Lake Superior North Watershed Total Maximum Daily Load

Flute Reed River

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Acronyms and Abbreviations

AUID	assessment unit ID
BANCS	Bank Assessment for Nonpoint source Consequences of Sediment
BEHI	Bank Erosion Hazard Index
DNR	Minnesota Department of Natural Resources
EPA	U.S. Environmental Protection Agency
EQuIS	Environmental Quality Information System
cfs	cubic feet per second
HSPF	Hydrologic Simulation Program–Fortran
HUC	hydrologic unit code
LA	load allocation
mg/L	milligrams per liter
MOS	margin of safety
MPCA	Minnesota Pollution Control Agency
NBS	Near Bank Stress
NPDES	National Pollutant Discharge Elimination System
SDS	State Disposal System
SWCD	soil and water conservation district
TMDL	total maximum daily load
TSS	total suspended solids
WARSSS	Watershed Assessment of River Stability and Sediment Supply
WLA	wasteload allocation
WRAPS	watershed restoration and protection strategy

Executive Summary

Northeastern Minnesota is blessed with many of the state's highest quality natural resources. These resources are important to both the native people and the more recent settlers in this area. The ultimate natural resource is Lake Superior itself, or Anishinaabewi-gichigami in Ojibwe, headwater of the Great Lakes. The Flute Reed River is tributary to Lake Superior, and is identified as impaired for aquatic life use due to excess sediment. The Clean Water Act, Section 303(d) requires Total Maximum Daily Loads (TMDLs) for surface waters that do not meet, and maintain, applicable water quality standards necessary to support their designated uses. A TMDL determines the maximum amount of a pollutant a receiving waterbody can assimilate while still achieving water quality standards. This TMDL study addresses two impaired reaches of the Flute Reed River.

The Flute Reed River is considered a valuable rainbow trout fishery among North Shore streams. Trout from Lake Superior enter the stream each spring to spawn. Young trout use the lower reaches of the river for one or two summers and were well represented in the most recent monitoring effort. The Flute Reed River Subwatershed is primarily forested with second and third generation forest cover. The principal community, the town of Hovland, was settled in the late 1800s. Hovland today is still small in population (~300). It is a non-incorporated community with four businesses, a church and post office clustered along a state highway. Residential areas are more dense near Lake Superior, and more scattered in the mid to headwaters area. There is significant private land ownership with associated rural homestead and seasonal home activities.

Sediment is the primary impairment, and is associated with highly erodible lacustrine clay deposits. Naturally high erosion rates have increased due to human activities, including historical forest harvesting, forest fires, and general development activities of the last century. Monitoring for total suspended solids (TSS) shows concentrations vary across the subwatershed from low (<10 mg/L) to very high (>400 mg/L). The majority of TSS standard violations occur as a result of snowmelt during April and May. Primary sources of sediment include overland runoff, near-channel erosion and bank failure, failed beaver dams and ponds, and road network infrastructure including ditches, road/driveway surfaces and culverts. There are no permitted point sources with the exception of activities that are regulated by general permits such as construction.

The pollutant load capacity of the Flute Reed River was determined using load duration curves for each impaired reach. The curves represent the allowable pollutant load at any given flow condition. Water quality data are compared with the load duration curves to determine load reduction needs. Both impaired reaches must make significant improvements at the highest flows (92% to 96% reduction). The middle portion of the stream shows the highest loading rate per the geomorphic evaluation.

The implementation strategy highlights an adaptive management process to achieve water quality standards and restore beneficial uses. Addressing near channel sources of erosion and the activities that create or prompt the erosion cycles are key strategies. Improving private land management on a sensitive landscape will be an ongoing challenge and need into the future. Understanding the dynamics of ownership patterns and potential development impacts to the stream should be a shared engagement between the community and local public professionals in land services.

Public participation in this TMDL process included meetings with watershed stakeholders to present and review data, discuss the TMDL elements in greater detail, develop a preliminary list of management strategies, and allow for open discussion of local issues of concern. The TMDL study is supported by previous work including the *Lake Superior North Watershed Monitoring and Assessment Report* (MPCA 2017a), *Lake Superior North Watershed Stressor Identification Report* (MPCA 2017b), and the Flute Reed Watershed hydrology and water quality model (Tetra Tech 2017).

1. Project Overview

1.1 Purpose

The Clean Water Act and U.S. Environmental Protection Agency (EPA) regulations require that TMDLs be developed for waters that do not support their designated uses. In simple terms, a TMDL is a study of what is required to attain and maintain water quality standards in waters that are not currently meeting them. This TMDL study addresses the Flute Reed River Subwatershed, located near Hovland, Minnesota within the Lake Superior North Watershed (U.S. Geological Survey Hydrologic Unit Code (HUC)-8 04010101; Figure 1). There are no tribal lands within the project area, however, the watershed is part of the of the La Pointe Treaty of 1854, which reserves hunting and fishing rights for the Ojibwa tribes of the Lake Superior region.

This TMDL Report is a component of a larger effort to develop Watershed Restoration and Protection Strategies (WRAPS) for the Lake Superior North Watershed. Other components of the larger effort include the *Lake Superior North Monitoring and Assessment Report* (MPCA 2017a), the *Lake Superior North Watershed Stressor Identification Report* (MPCA 2017b), the Flute Reed Watershed hydrology and water quality model (Tetra Tech 2017), and the *Lake Superior North WRAPS* (2018).

1.2 Identification of Waterbodies

This TMDL report addresses impairments along two reaches of the Flute Reed River (Table 1 and Figure 2). The impairments affect the aquatic life designated use due to high levels of turbidity and TSS. In addition to high levels of turbidity and TSS, the *Lake Superior North Watershed Stressor Identification Report* (MPCA 2017b) also identifies the following stressors to aquatic life in the stream: elevated water temperature, physical habitat degradation, and aquatic organism passage barriers. Both reaches are on the draft 2016 and 2018 303d lists of impaired water bodies.

TSS standards were promulgated for the state of Minnesota in 2015 (Minn. R. 7050.0222), replacing the turbidity standard. However, existing turbidity impairments will remain listed as turbidity impairments. TMDLs developed within this report for both the turbidity listing and TSS listing on the Flute Reed River are based on the new TSS standards.

Table 1. Impaired waters

Reach Name	AUID (04010101-xxx)	Use Class	Location/Reach Description	Affected Designated Use Class	Listing Year	Target Start/Completion	Pollutant or Stressor
Flute Reed River	D31	2A	Headwaters (Moosehorn Lk 16-0015-00) to Unnamed cr	Aquatic Life	2016	2013/2018	Total Suspended Solids
	D32	2A	Unnamed cr to Lk Superior	Aquatic Life	2010	2011/2018	Turbidity

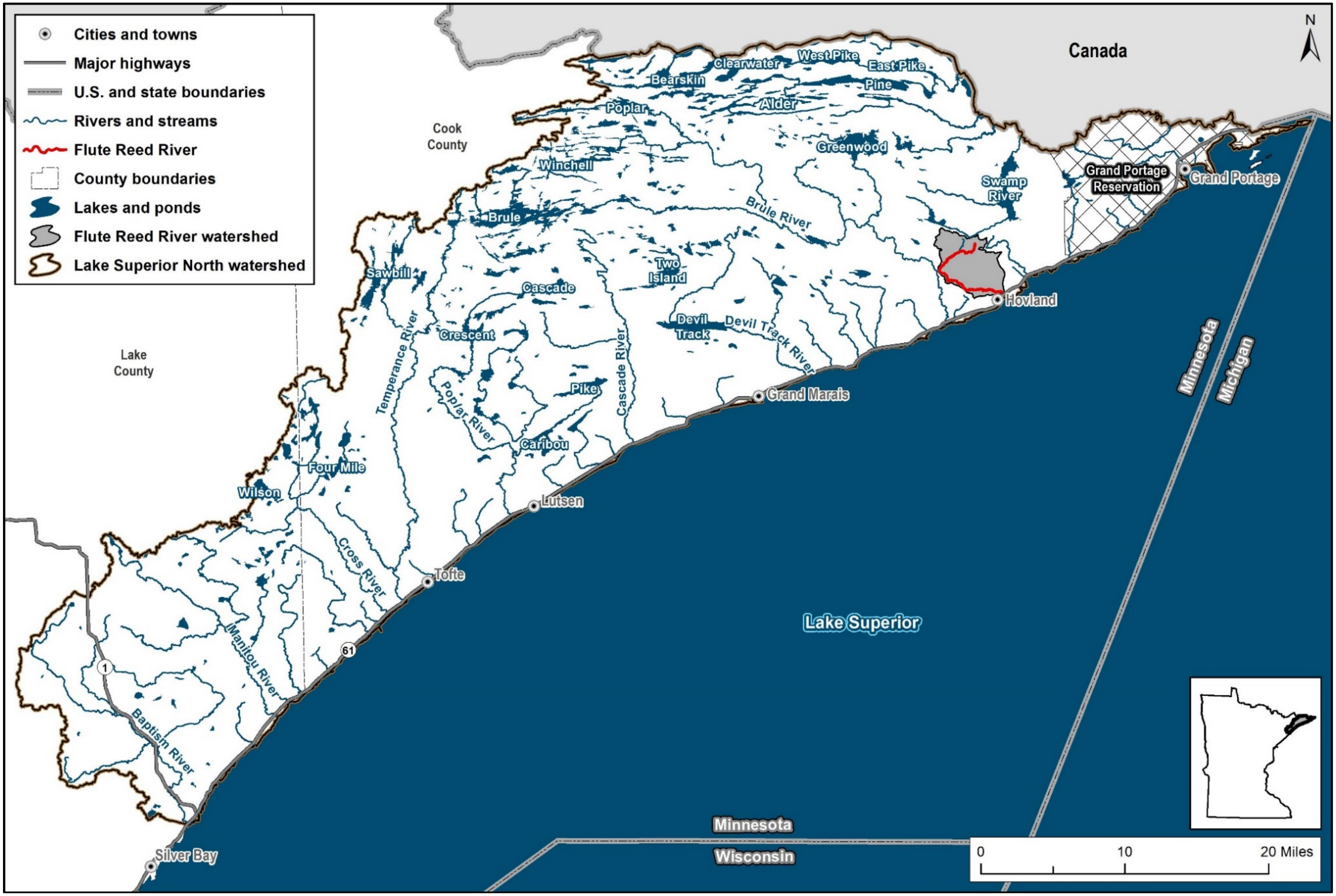

Figure 1. Flute Reed River Subwatershed location within the Lake Superior North Watershed.

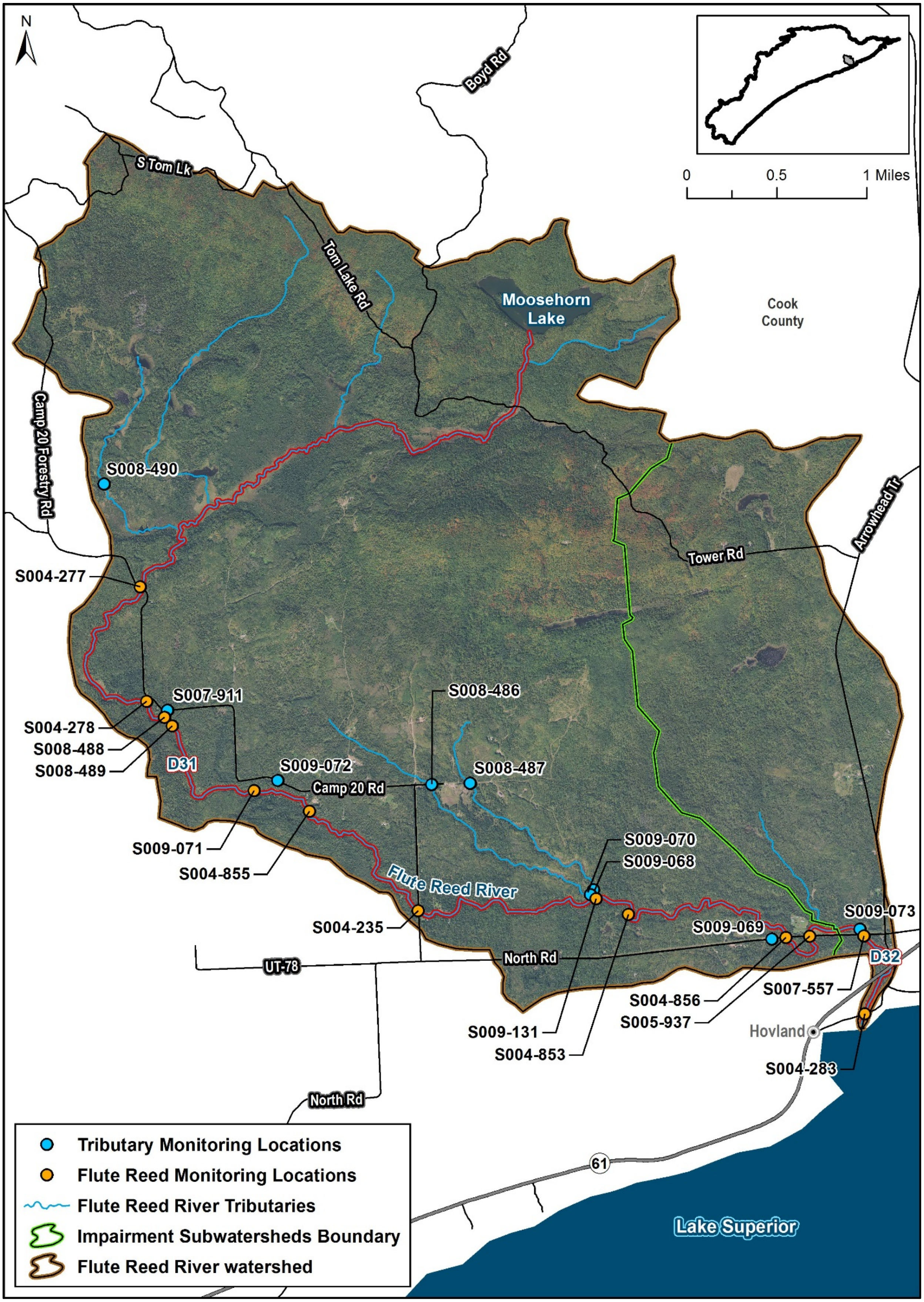

Figure 2. Flute Reed River impairment subwatersheds and water quality monitoring stations. The red line denotes the stream main stem with specific monitoring locations along it.

1.3 Priority Ranking

The MPCA's schedule for TMDL completions, as indicated on the 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned TMDL priorities with the watershed approach and WRAPS cycle. The schedule for TMDL completion corresponds to the WRAPS report completion on the 10-year cycle. The MPCA developed a state plan, Minnesota's TMDL Priority Framework Report, to meet the needs of the EPA's national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments which will be addressed by TMDLs by 2022. The waters addressed by this TMDL are part of the MPCA prioritization plan to help meet EPA's national TMDL progress measure.

2. Applicable Water Quality Standards and Numeric Water Quality Targets

Water quality standards are designed to protect designated uses. The standards consist of the designated uses, criteria to protect the uses, and other provisions such as antidegradation policies that protect the waterbody.

2.1 Designated Uses

Use classifications are defined in Minn. R. 7050.0140, and water use classifications for individual water bodies are provided in Minn. R. 7050.0470, 7050.0425, and 7050.0430. This TMDL report addresses two Flute Reed River reaches that do not meet the standards for Class 2A waters. Class 2A waters are protected for the propagation and maintenance of a healthy community of cold water sport or commercial fish, and associated aquatic life and their habitats, and are also protected for aquatic recreation activities including bathing.

2.2 Water Quality Criteria

Water quality criteria for Class 2A waters are defined in Minn. R. 7050.0222. The criteria include numeric criteria for various chemical and physical constituents in water, along with biological threshold criteria. Aquatic life use is considered impaired when the numeric water quality criteria are exceeded, according to MPCA assessment procedures. The MPCA also makes a determination of aquatic life use support directly with calculated Index of Biological Integrity (IBI) scores, determined by using fish and macroinvertebrate data collected in streams and rivers.

As noted earlier in this document, TSS standards replaced the older turbidity standards during a 2015 rulemaking. The TMDL endpoint for Class 2A streams is <10 mg/L TSS, exceeded no more than 10% of the time from April 1 through September 30. The previous turbidity standard for Class 2A waters was 10 nephelometric turbidity units. For the development of the TSS water quality standards, the MPCA relied on field-collected aquatic community or biological data. Statistical tools were also employed in standards development for more accurate and precise measures of biological thresholds. A complete discussion of the biological basis for the TSS standard is contained in the TSS technical report *Aquatic Life Water Quality Standards Draft Technical Support Document for Total Suspended Solids (Turbidity)* (MPCA 2011).

As discussed above, exceedances of the TSS criteria indicate that a waterbody does not meet the aquatic life designated use. The Flute Reed River was identified as impaired for aquatic life uses due to exceedances of the TSS water quality standard in 2010 and 2016. Subsequent biological monitoring in 2013-2015 and analysis of the fish and macroinvertebrate assemblages indicated the IBI scores met the thresholds for aquatic life. This presents a somewhat unique combination of water quality assessments that appear to say different things. An independent review of all data and scores by a professional judgment team upheld the designation of the aquatic life use impairment due to TSS.

Although the IBIs are above the impairment thresholds, there is evidence of stress on the condition of the biota. The *Lake Superior North Watershed Monitoring and Assessment Report* (MPCA 2017a) indicates the headwaters show less TSS impact. The biological communities there are described as in good-to-excellent condition. In the lower reaches, more TSS stress may be impacting the community from the more elevated levels of suspended sediment. Macroinvertebrate IBI scores decline from upstream to downstream, but still meet the general use biocriteria.

3. Watershed and Waterbody Characterization

The *Lake Superior North Watershed Monitoring and Assessment Report* (MPCA 2017a) provides a description of the watershed, including discussions of the following: ecoregion, surficial geology, land cover and ownership, surface hydrology, precipitation trends, hydrogeology, groundwater quality, and wetlands. Additional information about hydrogeology and groundwater quality is available within the *Lake Superior North Watershed Groundwater Report* (MPCA 2016) and *Lake Superior North Watershed Stressor Identification Report* (MPCA 2017b DRAFT).

3.1 Subwatersheds

The Flute Reed River headwaters begin in a wetland-rich landscape that includes Moosehorn Lake. Several small tributaries drain large wetland complexes in the upper portion of the subwatershed. Other small tributaries in the lower reaches of the subwatershed are also present. Beaver ponds become more prevalent in the middle reaches. Otis Creek is located to the north of the Flute Reed River Subwatershed and typically discharges directly to Lake Superior. When flows are high in Otis Creek, they can overflow at Arrowhead Road and flow directly into the Flute Reed River. Additional information on this connection is provided in Section 3.4.

Flute Reed River impairment subwatersheds are based on HUC12 watershed boundaries (Figure 2), with the subwatershed dividing line between impairment 04010101-D31 and 04010101-D32 delineated using Minnesota Department of Natural Resources (DNR) Level 09 subwatershed boundaries. The subwatershed area of impairment 04010101-D31 is 7,958 acres and the subwatershed area of 04010101-D32 (including upstream impairment 04010101-D31) is 9,907 acres.

The subwatersheds are dominated by privately-owned land (D31=69% and D32=66%), which is fairly unique in the overall Lake Superior North Watershed (Figure 4). The large proportion of private land, much of which was previously held by one business (Consolidated Papers, Inc.) for managed forestry use, could potentially lead to additional development. Current zoning ordinances allow for smaller lots than are currently present, which could allow subdivision of existing parcels and create increased development density. Per the recently updated county land use plan, Cook County’s desired future conditions for the area includes low density residential with relatively greater densities near Hovland (Applied Insights North 2015). The land use plan also identifies a commercial corridor for the community of Hovland.

Nearly half of the total overall Flute Reed River Subwatershed area falls into the “red clay” area of the Western Lake Superior Basin, which is composed of soils that are highly erodible. Bank erosion estimates prepared for the Flute Reed River show high erosion rates and sediment loading from numerous steeply sloped, large clay bluffs. Additional information for the red clay areas is provided in Section 3.4.

The Flute Reed River is characterized as a flashy stream, with high peak flows and very low baseflows. Flows in the River can be reviewed using a duration curve approach. Duration curves present the percentage of time during which specified flows are equaled or exceeded. The flow duration curve for impaired reach D32 is presented in Figure 3. Flows are based on daily average flows derived from the calibrated Flute Reed Watershed Hydrologic Simulation Platform-FORTRAN (HSPF) model application (Tetra Tech 2017); details on the HSPF model can be found in Appendix A. Very low flows in the Flute

Reed River ranging from 0.01 to 0.5 cubic feet per second (cfs) are exceeded a majority of the time, whereas very high flows ranging from 54 to greater than 800 cfs are exceeded infrequently.

Isotope analysis conducted as part of the stressor identification process (MCPA 2017b) concluded the Flute Reed River is an example of a lake-fed stream that is highly dependent on precipitation to supply flow. Because of this, the Flute Reed is more vulnerable to seasonality, particularly affecting low flow conditions, than most of the study streams nearby. Moosehorn Lake, shallow aquifer discharge, and perennial headwater tributaries are the primary sources of flow to the main stem Flute Reed River during the critical low flow months of summer.

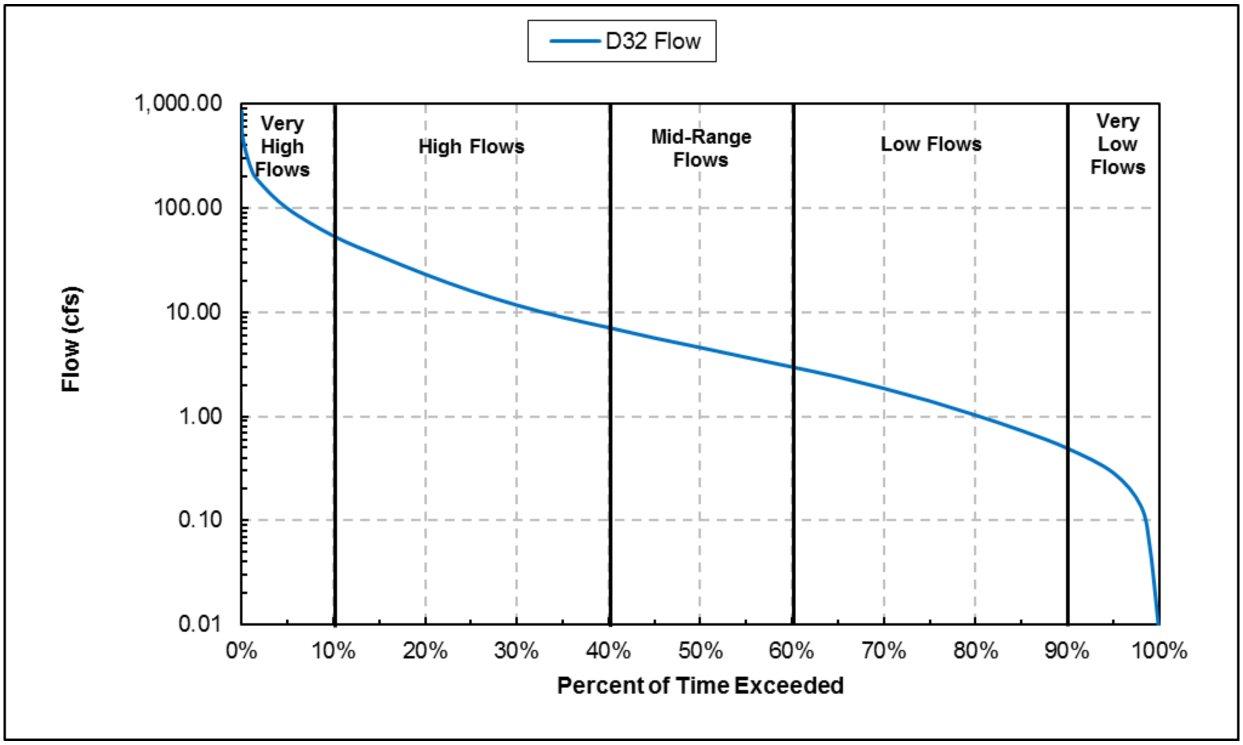

Figure 3. Flow duration curve for impaired reach D32 of the Flute Reed River.

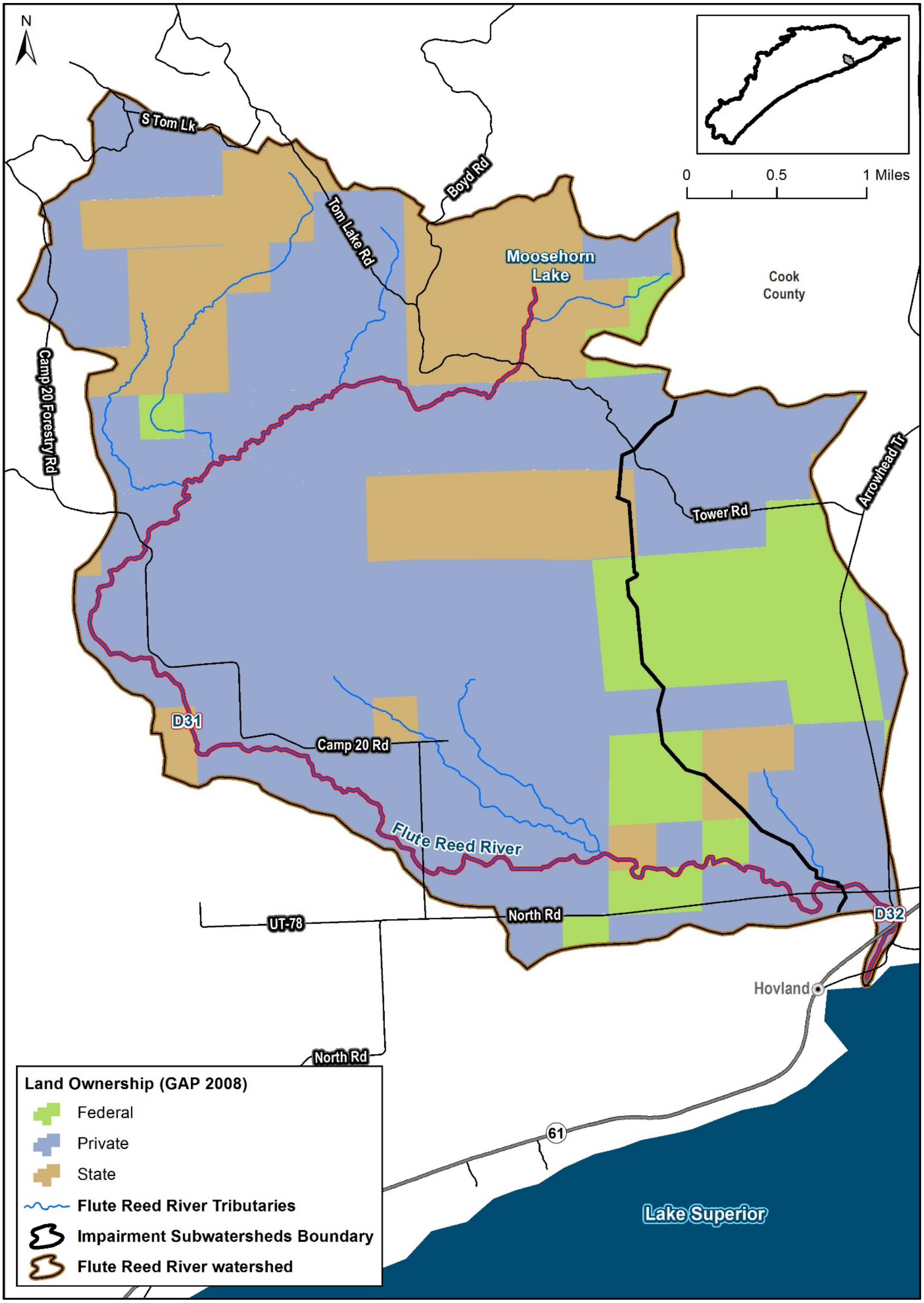

Figure 4. Flute Reed River Subwatershed land ownership.

3.2 Land Use

Land cover is dominated by forest within the Flute Reed River Subwatershed, with wetlands as the second most dominant land cover. The small amount of developed land cover increases with proximity to Hovland and within the 04010101-D32 impairment subwatershed. Historical, or pre-settlement, land cover in the Flute Reed Subwatershed consisted of forest and wetlands/bogs. The first growth forests primarily consisted of aspen, birch, white pine, and red pine (Figure 5), and were approximately 80% of the watershed (deciduous forests accounted for 50%; conifers accounted for 30%). Conifer bogs and swamps make up the remaining 20% of the pre-settlement landscape. These forests and wetlands represent the natural background conditions in the watershed.

Land cover datasets from the 2011 National Land Cover Database, 2016 National Oceanic and Atmospheric Administration's Coastal Change Analysis Program, and the updated Minnesota Land Cover Classification (University of Minnesota 2013) were compared to determine which dataset most accurately represents the Flute Reed River Subwatershed. There were minimal differences in forested and wetland land covers, and therefore the updated Minnesota Land Cover Classification was chosen based on better spatial resolution. The 2013 Minnesota Land Cover Classification is based on a 15-meter grid size, while the other two land cover datasets are based on a 30-meter grid size.

A summary of land cover within the impairment subwatersheds is provided in Table 2 and Figure 6. Wetlands are present along many sections of the Flute Reed River, with large wetland complexes between the Camp 20 road crossing and the outlet of Moosehorn Lake. Detailed wetland information from the updated National Wetlands Inventory developed by the DNR in 2016 is provided in Figure 7.

The changes from pre-settlement to current conditions are primarily the result of historic and current logging operations and development. Under current conditions, 4% of the watershed is identified as land cover that can be tied directly to anthropogenic effects (urban/developed and managed grass/natural grass). While the population of the watershed appears sparse, it is important to note that much of the anthropogenic effect on the landscape in the watershed is not represented within the land cover database due to scale. These effects are due to home and driveway construction and ditches along roads or driveways. These small scale landscape changes can have a large impact on sediment loading from both the watershed and near-channel areas.

Table 2. Land cover (University of Minnesota 2013)
Percent rounded to nearest whole number

Waterbody Name	**Percent of Watershed**								**Total Area (acres)**
	Urban/Developed	**Emergent Wetlands**	**Forested and Shrub Wetlands**	**Lakes, Ponds and Rivers**	**Conifer Forest**	**Deciduous Forest**	**Mixed Forest**	**Managed Grass/Natural Grass**	
Flute Reed River (04010101-D31)	2	2	13	2	15	44	20	2	7,958
Flute Reed River (04010101-D32)	2	2	12	2	14	45	21	2	9,907

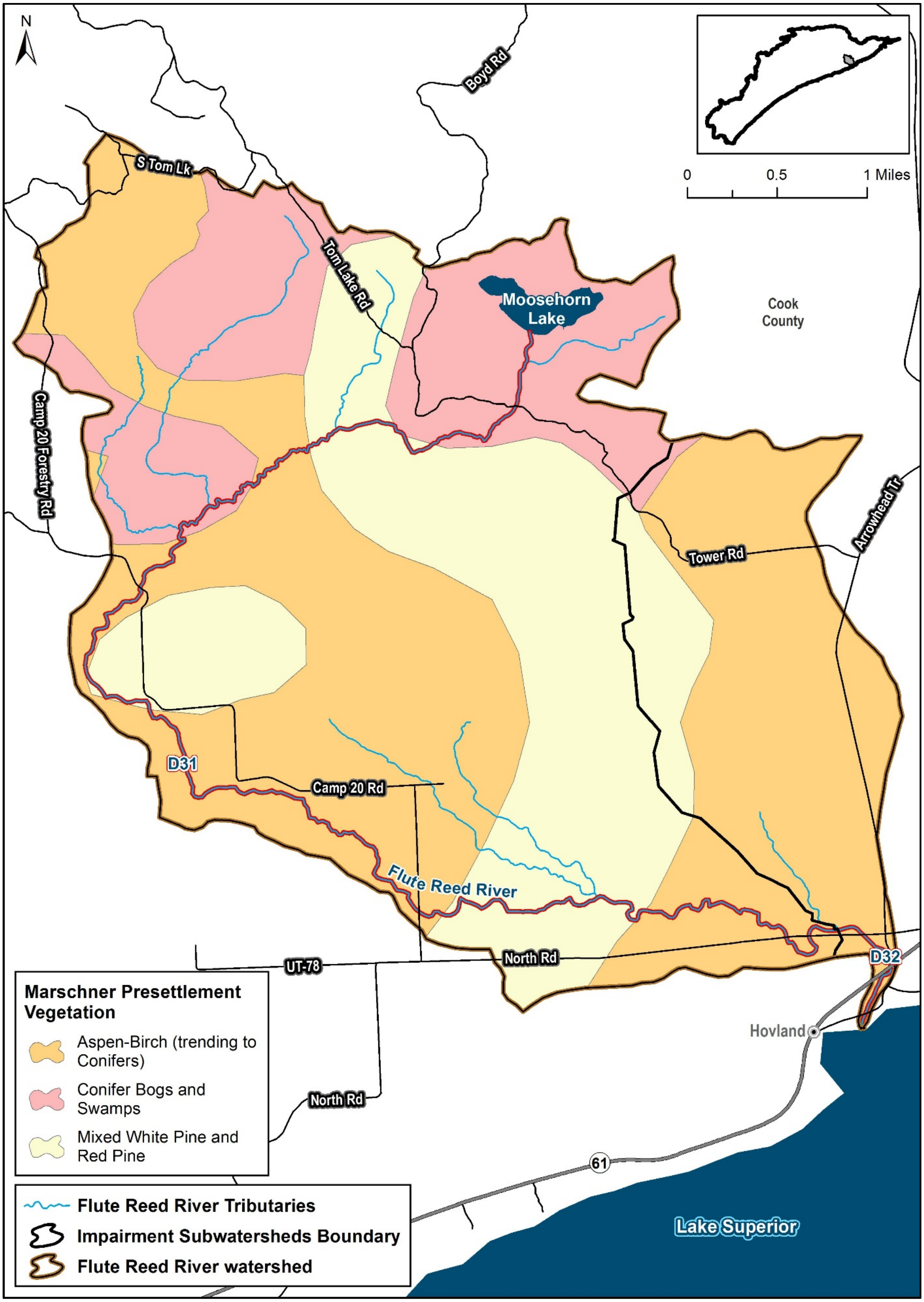

Figure 5. Flute Reed River Subwatershed pre-settlement vegetation.

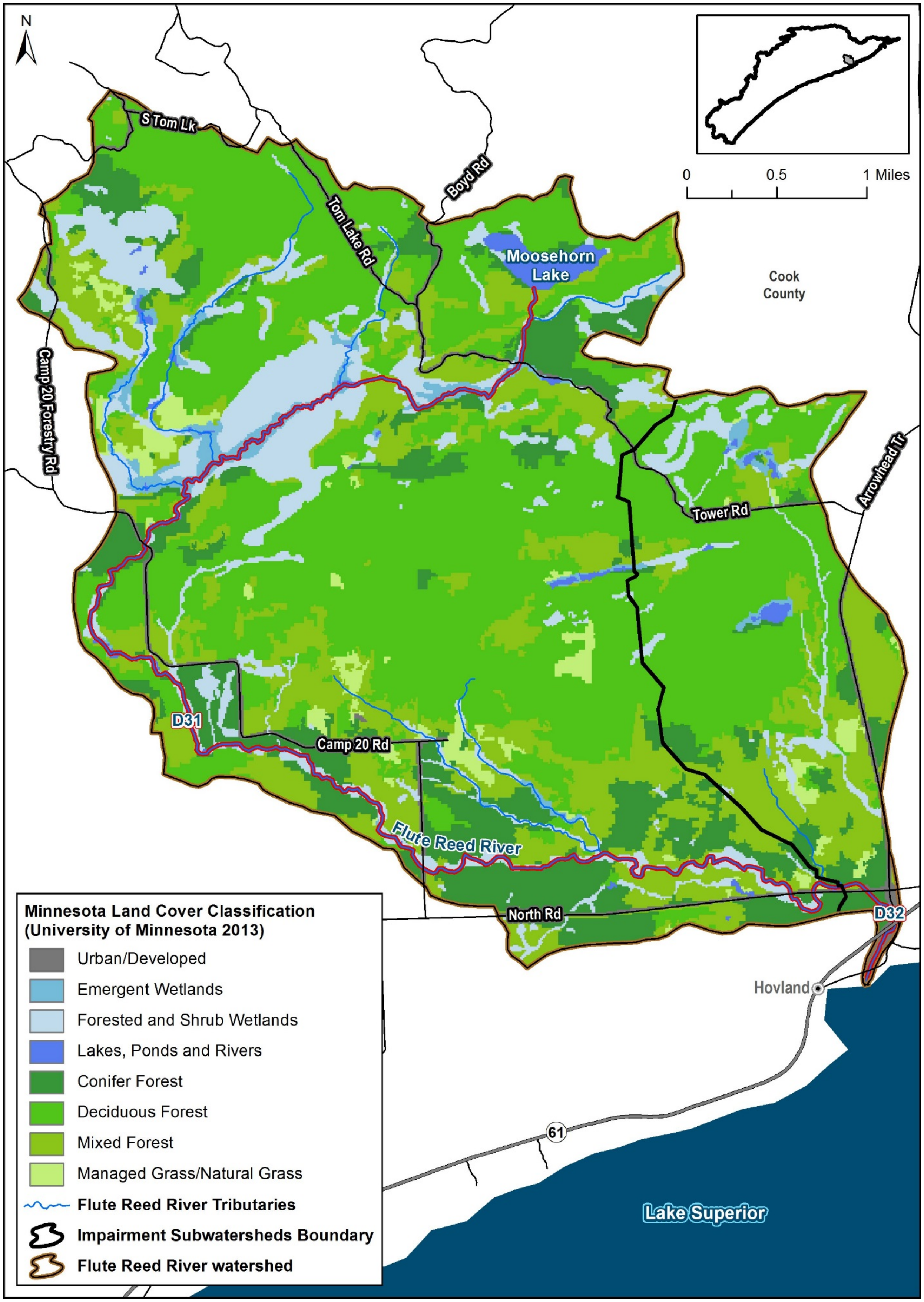

Figure 6. Flute Reed River Subwatershed land cover.

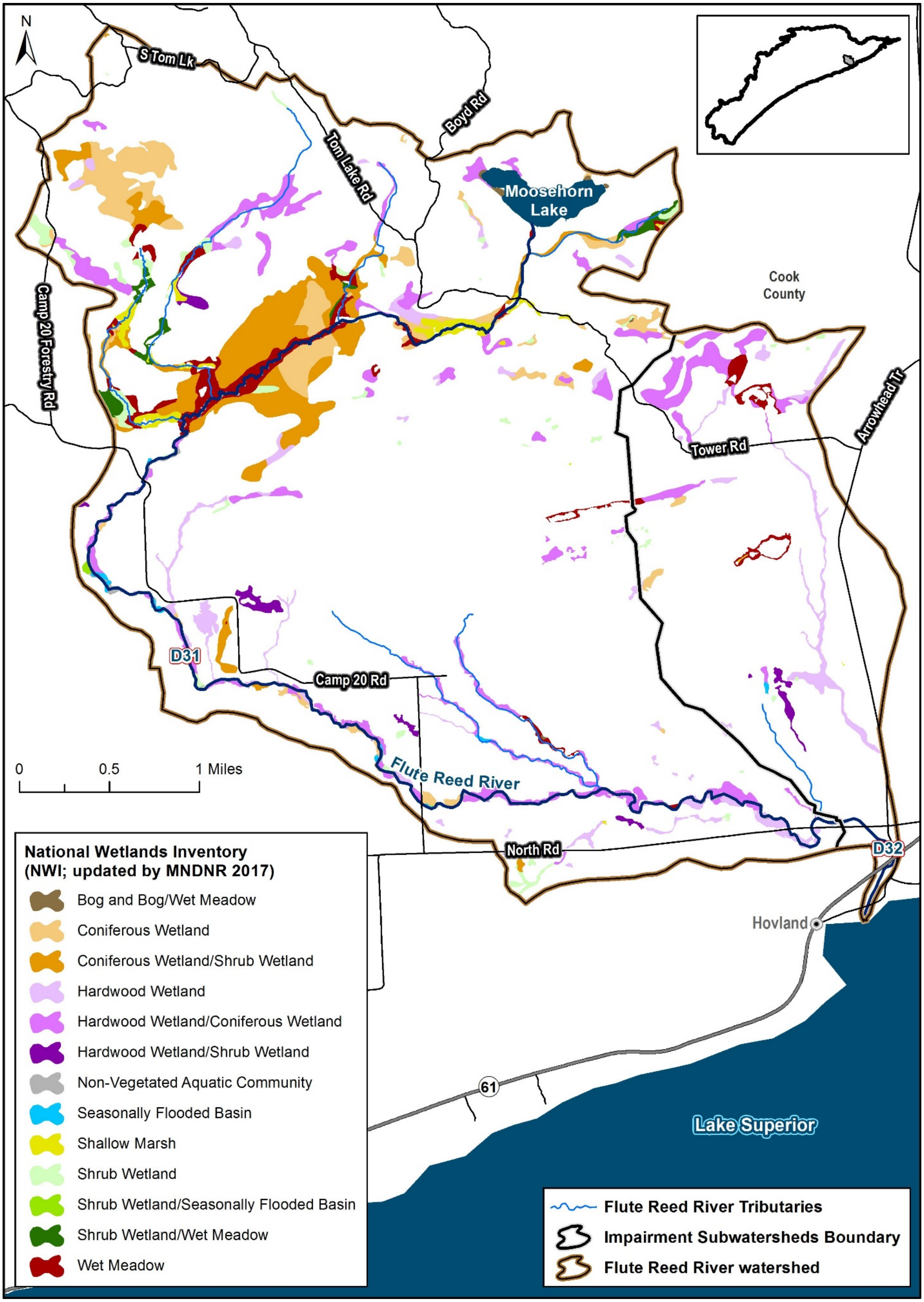

Figure 7. Wetlands identified within the Flute Reed River Subwatershed.

3.3 Current/Historic Water Quality

The Lake Superior North Watershed Monitoring and Assessment Report contains figures and tables that summarize recent water quality data on a HUC10 subwatershed basis, and address habitat, channel condition and stability, and water chemistry. *The Lake Superior North Watershed Stressor Identification Report* includes evaluations of fish, macroinvertebrates, flow alteration, habitat, water chemistry data and stream geomorphic assessment. Natural background influences, particularly beaver impacts, are documented and discussed in the stressor identification report. Natural background is the landscape condition that occurs outside of human influence. Natural causes in the Flute Reed River Subwatershed contributing to sediment impairments are primarily linked to wildlife activity (i.e., beaver). As described in Section 3.1 and 3.2, there are conditions in the watershed that have resulted in human-induced sediment loading.

The water quality analyses for the Flute Reed River are primarily based on data from the MPCA's Environmental Quality Information System (EQuIS database, received March 14, 2017, from the MPCA staff). Simulated flow from the Flute Reed River HSPF model application was used to supplement the analysis. Details on the HSPF model can be found in Appendix A.

Water quality monitoring stations along the Flute Reed River were aggregated by impairment subwatershed (Figure 2) for much of the analysis. Available water quality data from 2008 to 2016 are summarized for TSS, by year to evaluate annual trends in water quality, and by month to evaluate seasonal variation (note that data were not available for 2007). The summaries of data by year only consider data during the time period that the standard is in effect (April through September). The frequency of exceedances represents the percentage of samples that do not meet the water quality standard.

Water quality duration curves are also provided for both impaired reaches of the Flute Reed River. Water quality duration curves are used to evaluate the relationships between hydrology and water quality, because water quality is often a function of stream flow. For example, sediment concentrations typically increase with rising flows as a result of factors such as channel scour from higher velocities. The water quality duration curve approach provides a visual display of the relationship between stream flow and water quality. Water quality duration curves are provided using water quality monitoring data and simulated daily average stream flow from the Flute Reed River HSPF model application (Tetra Tech 2017). See Appendix A for model documentation, including calibration and validation statistics. Flow data from all months, even those outside of the time period that the standard is in effect, were used to develop the water quality duration figures. To investigate trends in sediment concentration along the length of the Flute Reed River, longitudinal profiles are also provided.

3.3.1 Flute Reed River (04010101-D31) Total Suspended Solids

There are 10 monitoring stations along impaired reach D31 of the Flute Reed River (Figure 2). The TSS water quality data for D31 is presented in Figure 8. Average annual TSS concentrations range from 14 to 50 mg/L and greater than 10% of samples exceeded the 10 mg/L standard in all monitored years (Table 3). During the months in which the standard applies, monthly means range from 5 to 44 mg/L, with exceedances occurring every month (Table 4). TSS concentration generally increases with flow, though exceedances were observed under all flow conditions (Figure 9).

Table 3. Annual Summary of TSS data for the Flute Reed River, 04010101-D31

(Monitoring sites: S004-235, S004-277, S004-278, S004-853, S004-855, S004-856, S005-937, S008-488, S008-489, and S009-071, Apr–Sep). Values in red indicate years in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Year	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
2010	1	50	50	50	1	100%
2013	12	21	2	130	4	33%
2014	25	14	2	88	11	44%
2015	37	25	0.5	180	14	38%
2016	16	27	3	71	11	69%

Table 4. Monthly Summary of TSS data for the Flute Reed River, 04010101-D31

(Monitoring sites: S004-235, S004-277, S004-278, S004-853, S004-855, S004-856, S005-937, S008-488, S008-489, and S009-071, 2010, 2013–2016). Values in red indicate months in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Month	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
March	9	14	3	58	NA	NA
April	17	44	10	103	16	94%
May	18	42	3	180	13	72%
June	26	10	2	88	6	23%
July	15	8	2	50	1	7%
August	6	16	3	41	3	50%
September	9	5	0.5	13	2	22%
October	8	3	0.5	7.2	NA	NA
November	2	17	8	26	NA	NA

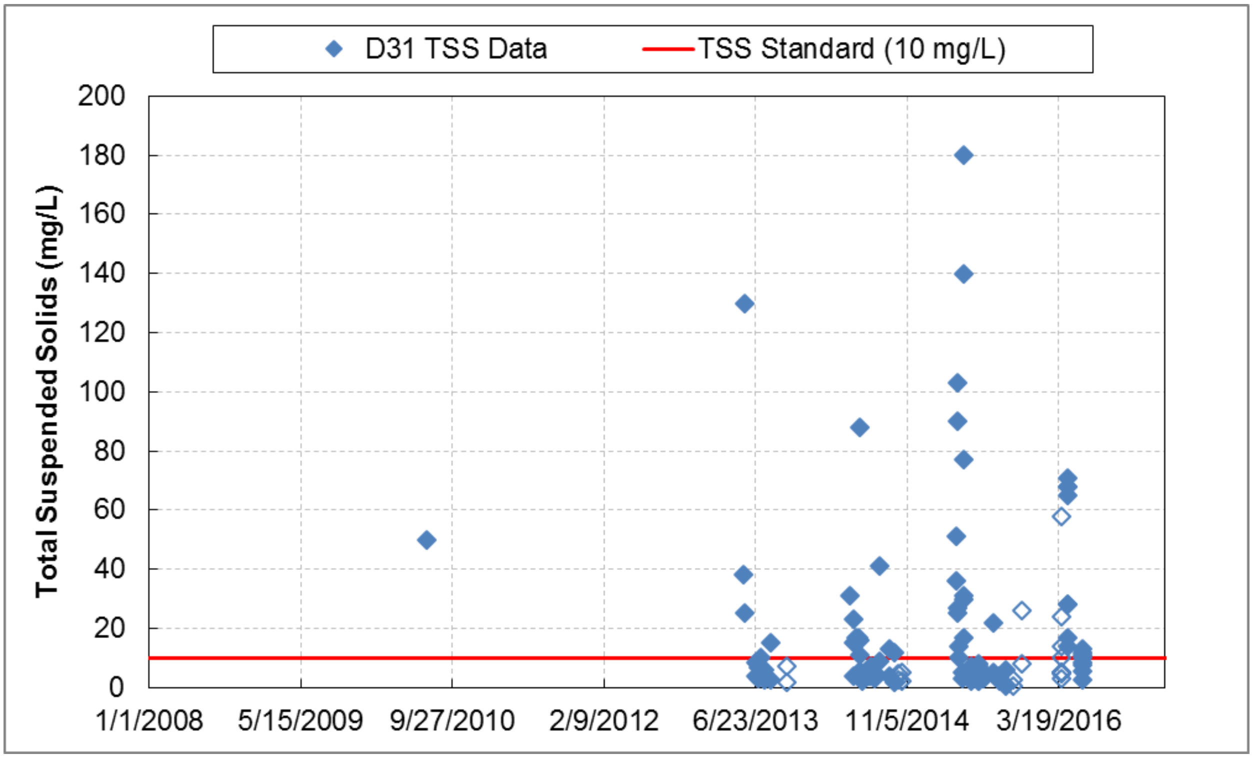

Figure 8. TSS time series plot, Flute Reed River (AUID 04010101-D31).

Hollow points indicate samples during months when the standard does not apply.

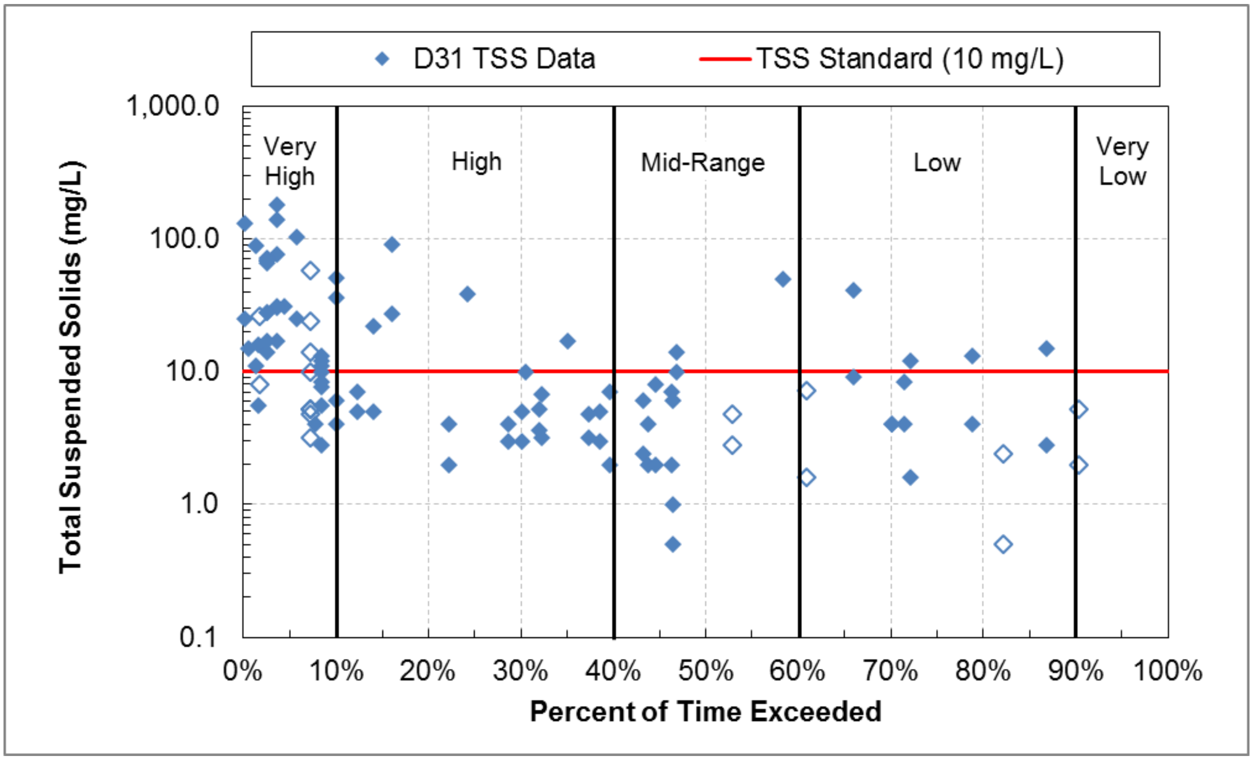

Figure 9. TSS water quality duration plot, Flute Reed River (AUID 04010101-D31), 2010, 2013–2016.
Hollow points indicate samples during months when the standard does not apply. Note that flow is represented on the X-axis.

3.3.2 Flute Reed River (04010101-D32) Total Suspended Solids

There are two monitoring stations located along impaired reach D32 of the Flute Reed River (Figure 2). The TSS water quality time series for D32 is presented in Figure 10. Average annual TSS concentrations range from 9 to 39 mg/L, and greater than 10% of samples exceeded the 10 mg/L standard in all monitored years (Table 5). Monthly means range from 3 to 51 mg/L, and exceedances occurred in all months with the exception of September (Table 6). TSS concentration generally increases with flow, with exceedances under all flow conditions except very low flows (Figure11).

Table 5. Annual Summary of TSS data for the Flute Reed River, 04010101-D32
(Monitoring sites: S004-283 and S007-557, Apr-Sep). Values in red indicate years in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Year	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
2008	14	22	0.5	176	5	36%
2009	15	9	0.5	60	3	20%
2013	24	25	1	160	12	50%
2014	30	21	4	116	14	47%
2015	37	25	3	181	14	38%
2016	4	39	10	70	2	50%

Table 6. Monthly Summary of TSS data for the Flute Reed River, 04010101-D32

(Monitoring sites: S004-283 and S007-557, 2008-2009, 2013-2016). Values in red indicate months in which the numeric criteria of 10 mg/L was exceeded in greater than 10% of the samples.

Month	Sample Count	Mean (mg/L)	Minimum (mg/L)	Maximum (mg/L)	Number of Exceedances	Frequency of Exceedances
March	2	23	20	25	NA	NA
April	17	51	10	176	16	94%
May	28	36	4	181	16	57%
June	29	18	2	116	9	31%
July	25	8	0.5	23	6	24%
August	12	7	0.5	28	3	25%
September	13	5	0.5	10	0	0%
October	13	3	0.5	6	NA	NA
November	3	19	5	28	NA	NA

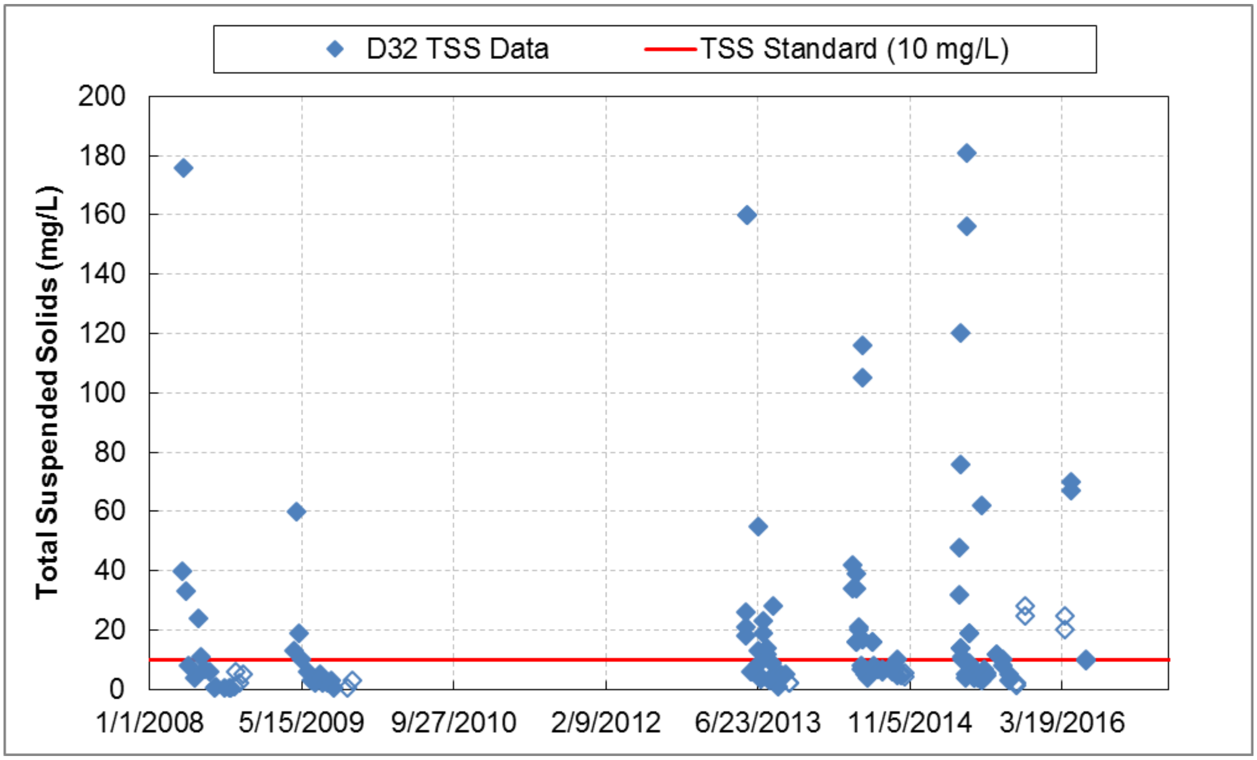

Figure 10. TSS time series plot, Flute Reed River (AUID 04010101-D32).

Hollow points indicate samples during months when the standard does not apply.

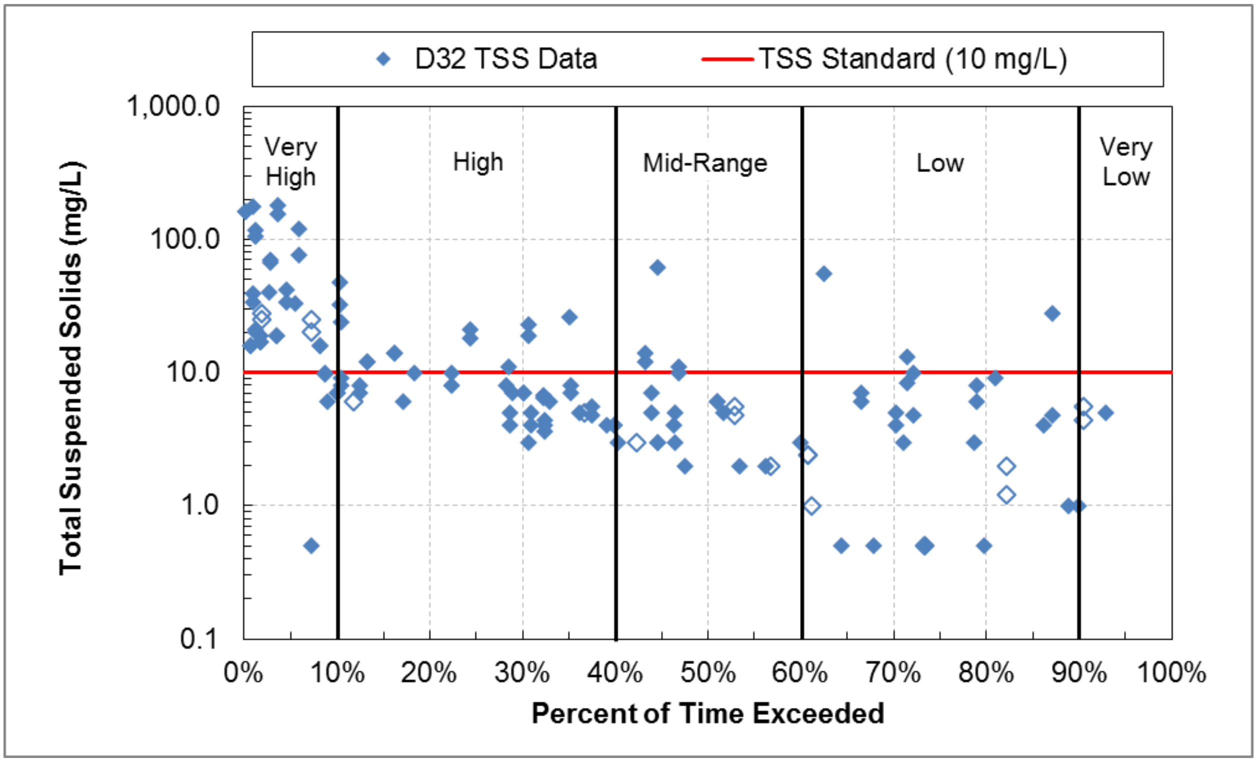

Figure 11. TSS water quality duration plot, Flute Reed River (AUID 04010101-D32), 2008-2009, 2013-2016.
Hollow points indicate samples during months when the standard does not apply. Note that flow is represented on the X-axis.

3.3.3 Flute Reed River Subwatershed Total Suspended Solids Longitudinal Analysis

TSS concentration data were evaluated longitudinally along the Flute Reed River to evaluate trends and potential hot spots. Annual average TSS concentrations at the most upstream monitoring site (S004-277, see Figure 14 for the monitoring site locations) met the standard in three of the four monitored years (Figure 12). TSS concentrations downstream of site S004-277 increase on average and remain high along the length of the river, indicating a potential hot spot in between monitoring sites S004-277 and S004-235. The high TSS concentrations at site S004-235 and downstream occur mainly under very high flow conditions (Figure 13).

The Flute Reed River and tributaries were monitored on the same day under high flows on April 18, 2016 (Figure 14). The limited data indicate that under high flow conditions tributaries can contribute to TSS concentrations violating the standard in the Flute Reed River. However, the concentrations in the monitored tributaries are not as high as the concentrations in the river itself, suggesting that the primary cause of the high TSS is not the monitored tributaries. Tributaries and the river were also monitored on June 6, 2016, under high flows. Concentrations were not as high on this sampling date, but the same pattern is evident—concentrations were lowest in the most upstream Flute Reed River site and the tributaries, and were highest on the downstream river sites.

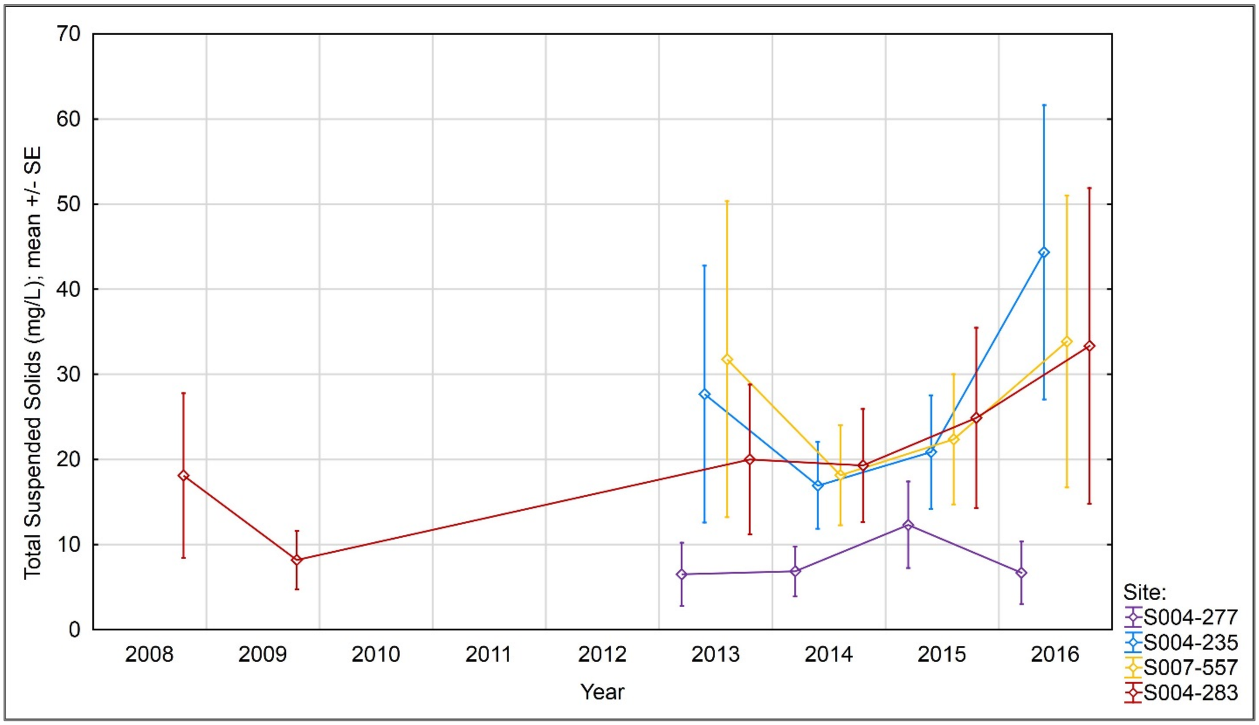

Figure 12. Annual average TSS concentration along the Flute Reed River, sites listed from upstream to downstream. Means and error bars are shifted within year to facilitate comparison among sites.

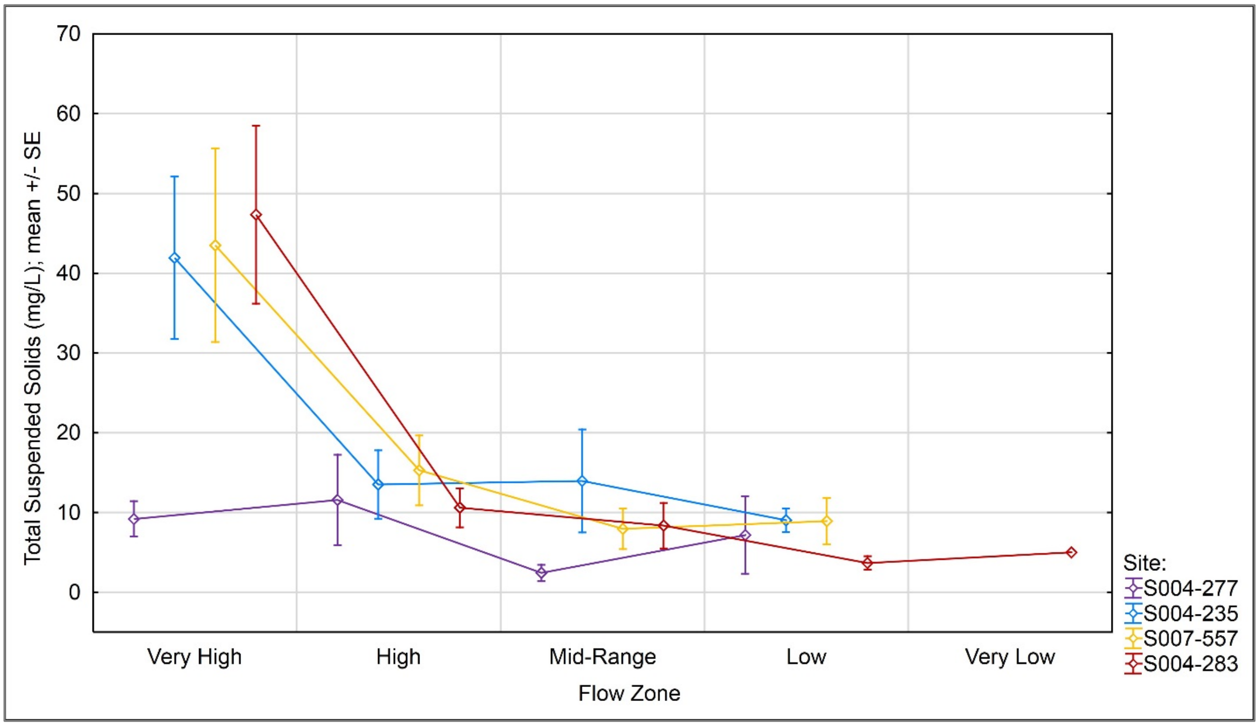

Figure 13. Average TSS concentration under five designated flow zones, sites listed from upstream to downstream. Means and error bars are shifted within year to facilitate comparison among sites.

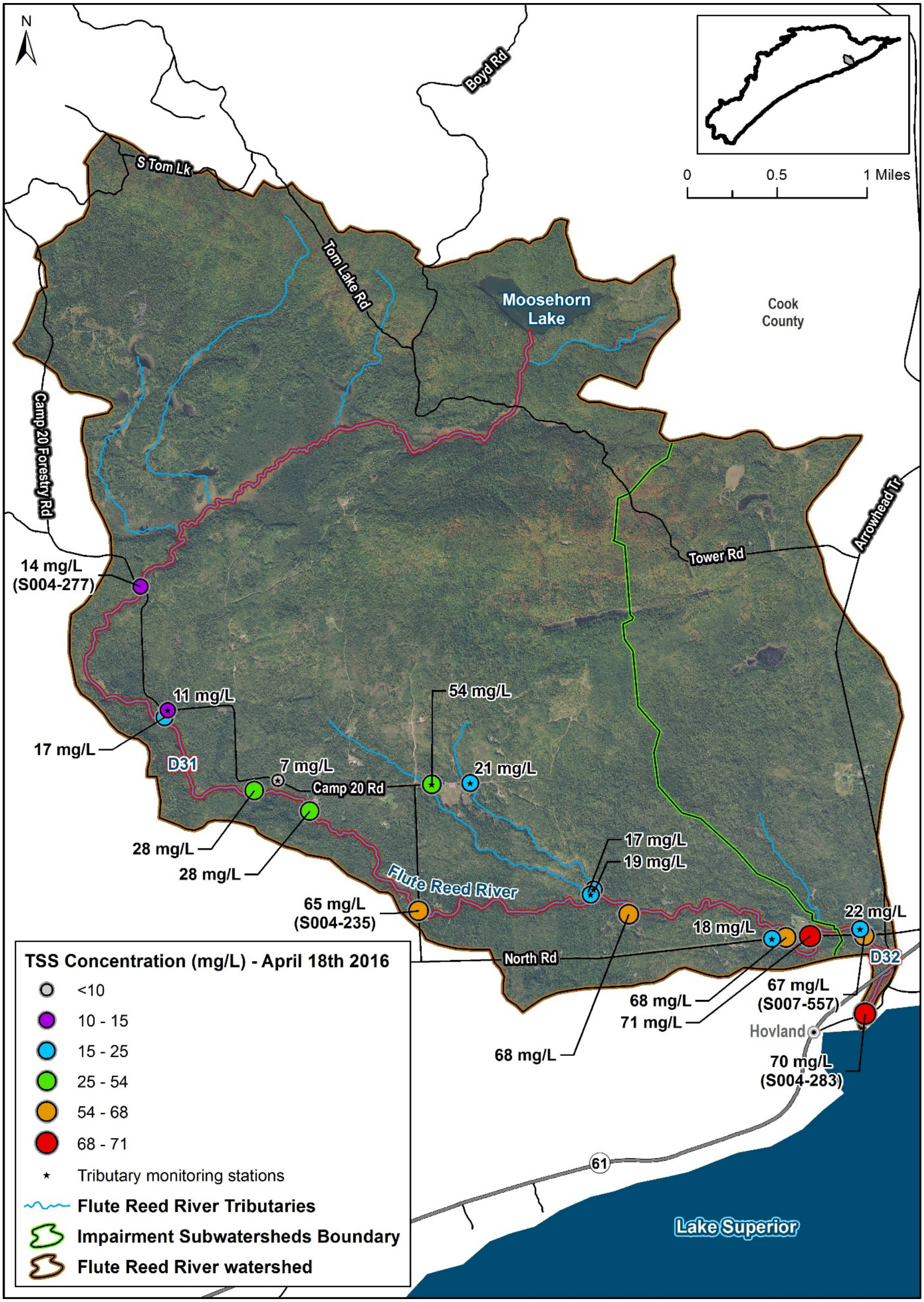

Figure 14. Tributary and Flute Reed River TSS concentrations in the spring of 2016.

Monitoring stations with sites numbers are the stations with data shown in Figure 12 and Figure 13.

3.4 TSS Pollutant Source Summary

There has been much work to date to locate and quantify sediment sources in the Flute Reed River, as described in detail in the *Lake Superior North Watershed Stressor Identification Report* (MPCA 2017b). The Flute Reed River Partnership and Cook County Soil and Water Conservation District (SWCD) have also been active in watershed monitoring and restoration activities since the original impairment designation in 2010.

The watershed is known for its flashy hydrology and erodible soils, which contribute to high sediment loads during snowmelt and rain events. Both watershed and near-channel sources contribute to impairment. Sediment loads contributing to the Flute Reed River are summarized by HSPF model catchment (Figure 16; Tetra Tech 2017). This HSPF model was refined for the Flute Reed Subwatershed and is provided at a smaller scale to inform TMDL development. The Flute Reed River HSPF model was calibrated for water quality collected between 2008 and 2016 and with flow data collected between 2013 and 2016.

Near-channel sources (banks, bluff, and channel scour) are highest in the middle reaches and correspond to the highest average annual sediment loading. Monitoring data, as summarized in Section 3.3, also identifies the middle reach between monitoring stations S004-277 and S004-235 as a significant contributor of sediment. Limited tributary monitoring data collected in the spring of 2016 indicate that tributaries are likely contributing to impairment, but are not a major source.

3.4.1 Watershed Sources

Watershed sources of sediment are the result of watershed runoff and flows associated with snowmelt and large rainfall events. Sediment, particularly in the red clay areas, is easily eroded and transported downstream. Logging activities and land clearing in the watershed for development, both current and historic, disturb the vegetation and allow more sediment movement.

Impervious surfaces, particularly the road, driveway, and trail network (see Figure 18), also contributes to watershed sources. Ditches are commonly used to convey runoff from roads and driveways; these ditches are prone to erosion particularly following maintenance activities. Establishment of vegetation in ditches is a significant challenge in this watershed; a lack of vegetation leads to sediment delivery downstream.

Figure 15. Logging activities in the Flute Reed River Subwatershed.

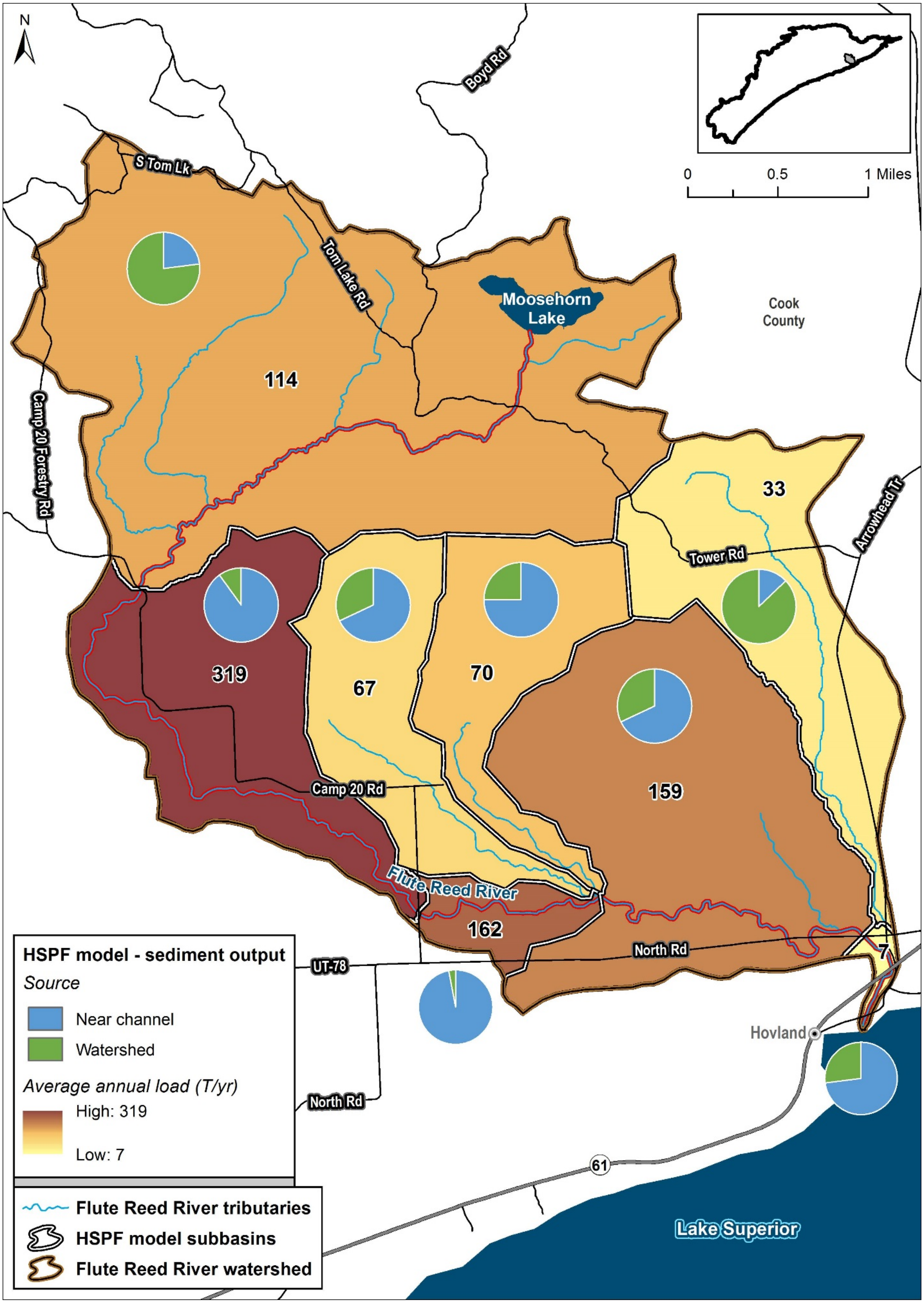

Figure 16. HSPF-modeled catchments (Tetra Tech 2017).

3.4.2 Near-channel Sources

Near-channel sources that are contributing to impairment in the Flute Reed River Subwatershed are the result of historic and current land alterations. These activities (e.g., logging, development) have changed the hydrology of the watershed resulting in increased snowmelt and runoff rates, decreased evapotranspiration, and increased storm peak flows and volumes. This change in hydrology sets in motion the channel evolution process which results in the river changing its form to accommodate this change in hydrology. Near-channel erosion is in part due to this process.

Figure 17. Examples of bank erosion and dam on the Flute Reed River.

Geomorphic assessment work completed in 2016 (MPCA 2017b) indicates that the stability of the stream channel and incision rates vary. Beaver dams were also identified throughout the stream, corresponding to areas with turbid water (Figure 18 and Table 7). Table 7 summarizes the MPCA field notes taken during the assessment. The corresponding assessment reaches are identified in Figure 19.

The geomorphic assessment was based mainly on the Bank Assessment for Nonpoint source Consequences of Sediment (BANCS) model developed by Dave Rosgen in 1996 and adopted by the EPA in 2006 as part of the Watershed Assessment of River Stability and Sediment Supply (WARSSS) framework. The BANCS model combines Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) measurements to estimate an erosion rate. Measurements are completed at an individual bank scale and extrapolated to a reach scale. In the MPCA assessment, 2 to 38 banks were assessed per reach depending on the length and reach complexity. At each assessment bank, characteristics such as plant root depth and density, bank height and bank angle were used to calculate a BEHI score, and the location of dominant channel flow relative to the bank or depositional properties and other channel characteristics were used to calculate a NBS score.

BEHI and NBS relationship curves developed for the BANCS model were then used to predict a bank recession rate. Length and height of the bank are multiplied by the predicted annual recession rate to estimate mean annual sediment loading rate (for both bedload and suspended sediment) for each bank. Five stream reaches were identified as contributing the highest levels of sediment: FLR017, FLR011, FLR009, FLR003, and FLR002. FLR011 had the highest estimated soil erosion; field notes indicate this reach was stagnant and turbid with many beaver dams and log jams. In addition, the incision ratio was measured to further evaluate erosional risk. The incision ratio is based on the low bank height and bankfull height, with a ratio of greater than one indicating the channel is incised and potentially disconnected from the floodplain. The assessment estimated that on average, 1,429 tons of sediment per year are lost from assessed stream banks within the watershed.

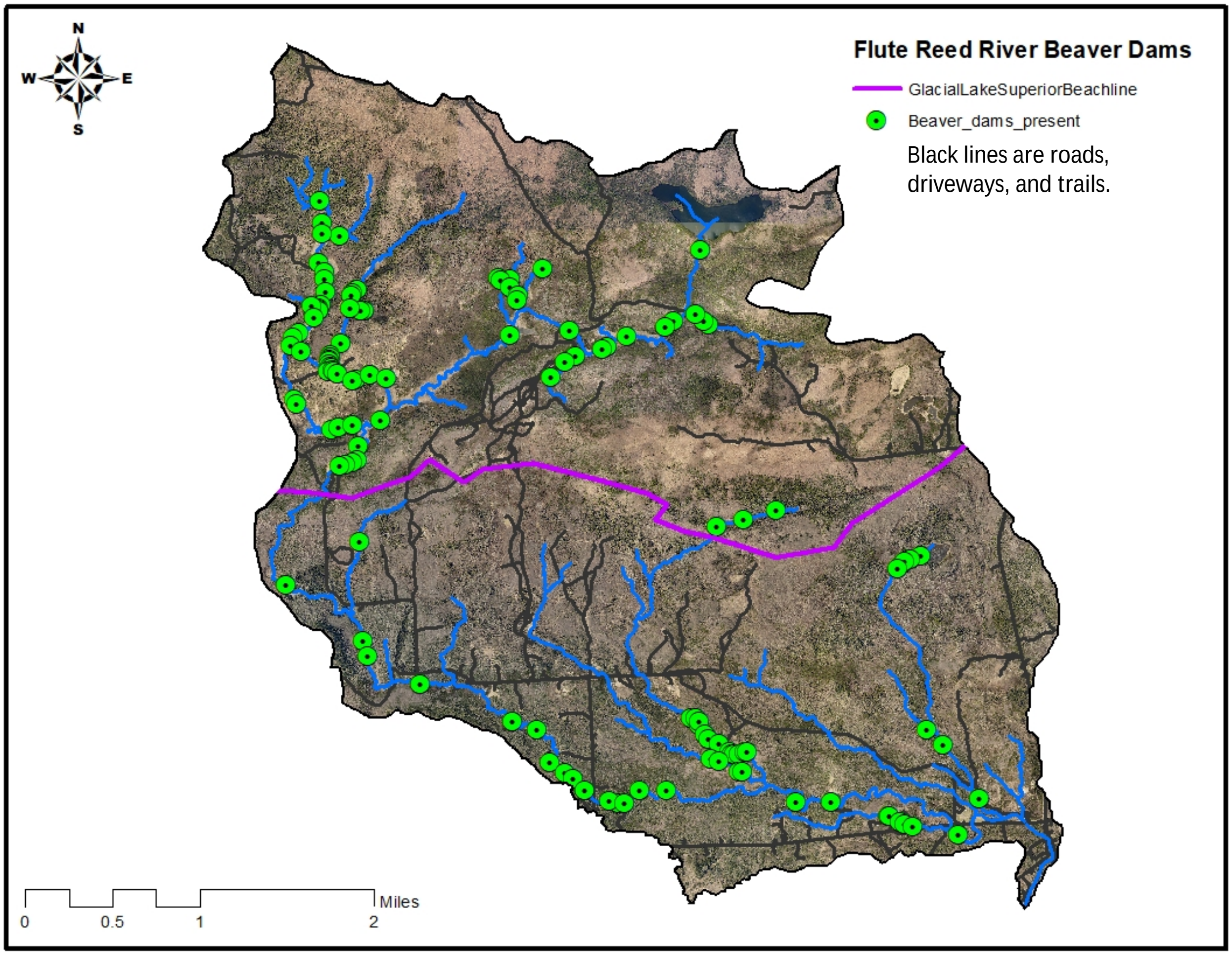

Figure 18. Beaver dams and infrastructure (map provided by MPCA).

Table 7. Geomorphic assessment notes (MPCA 2017b DRAFT)

ET=East Tributary WT=West Tributary

Reach Name	Incision Ratio	Comments
FL_ET 001	1	Stable B channel. Not a sediment source. Some fines on channel bottom. Width to depth ratio is high in places.
FL_ET 002	1.25	Turbid beaver dams dominate. Some span entire valley. Riparian corridor is mostly aspen. Natural channel is slightly incised.
FL_ET 003	1.5	Moderately incised, but erosion potential is low due to stream size. Many debris jams causing localized aggradation. Some areas of F channel with severe sand and silt deposition.
FL_WT 001	1	Mostly a stable B channel. A few unstable banks and debris jams. Cobble substrate dominant with moderate deposition of fines.
FL_WT 002	1	Entire reach is a series of beaver impoundments. Nearly the entire valley is flooded out. Dam at lower end is about 6 feet tall.
FL_WT 003	1.25	Stable just upstream of beaver dam, but areas of channel instability and slight channel incision upstream. Raw banks and debris jams prominent in the upper portion of this reach.
FL_WT 004	1	Stable B channel dominated by cobble substrate. Fines are present on substrate, but not as prominent as other reaches on this tributary.
FL_WT 005	1.25	Moderately unstable C3/4 channel with short stretches of more stable B3 channel. Extensive log jams causing bank erosion, channel avulsion/braiding, and deposition of fines.
FL_WT 006	1	Stable E channel through a former beaver impoundment. Wetland vegetation along banks, low gradient, but larger substrates. Extremely stable reach but limited habitat.
FL_WT 007	1.25	Areas of high w/d, incised C with extensive debris jams and sed dep. Some areas well connected to floodplain. Bank erosion more prominent here. Very high w/d and aggradation downstream road crossing.
FLR 000	1	High gradient B2, areas of A1. Slightly overwidened in areas.
FLR 001	1	
FLR 002	1.5	Several areas of hillslope erosion present.
FLR 003	1.5	
FLR 004	1	
FLR 005	1.75	
FLR 006	1	
FLR 007	1.25	Massive beaver dam in reach. Channel braiding in vicinity of dam. Significant sediment deposition downstream. Moderate to high bank erosion.
FLR 008	1	
FLR 009	1.5	
FLR 010	1.25	Beaver dam dominated.
FLR 011	1.25	Many beaver dams causing braiding. Stagnant, turbid water. Numerous log jams, some blowouts of beaver dams causing erosion. Poor shading.
FLR 012	1.25	Slightly incised, but good vegetation and roots. Erosion only occurring on outcurves and areas of higher NBS. Good habitat. Tribs appear unstable and are potential sediment sources.
FLR 013	1.25	Same notes as next downstream reach. More log jams though. Areas of valley wall sloughing/erosion.
FLR 014	1.25	C4 in places. Beaver dams and blown out beaver dams dominate the reach. Active dams are passage barriers. More of a sediment sink than source. Evolving towards a narrower E channel.
FLR 015	1	Clean substrate with deep pools and lots of LWD. Reference B channel. Very stable.

Reach Name	Incision Ratio	Comments
FLR 016	1.25	Braided in areas. Deep pools. Lots of gravel. Moderate embeddedness. Minor erosion on bends.
FLR 017	1.1	Lots of gravel. Good LWD. Deep pools. Minor erosion on bends. W/D high in spots. Vegetation is good.
FLR 018	1	Stable B channel. Some impacts from CR 70 crossing at top end of reach.

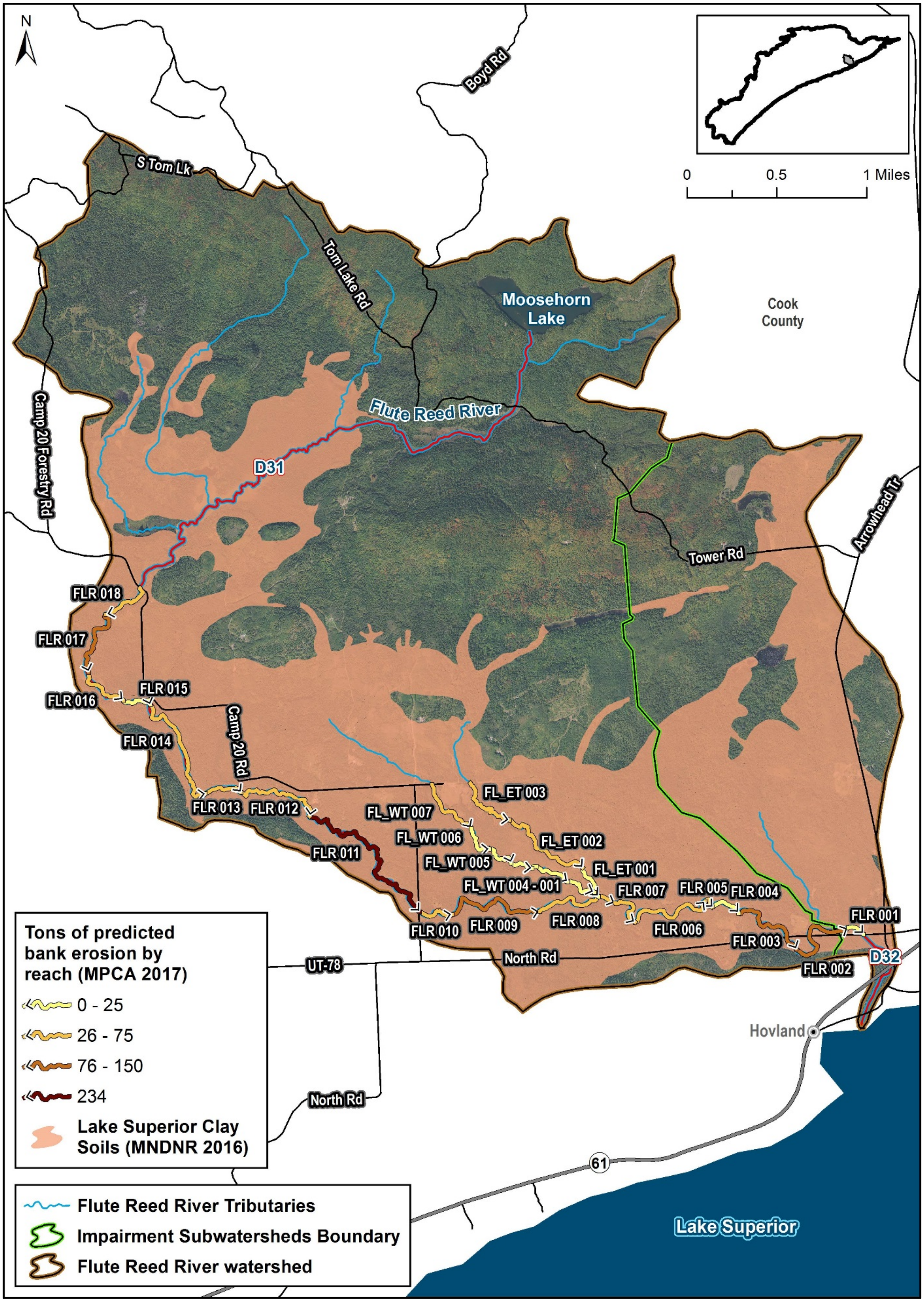

Figure 19. Bank erosion estimates (MPCA 2017b).

Impact of Otis Creek

Additional impacts to the stream geomorphology occur from overflows of nearby streams. Otis Creek is a small stream east of the Flute Reed main channel. A portion of the Otis Creek Subwatershed is found within the larger Flute Reed Subwatershed. The stream has a history of flooding roads at culvert locations, causing significant erosion and stream destabilization (Figure 20 and Figure 21). The flooding has become more frequent in recent years, due in part to cascading failures of beaver dams, heavy rainfall events, misaligned or undersized culverts, ice dams, rapid snowmelt runoff, and inadequate road ditches. High flows of the creek are easily re-routed to the main channel of the Flute Reed River (Cook County SWCD 2014a).

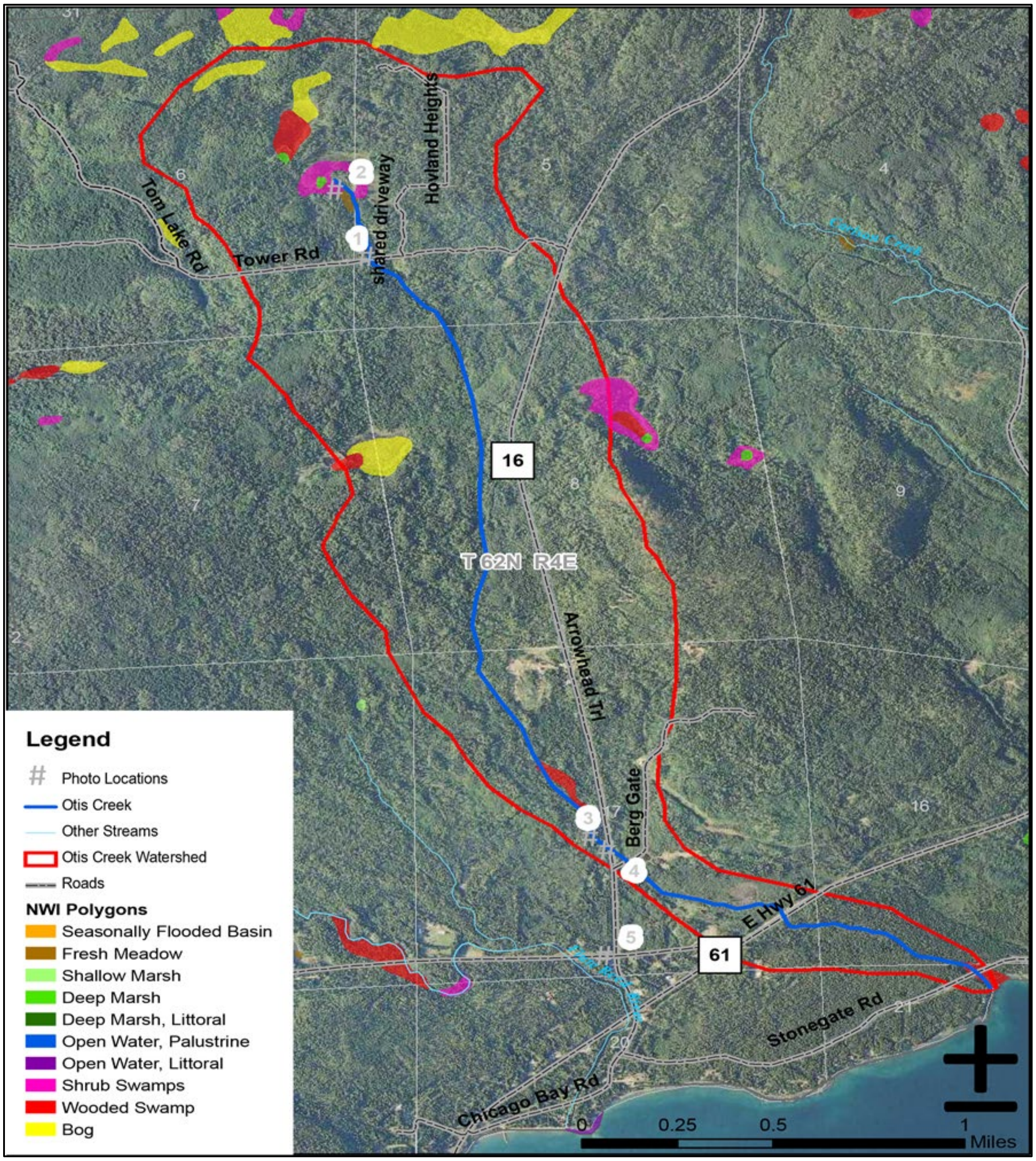

Figure 20. Otis Creek Subwatershed.

Storm flows will overtop the channel at map locations #3-4 with backup and storm flows entering the Flute Reed channel near location #5.

Figure 21. High water flows on Otis Creek.

The lower photo shows storm flows bypassing the road culvert, out of the drainage channel and roadway right-of-way. Storm flows are moving south to the Flute Reed River main channel. These additional flows can cause bank collapse when more water reaches already saturated banks.

4. TMDL Development

A TMDL is the total amount of a pollutant that a receiving waterbody can assimilate while still achieving water quality standards. TMDLs can be expressed in terms of mass per time or by other appropriate measures. TMDLs are composed of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and natural background levels. In addition, the TMDL includes a margin of safety (MOS), either implicit or explicit, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this is defined by the equation:

TMDL = WLA + LA + MOS

A summary of the allowable loads for TSS in the Flute Reed River Watershed is presented in this section. The allocations for each of the various sources are shown in the tables throughout this section.

Allowable pollutant loads in streams are determined through the use of load duration curves. A load duration curve is similar to a water quality duration curve, except that loads rather than concentrations are plotted on the vertical axis. Discussions of load duration curves are presented in *An Approach for Using Load Duration Curves in the Development of TMDLs* (EPA 2007). The approach involves calculating the allowable loadings over the range of flow conditions expected to occur in the impaired stream by taking the following steps:

1. A flow duration curve for the stream is developed by generating a flow frequency table and plotting the data points to form a curve. The data reflect a range of natural occurrences from extremely high flows to extremely low flows. The flow data are year-round simulated daily average flows (1993 through 2016) from the Flute Reed River HSPF model application, updated in 2017. The model report (Tetra Tech 2017) describes the framework and the data that were used to develop the model, and includes information on the calibration.
2. The flow curve is translated into a load duration curve by multiplying each flow value by the water quality standard/target for a pollutant (as a concentration), then multiplying by conversion factors to yield results in the proper unit. The resulting points are plotted to create a load duration curve.
3. Each water quality sample is converted to a load by multiplying the water quality sample concentration by the average daily flow on the day the sample was collected. Then, the individual loads are plotted as points on the load duration curve graph and can be compared to the water quality standard/target, or load duration curve.
4. Points plotting above the curve represent deviations from the water quality standard/target and the daily allowable load. Those plotting below the curve represent compliance with standards and the daily allowable load.
5. The area beneath the TMDL curve is interpreted as the loading capacity of the stream. The difference between this area and the area representing the current loading conditions is the load that must be reduced to meet water quality standards/targets.

The resulting load duration curve can provide insight into pollutant sources. The exceedances at the right side of the graph occur during low flow conditions, and may be derived from sources such as recreational vehicles crossing the channel. Exceedances on the left side of the graph occur during higher flow events, and may be derived from sources such as runoff and associated peak flows. The load duration curve approach helps select implementation practices that are most effective for reducing loads on the basis of flow regime. If loads are considerable during wet-weather events (including snowmelt), implementation efforts can target best management practices (BMPs) that will most effectively reduce stormwater runoff.

The stream flows displayed on load duration curves may be grouped into various flow regimes to aid with interpretation of the load duration curves. The flow regimes are typically divided into 10 groups, which can be further categorized into the following five hydrologic zones:

- Very high flow zone: stream flows that plot in the 0 to 10-percentile range, related to flood flows
- High flow zone: flows in the 10 to 40-percentile range, related to wet weather conditions
- Mid-range flow zone: flows in the 40 to 60-percentile range, median stream flow conditions
- Low flow zone: flows in the 60 to 90-percentile range, related to dry weather flows
- Very low flow zone: flows in the 90 to 100-percentile range, related to drought conditions

The load duration curve method was used to develop the stream TMDLs. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables, only five points on the entire loading capacity curve are depicted—the midpoints of the designated flow zones (e.g., for the high flow zone [0th to 10th percentile], the TMDL was calculated at the 5th percentile). However, the entire curve represents the TMDL and is what is ultimately approved by the EPA. Table 8 summarizes the TMDLs being developed.

Table 8. TMDL pollutants

Reach Name	AUID (04010101-xxx)	Location/Reach Description	Affected Designated Use Class	Pollutant or Stressor	TMDL Pollutant(s) [a]
Flute Reed River	D31	Headwaters (Moosehorn Lk 16-0015-00) to Unnamed cr	Aquatic Life	Total Suspended Solids	Total Suspended Solids
	D32	Unnamed cr to Lk Superior	Aquatic Life	Turbidity	Total Suspended Solids

a. In addition to high levels of turbidity and TSS, the *Lake Superior North Watershed Stressor Identification Report* (MPCA 2017b) also identifies the following stressors to aquatic life in the stream: elevated water temperature, physical habitat degradation, and aquatic organism passage barriers.

4.1 Natural Background Considerations

Natural background conditions refer to inputs that would be expected under natural, undisturbed conditions. Natural background sources can include inputs from natural geologic processes, such as soil loss from upland erosion and stream development, atmospheric deposition, and loading from forested land, wildlife, etc. Natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment and, therefore, natural background is accounted for and addressed through the MPCA's assessment process.

The TSS standard inherently addresses natural background conditions. Minnesota's regional TSS standards are based on reference or least-impacted streams, and take into account differing levels of sediment present in streams and rivers in the many ecoregions across the state, depending on factors such as topography, soils, and climate (MPCA 2011).

Natural background conditions were evaluated, where possible, within the source assessment portion of this study. The source assessment indicates watershed natural background inputs (i.e., forest and wetlands) are generally low compared to near-channel sources and developed land covers. The impact of beaver activity, a natural source, has been documented as contributing to sediment loading in the stream; however, it is not possible at this time to distinguish the proportion of near-channel loading attributed to beaver activity.

Other streams exist within the larger HUC 8 that have similar geologic and hydrologic conditions. It is important to note that, of the Lake Superior North streams assessed to date, the Flute Reed River is the only sediment-impaired stream. The lack of other impairments among this group of assessed streams provides evidence that additional factors are contributing to the Flute Reed River impairments, including a higher amount of development and a more extensive road network.

Based on the MPCA's waterbody assessment process and the TMDL source assessment, there is no evidence at this time to suggest that natural background sources are a major driver of the impairment and/or affect the waterbody's ability to meet state water quality standards. Natural background sources are implicitly included in the LA portion of the TMDL, and reductions should focus on the major anthropogenic sources including roads, developed land uses, and logging operations. Beaver, as a natural component of the watershed, can significantly influence the condition of the stream channel as indicated in the geomorphic analysis of the stream (see Section 3.4). These influences, as well as soil type and slope, were factored into the source assessment via the HSPF model (Tetra Tech 2017) and are included implicitly in the LA.

4.2 Total Suspended Solids

4.2.1 Loading Capacity

The loading capacity is calculated as flow multiplied by the TSS standard (10 mg/L), and represents the TSS load in the stream when the stream is at the TSS standard. Daily average stream flows at the downstream end of each impaired reach were simulated in the Flute Reed River HSPF model (Appendix A; Tetra Tech 2017). The model report describes the framework and the data that were used to develop the model, and includes information on the calibration.

The existing loads are calculated as the 90th percentile of observed TSS loads in each flow zone from the months that the standard applies (April through September); the monitored concentrations are multiplied by estimated flow and then multiplied by a unit conversion factor. The percent reductions needed to meet the TMDL are calculated as the TMDL minus the existing load, divided by the existing load; this calculation generates the portion of the existing load that must be reduced to achieve the TMDL. If the existing load is lower than the TMDL for a flow regime, the percent reduction needed to meet the TMDL is reported as 0%. If there are no monitoring data for a flow regime, the existing load and the load reduction are not reported. The TSS monitoring data used to calculate the percent reductions needed to meet the TMDL are from 2008 through 2016; 2016 is the baseline year against which future reductions will be compared.

The Clean Water Act requires that TMDLs take into account critical conditions for stream flow, loading, and water quality parameters as part of the analysis of loading capacity. Through the load duration curve approach it has been determined that load reductions are needed for specific flow conditions; however, the critical conditions (the periods when the greatest reductions are required) vary by location and are inherently addressed by specifying different levels of reduction according to flow.

4.2.2 Load Allocation Methodology

The LA represents the portion of the loading capacity that is allocated to pollutant loads that are not regulated through a National Pollutant Discharge Elimination System (NPDES) Permit (Permit) and is calculated as the loading capacity minus the MOS minus the WLAs. The LA implicitly includes natural background sources (e.g., beaver activities, load from forest land covers, etc.).

4.2.3 Wasteload Allocation Methodology

The WLA represents the portion of the loading capacity that is allocated to pollutant loads that are regulated through an NPDES Permit. Construction stormwater and industrial stormwater are the only NPDES regulated potential sources of TSS in the Flute Reed River Watershed (Construction Stormwater General Permit MNR100001 and Industrial Stormwater General Permit MNR050000). Categorical WLAs for construction and industrial stormwater are provided for each impaired segment. The average annual (2010 through 2015) percent area of Cook County that is regulated through the construction stormwater permit is 0.003% (Minnesota Stormwater Manual Contributors 2017). The construction stormwater WLA was calculated as the loading capacity (or TMDL) minus the MOS multiplied by the percent area:

$$\text{construction stormwater WLA} = (\text{TMDL} - \text{MOS}) \times 0.003\%$$

No known industrial stormwater sources are currently located within the Flute Reed River Watershed. To account for any potential future industrial activities in the watershed, a conservative estimate of double the construction stormwater WLA is used for the industrial stormwater WLAs.

4.2.4 Margin of Safety

An explicit 10% MOS was calculated for the TSS TMDLs. This MOS accounts for uncertainty in the flow data used to derive the TMDLs. The flow data are based on a calibrated and validated HSPF model application (Appendix A; Tetra Tech 2017); however calibration data were only available seasonally for 2013 through 2016 and, therefore, potential errors in the model's hydrologic calibration are expected. While additional MOS could be added to further account for uncertainty in the modeled flows, there would be no meaningful difference in the load reduction targets[1], which only address nonpoint sources. The adaptive management approach, described in Section 7.4, will address any further uncertainty related to the nonpoint sources in the watershed. This approach allows for the adjustment of implementation activities in the future, as projects are put into place and monitoring reveals the effect of those projects on the stream sediment conditions.

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[1] Current reductions are very high during high flow conditions; allocating additional load to the MOS would increase reductions needed for nonpoint sources.

4.2.5 Seasonal Variation

TSS concentrations and loads vary seasonally. Seasonal variation is partially addressed by the TSS water quality standard's application during the period where the highest TSS concentrations are expected via snowmelt and storm event runoff. The load duration approach also accounts for seasonal variation, by evaluating allowable loads on a daily basis over the entire range of observed flows and by presenting daily allowable loads that vary by flow.

4.2.6 TMDL Summaries

Flute Reed River (04010101-D31)

The load duration curve and TMDL allocations for impaired reach D31 of the Flute Reed River are presented in Figure 22 and Table 9, respectively. Large TSS load reductions are needed under all sampled flow regimes, with the largest reduction of 92% under very high flows. Samples were not collected under very low flow conditions.

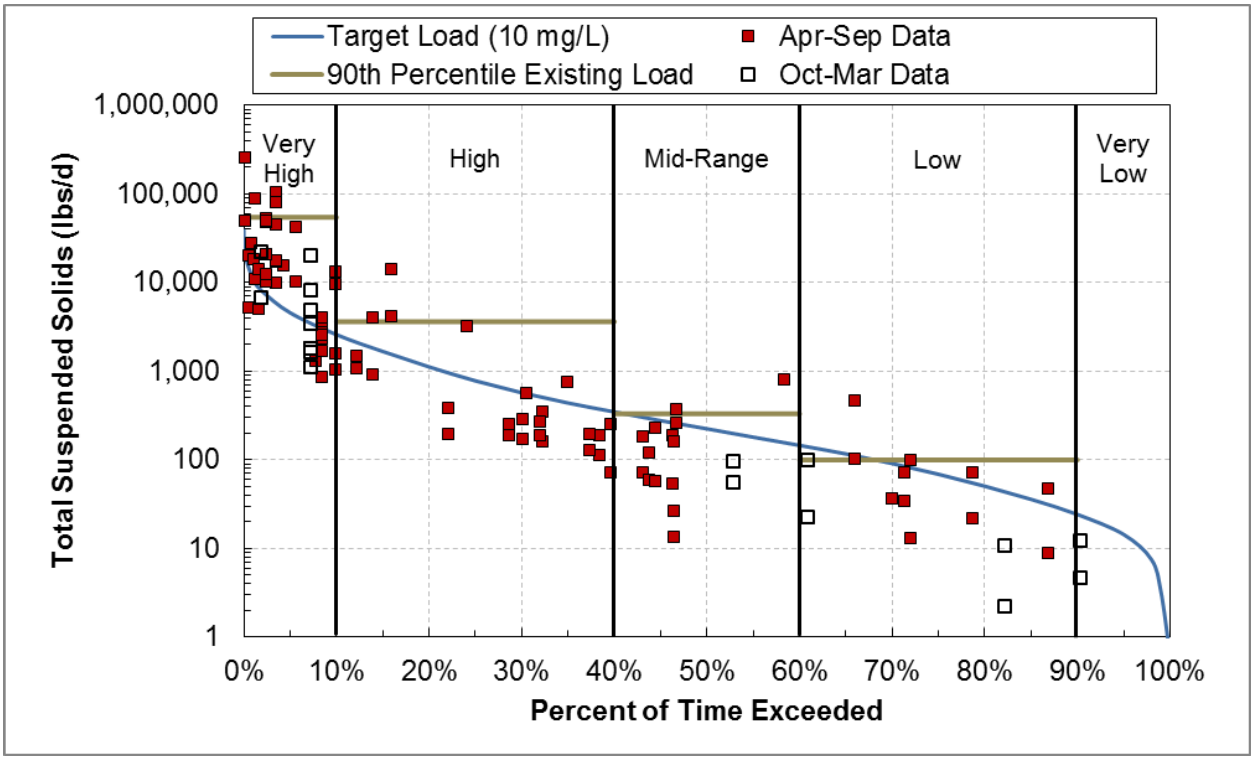

Figure 22. TSS load duration curve, Flute Reed River (04010101-D31).

Table 9. TSS TMDL Summary, Flute Reed River (04010101-D31)

All values except for construction and industrial stormwater WLAs are rounded to nearest whole number.

TMDL Parameter		Flow Regime				
		Very High	High	Mid-Range	Low	Very Low
		TSS Load (lbs/day)				
Wasteload Allocation	Construction Stormwater (MNR100001)	0.113	0.019	0.006	0.002	0.0004
	Industrial Stormwater (MNR050000)	0.225	0.038	0.011	0.003	0.001
Load Allocation		4,110	702	202	62	13
MOS		457	78	22	7	1
Loading Capacity		**4,567**	**780**	**224**	**69**	**14**
Existing Load		59,416	3,623	330	100	-
Percent Load Reduction		92%	78%	32%	31%	-

-: No data

Flute Reed River (04010101-D32)

The load duration curve and TMDL allocation for impaired reach D32 of the Flute Reed River are presented in Figure 23 and Table 10, respectively. Load reductions are needed under all flow regimes, with the exception of very low flows. The largest reductions are needed under very high and high flow conditions.

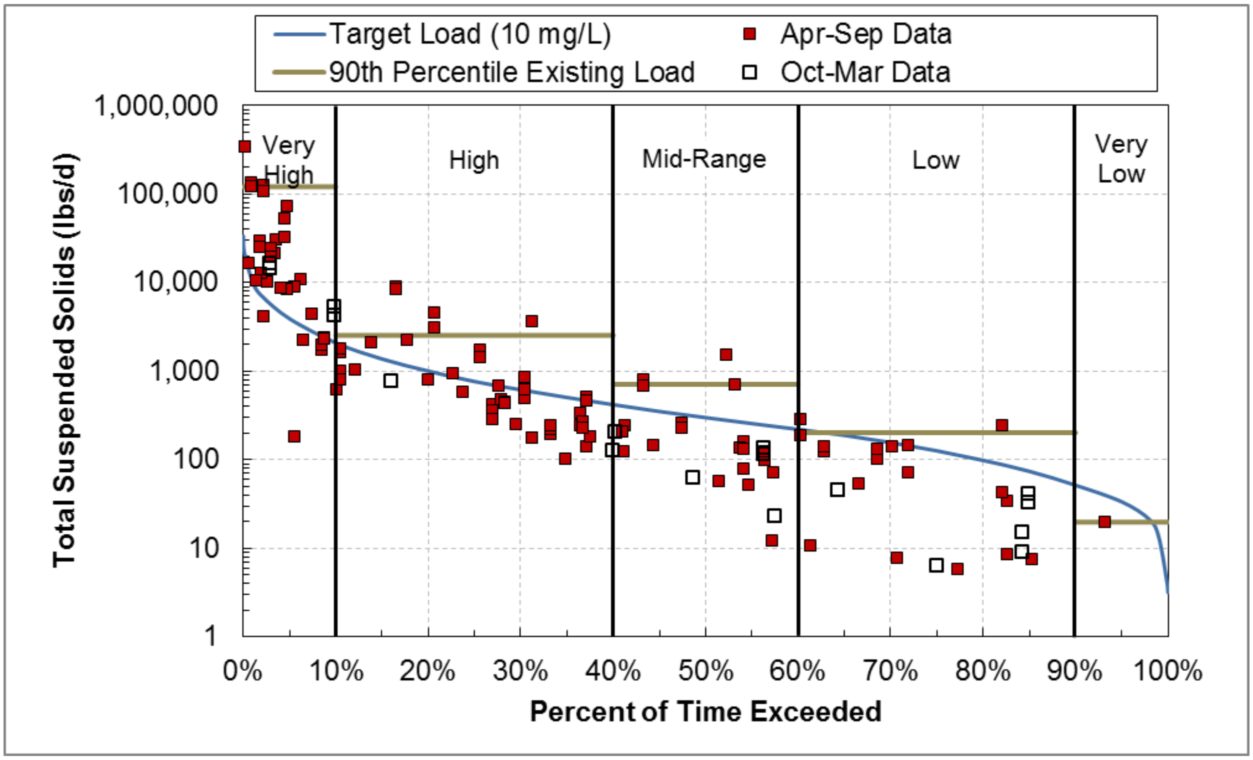

Figure 23. TSS load duration curve, Flute Reed River (04010101-D32).

Table 10. TSS TMDL Summary, Flute Reed River (04010101-D32)

All values except for construction and industrial stormwater WLAs are rounded to nearest whole number.

TMDL Parameter		**Flow Regime**				
		Very High	**High**	**Mid-Range**	**Low**	**Very Low**
		TSS Load (lbs/day)				
Wasteload Allocation	Construction Stormwater (MNR100001)	0.132	0.021	0.006	0.002	0.0004
	Industrial Stormwater (MNR050000)	0.264	0.043	0.012	0.004	0.001
Load Allocation		4,811	779	222	68	14
MOS		535	87	25	8	2
Loading Capacity		**5,346**	**866**	**247**	**76**	**16**
Existing Load		137,752	2,569	403	94	10
Percent Load Reduction		96%	66%	39%	19%	0%

5. Reasonable Assurance

The EPA requires reasonable assurance that TMDLs will be achieved and water quality standards will be met. Pollutant reductions in the Flute Reed River Watershed are only needed from nonpoint sources. Point sources in the watershed are limited to those activities permitted under general stormwater permits (i.e., General Stormwater Permit for Construction Activity [MNR100001], NPDES/ State Disposal System (SDS) Industrial Stormwater Multi- Sector General Permit [MNR050000]). There are no point source reductions needed for this TMDL beyond meeting the requirements of the general permits. See Section 7.2 for more information on the permits.

Restoration of the Flute Reed River will occur as part of local, regional, state, and federal efforts and will be led as appropriate by the Flute Reed Watershed Partnership, Cook County, Cook County SWCD, state and federal agencies, non-profit organization, and residents. A record of past and on-going activities, along with many potential funding sources, provide reasonable assurance that progress will be made toward pollutant load reductions and meeting the TMDLs.

The Flute Reed Watershed Partnership, a volunteer group of watershed residents, has been working to protect and restore the Flute Reed River since 2006. They provide outreach and education opportunities and lead monitoring activities and restoration projects throughout the watershed. This organization is expected to maintain a presence in the future advocating for watershed stewardship and protection and restoration activities.

A watershed-based plan, referred to as Lake Superior North One Watershed One Plan, was finalized in 2016 and addresses the greater Lake Superior North major watershed and a portion of the Lake Superior South major watershed, including the Flute Reed River Subwatershed. This plan, developed by Cook and Lake counties and Cook and Lake SWCDs, includes priorities, management goals, and implementation activities. The Flute Reed River is identified as a high priority area based on the following:

- Listed on the EPA 303(d) list of impaired waterbodies
- Identified as a designated trout stream
- Identified as a catchment vulnerable to pollution
- Includes areas of biological significance
- Susceptible to groundwater contamination

Agencies, organizations, and landowners in the Flute Reed River Watershed have been implementing water quality projects in an effort to reduce pollutant loading in the watershed, and are expected to continue this effort into the future. Examples include:

- Between 2008 and 2010, the Flute Reed Partnership led tree-planting activities that resulted in over 2,500 additional pine and spruce trees in the watershed.
- A Great Lakes Restoration Initiative grant was obtained in 2011 to reduce sediment and nutrient loading to Lake Superior by implementing high priority projects to stabilize streambanks and replace problem culvert crossings (Cook County SWCD 2014b). This project was led by Cook

County SWCD, Flute Reed Watershed Partnership, and the MPCA, with additional support provided by other state and federal agencies. Five streambank restoration projects were completed and four culverts were replaced along the Flute Reed River or its tributaries. The project was completed in 2014 and included post-construction tree and vegetation plantings.

- In 2017, Cook County SWCD offered shoreline restoration grants and technical assistance to residents funded in part by the Clean Water Land and Legacy Funds.
- During 2017, the U.S. Forest Service/Natural Resources Conservation Service forest management program focused on management development plans for residents in the watershed.
- The 2016 Otis Creek flood mitigation project corrected drainage and a culvert flooding residential property.

Past and potential future funding sources for implementation activities in the Flute Reed River Watershed include:

- Clean Water Fund, part of the Clean Water, Land, and Legacy Amendment
- Clean Water Partnership Loan Program
- Local government cost-share and loan programs
- Federal grants and technical assistance programs
- Federal Section 319 program for watershed improvements
- Great Lakes Restoration Initiative and other federal grant programs

The Lake Superior North WRAPS Report outlines additional implementation opportunities and best management practices that will lead to water quality improvements and achieving the TMDLs.

6. Monitoring Plan

Monitoring is important for several reasons:

- To evaluate water bodies to determine if they are meeting water quality standards and tracking trends
- To assess potential sources of pollutants
- To determine the effectiveness of implementation activities in the watershed
- To de-list waters that are no longer impaired

Monitoring is also a critical component of an adaptive management approach to help determine when a change in management is needed. The Flute Reed River is scheduled for intensive monitoring in 2023 as part of the MPCA's Watershed Approach. Additional monitoring of continuous flow would be beneficial to further understand the sources of sediment in the Flute Reed River Watershed. In addition, the following monitoring activities are recommended, contingent on resources available and priorities:

- Tributary monitoring to identify sources of turbidity;
- Monitoring station at Tower Road crossing to determine sediment-related impacts from Moosehorn Lake;
- In-lake monitoring of Moosehorn Lake including nutrients, algae, turbidity, and clarity;
- Additional longitudinal/synoptic sampling to further identify focus areas for implementation; and
- Bluff and bank erosion over time; further evaluate high erosion risk bluffs identified in NRRI 2015.

The DNR (2016) developed a stream management plan for the Flute Reed River. As part of that plan, the DNR has plans to monitor fish population annually at multiple stations along the Flute Reed River, as well as temperature and discrete flow measurements.

Additional modeling at a smaller subwatershed scale could improve the understanding of sediment loading in the watershed and near-channel areas. Many modeling tools exist, such as Watershed Erosion Prediction Project (WEPP), CONservational Channel Evolution and Pollutant Transport System (CONCEPTS), and the recently updated HEC-RAS model that has been integrated with the Bank Stability and Toe Erosion Model.

Flute Reed Partnership members have expressed interest in engaging in an expanded citizen stream sampling program to include tributaries and roadside ditches. Cook SWCD staff are also engaged in support to citizen stream monitoring programs.

7. Implementation Strategy Summary

Reduction of sediment loading in the Flute Reed River Subwatershed will require practices focused on both the watershed and near-channel sources.

7.1 Non-Permitted Sources

Non-permitted sources of sediment in the Flute Reed River Subwatershed include activities that are the result of human influences, as well as natural processes. The following activities are recommended to address nonpoint sources of sediment in the watershed:

- **Streambank restoration and stabilization**

  Continue to implement streambank restoration activities to address eroding banks and areas of instability in the stream channel (see Figure 19). Ensure construction activities produce minimal disturbance to existing vegetation. Several successful bank stabilization projects using toe wood stabilization techniques have been completed along the Flute Reed River as part of a 2011 Great Lakes Restoration Initiative grant (see Figure 25 for site locations).

Figure 24. Top: Restored ditch lacking established vegetation; Bottom: Culvert identified as fish passage barrier.

- **Channel restoration**

  Address channel incision and floodplain cutoffs to ensure stability of channel. Monitor debris and log jams, and address erosion issues and potential for infrastructure failure (for example in FLR011, as described in Section 3.4.2).

- **Ditch maintenance guidance**

  Develop and implement new guidance for public and private road ditch maintenance to minimize un-vegetated channels and associated erosion. Assess the state of existing roadside ditches and identify priority locations for ditch management (e.g., re-vegetation, armoring). Conduct maintenance activities to establish vegetation as needed.

- **Open lands management and forestry guidance**

  Develop and implement forestry guidelines to ensure a maximum of 60% open lands in the watershed. Work with private land owners to develop Forest Stewardship Plans. Emphasize long-lived conifers in critical riparian locations of the watershed and climate change resiliency in species selection. Consider additional guidance for forestry activities that minimizes soil erosion in clay-rich areas.

- **Culvert design guidelines/culvert inventory and upgrades**

  Several large culverts were identified by various resource and stakeholder groups as being barriers for fish passage or contributing to streambank and channel erosion (see Figure 25). Work with county and other agencies to prioritize and upgrade crossings. Emphasize climate change resiliency in infrastructure planning and rehabilitation. Address Otis Creek overflows to the Flute Reed River.

- **Education and outreach**

  Key education and outreach activities could include: providing information and hands-on workshops to landowners on stream crossings (e.g., ATV, driveway), forest management activities, BMPs for private ditches, beaver management, and habitat improvement projects. In the past, newsletters have been used to correspond with watershed residents, and local classes have brought together residents to learn about topics including tree planting, trail design, and controlling erosion on private property.

  Communication between county officials, SWCD staff and residents is important to meet long-term watershed goals and develop successful shorter term stream projects. Continued support is needed to ensure the Flute Reed Partnership's success. Collaboration is also important with the DNR's stream corridor easement programs, and other good steward programs aimed at protecting key watershed locations and minimizing negative impacts such as driveway crossings.

- **Land use planning**

  Community engagement in development pattern and design across the watershed should continue. The community may want to engage in particular watershed scenario modeling to better understand the possible impacts of general or specific development goals. Several landowners control large acreages that may eventually sub-divide to smaller lot sizes in the sensitive clay soils area.

  Use the principles of low impact design to minimize impacts of development, such as sharing driveways, minimizing disturbance footprints, and reducing impervious areas in future projects. Ensure erosion control and stormwater management on small sites, and long-term site maintenance and good housekeeping to minimize erosion including vegetation establishment and other appropriate cover in clay-rich areas. Consider additional guidance on building in clay-rich areas and reducing potential impacts.

7.2 Permitted Sources

7.2.1 Construction Stormwater

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

7.2.2 Industrial Stormwater

The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES Industrial Stormwater Permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local stormwater management requirements must also be met.

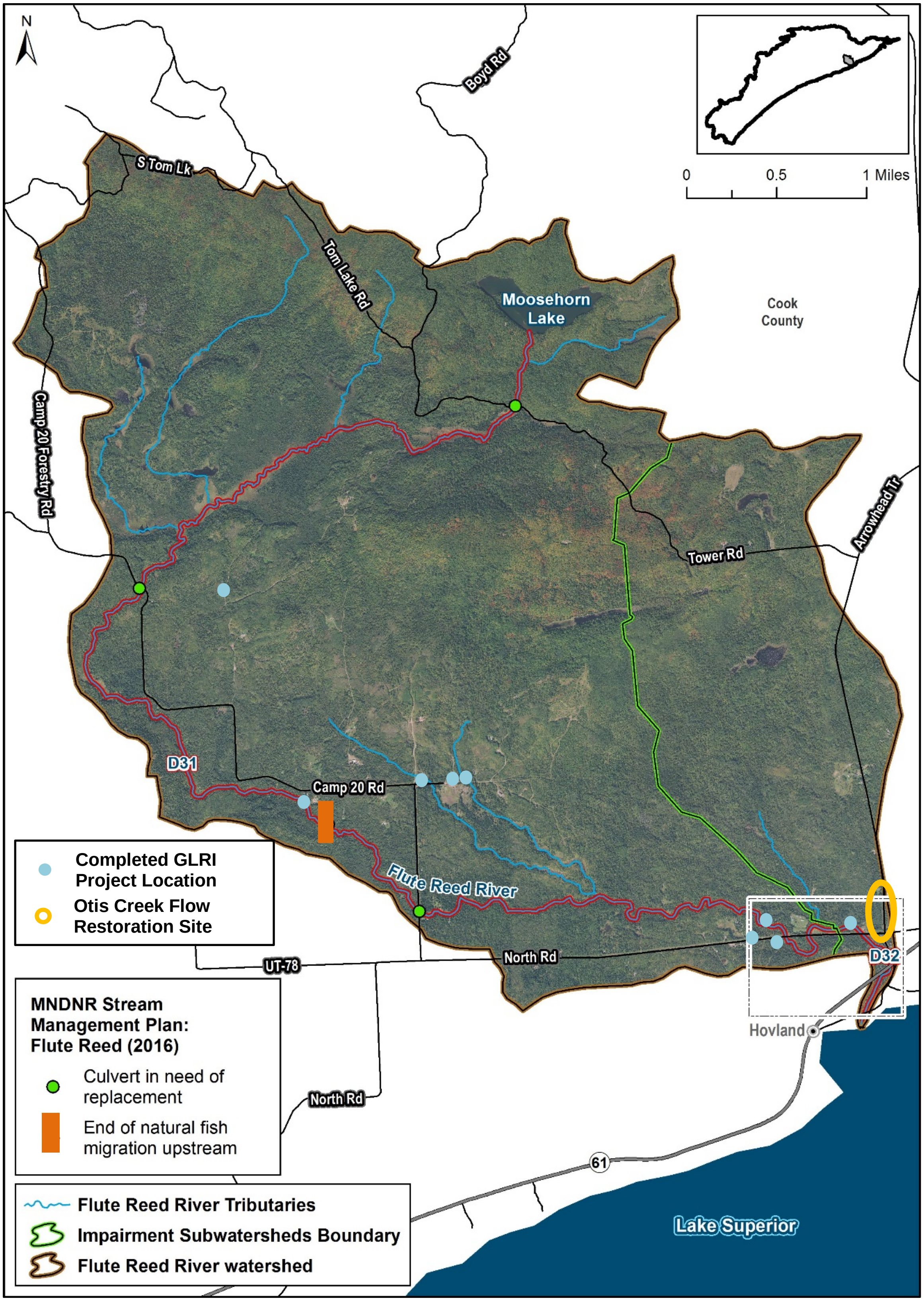

Figure 25. Completed projects and potential locations of future implementation activities in the Flute Reed Subwatershed. White rectangle indicates location with large number of road crossings, an identified stressor in 2016 DNR fisheries stream management plan (DNR 2016). GLRI – Culvert replacement and stream stabilization projects funded by the Great Lakes Restoration Initiative in 2011.

7.3 Cost

TMDLs are required to include an overall approximation of implementation costs (Minn. Stat. 2007, § 114D.25). The costs to implement the activities outlined in the strategy are approximately $1.5 to $2.5 million over the next 20 years. The cost estimate is based on historical project costs and best professional judgement. Easements are not included in the cost estimate nor is the cost for road reconstruction. Upgrading the stream crossings is assumed to be part of regular road construction activities.

7.4 Adaptive Management

This general implementation strategy and the more detailed WRAPS report focus on adaptive management (Figure 26) to ensure management decisions are based on the most recent knowledge. An adaptive management approach allows for changes in the management strategy if environmental indicators suggest that the strategy is inadequate or ineffective. Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL.

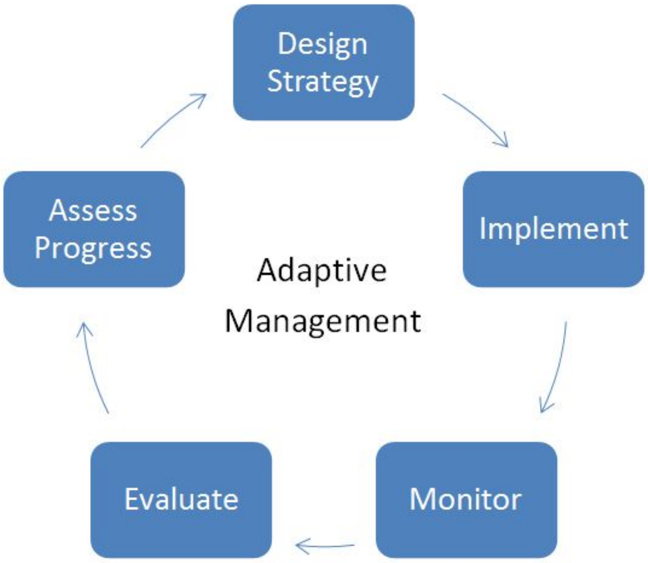

Figure 26. Adaptive management process.

Adaptive management is best suited to watersheds with active participation by agencies and other entities that are aware of and tracking changes in the watershed. For example, in the Flute Reed Subwatershed, changes in land ownership from public to private may be an important trigger for water quality. As additional land transfers into private ownership, the effect on water quality may be seen. Likewise, as landowners implement BMPs to improve their property, improvements to water quality may be realized. Adaptive management relies on all entities involved in management of the Flute Reed River maintaining communications and making adjustments as needed. Adjustments could include additional civic engagement or new guidance.

Natural resource management involves a temporal sequence of decisions (or implementation actions), in which the best action at each decision point depends on the state of the managed system (Williams et al. 2009). As a structured iterative implementation process, adaptive management offers the flexibility for responsible parties to monitor implementation actions, determine the success of such actions, and ultimately base management decisions upon the measured results of completed implementation actions and the current state of the system. This process enhances the understanding and estimation of predicted outcomes, and ensures refinement of necessary activities to better guarantee desirable results. In this way, understanding of the resource can be enhanced over time, and management can be improved (Williams et al. 2009).

8. Public Participation

A series of stakeholder meetings were held to obtain input on TMDL development. Representatives from various state and federal agencies as well as interested stakeholders, including the Flute Reed River Partnership, participated. Meetings were held on the following dates:

- **May 24, 2017**

  This meeting kicked off TMDL and WRAPS development and included an overview of the Watershed Approach, details on the Flute Reed River TMDLs, introduction to WRAPS, discussion on integrating these efforts with the Lake Superior North One Watershed One Plan, and discussion on potential modeling scenarios. Attendees shared information on current projects and efforts in the watershed.

- **July 17, 2017**

  This TMDL-specific meeting was held with the Flute Reed River Partnership. Topics included TMDL development, water quality assessment, pollutant reductions, and potential implementation activities.

- **July 27, 2017**

  TMDL updates were provided to the group in attendance. A list of potential implementation activities were shared.

Public notice

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from June 18, 2018 through July 18, 2018. There were no comment letters received.

9. Literature Cited

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For more information on the Flute Reed River, visit:

http://www.lakesuperiorstreams.org/northshore/fluteReed.html

Appendix A – Flute Reed River HSPF Model Report

TETRA TECH

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Memorandum

To:	Karen Evens	**Date:**	December 22, 2017
From:	Sam Sarkar	**Subject:**	Flute Reed River HSPF Model
cc:	Jennifer Olson, Jon Butcher		

1 Introduction

This memorandum summarizes the hydrology and water quality calibration for the Flute Reed River (FLR) watershed. A Hydrologic Simulation Program FORTRAN (HSPF) model for the Lake Superior North (LSN) watershed was developed by Tetra Tech for the Minnesota Pollution Control Agency (MPCA) in June, 2016. This model was generally developed at the scale of hydrologic unit code (HUC) 12 digit watersheds while accommodating large lakes, impaired waterbodies and reaches, and flow and water quality monitoring stations. A total maximum daily load (TMDL) requires quantification (and subsequent reduction) of sediment and nutrient loads in the FLR. The FLR HUC12 watershed is represented in the larger LSN model as a single subwatershed. This setup was deemed inadequate to reasonably quantify sources of sediment and nutrient loads for the purposes of this TMDL, especially with regard to in-stream and near bank sources. To address these inadequacies we have refined the representation of the FLR watershed in the LSN model based on recently completed geomorphic studies and stream cross-section surveys.

The revised subbasins and reaches for the FLR watershed are shown in Figure 1. Two delineations correspond with culverts on the FLR at intersections with County Road 70. A delineation was also incorporated for the Cooperative Stream Gaging (CSG) station at Hovland, CR69 (01015001). Two subbasins correspond to the un-named tributaries surveyed during the geomorphic assessment.

Local studies suggest that Otis Creek diverts to the Flute Reed during high flows instead of flowing directly to Lake Superior. The Minnesota DNR Level 8 catchments (which were used to delineate the HSPF model) already seems to address this issue by including the Otis Creek drainage area in the FLR watershed. In the revised delineation we have represented the Otis Creek drainage as a separate subbasin within the FLR watershed. In addition, we have configured Otis Creek (reach # 297) in the model with two outlets. Outlet one flows to reach # 298 and transmits flows less than or equal to 10 cfs. Outlet two discharges to reach # 249 for flows exceeding 10 cfs. Since there was no additional information available on the proportions of flows to the two outlets, the threshold of 10 cfs was set at the 99th percentile of the simulated baseflow time-series in Otis Creek.

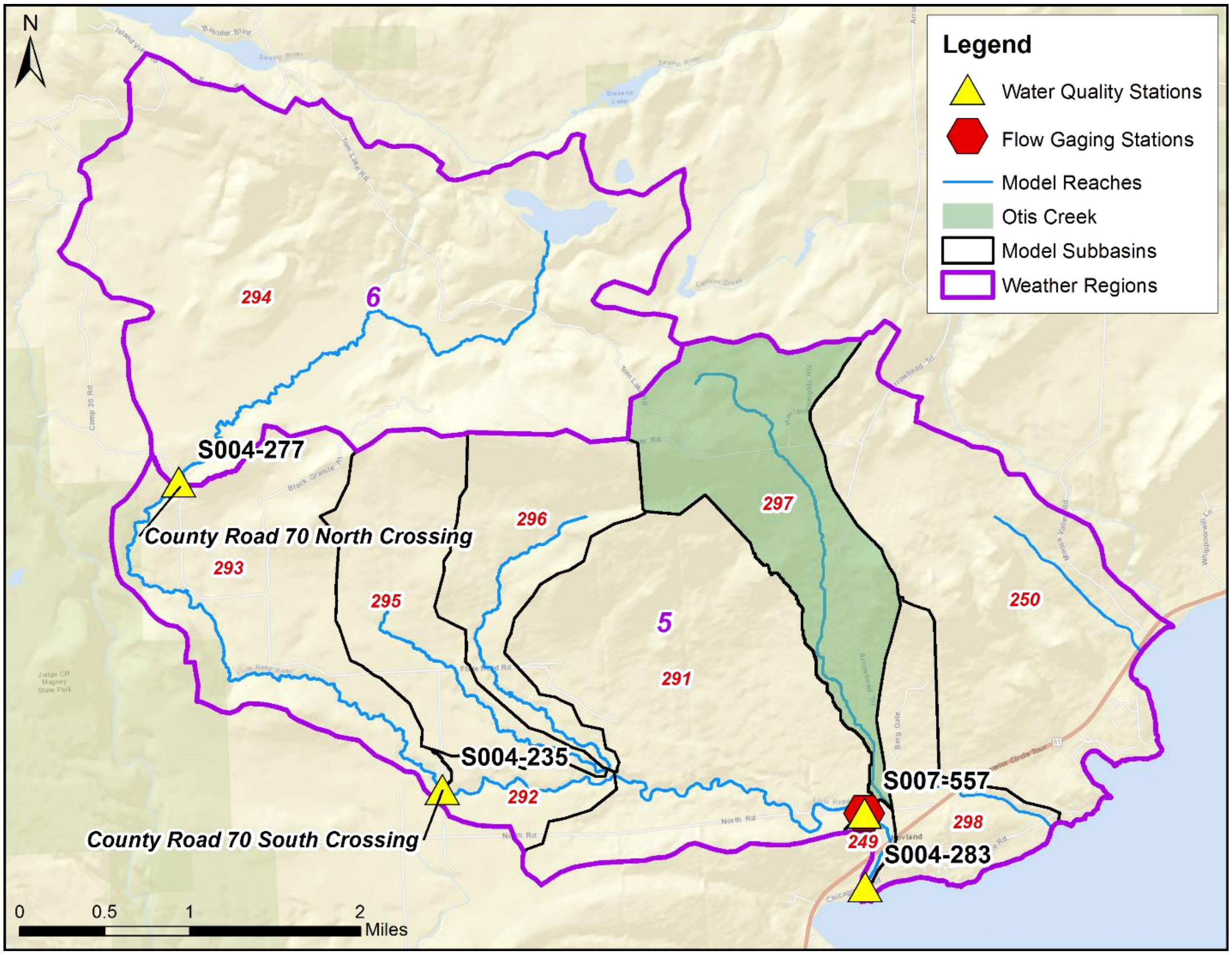

Figure 1. Revised delineation for the Flute Reed River watershed

Meteorological time-series data in the LSN model are based on gridded products (NLDAS and PRISM) spatially aggregated to larger weather regions based on precipitation and temperature patterns. To facilitate parameterization and refine the model performance we have defined two new weather regions the FLR watershed - 5 and 6. With the exception of precipitation, these weather regions use the same meteorological time-series as weather regions 15 and 16, respectively, in the LSN HSPF model. The area along the Lake Superior shore has strong precipitation gradients and to maintain the local precipitation patterns in the FLR, we have spatially aggregated the gridded precipitation data to the relatively smaller weather regions 5 and 6.

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 Function Tables (FTables) that describe the relationship of reach discharge, depth, and surface area to storage volume.

FTables for the modeled reaches with culverts were developed using the Federal Highway Administration (FHWA) HY-8 culvert hydraulics analysis program. Crossing and culvert elevation information were determined from LiDAR based elevation data. Culvert dimensions required for hydraulic analysis were based on a survey completed by the Minnesota Pollution Control Agency (MPCA). Rating curves were generated for the culverts using the HY-8 program and assuming a design flow equivalent to a 100-year flood. For station # 010015001 at Hovland, a rating curve was already available from MPCA. These rating curves were used along with LiDAR derived cross-section (in ArcGIS using 3D analyst) to develop FTables for the HSPF model (model reach # 294, 293 and 291). FTables for the other reaches were developed using regional regression relationships between stream discharge, and bankfull depth and width.

The performance of the FLR model for hydrology and water quality are summarized in the subsequent sections. The hydrology and water quality calibration approach can be found in Section 3 of the Lake Superior North and Lake Superior South Basins Watershed Model Development Report[1].

2 Hydrology Calibration

Streamflow calibration focused on the period of available data (2013-2016) at the station on the Flute Reed River at Hovland, CR69 (01015001). Calibration was completed by comparing time-series 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. Model performance was evaluated against criteria summarized in Table 1. The simulated and observed daily streamflow time-series matched well although the model under-predicts some snowmelt peaks. This indicates that snowfall is likely under-estimated in the FLR watershed. The model over-predicted summer flow volumes which is likely due to a combination of high lower zone storage and low summer evapotranspiration resulting in more groundwater outflow than observed. Given the rocky coastline, the maximum lower zone storage (LZSN) is already set to the recommended minimum of 2 inches. The simulated evapotranspiration also matches fairly well with satellite based estimates. There may also be seepage directly to the lake via rock fractures however evidence based proofs of such occurrences are generally not present.

Based on the magnitude of relative average errors, and daily and monthly Nash Sutcliffe Efficiency (NSE) (Table 2), the model performance for streamflow may be generally rated as good to very good. Complete graphical and tabular statistical results are provided in Appendix A.

The performance of the model for streamflow was also reviewed at an hourly time-step. It is important to note that the ability of the model to accurate predict the timing of hourly events is limited because it is configured at an hourly level. We however ensured that simulated and observed peak flows were comparable to each other by visually inspecting the observed and simulated flow duration curves, shown in Figure 2. The observed and simulated hourly flow time-series also tracked well with each other (Figure 3) with an NSE of 0.658 (and R^2 of 0.679).

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[1] Tetra Tech, 2016. Lake Superior North and Lake Superior South Basins Watershed Model Development Report. Minnesota Pollution Control Agency.

Table 1. Performance Targets for HSPF Flow Simulation (Magnitude of Annual and Seasonal Relative Average Error; 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

Table 2. Summary of Flow Calibration Results for the Flute Reed River

Errors (Simulated - Observed)	Error Statistics (%)
Time period	07/2013 to 12/2016
Error in total volume	1.46
Error in 50% lowest flows	8.25
Error in 10% highest flows	-2.58
Seasonal volume error - Summer	**43.31**
Seasonal volume error - Fall	10.60
Seasonal volume error - Winter	no data
Seasonal volume error - Spring	-10.16
Error in storm volumes	14.50
Nash-Sutcliffe Coefficient of Efficiency, E	0.714
Monthly NSE	0.920

BOLD – value is outside of calibration target

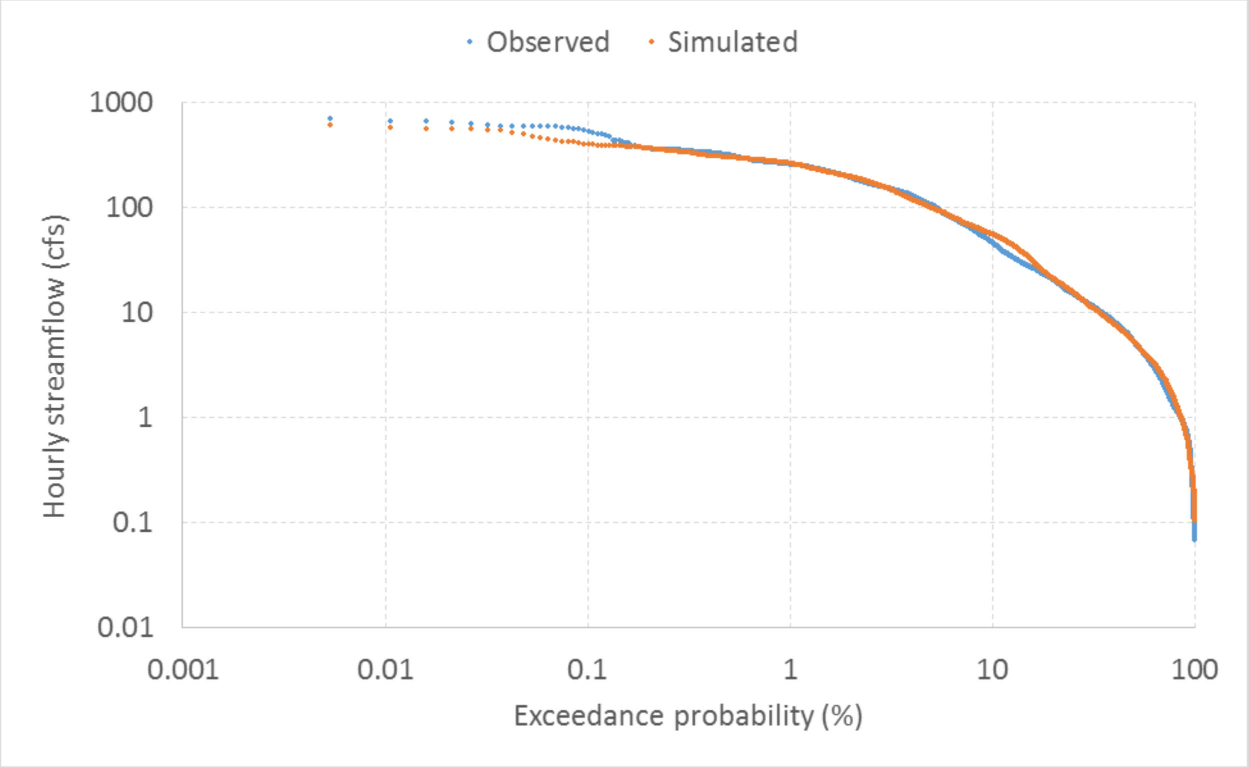

Figure 2. Hourly flow exceedance for the FLR at Hovland, CR69

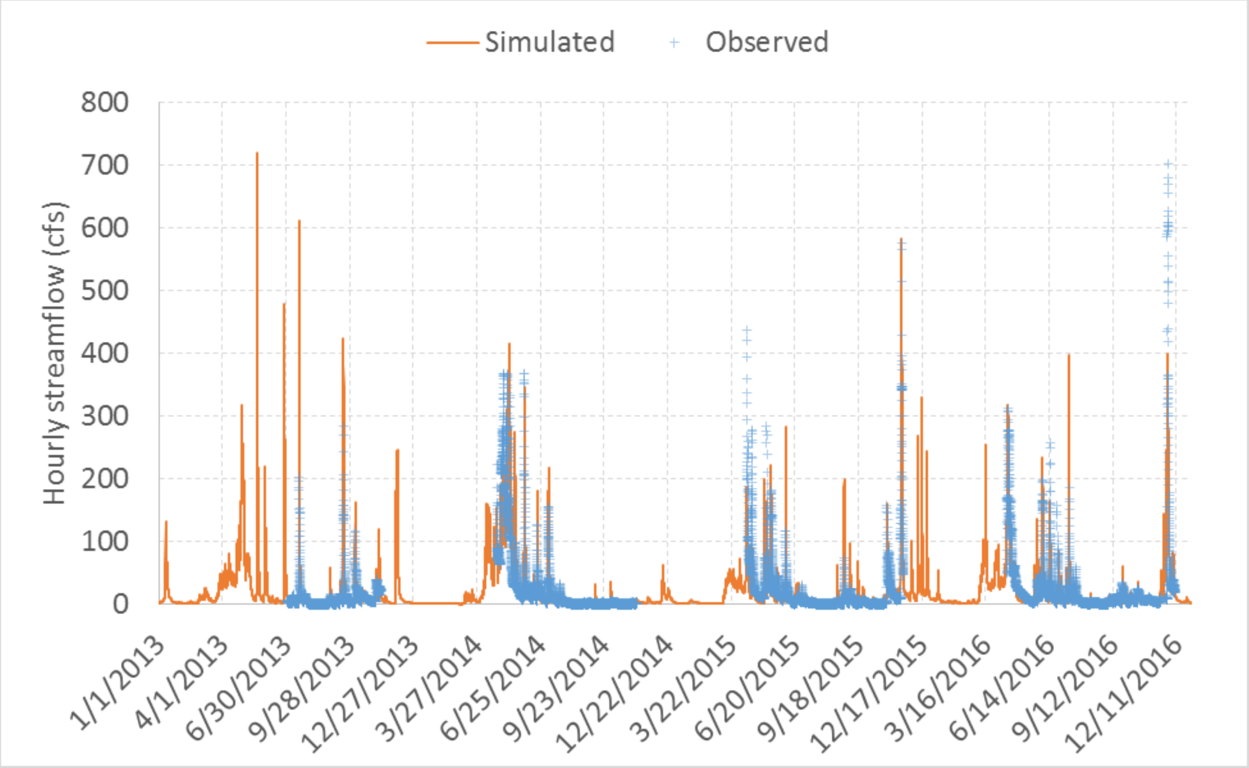

Figure 3. Time-series of observed and simulated hourly streamflow for the FLR at Hovland, CR69

3 Sediment and Nutrient Calibration

Calibration for sediment and nutrients primarily consisted of comparisons between model predictions and sample observations in terms of both concentration and inferred load (concentration times simulated or observed flow) at multiple water quality monitoring stations on the FLR. Performance targets for sediment and nutrient simulation are summarized in Table 3. Complete graphical and tabular statistical results for each station are provided in Appendix B. For each constituent the following plots are generated.

a. Standard time series plot, showing the observations and continuous model predictions of daily average concentrations.

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.

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. A similar plot of residuals versus month is used to diagnose potential seasonal biases.

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

Model Component	Very Good	Good	Fair	Poor
Suspended Sediment	≤ 20%	20 - 30%	30 - 45%	> 45%
Water Quality/Nutrients	≤ 15%	15 - 25%	25 - 35%	> 35%

SEDIMENT

Calibration for sediment also consisted of ensuring reasonable scour and deposition behavior on a reach by reach basis. The recently completed geomorphic assessment for the FLR identified bank erosion as an important source of sediment. It is however important to note that HSPF is a one dimensional flow model and some of the complicated processes associated with bluff and bank erosion cannot be mechanistically simulated. The effects of shallow lateral flow on the mechanical strength of clay soils is a major factor in bluff/bank collapse events, which partially decouples them from instream flow. In essence, bluff/bank collapse events are quasi-random processes.

To simulate bank erosion contributions with HSPF in the FLR watershed an approach similar to that adopted for the Minnesota River watershed[2] was used. In that approach, the load derived from bank erosion (a succession of quasi-random events) is represented by adding a constant load to the bed sediment of reaches with reported bank erosion. 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

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[2] Tetra Tech. 2009. Minnesota River Basin Turbidity TMDL and Lake Pepin Excessive Nutrient TMDL: Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency by Tetra Tech, Inc., Research Triangle Park, NC.

reaches receiving bank erosion loads to reflect the unconsolidated nature of these contributions. The bank erosion loads vary by modeled reach and are directly based on the results of the geomorphic assessment study mapped to modeled reaches in the FLR watershed (Table 4). For unassessed reaches, we have not added a bank erosion component in the HSPF model.

Table 4. Bank Erosion by Reach for the Flute Reed River

HSPF Reach #	Name	Erosion (tons/year)
249	FLR 000	Unassessed
291	FLR 001 - FLR 007	361
292	FLR 008 - FLR 010	225
293	FLR 011 - FLR 018	579
294	FLR 019	Unassessed
295	FLR_WT 001 - FLR_WT 008	130
296	FLR_ET 001 - FLR_ET 004	110
297	-	Unassessed
298	-	Unassessed
250	-	Unassessed

The scour/deposition characteristics for all modeled reaches in the FLR watershed are shown in Figure 4. Net scour/deposition over the 24 year time-period is generally less than ± 6 inches. It is evident from the figure that not all of the sediment load entering the stream system from bank erosion is transported and that a considerable proportion gets deposited. For example, for model reach # 291 a constant load of 0.0412 tons/hr (or 361 tons/yr) is added to the bed storage and represents erosion from bank sources. Mobilization and transport of this load is however dependent on the shear forces acting on the bed. Although 361 tons/yr is added to the bed only 102 tons/yr is transported over the modeling time-frame supported by the calibration of the model to observed sediment concentrations at multiple locations along the FLR. We discussed this apparent discrepancy with Karl Kohler of the Minnesota Department of Natural Resources (DNR). Our understanding from the discussion was that the bank erosion numbers reported by the geomorphic assessment are more representative of the loads during the rising limb of the hydrograph, do not account for depositional losses, and are expected to be much higher than those simulated by the model. It is important to note that the model simulates both erosion and deposition with erosion being the dominant process over the course of simulation. Some deposition of sediment derived from bank erosion is likely behind beaver dams and other obstructions in the stream system. It is also likely that the bank erosion rates are variable from year to year but the geomorphic assessment only provides a constant annual value. Based on an analysis of simulated loads, approximately 74% of the total sediment load can be attributed to in-stream and near channel sources in the FLR.

Calibration results for sediment (and nutrient) are summarized in Table 5. The average and median relative errors on concentration are generally low (less than ± 15 %) across all water quality monitoring sites. The average relative error on load is generally high but median errors are very low (< 1%) at all calibration locations. It is important to note that averages are often biased by extremes and in such cases median is a better predictor of model performance. Based on the criteria summarized in Table 3, the model performance for sediment may be rated as very good.

Performance of the model for sediment was also evaluated by comparing simulated loads against regression loads generated using daily flow and sparse concentration data (at S007-557). Regression loads were generated using the FLUX32 program developed by the US Army Corps of Engineers (USACE) and maintained by MPCA. Monthly simulated loads plotted against regression loads are shown in Figure 5. The simulated and regression loads show good agreement with an R^2 of 0.85 and an average error of 30.8%. The regression models are summarized in Appendix C.

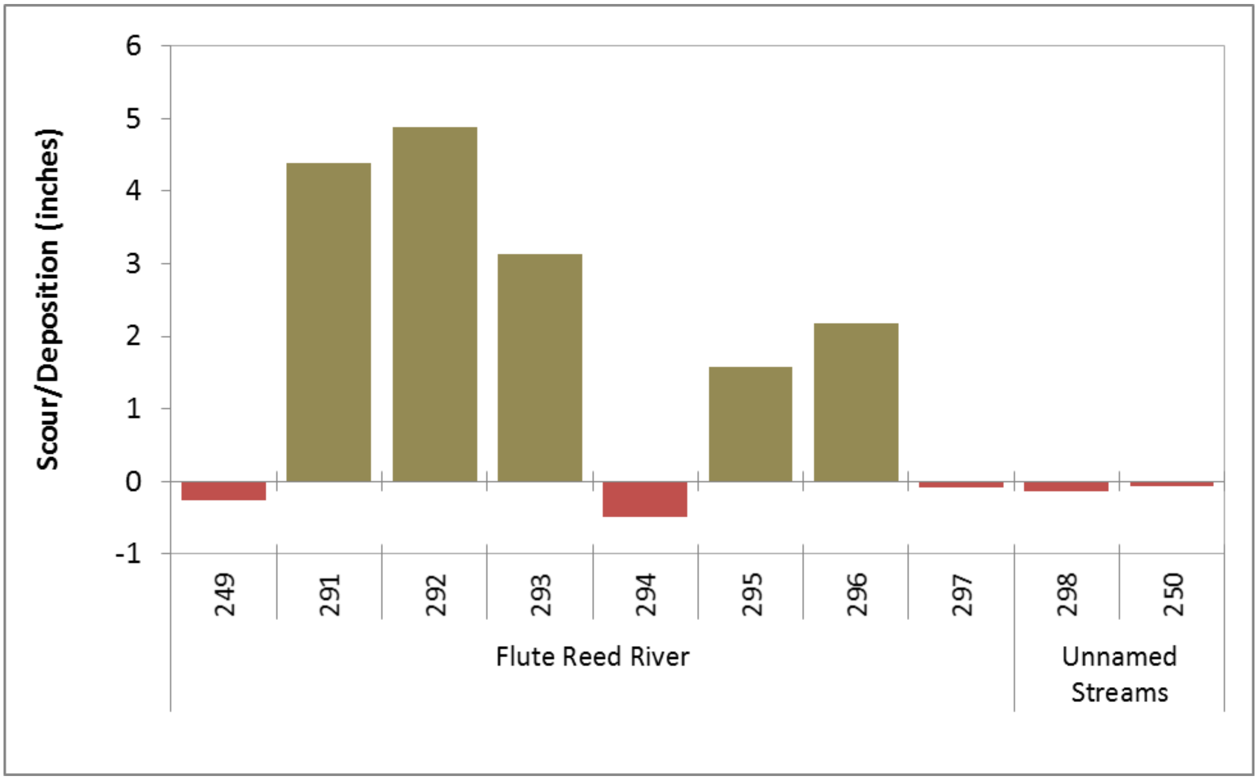


Figure 4. Reach Sediment Balance for the Flute Reed River, 1993-2016 (red indicates scour, brown indicates deposition).

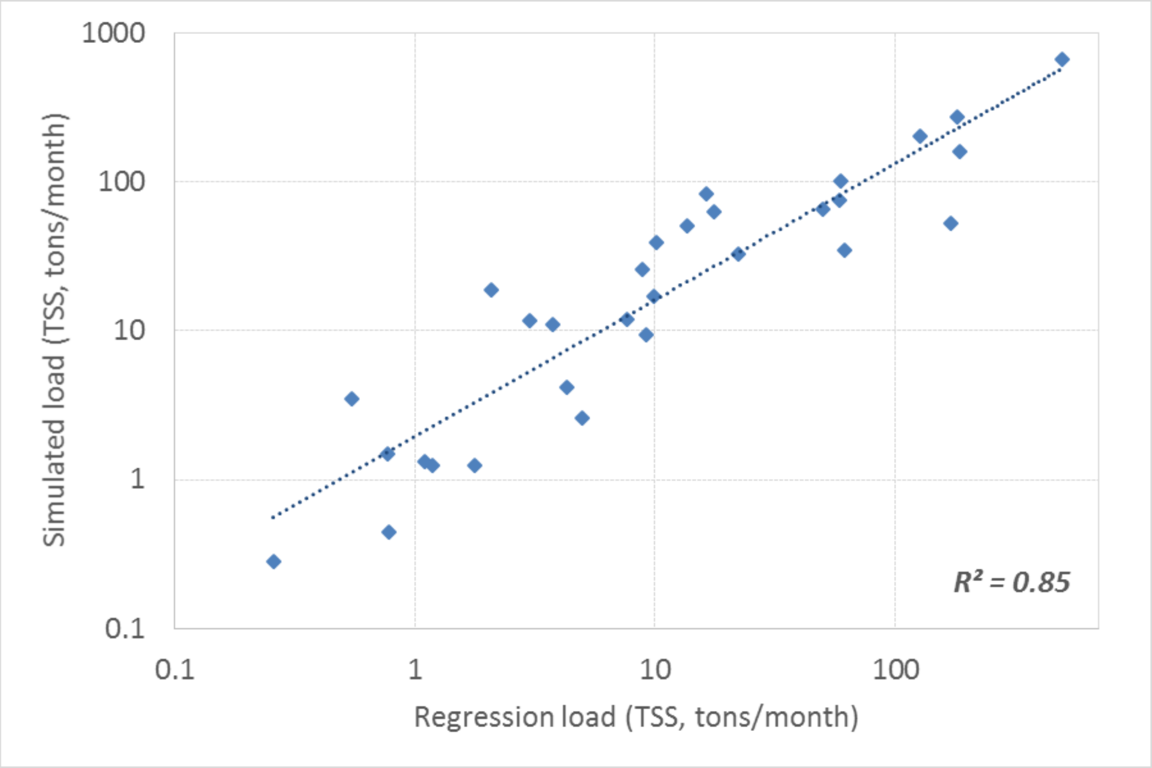


Figure 5. Scatter plot of monthly simulated and regression sediment load.

NUTRIENTS

The average and median relative errors on concentration for total phosphorus (TP) are generally low (less than ± 25%) across all water quality monitoring sites. The average concentration error is more than 25% at S004-235. The median concentration error is however low. The average and median relative errors on load are also generally less than ± 25%. Based on the concentration and load errors the model performance for TP may be rated as good.

Limited nitrate + nitrite nitrogen (NOx) and total Kjeldahl nitrogen (TKN) observations are available at S004-283. Average relative error on concentration is high for NOx but the median concentration error is low. It is important to note that a large number of observed samples are reported as non-detects which likely impact the error statistics. The average error on concentration is approximately 1% when these non-detects are removed from the calculation of summary statistics. The average and median relative errors on load are generally low. The average and median relative concentration and load errors for TKN are also very small. Based on the concentration and load errors the model performance for NOx and TKN may be rated as good.

Performance of the model for TP was also evaluated by comparing simulated loads against FLUX regression loads at S007-557. Monthly simulated loads plotted against regression loads are shown in Figure 6. The simulated and regression loads show good agreement with an R^2 of 0.90 and an average error of < 1%.

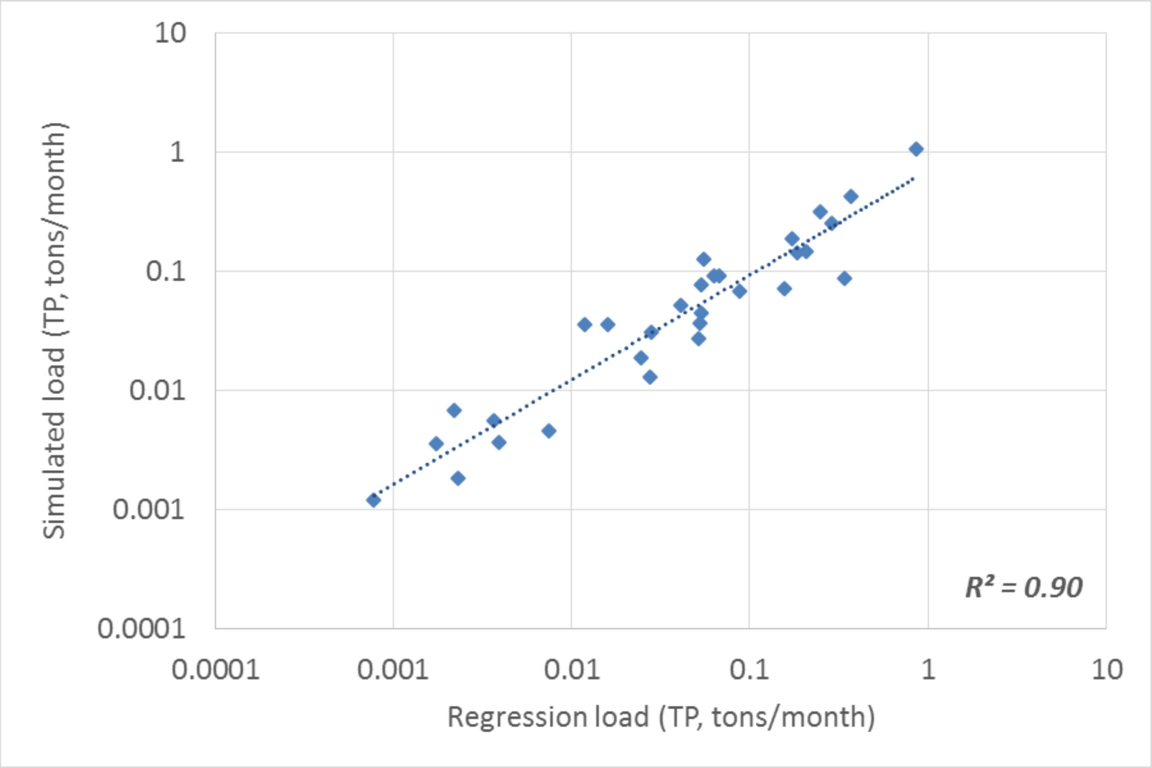


Figure 6. Scatter plot of monthly simulated and regression TP load.

Table 5. Summary of Sediment and Nutrient Calibration Results

Station #	Constituent	Dates	Number of Samples (# non-detects)	Relative Error on Concentration (%)		Relative Error on Load (%)	
				Average	Median	Average	Median
S004-277	TSS	2013-2016	41 (2)	-12	4	**76**	0
	TP	2013-2016	31 (0)	-15	**26**	4	3
S004-235	TSS	2013-2016	45 (0)	-7	-14	**38**	0
	TP	2013-2016	34 (0)	**-29**	-13	**-36**	-2
S007-557	TSS	2013-2016	49 (0)	12	-7	**32**	0
	TP	2013-2016	37 (0)	-19	**-29**	20	-2
S004-283	TSS	2008-2016	91 (6)	8	1	23	0
	TP	2008-2016	79 (0)	-1	4	15	0
	NOx	2008-2016	45 (34)	**89**	18	-9	1
	TKN	2008-2016	44 (14)	1	0	7	0

BOLD – value is outside of calibration target. Averages are often biased by extremes and in such cases median is a better predictor of model performance.

4 Conclusions and Discussion

This phase of model development for the LSN watershed consisted of refining the model performance for the FLR watershed. The delineation for the FLR watershed, represented in the larger LSN model as a single subbasin, was revised to represent major structures and to incorporate the results of a recently completed geomorphic assessment. The model was calibrated for streamflow at the station on the FLR at Hovland (01015001). Calibration for sediment and nutrients consisted of evaluating model performance at multiple monitoring stations along the FLR. Streamflow performance was generally good to very good, based on comparison of daily and seasonal flows. The over-estimation of the sub-daily peaks in the FLR was a concern which has been addressed in this revision of the model. The model was able to reproduce streamflow at an hourly time-step well with peak flows matching gaged observations. As noted earlier, hydraulic representation has significant impacts on the shape of the daily hydrograph and refined FTables using structure specific information has greatly improved model performance.

Revisions to the model also included updates to the bank erosion component based on the geomorphic assessment provided as part of the MPCA’s Stressor Identification project along the FLR. These revisions along with the updated hydraulic representation improved the model performance for sediment. Since phosphorus is closely correlated with sediment, the model performance for phosphorus was also improved. The model performance for species of nitrogen is also good, although there is very limited monitoring for nitrogen.

A key purpose of this model was to provide estimates of current sediment and nutrient loads by sources at different spatial scales to enable watershed managers to determine load reductions necessary to meet the requirements of a total maximum daily load (TMDL) for the FLR. The revised HSPF model for the FLR is well calibrated and therefore provides reasonable estimates of source loads.

Appendix A - Hydrology Calibration

FLUTE REED RIVER AT HOVLAND, CR69 (01015001)

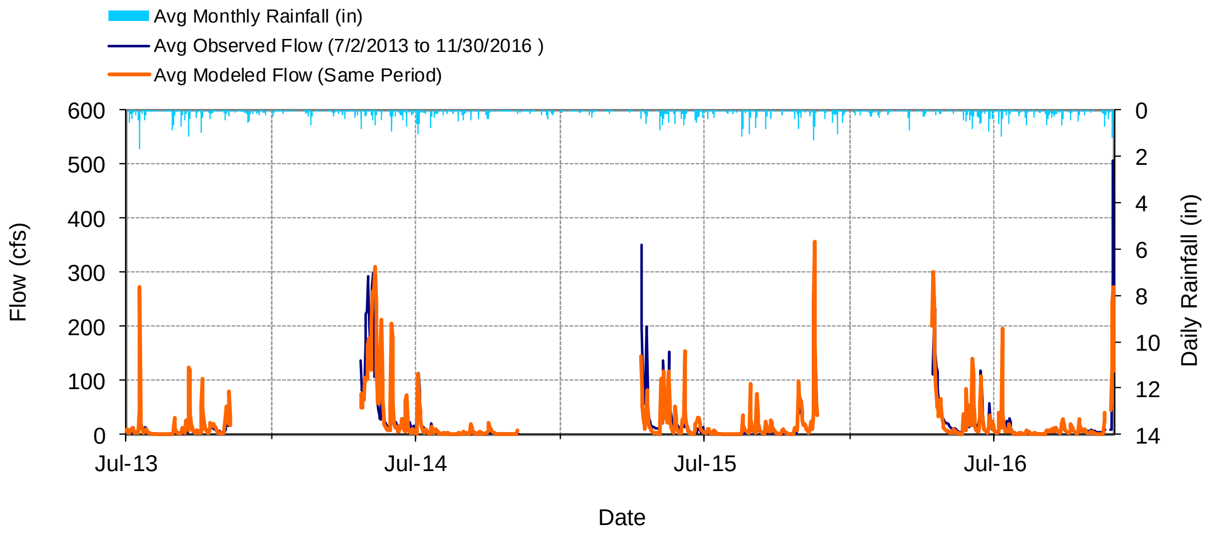


Figure 7. Mean daily flow at Flute Reed River at Hovland, CR69

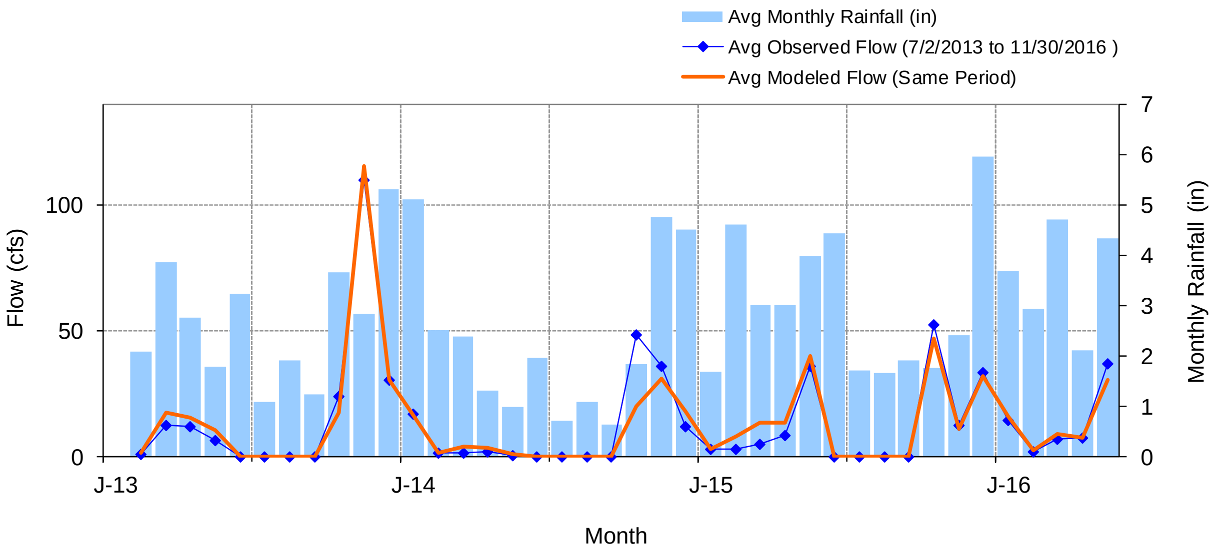


Figure 8. Mean monthly flow at Flute Reed River at Hovland, CR69

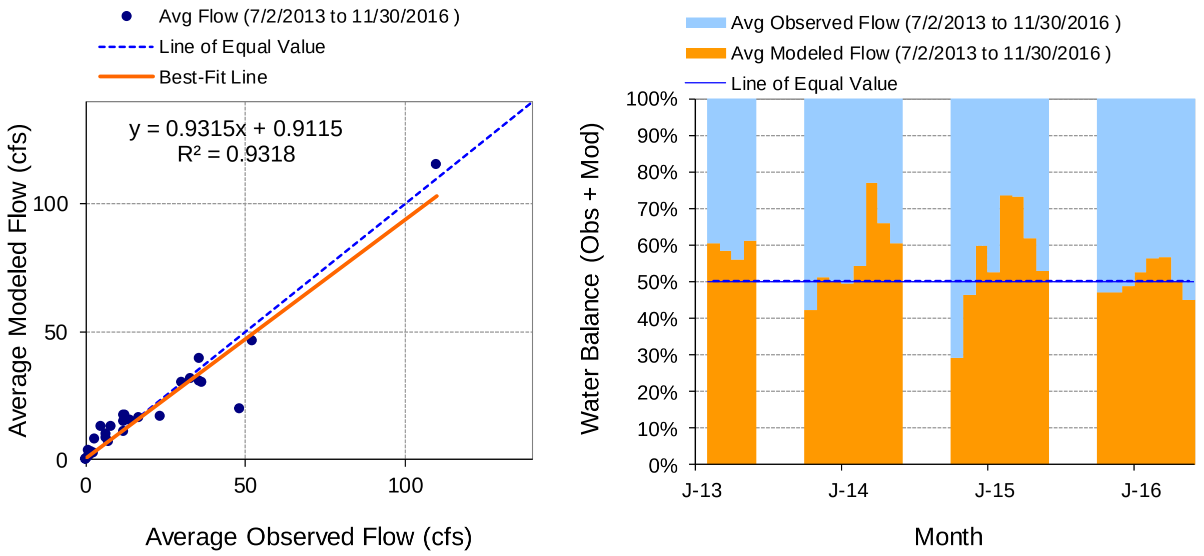


Figure 9. Monthly flow regression and temporal variation at Flute Reed River at Hovland, CR69

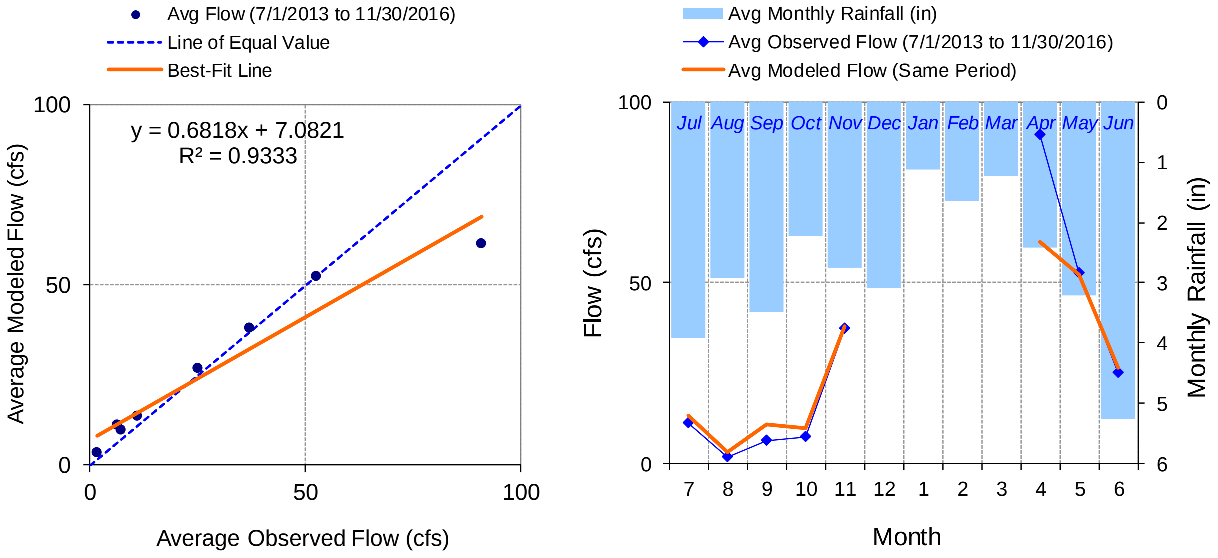


Figure 10. Seasonal regression and temporal aggregate at Flute Reed River at Hovland, CR69

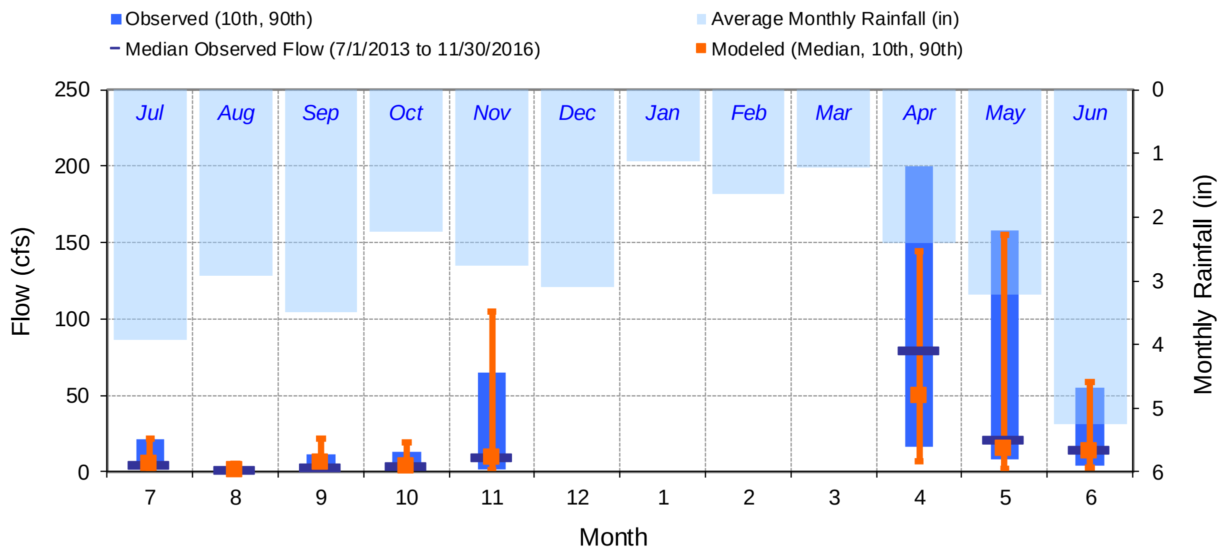


Figure 11. Seasonal medians and ranges at Flute Reed River at Hovland, CR69

Table 6. Seasonal summary at Flute Reed River at Hovland, CR69

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	10TH	90TH	MEAN	MEDIAN	10TH	90TH
Jul	11.07	4.86	1.65	21.35	13.21	5.08	1.11	21.72
Aug	1.62	0.95	0.18	2.54	3.17	0.99	0.30	5.68
Sep	6.21	2.91	0.85	11.36	10.73	6.02	1.42	22.04
Oct	7.18	3.58	1.05	13.03	9.63	3.84	0.78	19.46
Nov	37.10	9.19	1.67	65.37	37.77	9.18	1.11	105.03
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Apr	90.80	79.30	16.03	200.02	61.17	49.64	7.00	144.67
May	52.63	21.24	7.95	157.83	52.34	15.11	2.28	154.69
Jun	25.06	13.93	4.16	55.19	26.58	13.50	2.99	59.09

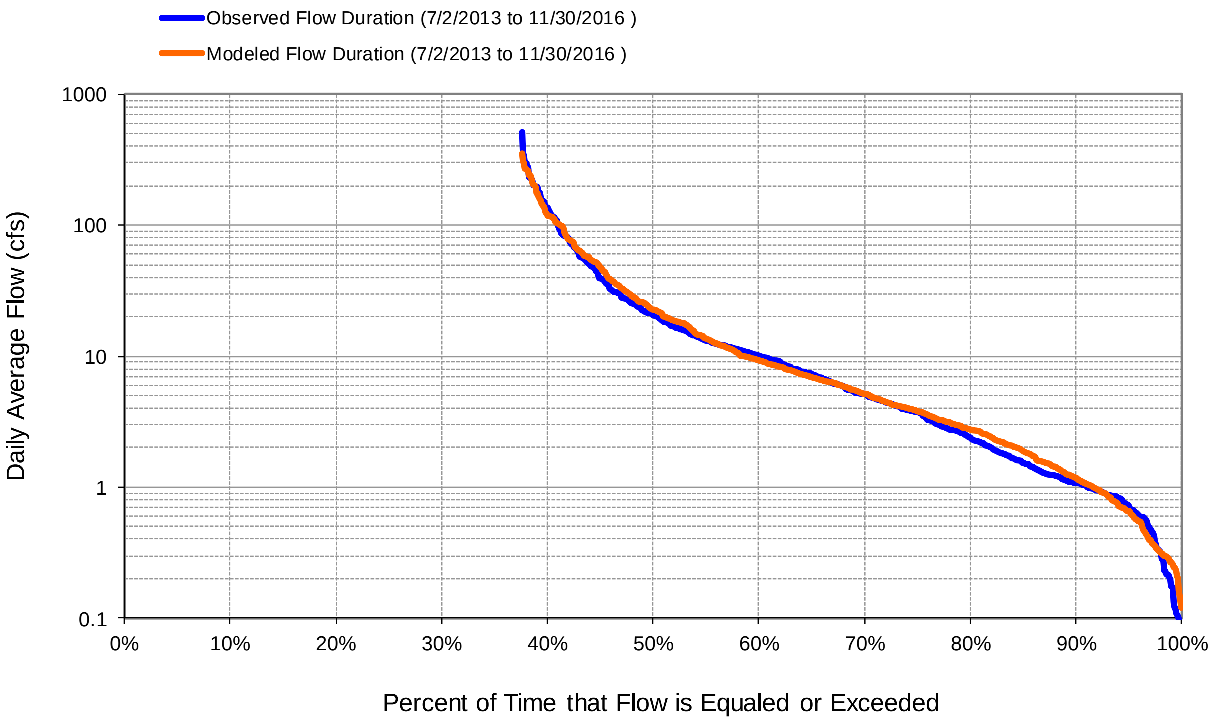


Figure 12. Flow exceedance at Flute Reed River at Hovland, CR69

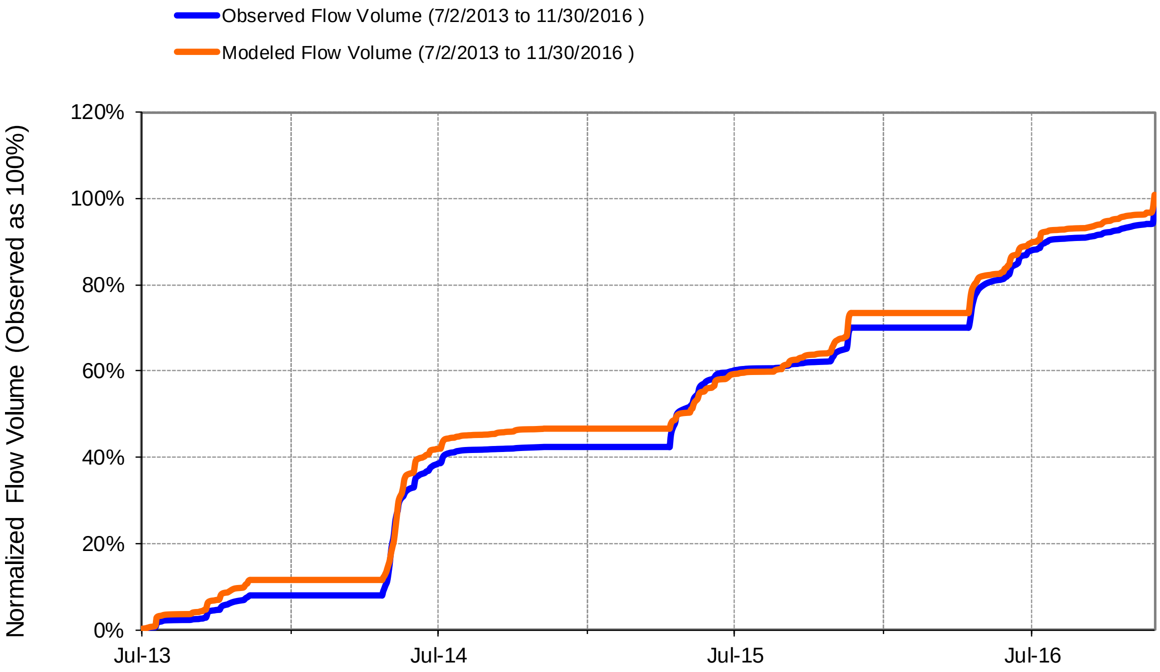
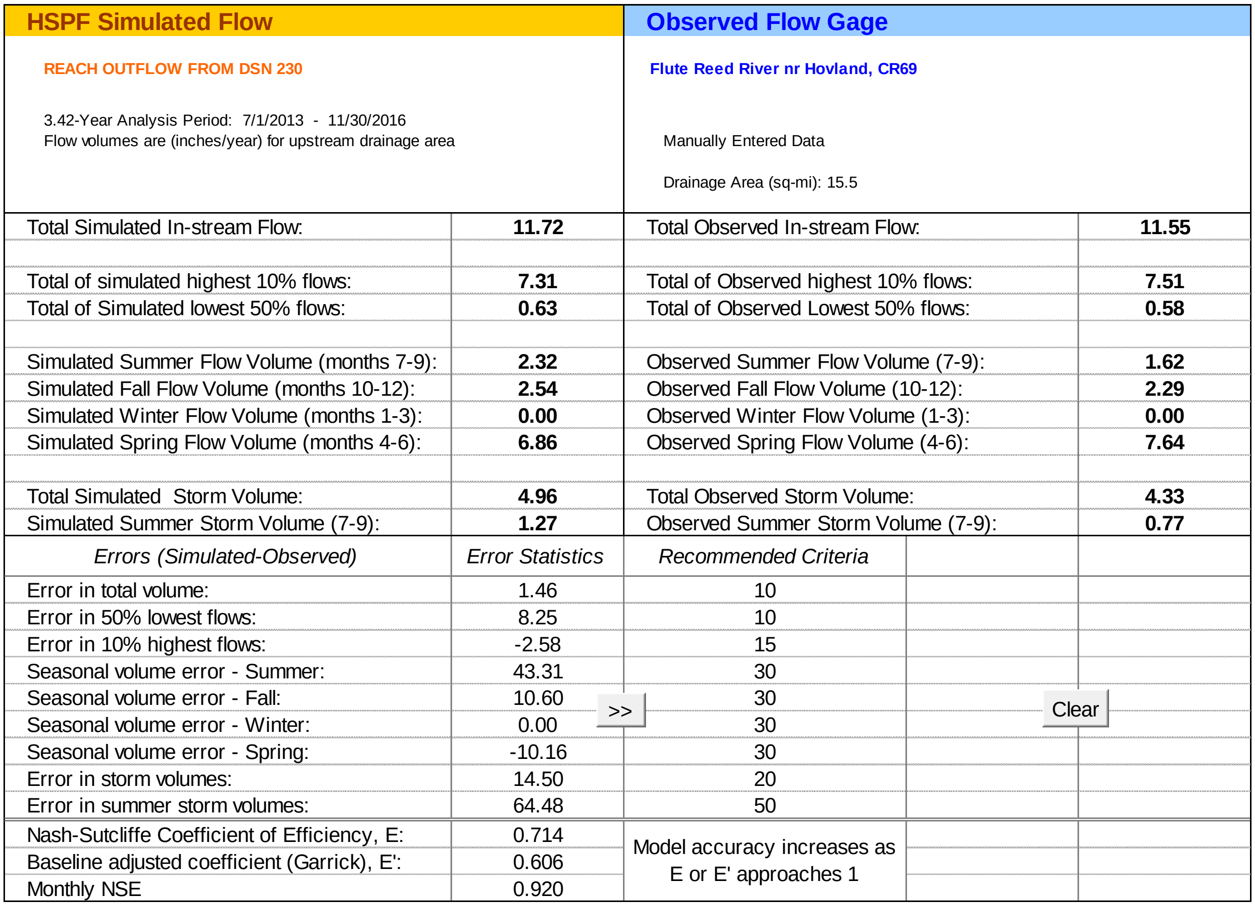


Figure 13. Flow accumulation at Flute Reed River at Hovland, CR69

Table 7. Summary statistics at Flute Reed River at Hovland, CR69



HSPF Simulated Flow		**Observed Flow Gage**	
REACH OUTFLOW FROM DSN 230 3.42-Year Analysis Period: 7/1/2013 - 11/30/2016 Flow volumes are (inches/year) for upstream drainage area		**Flute Reed River nr Hovland, CR69** Manually Entered Data Drainage Area (sq-mi): 15.5	
Total Simulated In-stream Flow:	**11.72**	Total Observed In-stream Flow:	**11.55**
Total of simulated highest 10% flows:	**7.31**	Total of Observed highest 10% flows:	**7.51**
Total of Simulated lowest 50% flows:	**0.63**	Total of Observed Lowest 50% flows:	**0.58**
Simulated Summer Flow Volume (months 7-9):	**2.32**	Observed Summer Flow Volume (7-9):	**1.62**
Simulated Fall Flow Volume (months 10-12):	**2.54**	Observed Fall Flow Volume (10-12):	**2.29**
Simulated Winter Flow Volume (months 1-3):	**0.00**	Observed Winter Flow Volume (1-3):	**0.00**
Simulated Spring Flow Volume (months 4-6):	**6.86**	Observed Spring Flow Volume (4-6):	**7.64**
Total Simulated Storm Volume:	**4.96**	Total Observed Storm Volume:	**4.33**
Simulated Summer Storm Volume (7-9):	**1.27**	Observed Summer Storm Volume (7-9):	**0.77**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	1.46	10		
Error in 50% lowest flows:	8.25	10		
Error in 10% highest flows:	-2.58	15		
Seasonal volume error - Summer:	43.31	30		
Seasonal volume error - Fall:	10.60	>> 30		Clear
Seasonal volume error - Winter:	0.00	30		
Seasonal volume error - Spring:	-10.16	30		
Error in storm volumes:	14.50	20		
Error in summer storm volumes:	64.48	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.714	Model accuracy increases as E or E' approaches 1		
Baseline adjusted coefficient (Garrick), E':	0.606			
Monthly NSE	0.920			

Appendix B -Water Quality Calibration

FLUTE REED RIVER AT CAMP 20 RD, ¾ MI NW OF HOVLAND (S004-277)

Total Suspended Solids (TSS)

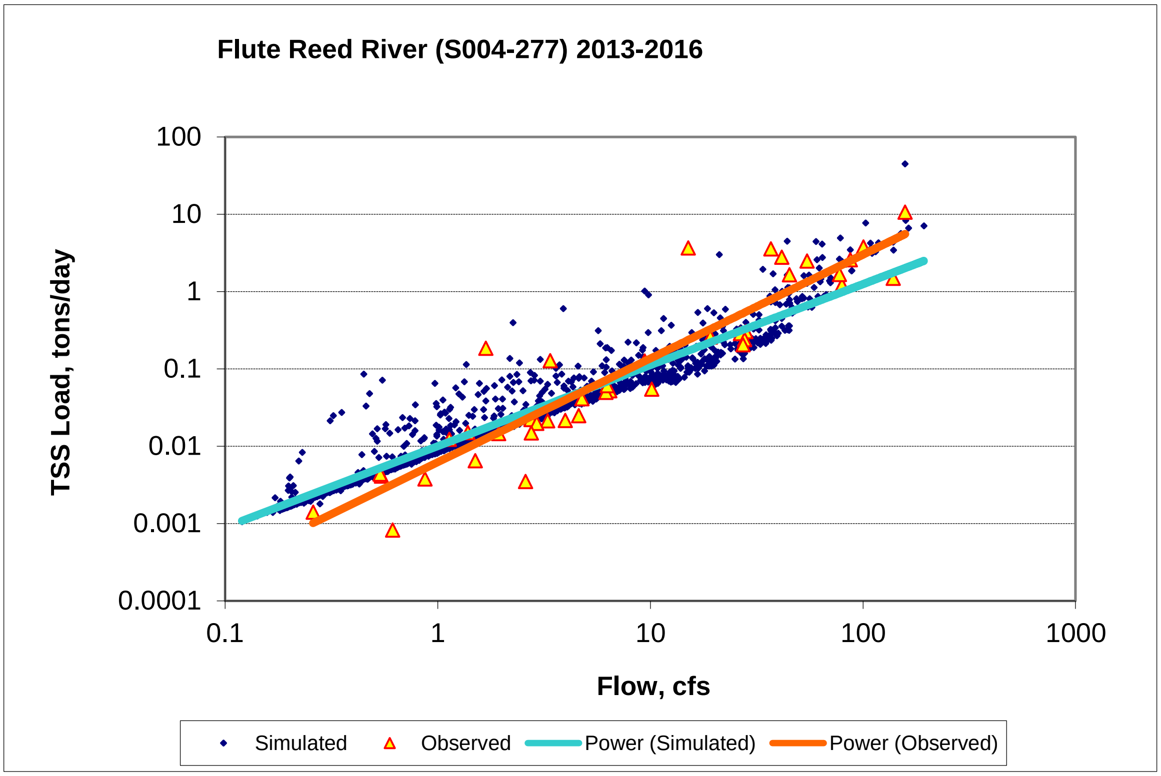


Figure 14. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow

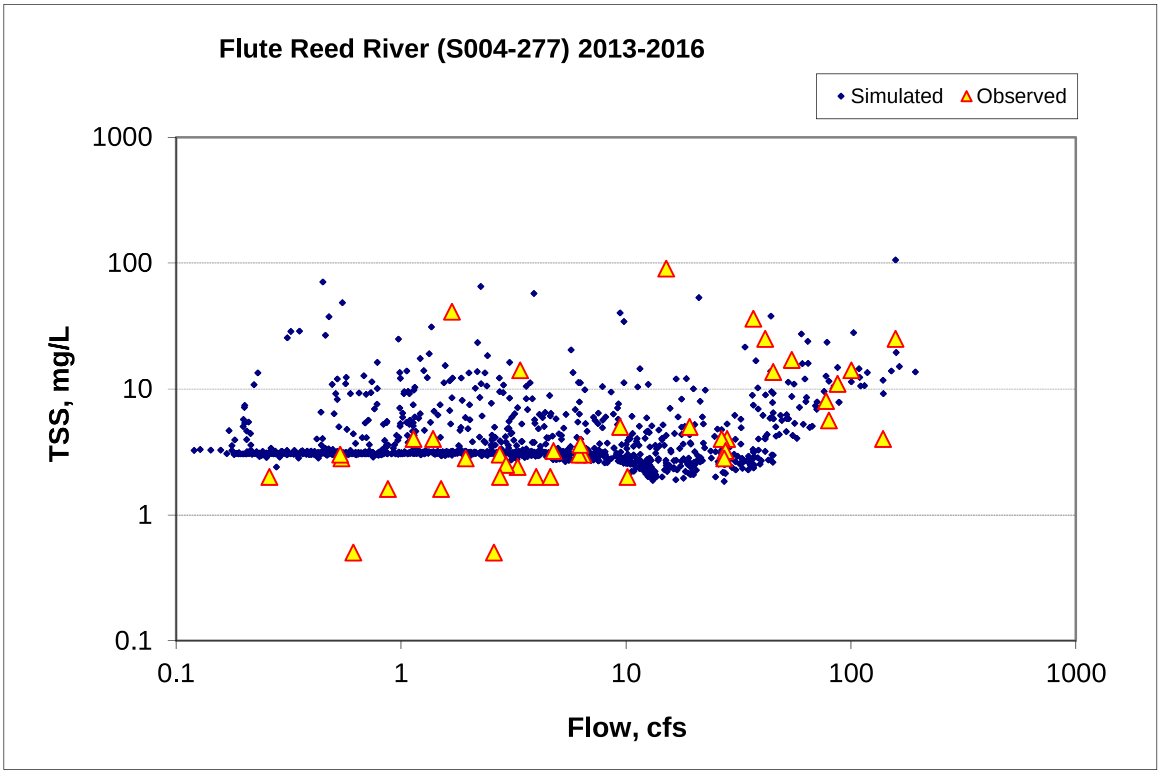


Figure 15. Simulated and observed Total Suspended Solids (TSS) concentration vs flow

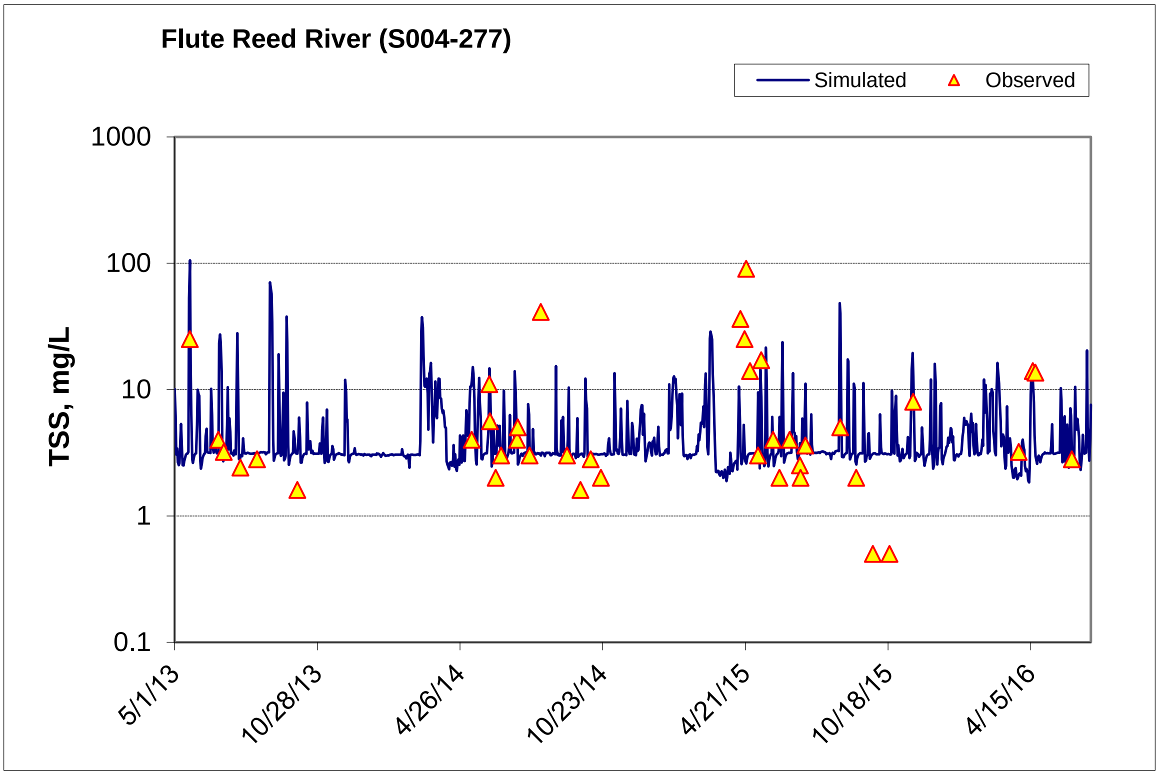


Figure 16. Time series of observed and simulated Total Suspended Solids (TSS) concentration

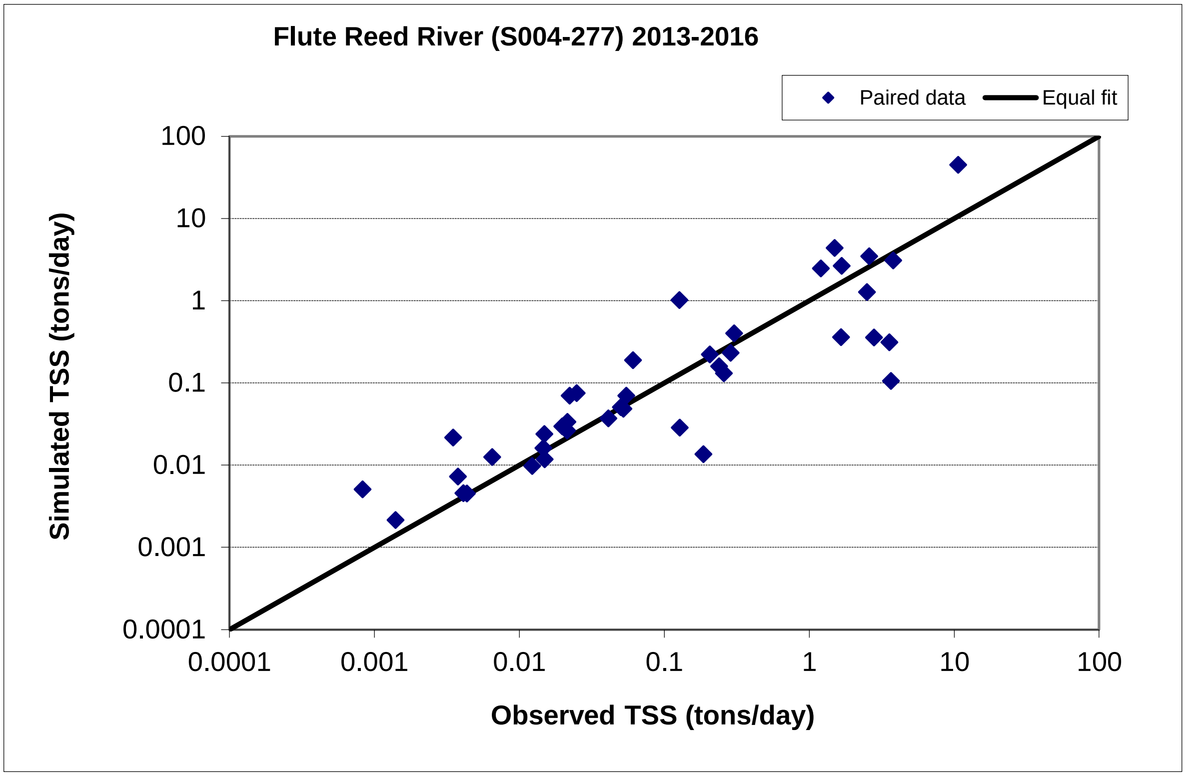


Figure 17. Paired simulated vs. observed Total Suspended Solids (TSS) load

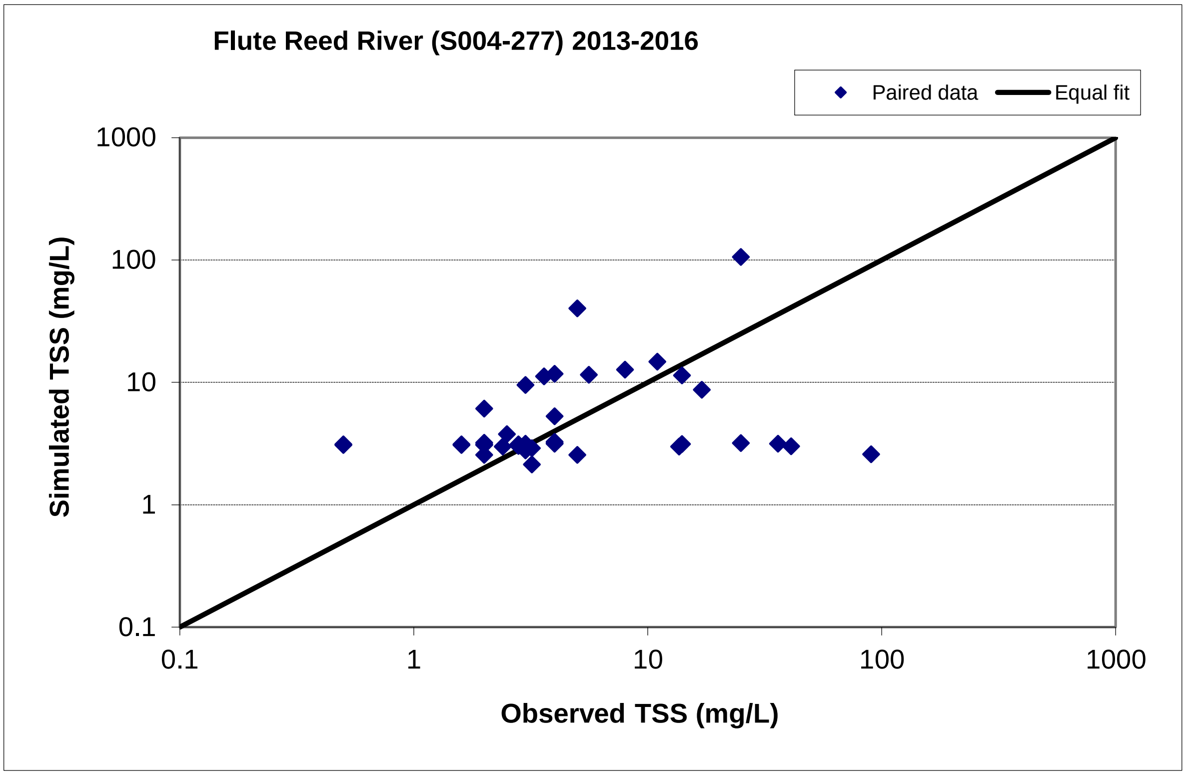


Figure 18. Paired simulated vs. observed Total Suspended Solids (TSS) concentration

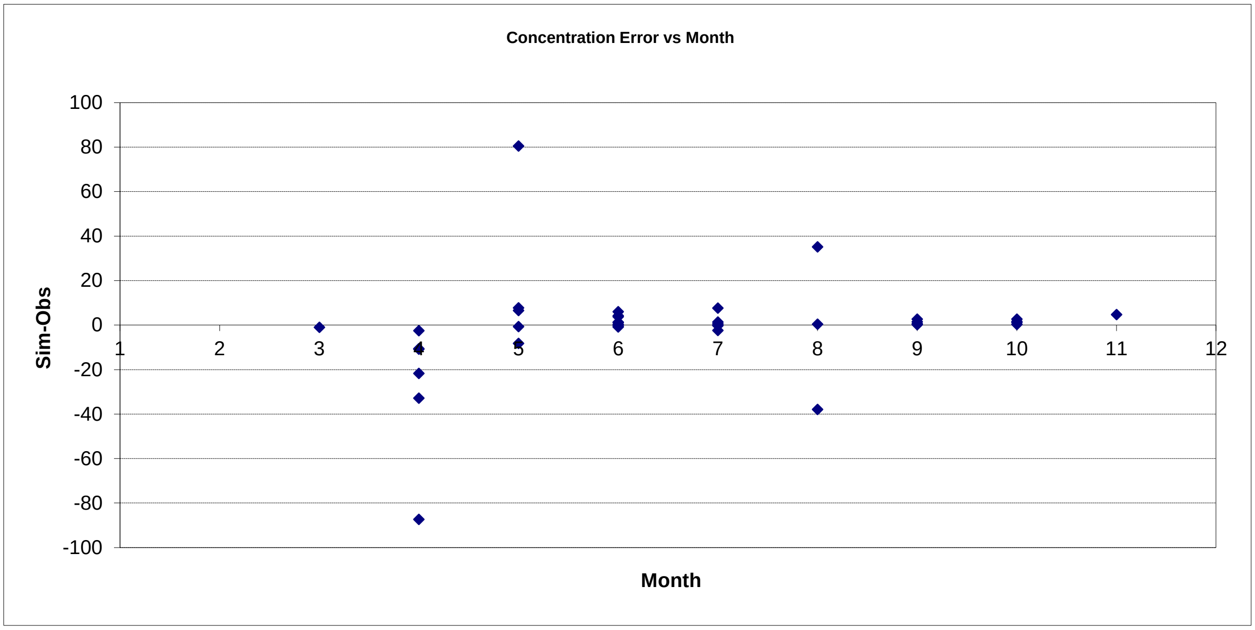


Figure 19. Residual (Simulated - Observed) vs. Month Total Suspended Solids (TSS)

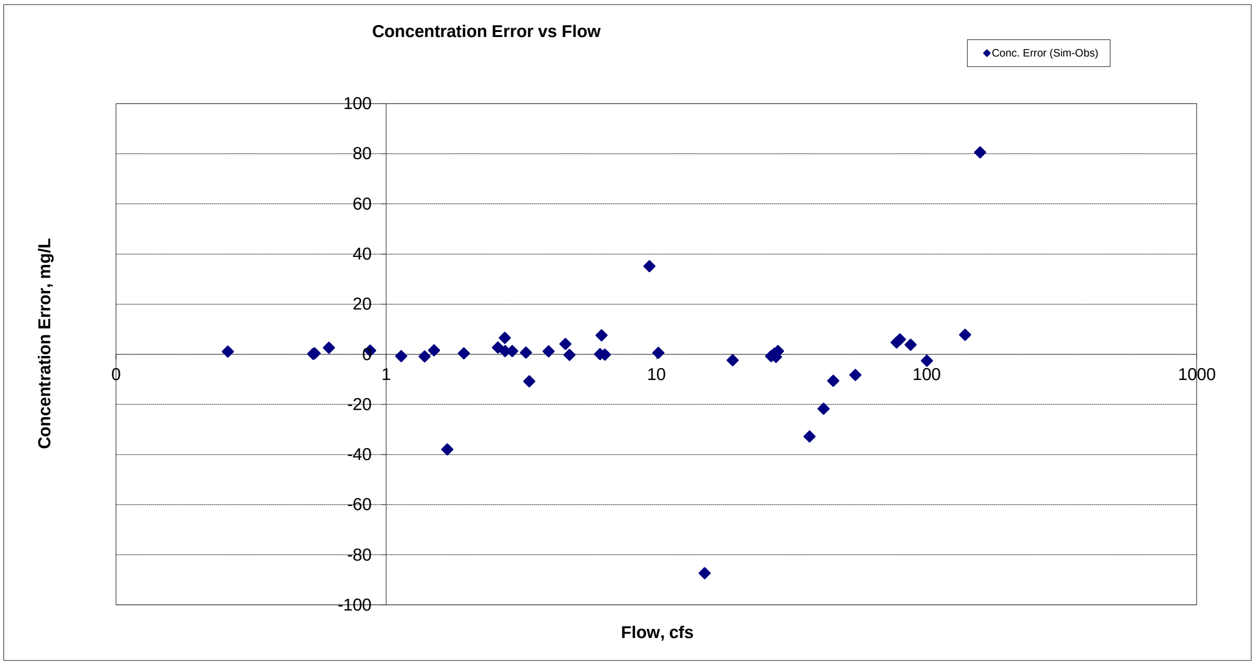


Figure 20. Residual (Simulated - Observed) vs. Flow Total Suspended Solids (TSS)

Total Phosphorus (TP)

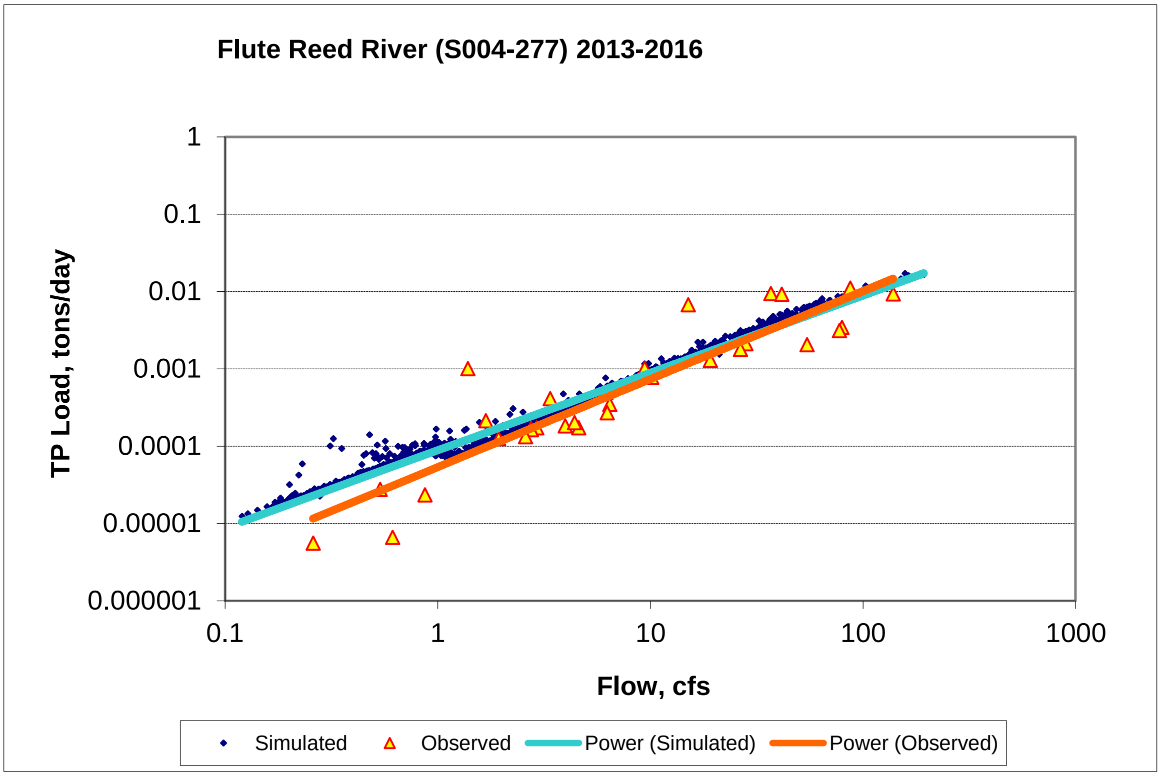


Figure 21. Power plot of simulated and observed Total Phosphorus (TP) load vs flow

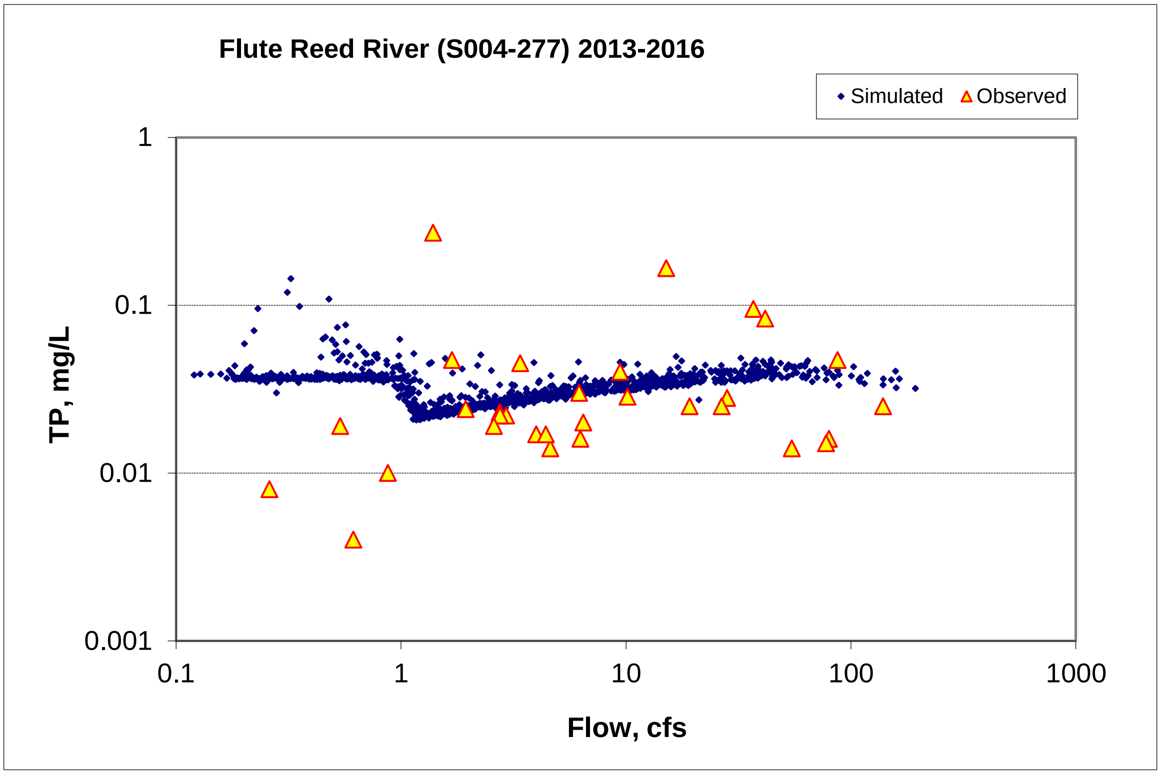


Figure 22. Simulated and observed Total Phosphorus (TP) concentration vs flow

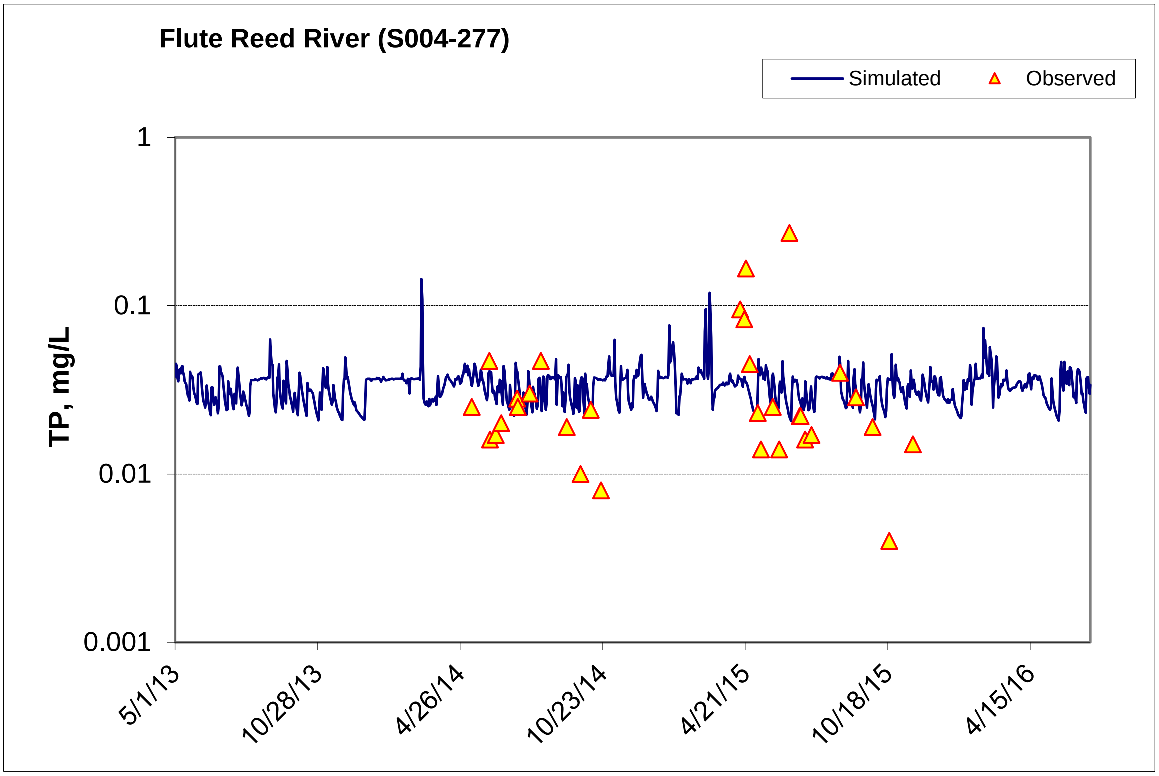


Figure 23. Time series of observed and simulated Total Phosphorus (TP) concentration

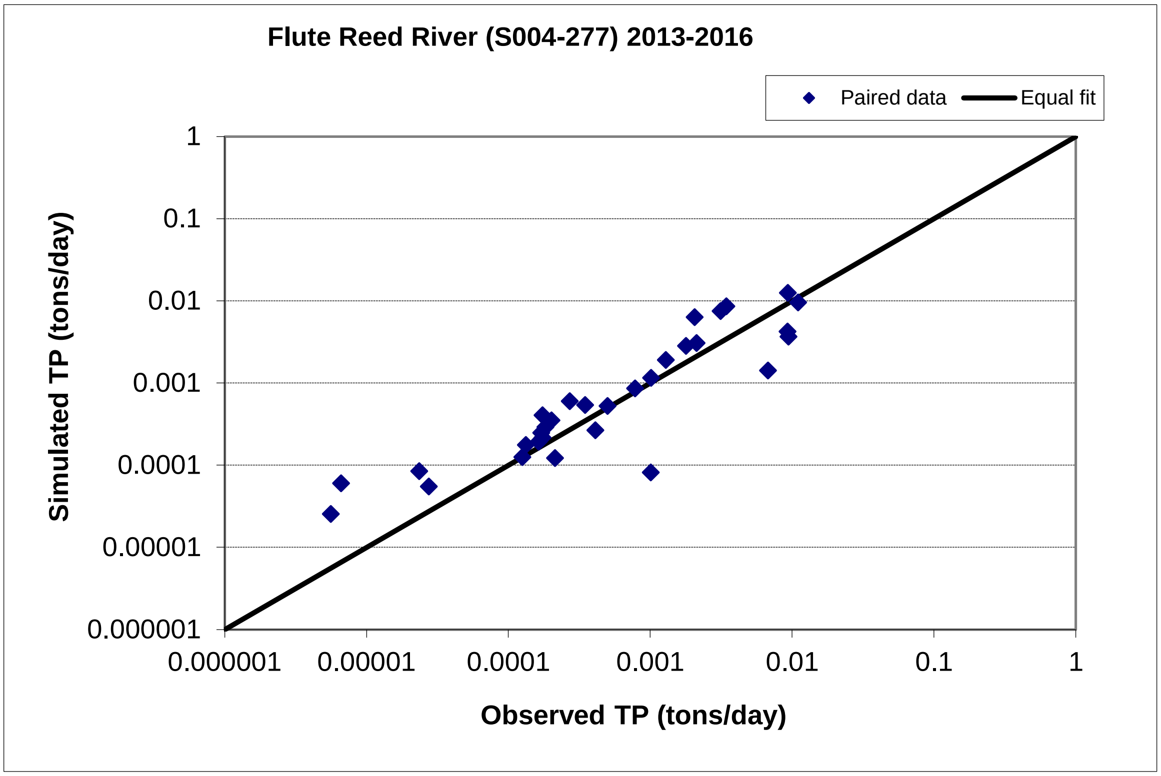


Figure 24. Paired simulated vs. observed Total Phosphorus (TP) load

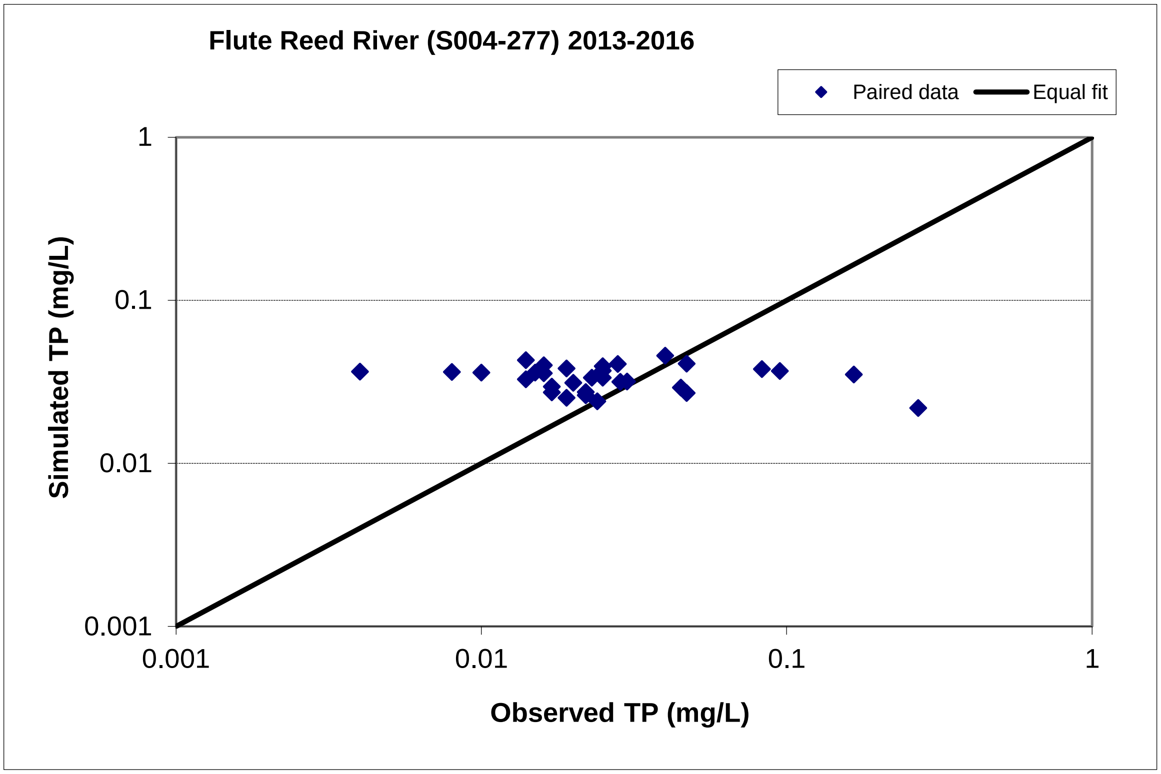


Figure 25. Paired simulated vs. observed Total Phosphorus (TP) concentration

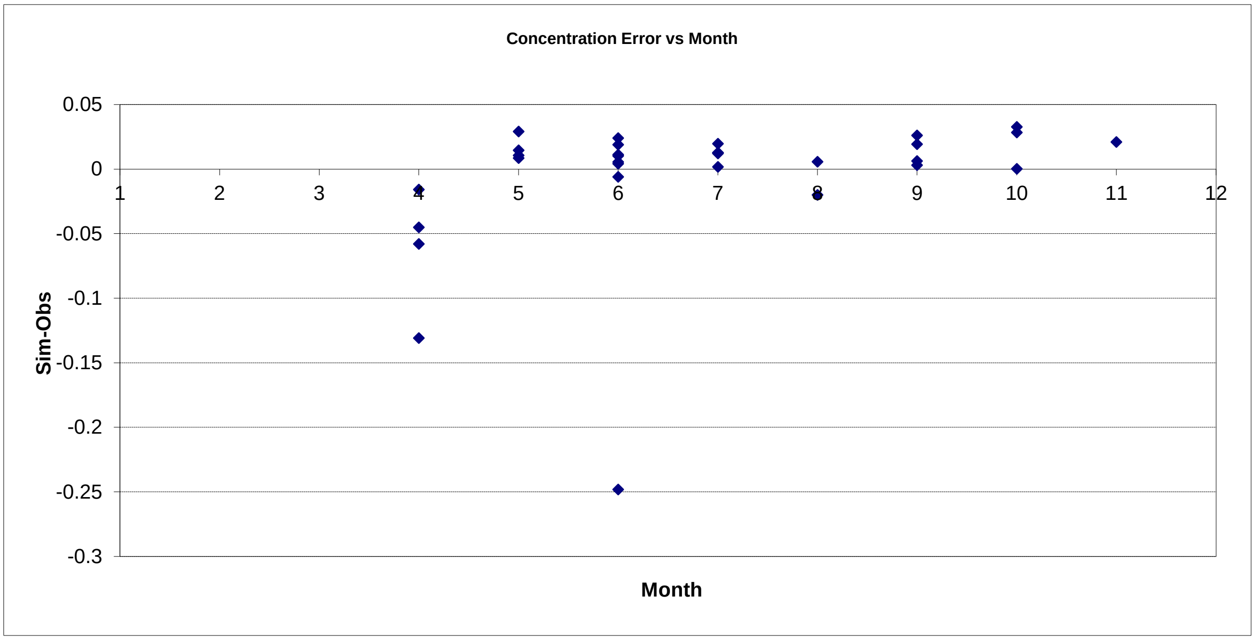


Figure 26. Residual (Simulated - Observed) vs. Month Total Phosphorus (TP)

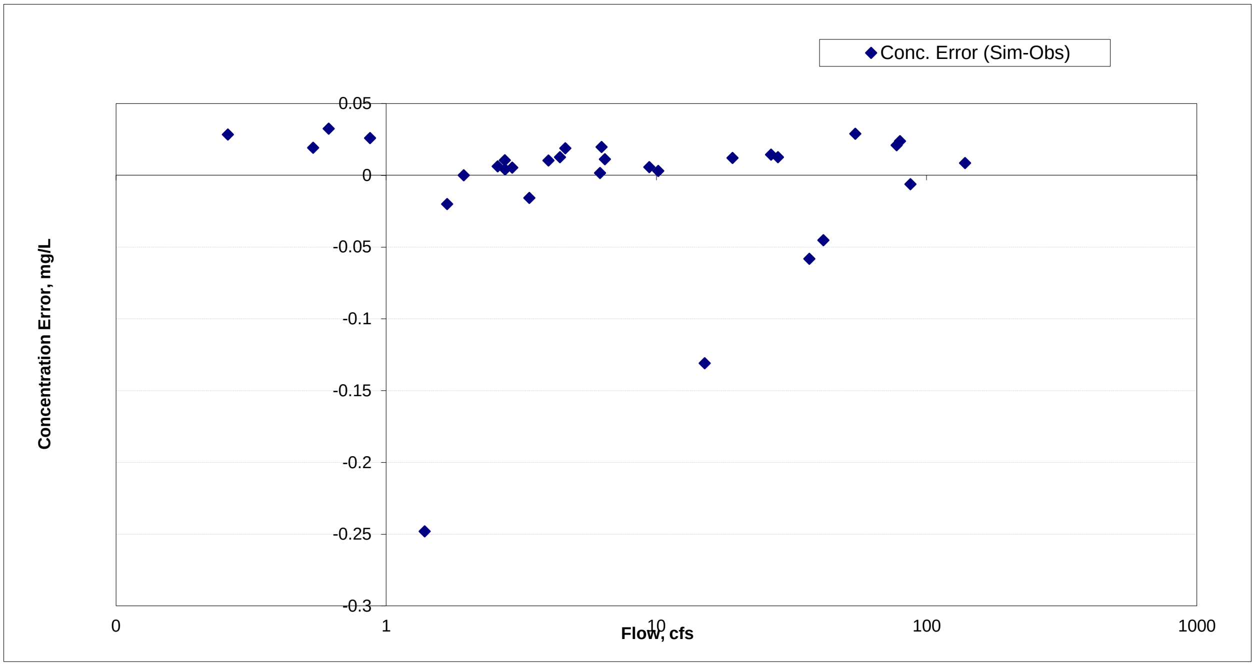


Figure 27. Residual (Simulated - Observed) vs. Flow Total Phosphorus (TP)

FLUTE REED RIVER AT CAMP 20 RD, 2.5 MI NW OF HOVLAND (S004-235)

Total Suspended Solids (TSS)

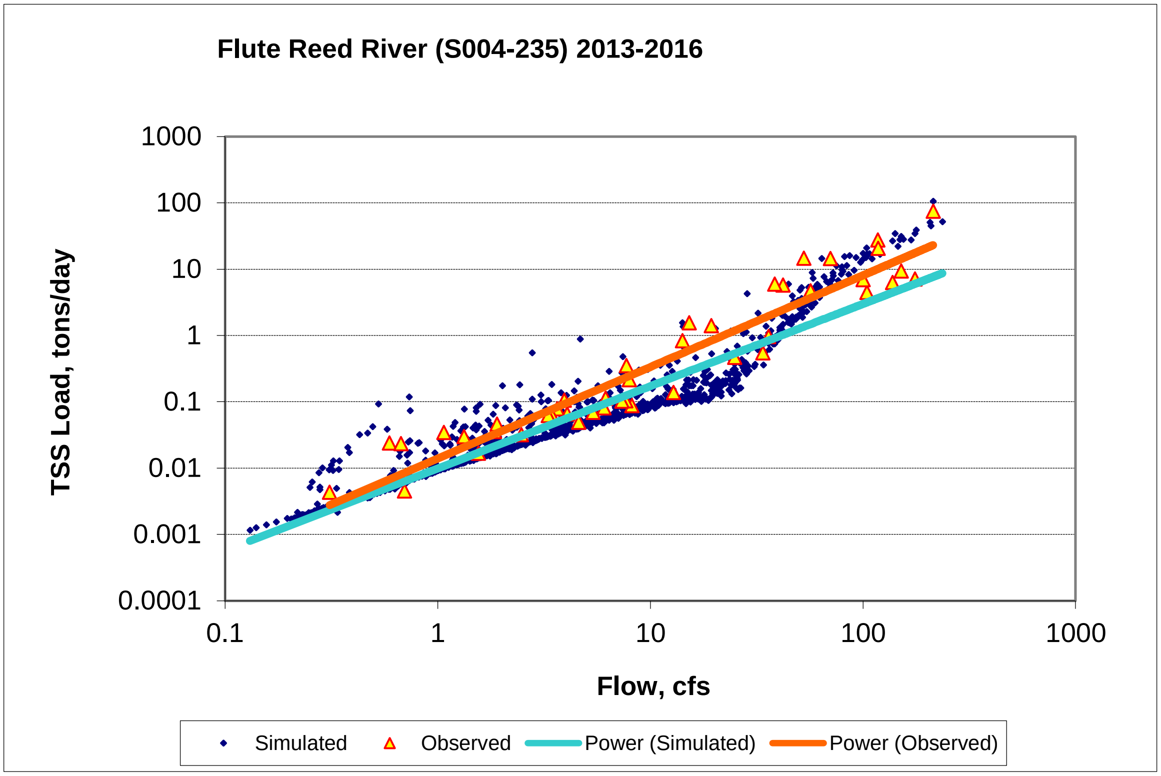


Figure 28. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow

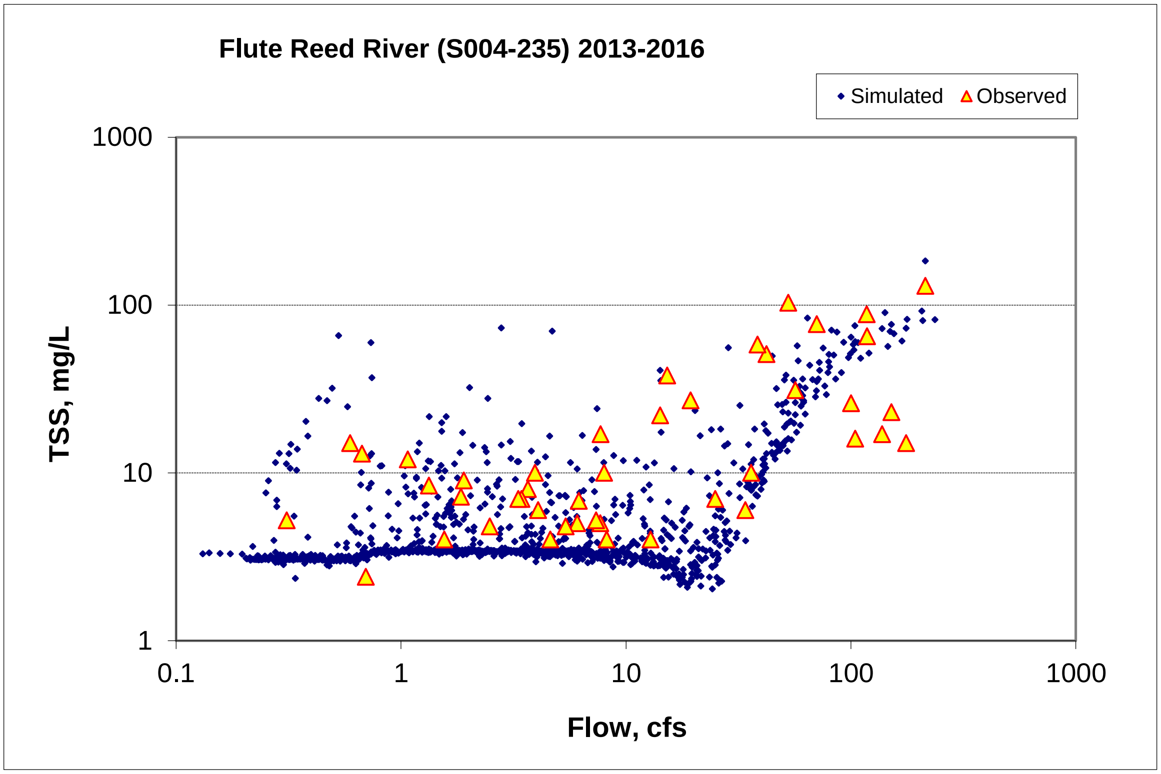


Figure 29. Simulated and observed Total Suspended Solids (TSS) concentration vs flow

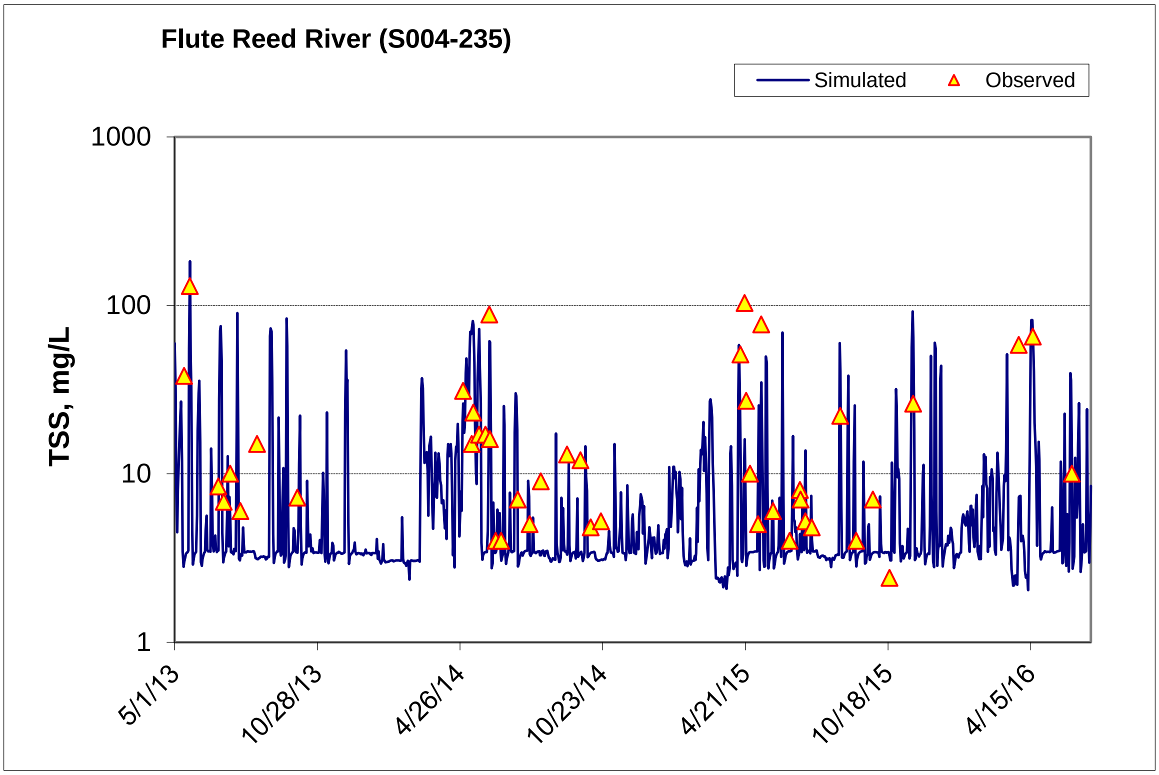


Figure 30. Time series of observed and simulated Total Suspended Solids (TSS) concentration

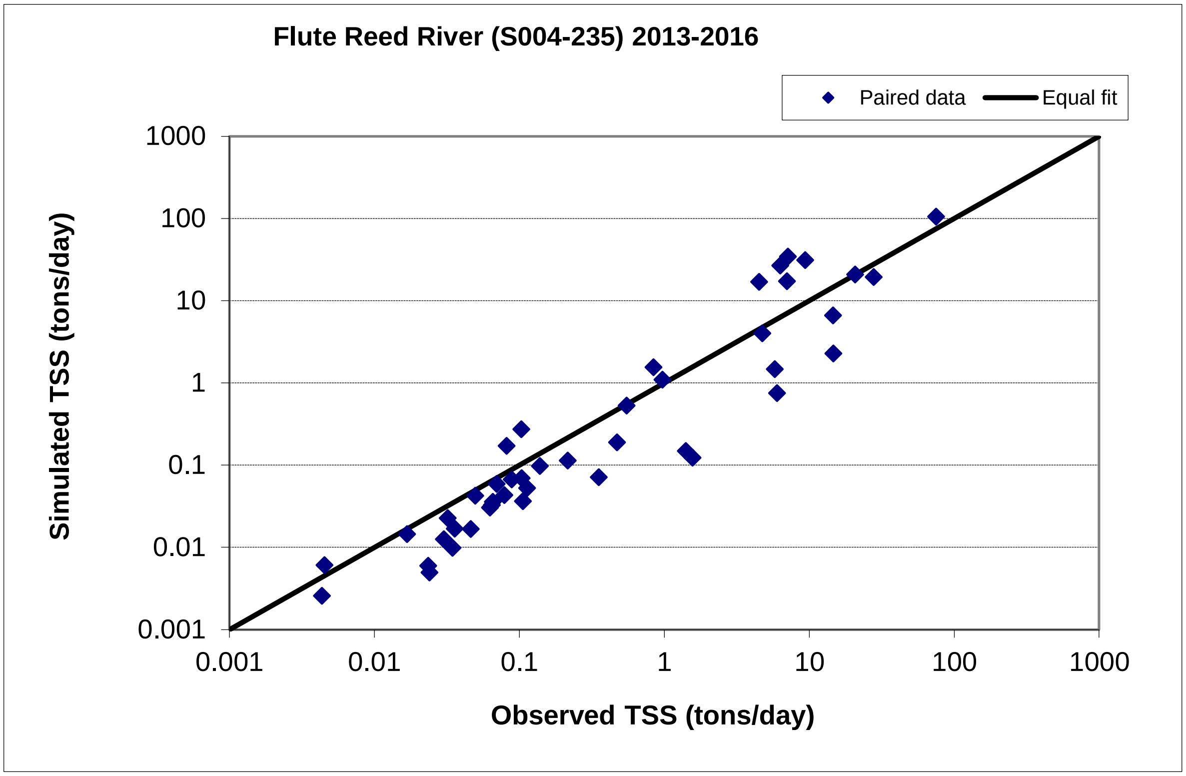


Figure 31. Paired simulated vs. observed Total Suspended Solids (TSS) load

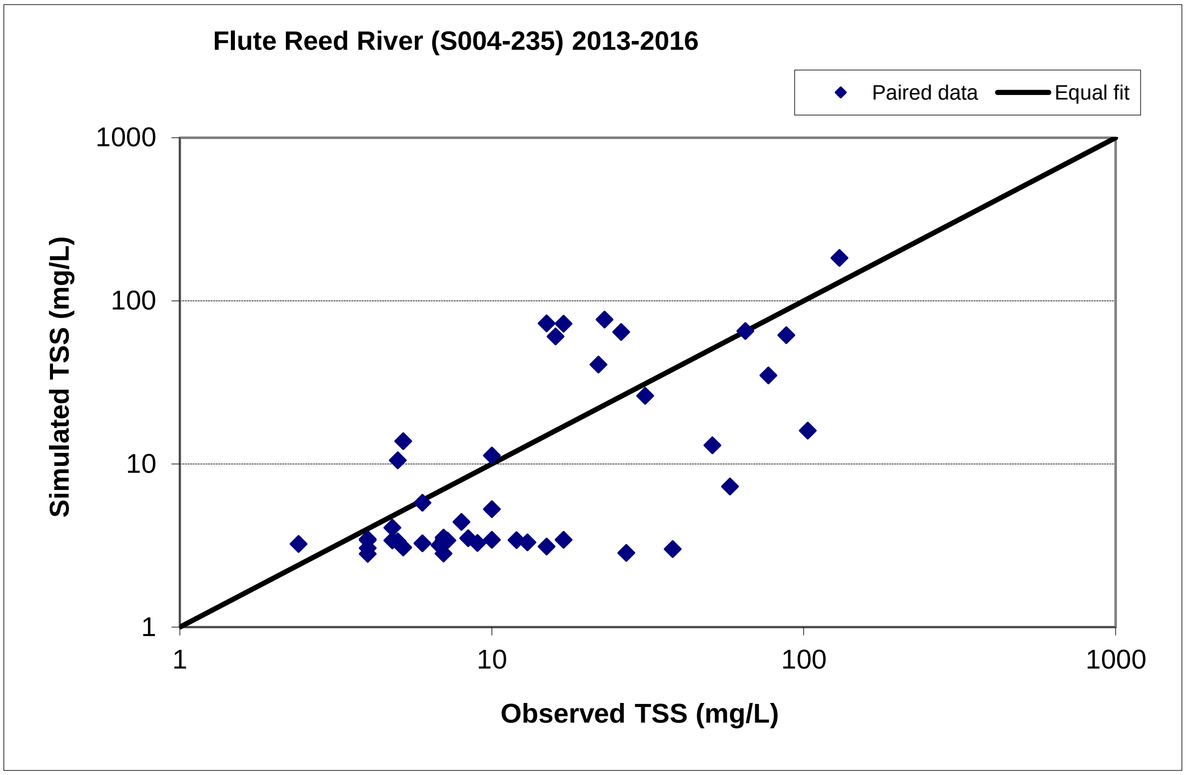


Figure 32. Paired simulated vs. observed Total Suspended Solids (TSS) concentration

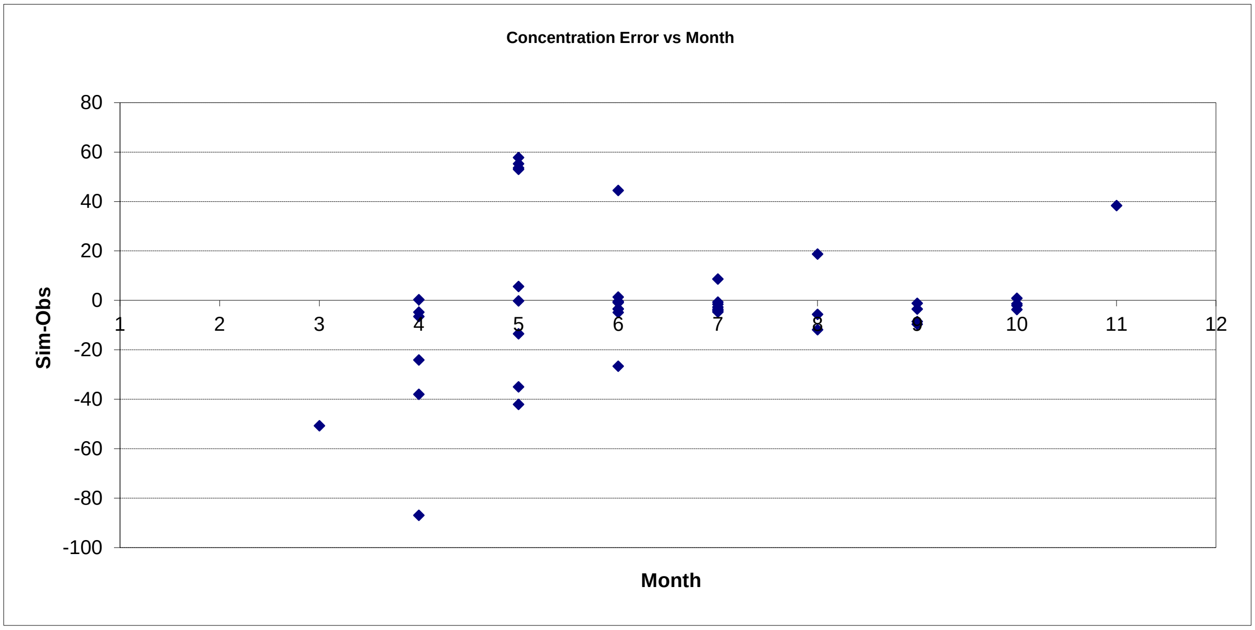


Figure 33. Residual (Simulated - Observed) vs. Month Total Suspended Solids (TSS)

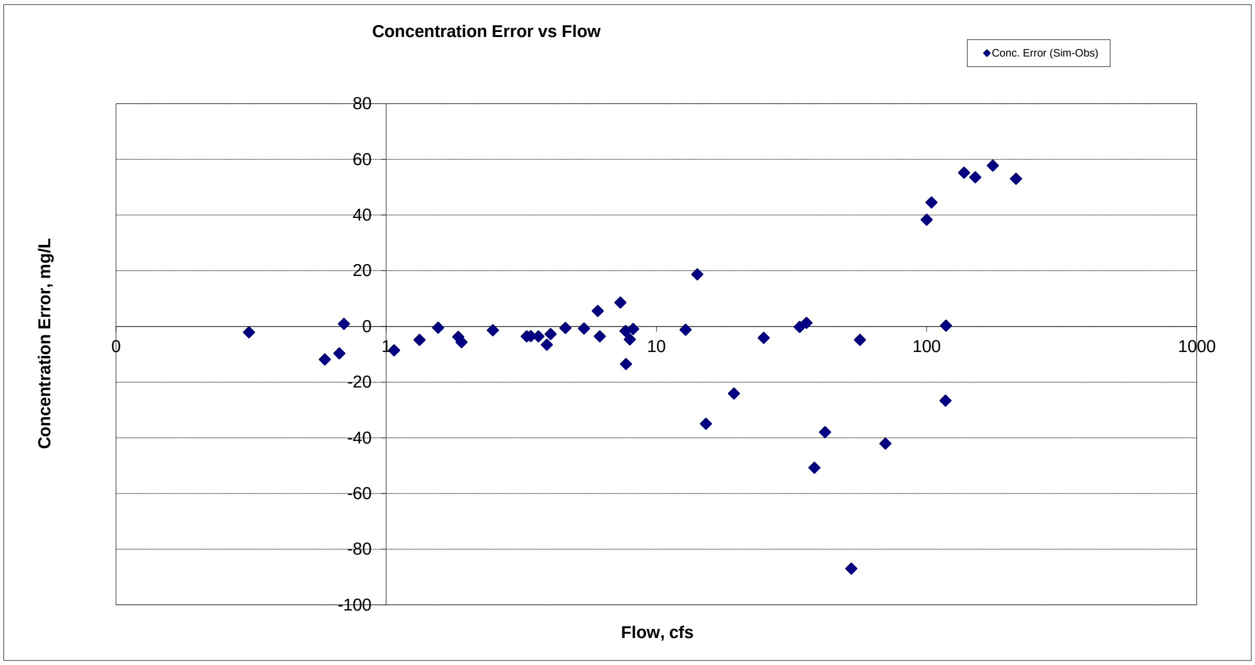


Figure 34. Residual (Simulated - Observed) vs. Flow Total Suspended Solids (TSS)

Total Phosphorus (TP)

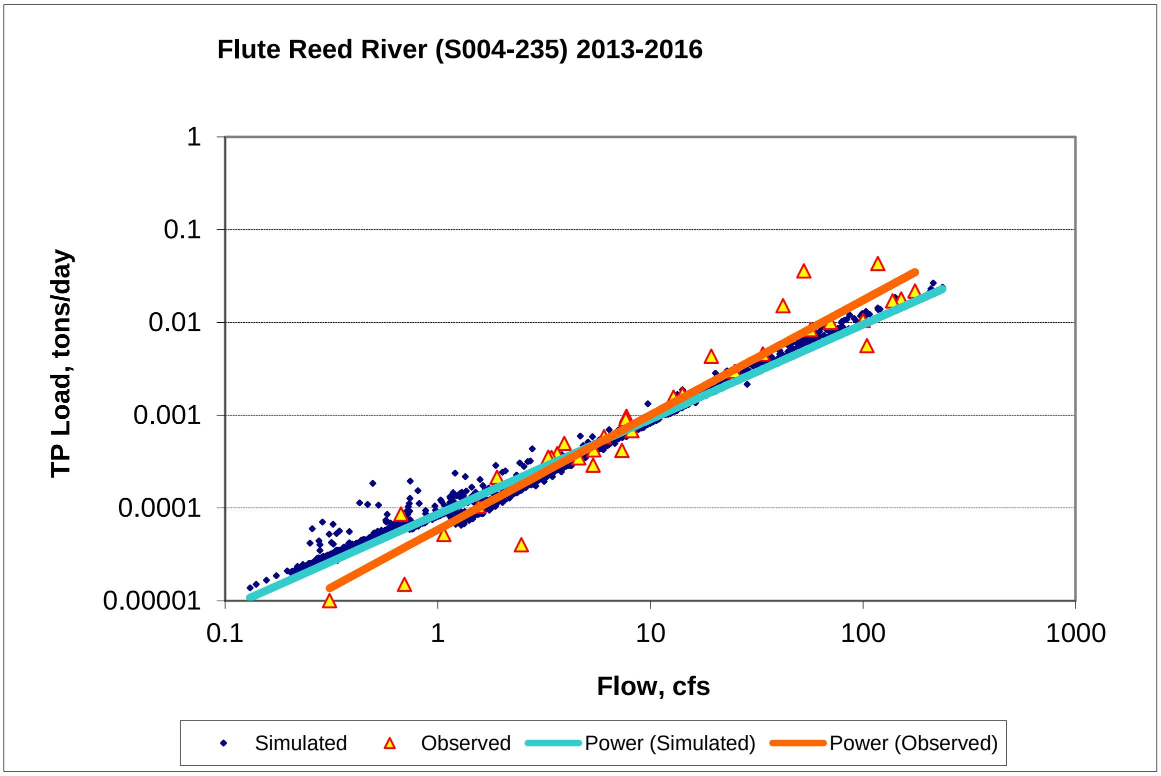


Figure 35. Power plot of simulated and observed Total Phosphorus (TP) load vs flow

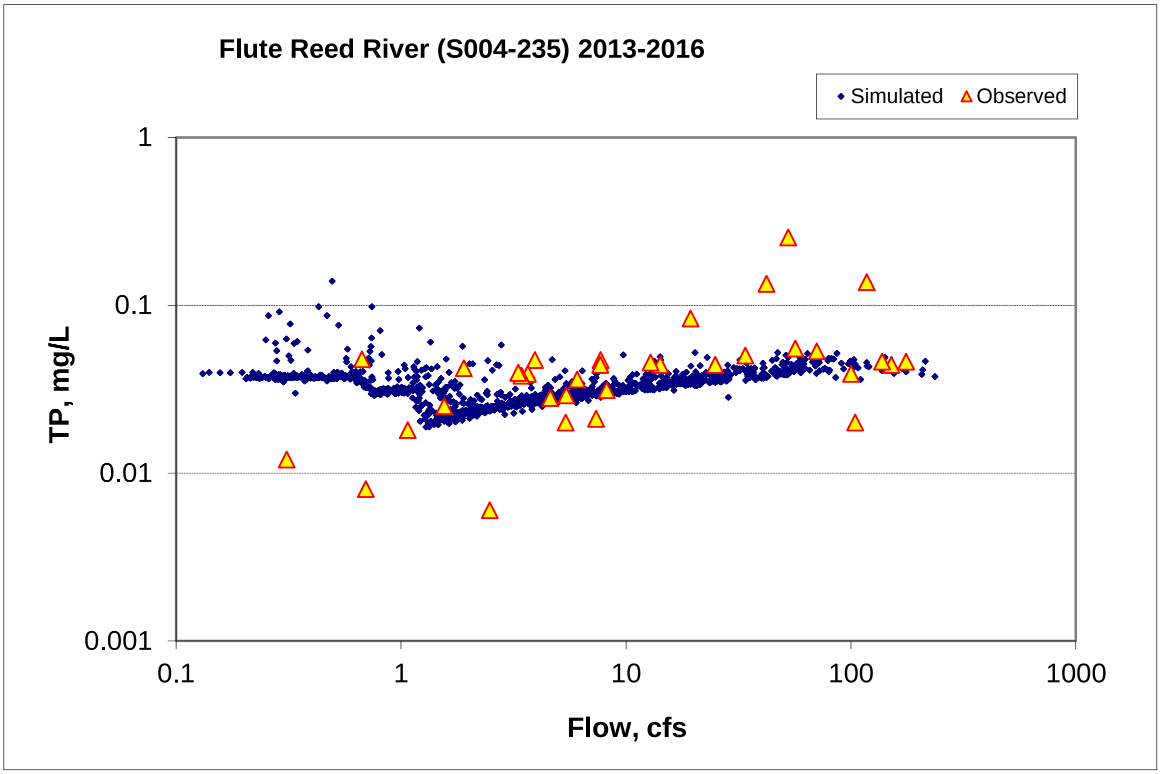


Figure 36. Simulated and observed Total Phosphorus (TP) concentration vs flow

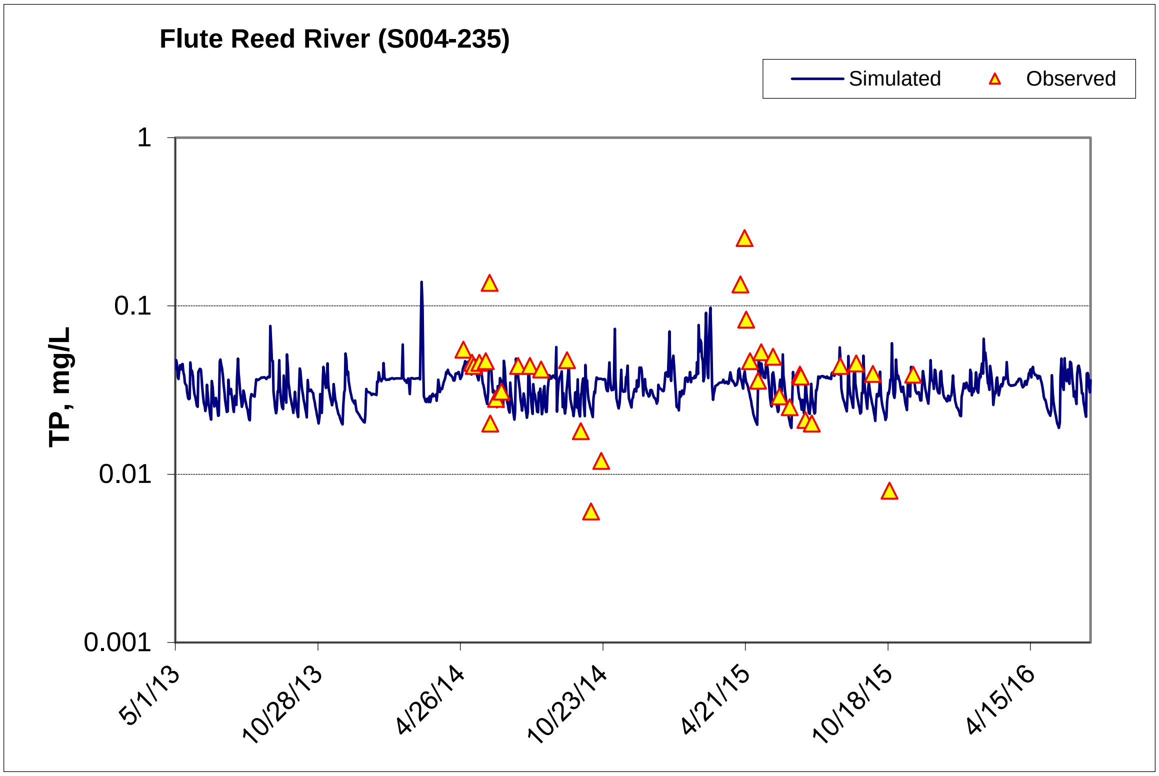


Figure 37. Time series of observed and simulated Total Phosphorus (TP) concentration

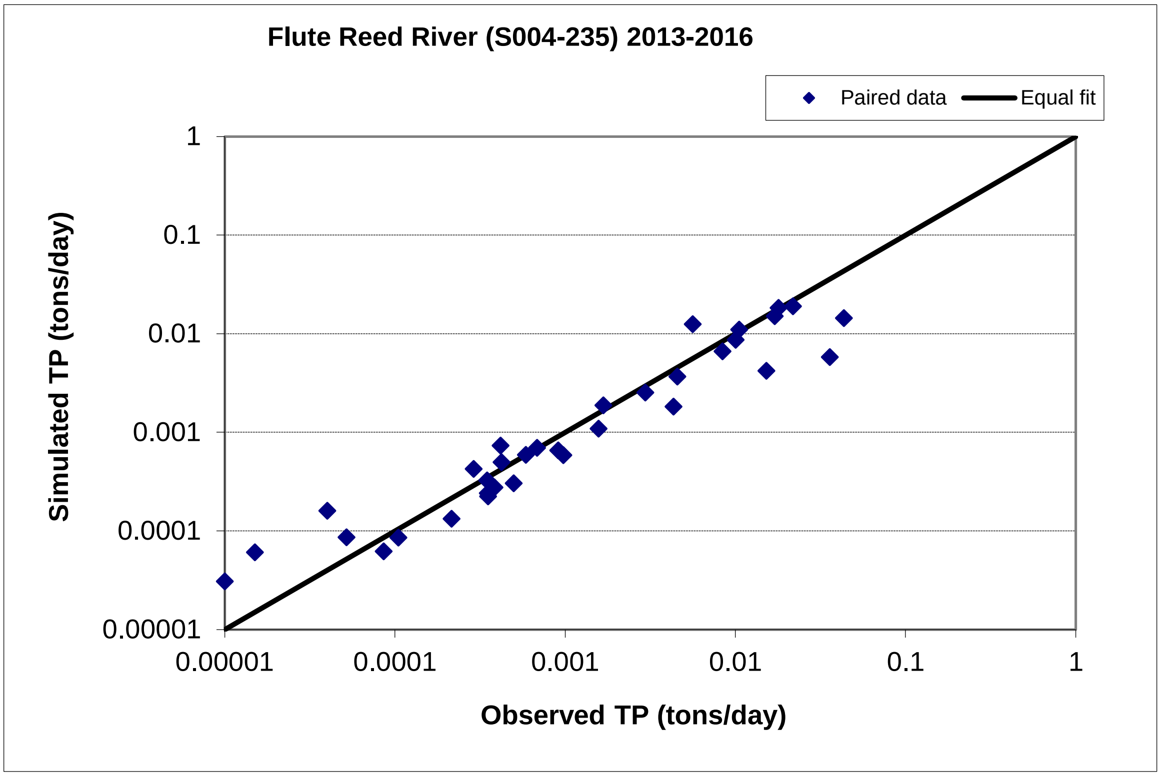


Figure 38. Paired simulated vs. observed Total Phosphorus (TP) load

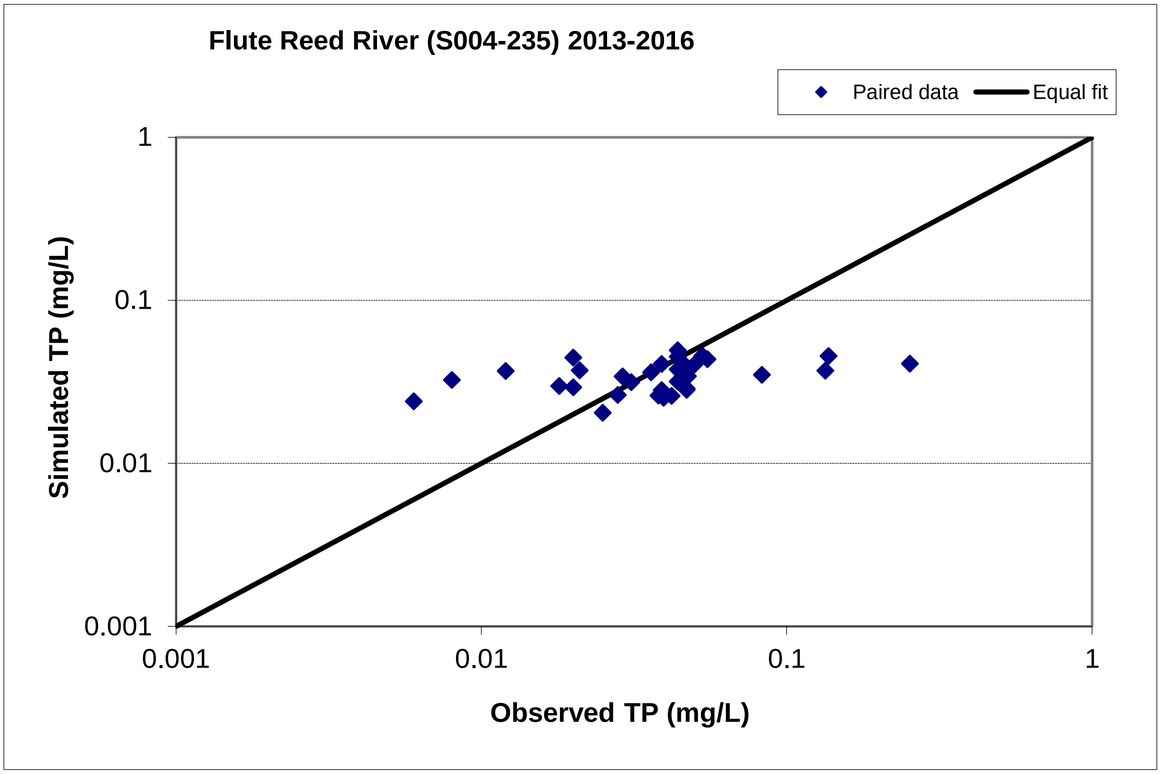


Figure 39. Paired simulated vs. observed Total Phosphorus (TP) concentration

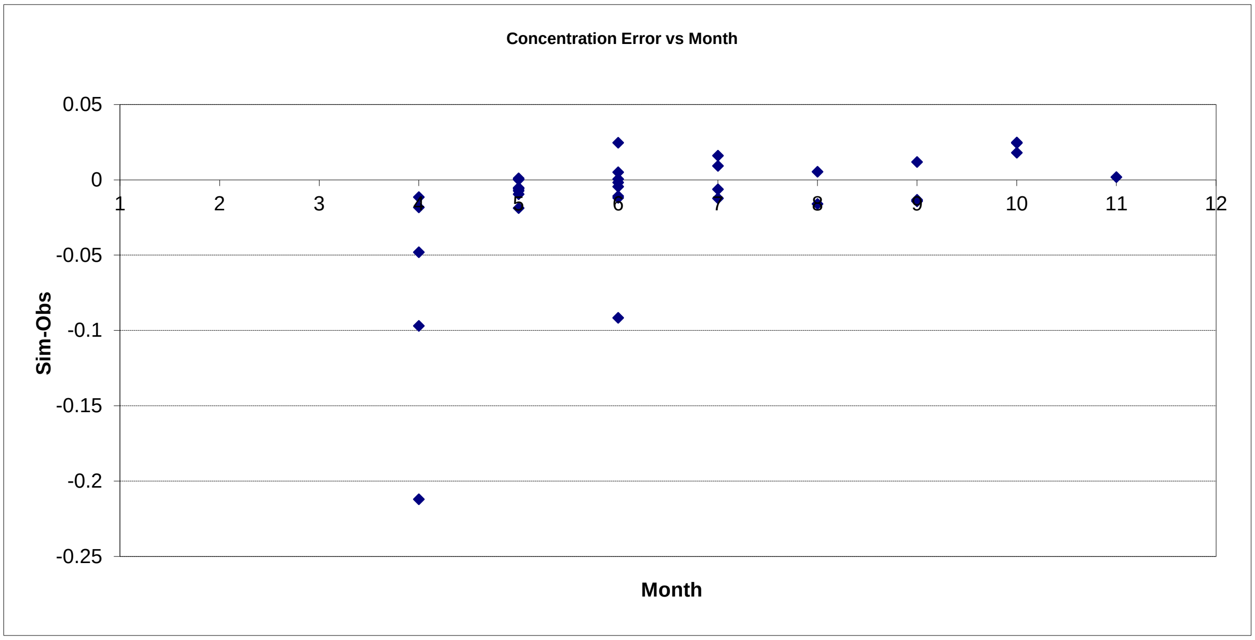


Figure 40. Residual (Simulated - Observed) vs. Month Total Phosphorus (TP)

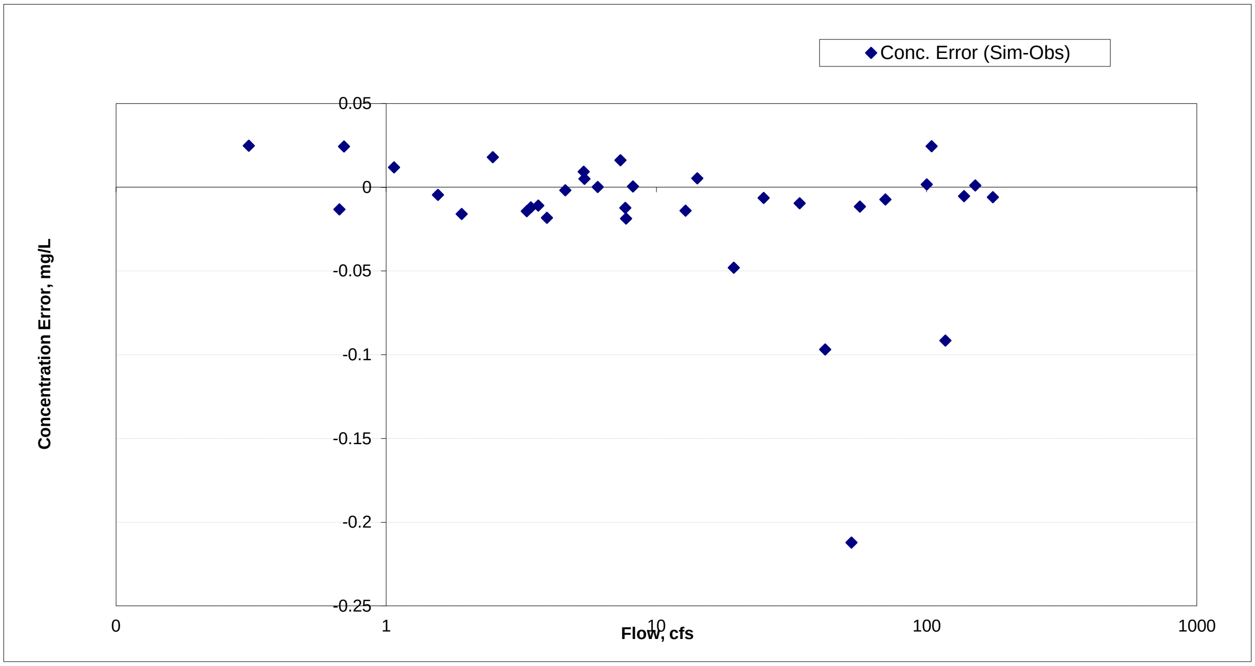


Figure 41. Residual (Simulated - Observed) vs. Flow Total Phosphorus (TP)

FLUTE REED RIVER AT CR-69, .2 MI NW OF HOVLAND (S007-557)

Total Suspended Solids (TSS)

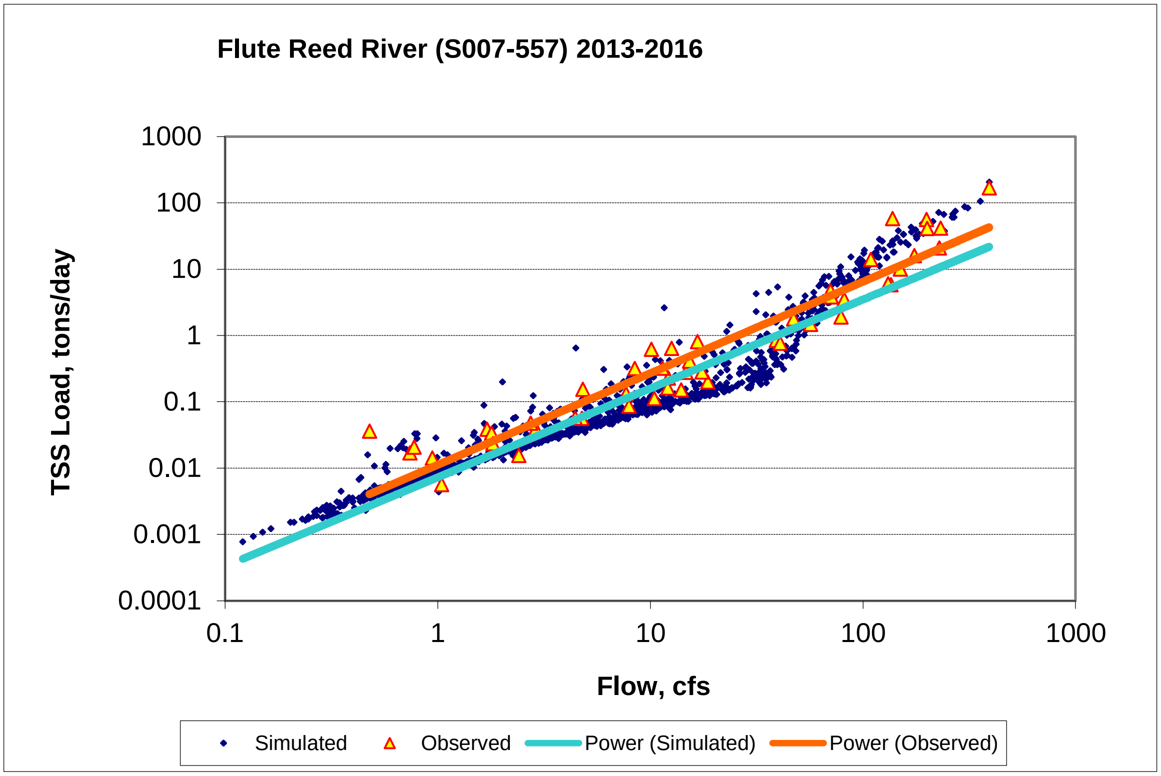


Figure 42. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow

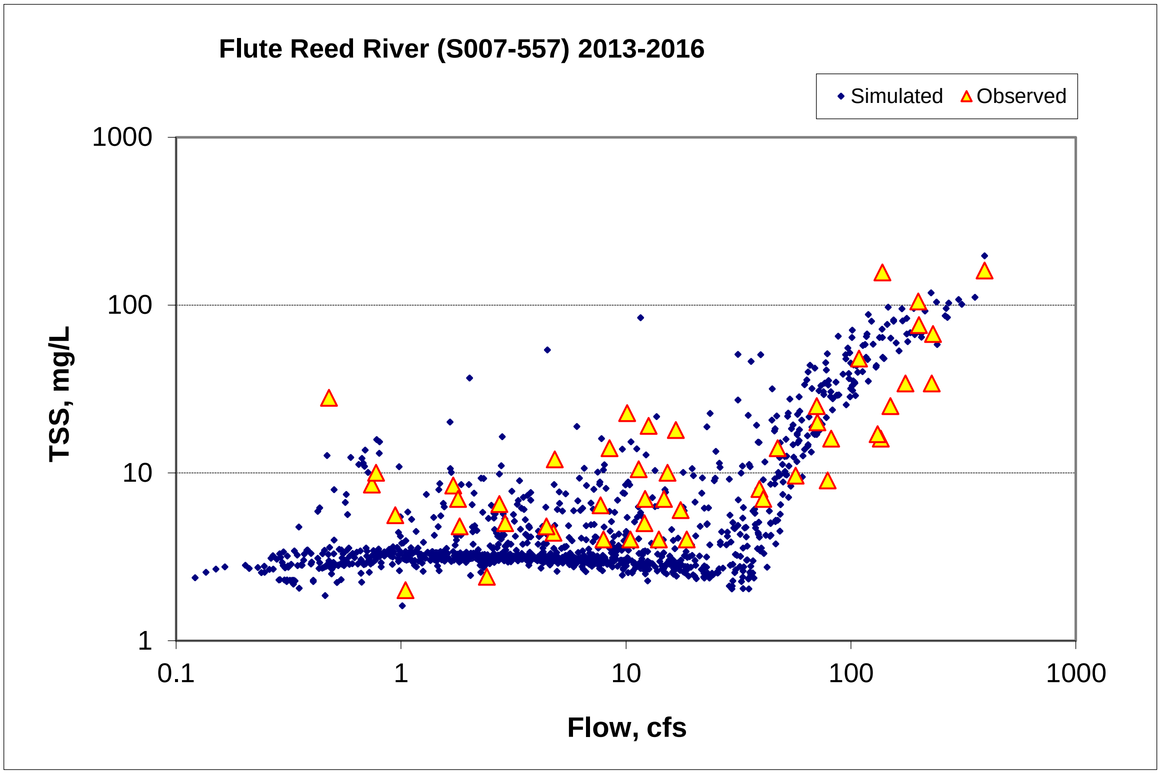


Figure 43. Simulated and observed Total Suspended Solids (TSS) concentration vs flow

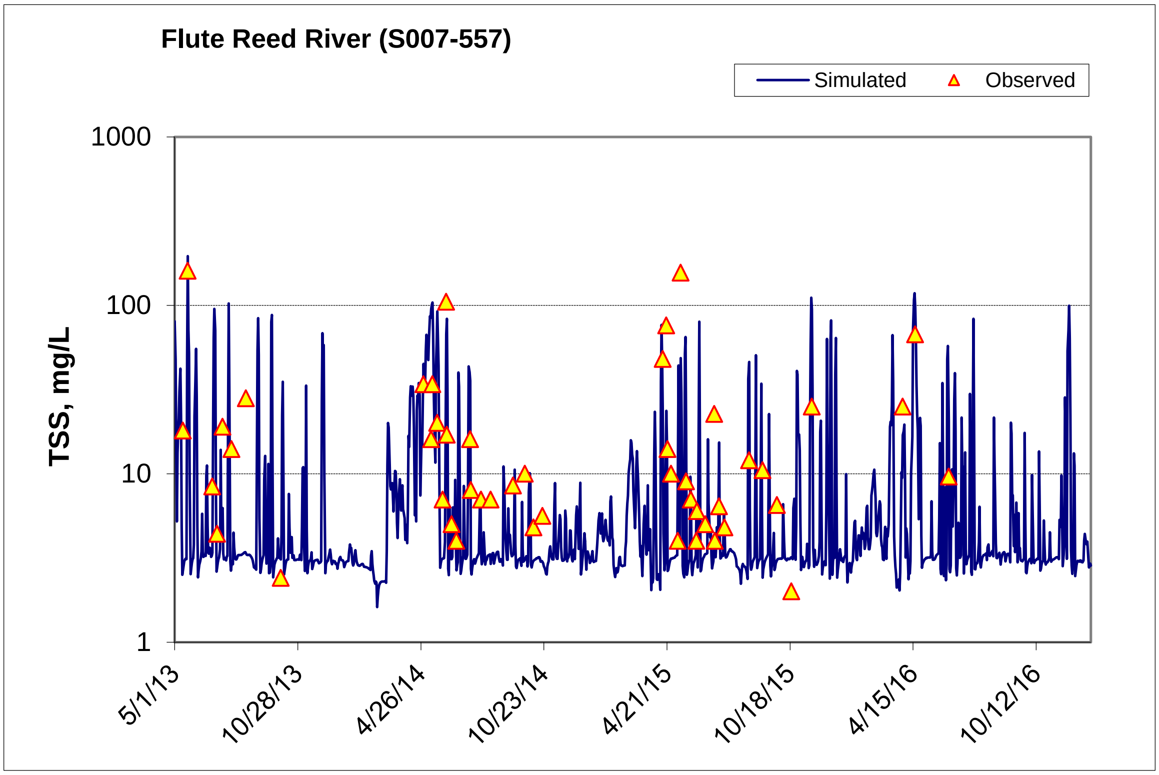


Figure 44. Time series of observed and simulated Total Suspended Solids (TSS) concentration

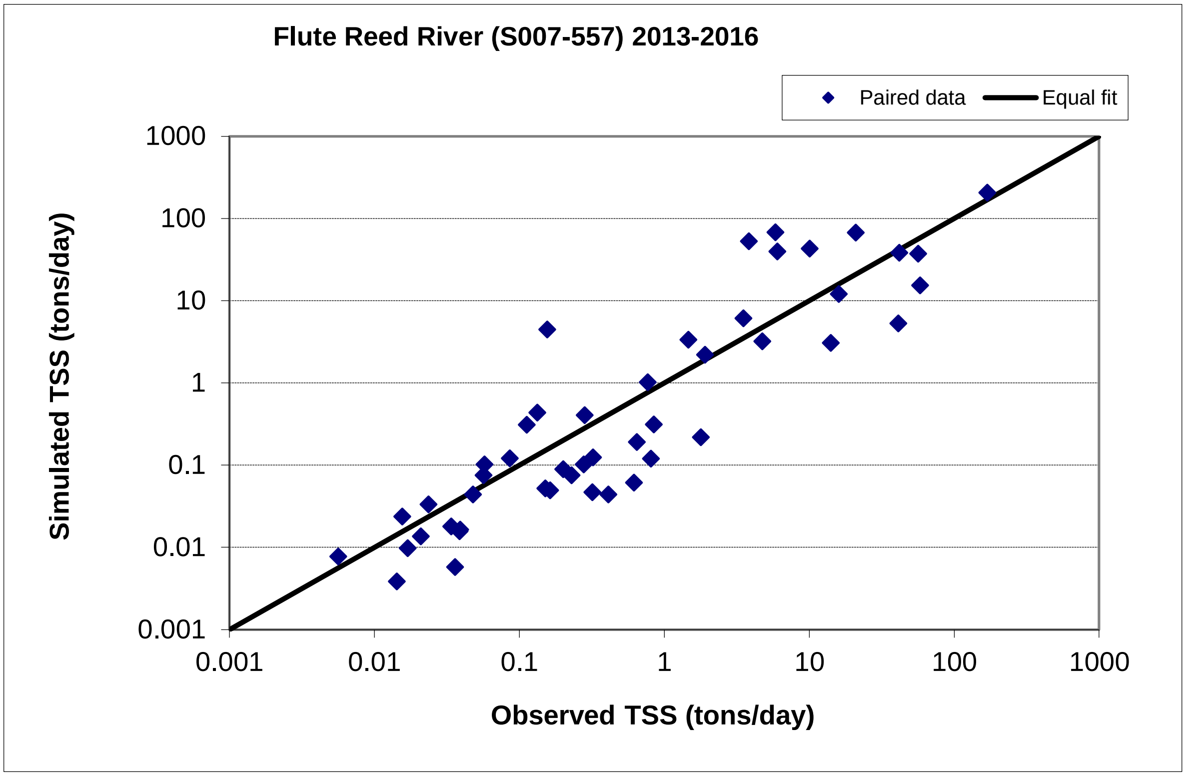


Figure 45. Paired simulated vs. observed Total Suspended Solids (TSS) load

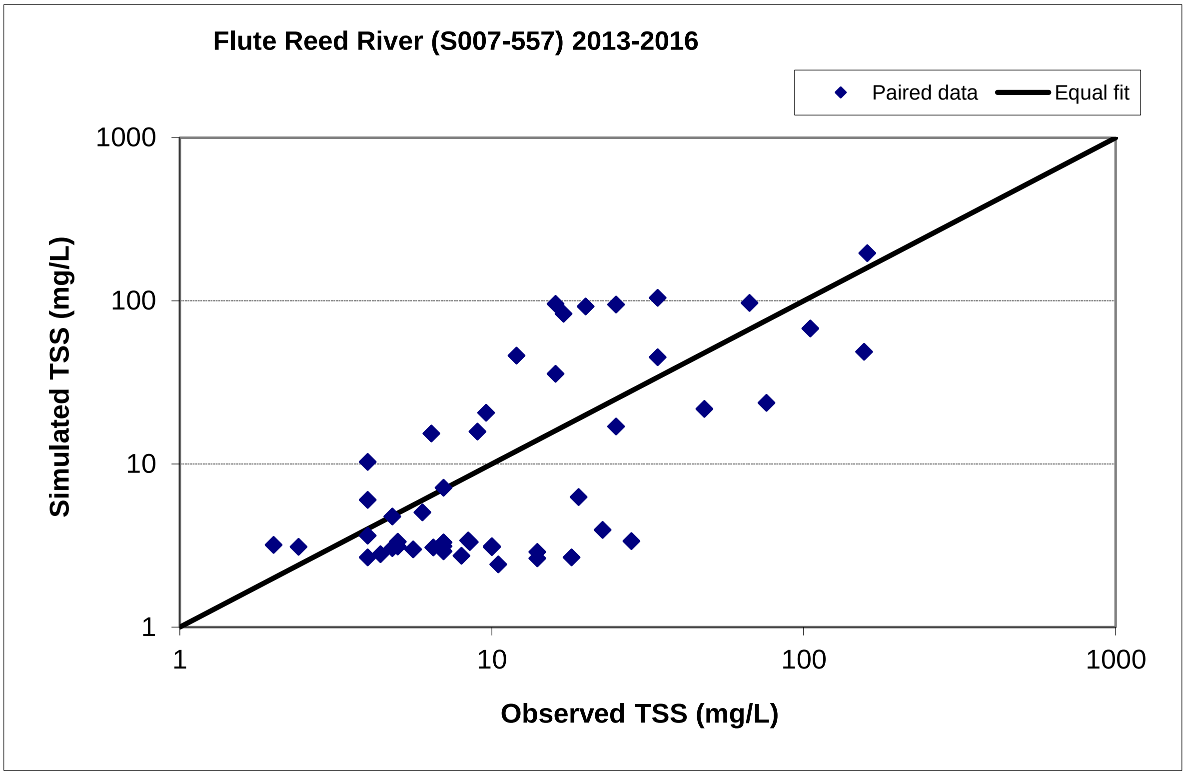


Figure 46. Paired simulated vs. observed Total Suspended Solids (TSS) concentration

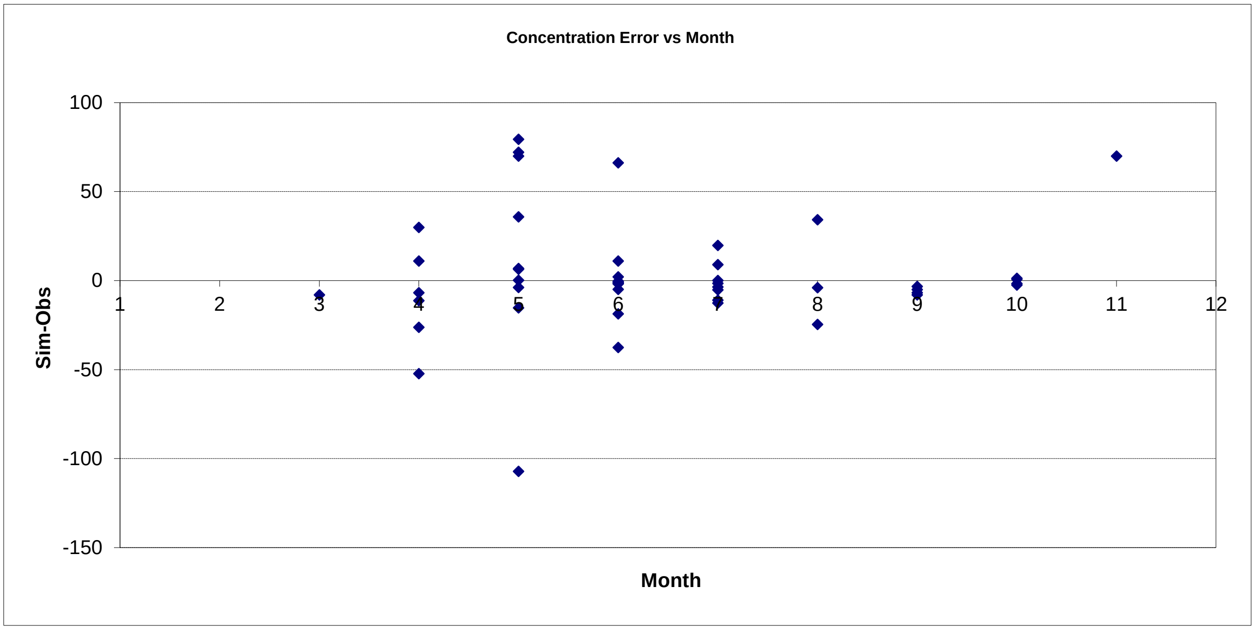


Figure 47. Residual (Simulated - Observed) vs. Month Total Suspended Solids (TSS)

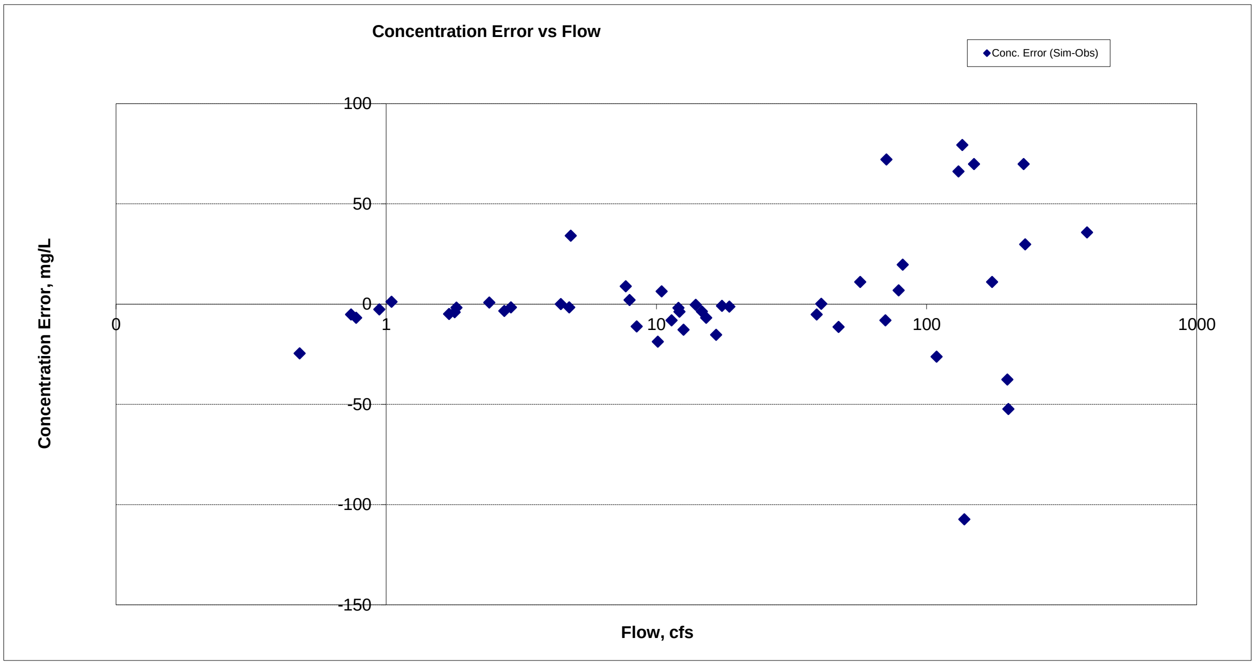


Figure 48. Residual (Simulated - Observed) vs. Flow Total Suspended Solids (TSS)

Total Phosphorus (TP)

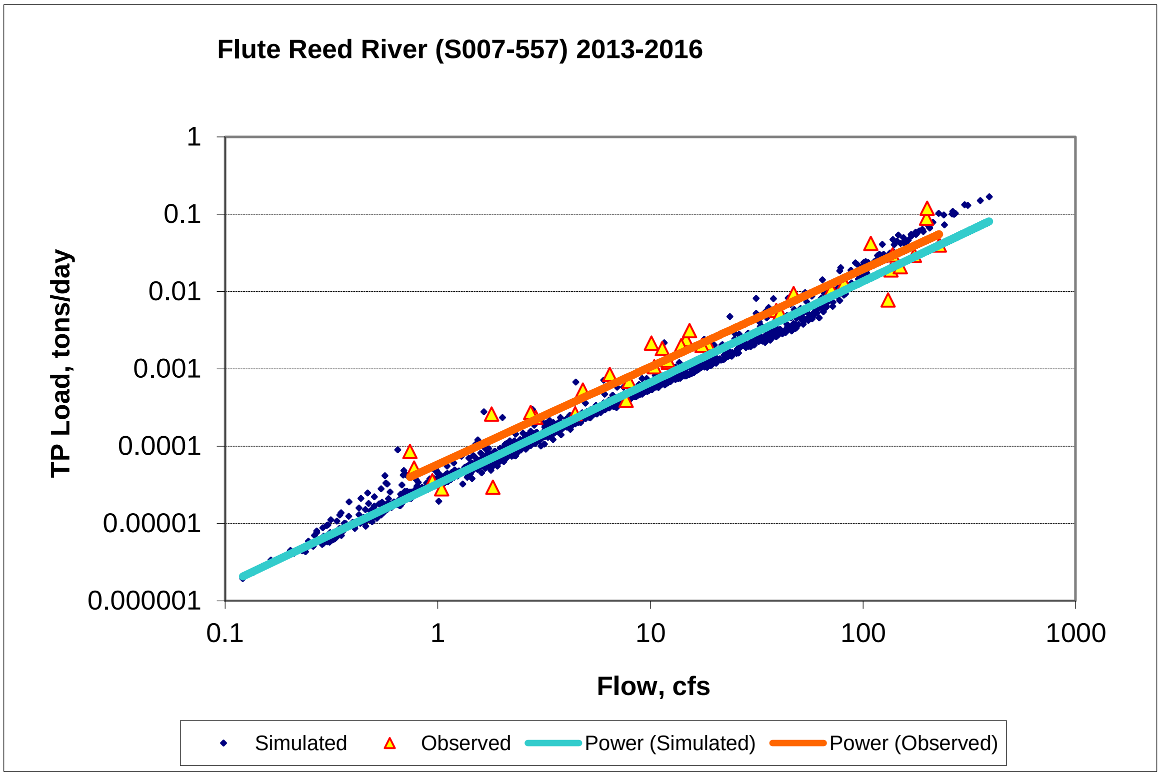


Figure 49. Power plot of simulated and observed Total Phosphorus (TP) load vs flow

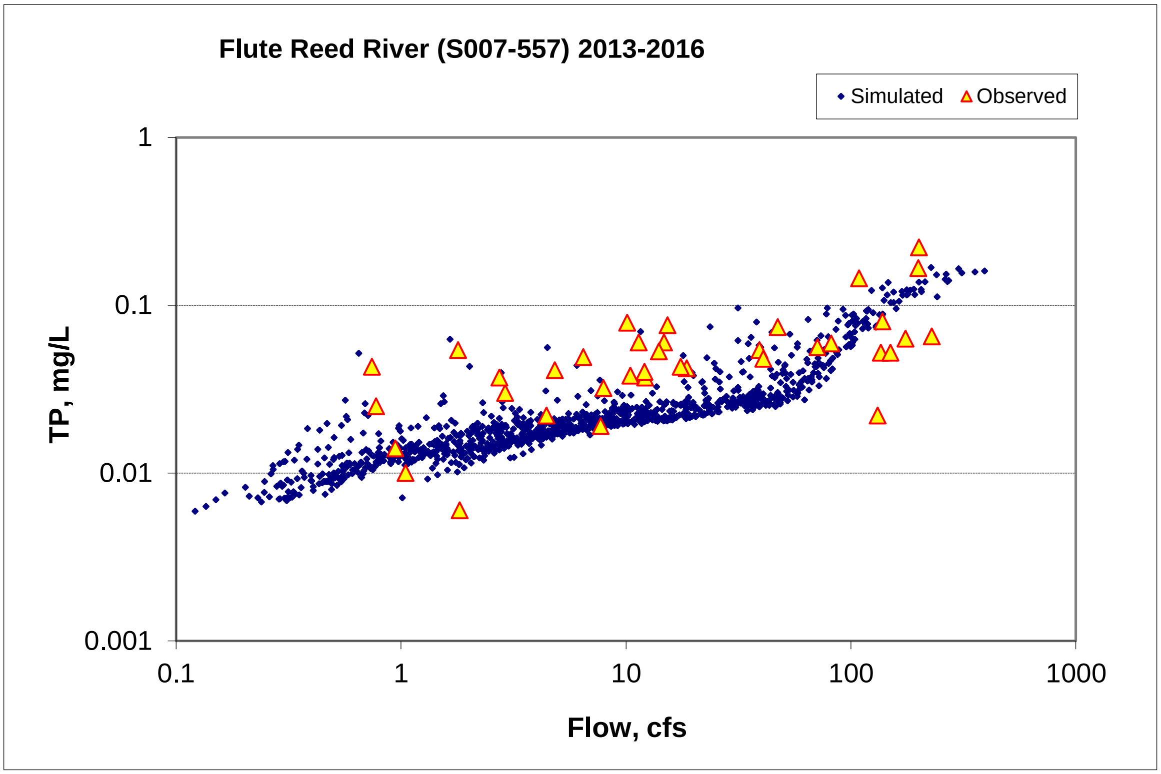


Figure 50. Simulated and observed Total Phosphorus (TP) concentration vs flow

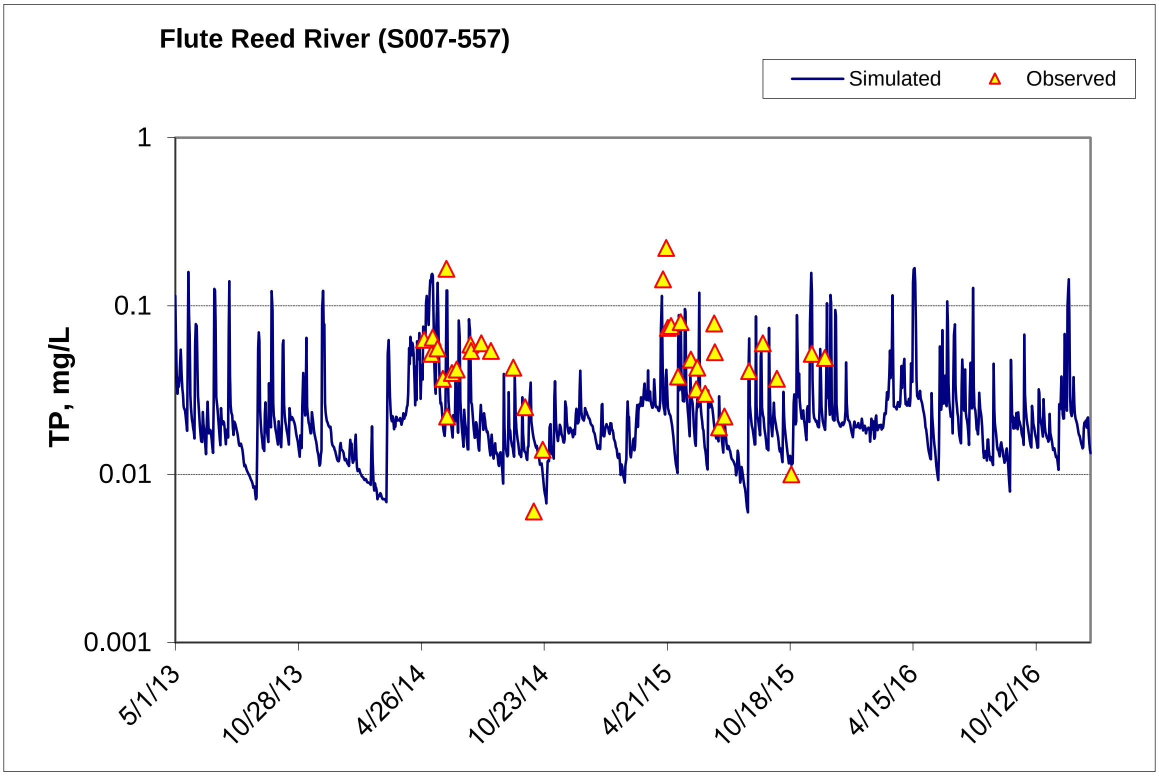


Figure 51. Time series of observed and simulated Total Phosphorus (TP) concentration

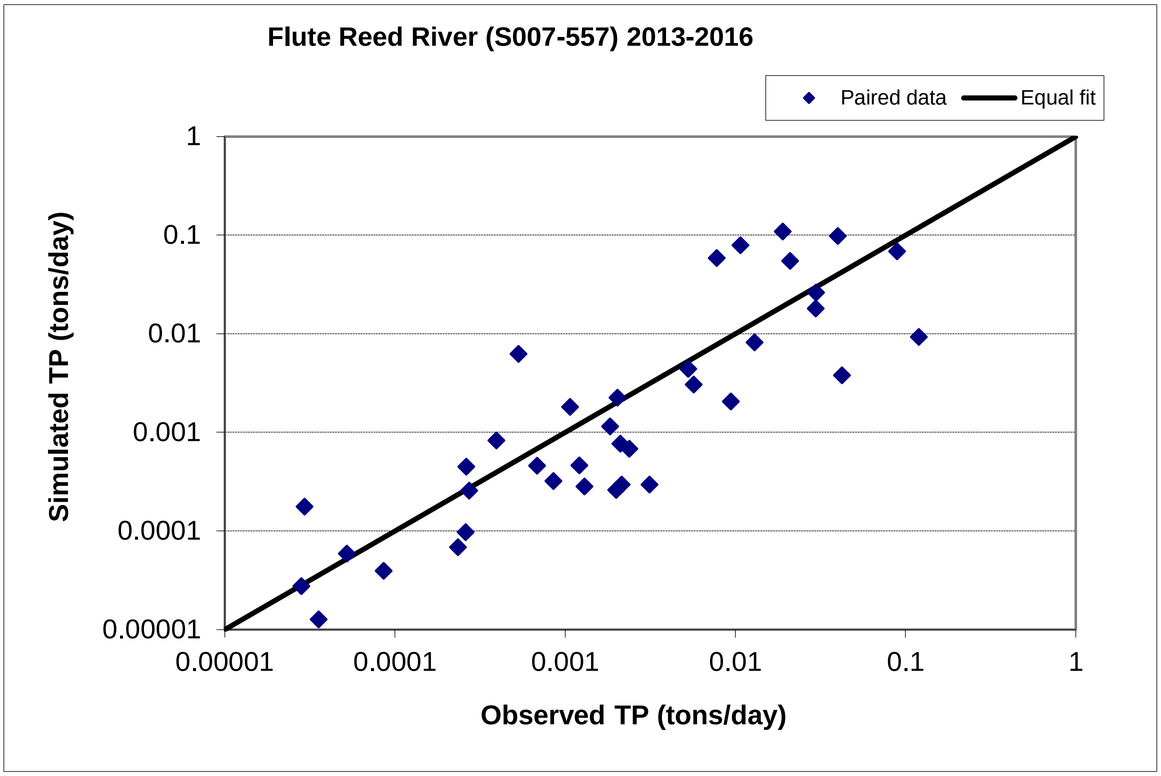


Figure 52. Paired simulated vs. observed Total Phosphorus (TP) load

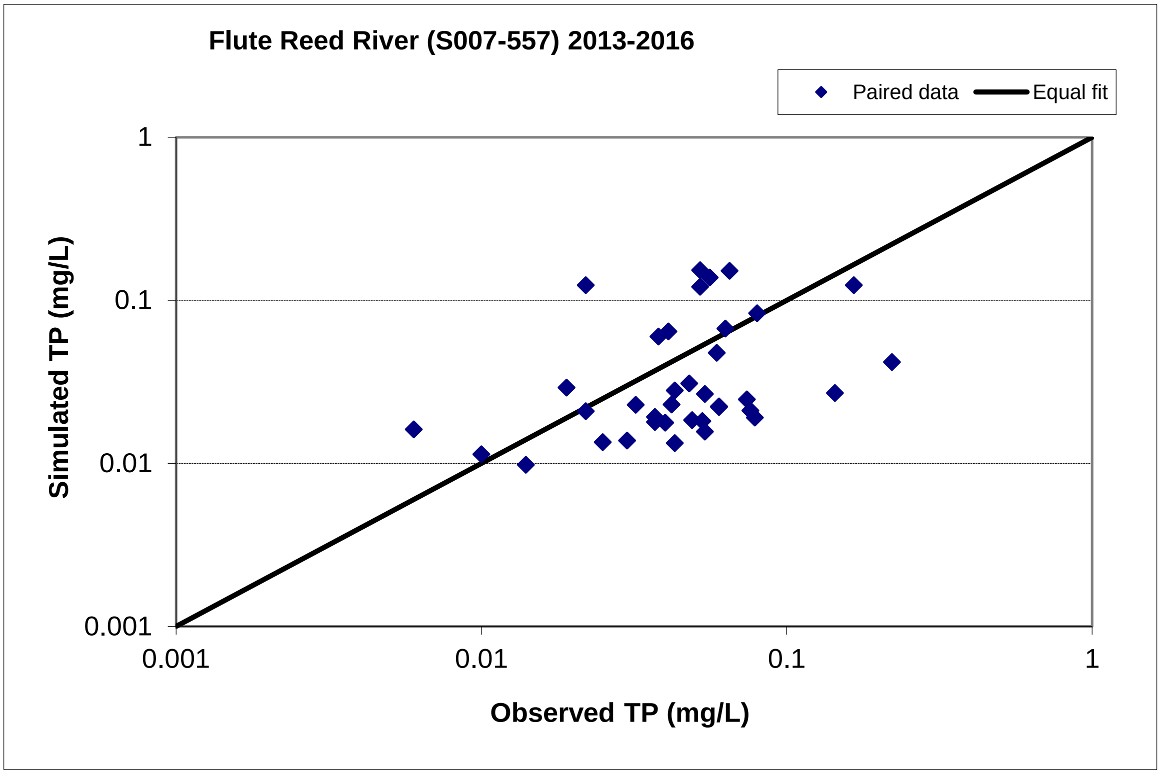


Figure 53. Paired simulated vs. observed Total Phosphorus (TP) concentration

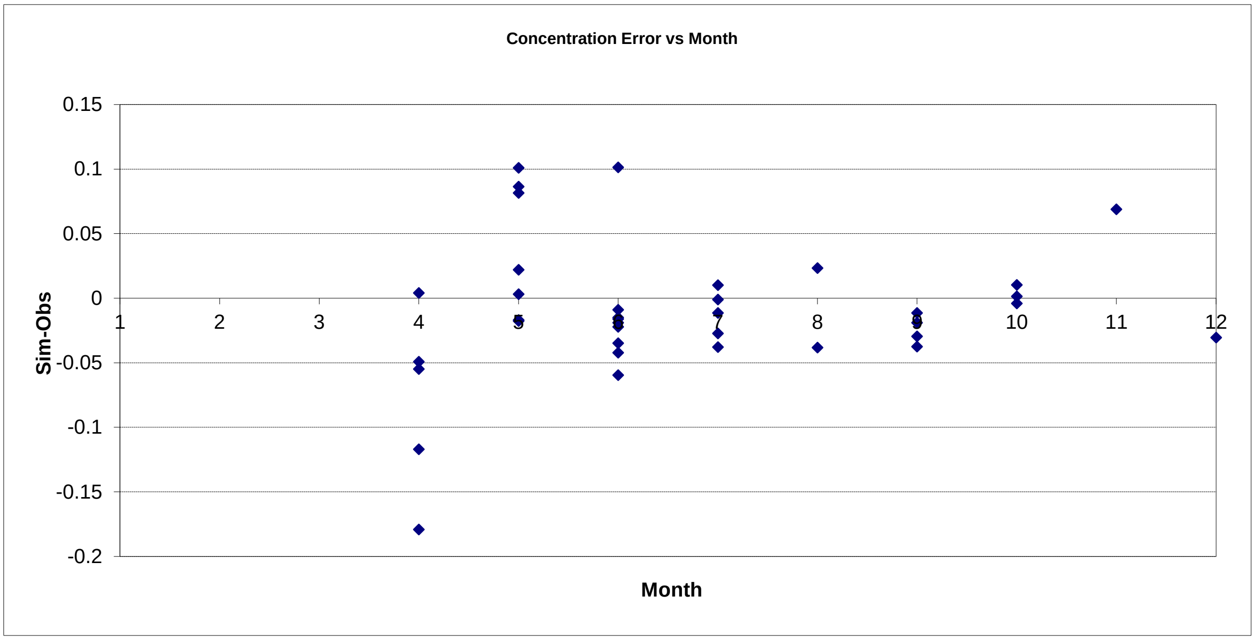


Figure 54. Residual (Simulated - Observed) vs. Month Total Phosphorus (TP)

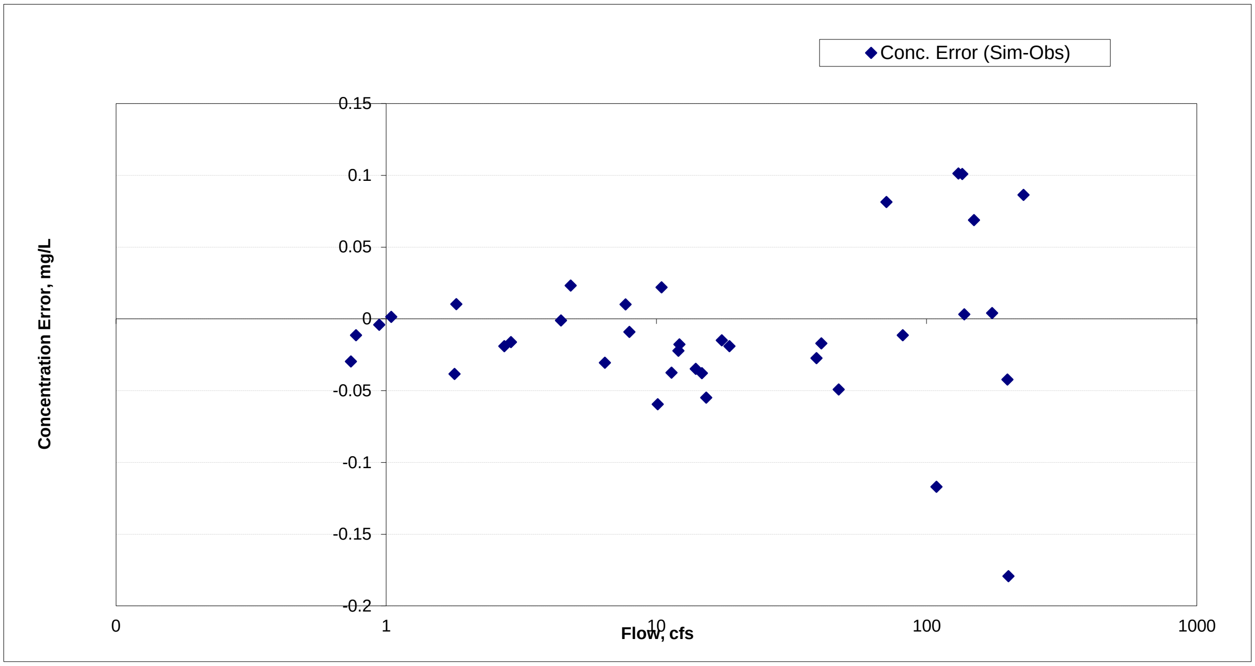


Figure 55. Residual (Simulated - Observed) vs. Flow Total Phosphorus (TP)

FLUTE REED RIVER AT CR-88 IN HOVLAND (S004-283)

Table 8. Water quality calibration statistics for Flute Reed River at CR-88 in Hovland (S004-283)

Statistic	TSS	NH3	ORGN	TKN	NOx	TN	SRP	ORGP	TP
Concentration average error	8%	45%	-2%	1%	89%	7%	-1%	18%	-1%
Concentration median error	1%	-22%	-7%	0%	18%	4%	8%	25%	4%
Load average error	23%	-14%	8%	7%	-9%	5%	-1%	0%	15%
Load median error	0%	-3%	0%	0%	1%	0%	0%	0%	0%
# Samples	91	45	44	44	45	44	35	35	79
# Non-detect	6	34	0	14	34	0	20	0	0

Total Suspended Solids (TSS)

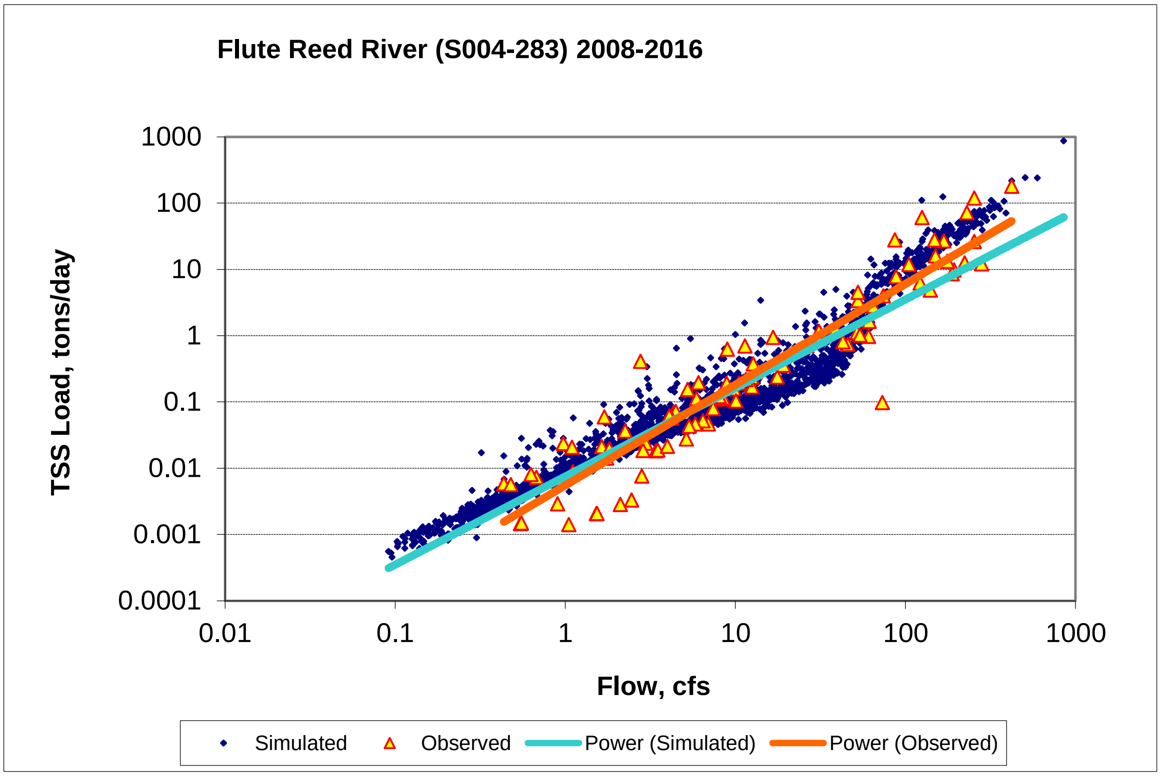


Figure 56. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow at Flute Reed River (S004-283)

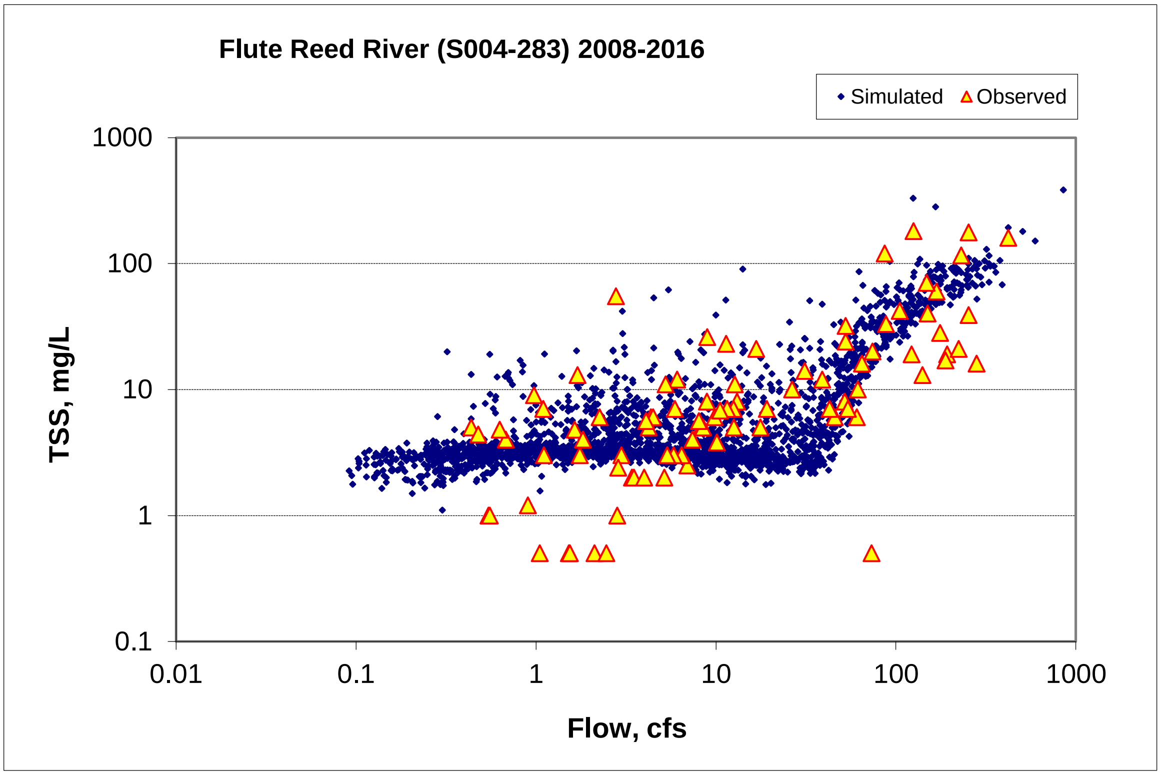


Figure 57. Simulated and observed Total Suspended Solids (TSS) concentration vs flow at Flute Reed River (S004-283)

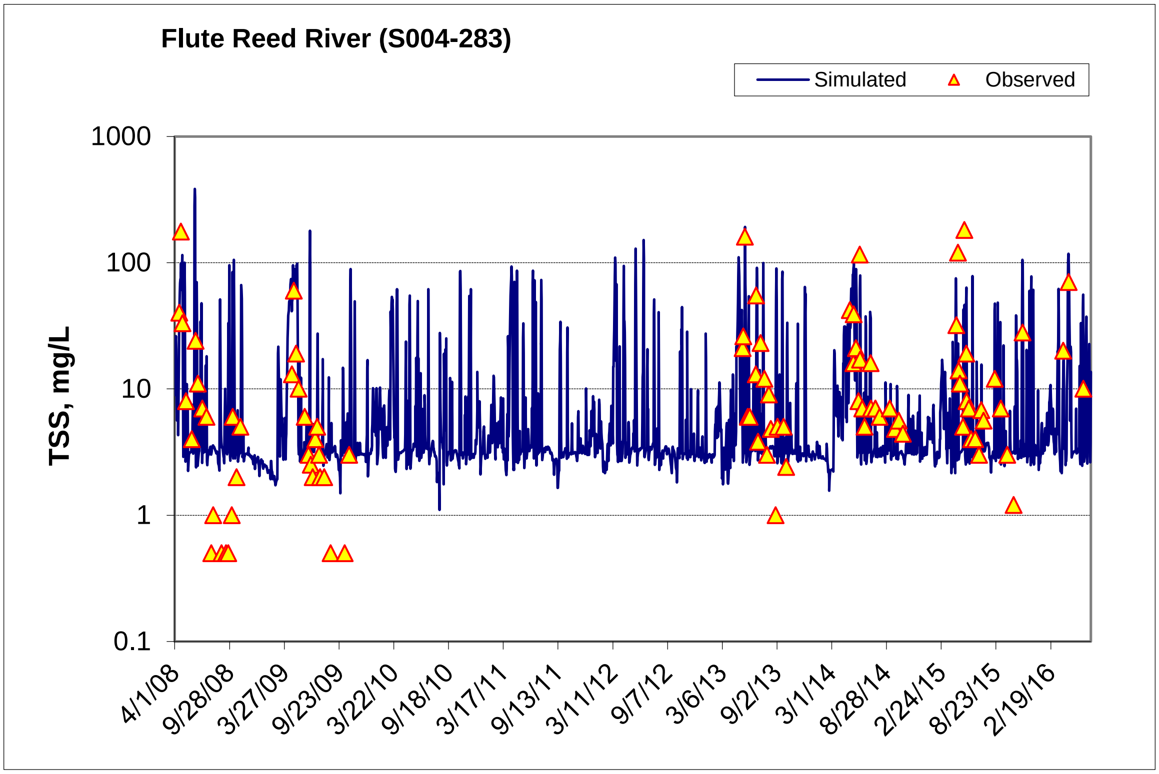


Figure 58. Time series of observed and simulated Total Suspended Solids (TSS) concentration at Flute Reed River (S004-283)

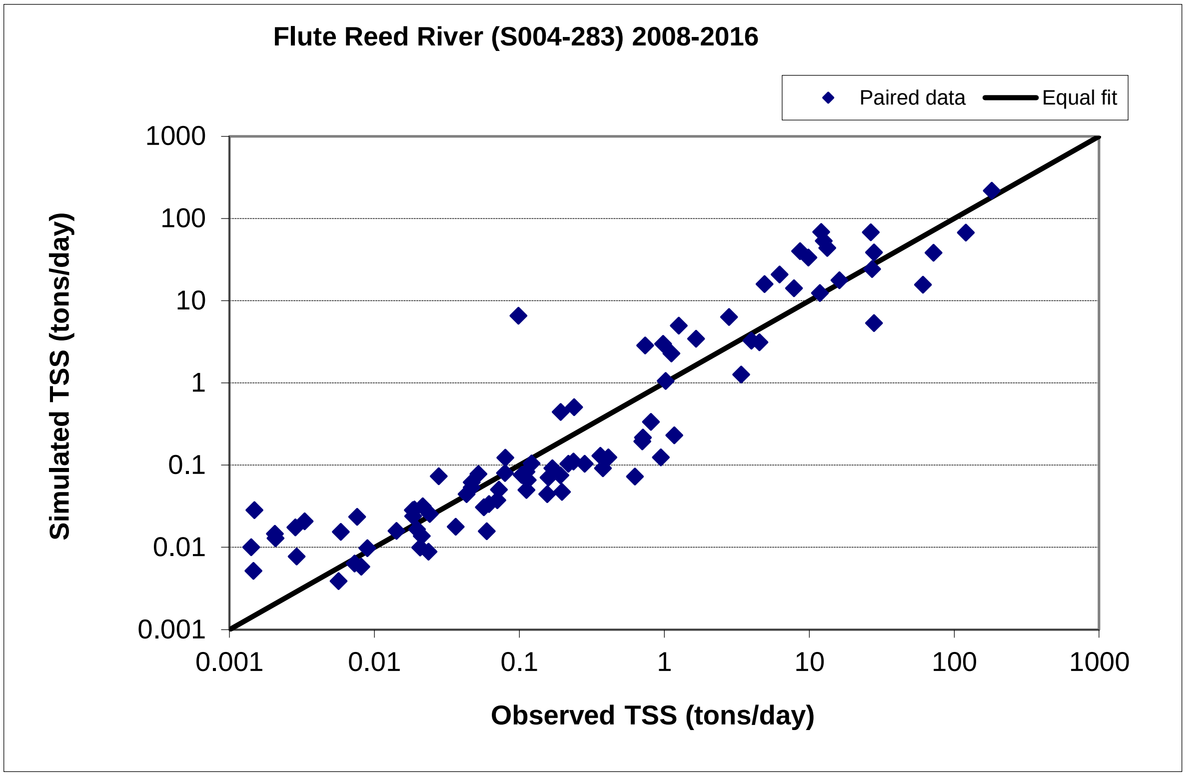


Figure 59. Paired simulated vs. observed Total Suspended Solids (TSS) load at Flute Reed River (S004-283)

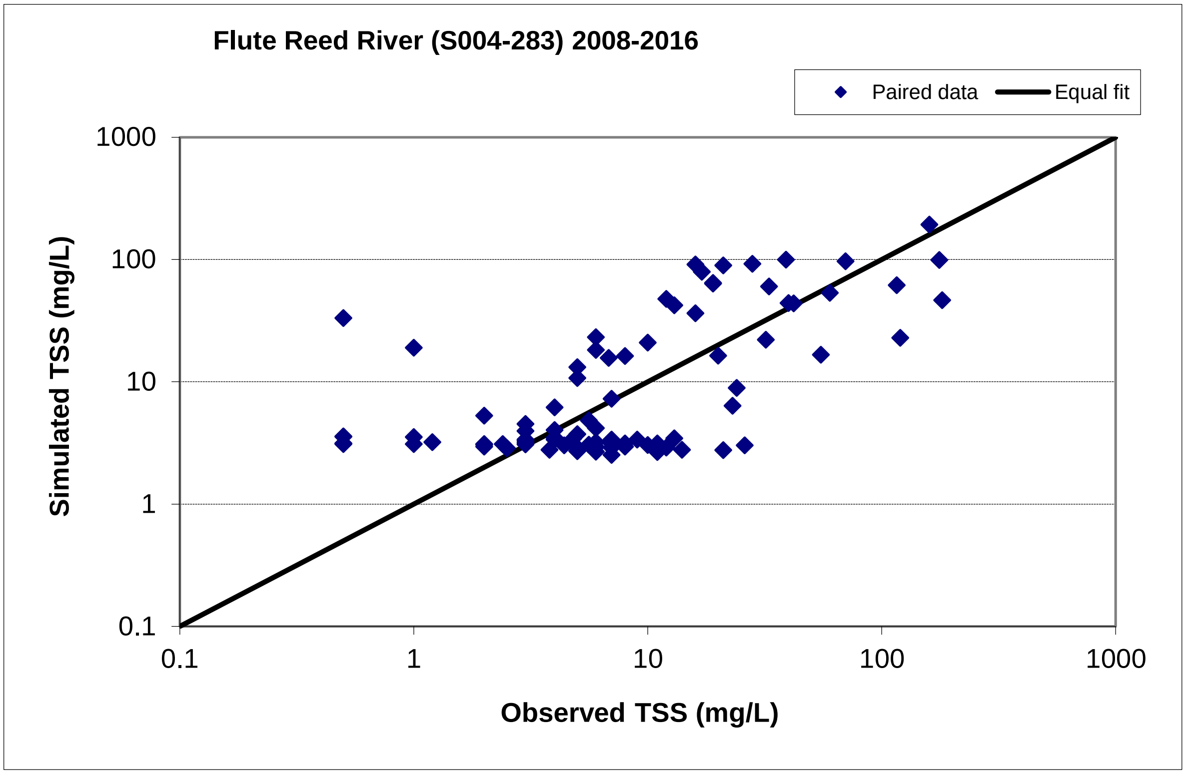


Figure 60. Paired simulated vs. observed Total Suspended Solids (TSS) concentration at Flute Reed River (S004-283)

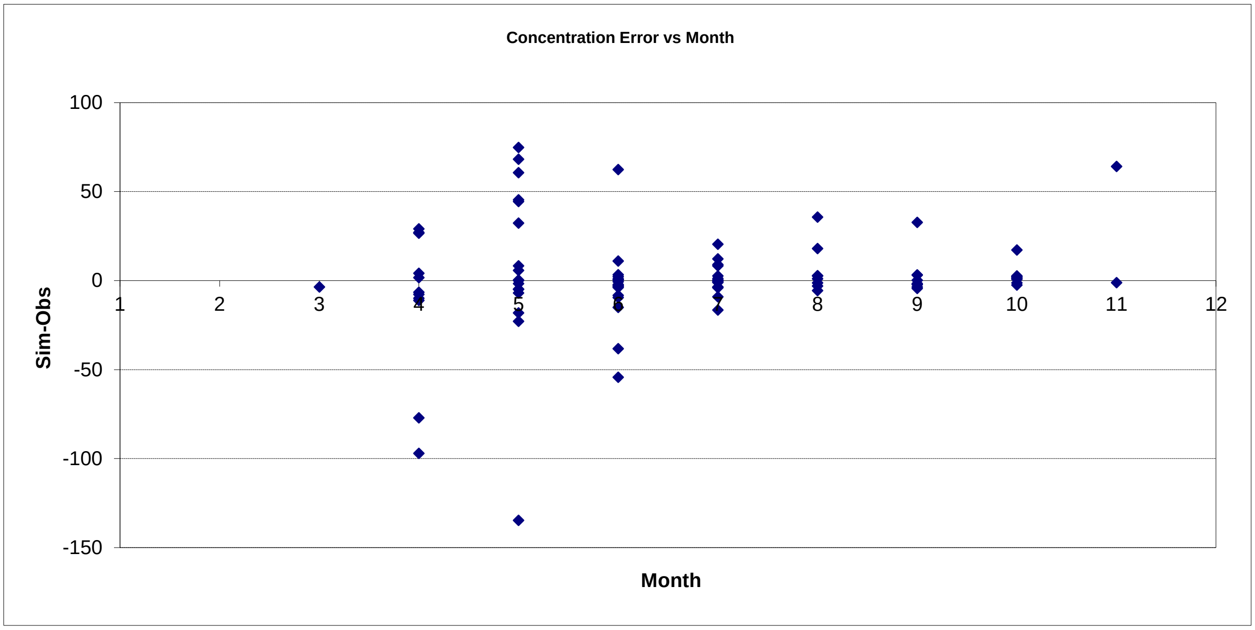


Figure 61. Residual (Simulated - Observed) vs. Month Total Suspended Solids (TSS) at Flute Reed River (S004-283)

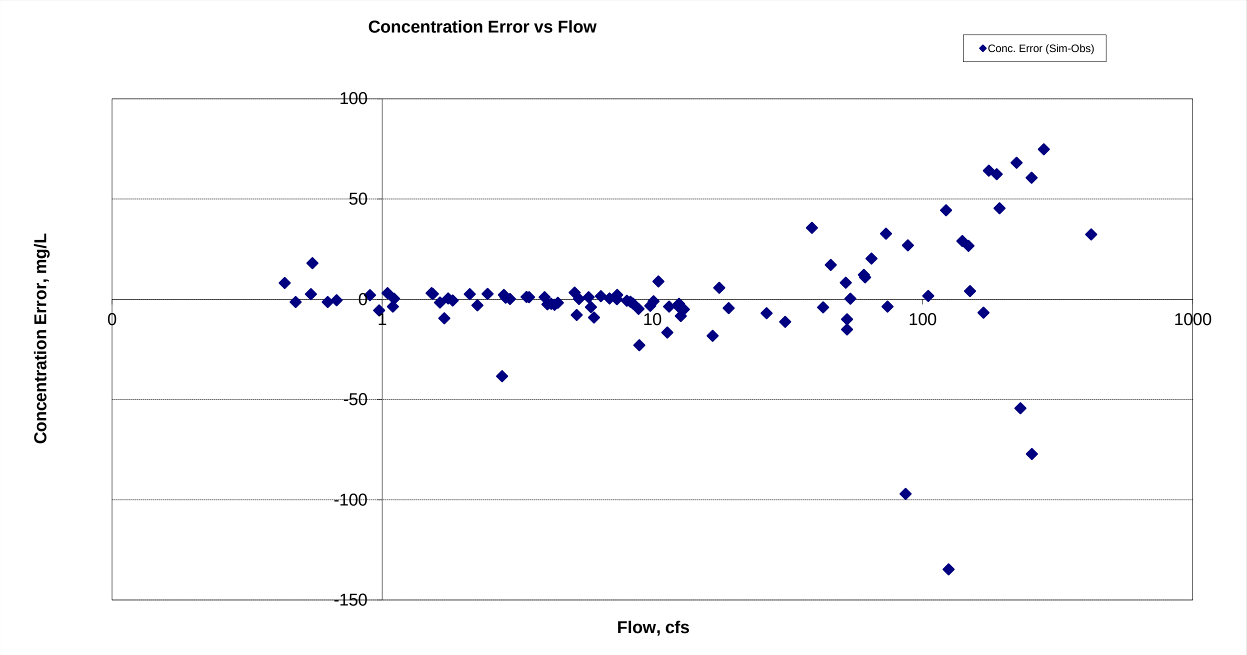


Figure 62. Residual (Simulated - Observed) vs. Flow Total Suspended Solids (TSS) at Flute Reed River (S004-283)

Ammonia Nitrogen (NH3)

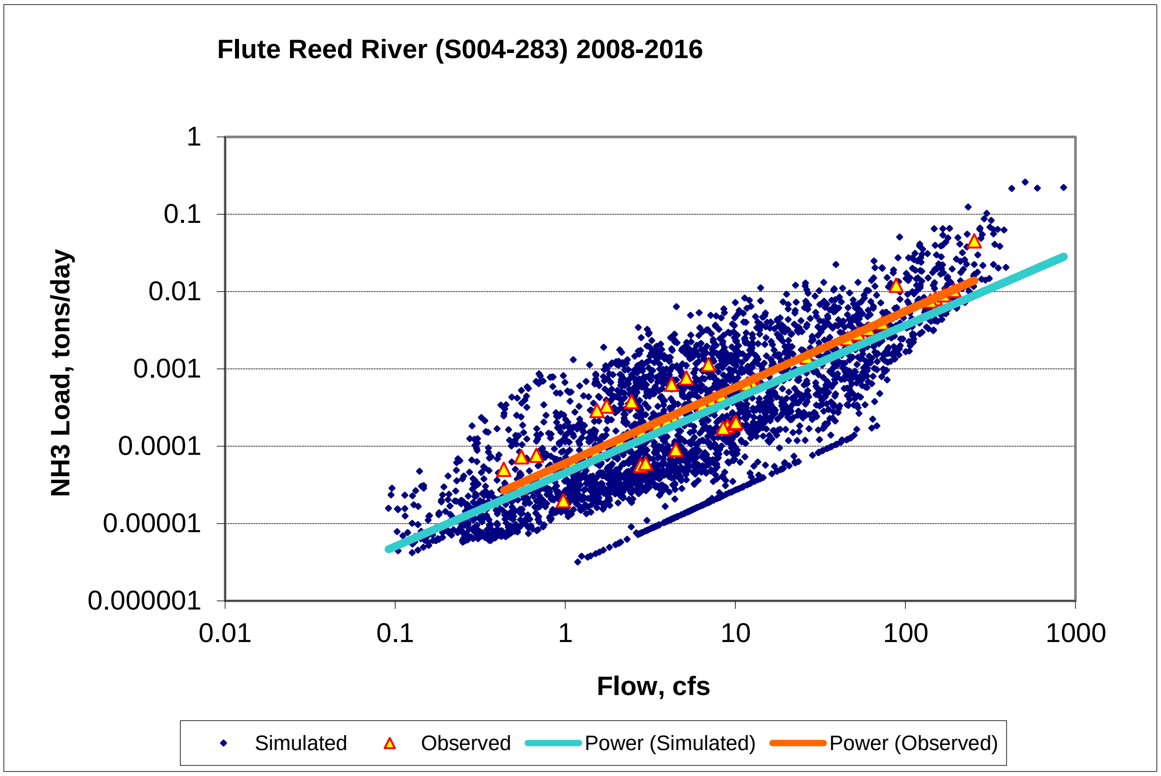


Figure 63. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Flute Reed River (S004-283)

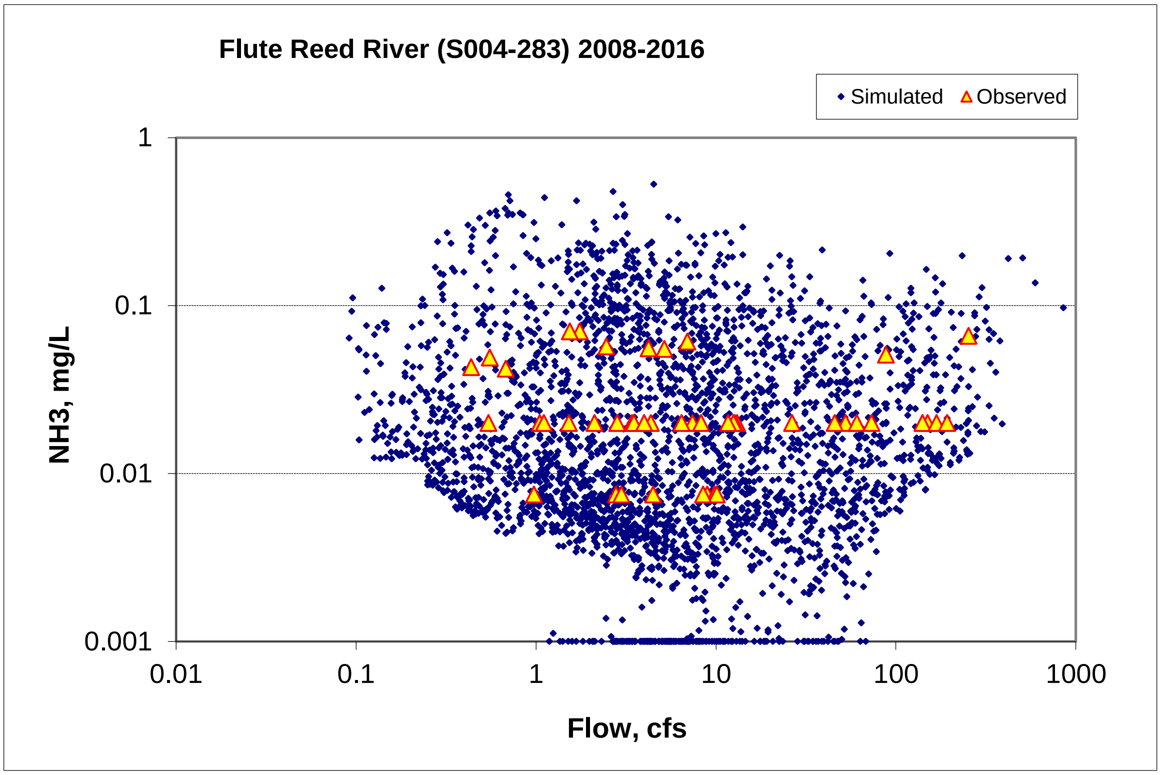


Figure 64. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Flute Reed River (S004-283)

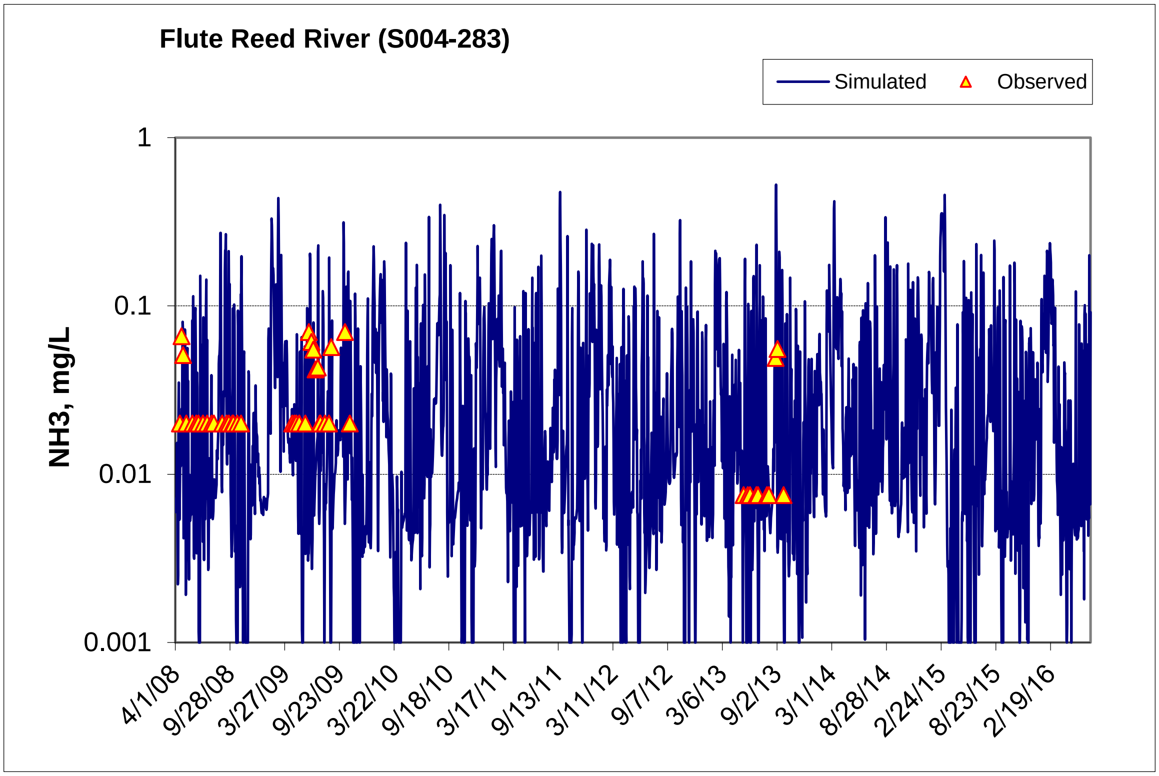


Figure 65. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Flute Reed River (S004-283)

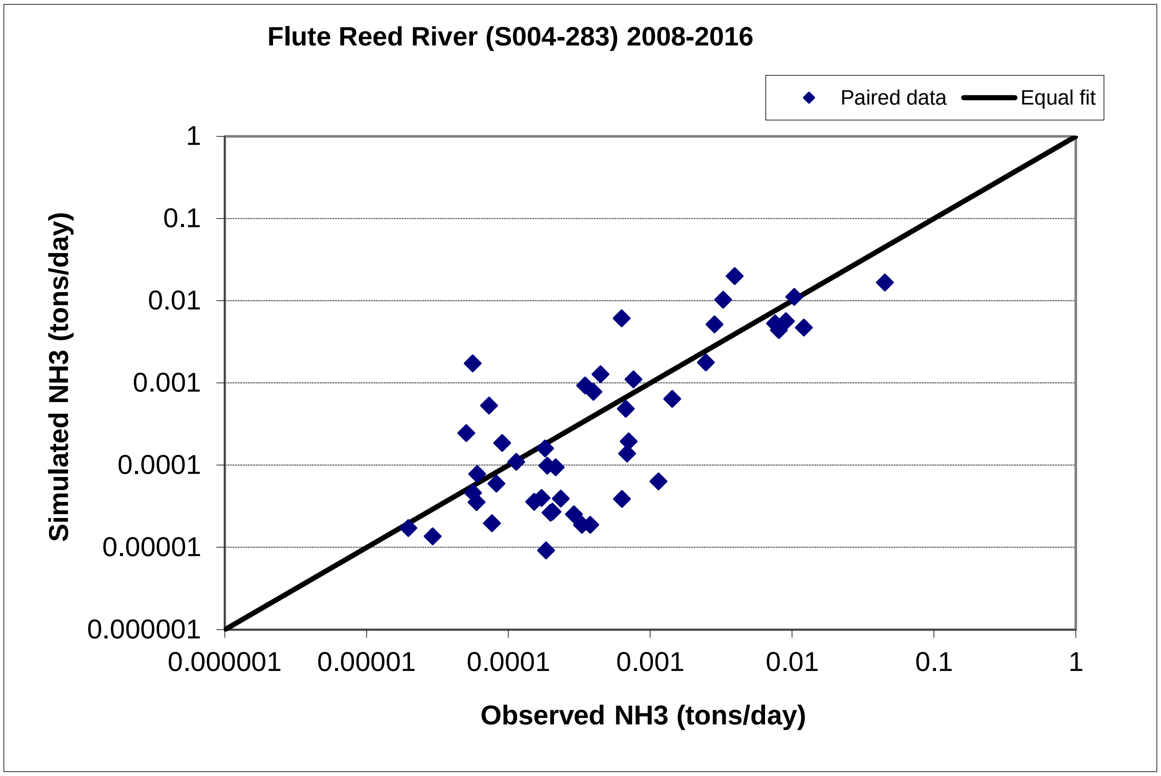


Figure 66. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Flute Reed River (S004-283)

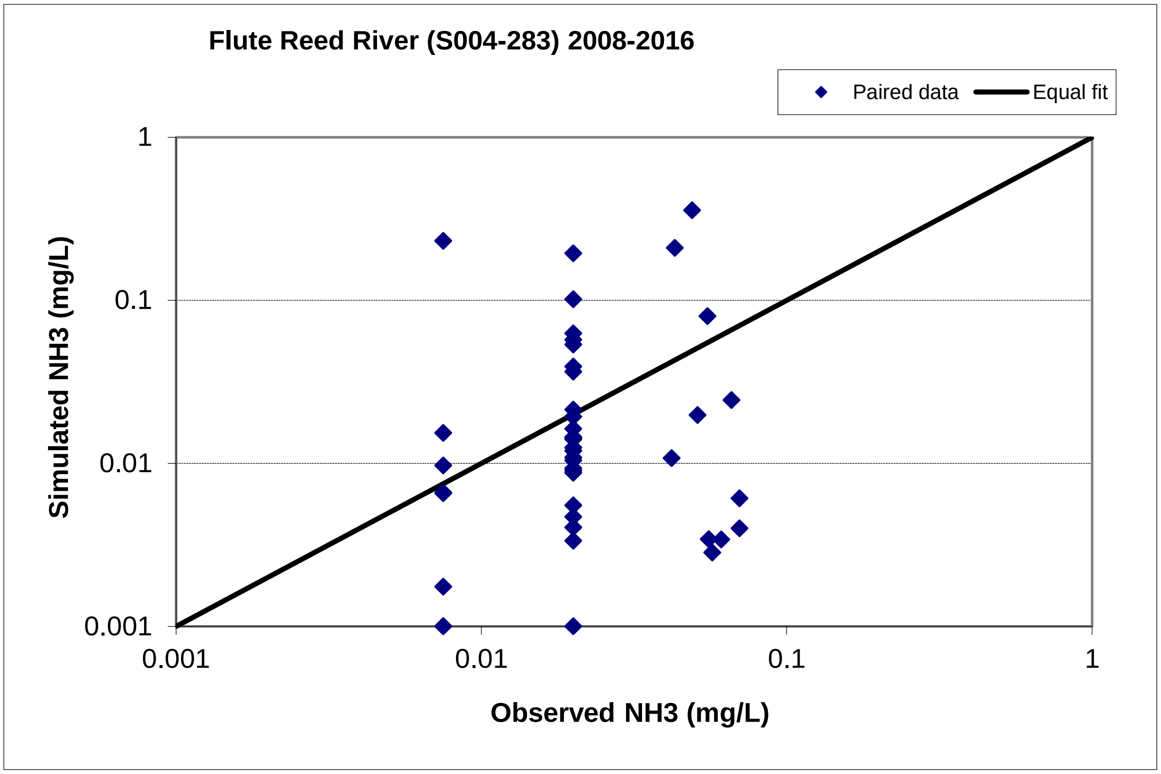


Figure 67. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Flute Reed River (S004-283)

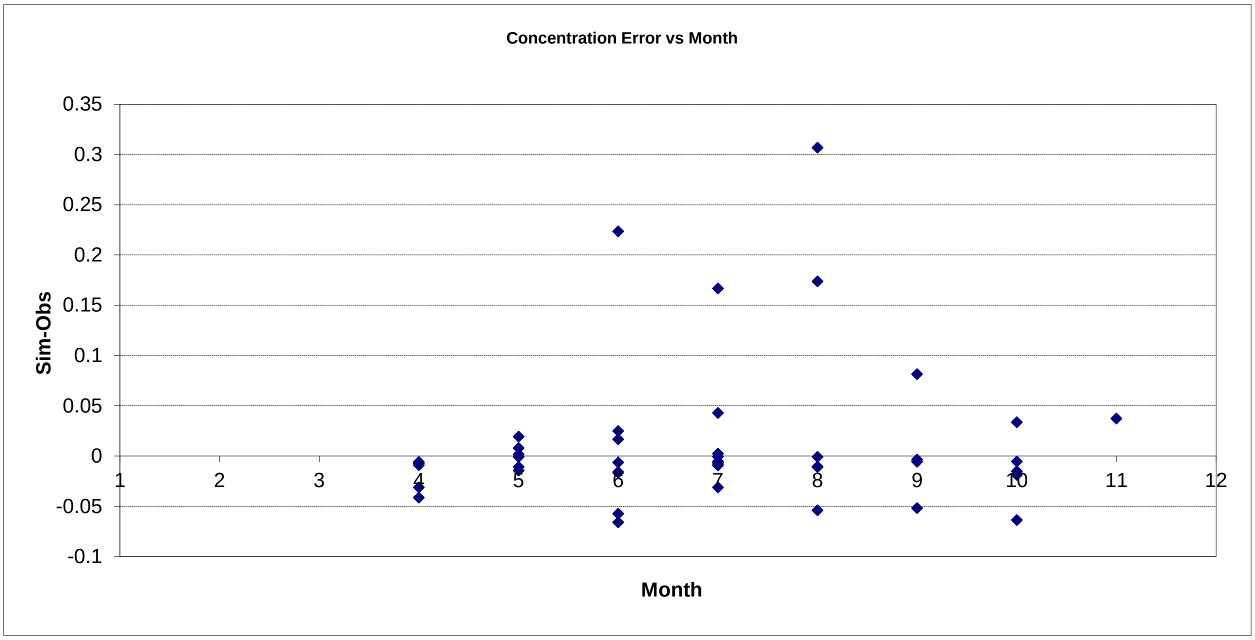


Figure 68. Residual (Simulated - Observed) vs. Month Ammonia Nitrogen (NH3) at Flute Reed River (S004-283)

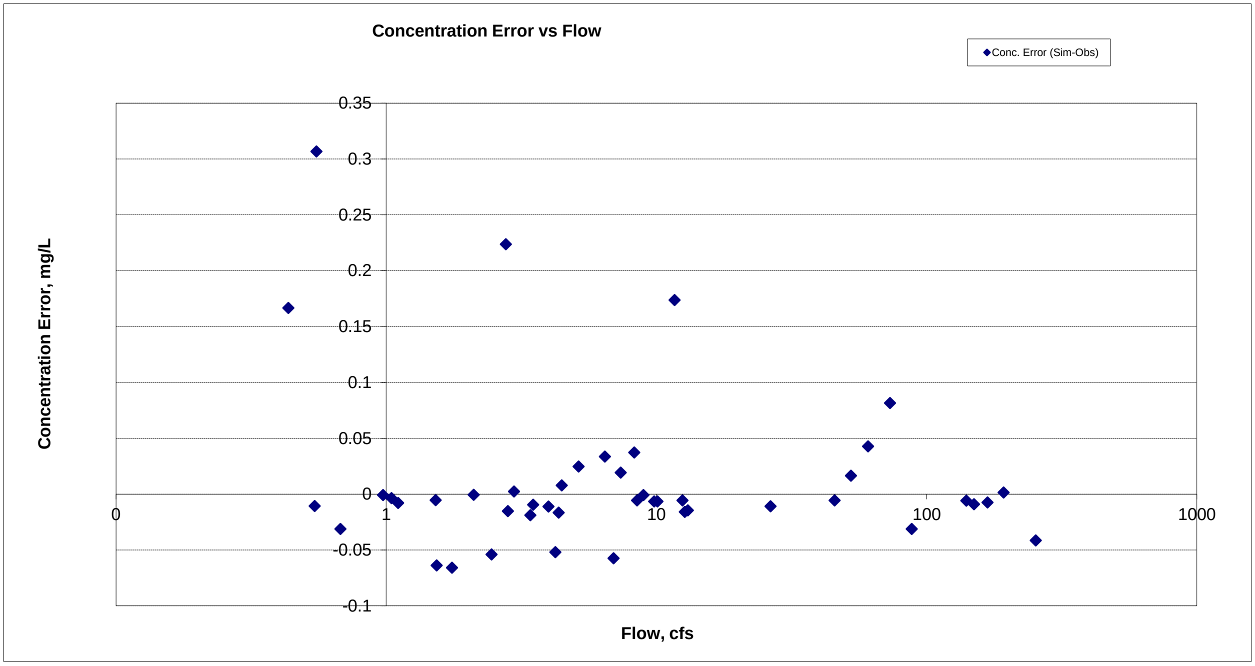


Figure 69. Residual (Simulated - Observed) vs. Flow Ammonia Nitrogen (NH3) at Flute Reed River (S004-283)

Organic Nitrogen (OrgN)

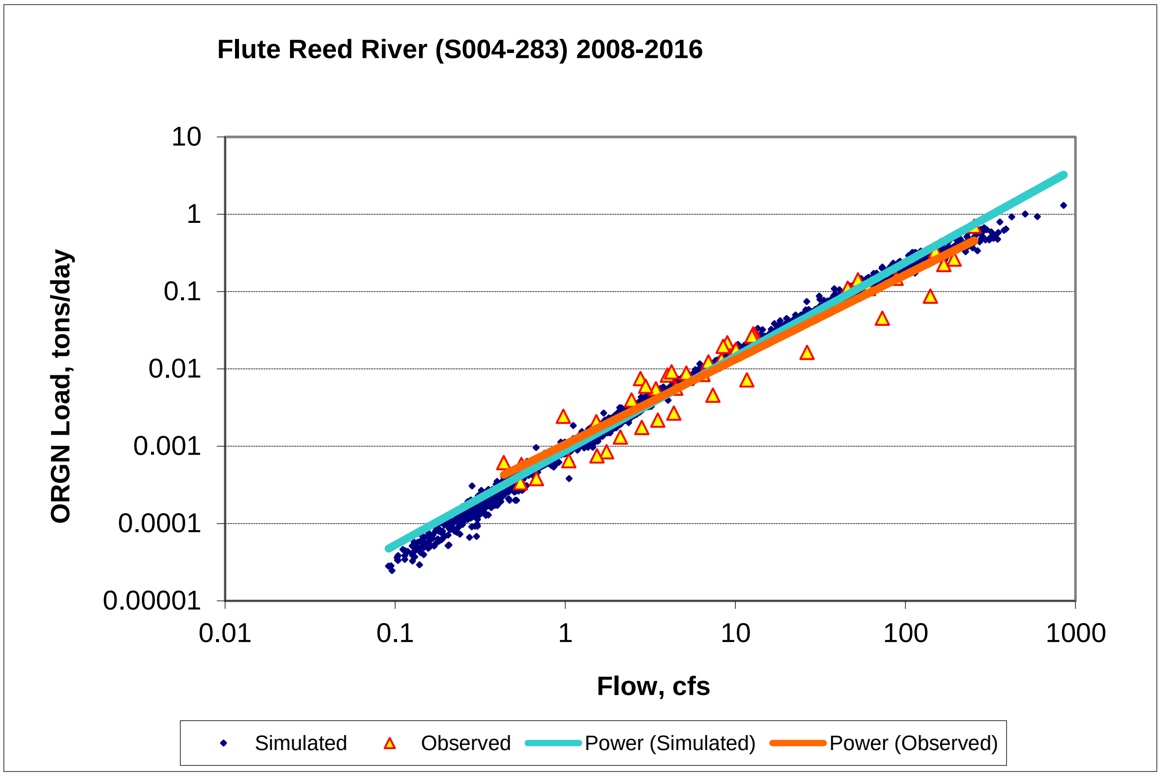


Figure 70. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Flute Reed River (S004-283)

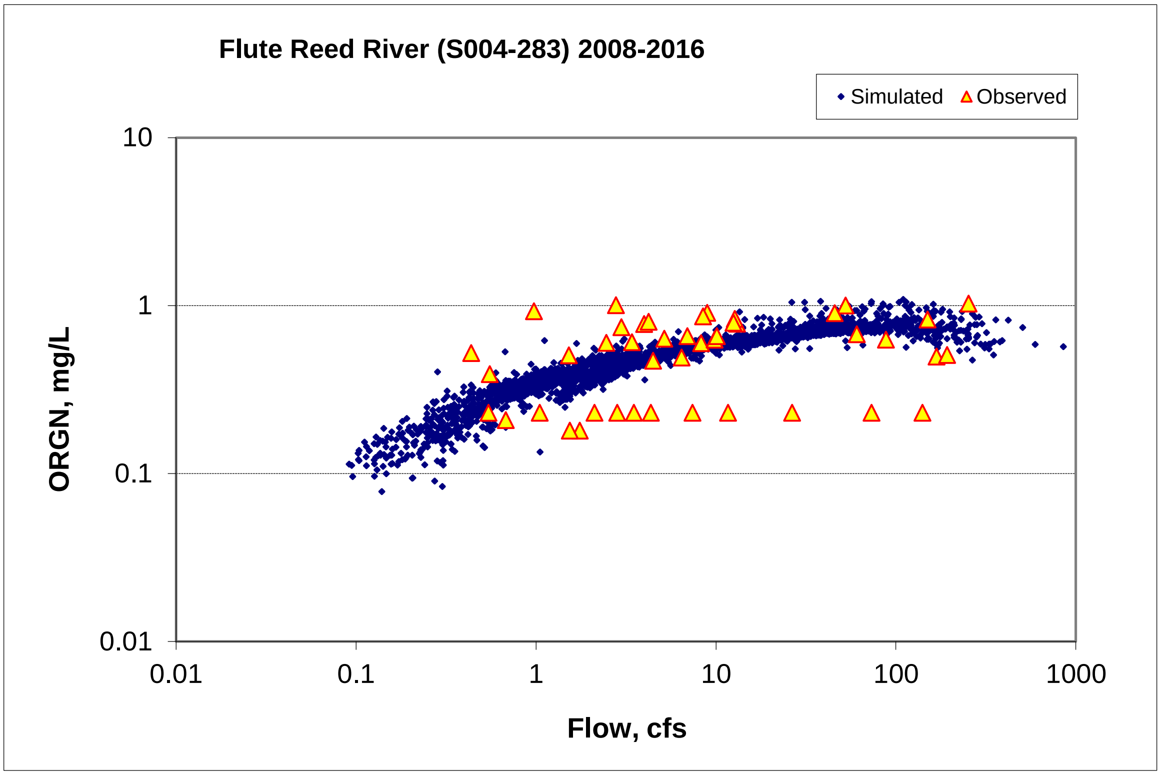


Figure 71. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Flute Reed River (S004-283)

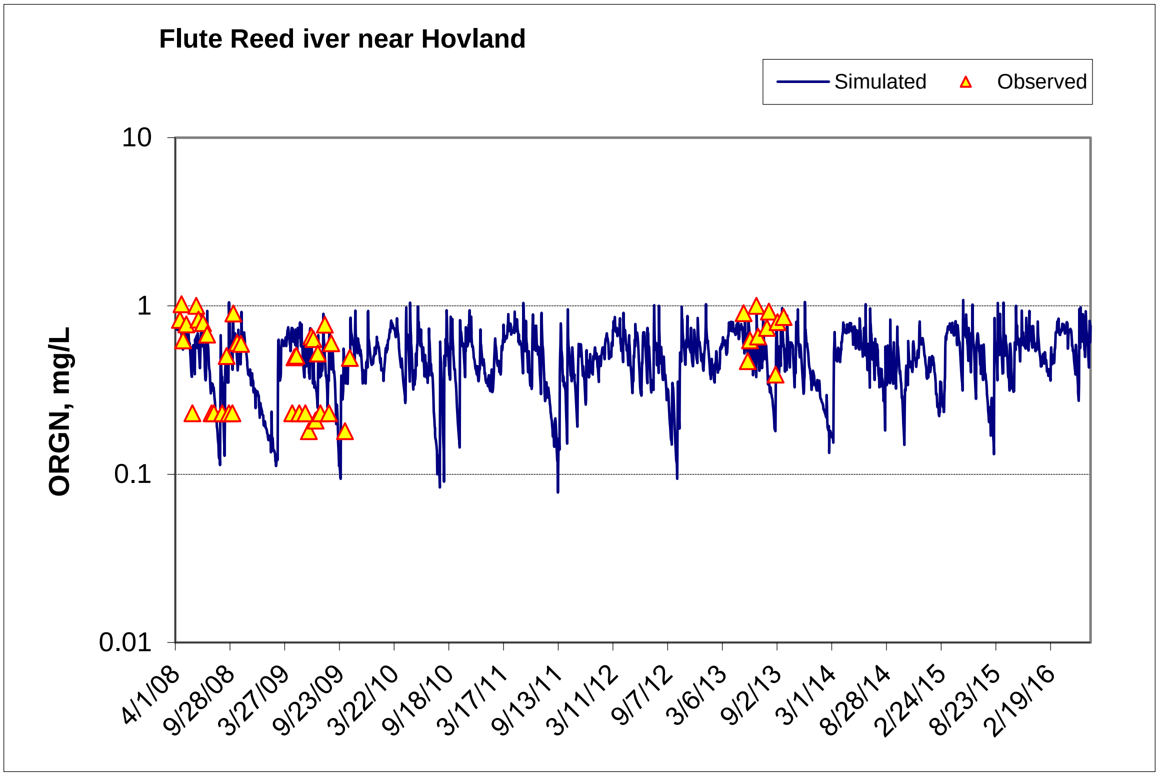


Figure 72. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Flute Reed River (S004-283)

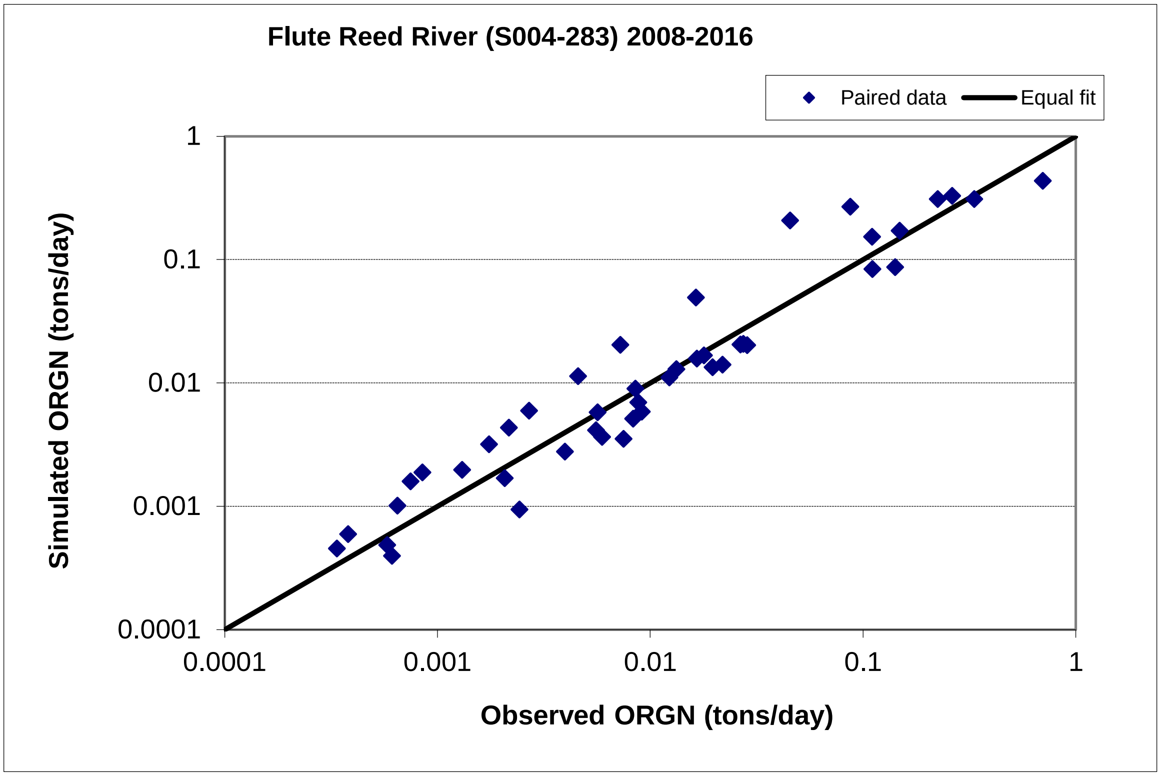


Figure 73. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Flute Reed River (S004-283)

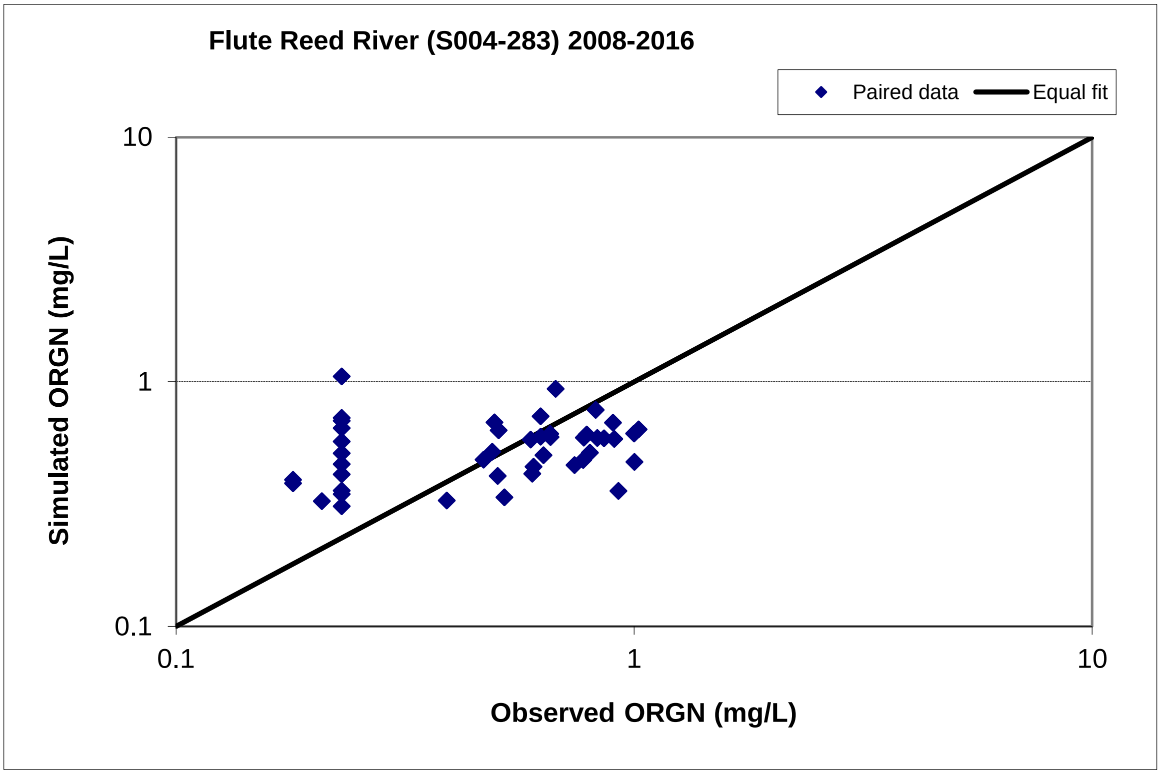


Figure 74. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Flute Reed River (S004-283)

Figure 75. Residual (Simulated - Observed) vs. Month Organic Nitrogen (OrgN) at Flute Reed River (S004-283)

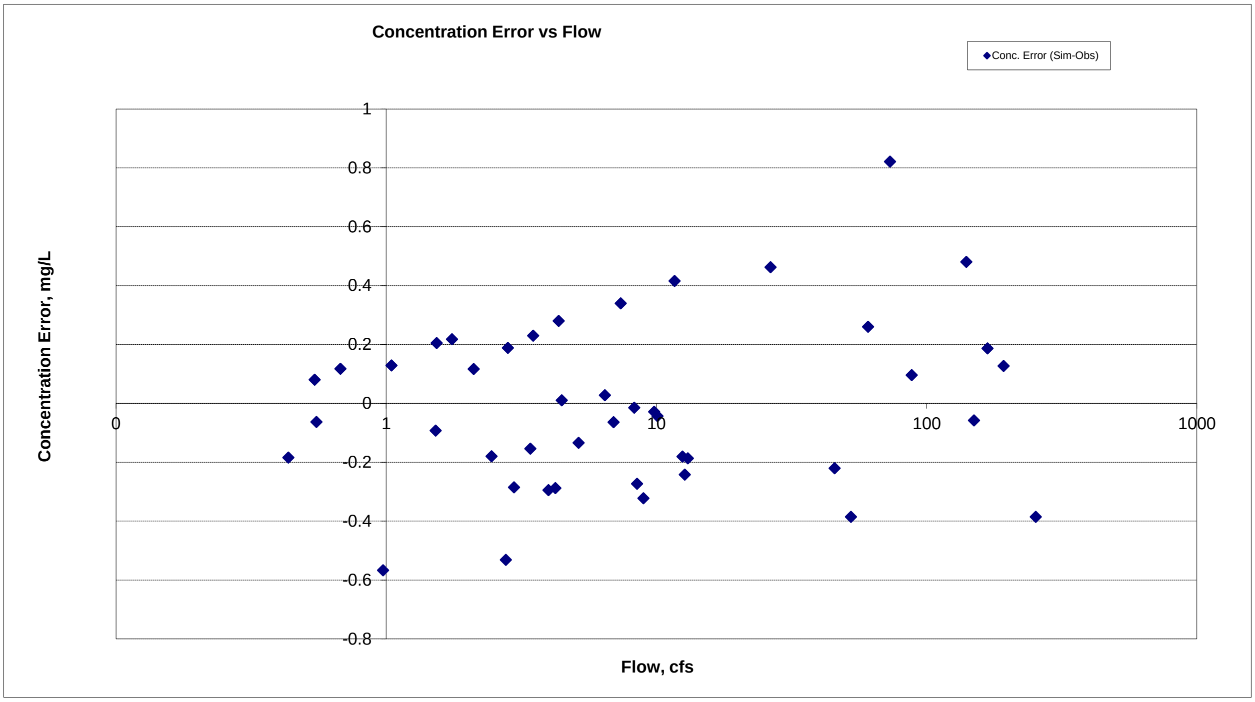


Figure 76. Residual (Simulated - Observed) vs. Flow Organic Nitrogen (OrgN) at Flute Reed River (S004-283)

Total Kjeldahl Nitrogen (TKN)

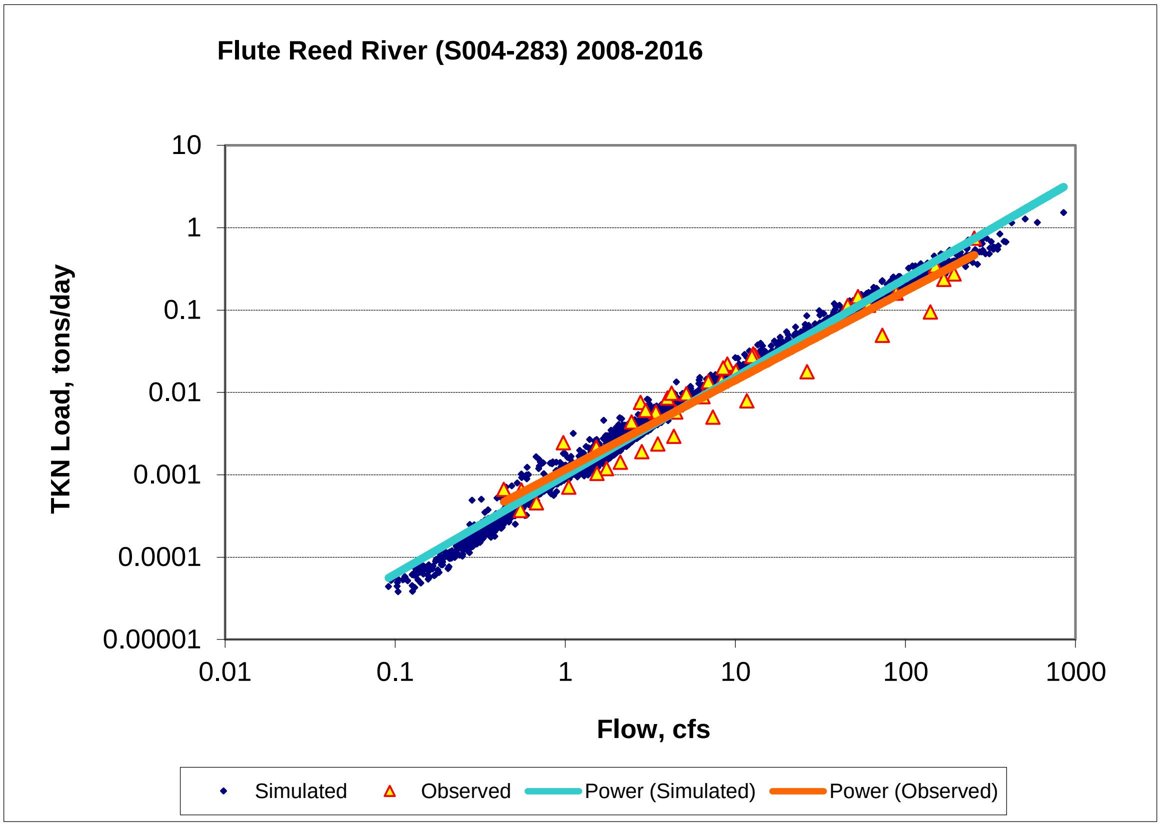


Figure 77. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Flute Reed River (S004-283)

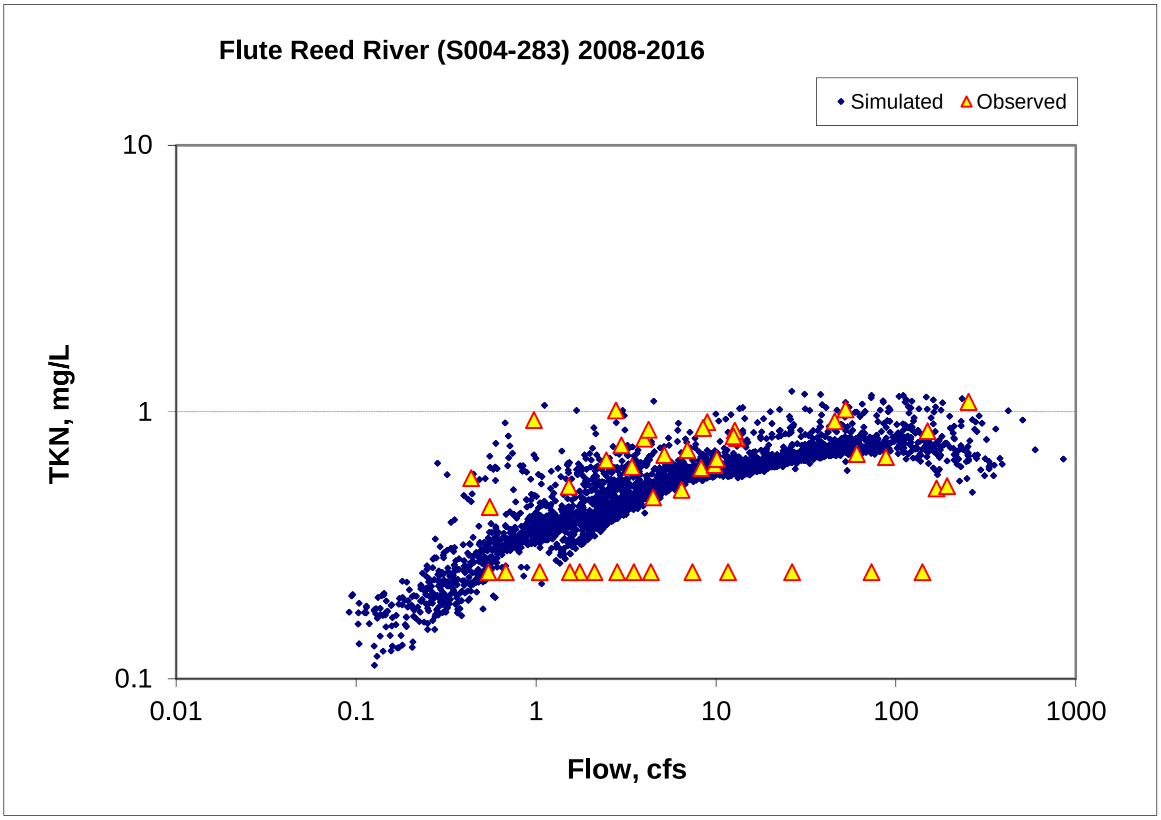


Figure 78. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Flute Reed River (S004-283)

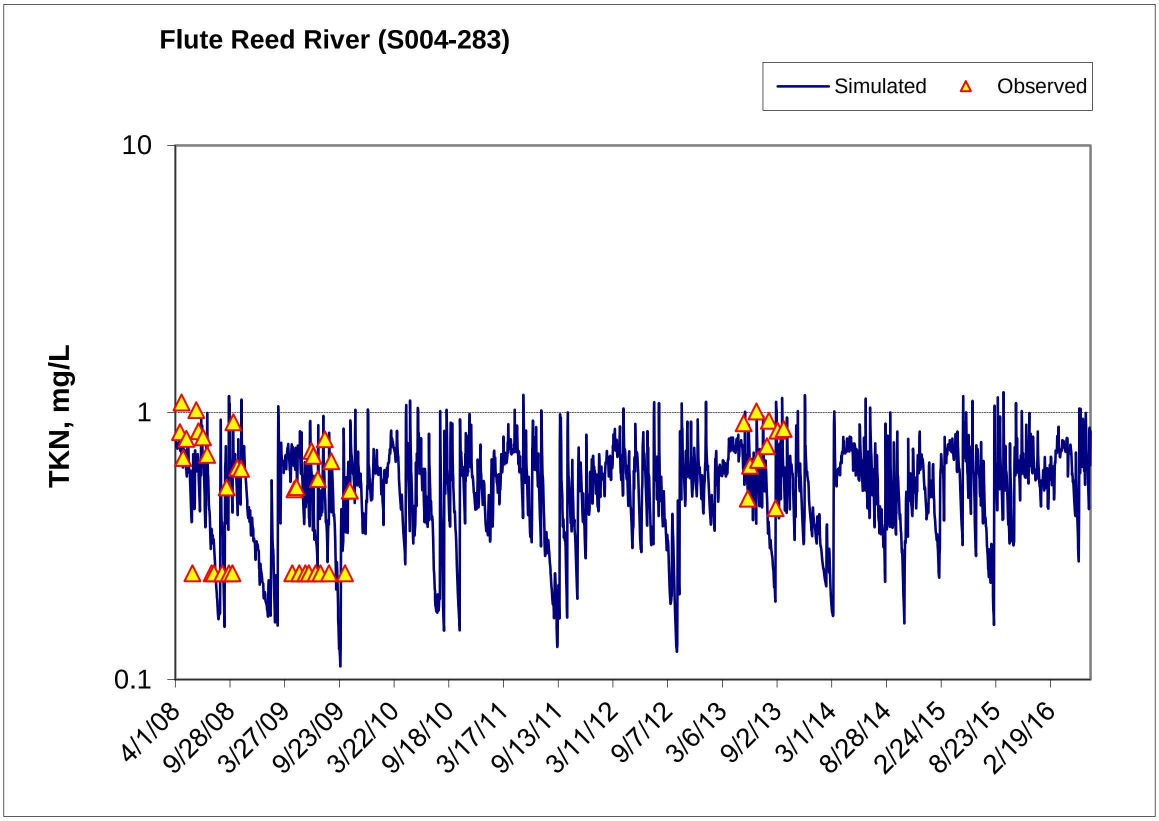


Figure 79. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Flute Reed River (S004-283)

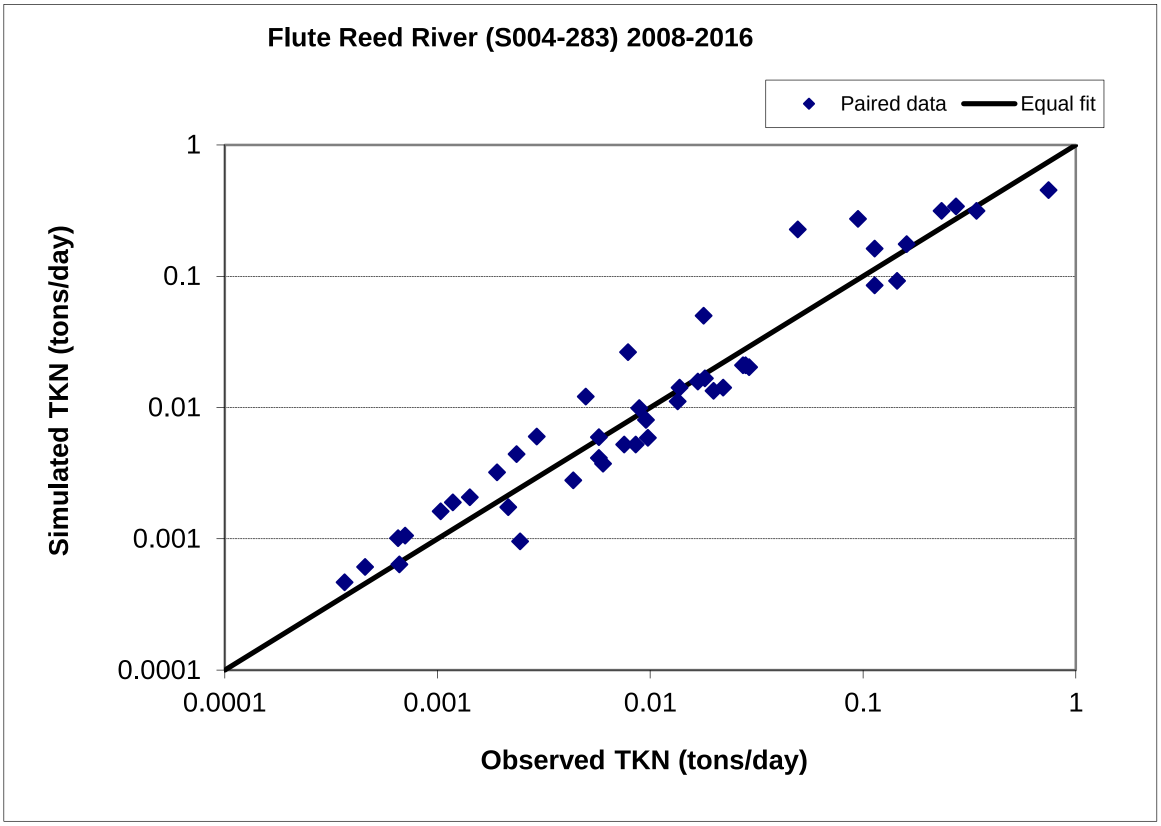


Figure 80. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Flute Reed River (S004-283)

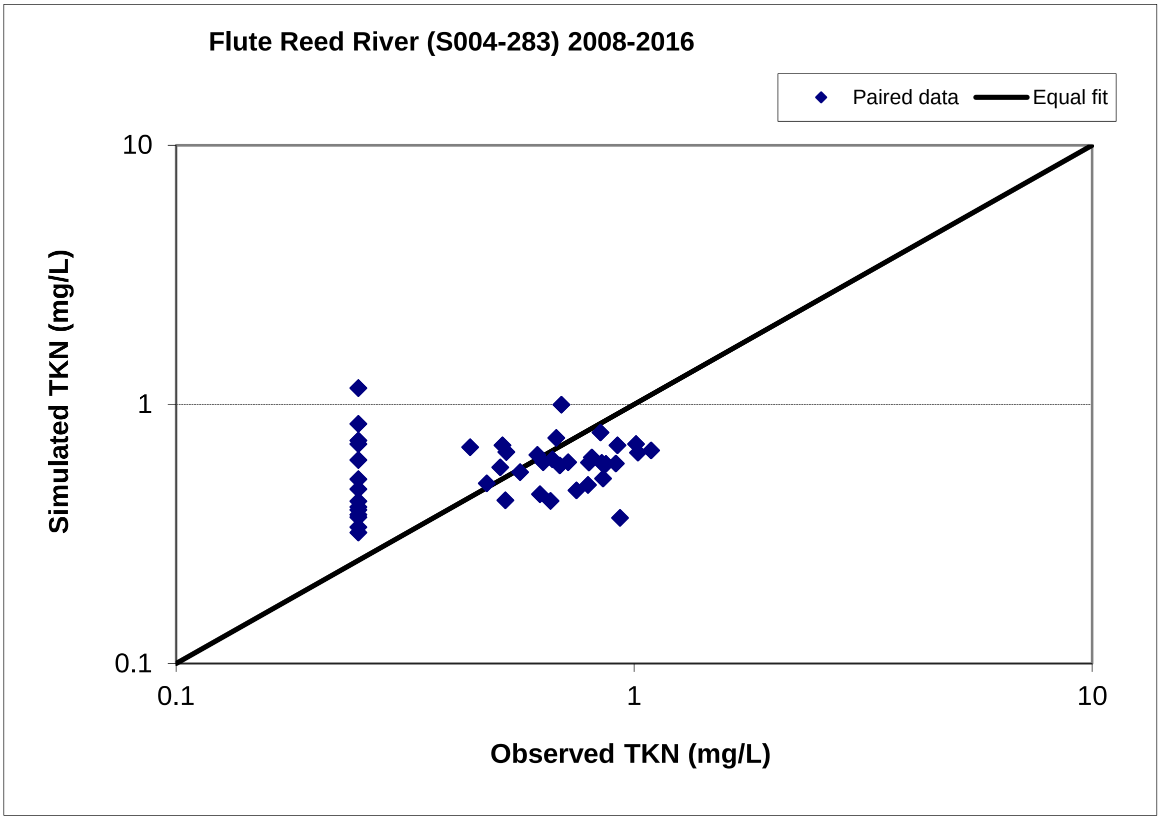


Figure 81. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Flute Reed River (S004-283)

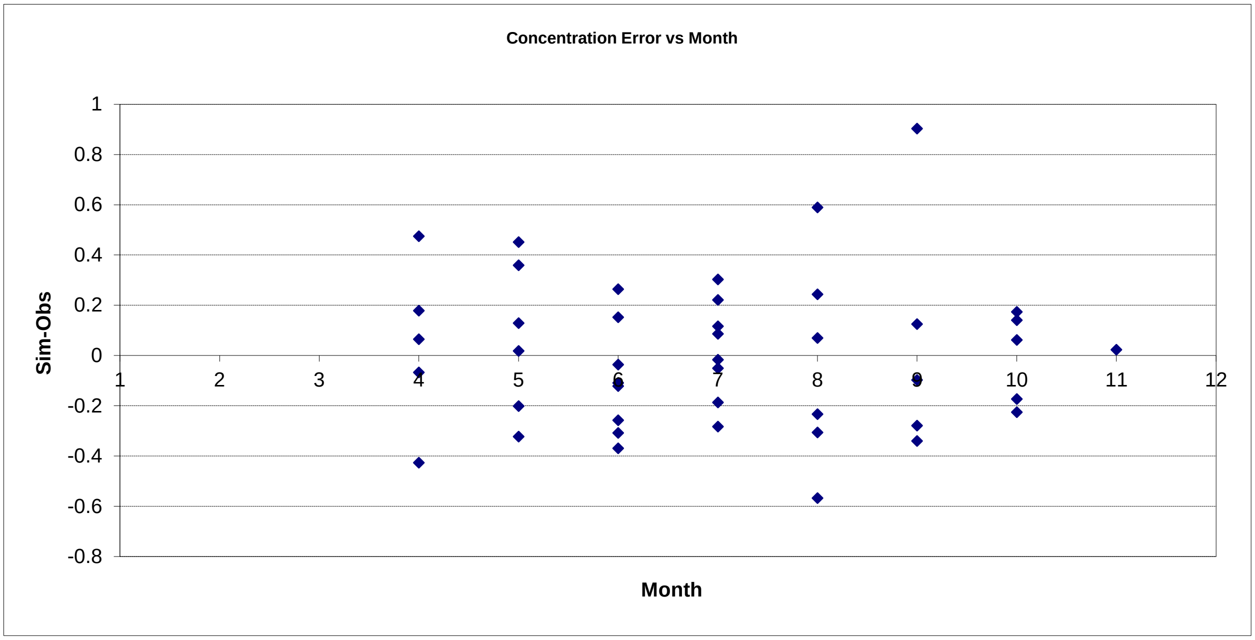


Figure 82. Residual (Simulated - Observed) vs. Month Total Kjeldahl Nitrogen (TKN) at Flute Reed River (S004-283)

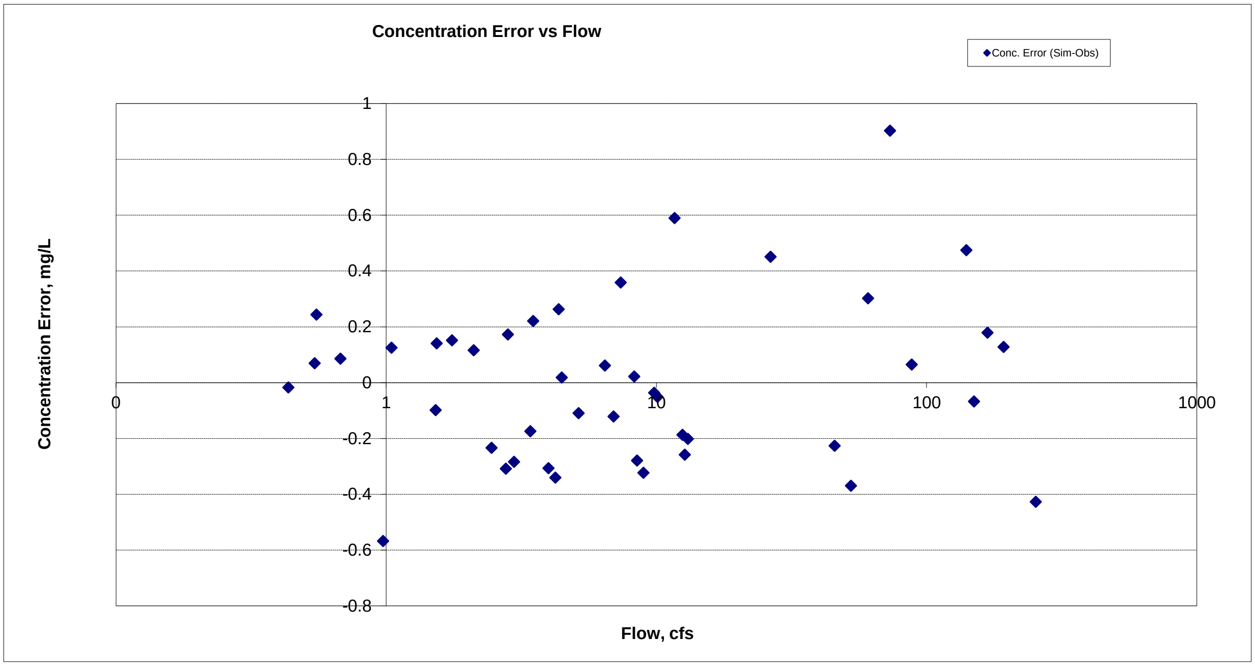


Figure 83. Residual (Simulated - Observed) vs. Flow Total Kjeldahl Nitrogen (TKN) at Flute Reed River (S004-283)

Nitrite+ Nitrate Nitrogen (NOx)

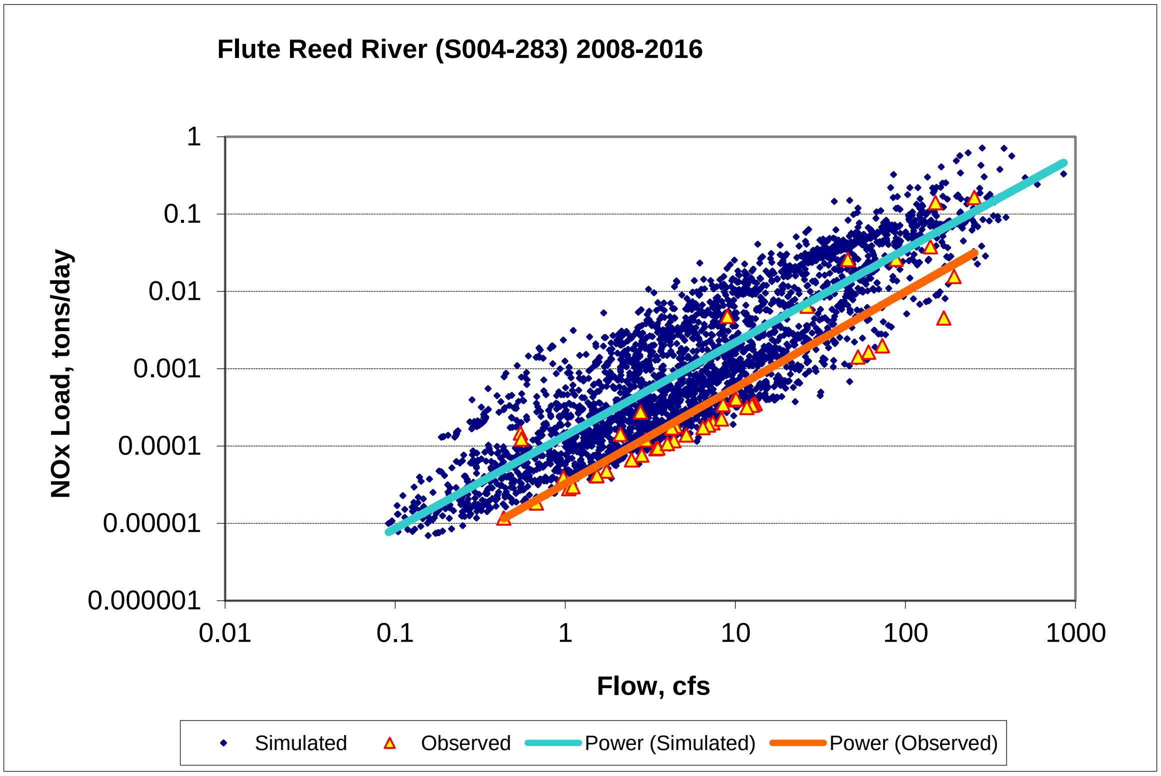


Figure 84. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Flute Reed River (S004-283)

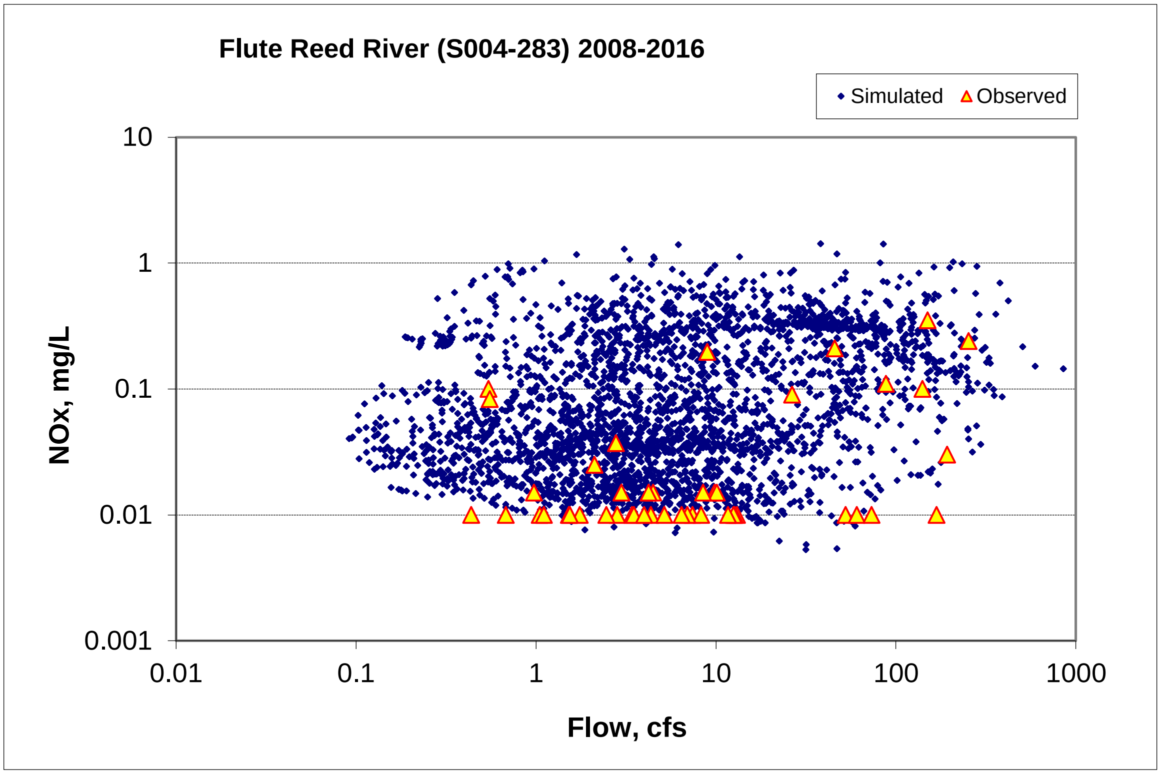


Figure 85. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Flute Reed River (S004-283)

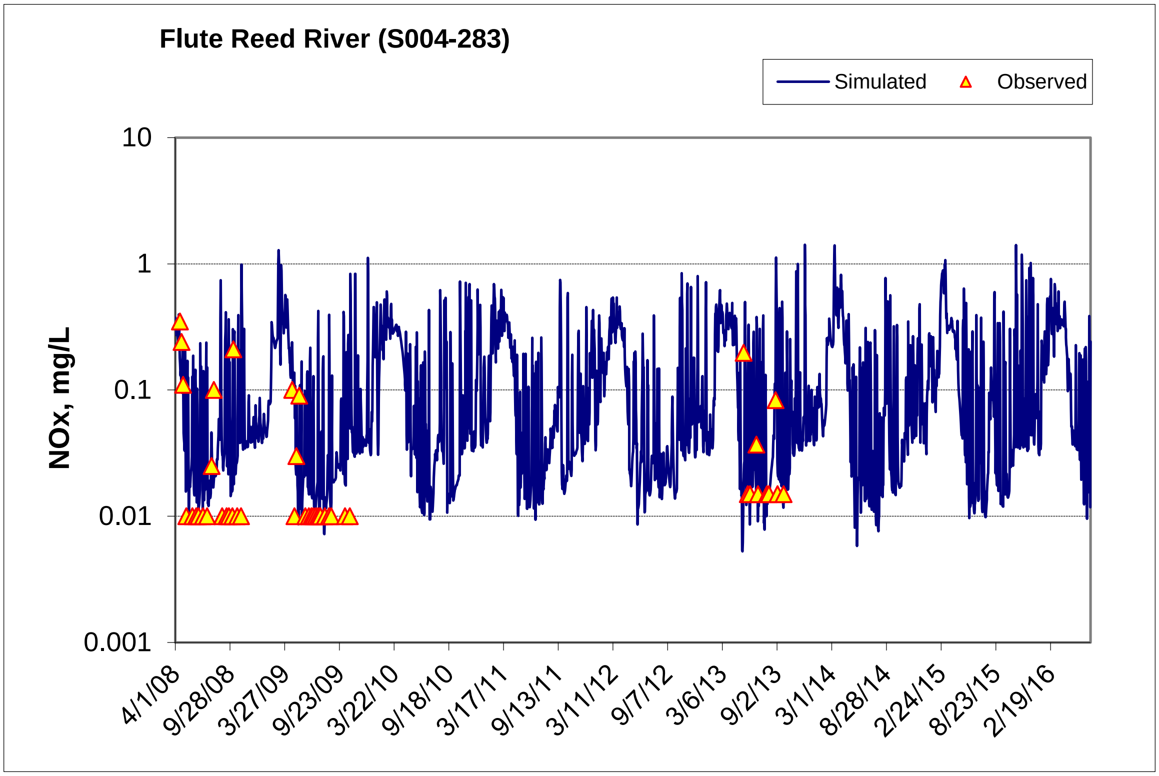


Figure 86. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Flute Reed River (S004-283)

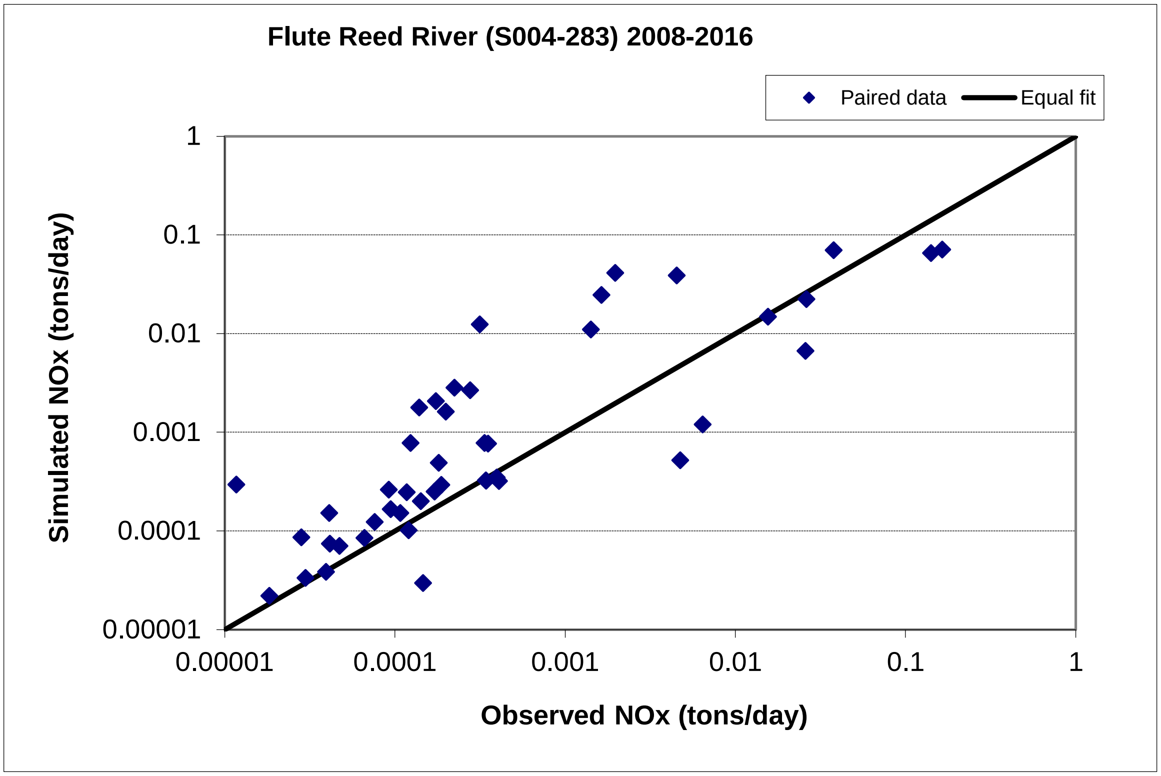


Figure 87. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Flute Reed River (S004-283)

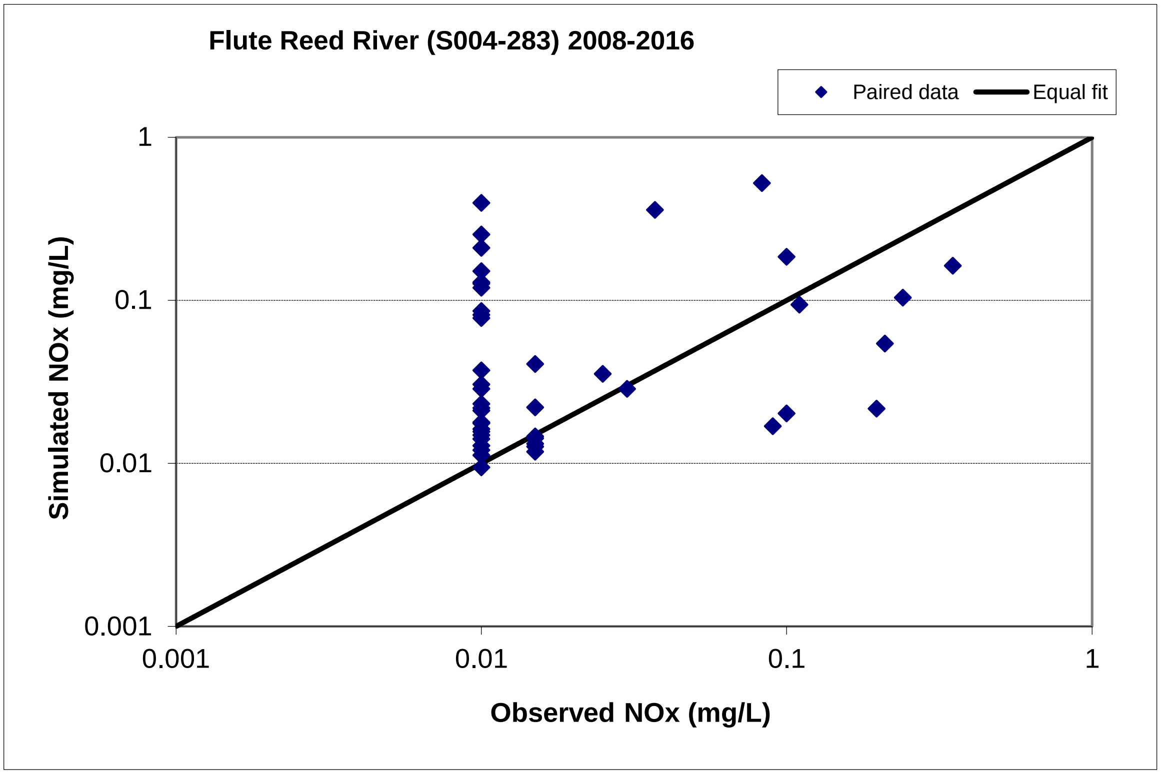


Figure 88. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Flute Reed River (S004-283)

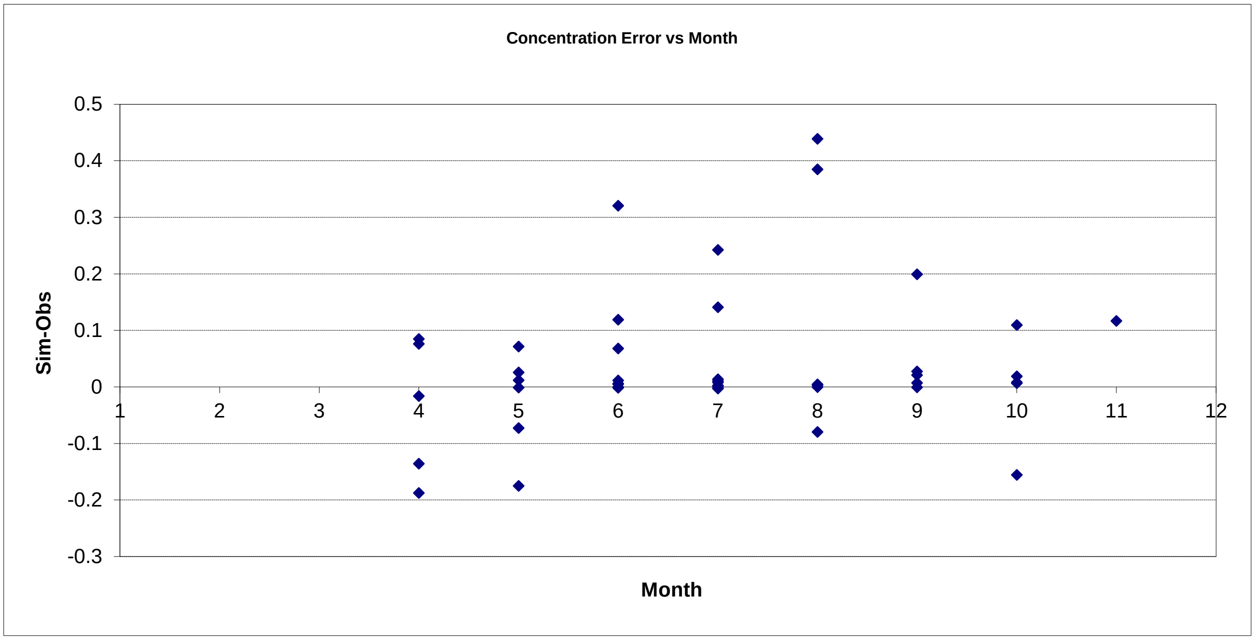


Figure 89. Residual (Simulated - Observed) vs. Month Nitrite+ Nitrate Nitrogen (NOx) at Flute Reed River (S004-283)

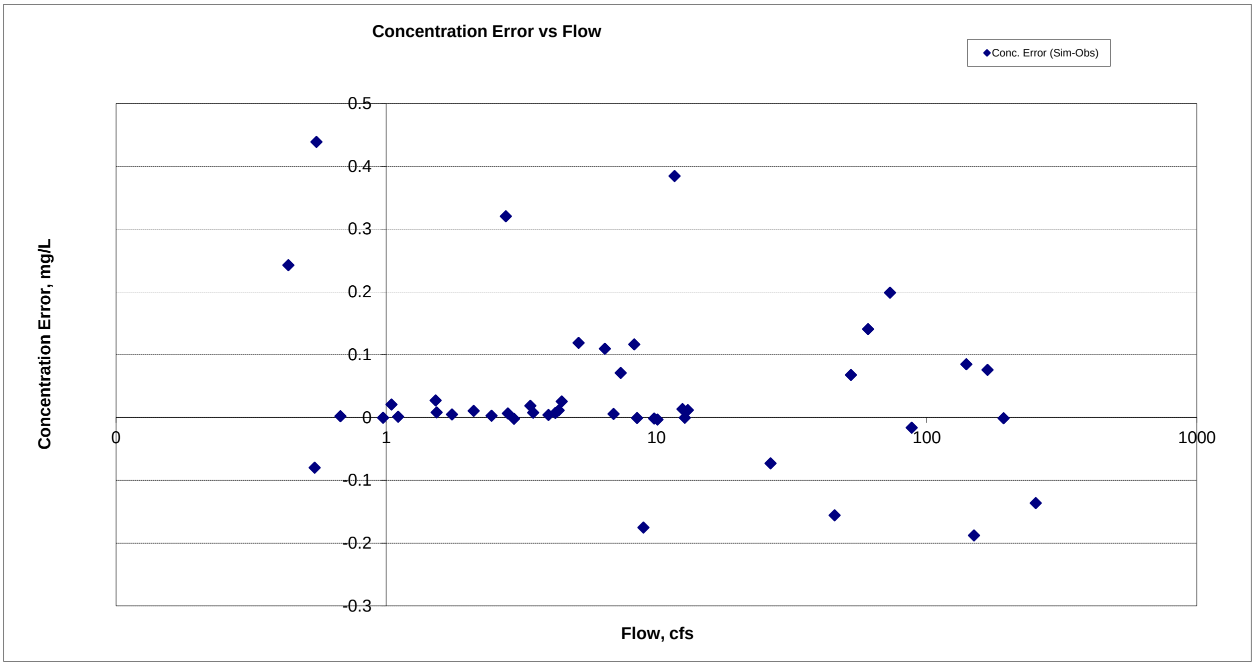


Figure 90. Residual (Simulated - Observed) vs. Flow Nitrite+ Nitrate Nitrogen (NOx) at Flute Reed River (S004-283)

Total Nitrogen (TN)

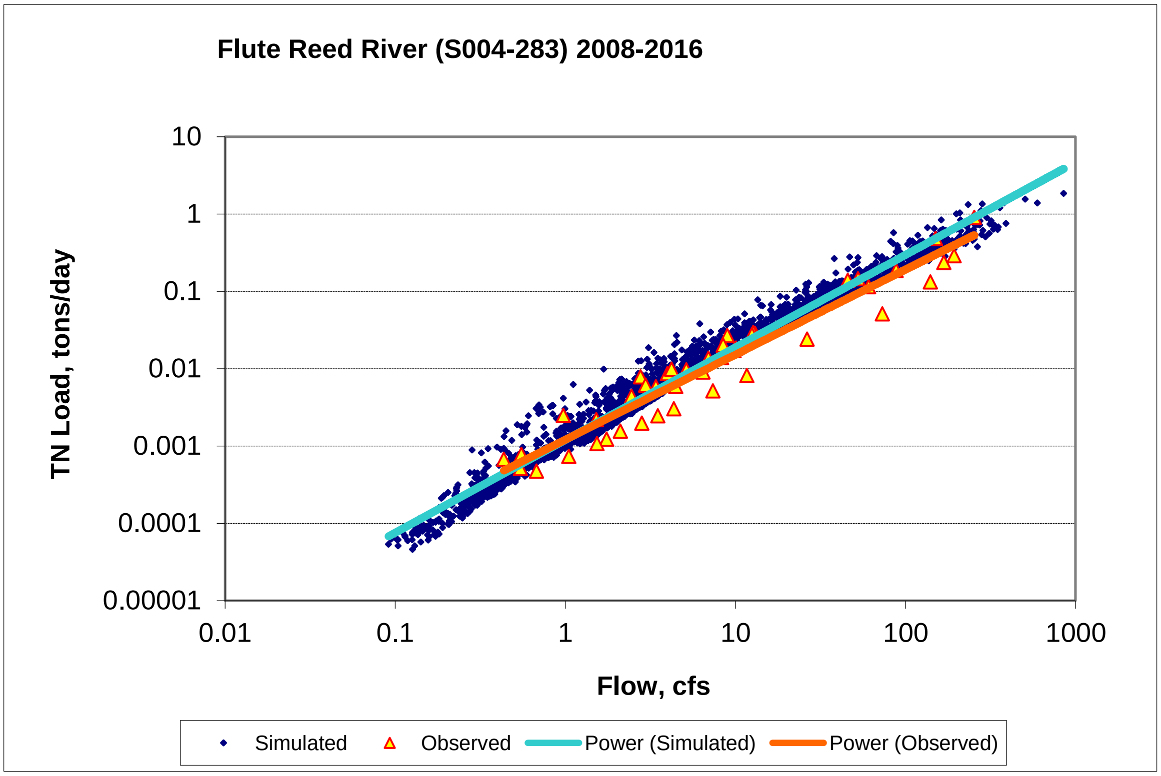


Figure 91. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Flute Reed River (S004-283)

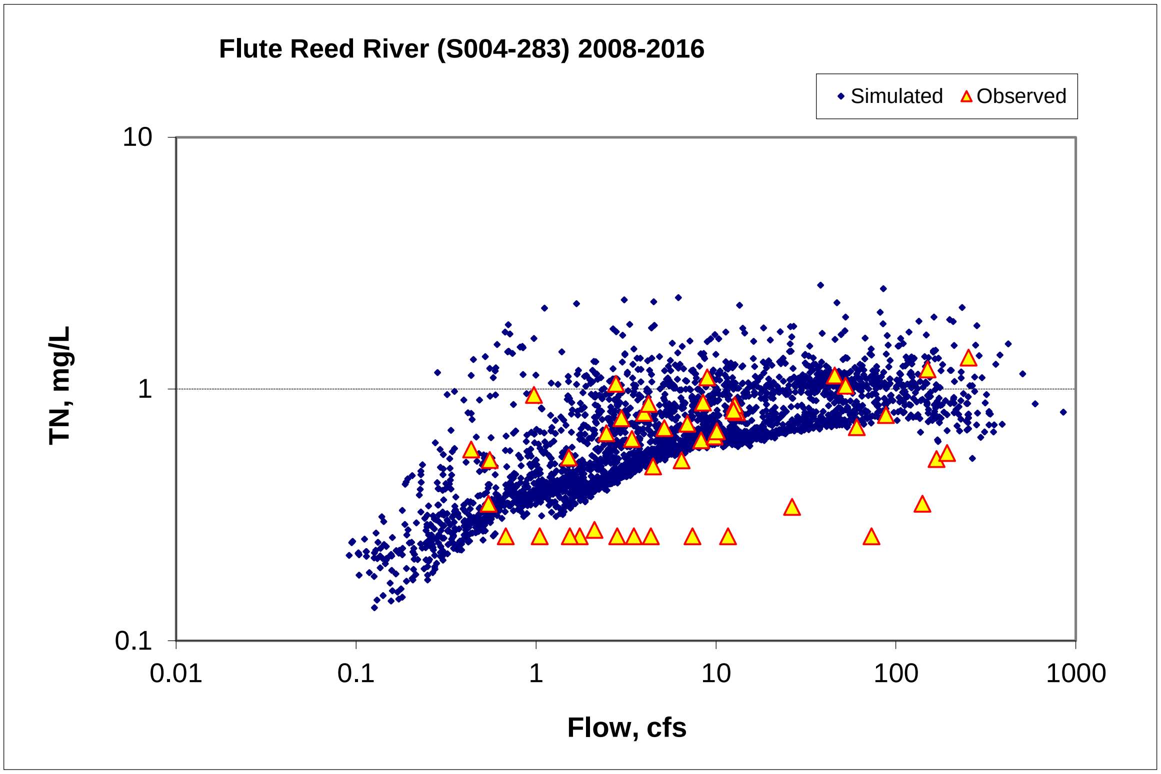


Figure 92. Simulated and observed Total Nitrogen (TN) concentration vs flow at Flute Reed River (S004-283)

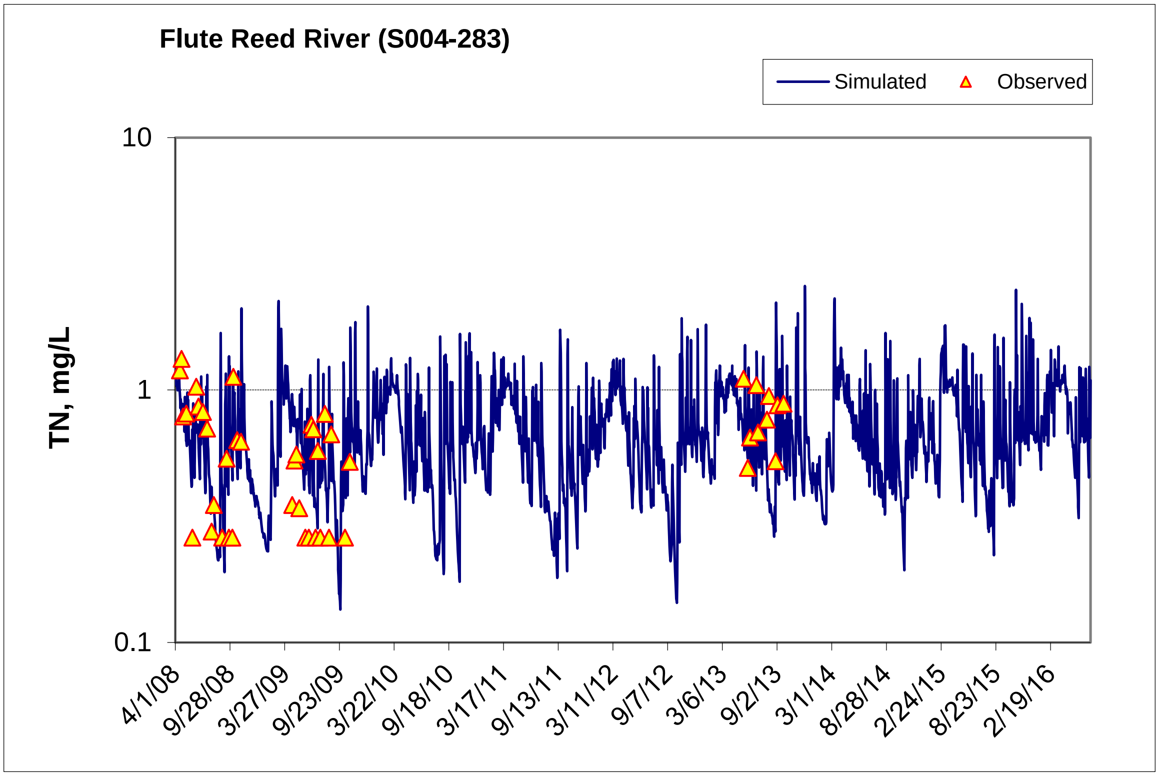


Figure 93. Time series of observed and simulated Total Nitrogen (TN) concentration at Flute Reed River (S004-283)

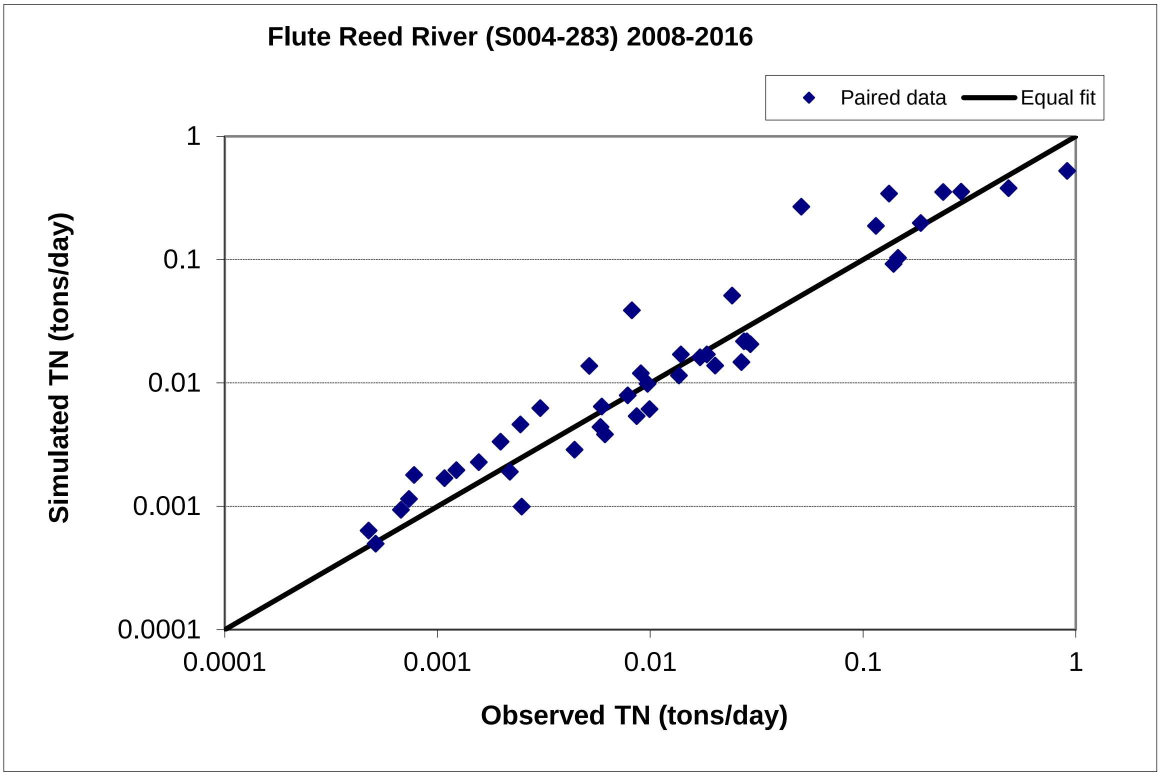


Figure 94. Paired simulated vs. observed Total Nitrogen (TN) load at Flute Reed River (S004-283)

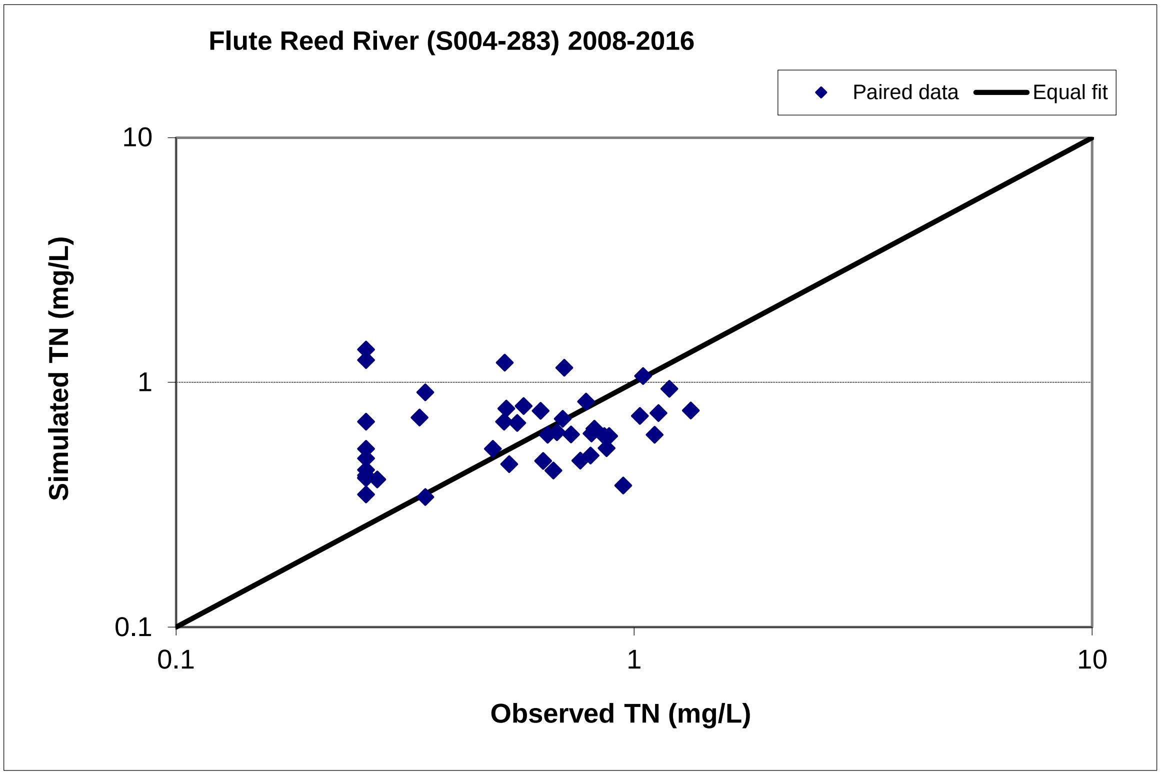


Figure 95. Paired simulated vs. observed Total Nitrogen (TN) concentration at Flute Reed River (S004-283)

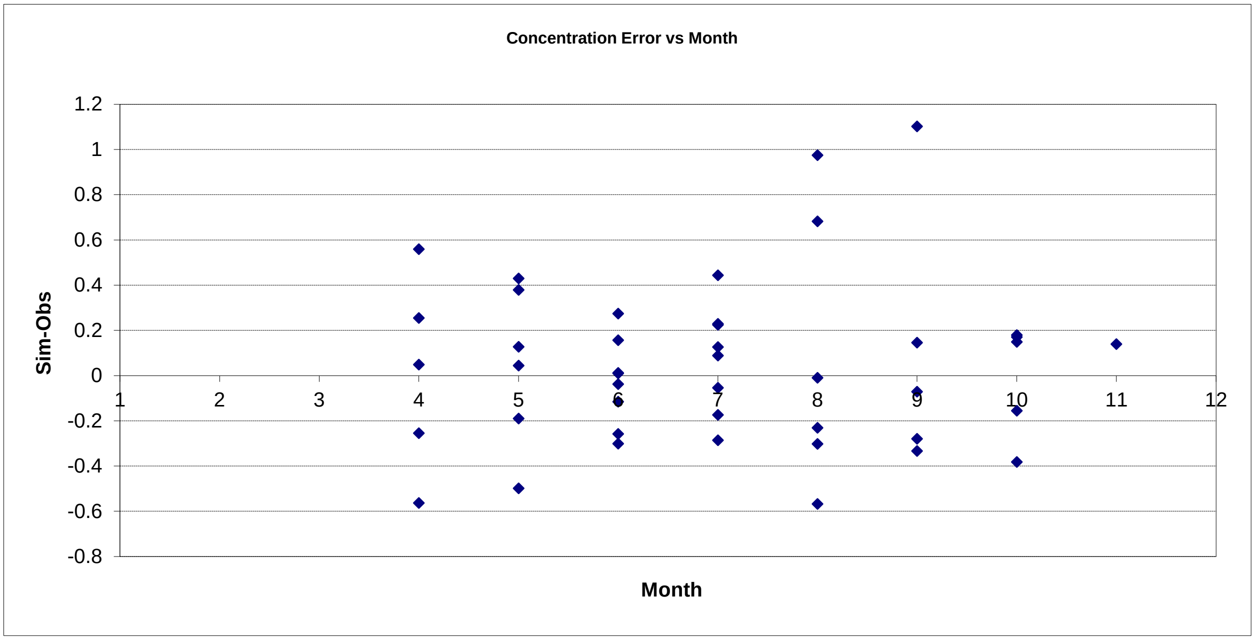


Figure 96. Residual (Simulated - Observed) vs. Month Total Nitrogen (TN) at Flute Reed River (S004-283)

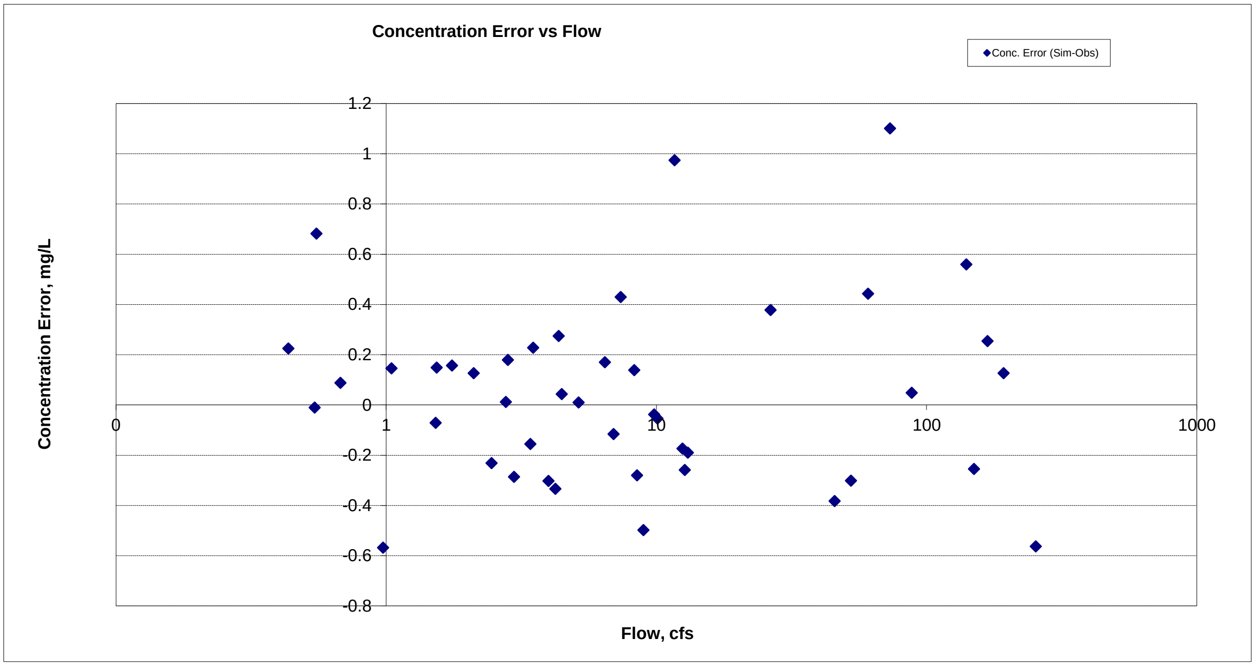


Figure 97. Residual (Simulated - Observed) vs. Flow Total Nitrogen (TN) at Flute Reed River (S004-283)

Soluble Reactive Phosphorus (SRP)

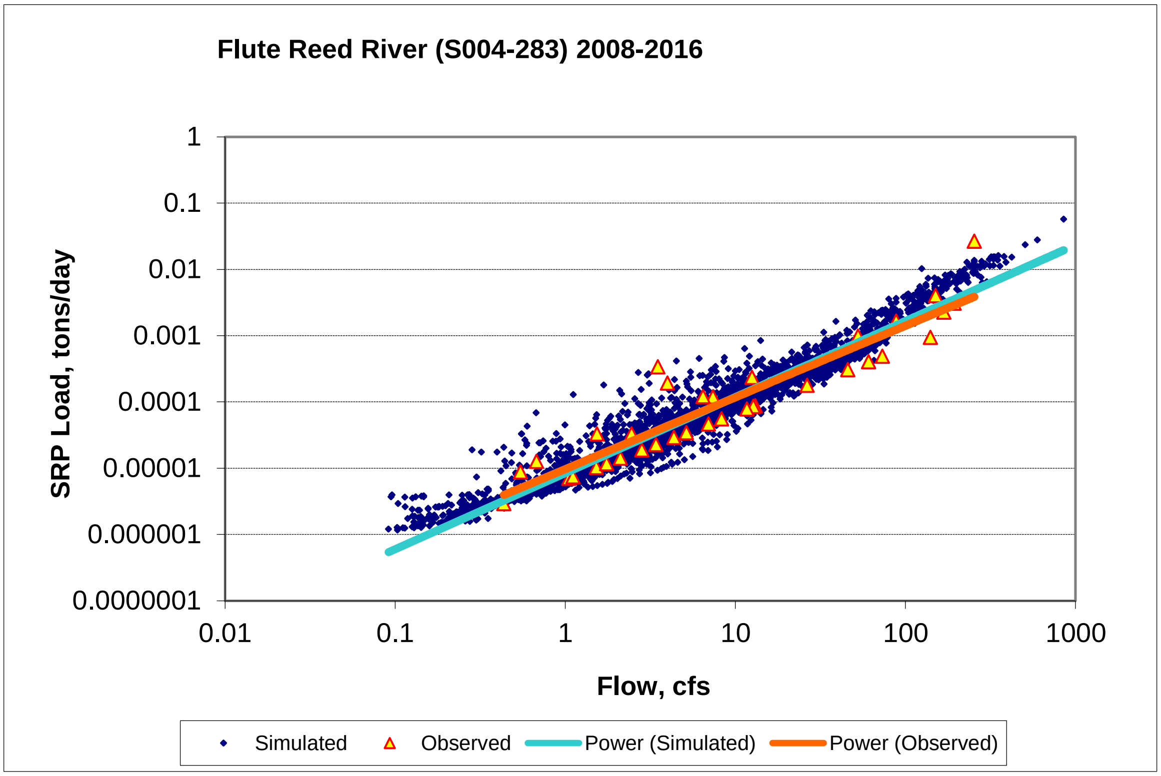


Figure 98. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Flute Reed River (S004-283)

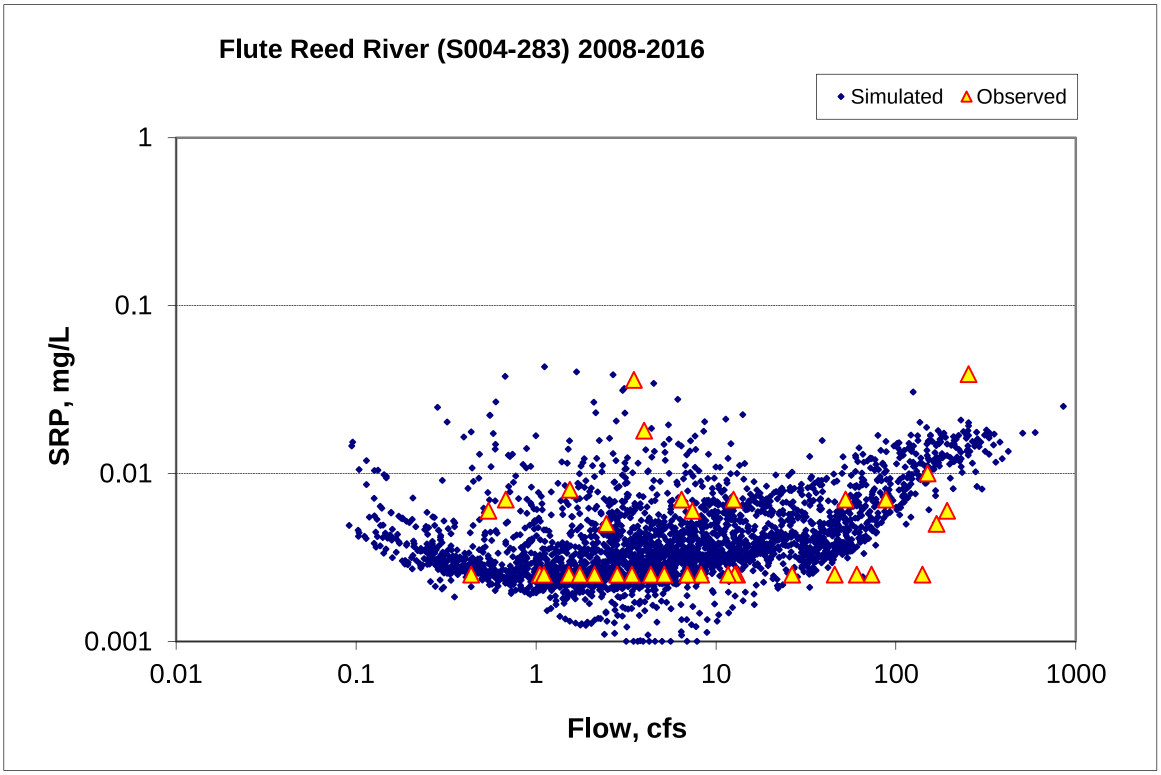


Figure 99. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at Flute Reed River (S004-283)

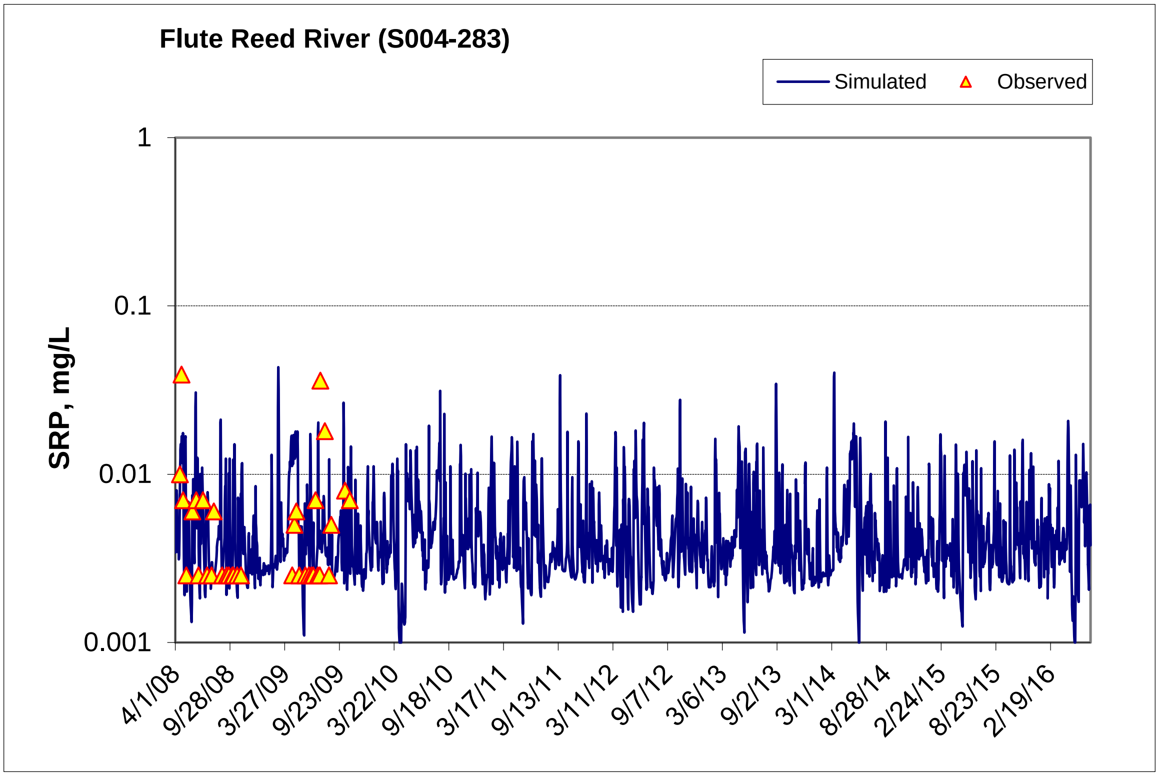


Figure 100. Time series of observed and simulated Soluble Reactive Phosphorus (SRP) concentration at Flute Reed River (S004-283)

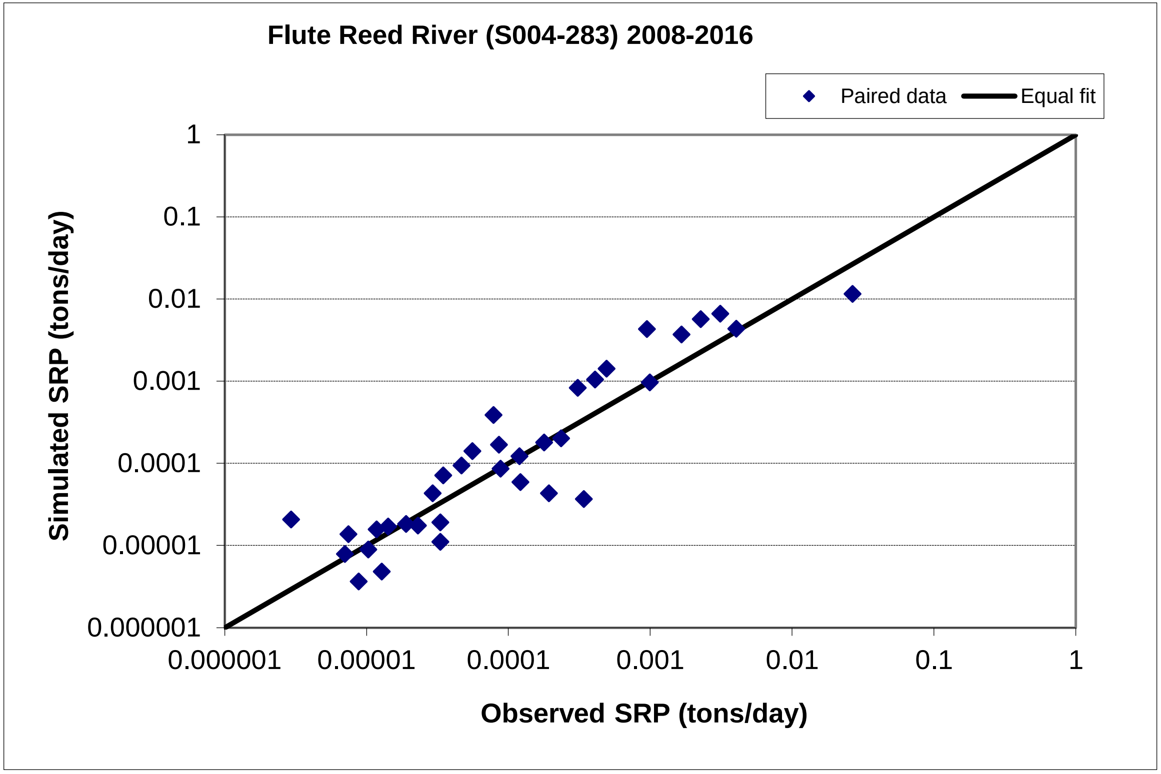


Figure 101. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at Flute Reed River (S004-283)

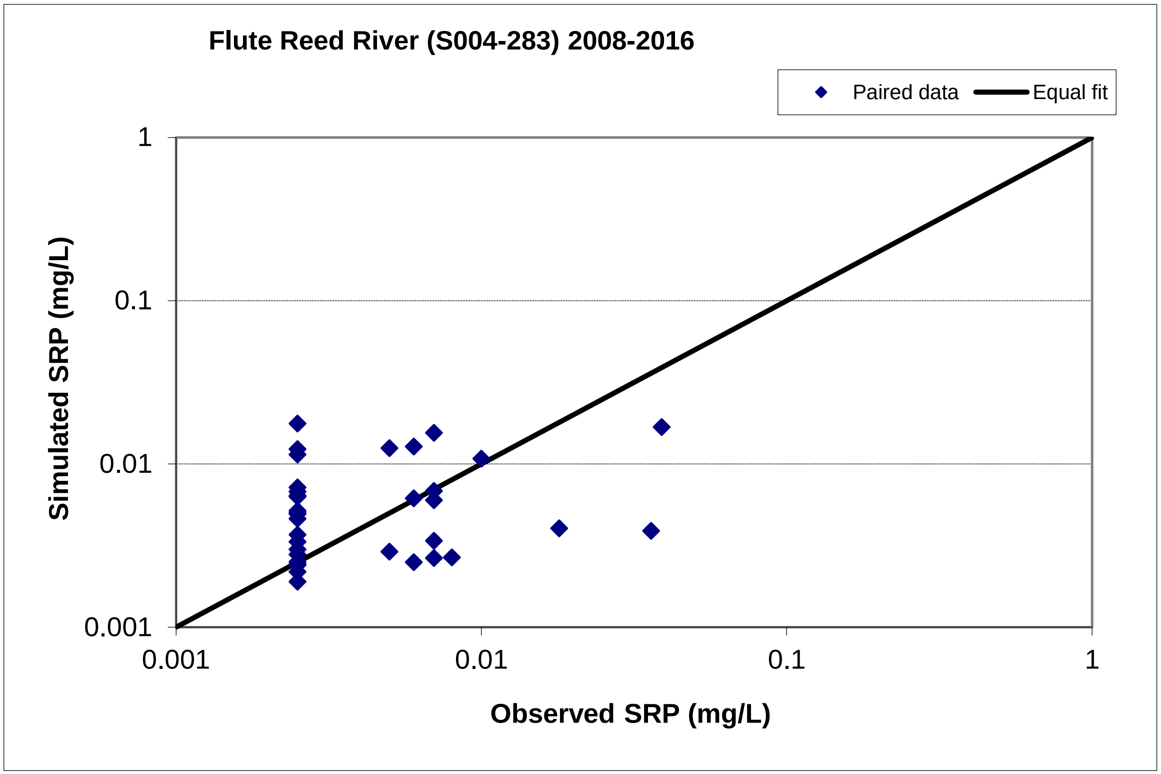


Figure 102. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at Flute Reed River (S004-283)

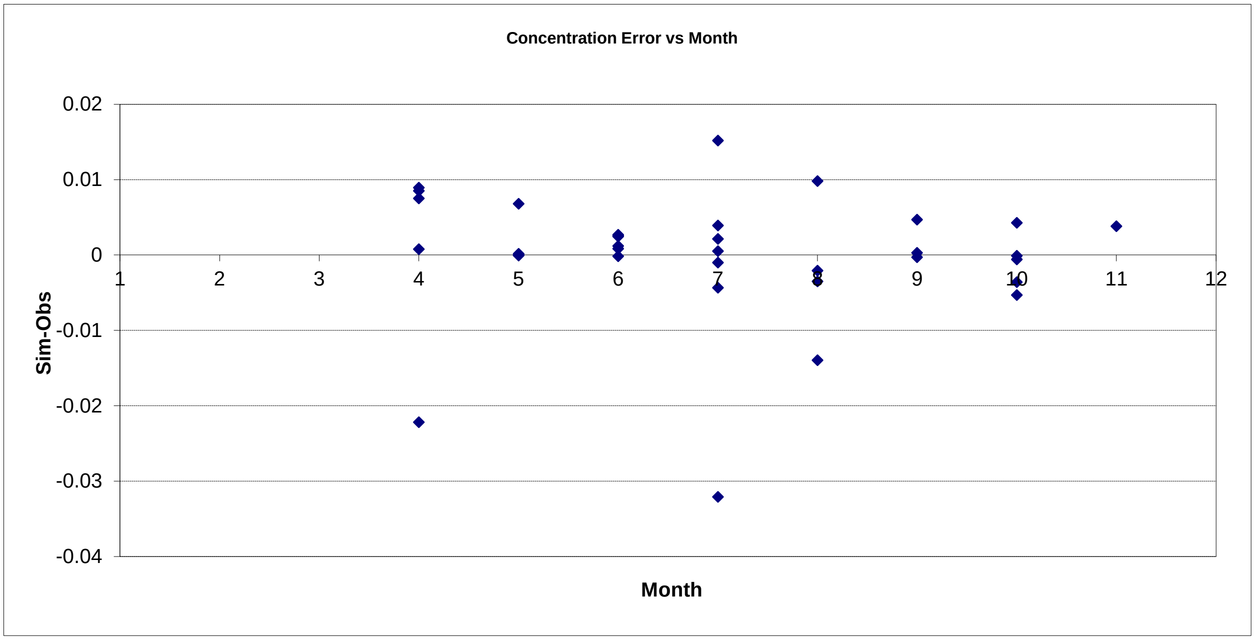


Figure 103. Residual (Simulated - Observed) vs. Month Soluble Reactive Phosphorus (SRP) at Flute Reed River (S004-283)

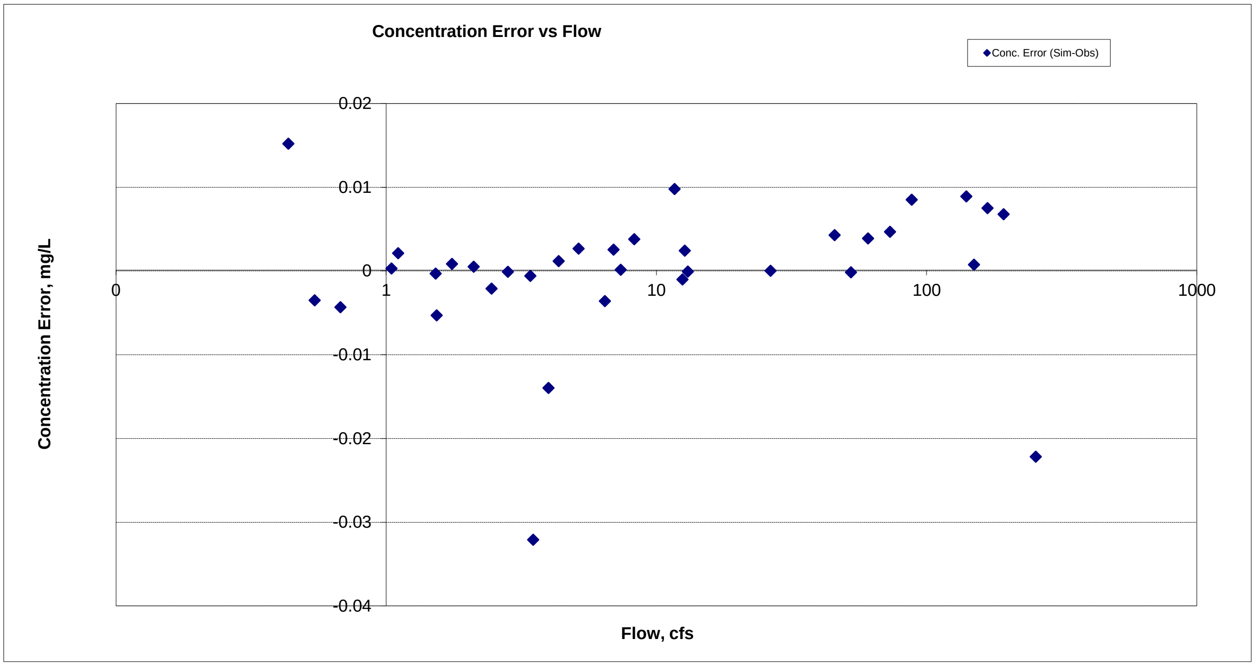


Figure 104. Residual (Simulated - Observed) vs. Flow Soluble Reactive Phosphorus (SRP) at Flute Reed River (S004-283)

Organic Phosphorus (OrgP)

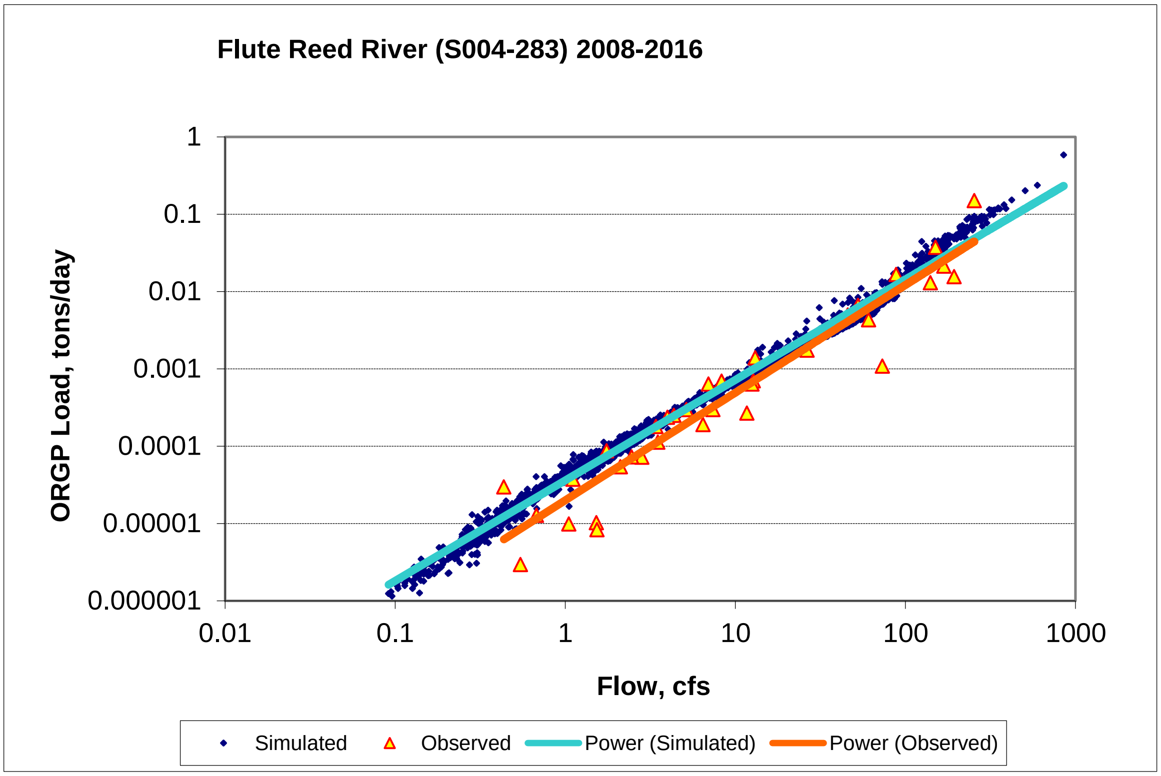


Figure 105. Power plot of simulated and observed Organic Phosphorus (OrgP) load vs flow at Flute Reed River (S004-283)

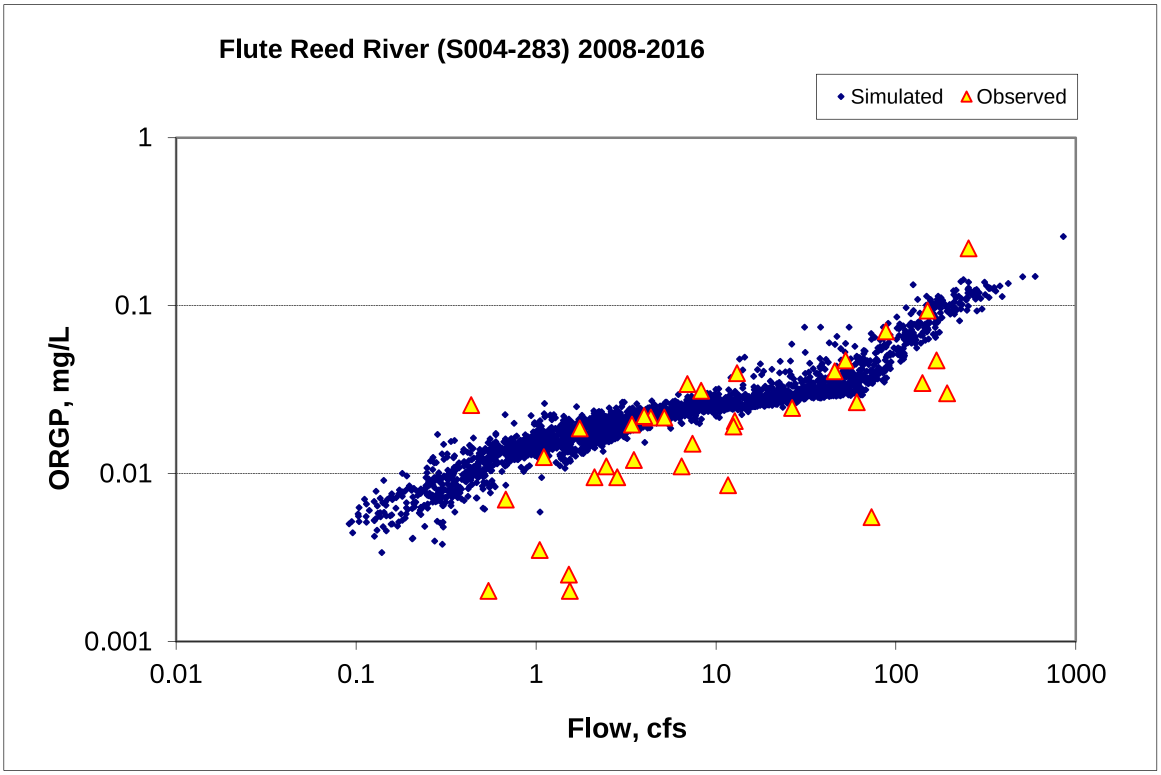


Figure 106. Simulated and observed Organic Phosphorus (OrgP) concentration vs flow at Flute Reed River (S004-283)

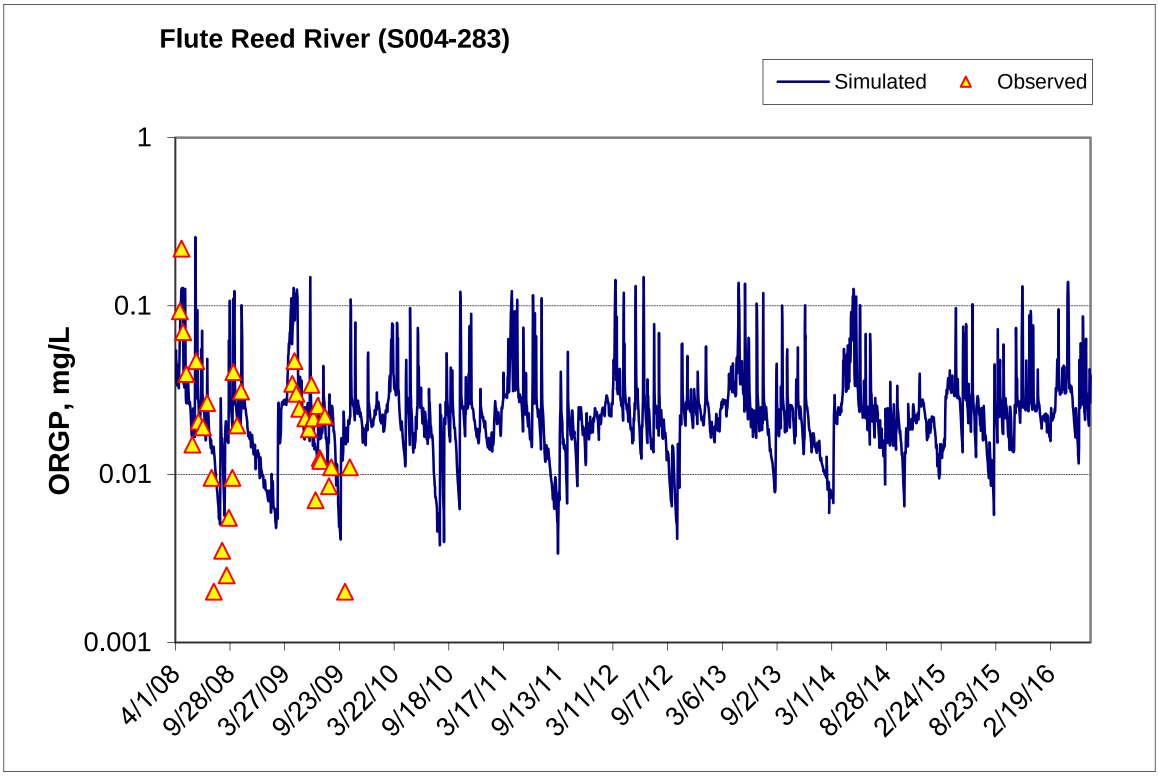


Figure 107. Time series of observed and simulated Organic Phosphorus (OrgP) concentration at Flute Reed River (S004-283)

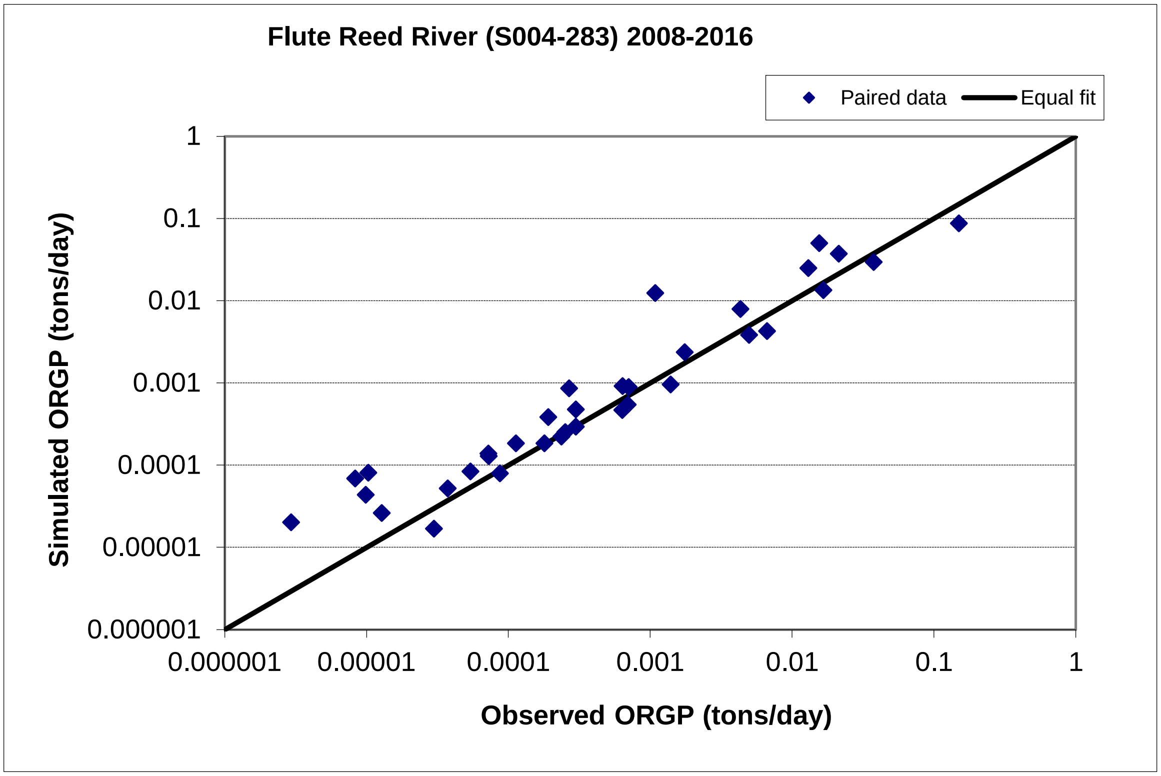


Figure 108. Paired simulated vs. observed Organic Phosphorus (OrgP) load at Flute Reed River (S004-283)

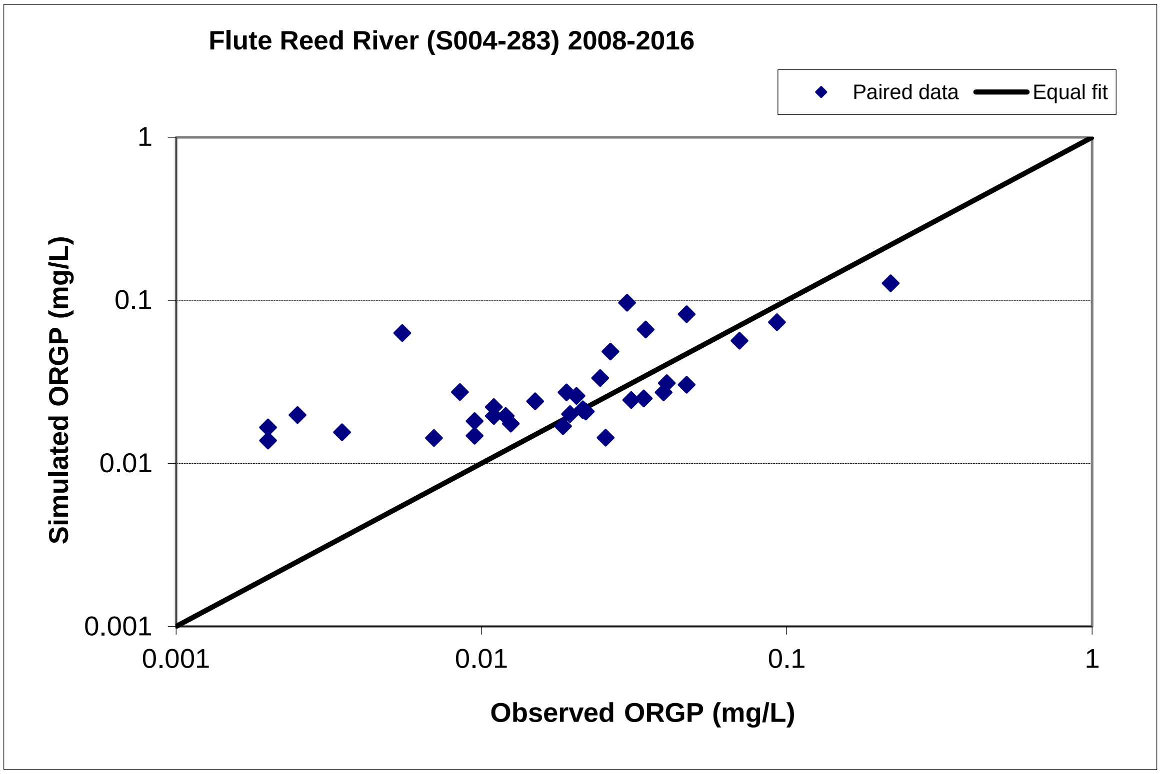


Figure 109. Paired simulated vs. observed Organic Phosphorus (OrgP) concentration at Flute Reed River (S004-283)

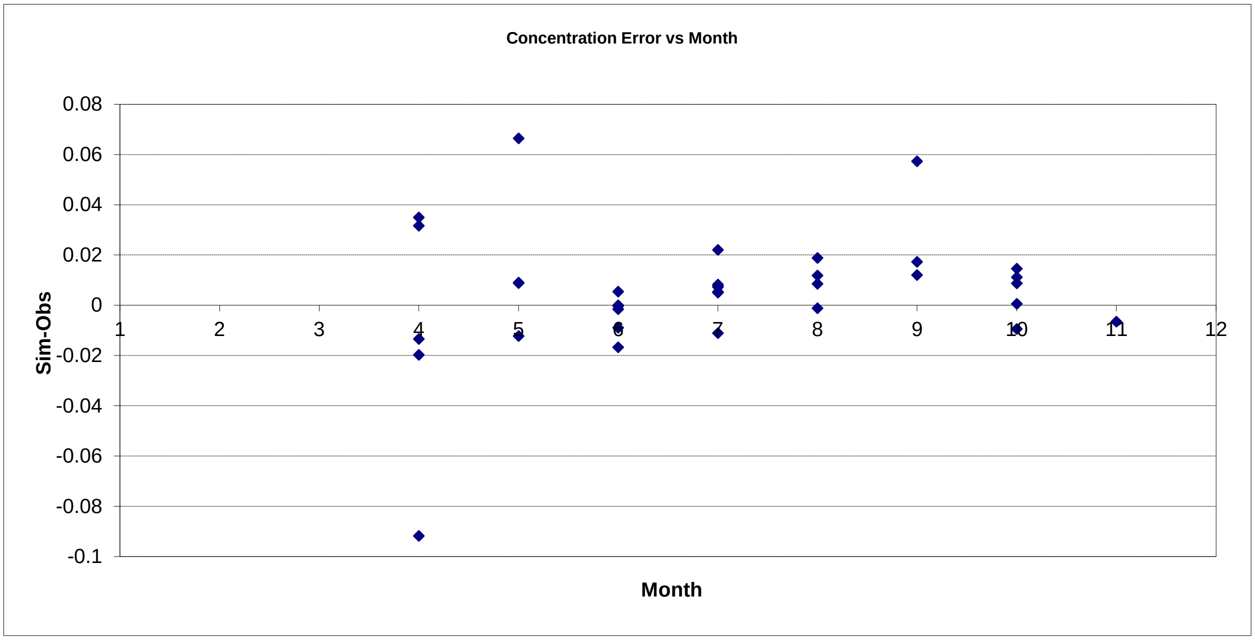


Figure 110. Residual (Simulated - Observed) vs. Month Organic Phosphorus (OrgP) at Flute Reed River (S004-283)

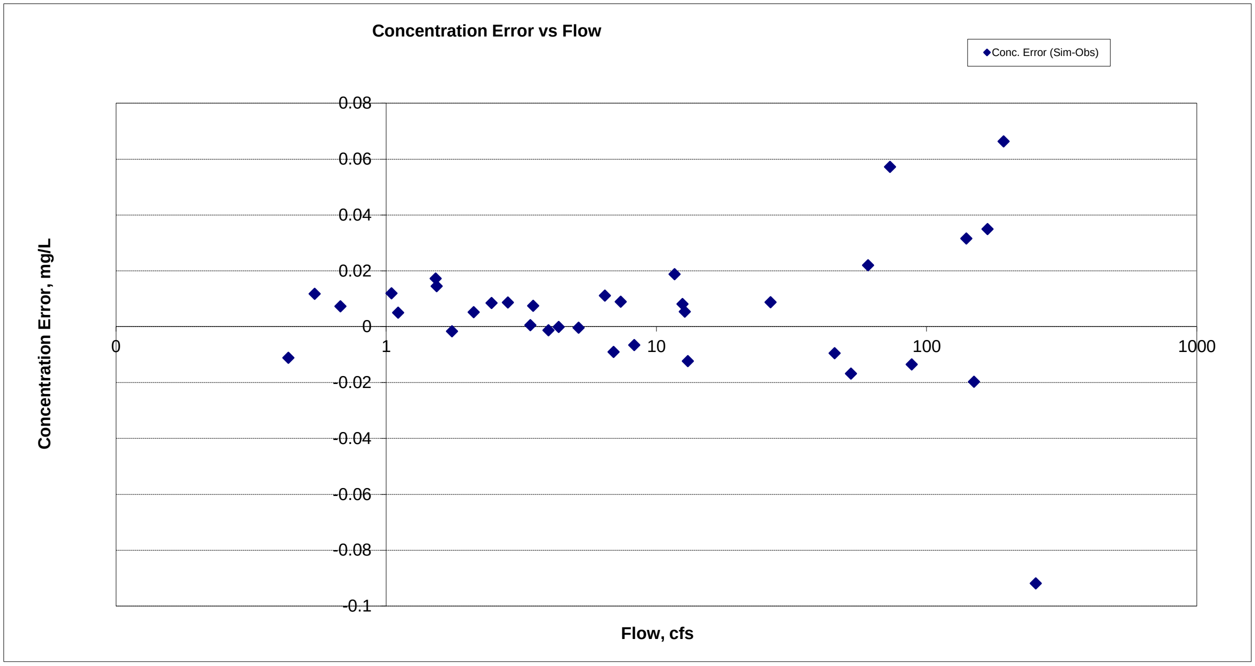


Figure 111. Residual (Simulated - Observed) vs. Flow Organic Phosphorus (OrgP) at Flute Reed River (S004-283)

Total Phosphorus (TP)

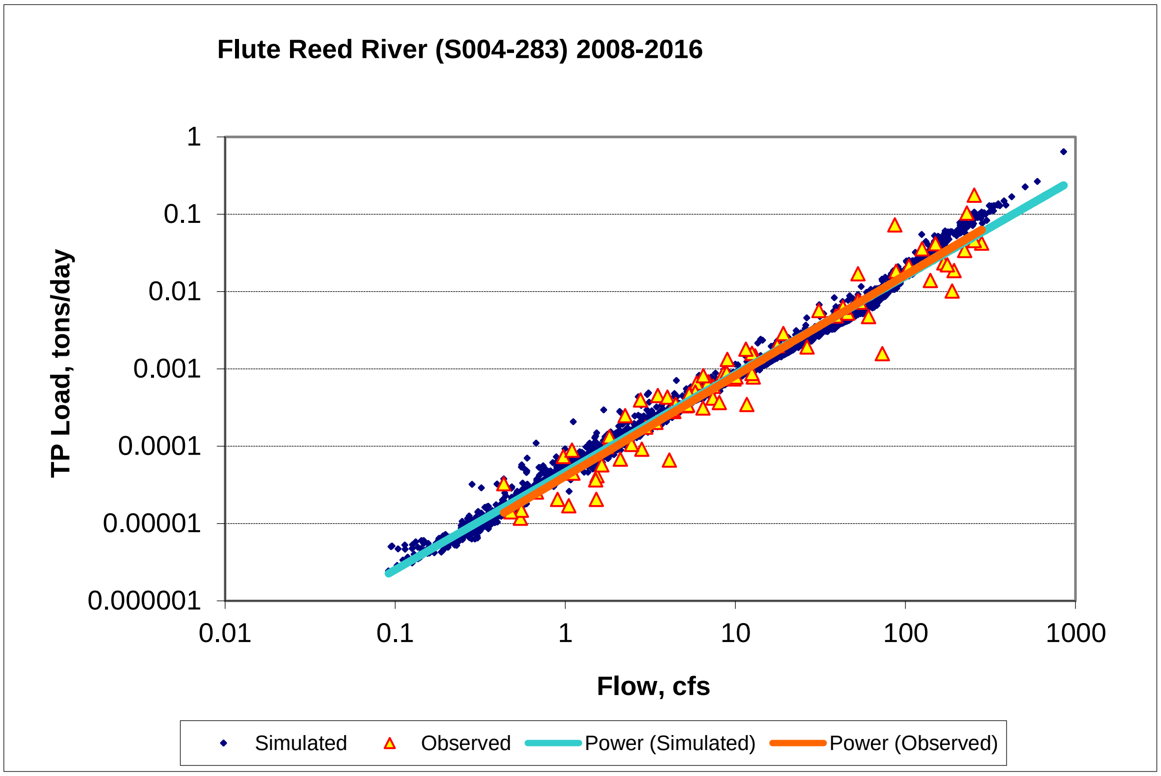


Figure 112. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Flute Reed River (S004-283)

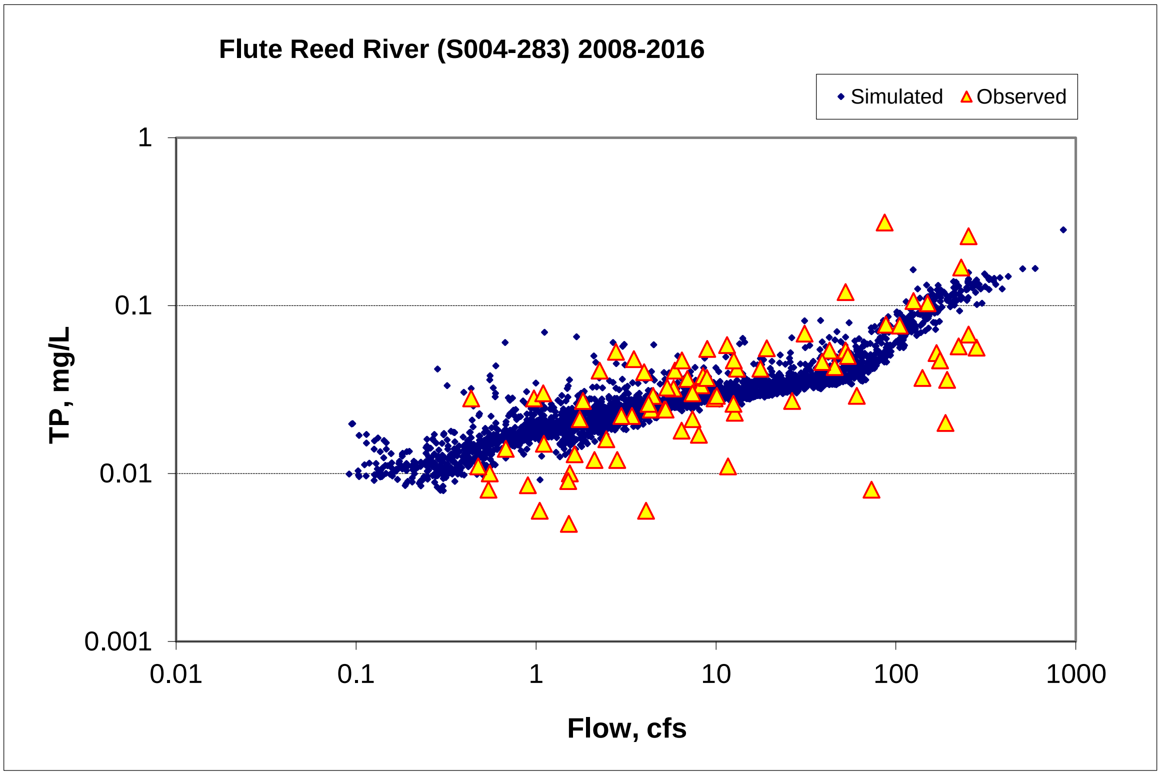


Figure 113. Simulated and observed Total Phosphorus (TP) concentration vs flow at Flute Reed River (S004-283)

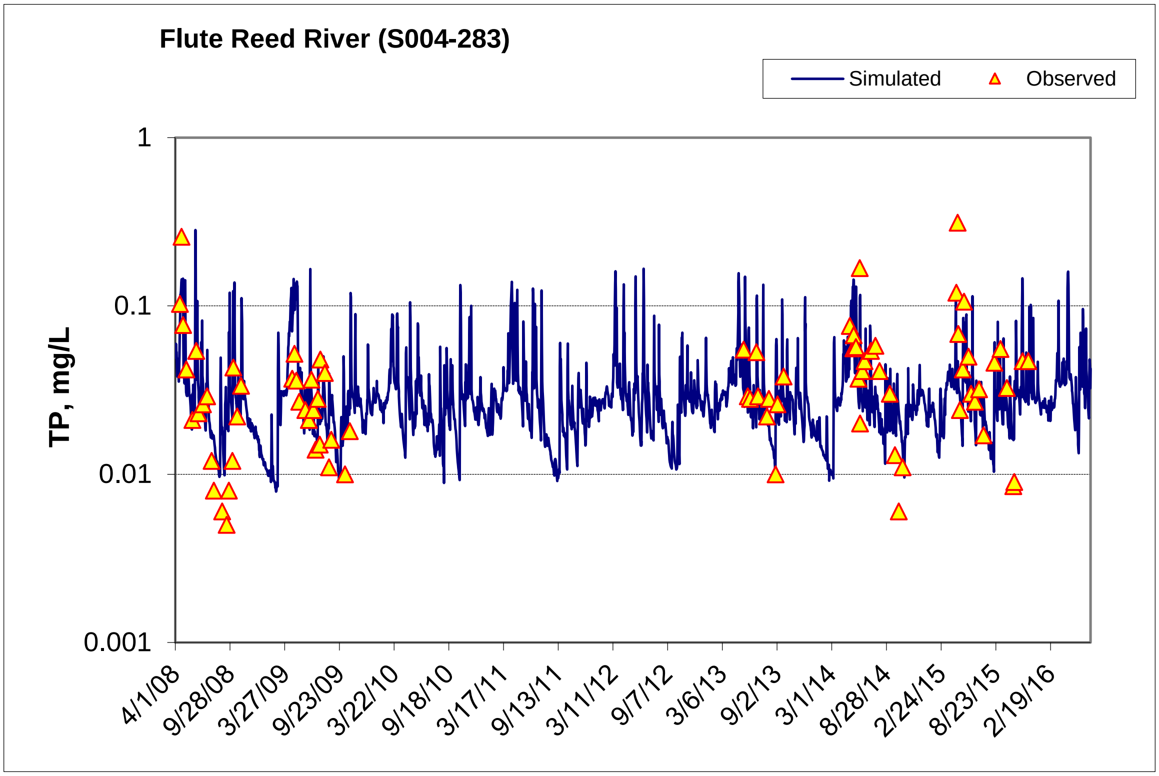


Figure 114. Time series of observed and simulated Total Phosphorus (TP) concentration at Flute Reed River (S004-283)

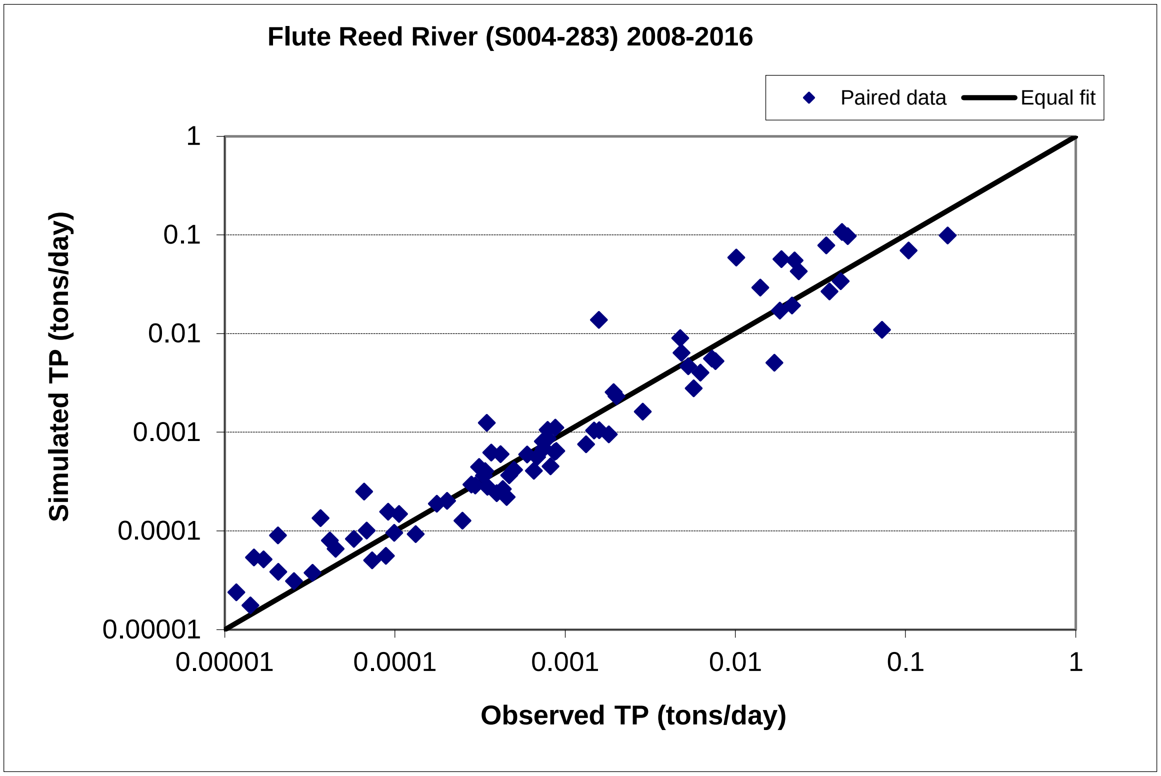


Figure 115. Paired simulated vs. observed Total Phosphorus (TP) load at Flute Reed River (S004-283)

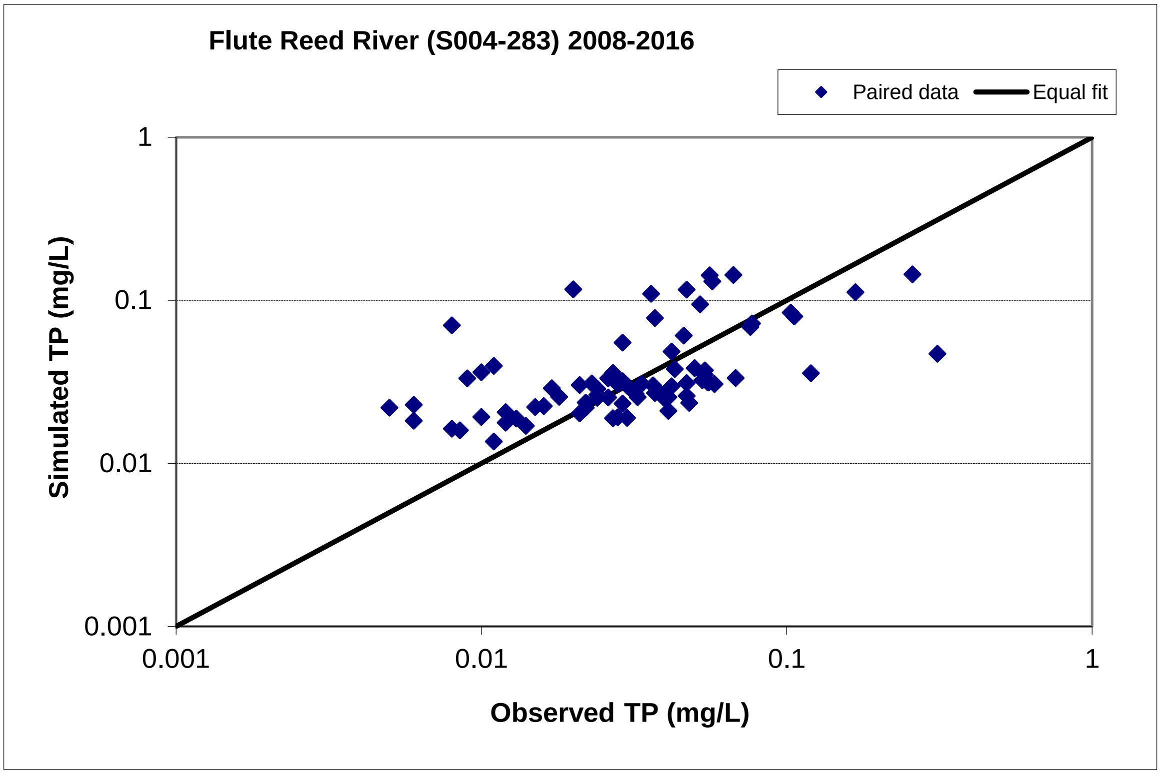


Figure 116. Paired simulated vs. observed Total Phosphorus (TP) concentration at Flute Reed River (S004-283)

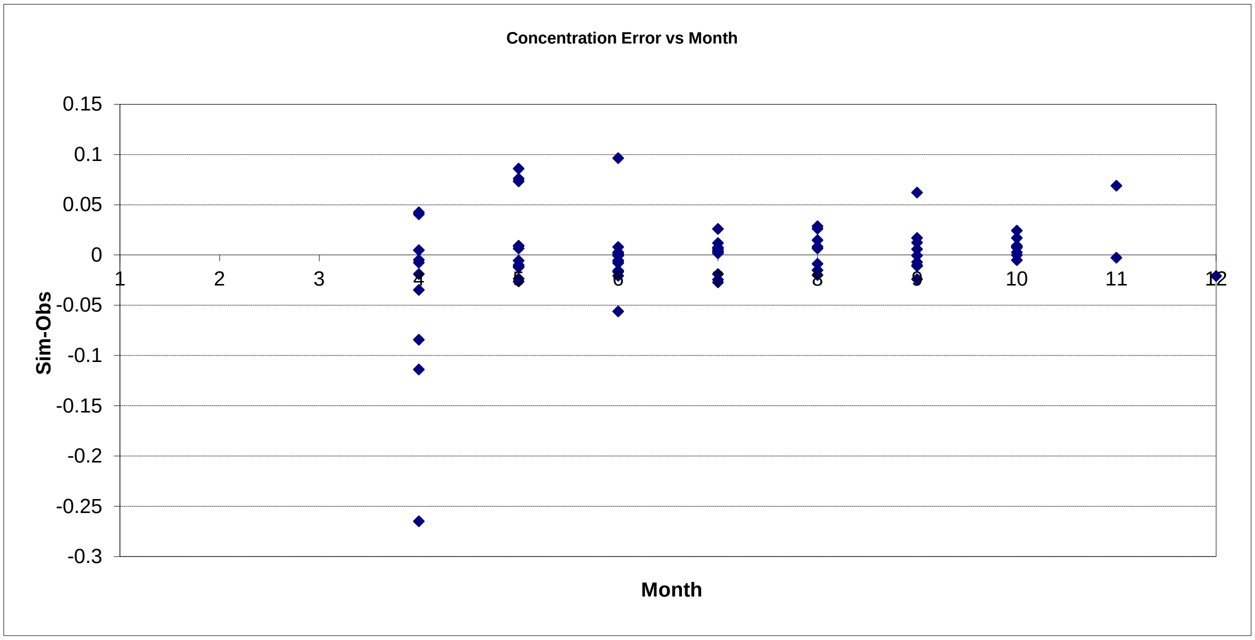


Figure 117. Residual (Simulated - Observed) vs. Month Total Phosphorus (TP) at Flute Reed River (S004-283)

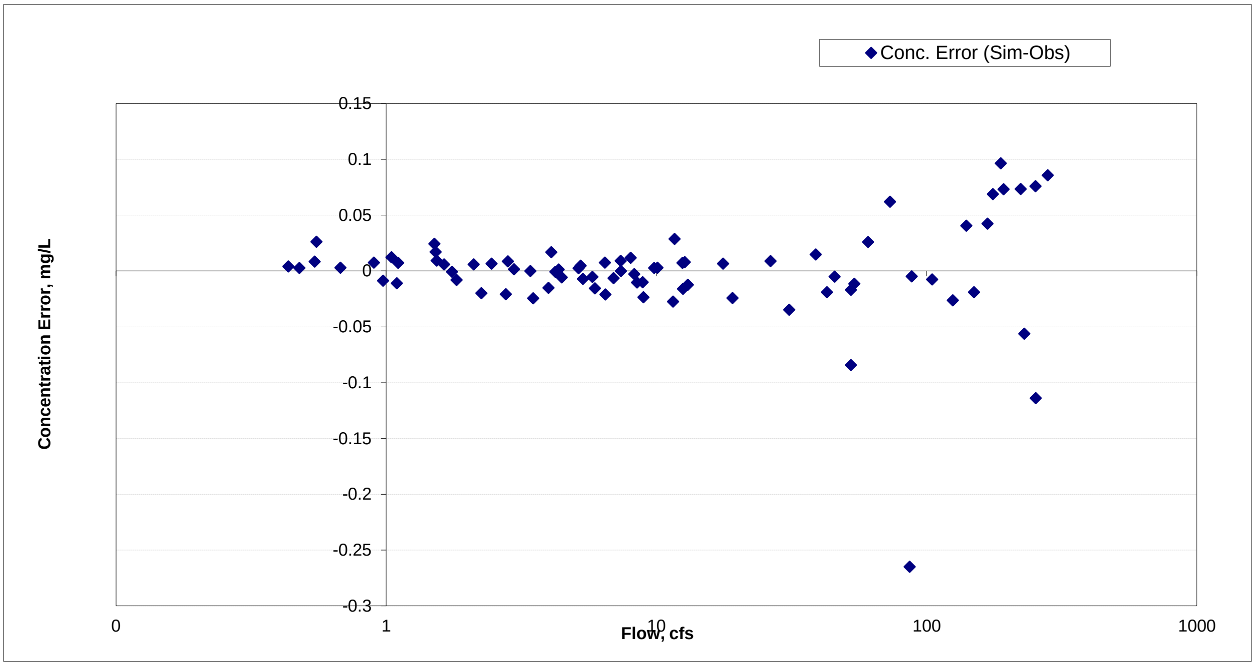
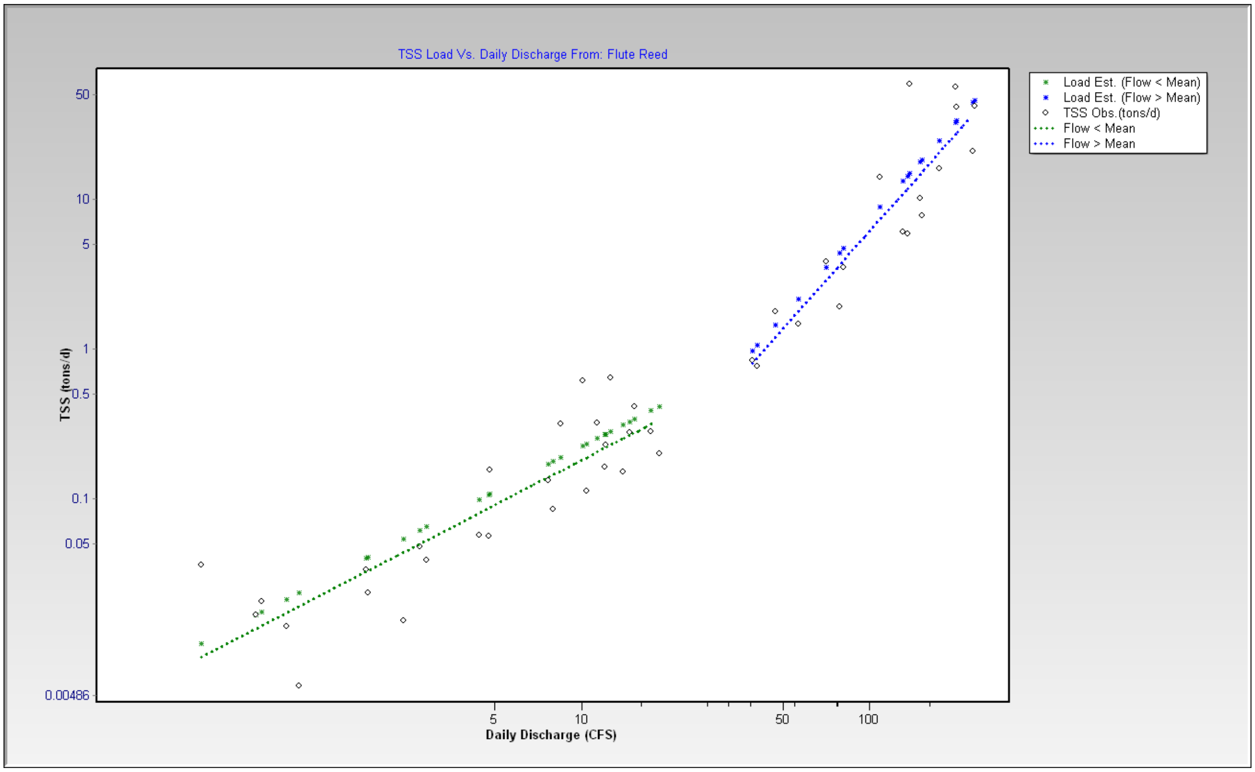


Figure 118. Residual (Simulated - Observed) vs. Flow Total Phosphorus (TP) at Flute Reed River (S004-283)

Appendix C - Regression Models

SEDIMENT

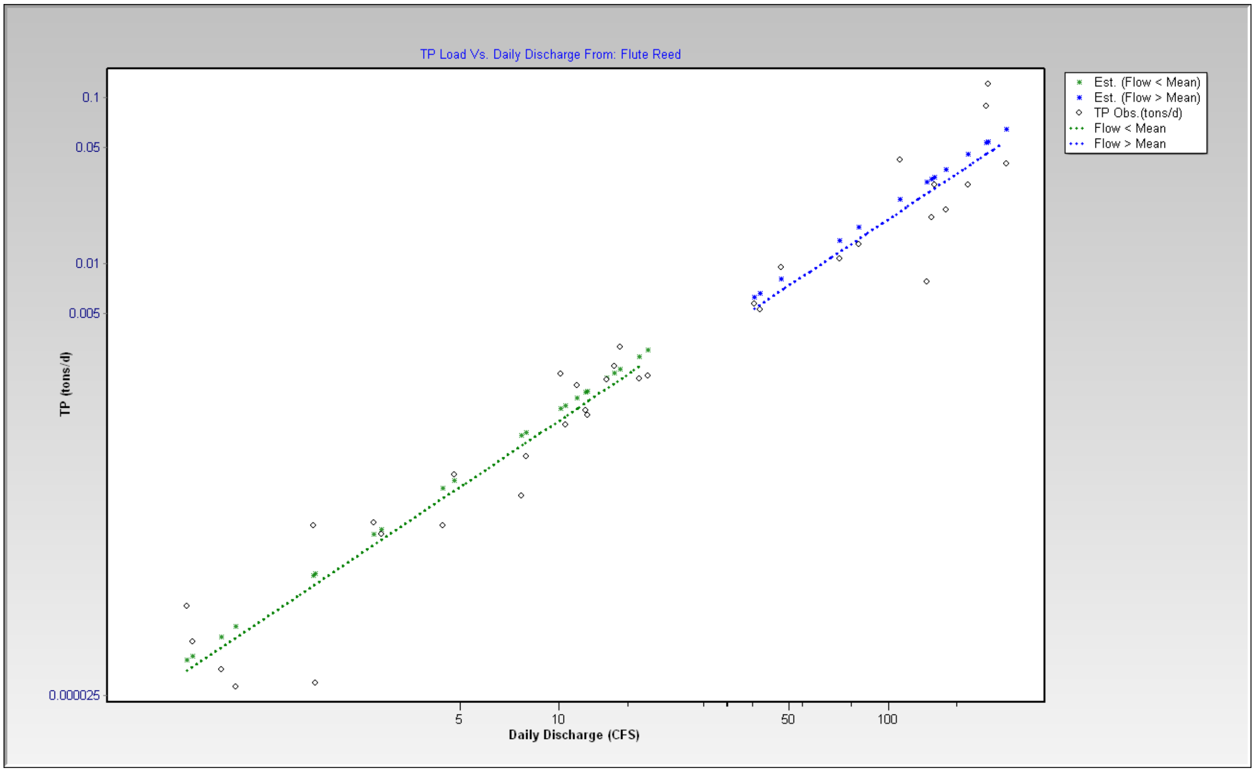


```
Log-Log Regression: Log(TSS (tons/d)) on Log(Daily Discharge (CFS))
Flux Estimation Method: 6 (C/Q Reg3(daily))
------------------------------------
Overall (No Strata)
  INTERCEPT (Log)     = -1.9410
  SLOPE               = 1.350690
  R²                  = 0.914
  MEAN SQUARED ERROR  = 0.1092
  STD. ERR. OF SLOPE  = 0.06338
  DEGREES OF FREEDOM  = 43
  T STATISTIC         = 21.310
  PROBABILITY(>|T|)   = 0.00000
  Y MEAN (Log)        = -0.2917
  Y STD DEV. (Log)    = 1.1110
  X MEAN (Log)        = 1.22090000
  X STD DEV. (Log)    = 0.7862
------------------------------------
 RESIDUALS ANALYSIS:
  RUNS TEST Z         = -0.8315
  PROBABILITY (>|Z|)  = 0.20282
  LAG-1 AUTOCORREL.   = -0.0129
  PROBABILITY (>|r|)  = 0.46546
  EFFECT. SMPL SIZE   = 45.00
  SLOPE SIGNIFICANCE  = 0.00000
------------------------------------
```

```
Regression Statistics By Stratum

Flow < Mean
  INTERCEPT (Log)    = -1.7340
  SLOPE              = 0.993098
  R²                 = 0.758
  MEAN SQUARED ERROR = 0.07754
  STD. ERR. OF SLOPE = 0.1122
  DEGREES OF FREEDOM = 25
  T STATISTIC        = 8.854
  PROBABILITY(>|T|)  = 0.00000
  Y MEAN (Log)       = -1.0606
  Y STD DEV. (Log)   = 0.5553
  X MEAN (Log)       = 0.67773000
  X STD DEV. (Log)   = 0.4869
------------------------------------
 RESIDUALS ANALYSIS:
  RUNS TEST Z        = -0.7290
  PROBABILITY (>|Z|) = 0.23298
  LAG-1 AUTOCORREL.  = -0.0786
  PROBABILITY (>|r|) = 0.34146
  EFFECT. SMPL SIZE  = 27.00
  SLOPE SIGNIFICANCE = 0.00000
------------------------------------

Flow > Mean
  INTERCEPT (Log)    = -3.5450
  SLOPE              = 2.164762
  R²                 = 0.821
  MEAN SQUARED ERROR = 0.07154
  STD. ERR. OF SLOPE = 0.2528
  DEGREES OF FREEDOM = 16
  T STATISTIC        = 8.563
  PROBABILITY(>|T|)  = 0.00001
  Y MEAN (Log)       = 0.8617
  Y STD DEV. (Log)   = 0.6131
  X MEAN (Log)       = 2.03560000
  X STD DEV. (Log)   = 0.2566
------------------------------------
 RESIDUALS ANALYSIS:
  RUNS TEST Z        = -1.6686
  PROBABILITY (>|Z|) = 0.04759
  LAG-1 AUTOCORREL.  = 0.1244
  PROBABILITY (>|r|) = 0.29877
  EFFECT. SMPL SIZE  = 14.00
  SLOPE SIGNIFICANCE = 0.00004
------------------------------------


----------------------------------------------------------------------------------
                C O M P A R I S O N   O F   R E G R E S S I O N   L I N E S
                                       (ANCOVA)

                                       Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                        3         51.2306          17.077     227.08   <0.0001
Error                       41         3.08323        0.075201
Corrected Total             44         54.3138


                 R-Square     Coeff Var      Root MSE    TSS Mean
```

```
                  0.9432       -94.0213      0.274227   -0.29167
-----------------------------------------------------------------------------------
                       M O D E L    D E T A I L S (Partitioning)

Source                    DF        Type I SS    Mean Square     F Value    Pr > F

Stratum                    1          39.906        39.906        530.65   <0.0001
Regression                 1          10.024        10.024         133.3   <0.0001
Regression x Stratum       1          1.3005        1.3005        17.294   <0.0002
-----------------------------------------------------------------------------------


Difference Among Slopes is Measured by the Regression x Stratum Interaction
In this Case F=17.29442),  p > F = <0.0002

The Significance of STRATUM effect can be viewed as a significant
difference in a least one of the regression intercepts (levels)
But this interpretation is only appropriate if the interaction
term (regression x stratum) is NOT significant
(i.e., the regression slopes are parallel)

-----------------------------------------------------------------------------------

               R E G R E S S I O N   O F   L O A D   O N   F L O W
                            Log(Load) vs. Log(Flow)

BY STRATUM
-------------------------------
Stratum(1) Flow < Mean
Intercept      = 8402
Log Intercept  = 3.924
Slope          = 0.9931
R²             = 0.758

-------------------------------
Stratum(2) Flow > Mean
Intercept      = 145.7
Log Intercept  = 2.163
Slope          = 2.165
R²             = 0.821
```

TOTAL PHOSPHORUS



```
Log-Log Regression: Log(TP (tons/d)) on Log(Daily Discharge (CFS))
Flux Estimation Method: 6 (C/Q Reg3(daily))
------------------------------------
Overall (No Strata)
  INTERCEPT (Log)     = -4.2450
  SLOPE               = 1.265559
  R²                  = 0.947
  MEAN SQUARED ERROR = 0.05483
  STD. ERR. OF SLOPE = 0.05141
  DEGREES OF FREEDOM = 34
  T STATISTIC         = 24.620
  PROBABILITY(>|T|)   = 0.00000
  Y MEAN (Log)        = -2.6988
  Y STD DEV. (Log)    = 1.0013
  X MEAN (Log)        = 1.22160000
  X STD DEV. (Log)    = 0.7699
------------------------------------
 RESIDUALS ANALYSIS:
  RUNS TEST Z         = -2.1505
  PROBABILITY (>|Z|) = 0.01576
  LAG-1 AUTOCORREL.  = 0.1998
  PROBABILITY (>|r|) = 0.11524
  EFFECT. SMPL SIZE  = 24.00
  SLOPE SIGNIFICANCE = 0.00000
------------------------------------


Regression Statistics By Stratum

Flow < Mean
  INTERCEPT (Log)     = -4.2790
```

```
  SLOPE              = 1.332083
  R²                 = 0.887
  MEAN SQUARED ERROR = 0.05433
  STD. ERR. OF SLOPE = 0.1062
  DEGREES OF FREEDOM = 20
  T STATISTIC        = 12.550
  PROBABILITY(>|T|)  = 0.00000
  Y MEAN (Log)       = -3.3386
  Y STD DEV. (Log)   = 0.6776
  X MEAN (Log)       = 0.70610000
  X STD DEV. (Log)   = 0.4792
------------------------------------
 RESIDUALS ANALYSIS:
  RUNS TEST Z        = -1.5293
  PROBABILITY (>|Z|) = 0.06309
  LAG-1 AUTOCORREL.  = 0.2105
  PROBABILITY (>|r|) = 0.16177
  EFFECT. SMPL SIZE  = 14.00
  SLOPE SIGNIFICANCE = 0.00001
------------------------------------

Flow > Mean
  INTERCEPT (Log)    = -4.3740
  SLOPE              = 1.319428
  R²                 = 0.675
  MEAN SQUARED ERROR = 0.06206
  STD. ERR. OF SLOPE = 0.2640
  DEGREES OF FREEDOM = 12
  T STATISTIC        = 4.997
  PROBABILITY(>|T|)  = 0.00051
  Y MEAN (Log)       = -1.6935
  Y STD DEV. (Log)   = 0.4201
  X MEAN (Log)       = 2.03170000
  X STD DEV. (Log)   = 0.2617
------------------------------------
 RESIDUALS ANALYSIS:
  RUNS TEST Z        = -1.9100
  PROBABILITY (>|Z|) = 0.02806
  LAG-1 AUTOCORREL.  = 0.1354
  PROBABILITY (>|r|) = 0.30612
  EFFECT. SMPL SIZE  = 10.0000
  SLOPE SIGNIFICANCE = 0.00323
------------------------------------


-----------------------------------------------------------------------------------
                C O M P A R I S O N   O F   R E G R E S S I O N   L I N E S
                                     (ANCOVA)

                                       Sum of
Source                     DF          Squares     Mean Square    F Value    Pr > F
Model                       3          33.2599          11.087     193.73   <0.0001
Error                      32          1.83132        0.057229
Corrected Total            35          35.0912


                 R-Square     Coeff Var      Root MSE    TP Mean

                  0.9478       -8.86401      0.239225    -2.6988
-----------------------------------------------------------------------------------
                       M O D E L    D E T A I L S (Partitioning)
```

```
Source                     DF        Type I SS    Mean Square     F Value    Pr > F

Stratum                     1           23.154         23.154      404.59   <0.0001
Regression                  1           10.105         10.105      176.58   <0.0001
Regression x Stratum        1       0.00012037     0.00012037   0.0021033   <0.0001
-----------------------------------------------------------------------------------


Difference Among Slopes is Measured by the Regression x Stratum Interaction
In this Case F=0.002103333),  p > F = <0.0000

The Significance of STRATUM effect can be viewed as a significant
difference in a least one of the regression intercepts (levels)
But this interpretation is only appropriate if the interaction
term (regression x stratum) is NOT significant
(i.e., the regression slopes are parallel)

-----------------------------------------------------------------------------------

               R E G R E S S I O N   O F   L O A D   O N   F L O W
                            Log(Load) vs. Log(Flow)

BY STRATUM
-------------------------------
Stratum(1) Flow < Mean
Intercept      = 23.37
Log Intercept  = 1.369
Slope          = 1.332
R²             = 0.887

-------------------------------
Stratum(2) Flow > Mean
Intercept      = 19.14
Log Intercept  = 1.282
Slope          = 1.319
R²             = 0.675
```