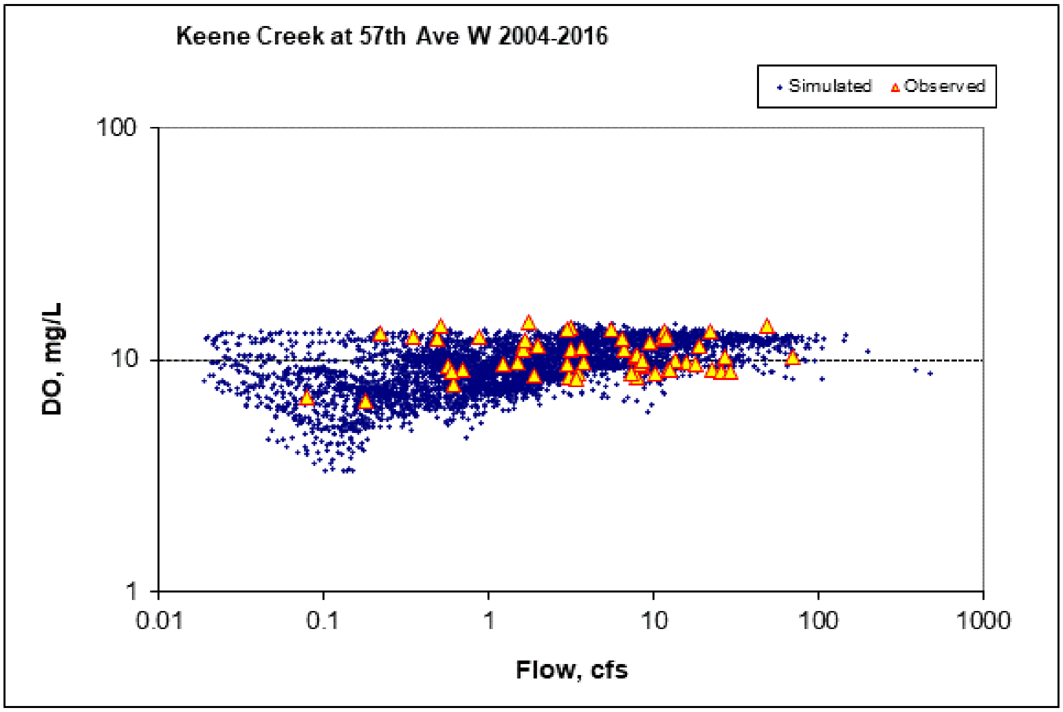
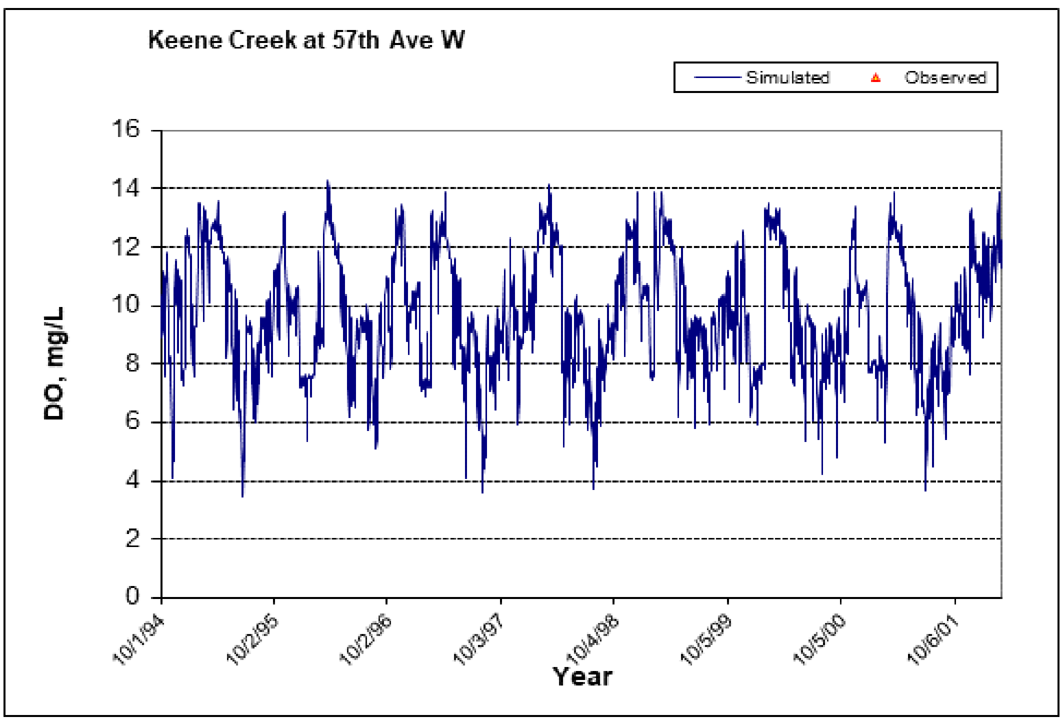
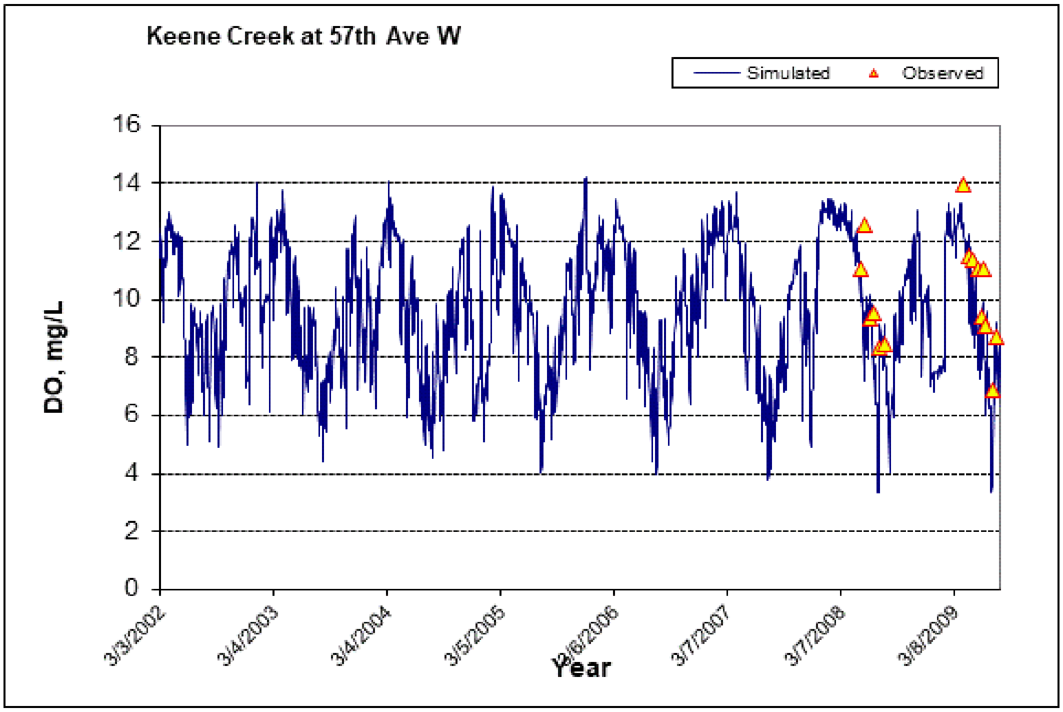


Figure E-770. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Keene Creek at 57th Ave W (calibration period)





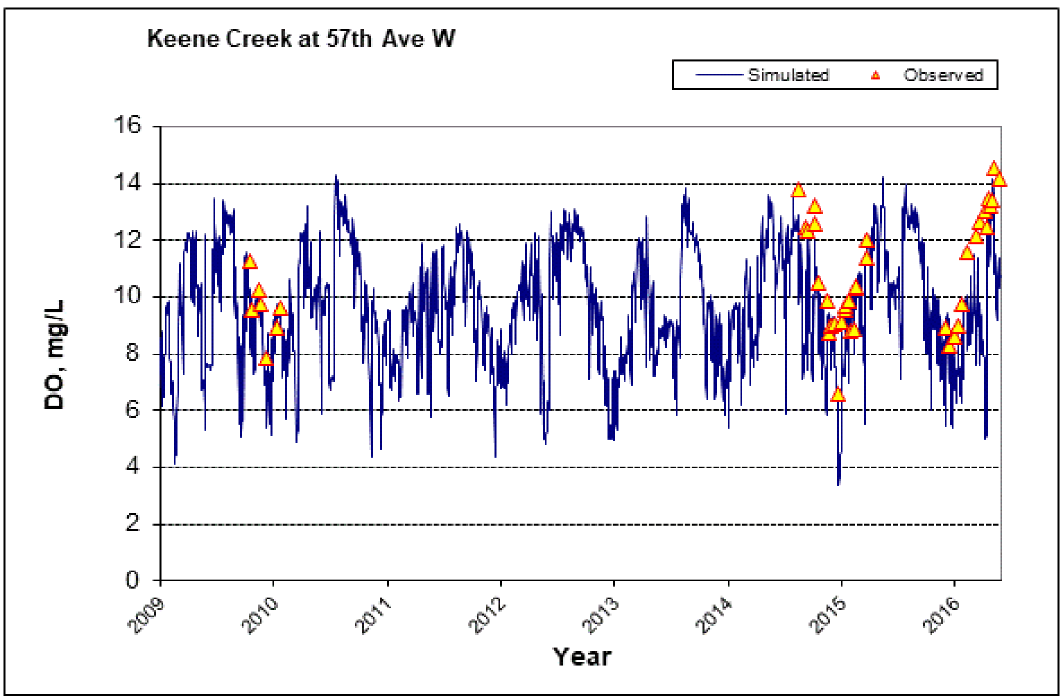


Figure E-771. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Keene Creek at 57th Ave W

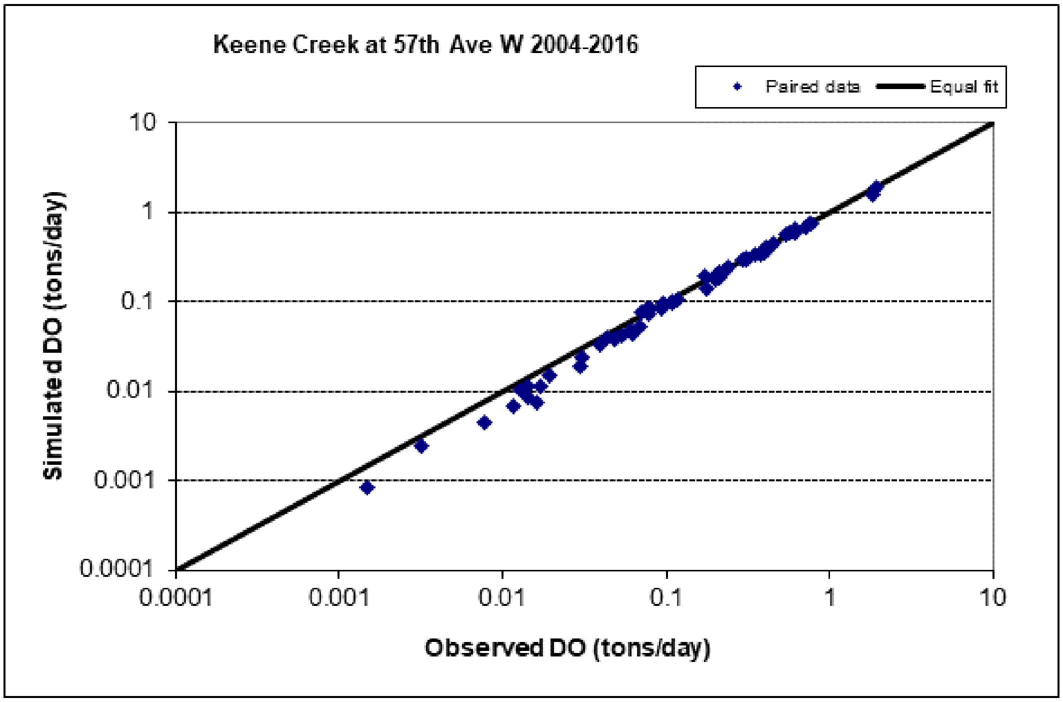


Figure E-772. Paired simulated vs. observed Dissolved Oxygen (DO) load at Keene Creek at 57th Ave W (calibration period)

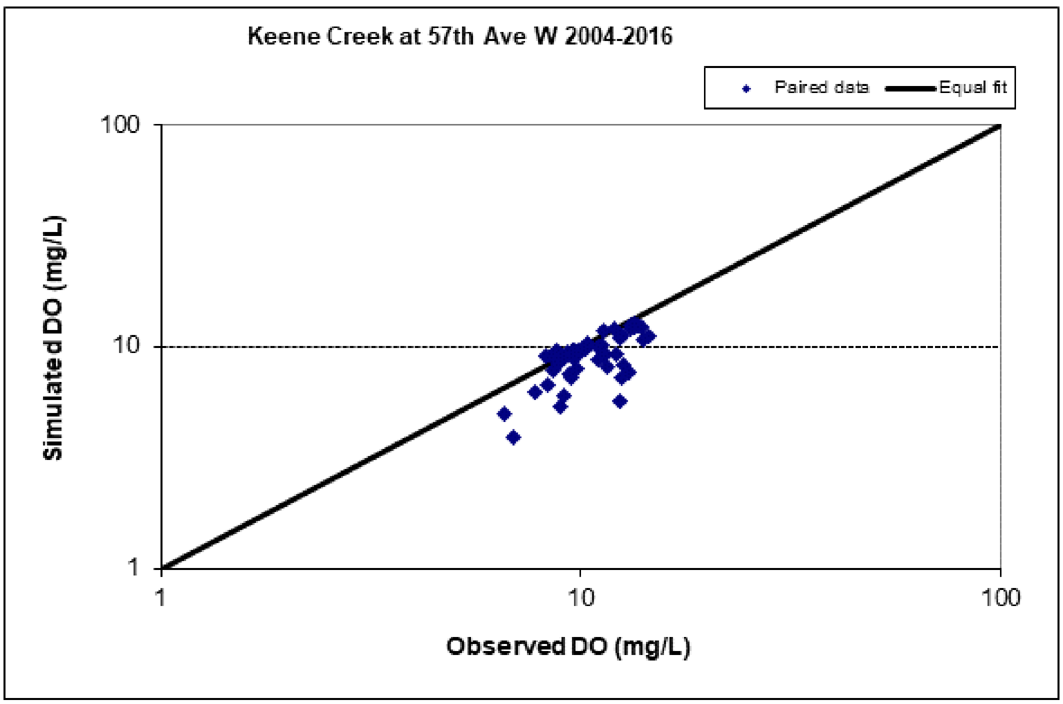


Figure E-773. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Keene Creek at 57th Ave W (calibration period)

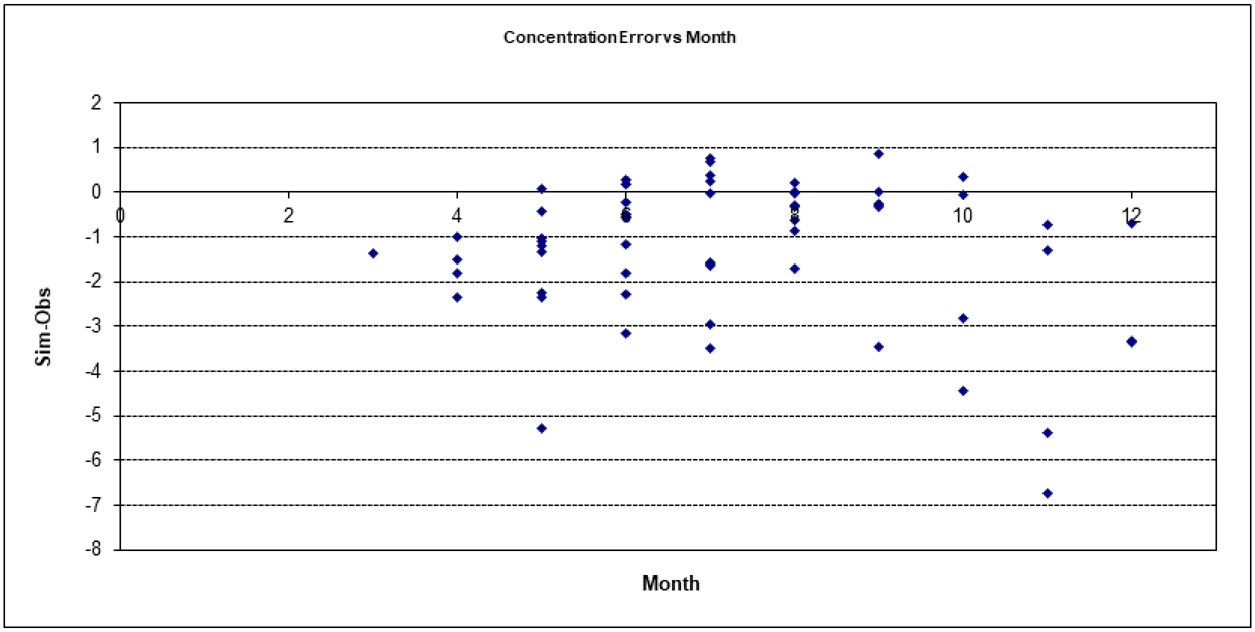


Figure E-774. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Keene Creek at 57th Ave W

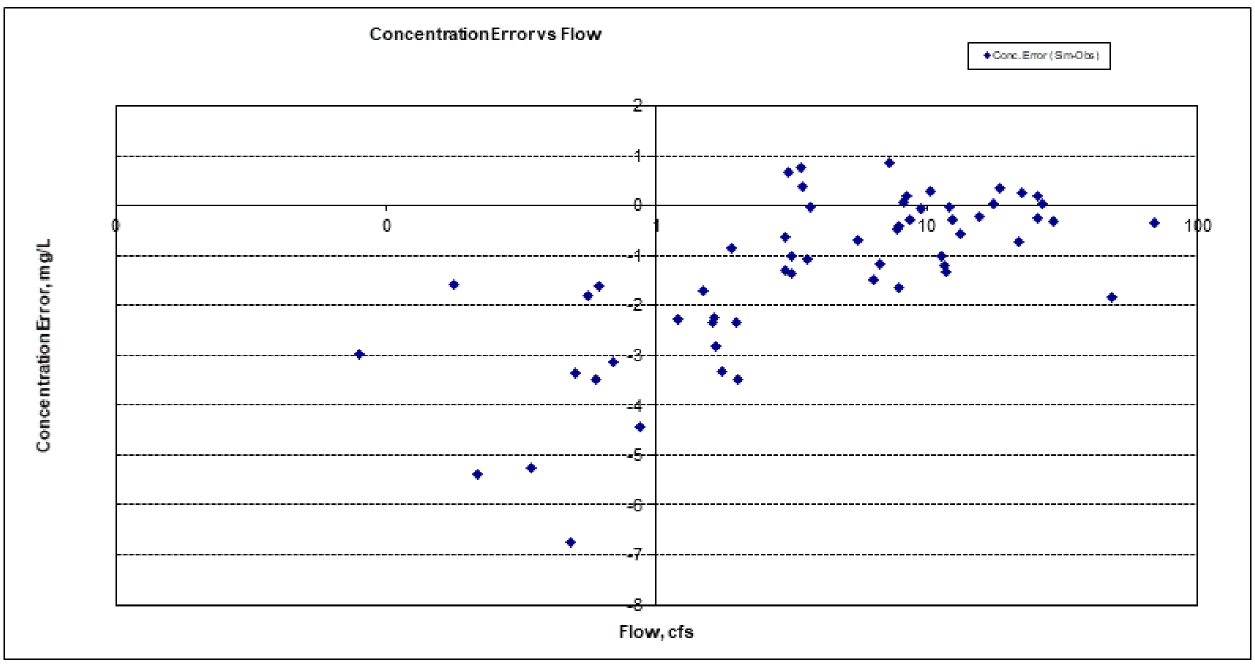


Figure E-775. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Keene Creek at 57th Ave W

E.17.2 Ammonia Nitrogen (NH3)

Table E-98. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	34
Concentration Average Error		86.84%
Concentration Median Error		5.39%
Load Average Error		147.91%
Load Median Error		0.06%
Paired t conc		0.04
Paired t load		0.04

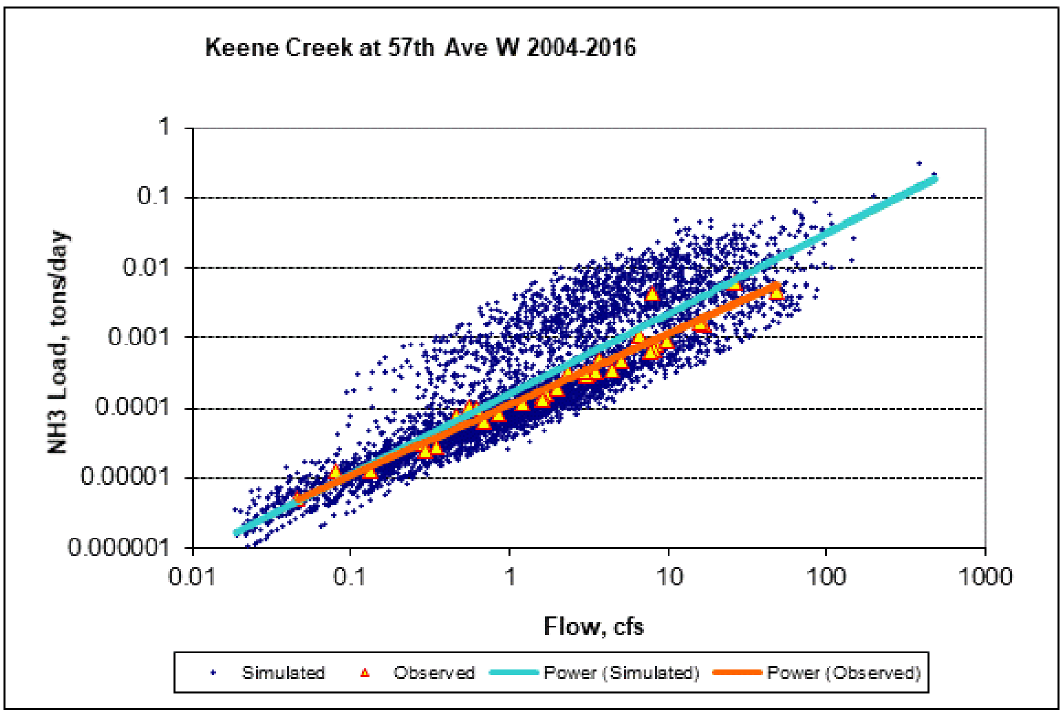


Figure E-776. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Keene Creek at 57th Ave W (calibration period)

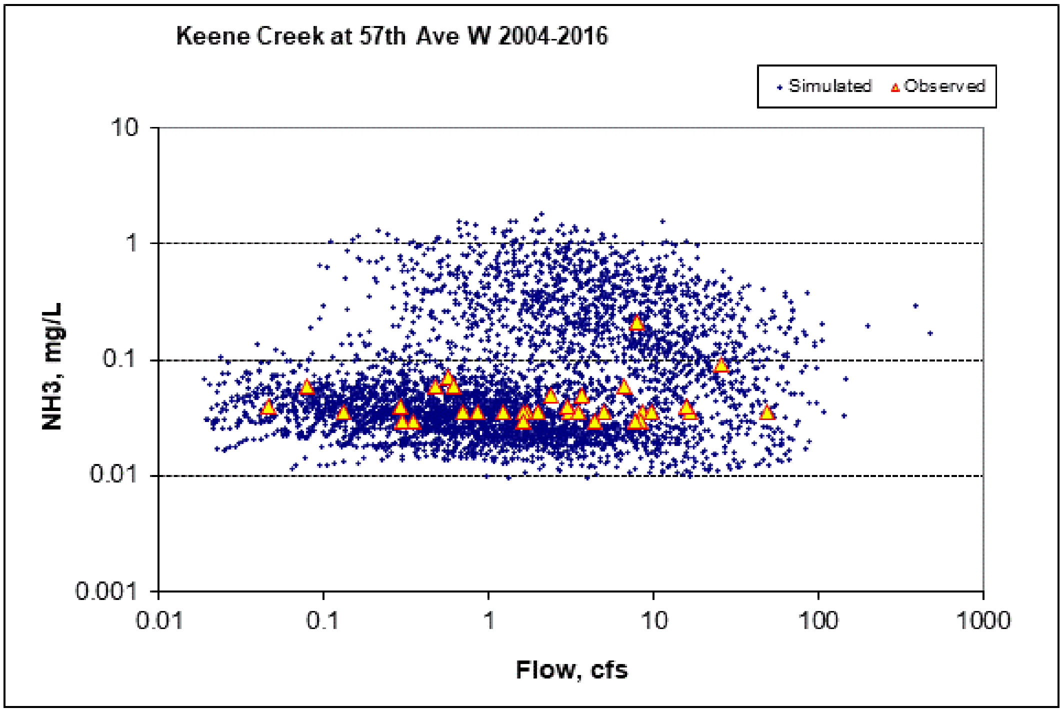
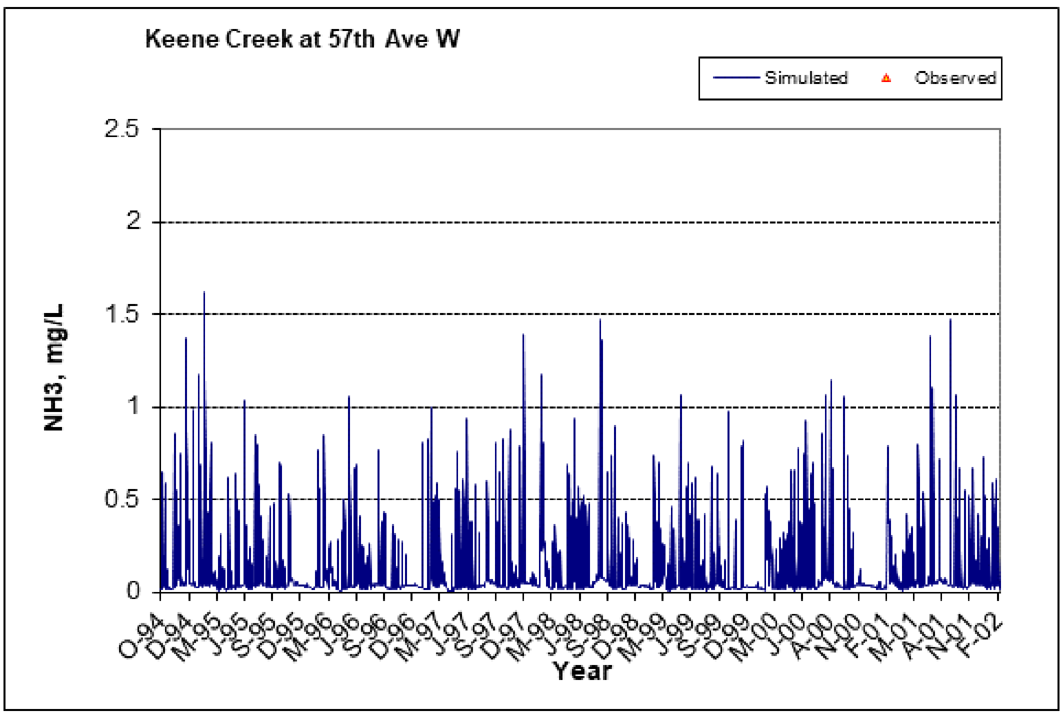
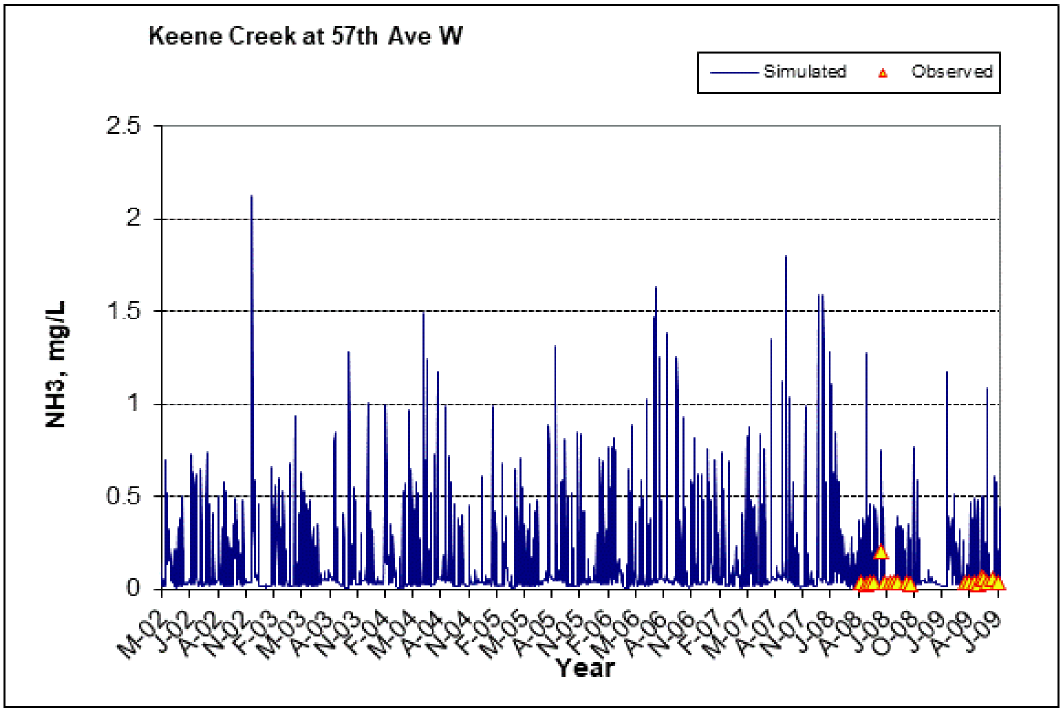


Figure E-777. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Keene Creek at 57th Ave W (calibration period)





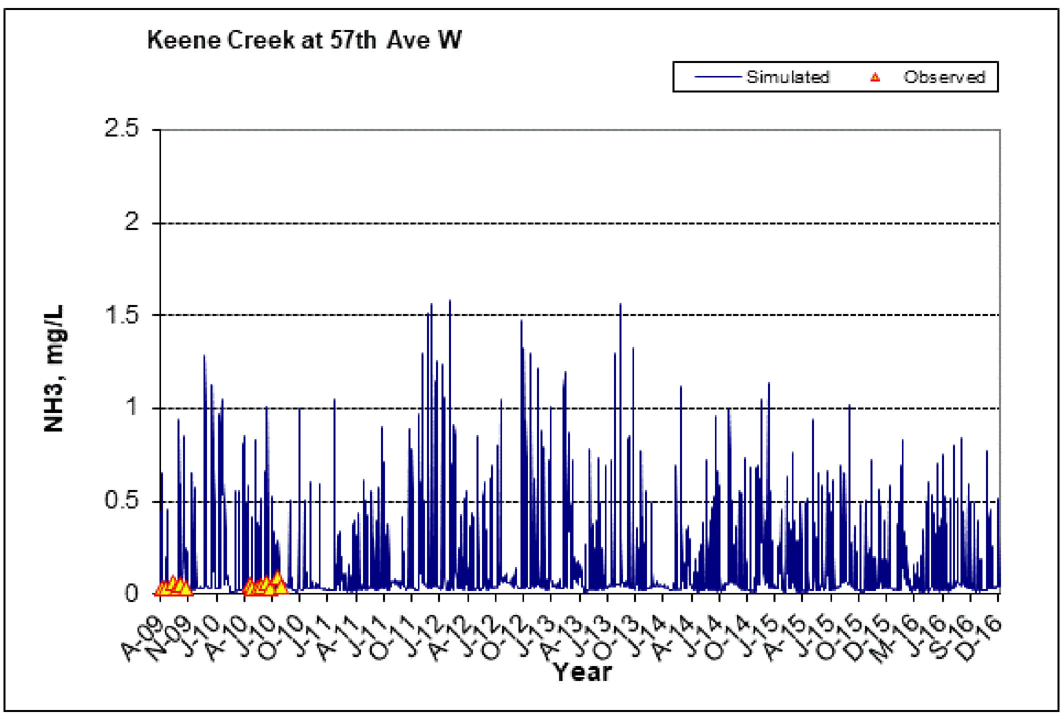


Figure E-778. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Keene Creek at 57th Ave W

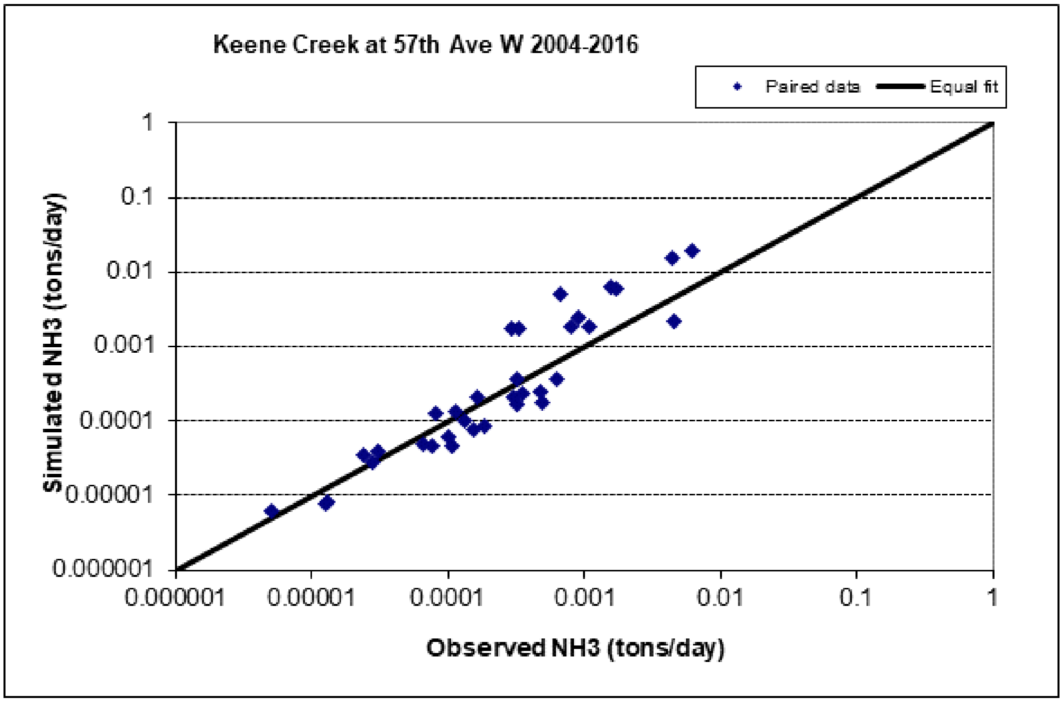


Figure E-779. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Keene Creek at 57th Ave W (calibration period)

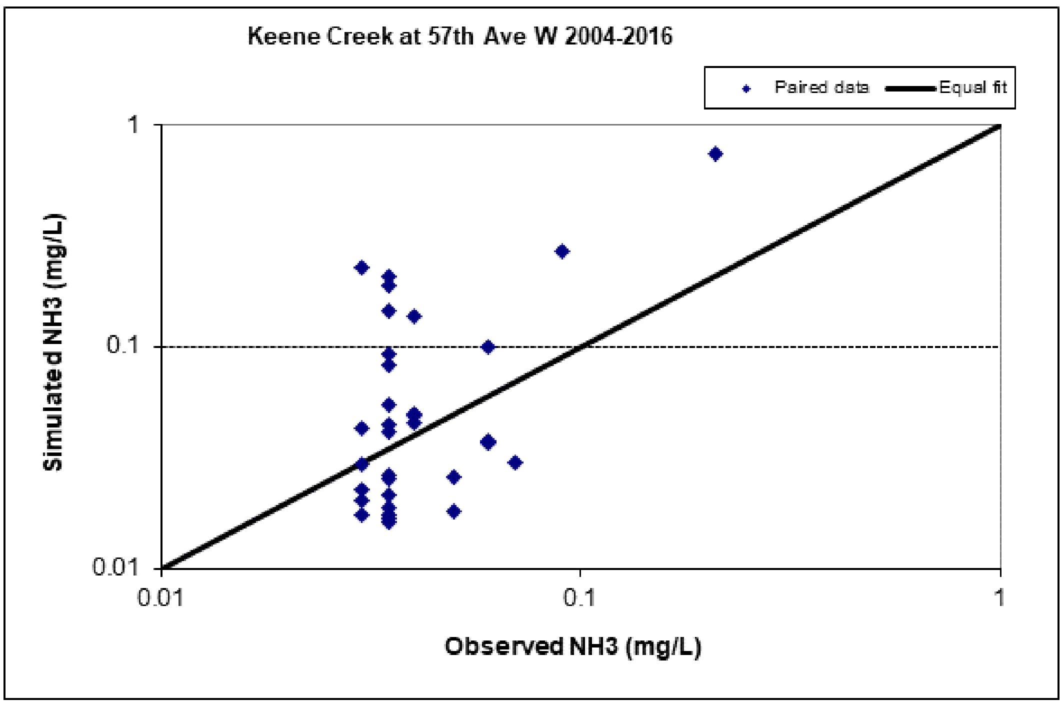


Figure E-780. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Keene Creek at 57th Ave W (calibration period)

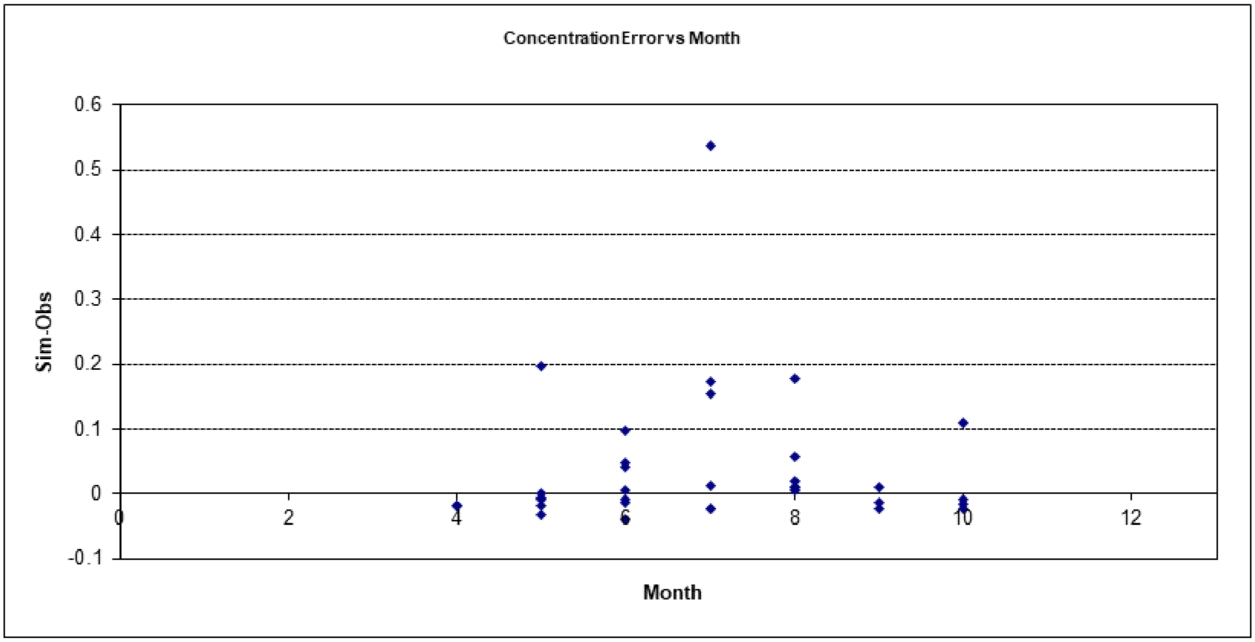


Figure E-781. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Keene Creek at 57th Ave W

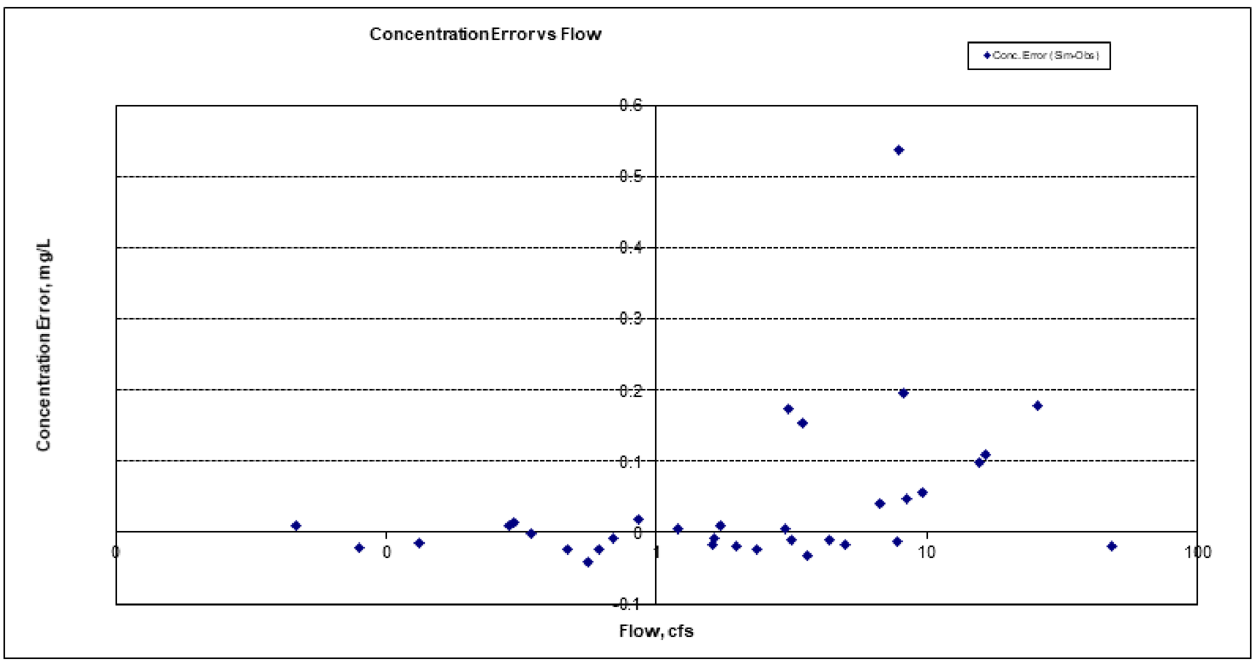


Figure E-782. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Keene Creek at 57th Ave W

E.17.3 Nitrite+ Nitrate Nitrogen (NOx)

Table E-99. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	48
Concentration Average Error		-21.02%
Concentration Median Error		-15.32%
Load Average Error		-11.48%
Load Median Error		-1.16%
Paired t conc		0.48
Paired t load		0.65

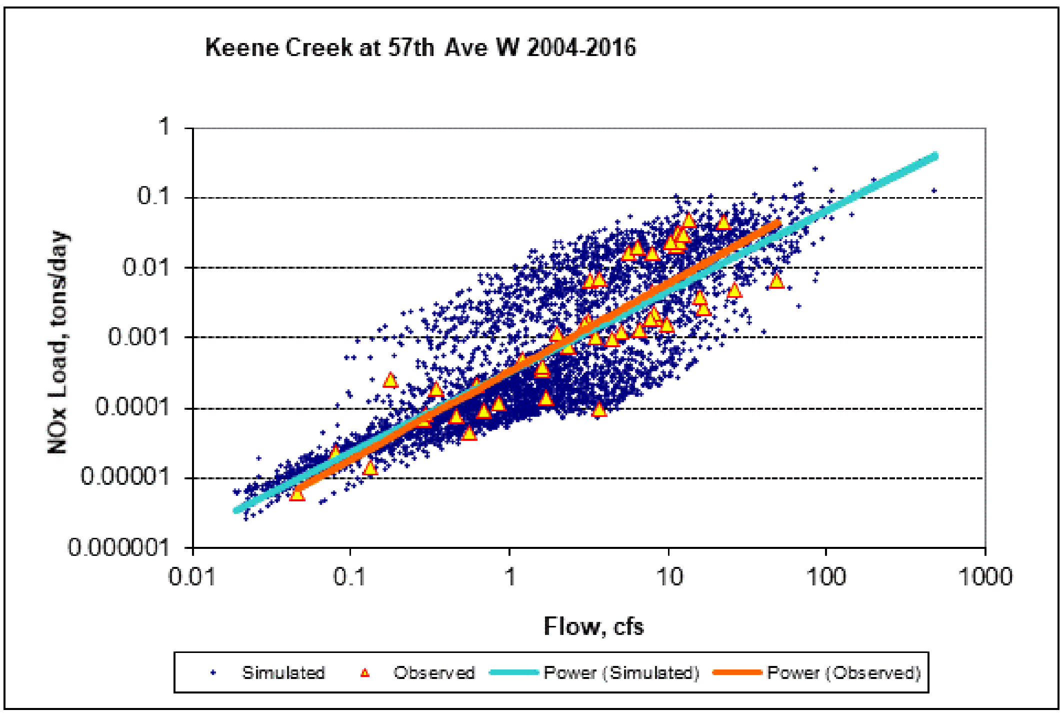


Figure E-783. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Keene Creek at 57th Ave W (calibration period)

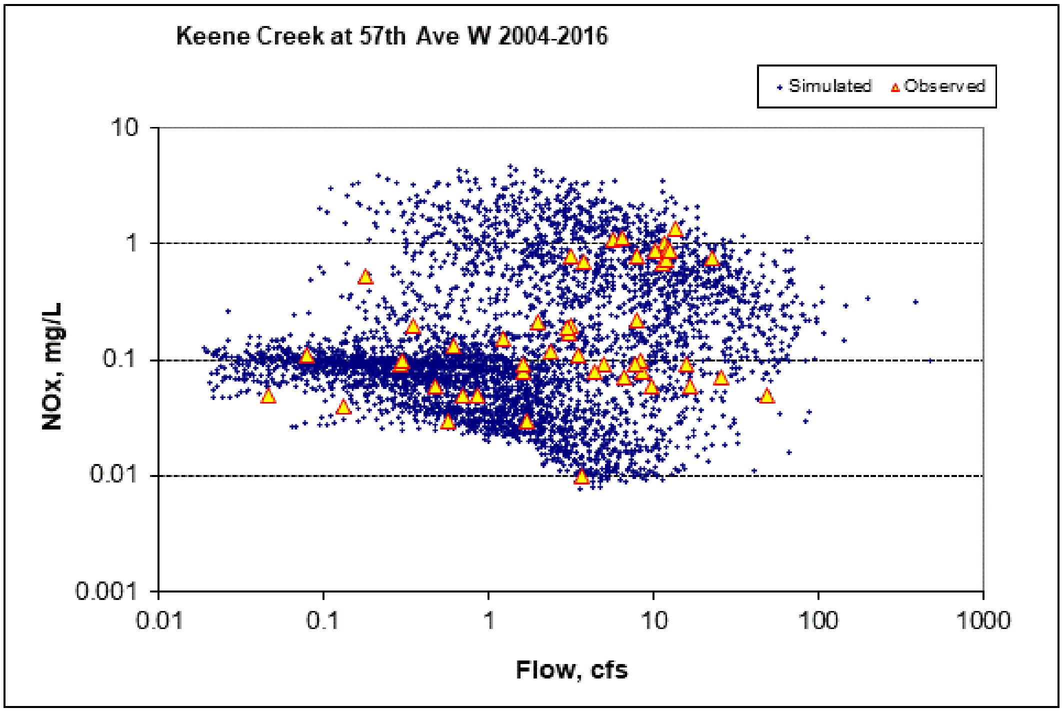
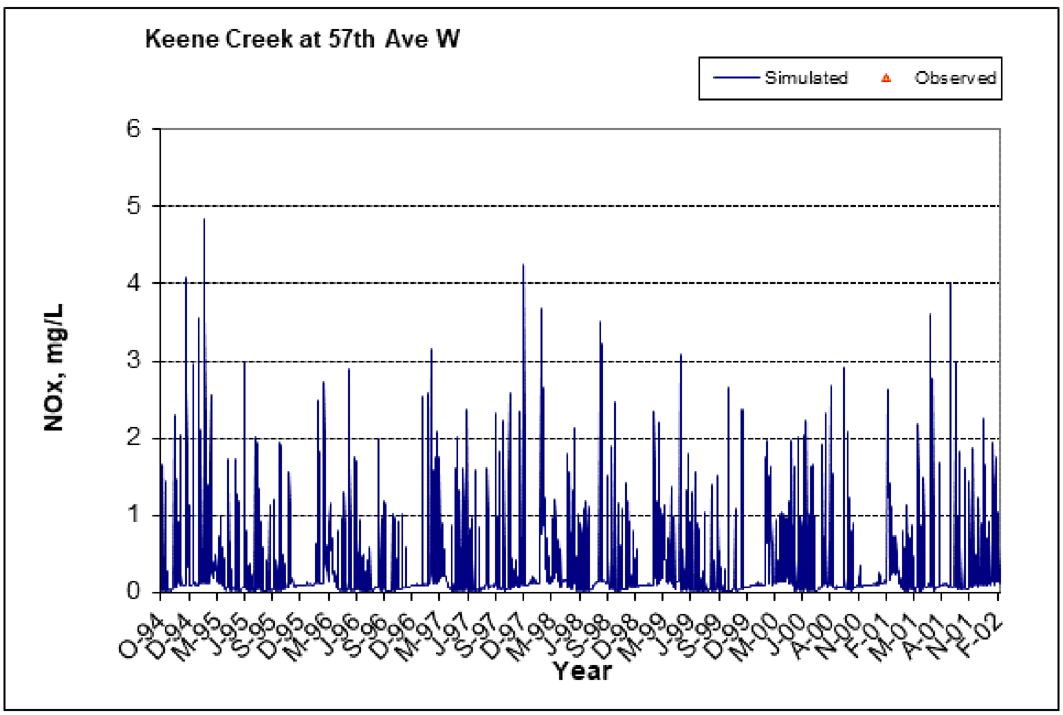


Figure E-784. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Keene Creek at 57th Ave W (calibration period)



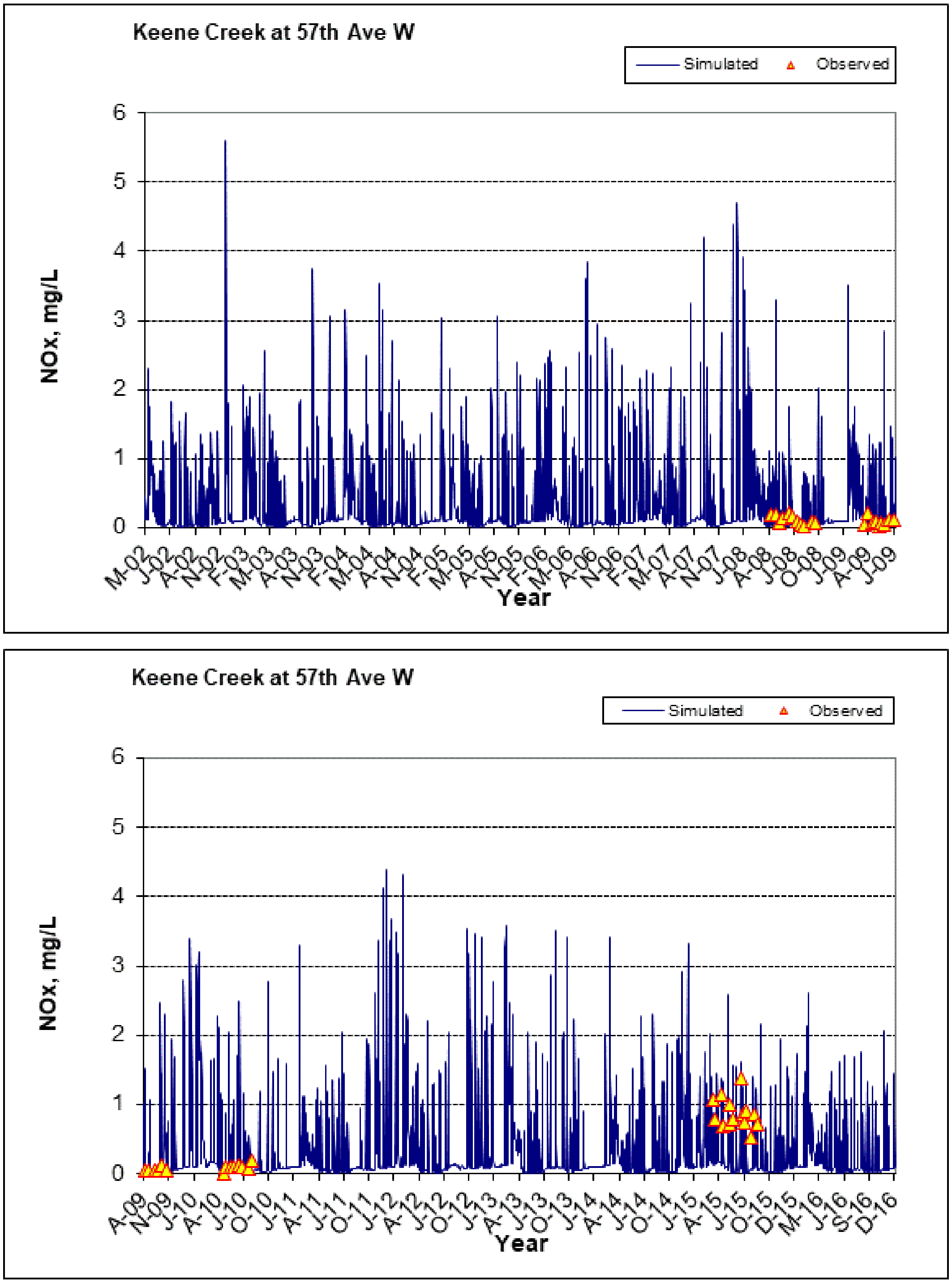


Figure E-785. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Keene Creek at 57th Ave W

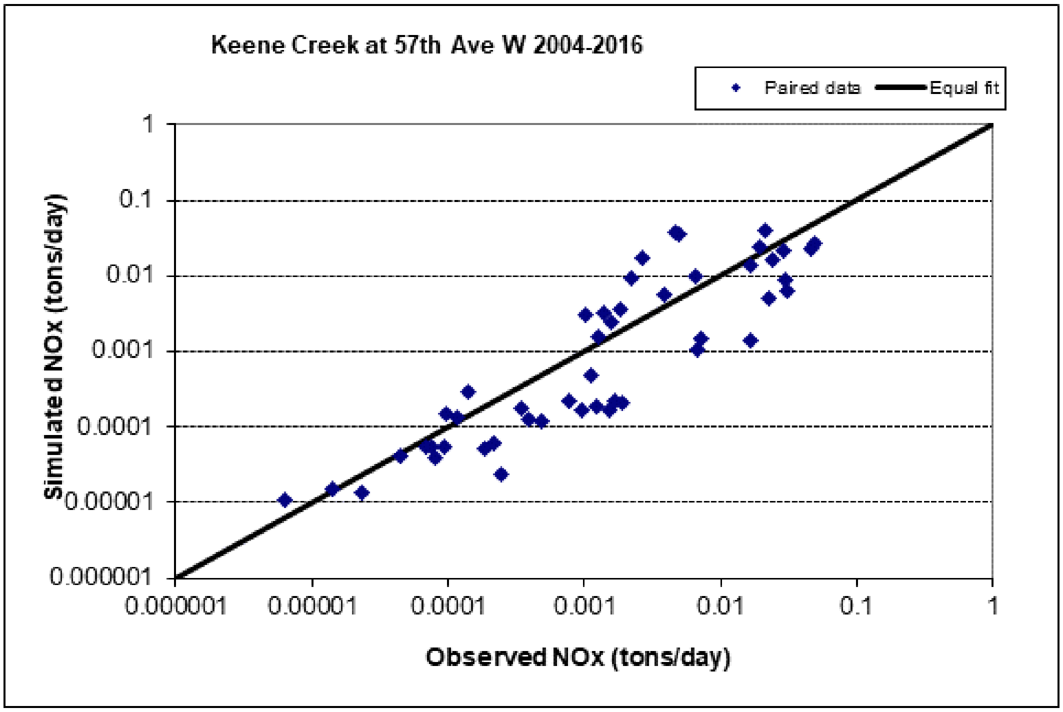


Figure E-786. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Keene Creek at 57th Ave W (calibration period)

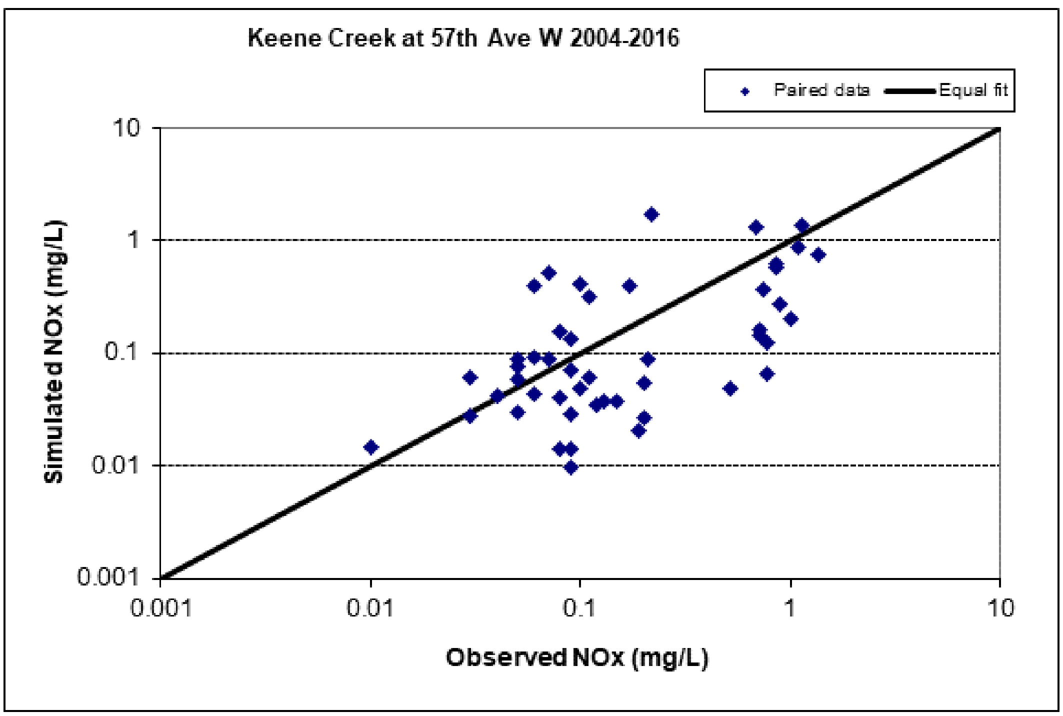


Figure E-787. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Keene Creek at 57th Ave W (calibration period)

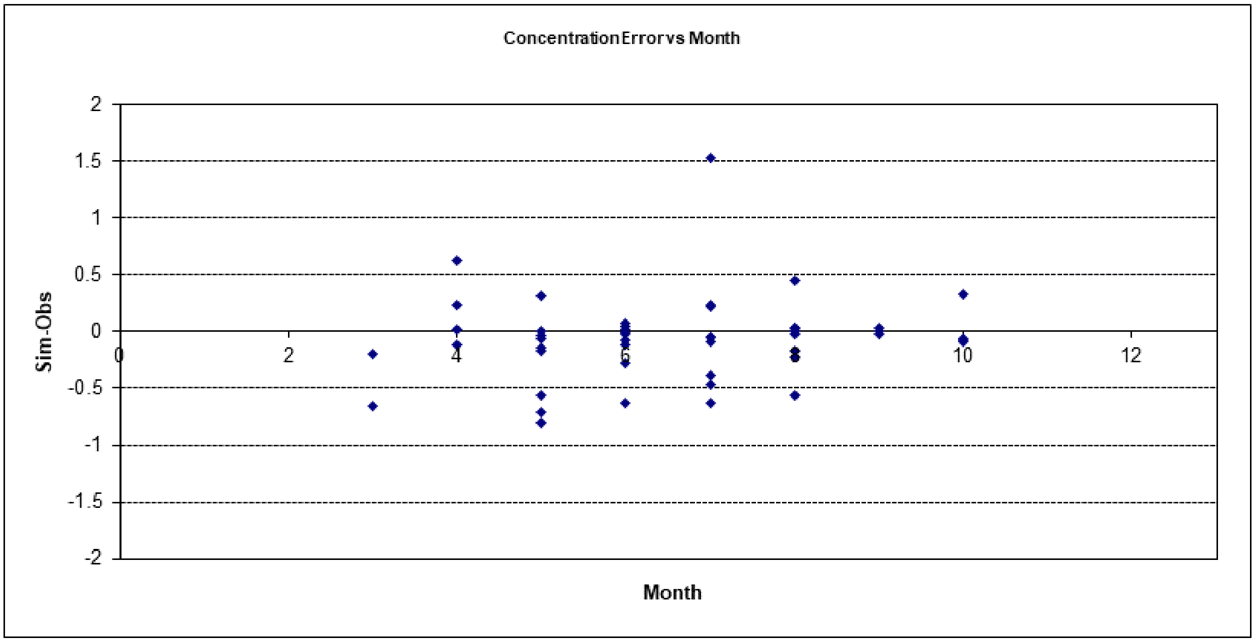


Figure E-788. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Keene Creek at 57th Ave W

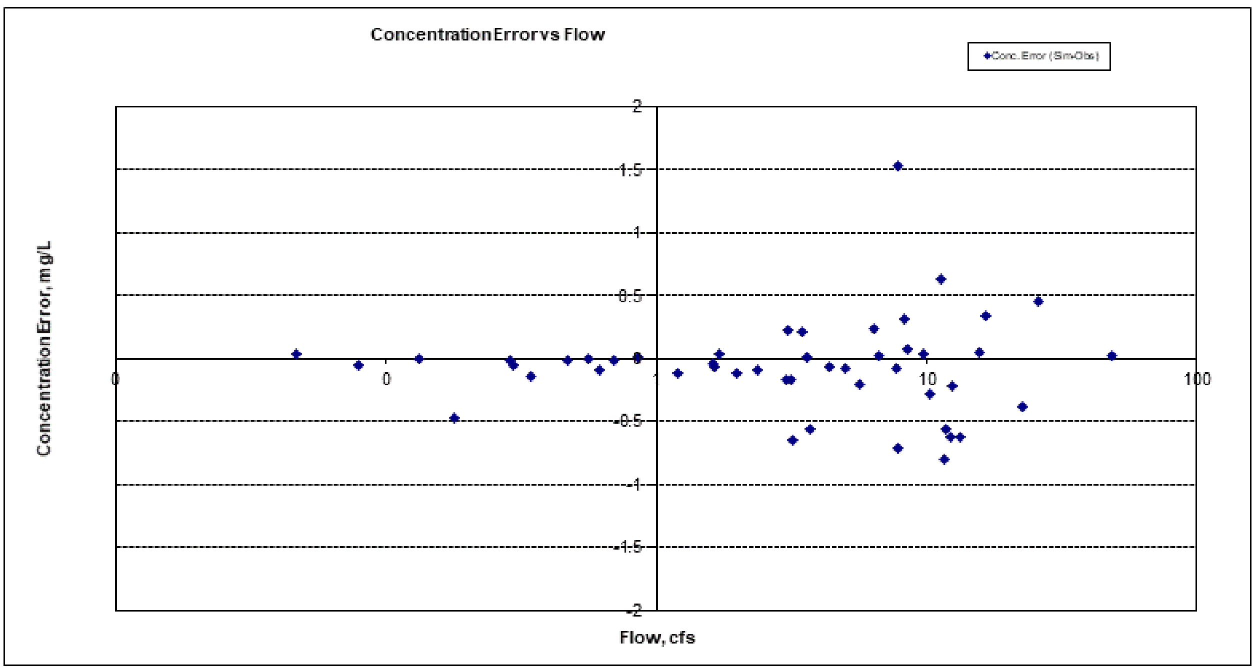


Figure E-789. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Keene Creek at 57th Ave W

E.17.4 Total Phosphorus (TP)

Table E-100. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	72
Concentration Average Error		-26.32%
Concentration Median Error		-7.84%
Load Average Error		-15.64%
Load Median Error		-0.34%
Paired t conc		0.30
Paired t load		0.57

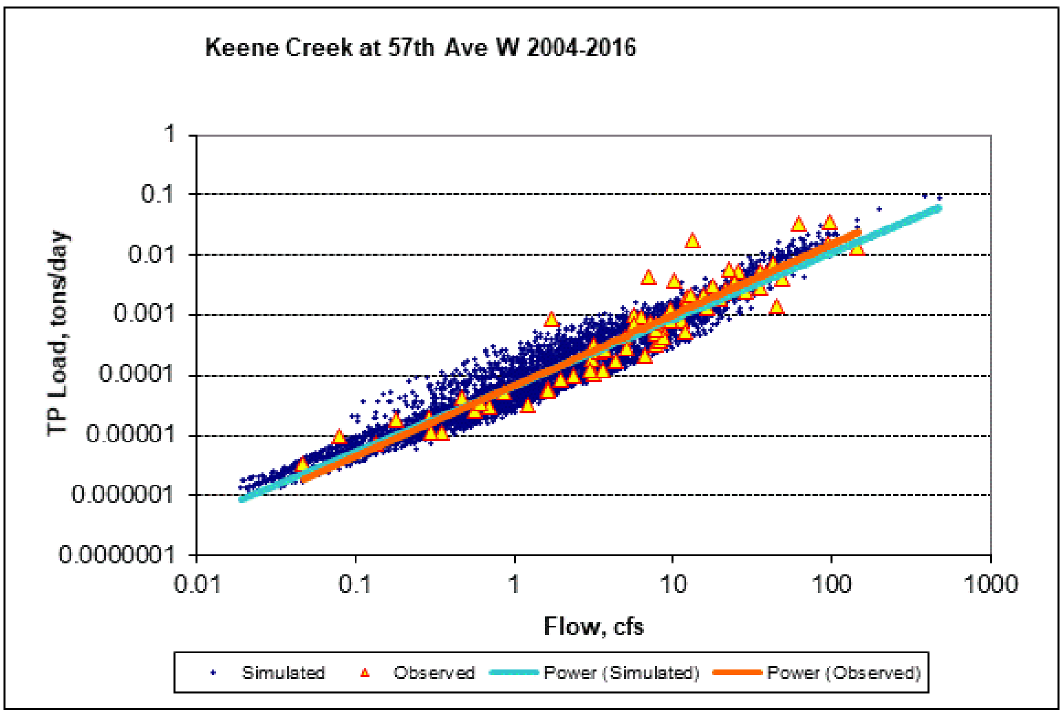


Figure E-790. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Keene Creek at 57th Ave W (calibration period)

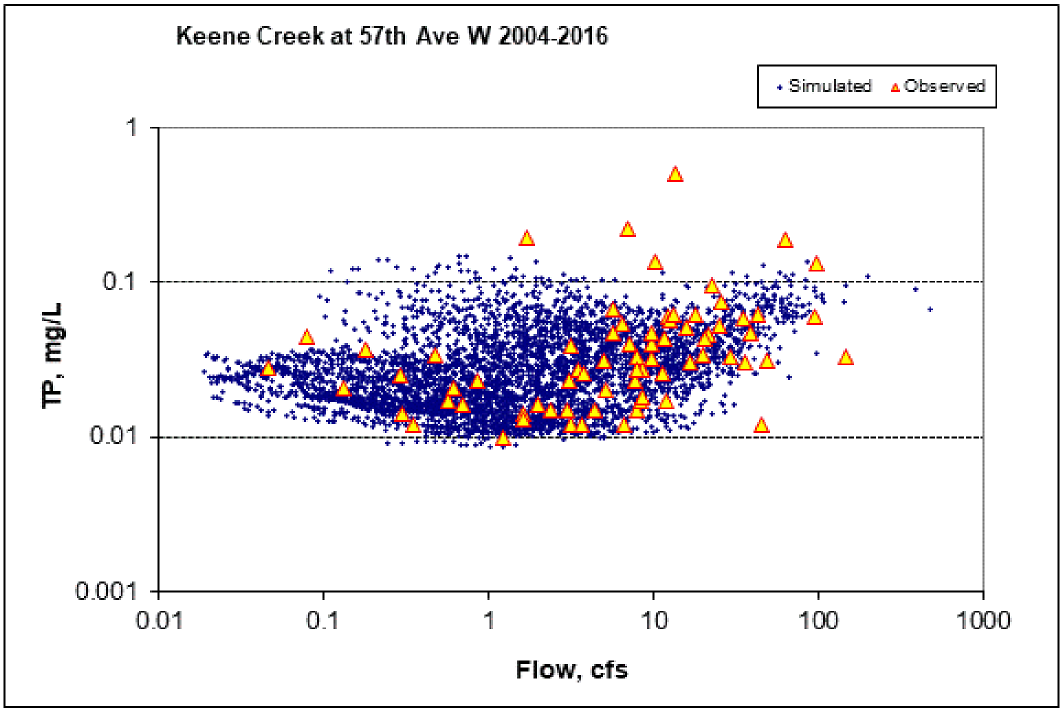
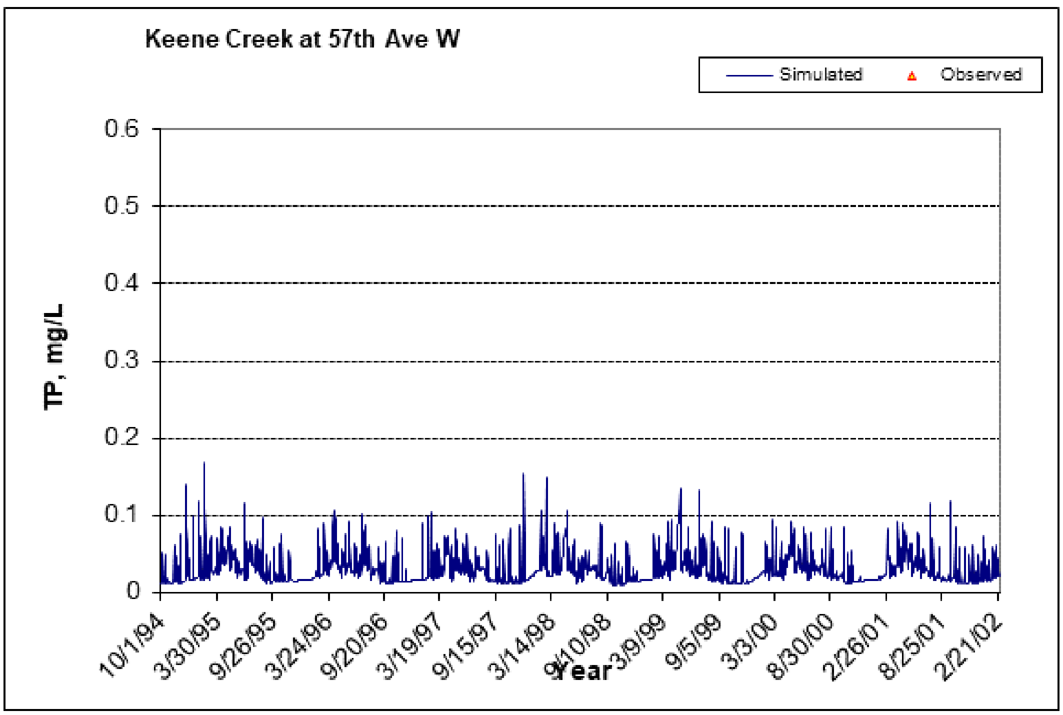


Figure E-791. Simulated and observed Total Phosphorus (TP) concentration vs flow at Keene Creek at 57th Ave W (calibration period)



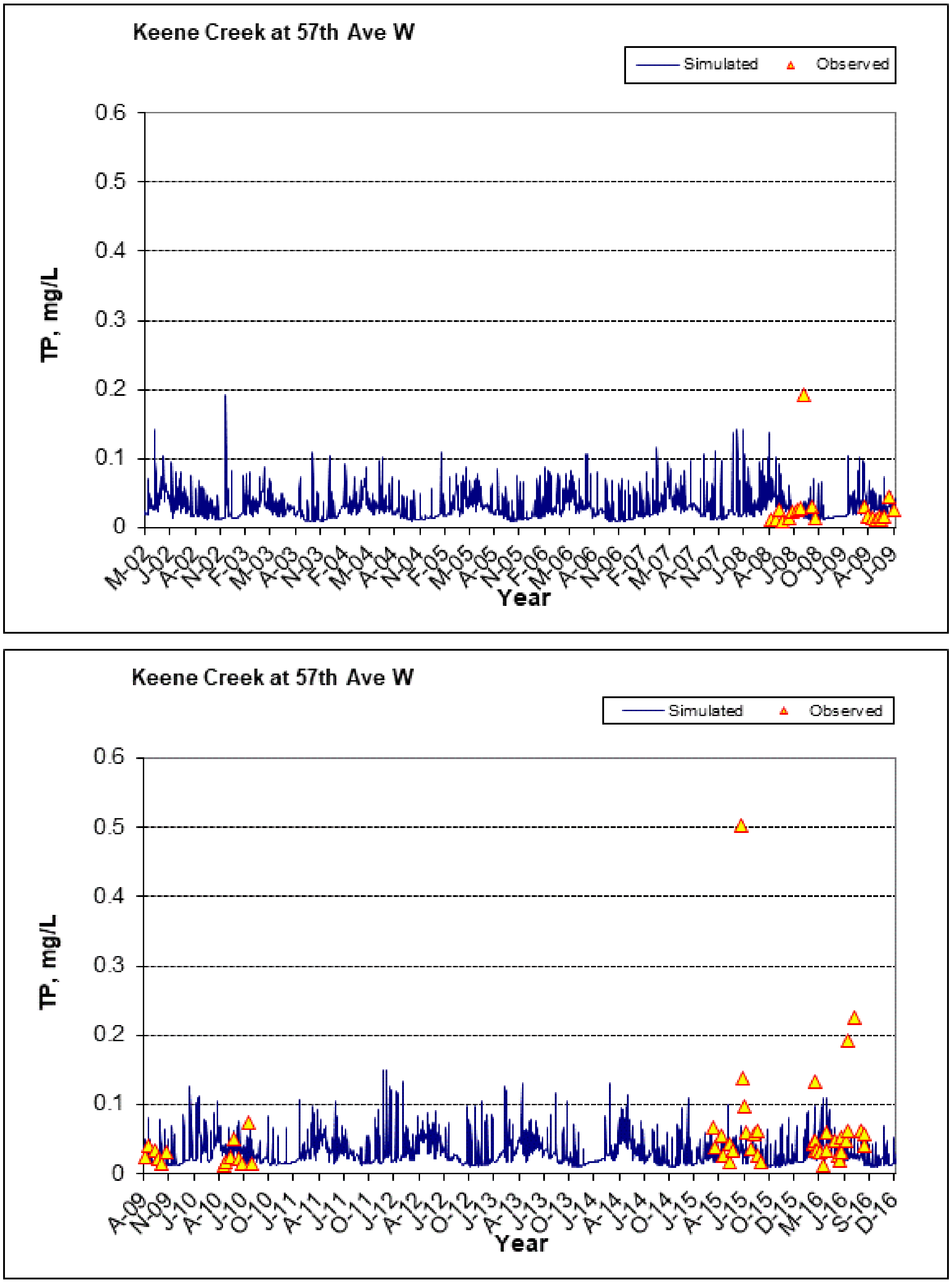


Figure E-792. Time series of observed and simulated Total Phosphorus (TP) concentration at Keene Creek at 57th Ave W

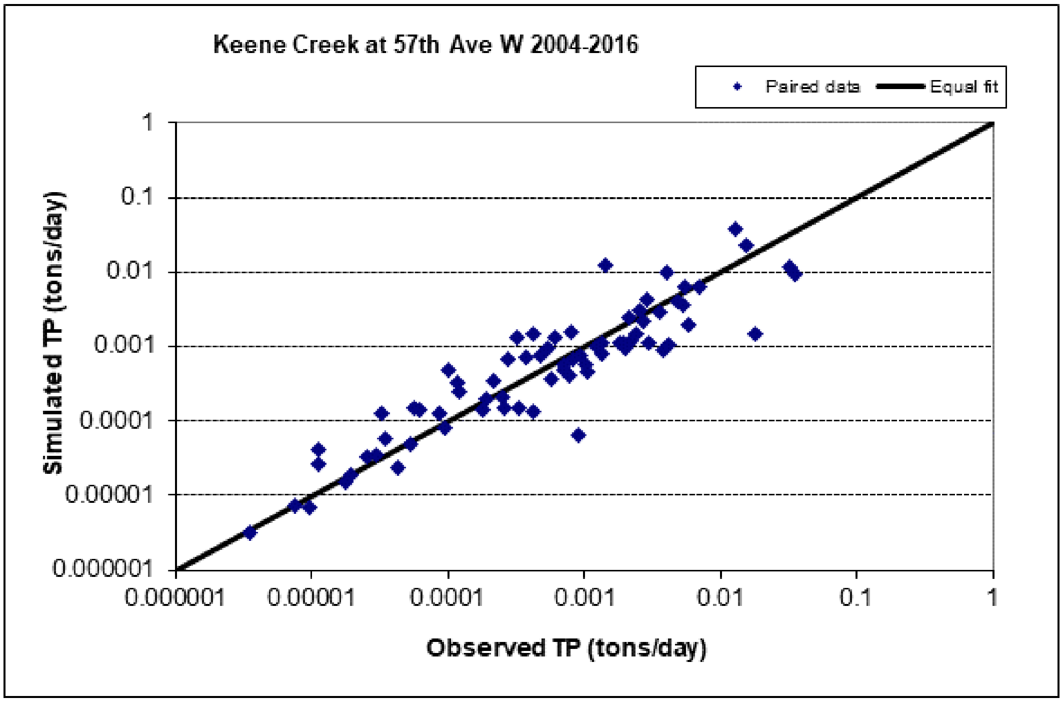


Figure E-793. Paired simulated vs. observed Total Phosphorus (TP) load at Keene Creek at 57th Ave W (calibration period)

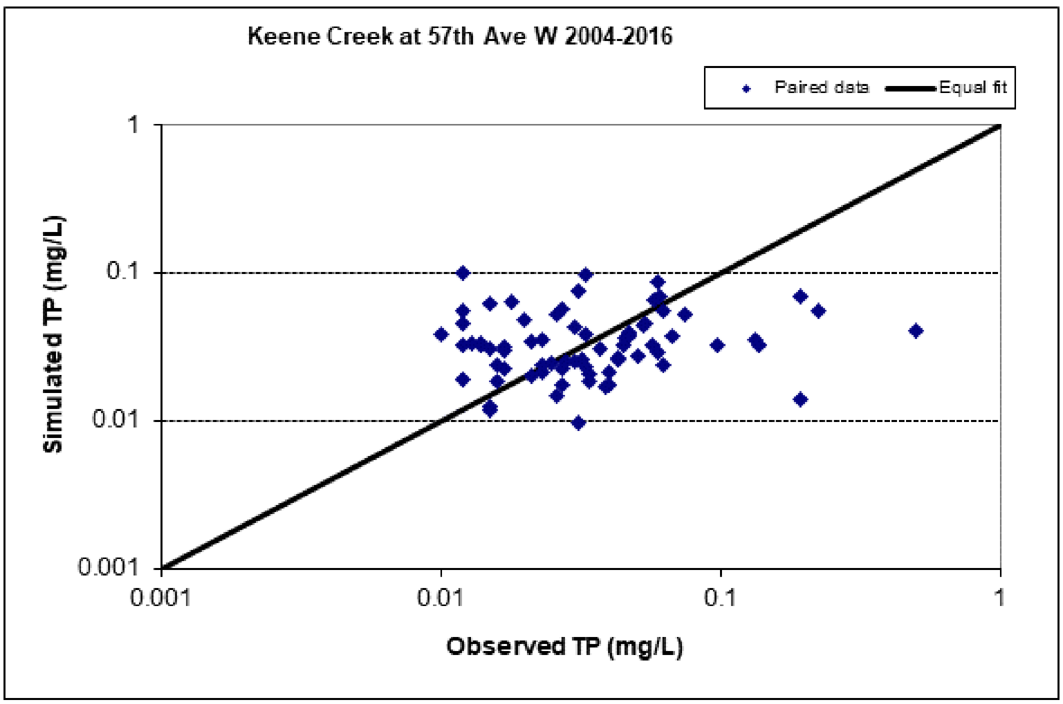


Figure E-794. Paired simulated vs. observed Total Phosphorus (TP) concentration at Keene Creek at 57th Ave W (calibration period)

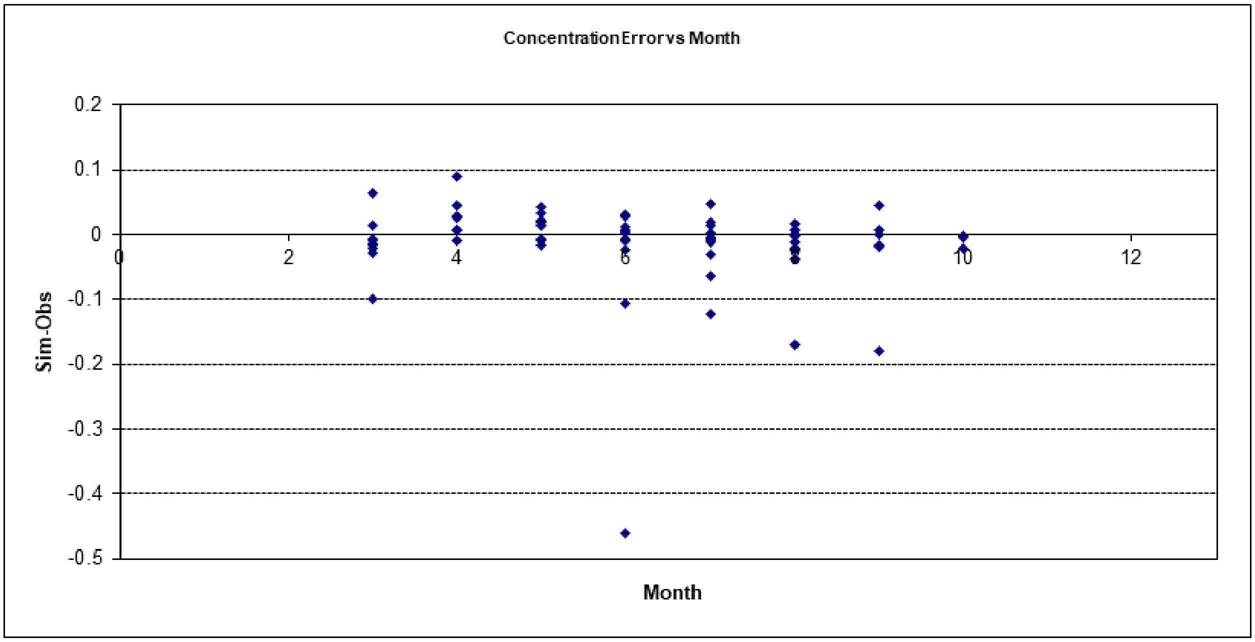


Figure E-795. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Keene Creek at 57th Ave W

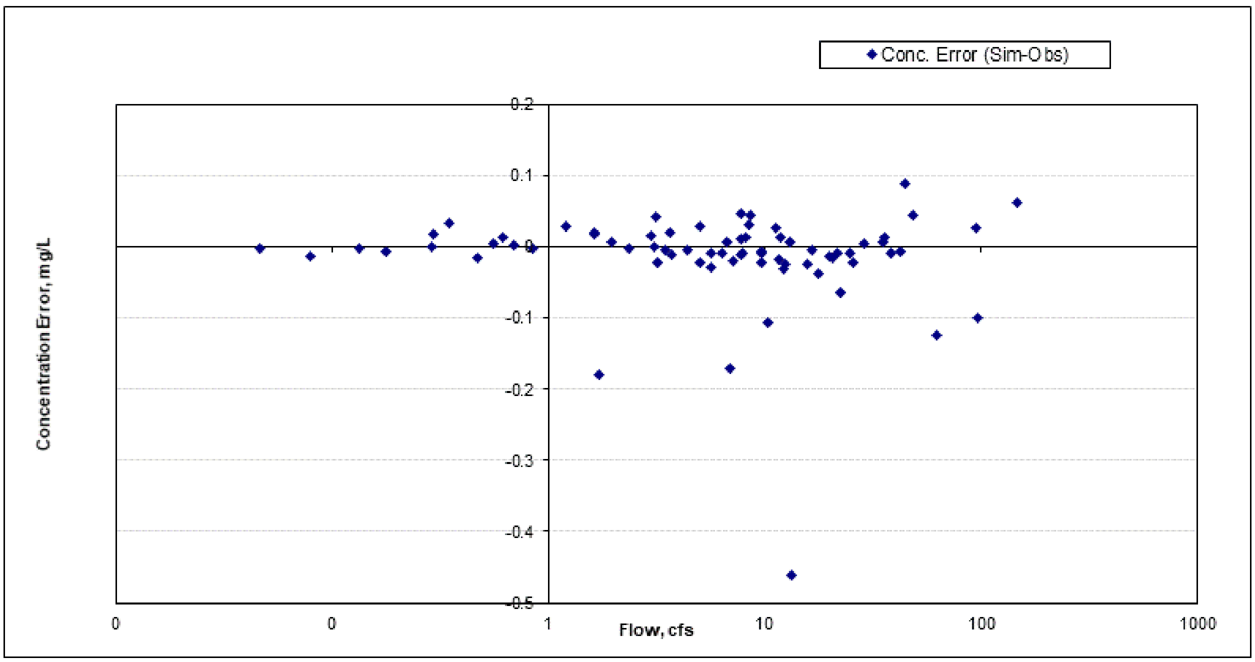


Figure E-796. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Keene Creek at 57th Ave W

E.18 Kingsbury Creek (multiple stations)

E.18.1 Dissolved Oxygen (DO)

Table E-101. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	36
Concentration Average Error		-14.60%
Concentration Median Error		-11.10%
Load Average Error		-11.04%
Load Median Error		-2.82%
Paired t conc		0.93
Paired t load		0.67

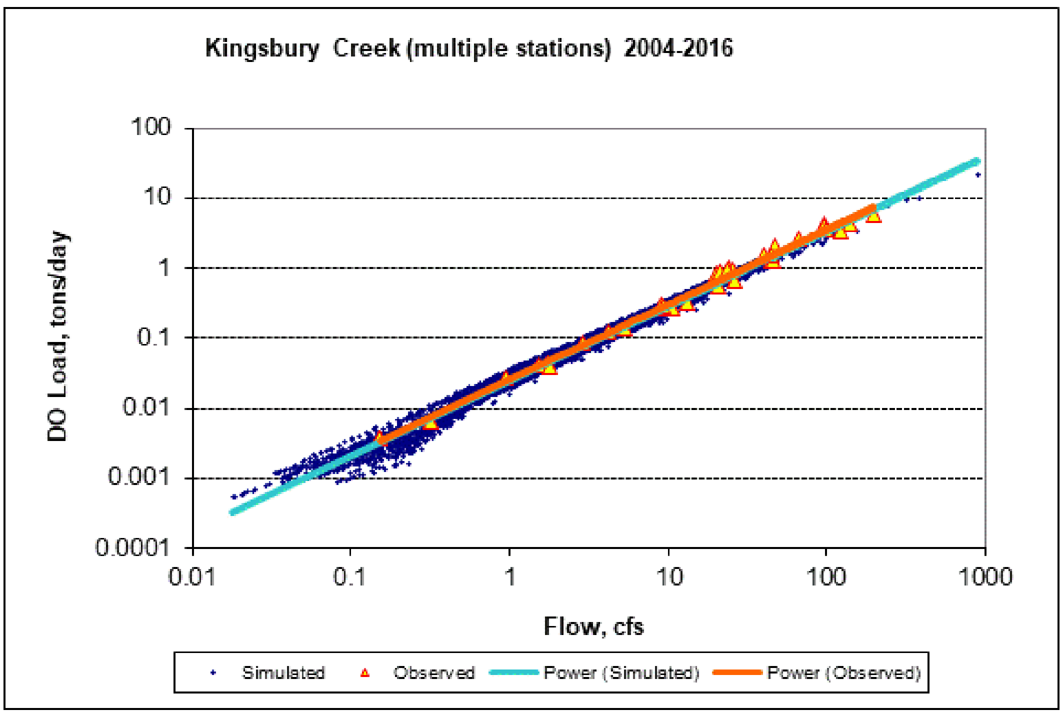


Figure E-797. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Kingsbury Creek (multiple stations) (calibration period)

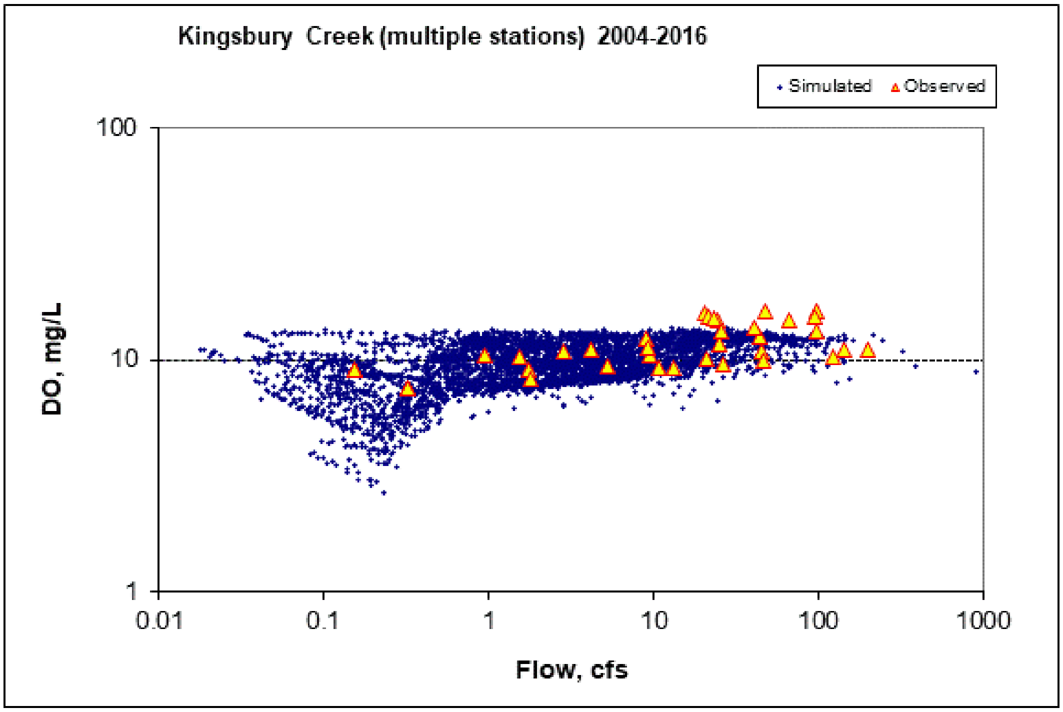
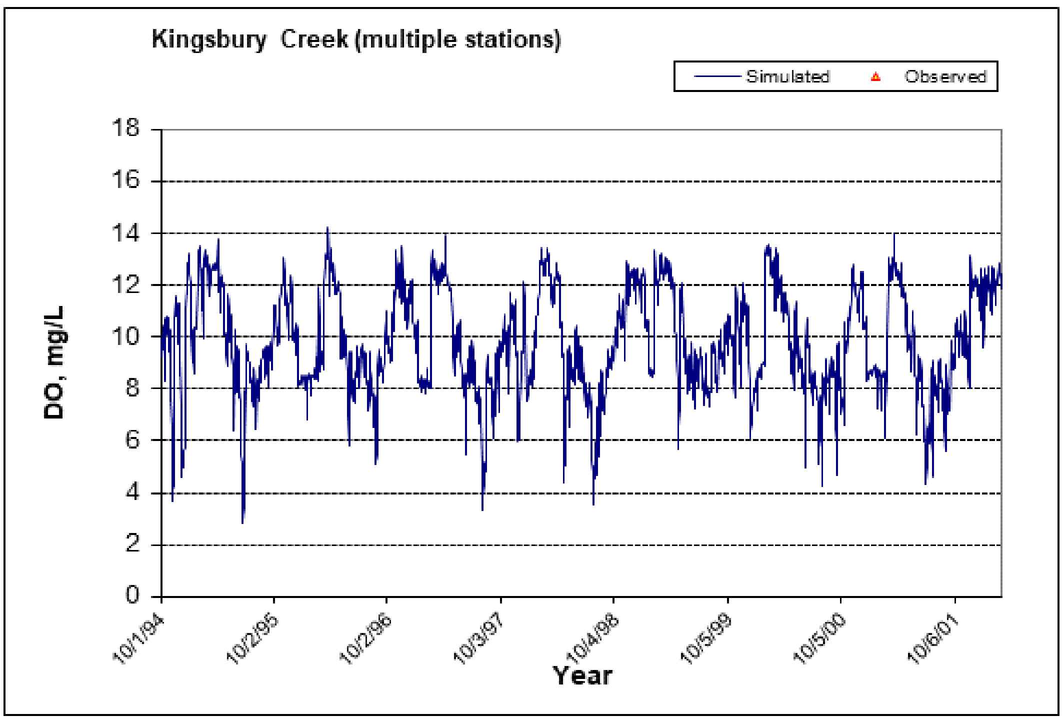


Figure E-798. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Kingsbury Creek (multiple stations) (calibration period)



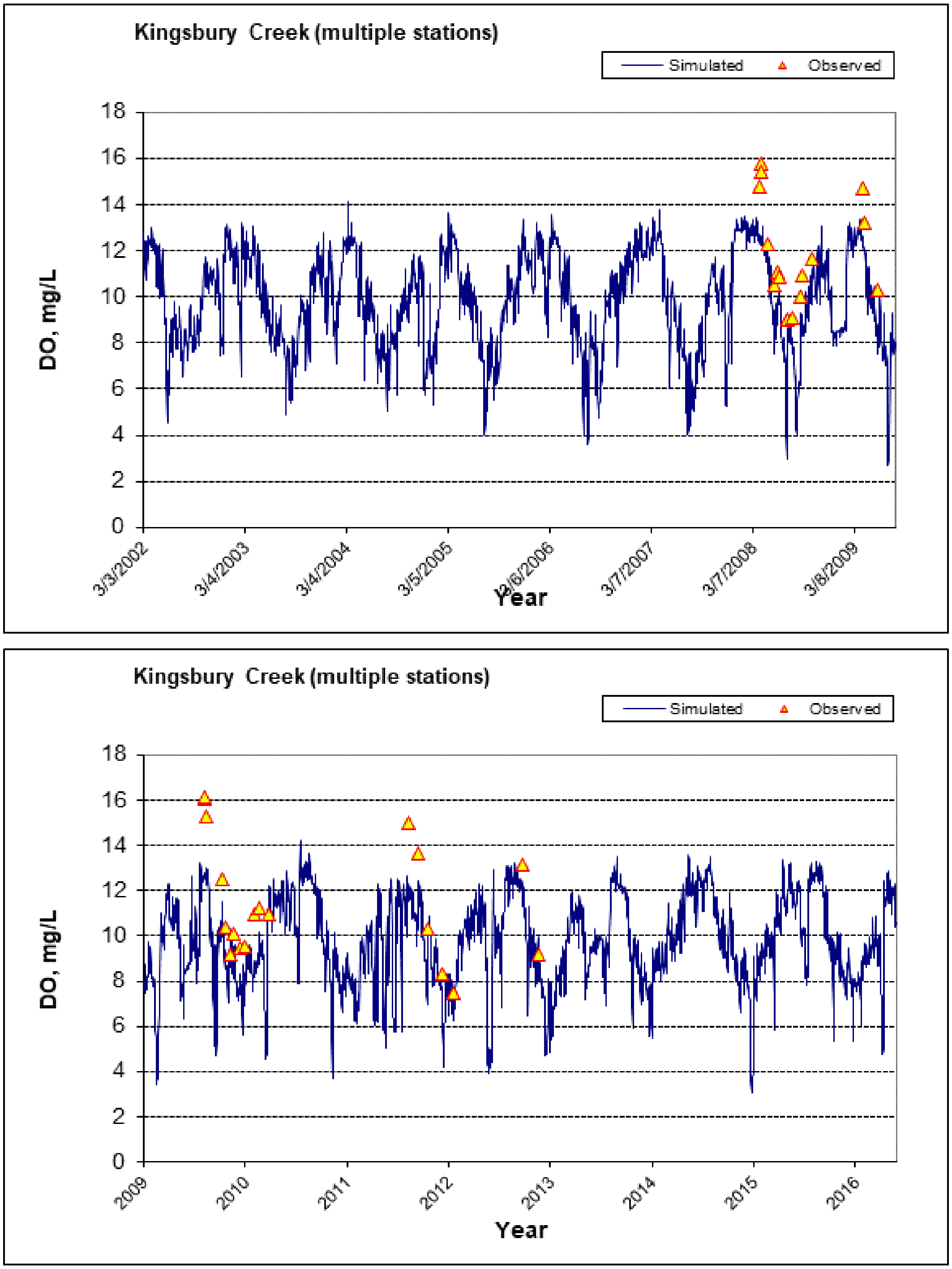


Figure E-799. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Kingsbury Creek (multiple stations)

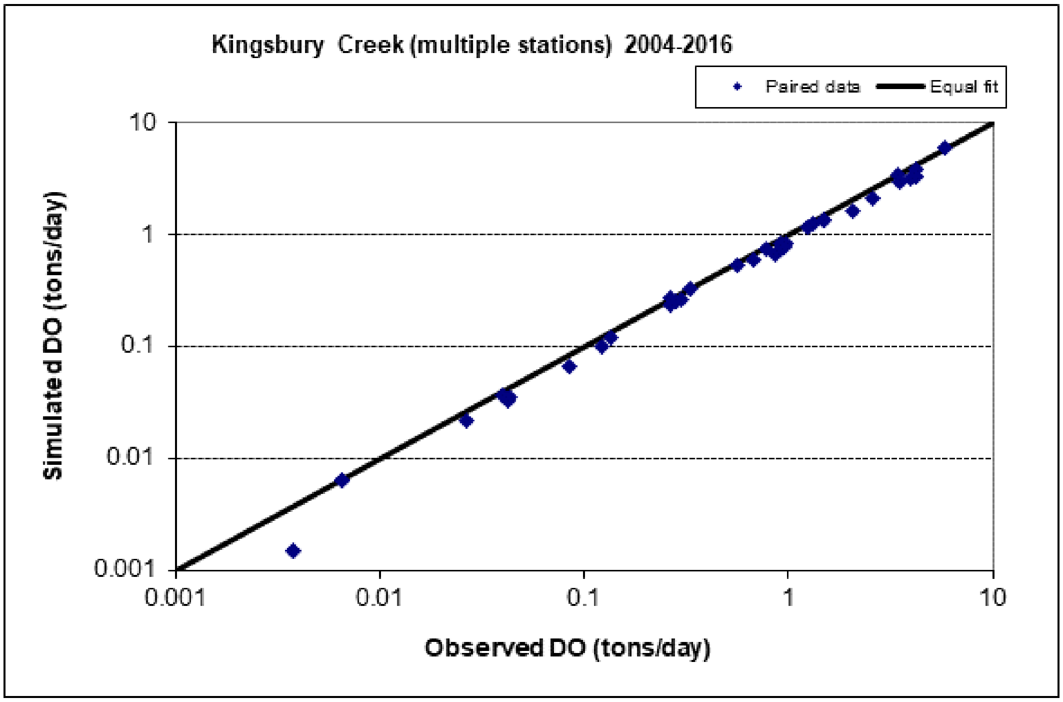


Figure E-800. Paired simulated vs. observed Dissolved Oxygen (DO) load at Kingsbury Creek (multiple stations) (calibration period)

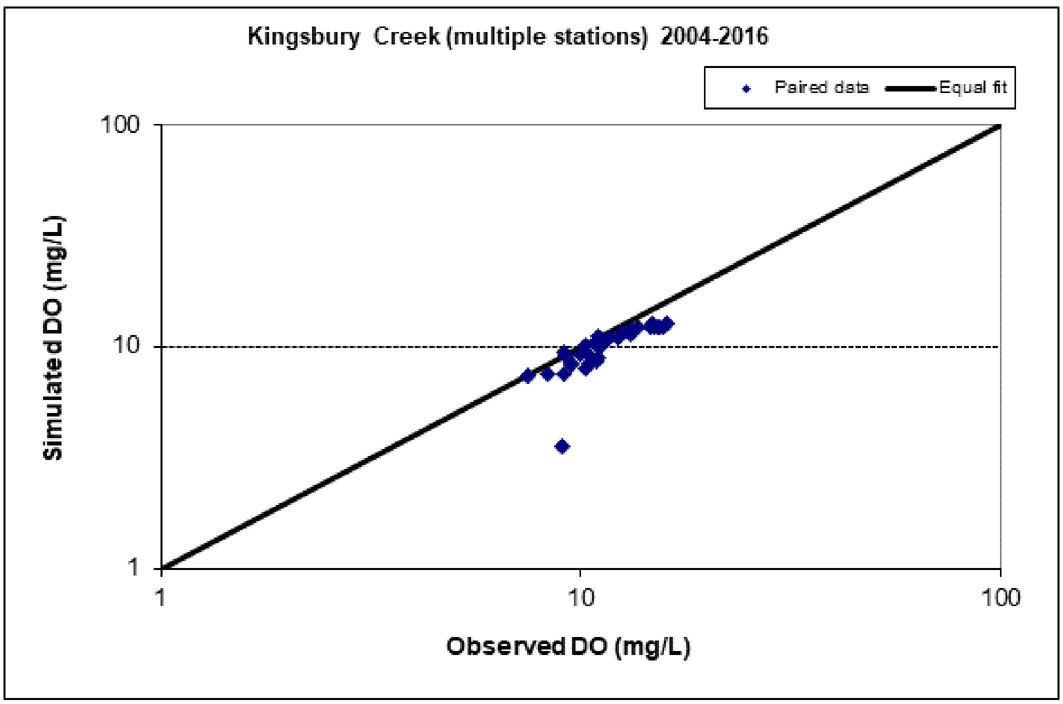


Figure E-801. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Kingsbury Creek (multiple stations) (calibration period)

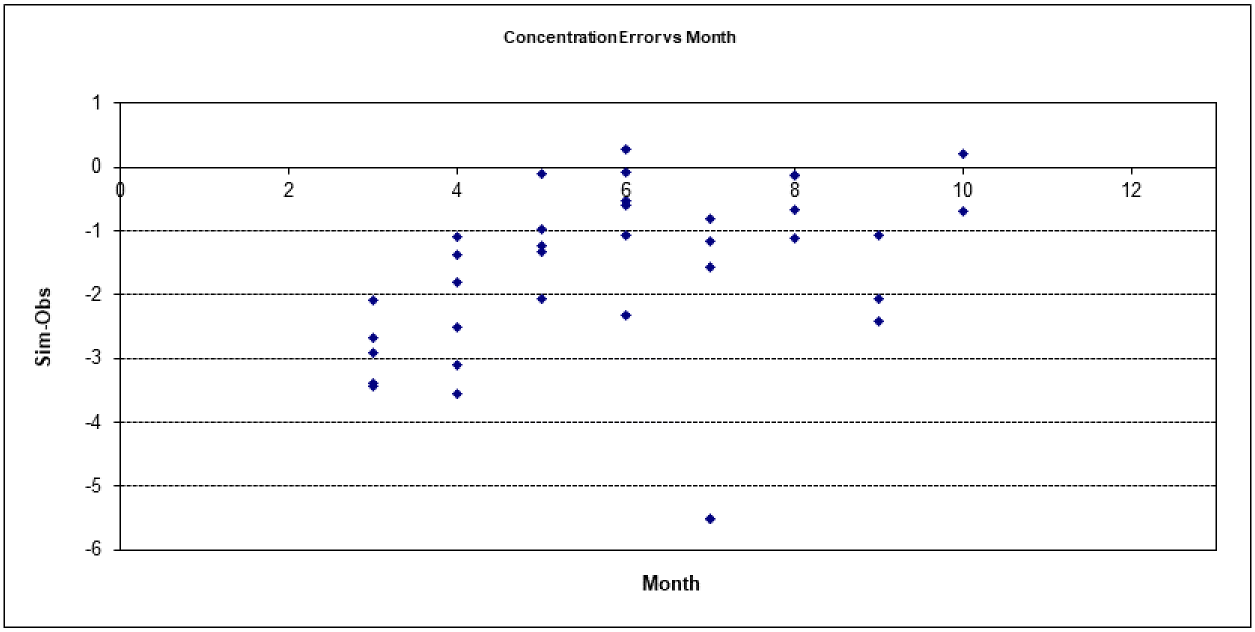


Figure E-802. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Kingsbury Creek (multiple stations)

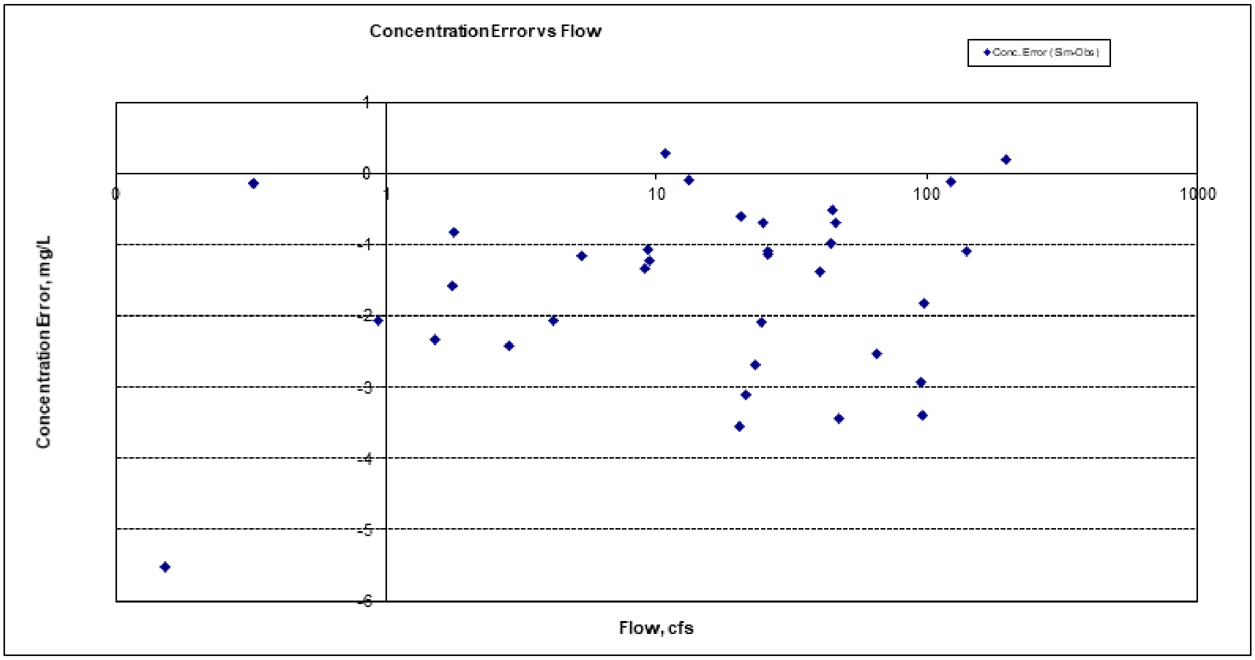


Figure E-803. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Kingsbury Creek (multiple stations)

E.18.2 Ammonia Nitrogen (NH3)

Table E-102. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	37
Concentration Average Error		194.66%
Concentration Median Error		66.91%
Load Average Error		154.78%
Load Median Error		15.99%
Paired t conc		0.00
Paired t load		0.00

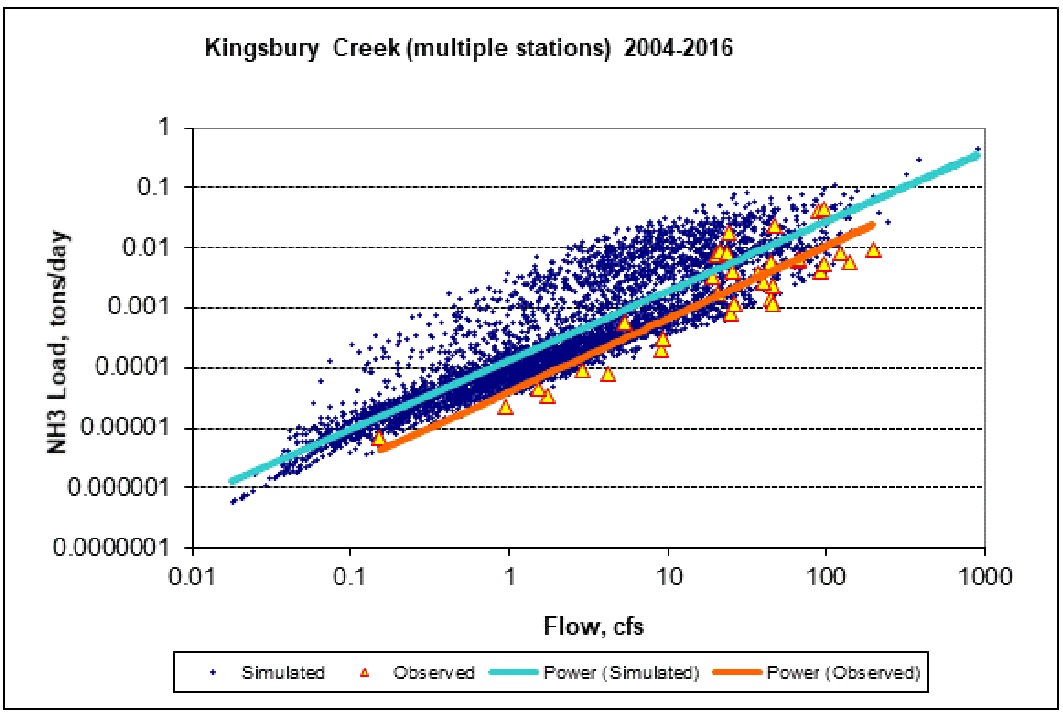


Figure E-804. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Kingsbury Creek (multiple stations) (calibration period)

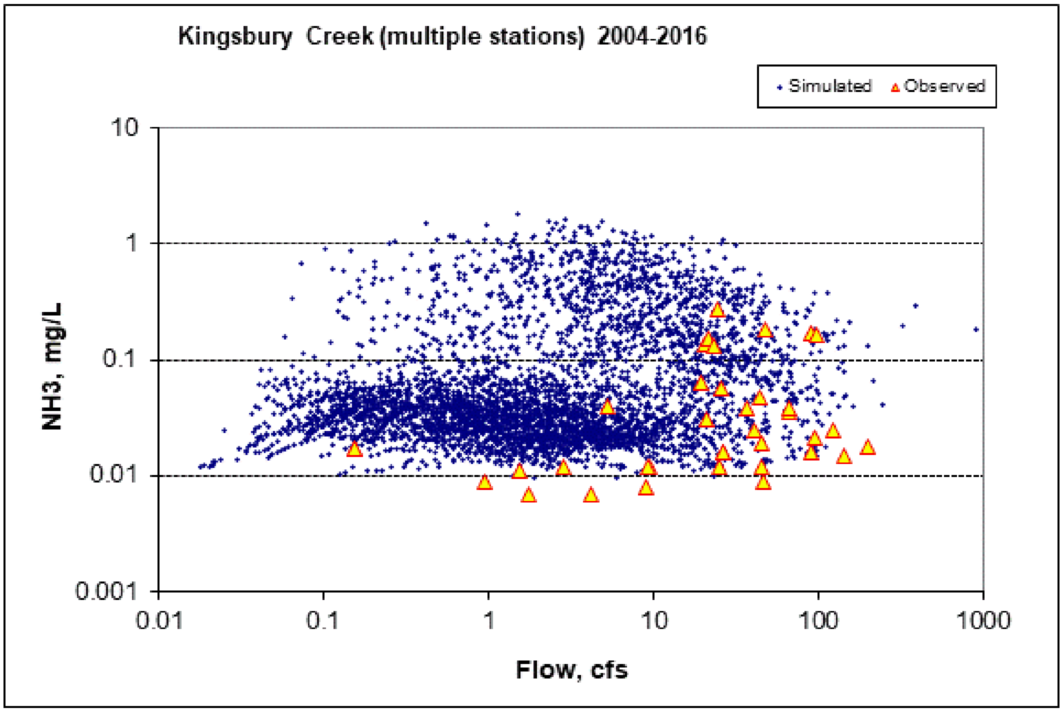
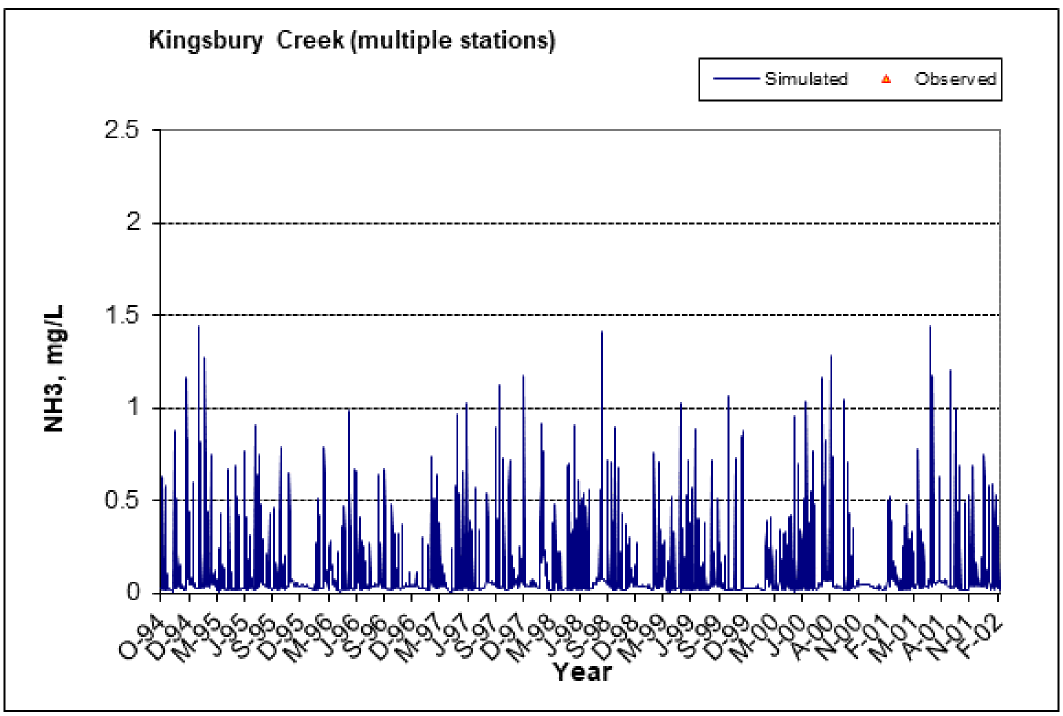
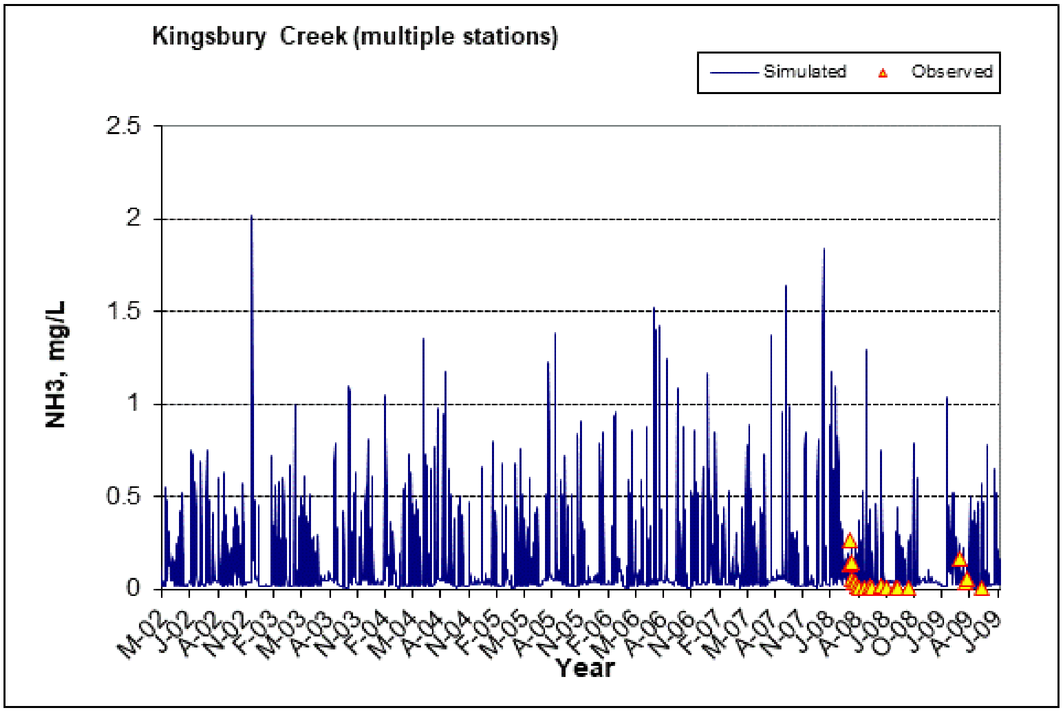


Figure E-805. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Kingsbury Creek (multiple stations) (calibration period)





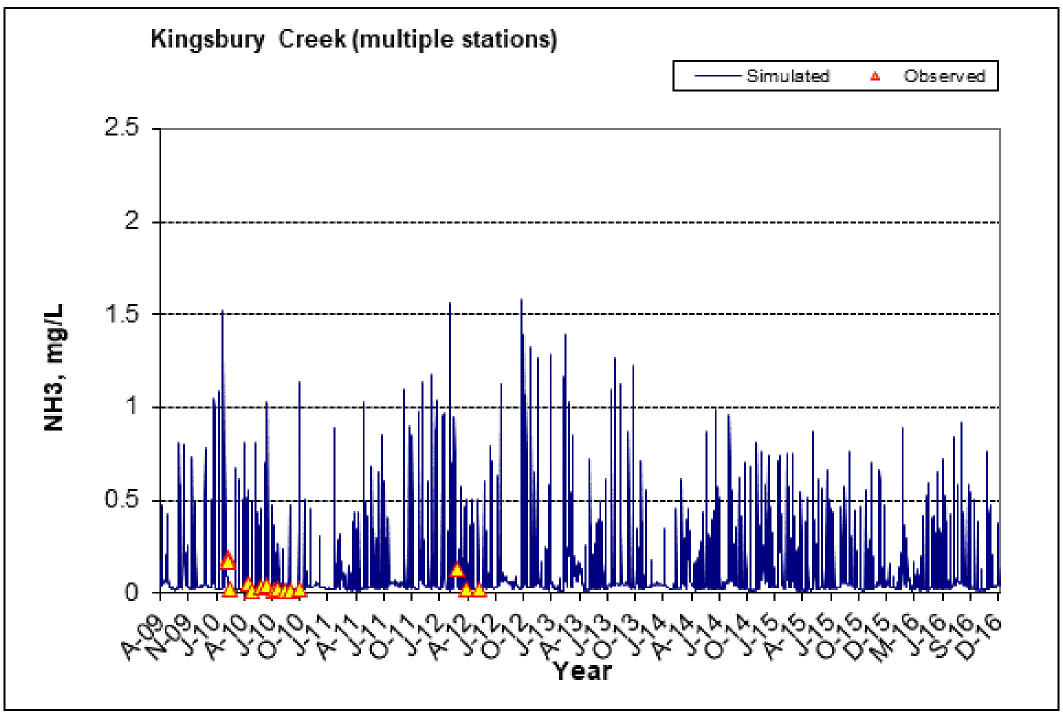


Figure E-806. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Kingsbury Creek (multiple stations)

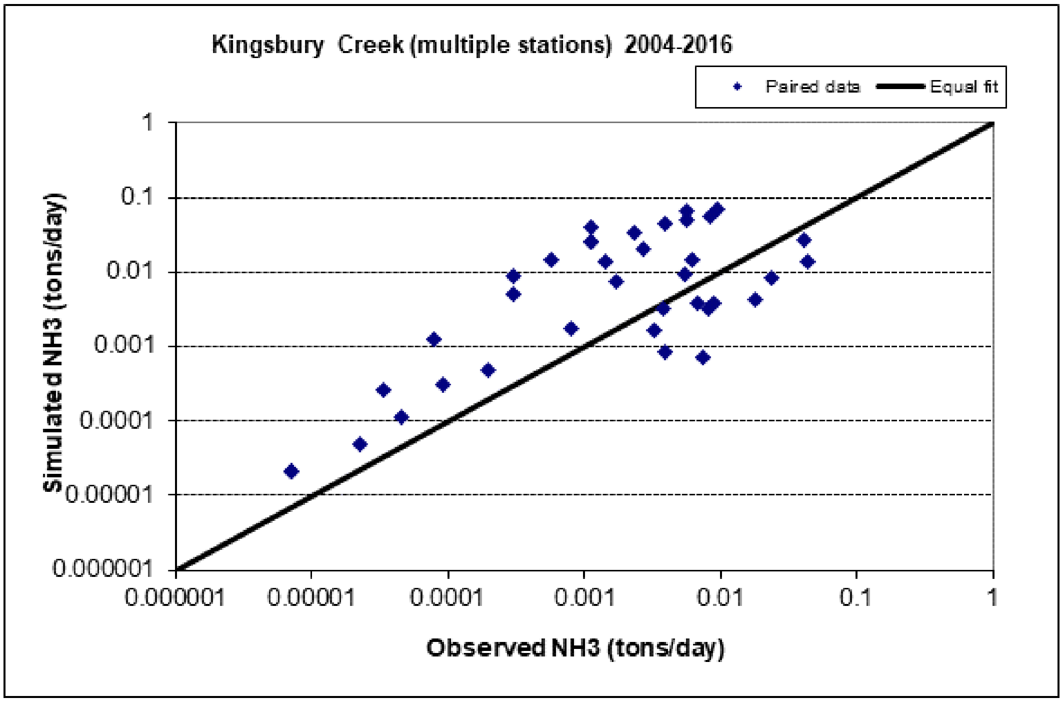


Figure E-807. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Kingsbury Creek (multiple stations) (calibration period)

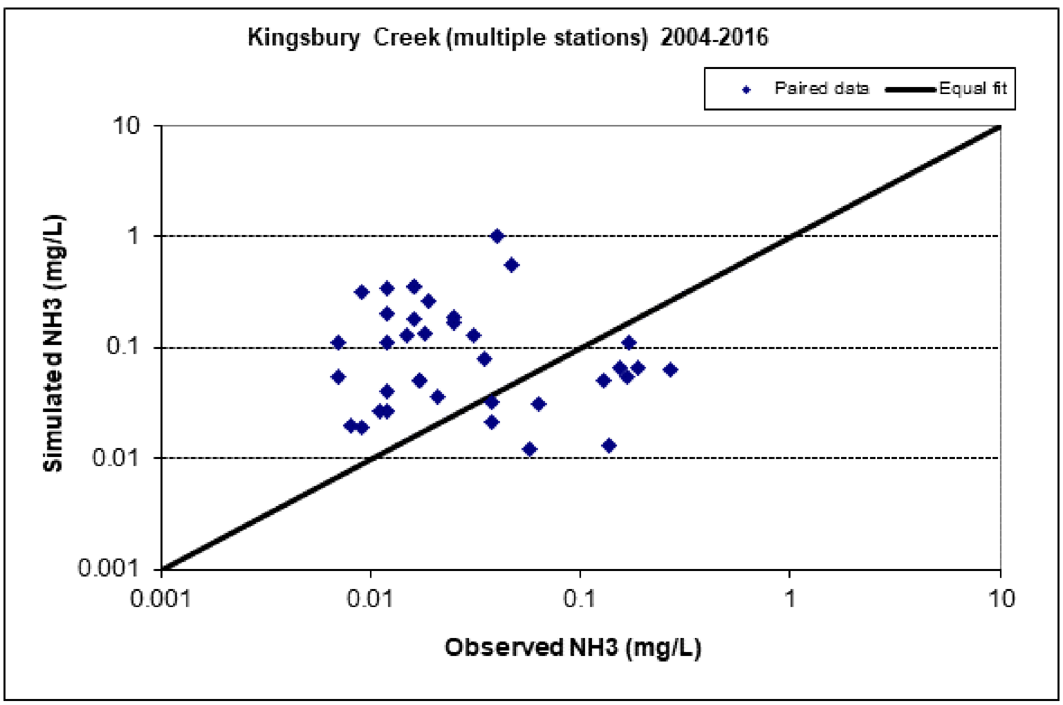


Figure E-808. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Kingsbury Creek (multiple stations) (calibration period)

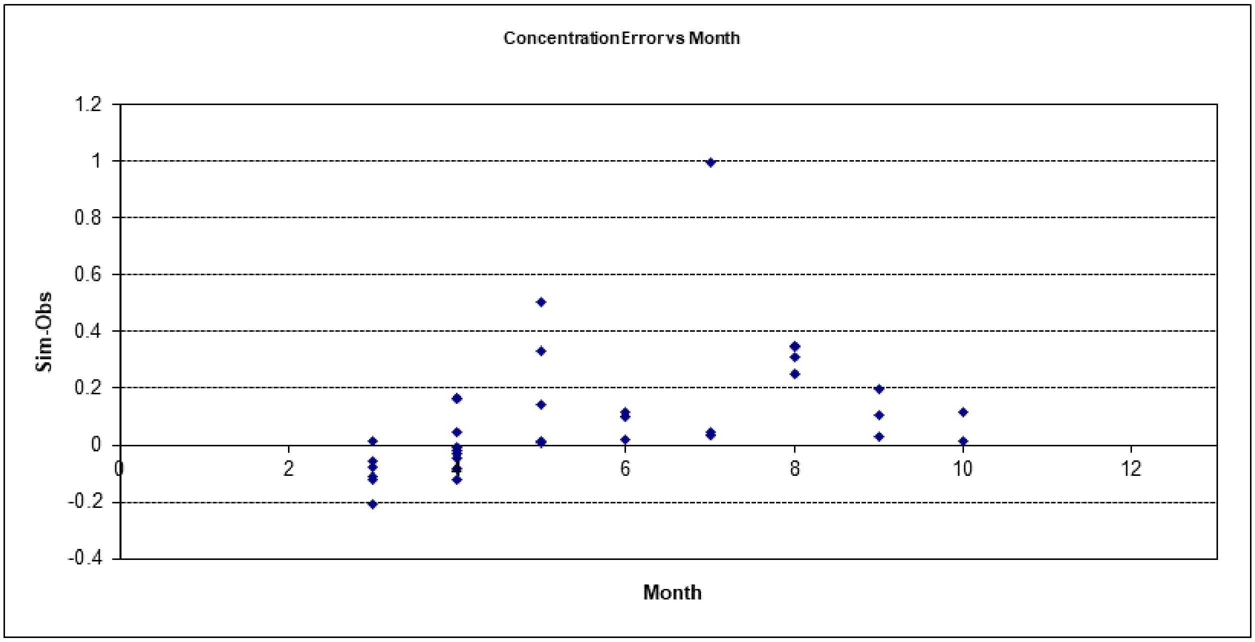


Figure E-809. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Kingsbury Creek (multiple stations)

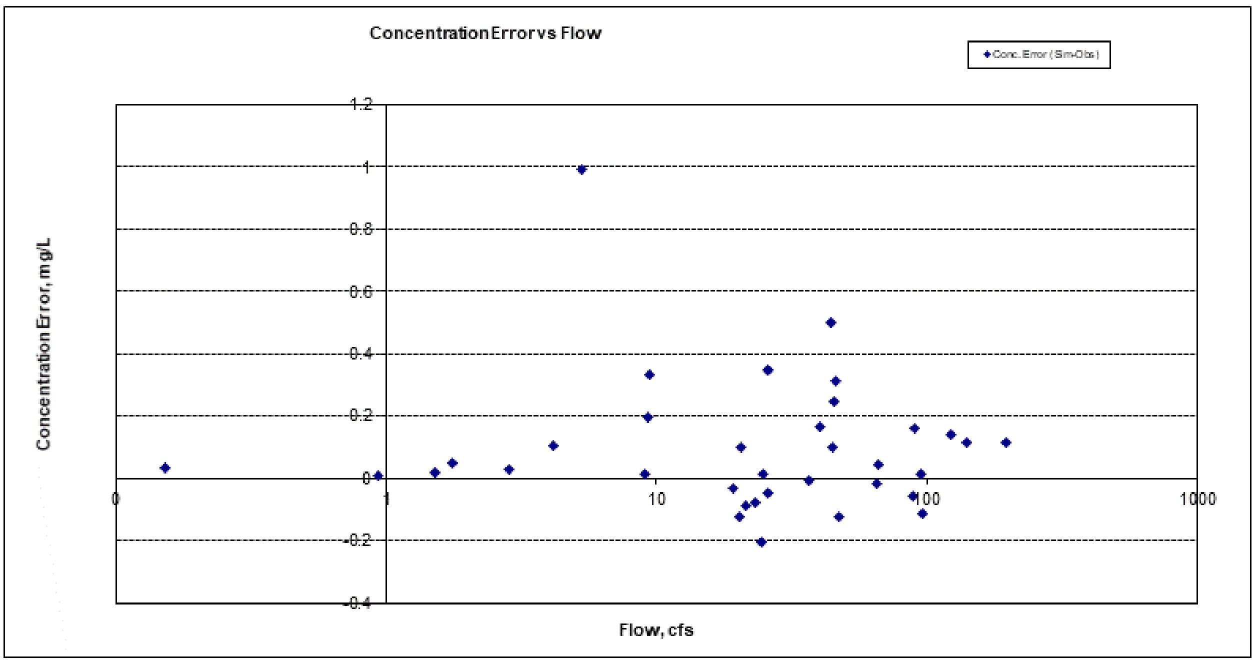


Figure E-810. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Kingsbury Creek (multiple stations)

E.18.3 Organic Nitrogen (OrgN)

Table E-103. Organic Nitrogen (OrgN) statistics

Period	1994-2004	2004-2016
Count	ND	35
Concentration Average Error		-18.74%
Concentration Median Error		-10.99%
Load Average Error		-10.44%
Load Median Error		-8.06%
Paired t conc		0.61
Paired t load		0.68

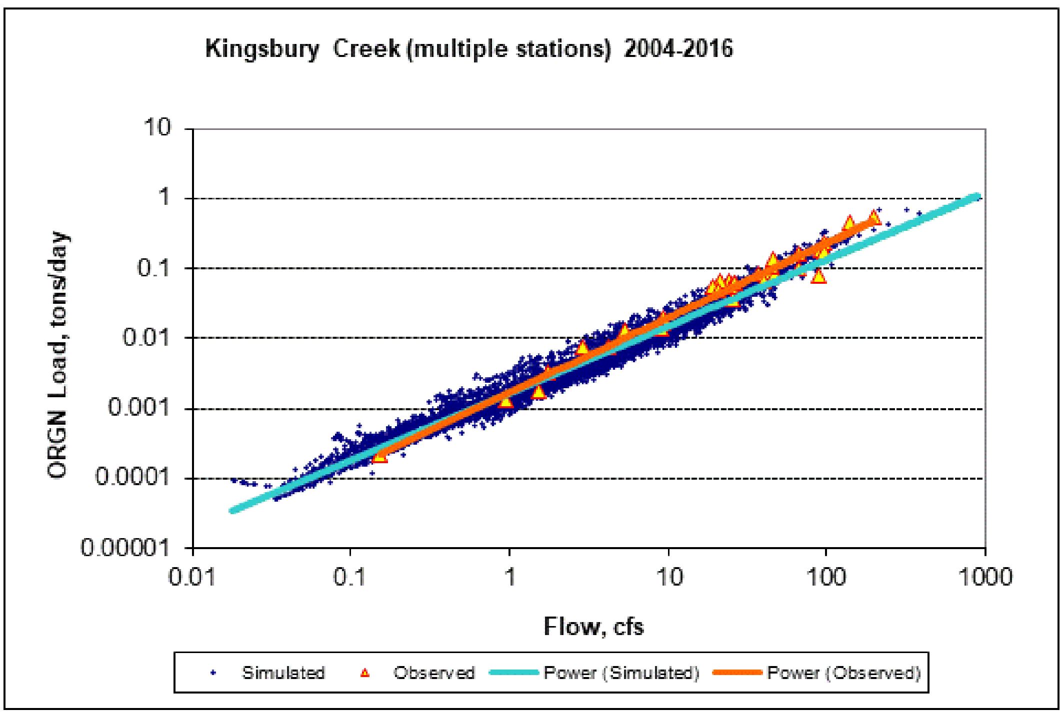


Figure E-811. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Kingsbury Creek (multiple stations) (calibration period)

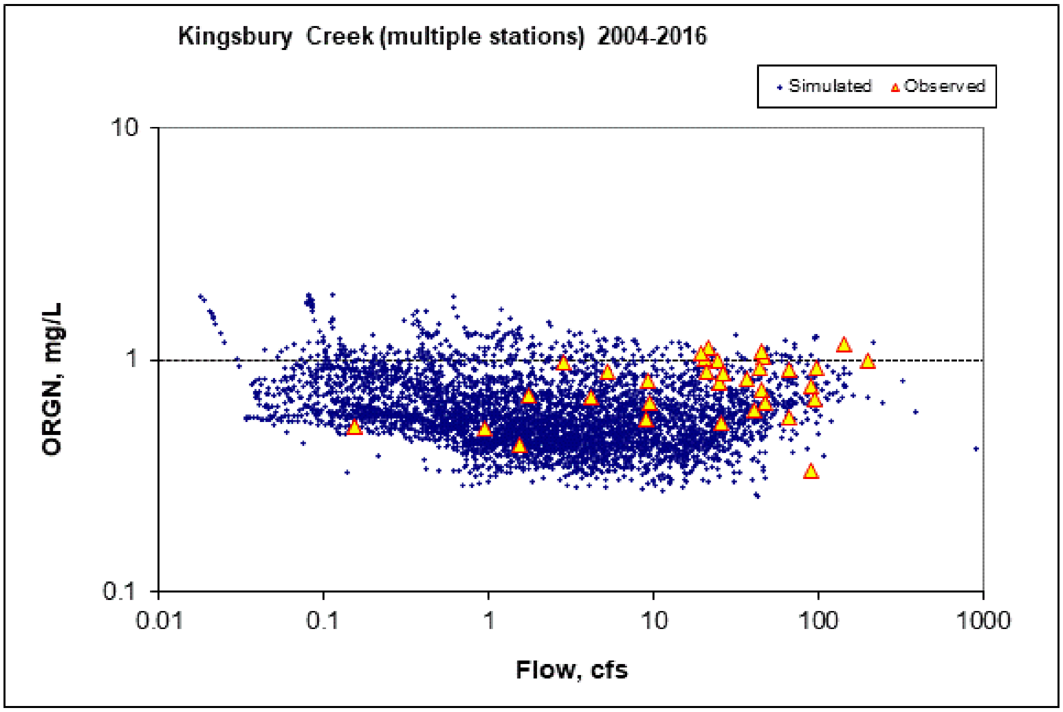
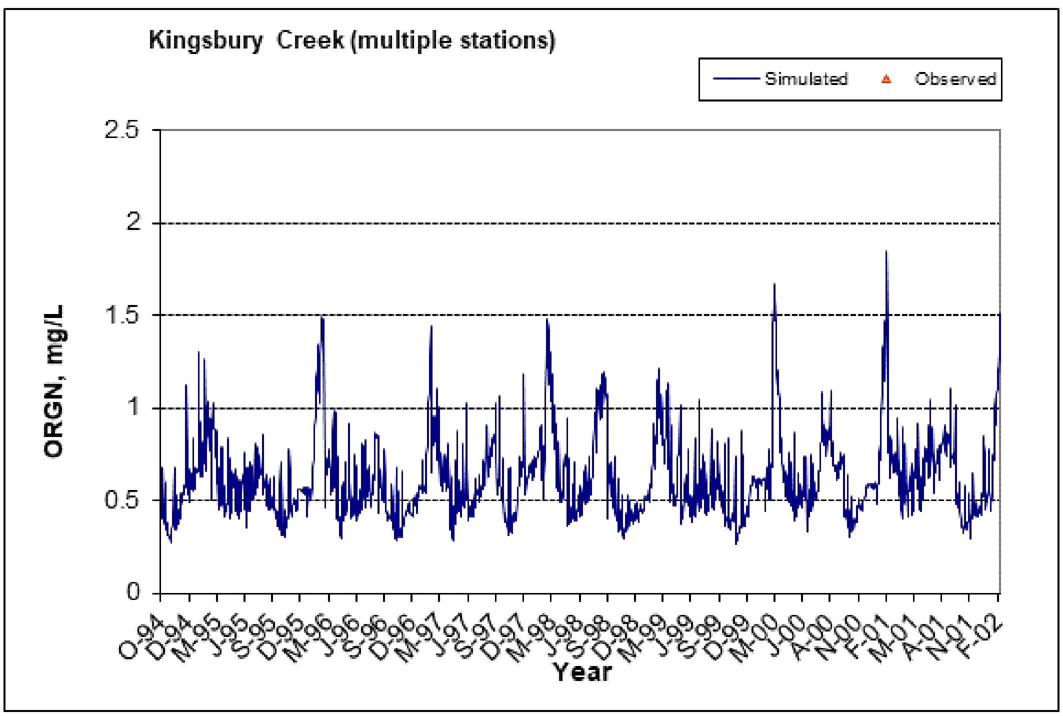


Figure E-812. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Kingsbury Creek (multiple stations) (calibration period)



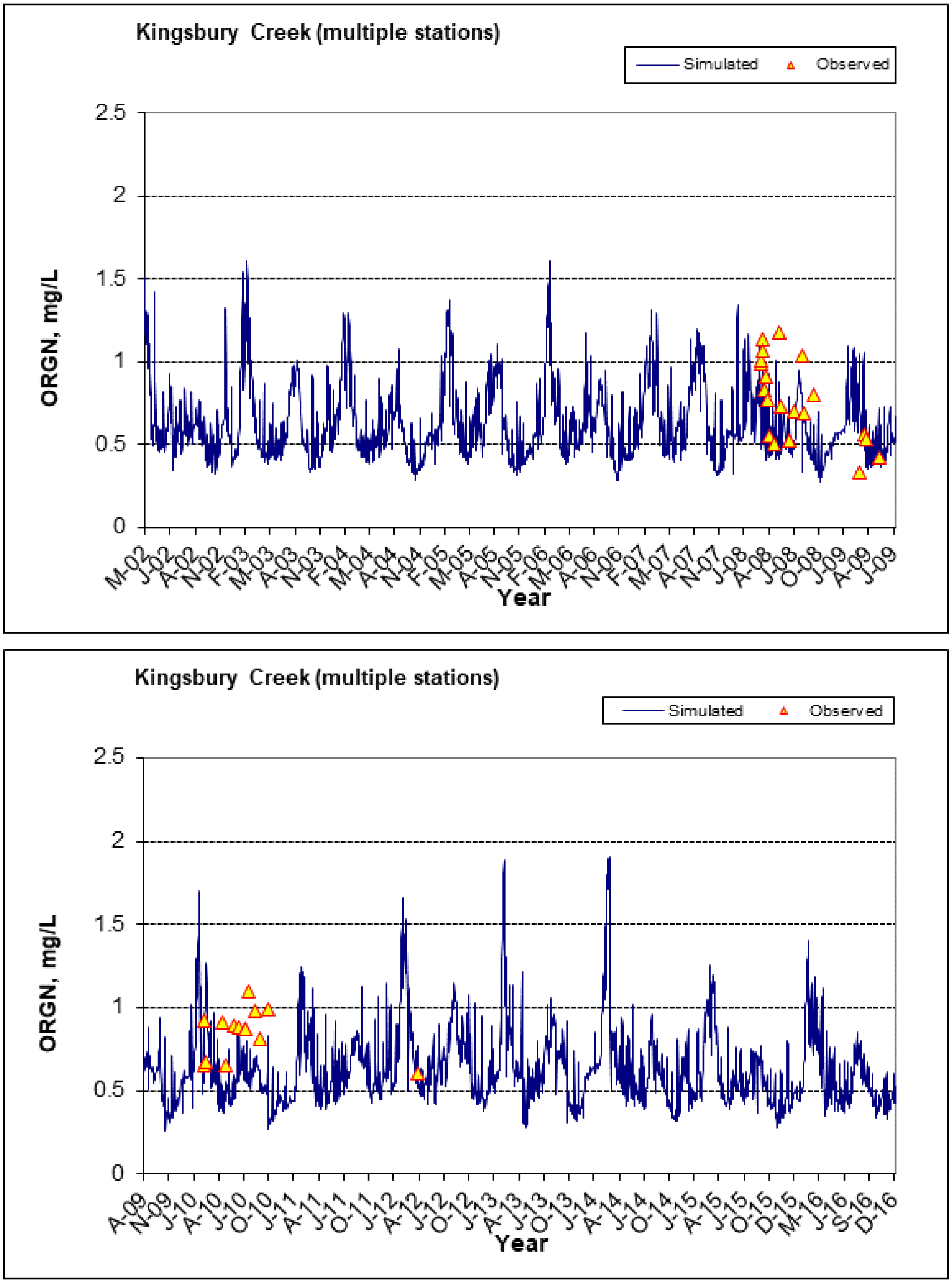


Figure E-813. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Kingsbury Creek (multiple stations)

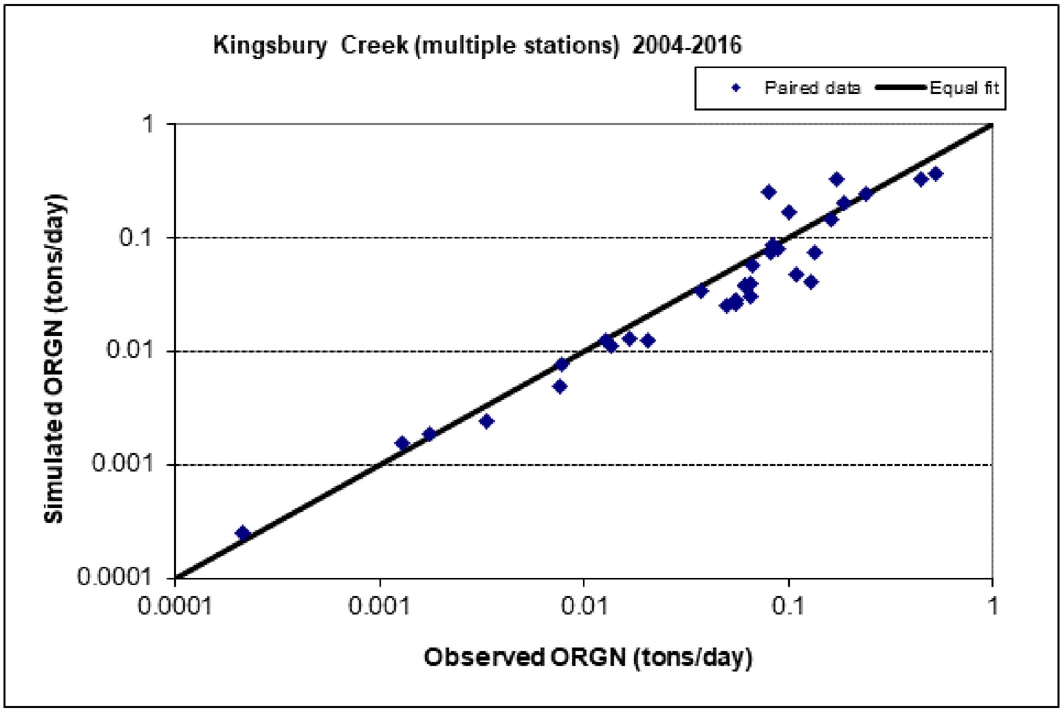


Figure E-814. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Kingsbury Creek (multiple stations) (calibration period)

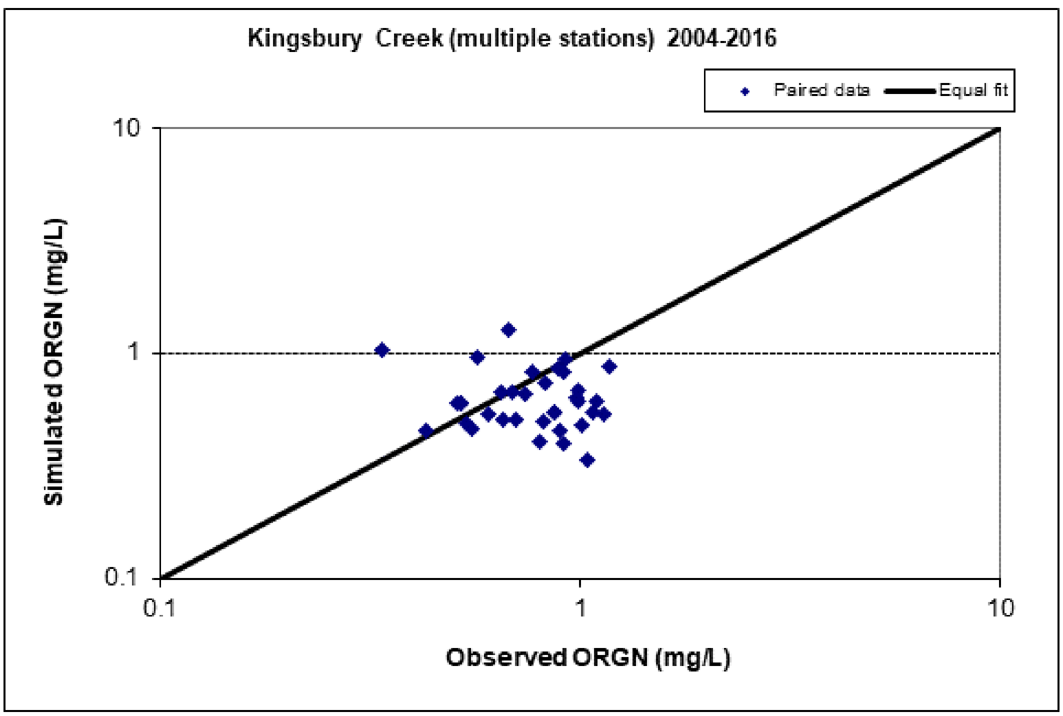


Figure E-815. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Kingsbury Creek (multiple stations) (calibration period)

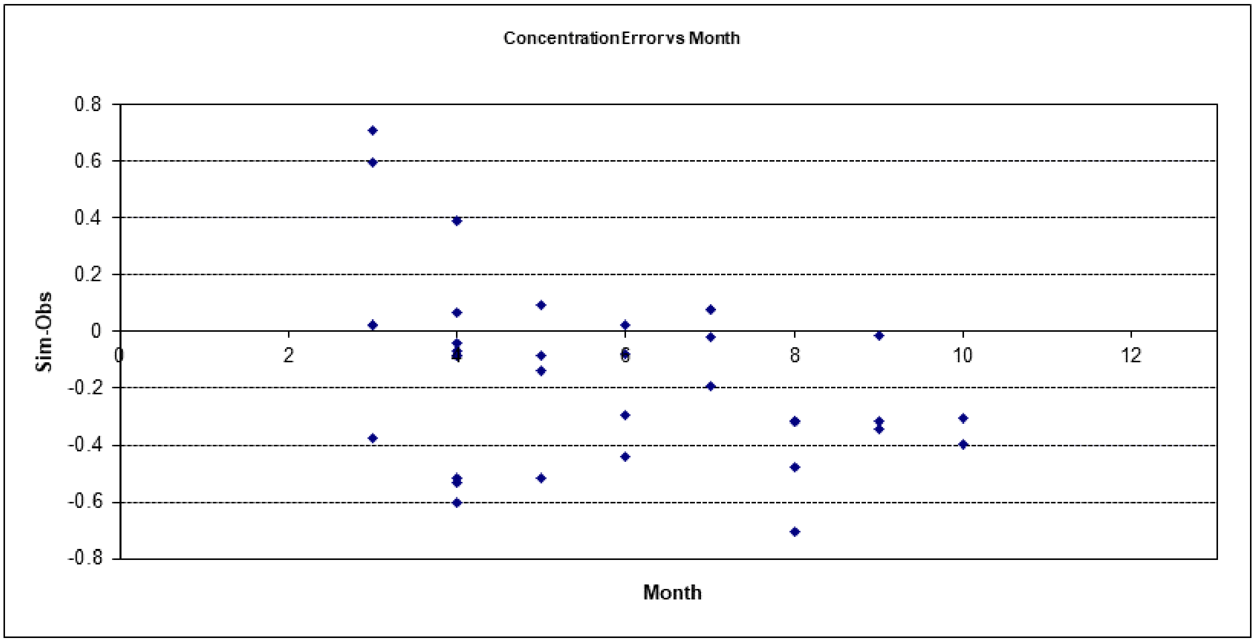


Figure E-816. Residual (Simulated - Observed) vs. Month, Organic Nitrogen (OrgN) at Kingsbury Creek (multiple stations)

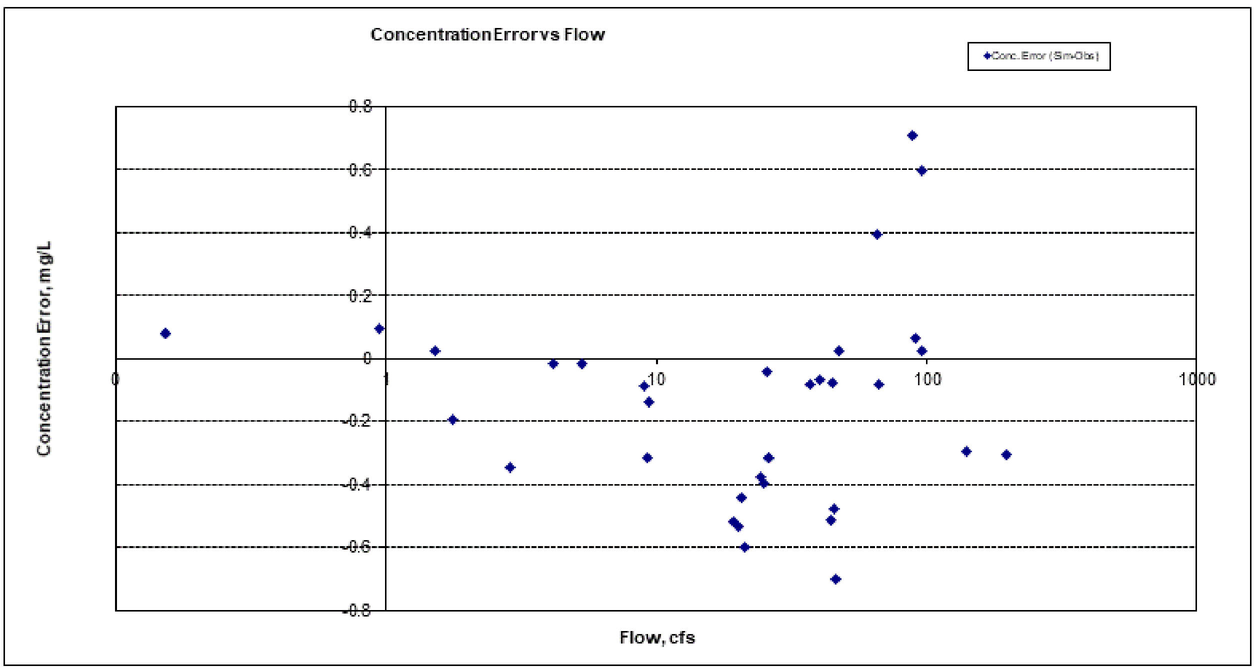


Figure E-817. Residual (Simulated - Observed) vs. Flow, Organic Nitrogen (OrgN) at Kingsbury Creek (multiple stations)

E.18.4 Total Kjeldahl Nitrogen (TKN)

Table E-104. Total Kjeldahl Nitrogen (TKN) statistics

Period	1994-2004	2004-2016
Count	ND	35
Concentration Average Error		-5.39%
Concentration Median Error		-8.91%
Load Average Error		-0.74%
Load Median Error		-1.86%
Paired t conc		1.00
Paired t load		0.82

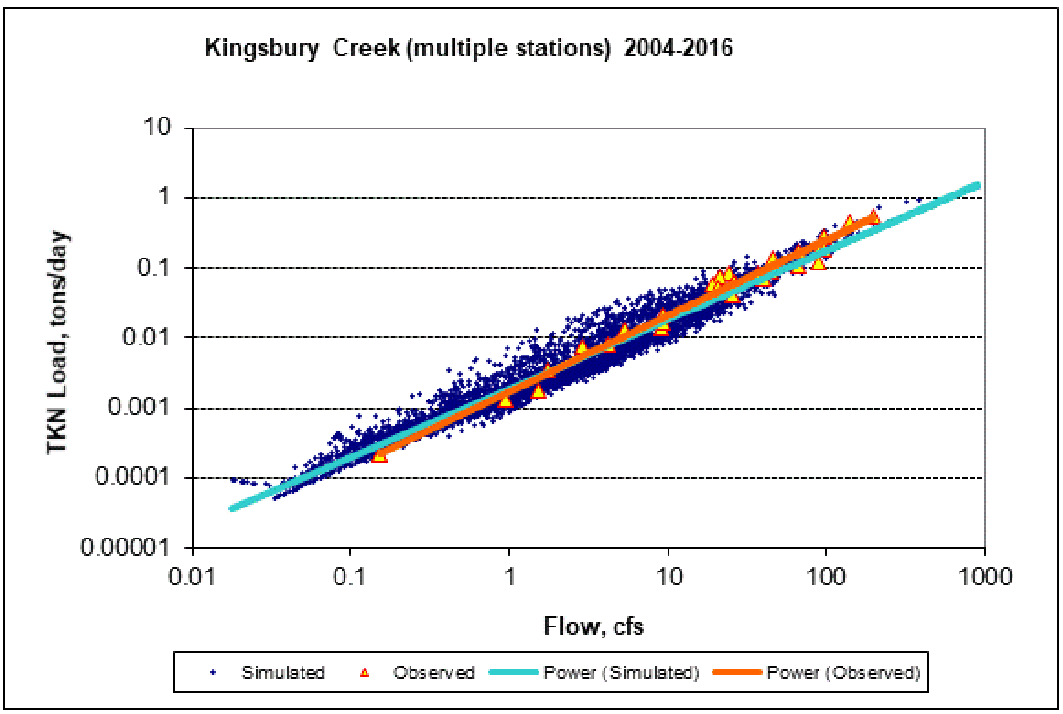


Figure E-818. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Kingsbury Creek (multiple stations) (calibration period)

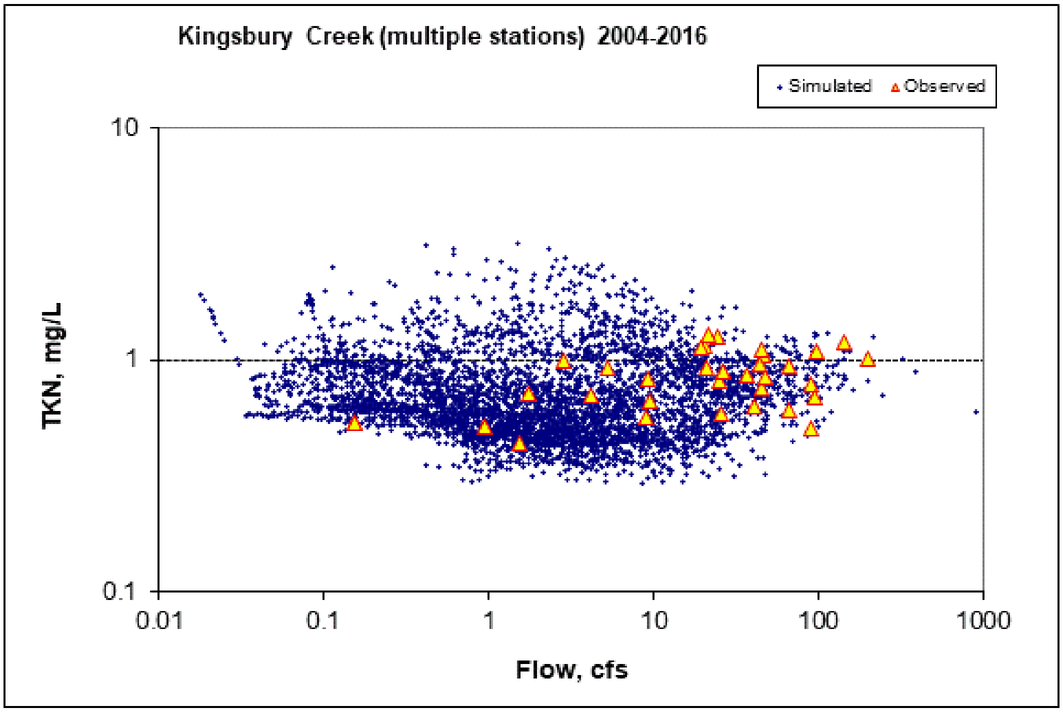
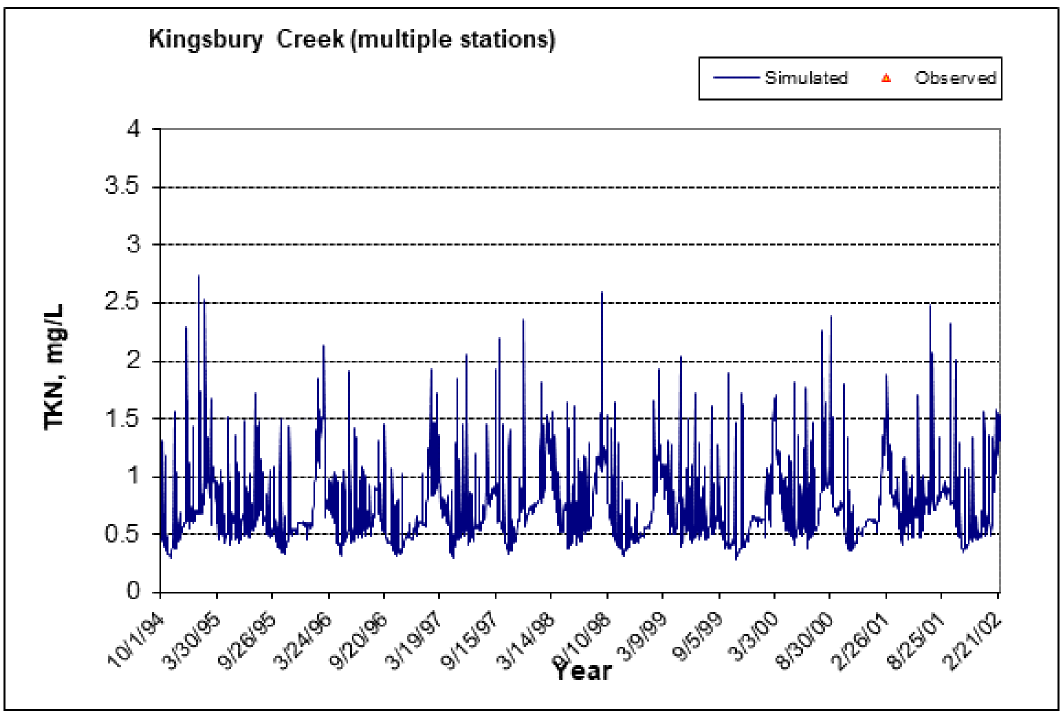


Figure E-819. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Kingsbury Creek (multiple stations) (calibration period)



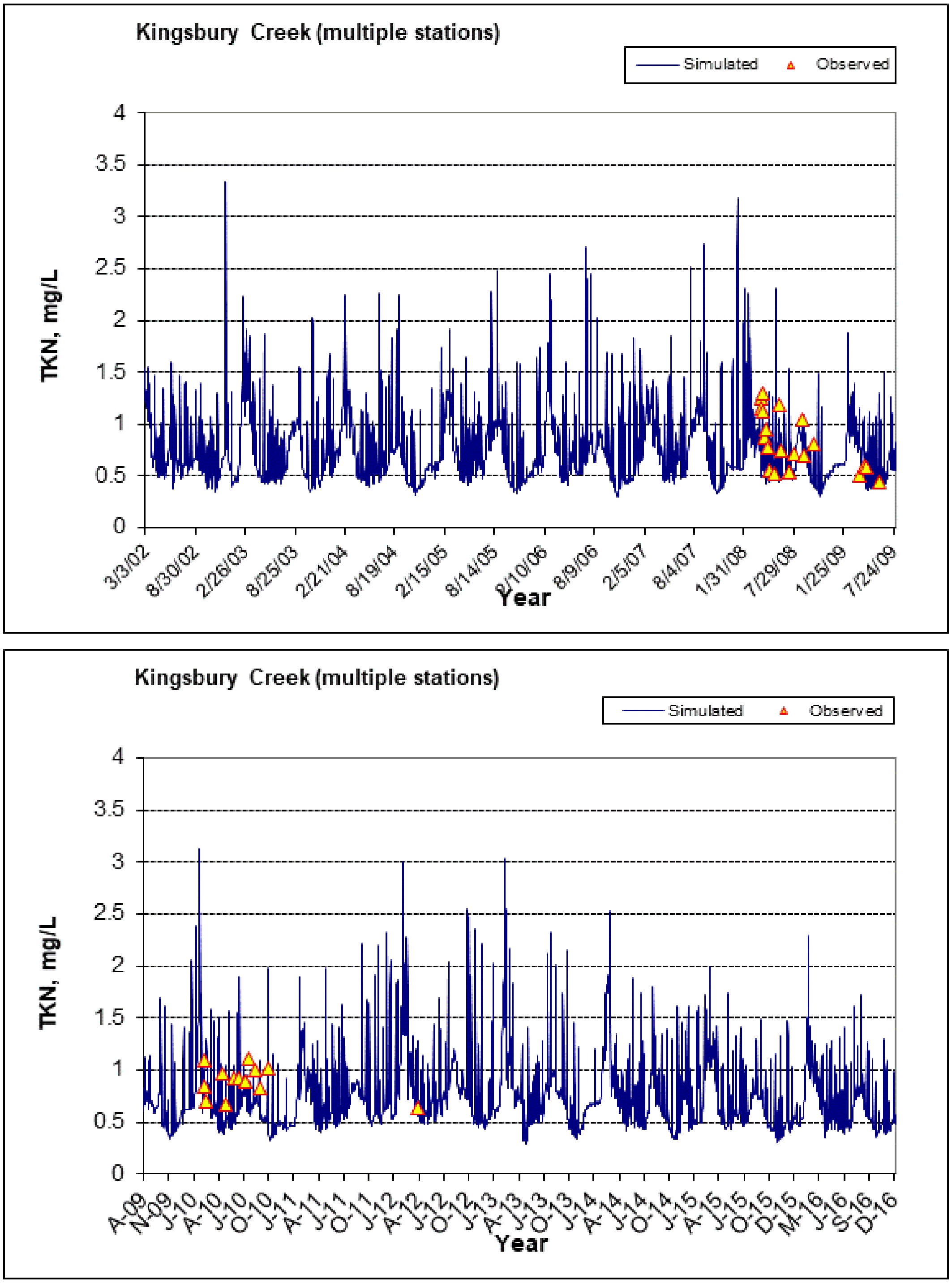


Figure E-820. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Kingsbury Creek (multiple stations)

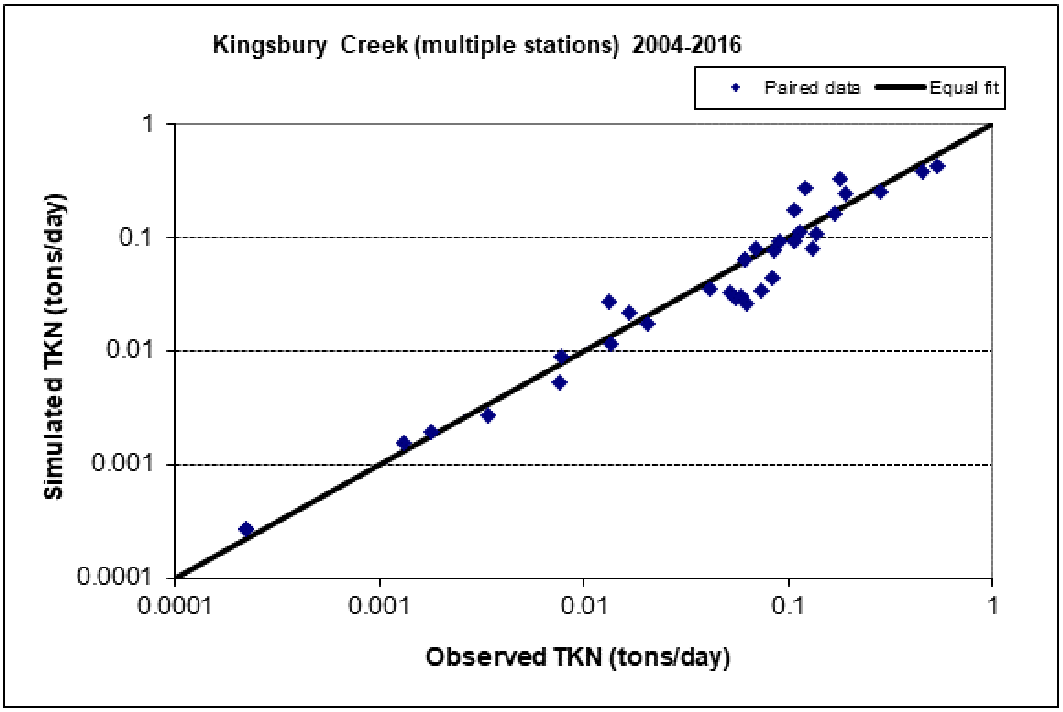


Figure E-821. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Kingsbury Creek (multiple stations) (calibration period)

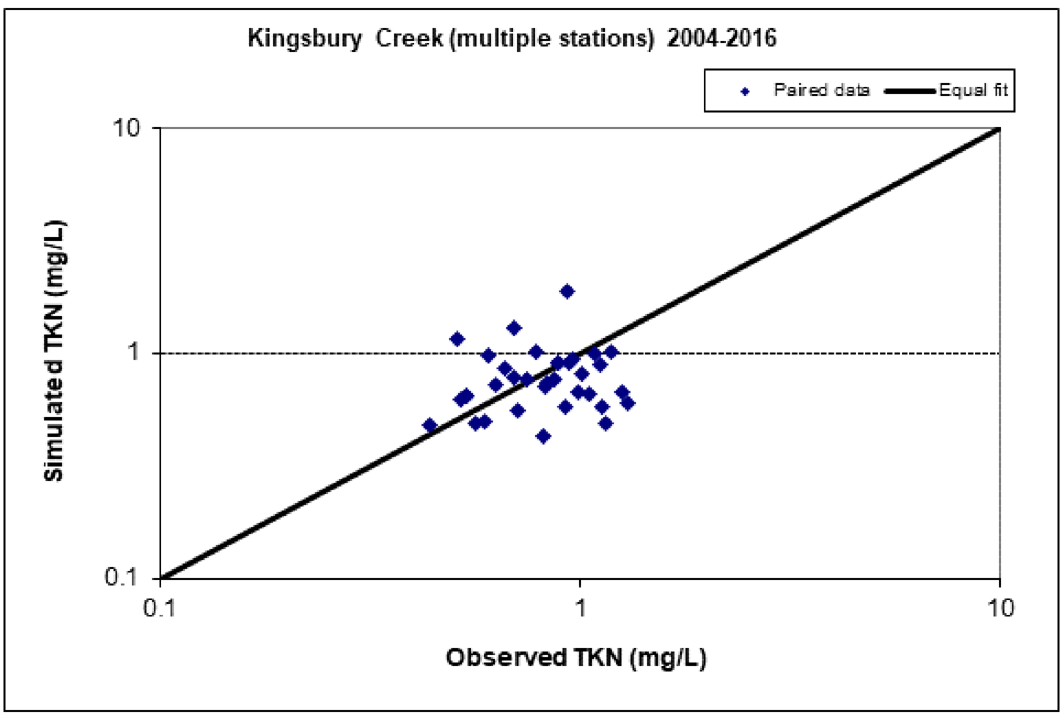


Figure E-822. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Kingsbury Creek (multiple stations) (calibration period)

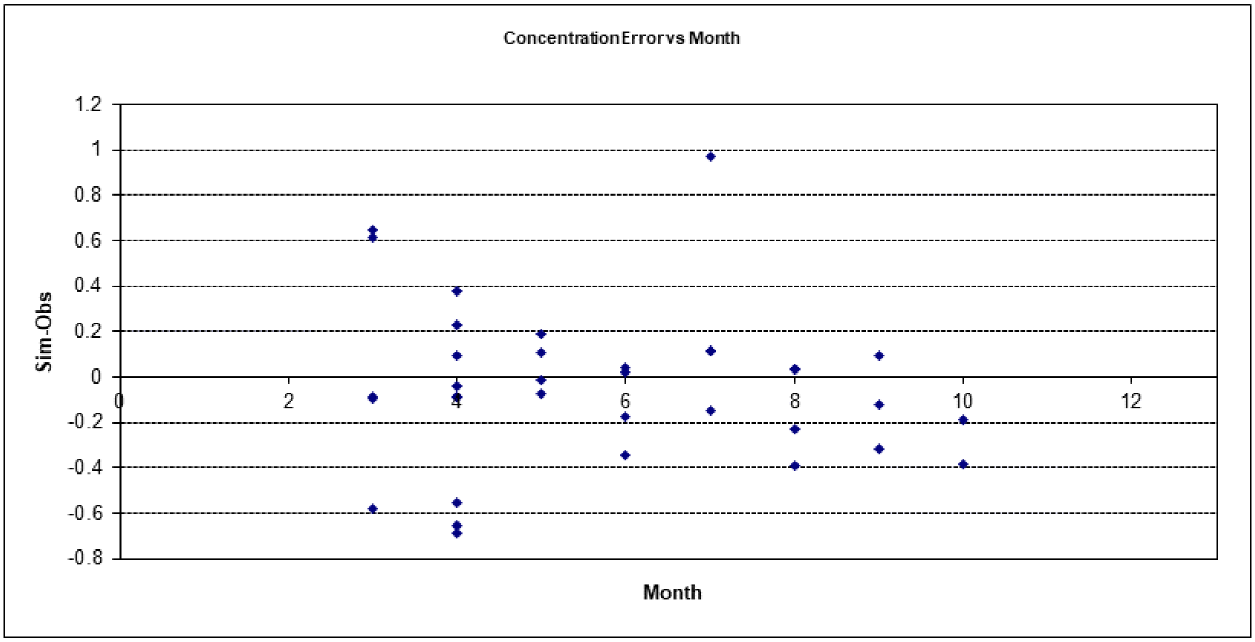


Figure E-823. Residual (Simulated - Observed) vs. Month, Total Kjeldahl Nitrogen (TKN) at Kingsbury Creek (multiple stations)

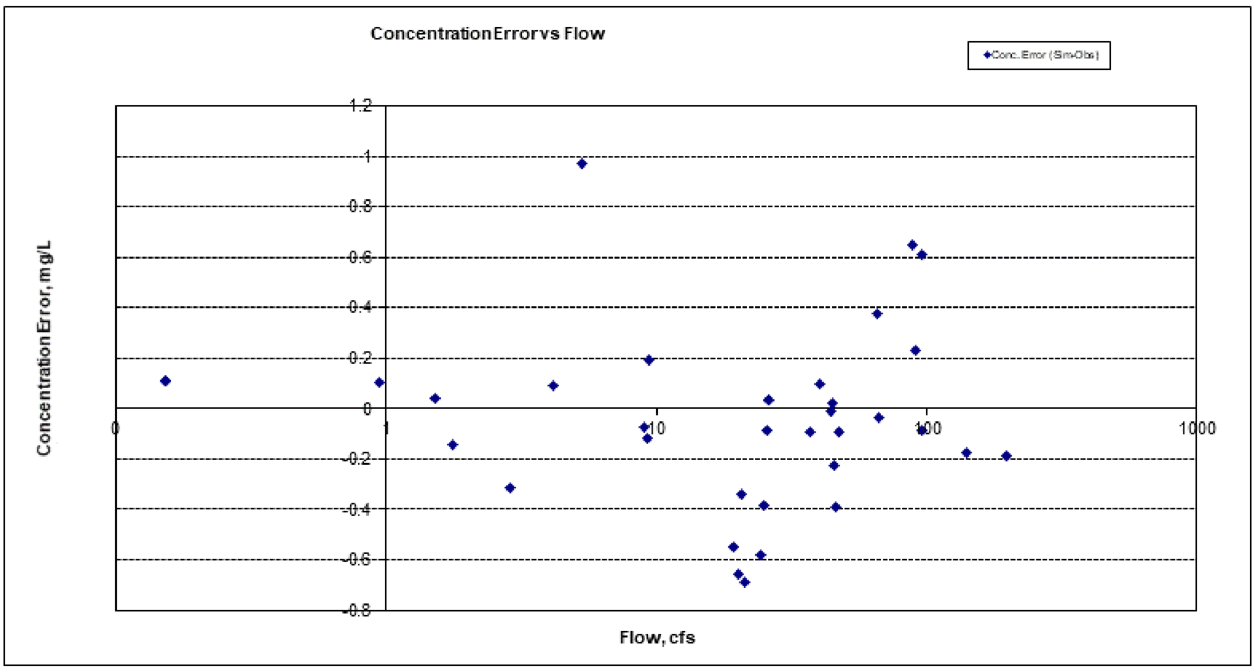


Figure E-824. Residual (Simulated - Observed) vs. Flow, Total Kjeldahl Nitrogen (TKN) at Kingsbury Creek (multiple stations)

E.18.5 Nitrite+ Nitrate Nitrogen (NOx)

Table E-105. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	37
Concentration Average Error		20.62%
Concentration Median Error		-7.90%
Load Average Error		8.87%
Load Median Error		-0.15%
Paired t conc		0.49
Paired t load		0.69

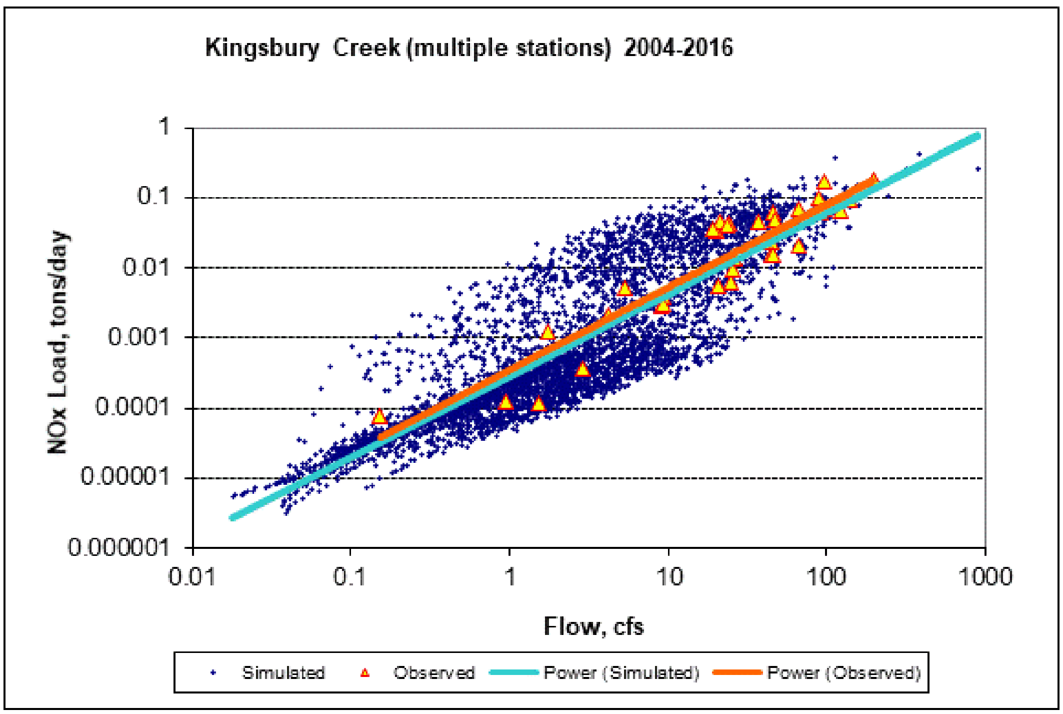


Figure E-825. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Kingsbury Creek (multiple stations) (calibration period)

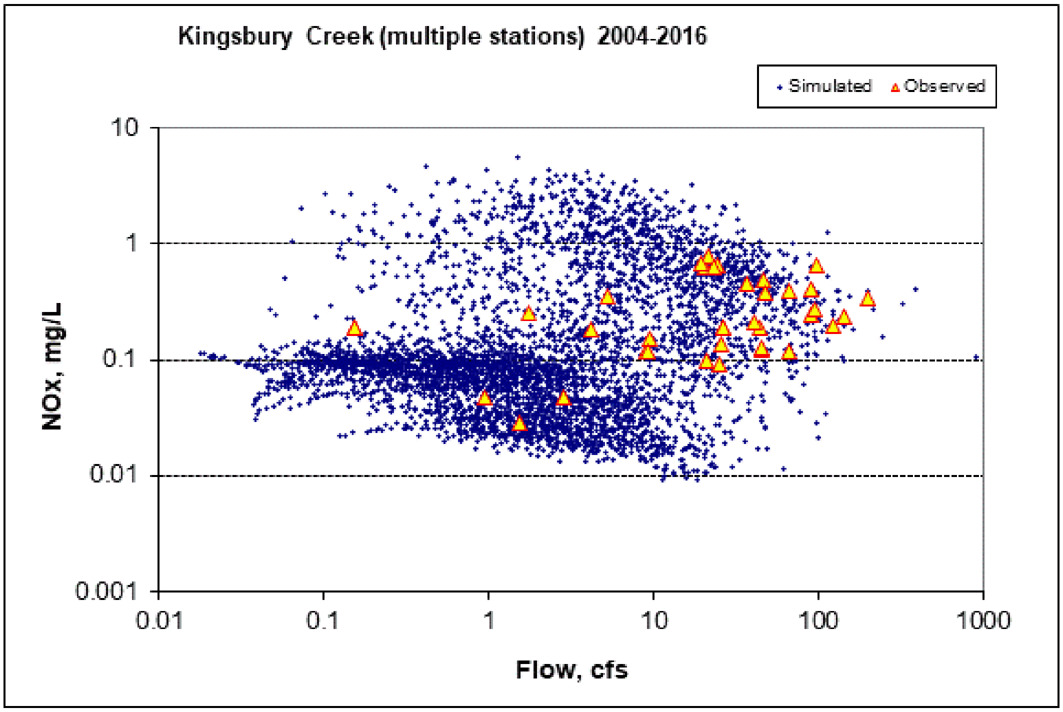
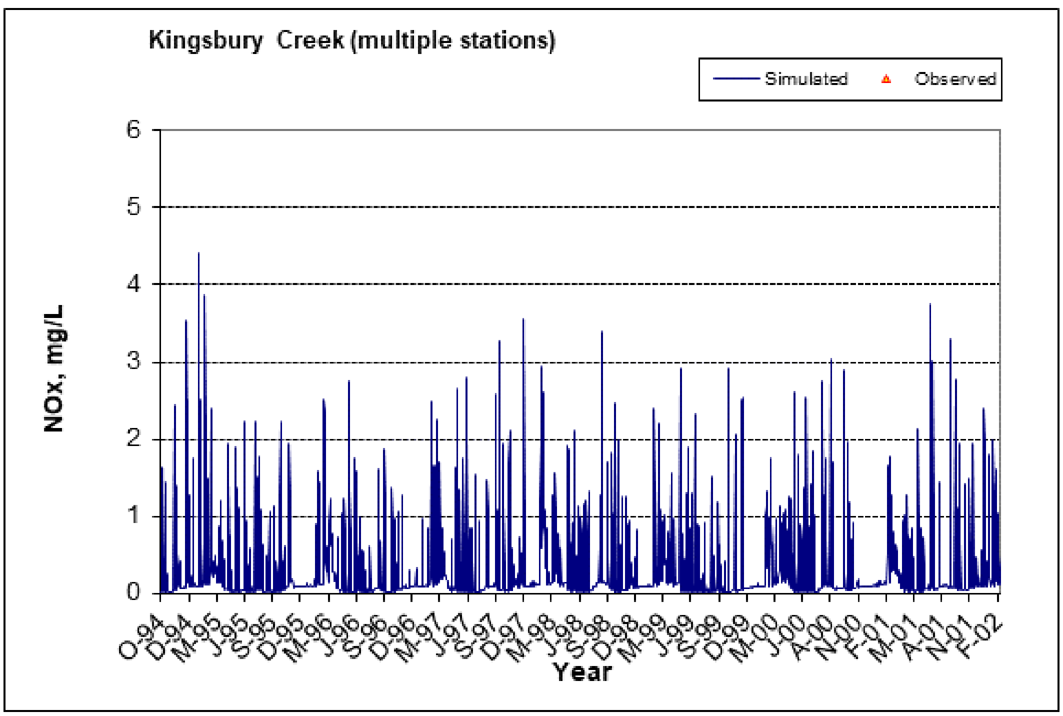


Figure E-826. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Kingsbury Creek (multiple stations) (calibration period)



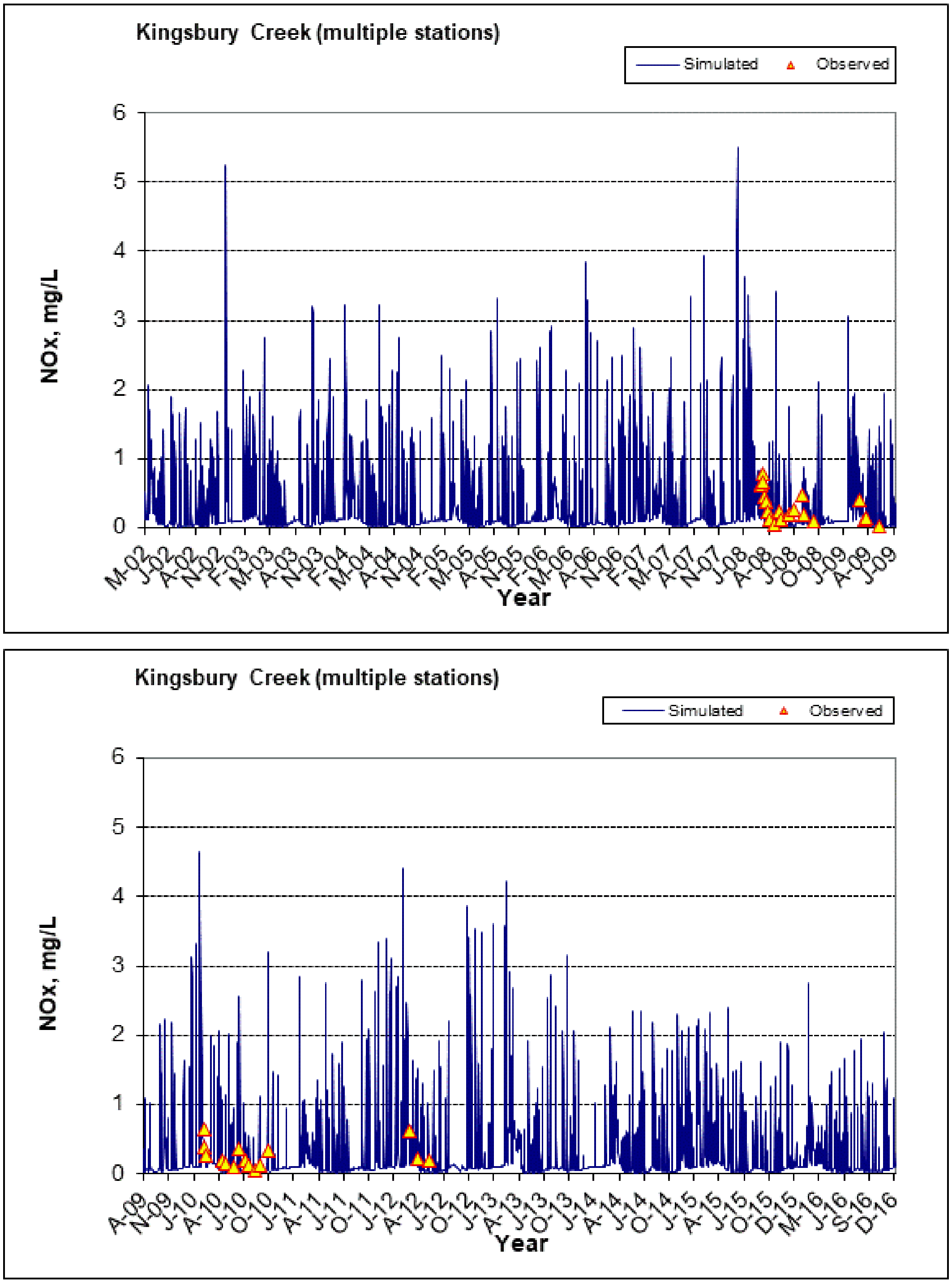


Figure E-827. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Kingsbury Creek (multiple stations)

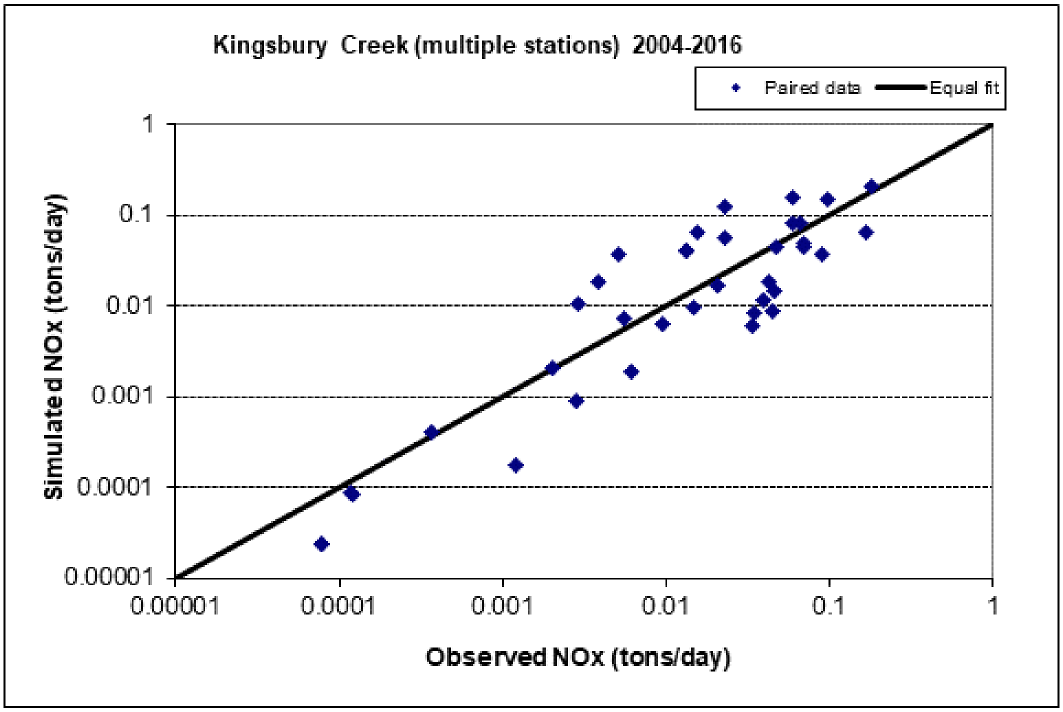


Figure E-828. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Kingsbury Creek (multiple stations) (calibration period)

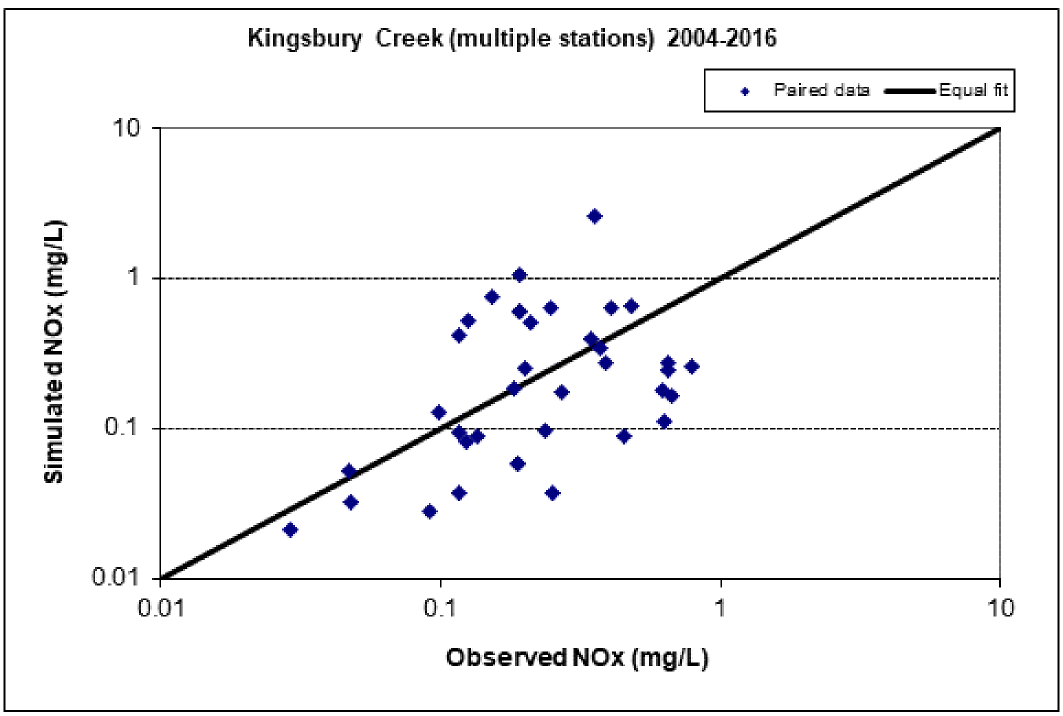


Figure E-829. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Kingsbury Creek (multiple stations) (calibration period)

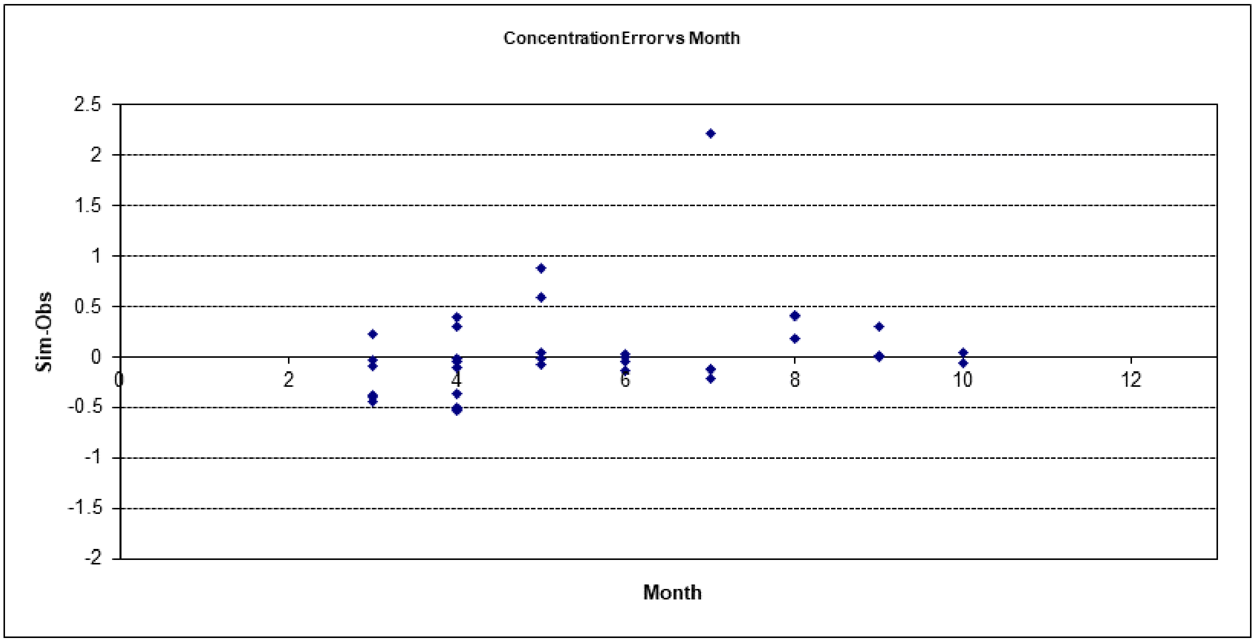


Figure E-830. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Kingsbury Creek (multiple stations)

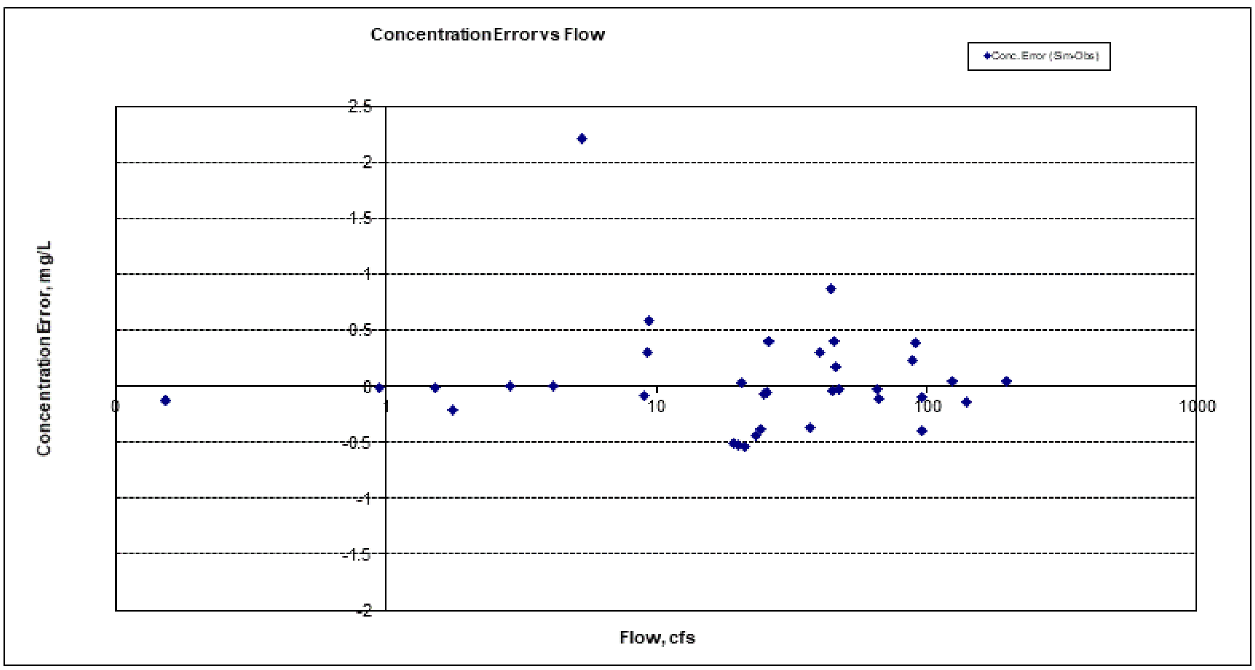


Figure E-831. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Kingsbury Creek (multiple stations)

E.18.6 Total Nitrogen (TN)

Table E-106. Total Nitrogen (TN) statistics

Period	1994-2004	2004-2016
Count	ND	35
Concentration Average Error		2.52%
Concentration Median Error		-1.83%
Load Average Error		2.23%
Load Median Error		-1.31%
Paired t conc		0.97
Paired t load		0.81

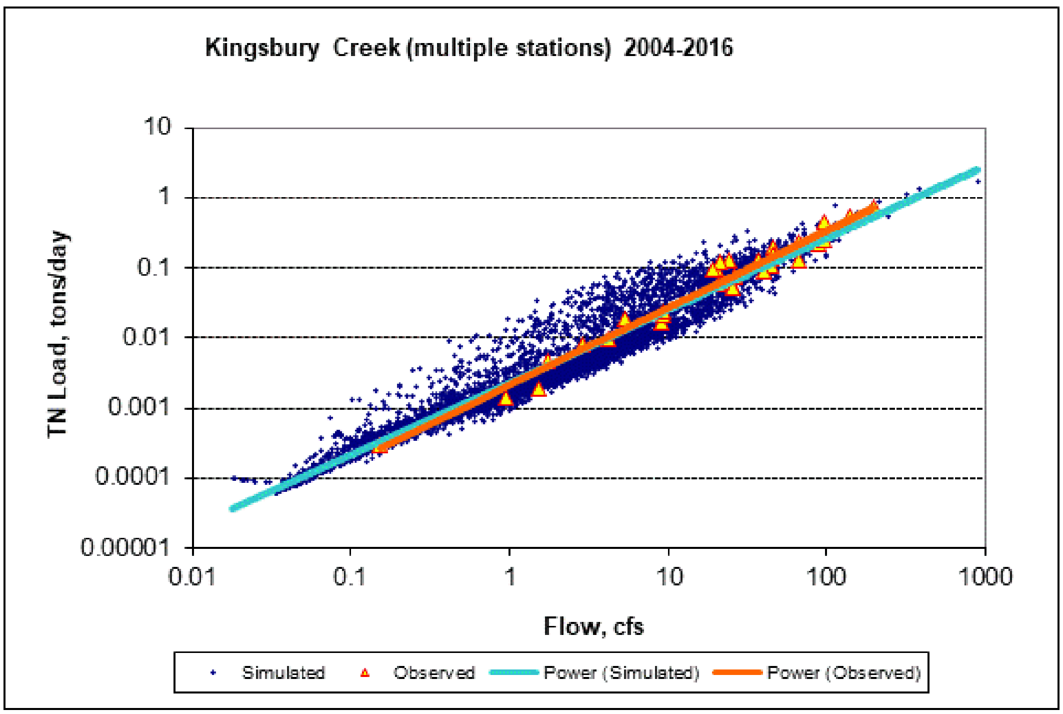


Figure E-832. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Kingsbury Creek (multiple stations) (calibration period)

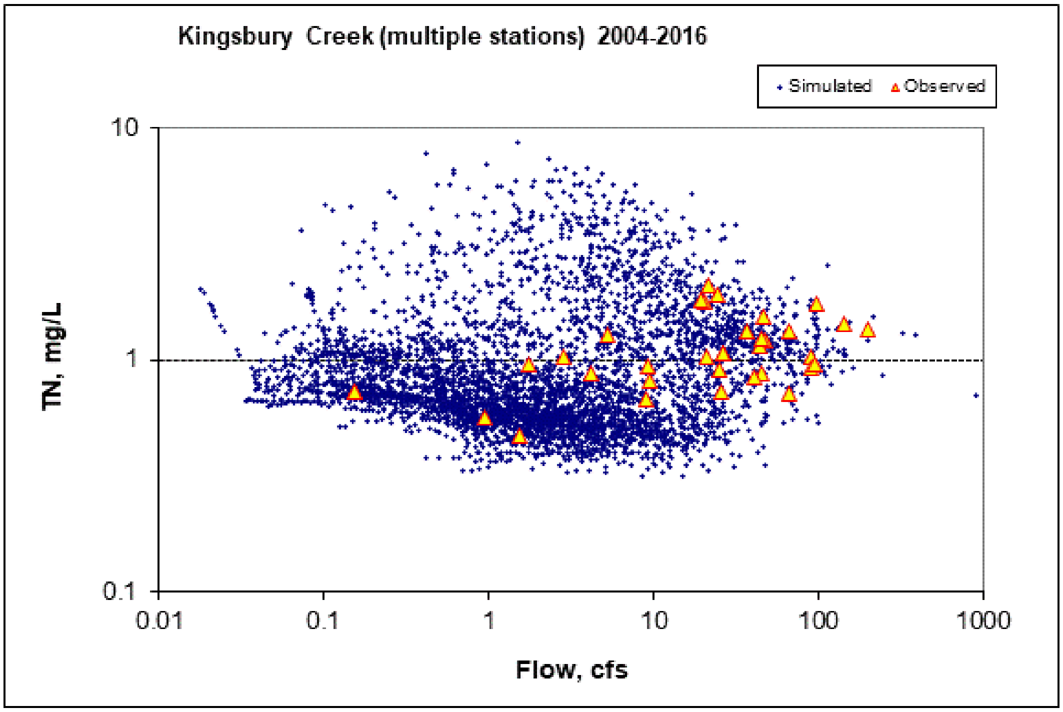
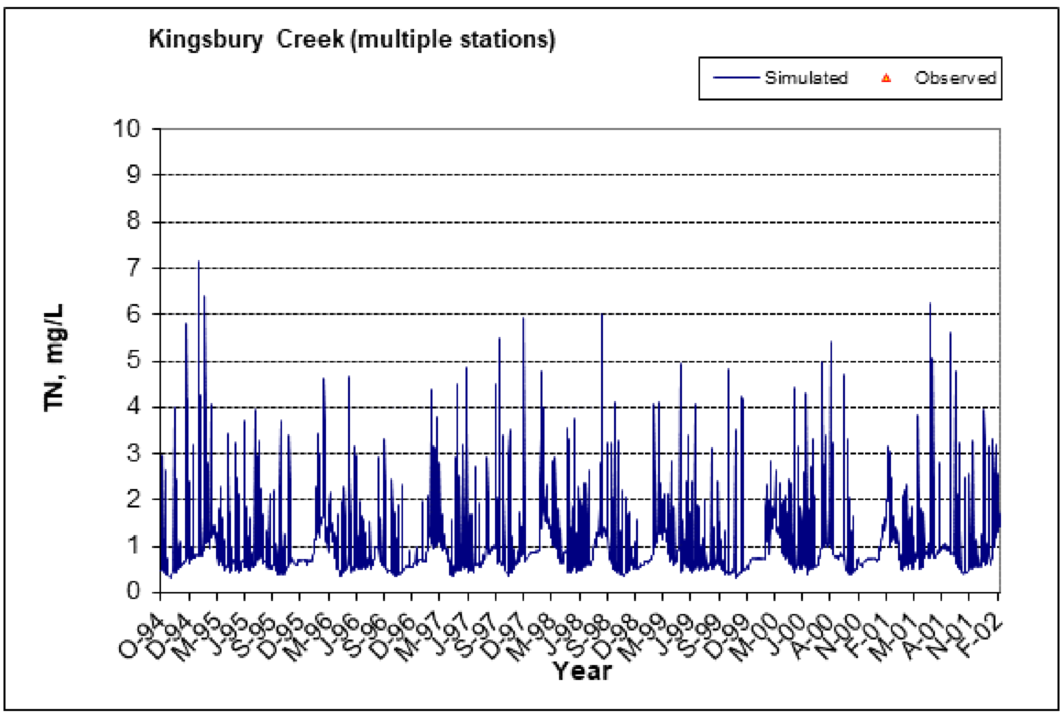
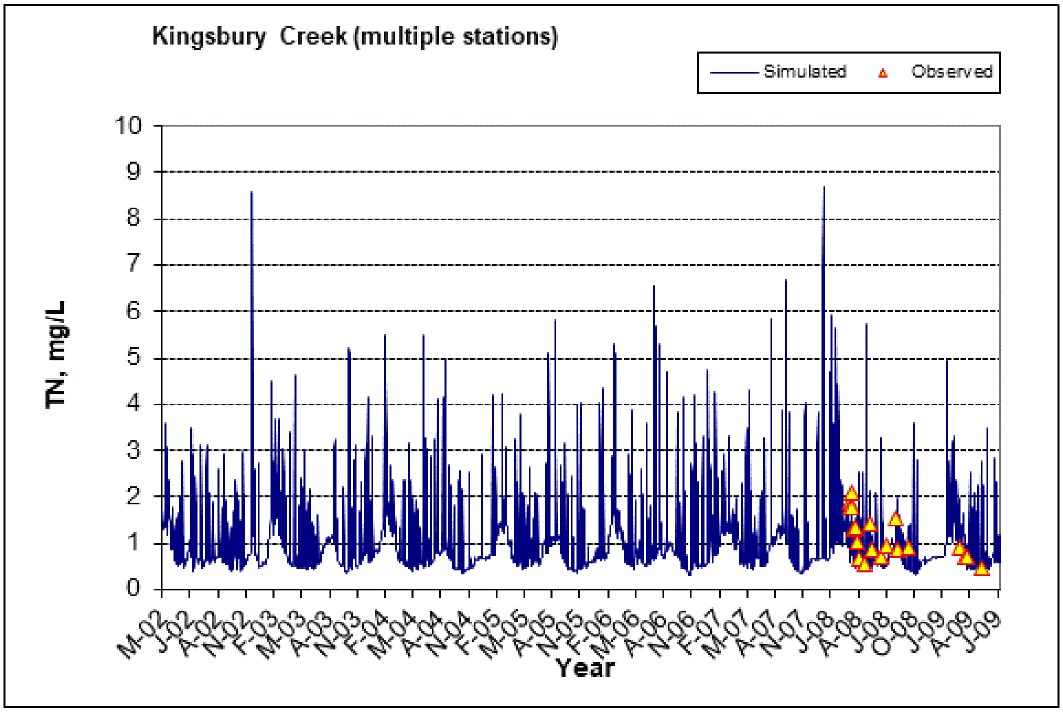


Figure E-833. Simulated and observed Total Nitrogen (TN) concentration vs flow at Kingsbury Creek (multiple stations) (calibration period)





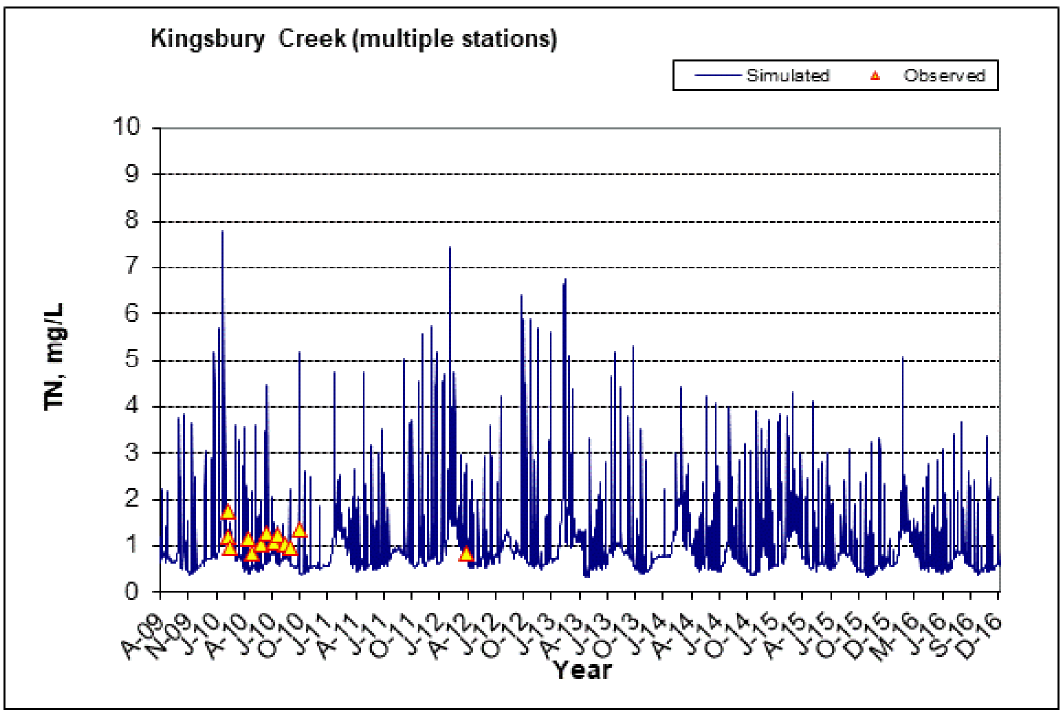


Figure E-834. Time series of observed and simulated Total Nitrogen (TN) concentration at Kingsbury Creek (multiple stations)

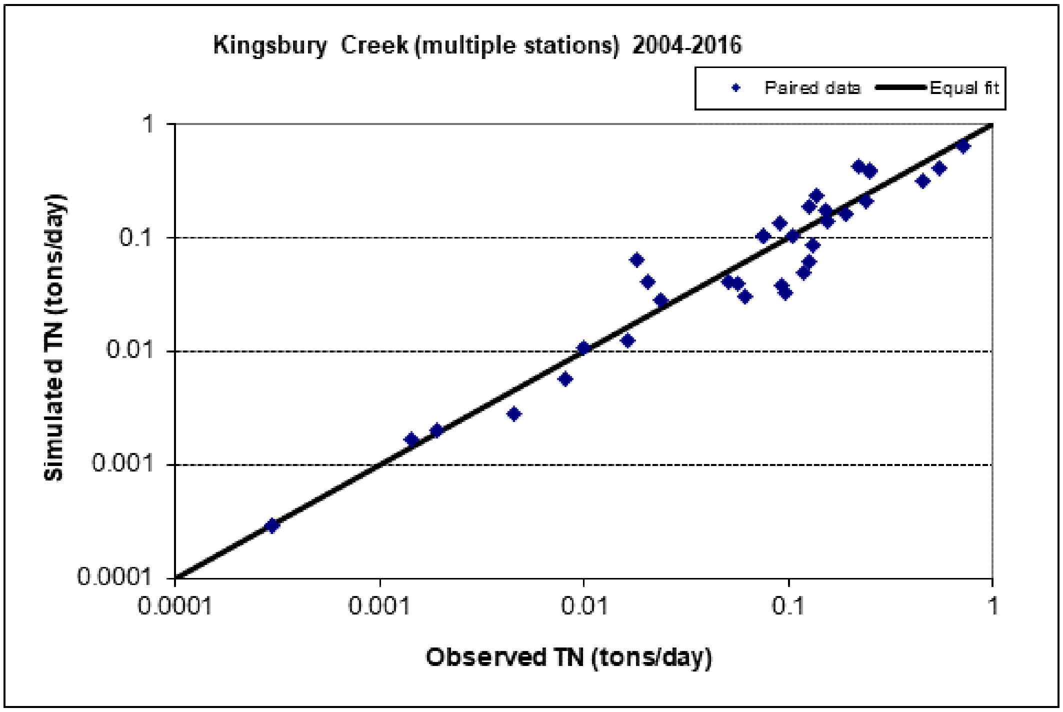


Figure E-835. Paired simulated vs. observed Total Nitrogen (TN) load at Kingsbury Creek (multiple stations) (calibration period)

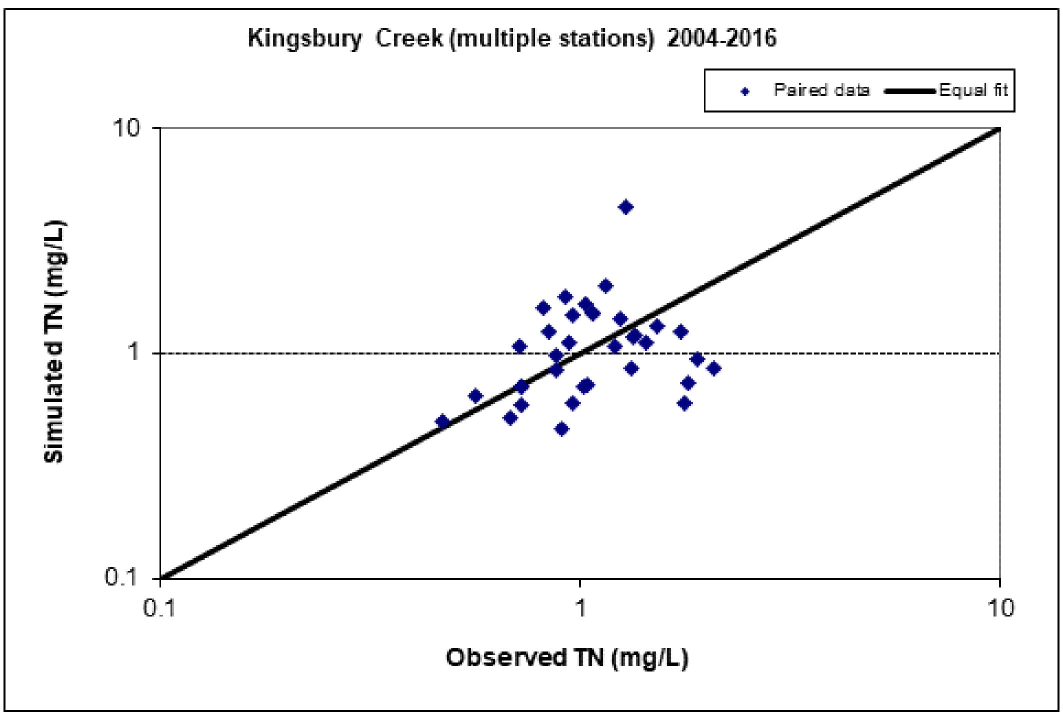


Figure E-836. Paired simulated vs. observed Total Nitrogen (TN) concentration at Kingsbury Creek (multiple stations) (calibration period)

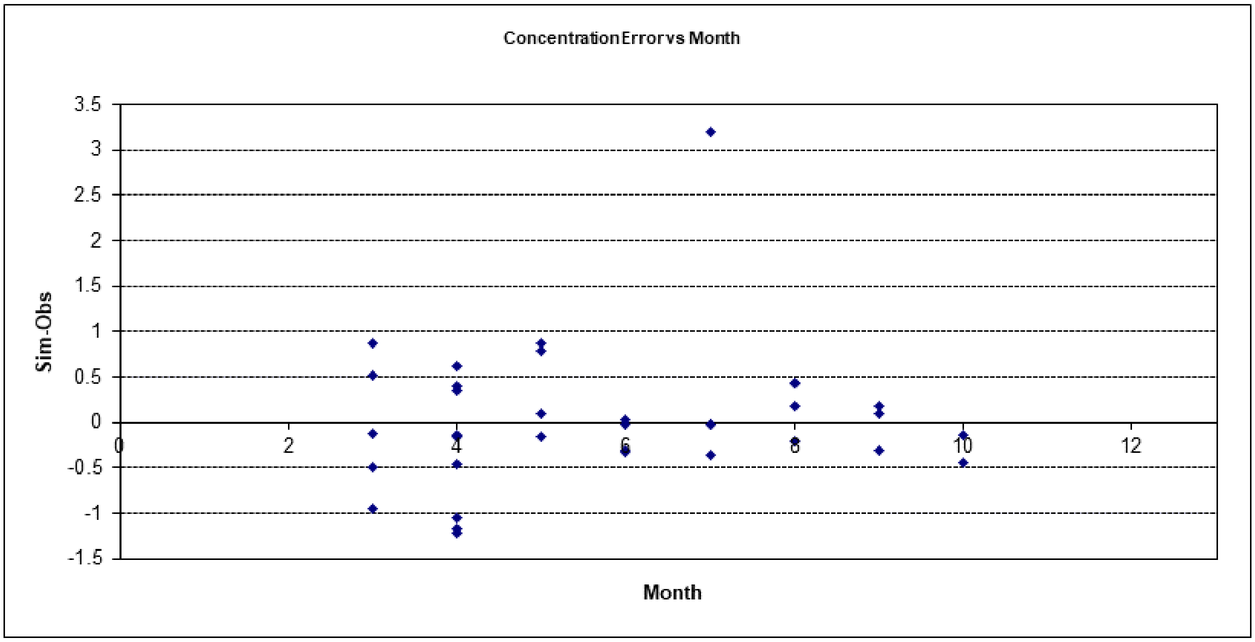


Figure E-837. Residual (Simulated - Observed) vs. Month, Total Nitrogen (TN) at Kingsbury Creek (multiple stations)

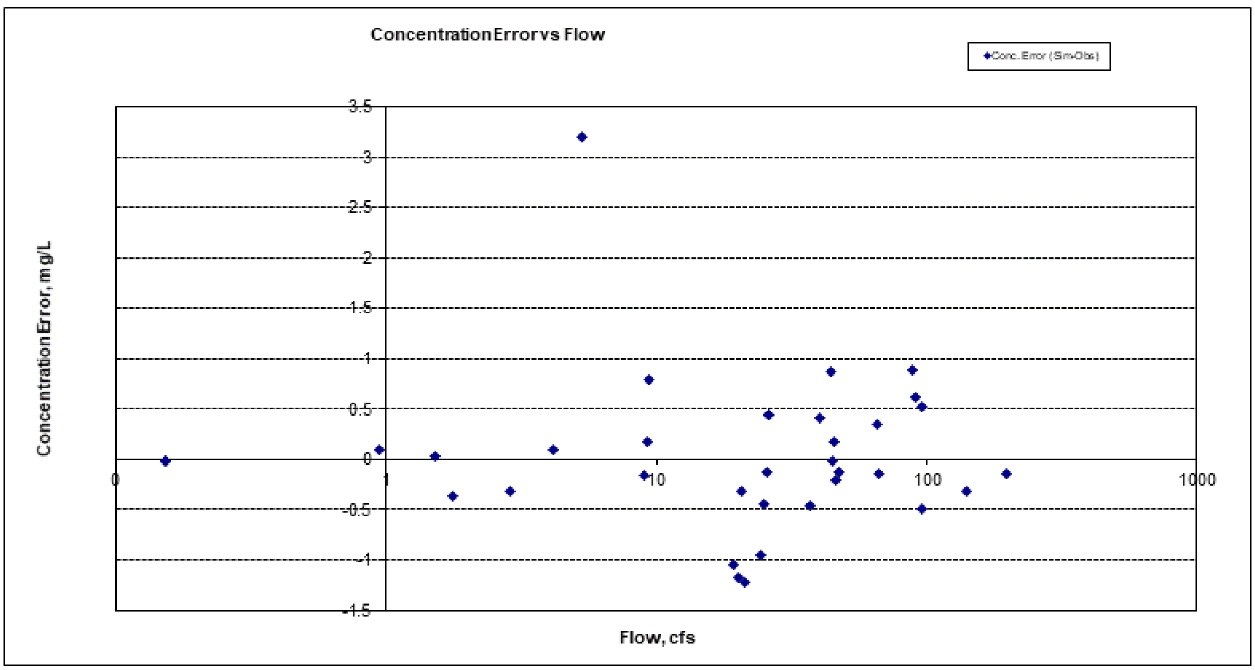


Figure E-838. Residual (Simulated - Observed) vs. Flow, Total Nitrogen (TN) at Kingsbury Creek (multiple stations)

E.18.7 Soluble Reactive Phosphorus (SRP)

Table E-107. Soluble Reactive Phosphorus (SRP) statistics

Period	1994-2004	2004-2016
Count	ND	3
Concentration Average Error		-11.06%
Concentration Median Error		-53.83%
Load Average Error		-22.99%
Load Median Error		-16.18%
Paired t conc		0.61
Paired t load		0.48

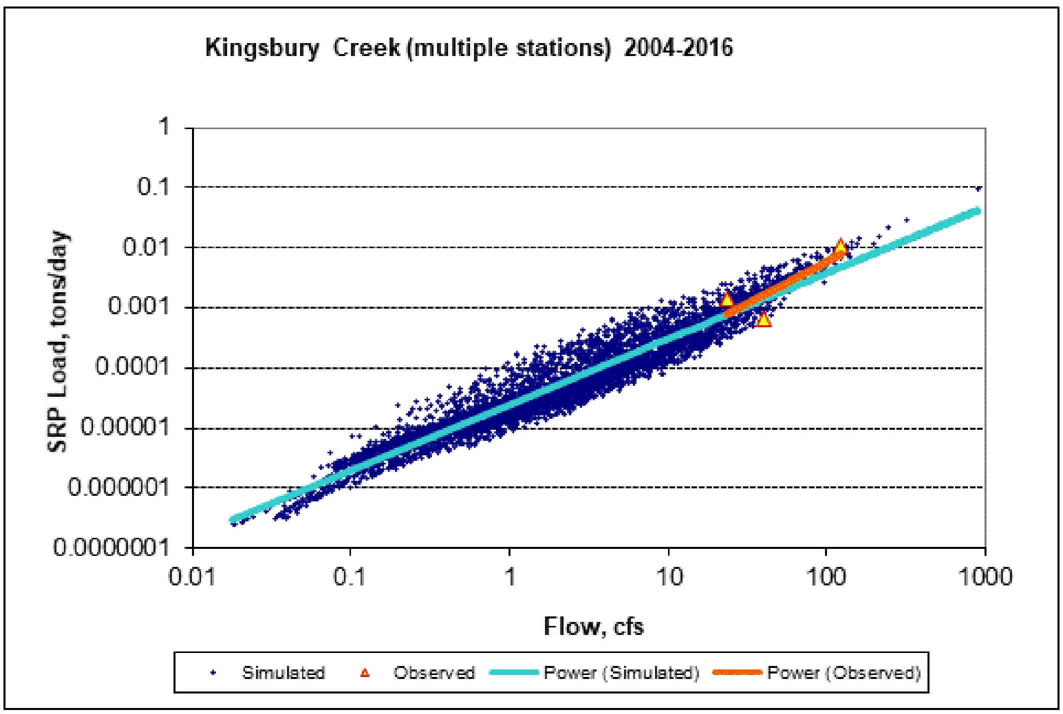


Figure E-839. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Kingsbury Creek (multiple stations) (calibration period)

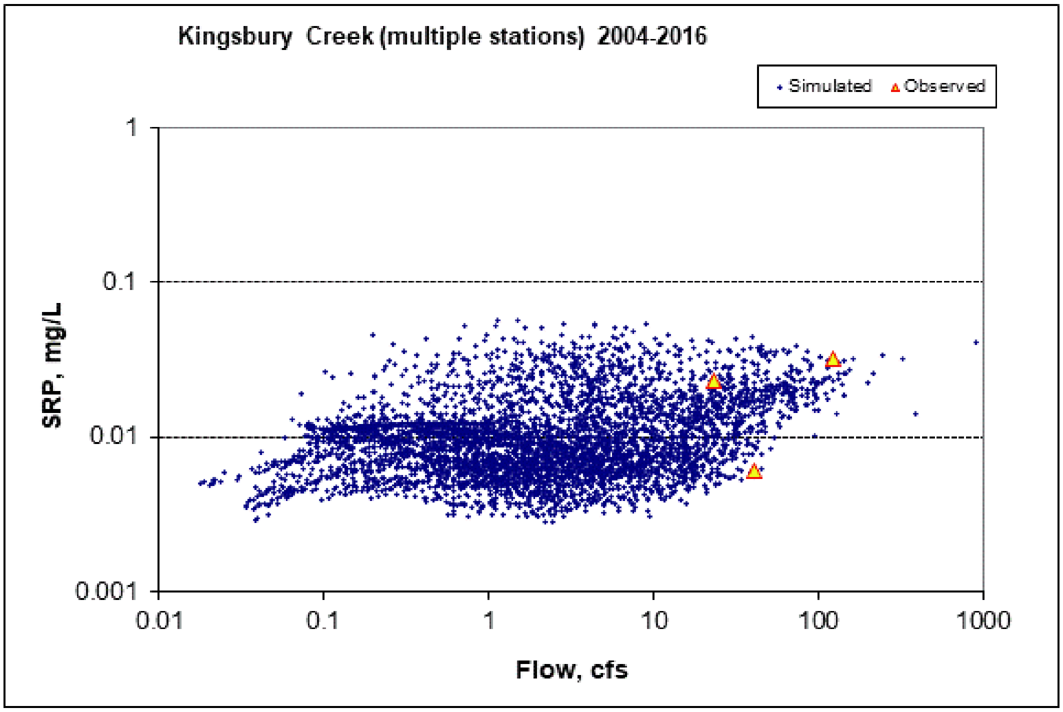
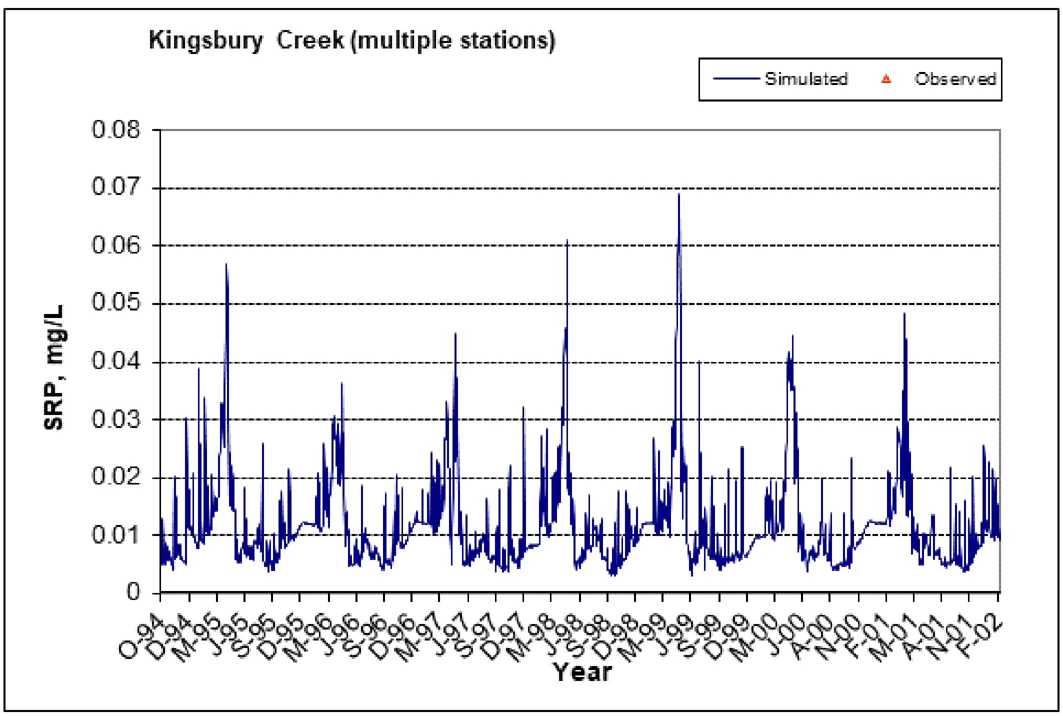


Figure E-840. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at Kingsbury Creek (multiple stations) (calibration period)



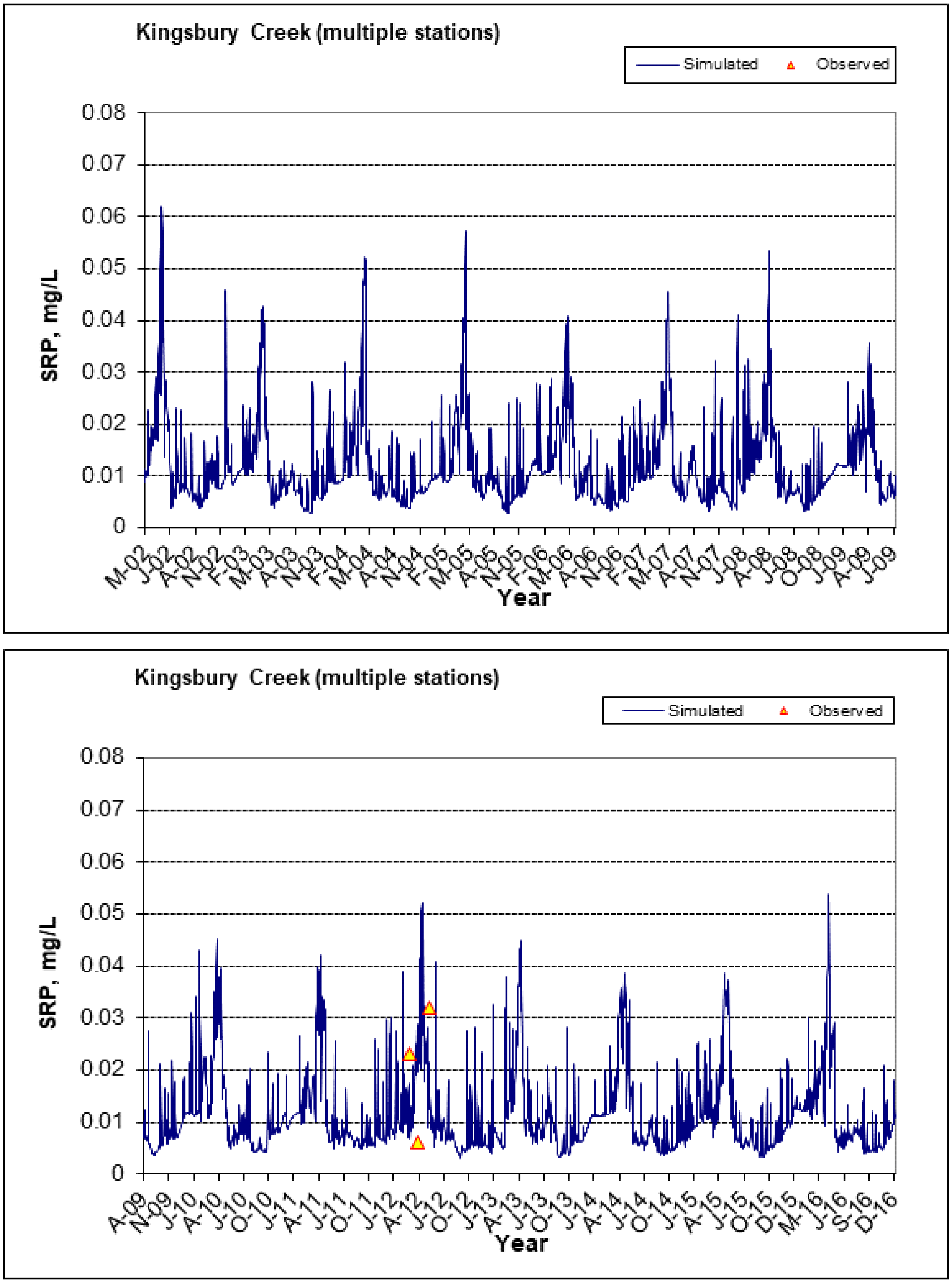


Figure E-841. Time series of observed and simulated Soluble Reactive Phosphorus (SRP) concentration at Kingsbury Creek (multiple stations)

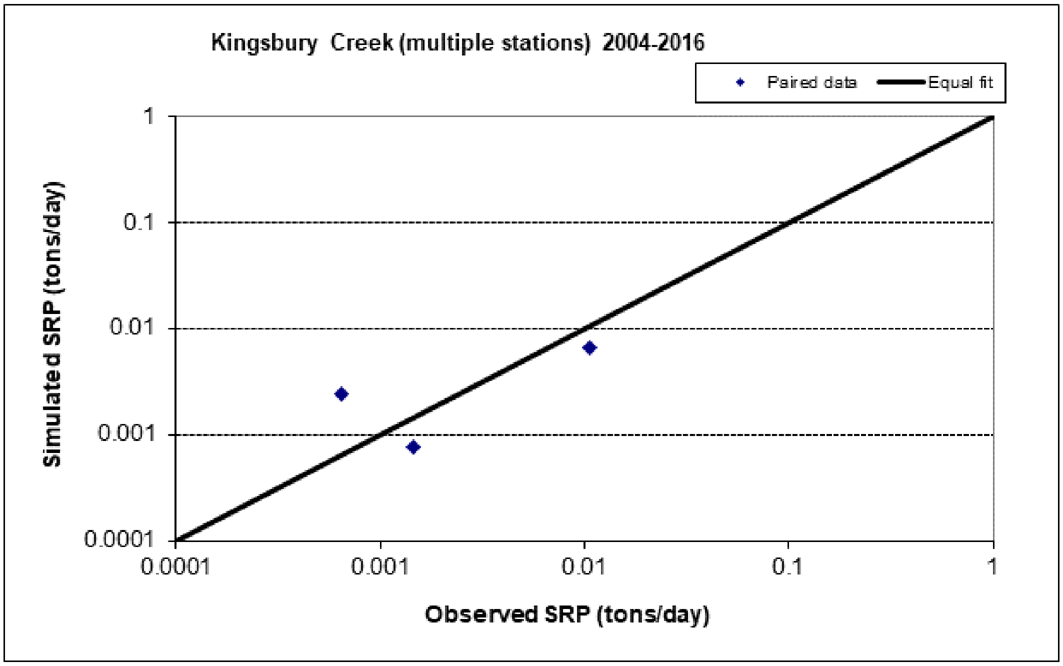


Figure E-842. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at Kingsbury Creek (multiple stations) (calibration period)

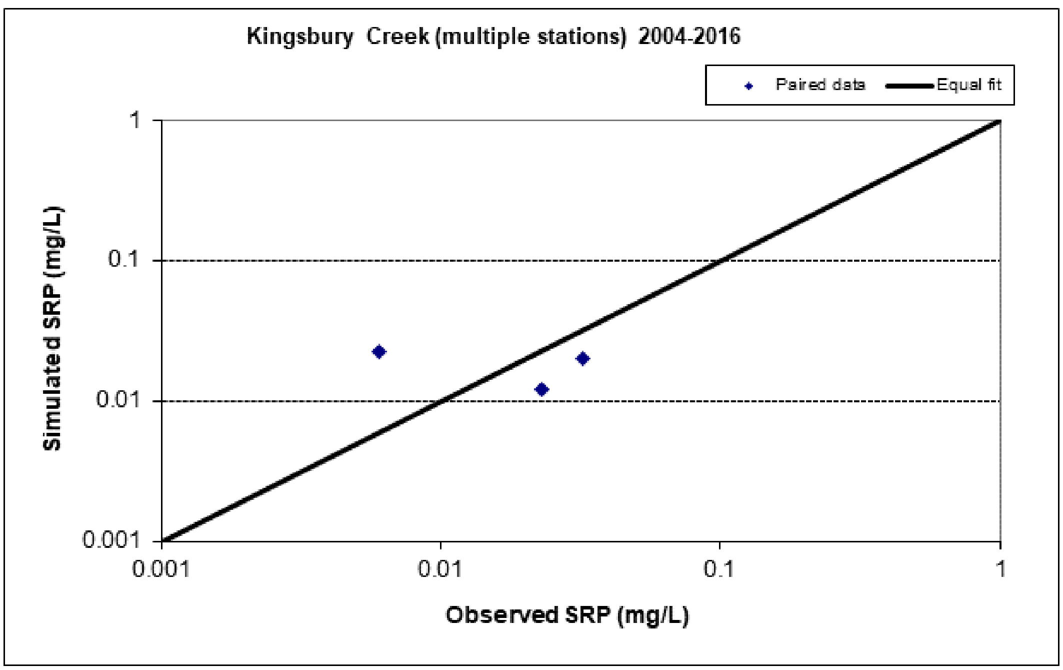


Figure E-843. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at Kingsbury Creek (multiple stations) (calibration period)

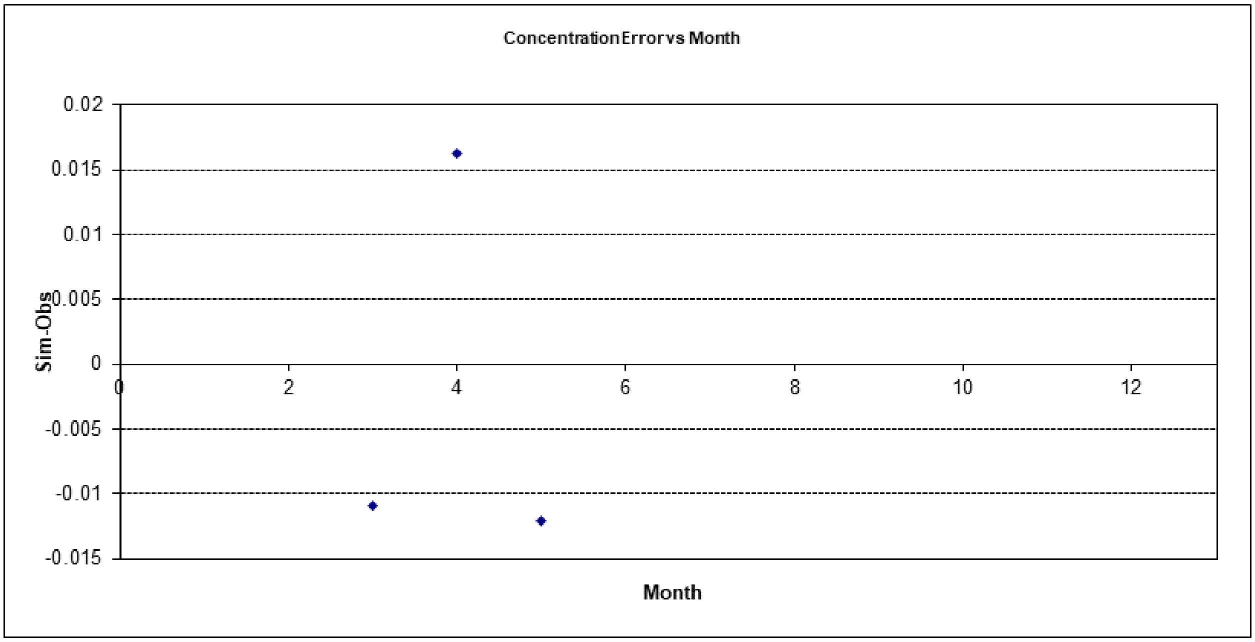


Figure E-844. Residual (Simulated - Observed) vs. Month, Soluble Reactive Phosphorus (SRP) at Kingsbury Creek (multiple stations)

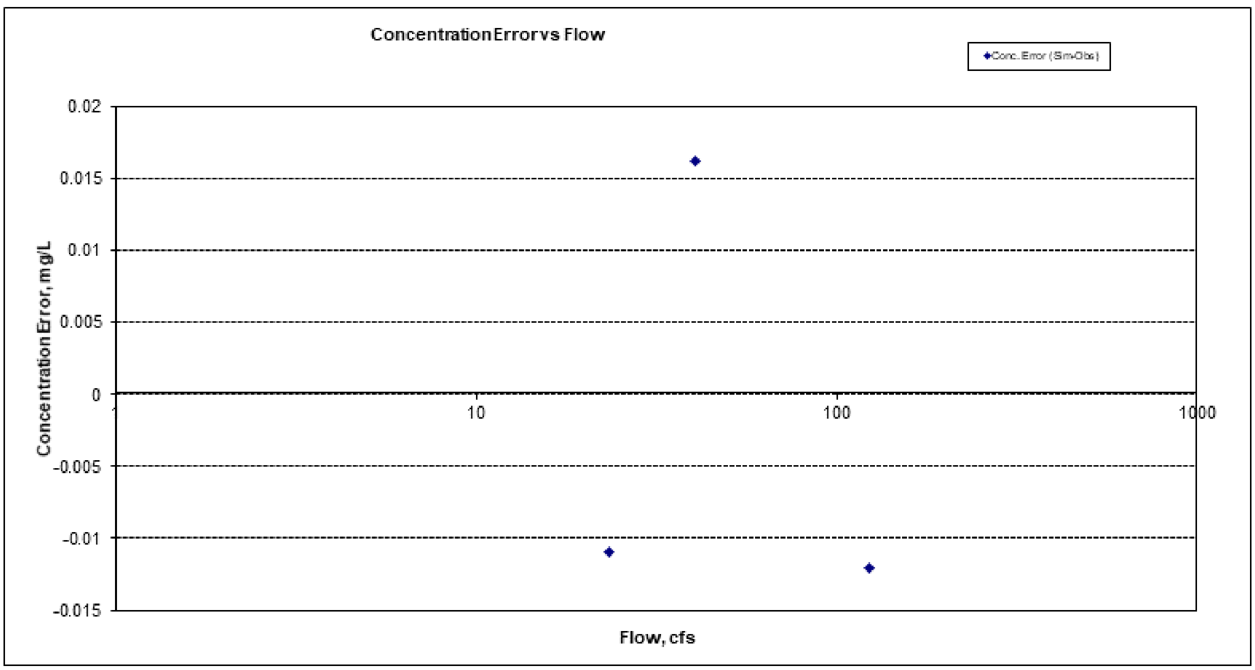


Figure E-845. Residual (Simulated - Observed) vs. Flow, Soluble Reactive Phosphorus (SRP) at Kingsbury Creek (multiple stations)

E.18.8 Total Phosphorus (TP)

Table E-108. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	36
Concentration Average Error		-9.27%
Concentration Median Error		-1.59%
Load Average Error		0.77%
Load Median Error		-0.71%
Paired t conc		0.82
Paired t load		0.74

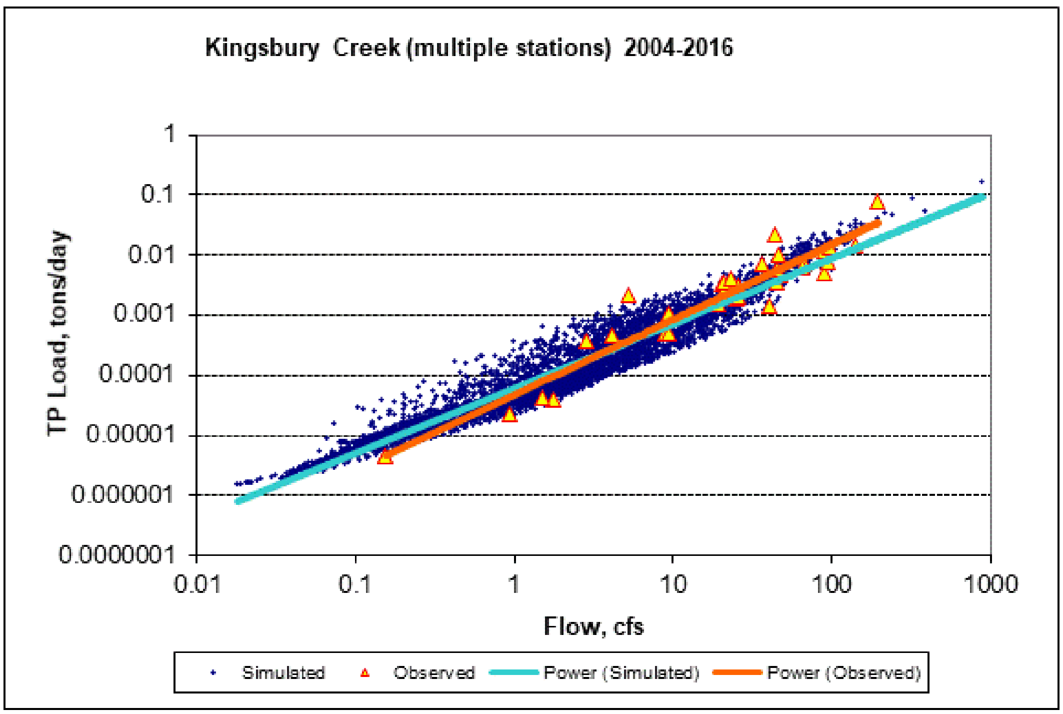


Figure E-846. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Kingsbury Creek (multiple stations) (calibration period)

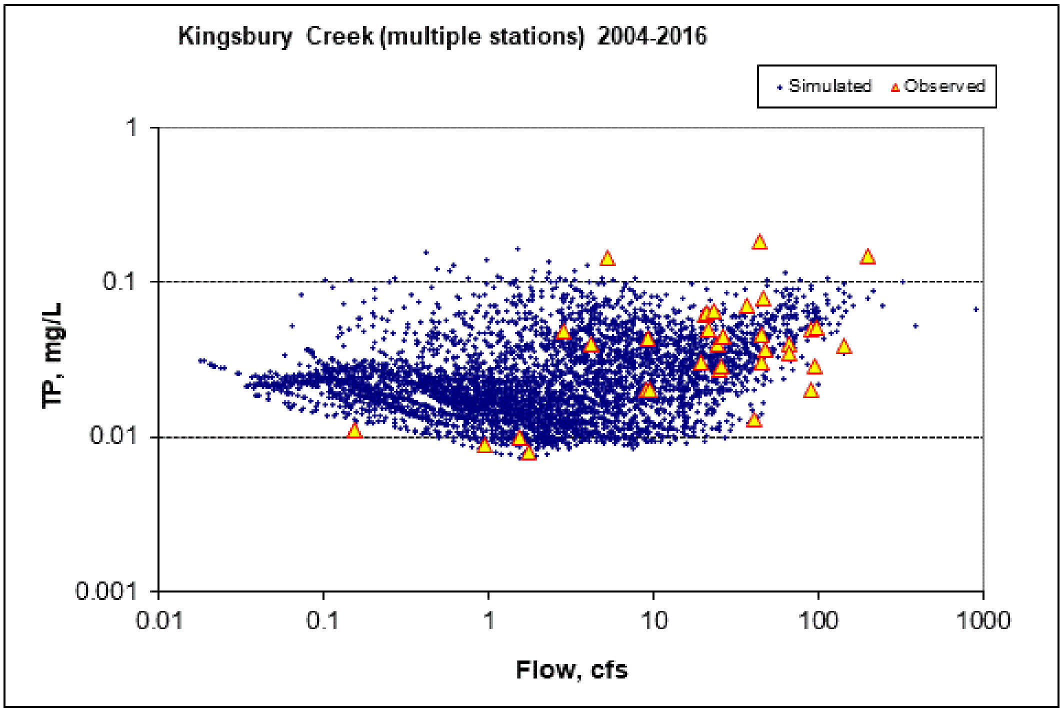
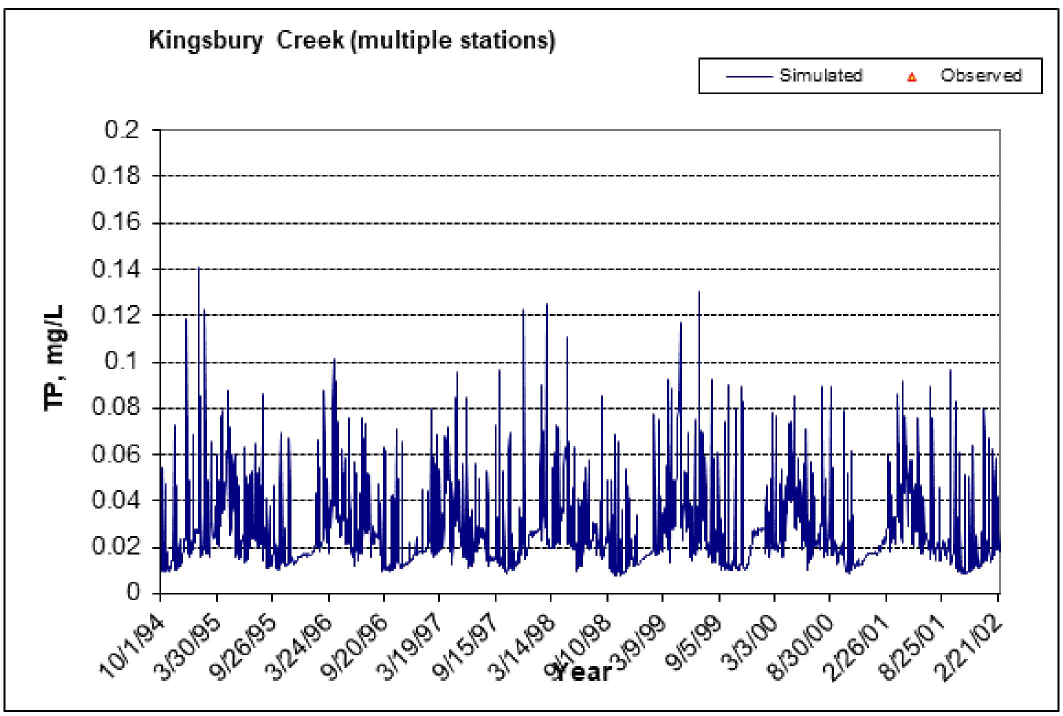


Figure E-847. Simulated and observed Total Phosphorus (TP) concentration vs flow at Kingsbury Creek (multiple stations) (calibration period)



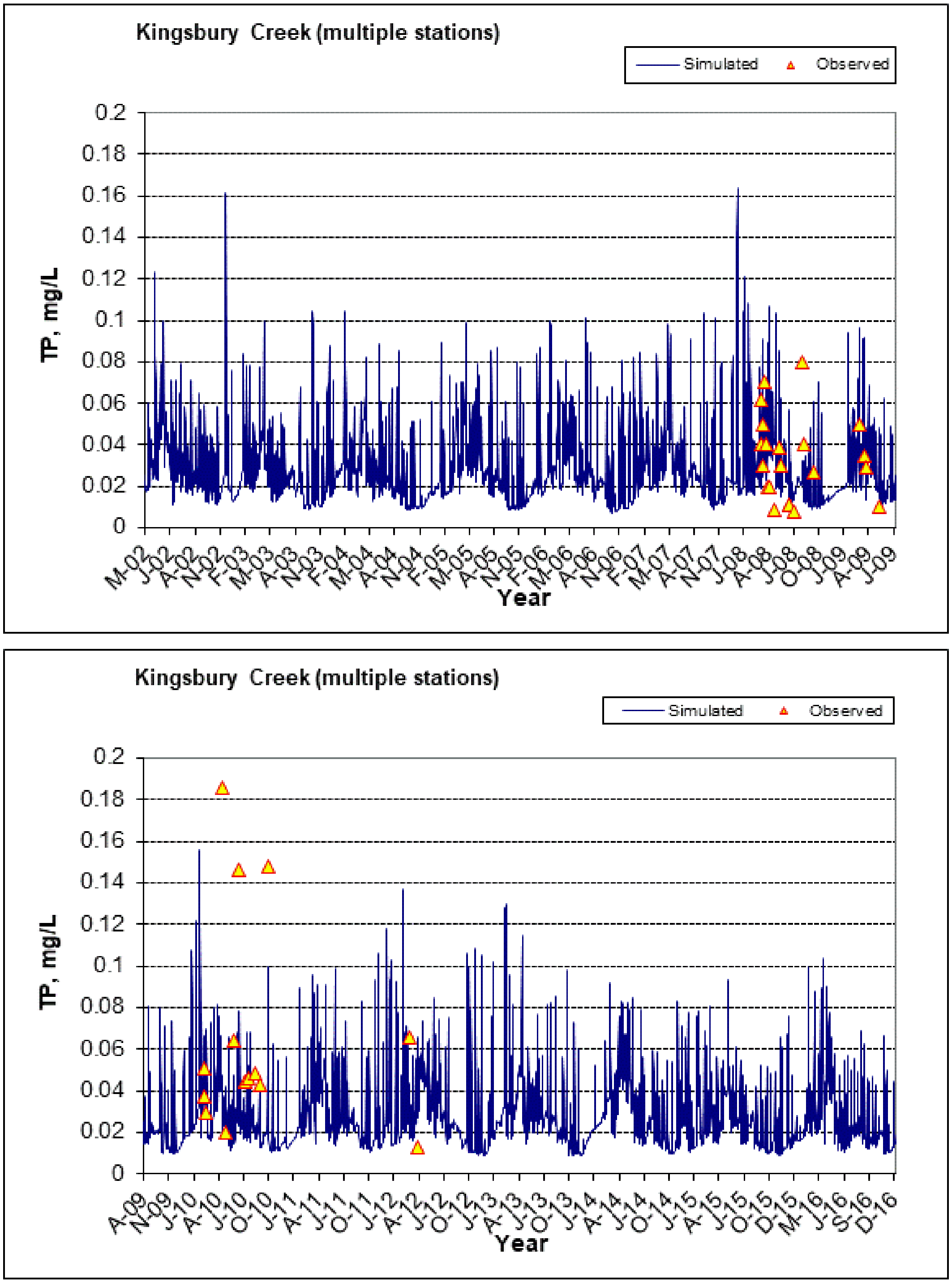


Figure E-848. Time series of observed and simulated Total Phosphorus (TP) concentration at Kingsbury Creek (multiple stations)

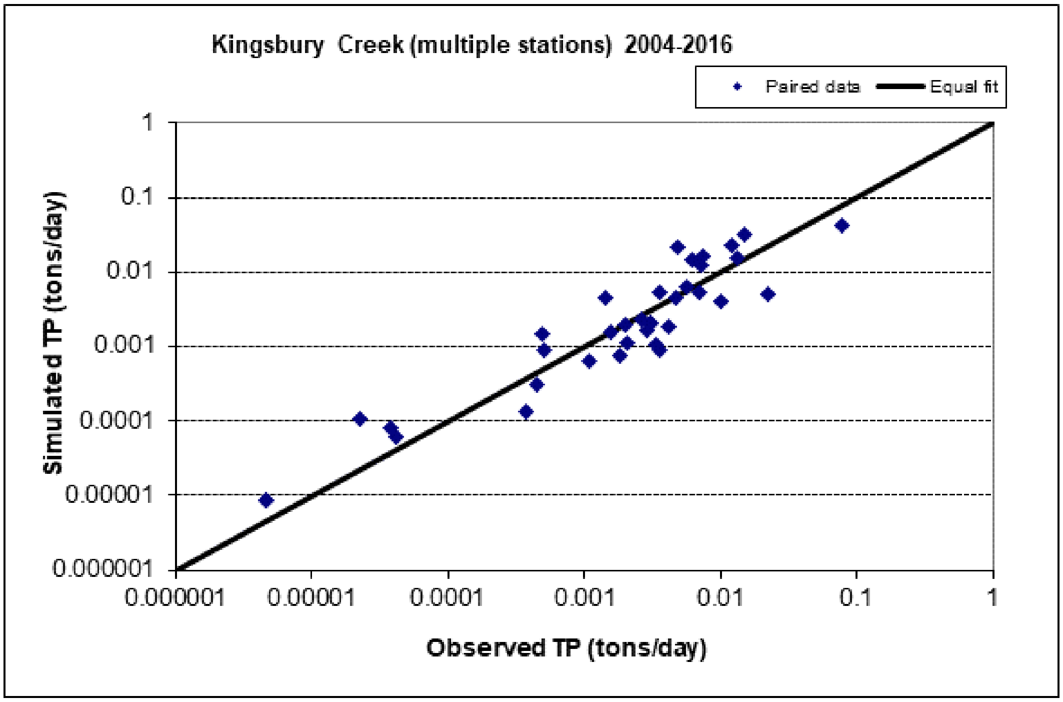


Figure E-849. Paired simulated vs. observed Total Phosphorus (TP) load at Kingsbury Creek (multiple stations) (calibration period)

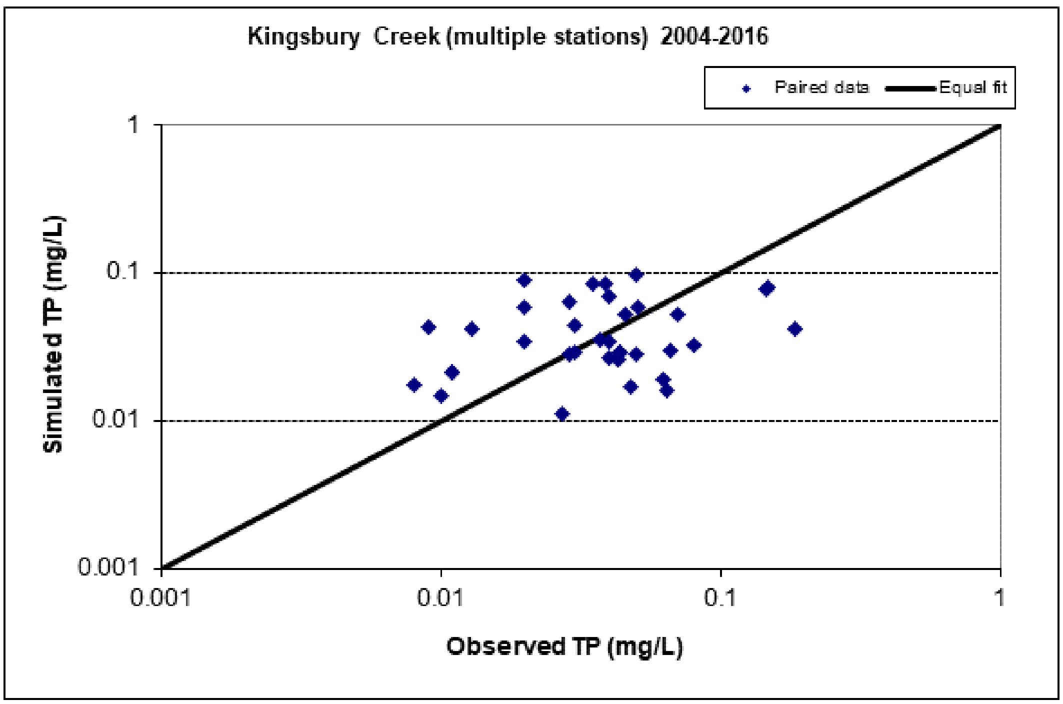


Figure E-850. Paired simulated vs. observed Total Phosphorus (TP) concentration at Kingsbury Creek (multiple stations) (calibration period)

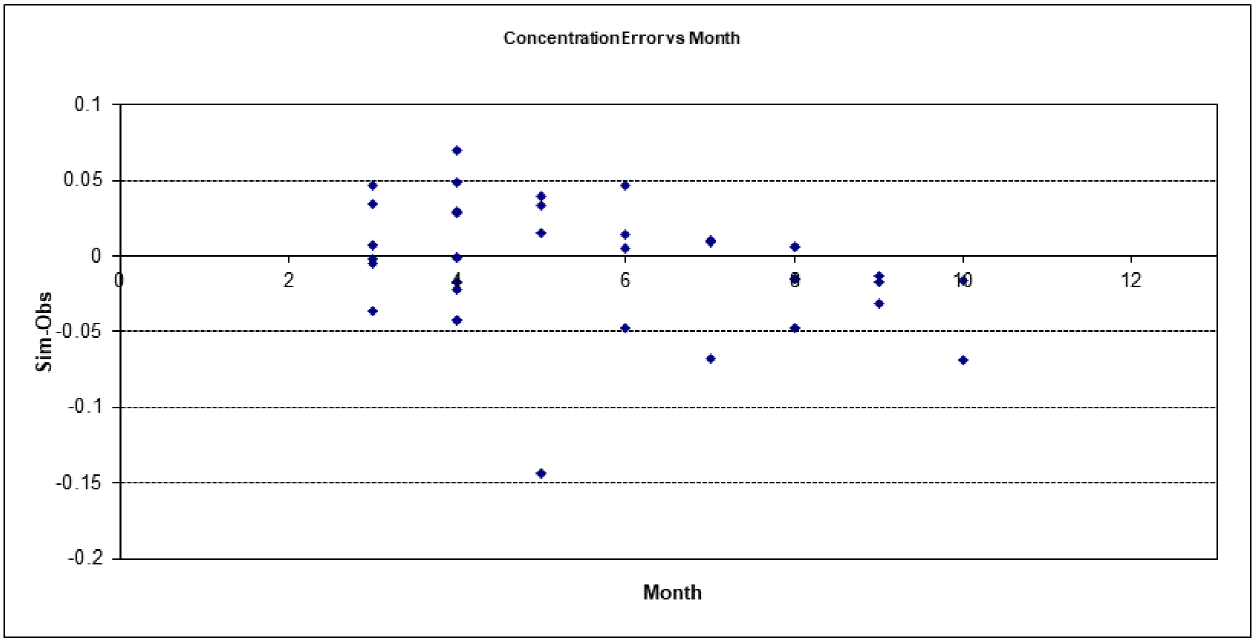


Figure E-851. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Kingsbury Creek (multiple stations)

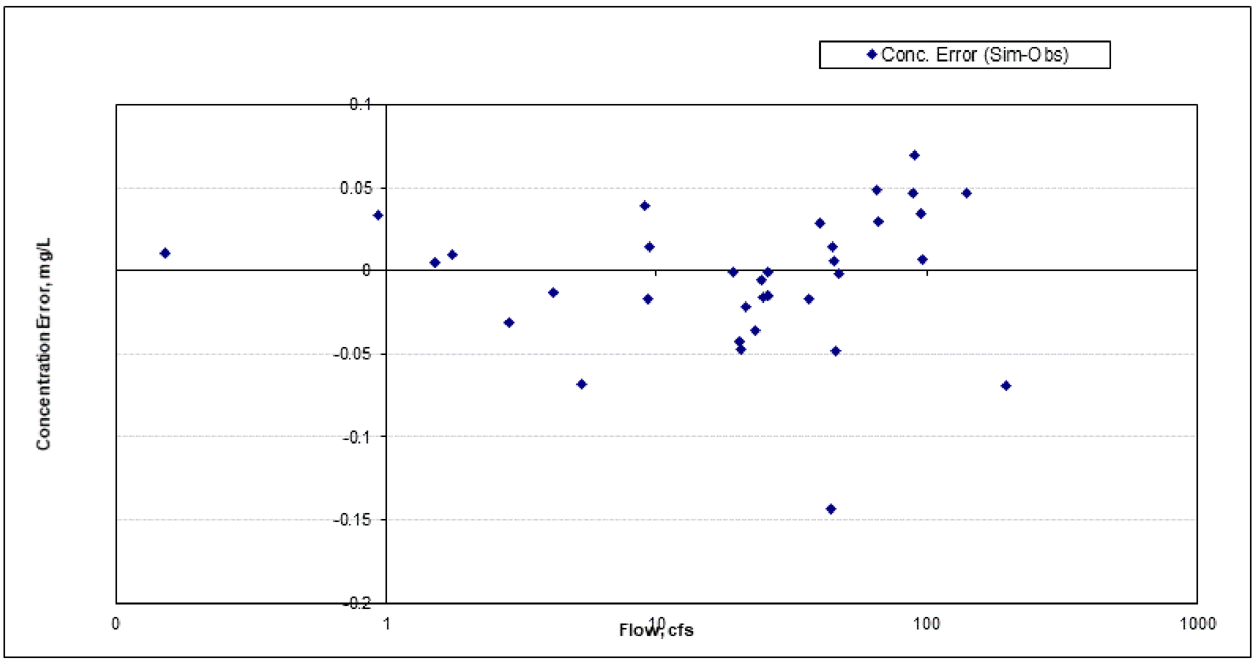


Figure E-852. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Kingsbury Creek (multiple stations)

E.19 Stewart Creek at US Steel RR

E.19.1 Dissolved Oxygen (DO)

Table E-109. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	18
Concentration Average Error		-32.10%
Concentration Median Error		-41.21%
Load Average Error		-19.90%
Load Median Error		-12.00%
Paired t conc		0.03
Paired t load		0.50

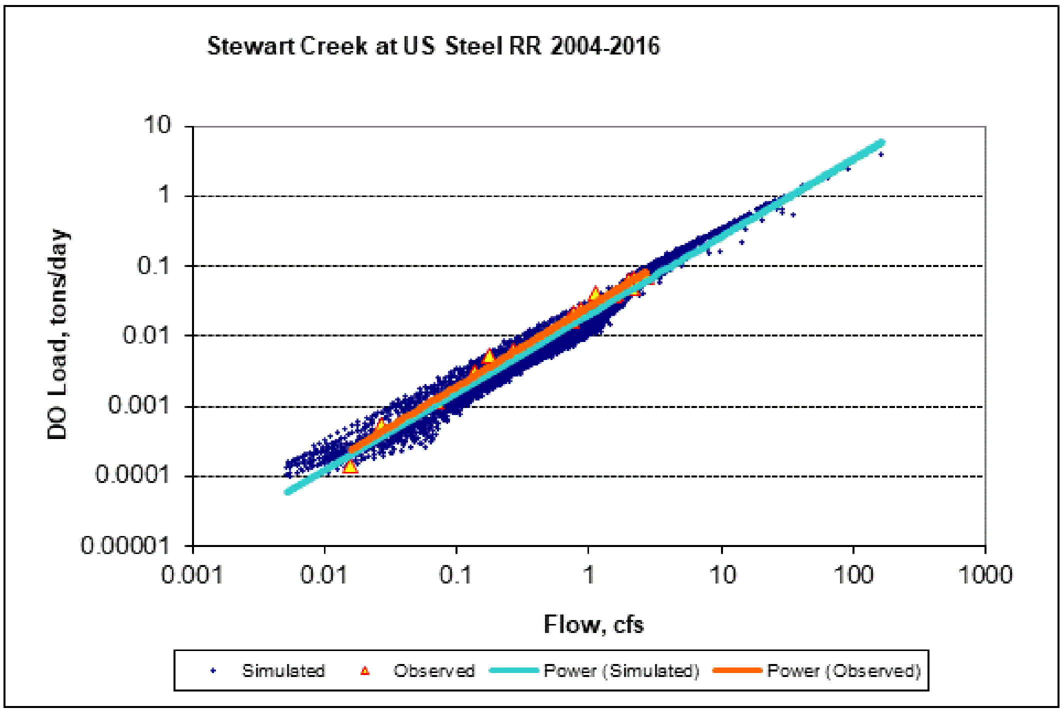


Figure E-853. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Stewart Creek at US Steel RR (calibration period)

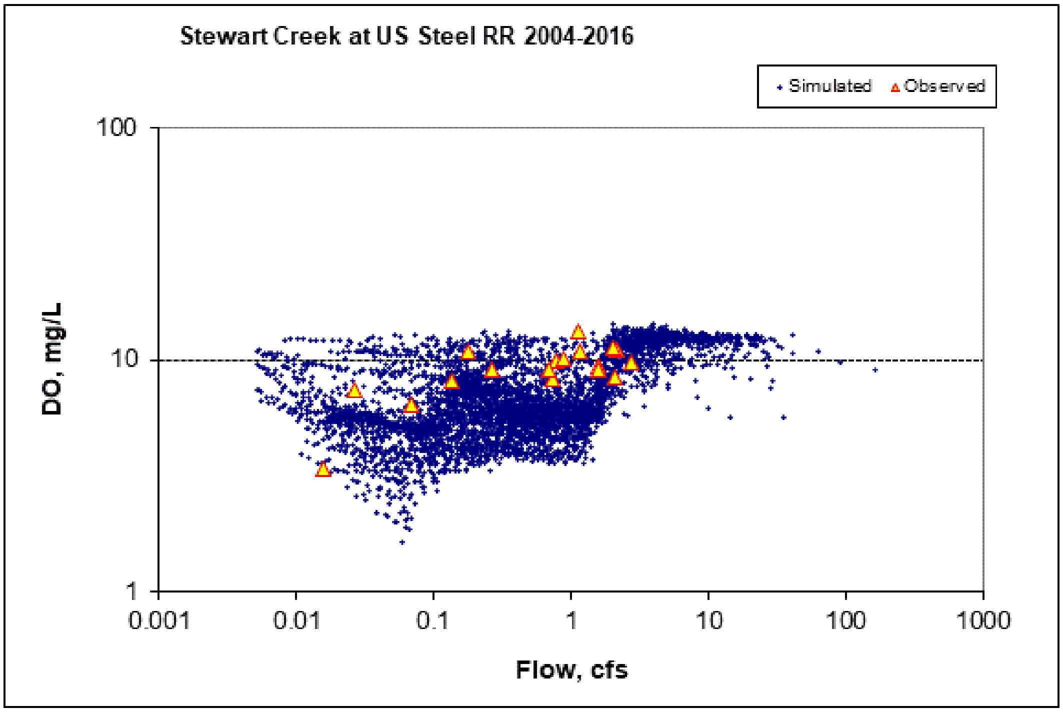
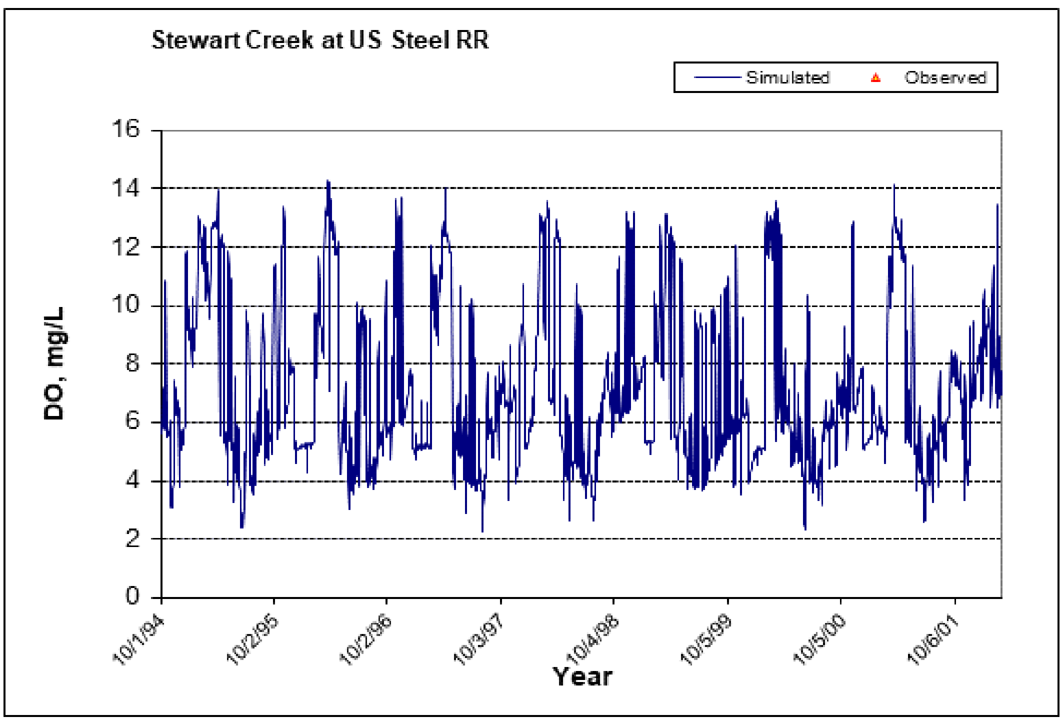
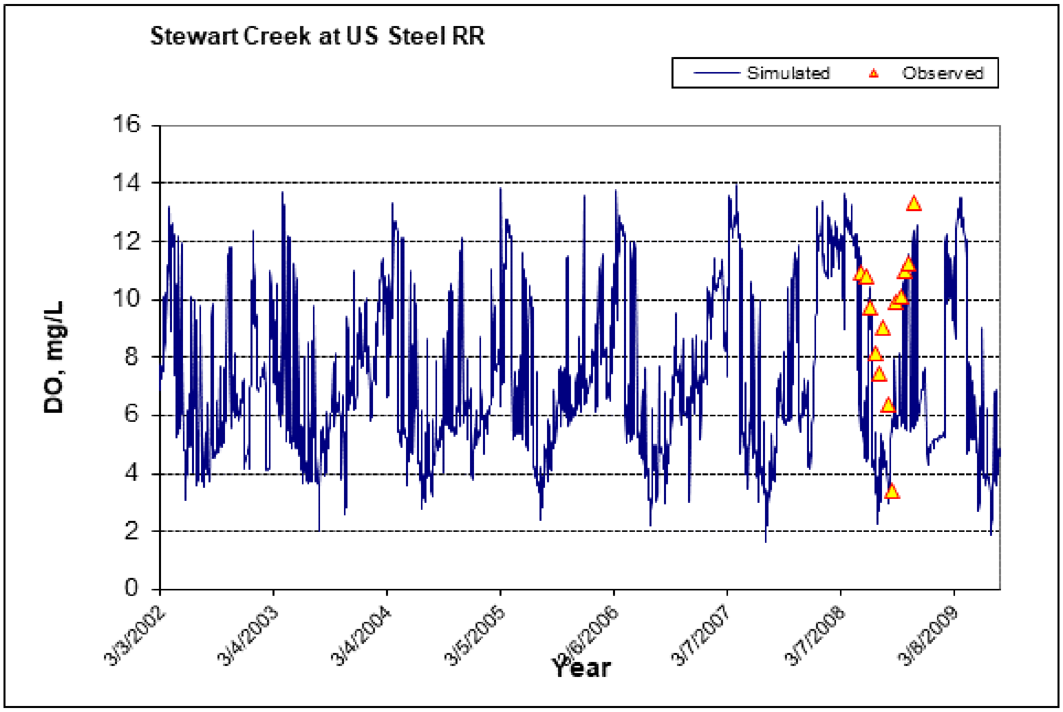


Figure E-854. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Stewart Creek at US Steel RR (calibration period)





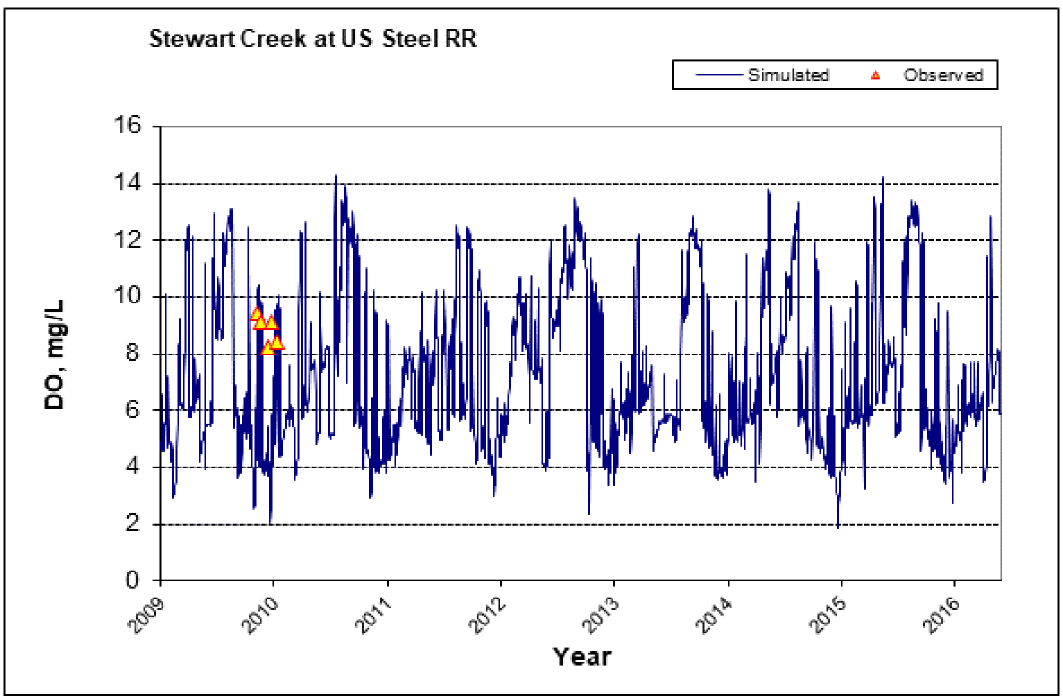


Figure E-855. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Stewart Creek at US Steel RR

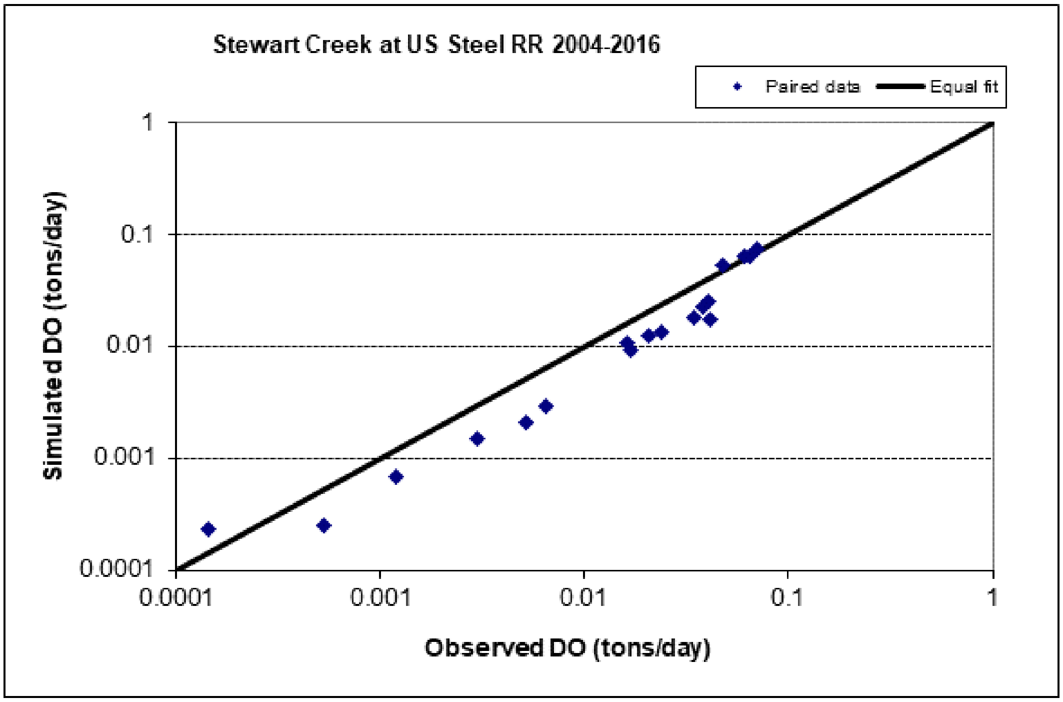


Figure E-856. Paired simulated vs. observed Dissolved Oxygen (DO) load at Stewart Creek at US Steel RR (calibration period)

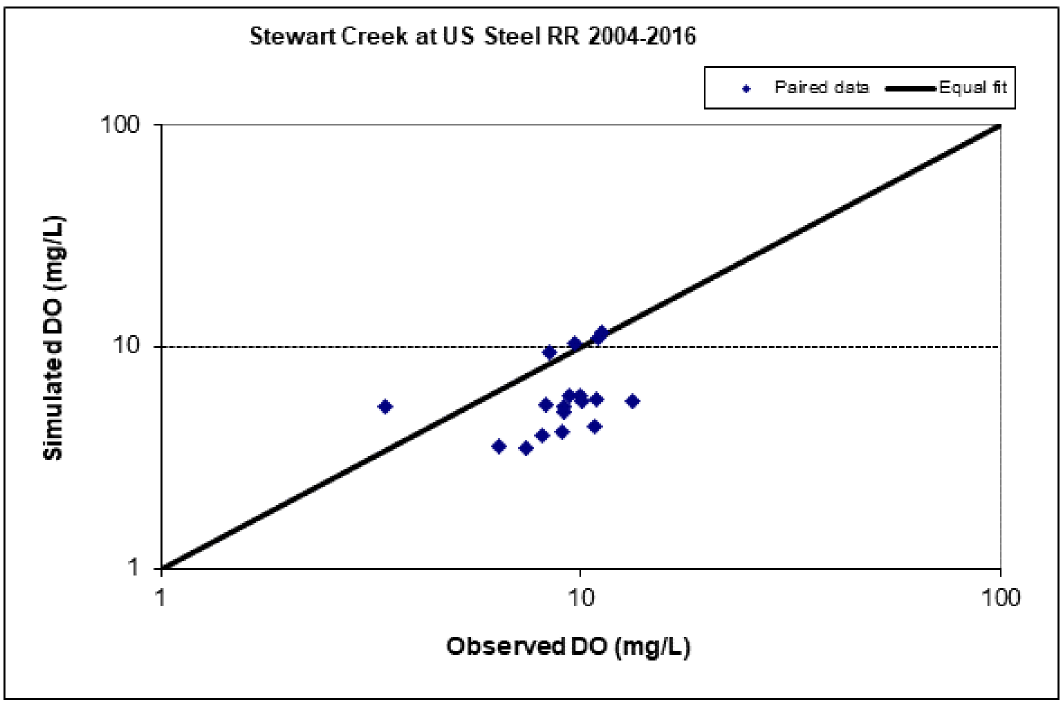


Figure E-857. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Stewart Creek at US Steel RR (calibration period)

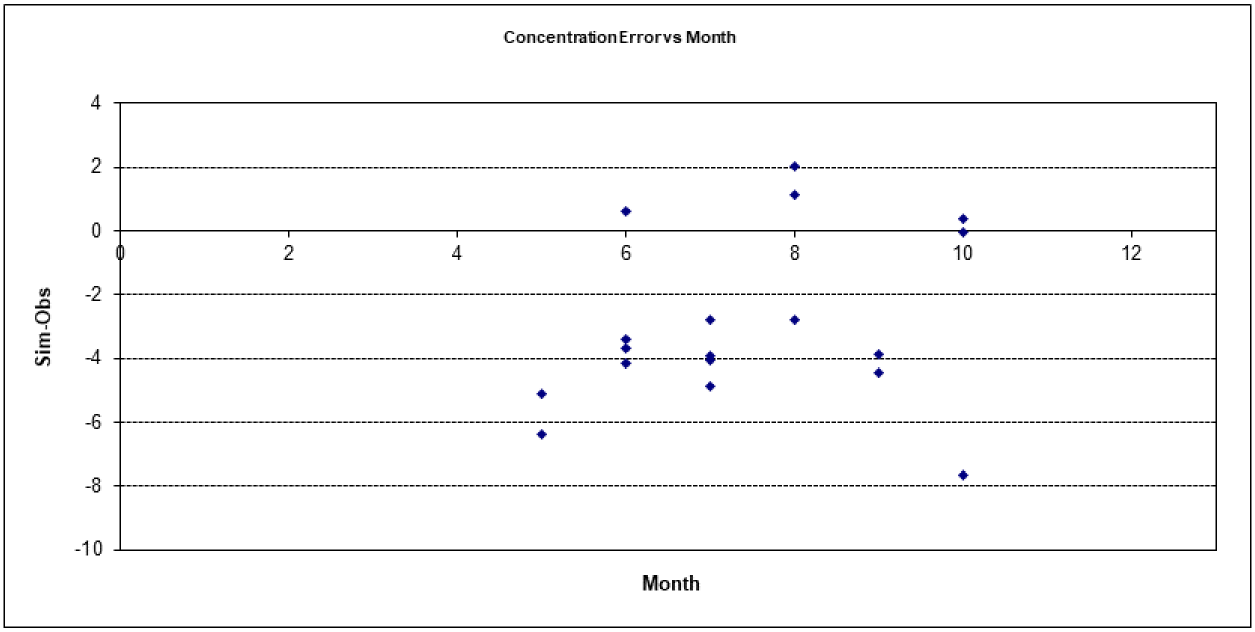


Figure E-858. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Stewart Creek at US Steel RR

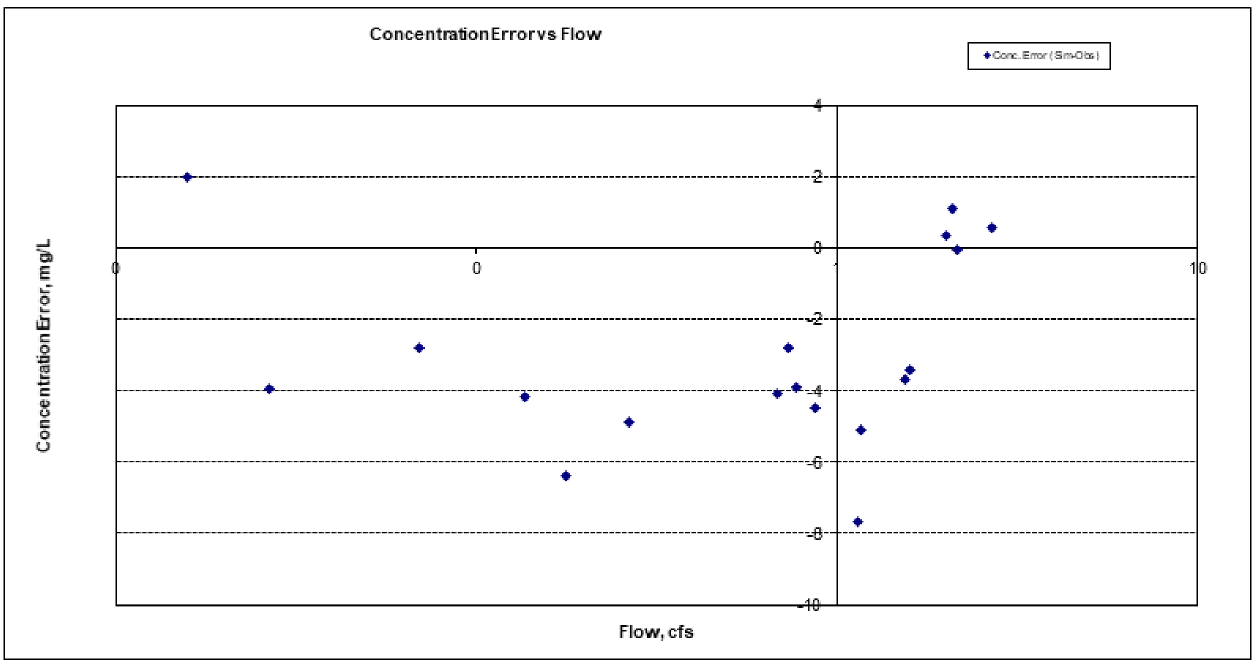


Figure E-859. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Stewart Creek at US Steel RR

E.19.2 Ammonia Nitrogen (NH3)

Table E-110. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	34
Concentration Average Error		30.29%
Concentration Median Error		-33.86%
Load Average Error		-24.39%
Load Median Error		-2.72%
Paired t conc		0.34
Paired t load		0.45

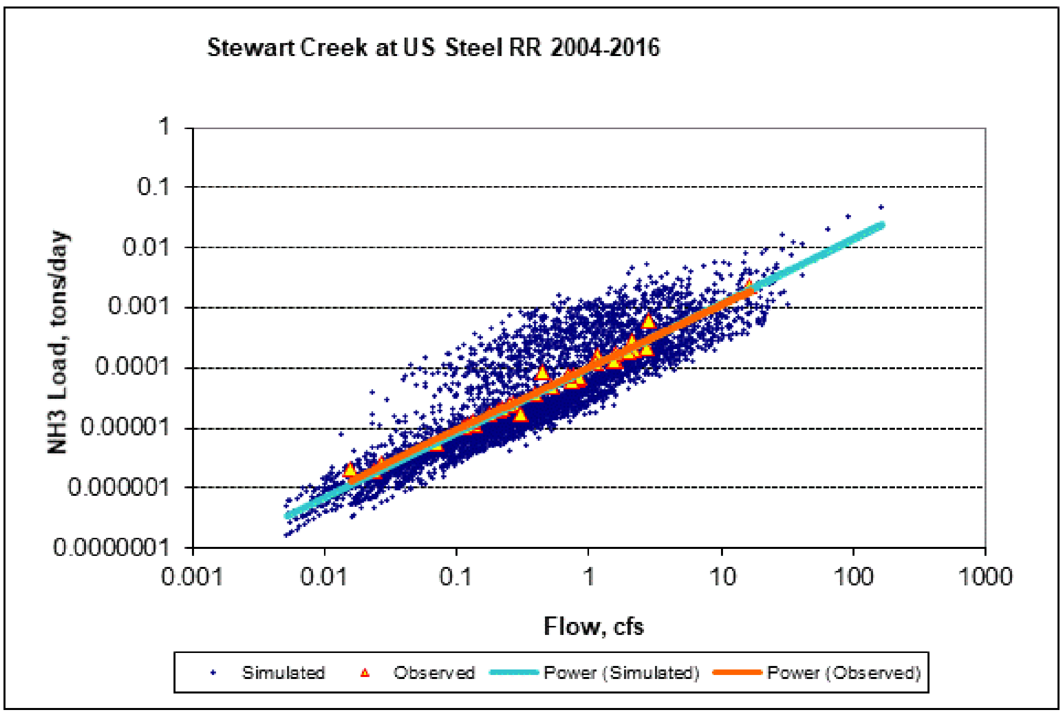


Figure E-860. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Stewart Creek at US Steel RR (calibration period)

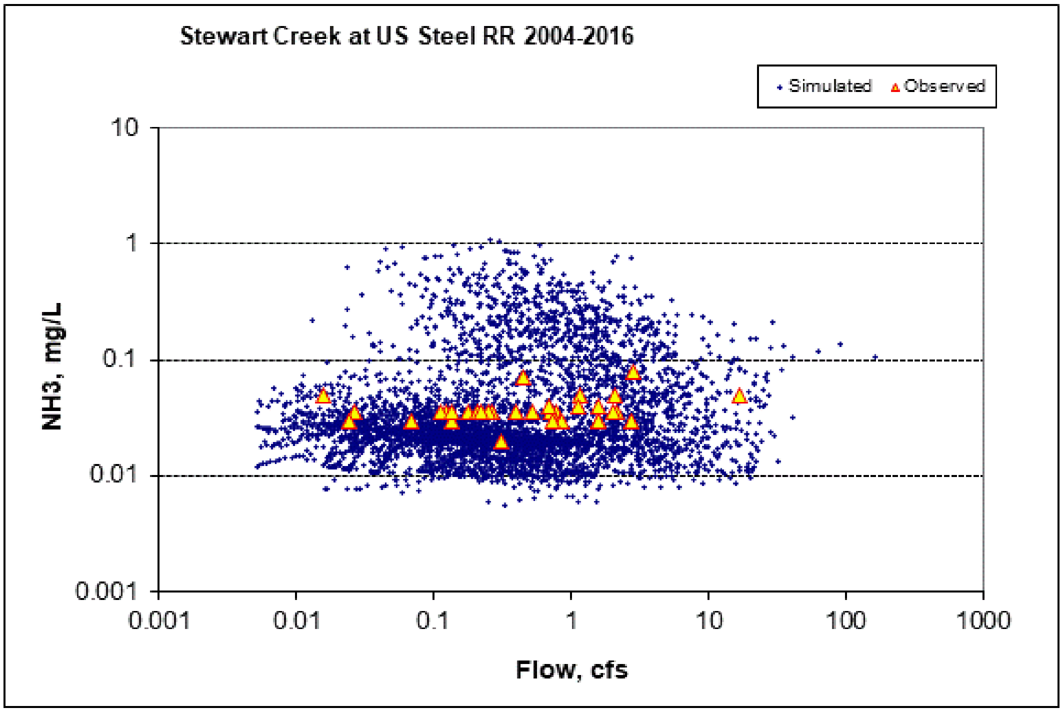
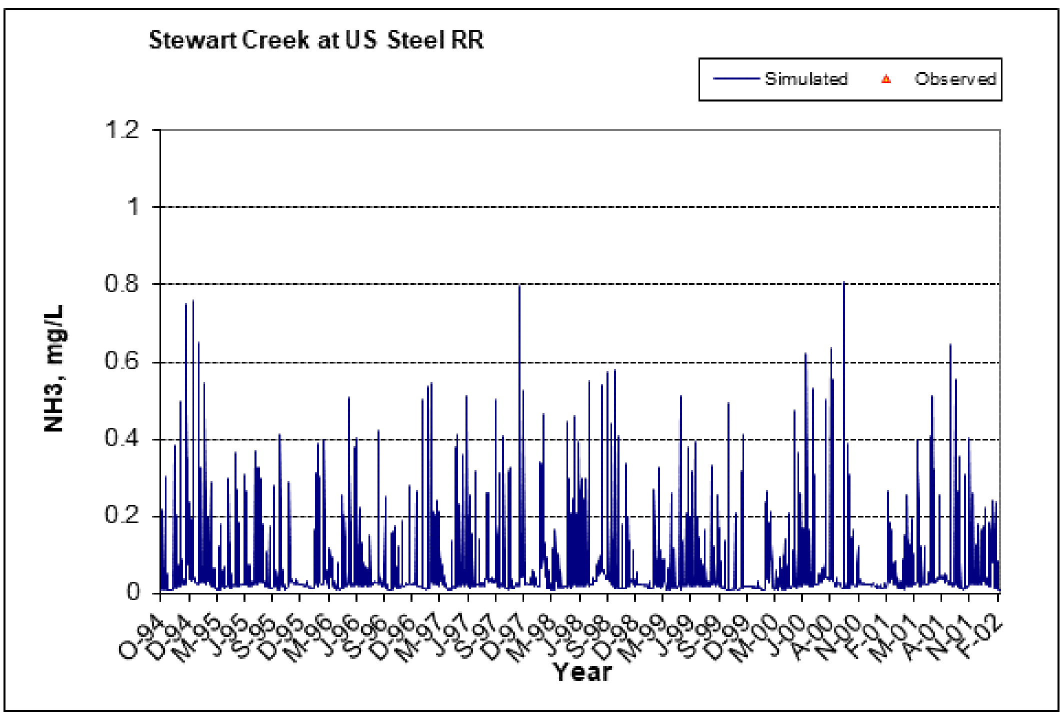
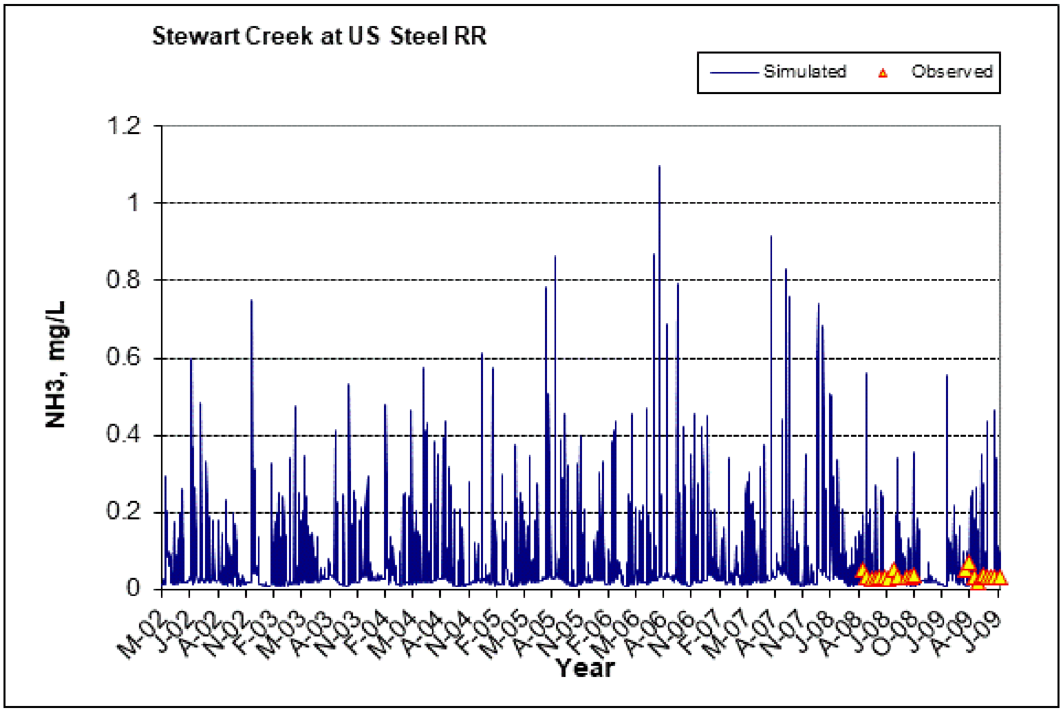


Figure E-861. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Stewart Creek at US Steel RR (calibration period)





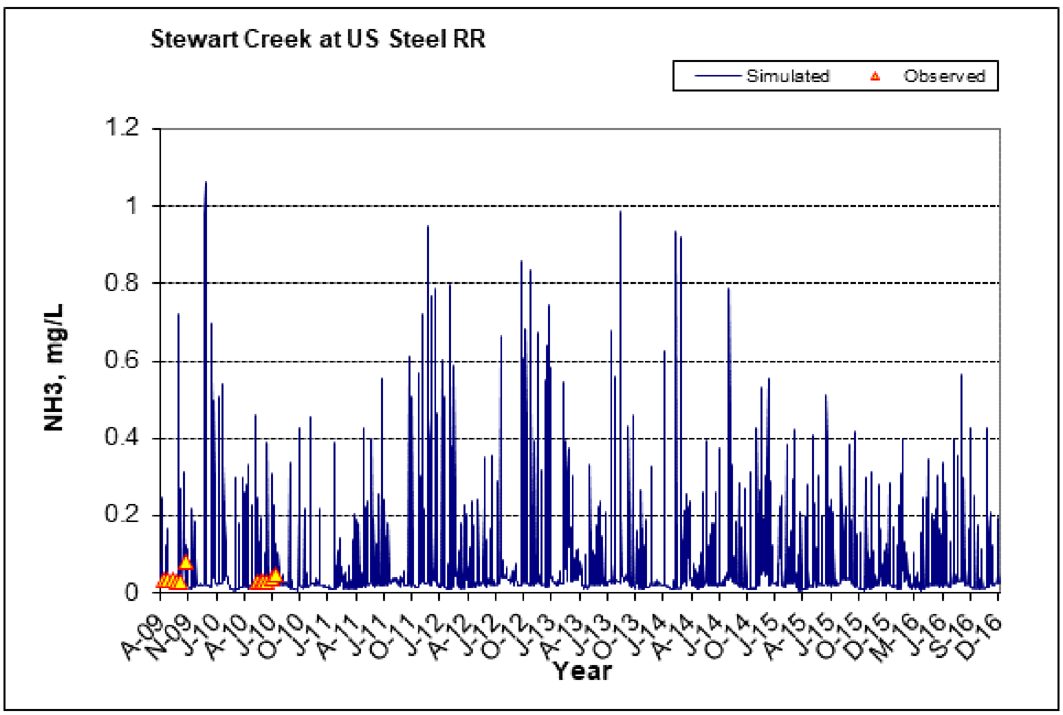


Figure E-862. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Stewart Creek at US Steel RR

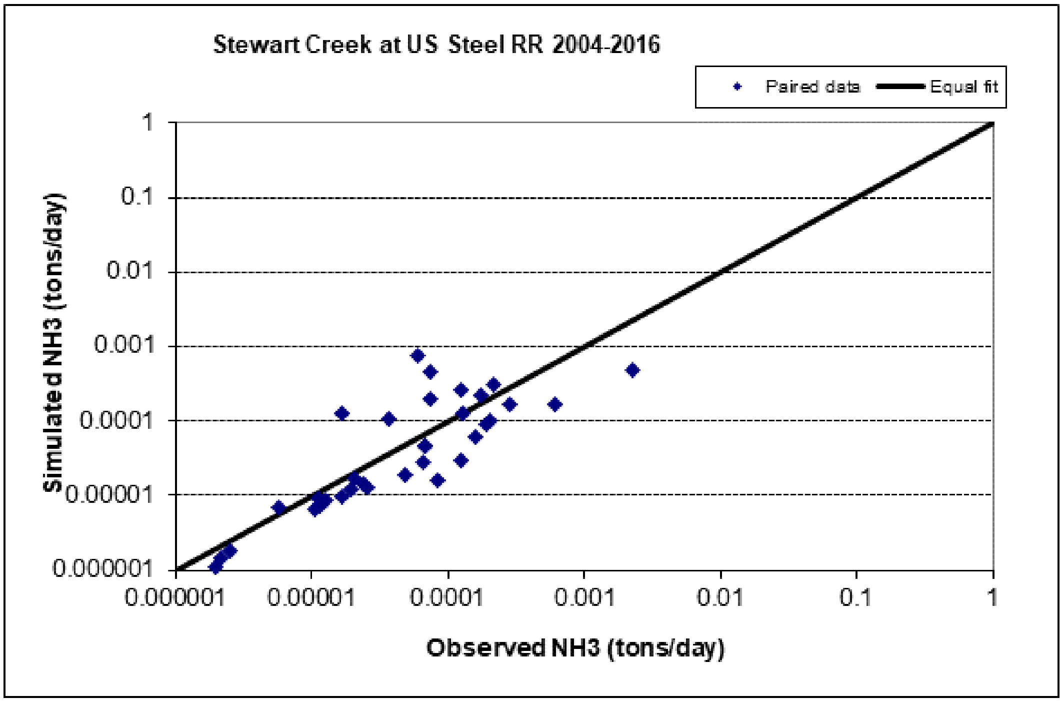


Figure E-863. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Stewart Creek at US Steel RR (calibration period)

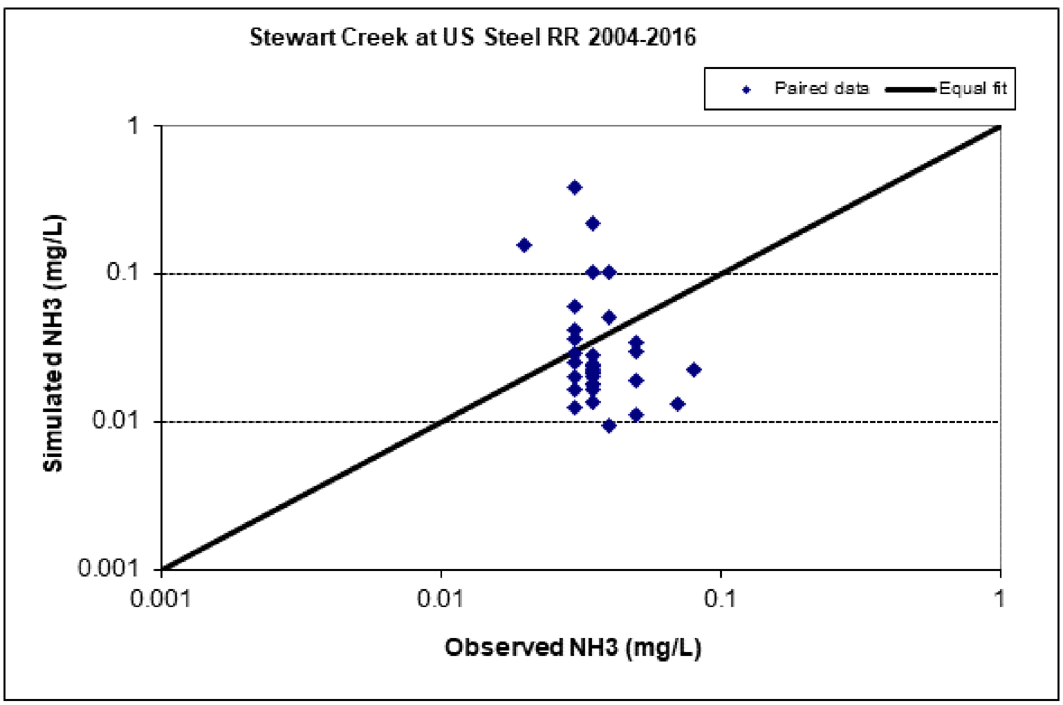


Figure E-864. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Stewart Creek at US Steel RR (calibration period)

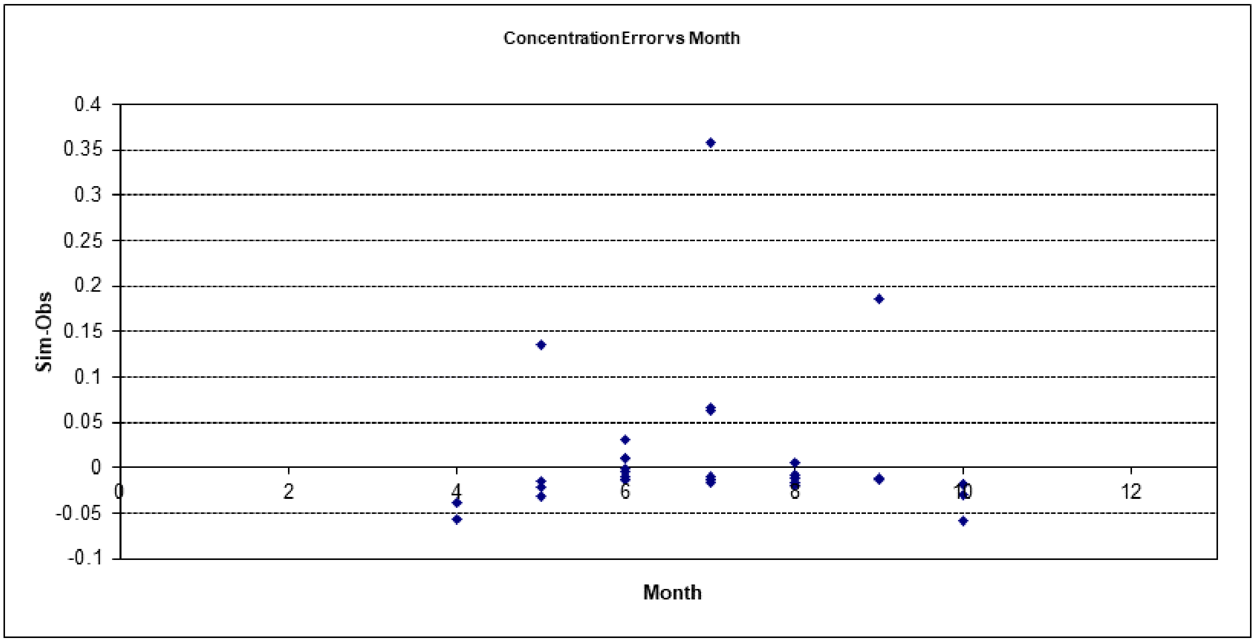


Figure E-865. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Stewart Creek at US Steel RR

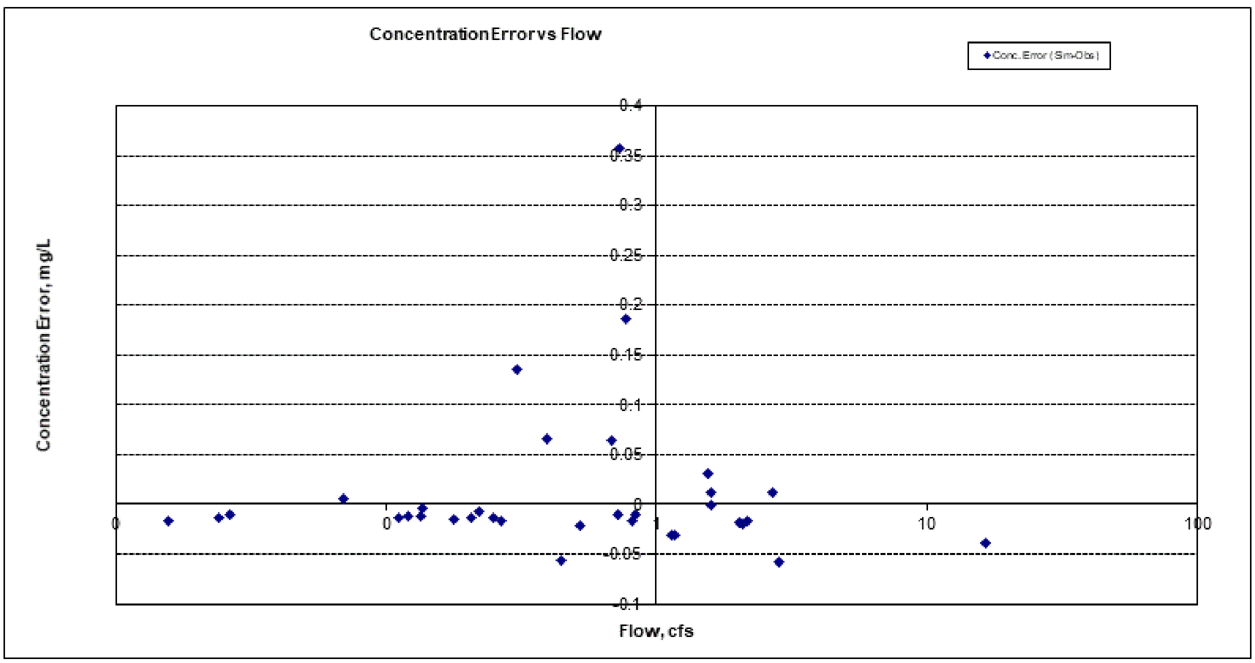


Figure E-866. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Stewart Creek at US Steel RR

E.19.3 Nitrite+ Nitrate Nitrogen (NOx)

Table E-111. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	27
Concentration Average Error		47.37%
Concentration Median Error		-4.84%
Load Average Error		68.99%
Load Median Error		-0.12%
Paired t conc		0.25
Paired t load		0.21

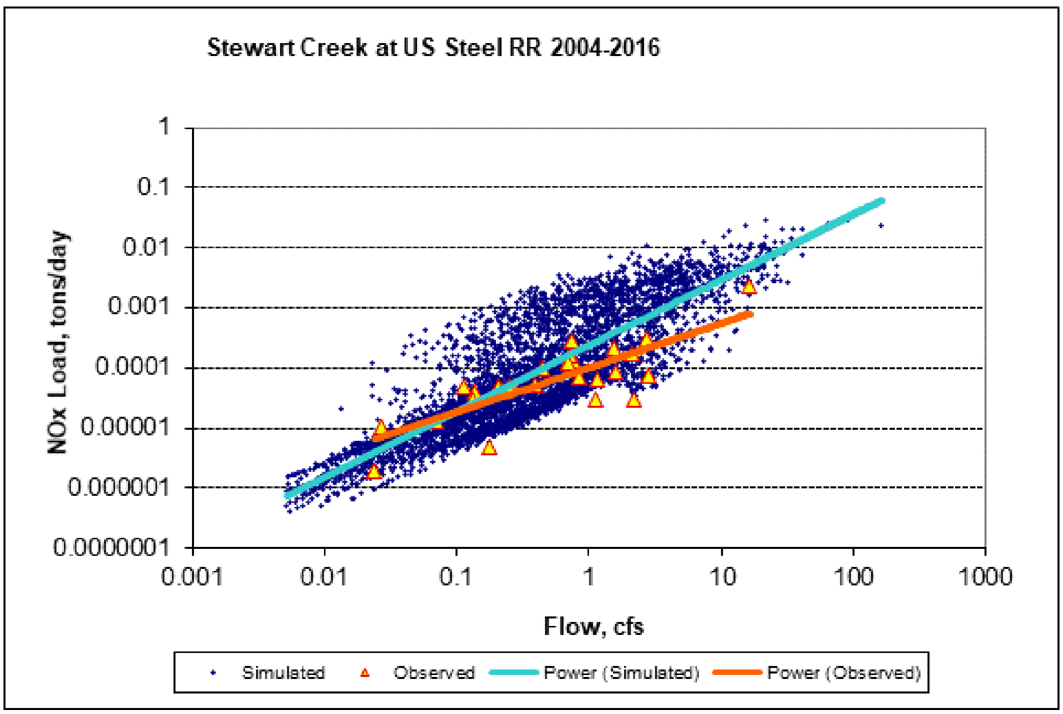


Figure E-867. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Stewart Creek at US Steel RR (calibration period)

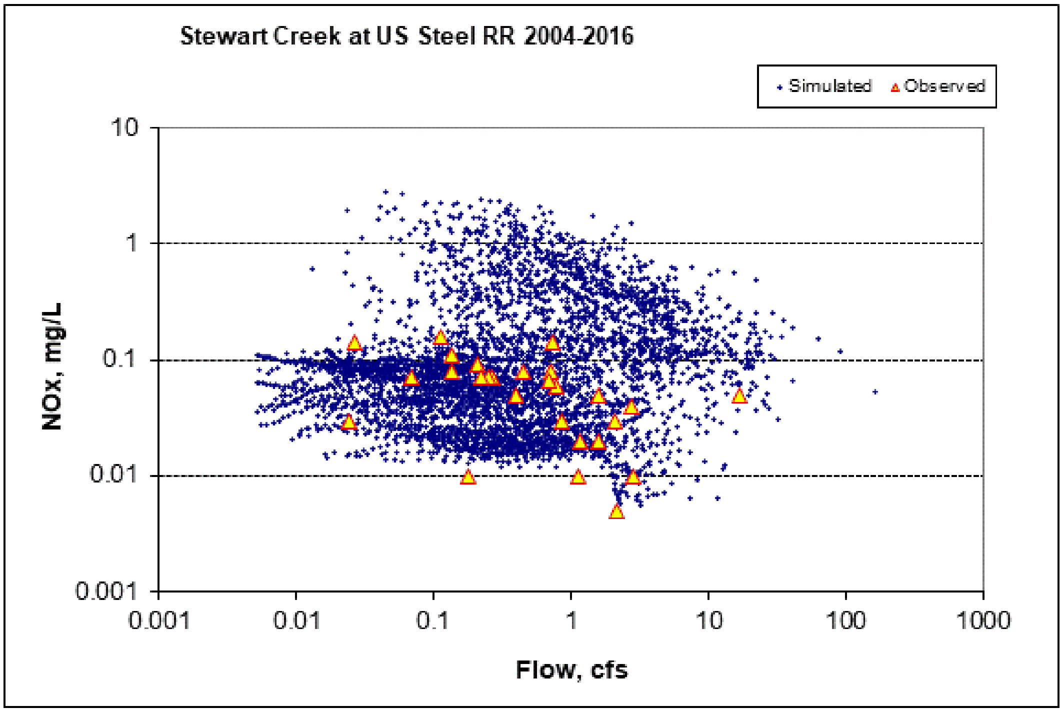
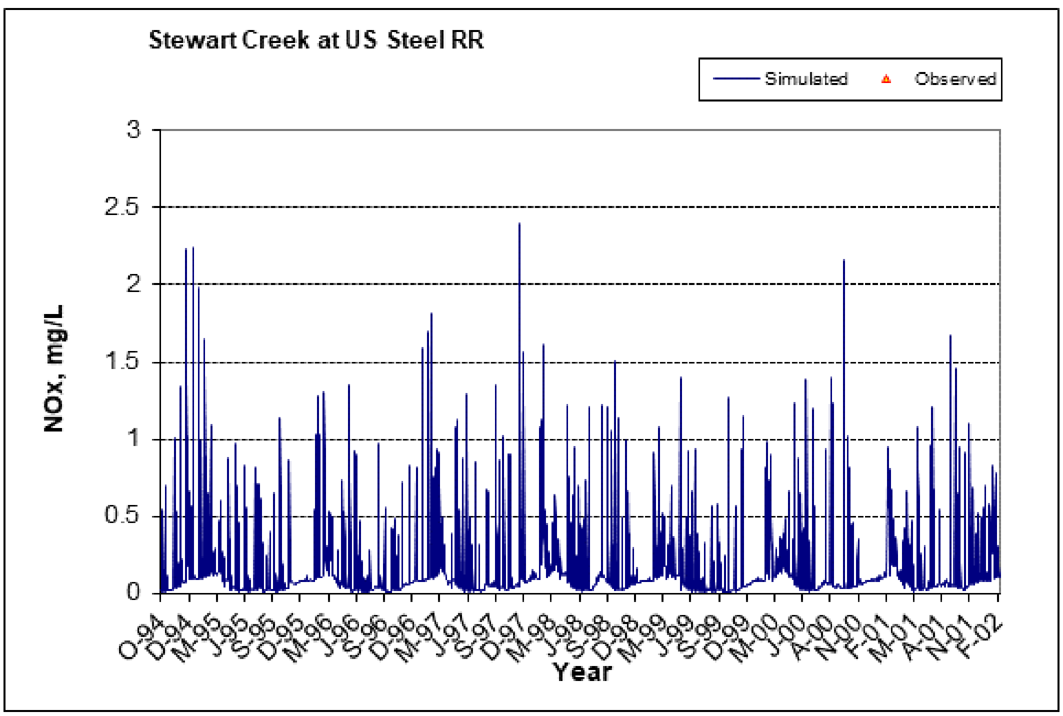
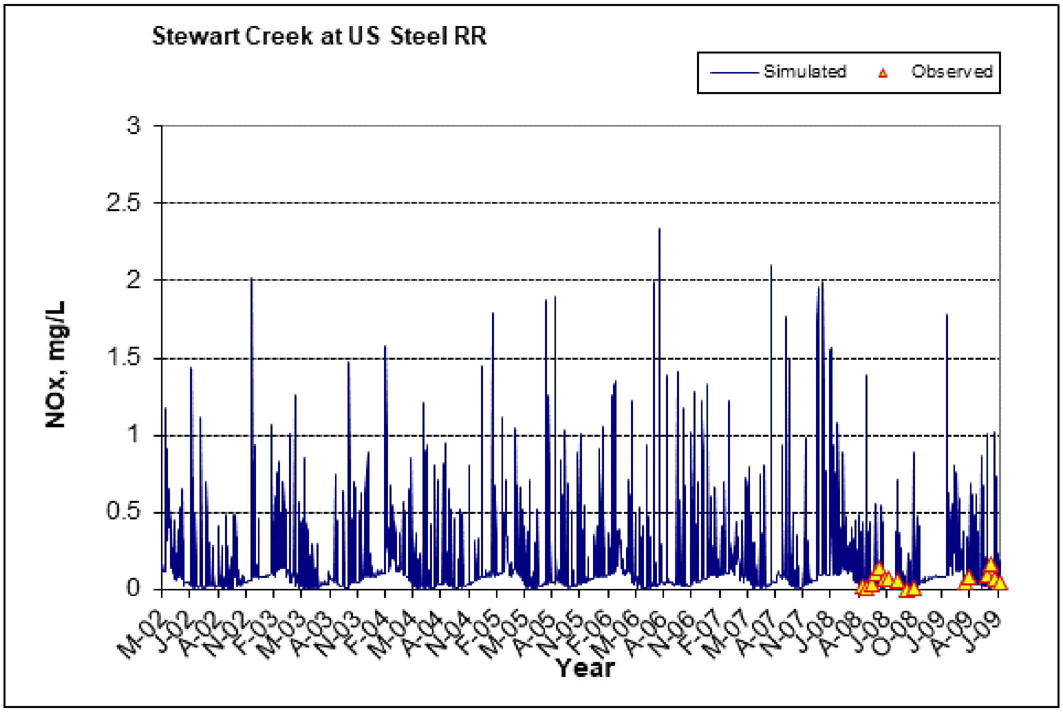


Figure E-868. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Stewart Creek at US Steel RR (calibration period)





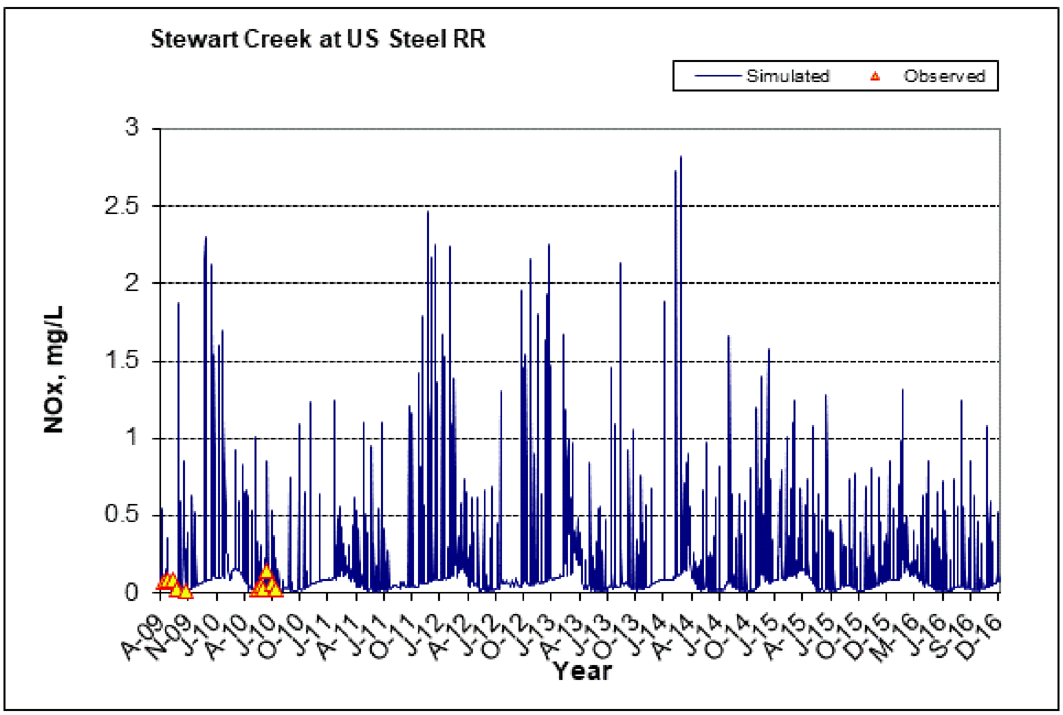


Figure E-869. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Stewart Creek at US Steel RR

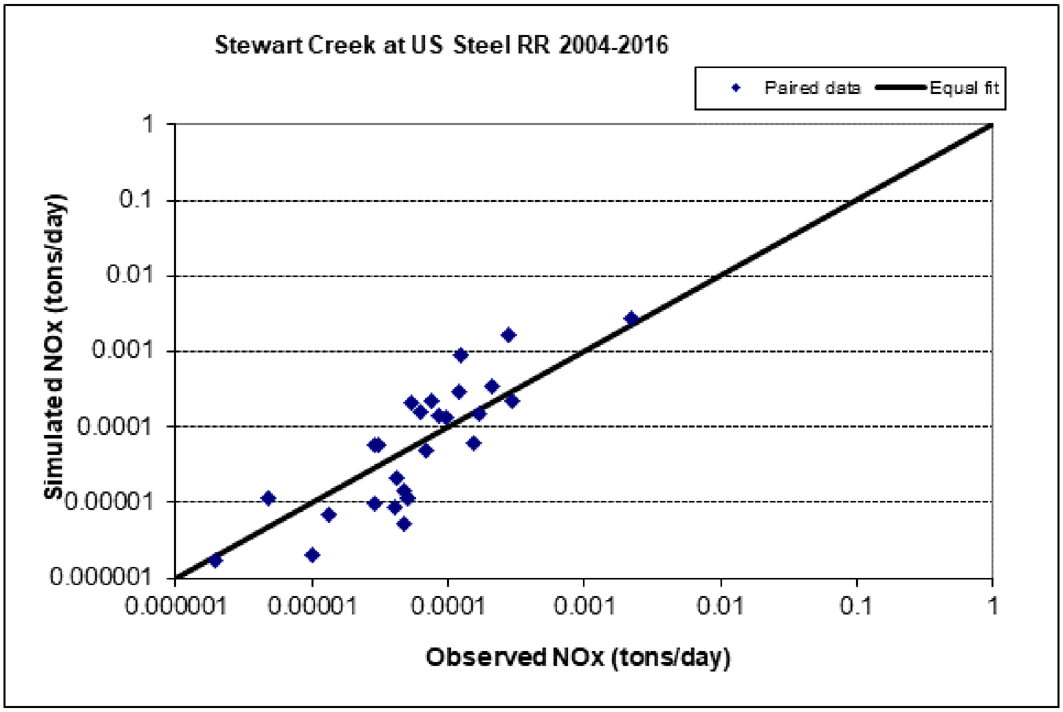


Figure E-870. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Stewart Creek at US Steel RR (calibration period)

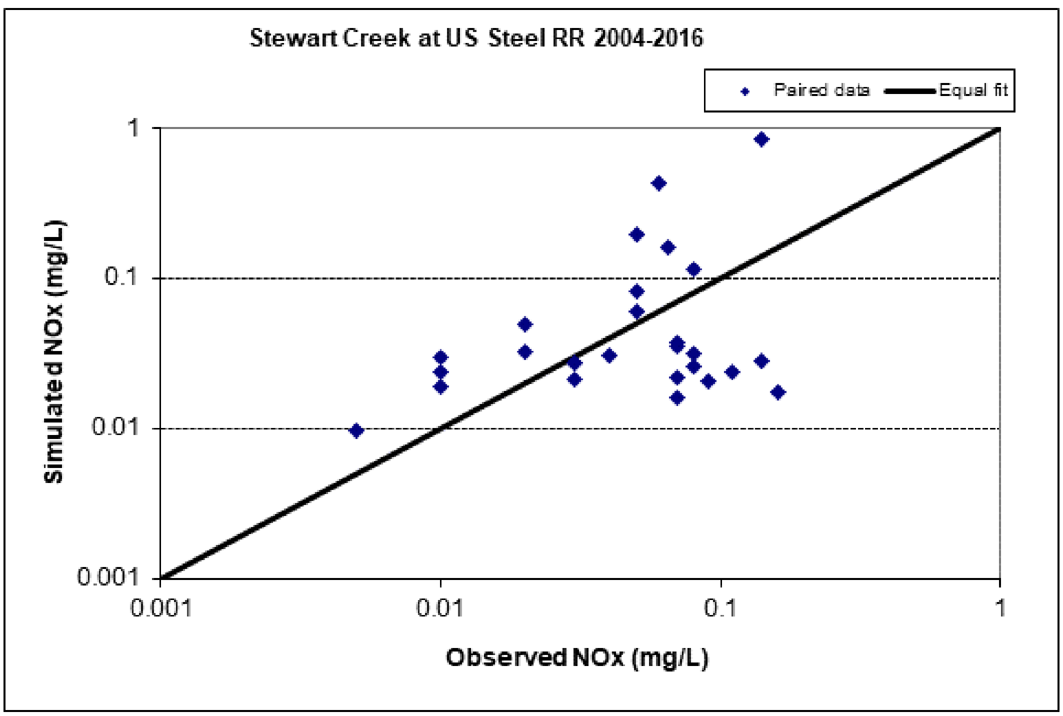


Figure E-871. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Stewart Creek at US Steel RR (calibration period)

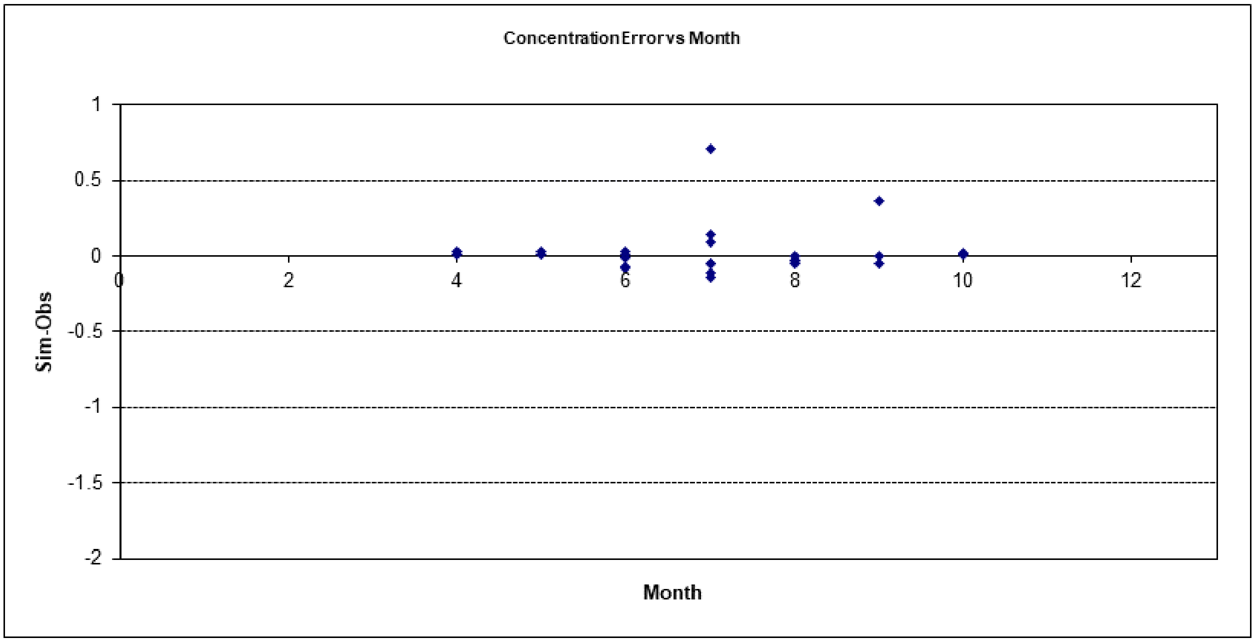


Figure E-872. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Stewart Creek at US Steel RR

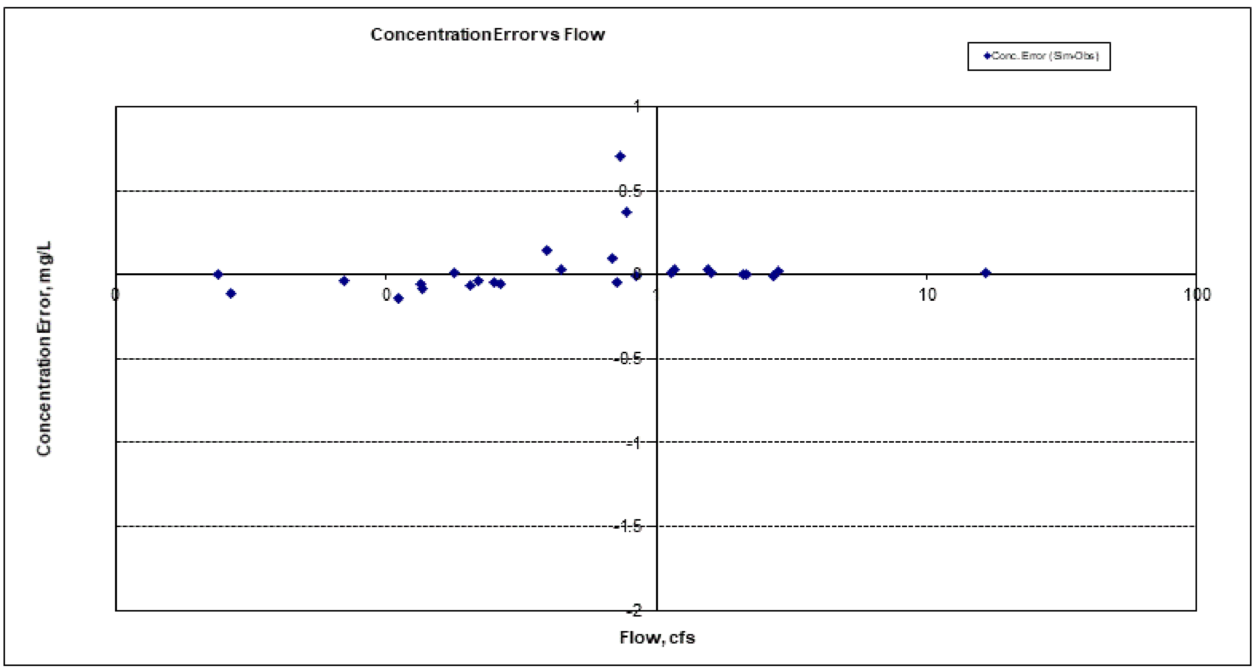


Figure E-873. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Stewart Creek at US Steel RR

E.19.4 Total Phosphorus (TP)

Table E-112. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	34
Concentration Average Error		-4.21%
Concentration Median Error		13.77%
Load Average Error		-20.57%
Load Median Error		1.06%
Paired t conc		0.93
Paired t load		0.50

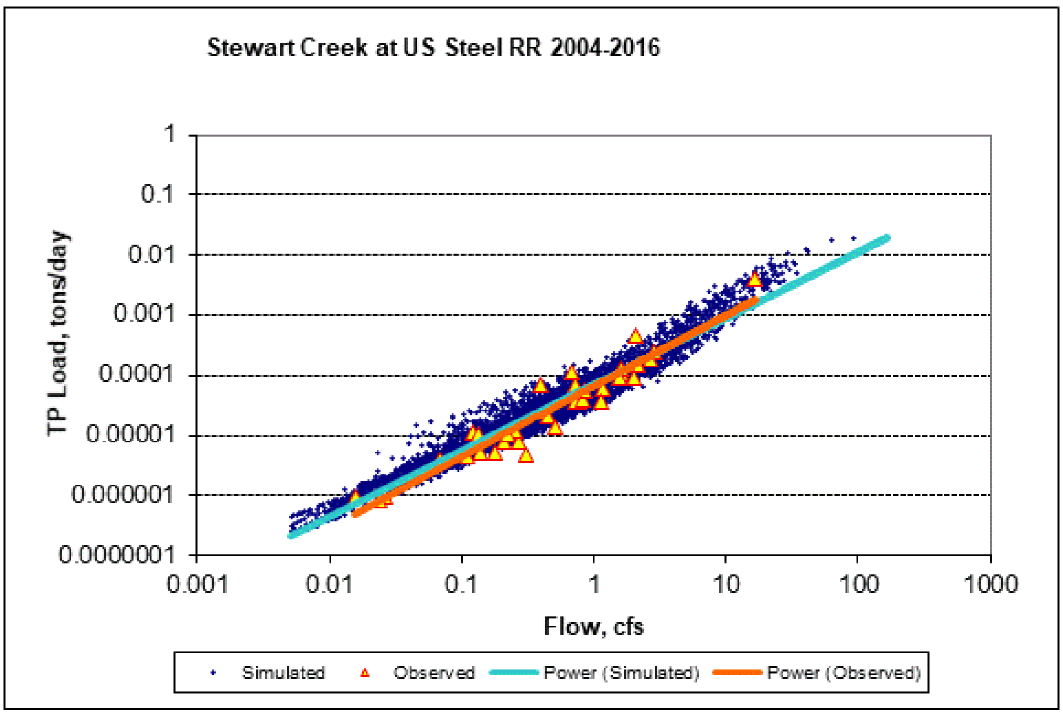


Figure E-874. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Stewart Creek at US Steel RR (calibration period)

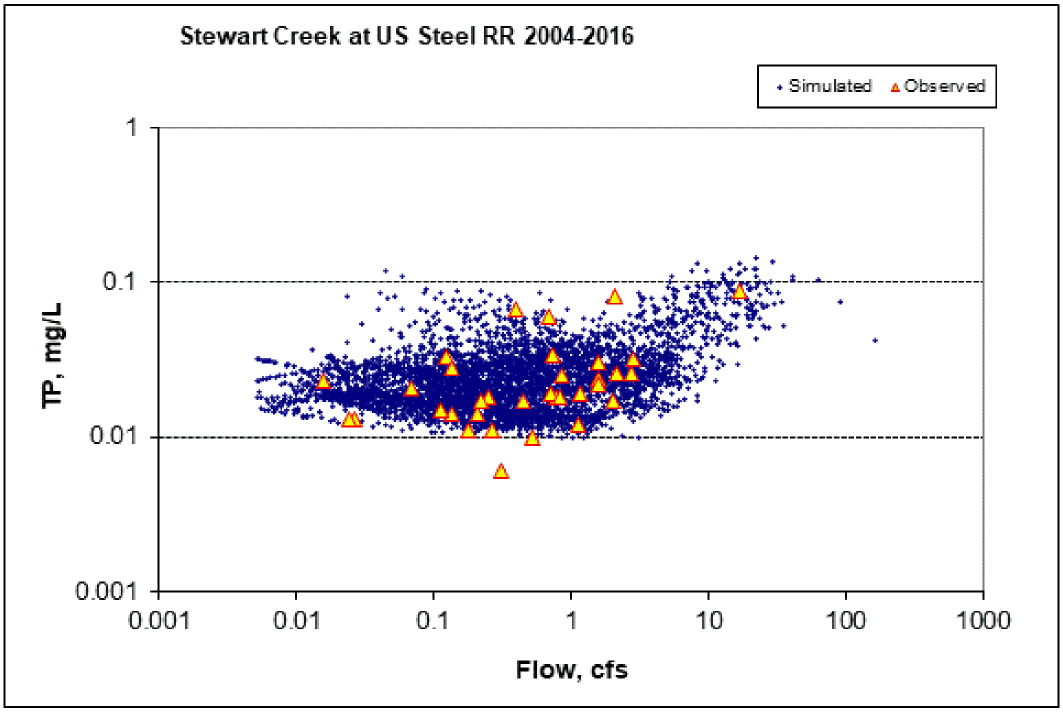
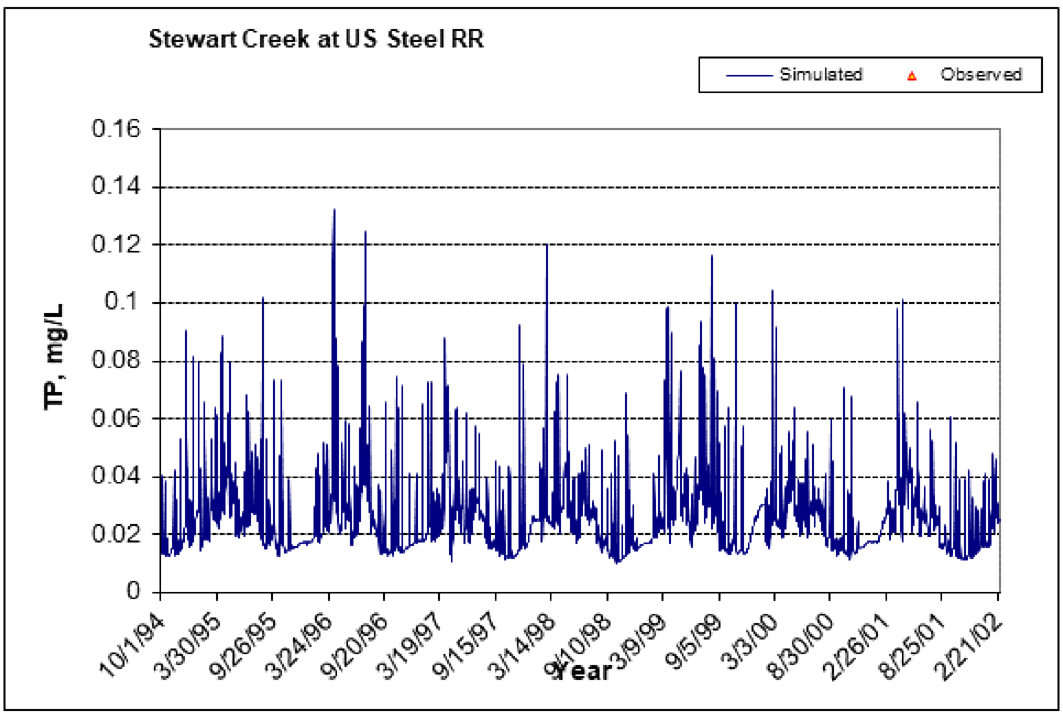


Figure E-875. Simulated and observed Total Phosphorus (TP) concentration vs flow at Stewart Creek at US Steel RR (calibration period)



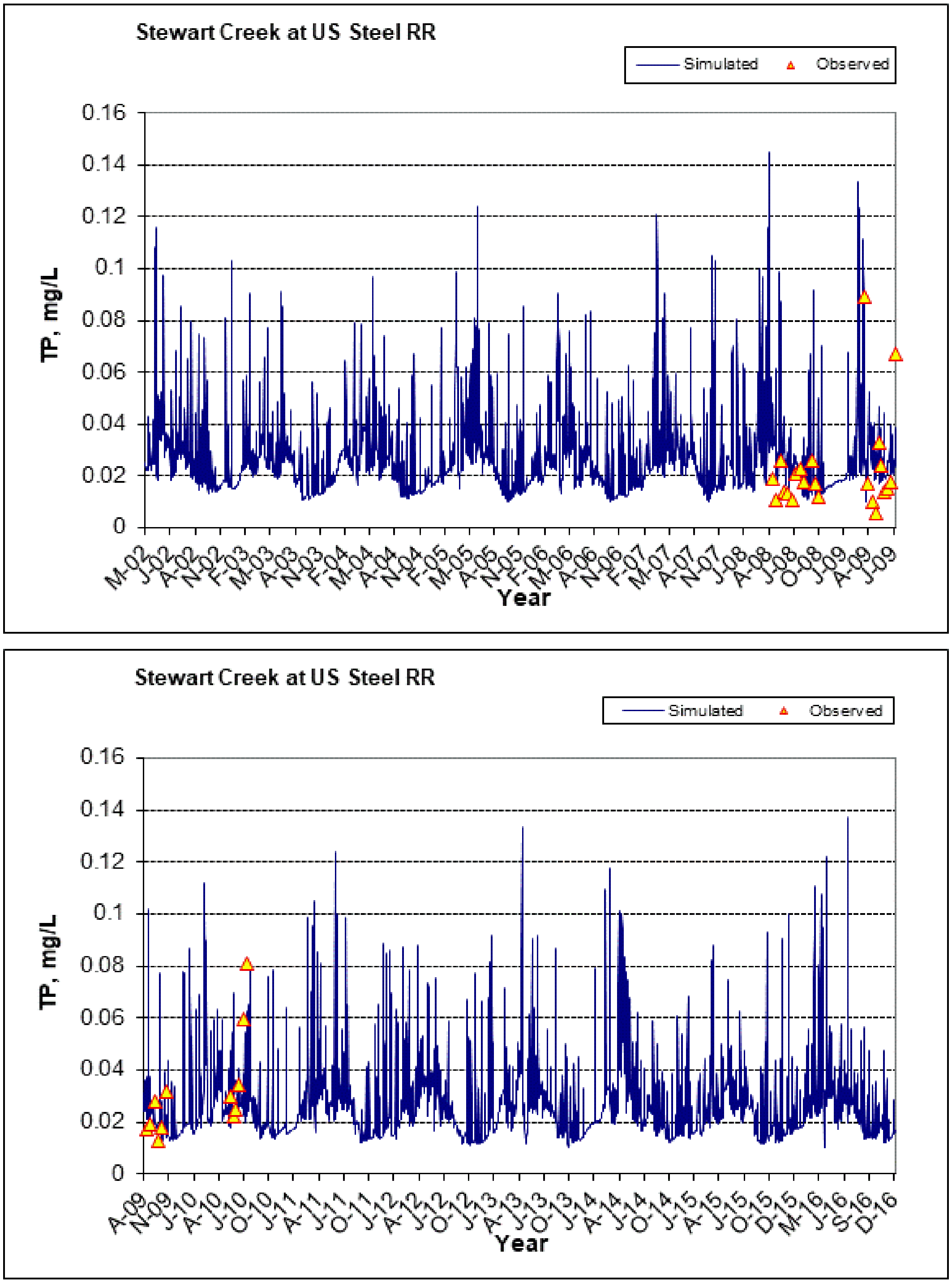


Figure E-876. Time series of observed and simulated Total Phosphorus (TP) concentration at Stewart Creek at US Steel RR

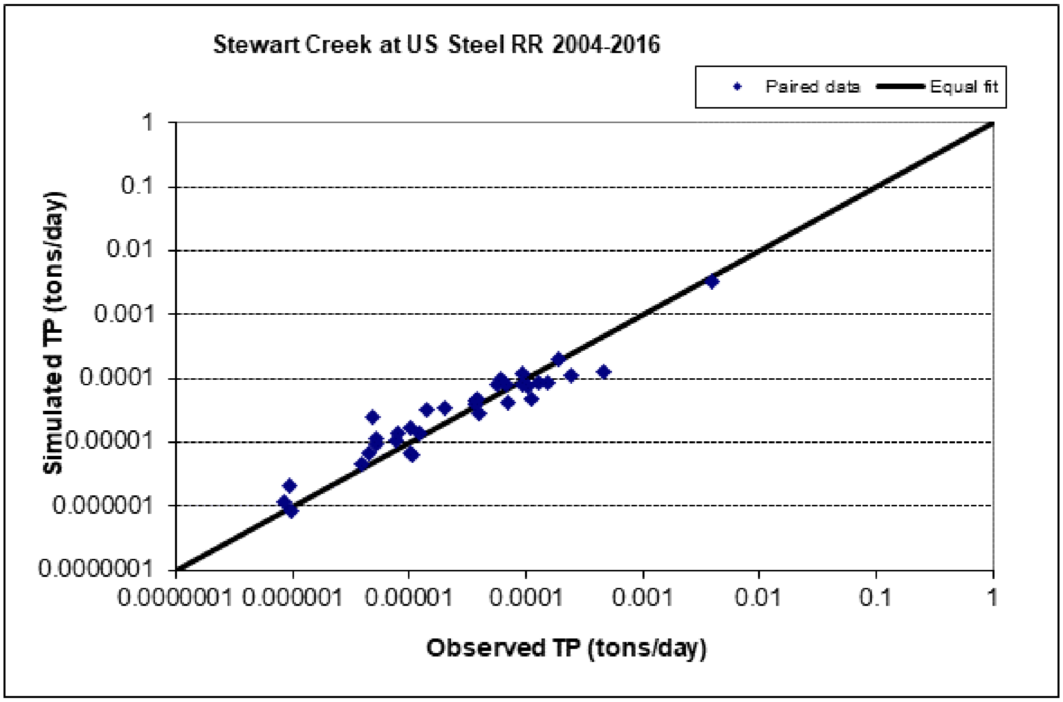


Figure E-877. Paired simulated vs. observed Total Phosphorus (TP) load at Stewart Creek at US Steel RR (calibration period)

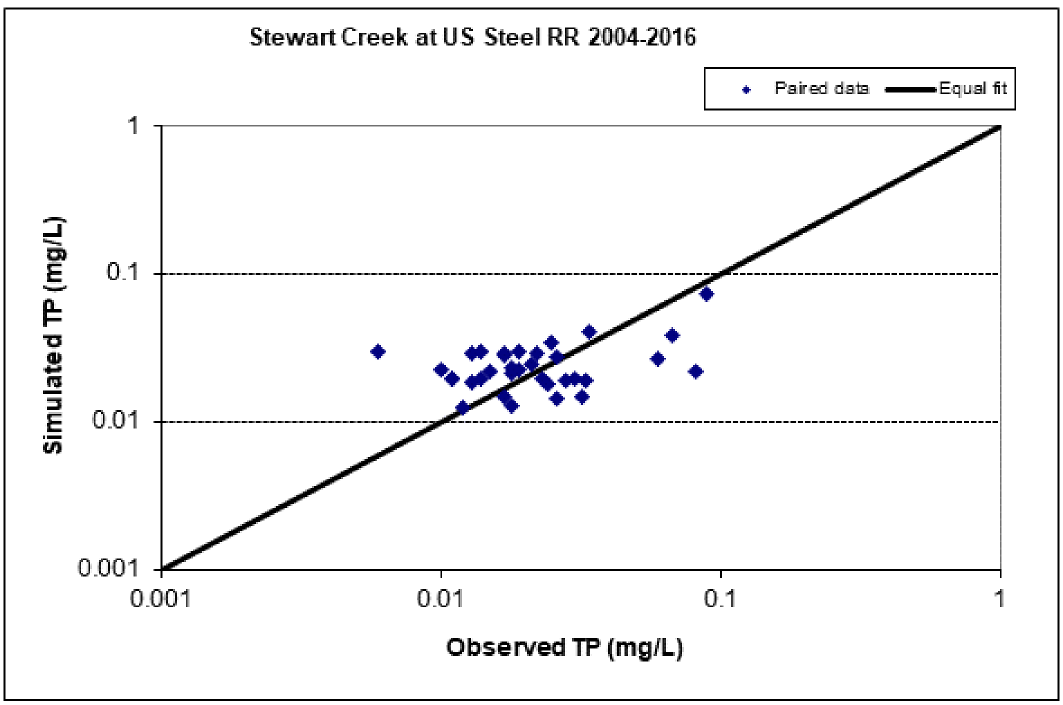


Figure E-878. Paired simulated vs. observed Total Phosphorus (TP) concentration at Stewart Creek at US Steel RR (calibration period)

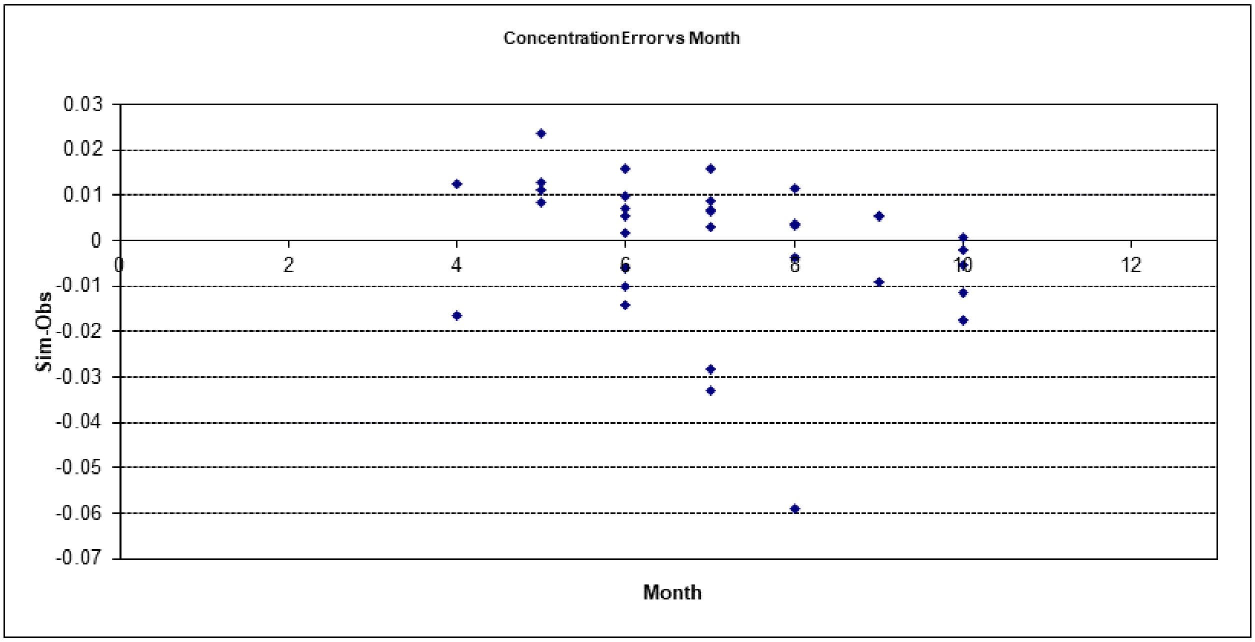


Figure E-879. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Stewart Creek at US Steel RR

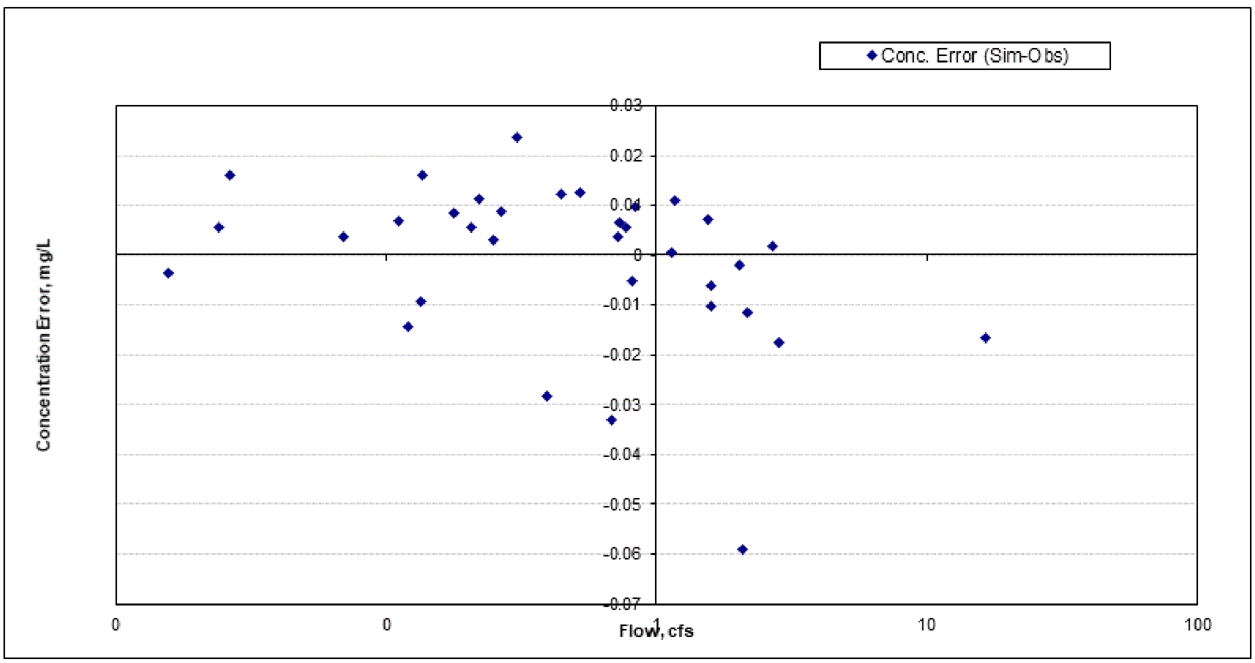


Figure E-880. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Stewart Creek at US Steel RR

E.20 SARGENT CREEK AT HUDSON BLVD

E.20.1 Dissolved Oxygen (DO)

Table E-113. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	18
Concentration Average Error		-12.66%
Concentration Median Error		-6.13%
Load Average Error		-1.88%
Load Median Error		-0.96%
Paired t conc		0.92
Paired t load		0.80

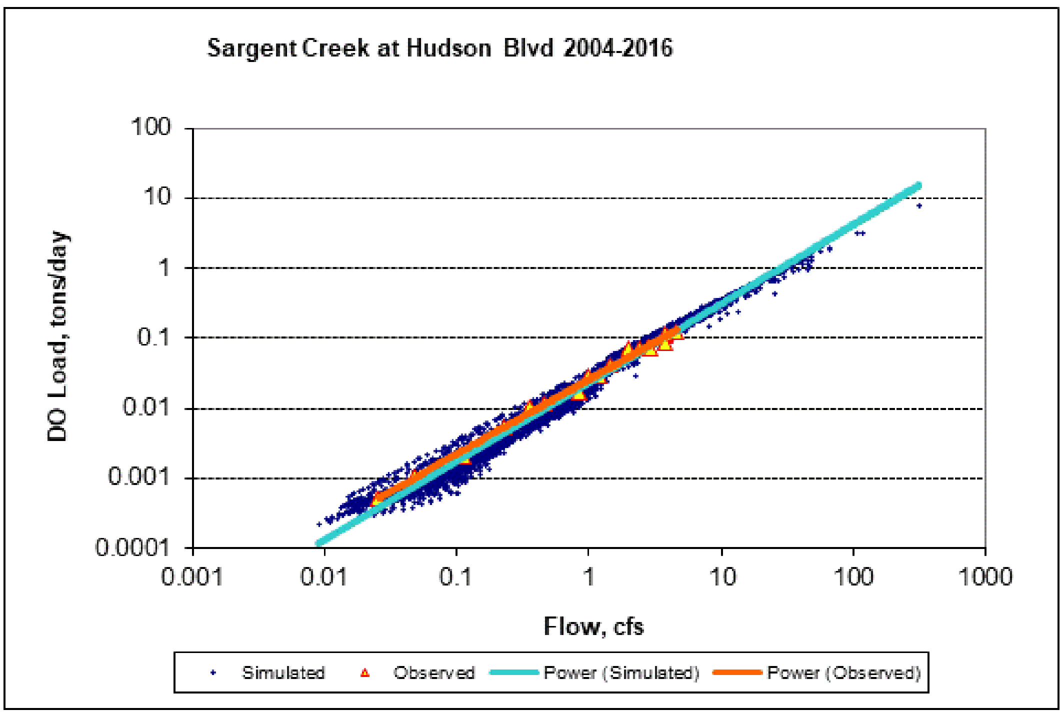


Figure E-881. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Sargent Creek at Hudson Blvd (calibration period)

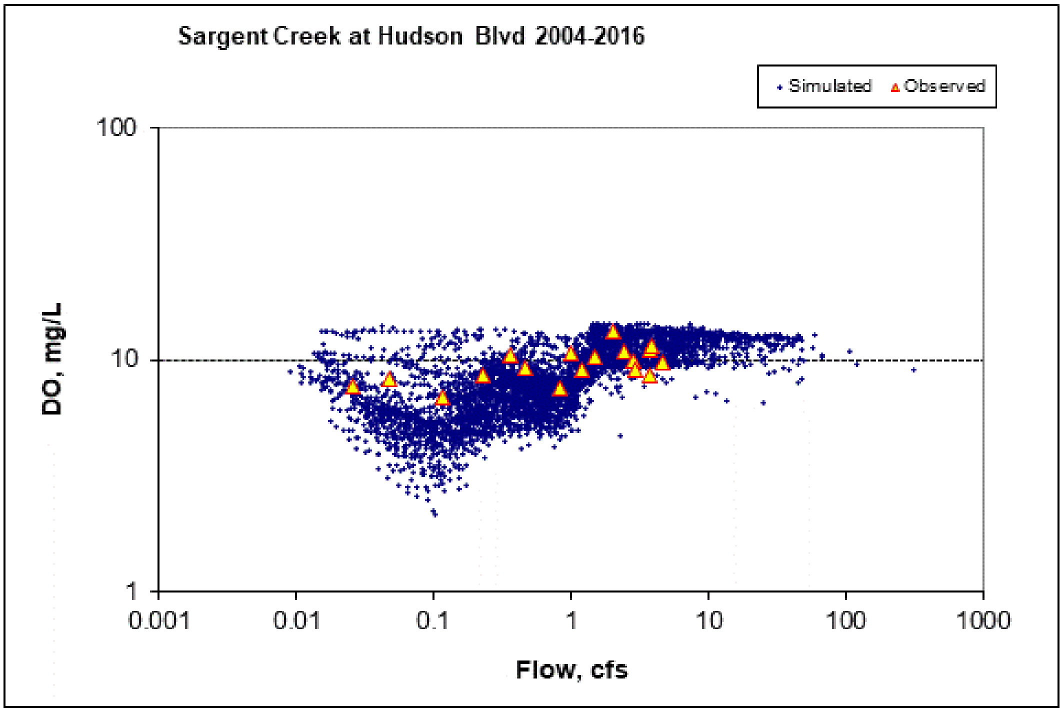
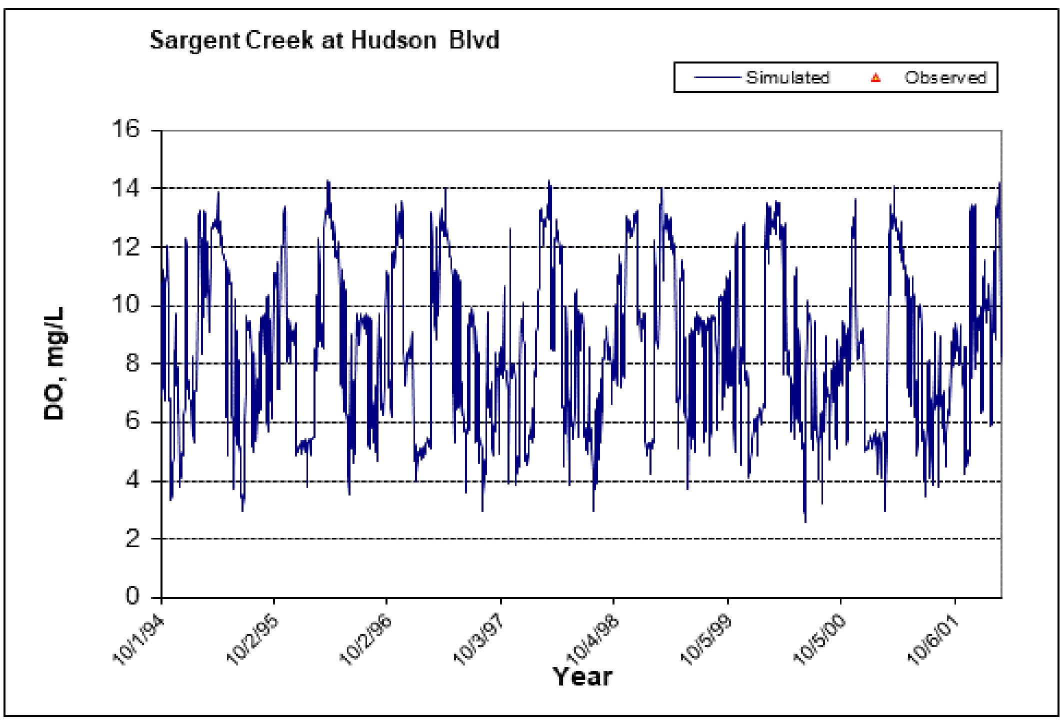


Figure E-882. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Sargent Creek at Hudson Blvd (calibration period)



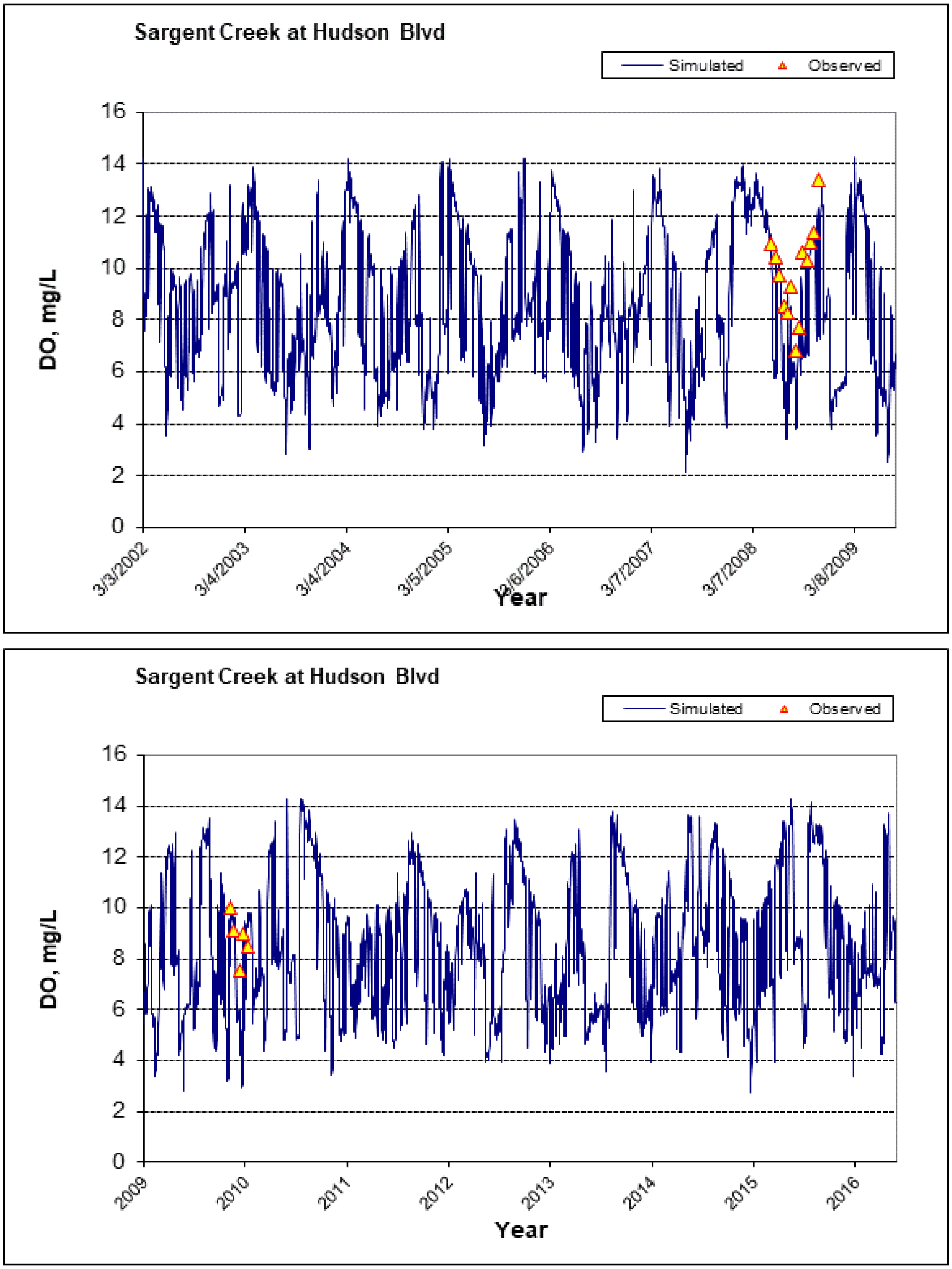


Figure E-883. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Sargent Creek at Hudson Blvd

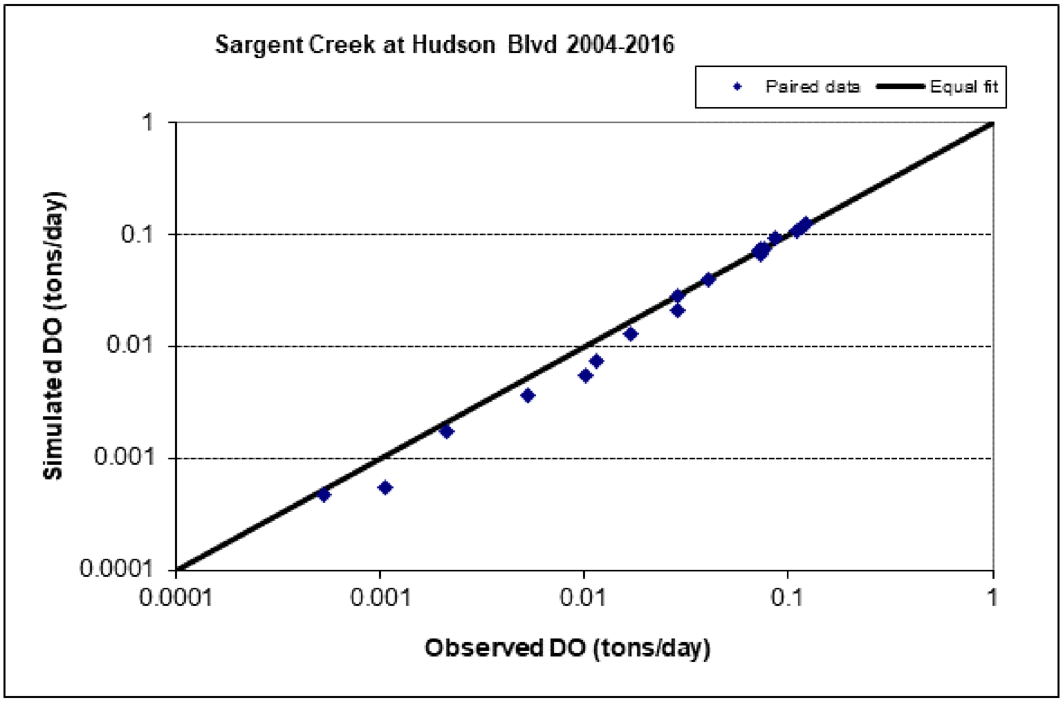


Figure E-884. Paired simulated vs. observed Dissolved Oxygen (DO) load at Sargent Creek at Hudson Blvd (calibration period)

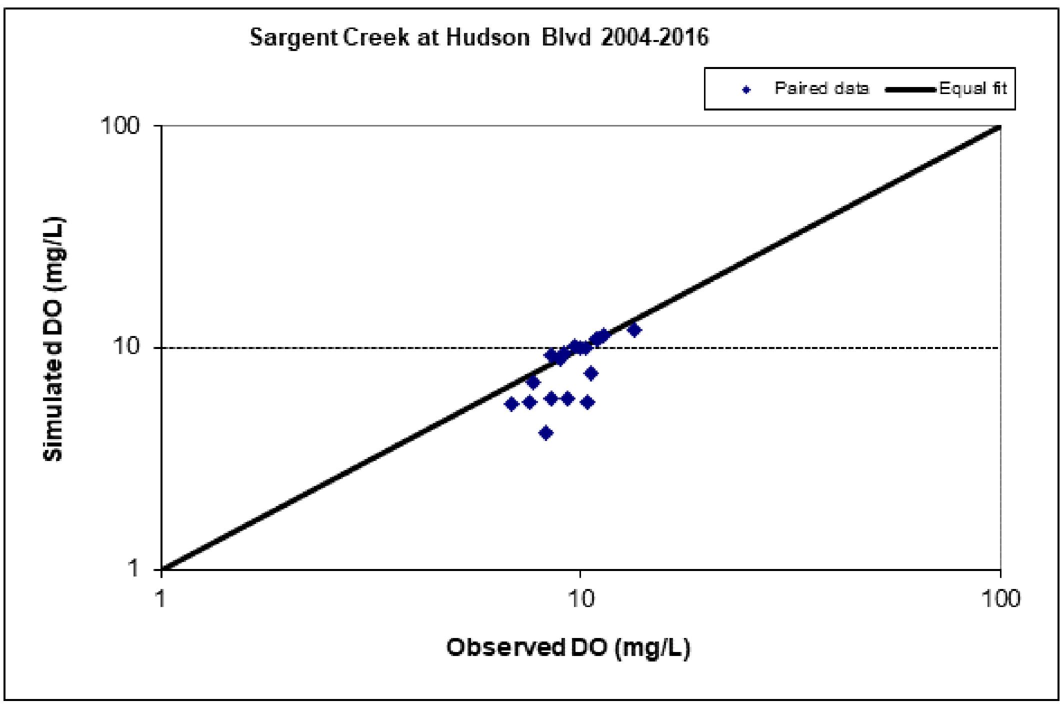


Figure E-885. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Sargent Creek at Hudson Blvd (calibration period)

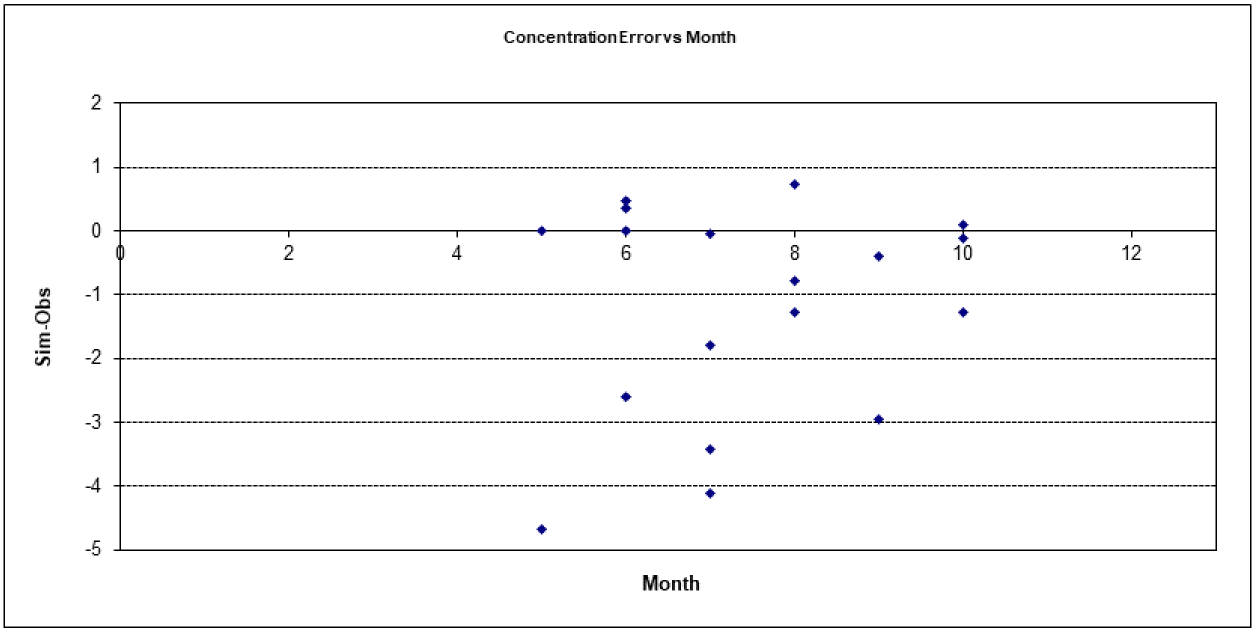


Figure E-886. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Sargent Creek at Hudson Blvd

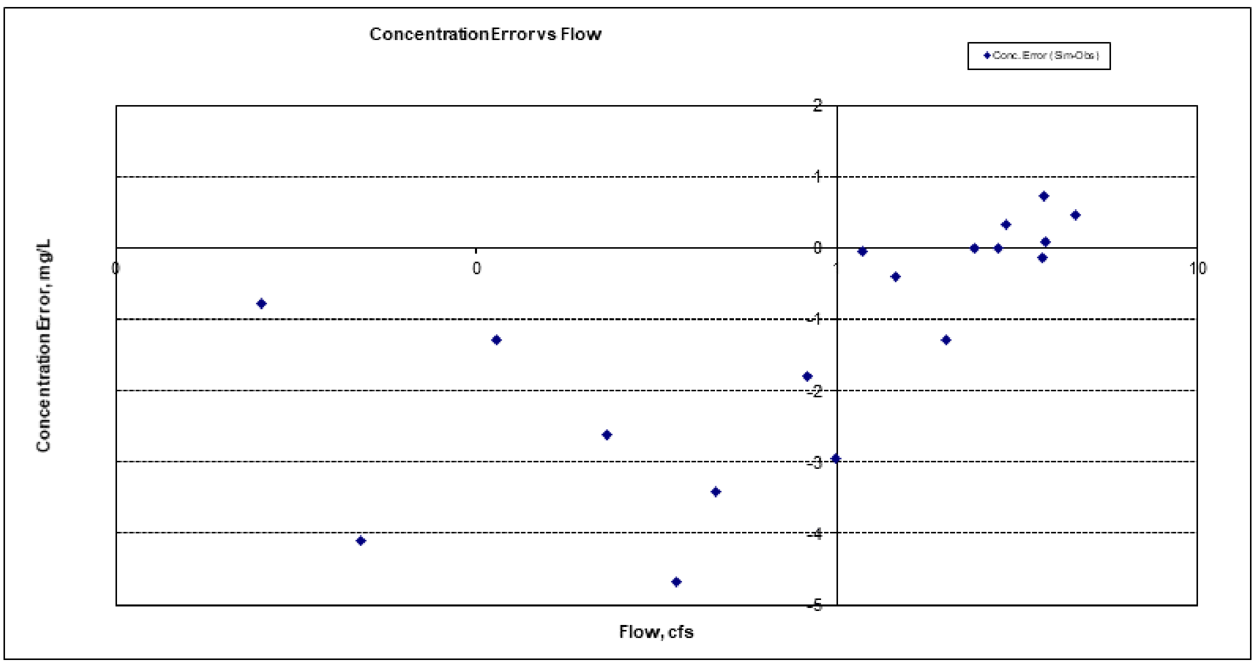


Figure E-887. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Sargent Creek at Hudson Blvd

E.20.2 Ammonia Nitrogen (NH3)

Table E-114. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	34
Concentration Average Error		23.80%
Concentration Median Error		-38.66%
Load Average Error		-63.74%
Load Median Error		-2.04%
Paired t conc		0.45
Paired t load		0.20

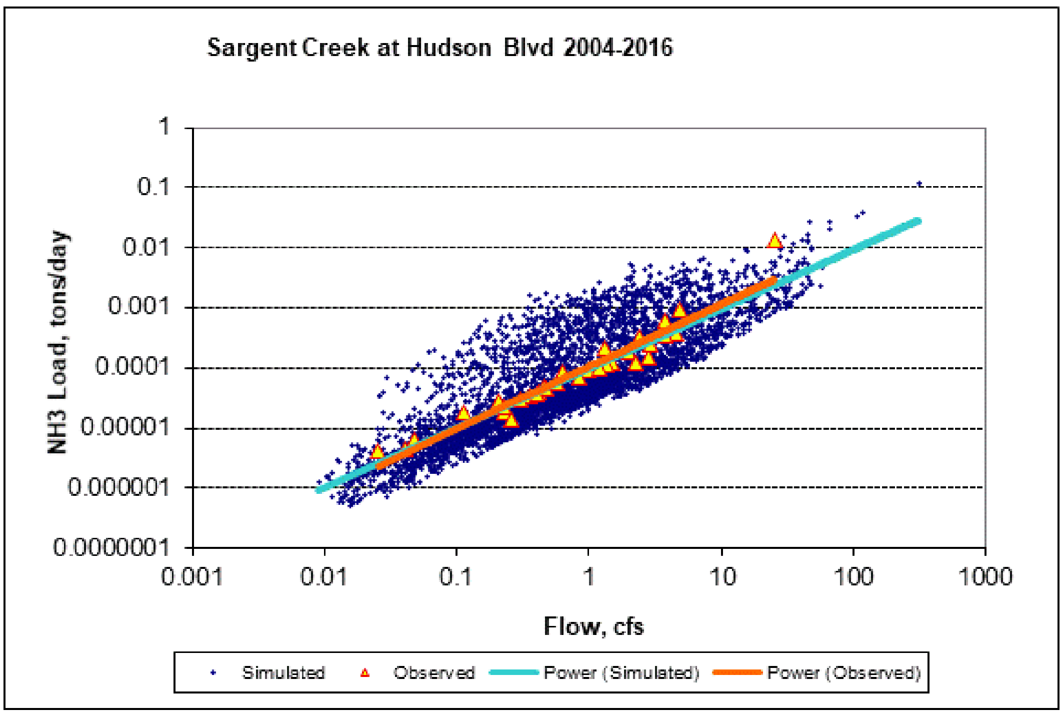


Figure E-888. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Sargent Creek at Hudson Blvd (calibration period)

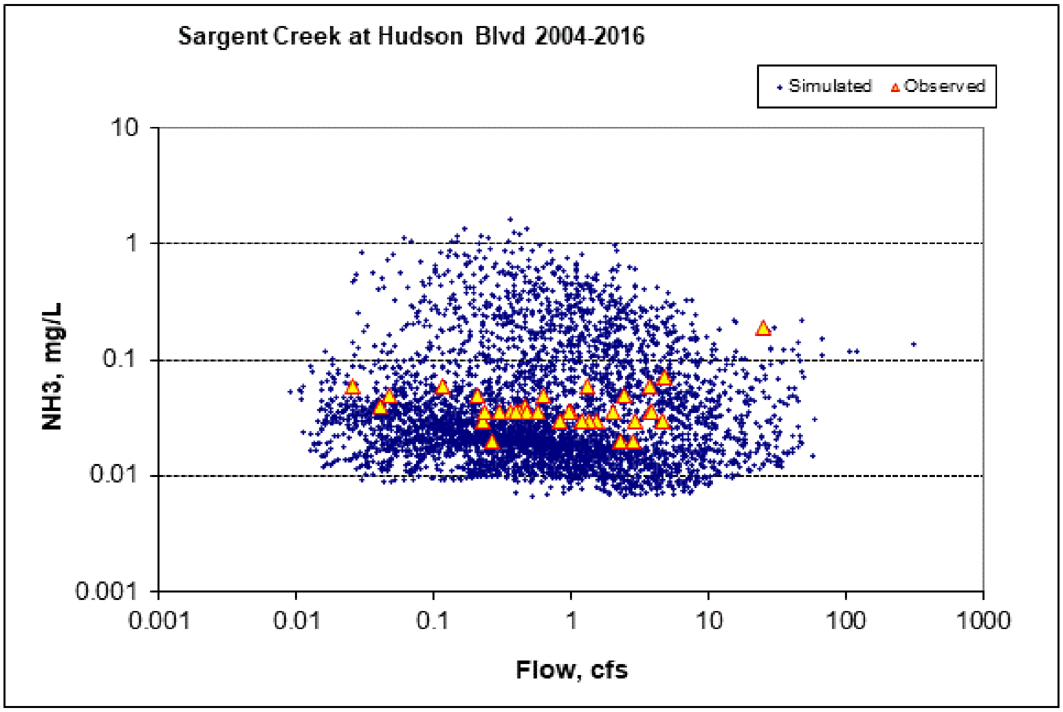
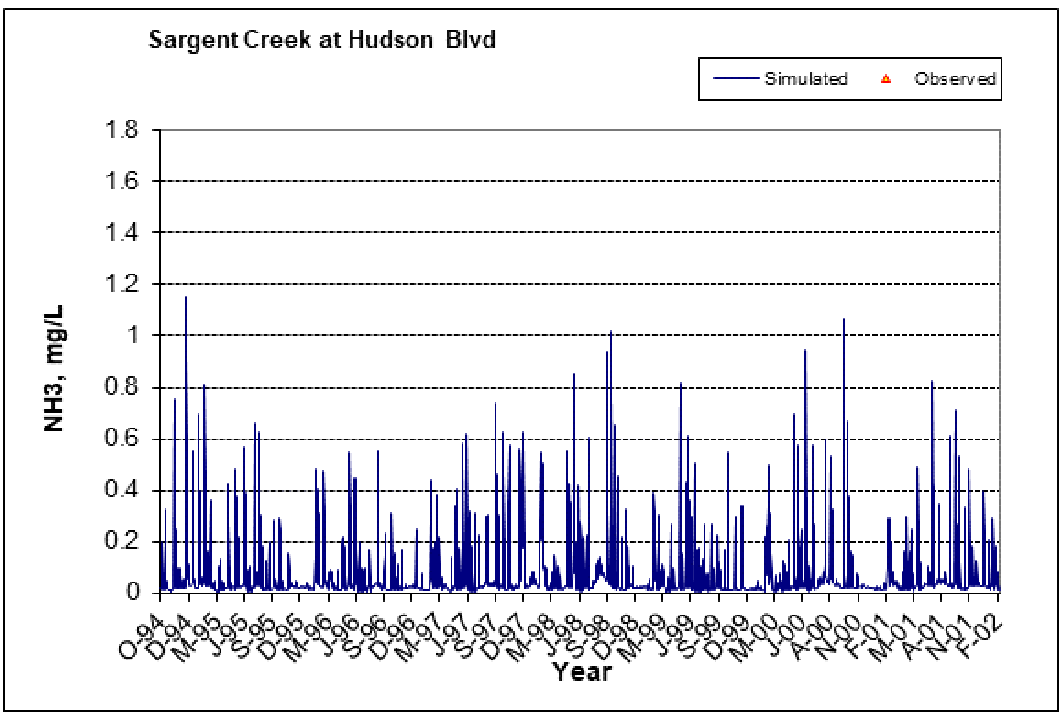
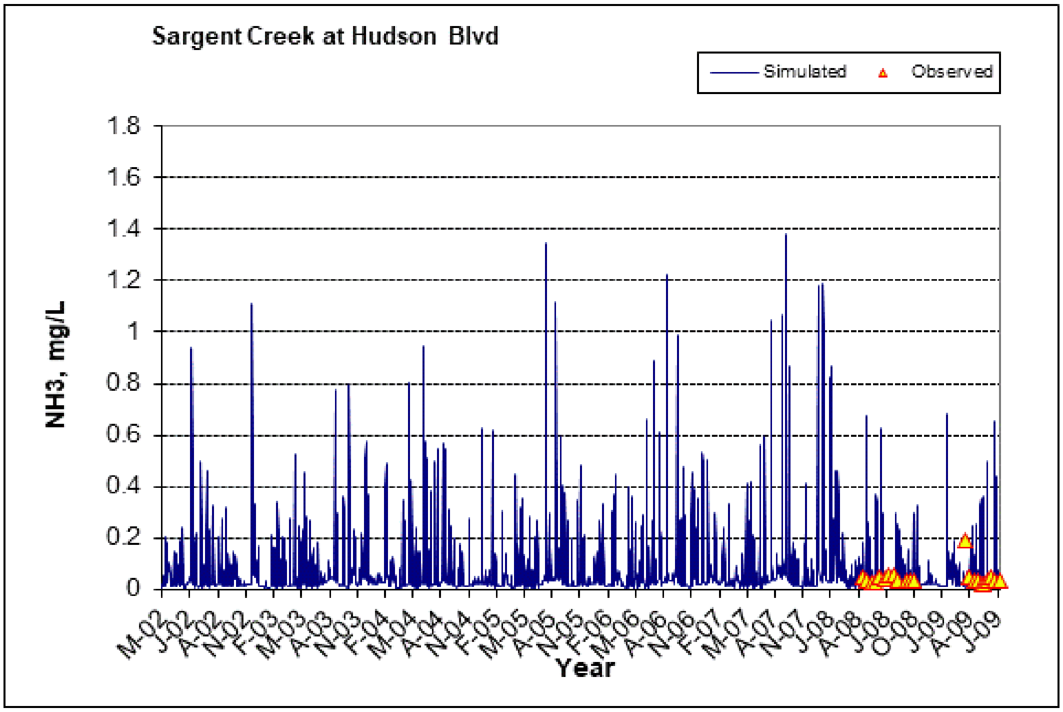


Figure E-889. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Sargent Creek at Hudson Blvd (calibration period)





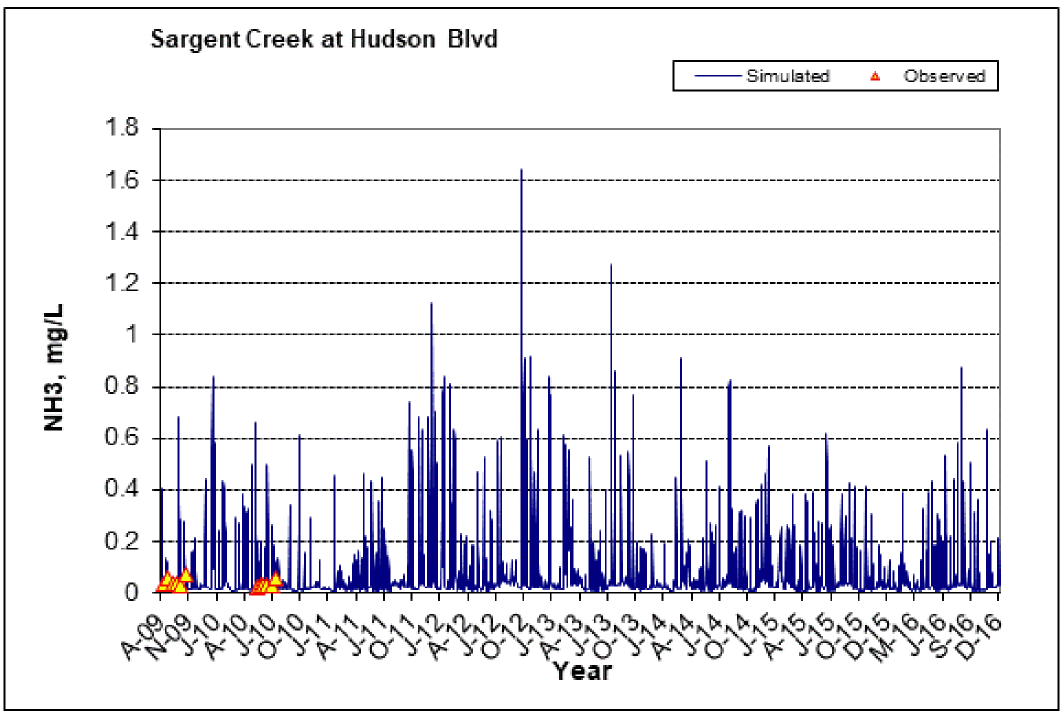


Figure E-890. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Sargent Creek at Hudson Blvd

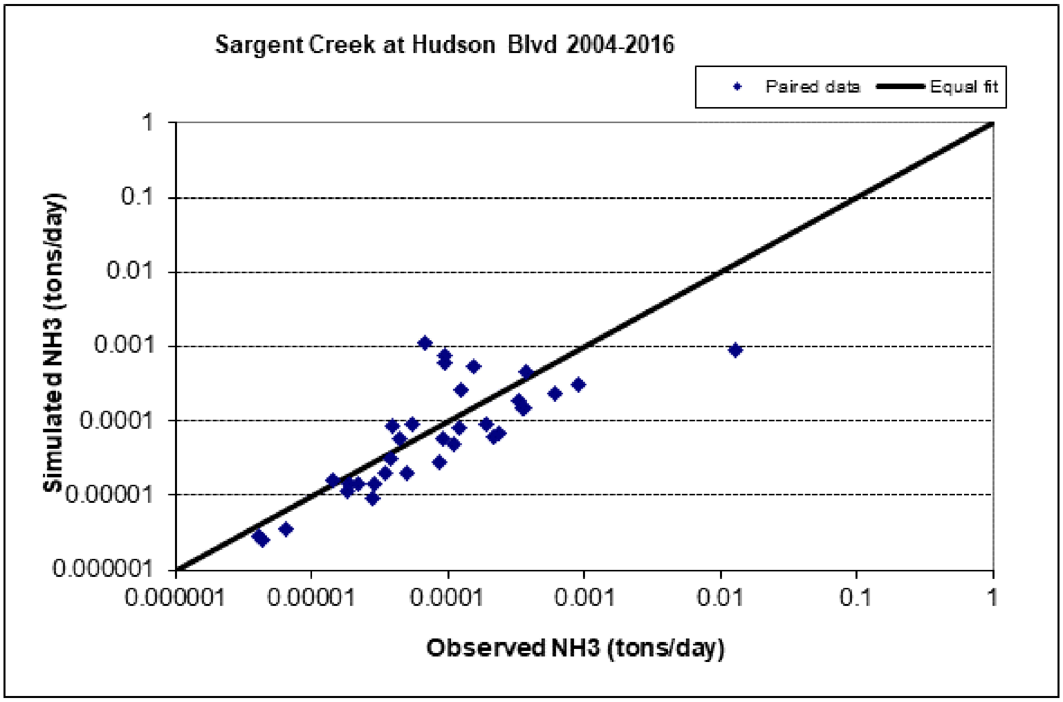


Figure E-891. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Sargent Creek at Hudson Blvd (calibration period)

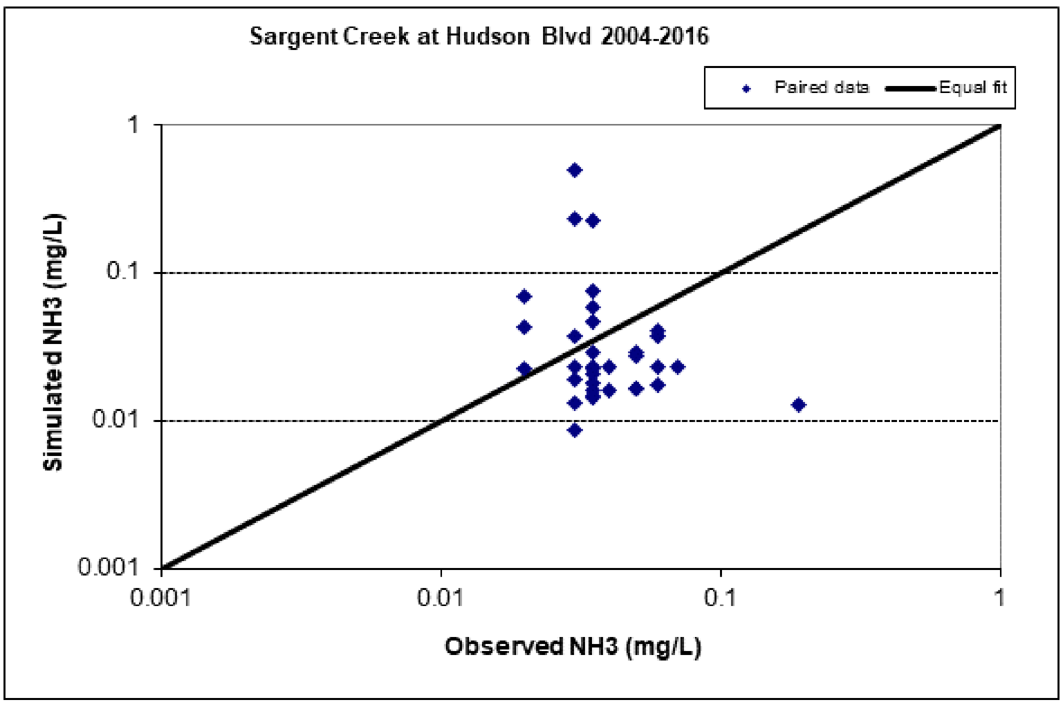


Figure E-892. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Sargent Creek at Hudson Blvd (calibration period)

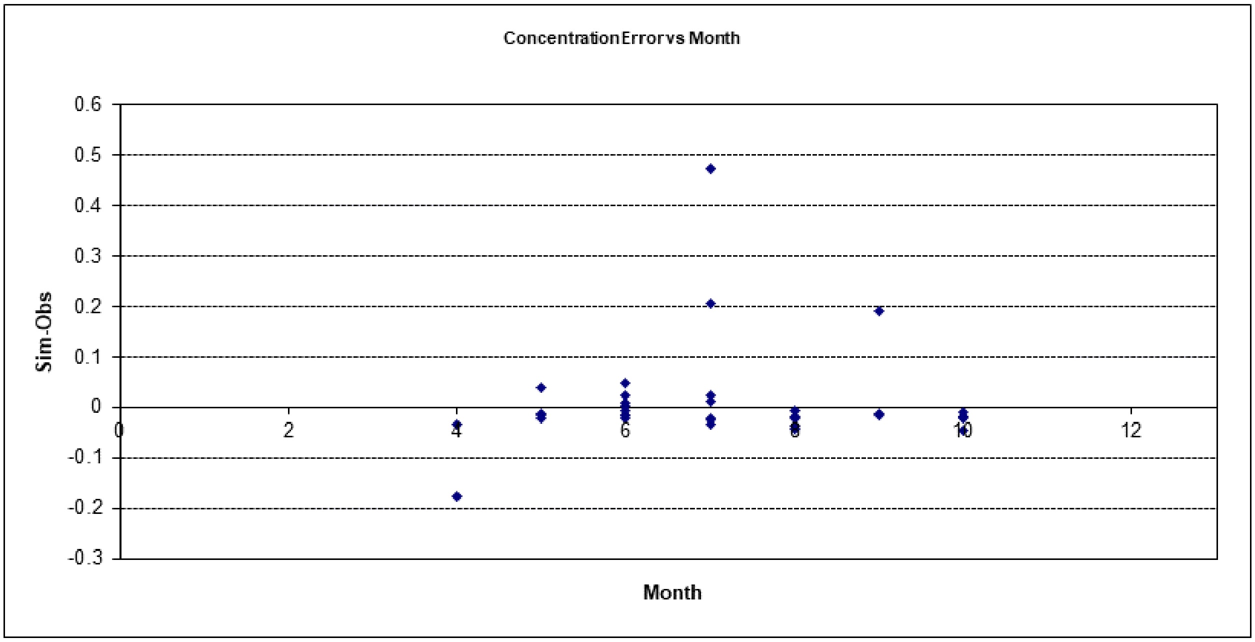


Figure E-893. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Sargent Creek at Hudson Blvd

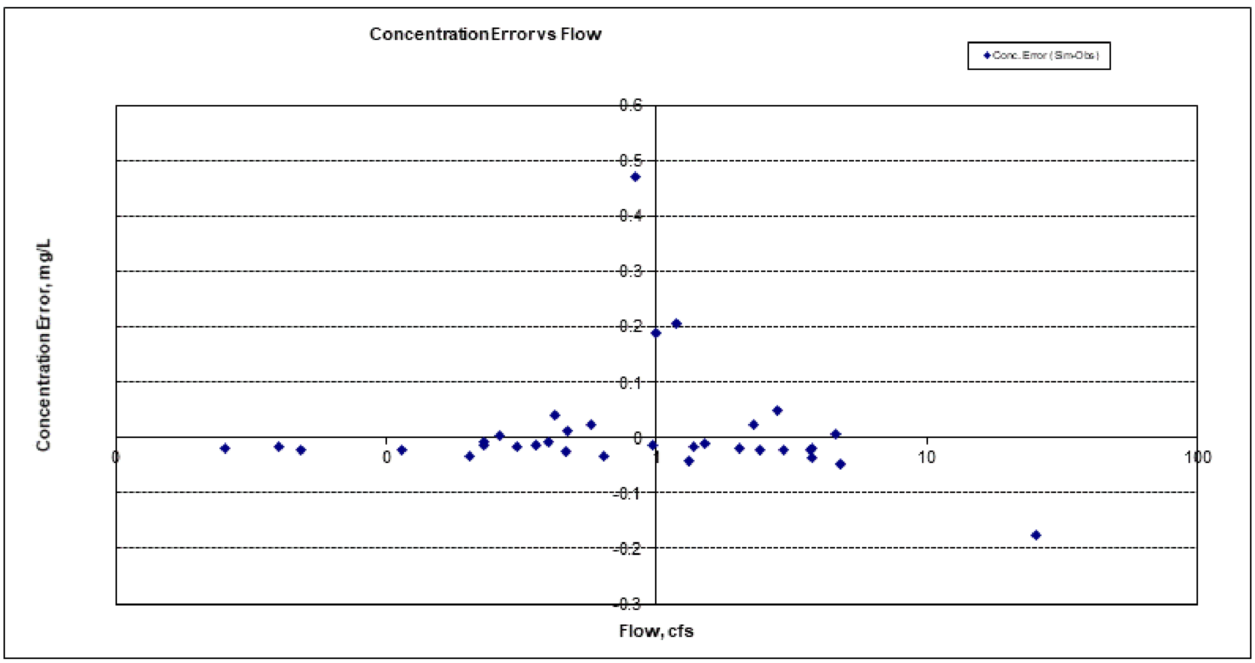


Figure E-894. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Sargent Creek at Hudson Blvd

E.20.3 Nitrite+ Nitrate Nitrogen (NOx)

Table E-115. Nitrite+ Nitrate Nitrogen (NOx) statistics

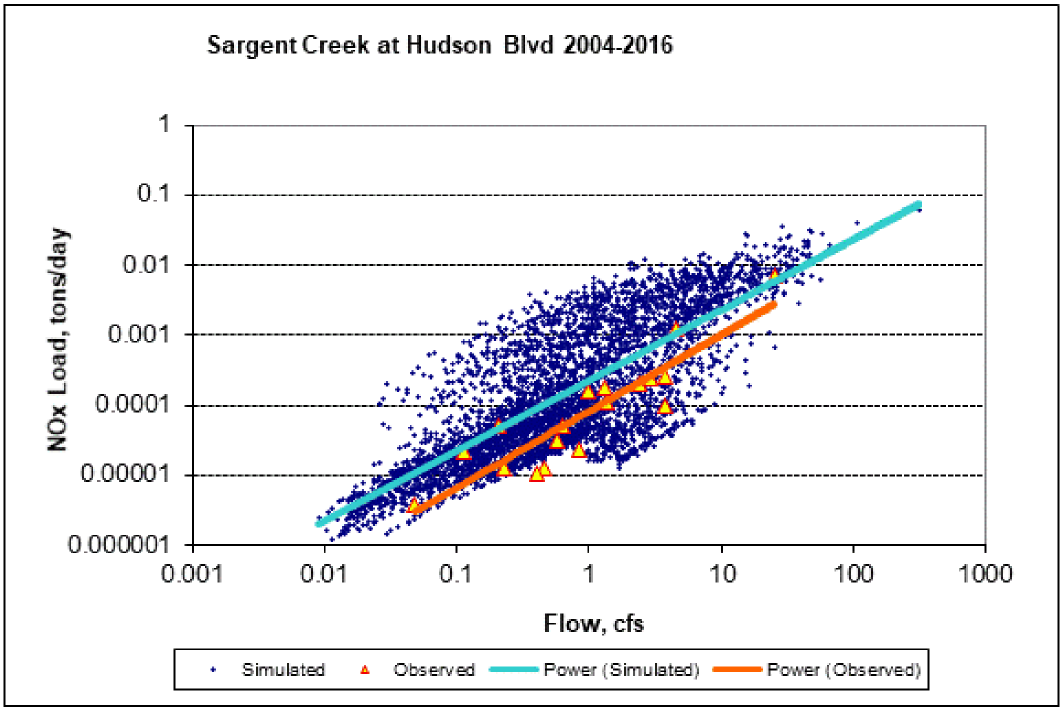


Figure E-895. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Sargent Creek at Hudson Blvd (calibration period)

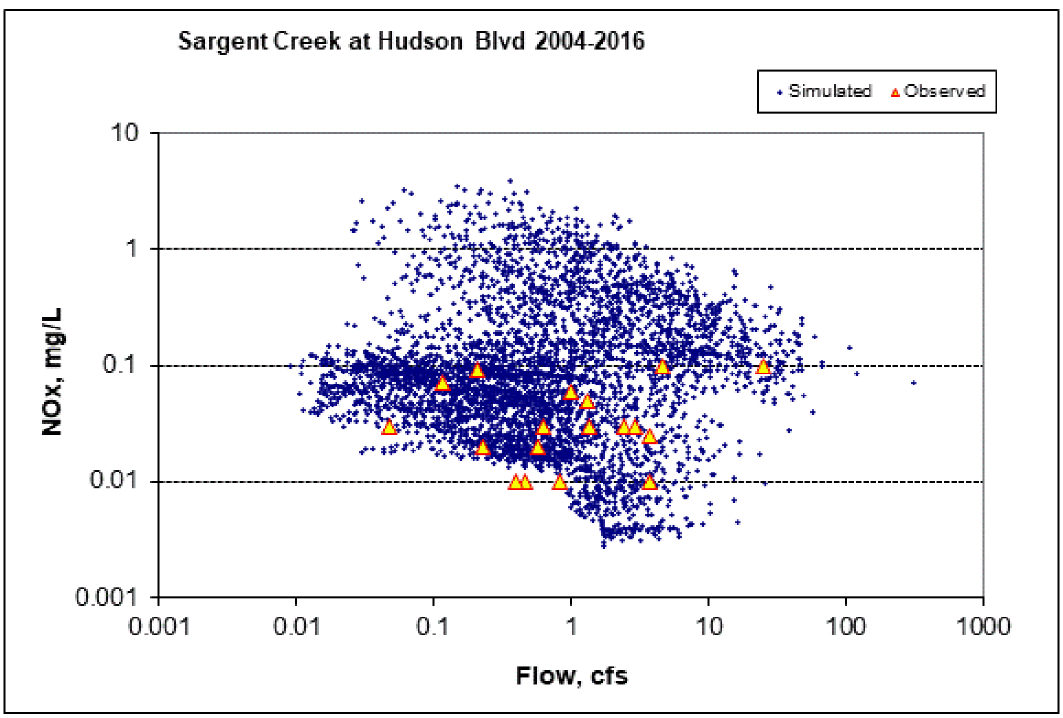
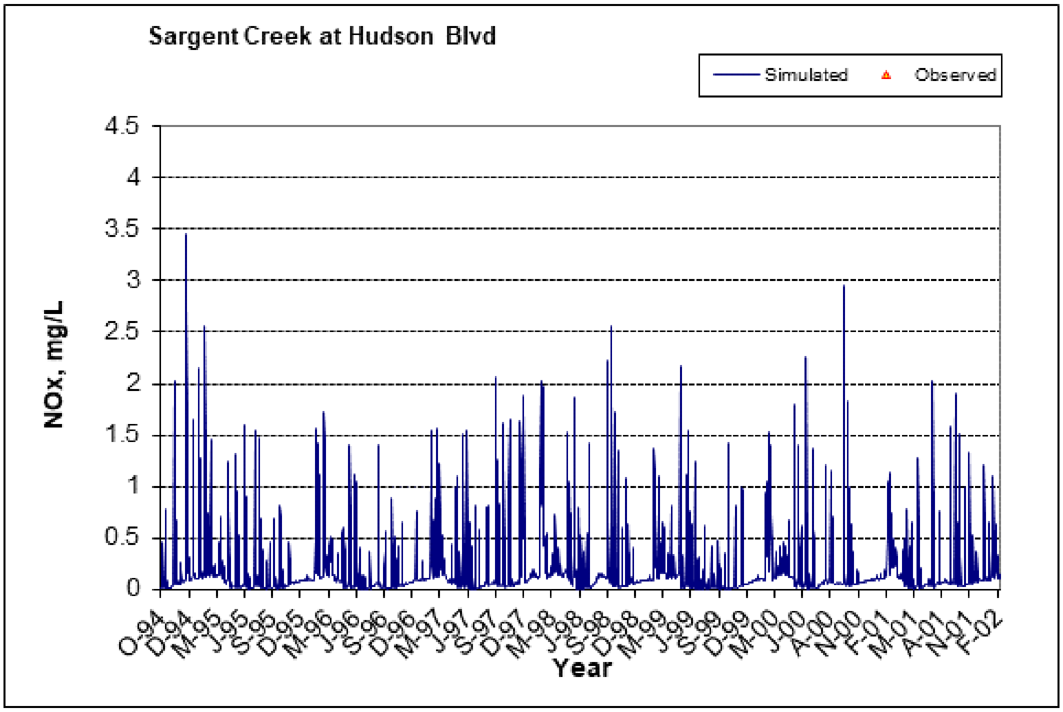
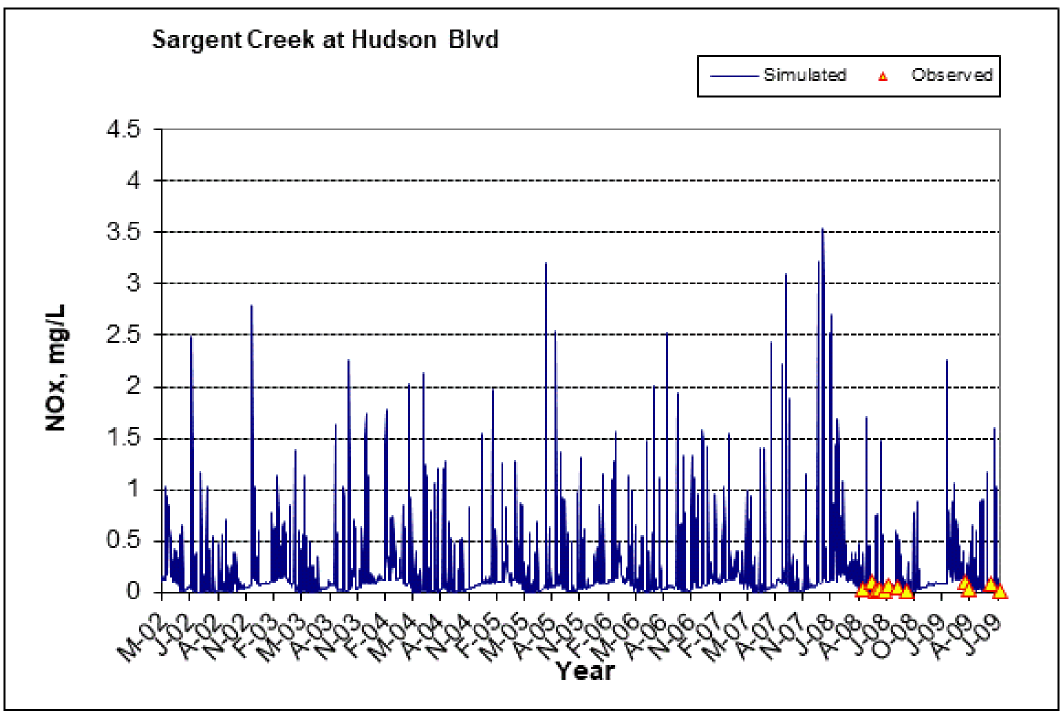


Figure E-896. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Sargent Creek at Hudson Blvd (calibration period)





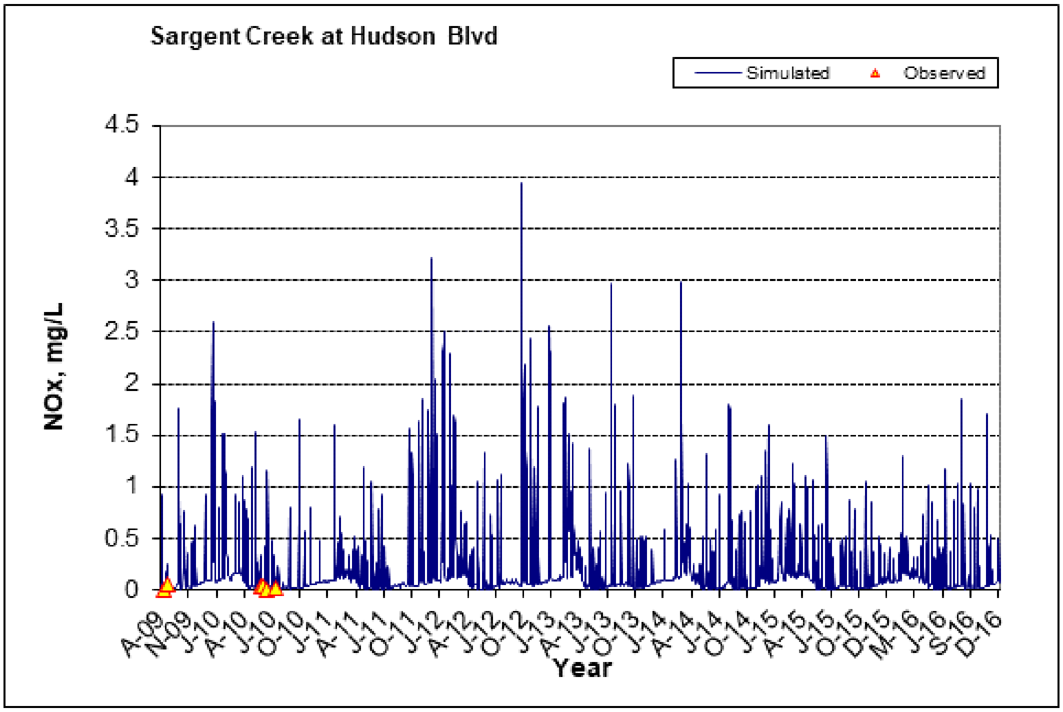


Figure E-897. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Sargent Creek at Hudson Blvd

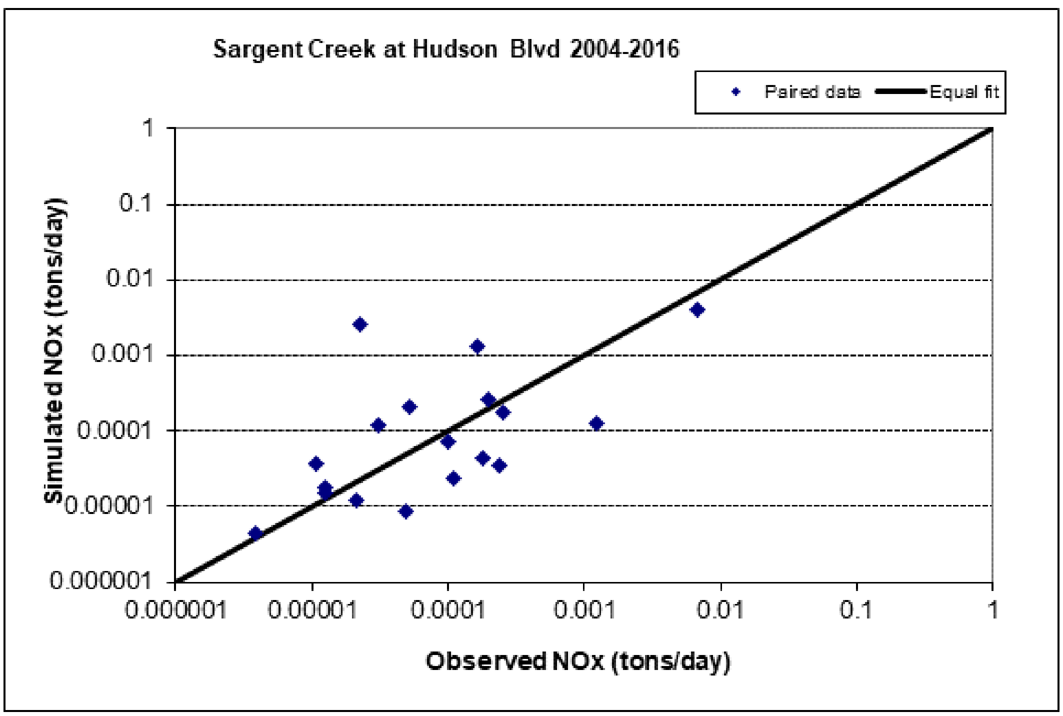


Figure E-898. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Sargent Creek at Hudson Blvd (calibration period)

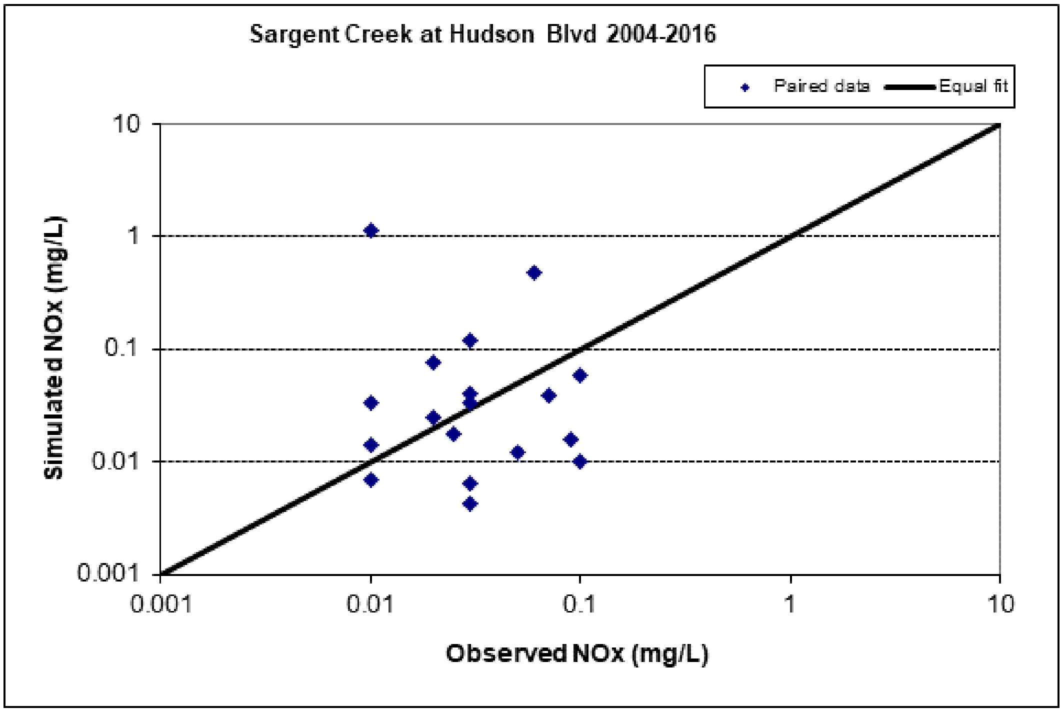


Figure E-899. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Sargent Creek at Hudson Blvd (calibration period)

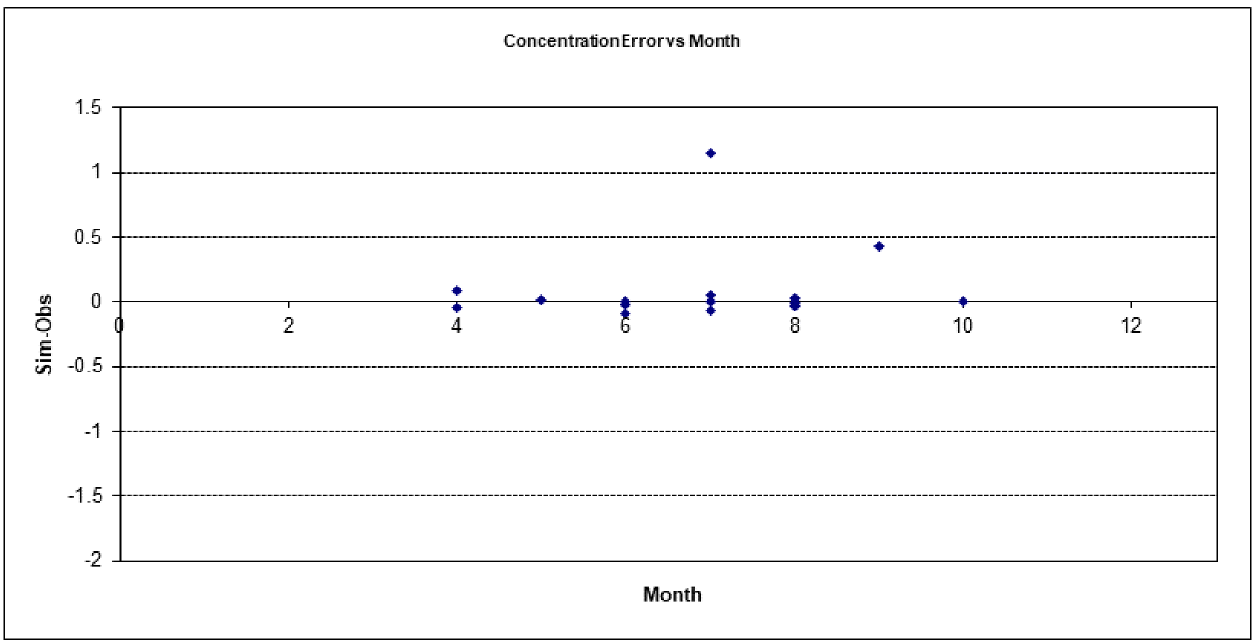


Figure E-900. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Sargent Creek at Hudson Blvd

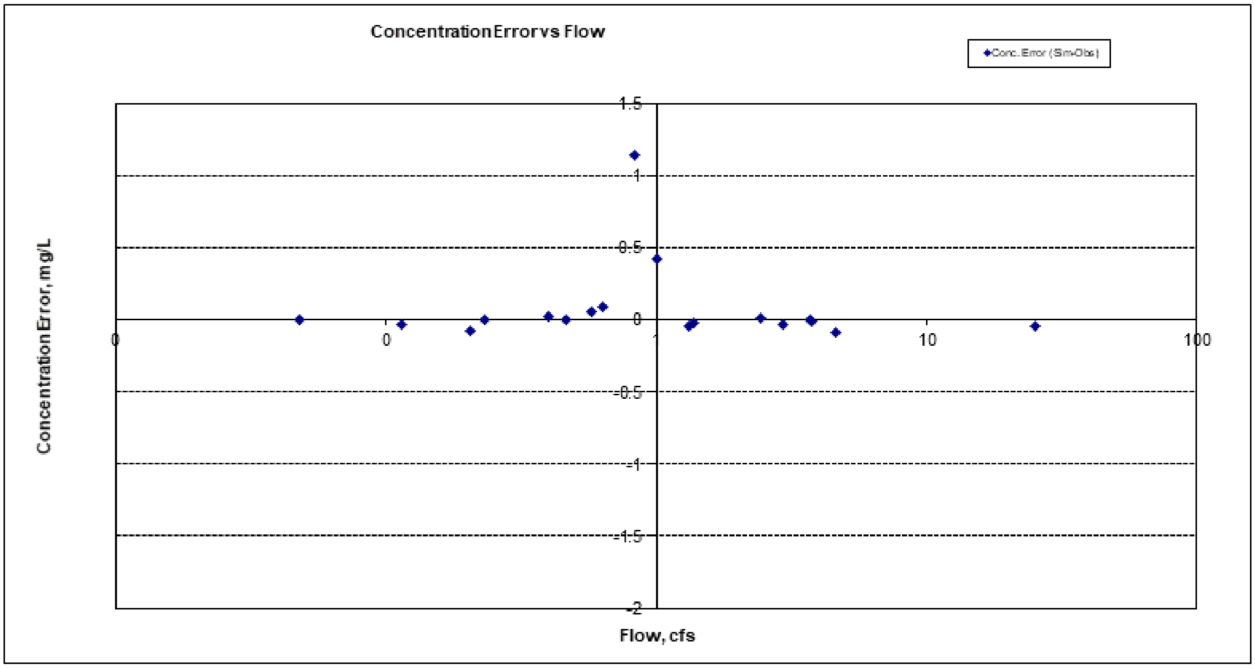


Figure E-901. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Sargent Creek at Hudson Blvd

E.20.4 Total Phosphorus (TP)

Table E-116. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	34
Concentration Average Error		-57.55%
Concentration Median Error		-12.41%
Load Average Error		-47.37%
Load Median Error		-1.57%
Paired t conc		0.09
Paired t load		0.28

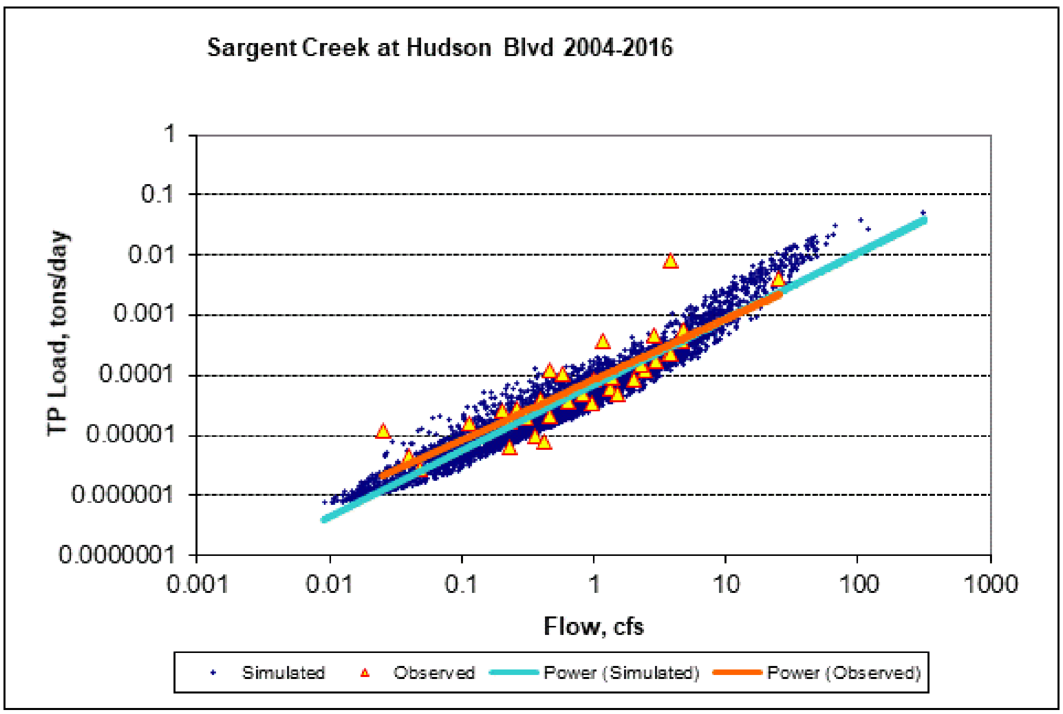


Figure E-902. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Sargent Creek at Hudson Blvd (calibration period)

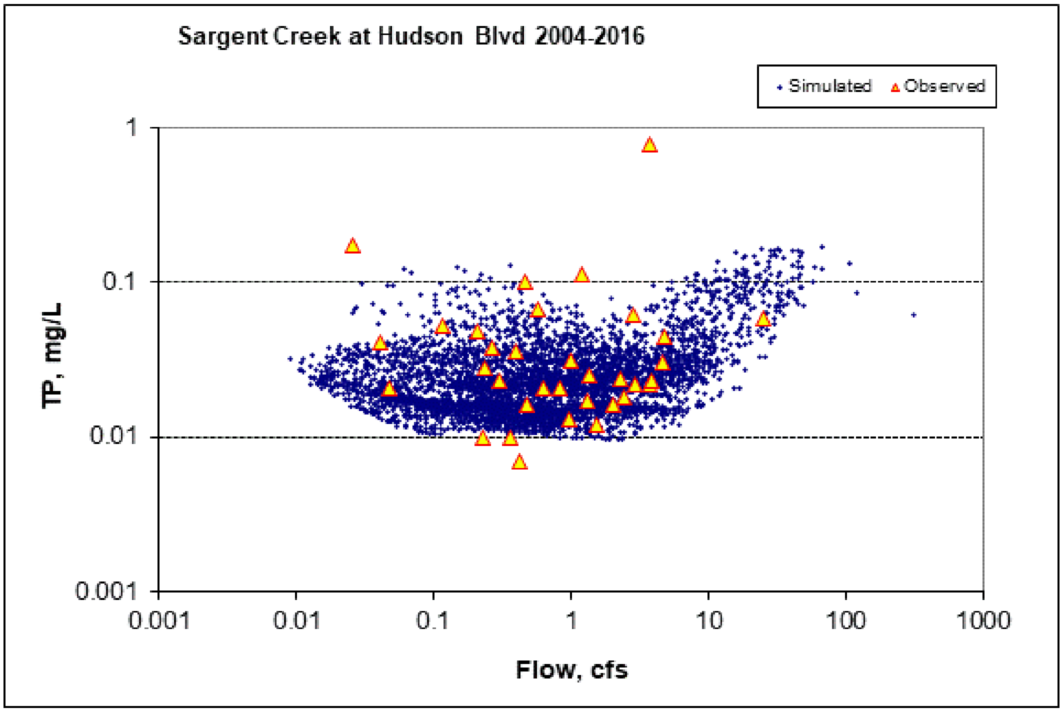
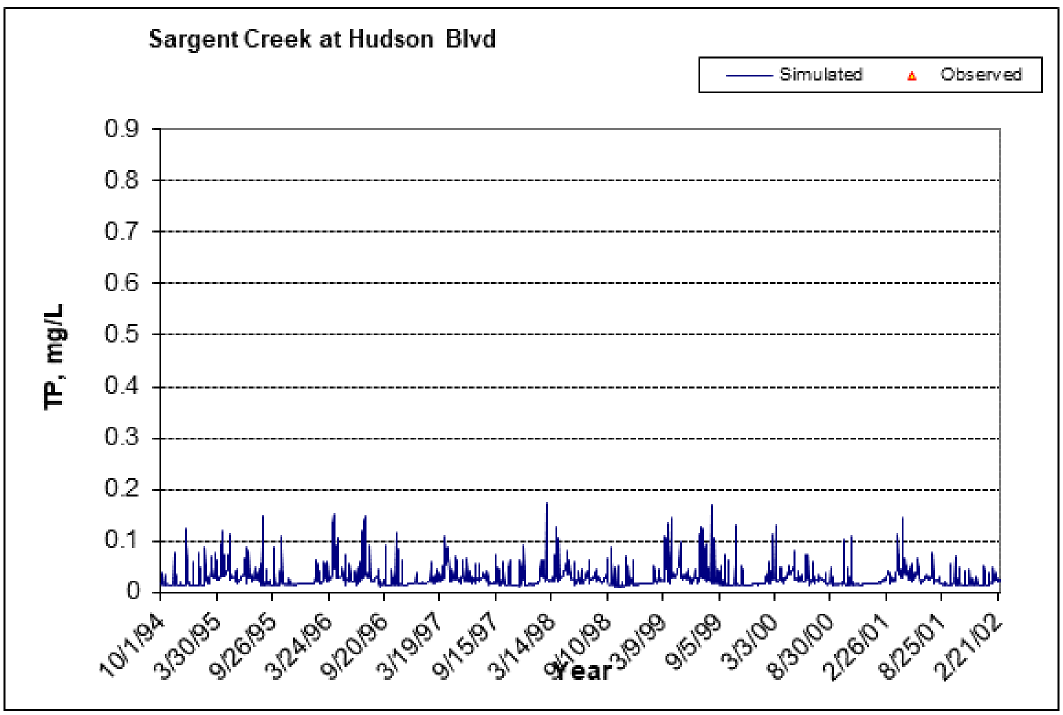
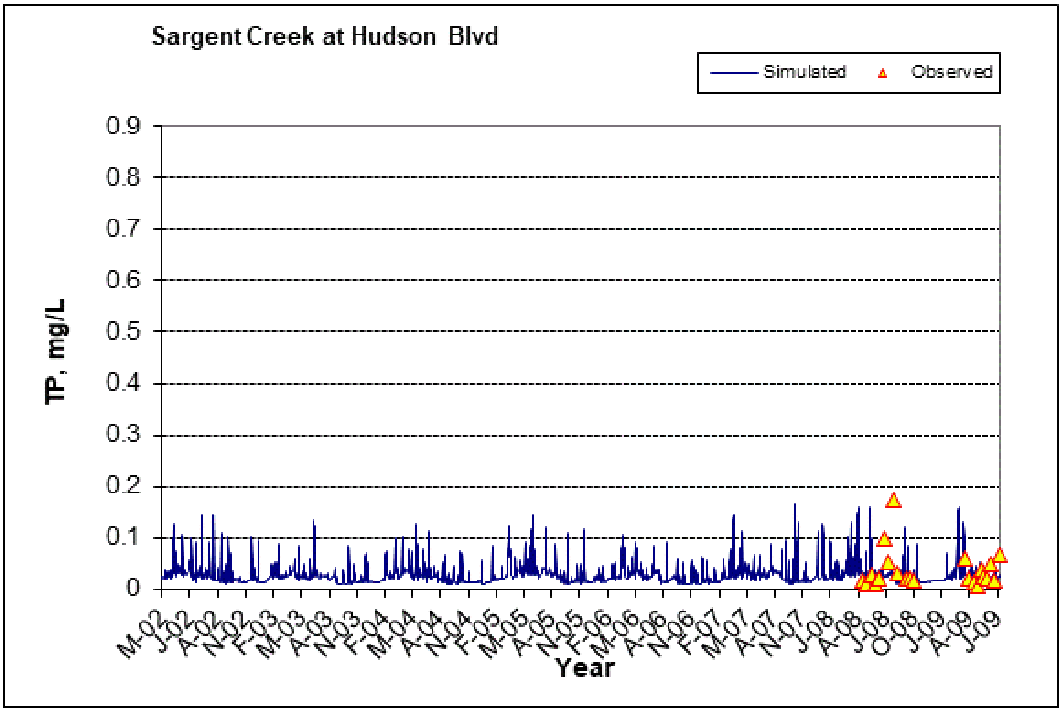


Figure E-903. Simulated and observed Total Phosphorus (TP) concentration vs flow at Sargent Creek at Hudson Blvd (calibration period)





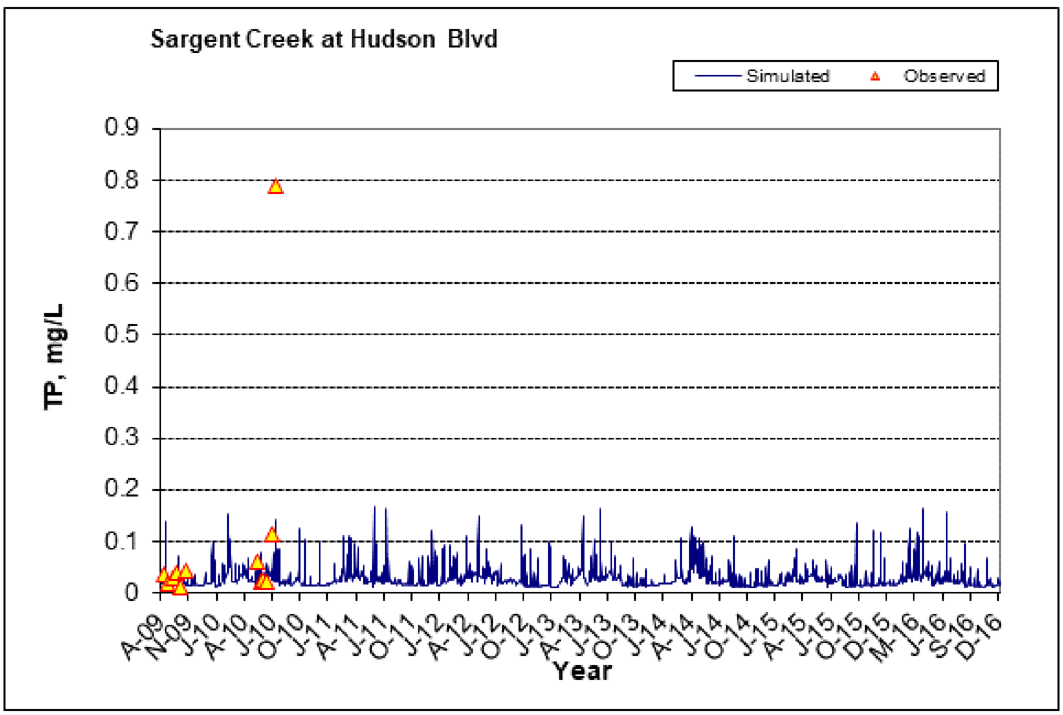


Figure E-904. Time series of observed and simulated Total Phosphorus (TP) concentration at Sargent Creek at Hudson Blvd

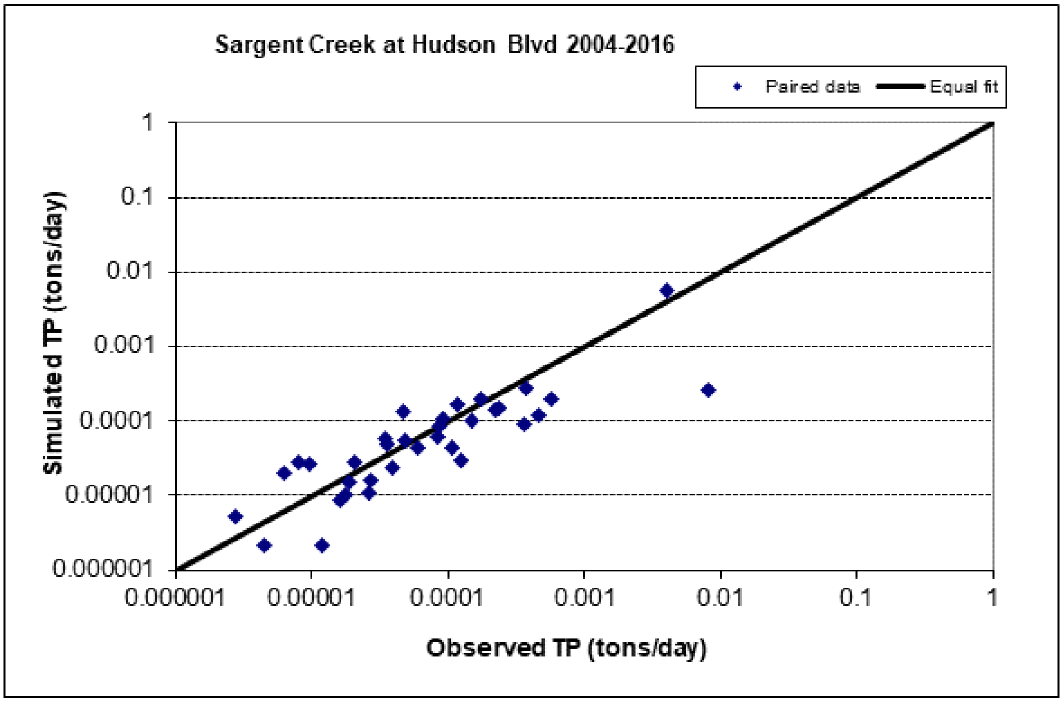


Figure E-905. Paired simulated vs. observed Total Phosphorus (TP) load at Sargent Creek at Hudson Blvd (calibration period)

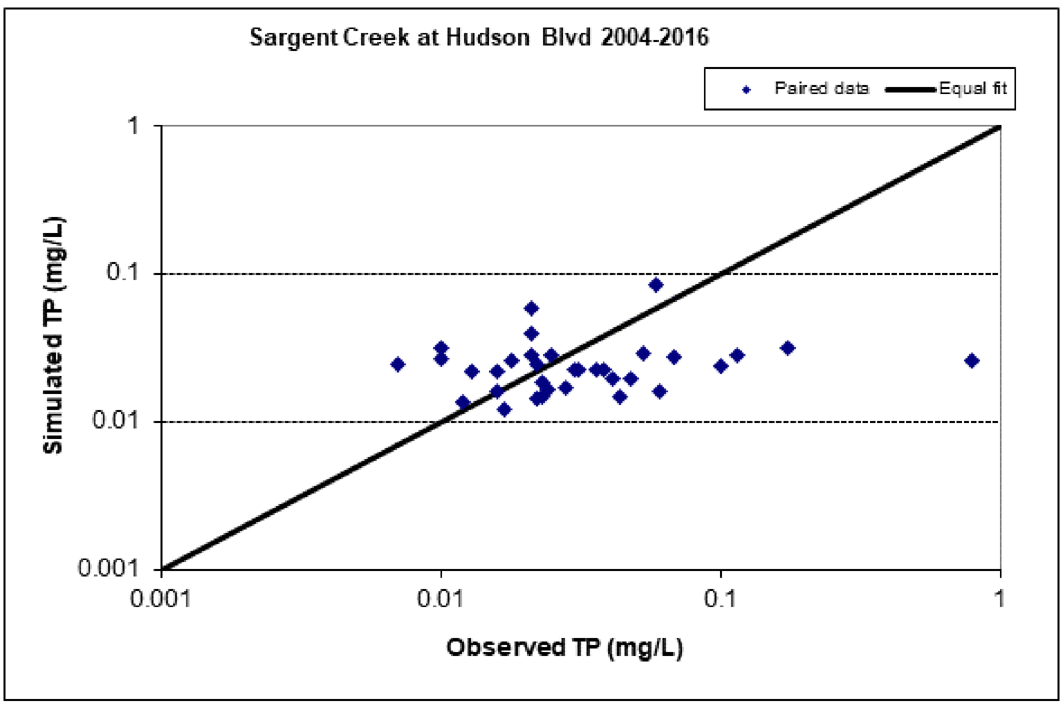


Figure E-906. Paired simulated vs. observed Total Phosphorus (TP) concentration at Sargent Creek at Hudson Blvd (calibration period)

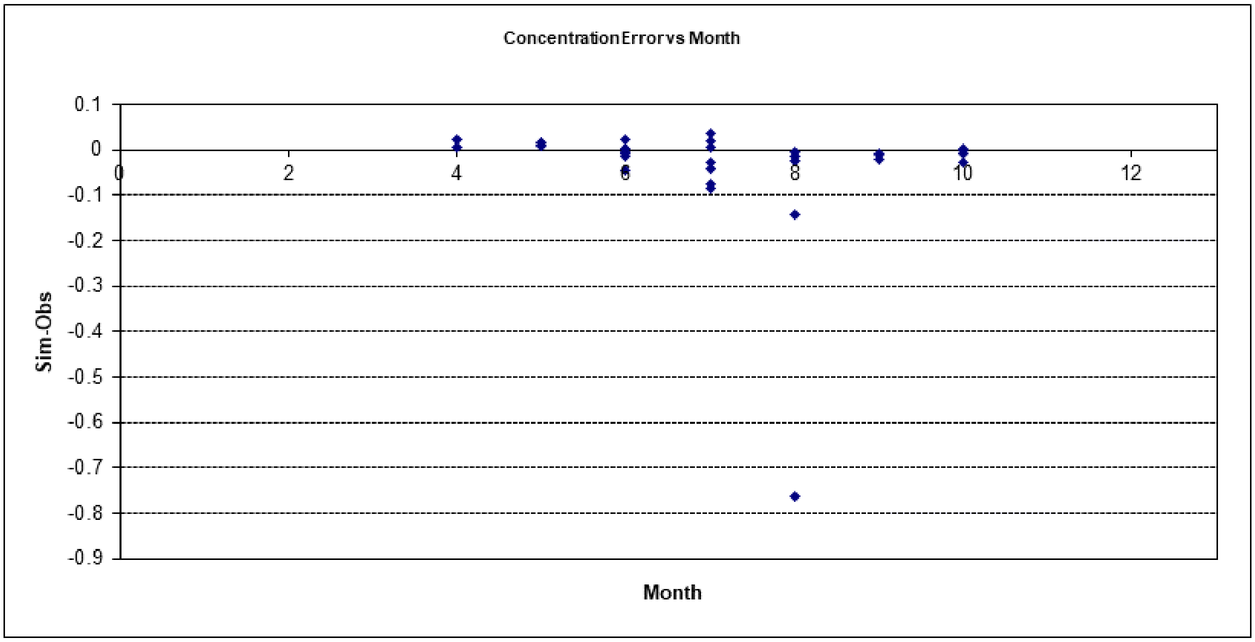


Figure E-907. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Sargent Creek at Hudson Blvd

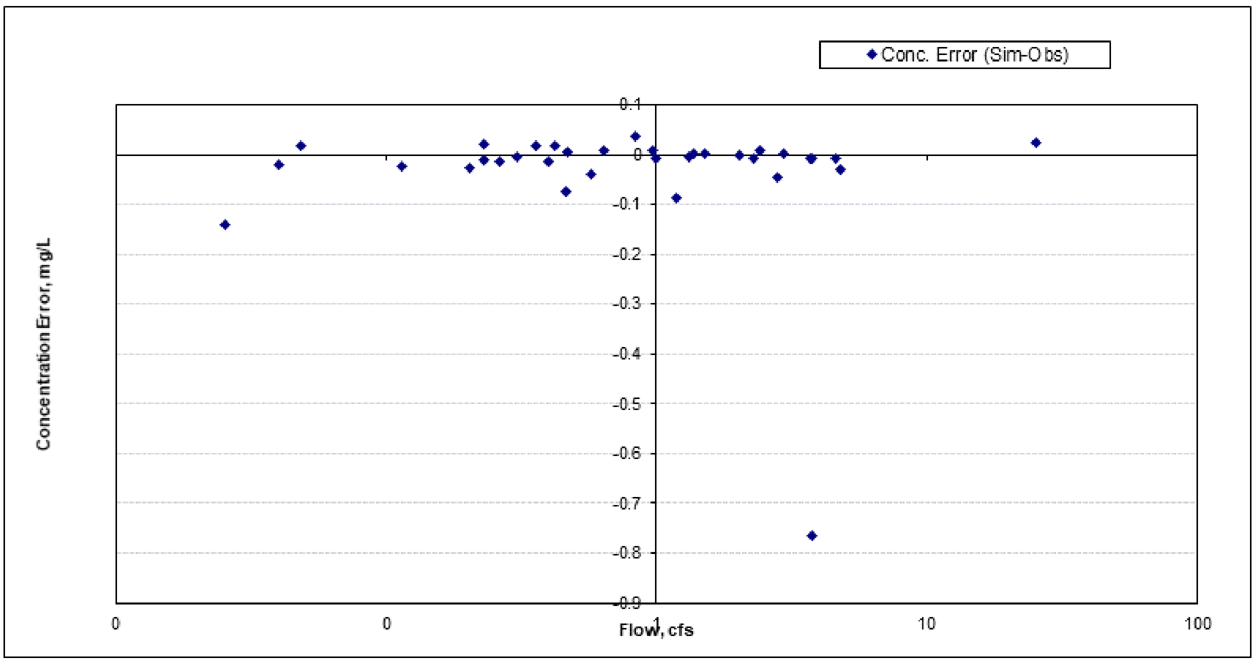


Figure E-908. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Sargent Creek at Hudson Blvd

E.21 Mission Creek at MN-23

E.21.1 Dissolved Oxygen (DO)

Table E-117. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	34
Concentration Average Error		-12.33%
Concentration Median Error		-11.78%
Load Average Error		-0.03%
Load Median Error		-3.32%
Paired t conc		0.96
Paired t load		0.84

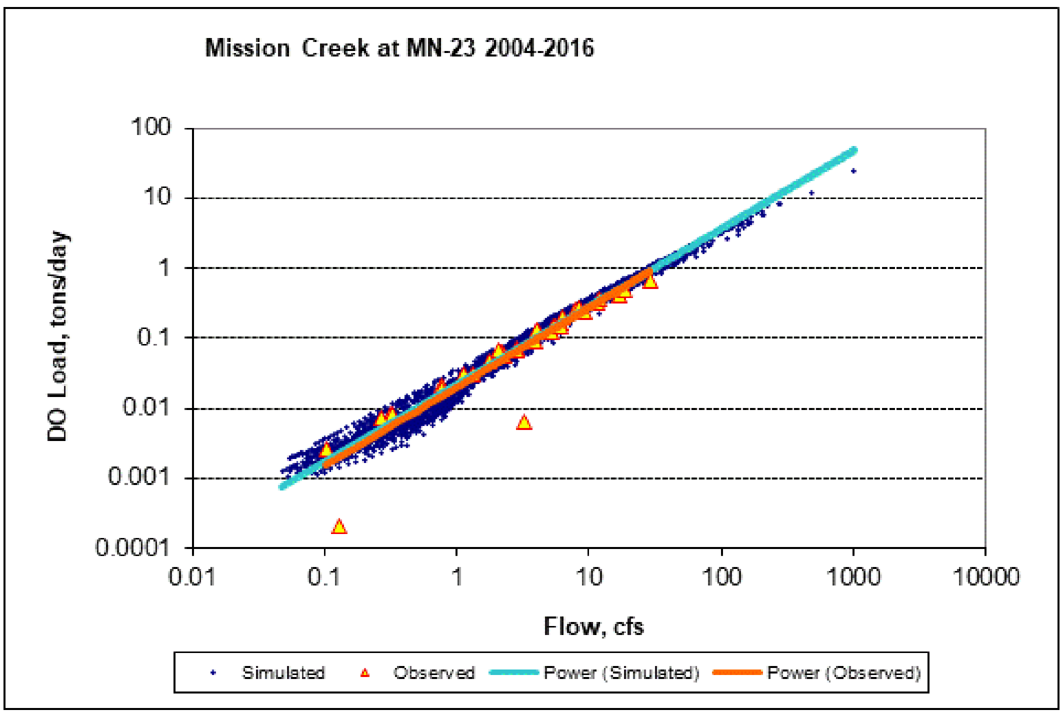


Figure E-909. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Mission Creek at MN-23 (calibration period)

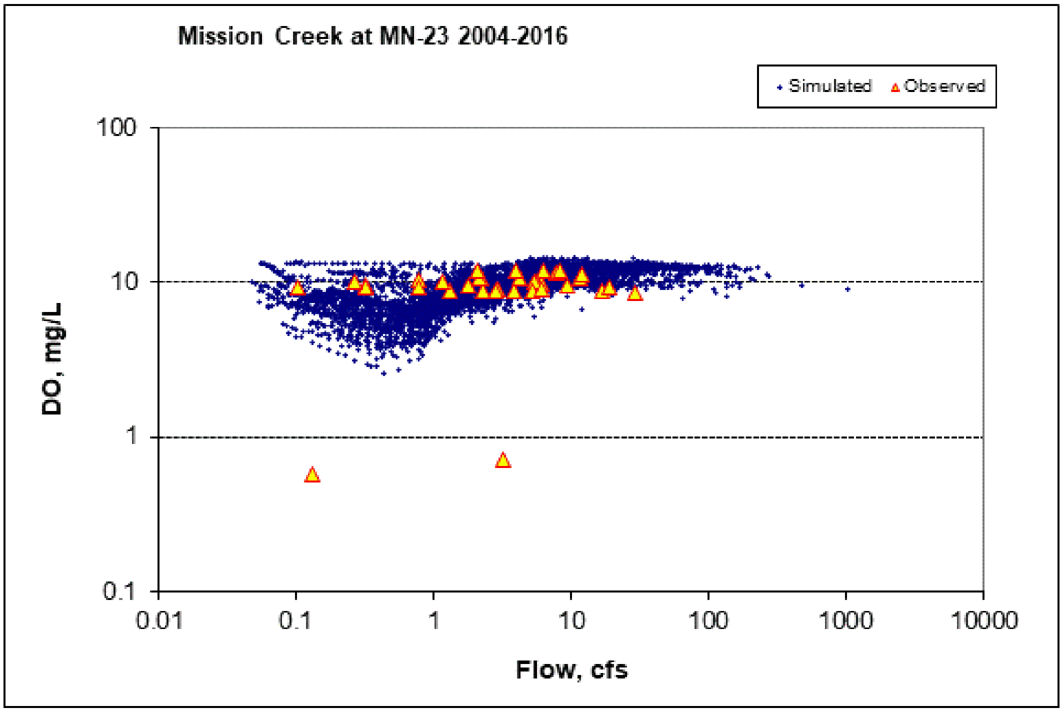
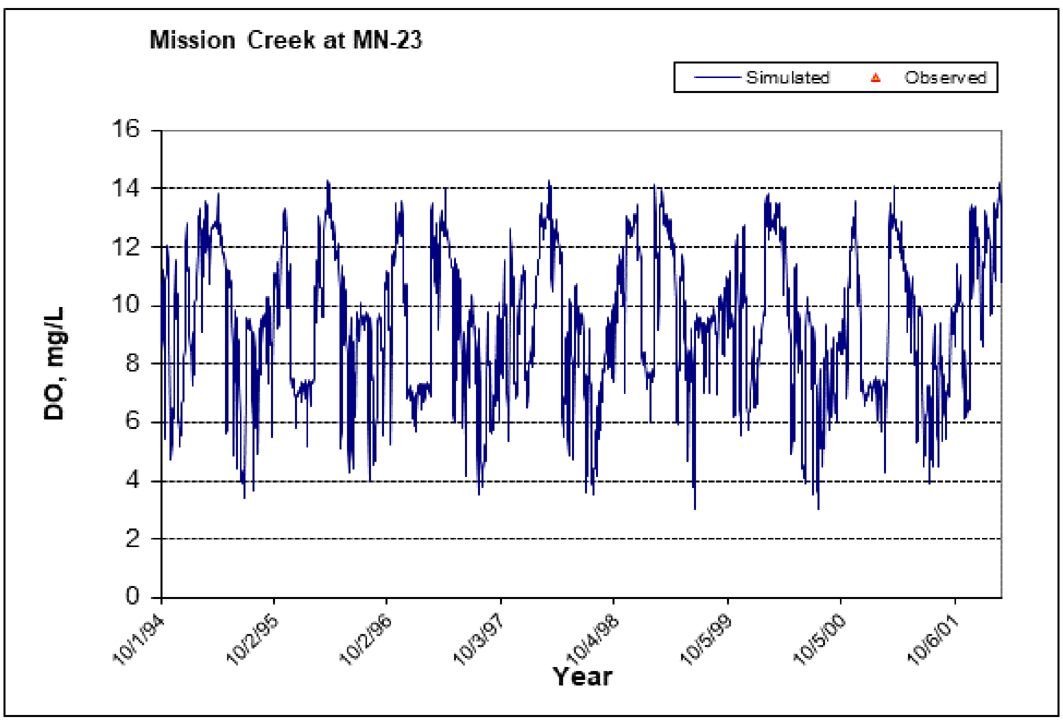
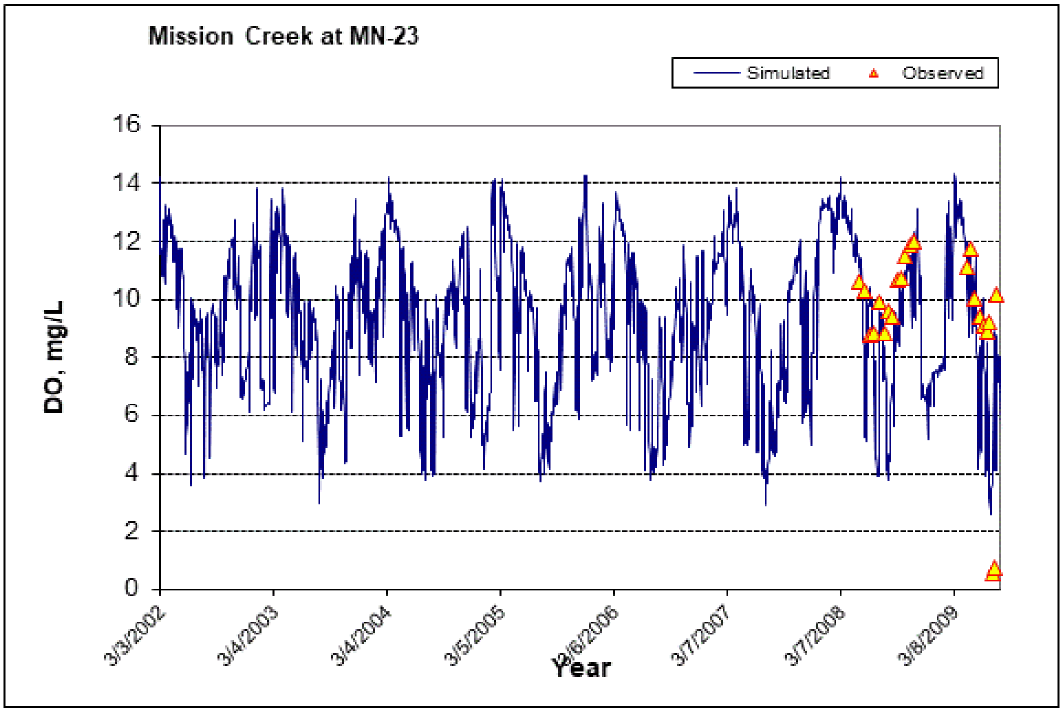


Figure E-910. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Mission Creek at MN-23 (calibration period)





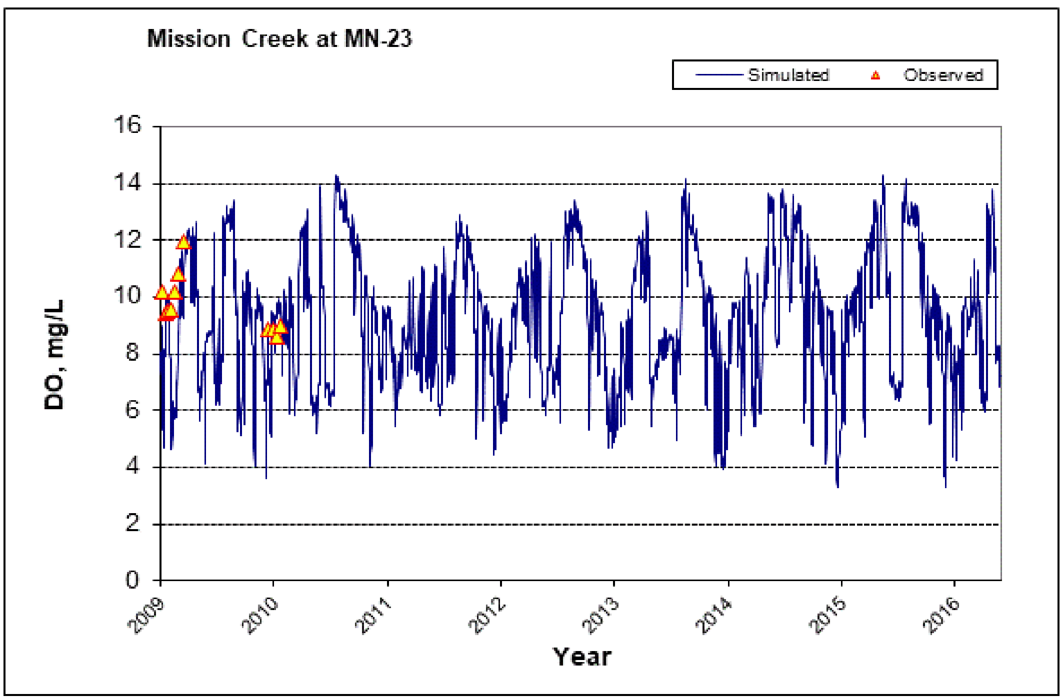


Figure E-911. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Mission Creek at MN-23

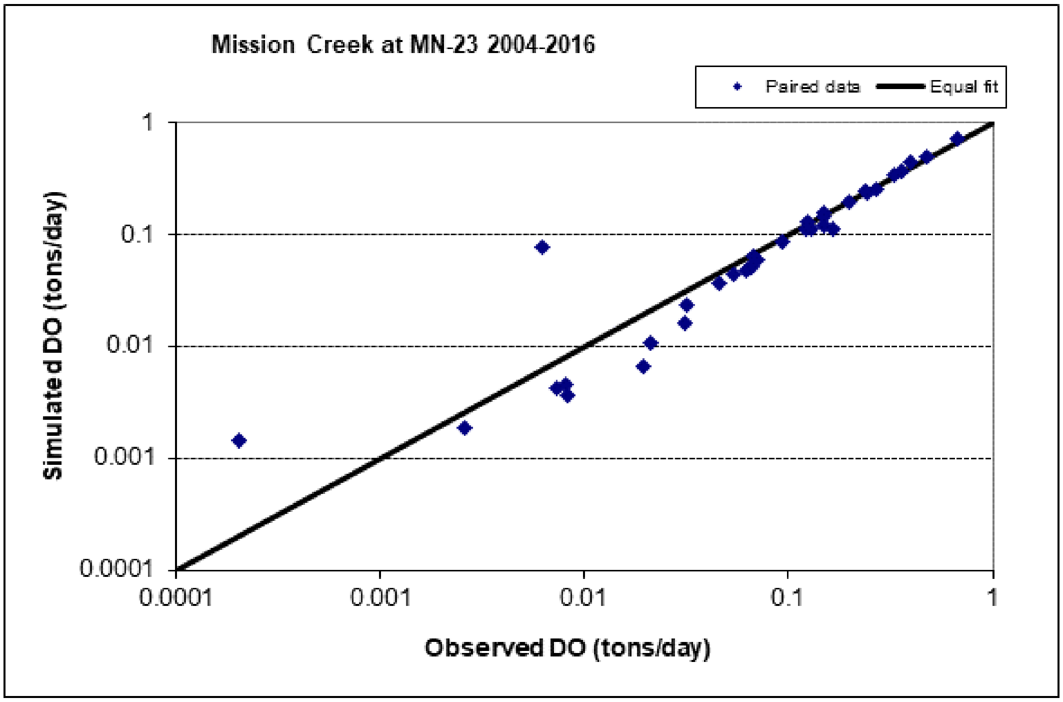


Figure E-912. Paired simulated vs. observed Dissolved Oxygen (DO) load at Mission Creek at MN-23 (calibration period)

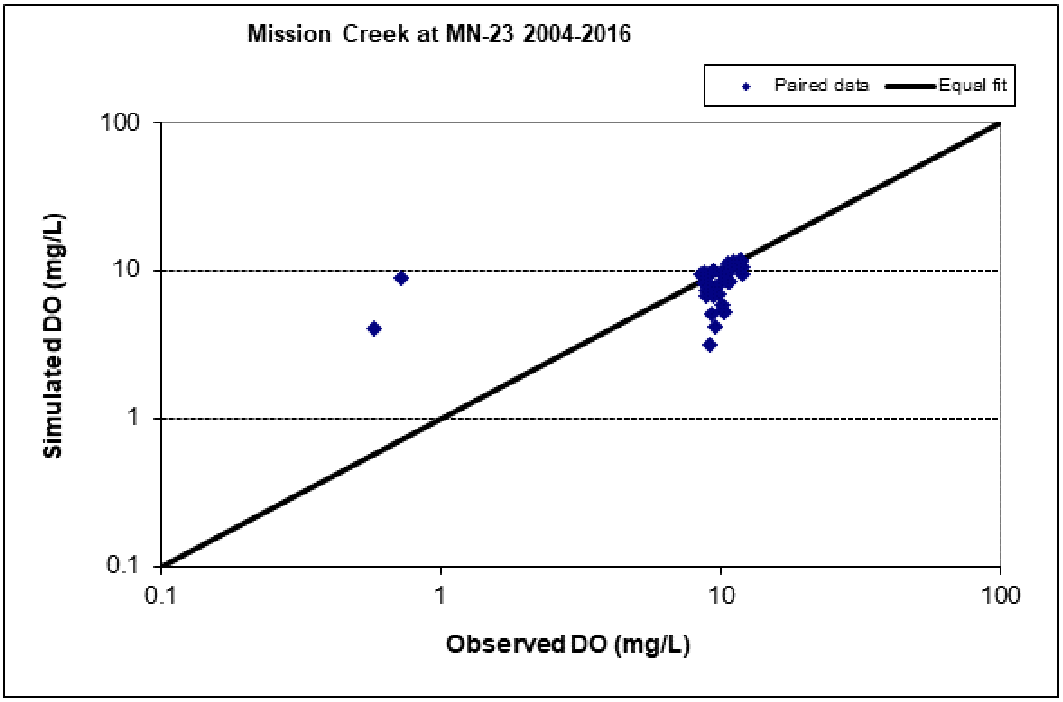


Figure E-913. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Mission Creek at MN-23 (calibration period)

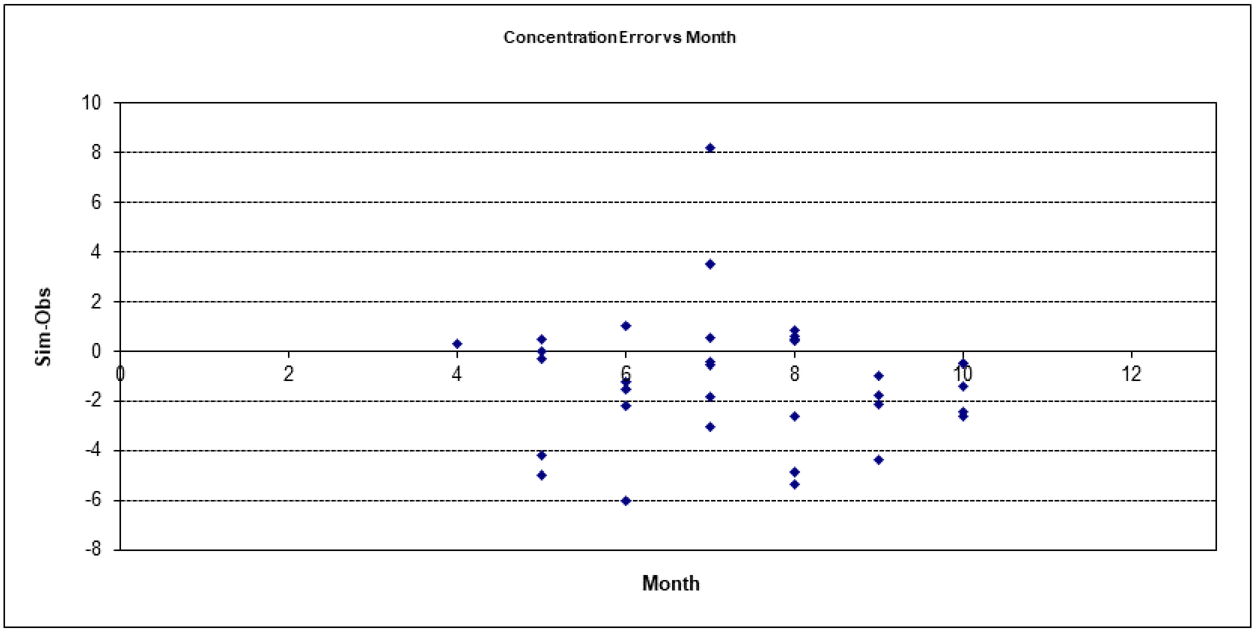


Figure E-914. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Mission Creek at MN-23

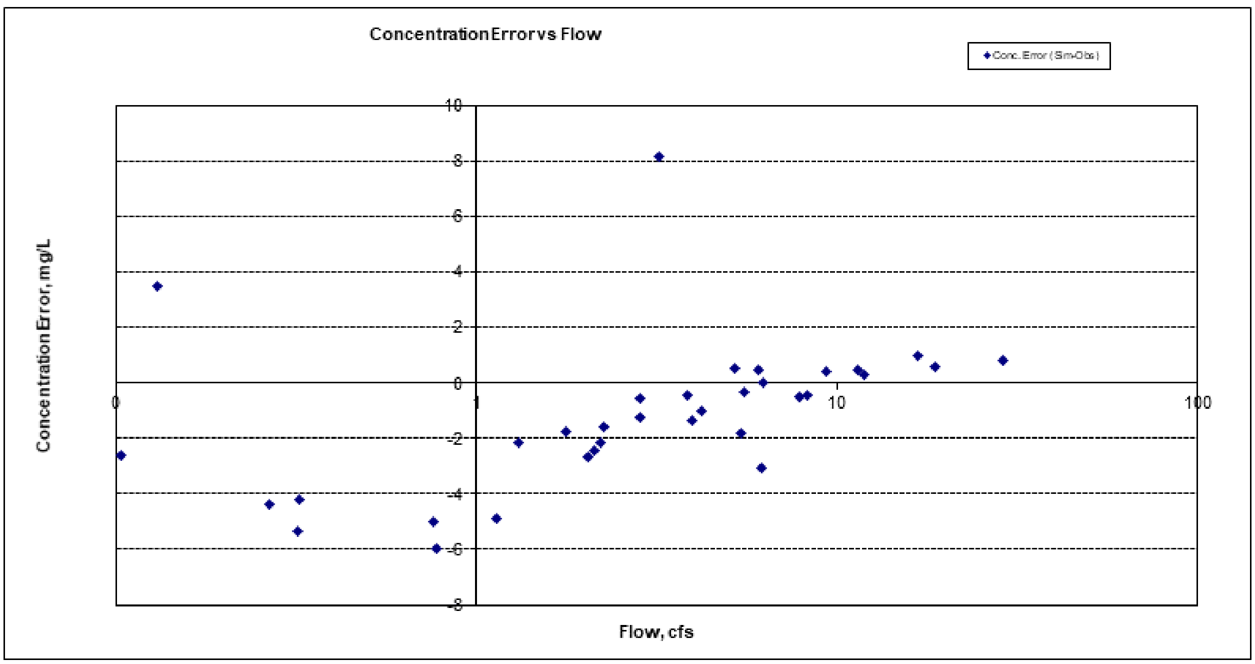


Figure E-915. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Mission Creek at MN-23

E.21.2 Ammonia Nitrogen (NH3)

Table E-118. Ammonia Nitrogen (NH3) statistics

Period	1994-2004	2004-2016
Count	ND	34
Concentration Average Error		157.41%
Concentration Median Error		-7.32%
Load Average Error		136.27%
Load Median Error		-0.45%
Paired t conc		0.00
Paired t load		0.02

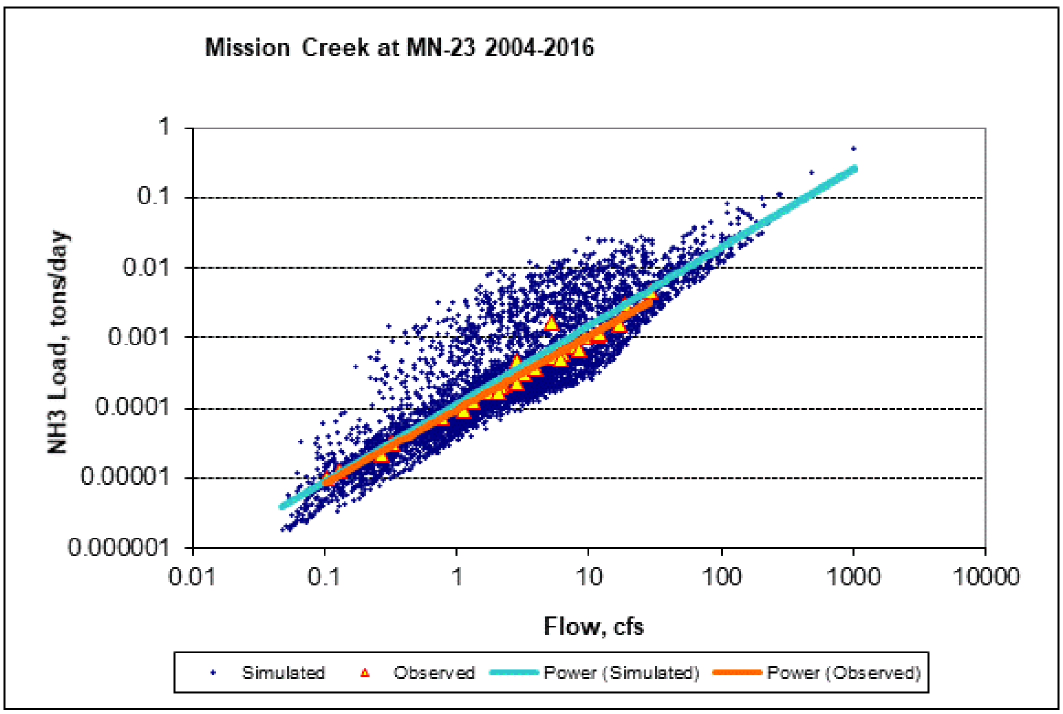


Figure E-916. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Mission Creek at MN-23 (calibration period)

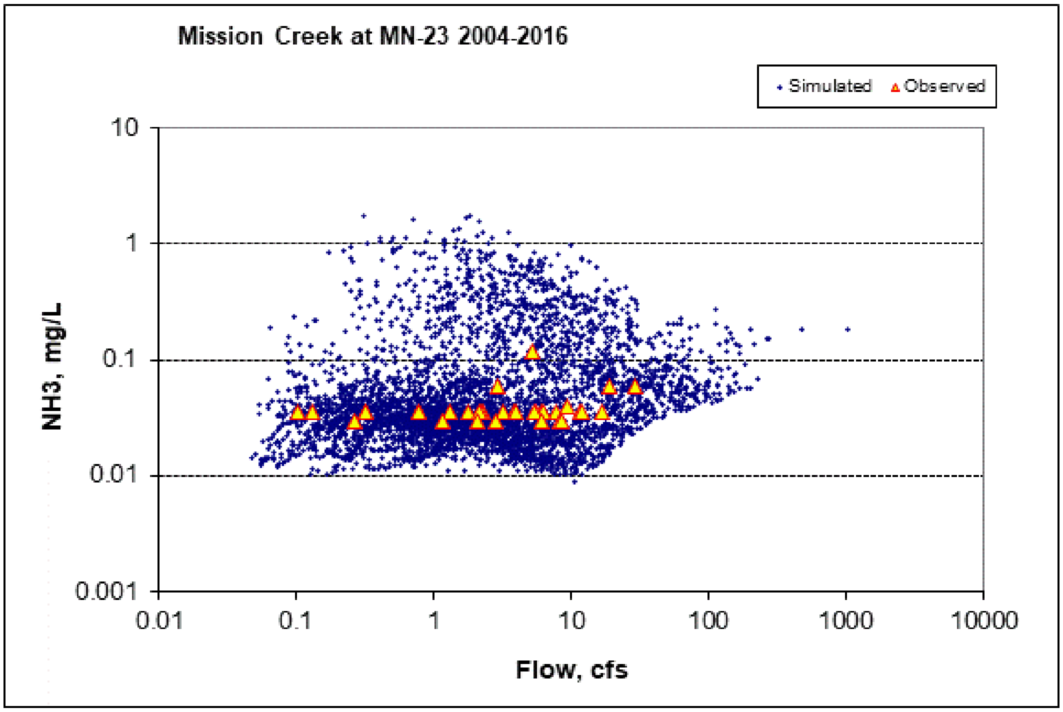
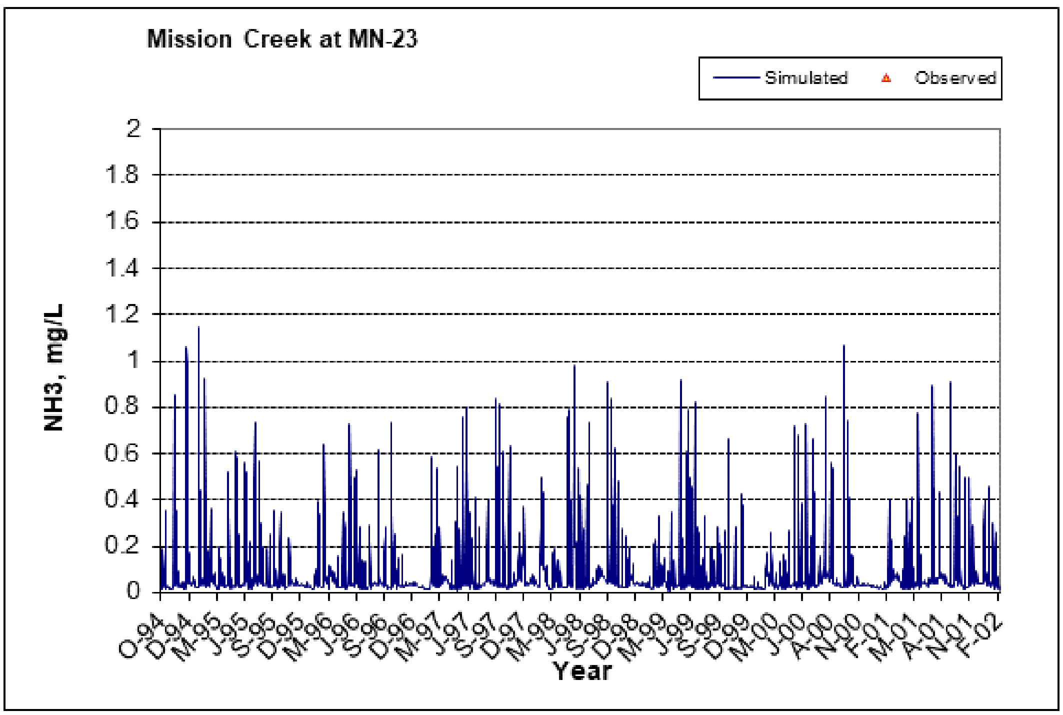
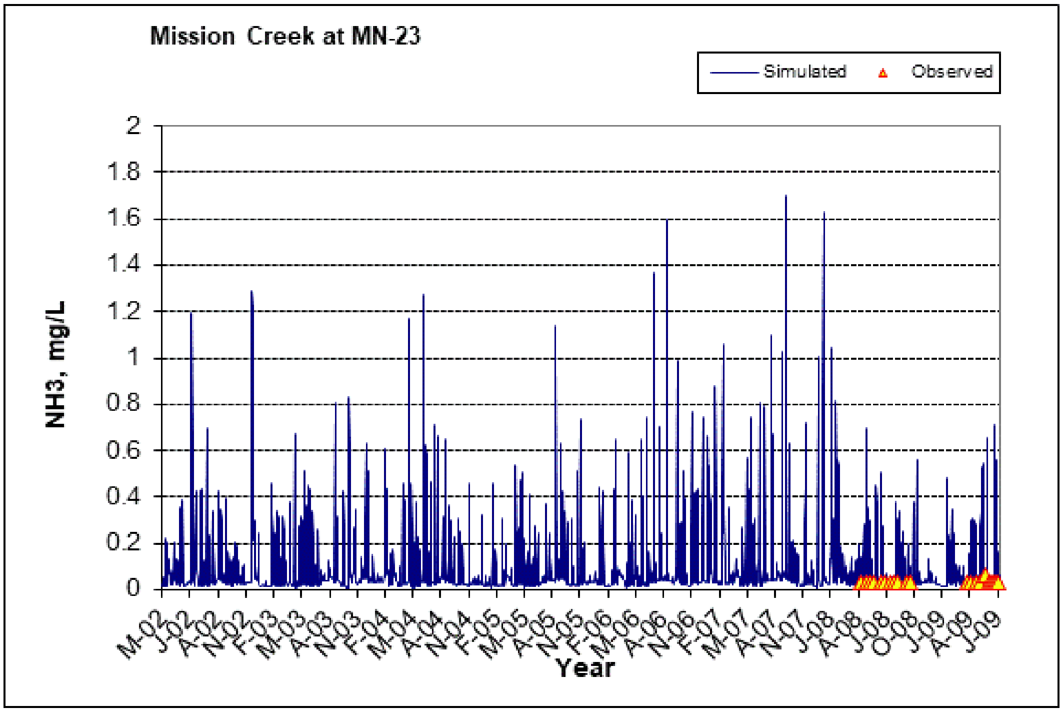


Figure E-917. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Mission Creek at MN-23 (calibration period)





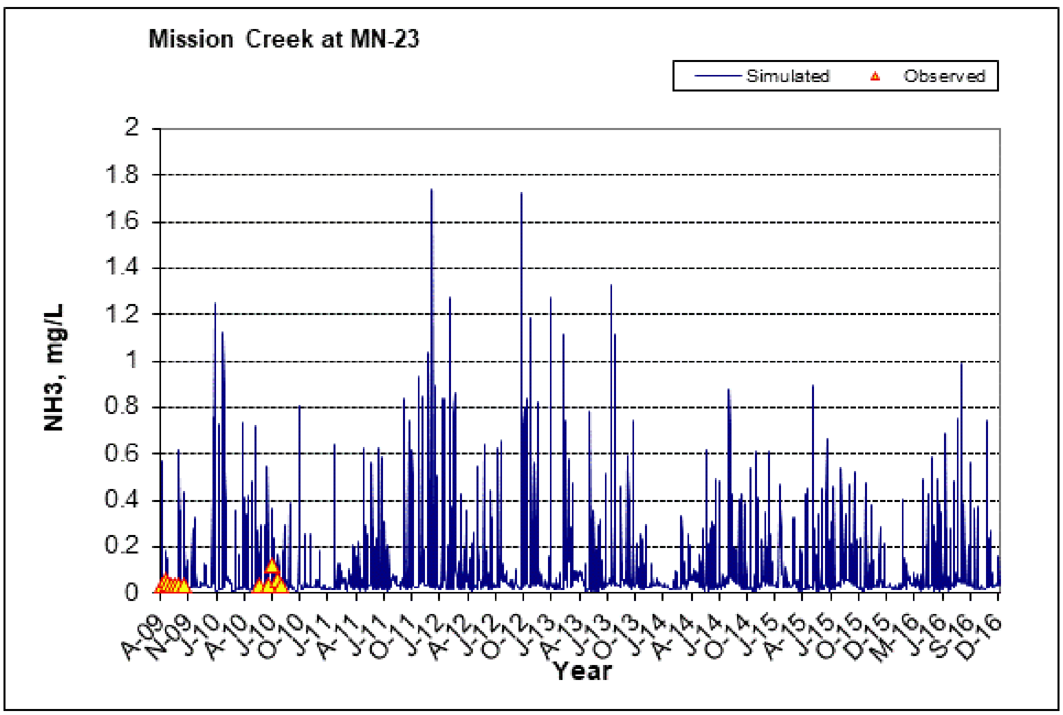


Figure E-918. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Mission Creek at MN-23

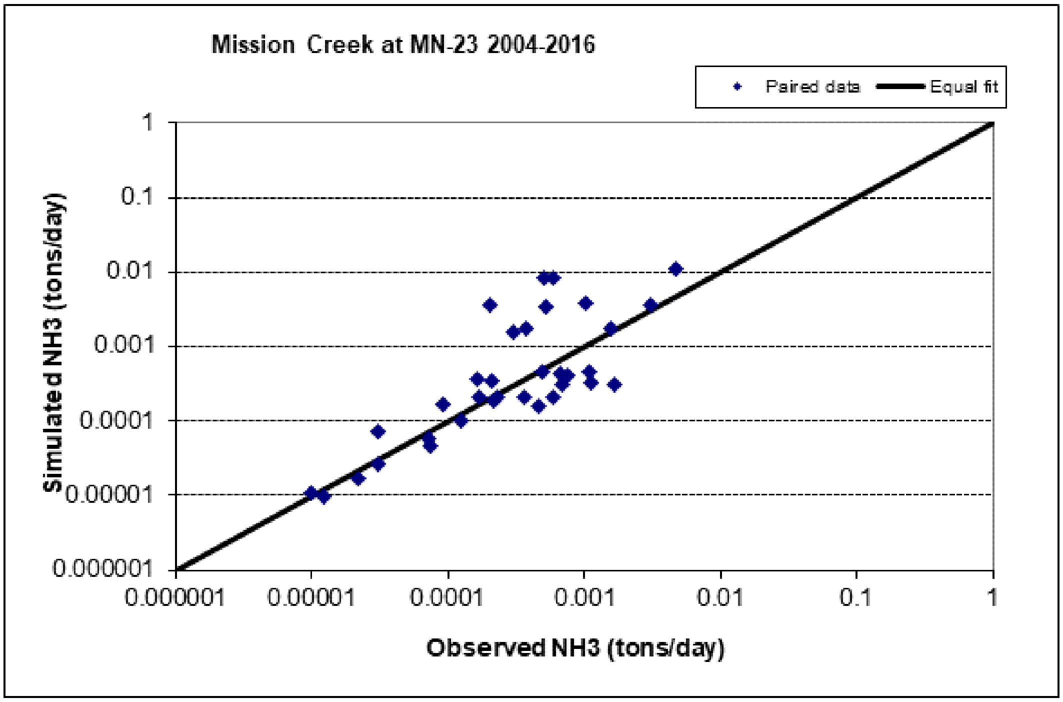


Figure E-919. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Mission Creek at MN-23 (calibration period)

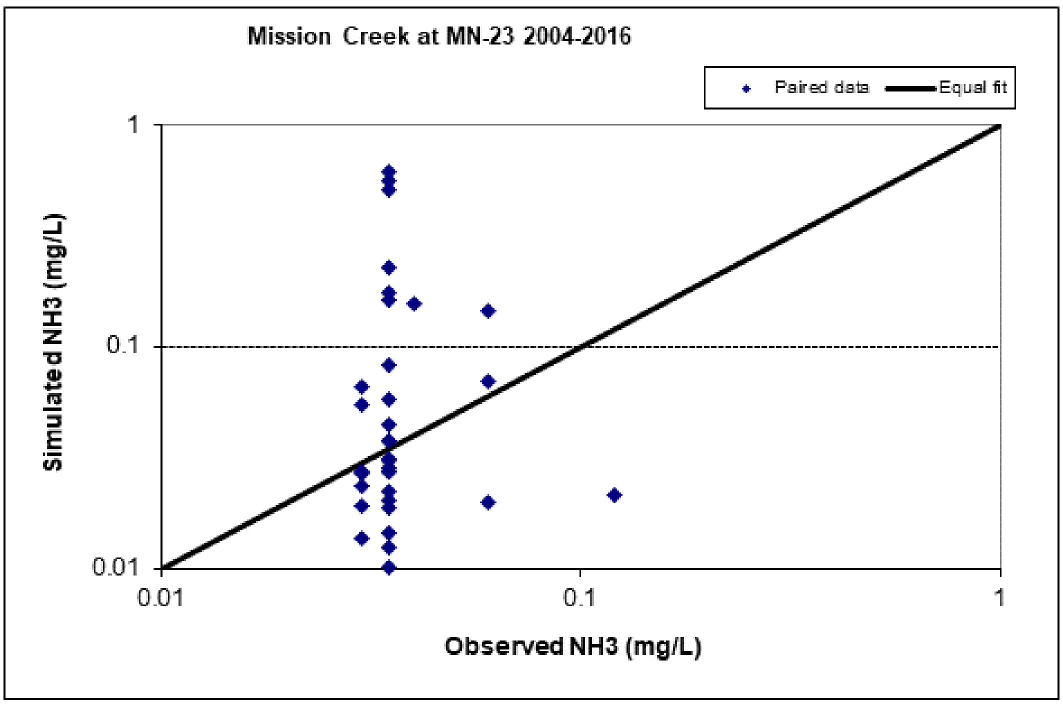


Figure E-920. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Mission Creek at MN-23 (calibration period)

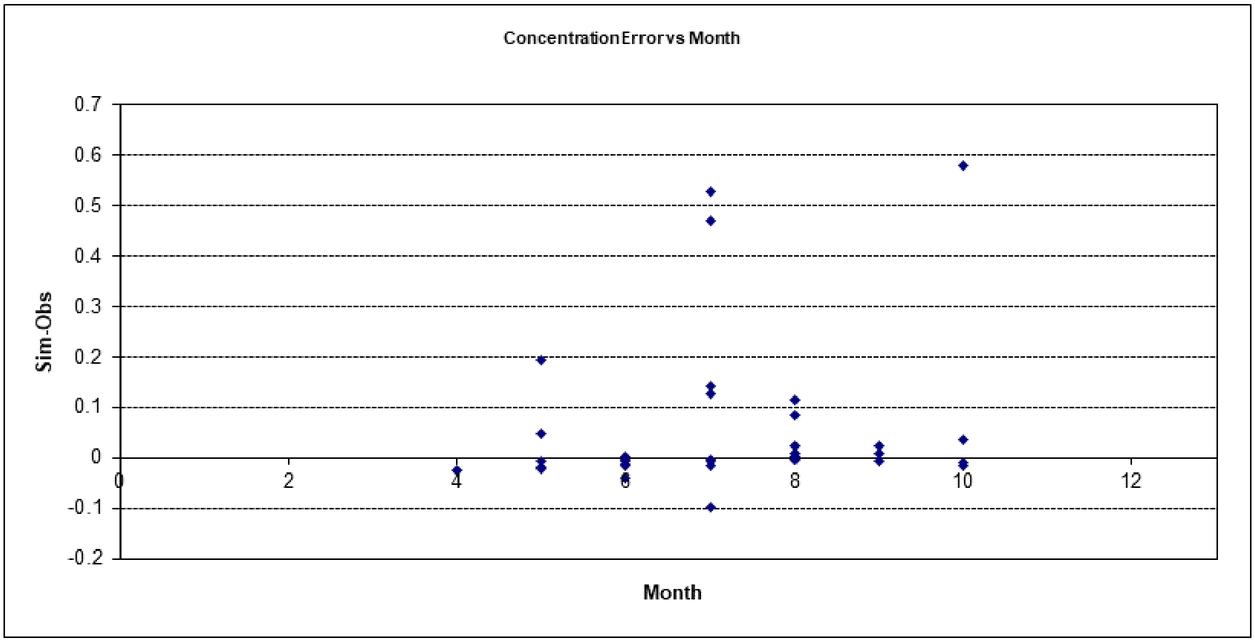


Figure E-921. Residual (Simulated - Observed) vs. Month, Ammonia Nitrogen (NH3) at Mission Creek at MN-23

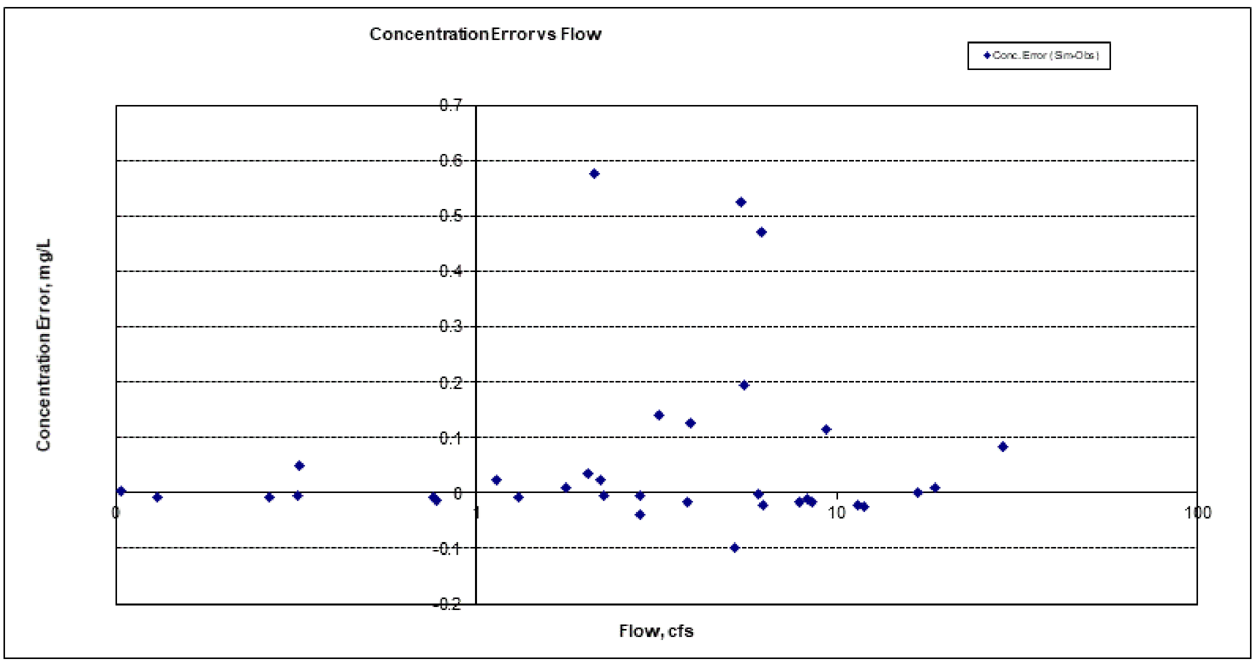


Figure E-922. Residual (Simulated - Observed) vs. Flow, Ammonia Nitrogen (NH3) at Mission Creek at MN-23

E.21.3 Nitrite+ Nitrate Nitrogen (NOx)

Table E-119. Nitrite+ Nitrate Nitrogen (NOx) statistics

Period	1994-2004	2004-2016
Count	ND	10
Concentration Average Error		102.11%
Concentration Median Error		19.98%
Load Average Error		280.17%
Load Median Error		9.88%
Paired t conc		0.10
Paired t load		0.09

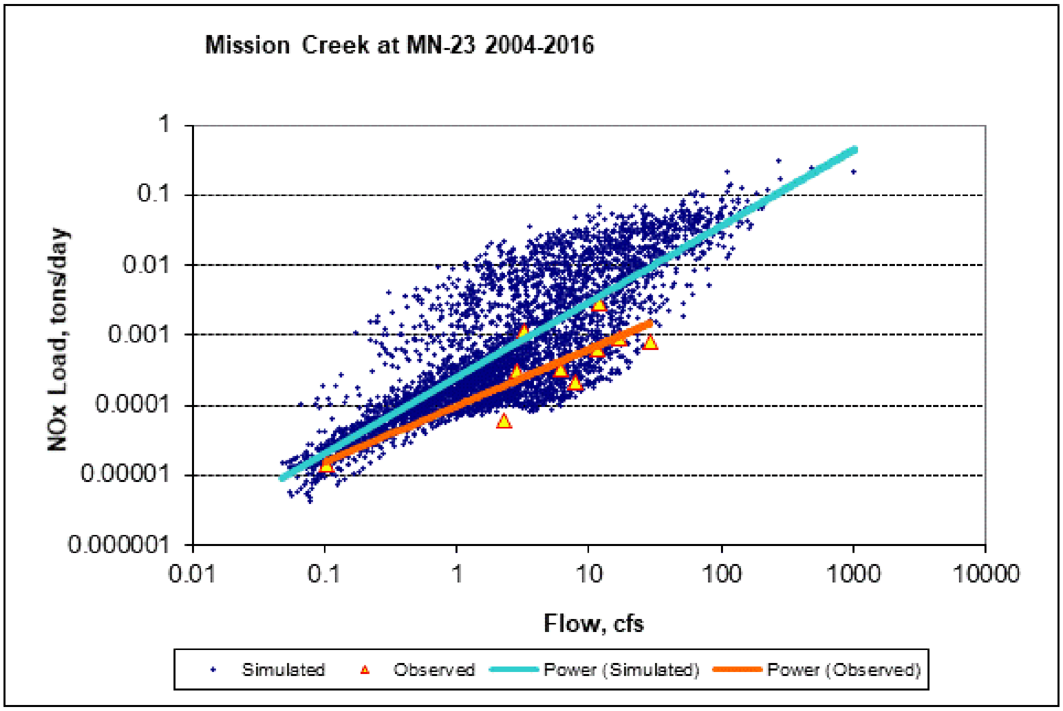


Figure E-923. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Mission Creek at MN-23 (calibration period)

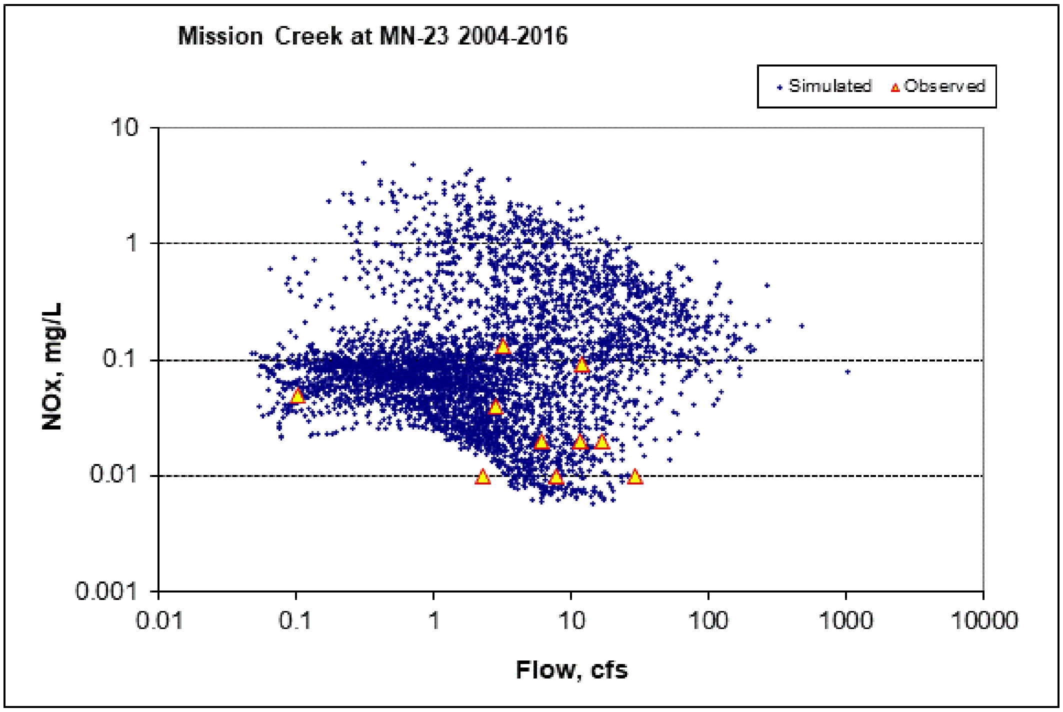
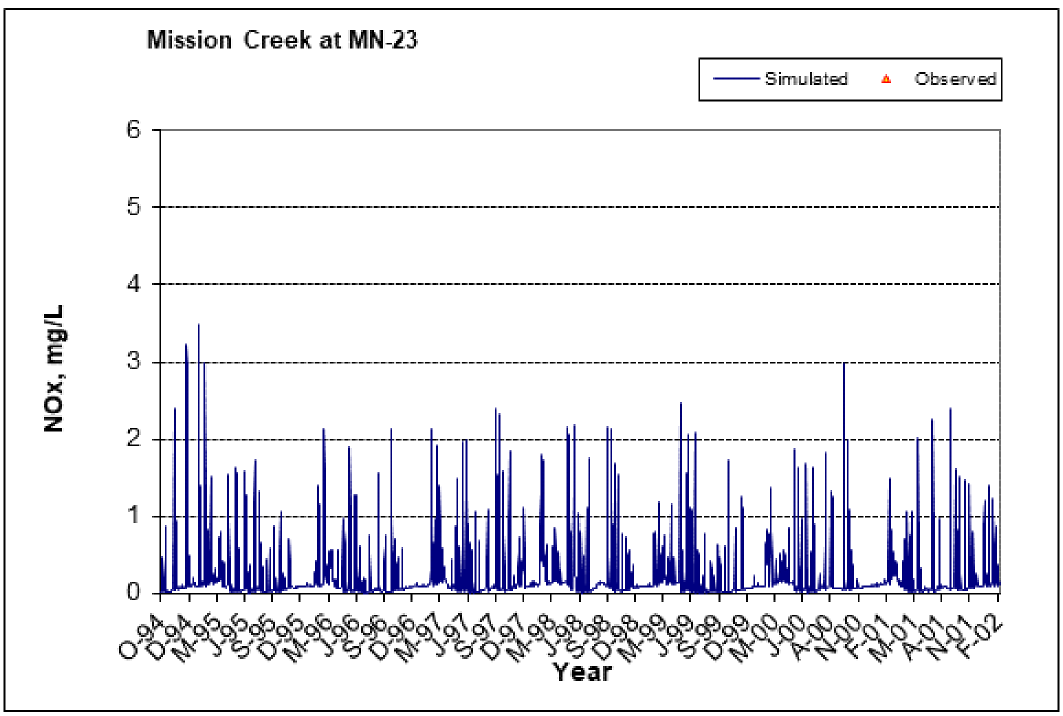
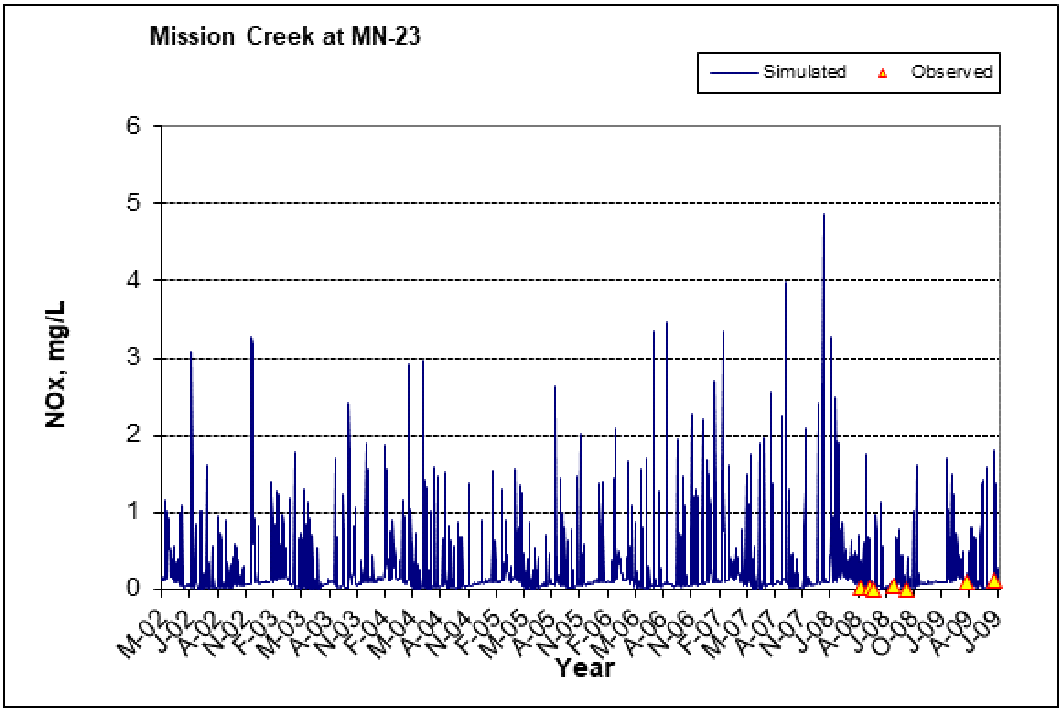


Figure E-924. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Mission Creek at MN-23 (calibration period)





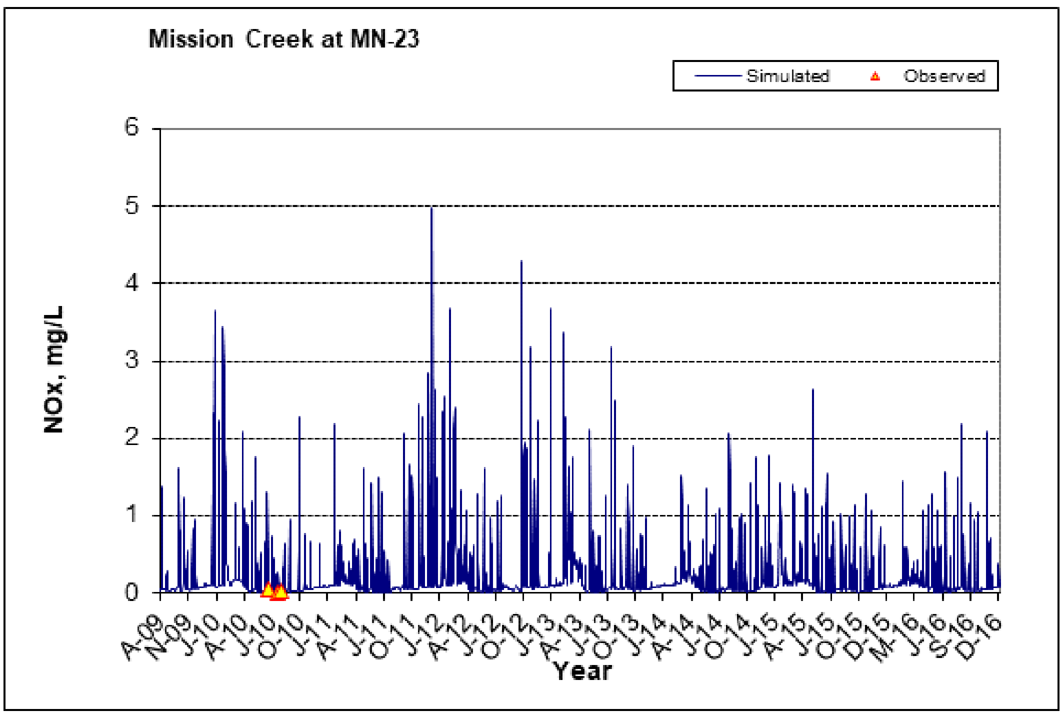


Figure E-925. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Mission Creek at MN-23

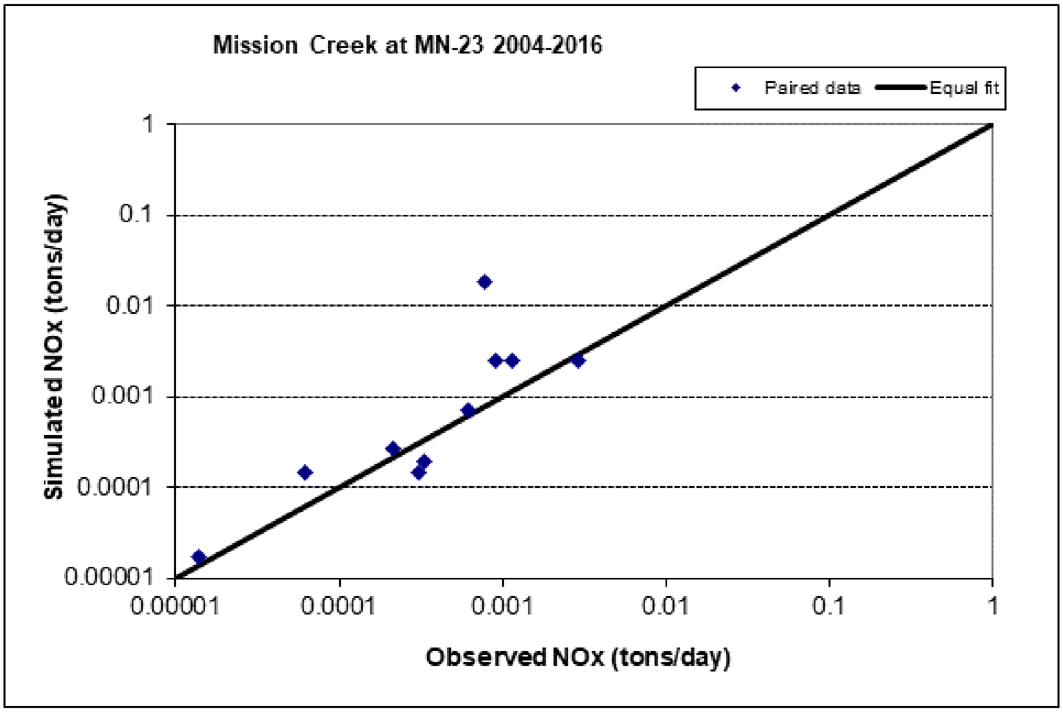


Figure E-926. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Mission Creek at MN-23 (calibration period)

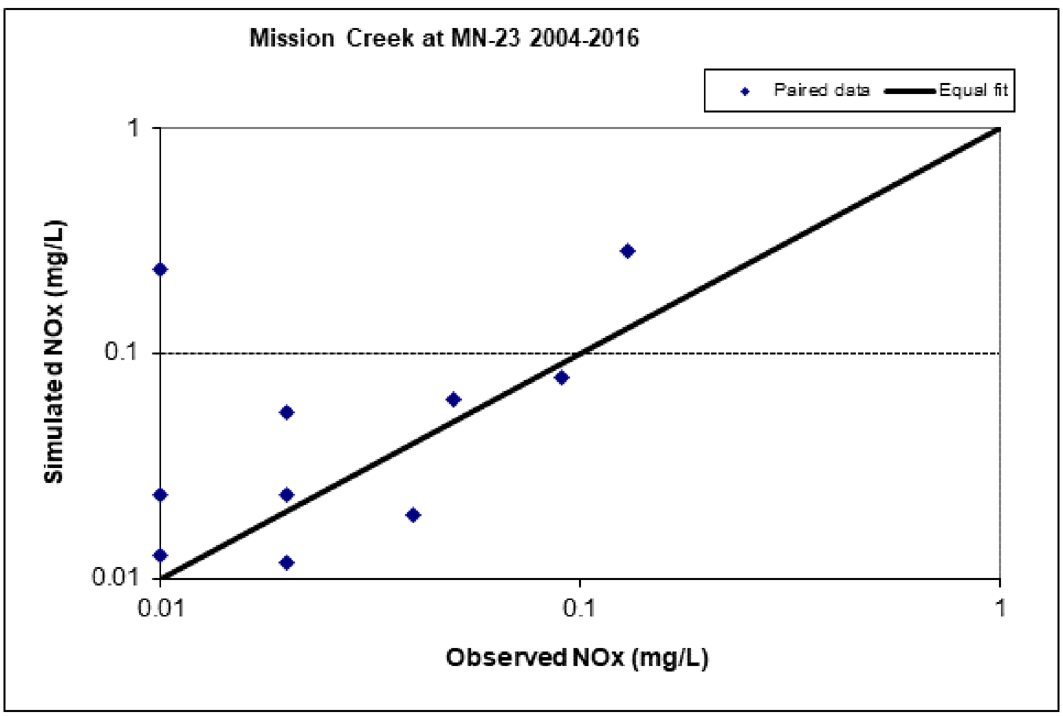


Figure E-927. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Mission Creek at MN-23 (calibration period)

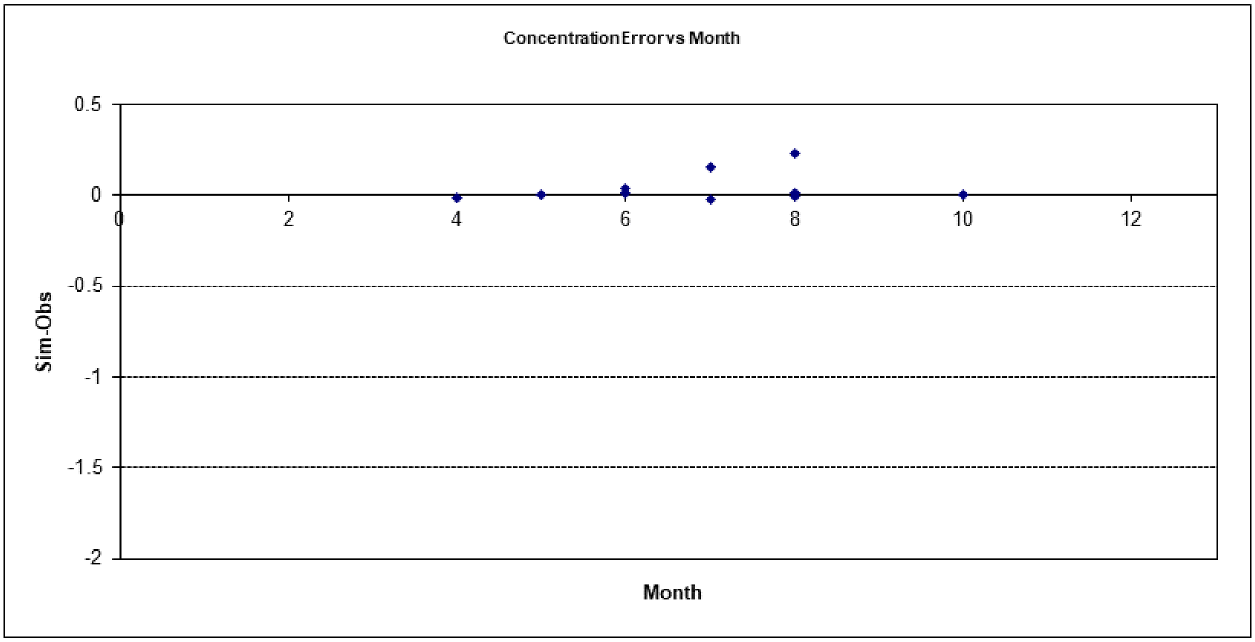


Figure E-928. Residual (Simulated - Observed) vs. Month, Nitrite+ Nitrate Nitrogen (NOx) at Mission Creek at MN-23

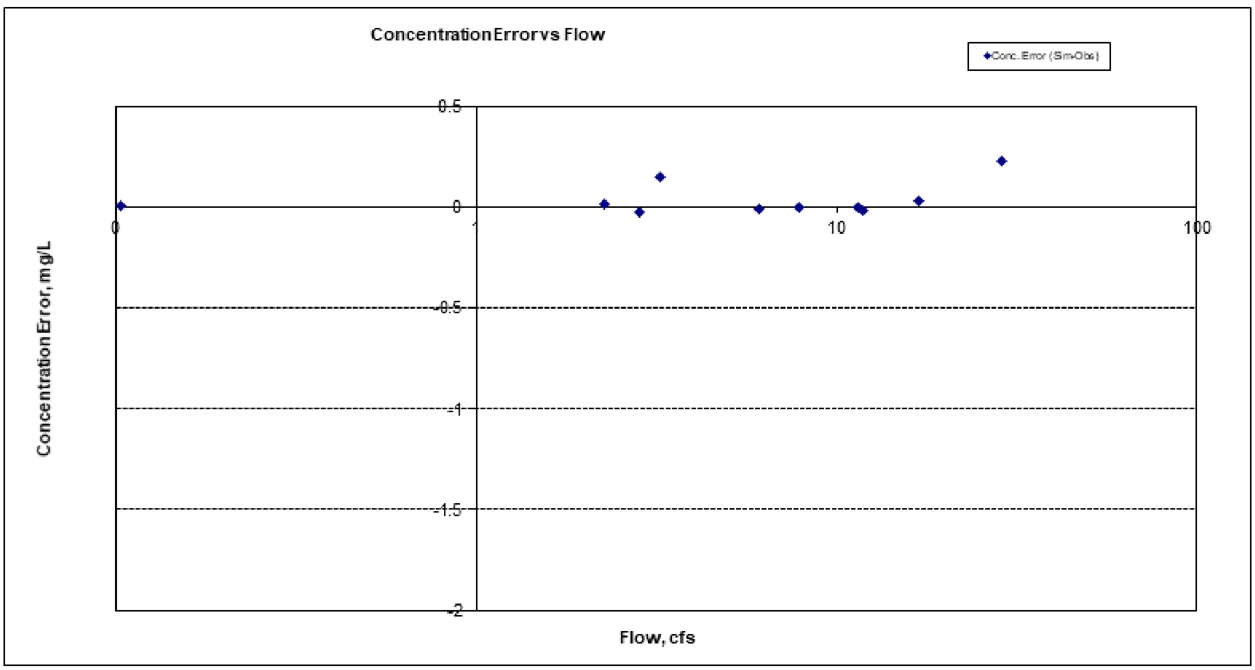


Figure E-929. Residual (Simulated - Observed) vs. Flow, Nitrite+ Nitrate Nitrogen (NOx) at Mission Creek at MN-23

E.21.4 Total Phosphorus (TP)

Table E-120. Total Phosphorus (TP) statistics

Period	1994-2004	2004-2016
Count	ND	34
Concentration Average Error		-21.69%
Concentration Median Error		14.02%
Load Average Error		-54.37%
Load Median Error		2.17%
Paired t conc		0.47
Paired t load		0.18

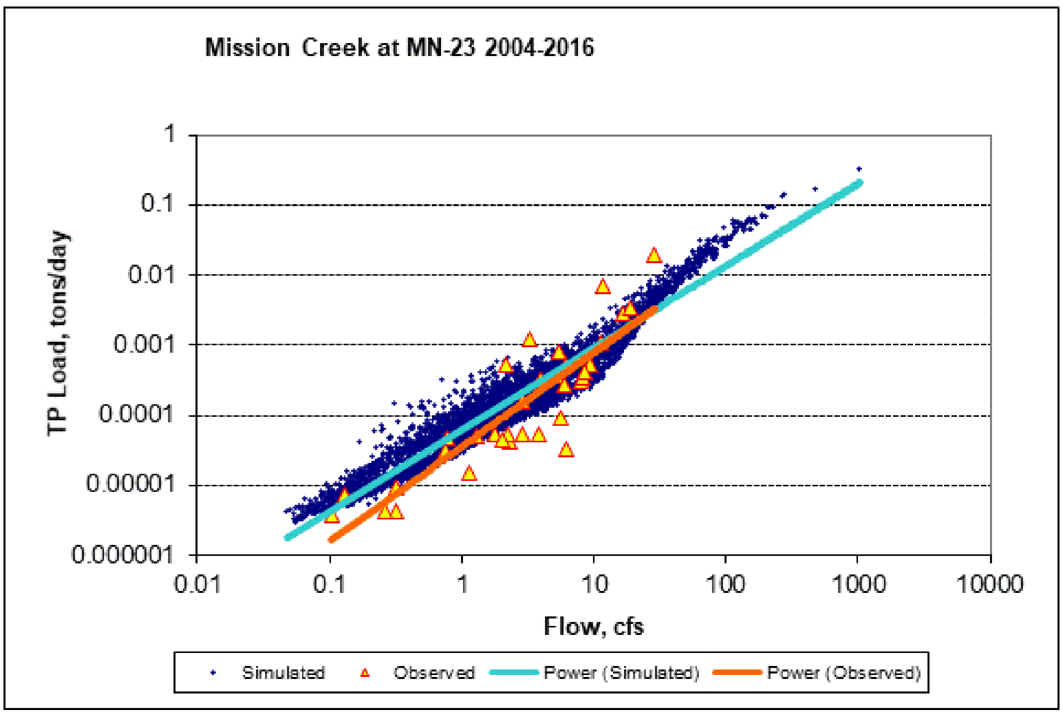


Figure E-930. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Mission Creek at MN-23 (calibration period)

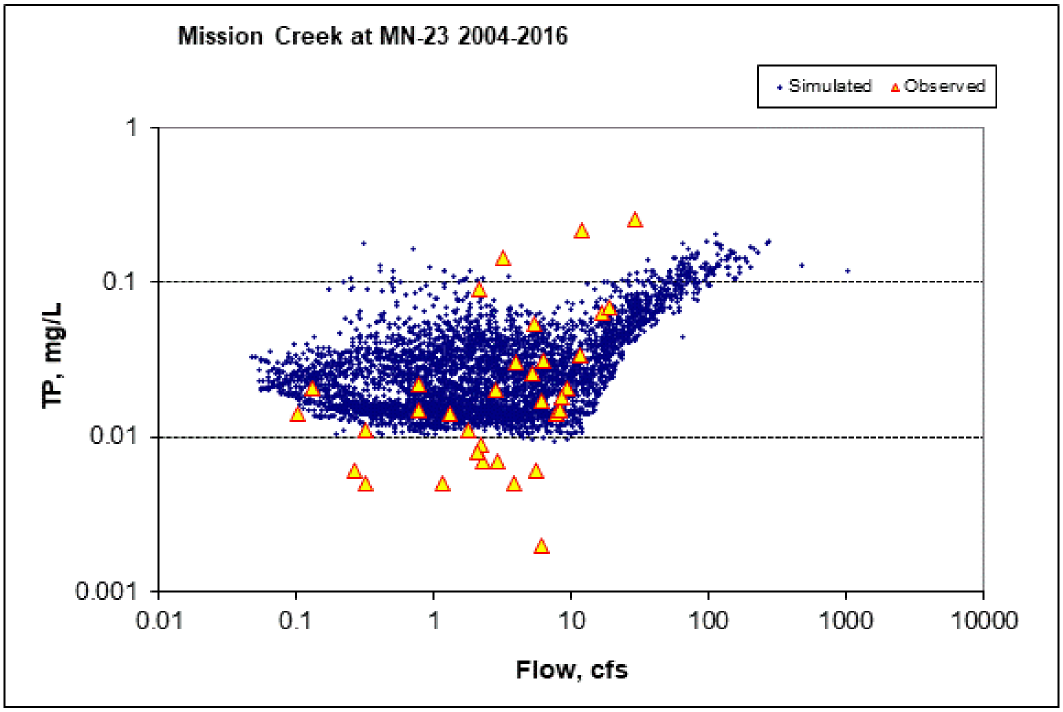
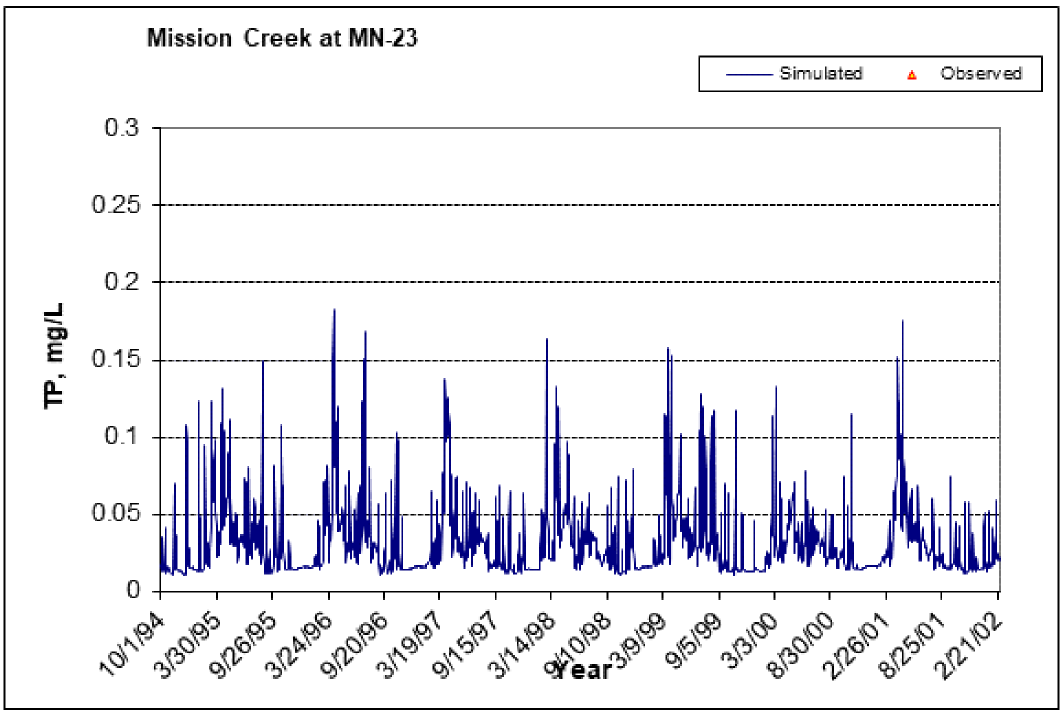
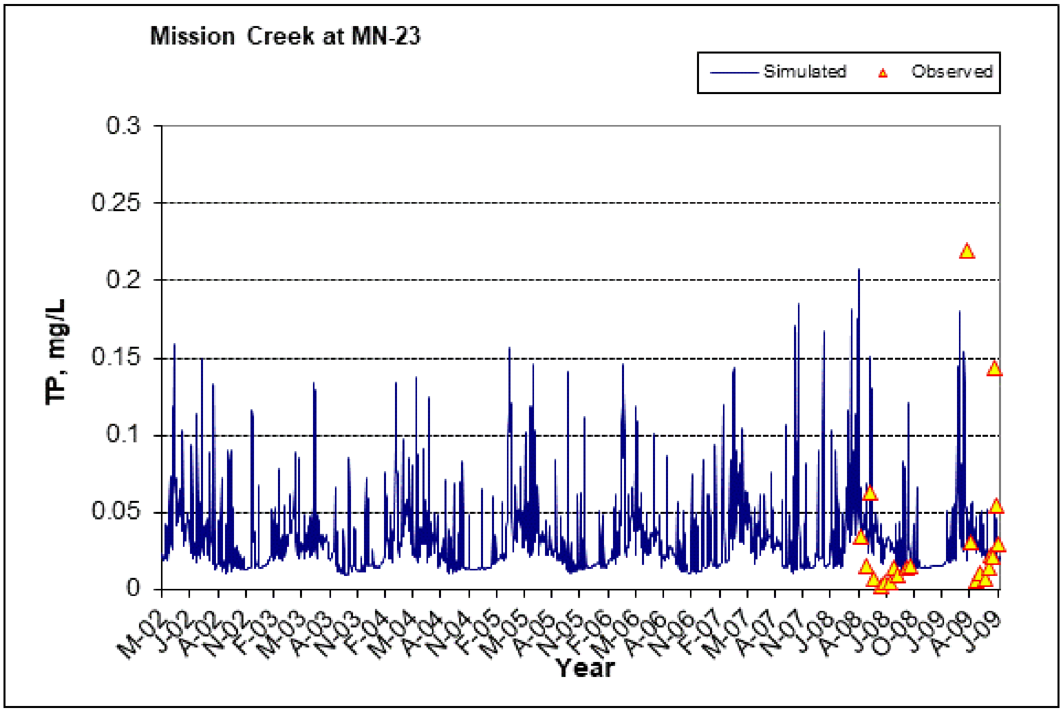


Figure E-931. Simulated and observed Total Phosphorus (TP) concentration vs flow at Mission Creek at MN-23 (calibration period)





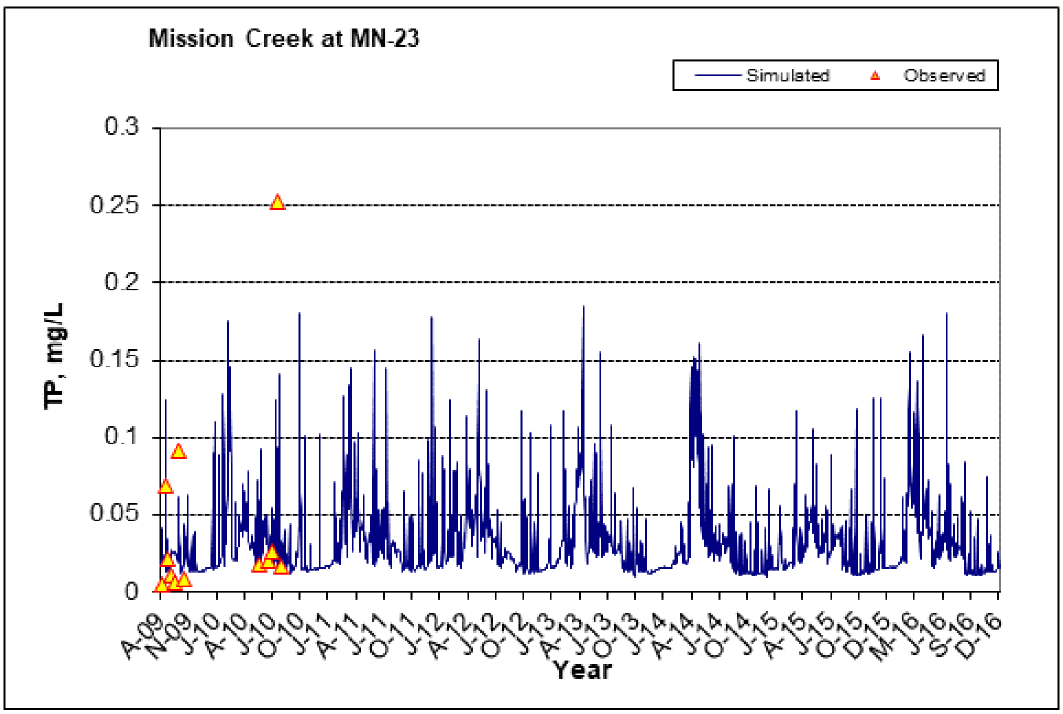


Figure E-932. Time series of observed and simulated Total Phosphorus (TP) concentration at Mission Creek at MN-23

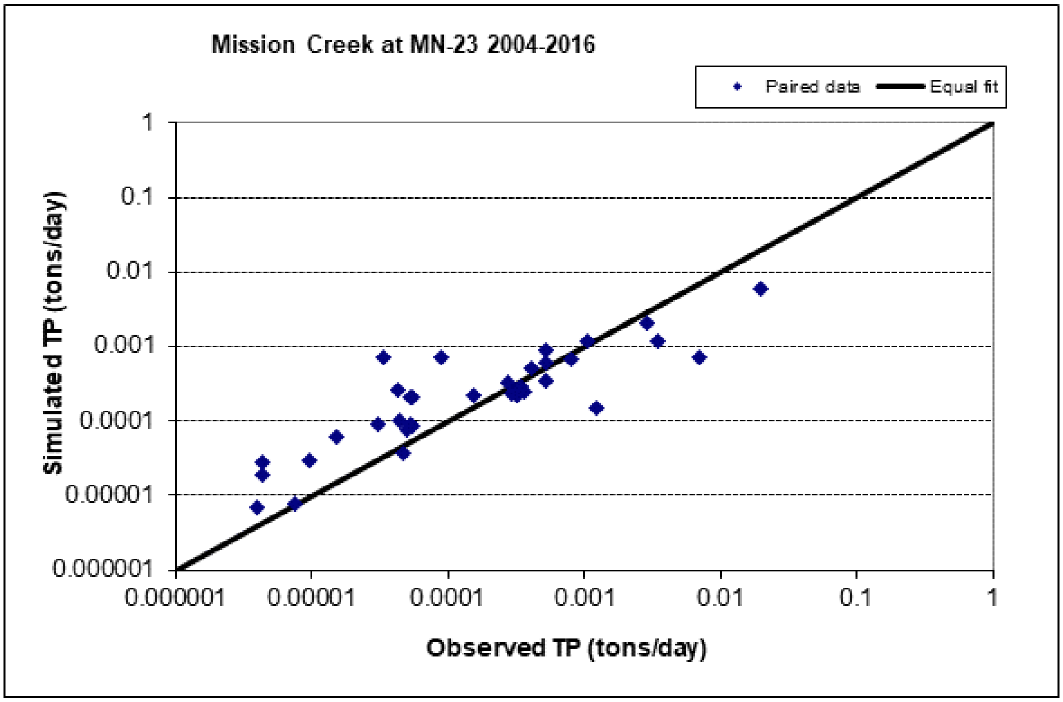


Figure E-933. Paired simulated vs. observed Total Phosphorus (TP) load at Mission Creek at MN-23 (calibration period)

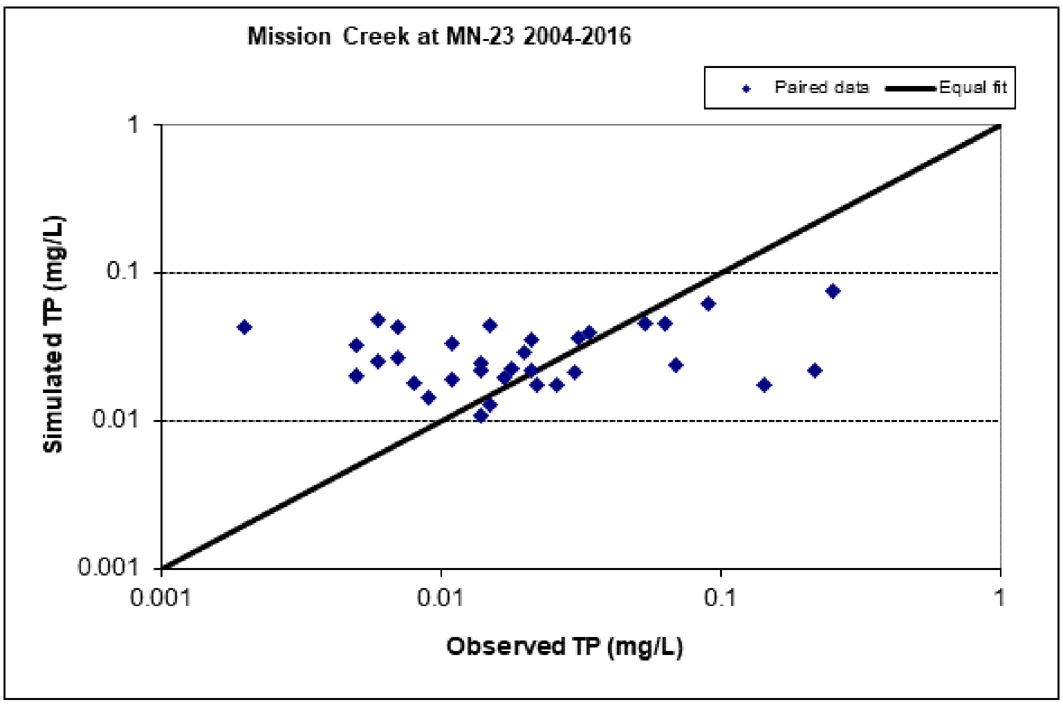


Figure E-934. Paired simulated vs. observed Total Phosphorus (TP) concentration at Mission Creek at MN-23 (calibration period)

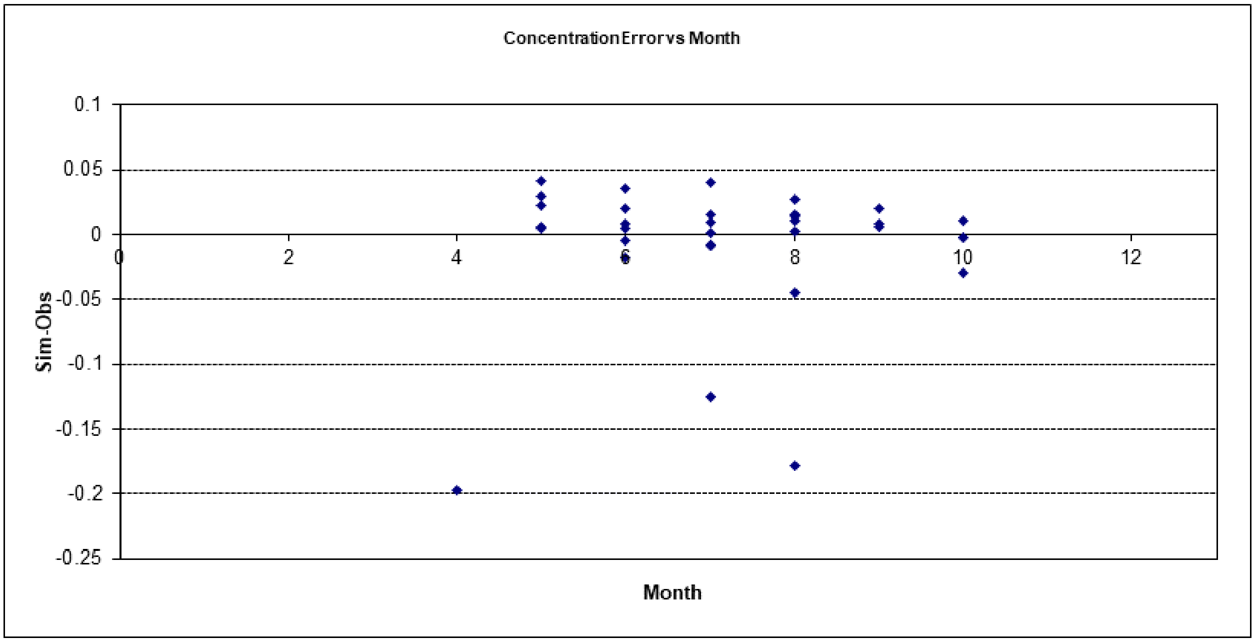


Figure E-935. Residual (Simulated - Observed) vs. Month, Total Phosphorus (TP) at Mission Creek at MN-23

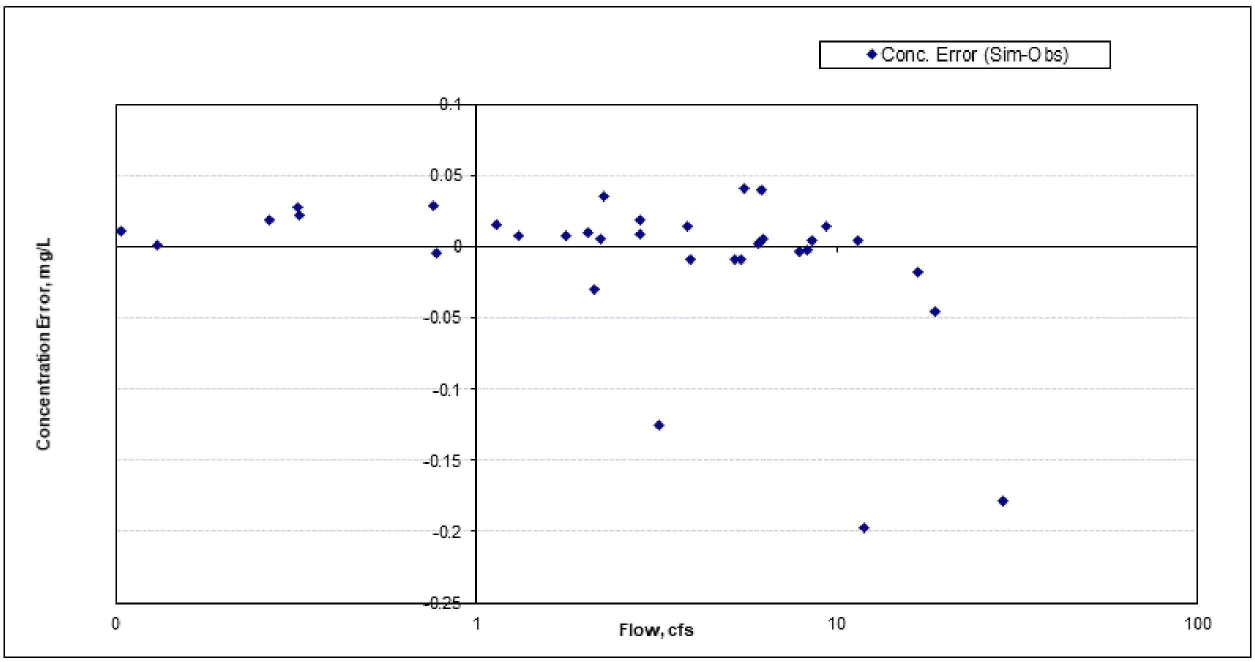


Figure E-936. Residual (Simulated - Observed) vs. Flow, Total Phosphorus (TP) at Mission Creek at MN-23

E.22 LESTER RIVER AT STRAND RD/CR-10

E.22.1 Dissolved Oxygen (DO)

Table E-121. Dissolved Oxygen (DO) statistics

Period	1994-2004	2004-2016
Count	ND	48
Concentration Average Error		-2.92%
Concentration Median Error		-1.70%
Load Average Error		-6.16%
Load Median Error		-0.22%
Paired t conc		1.00
Paired t load		0.73

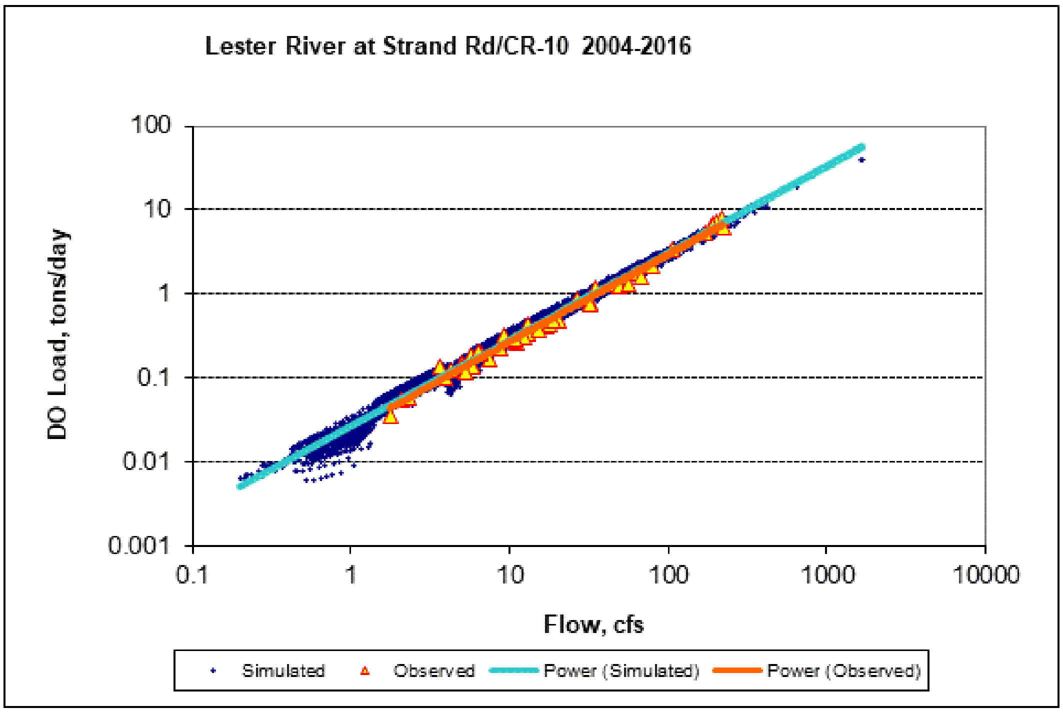


Figure E-937. Power plot of simulated and observed Dissolved Oxygen (DO) load vs flow at Lester River at Strand Rd/CR-10 (calibration period)

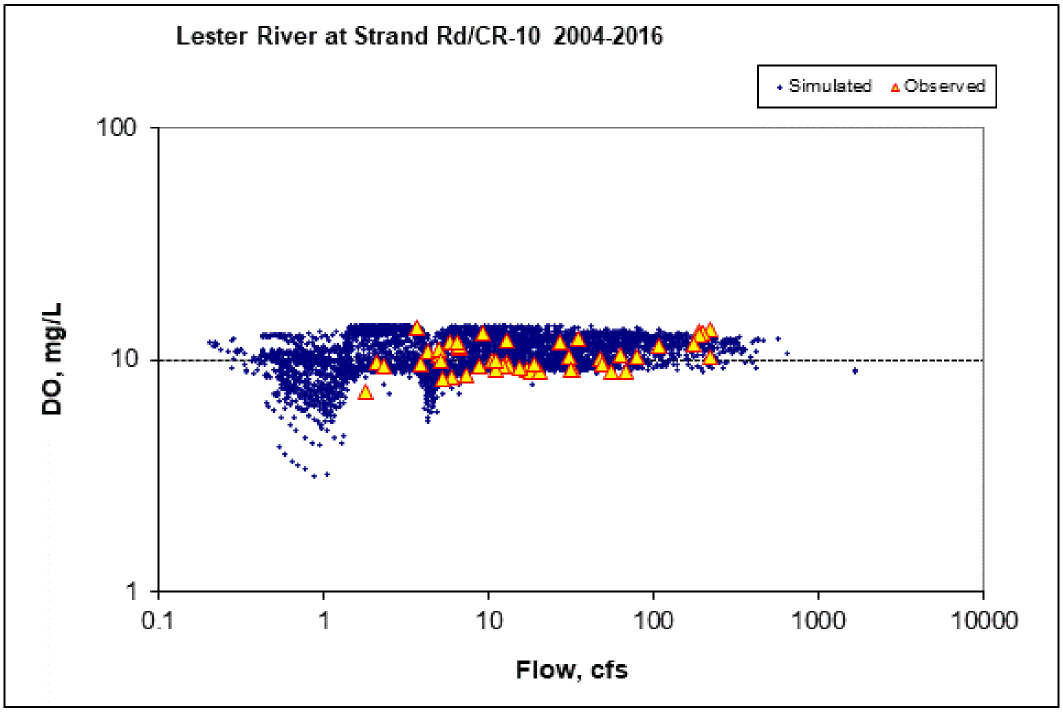
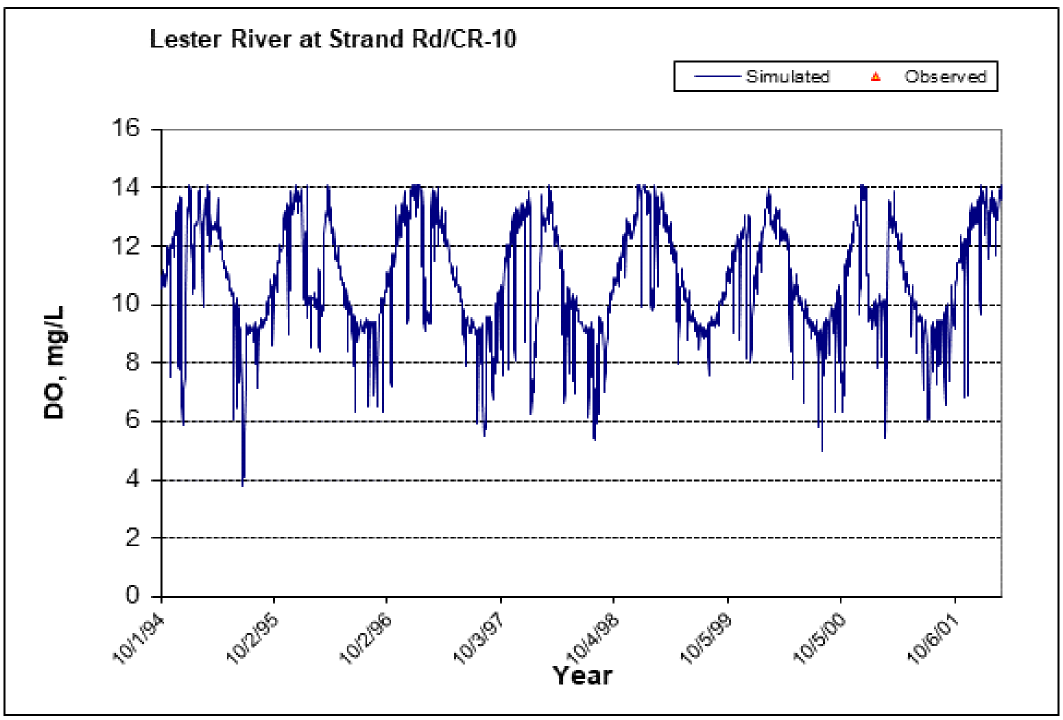


Figure E-938. Simulated and observed Dissolved Oxygen (DO) concentration vs flow at Lester River at Strand Rd/CR-10 (calibration period)



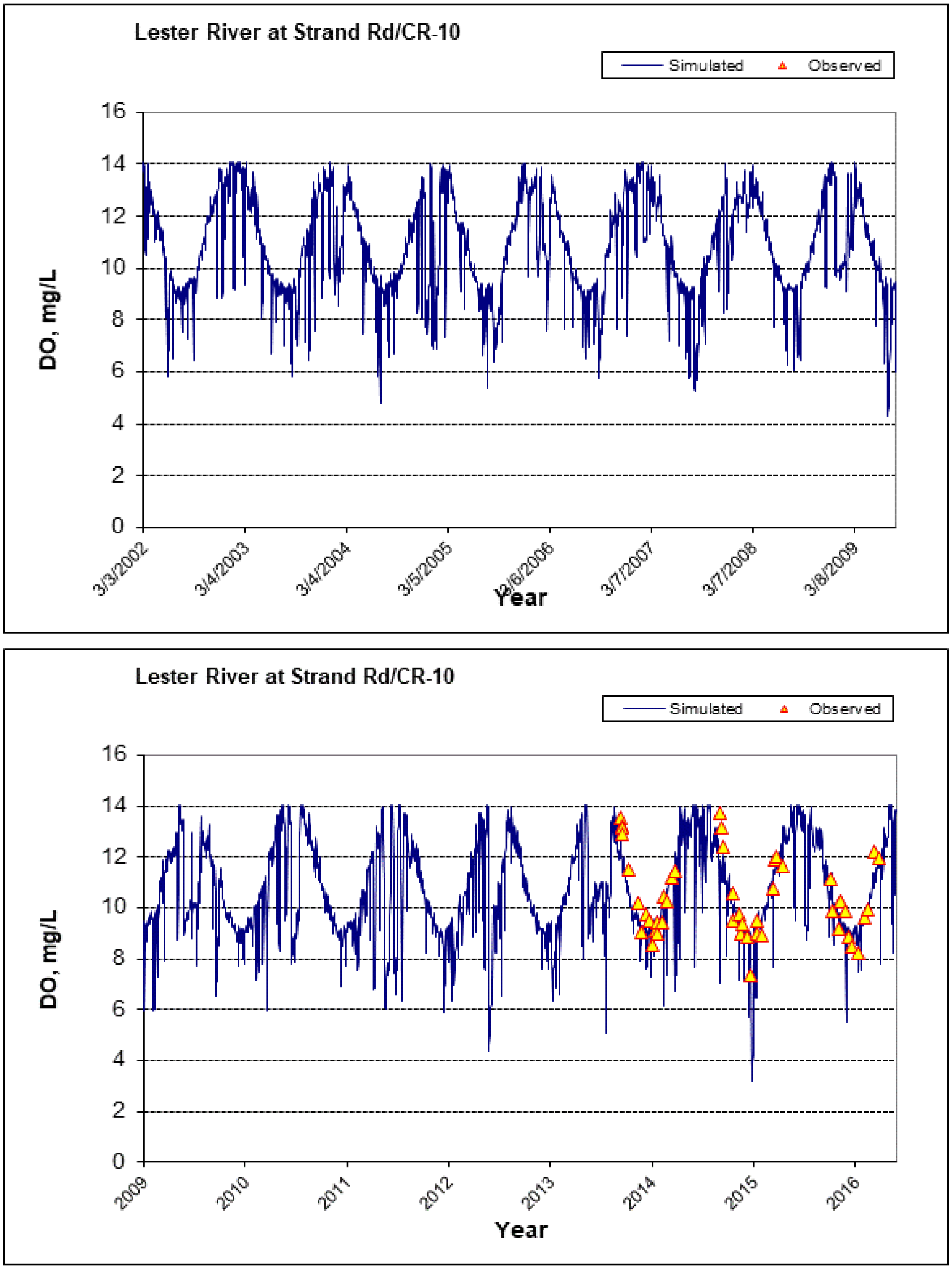


Figure E-939. Time series of observed and simulated Dissolved Oxygen (DO) concentration at Lester River at Strand Rd/CR-10

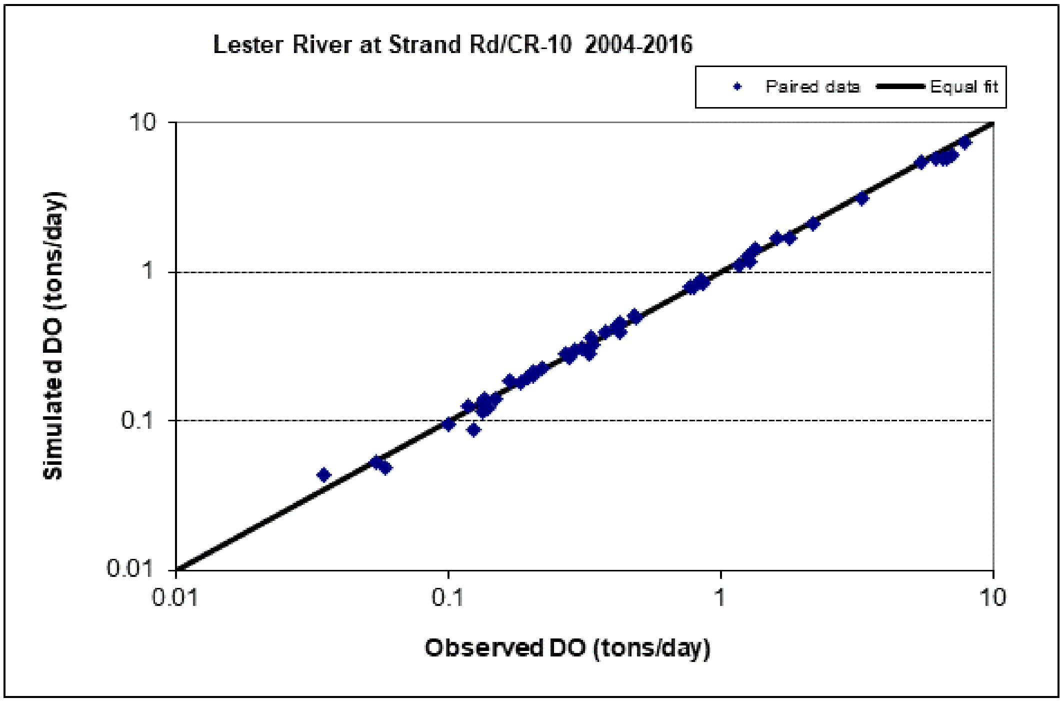


Figure E-940. Paired simulated vs. observed Dissolved Oxygen (DO) load at Lester River at Strand Rd/CR-10 (calibration period)

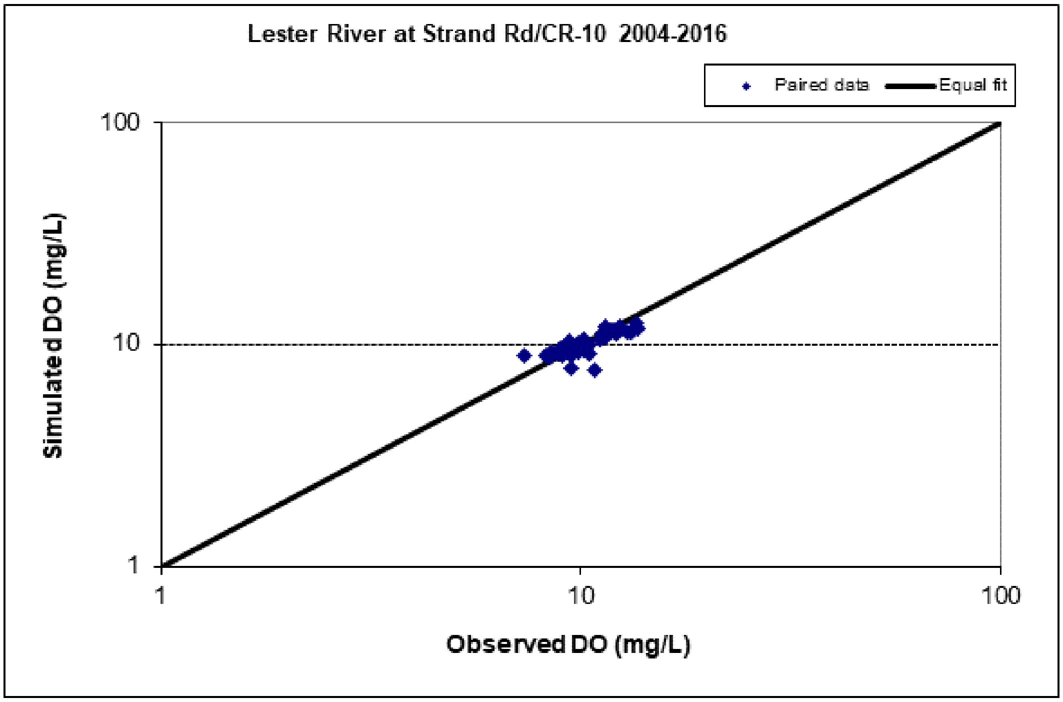


Figure E-941. Paired simulated vs. observed Dissolved Oxygen (DO) concentration at Lester River at Strand Rd/CR-10 (calibration period)

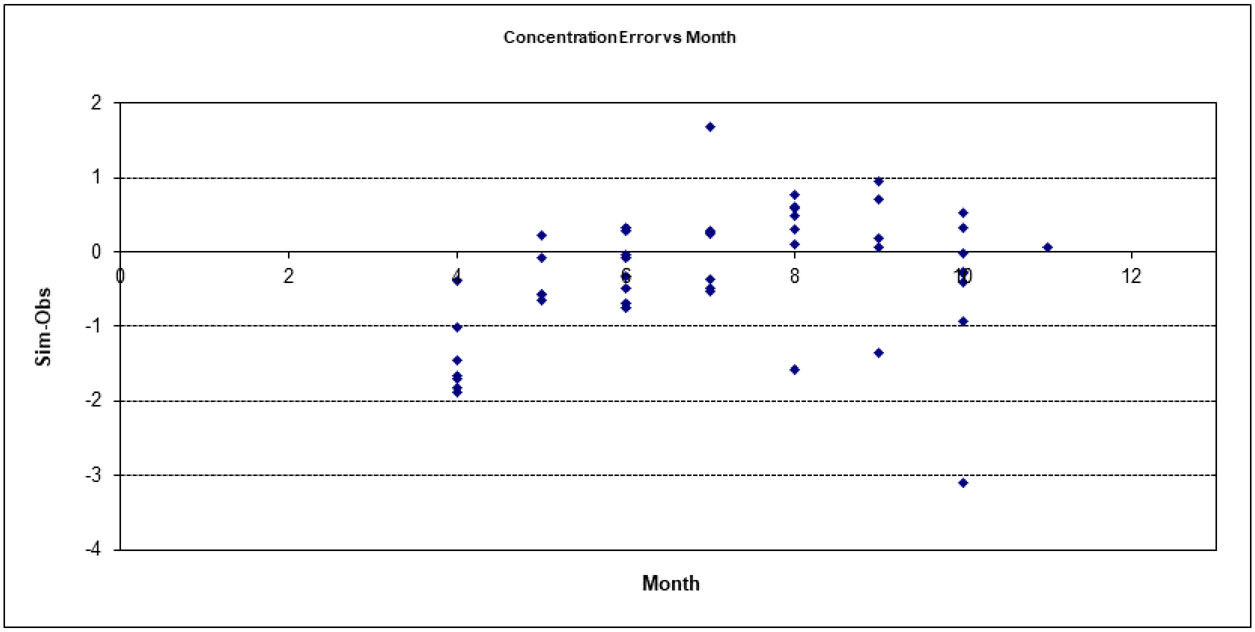


Figure E-942. Residual (Simulated - Observed) vs. Month, Dissolved Oxygen (DO) at Lester River at Strand Rd/CR-10

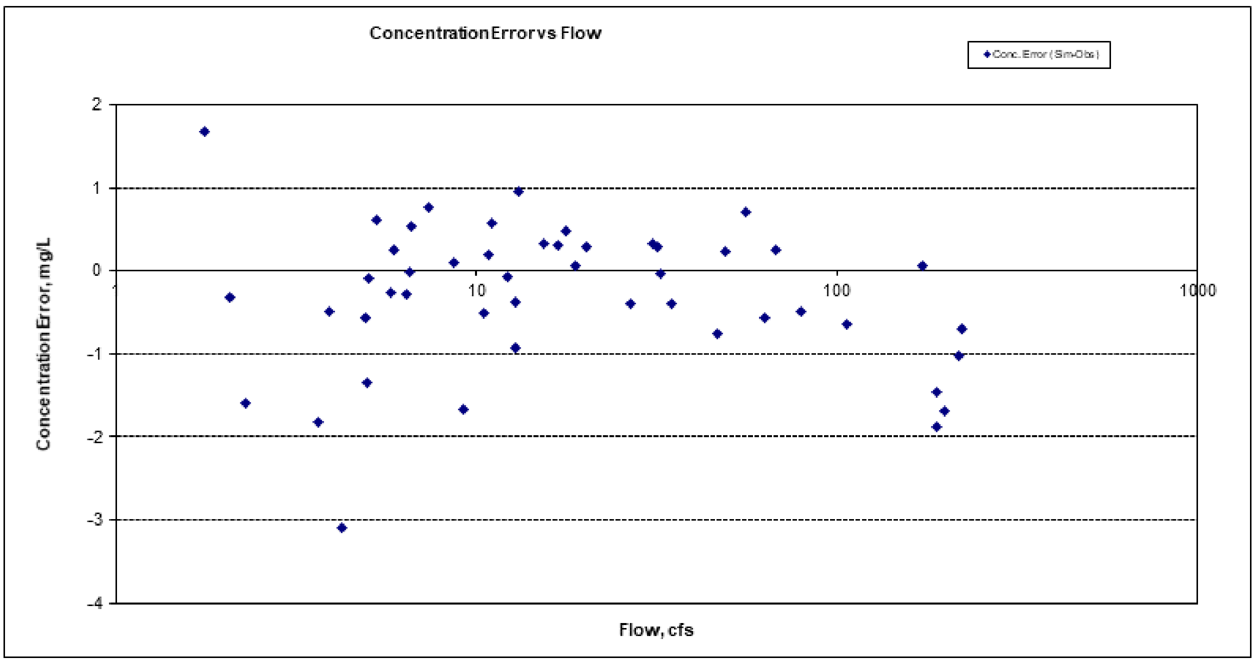


Figure E-943. Residual (Simulated - Observed) vs. Flow, Dissolved Oxygen (DO) at Lester River at Strand Rd/CR-10

Appendix F Chloride Calibration and Validation

F.1 Lester River upstream of Tischer Rd

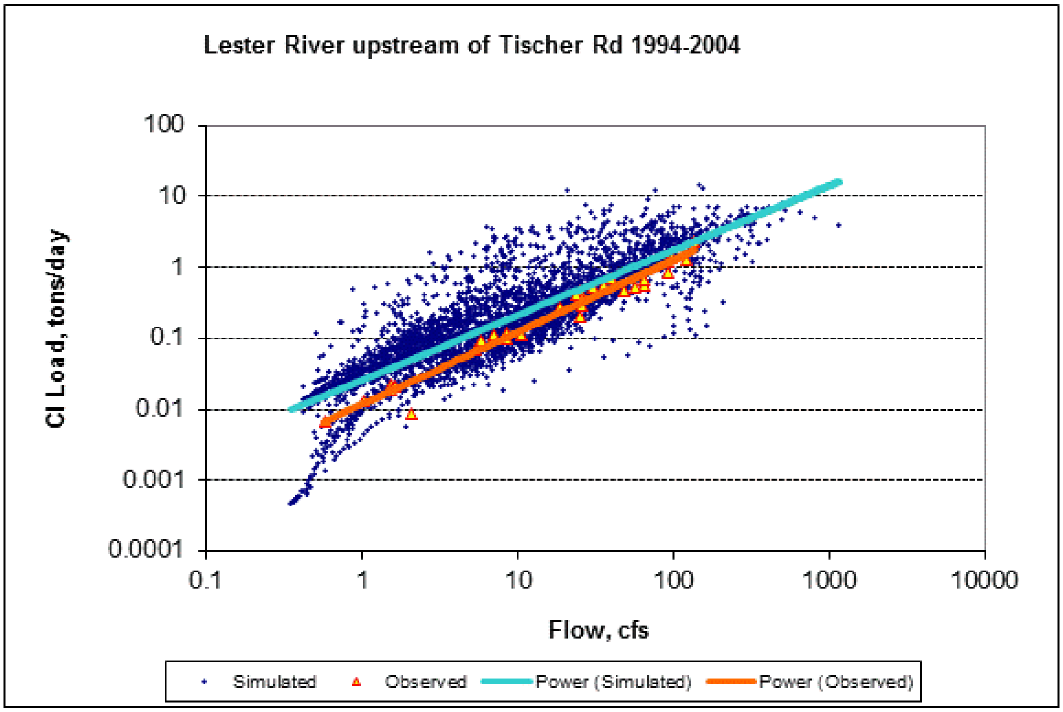


Figure F-1. Power Plot of Simulated and Observed Cl Load vs Flow at the Lester River upstream of Tischer Rd (Validation Period)

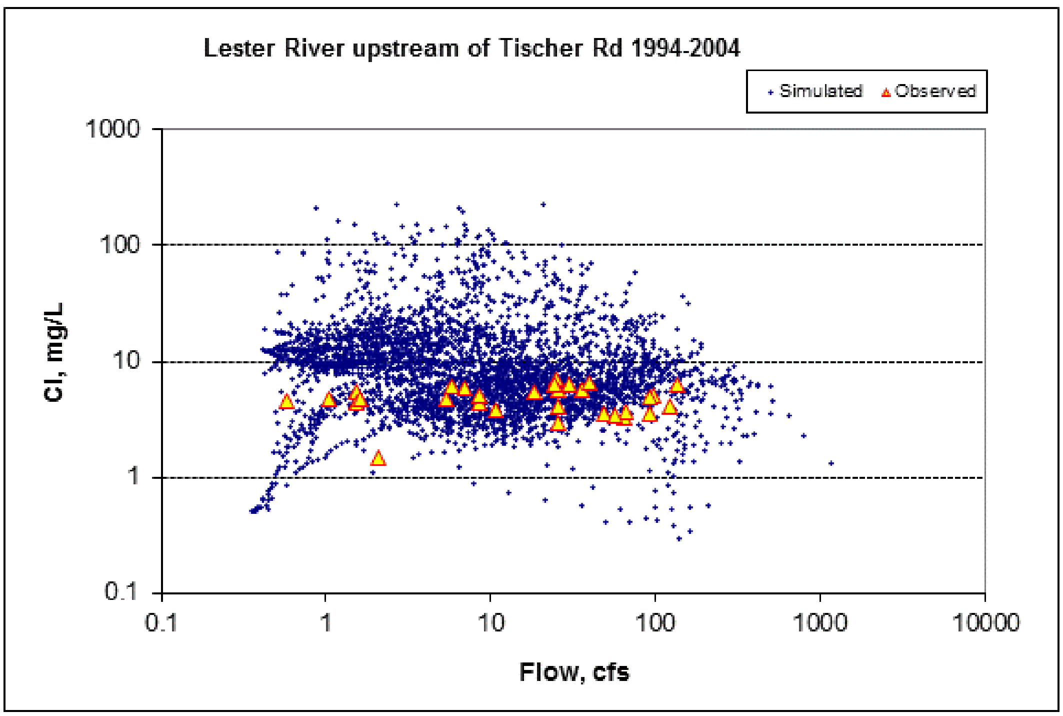


Figure F-2. Simulated and Observed Cl Concentration vs Flow Plot at the Lester River upstream of Tischer Rd (Validation Period)

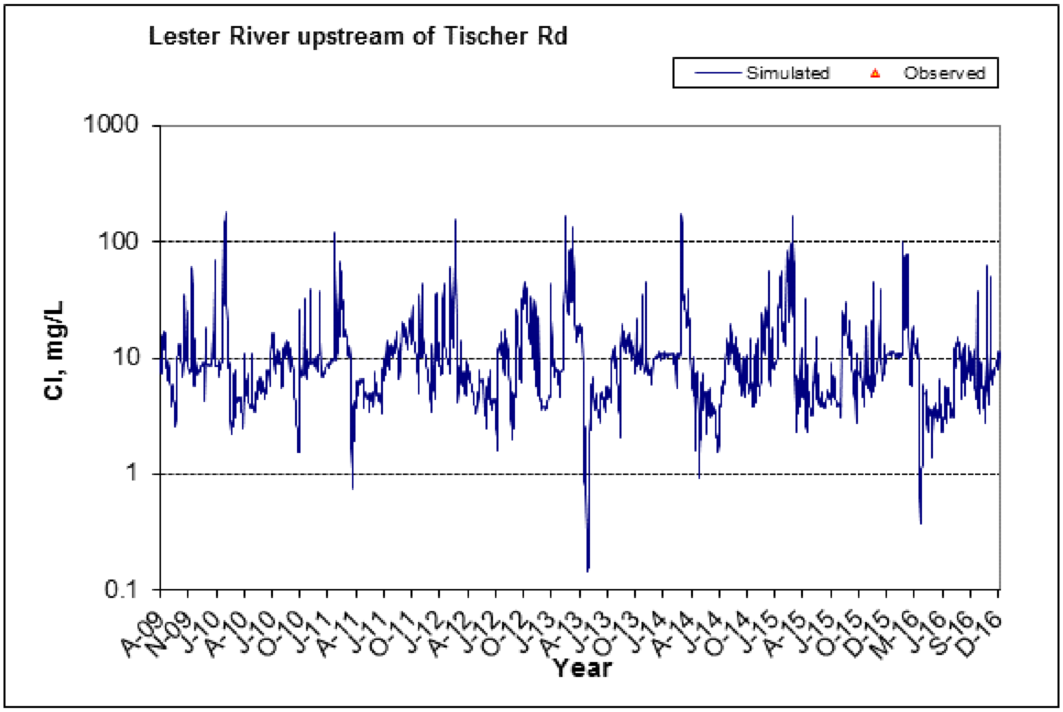


Figure F-3. Cl Concentration Time Series at the Lester River upstream of Tischer Rd (2008-2015)

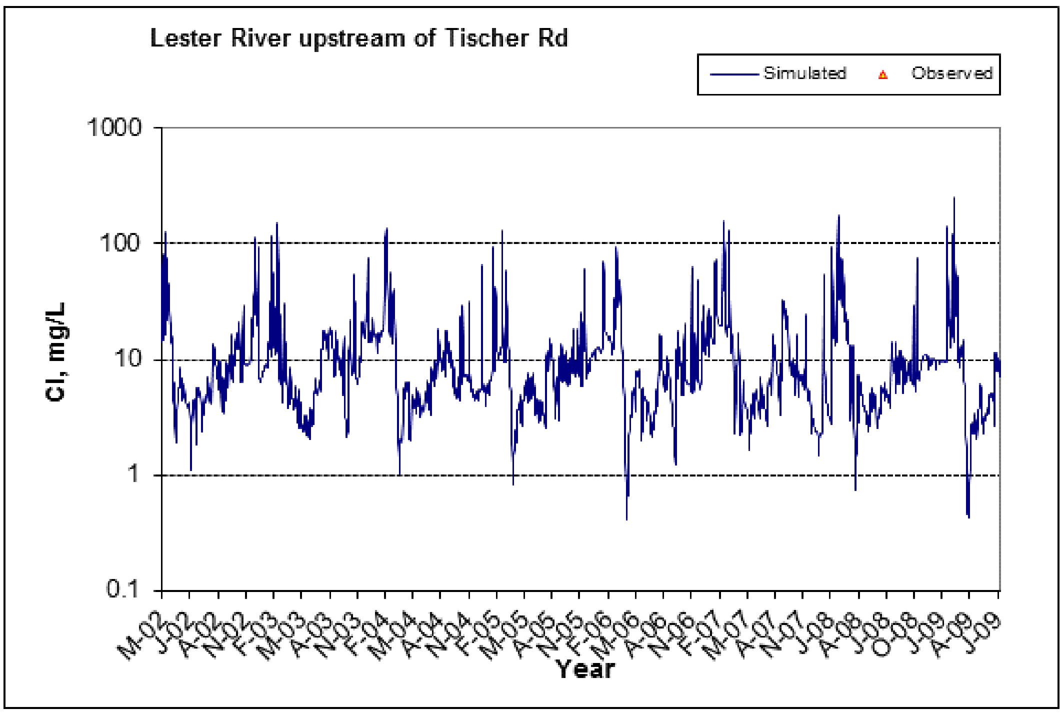


Figure F-4. Cl Concentration Time Series at the Lester River upstream of Tischer Rd (2001-2008)

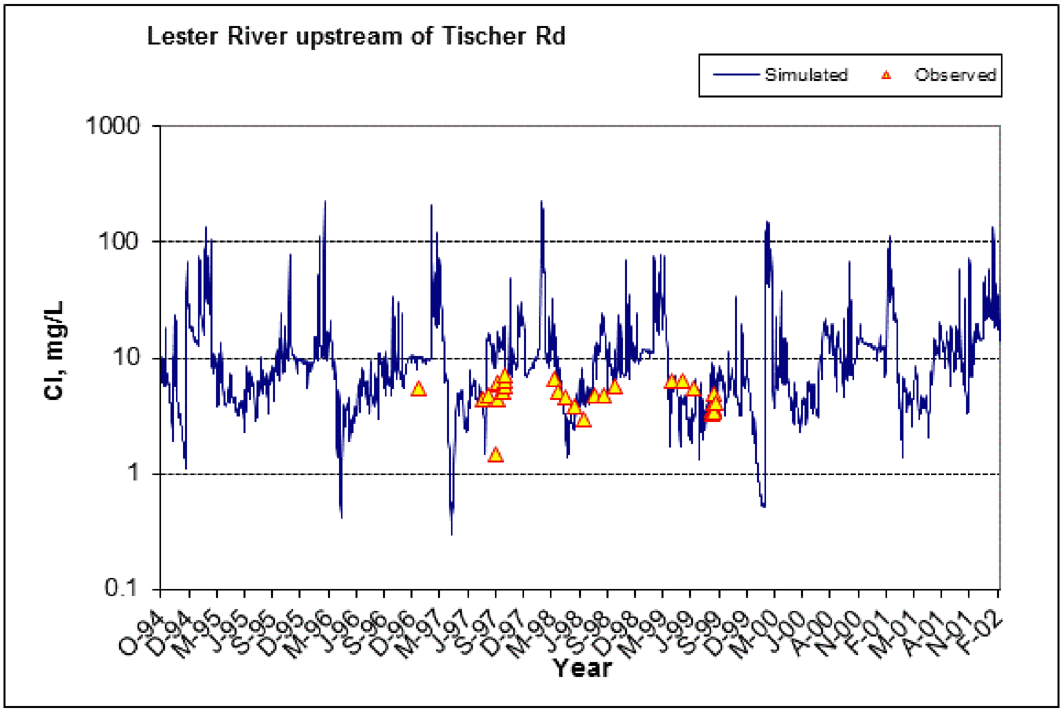


Figure F-5. Cl Concentration Time Series at the Lester River upstream of Tischer Rd (1994-2001)

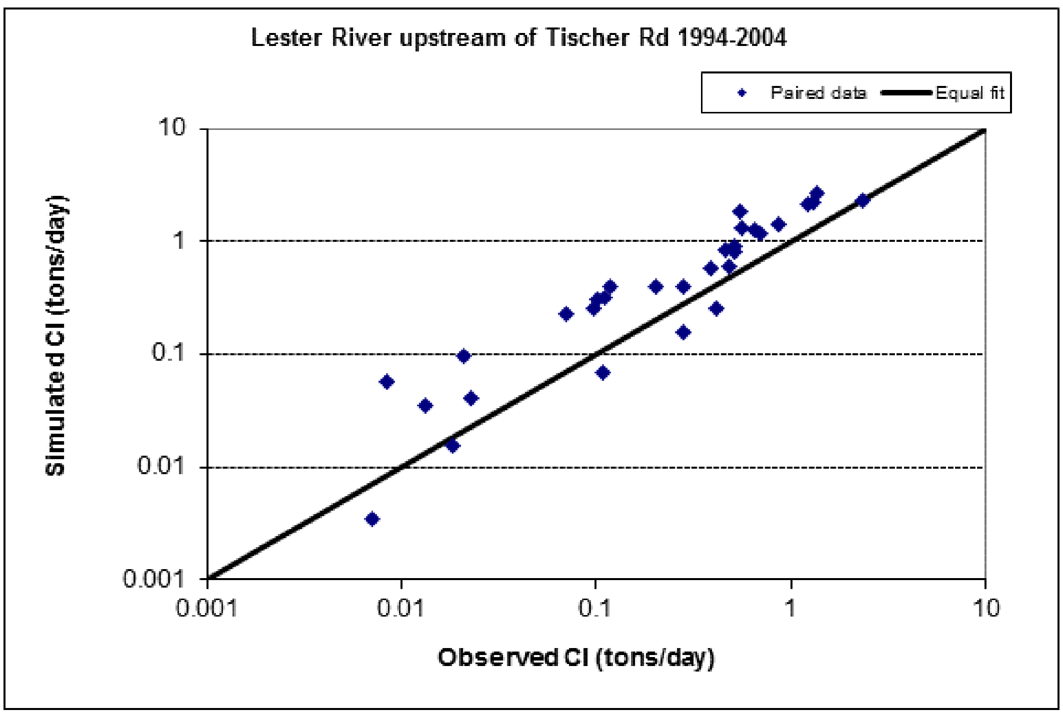


Figure F-6. Paired Simulated vs Observed Cl Load at the Lester River upstream of Tischer Rd (Validation Period)

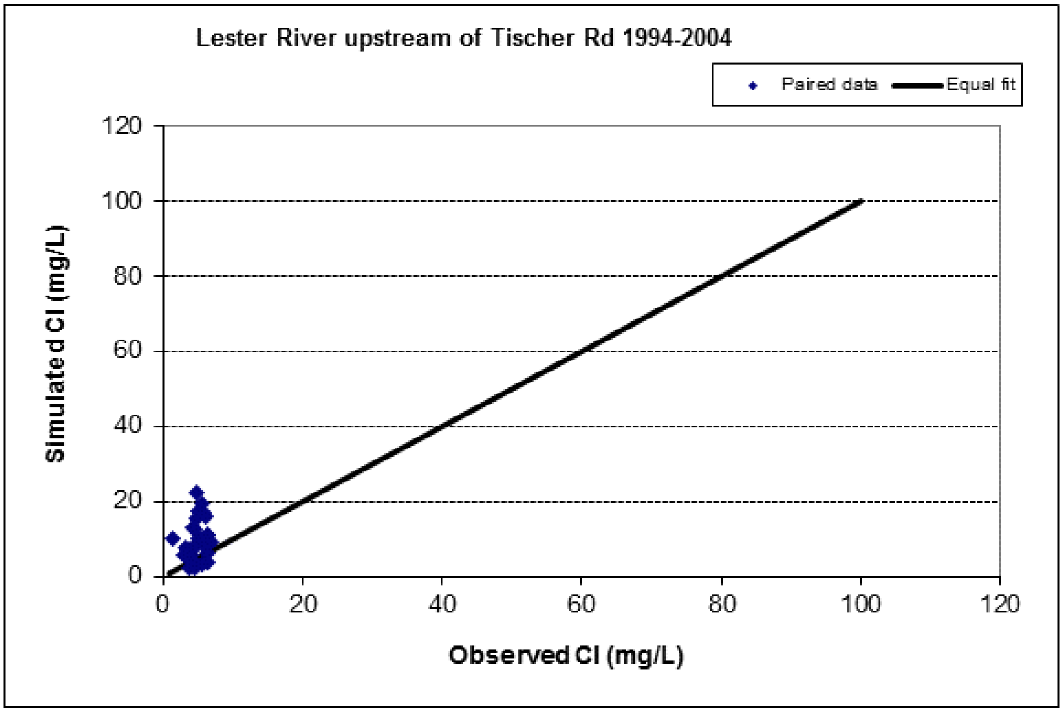


Figure F-7. Paired Simulated vs Observed Cl Concentration at the Lester River upstream of Tischer Rd (Validation Period)

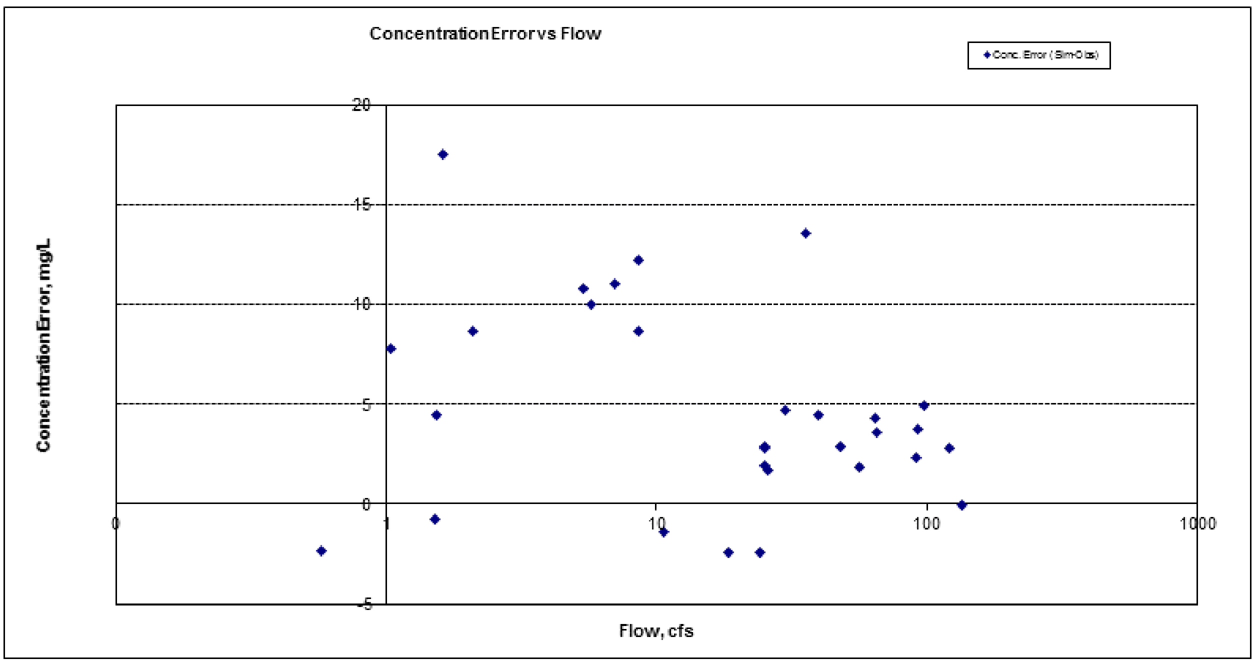


Figure F-8. Cl Concentration Error vs Flow at the Lester River upstream of Tischer Rd

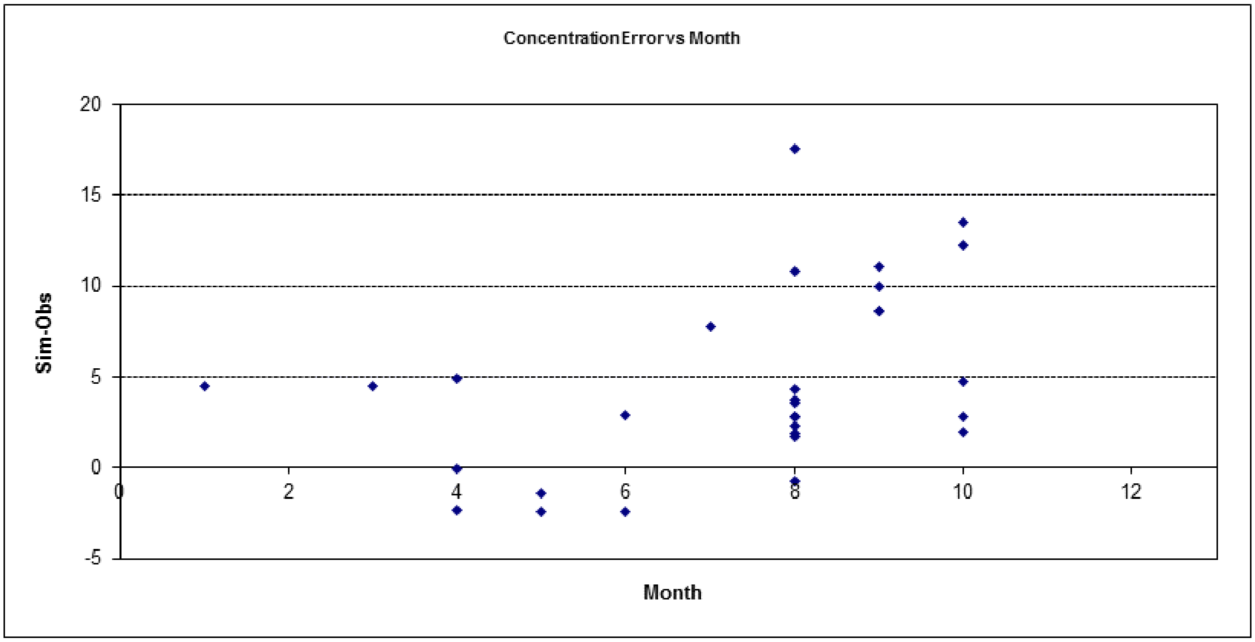


Figure F-9. Cl Concentration Error vs Month at the Lester River upstream of Tischer Rd

F.2 LESTER RIVER ABOVE SUPERIOR STREET

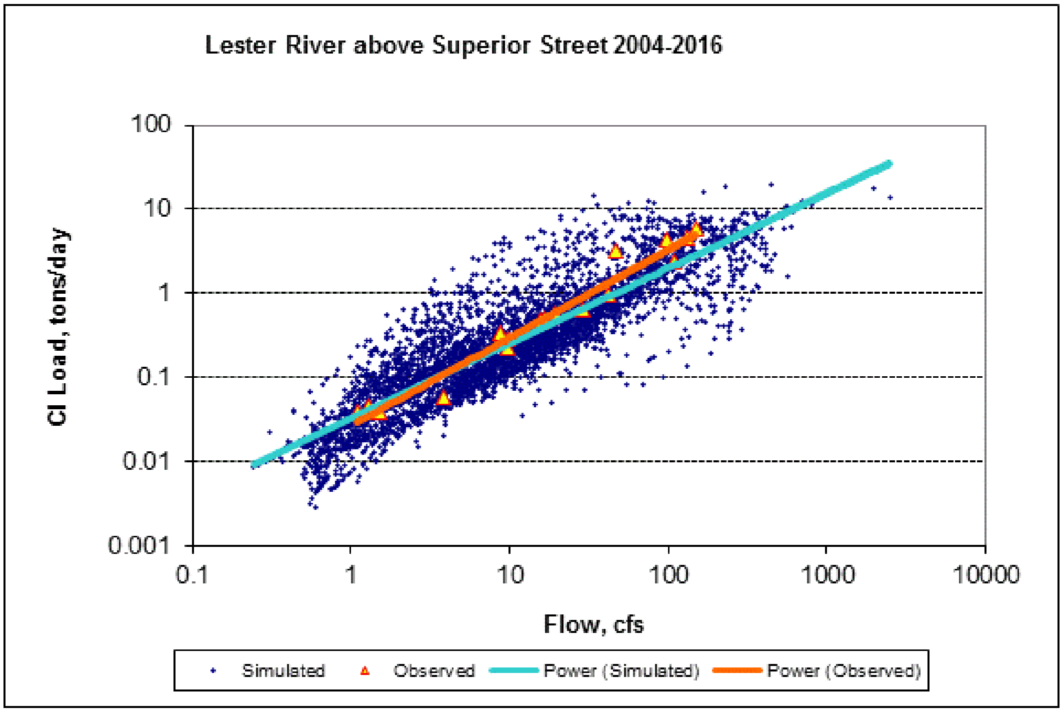


Figure F-10. Power Plot of Simulated and Observed Cl Load vs Flow at the Lester River above Superior Street (Calibration Period)

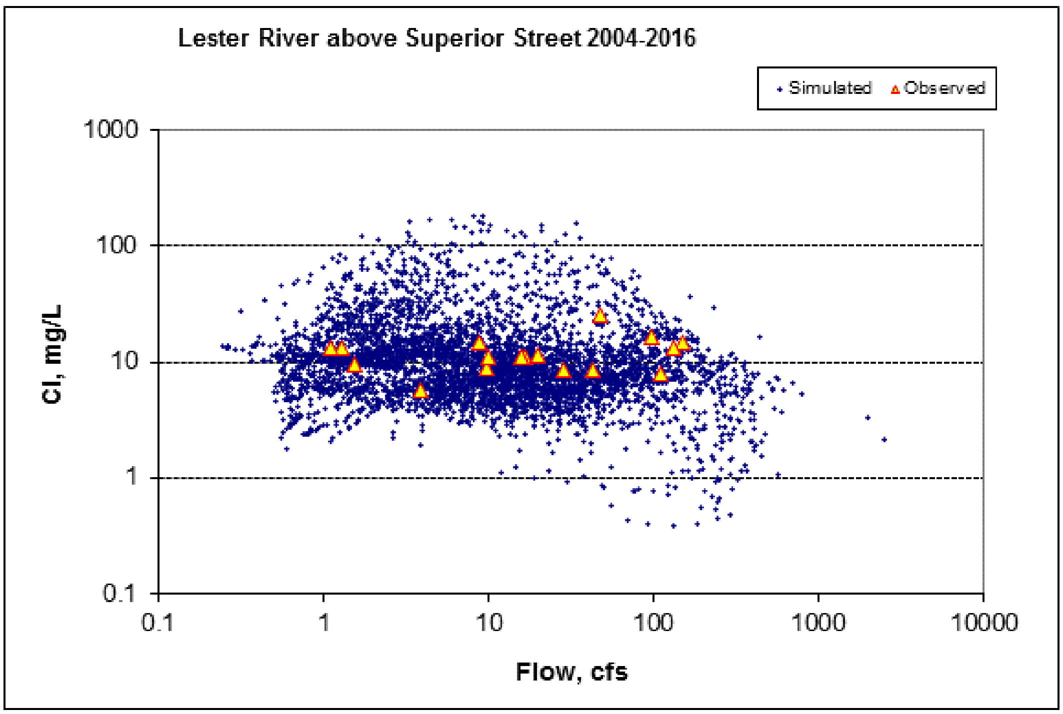


Figure F-11. Simulated and Observed Cl Concentration vs Flow Plot at the Lester River above Superior Street (Calibration Period)

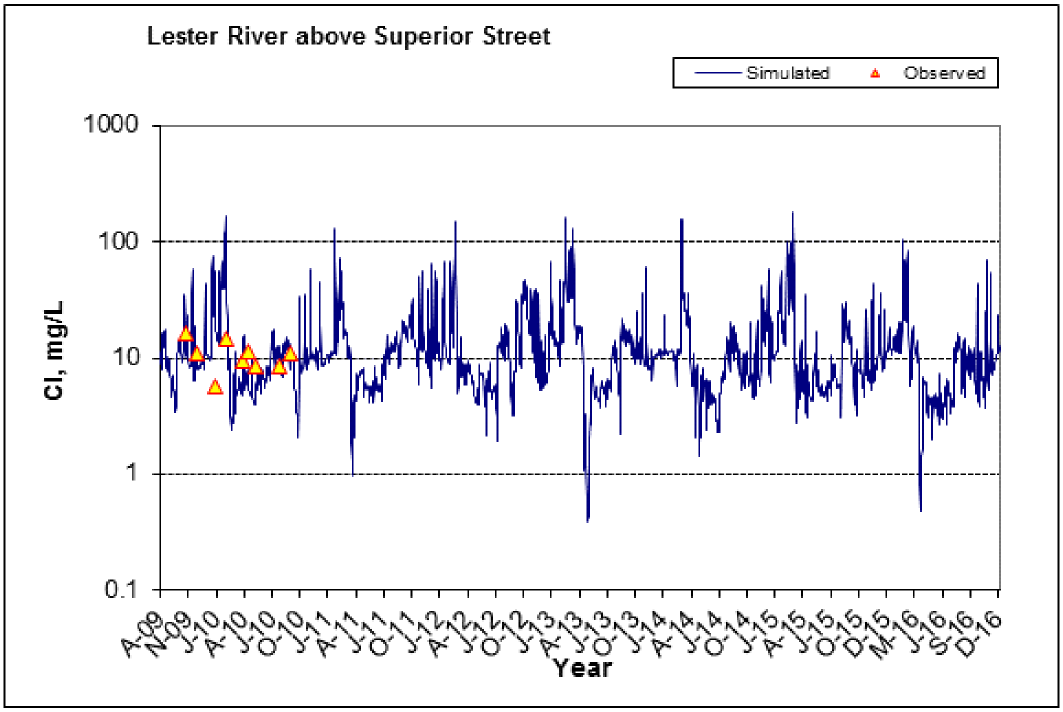


Figure F-12. Cl Concentration Time Series at the Lester River above Superior Street (2008-2015)

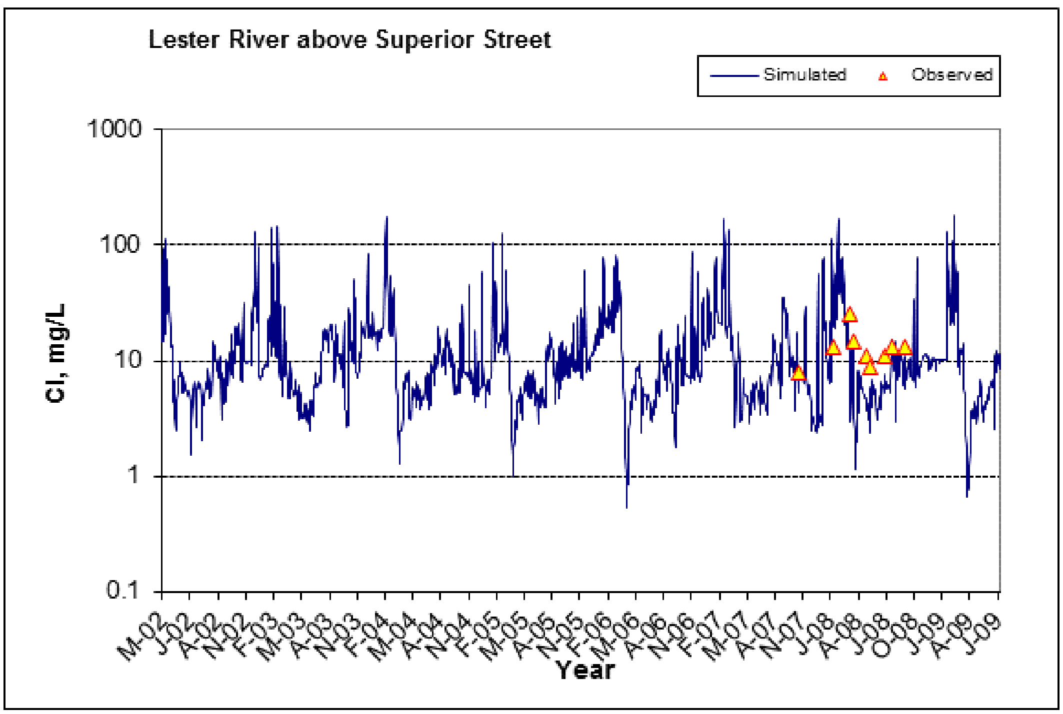


Figure F-13. Cl Concentration Time Series at the Lester River above Superior Street (2001-2008)

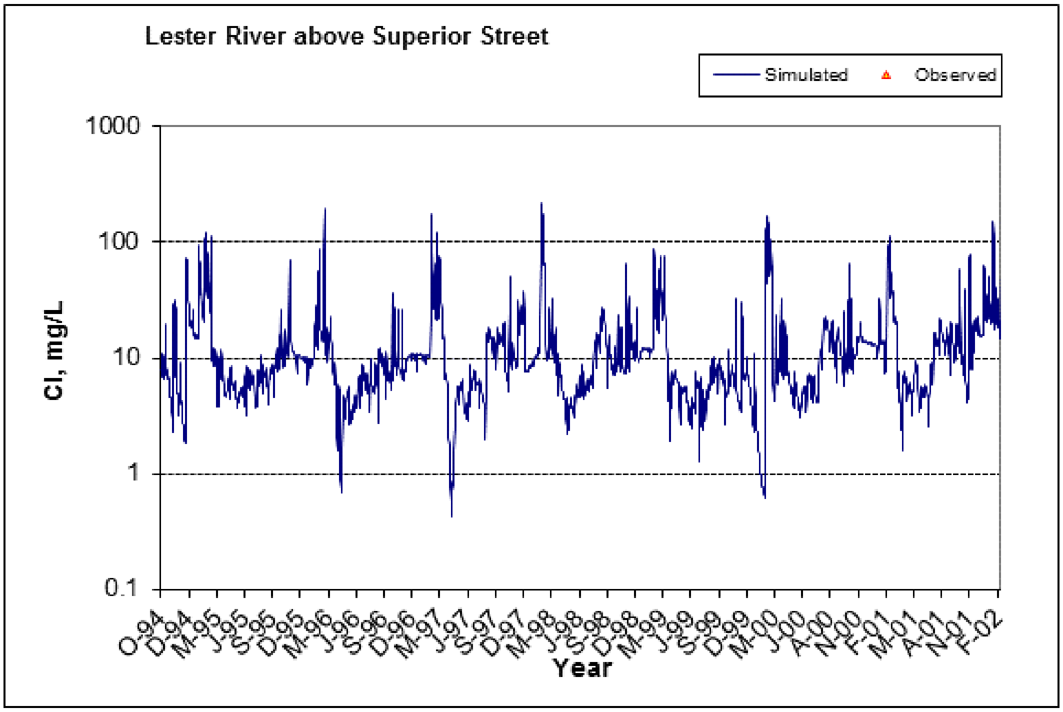


Figure F-14. Cl Concentration Time Series at the Lester River above Superior Street (1994-2001)

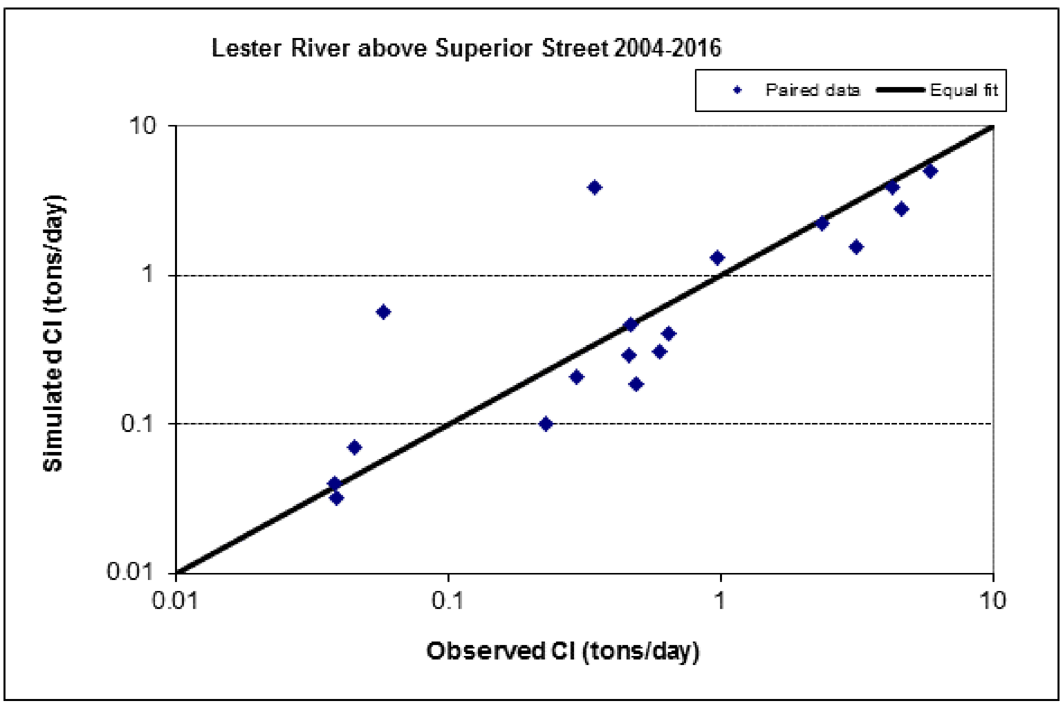


Figure F-15. Paired Simulated vs Observed Cl Load at the Lester River above Superior Street (Calibration Period)

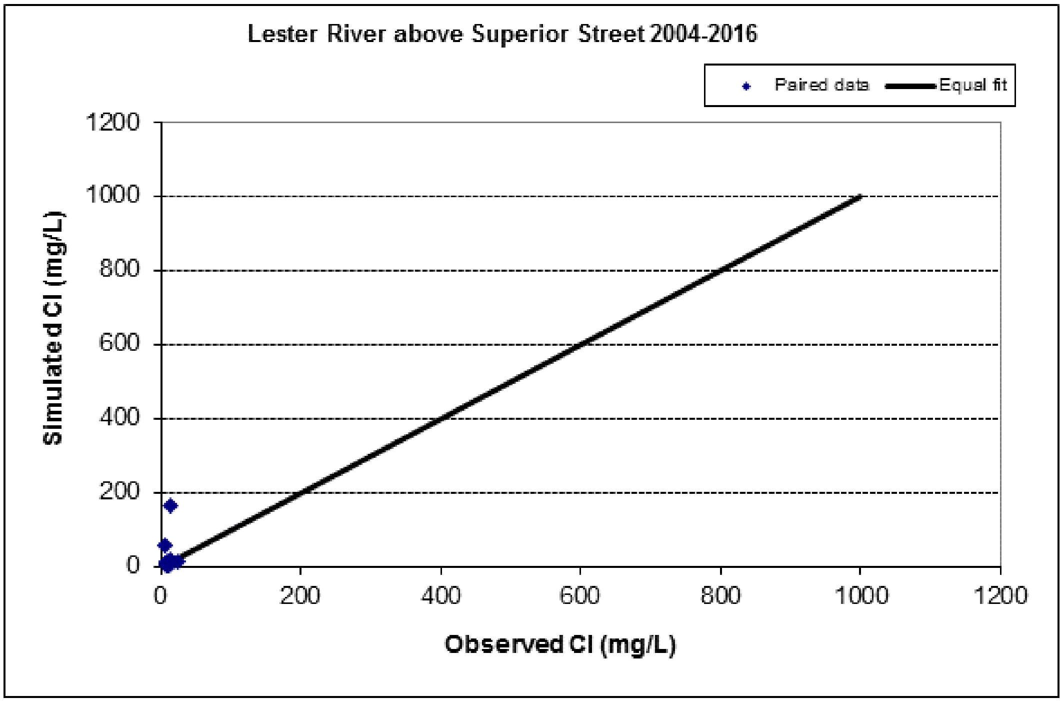


Figure F-16. Paired Simulated vs Observed Cl Concentration at the Lester River above Superior Street (Calibration Period)

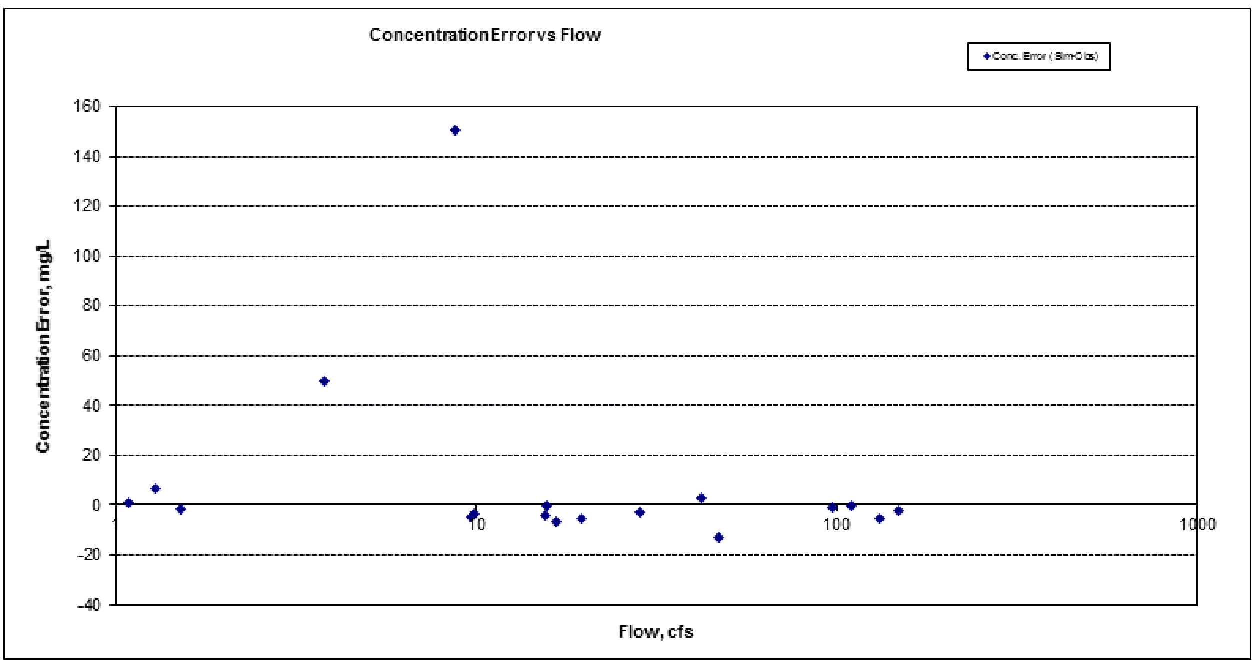


Figure F-17. Cl Concentration Error vs Flow at the Lester River above Superior Street

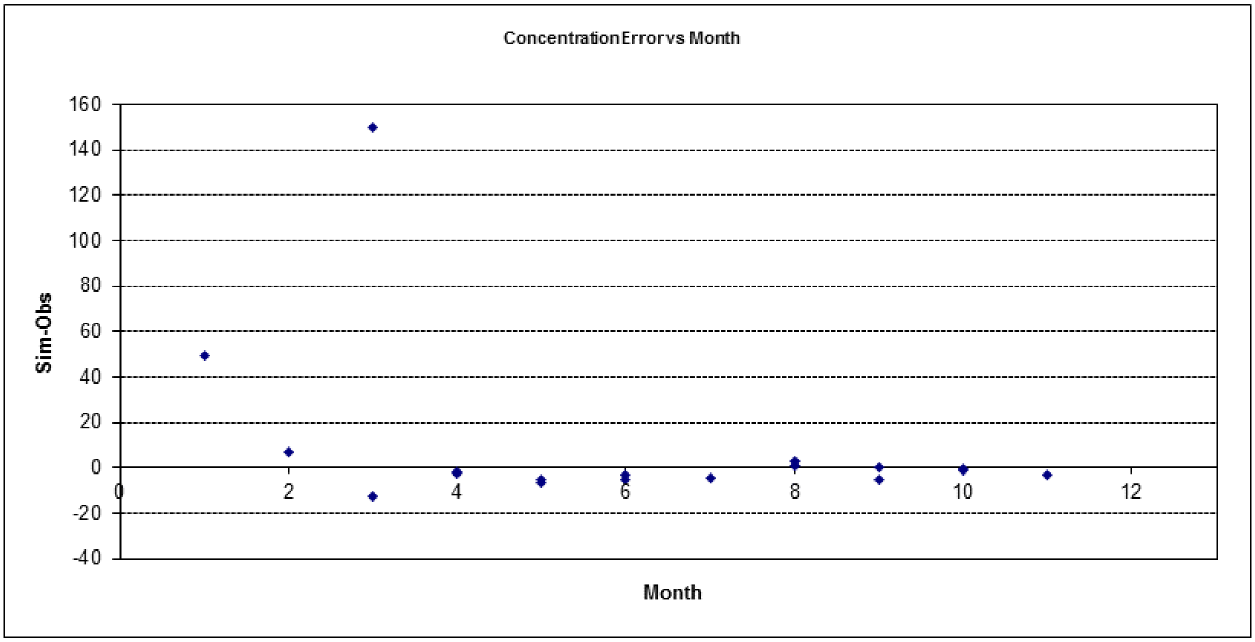


Figure F-18. Cl Concentration Error vs Month at the Lester River above Superior Street

F.3 EAST BR AMITY CR ABOVE CONFLUENCE WITH AMITY CR

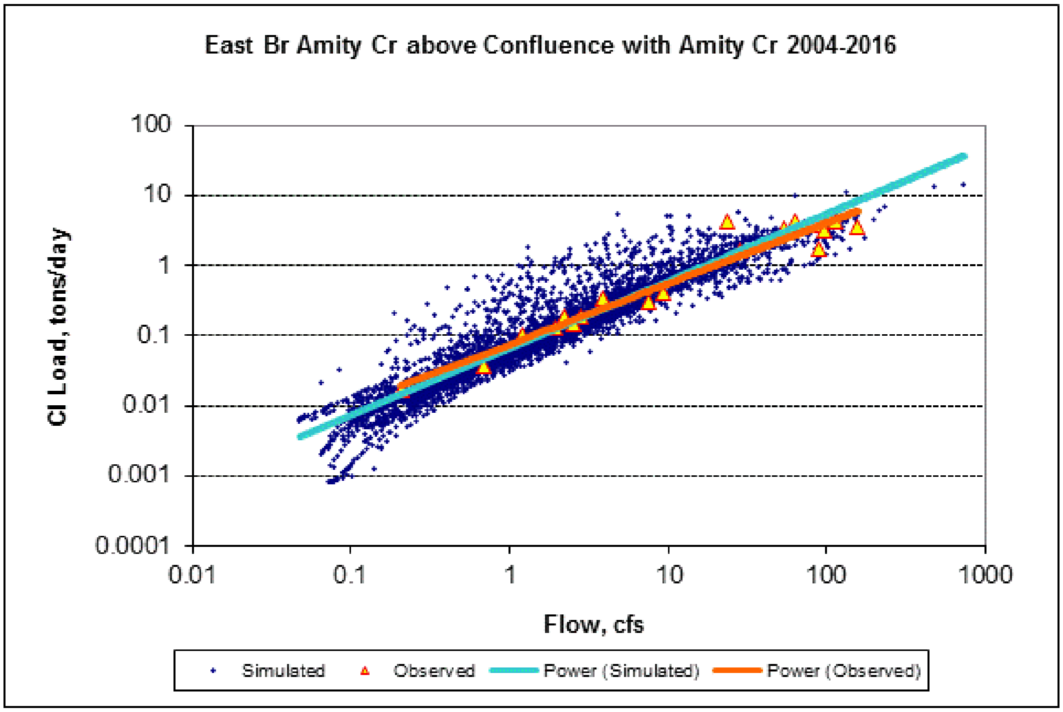


Figure F-19. Power Plot of Simulated and Observed Cl Load vs Flow at the East Br Amity Cr above Confluence with Amity Cr (Calibration Period)

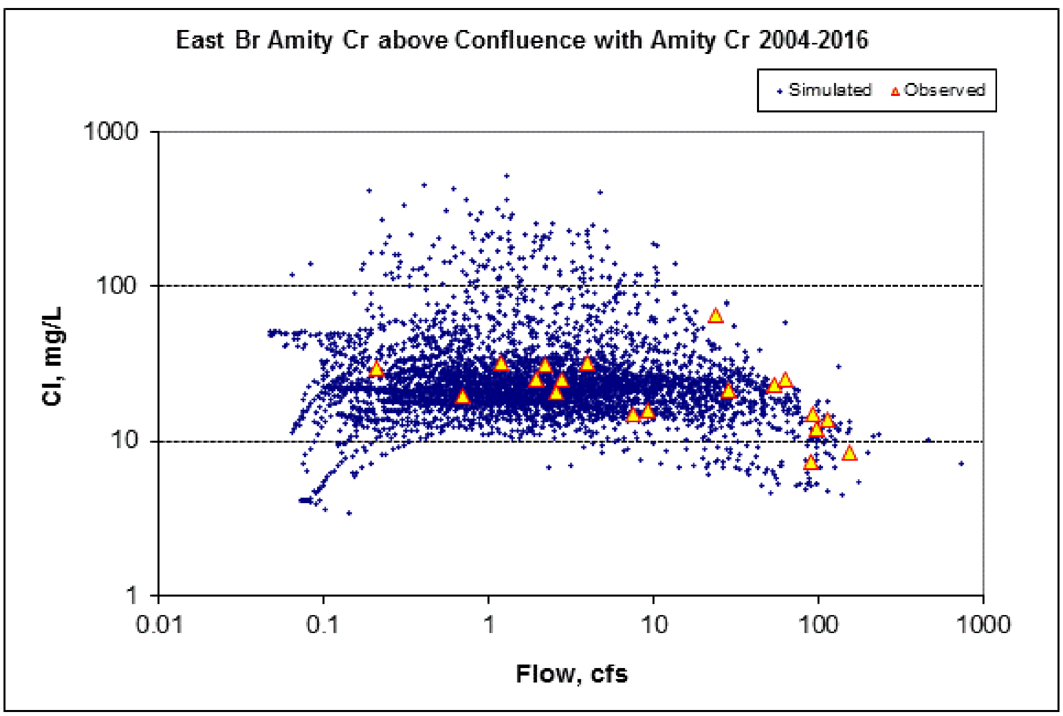


Figure F-20. Simulated and Observed Cl Concentration vs Flow Plot at the East Br Amity Cr above Confluence with Amity Cr (Calibration Period)

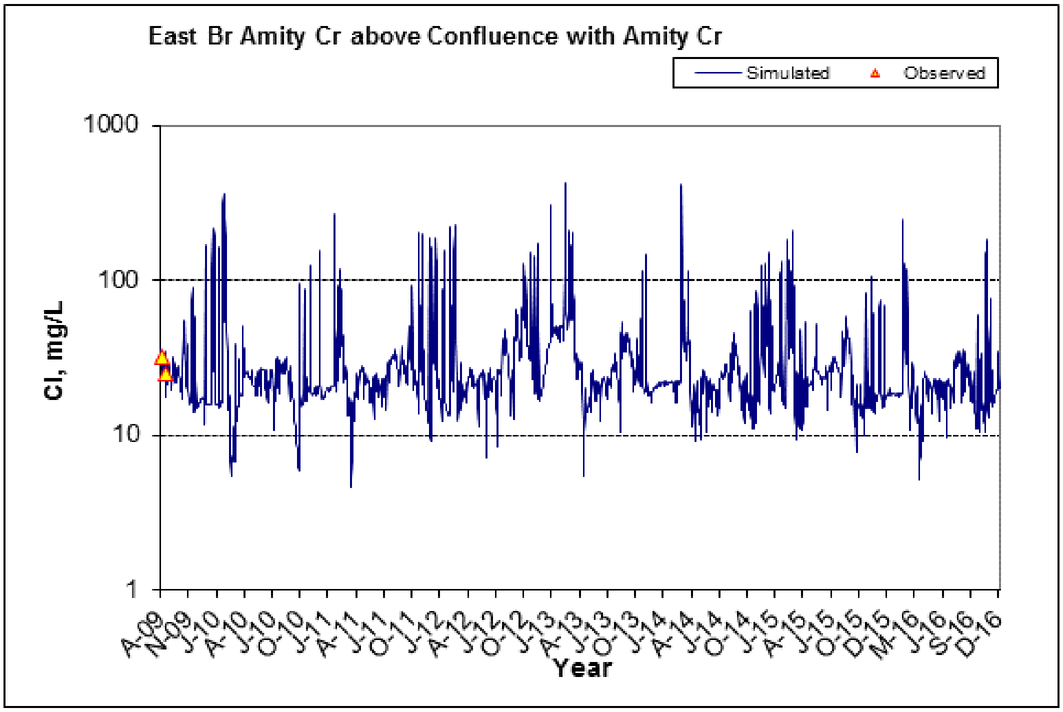


Figure F-21. Cl Concentration Time Series at the East Br Amity Cr above Confluence with Amity Cr (2008-2015)

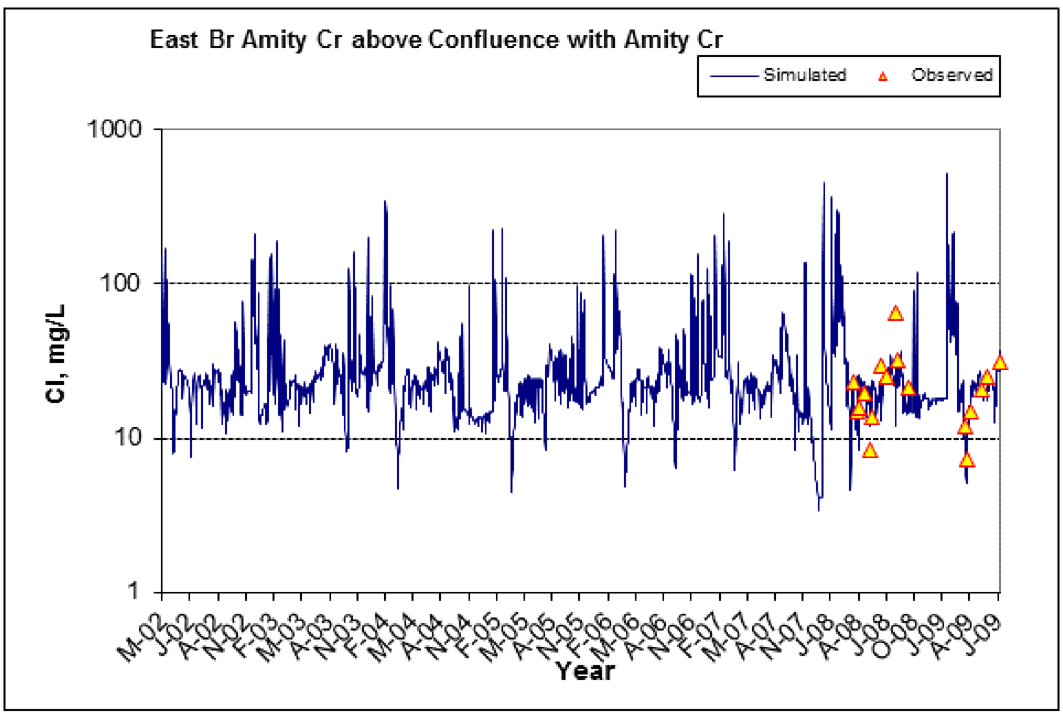


Figure F-22. Cl Concentration Time Series at the East Br Amity Cr above Confluence with Amity Cr (2001-2008)

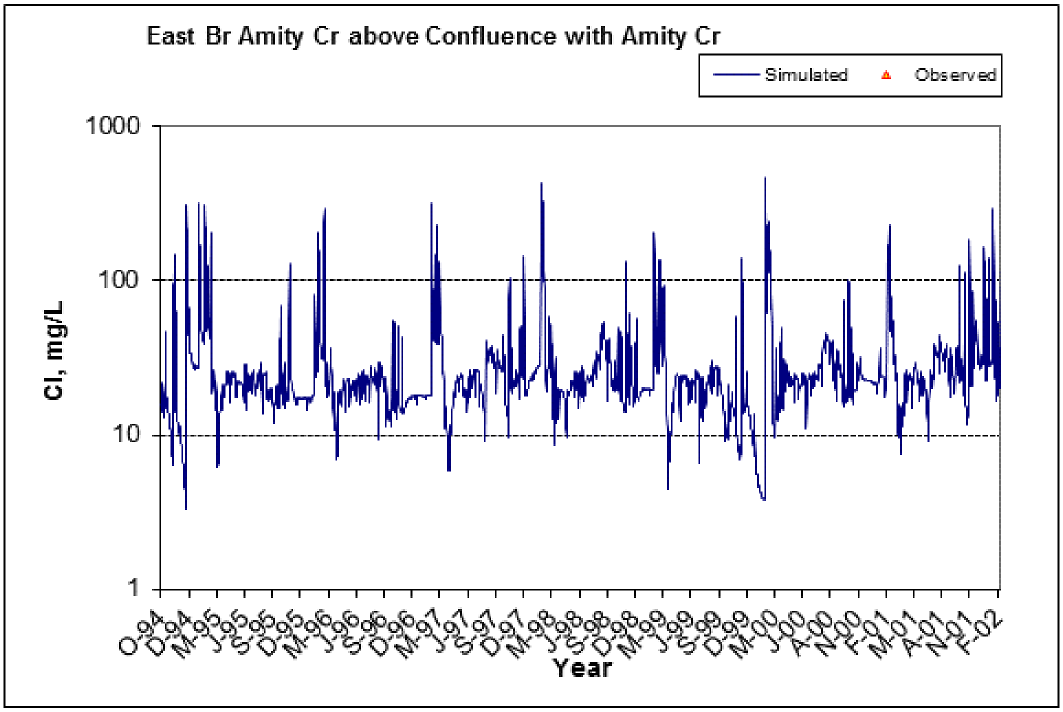


Figure F-23. Cl Concentration Time Series at the East Br Amity Cr above Confluence with Amity Cr (1994-2001)

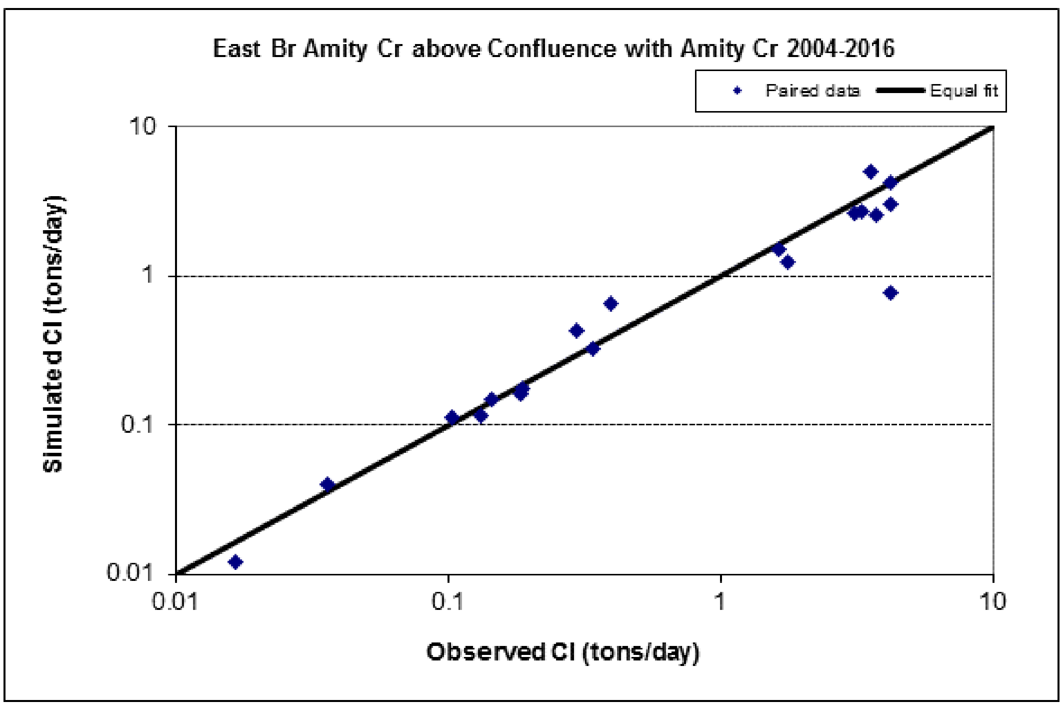


Figure F-24. Paired Simulated vs Observed Cl Load at the East Br Amity Cr above Confluence with Amity Cr (Calibration Period)

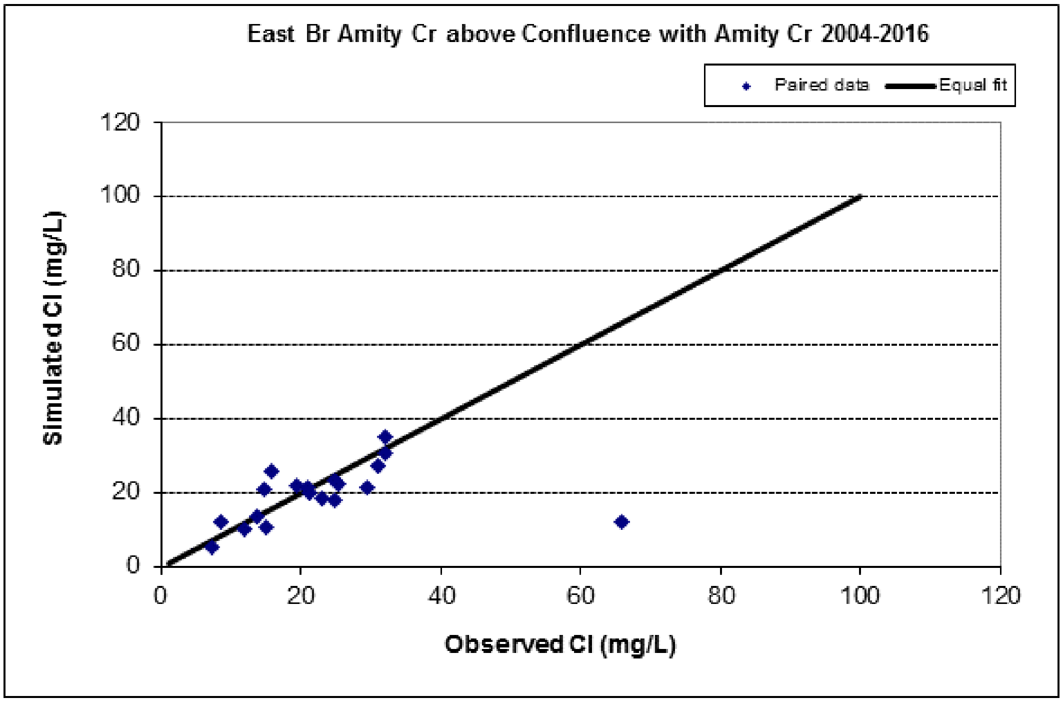


Figure F-25. Paired Simulated vs Observed Cl Concentration at the East Br Amity Cr above Confluence with Amity Cr (Calibration Period)

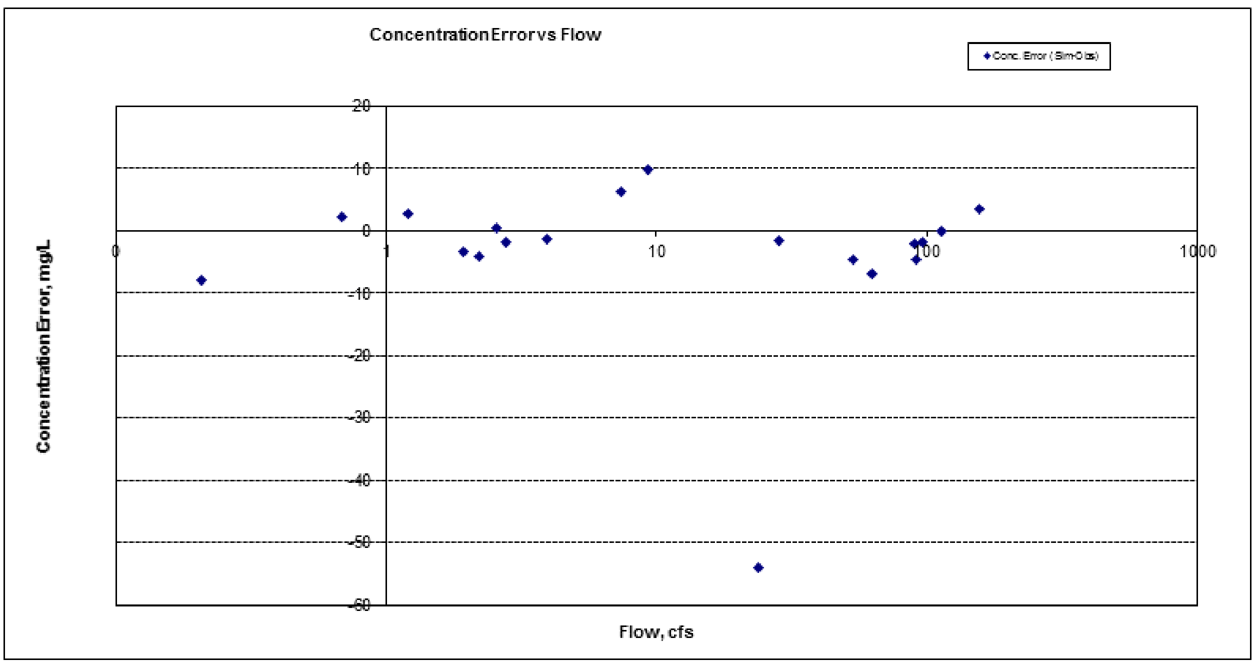


Figure F-26. Cl Concentration Error vs Flow at the East Br Amity Cr above Confluence with Amity Cr

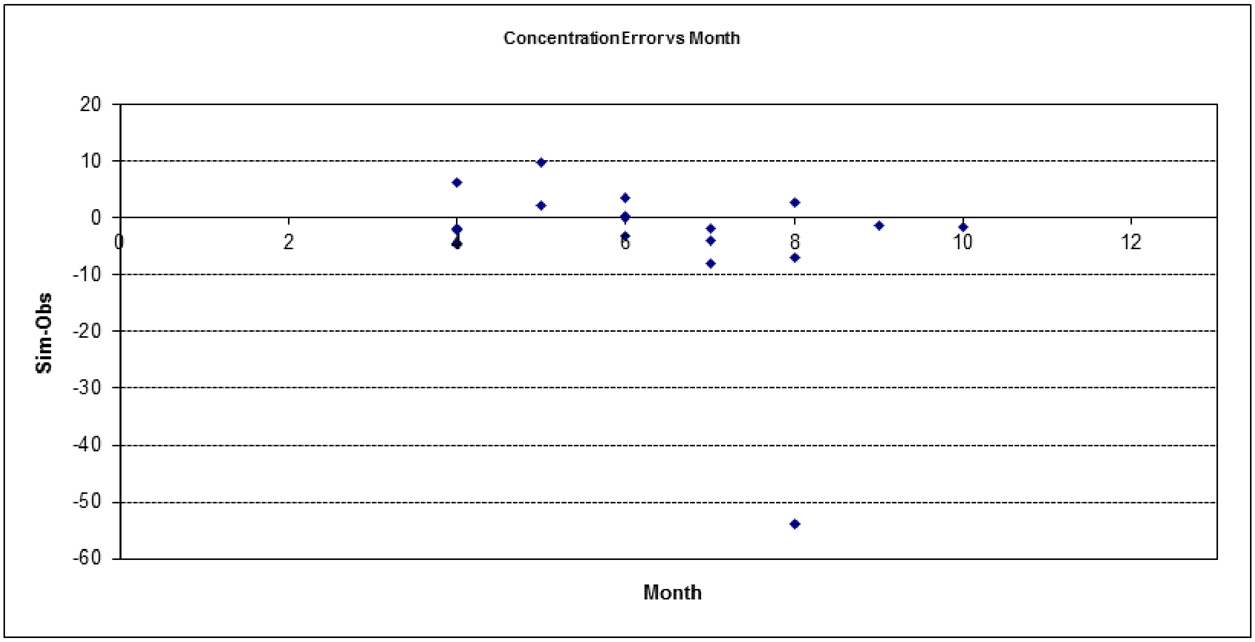


Figure F-27. Cl Concentration Error vs Month at the East Br Amity Cr above Confluence with Amity Cr

F.4 Amity Creek west of Skyline Pkway

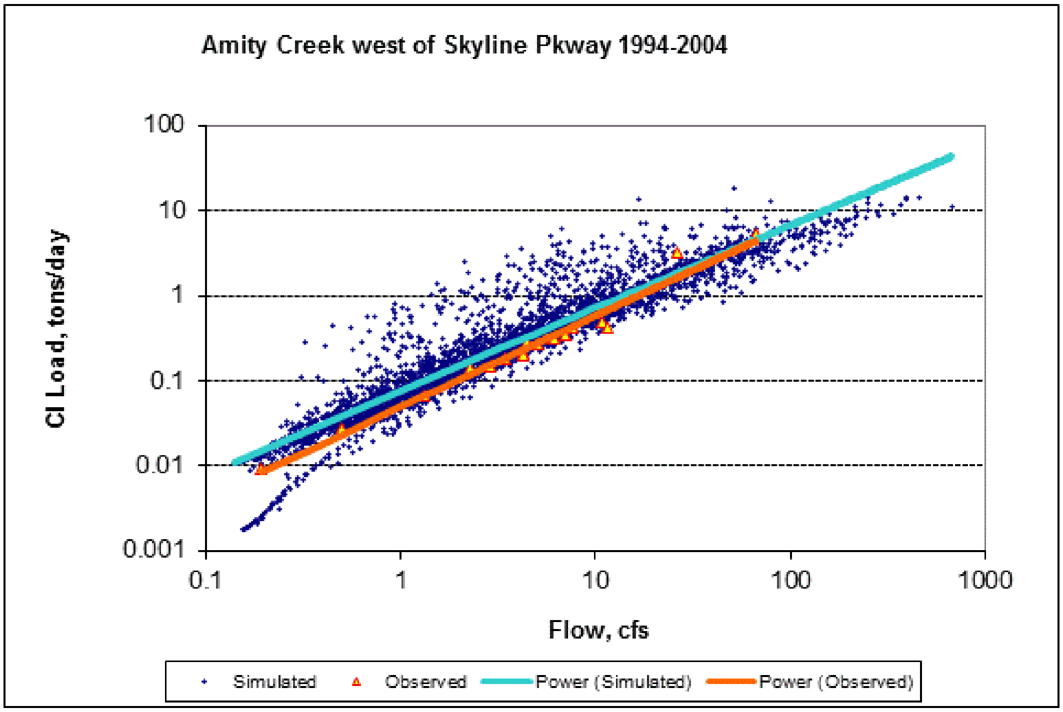


Figure F-28. Power Plot of Simulated and Observed Cl Load vs Flow at the Amity Creek west of Skyline Pkway (Validation Period)

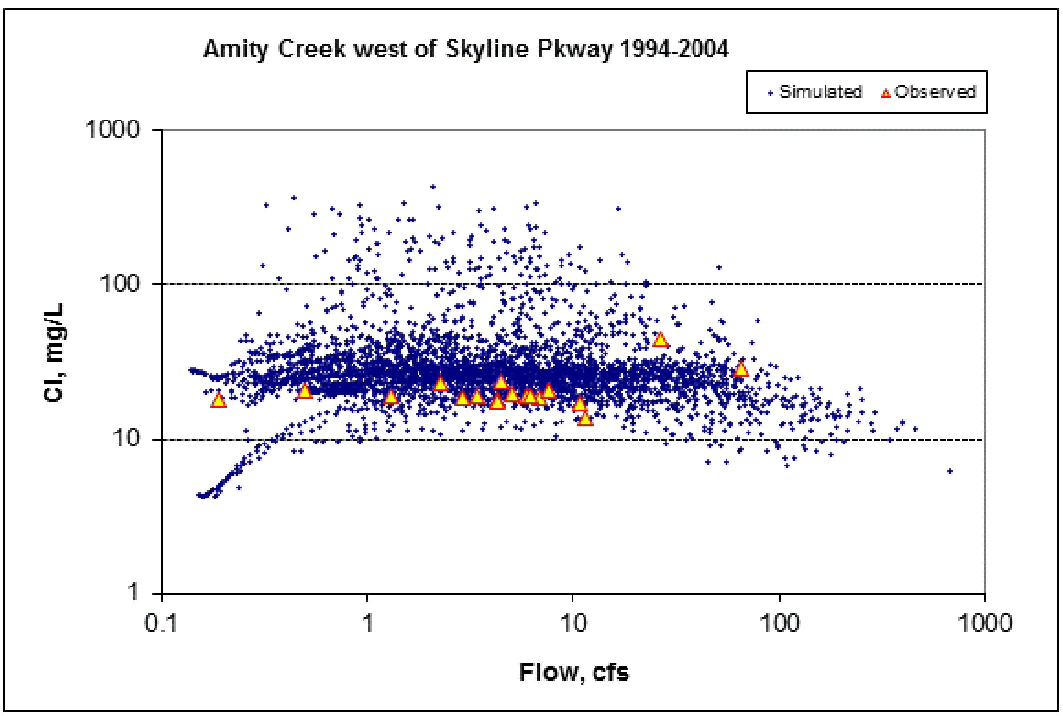


Figure F-29. Simulated and Observed Cl Concentration vs Flow Plot at the Amity Creek west of Skyline Pkway (Validation Period)

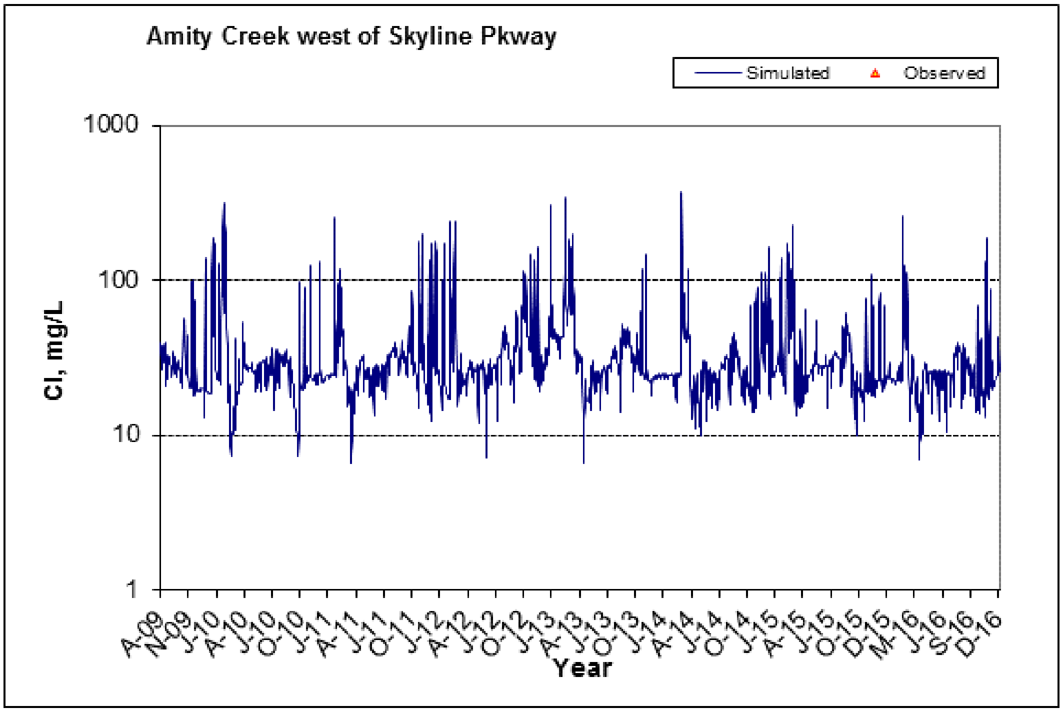


Figure F-30. Cl Concentration Time Series at the Amity Creek west of Skyline Pkway (2008-2015)

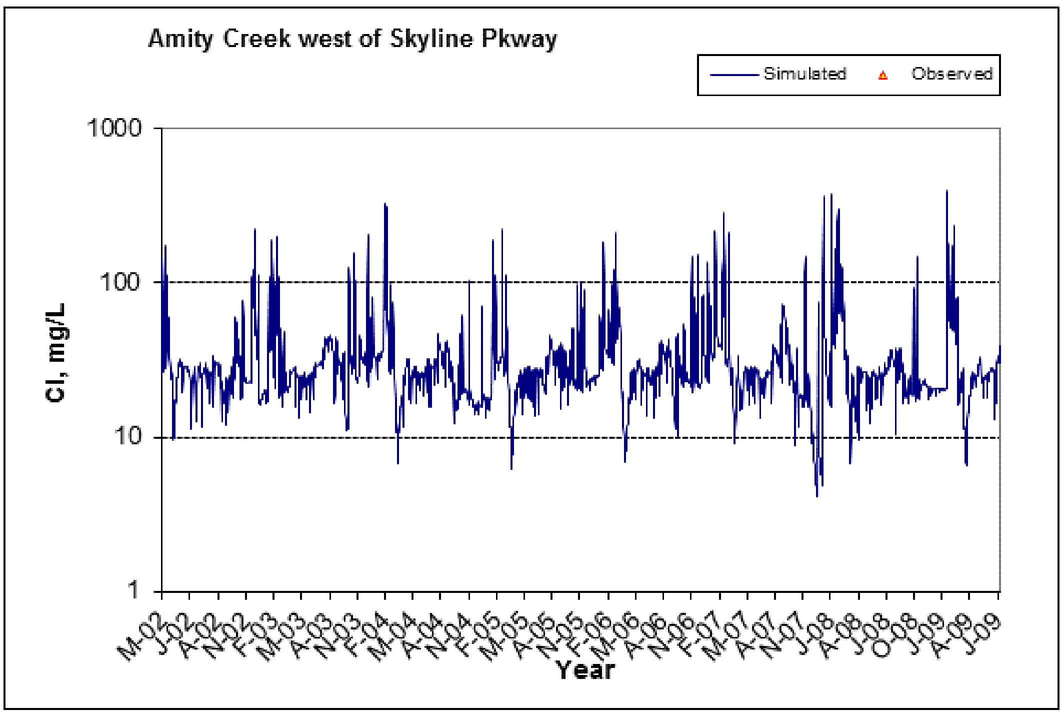


Figure F-31. Cl Concentration Time Series at the Amity Creek west of Skyline Pkway (2001-2008)

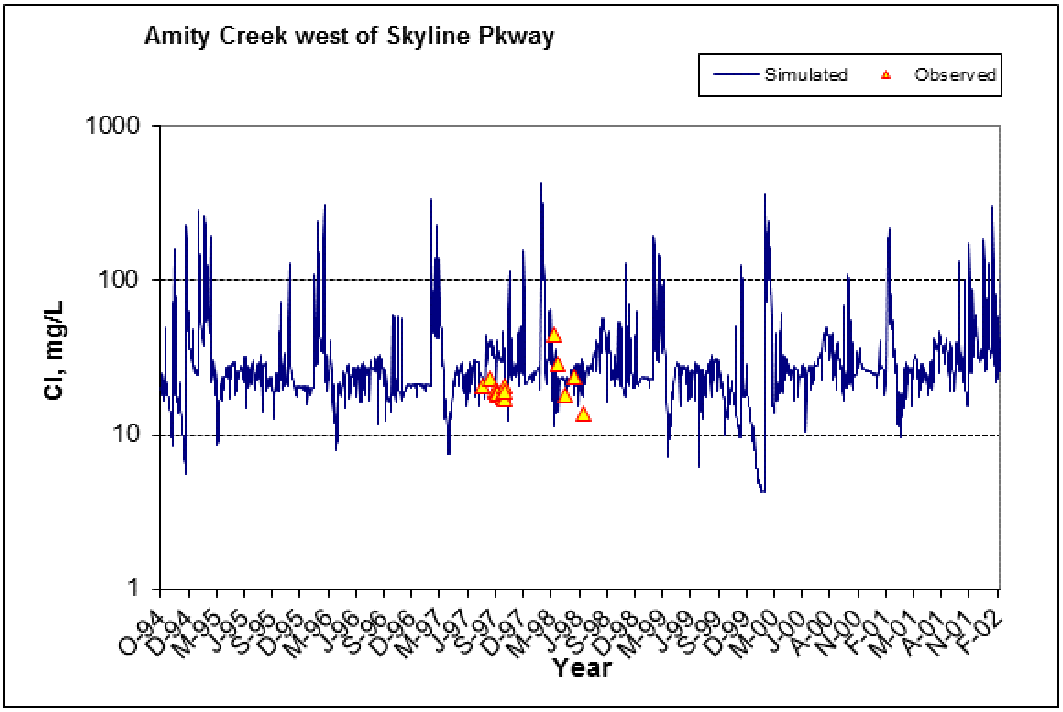


Figure F-32. Cl Concentration Time Series at the Amity Creek west of Skyline Pkway (1994-2001)

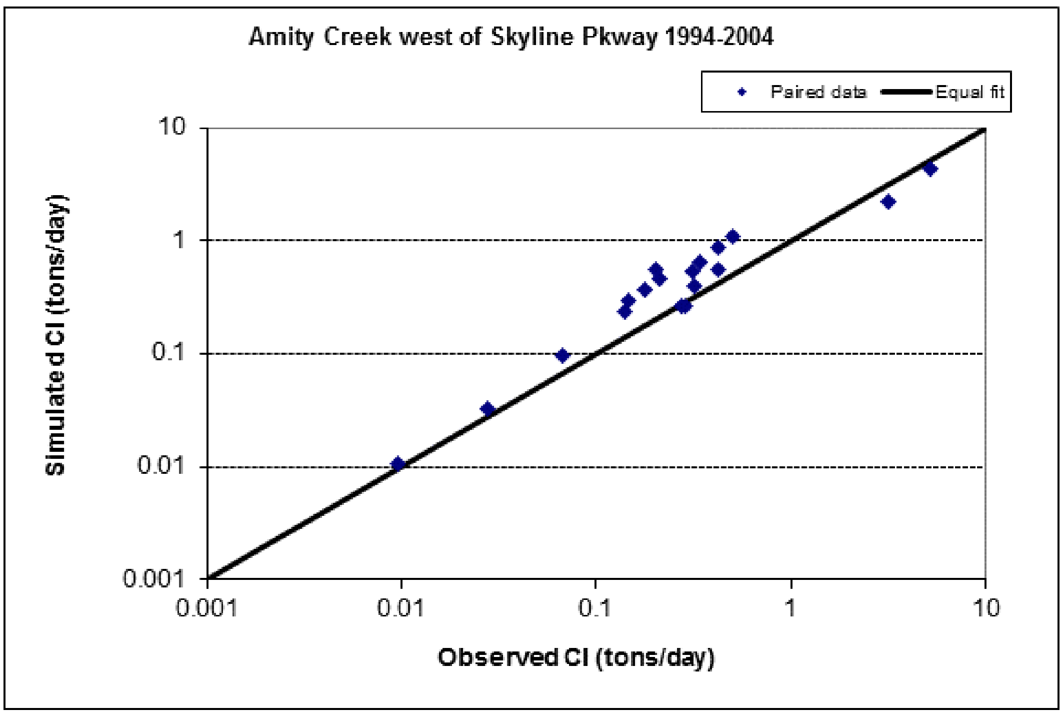


Figure F-33. Paired Simulated vs Observed Cl Load at the Amity Creek west of Skyline Pkway (Validation Period)

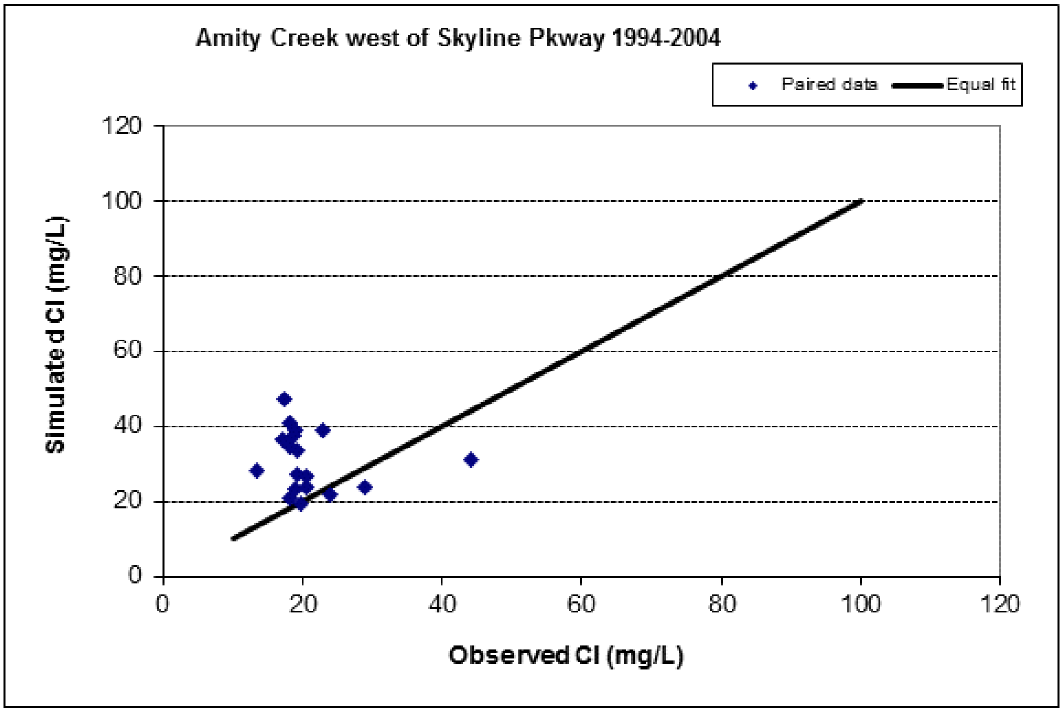


Figure F-34. Paired Simulated vs Observed Cl Concentration at the Amity Creek west of Skyline Pkway (Validation Period)

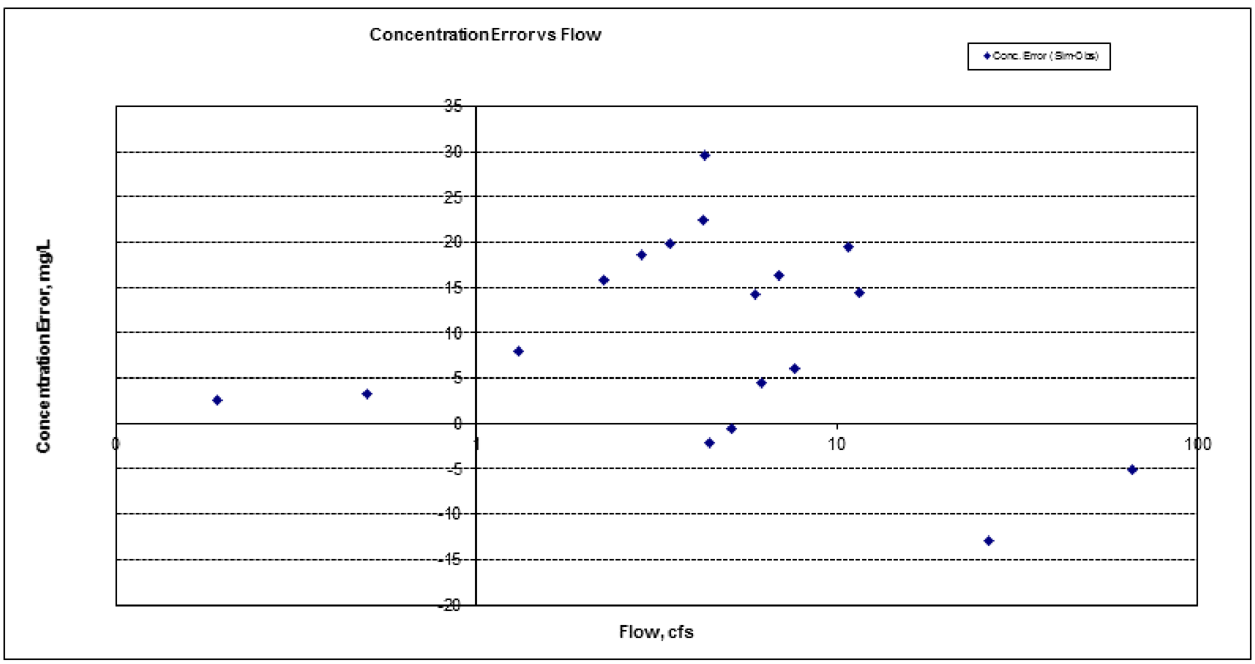


Figure F-35. Cl Concentration Error vs Flow at the Amity Creek west of Skyline Pkway

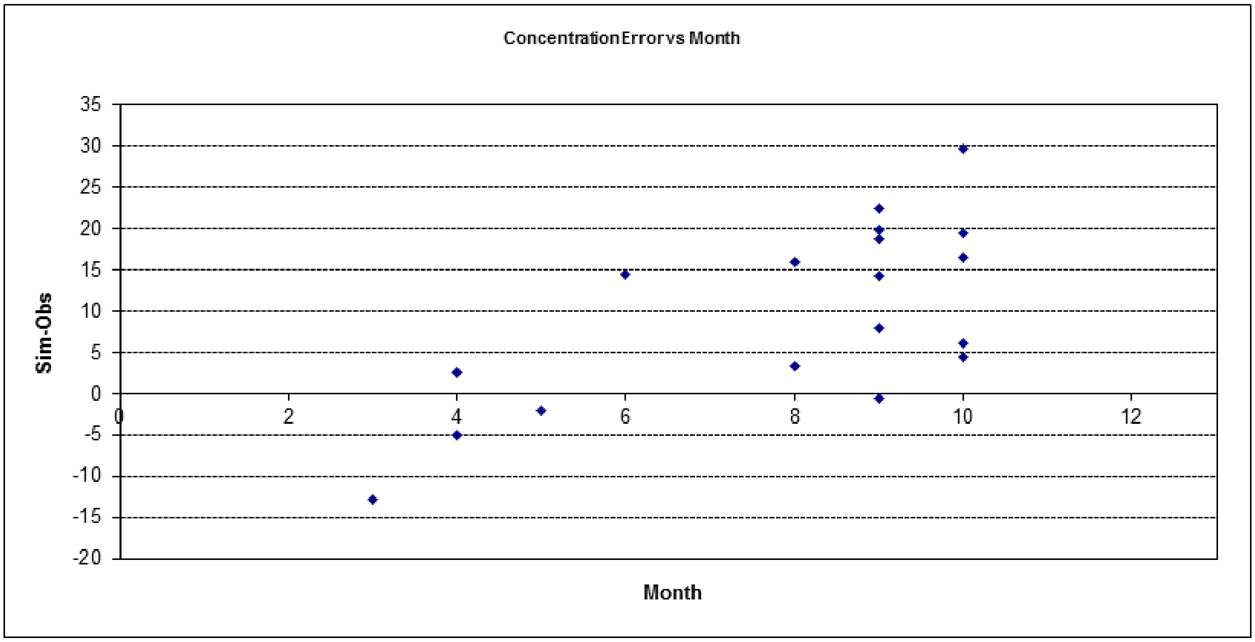


Figure F-36. Cl Concentration Error vs Month at the Amity Creek west of Skyline Pkway

F.5 AMITY CREEK AT OCCIDENTAL BLVD, DULUTH - DISCRETE

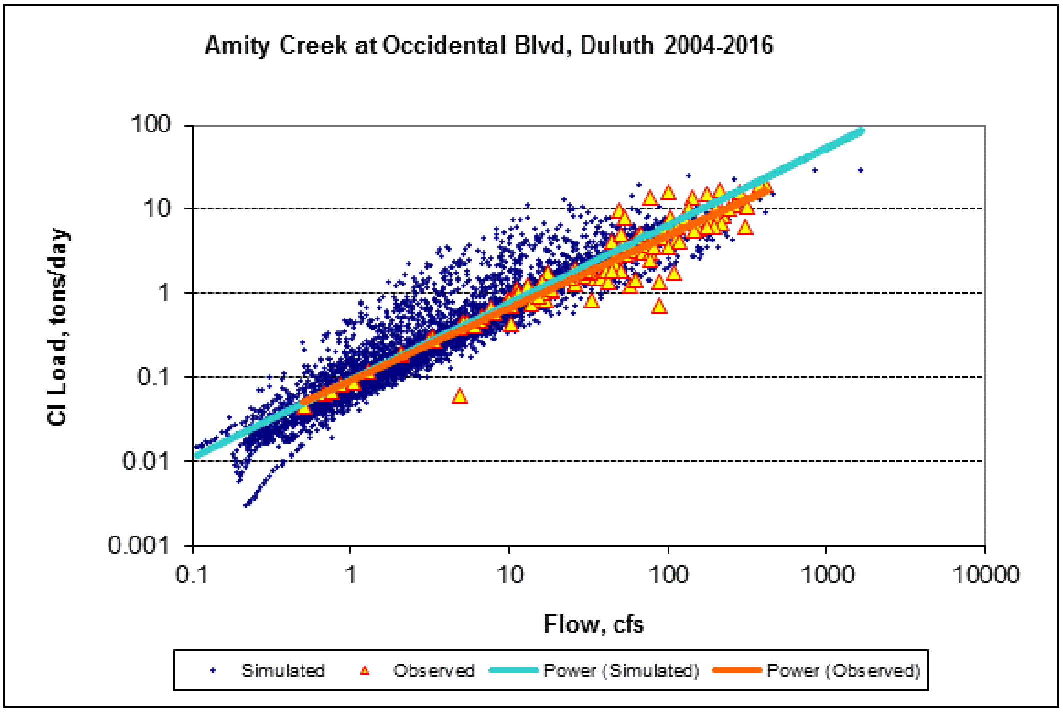


Figure F-37. Power Plot of Simulated and Observed Cl Load vs Flow at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

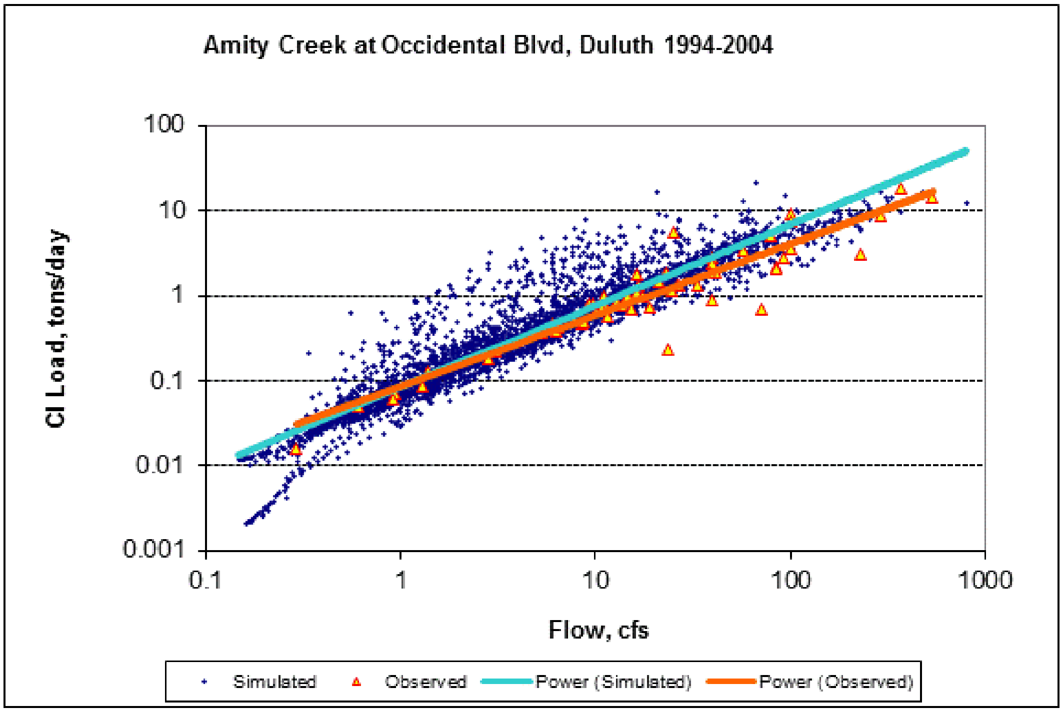


Figure F-38. Power Plot of Simulated and Observed Cl Load vs Flow at the Amity Creek at Occidental Blvd, Duluth (Validation Period)

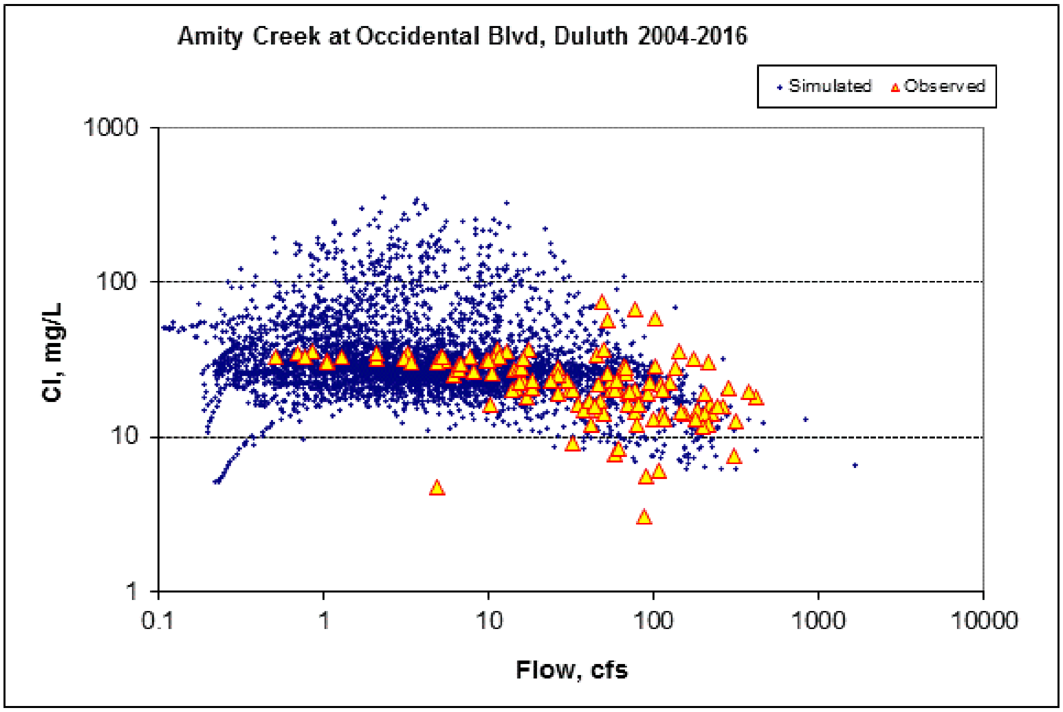


Figure F-39. Simulated and Observed Cl Concentration vs Flow Plot at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

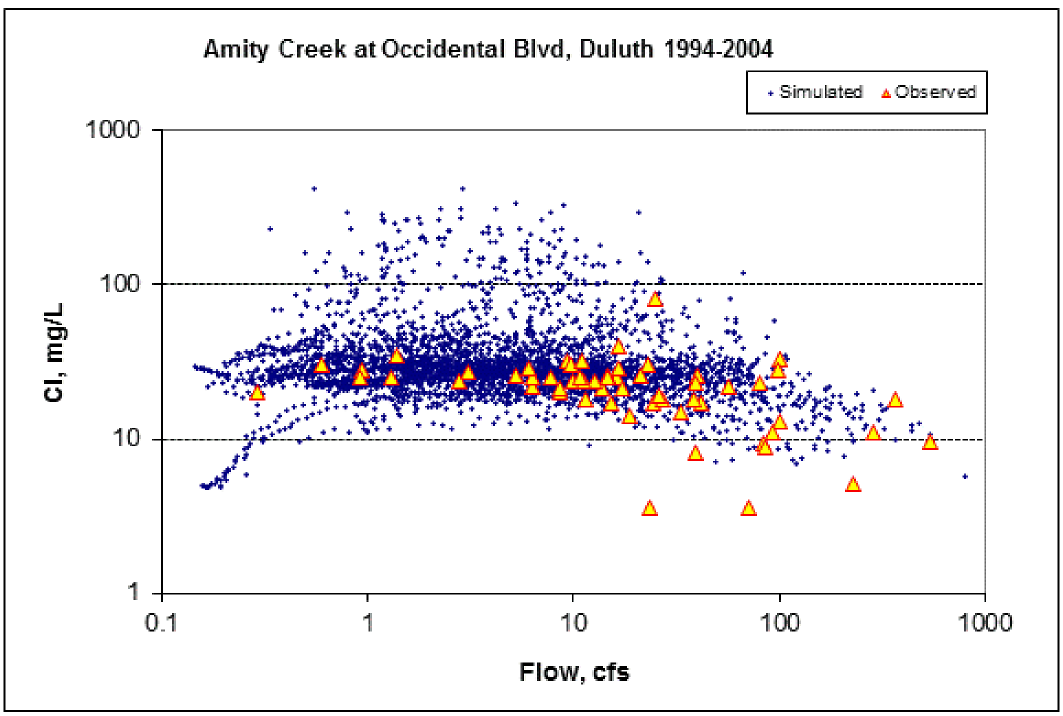


Figure F-40. Simulated and Observed Cl Concentration vs Flow Plot at the Amity Creek at Occidental Blvd, Duluth (Validation Period)

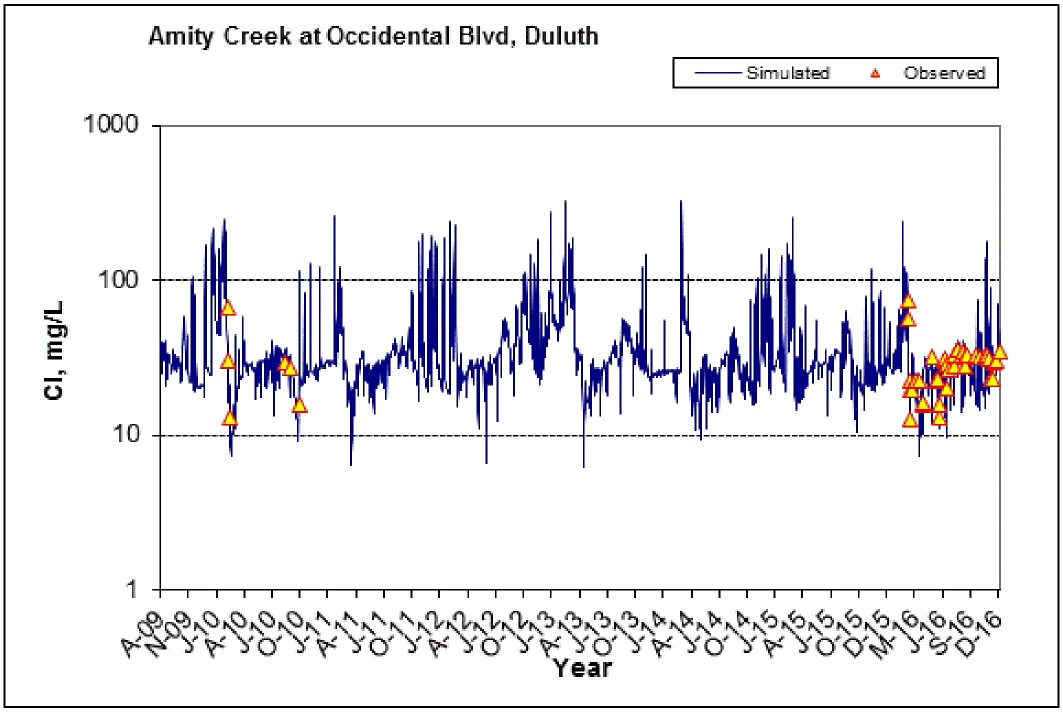


Figure F-41. Cl Concentration Time Series at the Amity Creek at Occidental Blvd, Duluth (2008-2015)

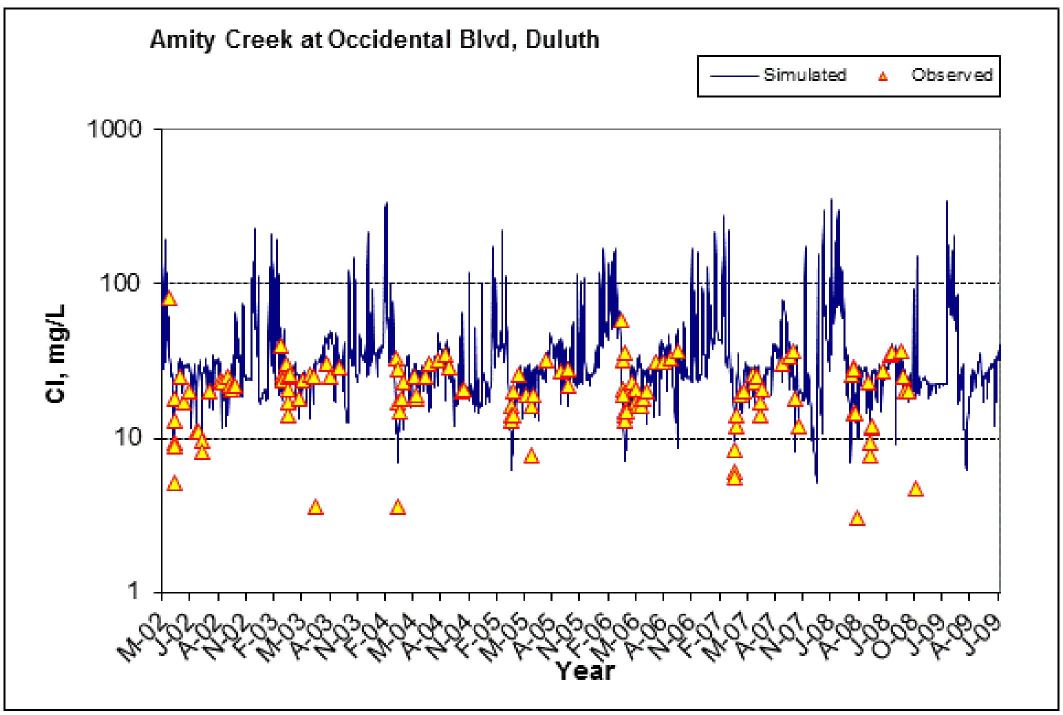


Figure F-42. Cl Concentration Time Series at the Amity Creek at Occidental Blvd, Duluth (2001-2008)

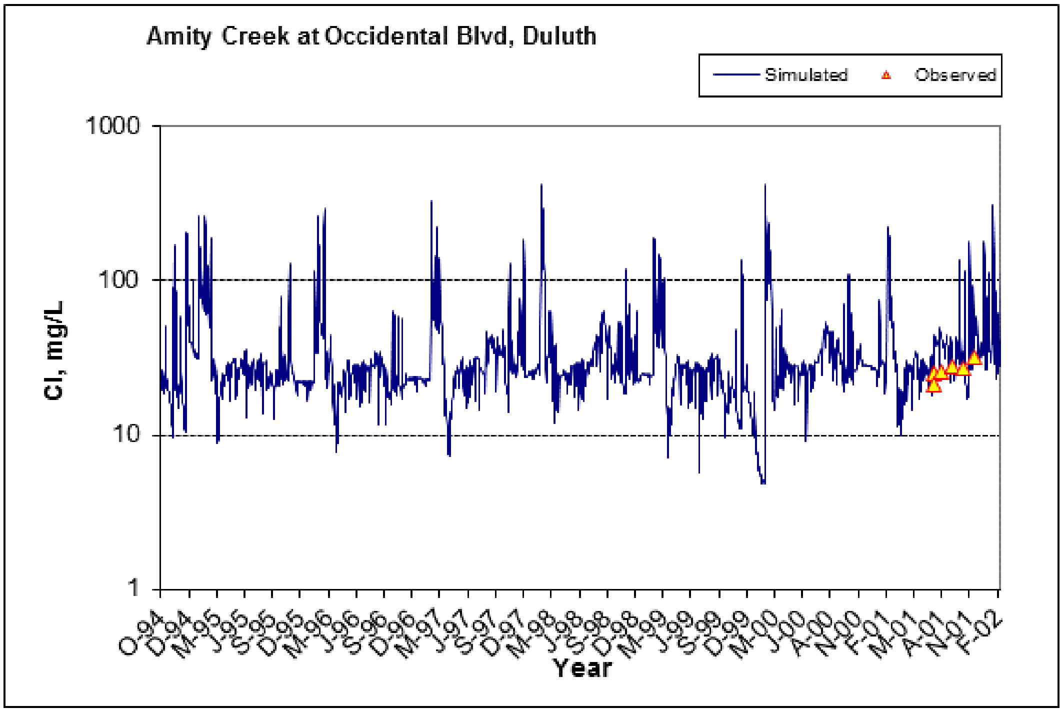


Figure F-43. Cl Concentration Time Series at the Amity Creek at Occidental Blvd, Duluth (1994-2001)

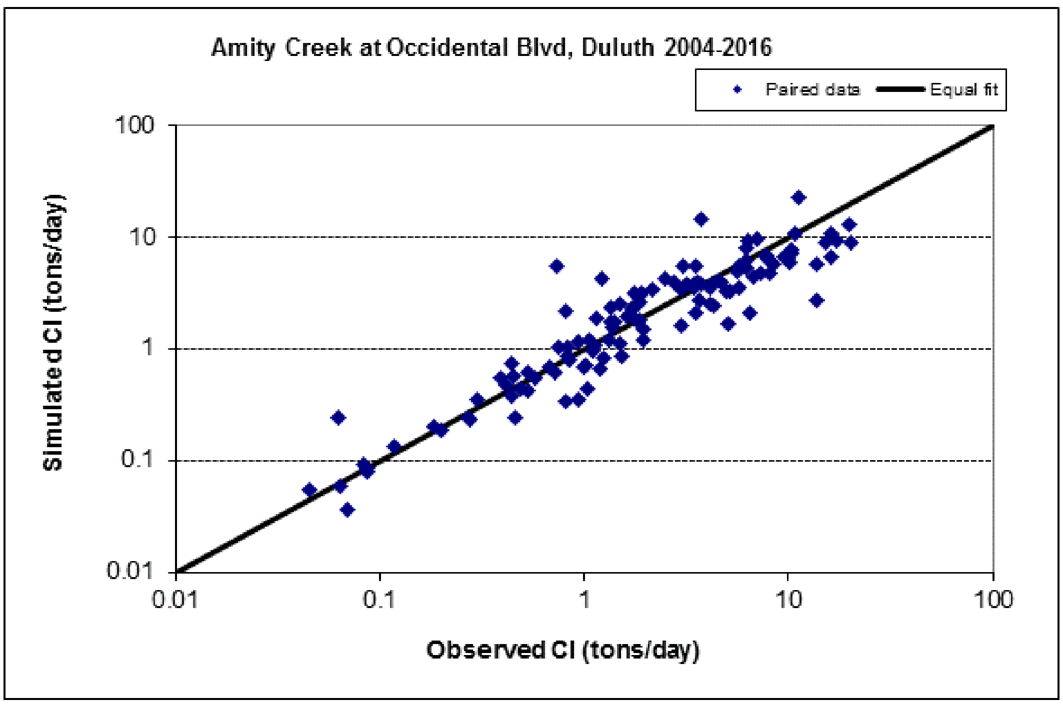


Figure F-44. Paired Simulated vs Observed Cl Load at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

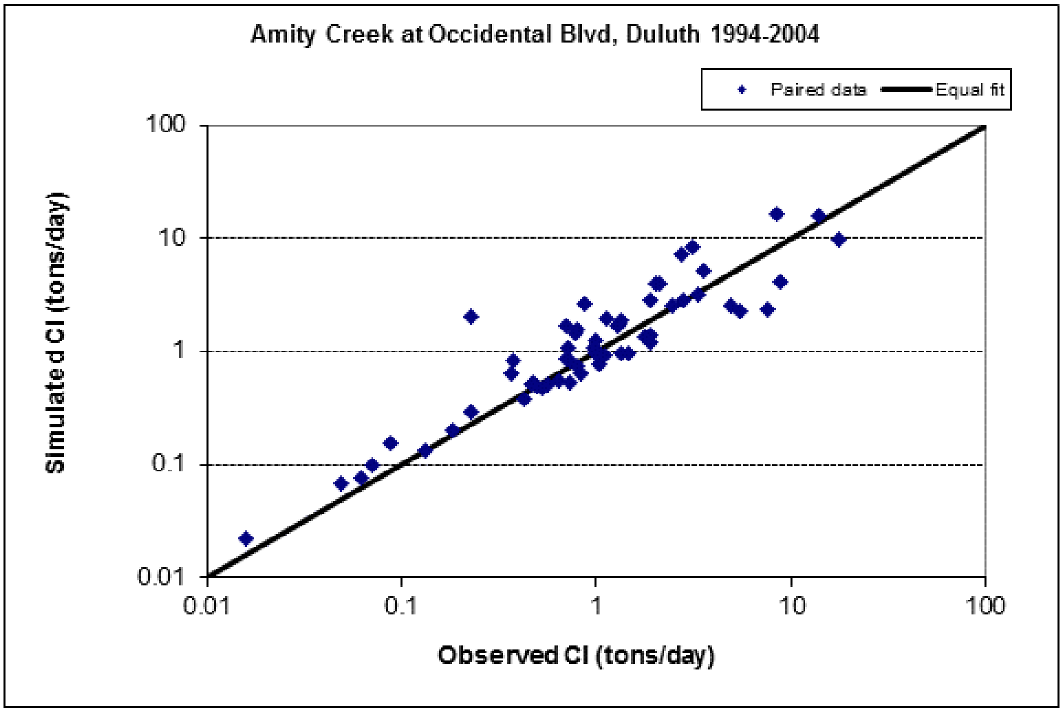


Figure F-45. Paired Simulated vs Observed Cl Load at the Amity Creek at Occidental Blvd, Duluth (Validation Period)

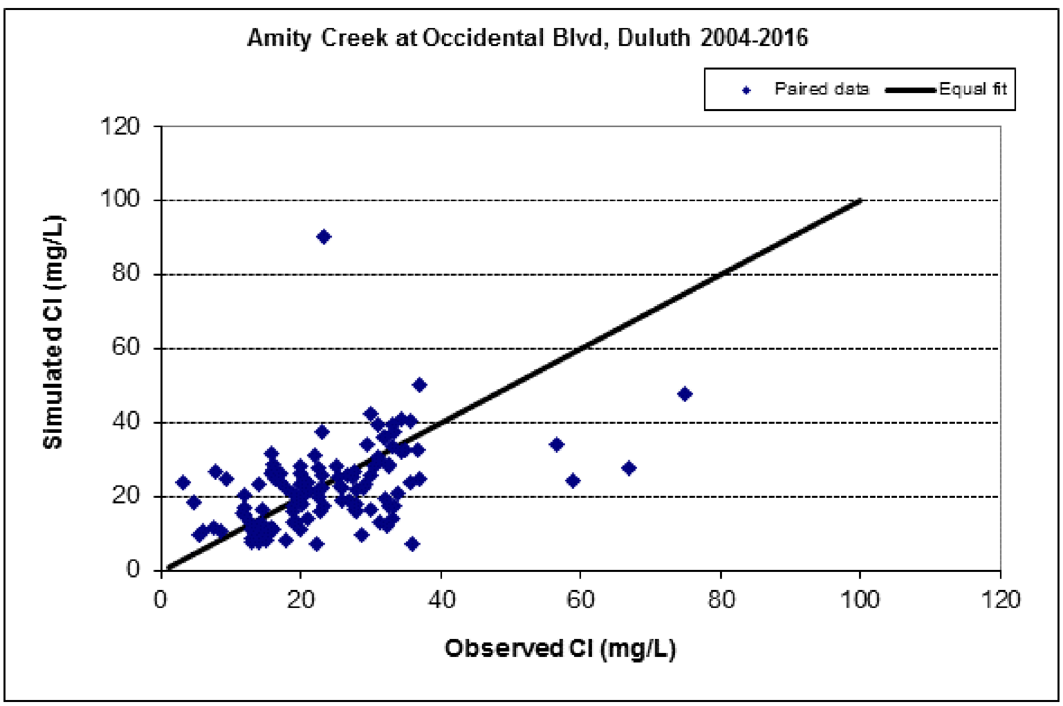


Figure F-46. Paired Simulated vs Observed Cl Concentration at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

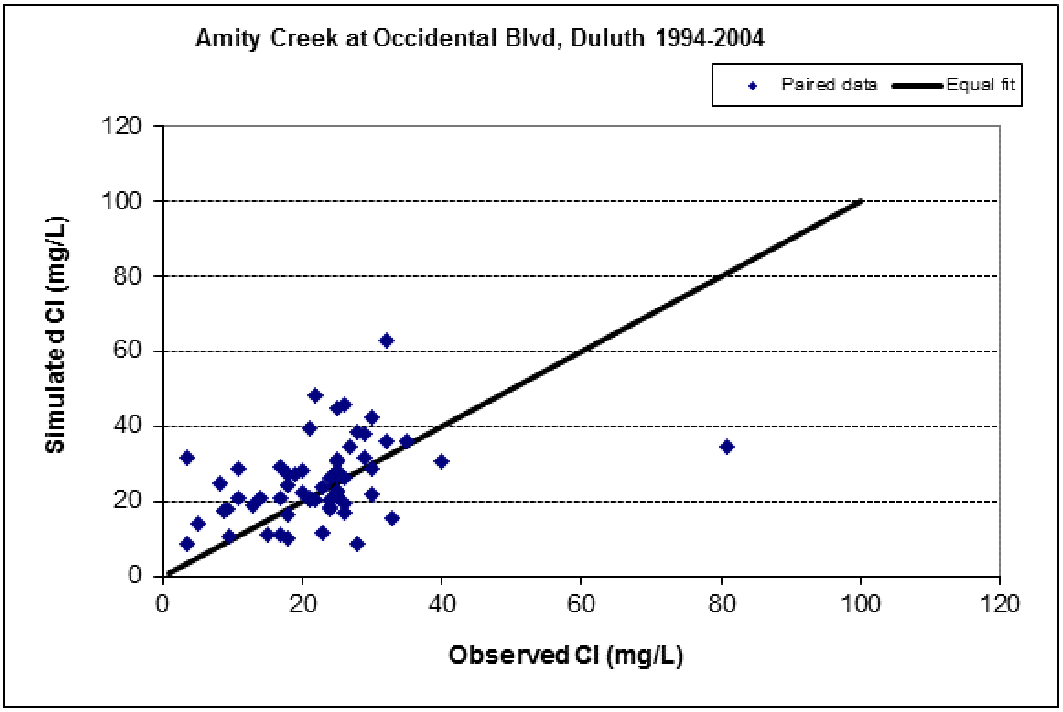


Figure F-47. Paired Simulated vs Observed Cl Concentration at the Amity Creek at Occidental Blvd, Duluth (Validation Period)

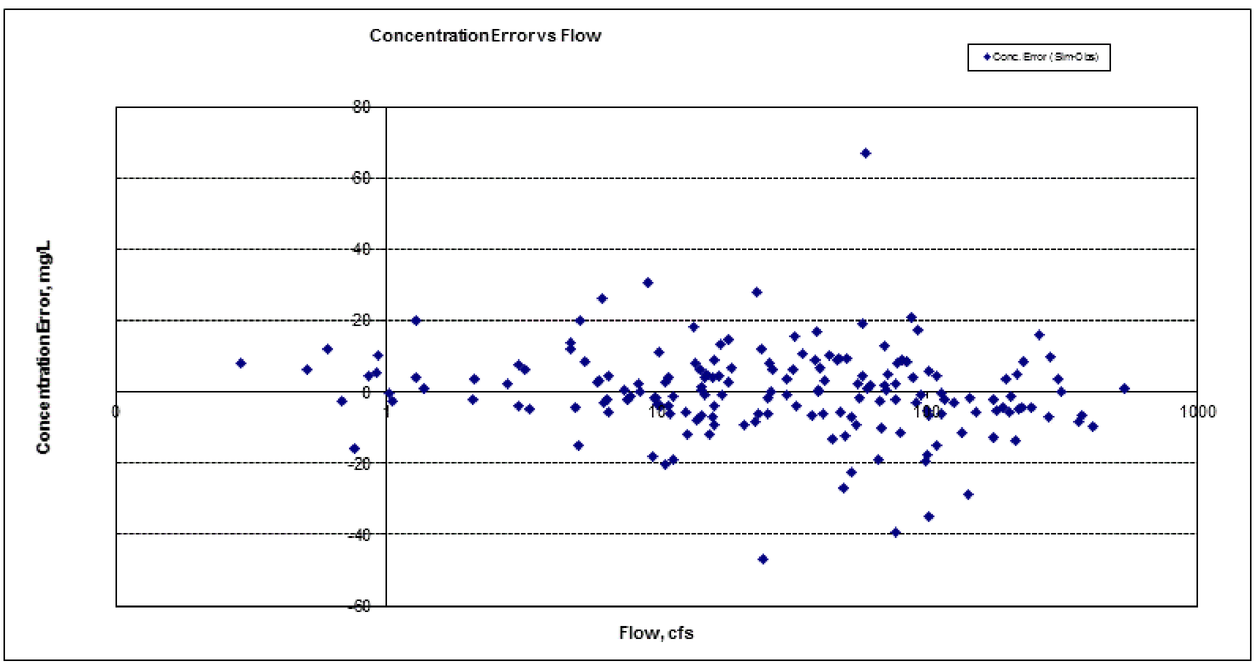


Figure F-48. Cl Concentration Error vs Flow at the Amity Creek at Occidental Blvd, Duluth

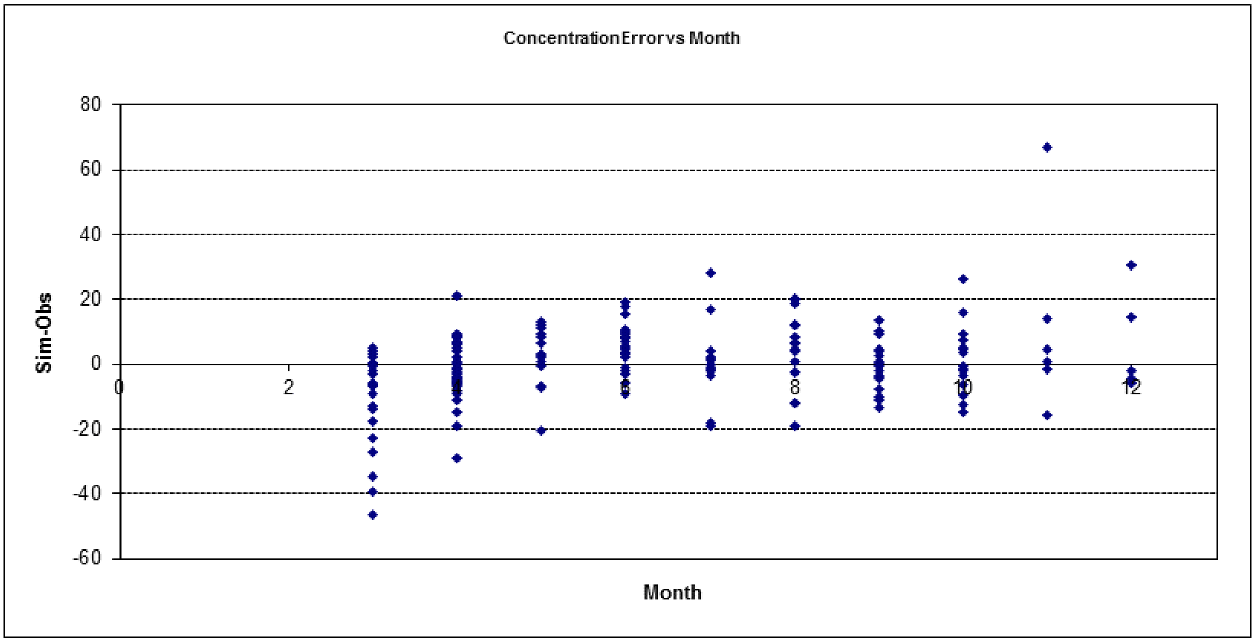


Figure F-49. Cl Concentration Error vs Month at the Amity Creek at Occidental Blvd, Duluth

F.6 Amity Creek at Occidental Blvd, Duluth - Continuous

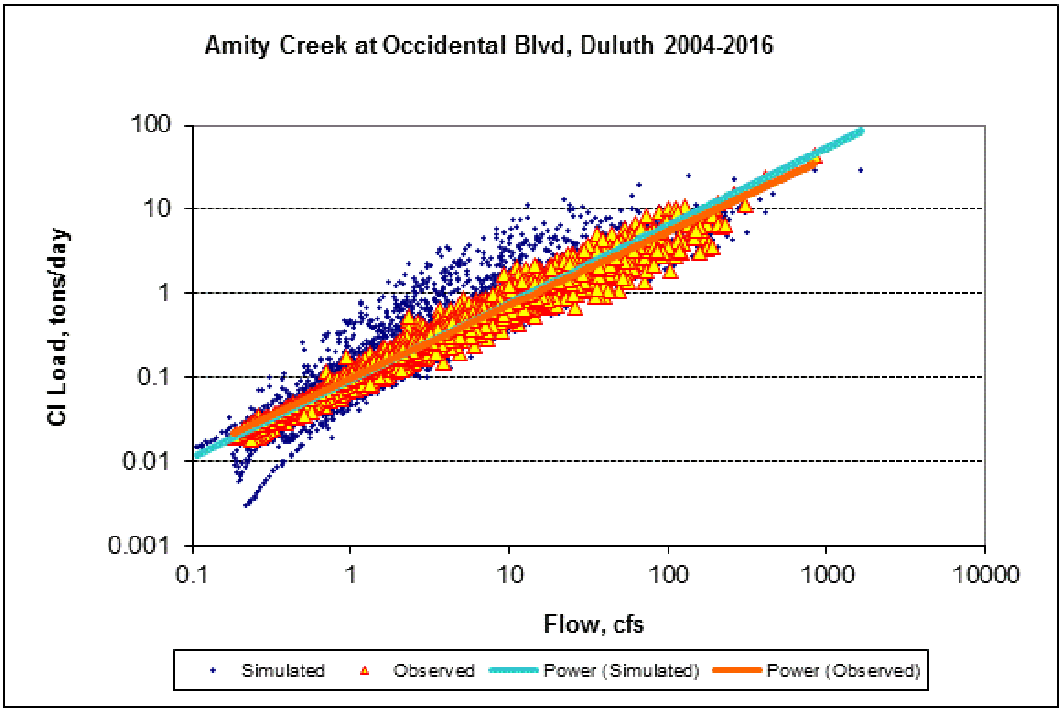


Figure F-50. Power Plot of Simulated and Observed Cl Load vs Flow at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

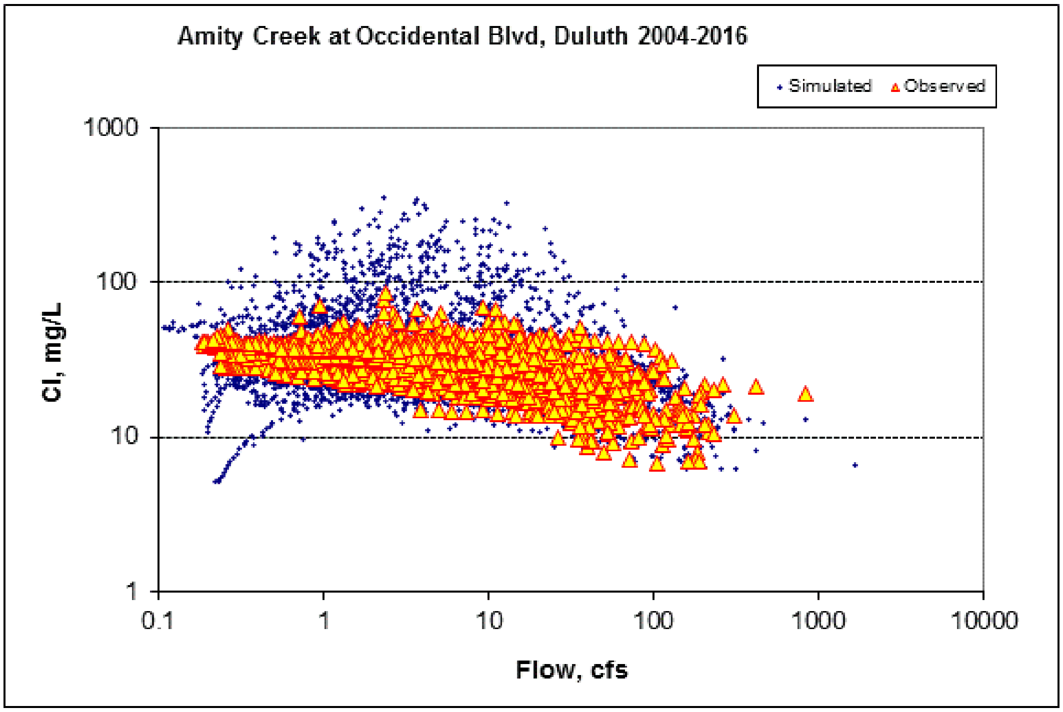


Figure F-51. Simulated and Observed Cl Concentration vs Flow Plot at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

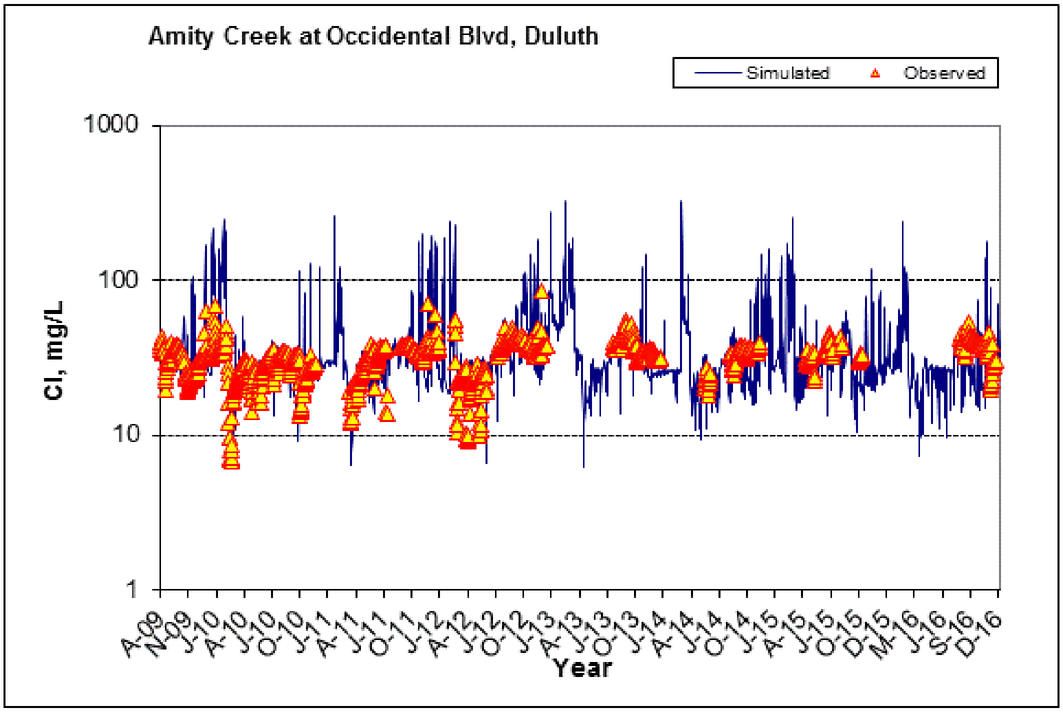


Figure F-52. Cl Concentration Time Series at the Amity Creek at Occidental Blvd, Duluth (2008-2015)

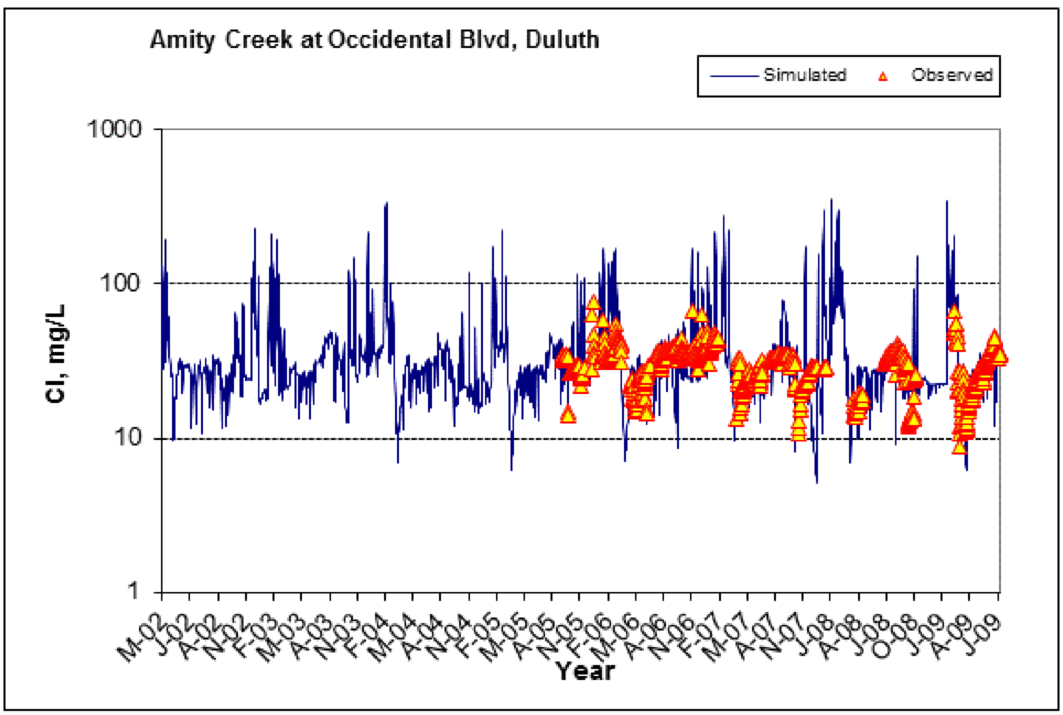


Figure F-53. Cl Concentration Time Series at the Amity Creek at Occidental Blvd, Duluth (2001-2008)

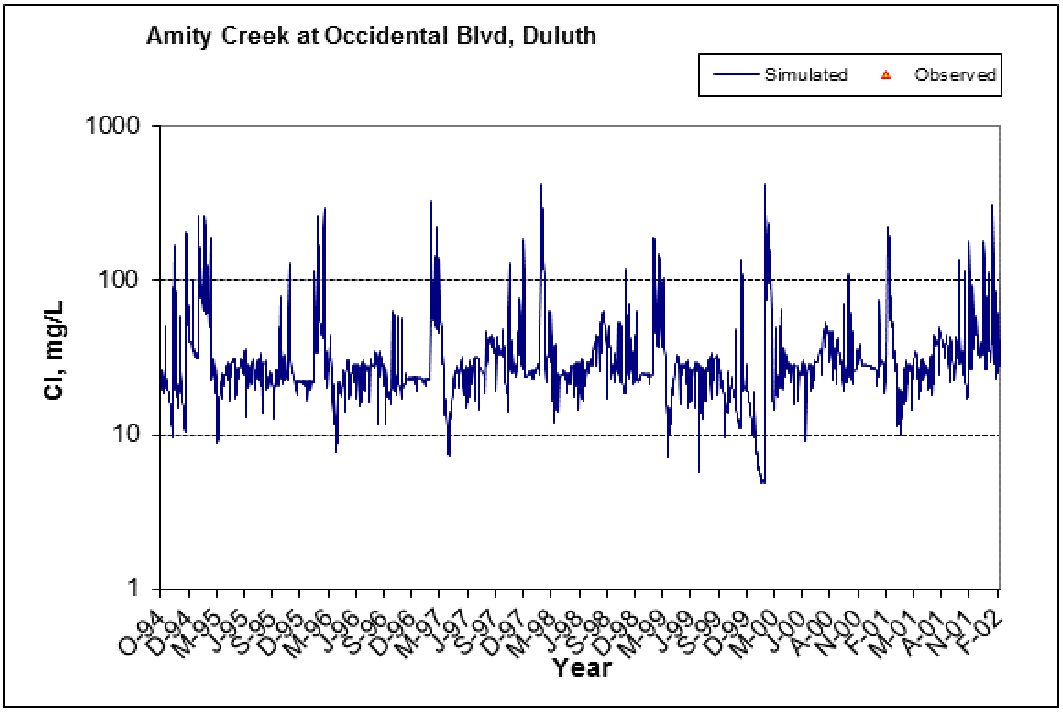


Figure F-54. Cl Concentration Time Series at the Amity Creek at Occidental Blvd, Duluth (1994-2001)

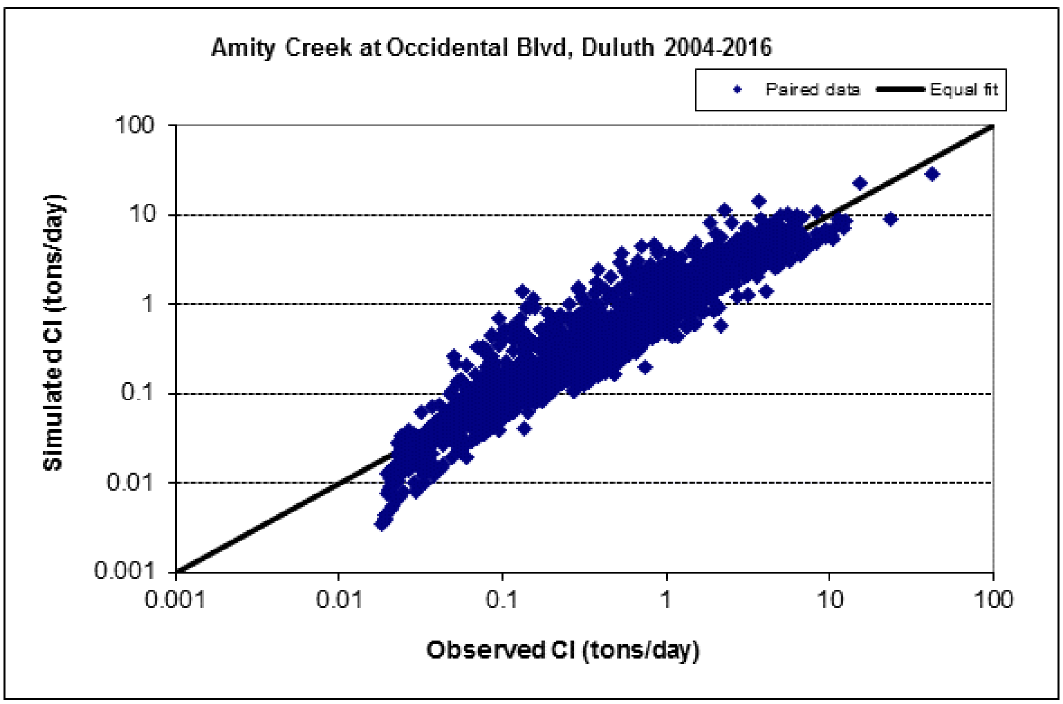


Figure F-55. Paired Simulated vs Observed Cl Load at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

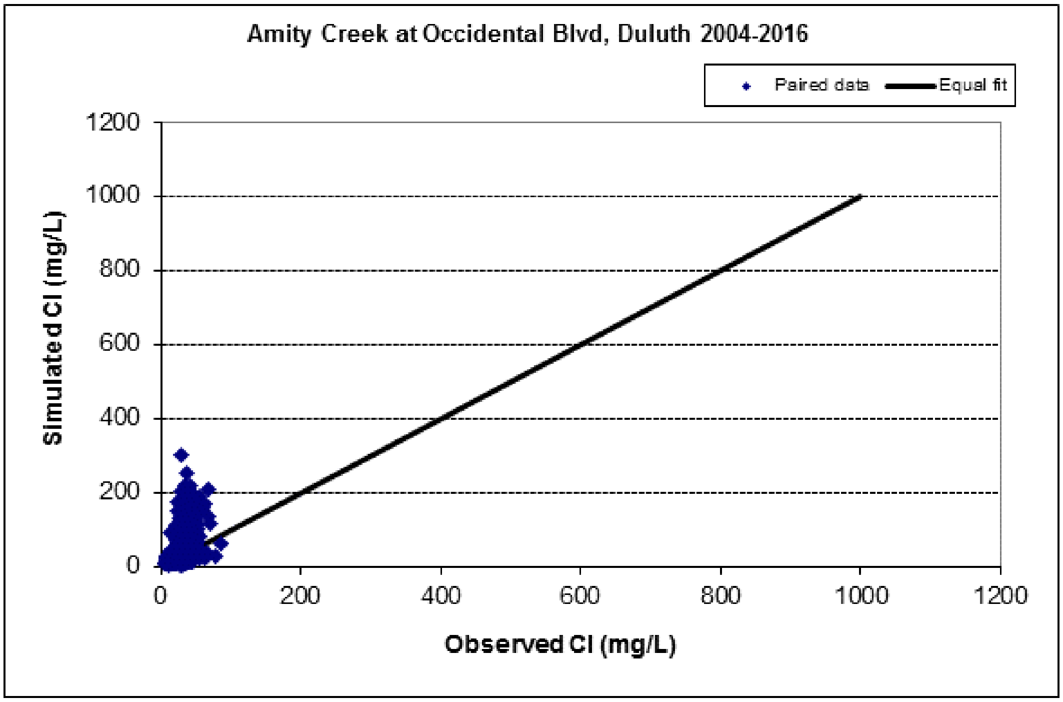


Figure F-56. Paired Simulated vs Observed Cl Concentration at the Amity Creek at Occidental Blvd, Duluth (Calibration Period)

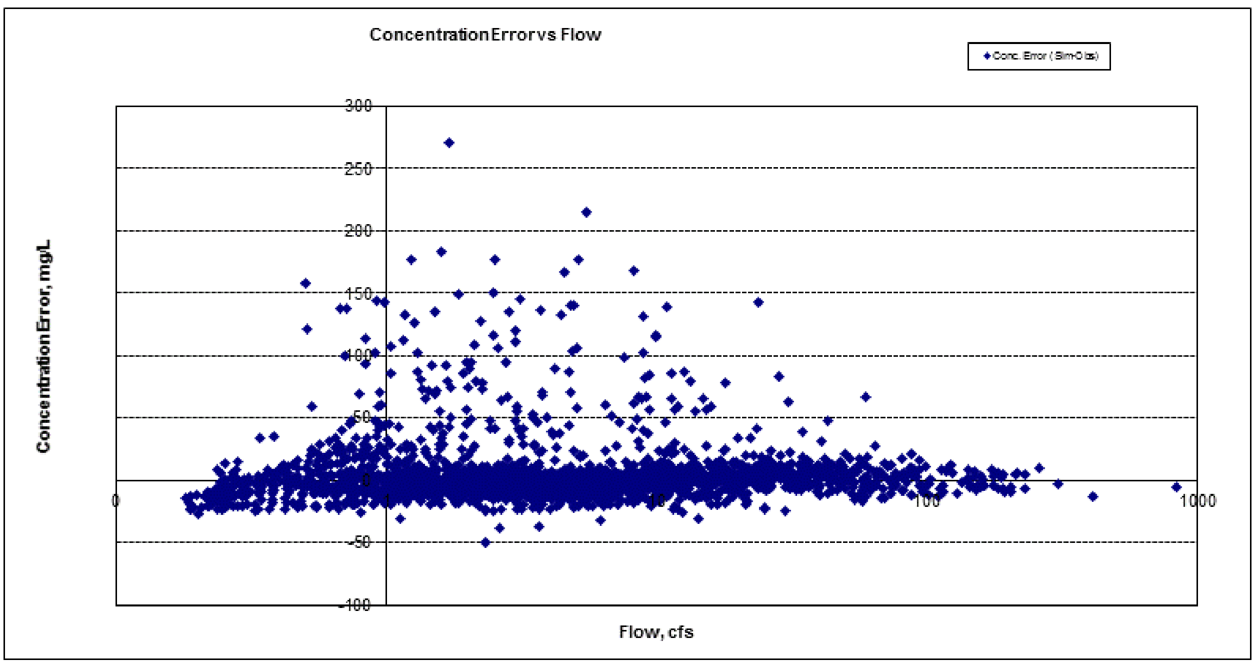


Figure F-57. Cl Concentration Error vs Flow at the Amity Creek at Occidental Blvd, Duluth

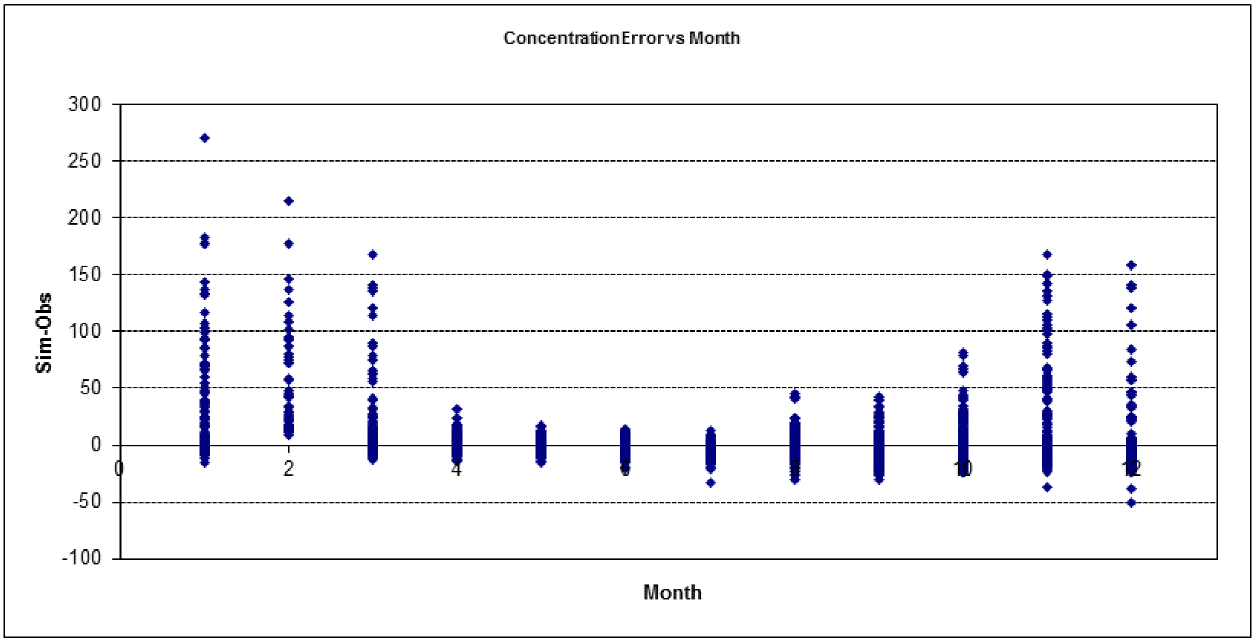


Figure F-58. Cl Concentration Error vs Month at the Amity Creek at Occidental Blvd, Duluth

F.7 Tischer Creek (Multiple Stations) - Continuous

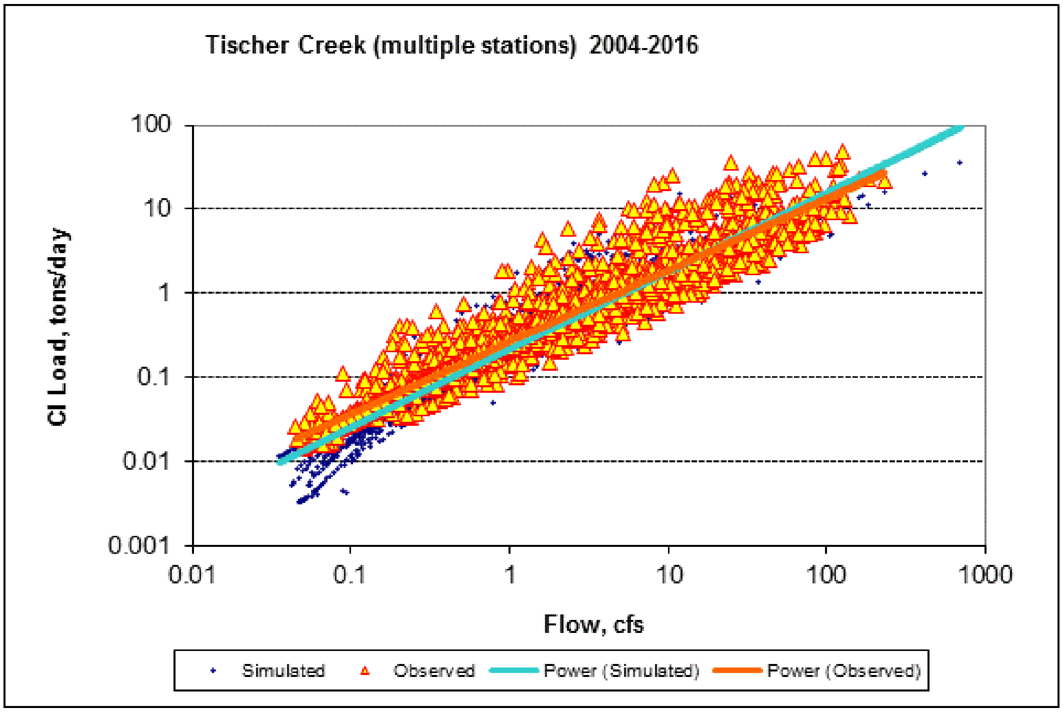


Figure F-59. Power Plot of Simulated and Observed Cl Load vs Flow at the Tischer Creek (multiple stations) (Calibration Period)

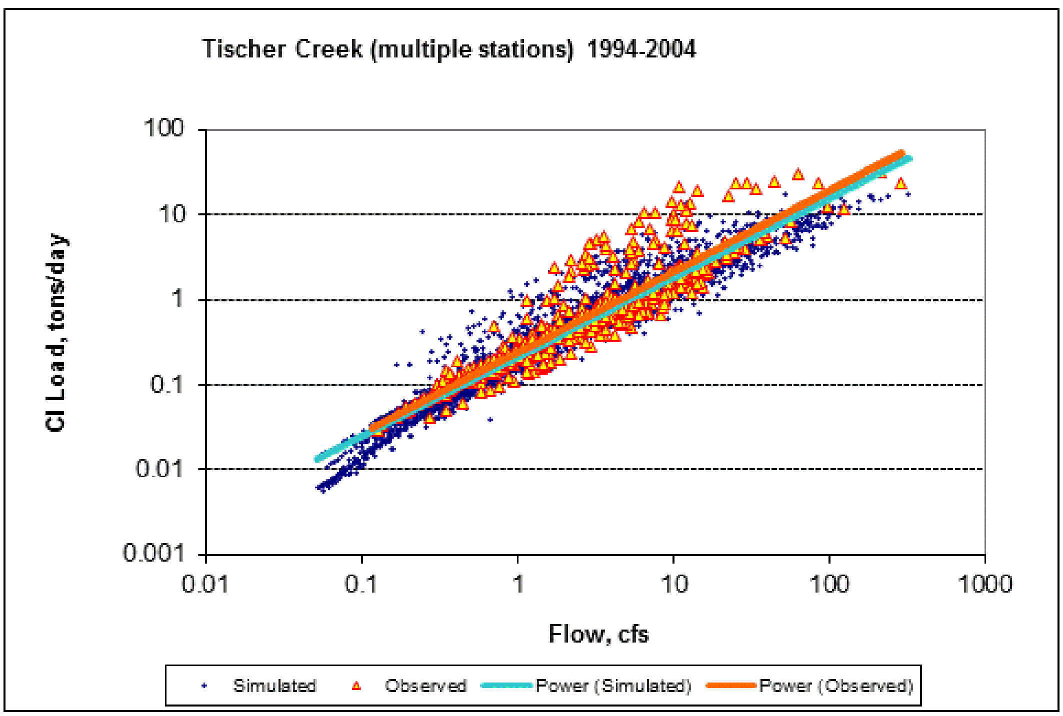


Figure F-60. Power Plot of Simulated and Observed Cl Load vs Flow at the Tischer Creek (multiple stations) (Validation Period)

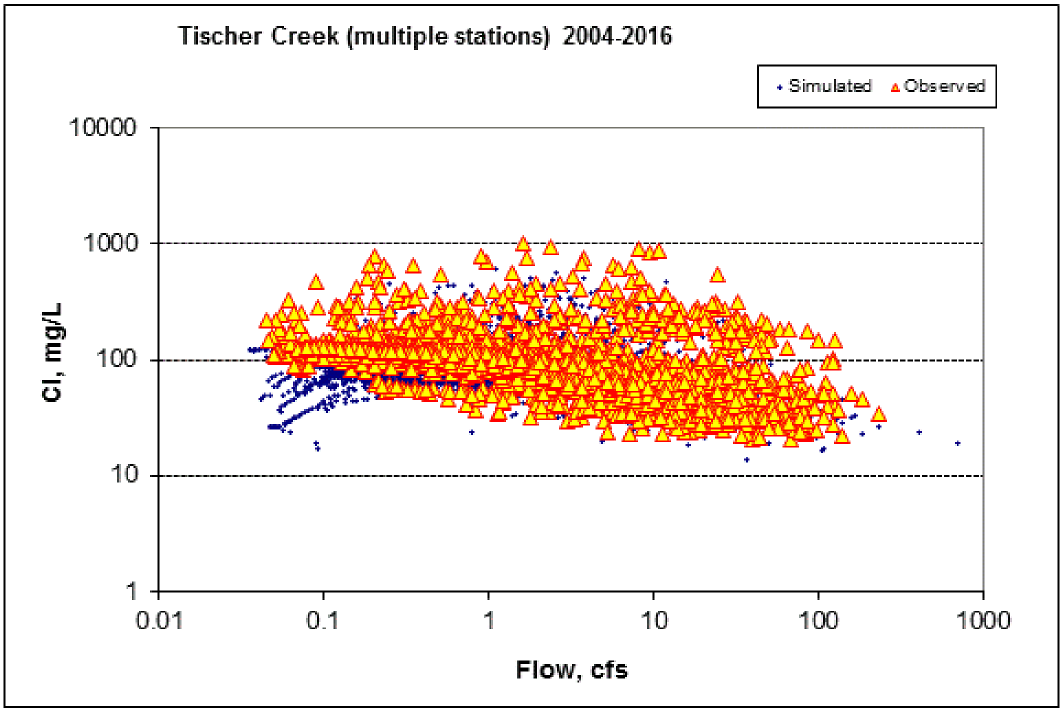


Figure F-61. Simulated and Observed Cl Concentration vs Flow Plot at the Tischer Creek (multiple stations) (Calibration Period)

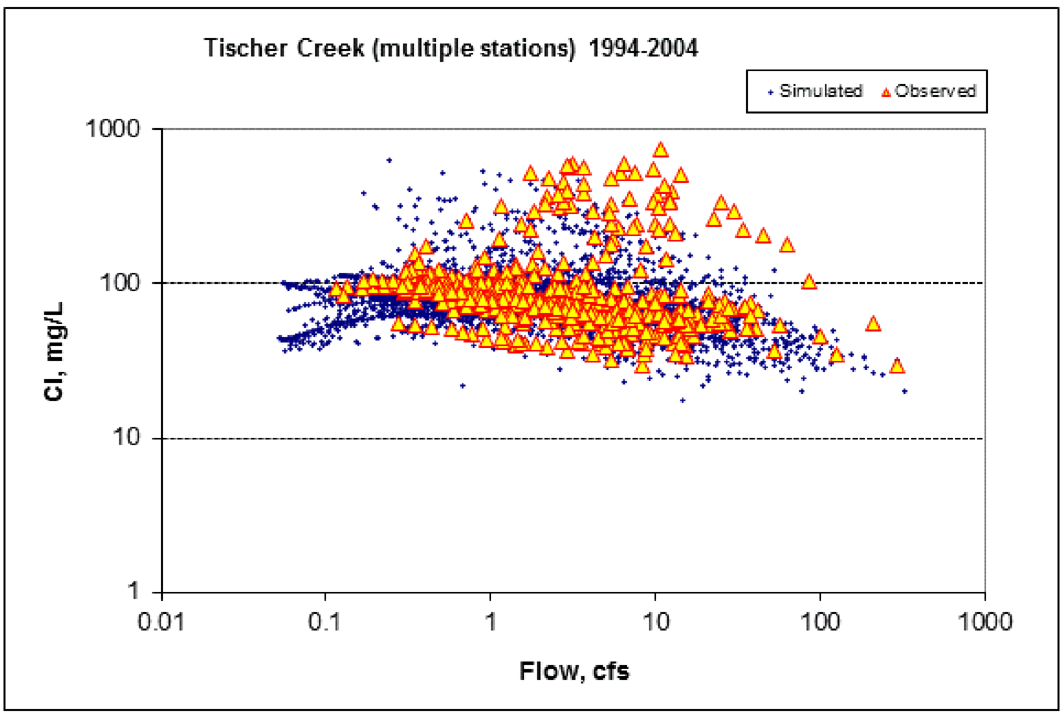


Figure F-62. Simulated and Observed Cl Concentration vs Flow Plot at the Tischer Creek (multiple stations) (Validation Period)

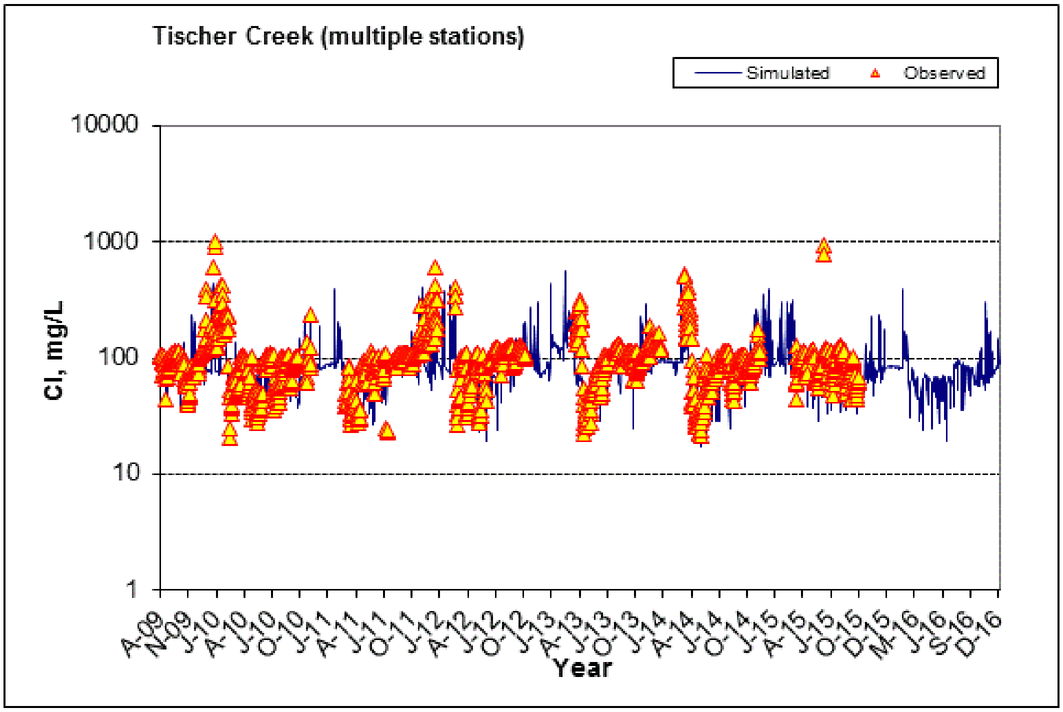


Figure F-63. Cl Concentration Time Series at the Tischer Creek (multiple stations) (2008-2015)

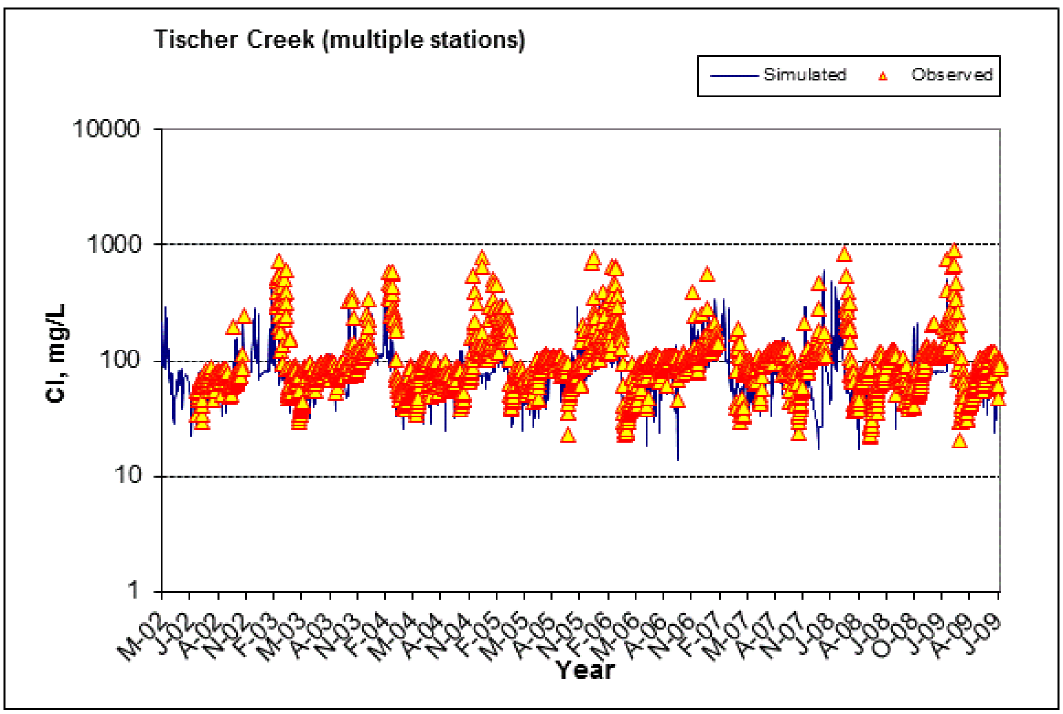


Figure F-64. Cl Concentration Time Series at the Tischer Creek (multiple stations) (2001-2008)

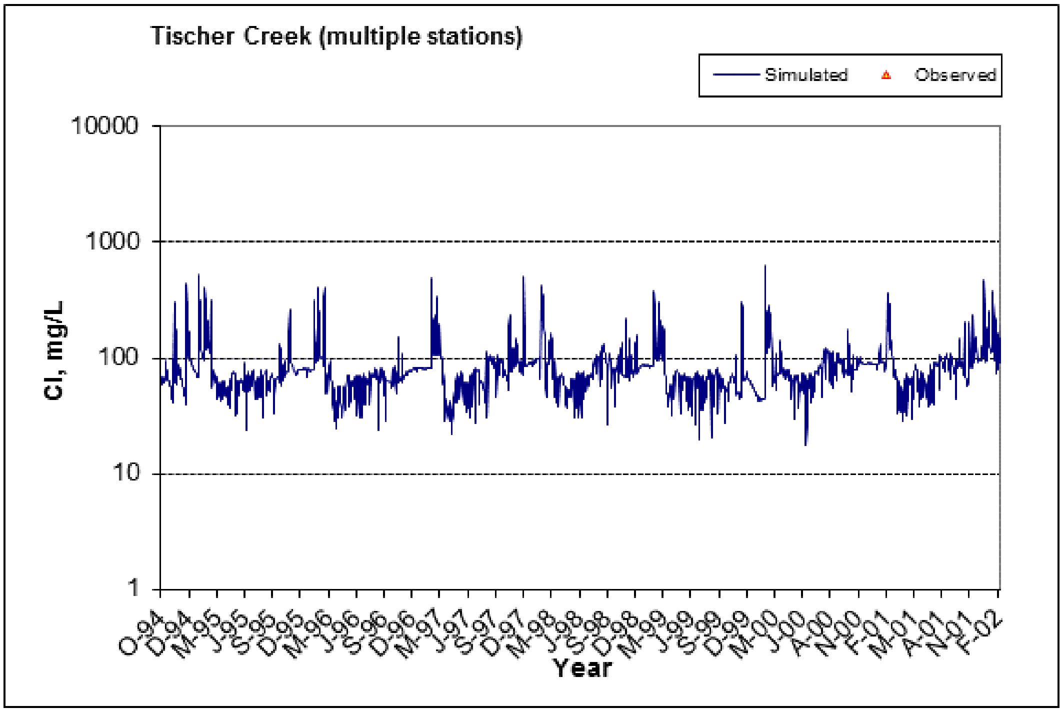


Figure F-65. Cl Concentration Time Series at the Tischer Creek (multiple stations) (1994-2001)

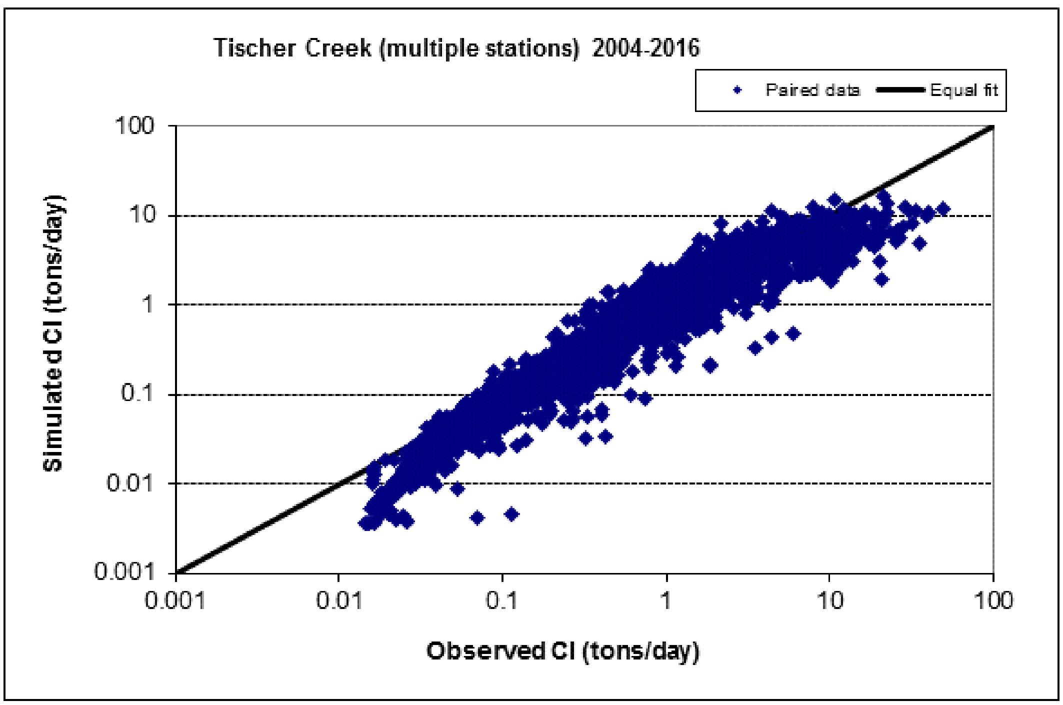


Figure F-66. Paired Simulated vs Observed Cl Load at the Tischer Creek (multiple stations) (Calibration Period)

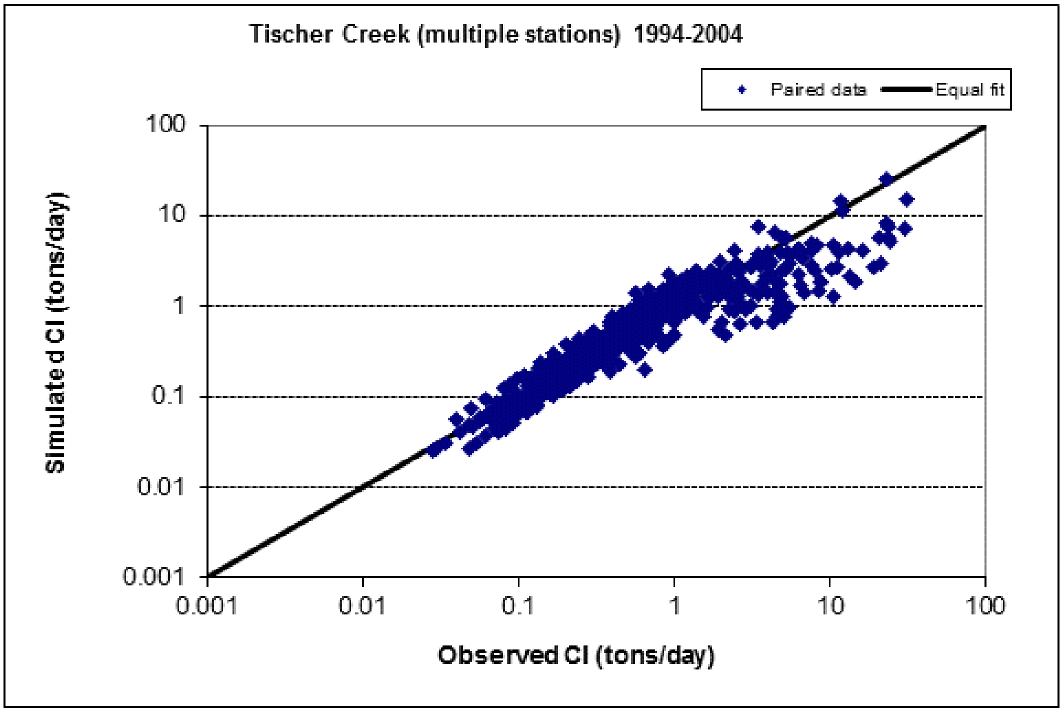


Figure F-67. Paired Simulated vs Observed Cl Load at the Tischer Creek (multiple stations) (Validation Period)

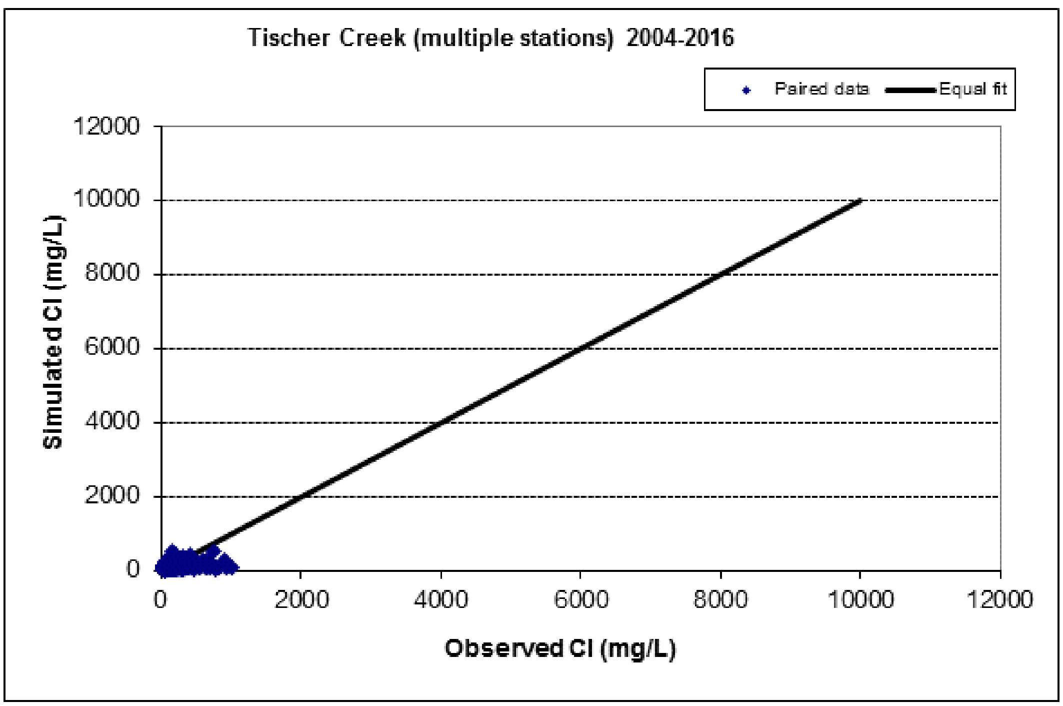


Figure F-68. Paired Simulated vs Observed Cl Concentration at the Tischer Creek (multiple stations) (Calibration Period)

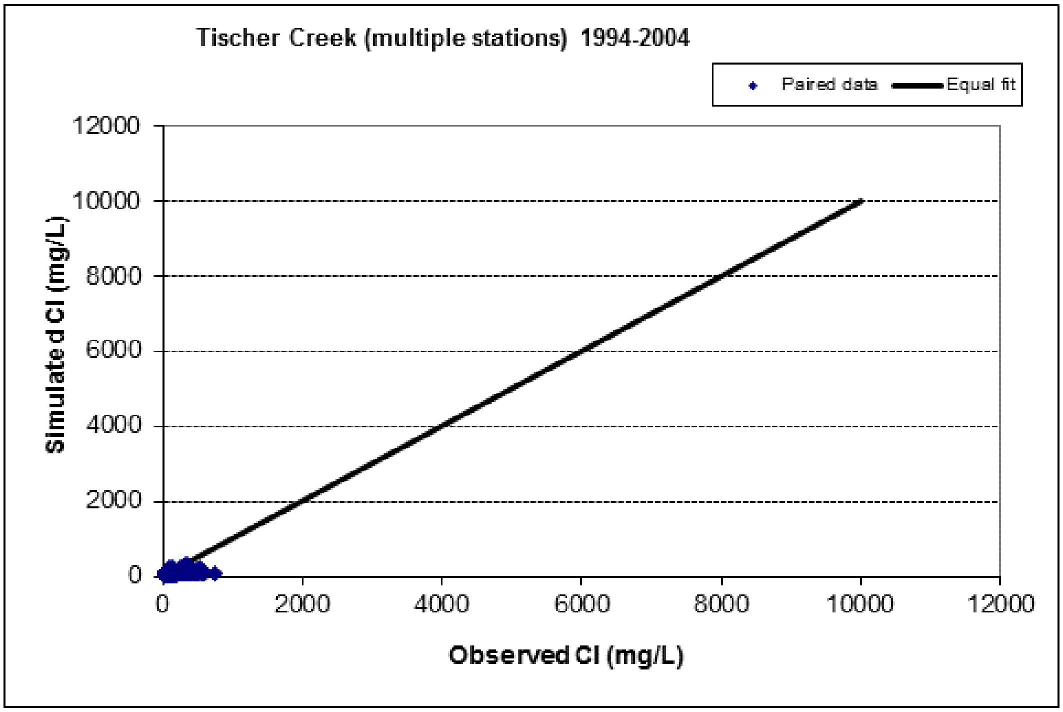


Figure F-69. Paired Simulated vs Observed Cl Concentration at the Tischer Creek (multiple stations) (Validation Period)

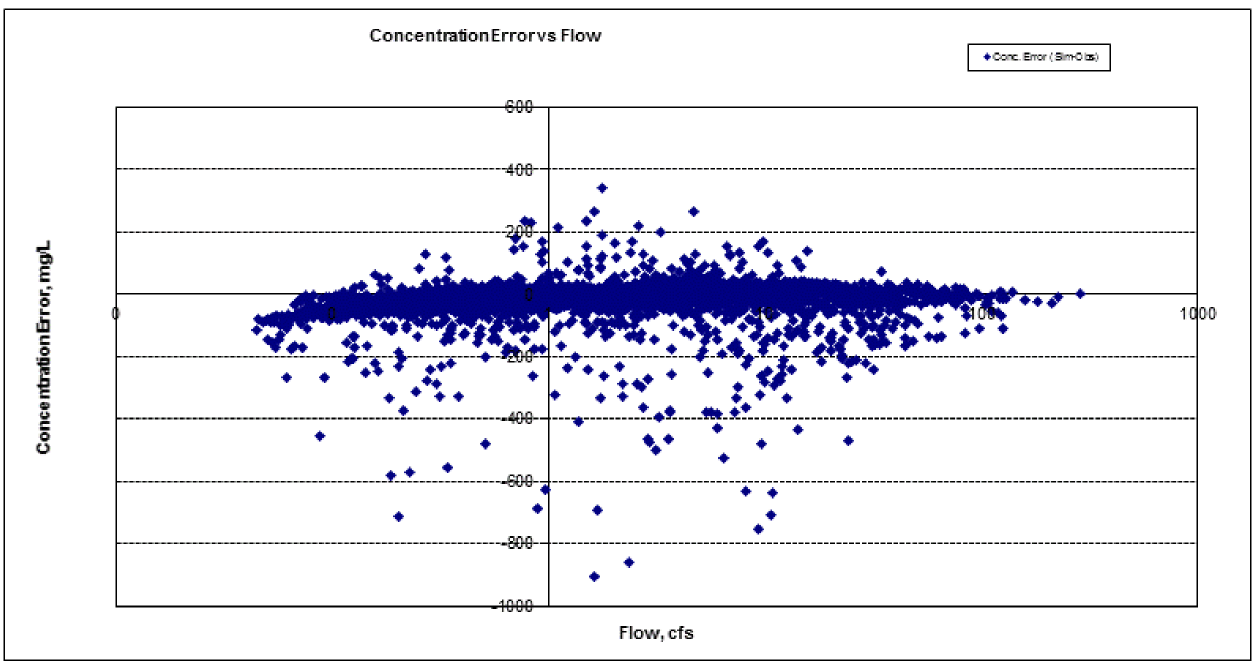


Figure F-70. Cl Concentration Error vs Flow at the Tischer Creek (multiple stations)

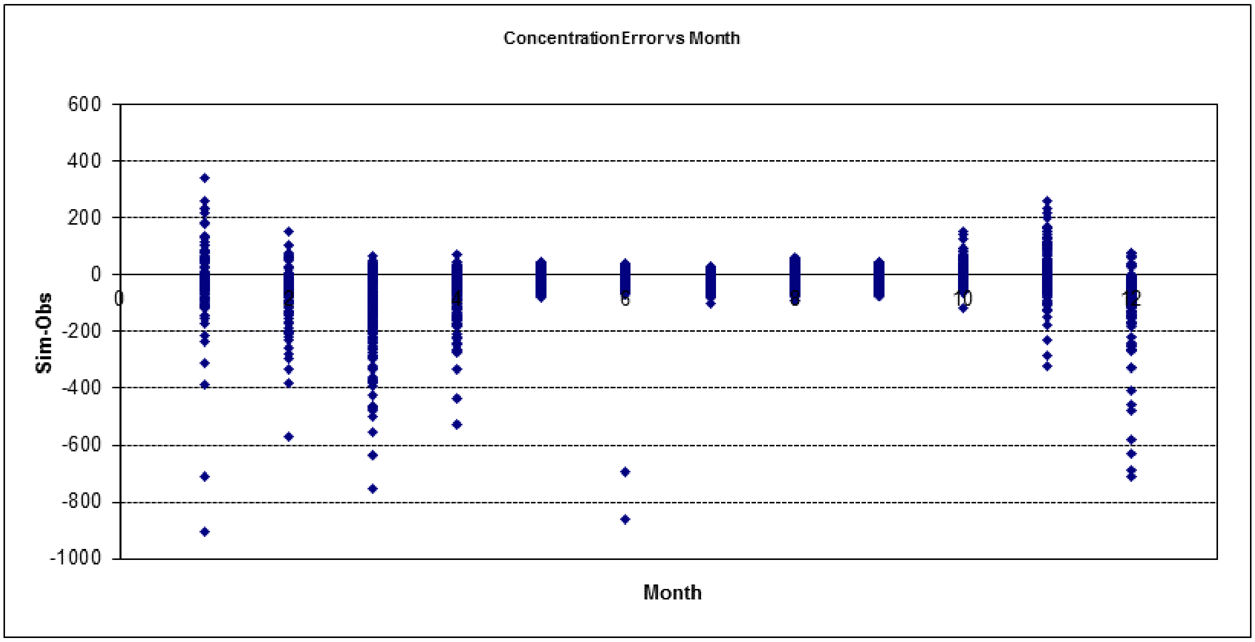


Figure F-71. Cl Concentration Error vs Month at the Tischer Creek (multiple stations)

F.8 TISCHER CREEK (MULTIPLE STATIONS) - DISCRETE

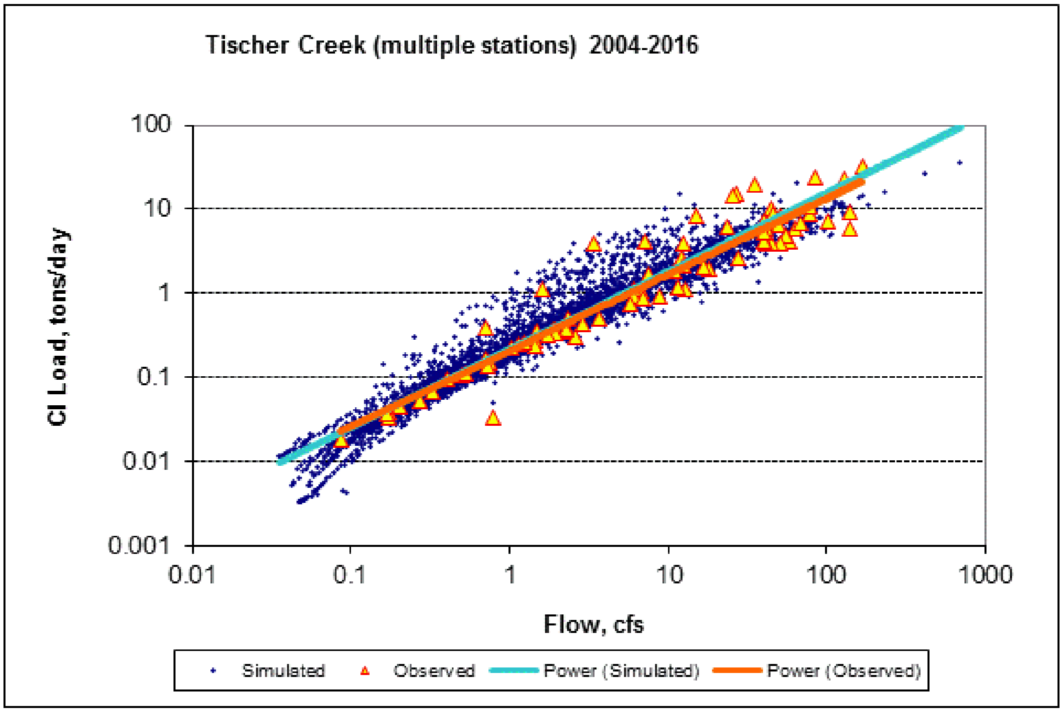


Figure F-72. Power Plot of Simulated and Observed Cl Load vs Flow at the Tischer Creek (multiple stations) (Calibration Period)

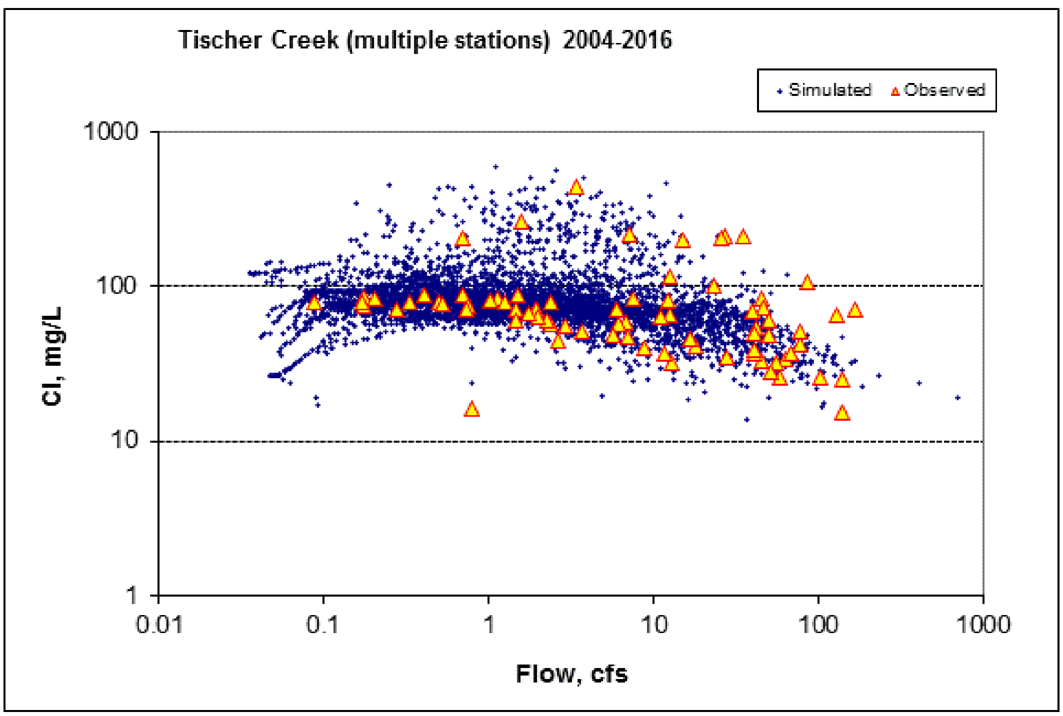


Figure F-73. Simulated and Observed Cl Concentration vs Flow Plot at the Tischer Creek (multiple stations) (Calibration Period)

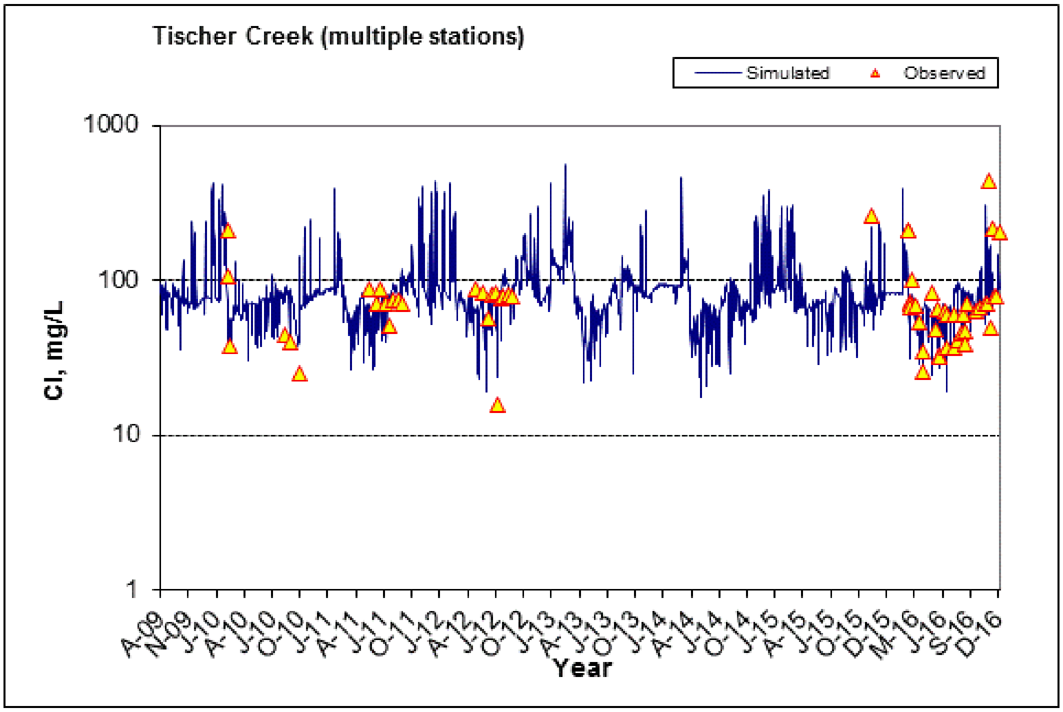


Figure F-74. Cl Concentration Time Series at the Tischer Creek (multiple stations) (2008-2015)

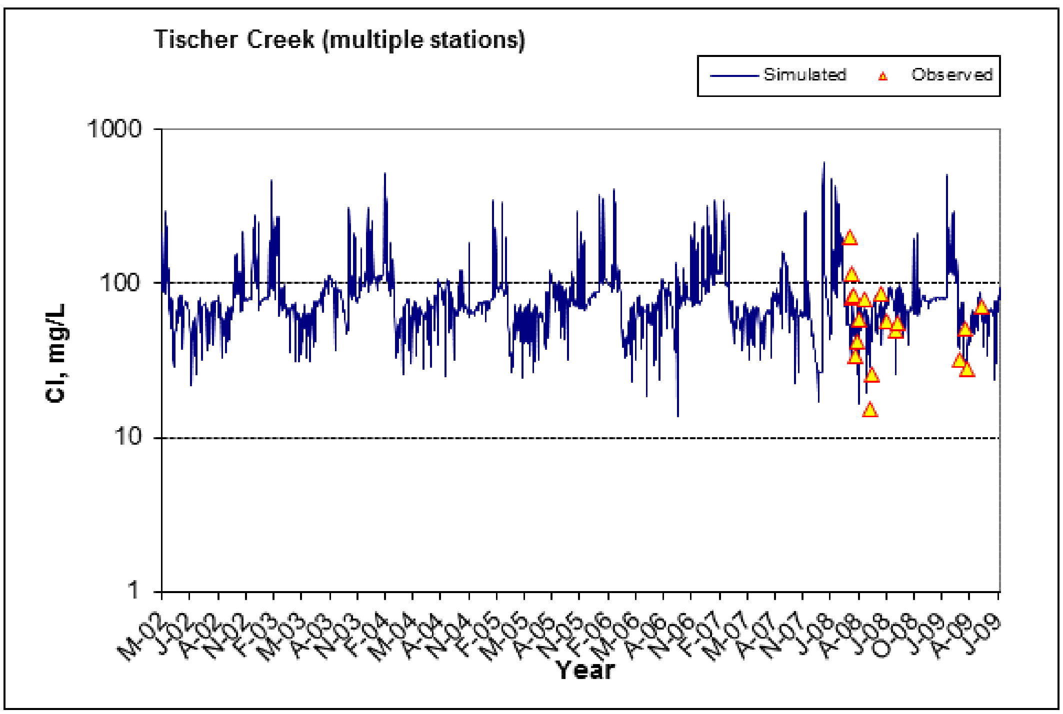


Figure F-75. Cl Concentration Time Series at the Tischer Creek (multiple stations) (2001-2008)

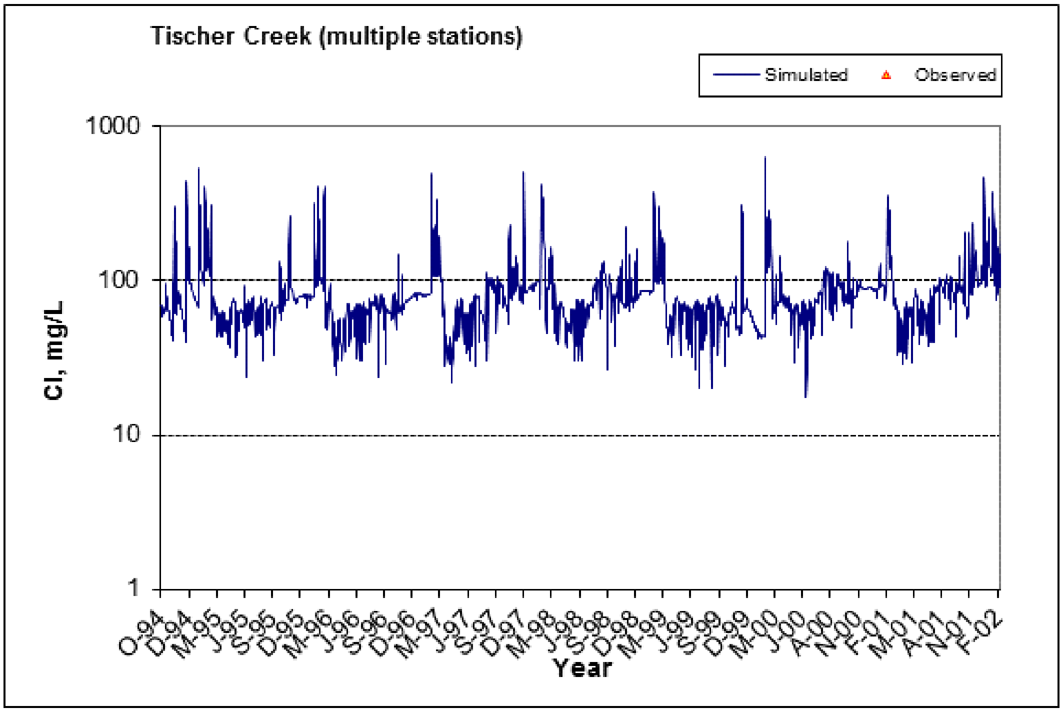


Figure F-76. Cl Concentration Time Series at the Tischer Creek (multiple stations) (1994-2001)

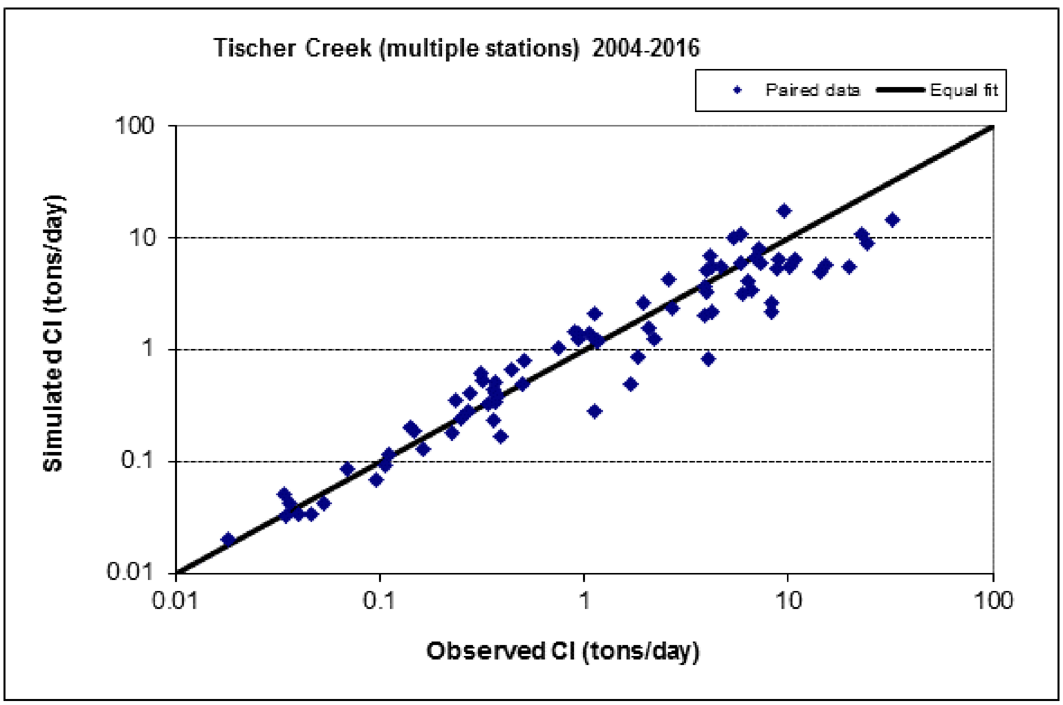


Figure F-77. Paired Simulated vs Observed Cl Load at the Tischer Creek (multiple stations) (Calibration Period)

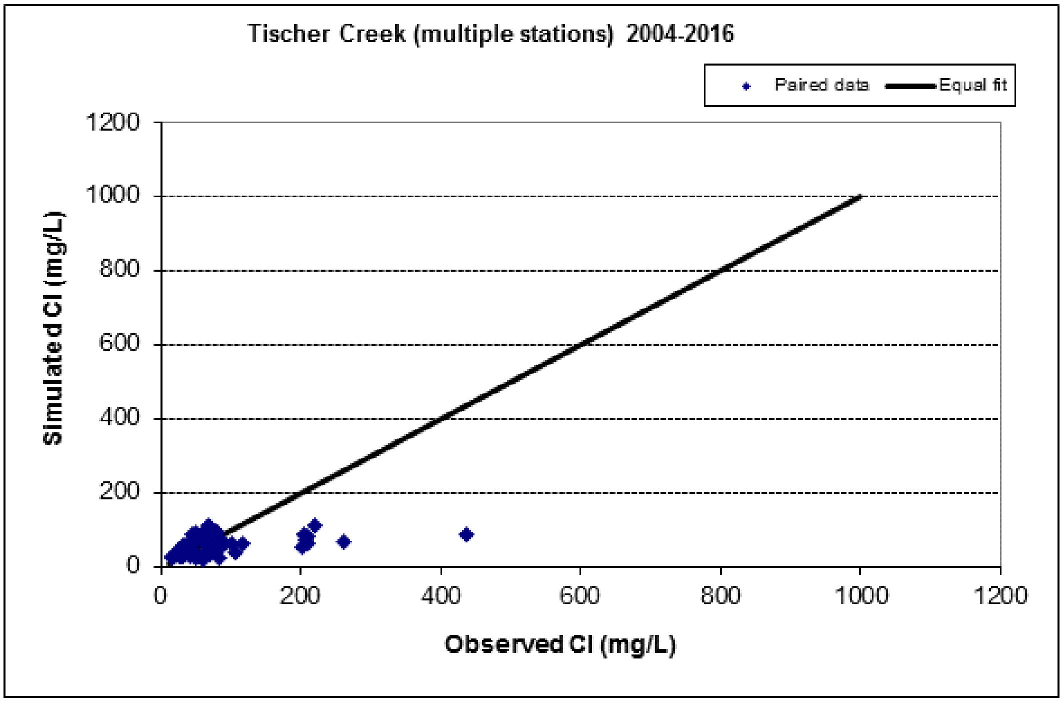


Figure F-78. Paired Simulated vs Observed Cl Concentration at the Tischer Creek (multiple stations) (Calibration Period)

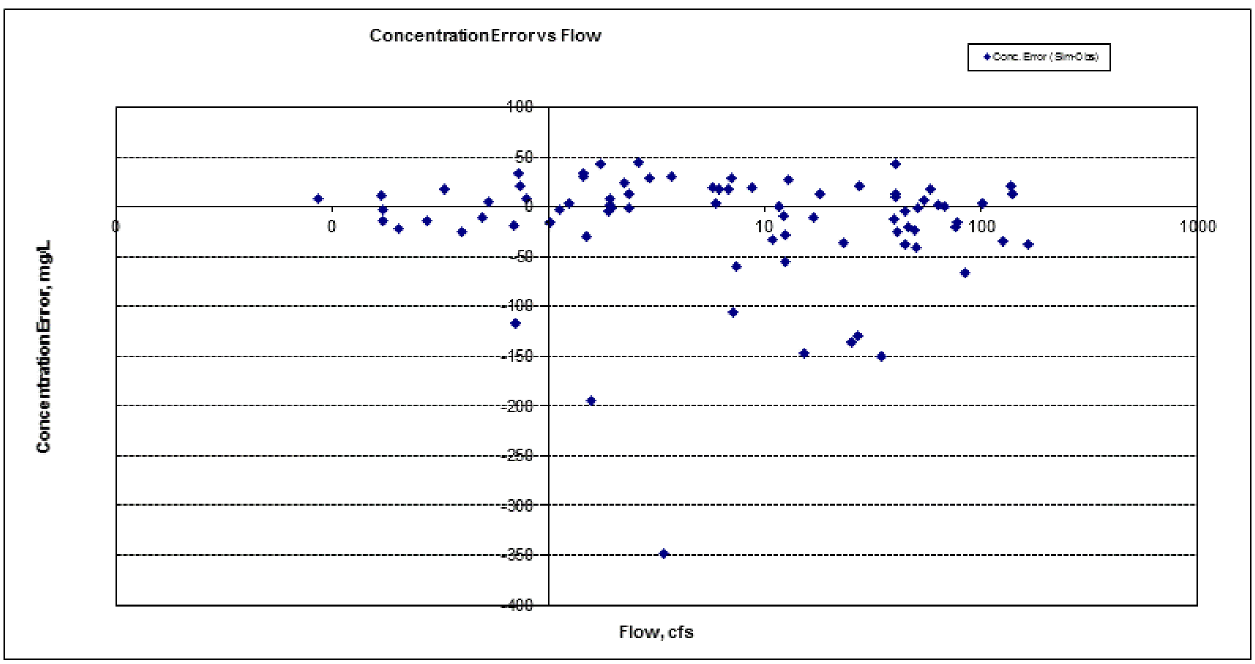


Figure F-79. Cl Concentration Error vs Flow at the Tischer Creek (multiple stations)

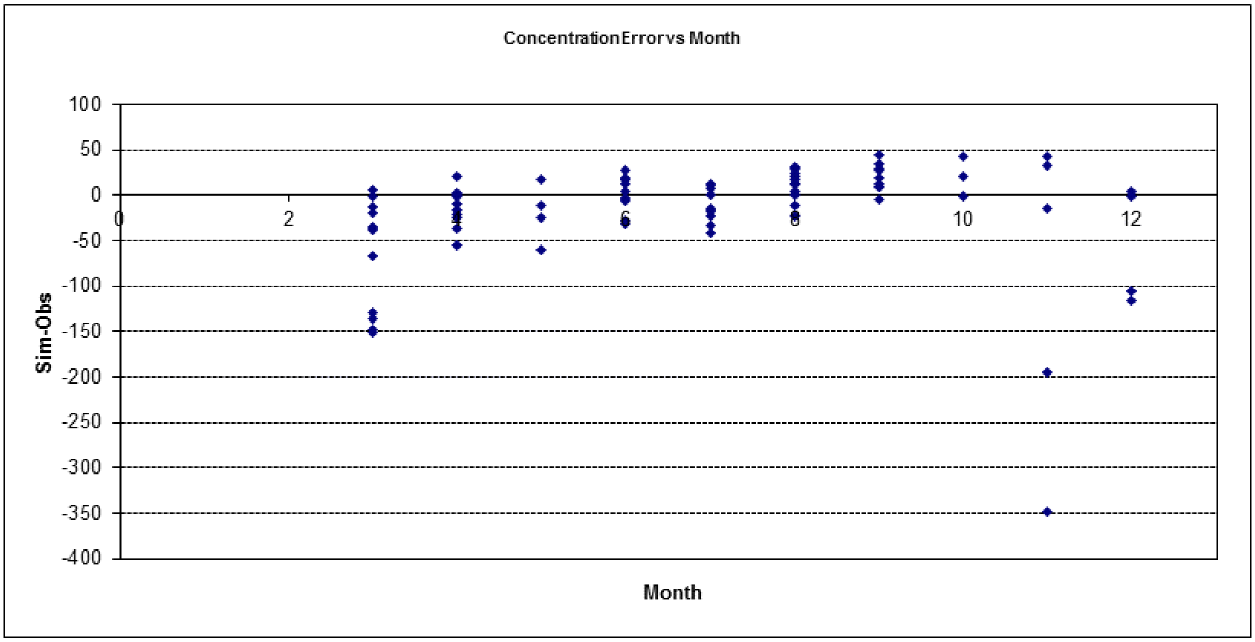


Figure F-80. Cl Concentration Error vs Month at the Tischer Creek (multiple stations)

F.9 Chester Creek (Multiple Stations) - Continuous

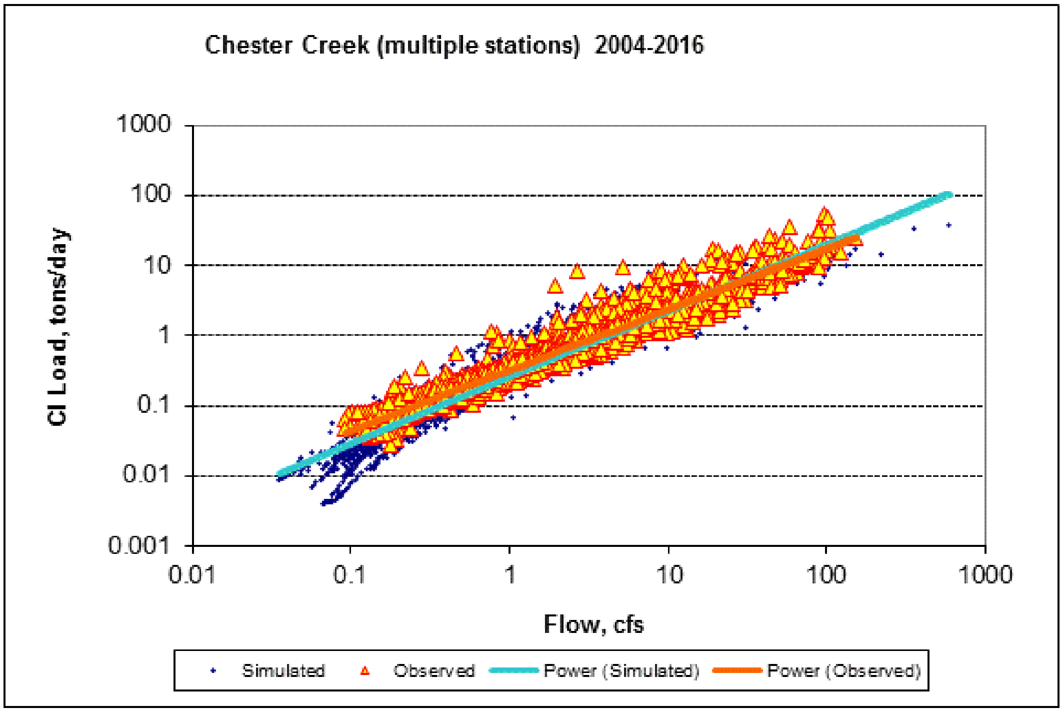


Figure F-81. Power Plot of Simulated and Observed Cl Load vs Flow at the Chester Creek (multiple stations) (Calibration Period)

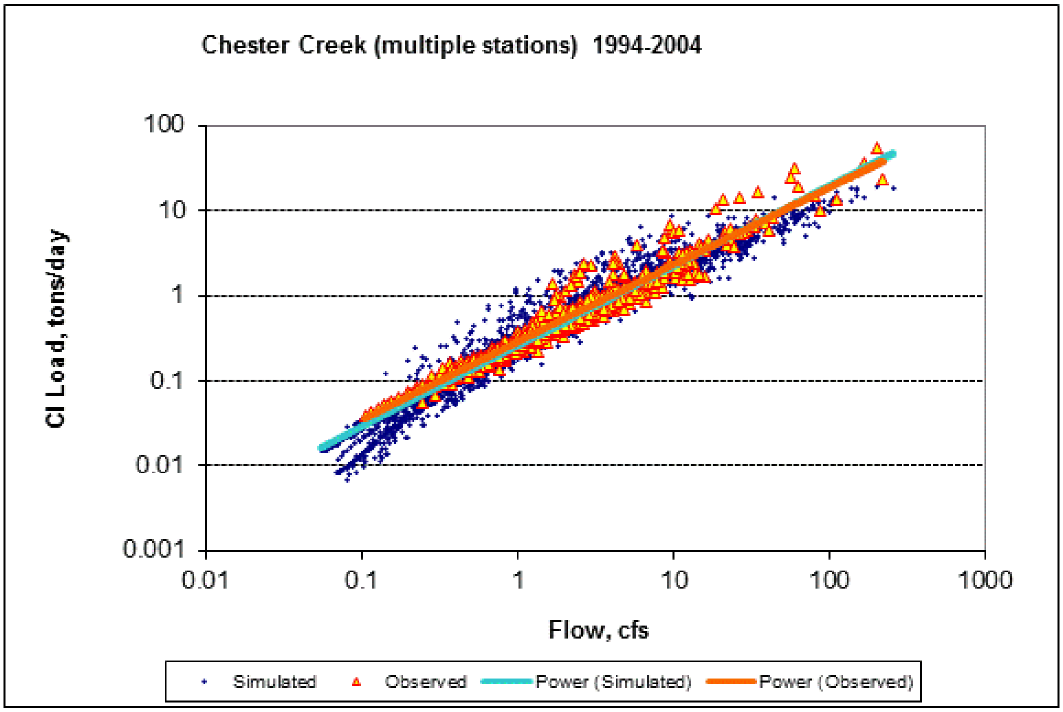


Figure F-82. Power Plot of Simulated and Observed Cl Load vs Flow at the Chester Creek (multiple stations) (Validation Period)

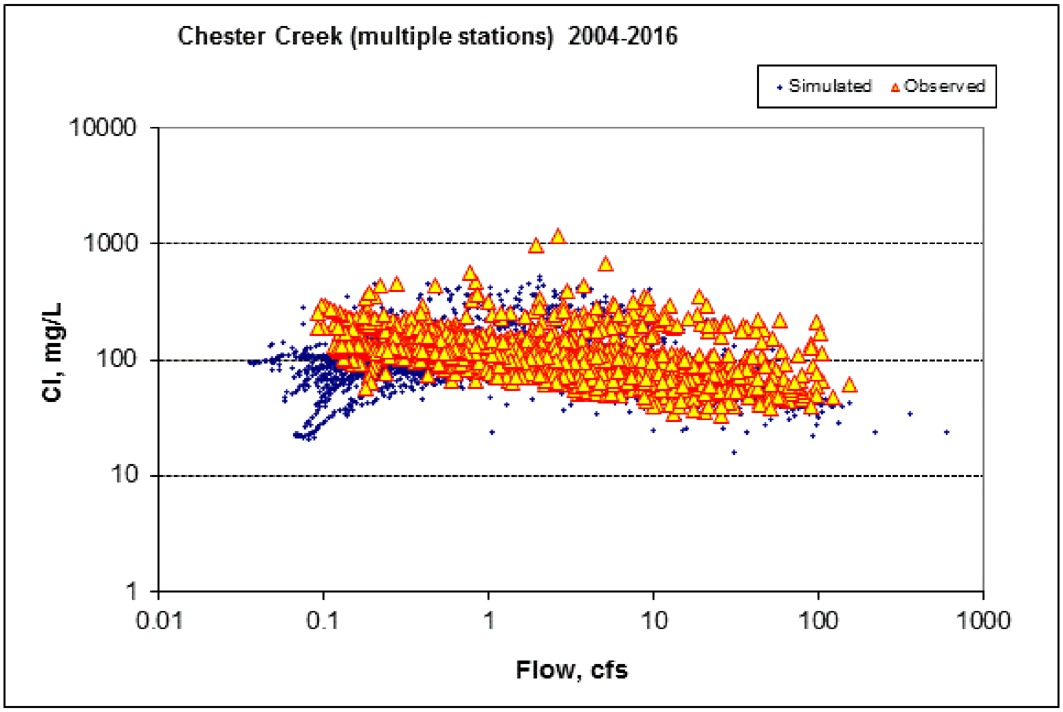


Figure F-83. Simulated and Observed Cl Concentration vs Flow Plot at the Chester Creek (multiple stations) (Calibration Period)

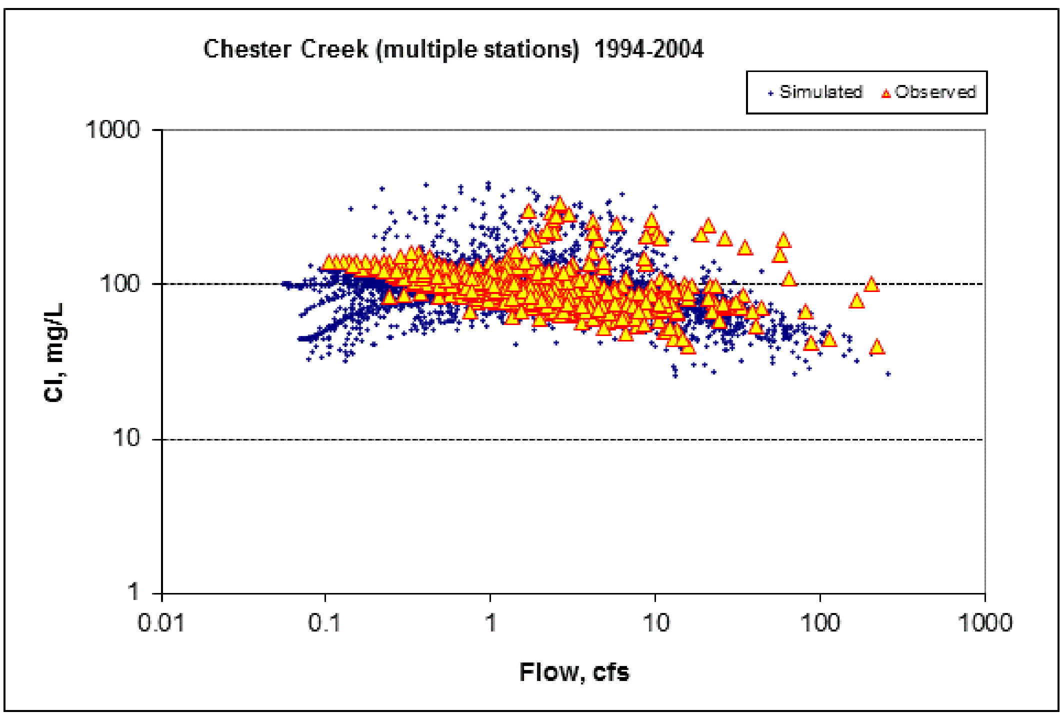


Figure F-84. Simulated and Observed Cl Concentration vs Flow Plot at the Chester Creek (multiple stations) (Validation Period)

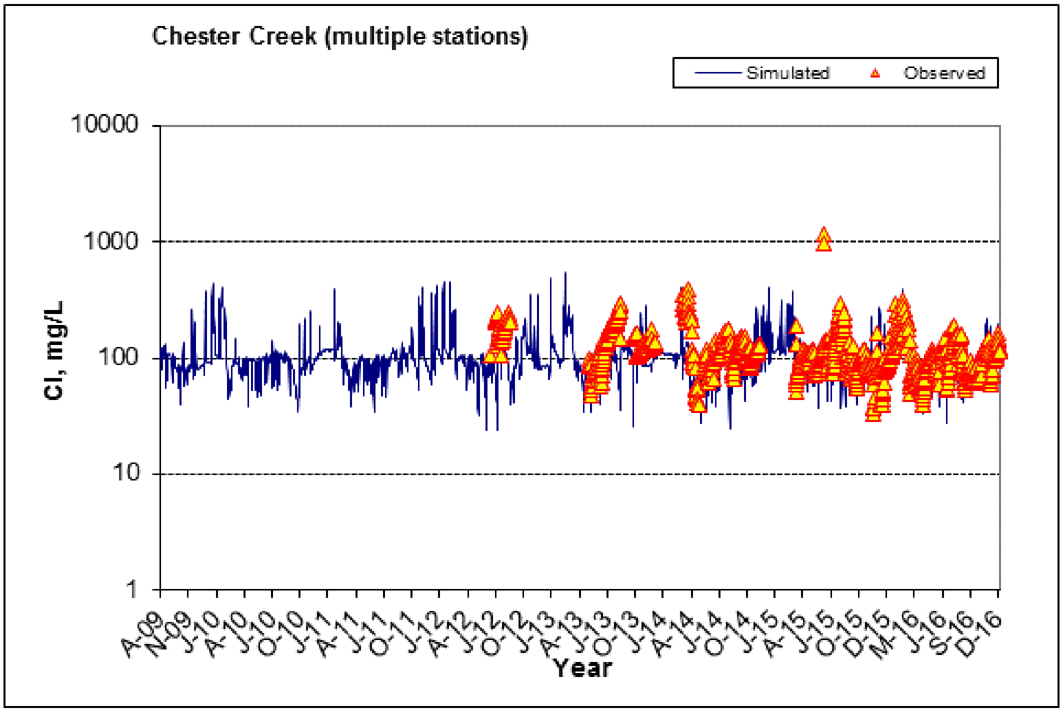


Figure F-85. Cl Concentration Time Series at the Chester Creek (multiple stations) (2008-2015)

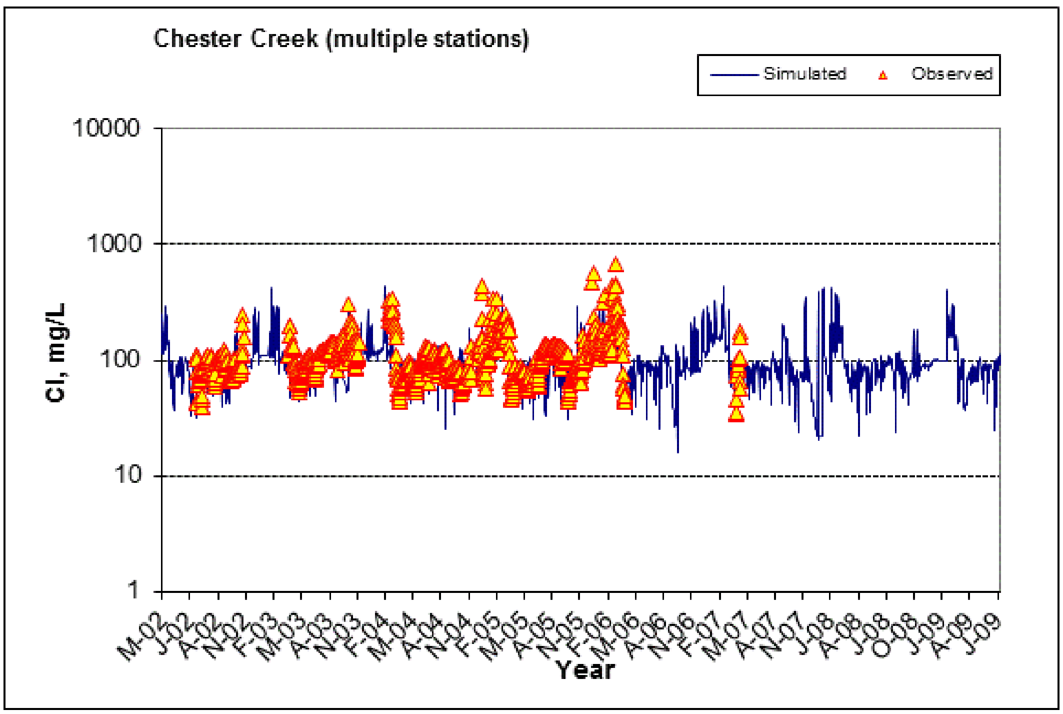


Figure F-86. Cl Concentration Time Series at the Chester Creek (multiple stations) (2001-2008)

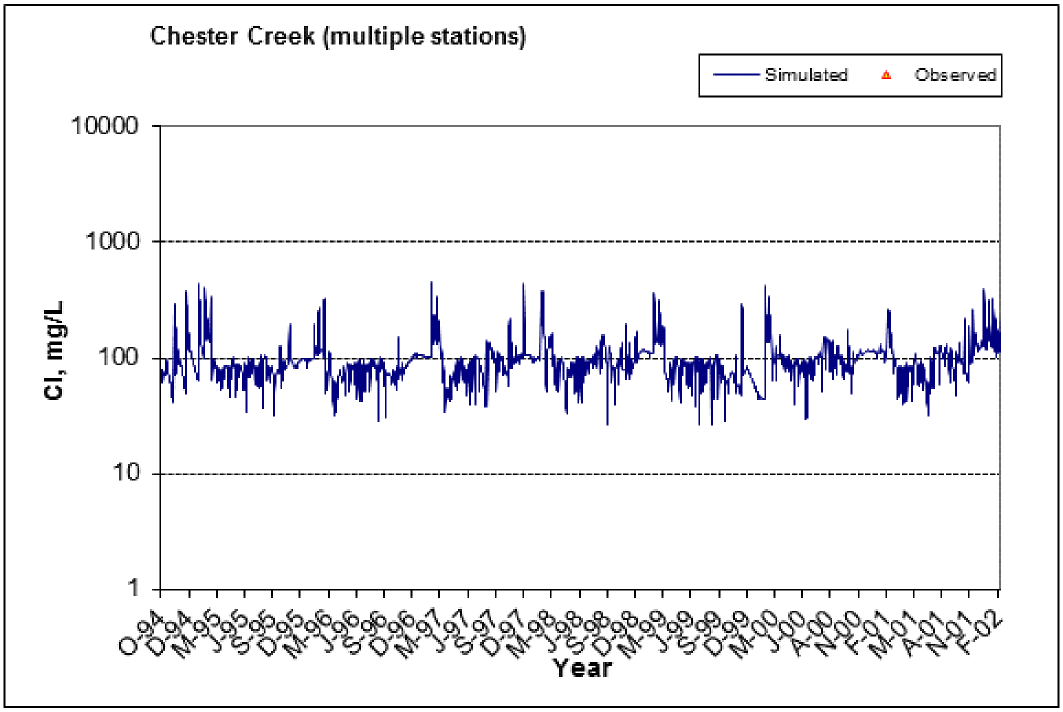


Figure F-87. Cl Concentration Time Series at the Chester Creek (multiple stations) (1994-2001)

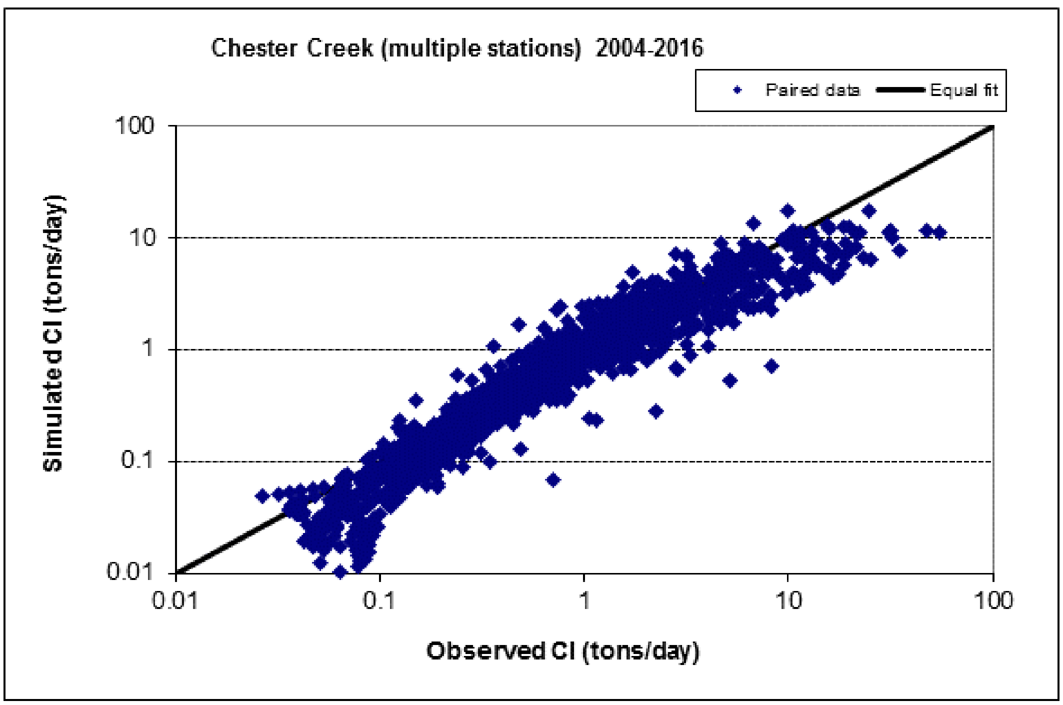


Figure F-88. Paired Simulated vs Observed Cl Load at the Chester Creek (multiple stations) (Calibration Period)

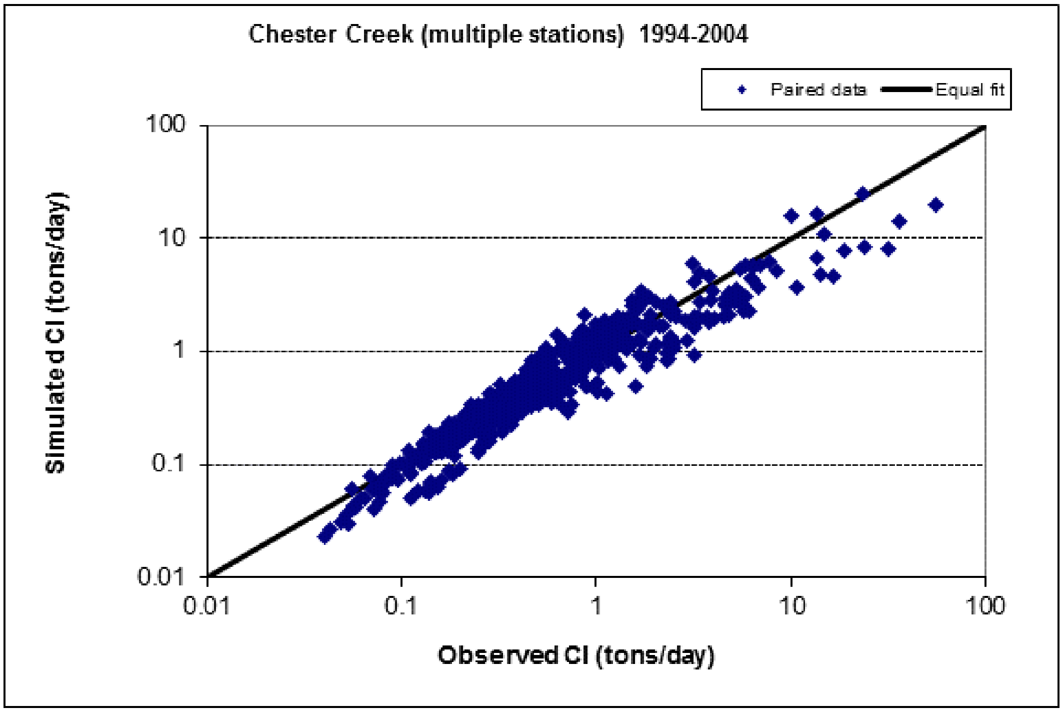


Figure F-89. Paired Simulated vs Observed Cl Load at the Chester Creek (multiple stations) (Validation Period)

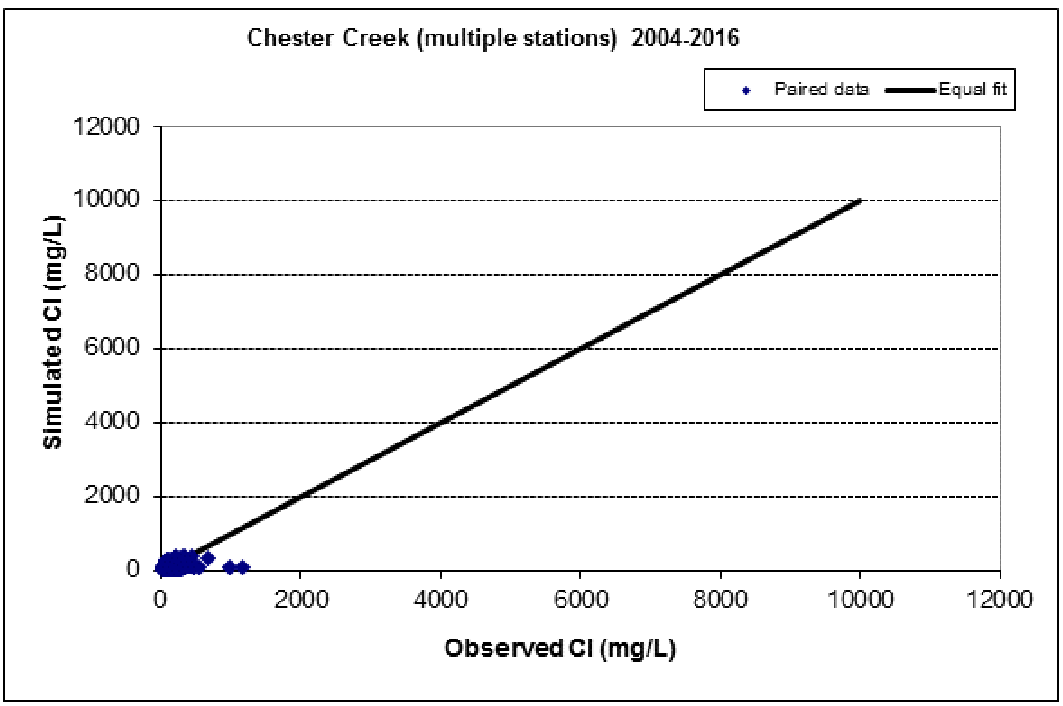


Figure F-90. Paired Simulated vs Observed Cl Concentration at the Chester Creek (multiple stations) (Calibration Period)

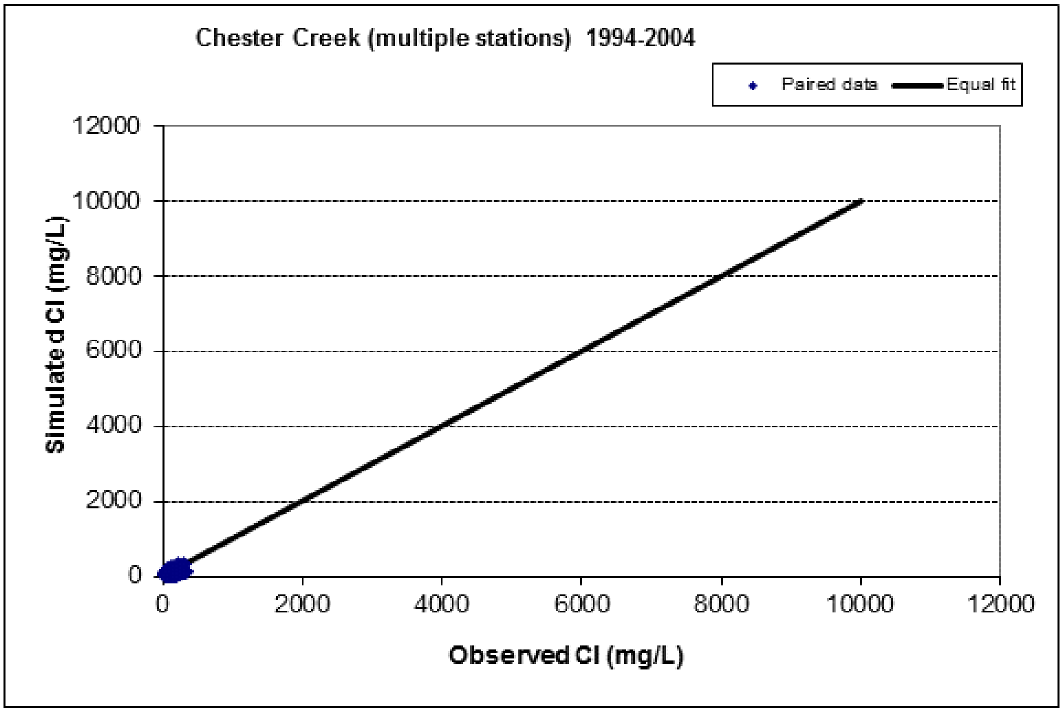


Figure F-91. Paired Simulated vs Observed Cl Concentration at the Chester Creek (multiple stations) (Validation Period)

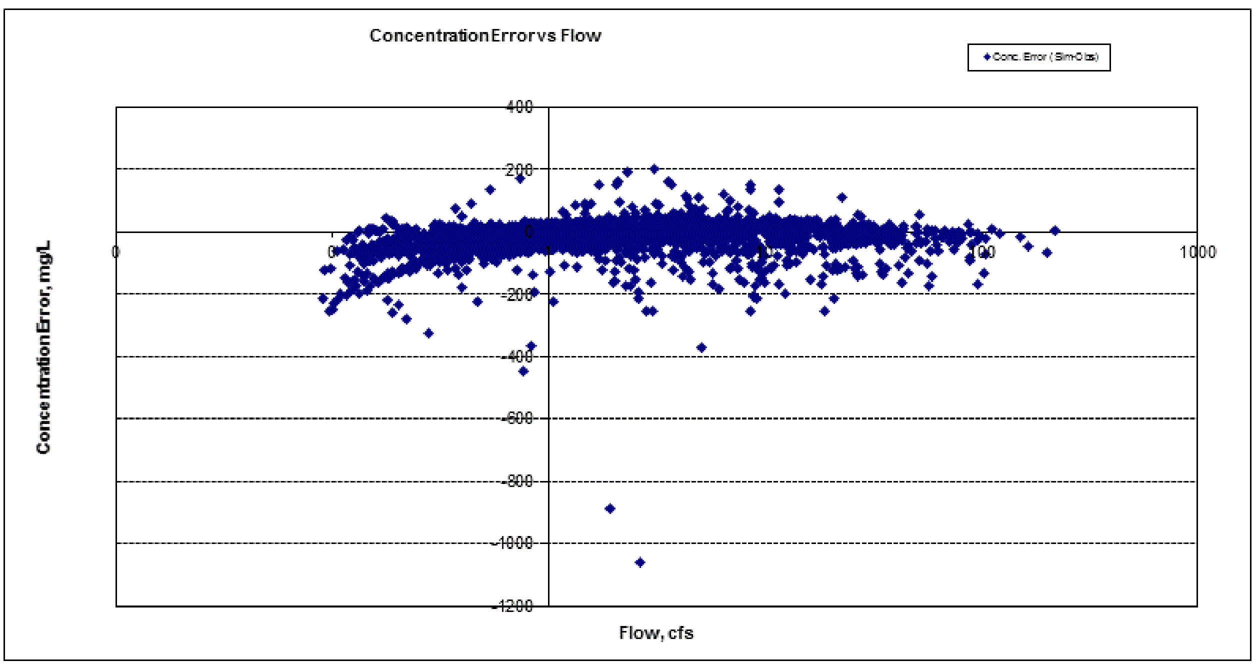


Figure F-92. Cl Concentration Error vs Flow at the Chester Creek (multiple stations)

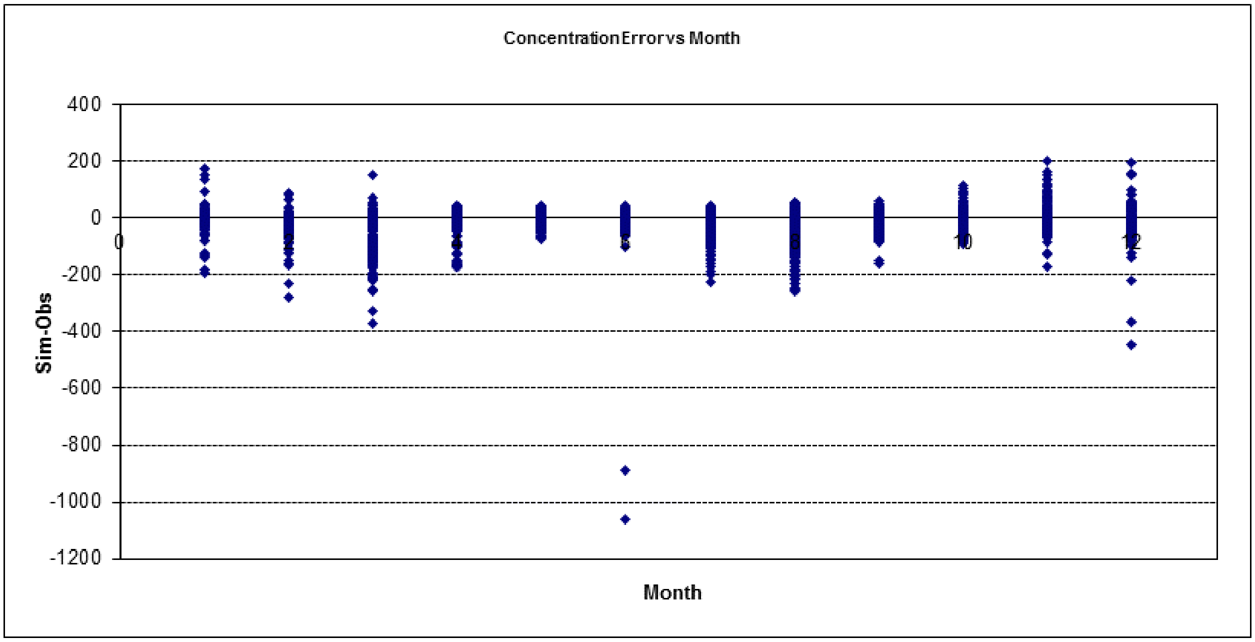


Figure F-93. Cl Concentration Error vs Month at the Chester Creek (multiple stations)

F.10 Chester Creek (Multiple Stations) - Discrete

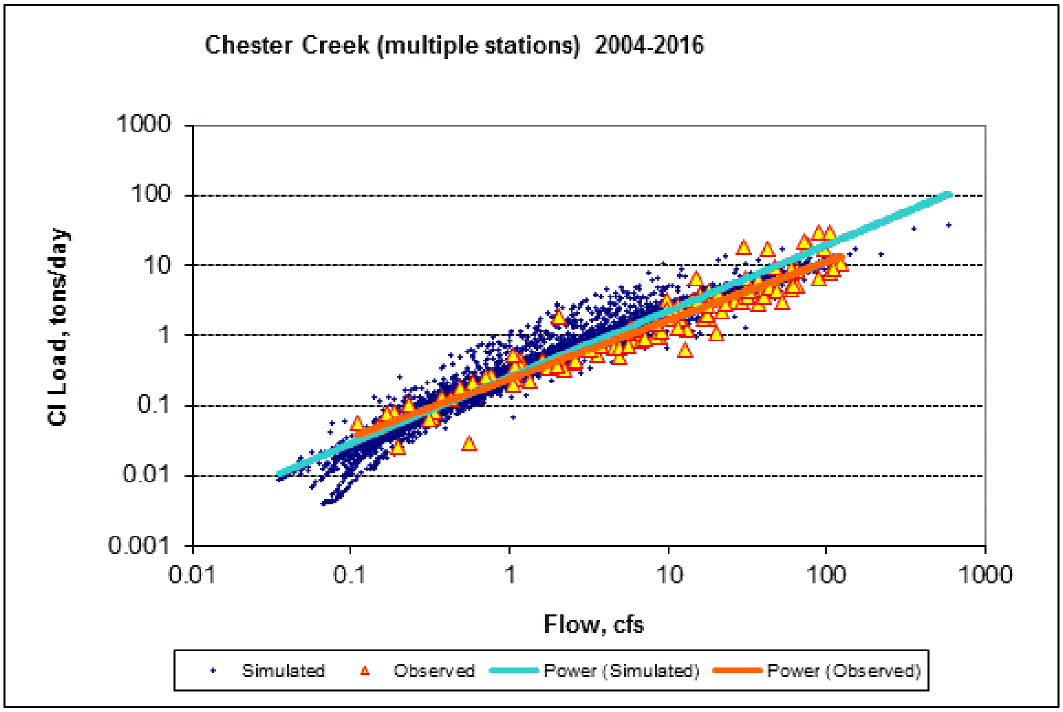


Figure F-94. Power Plot of Simulated and Observed Cl Load vs Flow at the Chester Creek (multiple stations) (Calibration Period)

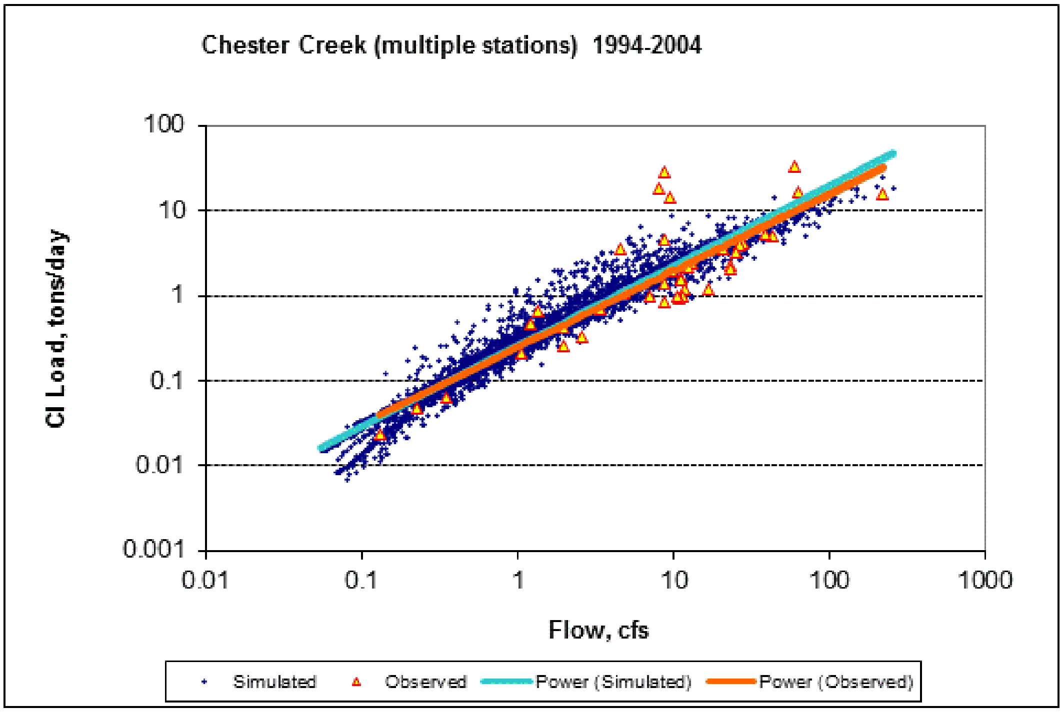


Figure F-95. Power Plot of Simulated and Observed Cl Load vs Flow at the Chester Creek (multiple stations) (Validation Period)

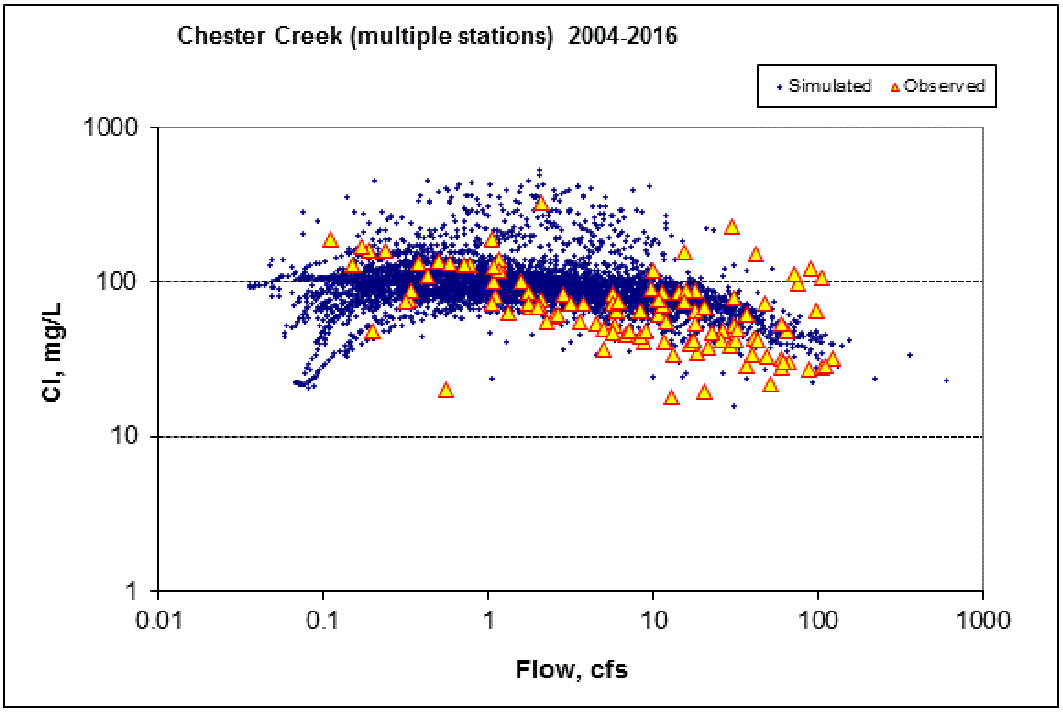


Figure F-96. Simulated and Observed Cl Concentration vs Flow Plot at the Chester Creek (multiple stations) (Calibration Period)

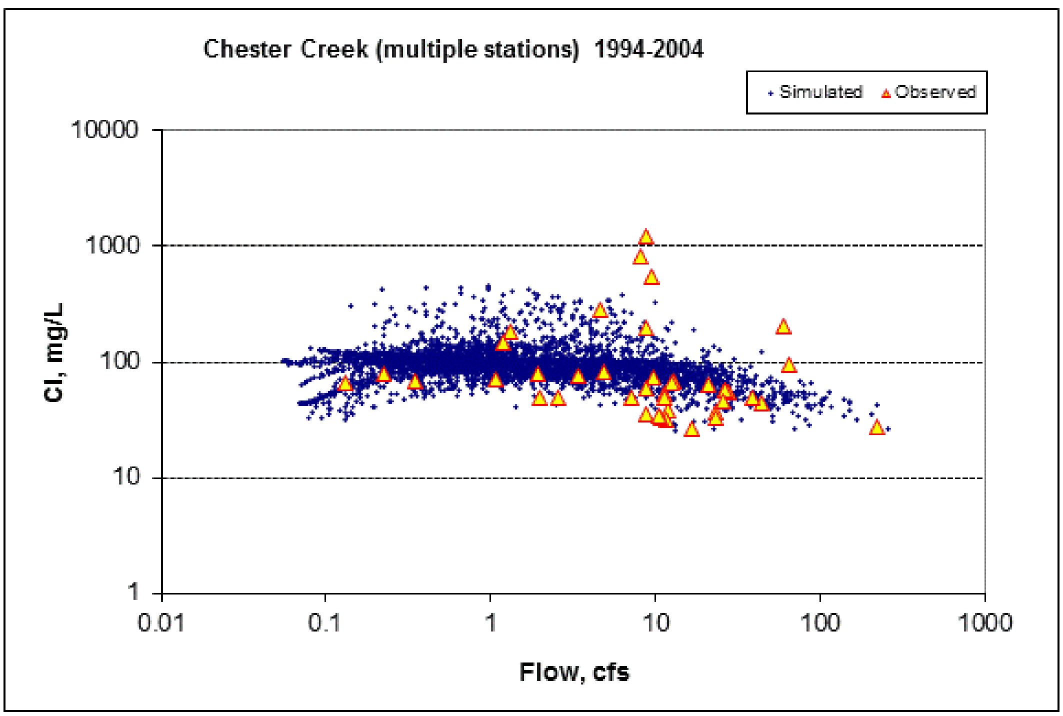


Figure F-97. Simulated and Observed Cl Concentration vs Flow Plot at the Chester Creek (multiple stations) (Validation Period)

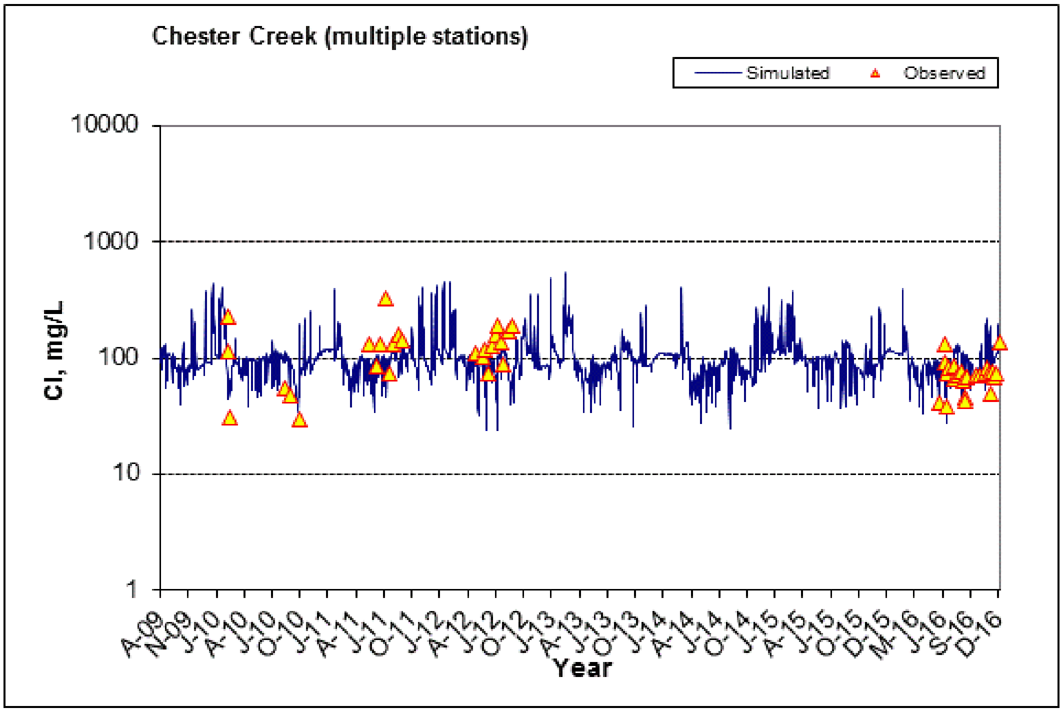


Figure F-98. Cl Concentration Time Series at the Chester Creek (multiple stations) (2008-2015)

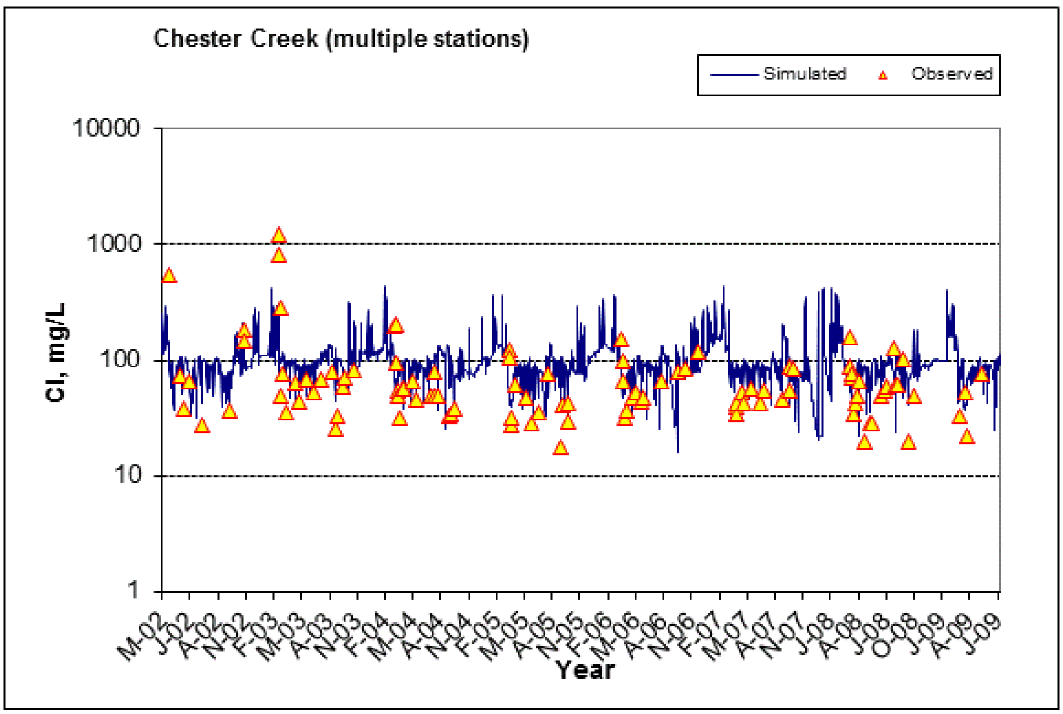


Figure F-99. Cl Concentration Time Series at the Chester Creek (multiple stations) (2001-2008)

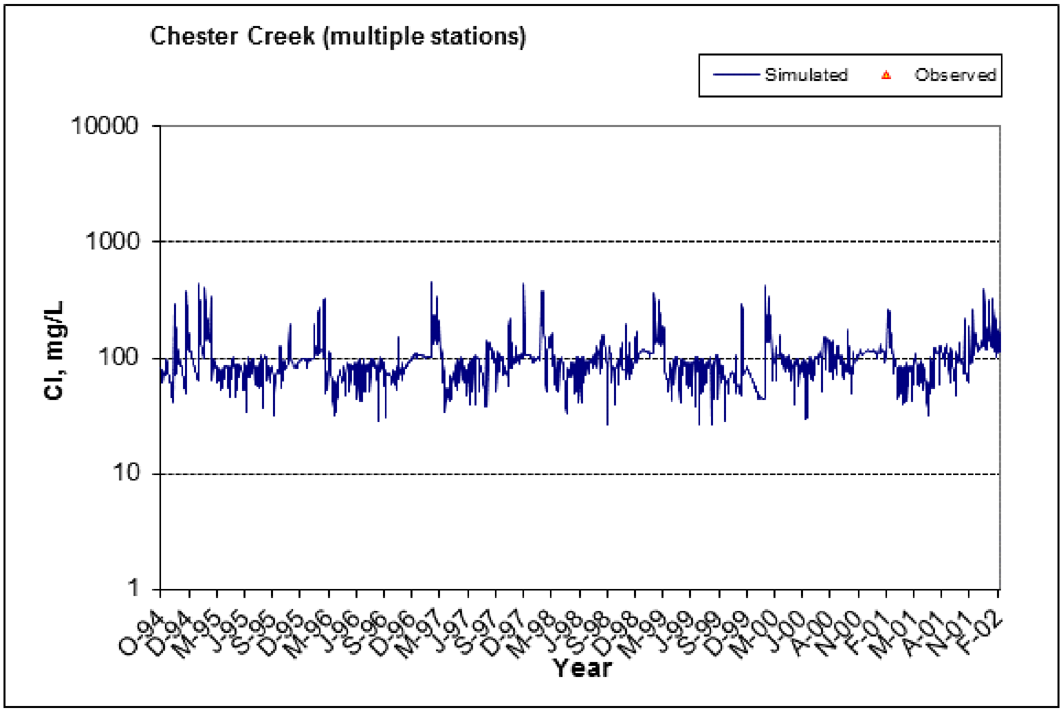


Figure F-100. Cl Concentration Time Series at the Chester Creek (multiple stations) (1994-2001)

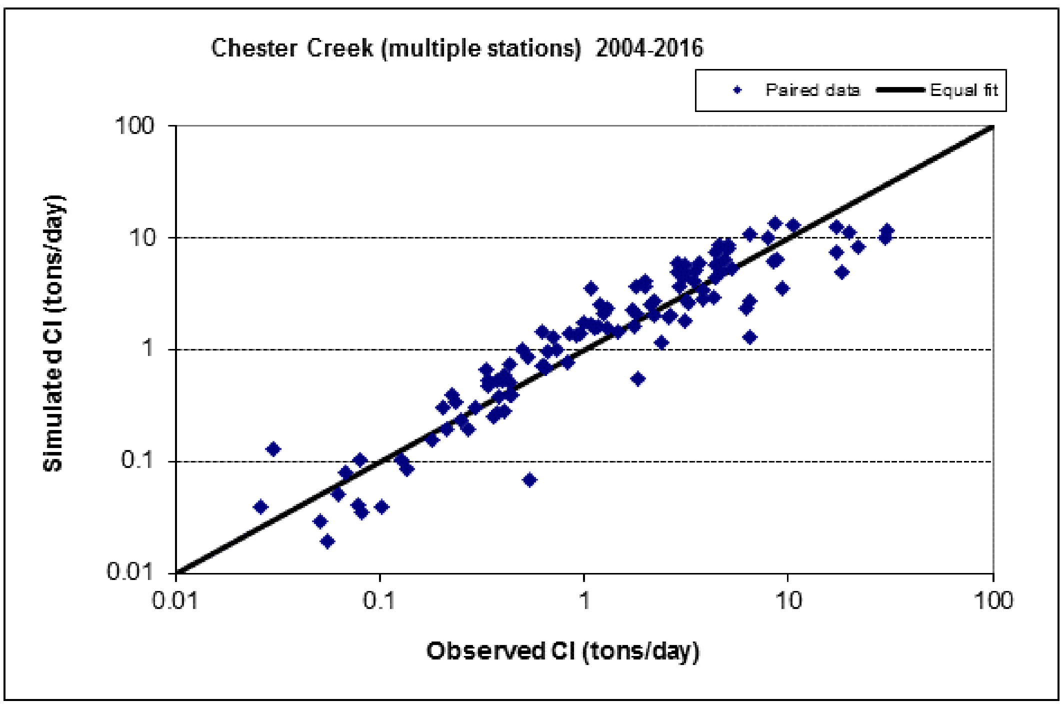


Figure F-101. Paired Simulated vs Observed Cl Load at the Chester Creek (multiple stations) (Calibration Period)

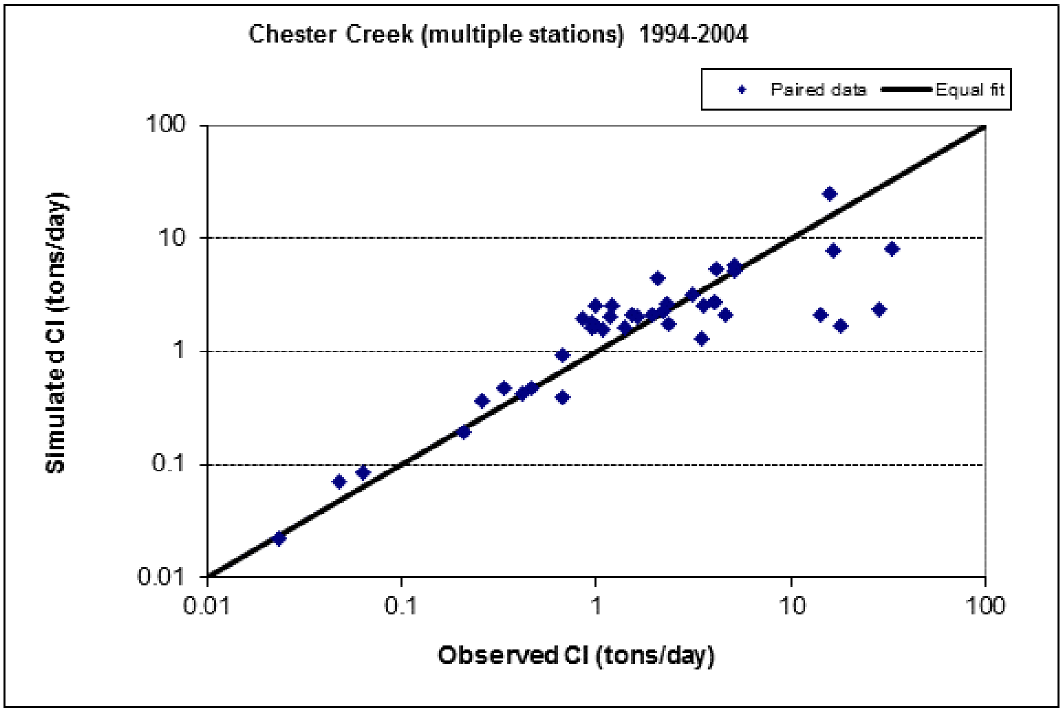


Figure F-102. Paired Simulated vs Observed Cl Load at the Chester Creek (multiple stations) (Validation Period)

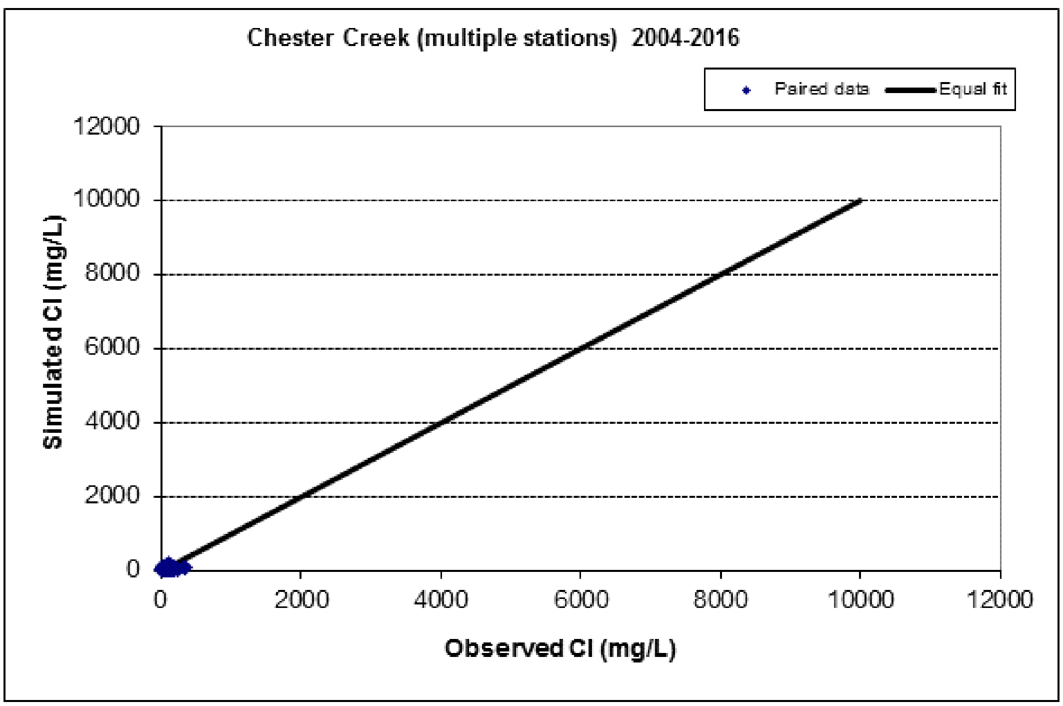


Figure F-103. Paired Simulated vs Observed Cl Concentration at the Chester Creek (multiple stations) (Calibration Period)

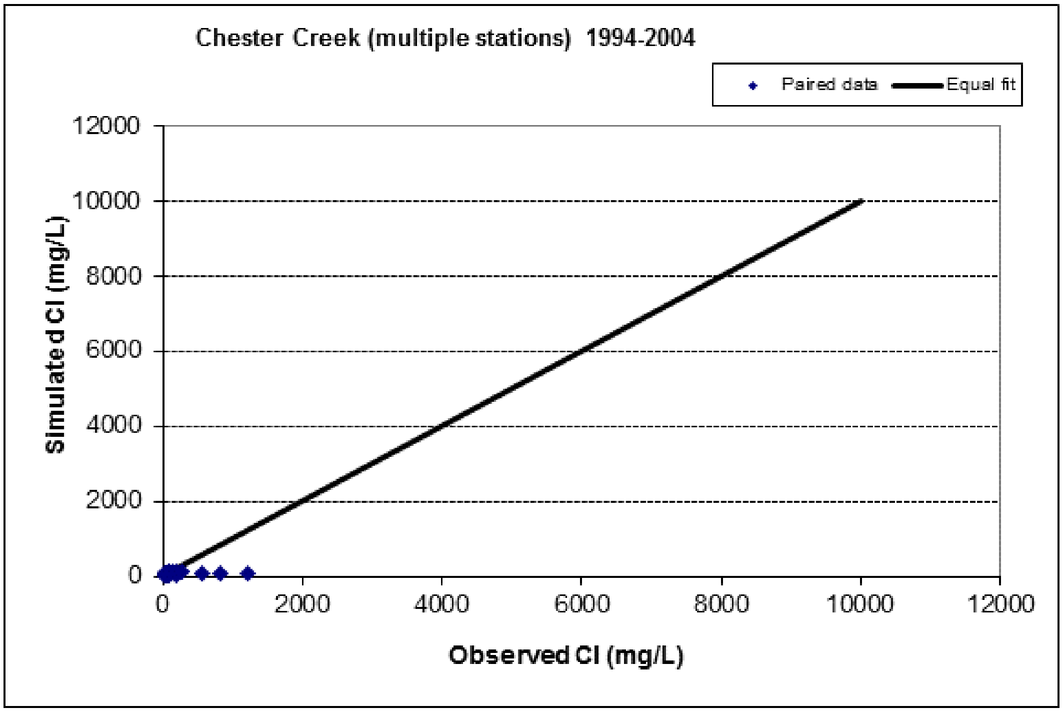


Figure F-104. Paired Simulated vs Observed Cl Concentration at the Chester Creek (multiple stations) (Validation Period)

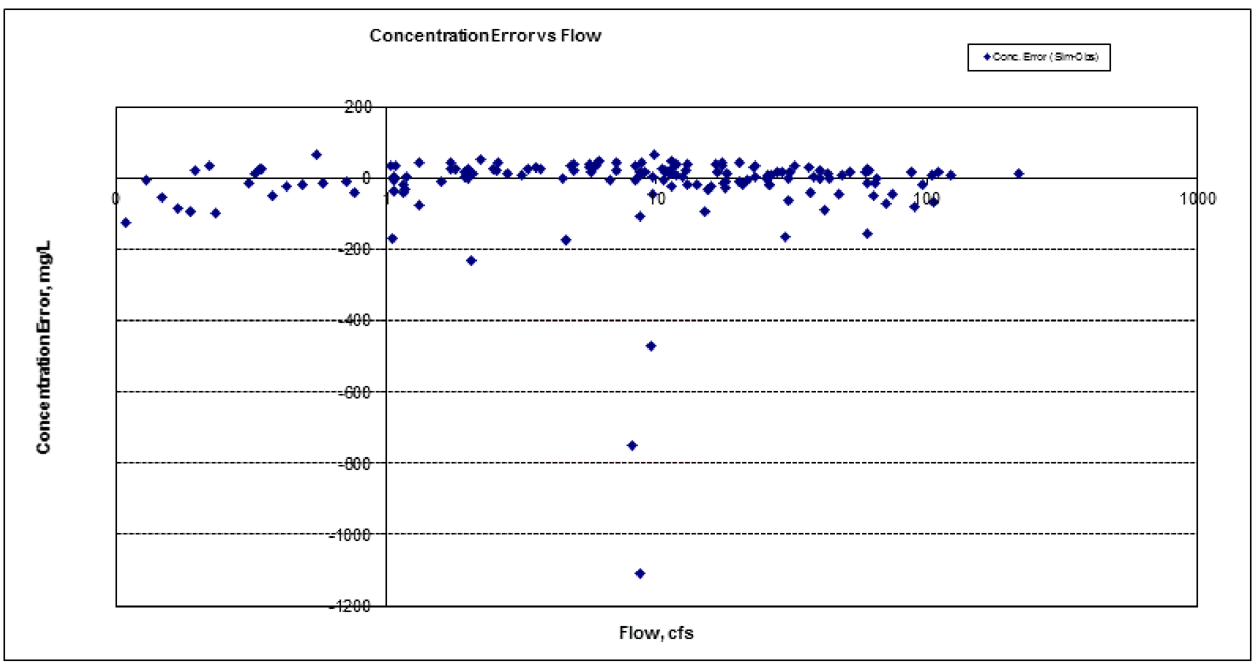


Figure F-105. Cl Concentration Error vs Flow at the Chester Creek (multiple stations)

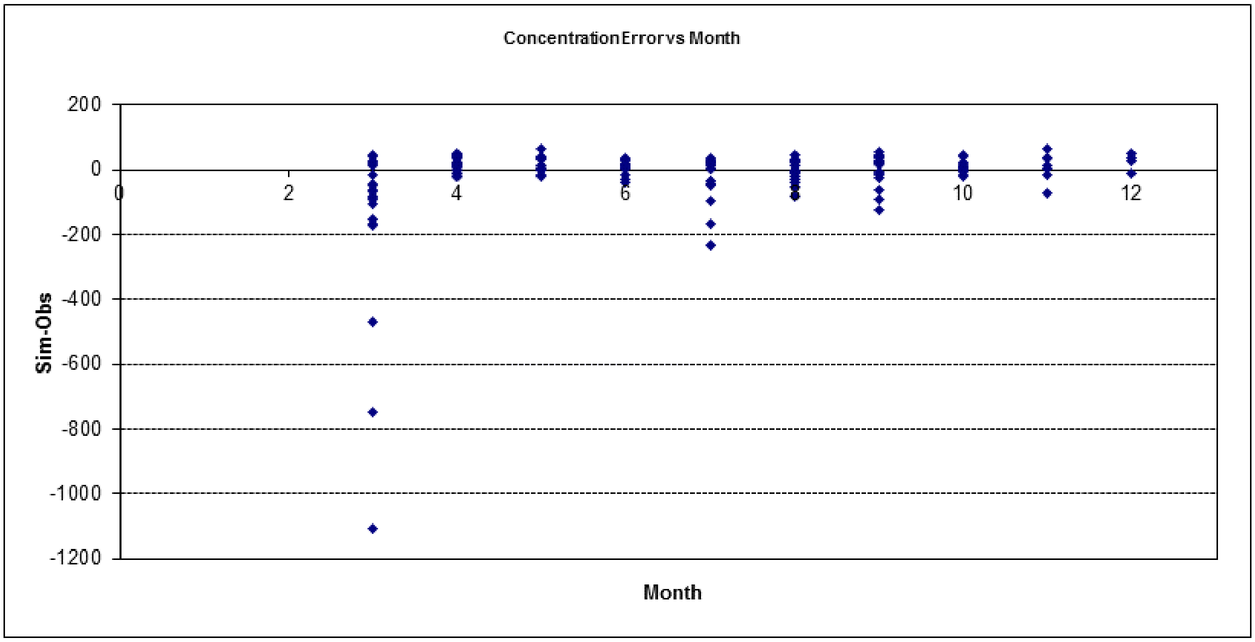


Figure F-106. Cl Concentration Error vs Month at the Chester Creek (multiple stations)

F.11 Miller Creek, Upper Gage at Hwy 53 - Discrete

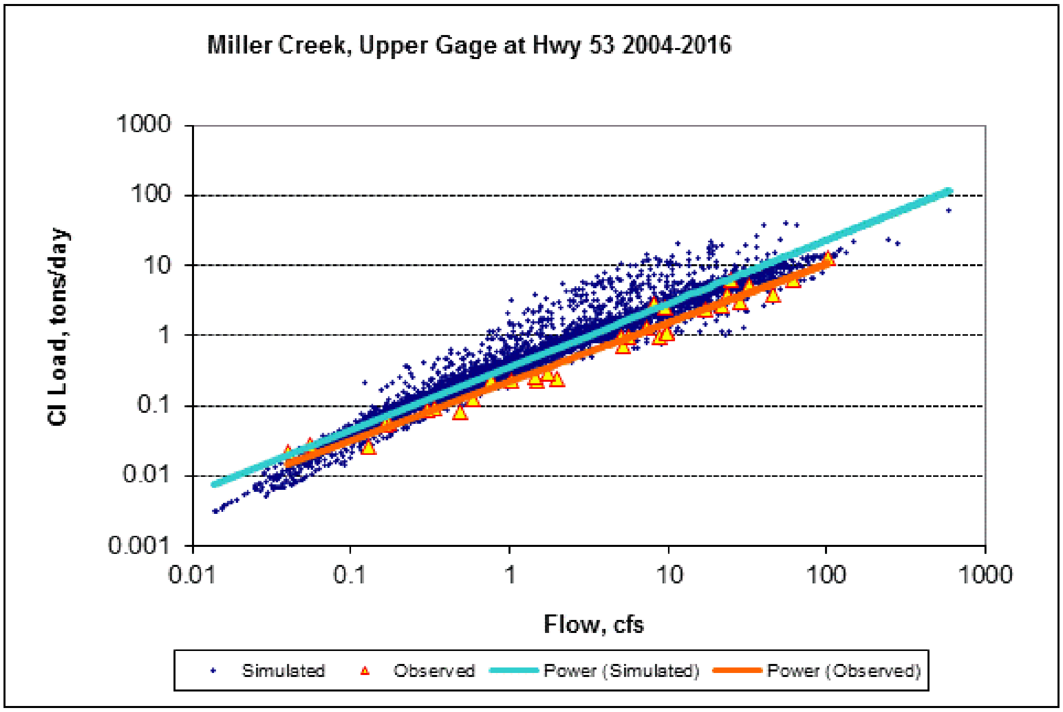


Figure F-107. Power Plot of Simulated and Observed Cl Load vs Flow at the Miller Creek, Upper Gage at Hwy 53 (Calibration Period)

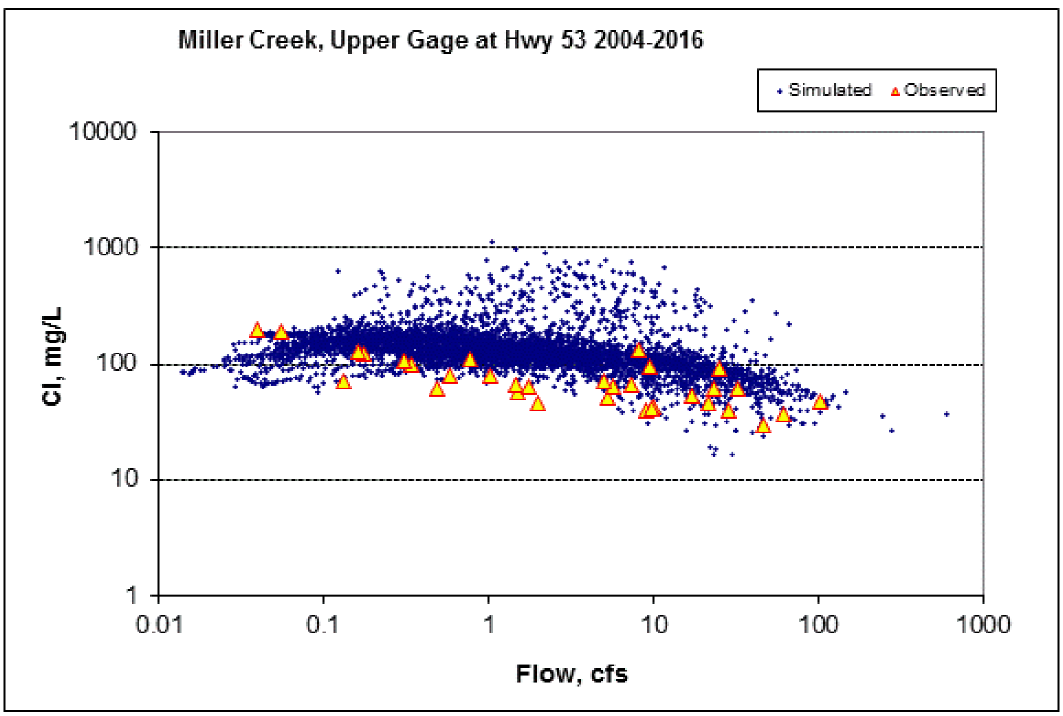


Figure F-108. Simulated and Observed Cl Concentration vs Flow Plot at the Miller Creek, Upper Gage at Hwy 53 (Calibration Period)

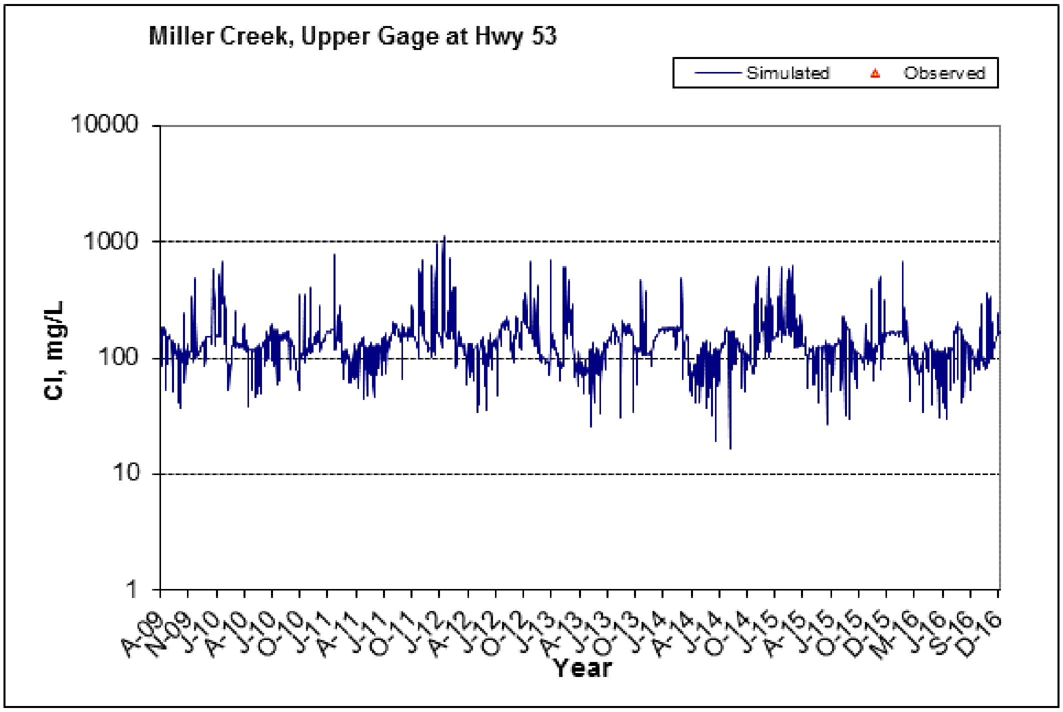


Figure F-109. Cl Concentration Time Series at the Miller Creek, Upper Gage at Hwy 53 (2008-2015)

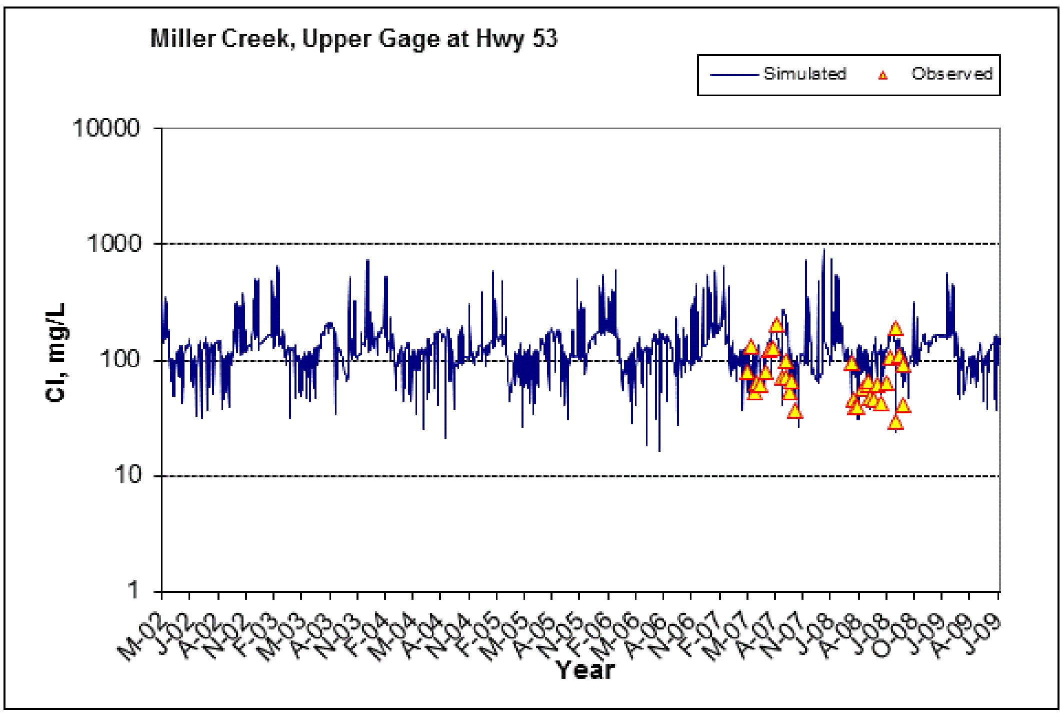


Figure F-110. Cl Concentration Time Series at the Miller Creek, Upper Gage at Hwy 53 (2001-2008)

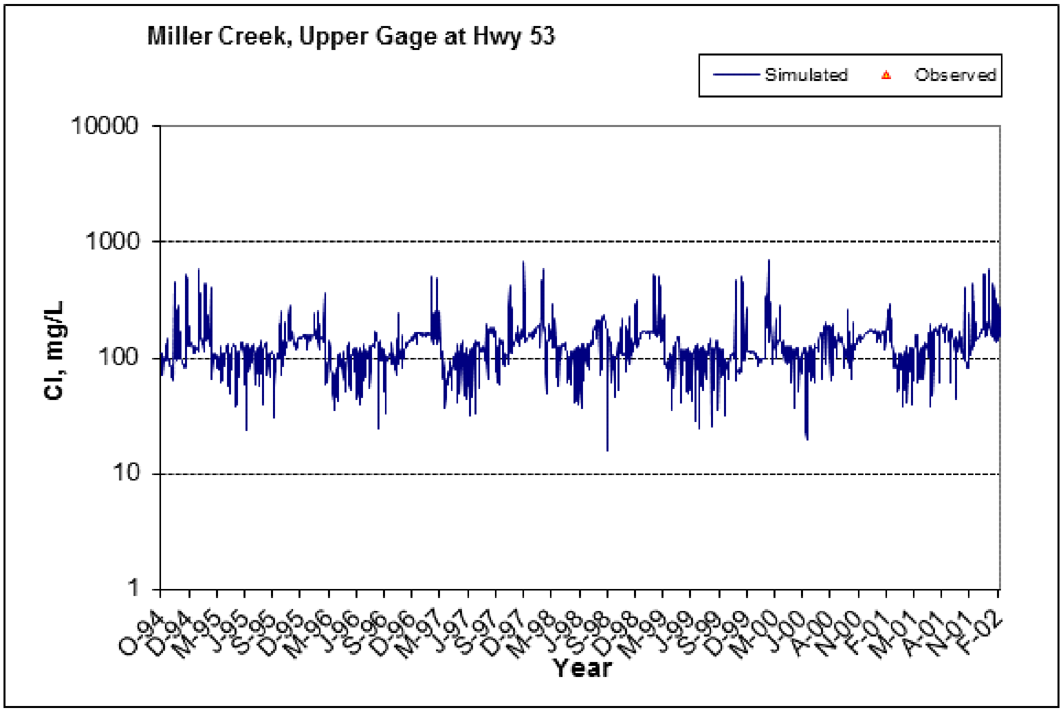


Figure F-111. Cl Concentration Time Series at the Miller Creek, Upper Gage at Hwy 53 (1994-2001)

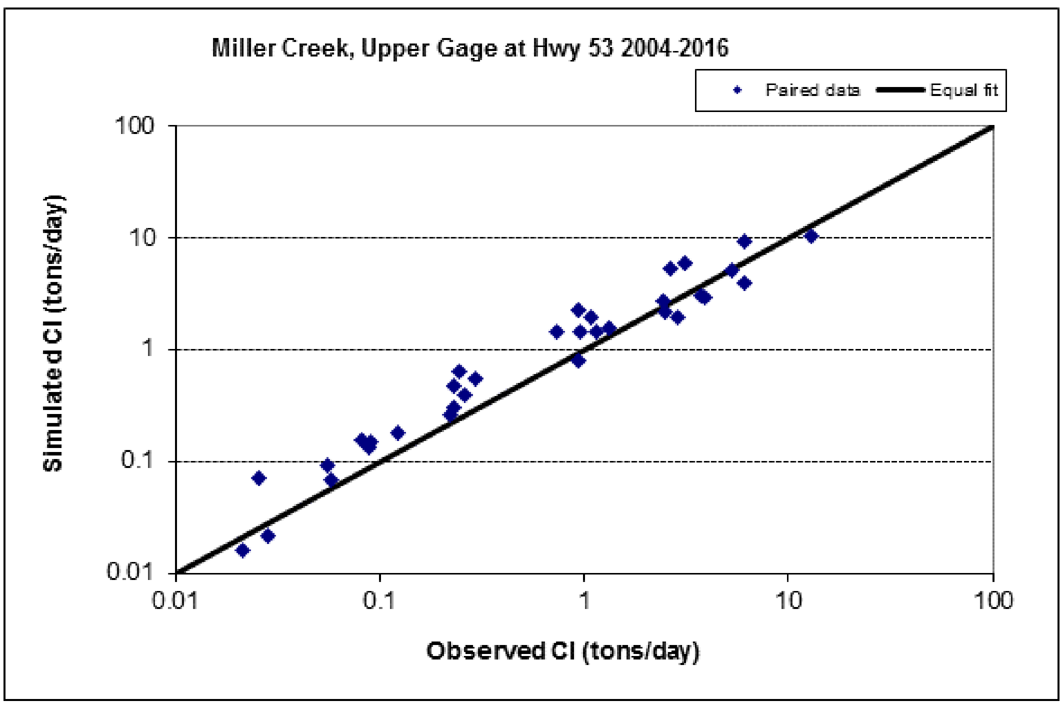


Figure F-112. Paired Simulated vs Observed Cl Load at the Miller Creek, Upper Gage at Hwy 53 (Calibration Period)

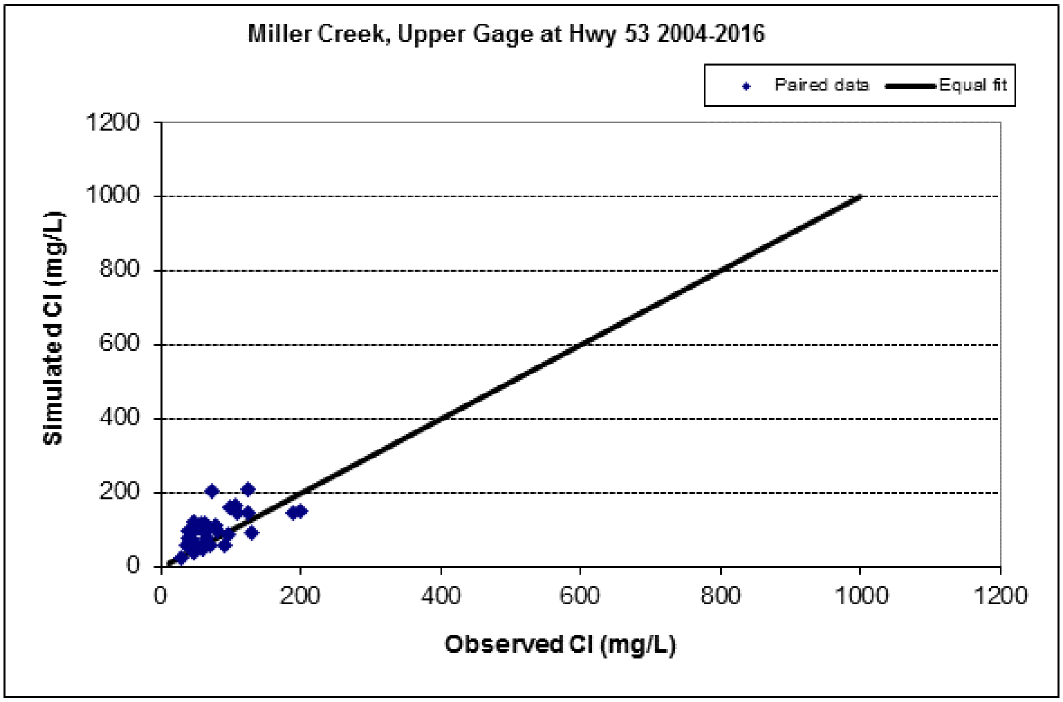


Figure F-113. Paired Simulated vs Observed Cl Concentration at the Miller Creek, Upper Gage at Hwy 53 (Calibration Period)

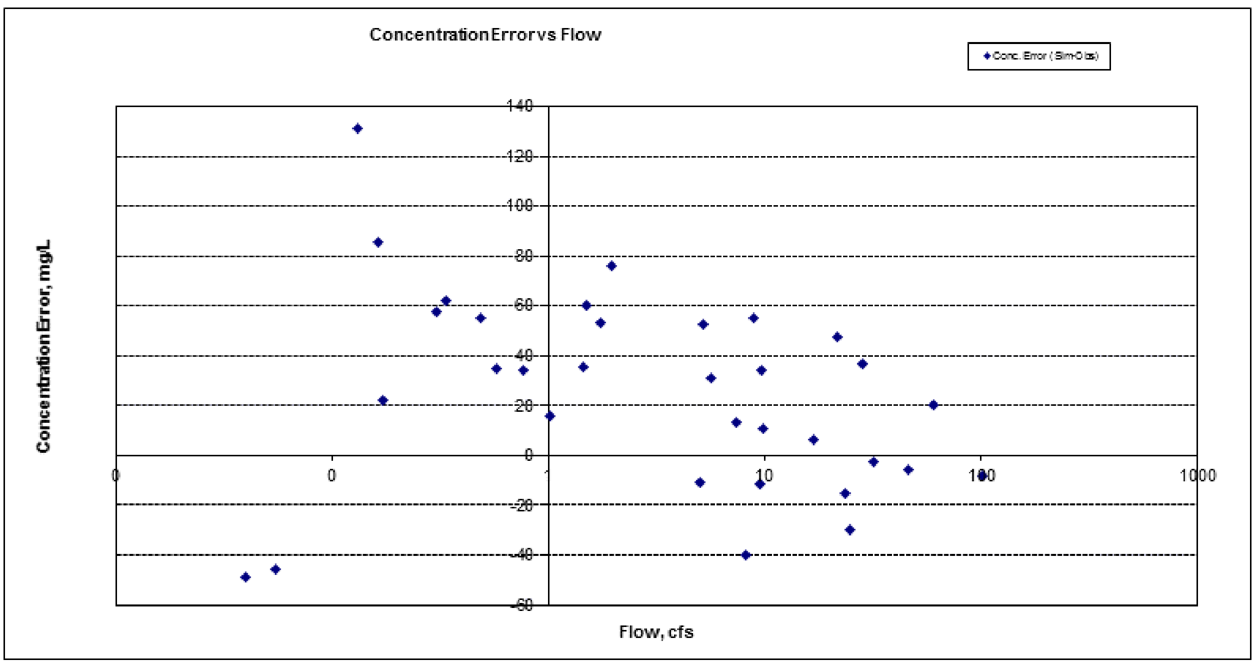


Figure F-114. Cl Concentration Error vs Flow at the Miller Creek, Upper Gage at Hwy 53

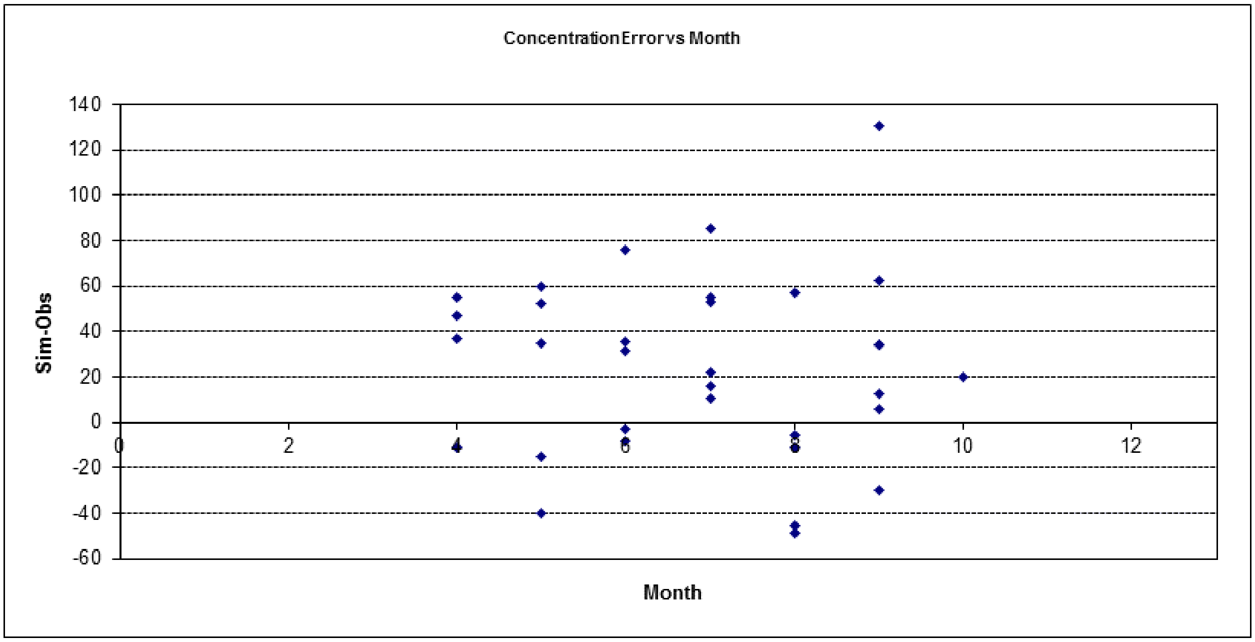


Figure F-115. Cl Concentration Error vs Month at the Miller Creek, Upper Gage at Hwy 53

F.12 Miller Creek, Upper Gage at Hwy 53 - Continuous

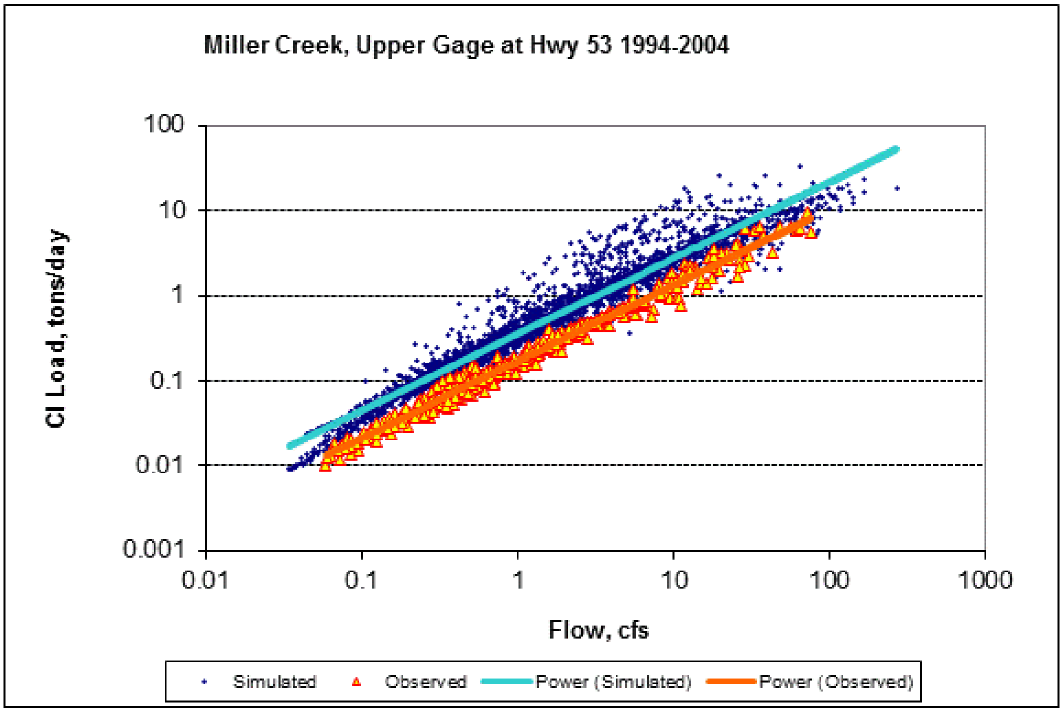


Figure F-116. Power Plot of Simulated and Observed Cl Load vs Flow at the Miller Creek, Upper Gage at Hwy 53 (Validation Period)

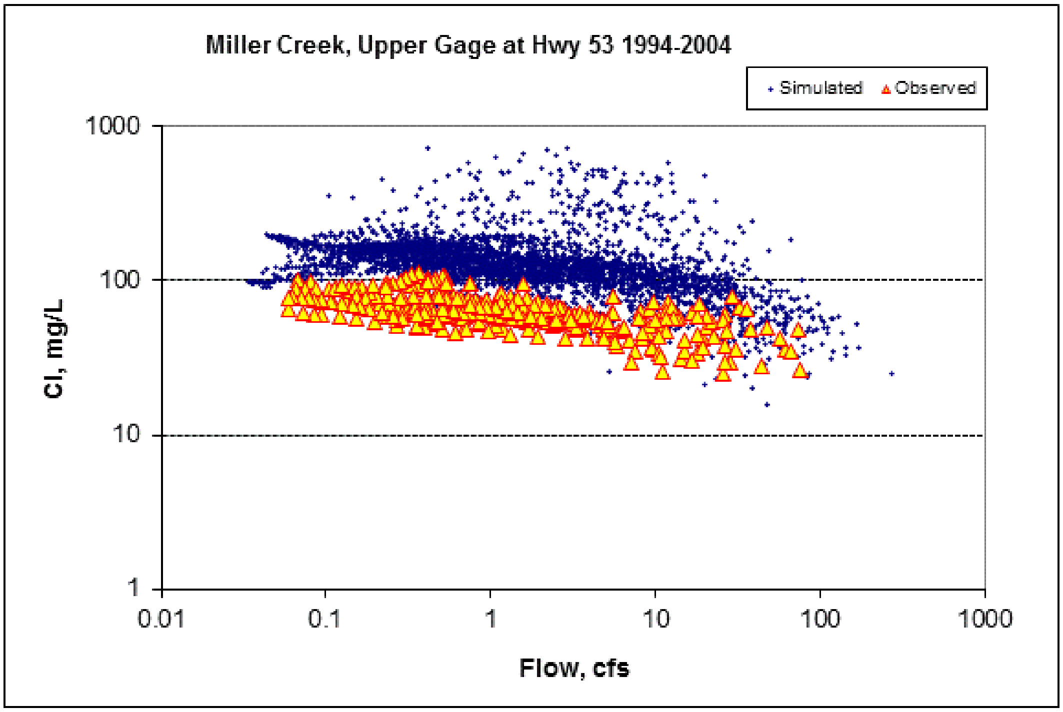


Figure F-117. Simulated and Observed Cl Concentration vs Flow Plot at the Miller Creek, Upper Gage at Hwy 53 (Validation Period)

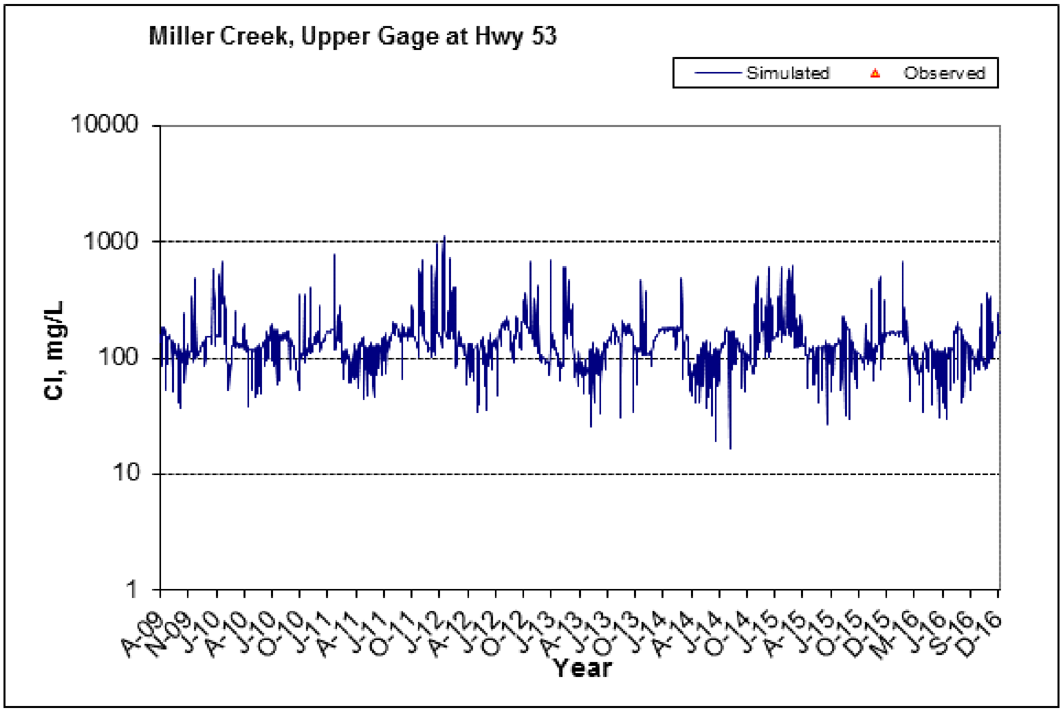


Figure F-118. Cl Concentration Time Series at the Miller Creek, Upper Gage at Hwy 53 (2008-2015)

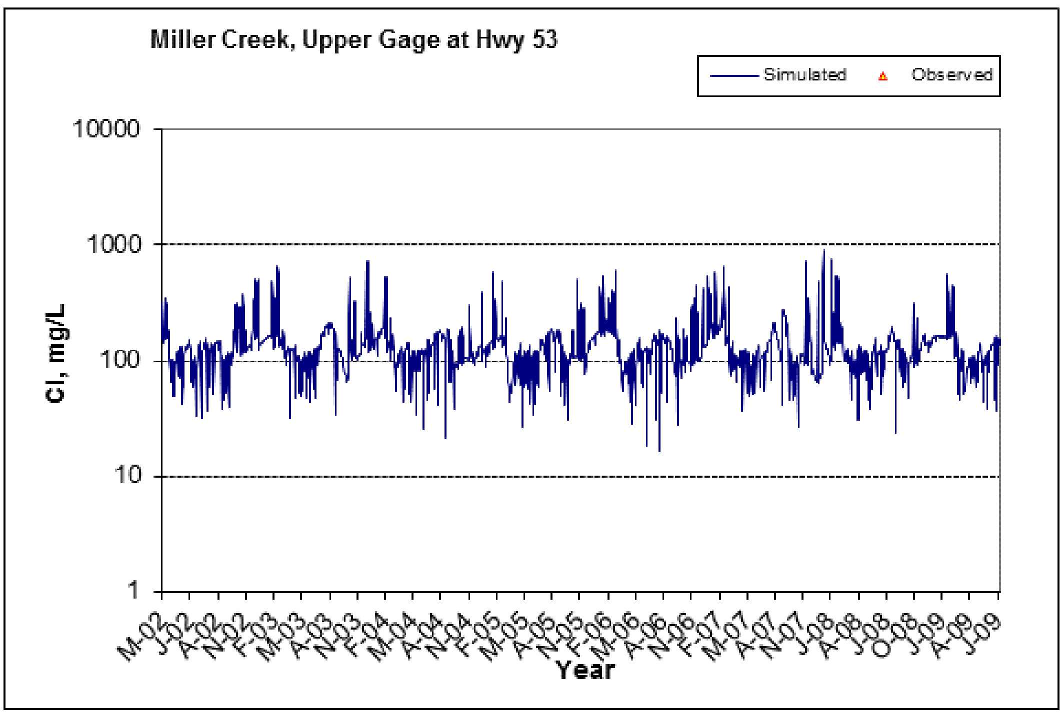


Figure F-119. Cl Concentration Time Series at the Miller Creek, Upper Gage at Hwy 53 (2001-2008)

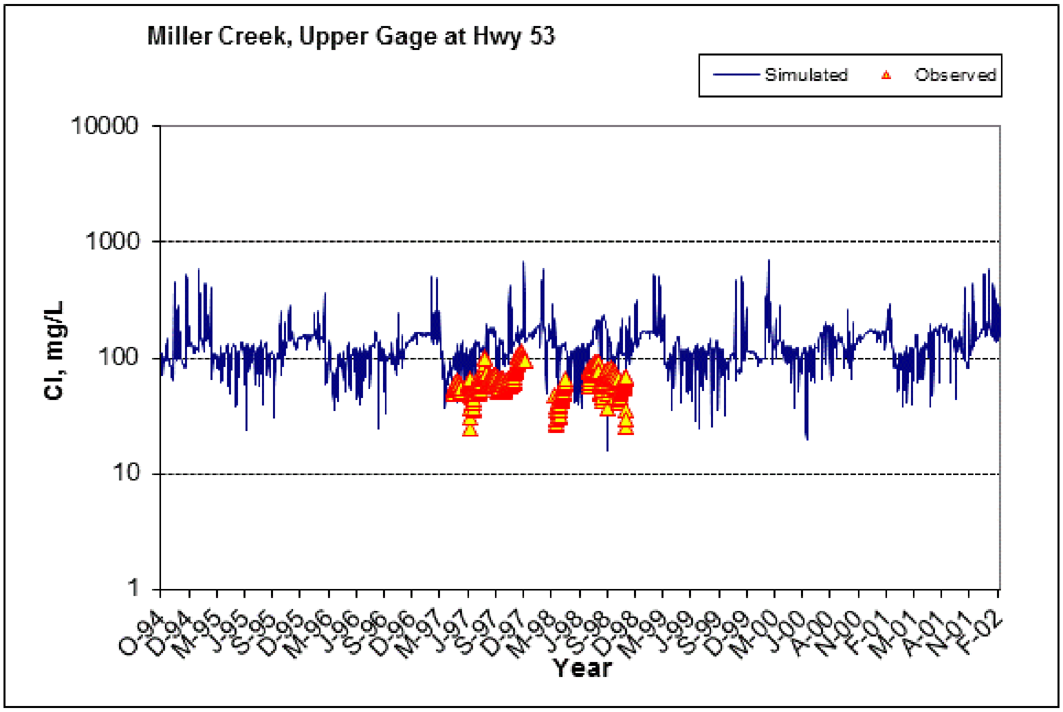


Figure F-120. Cl Concentration Time Series at the Miller Creek, Upper Gage at Hwy 53 (1994-2001)

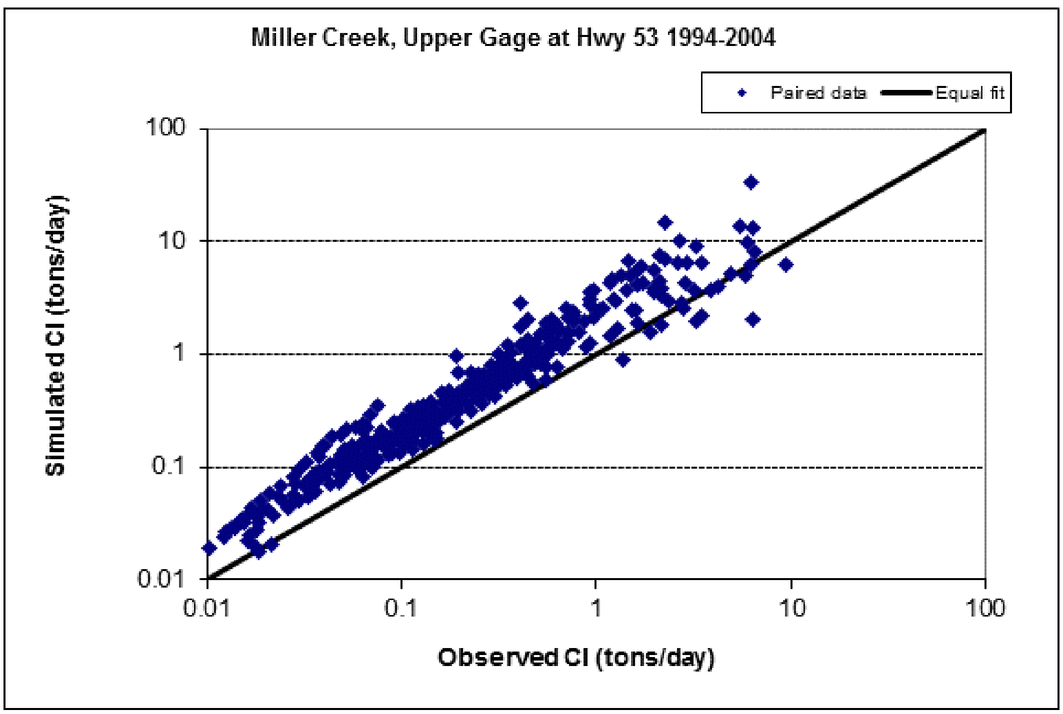


Figure F-121. Paired Simulated vs Observed Cl Load at the Miller Creek, Upper Gage at Hwy 53 (Validation Period)

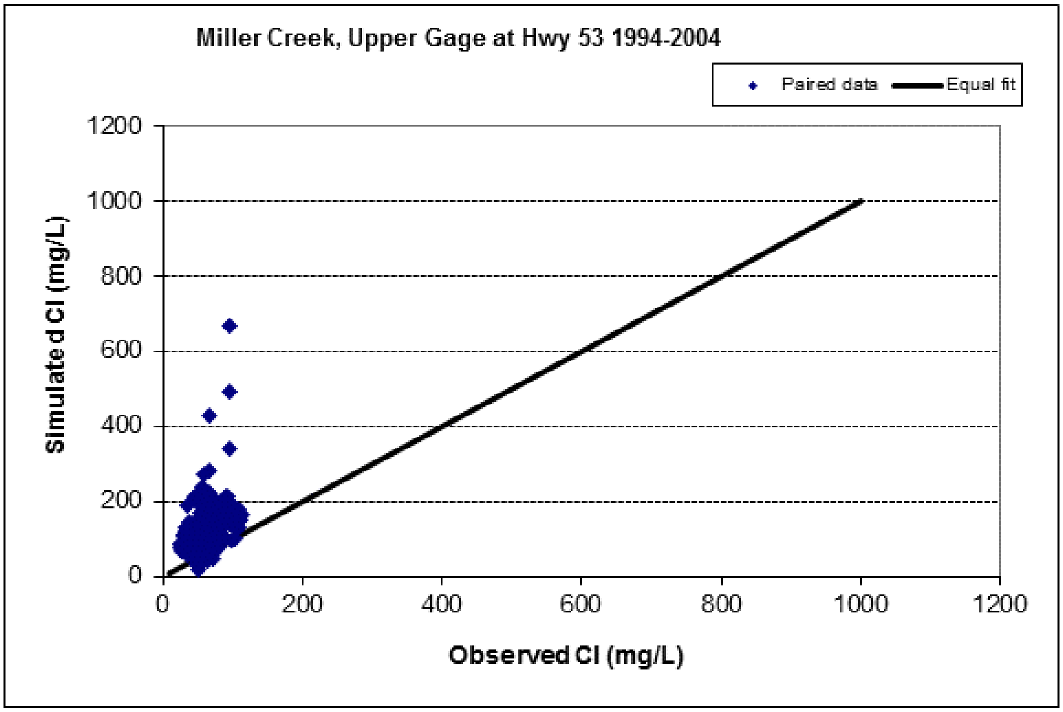


Figure F-122. Paired Simulated vs Observed Cl Concentration at the Miller Creek, Upper Gage at Hwy 53 (Validation Period)

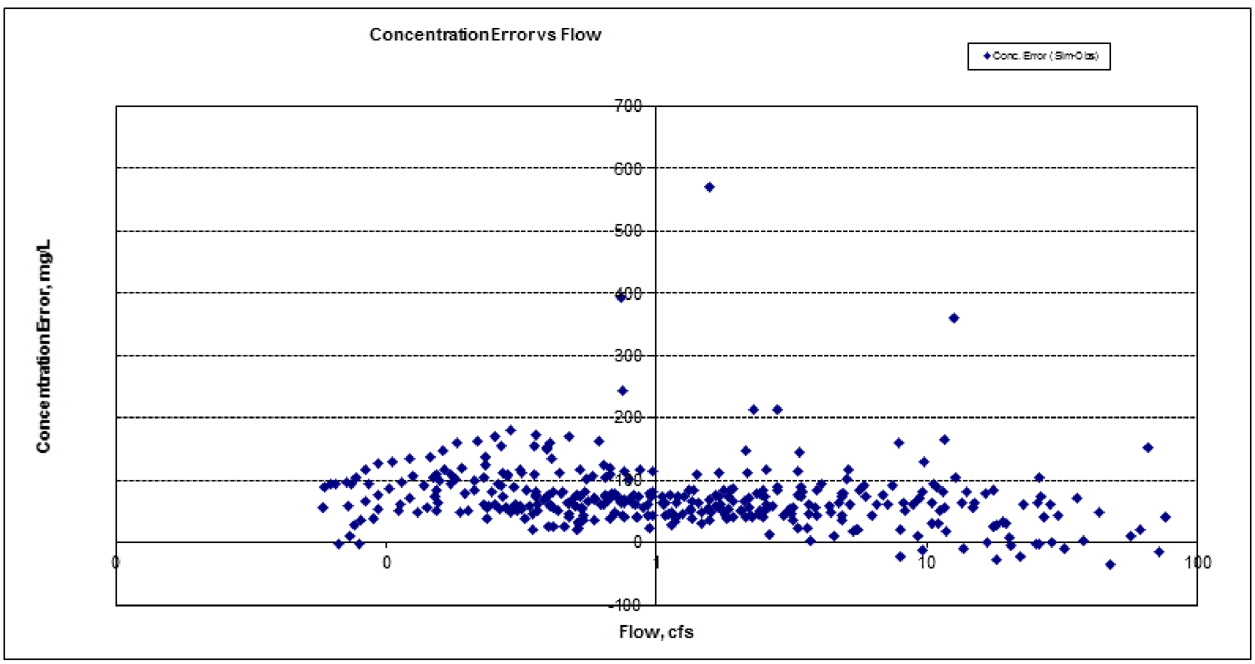


Figure F-123. Cl Concentration Error vs Flow at the Miller Creek, Upper Gage at Hwy 53

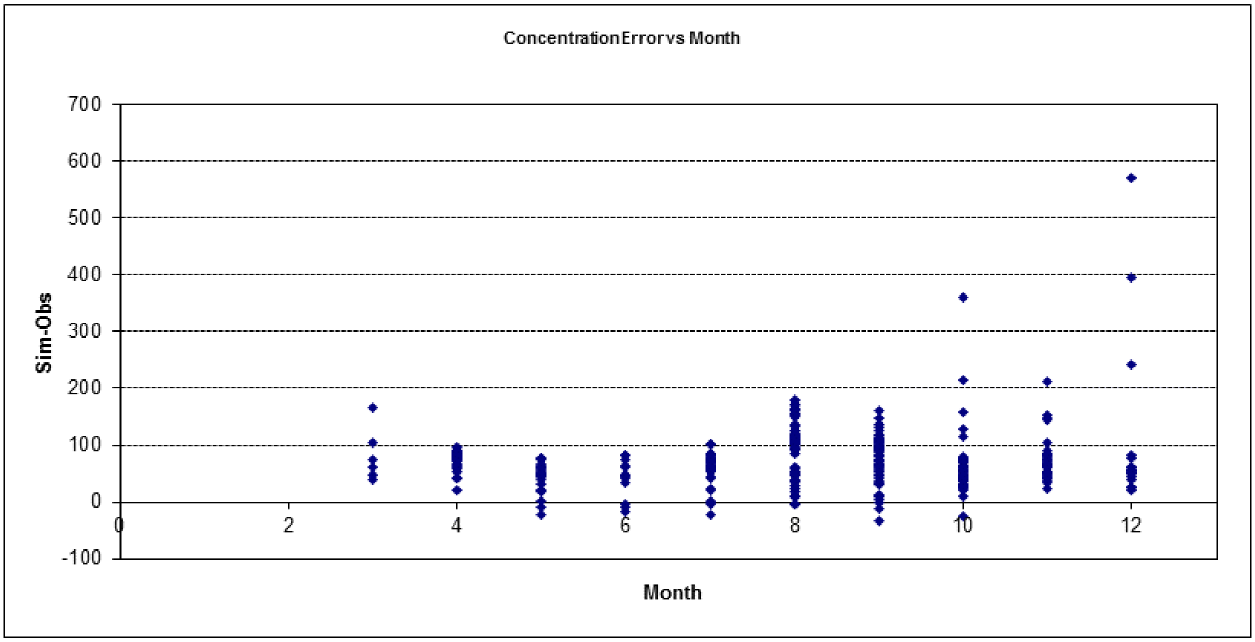


Figure F-124. Cl Concentration Error vs Month at the Miller Creek, Upper Gage at Hwy 53

F.13 Miller Creek at Chambersburg Rd - Discrete

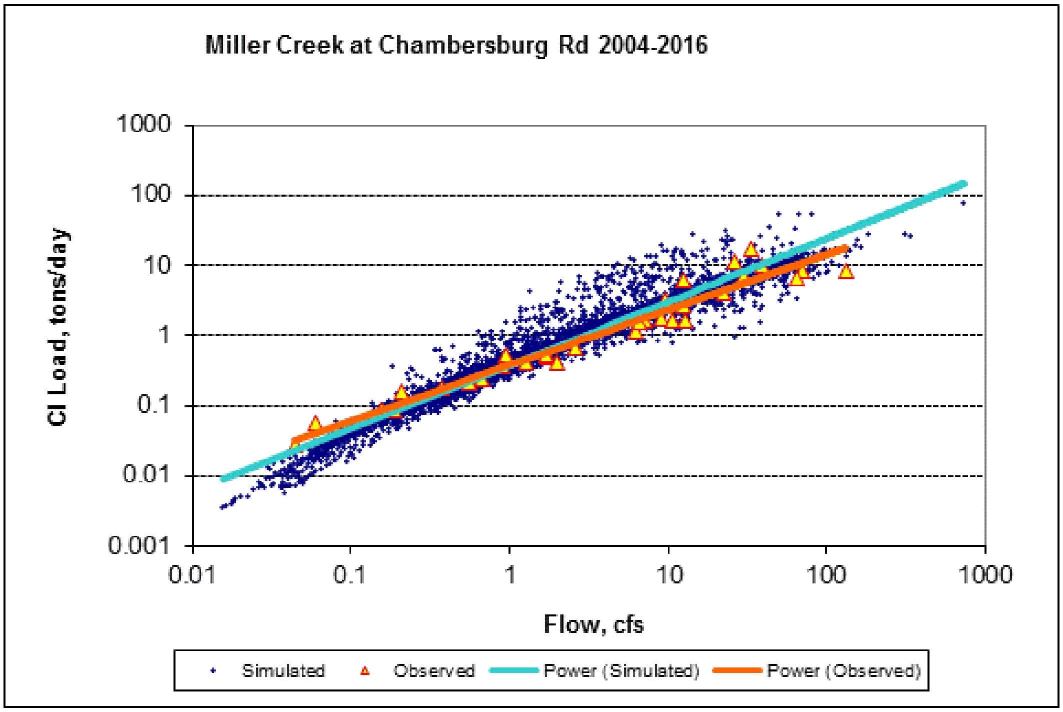


Figure F-125. Power Plot of Simulated and Observed Cl Load vs Flow at the Miller Creek at Chambersburg Rd (Calibration Period)

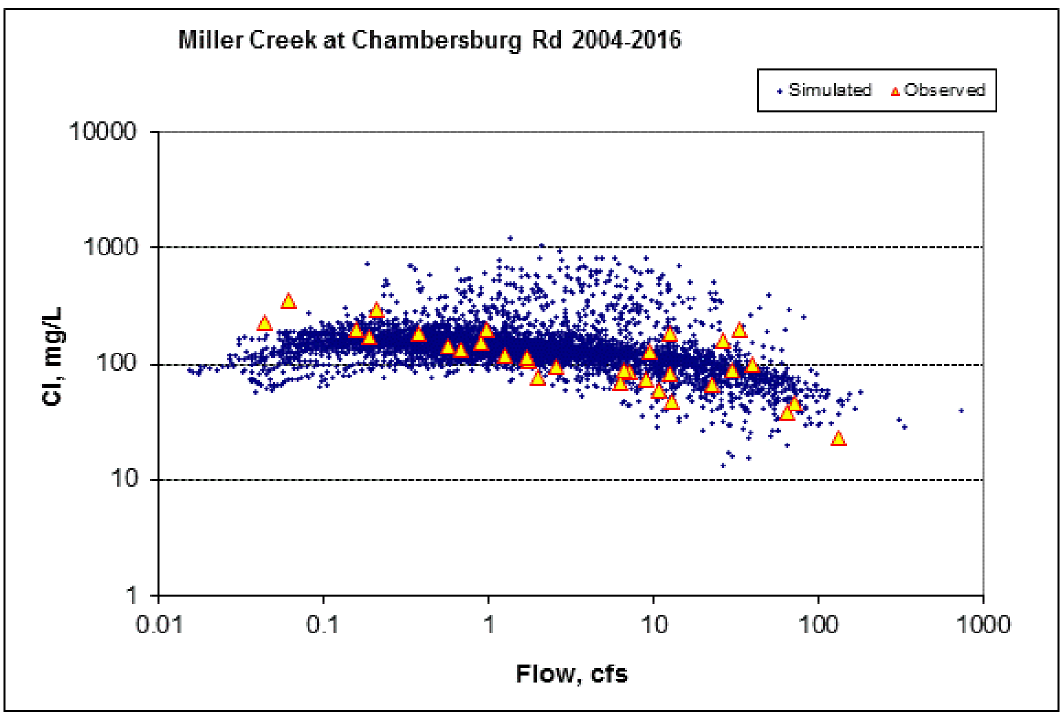


Figure F-126. Simulated and Observed Cl Concentration vs Flow Plot at the Miller Creek at Chambersburg Rd (Calibration Period)

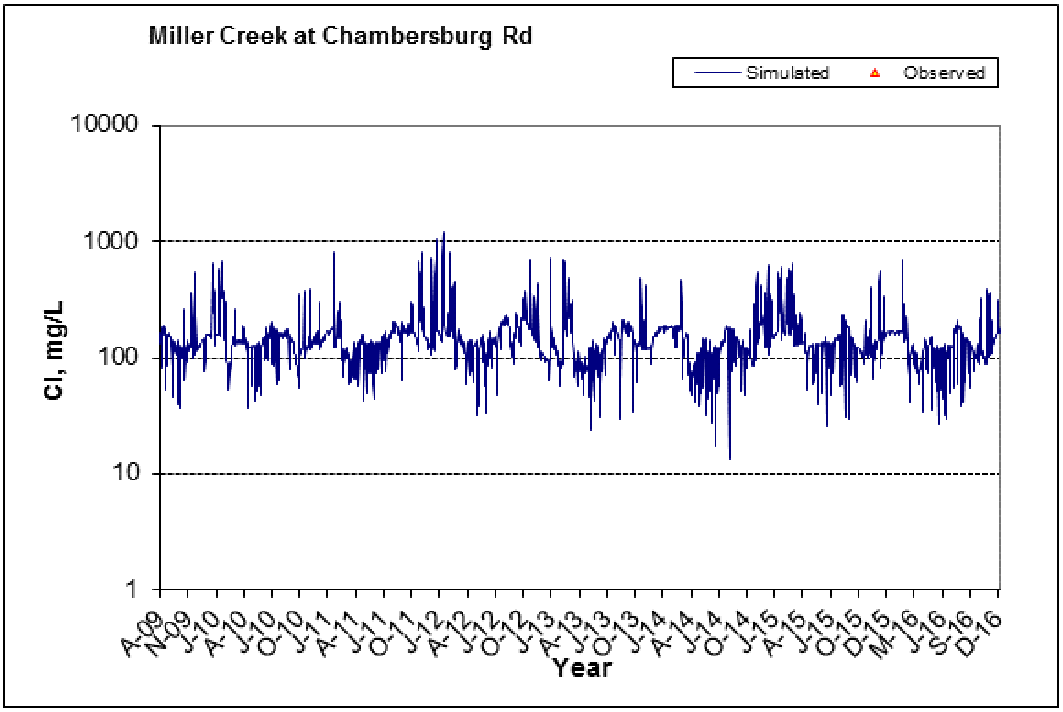


Figure F-127. Cl Concentration Time Series at the Miller Creek at Chambersburg Rd (2008-2015)

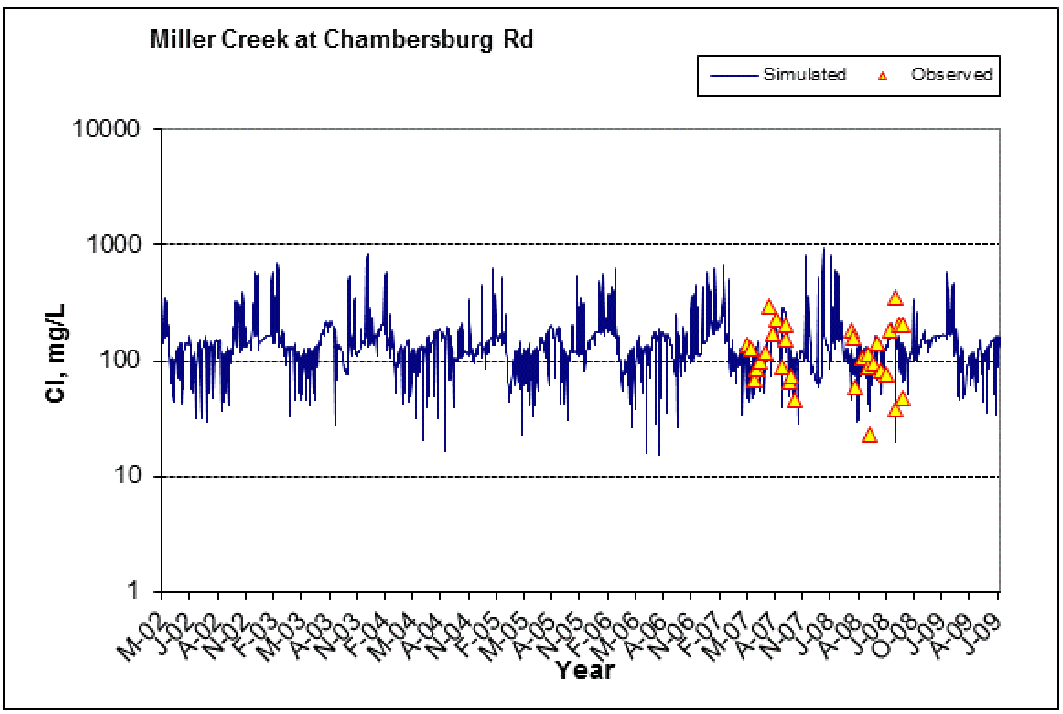


Figure F-128. Cl Concentration Time Series at the Miller Creek at Chambersburg Rd (2001-2008)

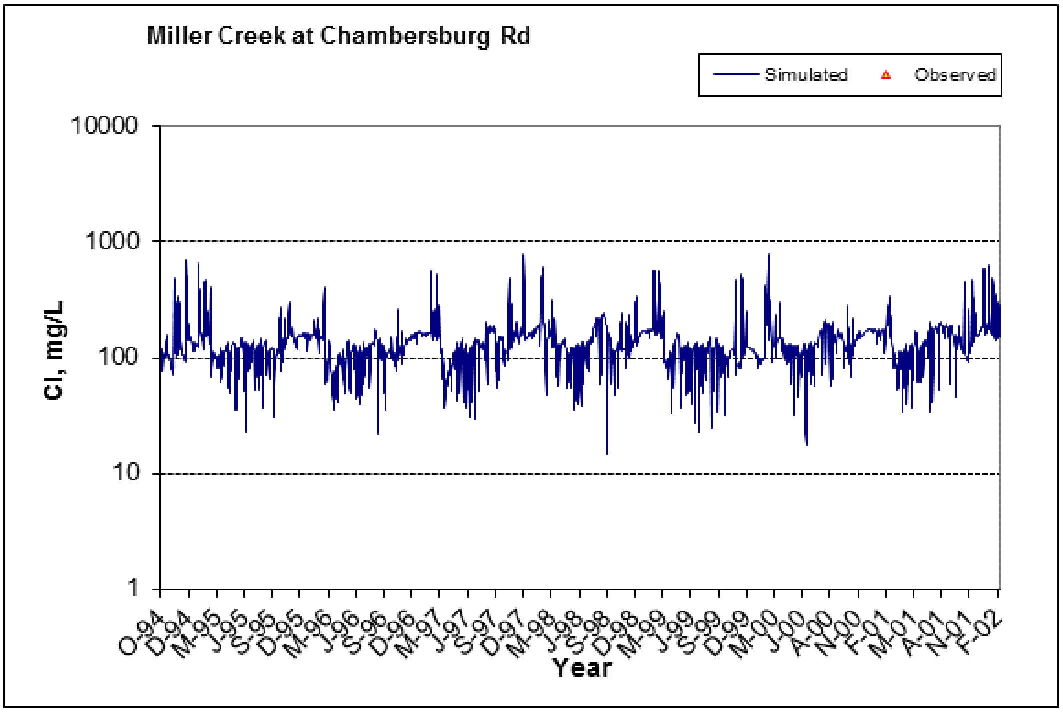


Figure F-129. Cl Concentration Time Series at the Miller Creek at Chambersburg Rd (1994-2001)

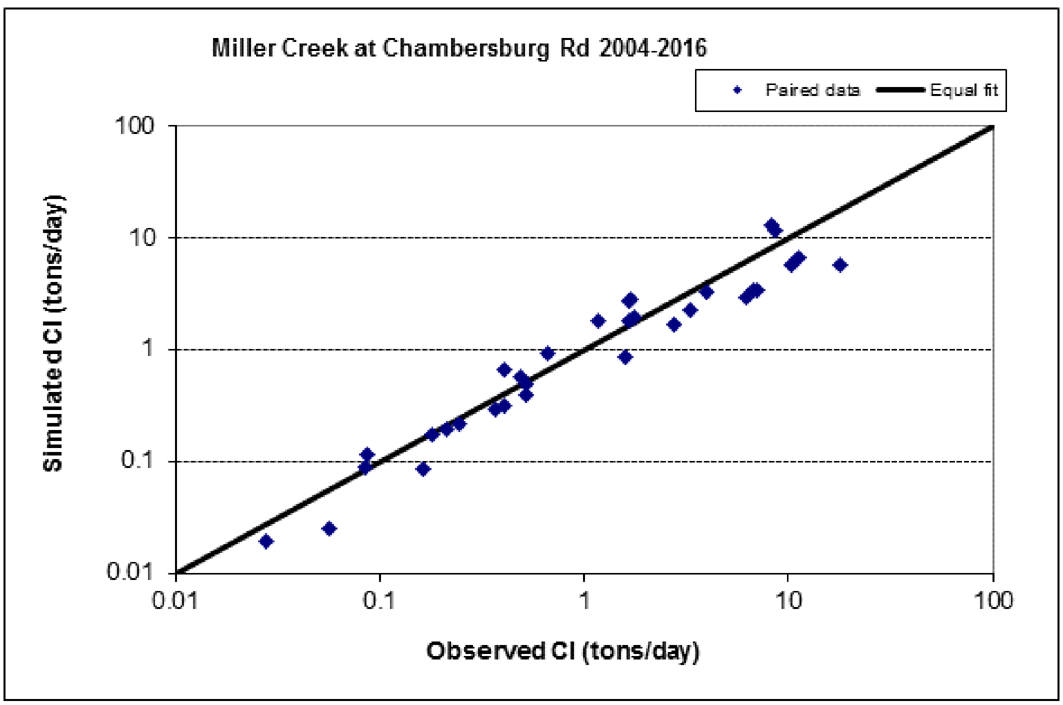


Figure F-130. Paired Simulated vs Observed Cl Load at the Miller Creek at Chambersburg Rd (Calibration Period)

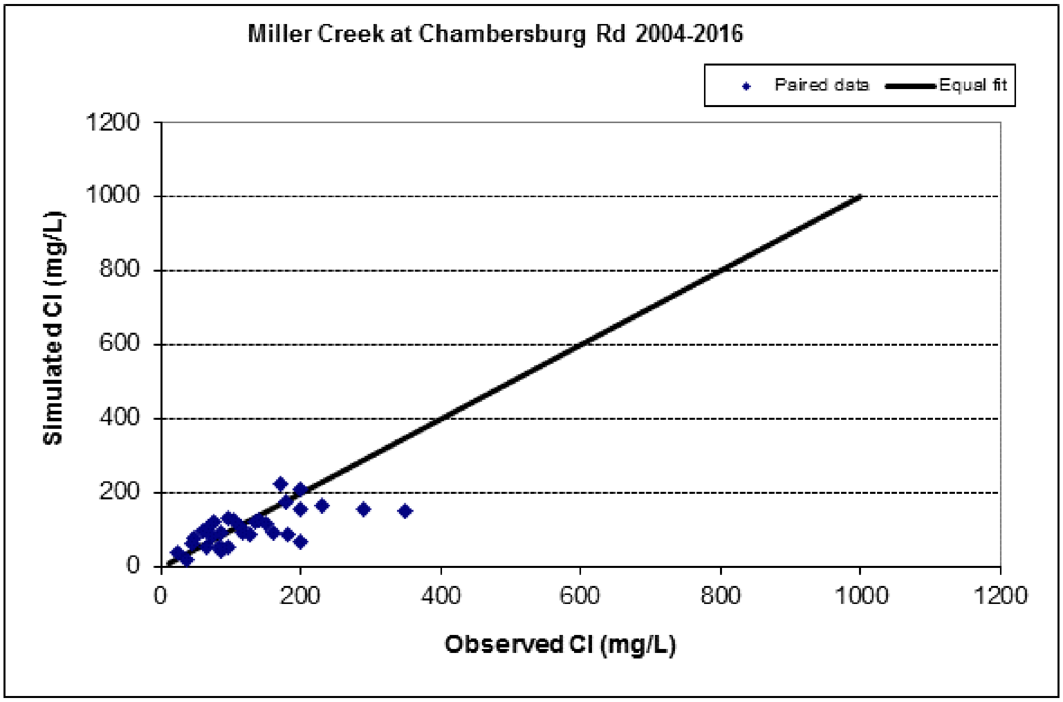


Figure F-131. Paired Simulated vs Observed Cl Concentration at the Miller Creek at Chambersburg Rd (Calibration Period)

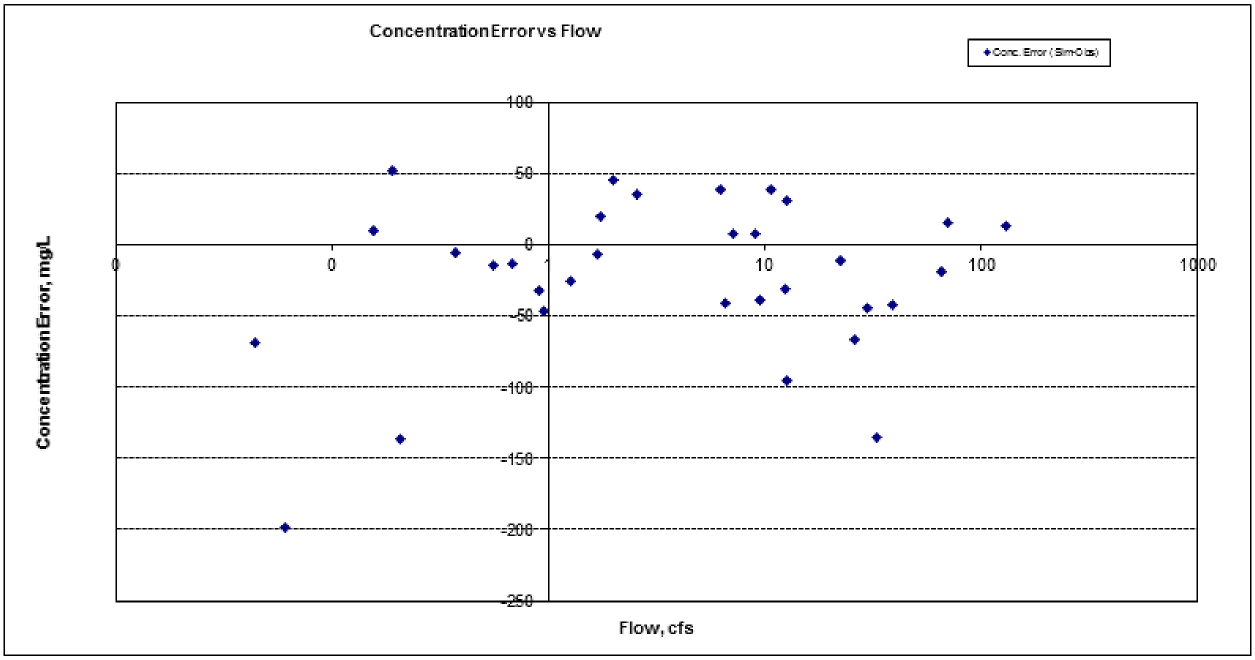


Figure F-132. Cl Concentration Error vs Flow at the Miller Creek at Chambersburg Rd

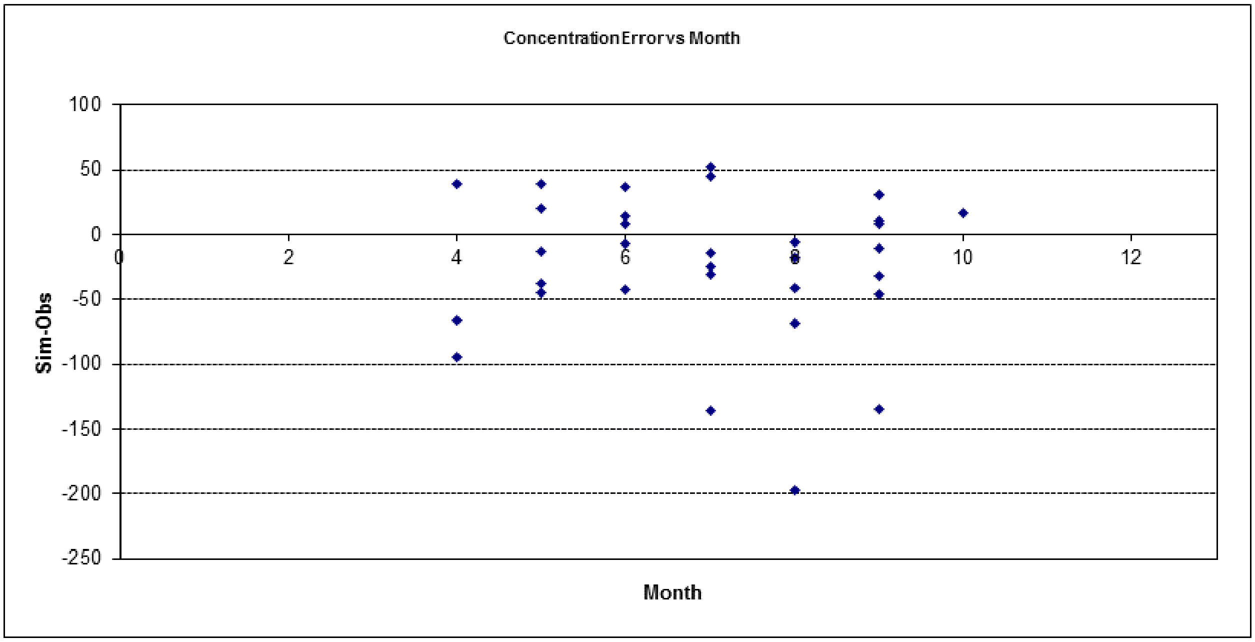


Figure F-133. Cl Concentration Error vs Month at the Miller Creek at Chambersburg Rd

F.14 Miller Creek at Chambersburg Rd - Continuous

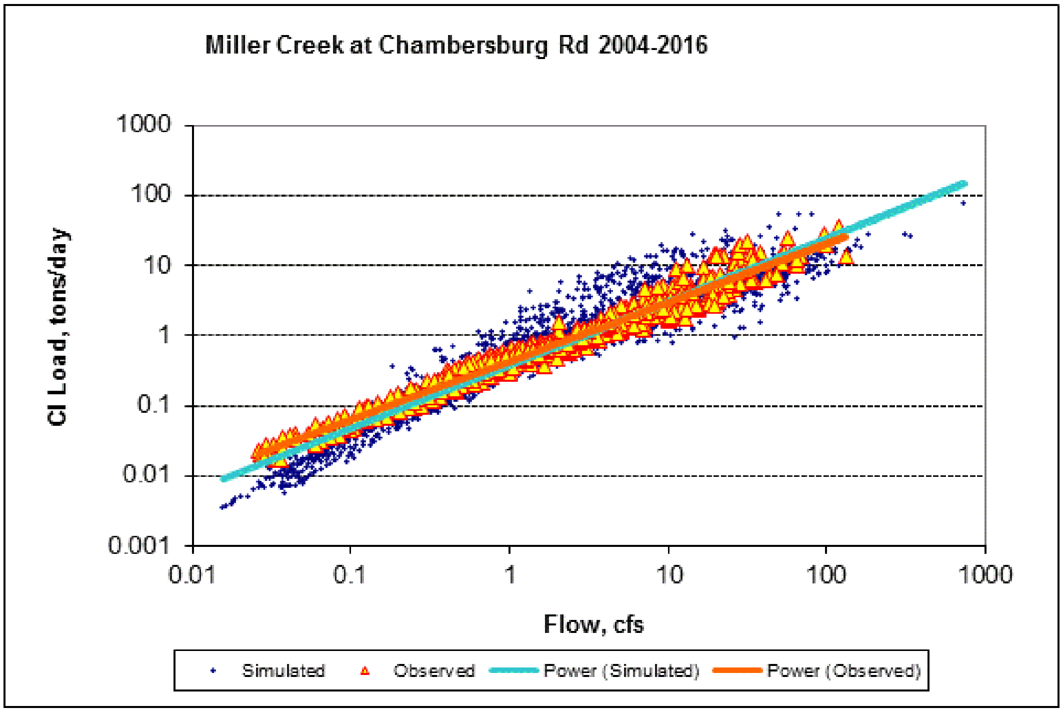


Figure F-134. Power Plot of Simulated and Observed Cl Load vs Flow at the Miller Creek at Chambersburg Rd (Calibration Period)

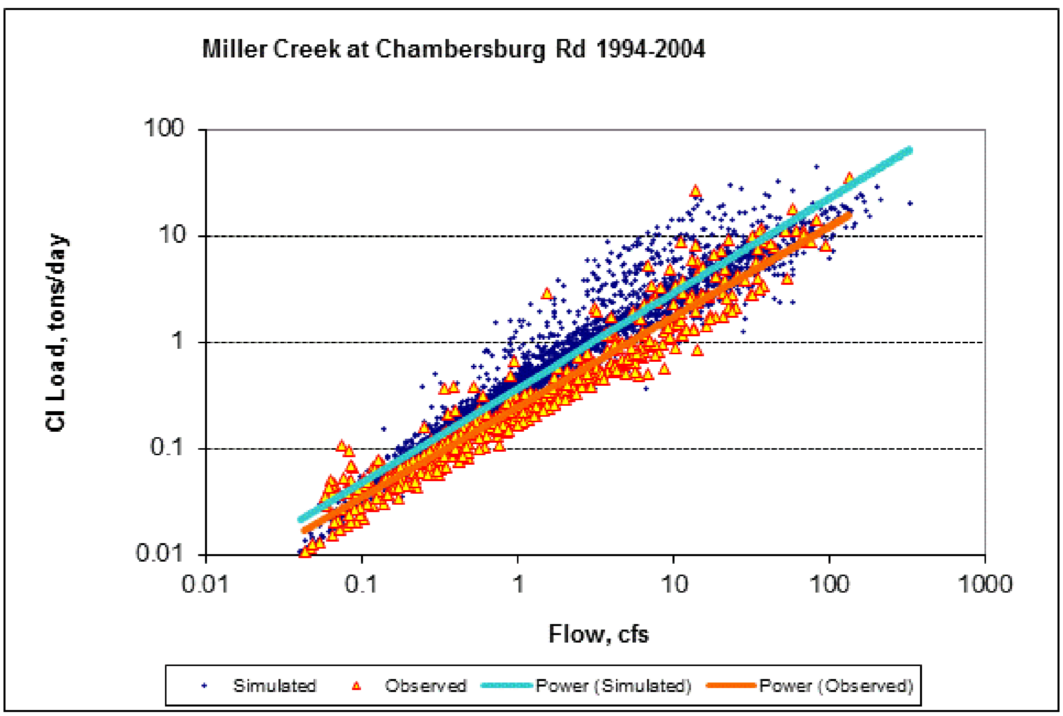


Figure F-135. Power Plot of Simulated and Observed Cl Load vs Flow at the Miller Creek at Chambersburg Rd (Validation Period)

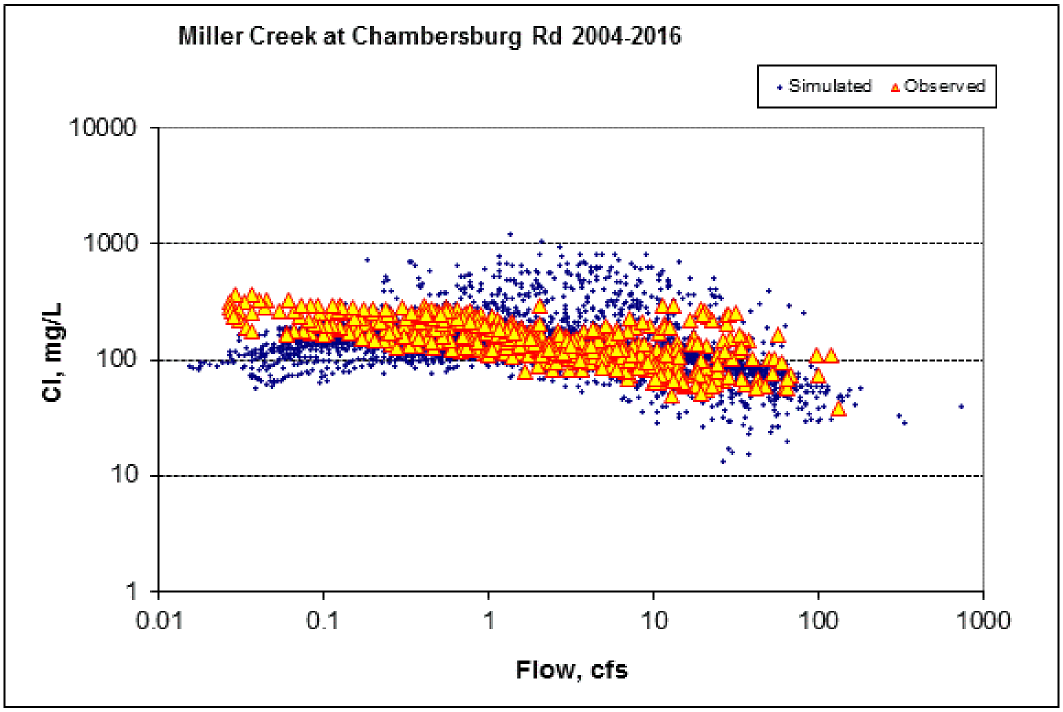


Figure F-136. Simulated and Observed Cl Concentration vs Flow Plot at the Miller Creek at Chambersburg Rd (Calibration Period)

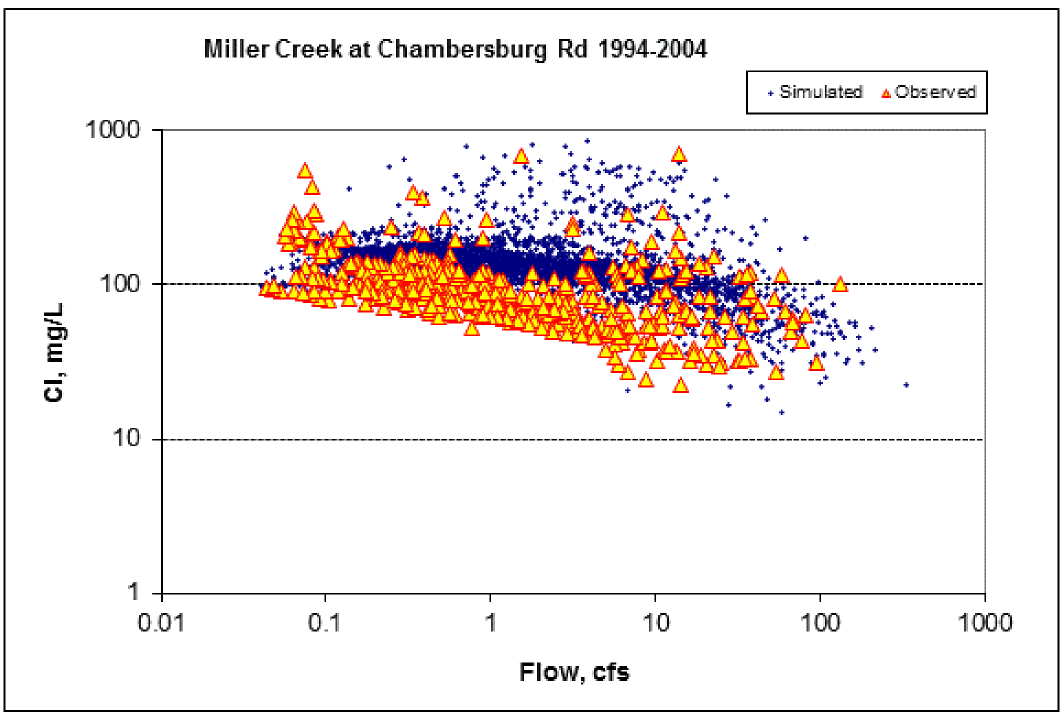


Figure F-137. Simulated and Observed Cl Concentration vs Flow Plot at the Miller Creek at Chambersburg Rd (Validation Period)

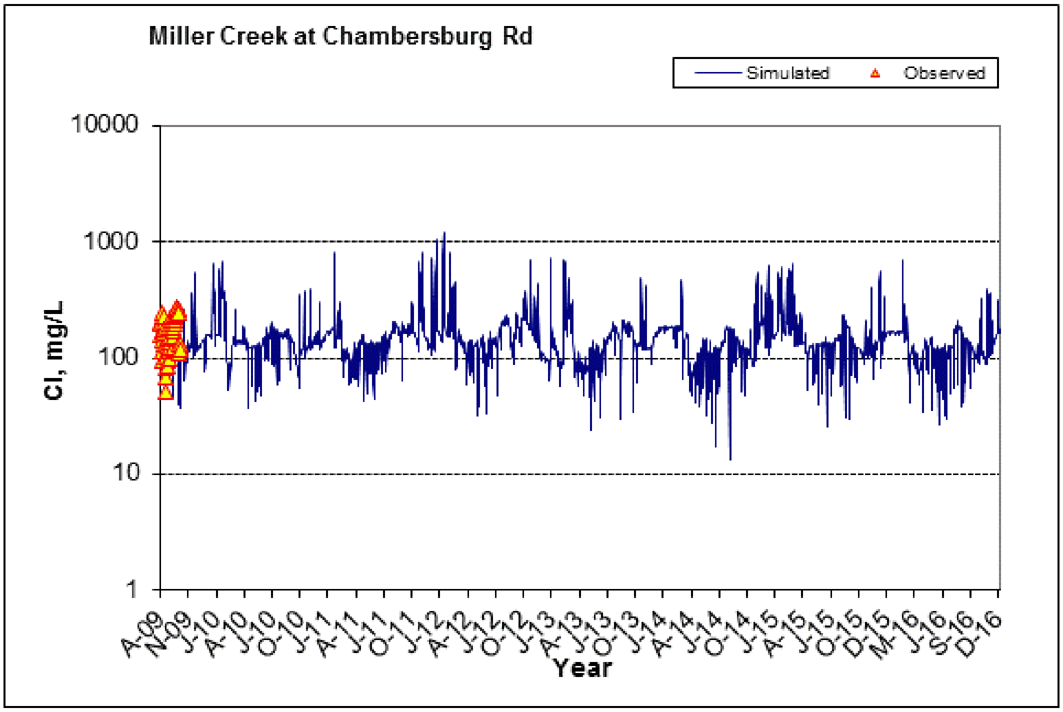


Figure F-138. Cl Concentration Time Series at the Miller Creek at Chambersburg Rd (2008-2015)

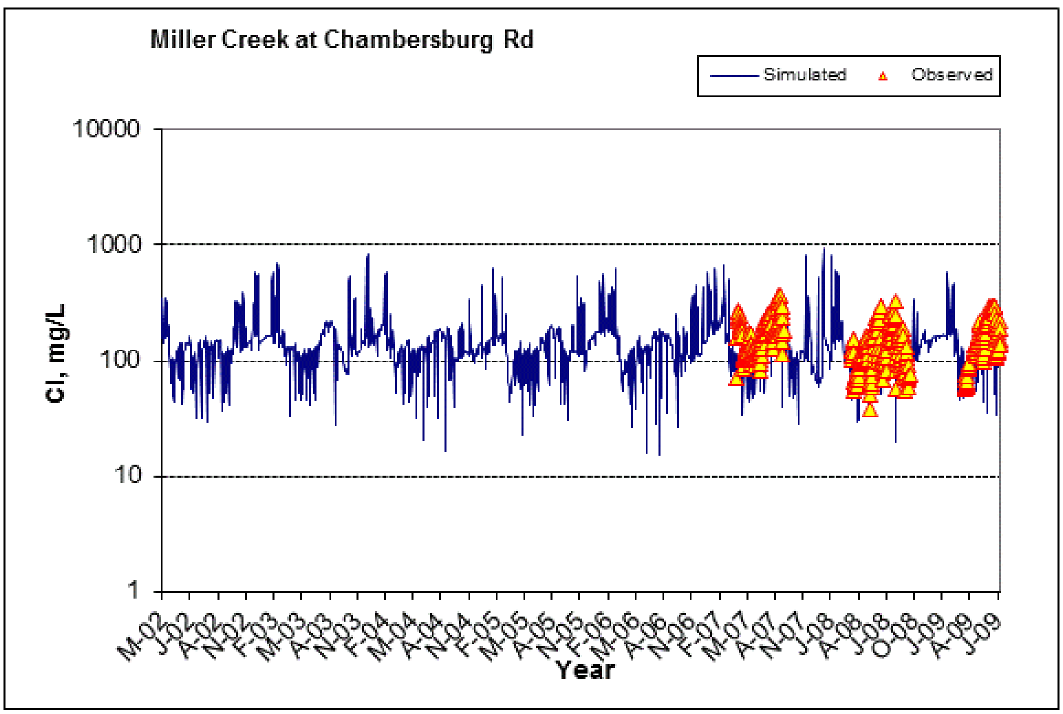


Figure F-139. Cl Concentration Time Series at the Miller Creek at Chambersburg Rd (2001-2008)

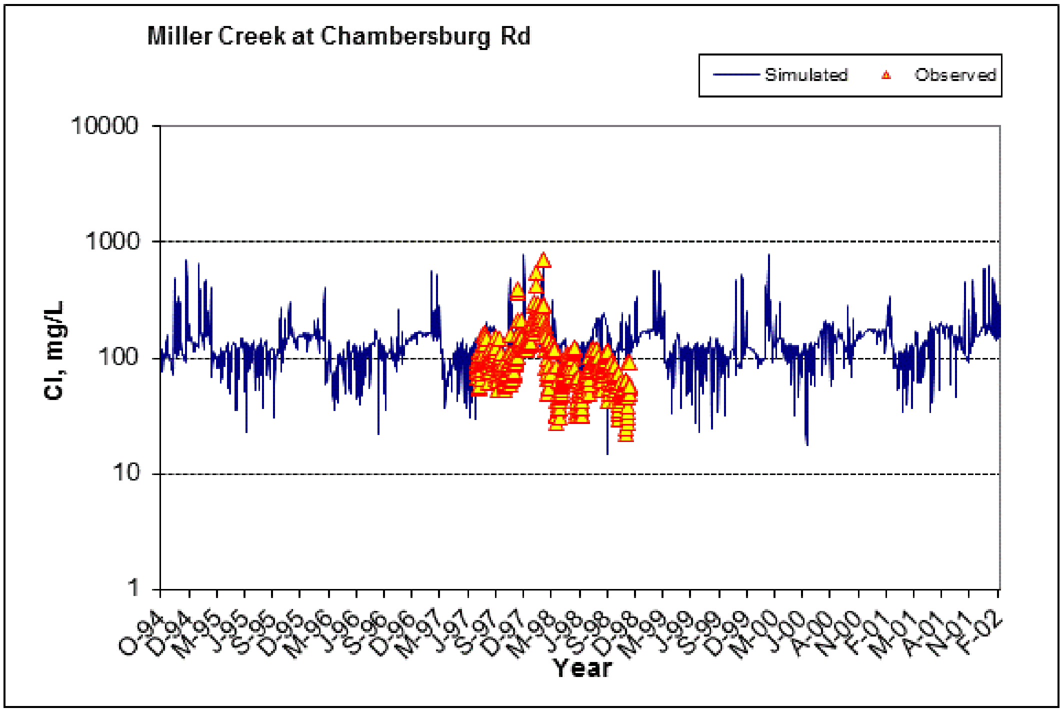


Figure F-140. Cl Concentration Time Series at the Miller Creek at Chambersburg Rd (1994-2001)

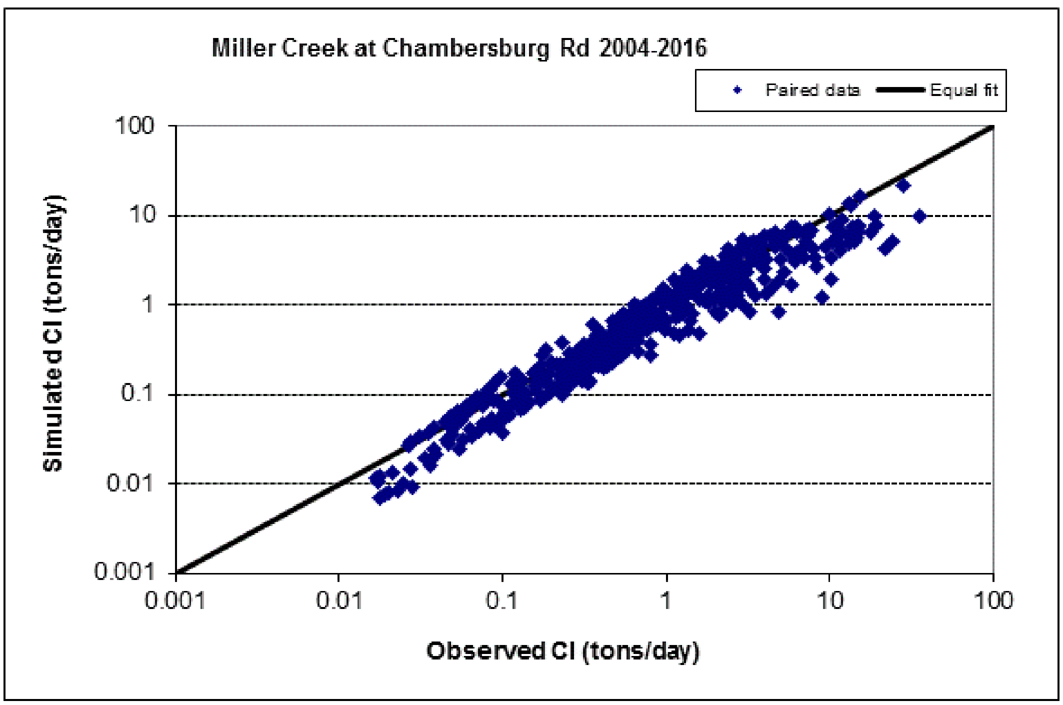


Figure F-141. Paired Simulated vs Observed Cl Load at the Miller Creek at Chambersburg Rd (Calibration Period)

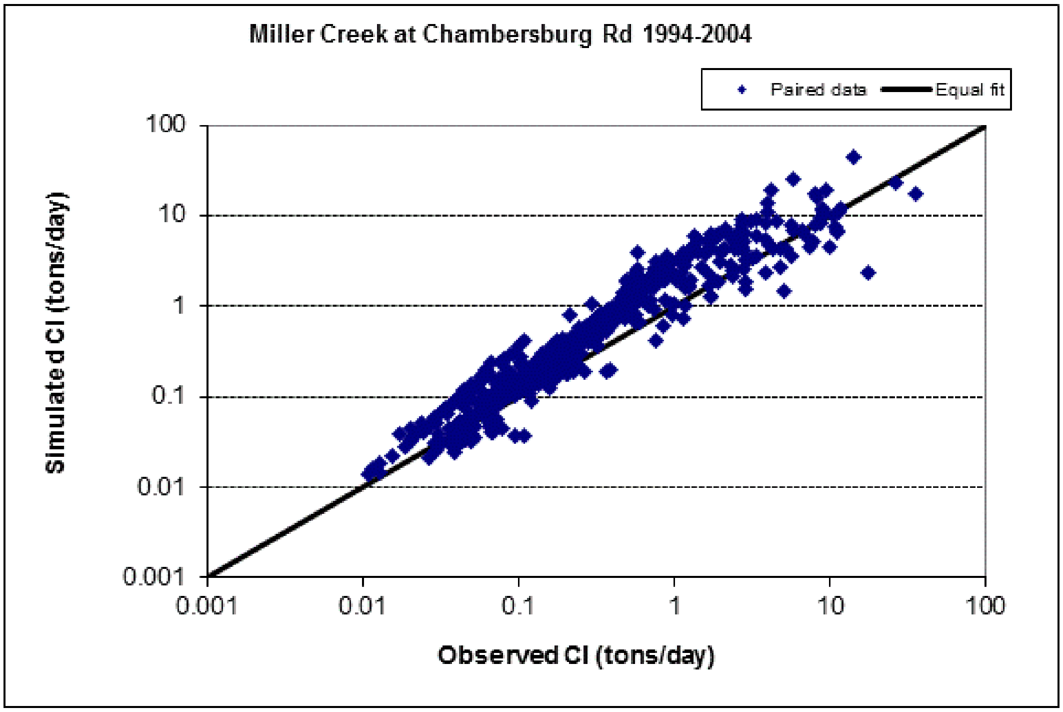


Figure F-142. Paired Simulated vs Observed Cl Load at the Miller Creek at Chambersburg Rd (Validation Period)

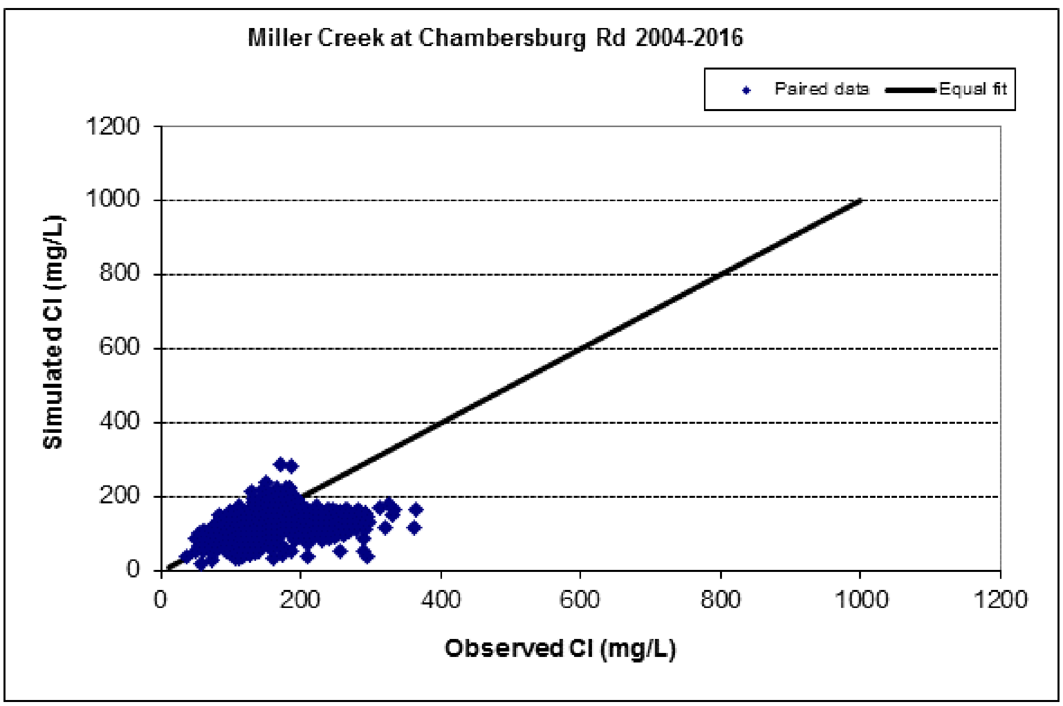


Figure F-143. Paired Simulated vs Observed Cl Concentration at the Miller Creek at Chambersburg Rd (Calibration Period)

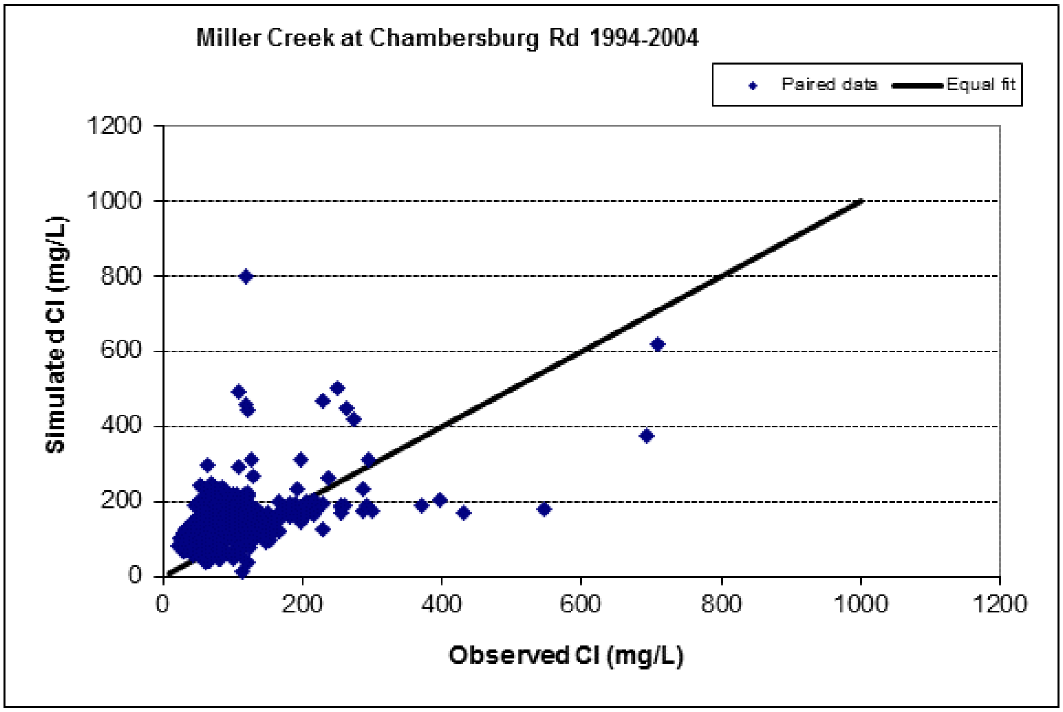


Figure F-144. Paired Simulated vs Observed Cl Concentration at the Miller Creek at Chambersburg Rd (Validation Period)

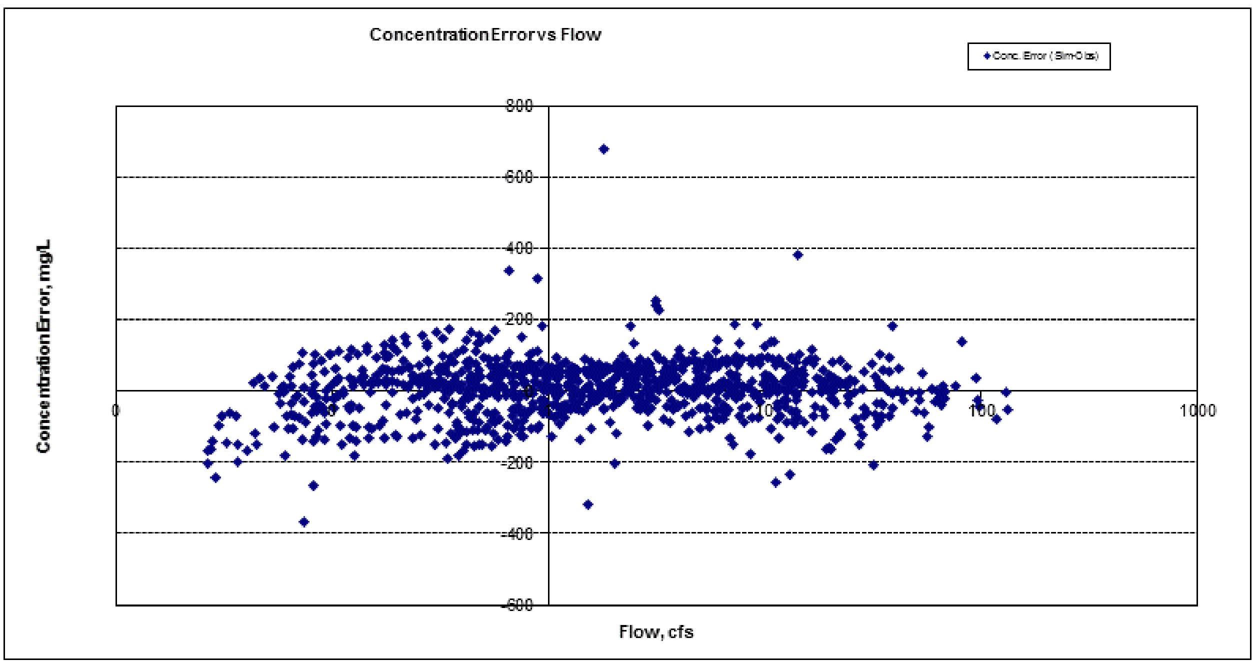


Figure F-145. Cl Concentration Error vs Flow at the Miller Creek at Chambersburg Rd

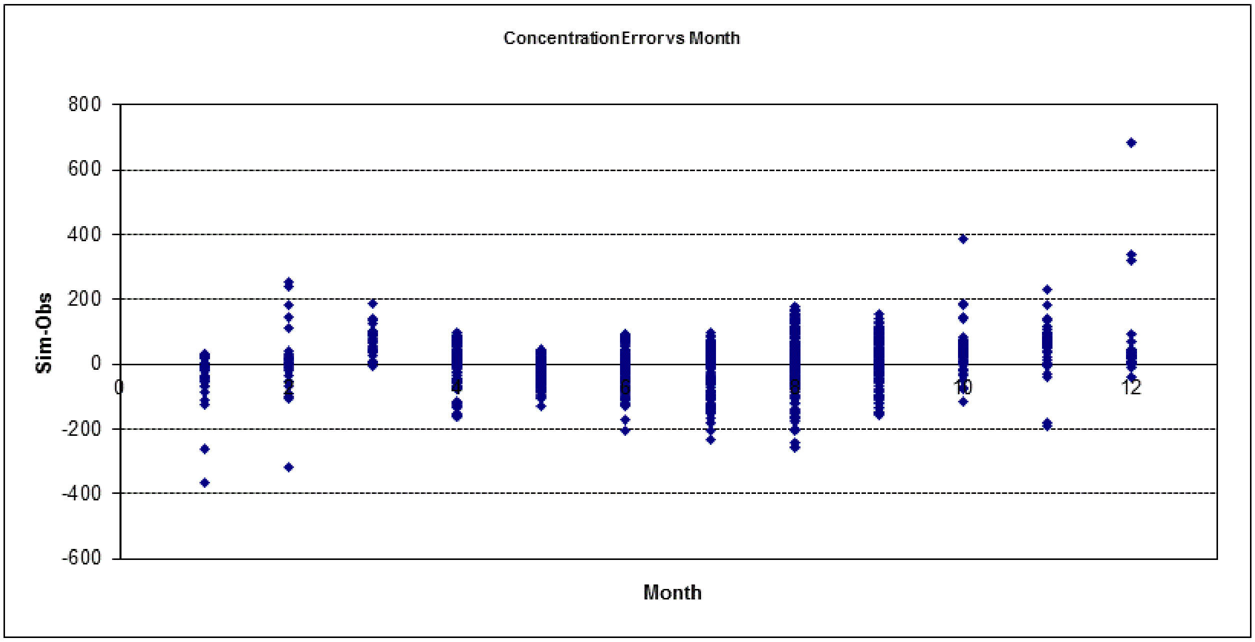


Figure F-146. Cl Concentration Error vs Month at the Miller Creek at Chambersburg Rd

F.15 Miller Creek nr Lower Gage (multiple stations) - Continuous

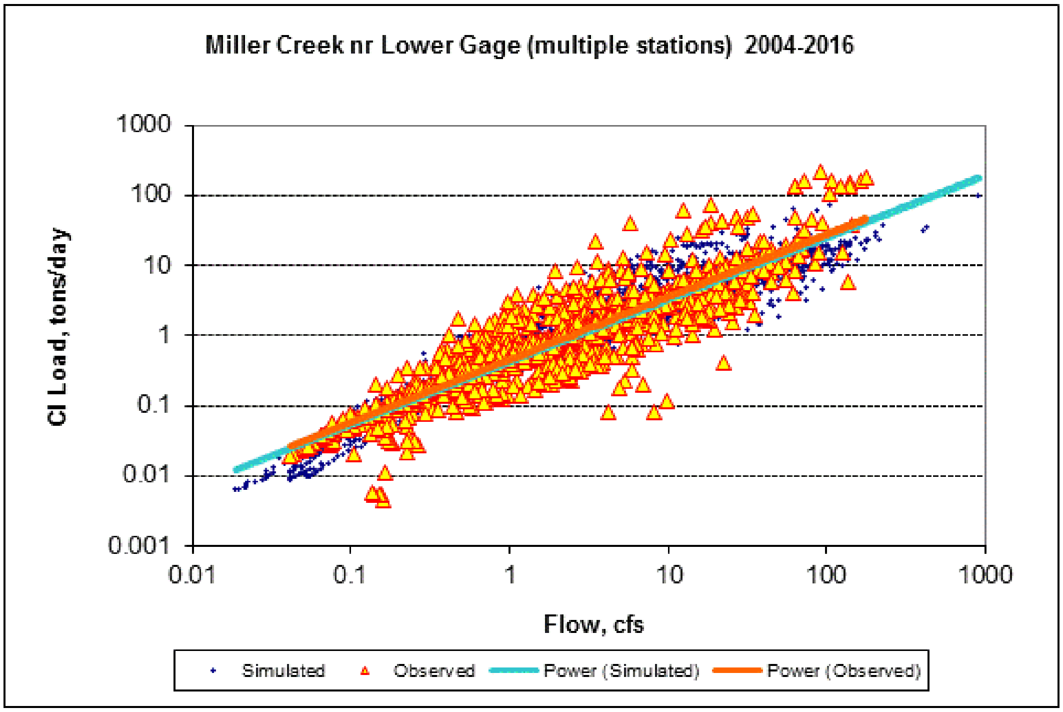


Figure F-147. Power Plot of Simulated and Observed Cl Load vs Flow at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

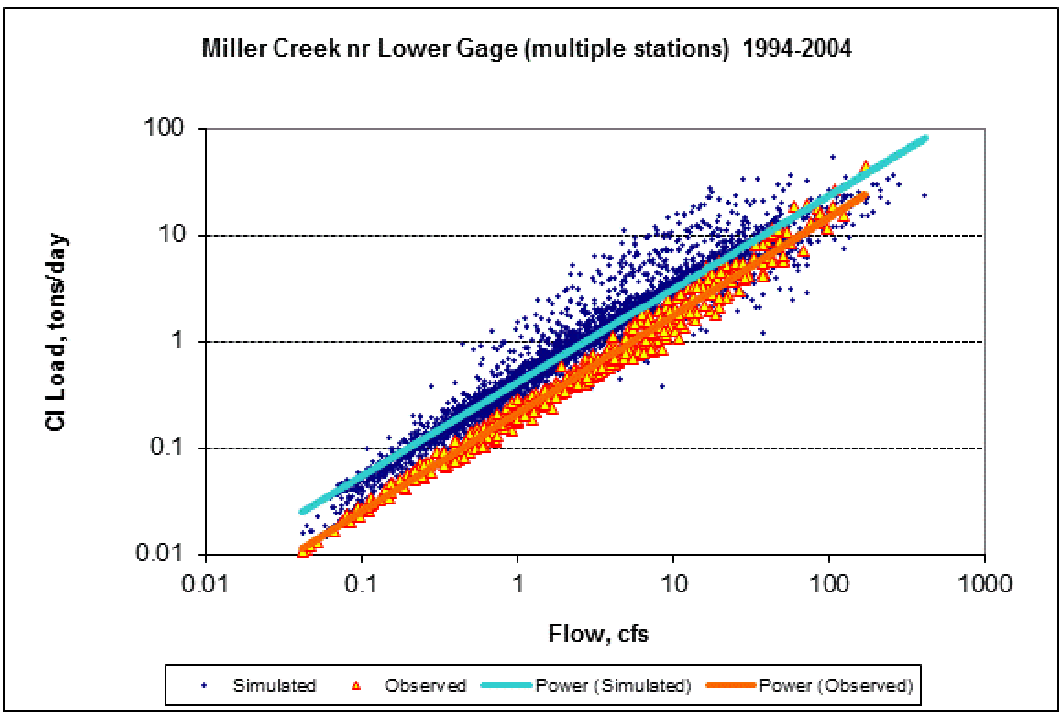


Figure F-148. Power Plot of Simulated and Observed Cl Load vs Flow at the Miller Creek nr Lower Gage (multiple stations) (Validation Period)

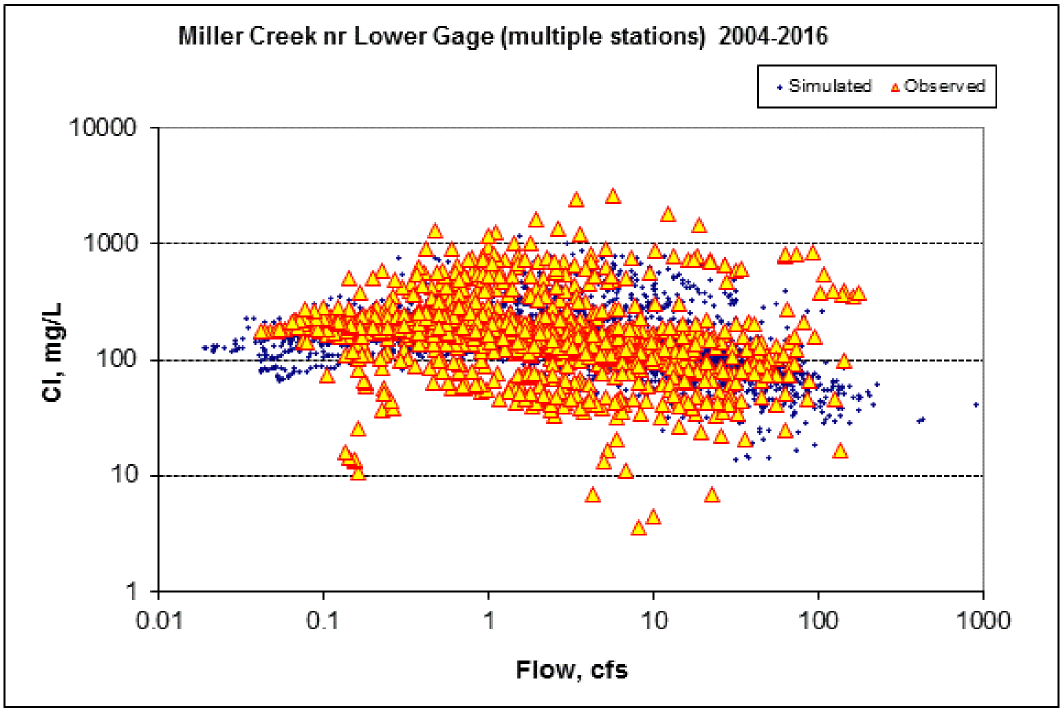


Figure F-149. Simulated and Observed Cl Concentration vs Flow Plot at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

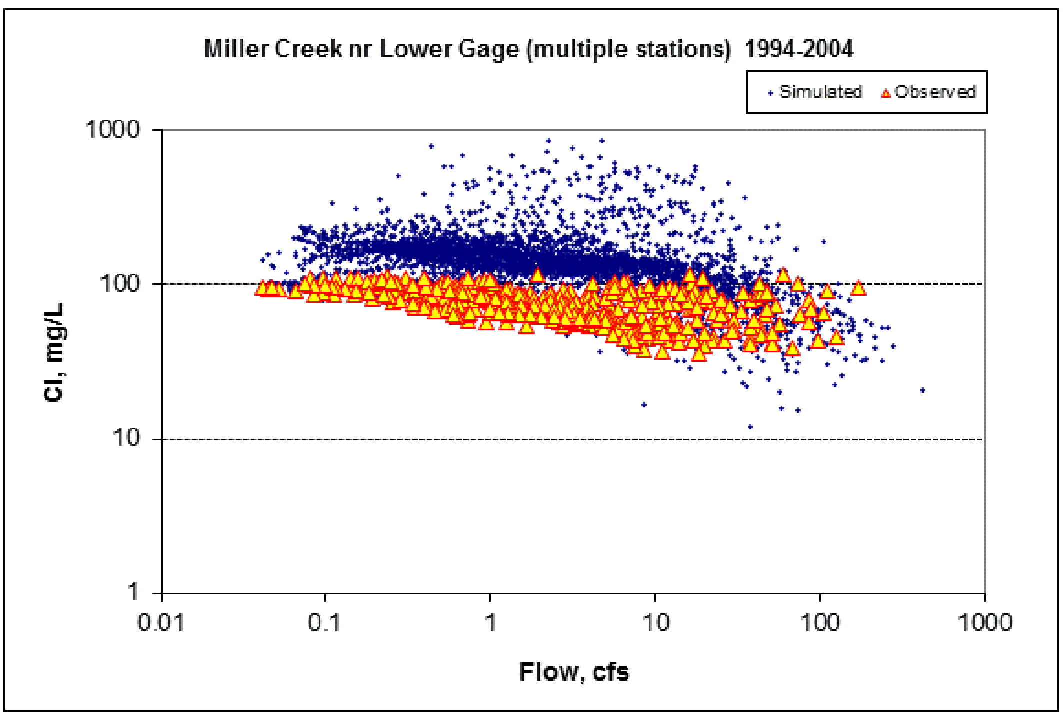


Figure F-150. Simulated and Observed Cl Concentration vs Flow Plot at the Miller Creek nr Lower Gage (multiple stations) (Validation Period)

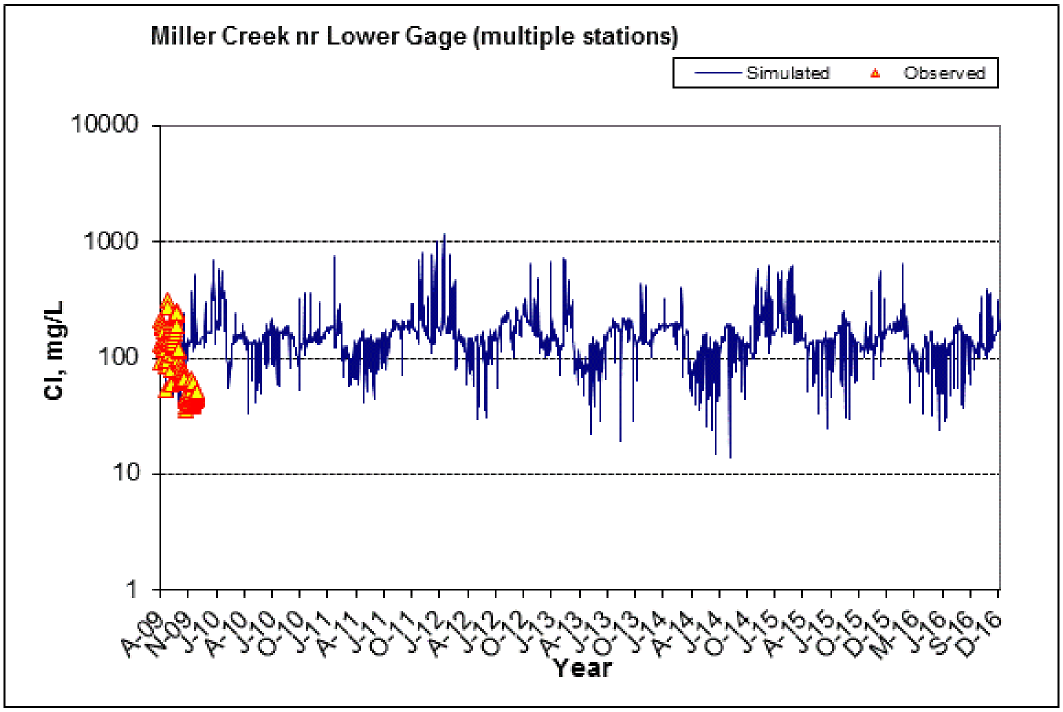


Figure F-151. Cl Concentration Time Series at the Miller Creek nr Lower Gage (multiple stations) (2008-2015)

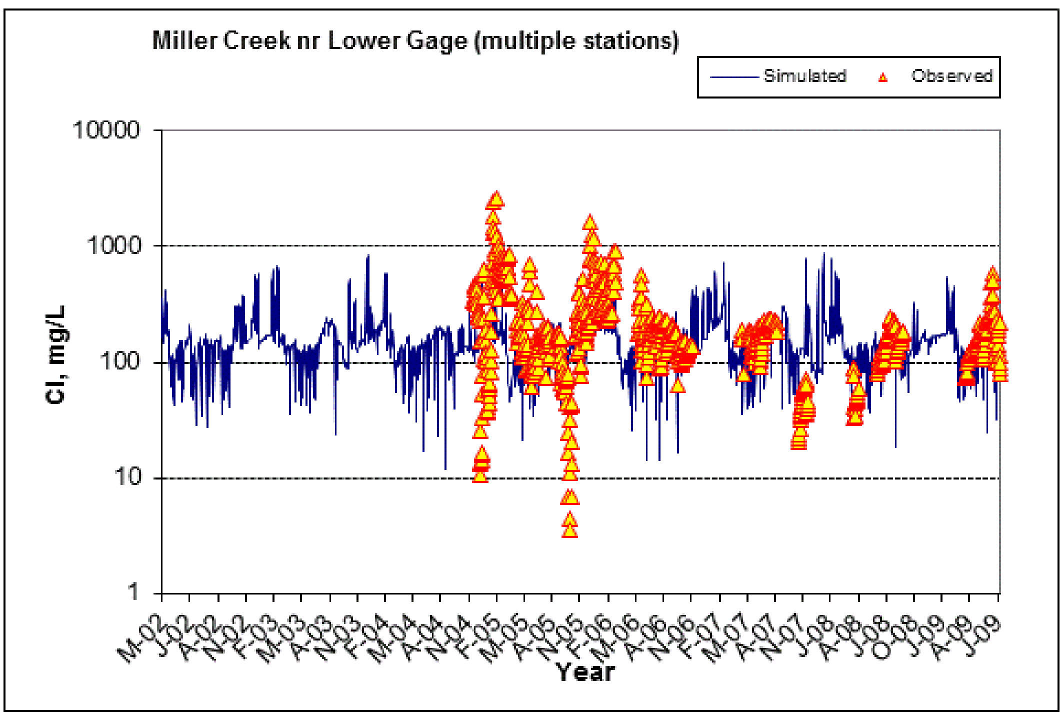


Figure F-152. Cl Concentration Time Series at the Miller Creek nr Lower Gage (multiple stations) (2001-2008)

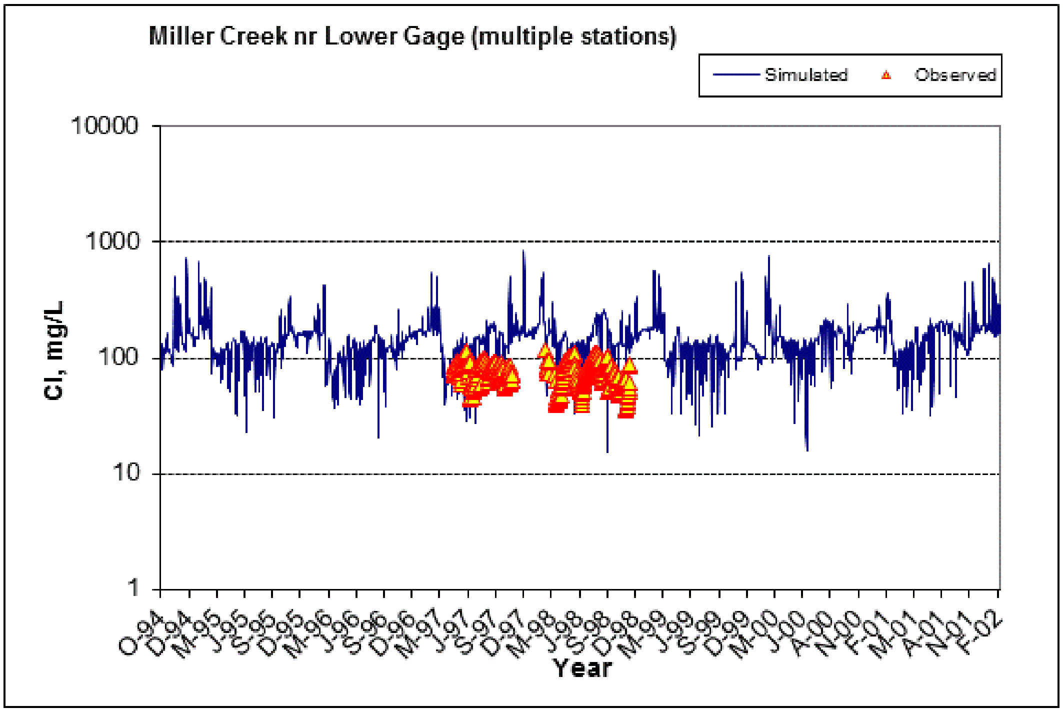


Figure F-153. Cl Concentration Time Series at the Miller Creek nr Lower Gage (multiple stations) (1994-2001)

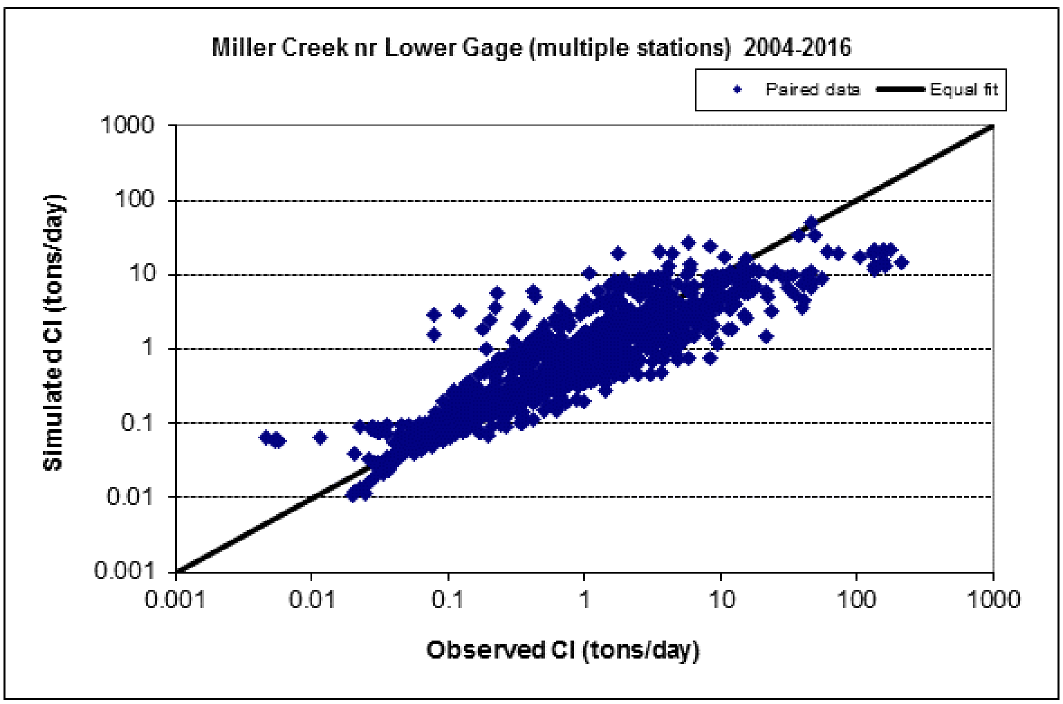


Figure F-154. Paired Simulated vs Observed Cl Load at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

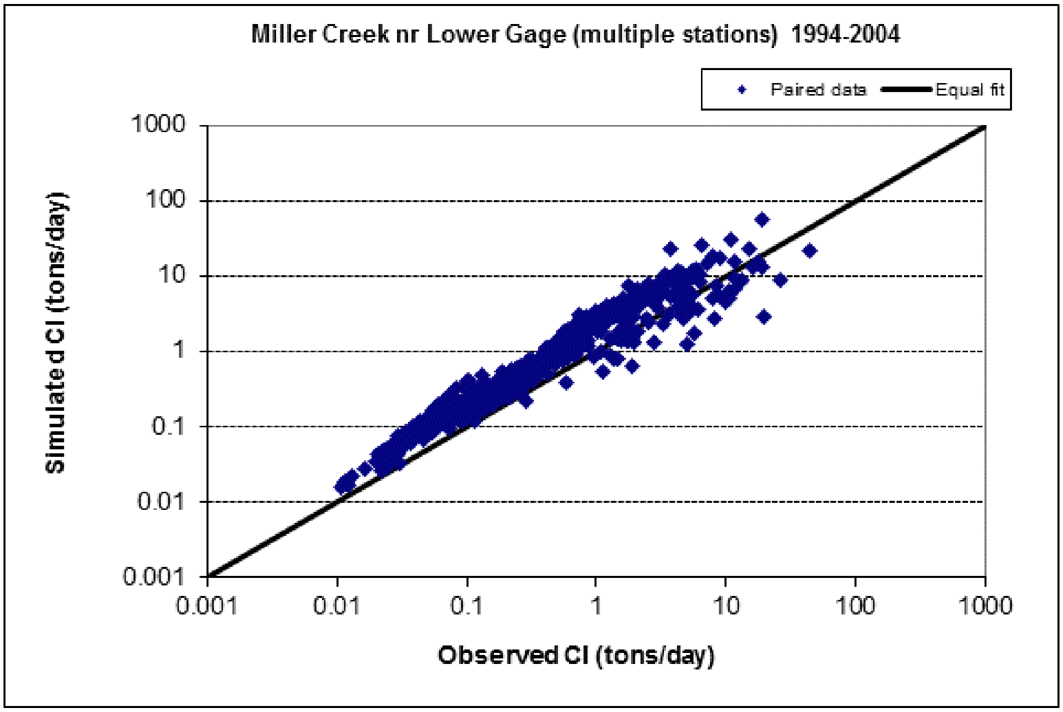


Figure F-155. Paired Simulated vs Observed Cl Load at the Miller Creek nr Lower Gage (multiple stations) (Validation Period)

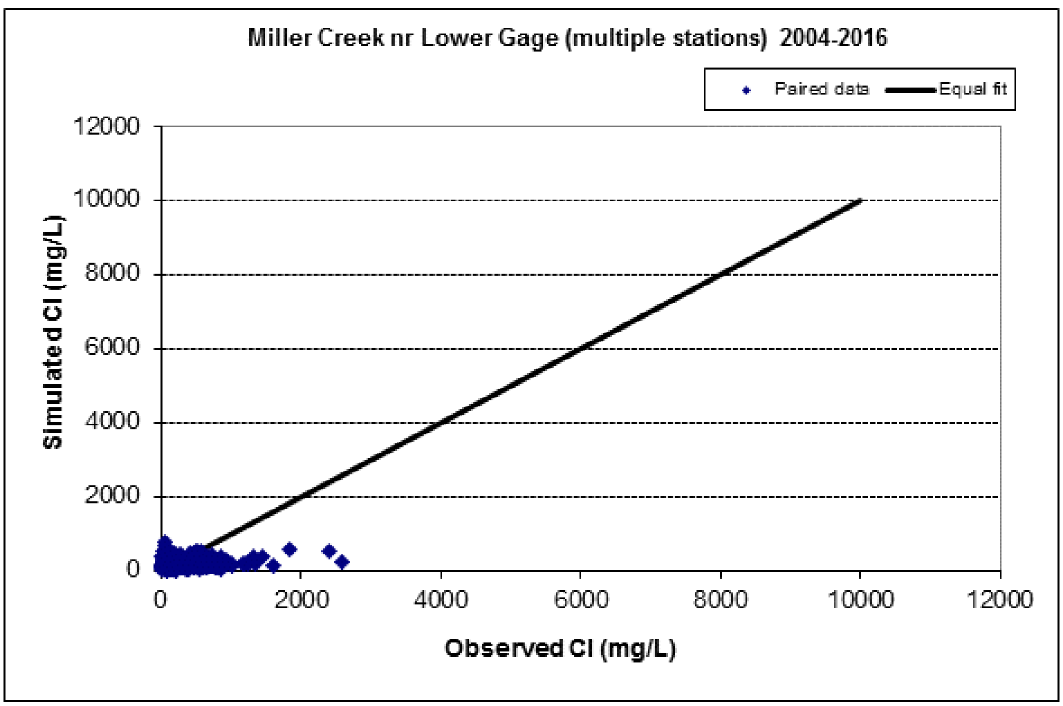


Figure F-156. Paired Simulated vs Observed Cl Concentration at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

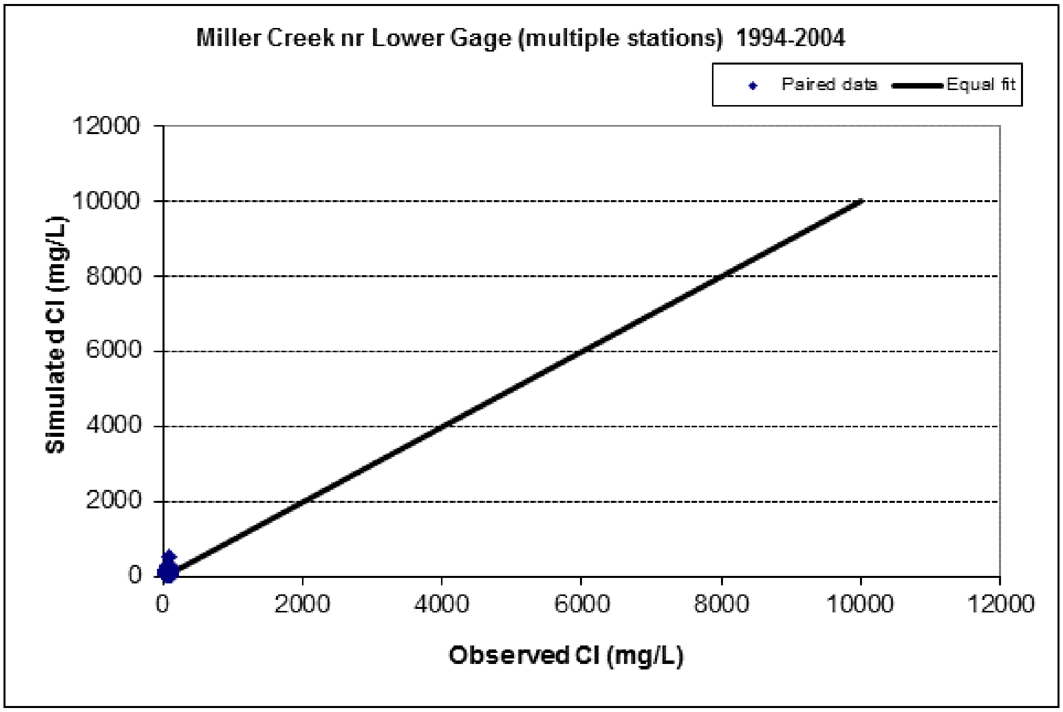


Figure F-157. Paired Simulated vs Observed Cl Concentration at the Miller Creek nr Lower Gage (multiple stations) (Validation Period)

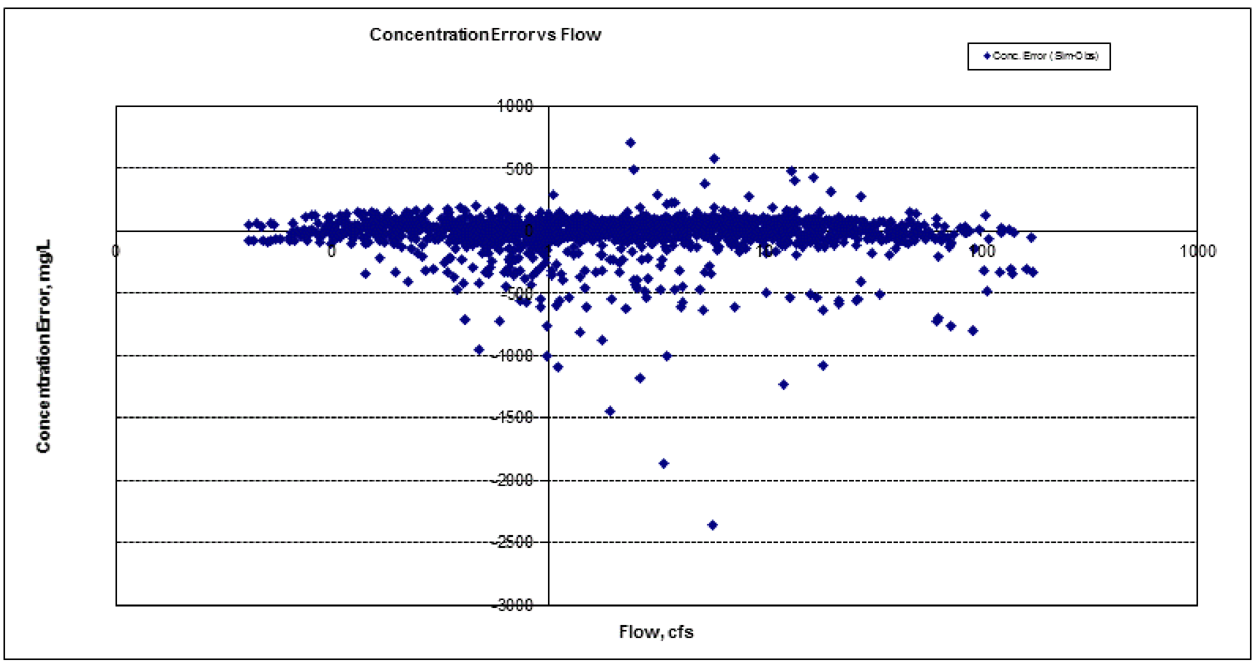


Figure F-158. Cl Concentration Error vs Flow at the Miller Creek nr Lower Gage (multiple stations)

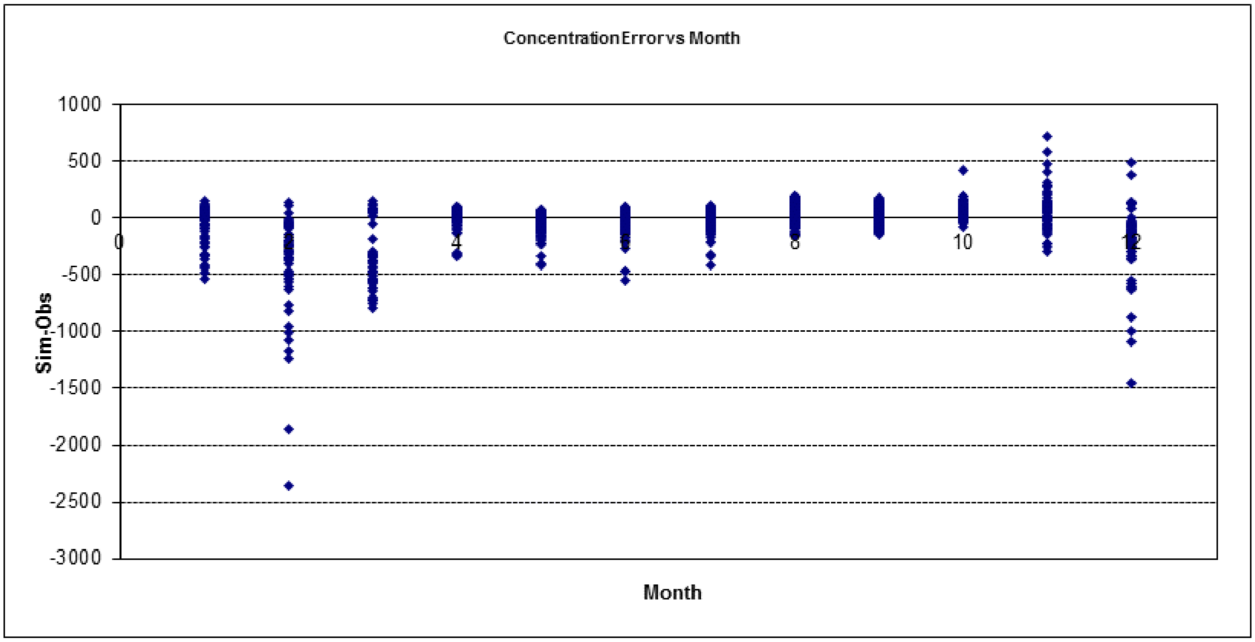


Figure F-159. Cl Concentration Error vs Month at the Miller Creek nr Lower Gage (multiple stations)

F.16 Miller Creek nr Lower Gage (multiple stations) - Discrete

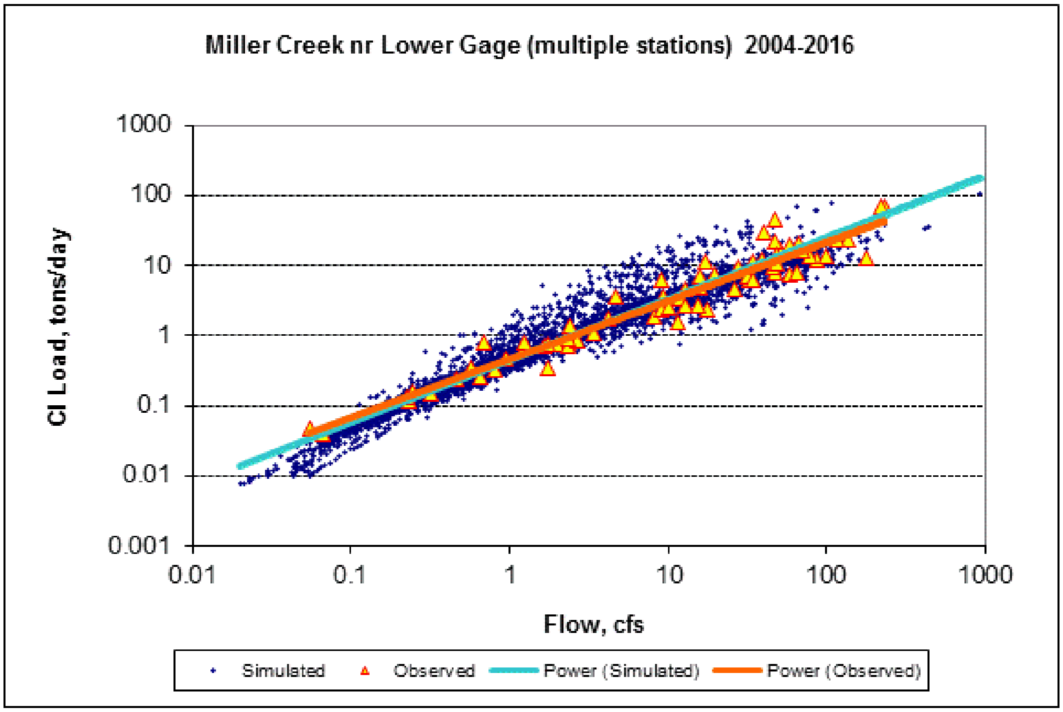


Figure F-160. Power Plot of Simulated and Observed Cl Load vs Flow at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

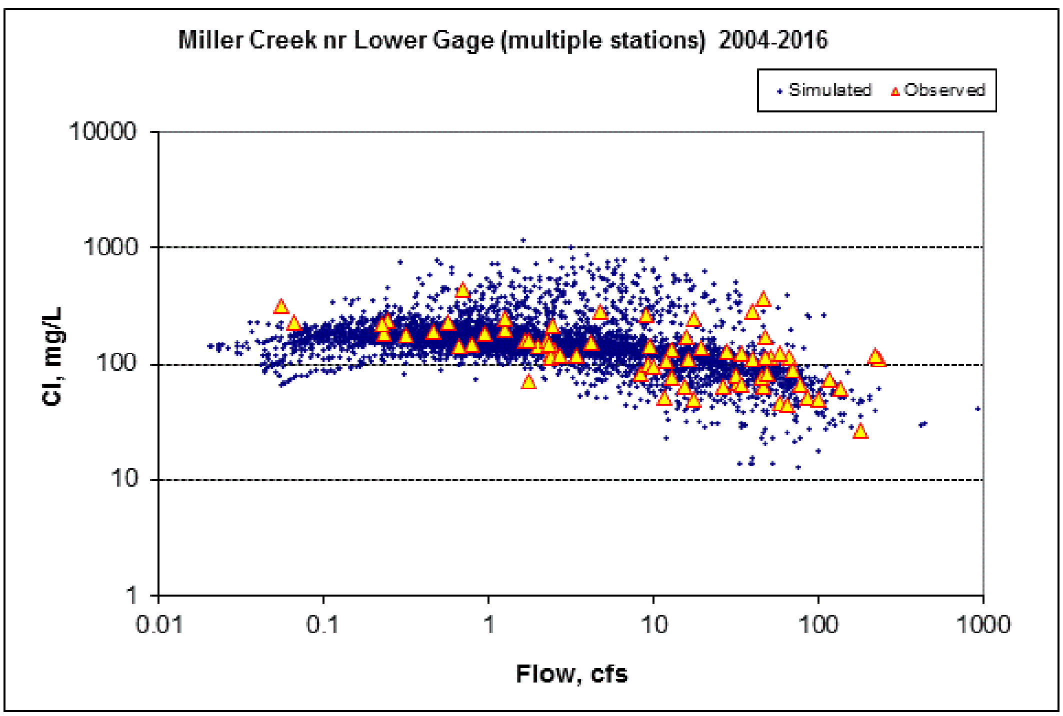


Figure F-161. Simulated and Observed Cl Concentration vs Flow Plot at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

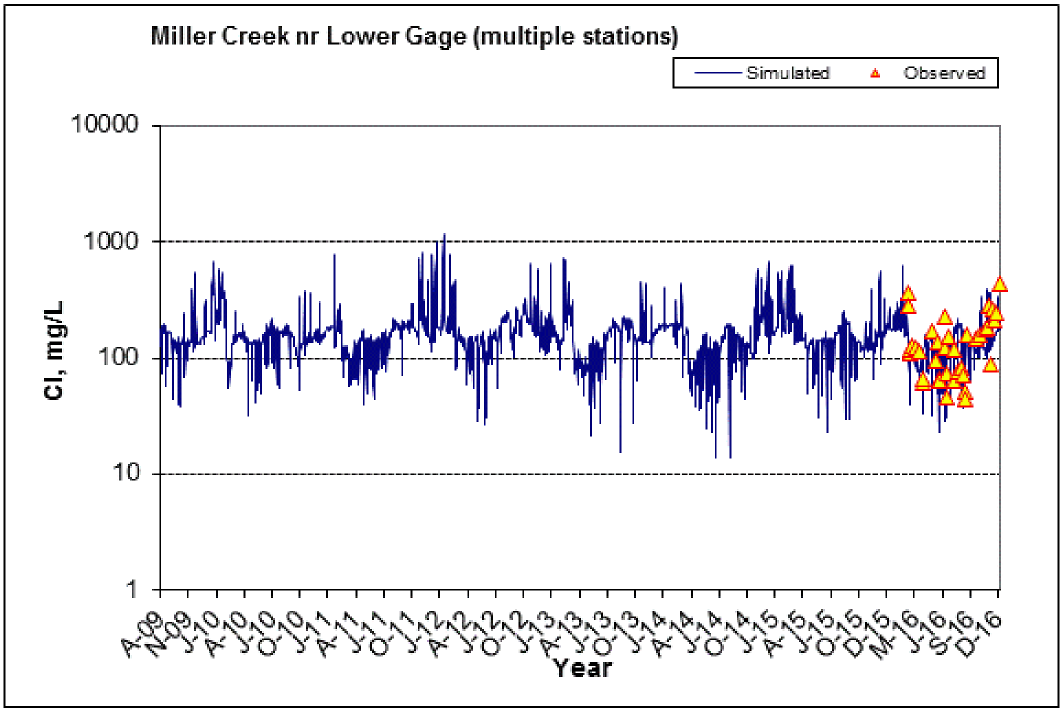


Figure F-162. Cl Concentration Time Series at the Miller Creek nr Lower Gage (multiple stations) (2008-2015)

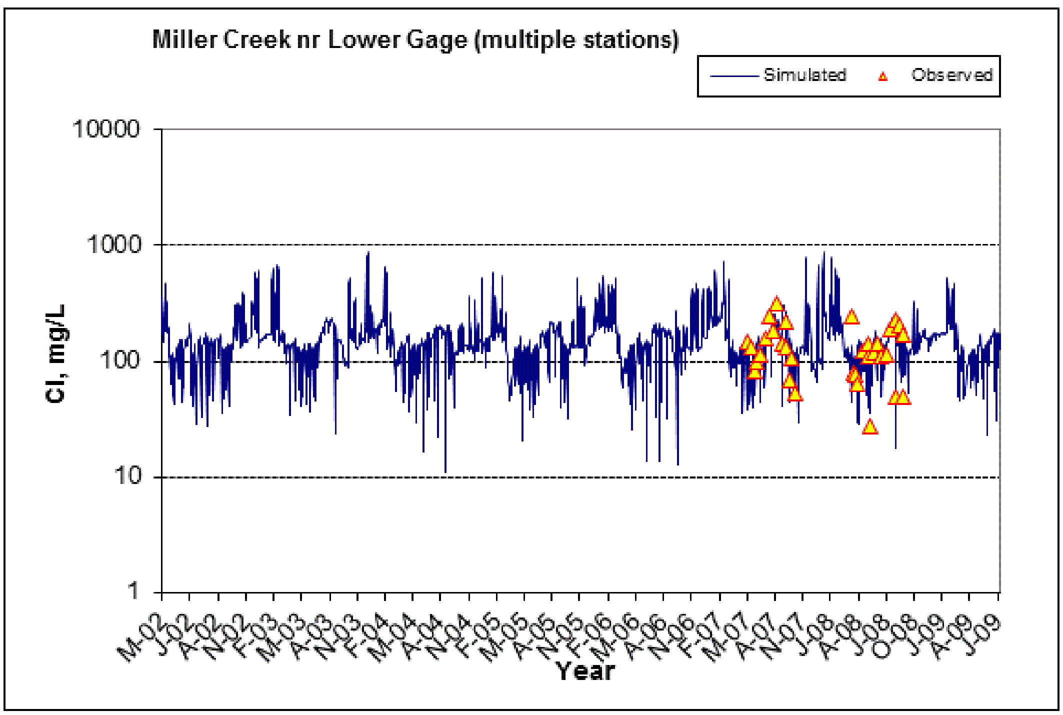


Figure F-163. Cl Concentration Time Series at the Miller Creek nr Lower Gage (multiple stations) (2001-2008)

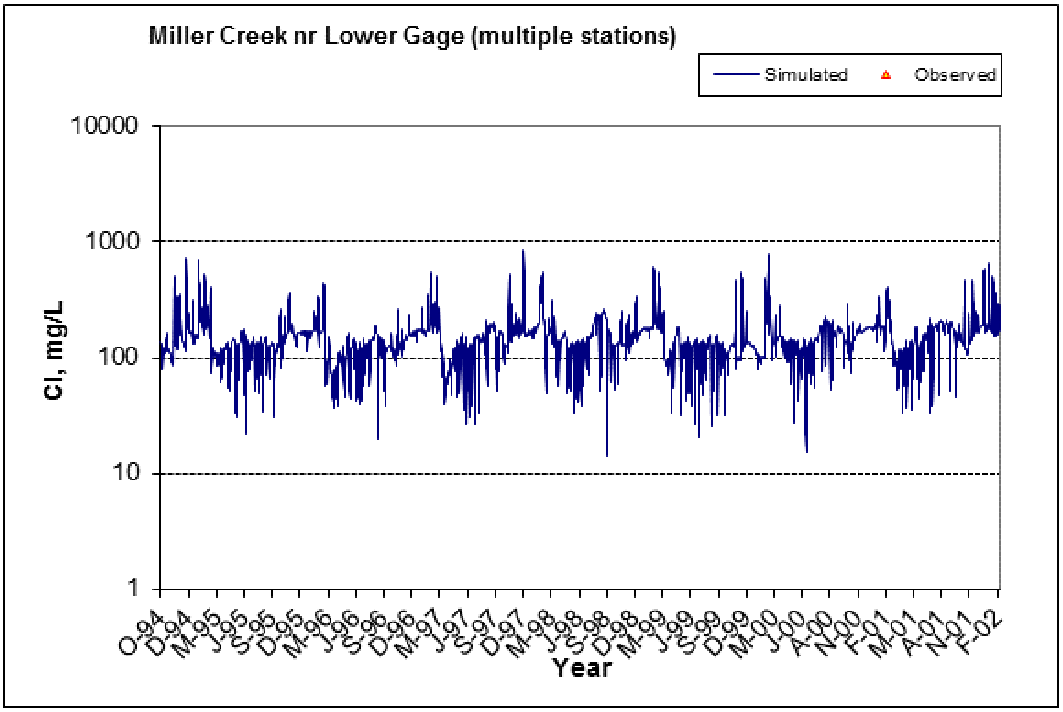


Figure F-164. Cl Concentration Time Series at the Miller Creek nr Lower Gage (multiple stations) (1994-2001)

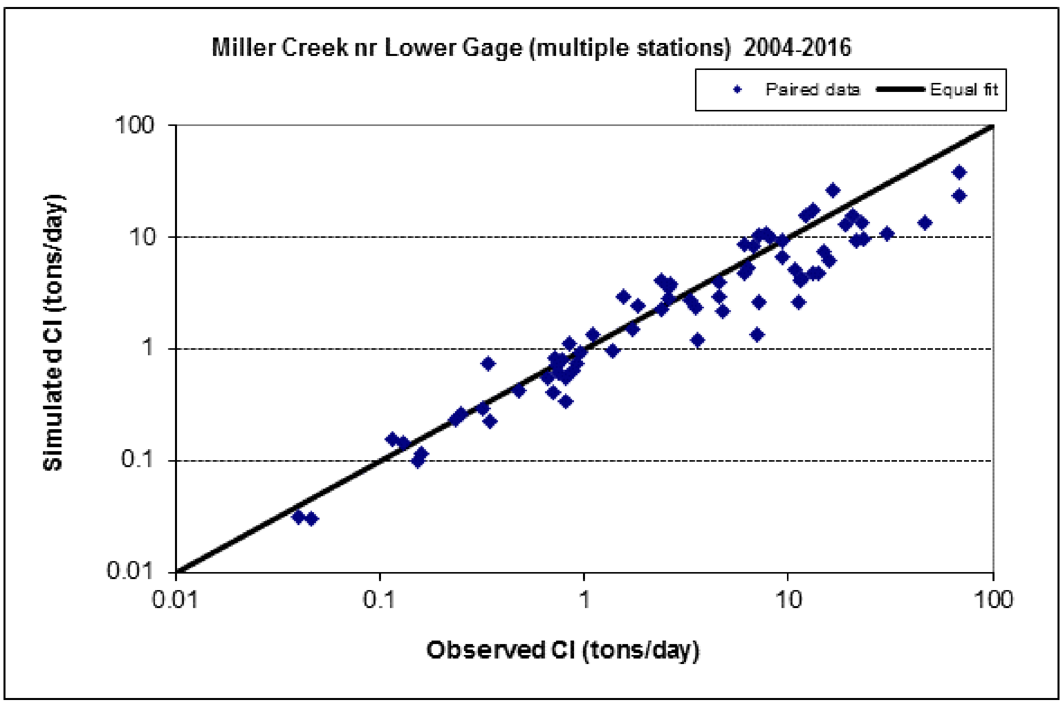


Figure F-165. Paired Simulated vs Observed Cl Load at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

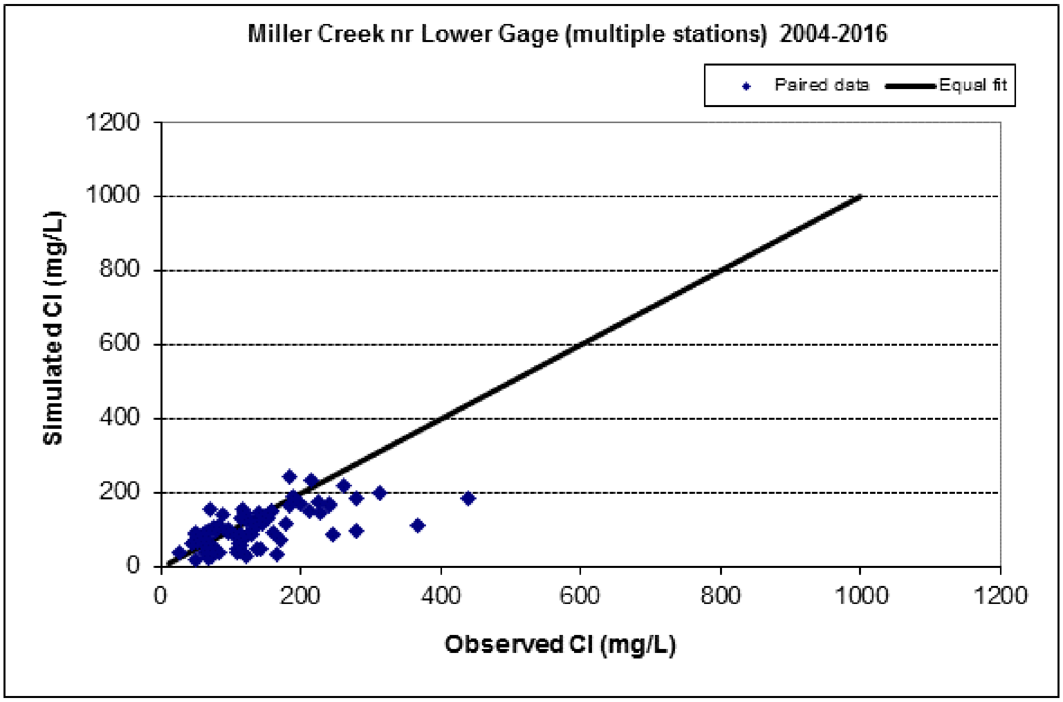


Figure F-166. Paired Simulated vs Observed Cl Concentration at the Miller Creek nr Lower Gage (multiple stations) (Calibration Period)

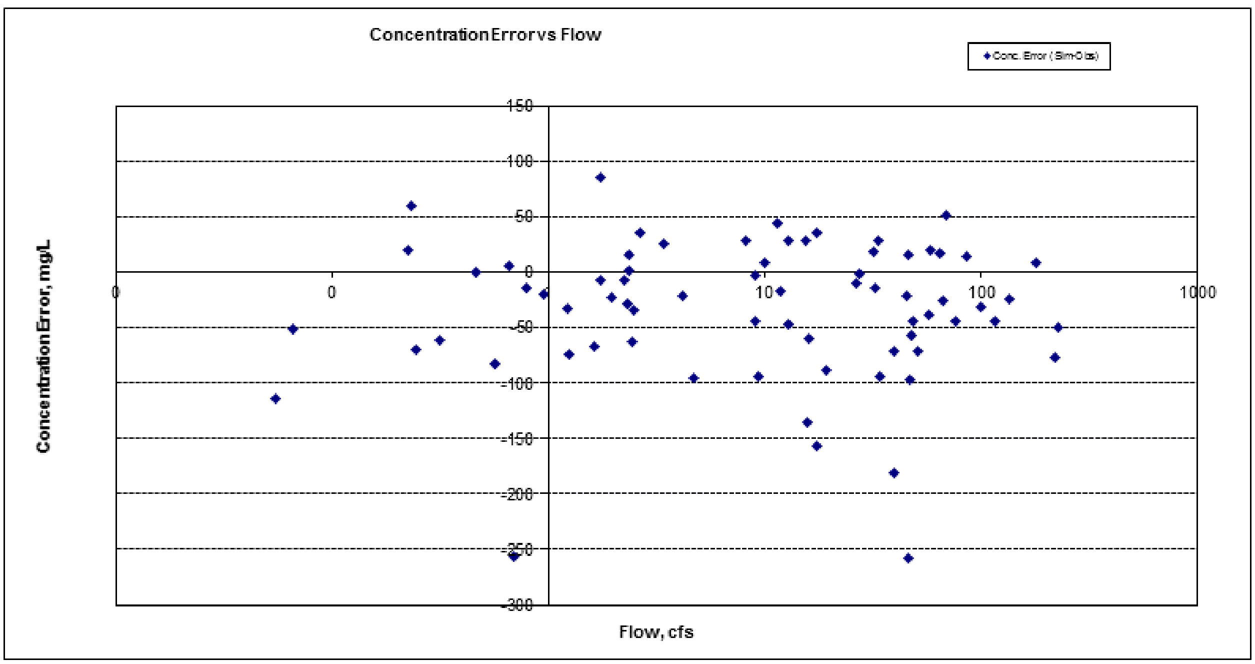


Figure F-167. Cl Concentration Error vs Flow at the Miller Creek nr Lower Gage (multiple stations)

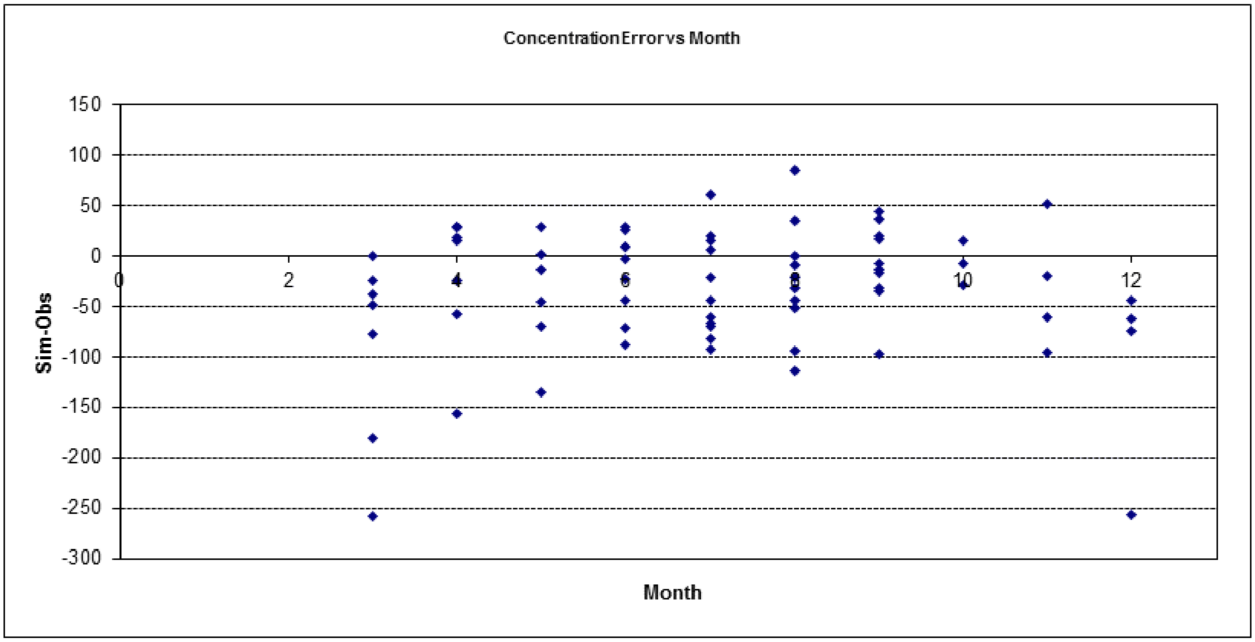


Figure F-168. Cl Concentration Error vs Month at the Miller Creek nr Lower Gage (multiple stations)

F.17 Kingsbury Creek (multiple stations) - Continuous

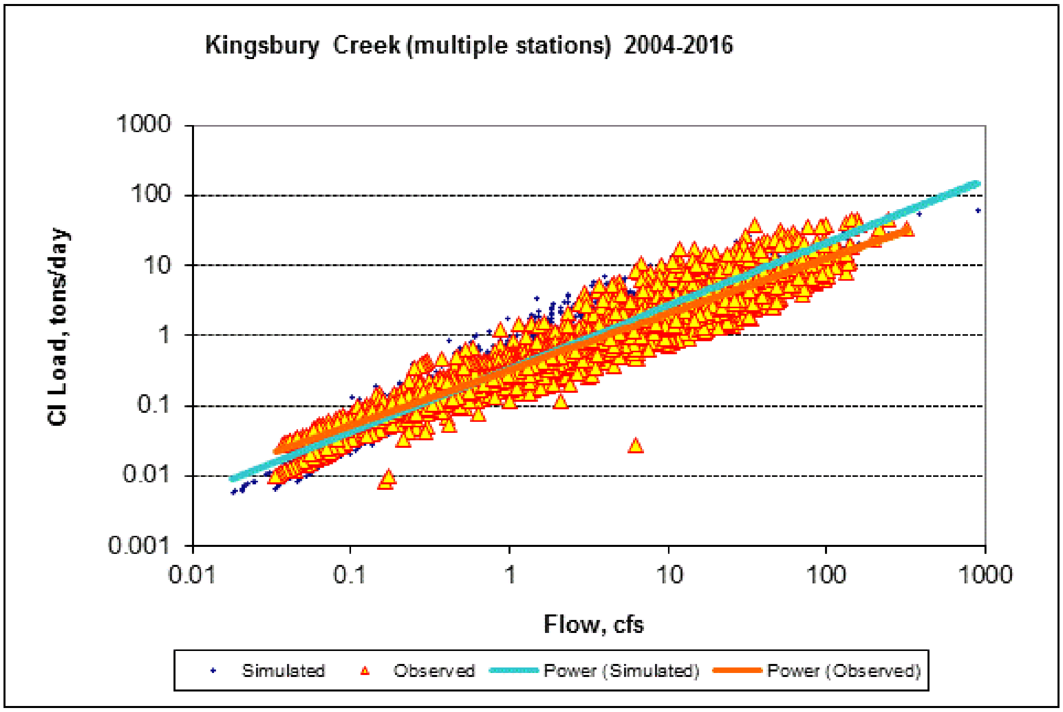


Figure F-169. Power Plot of Simulated and Observed Cl Load vs Flow at the Kingsbury Creek (multiple stations) (Calibration Period)

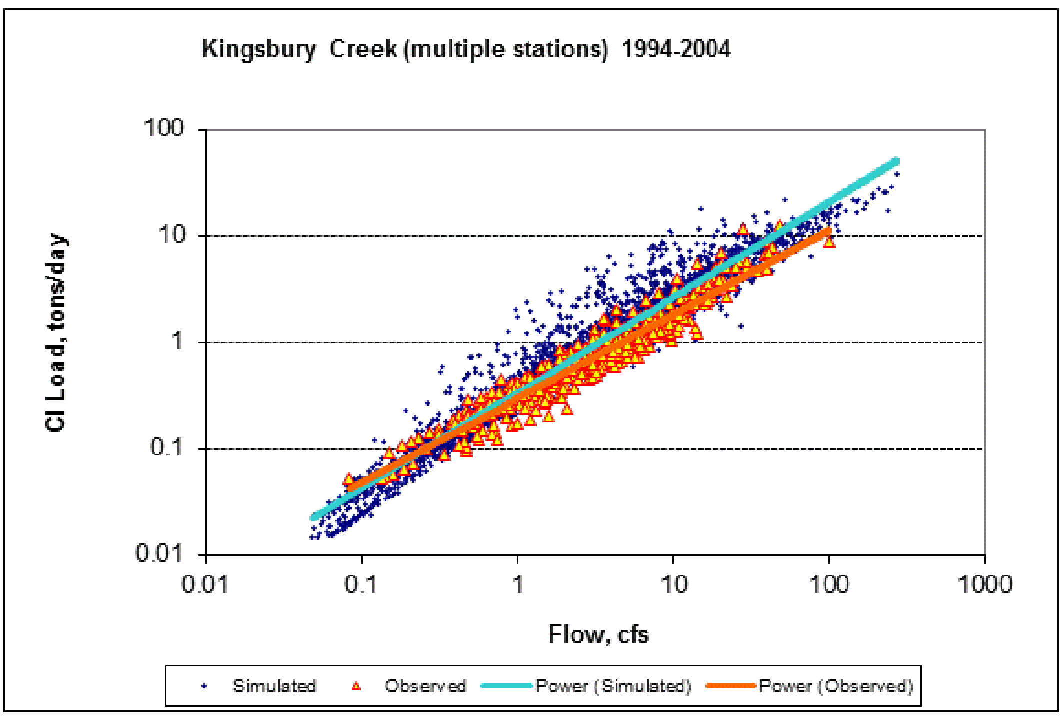


Figure F-170. Power Plot of Simulated and Observed Cl Load vs Flow at the Kingsbury Creek (multiple stations) (Validation Period)

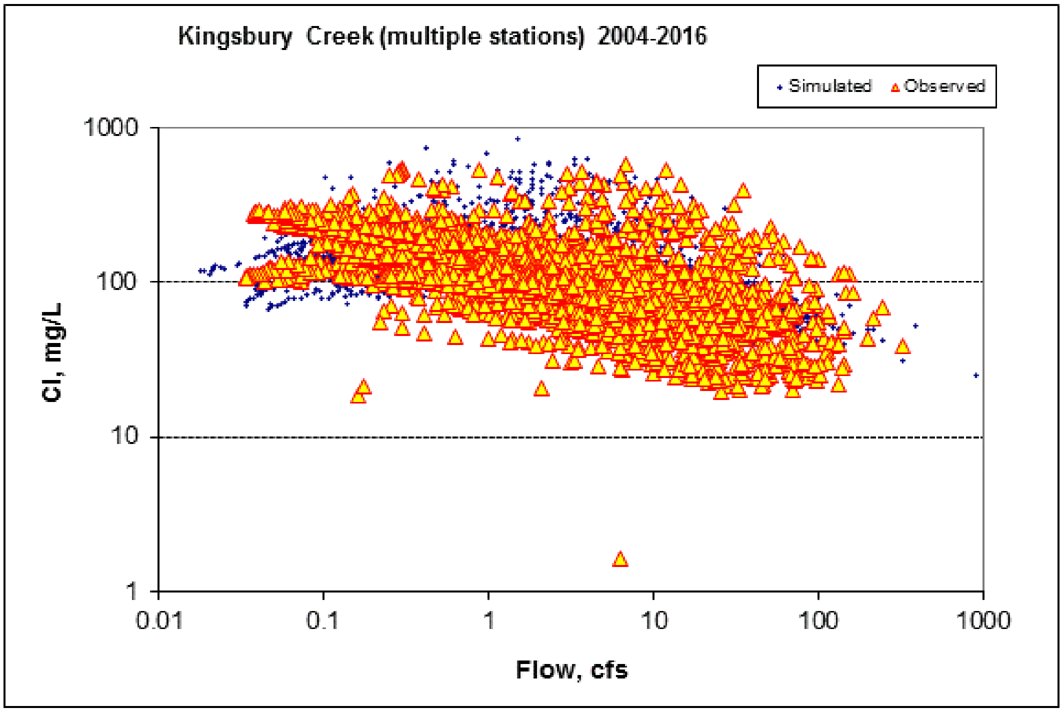


Figure F-171. Simulated and Observed Cl Concentration vs Flow Plot at the Kingsbury Creek (multiple stations) (Calibration Period)

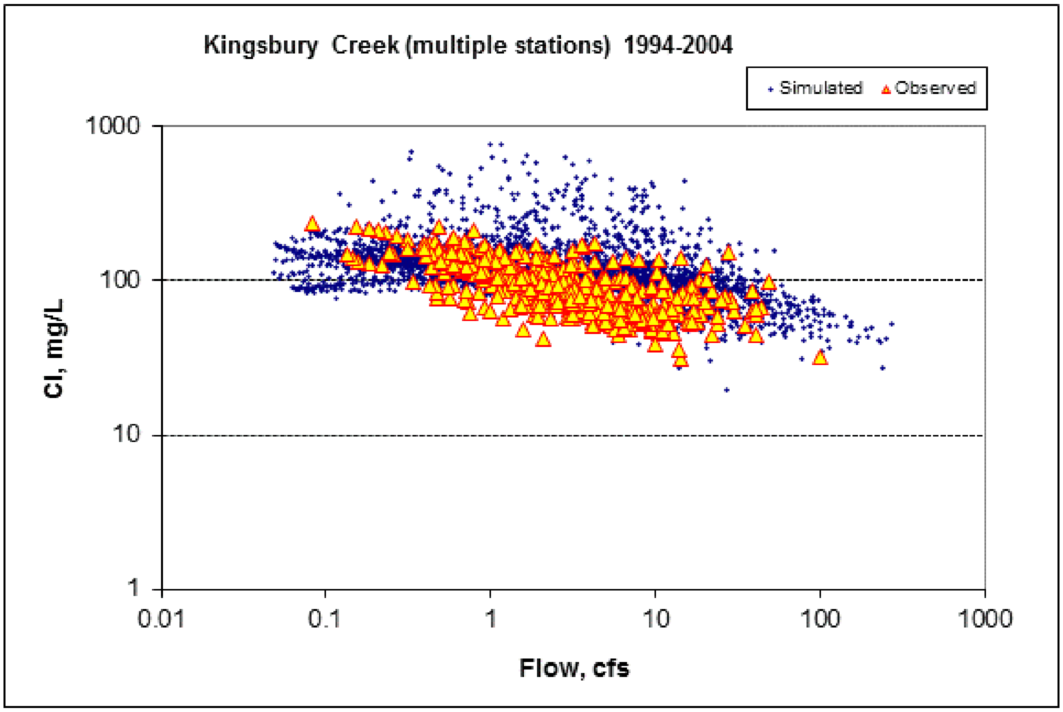


Figure F-172. Simulated and Observed Cl Concentration vs Flow Plot at the Kingsbury Creek (multiple stations) (Validation Period)

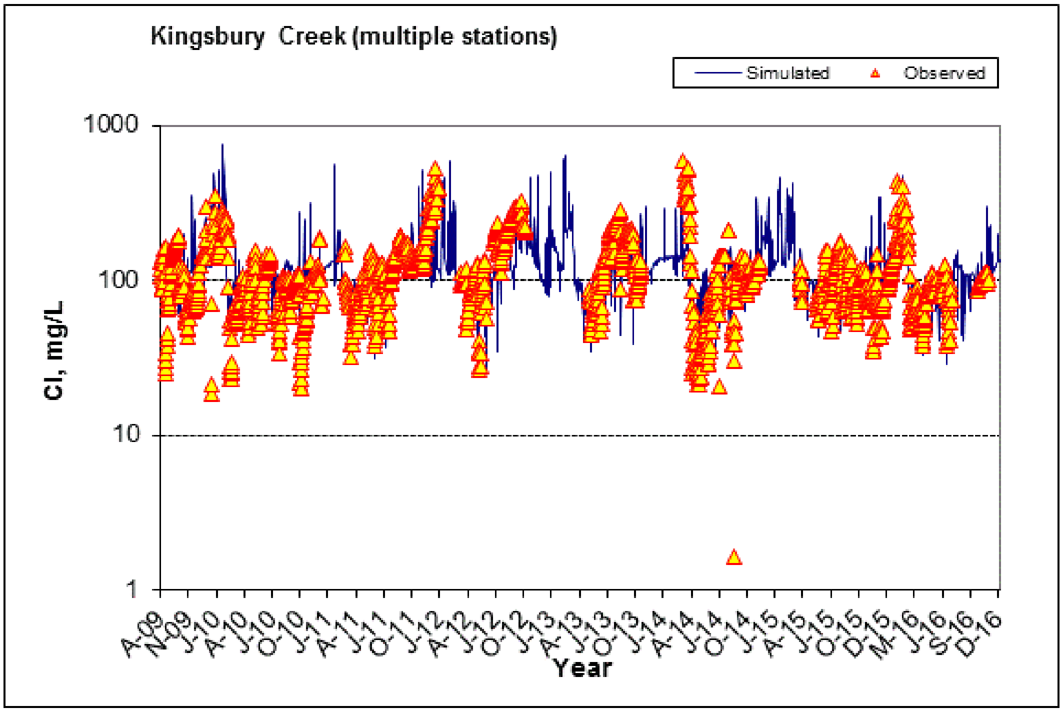


Figure F-173. Cl Concentration Time Series at the Kingsbury Creek (multiple stations) (2008-2015)

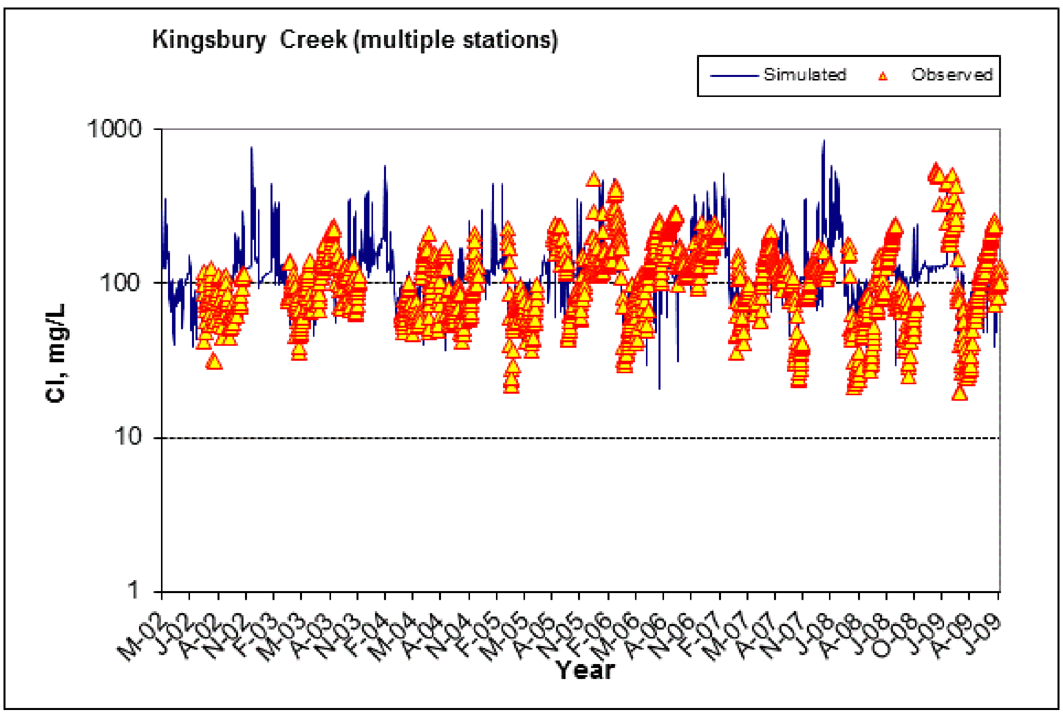


Figure F-174. Cl Concentration Time Series at the Kingsbury Creek (multiple stations) (2001-2008)

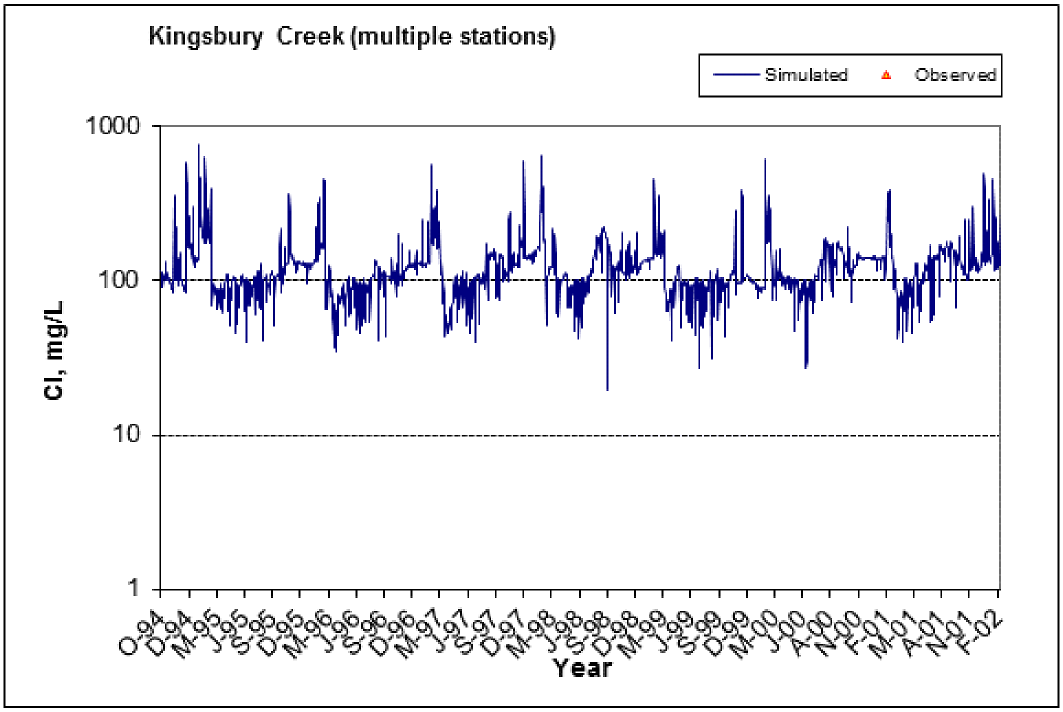


Figure F-175. Cl Concentration Time Series at the Kingsbury Creek (multiple stations) (1994-2001)

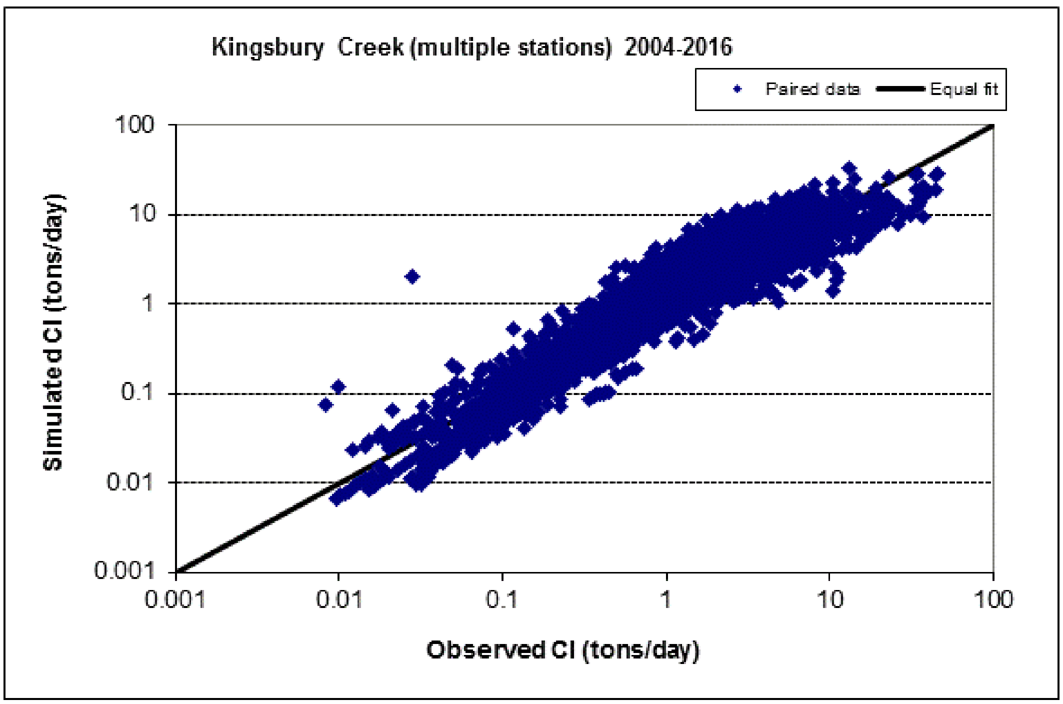


Figure F-176. Paired Simulated vs Observed Cl Load at the Kingsbury Creek (multiple stations) (Calibration Period)

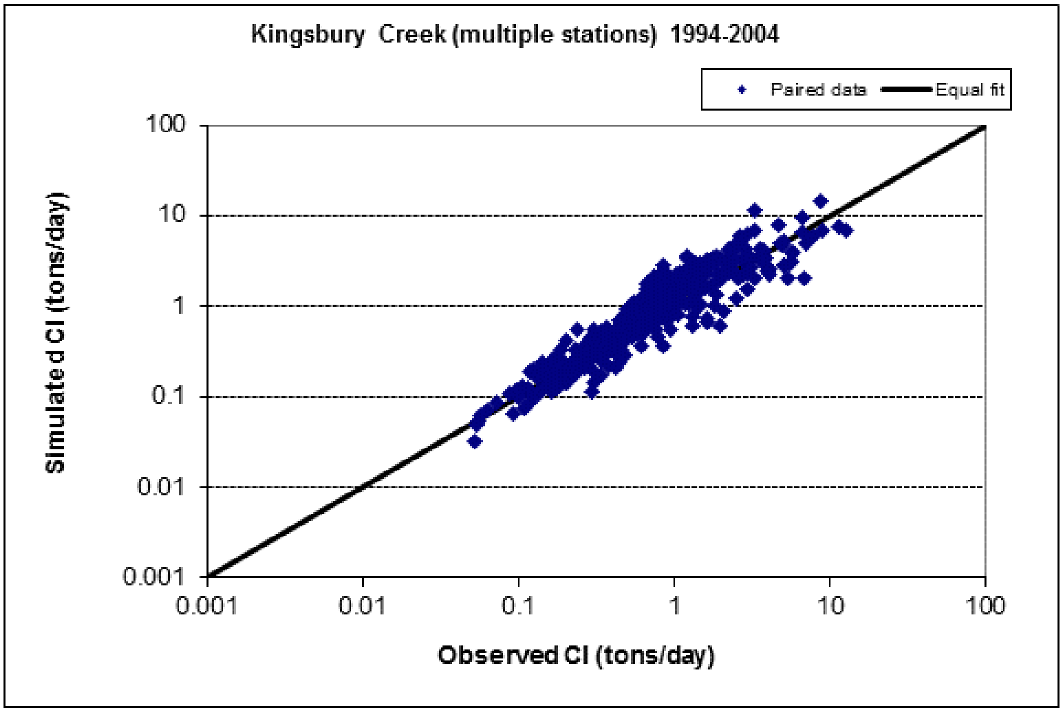


Figure F-177. Paired Simulated vs Observed Cl Load at the Kingsbury Creek (multiple stations) (Validation Period)

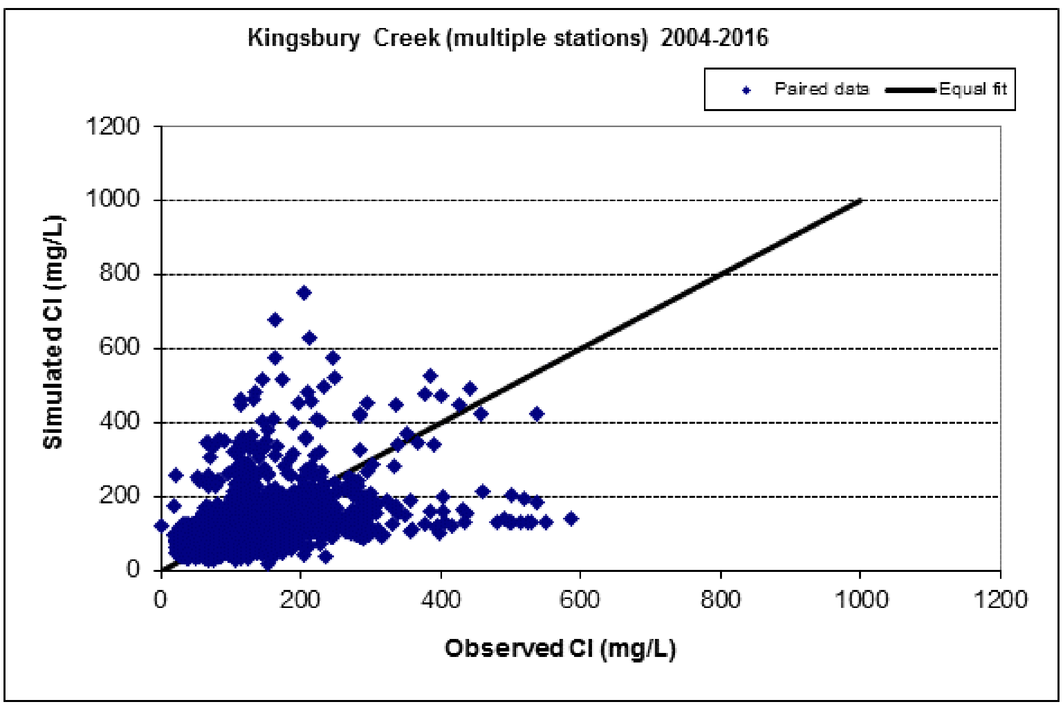


Figure F-178. Paired Simulated vs Observed Cl Concentration at the Kingsbury Creek (multiple stations) (Calibration Period)

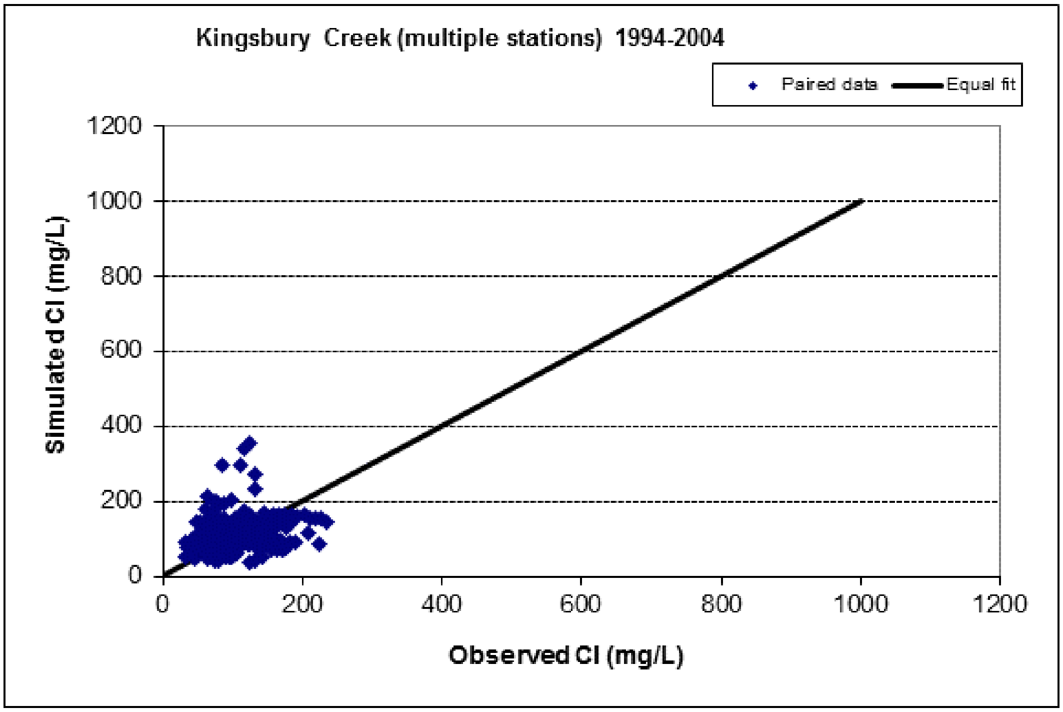


Figure F-179. Paired Simulated vs Observed Cl Concentration at the Kingsbury Creek (multiple stations) (Validation Period)

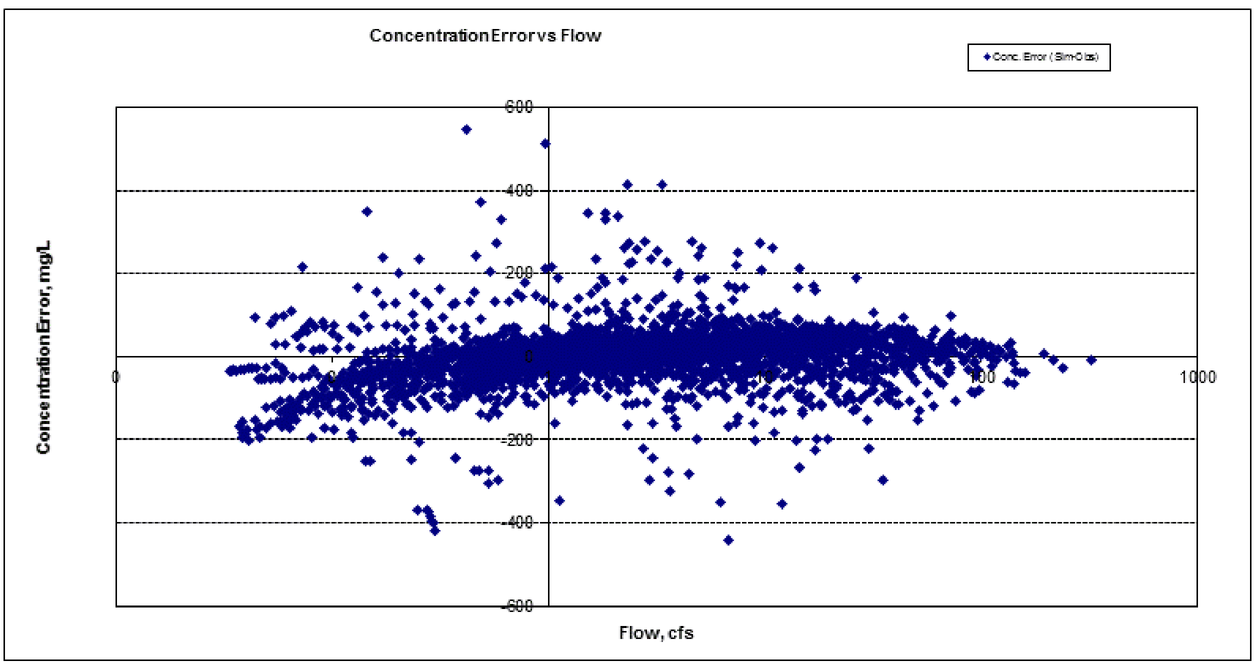


Figure F-180. Cl Concentration Error vs Flow at the Kingsbury Creek (multiple stations)

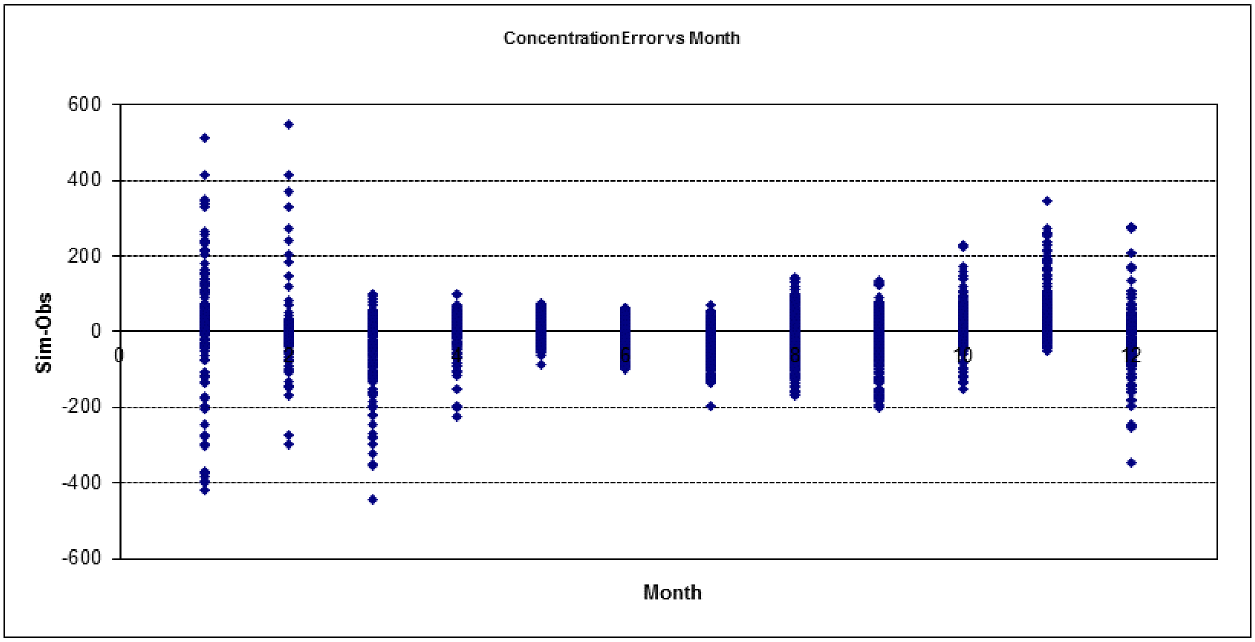


Figure F-181. Cl Concentration Error vs Month at the Kingsbury Creek (multiple stations)

F.18 Kingsbury Creek (Multiple Stations) - Discrete

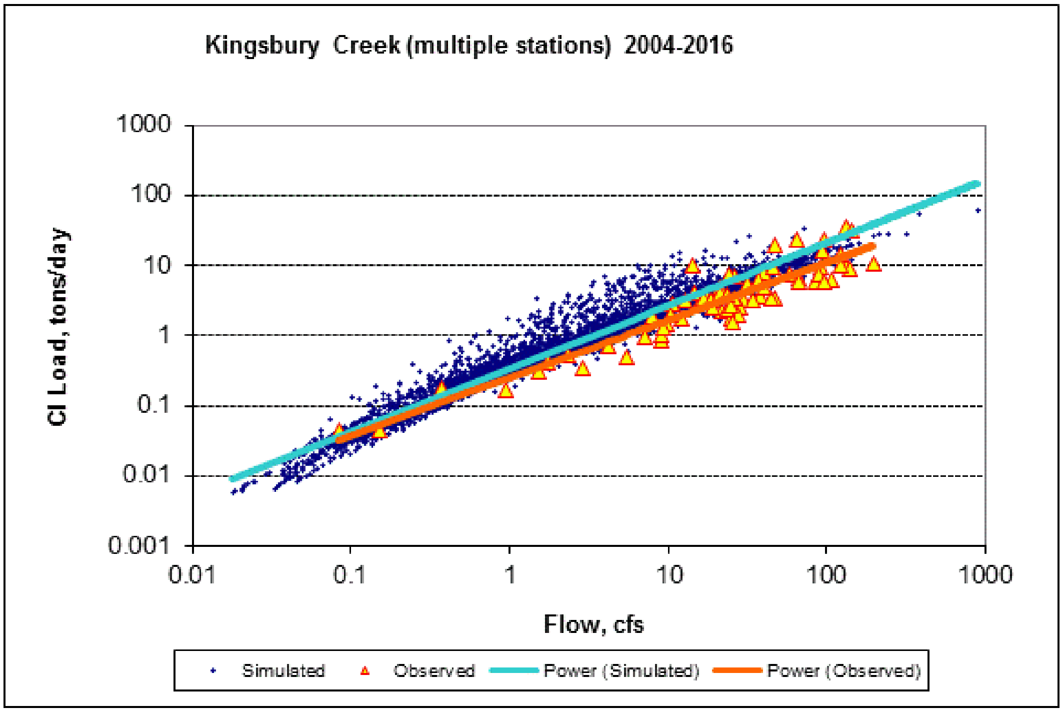


Figure F-182. Power Plot of Simulated and Observed Cl Load vs Flow at the Kingsbury Creek (multiple stations) (Calibration Period)

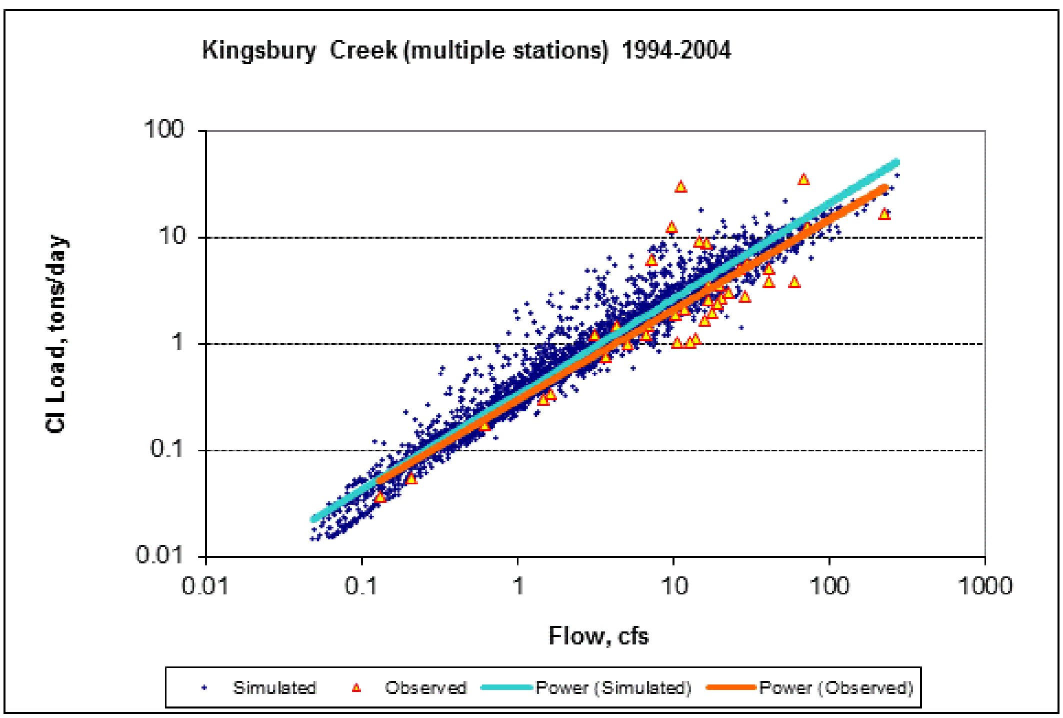


Figure F-183. Power Plot of Simulated and Observed Cl Load vs Flow at the Kingsbury Creek (multiple stations) (Validation Period)

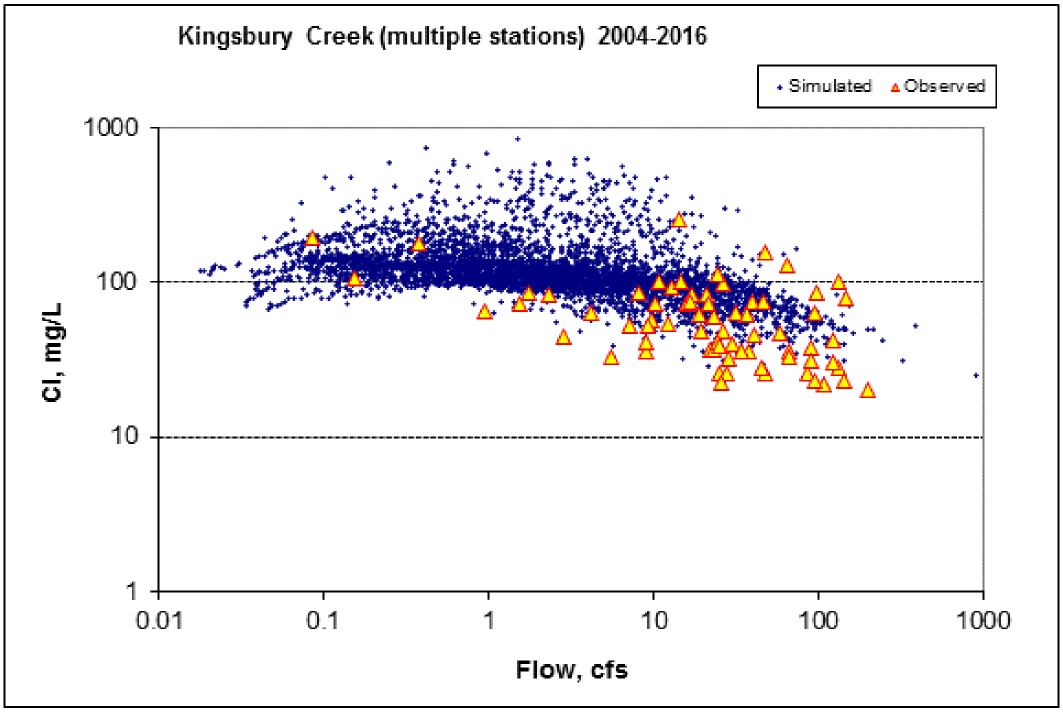


Figure F-184. Simulated and Observed Cl Concentration vs Flow Plot at the Kingsbury Creek (multiple stations) (Calibration Period)

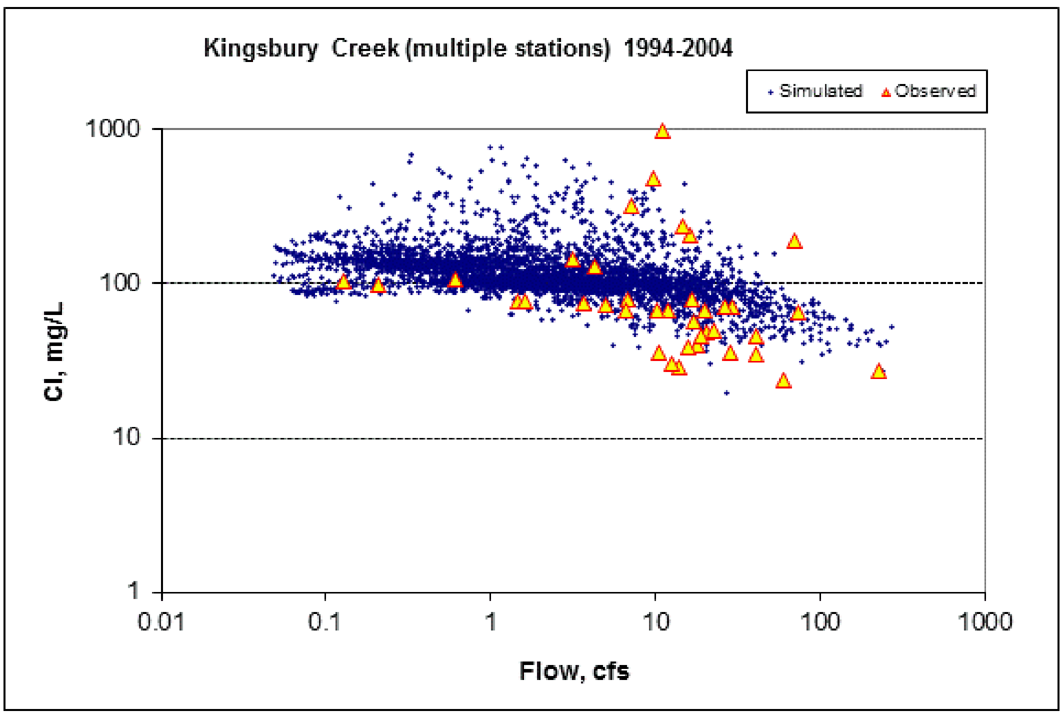


Figure F-185. Simulated and Observed Cl Concentration vs Flow Plot at the Kingsbury Creek (multiple stations) (Validation Period)

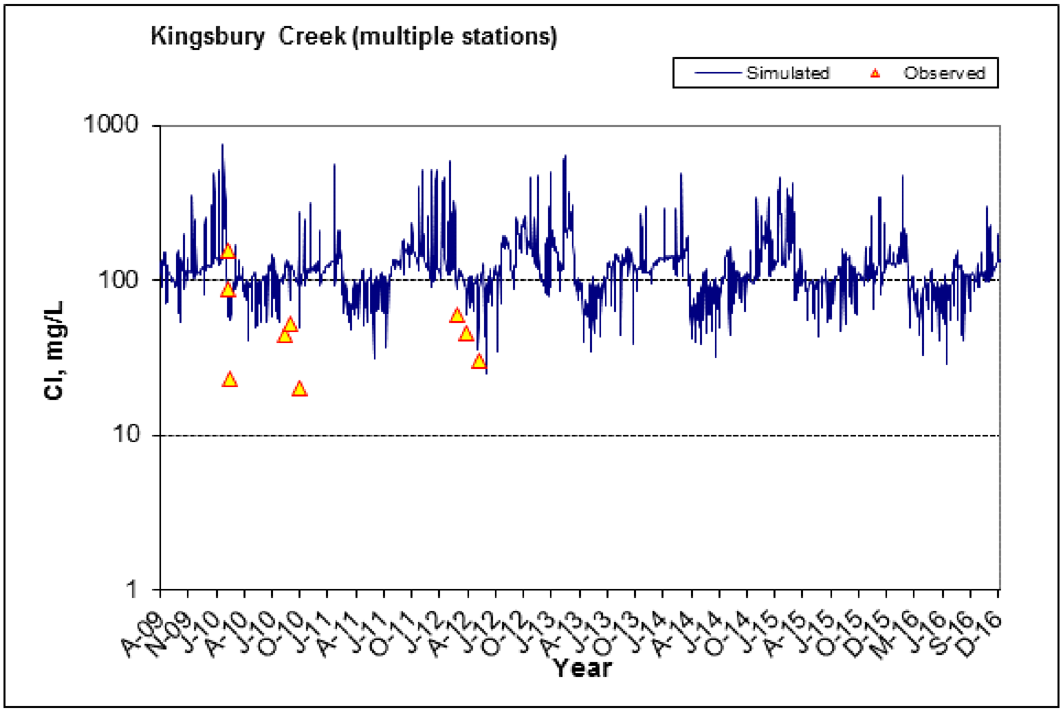


Figure F-186. Cl Concentration Time Series at the Kingsbury Creek (multiple stations) (2008-2015)

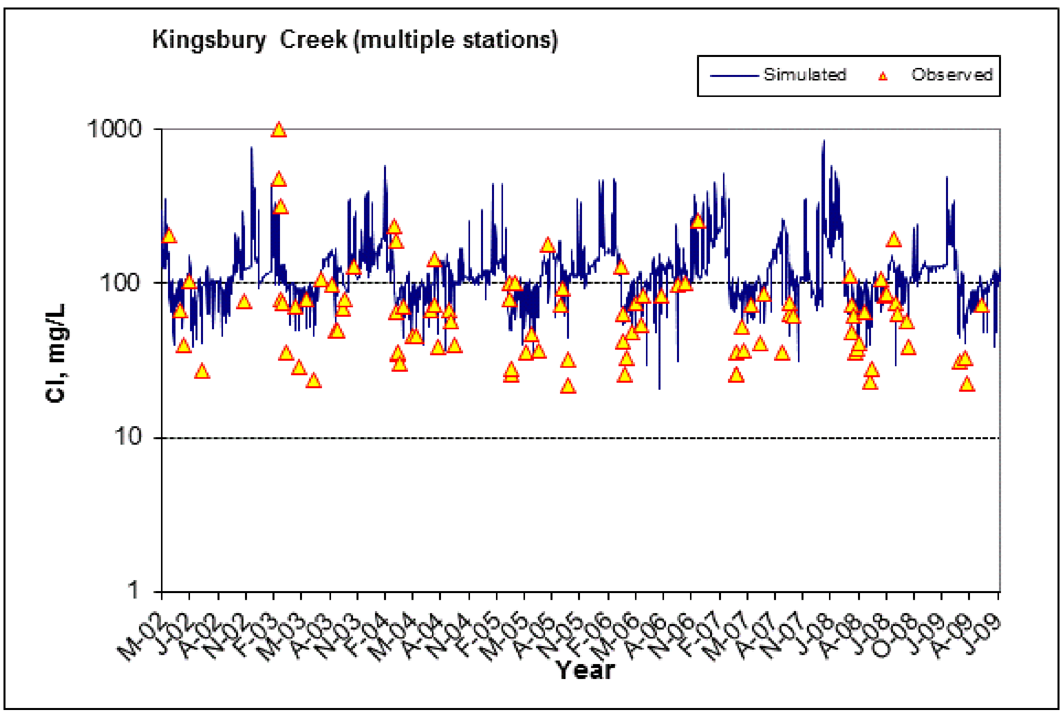


Figure F-187. Cl Concentration Time Series at the Kingsbury Creek (multiple stations) (2001-2008)

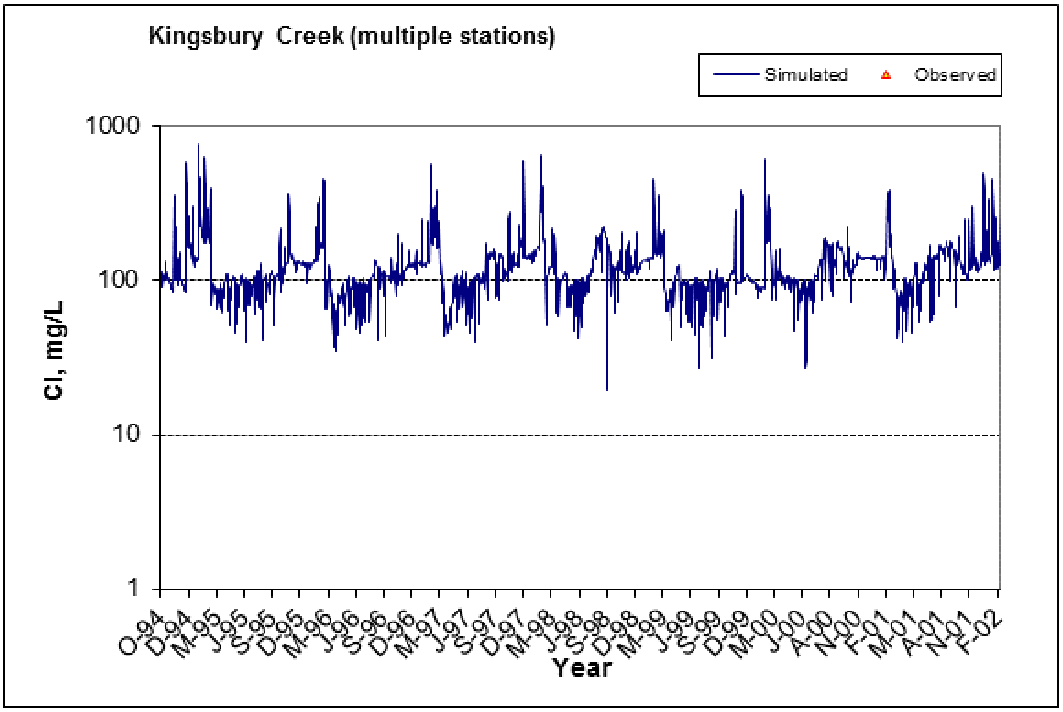


Figure F-188. Cl Concentration Time Series at the Kingsbury Creek (multiple stations) (1994-2001)

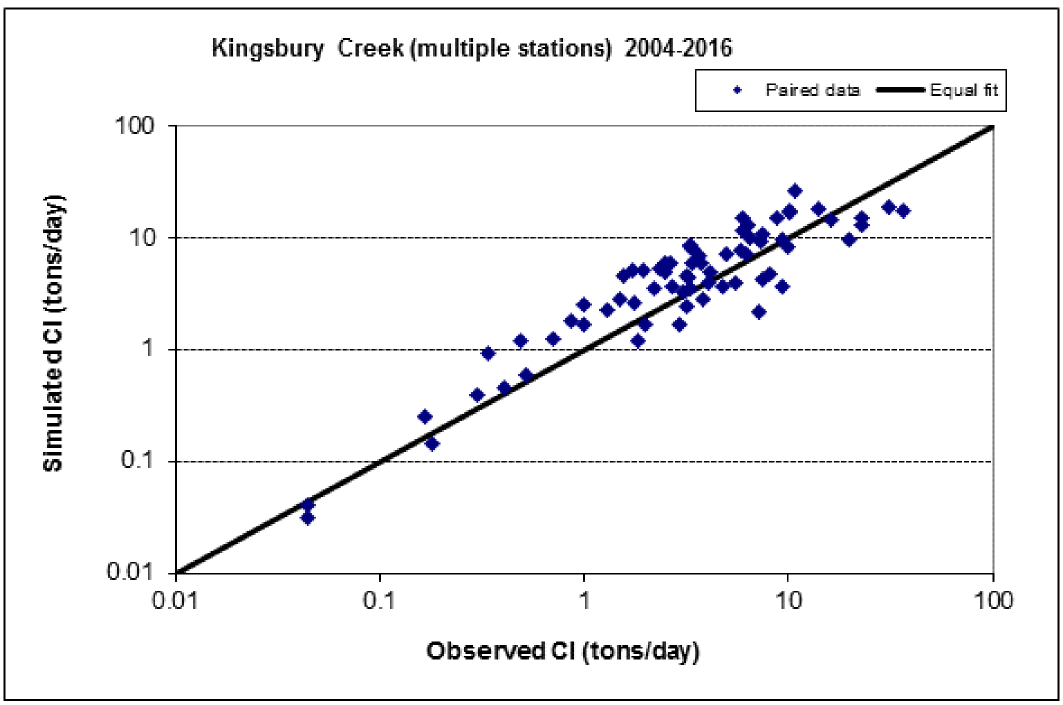


Figure F-189. Paired Simulated vs Observed Cl Load at the Kingsbury Creek (multiple stations) (Calibration Period)

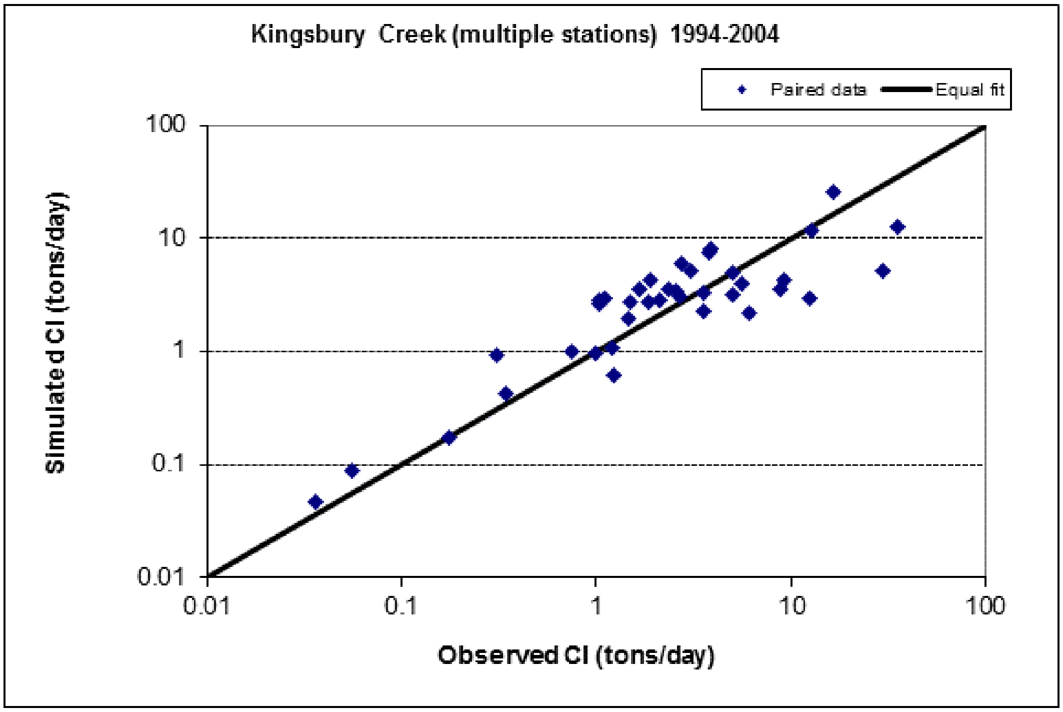


Figure F-190. Paired Simulated vs Observed Cl Load at the Kingsbury Creek (multiple stations) (Validation Period)

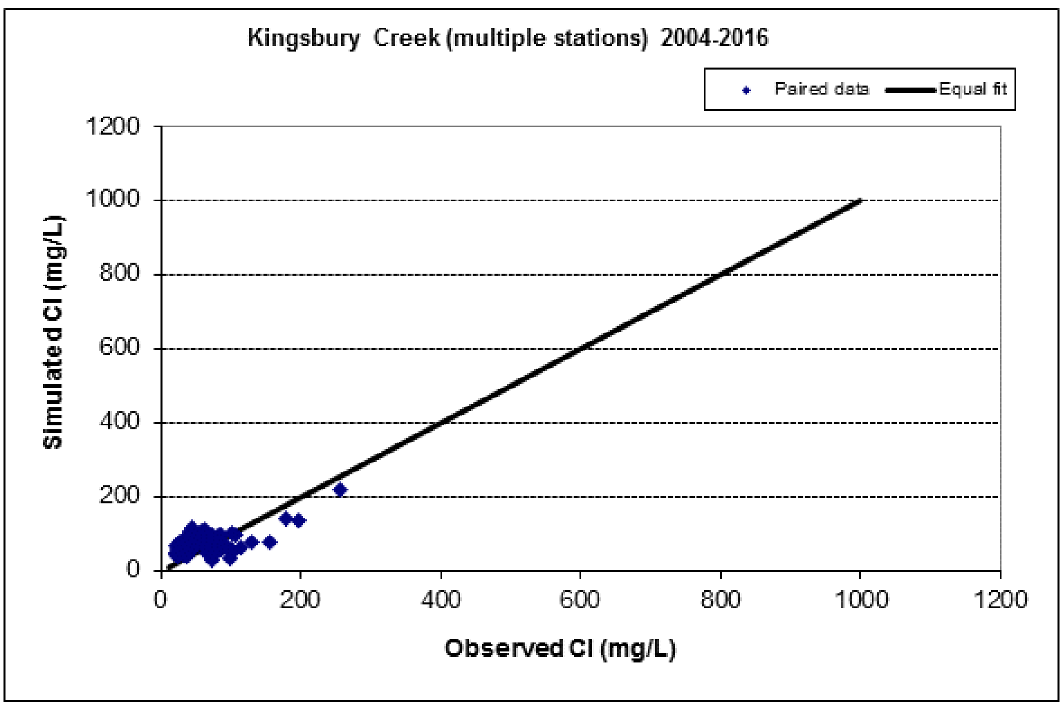


Figure F-191. Paired Simulated vs Observed Cl Concentration at the Kingsbury Creek (multiple stations) (Calibration Period)

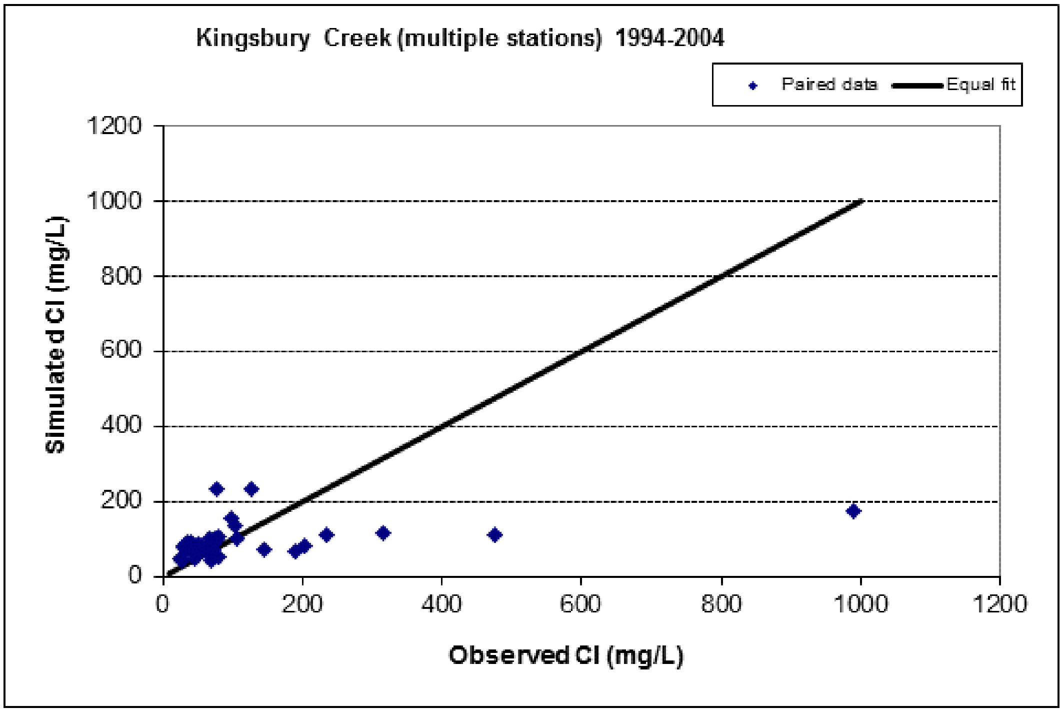


Figure F-192. Paired Simulated vs Observed Cl Concentration at the Kingsbury Creek (multiple stations) (Validation Period)

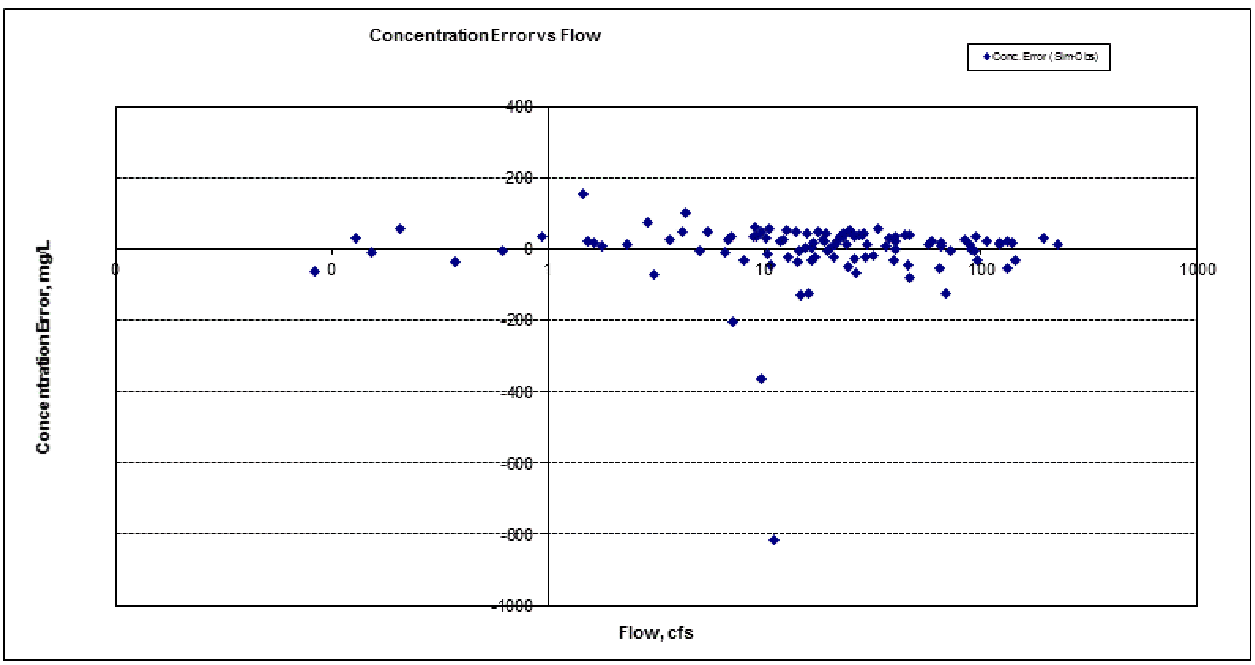


Figure F-193. Cl Concentration Error vs Flow at the Kingsbury Creek (multiple stations)

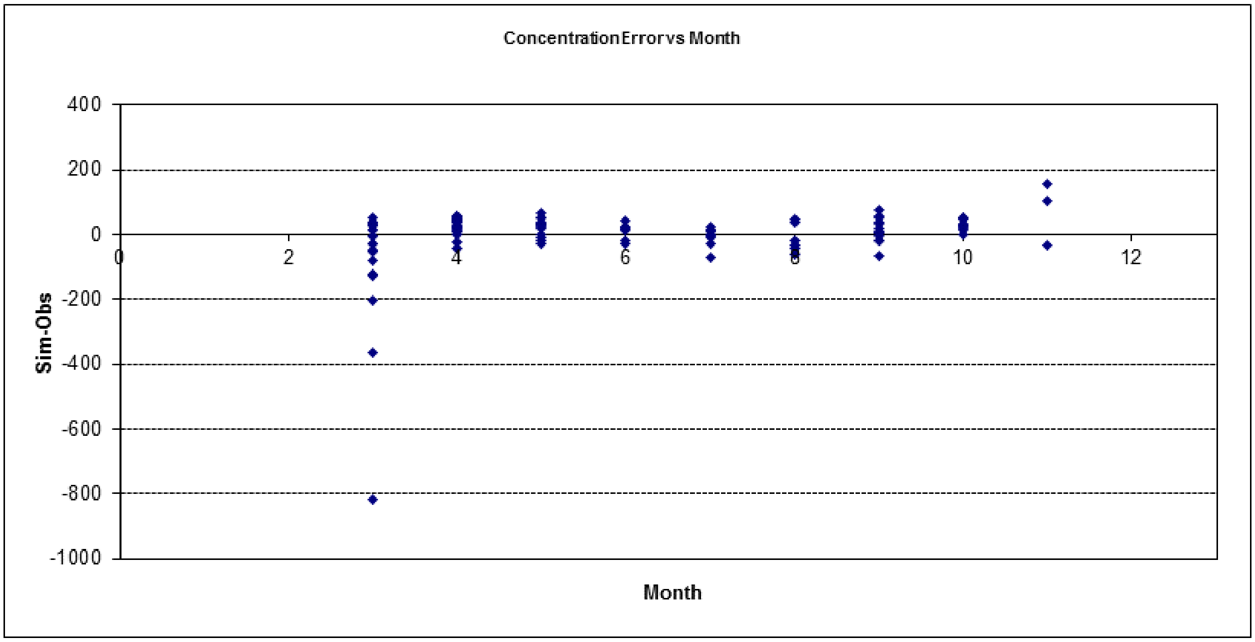


Figure F-194. Cl Concentration Error vs Month at the Kingsbury Creek (multiple stations)

F.19 Mission Creek at MN-23

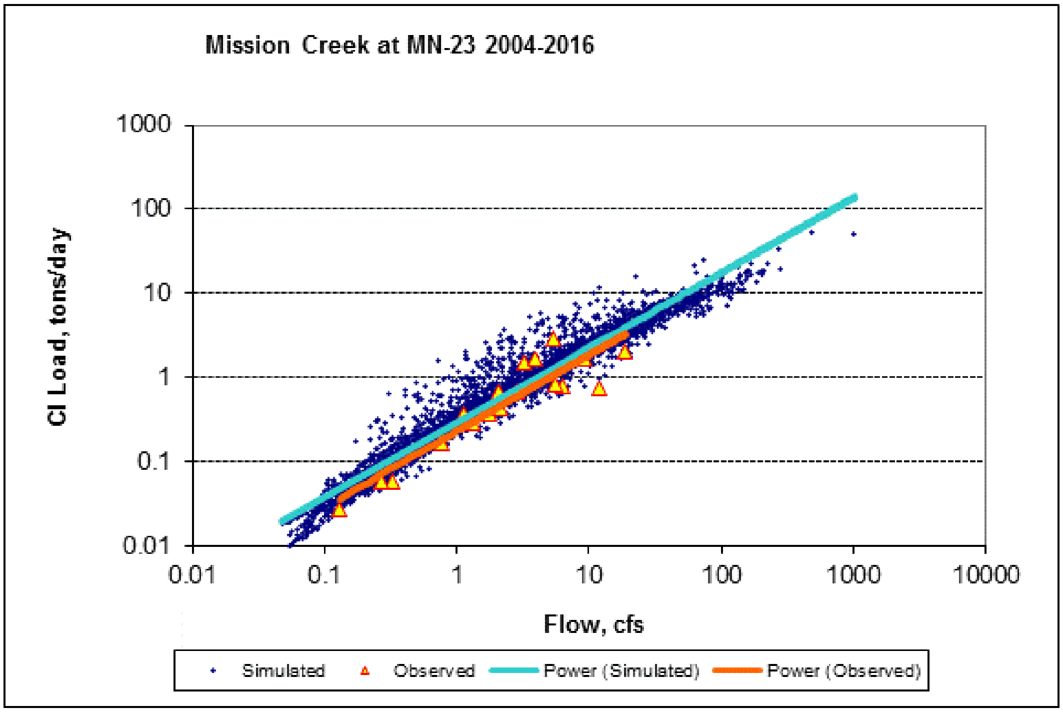


Figure F-195. Power Plot of Simulated and Observed Cl Load vs Flow at the Mission Creek at MN-23 (Calibration Period)

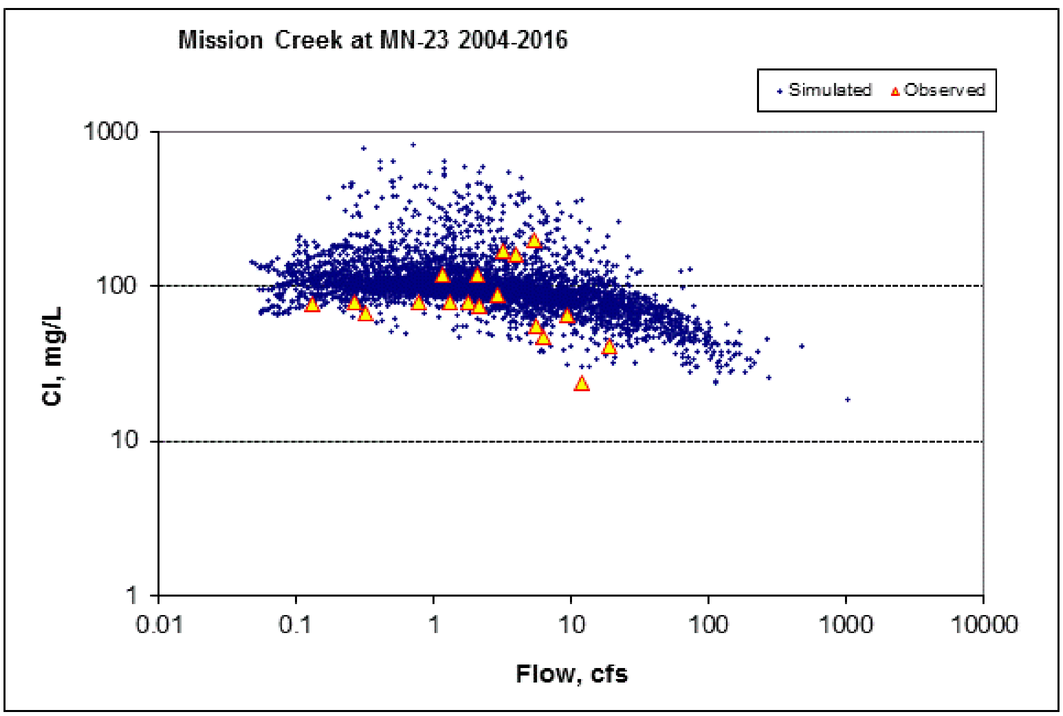


Figure F-196. Simulated and Observed Cl Concentration vs Flow Plot at the Mission Creek at MN-23 (Calibration Period)

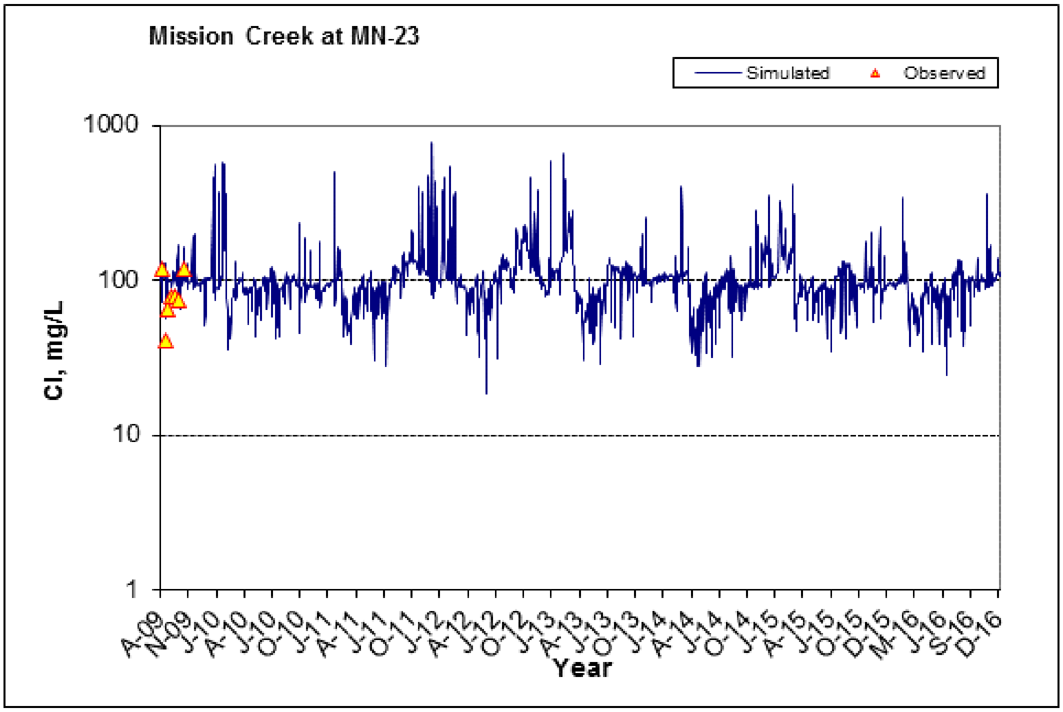


Figure F-197. Cl Concentration Time Series at the Mission Creek at MN-23 (2008-2015)

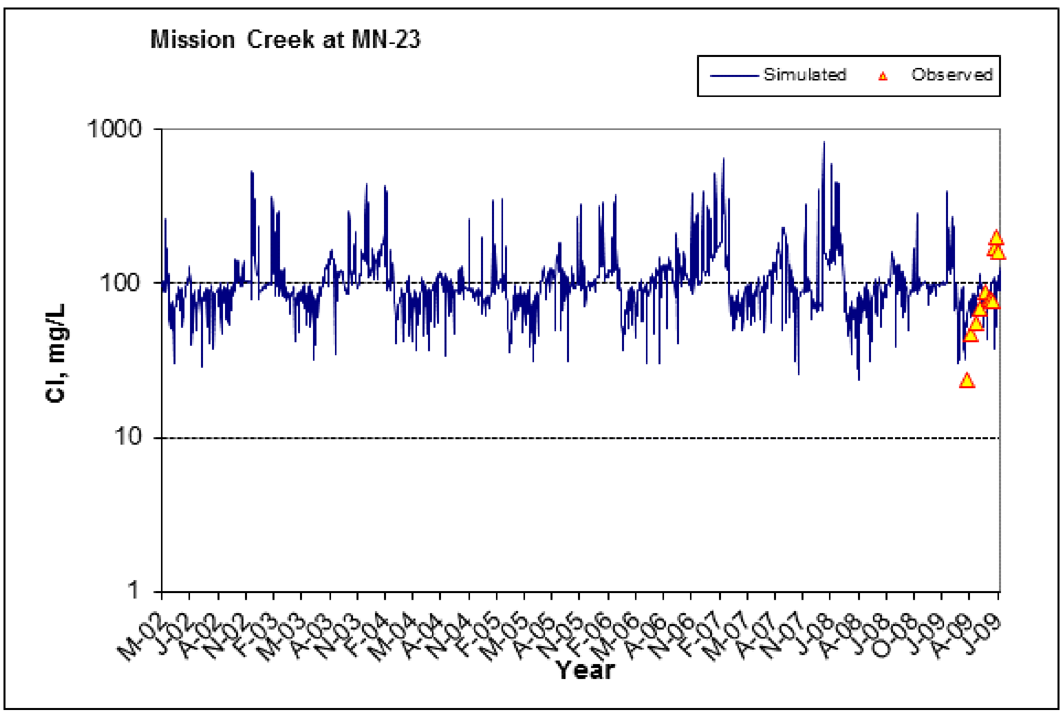


Figure F-198. Cl Concentration Time Series at the Mission Creek at MN-23 (2001-2008)

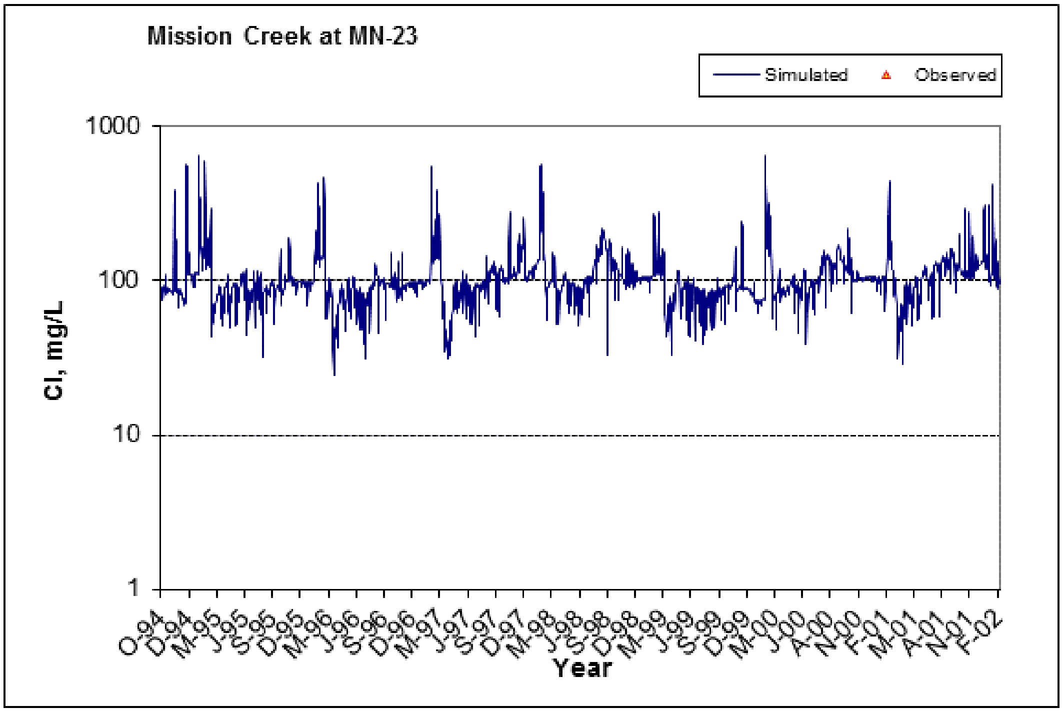


Figure F-199. Cl Concentration Time Series at the Mission Creek at MN-23 (1994-2001)

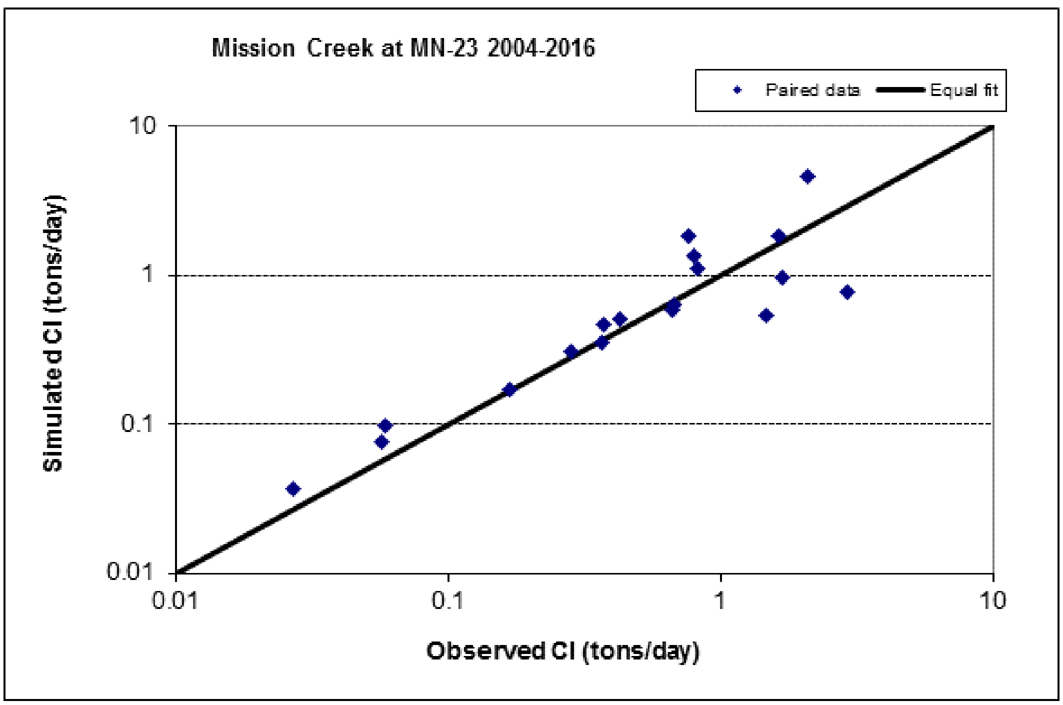


Figure F-200. Paired Simulated vs Observed Cl Load at the Mission Creek at MN-23 (Calibration Period)

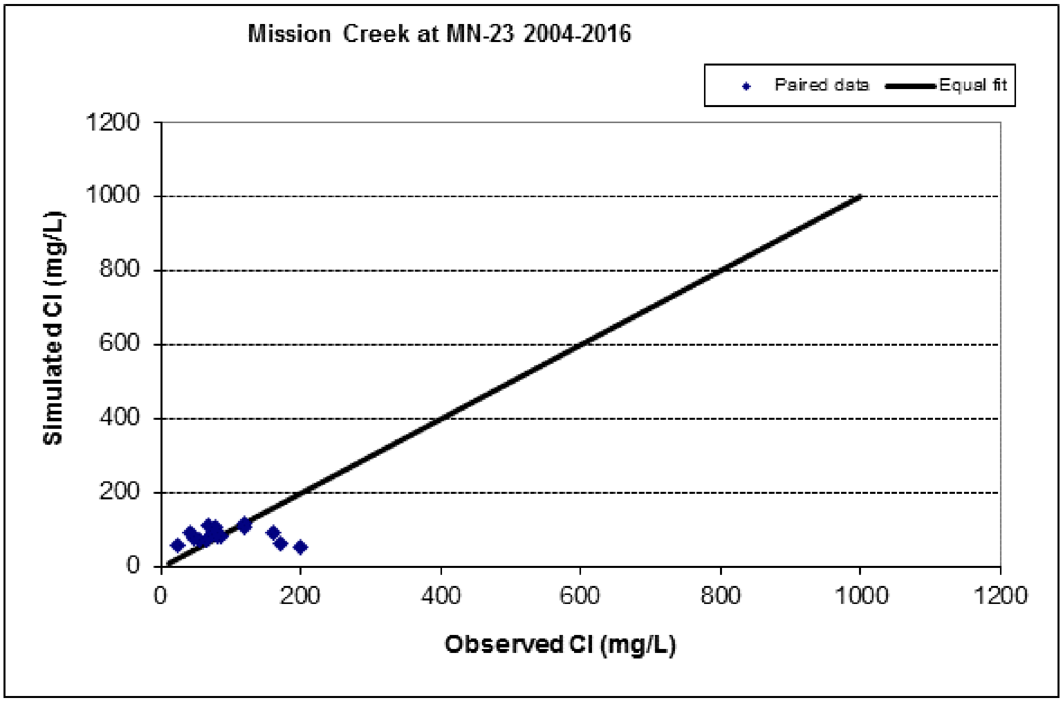


Figure F-201. Paired Simulated vs Observed Cl Concentration at the Mission Creek at MN-23 (Calibration Period)

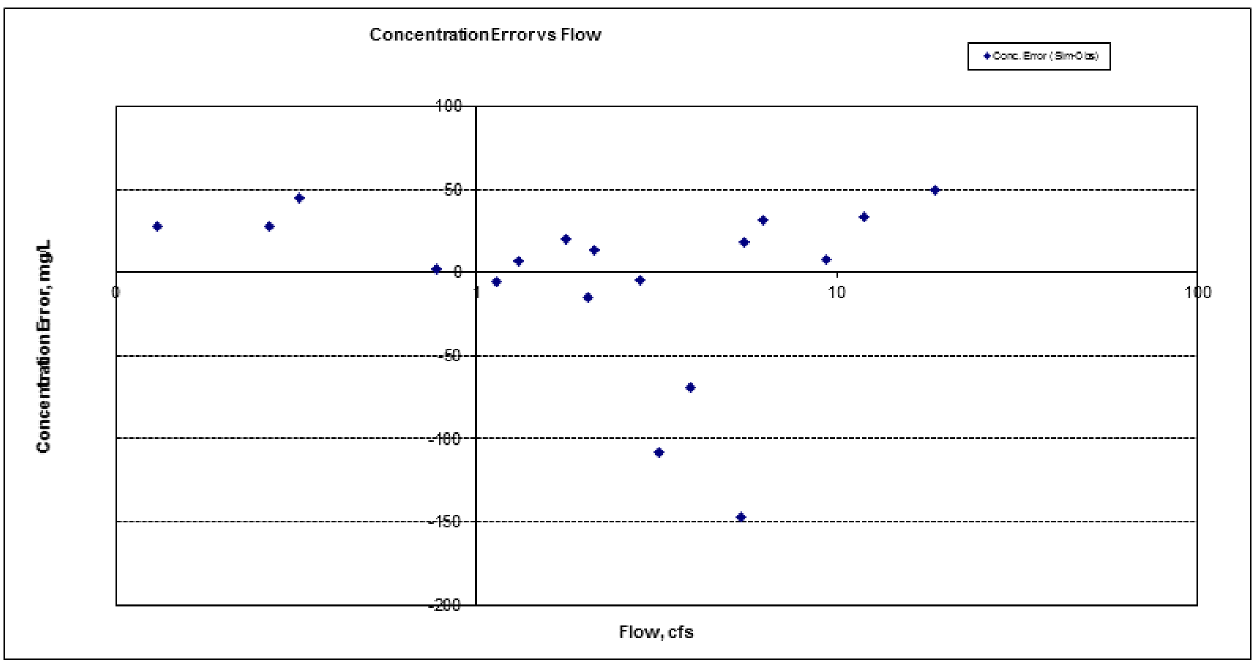


Figure F-202. Cl Concentration Error vs Flow at the Mission Creek at MN-23

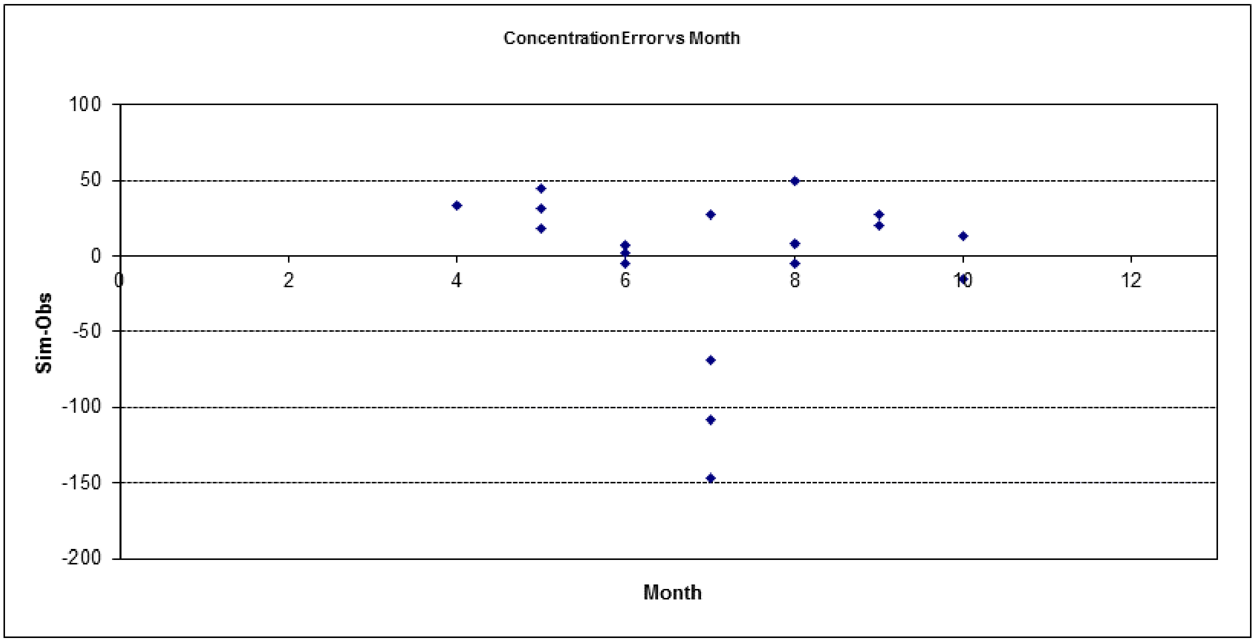


Figure F-203. Cl Concentration Error vs Month at the Mission Creek at MN-23

F.20 KEENE CREEK CENTRAL AVENUE (MILE 0.5)

F.21 Keene Creek Central Avenue (mile 0.5)

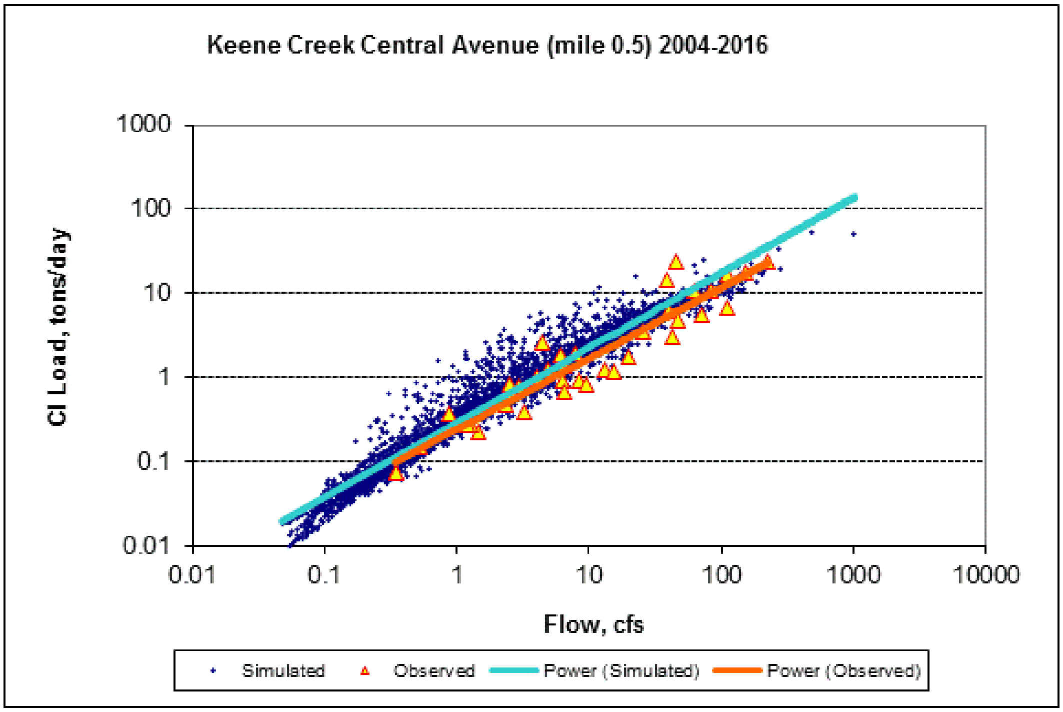


Figure F-204. Power Plot of Simulated and Observed Cl Load vs Flow at the Keene Creek Central Avenue (mile 0.5) (Calibration Period)

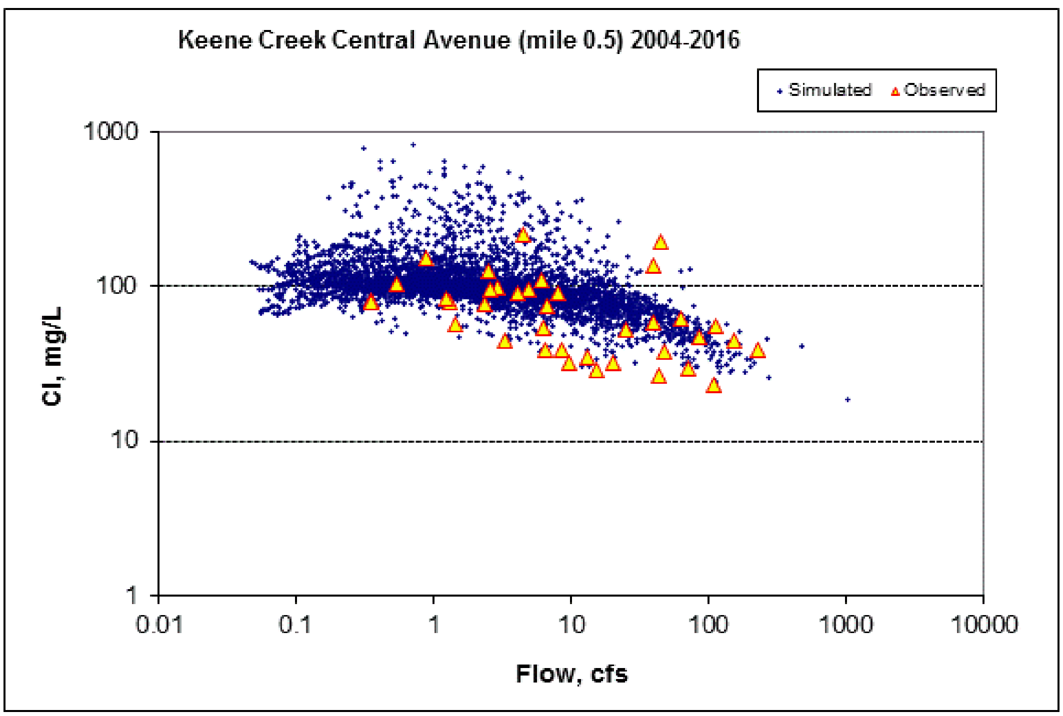


Figure F-205. Simulated and Observed Cl Concentration vs Flow Plot at the Keene Creek Central Avenue (mile 0.5) (Calibration Period)

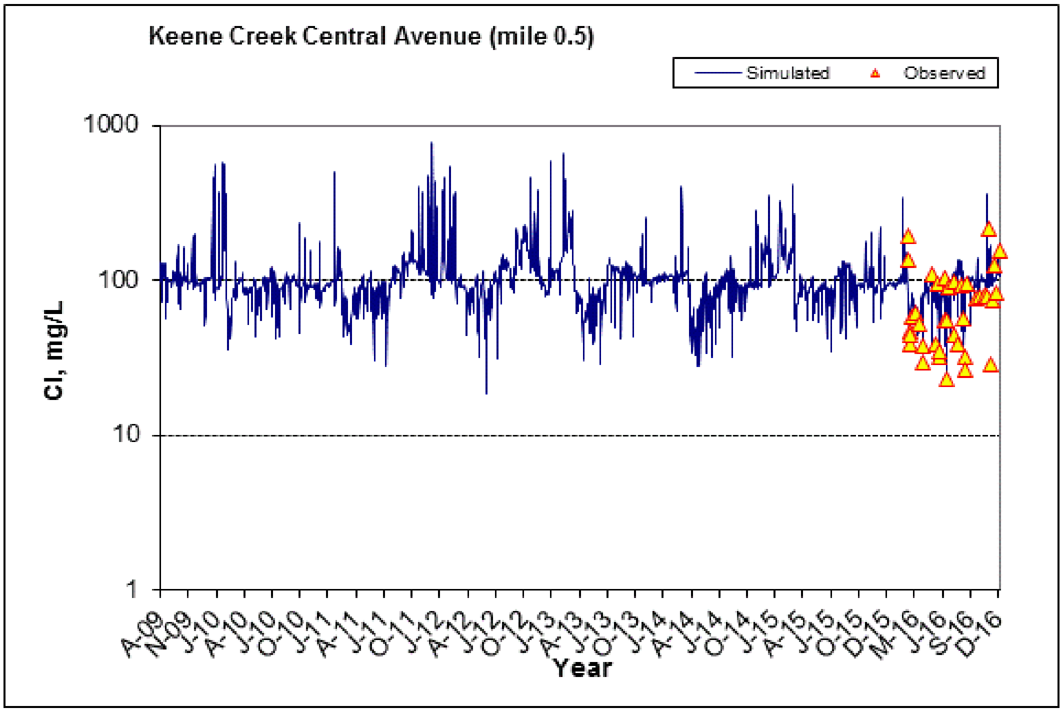


Figure F-206. Cl Concentration Time Series at the Keene Creek Central Avenue (mile 0.5) (2008-2015)

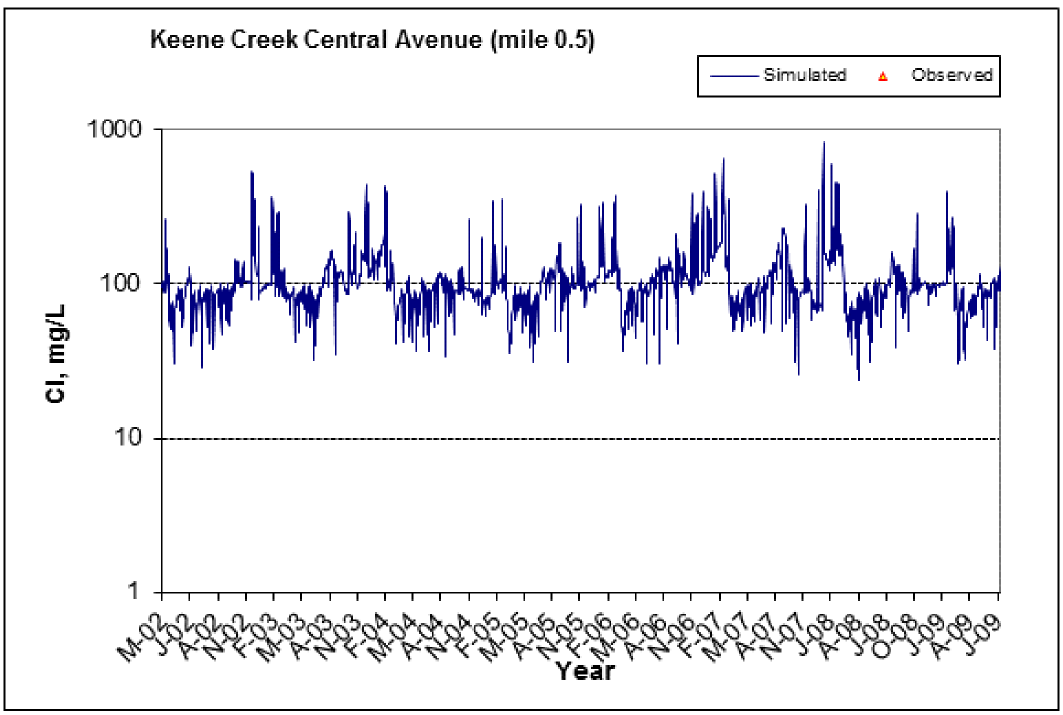


Figure F-207. Cl Concentration Time Series at the Keene Creek Central Avenue (mile 0.5) (2001-2008)

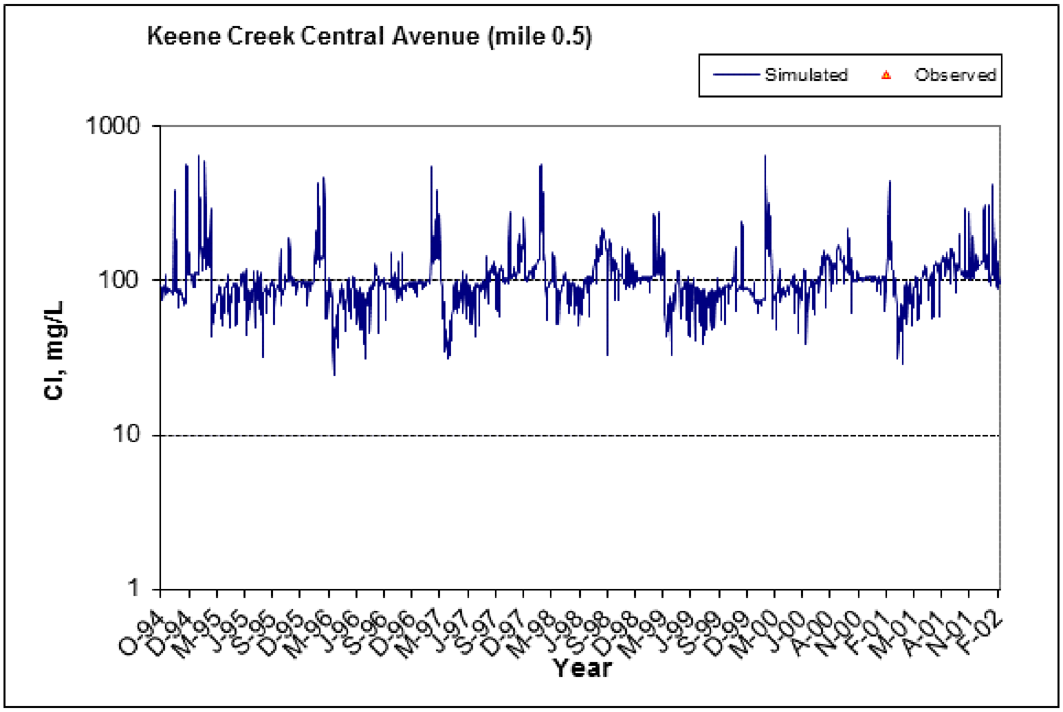


Figure F-208. Cl Concentration Time Series at the Keene Creek Central Avenue (mile 0.5) (1994-2001)

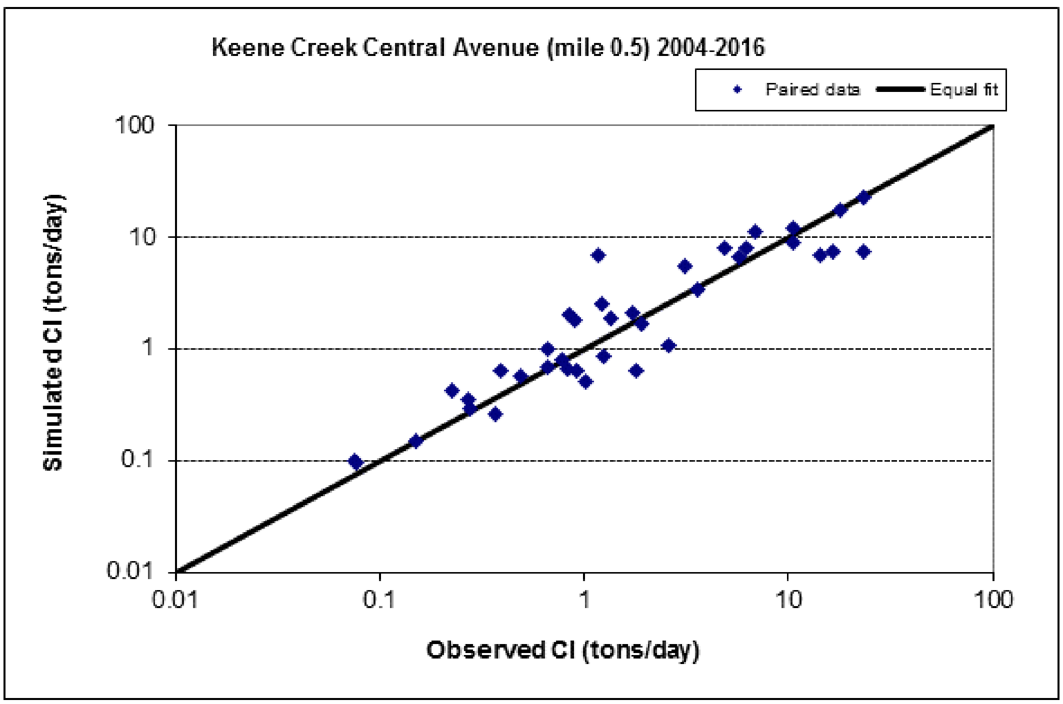


Figure F-209. Paired Simulated vs Observed Cl Load at the Keene Creek Central Avenue (mile 0.5) (Calibration Period)

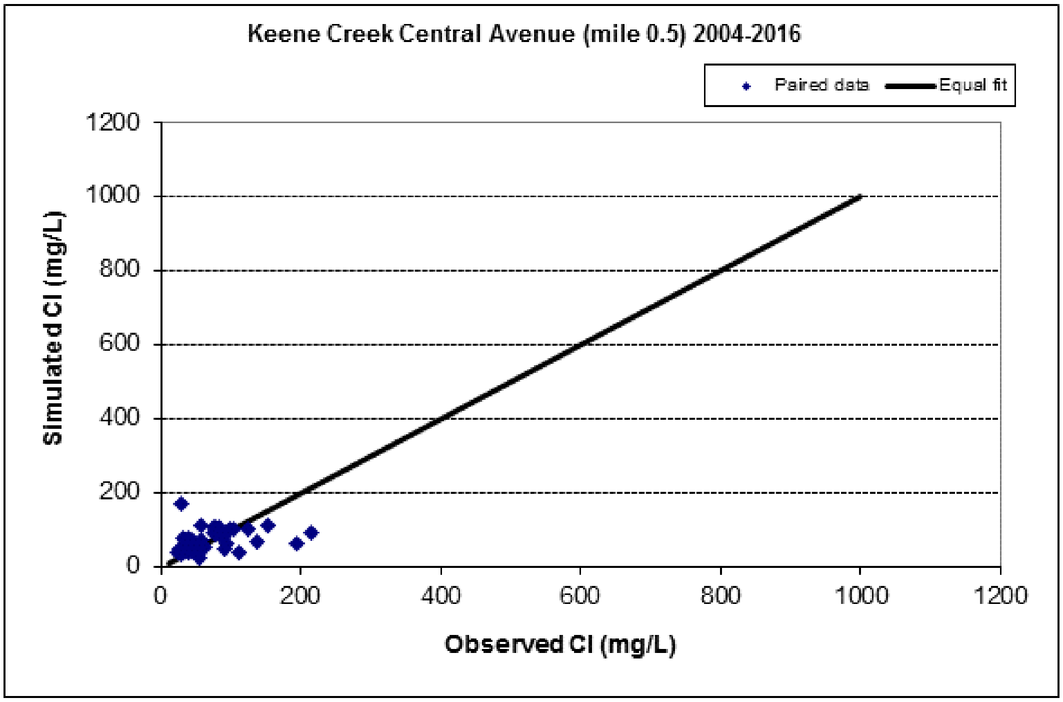


Figure F-210. Paired Simulated vs Observed Cl Concentration at the Keene Creek Central Avenue (mile 0.5) (Calibration Period)

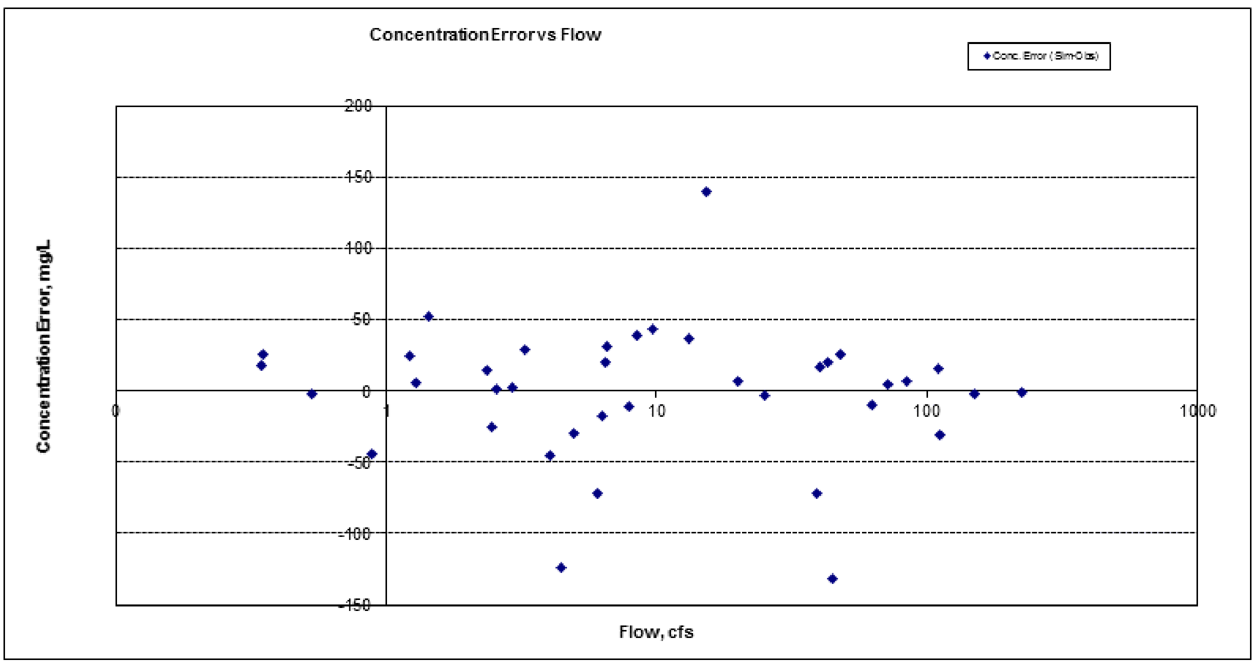


Figure F-211. Cl Concentration Error vs Flow at the Keene Creek Central Avenue (mile 0.5)

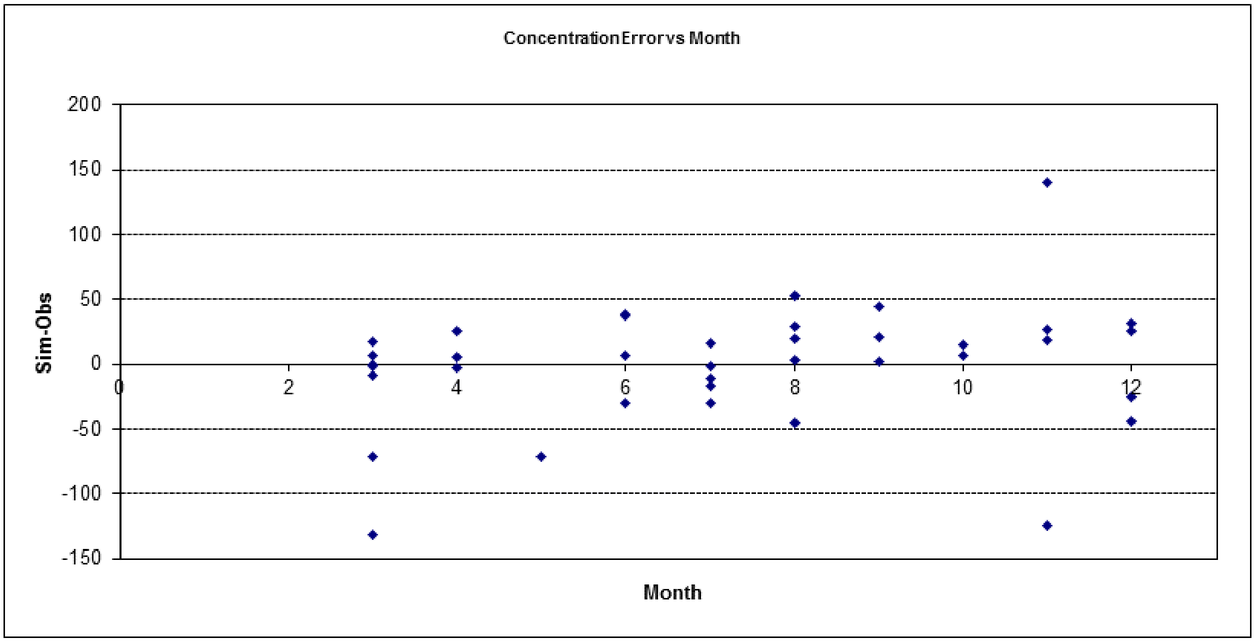


Figure F-212. Cl Concentration Error vs Month at the Keene Creek Central Avenue (mile 0.5)

F.22 Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN

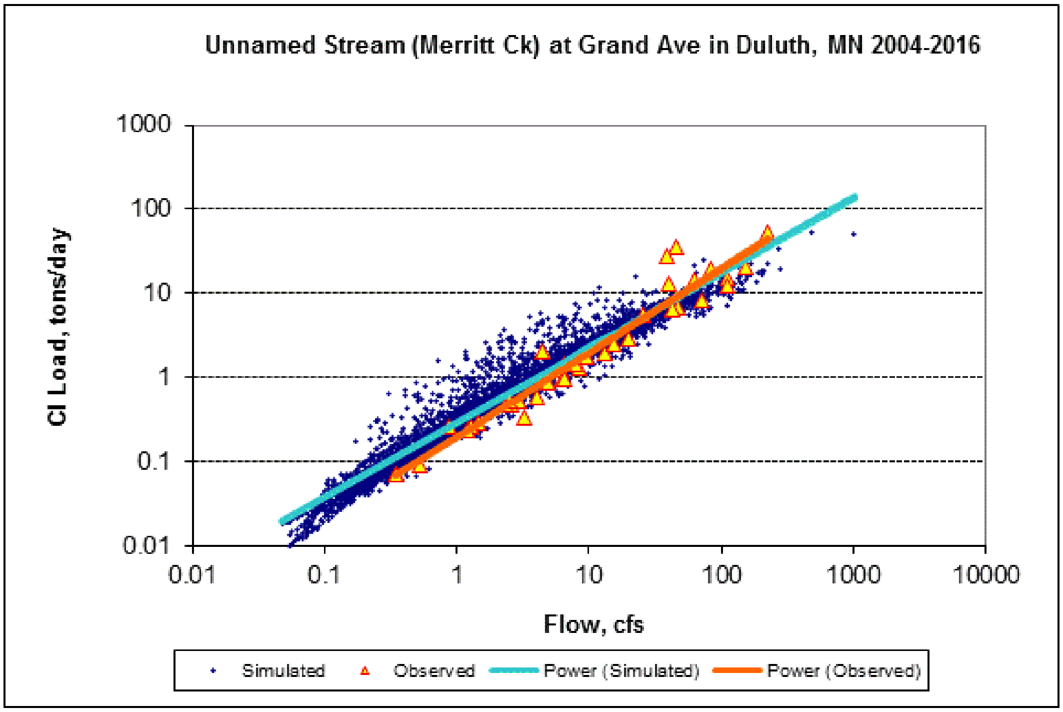


Figure F-213. Power Plot of Simulated and Observed Cl Load vs Flow at the Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN (Calibration Period)

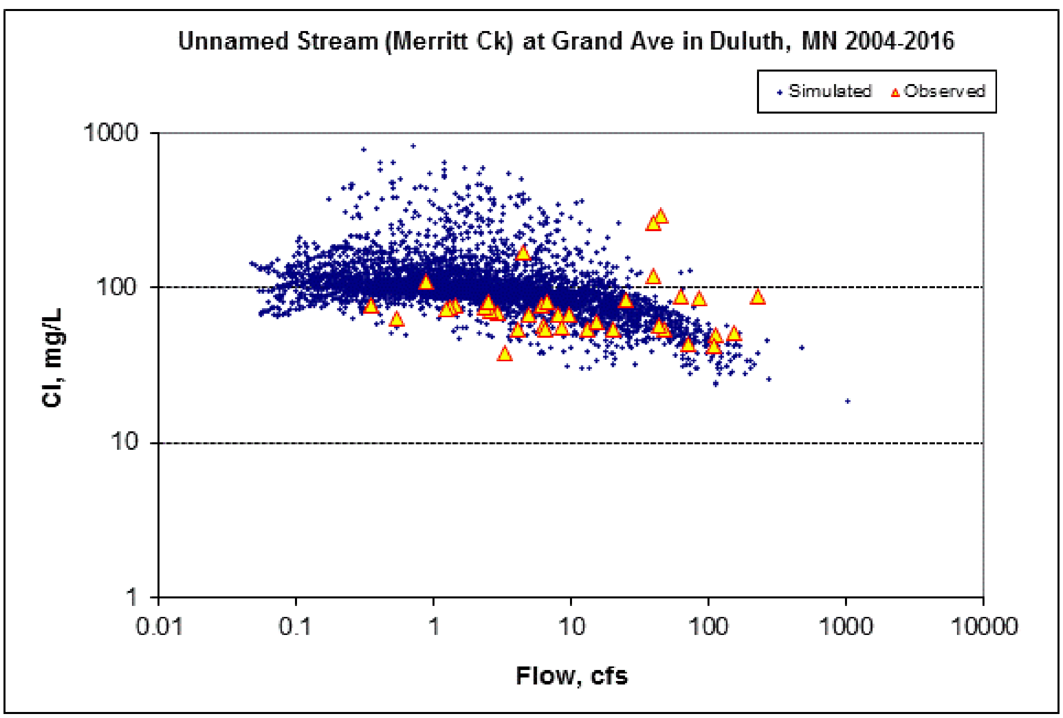


Figure F-214. Simulated and Observed Cl Concentration vs Flow Plot at the Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN (Calibration Period)

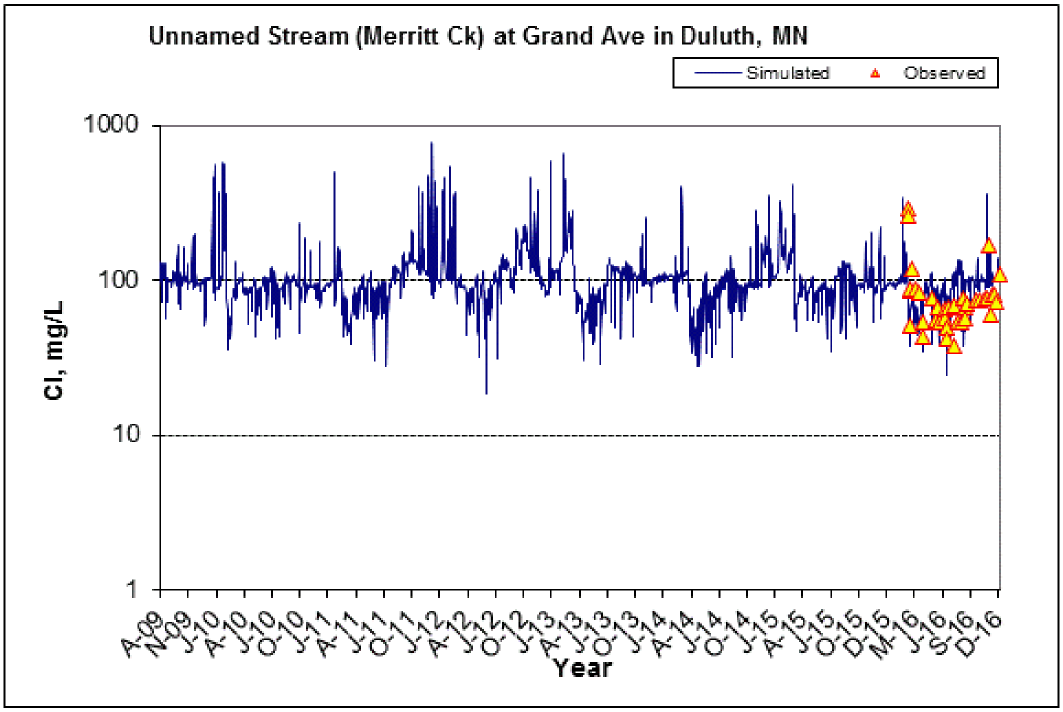


Figure F-215. Cl Concentration Time Series at the Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN (2008-2015)

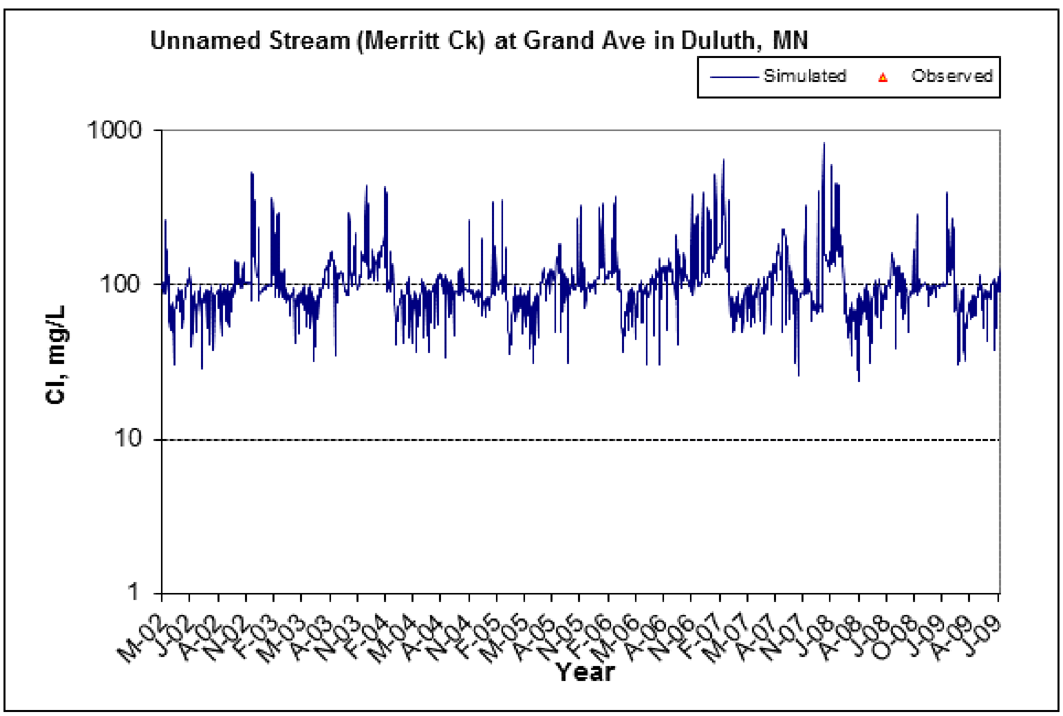


Figure F-216. Cl Concentration Time Series at the Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN (2001-2008)

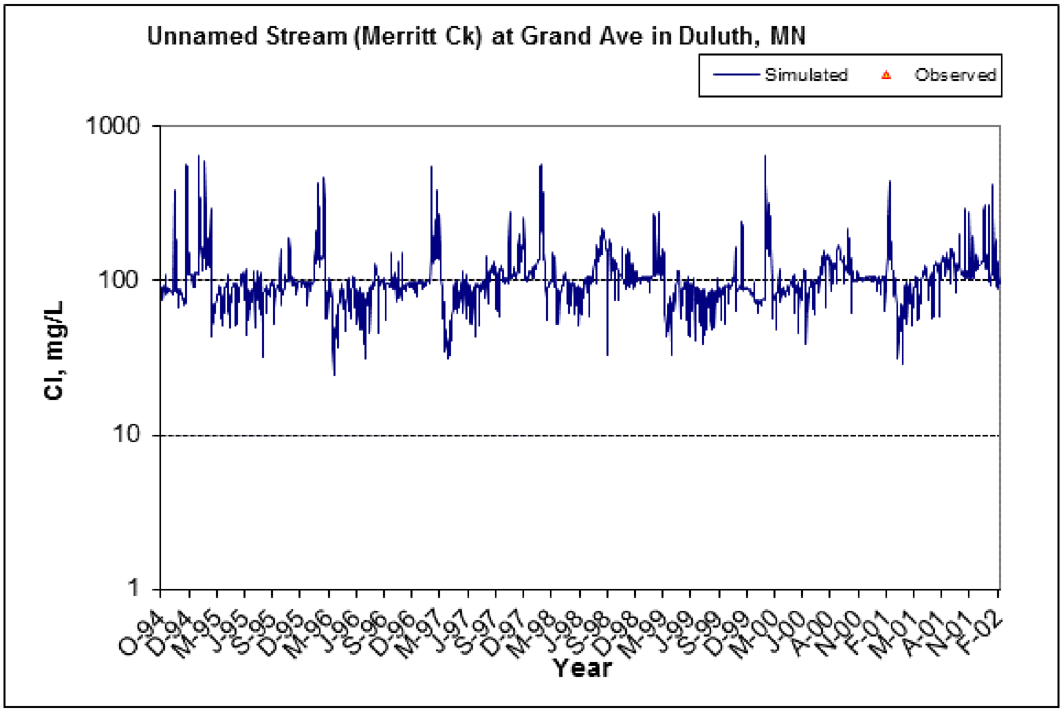


Figure F-217. Cl Concentration Time Series at the Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN (1994-2001)

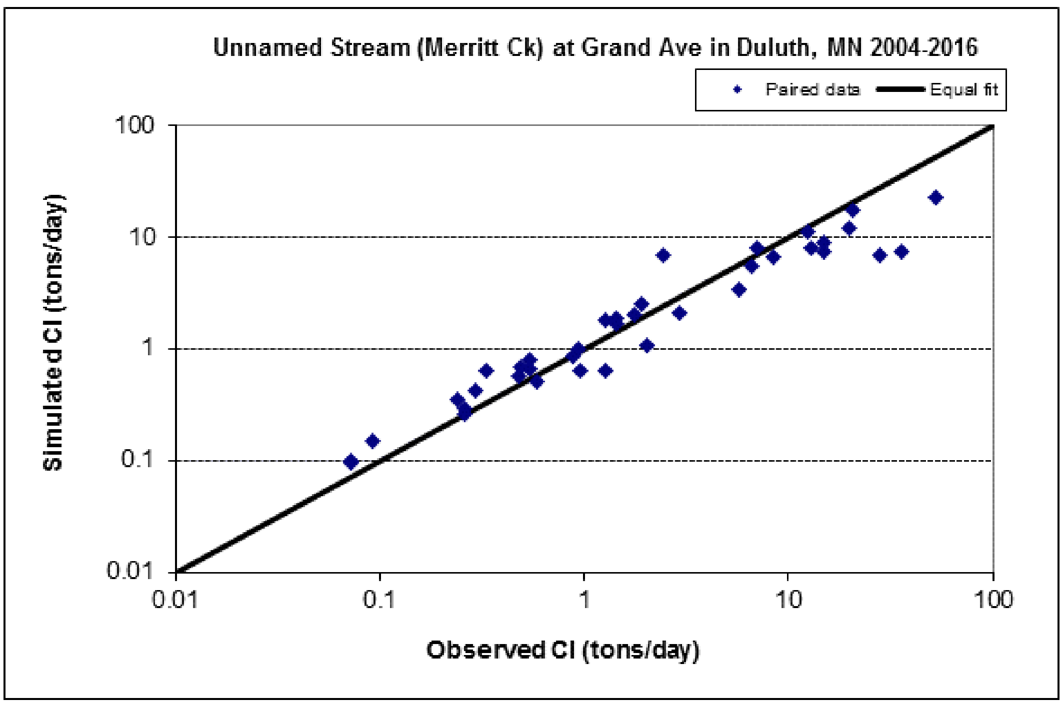


Figure F-218. Paired Simulated vs Observed Cl Load at the Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN (Calibration Period)

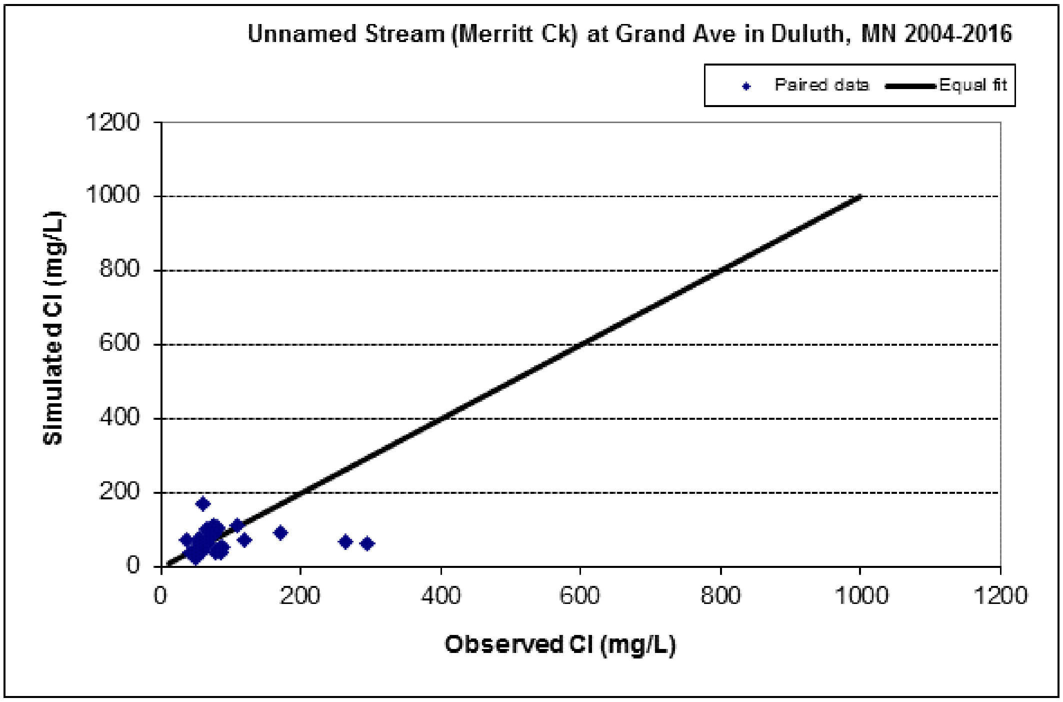


Figure F-219. Paired Simulated vs Observed Cl Concentration at the Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN (Calibration Period)

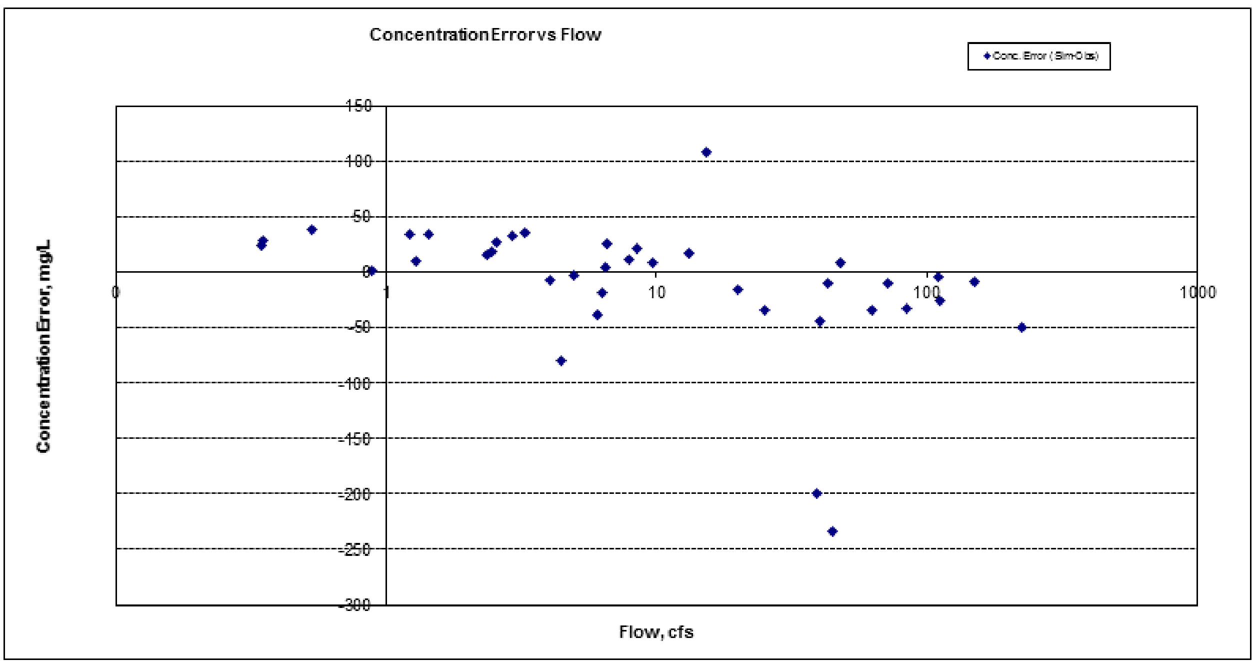


Figure F-220. Cl Concentration Error vs Flow at the Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN

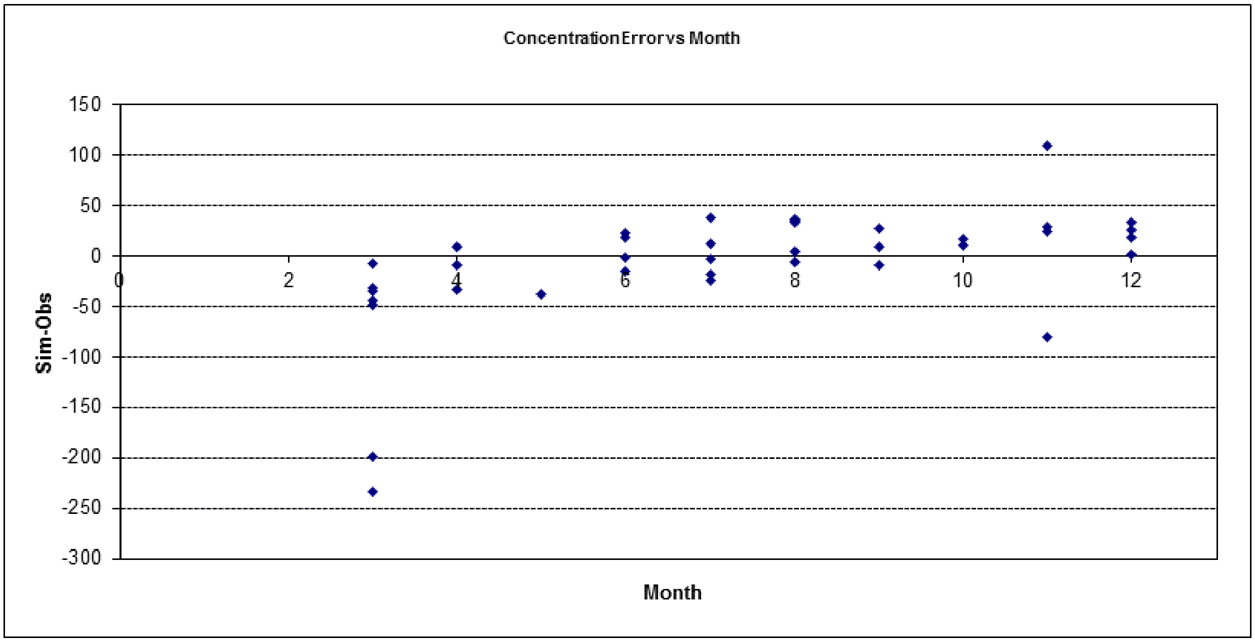


Figure F-221. Cl Concentration Error vs Month at the Unnamed Stream (Merritt Ck) at Grand Ave in Duluth, MN