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TETRA TECH

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 99^{th} percentile of the simulated baseflow time-series in Otis Creek.

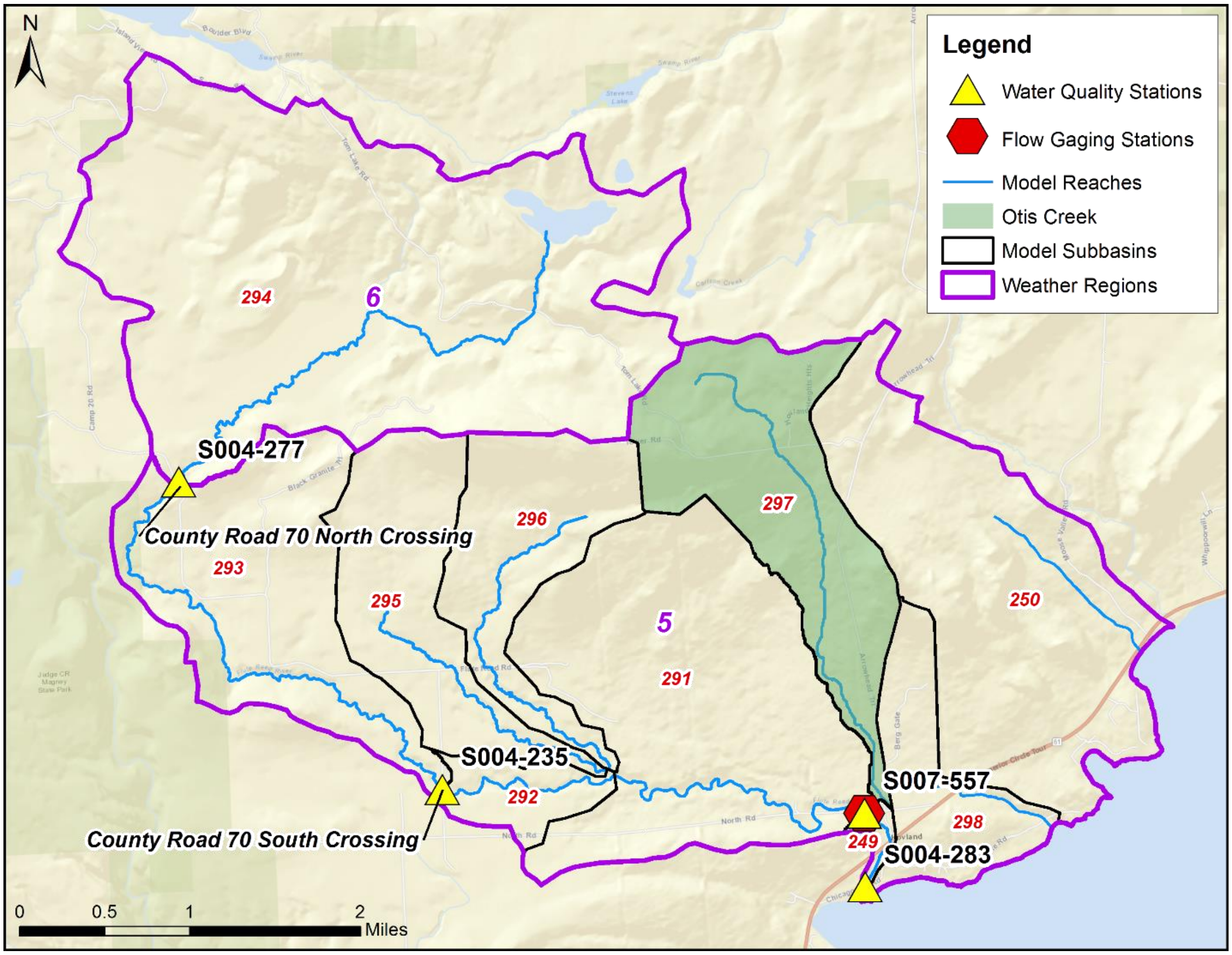

Figure 1. Revised delineation for the Flute Reed River watershed

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).

[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

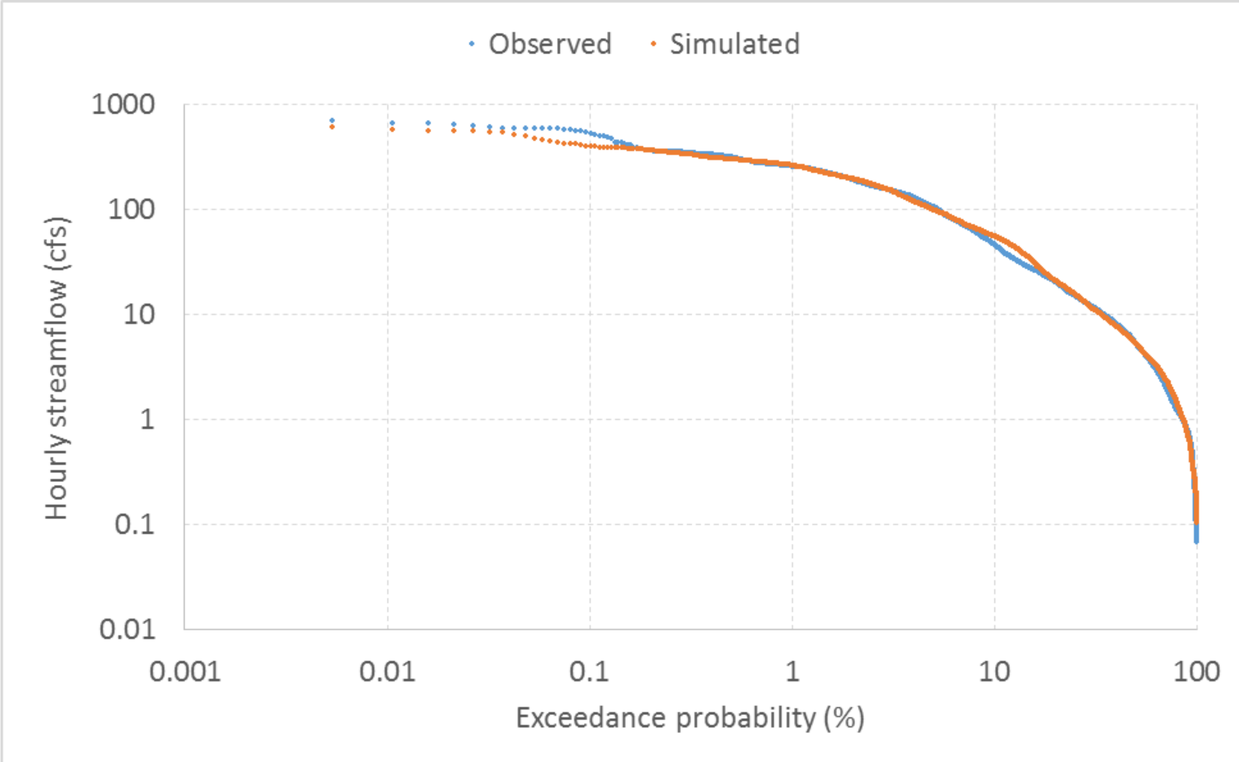

Figure 2. Hourly flow exceedance for the FLR at Hovland, CR69

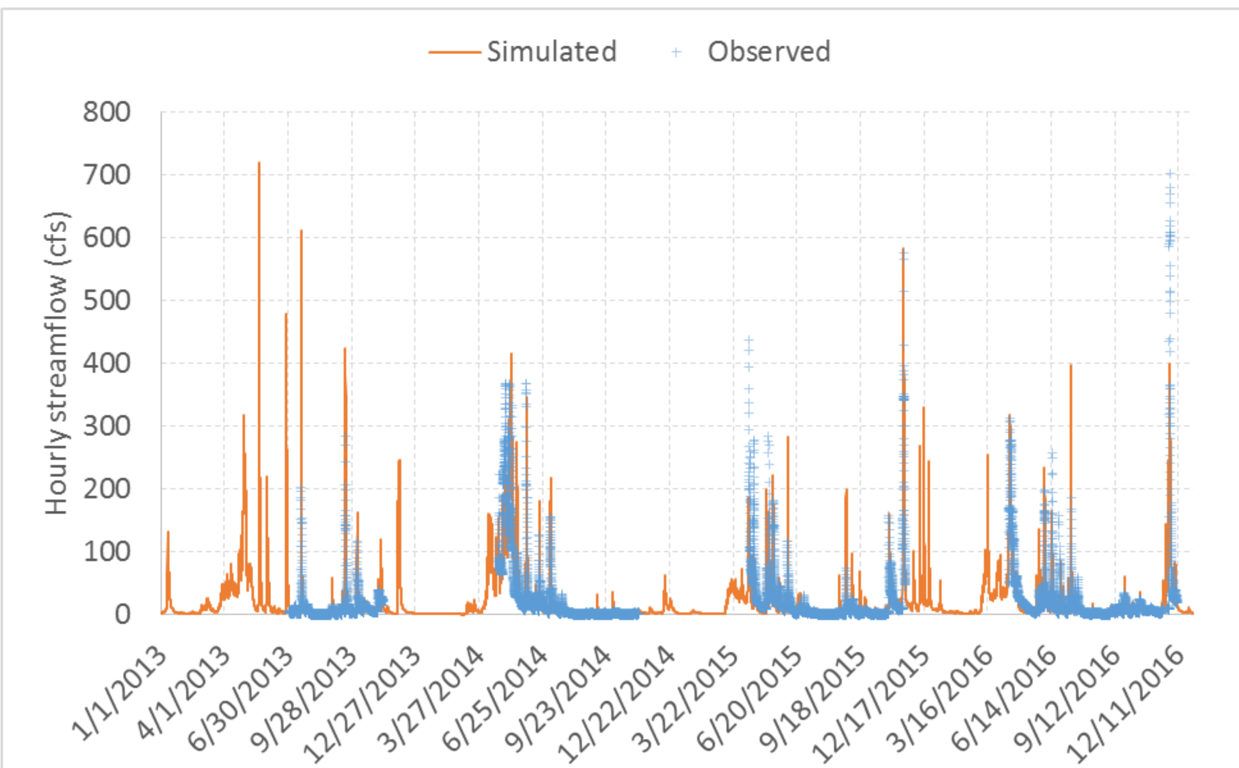

Figure 3. Time-series of observed and simulated hourly streamflow for the FLR at Hovland, CR69

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

[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.

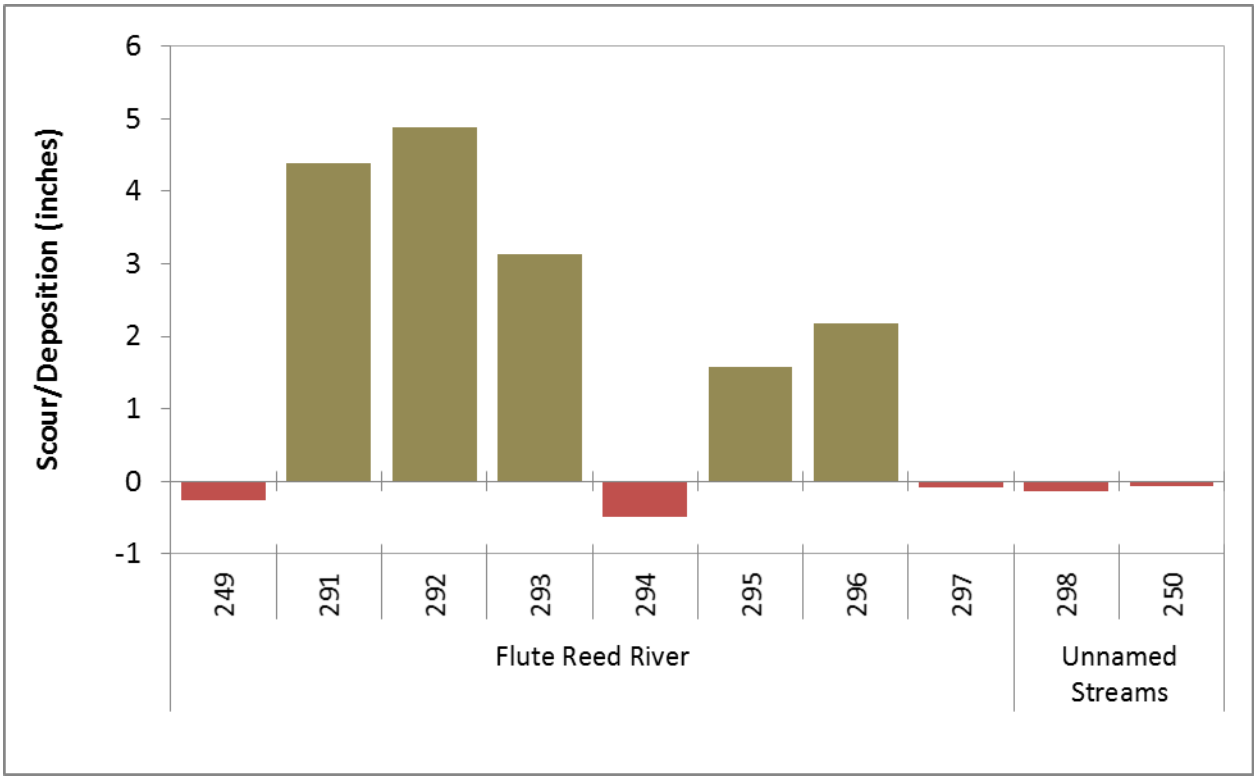

Figure 4. Reach Sediment Balance for the Flute Reed River, 1993-2016 (red indicates scour, brown indicates deposition).

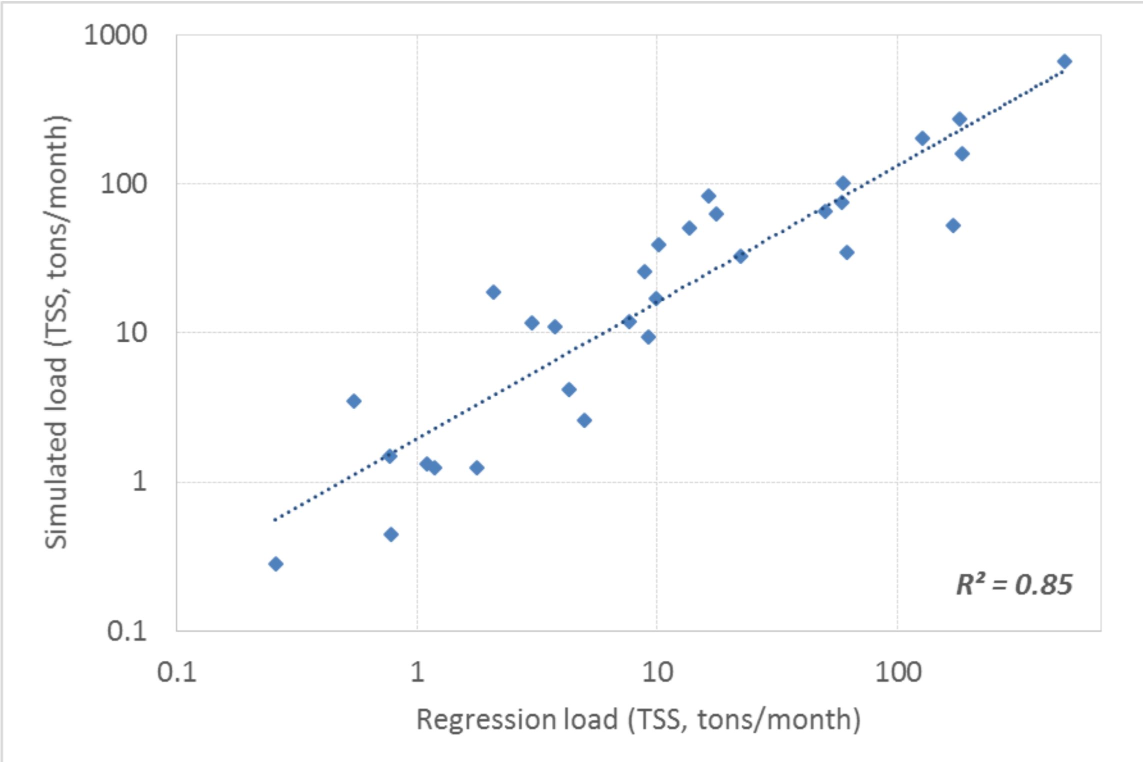

Figure 5. Scatter plot of monthly simulated and regression sediment load.

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%.

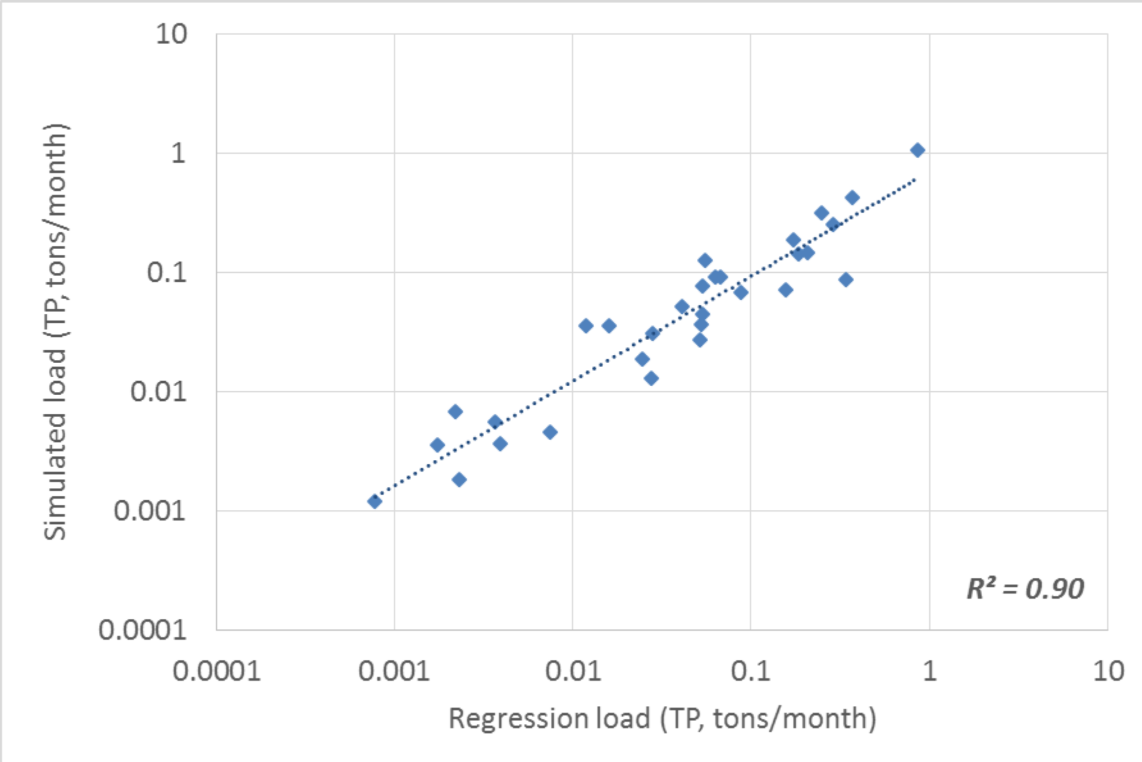

Figure 6. Scatter plot of monthly simulated and regression TP load.

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)

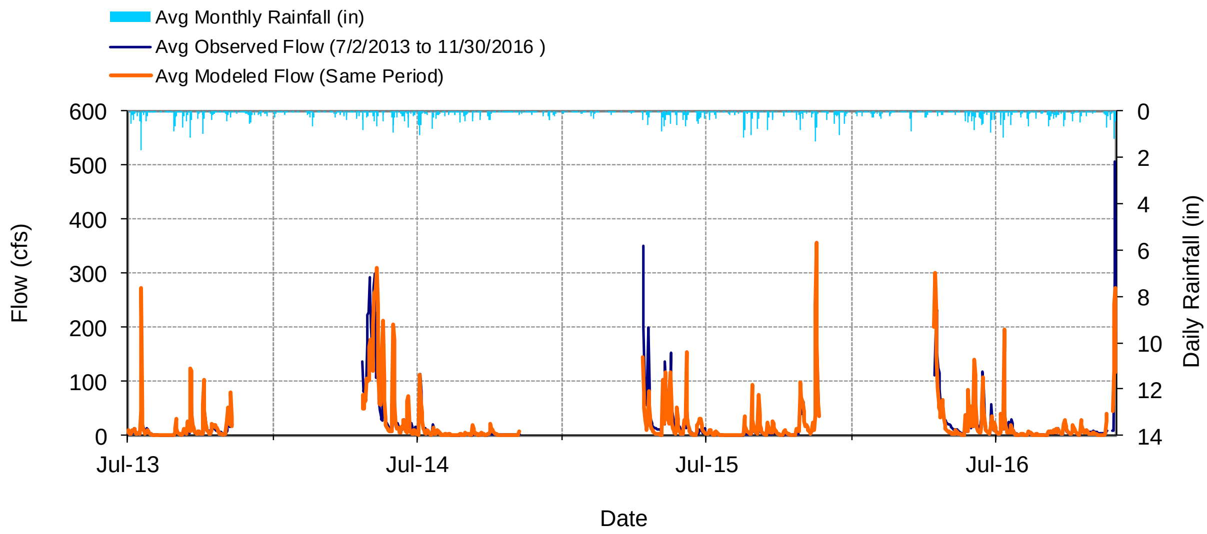

Figure 7. Mean daily flow at Flute Reed River at Hovland, CR69

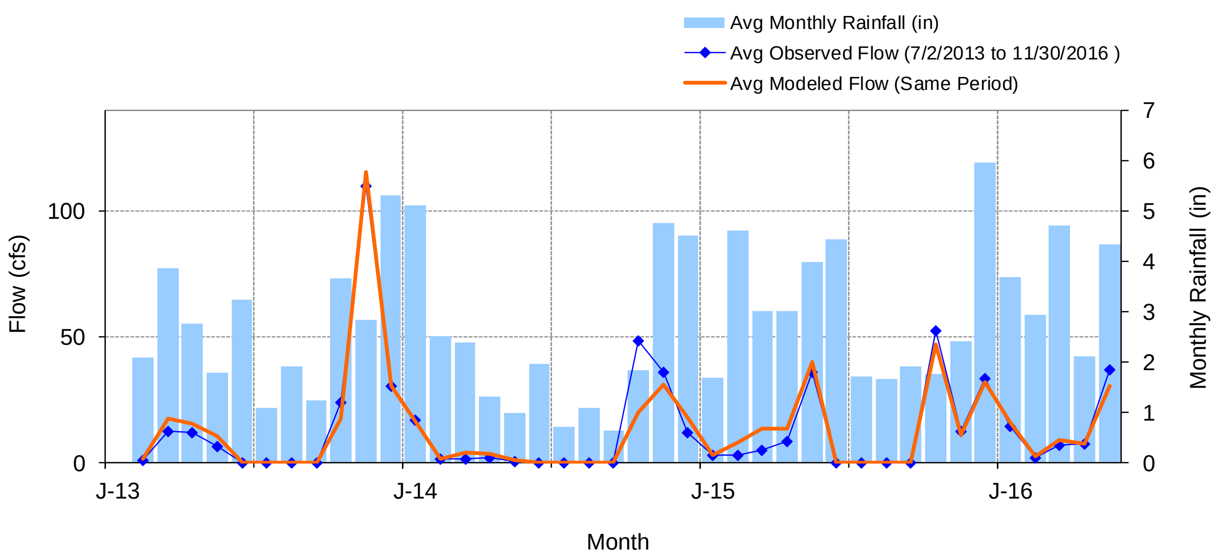

Figure 8. Mean monthly flow at Flute Reed River at Hovland, CR69

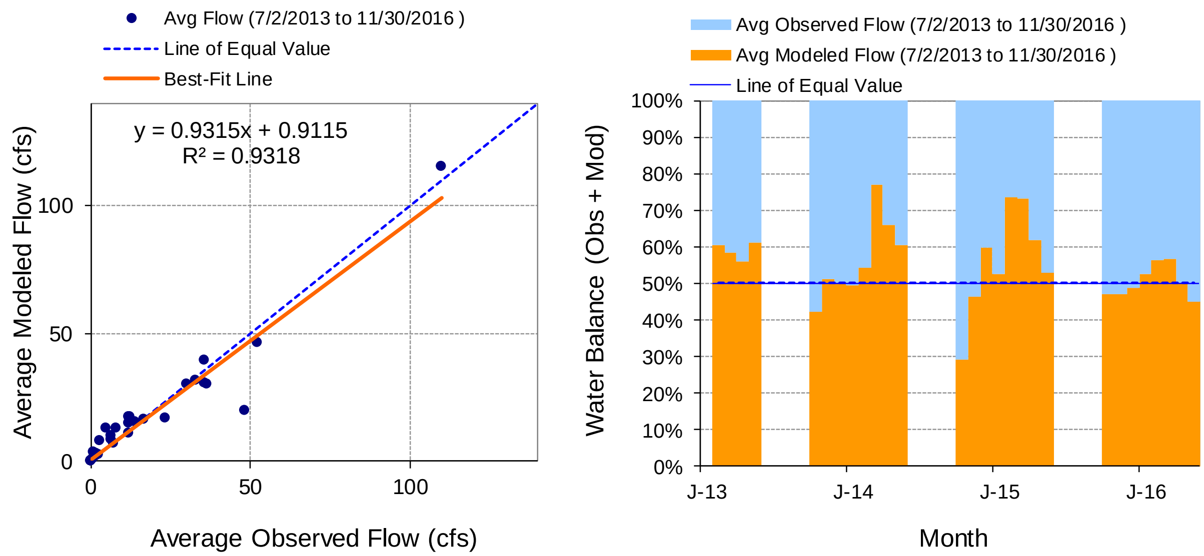

Figure 9. Monthly flow regression and temporal variation at Flute Reed River at Hovland, CR69

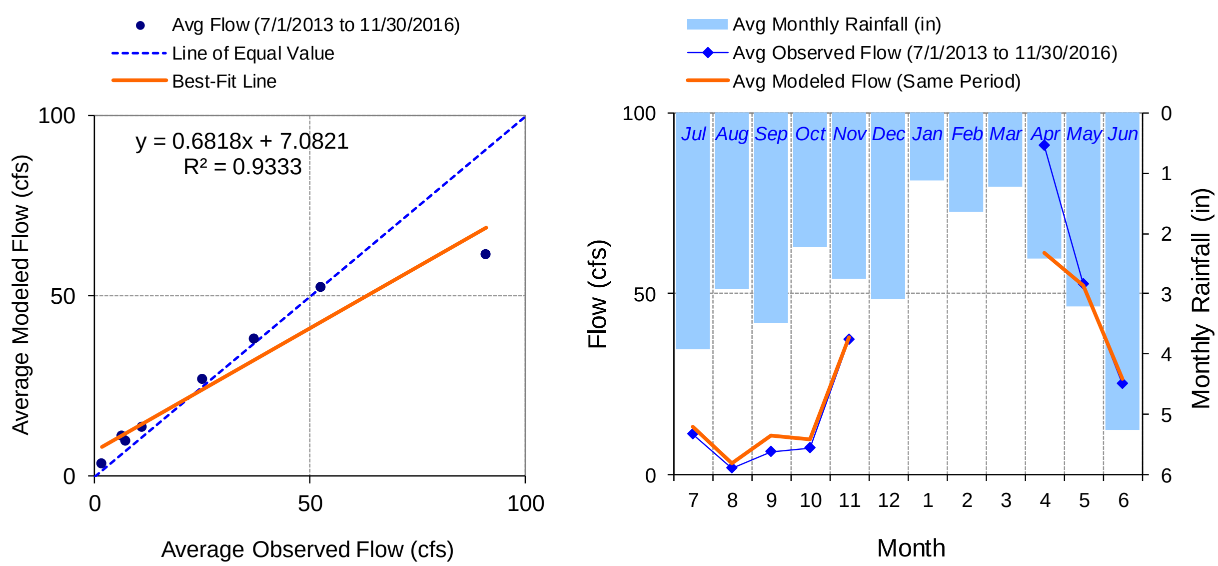

Figure 10. Seasonal regression and temporal aggregate at Flute Reed River at Hovland, CR69

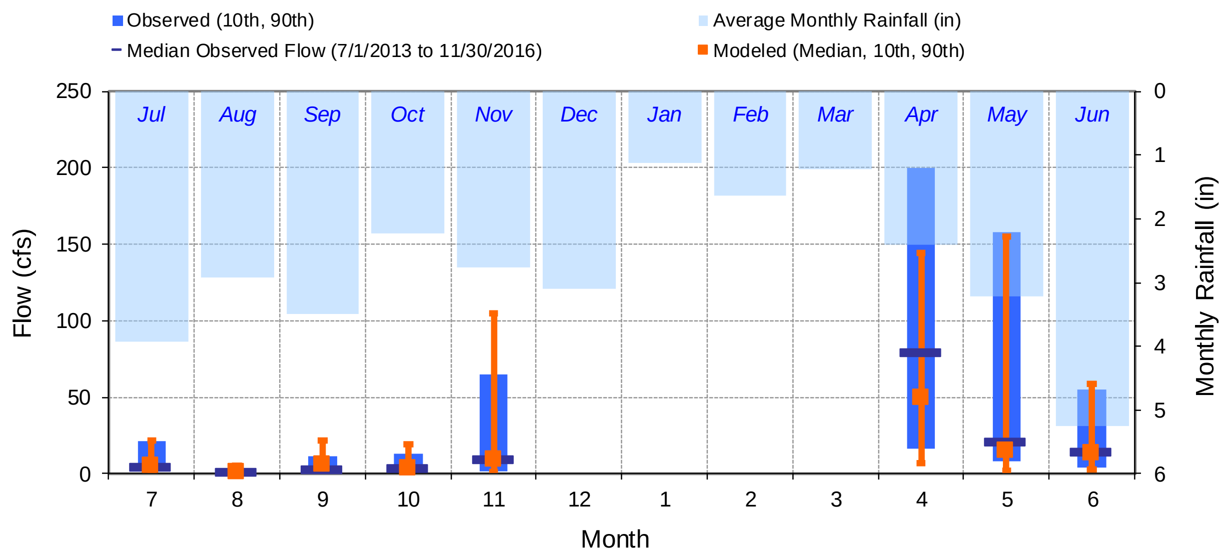

Figure 11. Seasonal medians and ranges at Flute Reed River at Hovland, CR69

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

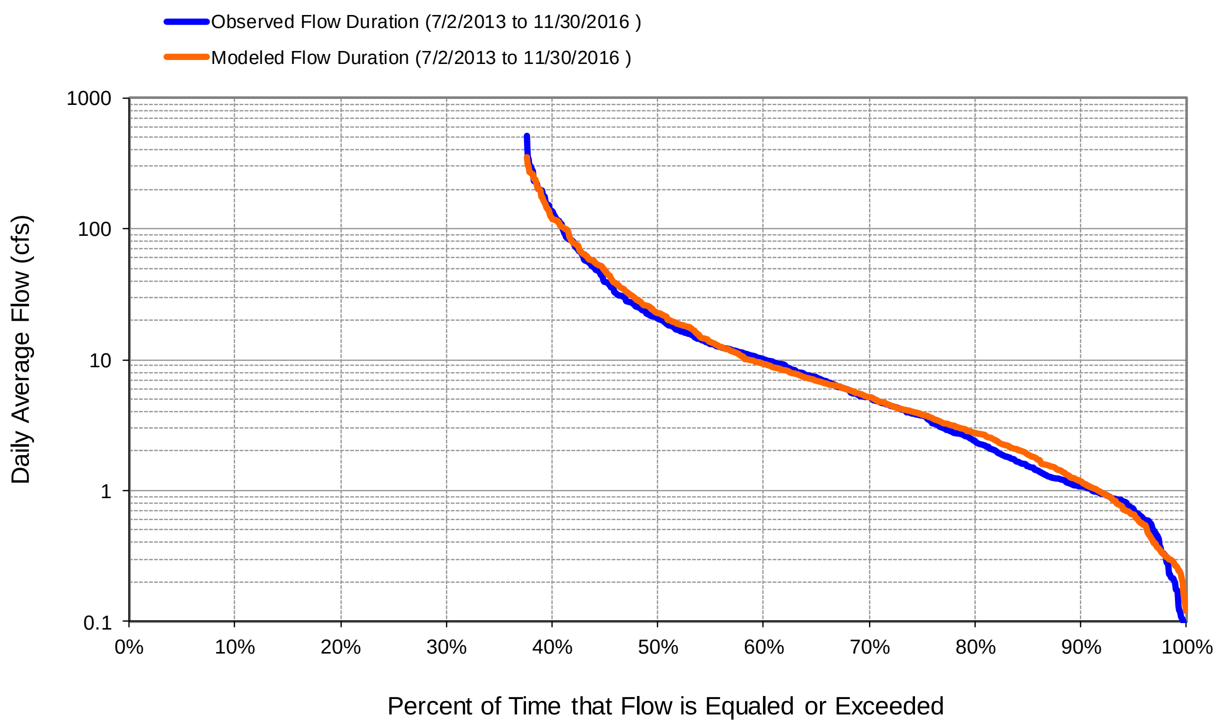

Figure 12. Flow exceedance at Flute Reed River at Hovland, CR69

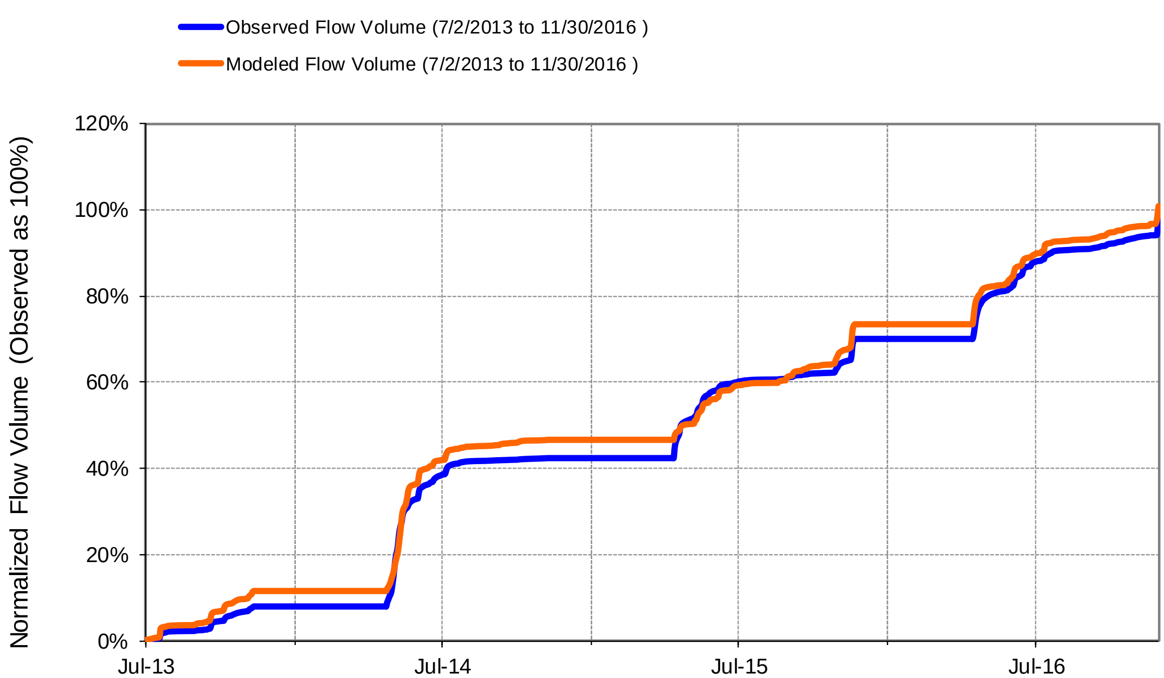

Figure 13. Flow accumulation at Flute Reed River at Hovland, CR69

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	
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		

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Appendix B -Water Quality Calibration

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

Total Suspended Solids (TSS)

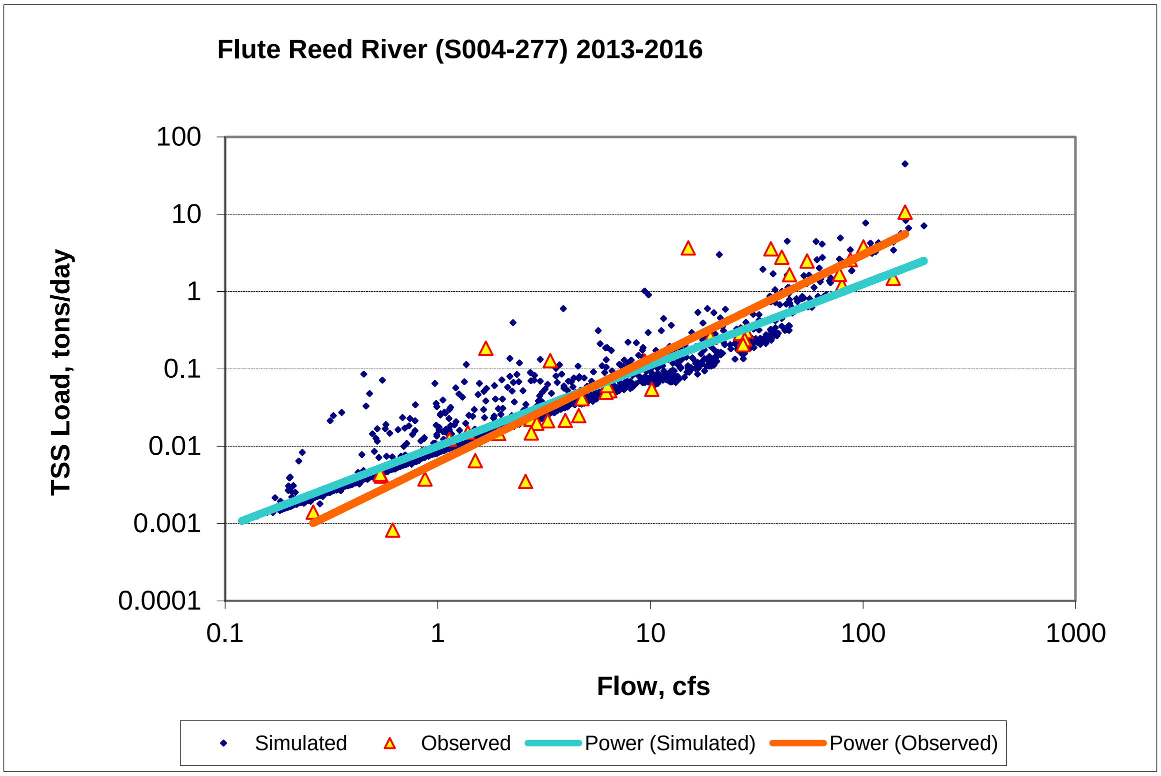


Figure 14. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow

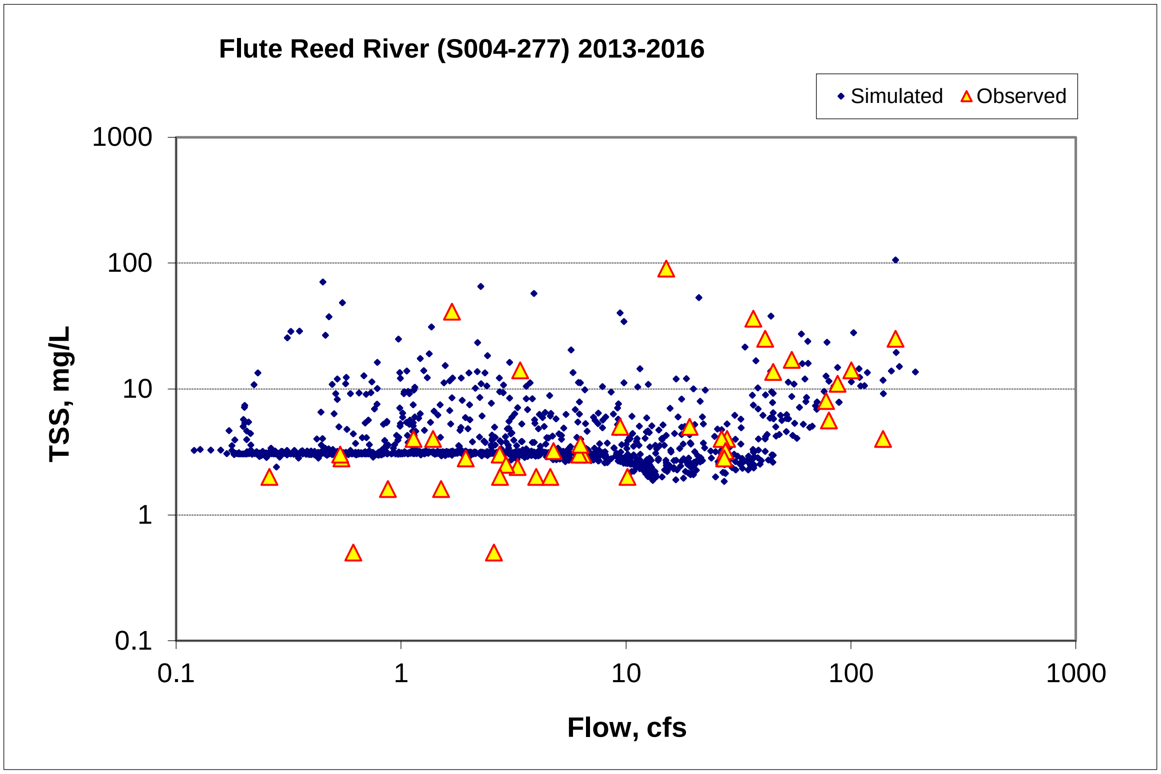


Figure 15. Simulated and observed Total Suspended Solids (TSS) concentration vs flow

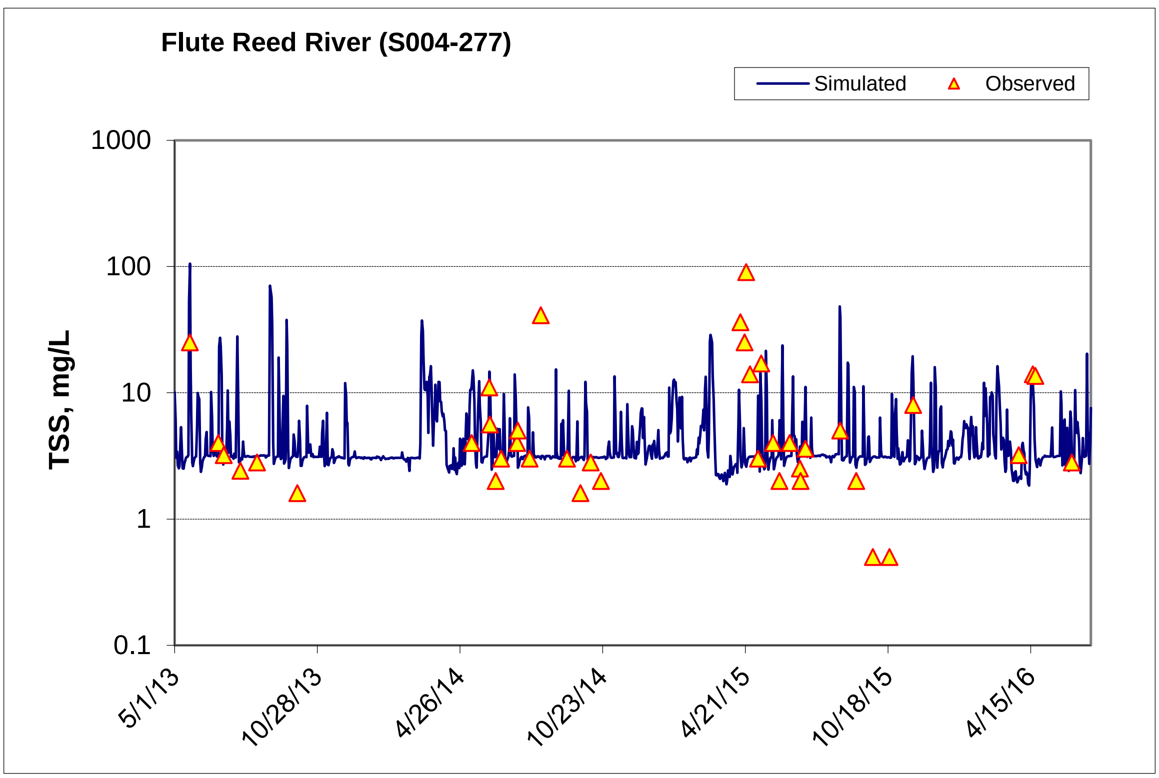


Figure 16. Time series of observed and simulated Total Suspended Solids (TSS) concentration

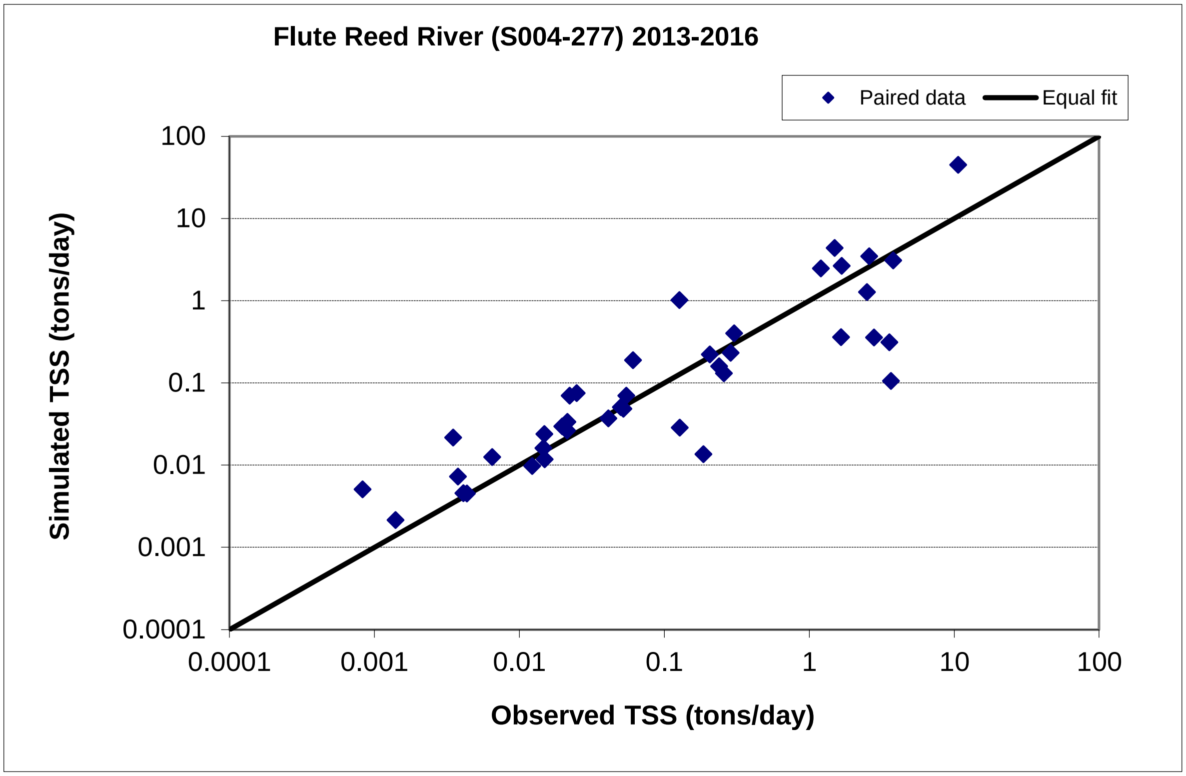


Figure 17. Paired simulated vs. observed Total Suspended Solids (TSS) load

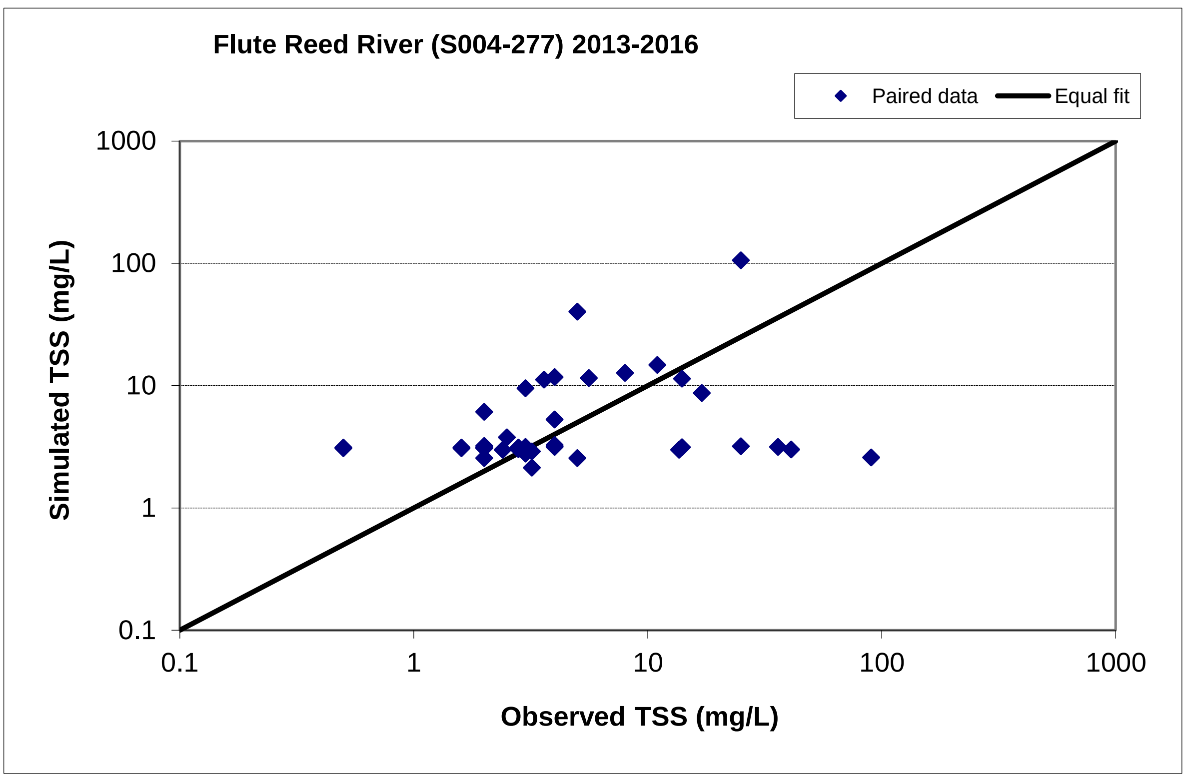


Figure 18. Paired simulated vs. observed Total Suspended Solids (TSS) concentration

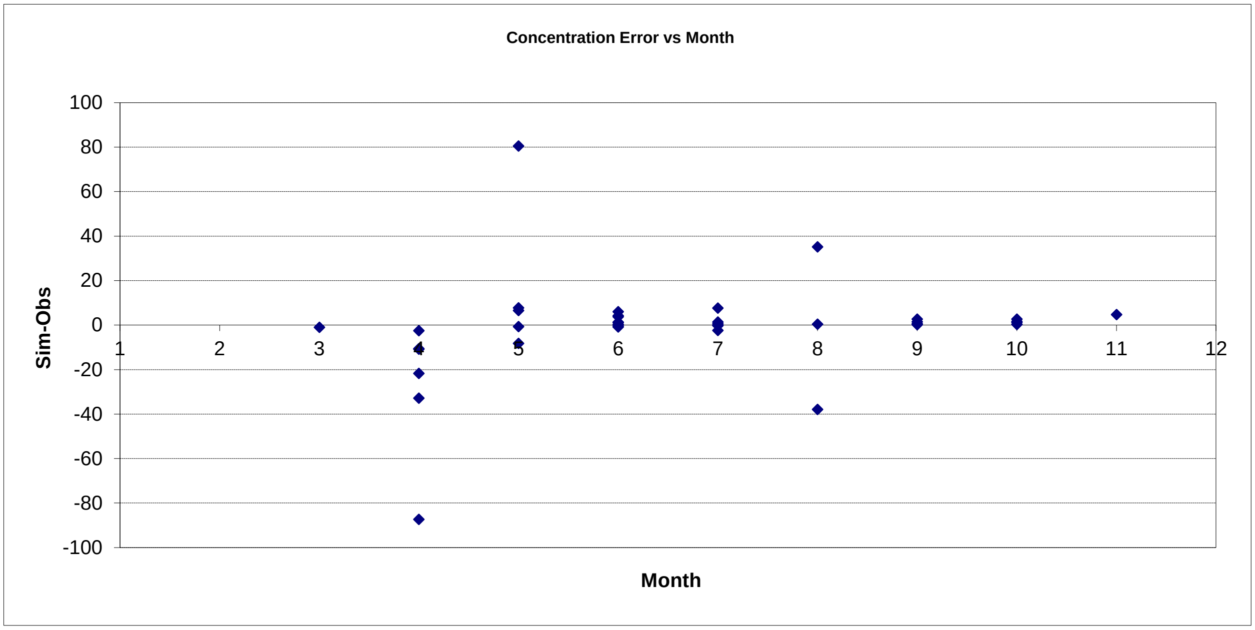


Figure 19. Residual (Simulated - Observed) vs. Month Total Suspended Solids (TSS)

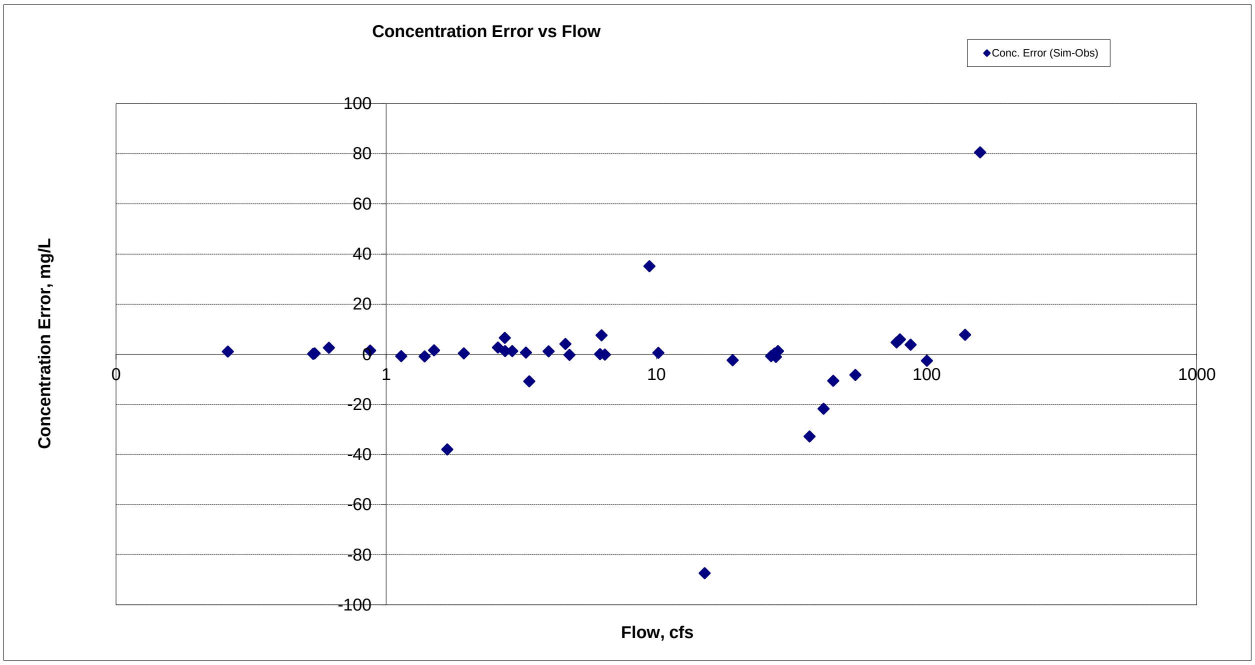


Figure 20. Residual (Simulated - Observed) vs. Flow Total Suspended Solids (TSS)

Total Phosphorus (TP)

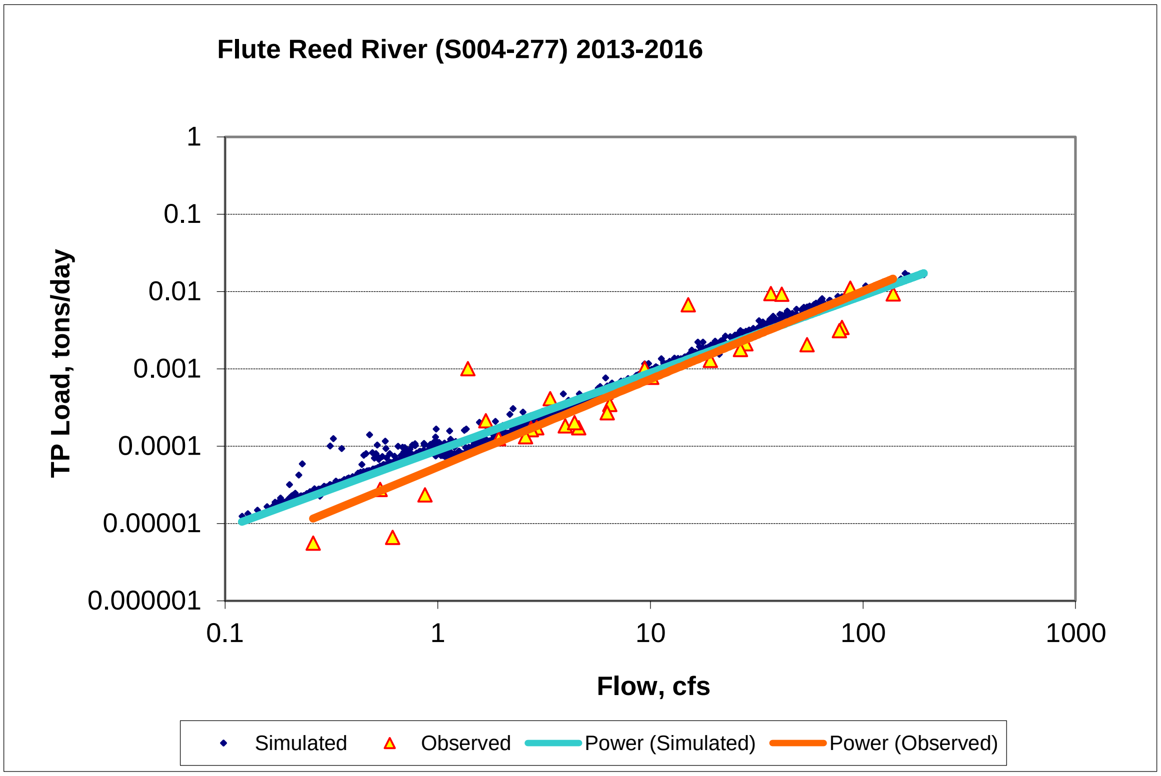


Figure 21. Power plot of simulated and observed Total Phosphorus (TP) load vs flow

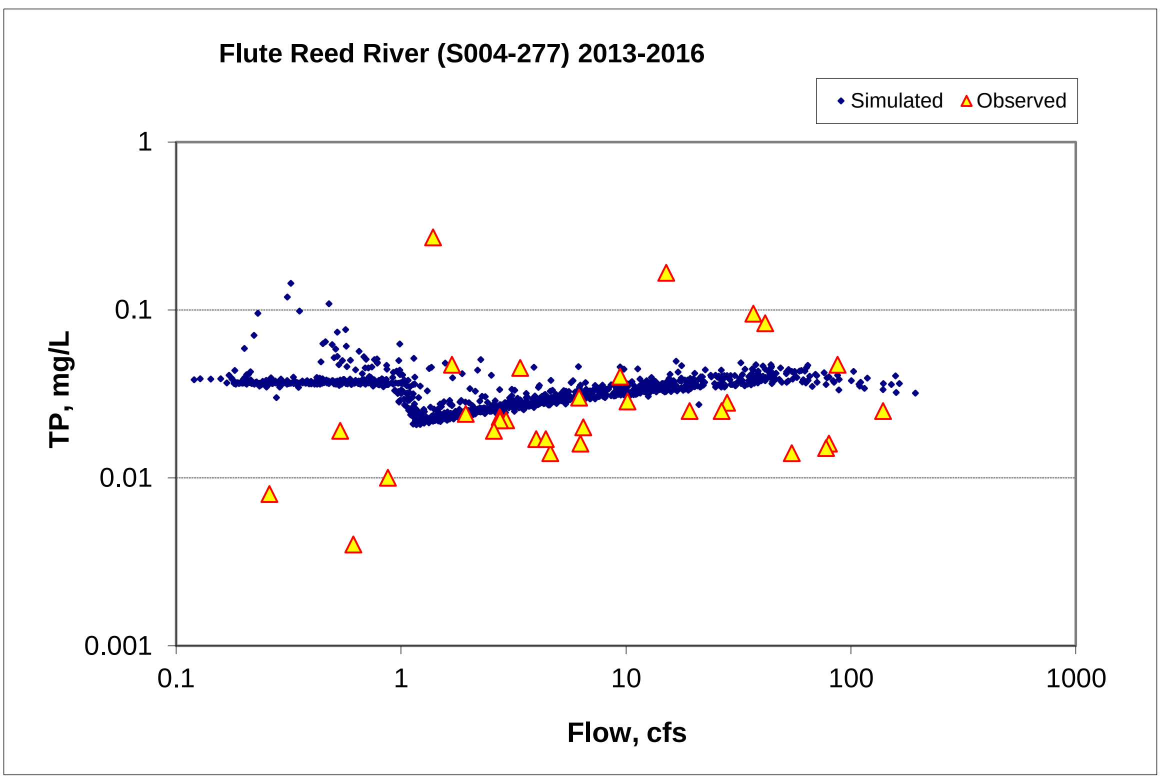


Figure 22. Simulated and observed Total Phosphorus (TP) concentration vs flow

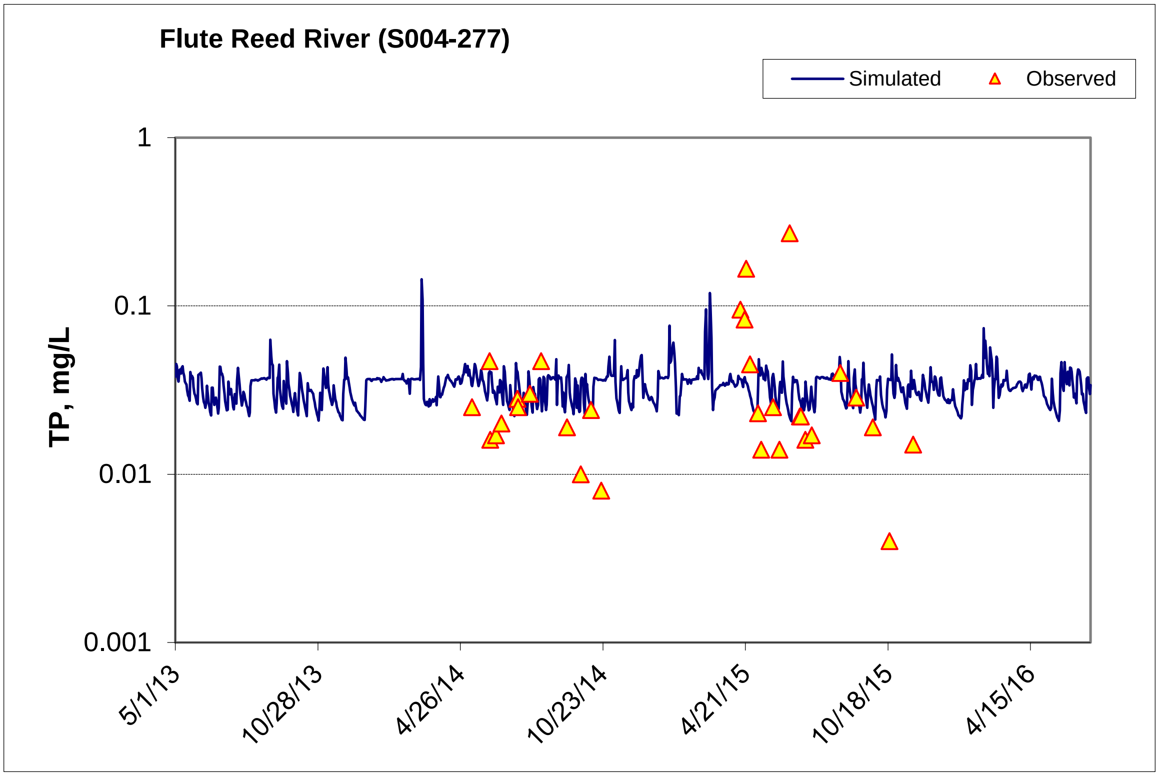


Figure 23. Time series of observed and simulated Total Phosphorus (TP) concentration

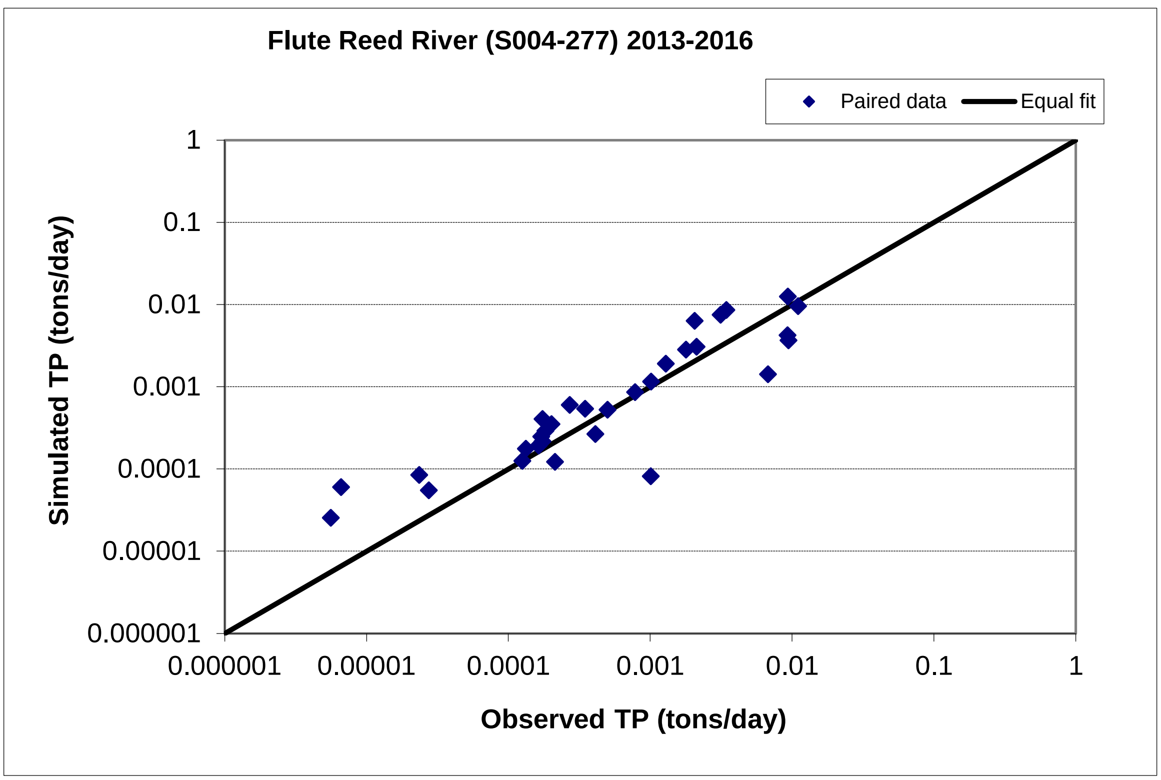


Figure 24. Paired simulated vs. observed Total Phosphorus (TP) load

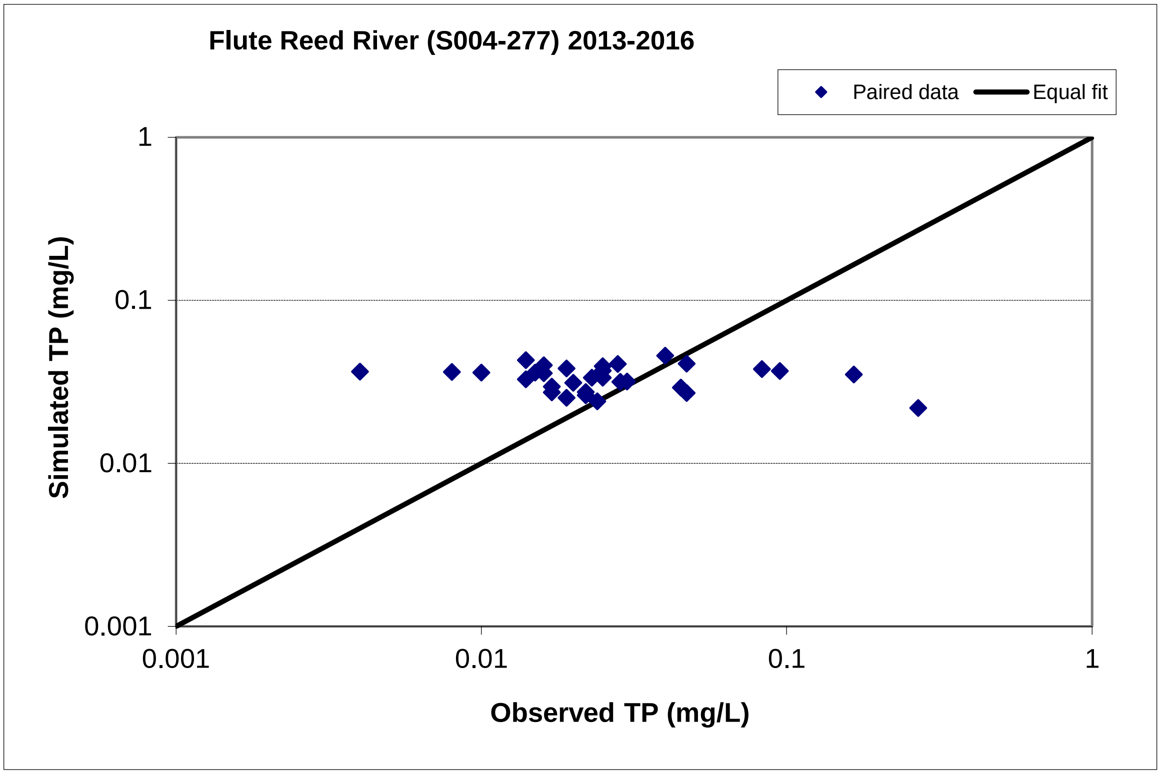


Figure 25. Paired simulated vs. observed Total Phosphorus (TP) concentration

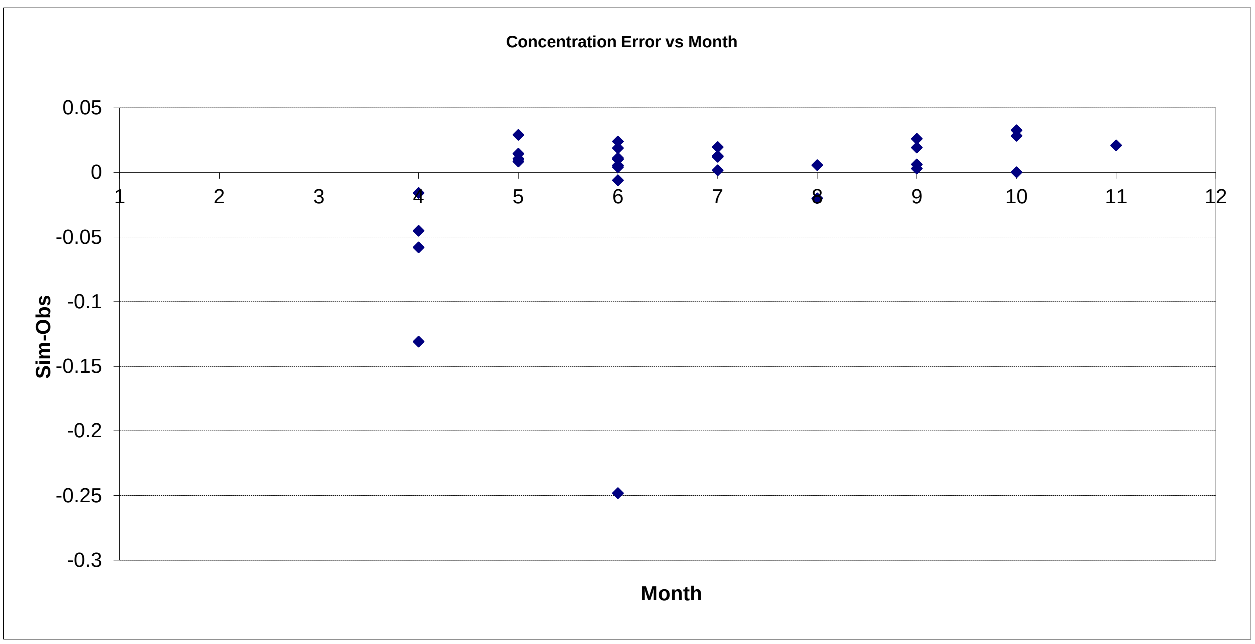


Figure 26. Residual (Simulated - Observed) vs. Month Total Phosphorus (TP)

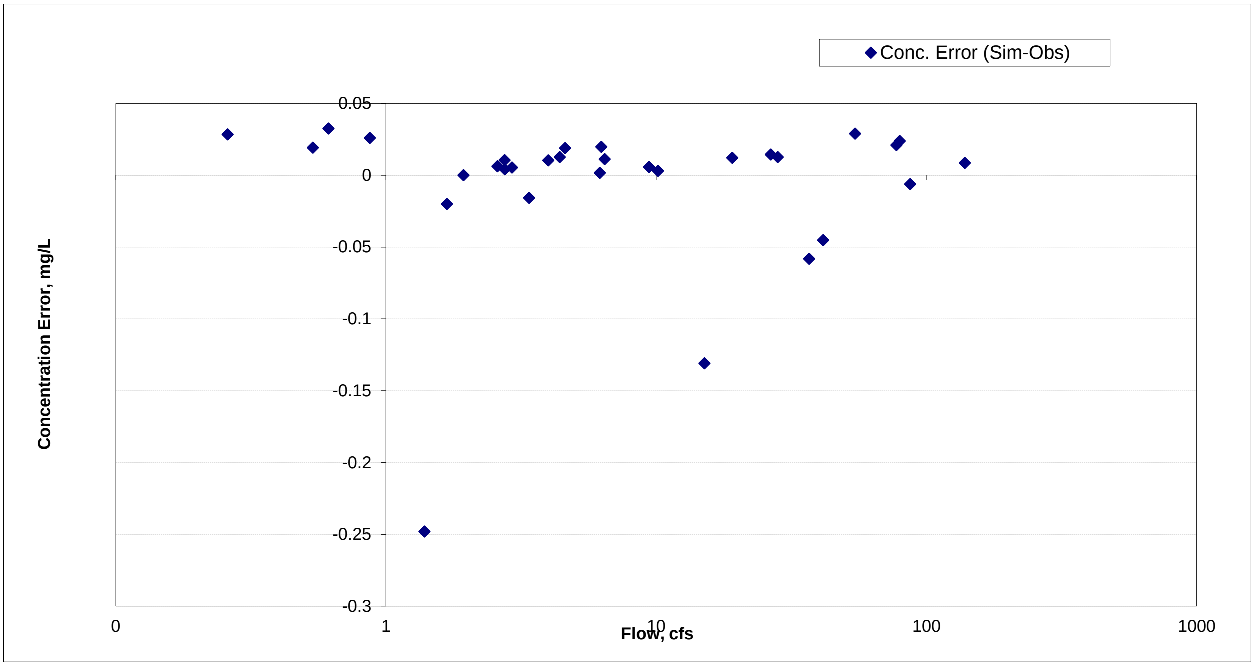


Figure 27. Residual (Simulated - Observed) vs. Flow Total Phosphorus (TP)

Flute Reed River at Camp 20 Rd, 2.5 mi NW of Hovland (S004-235)

Total Suspended Solids (TSS)

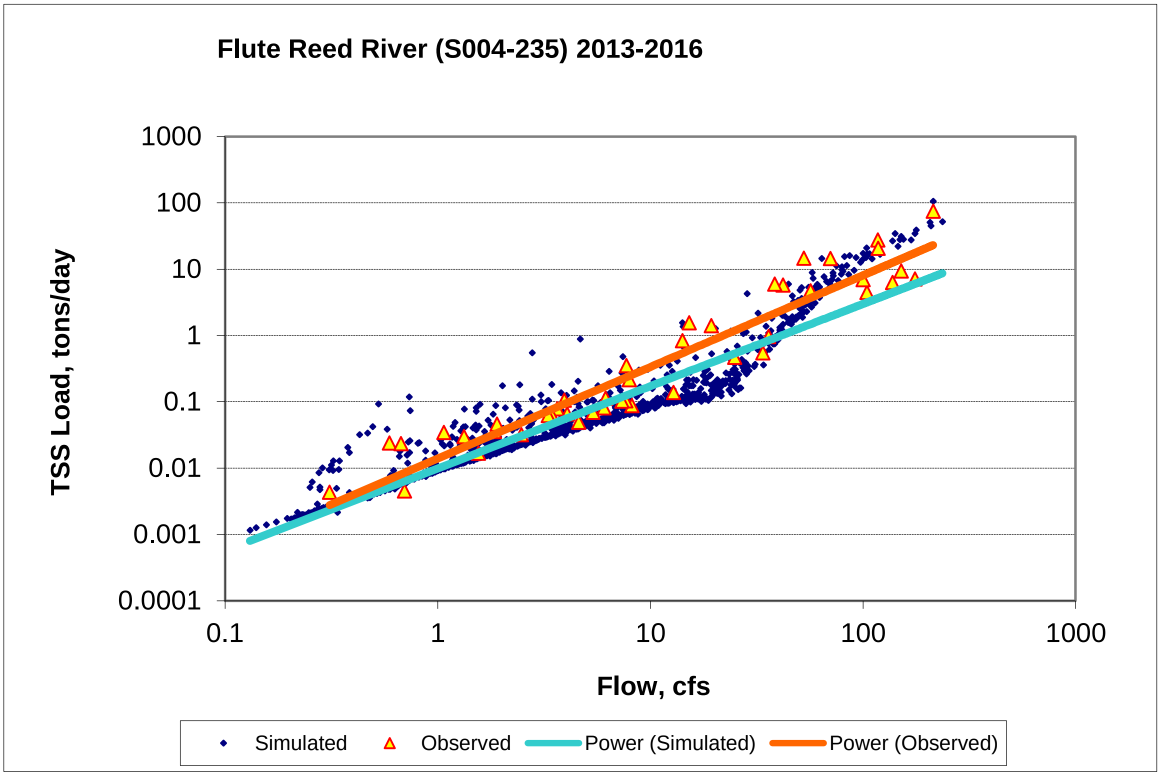


Figure 28. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow

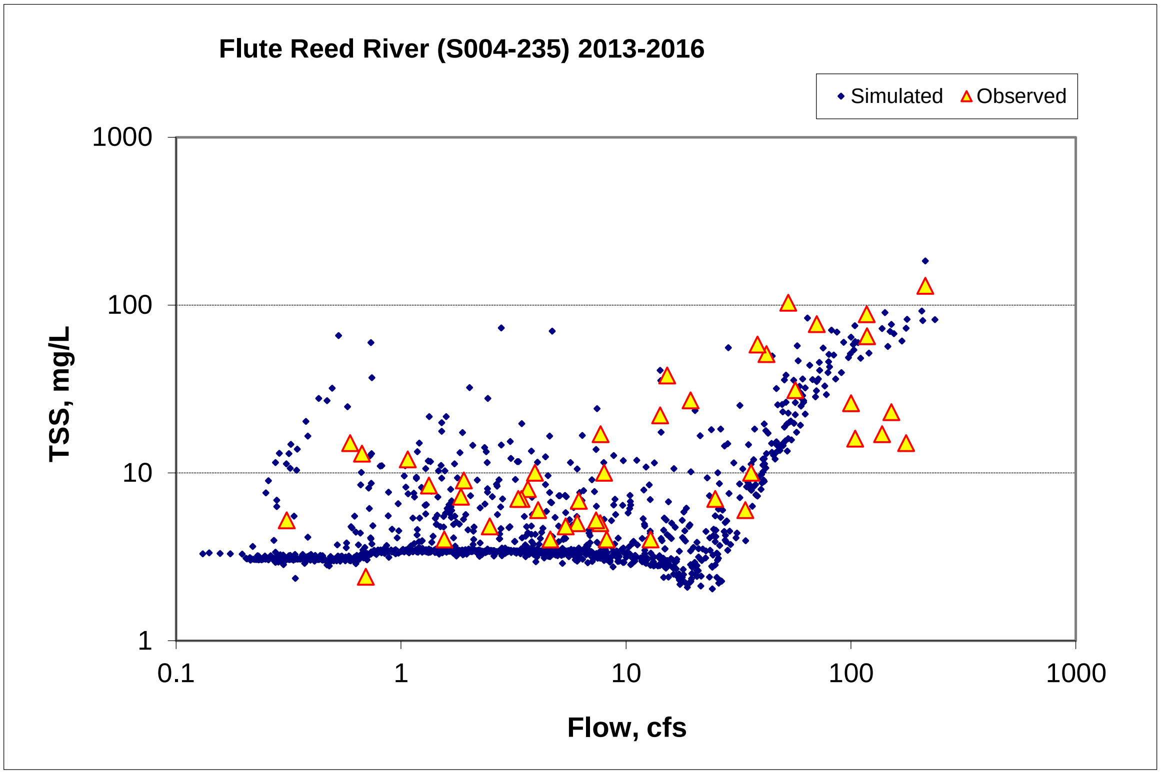


Figure 29. Simulated and observed Total Suspended Solids (TSS) concentration vs flow

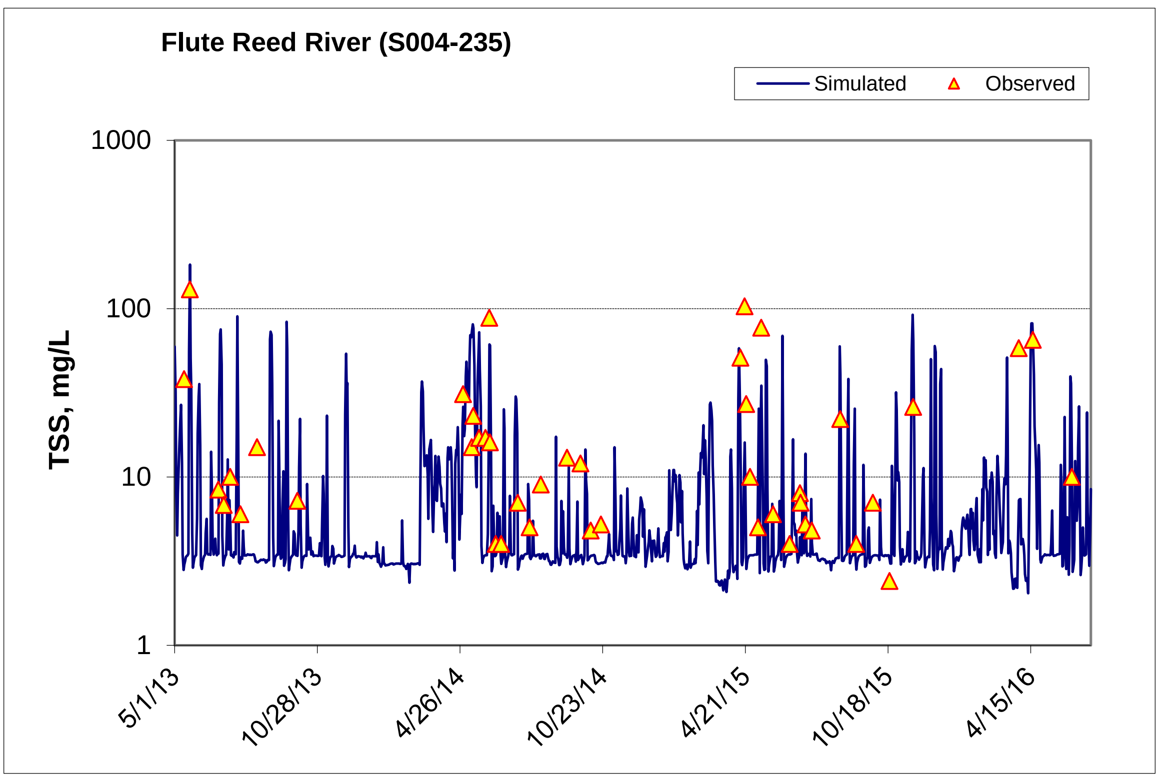


Figure 30. Time series of observed and simulated Total Suspended Solids (TSS) concentration

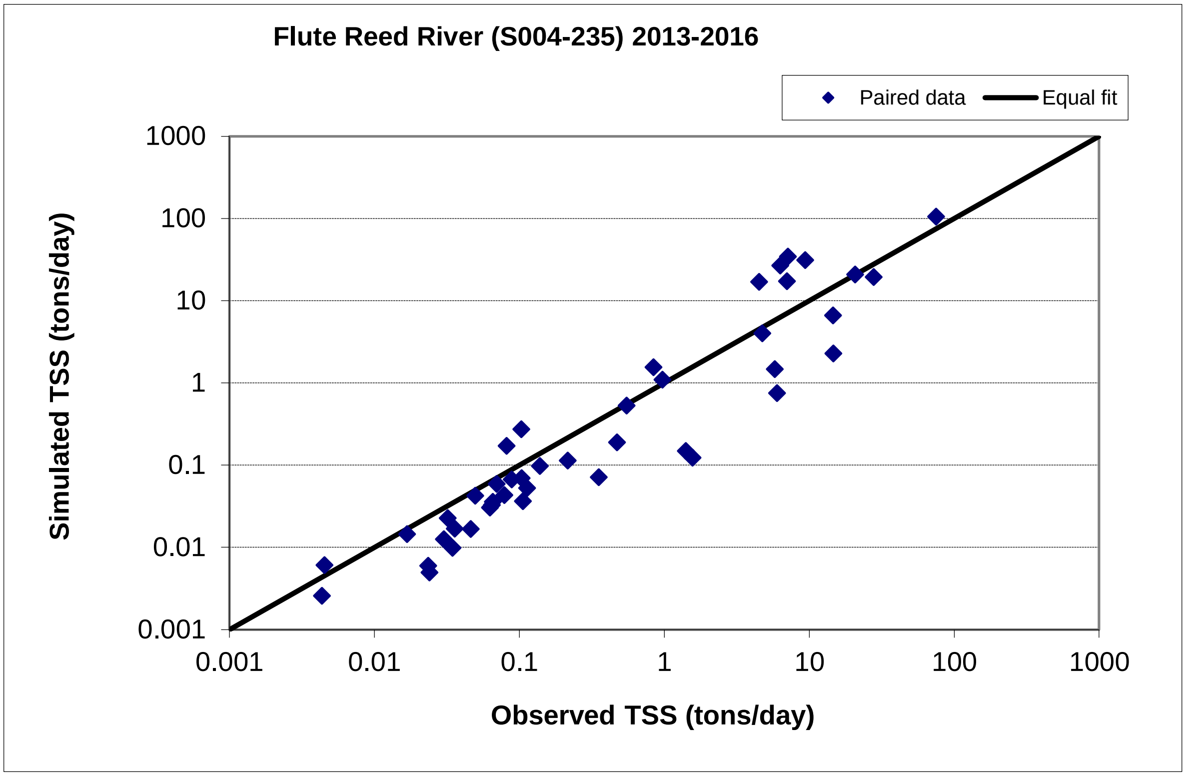


Figure 31. Paired simulated vs. observed Total Suspended Solids (TSS) load

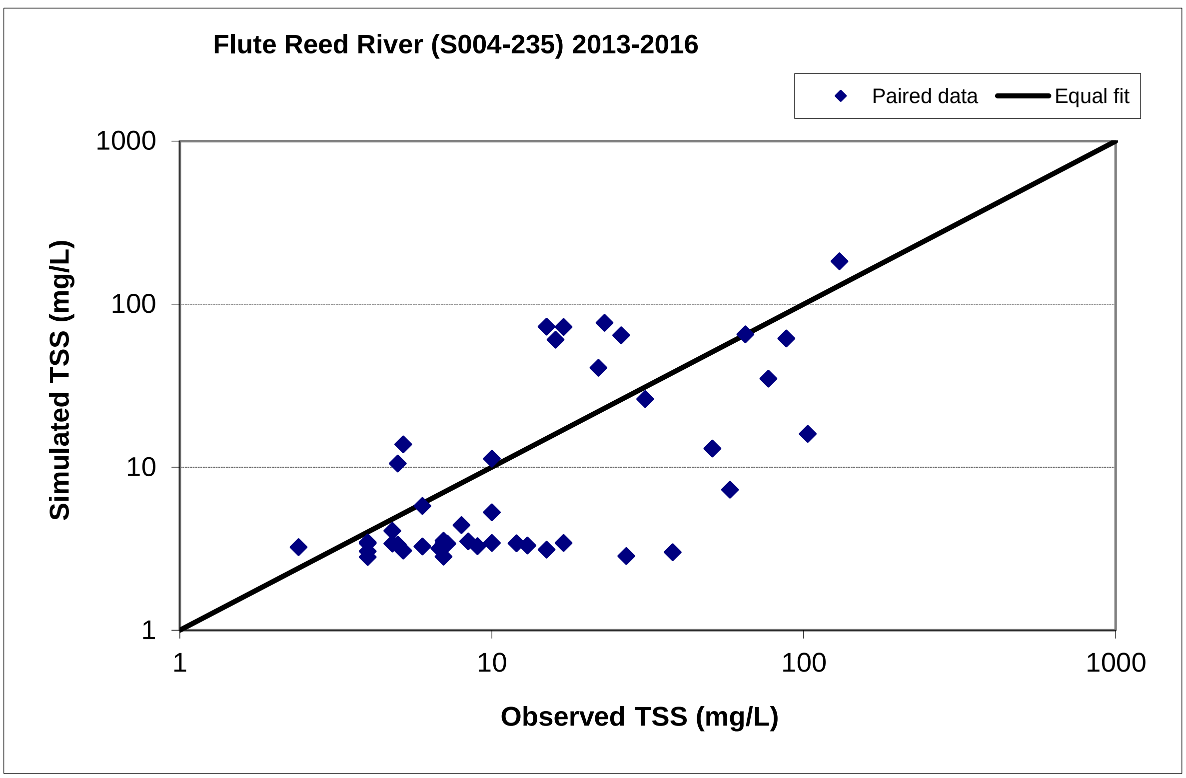


Figure 32. Paired simulated vs. observed Total Suspended Solids (TSS) concentration

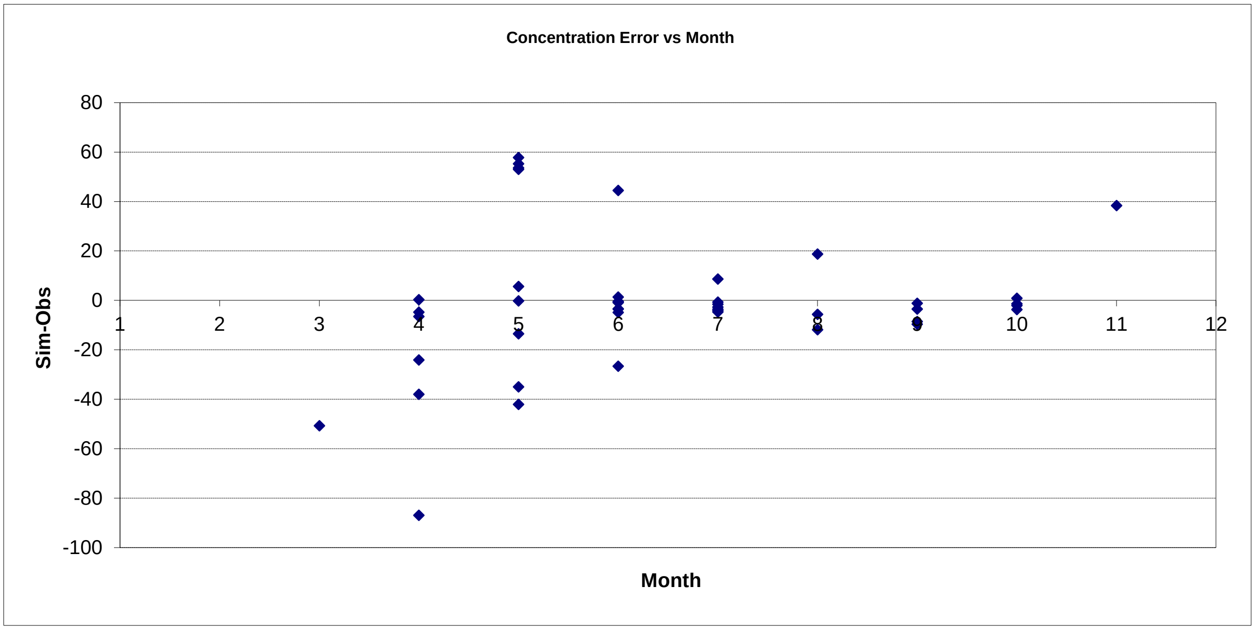


Figure 33. Residual (Simulated - Observed) vs. Month Total Suspended Solids (TSS)

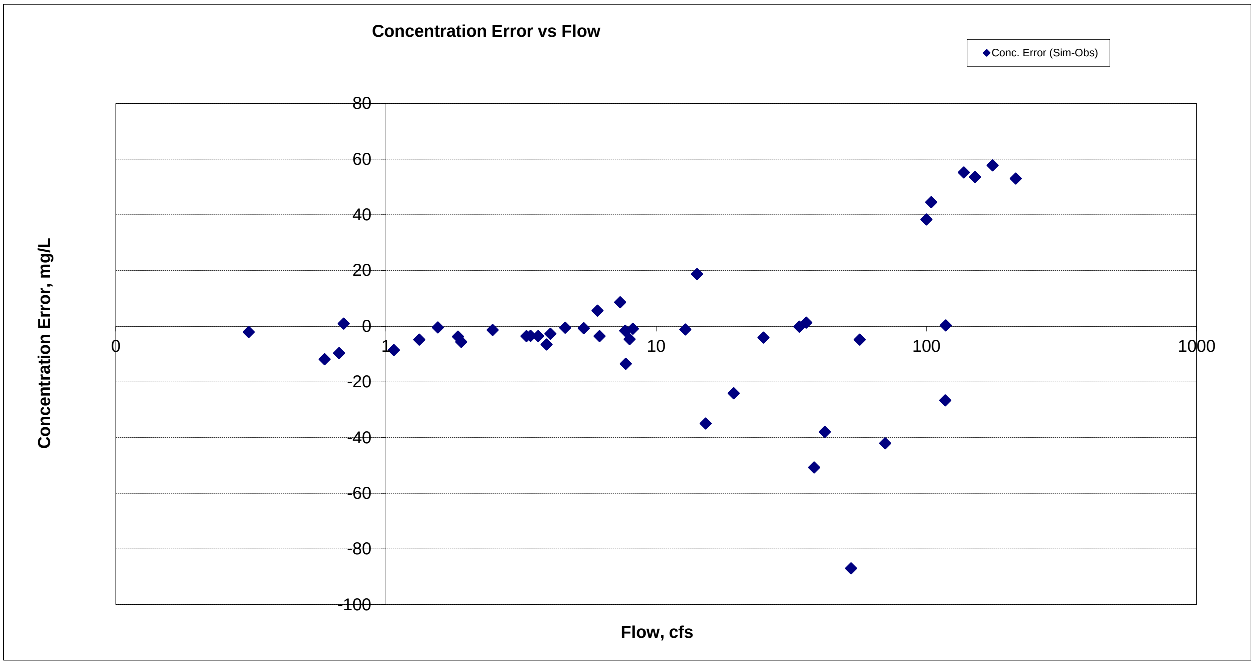


Figure 34. Residual (Simulated - Observed) vs. Flow Total Suspended Solids (TSS)

Total Phosphorus (TP)

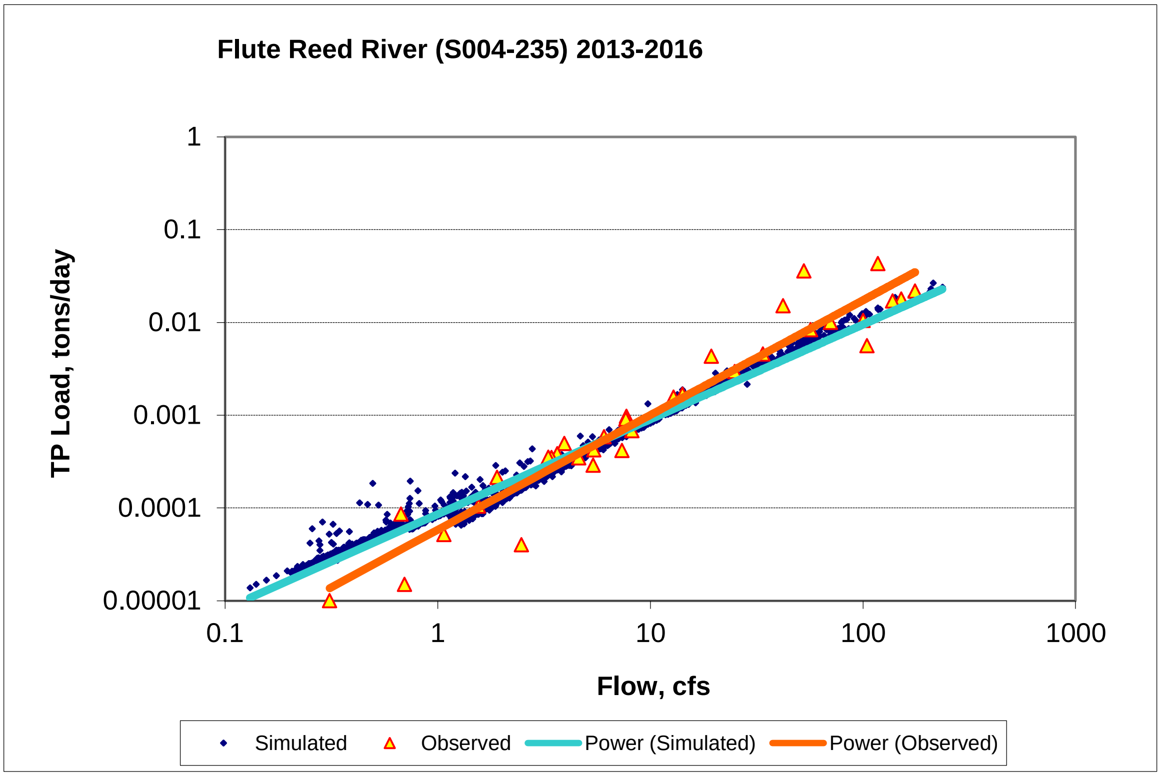


Figure 35. Power plot of simulated and observed Total Phosphorus (TP) load vs flow

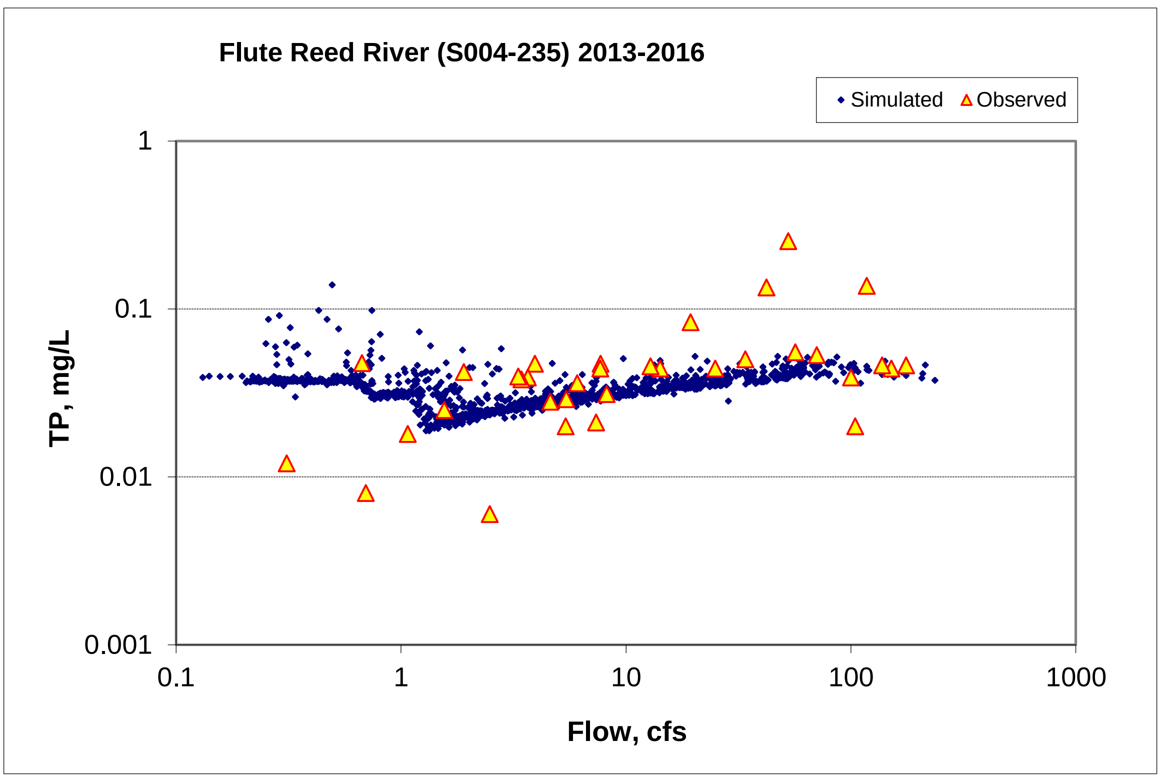


Figure 36. Simulated and observed Total Phosphorus (TP) concentration vs flow

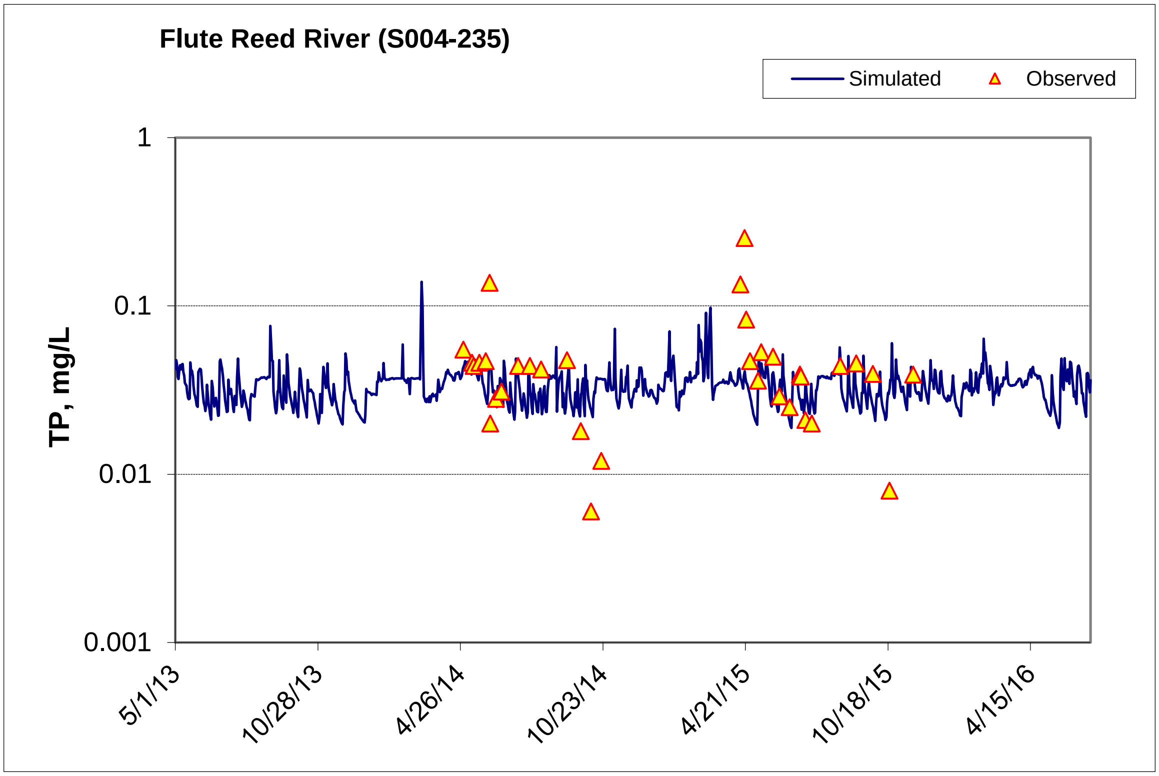


Figure 37. Time series of observed and simulated Total Phosphorus (TP) concentration

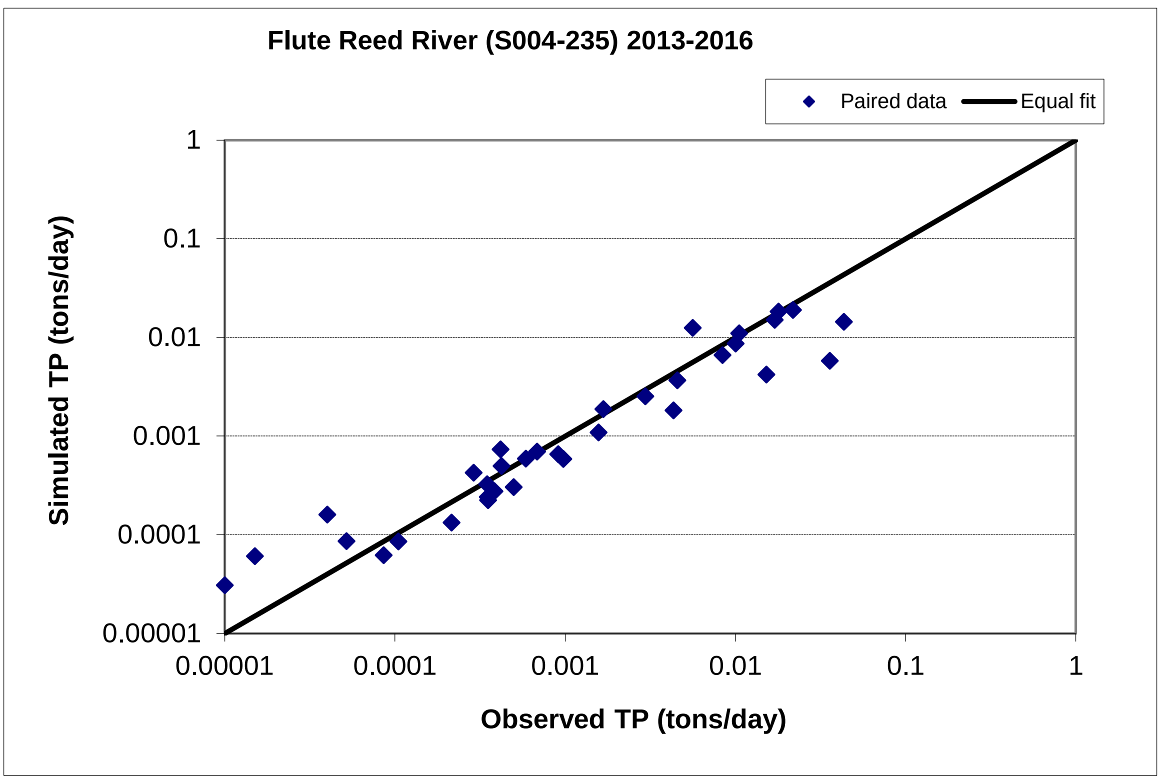


Figure 38. Paired simulated vs. observed Total Phosphorus (TP) load

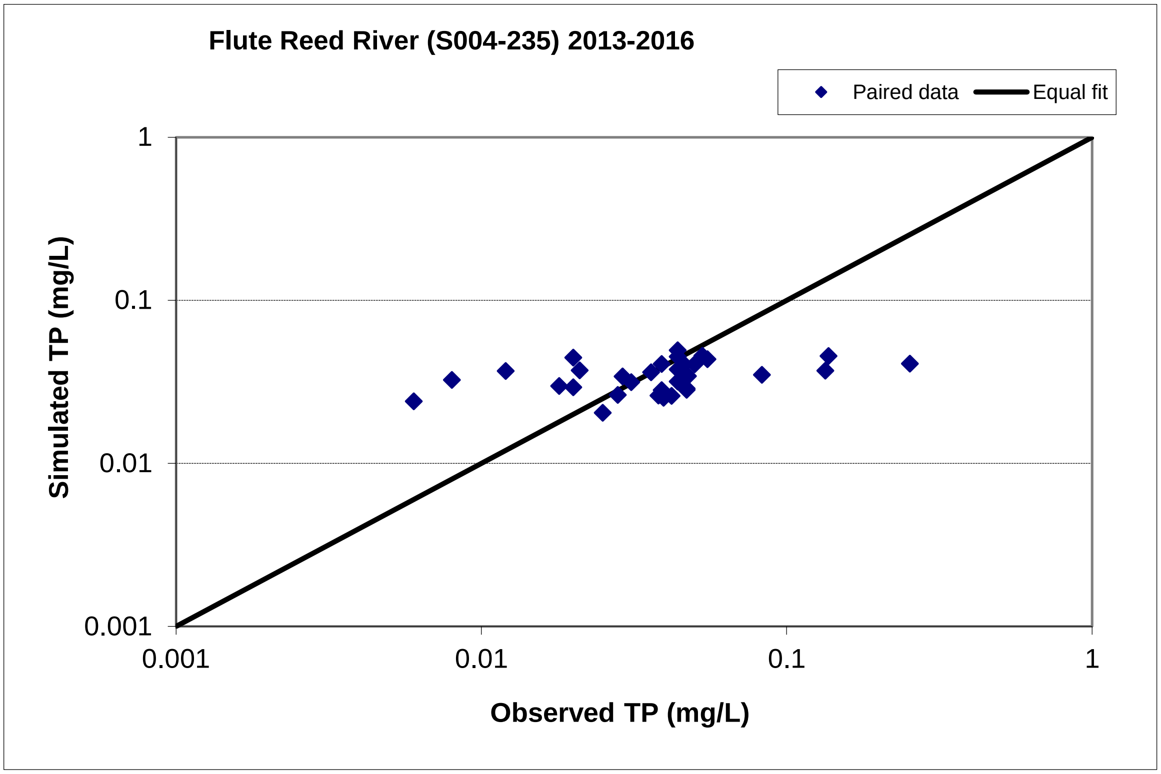


Figure 39. Paired simulated vs. observed Total Phosphorus (TP) concentration

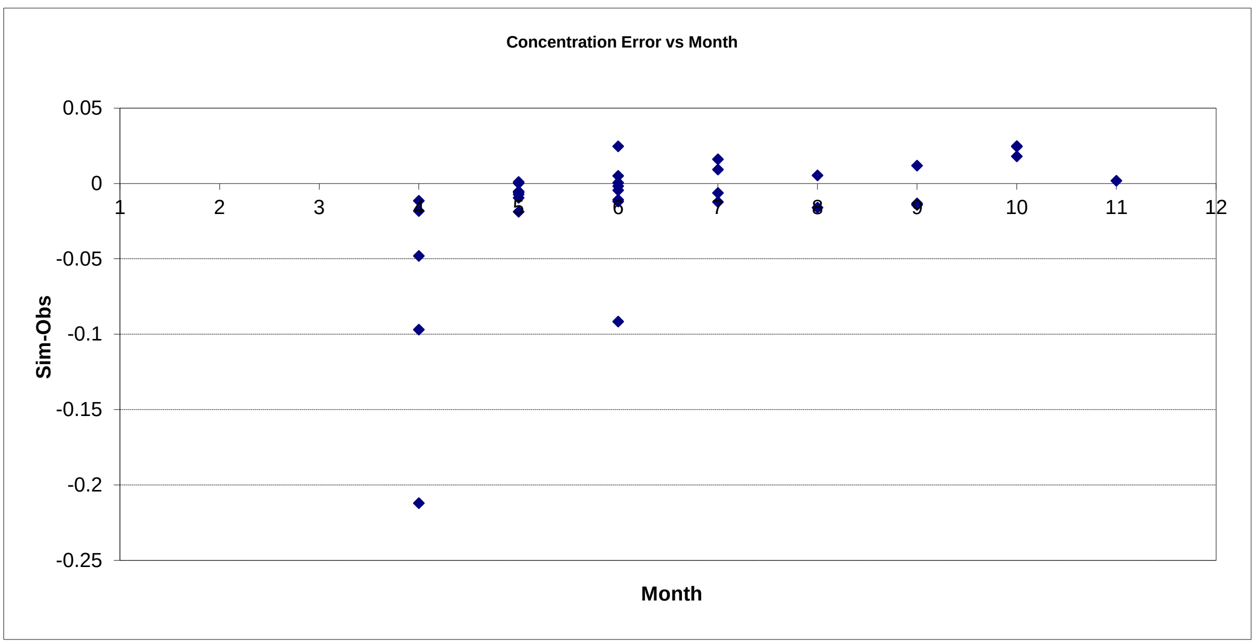


Figure 40. Residual (Simulated - Observed) vs. Month Total Phosphorus (TP)

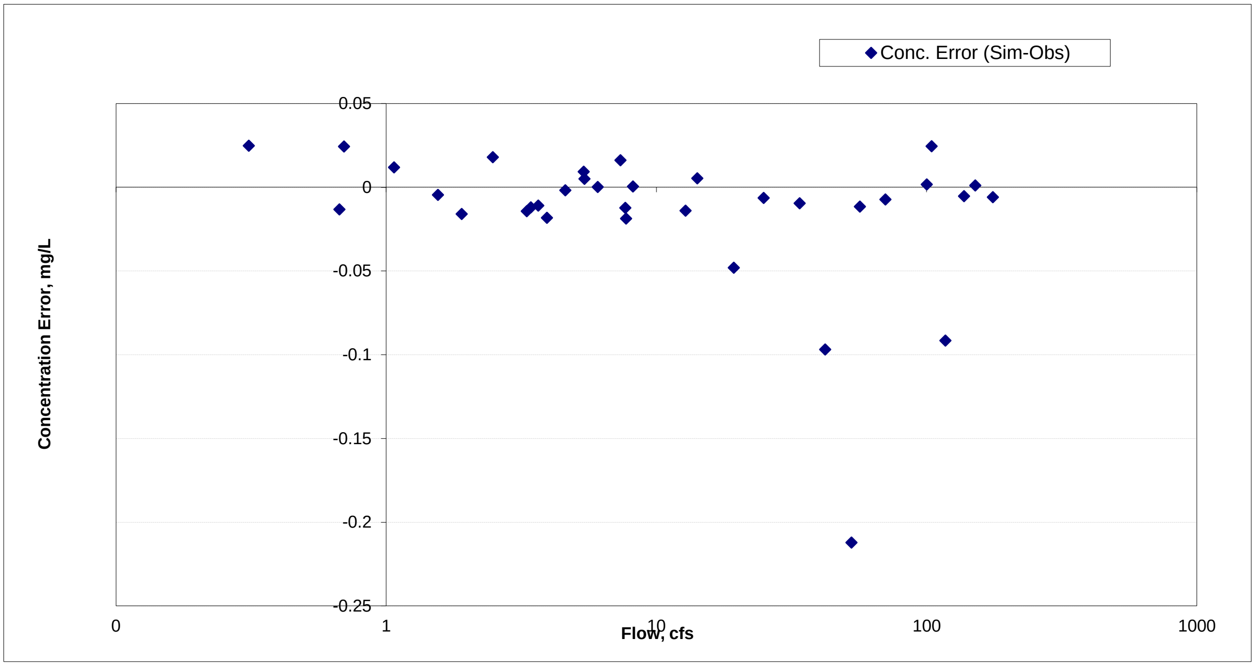


Figure 41. Residual (Simulated - Observed) vs. Flow Total Phosphorus (TP)

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

Total Suspended Solids (TSS)

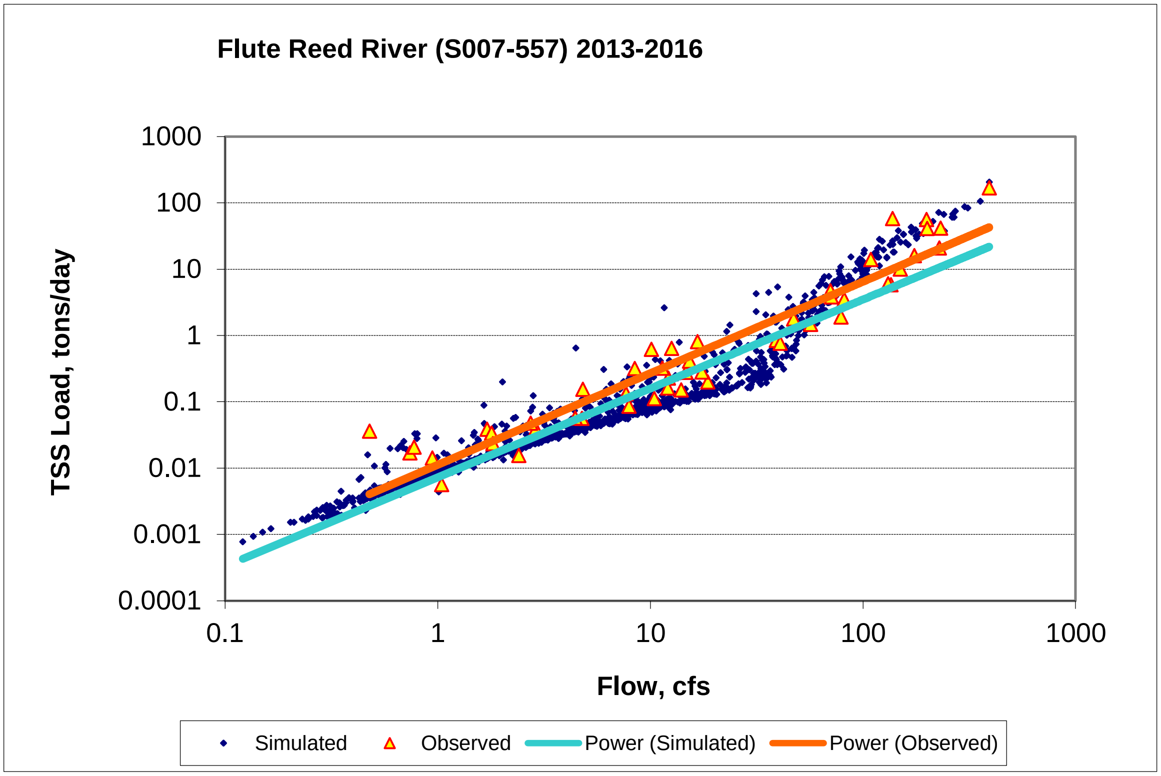


Figure 42. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow

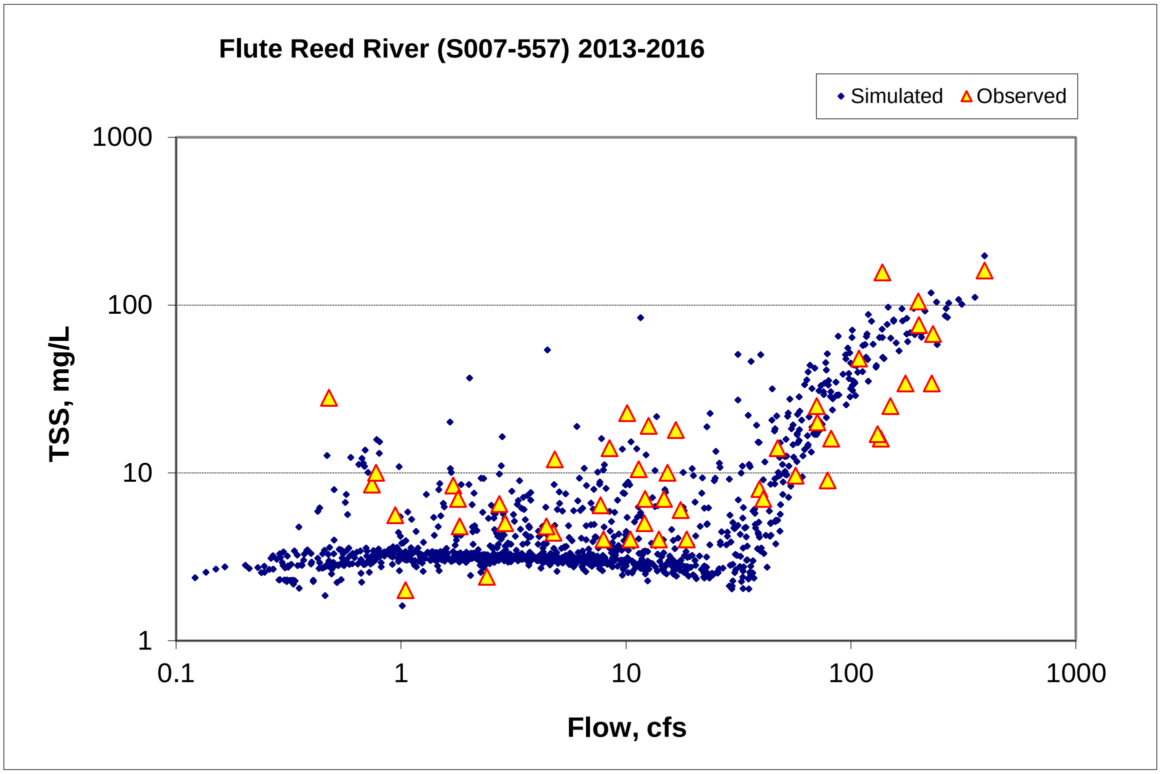


Figure 43. Simulated and observed Total Suspended Solids (TSS) concentration vs flow

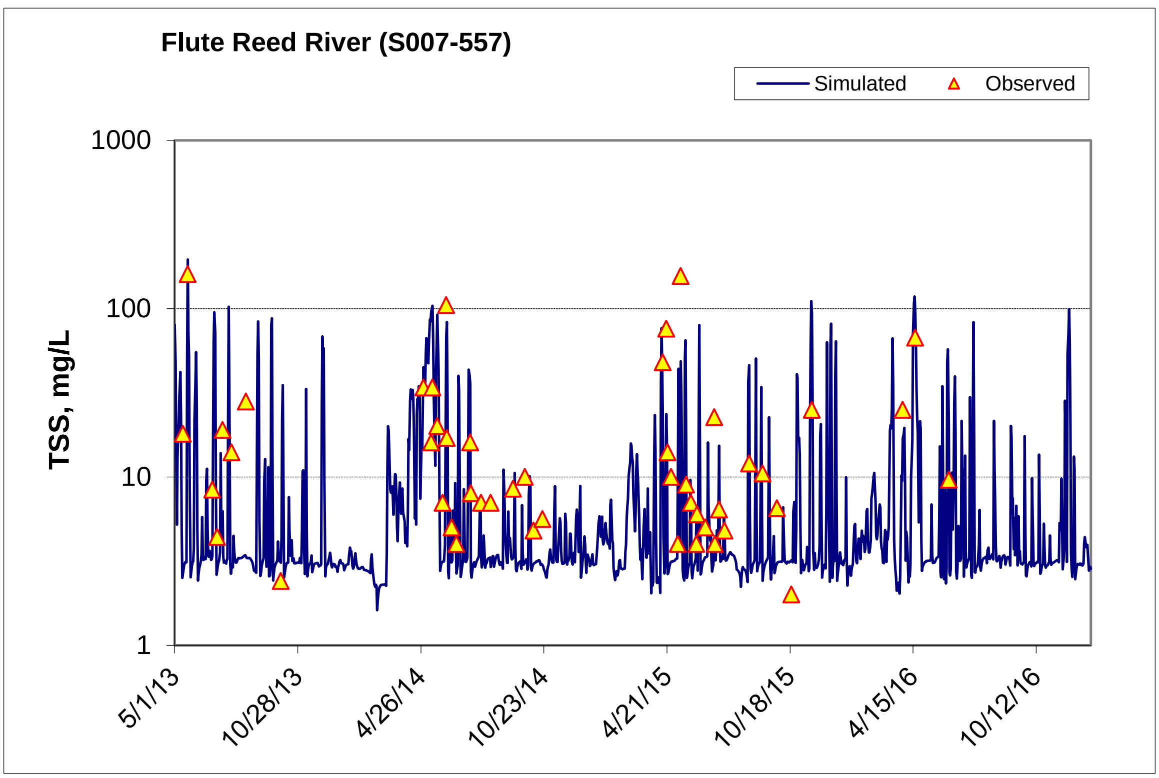


Figure 44. Time series of observed and simulated Total Suspended Solids (TSS) concentration

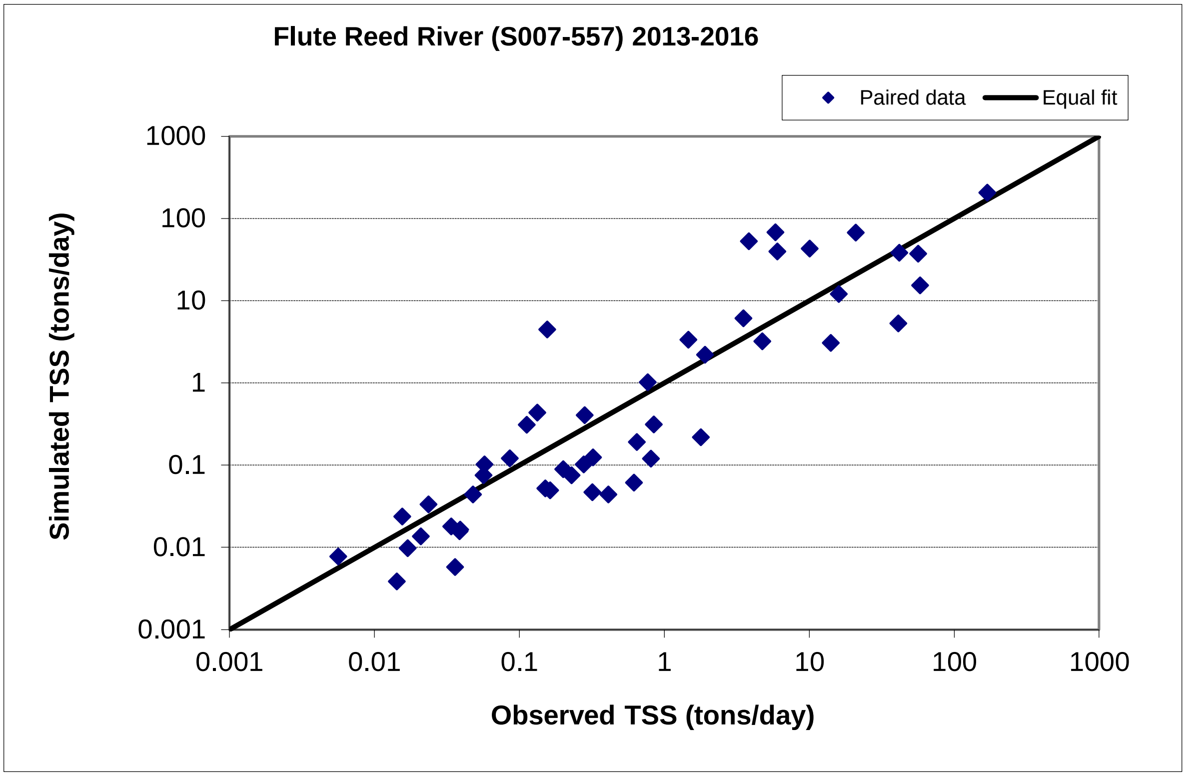


Figure 45. Paired simulated vs. observed Total Suspended Solids (TSS) load

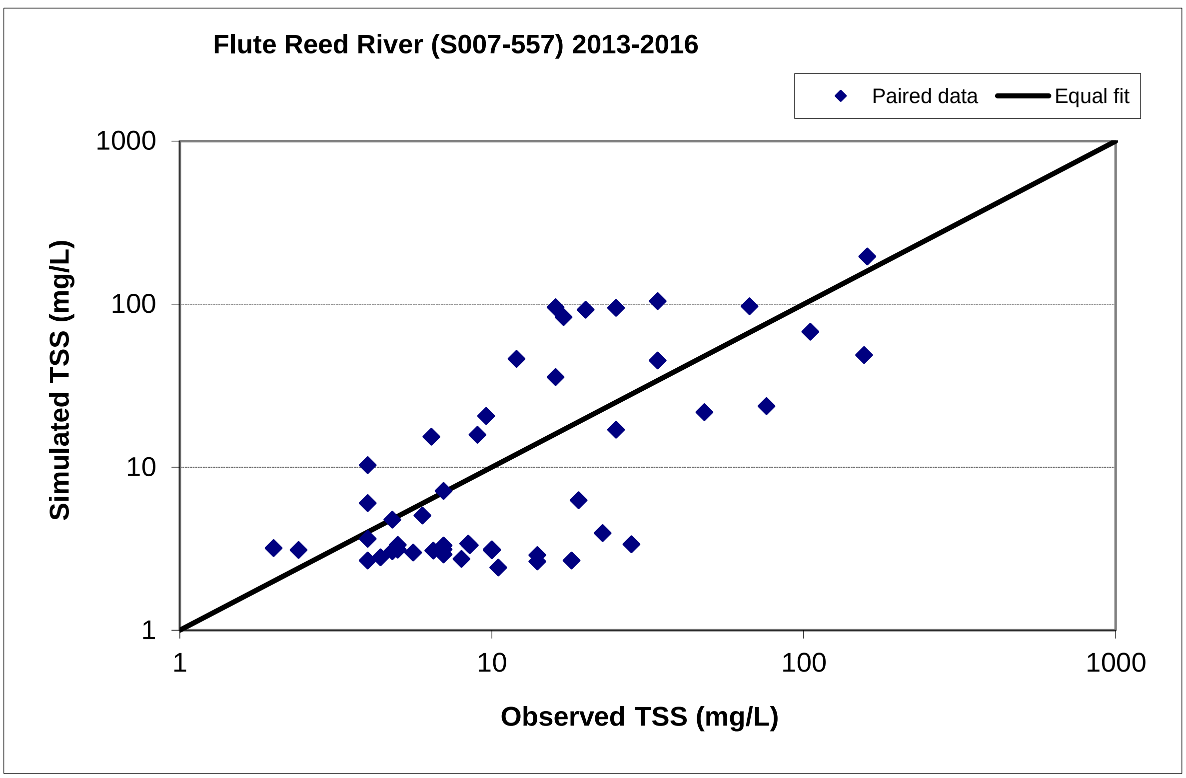


Figure 46. Paired simulated vs. observed Total Suspended Solids (TSS) concentration

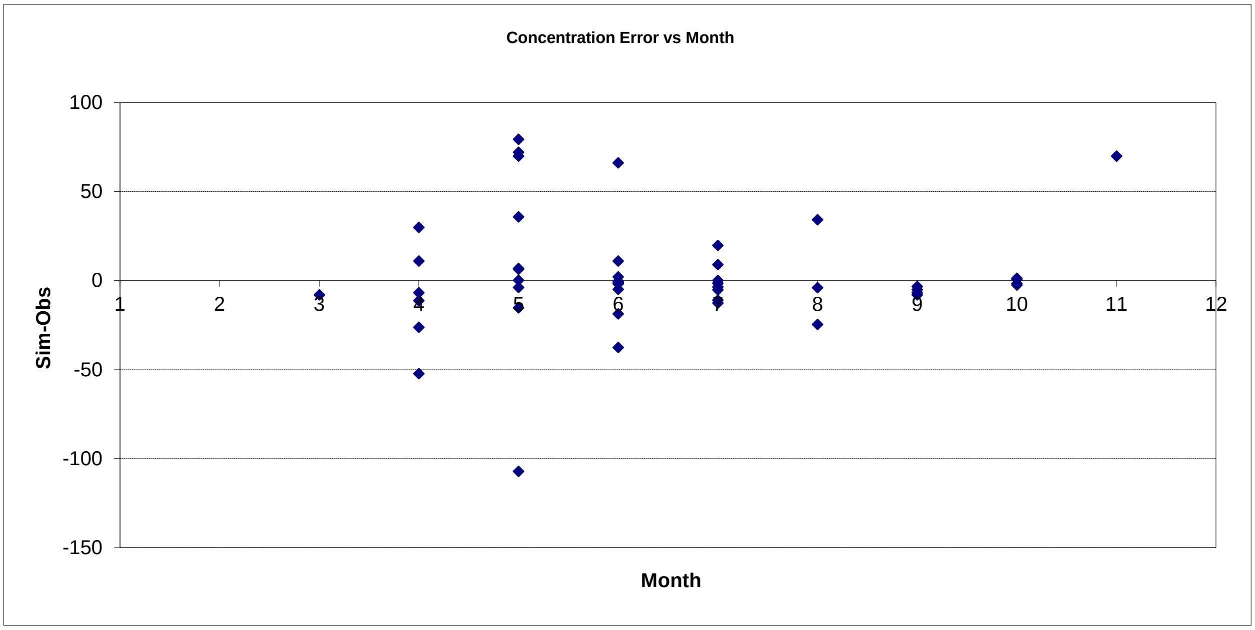


Figure 47. Residual (Simulated - Observed) vs. Month Total Suspended Solids (TSS)

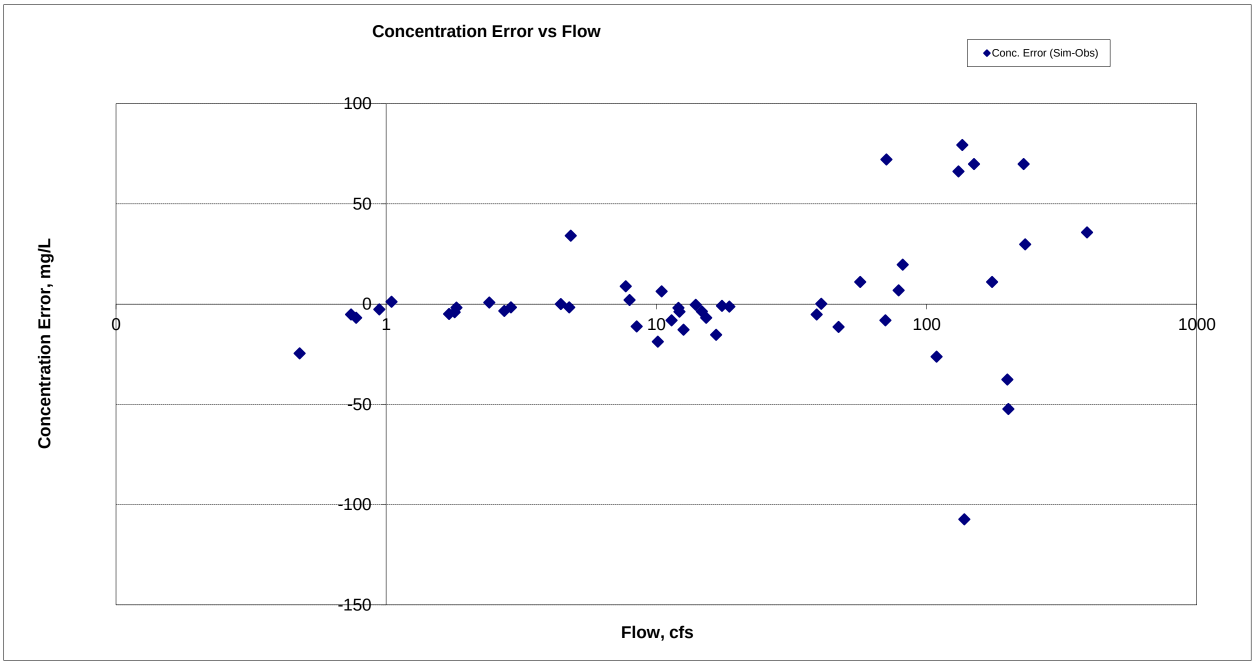


Figure 48. Residual (Simulated - Observed) vs. Flow Total Suspended Solids (TSS)

Total Phosphorus (TP)

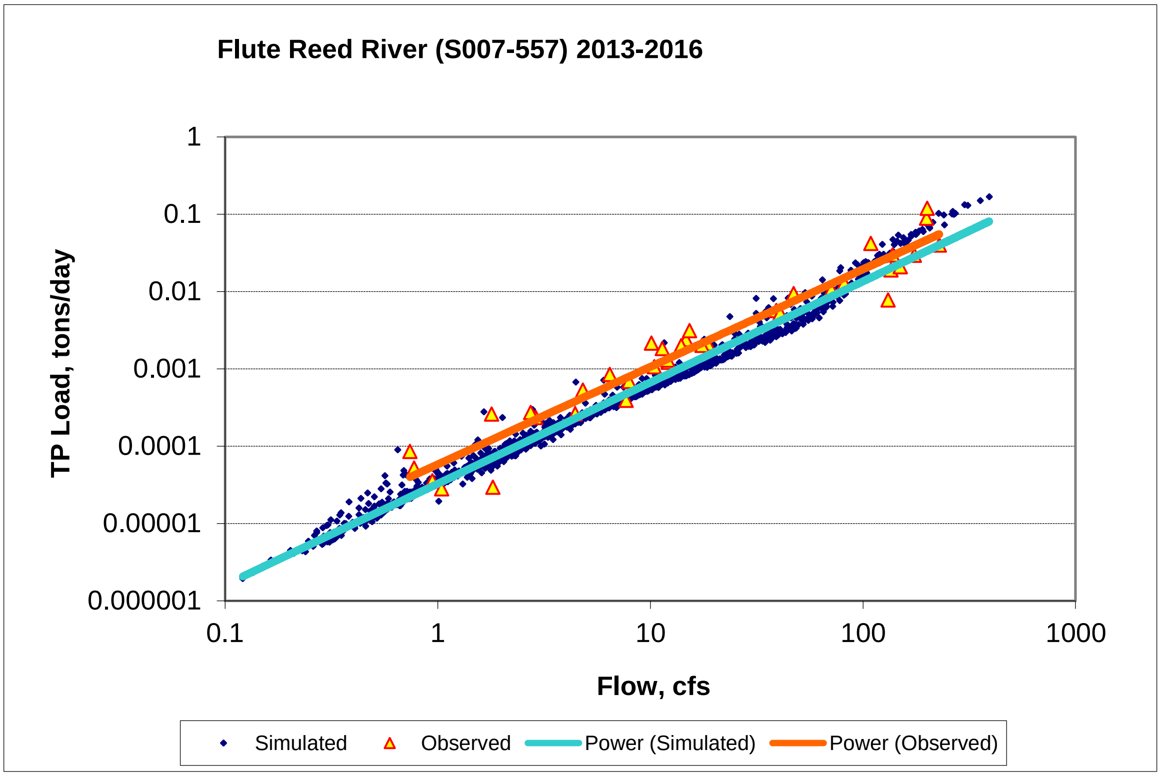


Figure 49. Power plot of simulated and observed Total Phosphorus (TP) load vs flow

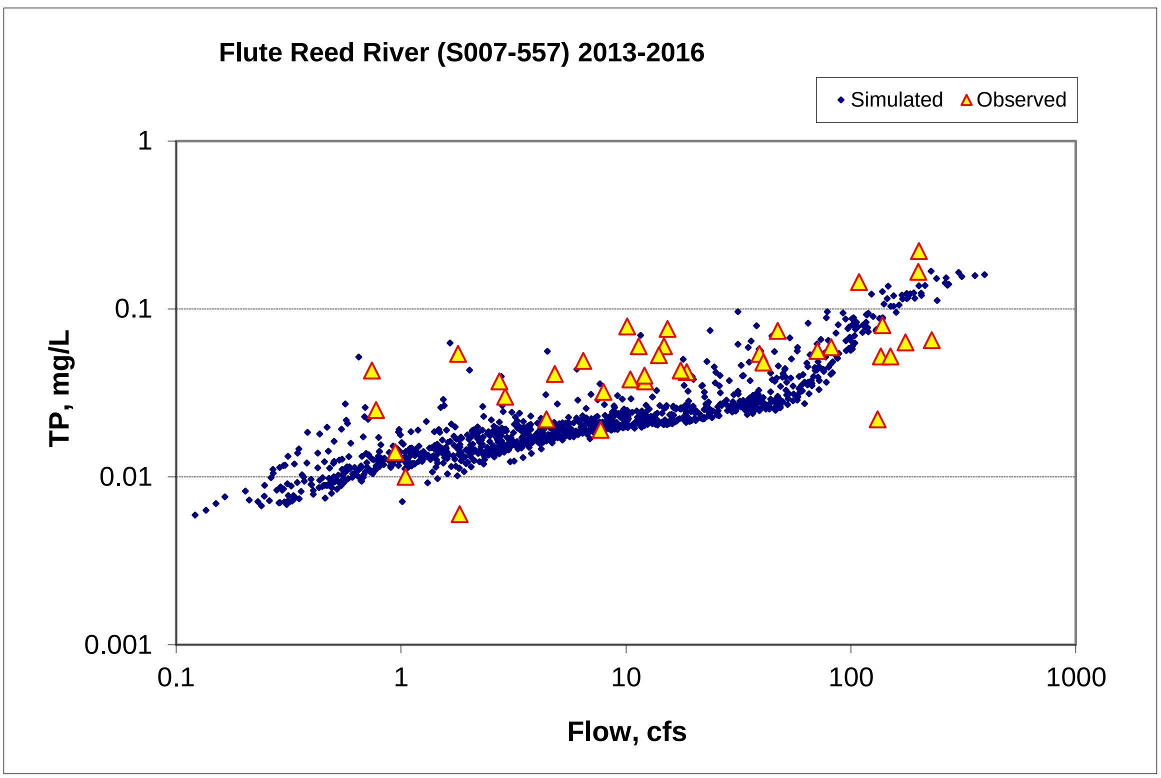


Figure 50. Simulated and observed Total Phosphorus (TP) concentration vs flow

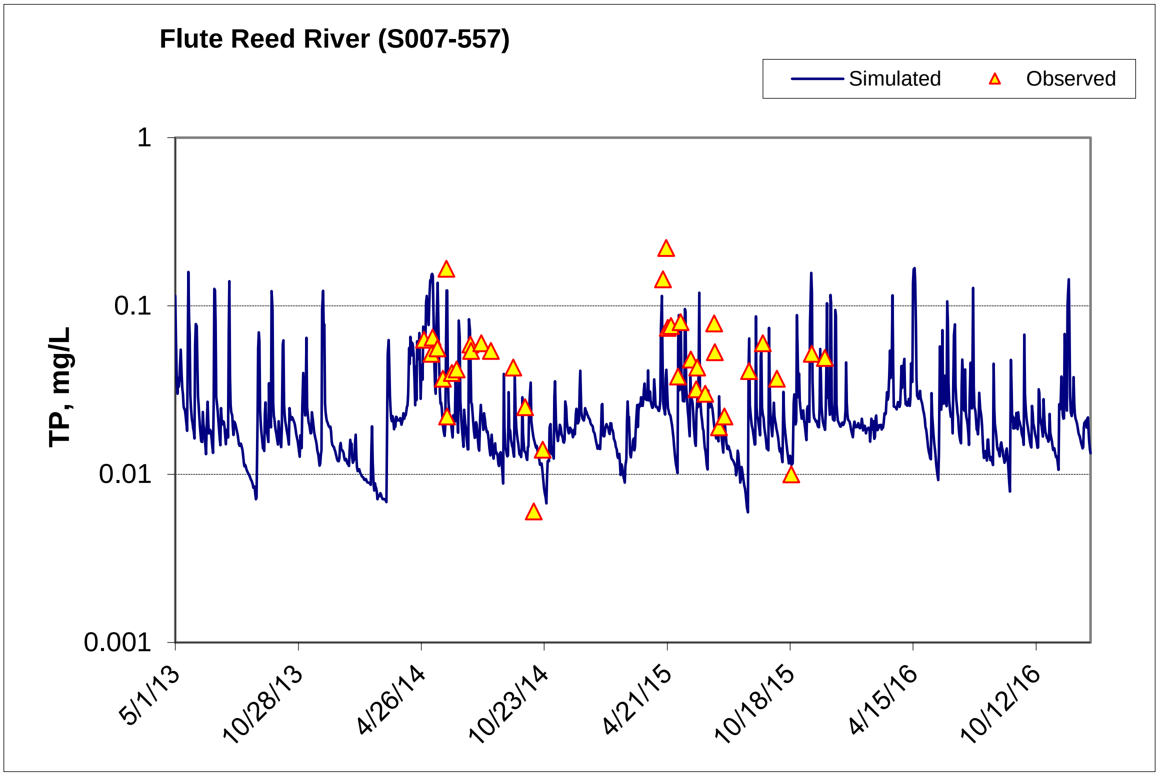


Figure 51. Time series of observed and simulated Total Phosphorus (TP) concentration

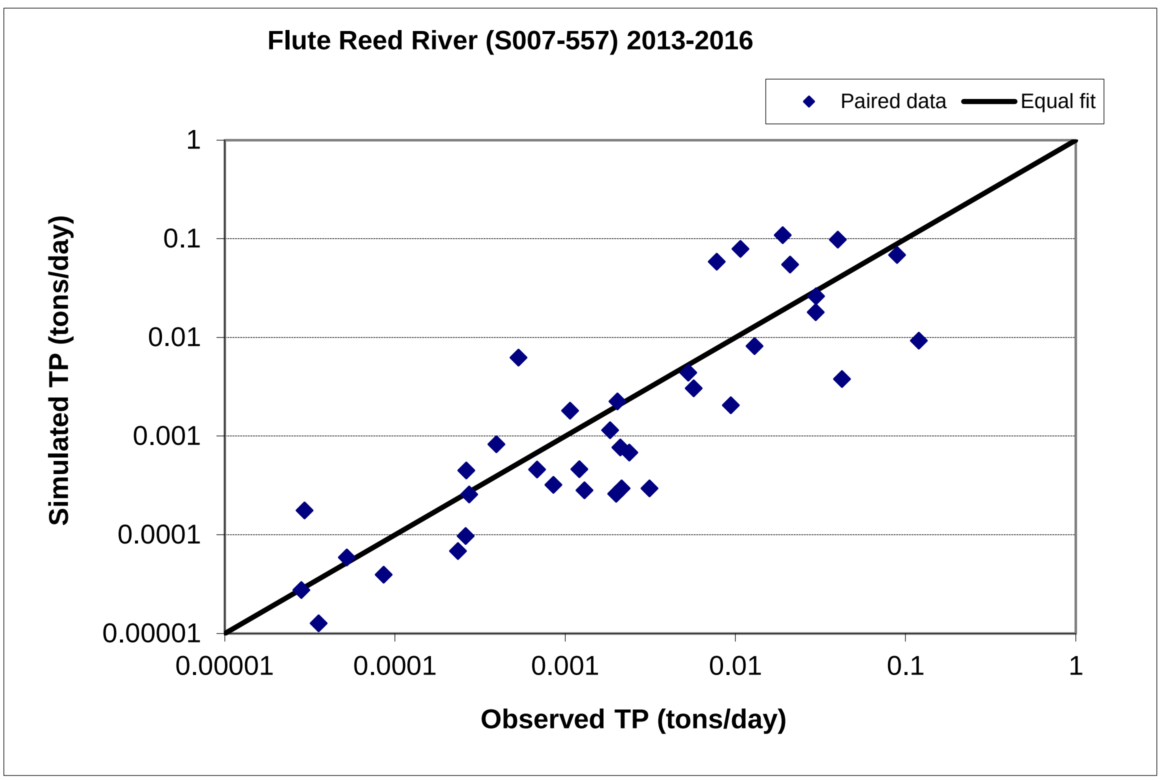


Figure 52. Paired simulated vs. observed Total Phosphorus (TP) load

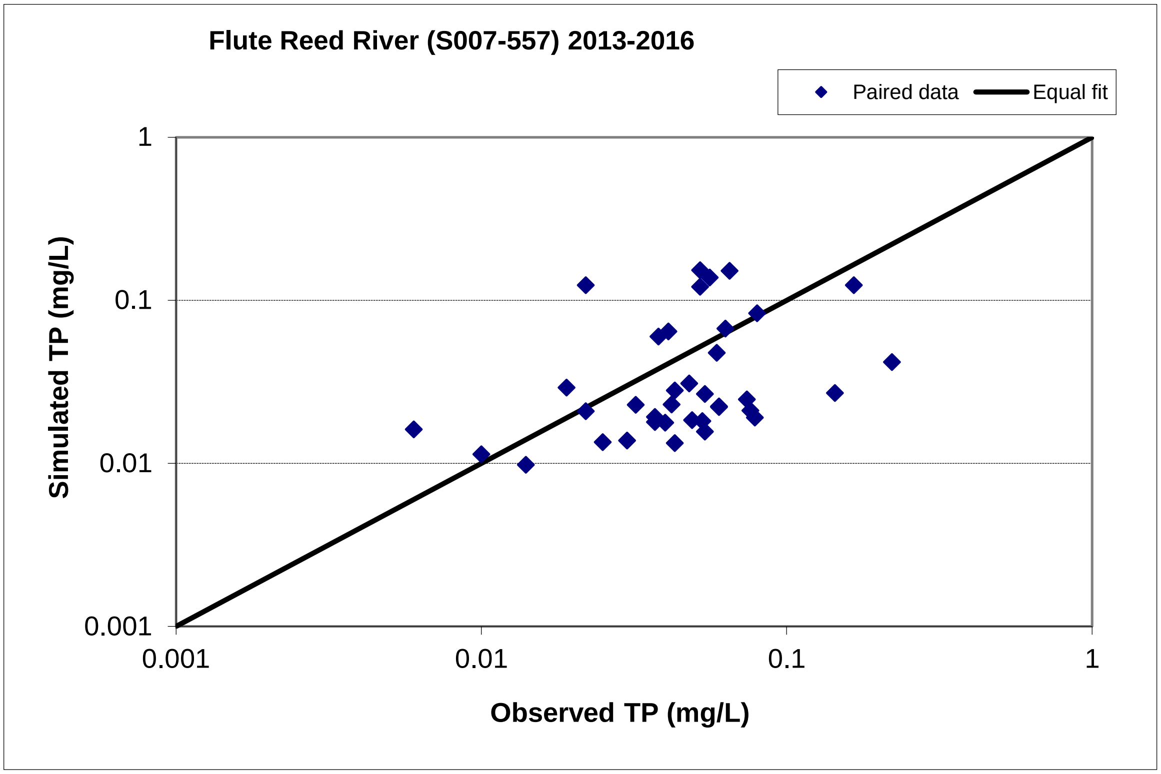


Figure 53. Paired simulated vs. observed Total Phosphorus (TP) concentration

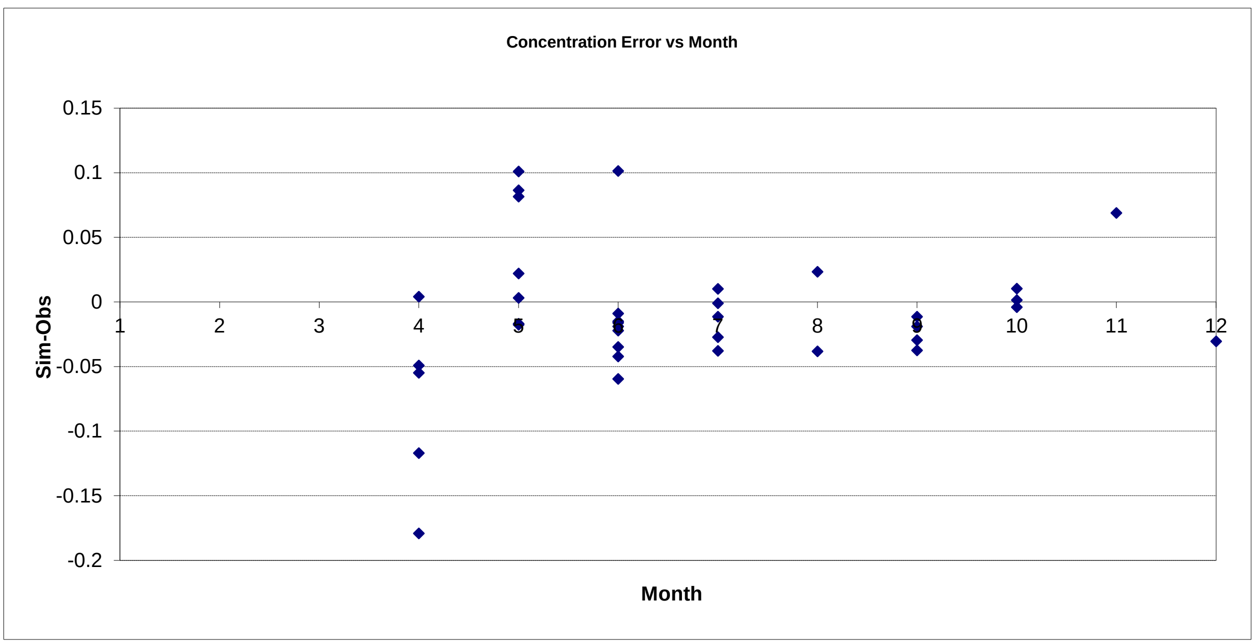


Figure 54. Residual (Simulated - Observed) vs. Month Total Phosphorus (TP)

TETRA TECH

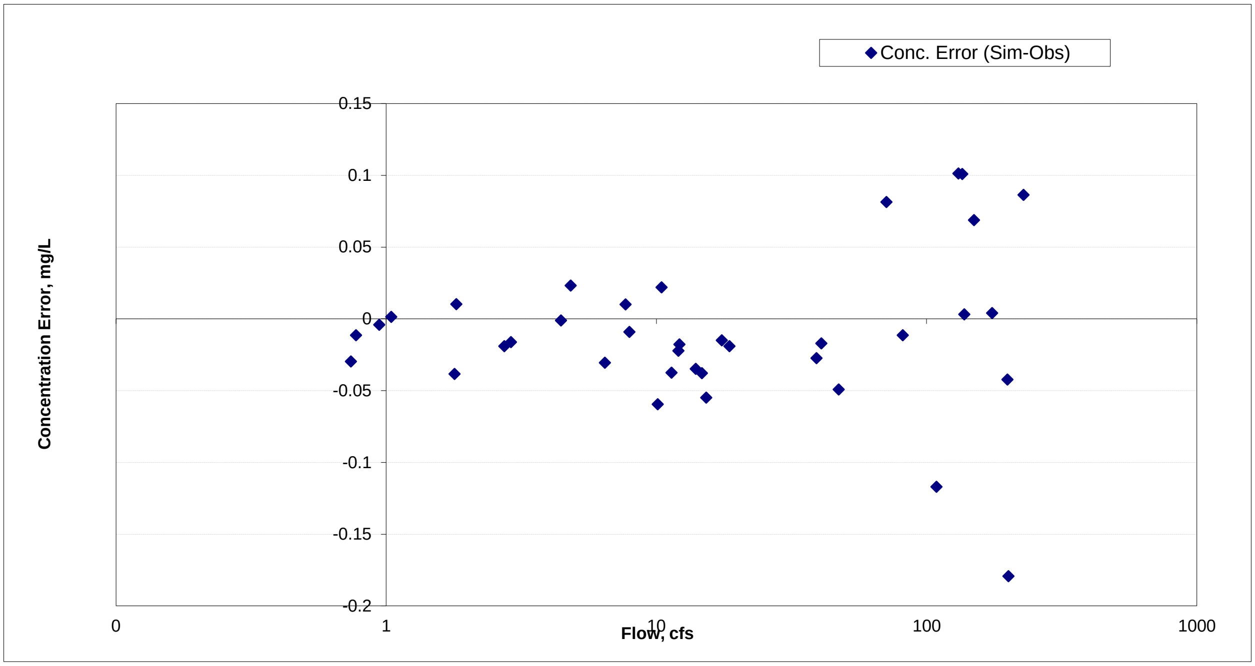


Figure 55. Residual (Simulated - Observed) vs. Flow Total Phosphorus (TP)

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)

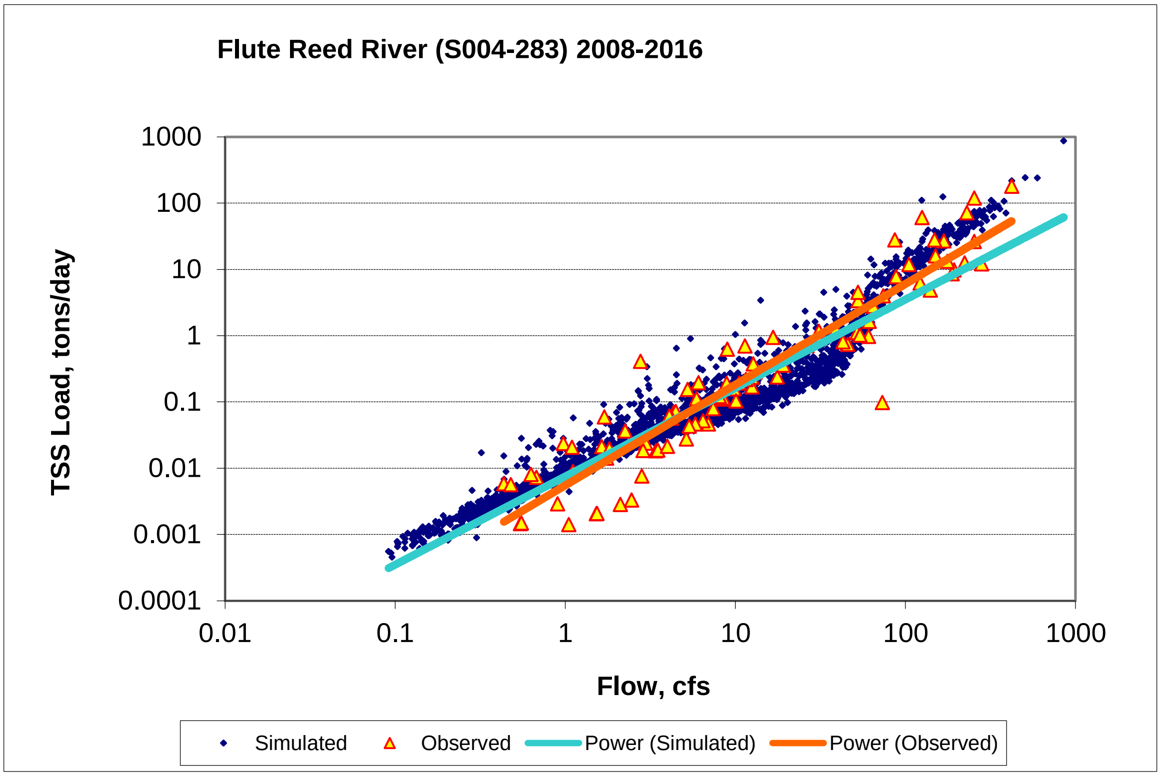


Figure 56. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow at Flute Reed River (S004-283)

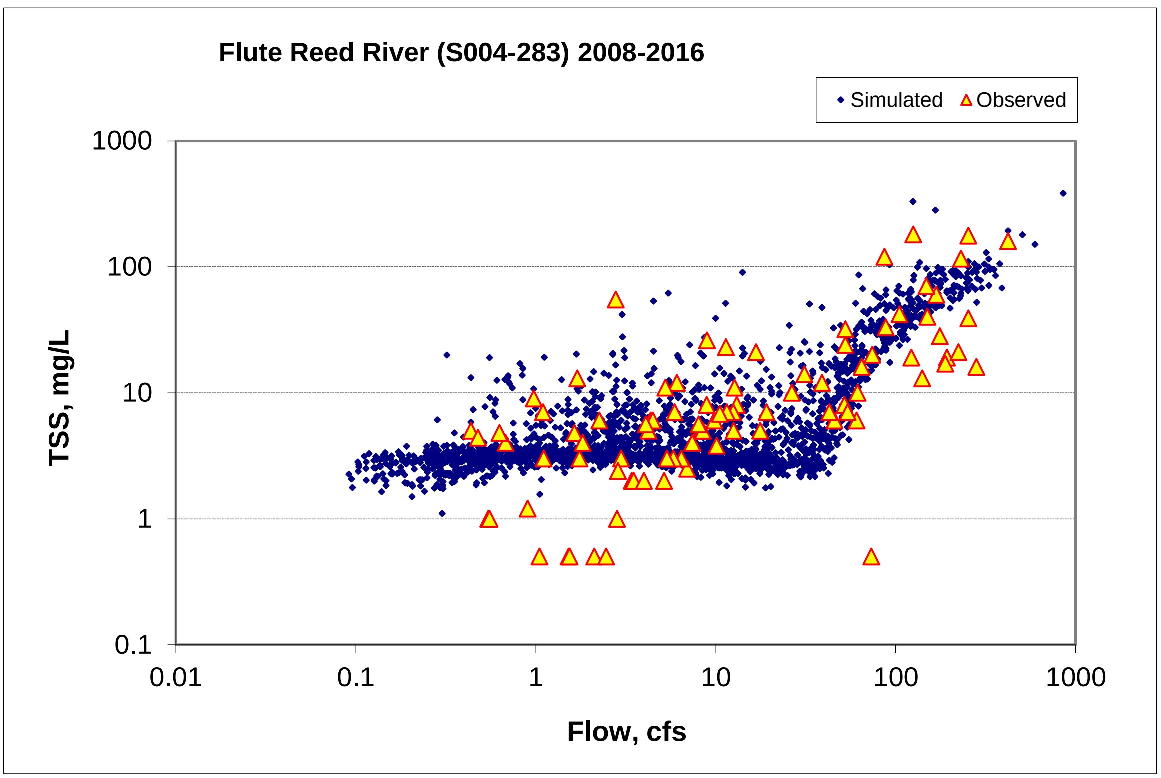


Figure 57. Simulated and observed Total Suspended Solids (TSS) concentration vs flow at Flute Reed River (S004-283)

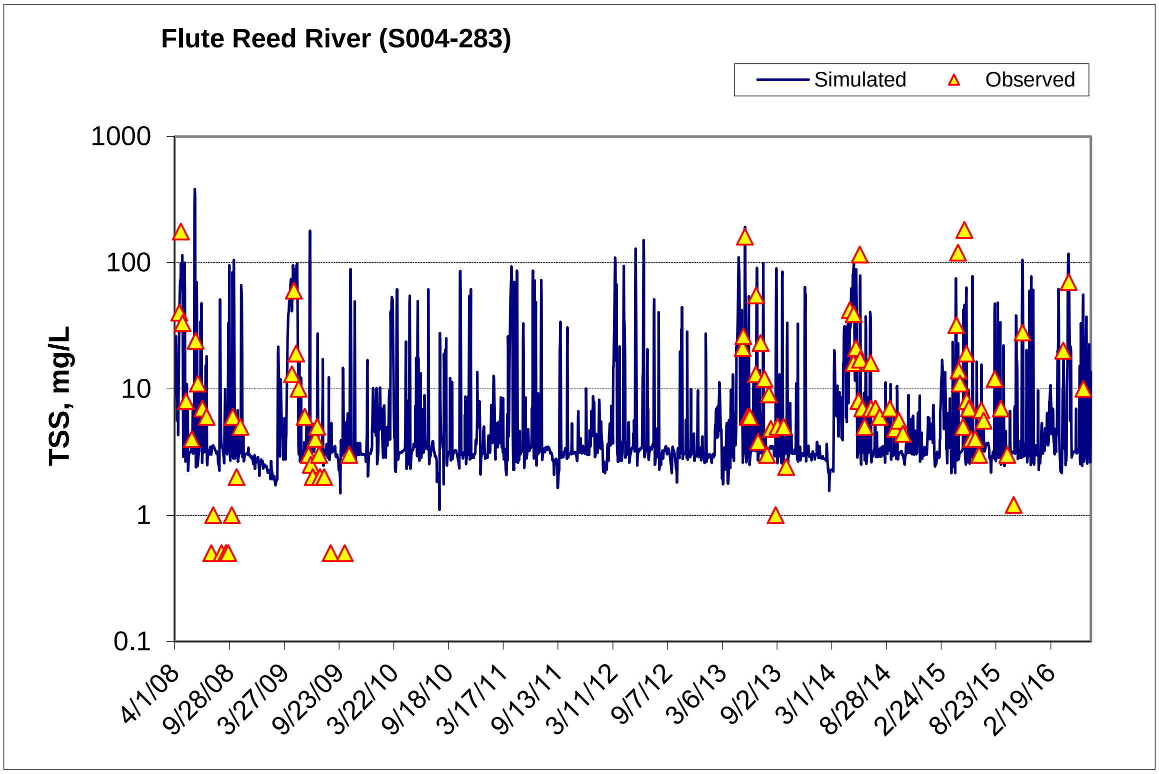


Figure 58. Time series of observed and simulated Total Suspended Solids (TSS) concentration at Flute Reed River (S004-283)

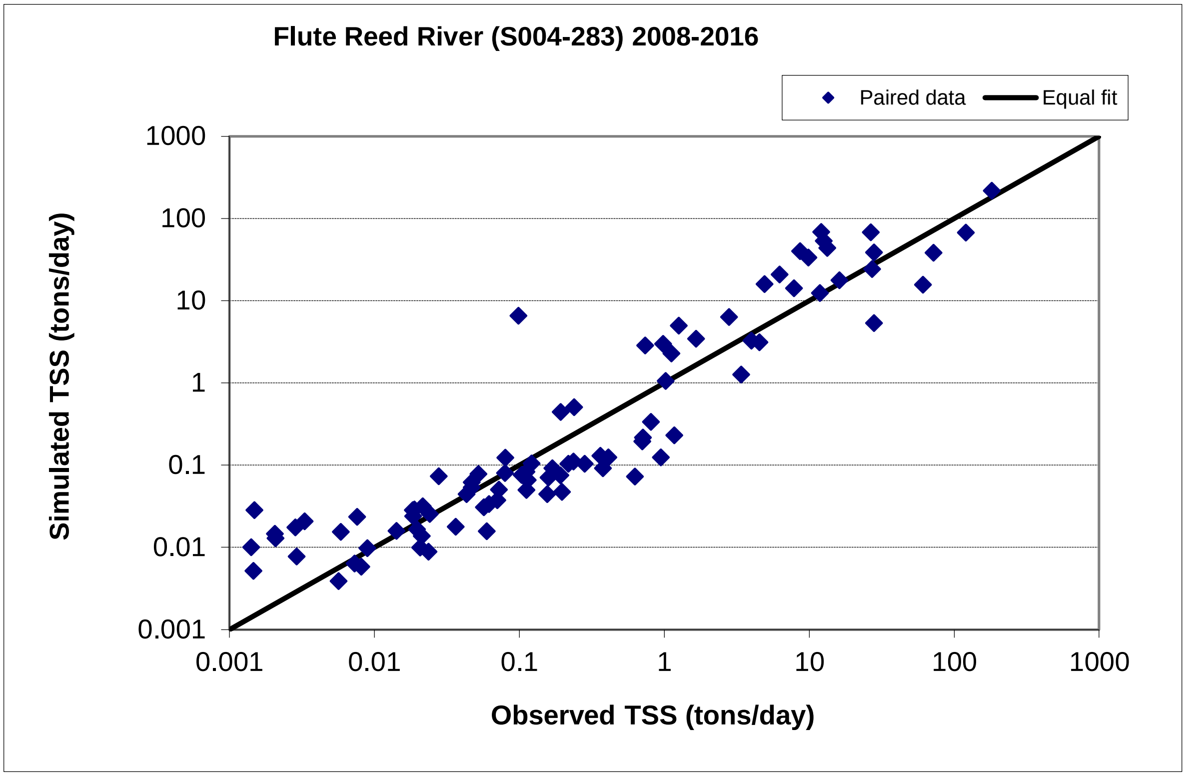


Figure 59. Paired simulated vs. observed Total Suspended Solids (TSS) load at Flute Reed River (S004-283)

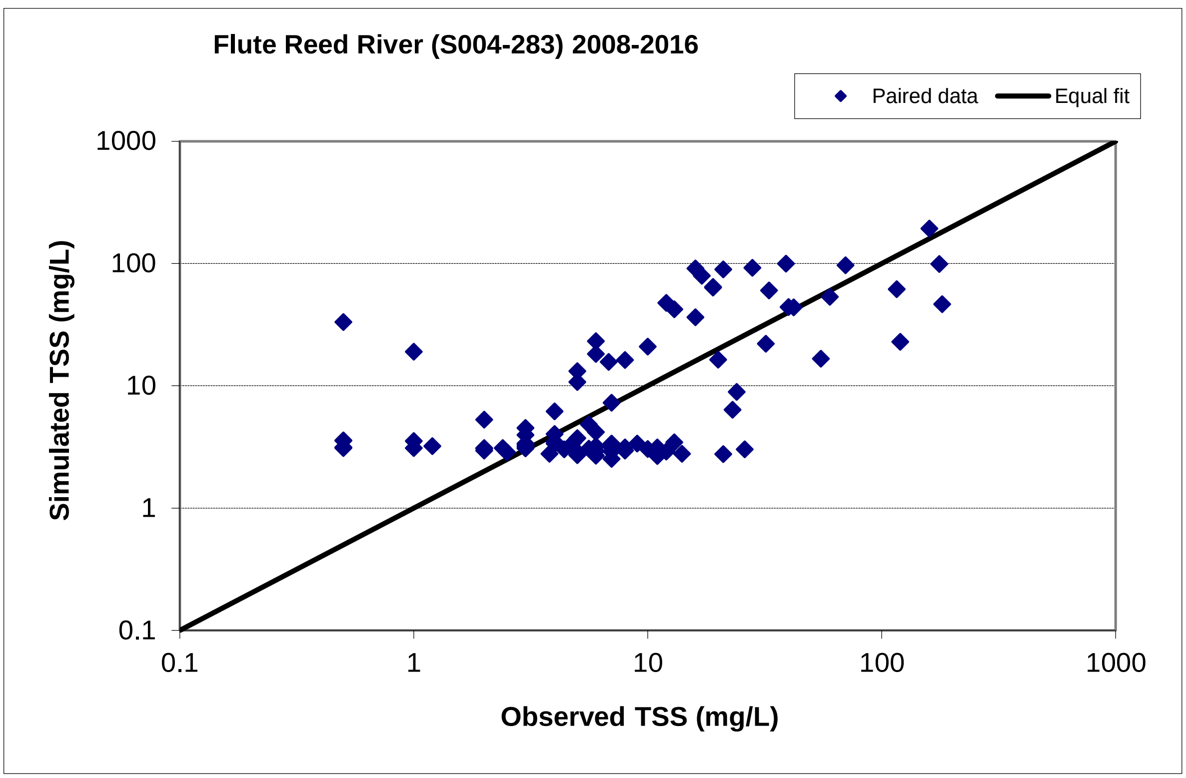


Figure 60. Paired simulated vs. observed Total Suspended Solids (TSS) concentration at Flute Reed River (S004-283)

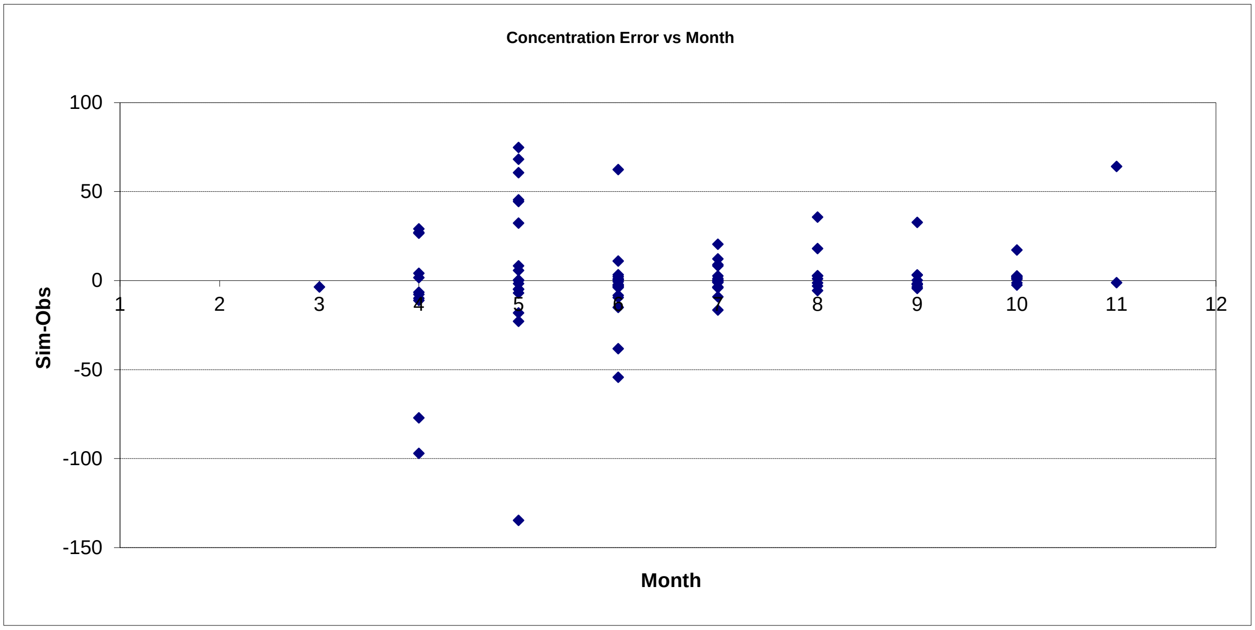


Figure 61. Residual (Simulated - Observed) vs. Month Total Suspended Solids (TSS) at Flute Reed River (S004-283)

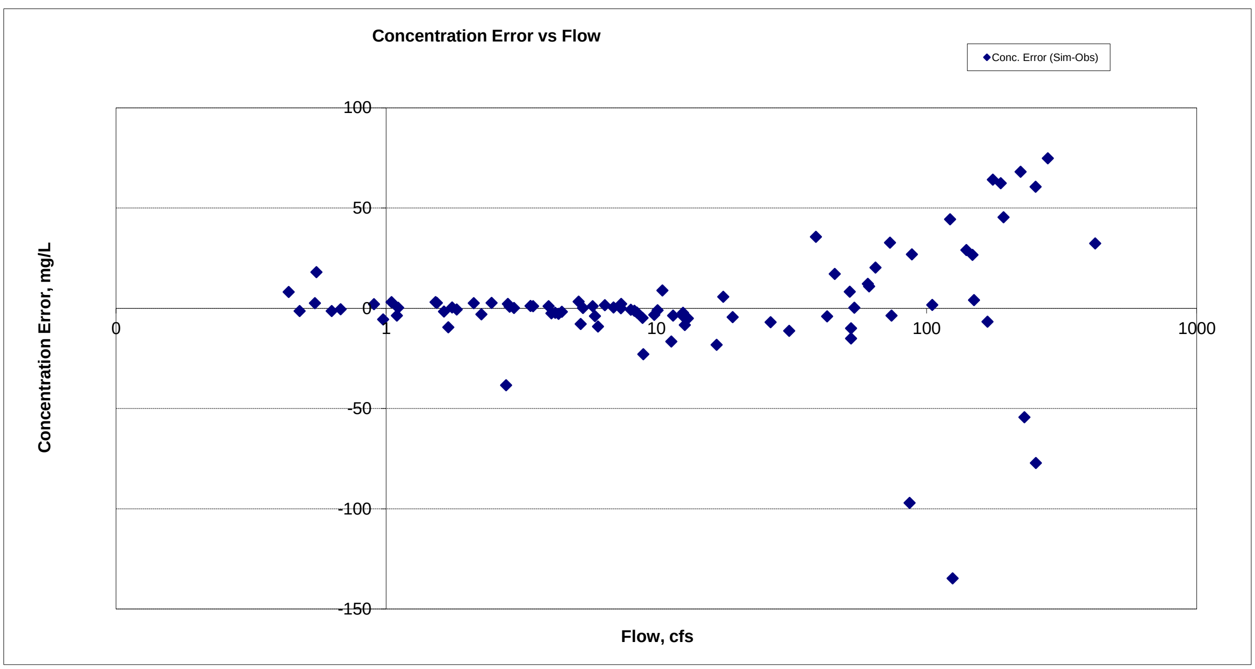


Figure 62. Residual (Simulated - Observed) vs. Flow Total Suspended Solids (TSS) at Flute Reed River (S004-283)

Ammonia Nitrogen (NH3)

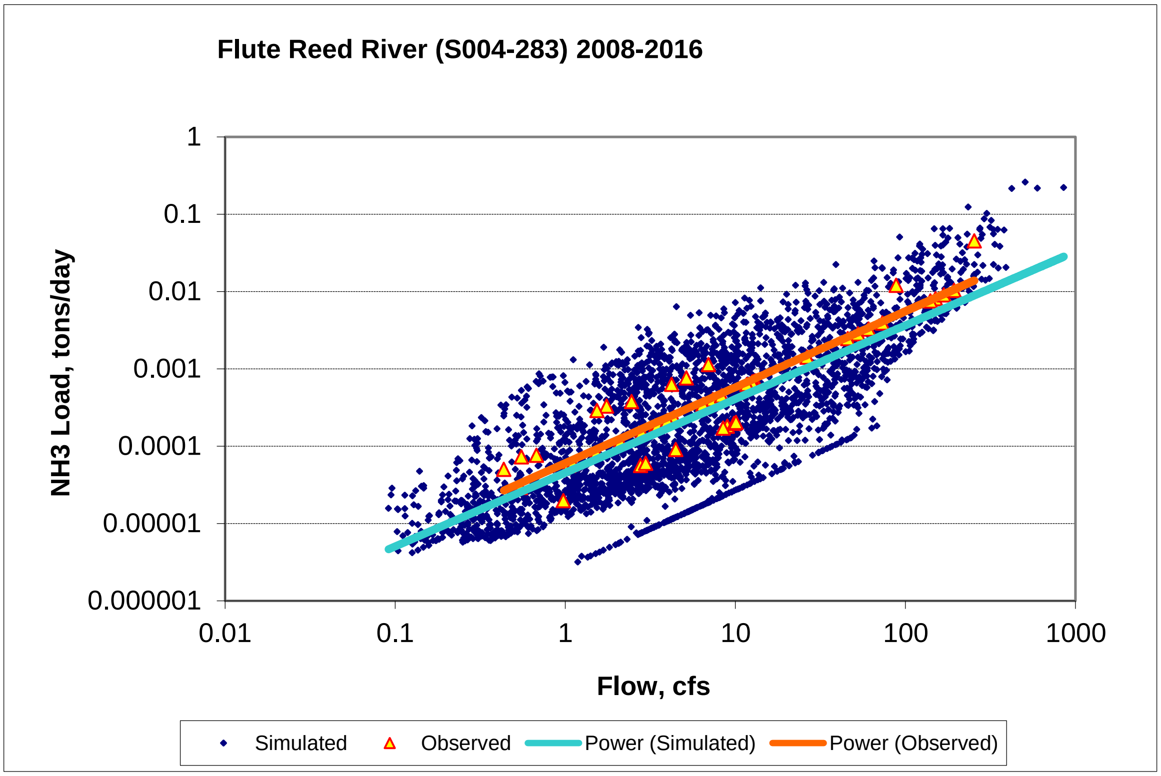


Figure 63. Power plot of simulated and observed Ammonia Nitrogen (NH3) load vs flow at Flute Reed River (S004-283)

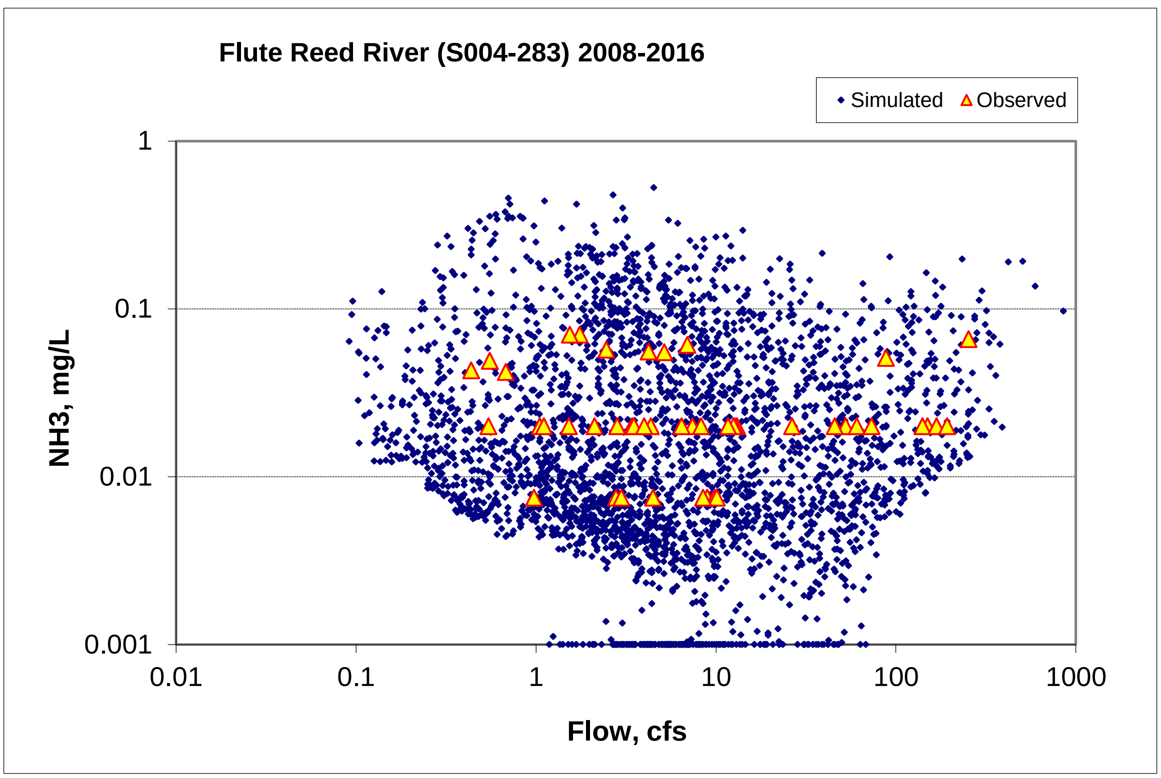


Figure 64. Simulated and observed Ammonia Nitrogen (NH3) concentration vs flow at Flute Reed River (S004-283)

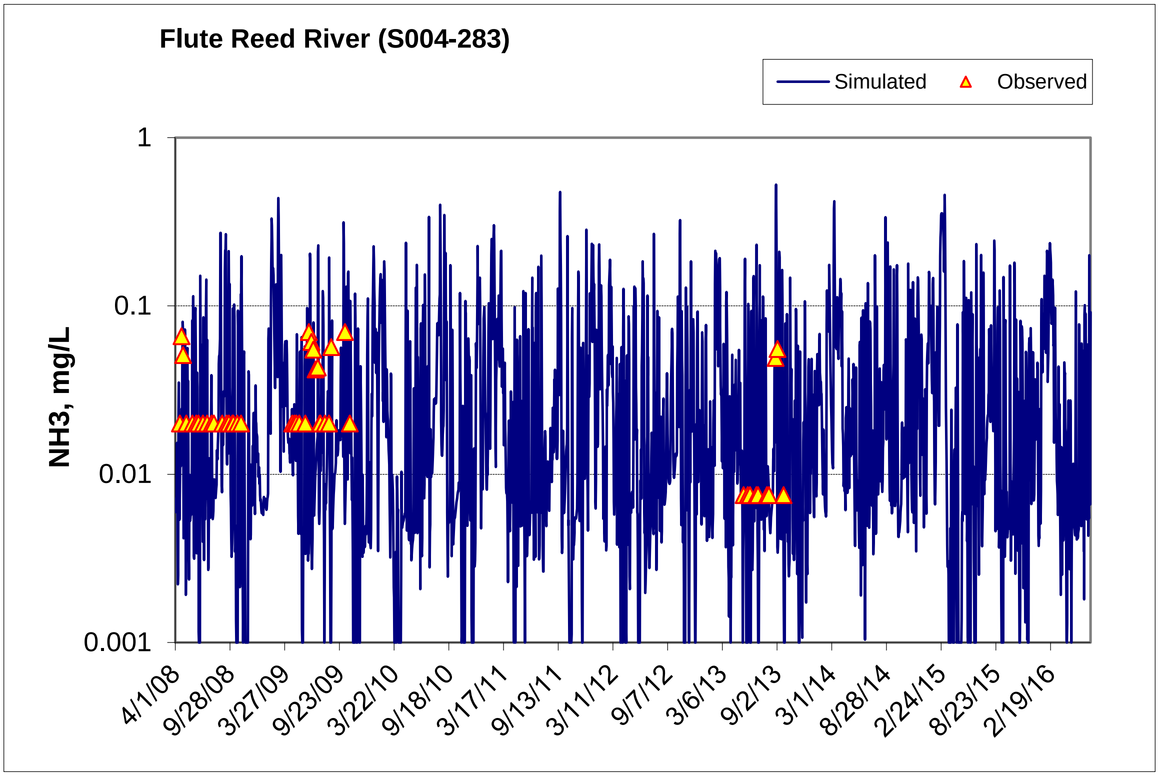


Figure 65. Time series of observed and simulated Ammonia Nitrogen (NH3) concentration at Flute Reed River (S004-283)

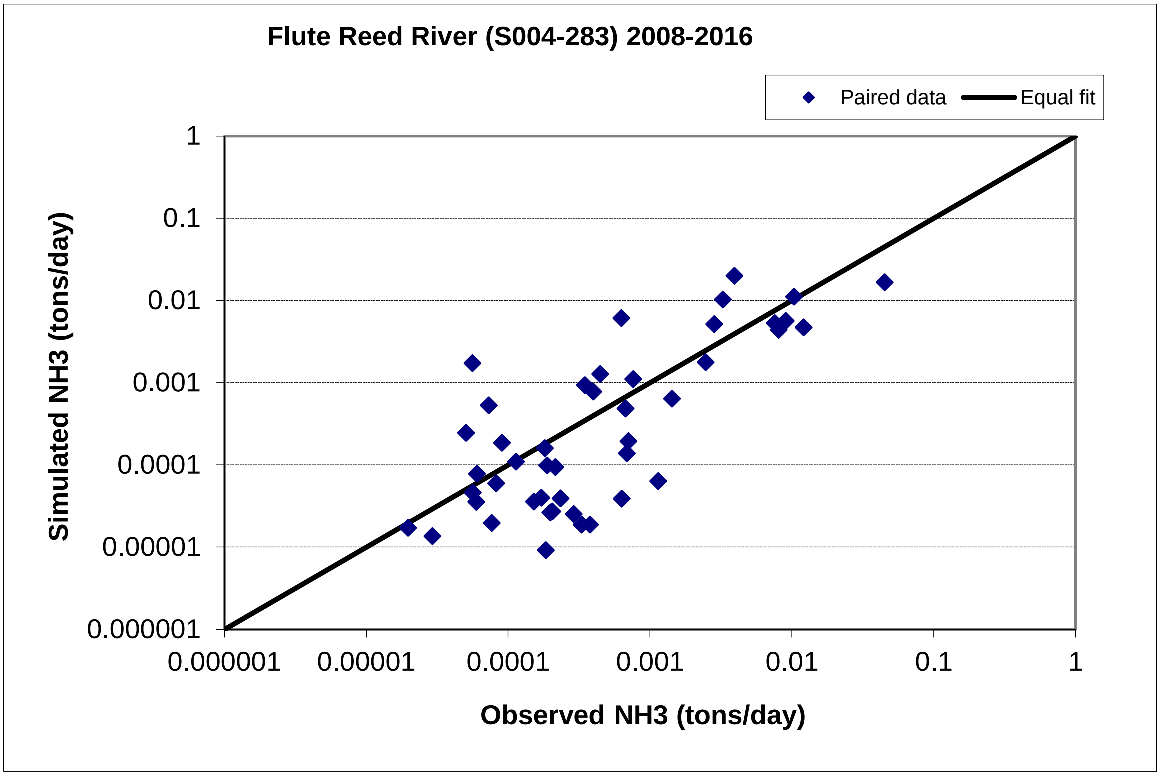


Figure 66. Paired simulated vs. observed Ammonia Nitrogen (NH3) load at Flute Reed River (S004-283)

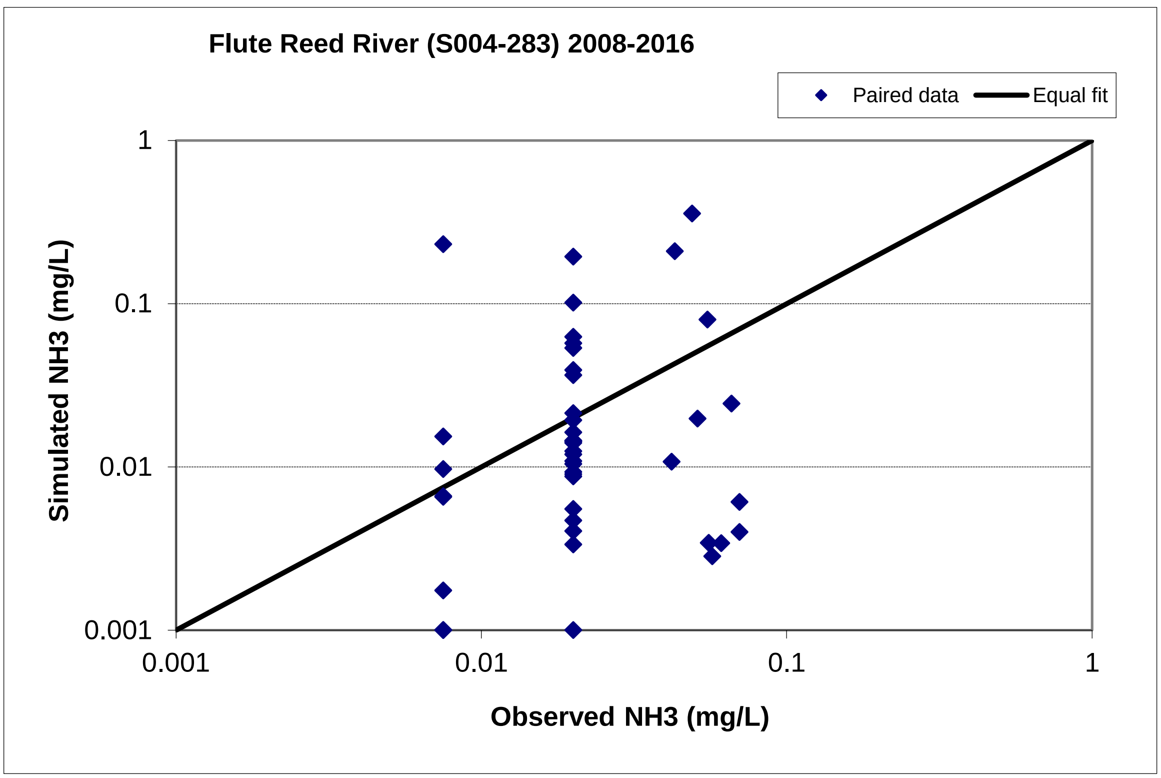


Figure 67. Paired simulated vs. observed Ammonia Nitrogen (NH3) concentration at Flute Reed River (S004-283)

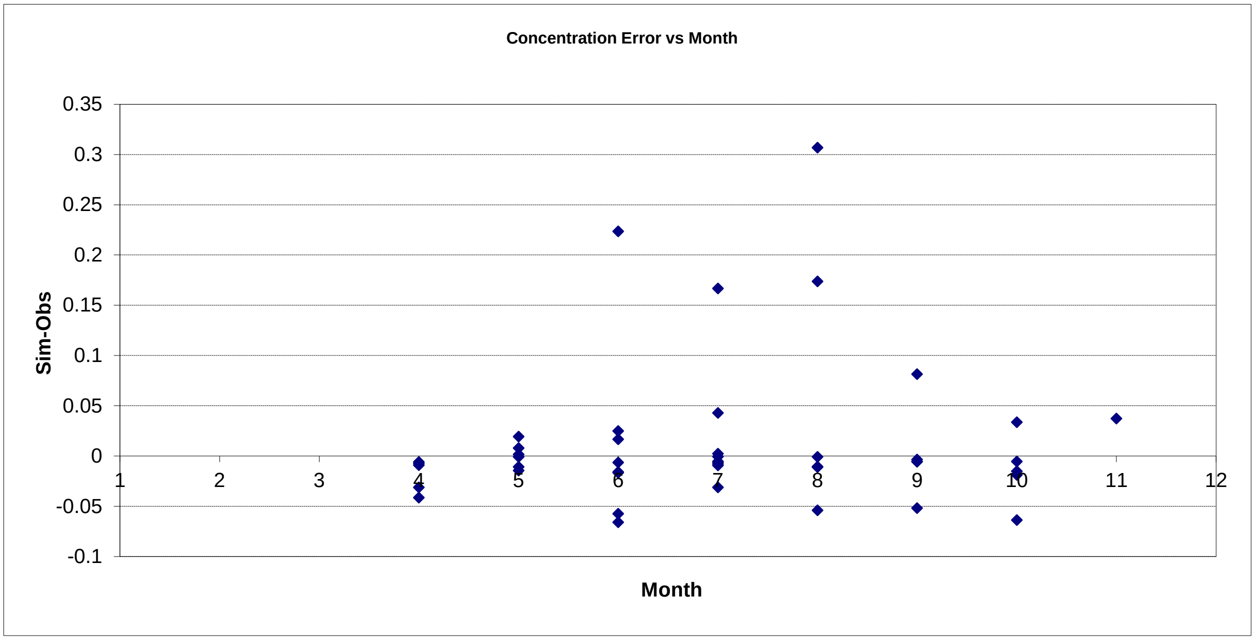


Figure 68. Residual (Simulated - Observed) vs. Month Ammonia Nitrogen (NH3) at Flute Reed River (S004-283)

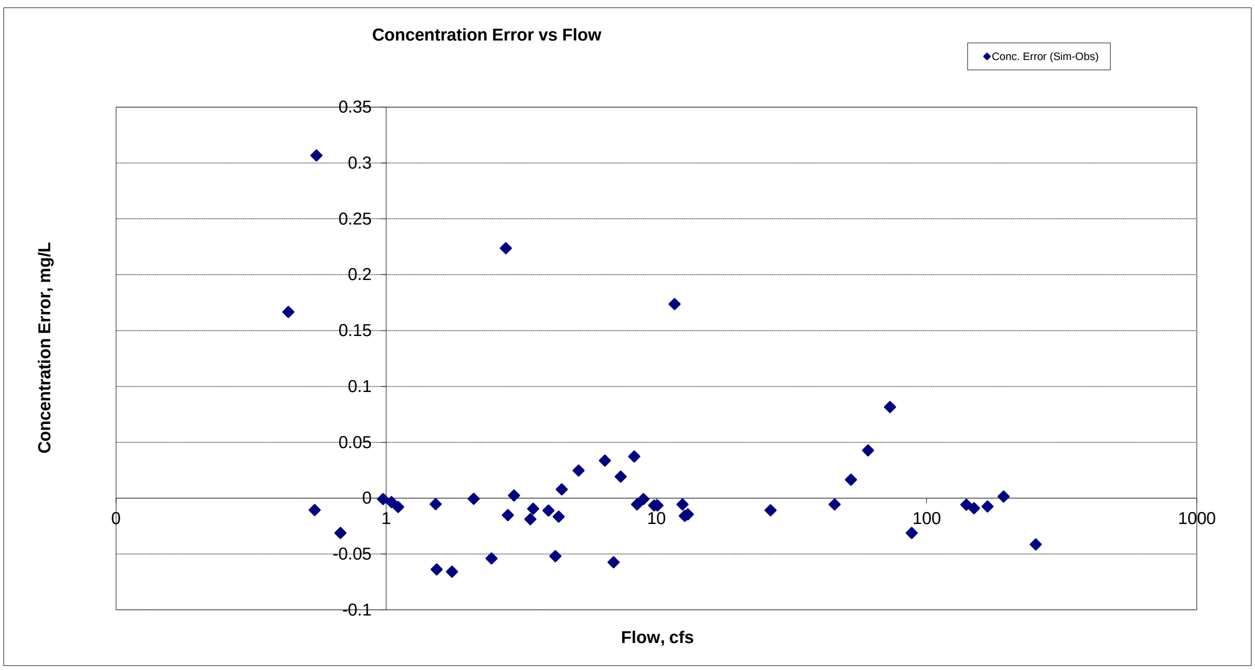


Figure 69. Residual (Simulated - Observed) vs. Flow Ammonia Nitrogen (NH3) at Flute Reed River (S004-283)

Organic Nitrogen (OrgN)

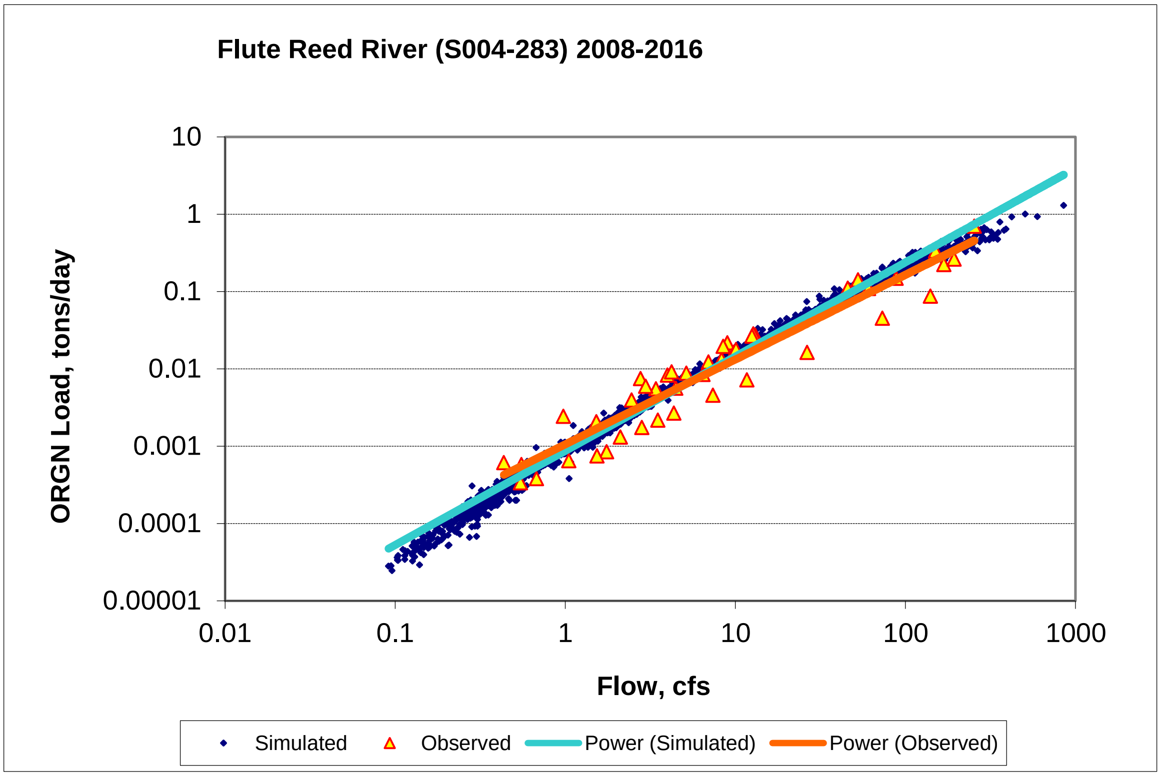


Figure 70. Power plot of simulated and observed Organic Nitrogen (OrgN) load vs flow at Flute Reed River (S004-283)

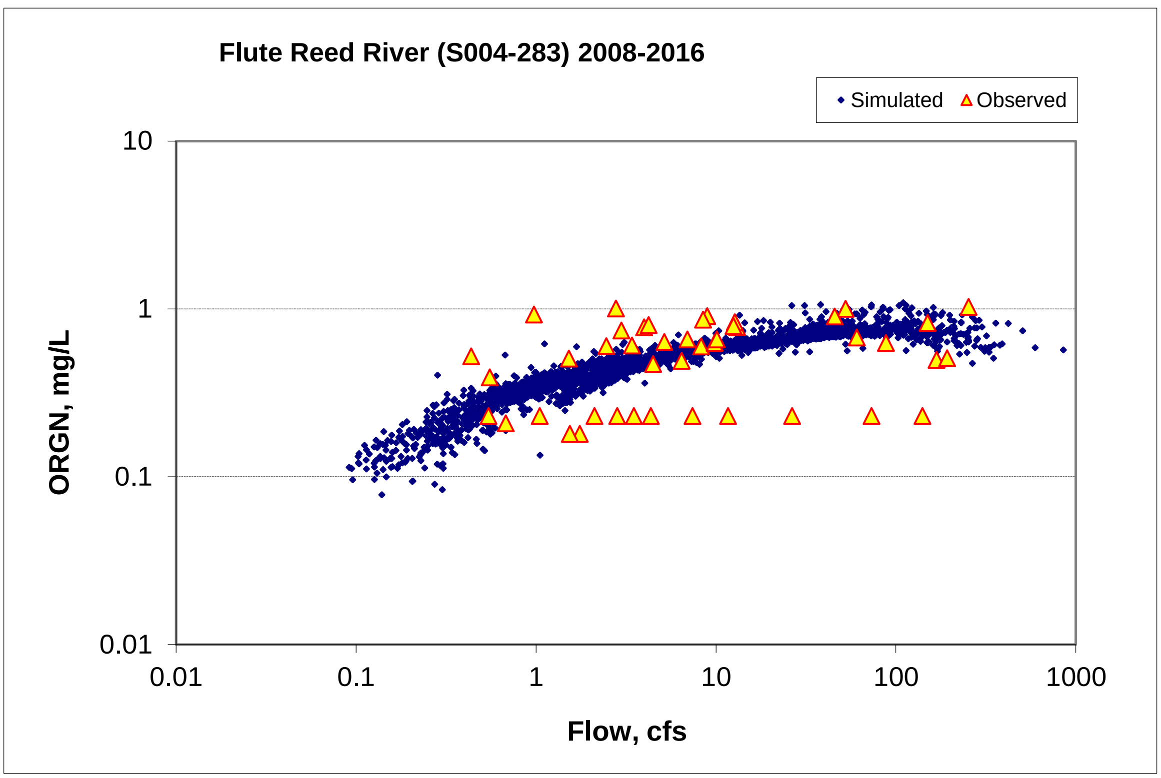


Figure 71. Simulated and observed Organic Nitrogen (OrgN) concentration vs flow at Flute Reed River (S004-283)

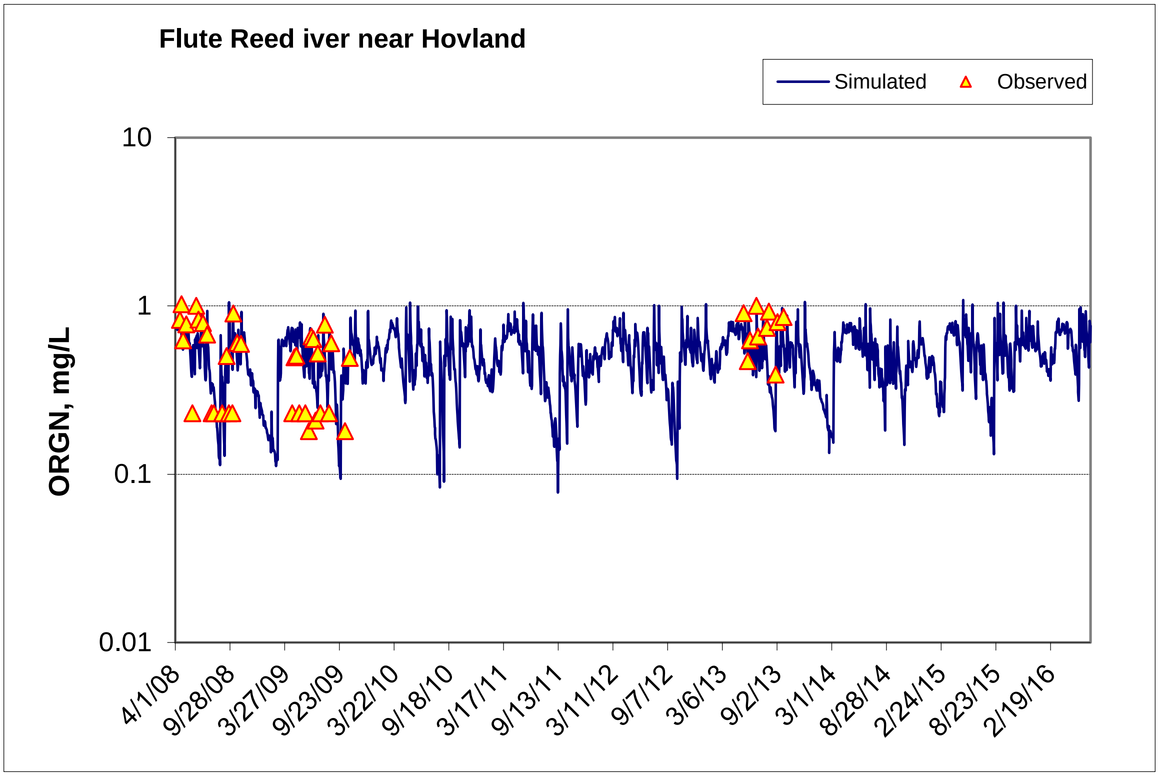


Figure 72. Time series of observed and simulated Organic Nitrogen (OrgN) concentration at Flute Reed River (S004-283)

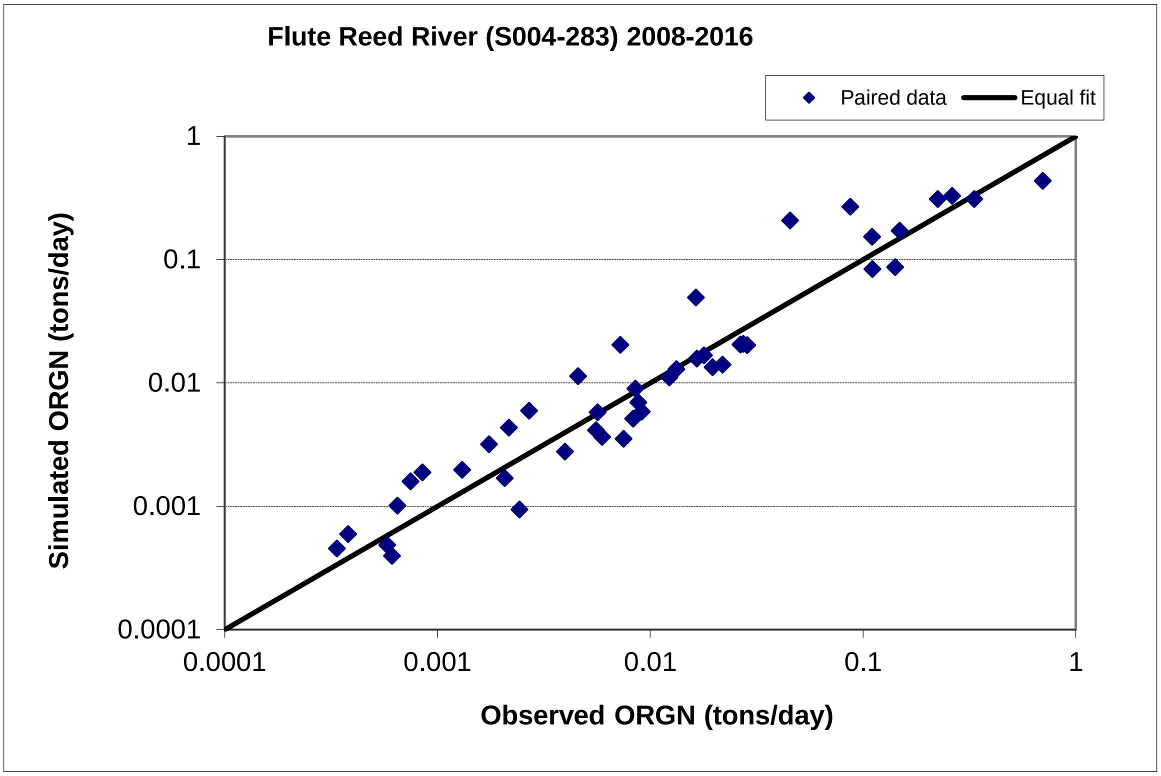


Figure 73. Paired simulated vs. observed Organic Nitrogen (OrgN) load at Flute Reed River (S004-283)

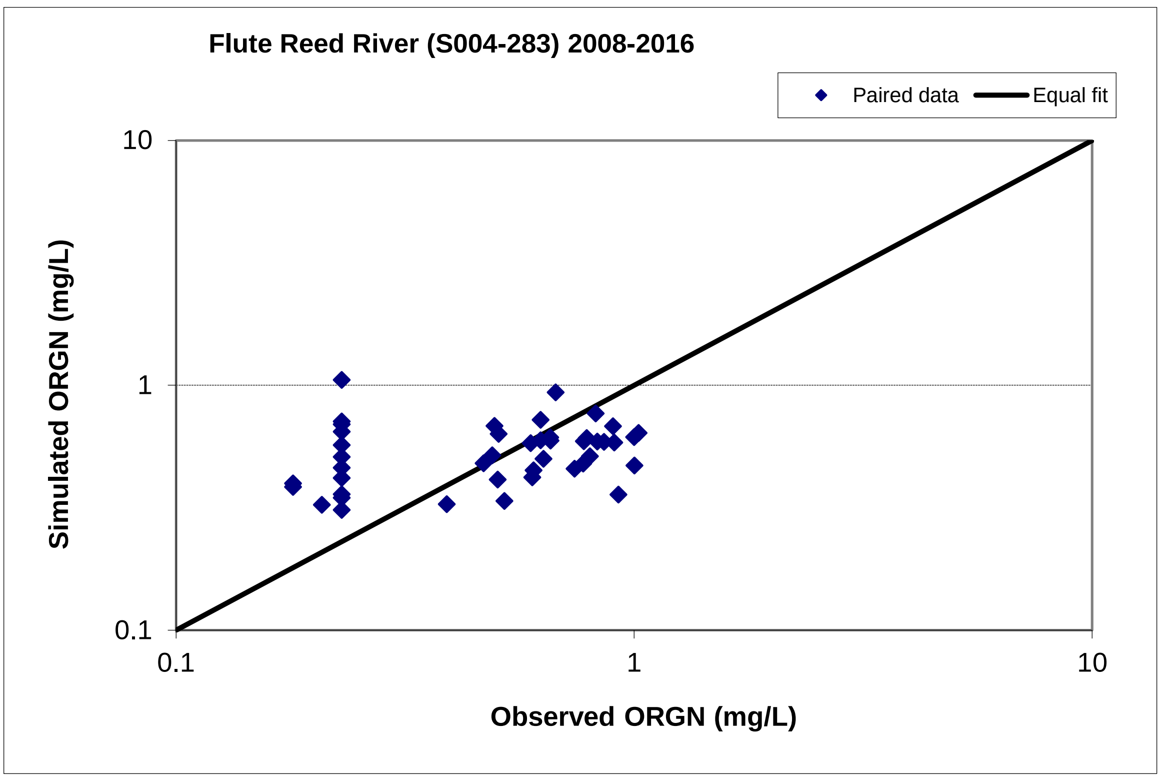


Figure 74. Paired simulated vs. observed Organic Nitrogen (OrgN) concentration at Flute Reed River (S004-283)

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

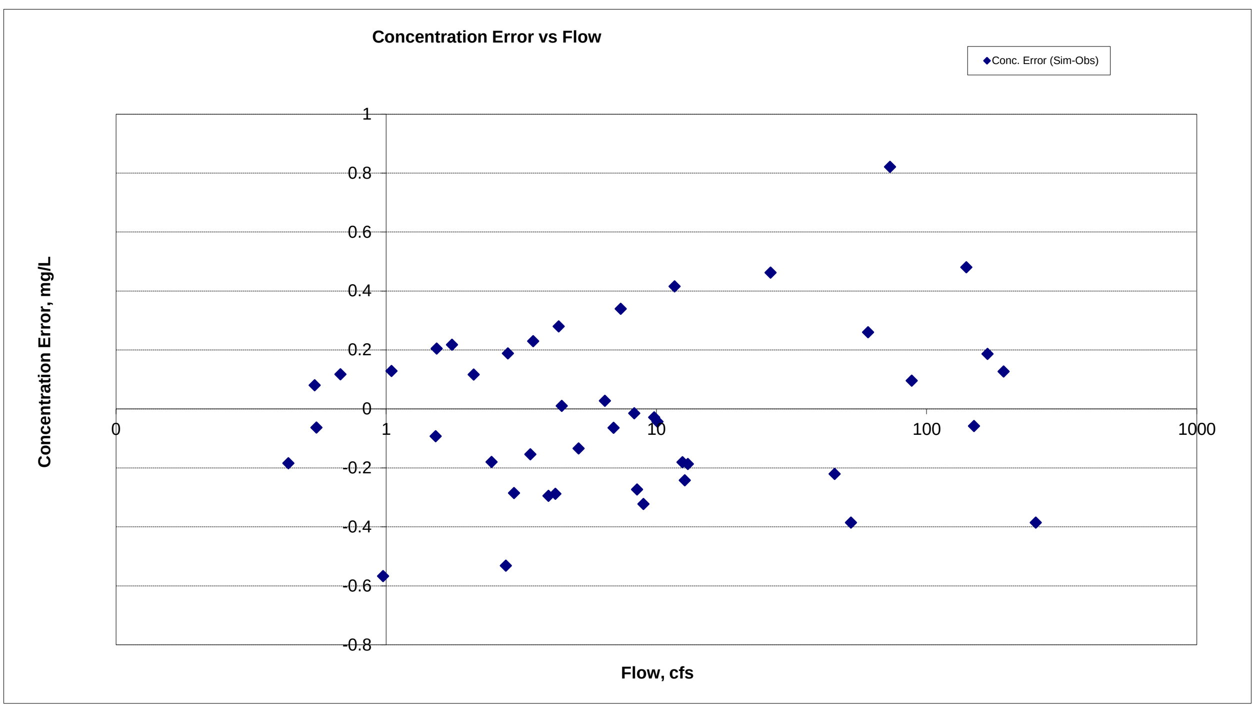


Figure 76. Residual (Simulated - Observed) vs. Flow Organic Nitrogen (OrgN) at Flute Reed River (S004-283)

Total Kjeldahl Nitrogen (TKN)

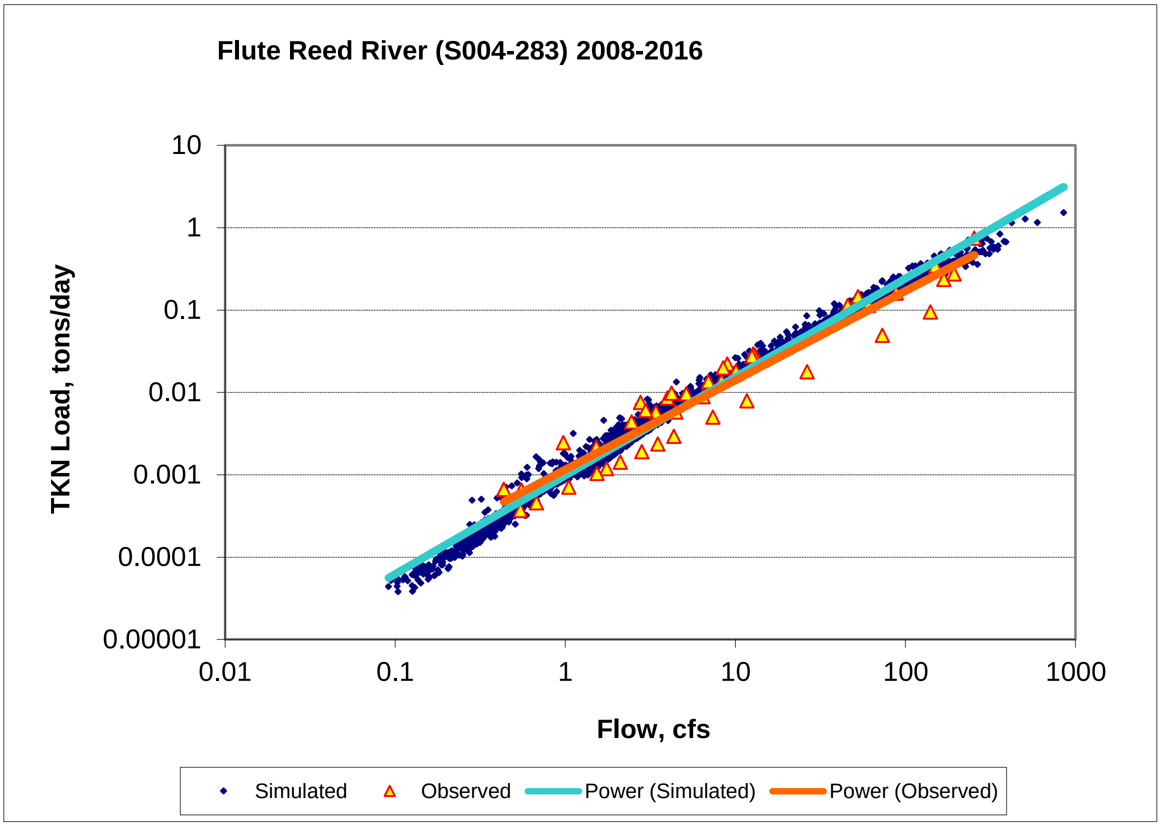


Figure 77. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Flute Reed River (S004-283)

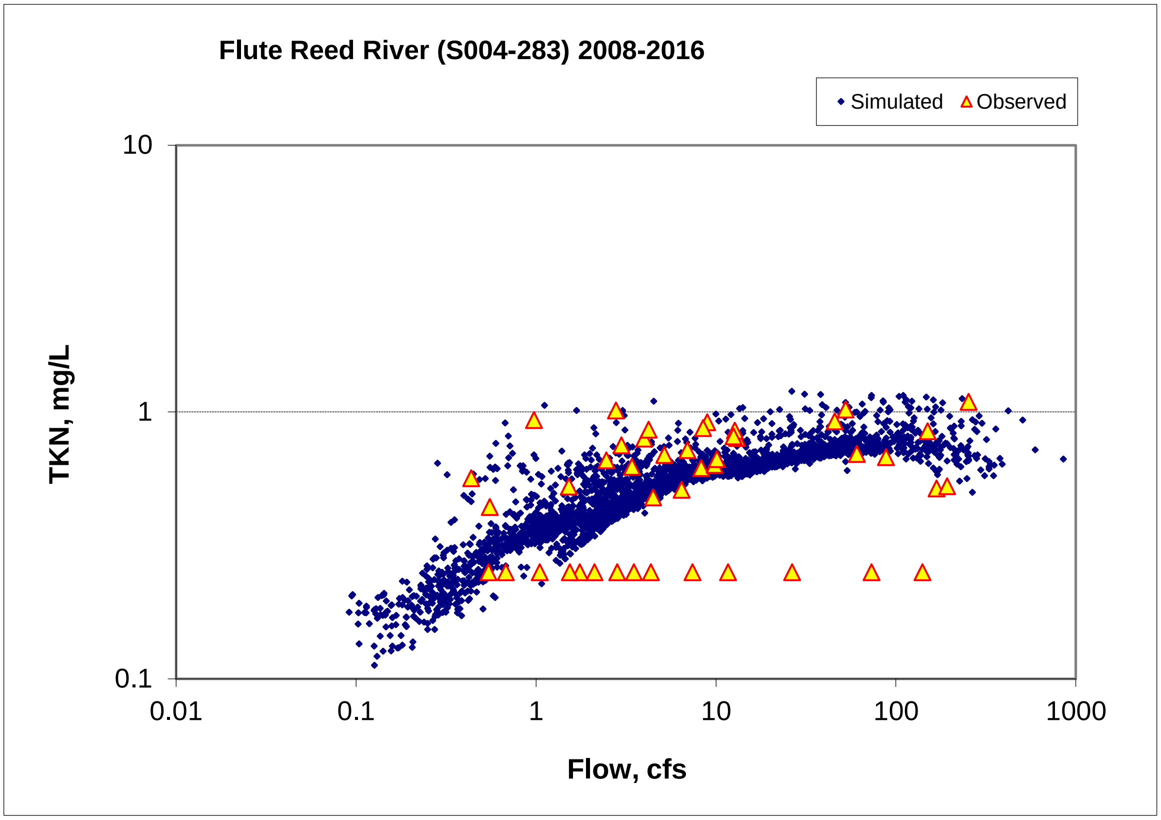


Figure 78. Simulated and observed Total Kjeldahl Nitrogen (TKN) concentration vs flow at Flute Reed River (S004-283)

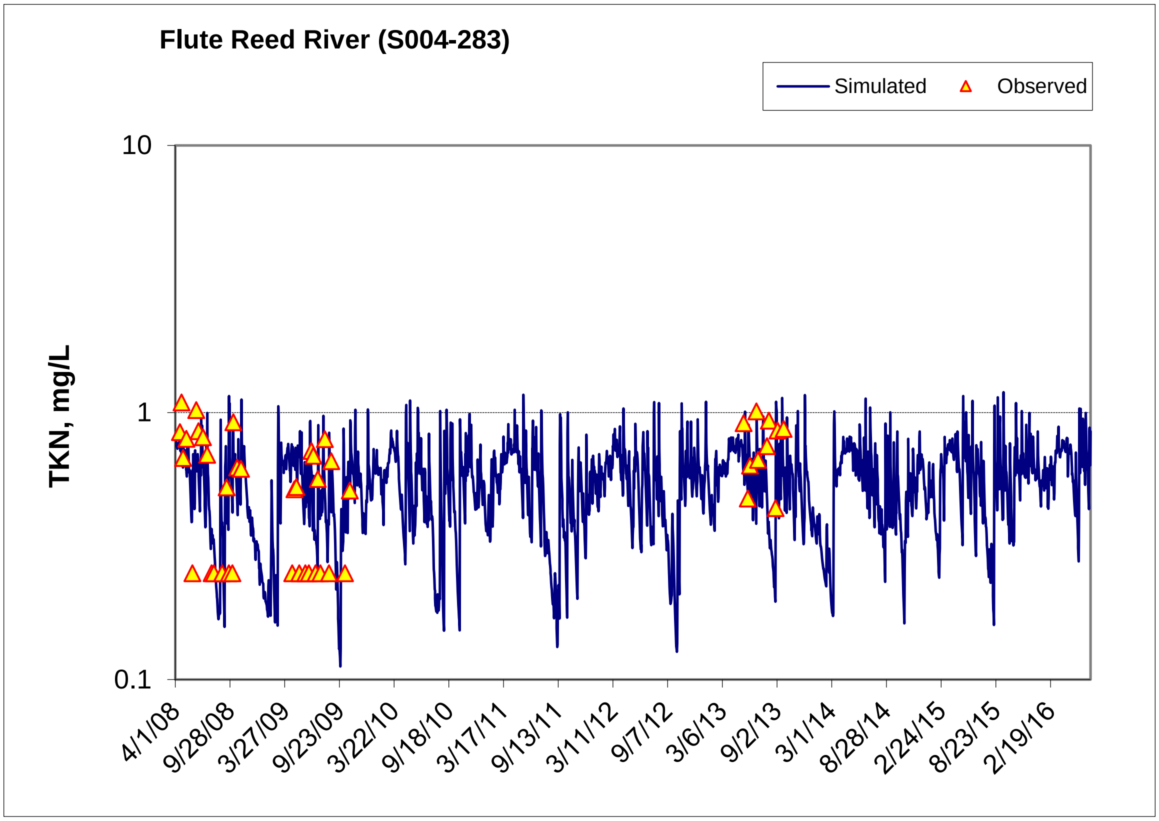


Figure 79. Time series of observed and simulated Total Kjeldahl Nitrogen (TKN) concentration at Flute Reed River (S004-283)

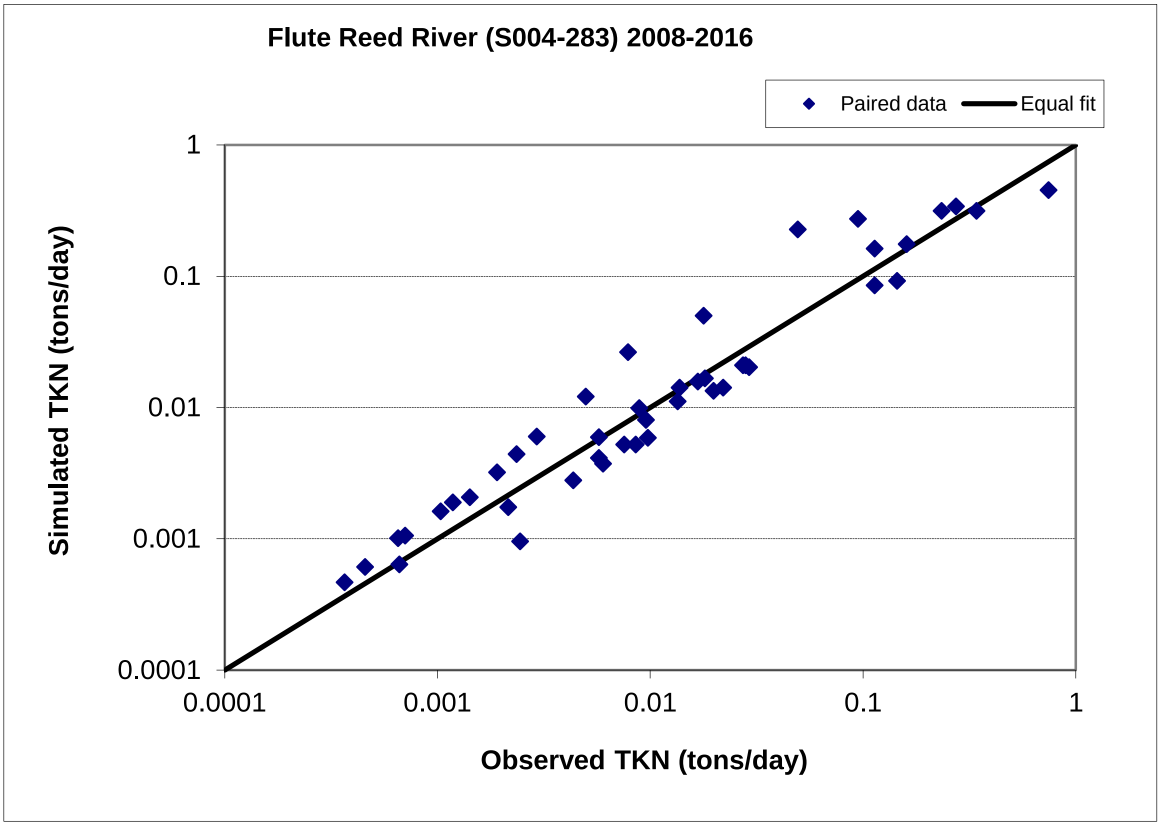


Figure 80. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) load at Flute Reed River (S004-283)

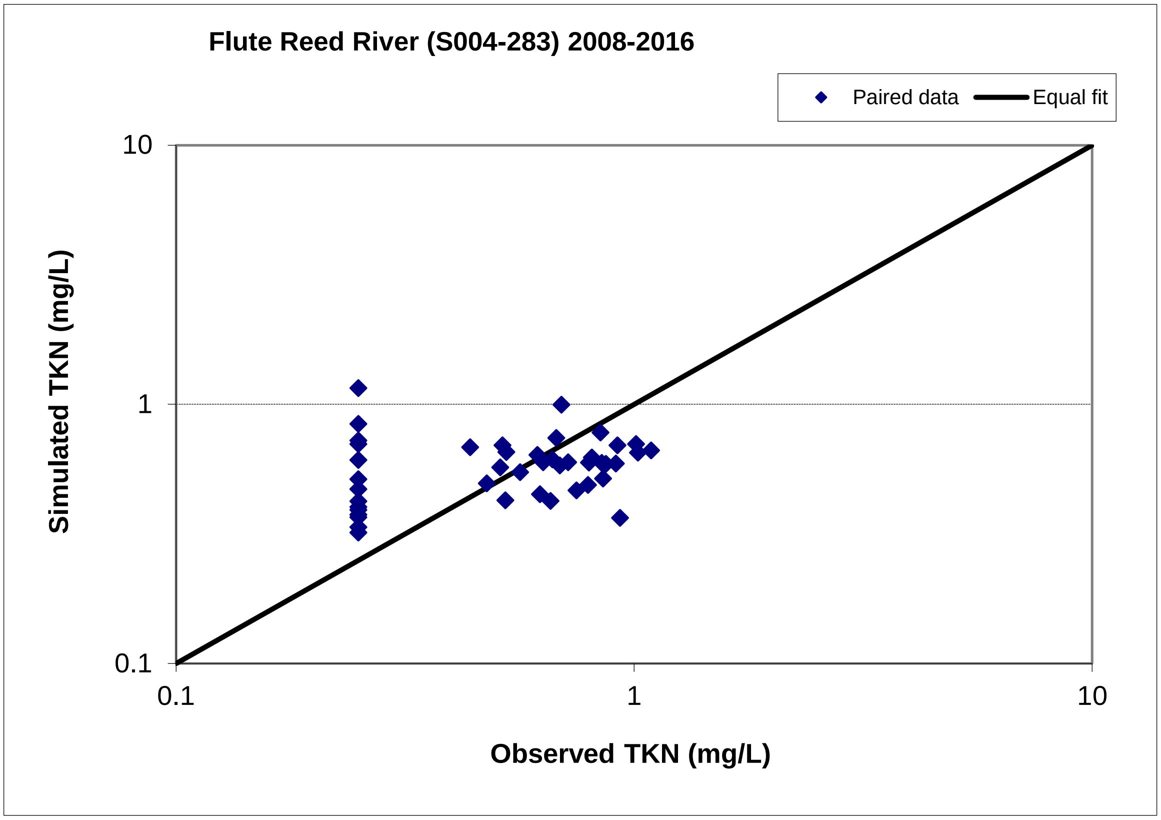


Figure 81. Paired simulated vs. observed Total Kjeldahl Nitrogen (TKN) concentration at Flute Reed River (S004-283)

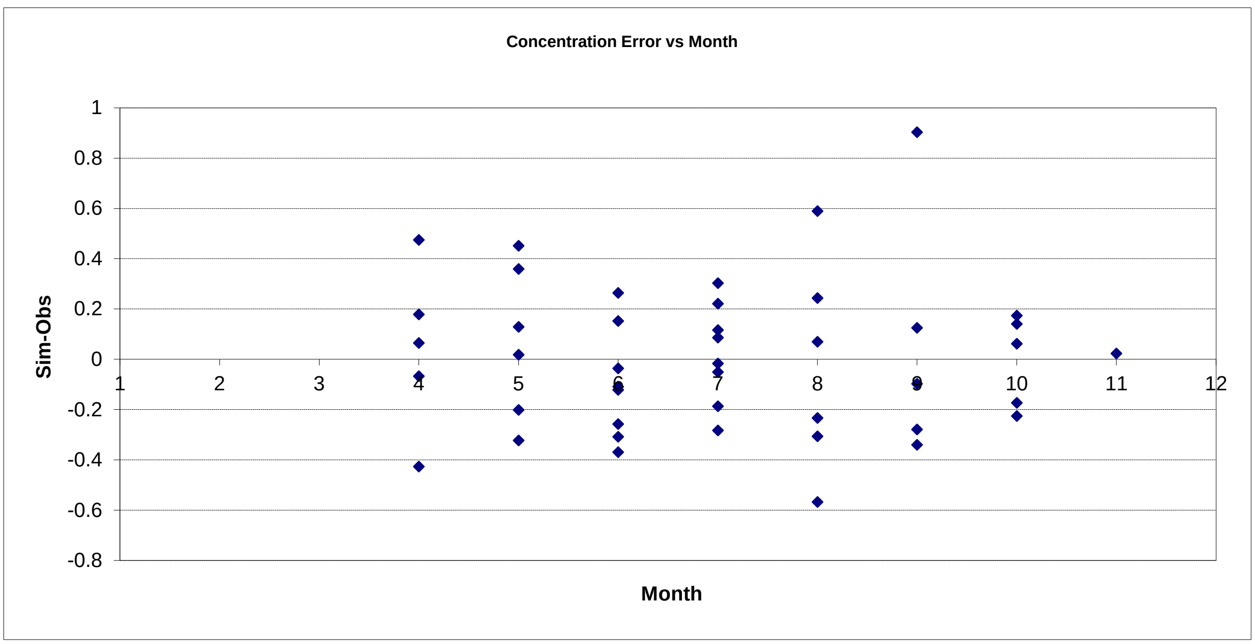


Figure 82. Residual (Simulated - Observed) vs. Month Total Kjeldahl Nitrogen (TKN) at Flute Reed River (S004-283)

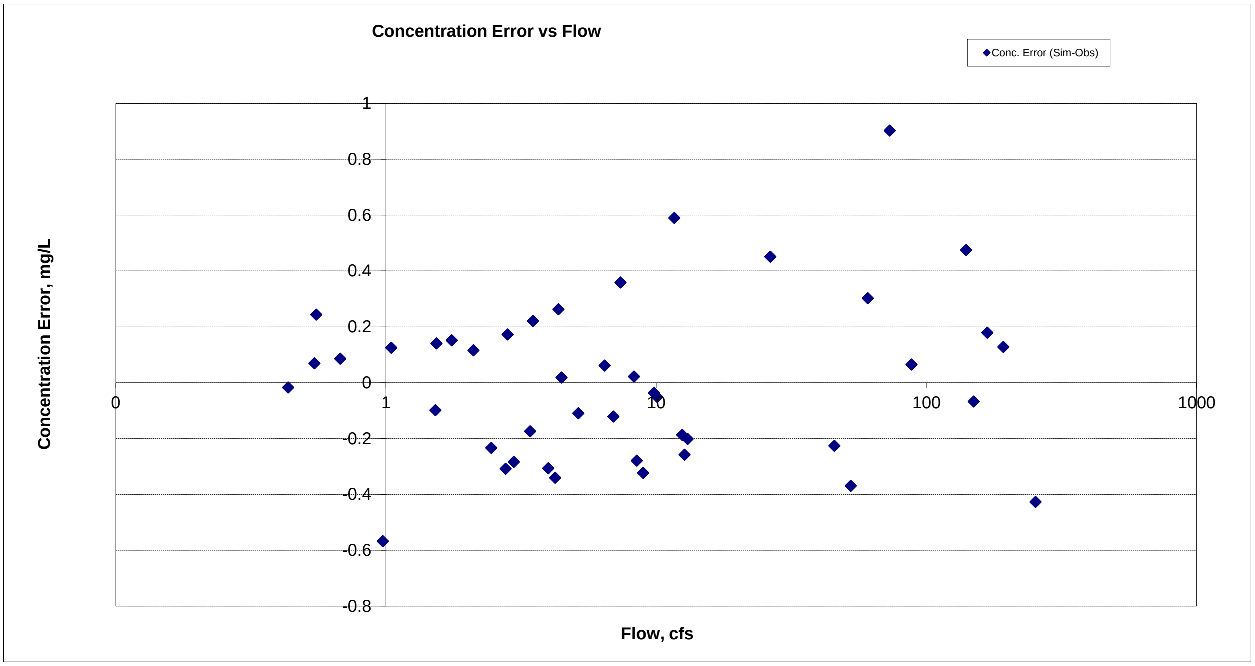


Figure 83. Residual (Simulated - Observed) vs. Flow Total Kjeldahl Nitrogen (TKN) at Flute Reed River (S004-283)

Nitrite+ Nitrate Nitrogen (NOx)

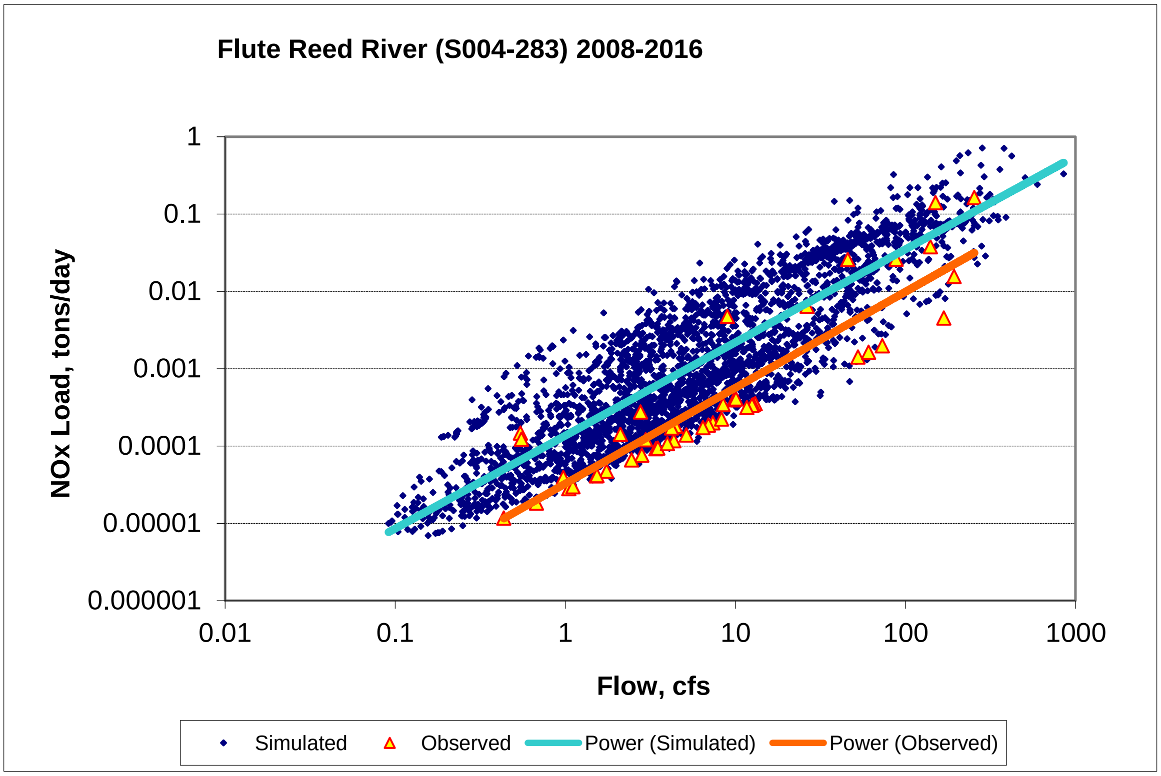


Figure 84. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Flute Reed River (S004-283)

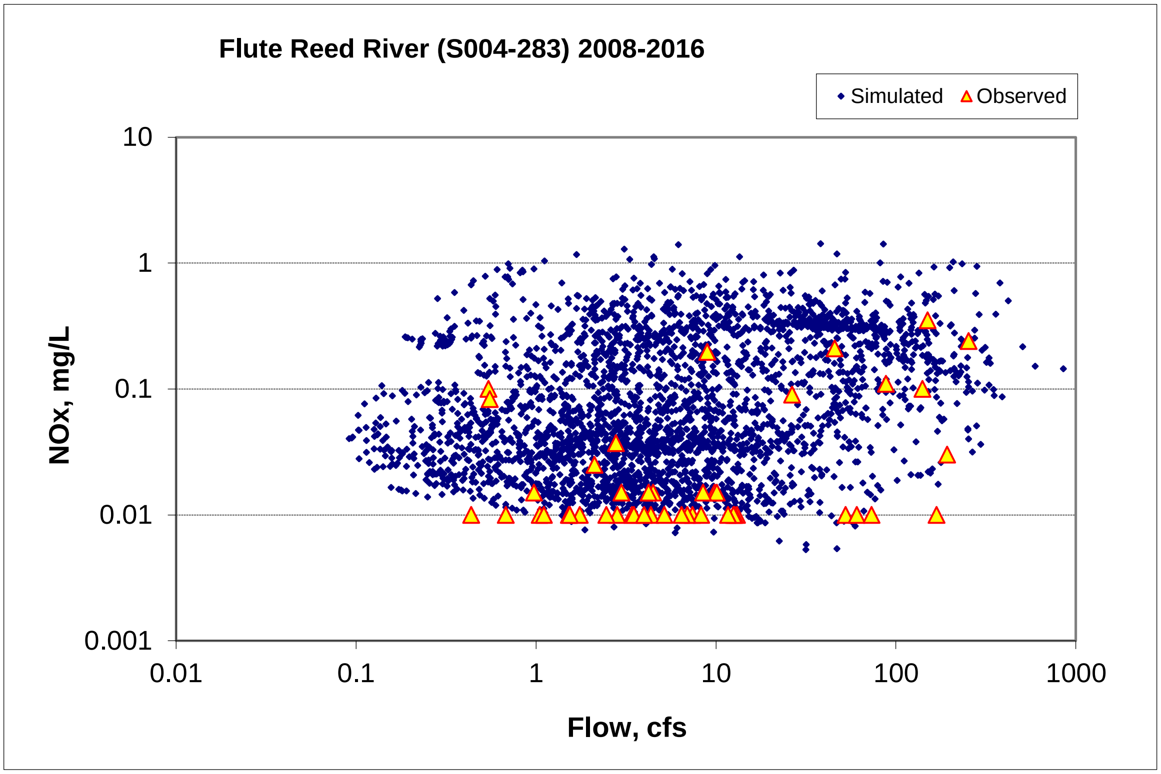


Figure 85. Simulated and observed Nitrite+ Nitrate Nitrogen (NOx) concentration vs flow at Flute Reed River (S004-283)

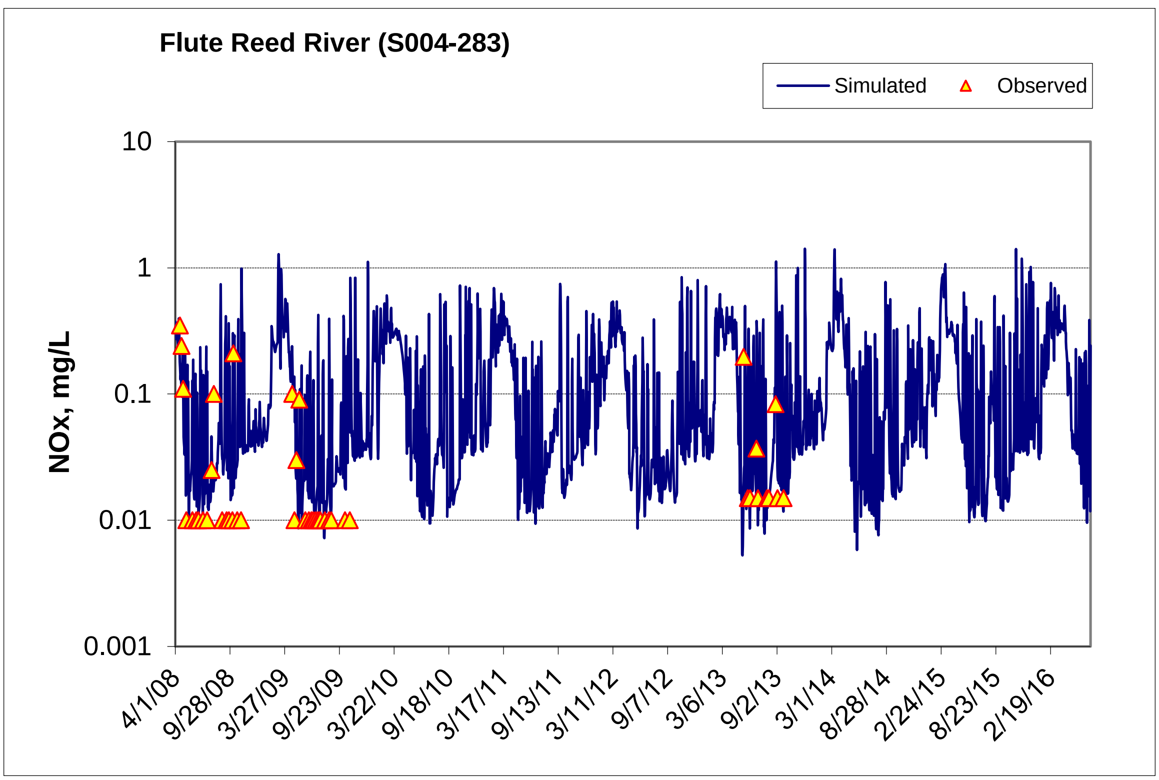


Figure 86. Time series of observed and simulated Nitrite+ Nitrate Nitrogen (NOx) concentration at Flute Reed River (S004-283)

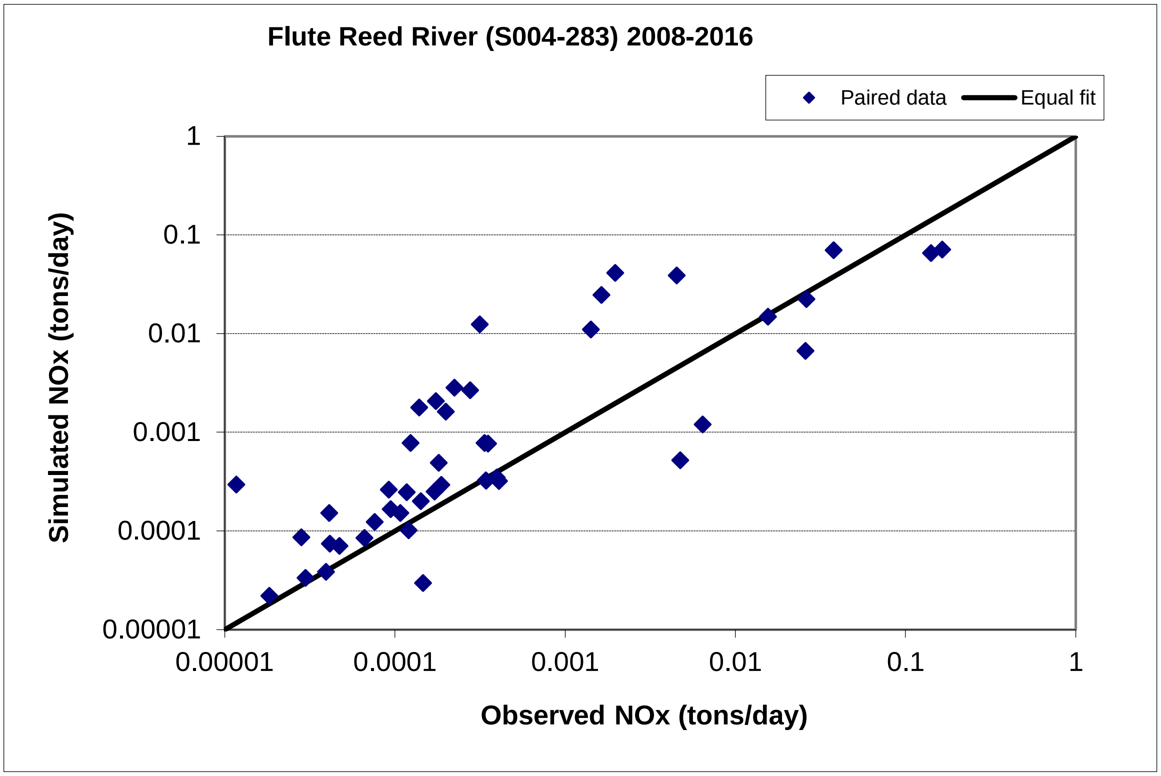


Figure 87. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) load at Flute Reed River (S004-283)

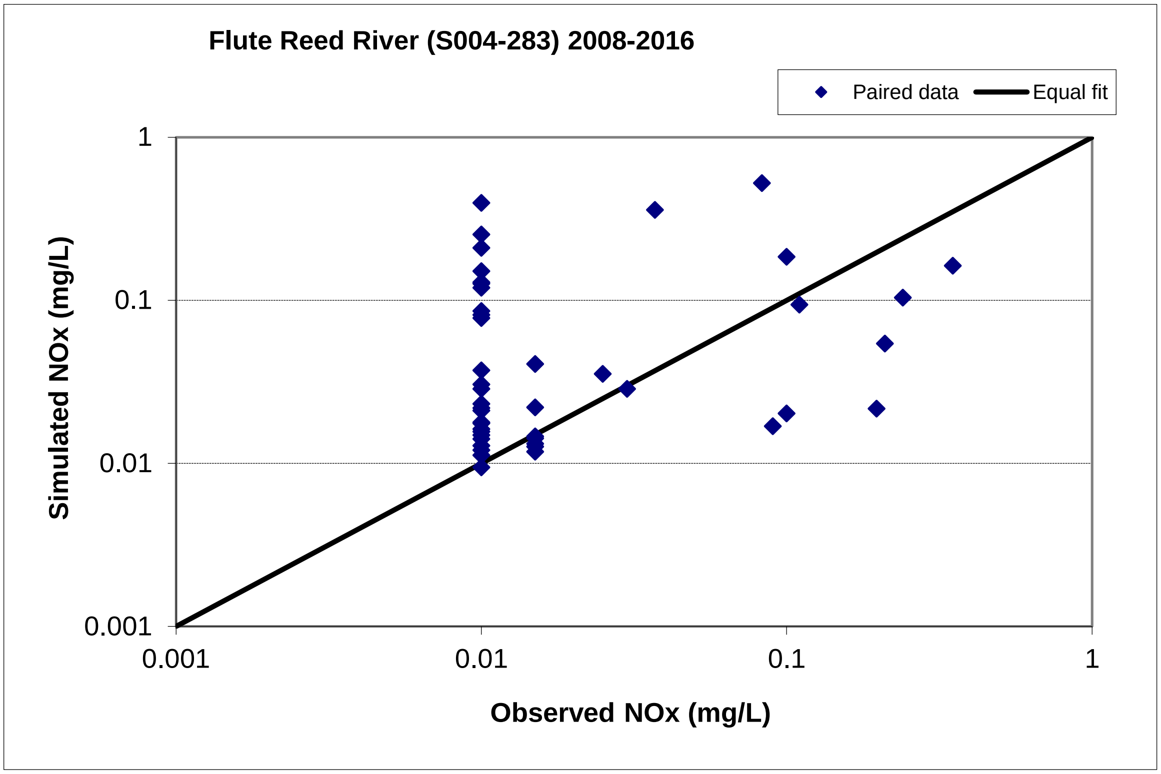


Figure 88. Paired simulated vs. observed Nitrite+ Nitrate Nitrogen (NOx) concentration at Flute Reed River (S004-283)

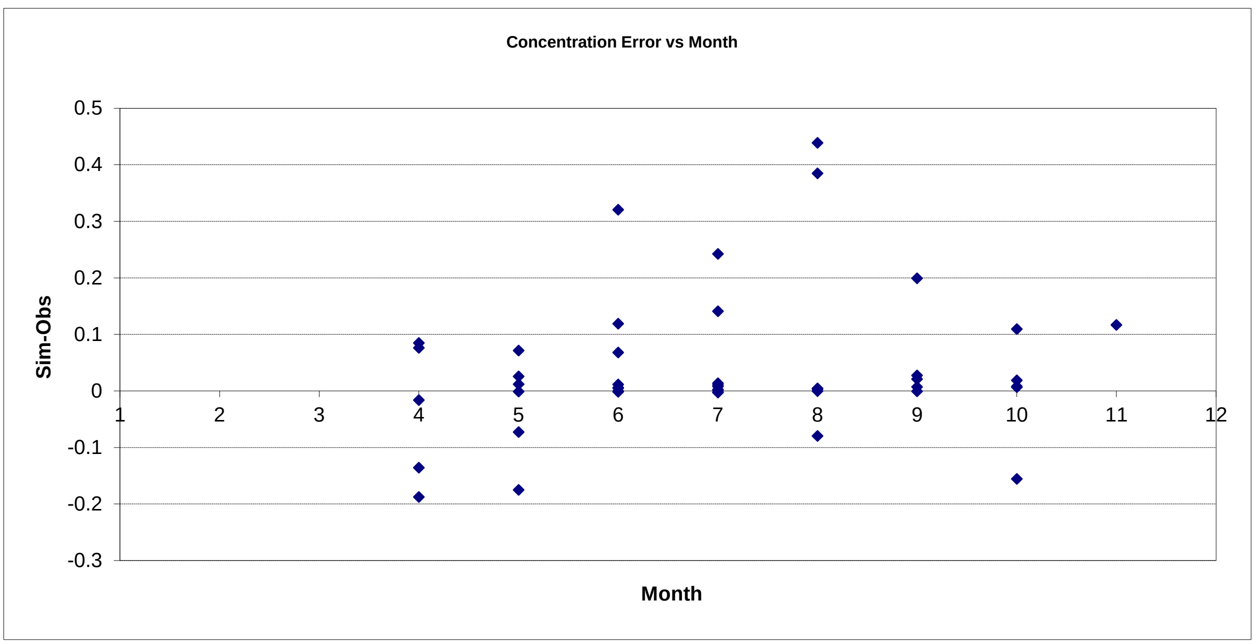


Figure 89. Residual (Simulated - Observed) vs. Month Nitrite+ Nitrate Nitrogen (NOx) at Flute Reed River (S004-283)

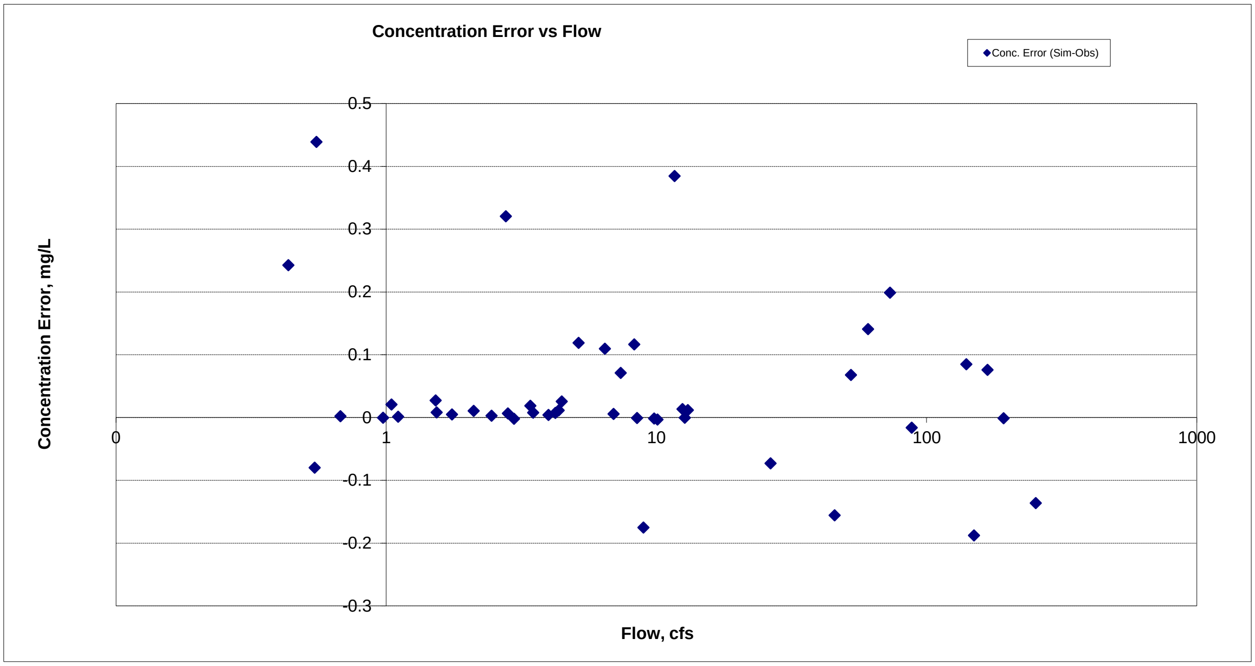


Figure 90. Residual (Simulated - Observed) vs. Flow Nitrite+ Nitrate Nitrogen (NOx) at Flute Reed River (S004-283)

Total Nitrogen (TN)

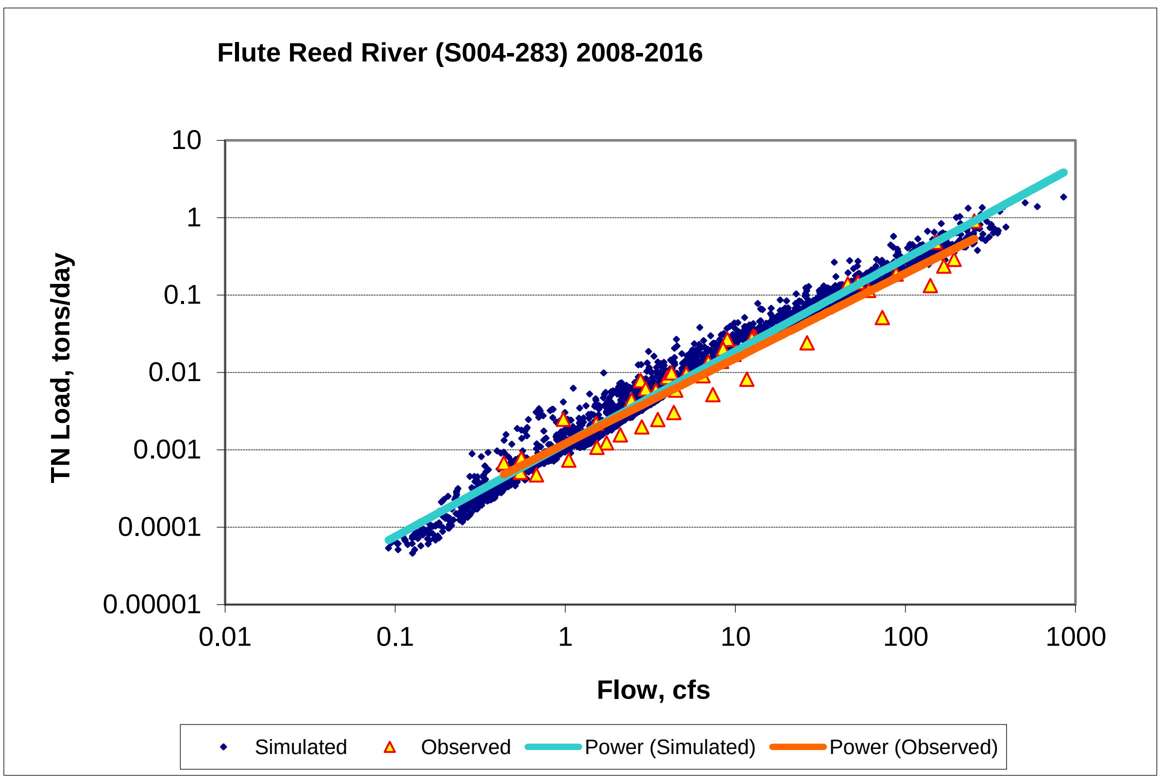


Figure 91. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Flute Reed River (S004-283)

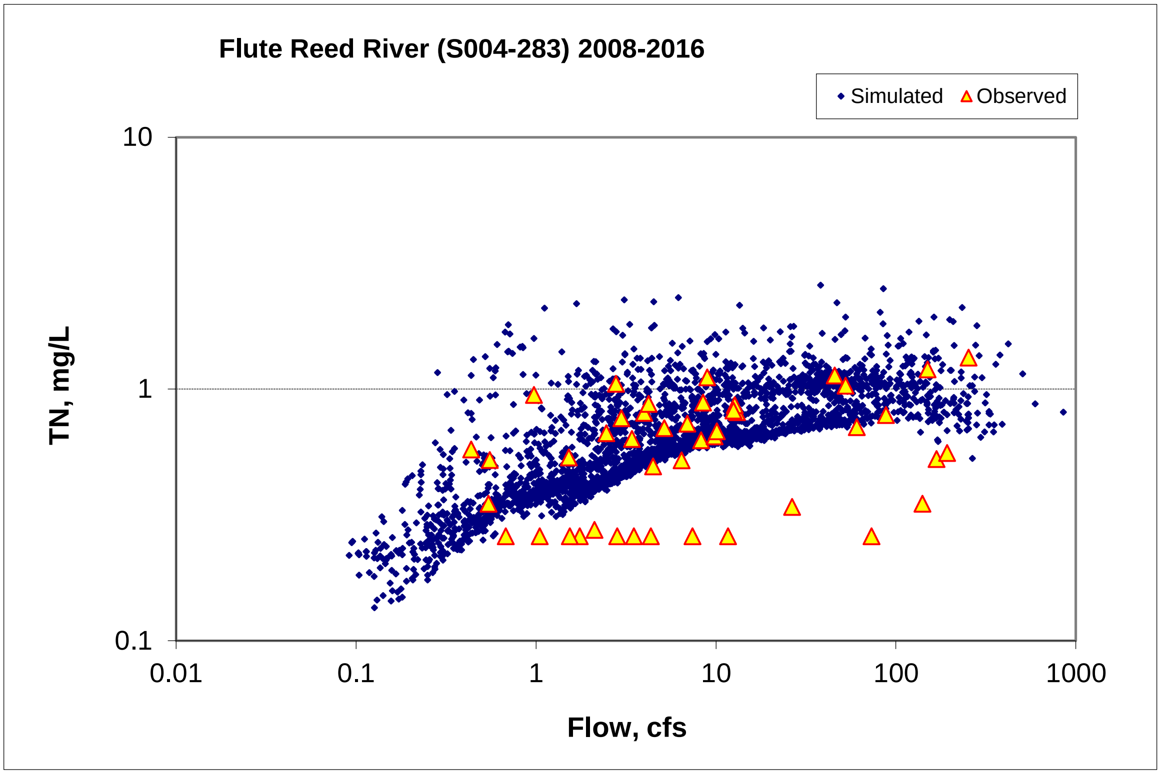


Figure 92. Simulated and observed Total Nitrogen (TN) concentration vs flow at Flute Reed River (S004-283)

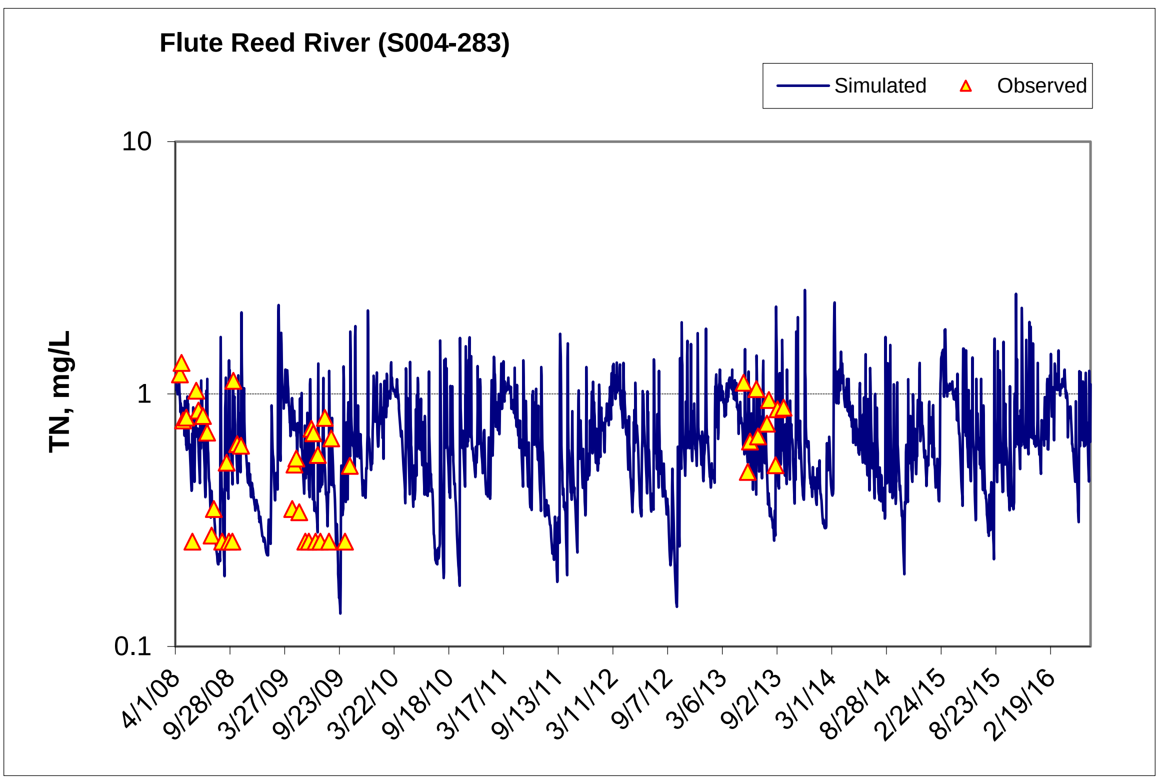


Figure 93. Time series of observed and simulated Total Nitrogen (TN) concentration at Flute Reed River (S004-283)

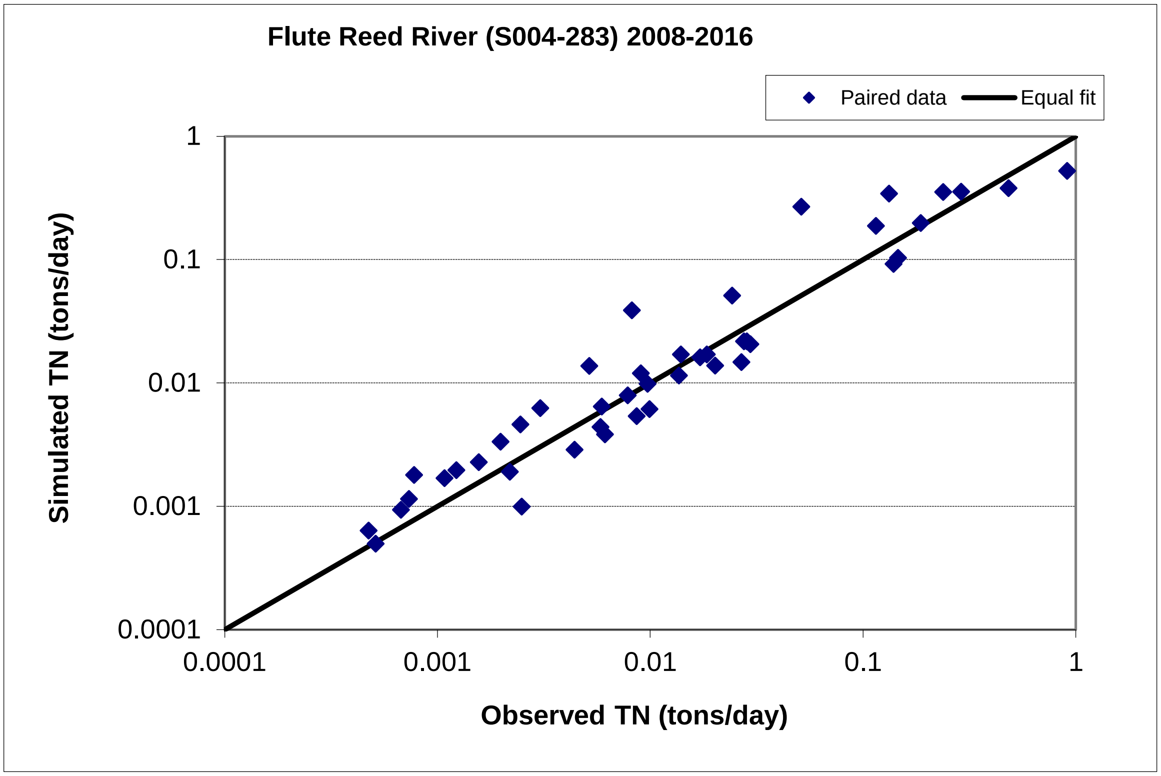


Figure 94. Paired simulated vs. observed Total Nitrogen (TN) load at Flute Reed River (S004-283)

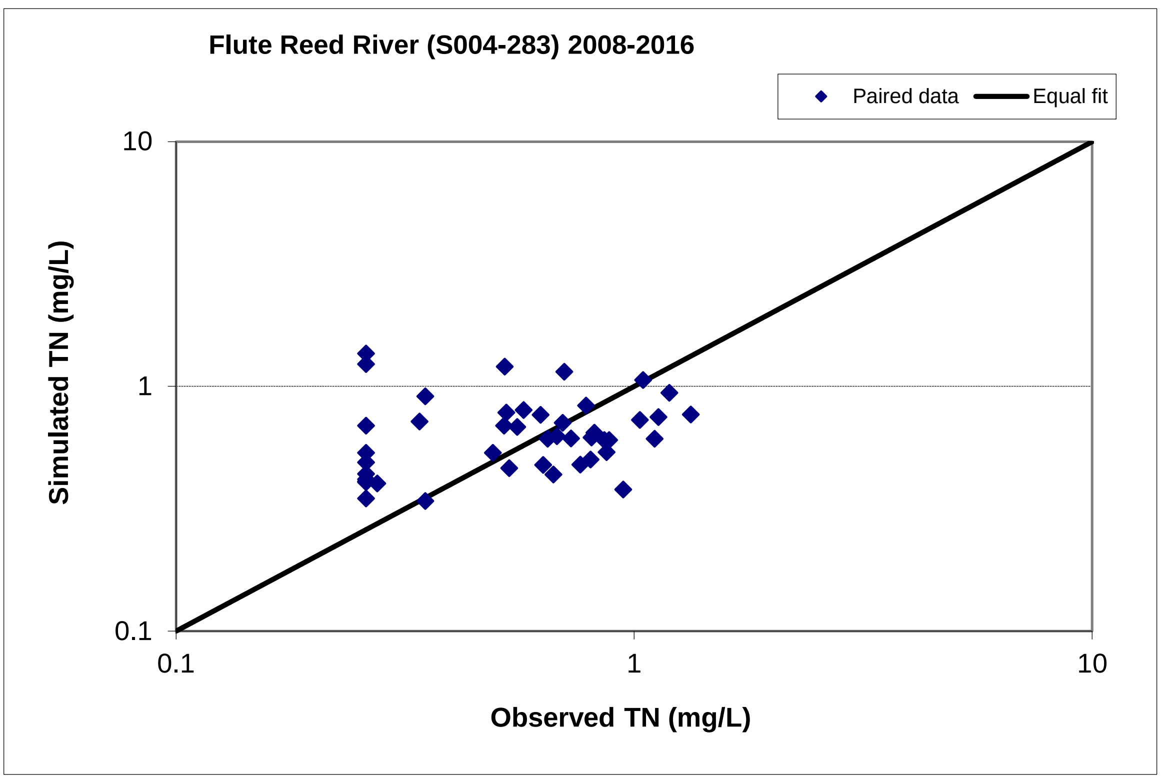


Figure 95. Paired simulated vs. observed Total Nitrogen (TN) concentration at Flute Reed River (S004-283)

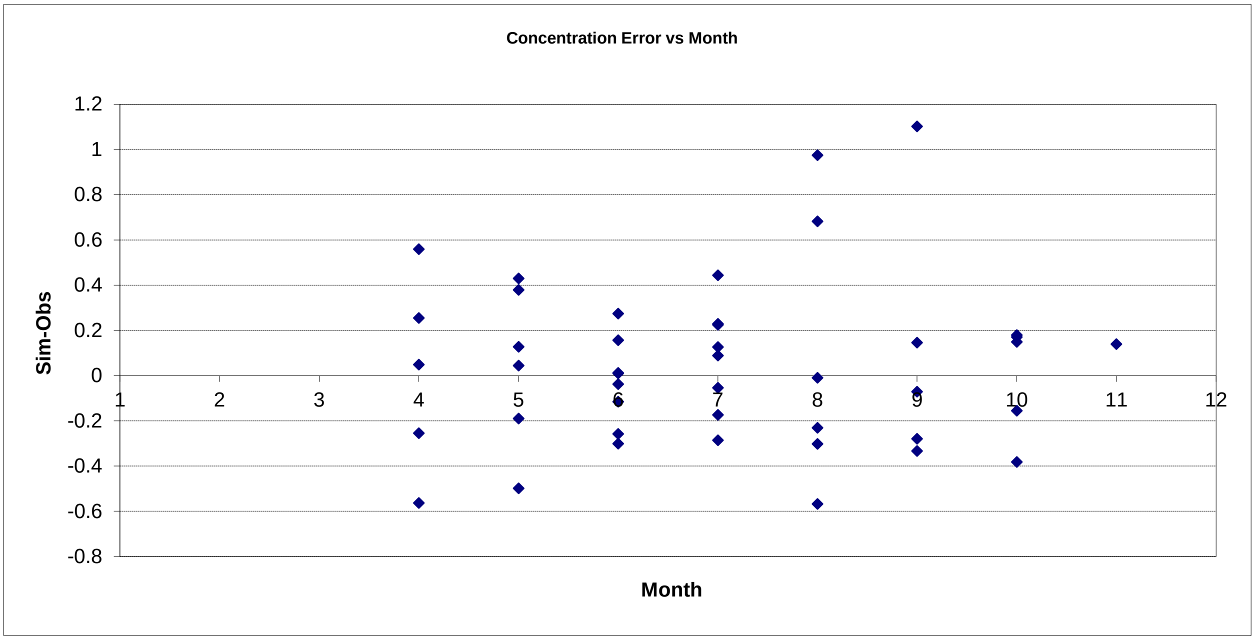


Figure 96. Residual (Simulated - Observed) vs. Month Total Nitrogen (TN) at Flute Reed River (S004-283)

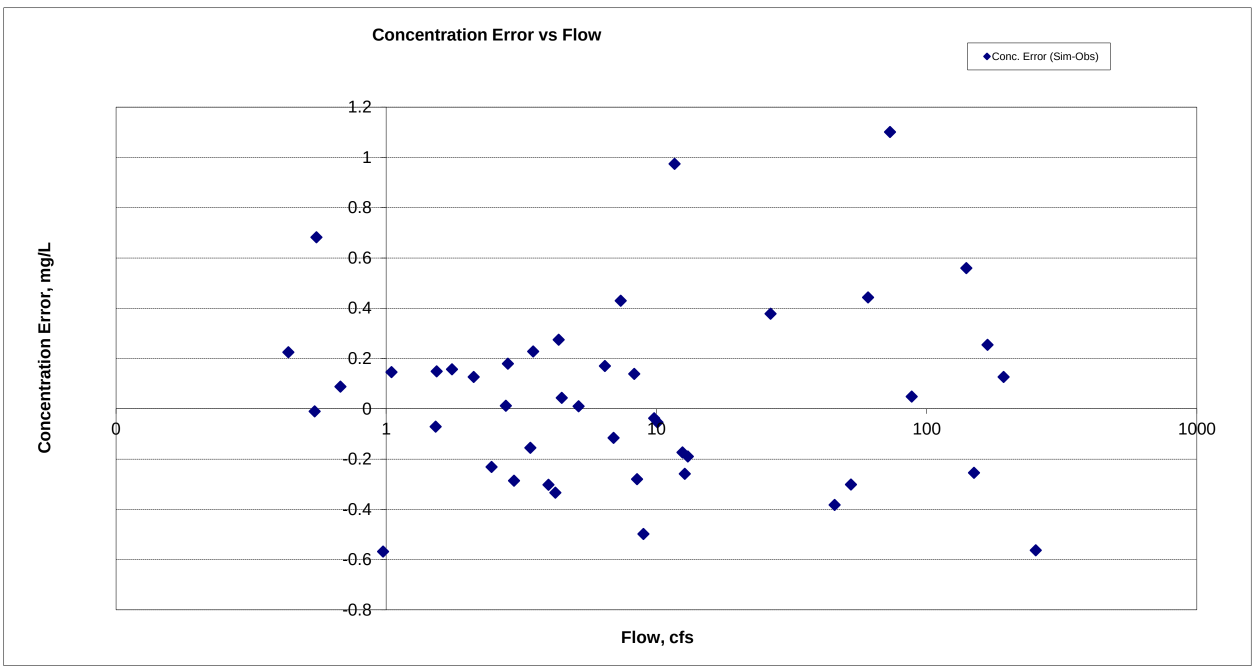


Figure 97. Residual (Simulated - Observed) vs. Flow Total Nitrogen (TN) at Flute Reed River (S004-283)

Soluble Reactive Phosphorus (SRP)

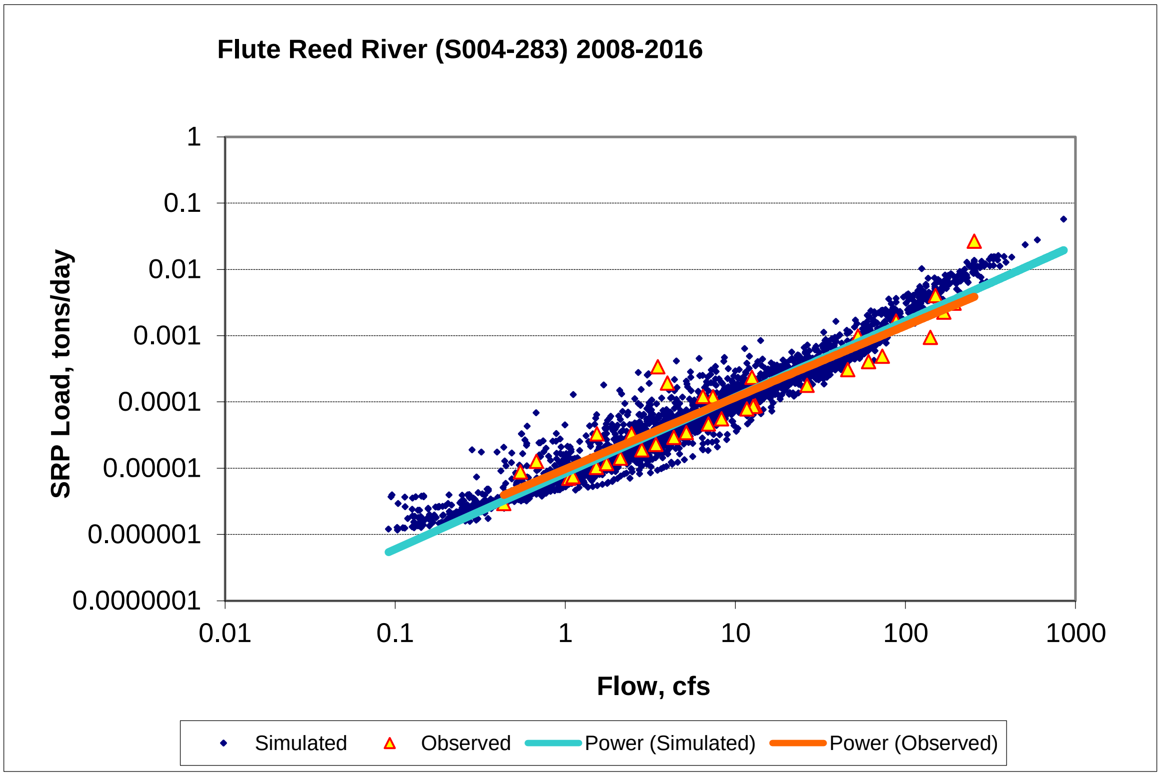


Figure 98. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Flute Reed River (S004-283)

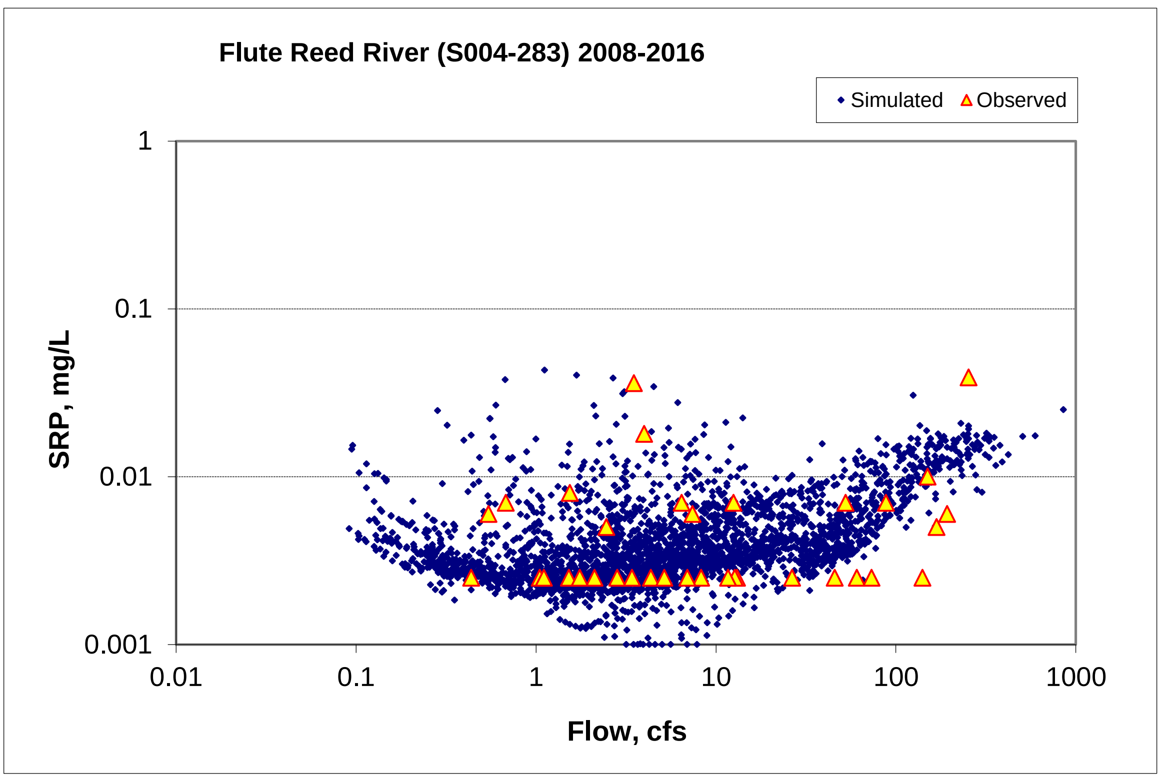


Figure 99. Simulated and observed Soluble Reactive Phosphorus (SRP) concentration vs flow at Flute Reed River (S004-283)

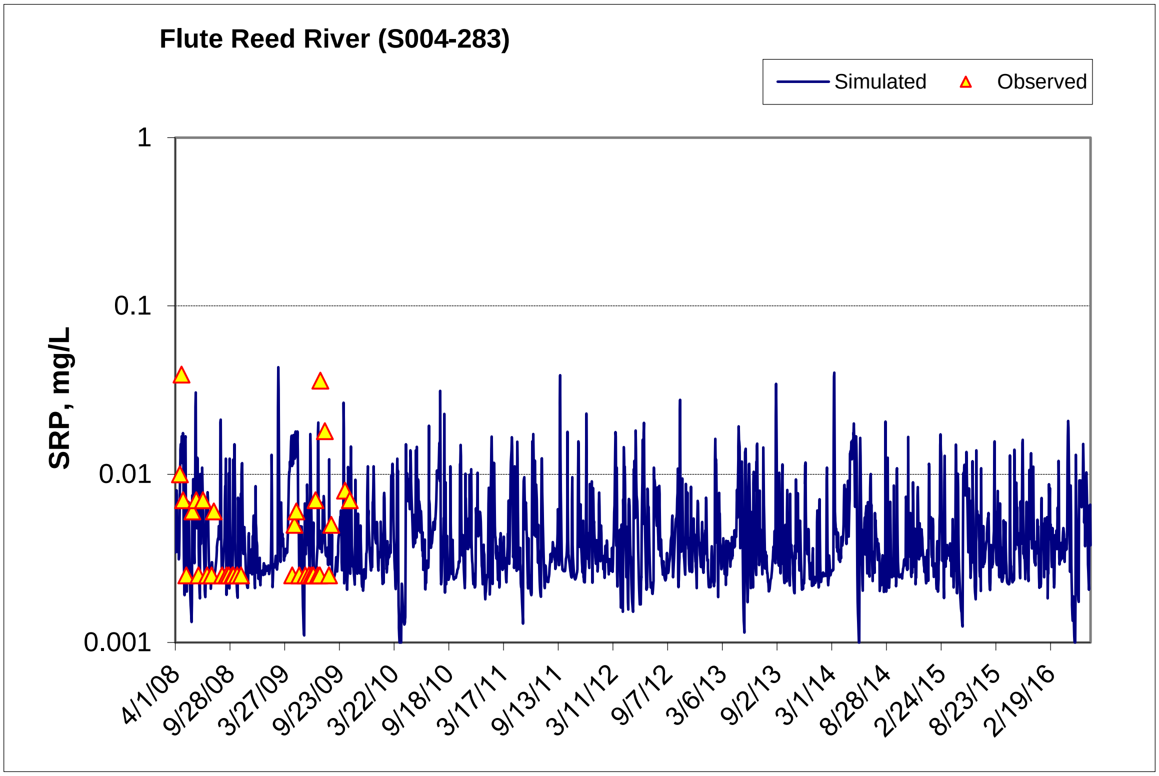


Figure 100. Time series of observed and simulated Soluble Reactive Phosphorus (SRP) concentration at Flute Reed River (S004-283)

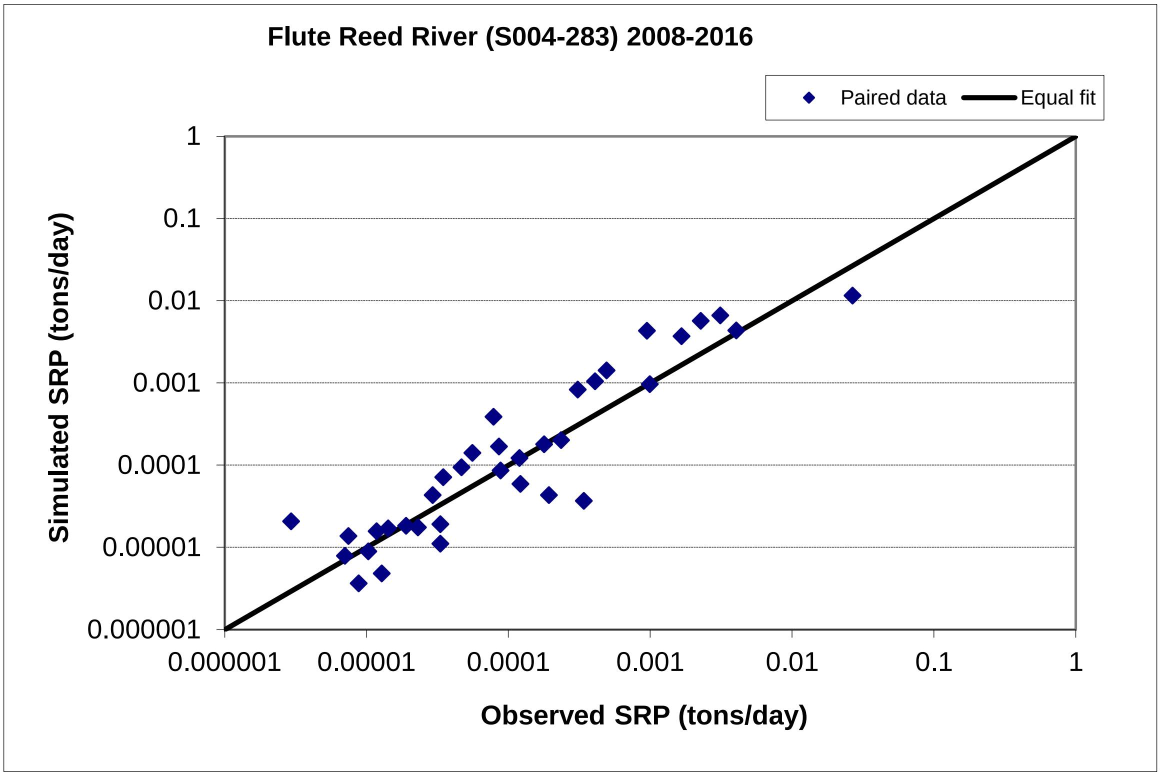


Figure 101. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) load at Flute Reed River (S004-283)

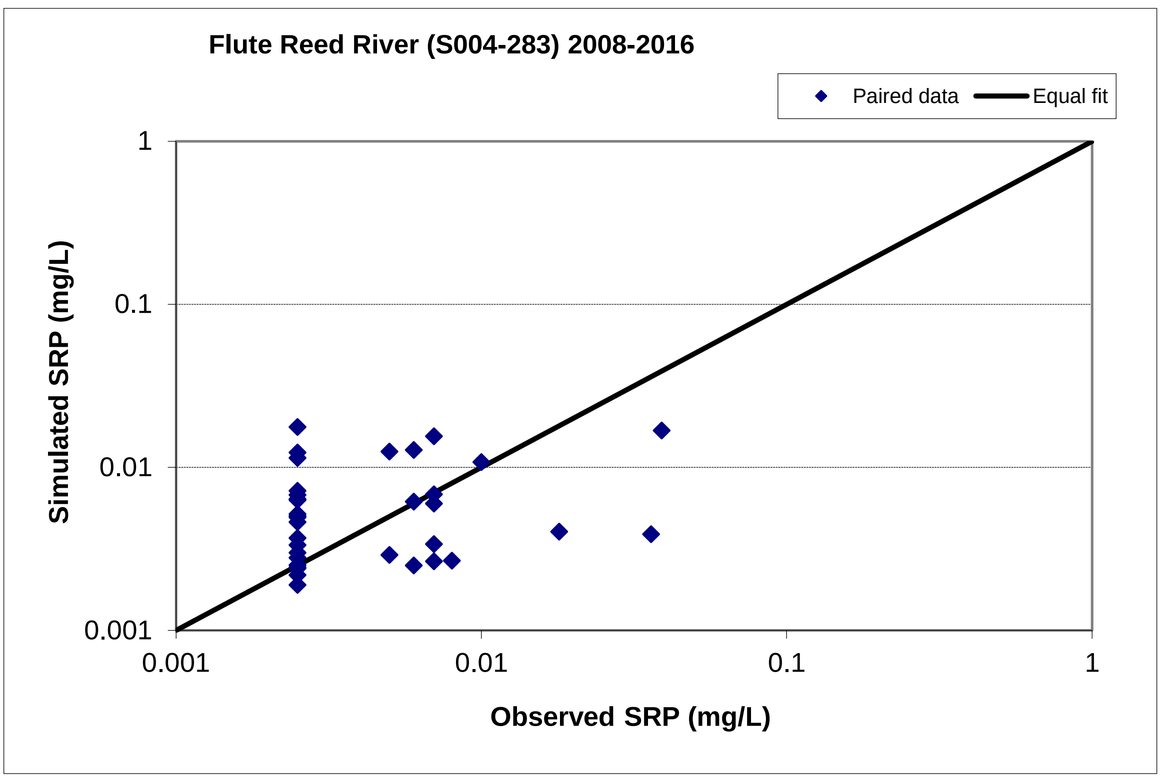


Figure 102. Paired simulated vs. observed Soluble Reactive Phosphorus (SRP) concentration at Flute Reed River (S004-283)

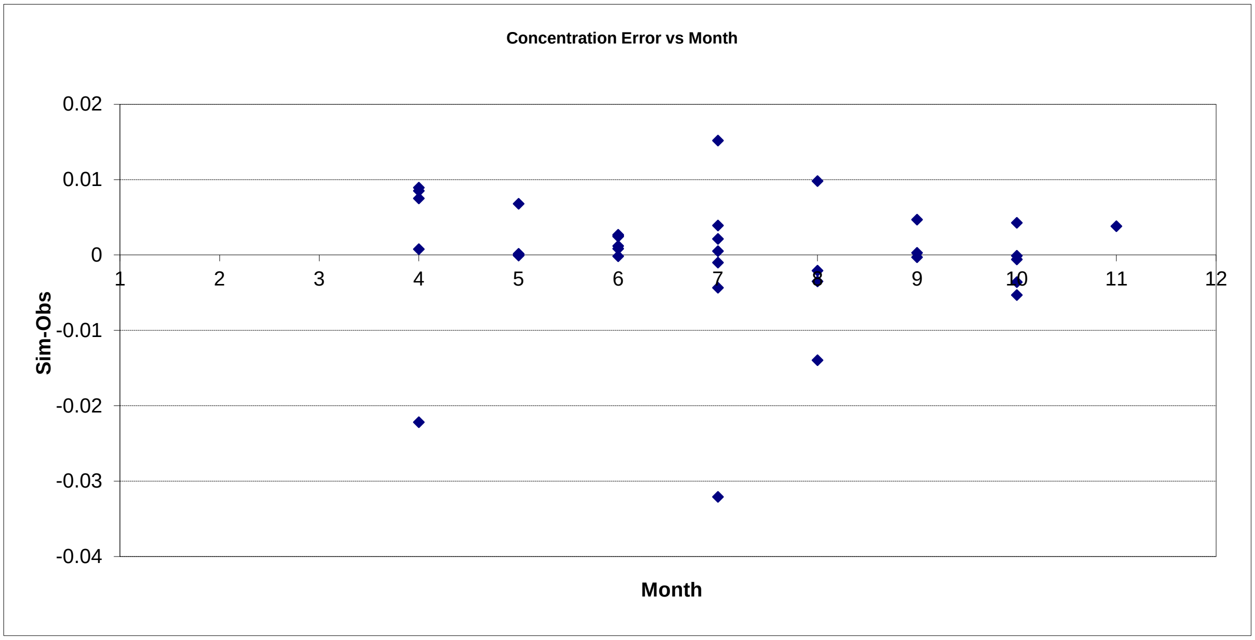


Figure 103. Residual (Simulated - Observed) vs. Month Soluble Reactive Phosphorus (SRP) at Flute Reed River (S004-283)

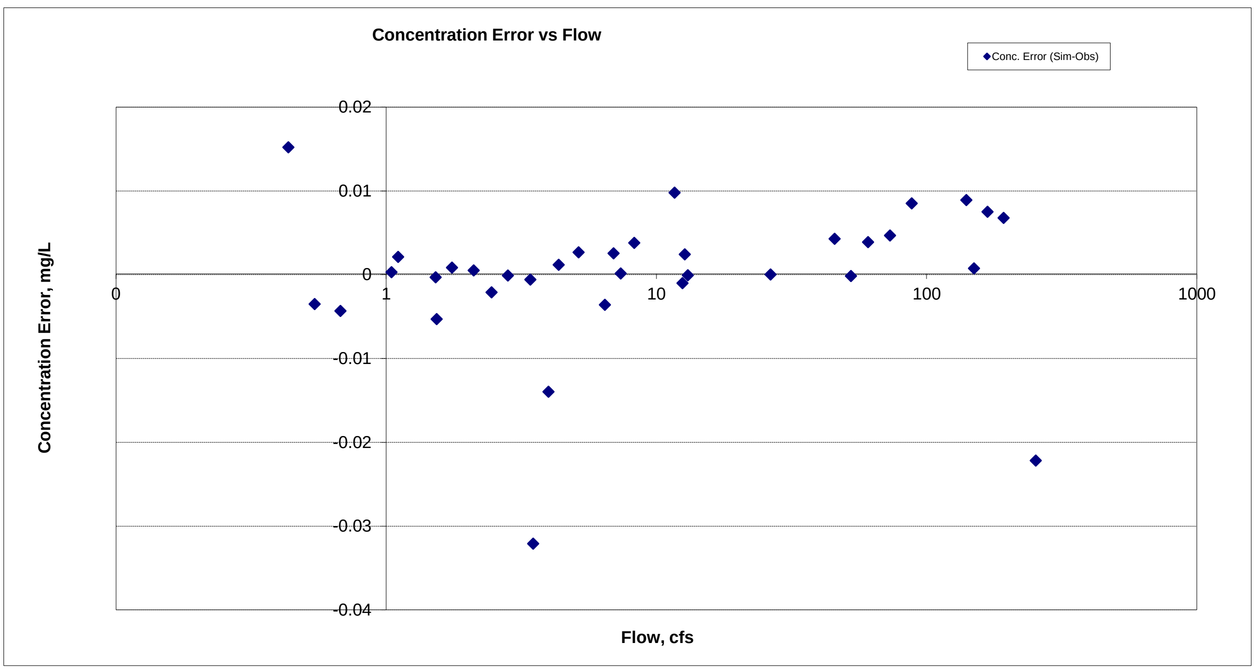


Figure 104. Residual (Simulated - Observed) vs. Flow Soluble Reactive Phosphorus (SRP) at Flute Reed River (S004-283)

Organic Phosphorus (OrgP)

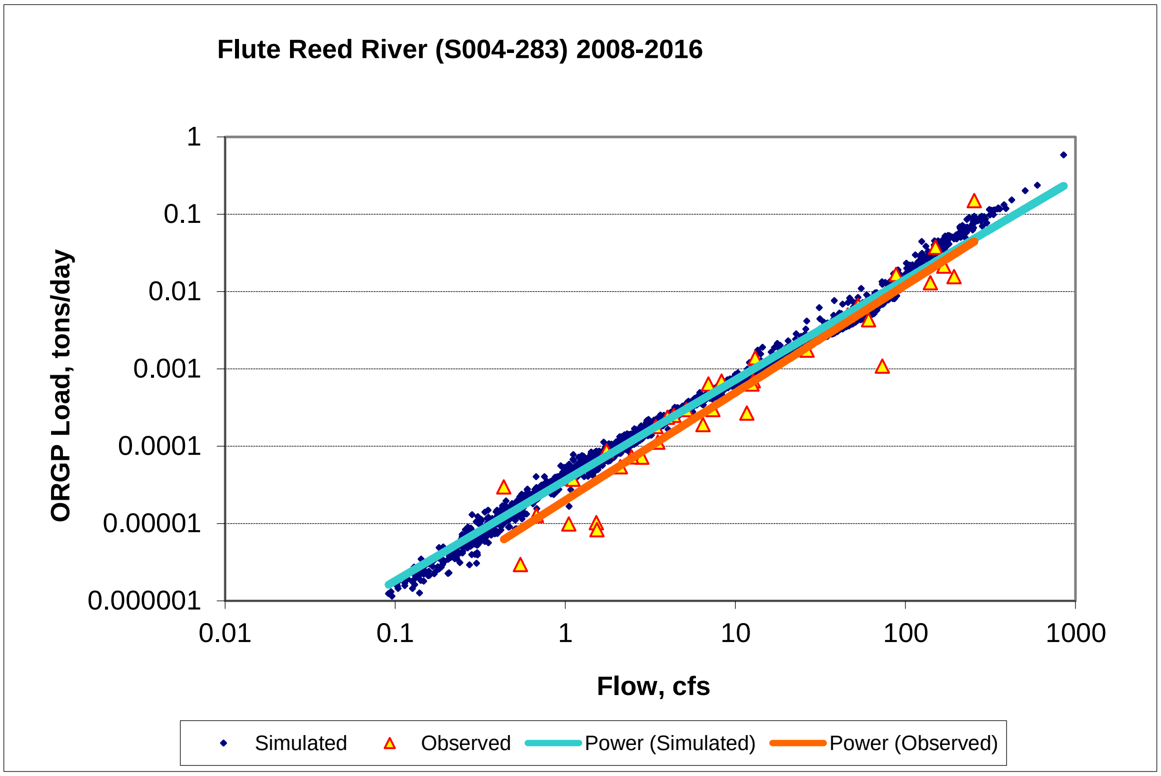


Figure 105. Power plot of simulated and observed Organic Phosphorus (OrgP) load vs flow at Flute Reed River (S004-283)

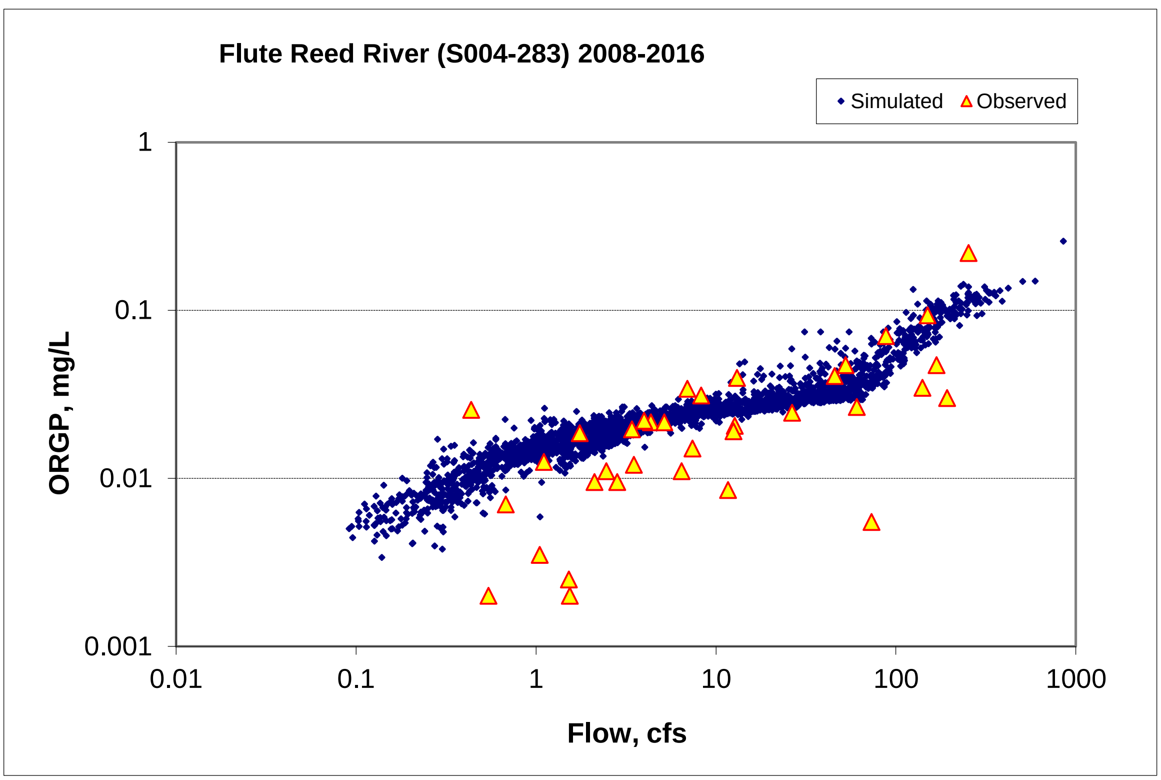


Figure 106. Simulated and observed Organic Phosphorus (OrgP) concentration vs flow at Flute Reed River (S004-283)

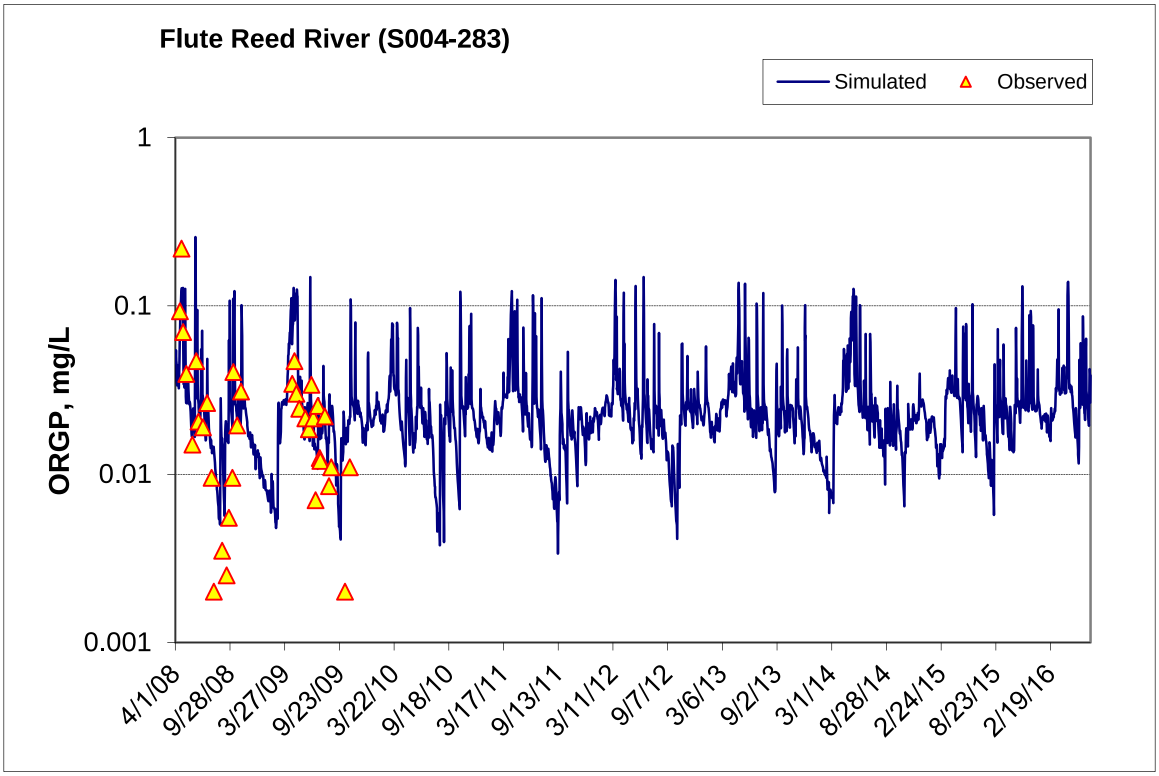


Figure 107. Time series of observed and simulated Organic Phosphorus (OrgP) concentration at Flute Reed River (S004-283)

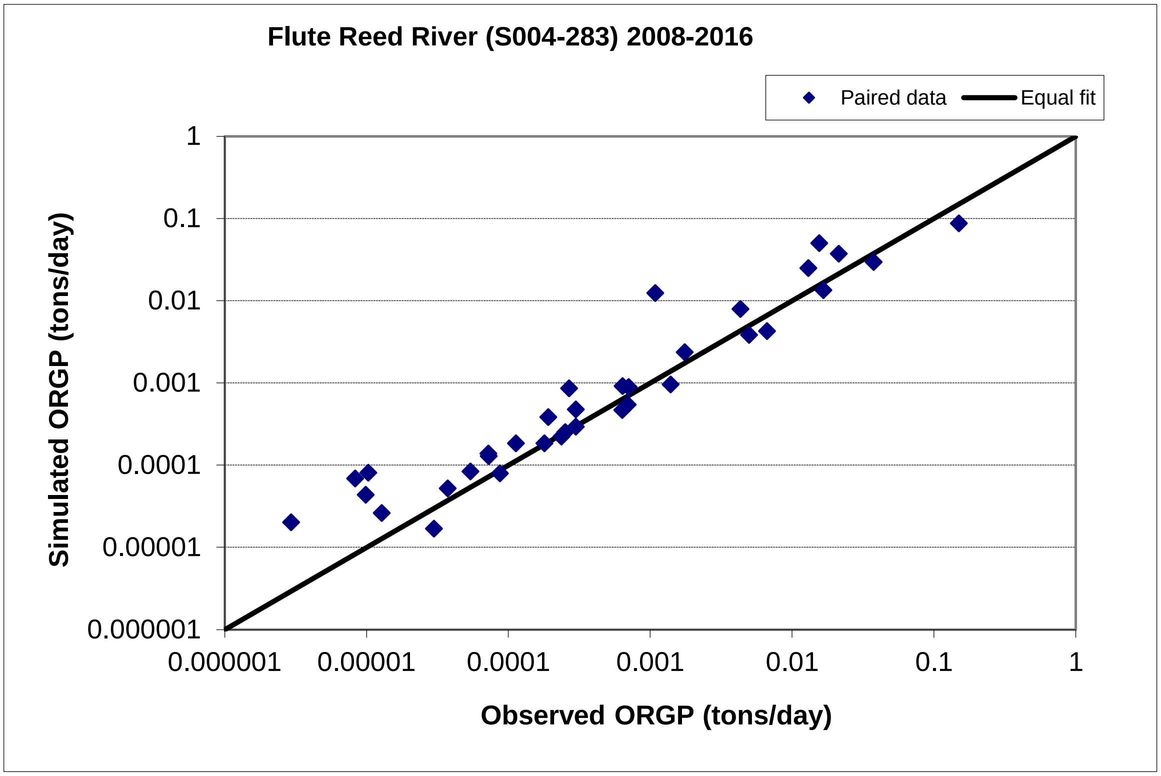


Figure 108. Paired simulated vs. observed Organic Phosphorus (OrgP) load at Flute Reed River (S004-283)

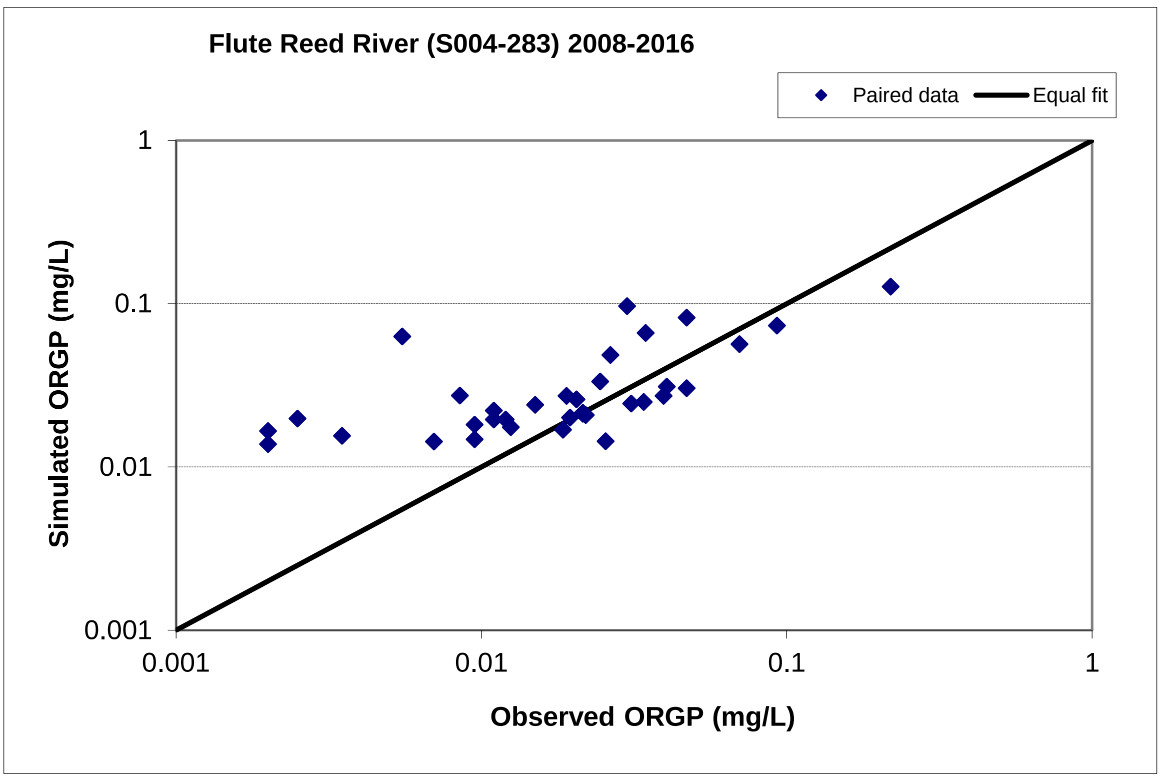


Figure 109. Paired simulated vs. observed Organic Phosphorus (OrgP) concentration at Flute Reed River (S004-283)

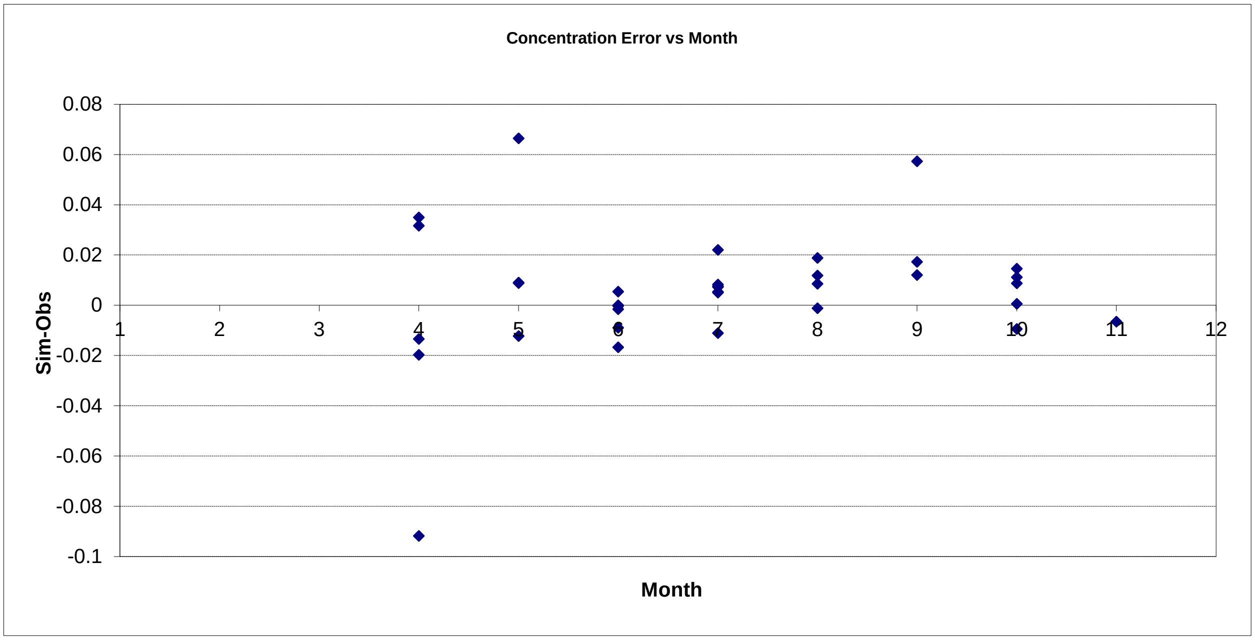


Figure 110. Residual (Simulated - Observed) vs. Month Organic Phosphorus (OrgP) at Flute Reed River (S004-283)

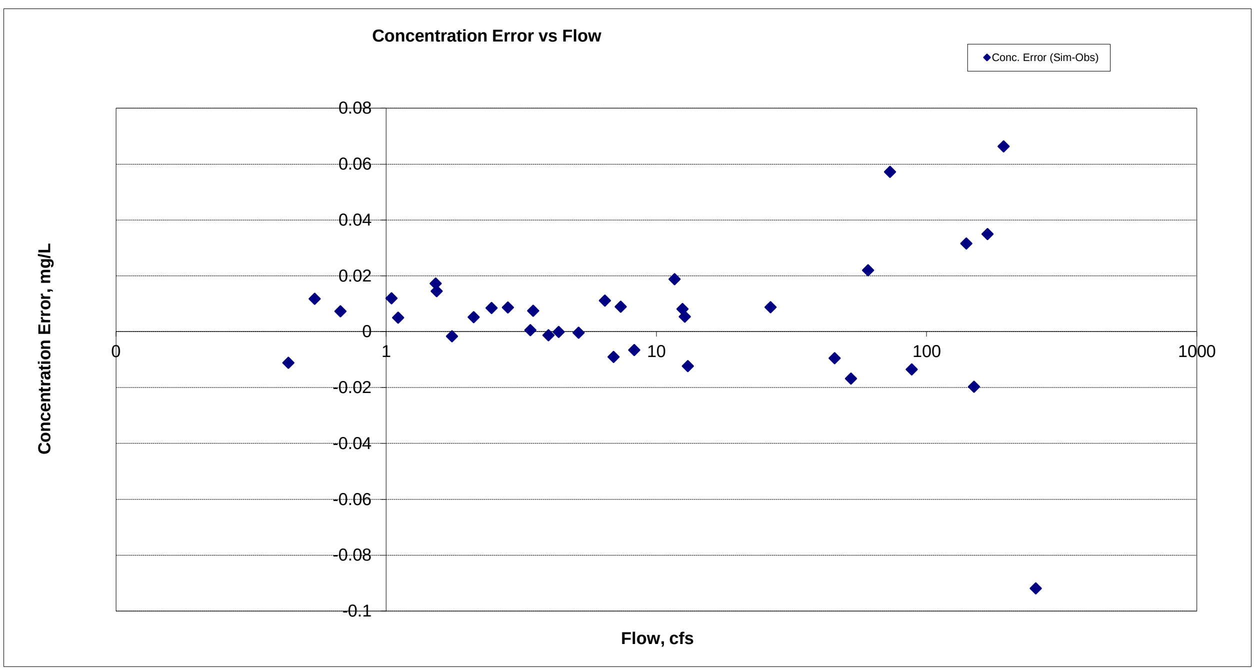


Figure 111. Residual (Simulated - Observed) vs. Flow Organic Phosphorus (OrgP) at Flute Reed River (S004-283)

Total Phosphorus (TP)

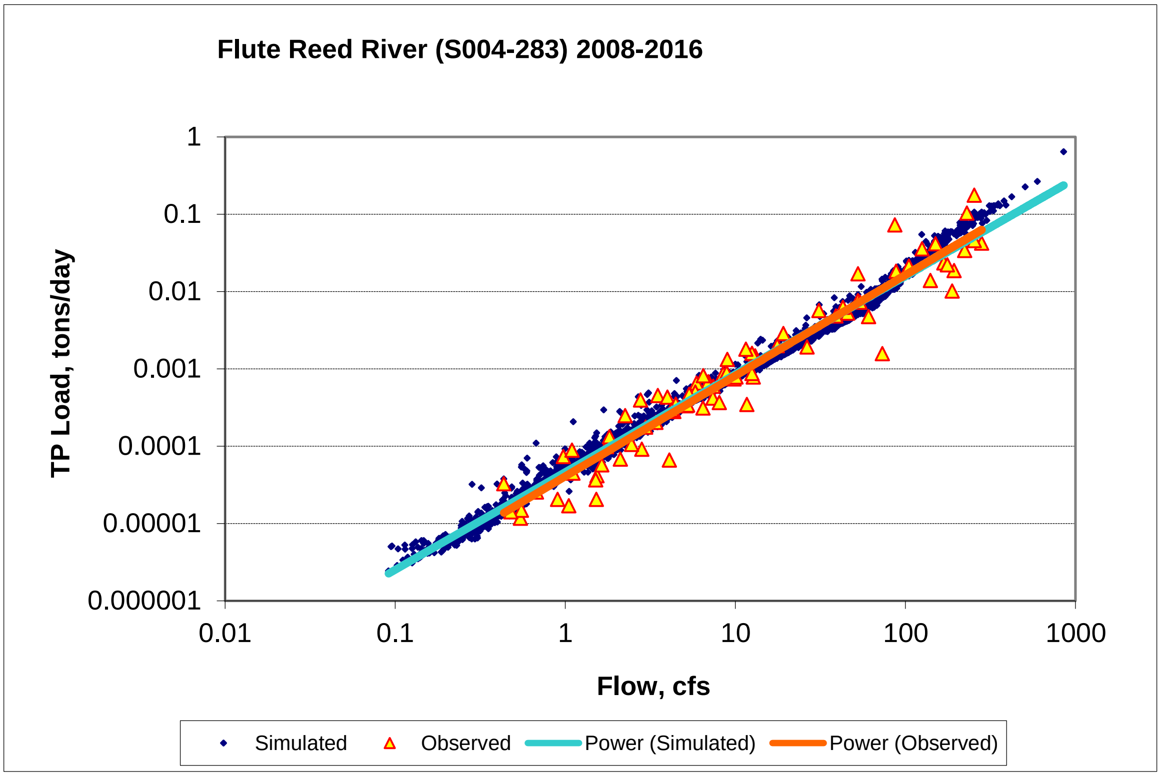


Figure 112. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Flute Reed River (S004-283)

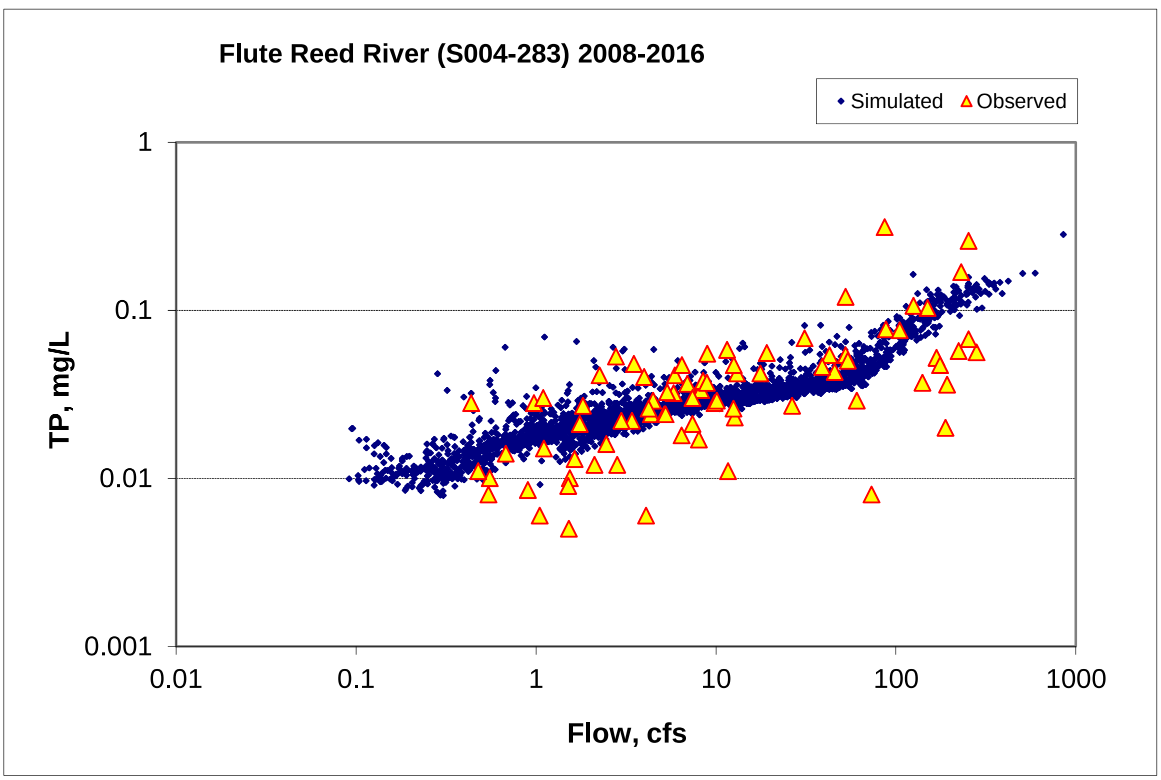


Figure 113. Simulated and observed Total Phosphorus (TP) concentration vs flow at Flute Reed River (S004-283)

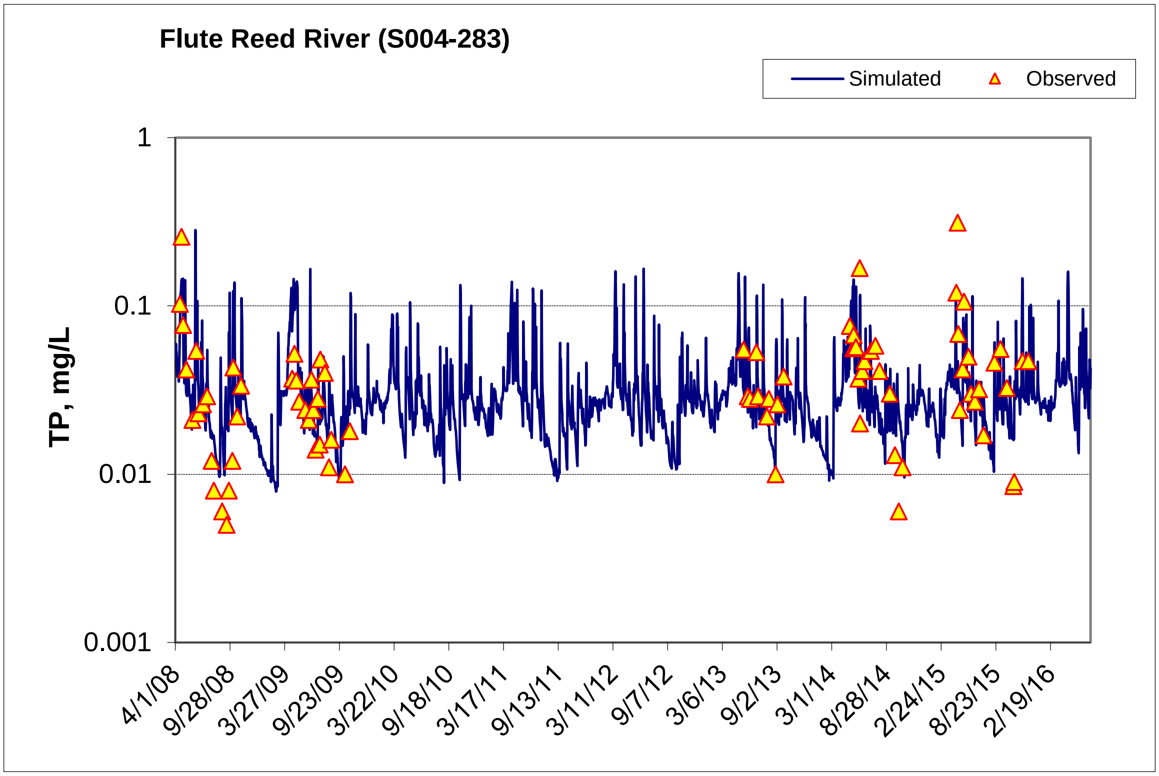


Figure 114. Time series of observed and simulated Total Phosphorus (TP) concentration at Flute Reed River (S004-283)

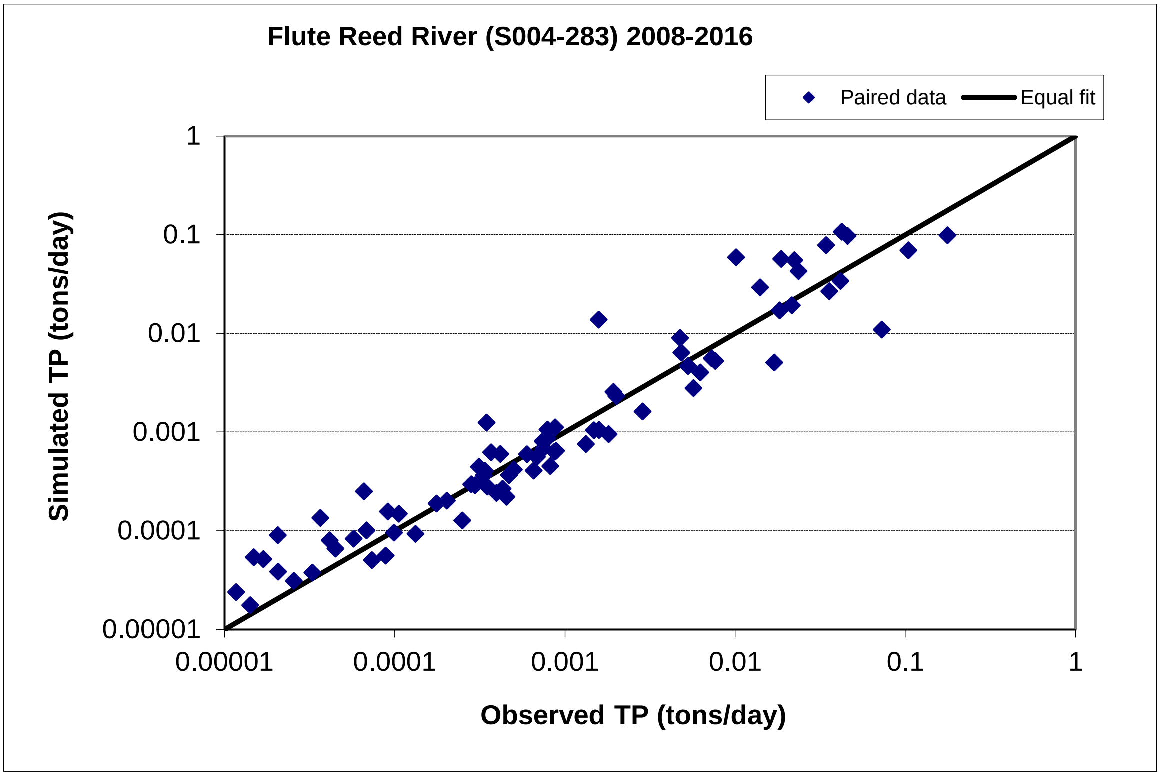
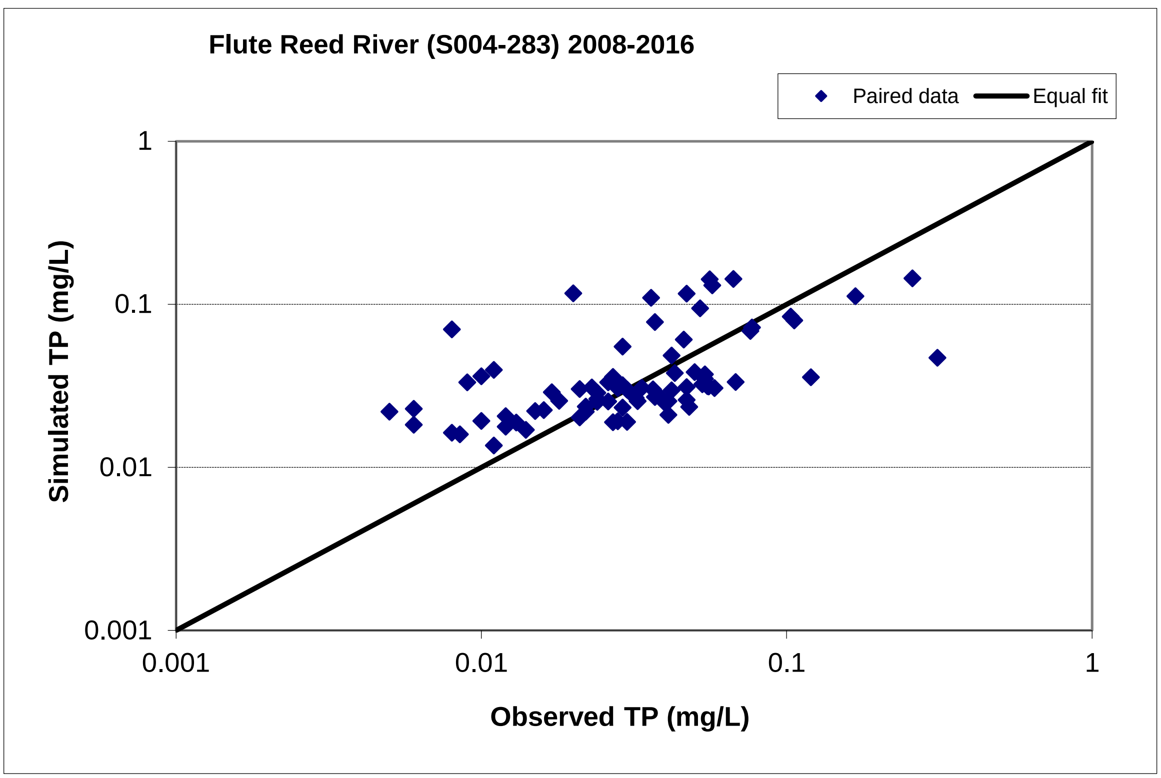


Figure 115. Paired simulated vs. observed Total Phosphorus (TP) load at Flute Reed River (S004-283)



TETRA TECH

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

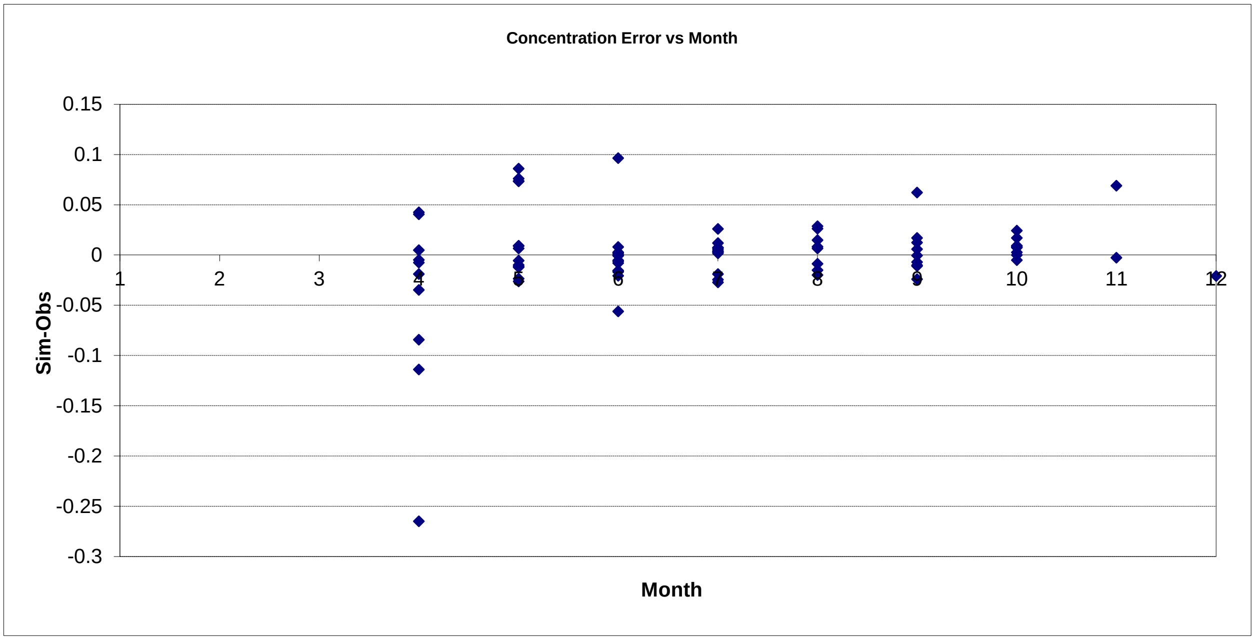


Figure 117. Residual (Simulated - Observed) vs. Month Total Phosphorus (TP) at Flute Reed River (S004-283)

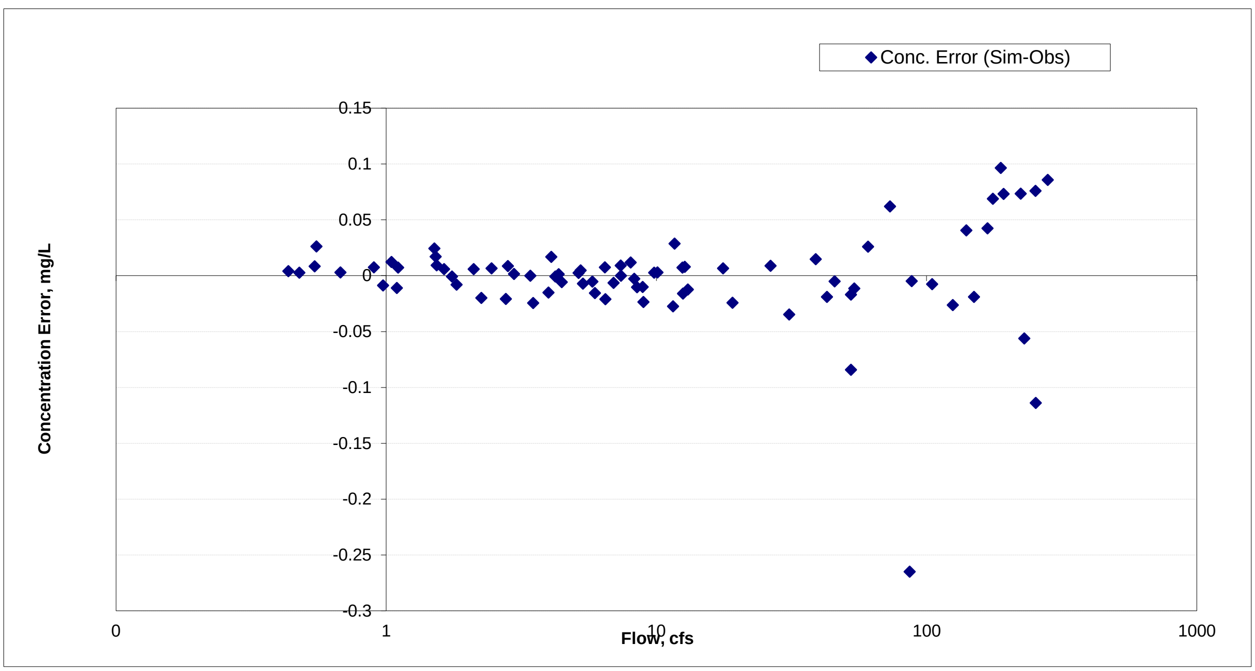
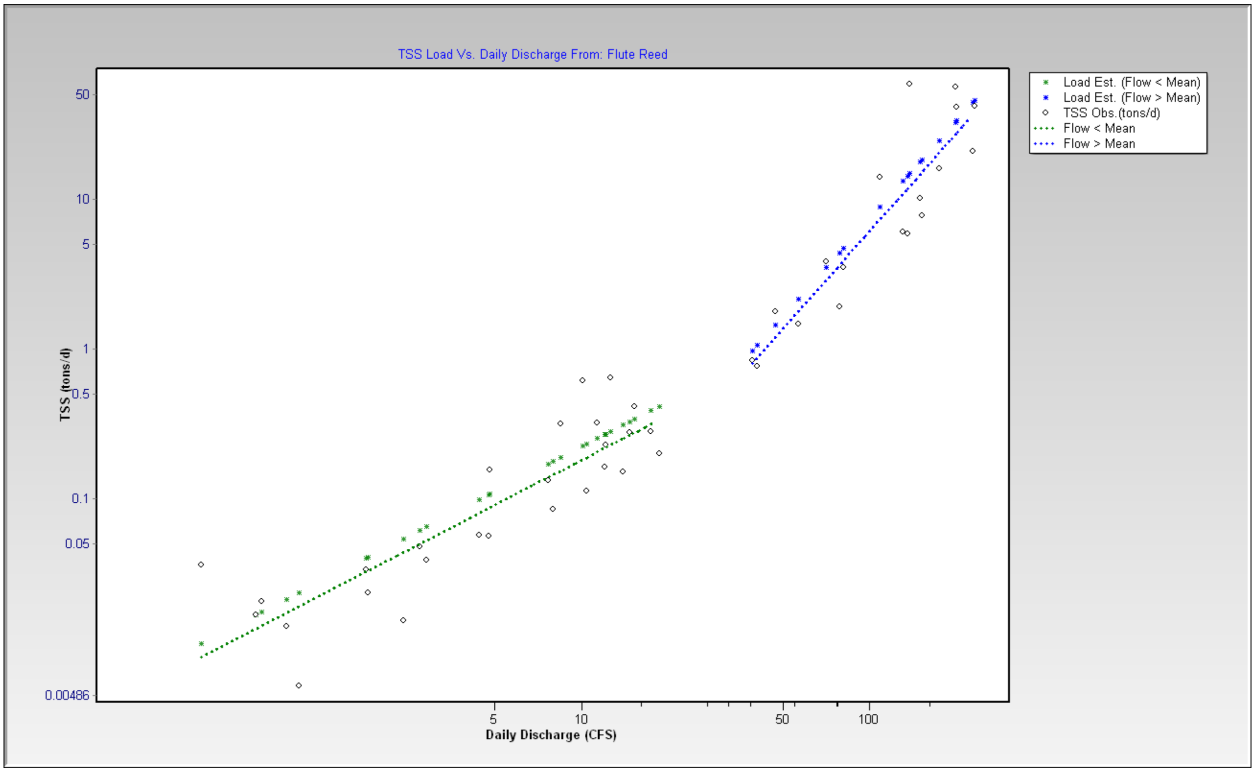


Figure 118. Residual (Simulated - Observed) vs. Flow Total Phosphorus (TP) at Flute Reed River (S004-283)

Appendix C - Regression Models

SEDIMENT

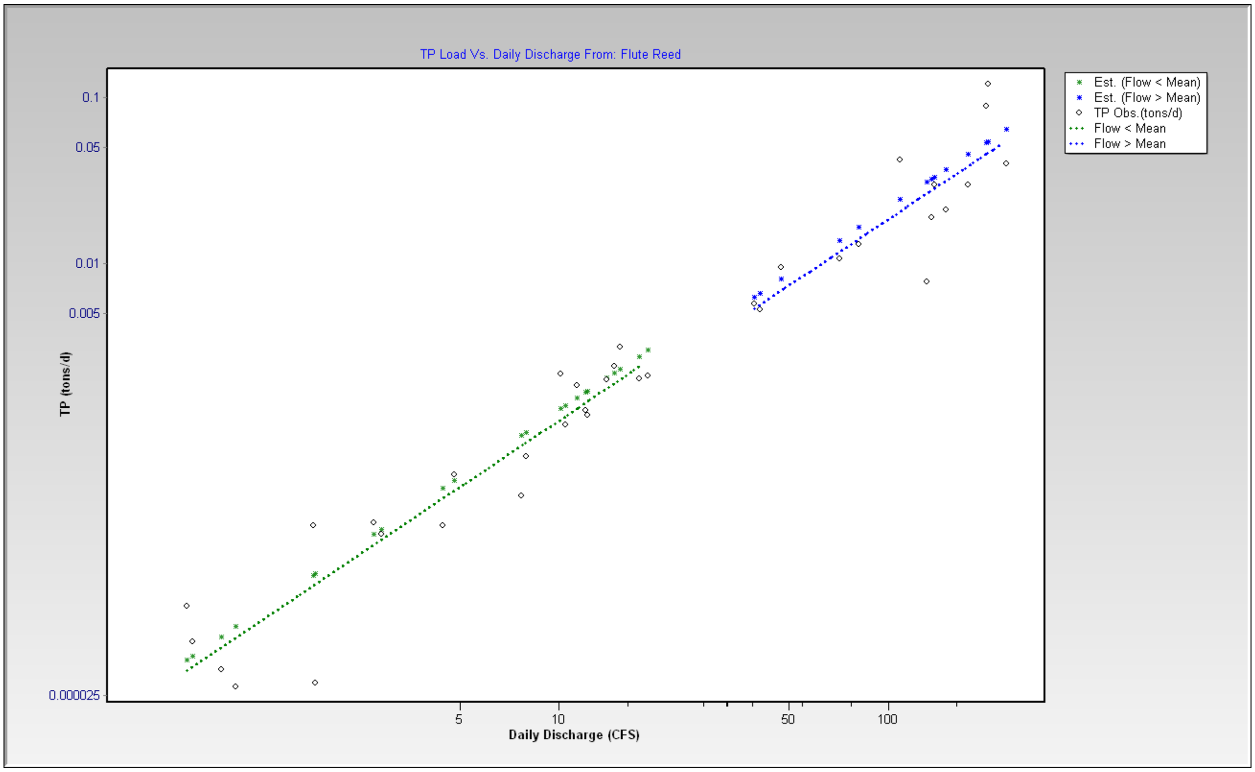



```
Log-Log Regression: Log(TSS (tons/d)) on Log(Daily Discharge (CFS))
Flux Estimation Method: 6 (C/Q Reg3(daily))
------------------------------------
Overall (No Strata)
  INTERCEPT (Log)     = -1.9410
  SLOPE               = 1.350690
  R²                  = 0.914
  MEAN SQUARED ERROR  = 0.1092
  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
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 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
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-----------------------------------------------------------------------------------
                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
R^2 = 0.887

Stratum(2) Flow > Mean
Intercept = 19.14
Log Intercept = 1.282
Slope = 1.319
R^2 = 0.675