ANL/ESD-13/12

Analysis of Riverine Sediment and Nutrient Exports in Missouri River Basin by Application of SWAT Model

Energy Systems Division

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ACRONYMS AND ABBREVIATIONS

ARS	U.S. Department of Agriculture Agricultural research service
CDL	Cropland Data Layer
CT	Conventional Tillage
CTIC	Conservation Technology Information Center
DEM	Digital Elevation Model
HRU	Hydrological Response Units
HUC8	8-digit Hydrologic Unit Watersheds
LMORB	Lower Missouri River Basin
Manning's N	Empirical coefficient used in Manning's formulation to compute flow discharge
MORB	Missouri River Basin
NASS	National Agricultural Statistic Service
NCDC	National Climate Data Center
NH4	Ammonium
NH4-N	Ammonia Nitrogen
NID	National Inventory of Dams
NO2-N	Nitrite Nitrogen
NO3	Nitrate
NO3-N	Nitrate Nitrogen
NSE	Nashe-Sutcliffe Efficiency
NT	No-Tillage
OTRB	Ohio-Tennessee River Basin
PBIAS	Percent bias
PCS	Permit Compliance System
RF1	USEPA Stream Network Data
RMSE	Root Mean Square Error
RSR	Ratio of RMSE to standard deviation
RT	Reduced Tillage
SCS	Soil Conservation Service
STATSGO	State Soil Geographic Data Base
SWAT	Soil Water Analysis Tool
TN	Total Nitrogen
TP	Total Phosphorus

UMoRB	Upper Missouri River Basin
UMRB	Upper Mississippi River Basin
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

The U.S. Department of Energy's Bioenergy Technology Office has set a goal of developing the resources, technologies, and systems needed to grow a biofuels industry in a way that is economically feasible, socially responsible, and environmentally sustainable (US DOE, 2011). Environmental sustainability emphasizes maintaining the services provided by natural resources — one of the critical components to a sustainable bioenergy industry. Among the natural resources, water use and water quality are key factors that intrinsically link to energy and fuel production across its supply chain and are affected by climate change. In the context of water quality, the delivery of large volumes of nutrients from the Mississippi River to the Gulf of Mexico is a significant national concern. Given the importance of the Mississippi River Basin (MRB) and its role in large-scale biofuel feedstock production, there is an urgent need to examine the interactions between biofuel feedstock production and water quality at a regional scale. Simulations of changes in water quality in response to future scenarios could provide valuable regional-specific information to assist decision makers in project planning and site selection.

With the support from Bioenergy Technology Office, a multi-institute watershed simulation effort that focuses on the tributaries of the Mississippi River Basin was initiated in 2009. The study used the Soil and Water Assessment Tool (SWAT) — a public domain watershed model developed by the U.S. Department of Agriculture Agricultural research Service (ARS) — to identify major nonpoint sources, predict riverine sediment and nutrient exports, and track their delivery to the Mississippi River. As a part of the larger study, this report focuses on modeling and analysis of riverine sediment and nutrient loads associated with the Missouri River Basin (MORB). A SWAT model was calibrated and validated with 20 years of measured stream flow data collected from 20 U.S. Geological Survey stream flow gage stations for watershed hydrology. The calibration of riverine sediment and nutrient load was based on a subset of the locations used in the calibration of hydrology with limited measured data. SWAT model parameterization and evaluation are presented, along with the decisions made to overcome problems related to data representation in the basin. Model performance ranges from satisfactory to very good for both calibration and validation periods. Results for the riverine sediment and nutrient loads indicate a need for an increase in measured data, as well as more refined model discretion.

Further analysis revealed considerable variation in loads and yields of sediment, total nitrogen, and total phosphorus among the major tributaries of the MORB. The largest total nitrogen and total phosphorus loads were in the Lower Missouri River sub-basin and Middle Missouri River sub-basin. The smallest loads were from the Upper Missouri and Yellowstone River sub-basins, where inputs from all sources are modest and attributable to the large pasture and range land in this area. The total load delivered to the Mississippi River from the MORB included approximately 6.1×10^7 tons/yr of total suspended sediment, 4.5×10^8 kg⁄yr of total nitrogen, and 1.0×10^8 kg⁄yr of total phosphorus. Of these loads, Middle Missouri and Lower Missouri River sub-basins contribute 28.4% and 29.1% of the nitrogen, respectively, and 18.6% and 38.7% of the phosphorus, respectively; however, the nitrogen and phosphorus contributions by the Upper Missouri and Yellowstone sub-basins were less than 0.4%. In terms of total

suspended sediments load, the Lower Missouri sub-basin has the largest share and Upper Missouri and Kansas sub-basins the smallest.

The study shows that SWAT can be used to adequately estimate stream flow and riverine sediment and nutrient loads throughout the MORB, especially at the monthly increments. The most critical areas of sediment and nutrient losses to riverine systems can be adequately identified. With additional parameterization with respect to land use change and management, the model is able to evaluate the impact that new crop production, implementation of land management practices, and climate changes could have on the MORB — information that could aid in the selection and placement of suitable agricultural practices and in the choice landscape management strategies for cost-effective reductions in sediment and nutrient pollution. This evaluation is particularly valuable in biofuel feedstock cultivation in the river basin. We have confidence that the SWAT model will be useful for future studies in this region to predict changes in average sediment and nutrient loads in response to increased biofuel feedstock production under various future scenarios.

Analysis of Riverine Sediment and Nutrient Exports in Missouri River Basin by Application of SWAT Model

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1 INTRODUCTION

Nutrient enrichment has been identified by U.S. Environmental Protection Agency (USEPA) as one of the leading causes of water quality impairment in rivers, lakes, and estuaries (USEPA, 2009). Losses of the major nutrients, nitrogen (N) and phosphorus (P), from agricultural lands to water bodies cause water quality concerns relative to the health of both humans and aquatic systems, and impair water resource uses. Soil erosion that moves sediments, and sediment-bound nutrients into waterways is another factor influencing water quality. There is a strong correlation between suspended sediment and total phosphorus concentrations (Wetzel, 2001). In the Missouri River Basin (MORB), more than 160 stream reaches, lakes or reservoirs, and points were reported to the USEPA for nutrient-related impairment on the 2006 303(d) lists (USEPA Water Quality Assessment and Total Maximum Daily Loads Information, http://www.epa.gov/waters/ir/). The Missouri River had the largest sediment loads of any large river in the United States and contributed nearly one-half the sediment delivered to the Gulf of Mexico by the Mississippi River (Meade, 1995). In addition, nutrient loading from the MORB and other major tributary basins of the Mississippi River has been linked to hypoxic conditions in the northern Gulf of Mexico (Rabalais et al., 2002; Donner and Scavia, 2007; Scavia and Donnelly, 2007; Turner et al., 2008). Across the nation, nutrient concentrations in all measured watersheds increased between 1940 and 1980 compared to baseline levels [22], but since then the changes have been minimal.

Historically, in streams, nutrient inputs to the MORB come from several sources, including agricultural, livestock, municipal wastewater treatment plants (WWTPs), and industries. To support crop growth, chemical fertilizers are supplied, although the application rate varies considerably from place to place within the basin. Throughout the region, the amount of nitrogen applied increased rapidly beginning in 1964, until it reached a plateau in 1976. Since 1980, the application of nitrogen fertilizer has remained relatively stable, and has even decreased, as have inputs from manure and nitrogen from atmospheric deposition.

Another key source of nitrogen and phosphorus is manure produced from livestock operation. In the United States, about 5% of all croplands are fertilized with livestock manure (USDA ERS 2009). Within a cropland, corn accounts for over half the acreage to which manure is applied. In recent years, livestock production has shifted to concentrated animal operation facilities, which generate large quantities of manure in limited geographic areas. When the

aggregated manure from these operations exceeds the local crop nutrient requirement, excess nutrients from the manure can lead to water pollution.

The hypoxic zone in the Gulf is one of the largest in the world and its size is related to the fluxes of nutrients from the Mississippi River (Rabalais et al., 2002). In 2008, led by the USEPA, The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force – Hypoxia Task Force (HTF) began to develop a plan to reducing nutrient export by the Mississippi and Atchafalaya Rivers. It was suggested that nitrogen export may need to be reduced by up to 55% to achieve the hypoxia-reduction goal because of annual climate-driven variability in nitrogen flux and annual variability in ocean dynamics (Donner and Scavia, 2007; Scavia and Donnelly, 2007). The HTF set a goal of 50% reduction of nutrient in the watersheds of the 12 Mississippi River basin states (USEPA 2008). A five-year re-assessment in 2013 has already shown promising results in several states (USEPA 2013). Therefore, the ability to estimate stream flow, sediment and nutrient loading at any point on a river throughout the MORB can further provide valuable information for quantifying the effect of water resource management.

This study focuses on the use of the Soil and Water Assessment Tool (SWAT) for making such estimates while utilizing typical data available at the national level and evaluating riverine sediment and nutrient exports. The SWAT model was chosen because of its capability of assessing the impact of land management and climate patterns on water, sediment, and nutrient yields over long periods in large watersheds and from an agricultural perspective. Furthermore, in earlier studies, SWAT has been successfully applied over a wide range of scales including the Upper Mississippi River Basin (UMRB) and the Ohio-Tennessee River Basin (OTRB).

We focused on the MORB because it is the largest U.S. watershed of the Mississippi River and because of its role in large-scale biofuel feedstock production (Wu et al. 2012; Demissie et al. 2012). The long-term implications of land use change and land management and practices on water quality compare with a baseline at river basin scale has not been fully understood, therefore warrant an investigation. Even though cultivated cropland is not the dominant land cover in the MORB, the amount of cultivated cropland is about equal to that of cultivated cropland in the UMRB and the OTRB combined. Compared to other sub-basins like UMRB and OTRB, the whole MORB has not been modeled, including an assessment of how potential land management practices and weather changes could influence riverine sediment and nutrient exports in this region. SWAT has previously been used to model various physical and biogeochemical processes and predict the riverine sediment and nutrient exports in the UMRB and OTRB. SWAT is considered suitable for simulating the long-term impacts of land management practices and weather changes on water, sediment, and nutrient loss from large, complex watersheds (Arnold et al., 1998; Gassman et al., 2007; Arabi et al., 2008; Sahu and Gu, 2009). Many studies have used SWAT because of its physical representation capabilities in conjunction with varied management options. However, improving SWAT model predictions for a large river basin under data limitations is still a great challenge, in the context of providing realistic riverine sediment and nutrient predictions. Especially for sediments and nutrients, only a few grab samples per year and only for a few years are often available. Moreover, it is usual that available observed data in a large river basin come from different stations without time overlap, thus evaluation of riverine sediment and nutrient model predictions must often be conducted for different periods and locations across the basin under different scenarios.

This study is a long-term, detailed analysis of riverine sediment, nitrogen and phosphorus loads for the MORB using SWAT. Our approach is to fully calibrate and evaluate the model to 20 years of observations for stream flows, riverine sediment and nutrient loads if observed data are available. The other main objective of this study is to investigate potential factors controlling riverine sediment and nutrient exports as part of an investigation of the large-scale biofuel feedstock production impacts on water quality. The SWAT model was used to explore the role of land use, management practices and weather changes on sediment and nutrient loading and explore potential reasons for the increased riverine sediment and nutrient loads — key parameters considered include (1) land use changes; (2) changes in in fertilizer application rates and tillage practices; and (3) changes in rainfall patterns. The results from this study are expected to aid in predicting the potential impacts of projected changes in land use, management practice and weather, especially in regard to a shift toward biofuel feedstock production. It is our hope that this study will result in a further understanding of nutrient transport and fate in the MORB — that understanding is critical to designing and implementing the right management practices to effectively reduce nutrient losses into waterways.

2 SUMMARY OF SWAT MODEL

SWAT is a public domain watershed model developed by the U.S. Department of Agriculture Agricultural research Service (ARS). The details of SWAT model used are kept to a minimum here because it is well-documented elsewhere in the peer-reviewed scientific literatures (e.g., Arnold et al., 1998, Neitsch et al., 2011). In SWAT the watershed is delineated into a number of sub-basins based on topography. Each sub-basin possesses a geographic position in the watershed and is spatially related to adjacent sub-basins. Each sub-basin is further divided into hydrological response units (HRUs) based on land use, soil and slope classes. HRUs are the smallest computational units in SWAT with unique land use, soil type and slope within a sub-basin. Thus, SWAT can take two levels of the spatial heterogeneity into account. The first level (sub-basin) supports the spatial heterogeneity associated with hydrology, and the second level (HRU) incorporates the spatial heterogeneity associated with land use, soil type and slope class. Within a sub-basin, SWAT does not retain the spatial location of each HRU. Hydrologic, soil, water quality and other processes are modeled within the sub-basins through the use of HRUs. Flow generation, sediment yield, and pollutant loadings are summed across all HRUs in a sub-basin, and the resulting flow and loads are then routed through channels, ponds, and/or reservoirs to the watershed outlet. All model calculations are performed on a daily time step.

Major model components include climate, hydrology, erosion and sedimentation, nutrient cycle, plant growth, and land management. For climate, SWAT uses the data from the station nearest to the centroid of each sub-basin. The hydrological model is based on the water balance equation in the soil profile, where the processes simulated include surface runoff/infiltration, evapotranspiration, lateral flow, percolation, and return flow. SWAT considers a shallow unconfined aquifer, which contributes to the return flow and a deep confined aquifer acting as a source or sink. Surface runoff volume and infiltration are computed by using the modified SCS curve number method or Green and Ampt equation. The peak rate component uses Manning's formula to determine the watershed time of concentration and considers both

overland and channel flow. Groundwater flow contribution to total stream flow is simulated by routing a shallow aquifer storage component to the stream (Arnold and Allen, 1996). Channel routing is simulated by using either the variable-storage method or the Muskingum method; both methods are variations of the kinematic wave model.

Erosion and sediment yield are estimated for each HRU with the Modified Universal Soil Loss Equation (Williams and Berndt, 1977). The SWAT model also calculates the contribution of sediment to channel flow from lateral and groundwater sources. The channel sediment routing uses a modification of Bagnold's sediment transport equation (Bagnold, 1977) that estimates the transport concentration capacity as a function of velocity. The model either deposits excess sediment or re-entrains sediment through channel erosion depending on the sediment load entering the channel. The delivery ratio is estimated for each particle size as a linear function of fall velocity, travel time, and flow depth.

SWAT simulates the transformation and movement of nitrogen and phosphorus in several organic and inorganic pools (Fig. 1). The soil nitrogen cycle is simulated by using five different pools; two are inorganic forms (ammonium and nitrate) while the other three are organic forms (fresh, stable, and active). The SWAT model simulates movement between N pools, such as mineralization, decomposition and immobilization, nitrification, denitrification, and ammonia volatilization. Other soil N processes — such as plant uptake, N fixation by legumes and NO3-N movement in water — are also included in the model. Nitrates are removed from soil with surface and subsurface runoff, while the amount of organic N transported with sediments is calculated as a function of organic N in the top soil layer and the sediment yield. The loading function estimates daily organic nitrogen runoff loss on the basis of the concentrations of constituents in the top soil layer, the sediment yield, and an enrichment ratio. Nitrate export with runoff, lateral flow, and percolation are estimated as products of the volume of water and the average concentration of nitrate in the soil layer. Once N enters channel flow, the SWAT model partitions N into four pools: organic N, NH4-N, nitrite-N (NO2-N), and NO3-N. The SWAT model simulates changes in N that result in movement of N between pools. SWAT simulates six different pools of phosphorus in soil; three are inorganic forms and the rest are organic forms. Transformations of soil P among these six pools are regulated by algorithms that represent mineralization, decomposition, and immobilization. The solution (labile) pool is considered to be in rapid equilibrium (days to weeks) with active pools that subsequently are considered to be in slow equilibrium with stable pools. The amount of soluble P removed in runoff is predicted by using labile P concentration in the top soil layer, the runoff volume and a phosphorus soil-partitioning factor. Sediment transport of P is simulated with a loading function similar to the organic N transport. In-stream P dynamics in SWAT are also simulated by using two state variables as inorganic and organic P adopted from the QUAL2E model (Brown and Barnwell, 1987).

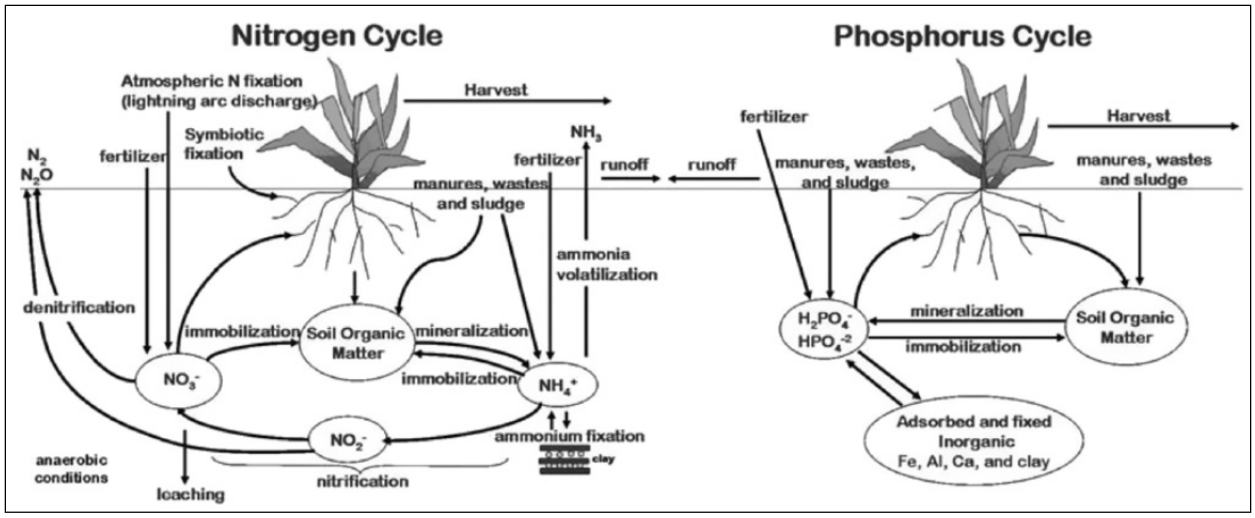


FIGURE 1 Nitrogen and phosphorus cycles modeled by SWAT (Neitsch et al., 2011).

Vegetation growth is dynamically simulated with a heat unit phenological development method. Crop yield is determined from the biomass at harvest and the harvest index. Plant growth is limited by temperature, water, and nutrient deficiencies; and is influenced by agricultural management (e.g., fertilization, irrigation, and timing of operations). SWAT utilizes routines for computing plant development on the basis of plant-specific input parameters included in the plant growth database.

3 STUDY AREA AND DATA

The focus of this study is on the MORB. The MORB is the largest of the water resource regions that make up the Mississippi River Basin. The basin drains about 1,502,000 km^2, one-sixth of the conterminous United States, and is located in parts of 10 States and Canada (Fig. 2). The Missouri River is the longest river in the U.S. The main stem of the Missouri River flows 3,768 km from Three Forks, Montana to its confluence with the Mississippi River near St. Louis, Missouri, which eventually flows to the Gulf of Mexico. The Missouri's largest tributaries by runoff are the Yellowstone in Montana and Wyoming, the Platte in Wyoming, Colorado, and Nebraska, and the Kansas–Republican/Smoky Hill and Osage in Kansas and Missouri. Each of these tributaries drains an area greater than 26,000 km^2, and has an average discharge greater than140 m^3/s.

The dominant land cover in the MORB is rangeland (51% of the area), most of which is grass rangeland located in the western and central parts of the basin. Cultivated cropland accounts for about 25% of the area, the bulk of which is located in the eastern and southern parts of the basin. Corn and soybeans are the principal crops grown in the eastern portion of the basin and wheat and other small grain crops are the principal crops grown in the western portion. Agriculture in the MORB is not as inherently productive as in the UMRB or the OTRB because of lower precipitation and generally less fertile soils. Forestland accounts for 9% of the area,

most of which is located in the west and in central Missouri. Permanent pasture and hay land represent only 6% of the area, and water, wetlands, horticulture, and barren land account for about 4% of the area. Urban areas comprise only a small part of the basin (3%) and are concentrated near large cities like Denver, Colorado; Omaha, Nebraska; and Kansas City, Missouri. The remaining 2% of the area belongs to the Canada.

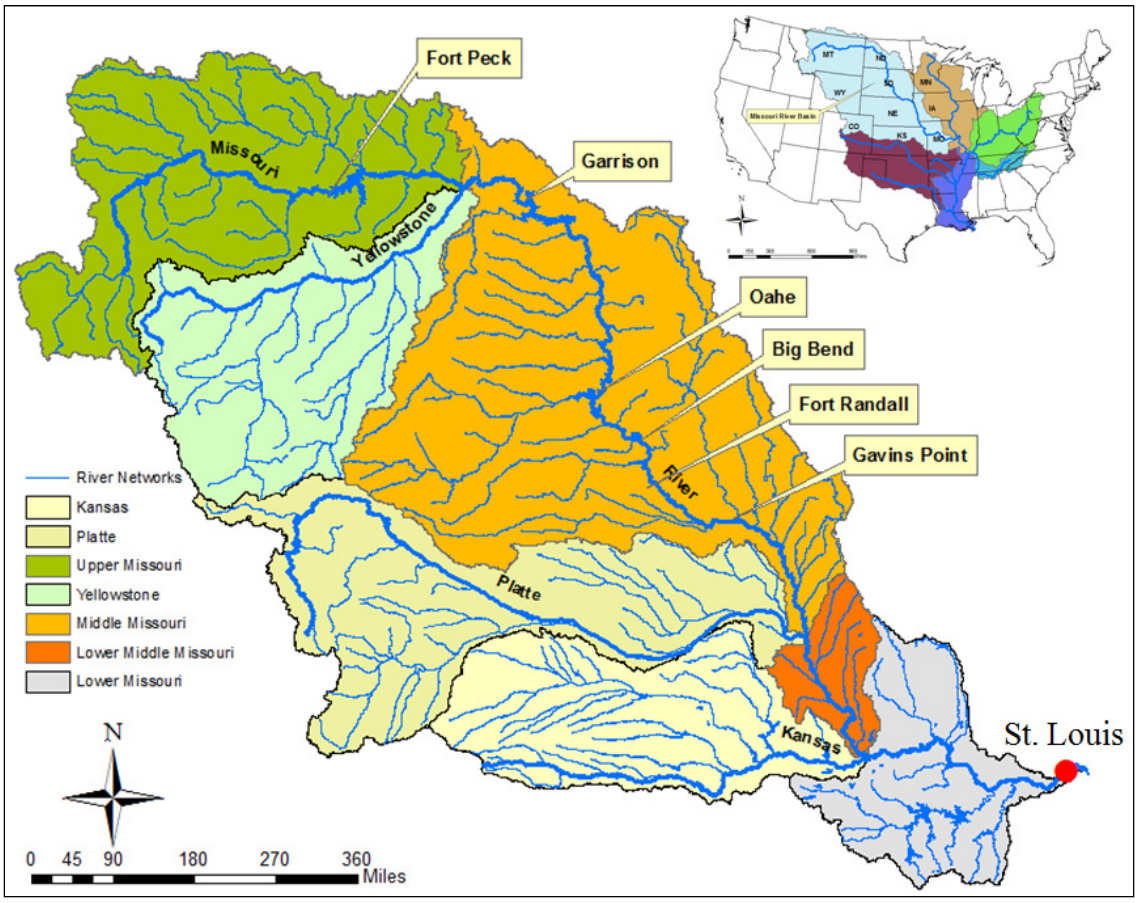


FIGURE 2 Location of the MORB and its major sub-basins and tributaries.

The MORB is an extremely diverse basin in many respects. The Rocky Mountains form the basin's western boundary. They have an exceptionally rugged topography. Its geography varies from the mountains of Colorado, Montana and Wyoming with some peaks as high as 14,000 feet above sea level to the low lands of Missouri of less than 500 feet. The climate varies from arid and semi-arid to sub-humid. Most of the basin receives an average of 200 to 250 mm of precipitation each year. However, the westernmost portions of the basin in the Rockies and the southeastern regions in Missouri may receive as much as 1,000 mm. The vast majority of precipitation occurs in winter. Because of its mid-continent location, the MORB experiences large temperature fluctuations and extremes. Winter temperatures in Montana, Wyoming and Colorado may drop as low as −51°C, while summer highs in Kansas and Missouri have reached 49°C.

The input data needed to run the SWAT model include elevation, soil, land use, weather, management conditions, stream network, and watershed configuration data. The elevation data were represented by a 60m USGS Digital Elevation Model (DEM), while the State Soil Geographic (STATSGO) Database was used to define the soil properties and distribution. The physical soil properties needed by SWAT are texture, bulk density, available water capacity, saturated hydraulic conductivity, and soil albedo for up to 10 soil layers. The USDA National Agricultural Statistics Service (NASS) 2007–2010 Cropland Data Layer (CDL) was acquired and assessed to estimate land-cover types. The CDL was selected to represent land cover because of the great detail that is provided for the land cover-classes — specifically agricultural crops. The CDL contains crop-specific digital data layers and allows land cover to be categorized into specific agricultural land classes. The classification of interest in this study is row crops, which includes corn, soybeans, and wheat. Historical information on agricultural management was obtained from USGS, USDA. Table 1 summarizes the data used in this study as well as their sources and formats. Most of these datasets are downloadable through the public websites from the listed agencies.

TABLE 1 MORB data used in the SWAT model and their sources.

Dataset	Source of Data	Type of Data
Crop yield	USDA's National Agricultural Statistics Service (NASS)	Text
Commercial fertilizer application	USDA's Economic Research Service (ERS)	Text
Manure application	USDA's National Agricultural Library – Water Quality Information Center (WQIC); NASS	Text
Digital Elevation Model (DEM)	USEPA, Canada	Raster
8-digit Hydrologic Unit Code (HUC)	USGS	Shapefile
Stream network (RF1)	USEPA	Shapefile
Crop Data Layer (CDL)	USDA	Raster
State Soil Geographic (STATSGO) Data	ArcSWAT	Geodatabase
Tillage practice	USGS	Shapefile
Point sources	USEPA	Text
Atmospheric deposition	NADP	Text
Weather	USDA	Text
Tillage practice	Conservation Tillage Information Center (CTIC)	Text

Historical daily weather data from over 1800 NWS stations located throughout and surrounding the basin from 1960 until the end of September 2009 were obtained. The 50-year record is a serially complete daily data set of weather station data available from the NCDC (National Climatic Data Center) for the period 1960–2009, including precipitation, temperature maximum, and temperature minimum. The weather data were then screened for missing values and interpolated from the nearest weather station from which the data were available. Data for point source loading from permitted dischargers were estimated by using available monitoring

data contained in the U.S. Environmental Protection Agency's Permit Compliance System (PCS). Thirty-seven (20 for the UMORB and 17 for the LOMORB) of point sources representing major wastewater treatment plants and industrial facilities were included and assigned with a daily constant nutrient flow in this study (Fig. 3).

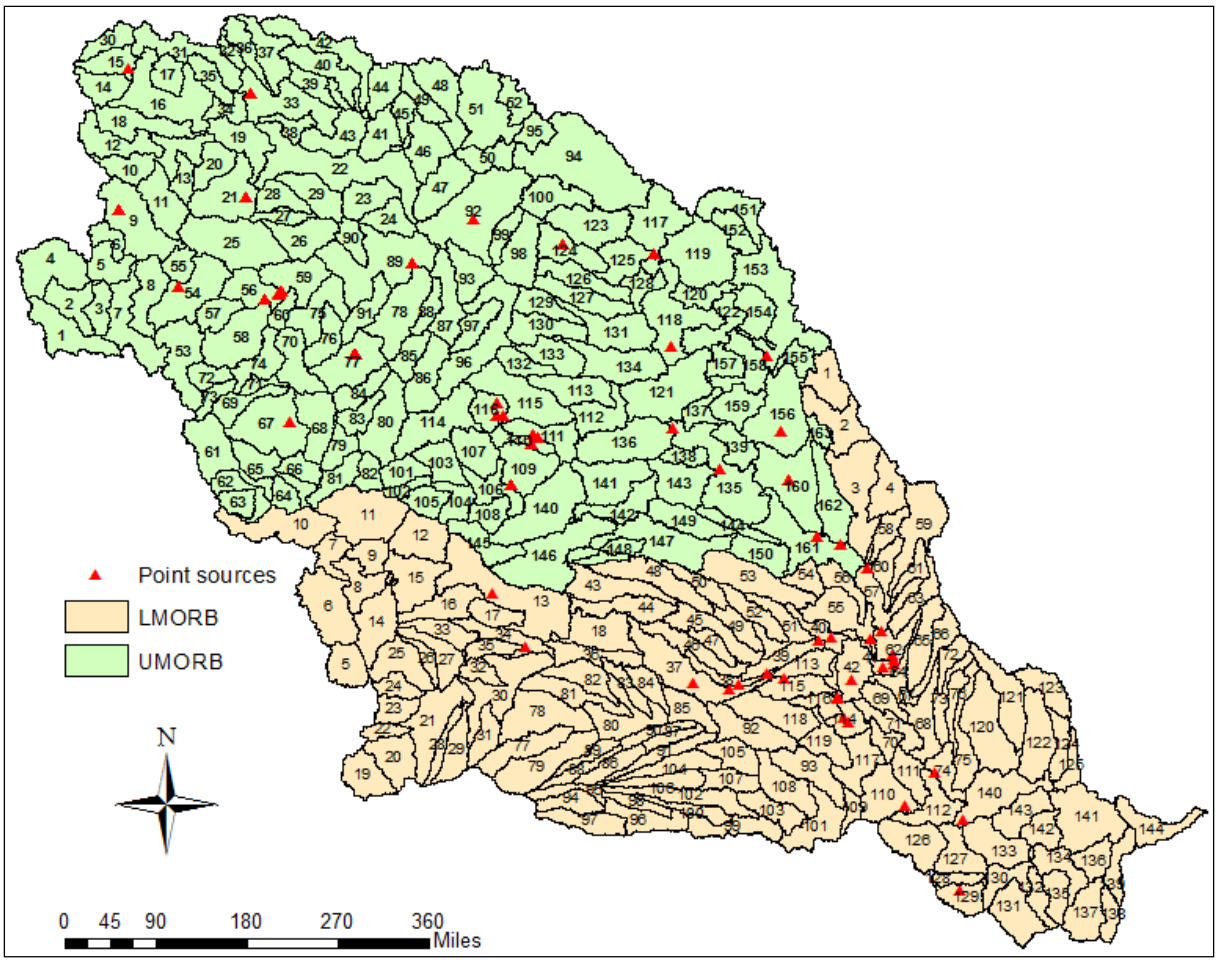


FIGURE 3 8-Digit hydrologic units (HUC) and major point source locations in the MORB.

The Missouri River Mainstem Reservoir System is comprised of six reservoirs that were constructed by the U.S. Army of Corps of Engineers. These six reservoirs contain about 73.4 million acre-feet of storage capacity, which constitutes over 52% of the total storage in the basin's reservoirs. This enormous capacity makes it the largest reservoir system in the U.S and one of the largest in North America. The six dams on the main stem system, Fort Peck, Garrison, Oahe, Big Bend, Fort Randell, and Gavins Point Dam are among the largest dams in the world by volume (Table 2). The Mainstem Reservoir System is a hydraulically and electrically integrated system that is regulated for flood control, navigation, hydropower, water supply, water quality, irrigation, recreation, and fish and wildlife. All these factors affect the timing and magnitude of Mainstem Reservoir System releases. The Mainstem Reservoir System is operated under the guidelines described in the Missouri River Mainstem System Master Water Control

Manual (USACE, 2004). Reservoir characteristics such as storage volume, surface area, and maximum flow rate of the principal spillway and drainage area were obtained from National Inventory of Dams (NID) from the U.S. Army Corps of Engineers. Daily release data on major reservoirs and water transfers were obtained from the U.S. Army Corps of Engineer Omaha District, and used in this study.

TABLE 2 Missouri river main stem dams and reservoirs.

Dam	Reservoir	Area (acres)	Volume (acre-feet)
Fort Peck Dam	Fort Peck Lake	246,000	18,700,000
Garrison Dam	Lake Sakakawea	384,480	23,000,000
Oahe Dam	Lake Oahe	359,000	23,500,000
Big Bend Dam	Lake Sharpe	63,000	1,900,000
Fort Randell Dam	Lake Francis Case	95,000	5,500,000
Gavins Point Dam	Lewis & Clark Lake	29,000	492,000

4 MODEL DEVELOPMENT, CALIBRATION AND VALIDATION

4.1 MODEL SETUP AND PARAMETERIZATION

Because of the size and complexity of the MORB, the MORB was divided into two watersheds. One is the Upper Missouri River Basin (UMORB) covering a drainage area of approximately 786,364 km^2, the other one is the Lower Missouri River Basin (LMORB) covering a drainage area of approximately 562,936 km^2. The UMORB outlet in this study is assumed to be at Sioux City, IA (Fig. 4). Two SWAT models were developed. SWAT results of the UMORB were used as the model inputs for the LMORB. A key aspect of the SWAT model parameterization is the delineation of the study watershed into sub-basin and then HRU units to facilitate the depiction of the wide range of climate, soils, land use, and management practices that exists in the watershed. 8-digit HUC watershed boundaries defined by the USEPA and USGS were selected as SWAT sub-basins in this study (Fig. 3). The UMORB was configured with 163 sub-basins. The LMORB includes 144 sub-basins. If sub-basins are predefined, the SWAT model requires a user-defined stream network data set to determine preferred flow paths within the sub-basin. The stream network is the primary means of surface water and water quality routing. The RF1 data set developed by the USGS and USEPA was used as the stream network layer for SWAT (Fig. 2).

To realistically simulate the baseline flow, sediment and water quality loadings, it is important to know the distribution of crop rotations in the MORB. Row crop agriculture in the MORB consisted of various rotational schedules and combinations utilizing mostly corn, soybean, and wheat crop production, whereas miscellaneous grain classes were combined as a general agricultural land. In this study, possible crop rotations were defined on the basis of the crops grown over the 4 years that information was obtained from 2007–2010 CDL data. All

rotations repeat after the fourth year. Twenty-three rotations were developed for the UMORB on the basis of analyzing 4 years of CDL data. Predominant cropping systems in the LMORB are markedly different from those in the UMORB. Eighteen rotations were developed for the LMORB. The classes of crop rotations implemented in this study are given in Table 3. Figure 4 presents land use and water features in the entire MORB in baseline year 2007.

TABLE 3 List of major crops and rotational classes.

Upper Missouri River Basin		Lower Missouri River Basin	
SWAT Symbol	**Crop Rotation**	**SWAT Symbol**	**Crop Rotation**
DWHT	Wheat	CORN	Corn
CORN	Corn	SOYB	Soybean
SOYB	Soybean	SWHT	Spring Wheat
ALFA	Alfalfa	WWHT	Winter Wheat
WWWI	Wheat-Wheat-Wheat-Idle	CSCS	Corn-Soyb-Corn-Soyb
WWWH	Wheat-Wheat-Wheat-Hay	SCSC	Soyb-Corn-Soyb-Corn
WWHW	Wheat-Wheat-Hay-Wheat	CCSC	Corn-Corn-Soyb-Corn
WHWW	Wheat-Hay-Wheat-Wheat	CSCC	Corn-Soyb-Corn-Corn
WCWW	Wheat-Corn-Wheat-Wheat	CCCS	Corn-Corn-Corn-Soyb
WWWC	Wheat-Wheat-Wheat-Corn	SCCC	Soyb-Corn-Corn-Corn
WWCW	Wheat-Wheat-Corn-Wheat	CSSS	Corn-Soyb-Soyb-Soyb
CWWW	Corn-Wheat-Wheat-Wheat	SCCS	Soyb-Corn-Corn-Soyb
CSCC	Corn-Soyb-Corn-Corn	CSSC	Corn-Soyb-Soyb-Corn
CSHS	Corn-Soyb-Hay-Soyb	SCSS	Soyb-Corn-Soyb-Soyb
CCSC	Corn-Corn-Soyb-Corn	SSCS	Soyb-Soyb-Corn-Soyb
CSCS	Corn-Soyb-Corn-Soyb	SSSC	Soyb-Soyb-Soyb-Corn
CSCH	Soyb-Corn-Soyb-Corn	CCSS	Corn-Corn-Soyb-Soyb
SCSC	Corn-Soyb-Corn-Hay	SSCC	Soyb-Soyb-Corn-Corn
HHHA	Hay-Hay-Hay-Alfalfa		
HHHW	Hay-Hay-Hay-Wheat		
HWWW	Hay-Wheat-Wheat-Wheat		
HAAA	Hay-Alfalfa-Alfalfa-Alfalfa		

Each of the sub-basins was further divided into a number of spatially uniform HRUs on the basis of land use, soil type, and topography. First, the land-use categories required for the watershed simulations were determined, and then the different soil types that were associated with each land use were selected. Spatially varied values of soil physical properties (available water capacity, saturated conductivity, bulk density, texture, and organic matter) were assigned to different HRUs by SWAT on the basis of the STATSGO database. Finally, the land slope classes were assigned for each HRU. User-specified land cover, soil area and slope class thresholds can be applied that limit the number of HRUs in each sub-basin. For this study, the number of HRUs in SWAT was based on thresholds of 5% for land use, 15% for soil, and 10% for slope. Because the study focuses on more crop cultivation and its impact, all croplands were exempted from the threshold — the cropland use category remains as a separate HRU even if the

area is pretty small. With 163 sub-basins in the UMORB, these thresholds result in 14539 HRUs in the SWAT model. The LMORB SWAT model includes 8811 HRUs.

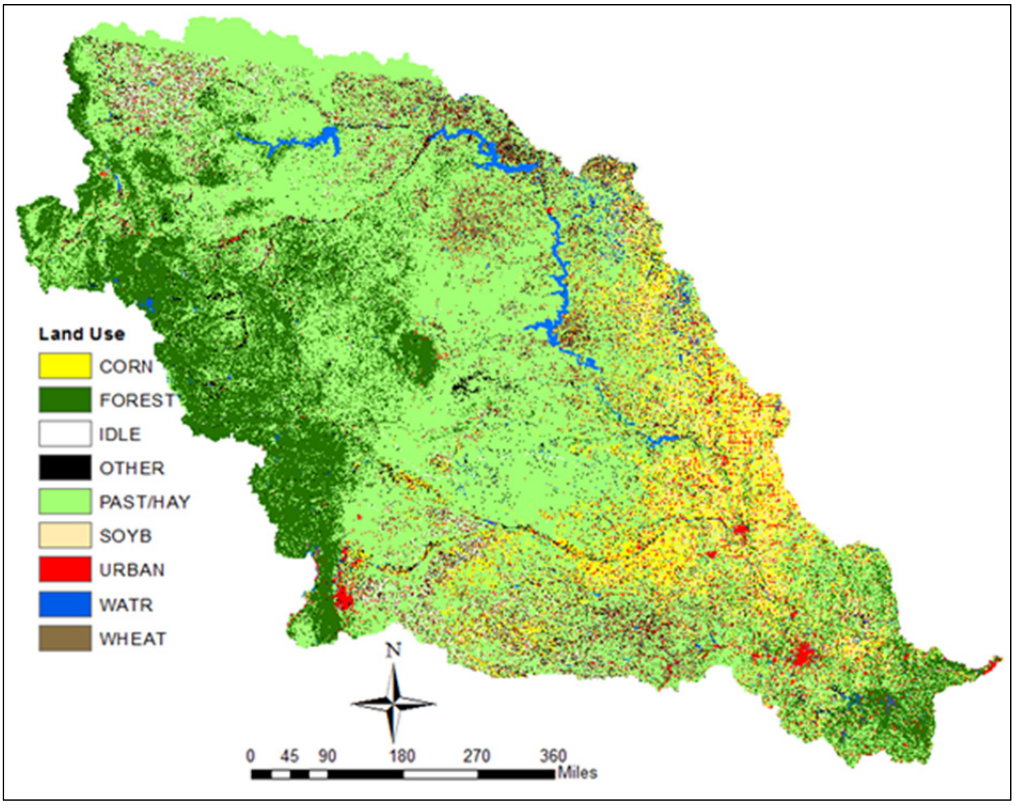


FIGURE 4 Land use of MORB under baseline year of 2007.

After HRU units were constructed, SWAT operation schedules were defined according to crop rotation patterns for each HRU individually as well as for corresponding practices (such as tillage, fertilizer application, crop planting, and crop harvesting). Typically, SWAT applies its default values for crop inputs unless otherwise instructed. Tillage systems include three types of conservation: tillage, reduced tillage, and intensive tillage. Tillage systems are defined on the basis of the amount of crop residue that remains on the soil after planting and resulting disturbance to the soil. Conservation tillage leaves at least one-third of the soil covered with crop residue after planting. Conservation tillage types include: no-till/strip-till, ridge-till, and mulch-till. No-till (NT) leaves more than 50% residue. On NT agricultural fields, residue from the previous crop is left on the surface of the field and the soil is not disturbed by tillage. Reduced tillage (RT) leaves 15–30% residue on the soil surface after planting. Reduced tillage or conservation tillage includes practices that result in less soil disturbance and less residue incorporation than standard tillage practices that leave fields bare. For the purposes of modeling, mulch tillage and conservation tillage were lumped together and refer to the category as RT. Intensive or conventional tillage (CT) involves full-width tillage. However, there is less than 15% residue on the soil surface after planting. Simulations of the use of residue and tillage practices were based on the survey data reported by the Conservation Technology Information

Center (CTIC). The CTIC collects tillage data by conducting surveys about tillage systems for all counties in the United States. The CTIC county-level tillage data were aggregated to 8-digit hydrologic unit watersheds (HUC8) in the conterminous United States (Baker, 2011). The HUC8 datasets included planted acreage of conservation tillage (NT, ridge-till, and mulch-till), RT, and intensive or conventional tillage for selected crops for 1989–2004. A distribution of tillage for corn and soybean cultivated in the MORB is presented in Fig. 5 and Fig. 6.

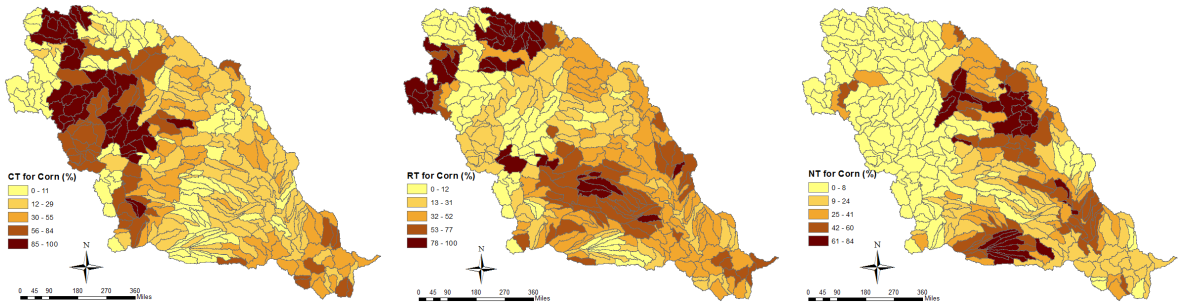


FIGURE 5 Percent of tillage practices under (a) CT, (b) RT, (c) NT for corn in the MORB baseline year.

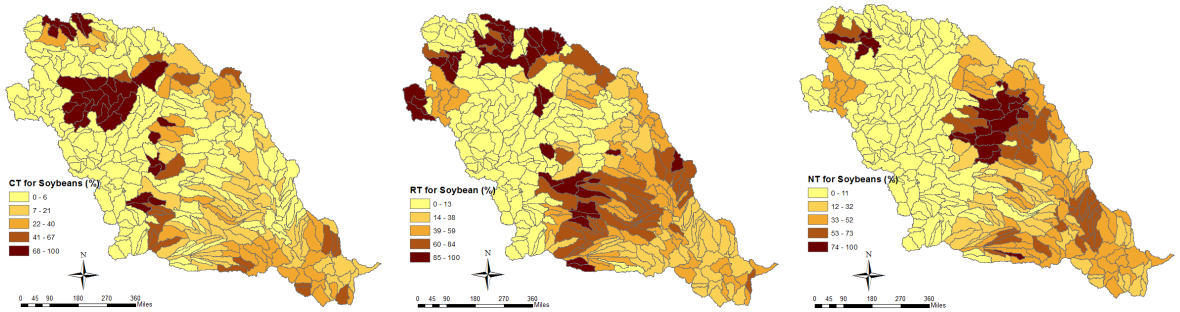


FIGURE 6 Percent of tillage practices under (a) CT, (b) RT, (c) NT for soybeans.

For corn and soybean crops in the model, CT included three tillage operations: chisel plowing either after harvest or in the spring before planting as the primary tillage, disk plowing in the spring as secondary tillage, and a pass with a field cultivator after planting. The disk plowing operation was eliminated under RT, and all tillage operations were eliminated under NT. Surface residue can intercept raindrops and prevent soil detachment, detain water in small pools, and retard the smooth flow of water over the surface of the soil (Unger and Kaspar, 1994). Increased roughness and decreased soil detachment can decrease the amount of sediment exported from a field. For corn and soybean crops, the initial Manning's N was raised from 0.12 to 0.22 for CT, to 0.32 for RT and for NT (DiLuzio et al., 2002). The SCS curve number recommendations for row crops list decreases from 1 to 4 points to account for additional infiltration on fields with reduced tillage (residue remaining). Biological mixing was raised from the default value of 0.2 to 0.3 for RT and 0.4 for NT.

Commercial fertilizers are widely used on agricultural land in the MORB. State-level chemical fertilizer application has been reported by USDA. However, the distribution of fertilizer applications within the states is not well known, because the collection of county-level agricultural chemical use data by USDA was discontinued in 1990. Instead, state-level commercial fertilizer use over the croplands and hay lands in 2005 and 2006 was distributed at the county-level on the basis of crop yield distribution. The county-level fertilizer application rates were then aggregated back to the sub-basin level by using crop area and the weighted-average method given below, by assuming that sub-basin application is directly proportional to crop acreage. When sub-basins only partially extended into one or more counties, county-level data were apportioned according to the amount of agricultural land contained within the sub-basin, as described by Nakagaki and Wolock (2005).

Manure was applied over the crop and pasture lands. Its production was estimated for beef cattle, dairy cow, and swine grown in the UMRB states. Manure production was estimated for beef cattle, dairy cow, and swine grown in the UMRB according to USDA-NASS (2006a) county-level animal inventory data for 2005 (when available) or for the nearest year. Average manure output was calculated for beef, dairy, and swine according to a nutrient management program (University of Wisconsin Extension 2009). The county-level manure production was then distributed to the crop and hay lands in sub-basins. Since SWAT requires dry fresh manure without urine and feces, the observed fresh manure data were converted to dry weight via solids fractions of 14%, 14.7%, and 13.1% for dairy, beef, and swine, respectively (ASAE, 2003).

Furthermore, there are noticeable discrepancies between the values used in SWAT and the ASAE (2003) standard for nutrient content in the manure (total nitrogen, ammonium, organic phosphorus, and mineral phosphorus). For example, organic nitrogen in dairy manure is 0.038 lb/lb dry weight, as recommended by ASAE (2003), while it is 0.031 lb/lb dry weight in SWAT. In particular, SWAT default values for swine differ significantly from the default ASAE values. The amount of organic nitrogen in swine manure suggested by ASAE (0.047 lb/lb dry weight) is more than twice that in SWAT (0.021 lb/lb dry weight), and the value of organic phosphorus suggested by ASAE is almost ten-fold higher than the SWAT value. For this modeling effort, we used the ASAE (2003) value to calculate the amount of nutrients in the manure and modify the existing SWAT fertilizer database.

Nitrogen and phosphorus is applied by using SWAT default scheduling, which fully meets crop nutrient requirements and there is no nutrient stress from the crop. Data for nitrogen in atmospheric deposition were derived from 1-km resolution grids of atmospheric deposition that were based on data from the National Atmospheric Deposition Program.

4.2 MODEL CALIBRATION AND VALIDATION

To capture the effects of weather, the MORB was simulated by using 20 years of actual daily weather data for the period 1990 through 2009. This period of record encompassed a wide range of climatic conditions including wet, dry and average years. SWAT model output for each individual riverine reach in the watershed consists of flow discharge, sediment and nutrient loads. Observed stream flow records are fundamental during the calibration and validation

phases of SWAT model, as they make it possible to check if the value of each selected calibration parameter is suitable for the watershed of interest. Calibration and validation of MORB SWAT were based on a balanced, split-sample approach. Once configured and initially parameterized, SWAT models were run on a daily basis. In this study, available historical weather data (1990–2009) were divided into two datasets: 13 years (1990–2002) for calibration and 7 years for validation (2003–2009). The validation is used to evaluate the reliability of a calibrated model. SWAT models for the UMORB and LMORB were run for the 13-year period of 1990 through 2002. The first two years for the simulation period were treated to equilibrate to ambient conditions as warm-up years, and were not included in the model outputs. The stream flow predictions made by SWAT were compared with observed stream flow data at USGS gages in the MORB to evaluate the model's hydrologic predictions (Fig. 7). The USGS stream flow gage stations were screened for observed data availability, length and coverage of the data record. The final number of calibration sites for the MORB was 18 for stream flows, sediment, TN, and TP. Stream flow and water quality data were obtained for each of the stream flow gage stations used in model calibration and validation from the USGS and the U.S. Army Corps of Engineers (USACE).

To avoid over parameterization, the initial group of calibration parameters was selected based on previous published studies that assessed the sensitivity of SWAT parameters, as well as, other Midwestern river basins, specifically Arnold *et al.* (1998); Santhi *et al.* (2001a, 2001b); Van Liew and Garbrecht (2003); Van Liew *et al.* (2005); White and Chaubey (2005); Neitsch *et al.* (2011). Calibration was completed by adjusting parameter values within their acceptable ranges to match simulated to observed stream flow at each of the USGS stream flow gage stations shown in Fig. 7.

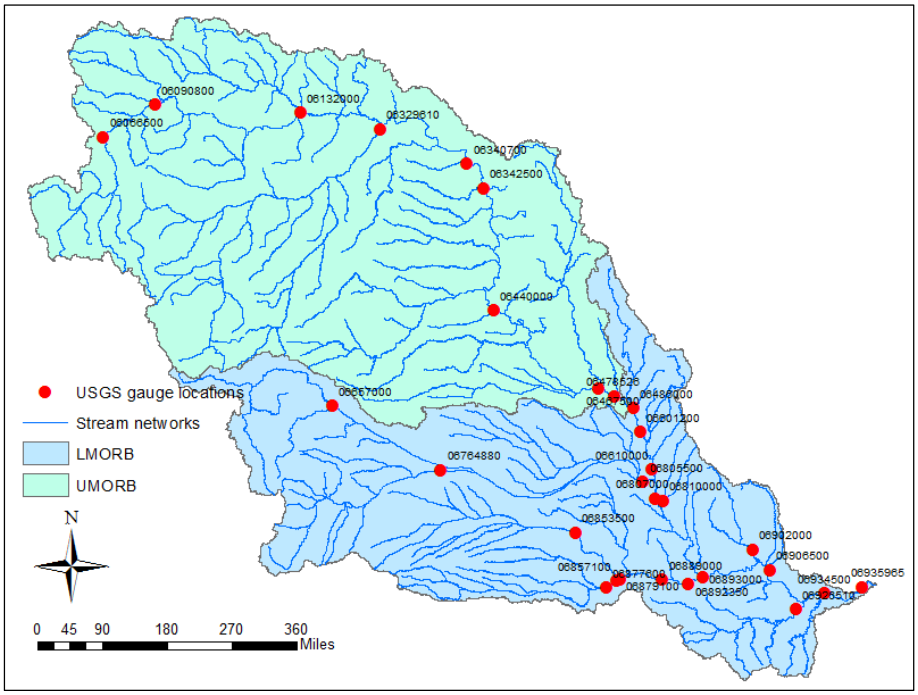


FIGURE 7 Locations of USGS stream flow gage stations in the MORB.

To assess the model performance in regard to sediment and nutrient predictions, acceptable simulation of hydrology is important. During model calibration and validation, agreement between observed and modeled stream flows on an annual and monthly basis was evaluated visually and quantitatively. For the quantitative approach coefficient of determination (R^2), Nashe-Sutcliffe efficiency (NSE), Percent bias (PBIAS), and the ratio of the root mean square error (RMSE) to observations standard deviation (RSR) are used as evaluators of model performance.

$$R^2 = \frac{\left(\sum_i (OV_i - \overline{OV})(MV_i - \overline{MV})\right)^2}{\sum_i (OV_i - \overline{OV})^2 \sum_i (MV_i - \overline{MV})^2} \quad (1)$$

$$NSE = 1.0 - \frac{\sum_i (OV_i - MV_i)^2}{\sum_i (OV_i - \overline{OV})^2} \quad (2)$$

$$PBIAS = \frac{\sum_i (OV_i - MV_i)}{\sum_i OV_i} * 100 \quad (3)$$

$$RSR = \frac{\sqrt{\frac{1}{n}\sum_i (OV_i - MV_i)^2}}{\sqrt{\frac{1}{n}\sum_i (OV_i - \overline{OV})^2}} \quad (4)$$

where n is the number of observations during the simulation period, OV_i is the observed value at the i time step, $\overline{OV}$ is the mean observed value for the rime period, MV_i = modeled value at the i time step, $\overline{MV}$ is the mean modeled value for the time period.

R^2, NSE, PBIAS, and RSR statistics are often used to evaluate model performance but there are no rules to determine if a 0.5 value for any statistic is good or bad. Moriasi *et al.* (2007) state that the monthly fits between simulated and observed stream flows can be considered "successful" when the NSE, PBIAS, and RSR for these individual fits are greater than 0.5 (> 0.5), less than 25 percent (<25%), and less than 0.7 (< 0.7), respectively. The R^2 indicates how well the plot of observed versus simulated data fit the 1:1 line, and a value of R = 1.0 indicates perfect fit. Gassman and others (2007) considered an R^2 value of greater than 0.5 as satisfactory when comparing across multiple SWAT studies. In this study model calibration was first completed for average annual conditions, followed by average monthly conditions, starting with the farthest upstream stream flow gage station for each tributary and moving downstream to the next consecutive stream flow gage station. Performance was evaluated by determining the R^2, NSE, PBIAS, and RSR for each stream flow gage station.

5 BASE MODEL CALIBRATION AND VALIDATION RESULTS

Observed daily stream flows for 18 gage stations were available for the twenty-year period of 1990 through 2009. These daily stream flows were used to calculate averaged annual and monthly stream flows. Monthly loads of suspended sediment (TSS), total nitrogen (TN) and total phosphorus (TP) were estimated by using averaged daily flow discharge rate and grab sample concentration measurements. These monthly based estimates may bring high uncertainty into model results, in particular, sample measurements of sediment, TN and TP at selected stations varied widely.

5.1 HYDROLOGY

Annual and monthly model calibration statistics, comparing observed and simulated stream flows for all gage stations, are presented in Table 4. Both SWAT models were validated by using observed stream flow data from the same USGS gages but for a different 7-year period (2003 through 2009) that was not used for model calibration. Table 5 displays statistical comparisons for the entire validation period.

Model results indicate that SWAT is capable of predicting MORB hydrology, calibration R^2 and ENS values are greater than 0.5 for a majority of monitoring gages and at all of the time steps. The overall statistical indices for the entire period of annual calibration for all locations varied from 0.65 to 1.0 for R^2, from 0.06 to 0.99 for ENS, and from 0.08 to 1.27 for RSR. Monthly calibration values ranged from 0.29 to 0.86 for R^2, from 0.14 to 0.81 for ENS, and from 0.5 to 1.01 for RSR. Annual and monthly calibration PBIAS ranged from -44% to 1.8% and -44% to 2.8% respectively. Annual and monthly PBIAS results indicate satisfactory to very good model performance. In fact, NSE, PBIAS, and RSR statistic values were mostly "good" with a few exceptions according to criteria developed by Moriasi *et al.* (2007). There were decreases and increases in the R^2, ENS, PBIAS and RSR values for the validation period relative to calibration. Somewhat surprisingly, SWAT prediction of stream flow was more accurate during the calibration period than the validation time period overall. Decreases in model performance during the validation period can be attributed to a number of factors, such as projecting calibration parameters from one sub-basin to another sub-basin that has vastly different physical characteristics or land cover and management practices, or both. Though all SWAT models performed well, across the MORB, stream flow was best predicted for the outlets of the UMORB and LMORB. The ENS values for all time steps for calibration and validation for the MORB outlet, the Missouri River near St. Louis, MO, station ranged from 0.75 to 0.92, R^2 values ranged from 0.86 to 0.97, while PBIAS was less than 7%. The model performance based on the statistical measures is very good. The high R^2 and the NSE indicate that the model is predicting watershed hydrology well. However, a high RSR (RMSE) is indicative of the model not predicting peaks well. The theory and mathematical equations used in SWAT are for long term simulation with less emphasis on event flows (Borah and Berra, 2003a; SWAT, 2005a), which is evident in Fig. 8 and Fig. 9.

TABLE 4 Hydrology calibration (1990–2002) results for each stream flow gage station.

USGS Station	SWAT Sub-basin	Mean (m^3/s)		R^2	NSE	PBIAS (%)	RSR
		Observed	Modeled				
Annual Calibration							
Upper Missouri River Basin							
06066500	9	136.79	143.54	0.67	0.45	-4.94	0.58
06090800	10	174.44	203.21	0.67	0.22	-16.49	0.70
06115200	19	216.02	244.90	0.65	0.41	-13.37	0.67
06185500	50	251.30	258.52	0.91	0.90	-2.87	0.30
06329500	92	285.20	332.08	0.68	0.25	-16.44	0.69
06342500	117	571.95	612.32	0.78	0.74	-7.06	0.60
06486000	161	929.81	966.30	0.97	0.95	-3.92	0.37
Lower Missouri River Basin							
06610000	62	1095.05	1067.46	0.96	0.95	2.52	0.21
06807000	64	1269.71	1446.07	0.94	0.62	-13.89	1.27
06810000	67	52.68	76.08	0.90	0.06	-44.41	0.93
06857100	93	27.91	18.26	0.86	0.59	34.58	1.27
06877600	101	58.10	49.33	0.82	0.79	15.10	0.44
06879100	109	98.74	76.39	0.87	0.77	22.63	0.46
06889000	110	209.52	184.40	0.89	0.86	11.99	1.27
06892350	112	268.15	255.51	0.91	0.90	4.71	0.30
06902000	122	138.87	199.54	0.90	0.14	-43.69	0.89
06926510	136	327.50	321.52	1.00	0.99	1.83	0.08
06935965	144	2884.93	3067.50	0.97	0.92	-6.33	0.28
Monthly Calibration							
Upper Missouri River Basin							
06066500	9	136.65	143.59	0.31	0.16	-5.08	1.00
06090800	10	174.30	203.23	0.48	0.14	-16.59	0.77
06115200	19	220.71	244.87	0.50	0.15	-10.95	0.73
06185500	50	251.41	258.55	0.56	0.55	-2.84	0.90
06329500	92	284.94	331.94	0.28	-0.38	-16.49	0.89
06342500	117	571.25	612.15	0.40	0.35	-7.16	1.01
06486000	161	854.58	965.16	0.88	0.81	-12.94	0.44
Lower Missouri River Basin							
06610000	62	1093.78	1065.14	0.82	0.74	2.62	0.51
06807000	64	1268.61	1442.78	0.80	0.23	-13.73	0.87
06810000	67	52.63	75.89	0.76	0.03	-44.19	0.98
06857100	93	27.81	18.18	0.29	0.19	34.64	0.89
06877600	101	57.99	49.08	0.77	0.75	15.36	0.50
06879100	109	98.53	76.05	0.79	0.76	22.82	0.49
06889000	110	209.05	183.61	0.76	0.73	12.17	0.51
06892350	112	267.64	254.63	0.75	0.70	4.86	0.55
06902000	122	138.89	199.03	0.73	0.64	-43.30	0.60
06926510	136	851.05	956.67	0.83	0.78	-12.41	0.47
06935965	144	2883.29	3061.85	0.86	0.75	-6.19	0.50

TABLE 5 Hydrology validation (2003–2009) results for each stream flow gage station.

USGS Station	SWAT Sub-basin	Mean (m^3/s)		R^2	NSE	PBIAS (%)	RSR
		Observed	Modeled				
Annual Validation							
Upper Missouri River Basin							
06066500	9	78.10	112.61	0.58	-6.18	-44.19	2.45
06090800	10	99.98	162.44	0.77	-4.15	-62.46	2.07
06115200	19	117.33	191.38	0.87	-2.95	-63.12	1.81
06185500	50	197.98	194.82	0.91	0.89	1.60	0.30
06329500	92	236.43	239.86	0.04	-0.63	-1.45	1.17
06342500	117	400.25	456.49	0.72	-0.48	-14.05	1.11
06486000	161	629.85	619.80	0.08	-0.18	1.60	0.99
Lower Missouri River Basin							
06610000	62	706.10	811.70	0.02	-19.61	-14.96	4.14
06807000	64	883.98	1248.42	0.76	-25.27	-41.23	4.68
06810000	67	45.14	73.91	0.95	-0.29	-63.72	1.04
06857100	93	10.74	25.99	0.78	-8.11	-142.06	2.75
06877600	101	23.69	66.05	0.96	-9.20	-178.76	2.92
06879100	109	38.15	103.22	0.98	-10.29	-170.59	3.07
06889000	110	110.25	254.83	0.95	-6.99	-131.13	2.58
06892350	112	149.75	328.67	0.96	-5.56	-119.47	2.34
06902000	122	112.29	158.92	0.93	0.66	-41.53	0.53
06926510	136	311.16	328.68	1.00	0.99	-5.63	0.10
06906500	140	1493.05	2102.67	0.96	-1.15	-40.83	1.34
06935965	144	2035.30	2796.67	0.99	-0.29	-37.41	1.04
Monthly Validation							
Upper Missouri River Basin							
06066500	9	83.70	117.92	0.31	-0.31	-40.88	1.14
06090800	10	107.59	169.18	0.51	-0.76	-57.25	1.32
06115200	19	231.51	199.02	0.43	0.20	14.03	0.89
06185500	50	195.74	192.98	0.55	0.54	1.41	0.67
06329500	92	231.94	259.43	0.14	-0.48	-11.85	1.21
06342500	117	410.50	457.78	0.25	0.18	-11.52	0.90
06486000	161	588.50	634.01	0.70	0.66	-7.73	0.58
Lower Missouri River Basin							
06610000	62	719.61	821.88	0.73	-0.44	-14.21	1.19
06807000	64	901.09	1275.40	0.75	-3.13	-41.54	2.02
06810000	67	46.02	74.70	0.88	0.36	-62.32	0.80
06857100	93	10.95	27.50	0.22	-6.99	-151.22	2.81
06877600	101	24.59	67.65	0.62	-2.34	-175.09	1.82
06879100	109	39.83	106.48	0.73	-3.98	-167.34	2.22
06889000	110	112.95	256.11	0.70	-2.27	-126.75	1.80
06892350	112	372.21	357.49	0.74	0.68	3.95	0.56
06902000	122	126.16	186.09	0.63	0.39	-47.50	0.78
06926510	136	332.68	349.36	0.99	0.99	-5.01	0.09
06906500	140	1558.98	2180.52	0.82	-0.07	-39.87	1.03
06935965	144	2134.11	2912.17	0.84	0.20	-36.46	0.89

One of the drawbacks of R^2 and ENS for model evaluation is that both indices can be satisfactory while the model in general is over- or under-predicting (Krause et al., 2005). Therefore, observed and predicted stream flows were visually compared for the period of study. Time-series plots of modeled and observed annual and monthly stream flows are only shown for the UMORB and LMORB outlet gages (Figs. 8, 9). These figures show the seasonal changes in modeled and observed annual and monthly stream flows over the entire calibration and verification periods, respectively. SWAT generally overestimated peak flows. Overall comparative plots of observed and simulated stream flows along the mainstem and tributaries, and at different locations, indicated satisfactory simulation of the MORB hydrology.

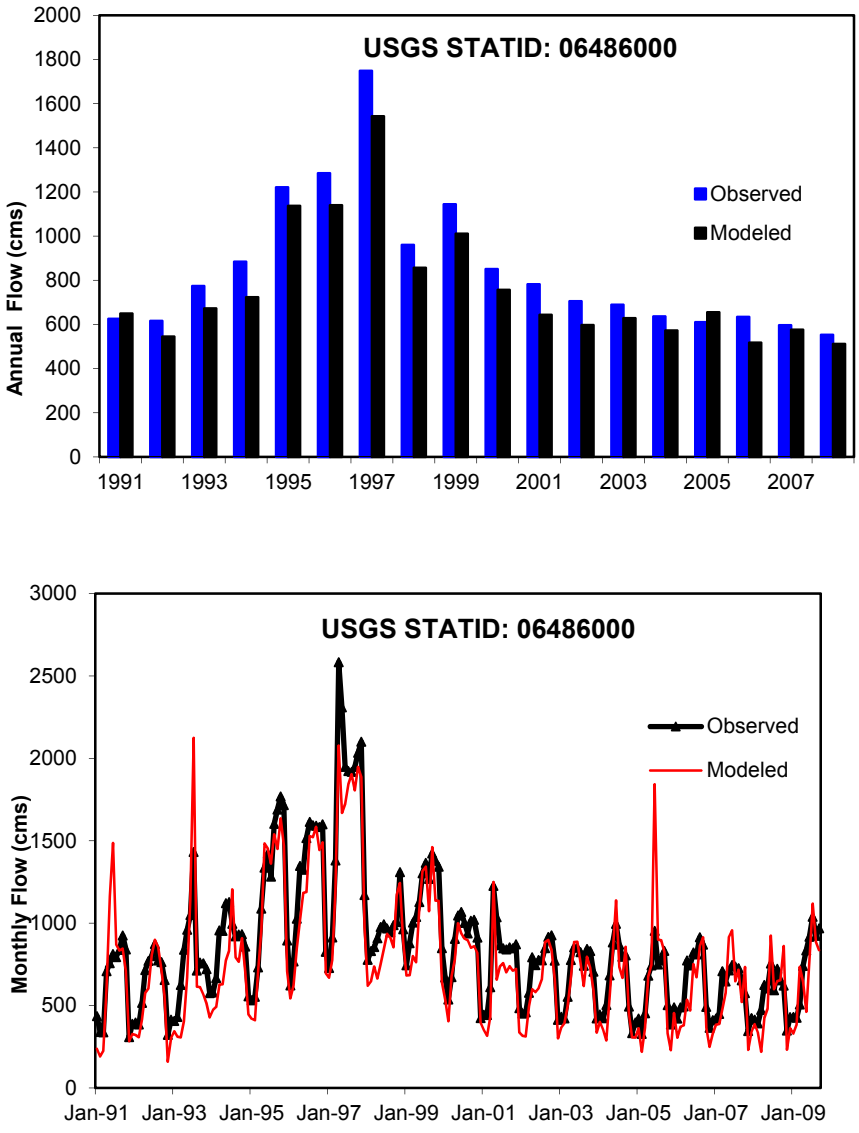


FIGURE 8 Time series plots of observed and modeled annual (top) and monthly (bottom) mean stream flow (m^3/s) over the calibration (1990–2002) and validation (2003–2009) time periods at the outlet of UMORB.

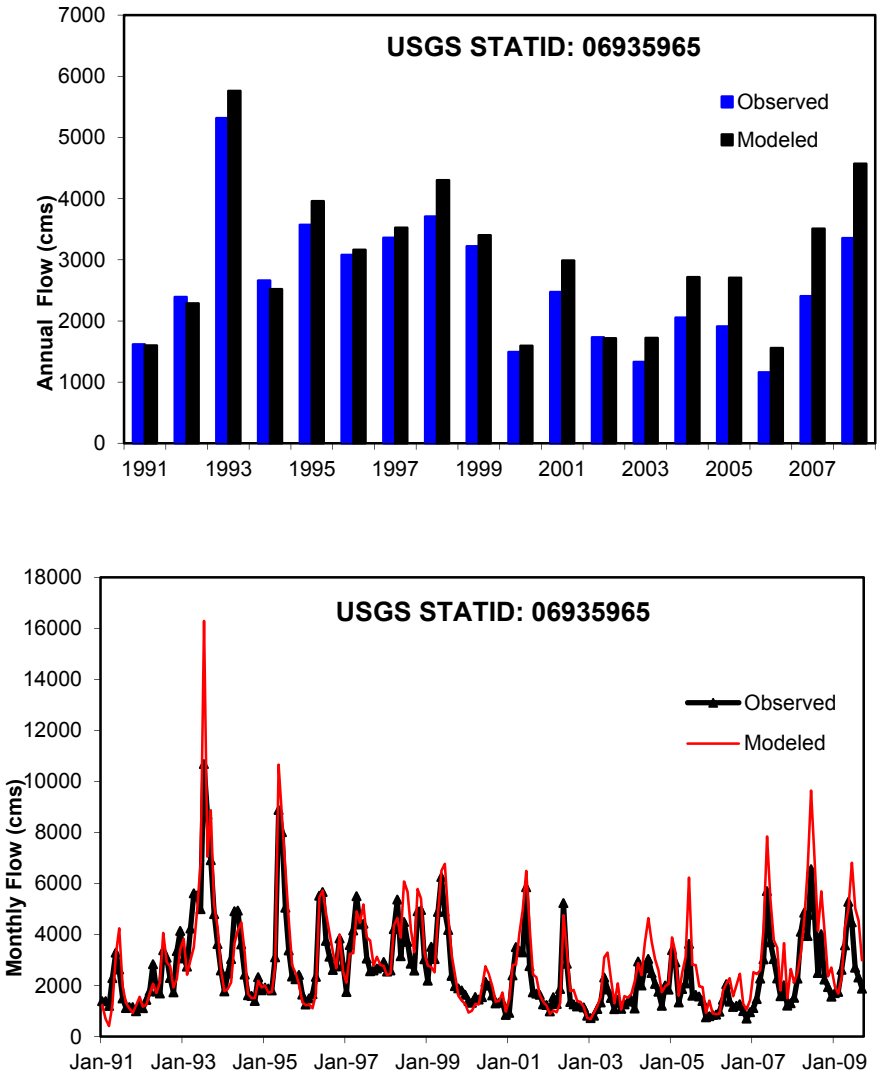
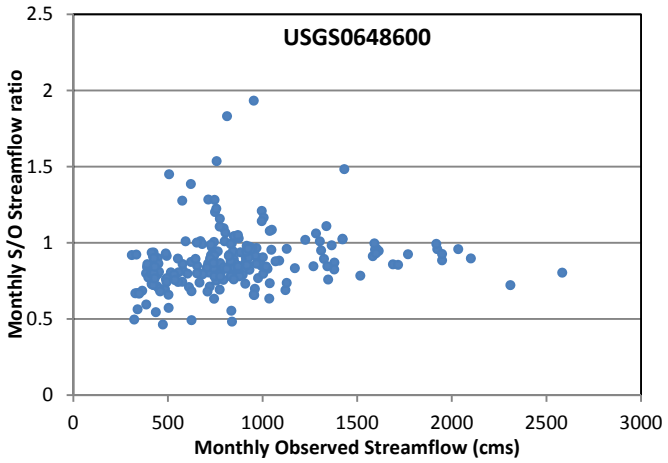


FIGURE 9 Time series plots of observed and modeled annual (top) and monthly (bottom) mean stream flow (m^3/s) over the calibration (1990–2002) and validation (2003–2009) periods for the gage at LMORB outlet.

A comparison of monthly observed stream flows to the simulated/observed stream flow ratios (S/O) is shown in Fig. 10. Scatter plots of observed stream flow versus S/O ratio were used to determine if there were any systematic errors related to the magnitude of the observed monthly stream flows. Mean monthly flows were estimated well by SWAT as indicated by the uniform scatter of points around the S/O equal to 1 line in Fig.10. Fig. 10 shows that the flow residuals are randomly distributed with no bias. Fig. 11 shows the flow duration values of simulated and observed monthly stream flows. The monthly stream flow duration curves confirm the SWAT tendency to slightly overestimate peak flows. Overall, both models estimated the daily flows as satisfactorily. It should be noted that these modeled results were obtained by using the DEM, soil, land use, and weather data from readily available data sources. SWAT predicted well measured stream flow for all gauges during both the calibration and validation periods.



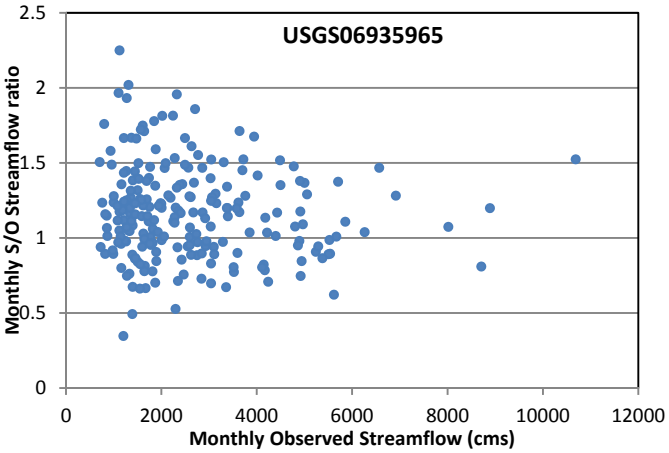
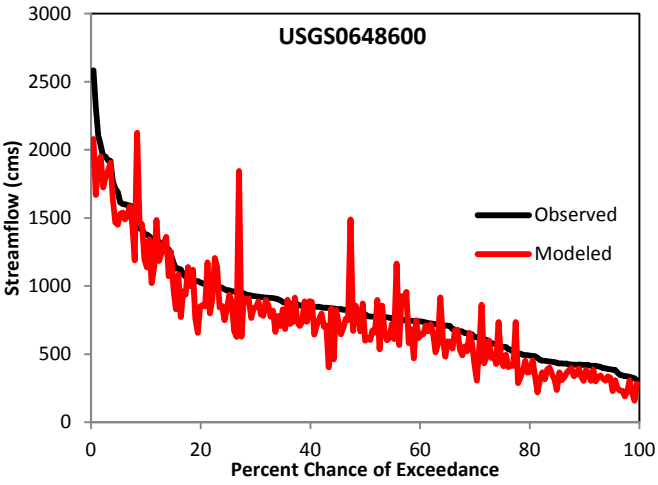


FIGURE 10 Scatter plots of monthly observed stream flow versus monthly simulated/observed stream flow ratio for the calibration and validation period for the outlet of UMORB and LMORB.



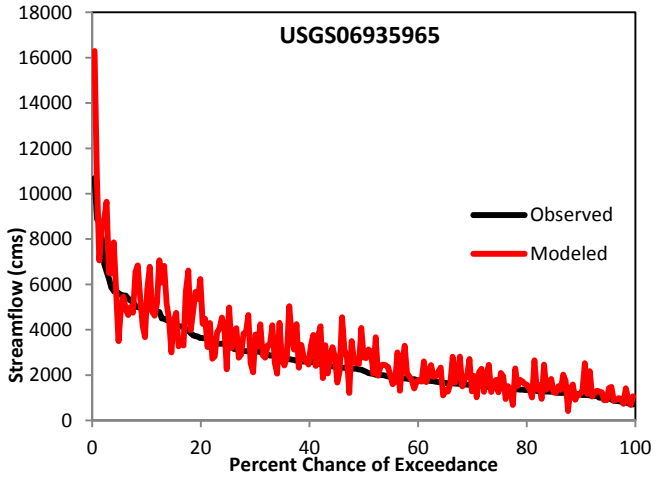


FIGURE 11 Observed and simulated monthly stream flow duration curves for the model calibration and validation time period.

5.2 TOTAL SUSPENDED SEDIMENT

After the model hydrology is calibrated, total suspended sediment calibration is performed accordingly for the MORB. The USGS, in cooperation with the USACE, has collected and analyzed suspended-sediment data in the Missouri River. Annual suspended-sediment loads and yields for 18 stations within the LMORB were provided by Heimann *et al.* (2010). At each station, annual suspended-sediment loads were computed by using available data for water years 1976 through 2008 (defined as the 12-month period from October 1 through September 30). In addition, sparse measurements of TSS concentrations from collected samples were also available for six USGS gauge stations (Table 7). Sediment calibration statistics for annual and monthly suspended-sediment loads at six selected stations for the period encompassing 1990–2009 are presented in Tables 6 and 7. The periods used for the summary

statistics of the annual and monthly sediment loads vary by station because they are limited to available data.

TABLE 6 Annual sediment calibration and validation results for selected stream flow gages.

USGS Station	SWAT Sub-basin	Mean (tons/yr)		R^2	NSE	PBIAS (%)	RSR
		Observed	Modeled				
Calibration (1990–2002)							
06486000	161	9881504	9888100	0.92	0.92	-0.07	0.27
06805500	41	16774166	8591166	0.36	0.09	48.78	0.91
06610000	62	17167500	23940408	0.88	0.17	-39.45	0.87
06807000	64	27625000	30291450	0.82	0.74	-9.65	0.49
06906500	140	57091666	34840100	0.87	0.50	38.98	0.68
06935965	144	74590909	56831036	0.95	0.78	23.81	0.45
Validation (2003–2009)							
06486000	161	3498680	4403666	0.66	-0.07	-25.87	0.94
06805500	41	772333	7796351	0.53	0.34	-0.95	0.74
06807000	64	18421666	21761916	0.42	-0.40	-18.13	1.08
06877600	101	1163165	813315	0.66	0.56	30.08	0.61
06906500	140	34783333	21775200	0.19	-0.48	37.40	1.11
06935965	144	39596666	32373950	0.33	0.25	18.24	0.79

TABLE 7 Monthly sediment calibration and validation results for selected stream flow gages.

USGS Station	SWAT Sub-basin	Mean (tons/month)		R^2	NSE	PBIAS (%)	RSR
		Observed	Modeled				
Calibration (1990–2002)							
06486000	161	869706	640682	0.48	0.57	1.78	0.69
06610000	62	1536291	2012525	0.52	-0.49	-39.73	1.23
06807000	64	2468982	2541009	0.57	0.36	-9.78	-0.80
Validation (2003–2009)							
06486000	161	312116	399094	0.35	-1.3	-27.87	1.51
06807000	64	1528001	2418801	0.54	-0.32	-58.30	1.14
06877600	101	94858	68754	0.49	0.33	27.52	0.81
06935965	144	2578205	2949311	0.83	0.80	-14.39	0.44

Time-series plots of modeled and observed annual and monthly TSS loads are shown for the UMORB and LMORB outlet locations (Figs. 12, 13). These figures show the seasonal changes in modeled and observed annual and monthly TSS loads, respectively. For the MORB outlet, no observed sediment data suitable for calibration were available; sediment load for this location was plotted only for the validation period. With respect to TSS, the model calibration

shows that over-predictions occur during low flow events and that some large flow events are not simulated well (Fig. 12). In fact, R^2 and ENS indices for the calibration and validation period were "good" for six gage stations according to the ranges given by Moriasi *et al.* (2007). Sediment loads were best predicted for the MORB outlet. R^2 and ENS values represent a significant relationship between predicted and observed values of TSS. PBIAS values were largely categorized as "good" across all watersheds, indicating that model predictions of riverine TSS loads were not generally higher or lower than observed data. Thus, SWAT predicted riverine TSS loads accurately on average.

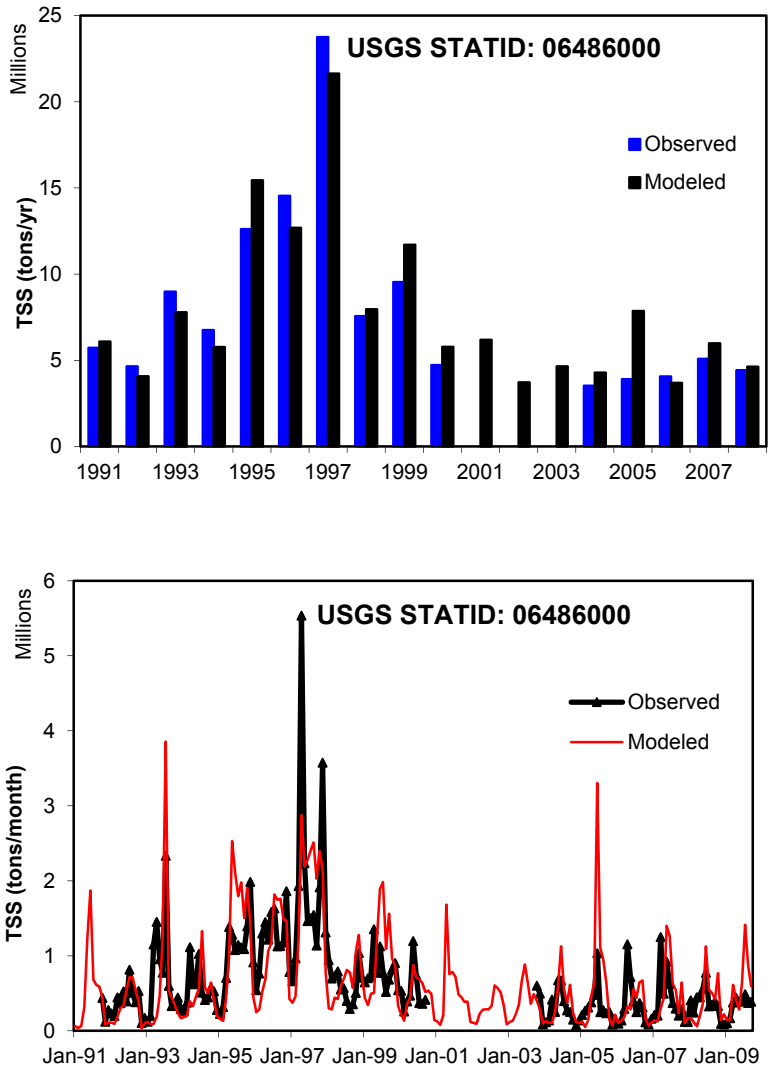


Figure 12 Time series plots of observed and modeled annual (top) and monthly (bottom) riverine total suspended sediment loads of a monitoring gage over the calibration (1990–2002) and validation (2003–2009) periods.

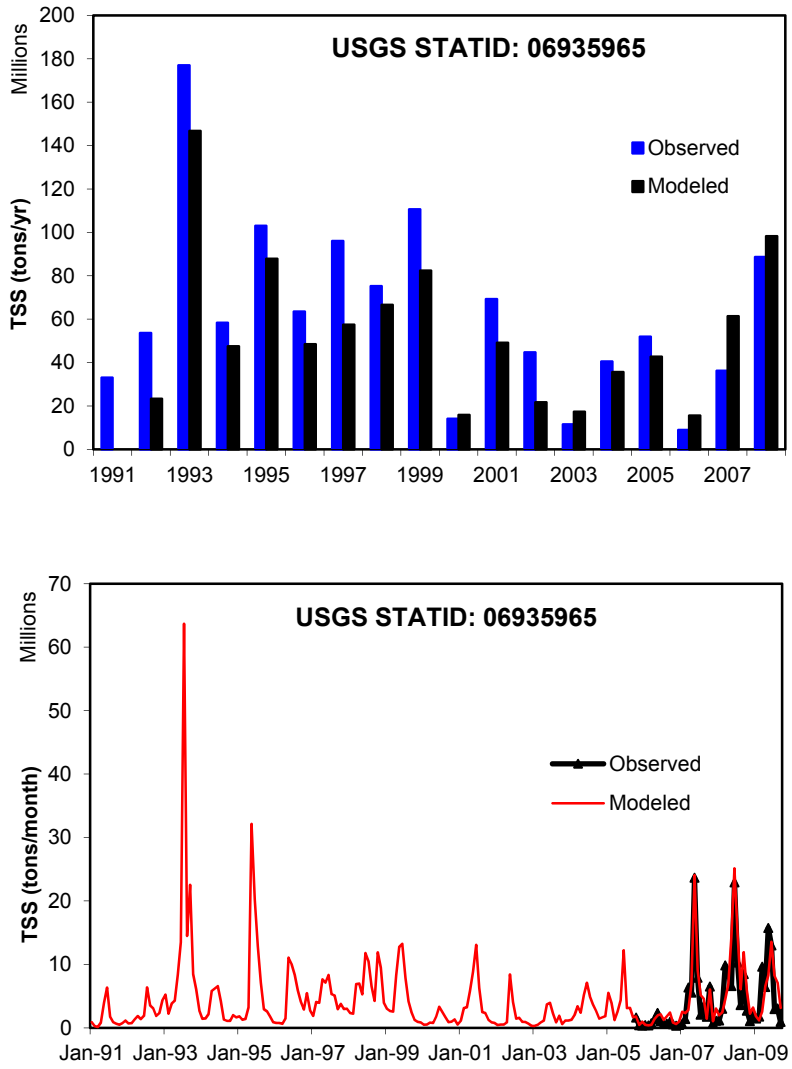


FIGURE 13 Time series plots of observed and modeled annual (top) and monthly (bottom) riverine total suspended sediment loads of a monitoring gage over the calibration (1990–2002) and validation (2003–2009) periods.

5.3 NITROGEN AND PHOSPHORUS

Regarding nutrient (N, P) data, measurements of NH4, NO3, TKN, or TN and TP concentrations from collected samples were available for six USGS gage stations for the period 1990–2009. In general monthly grab-sample data were available for these stations, limiting the data available for model calibration. In addition, the monthly data were used to estimate average monthly and yearly values. Additional errors may be introduced to make these average measured estimates for use in calibration. Riverine TN and TP concentrations were compiled for each calibration site by using either direct measurements or, where possible, a summation of component nutrient species. The technique of comparing riverine TN and TP instead of individual components is used to overcome differences between model outputs and observed

data. The soil denitrification and aquatic degradation rate parameter in the reservoir and riverine water quality component of SWAT were calibrated.

The simulated and observed riverine TN and TP loads for the MORB outlet locations are shown in Fig. 14. Simulated temporal patterns for TN and TP follow the general trend of the observed data with some over-predictions for TN and TP. The monthly variability of riverine TN and TP loads are accurately simulated. It can be seen in these figures that the highest nutrient loads in the time series correspond to the rainfall events. The high load dissipates quickly. The trend components of the time series do not show any significant long-term upward trend for any of the major tributaries irrespective of the magnitude and duration of the riverine TN and TP loads during individual years. This shows that the potential for long-term accumulation of TN and TP in Missouri river is very low.

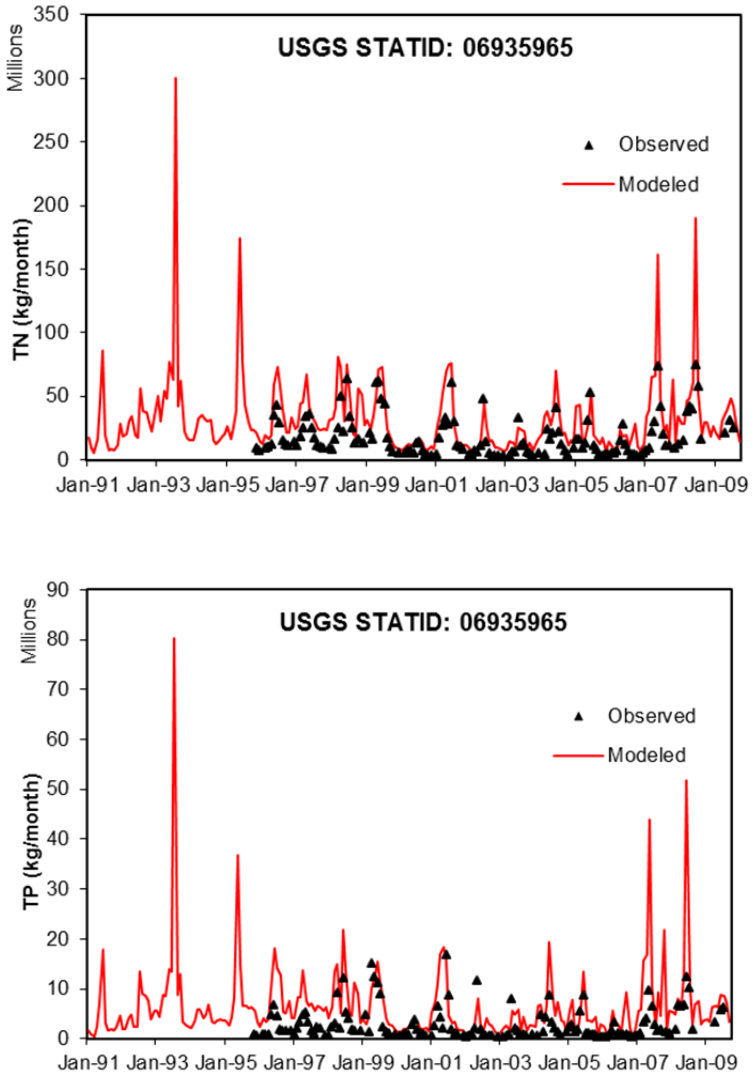


FIGURE 14 Time series plots of observed and modeled monthly riverine TN (top) and TP (bottom) loads over the calibration and validation periods.

6 ANALYSIS OF RIVERINE SEDIMENT AND NUTRIENT EXPORTS FROM MORB TRIBUTARIES

Model performance statistics and graphical plots reveal that baseline SWAT model was effective in capturing watershed hydrology and capable of estimating riverine sediment and nutrient exports in the MORB. To compare riverine sediment and nutrient loads across the basin, the mainstem Missouri River is divided into four reaches: Upper, Middle, Lower Middle, and Lower Missouri River (Fig. 2). There are three major tributaries of the Missouri River including Yellowstone, Platte, and Kansas. The Yellowstone River contributes the largest volume of water of all the tributaries of the Missouri River. Long-term mean annual riverine loads were then estimated by using SWAT. For three major tributaries and the Upper Missouri River, their loads are presented as the loads in the river reach transported to the reach outlet after accounting for the effects of in-stream processes. Riverine sediment and nutrient exports from the Middle, Lower Middle, and Lower Missouri River reaches include sub-basins draining directly to a given reach and all of the upstream sub-basins draining to that reach. The Lower Missouri river loads include all of the sub-basins draining to the Missouri River and are ultimately delivered to the Mississippi River.

Modeled riverine sediment and nutrient loads are summarized for the major tributaries and main stem Missouri River reaches. The simulation results from SWAT model are summarized in Table 8 in terms of riverine TSS, TN, and TP loads, reported as the annual average for three base years of 2006 to 2008. Loads and yields from each tributary outlet are also illustrated in Fig. 14.

TABLE 8 Summary of riverine sediment and nutrient export loads.

Tributary or River Reach	TSS Load (ton/yr)	TN Load (kg/yr)	TP Load (kg/yr)
Upper Missouri	9.E+05	2.E+07	5.E+06
Yellowstone	1.E+07	2.E+07	3.E+06
Middle Missouri	2.E+07	2.E+08	4.E+07
Platte	2.E+07	7.E+07	2.E+07
Lower Middle Missouri	4.E+07	3.E+08	8.E+07
Kansas	8.E+06	5.E+07	9.E+06
Lower Missouri	6.E+07	4.E+08	1.E+08

Loads and yields of sediment, TN and TP varied considerably among the major tributaries of the MORB. Because of the large size of the Middle Missouri River sub-basin and the relatively high inputs in the Lower Missouri River sub-basin, the largest TN and TP loads were in these two sub-basins, although the TP loads from the Platte, Lower Middle Missouri, and Kansas River sub-basins were nearly as large as the TP load from the Middle Missouri River sub-basin (Fig. 15). The smallest loads were from the Upper Missouri and Yellowstone River sub-basins where inputs from all sources are low when compared with inputs from the other sub-

basins. This is likely attributable to the large pasture and range land in this area where fertilizer input is relatively low.

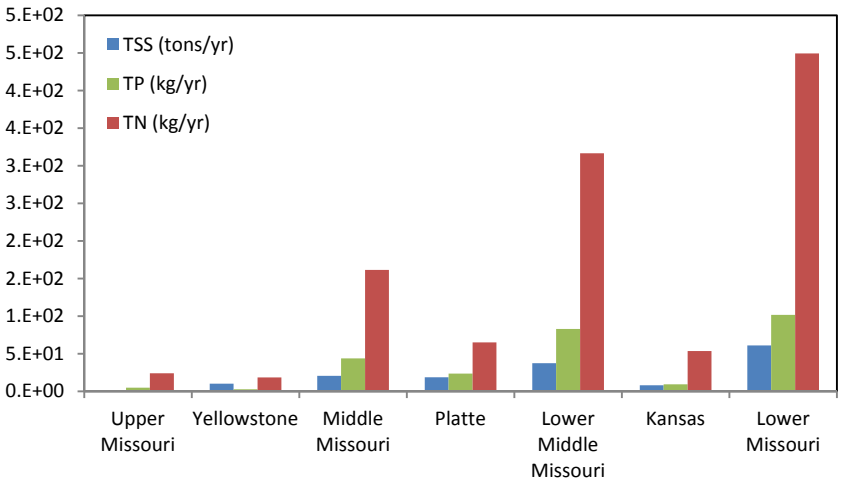


FIGURE 15 Simulated annual mean riverine sediment and nutrient loads for the period 2006–2008. Note: tons = metric tons

The total load delivered to the Mississippi River from the MORB was approximately 6.1×10^7 ton/yr for TSS, 4.5×10^8 kg/yr for TN and 1.0×10^8 kg/yr for TP (Table 8). Of these loads, the largest percentage was contributed by the Middle Missouri and Lower Missouri River sub-basins (28.4 and 29.1% for TN, respectively; 18.6 and 38.7% for TP, respectively), whereas the smallest percentage was contributed by the Upper Missouri and Yellowstone sub-basins (0.2 and 0.4% for TN, respectively; 0.1% each for TP), as also indicated in Fig. 15.

7 SUMMARY AND CONCLUSIONS

The SWAT model was applied to the MORB to simulate hydrology, sediment, and nutrients. This study used the best available data including highly detailed weather records distributed across the watershed and land cover classification. The model was calibrated for a period of 13 years (1990–2002) and then followed by a validation period of seven years (2003–2009). Monthly and annual ENS, R^2, PBIAS, and RSR values were determined for hydrology calibration and validation for all 19 stream flow gaging station locations and illustrate the capability of SWAT for predicting hydrology; calibration ENS and R^2 values are greater than 0.5 for all locations and time steps with the exception of few stations while PBIAS results indicate satisfactory to very good performance for all locations. Results generated from the SWAT model for nitrogen load, phosphorus loads, TSS loads, and flow at sub-basin and tributary levels, on average, were not seriously biased. SWAT accurately predicted overall average loads for all USGS gage locations during both the calibration and validation time periods. Thus, when accompanied by acknowledgment of model uncertainty, we have confidence

that the SWAT model will be readily useful for future studies in this region to predict changes in average sediment and nutrient load in response to new crop production, implementation of land management practices, and climate changes.

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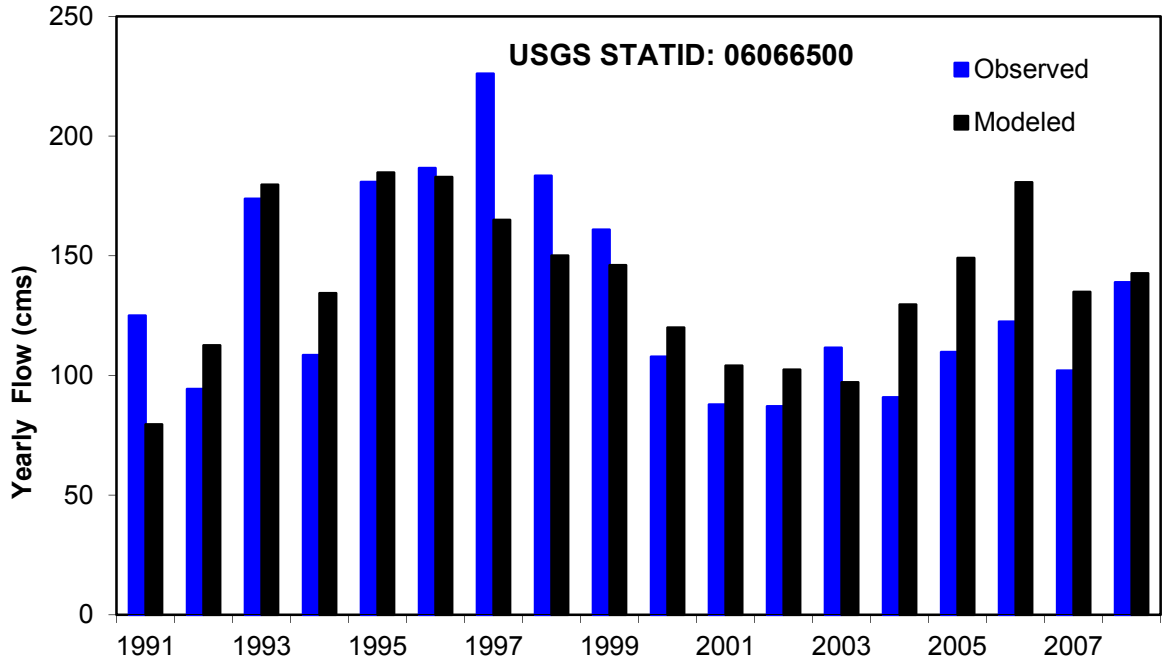
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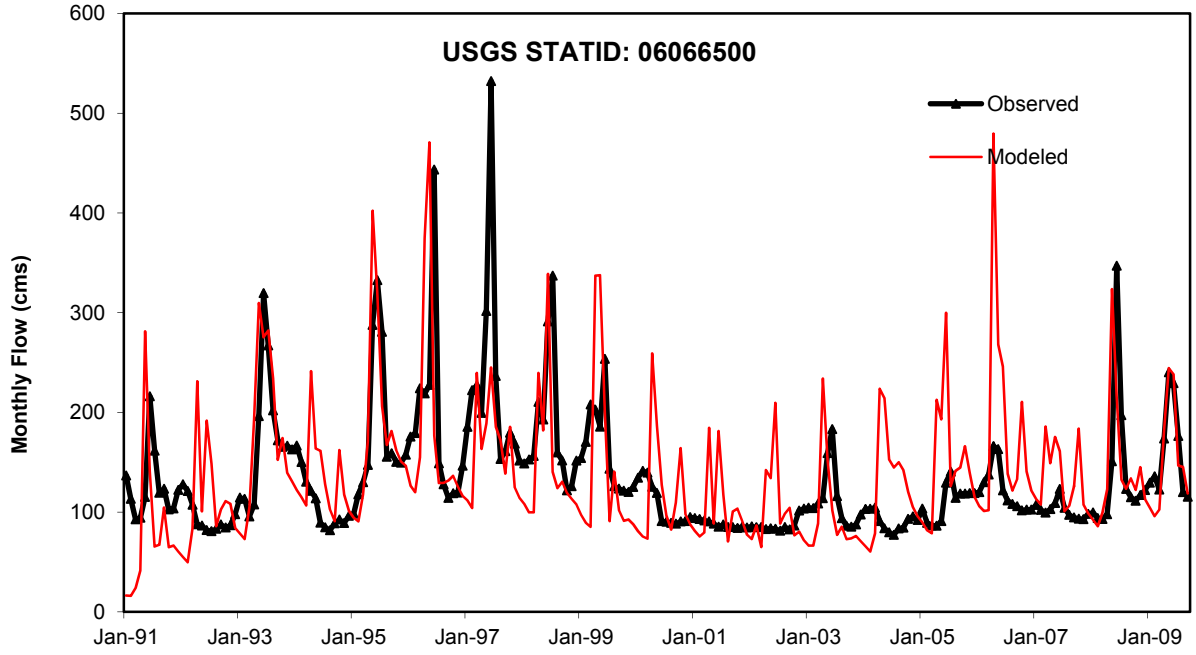
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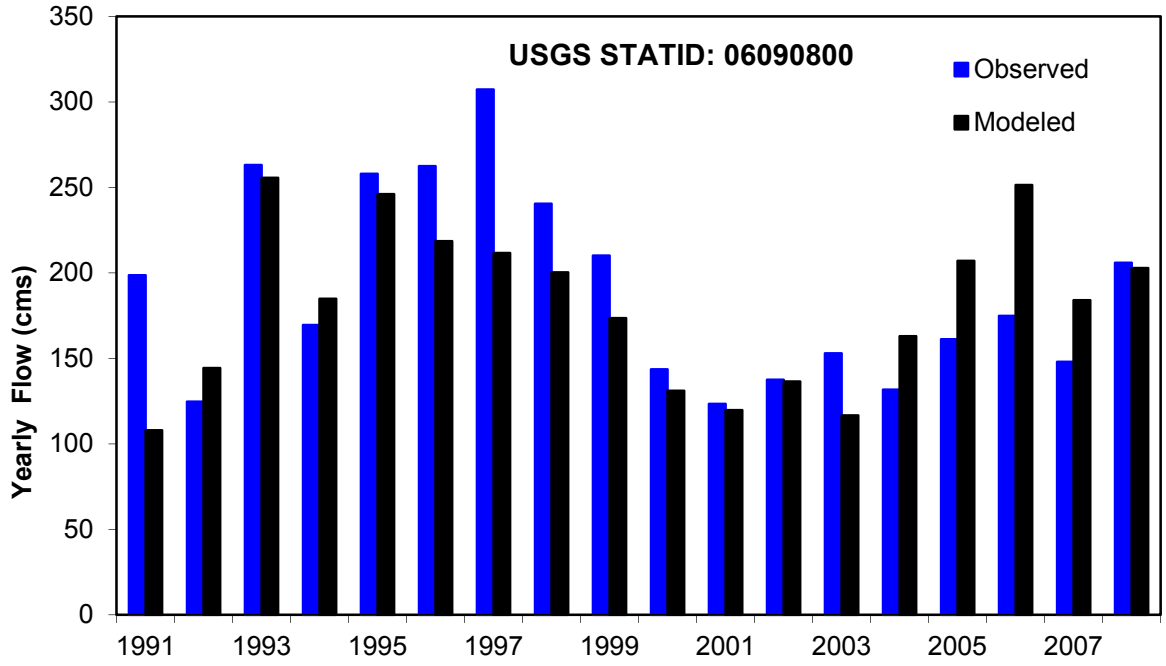
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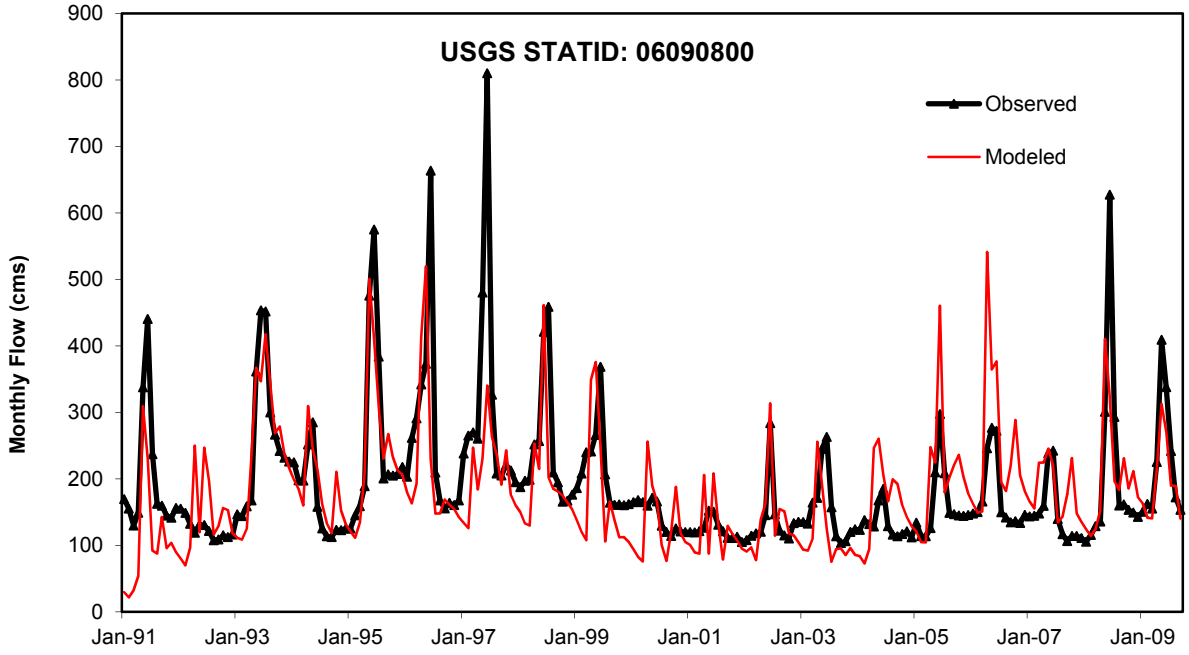
APPENDIX A

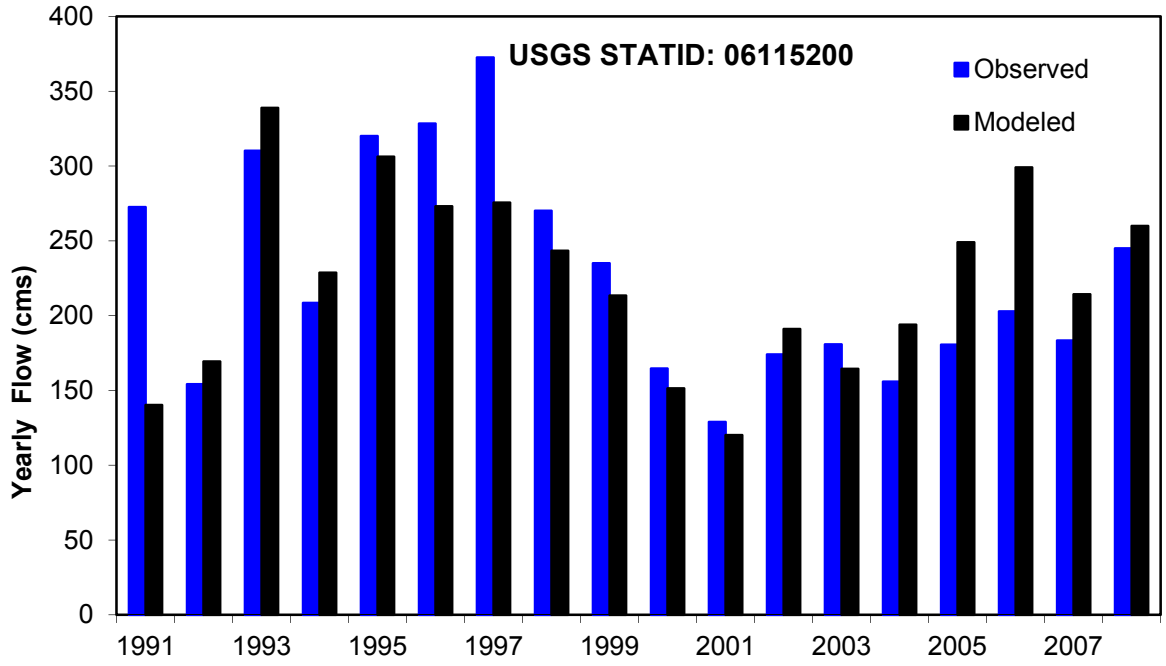
Observed and Modeled Time Series Plots of Annual and Monthly Averaged Flow for Nineteen Stations in the Missouri River Basin

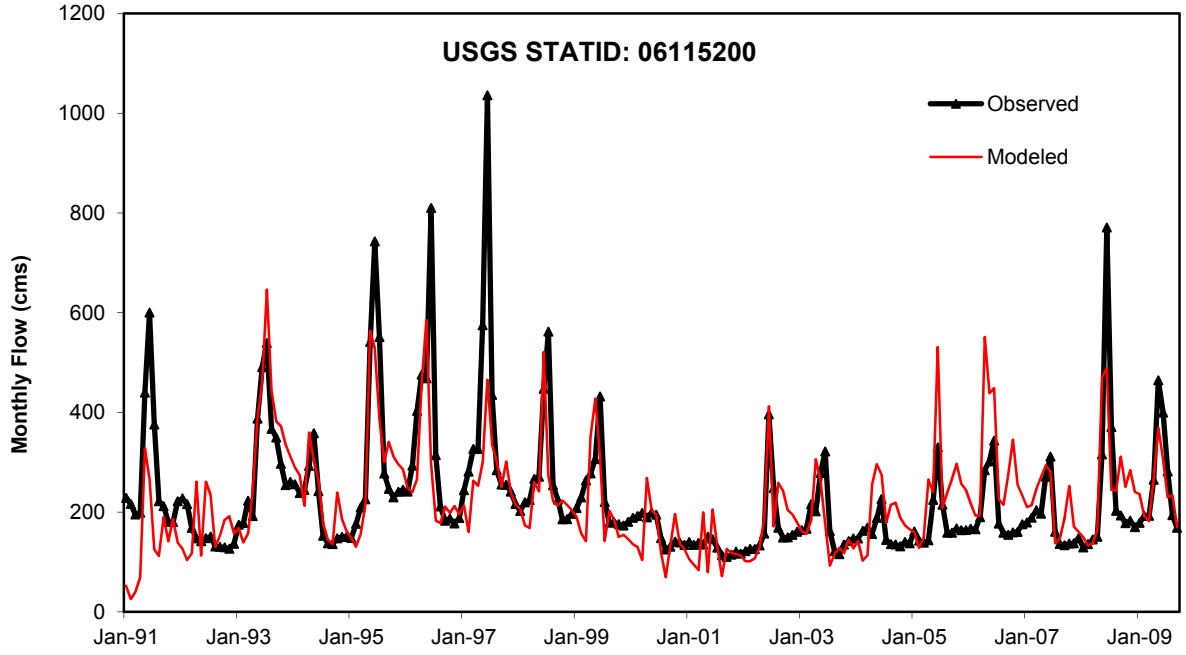

USGS STATID: 06066500
Observed
Modeled
Yearly Flow (cms)
250
200
150
100
50
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

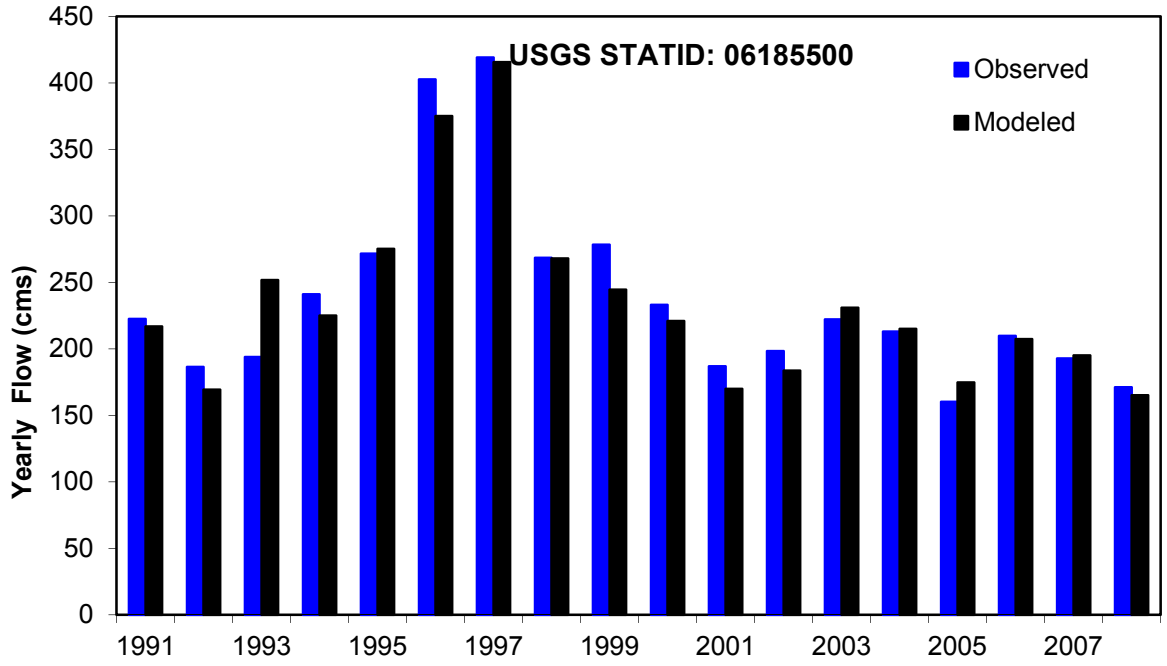

USGS STATID: 06066500
Observed
Modeled
Monthly Flow (cms)
600
500
400
300
200
100
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

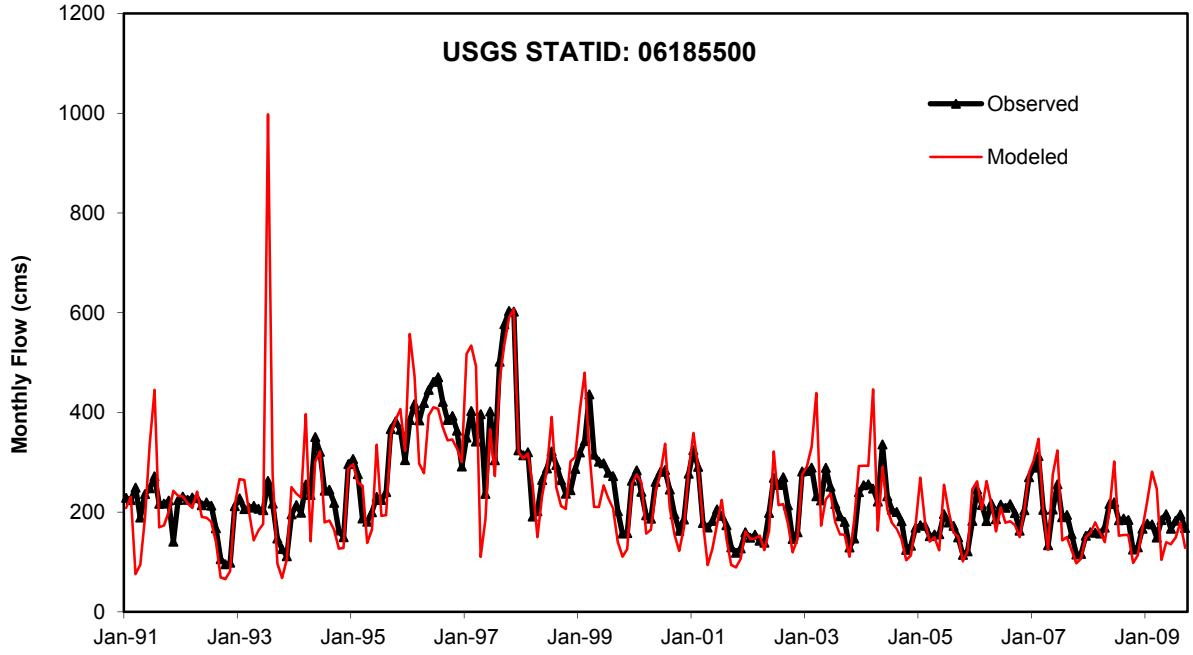

USGS STATID: 06090800
Observed
Modeled
Yearly Flow (cms)
350
300
250
200
150
100
50
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

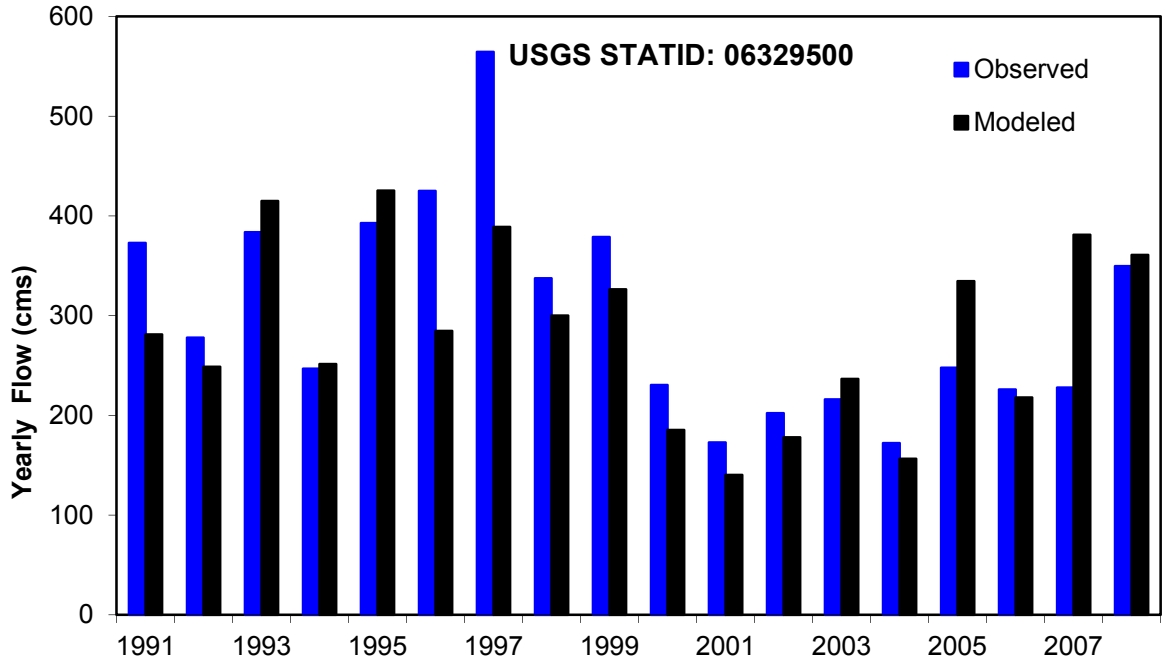

USGS STATID: 06090800
Observed
Modeled
Monthly Flow (cms)
900
800
700
600
500
400
300
200
100
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

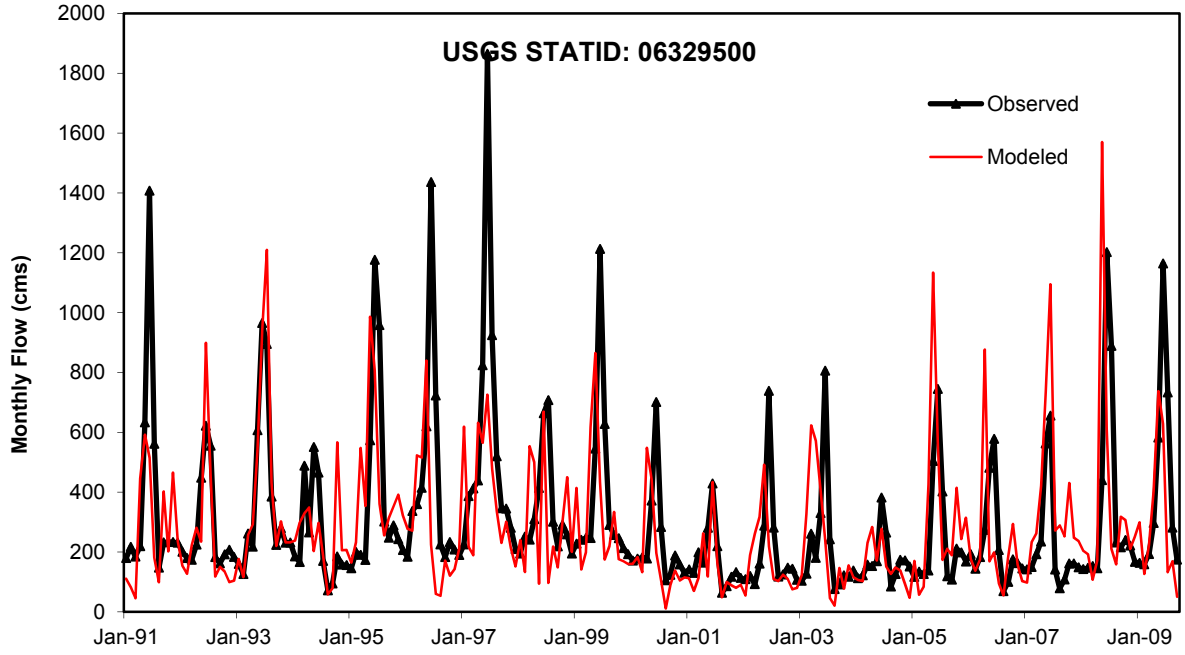

USGS STATID: 06115200
Observed
Modeled
Yearly Flow (cms)
400
350
300
250
200
150
100
50
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

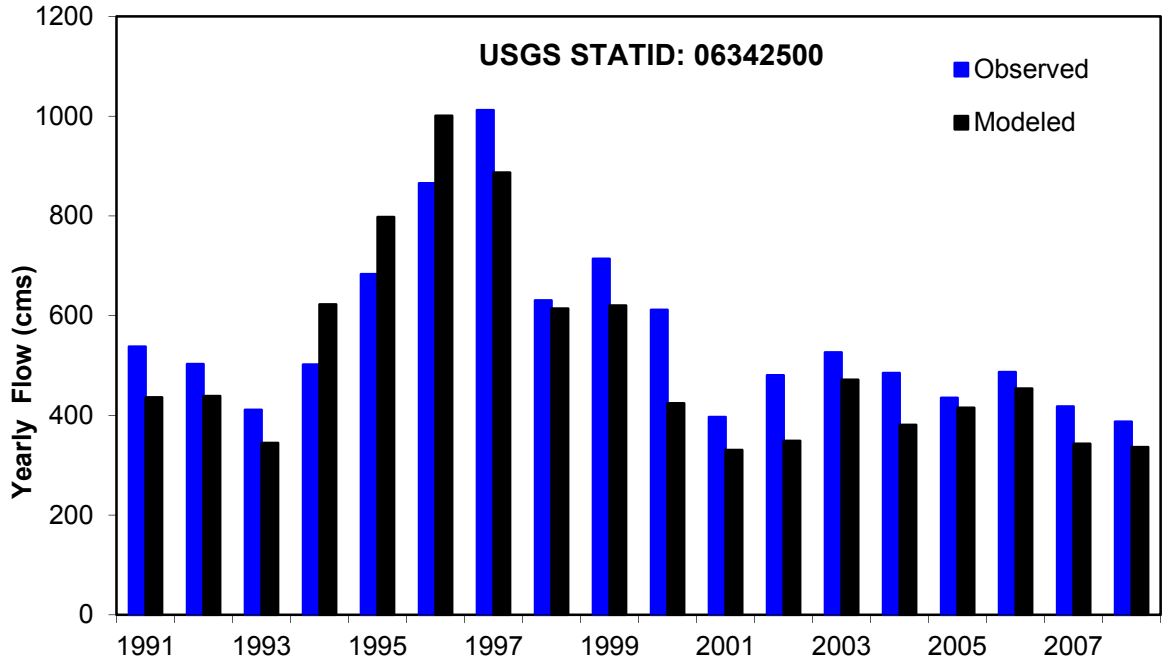

USGS STATID: 06115200
Observed
Modeled
Monthly Flow (cms)
1200
1000
800
600
400
200
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

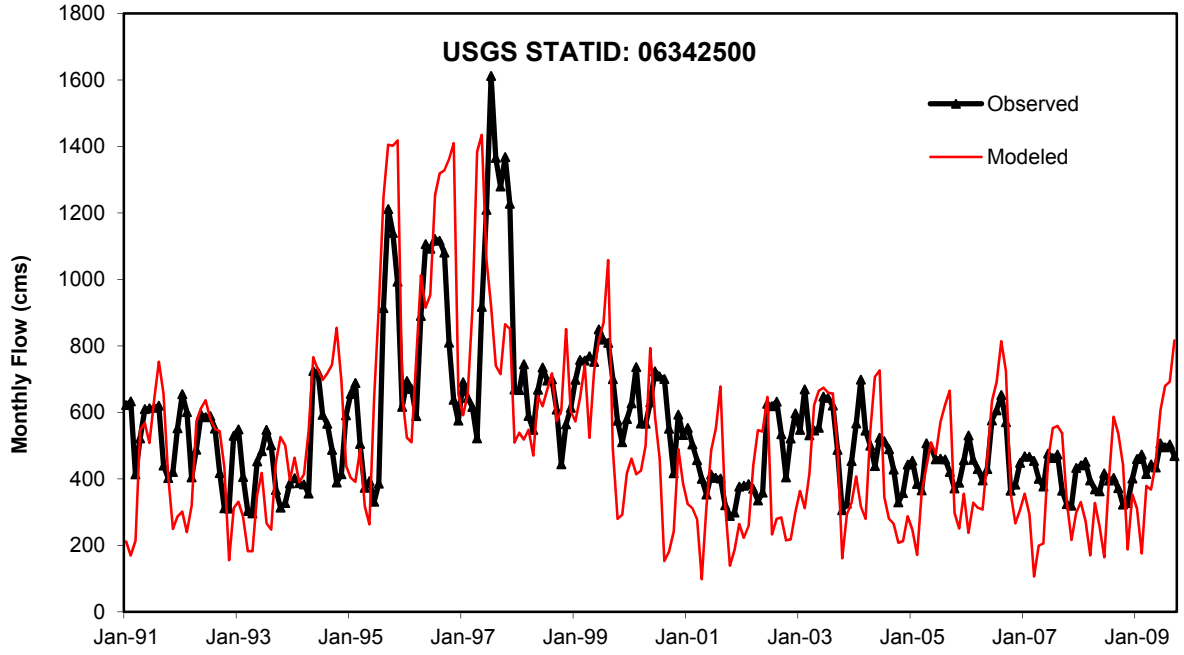

USGS STATID: 06185500
Observed
Modeled
Yearly Flow (cms)
450
400
350
300
250
200
150
100
50
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

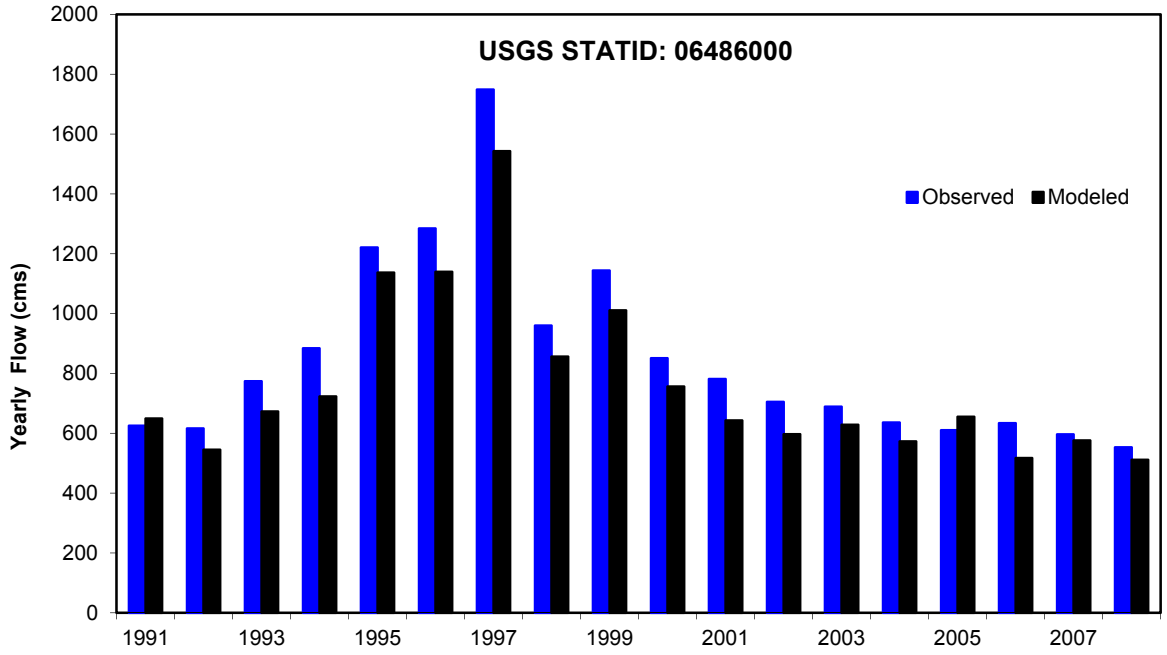

USGS STATID: 06185500
Observed
Modeled
Monthly Flow (cms)
1200
1000
800
600
400
200
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

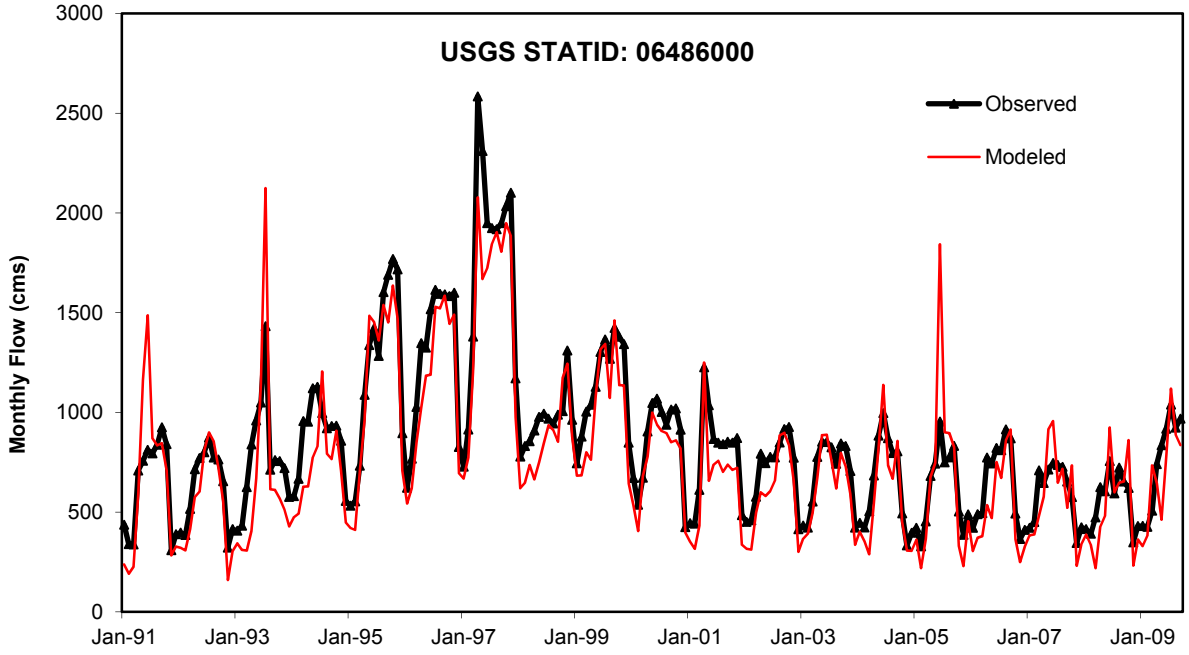

USGS STATID: 06329500
Observed
Modeled
Yearly Flow (cms)
600
500
400
300
200
100
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

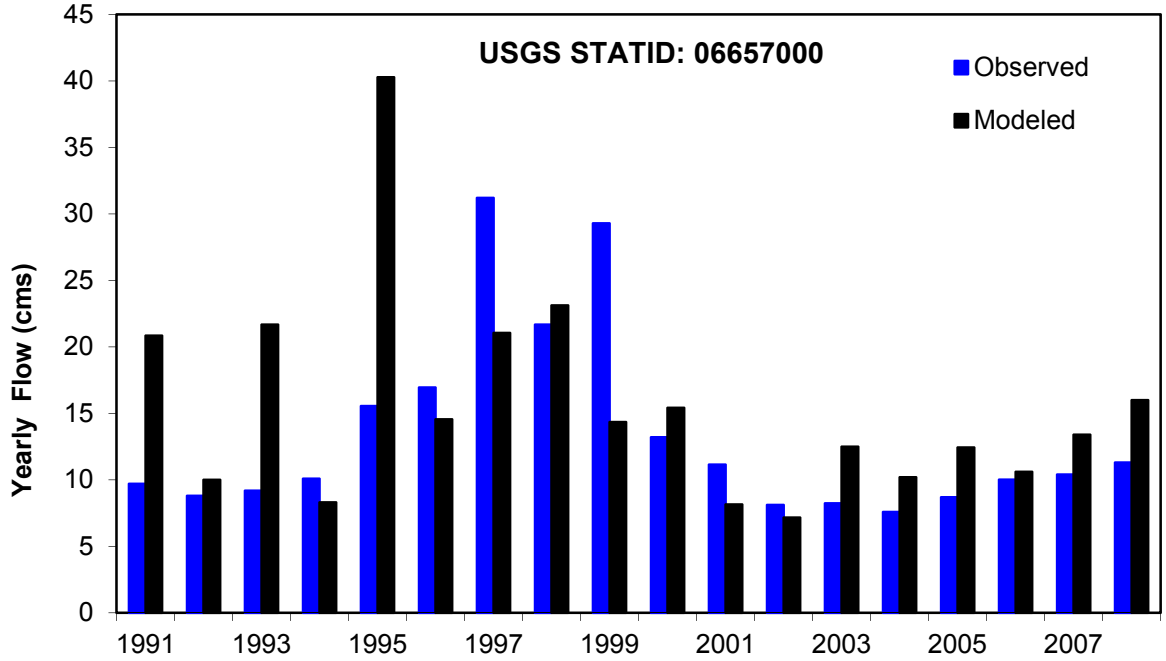

USGS STATID: 06329500
Observed
Modeled
Monthly Flow (cms)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

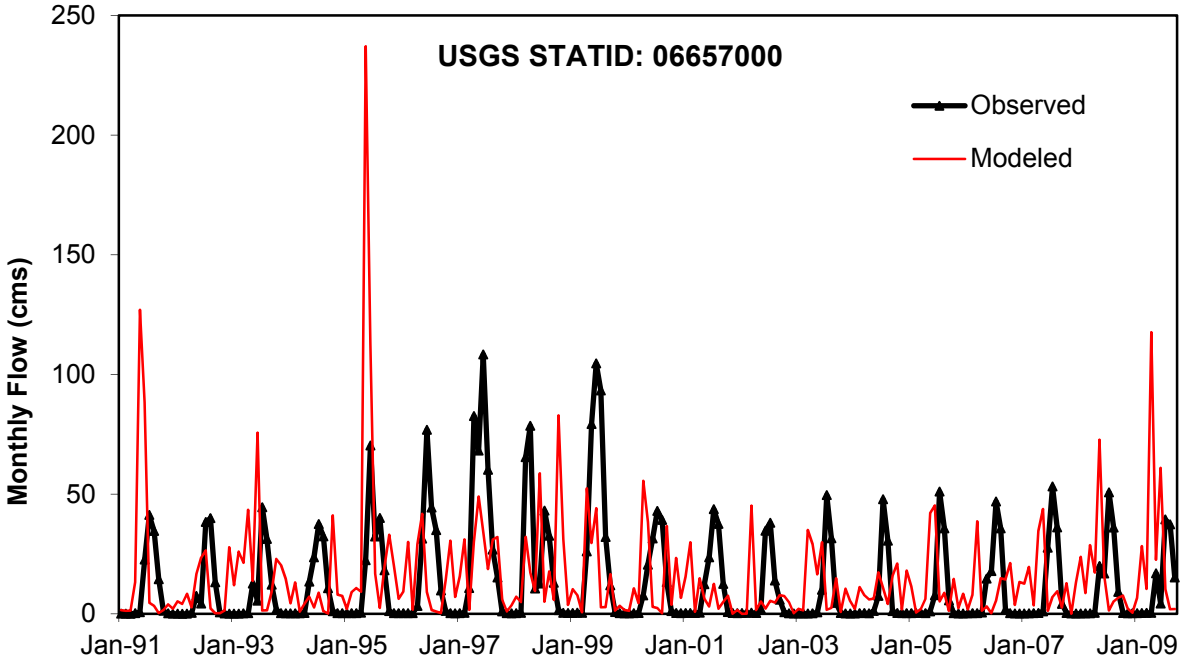

USGS STATID: 06342500
Observed
Modeled
Yearly Flow (cms)
1200
1000
800
600
400
200
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

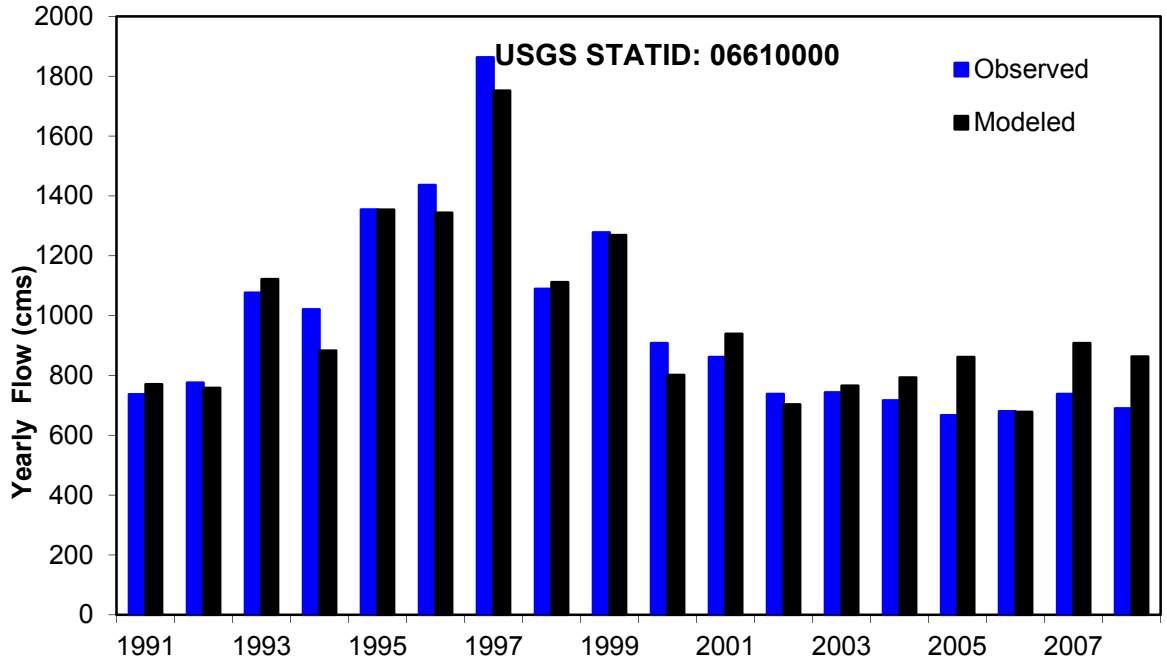

USGS STATID: 06342500
Observed
Modeled
Monthly Flow (cms)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

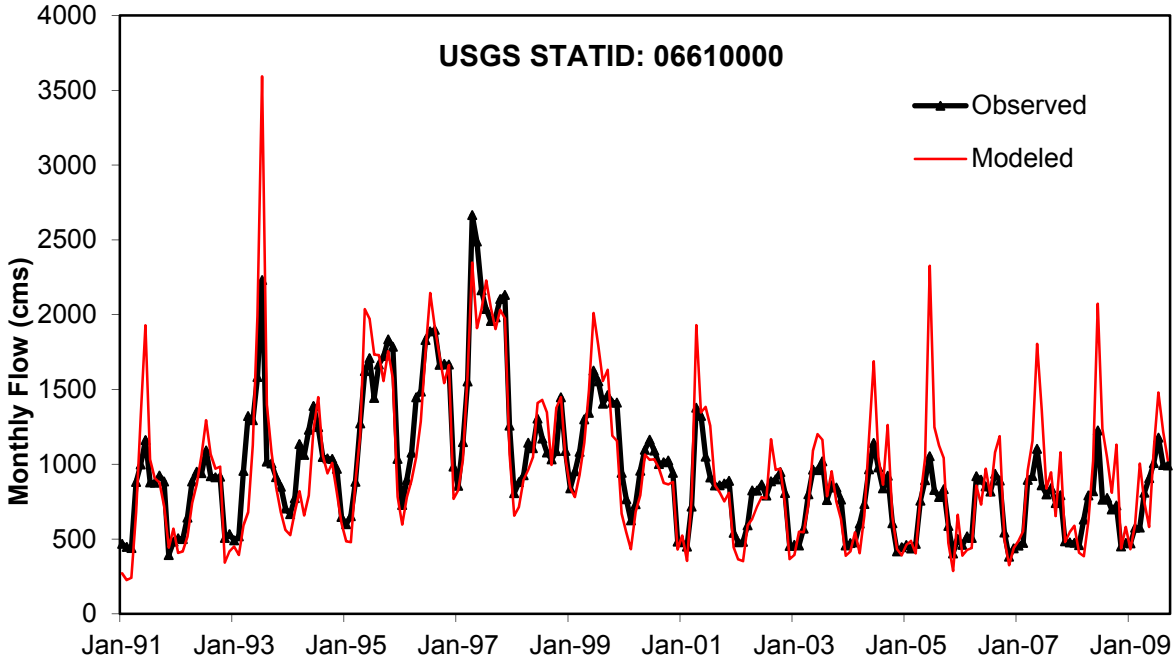

USGS STATID: 06486000
Observed
Modeled
Yearly Flow (cms)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

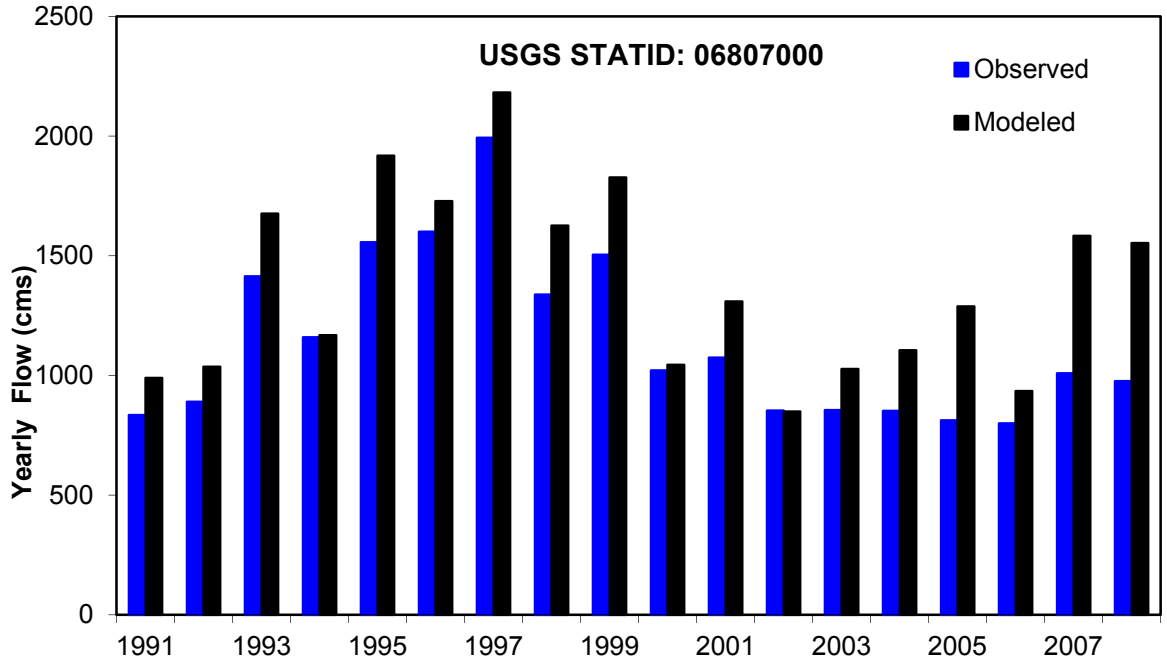

USGS STATID: 06486000
Observed
Modeled
Monthly Flow (cms)
3000
2500
2000
1500
1000
500
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

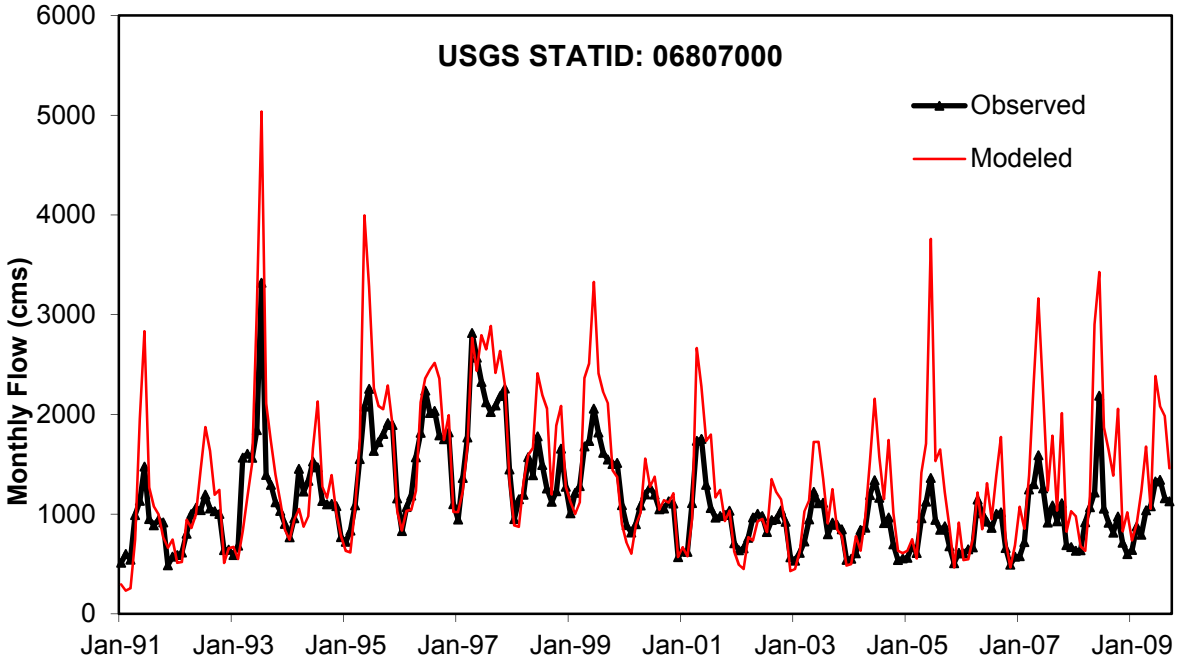

USGS STATID: 06657000
Observed
Modeled
Yearly Flow (cms)
45
40
35
30
25
20
15
10
5
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

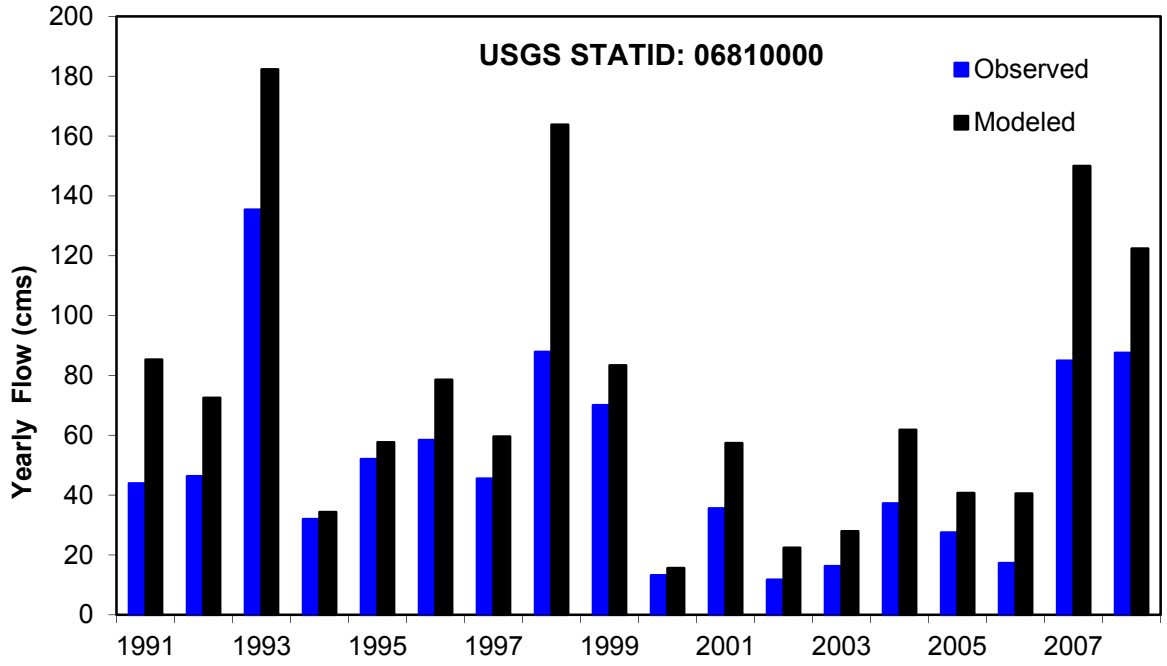

USGS STATID: 06657000
Observed
Modeled
Monthly Flow (cms)
250
200
150
100
50
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

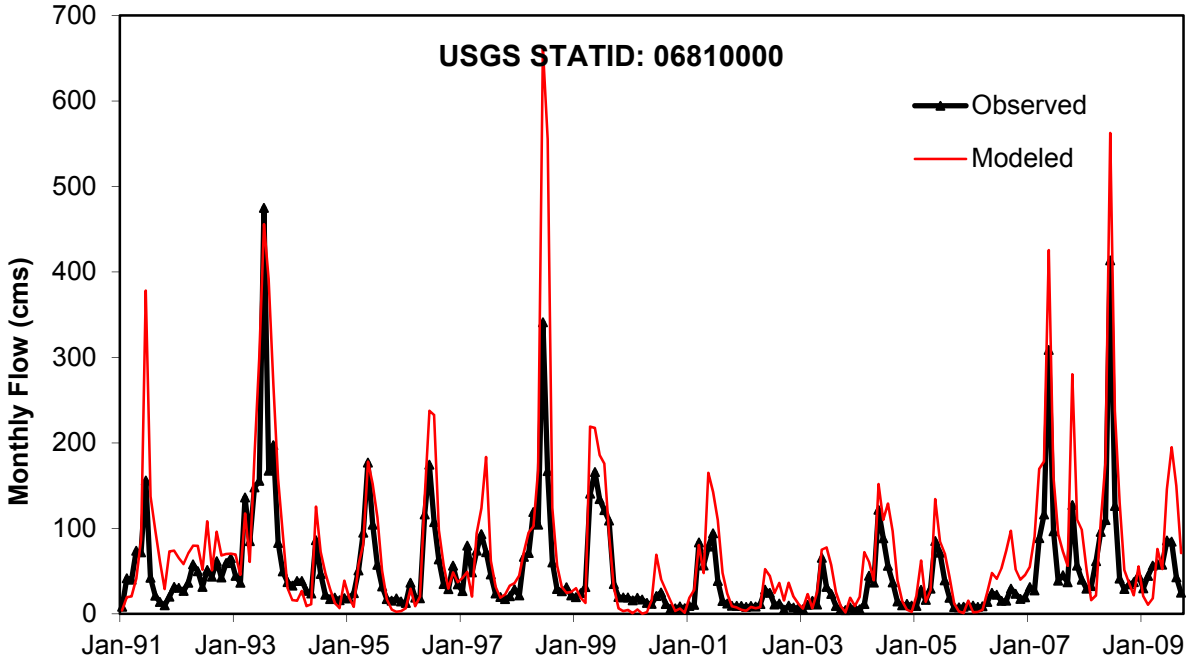

USGS STATID: 06610000
Observed
Modeled
Yearly Flow (cms)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

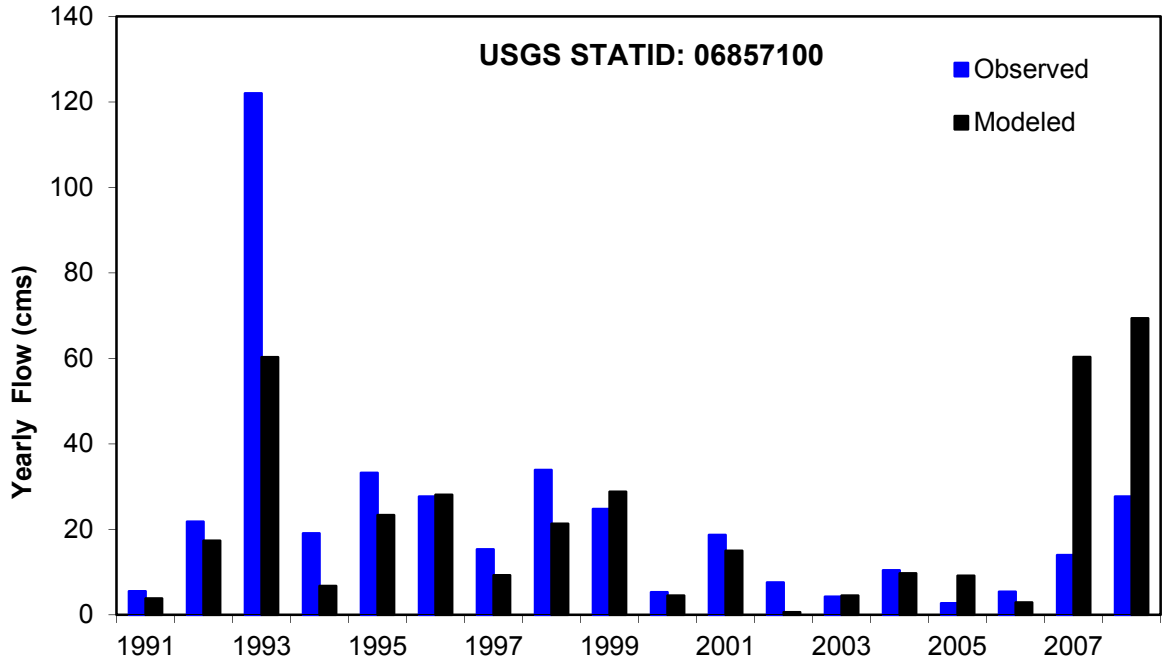

USGS STATID: 06610000
Observed
Modeled
Monthly Flow (cms)
4000
3500
3000
2500
2000
1500
1000
500
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

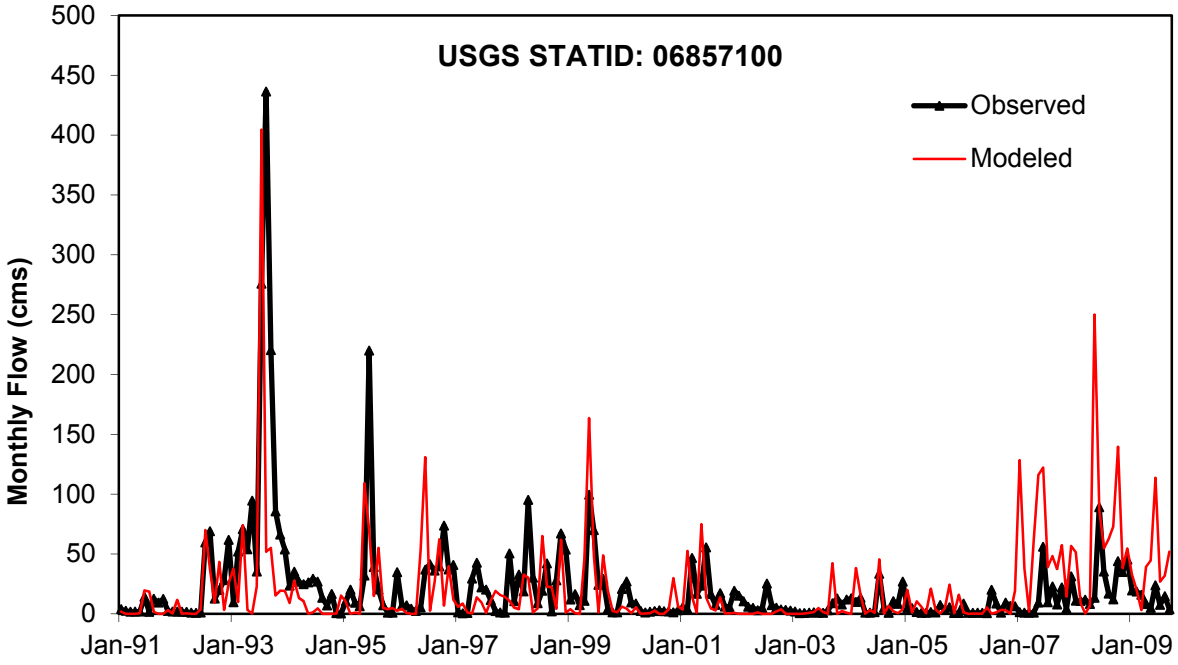

USGS STATID: 06807000
Observed
Modeled
Yearly Flow (cms)
2500
2000
1500
1000
500
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

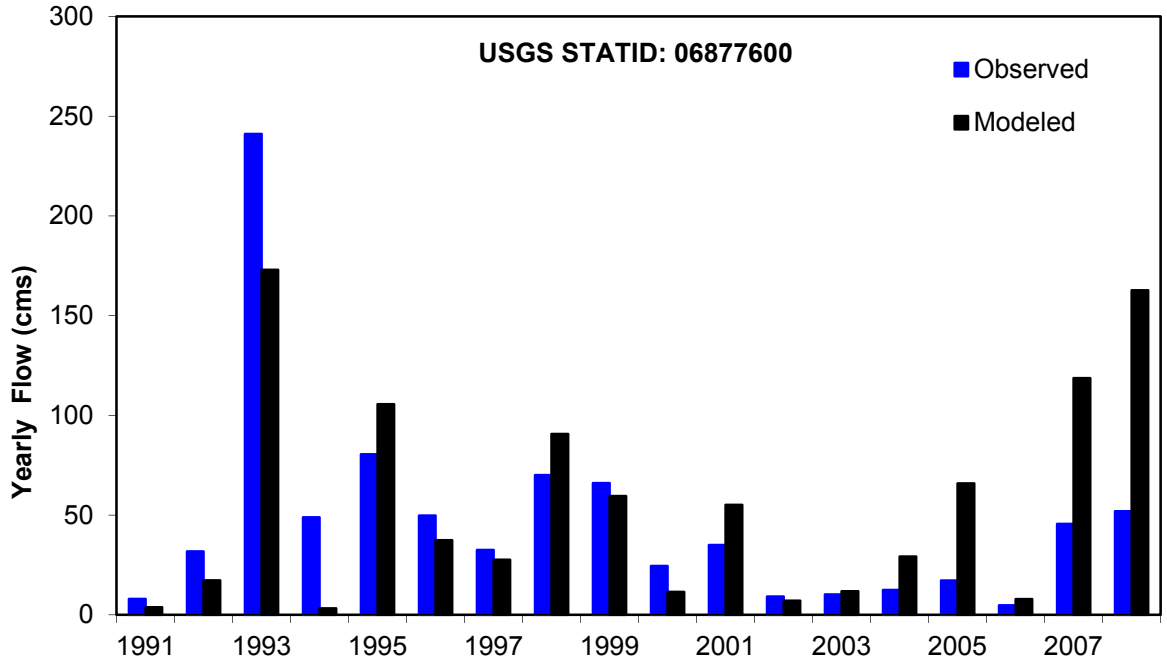

USGS STATID: 06807000
Observed
Modeled
Monthly Flow (cms)
6000
5000
4000
3000
2000
1000
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

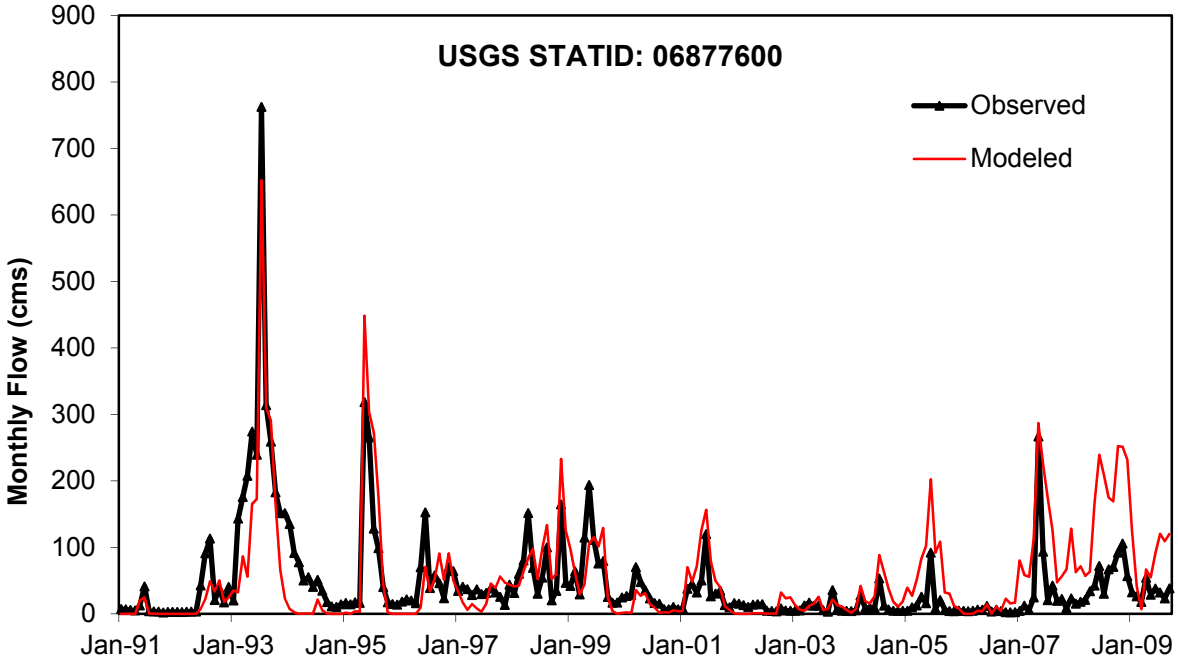

USGS STATID: 06810000
Observed
Modeled
Yearly Flow (cms)
200
180
160
140
120
100
80
60
40
20
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

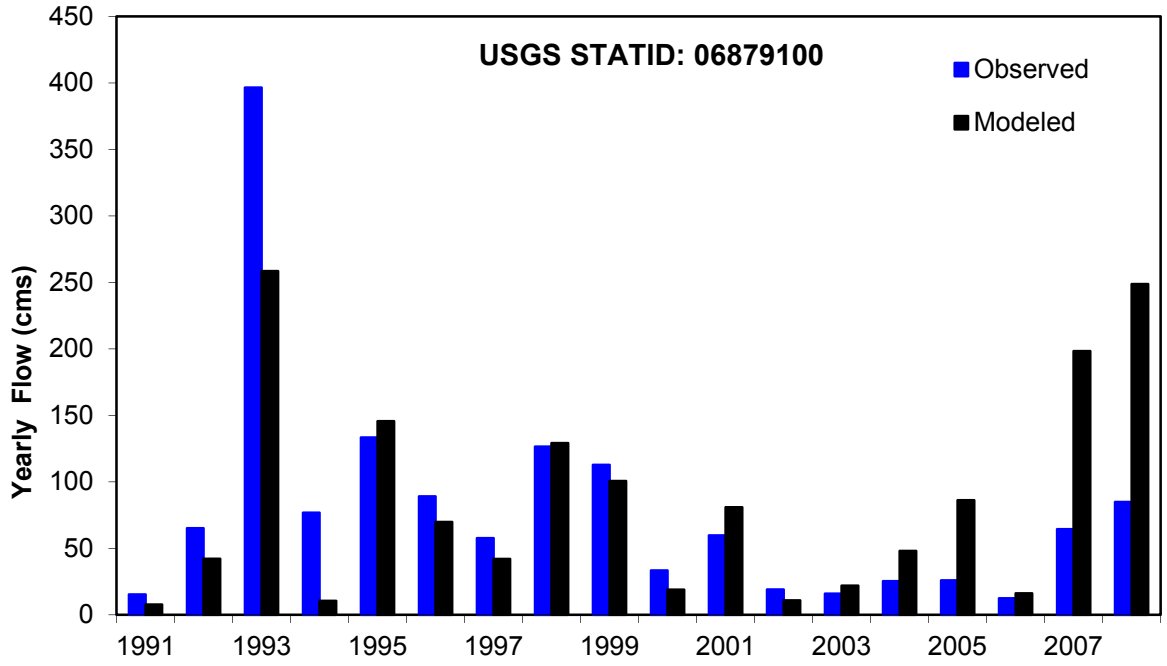

USGS STATID: 06810000
Observed
Modeled
Monthly Flow (cms)
700
600
500
400
300
200
100
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

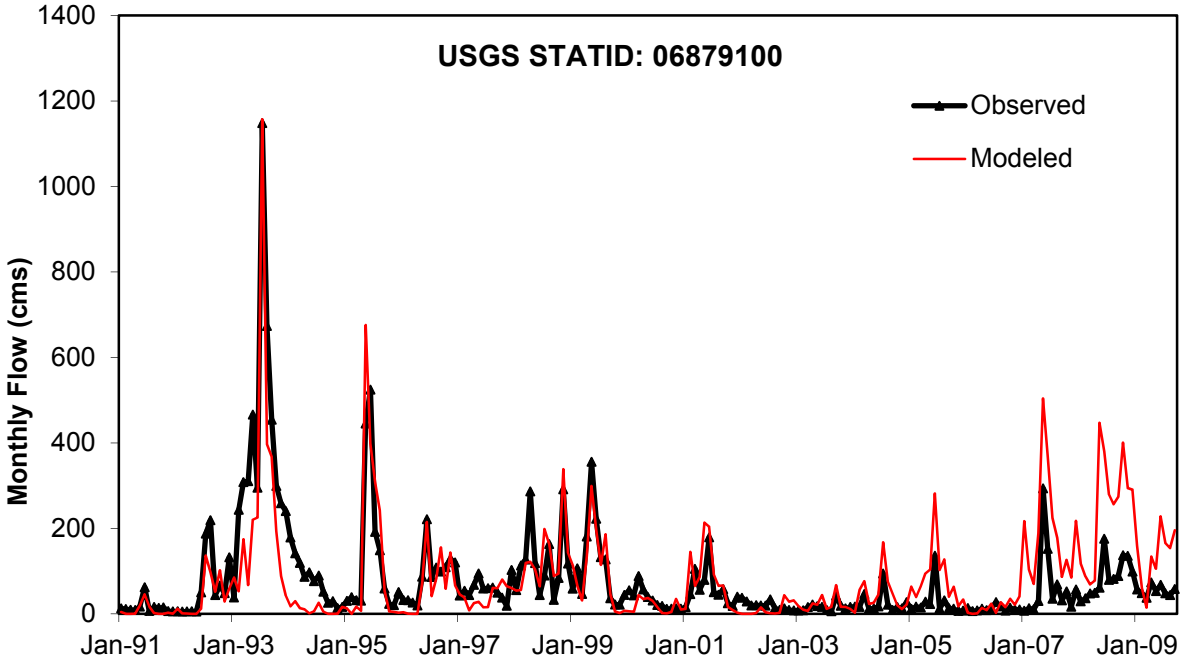

USGS STATID: 06857100
Observed
Modeled
Yearly Flow (cms)
140
120
100
80
60
40
20
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

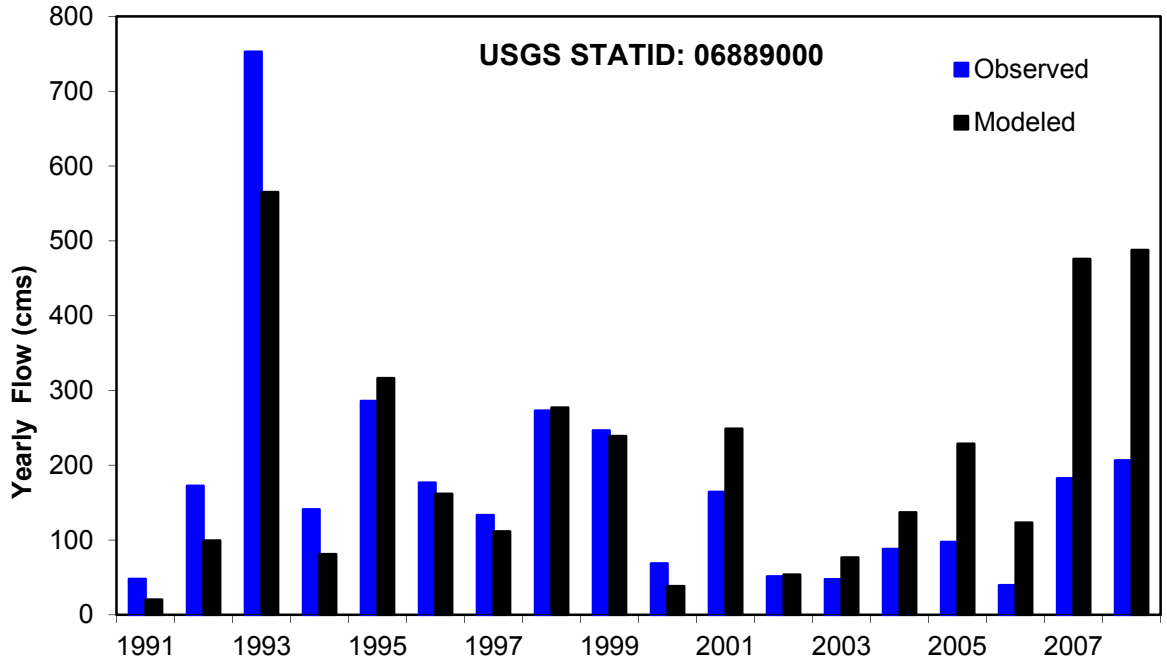

USGS STATID: 06857100
Observed
Modeled
Monthly Flow (cms)
500
450
400
350
300
250
200
150
100
50
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

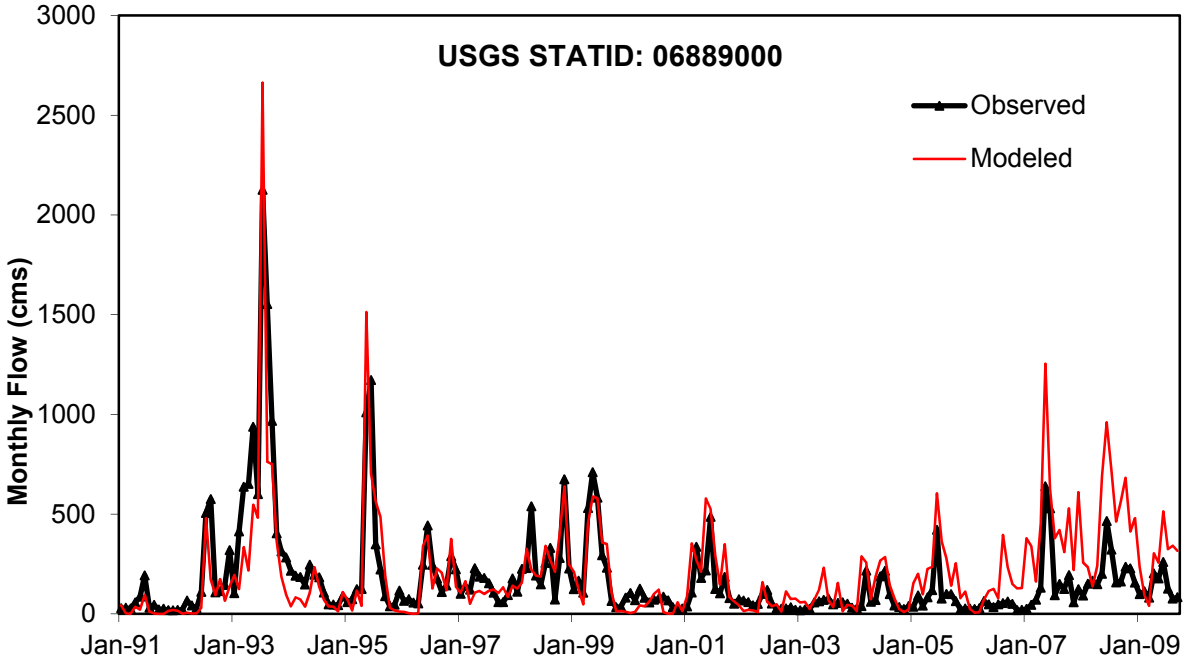

USGS STATID: 06877600
Observed
Modeled
Yearly Flow (cms)
300
250
200
150
100
50
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

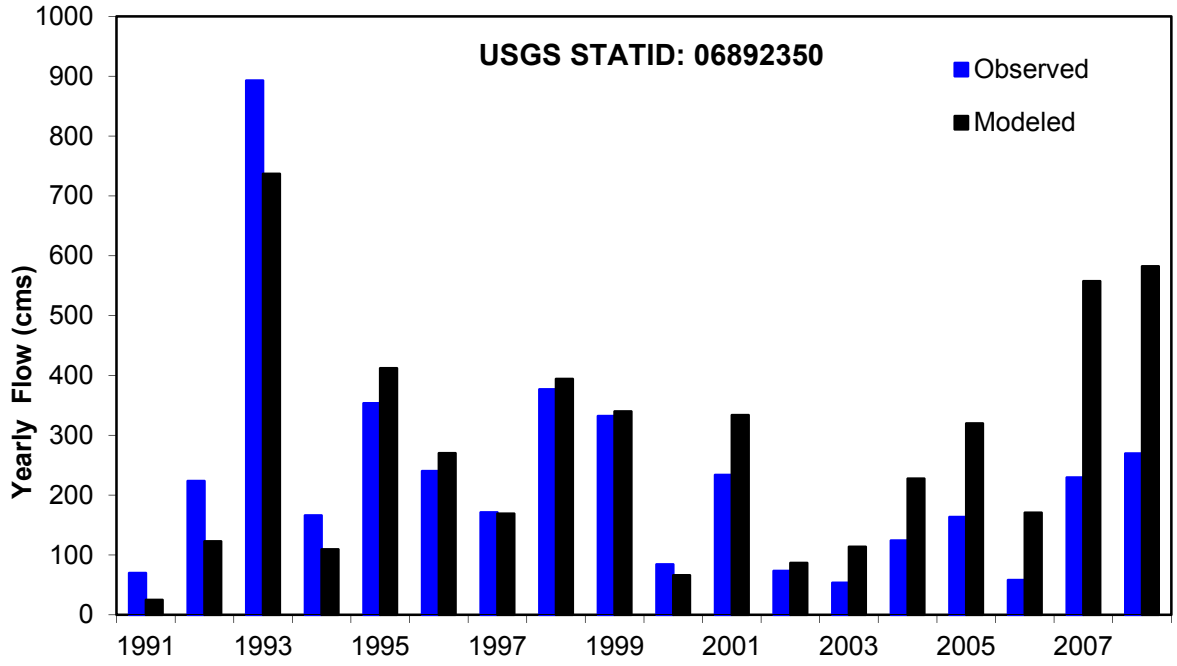

USGS STATID: 06877600
Observed
Modeled
Monthly Flow (cms)
900
800
700
600
500
400
300
200
100
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

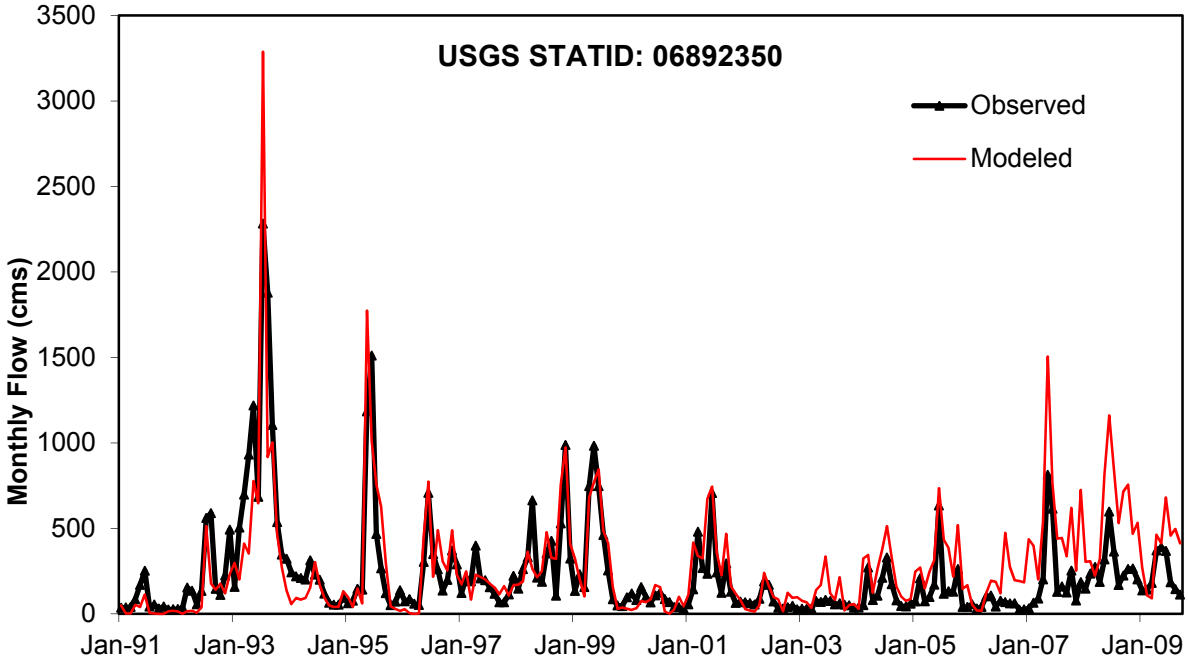

USGS STATID: 06879100
Observed
Modeled
Yearly Flow (cms)
450
400
350
300
250
200
150
100
50
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

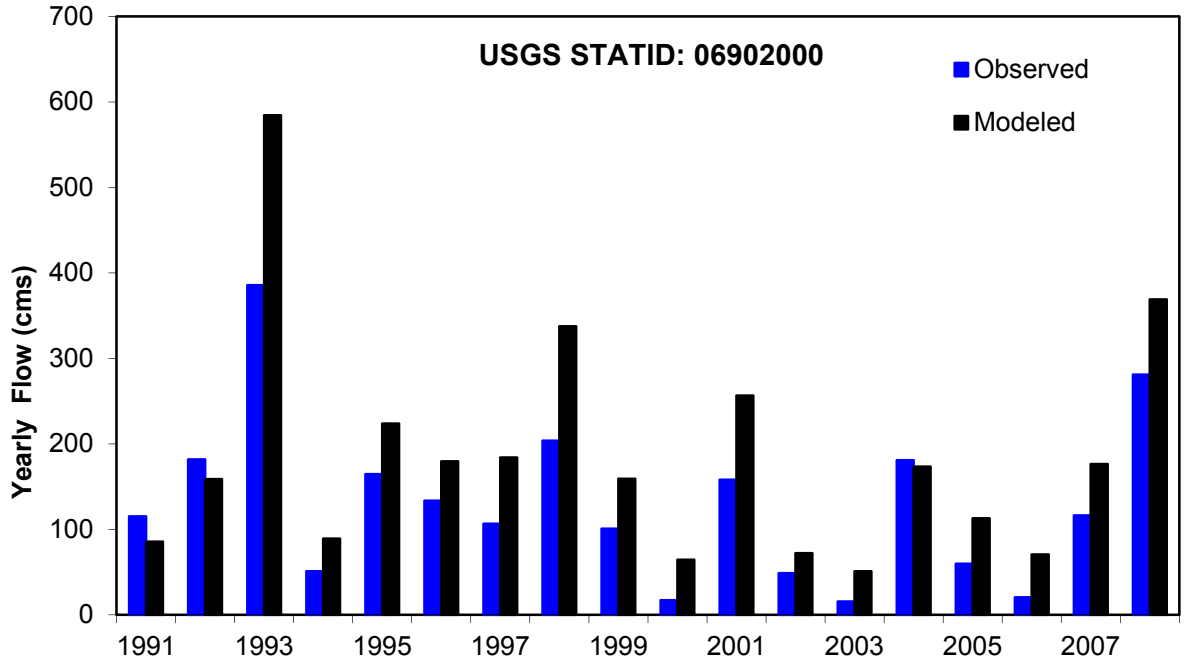

USGS STATID: 06879100
Observed
Modeled
Monthly Flow (cms)
1400
1200
1000
800
600
400
200
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

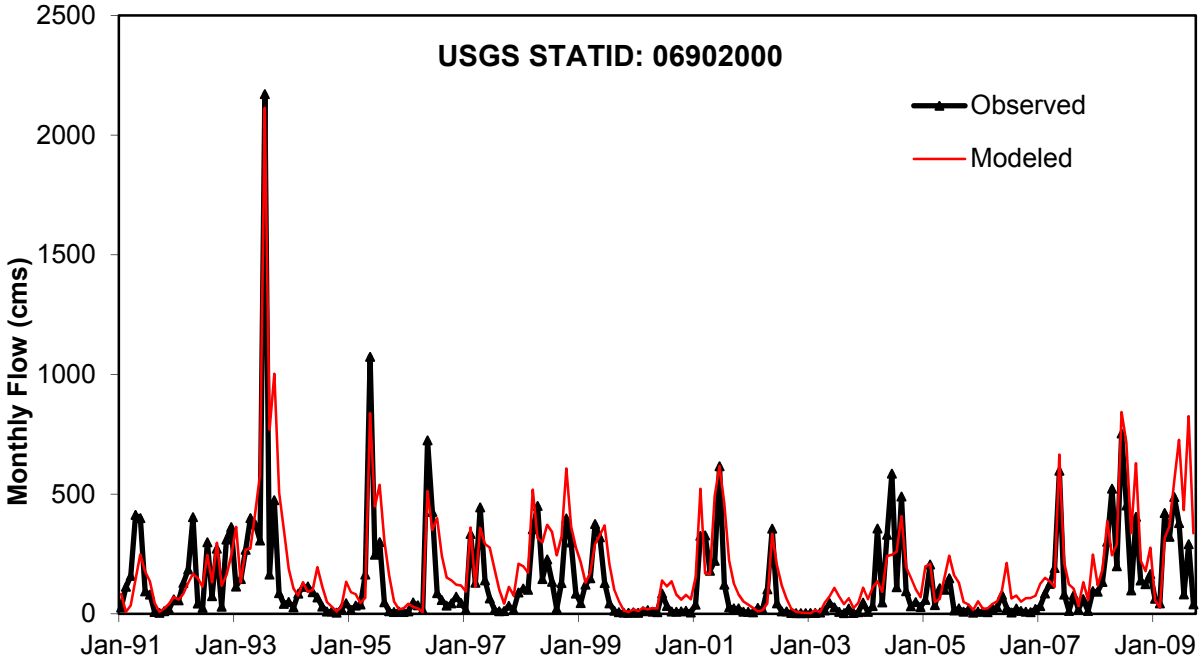

USGS STATID: 06889000
Observed
Modeled
Yearly Flow (cms)
800
700
600
500
400
300
200
100
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

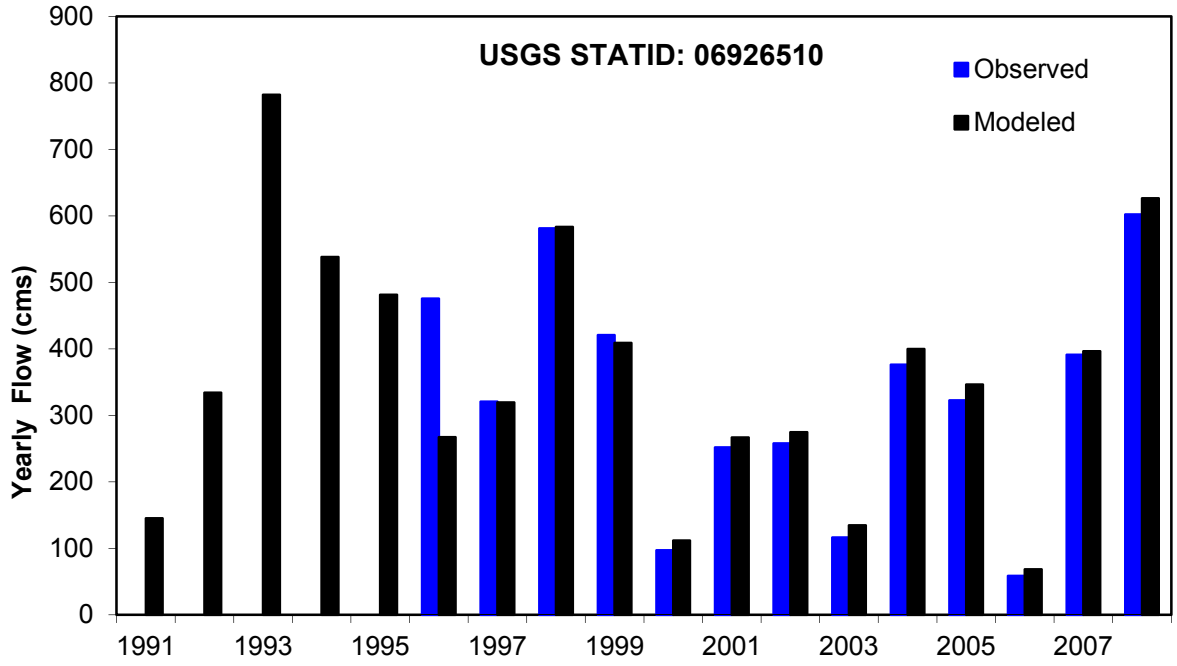

USGS STATID: 06889000
Observed
Modeled
Monthly Flow (cms)
3000
2500
2000
1500
1000
500
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

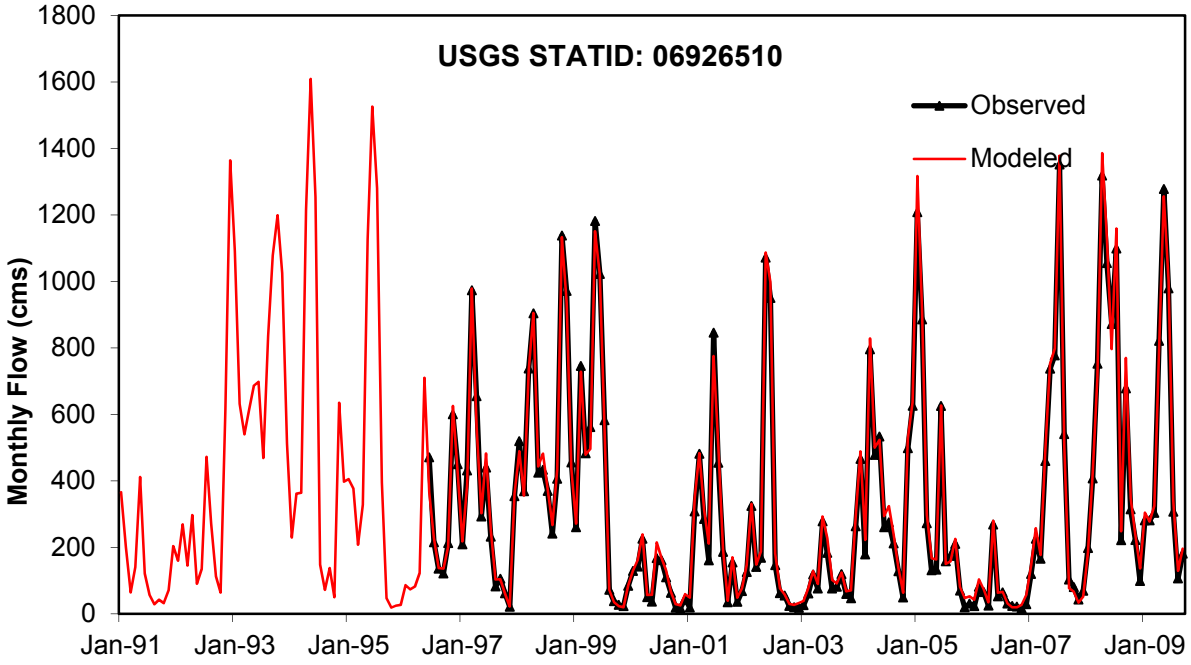

USGS STATID: 06892350
Observed
Modeled
Yearly Flow (cms)
1000
900
800
700
600
500
400
300
200
100
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

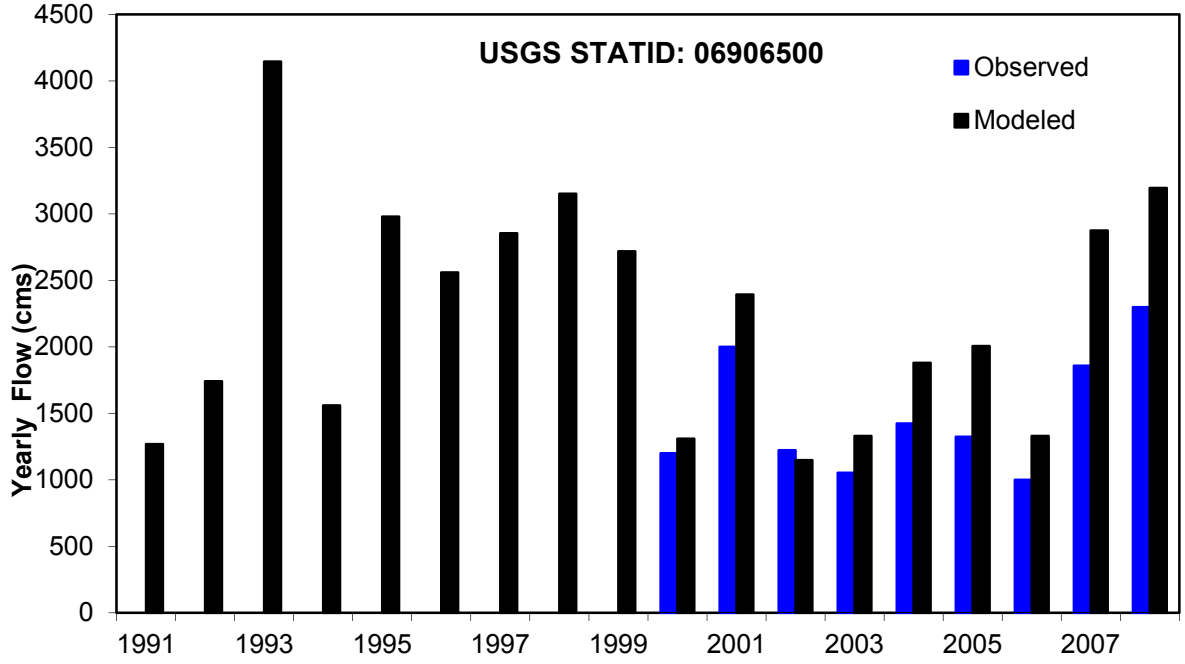

USGS STATID: 06892350
Observed
Modeled
Monthly Flow (cms)
3500
3000
2500
2000
1500
1000
500
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

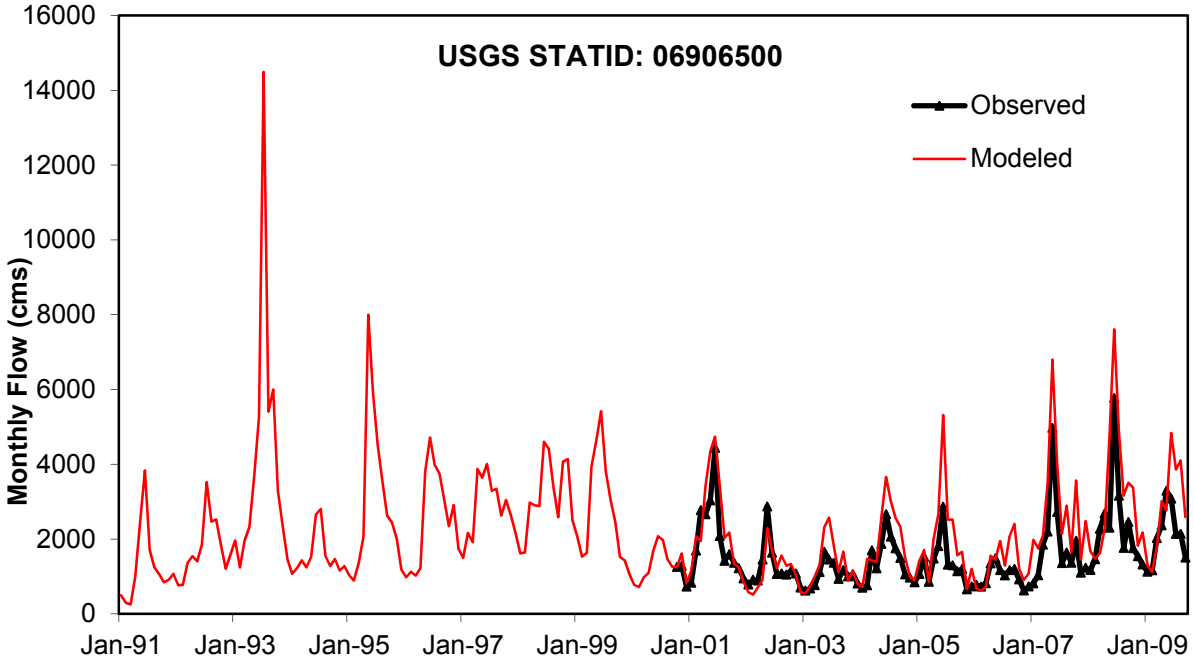

USGS STATID: 06902000
Observed
Modeled
Yearly Flow (cms)
700
600
500
400
300
200
100
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

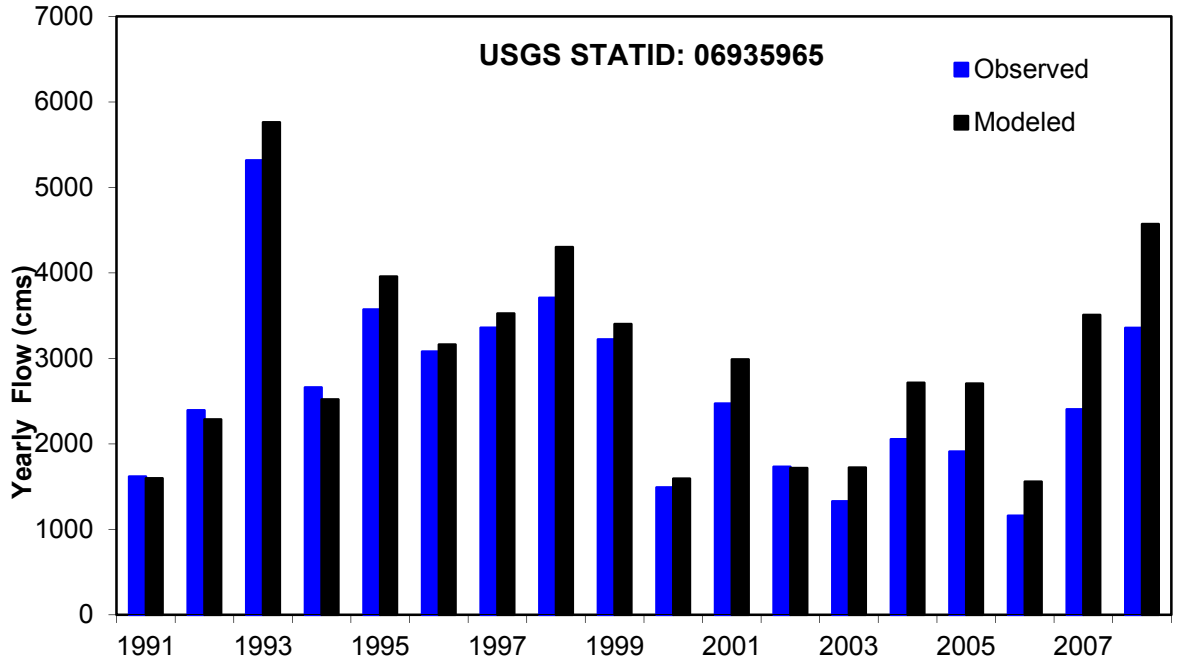

USGS STATID: 06902000
Observed
Modeled
Monthly Flow (cms)
2500
2000
1500
1000
500
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

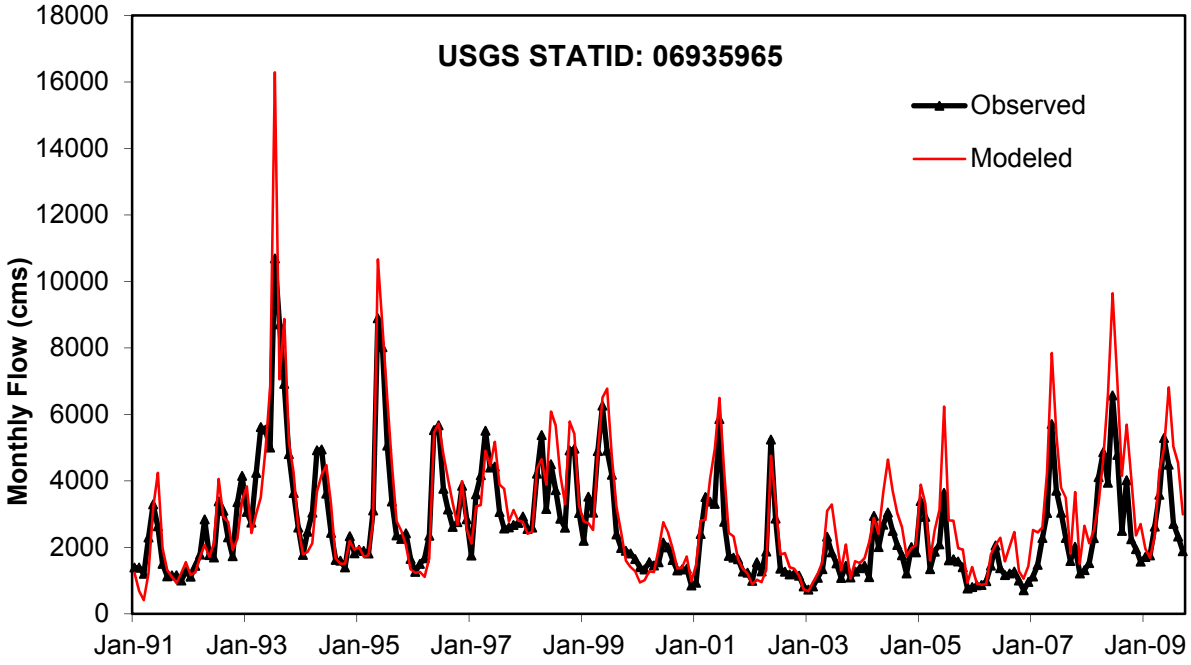

USGS STATID: 06926510
Observed
Modeled
Yearly Flow (cms)
900
800
700
600
500
400
300
200
100
0
1991
1993
1995
1997
1999
2001
2003
2005
2007


USGS STATID: 06926510
Observed
Modeled
Monthly Flow (cms)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09


USGS STATID: 06906500
Observed
Modeled
Yearly Flow (cms)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1991
1993
1995
1997
1999
2001
2003
2005
2007


USGS STATID: 06906500
Observed
Modeled
Monthly Flow (cms)
16000
14000
12000
10000
8000
6000
4000
2000
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

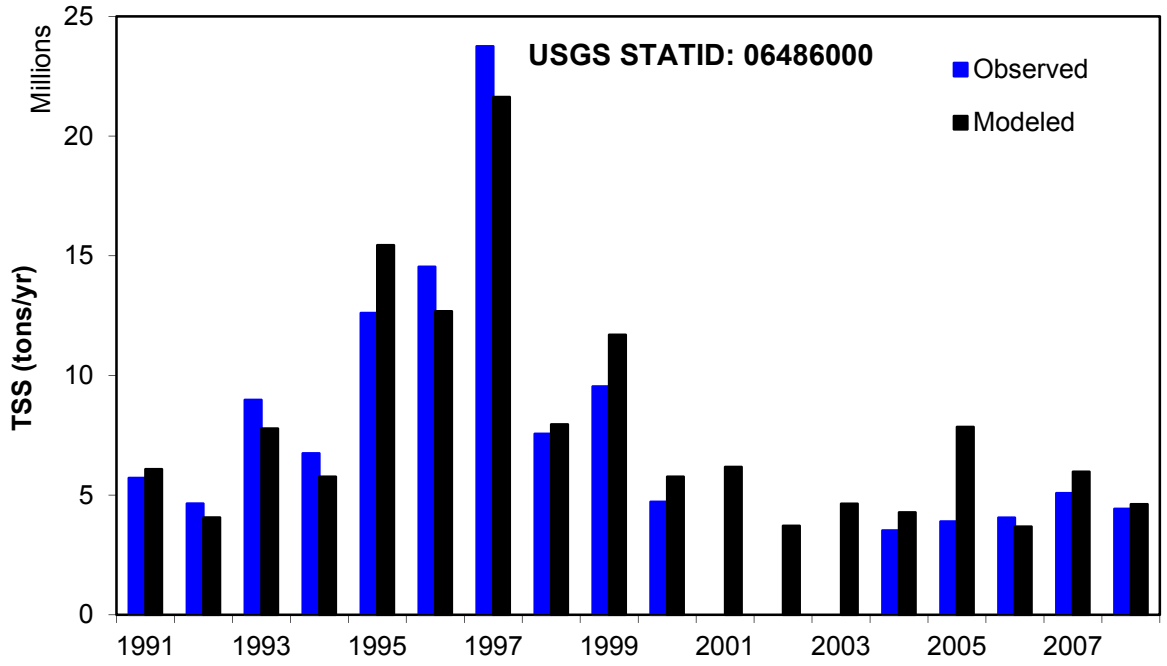

USGS STATID: 06935965
Observed
Modeled
Yearly Flow (cms)
7000
6000
5000
4000
3000
2000
1000
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

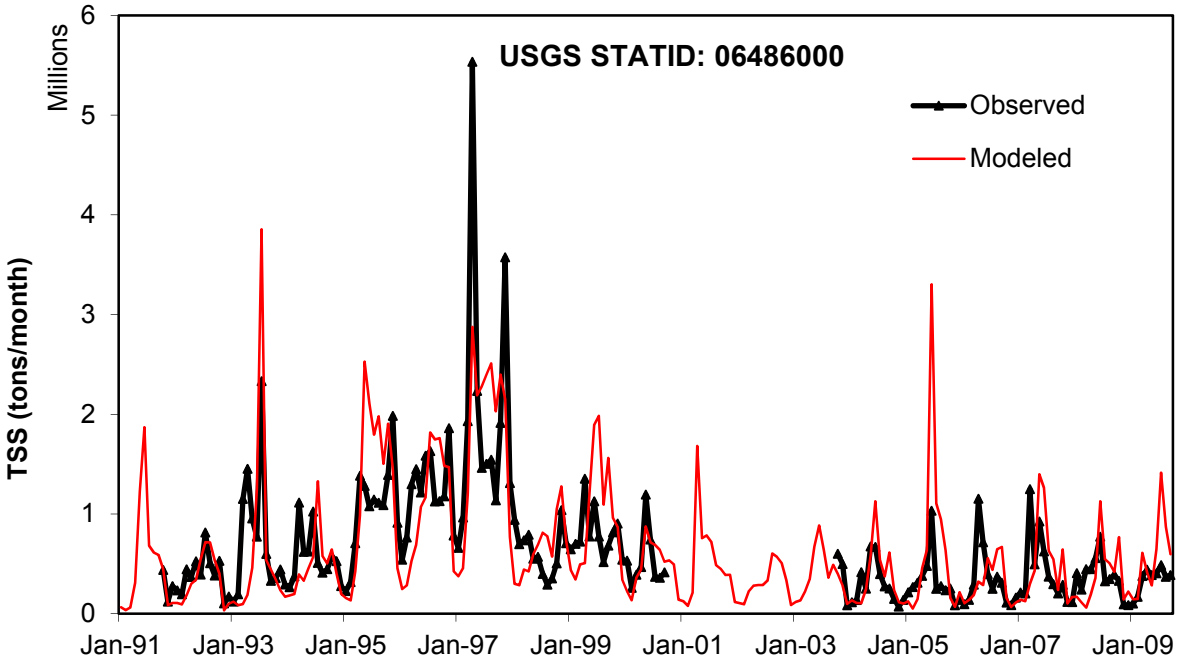

USGS STATID: 06935965
Observed
Modeled
Monthly Flow (cms)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

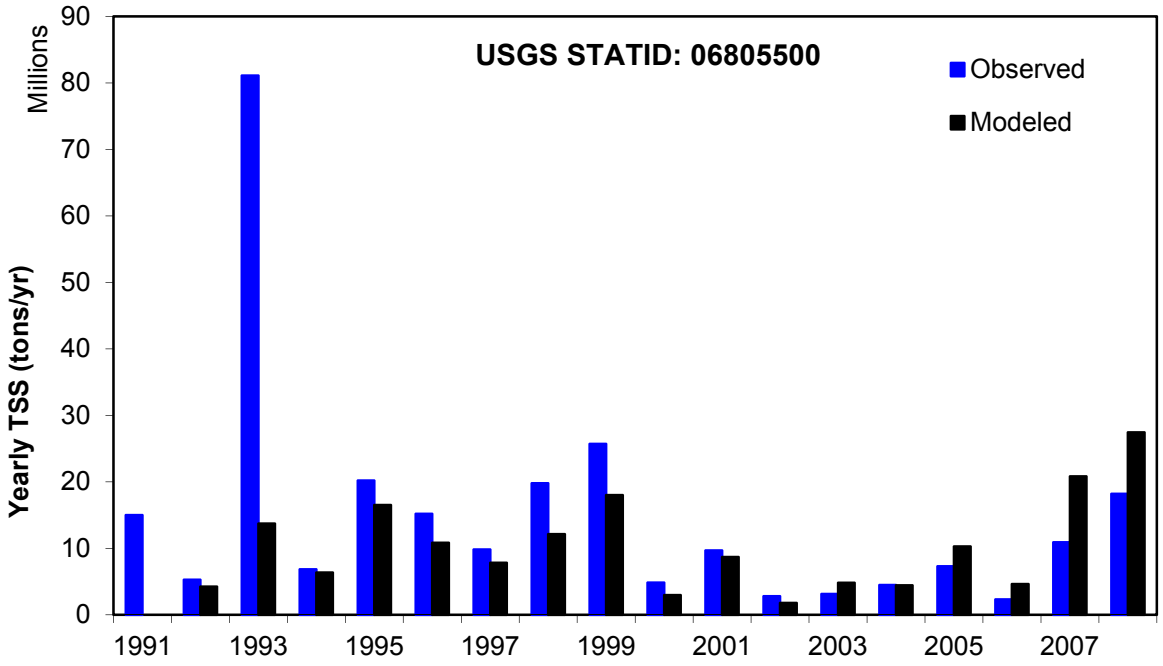
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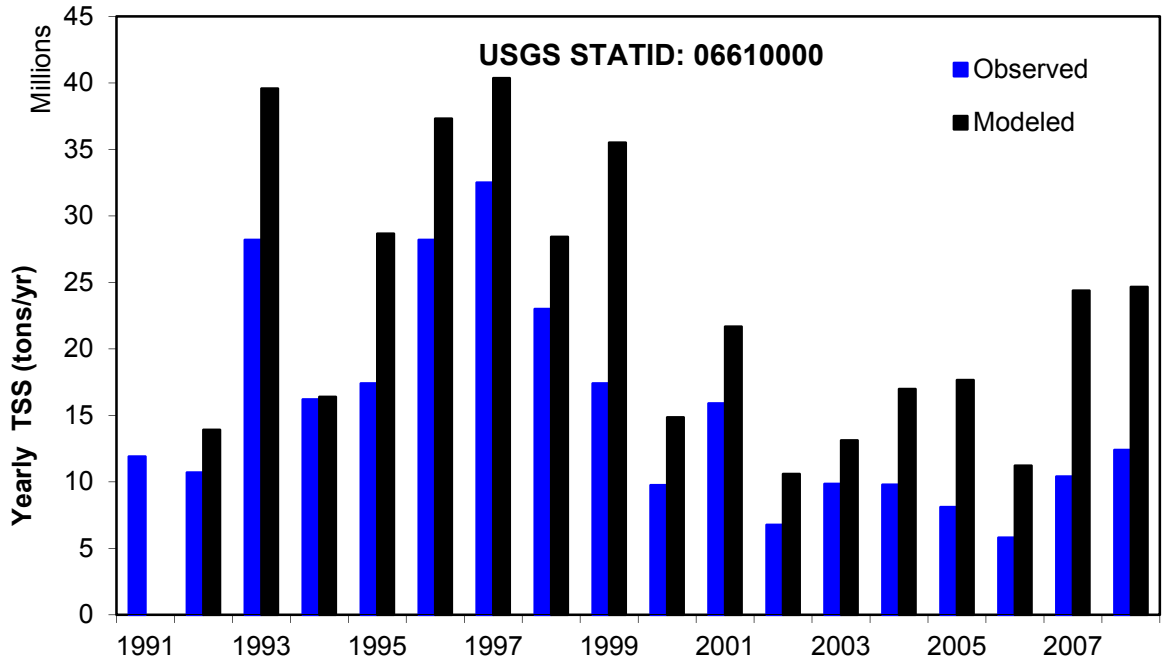
APPENDIX B

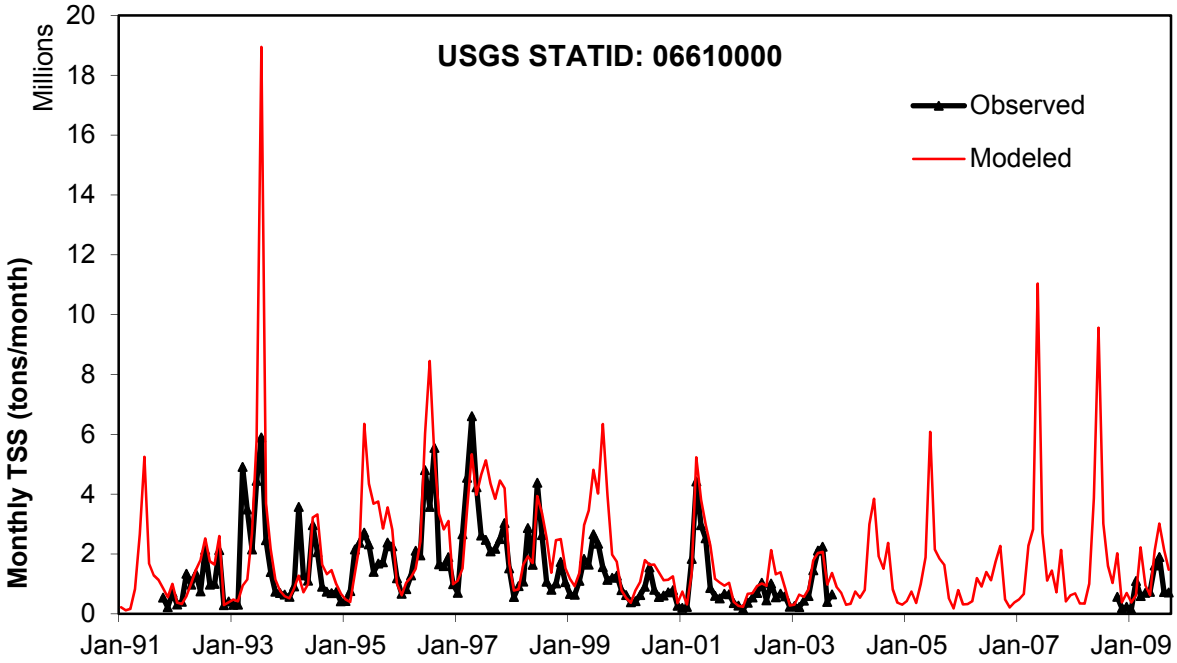
Observed and Modeled Time Series Plots of Annual (Water Year) and Monthly Total Suspended Sediment for Ten Stations in the Missouri River Basin

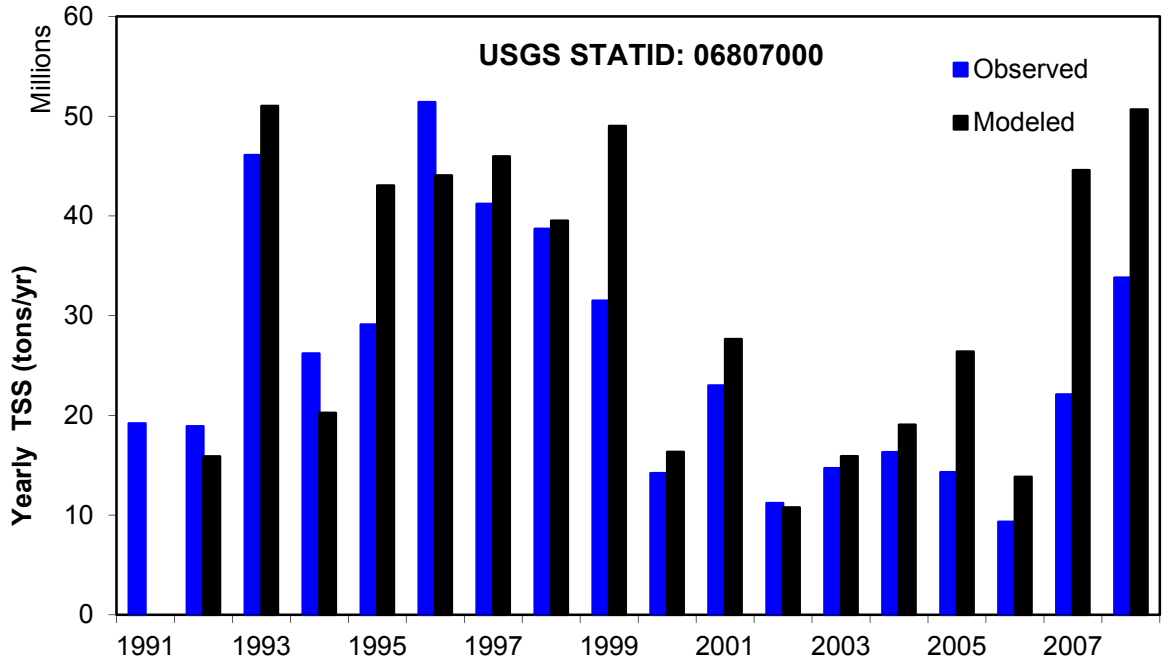

USGS STATID: 06486000
Observed
Modeled
Millions
TSS (tons/yr)
25
20
15
10
5
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

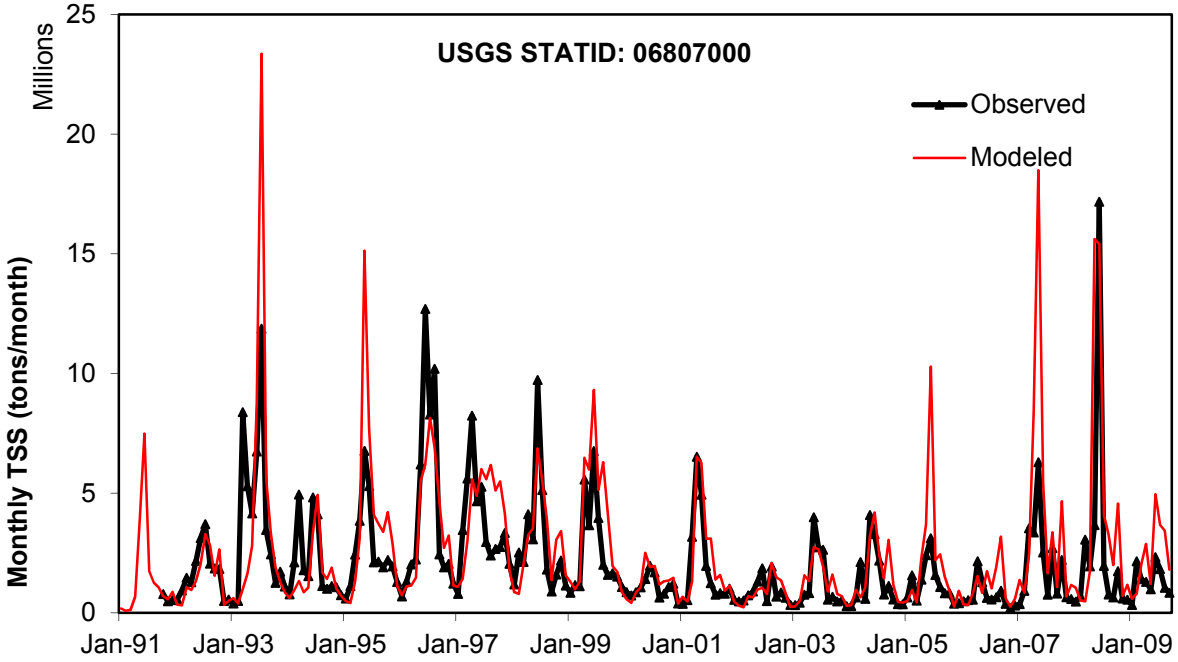

USGS STATID: 06486000
Observed
Modeled
Millions
TSS (tons/month)
6
5
4
3
2
1
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

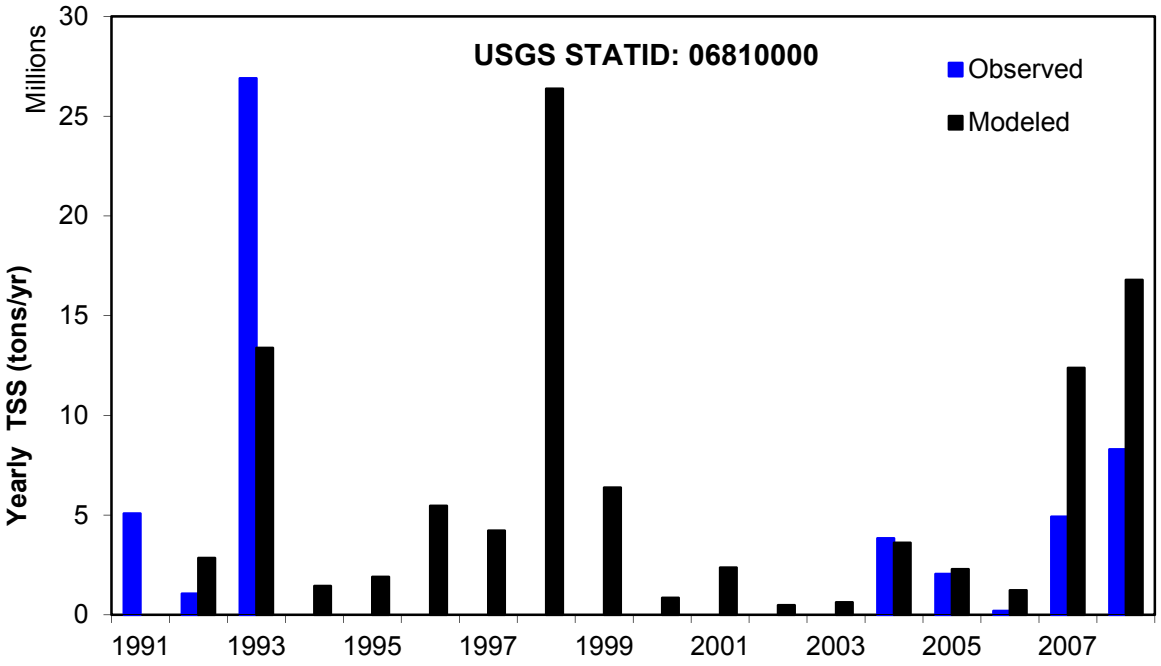

USGS STATID: 06805500
Observed
Modeled
Millions
Yearly TSS (tons/yr)
90
80
70
60
50
40
30
20
10
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

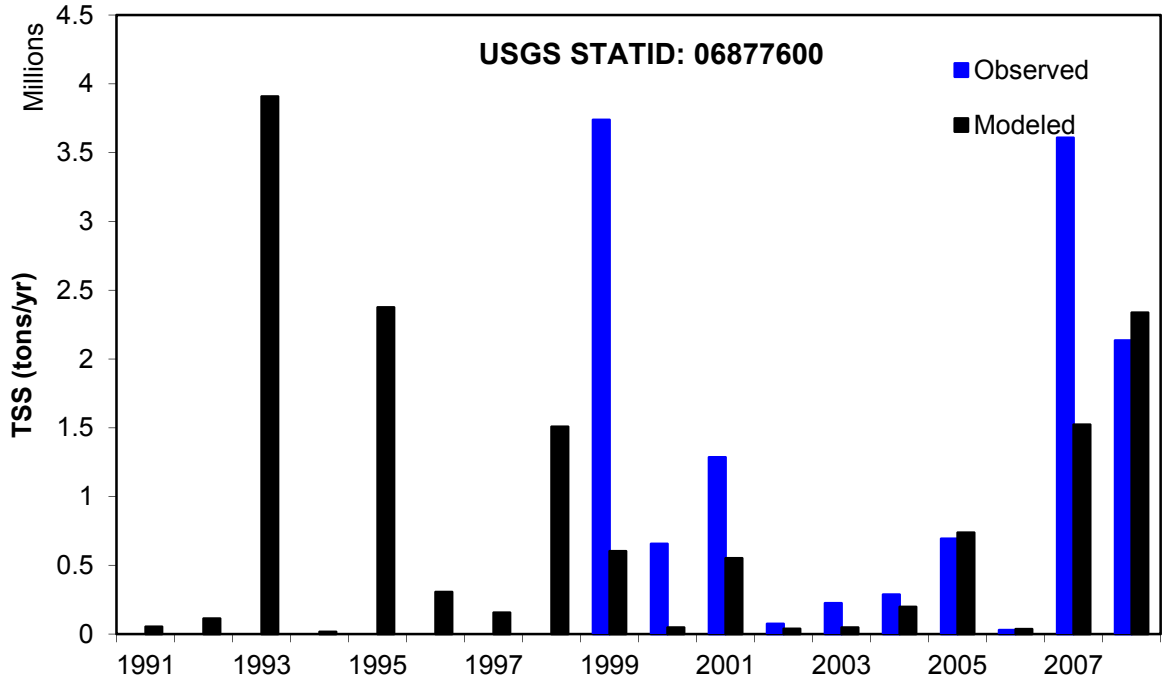

USGS STATID: 06610000
Observed
Modeled
Millions
Yearly TSS (tons/yr)
45
40
35
30
25
20
15
10
5
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

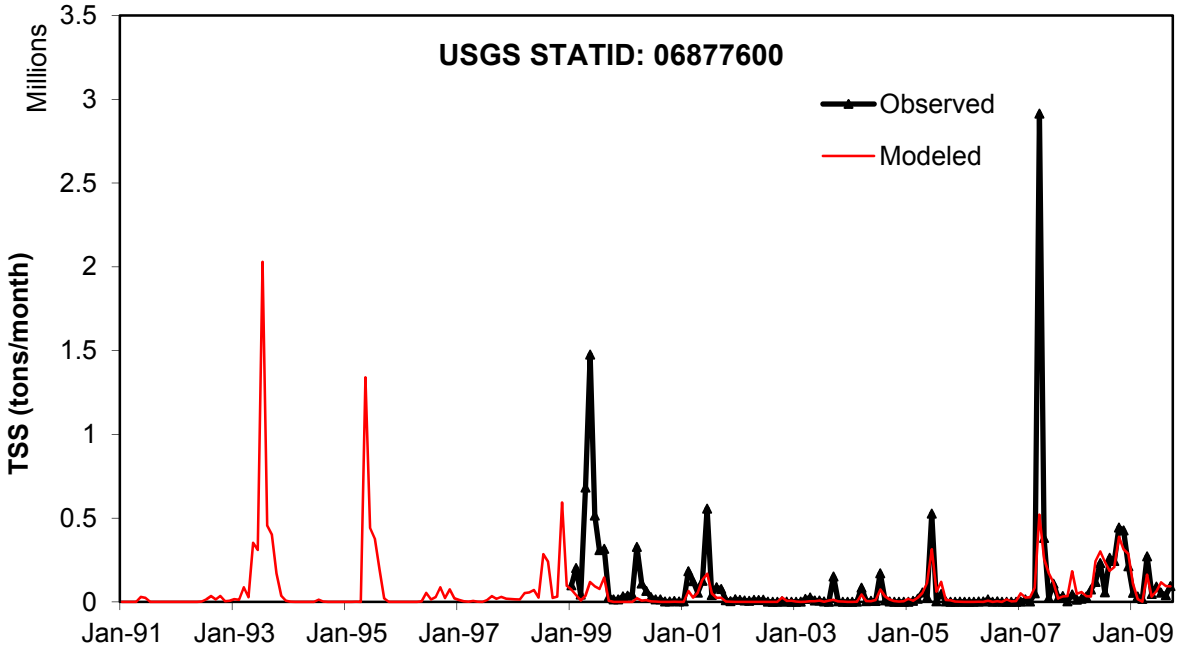

USGS STATID: 06610000
Observed
Modeled
Millions
Monthly TSS (tons/month)
20
18
16
14
12
10
8
6
4
2
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

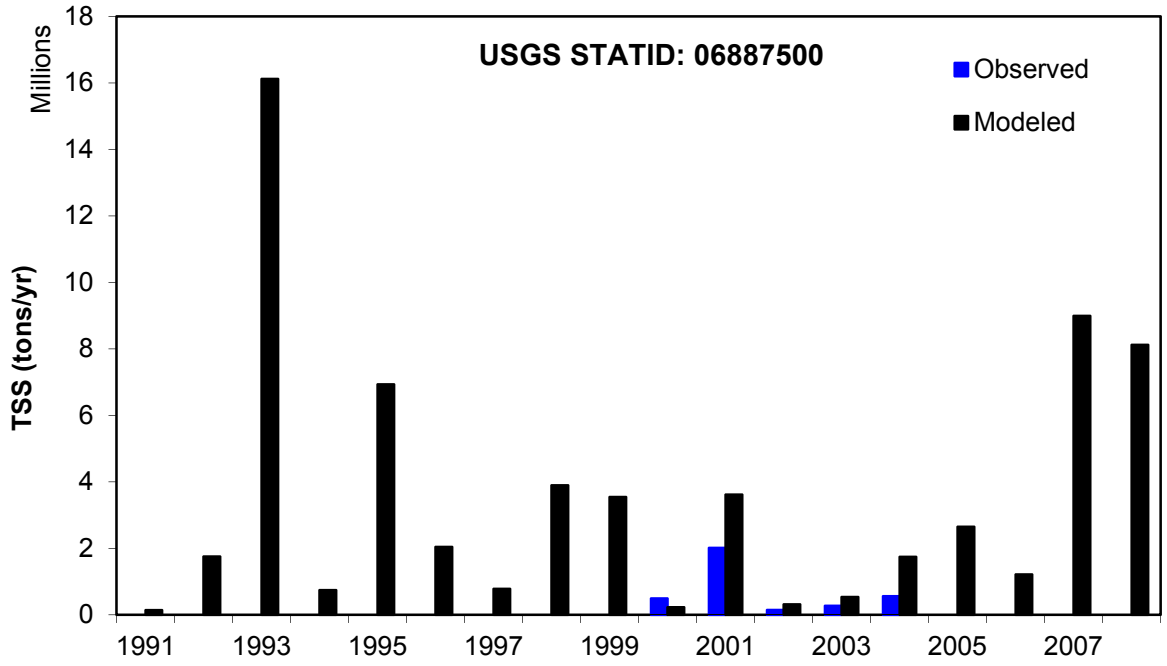

USGS STATID: 06807000
Observed
Modeled
Millions
Yearly TSS (tons/yr)
60
50
40
30
20
10
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

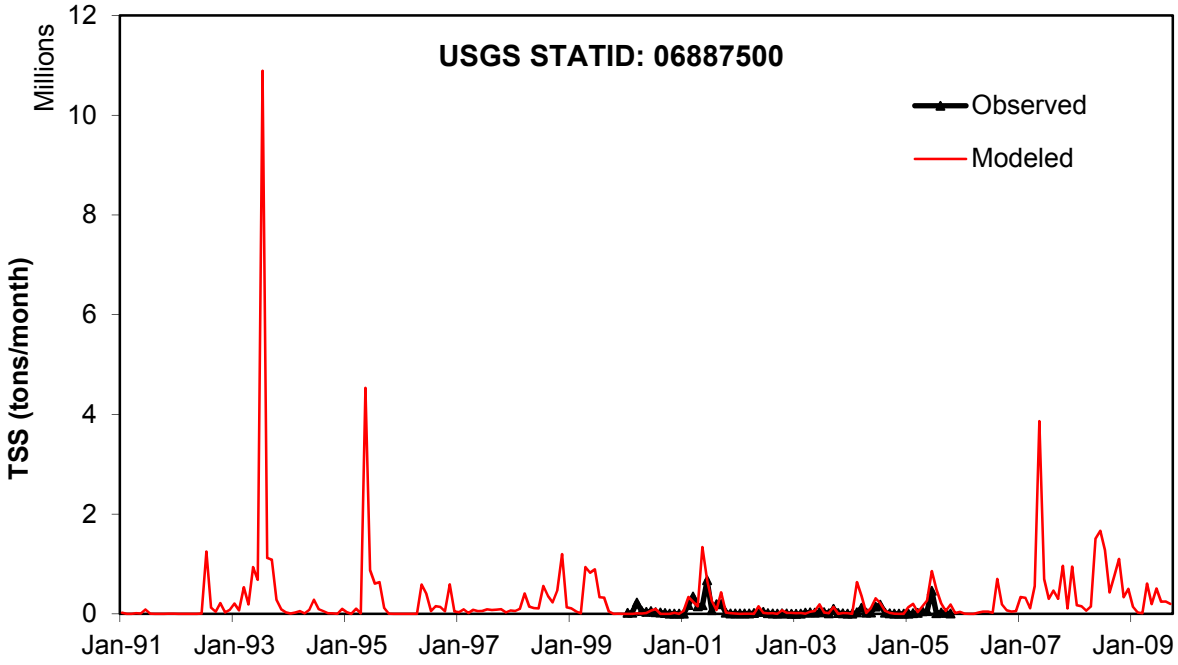

USGS STATID: 06807000
Observed
Modeled
Millions
Monthly TSS (tons/month)
25
20
15
10
5
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

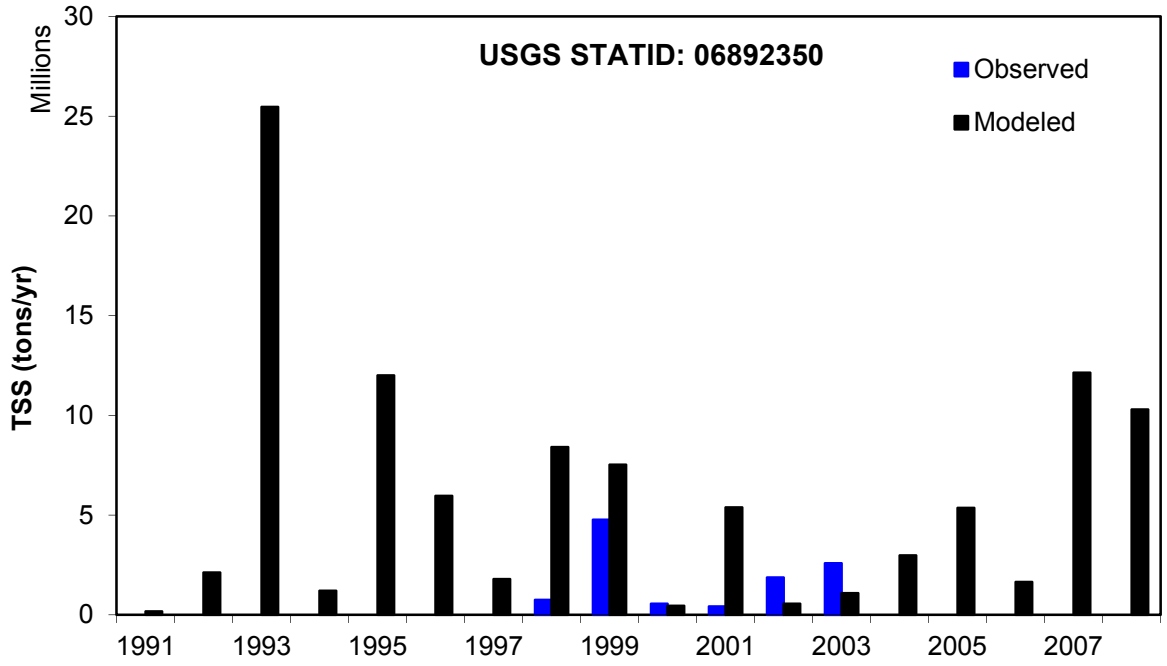

USGS STATID: 06810000
Observed
Modeled
Yearly TSS (tons/yr)
Millions
30
25
20
15
10
5
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

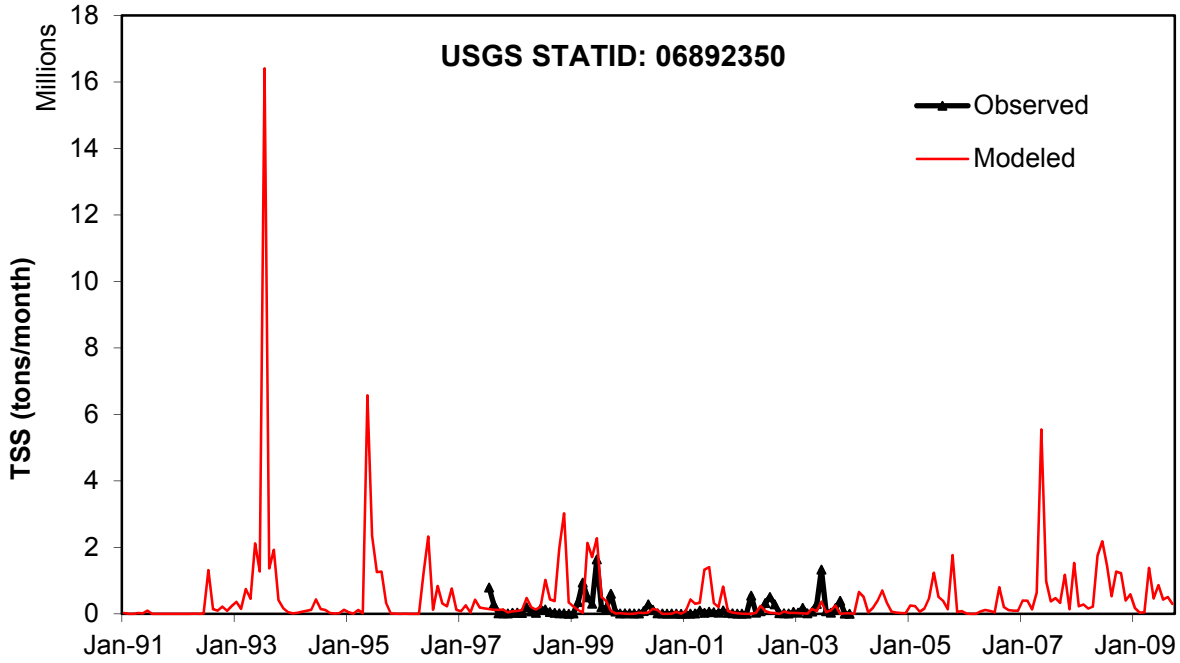

USGS STATID: 06877600
Observed
Modeled
Millions
TSS (tons/yr)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

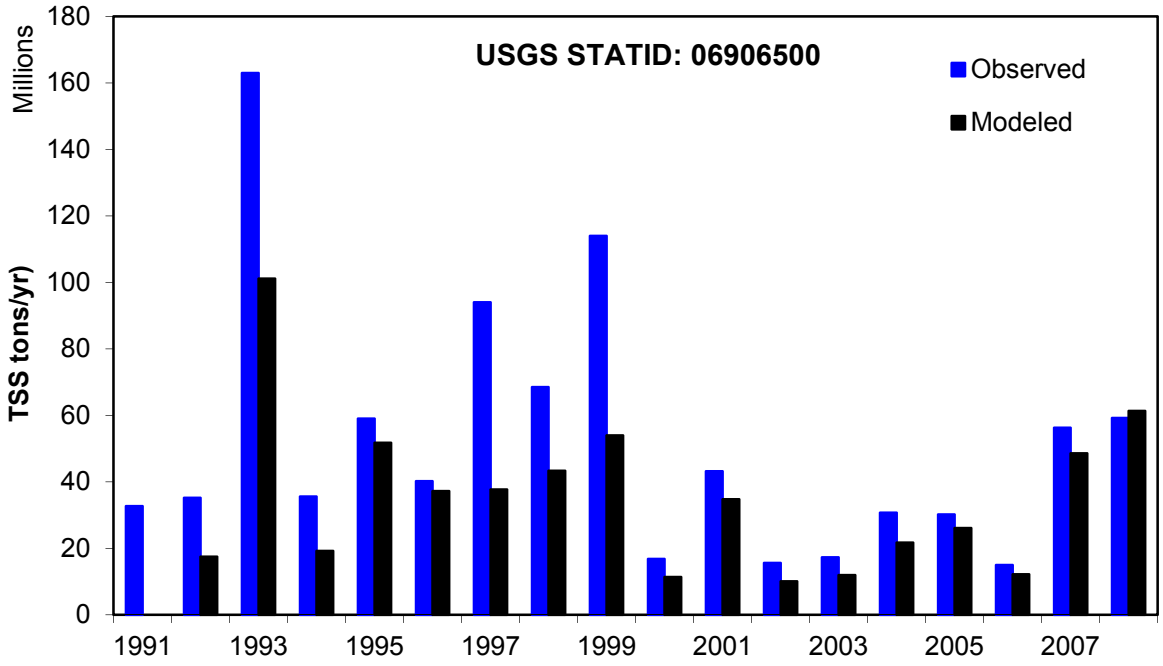

USGS STATID: 06877600
Observed
Modeled
Millions
TSS (tons/month)
3.5
3
2.5
2
1.5
1
0.5
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

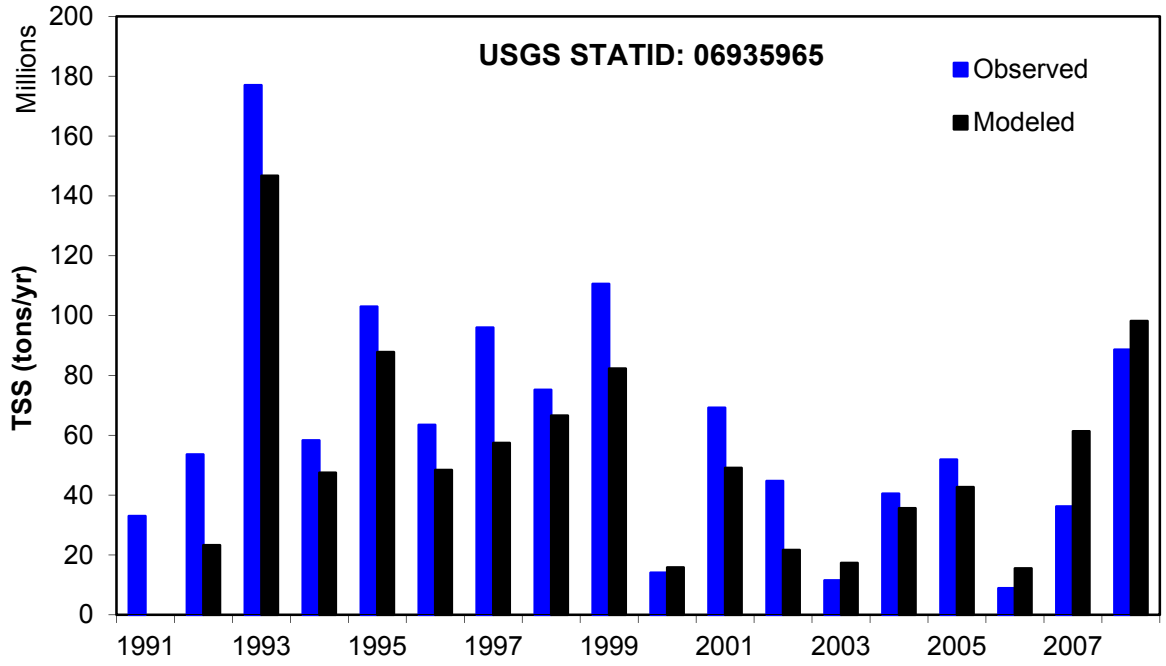

USGS STATID: 06887500
Observed
Modeled
Millions
TSS (tons/yr)
18
16
14
12
10
8
6
4
2
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

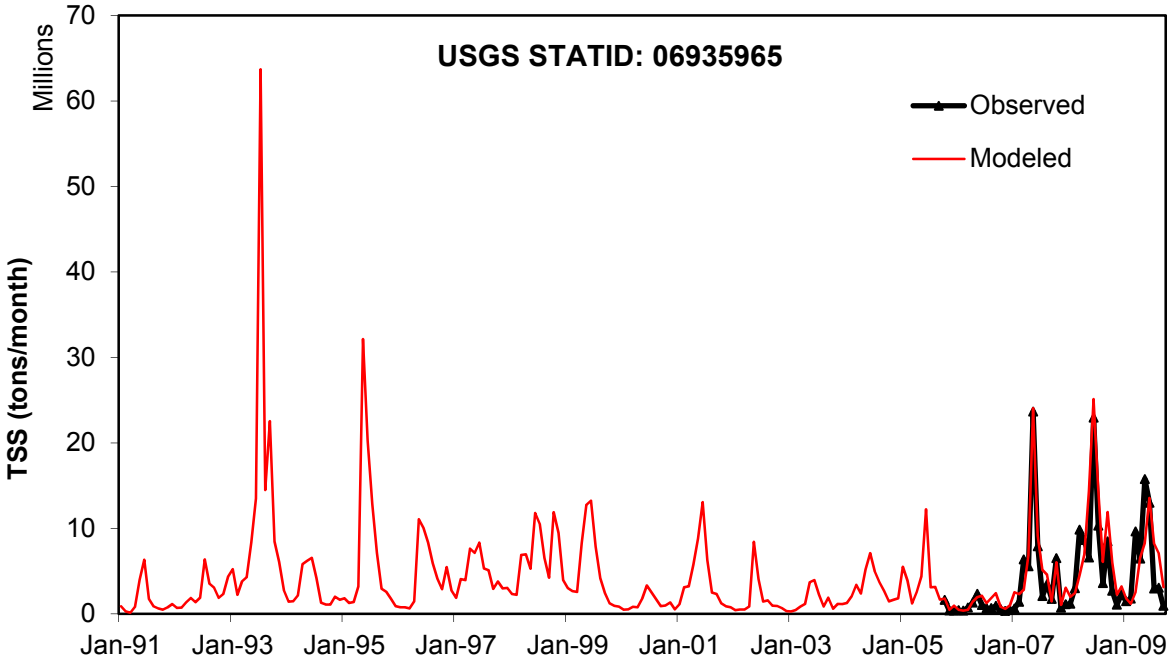

USGS STATID: 06887500
Observed
Modeled
Millions
TSS (tons/month)
12
10
8
6
4
2
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09


USGS STATID: 06892350
Observed
Modeled
Millions
TSS (tons/yr)
30
25
20
15
10
5
0
1991
1993
1995
1997
1999
2001
2003
2005
2007


USGS STATID: 06892350
Observed
Modeled
Millions
TSS (tons/month)
18
16
14
12
10
8
6
4
2
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09


USGS STATID: 06906500
Observed
Modeled
Millions
TSS tons/yr)
180
160
140
120
100
80
60
40
20
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

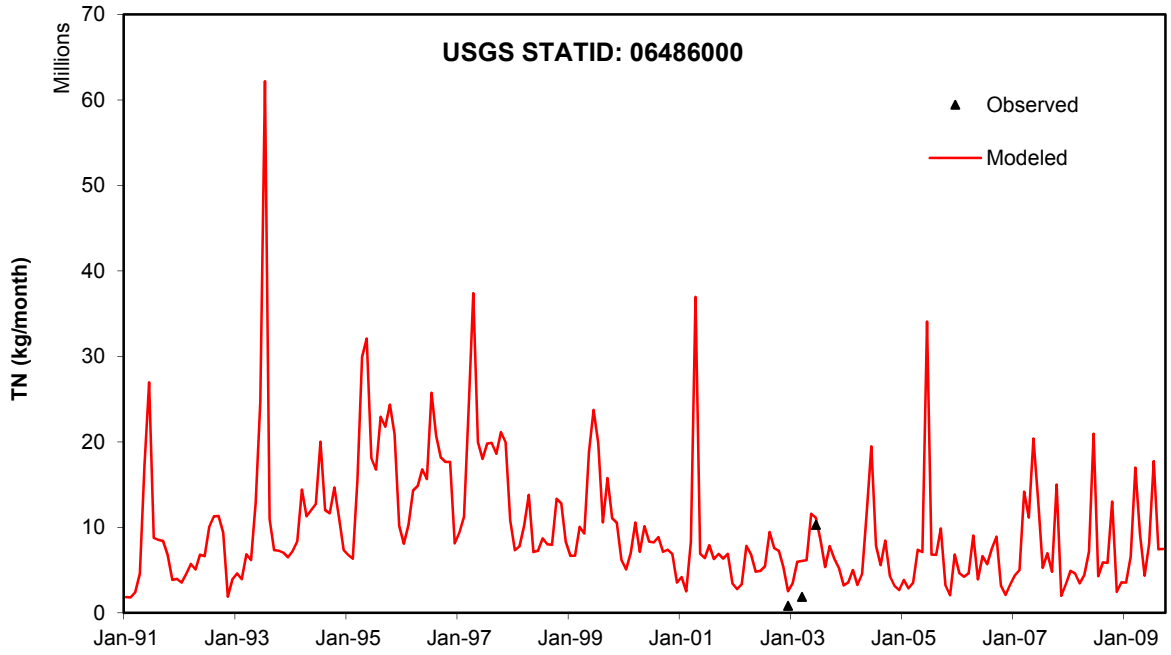

USGS STATID: 06935965
Observed
Modeled
Millions
TSS (tons/yr)
200
180
160
140
120
100
80
60
40
20
0
1991
1993
1995
1997
1999
2001
2003
2005
2007

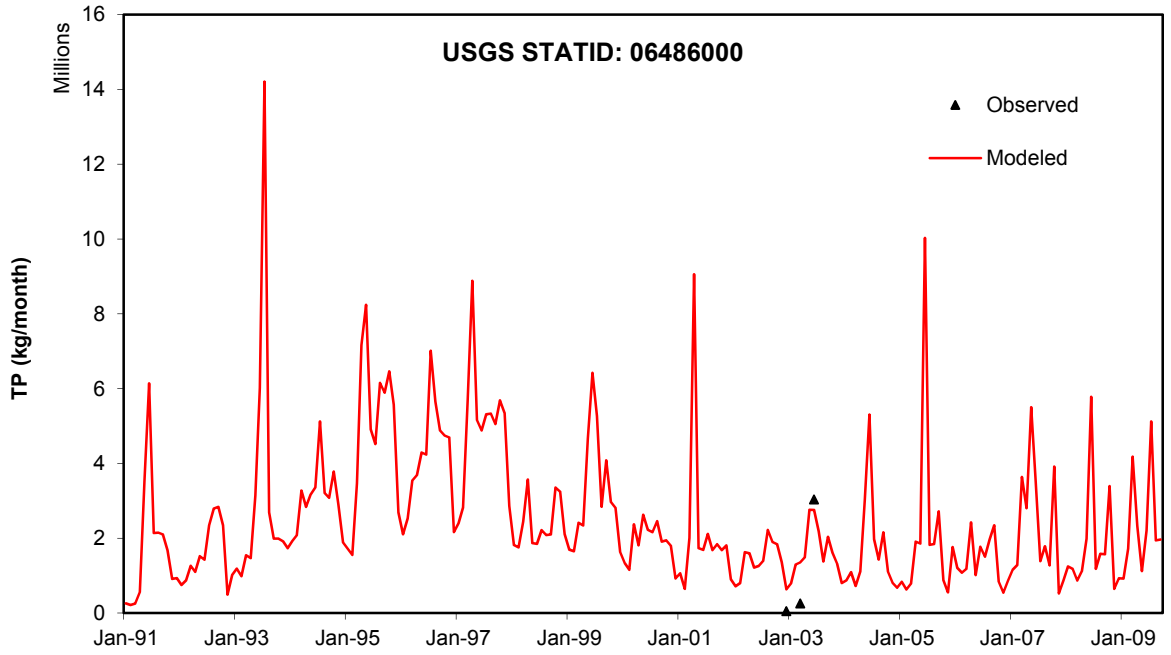

USGS STATID: 06935965
Observed
Modeled
Millions
TSS (tons/month)
70
60
50
40
30
20
10
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

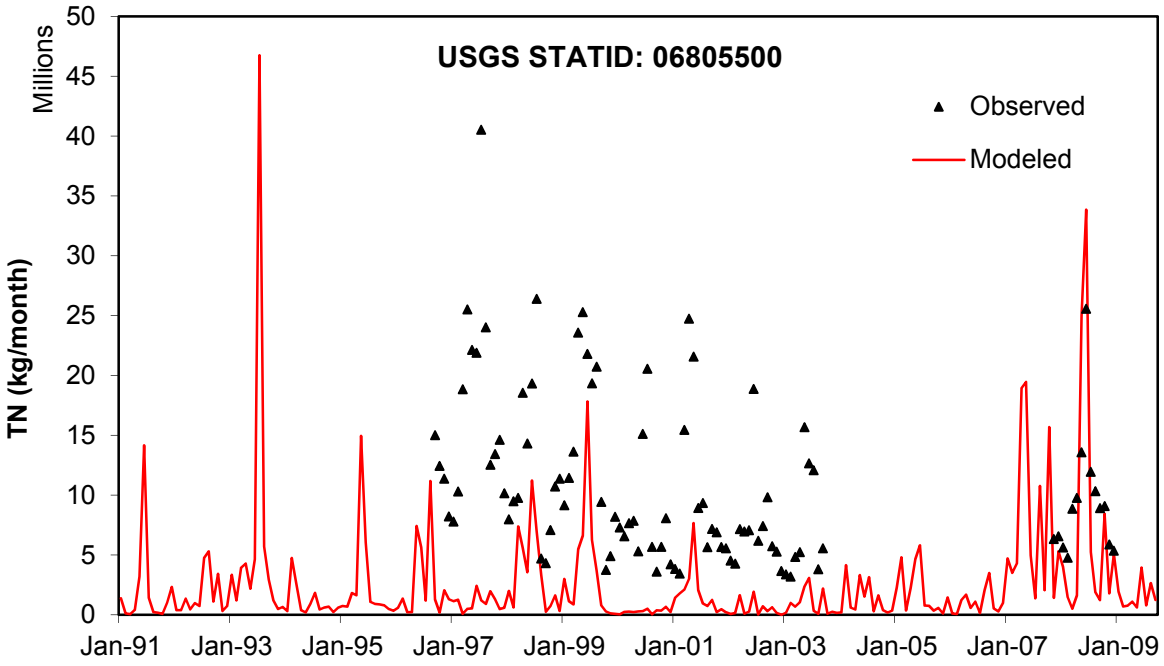
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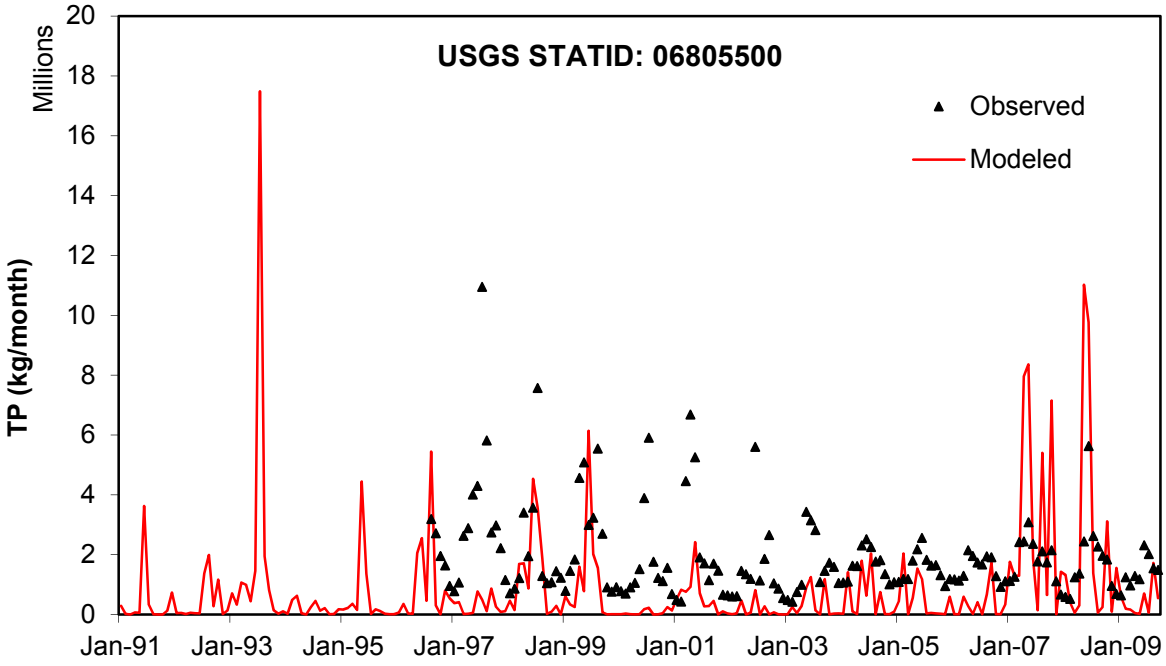
APPENDIX C

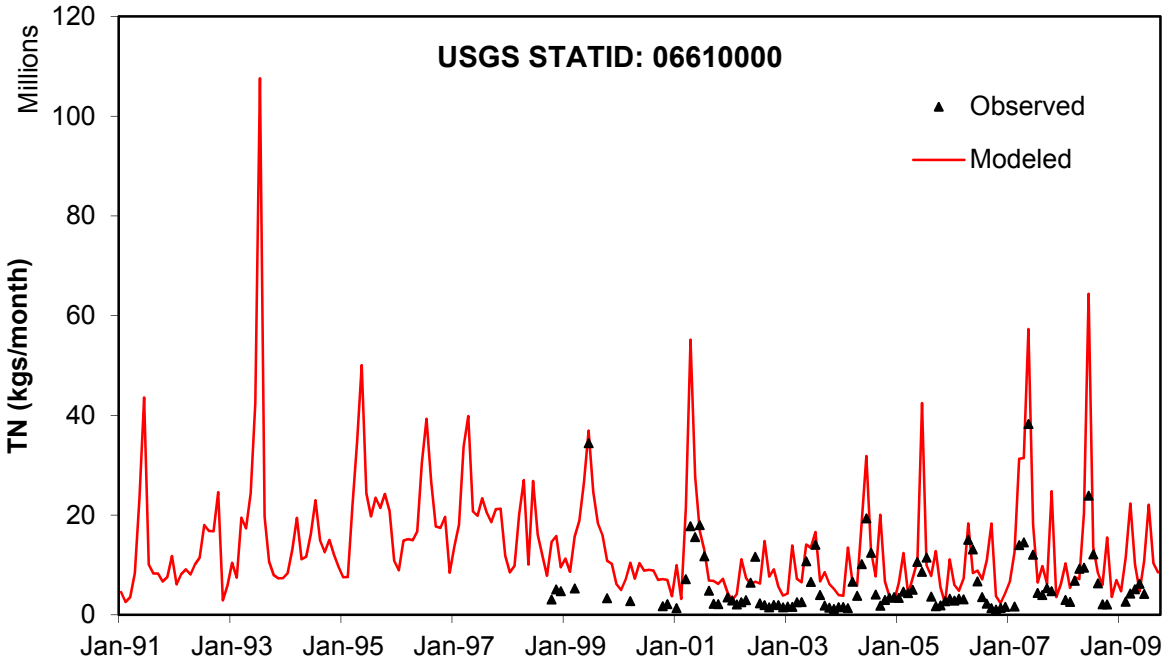
Observed and Modeled Time Series Plots of Monthly Total Nitrogen and Phosphorous for Seven Stations in the Missouri River Basin

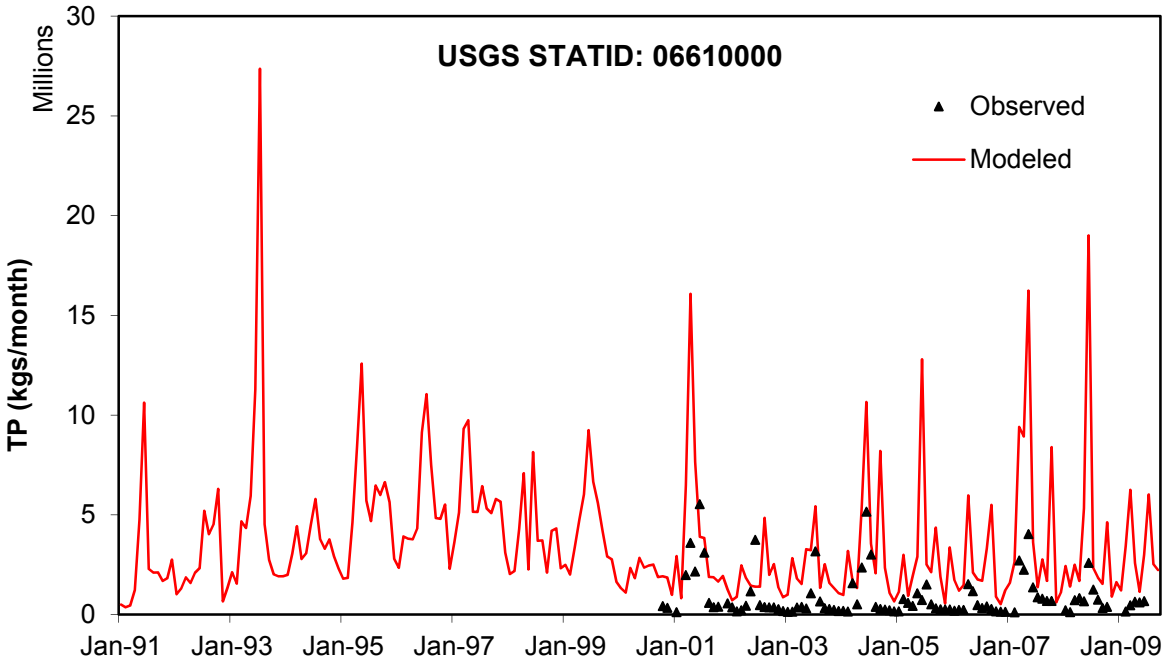

USGS STATID: 06486000
Observed
Modeled
TN (kg/month)
Millions
70
60
50
40
30
20
10
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

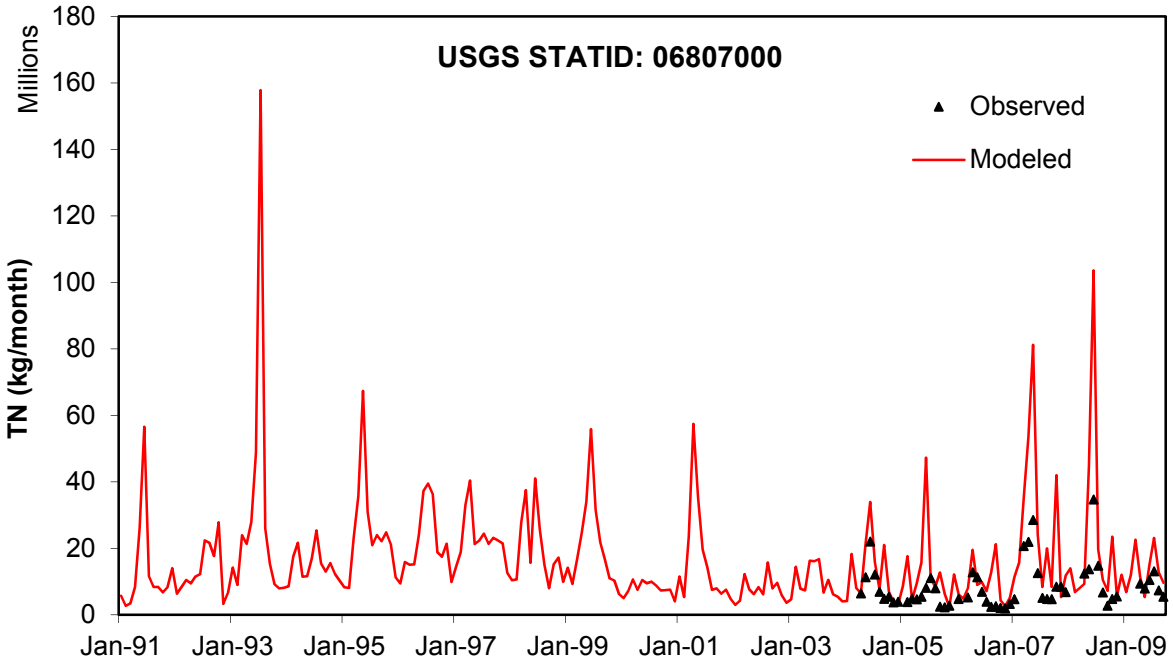

USGS STATID: 06486000
Observed
Modeled
TP (kg/month)
Millions
16
14
12
10
8
6
4
2
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

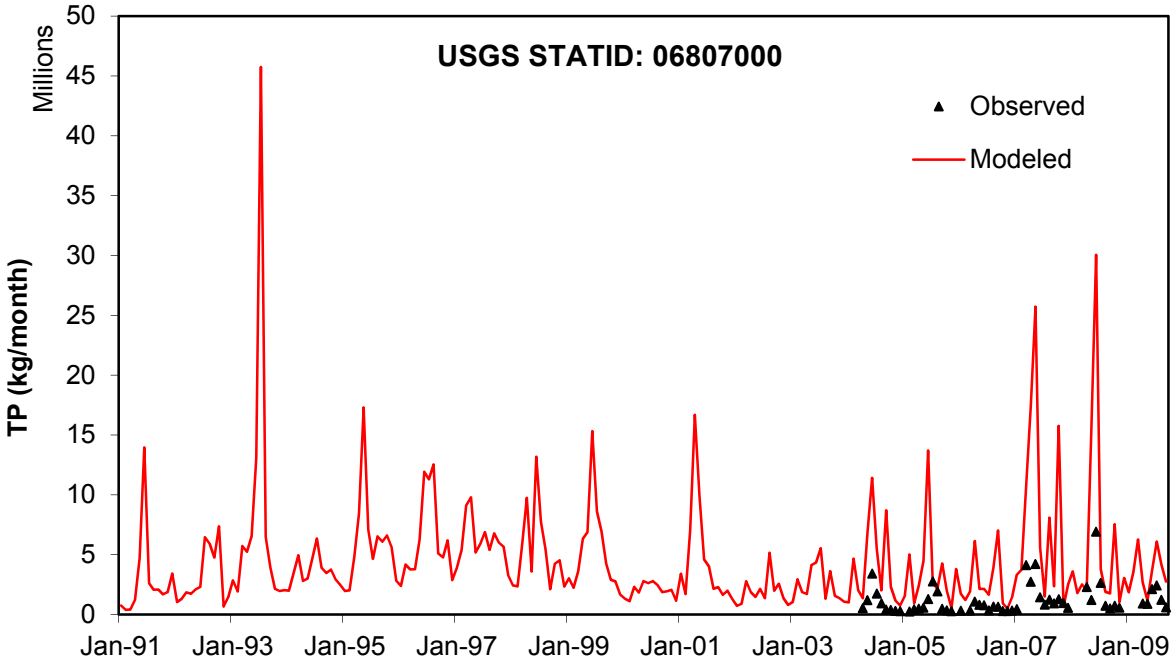

USGS STATID: 06805500
Observed
Modeled
Millions
TN (kg/month)
50
45
40
35
30
25
20
15
10
5
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

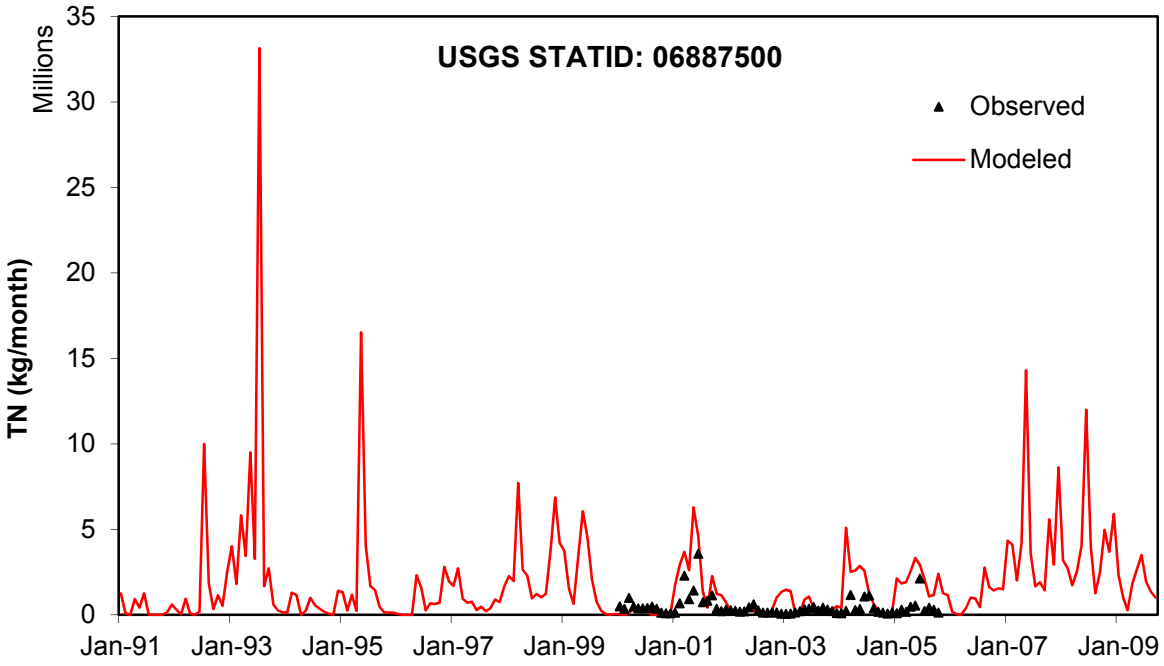

USGS STATID: 06805500
Observed
Modeled
Millions
TP (kg/month)
20
18
16
14
12
10
8
6
4
2
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

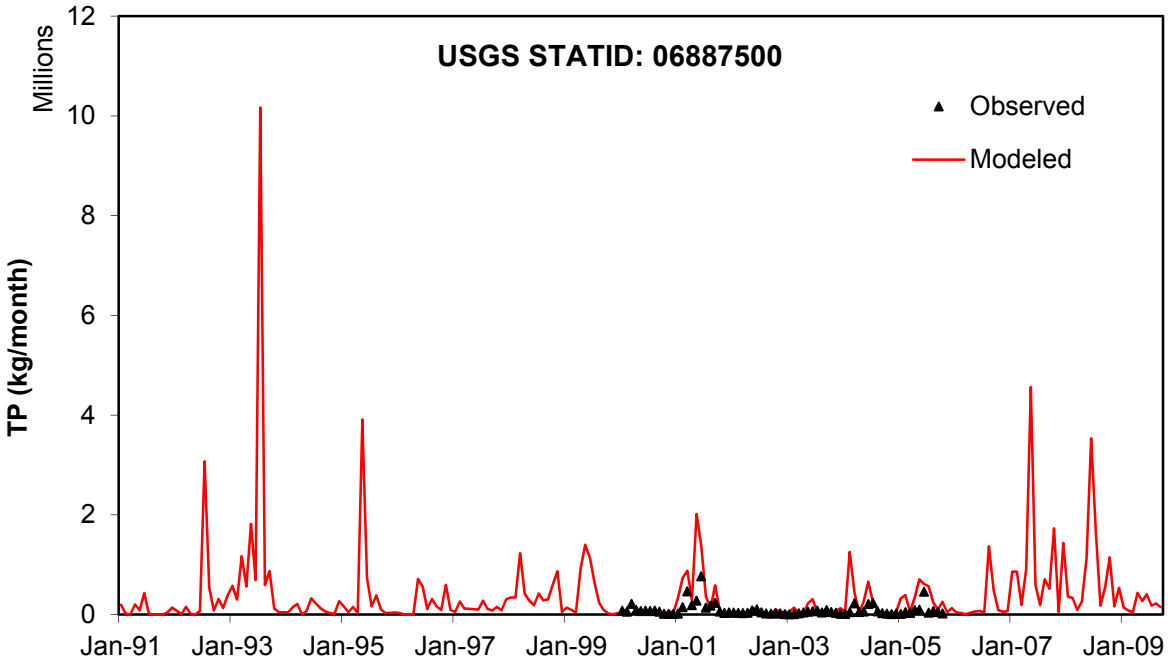

USGS STATID: 06610000
Observed
Modeled
Millions
TN (kgs/month)
120
100
80
60
40
20
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

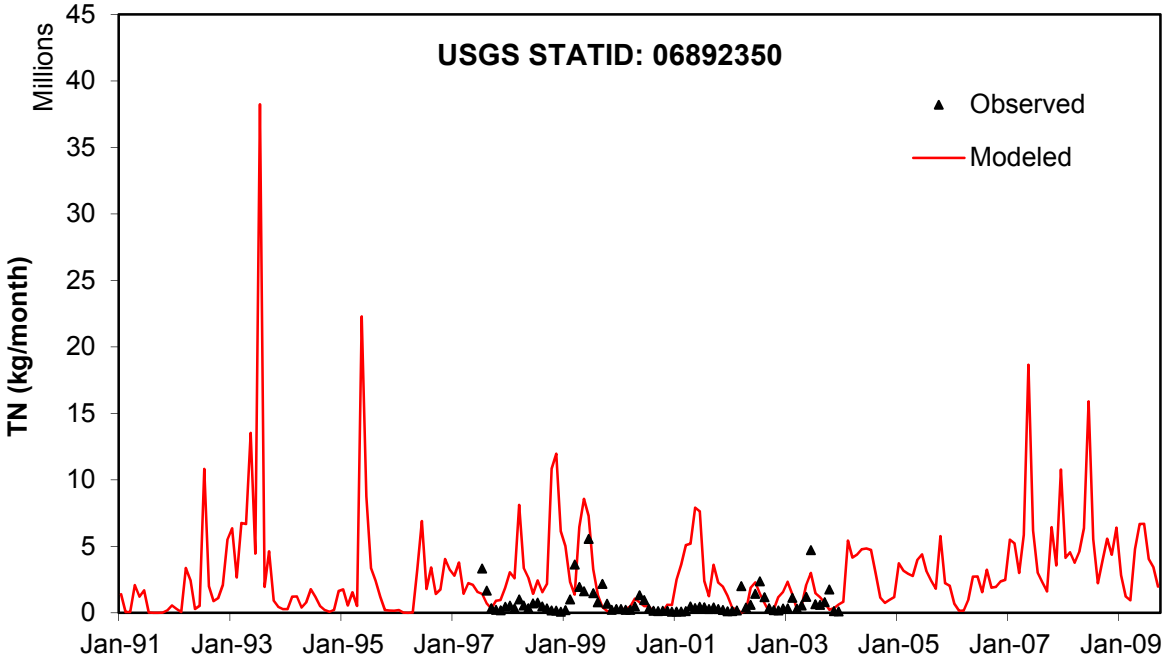

USGS STATID: 06610000
Observed
Modeled
Millions
TP (kgs/month)
30
25
20
15
10
5
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

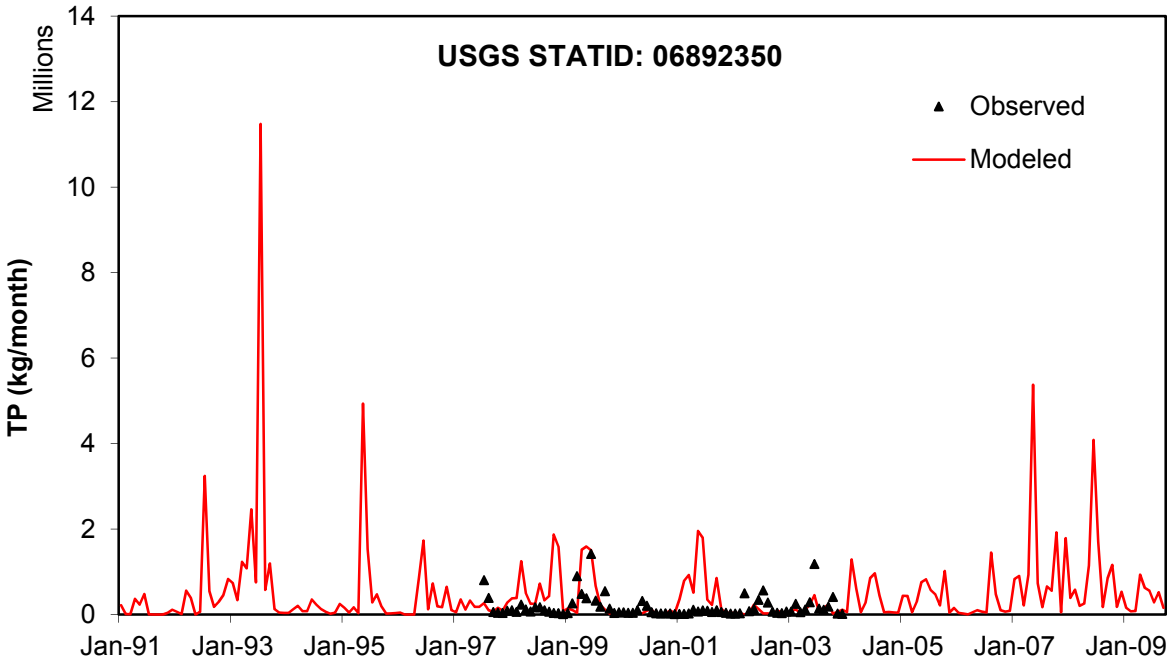

USGS STATID: 06807000
Observed
Modeled
Millions
TN (kg/month)
180
160
140
120
100
80
60
40
20
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

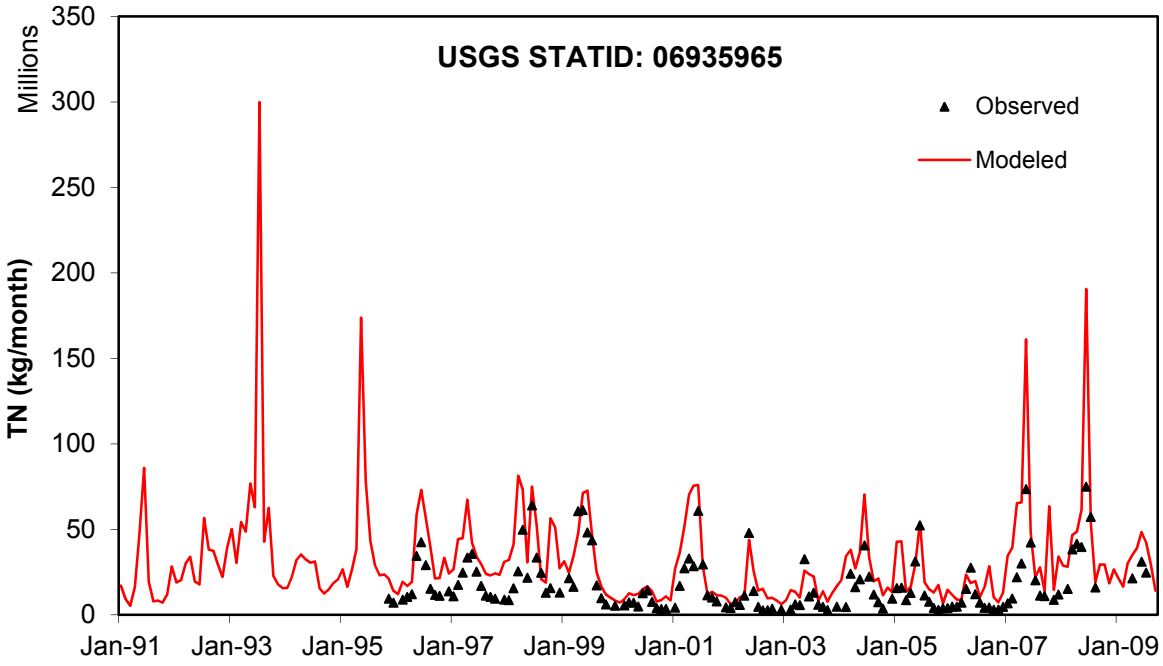

USGS STATID: 06807000
Observed
Modeled
Millions
TP (kg/month)
50
45
40
35
30
25
20
15
10
5
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

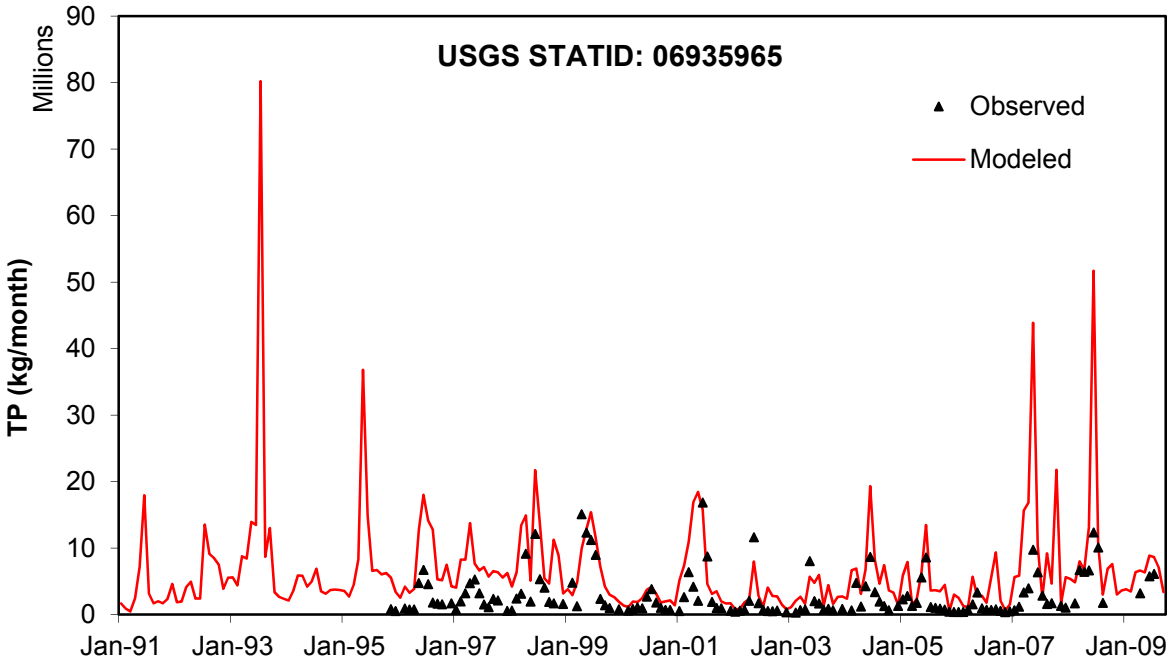

USGS STATID: 06887500
Observed
Modeled
TN (kg/month)
Millions
35
30
25
20
15
10
5
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09


USGS STATID: 06887500
Observed
Modeled
TP (kg/month)
Millions
12
10
8
6
4
2
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09


USGS STATID: 06892350
Observed
Modeled
TN (kg/month)
Millions
45
40
35
30
25
20
15
10
5
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09


USGS STATID: 06892350
Observed
Modeled
TP (kg/month)
Millions
14
12
10
8
6
4
2
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09


USGS STATID: 06935965
Observed
Modeled
Millions
TN (kg/month)
350
300
250
200
150
100
50
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09


USGS STATID: 06935965
Observed
Modeled
Millions
TP (kg/month)
90
80
70
60
50
40
30
20
10
0
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09

APPENDIX D

Modeled Annual Averaged (2006–2008) Results for Each Sub-basin in the Missouri River Basin

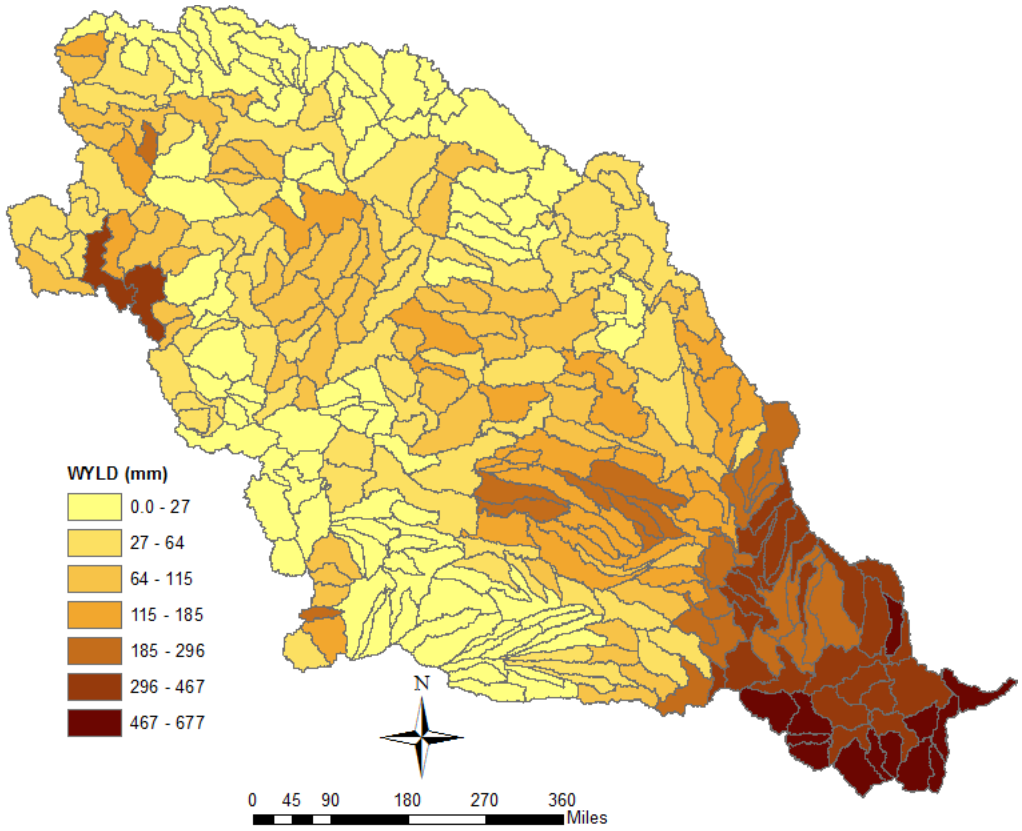


FIGURE D.1 Net amount of water that leaves the sub-basin and contributes to stream flow.

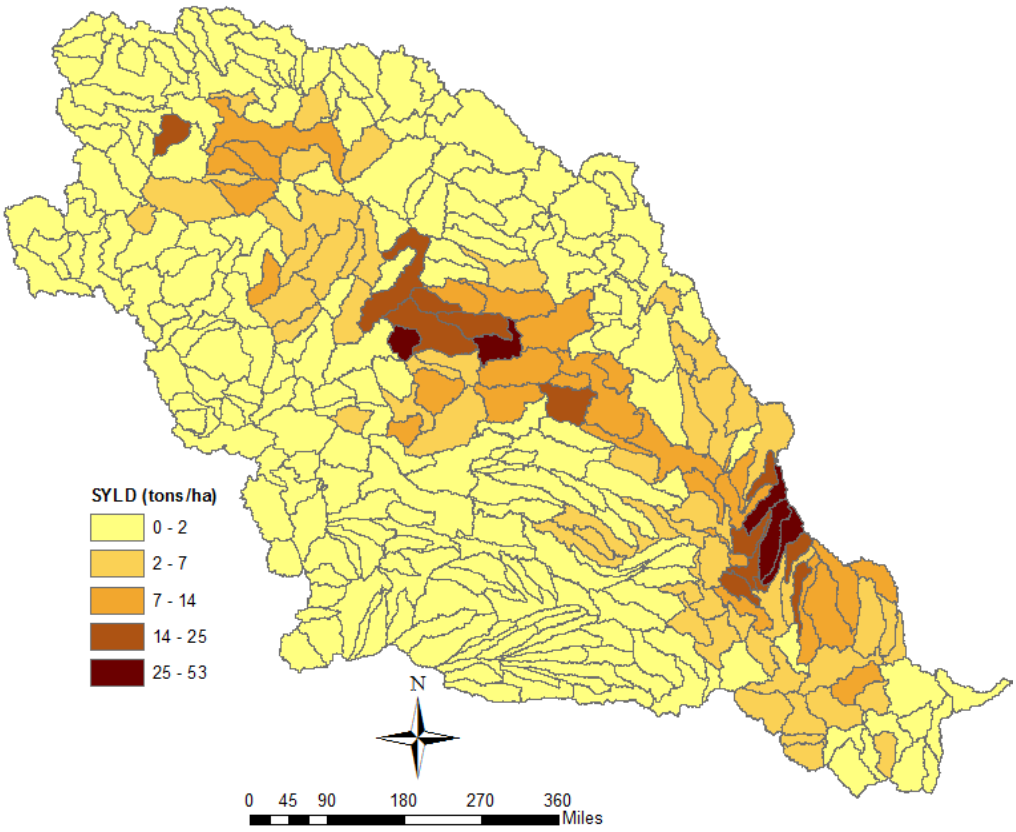


FIGURE D.2 Sediment yield transported from each sub-basin into the reach.

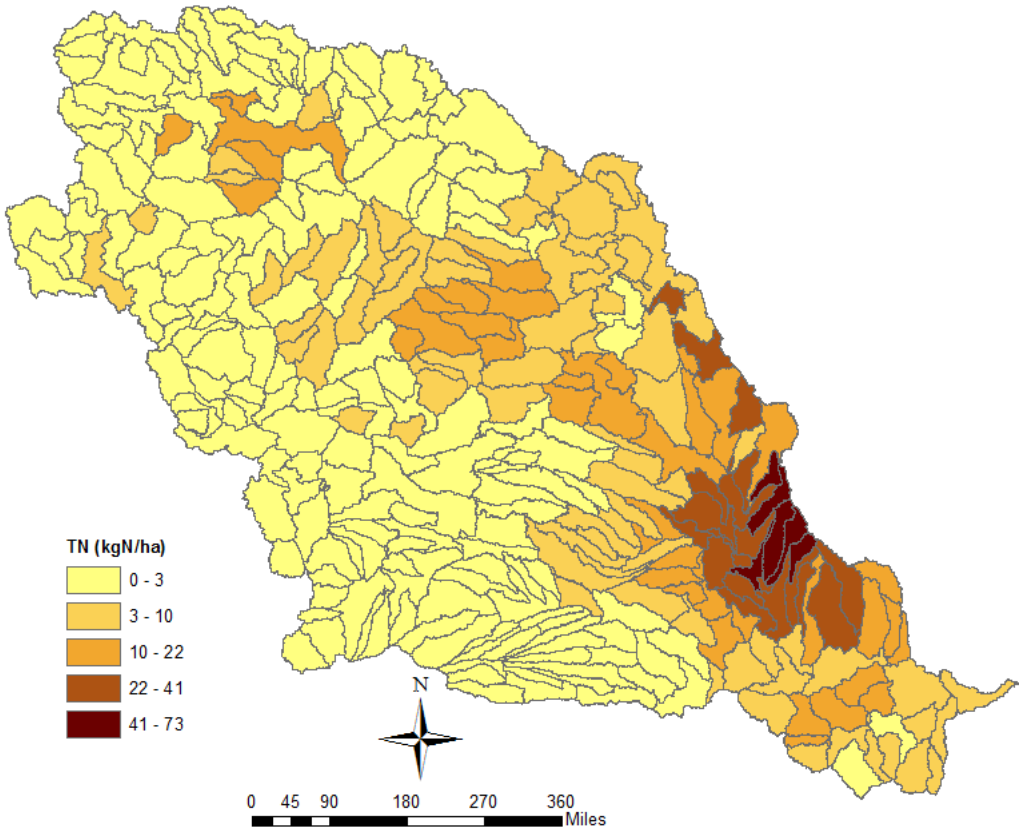


FIGURE D.3 Total Nitrogen (TN) yield transported from each sub-basin into the reach.

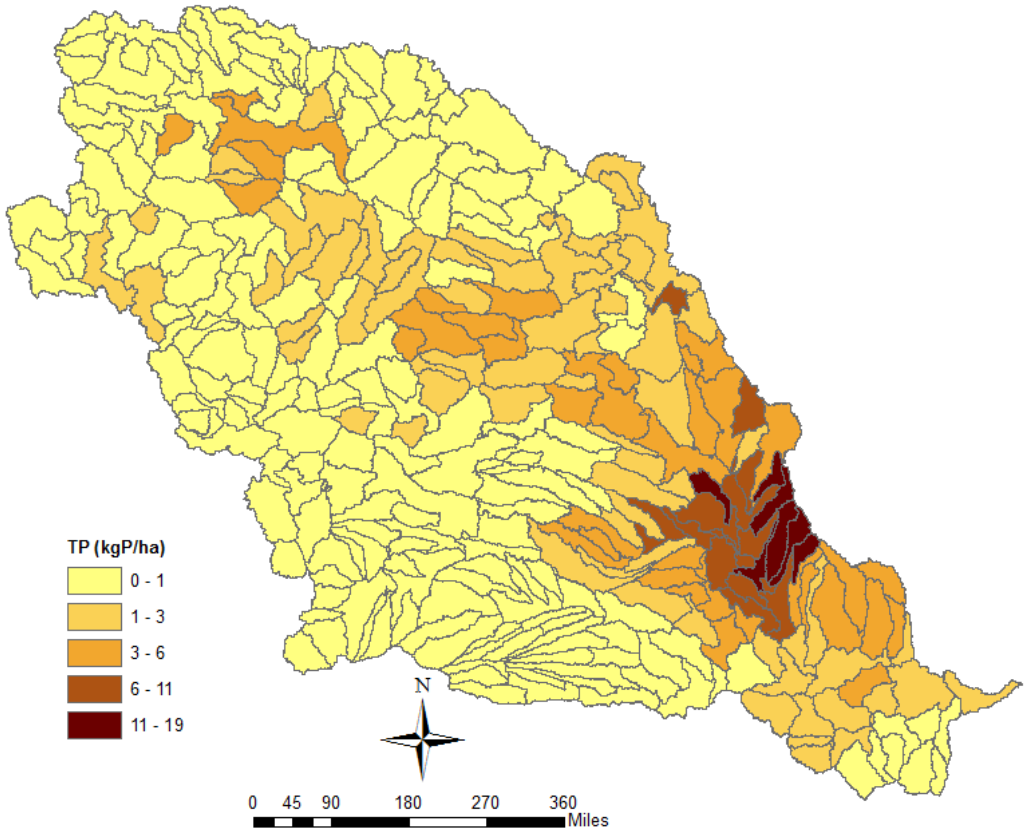


FIGURE D.4 Total Phosphorous (TP) yield transported from each sub-basin into the reach.

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APPENDIX E

Water Quality Results, Land Use, and Fertilizer Application Rates at Sub-basin Scale

TABLE E.1 Water yield, flow, total nitrogen and total phosphorus loadings.

Sub-basin	Huc #	Land Area (ha)	WYLD (water yield) mm (per year)	SYLDtha (TSS metric ton/ha)	Tnkgha (TN kg/ha)	Tpkgha (TP kg/ha)	Flow (m3/s)
1	10020001	599347	76.1460012	0	0	0	14.47168
2	10020002	389087	39.2403336	0	0	0	4.841421
3	10020003	250135	60.3883362	0	0	0	4.789843
4	10020004	722827	57.2949982	0	0	0	13.1324
5	10020005	336666	55.3363342	0	0	0	5.907489
6	10020006	196564	46.3789978	0	0	0	2.890799
7	10020007	661958	451.430664	1.245667	6.179667	1.212667	94.75785
8	10020008	478475	121.65566	0	0	0	18.45801
9	10030101	867717	36.6686656	0	0	0	10.08943
10	10030102	673803	94.8069967	0	0	0	20.25661
11	10030103	519737	160.534668	0	0	0	26.45734
12	10030104	486262	98.2733358	0	0	0	15.15302
13	10030105	206910	225.774658	0	0	0	14.81325
14	10030201	333443	96.0963338	0	0	0	10.16065
15	10030202	310921	160.881327	0	0	0	15.86166
16	10030203	956393	35.6253357	0	0	0	10.8041
17	10030204	257152	14.4246674	0	0	0	1.17622
18	10030205	530775	29.9783325	0	0	0	5.045586
19	10040101	500966	72.9273275	0	0	0	11.5849
20	10040102	329557	52.8243306	25.04933	13.477	3.582667	5.520233
21	10040103	716287	14.2053337	0.878333	1.858333	0.471667	3.226502
22	10040104	1359985	56.4196676	13.02067	14.56433	4.092667	24.33089
23	10040105	401257	17.3873342	3.527333	1.262	0.673667	2.212328
24	10040106	316777	9.61866633	1.604	0.859333	0.464	0.966187
25	10040201	1040047	26.6859996	3.844333	3.399334	0.983667	8.800955
26	10040202	498428	64.4463298	13.80033	11.03	3.358	10.18577
27	10040203	176073	90.6849976	6.814667	8.134667	2.242	5.063149
28	10040204	303678	110.12266	8.052667	9.075	2.737	10.60432
29	10040205	437608	68.364329	13.22433	12.99833	3.903667	9.486548
30	10050001	249933	19.9593341	2.373333	3.394333	0.862	1.581843
31	10050002	585085	10.4860001	0.514667	1.092667	0.266333	1.945459
32	10050003	121266	9.2253329	0.377	1.237	0.291667	0.354744
33	10050004	909646	10.1489995	0.290667	0.788	0.193333	2.927447
34	10050005	209094	6.81966654	0.518667	1.241333	0.316667	0.452167
35	10050006	256380	4.54833349	0.338667	0.935667	0.226333	0.369768

TABLE E.1 (Cont.)

Sub-basin	Huc #	Land Area (ha)	WYLD (water yield) mm (per year)	SYLDtha (TSS metric ton/ha)	Tnkgha (TN kg/ha)	Tpkgha (TP kg/ha)	Flow (m3/s)
36	10050007	282575	7.09200033	0.293667	0.986	0.226667	0.635471
37	10050008	445068	6.05599976	0.064	0.284333	0.057	0.854685
38	10050009	183993	74.7423299	7.717	16.33167	4.018	4.360761
39	10050010	244902	7.81866709	1.284667	1.637667	0.443333	0.607183
40	10050011	468178	3.8326664	0.161333	0.452333	0.114333	0.568991
41	10050012	394992	43.7873332	4.201	8.158	2.326667	5.484412
42	10050013	619599	3.9240001	0.000333	0.039	0.001	0.770962
43	10050014	473759	13.7290014	1.298667	2.837667	0.790333	2.06248
44	10050015	354394	10.9566663	0.904667	1.823	0.491667	1.231283
45	10050016	187986	6.64333344	0.859667	1.240333	0.329333	0.396008
46	10060001	519223	17.8803329	1.184667	3.155333	0.790667	2.943898
47	10060002	547784	11.6079992	5.814667	3.655667	0.954333	2.016324
48	10060003	600858	7.60433324	0.522333	1.507333	0.353333	1.44886
49	10060004	265448	3.73533312	0.322333	0.824333	0.198667	0.314414
50	10060005	325679	27.0570017	0.863333	2.074667	0.528333	2.794234
51	10060006	889917	5.17566649	0.153667	0.626	0.157333	1.460526
52	10060007	264153	12.8923327	0.711667	2.188667	0.576	1.079892
53	10070001	671484	453.35734	0.169	2.725333	1.505667	96.5317
54	10070002	767713	73.4079997	0.367	1.338667	0.304	17.87046
55	10070003	221267	86.5503337	4.496667	8.364333	1.832	6.072651
56	10070004	406943	53.6633301	0.633667	2.102333	0.482333	6.924755
57	10070005	276230	101.237325	1.477333	2.800333	0.603667	8.867564
58	10070006	723309	14.4060008	0.114	0.236	0.067	3.304159
59	10070007	520156	30.9609985	0.361333	0.931	0.224	5.106724
60	10070008	155970	63.2666677	0.641	1.324667	0.369	3.12902
61	10080001	660240	44.1126658	0.002667	0.006	0.001	9.235465
62	10080002	288891	36.9090017	1.367	2.253333	0.612333	3.381114
63	10080003	208079	49.7309977	0.663	1.190333	0.349667	3.281321
64	10080004	190468	6.65399996	0.172667	0.264667	0.072	0.401883
65	10080005	441815	19.9020004	0.068	0.042333	0.024	2.788243
66	10080006	221727	19.9980011	0.155	0.178667	0.066	1.406041
67	10080007	899443	10.8956655	0.604667	0.816667	0.248333	3.107571
68	10080008	521273	28.8203328	1.148667	2.928	0.650667	4.763843
69	10080009	297761	50.0916646	1.216333	1.118	0.38	4.729623
70	10080010	466664	37.2179972	0.026	0.070667	0.017333	5.507446
71	10080011	112894	7.57199987	0.178333	0.173	0.070333	0.271066
72	10080012	221137	68.717336	0.005	0.050333	0.014	4.818602
73	10080013	168513	91.7593282	0.046667	0.176667	0.055	4.903165
74	10080014	384554	1.53000005	0.002	0.003667	0.001	0.18657

TABLE E.1 (Cont.)

Sub-basin	Huc #	Land Area (ha)	WYLD (water yield) mm (per year)	SYLDtha (TSS metric ton/ha)	Tnkgha (TN kg/ha)	Tpkgha (TP kg/ha)	Flow (m3/s)
75	10080015	508020	54.2516683	2.278667	1.639333	0.796667	8.73951
76	10080016	336096	110.949331	12.89333	7.94	2.751667	11.82447
77	10090101	656269	73.7663269	4.425333	3.581334	1.135333	15.35088
78	10090102	744083	106.048004	6.628333	7.404	2.126667	25.02174
79	10090201	254186	71.1446635	0.538333	0.780333	0.231333	5.734391
80	10090202	649502	80.8153381	1.416333	3.816	0.991333	16.64437
81	10090203	315121	29.2660014	0.199667	0.396	0.116	2.924383
82	10090204	208925	72.4156698	1.169333	2.361667	0.661667	4.79752
83	10090205	247386	53.2590027	2.585667	4.885334	1.331	4.177929
84	10090206	298899	83.3050028	5.314667	8.079667	2.215667	7.895675
85	10090207	275725	67.0146688	1.894	2.922666	0.865333	5.859222
86	10090208	524939	107.935669	6.103333	8.780333	2.696333	17.96666
87	10090209	486287	66.9423319	3.217667	4.434667	1.475667	10.32254
88	10090210	208140	78.741333	3.087333	3.549667	1.258	5.196993
89	10100001	1244475	136.026326	3.397	3.738	1.27	53.67875
90	10100002	226040	17.0423342	0.195667	0.525	0.142	1.22154
91	10100003	338745	91.1539917	6.47	6.811667	1.979667	9.791328
92	10100004	1379018	35.545667	0.193	0.358	0.093667	15.54354
93	10100005	409176	38.2323329	2.201667	3.846667	1.070667	4.960599
94	10110101	1758238	12.3453331	0.534	2.270667	0.509667	6.882939
95	10110102	241127	6.61400032	0.727	3.228667	0.728	0.505712
96	10110201	899431	38.3536682	18.00567	7.894666	2.819	10.93876
97	10110202	309164	43.0333354	2.635	4.053667	1.368333	4.218779
98	10110203	562825	102.83667	0.308	1.336	0.593667	18.35334
99	10110204	225787	55.2419993	0.219	1.053333	0.341	3.95514
100	10110205	467213	70.3276672	0.160333	0.697333	0.242667	10.41921
101	10120101	269241	20.5556666	1.463	1.351667	0.523	1.754957
102	10120102	128094	9.81666692	0.785667	1.629333	0.434333	0.398737
103	10120103	372143	24.9046656	1.336333	2.457667	0.675667	2.938894
104	10120104	281559	11.8106664	1.143667	1.998667	0.523	1.054477
105	10120105	259767	22.8926646	3.171667	4.631334	1.314667	1.885702
106	10120106	363248	29.2910004	2.974333	2.415333	0.773	3.37389
107	10120107	431165	29.1143341	1.039	1.375333	0.440333	3.980553
108	10120108	250749	42.4476649	11.23367	7.540333	2.163333	3.375099
109	10120109	549986	77.1116638	13.99767	10.00567	2.759	13.44822
110	10120110	185230	133.481669	4.48	4.601667	1.221667	7.840183
111	10120111	408864	54.6719971	6.235667	7.321667	2.065	7.088216
112	10120112	419775	115.409332	31.62966	16.80067	4.640667	15.3621
113	10120113	479704	108.648661	17.85133	12.52767	3.327	16.52688

TABLE E.1 (Cont.)

Sub-basin	Huc #	Land Area (ha)	WYLD (water yield) mm (per year)	SYLDtha (TSS metric ton/ha)	Tnkgha (TN kg/ha)	Tpkgha (TP kg/ha)	Flow (m3/s)
114	10120201	760758	29.6486664	1.586	2.771	0.775667	7.152289
115	10120202	840817	182.326335	15.69933	15.07133	4.161333	48.61208
116	10120203	272141	100.546672	40.439	14.36767	3.456	8.676719
117	10130101	654456	22.0760015	1.317	4.874	1.128333	4.581357
118	10130102	941810	55.1486715	2.43	5.146333	1.445667	16.46992
119	10130103	941115	36.9573313	0.936667	4.359666	1.040667	11.02901
120	10130104	268242	45.7236684	2.267333	7.474	1.827	3.889203
121	10130105	992749	104.300334	9.547	8.649334	2.580333	32.83359
122	10130106	421367	52.2639974	2.173	9.961667	2.368	6.983238
123	10130201	648307	1.51000007	0.208333	0.931333	0.215667	0.310421
124	10130202	444044	26.4390004	0.982667	3.337334	0.764	3.722755
125	10130203	422977	26.804334	1.046667	4.558	1.089333	3.595134
126	10130204	423454	13.6836675	0.625667	2.375667	0.599	1.837393
127	10130205	462617	15.1643333	1.904333	6.192	1.523667	2.22453
128	10130206	231727	15.6686656	0.369	1.676667	0.401	1.151336
129	10130301	322700	36.9329987	2.317667	9.195333	1.991333	3.779258
130	10130302	451860	24.6993332	1.718	4.072667	0.953333	3.539013
131	10130303	620750	52.364329	4.9	12.60233	2.660333	10.30731
132	10130304	262456	74.976003	15.45033	11.519	3.222	6.239831
133	10130305	406127	79.6186676	14.291	11.15367	2.842667	10.25347
134	10130306	688446	105.648336	10.31167	14.17367	3.742	23.06352
135	10140101	1105273	143.520325	12.23833	13.20233	3.651334	50.30096
136	10140102	822589	30.5559998	10.116	5.962666	1.736	7.970264
137	10140103	217031	28.3776652	1.957333	4.820667	1.341333	1.952951
138	10140104	179465	72.5393372	8.922667	11.027	2.741	4.128069
139	10140105	301935	102.400004	10.18033	13.904	4.041333	9.804064
140	10140201	980158	68.2976685	3.448333	2.785	0.989	21.22732
141	10140202	630174	138.375336	10.49967	4.246667	1.681667	27.6511
142	10140203	420972	58.4969991	1.093667	1.13	0.318333	7.808723
143	10140204	545513	108.57666	15.023	11.94633	3.207333	18.7817
144	10150001	213701	101.136332	9.908334	8.962667	2.300667	6.853431
145	10150002	383846	5.39399974	0.684333	0.254	0.095667	0.65654
146	10150003	1075327	45.308665	0.273667	0.142333	0.053	15.44953
147	10150004	980931	134.003998	0.030333	0.098667	0.029667	41.68211
148	10150005	223182	148.492666	0.000667	0.002333	0.001	10.50889
149	10150006	446424	89.782664	0.166667	0.511	0.147	12.70963
150	10150007	386390	185.29067	7.598333	9.001	2.416667	22.70247
151	10160001	439652	40.7283325	0.984	8.613	1.759333	5.678044
152	10160002	277250	32.5049998	1.489	9.041666	2.117	2.857693

TABLE E.1 (Cont.)

Sub-basin	Huc #	Land Area (ha)	WYLD (water yield) mm (per year)	SYLDtha (TSS metric ton/ha)	Tnkgha (TN kg/ha)	Tpkgha (TP kg/ha)	Flow (m3/s)
153	10160003	1158335	45.5726674	0.971	7.935667	1.688	16.7391
154	10160004	401043	45.3683319	1.039	7.949334	1.734333	5.769487
155	10160005	217091	94.5526733	4.928	30.87666	6.718	6.508927
156	10160006	960379	60.1019999	1.537667	8.698333	2.182333	18.30311
157	10160007	248041	37.6549988	1.221333	7.620667	1.846	2.961688
158	10160008	440923	11.6879997	0.377	2.951333	0.634333	1.634167
159	10160009	388712	14.8653336	0.346	1.810333	0.553667	1.832299
160	10160011	942856	60.2853292	1.569333	8.334	2.162333	18.02396
161	10170101	836348	101.731333	10.74667	20.43333	5.659667	26.97957
162	10170102	548751	79.206665	3.255667	16.40433	4.121333	13.78259
163	10170103	123793	68.3550008	3.468667	17.71133	4.173333	2.683233
1	10170201	422955	67.9926656	1.225333	9.888333	2.304333	9.119044
2	10170202	547369	153.664998	4.269334	23.438	5.546667	26.67155
3	10170203	885453	132.513	3.363333	18.00667	4.726	37.2064
4	10170204	434870	148.196004	5.476334	27.02633	7.054333	20.43571
5	10180001	368937	24.8176676	0.006	0.138667	0.013333	2.903396
6	10180002	766577	13.4246674	0.001	0.105	0.003	3.263269
7	10180003	266936	9.41366641	0.000333	0.003333	0	0.796817
8	10180004	373345	4.31133334	0	0.009	0.000333	0.510406
9	10180005	265053	2.2863334	0.000333	0.002	0	0.192161
10	10180006	751384	3.63966688	0	0.002333	0	0.867195
11	10180007	899646	10.3536669	0.001	0.007333	0	2.95365
12	10180008	551033	34.0356649	0.005333	0.105	0.002667	5.947099
13	10180009	1335159	35.9013316	0	0	0	15.19977
14	10180010	588624	5.65600014	0	0	0	1.0557
15	10180011	604653	46.2870026	0.000333	0.002	0	8.874808
16	10180012	441324	17.8656667	0.001333	0.005667	0.000667	2.500176
17	10180013	266355	22.2263336	0.003	0.034333	0.001667	1.877246
18	10180014	568481	144.698669	0.001333	0.013667	0.004333	26.084
19	10190001	415504	36.3366648	0.000333	0.015	0.000667	4.787549
20	10190002	479080	120.799662	0.012	0.997667	0.086333	18.3513
21	10190003	745569	7.32533264	0.001	0.017333	0.004667	1.731842
22	10190004	146538	191.954997	0.013667	1.265667	0.094667	8.919561
23	10190005	253615	95.3730062	0.065333	0.325667	0.058667	7.669964
24	10190006	215476	75.633667	0.019	0.099	0.017	5.167826
25	10190007	489640	70.8796692	0.005	0.030333	0.004667	11.00505
26	10190008	149689	23.1096675	0	0.003667	0	1.096928
27	10190009	359954	1.25933329	0	0	0	0.143741
28	10190010	185646	7.4873333	0.076333	0.298333	0.057333	0.440765

TABLE E.1 (Cont.)

Sub-basin	Huc #	Land Area (ha)	WYLD (water yield) mm (per year)	SYLDtha (TSS metric ton/ha)	Tnkgha (TN kg/ha)	Tpkgha (TP kg/ha)	Flow (m3/s)
29	10190011	358372	13.9626668	0.057	0.234333	0.045667	1.586706
30	10190012	772547	12.5856667	0.024	0.149333	0.021	3.083149
31	10190013	286559	4.3793335	0.023667	0.123333	0.020667	0.397938
32	10190014	187442	0.84766666	0.000667	0.015667	0.001333	0.050383
33	10190015	306258	8.15233358	0.000333	0.000667	0	0.791704
34	10190016	345539	5.20366669	0.002	0.016	0.004	0.570165
35	10190017	194764	2.95600001	0	0	0	0.182561
36	10190018	365743	60.5676676	0.039	0.251667	0.086667	7.024409
37	10200101	865092	154.839661	0.962	4.473667	1.727333	42.47543
38	10200102	189153	95	1.071333	4.816333	1.525667	5.698089
39	10200103	285443	183.743327	1.002333	8.882667	2.582667	16.63125
40	10200201	222283	123.02533	7.104666	24.29667	8.725333	8.6715
41	10200202	135965	194.200684	8.238667	27.72667	8.91	8.372784
42	10200203	426642	192.452332	6.763334	24.68233	7.621667	26.03635
43	10210001	541456	196.717672	0	0	0	33.77537
44	10210002	469579	209.093994	0	0.004333	0.001333	31.13463
45	10210003	462816	178.407328	2.812667	7.462334	3.277	26.1827
46	10210004	409430	158.411001	3.334	9.432667	3.264	20.56642
47	10210005	191857	169.289001	3.457	9.101333	3.592	10.29914
48	10210006	608494	159.51767	0.001	0.015667	0.003333	30.77927
49	10210007	253275	143.195333	1.378667	5.792	2.285	11.50046
50	10210008	256752	222.129679	0.001667	0.01	0.005333	18.0848
51	10210009	397219	190.913005	6.497667	19.62467	9.605	24.04691
52	10210010	318554	232.572673	1.230333	4.435333	2.066	23.49283
53	10220001	749227	193.914998	1.456667	5.123	2.699	46.07002
54	10220002	219779	146.671326	0.720667	3.826	1.596667	10.22175
55	10220003	571508	123.545329	7.036	24.488	11.74967	22.38936
56	10220004	272753	168.721334	12.62967	41.99233	16.376	14.59258
57	10230001	416671	250.713664	9.569	32.48333	9.280667	33.12566
58	10230002	237228	63.4639994	0.647333	4.359666	1.35	4.774044
59	10230003	733458	247.38798	3.467	19.17733	5.443333	57.537
60	10230004	250251	255.893677	11.079	33.239	7.413667	20.30622
61	10230005	191639	225.778341	16.01067	45.48	13.383	13.72021
62	10230006	288480	339.835002	17.47833	34.16	10.024	31.08694
63	10230007	308196	350.877686	44.076	71.24233	17.46	34.29065
64	10240001	217036	351.139648	20.563	45.807	12.199	24.16602
65	10240002	427746	432.912679	53.586	73.24266	19.01233	58.71909
66	10240003	297519	417.768677	41.494	65.062	17.31333	39.41337
67	10240004	45333	358.501343	16.79133	37.453	9.025333	5.153424

TABLE E.1 (Cont.)

Sub-basin	Huc #	Land Area (ha)	WYLD (water yield) mm (per year)	SYLDtha (TSS metric ton/ha)	Tnkgha (TN kg/ha)	Tpkgha (TP kg/ha)	Flow (m3/s)
68	10240005	440532	225.460002	5.926	25.65467	6.843667	31.49492
69	10240006	231202	346.865682	16.259	37.85	9.522333	25.43003
70	10240007	184138	415.317017	6.649666	15.58267	4.036667	24.25029
71	10240008	313295	410.520671	12.263	27.75433	7.523333	40.78327
72	10240009	205910	462.146647	25.854	52.74267	12.23633	30.17527
73	10240010	258817	242.525675	7.536333	24.152	6.022667	19.90419
74	10240011	269962	296.298014	2.289	5.423	2.36	25.36446
75	10240012	431051	264.837687	8.507001	17.214	2.316667	36.19947
76	10240013	201147	442.095337	18.718	29.922	4.155	28.19827
77	10250001	478365	18.4906667	0.051333	0.269	0.042333	2.804823
78	10250002	763693	14.9860001	0.007	0.037333	0.005667	3.629091
79	10250003	698728	1.49866676	0.064	0.299667	0.045	0.332052
80	10250004	558122	0.63833336	0.045333	0.194667	0.042	0.112972
81	10250005	426612	13.1786664	0.065	0.600333	0.116	1.782779
82	10250006	374504	49.7319997	0.387667	2.127	0.408	5.905897
83	10250007	205533	39.481664	0.053	0.257667	0.079	2.573178
84	10250008	240209	75.5706635	0.497667	1.544333	0.444667	5.756198
85	10250009	349396	47.6640015	1.252667	3.81	1.012	5.280818
86	10250010	274769	5.27399985	0.066333	0.349333	0.094667	0.459516
87	10250011	169184	9.06200027	0.345	1.136667	0.334667	0.486158
88	10250012	194627	1.28299999	0.039667	0.146	0.053333	0.079181
89	10250013	166616	0.061	0	0.001333	0	0.003223
90	10250014	189660	3.32833354	0.254	0.793667	0.193333	0.200169
91	10250015	287198	21.2700005	0.298333	0.979667	0.269667	1.937057
92	10250016	562392	59.7826691	0.584	2.544333	0.763667	10.66124
93	10250017	512540	34.811999	0.747667	2.807	0.620333	5.657828
94	10260001	272661	11.072333	0	0.001	0	0.957318
95	10260002	188982	0.042	0	0	0	0.002517
96	10260003	382882	0.09733333	0.001333	0.004667	0.001	0.011817
97	10260004	366904	0.051	0	0	0	0.005934
98	10260005	168003	0.035	0.000333	0.000667	0	0.001865
99	10260006	408990	105.412669	0.002333	0.037	0.010667	13.67094
100	10260007	223171	59.7690023	0.010667	0.077333	0.022333	4.229684
101	10260008	517408	207.582662	0.771	2.661	0.597333	34.0579
102	10260009	497613	30.2670008	0.041333	0.094	0.032667	4.775891
103	10260010	352475	108.786997	0.022	0.085667	0.014333	12.15903
104	10260011	363457	25.1176682	0.001	0.002667	0.000667	2.894847
105	10260012	348012	81.4473368	0.244	1.022667	0.218333	8.988019
106	10260013	299656	53.9293315	0.031667	0.080333	0.026	5.124375

TABLE E.1 (Cont.)

Sub-basin	Huc #	Land Area (ha)	WYLD (water yield) mm (per year)	SYLDtha (TSS metric ton/ha)	Tnkgha (TN kg/ha)	Tpkgha (TP kg/ha)	Flow (m3/s)
107	10260014	275480	110.780334	0.055	0.184333	0.037333	9.677132
108	10260015	491287	38.5766652	0.015333	0.072	0.018333	6.009705
109	10270101	138965	325.340658	1.004	3.877	0.850333	14.33634
110	10270102	564784	343.839315	1.057	4.742333	1.119667	61.57882
111	10270103	299650	296.322673	3.953667	9.379667	2.348	28.15613
112	10270104	428771	368.809001	3.042	7.934333	2.163	50.1442
113	10270201	286881	102.057332	2.366333	14.01967	4.095667	9.284076
114	10270202	327311	213.942668	5.139333	18.19667	5.125667	22.20505
115	10270203	347071	123.301331	2.522	16.385	4.353333	13.56997
116	10270204	188718	174.01534	3.809	17.78467	4.716	10.41345
117	10270205	441986	287.161336	6.024334	14.31667	4.549	40.2465
118	10270206	582064	98.0590007	0.796	5.681667	1.399667	18.09888
119	10270207	346940	224.42334	2.750667	9.587667	2.529667	24.68973
120	10280101	861417	265.377991	8.475	27.169	4.985667	72.48897
121	10280102	570092	396.14799	10.38533	28.302	5.471	71.61361
122	10280103	611445	417.923014	4.333667	16.50333	3.415333	81.03029
123	10280201	350227	362.61499	10.045	21.3	4.646667	40.27064
124	10280202	264085	526.642008	3.590333	14.41533	3.287667	44.10139
125	10280203	180960	455.301351	4.534334	13.06467	2.912333	26.12605
126	10290101	563677	480.361979	4.601333	10.24733	2.417	85.8603
127	10290102	408239	594.431315	5.859	15.34567	3.107333	76.95013
128	10290103	150442	575.188354	3.964	11.532	2.369667	27.4393
129	10290104	295566	544.10498	4.171333	10.21933	2.056667	50.99541
130	10290105	311722	351.919027	1.814667	5.227667	1.209667	34.78588
131	10290106	510403	495.225993	0.379667	2.380333	0.438333	80.15127
132	10290107	219065	509.797038	1.588	3.87	0.545	35.41303
133	10290108	530223	386.791016	3.950666	15.131	2.728	65.03215
134	10290109	359147	467.068685	0.382	2.069333	0.32	53.192
135	10290110	266605	598.426025	3.704667	5.121667	0.698333	50.59094
136	10290111	279140	481.036662	1.812	5.278667	0.808667	42.57886
137	10290201	463009	677.220662	2.143	6.665	0.841333	99.42898
138	10290202	195588	614.182007	2.015	4.877666	0.632	38.09196
139	10290203	267580	490.132324	1.402333	4.762333	0.668333	41.58728
140	10300101	699076	371.76001	3.583	10.41967	2.763333	82.41013
141	10300102	880813	386.967	1.655667	4.950333	1.411	108.0814
142	10300103	287938	345.487345	4.453334	11.91167	3.070333	31.5446
143	10300104	399991	357.907308	12.17467	22.09233	6.206	45.39567
144	10300200	411954	592.156006	1.208	5.965333	1.419667	77.35313

TABLE E.2 Land use.

Huc #	WHEAT_SUM (ha)	SOYB_SUM (ha)	CORN_SUM (ha)	Pasture Land Area HAY/PAST/GRASS_SUM (ha)	Other Agricultural Land Area (ha)	Idle Land/CRP (ha)
10020001	6.480042	0	0	318072.8	0	4.68
10020002	6270.161	0	33.84022	245365.5	0	114.12
10020003	384.4825	0	7.560049	121888	0	9
10020004	104.7607	0	3.240021	283956.8	0	89.28
10020005	2404.816	0	34.56023	185953.3	0	705.6
10020006	172.4411	0	3.240021	53727.06	0	29.88
10020007	895.6858	0	4.68003	180730.6	0	422.28
10020008	14999.86	0	189.7212	152720.7	0	2360.9
10030101	10611.07	0	82.08054	354267	0	4325.43
10030102	77819.91	0	20.88014	398604.6	0	41984.55
10030103	2856.619	0	1.080007	268770.7	0	511.2
10030104	20802.74	0	16.92011	271819.1	0	7839.77
10030105	7600.73	0	0	91358.58	0	3486.98
10030201	8568.416	0	2.520016	190559.7	0	4720.71
10030202	38913.01	0	2.520016	235137.6	21754.65	20209.45
10030203	218229.1	0.720005	465.483	589589.5	0	169615.1
10030204	56303.29	0	10.80007	157844.8	0	47767.99
10030205	86989.89	0	59.40039	361308.8	0	64890.78
10040101	46495.02	0	2.880019	345967.3	0	32824.65
10040102	32202.57	0	6.480042	267706.8	0	16660.55
10040103	67312.52	0	9.720063	434048.7	0	18239.52
10040104	8817.897	0	28.44019	956811.2	0	5910.52
10040105	12039.56	0	2.160014	383416.9	0	9563.1
10040106	12750.56	0	73.44048	294694.3	0	10531.87
10040201	20769.62	0	32.76021	760257.9	0	9904.74
10040202	6733.484	0	54.36035	409353.7	0	1240.57
10040203	2071.813	0	3.960026	130386.5	0	823.33
10040204	4676.79	0	2.160014	248922.1	0	2932.22
10040205	3821.785	0	1.800012	343684	0	1672.21
10050001	5135.073	0	0	222389.3	0	2494.46
10050002	52242.82	0	21.24014	500415.9	0	39122.54
10050003	1263.248	0	1.080007	119247.5	0	1663.21
10050004	82243.98	1.080007	81.00053	784879.3	0	57376.45
10050005	46925.23	0	2.880019	102127.5	0	36152.52
10050006	70096.78	0	69.84045	150731.9	0	43233.4
10050007	10207.87	0	8.640056	264401.9	0	9124.98
10050008	4657.35	0	1.800012	437539.3	0	3629.9
10050009	8036.692	0	0.360002	146219.4	0	4383.75
10050010	26625.41	0	2.520016	206058.9	0	16434.47

TABLE E.2 (Cont.)

Huc #	WHEAT_SUM (ha)	SOYB_SUM (ha)	CORN_SUM (ha)	Pasture Land Area HAY/PAST/GRASS_SUM (ha)	Other Agricultural Land Area (ha)	Idle Land/CRP (ha)
10050011	8014.732	0	1.080007	457521.6	0	4179.63
10050012	21455.42	1.080007	219.9614	370450.7	0	8757.78
10050013	1009.807	0	1.440009	618805.2	0	363.6
10050014	13213.53	0.720005	25.92017	462711	0	4377.63
10050015	3828.985	0	0.360002	351079.7	0	975.97
10050016	34543.67	0	7.920052	161978	0	5884.24
10060001	72153.47	1.440009	704.5246	437943.6	0	20158.33
10060002	95107.22	0	161.2811	442622.5	0	27082.62
10060003	87797.37	0	57.24037	510194.6	0	19052.4
10060004	48818.84	0	7.560049	235270.5	0	4419.75
10060005	37406.76	0.360002	1219.688	285099.9	0	7331.45
10060006	186470.1	0	586.8038	716195.9	0	17767.92
10060007	44912.09	0	399.2426	220717.8	0	4178.55
10070001	0.720005	0	0.720005	45832.89	0	50.4
10070002	594.7239	0	29.88019	301125.6	0	42.48
10070003	1121.047	0	2.520016	110737	0	271.44
10070004	11880.08	0	2630.177	290934.9	0	5522.08
10070005	100.0807	0	6.480042	115156.4	0	26.64
10070006	2327.055	0	2249.295	231384.9	0	771.49
10070007	19756.57	0	2396.176	409555.1	0	10670.47
10070008	7315.248	0	10.08007	67507.33	0	1911.97
10080001	201.9613	0	336.9622	118042.8	0	61.92
10080002	68.04045	0	69.48045	47097.05	0	75.6
10080003	28.44019	0	9.720064	31460.37	0	26.64
10080004	1.080007	0	0	31646.47	0	0.72
10080005	641.5242	0	1091.887	127489.8	0	202.32
10080006	6.840044	0	0	66194.18	0	17.28
10080007	434.1628	0	2550.977	317478.2	0	478.08
10080008	90.72059	0	168.1211	150818.9	0	44.64
10080009	613.084	0	1211.408	96881.24	0	990.01
10080010	227.8815	0	425.5228	157742.7	0	506.16
10080011	118.4408	0	198.0013	41590.13	0	199.44
10080012	0	0	0	45023.52	0	2.88
10080013	17.28011	0	1.080007	57474.09	0	15.84
10080014	1351.449	0	2447.656	159918.6	25199.79	1093.33
10080015	21686.54	0	1032.847	317184.6	0	6438.64
10080016	4021.946	0	359.2824	138251.4	0	1074.25
10090101	5696.317	0	315.3621	294911.4	0	316.08
10090102	957.2462	0	1027.447	379139.5	0	309.96

TABLE E.2 (Cont.)

Huc #	WHEAT_SUM (ha)	SOYB_SUM (ha)	CORN_SUM (ha)	Pasture Land Area HAY/PAST/GRASS_SUM (ha)	Other Agricultural Land Area (ha)	Idle Land/CRP (ha)
10090201	28.80019	0	6.840045	84673.9	0	9
10090202	1224.368	0	52.92035	517144.5	0	1711.81
10090203	147.601	0	0.720005	96293.77	0	729.72
10090204	0.720005	0	0	90733.87	0	42.84
10090205	36.00023	0	1.800012	132008.8	0	30.6
10090206	110.1607	0	120.2408	190531.3	0	29.88
10090207	512.6433	0	1.080007	157057.4	0	585
10090208	2651.057	0	0.720005	380313.2	0	3174.14
10090209	1613.171	0	46.0803	352891.4	0	803.53
10090210	1209.968	0	22.32015	146668.7	0	655.56
10100001	17386.31	0	5558.796	950639.3	0	8122.37
10100002	1318.329	0	20.16013	224385.1	0	376.56
10100003	244.4416	0	18.36012	128223.2	0	258.48
10100004	114061	43.56028	4726.111	1253451	0	26872.38
10100005	4344.148	0	119.1608	332591.6	0	1490.77
10110101	385903.1	371.5224	8869.378	989825	194451	16516.91
10110102	95327.18	0	481.6831	94256.19	31982.3	9526.02
10110201	11658.32	0	132.1209	671687.8	0	3419.66
10110202	5598.396	0	32.40021	234872.6	0	1091.17
10110203	31899.45	0	2429.296	531300.5	0	993.61
10110204	27658.98	0	2001.973	202058.2	0	2385.74
10110205	18496.2	2.160014	436.6828	369795	0	1688.05
10120101	0.360002	0	0.360002	186063.5	0	635.4
10120102	0	0	0	99197.7	0	7.56
10120103	5.400035	0	18.36012	276917.9	0	50.04
10120104	105.8407	0	6.12004	221505.7	0	181.8
10120105	14.40009	0	0	200765.5	0	56.52
10120106	1516.69	1.080007	8.280054	309614.8	0	271.08
10120107	420.4827	0	105.1207	215849.1	0	770.77
10120108	176.4011	0	4.320028	251882.1	0	203.4
10120109	1726.571	0	77.76051	374294.5	0	623.16
10120110	2286.375	0	0.720005	82505.98	0	277.2
10120111	20911.1	0.360002	155.521	315402.1	0	3772.1
10120112	27919.98	0.360002	1404.369	388573.6	0	5967.4
10120113	10084.39	0	310.322	475850	0	2570.42
10120201	2033.293	0	7.920052	565046.3	0	7089.53
10120202	7961.812	19.80013	2284.215	711089.3	0	3494.54
10120203	453.603	0	39.96026	110482.3	0	284.04
10130101	104092.5	1409.409	13434.21	495749.2	46678.89	1120.69

TABLE E.2 (Cont.)

Huc #	WHEAT_SUM (ha)	SOYB_SUM (ha)	CORN_SUM (ha)	Pasture Land Area HAY/PAST/GRASS_SUM (ha)	Other Agricultural Land Area (ha)	Idle Land/CRP (ha)
10130102	75745.93	7511.089	30816.56	768108.4	0	1253.53
10130103	73554.6	10993.75	26064.17	750135.9	0	875.53
10130104	35211.47	2545.577	9661.743	205125.3	16599.02	225.36
10130105	155232.7	16112.62	59787.75	682837.5	0	5006.19
10130106	34399.66	15668.38	28375.03	319439.8	0	523.44
10130201	95115.14	25.56017	6148.12	560583	0	1394.65
10130202	119301.5	18.36012	6175.84	340848.8	0	442.44
10130203	73071.84	70.92046	5755.717	352515.7	0	533.16
10130204	143681.3	10.44007	4479.869	302338.3	0	705.96
10130205	118924.3	12.24008	4824.751	371594.4	0	956.89
10130206	9956.945	53.64035	1788.492	220743.7	0	213.84
10130301	55167.48	1.080007	4236.868	274103.3	0	812.89
10130302	15202.18	0.360002	1708.571	446268.6	0	481.32
10130303	40160.42	1.080007	5582.196	591232.6	0	1250.65
10130304	1383.489	0	6.12004	261266.7	0	343.08
10130305	7834.371	0	618.844	403729.7	0	1663.21
10130306	36375	2.880019	8079.533	655286	0	5360.79
10140101	119140.6	34807.19	100141.5	929350.1	0	1860.85
10140102	80739.53	30.2402	2996.66	738139.1	0	15287.86
10140103	69104.61	2066.413	19635.97	105299.8	21254.36	272.52
10140104	28590.67	77.0405	5484.996	144647.9	0	2780.3
10140105	25186.84	3786.505	25376.2	286088.9	0	81
10140201	13655.61	1.080007	756.3649	847436	0	6021.76
10140202	21833.78	46.0803	795.9652	561312.1	0	4496.43
10140203	18858.72	72.72047	3015.74	395875.5	0	5702.8
10140204	51009.81	551.1636	18207.84	477081.6	0	3524.42
10150001	5446.835	4845.272	14085.09	168546	0	14.4
10150002	1211.048	0	2107.814	381806.2	0	1140.13
10150003	44706.89	2.520016	34837.07	963699.6	0	25042.48
10150004	920.166	2923.939	28859.23	945619.6	0	15.48
10150005	87.12057	0	49.32032	222877.5	0	1.8
10150006	1696.331	577.0838	10319.47	431910.3	0	36
10150007	5840.318	13585.05	64715.1	295829.4	0	15.48
10160001	113877	64527.9	38335.93	196181.7	35258.88	668.16
10160002	41703.03	38009.05	20720.66	165603.8	0	391.68
10160003	73366.68	255720.8	239772.4	680120.3	0	2078.29
10160004	27207.54	63413.69	63871.98	361794.1	0	933.13
10160005	18760.08	53718.83	59627.19	93001.63	0	51.84
10160006	89412.34	164427.1	234003.7	815004.4	0	162.72

TABLE E.2 (Cont.)

Huc #	WHEAT_SUM (ha)	SOYB_SUM (ha)	CORN_SUM (ha)	Pasture Land Area HAY/PAST/GRASS_SUM (ha)	Other Agricultural Land Area (ha)	Idle Land/CRP (ha)
10160007	32360.97	27253.98	51896.86	157521.6	0	37.8
10160008	47909.83	59006.19	88330.17	354695.7	0	19.8
10160009	67949.72	23087.67	55297.08	315321.2	0	58.32
10160011	70124.14	180470.3	223481.9	874893.5	0	4.32
10170101	27265.14	114406.6	189122.2	610552.2	0	8.28
10170102	11809.16	149453.5	196443.9	342228.3	0	14.04
10170103	3875.425	28187.82	32920.41	57465.51	0	7.56
10170201	31250.9	52324.2	69151.7	194442.1	1326.2	56.52
10170202	21616.6	107873	159822	202283.8	1141.9	655.56
10170203	3480.48	213539	349096	214317.5	573.1	6.48
10170204	649.8	130287	187404	67977.7	128.2	0.36
10180001	0.36	0	0.36	56183.5		0.36
10180002	0	0	0	85965.9	136.4	0.36
10180003	0.36	0	0	27569.8	11.5	1.44
10180004	0	0	0	41997.0		0
10180005	0	0	0	26382.7		0
10180006	0.72	0	1.44	72122.8	49.3	23.04
10180007	18.72	0	134.64	290602.1	704.9	152.28
10180008	360	0	465.48	267779.2	1156.0	402.84
10180009	32558.1	209.88	81836.7	1167134.1	26027.3	27404.29
10180010	1.08	0	0	76159.9	2.2	4.68
10180011	1406.88	0	6519.6	226577.5	1099.4	896.76
10180012	4488.48	0	5591.16	393522.8	2219.0	5371.56
10180013	6681.96	0	6471	247911.9	3182.8	2099.16
10180014	11129.4	664.2	15959.9	529888.5	1694.2	9135.72
10190001	4.32	0	0.72	268011.8	6.8	0.72
10190002	90.72	0	13.32	70553.9	19.1	210.96
10190003	54553.7	5.04	31173.1	527231.6	12673.4	62508.98
10190004	14.4	0	5.76	33033.6	10.8	36.72
10190005	5006.88	0	5056.2	71924.2	2800.4	2931.12
10190006	3341.88	0	6082.2	48740.1	2267.6	3086.64
10190007	3807.36	0	19023.8	192660.0	3501.4	2252.52
10190008	1826.28	0.72	7148.16	139483.9	637.6	585.36
10190009	3902.4	0.36	3178.8	351148.4	608.4	1124.64
10190010	22711.7	2.16	1738.08	135289.1	2872.1	23044.33
10190011	31039.2	0	4590	284086.9	3841.6	34804.45
10190012	44937	105.12	41173.6	633171.1	12967.2	40185.38
10190013	37235.9	1.44	4059	205310.2	4534.6	35423.65
10190014	3412.08	5.04	3427.2	174124.9	1741.3	4732.2

TABLE E.2 (Cont.)

Huc #	WHEAT_SUM (ha)	SOYB_SUM (ha)	CORN_SUM (ha)	Pasture Land Area HAY/PAST/GRASS_SUM (ha)	Other Agricultural Land Area (ha)	Idle Land/CRP (ha)
10190015	11211.5	0	1103.04	281191.4	2316.2	10424.88
10190016	34563.6	6.84	12730.3	245212.1	8978.8	26276.05
10190017	5570.64	0	1206.36	181823.1	1685.5	4472.64
10190018	51823.1	3712.32	65687.1	182485.7	5113.1	36876.61
10200101	7308	36421.6	224441	541817.3	2493.7	1542.24
10200102	799.2	8113.68	60376.3	104099.8	821.2	114.48
10200103	2291.04	23317.9	130749	98599.4	811.4	44.64
10200201	821.52	41566.7	91026.8	63100.0	194.0	28.44
10200202	613.44	30919.7	40100.4	30707.0	39.6	32.4
10200203	5119.92	90426.6	97872.9	183899.9	432.0	28.8
10210001	58.68	2.88	127.8	541178.9	64.1	8.64
10210002	31.68	1.8	318.24	468790.4	428.0	5.04
10210003	1149.84	9395.64	64716.5	386679.8	802.4	82.08
10210004	3014.64	9782.28	60097.3	334141.3	1630.1	754.2
10210005	1035	4834.44	35894.9	136505.9	579.2	146.88
10210006	126.72	183.24	2566.44	605218.9	362.5	46.44
10210007	956.16	6407.28	41479.2	187692.4	327.6	79.2
10210008	6.48	296.28	1083.6	255237.2	127.4	3.96
10210009	1975.68	40908.3	105152	217980.1	586.4	105.12
10210010	713.88	12183.1	40966.9	264419.4	268.2	13.32
10220001	2148.12	42191.7	111682	592258.9	889.2	51.84
10220002	1141.56	42975	78549.9	72486.8	297.4	43.56
10220003	2135.88	147244	208548	142403.2	579.6	84.6
10220004	441.36	82207.5	116441	40488.8	336.2	9.72
10230001	110.16	97312.4	146352	95962.5	758.2	5.76
10230002	52.56	73974.3	108228	25410.2	58.3	0
10230003	115.2	216608	289457	132426.3	280.8	0
10230004	0.72	80541.4	109618	34535.9	39.6	0
10230005	2.52	62377.2	82284.9	25288.2	53.3	0
10230006	177.84	53452.5	72026.7	68464.7	148.7	68.4
10230007	3.6	80159.1	123019	65167.3	157.7	0
10240001	370.44	56818.5	63509.1	47279.7	41.8	403.2
10240002	2.88	146718	179055	32306.4	132.1	0
10240003	6.48	86314.7	108355	47606.1	132.5	1.44
10240004	114.48	12036.6	16837.9	7220.3	24.5	0
10240005	1202.04	118552	148308	83229.4	388.8	12.24
10240006	3060.72	50482.8	57507.1	78060.9	92.5	82.44
10240007	6513.84	20525	19932.8	99049.1	1079.6	93.96
10240008	5274	54139.7	67806	125304.4	476.3	95.76

TABLE E.2 (Cont.)

Huc #	WHEAT_SUM (ha)	SOYB_SUM (ha)	CORN_SUM (ha)	Pasture Land Area HAY/PAST/GRASS_SUM (ha)	Other Agricultural Land Area (ha)	Idle Land/CRP (ha)
10240009	3.96	40025.2	50974.2	87808.7	158.0	0
10240010	38.88	49378.7	58313.5	99424.8	69.1	1.44
10240011	1702.44	38760.5	40894.9	68435.7	268.6	18.36
10240012	976.68	65179.5	68559.1	195345.7	249.1	1.44
10240013	62.28	32083.6	35757.7	90394.2	39.2	0.36
10250001	66473.3	299.16	33602.4	303040.2	14224.0	60727.7
10250002	98981.7	899.28	100025	447207.3	36116.3	80464.71
10250003	107983	324.36	50479.9	436385.7	16081.9	87478.95
10250004	62406.7	3046.32	78954.1	350337.0	16951.7	46410.14
10250005	61096	1022.76	95422.7	201654.8	21841.9	45577.46
10250006	71319.3	1613.16	78930.4	166574.2	10220.8	45843.14
10250007	13608	1411.92	35624.5	144451.1	2733.1	7706.88
10250008	10368	3080.88	27273.3	190035.1	3796.6	5658.12
10250009	22095.7	14754.2	71021.2	205051.9	6172.2	8289.72
10250010	70796.2	690.12	43436.9	104124.6	16803.7	38910.97
10250011	25299.4	599.76	21448.8	101803.0	6493.7	13529.89
10250012	39353.4	62.64	35044.2	88213.4	6117.1	25853.05
10250013	43821.7	170.28	27526	60016.7	5832.7	29239.57
10250014	27541.5	621	17392.7	117261.0	10231.6	16630.21
10250015	47932.2	1875.96	48901	132032.6	13835.5	27214.21
10250016	44559.7	48059.3	98909.3	318411.8	12089.9	2215.44
10250017	99668.9	39133.1	22603.3	256510.7	32243.1	1287
10260001	33440.4	18.72	14256.4	187311.3	7660.1	29968.93
10260002	33660.4	117.72	28852.6	94193.0	4825.4	27330.49
10260003	58858.6	381.6	18059.8	236936.6	27008.7	41643.02
10260004	82891.5	168.84	52829.3	154864.1	19404.4	56743.58
10260005	36418.3	282.96	19248.8	73883.9	14482.8	23686.93
10260006	77566	1368.72	1394.64	247968.6	28494.0	25954.93
10260007	44817.1	330.12	11268	101019.7	22504.3	26885.53
10260008	107240	17137.8	5184.72	337181.2	17030.5	453.6
10260009	69100.6	1395.36	29675.9	329307.6	35135.7	33011.29
10260010	61479.7	4231.08	618.48	261505.5	18355.7	6288.48
10260011	56636.7	2469.96	48024	210630.0	18088.9	27599.77
10260012	79309.5	6687.36	8111.52	185306.7	32911.9	16513.21
10260013	43813.8	1632.6	32137.9	179708.5	18754.9	23600.17
10260014	57004.9	3164.4	2481.84	177185.2	22756.7	12880.44
10260015	145982	13385.2	3071.16	262348.1	33993.0	4757.04
10270101	6433.56	4121.28	2046.6	98654.2	1490.0	10.44
10270102	9049.32	33499.1	34855.2	383853.6	2256.8	14.04

TABLE E.2 (Cont.)

Huc #	WHEAT_SUM (ha)	SOYB_SUM (ha)	CORN_SUM (ha)	Pasture Land Area HAY/PAST/GRASS_SUM (ha)	Other Agricultural Land Area (ha)	Idle Land/CRP (ha)
10270103	7059.24	33073.6	29651.8	150179.8	813.6	5.4
10270104	9425.52	38169.7	33475.3	175393.7	899.3	45
10270201	2144.16	67989.3	158938	30079.7	763.9	43.56
10270202	12778.6	69221.5	87649.6	119771.0	2819.2	10.8
10270203	6411.24	65993.1	190193	48975.1	1618.9	55.8
10270204	6629.4	38877.1	70745.1	50860.9	3373.6	17.64
10270205	34661.2	49105.8	31573.5	244729.6	10936.4	47.16
10270206	34049.9	81000.8	229964	177206.9	7884.4	743.4
10270207	34628.1	35835.9	31925.9	185333.9	14140.4	100.08
10280101	3301.92	88812.4	63075.3	496424.5	586.1	3.6
10280102	1037.52	57094.9	54576.4	304200.8	435.2	0.36
10280103	6021.36	77145.9	34632	336458.9	171.4	11.52
10280201	157.32	29099.2	27118.8	158604.2	153.7	3.24
10280202	2475.72	29269.1	15088.7	113652.0	7.2	0.72
10280203	2230.92	14990	10472.4	89965.9	113.0	2.52
10290101	29278.5	65270.2	33329.2	319059.9	3338.3	34.92
10290102	14699.5	43125.5	19568.5	212585.7	1312.9	136.08
10290103	6019.56	12101.4	10338.8	78462.2	259.6	44.28
10290104	11029.3	14205.6	13243	179935.1	695.5	14.76
10290105	8475.84	9767.52	8588.16	117945.0	140.4	58.68
10290106	3145.68	2900.52	3723.12	253837.2	103.0	4.32
10290107	67.32	169.92	102.96	96813.8	6.1	10.08
10290108	12124.1	42436.8	26026.9	292549.6	231.5	50.4
10290109	317.88	528.84	512.64	82401.5	1.8	0.36
10290110	6.12	9	65.52	82143.0	5.0	0
10290111	426.6	1194.84	924.48	95119.6	43.6	0
10290201	20.16	186.48	375.84	173500.6	9.4	3.6
10290202	2.16	4.32	15.48	51951.3		0
10290203	238.32	1555.2	898.2	66883.7	22.0	0.36
10300101	7429.68	106814	72821.5	238690.4	346.3	14.04
10300102	11466.4	46517.1	43976.5	322245.1	1144.8	287.64
10300103	7645.68	25116.1	20408.4	122642.7	127.8	11.16
10300104	4543.56	64445.1	65991.3	135926.3	95.0	4.32
10300200	2833.92	18058	19157	88254.8	478.8	22.68

TABLE E.3 Fertilizer application rate.

Sub-basin	Huc #	N Fertilizer Input (kg/Ha)	P Fertilizer Input (kg/Ha)
1	10020001	0.83	0.23
2	10020002	0.17	0.05
3	10020003	0.62	0.18
4	10020004	0.51	0.14
5	10020005	0.28	0.08
6	10020006	0.56	0.16
7	10020007	1.87	0.55
8	10020008	1.53	0.65
9	10030101	0.25	0.07
10	10030102	0.31	0.09
11	10030103	1.73	0.50
12	10030104	0.54	0.16
13	10030105	3.54	1.03
14	10030201	3.84	1.18
15	10030202	0.57	0.18
16	10030203	0.16	0.05
17	10030204	0.50	0.16
18	10030205	0.37	0.11
19	10040101	0.40	0.11
20	10040102	0.58	0.16
21	10040103	0.22	0.06
22	10040104	0.79	0.22
23	10040105	0.22	0.06
24	10040106	0.28	0.08
25	10040201	0.15	0.04
26	10040202	0.46	0.13
27	10040203	2.54	0.71
28	10040204	1.55	0.44
29	10040205	0.86	0.24
30	10050001	1.16	0.36
31	10050002	0.11	0.03
32	10050003	0.69	0.22
33	10050004	0.16	0.05
34	10050005	0.45	0.13
35	10050006	0.44	0.14
36	10050007	0.10	0.03
37	10050008	0.18	0.05
38	10050009	1.21	0.34
39	10050010	0.37	0.10

TABLE E.3 (Cont.)

Sub-basin	Huc #	N Fertilizer Input (kg/Ha)	P Fertilizer Input (kg/Ha)
40	10050011	0.11	0.03
41	10050012	0.57	0.16
42	10050013	0.09	0.03
43	10050014	0.61	0.17
44	10050015	1.28	0.35
45	10050016	0.35	0.10
46	10060001	0.18	0.05
47	10060002	0.11	0.03
48	10060003	0.04	0.01
49	10060004	0.20	0.06
50	10060005	4.76	2.30
51	10060006	6.46	3.32
52	10060007	9.10	4.63
53	10070001	42.97	11.23
54	10070002	0.63	0.22
55	10070003	0.99	0.26
56	10070004	0.50	0.14
57	10070005	3.88	1.16
58	10070006	0.47	0.17
59	10070007	0.92	0.25
60	10070008	2.68	0.73
61	10080001	0.52	0.12
62	10080002	0.61	0.13
63	10080003	0.66	0.15
64	10080004	1038.41	247.13
65	10080005	0.64	0.14
66	10080006	23.77	5.21
67	10080007	0.24	0.06
68	10080008	0.67	0.17
69	10080009	0.17	0.05
70	10080010	1.03	0.32
71	10080011	1.94	0.51
72	10080012	1.61	0.42
73	10080013	0.27	0.07
74	10080014	0.26	0.09
75	10080015	0.38	0.10
76	10080016	2.98	0.89
77	10090101	1.56	0.43
78	10090102	0.88	0.24

TABLE E.3 (Cont.)

Sub-basin	Huc #	N Fertilizer Input (kg/Ha)	P Fertilizer Input (kg/Ha)
79	10090201	0.83	0.18
80	10090202	0.40	0.09
81	10090203	21.89	4.72
82	10090204	189.45	41.03
83	10090205	0.68	0.15
84	10090206	0.28	0.07
85	10090207	1.51	0.38
86	10090208	0.81	0.20
87	10090209	1.20	0.33
88	10090210	0.98	0.27
89	10100001	0.15	0.04
90	10100002	2.82	0.78
91	10100003	2.79	0.78
92	10100004	2.69	1.35
93	10100005	0.70	0.19
94	10110101	9.18	4.70
95	10110102	11.78	5.98
96	10110201	1.39	0.50
97	10110202	1.06	0.43
98	10110203	2.80	1.35
99	10110204	2.81	1.38
100	10110205	4.96	2.23
101	10120101	20.59	4.54
102	10120102	380.85	84.16
103	10120103	0.16	0.04
104	10120104	1.04	0.23
105	10120105	4.06	0.89
106	10120106	0.91	0.25
107	10120107	0.18	0.06
108	10120108	3.18	0.89
109	10120109	0.59	0.23
110	10120110	3.12	1.07
111	10120111	1.17	0.54
112	10120112	2.71	1.29
113	10120113	1.30	0.63
114	10120201	0.42	0.11
115	10120202	0.84	0.32
116	10120203	1.00	0.27
117	10130101	9.02	4.50

TABLE E.3 (Cont.)

Sub-basin	Huc #	N Fertilizer Input (kg/Ha)	P Fertilizer Input (kg/Ha)
118	10130102	4.14	2.06
119	10130103	5.21	2.88
120	10130104	5.73	2.95
121	10130105	8.84	4.50
122	10130106	7.78	4.32
123	10130201	5.25	2.56
124	10130202	7.77	3.84
125	10130203	8.38	3.92
126	10130204	9.11	4.59
127	10130205	5.61	2.81
128	10130206	9.24	3.52
129	10130301	4.13	2.01
130	10130302	1.01	0.44
131	10130303	2.91	1.40
132	10130304	4.33	1.25
133	10130305	2.04	0.82
134	10130306	1.30	0.62
135	10140101	7.92	4.52
136	10140102	3.11	1.55
137	10140103	13.88	6.76
138	10140104	6.41	3.02
139	10140105	9.21	4.91
140	10140201	1.54	0.65
141	10140202	2.01	0.92
142	10140203	2.70	1.16
143	10140204	5.11	2.40
144	10150001	6.41	2.87
145	10150002	4.32	1.17
146	10150003	5.22	2.15
147	10150004	8.12	2.47
148	10150005	2.64	0.84
149	10150006	5.20	1.97
150	10150007	24.76	9.07
151	10160001	13.22	8.88
152	10160002	14.43	9.69
153	10160003	15.40	10.15
154	10160004	13.76	8.56
155	10160005	15.54	9.56
156	10160006	16.19	10.39

TABLE E.3 (Cont.)

Sub-basin	Huc #	N Fertilizer Input (kg/Ha)	P Fertilizer Input (kg/Ha)
157	10160007	16.71	9.79
158	10160008	14.79	9.07
159	10160009	13.30	7.43
160	10160011	15.47	10.43
161	10170101	16.47	9.53
162	10170102	21.01	14.06
163	10170103	19.48	12.58
1	10170201	27.3	14.4
2	10170202	41.6	22.3
3	10170203	51.5	28.2
4	10170204	67.0	38.5
5	10180001	0.0	0.0
6	10180002	0.0	0.0
7	10180003	0.0	0.0
8	10180004	0.0	0.0
9	10180005	0.0	0.0
10	10180006	0.1	0.0
11	10180007	0.1	0.0
12	10180008	0.5	0.1
13	10180009	9.8	3.0
14	10180010	0.0	0.0
15	10180011	2.5	0.7
16	10180012	3.1	0.9
17	10180013	5.3	1.7
18	10180014	5.2	1.9
19	10190001	0.2	0.0
20	10190002	0.5	0.1
21	10190003	9.0	3.0
22	10190004	3.2	0.8
23	10190005	6.9	1.9
24	10190006	7.4	2.1
25	10190007	7.0	1.9
26	10190008	8.2	2.4
27	10190009	1.8	0.6
28	10190010	8.8	4.6
29	10190011	9.3	4.3
30	10190012	12.1	4.4
31	10190013	10.6	5.2
32	10190014	8.3	2.8

TABLE E.3 (Cont.)

Sub-basin	Huc #	N Fertilizer Input (kg/Ha)	P Fertilizer Input (kg/Ha)
33	10190015	2.6	1.3
34	10190016	10.4	4.4
35	10190017	3.0	1.4
36	10190018	33.1	12.4
37	10200101	36.1	12.8
38	10200102	49.5	16.4
39	10200103	70.4	24.4
40	10200201	61.2	25.8
41	10200202	46.2	23.0
42	10200203	37.7	19.4
43	10210001	0.6	0.2
44	10210002	0.2	0.1
45	10210003	22.3	7.4
46	10210004	21.7	7.5
47	10210005	32.0	10.6
48	10210006	0.8	0.3
49	10210007	23.3	11.1
50	10210008	0.9	0.5
51	10210009	42.4	24.9
52	10210010	20.8	11.0
53	10220001	22.3	13.7
54	10220002	50.6	30.0
55	10220003	59.6	40.3
56	10220004	63.5	40.8
57	10230001	48.1	31.0
58	10230002	65.3	41.8
59	10230003	55.5	32.2
60	10230004	49.2	24.0
61	10230005	57.8	39.1
62	10230006	35.7	22.1
63	10230007	51.7	23.9
64	10240001	42.3	23.6
65	10240002	56.9	31.4
66	10240003	46.7	26.2
67	10240004	48.8	26.1
68	10240005	44.6	24.8
69	10240006	38.4	20.9
70	10240007	17.8	9.9
71	10240008	33.6	17.3

TABLE E.3 (Cont.)

Sub-basin	Huc #	N Fertilizer Input (kg/Ha)	P Fertilizer Input (kg/Ha)
72	10240009	32.6	16.9
73	10240010	32.7	17.9
74	10240011	22.3	16.1
75	10240012	0.0	0.0
76	10240013	0.1	0.0
77	10250001	13.4	4.6
78	10250002	11.6	4.0
79	10250003	11.6	4.4
80	10250004	15.2	5.0
81	10250005	33.2	10.5
82	10250006	22.6	7.6
83	10250007	27.3	11.2
84	10250008	16.1	5.9
85	10250009	24.2	9.9
86	10250010	40.8	17.1
87	10250011	29.9	13.6
88	10250012	40.3	18.3
89	10250013	33.3	12.4
90	10250014	24.9	9.3
91	10250015	31.5	11.2
92	10250016	28.0	15.0
93	10250017	17.9	12.0
94	10260001	14.0	5.6
95	10260002	30.7	11.0
96	10260003	15.7	7.3
97	10260004	31.1	12.4
98	10260005	30.3	12.4
99	10260006	12.5	6.7
100	10260007	15.0	6.6
101	10260008	11.7	7.7
102	10260009	14.6	6.2
103	10260010	9.3	5.3
104	10260011	22.6	8.9
105	10260012	16.7	8.9
106	10260013	21.7	8.6
107	10260014	15.1	7.9
108	10260015	17.3	10.3
109	10270101	5.6	3.4
110	10270102	9.0	5.6

TABLE E.3 (Cont.)

Sub-basin	Huc #	N Fertilizer Input (kg/Ha)	P Fertilizer Input (kg/Ha)
111	10270103	15.5	9.6
112	10270104	13.1	8.8
113	10270201	68.8	31.0
114	10270202	38.1	20.3
115	10270203	71.7	28.7
116	10270204	51.3	24.0
117	10270205	15.0	10.2
118	10270206	51.1	21.8
119	10270207	18.4	11.0
120	10280101	11.1	7.6
121	10280102	14.1	10.5
122	10280103	10.1	10.2
123	10280201	12.0	8.7
124	10280202	11.3	9.2
125	10280203	11.4	8.2
126	10290101	10.4	6.6
127	10290102	9.2	6.4
128	10290103	11.6	6.4
129	10290104	9.0	4.7
130	10290105	6.5	3.9
131	10290106	2.2	1.0
132	10290107	1.2	0.3
133	10290108	9.4	6.6
134	10290109	0.8	0.3
135	10290110	1.0	0.3
136	10290111	2.9	1.2
137	10290201	1.3	0.3
138	10290202	1.2	0.3
139	10290203	1.2	0.6
140	10300101	19.3	13.2
141	10300102	9.0	5.7
142	10300103	14.9	9.5
143	10300104	29.7	18.3
144	10300200	7.8	4.7



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