Appendix D.

SWAT Model Report

SWAT Model Calibration Report for Sandusky River Watershed

October 18, 2013

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EPA Region 5

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Sandusky River Watershed

This document presents the results of a modeling approach adopted for the Sandusky River watershed using the Soil and Water Assessment Tool (SWAT). A watershed model for Sandusky River watershed was constructed using SWAT 2012 *rev 591*. The watershed model was calibrated and validated to observed flow using several USGS Stations, and water quality data from the USGS, Ohio EPA, and Heidelberg University.

Qi and Grunwald (2005) have built a SWAT model for the Sandusky River watershed. The model was calibrated and validated for hydrology only for a short time frame. The current model by Tt has a 30+ year simulation time-frame and it is calibrated and validated for hydrology, sediment and nutrients. The purpose of this model is to help in the establishment of total maximum daily loads (TMDL) for impaired streams in the watershed.

The Sandusky River is located in northern Ohio, west of Cleveland and southeast of Toledo, and drains into the Sandusky Bay of Lake Erie (Figure 1). The river is about 125 miles long, one of Ohio's longest waterways, and approximately 70 miles of the main stem are designated as Scenic River. The 1,827 square mile Sandusky watershed falls within twelve different counties, with the majority of the watershed located in Crawford, Wyandot, Seneca, and Sandusky Counties. The entire watershed is identified by the 8-digit hydrologic unit code (HUC) 04100011, and consists of 72 different 12-digit HUCs. The major towns and cities within the watershed include Sandusky, Bellevue, Tiffin, Upper Sandusky, Bucyrus, Fremont, Clyde, Fostoria, and Carey.

This area of northern Ohio is heavily agricultural (75% of the land area in this watershed), with only limited urban land (8%) and forested land (8%), with some wetland area near the bay. These lacustrine areas where Lake Erie water mixes with fresh river water yield unique hydrology through large wetland complexes. Due to the large amount of crop cultivation, the waterways are sensitive to nutrient loading, and tile drains play a large role in cropland hydrology. The Sandusky watershed also hosts karst geology which results in sinkholes and complex surface-to-groundwater interactions.

Lake Erie is the smallest and shallowest of the Great Lakes. "The shallowness of the basin and the warmer temperatures make it the most biologically productive of the Great Lakes" (Lake Erie Lake Management Plan [LaMP], 2011). In the 1960s and 1970s, excessive phosphorus loads from its tributaries caused harmful algal blooms in Lake Erie. While phosphorus loads were reduced in the 1970s and 1980s by addressing point source discharges, excessive phosphorus concentration, began to return in the 1990s and the Lake Erie ecosystem is again threatened by harmful algal blooms (Lake Erie LaMP, 2009; 2011). The recent algal blooms are caused by many new, more complex factors in addition to non-point source total phosphorus loading, including: changes in nutrient cycling through the food web due to the invasion of nonnative species, increases in water temperatures, and shorter and smaller ice coverage during the winter, and a change in the form of phosphorus entering the lake (Lake Erie LaMP, 2011).

The Sandusky River is the second largest Lake Erie tributary in Ohio, and along with the Detroit and Maumee rivers, is one of the three major tributaries to Lake Erie contributing large phosphorus loads. The Sandusky River and other tributaries to Lake Erie "contain a mix of non-point source pollution, including agricultural and urban runoff, and point source pollution, such as treated municipal sewage" (Lake Erie LaMP, 2011). The more bioavailable form of phosphorus (i.e., orthophosphate or soluble reactive phosphorus) is found in sewage and fertilizers, and its export maybe promoted by the drains (Lake Erie LaMP, 2011). Recent evaluations show that soluble reactive phosphorus loads are increasing in the Maumee and Sandusky rivers (Lake Erie LaMP, 2009; 2011).

Tributaries in the Sandusky Basin (HUC 04100011) are not attaining their designated aquatic life uses (ALUs) due to excessive nutrients and sediment and are on Ohio's 2012 Clean Water Act section 303(d) list (Ohio EPA 2012). The Sandusky River (lower) is not attaining its designated ALU due to sediment and is not attaining its designated public drinking water supply (PDWS) use at the city of Freemont's water treatment plant raw water intake due to elevated nitrate levels found in the raw (i.e., in-stream) and finished water[1]. The scope of this project is limited to impairments to designated ALUs and public drinking water uses. Table 1 summarizes the waterways and their impairments.

[1] Elevated nitrate levels in the finished water triggered the listing in Ohio's 303(d) list (Ohio EPA 2011, p. 27).

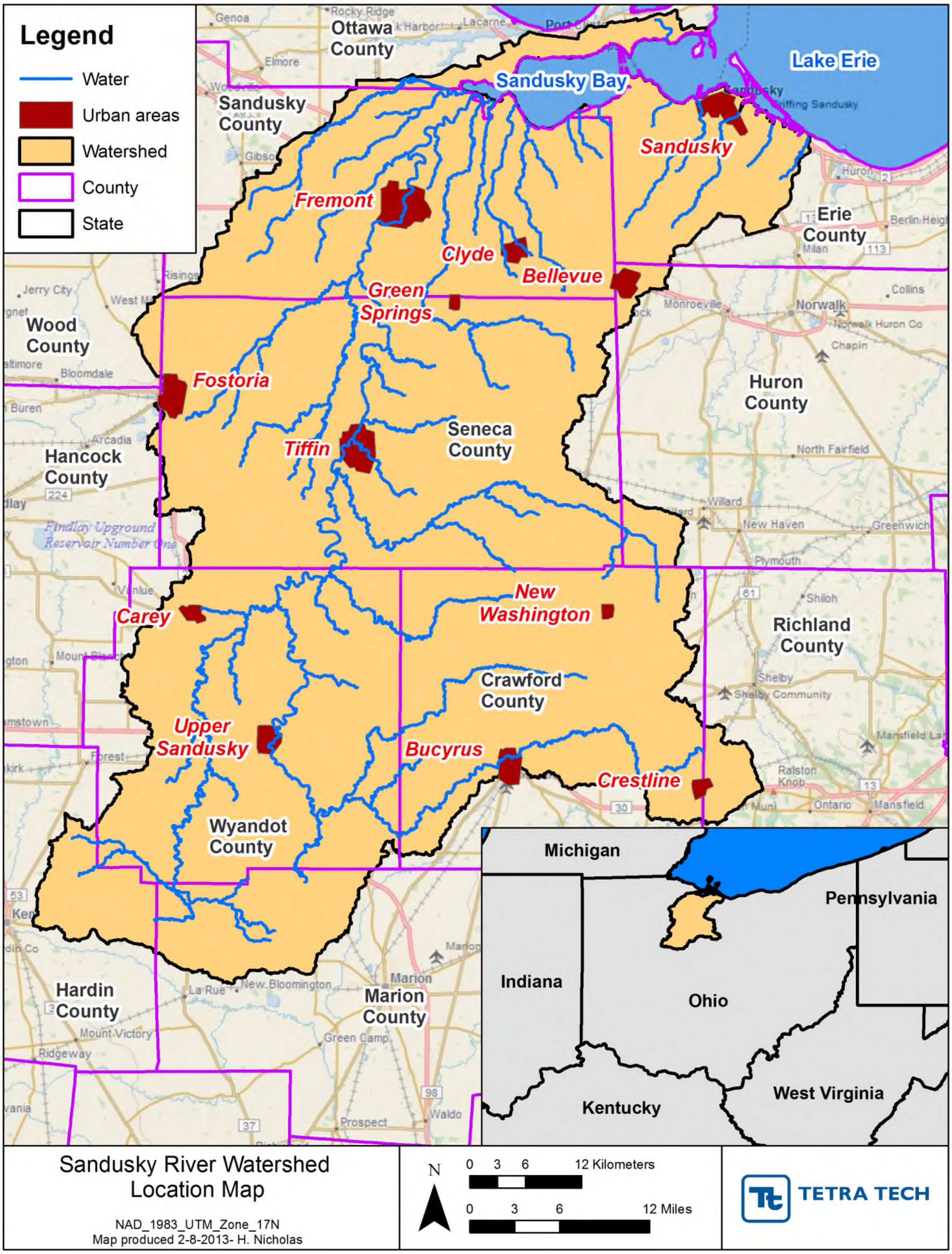

Figure 1. Sandusky River Watershed Location Map

Table 1. Identified Water Quality Impairments in the Sandusky River Watershed

Watershed assessment unit (04100010)	Direct habitat alteration	Natural conditions	Nitrate	Nutrient/eutrophication	Organic enrichment (sewage)	Other flow regime alterations	Particle distribution	Pesticides	Phosphorus	Sedimentation/siltation
Mills Creek-Frontal Lake Erie										
Pipe Creek – Frontal Sandusky Bay (01 02)						X				X
Mill Creek (01 03)				X	X		X		X	X
Pickerel Creek-Frontal Sandusky Bay										
Frontal south side of Sandusky Bay (02 01)		X					X			X
Pickerel Creek (02 03)							X			X
Raccoon Creek (02 04)	X			X	X		X	X	X	X
South Creek (02 05)				X	X		X		X	X
Wolf Creek										
East Branch East Branch Wolf Creek (10 01)	X		X	X					X	
Snuff Creek - East Branch Wolf Creek (10 02)			X	X					X	
Wolf Creek (10 04)	X		X	X						
Rock Creek-Sandusky River										
Spicer Creek - Sandusky River (11 05)				X	X					
Green Creek										
Beaver Creek (12 02)	X									X
Green Creek (12 03)										X
Muskellunge Creek-Sandusky River										
Muskellunge Creek (13 01)				X					X	X
Mouth Sandusky River (13 03)	X			X			X		X	X
Muddy Creek-Frontal Sandusky Bay										
Little Muddy Creek (14 03)			X	X					X	X
Town of Lindsey –Muddy Creek (14 04)	X					X			X	
Large River Assessment Units										
Sandusky River mainstem (Tymochtee Creek to Wolf Creek) (09 01)										X
Sandusky River mainstem (Wolf Creek to Sandusky Bay)(09 02)	X		X				X			X

Source: Ohio EPA 2012.

SWAT Model Configuration

SWAT is run via ArcSWAT, an ArcGIS based platform, to model the Sandusky River watershed the following data were required:

1. Digital Elevation Model (for elevation and slope calculation)
2. Watershed and subbasin physical boundaries (requires delineation)
3. Hydrologic network (to define model reaches, tributaries, and reservoirs)
4. Land use and land cover
5. Soils map showing soil types and locations
6. Meteorological data (precipitation, temperature, etc.)
7. Stream flow gaging data
8. Water quality data

These data are used to develop model input files, either as time series or spatial layers. More detailed descriptions for each configuration step are detailed below.

Elevation and Slope

A 30-meter digital elevation model (DEM) was used for the SWAT model setup. The ArcSWAT interface uses the DEM to determine the physical characteristics of reaches, subbasins and hydrologic response units (HRUs). Elevation in the Sandusky River watershed ranges from about 165 meters to 412 meters (Figure 2).

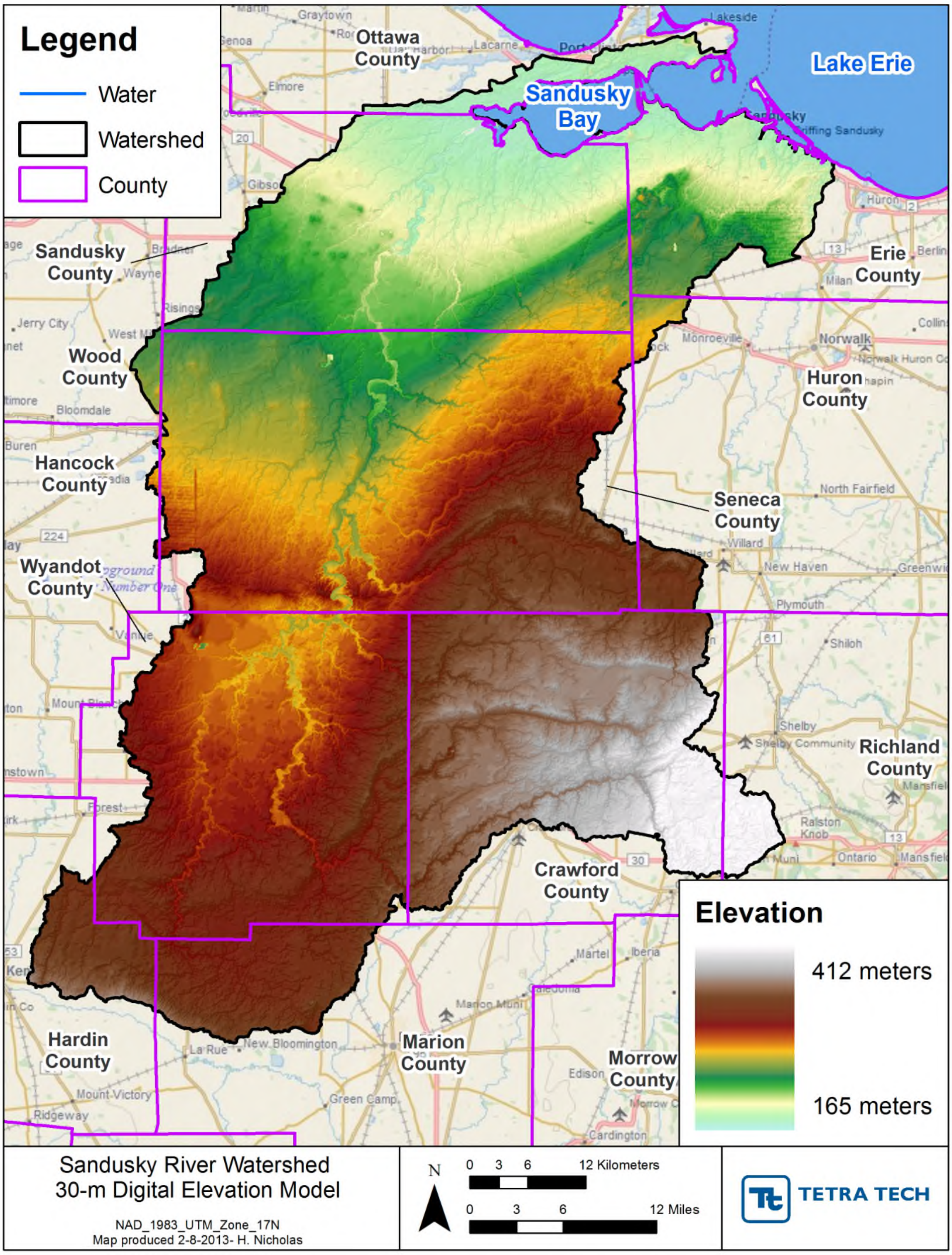

Figure 2. Elevation in the Sandusky River Watershed

Watershed Model Segmentation

The Sandusky River watershed was divided into 113 sub-watersheds for the purpose of modeling the area (Figure 3). The sub-watershed divisions were based on the 72 HUC-12 delineations, with topographical cuts made for monitoring stations and smaller impaired tributaries. A number of HUC-12 drainage areas near the outlet of the watershed are considered impaired and are the focus of TMDL (Total Maximum Daily Load) development (Table 1). The model includes areas that drain to the Sandusky Bay. While Sandusky Bay itself cannot be simulated in SWAT, which only represents uni-directional flow in waterbodies, watershed loading from these areas is simulated.

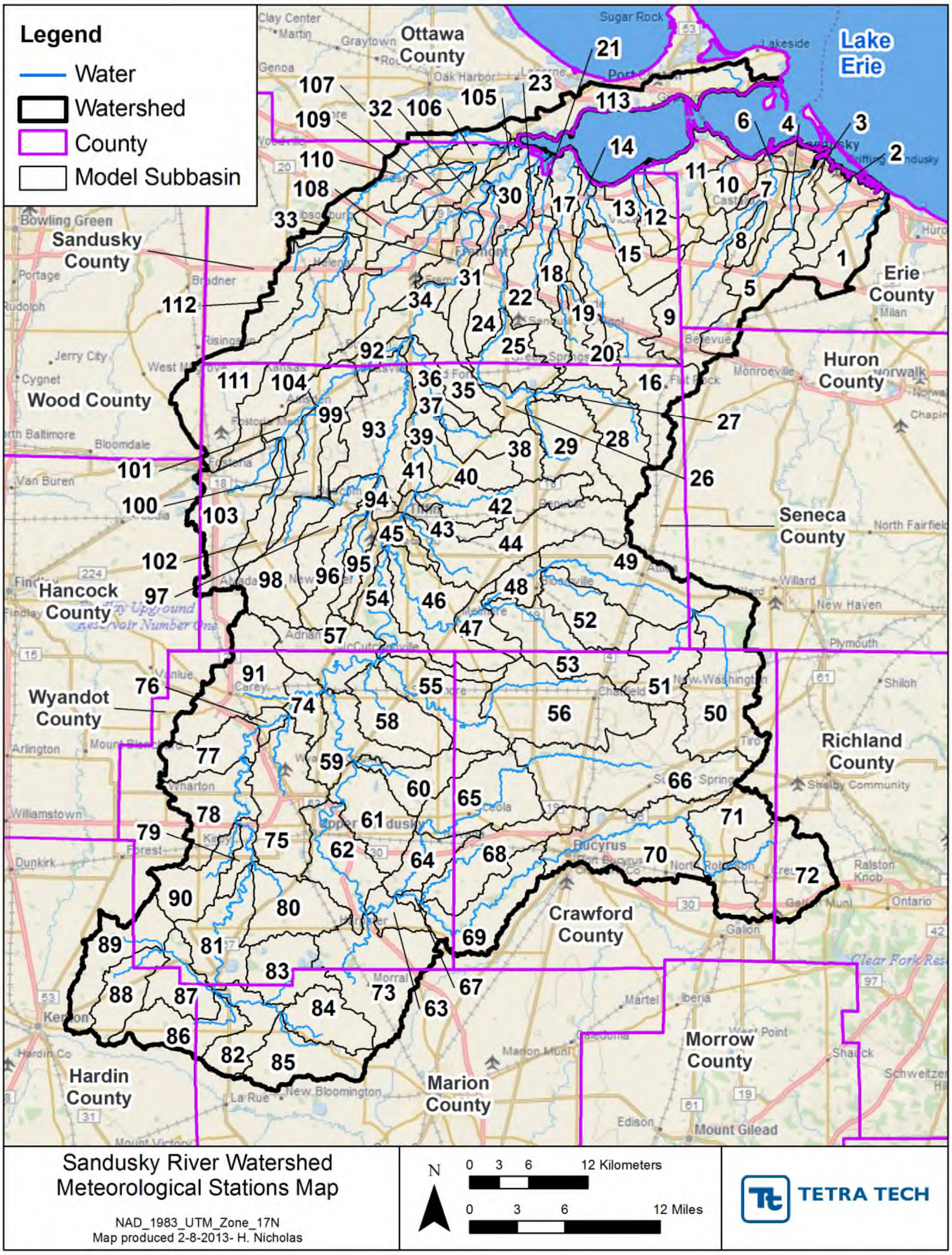

Figure 3. Model Segmentation for the Sandusky River Watershed

Land Use Representation

Land use is the third element of HRU-delineation which determines how specific types of land cover will respond to changes in hydrology. Whether a parcel of land is managed row-crop agriculture, swampy wetlands, or old-growth forest, the way that parcel of land responds to inputs of precipitation and climate forcing will be tied to slope and soil type. Land use/cover in this watershed is based on the 2006 National Land Cover Database (NLCD) coverage (Figure 4). Cropland Data Layer (CDL) spatial coverages from the USDA for years 2010 and 2011 along with information from county extension service were used to inform the breakout of agricultural land into corn, soybeans and winter wheat. NLCD land cover classes were aggregated according to the scheme shown in Table 2. The distribution of land use in the watersheds is summarized in Table 3. The agricultural land class was subdivided as shown in Table 4 based on crop coverage data and rotation practices in the watershed. Information about row crops, tillage, and fertilizer practices were obtained from county-specific Agricultural Cooperative Extension Offices and literature obtained from the Tri-State Recommendations bulletin (Vitosh et al., 1995). The agricultural practices adopted are summarized below.

Corn	Chisel Plow - April 15 Planting - April 21 Fertilizer - April 22 (20-70-0) Fertilizer - June 20 (130-0-0) Harvest - October 21
Soybean	Planting - May 1 Fertilizer - May 2 (0-40-0) Harvest - October 21
Wheat	Planting - October 21 Fertilizer - October 22 (14-55-0) Fertilizer - March 1 (60-0-0) Harvest - July 1

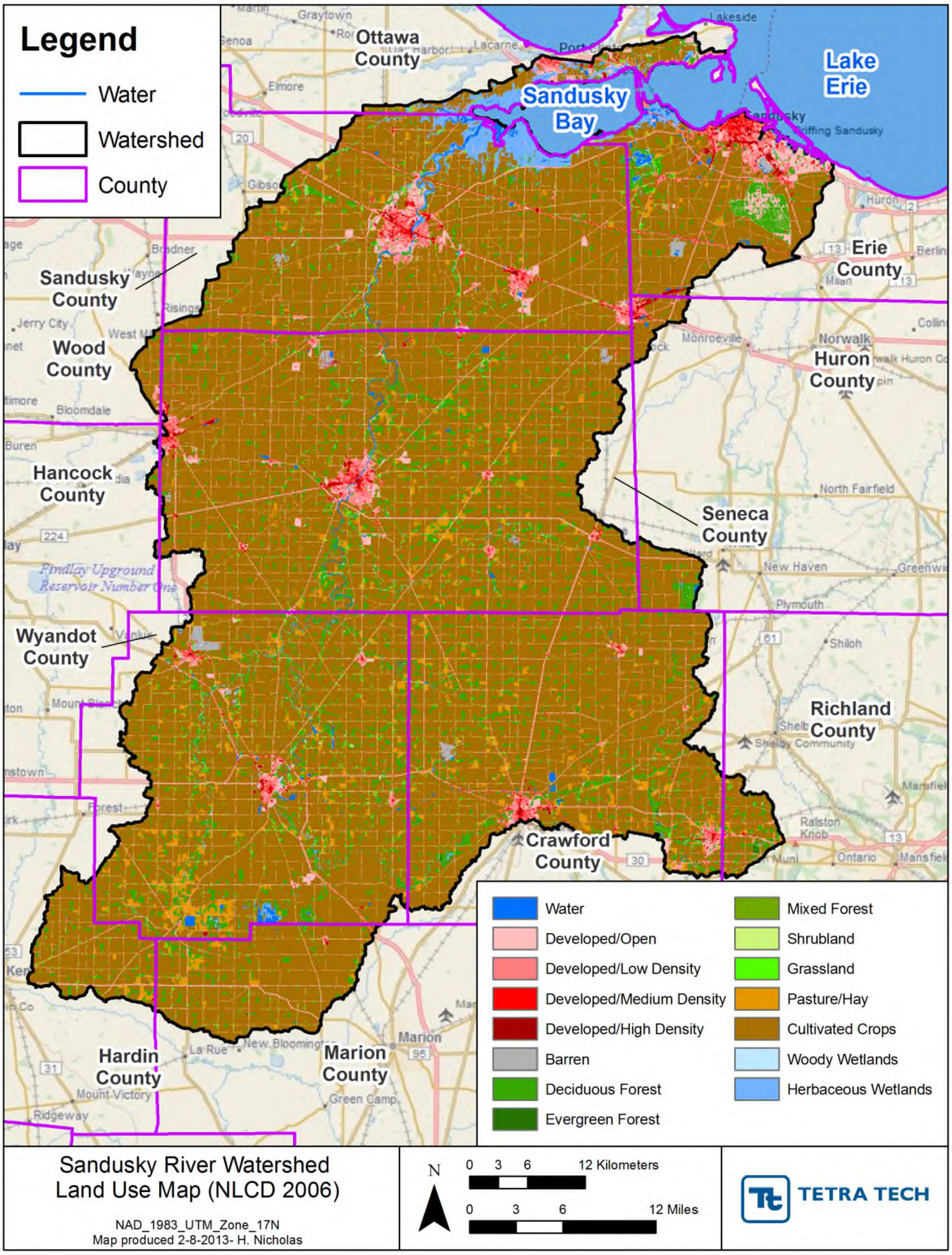

Figure 4. Land use in the Sandusky River Watershed

Table 2. Aggregation of NLCD Land Cover Classes

NLCD Class	Comments	SWAT class
11 Water	Water surface area usually accounted for as reach area	WATR
21 Developed open space		URLD
22 Dev. Low Intensity		URMD
23 Dev. Med. Intensity		URHD
24 Dev. High Intensity		UIDU
31 Barren Land		SWRN
41 Forest	Deciduous	FRSD
42 Forest	Evergreen	FRSE
43 Forest	Mixed	FRST
51-52 Shrubland		RNGB
71-74 Herbaceous Grassland		RNGE
81 Pasture/Hay		HAY*
82 Cultivated		AGRR*
91-97 Wetland	Emergent & woody wetlands	WETF, WETL, WETN
98-99 Wetland	Aquatic bed wetlands (not emergent)	WATR

*Tiled drained under HAY and AGRR were assigned SWAT classes HATI and AGTI, respectively.

Table 3. Land Use Distribution for Sandusky River Watershed (NLCD 2006)

Watershed	Open water	Developed				Barren Land	Forest	Shrubland	Pasture/Hay	Cultivated	Wetland	Total
		Open Space	Low Density	Medium Density	High Density							
Area (square miles)	17.74	118.25	50.59	15.07	7.06	6.24	146.94	0.07	44.64	1,386.54	30.74	**1844.69**
Percentages	1.0%	6.4%	2.7%	0.8%	0.4%	0.3%	8.0%	0.0%	2.4%	75.2%	1.7%	**100.0%**

Table 4. Agriculture Class Specificity for SWAT Model

NLCD Class	SWAT Class	Crop Code	Crop Description	Percentage of Agricultural Land
82 Cultivated land	AGRR and AGTI (cultivated land with tile drains)	CS	Corn-Soybeans 2-year rotation	37.5%
		SC	Soybeans-Corn 2-year rotation	37.5%
		SWC	Soybeans-Winter Wheat-Corn 2-year rotation	12.5%
		SCW	Soybeans-Corn-Winter Wheat 2-year rotation	12.5%

Soil Characteristics

The USDA Soil Survey Geographic database (SSURGO) was used to populate the model with information on soil depth, particle size distribution, bulk density, hydraulic conductivity, and available water capacity. Soil information for each unique MUKEY (a numerical key which is used to join tabular data and spatial data; a unique key is used for each soil series or complex mapped) was extracted from the SSURGO dataset using an Excel VBA based tool developed by Tetra Tech, Inc. There were 663 unique soils (based on MUKEY) that were identified for the Sandusky River watershed. These soils are classified into Hydrologic Soil Groups (A, B, C, and D) based on soil characteristics in the SSURGO database (Figure 5). Note that soils in Group A have the lowest runoff potential and highest infiltration rates, while those in Group D have the highest runoff potential and lowest infiltration rates. The vast majority of the soils in the Sandusky River watershed were cross-listed HSGs such as A/D, B/D, and C/D which represents areas that are naturally poorly drained (D), but can be improved to the first listing (A,B, or C) with artificial drainage (i.e., tile drains). Soils listed as HSG class D or a cross-listed class with D on agricultural lands were considered to be tile-drained and modeled with tile drain characteristics. Agriculture statistics and literature suggest that about 90% of agricultural land in the Sandusky watershed employ some kind of tile drainage (Heidelberg University, 2011). This modeling scenario which links D-soils with agricultural lands resulted in about 89% of agricultural lands having tile drains employed to some degree, which encompass about 67% of the watershed area.

Karst topography is present in the north-western part of the Sandusky River watershed (Figure 6). Areas of karst are not well-mapped, but are probably present in the lower half of the watershed, around the city of Bellevue. Note that karst topography is characteristic of sinkholes and caves, and the Silurian-Devonian geology of upper Ohio is limestone rich in areas buried by glacial drift which can cause problems such as subsidence (Ohio Division of Geology Survey, 1999). Karst topography is modeled using the ‘hydraulic conductivity of tributary channels’ parameter (CH_N1) in *.sub* files in the SWAT model. This variable reduces surface runoff from the subbasin depending upon the value of CH_N1 and redirects this water to the shallow groundwater pool in the SWAT model.

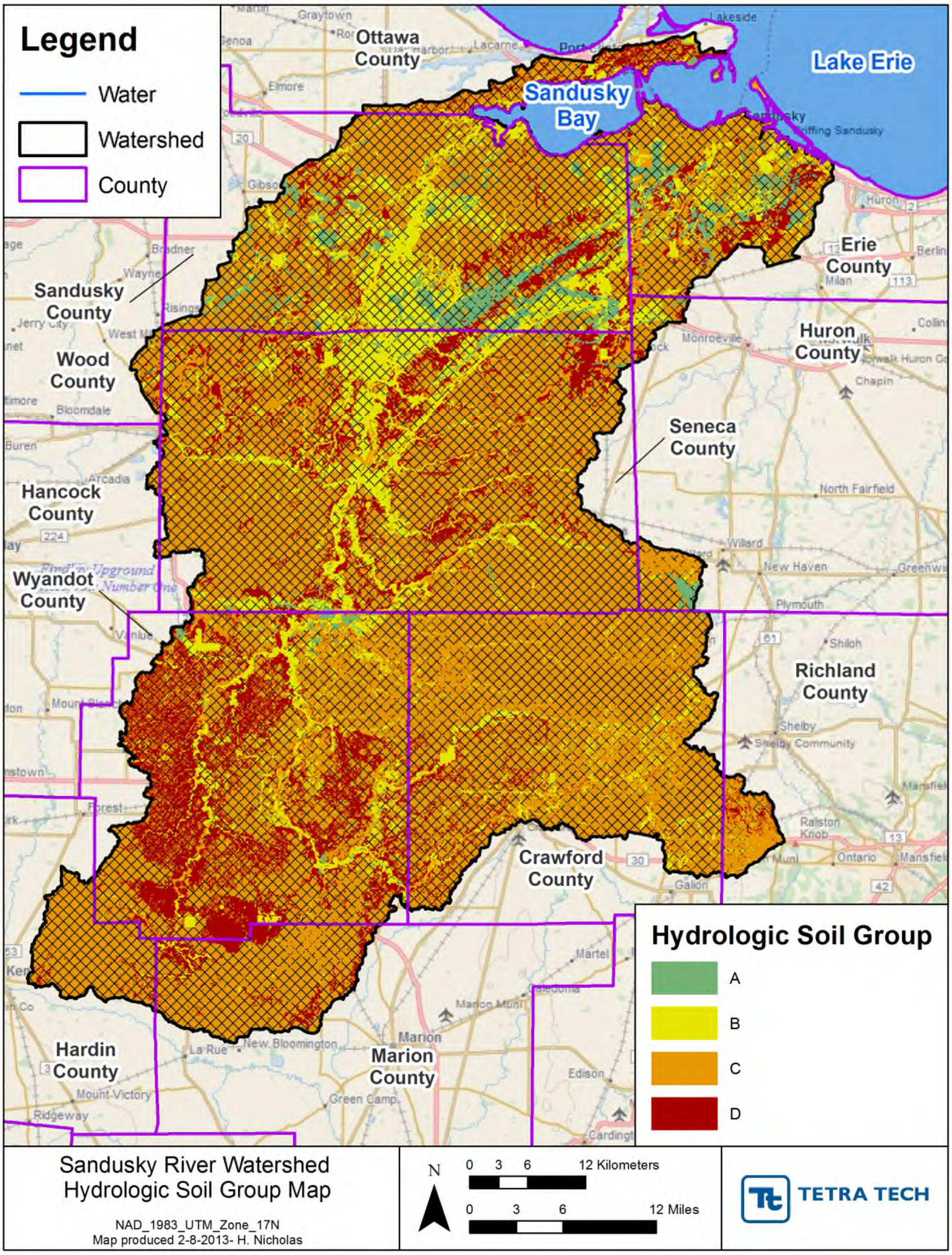

Figure 5. Hydrologic Soil Groups in the Sandusky River Watershed (the cross-hatched areas represent dual HSGs, that is, A/D, B/D, and C/D)

Hydrologic Response Unit Delineation

In order to model the watershed as accurately as possible, the physical conditions of upland areas are used to break up the model into lumped areas of similar parameters based on soil type, land slope, and land use called Hydrologic Response Units (HRUs). Areas throughout the watershed with similar composition of soil/slope/land use are designated as lumped HRUs because of similar responses in hydrology (Kouwen et al, 1993). Each HRU is a unique combination of land use, soil and slope. The SWAT model calculates load from each HRU within a subbasin on a daily time step basis and reports the output at the HRU and subbasin level. The subbasin level output is basically sum of the outputs of all HRUs within a subbasin. During the HRU creation process, the user is allowed to enforce a minimum threshold on land use, soil and slope. For example, a 5 percent threshold on land use would imply that land use categories occupying less than 5 percent area of a subbasin will be ignored and the remaining land use categories will be adjusted to represent 100 percent of the subbasin area. Enforcing a threshold ensures limits the number of HRUs that are produced (which helps control model run times) while representing the significant physical aspects of the watershed accurately. Thresholds of 5, 10 and 5 percent were applied on land use, soil and slope, respectively, during the setup process of the Sandusky River watershed model. This process resulted in 4,714 unique HRUs in the watershed model. Developed areas were exempt from the thresholds on land use. The majority of slopes within the watershed range from 0 - 10 percent. As a result three slope classes were used during the HRU setup process, 0 – 1%, 1 – 3%, and >3%.

Meteorological Data

The meteorological time series input to the SWAT models consisted of precipitation and air temperature. The model simulations do not include water temperature and uses a degree-day method for snowmelt. SWAT estimates Penmann-Monteith potential evapotranspiration using a statistical weather generator that represents the characteristics of local climatology for inputs other than temperature and precipitation. The meteorological time series for the Sandusky River watershed model are drawn from the Summary of the Day (SOD) dataset available from NOAA-NCDC. Data gaps were filled using the MetADAPT tool developed by Tetra Tech, Inc. The Sandusky River watershed SWAT model was setup for a time-frame of 36 years from 1/1/1975 to 12/31/2010. Daily precipitation and air temperature data were obtained from the Summary of the Day meteorological stations. Table 5 lists the stations used in the watershed model, and Figure 6 shows the locations of these stations.

Table 5. Meteorological Stations for the Sandusky River Watershed Model

ID	Name	Latitude	Longitude	Data Used	Elevation (m)
338534	OH UPPER SANDUSKY	40.8333	-83.2833	Temperature Only	260.3
331072	OH BUCYRUS	40.8128	-82.9694	Precipitation and Temperature	291.1
338313	OH TIFFIN	41.1167	-83.1667	Precipitation and Temperature	225.6
332974	OH FREMONT	41.3333	-83.1167	Precipitation and Temperature	182.9
337447	OH SANDUSKY	41.4500	-82.7167	Temperature Only	178.0

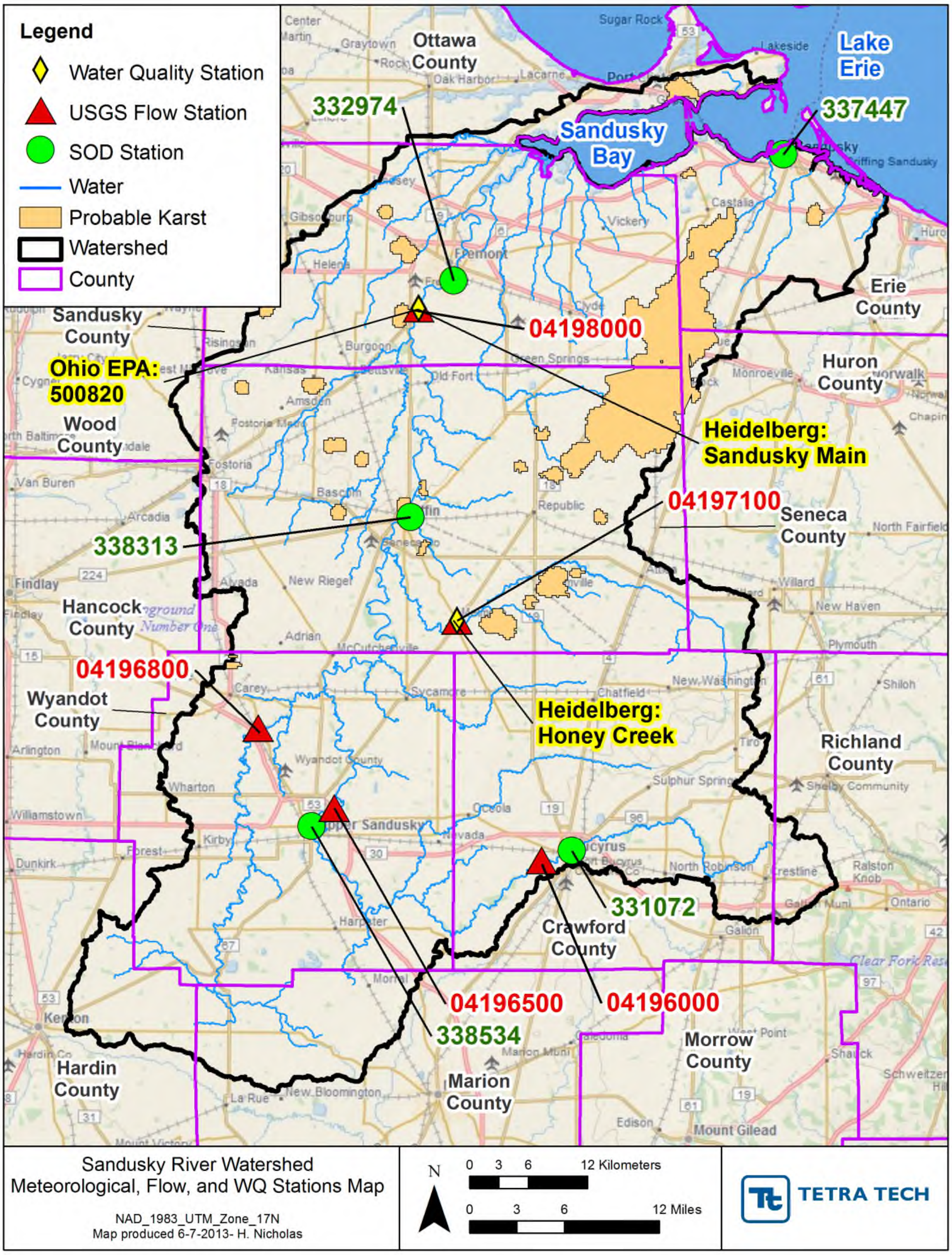

Figure 6. Meteorological Station Locations for the Sandusky River Watershed (Summary of the Day Stations), USGS Flow Stations, Ohio EPA Water Quality Stations, Heidelberg University Water Quality Stations, and probable karst.

Point Sources

Data from the National Pollutant Discharge Elimination System (NPDES) and Surface Water Integrated Monitoring System (SWIMS) provided point source data for use in the model. There was a total of 22 point sources included in the model (Figure 7), ranging from mining and refinery operations to city water and wastewater treatment plants.

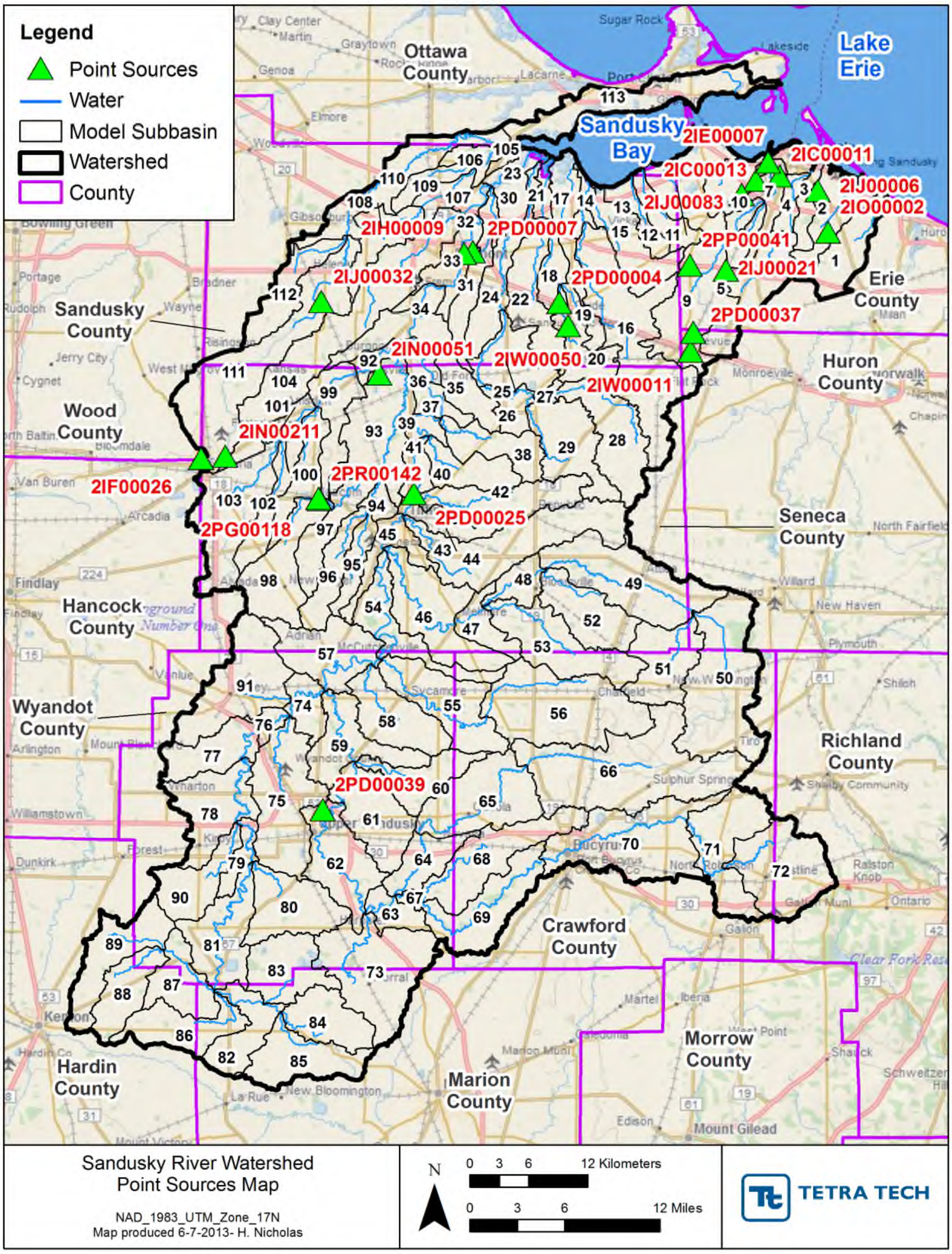

Figure 7. Point Sources in the Sandusky River watershed

Household Sewage Treatment Systems (HSTS)

According to USEPA many people in small communities (those with fewer than 10,000 people) don't have access to public sewers. According to the census bureau (USEPA, 1999) of the 1,276,835 households units in small communities in Ohio, 940,943 (~ 75%) had a septic tank or cesspool.

The SWAT model was configured to have septic areas for all towns/villages with a population of 10,000 or less and not having a WWTP. A GIS layer containing the location of these towns/villages was intersected with the SWAT subbasin layer to determine the population in each subbasin potentially using HSTS. A default septic area of 4 m^2 was assumed for each person. The total septic area in a subbasin was subsequently deducted from the low-density urban landuse (URLD) in the SWAT model.

A septic system can be simulated as an active or failing system. The SWAT model was configured to simulate all septic systems as active at the beginning of simulation. However, it was ensured that once a system failed it did not become active again during the course of the simulation.

Karst Topography

Karst behavior has been approximated in SWAT using seepage losses from ponds and tributary channels (Baffaut and Benson, 2009). A groundwater pollution potential study conducted by the Ohio DNR for the Sandusky, Seneca, and Erie counties suggest that the net recharge in the karst region is generally higher compared to the other areas. Karst behavior in the subbasins of the Sandusky River watershed with field verified sinkholes (SWAT subbasin 9, 16, 28 and 29) was simulated using seepage losses from tributary channels. Seepage losses to the shallow aquifer for these subbasins were simulated by using high values of hydraulic conductivity in tributary channels.

Calibration Data and Locations

USGS (United States Geological Survey) locations were selected for hydrology calibration. However, due to the limited availability of data at these sites, water quality data from Ohio EPA and Heidelberg University sampling efforts were used. Sites used for the Sandusky River watershed model calibration and validation are shown in Table 6 and Figure 6 (above).

Table 6. Calibration and Validation Locations in the Sandusky River Watershed

Agency	Station Name	ID	Hydrology Calibration	Hydrology Validation	Water Quality Calibration	Water Quality Validation
USGS	Sandusky River near Upper Sandusky, OH	04196500	✓	✓		
USGS	Sandusky River near Fremont, OH	04198000	✓	✓		
USGS	Honey Creek at Melmore, OH	04197100	✓	✓		
USGS	Sandusky River near Bucyrus, OH	04196000	✓	✓		
USGS	Tymochtee Creek at Crawford, OH	04196800	✓			
Ohio EPA	Sandusky River at Fremont, OH (co-located with USGS 04198000)	500820			✓	✓
Heidelberg University	Sandusky River near Fremont, OH (co-located with USGS 04198000)	N/A			✓	✓
Heidelberg University	Honey Creek at Melmore, OH (co-located with USGS 04197100)	N/A			✓	✓

The SWAT model was run from 1/1/1975 to 12/31/2010 in order to capture the long-term processes of the watershed. The calibration for both hydrology and water quality was performed on water years 2005-2010, while the validation period for both hydrology and water quality was water years 2000-2004. For hydrology calibration and validation, USGS gage data was compared to the model results. For water quality calibration and validation, data from Ohio EPA and Heidelberg University sampling sites were compared to model results.

SWAT Modeling Results

Hydrology Calibration and Validation

The calibration approach adopted for modeling the Sandusky River watershed involved systematic adjustment of parameters which were generally applied throughout the basin. Calibration efforts were geared toward getting the closest match between simulated and observed flows at all available USGS sites along the main stem and key tributaries. Note that some model parameters used for calibration were taken from a previous SWAT model of the area (Qi and Grunwald, 2005).

Two criteria for goodness of fit were used for calibration: graphical comparison and the relative error method. Graphical comparisons are extremely useful for judging the results of model calibration; time-variable plots of observed versus modeled flow provide insight into the model's representation of storm hydrographs, baseflow recession, time distributions, and other pertinent factors often overlooked by statistical comparisons. The model's accuracy was primarily assessed by interpreting the time-variable plots. The relative error method was used to support the goodness of fit evaluation through a quantitative comparison. A small relative error indicates a better goodness of fit for calibration.

Models are deemed acceptable when they can simulate field data within predetermined statistical measures. Tetra Tech used a hydrologic calibration spreadsheet to determine the acceptability of modeling results on the basis of statistical criteria in Table 7. The spreadsheet computes the relative error for various aspects of the hydrologic system. Statistical targets developed and implemented in previous studies (Lumb et al., 1994) are defined and met for each aspect of the system before accepting the model. The following criteria were used to judge the quality of calibration:

Table 7. Hydrology Calibration Criteria

Statistic	Criteria
Error in total volume	≤ 10%
Error in 50% lowest flows	≤ 10%
Error in 10% highest flows	≤ 15%
Seasonal volume error (summer)	≤ 30%
Seasonal volume error (fall)	≤ 30%
Seasonal volume error (winter)	≤ 30%
Seasonal volume error (spring)	≤ 30%
Error in storm volumes	≤ 20%
Error in summer storm volumes	≤ 50%

In addition, the Nash-Sutcliffe efficiency (NSE) coefficient (Nash and Sutcliffe, 1970) was calculated at each calibration location. The NSE is an indicator of a model's ability to predict the timing and magnitude of observed data. Values may vary from $-\infty$ to 1.0. A value of $E = 1.0$ indicates a perfect fit between modeled and observed data, while values equal to or less than 0 indicate the model's predictions are no better than using the average of observed data. The accuracy of the model increases as the value gets closer to 1.0.

An overall assessment of the success of the calibration can be expressed using calibration levels:

- Level 1: Simulated values fall within the target range (highest degree of calibration).
- Level 2: Simulated values fall within two times the desired range of the calibration target.
- Level 3: Simulated values fall within three times the desired range of the calibration target.

- Level 4: Simulated values are greater than four times the desired range of the calibration target (lowest degree of calibration).

The water balance of the Sandusky River watershed predicted by the SWAT model over the 36-year simulation period is as follows:

Table 8. Water Balance for the Sandusky River Watershed SWAT Model

Constituent	Modeled (mm)
Precipitation	987.10
Snowfall	67.97
Snowmelt	64.88
Sublimation	2.62
Surface runoff	197.06
Lateral soil flow	8.81
Tile flow	111.88
Groundwater recharge (shallow aquifer)	67.45
Groundwater recharge (deep aquifer)	0.00
Re-evaporation (shallow aquifer to soil/plants)	22.47
Deep aquifer recharge	0.00
Total aquifer recharge	90.19
Yield	385.08
Percolation out of soil	90.19
Actual evapotranspiration	540.50
Potential evapotranspiration	972.20
Transmission losses	0.00
Septic inflow	3.81

Hydrologic calibration adjustments focused on the following parameters:

- CN2 (initial SCS runoff curve number for moisture condition II)
- ESCO (soil evaporation compensation factor)
- SFTMP (snowfall temperature)
- SMTMP (snowmelt base temperature)
- SMFMX (maximum melt rate for snow during year)
- SMFMN (minimum melt rate for snow during year)
- SURLAG (surface runoff lag coefficient)
- ALPHA_BF (baseflow alpha factor, days)
- GW_DELAY (groundwater delay time, days)
- CH_N2 (Manning’s “n” value for main channels)
- CH_N1 (Manning’s “n” value for tributary channels)

The results for the hydrology calibration and validation can be found in Appendix A. The calibration and validation process met most of the criteria set out. However, some criteria were exceeded, which generally puts the assessed quality of calibration and validation between levels 1 and 2. Table 9 provides a summary of error statistics for hydrology calibration and validation.

Table 9. Hydrology calibration and validation summary

	Errors (Simulated - Observed)	04196000 Sandusky R nr Bucyrus	04196500 Sandusky R nr Upper Sandusky	04196800 Tymochtee Cr at Crawford	04197100 Honey Cr at Melmore	04198000 Sandusky R nr Fremont
CALIBRATION	Error in total volume (%)	-1.10	-2.01	-3.55	-3.88	-3.43
	Error in 50% lowest flows (%)	-8.17	14.97	11.66	0.88	18.36
	Error in 10% highest flows (%)	-4.92	-6.28	-2.81	-7.59	-5.25
	Seasonal volume error - Summer (%)	7.70	12.20	22.28	86.49	17.99
	Seasonal volume error - Fall (%)	1.86	6.72	14.09	10.75	11.77
	Seasonal volume error - Winter (%)	-11.06	-14.67	-20.87	-21.14	-18.58
	Seasonal volume error - Spring (%)	10.57	10.71	11.84	6.73	8.89
	Error in storm volumes (%)	-8.31	-4.04	-0.96	3.72	-0.06
	Error in summer storm volumes (%)	-2.91	-3.16	38.55	83.39	7.48
	Nash-Sutcliffe Coefficient of Efficiency, E (unit-less)	0.77	0.76	0.62	0.71	0.73
	Baseline adjusted coefficient (Garrick), E' (unit-less)	0.56	0.62	0.50	0.58	0.60
	Monthly NSE (unit-less)	0.89	0.88	0.86	0.85	0.89
	Errors (Simulated - Observed)	**04196000 Sandusky R nr Bucyrus**	**04196500 Sandusky R nr Upper Sandusky**	**04196800 Tymochtee Cr at Crawford**	**04197100 Honey Cr at Melmore**	**04198000 Sandusky R nr Fremont**
VALIDATION	Error in total volume (%)	1.58	-6.85	NO DATA	-0.76	-8.66
	Error in 50% lowest flows (%)	11.70	-0.55		8.68	13.52
	Error in 10% highest flows (%)	-7.97	-11.00		-8.20	-14.31
	Seasonal volume error - Summer (%)	45.67	46.87		66.20	54.95
	Seasonal volume error - Fall (%)	0.71	-0.36		5.28	2.46
	Seasonal volume error - Winter (%)	-3.27	-24.05		-20.80	-28.62
	Seasonal volume error - Spring (%)	-4.14	-5.14		3.48	-7.91
	Error in storm volumes (%)	-9.45	-8.03		8.97	-5.32
	Error in summer storm volumes (%)	29.97	36.86		65.23	53.00
	Nash-Sutcliffe Coefficient of Efficiency, E (unit-less)	0.69	0.78		0.66	0.72
	Baseline adjusted coefficient (Garrick), E' (unit-less)	0.56	0.65		0.53	0.58
	Monthly NSE (unit-less)	0.88	0.87		0.78	0.83

Water Quality Calibration and Validation

SWAT model water quality calibration and validation were conducted for total suspended solids (TSS), total phosphorus (TP) and soluble reactive phosphorus (SRP), total nitrogen (TN), and species of nitrogen, namely, total Kjeldahl nitrogen (TKN) and nitrate+nitrite nitrogen (NO_X) using observed data measured at the above mentioned Ohio EPA and Heidelberg University stations. Water quality calibration and validation focused on the periods of water years 2005–2010 and 2000–2004, respectively. A monthly regression approach was adopted for water quality calibration and validation.

Consistent with recommendations of Moriasi et al. (2007), SWAT water quality calibration focused on replicating monthly loads. For simulation of pollutant loads, Moriasi et al. summarized recent research and recommended performance targets in terms of the Nash-Sutcliffe coefficient (E_{NS}) and the magnitude of the relative average error (*RE*, which Moriasi refers to as PBIAS) (Table 10). Model performance will be deemed acceptable where a performance evaluation of “good” or “very good” is attained.

Table 10. Performance Targets for Water Quality Simulation of Monthly Averages (Moriasi et al., 2007)

Model Component	Very Good	Good	Fair	Poor
Flow and Quality, E_{NS}	> 0.75	> 0.65	> 0.50	≤ 0.50
Flow, *RE*	< 10%	10 - 15%	15 - 25%	> 25%
Sediment, *RE*	< 15%	15 - 30%	30 - 55%	> 55%
Nutrients, *RE*	< 25%	15 - 40%	40 - 70%	> 70%

Moriasi et al. note that these comparisons are most appropriate for evaluation of the quality of water quality simulations when a nearly complete measured time series exists, and, when only scattered grab samples are available, “comparison of frequency distributions and/or percentiles…may be more appropriate than the quantitative statistics guidelines.”

Comparison of model results to monthly loads presents challenges because monthly loads are not observed. Instead, monthly loads must be estimated from scattered concentration grab samples and continuous flow records. As a result, the monthly load calibration is inevitably based on comparing two uncertain numbers.

Flow stratified log-log regression and averaging approaches were used to estimate constituent loads. A flow stratified approach uses different functions to fit constituent load over varying ranges of flow. The change from low rates to high rates of constituent transport occurs at a *breakpoint*, which is defined as the flow where the fitted functions intersect. The model used here fits linear segments on a log-log scale. Identifying the transition phase is done by visually inspecting the plot of constituent load against flow on a log-log scale. The regression approach is adopted when the constituent has a strong correlation with flow. An averaging approach is adopted when there is little or no correlation between the constituent load and flow. The averaging approach consists of estimating loads using observed flow and average observed concentration in a stratum.

The results for the water quality calibration and validation can be found in Appendix B. The calibration and validation are able to achieve a reasonable agreement (Table 11). The load comparisons were supported by detailed examinations of the relationships of flows to loads and concentrations and the distribution of concentration prediction errors versus flow, time, and season, as well as standard time-series plots. The key statistic is the relative percent error, which shows the total error in the prediction of monthly load normalized to the estimated load. Relative average absolute error was also calculated, which is the average of the relative magnitude of errors in individual monthly load predictions. That number is inflated by outlier months in which the simulated and estimated loads differ by large amounts (which could be as easily from uncertainty in the estimated load because of limited data as to problems with the model). The third statistic, the relative median absolute error, is likely more relevant and shows better agreement because it is not influenced by outlier months.

Table 11. Water quality calibration and validation summary

Honey Cr at Melmore (Heidelberg)	Error (Observed - Simulated)	Calibration						Validation					
		TSS	TKN	NOx	TN	SRP	TP	TSS	TKN	NOx	TN	SRP	TP
	Average absolute error	46.9%	48.4%	47.0%	37.7%	54.7%	53.3%	55.3%	65.4%	59.7%	52.6%	63.4%	66.1%
	Median absolute error	9.2%	22.5%	17.4%	17.0%	24.7%	23.8%	22.7%	34.2%	22.5%	29.1%	38.7%	38.0%
	Regression error	21.8%	29.0%	21.5%	14.2%	14.4%	20.1%	15.8%	30.2%	-0.3%	-2.7%	9.6%	17.4%
	NSE	0.633	0.618	0.590	0.757	0.624	0.642	0.753	0.566	0.301	0.498	0.606	0.623
	NSE'	0.597	0.518	0.505	0.598	0.476	0.517	0.489	0.317	0.324	0.402	0.356	0.360

Sandusky R at Fremont (Heidelberg)	Error (Observed - Simulated)	Calibration						Validation					
		TSS	TKN	NOx	TN	SRP	TP	TSS	TKN	NOx	TN	SRP	TP
	Average absolute error	30.6%	43.5%	49.0%	36.8%	39.5%	41.9%	46.7%	48.0%	47.0%	40.8%	48.6%	50.2%
	Median absolute error	8.7%	24.1%	19.5%	20.7%	20.8%	25.0%	13.5%	23.2%	27.2%	27.0%	25.5%	21.5%
	Regression error	7.8%	10.6%	24.2%	11.1%	1.5%	9.1%	21.4%	17.1%	14.9%	7.3%	15.5%	16.0%
	NSE	0.867	0.709	0.547	0.772	0.805	0.758	0.770	0.675	0.521	0.684	0.685	0.712
	NSE'	0.739	0.554	0.474	0.596	0.617	0.614	0.566	0.476	0.447	0.511	0.497	0.503

Sandusky R at Fremont (USGS)	Error (Observed - Simulated)	Calibration			Validation		
		TSS	TN	TP	TSS	TN	TP
	Average absolute error	47.0%	31.5%	53.2%	49.1%	32.8%	42.2%
	Median absolute error	9.3%	19.8%	32.6%	19.1%	23.0%	40.5%
	Regression error	36.4%	6.2%	-22.6%	38.3%	11.5%	-7.3%
	NSE	0.705	0.807	0.706	0.628	0.786	0.809
	NSE'	0.620	0.638	0.505	0.517	0.595	0.538

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APPENDICES

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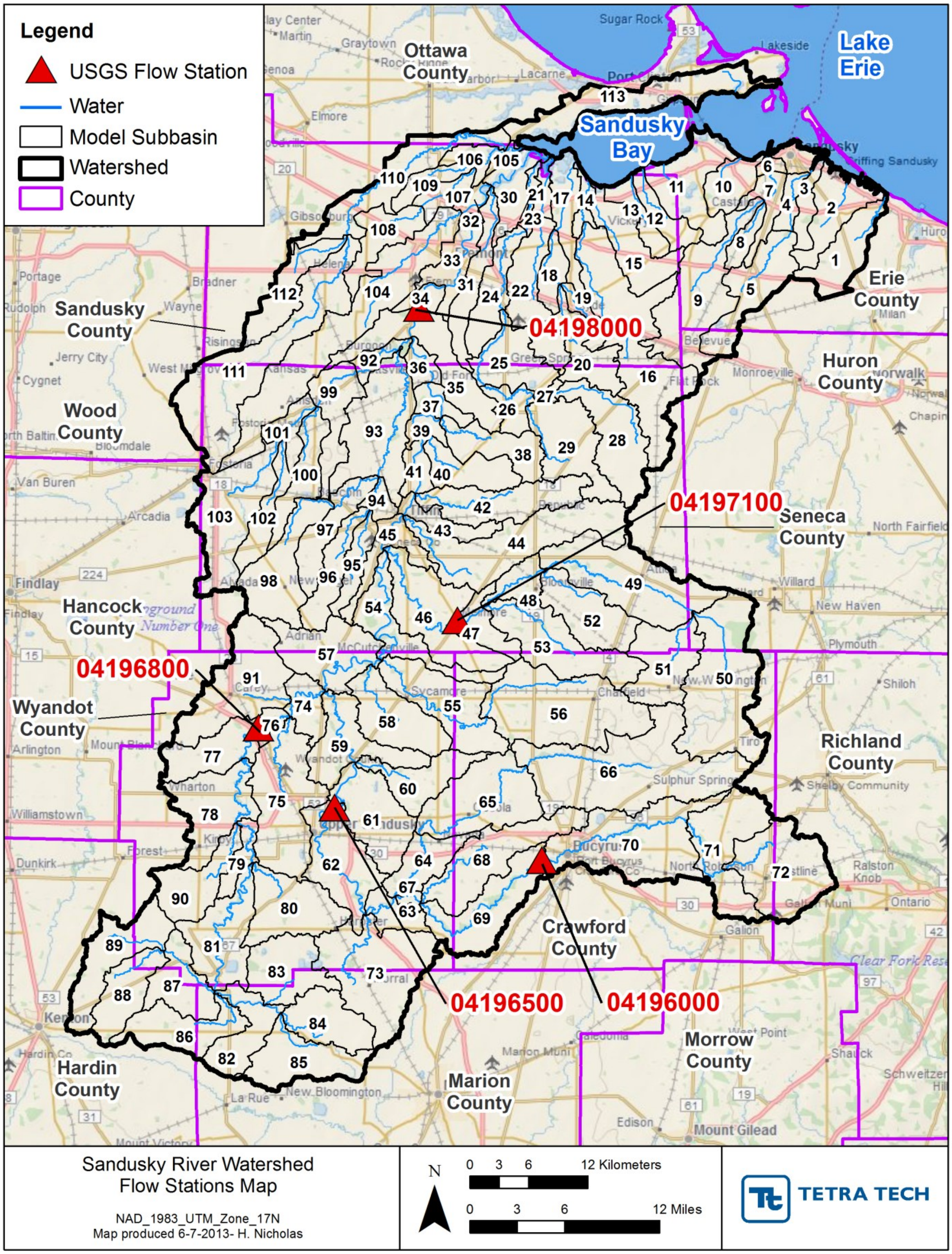
Figures

Tables

Appendix A - Hydrology Calibration/Validation



USGS 04196000 Sandusky River near Bucyrus OH - Calibration

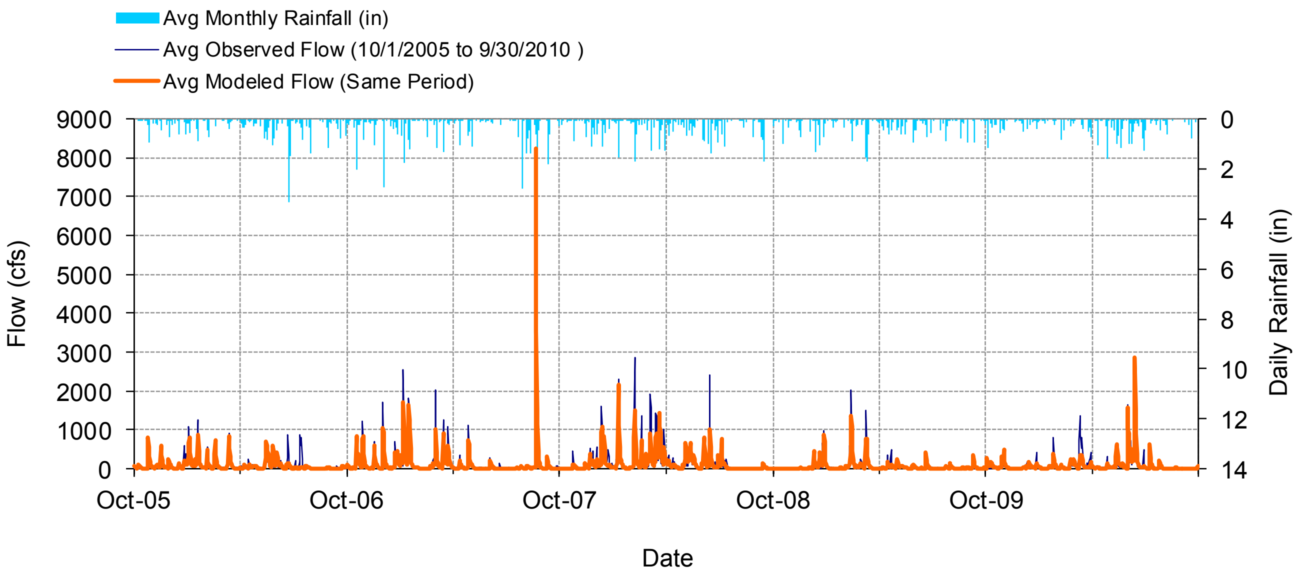


Figure A-1. Mean daily flow at USGS 04196000 Sandusky River near Bucyrus OH

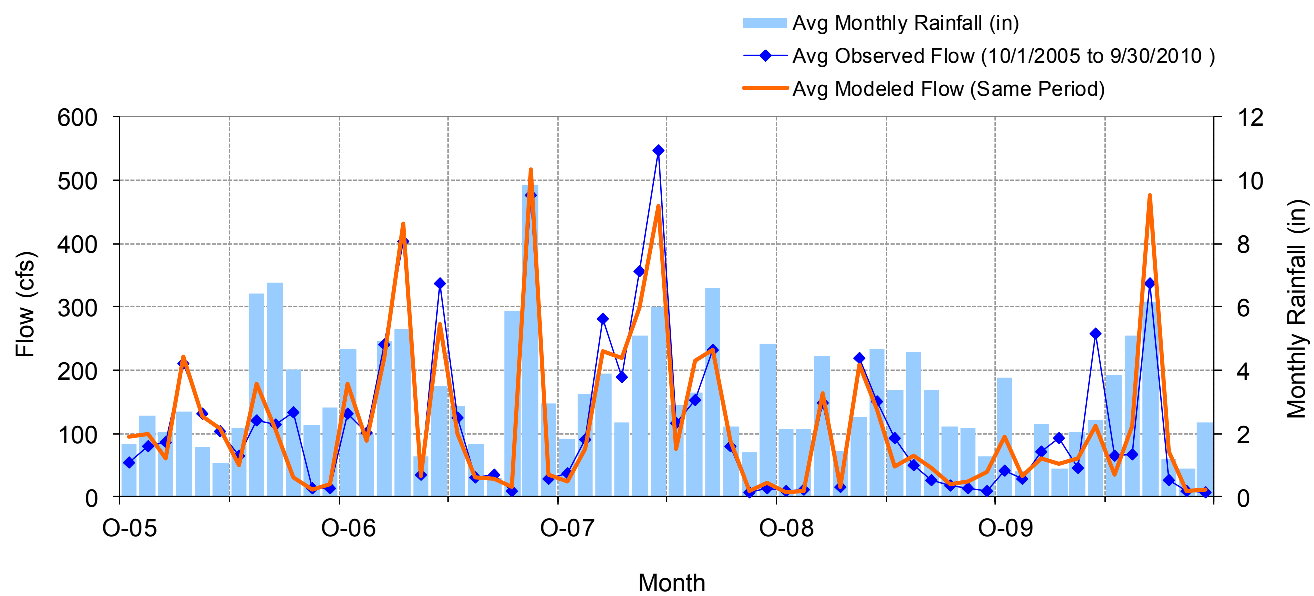


Figure A-2. Mean monthly flow at USGS 04196000 Sandusky River near Bucyrus OH

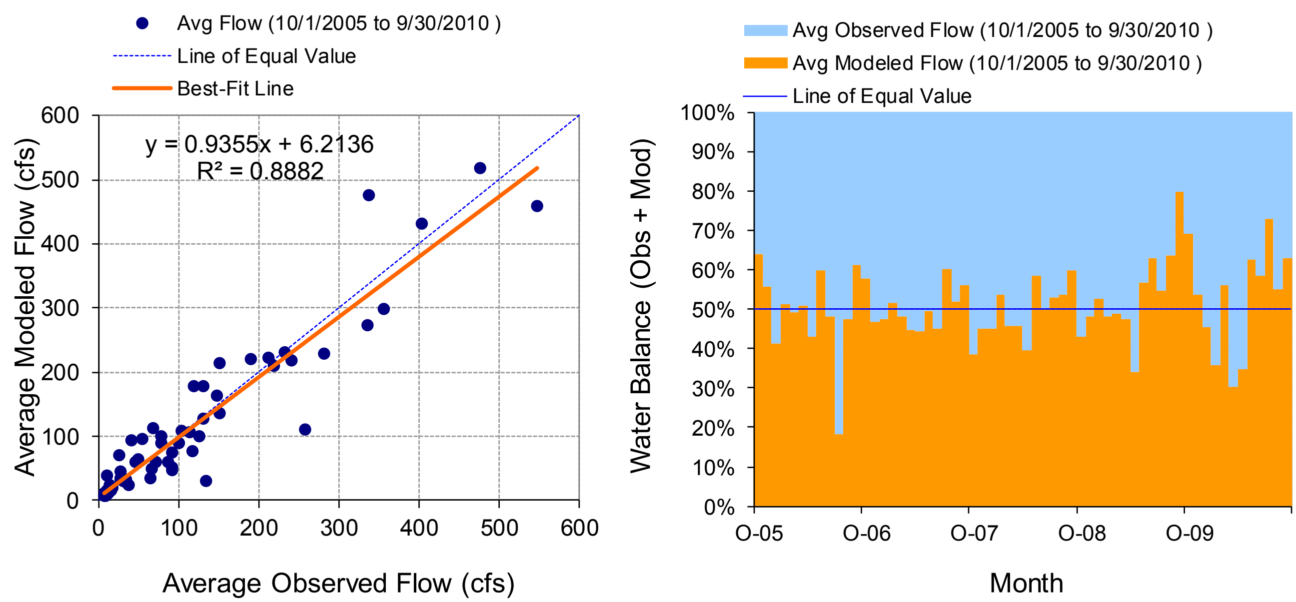


Figure A-3. Monthly flow regression and temporal variation at USGS 04196000 Sandusky River near Bucyrus OH

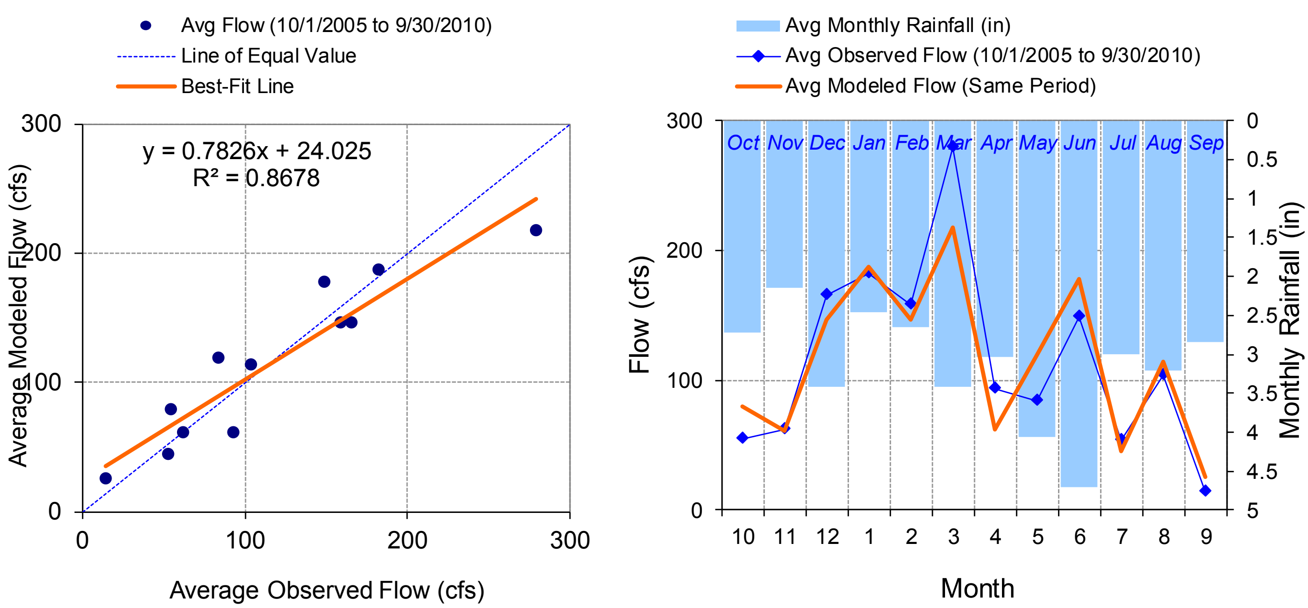


Figure A-4. Seasonal regression and temporal aggregate at USGS 04196000 Sandusky River near Bucyrus OH

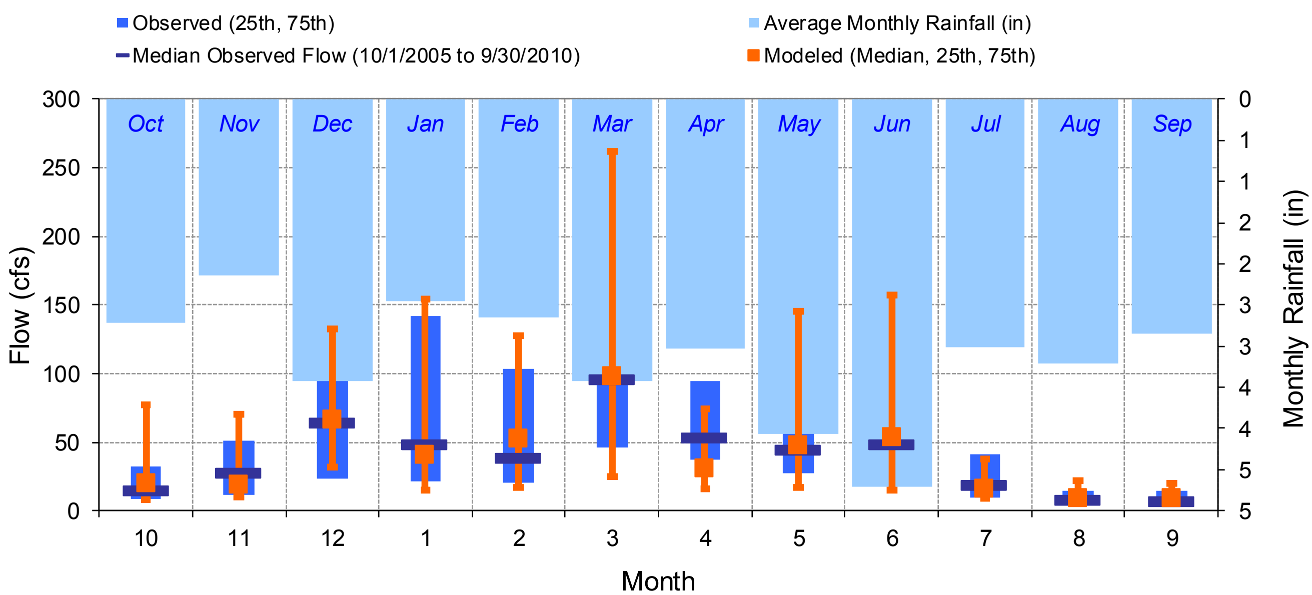


Figure A-5. Seasonal medians and ranges at USGS 04196000 Sandusky River near Bucyrus OH

Table A-1. Seasonal summary at USGS 04196000 Sandusky River near Bucyrus OH

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	54.70	15.00	8.55	32.00	79.82	20.06	7.78	77.60
Nov	61.90	28.00	12.00	50.75	61.13	18.95	9.85	70.67
Dec	165.55	64.00	23.50	164.00	146.39	66.25	31.82	132.69
Jan	182.70	49.00	21.00	142.00	187.83	40.82	14.57	154.17
Feb	158.64	39.00	20.00	103.00	146.50	53.01	16.66	127.17
Mar	279.17	96.00	46.00	281.50	218.01	97.89	25.33	261.61
Apr	93.14	53.50	37.25	94.25	61.75	30.61	15.74	74.07
May	83.64	45.00	27.00	82.00	119.79	47.46	17.28	145.25
Jun	148.98	49.00	21.00	134.25	177.73	53.13	15.13	156.87
Jul	53.16	19.00	9.75	41.00	45.01	16.04	9.31	37.22
Aug	103.66	7.80	5.50	14.50	114.11	9.09	6.79	21.49
Sep	14.33	7.55	4.10	14.75	25.53	9.22	7.00	19.43

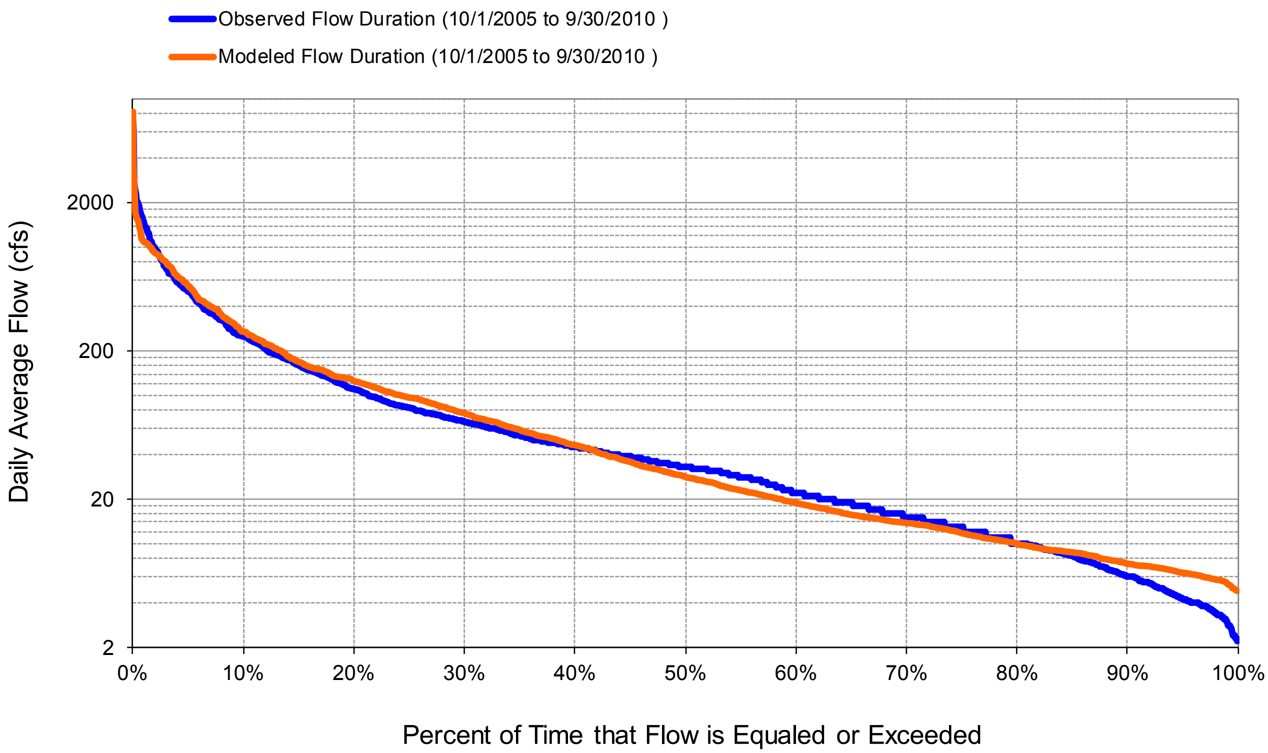


Figure A-6. Flow exceedence at USGS 04196000 Sandusky River near Bucyrus OH

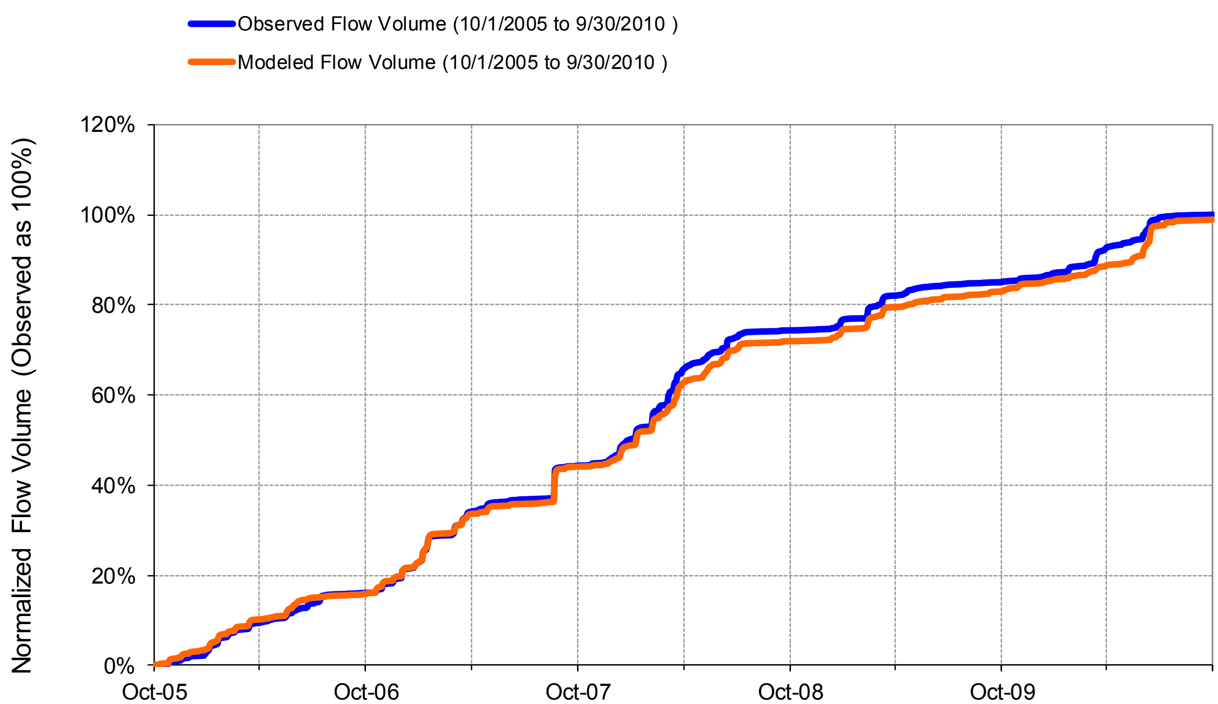


Figure A-7. Flow accumulation at USGS 04196000 Sandusky River near Bucyrus OH

Table A-2. Summary statistics at USGS 04196000 Sandusky River near Bucyrus OH

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 70		USGS 04196000 Sandusky River near Bucyrus OH	
5-Year Analysis Period: 10/1/2005 - 9/30/2010 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 04100011 Latitude: 40°48'13" Longitude: -83°00'21" Drainage Area (sq-mi): 88.8	
Total Simulated In-stream Flow:	**17.66**	Total Observed In-stream Flow:	**17.85**
Total of simulated highest 10% flows:	**10.94**	Total of Observed highest 10% flows:	**11.50**
Total of Simulated lowest 50% flows:	**1.01**	Total of Observed Lowest 50% flows:	**1.10**
Simulated Summer Flow Volume (months 7-9):	**2.39**	Observed Summer Flow Volume (7-9):	**2.22**
Simulated Fall Flow Volume (months 10-12):	**3.71**	Observed Fall Flow Volume (10-12):	**3.64**
Simulated Winter Flow Volume (months 1-3):	**7.00**	Observed Winter Flow Volume (1-3):	**7.87**
Simulated Spring Flow Volume (months 4-6):	**4.56**	Observed Spring Flow Volume (4-6):	**4.13**
Total Simulated Storm Volume:	**10.36**	Total Observed Storm Volume:	**11.30**
Simulated Summer Storm Volume (7-9):	**1.67**	Observed Summer Storm Volume (7-9):	**1.72**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	-1.10	10		
Error in 50% lowest flows:	-8.17	10		
Error in 10% highest flows:	-4.92	15		
Seasonal volume error - Summer:	7.70	30		
Seasonal volume error - Fall:	1.86	>> 30		Clear
Seasonal volume error - Winter:	-11.06	30		
Seasonal volume error - Spring:	10.57	30		
Error in storm volumes:	-8.31	20		
Error in summer storm volumes:	-2.91	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.770	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.558	as E or E' approaches 1.0		
Monthly NSE	0.886			

USGS 04196000 Sandusky River near Bucyrus OH - Validation

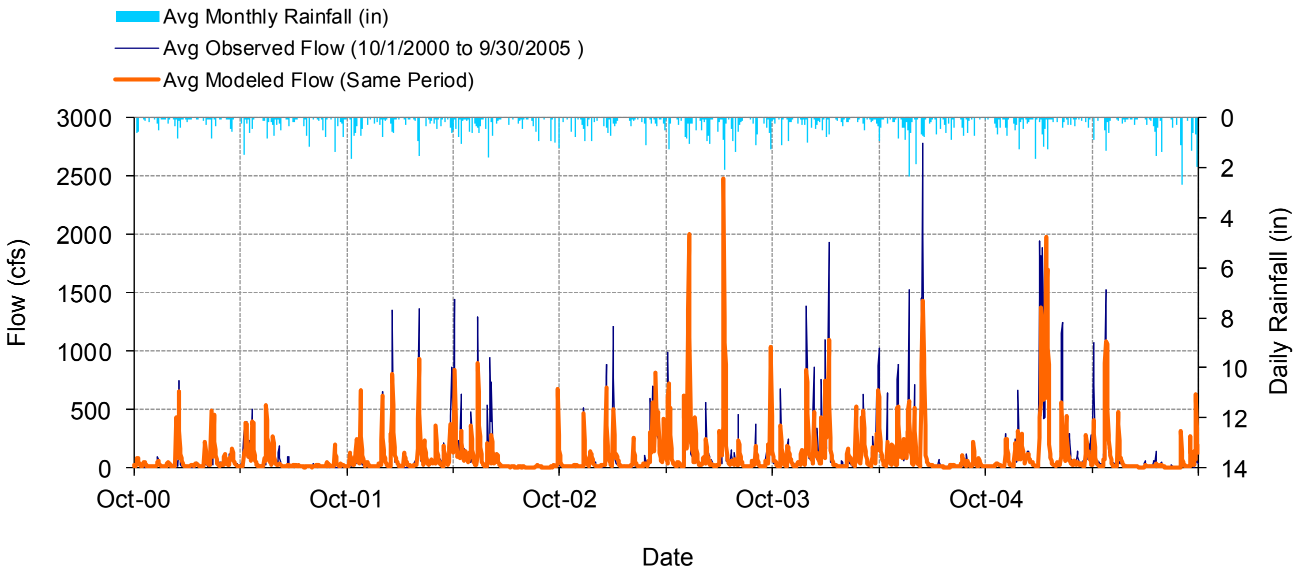


Figure A-8. Mean daily flow at USGS 04196000 Sandusky River near Bucyrus OH

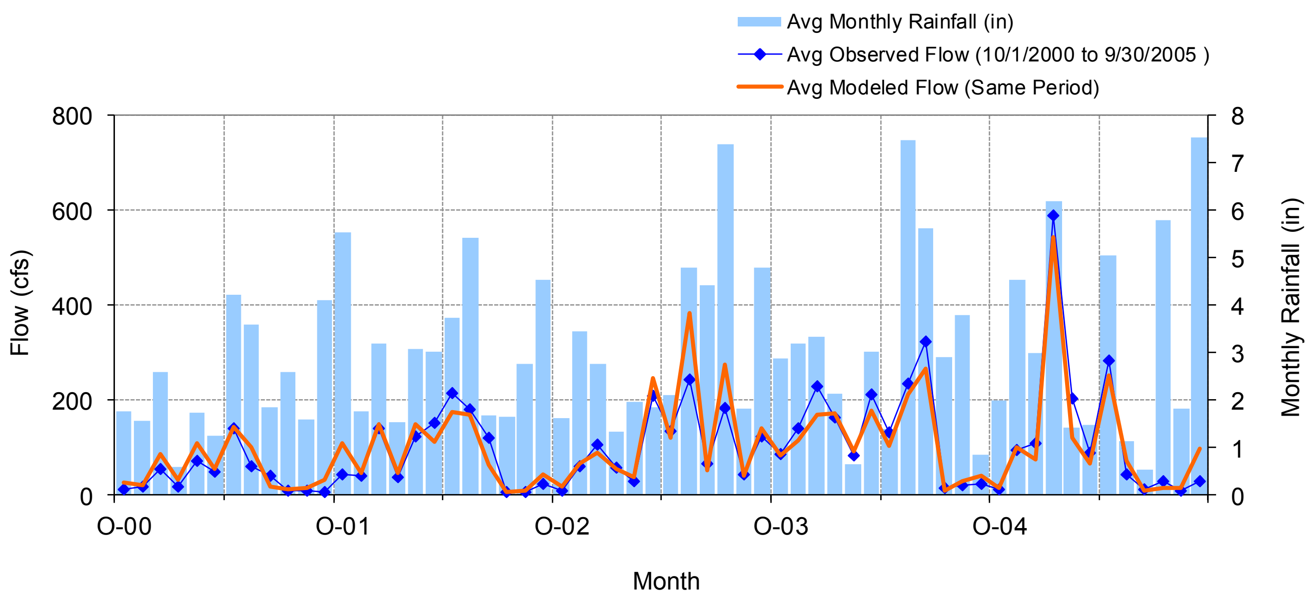


Figure A-9. Mean monthly flow at USGS 04196000 Sandusky River near Bucyrus OH

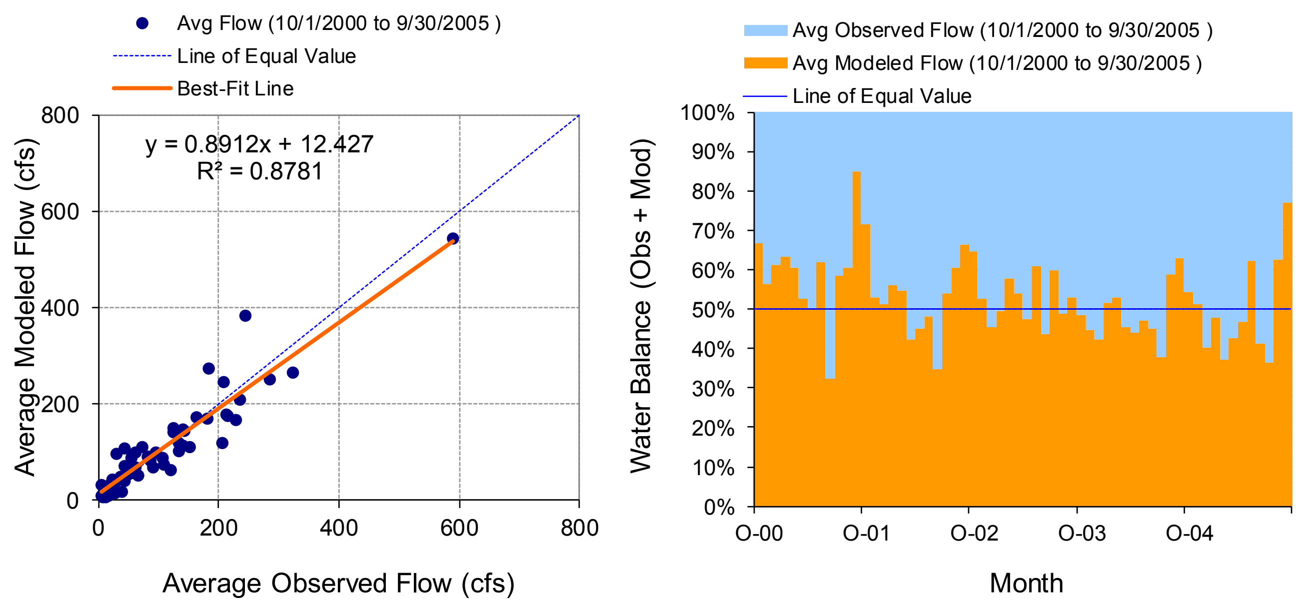


Figure A-10. Monthly flow regression and temporal variation at USGS 04196000 Sandusky River near Bucyrus OH

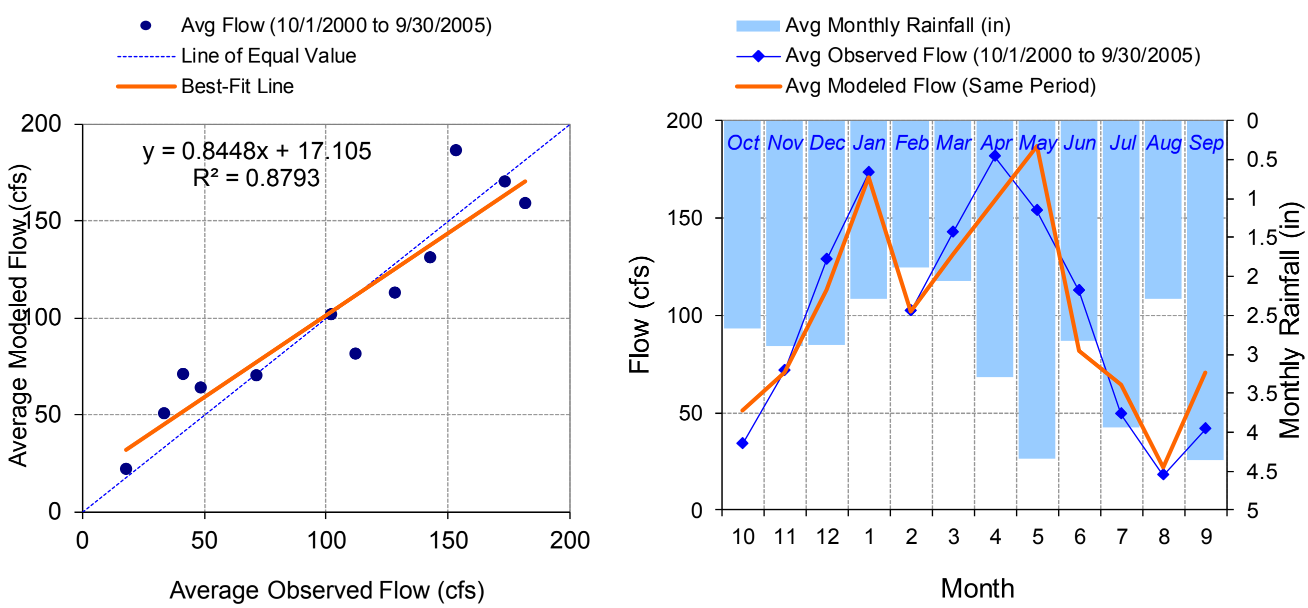


Figure A-11. Seasonal regression and temporal aggregate at USGS 04196000 Sandusky River near Bucyrus OH

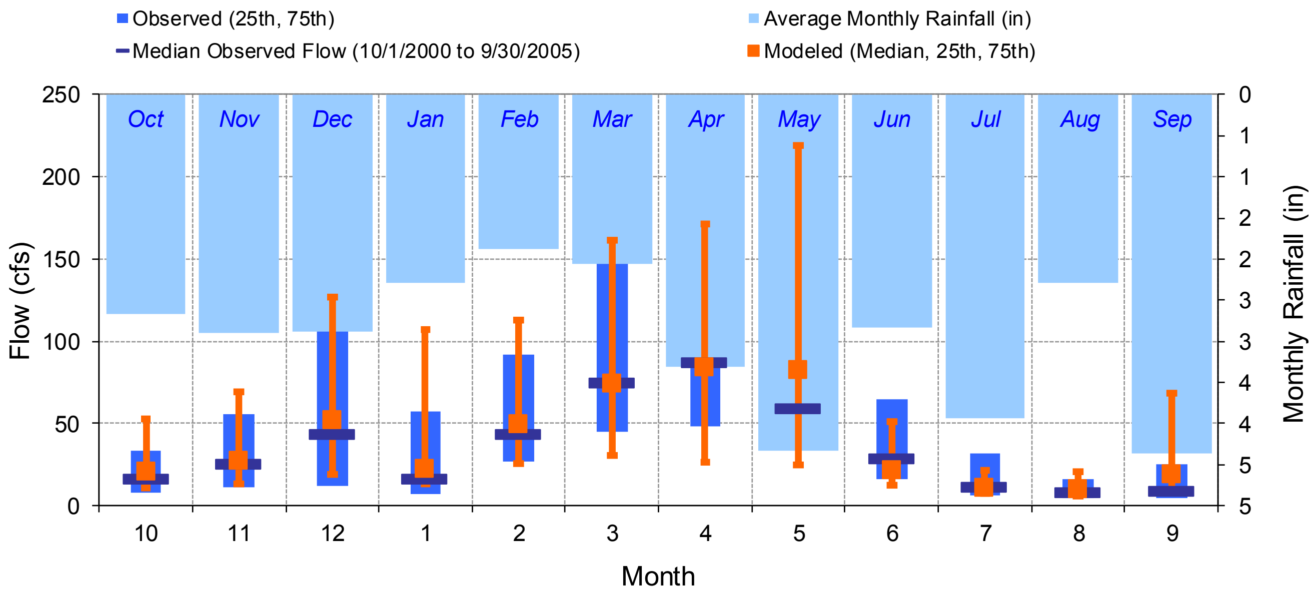


Figure A-12. Seasonal medians and ranges at USGS 04196000 Sandusky River near Bucyrus OH

Table A-3. Seasonal summary at USGS 04196000 Sandusky River near Bucyrus OH

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	33.63	17.00	7.80	33.50	50.97	20.87	11.08	53.01
Nov	71.37	25.50	11.00	55.50	70.55	27.32	13.48	69.15
Dec	128.28	44.00	12.00	107.00	113.36	52.09	18.76	126.50
Jan	173.14	17.00	7.40	57.00	170.68	22.65	13.42	106.83
Feb	102.20	44.00	27.00	92.00	102.28	49.23	25.29	112.76
Mar	142.54	75.00	45.00	153.00	131.57	73.95	30.45	161.48
Apr	181.77	87.00	48.25	174.00	159.15	83.73	26.88	171.35
May	153.34	59.00	38.00	120.00	186.92	82.81	25.06	218.90
Jun	112.26	29.00	16.00	64.75	81.44	21.79	12.49	51.17
Jul	48.80	12.00	6.50	31.50	64.29	11.19	7.62	21.61
Aug	17.83	8.20	4.70	16.50	22.15	10.09	6.16	20.89
Sep	41.18	9.10	4.73	25.00	70.96	19.11	9.54	68.78

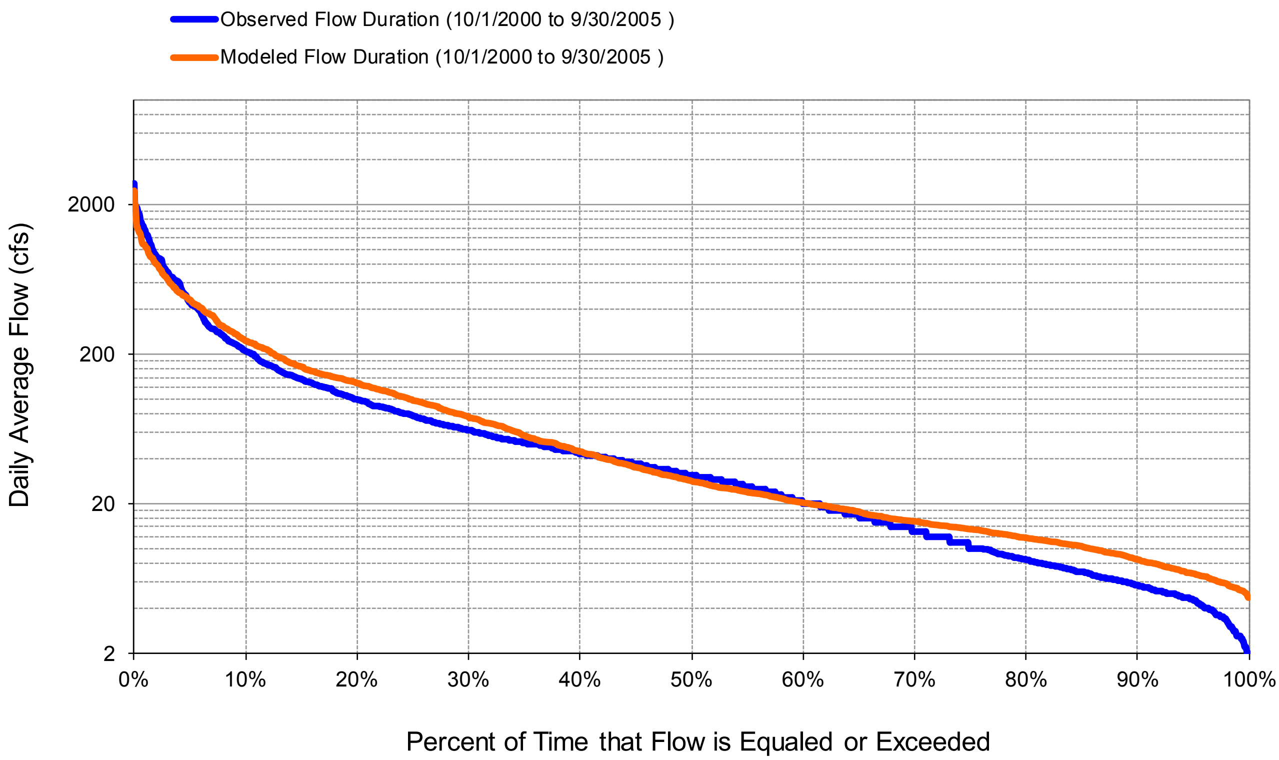


Figure A-13. Flow exceedence at USGS 04196000 Sandusky River near Bucyrus OH

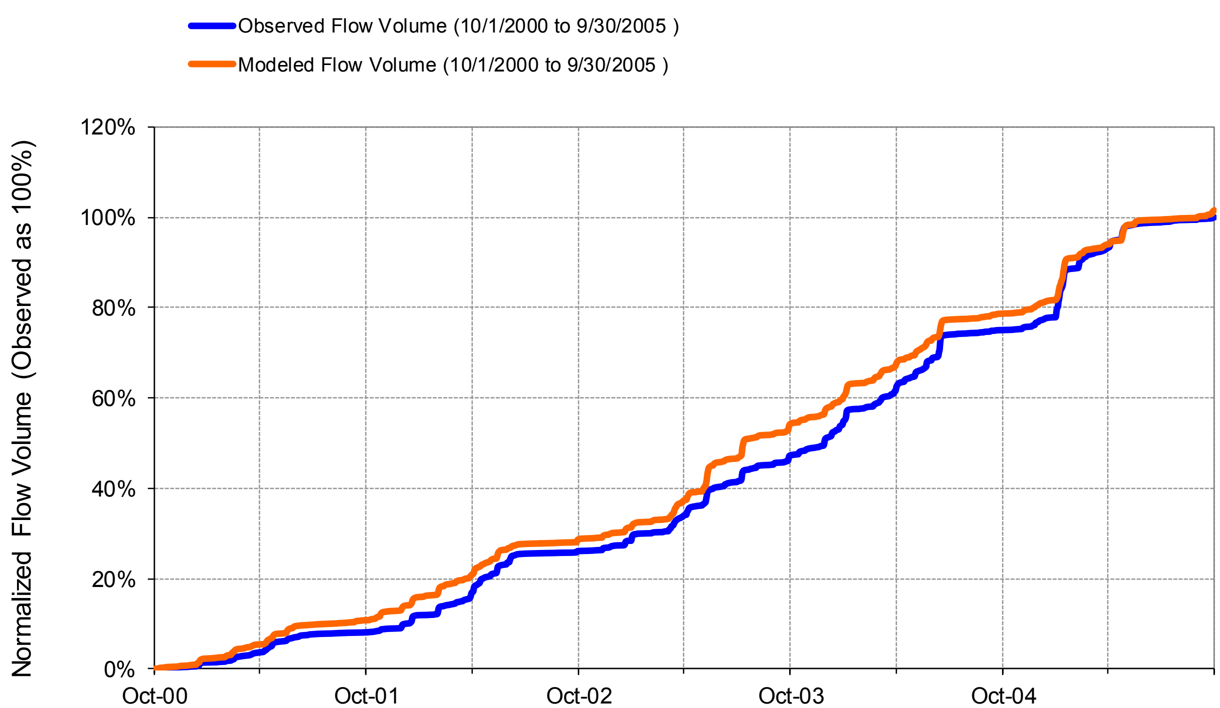


Figure A-14. Flow accumulation at USGS 04196000 Sandusky River near Bucyrus OH

Table A-4. Summary statistics at USGS 04196000 Sandusky River near Bucyrus OH

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 70 5-Year Analysis Period: 10/1/2000 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		USGS 04196000 Sandusky River near Bucyrus OH Hydrologic Unit Code: 04100011 Latitude: 40°48'13" Longitude: -83°00'21" Drainage Area (sq-mi): 88.8	
Total Simulated In-stream Flow:	**15.62**	Total Observed In-stream Flow:	**15.37**
Total of simulated highest 10% flows:	**8.91**	Total of Observed highest 10% flows:	**9.68**
Total of Simulated lowest 50% flows:	**1.11**	Total of Observed Lowest 50% flows:	**0.99**
Simulated Summer Flow Volume (months 7-9):	**2.01**	Observed Summer Flow Volume (7-9):	**1.38**
Simulated Fall Flow Volume (months 10-12):	**3.02**	Observed Fall Flow Volume (10-12):	**3.00**
Simulated Winter Flow Volume (months 1-3):	**5.13**	Observed Winter Flow Volume (1-3):	**5.31**
Simulated Spring Flow Volume (months 4-6):	**5.45**	Observed Spring Flow Volume (4-6):	**5.69**
Total Simulated Storm Volume:	**8.08**	Total Observed Storm Volume:	**8.93**
Simulated Summer Storm Volume (7-9):	**1.15**	Observed Summer Storm Volume (7-9):	**0.89**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*
Error in total volume:	1.58	10
Error in 50% lowest flows:	11.70	10
Error in 10% highest flows:	-7.97	15
Seasonal volume error - Summer:	45.67	30
Seasonal volume error - Fall:	0.71	30
Seasonal volume error - Winter:	-3.27	30
Seasonal volume error - Spring:	-4.14	30
Error in storm volumes:	-9.45	20
Error in summer storm volumes:	29.97	50

Nash-Sutcliffe Coefficient of Efficiency, E:	0.694	Model accuracy increases
Baseline adjusted coefficient (Garrick), E':	0.557	as E or E' approaches 1.0
Monthly NSE	0.878	

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USGS 04196500 Sandusky River near Upper Sandusky OH - Calibration

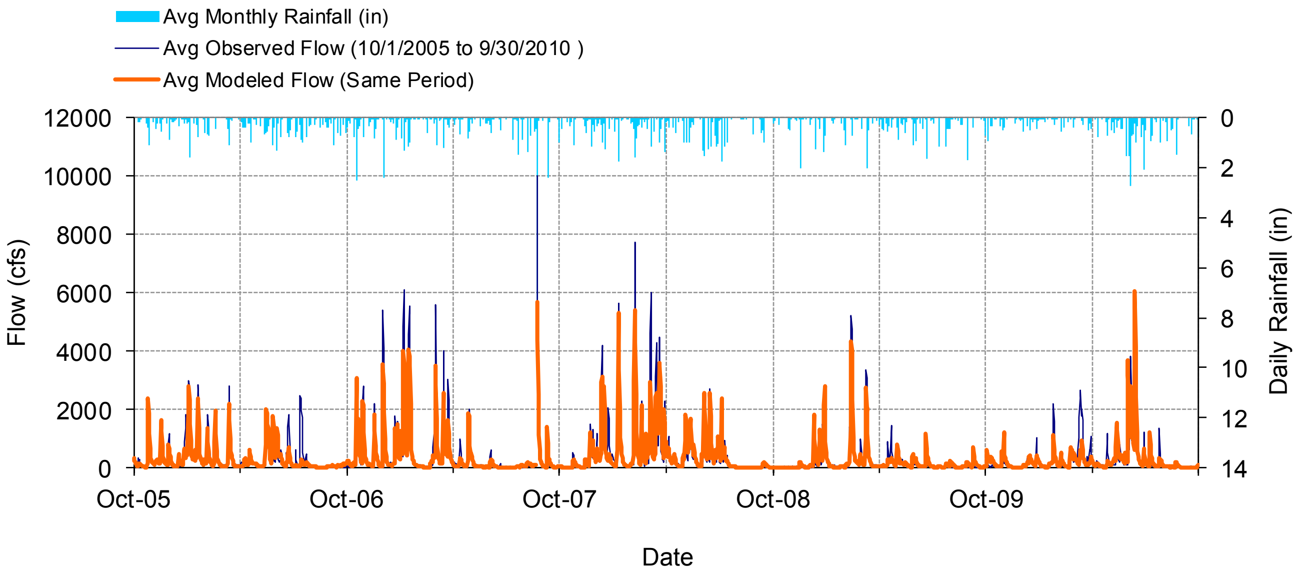


Figure A-15. Mean daily flow at USGS 04196500 Sandusky River near Upper Sandusky OH

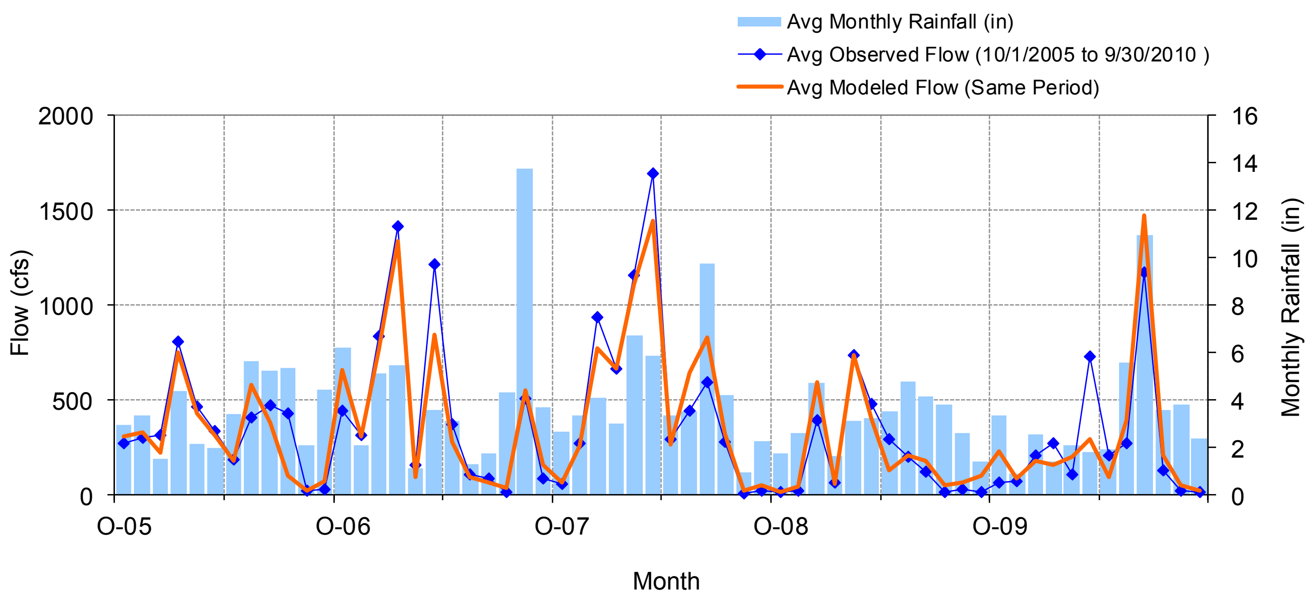


Figure A-16. Mean monthly flow at USGS 04196500 Sandusky River near Upper Sandusky OH

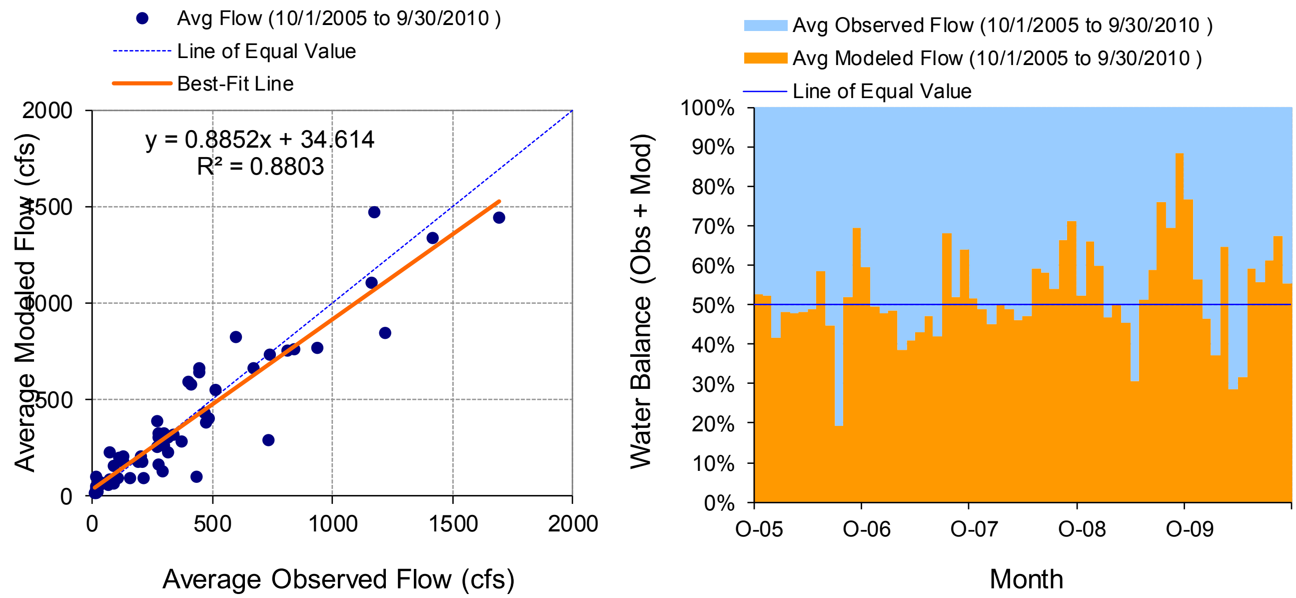


Figure A-17. Monthly flow regression and temporal variation at USGS 04196500 Sandusky River near Upper Sandusky OH

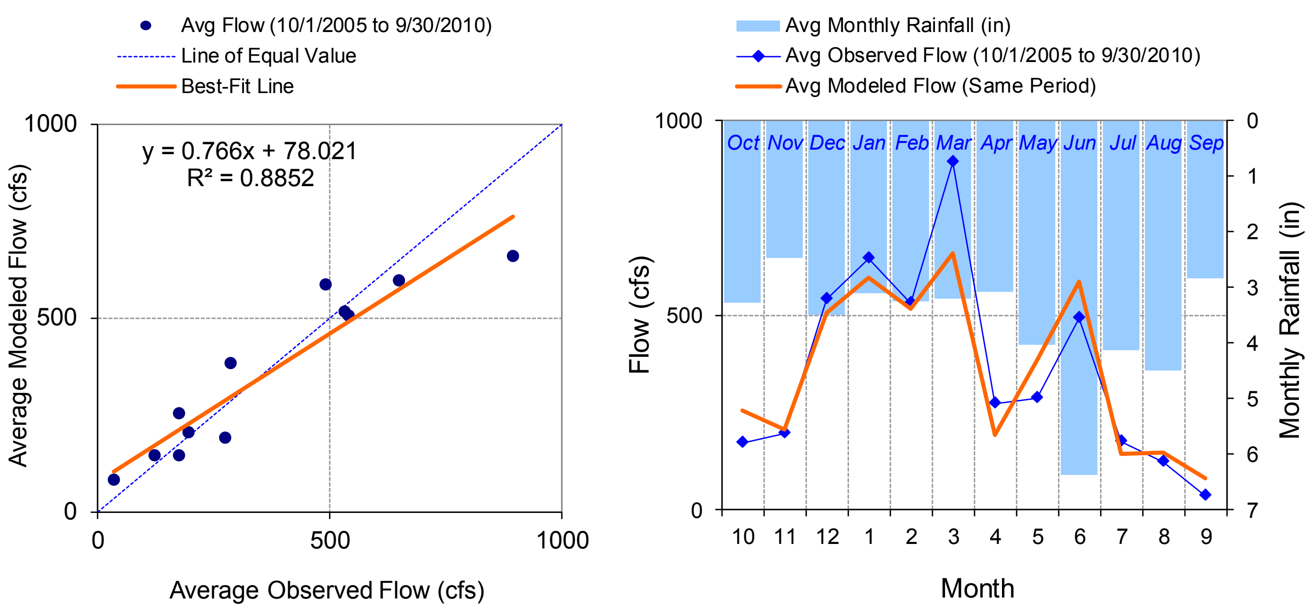


Figure A-18. Seasonal regression and temporal aggregate at USGS 04196500 Sandusky River near Upper Sandusky OH

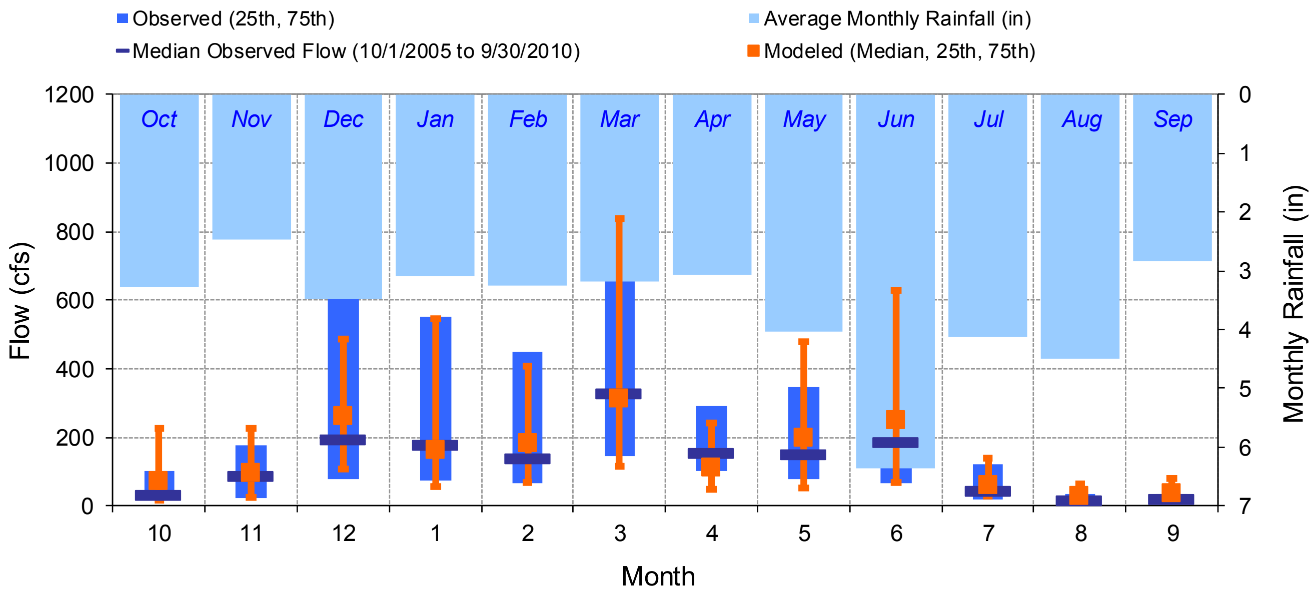


Figure A-19. Seasonal medians and ranges at USGS 04196500 Sandusky River near Upper Sandusky OH

Table A-5. Seasonal summary at USGS 04196500 Sandusky River near Upper Sandusky OH

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	173.09	32.00	21.00	101.50	255.68	71.02	18.25	226.16
Nov	195.82	87.50	24.25	177.00	206.40	93.81	22.55	227.36
Dec	539.72	196.00	79.00	627.00	507.55	259.77	109.09	484.69
Jan	647.46	180.00	73.00	552.00	596.03	160.89	54.17	545.96
Feb	530.85	140.00	64.00	450.00	518.05	181.87	67.42	406.12
Mar	893.66	329.00	143.50	1035.00	659.74	311.33	113.47	837.66
Apr	273.25	154.00	102.00	291.75	191.26	112.46	49.37	240.69
May	286.74	149.00	76.50	347.00	385.24	197.41	53.66	479.57
Jun	491.83	185.00	66.25	527.25	585.66	250.98	68.61	629.84
Jul	175.02	44.00	18.00	120.50	145.07	60.99	29.92	137.16
Aug	121.58	17.00	10.00	34.00	146.24	29.31	19.99	65.19
Sep	35.05	19.00	8.03	35.00	82.33	37.20	19.37	78.80

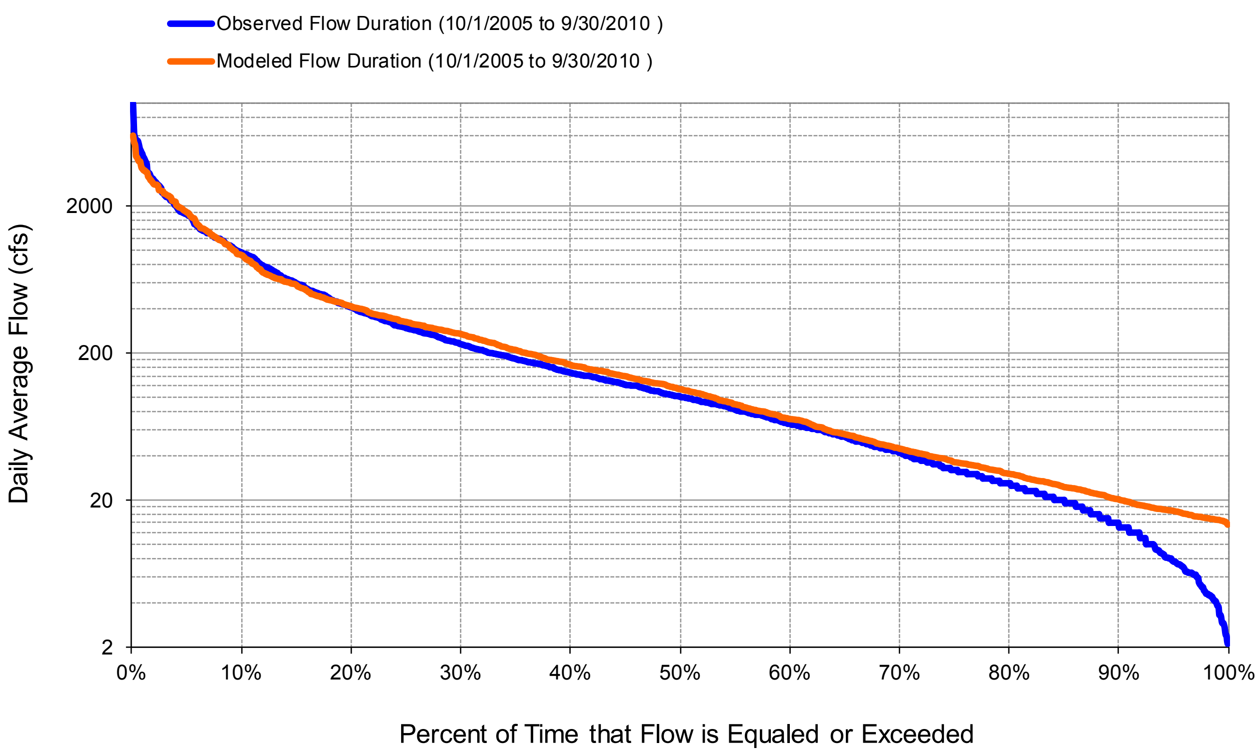


Figure A-20. Flow exceedence at USGS 04196500 Sandusky River near Upper Sandusky OH

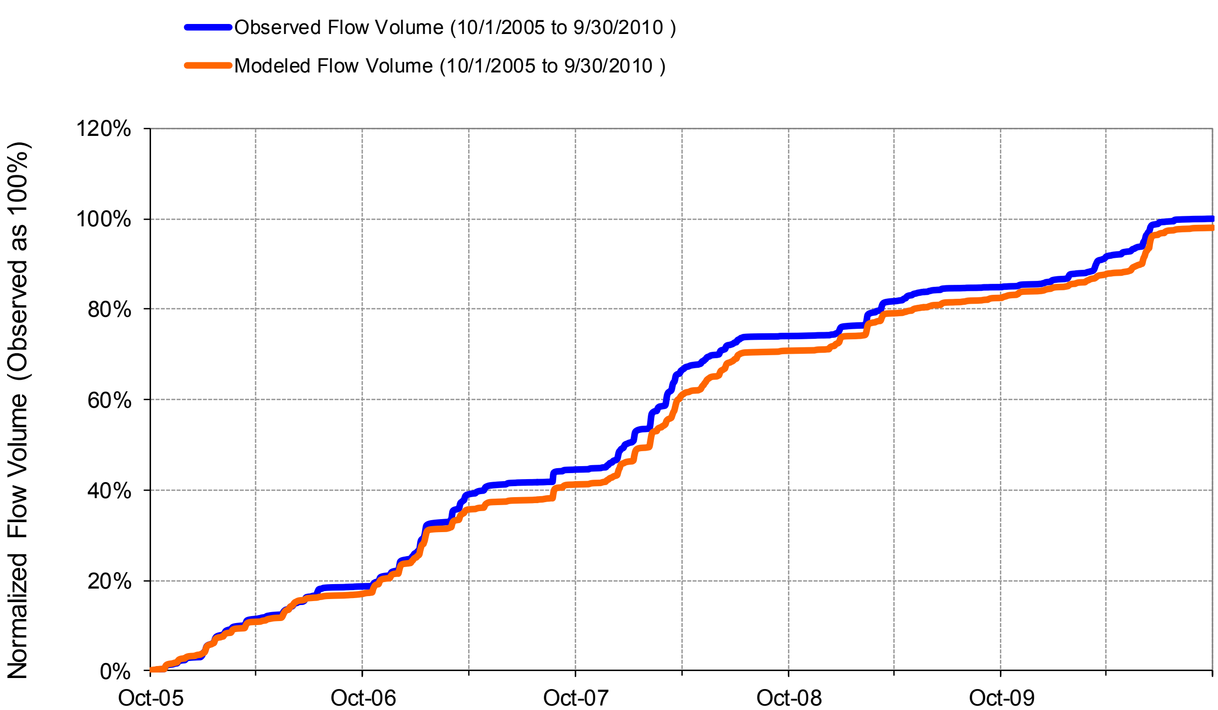


Figure A-21. Flow accumulation at USGS 04196500 Sandusky River near Upper Sandusky OH

Table A-6. Summary statistics at USGS 04196500 Sandusky River near Upper Sandusky OH

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 62 5-Year Analysis Period: 10/1/2005 - 9/30/2010 Flow volumes are (inches/year) for upstream drainage area		Sandusky River near Upper Sandusky OH Manually Entered Data Drainage Area (sq-mi): 298	
Total Simulated In-stream Flow:	**16.24**	Total Observed In-stream Flow:	**16.57**
Total of simulated highest 10% flows:	**9.42**	Total of Observed highest 10% flows:	**10.05**
Total of Simulated lowest 50% flows:	**1.03**	Total of Observed Lowest 50% flows:	**0.90**
Simulated Summer Flow Volume (months 7-9):	**1.43**	Observed Summer Flow Volume (7-9):	**1.27**
Simulated Fall Flow Volume (months 10-12):	**3.73**	Observed Fall Flow Volume (10-12):	**3.49**
Simulated Winter Flow Volume (months 1-3):	**6.68**	Observed Winter Flow Volume (1-3):	**7.83**
Simulated Spring Flow Volume (months 4-6):	**4.40**	Observed Spring Flow Volume (4-6):	**3.97**
Total Simulated Storm Volume:	**11.33**	Total Observed Storm Volume:	**11.80**
Simulated Summer Storm Volume (7-9):	**0.95**	Observed Summer Storm Volume (7-9):	**0.98**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*
Error in total volume:	-2.01	10
Error in 50% lowest flows:	14.97	10
Error in 10% highest flows:	-6.28	15
Seasonal volume error - Summer:	12.20	30
Seasonal volume error - Fall:	6.72	30
Seasonal volume error - Winter:	-14.67	30
Seasonal volume error - Spring:	10.71	30
Error in storm volumes:	-4.04	20
Error in summer storm volumes:	-3.16	50
Nash-Sutcliffe Coefficient of Efficiency, E:	0.760	Model accuracy increases
Baseline adjusted coefficient (Garrick), E':	0.621	as E or E' approaches 1.0
Monthly NSE	0.880	

>> Clear

USGS 04196500 Sandusky River near Upper Sandusky OH - Validation

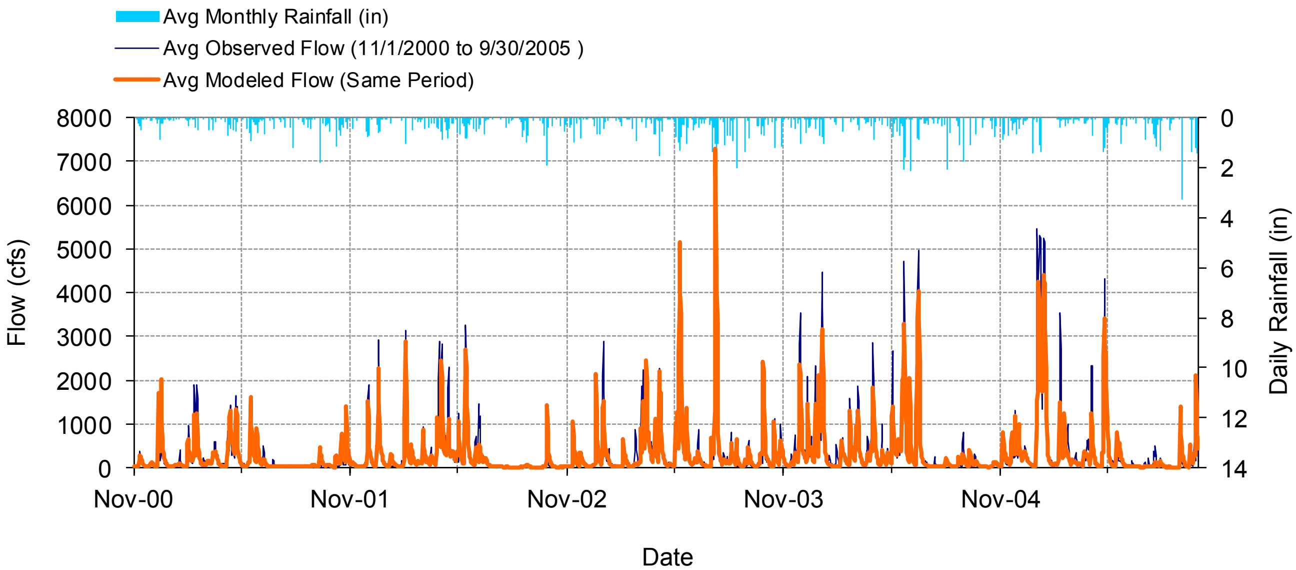


Figure A-22. Mean daily flow at USGS 04196500 Sandusky River near Upper Sandusky OH

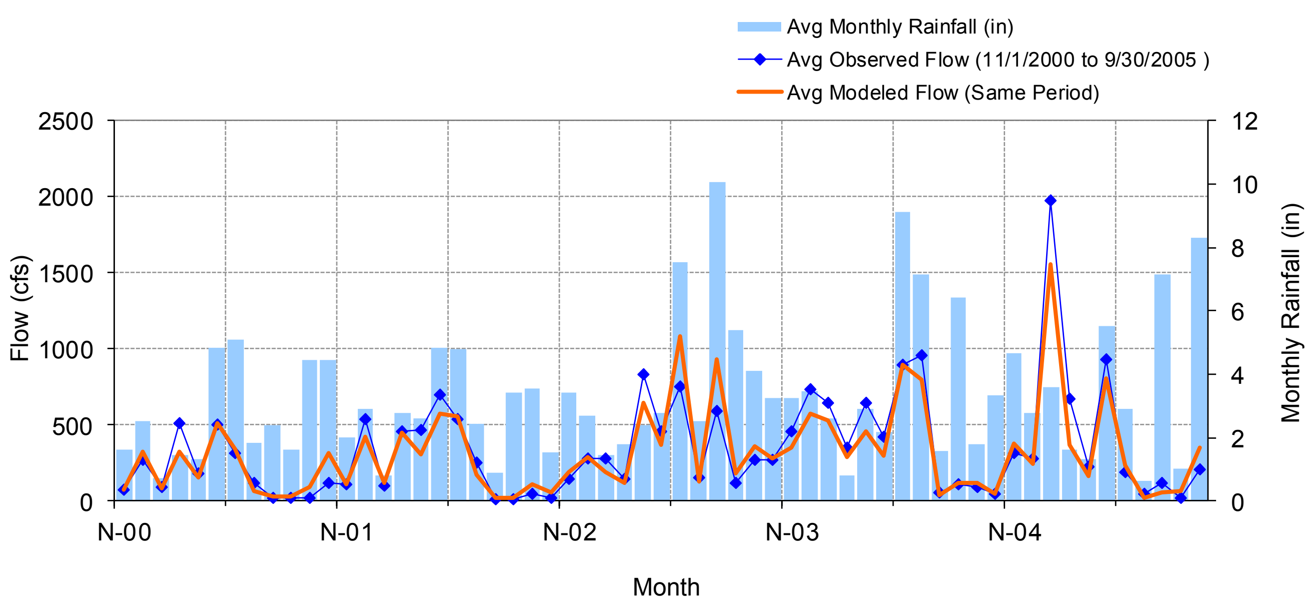


Figure A-23. Mean monthly flow at USGS 04196500 Sandusky River near Upper Sandusky OH

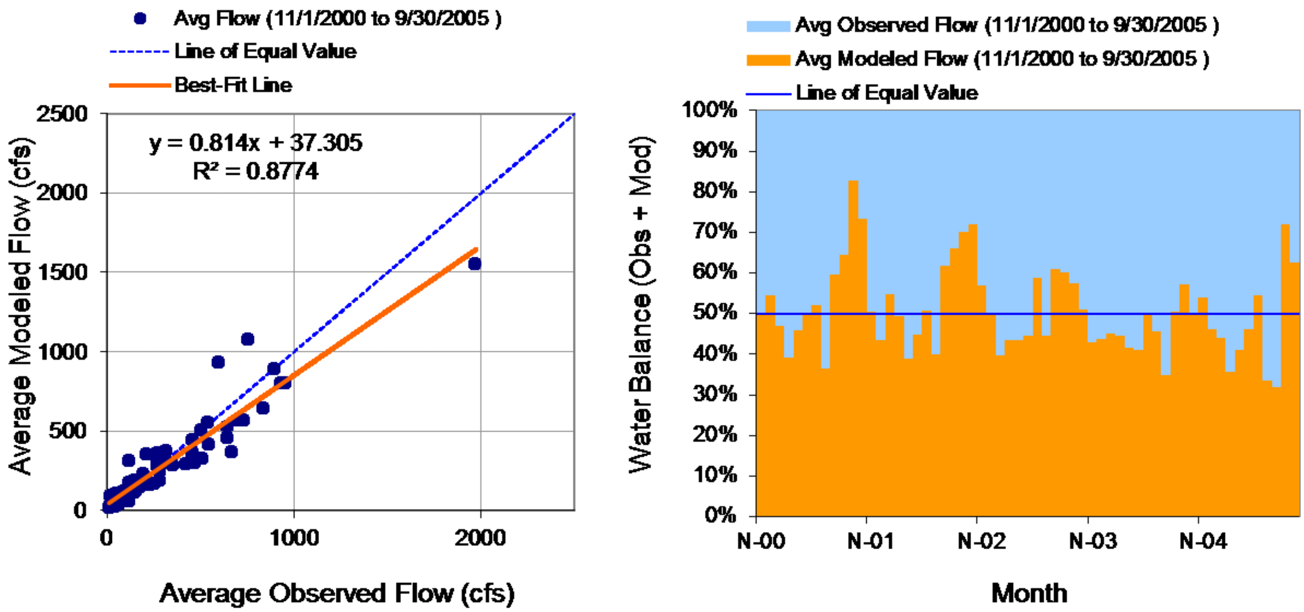


Figure A-24. Monthly flow regression and temporal variation at USGS 04196500 Sandusky River near Upper Sandusky OH

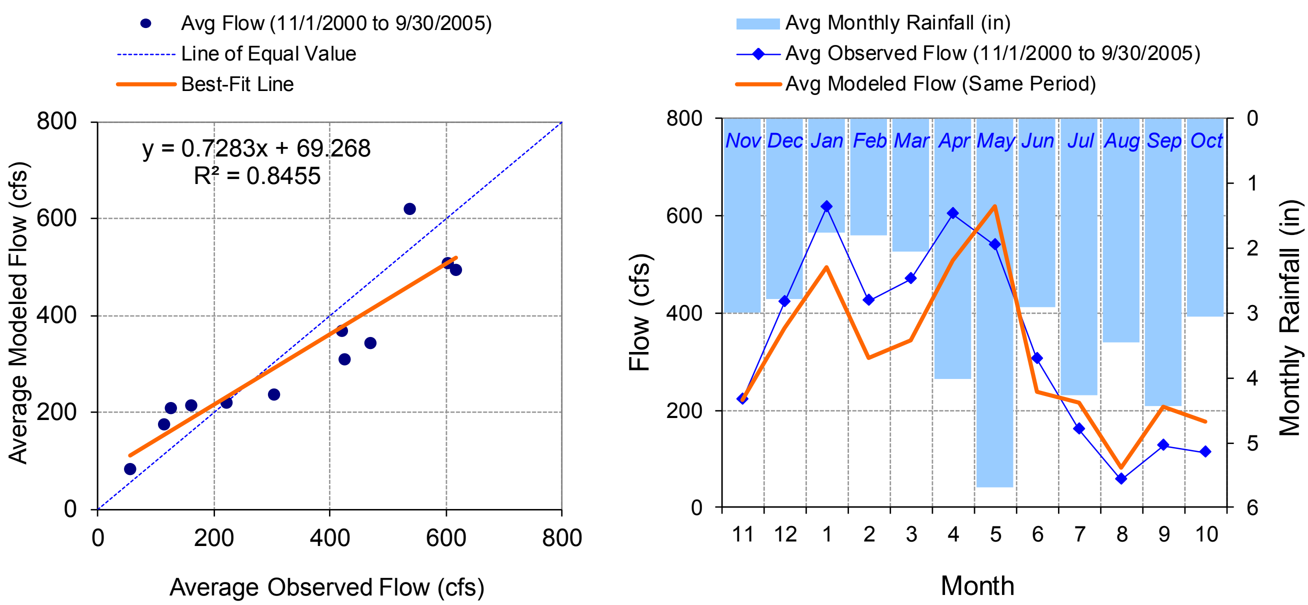


Figure A-25. Seasonal regression and temporal aggregate at USGS 04196500 Sandusky River near Upper Sandusky OH

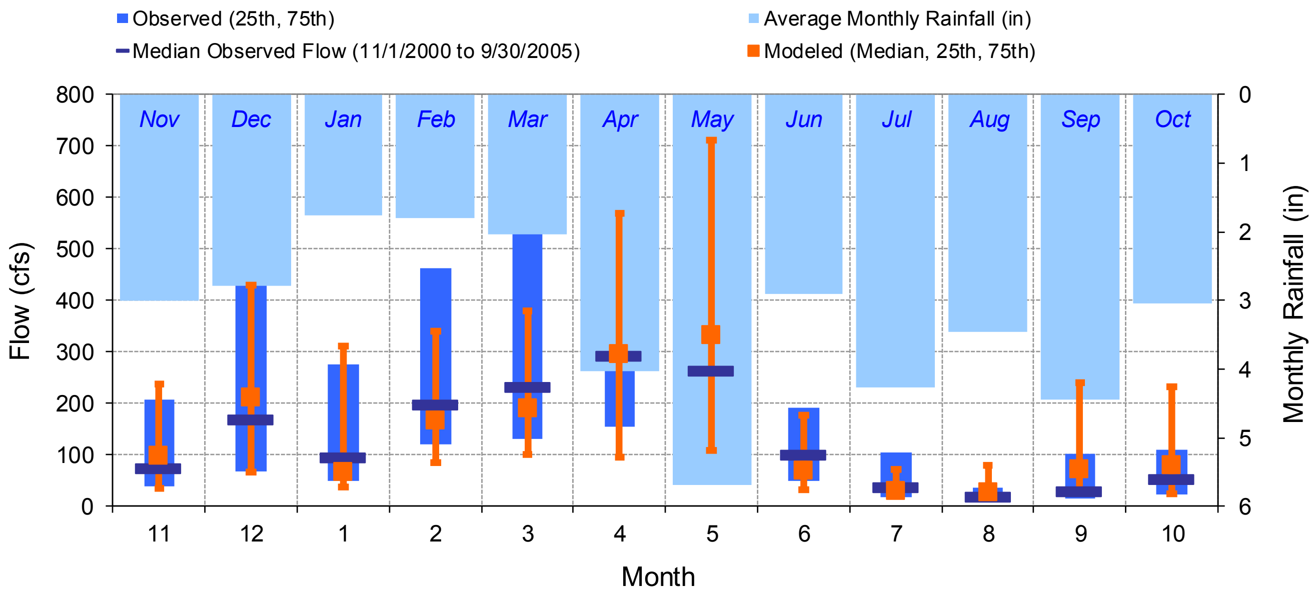


Figure A-26. Seasonal medians and ranges at USGS 04196500 Sandusky River near Upper Sandusky OH

Table A-7. Seasonal summary at USGS 04196500 Sandusky River near Upper Sandusky OH

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Nov	220.70	73.50	38.00	206.25	220.49	96.66	35.69	236.76
Dec	421.59	170.00	67.00	459.50	368.61	210.76	65.91	429.96
Jan	617.91	94.00	48.50	275.00	495.25	65.86	37.19	311.25
Feb	425.37	199.00	120.00	463.00	308.97	165.84	85.53	340.26
Mar	469.89	232.00	131.00	588.00	343.76	189.50	101.19	381.05
Apr	603.26	292.50	154.00	685.00	509.58	294.49	96.38	568.30
May	538.45	263.00	133.00	536.00	620.70	332.13	109.60	712.12
Jun	304.49	99.50	48.50	192.50	237.98	68.03	31.93	177.09
Jul	160.89	37.00	17.00	104.50	214.63	30.31	22.02	71.99
Aug	56.14	18.00	9.25	36.00	82.20	26.18	18.59	80.22
Sep	126.58	29.50	14.00	103.00	208.56	70.33	28.07	240.64
Oct	113.41	54.00	21.75	109.75	176.60	79.48	24.11	233.49

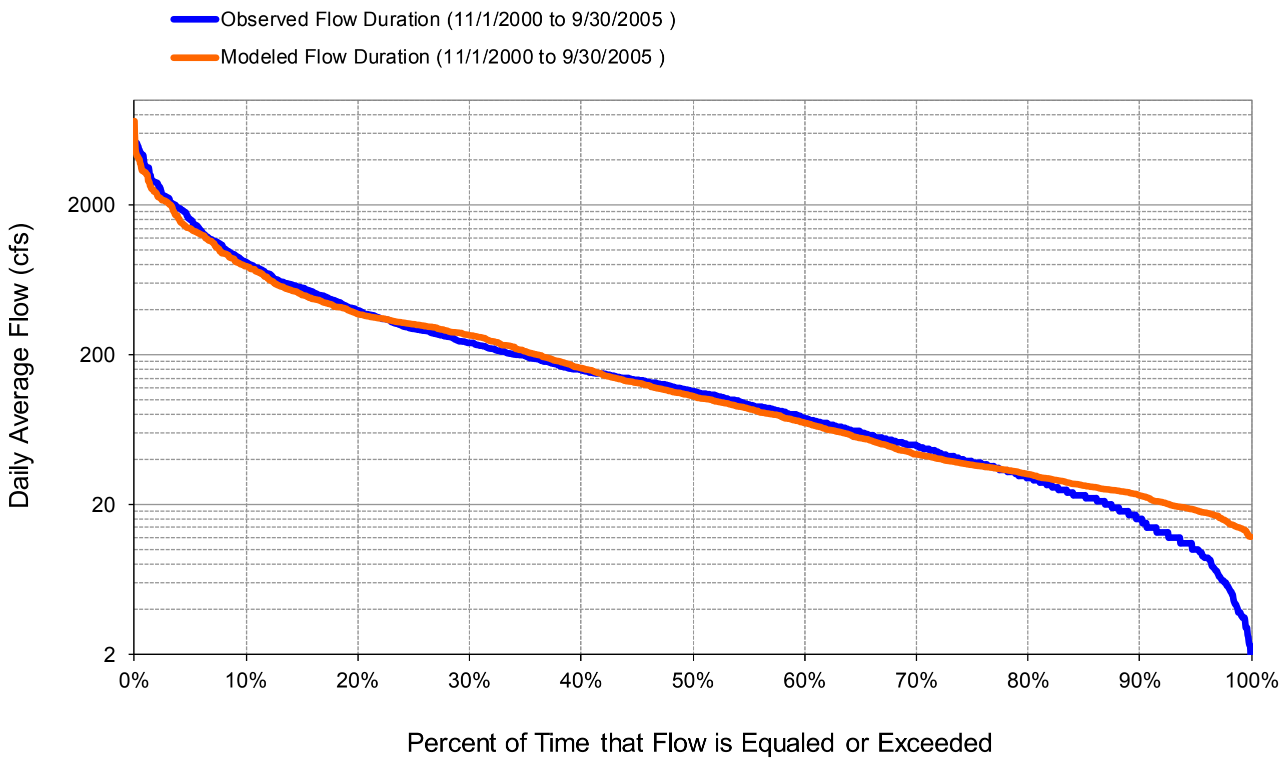


Figure A-27. Flow exceedence at USGS 04196500 Sandusky River near Upper Sandusky OH

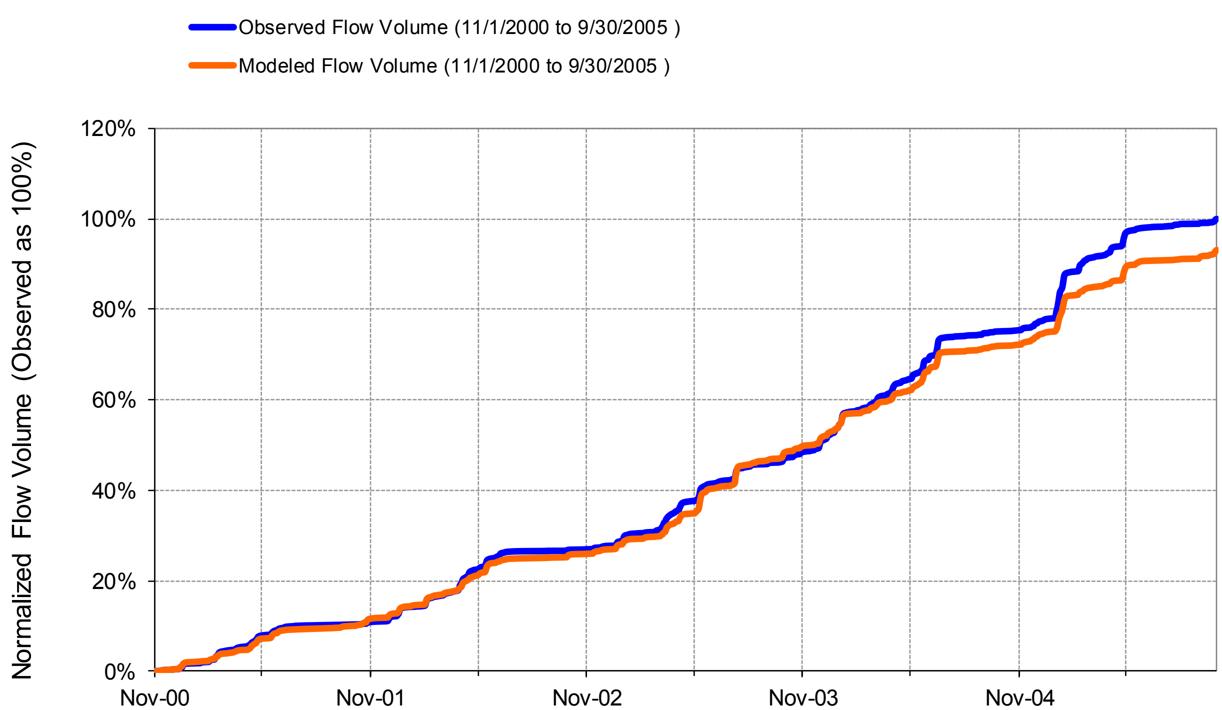


Figure A-28. Flow accumulation at USGS 04196500 Sandusky River near Upper Sandusky OH

Table A-8. Summary statistics at USGS 04196500 Sandusky River near Upper Sandusky OH

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 62 4.91-Year Analysis Period: 11/1/2000 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		Sandusky River near Upper Sandusky OH Manually Entered Data Drainage Area (sq-mi): 298	
Total Simulated In-stream Flow:	**14.51**	Total Observed In-stream Flow:	**15.58**
Total of simulated highest 10% flows:	**8.06**	Total of Observed highest 10% flows:	**9.05**
Total of Simulated lowest 50% flows:	**1.03**	Total of Observed Lowest 50% flows:	**1.04**
Simulated Summer Flow Volume (months 7-9):	**1.96**	Observed Summer Flow Volume (7-9):	**1.34**
Simulated Fall Flow Volume (months 10-12):	**2.85**	Observed Fall Flow Volume (10-12):	**2.86**
Simulated Winter Flow Volume (months 1-3):	**4.41**	Observed Winter Flow Volume (1-3):	**5.80**
Simulated Spring Flow Volume (months 4-6):	**5.29**	Observed Spring Flow Volume (4-6):	**5.58**
Total Simulated Storm Volume:	**9.58**	Total Observed Storm Volume:	**10.42**
Simulated Summer Storm Volume (7-9):	**1.38**	Observed Summer Storm Volume (7-9):	**1.01**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*
Error in total volume:	-6.85	10
Error in 50% lowest flows:	-0.55	10
Error in 10% highest flows:	-11.00	15
Seasonal volume error - Summer:	46.87	30
Seasonal volume error - Fall:	-0.36	30
Seasonal volume error - Winter:	-24.05	30
Seasonal volume error - Spring:	-5.14	30
Error in storm volumes:	-8.03	20
Error in summer storm volumes:	36.86	50
Nash-Sutcliffe Coefficient of Efficiency, E:	0.779	Model accuracy increases
Baseline adjusted coefficient (Garrick), E':	0.648	as E or E' approaches 1.0
Monthly NSE	0.870	

>> Clear

USGS 04196800 Sandusky River at Crawford OH - Calibration

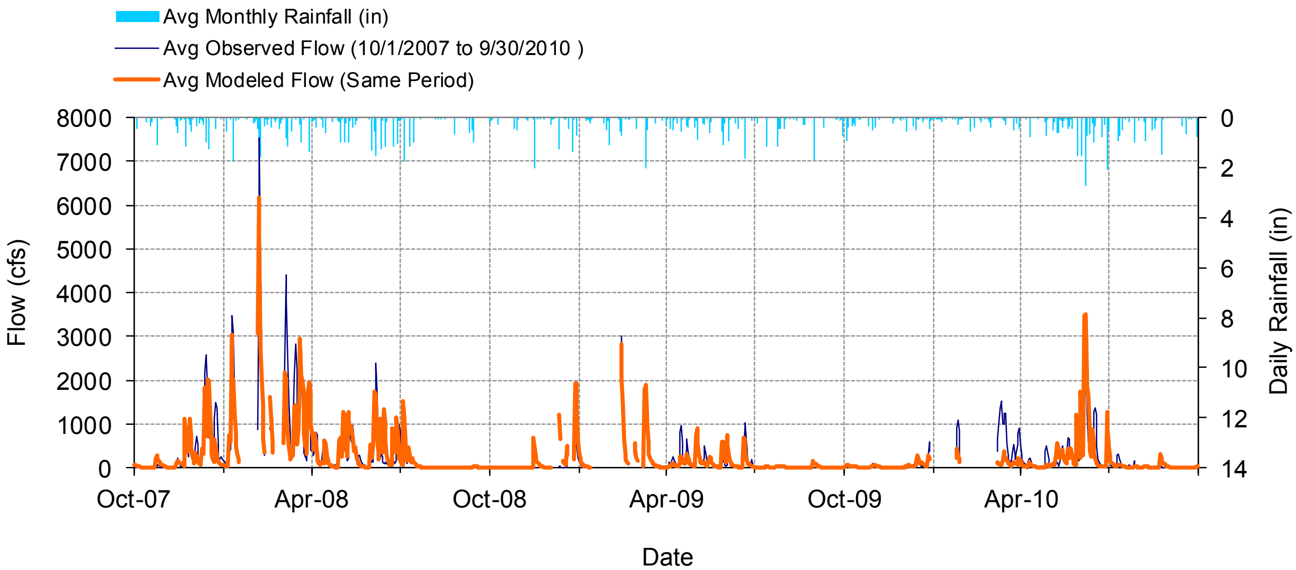


Figure A-29. Mean daily flow at USGS 04196800 Sandusky River at Crawford OH

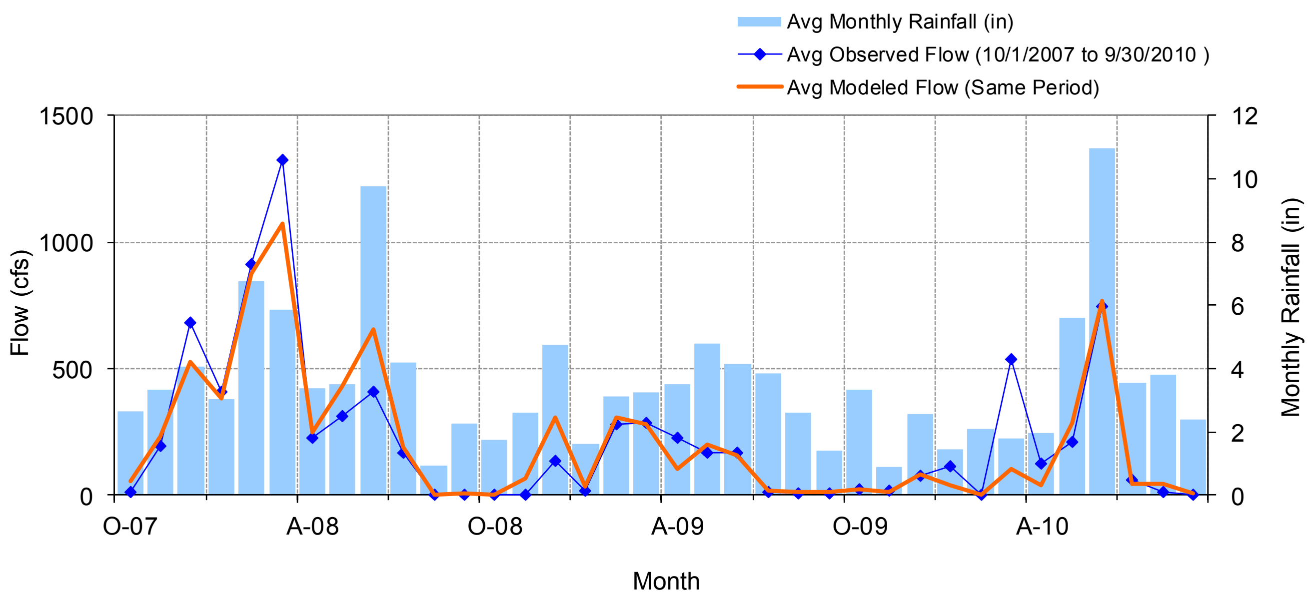


Figure A-30. Mean monthly flow at USGS 04196800 Sandusky River at Crawford OH

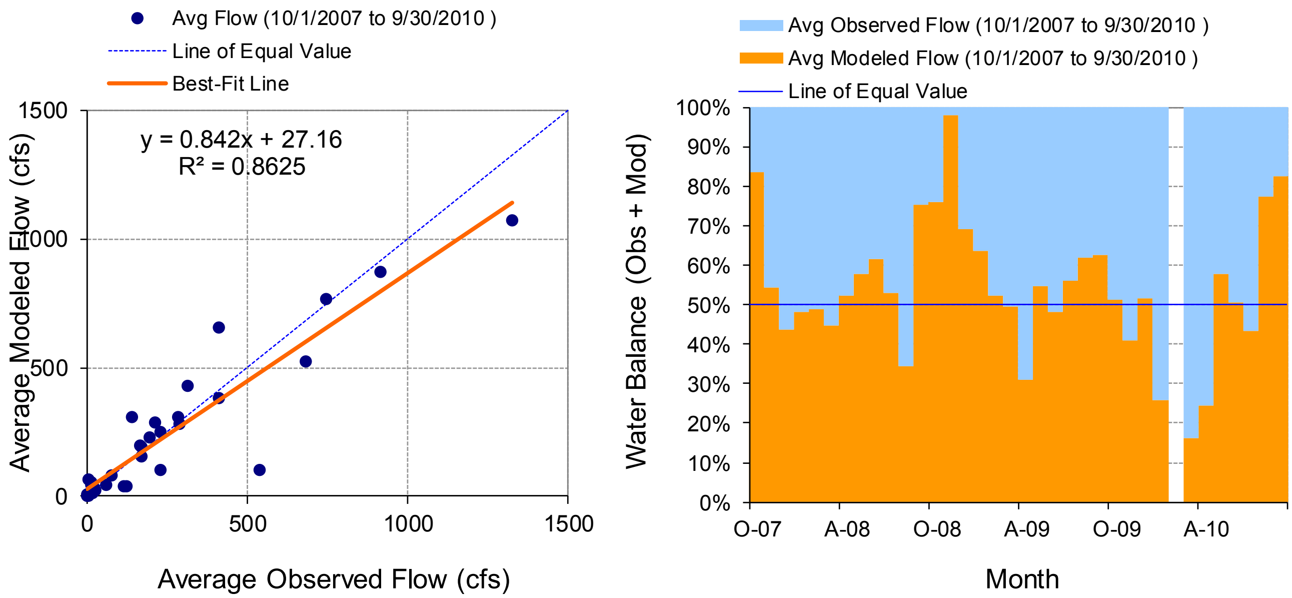


Figure A-31. Monthly flow regression and temporal variation at USGS 04196800 Sandusky River at Crawford OH

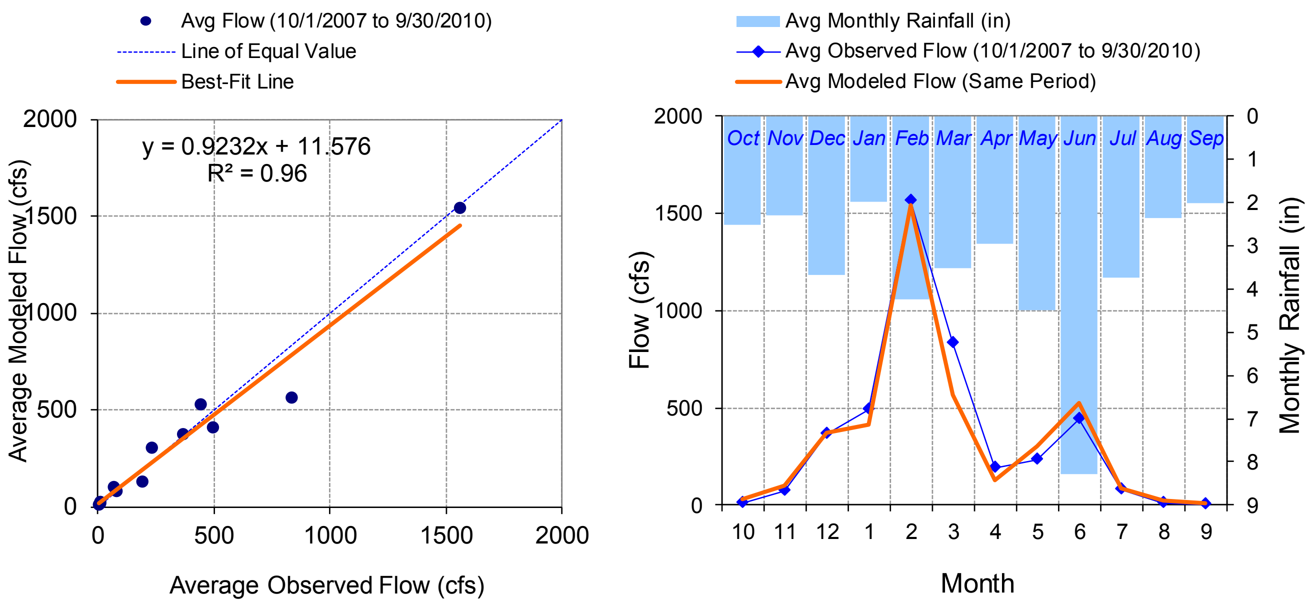


Figure A-32. Seasonal regression and temporal aggregate at USGS 04196800 Sandusky River at Crawford OH

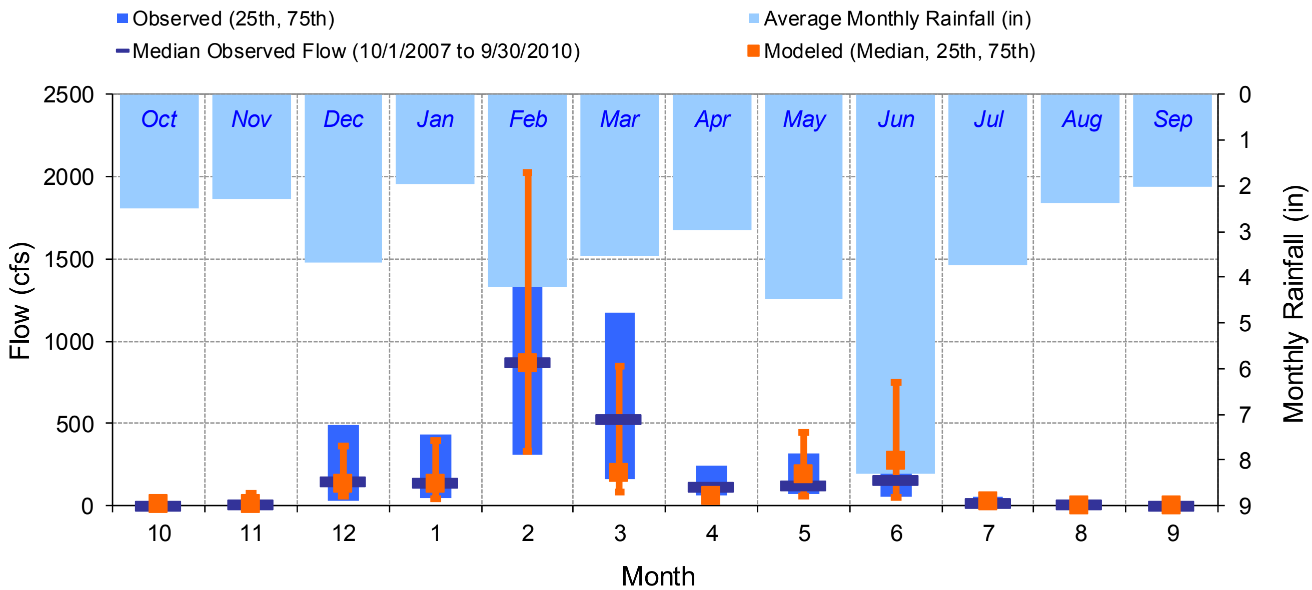


Figure A-33. Seasonal medians and ranges at USGS 04196800 Sandusky River at Crawford OH

Table A-9. Seasonal summary at USGS 04196800 Sandusky River at Crawford OH

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	11.32	3.10	0.53	16.00	26.74	6.52	1.40	33.25
Nov	70.25	7.77	2.54	16.92	102.73	6.97	1.04	71.66
Dec	364.74	145.75	26.15	488.78	372.46	133.68	62.59	361.07
Jan	493.26	144.77	45.95	430.11	412.71	131.74	39.74	397.65
Feb	1562.84	872.35	308.79	1977.52	1544.44	866.80	334.65	2029.45
Mar	834.03	528.39	162.63	1175.27	565.81	200.30	79.77	849.41
Apr	191.87	115.30	60.13	243.40	130.17	60.74	30.04	114.46
May	229.48	127.81	74.28	317.22	304.96	188.76	60.81	444.61
Jun	440.50	159.09	56.59	647.69	527.12	270.25	52.44	754.06
Jul	79.50	17.96	12.27	57.79	83.72	23.81	7.70	60.64
Aug	8.34	6.57	4.54	10.69	20.02	2.60	2.02	13.46
Sep	3.73	1.93	1.14	4.48	8.51	2.82	1.37	9.12

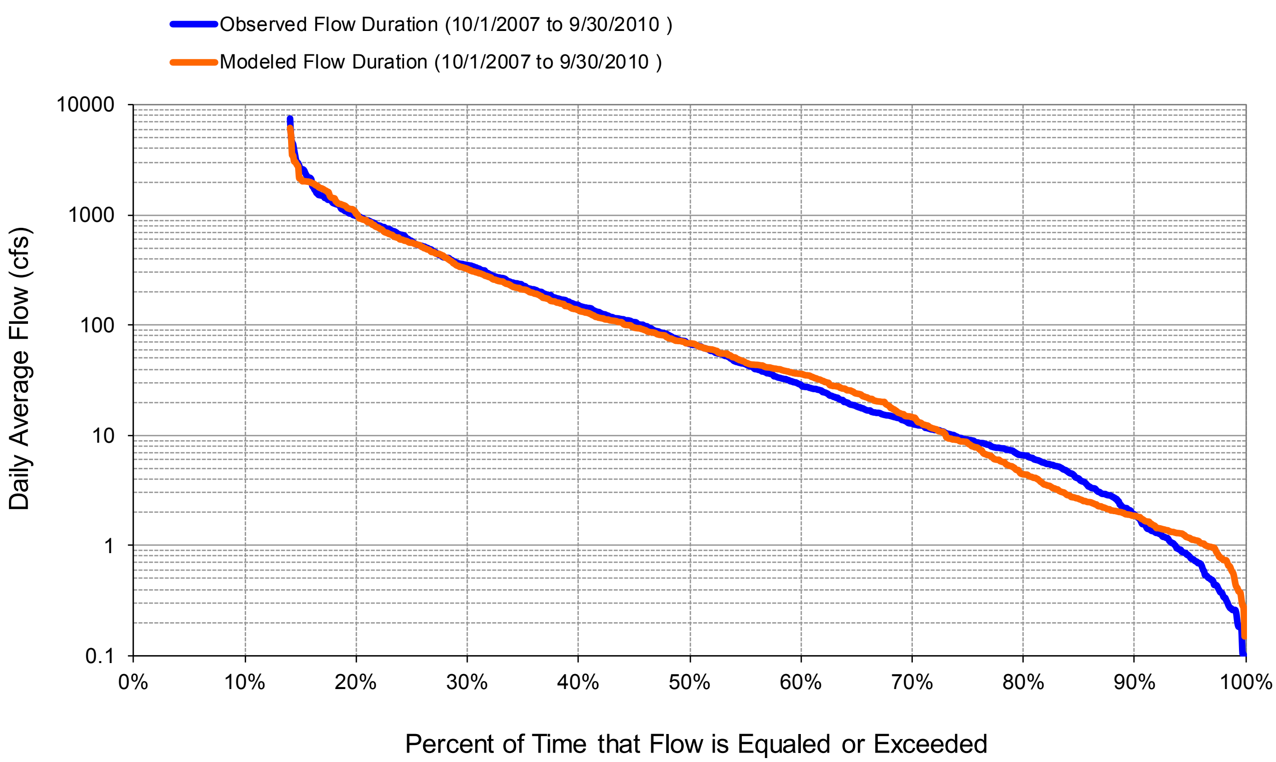


Figure A-34. Flow exceedence at USGS 04196800 Sandusky River at Crawford OH

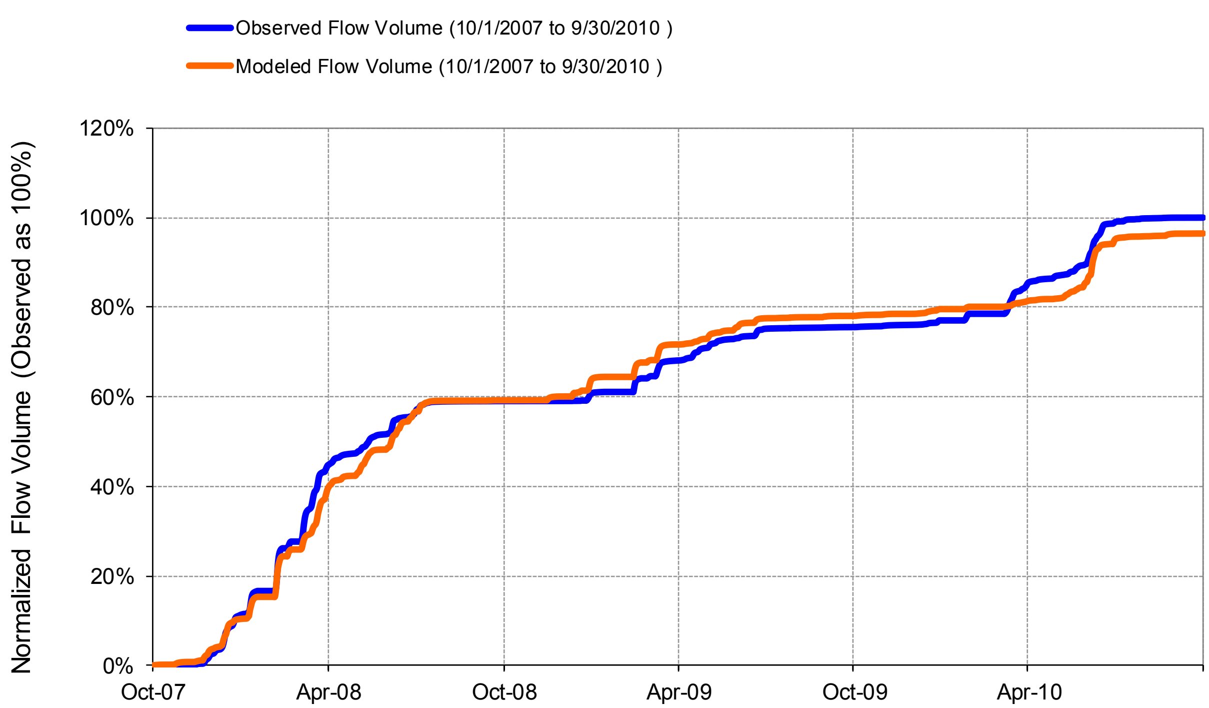


Figure A-35. Flow accumulation at USGS 04196800 Sandusky River at Crawford OH

Table A-10. Summary statistics at USGS 04196800 Sandusky River at Crawford OH

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 77 3-Year Analysis Period: 10/1/2007 - 9/30/2010 Flow volumes are (inches/year) for upstream drainage area		Tymochtee Creek at Crawford OH Manually Entered Data Drainage Area (sq-mi): 229	
Total Simulated In-stream Flow:	**12.51**	Total Observed In-stream Flow:	**12.97**
Total of simulated highest 10% flows:	**7.99**	Total of Observed highest 10% flows:	**8.22**
Total of Simulated lowest 50% flows:	**0.29**	Total of Observed Lowest 50% flows:	**0.26**
Simulated Summer Flow Volume (months 7-9):	**0.56**	Observed Summer Flow Volume (7-9):	**0.46**
Simulated Fall Flow Volume (months 10-12):	**2.17**	Observed Fall Flow Volume (10-12):	**1.90**
Simulated Winter Flow Volume (months 1-3):	**5.05**	Observed Winter Flow Volume (1-3):	**6.38**
Simulated Spring Flow Volume (months 4-6):	**4.74**	Observed Spring Flow Volume (4-6):	**4.24**
Total Simulated Storm Volume:	**7.83**	Total Observed Storm Volume:	**7.90**
Simulated Summer Storm Volume (7-9):	**0.35**	Observed Summer Storm Volume (7-9):	**0.25**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-3.55	10	
Error in 50% lowest flows:	11.66	10	
Error in 10% highest flows:	-2.81	15	
Seasonal volume error - Summer:	22.28	30	
Seasonal volume error - Fall:	14.09	30	
Seasonal volume error - Winter:	-20.87	30	
Seasonal volume error - Spring:	11.84	30	
Error in storm volumes:	-0.96	20	
Error in summer storm volumes:	38.55	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.616	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.502	as E or E' approaches 1.0	
Monthly NSE	0.859		

>> Clear

USGS 04197100 Sandusky River at Melmore OH - Calibration

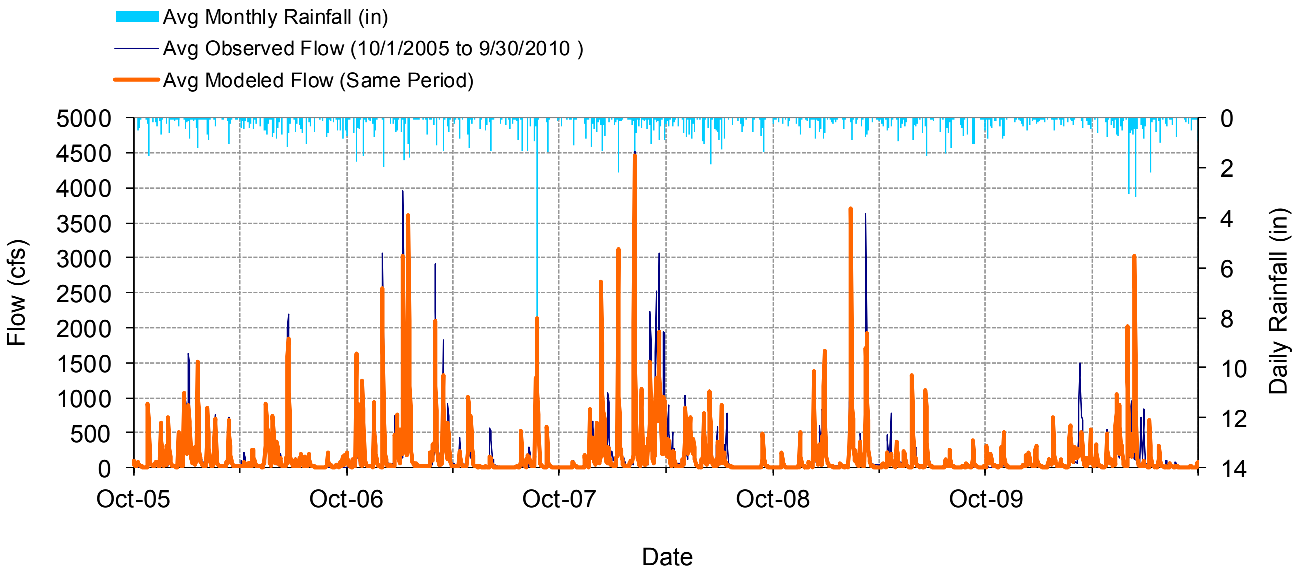


Figure A-36. Mean daily flow at USGS 04197100 Sandusky River at Melmore OH

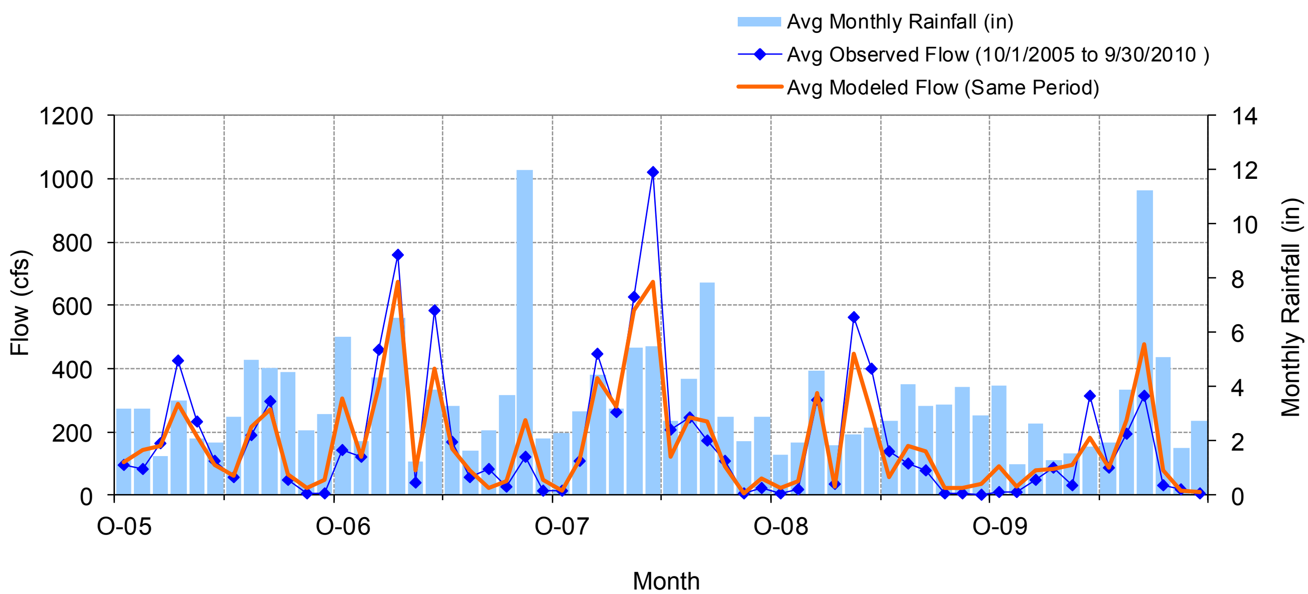


Figure A-37. Mean monthly flow at USGS 04197100 Sandusky River at Melmore OH

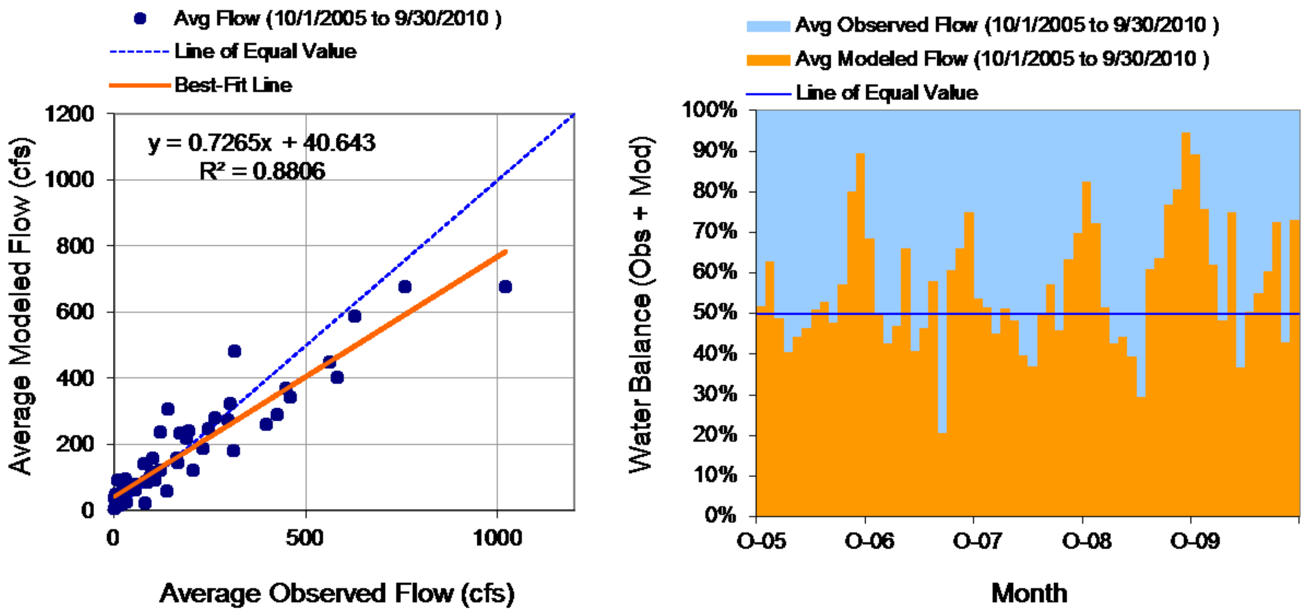


Figure A-38. Monthly flow regression and temporal variation at USGS 04197100 Sandusky River at Melmore OH

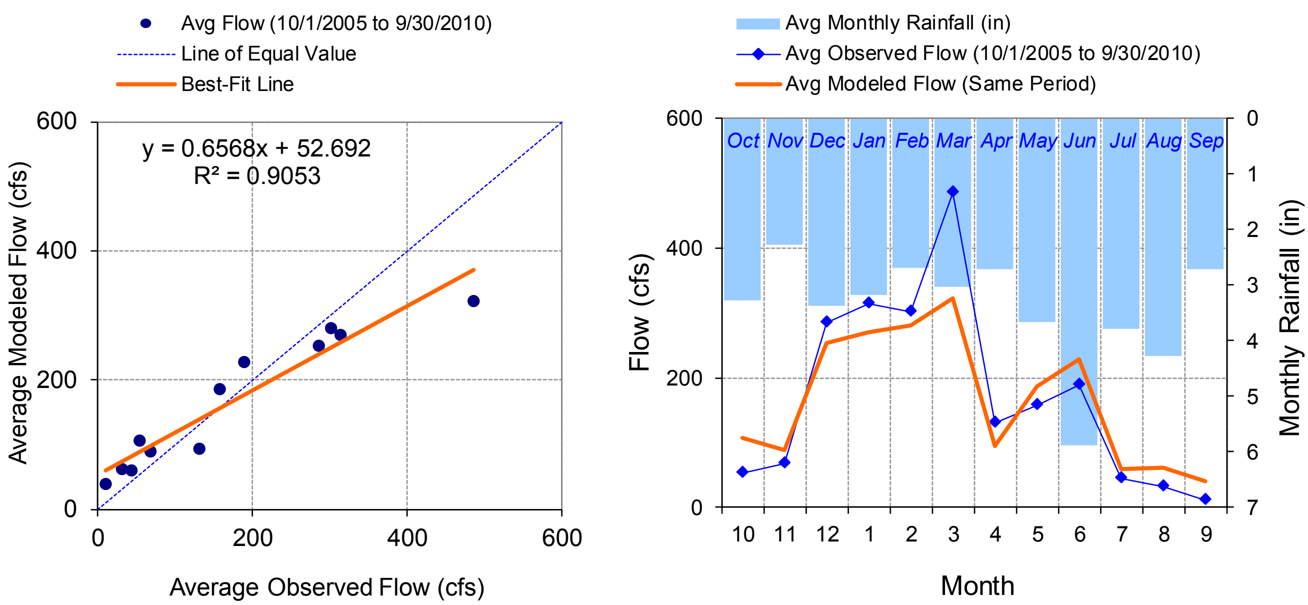


Figure A-39. Seasonal regression and temporal aggregate at USGS 04197100 Sandusky River at Melmore OH

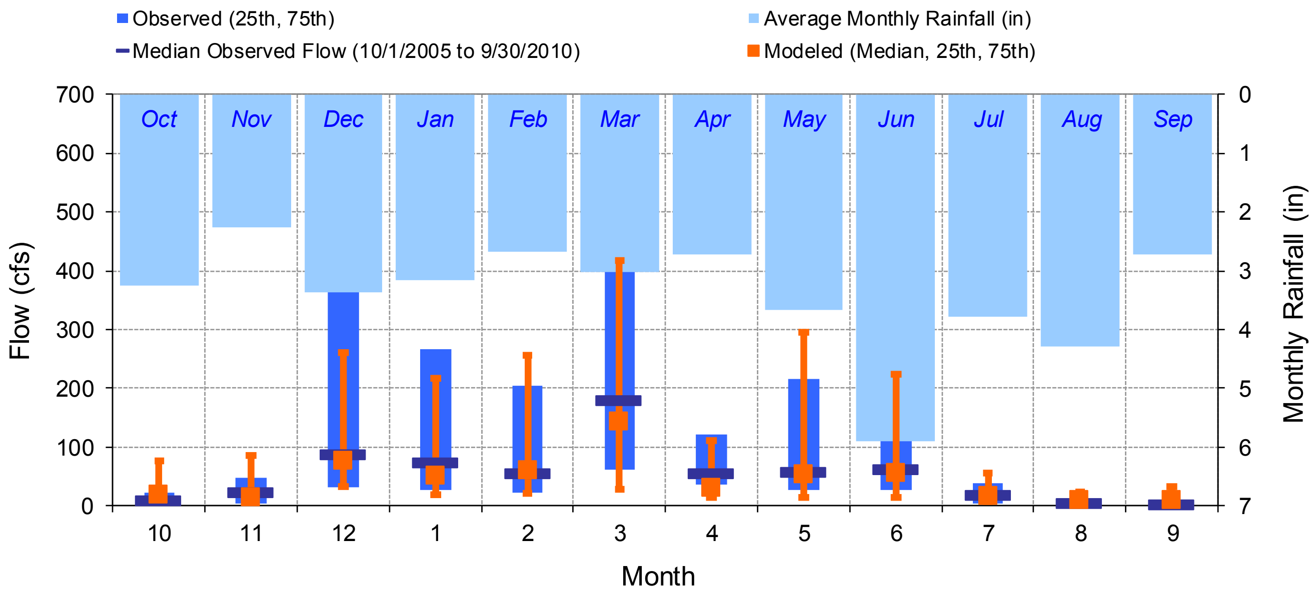


Figure A-40. Seasonal medians and ranges at USGS 04197100 Sandusky River at Melmore OH

Table A-11. Seasonal summary at USGS 04197100 Sandusky River at Melmore OH

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	53.17	8.50	5.10	21.50	107.06	18.77	7.67	75.61
Nov	68.06	24.50	4.60	48.75	89.29	15.09	9.12	84.97
Dec	284.76	88.00	31.50	383.00	253.74	76.95	31.85	260.87
Jan	314.50	75.00	27.00	266.00	270.35	51.81	18.99	217.29
Feb	301.61	55.00	22.00	205.00	280.18	60.46	20.64	256.00
Mar	485.24	181.00	62.00	581.50	321.84	142.92	28.77	418.48
Apr	131.09	56.50	35.00	120.50	94.12	30.26	14.89	110.69
May	157.85	57.00	28.00	216.50	186.74	52.87	14.29	294.37
Jun	189.19	62.00	26.00	203.75	228.83	54.68	13.80	223.51
Jul	43.86	18.00	4.75	37.50	59.69	15.91	7.76	55.99
Aug	31.61	5.20	3.10	9.30	61.22	9.34	7.01	24.54
Sep	10.19	3.15	2.20	6.28	39.53	8.77	5.68	32.38

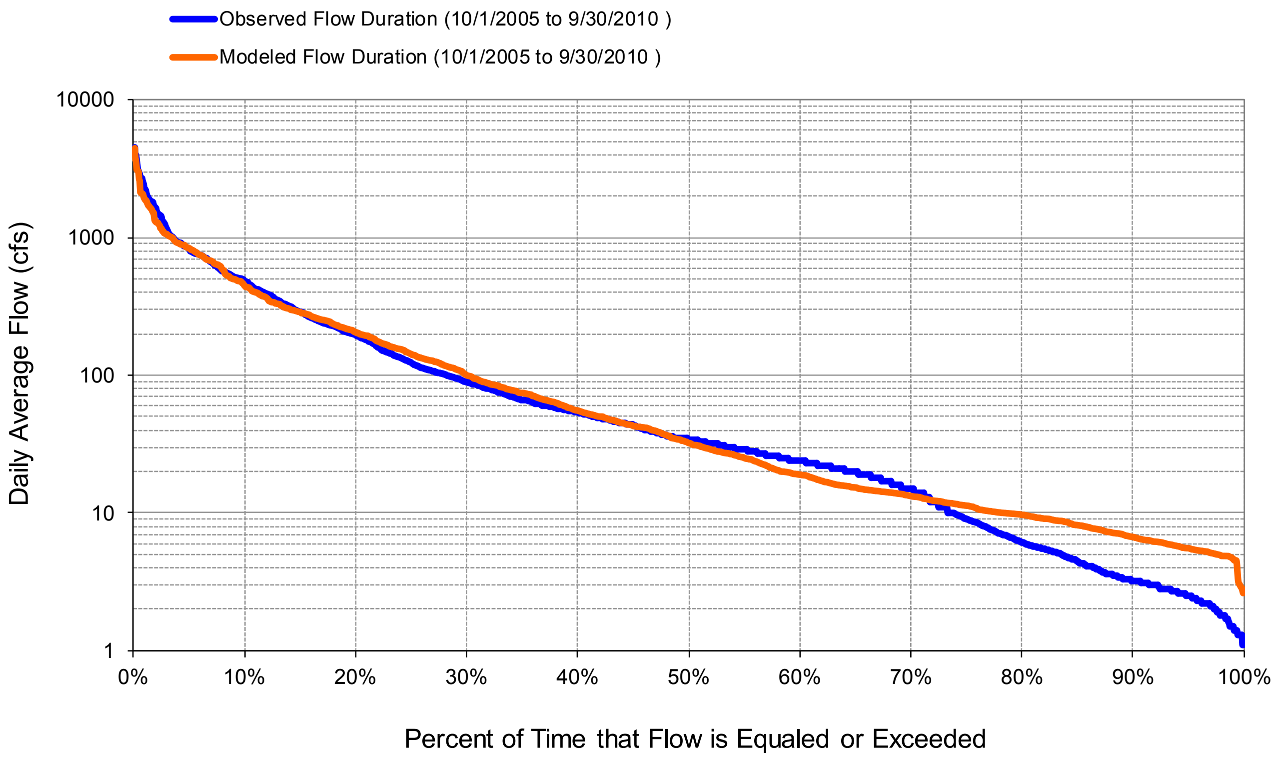


Figure A-41. Flow exceedence at USGS 04197100 Sandusky River at Melmore OH

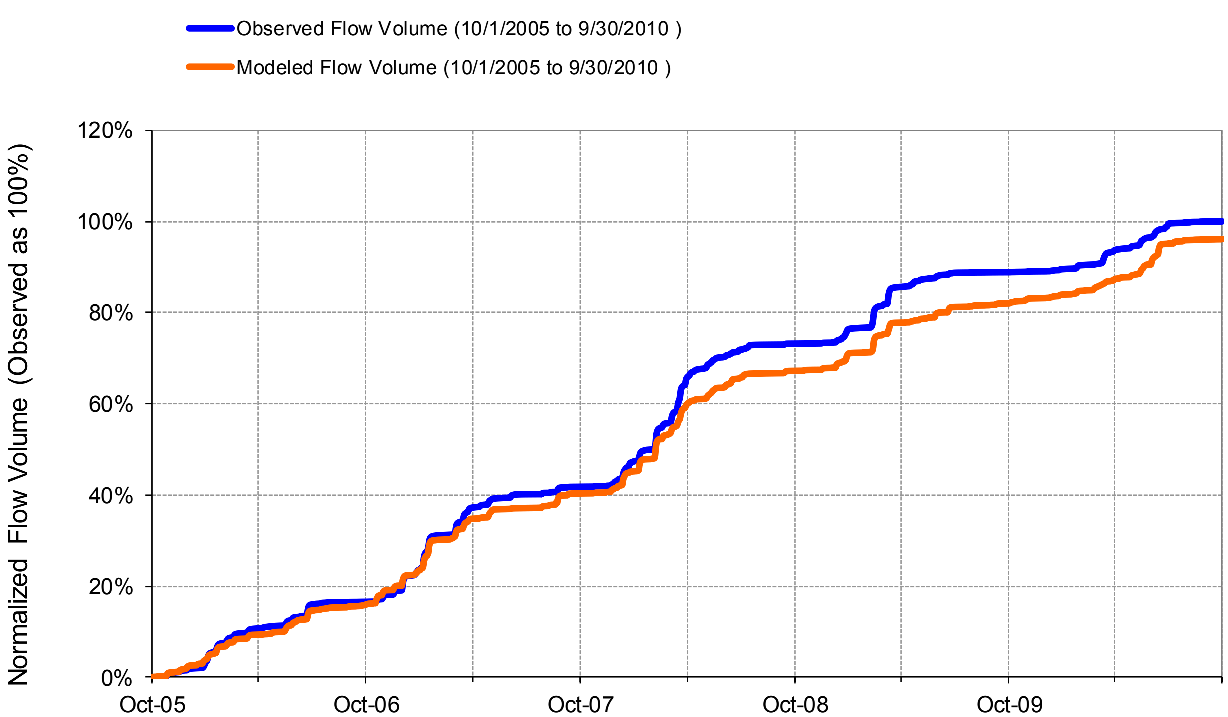


Figure A-42. Flow accumulation at USGS 04197100 Sandusky River at Melmore OH

Table A-12. Summary statistics at USGS 04197100 Sandusky River at Melmore OH

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 47 5-Year Analysis Period: 10/1/2005 - 9/30/2010 Flow volumes are (inches/year) for upstream drainage area		Honey Creek at Melmore OH Manually Entered Data Drainage Area (sq-mi): 149	
Total Simulated In-stream Flow:	**15.11**	Total Observed In-stream Flow:	**15.71**
Total of simulated highest 10% flows:	**9.41**	Total of Observed highest 10% flows:	**10.19**
Total of Simulated lowest 50% flows:	**0.60**	Total of Observed Lowest 50% flows:	**0.59**
Simulated Summer Flow Volume (months 7-9):	**1.23**	Observed Summer Flow Volume (7-9):	**0.66**
Simulated Fall Flow Volume (months 10-12):	**3.46**	Observed Fall Flow Volume (10-12):	**3.12**
Simulated Winter Flow Volume (months 1-3):	**6.56**	Observed Winter Flow Volume (1-3):	**8.31**
Simulated Spring Flow Volume (months 4-6):	**3.86**	Observed Spring Flow Volume (4-6):	**3.62**
Total Simulated Storm Volume:	**10.69**	Total Observed Storm Volume:	**10.30**
Simulated Summer Storm Volume (7-9):	**0.79**	Observed Summer Storm Volume (7-9):	**0.43**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	-3.88	10		
Error in 50% lowest flows:	0.88	10		
Error in 10% highest flows:	-7.59	15		
Seasonal volume error - Summer:	86.49	30		
Seasonal volume error - Fall:	10.75	>> 30		Clear
Seasonal volume error - Winter:	-21.14	30		
Seasonal volume error - Spring:	6.73	30		
Error in storm volumes:	3.72	20		
Error in summer storm volumes:	83.39	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.710	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.580	as E or E' approaches 1.0		
Monthly NSE	0.853			

USGS 04197100 Sandusky River at Melmore OH - Validation

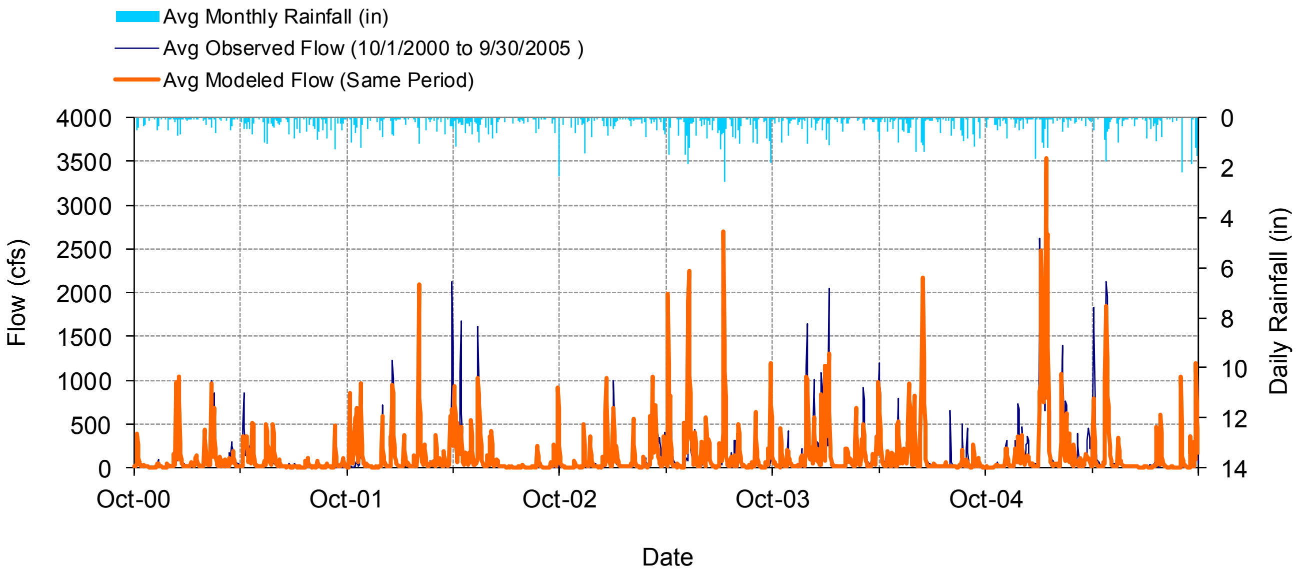


Figure A-43. Mean daily flow at USGS 04197100 Sandusky River at Melmore OH

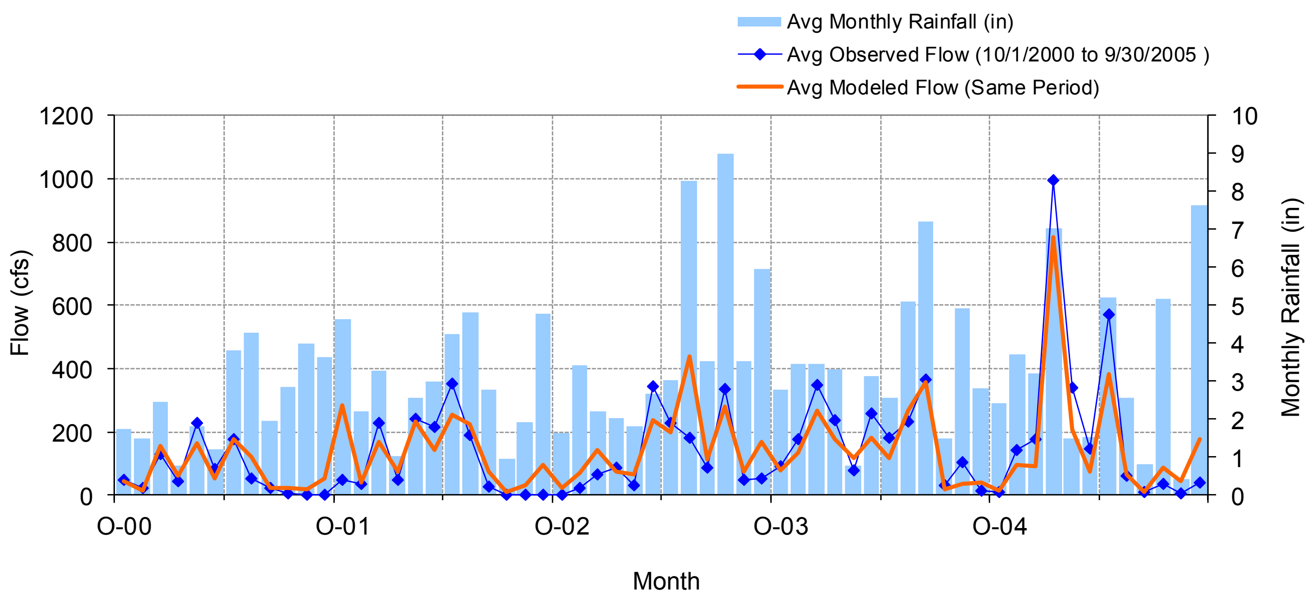


Figure A-44. Mean monthly flow at USGS 04197100 Sandusky River at Melmore OH

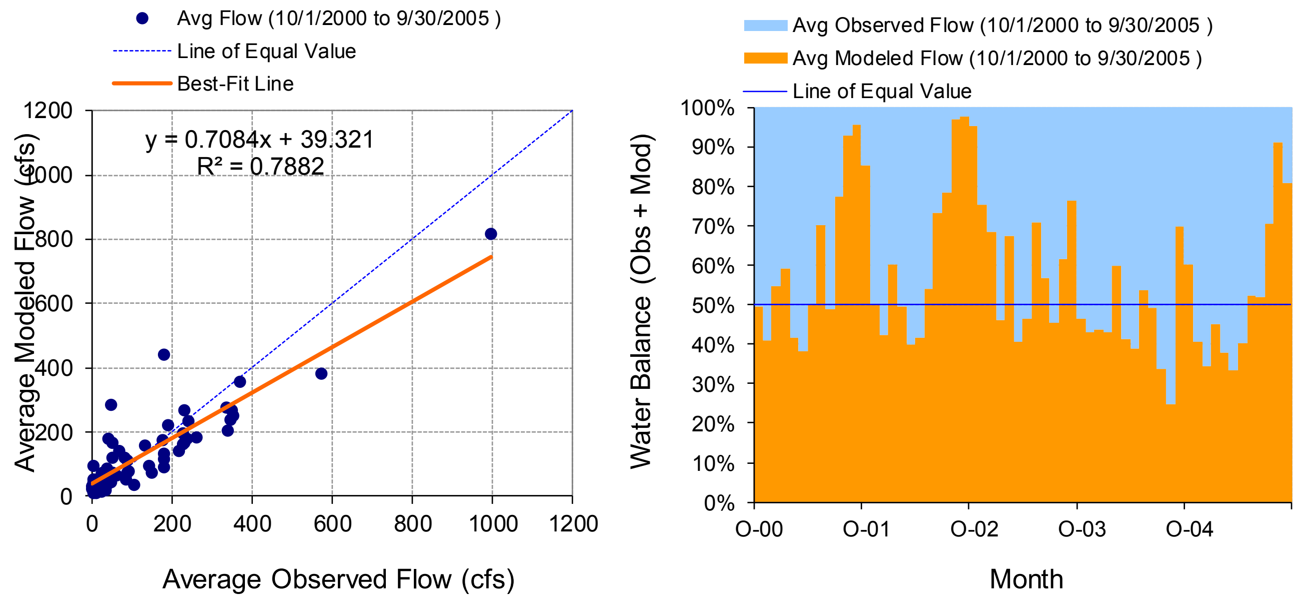


Figure A-45. Monthly flow regression and temporal variation at USGS 04197100 Sandusky River at Melmore OH

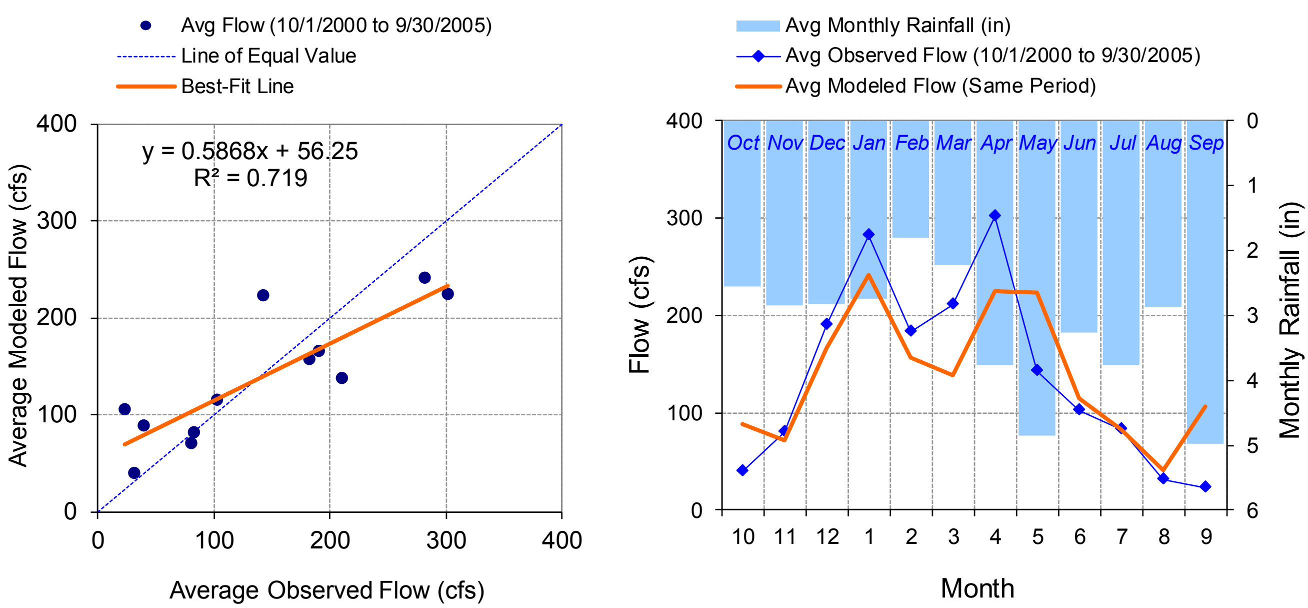


Figure A-46. Seasonal regression and temporal aggregate at USGS 04197100 Sandusky River at Melmore OH

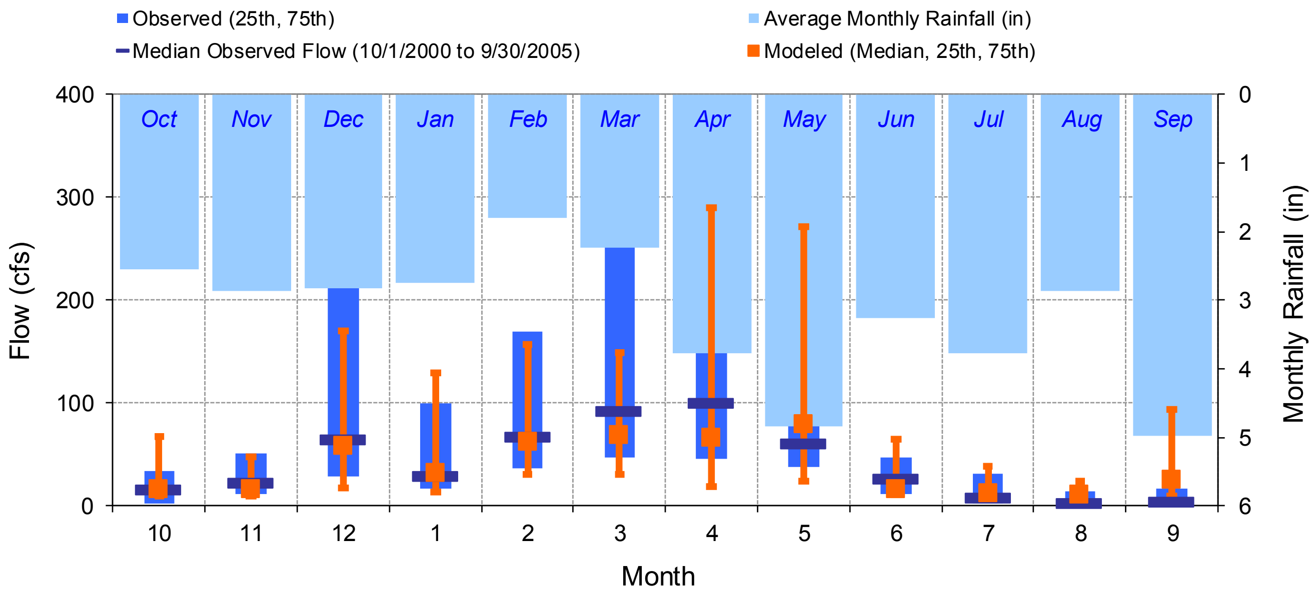


Figure A-47. Seasonal medians and ranges at USGS 04197100 Sandusky River at Melmore OH

Table A-13. Seasonal summary at USGS 04197100 Sandusky River at Melmore OH

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	39.26	16.00	1.55	34.00	88.76	16.36	9.00	67.38
Nov	80.54	22.00	11.25	51.00	71.04	15.59	9.68	47.81
Dec	189.89	65.00	29.00	227.50	165.80	58.13	16.91	170.76
Jan	282.18	29.00	17.00	100.00	241.17	31.80	13.18	128.72
Feb	182.48	67.00	37.00	170.00	157.10	62.26	30.01	156.66
Mar	210.83	93.00	47.50	295.00	137.84	69.32	30.09	148.97
Apr	301.40	100.00	46.25	312.25	224.68	66.64	19.22	289.80
May	142.61	61.00	38.00	120.00	223.35	78.68	24.21	271.22
Jun	102.60	26.00	11.00	47.00	115.07	16.13	10.20	64.47
Jul	82.24	8.60	2.60	31.00	82.31	12.03	9.02	37.87
Aug	31.44	2.60	1.20	14.50	40.35	11.18	8.05	24.42
Sep	22.81	4.15	1.30	16.75	106.40	24.61	8.92	93.25

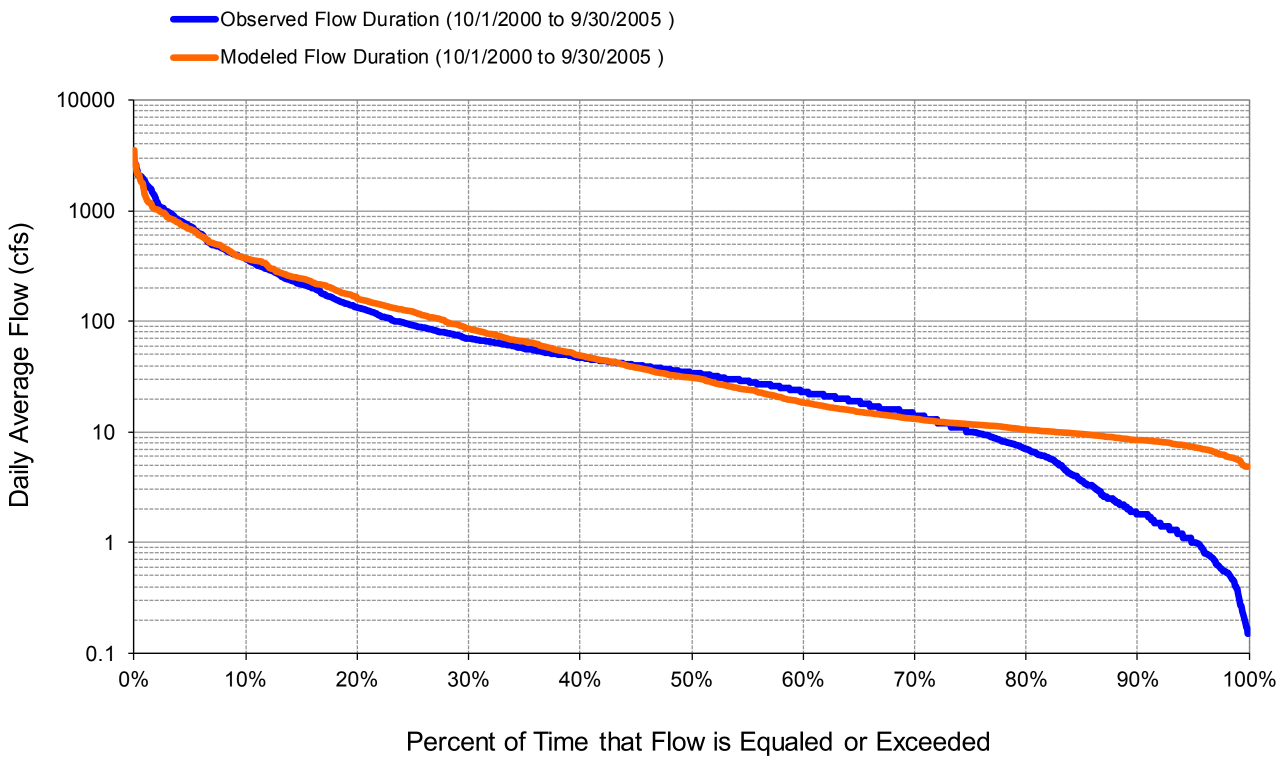


Figure A-48. Flow exceedence at USGS 04197100 Sandusky River at Melmore OH

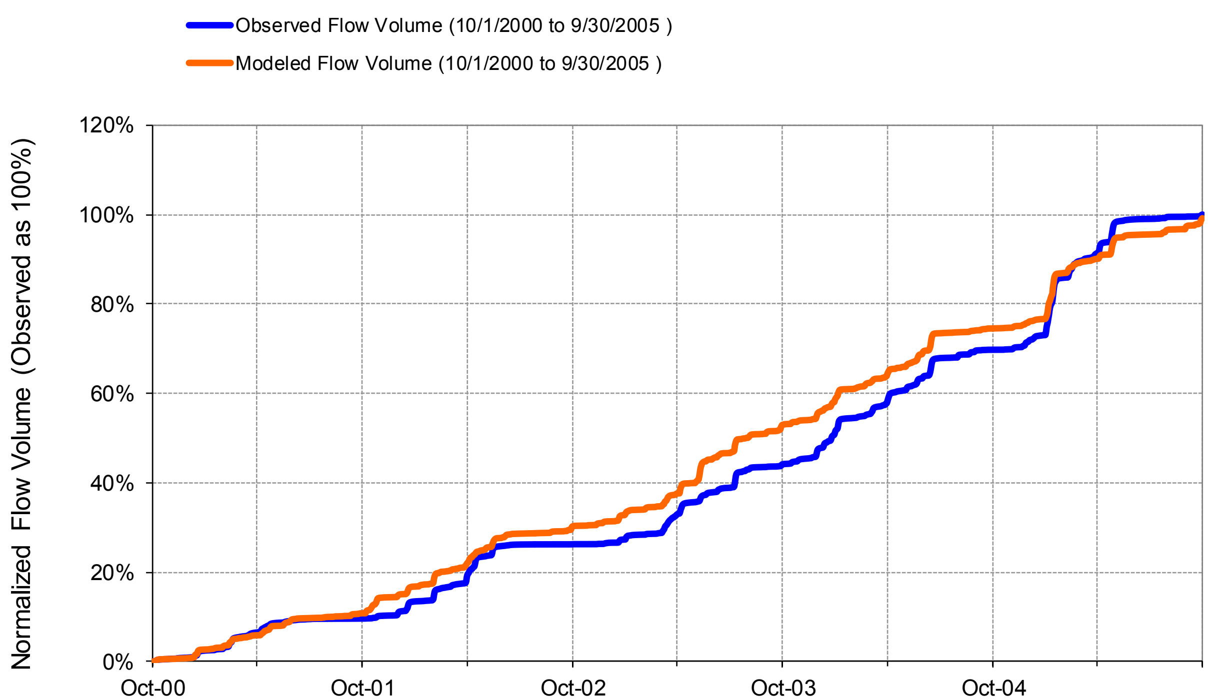


Figure A-49. Flow accumulation at USGS 04197100 Sandusky River at Melmore OH

Table A-14. Summary statistics at USGS 04197100 Sandusky River at Melmore OH

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 47 5-Year Analysis Period: 10/1/2000 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		Honey Creek at Melmore OH Manually Entered Data Drainage Area (sq-mi): 149	
Total Simulated In-stream Flow:	**12.56**	Total Observed In-stream Flow:	**12.66**
Total of simulated highest 10% flows:	**7.59**	Total of Observed highest 10% flows:	**8.26**
Total of Simulated lowest 50% flows:	**0.62**	Total of Observed Lowest 50% flows:	**0.57**
Simulated Summer Flow Volume (months 7-9):	**1.75**	Observed Summer Flow Volume (7-9):	**1.05**
Simulated Fall Flow Volume (months 10-12):	**2.50**	Observed Fall Flow Volume (10-12):	**2.38**
Simulated Winter Flow Volume (months 1-3):	**4.04**	Observed Winter Flow Volume (1-3):	**5.10**
Simulated Spring Flow Volume (months 4-6):	**4.27**	Observed Spring Flow Volume (4-6):	**4.13**
Total Simulated Storm Volume:	**8.47**	Total Observed Storm Volume:	**7.77**
Simulated Summer Storm Volume (7-9):	**1.32**	Observed Summer Storm Volume (7-9):	**0.80**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*
Error in total volume:	-0.76	10
Error in 50% lowest flows:	8.68	10
Error in 10% highest flows:	-8.20	15
Seasonal volume error - Summer:	66.20	30
Seasonal volume error - Fall:	5.28	30
Seasonal volume error - Winter:	-20.80	30
Seasonal volume error - Spring:	3.48	30
Error in storm volumes:	8.97	20
Error in summer storm volumes:	65.23	50
Nash-Sutcliffe Coefficient of Efficiency, E:	0.662	Model accuracy increases
Baseline adjusted coefficient (Garrick), E':	0.534	as E or E' approaches 1.0
Monthly NSE	0.780	

>> Clear

USGS 04198000 Sandusky River near Fremont OH - Calibration

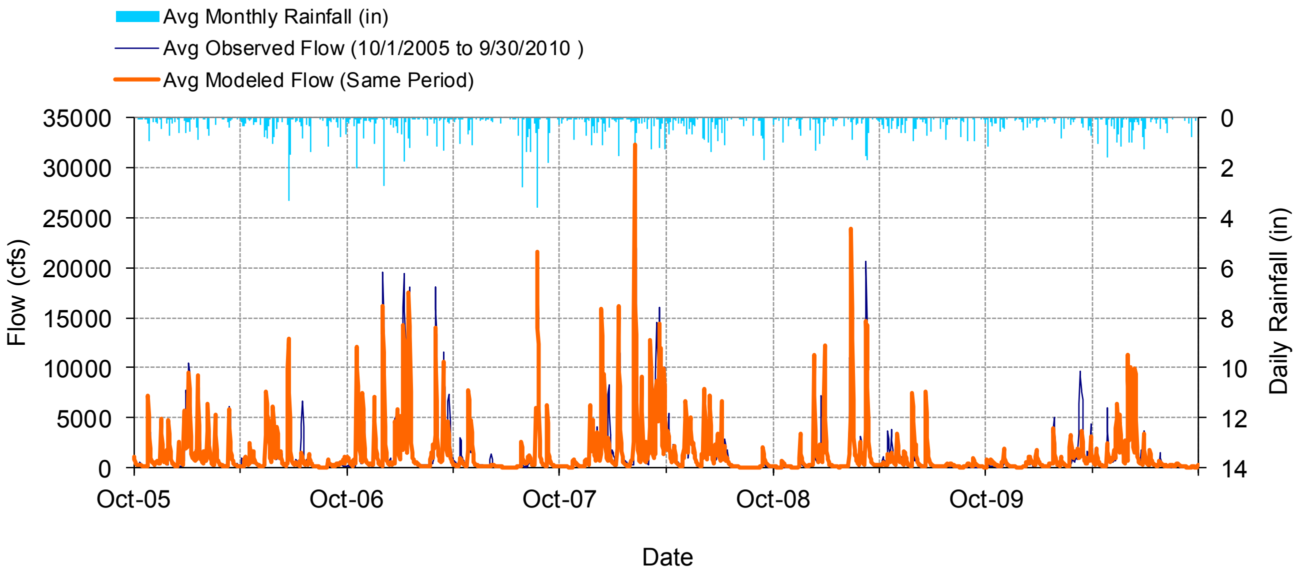


Figure A-50. Mean daily flow at USGS 04198000 Sandusky River near Fremont OH

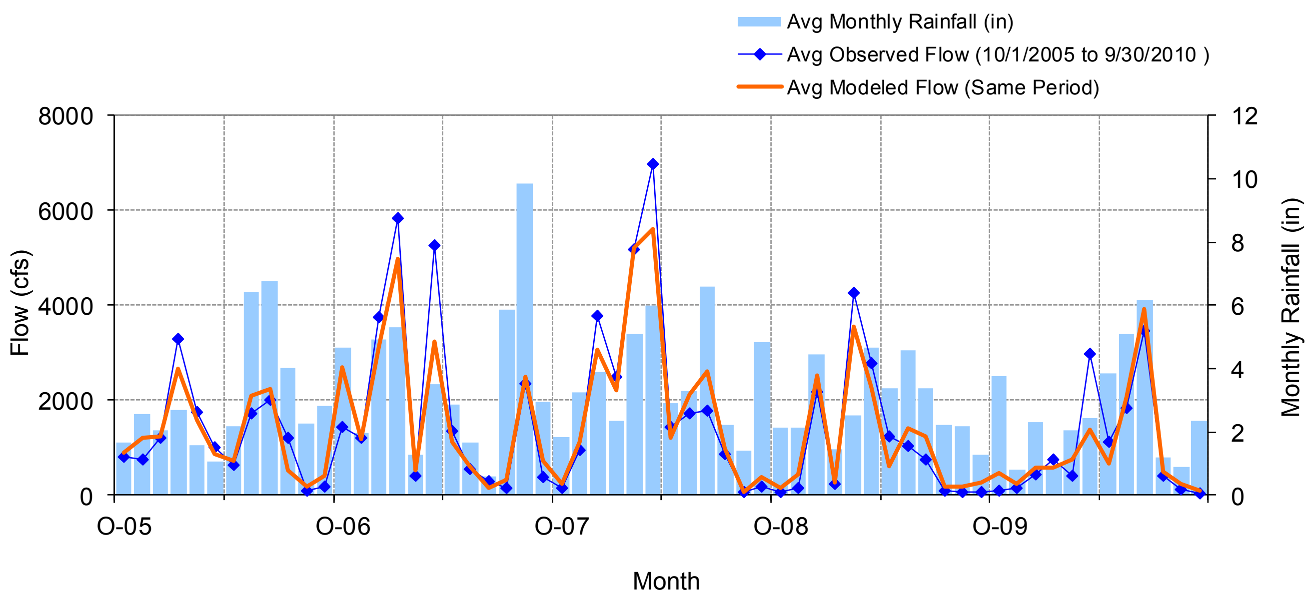


Figure A-51. Mean monthly flow at USGS 04198000 Sandusky River near Fremont OH

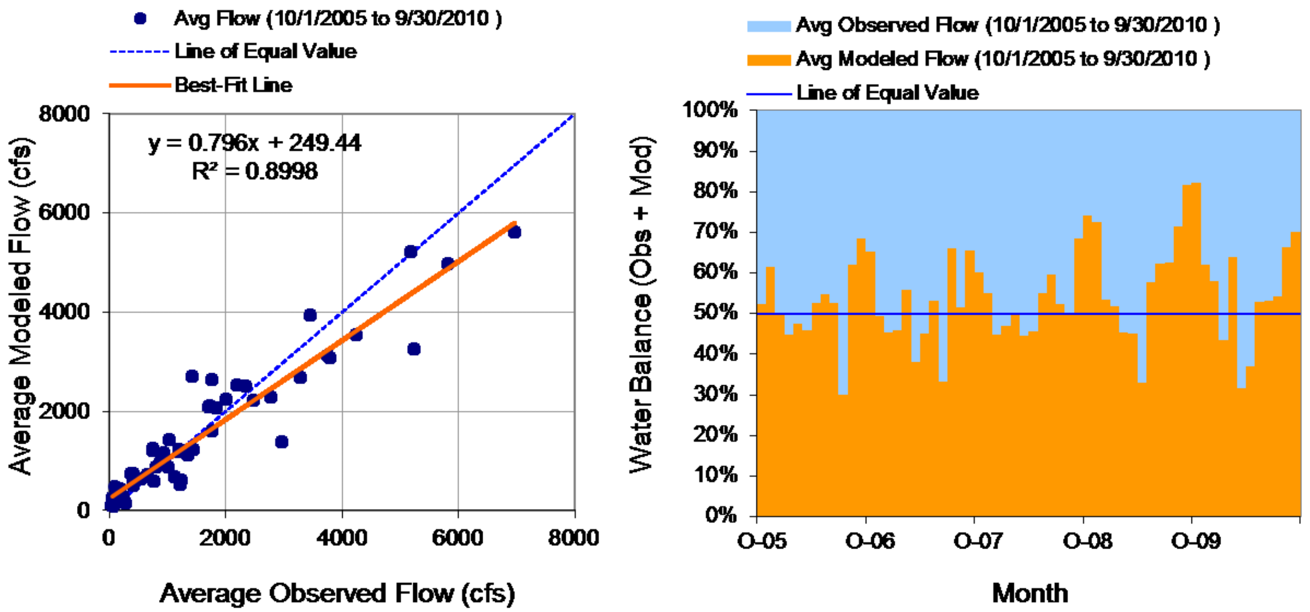


Figure A-52. Monthly flow regression and temporal variation at USGS 04198000 Sandusky River near Fremont OH

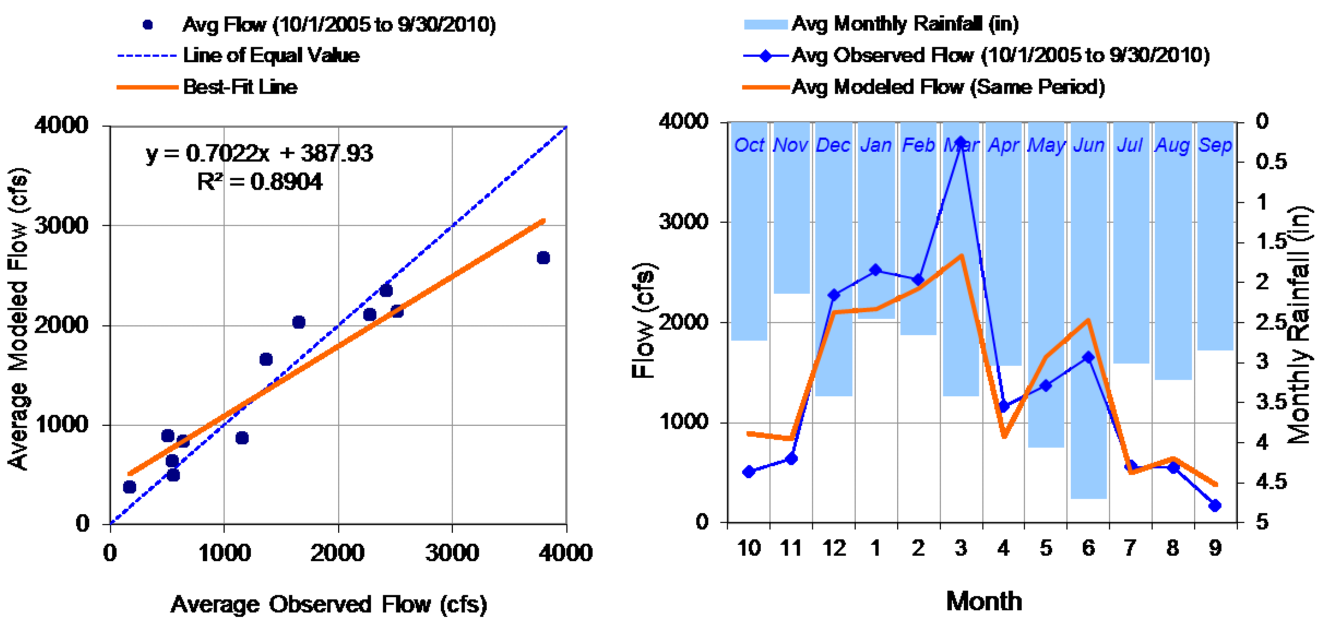


Figure A-53. Seasonal regression and temporal aggregate at USGS 04198000 Sandusky River near Fremont OH

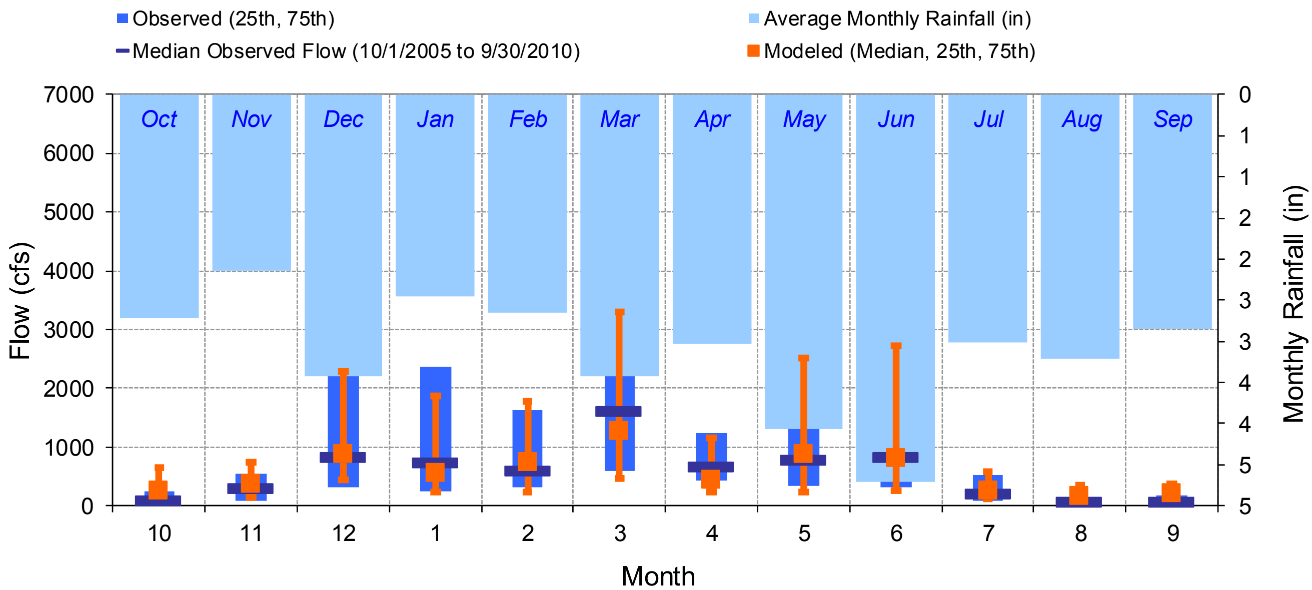


Figure A-54. Seasonal medians and ranges at USGS 04198000 Sandusky River near Fremont OH

Table A-15. Seasonal summary at USGS 04198000 Sandusky River near Fremont OH

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	507.59	106.00	66.00	251.50	889.28	262.11	125.14	658.97
Nov	639.40	306.50	85.75	544.00	833.54	375.22	139.58	747.88
Dec	2276.52	836.00	305.50	3030.00	2107.38	875.10	448.14	2290.69
Jan	2523.43	735.00	235.00	2370.00	2141.34	546.67	229.17	1869.03
Feb	2427.56	600.00	310.00	1620.00	2342.47	732.07	239.33	1787.98
Mar	3798.65	1610.00	596.50	6260.00	2673.48	1266.38	463.86	3301.74
Apr	1164.07	662.00	429.75	1232.50	865.93	445.49	237.54	1151.43
May	1371.10	791.00	337.00	1945.00	1657.45	875.80	240.09	2506.99
Jun	1654.85	829.50	320.75	2202.50	2033.86	809.06	247.30	2728.85
Jul	556.70	210.00	87.50	516.00	495.79	259.32	123.51	574.75
Aug	549.09	78.00	64.00	136.00	637.82	160.26	71.23	339.37
Sep	169.46	83.50	45.25	169.00	376.64	204.21	95.09	366.65

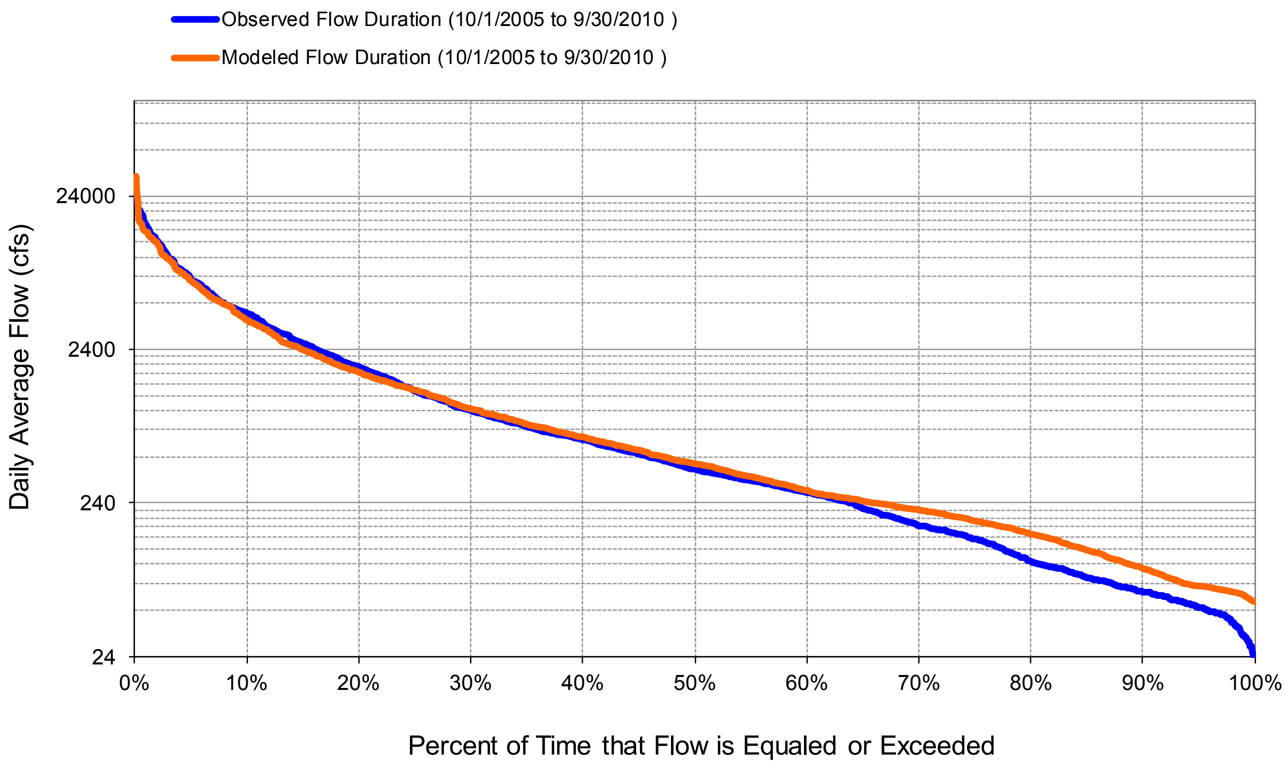


Figure A-55. Flow exceedence at USGS 04198000 Sandusky River near Fremont OH

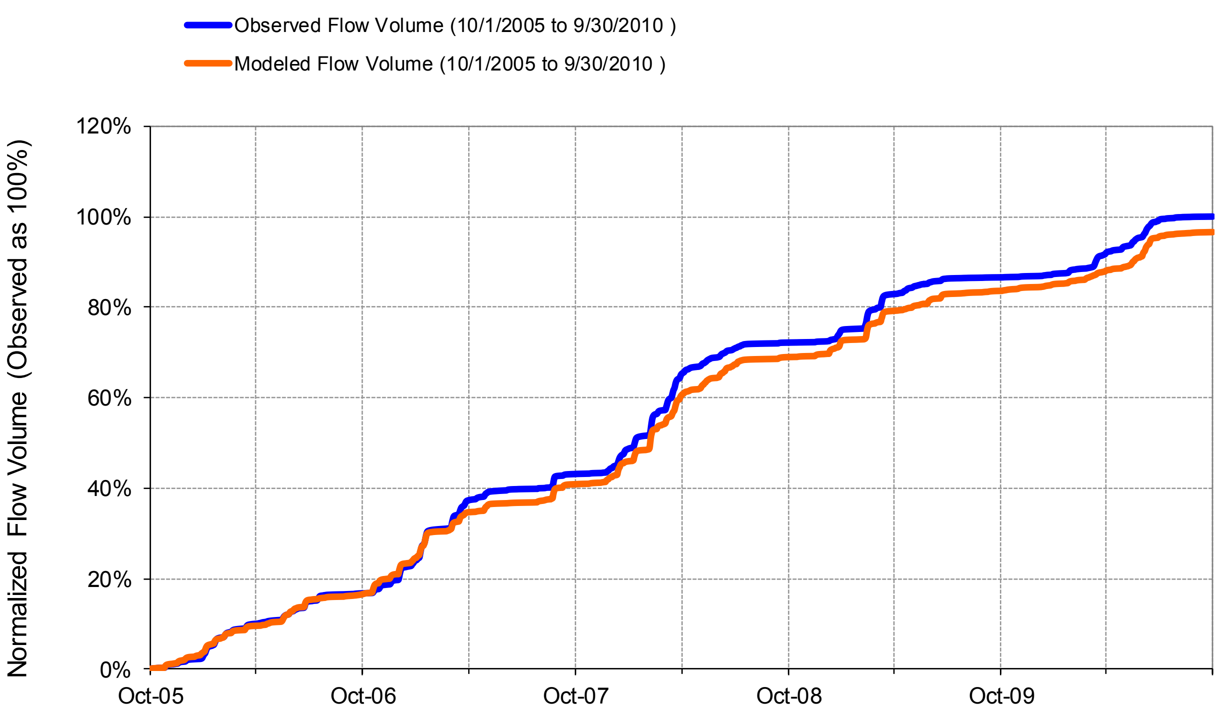


Figure A-56. Flow accumulation at USGS 04198000 Sandusky River near Fremont OH

Table A-16. Summary statistics at USGS 04198000 Sandusky River near Fremont OH

SWAT Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM OUTLET 35 5-Year Analysis Period: 10/1/2005 - 9/30/2010 Flow volumes are (inches/year) for upstream drainage area		Sandusky River near Fremont OH Manually Entered Data Drainage Area (sq-mi): 1251		
Total Simulated In-stream Flow:	**15.39**	Total Observed In-stream Flow:		**15.94**
Total of simulated highest 10% flows:	**8.78**	Total of Observed highest 10% flows:		**9.27**
Total of Simulated lowest 50% flows:	**1.07**	Total of Observed Lowest 50% flows:		**0.90**
Simulated Summer Flow Volume (months 7-9):	**1.37**	Observed Summer Flow Volume (7-9):		**1.16**
Simulated Fall Flow Volume (months 10-12):	**3.51**	Observed Fall Flow Volume (10-12):		**3.14**
Simulated Winter Flow Volume (months 1-3):	**6.40**	Observed Winter Flow Volume (1-3):		**7.86**
Simulated Spring Flow Volume (months 4-6):	**4.11**	Observed Spring Flow Volume (4-6):		**3.78**
Total Simulated Storm Volume:	**11.54**	Total Observed Storm Volume:		**11.55**
Simulated Summer Storm Volume (7-9):	**0.90**	Observed Summer Storm Volume (7-9):		**0.83**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	-3.43	10		
Error in 50% lowest flows:	18.36	10		
Error in 10% highest flows:	-5.25	15		
Seasonal volume error - Summer:	17.99	30		
Seasonal volume error - Fall:	11.77	>> 30	Clear	
Seasonal volume error - Winter:	-18.58	30		
Seasonal volume error - Spring:	8.89	30		
Error in storm volumes:	-0.06	20		
Error in summer storm volumes:	7.48	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.729	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.601	as E or E' approaches 1.0		
Monthly NSE	0.887			

USGS 04198000 Sandusky River near Fremont OH - Validation

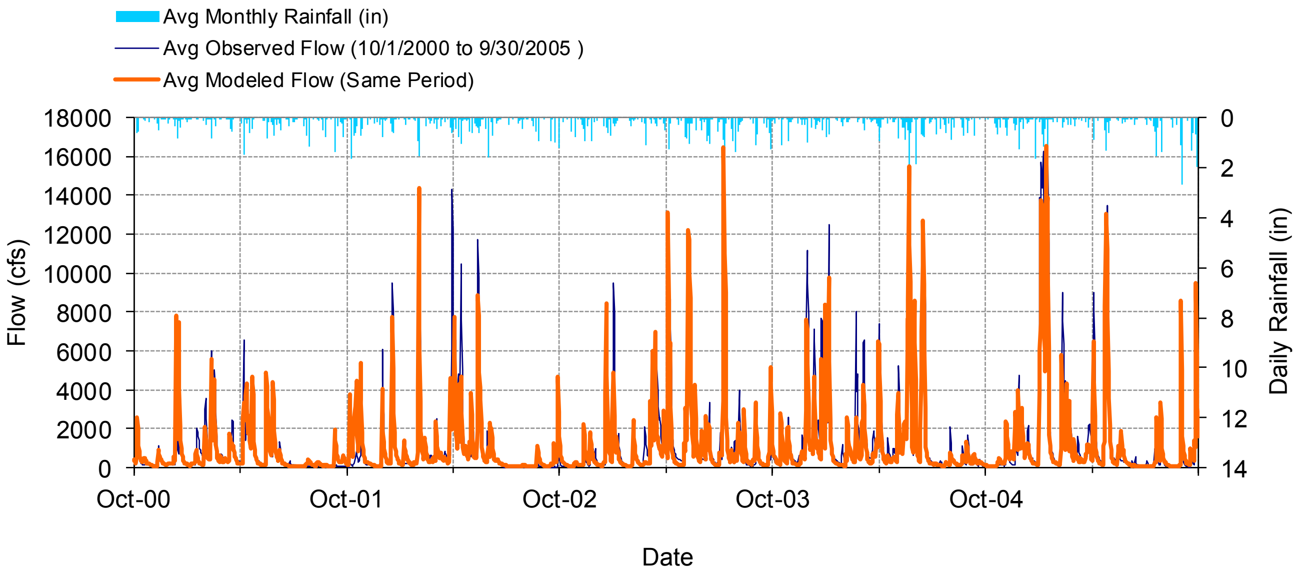


Figure A-57. Mean daily flow at USGS 04198000 Sandusky River near Fremont OH

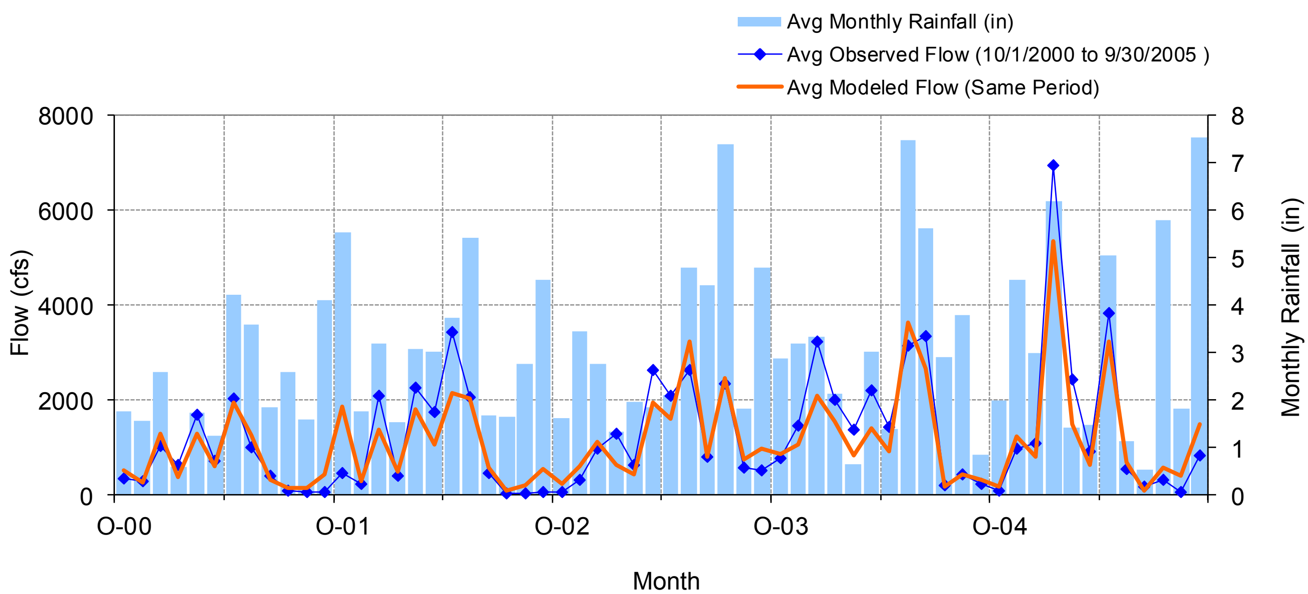


Figure A-58. Mean monthly flow at USGS 04198000 Sandusky River near Fremont OH

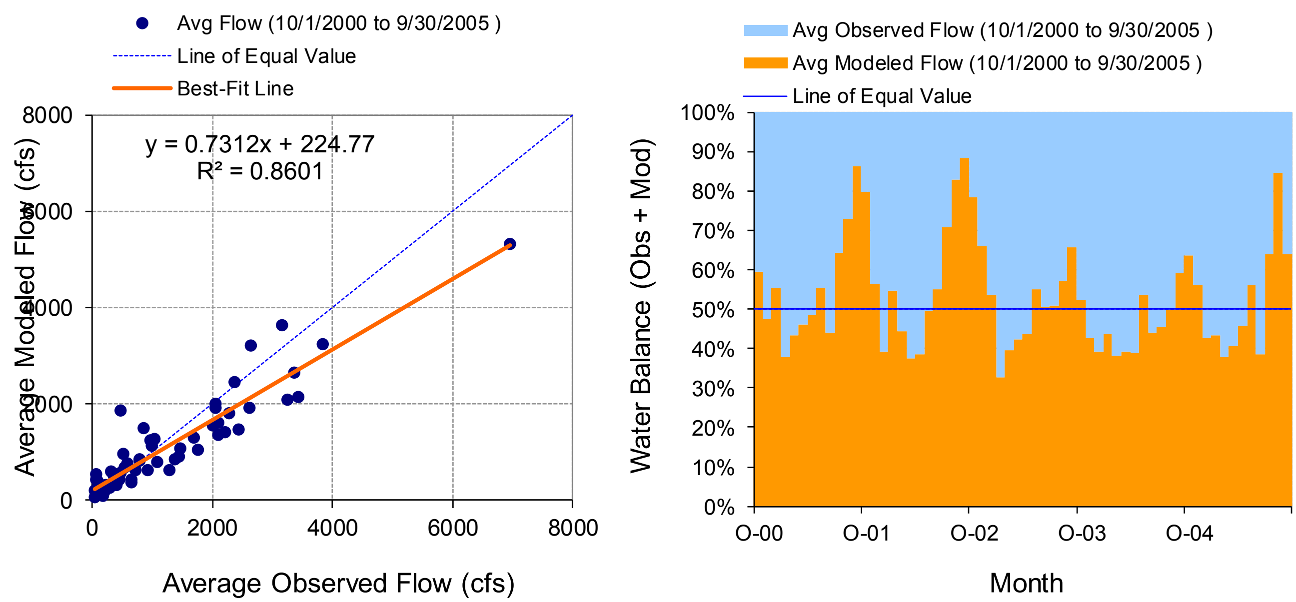


Figure A-59. Monthly flow regression and temporal variation at USGS 04198000 Sandusky River near Fremont OH

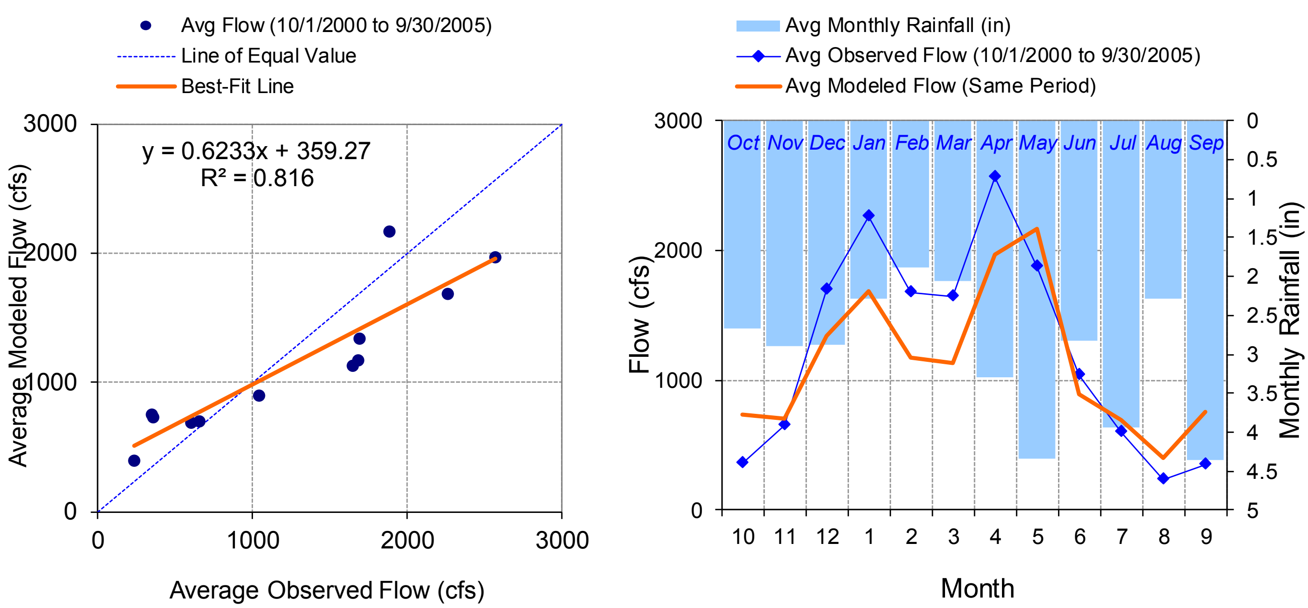


Figure A-60. Seasonal regression and temporal aggregate at USGS 04198000 Sandusky River near Fremont OH

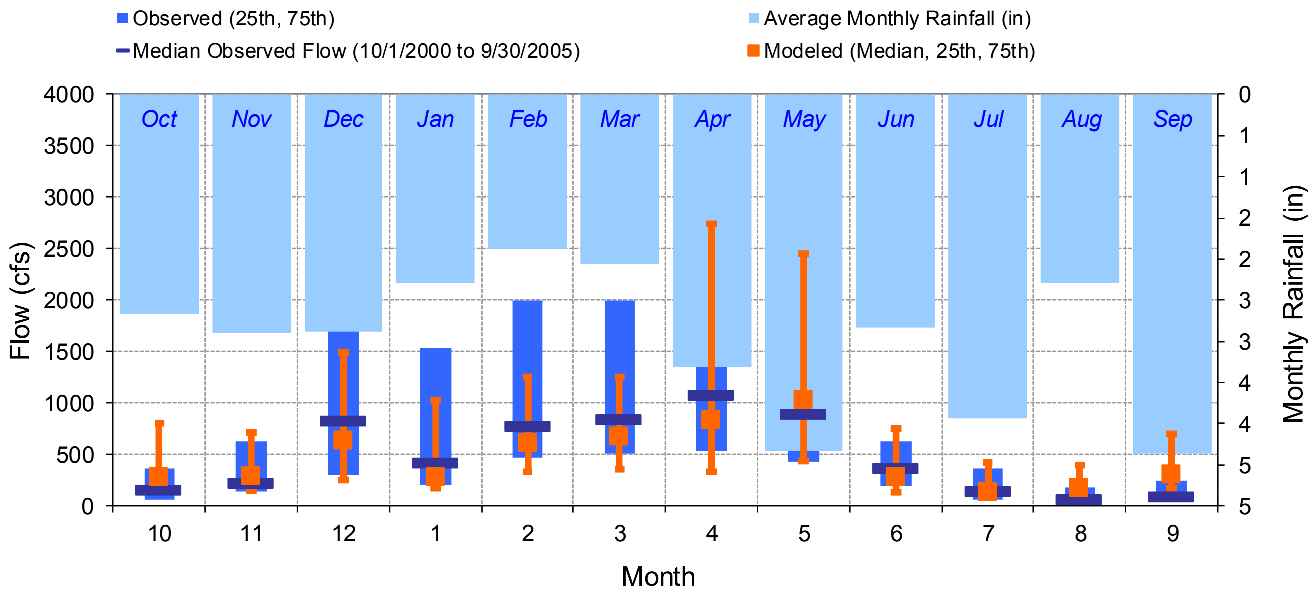


Figure A-61. Seasonal medians and ranges at USGS 04198000 Sandusky River near Fremont OH

Table A-17. Seasonal summary at USGS 04198000 Sandusky River near Fremont OH

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	354.77	165.00	67.50	359.50	731.81	285.17	150.67	812.06
Nov	655.09	230.00	144.00	629.00	700.39	286.35	152.32	711.06
Dec	1692.25	826.00	305.00	2060.00	1337.40	631.07	247.11	1492.40
Jan	2263.31	430.00	210.00	1540.00	1682.77	275.88	169.17	1026.42
Feb	1679.66	773.00	467.00	2000.00	1171.85	601.76	330.40	1250.14
Mar	1649.07	851.00	508.50	1995.00	1134.30	676.28	362.33	1258.61
Apr	2567.39	1085.00	529.75	3602.50	1973.08	826.01	333.16	2740.15
May	1879.96	899.00	425.50	1910.00	2169.55	1027.66	442.85	2447.48
Jun	1038.25	377.50	188.75	633.50	894.43	279.07	132.54	754.06
Jul	603.42	146.00	65.00	364.50	692.02	127.66	87.46	417.07
Aug	237.23	63.00	46.00	179.50	396.07	177.17	101.42	391.64
Sep	344.83	97.00	47.25	249.75	756.02	305.01	174.62	705.68

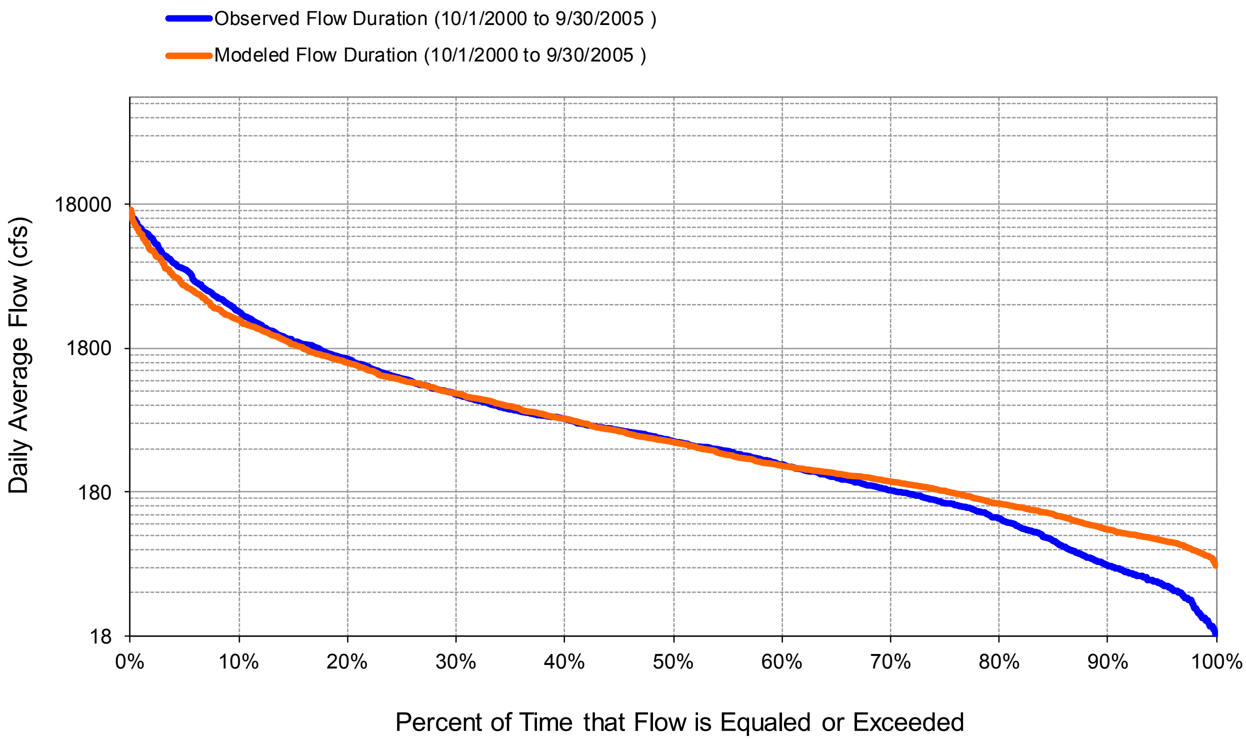


Figure A-62. Flow exceedence at USGS 04198000 Sandusky River near Fremont OH

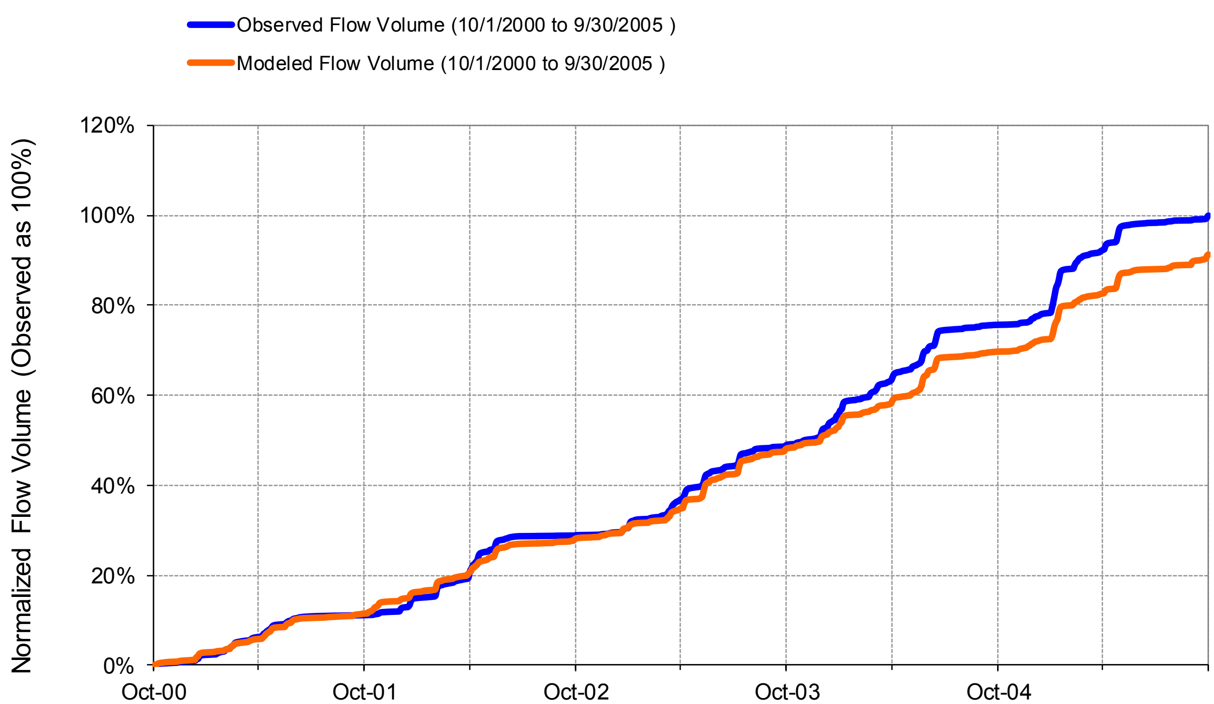
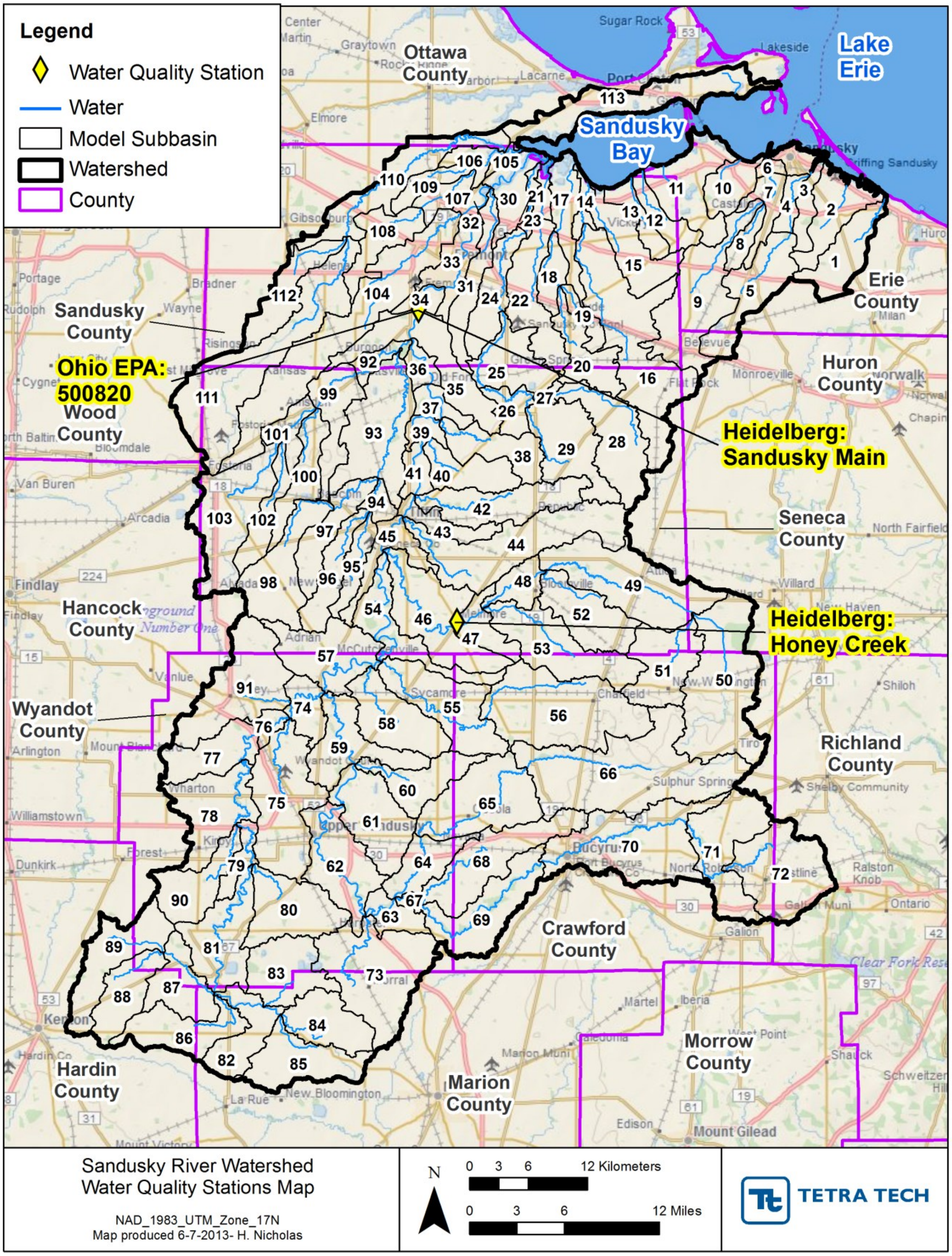


Figure A-63. Flow accumulation at USGS 04198000 Sandusky River near Fremont OH

Table A-18. Summary statistics at USGS 04198000 Sandusky River near Fremont OH

SWAT Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM OUTLET 35 5-Year Analysis Period: 10/1/2000 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		Sandusky River near Fremont OH Manually Entered Data Drainage Area (sq-mi): 1251		
Total Simulated In-stream Flow:	**12.35**	Total Observed In-stream Flow:		**13.52**
Total of simulated highest 10% flows:	**6.66**	Total of Observed highest 10% flows:		**7.78**
Total of Simulated lowest 50% flows:	**1.05**	Total of Observed Lowest 50% flows:		**0.92**
Simulated Summer Flow Volume (months 7-9):	**1.68**	Observed Summer Flow Volume (7-9):		**1.08**
Simulated Fall Flow Volume (months 10-12):	**2.53**	Observed Fall Flow Volume (10-12):		**2.47**
Simulated Winter Flow Volume (months 1-3):	**3.58**	Observed Winter Flow Volume (1-3):		**5.01**
Simulated Spring Flow Volume (months 4-6):	**4.56**	Observed Spring Flow Volume (4-6):		**4.95**
Total Simulated Storm Volume:	**8.73**	Total Observed Storm Volume:		**9.23**
Simulated Summer Storm Volume (7-9):	**1.19**	Observed Summer Storm Volume (7-9):		**0.78**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	-8.66	10		
Error in 50% lowest flows:	13.52	10		
Error in 10% highest flows:	-14.31	15		
Seasonal volume error - Summer:	54.95	30		
Seasonal volume error - Fall:	2.46	30		
Seasonal volume error - Winter:	-28.62	>> 30	Clear	
Seasonal volume error - Spring:	-7.91	30		
Error in storm volumes:	-5.32	20		
Error in summer storm volumes:	53.00	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.719	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.577	as E or E' approaches 1.0		
Monthly NSE	0.833			

Appendix B - Water Quality Calibration/Validation



Honey Creek at Melmore (Heidelberg)

Table B-1. Summary statistics

Statistic	Calibration						Validation					
	TSS	TKN	NOx	TN	SRP	TP	TSS	TKN	NOx	TN	SRP	TP
Average absolute error	46.9%	48.4%	47.0%	37.7%	54.7%	53.3%	55.3%	65.4%	59.7%	52.6%	63.4%	66.1%
Median absolute error	9.2%	22.5%	17.4%	17.0%	24.7%	23.8%	22.7%	34.2%	22.5%	29.1%	38.7%	38.0%
Regression error	21.8%	29.0%	21.5%	14.2%	14.4%	20.1%	15.8%	30.2%	-0.3%	-2.7%	9.6%	17.4%
NSE	0.633	0.618	0.590	0.757	0.624	0.642	0.753	0.566	0.301	0.498	0.606	0.623
NSE'	0.597	0.518	0.505	0.598	0.476	0.517	0.489	0.317	0.324	0.402	0.356	0.360

Total Suspended Solids (TSS)

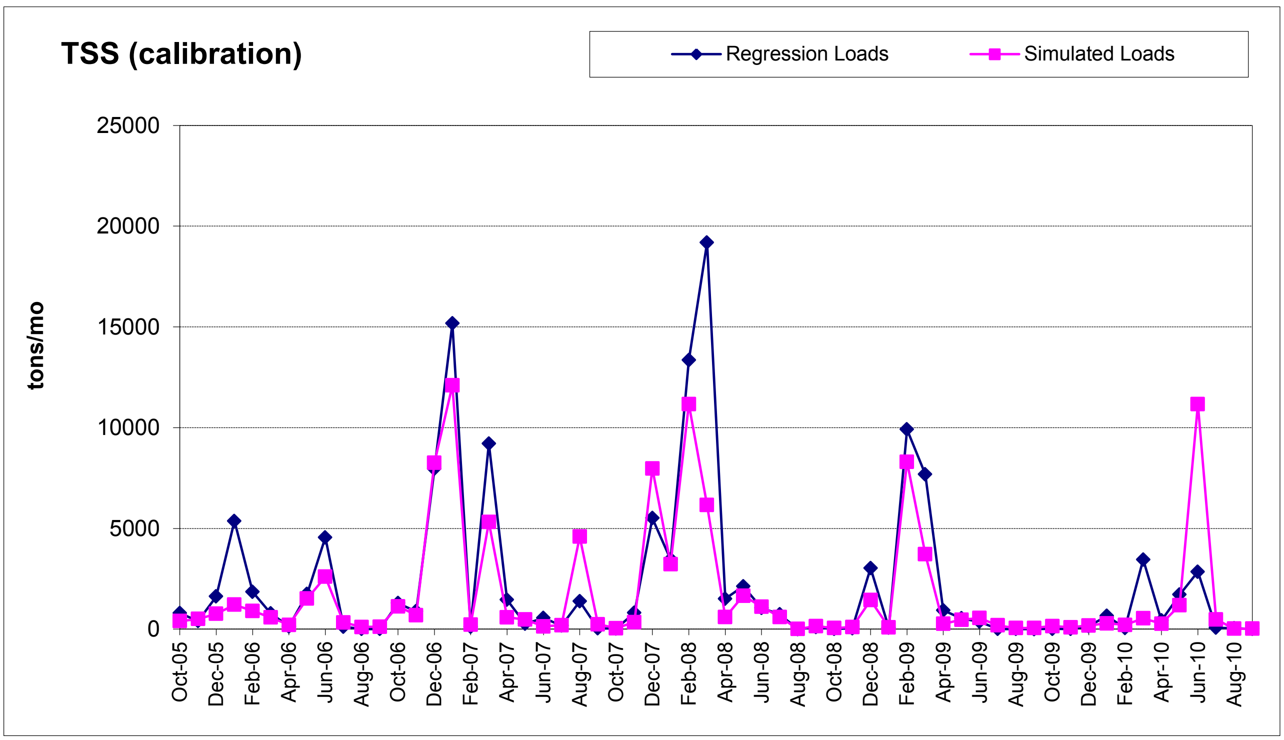


Figure B-1. Monthly simulated and estimated Total Suspended Solids (TSS) load at Honey Creek at Melmore (calibration period)

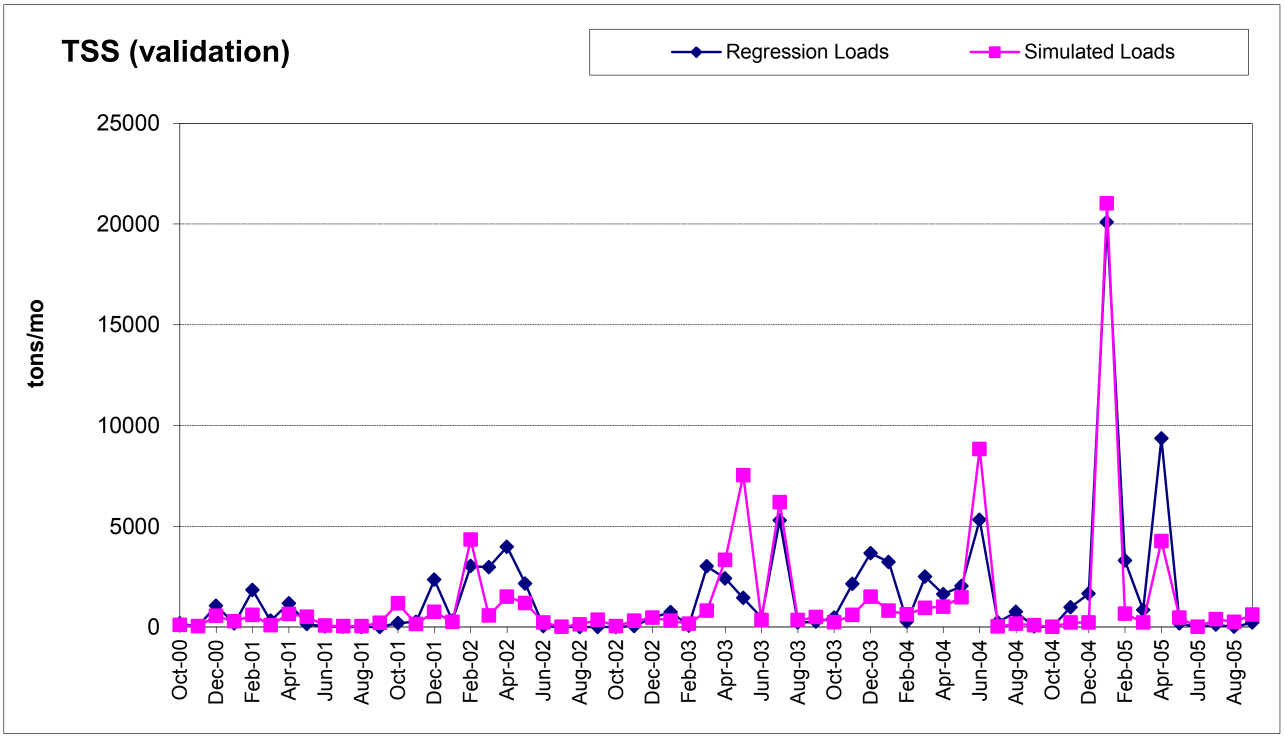


Figure B-2. Monthly simulated and estimated Total Suspended Solids (TSS) load at Honey Creek at Melmore (validation period)

Table B-2. Paired daily Total Suspended Solids (TSS) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	**Ave**	**Median**	**Ave**	**Median**	**Ave**	**Median**
Simulated	40.961	2.046	63.284	2.782	50.161	2.387
Observed	39.559	0.779	71.224	1.290	52.610	0.921

The power plots of TSS loads versus flow (Figure B-3 and Figure B-4) show that the simulated and observed loads generally track well with each other. However, sometimes the simulated loads are very low compared to the observed loads. This is probably on account of the method used by the developers of SWAT to simulate deposition of sediment size fractions in a reach. SWAT uses Einstein's equations to simulate settling of sediment in a reach. Einstein's equations are applicable only to non-cohesive sediment fractions. However, the SWAT code uses these equations for both cohesive and non-cohesive sediment fractions. As a result, under certain circumstances majority of the sediment load settles out. It is important to note that these discrepancies have little to no impact when comparing loads at a monthly or annual scale.

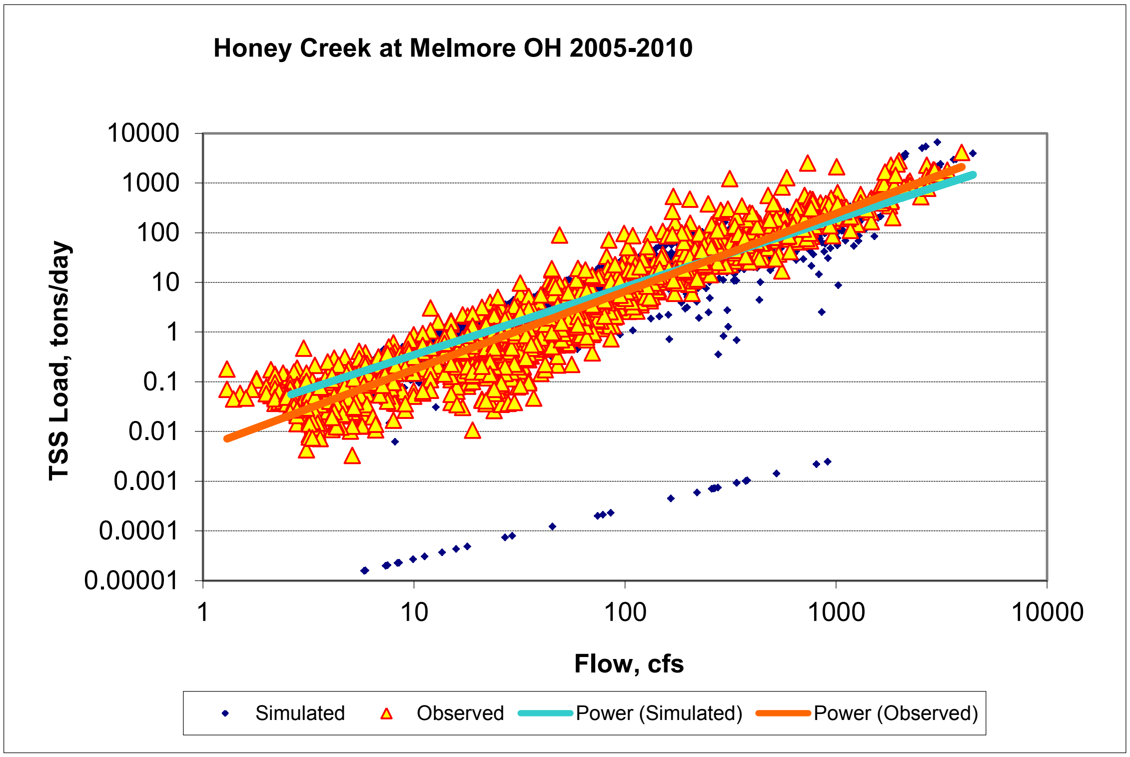


Figure B-3. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow at Honey Creek at Melmore (calibration period)

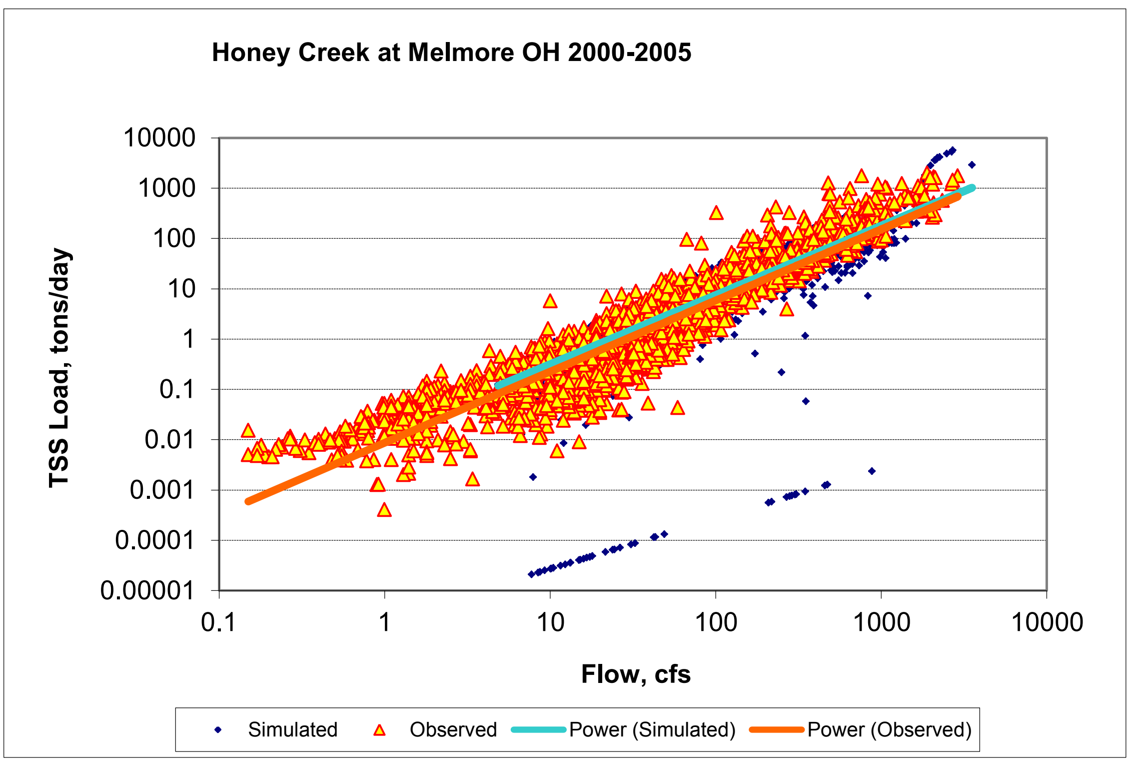


Figure B-4. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow at Honey Creek at Melmore (validation period)

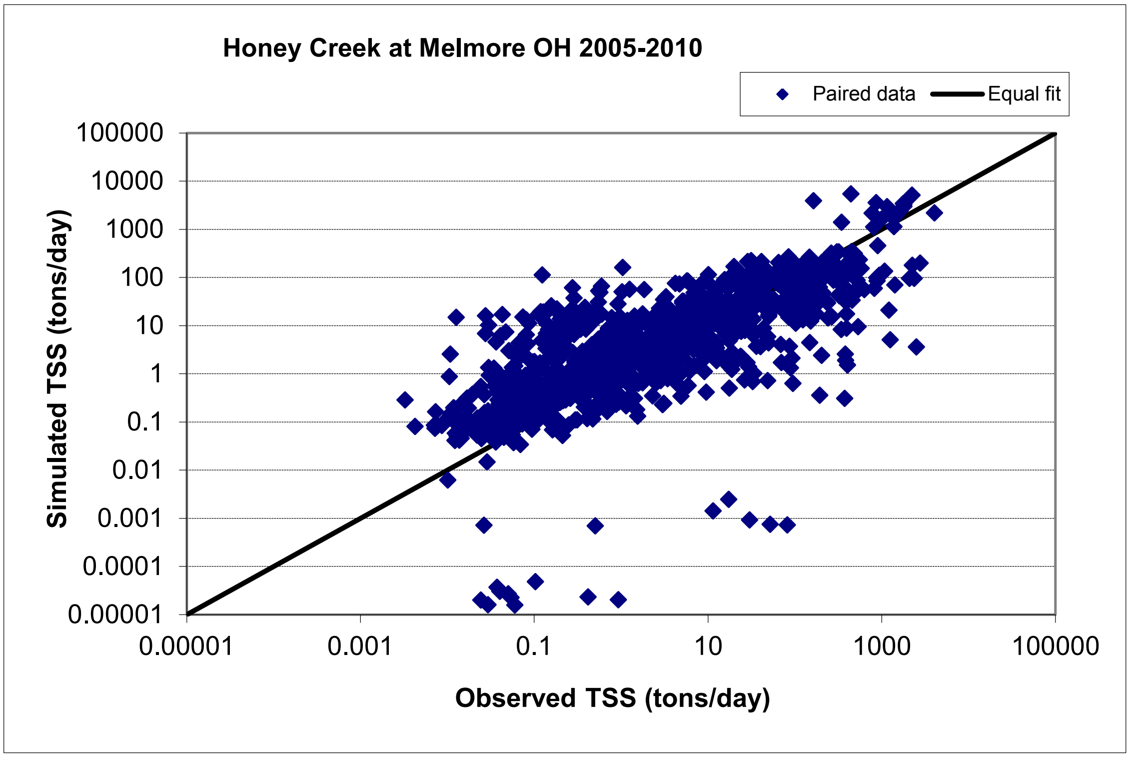


Figure B-5. Paired simulated vs observed Total Suspended Solids (TSS) load at Honey Creek at Melmore (calibration period)

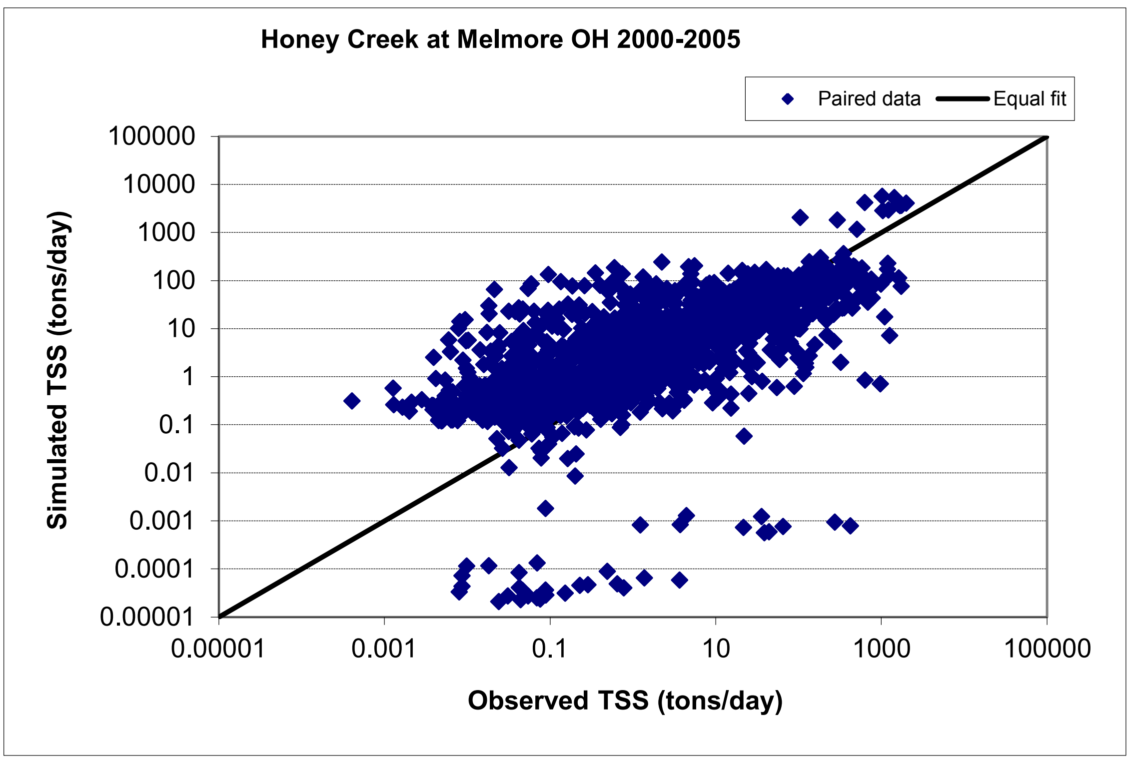


Figure B-6. Paired simulated vs observed Total Suspended Solids (TSS) load at Honey Creek at Melmore (validation period)

Total Kjeldahl Nitrogen (TKN)

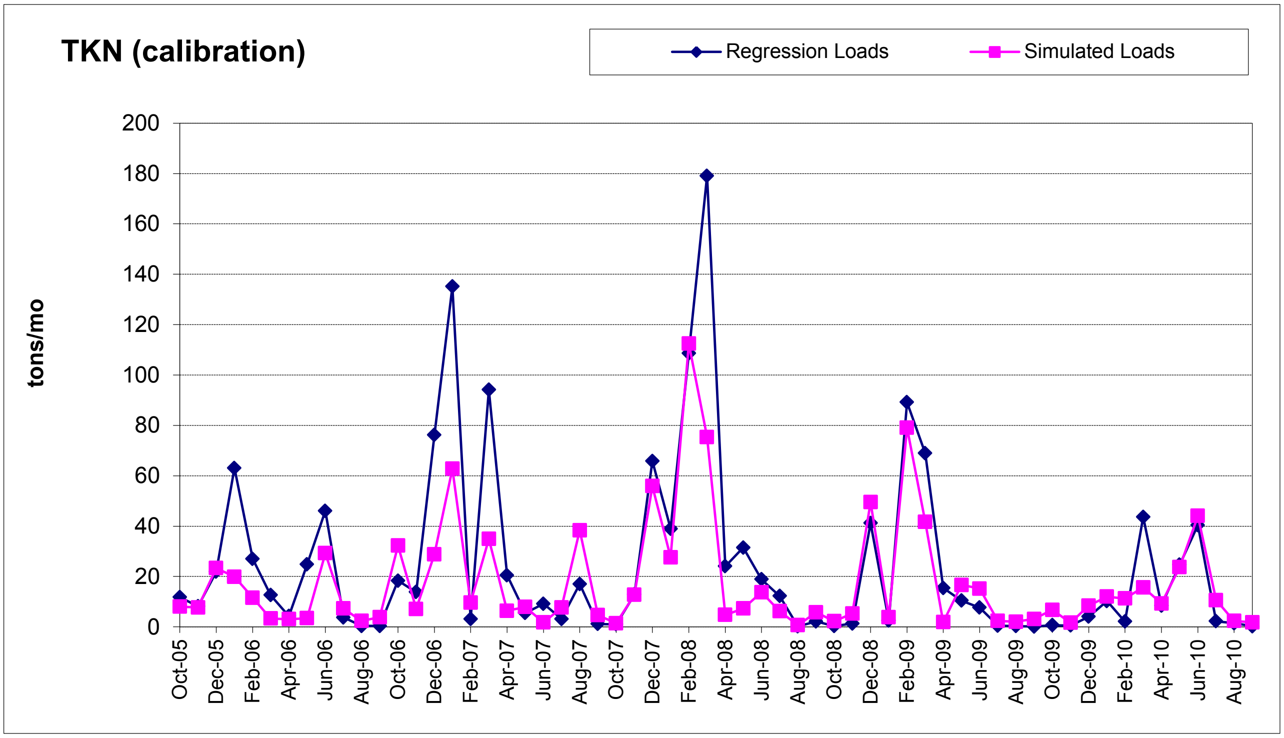


Figure B-7. Monthly simulated and estimated Total Kjeldahl Nitrogen (TKN) load at Honey Creek at Melmore (calibration period)

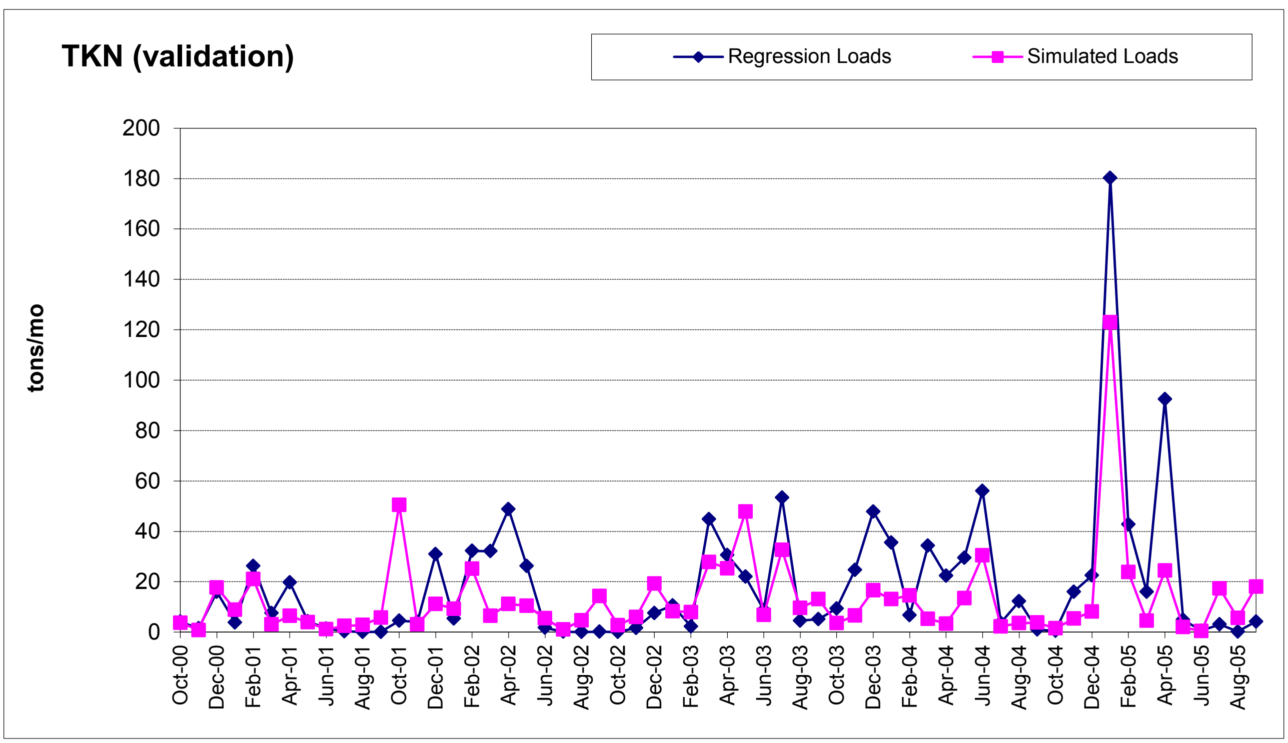


Figure B-8. Monthly simulated and estimated Total Kjeldahl Nitrogen (TKN) load at Honey Creek at Melmore (validation period)

Table B-3. Paired daily Total Kjeldahl Nitrogen (TKN) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	0.416	0.068	0.596	0.080	0.492	0.071
Observed	0.567	0.068	0.862	0.075	0.691	0.071

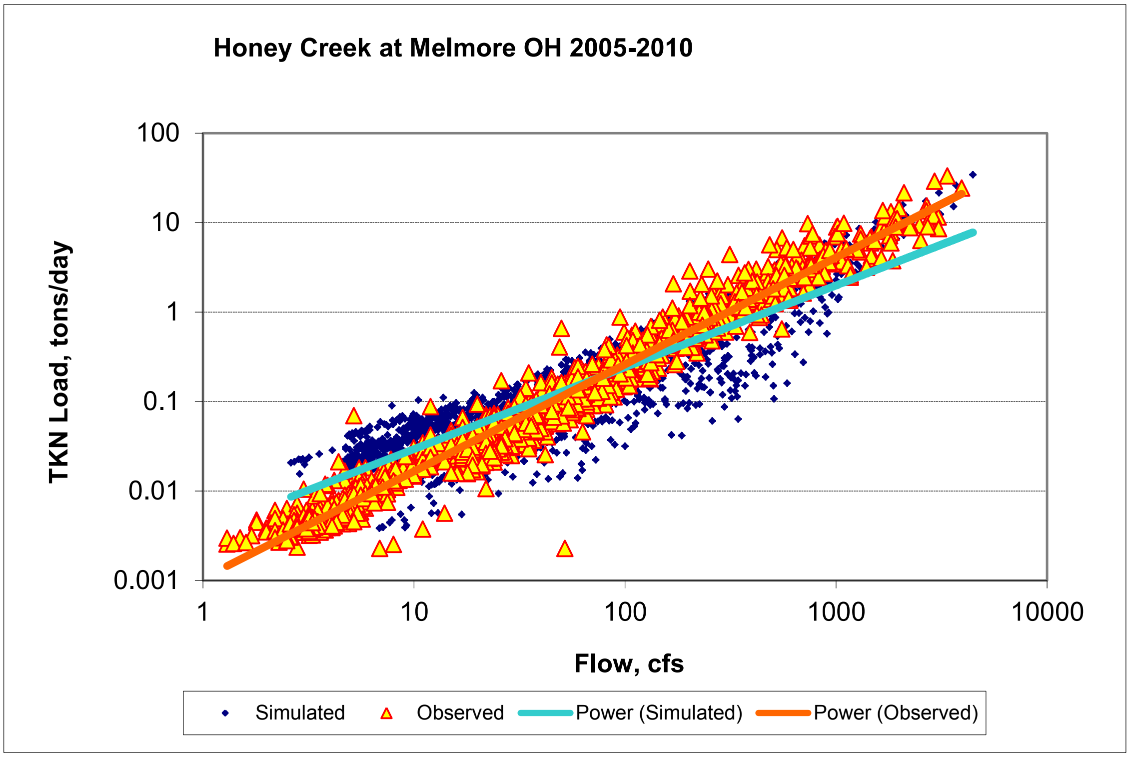


Figure B-9. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Honey Creek at Melmore (calibration period)

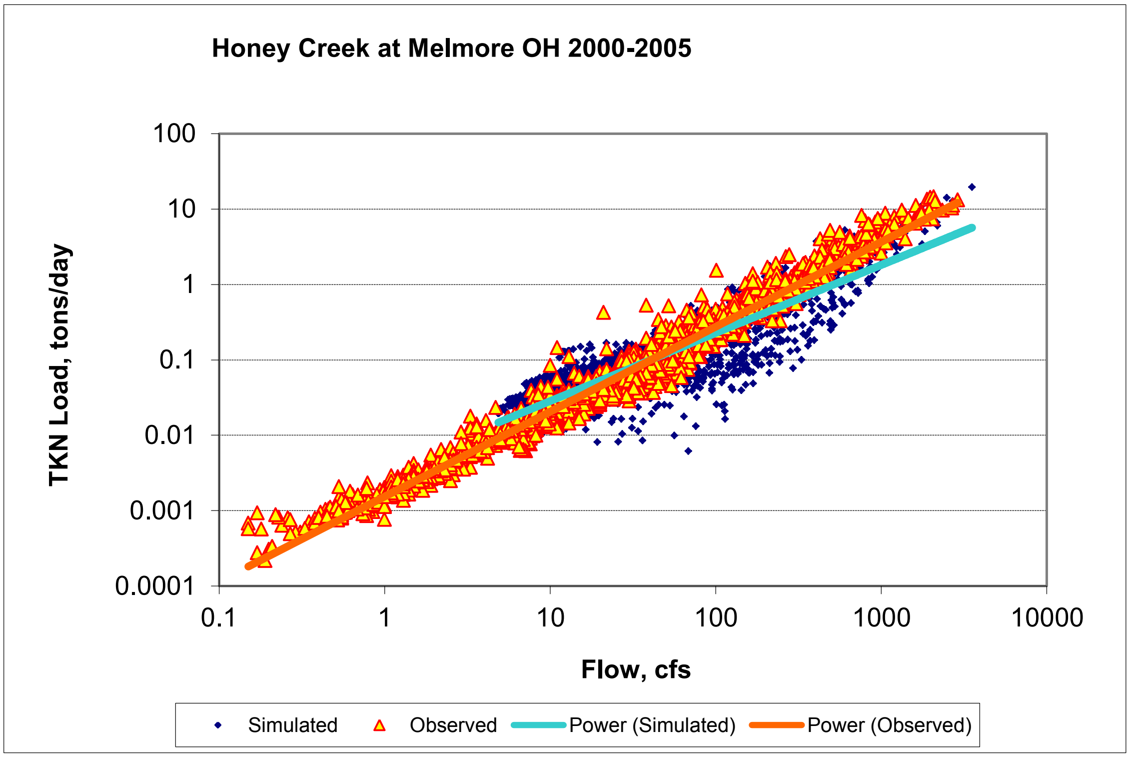


Figure B-10. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Honey Creek at Melmore (validation period)

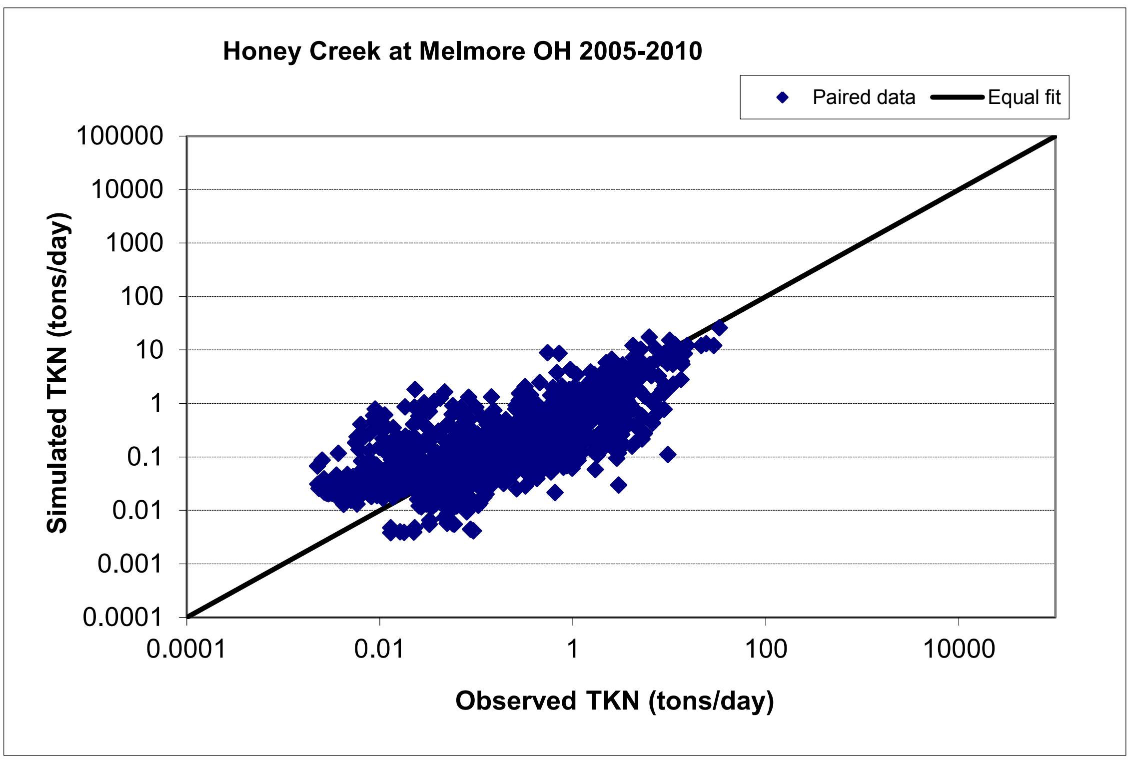


Figure B-11. Paired simulated vs observed Total Kjeldahl Nitrogen (TKN) load at Honey Creek at Melmore (calibration period)

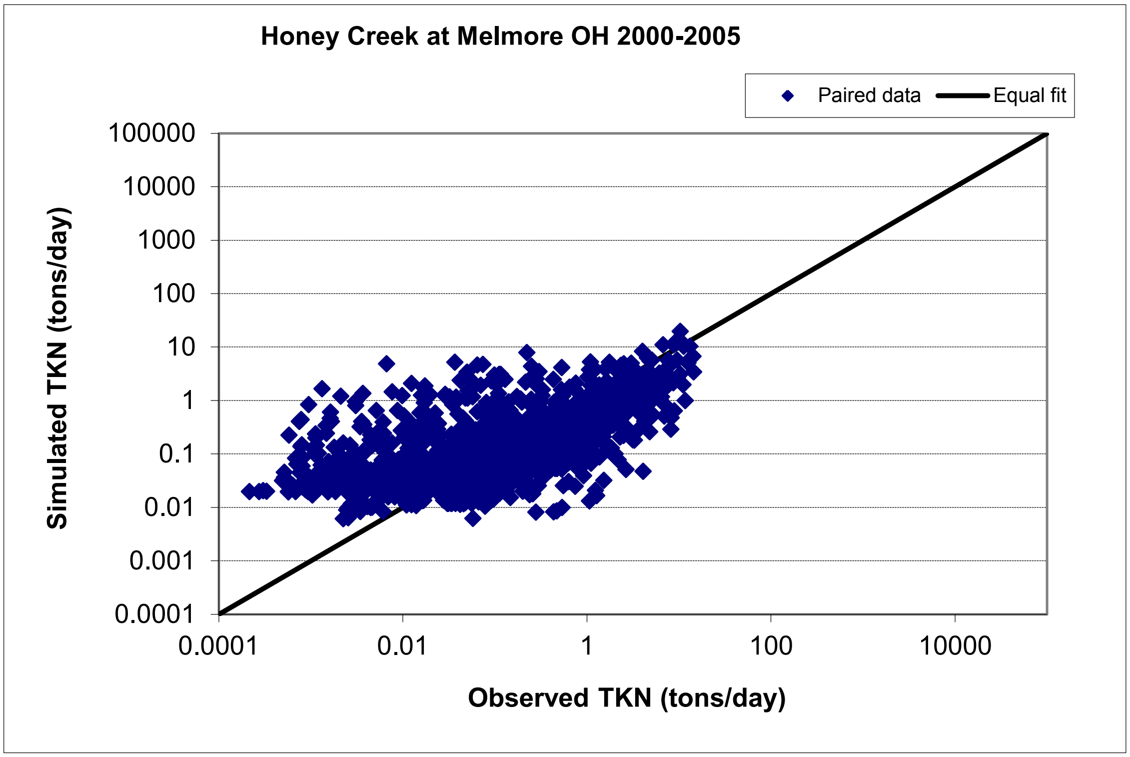


Figure B-12. Paired simulated vs observed Total Kjeldahl Nitrogen (TKN) load at Honey Creek at Melmore (validation period)

Nitrite+ Nitrate Nitrogen (NOx)

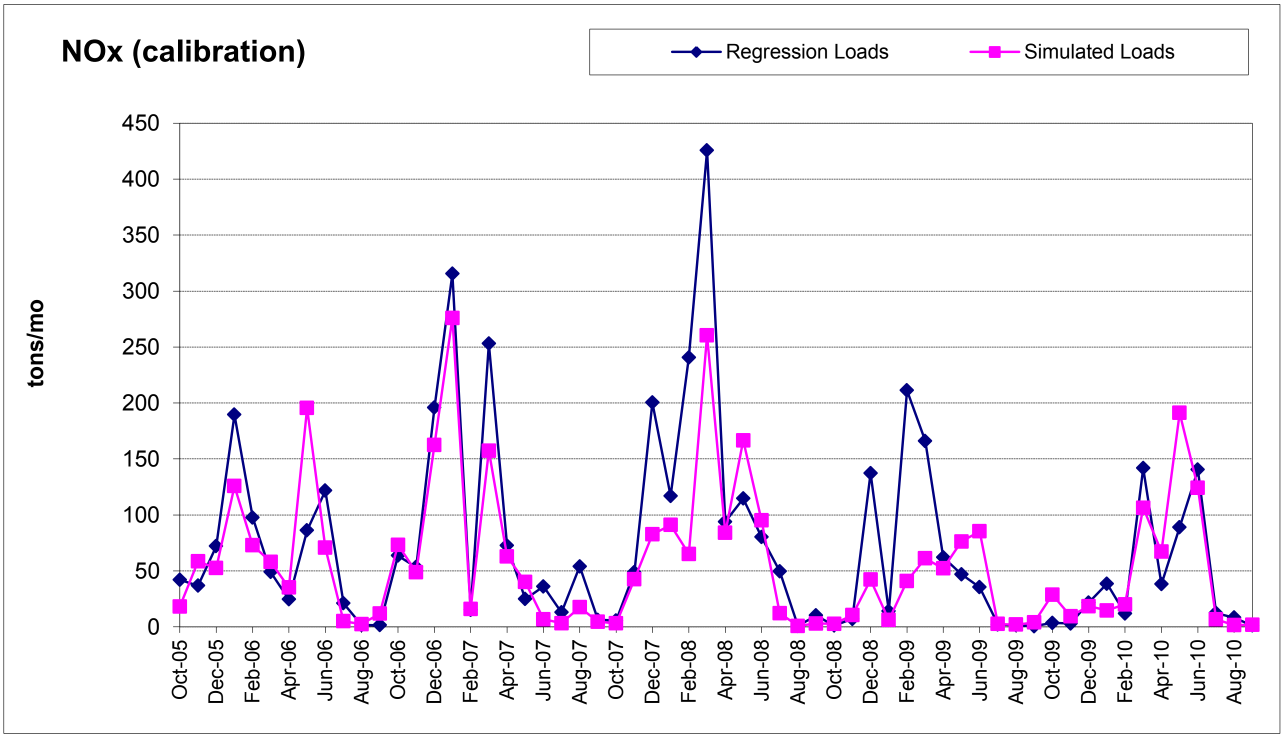


Figure B-13. Monthly simulated and estimated Nitrite+ Nitrate Nitrogen (NOx) load at Honey Creek at Melmore (calibration period)

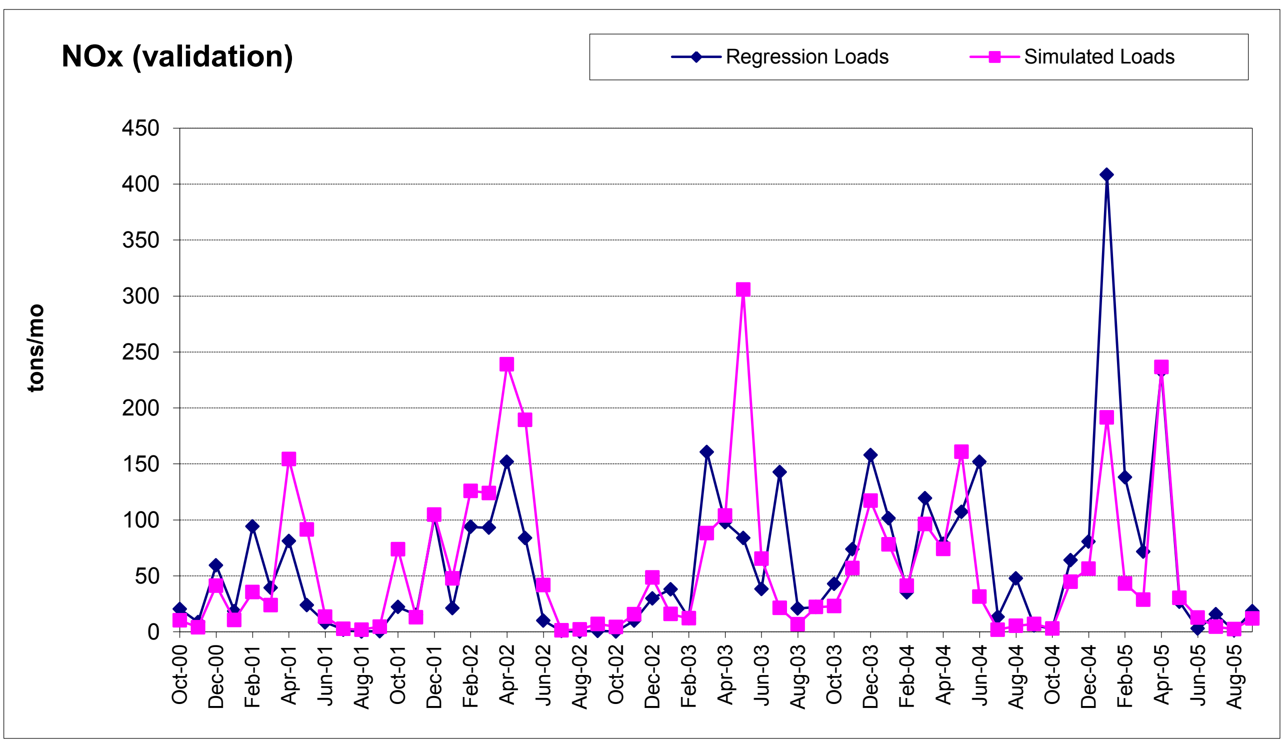


Figure B-14. Monthly simulated and estimated Nitrite+ Nitrate Nitrogen (NOx) load at Honey Creek at Melmore (validation period)

Table B-4. Paired daily Nitrite+ Nitrate Nitrogen (NOx) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	1.892	0.278	2.081	0.319	1.971	0.294
Observed	2.049	0.397	2.298	0.442	2.153	0.411

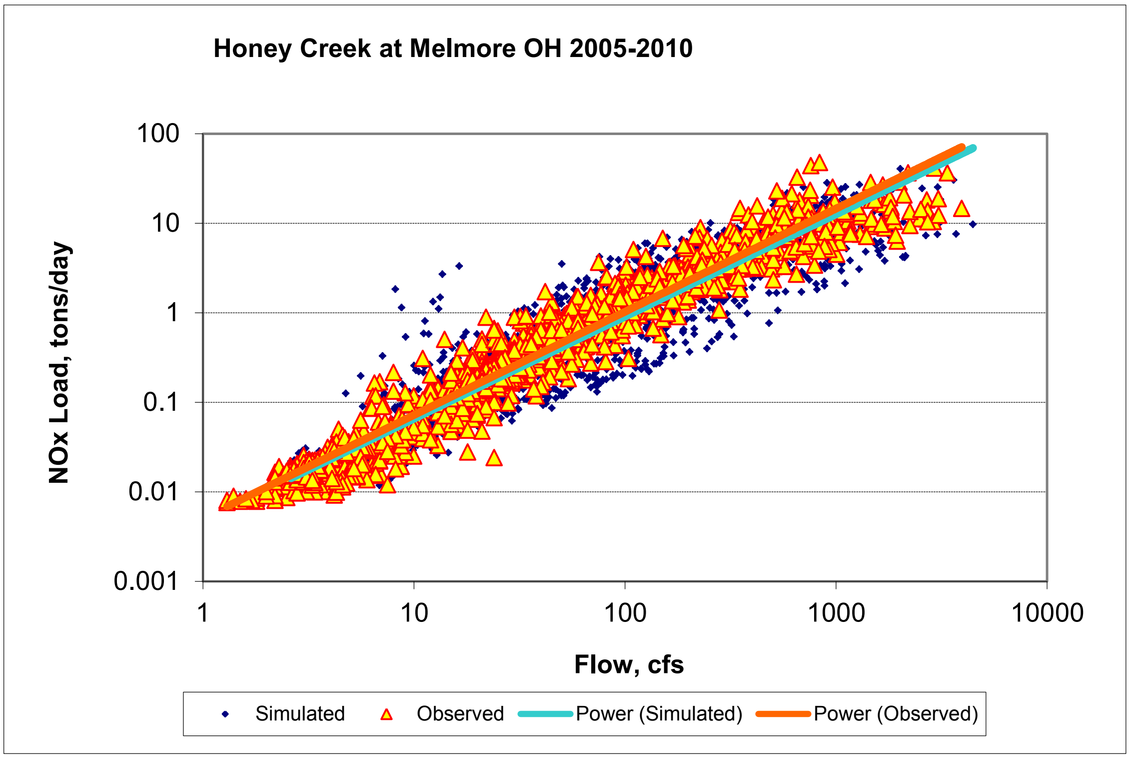


Figure B-15. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Honey Creek at Melmore (calibration period)

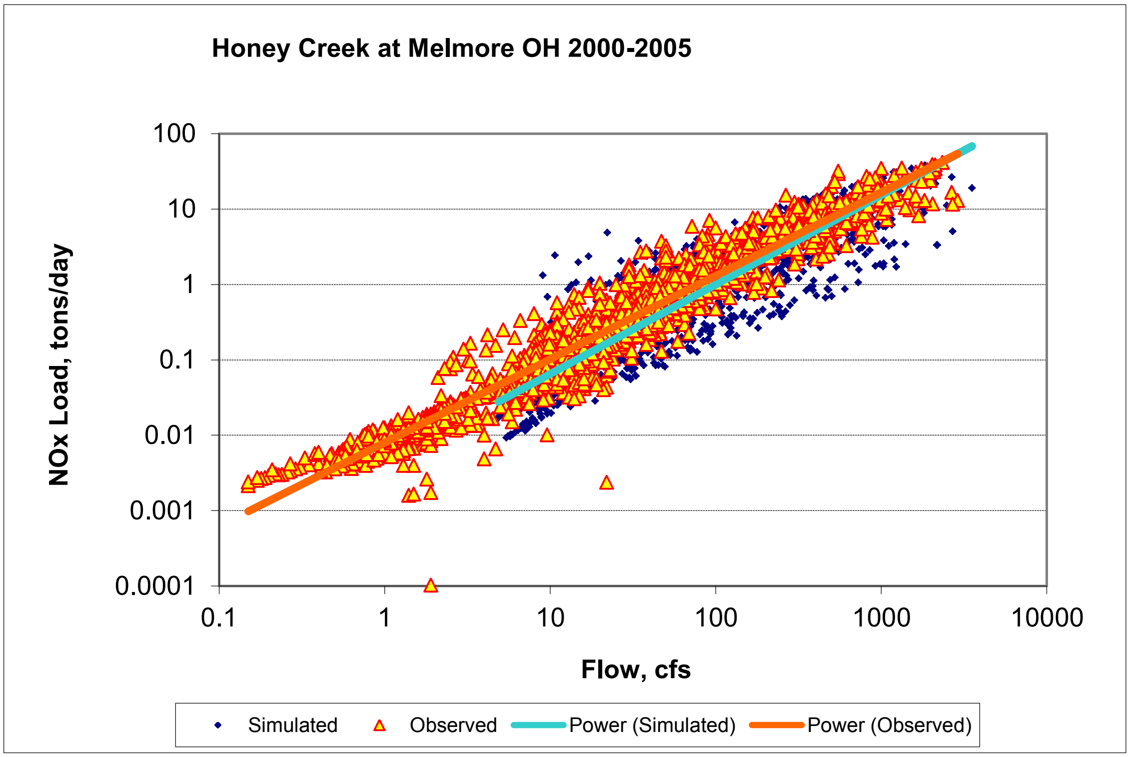


Figure B-16. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Honey Creek at Melmore (validation period)

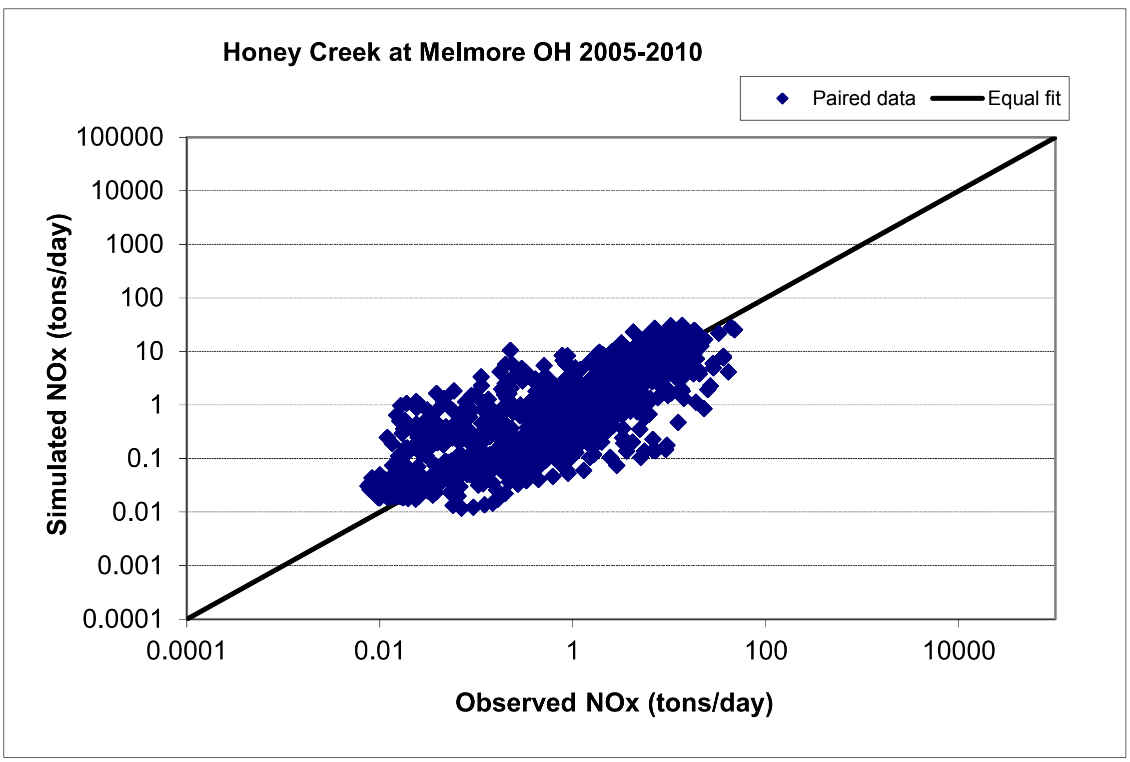


Figure B-17. Paired simulated vs observed Nitrite+ Nitrate Nitrogen (NOx) load at Honey Creek at Melmore (calibration period)

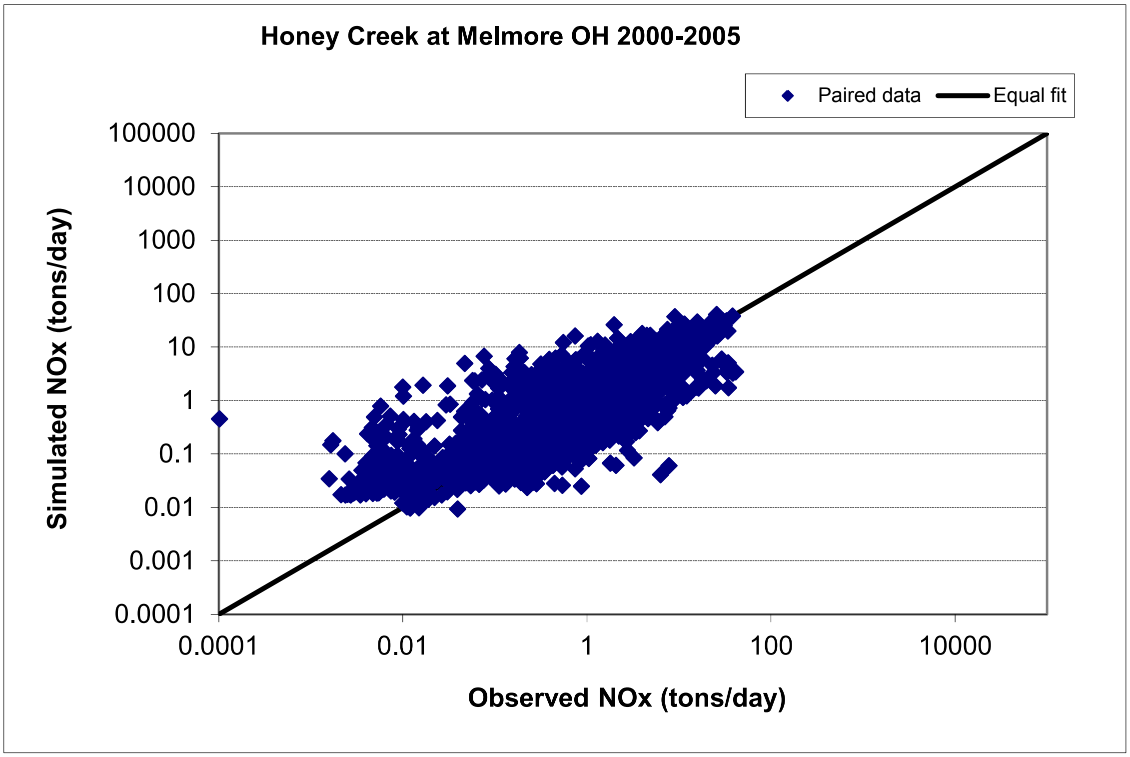


Figure B-18. Paired simulated vs observed Nitrite+ Nitrate Nitrogen (NOx) load at Honey Creek at Melmore (validation period)

Total Nitrogen (TN)

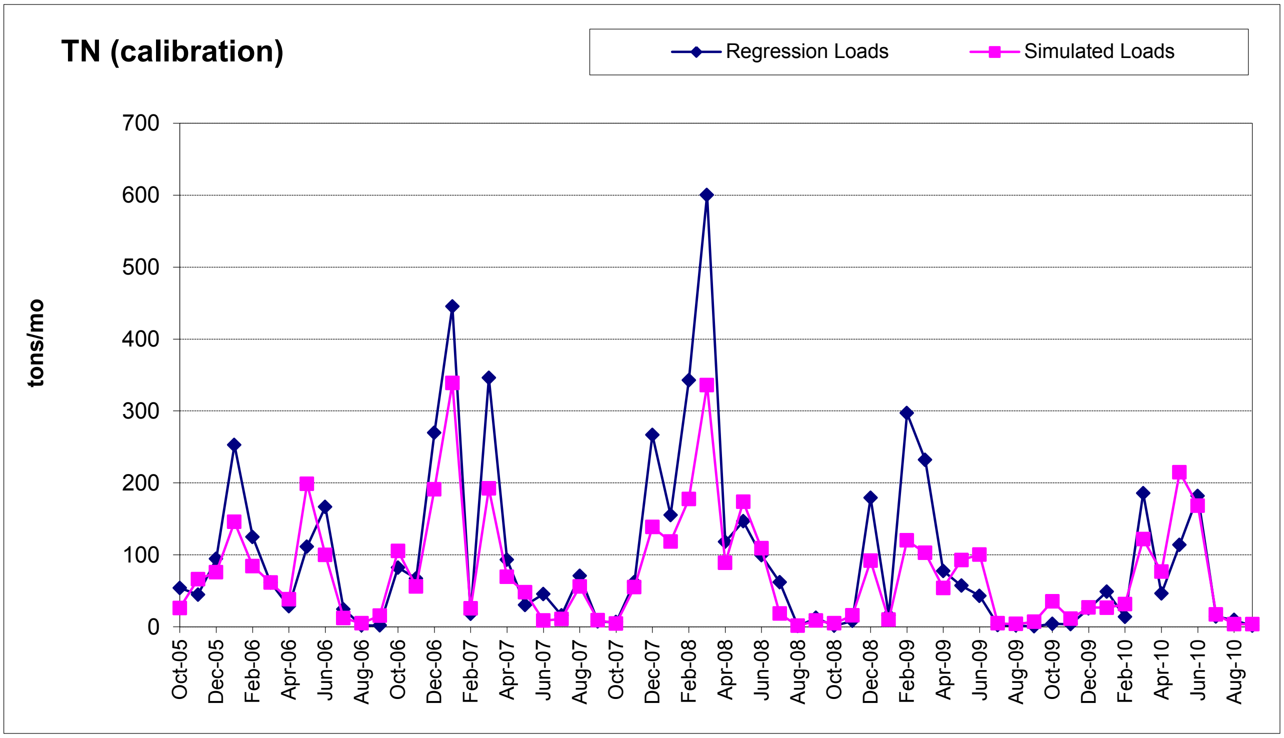


Figure B-19. Monthly simulated and estimated Total Nitrogen (TN) load at Honey Creek at Melmore (calibration period)

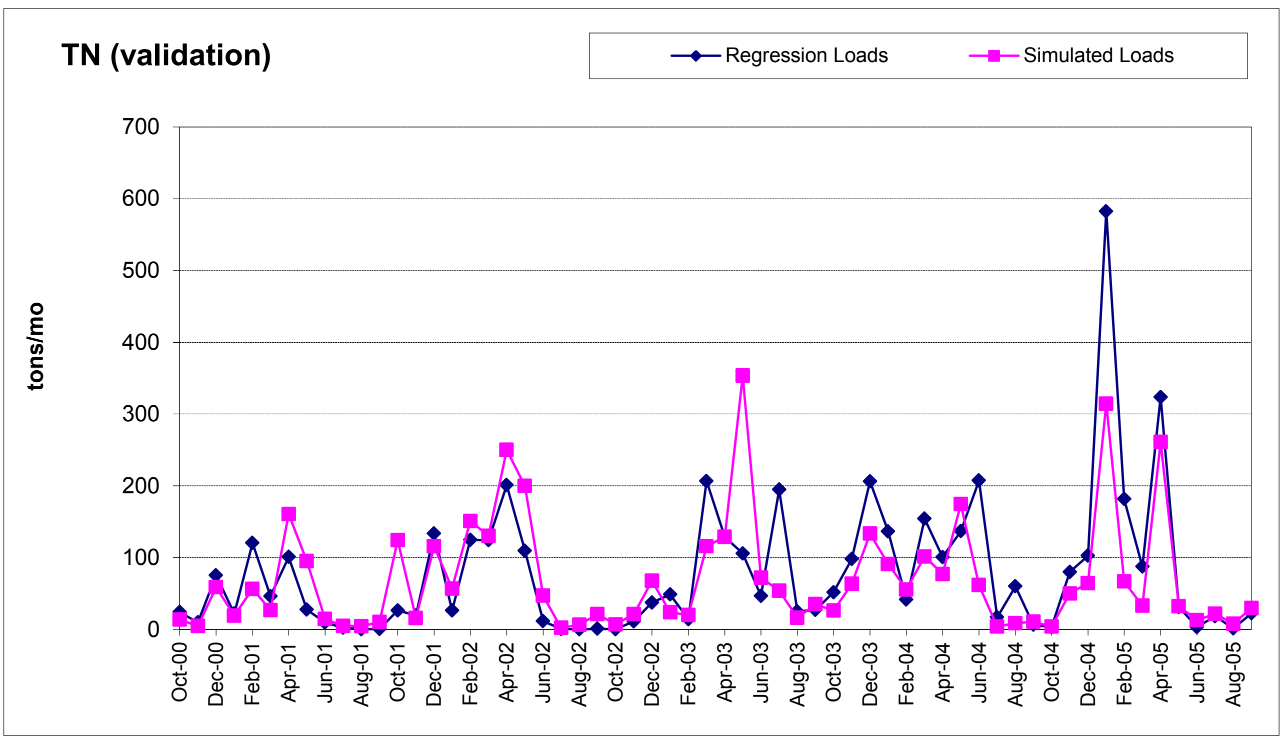


Figure B-20. Monthly simulated and estimated Total Nitrogen (TN) load at Honey Creek at Melmore (validation period)

Table B-5. Paired daily Total Nitrogen (TN) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	**Ave**	**Median**	**Ave**	**Median**	**Ave**	**Median**
Simulated	2.332	0.417	2.687	0.460	2.481	0.435
Observed	2.643	0.476	3.170	0.509	2.865	0.490

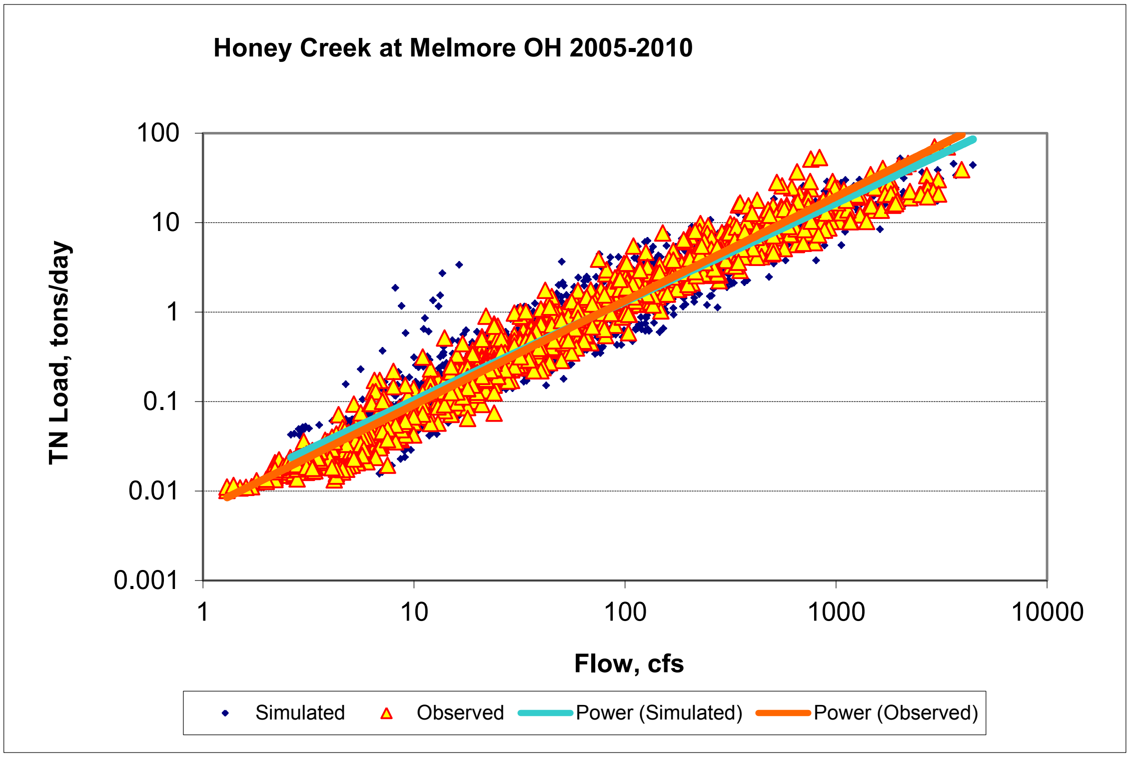


Figure B-21. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Honey Creek at Melmore (calibration period)

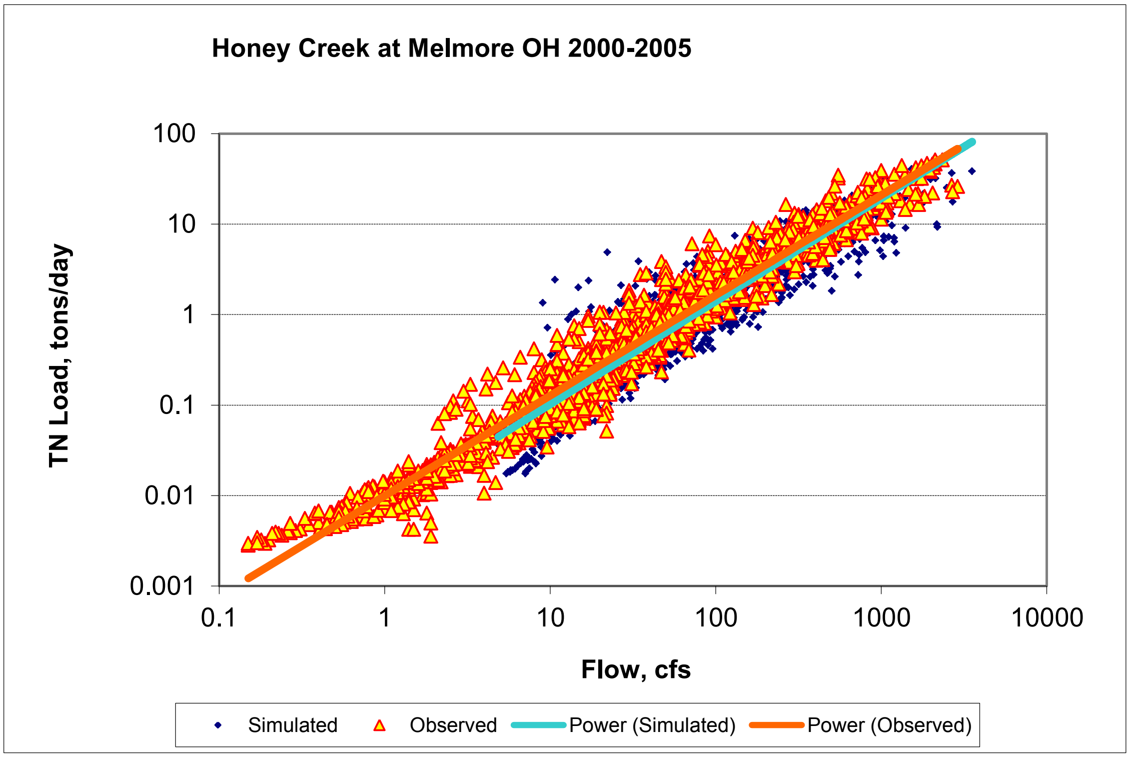


Figure B-22. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Honey Creek at Melmore (validation period)

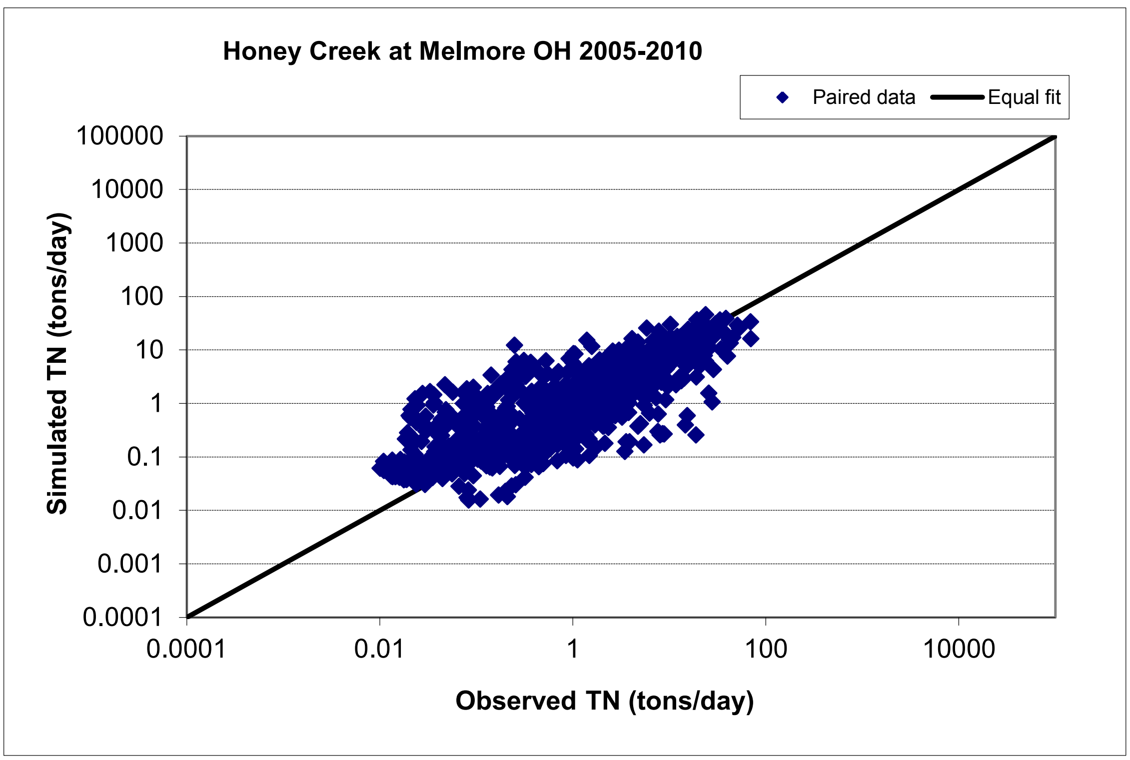


Figure B-23. Paired simulated vs observed Total Nitrogen (TN) load at Honey Creek at Melmore (calibration period)

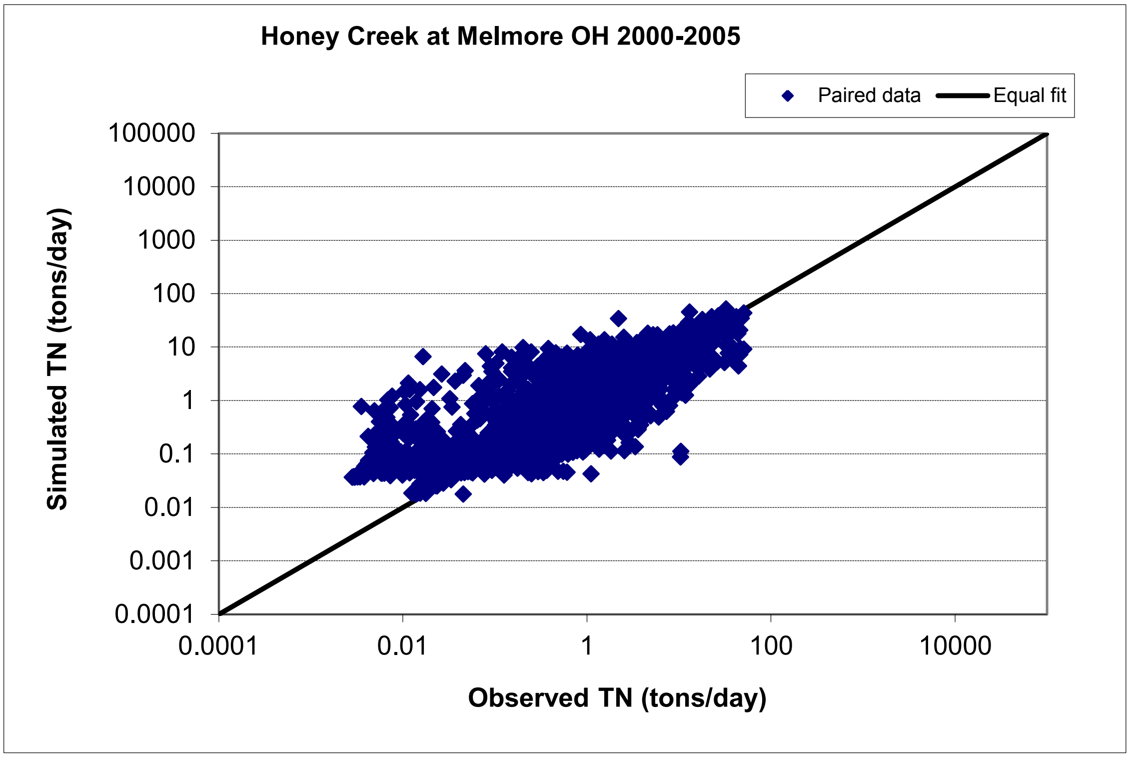


Figure B-24. Paired simulated vs observed Total Nitrogen (TN) load at Honey Creek at Melmore (validation period)

Soluble Reactive Phosphorus (SRP)

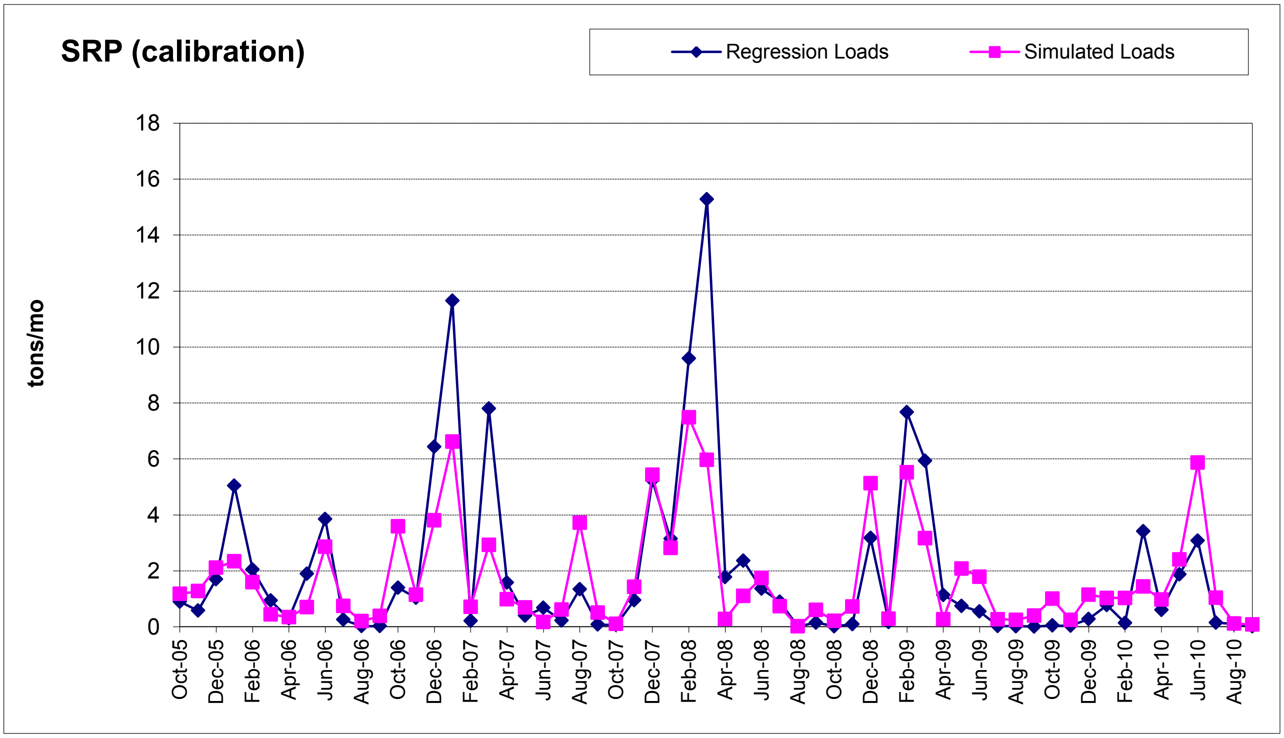


Figure B-25. Monthly simulated and estimated Soluble Reactive Phosphorus (SRP) load at Honey Creek at Melmore (calibration period)

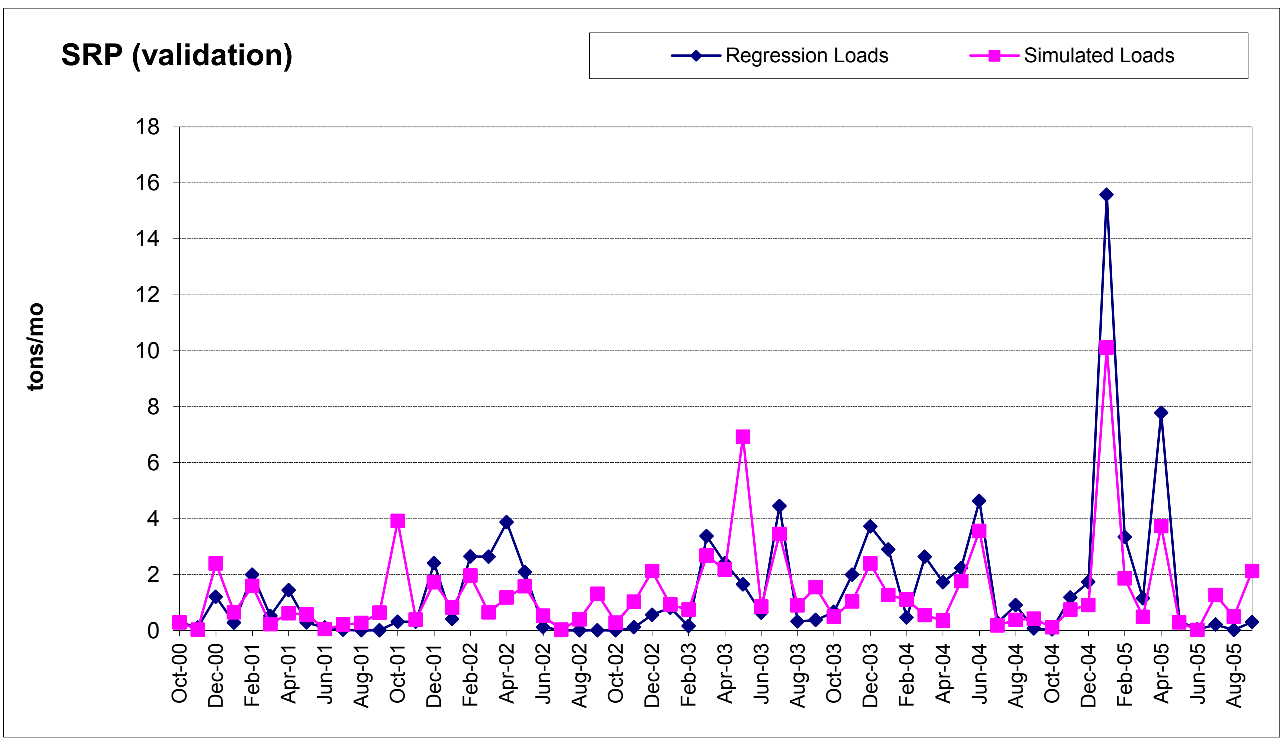


Figure B-26. Monthly simulated and estimated Soluble Reactive Phosphorus (SRP) load at Honey Creek at Melmore (validation period)

Table B-6. Paired daily Soluble Reactive Phosphorus (SRP) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	0.043	0.006	0.060	0.008	0.050	0.007
Observed	0.036	0.003	0.067	0.005	0.049	0.004

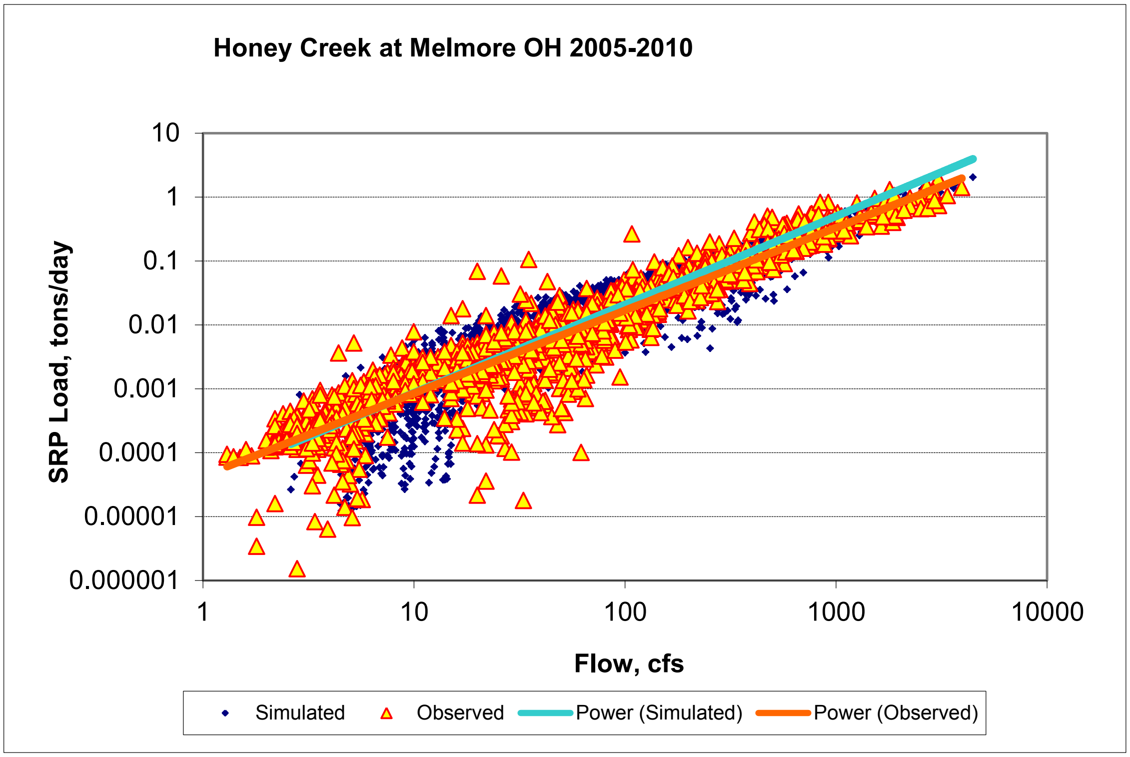


Figure B-27. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Honey Creek at Melmore (calibration period)

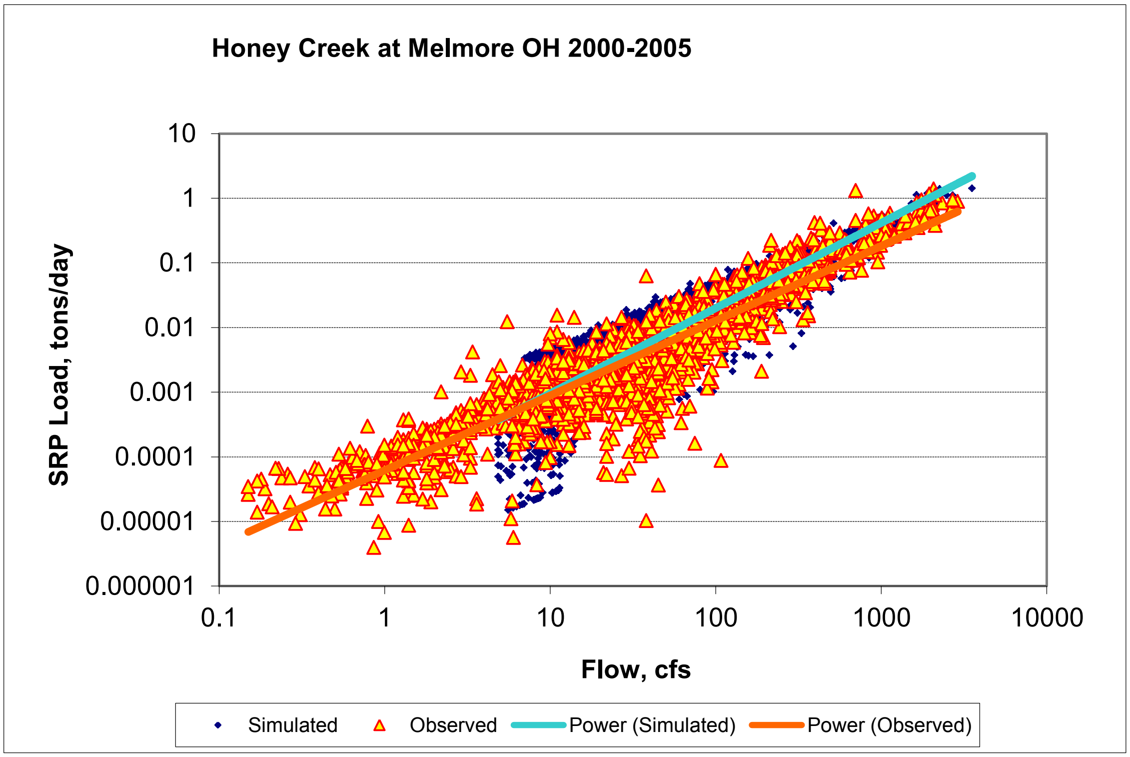


Figure B-28. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Honey Creek at Melmore (validation period)

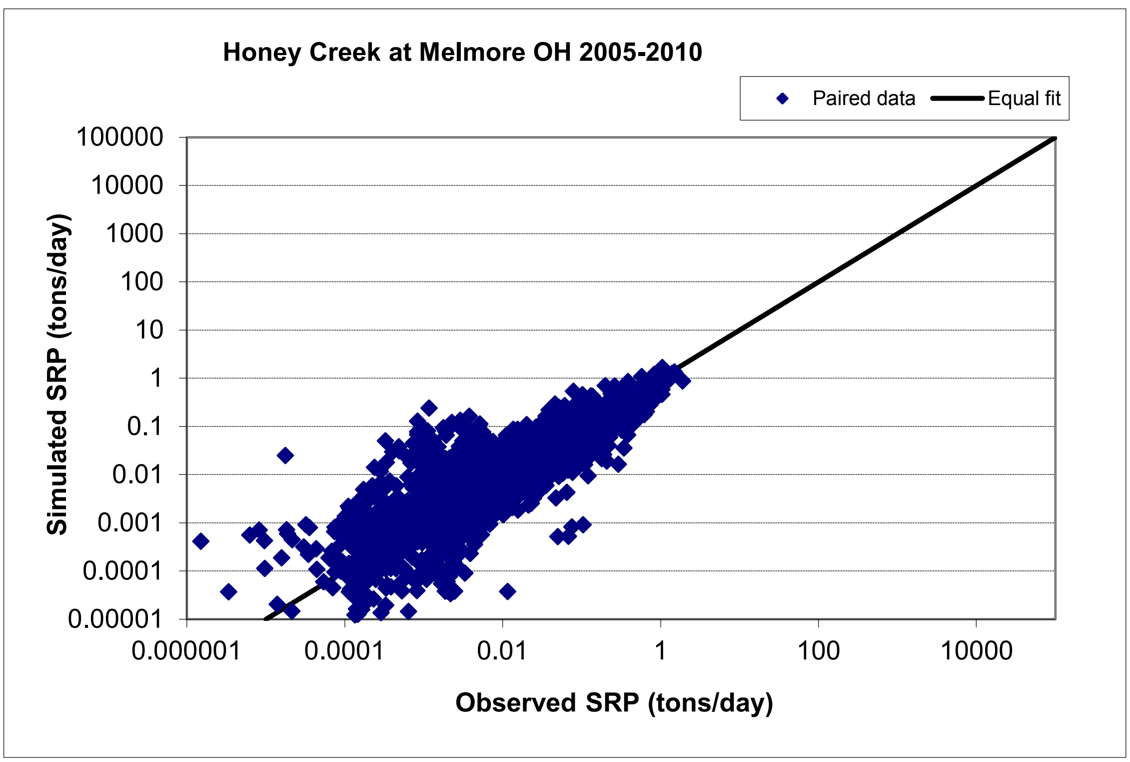


Figure B-29. Paired simulated vs observed Soluble Reactive Phosphorus (SRP) load at Honey Creek at Melmore (calibration period)

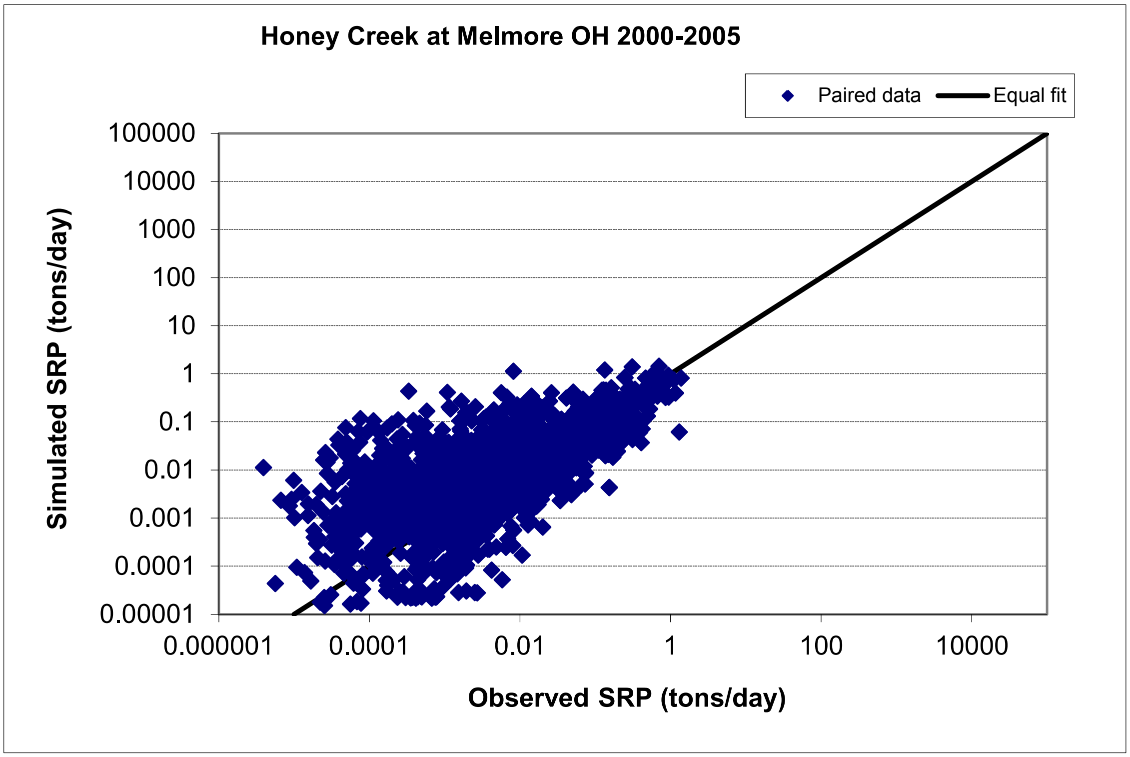


Figure B-30. Paired simulated vs observed Soluble Reactive Phosphorus (SRP) load at Honey Creek at Melmore (validation period)

Total Phosphorus (TP)

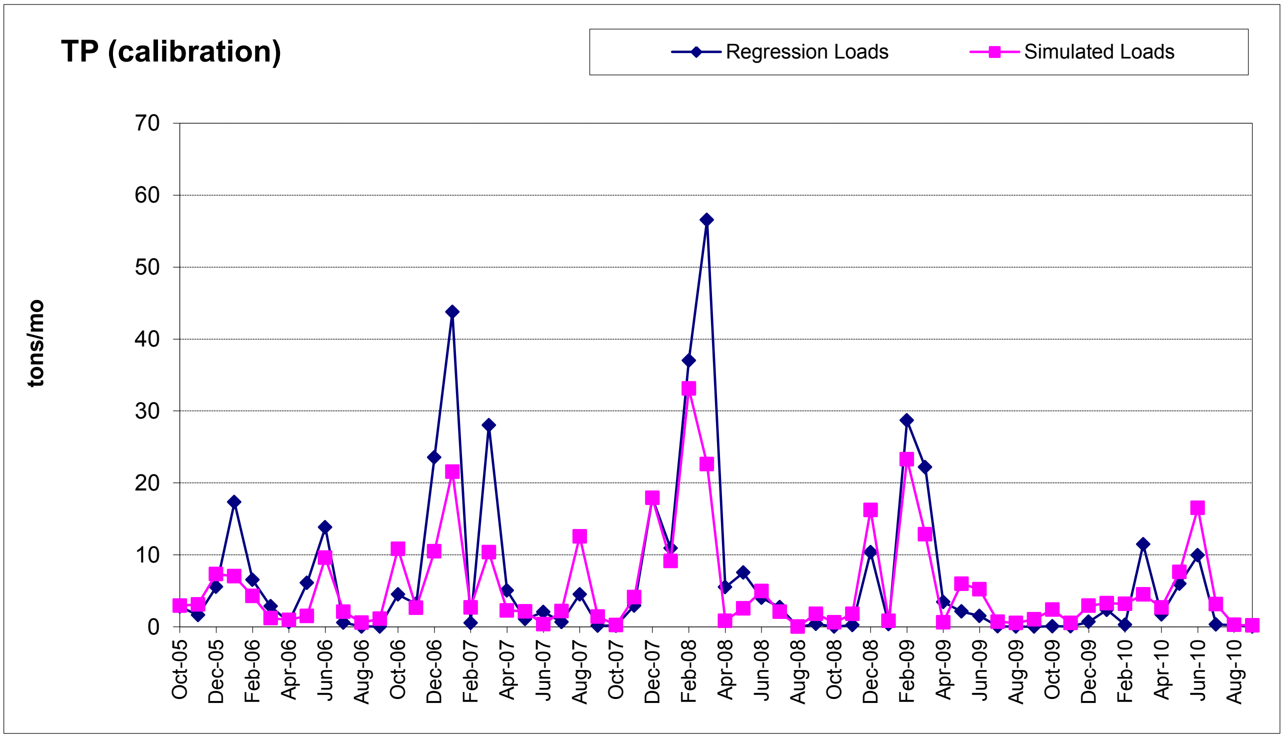


Figure B-31. Monthly simulated and estimated Total Phosphorus (TP) load at Honey Creek at Melmore (calibration period)

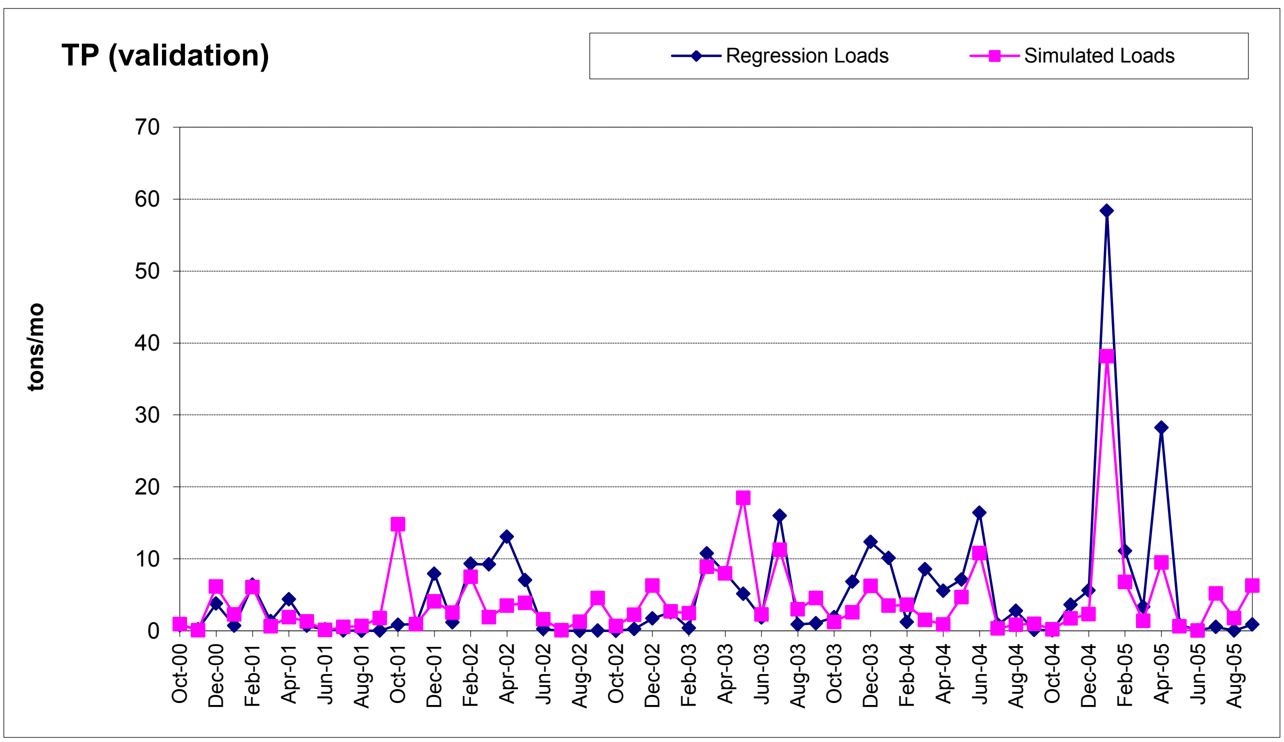


Figure B-32. Monthly simulated and estimated Total Phosphorus (TP) load at Honey Creek at Melmore (validation period)

Table B-7. Paired daily Total Phosphorus (TP) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	0.131	0.012	0.190	0.016	0.156	0.013
Observed	0.126	0.007	0.237	0.011	0.172	0.008

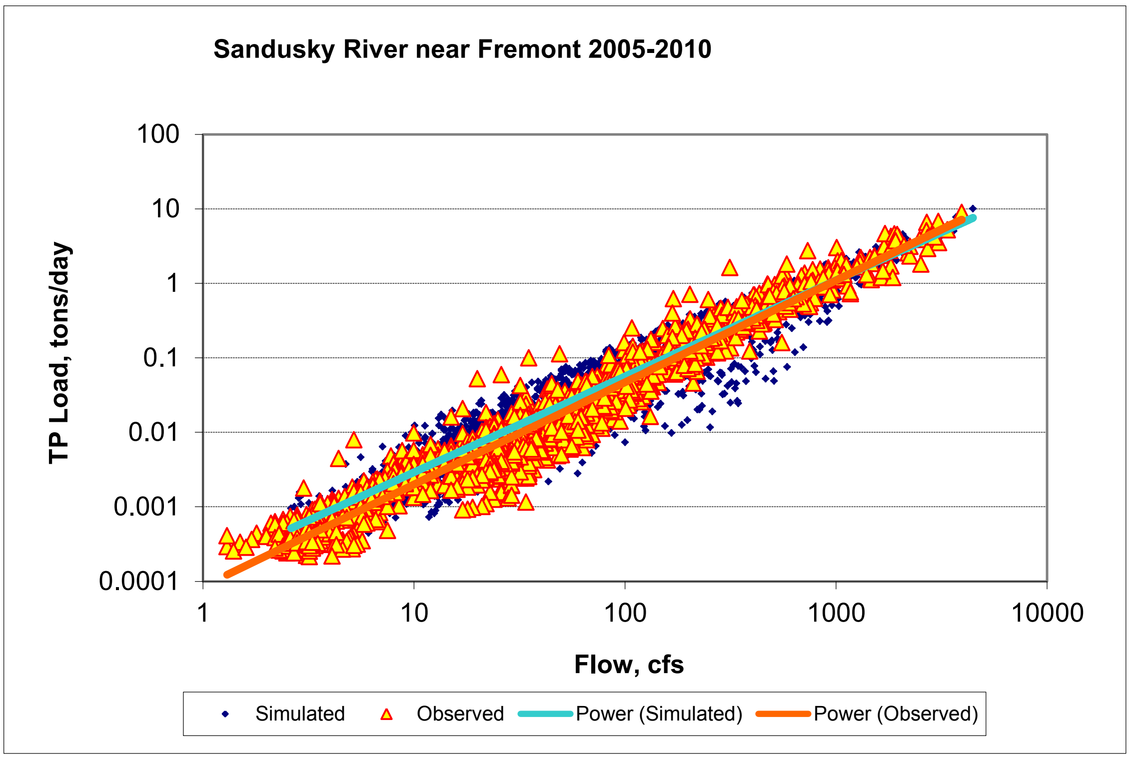


Figure B-33. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Honey Creek at Melmore (calibration period)

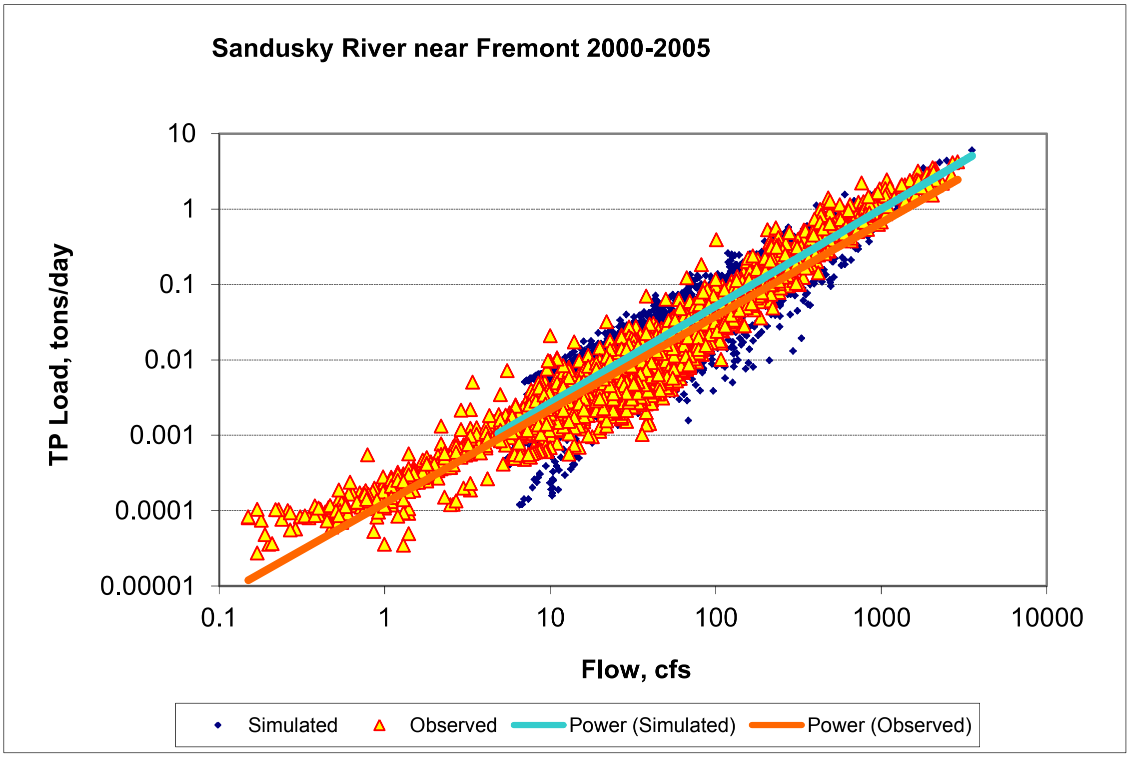


Figure B-34. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Honey Creek at Melmore (validation period)

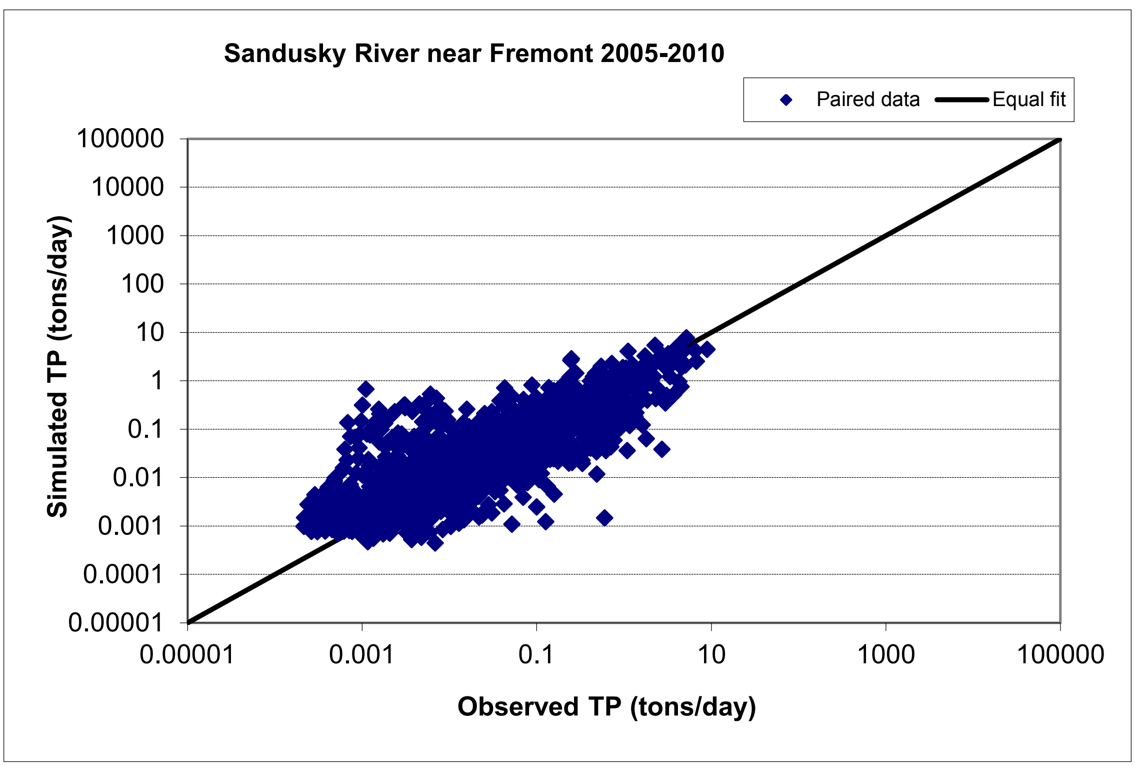


Figure B-35. Paired simulated vs observed Total Phosphorus (TP) load at Honey Creek at Melmore (calibration period)

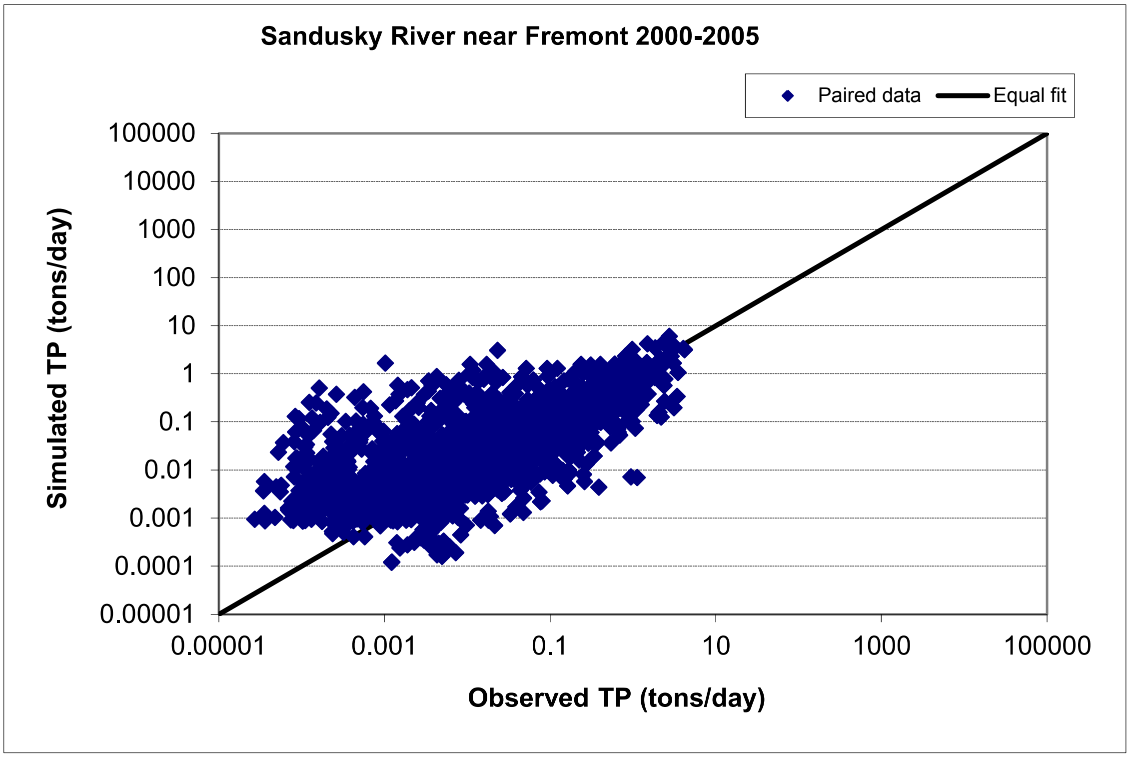


Figure B-36. Paired simulated vs observed Total Phosphorus (TP) load at Honey Creek at Melmore (validation period)

Sandusky River near Fremont (Heidelberg)

Table B-8. Summary statistics

Statistic	Calibration						Validation					
	TSS	TKN	NOx	TN	SRP	TP	TSS	TKN	NOx	TN	SRP	TP
Average absolute error	30.6%	43.5%	49.0%	36.8%	39.5%	41.9%	46.7%	48.0%	47.0%	40.8%	48.6%	50.2%
Median absolute error	8.7%	24.1%	19.5%	20.7%	20.8%	25.0%	13.5%	23.2%	27.2%	27.0%	25.5%	21.5%
Regression error	7.8%	10.6%	24.2%	11.1%	1.5%	9.1%	21.4%	17.1%	14.9%	7.3%	15.5%	16.0%
NSE	0.867	0.709	0.547	0.772	0.805	0.758	0.770	0.675	0.521	0.684	0.685	0.712
NSE'	0.739	0.554	0.474	0.596	0.617	0.614	0.566	0.476	0.447	0.511	0.497	0.503

Total Suspended Solids (TSS)

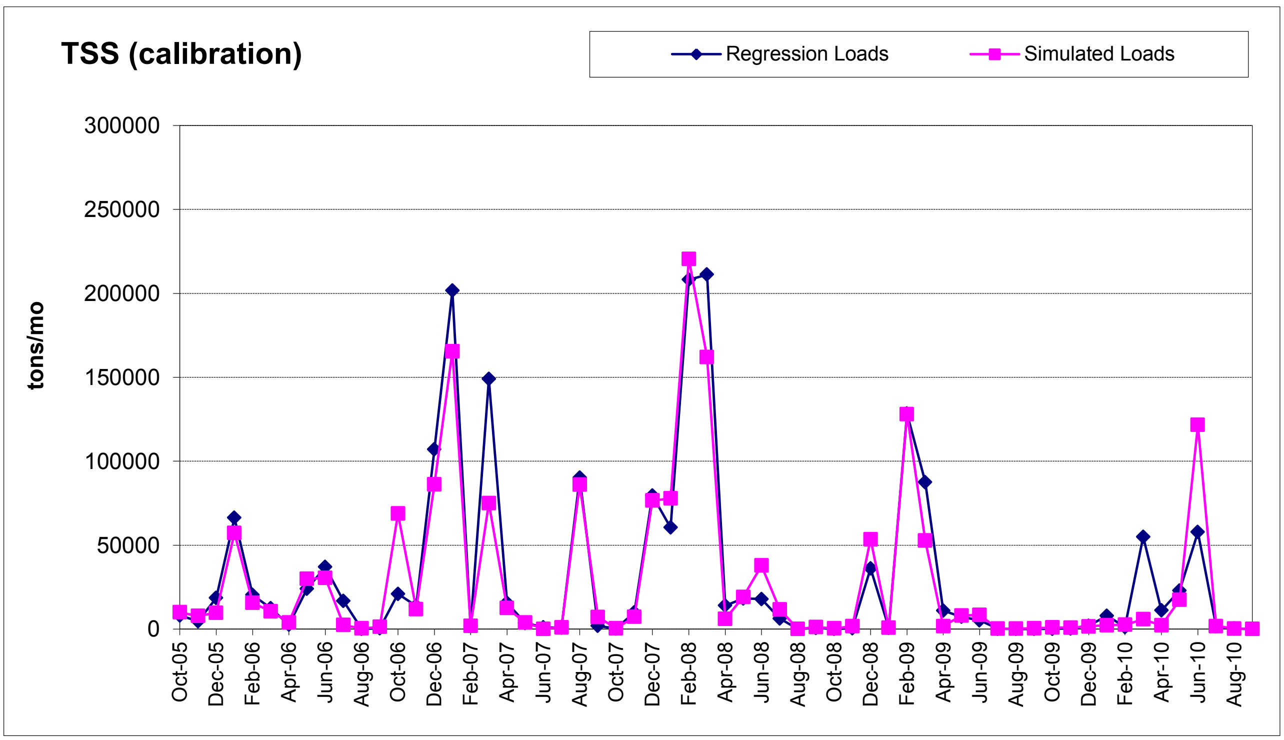


Figure B-37. Monthly simulated and estimated Total Suspended Solids (TSS) load at Sandusky River near Fremont (calibration period)

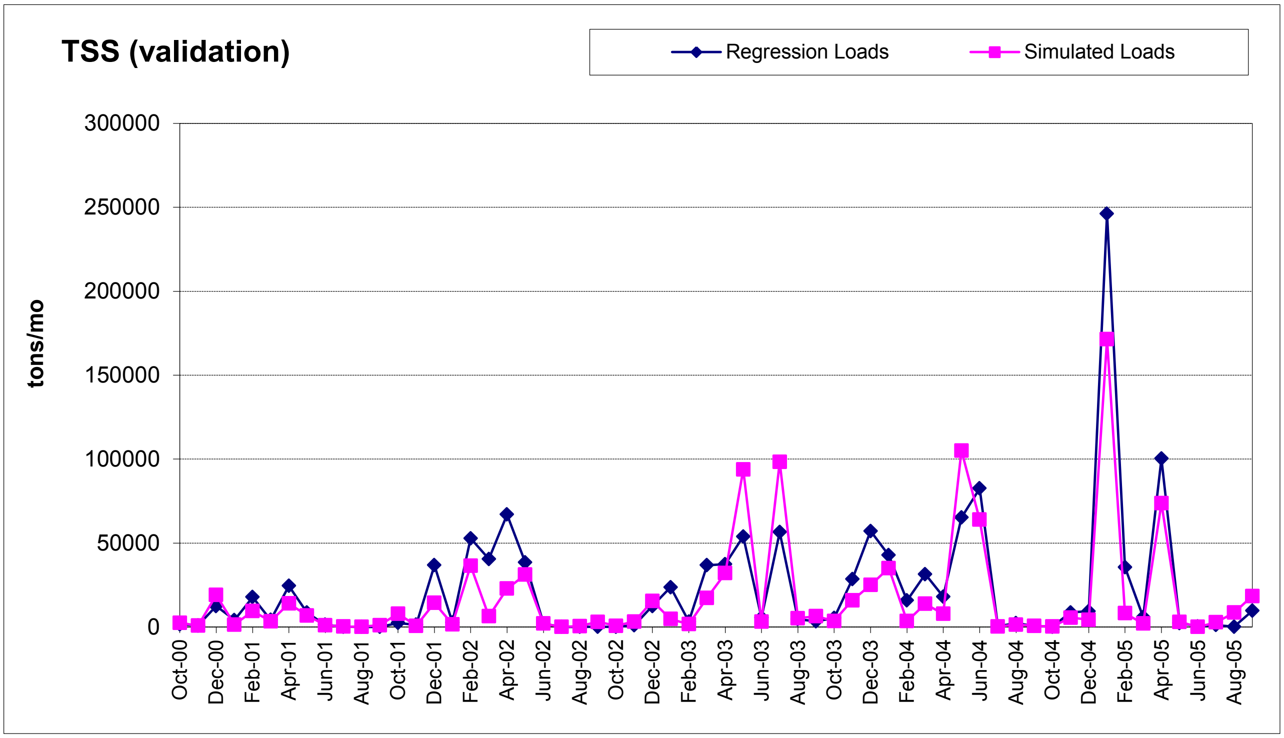


Figure B-38. Monthly simulated and estimated Total Suspended Solids (TSS) load at Sandusky River near Fremont (validation period)

Table B-9. Paired daily Total Suspended Solids (TSS) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	614.244	32.132	951.553	37.622	809.339	34.546
Observed	626.748	24.265	711.558	26.474	675.801	25.485

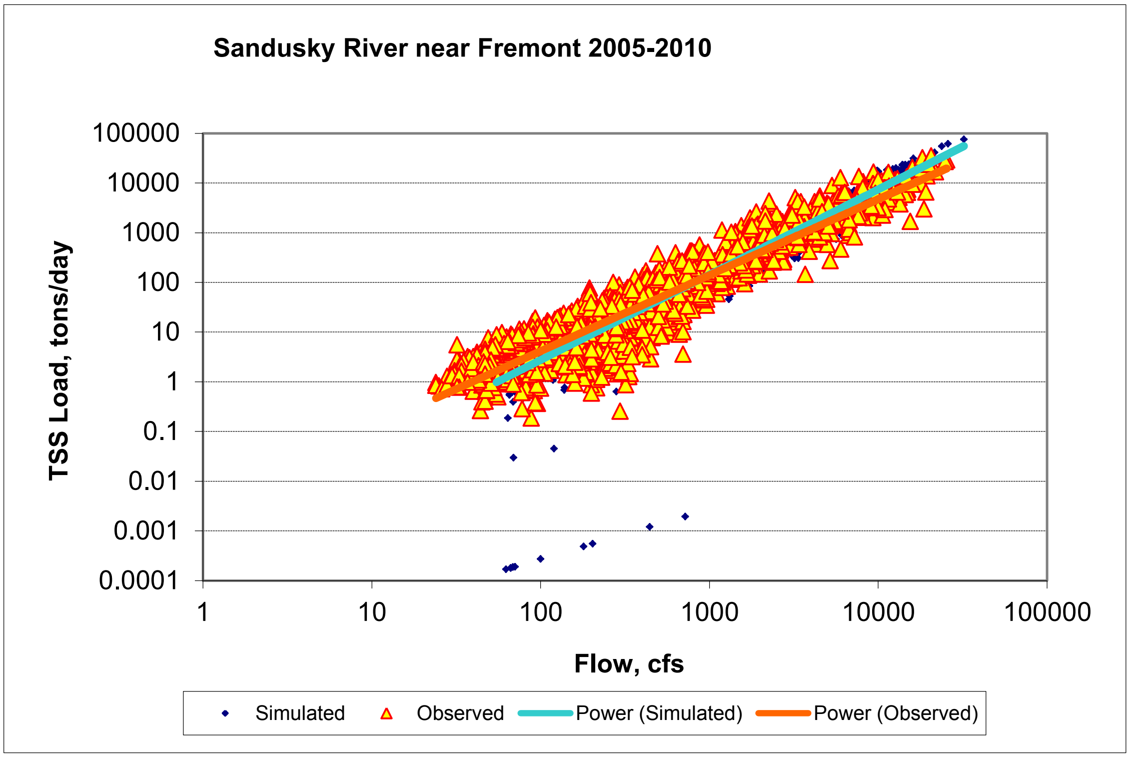


Figure B-39. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow at Sandusky River near Fremont (calibration period)

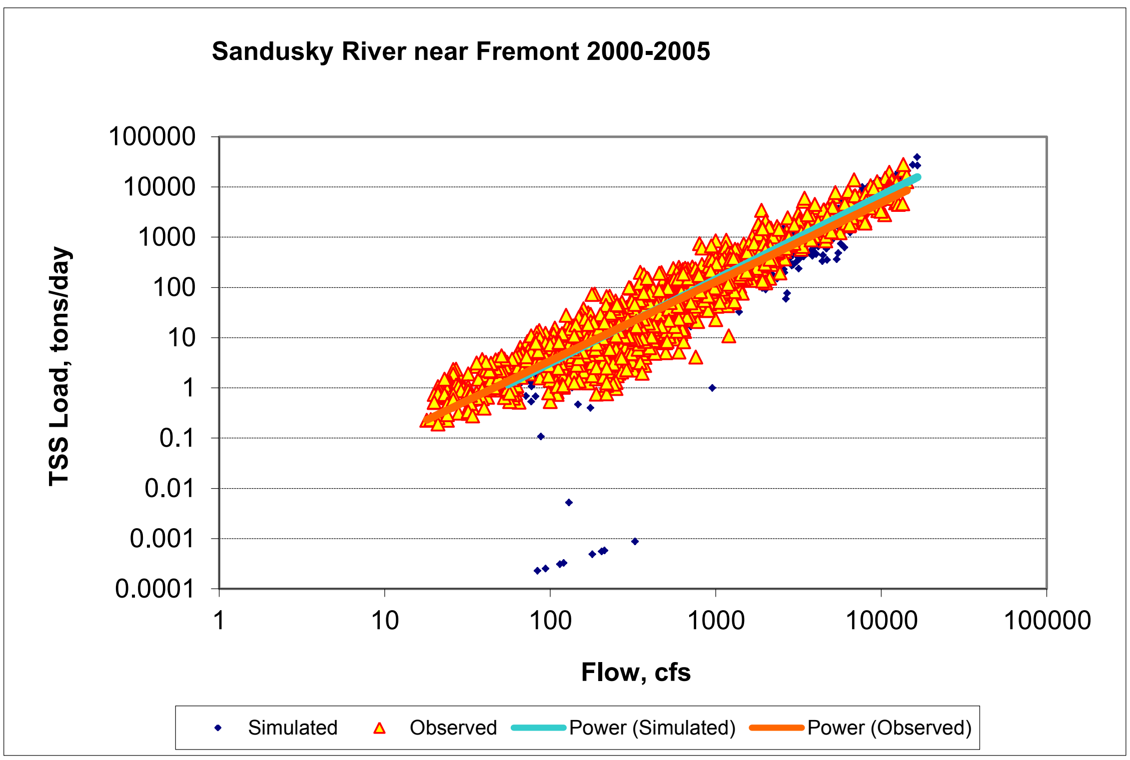


Figure B-40. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow at Sandusky River near Fremont (validation period)

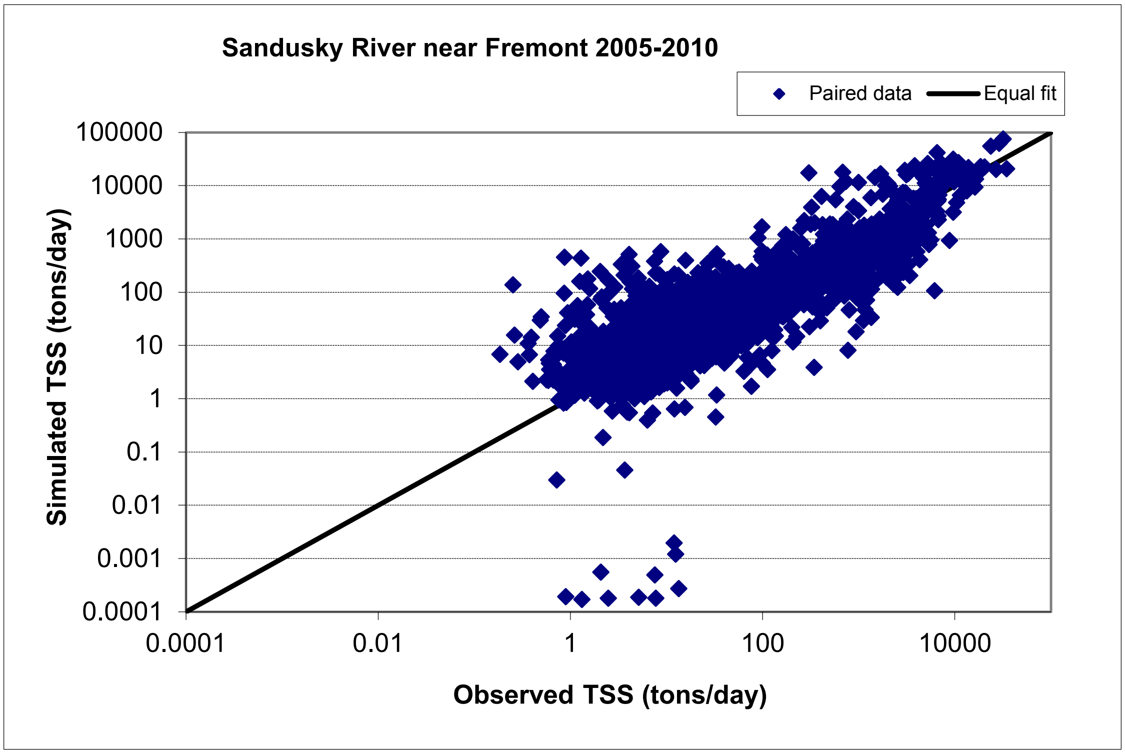


Figure B-41. Paired simulated vs observed Total Suspended Solids (TSS) load at Sandusky River near Fremont (calibration period)

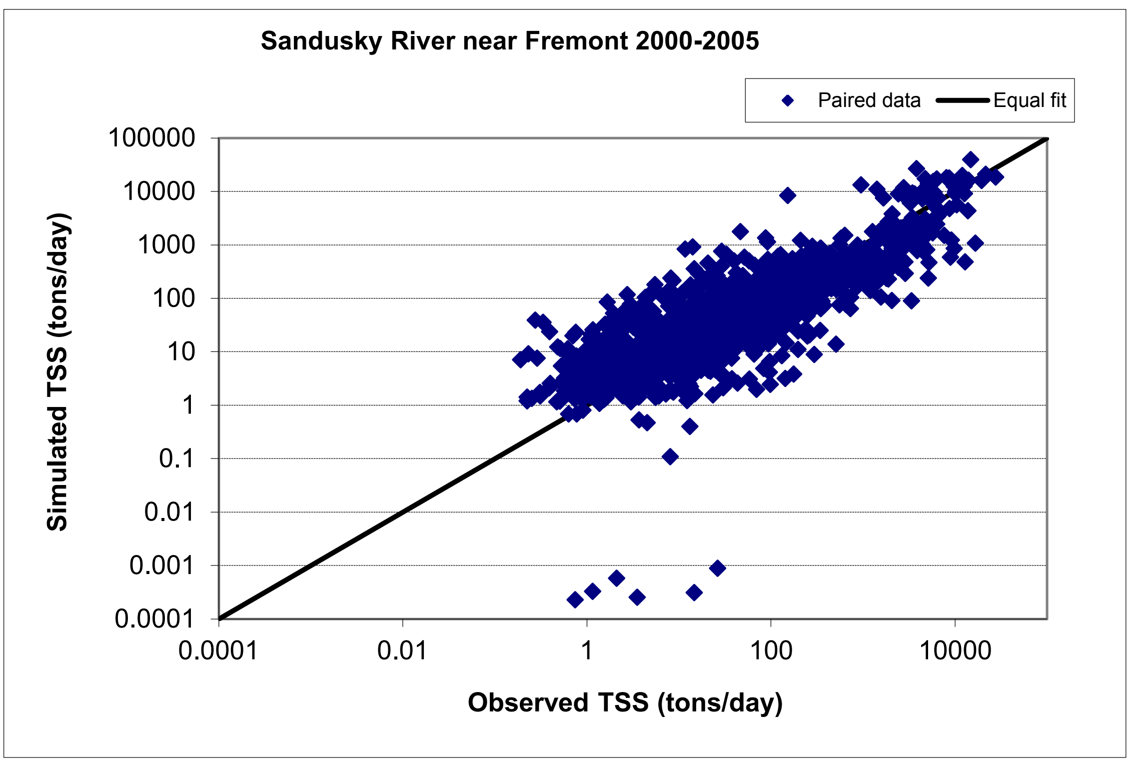


Figure B-42. Paired simulated vs observed Total Suspended Solids (TSS) load at Sandusky River near Fremont (validation period)

Total Kjeldahl Nitrogen (TKN)

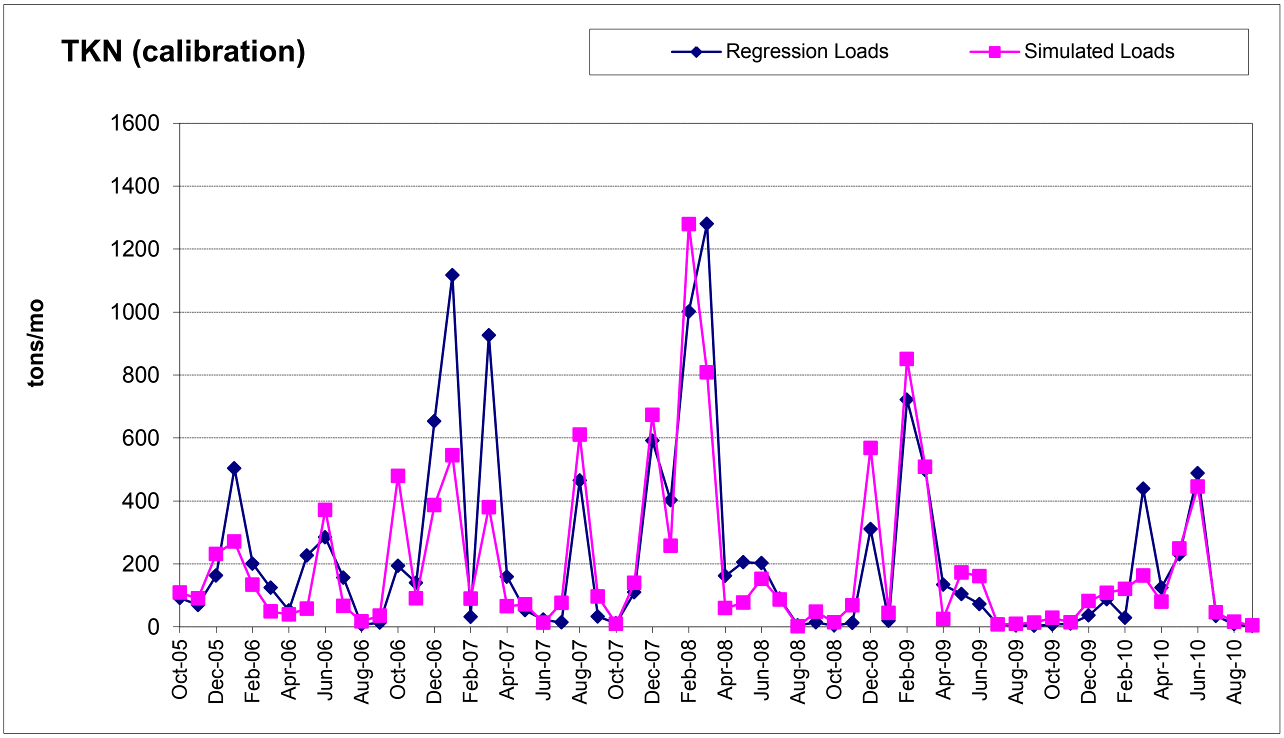


Figure B-43. Monthly simulated and estimated Total Kjeldahl Nitrogen (TKN) load at Sandusky River near Fremont (calibration period)

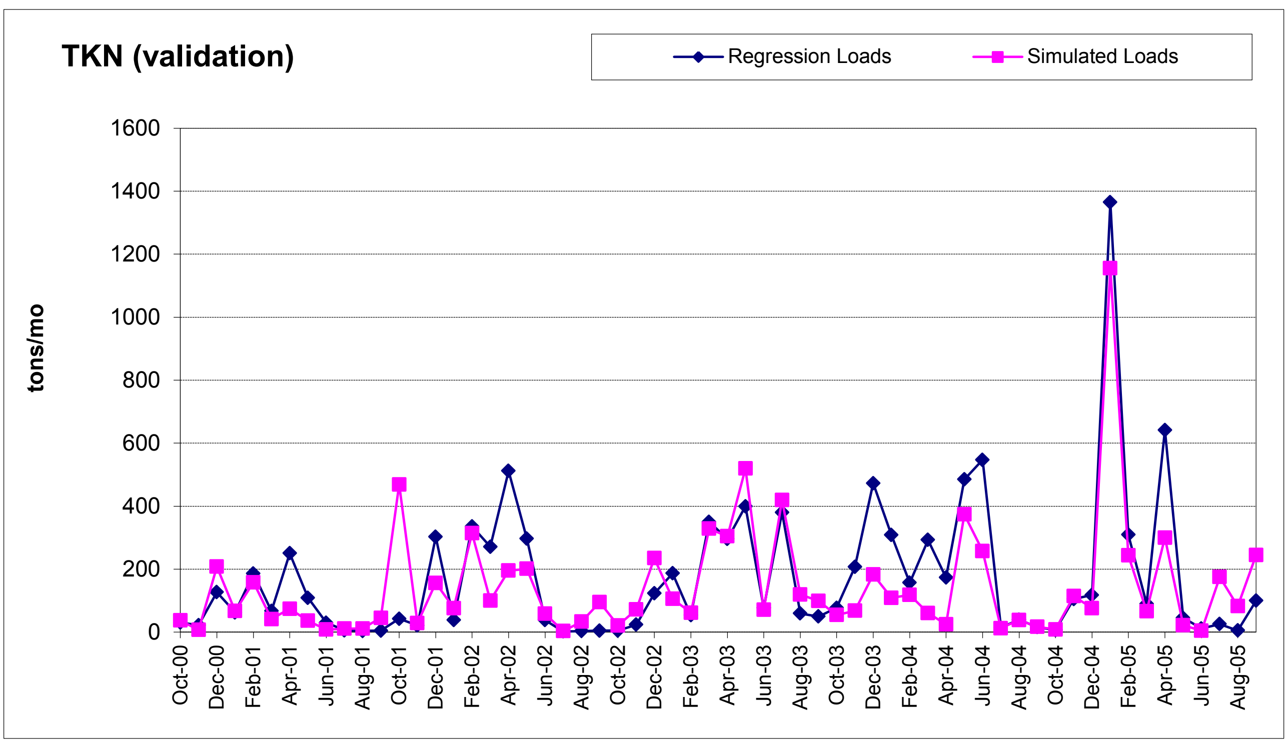


Figure B-44. Monthly simulated and estimated Total Kjeldahl Nitrogen (TKN) load at Sandusky River near Fremont (validation period)

Table B-10. Paired daily Total Kjeldahl Nitrogen (TKN) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	4.537	0.768	6.332	0.849	5.585	0.815
Observed	5.851	0.904	6.496	0.828	6.228	0.862

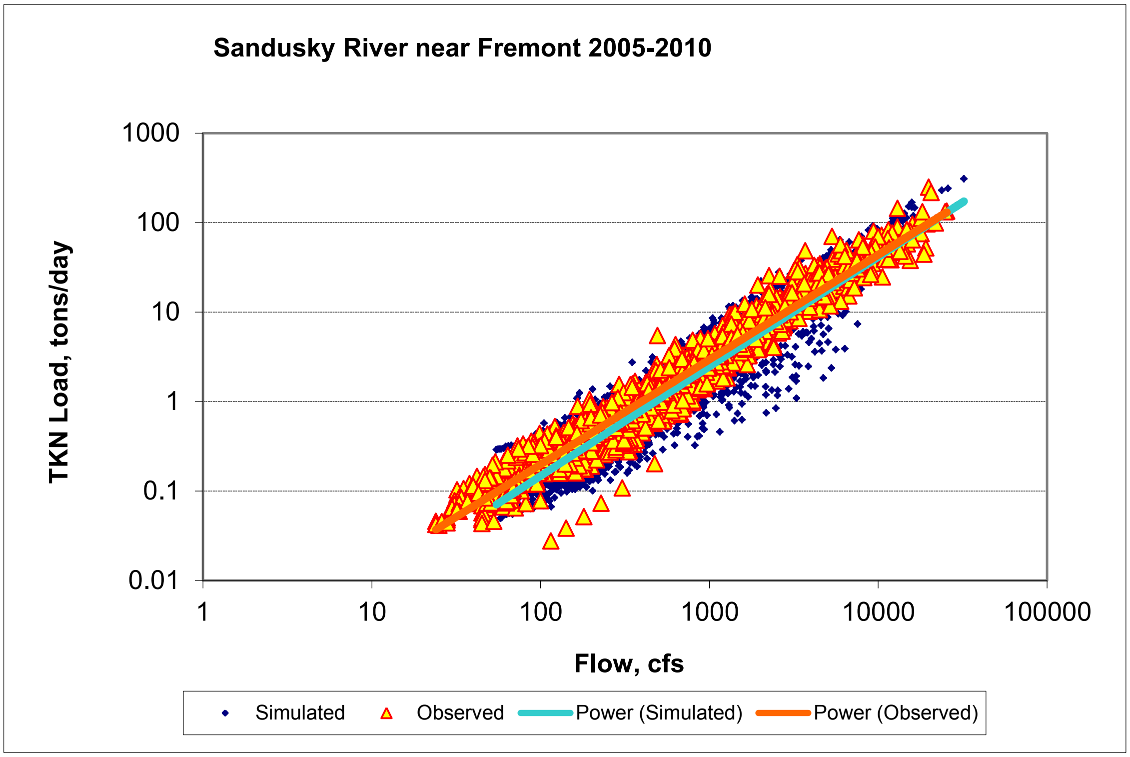


Figure B-45. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Sandusky River near Fremont (calibration period)

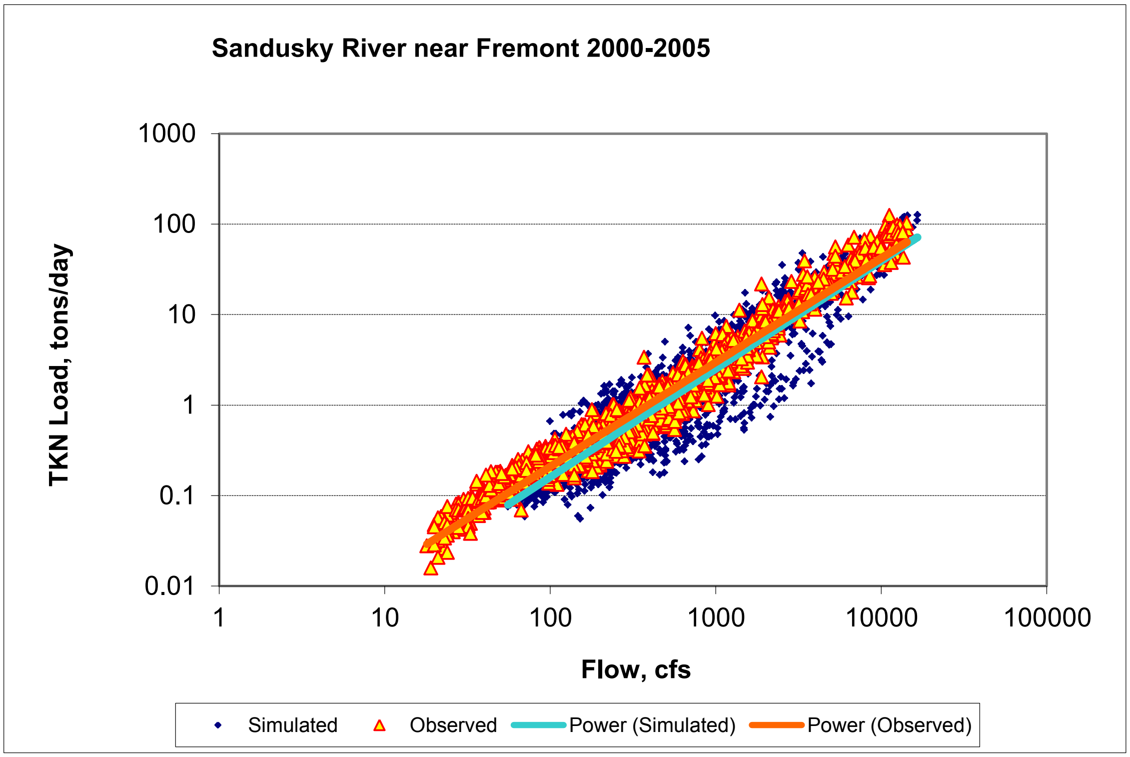


Figure B-46. Power plot of simulated and observed Total Kjeldahl Nitrogen (TKN) load vs flow at Sandusky River near Fremont (validation period)

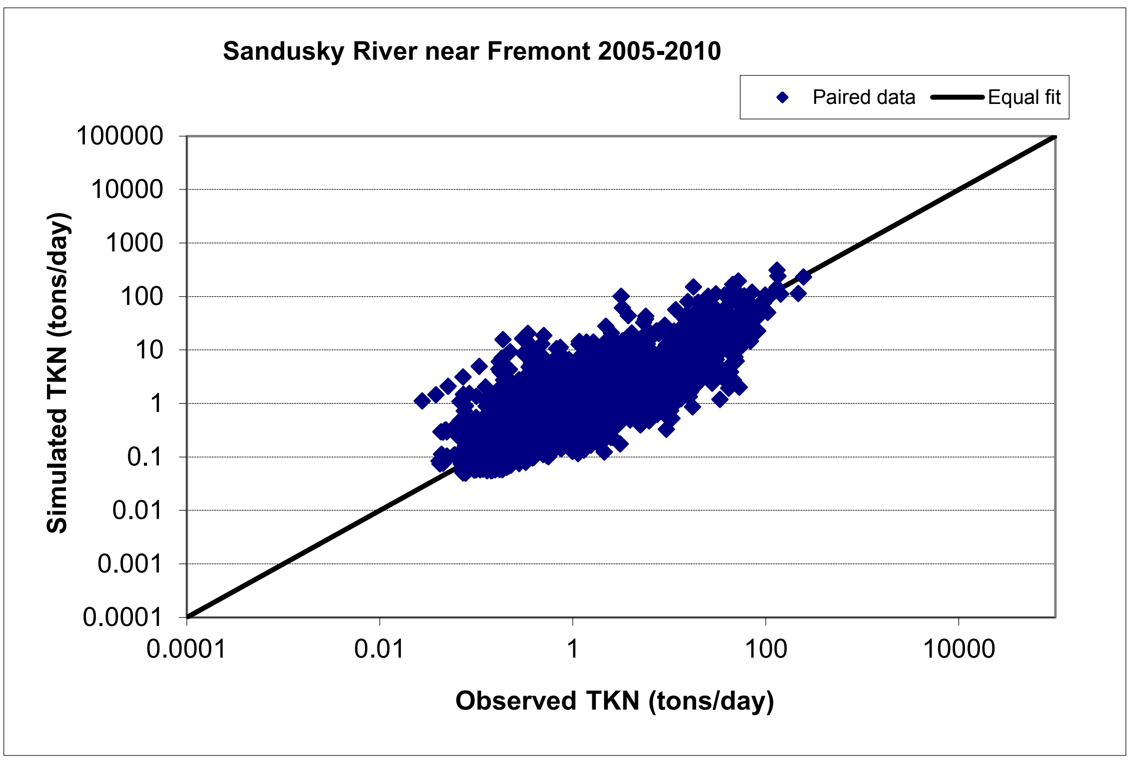


Figure B-47. Paired simulated vs observed Total Kjeldahl Nitrogen (TKN) load at Sandusky River near Fremont (calibration period)

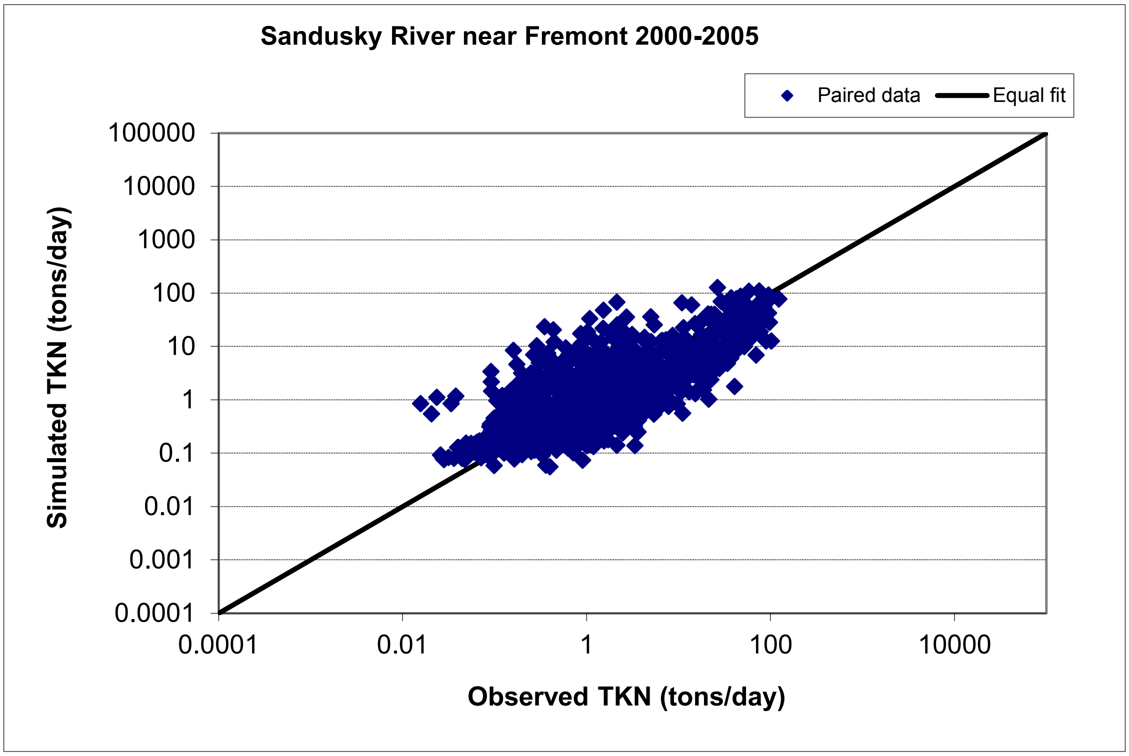


Figure B-48. Paired simulated vs observed Total Kjeldahl Nitrogen (TKN) load at Sandusky River near Fremont (validation period)

Nitrite+ Nitrate Nitrogen (NOx)

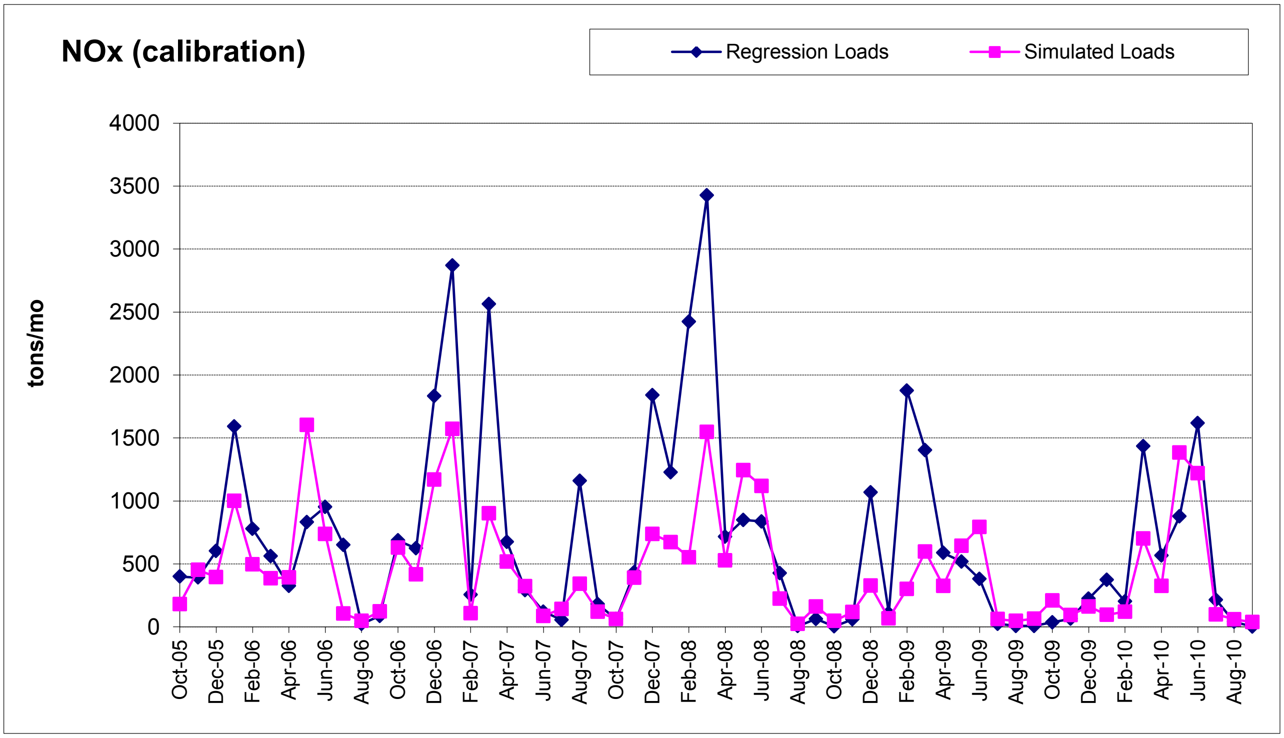


Figure B-49. Monthly simulated and estimated Nitrite+ Nitrate Nitrogen (NOx) load at Sandusky River near Fremont (calibration period)

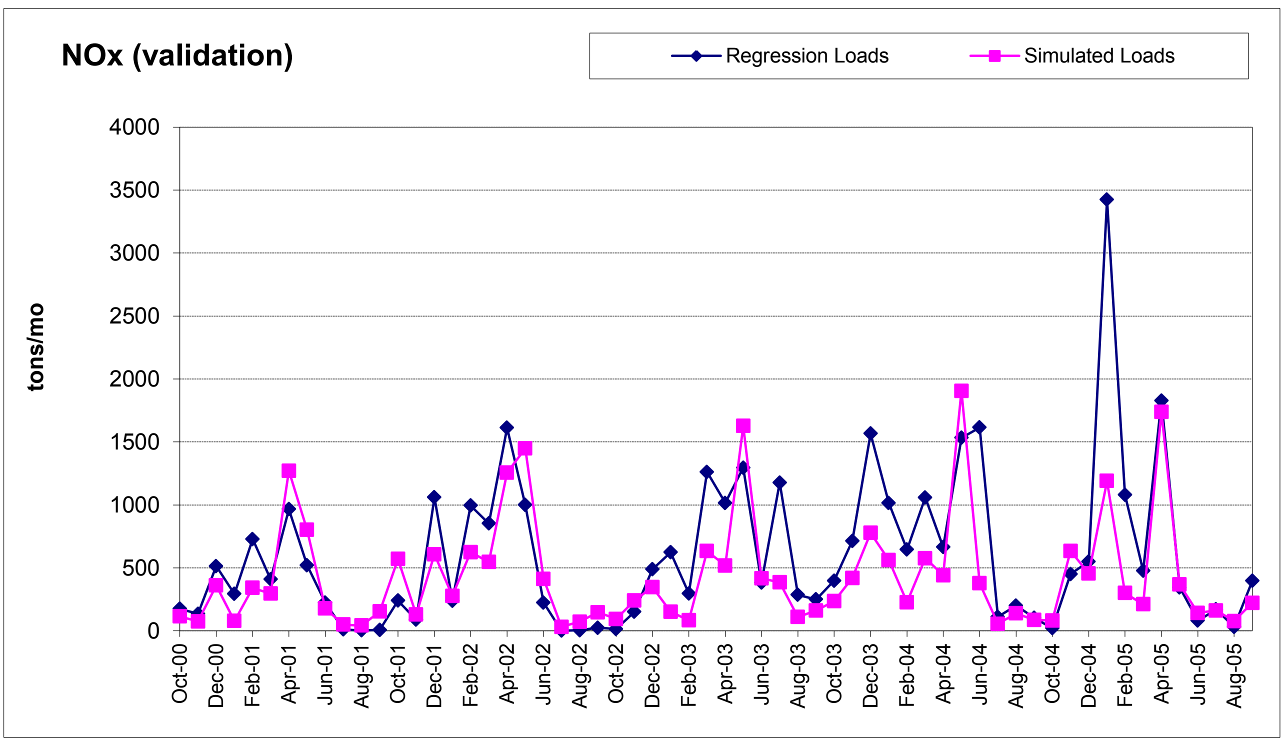


Figure B-50. Monthly simulated and estimated Nitrite+ Nitrate Nitrogen (NOx) load at Sandusky River near Fremont (validation period)

Table B-11. Paired daily Nitrite+ Nitrate Nitrogen (NOx) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	14.842	5.109	15.889	5.392	15.443	5.281
Observed	21.361	5.451	19.082	4.384	20.052	4.829

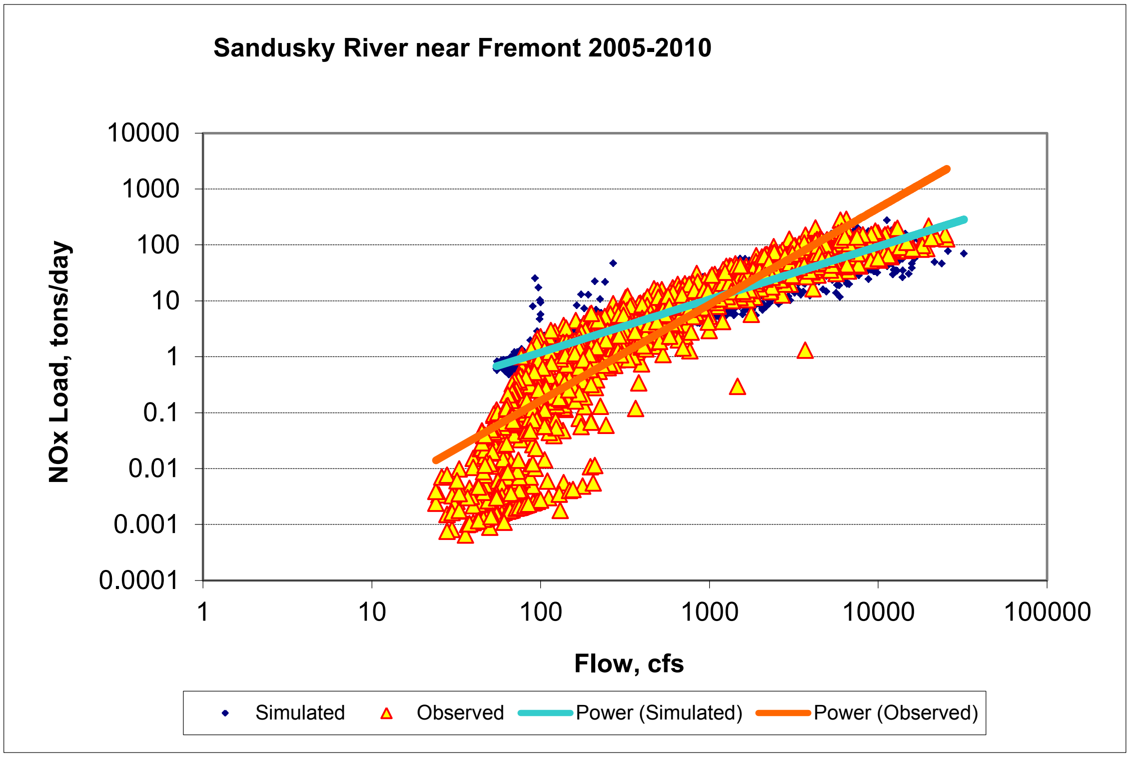


Figure B-51. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Sandusky River near Fremont (calibration period)

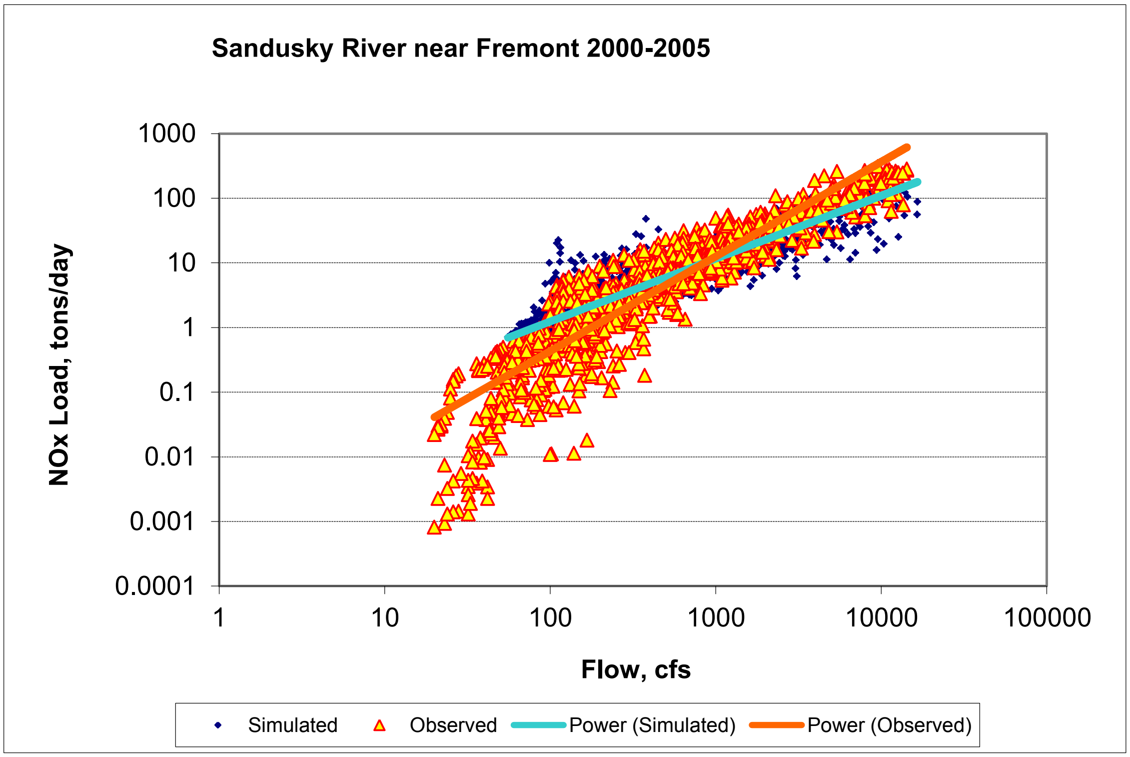


Figure B-52. Power plot of simulated and observed Nitrite+ Nitrate Nitrogen (NOx) load vs flow at Sandusky River near Fremont (validation period)

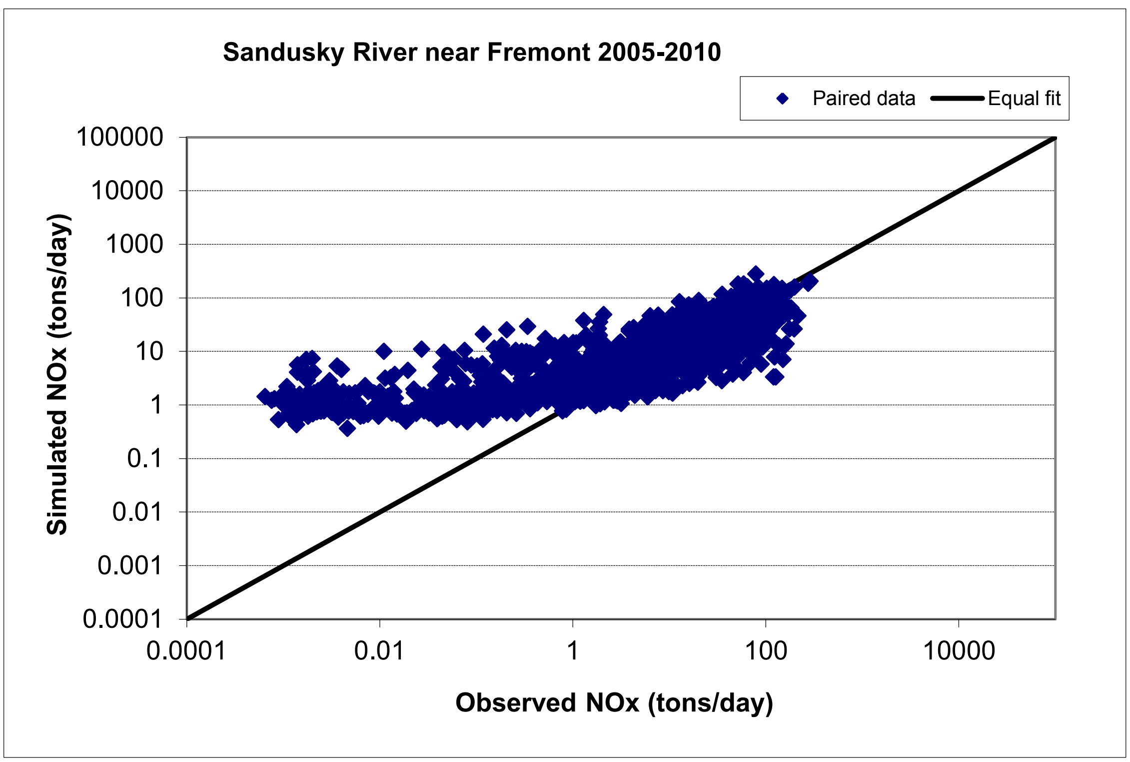


Figure B-53. Paired simulated vs observed Nitrite+ Nitrate Nitrogen (NOx) load at Sandusky River near Fremont (calibration period)

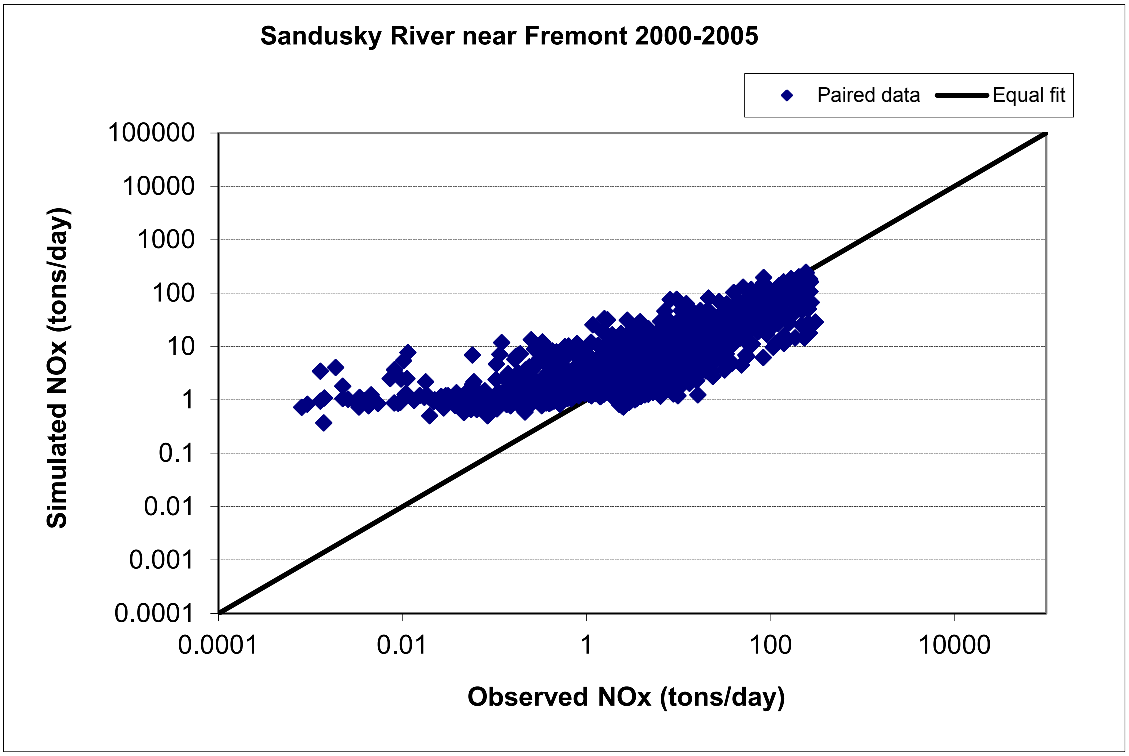


Figure B-54. Paired simulated vs observed Nitrite+ Nitrate Nitrogen (NOx) load at Sandusky River near Fremont (validation period)

Total Nitrogen (TN)

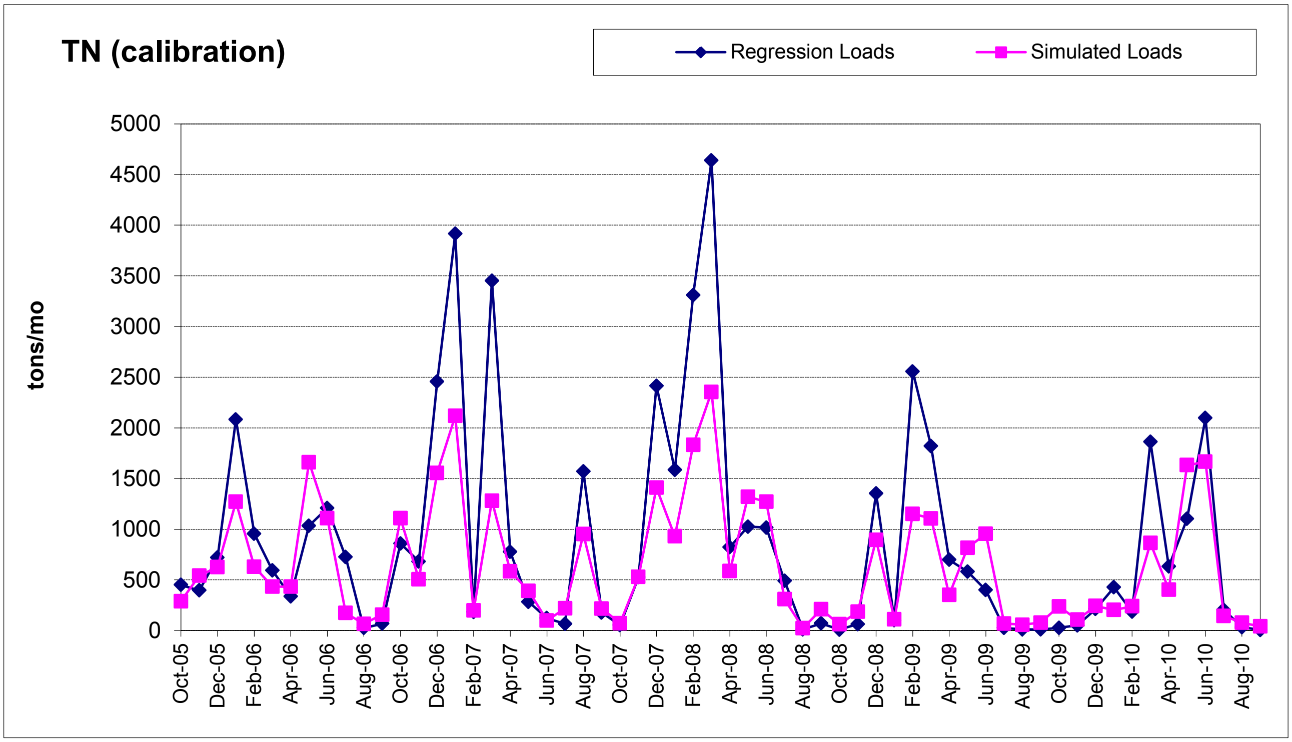


Figure B-55. Monthly simulated and estimated Total Nitrogen (TN) load at Sandusky River near Fremont (calibration period)

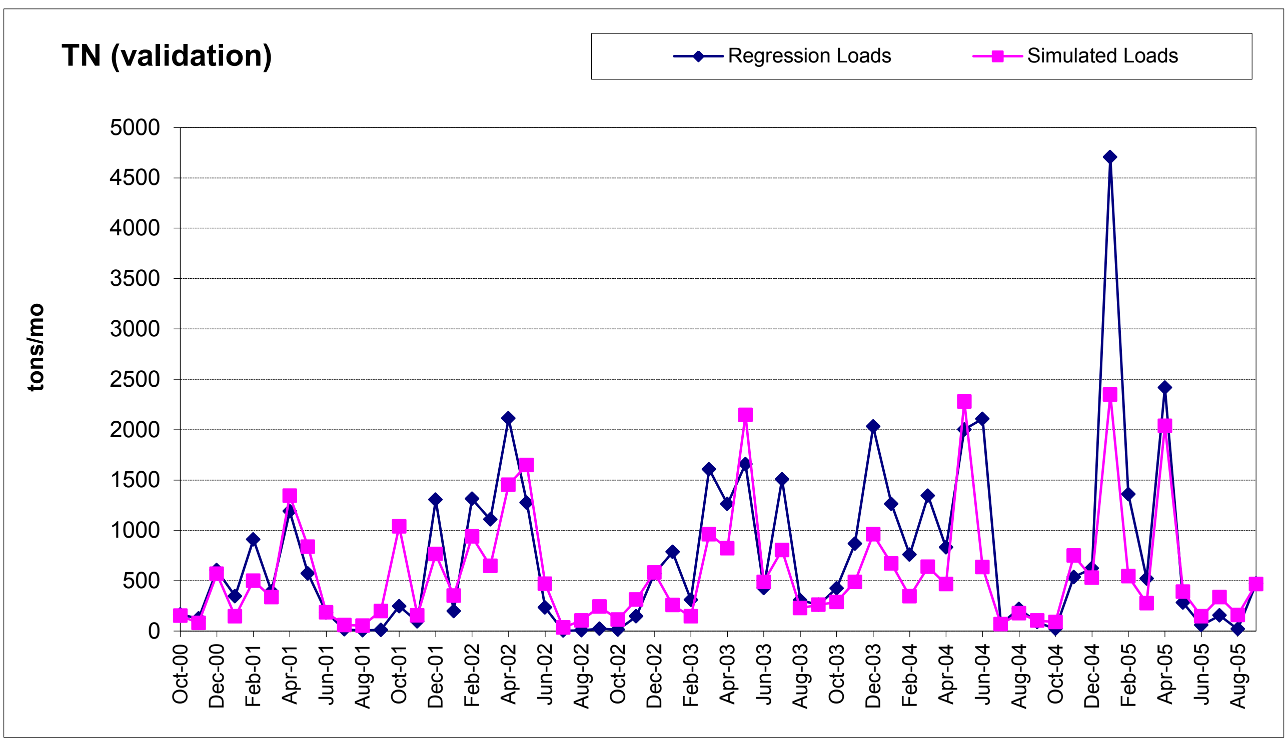


Figure B-56. Monthly simulated and estimated Total Nitrogen (TN) load at Sandusky River near Fremont (validation period)

Table B-12. Paired daily Total Nitrogen (TN) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	19.307	6.094	22.471	6.875	21.153	6.562
Observed	27.439	6.628	25.824	5.219	26.497	5.951

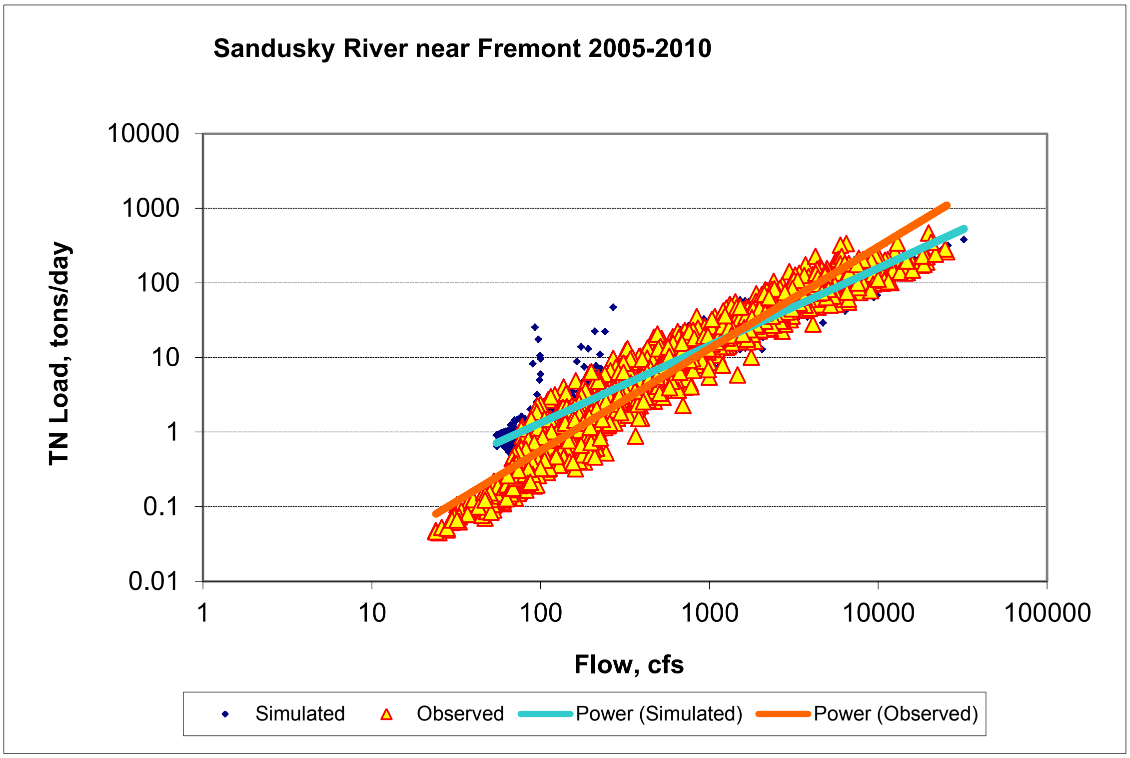


Figure B-57. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Sandusky River near Fremont (calibration period)

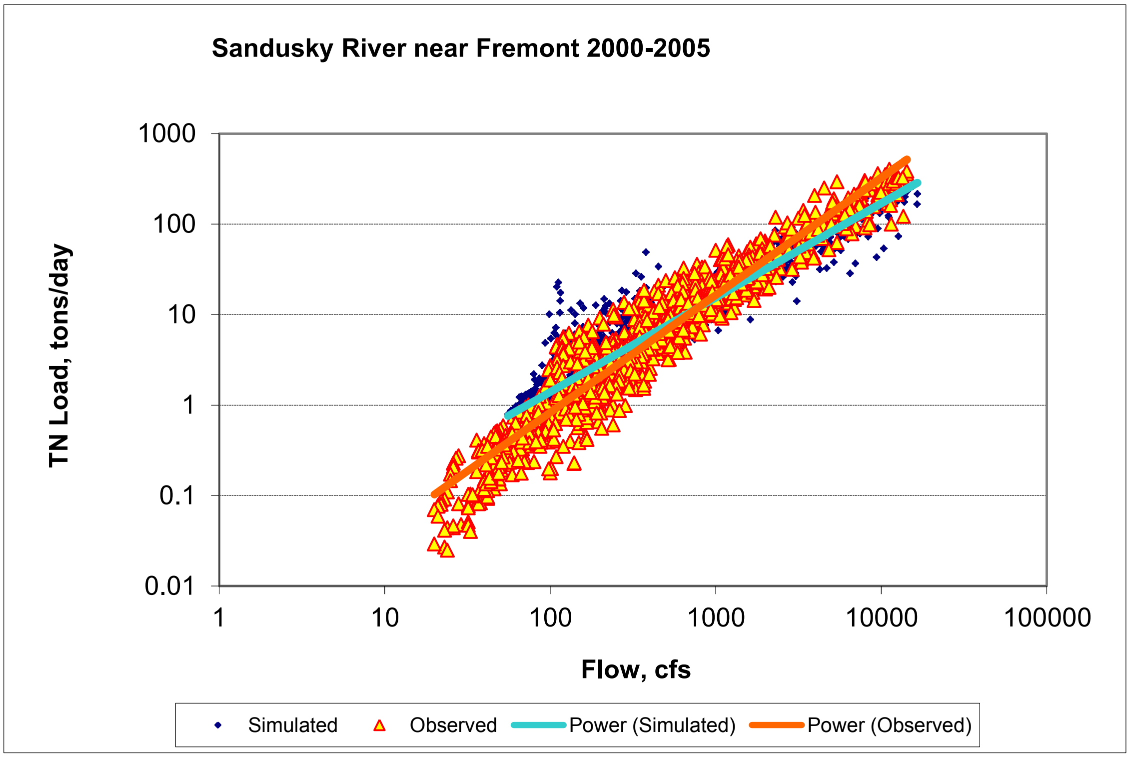


Figure B-58. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Sandusky River near Fremont (validation period)

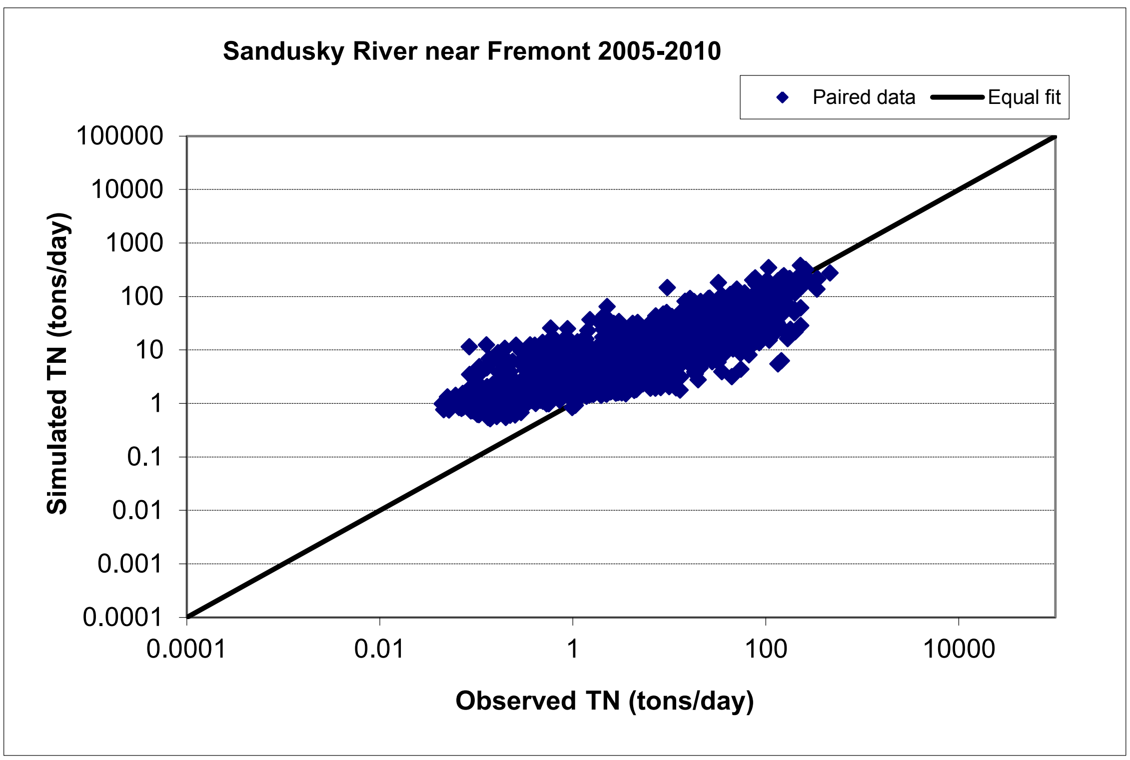


Figure B-59. Paired simulated vs observed Total Nitrogen (TN) load at Sandusky River near Fremont (calibration period)

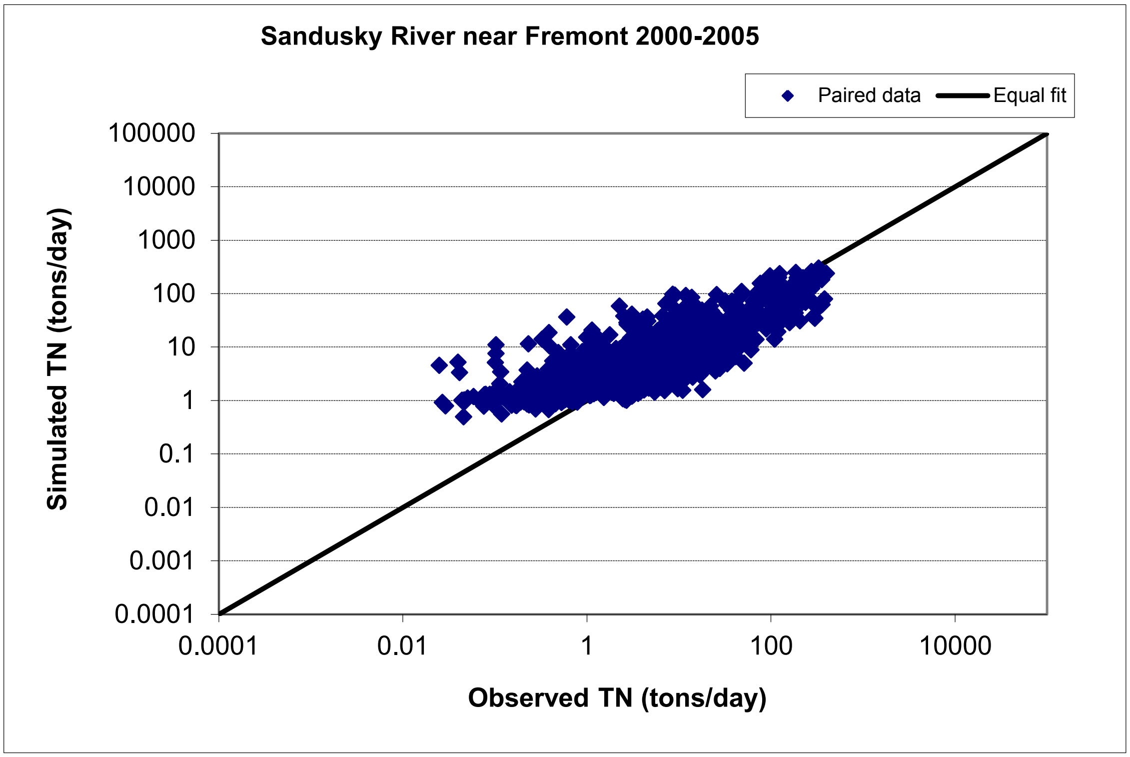


Figure B-60. Paired simulated vs observed Total Nitrogen (TN) load at Sandusky River near Fremont (validation period)

Soluble Reactive Phosphorus (SRP)

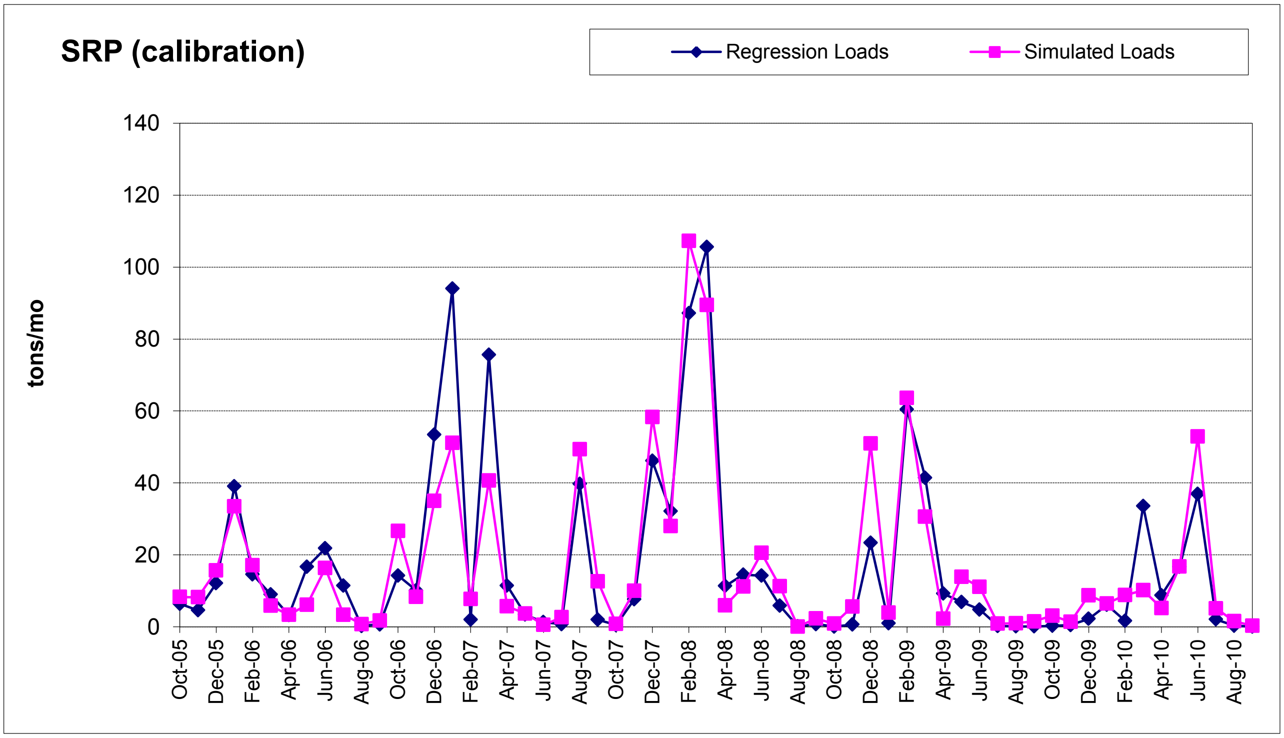


Figure B-61. Monthly simulated and estimated Soluble Reactive Phosphorus (SRP) load at Sandusky River near Fremont (calibration period)

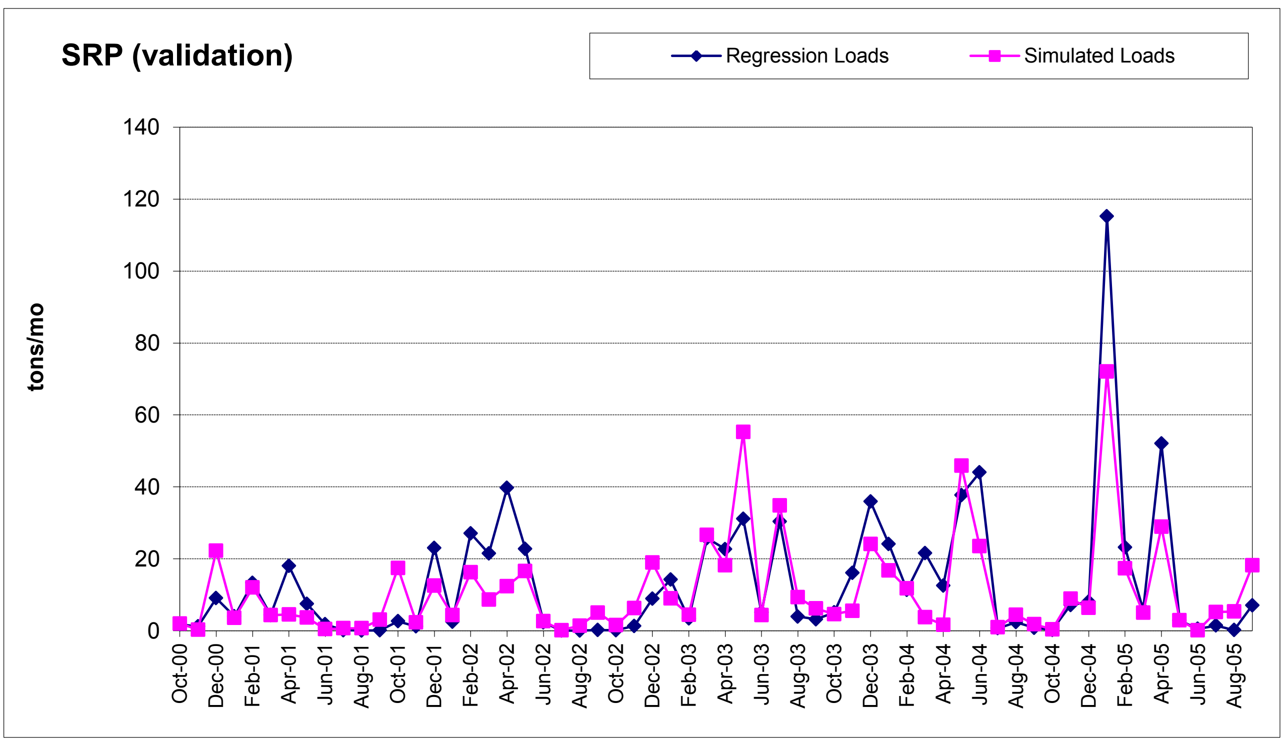


Figure B-62. Monthly simulated and estimated Soluble Reactive Phosphorus (SRP) load at Sandusky River near Fremont (validation period)

Table B-13. Paired daily Soluble Reactive Phosphorus (SRP) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	0.381	0.062	0.567	0.086	0.489	0.074
Observed	0.290	0.036	0.394	0.050	0.350	0.044

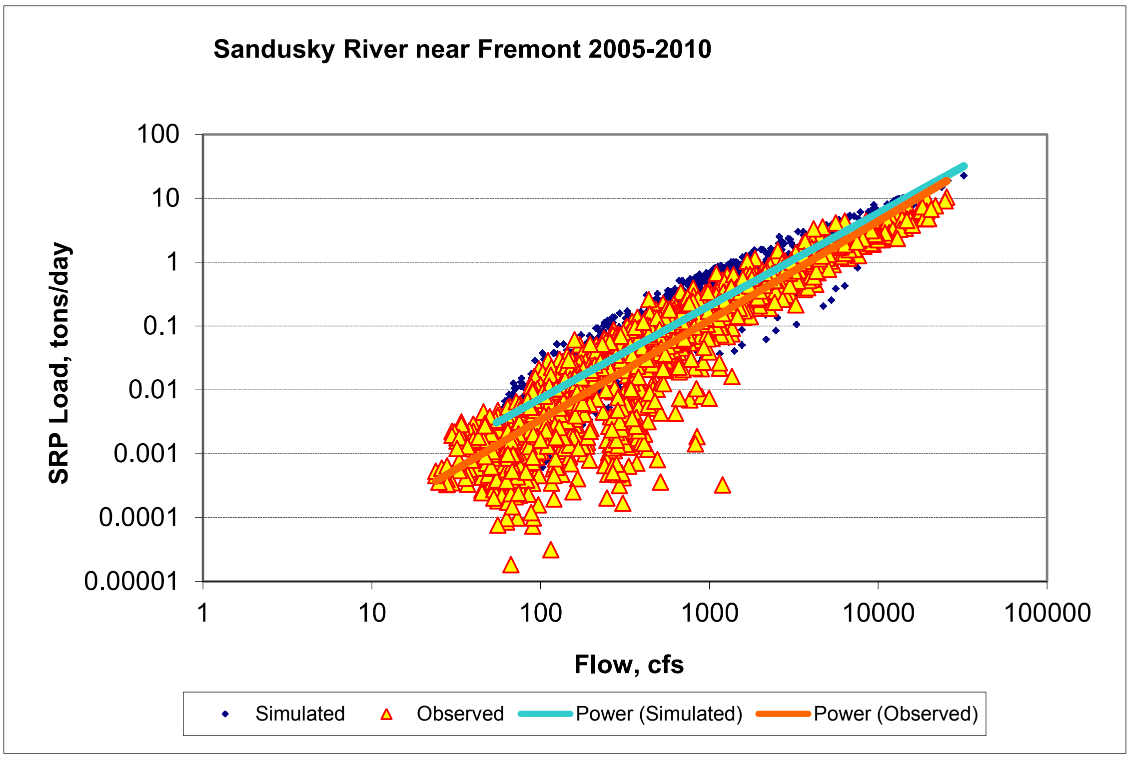


Figure B-63. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Sandusky River near Fremont (calibration period)

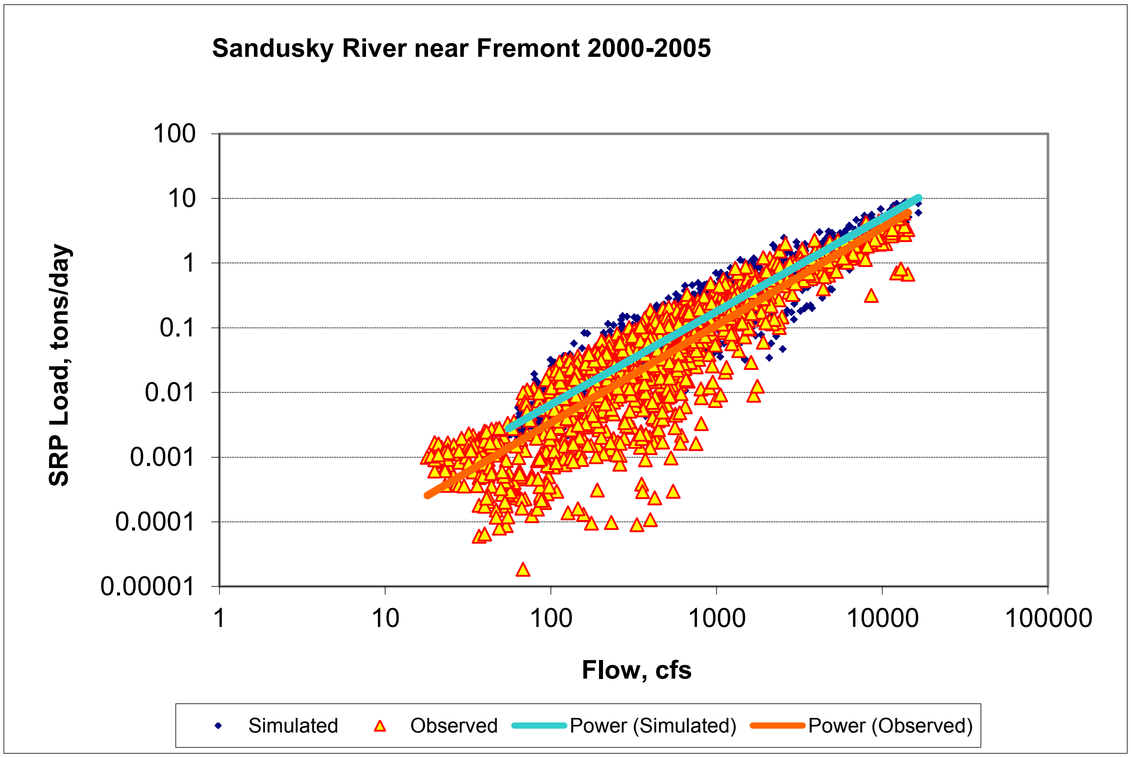


Figure B-64. Power plot of simulated and observed Soluble Reactive Phosphorus (SRP) load vs flow at Sandusky River near Fremont (validation period)

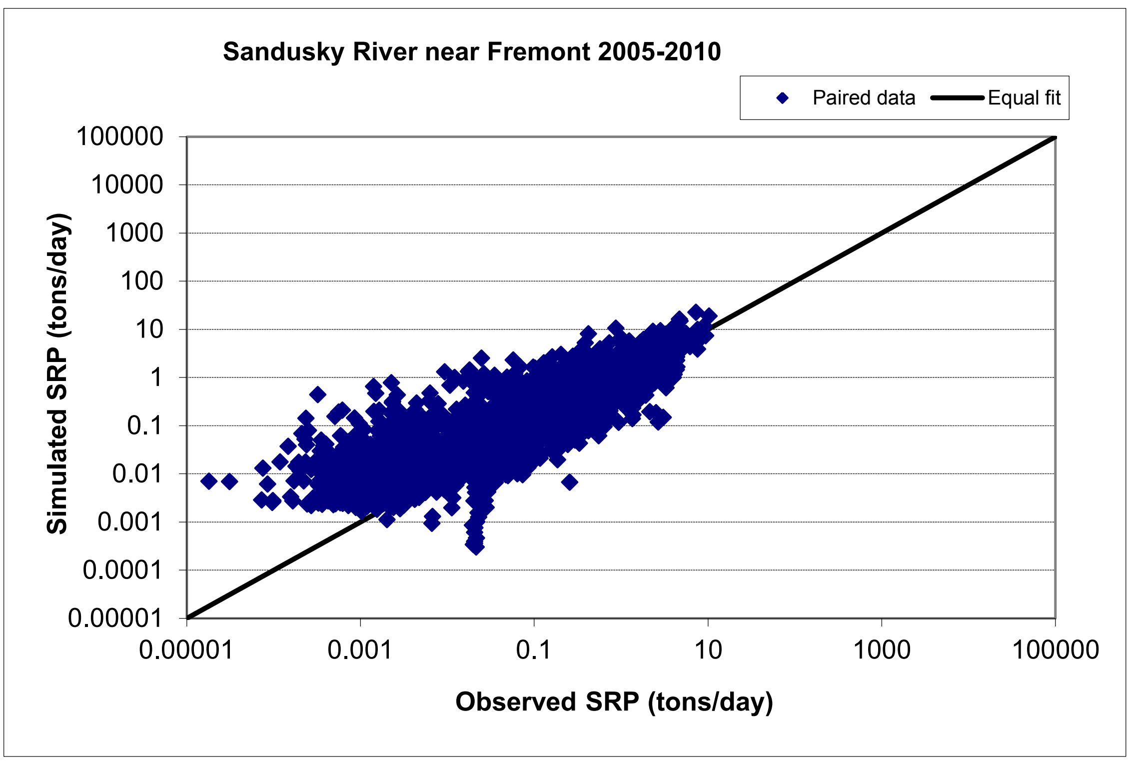


Figure B-65. Paired simulated vs observed Soluble Reactive Phosphorus (SRP) load at Sandusky River near Fremont (calibration period)

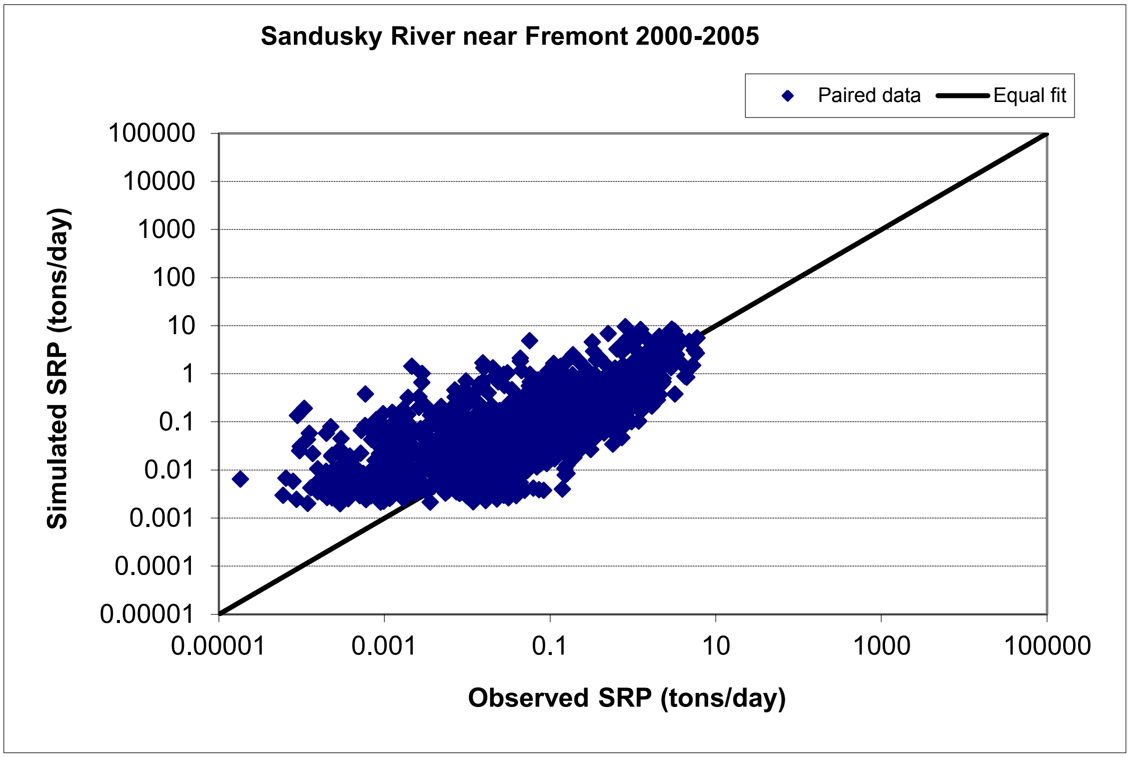


Figure B-66. Paired simulated vs observed Soluble Reactive Phosphorus (SRP) load at Sandusky River near Fremont (validation period)

Total Phosphorus (TP)

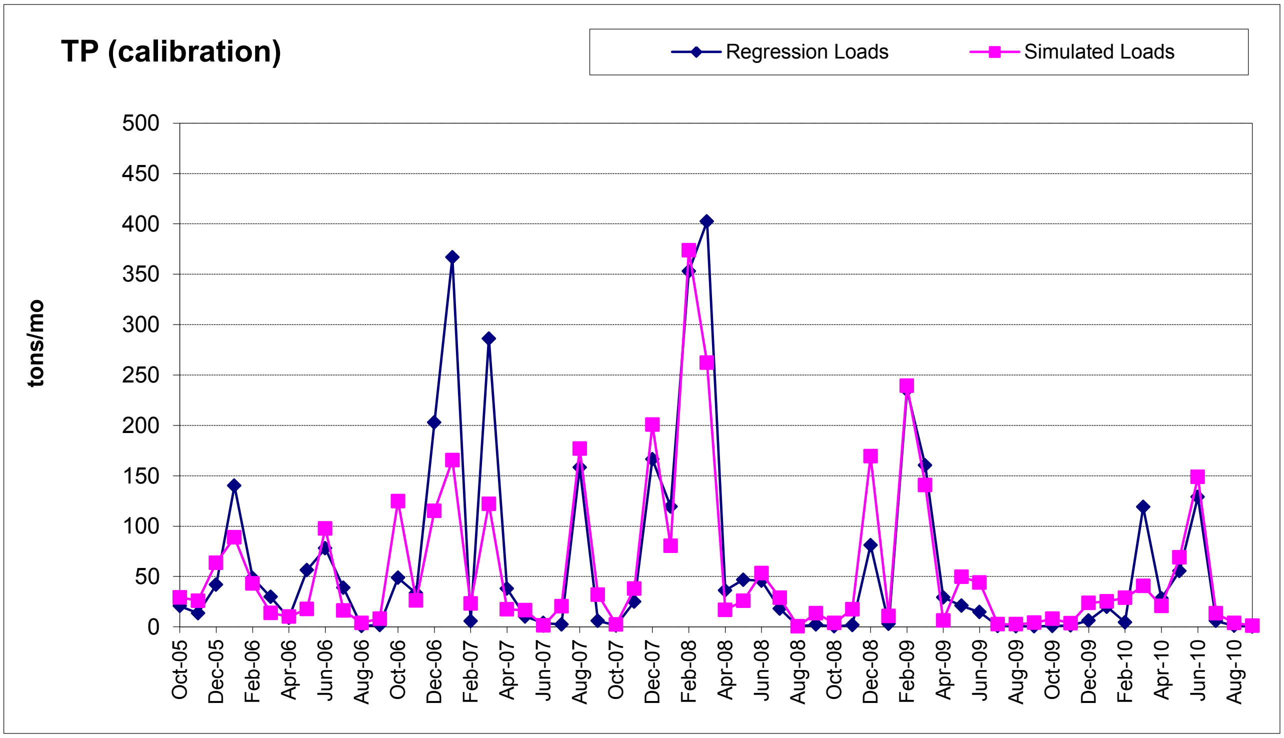


Figure B-67. Monthly simulated and estimated Total Phosphorus (TP) load at Sandusky River near Fremont (calibration period)

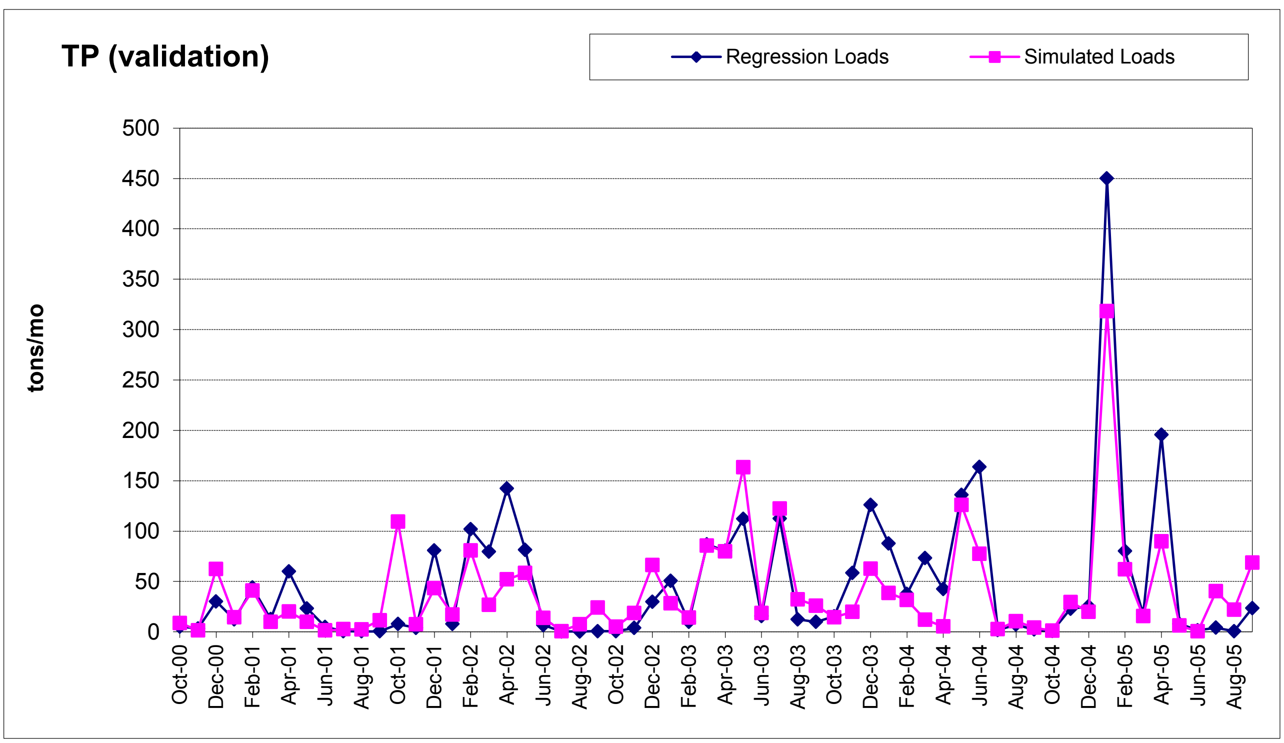


Figure B-68. Monthly simulated and estimated Total Phosphorus (TP) load at Sandusky River near Fremont (validation period)

Table B-14. Paired daily Total Phosphorus (TP) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	1.257	0.143	1.855	0.202	1.601	0.177
Observed	1.324	0.106	1.749	0.127	1.569	0.120

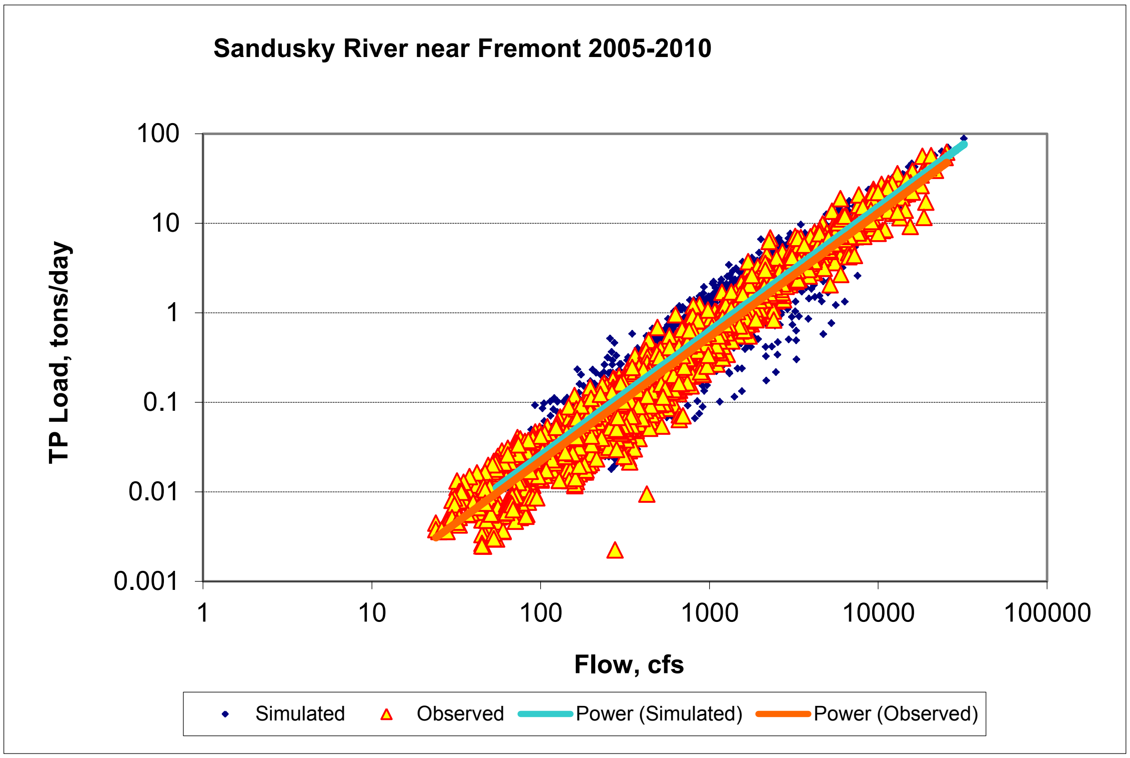


Figure B-69. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Sandusky River near Fremont (calibration period)

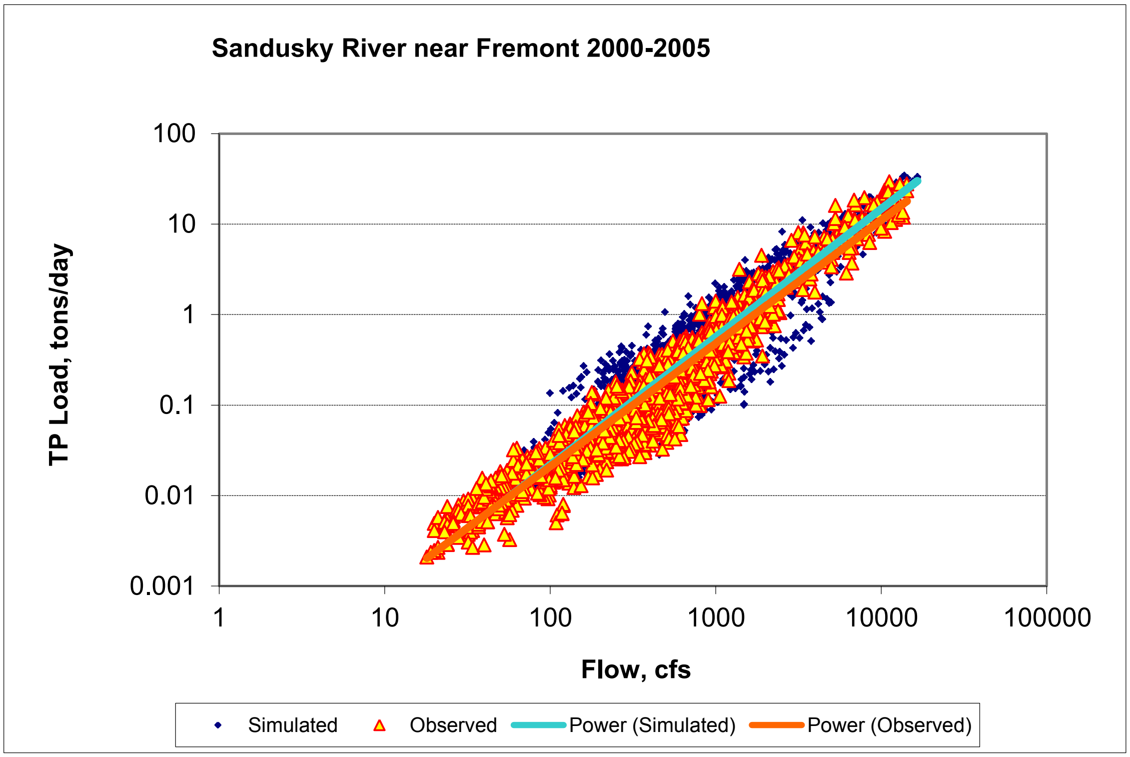


Figure B-70. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Sandusky River near Fremont (validation period)

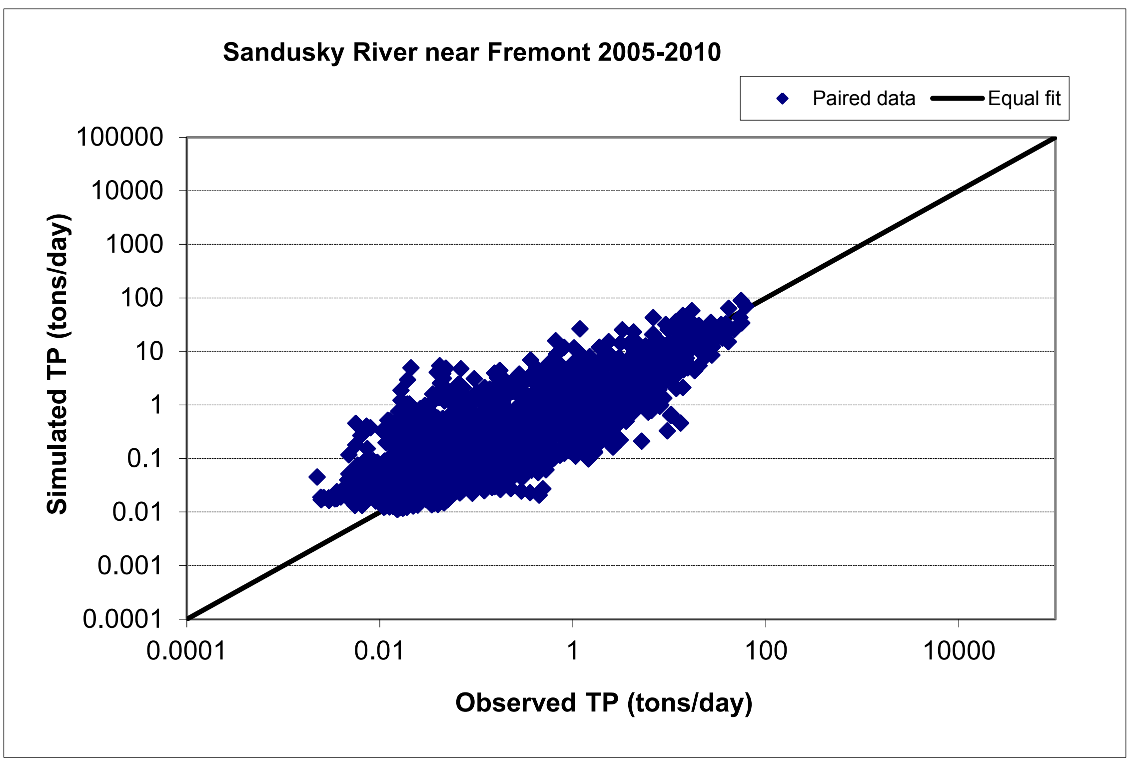


Figure B-71. Paired simulated vs observed Total Phosphorus (TP) load at Sandusky River near Fremont (calibration period)

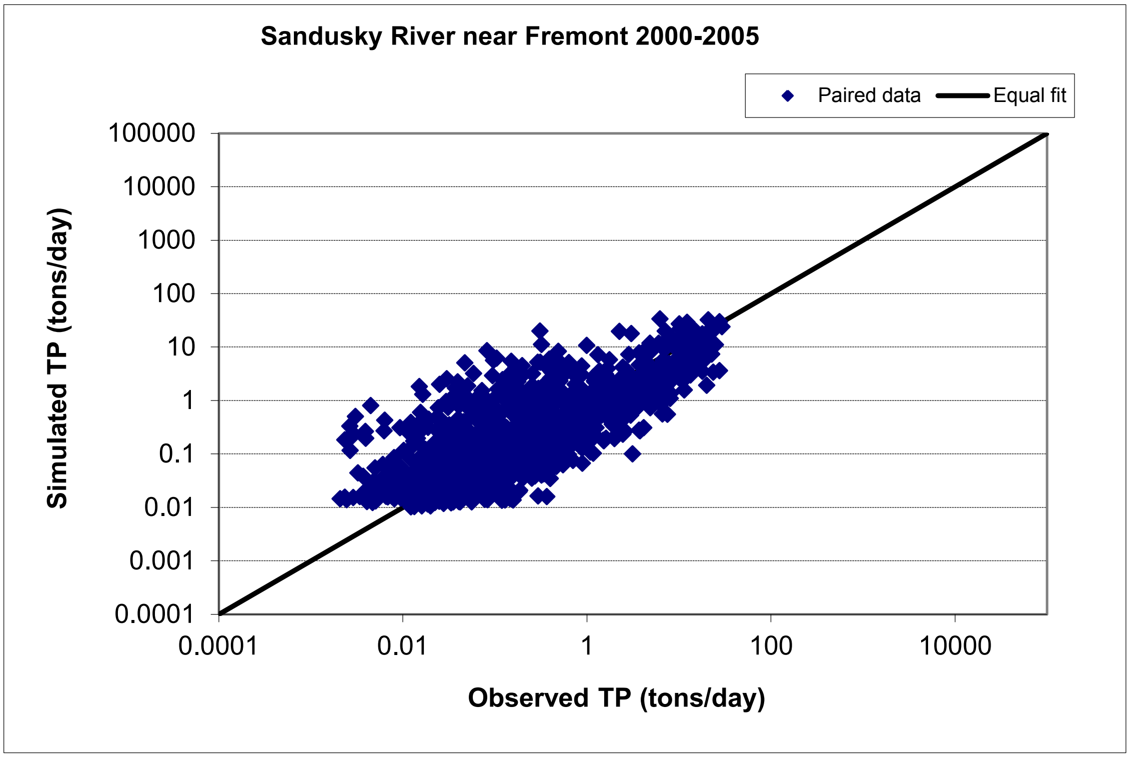


Figure B-72. Paired simulated vs observed Total Phosphorus (TP) load at Sandusky River near Fremont (validation period)

Sandusky River near Fremont (USEPA)

Table B-15. Summary statistics

Statistic	Calibration			Validation		
	TSS	TN	TP	TSS	TN	TP
Average absolute error	47.0%	31.5%	53.2%	49.1%	32.8%	42.2%
Median absolute error	9.3%	19.8%	32.6%	19.1%	23.0%	40.5%
Regression error	36.4%	6.2%	-22.6%	38.3%	11.5%	-7.3%
NSE	0.705	0.807	0.706	0.628	0.786	0.809
NSE'	0.620	0.638	0.505	0.517	0.595	0.538

Total Suspended Solids (TSS)

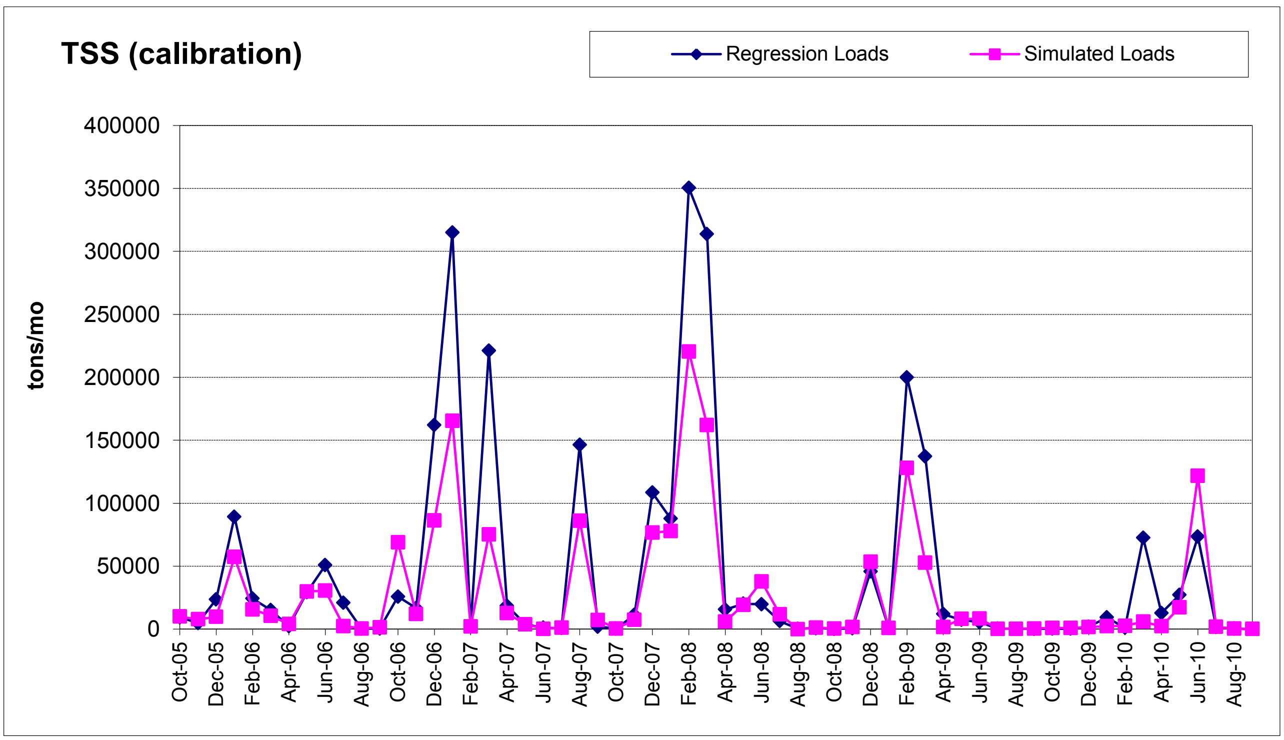


Figure B-73. Monthly simulated and estimated Total Suspended Solids (TSS) load at Sandusky River near Fremont (calibration period)

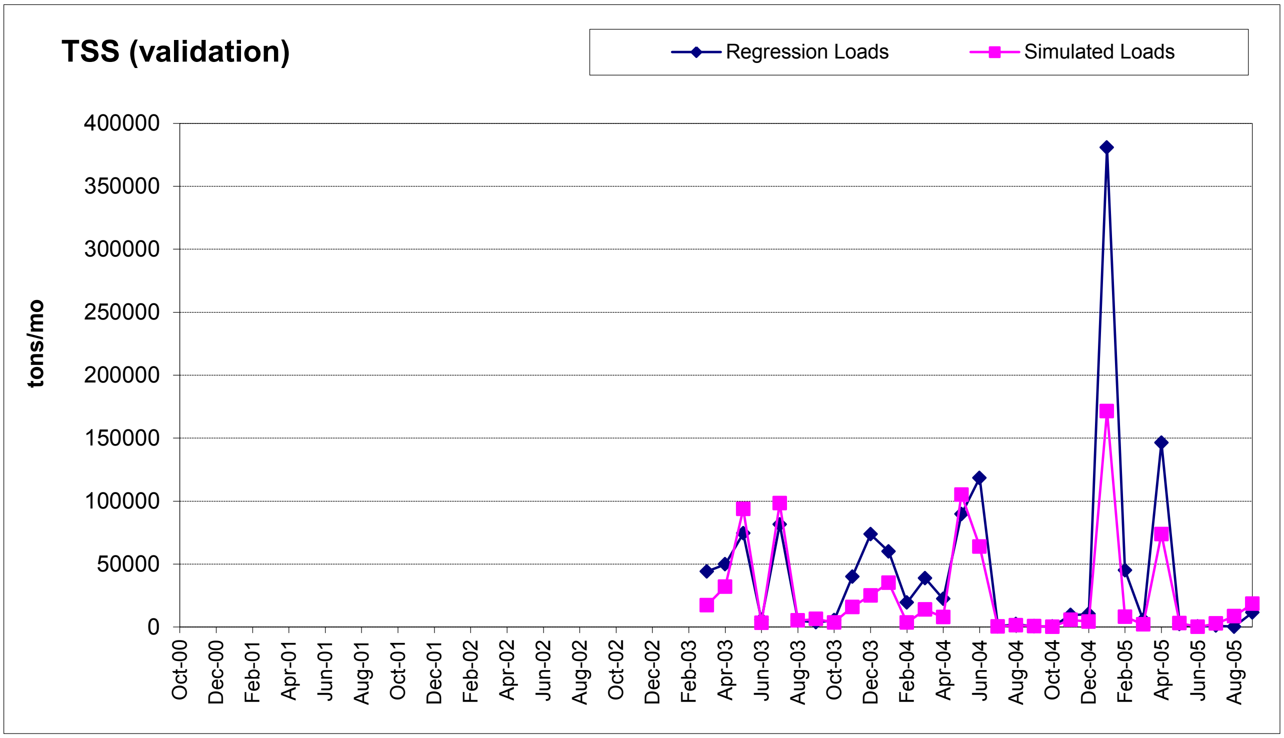


Figure B-74. Monthly simulated and estimated Total Suspended Solids (TSS) load at Sandusky River near Fremont (validation period)

Table B-16. Paired daily Total Suspended Solids (TSS) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	**Ave**	**Median**	**Ave**	**Median**	**Ave**	**Median**
Simulated	259.765	39.187	1139.184	46.716	850.624	42.340
Observed	475.160	24.504	684.943	38.700	616.108	37.123

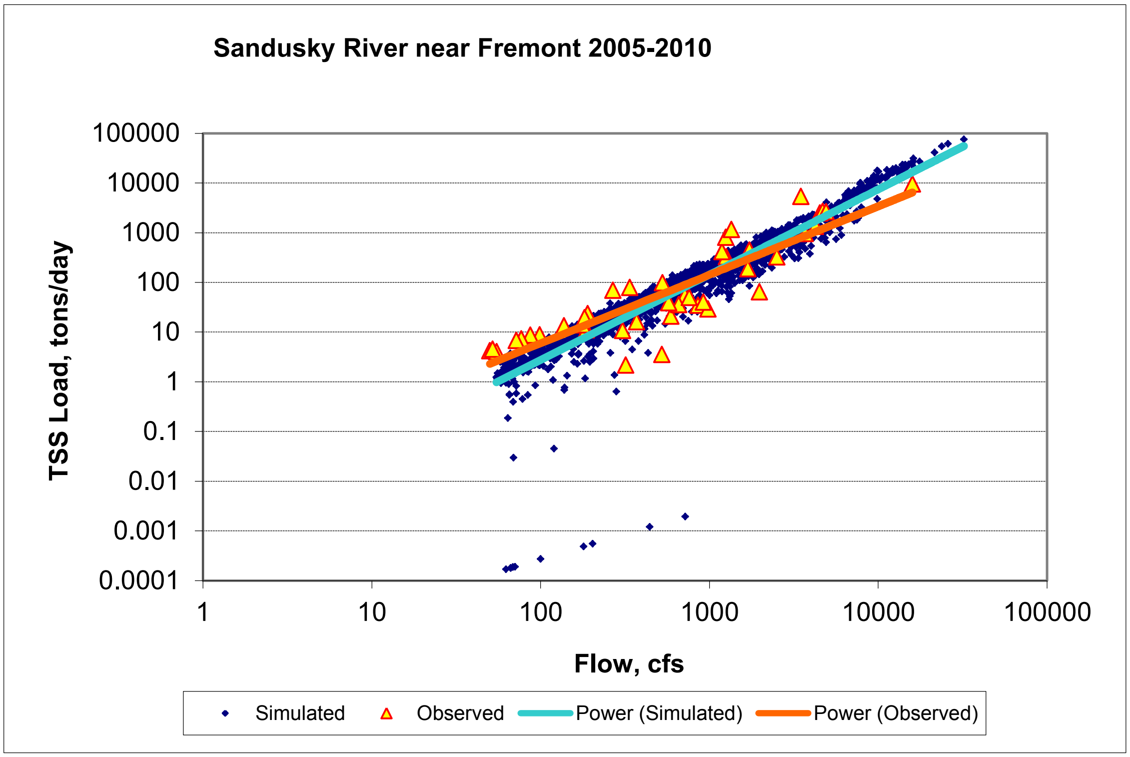


Figure B-75. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow at Sandusky River near Fremont (calibration period)

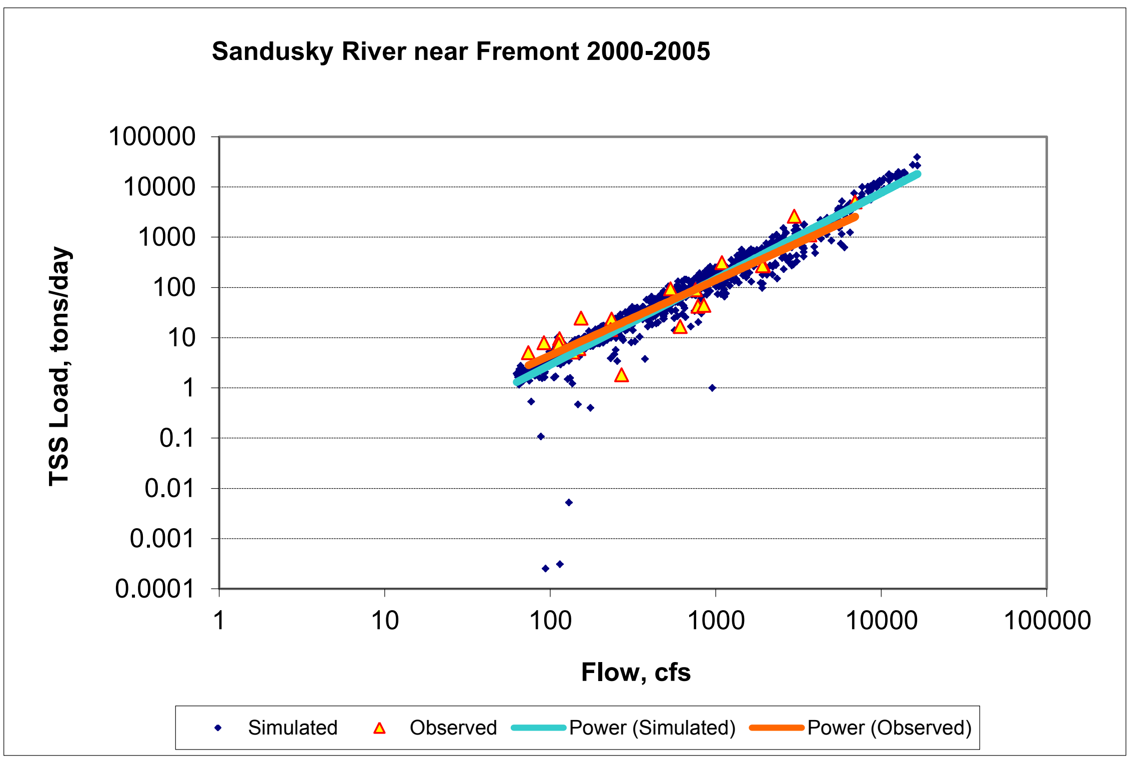


Figure B-76. Power plot of simulated and observed Total Suspended Solids (TSS) load vs flow at Sandusky River near Fremont (validation period)

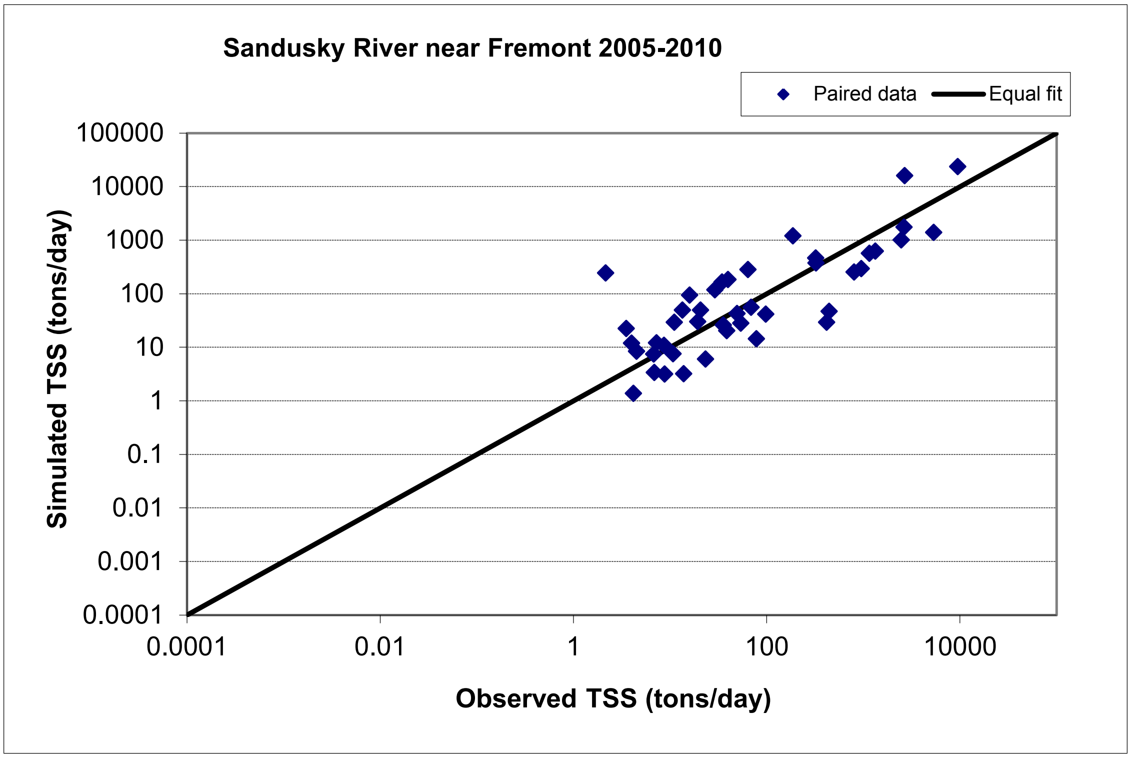


Figure B-77. Paired simulated vs observed Total Suspended Solids (TSS) load at Sandusky River near Fremont (calibration period)

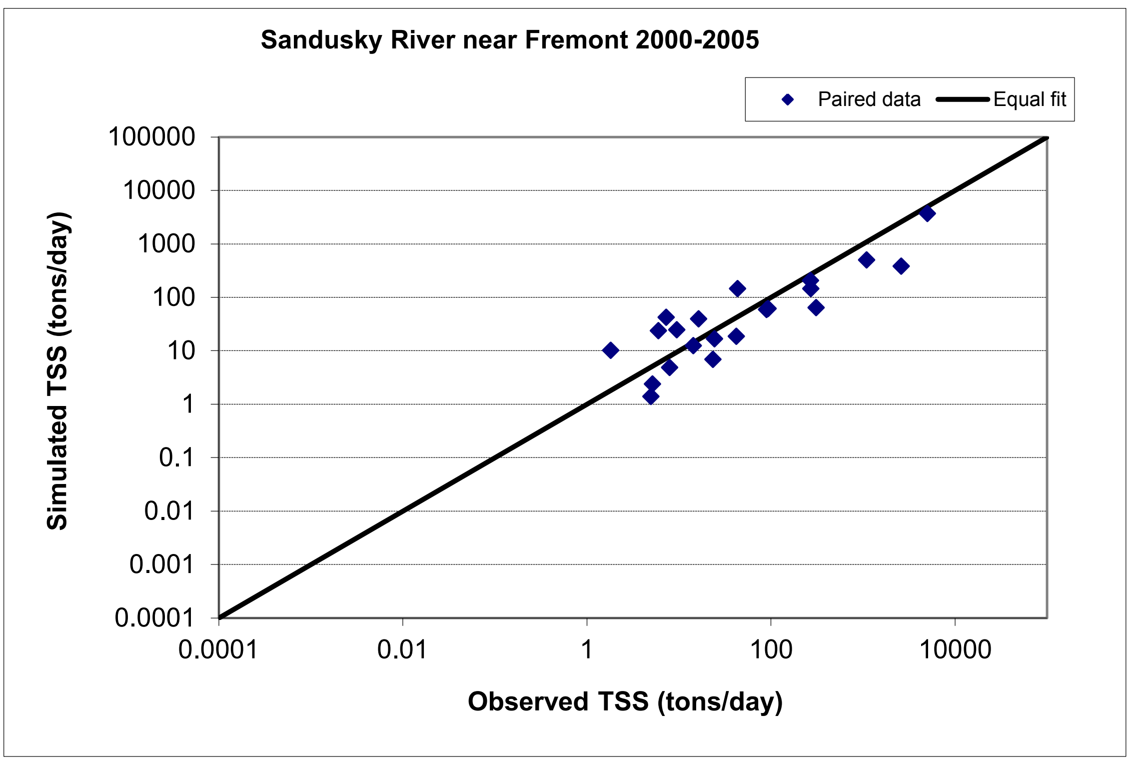


Figure B-78. Paired simulated vs observed Total Suspended Solids (TSS) load at Sandusky River near Fremont (validation period)

Total Nitrogen (TN)

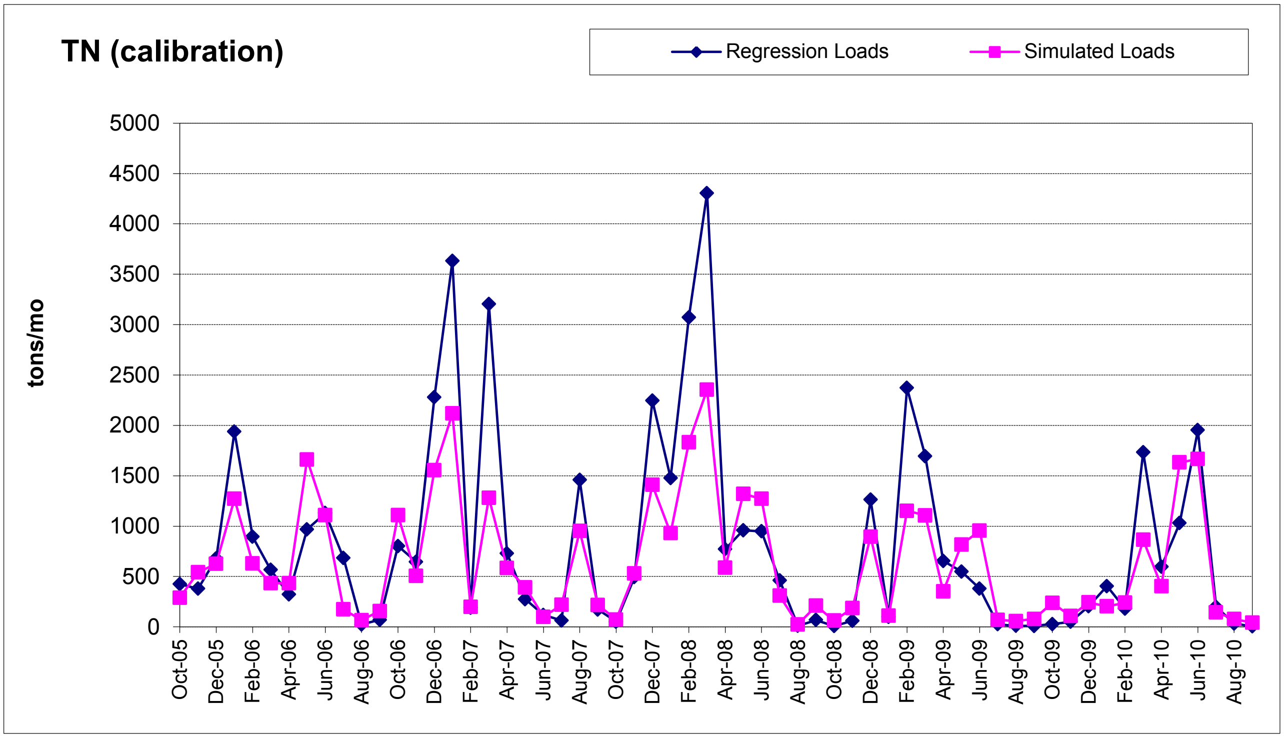


Figure B-79. Monthly simulated and estimated Total Nitrogen (TN) load at Sandusky River near Fremont (calibration period)

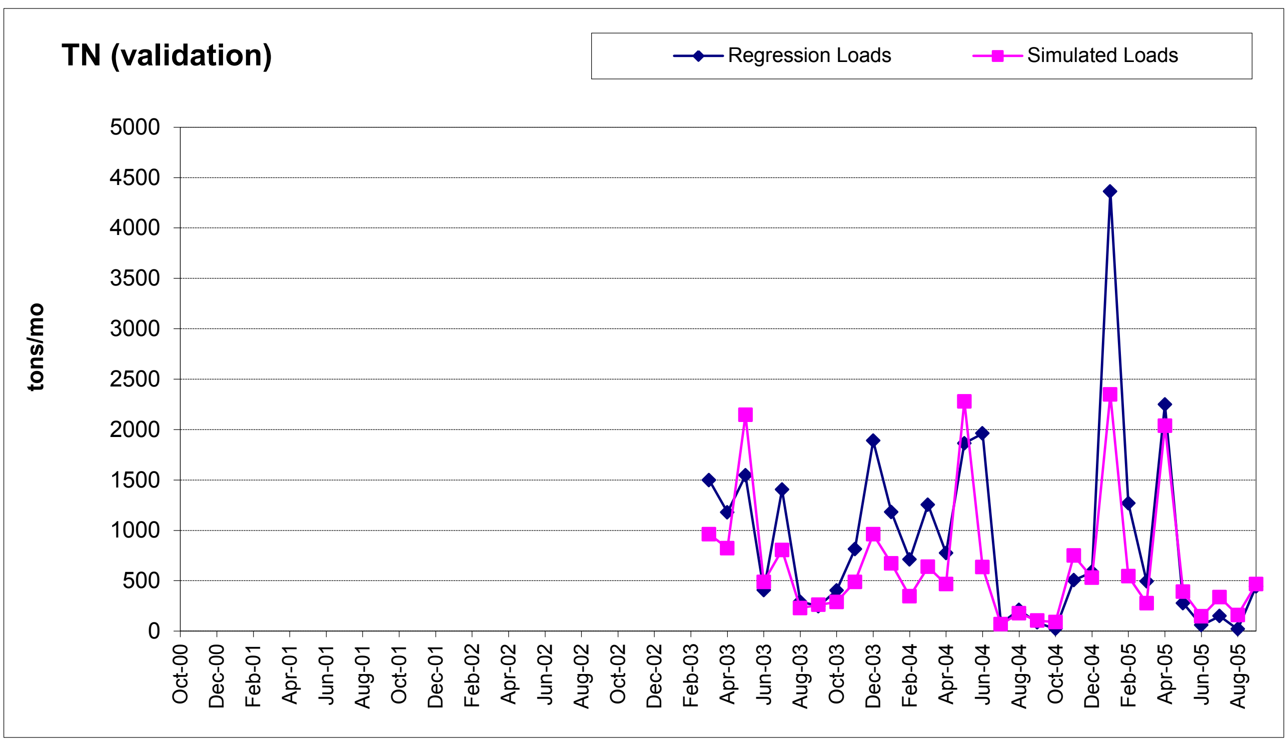


Figure B-80. Monthly simulated and estimated Total Nitrogen (TN) load at Sandusky River near Fremont (validation period)

Table B-17. Paired daily Total Nitrogen (TN) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	13.328	4.995	22.976	8.951	19.540	7.278
Observed	19.267	5.738	20.742	5.752	20.217	5.752

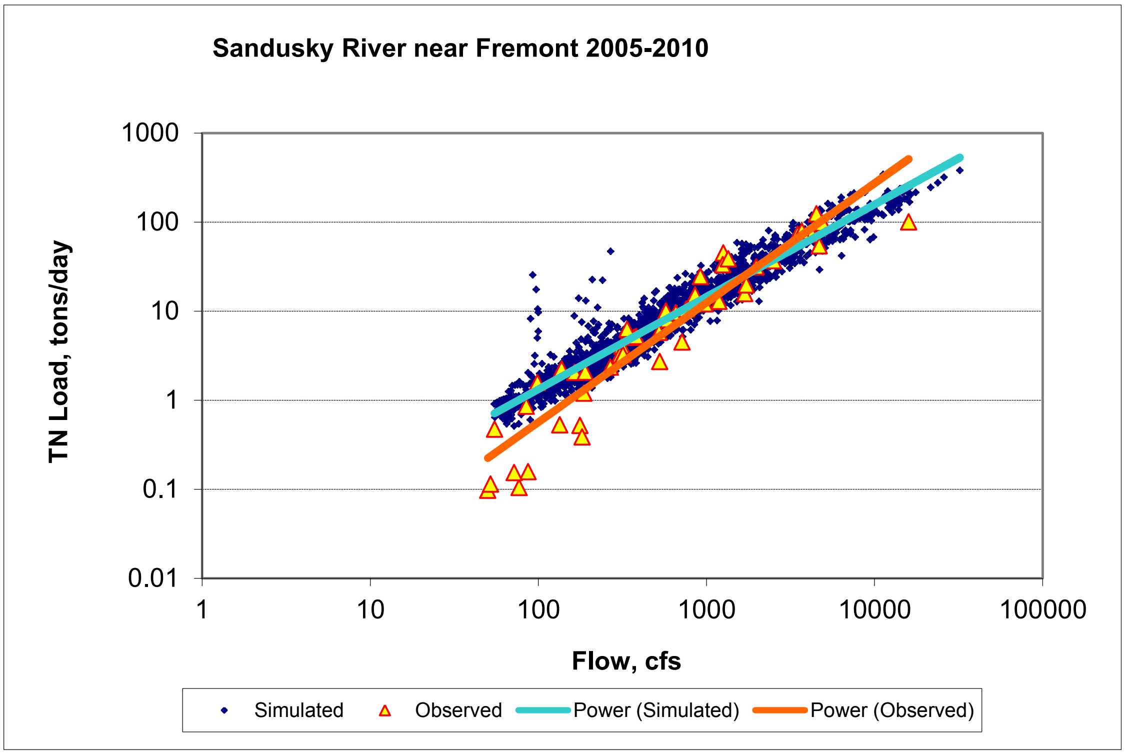


Figure B-81. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Sandusky River near Fremont (calibration period)

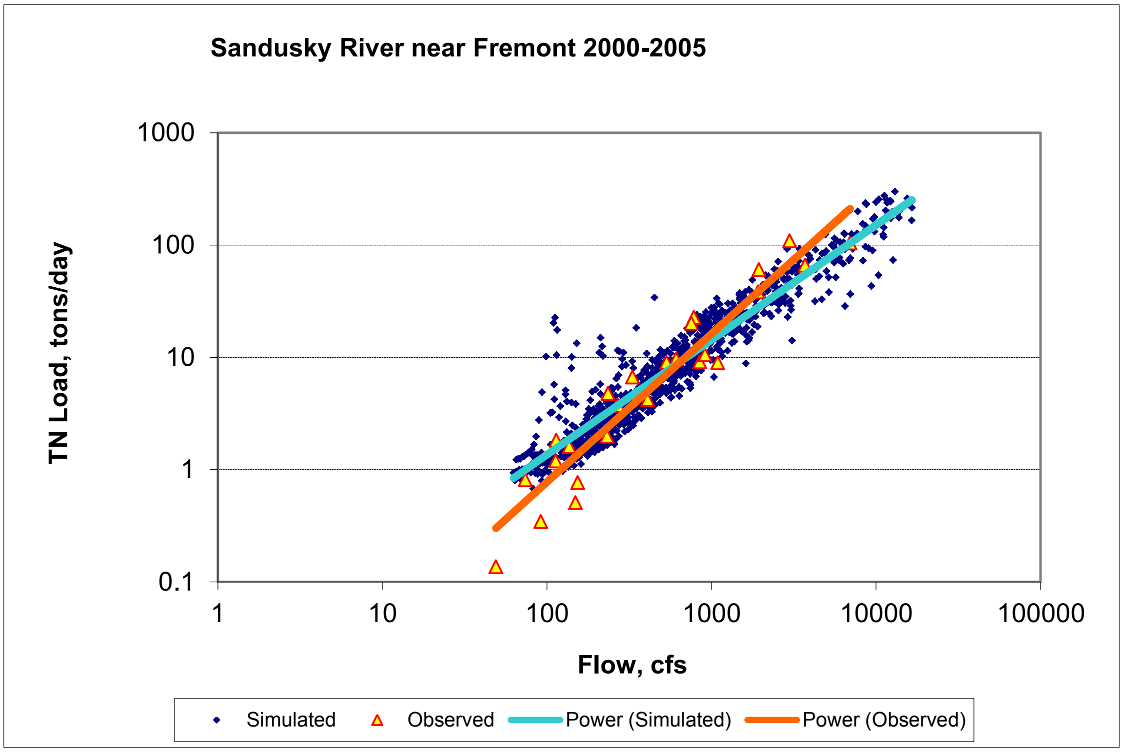


Figure B-82. Power plot of simulated and observed Total Nitrogen (TN) load vs flow at Sandusky River near Fremont (validation period)

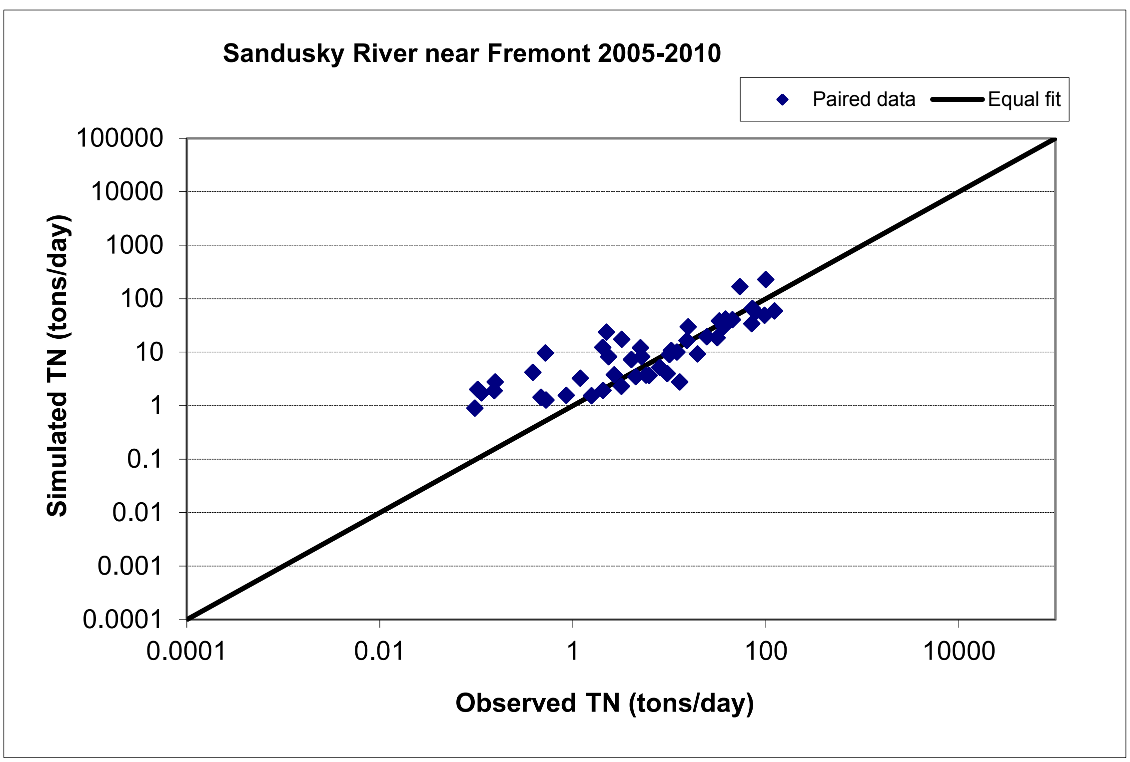


Figure B-83. Paired simulated vs observed Total Nitrogen (TN) load at Sandusky River near Fremont (calibration period)

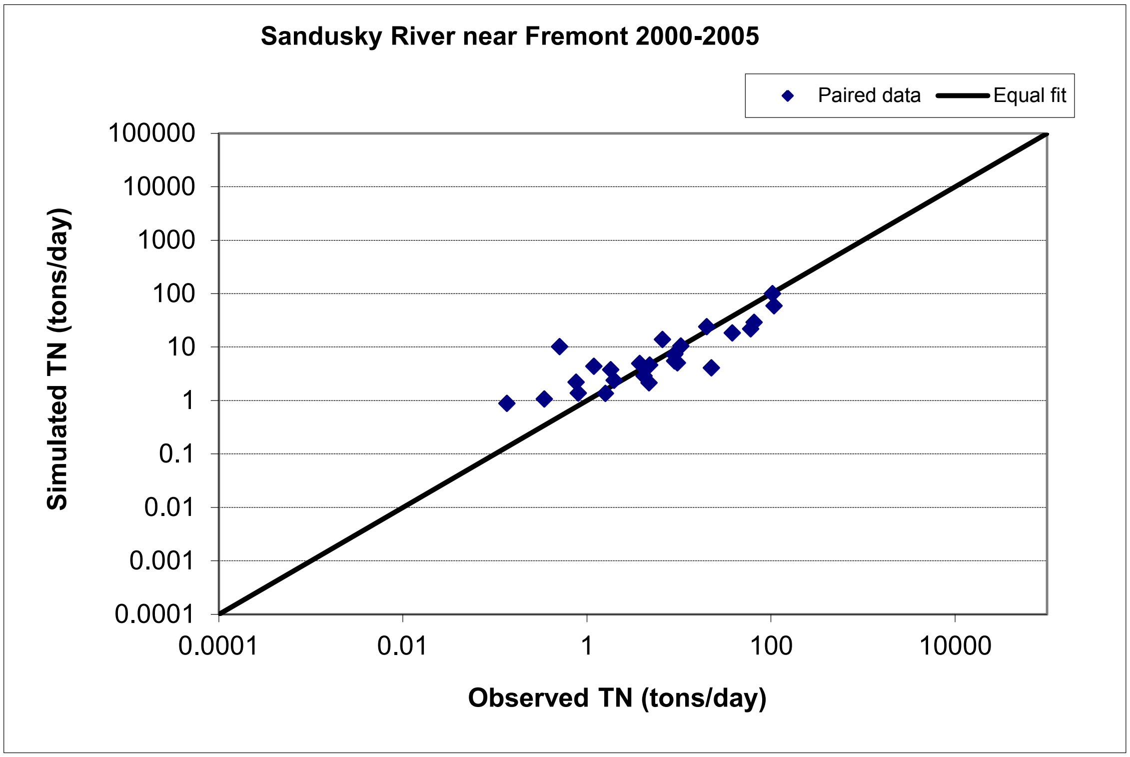


Figure B-84. Paired simulated vs observed Total Nitrogen (TN) load at Sandusky River near Fremont (validation period)

Total Phosphorus (TP)

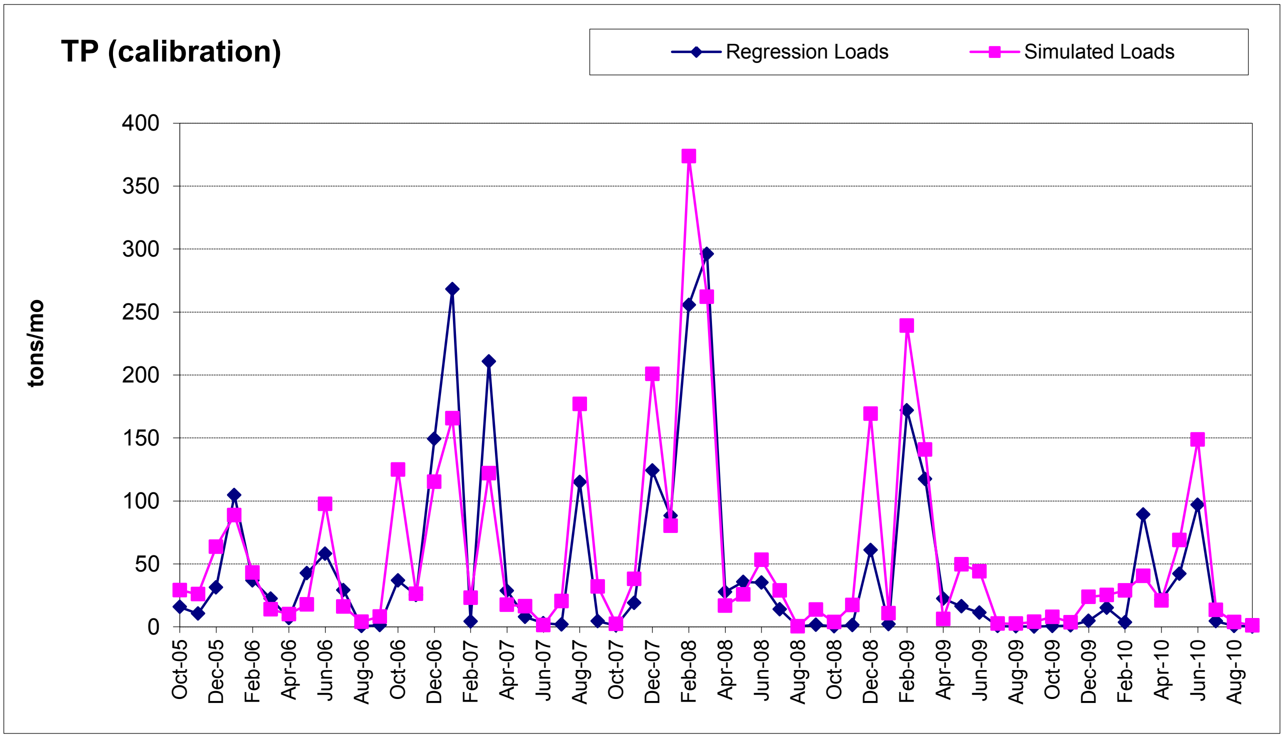


Figure B-85. Monthly simulated and estimated Total Phosphorus (TP) load at Sandusky River near Fremont (calibration period)

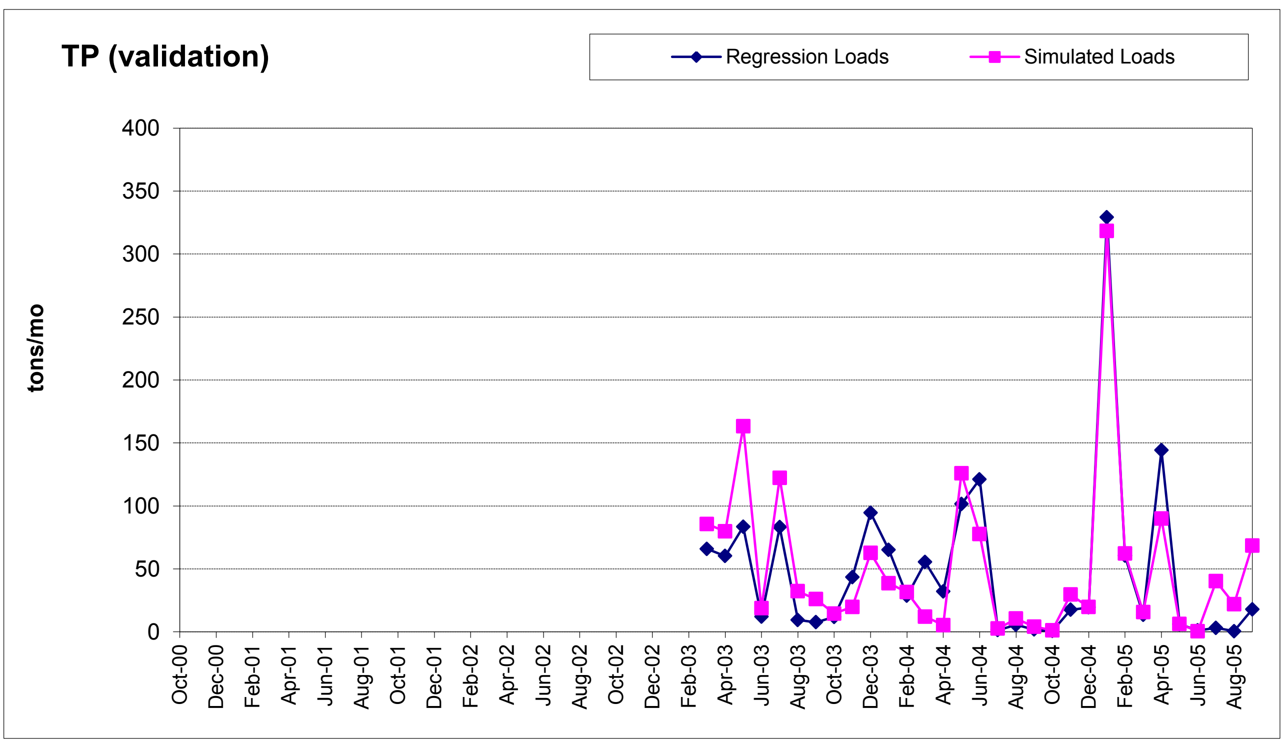


Figure B-86. Monthly simulated and estimated Total Phosphorus (TP) load at Sandusky River near Fremont (validation period)

Table B-18. Paired daily Total Phosphorus (TP) load (tons/day)

Period	2000-2005		2005-2010		2000-2010	
Statistic	Ave	Median	Ave	Median	Ave	Median
Simulated	0.509	0.233	1.945	0.217	1.434	0.231
Observed	0.617	0.038	0.888	0.139	0.792	0.122

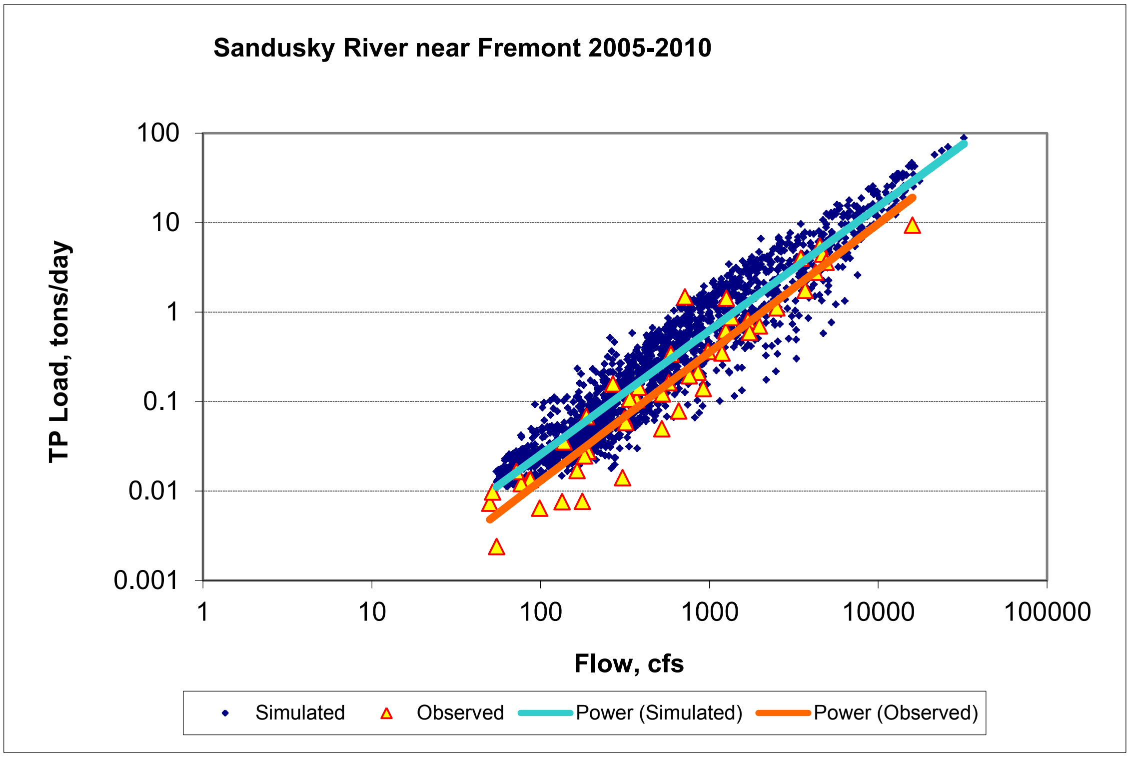


Figure B-87. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Sandusky River near Fremont (calibration period)

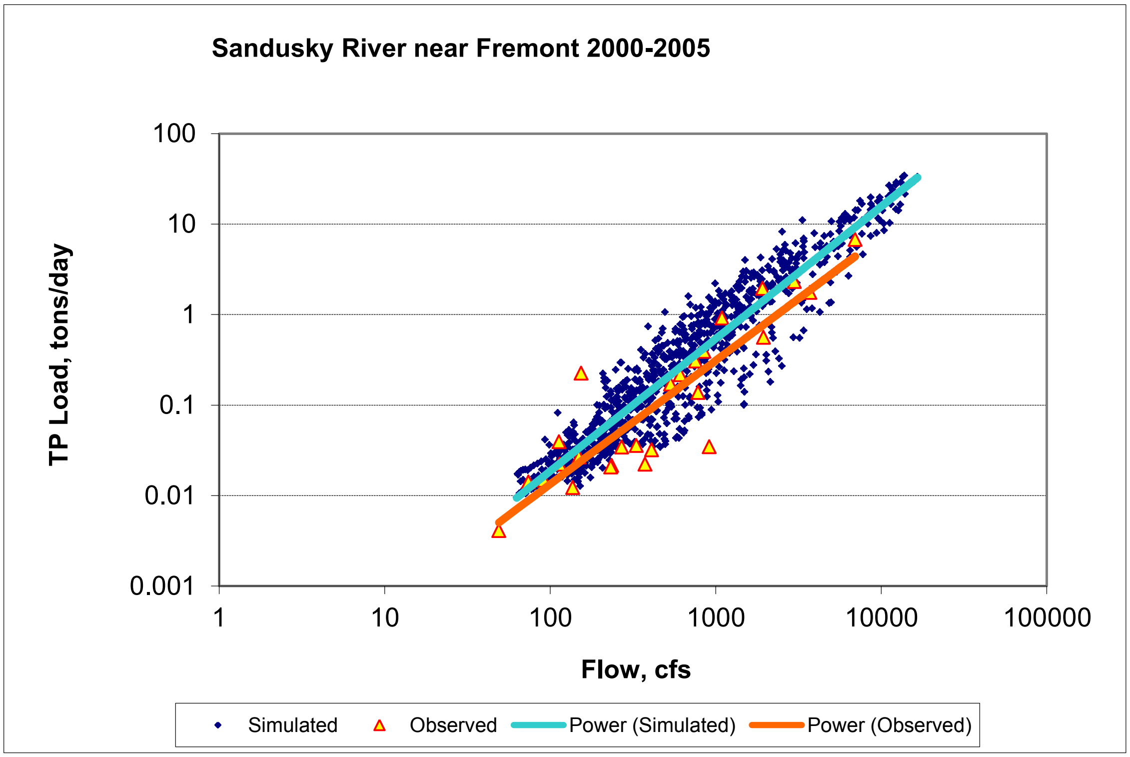


Figure B-88. Power plot of simulated and observed Total Phosphorus (TP) load vs flow at Sandusky River near Fremont (validation period)

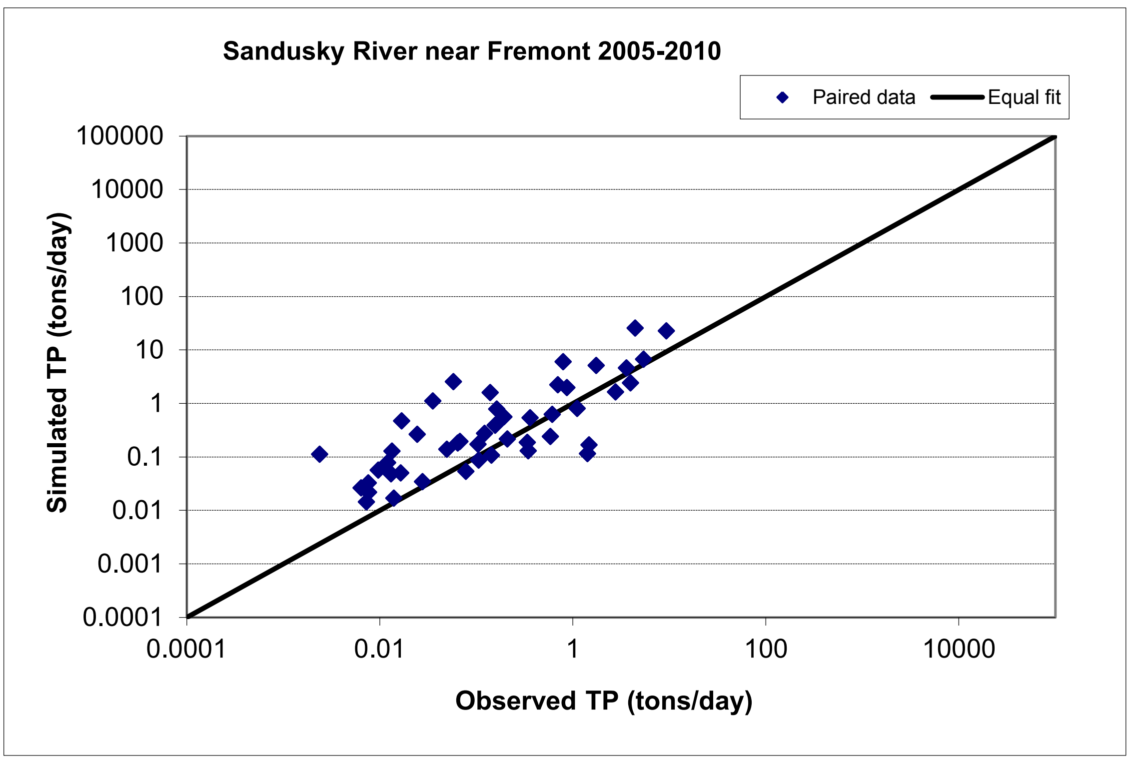


Figure B-89. Paired simulated vs observed Total Phosphorus (TP) load at Sandusky River near Fremont (calibration period)

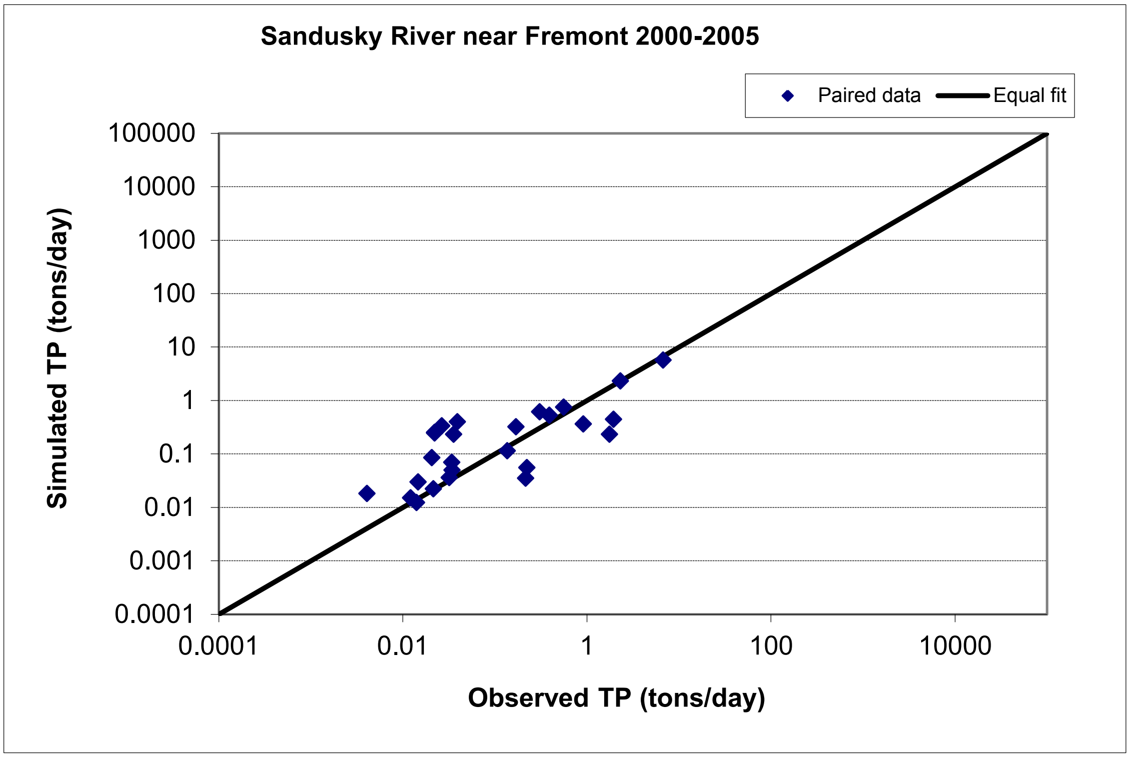


Figure B-90. Paired simulated vs observed Total Phosphorus (TP) load at Sandusky River near Fremont (validation period)