APPENDIX D

Soil and Water Assessment Tool

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EXECUTIVE SUMMARY

A calibrated Soil and Water Assessment tool (SWAT) model was developed for the Sulphur River Watershed upstream of Wright Patman Dam to investigate sedimentation issues in the watershed. Input data including elevation, soil, land use, climate, stream flow, sediment loads, pond characteristics and reservoir characteristics were obtained from a variety of sources. Attachment 1.1 is a map of the watershed showing the 25 subbasins.

The SWAT model was calibrated for flow using flow data from 1992 to 2000 measured at five U.S. Geological Survey streamgages and calculated U.S. Army Corps of Engineers adjusted inflow data for Wright Patman Lake. Data from the same locations were used for model validation from 2001 to 2010. Comparison of calibrated modeled flow to measured flow data produced Nash-Sutcliffe coefficient (NSE) of determination values of 0.59 to 0.75 at the six calibration subbasins on a monthly time step. Comparison of validation time period modeled flow to measure flow data produced NSE values of 0.70 to 0.85 at the six validation subbasins on a monthly time step. Sediment loading to Wright Patman Lake was calibrated using the average annual sedimentation rate for 1997 to 2010 measure by Texas Water Development board. For a simulation period of 1997 to 2010, the calibrated SWAT model produced an average annual sediment load of 812, 181 metric tons to the lake. The entire quality control review summary is available in Attachment 2.

This model was then used to assess six sediment best management practices (BMP) in the Sulphur River Watershed for the potential to reduce sediment loads to Wright Patman Lake. This assessment was conducted by evaluating two BMP scenarios against a baseline scenario which assumed the proposed Lake Ralph Hall reservoir was in use and no additional BMPs were implemented. It was concluded that four of the six BMPs (Filter Strips, Cropland to Pasture, Channel Grade Control, and Riparian Buffer Strips) provided the greatest reduction in sediment loads to Wright Patman Reservoir (28% reduction).

Additional iterations of the baseline and BMP scenarios were conducted to assess effects of future water supply reservoir alternative locations. Each of four alternative locations for new water storage (Parkhouse I, Parkhouse II, Talco, and Marvin Nichols 1A) were assessed separately for the three scenarios. Modeled results suggest that yields of all of the future water supply alternatives would be affected over time by sedimentation and that this impact could be substantially mitigated by implementation of sediment BMP's.

1.0 INTRODUCTION

Freese and Nichols, Inc. was contracted to conduct a study of sedimentation within the Sulphur River watershed and an assessment of sediment best management practices (BMPs) designed to reduce sediment loads to existing and potential future water supply reservoirs. This investigation was conducted in three parts: **(1)** The sediment study, which used the Soil and Water Assessment Tool (SWAT) model for the Sulphur River Watershed upstream of Wright Patman Dam to calculate subbasin sediment loads, **(2)** The sediment BMP analysis, which used the SWAT model to assess priority locations and evaluate potential effectiveness of BMP implementation, and **(3)** The future alternatives assessment, which used the SWAT model to calculate changes in sediment loading within the Sulphur River Watershed following the construction of future proposed water reservoirs within the study area. This document provides a consolidated report of these three project tasks, covering the methods and analysis used to evaluate sedimentation during the calibration period (1992 -2000) and the validation period (2000 – 2010) as well as the results of modeled annual sedimentation rates and predicted BMP scenario effects on sediment loads and sediment yields within the watershed.

1.1 SULPHUR RIVER WATERSHED OVERVIEW

The Sulphur River watershed drains approximately 3,410 square miles (8,834 square kilometers) upstream of Wright Patman Dam near Texarkana, TX (Attachment 1.1). The Sulphur River watershed contains all or part of Bowie, Cass, Delta, Fannin, Franklin, Hopkins, Hunt, Lamar, Morris, Red River, and Titus counties. Downstream of Wright Patman Dam, the Sulphur River flows generally east and southeast and is a tributary to the Red River.

The North Sulphur River and the South Sulphur River both originate in Fannin County and flow eastward to their confluence in southeast Lamar County. This confluence is the start of the Sulphur River. An extensive channelization program in the Sulphur River watershed began in the 1920's, primarily for the North Sulphur River and South Sulphur River. White Oak Creek drains the southern portion of the watershed and is the largest tributary of the Sulphur River.

The White Oak Creek–Sulphur River confluence is north of Naples, TX in northeast Morris County.

The Sulphur River basin is located in the Texas Gulf Coastal Plain physiographic province and occupies portions of the Blackland Prairie and Interior Coastal Plains physiographic subprovinces. The Blackland Prairie, in the western portion of the watershed, is described as having a gently undulating surface that has been cleared of most natural vegetation for agricultural purposes and underlain by chalks and marls that have weathered to deep, black, fertile clay soils (Wermund, 1996). The Interior Coastal Plains are characterized by pine and hardwood forests with numerous permanent streams, underlain by alternating belts of shale and un-cemented sands (Wermund, 1996). Trees are present on the majority of the floodplains in watershed. Elevation in the watershed ranges from approximately 180 feet (56 meters) to 925 feet (282 meters) above mean sea level (Attachment 1.2).

The climate of the Sulphur River watershed is classified as humid subtropical (R.J. Brandes Company, 1999). Rainfall ranges from approximately 1,005 millimeters (40 inches) in the western portion of the watershed to approximately 1,285 millimeters (51 inches) at the Texas–Louisiana State Line (Attachment 1.3). Land use in the Sulphur River watershed is primarily pasture, forest, and rangeland. Urban development in the basin is concentrated around a few small cities including Commerce, Paris, Sulphur Springs, New Boston and Clarksville.

The Sulphur River watershed contains two large water supply reservoirs. Wright Patman Lake (formerly Lake Texarkana) was impounded in 1956 and is located in the Sulphur River near the Texas-Louisiana state border near Texarkana, TX. Wright Patman Lake has a water storage volume of approximately 97,927 acre-feet as measured in 2010 at elevation 220.6 feet (TWDB, 2012). The original storage volume of the lake was approximately 158,000 acre-feet (TWDB, 2012), producing an approximate storage reduction of approximately 60,073 acre-feet over 54 years. Lake Jim Chapman (formerly Cooper Lake) is on the South Sulphur River near Cooper, TX and was impounded in 1991. According to the 2007 TWDB survey of the reservoir, Lake Jim Chapman had a water conservation storage volume of approximately 260,332 acre-feet at conservation pool elevation (440.0 feet) (TWDB, 2008). The original storage volume of the lake was 273,120 acre-feet, yielding an approximate storage reduction of 12,788 acre-feet over 16 years.

1.1.1 Watershed Reconnaissance

On March 5-7 2012, FNI Hydrologists/Fluvial Geomorphologists performed a field watershed reconnaissance in the Sulphur River watershed to investigate the prevalence of channel erosion/sedimentation in 1st through 6th order channels. A total of 48 sites distributed throughout the watershed were visited during the reconnaissance. All sites were located upstream or downstream of bridge or culvert crossing locations. Evidence of channel erosion and/or sedimentation (deposition) was observed in nearly all of the sites that were visited. During the field reconnaissance, it appeared that the majority of sediment being deposited on the floodplains immediately adjacent to the channels was sediment of sand-size or larger. This suggests the fine grained material (<0.0625 mm) is being transported downstream instead of deposing on the floodplains during flood events. Figure 1 through Figure 6 show examples of some of the channels that were visited.

Figure 1: Looking downstream at Wolf Pen Creek at FM 69 near Sulphur Bluff, TX

Note: At this location, Wolf Pen Creek is a 1st-order stream. Erosion was observed on the channel bed and banks. Bank erosion is providing a sediment source.

Figure 2: Looking upstream at Canes Creek at Highway 137 near Roxton, TX

Note: At this location, Canes Creek is a 1st-order stream. This channel was incised into shale bedrock and was a major sediment source not typical of other first-order streams in the watershed.

Figure 3: Looking downstream at the Sulphur River floodplain at TX 37 near Bogata, TX

Note: At this location, the Sulphur River is a 5th-order stream. The start of the Sulphur River log jam is downstream of the TX 37 bridge. Sediment is being deposited on the floodplain in the form of dunes.

Figure 4: Looking upstream at the North Sulphur River at TX 24 near Ladonia, TX

Note: At this location, the North Sulphur River is a 4th-order stream. The channel is incised and widening as a result of past channelization. Shale that composes the bed and banks of the channel is a major sediment source and slakes to 75% silt and clay (Harvey et al., 2007).

Figure 5: Looking upstream at an unnamed creek at TX 154 near Birthright, TX

Note: At this location, the unnamed creek is a 1st-order stream. The stream appears channelized, but has remained stable because vegetation is growing on the banks. This channel is not a significant sediment source.

Figure 6: Looking downstream at White Oak Creek at US 259 near Omaha, TX.

Note: At this location, White Oak Creek is a 4th-order stream. The right bank was eroding, while the left bank appeared mostly stable. The eroding bank is a sediment source

2.0 METHODOLOGY

The assessment of annual sediment loads within the Sulphur Watershed and the potential effects of sediment BMPs was conducted using a calibrated and validated SWAT model. The SWAT model (Arnold et al., 1998) is a continuous simulation model that operates on a daily time step. SWAT was developed by the USDA-Agricultural Research Service as a method to simulate non-point source pollution transport at the watershed scale. Primarily, SWAT is used to predict the impact of watershed management practices on downstream flows, sediment loading, and nutrient and chemical yields in small (less than 0.4 square miles) to large (>200,000 square miles) gaged and ungaged watersheds (Gassman et al., 2007). Watershed management practices include reservoir construction and operations, groundwater pumping, inter-basin water transfers, agricultural practices, best management practices (BMPs), urbanization, and wastewater effluent discharges, among many others. The SWAT model is a watershed-scale model that is 1) spatially and physically based, 2) uses readily available input data, and 3) is capable of producing valid results over long time periods under a number of land-management scenarios (Arnold et al., 1998).

2.1 The SWAT Model

SWAT2009 is the latest version of the model and is available as an extension to ESRI's ArcMap 10 geographical information system (GIS) software. SWAT utilizes ESRI's Spatial Analyst tools to delineate watersheds using a digital elevation model (DEM) and user-defined outlet points. The SWAT model watershed delineator divides the investigation watershed (or watersheds) into multiple sub-watersheds (subbasins) on the basis of user-specified criteria. SWAT will choose subbasin outlet points based on a user-specified delineation area threshold, or the user can input specific outlet locations. Subbasins are further divided into Hydrologic Response Units (HRU's), each with a unique combination of soils, slope, and land use characteristics, on the basis of user-defined delineation thresholds. Elevation (DEM), soil, and land use data are supplied by the modeler. Reservoirs, as with BMPs, are modeled in SWAT at the subbasin level. Outflow from the subbasin (water, sediment, nutrients, etc.) is routed through the reservoir before entering the next subbasin. Measured daily weather data (precipitation, minimum and maximum temperature, wind speed, solar radiation, and relative humidity) can be provided as input to the model, or weather parameters can be simulated and distributed across the watershed. Watershed management scenarios are manipulated by editing various input parameters that affect water, sediment, and nutrient sources and routing, agricultural practices, physical landscape and channel characteristics, and land use change over time.

2.1.1 SWAT Model Inputs and Data Sources

Digital model input data were obtained from various public sources. All spatial data were re-projected into the North American Datum 1983 Texas Centric Mapping Systems Albers geographic coordinate system using ESRI ArcMap.

2.1.2 Elevation Data

Digital elevation data were obtained from the USGS National Elevation Dataset (USGS, 2012). The elevation data used in the SWAT model had a resolution of one arc-second (30 meters), which allowed for detailed subbasin delineation (Figure B-2). The data were downloaded from the USDS-NRCS Geospatial Data Gateway at the county scale.

2.1.3 Soil Data

Soils data model input for the Sulphur River watershed were developed using the USDA-NRCS Soil Survey Geographic (SSURGO) database (USDA-NRCS, 2009a-2009g, 2010a and 2010b). This soils database has a scale of 1:24,000 and is published in ESRI Shapefile format with an associated tabular database for each county (or counties). The coverages of the individual digital databases have the same coverage as the printed county soil survey reports. The shapefiles were re-formatted as ESRI grid files (raster) with 30-meter resolution for use in the SWAT model.

2.1.4 Land Use Data

Land use data were obtained from two sources: the National Land Cover Dataset (NLCD) (USGS, 2011) and the National Agricultural Statistics Service (NASS) (USDA-NASS, 2012). The NLCD

2006 dataset was used as input to the Sulphur River watershed SWAT model (Table 2.1 and Attachment 1.4 – 1.5). SWAT is pre-programmed to use the land use and land cover types/names in the NLCD dataset. The NLCD dataset had a resolution of 30 meters.

The NASS data were used to determine the amount of cropland in the watershed and the relative effects that crop rotation may have on water, sediment and nutrient outputs. SWAT models water, sediment, and nutrient runoff from cropland differently for different types of crops. Therefore, semiannual, annual or biannual crop rotation practices can affect the annual runoff and loading results from cropland. Approximately 4.5% to 8 % of the Sulphur River watershed was characterized as cropland in the three years (2009, 2009, and 2010) of NASS data. It was assumed that crop rotation practices on this small of a percentage of the total land area in the watershed would not appreciably affect water, sediment and nutrient output values.

Table 2.1: Land Use Percentages in the Sulphur River Watershed

Land use	Percent Cover
Urban	5.8
Forest	22.5
Rangeland	16.8
Pasture/Hay	34.0
Cropland	7.9
Wetland	9.8
Water	3.1
Other	0.1

2.1.5 Climate

Daily precipitation and maximum and minimum temperature data were obtained for National Oceanic and Atmospheric Administration (NOAA) weather stations in the following Texas counties in and around the Sulphur River watershed from 1950 to 2010. The USDA-ARS has compiled precipitation and minimum and maximum temperature data for all weather stations in the United States from January 1, 1950 to December 30, 2010 (USDA-ARS, 2012). Climate data from USDA-ARS are delivered in SWAT rainfall and temperature format, and no additional formatting was necessary.

2.1.6 Reservoirs

Reservoir data required by SWAT include the start date of reservoir operations, the storage volume and surface area at the conservation storage elevation, storage volume and surface are at the emergency spillway elevation, the initial sediment concentration in the reservoir, and the normal suspended sediment concentration in the reservoir. The storage volume and surface area data for Wright Patman Lake and Jim Chapman Lake were obtained from the USACE reservoir pertinent data sheets (USACE, 2012a and 2012b). Sediment data for Wright Patman Lake were obtained from limited suspended sediment measurements at two USGS streamgages: 07343200 (Sulphur River near Talco, TX) and 07344210 (Sulphur River near Texarkana, TX). Sediment data for Jim Chapman Lake were obtained from the USGS streamgage 07342500 (South Sulphur River near Cooper, TX). Reservoir outflows were simulated by SWAT based on upstream inflows, evapotranspiration rates, reservoir seepage loss, and input original/historical reservoir storage volume. Reservoir trap efficiency is the difference between the amount of sediment coming into the reservoir and the amount of sediment leaving the reservoir through releases. The amount of sediment retained in a reservoir during a SWAT model time step is determined by the amount of sediment carried into the reservoir and the amount of water leaving the reservoir as suspend sediment in the released water. The amount of water suspended in the release water is dependent on the normal suspended sediment concentration in the water; the higher the concentration of suspended sediment, the lower amount of sediment retained in the reservoir.

2.1.7 Ponds

Ponds are smaller impoundments such as stock tanks or SCS/NRCS PL-566 flood control structures. The SWAT model aggregates these smaller impoundments in each subbasin. According to the 2010 USACE National Inventory of Dams (NID) database, there are approximately 160 dammed ponds in the Sulphur River watershed (USACE, 2010). For a dam to be included in the NID, it must meet at least one of the following criteria: 1) High hazard classification – loss of one human life is likely if the dam fails, 2) Significant hazard classification – possible loss of human life and likely significant property damage of environmental destruction if the dam fails, 3) Equal or exceed 25 feet in height and exceed 15 acre-feet in storage, or 4) Equal or exceed 50-acre-feet storage and exceed six feet in height. Ponds act as water, sediment and nutrient traps. Subbasin water, sediment and nutrient yields are affected by the percentage of subbasin area that drains to a pond. SWAT requires the percentage of subbasin area draining to ponds as an input. Pond drainage area data in the NID database can be unreliable, so new pond drainage areas were calculated for the NID ponds in the Sulphur River watershed using ArcGIS ArcHydro tools. Other ponds, not included in the NID, are present in the watershed and were observed on aerial photographs. These smaller ponds were not included in the NID, and the area draining to these ponds was assumed to be insignificant for the purposes of this analysis. Other pond data required by SWAT include total pond surface area and storage volume in each subbasin and sediment concentration in the water spilling out of the ponds. Sediment concentration was set to zero to simulate 100% sediment trap efficiency. Any residual model bias (bias is a measure of the tendency of a model to over-predict or under-predict) caused by this assumption was eliminated during the flow and sediment calibration phase. Other input parameters were obtained from the NID database when available.

2.2 WATERSHED CONFIGURATION

2.2.1 Subbasin Delineation

ArcSWAT Version 2009.10.1 Beta3 (released 7/26/2011) was used in ERSI ArcMap 10.0 (Build 4000) to delineate subbasins (automatic delineation) within the Sulphur River watershed. A stream definition threshold of 10,000 hectares was used for subbasin delineation. Subbasin outlet points were added at existing and potential future reservoir locations. Automatically delineated subbasin outlet points were adjusted until all subbasins were relatively similar in areal extent. The watershed was delineated with 25 subbasins (Attachment 1-1). Subbasin 13 was located downstream of Wright Patman Dam for model stability purposes and was not included in additional analysis.

2.2.2 Hydrologic Response Units

SWAT further divides subbasins into Hydrologic Response Units (HRUs.) HRUs are delineated on the basis of land use, soil type, and slope, and each HRU has a unique combination of land use, soil type, and slope. Additionally, each HRU is modeled with one management practice based on the combination of land use, soil and slope. Three slope classes (m1, m2, and m3), with slope in units of meter/meter, were defined as $0 \leq m1 < 2$, $2 \leq m2 < 5$, and $5 \leq m3 < \infty$ after Amatya et al (2008). Multiple HRUs were defined by setting the land use, soils, and slope class area thresholds to 10%. First, all land use classes not equal or exceeding 10% of the area in each subbasin were removed. Second, all soil classes were removed that did not account for at least 10% of the area of a land use class. This step generates a number of unique land use/soil classes in each subbasin. Finally, all slope classes were removed that did not account for at least 10% of the area of a soil class within a land use class. The HRU delineation process produced 447 unique HRUs for the Sulphur River watershed.

2.2.2 Other Model Inputs

In addition to the input parameters discussed in the previous sections, SWAT simulates surface runoff, groundwater-surface water interactions, and flow using a number of other input values and coefficients. The following parameters were set to the model default values during the initial model runs and were adjusted during the model calibration phase.

2.2.3 Groundwater

SWAT simulates shallow aquifer storage and its effects on soil moisture and streamflow. ALPHA_BF is the baseflow alpha factor, or the baseflow recession constant. It is an index of groundwater flow response in response to changes in recharge (Smedema and Rycroft, 1983). ALPHA_BF values can range from 0.0 to 1.0. The higher the value, the higher the rate of groundwater flow to the main channel. GW_DELAY is the groundwater delay time, in days. It is a measure of the amount of time necessary for water to pass through the soil profile and enter the shallow aquifer as recharge. The GW_DELAY value depends on the thickness of the soil profile and the hydrogeological properties of the soil and underlying geology. GWQMIN is the threshold depth of water in the shallow aquifer required for return flow to occur to the channel. Flow from the shallow aquifer to the channel is not allowed until the defined GWQMIN threshold is reached. GW_REVAP is a coefficient that controls the amount of water allowed to move from the shallow aquifer up into the root zone for evaporation or use by plants. Higher values of GW_REVAP mean more water is available for evaporation or uptake.

2.2.4 Soil Properties

ESCO is the soil evaporation compensation coefficient. As ESCO values are reduced, the model is able to extract more water from lower levels of the soil for evaporation. For example, if soil evaporation increases, soil moisture content decreases, curve number decreases, and surface runoff decreases. ESCO values can be adjusted to affect the amount of surface runoff in an HRU on a daily time step.

2.2.5 Channel Properties

The effective hydraulic conductivity in the main channel alluvium is controlled by CH_K(2). It is a measure of the amount of water lost from the stream channel to the underlying shallow aquifer. Higher values of CH_K(2) allow more water to be lost from the channel bottom during routing. CH_N(2) is the Manning's n value for the main channel. Manning's n is a coefficient that represents channel roughness. Flow velocities decrease as channel roughness increases, decreasing the sediment transport capacity of the channel. SURLAG is the surface runoff lag coefficient. It controls the fraction of the total available surface runoff volume that is allowed to enter the reach on any one day. Higher values of SURLAG increase the amount of time necessary for surface runoff to reach the stream channel, thus smoothing the modeled streamflow hydrograph. CH_COV1 is the channel erodibility factor and CH_COV2 is the channel cover factor. Both variables can range from 0.0 to 1.0, and higher values allow for more channel erosion. SPCON is a linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing. Higher values of SPCON reduce the amount of sediment transported through the reach during the time step. SPEXP is an exponent that also affects sediment re-entrainment. Higher values of SPEXP increases the amount of sediment transported through the reach during the time step.

2.3 MODEL CALIBRATION AND VALIDATION FOR SEDIMENT ANALYSIS

2.3.1 Flow Calibration

Model calibration is the practice of comparing simulated (modeled) values to measured (observed) values over a period of time, and adjusting model input parameters until modeled values satisfactorily match observed values. Flow data from five USGS streamgages were used for progressive model calibration (Table 2.2). USACE-adjusted reservoir inflow data for Wright Patman Lake were used for an additional calibration point in subbasin 12.

Table 2.2: USGS Streamgages used for SWAT Model Calibration and Validation

USGS Streamgage ID	Streamgage Name	SWAT Subbasin
07342465	South Sulphur River near Commerce, TX	23
07342480	Middle Sulphur River near Commerce, TX	21
07343000	North Sulphur River near Cooper, TX	3
07343200	Sulphur River near Talco, TX	10
07343500	White Oak Creek near Talco, TX	19

Flow data at the five stream gages and Wright Patman Lake were available from 1992 to 2010. The Sulphur River watershed SWAT model was calibrated for flow on a daily time step from January, 1 1992 to December 31, 2000. USGS measured daily mean flow (adjusted for subbasin drainage area) was compared to FLOW_OUT (average daily flow out of reach during time step) using SWAT-CUP Version 4.3.7.1 and the SUFI-2 optimization algorithm (Abbaspour, 2011). SWAT-CUP is an automatic calibration tool that allows the user to evaluate multiple ranges and combinations of sensitive input parameters during multiple iterations to determine the best combination of input parameter values. The Nash-Sutcliffe coefficient of determination (NSE) (Nash and Sutcliffe, 1970) was the objective function used to determine how well the model output matched the measured flow values. NSE can range from $-\infty$ to 1. An NSE = 1 corresponds to an exact match of modeled values to observed values. An NSE = 0 indicates that the model produces results as accurate as the mean of the observed values. If NSE < 0, the mean of the measured values is a better predictor than the model. Coefficient of determination (R2) values were also used to indicate the goodness-of-fit of the modeled data to the measured data. R2 values range from 0 to 1 with higher values indicating less model error.

R2 values are over-sensitive to outliers, and are not able to account for model bias (Moriasi et al., 2007). Moriasi et al. (2007) suggests that NSE is the best method for measuring model efficiency in watershed models because it is able to account for the tendency of a model to under-predict or over-predict observed values.

Progressive model calibration means that the subbasins upstream of the farthest upstream streamgages are calibrated first, and calibration continues for the next downstream streamgages using upstream calibrated values. ALPHA_BF, GW_DELAY, GWQMN, GW_REVAP, ESCO, CH_K(2), and CH_N2 were used as flow calibration parameters. These values were adjusted to accurately simulate flow and produce the highest possible NSE values on a daily time step (Attachment 2).

2.3.2 Flow Validation

Model validation is the process of comparing calibrated model results to observed values during a time period different that that used for model calibration. The Sulphur River watershed SWAT model was validated using NSE from January 1, 2001 to December 30, 2010.

2.3.3 Sediment Calibration

SWAT model sediment calibration was performed by comparing the average annual modeled sediment loads to Wright Patman Lake as measured by TWDB with the average annual sediment loads predicted by the SWAT model. The TWDB performed reservoir volumetric surveys for Wright Patman Lake in 1996-1997 and in 2010 (TWDB, 2003 and TWBD, 2012). According to the TWDB, Wright Patman Lake lost 17,788 acre-feet of capacity at elevation 220.6 feet. between the two sediment survey dates. This equates to an approximate annual sedimentation rate of 1,368 acre-feet per year.

The measured annual sediment rate had to be converted to an annual sediment load in order to compare it to modeled sediment loads. As part of this project, Specialty Devices Inc. (SDI) collected five sediment cores in Wright Patman Lake at the approximate locations that the TWDB collected cores as part of their sedimentation survey. The density of lake-bottom sediment was measured from each core and averaged to produce an average lake sediment density of 31.14 pounds per cubic foot (Attachment 3. This sediment density produced a measured annual average sediment load of 841,701 metric tons per year between the two TWDB survey dates.

The simulated average annual sediment load from January 1997 to June, 2010 (13.5 years) was compared to measured sediment load, and appropriate sediment input parameters (CH_COV1, CH_COV2, SPCON, and SPEXP) were adjusted until the modeled annual sediment load to Wright Patman Lake was equal to the measured load (Attachment 3). The final adjusted input values for flow and sediment model calibration are presented in Table 2.3.

Table 2.3: SWAT input variables adjusted for calibration of flow and sediment

Variable	Description	Units	Input Value
ALPHA_BF	Baseflow alpha factor	days	0.30 to 0.69
GW_DELAY	Groundwater delay time	days	5 to 22
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	mm	86.5 to 176.6
GW_REVAP	Groundwater re-evaporation coefficient	-	0.06 to 0.17
ESCO	Soil evaporation compensation factor	-	0.81 to 0.86
CH_K(2)	Effective hydraulic conductivity in main channel alluvium	mm/hr	0.17 to 4.23
CH_N(2)	Manning's "n" value for the main channel	-	0.025
SURLAG	Surface runoff lag coefficient	-	1.69
CH_COV1	Channel erodibility factor	-	0.3
CH_COV2	Channel cover factor	-	0.5
SPCON	Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing	-	0.0008
SPEXP	Exponent parameter for calculating sediment re-entrained in channel sediment routing	-	1.15

2.4 BMP FORMULATION AND ASSESSMENT OF EFFECTIVENESS

2.4.1 Assessment of Sediment BMPs

Lee et al. (2010) investigated the potential adoption rates of 21 Best Management Practices (BMPs) whose effectiveness for sediment and nutrient reduction in the Cedar Creek watershed was first assessed by Rister et al. (2009). Lee et al. (2010) reduced this list to eight preferred BMPs based on total phosphorus reduction at 100% application rate and the cost of BMP implementation per ton of total phosphorus reduction, with cost effectiveness having the highest priority. The BMPs that reduced total phosphorus loads the greatest amounts were also the most effective at reducing sediment loads. These eight BMPs were considered for use in this evaluation. Two BMPs were added to the Sulphur River Basin BMP analysis based on the experience of the FNI investigators. These BMPs were channel grade control and riparian buffer strips. The FNI investigators noted channel erosion in the majority of sites visited (48 total) during the watershed reconnaissance. Channel grade control structures have been observed to decrease channel erosion in other streams and rivers in North Texas. It is assumed that they could have the same effect on channel erosion in the Sulphur River Basin. Riparian buffer strips were addressed in Lee et al. (2010) but were not included in their final analysis. In an earlier study (Narashimhan et al., 2007), riparian buffer strips significantly reduced sediment loads, but only generated minimal reductions in phosphorus loading. It was determined that they were not a cost-effective BMP for phosphorus reduction and were not included in the Lee et al. (2010) final assessment, but were expected to be relevant in this effort.

The BMPs assessed as part of this study are as follows (asterisk denotes BMP included in the Lee et al. (2010) study):

- Filter Strips*
    - Strips of dense vegetation located between agricultural fields and adjacent water bodies. The filter strip intercepts runoff from upslope (field with crop, pasture, disturbance, etc.) and filters it before it enters the water body. The vegetation in the filter strip slows the flow velocity of the runoff causing suspended sediment to settle out and increases infiltration which reduces runoff volume.

- Terrace*
    - An embankment within a field designed to intercept runoff and prevent erosion. Terraces are constructed across the field slope, on a contour. Terraces reduce slope length, thereby reducing surface runoff velocity. Terracing also promotes infiltration of surface water runoff.
- Cropland to Pasture*
    - Fields that have traditionally been used for row crop agriculture are converted to improved pasture. Improved pasture is pasture where crops such as hay are planted and grazing is permitted. Runoff rates and volumes are typically higher in row crop agriculture than in any other rural land use. Increased ground cover in an improved pasture reduces surface runoff rates and promotes infiltration.
- Critical Pasture Planting*
    - Existing drainage swales in agricultural fields are planted with perennial grasses to decrease erosion and increase roughness. Increased roughness decreases flow velocities, which promotes settling of suspended particles and increases infiltration.
- Channel Grade Control
    - Channel grade control involves the placement of grade (slope) stabilization structures in stream or river channels. Channel grade control structures are typically constructed of concrete, rock, and/or compacted earth and artificially decrease the slope of the channel. Decreased channel slopes (flatter slopes) produce lower flow velocities, which generate less erosive forces. Slower velocity flow also promotes settling of suspended particles and increased infiltration through the channel bed and banks.

- Riparian Buffer Strip
    - An area of predominantly trees and/or shrubs located adjacent to a water body (stream, river, lake, etc.). Riparian buffer strips, also known as riparian corridors and riparian forest buffers, reduce the sediment load to a stream from the surround landscape by reducing runoff velocity, causing particulate suspended particles to drop out, and increasing infiltration.

Lee et al. (2010) reports the following sediment reduction amounts for the BMPs that are listed above (Table 2.4). The rates were initially reported by Narashimhan et al. (2007). They represent the BMP effectiveness at 100% adoption rates in the Cedar Creek watershed.

Table 2.4: BMP Effectiveness at 100% Adoption Rate in Cedar Creek Watershed (from Narashimhan et al. (2007) reported in Lee et al. (2010)

BMP	Note	Annual Sediment Reduction Rate (%)
Filter Strips	15 meter width	22.0
Terrace	Cropland with slope steeper than 2%	7.0
Cropland to Pasture	--	28.0
Critical Pasture Planting	Only in critical areas	4.4
Channel Grade Control	--	2.4
Riparian Buffer Strip	--	23.0

A number of the BMPs discussed by Lee et al. (2010) were not applicable to the Sulphur River Basin study. The non-applicable BMPs included grade stabilization structures, Waste Water Treatment (WWTP) level II, prescribed grazing, and 2,000 foot buffer. The following bullet points describe the non-applicable BMPs and describe why they were not included in this BMP analysis for the Sulphur River watershed.

- Grade stabilization structures essentially decrease the land surface slope of all land surfaces. For this study, it was assumed that terracing would provide adequate land surface slope reduction.

- Wastewater level II treatment is a BMP that is used to primarily decrease nutrient loading, and had no effect on sediment loads in Lee et al. (2010).
- Prescribed grazing is typically used as a nutrient reduction BMP. Its benefits are two-fold: 1) cattle waste (manure) is limited in a pasture which reduced nutrient loads, and 2) the potential for over grazing is reduced and the remaining vegetation slows surface runoff to increase infiltration, nutrient absorption, and sediment deposition. Other studies suggest that by limiting manure deposition in pasture fields, crop yields can be reduced to the point that the sediment loads increase because of decreased biomass and ground cover. The sediment reduction benefit of prescribed grazing was lower than other land surface BMPs in Lee et al. (2010), so it was not included in this analysis.
- The 2,000 foot buffer referred to a fertilizer exclusion zone around Cedar Creek Reservoir. It had minimal effects on sediment loads in Lee et al. (2010).

2.4.2 Sediment Load versus Sediment Yield

BMPs applied to cropland decrease sediment yield. A lower sediment yield produces a lower sediment load. It is important to note that the reduction in sediment load is not always proportional to the reduction in sediment yield. Also, sediment yields are only affected by land surface BMPs (filter strips, terraces, converting cropland to pasture, and critical pasture planting). Sediment loads are affected by the cumulative effects of land surface BMPs and channel BMPs (channel grade control and riparian buffer strips). The differences between terms "sediment load" and "sediment yield" are described in the following bullet points:

- Sediment load
  - Sediment load is the total amount of sediment that passes through the outlet of each subbasin, carried by flowing water in the channel; also known as sediment discharge.
  - Units = mass per unit time
- Sediment yield

- Sediment yield is the amount of sediment that enters the main channel in each individual subbasin per unit area of the subbasin, originating from overland erosion.
- Units = mass per unit area per unit time

- Total sediment yield
    - Total sediment yield is the total amount of sediment entering the main channel from overland erosion in each individual subbasin.
    - Total sediment yield is calculated by multiplying the SWAT-calculated sediment yield by the total area of the individual subbasin.
    - Units = mass per unit time

2.4.3 BMP Model Scenarios

This BMP assessment consisted of three SWAT model scenarios. The first scenario (Baseline Scenario) was a modified version of the existing condition model run from the methods described in Section 2.1. The existing condition model run was modified for this BMP study by adding the proposed Lake Ralph Hall on the North Sulphur River in Fannin County, TX. The results from this scenario provided the baseline (without-BMP) model results to which the other model runs would be compared. The second and third model scenarios were run by applying two different combinations of BMPs to the watershed. BMPs were modeled assuming a 100% BMP adoption rate.

BMPs were not applied in the entire watershed. BMP modeling efforts were focused on the subbasins that produced the highest sediment yields in the baseline model scenario. Land surface BMPs (filter strips, terraces, converting cropland to pasture, and critical pasture planting) were only applied to cropland in the Sulphur River watershed. Cropland accounts for approximately 7.9 percent of the land cover in the watershed (FNI, 2012). Channel BMPs (channel grade control and riparian buffer strips) were only applied to the main channels in the target subbasins that met the application criteria.

The application criteria considered the existing channel slope relative to channel slope prior to the channelization efforts on the North Sulphur River and South Sulphur Rivers. Harvey et al. (2007) reported that the slope of the channel of the North Sulphur River was 0.0008 feet/foot (ft/ft) prior to channelization. It was assumed that this channel slope was the stable channel slope for the main channels. The channel grade control BMP was applied to only the target subbasin with an average main channel slope steeper than 0.0008 ft/ft. Channel BMPs were not applied to tributary channels because other land surface BMPs (filter strips and critical pasture planting) affect some of the tributary channels. Assessing multiple alternative channel BMP effectiveness in tributary channels was beyond the scope of this study. Channel BMPs could also have been applied to other subbasins in the watershed, but focus was put on the subbasins with the highest sediment yields. A future BMP feasibility study could better address the applicability and effectiveness of multiple channel BMPs throughout the entire watershed. The following bullet points describe the locations where BMPs were applied in the target subbasins and the values given to the applicable model variables to simulate them in SWAT:

- Filter Strips – Subbasins 3, 4, 6, 7, 15, 18, 21, 22, 23, 24
    - Applied to all cropland in the target subbasins
    - VFSI = 1
    - VFSRATIO = 40
    - VFSCON = 0.5
    - VFSCH = 0.0
- Terrace – Subbasins 3, 4, 6, 7, 15, 18, 21, 22, 23, 24
    - Applied to all cropland and pasture with slope >2% in the target subbasins
    - TERR_P = 0.12
    - TERR_CN = 60
    - TERR_SL = 20

- Cropland to Pasture – Subbasins 3, 4, 6, 7, 15, 18, 21, 22, 23, 24
    - Applied to all cropland in the target subbasins
    - Change existing default agriculture management operations to pasture operation. Planting of hay scheduled by heat units
    - PLANT_ID = Hay
    - CNOP = 40
- Critical Pasture Planting – Subbasins 3, 4, 6, 7, 15, 18, 21, 22, 23, 24
    - Applied to all land uses in target subbasins
    - Change Manning's n value (roughness factor) of tributaries in the target subbasins from the default values of 0.035 to 0.15
- Channel Grade Control – Subbasins 4, 7, 21, 22, 23, 24
    - Applied to target subbasins with main channel slope greater than 0.0008 feet/foot
    - Reduced the main channel slope in the target subbasins to the stable North Sulphur River channel slope prior to channelization (Harvey et al., 2007) = 0.0008 ft/ft
- Riparian Buffer Strips – Subbasins 3, 4, 6, 7, 15, 18, 21, 22, 23, 24
    - Channel cover factor increased from default (0.5) to 0.1 to simulate riparian vegetation growth

Table 2.5 provides the total area of the target subbasins and the extents of BMP application in each target subbasin.

The second model scenario (Intensive BMP Scenario) used all six BMP's listed above. Sediment reduction rates were estimated by comparing the sediment load and sediment yield results from the Baseline Scenario to the results of the Intensive BMP Scenario. The third model scenario (Feasible BMP Scenario) used a reduced number of BMPs to investigate the sediment reduction value of the subset of BMPs judged to be the most feasible based on the evaluation of the Intensive BMP Scenario and the experience of the FNI investigators. These BMPs were

Filter Strips, Cropland to Pasture, Channel Grade Control and Riparian Buffer Strips. The results from the Feasible BMP Scenario were compared with the results from the Baseline Scenario to estimate sediment load reduction. The results of the Intensive and Feasible BMP Scenarios were also compared to provide an estimate of the difference in the sediment reduction potential of the two scenarios.

An adoption rate of 100% for any BMP in any part of the watershed is not likely. Rister et al. (2009) developed marginal, or expected adoption rates for BMPs in the Cedar Creek watershed. The marginal adoption rate is rate at which each BMP would likely be implemented in the watershed. Factors influencing BMP adoption were listed earlier and include cost of implementation, cost of implementation versus economic benefit, the willingness of landowners to participate, available government assistance funding, current and anticipated agricultural commodity prices, perceived climate trends, and local versus regional benefits. The marginal adoption rates presented by Rister et al. (2009) were developed through extensive surveys and talks with local stakeholders including landowners, government agencies, and academics and included information such as cost of implementation, maintenance, and design life of each BMP. A similar study would need to be performed in the Sulphur River watershed to develop accurate estimates of marginal BMP implementation. It is likely that the sediment loads generated under marginal BMP application rates would be higher and more realistic than those generated under assumed 100% BMP application rates.

Table 2.5: Modeled BMP application extent assuming 100% BMP adoption rate in the Sulphur River Watershed

Subbasin	Total Subbasin Area (acres)	Filter Strips (acres)[1]	Terrace (acres)[2]	Cropland to Pasture (acres)[3]	Critical Pasture Planting (linear feet)[4]	Channel Grade Control[5]		Riparian Buffer Strip (linear feet)[6]
						Linear feet	Number of 3-foot drops	
3	93,650	293	10,056	28,990	130,840	--	--	78,740
4	64,339	182	802	17,946	86,352	38,451	9.6	38,451
6	102,034	175	9,433	17,319	147,441	--	--	84,679
7	33,747	64	2,572	6,364	93,832	19,587	1.4	19,587
15	93,060	131	16,973	12,972	159,088	--	--	95,243
18	100,171	207	14,191	20,406	144,849	--	--	90,846
21	70,111	120	3,931	11,857	126,837	40,617	2.3	40,617
22	35,306	60	7,814	5,961	102,822	31,791	2.4	31,791
23	137,734	221	22,017	21,847	224,475	156,791	1.6	156,791
24	809,731	111	31,102	10,957	93,930	65,551	4.4	65,551

[1] Filter strip acreage represents the area of cropland that would be taken out of production and converted to filter strips in each subbasin.

[2] Terrace acreage represents the area of cropland and pasture where terraces would be installed in each subbasin.

[3] Cropland to pasture acreage is the total number of acres in each watershed that would be converted from cropland to pasture. At the 100% adoption rate, the cropland to pasture acreage is equal to the total acres of cropland in each subbasin.

[4] Critical pasture planting linear footage is the length of tributary channel in each subbasin that was affected by the critical pasture planting BMP.

[5] Channel grade control linear footage is a measure of the total channel length impacted in each subbasin that would be affected by grade control practices under a 100% adoption rate. The number of 3-foot drops is provided as an example of how many 3-foot high drop structures would be needed to artificially lower the existing channel slope the equilibrium channel slope of 0.0008 ft/ft. The difference between the existing and equilibrium channel slopes was multiplied by the total main channel length to calculate the expected amount of downcutting need for the channel to reach the equilibrium slope. It is a standard engineering practice to limit drop structure height to three feet in order to avoid dangerous hydraulic conditions that can be generated with greater drop heights.

[6] The riparian buffer strip linear footage represents the number of feet of channel in each subbasin where riparian buffer strips would be established. At the assumed 100% adoption rate, this value is equal to the total main channel length in each subbasin

2.5 MODELING EFFECTS FROM POTENTIAL FUTURE WATER SUPPLY ALTERNATIVES

The calibrated and validated SWAT model was used to predict future sediment loads to Wright Patman Lake, both with and without the simulated BMP's. The results of this analyses were used to estimate the loss of storage in Wright Patman Lake over time. These data, in turn, were used to evaluate the effect of sedimentation on future reservoir yields under a variety of reallocation scenarios. A similar process was used to evaluate the effects of sedimentation, and sediment reduction, on alternative new reservoirs considered for implementation within the Sulphur River Basin. The alternative potential reservoir locations are shown in Attachment 1.6.

In order to model potential sedimentation rates in the alternative reservoirs and the subsequent effects on sedimentation in Wright Patman Lake, reservoir characteristics (surface area and capacity at two elevations) were input to the SWAT model. The data were obtained from TWBD (2008) for Parkhouse 1, Parkhouse 2, and Marvin Nichols 1A. Surface area and capacity information for the Talco alternative were obtained from FNI modeling that was completed as part of this study. The input surface area and capacity information are in Table 2.6.

Table 2.6: Potential Future Reservoir Site Water Surface Area and Capacity Information

Reservoir	Elevation (feet)	Surface Area (acres)	Capacity (acre-feet)	Significance
Parkhouse 1	401	22,855	651,712	Conservation Pool
	410	33,506	932,332	Maximum Elevation
Parkhouse 2	410	14,387	330,871	Conservation Pool
	412	15,077	357,920	Maximum Elevation
Marvin Nichols 1A	328	67,392	1,562,669	Conservation Pool
	330	71,406	1,701,463	Maximum Elevation
Talco	370	48,077	1,199,690	Conservation Pool
	380	61,327	1,769,879	Maximum Elevation

2.5.1 Alternative Supplies Model Scenarios

Each reservoir was modeled individually to assess potential sedimentation impacts on the reservoir and on Wright Patman Lake. All model runs assumed Lake Ralph Hall was constructed and fully operating. This resulted in a total of four model runs under Baseline Scenario conditions and four model runs under Feasible BMP Scenario conditions. The sediment concentration in the water of each reservoir was adjusted until the reservoir sediment trap efficiency was greater than 90% (ranged from 92% to 97%). This range is reasonable for Texas reservoirs (Martinez, 2008). The model was run during the sediment calibration period (1997-2010), and sediment inflows to each reservoir over that 14 year period were averaged to produce an average annual sediment load for each reservoir and corresponding sediment loads at Wright Patman Lake.

3.0 RESULTS

3.1 SWAT CALIBRATION, VALIDATION, AND MODELED SEDIMENTATION

3.1.1 Results of Calibration and Validation of the Sulphur SWAT Model

Predicted flow matched well for both the calibration and validation time periods. Flow calibration and validation results were evaluated using NSE and R2 (Section 2.1.4) values on a monthly time step. Table 3.1 contains monthly flow calibration and validation results for the Sulphur River watershed SWAT model. These values indicate an excellent level of model calibration.

Table 3.1: SWAT flow calibration and validation results

	Calibration		Validation	
Subbasin	NSE	R2	NSE	R2
3	0.59	0.70	0.85	0.87
10	0.61	0.74	0.79	0.83
12	0.63	0.72	0.80	0.87
19	0.75	0.75	0.81	0.83
21	0.75	0.79	0.70	0.82
23	0.62	0.76	0.80	0.86

Validation results were slightly higher than the calibration period due to the accurate model predictions of three large runoff events (>1,700 cubic feet per second) during the validation period.

Attachment 2 contains plots illustrating calibration and validation results for the six calibrated subbasins. The flow mass curves and flow duration curves in Attachment 2 suggest that in general, the model over-predicted stream flow during both the calibration and validation period. The model did, however, accurately predict high flow events, which are the most significant flow events when investigating sediment loading.

As stated previously, the sediment calibration was completed by comparing average annual measured sediment loads and volumetric surveys of Wright Patman Lake along with sediment density measurements to modeled average annual sediment loads. The measured average annual sediment load for the assessed time period was 841,701 metric tons per year and the calibrated modeled average annual sediment load was 841,837 tons per year, showing an excellent calibration for this period.

3.1.2 Annual Sediment Yields and Sediment Loads

The Sulphur River watershed SWAT model was run for the entire flow and sediment calibration period (January 1, 1997 to December 30 2010) to produce final existing condition model results. Attachments 1.7 through 1.9 illustrate the spatial distribution of average annual water yield, overland sediment yield, and total sediment loads. Water yield is the volume of water per unit area that enters the main stream channel in each subbasin from overland runoff in units of depth per unit area per unit time. The average annual water yield values in Attachment 1.6 represent the amount of water from each individual subbasin in units of millimeters/hectare/year. Similarly, sediment yield is a measure of the amount of sediment entering the stream channel in each individual subbasin, originating from overland erosion, in units of mass per unit area per unit time. The average annual sediment yields presented in Attachment 1.8 are in units of metric tons/hectare/year. A sediment load can be thought of as a sediment discharge. In other words, it is the amount of sediment passing a point in the watershed over a given period of time in units of mass per unit time. Sediment load values from SWAT are cumulative, meaning that sediment from the upstream subbasins is combined with sediment from a downstream subbasin to produce the total sediment load for the downstream subbasin. The average annual sediment loads presented in Attachment 1.9 are in units of metric tons/year. It is important to remember that the average annual yields and loads modeled using SWAT are average values that can, and will, fluctuate on an annual basis.

In general, average annual water yield increases from west to east in the Sulphur River watershed, with the lowest yields occurring in some northern and central watershed subbasins (Figure B-5). Water yield is affected by a number of parameters including rainfall, soil properties, vegetation, land use, slope, and the percentage of subbasin area draining to ponds. Attachment 1.3 shows that rainfall amounts also increase from west to east.

In general, overland sediment yield decreases from west to east. Sediment yield is affected by similar parameters as water yield including soil properties, density of vegetative cover, land management practices, slope, and the percentage of subbasin area draining to ponds. The soils in the western portion of the watershed are generally more erodible than those in the east. These soils include the Houston Black, Lesson, Crocket, and Freestone soil series. The western subbasins also have higher amounts of cropland (Attachment 1.4 and 1.5) than subbasins in the eastern watershed. Agricultural land uses such as row crops typically produce higher sediment yields than rangeland or forest land uses.

The low sediment yield in subbasin 25 can be attributed to Lake Sulphur Springs. Lake Sulphur Springs was modeled as a pond, because the necessary reservoir operations data were not available. This resulted in 100 percent of the subbasin being modeled as draining to a pond, which means sediment only entered the main channel during times when pond spilling was simulated. Subbasins 3 and 24 have the highest average annual sediment yields. These two subbasins have the highest combinations of agricultural land uses on erodible soils, with minimal amounts of subbasin area draining to ponds.

Total average annual sediment load increases in the downstream direction along the main channel. This was expected, as sediment load is modeled as a cumulative output in SWAT. Increasing sediment loads in the downstream direction simply mean that more sediment is being transported though the downstream subbasins than is being deposited. These results are supported by observations made during the field reconnaissance. Sediment load is modeled as the amount of sediment transported out of the subbasin at by water at the subbasin outlet. Attachment 1.9 shows the Jim Chapman Lake in subbasin 18 is acting as sediment trap; the sediment load in subbasin 18 is higher than the load for subbasin 15 downstream. This shows that sediment modeled as leaving subbasin 18 is trapped by Jim Chapman Lake and is not transported into subbasin 15. It can be expected that potential and planned future reservoirs in the Sulphur River watershed will similarly affect downstream sediment delivery by partially acting as a sediment trap. The total average annual sediment load to Wright Patman Lake for the model period was 812,181 metric tons/year.

The Sulphur River log jam (downstream of Highway 37 near Bagota, TX) is in subbasin 10. The SWAT model suggests that sediment is being transported out of subbasin 10. However, field observations suggest that sand-size and larger particles are being deposited on the floodplain in this location. The geology upstream of the log jam is primarily shale composed of 75% silt and clay (Harvey et al., 2007), and the upstream soil material has a high clay content. It is likely that the majority of the sediment being routed through subbasin 10 is fine grained (<0.0625 mm) material that would stay in suspension and be transported downstream, whereas coarser material (sand size and larger) are likely deposited on the floodplain. Further studies including sediment discharge monitoring upstream and downstream of the log jam location are suggested to quantify the sediment trapping efficiency of the log jam.

The calibrated input values were also applied to simulate historical sedimentation rates under historical climate conditions. The calibrated model over-predicted sediment yields to Wright Patman Lake over the entire period reservoir operation. These results were expected. TWDB sedimentation surveys of Wright Patman Lake (TWDB, 2012) show that sedimentation rates have increased since reservoir operations started in 1956. In summary, historical sedimentation rates were over-predicted because the model was calibrated to present-day sedimentation rates. The increases in erosion and sedimentation over time could have been caused by a number of factors including stream and river channelization, changes in land use practices, and/or climate change. The model may appropriately be used to simulate sediment loads under current or modeled future conditions.

3.2 THE SWAT MODEL AND THE ASSESSMENT OF SEDIMENT BMPS

Given the accuracy of the results for the calibrated SWAT model, this model was used to assess the effects of sediment BMP implementation within the Sulphur Basin study area. This analysis assumes BMP adoption in 100% of the locations where they are proposed. It is likely that some BMPs are already in use in the Sulphur River watershed. If that is the case, it is assumed that those BMPs were included in the landuse, land cover and slope data input to the SWAT model, and are already included in the assessment. A BMP feasibility study that would investigate marginal BMP adoption rates in the Sulphur River watershed would establish the current extent of BMP applications, and the marginal adoption rate could be adjusted accordingly.

The average annual sediment load, sediment yield, and total sediment yield results in Tables 3.2-3.4 include the percentage reduction from the baseline condition (non-BMP scenario) to the two alternative BMP scenarios. Sediment load, sediment yield, and total sediment yield are presented by individual subbasin. All model results in Tables 3.2-3.4 and Attachment 1.10 -1.18 are presented in SWAT standard units (metric). The following are conversion factors that can be used for the reported model results

- 1 metric ton = 1.10231 US tons = 2204.62 pounds
- 1 hectare = 2.47 acres

Average annual sediment loads are reduced to Wright Patman Lake by 31% (240,767 metric tons) and 28% (223,518 metric tons) under the Intensive BMP Scenario and the Feasible BMP Scenario, respectively. It can be concluded from these results that a significant reduction in sediment load to Wright Patman Lake could be obtained by using feasible, cost-efficient BMPs in the Sulphur River watershed. Attachment 1.10 -1.18 illustrate the changes in sediment loads and yields under the different sediment scenarios.

Under baseline conditions (Attachment 1.10) average annual sediment load increased in the downstream direction along the main channel. Under the Intensive BMP Scenario (Attachment 1.11), sediment load still increases in the downstream direction, but with lower sediment loads in the upstream subbasins (where the BMPs were applied) than under baseline conditions. This reduction in upstream sediment loads was the cause of the lower average annual sediment yield to Wright Patman Lake. A similar pattern can be seen in Attachment 1.12, where the Feasible BMP Scenario reduced sediment loads in the upstream subbasins and in Wright Patman Lake, but to a lesser extent than the Intensive BMP Scenario.

The baseline condition sediment yield results are plotted on Attachment 1.13. It is apparent that the upstream subbasins in the Sulphur River watershed produce the highest sediment yields. This is likely dues to land management practices and the erodible soils present in these watersheds. Sediment yields decrease in the downstream subbasins as land use changes, vegetative cover increases and soils become less erodible. Attachment 1.14 and 1.15 show that sediment yields are decreased dramatically in the subbasins where the BMPs were applied. (The sediment yields in the subbasins in which BMPs were not modeled did not change.) The decrease in the sediment yields of the target subbasins under the two with-BMP scenarios result in reduced sediment loads downstream.

The results for the average annual total subbasin sediment yields shown in Attachment 1.16 – 1.18 are graphically similar to the subbasin sediment yield results. Total subbasin sediment yields were reduced only in the subbasins where BMPs were applied. The Intensive BMP Scenario had a slightly greater impact on sediment loads than the Feasible BMP Scenario.

Table 3.2: Average Annual Sediment Load Comparison – Baseline Scenario, Intensive BMP Scenario, and Feasible BMP Scenario

Subbasin	Baseline Scenario (metric tons)	Intensive BMP Scenario (metric tons)	Intensive BMP Scenario (percent reduction)	Feasible BMP Scenario (metric tons)	Feasible BMP Scenario (percent reduction)
1	2,943	2,943	0%	2,943	0%
2	2,629	2,629	0%	2,629	0%
3	190,004	10,497	94%	14,969	92%
4	80,977	7,293	91%	9,919	88%
5	2,454	2,454	0%	2,454	0%
6	292,656	16,841	94%	24,118	92%
7	23,799	579	98%	939	96%
8	3,002	3,002	0%	3,002	0%
9	526,960	204,875	61%	216,191	59%
10	444,534	96,785	78%	107,148	76%
11	3,361	3,361	0%	3,361	0%
12*	785,823	545,056	31%	562,305	28%
14	3,897	3,897	0%	3,897	0%
15	123,909	31,387	75%	34,149	72%
16	290,776	77,647	73%	104,094	64%
17	267,021	208,859	22%	217,446	19%
18	368,655	12,700	97%	20,861	94%
19	212,831	34,655	84%	39,617	81%
20	208,544	26,221	87%	31,179	85%
21	89,022	3,127	96%	4,981	94%
22	48,756	295	99%	1,246	97%
23	164,456	3,605	98%	7,876	95%
24	143,982	5,230	96%	9,232	94%
25	2,207	2,207	0%	2,207	0%

* Location of Wright Patman Lake

Table 3.3: Average Annual Sediment Yield Comparison – Baseline Scenario, Intensive BMP Scenario, and Feasible BMP Scenario

Subbasin	Baseline Scenario (metric tons/hectare)	Intensive BMP Scenario (metric tons/hectare)	Intensive BMP Scenario (percent reduction)	Feasible BMP Scenario (metric tons/hectare)	Feasible BMP Scenario (percent reduction)
1	0.147	0.147	0%	0.147	0%
2	0.110	0.110	0%	0.110	0%
3	4.932	0.161	97%	0.280	94%
4	3.110	0.280	91%	0.381	88%
5	0.169	0.169	0%	0.169	0%
6	2.256	0.091	96%	0.161	93%
7	1.743	0.042	98%	0.069	96%
8	0.112	0.112	0%	0.112	0%
9	0.220	0.220	0%	0.220	0%
10	0.123	0.123	0%	0.123	0%
11	0.121	0.121	0%	0.121	0%
12*	0.154	0.154	0%	0.154	0%
14	0.182	0.182	0%	0.182	0%
15	2.263	0.077	97%	0.138	94%
16	0.213	0.213	0%	0.213	0%
17	0.435	0.435	0%	0.435	0%
18	3.449	0.074	98%	0.125	96%
19	0.128	0.128	0%	0.128	0%
20	0.220	0.220	0%	0.220	0%
21	3.138	0.110	96%	0.176	94%
22	3.413	0.020	99%	0.087	97%
23	3.194	0.072	98%	0.155	95%
24	4.531	0.065	99%	0.187	96%
25	0.121	0.121	0%	0.121	0%

* Location of Wright Patman Lake

Table 3.4: Average Annual Total Sediment Yield Comparison – Baseline Scenario, Intensive BMP Scenario, and Feasible BMP Scenario

Subbasin	Baseline Scenario (metric tons)	Intensive BMP Scenario (metric tons)	Intensive BMP Scenario (percent reduction)	Feasible BMP Scenario (metric tons)	Feasible BMP Scenario (percent reduction)
1	2,944	2,944	0%	2,944	0%
2	2,663	2,663	0%	2,663	0%
3	186,904	6,094	97%	10,612	94%
4	80,980	7,285	91%	9,918	88%
5	2,451	2,451	0%	2,451	0%
6	93,149	3,775	96%	6,666	93%
7	23,804	573	98%	942	96%
8	3,018	3,018	0%	3,018	0%
9	18,404	18,404	0%	18,404	0%
10	3,026	3,026	0%	3,026	0%
11	3,472	3,472	0%	3,472	0%
12*	21,811	21,811	0%	21,811	0%
14	3,905	3,905	0%	3,905	0%
15	85,218	2,884	97%	5,213	94%
16	12,427	12,427	0%	12,427	0%
17	14,861	14,861	0%	14,861	0%
18	139,823	2,980	98%	5,047	96%
19	2,020	2,020	0%	2,020	0%
20	9,458	9,458	0%	9,458	0%
21	89,024	3,123	96%	4,979	94%
22	48,758	290	99%	1,246	97%
23	178,023	4,013	98%	8,659	95%
24	148,468	2,114	99%	6,130	96%
25	2,199	2,199	0%	2,199	0%

* Location of Wright Patman Lake

It can been seen in Tables 3.2-3.4 and Attachment 1.10 – 1.18 that the difference in the reduction of sediment loads and yields resulting from the two different BMP scenarios is minor at both the subbasin and watershed levels. As expected, sediment yields were only reduced in the subbasins where BMPs were applied. The reductions in sediment load were higher at the subbasin level than at the watershed level. This is likely because the BMPs were only applied to subbasins in the upstream (western) portion of the watershed, where cropland occupies a greater percentage of the total land use. The effects of the upstream subbasin decreases in sediment load were then attenuated through the routing process in the downstream direction. Similar occurrences have been observed by researchers in other Texas watersheds (Santi et al., 2003; Santi et al., 2005; Narasimhan et al., 2007; and Tuppad et al., 2010). Sediment attenuation is a natural occurrence and is similar to the attenuation of flood flows in large rivers in the downstream direction. As channel size increases and channel slope decreases in the downstream direction, flow velocities slow and larger sediment particles are more likely to be deposited. A future BMP feasibility study could be designed to better evaluate the sediment and flood attenuation properties of the Sulphur River.

3.3 THE SWAT MODEL AND THE ASSESSMENT OF ALTERNATIVE WATER SUPPLIES

Using the three BMP scenarios, an evaluation was conducted for future water supply alternatives within the Sulphur Basin including, reallocating storage within Wright Patman Lake and/or construction of one of four potential water supply reservoirs (Parkhouse I, Parkhouse II, Marvin Nichols 1A, and Talco). Similar to the BMP analysis, the SWAT model was used to assess potential changes in sediment yields and sediment loads within these future water supply alternatives and the subsequent effect on the Sulphur River Watershed. As expected, all of the alternative potential reservoirs assessed during this analysis trapped sediment, which in turn decreased sediment loads to Wright Patman Lake, located on the downstream portion of the Sulphur Basin study area. Additionally, sediment loads to all reservoirs under the Feasible BMP Scenario were less than under the Baseline Scenario. Table 3.5 contains the sediment loads to each of the potential reservoirs under both scenarios and the resulting sediment loads to

Wright Patman Lake. All model results are presented in SWAT standard units (metric). The following is the conversion factor that can be used for the reported model results:

Table 3.5: Average Annual Sediment Load Comparison for Alternative Reservoirs and Wright Patman Lake – Baseline Scenario and Feasible BMP Scenario

Proposed Future Reservoir	Baseline Scenario		Feasible BMP Scenario	
	Sediment Load (metric tons)	Wright Patman Sediment Load (metric tons)	Sediment Load (metric tons)	Wright Patman Sediment Load (metric tons)
Parkhouse 1	123,902	729,025	34,149	550,702
Parkhouse 2	292,656	637,610	24,118	546,294
Marvin Nichols 1A	526,960	477,250	216,191	447,696
Talco	212,831	760,683	39,617	566,742

It can be seen in Table 3.5 that significantly less sediment (up to an 82% reduction) is transported to all alternative reservoir sites under the Feasible BMP Scenario (up to an 82% reduction at Parkhouse 2) when compared to the Baseline Scenario. The greatest reduction in sediment loads to Wright Patman is provided by Marvin Nichols 1A in both the Baseline and Feasible BMP Scenarios. Under the Baseline Scenario, the results suggest that the greatest reduction in reservoir capacity over 50 years of operation would occur at Parkhouse 2 (7.2%) and that the lowest reduction in capacity over 50 years of operation would occur at Talco (1.4%). These values were calculated by multiplying the average annual volumetric sediment load to each reservoir by 50 years, then dividing by the reservoir capacity at the conservation pool elevation.

4.0 SUMMARY AND CONCLUSIONS

As part of a study of sedimentation within the Sulphur River Watershed, hydrologists/fluvial geomorphologists with Freese and Nichols, Inc calibrated and validated a SWAT model used to estimate average annual sediment yields and sediment loads for 25 subbasins. Analysis of the calibration and validation results for the SWAT model show a correlation (0.59 to 0.75) between modeled average annual flow and sediment volumes to measurements collected by the USGS, USACE and TWDB within the Sulphur River Watershed.

Using the calibrated and validated SWAT model, six sediment BMPs, chosen based on successful implementation within similar conditions for other studies in Texas, were assessed for effectiveness in reducing sedimentation within the Sulphur River Watershed. Three scenarios were compared during this assessment. The Baseline Scenario was a modified form of the calibrated SWAT model that incorporated the future Ralph Hall Reservoir. The Intensive BMP Scenario used six sediment BMPs applied to 10 subbasins with modeled sediment yield greater than 1 metric ton per year. The Feasible BMP Scenario used four of the six BMPs applied to the same 10 subbasins. Given the assumption of 100% BMP adoption, modeled sediment loads to Wright Patman Lake were reduced by 31% (240,767 metric tons) in the Intensive BMP Scenario and by 28% (223,518 metric tons) in the Feasible Scenario. Given the slight difference in modeled sediment load reduction between the Intensive and the Feasible BMP Scenarios, it is expected that the four sediment BMPs used during the Feasible Scenario (Filter Strips, Cropland to Pasture, Channel Grade Control, and Riparian Buffer Strips) are the most effective options for sediment reduction. Based on the results of this assessment, implementation of these sediment BMPs not only reduce sediment yields within the subbasin for which they are applied, but have a cumulative effect on sediment reduction for the watershed that are expected to decrease sediment loads to Wright Patman Lake.

Using the Baseline and Feasible BMP Scenarios, additional iterations of the SWAT model were conducted for each of the four future water supply reservoir alternative locations within the Sulphur River Watershed. Modeled annual sediment loads entering Wright Patman Reservoir were reduced with the addition of each proposed future reservoir alternative. Sediment reduction in the Feasible BMP Scenarios were modeled for each alternative water supply location and provided significant differences (up to 82% reduction) in sediment loads over the Baseline Scenarios. Based on the results of this study, it is expected that the application of any of the water supply alternatives would be affected by sedimentation, and that the effect of sedimentation would be substantially mitigated by the implementation of a sediment BMP program.

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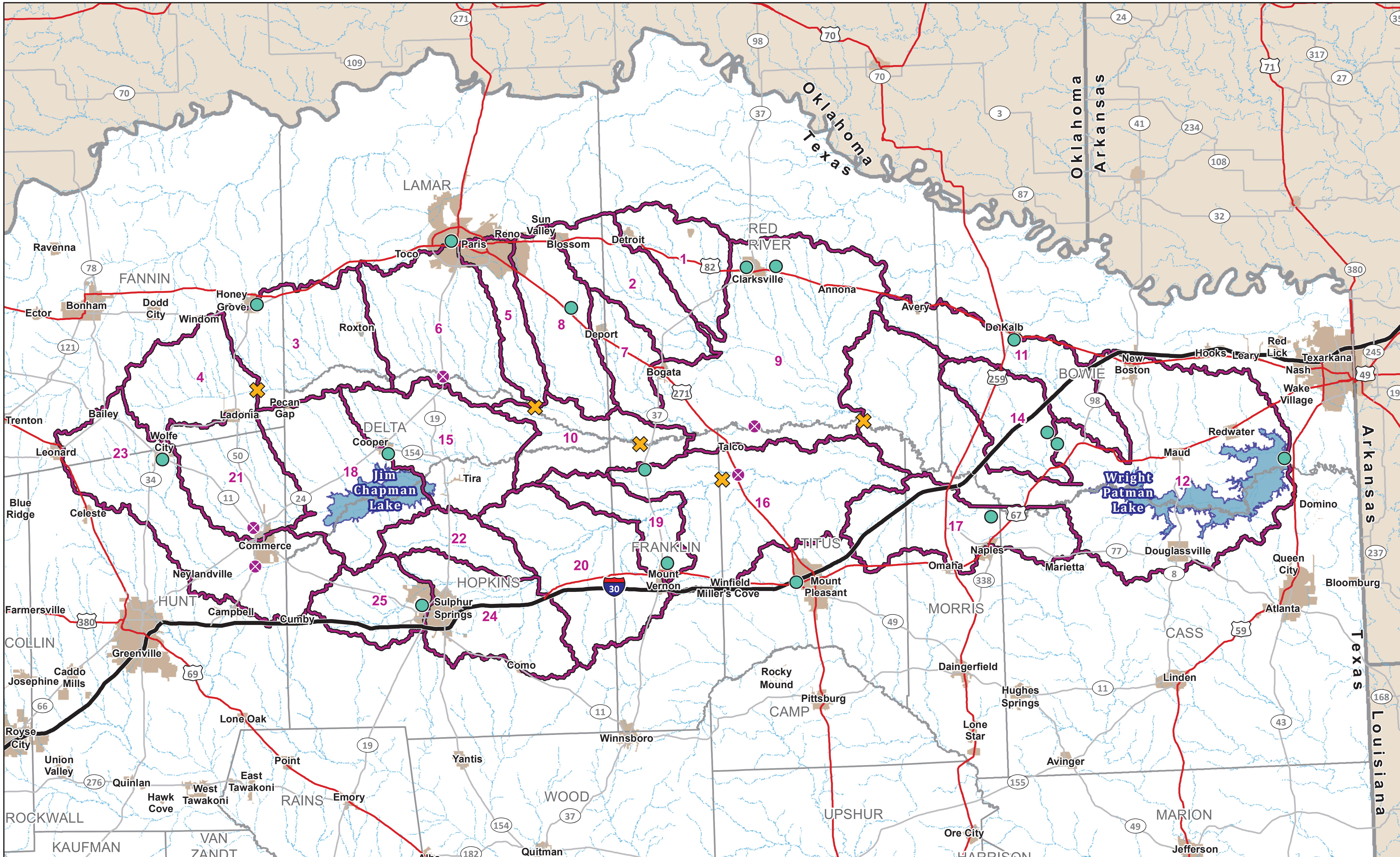
ATTACHMENT 1

Maps

Calibration and Validation QC Results



✕	Proposed Reservoir Location
⊗	Stream Gage
●	Weather Station
	Subbasin
	Existing Lake
	NHD Flowline

PROJECT LOCATION

1:575,000

0 4.5 9 18 Miles

N W E S

FN PROJECT NO.	MHP11453
DATE CREATED	10/16/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	Att 1-1
PREPARED BY	SSJ

U.S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT

Sulphur River Watershed Overview - SWAT Model

Project Location

FREESE AND NICHOLS
4500 International Plaza Suite 200
Fort Worth, Texas 76109-4895
(817) 735-7300

1.1

ATTACHMENT

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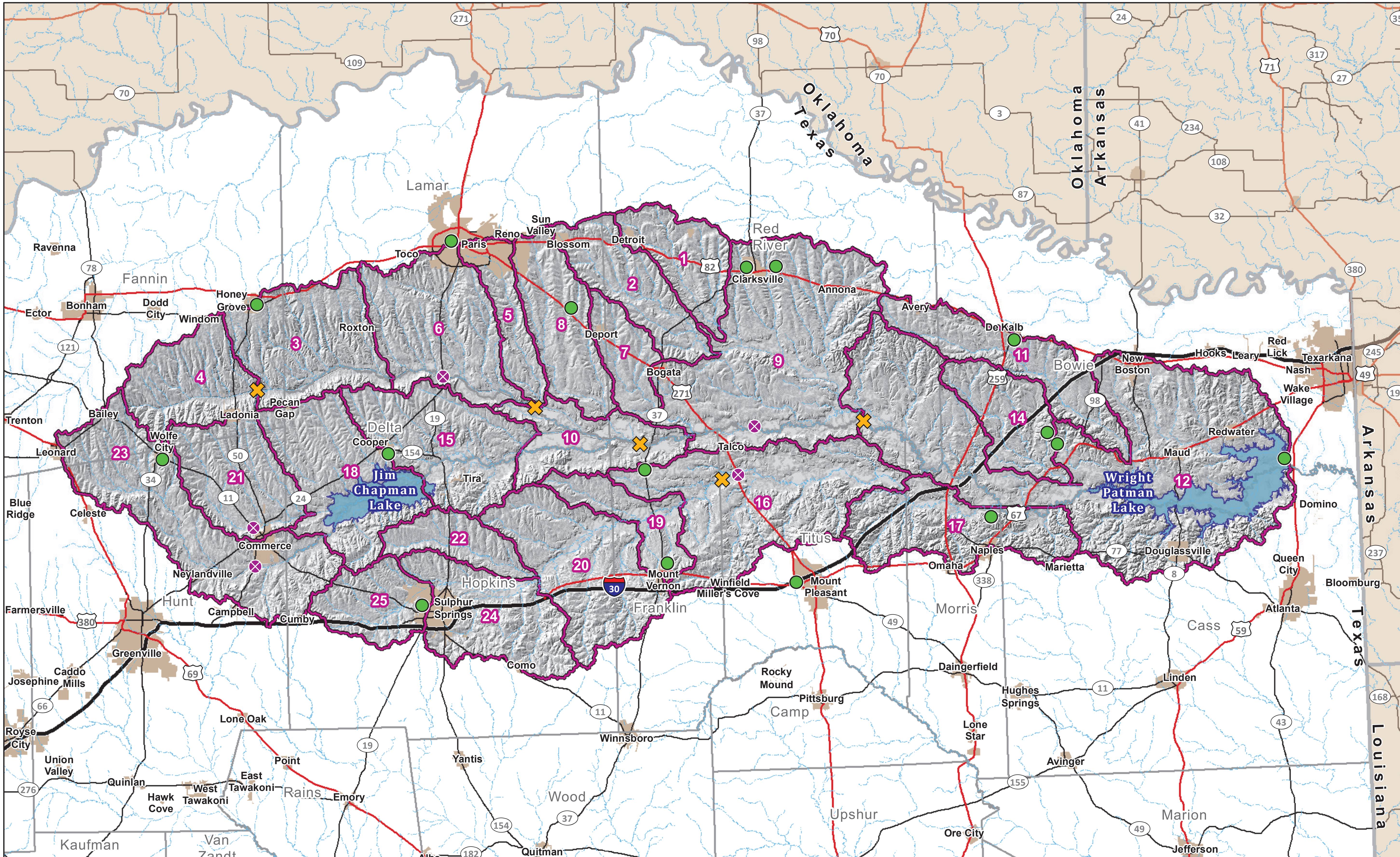

FN PROJECT NO.	MHP11453
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DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	Att 1-2
PREPARED BY	SSJ

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Sulphur River Watershed Overview - SWAT Model

Elevation

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- Proposed Reservoir Location
- Stream Gage
- Weather Station
- Subbasin
- Existing Lake
- NHD Flowline

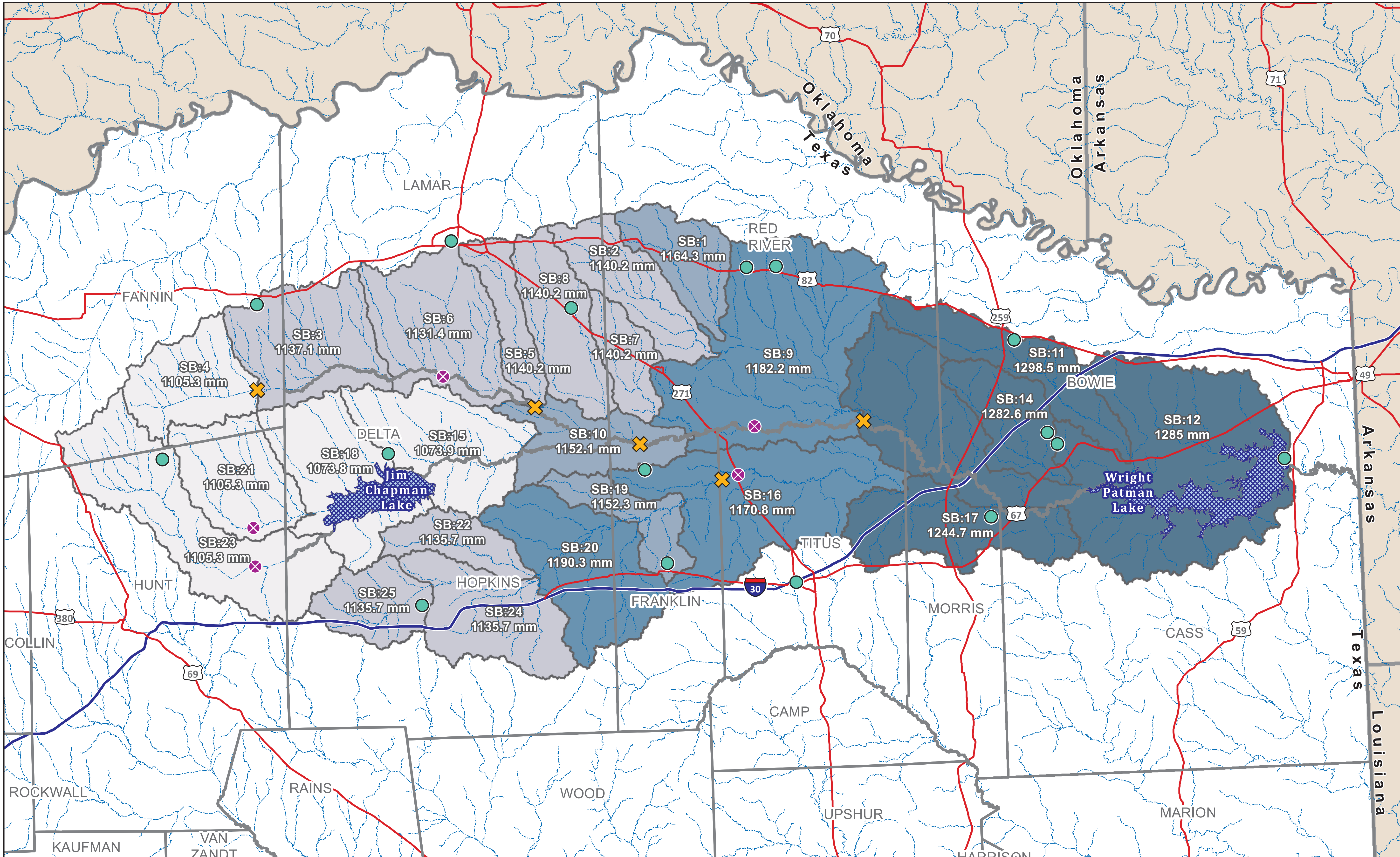
1:575,000

0 4.5 9 18 Miles

N S E W

1.2

ATTACHMENT



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Sulphur River Watershed Overview - SWAT Model

Average Annual Rainfall (mm)

FN PROJECT NO.	MHP11453
DATE CREATED	10/16/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	Att 1-3
PREPARED BY	SSJ

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Proposed Reservoir Location
Stream Gage
Weather Station
Subbasin
Existing Lake
NHD Flowline

Average Annual Rainfall (mm) Between1997-2010

1074 - 1105
1106 - 1140
1141 - 1164
1165 - 1190
1191 - 1299

1:575,000

0 4.5 9 18 Miles

N W E S

1.3

ATTACHMENT

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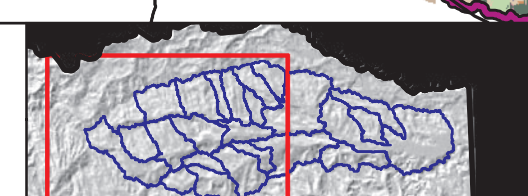
Proposed Reservoir Location
Stream Gage
Weather Station

Subbasin
Existing Lake

Land Use
Crop
Forest
Other
Pasture/Hay
Rangeland
Urban
Water
Wetland



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Miles

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Sulphur River Watershed Overview - SWAT Model
Land Use

FN PROJECT NO.	MHP11453
DATE CREATED	10/16/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	Att 1-4 and 5
PREPARED BY	SSJ

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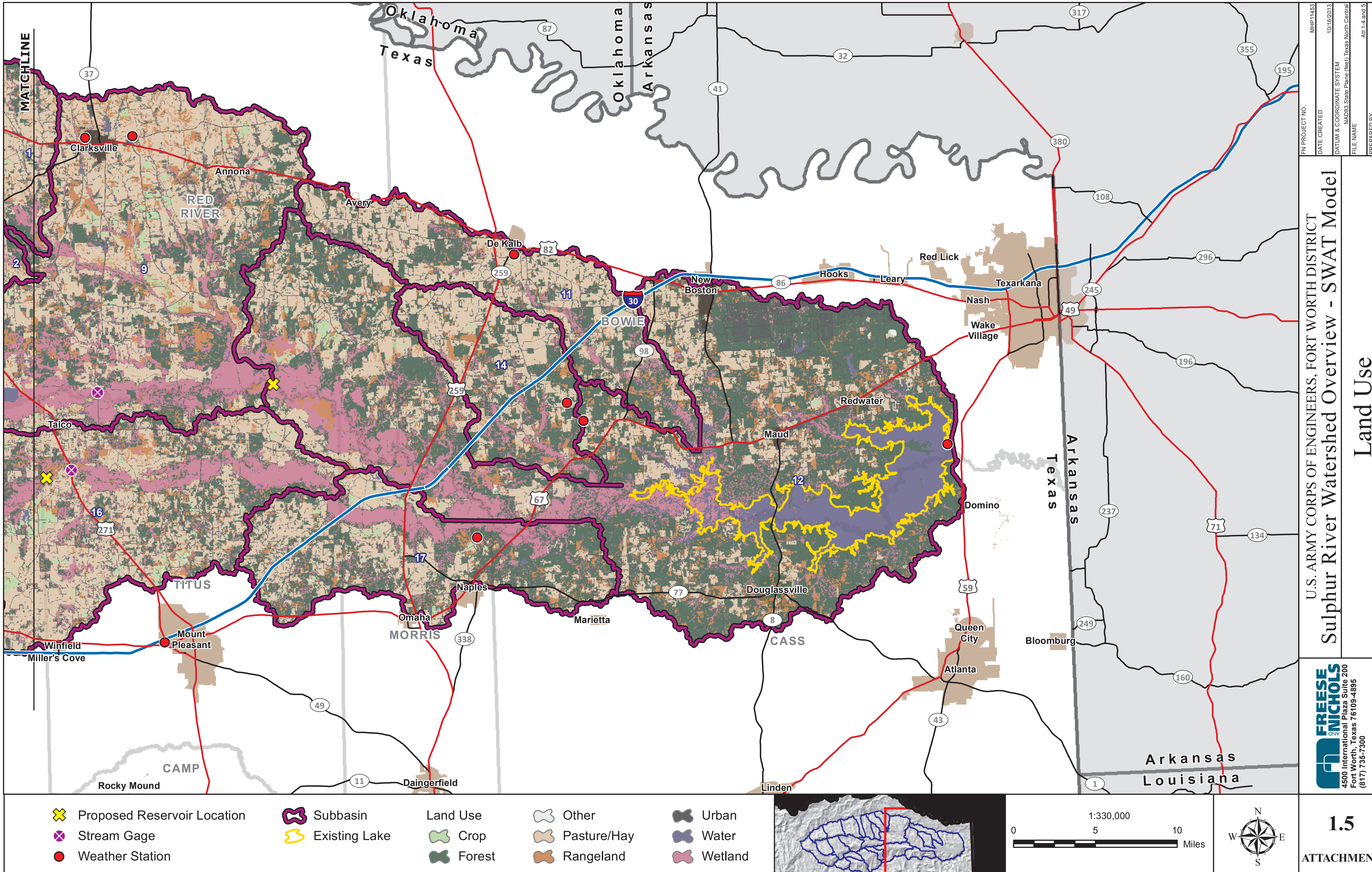
U.S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT
Sulphur River Watershed Overview - SWAT Model
Land Use
ATTACHMENT
1.5
FN PROJECT NO. MHP11453
DATE CREATED 10/16/2013
DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas North Central
FILE NAME Att 1-4 and 5
PREPARED BY SSJ
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MATCHLINE
Oklahoma
Texas
Arkansas
Louisiana
RED RIVER
BOWIE
TITUS
MORRIS
CASS
CAMP
Clarksville
Annona
Avery
De Kalb
New Boston
Hooks
Leary
Red Lick
Texarkana
Nash
Wake Village
Redwater
Maud
Domino
Douglassville
Marietta
Naples
Omaha
Talco
Winfield
Miller's Cove
Mount Pleasant
Queen City
Atlanta
Bloomburg
Linden
Daingerfield
Rocky Mound
Proposed Reservoir Location
Stream Gage
Weather Station
Subbasin
Existing Lake
Land Use
Crop
Forest
Other
Pasture/Hay
Rangeland
Urban
Water
Wetland
1:330,000
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Miles
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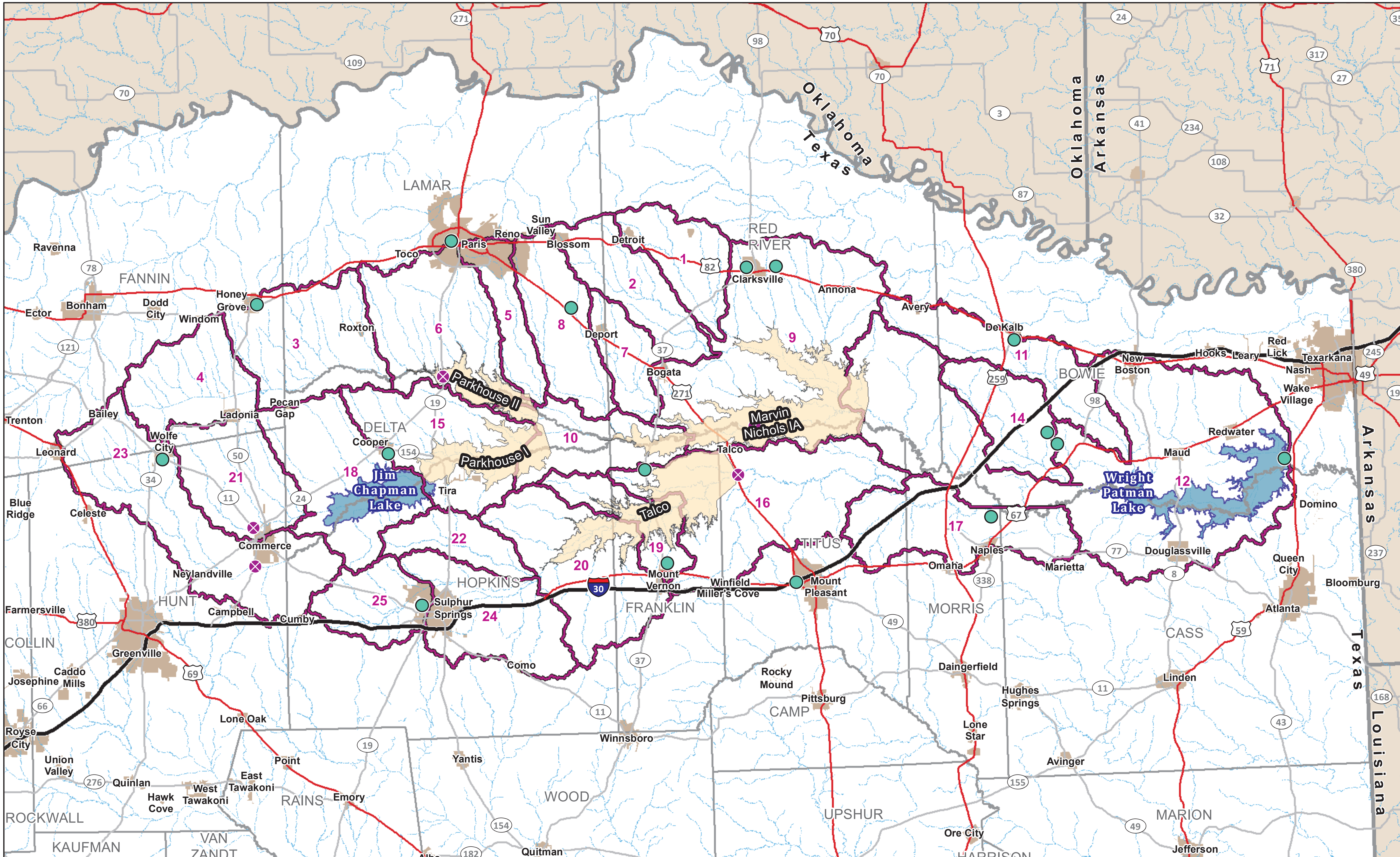

Stream Gage
Weather Station
Proposed Reservoir
Subbasin
Existing Lake
NHD Flowline

1:575,000
0 4.5 9 18 Miles

N
S
E
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U.S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT
Sulphur River Watershed Overview - Alternative Sources Sediment Evaluation

Project Location Showing Potential Reservoir Locations

FN PROJECT NO.	MHP11453
DATE CREATED	04/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	Att 1.6
PREPARED BY	DKC

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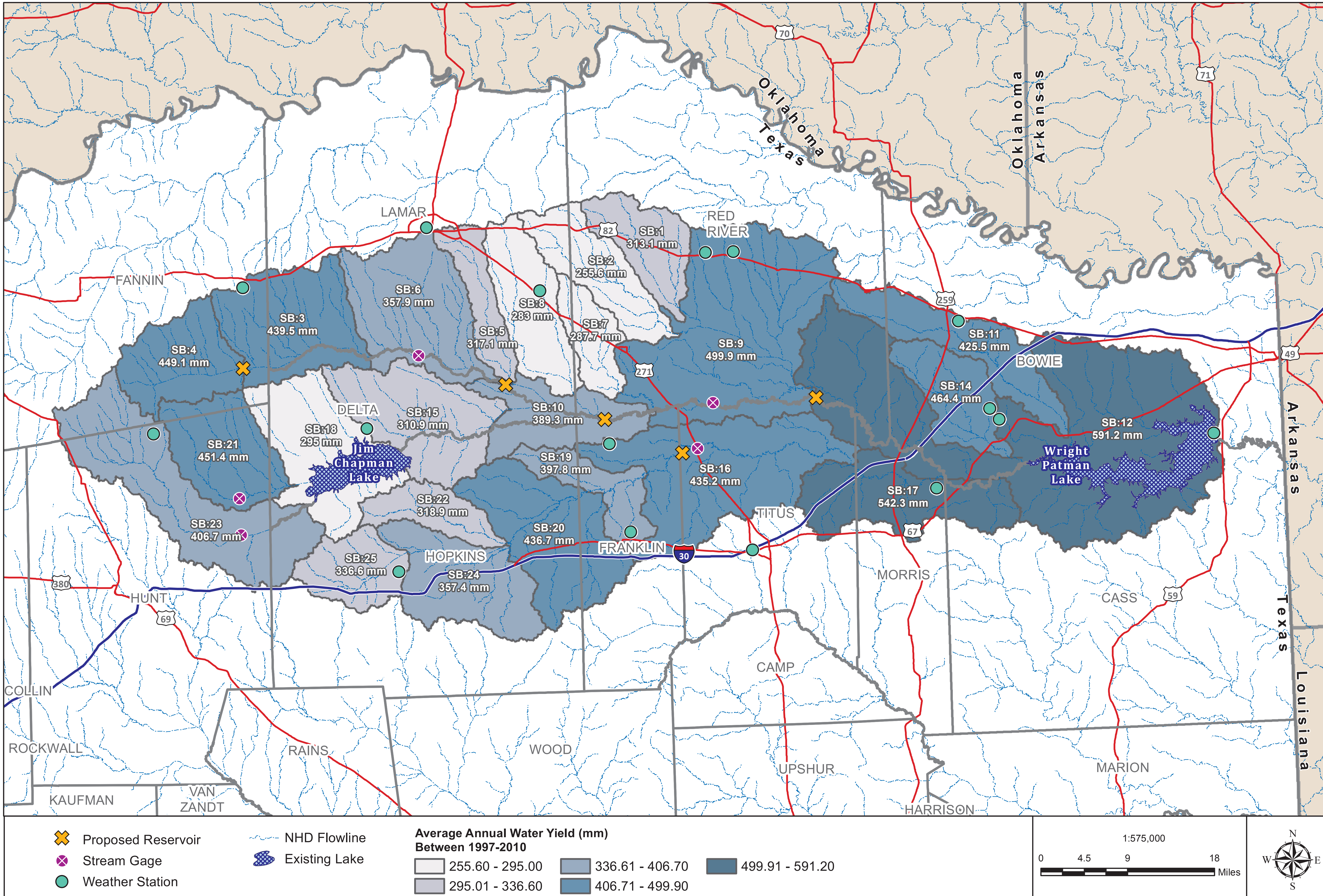

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DATE CREATED	10/16/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	ATT 1-7
PREPARED BY	SSJ

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Sulphur River Watershed Overview - SWAT Model

Average Annual Water Yield (mm)

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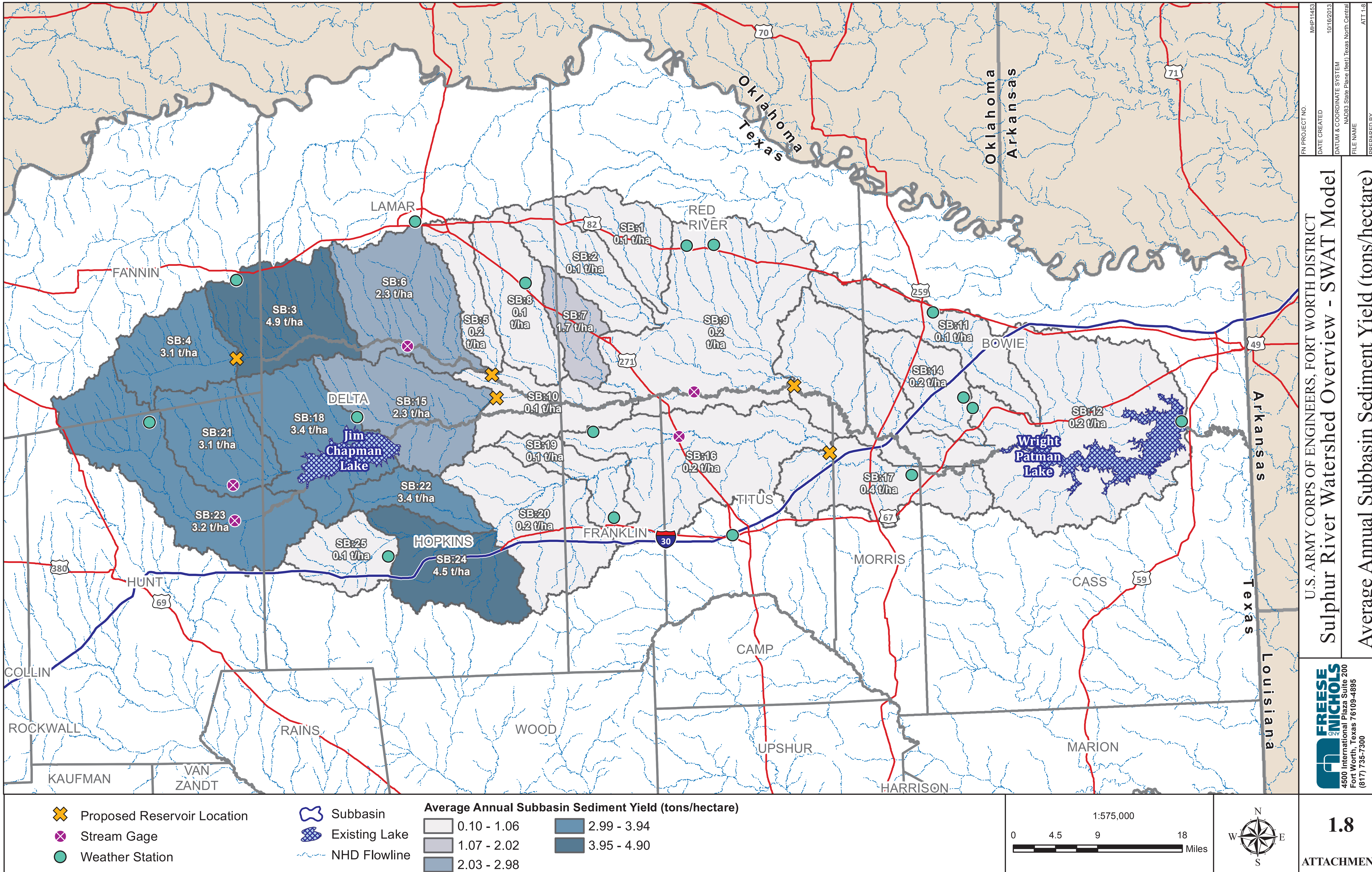
1.7
ATTACHMENT



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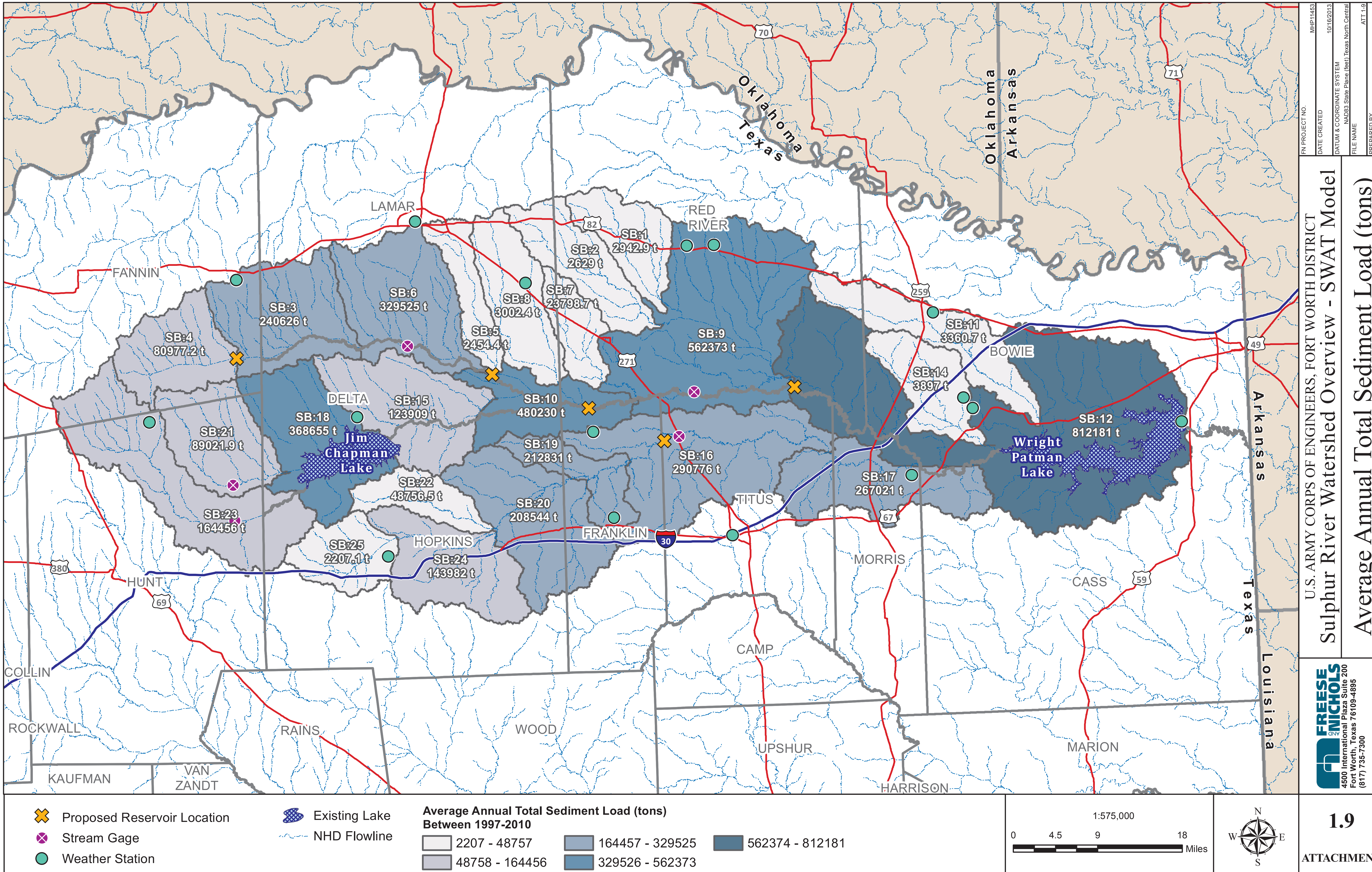

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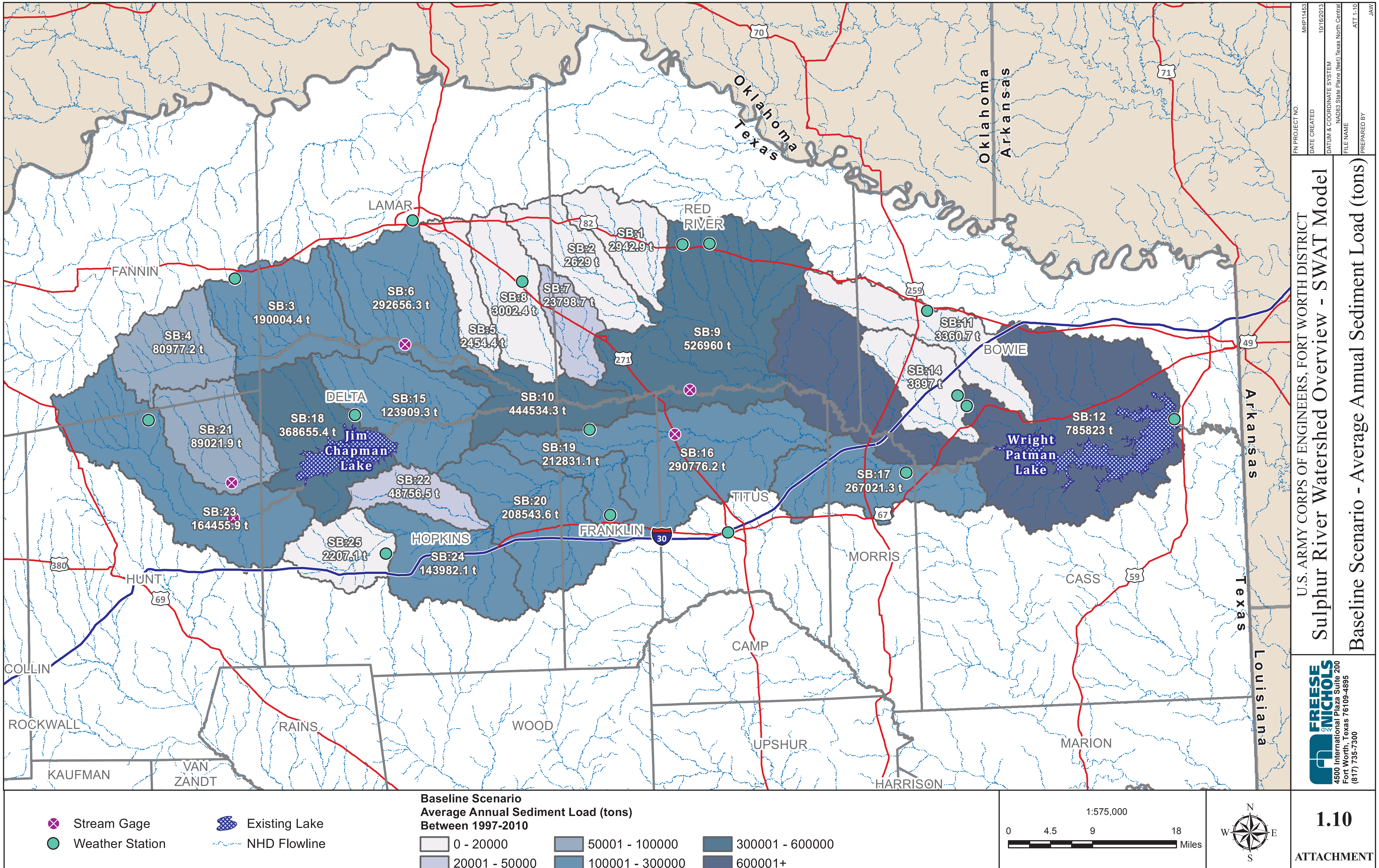

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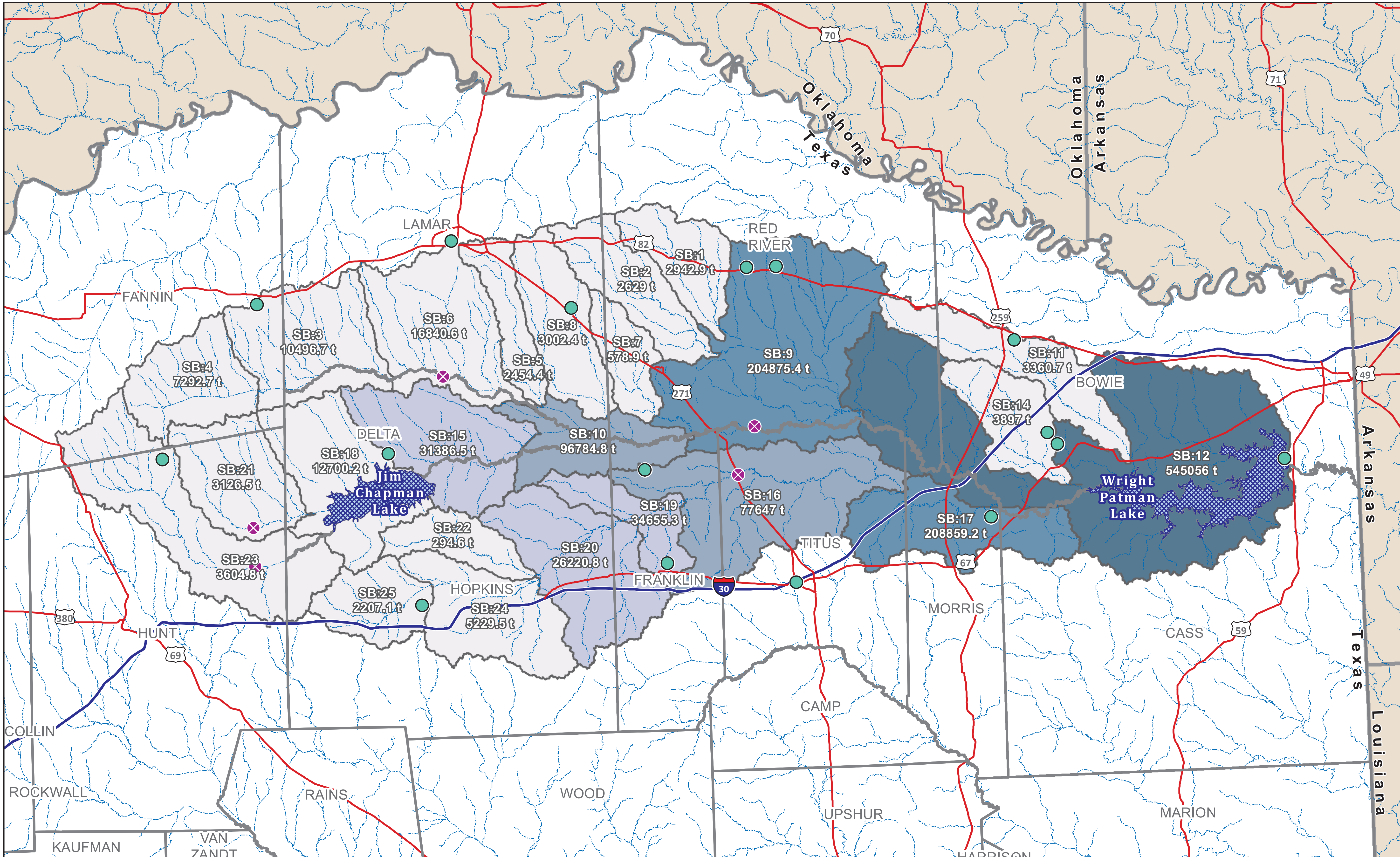

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Sulphur River Watershed Overview - SWAT Model

Intensive BMP Scenario- Average Annual Sediment Load (tons)

FN PROJECT NO.	MHP11453
DATE CREATED	10/16/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	ATT 1-11
PREPARED BY	JAW

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Stream Gage
Weather Station
Existing Lake
NHD Flowline

Intensive BMP Scenario
Average Annual Sediment Load (tons)
Between 1997-2010

0 - 20000
200001 - 50000
50001 - 100000
100001 - 300000
300001 - 600000
600001+

1:575,000
0 4.5 9 18 Miles

N W E S

1.11

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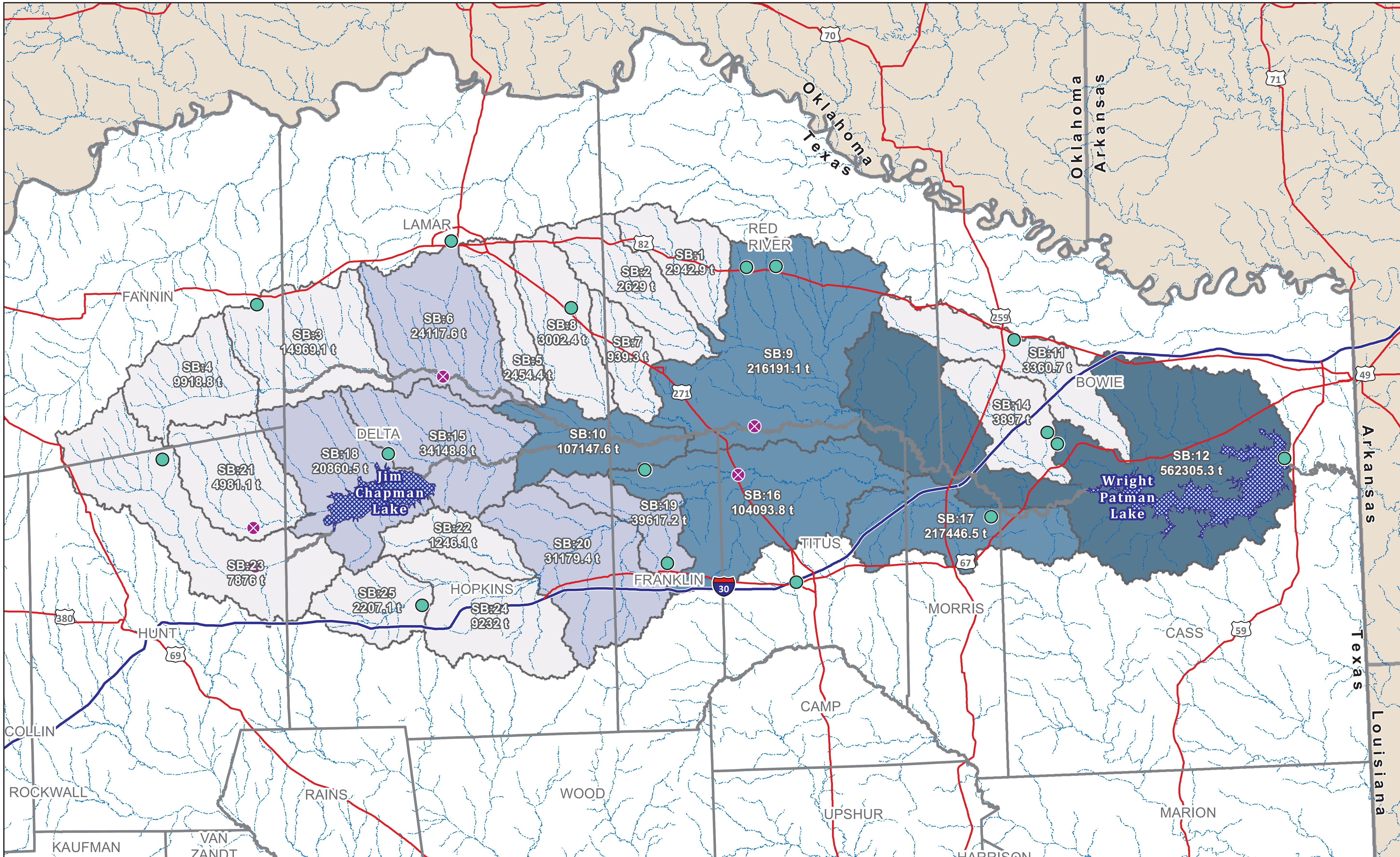

Stream Gage
Weather Station
Existing Lake
NHD Flowline

Feasible BMP Scenario
Average Annual Sediment Load (tons)
Between 1997-2010

0 - 20000	50001 - 100000
20001 - 50000	100001 - 300000
300001 - 600000	600001+

1:575,000

0 4.5 9 18 Miles

N W E S

1.12

ATTACHMENT

FN PROJECT NO. MHP11453
DATE CREATED 10/16/2013
DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas North Central
FILE NAME ATT 1-12
PREPARED BY JAW

U.S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT

Sulphur River Watershed Overview - SWAT Model

Feasible BMP Scenario- Average Annual Sediment Load (tons)

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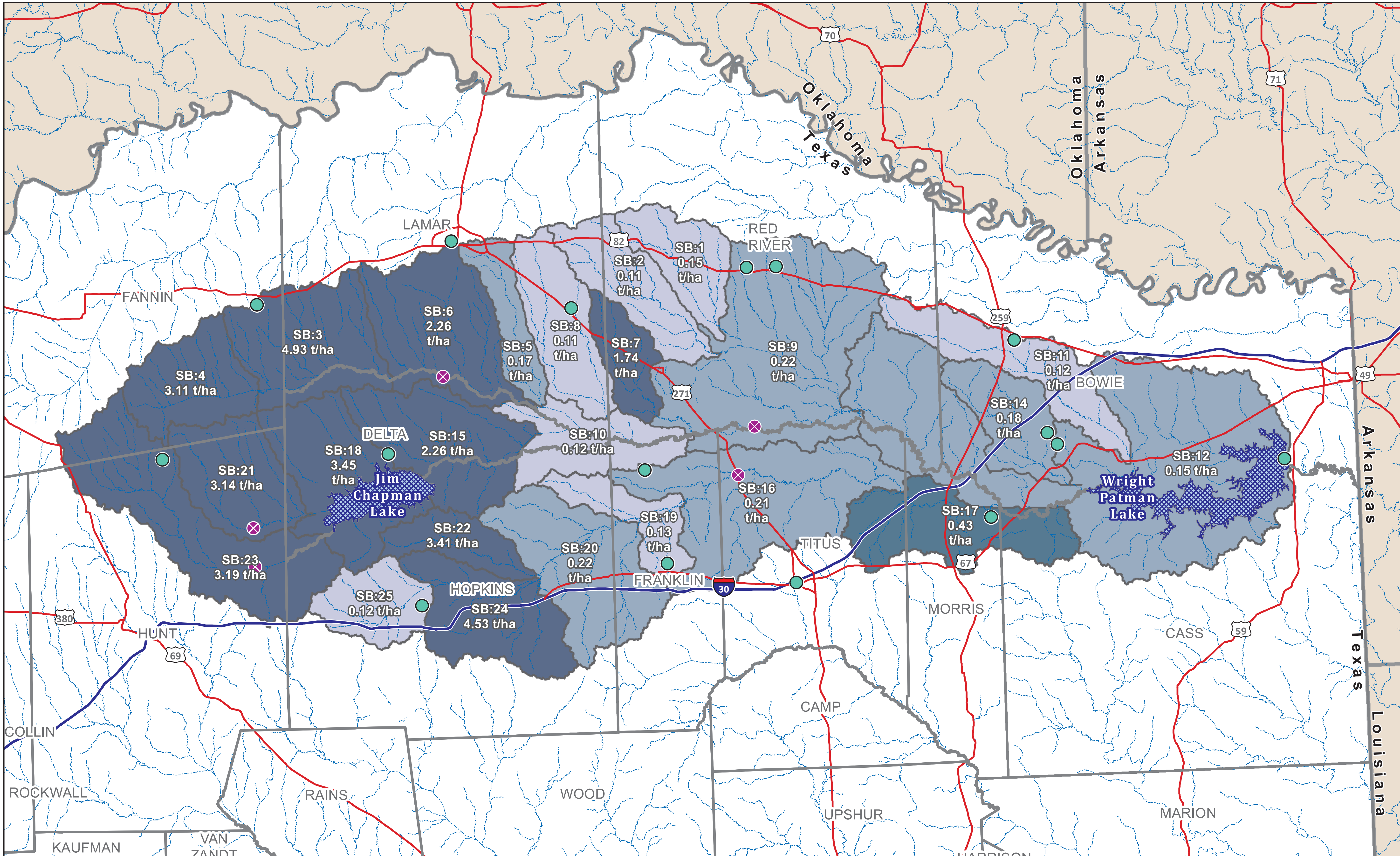
Sulphur River Watershed Overview - SWAT Model

Baseline Scenario - Average Annual Sediment Yield (tons/hectare)

FN PROJECT NO.	MHP11453
DATE CREATED	10/16/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	ATT 1-13
PREPARED BY	JAW



Stream Gage
Weather Station
Existing Lake
NHD Flowline

Baseline Scenario
Average Annual Sediment Yield (tons/hectare)
Between 1997-2010

0.00 - 0.07
0.08 - 0.15
0.16 - 0.25
0.26 - 0.35
0.36 - 1.00
1.01+

1:575,000

0 4.5 9 18 Miles

N S E W

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1.13

ATTACHMENT

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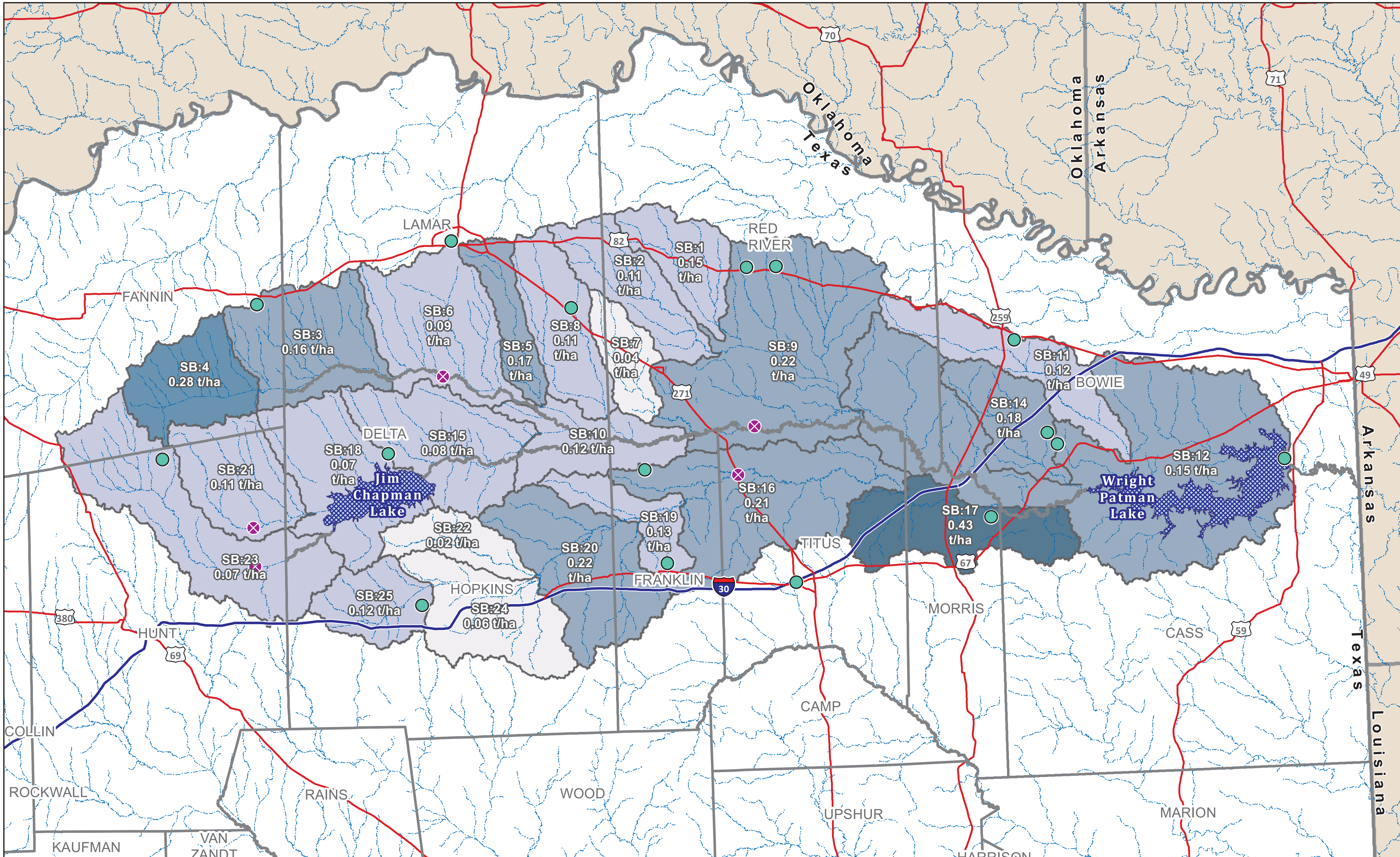


Stream Gage
Weather Station
Existing Lake
NHD Flowline

Intensive BMP Scenario
Average Annual Sediment Yield (tons/hectare)
Between 1997-2010

0.00 - 0.07
0.08 - 0.15
0.16 - 0.25
0.26 - 0.35
0.36 - 1.00
1.01+

1:575,000

0 4.5 9 18 Miles

N S E W

U.S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT

Sulphur River Watershed Overview - SWAT Model

Intensive BMP Scenario - Average Annual Sediment Yield (tons/hectare)

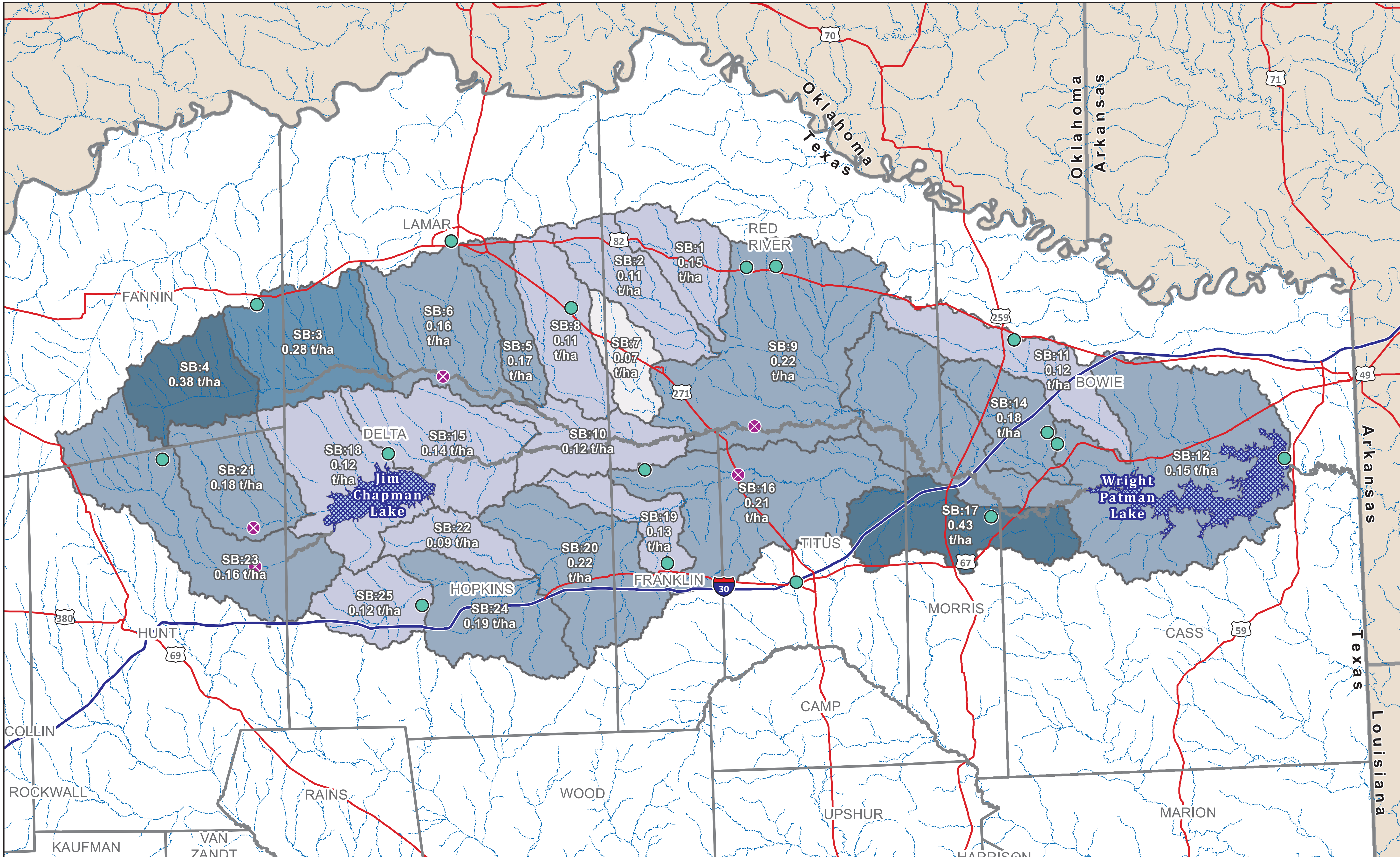
FN PROJECT NO.	MHP11453
DATE CREATED	10/16/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	ATT 1-14
PREPARED BY	JAW

FREESE NICHOLS
4500 International Plaza Suite 200
Fort Worth, Texas 76109-4895
(817) 735-7300

1.14

ATTACHMENT

Path: H:\ENVIRONMENTAL\FINAL_EXHIBITS\Consolidated Report\ATT 1-14.mxd



Stream Gage
Weather Station
Existing Lake
NHD Flowline

Feasible BMP Scenario
Average Annual Sediment Yield (tons/hectare)
Between 1997-2010

0.00 - 0.07	0.16 - 0.25	0.36 - 1.00
0.08 - 0.15	0.26 - 0.35	1.01+

1:575,000

0 4.5 9 18 Miles

1 inch = 9 miles

N W E S

FN PROJECT NO.	MHP11453
DATE CREATED	10/16/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	ATT 1-15
PREPARED BY	JAW

U.S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT

Sulphur River Watershed Overview - SWAT Model

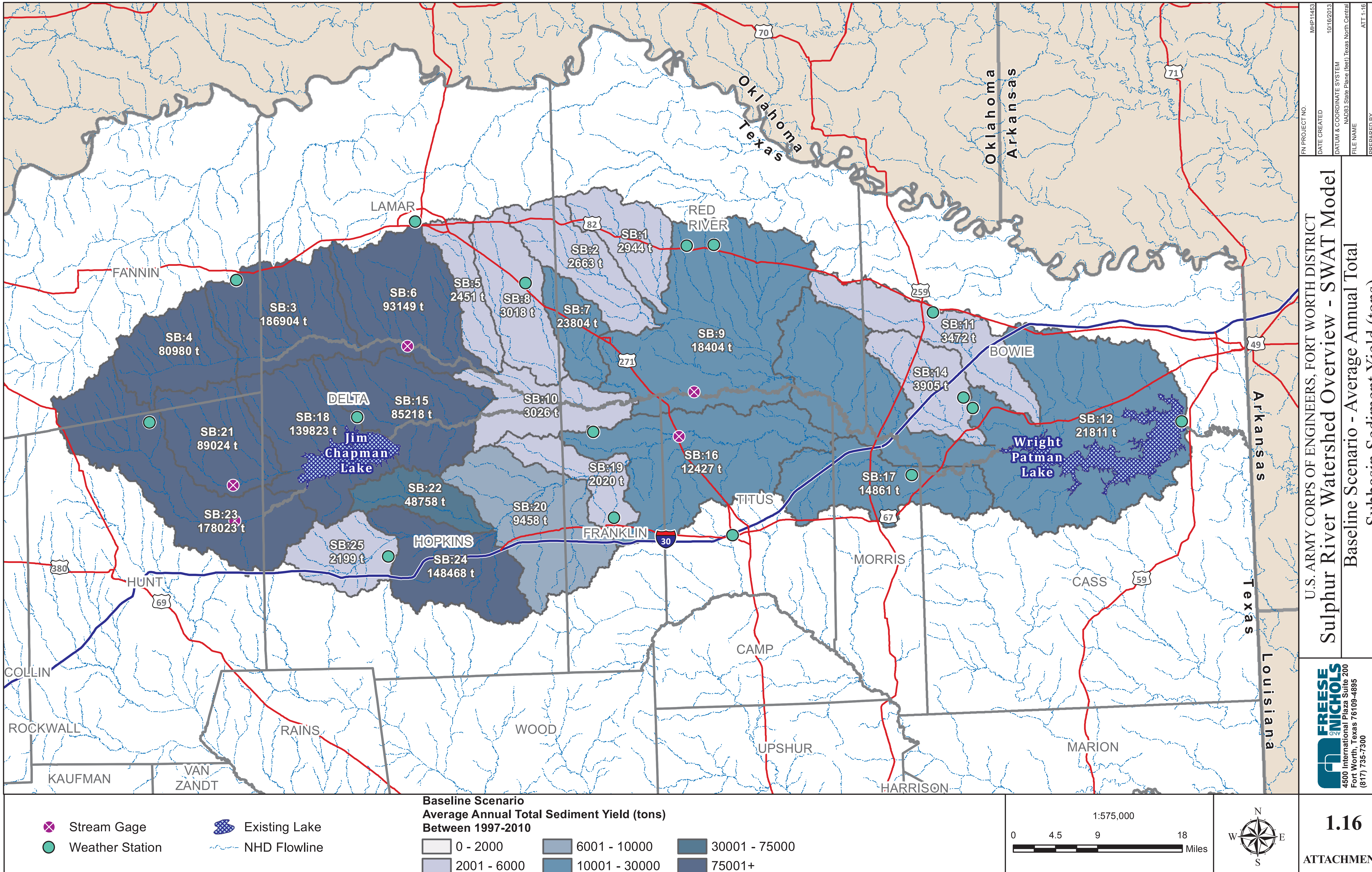
Feasible BMP Scenario - Average Annual Sediment Yield (tons/hectare)

FREESE AND NICHOLS
4500 International Plaza Suite 200
Fort Worth, Texas 76109-4895
(817) 735-7300

1.15

ATTACHMENT

Path: H:\ENVIRONMENTAL\FINAL_EXHIBITS\Consolidated Report\ATT 1-15.mxd



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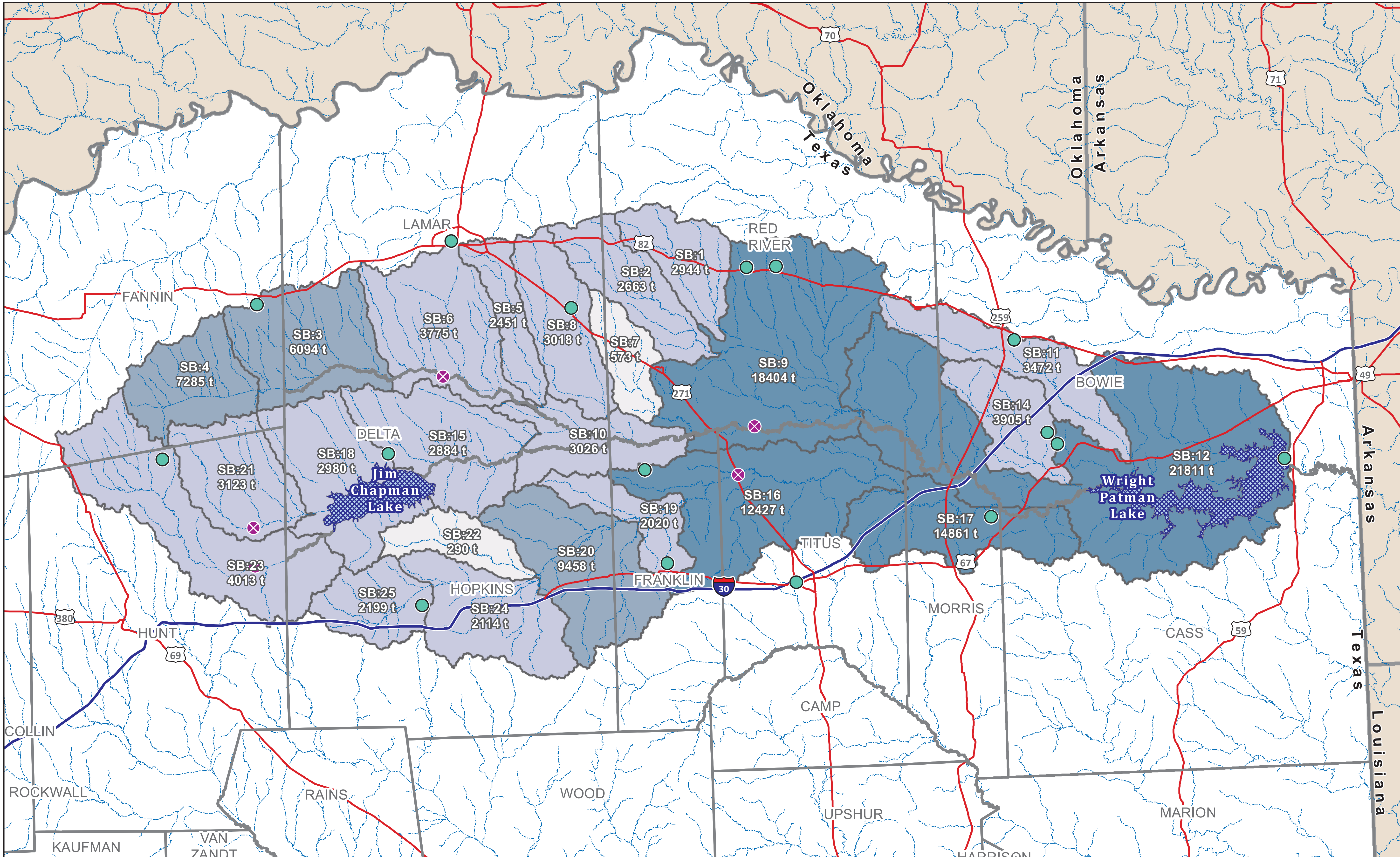

Stream Gage
Weather Station
Existing Lake
NHD Flowline

Intensive BMP Scenario
Average Annual Total Subbasin Sediment Yield (tons)
Between 1997-2010

0 - 2000
2001 - 6000
6001 - 10000
10001 - 30000
30001 - 75000
75001+

1:575,000
0 4.5 9 18 Miles

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W E
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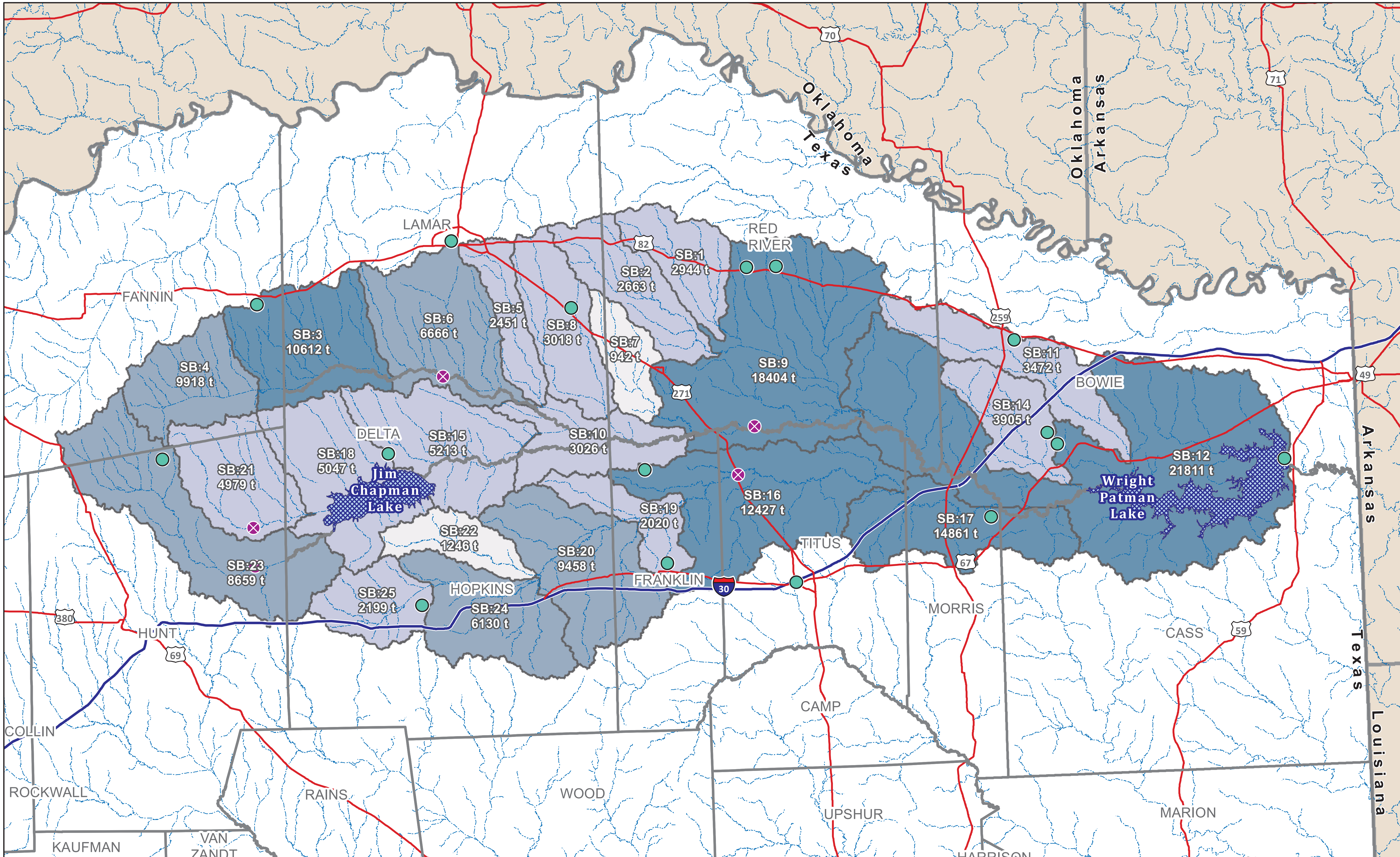
U.S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT
Sulphur River Watershed Overview - SWAT Model
Intensive BMP Scenario - Average Annual Total
Subbasin Sediment Yield (tons)

FN PROJECT NO.	MHP11453
DATE CREATED	10/16/2013
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas North Central
FILE NAME	ATT 1-17
PREPARED BY	JAW

FREESE AND NICHOLS
4500 International Plaza Suite 200
Fort Worth, Texas 76109-4895
(817) 735-7300

1.17
ATTACHMENT

Path: H:\ENVIRONMENTAL\FINAL_EXHIBITS\Consolidated Report\ATT 1-17.mxd



Stream Gage
Weather Station
Existing Lake
NHD Flowline

Feasible BMP Scenario
Average Annual Total Subbasin Sediment Yield (tons)
Between 1997-2010

0 - 2000	6001 - 10000
2001 - 6000	10001 - 30000
30001 - 75000	75001+

1:575,000

0 4.5 9 18 Miles

N W E S

U.S. ARMY CORPS OF ENGINEERS, FORT WORTH DISTRICT

Sulphur River Watershed Overview - SWAT Model

Feasible BMP Scenario - Average Annual Total Subbasin Sediment Yield (tons)

FN PROJECT NO. MHP11453
DATE CREATED 10/16/2013
DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas North Central
FILE NAME ATT 1-18
PREPARED BY JAW

FREESE NICHOLS
4500 International Plaza Suite 200
Fort Worth, Texas 76109-4895
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1.18

ATTACHMENT

Path: H:\ENVIRONMENTAL\FINAL_EXHIBITS\Consolidated Report\ATT 1-18.mxd

ATTACHMENT 2

Calibration and Validation QC Results

United States Department of Agriculture

Agricultural Research Service

May 7, 2012

To: Mr. David Coffman, Hydrologist
Cc: Dr. Rebecca Griffith
Subject: Sulphur River Basin SWAT Model – MHP11453

Mr. Coffman has done an excellent job calibrating and validating the SWAT model. Stream flow regression statistics for all stream gages are well above acceptable ranges as suggested by Moriasi et al (2007). Validation results are surprisingly higher that the calibration period due to accurate model predictions of three large runoff events (> 50 m3/s). Sediment calibration consisted of comparing sediment survey data from Wright Patman Lake from 1997 to 2010 with SWAT results using only one variable (SPEXP) were excellent with both measured and predicted lake sediment loads at 842,000 tons/year.

It is also important that the model captures the landscape and channel processes realistically. I reviewed the SWAT output files to ensure that hydrologic and sediment processes were reasonable for the watershed. All water balance components were reasonable. The baseflow ratio (14% of total flow) is low which is common in this region. ET, surface runoff and baseflow were all close to measured estimates for the region. Plant growth and nitrogen and phosphorus balances all are reasonable for the climate and land use. Sediment yields from agriculture appear to be somewhat high at 14 t/ha, the literature and ARS monitored data at Riesel, Texas suggest values on the low side of the 5-10 t/ha range depending on tillage management. There is not a considerable amount of agriculture in the basin and a moderate over prediction should not appreciably affect the sediment balance.

The model predicts that 75% of the sediment is coming from channels (with 25% from the landscape). Personal communication with Dr. Peter Allen, Professor of Geology at Baylor, and relevant literature suggest that this distribution of sediment sources is reasonable. Nutrient transformations in the channel also appear reasonable, however, transmission (water) losses in the channel seem high at 30%. This suggests that surface runoff predictions may be over predicted and offset by transmission losses.

Overall, the calibration and validation statistics look excellent and most processes are well within reasonable ranges. The sediment loss on agriculture and transmission losses in the channels are definitely on the high side but should not have a significant impact on future scenario analysis.

Sincerely,

Jeffrey G. Arnold

Jeffrey G. Arnold

Grassland Soil and Water Research Laboratory
808 East Blackland Road • Temple, TX 76502
Phone: (254)770-6502 • Fax: (254)770-6561 • E-mail: jeff.arnold@ars.usda.gov

ATTACHMENT 3

Wright Patman Lake Sediment Analysis

8908 Ambassador Row, Dallas, TX 75247
7701 W Little York, Ste 600, Houston, TX 77040
4421 Freidrich, Ste 195, Austin, TX 78744
Corporate Phone: (214) 630-9745

Report of Bulk Density and Moisture Content

Client: Specialty Devices, Inc.
2905 Capital Street
Wylie, TX 75098

Report No.: 411840
Project No.: 1217478
Date of Service: 04/24/2012
Report Date: 05/08/2012

Project: Wright-Patman Lake
Texarkana, Texas

Services: Bulk Density and Moisture Content

Report of Tests

On this date, a Rone Engineering Services, Ltd. representative(s) received a sample of soil material for laboratory testing. The results are attached.

Technician: Doyle Mackey
Report Distribution:
Orig: Specialty Devices, Inc. (Wylie, TX)
Attn: Ms. Ruth Josey (1-ec copy)
1-ec Rone Project Manager Attn: Mr. K. Scott Watson AET

Rone Engineering

K. Scott Watson, AET
Project Manager

8908 Ambassador Row, Dallas, TX 75247
7701 W. Little York, Suite 600, Houston Texas 77040
4221 Freidrich Lane, Suite 195, Austin Texas 78744
Corporate Phone: (214) 630-9745

Client: Specialty Devices, Inc
Project: Wright-Patman Lake, Texarkana, Tx

Project No.: 1217478
Report No.: 411840

Bulk Density and Moisture Content

Sample ID	Sample Location	Wet Density, pcf	Dry Density, pcf	% Moisture
1	33.315826/-94.168872	72.3	31.7	132.1
2	33.296750/-94.189104	80.1	28.7	178.9
3	33.253731/-94.235282	73.5	23.1	218.4
4	33.325308/-94.222298	68.2	40.3	69.2
5	33-247328/-94.288065	75.9	31.9	138.3

Bulk Density and Moisture Content Results

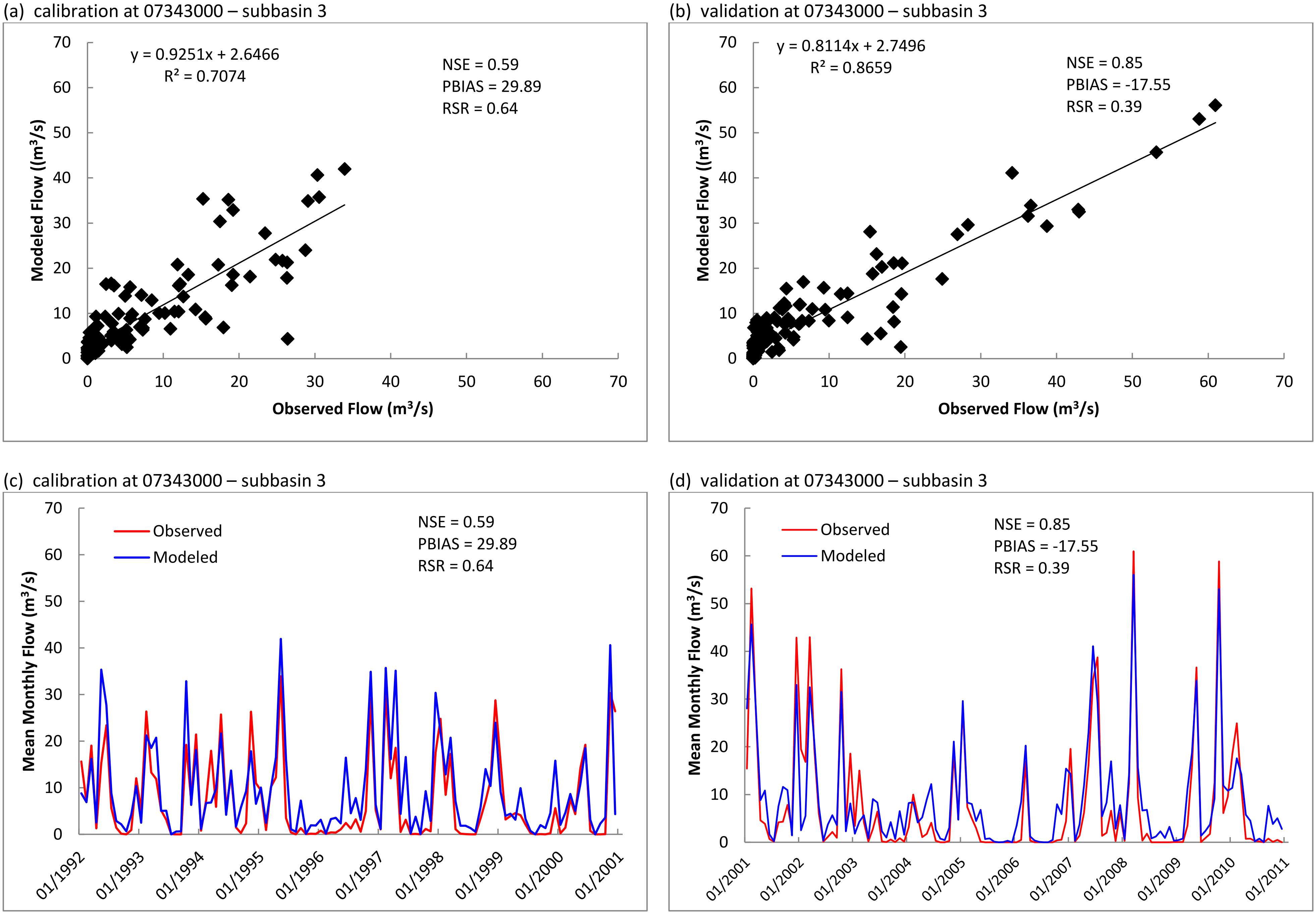
ROUTINE LAB TESTING	**PROJECT #**	12-17478	**TESTED BY:**	AM	
PROJECT: Specialty Devices	**TEST DATE:**	4/25/2012	**COMPUTED BY:**	KLA	**CHECKED BY:**

DESCRIPTION	**BORING #**								
	SAMPLE #	1	2	3	4	5			
	DEPTH INTERVAL (FT)								
	MATERIAL DESCRIPTION type, color, consistency, structure, etc..								
MOISTURE	TARE #	14	T	22	D	N			
CONTENT	A WET WEIGHT + TARE (g)	2816.00	1659.70	8469.60	2830.30	1254.40			
	B DRY WEIGHT + TARE (g)	1452.80	776.70	3604.40	1774.80	646.60			
	C TARE WEIGHT (g)	421.10	283.00	1376.80	249.50	207.10			
	D MOISTURE=(A-B)/(B-C)x 100	**132.1**	**178.9**	**218.4**	**69.2**	**138.3**			
WET	E WET WEIGHT + BAG (g)	2545.70	1561.50	7599.30	2876.30	1140.30			
WEIGHT	F	38.28	34.31	83.17	37.66	21.47			
OF SAMPLE	G WET WEIGHT OF SAMPLE (g)	**2507.42**	**1527.19**	**7516.13**	**2838.64**	**1118.83**			
BULK	H. VOLUME OF SAMPLE, CU. IN.	132.104	72.6572	389.7068	158.5248	56.1442			
DENSITY	I. VOLUME OF SAMPLE, CU. FT.	0.07645	0.04205	0.22552	0.09174	0.03249			
OF	J. WET DENSITY, PCF=(G/453.6)/I	**72.3**	**80.1**	**73.5**	**68.2**	**75.9**			
SAMPLE	H. DRY DENSITY, PCF=J/(1+(D/100))	**31.1**	**28.7**	**23.1**	**40.3**	**31.9**			
COMMENTS									

ATTACHMENT 4

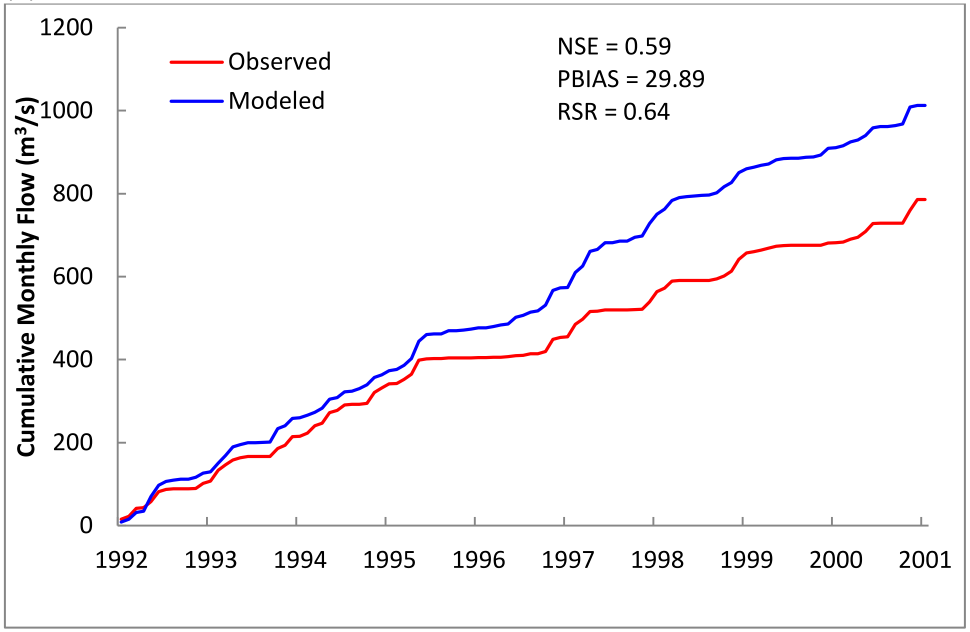
Calibration and Validation Plots

Calibration and validation at USGS streamgage 07343000 – subbasin 3

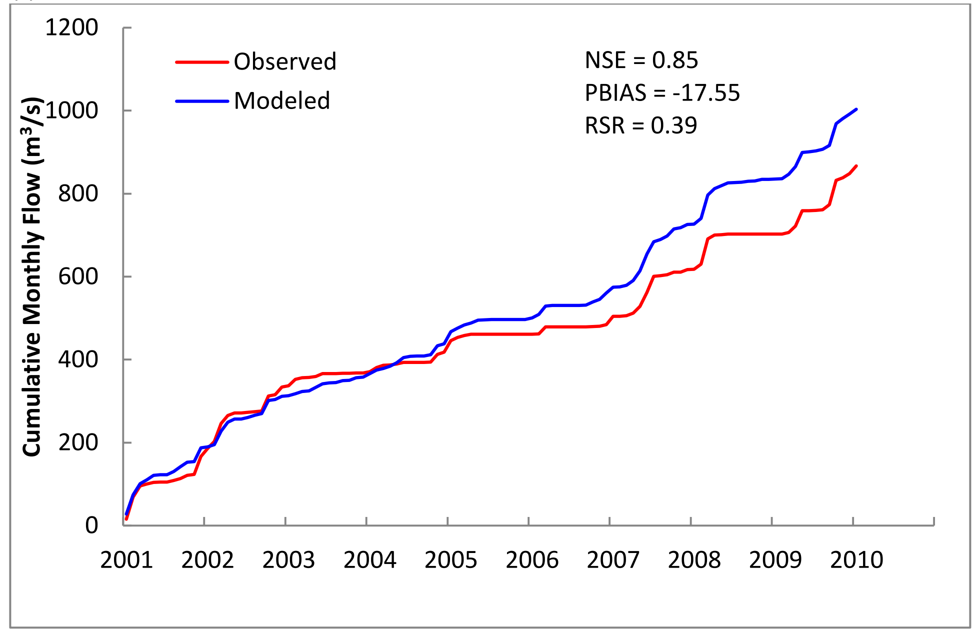


Calibration and validation at USGS streamgage 07343000 – subbasin 3 (cont.)

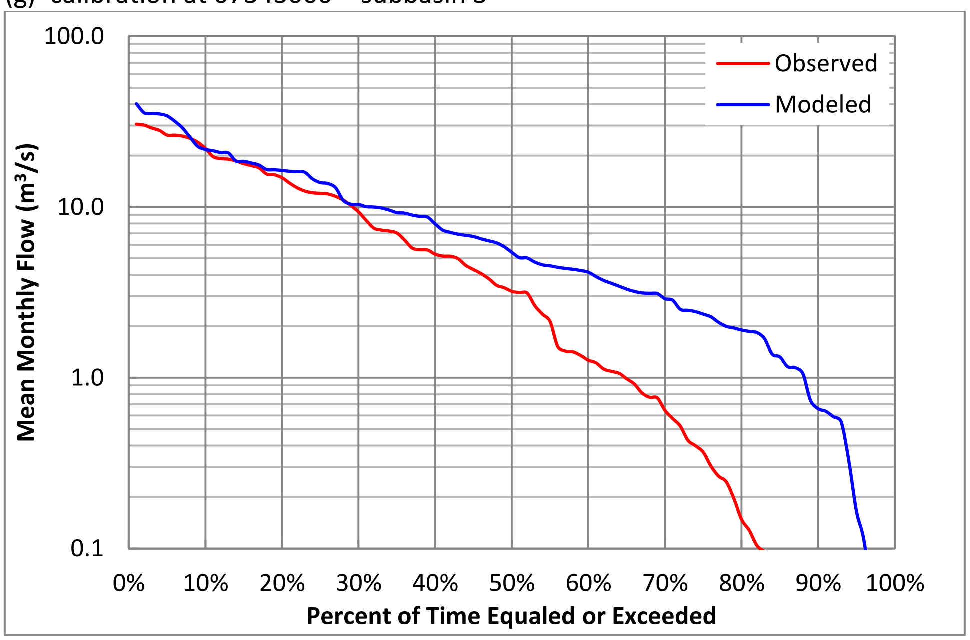
(e) calibration at 07343000 – subbasin 3



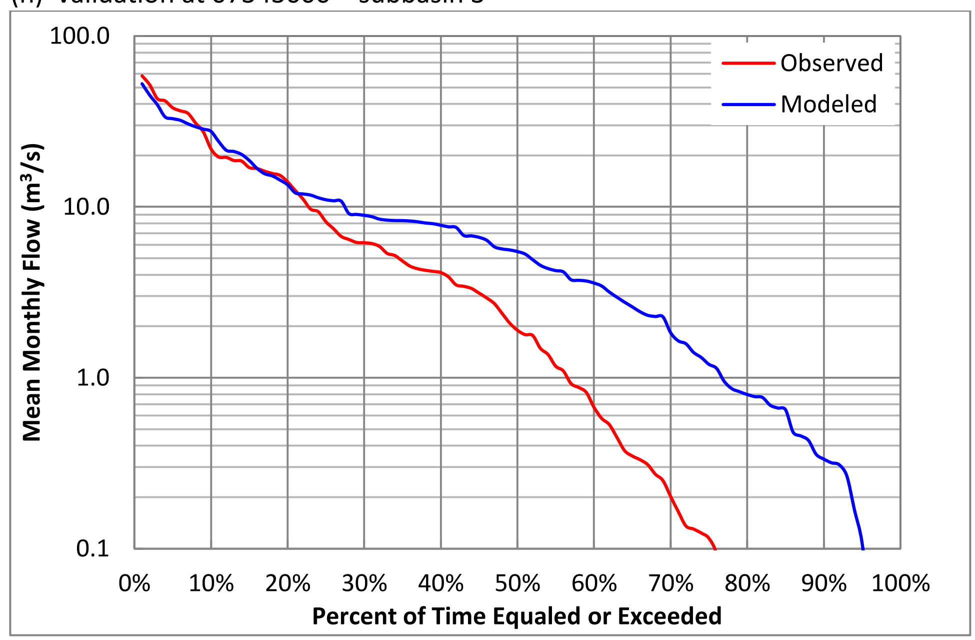
(f) validation at 07343000 – subbasin 3



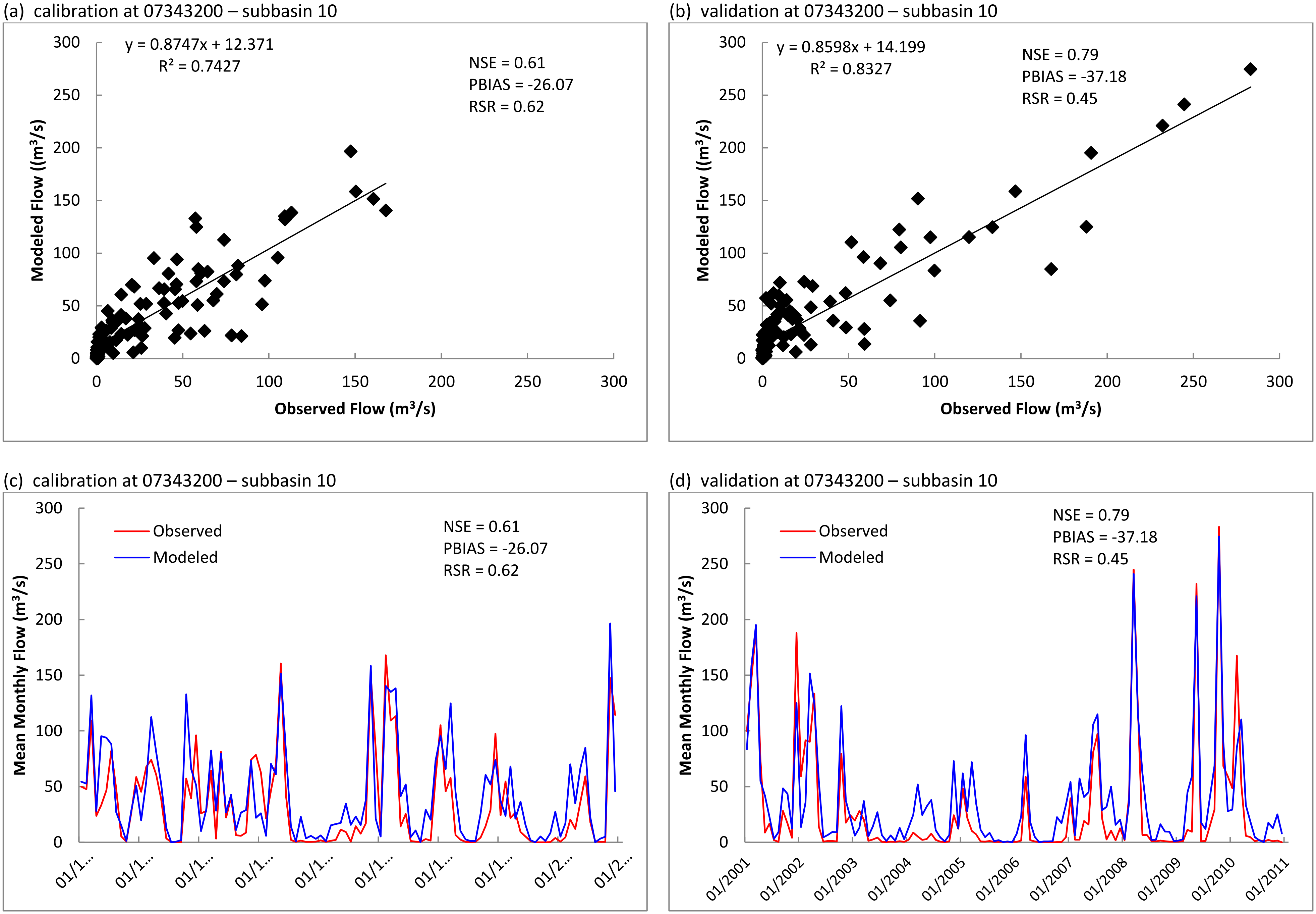
(g) calibration at 07343000 – subbasin 3



(h) validation at 07343000 – subbasin 3

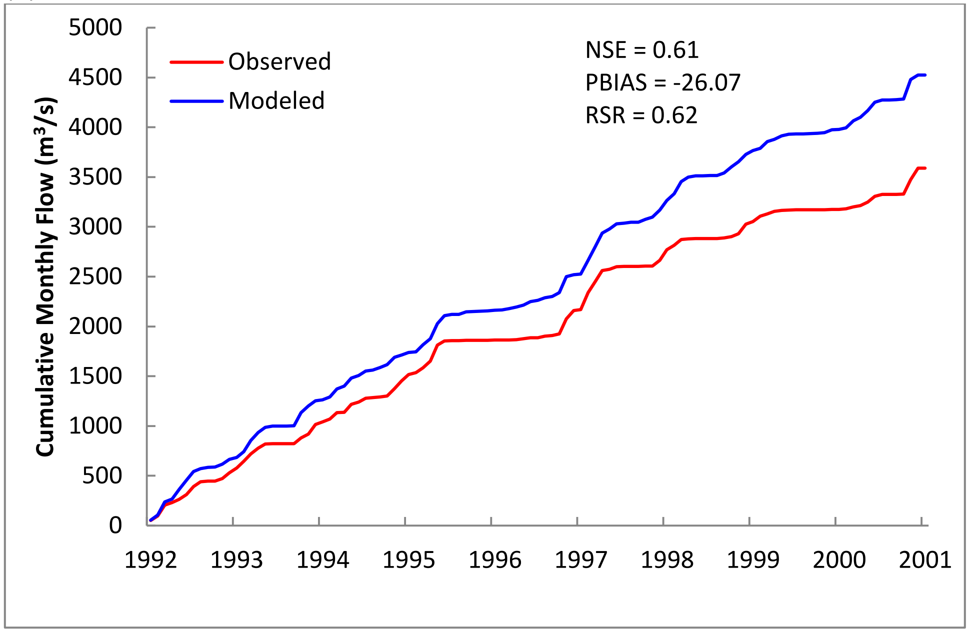


Calibration and validation at USGS streamgage 07343200 – subbasin 10

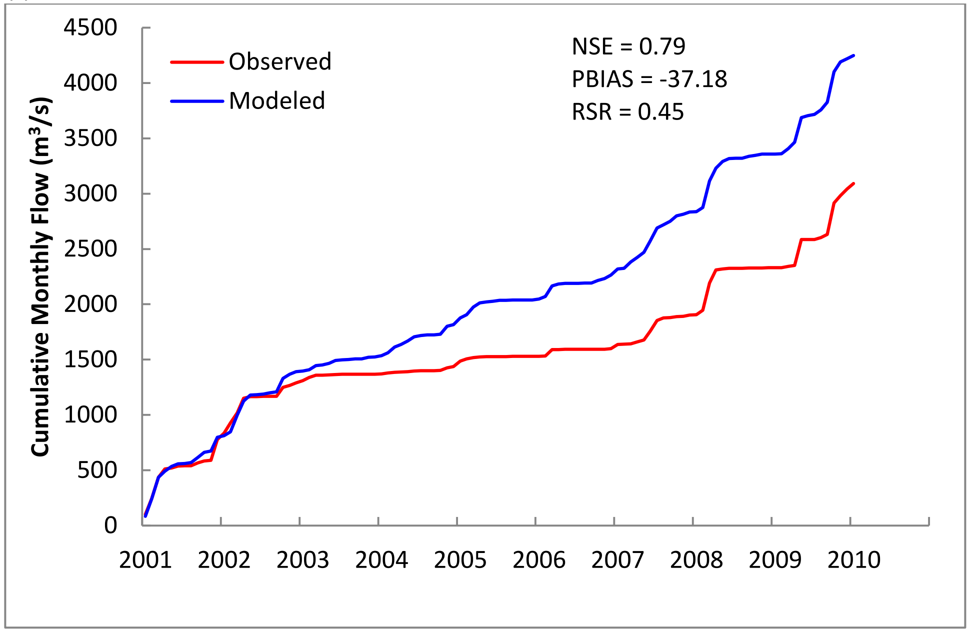


Calibration and validation at USGS streamgage 07343200 – subbasin 10 (cont.)

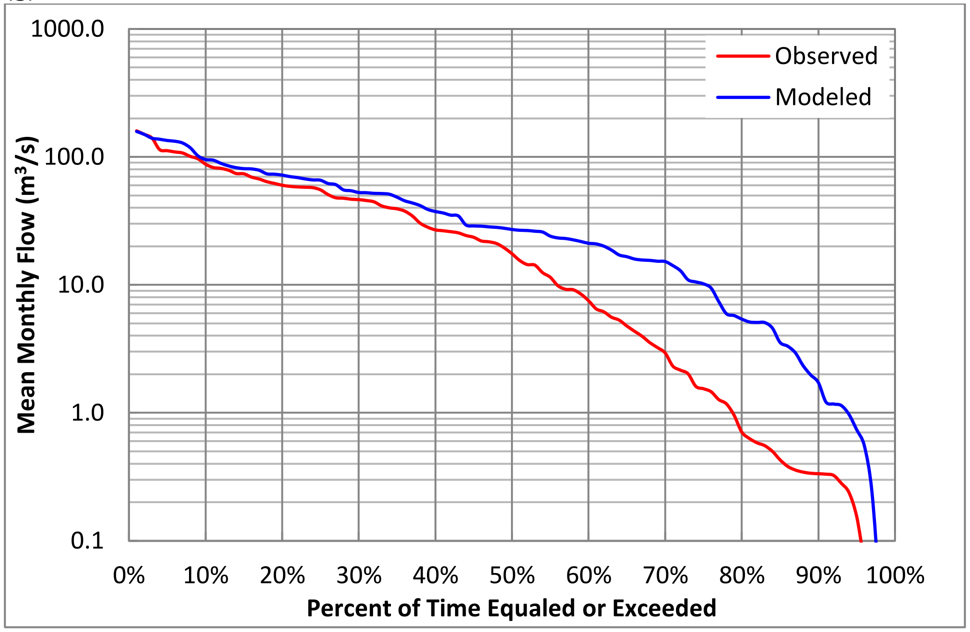
(e) calibration at 07343200 – subbasin 10



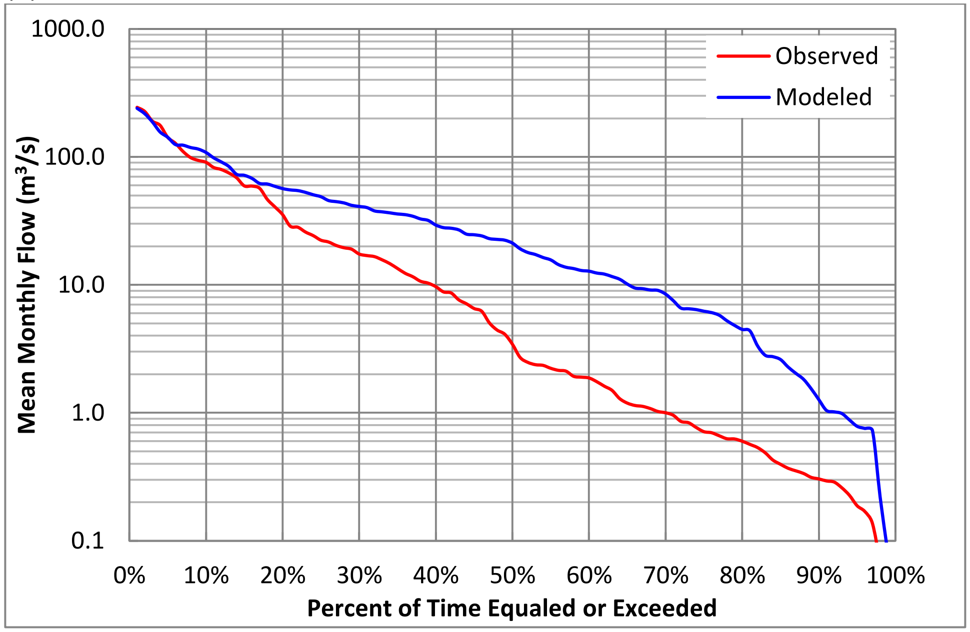
(f) validation at 07343200 – subbasin 10



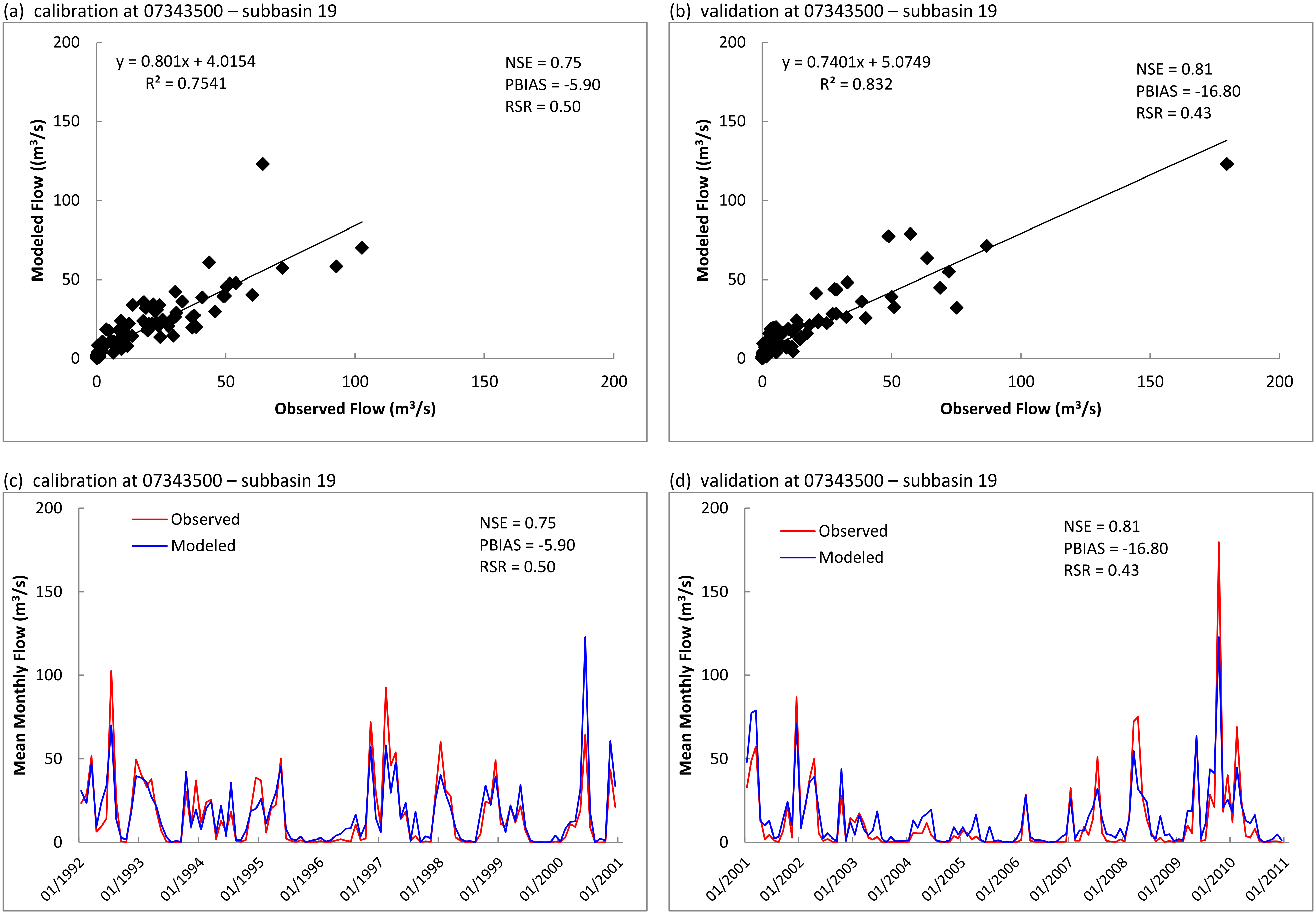
(g) calibration at 07343200 – subbasin 10



(h) validation at 07343200 – subbasin 10

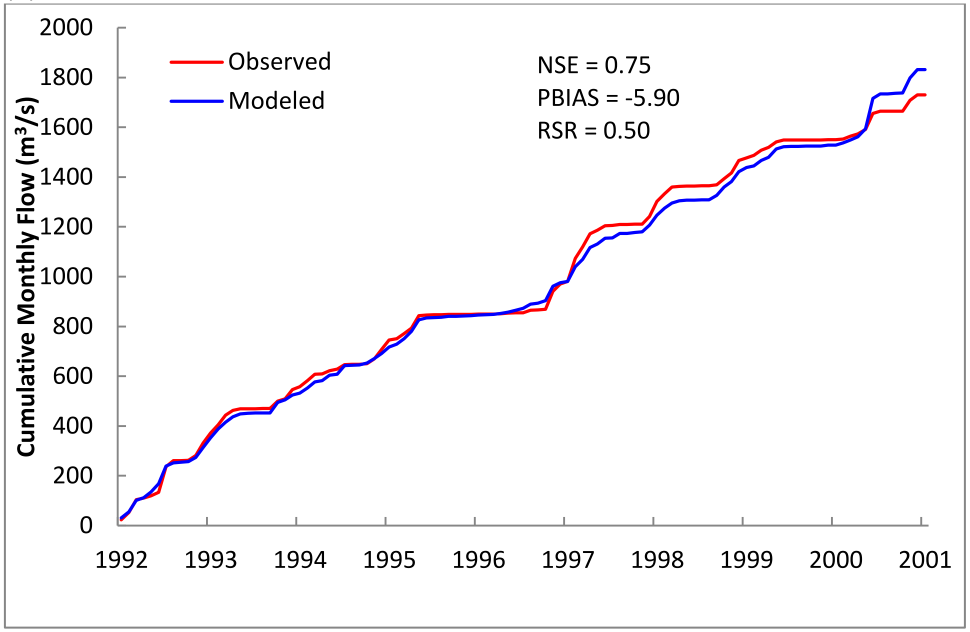


Calibration and validation at USGS streamgage 07343500 – subbasin 19

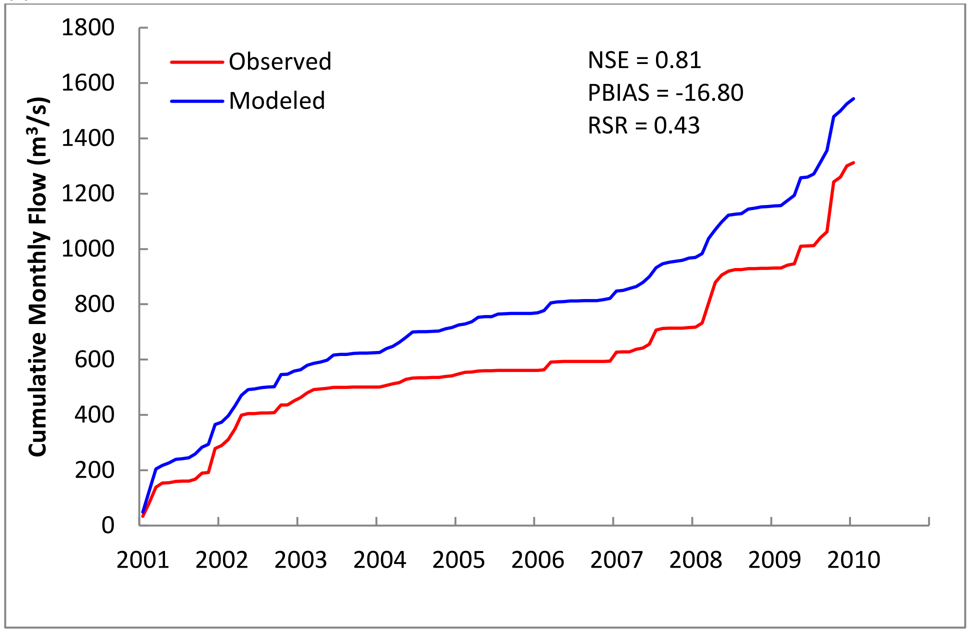


Calibration and validation at USGS streamgage 07343500 – subbasin 19 (cont.)

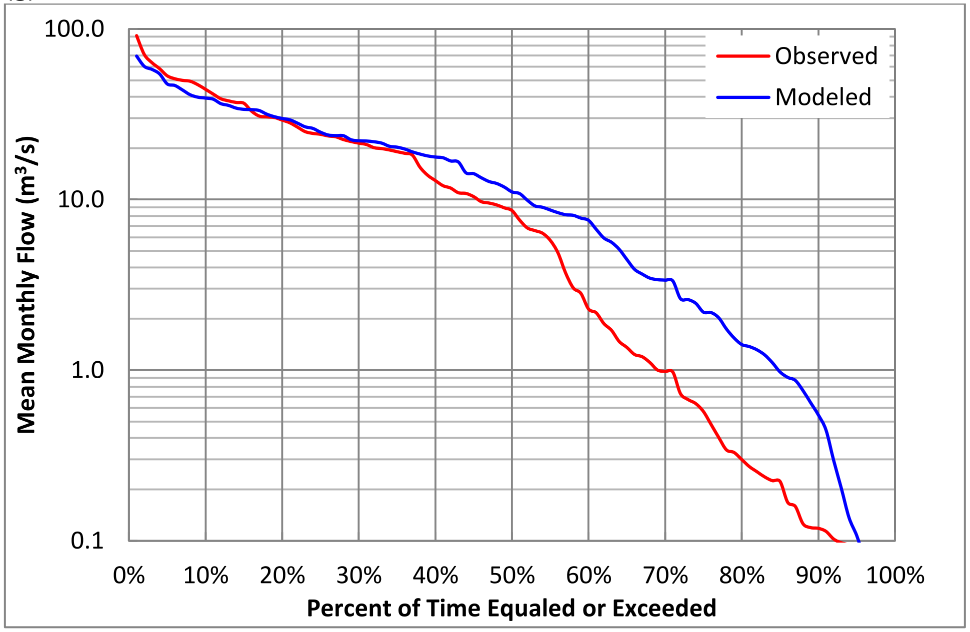
(e) calibration at 07343500 – subbasin 19



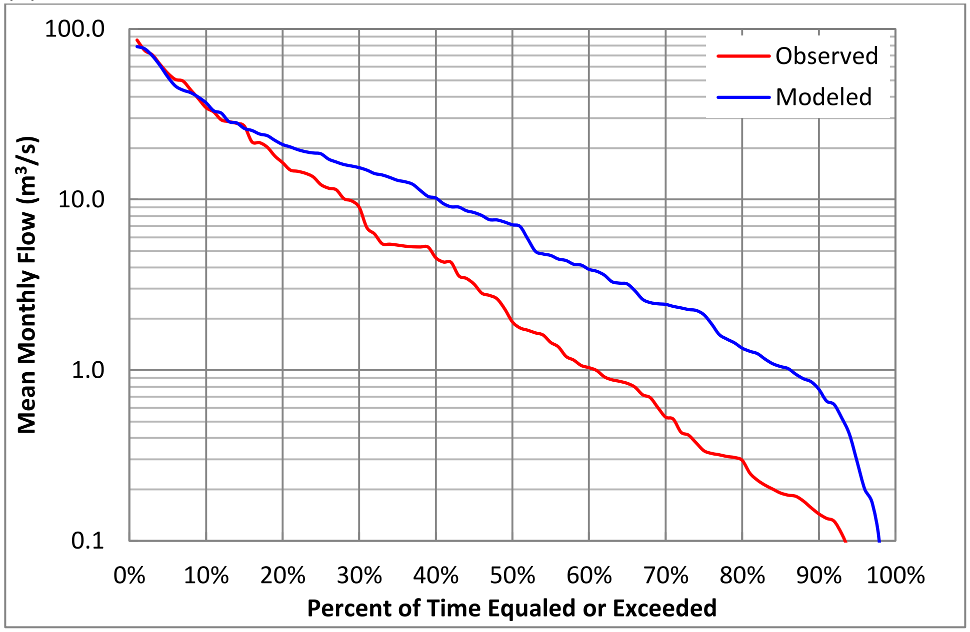
(f) validation at 07343500 – subbasin 19



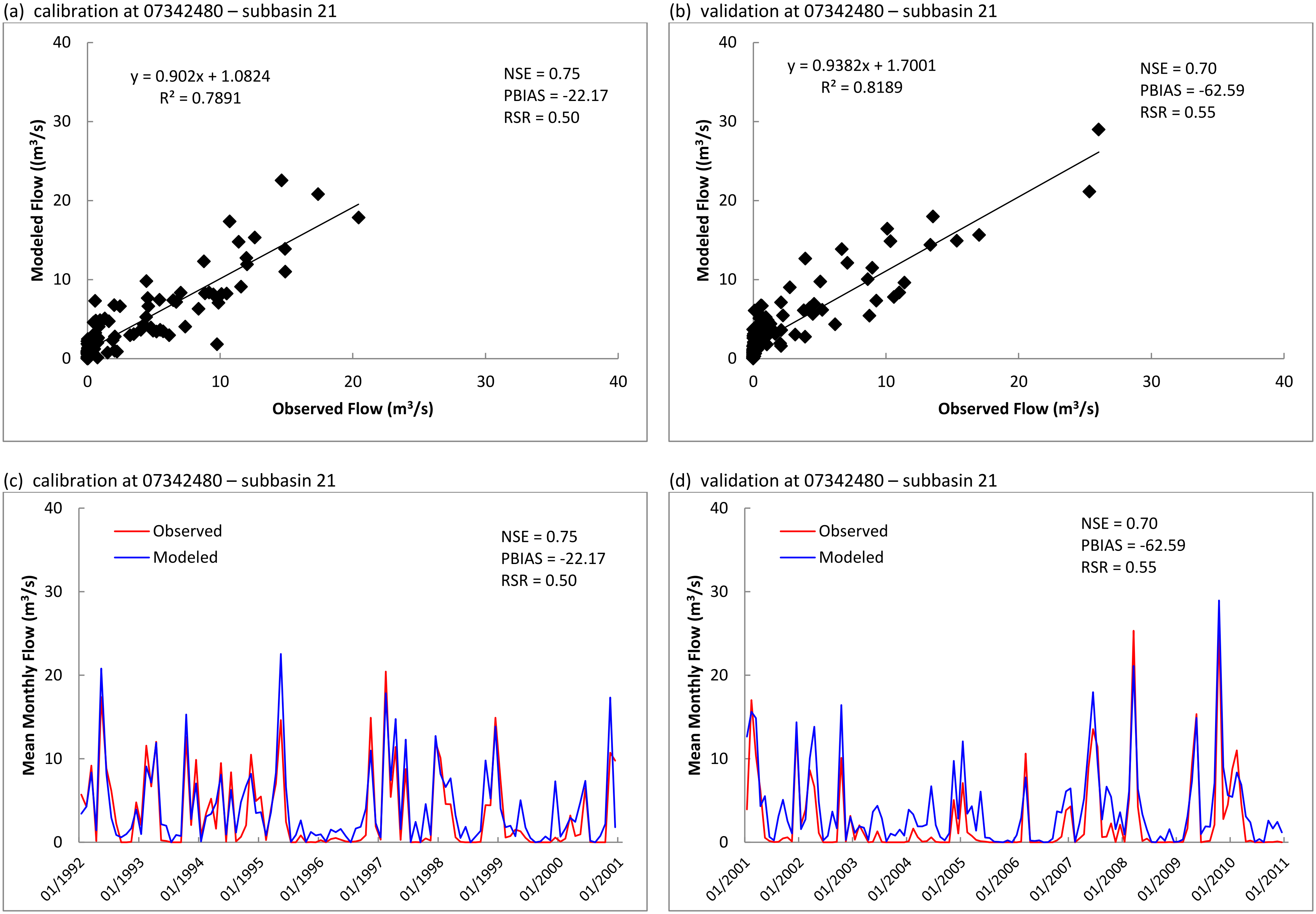
(g) calibration at 07343500 – subbasin 19



(h) validation at 07343500 – subbasin 19

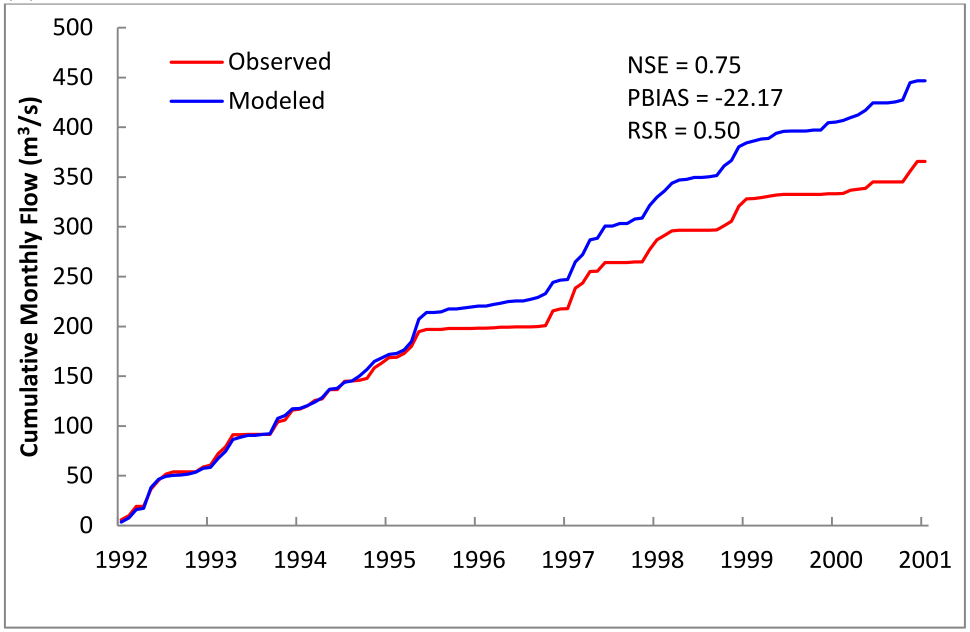


Calibration and validation at USGS streamgage 07342480 – subbasin 21

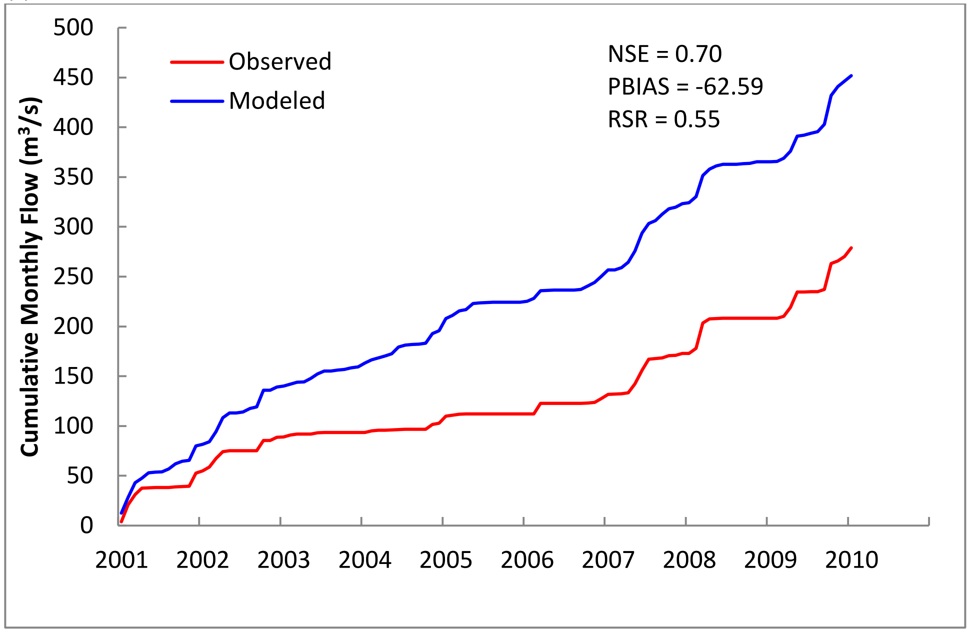


Calibration and validation at USGS streamgage 07342480 – subbasin 21 (cont.)

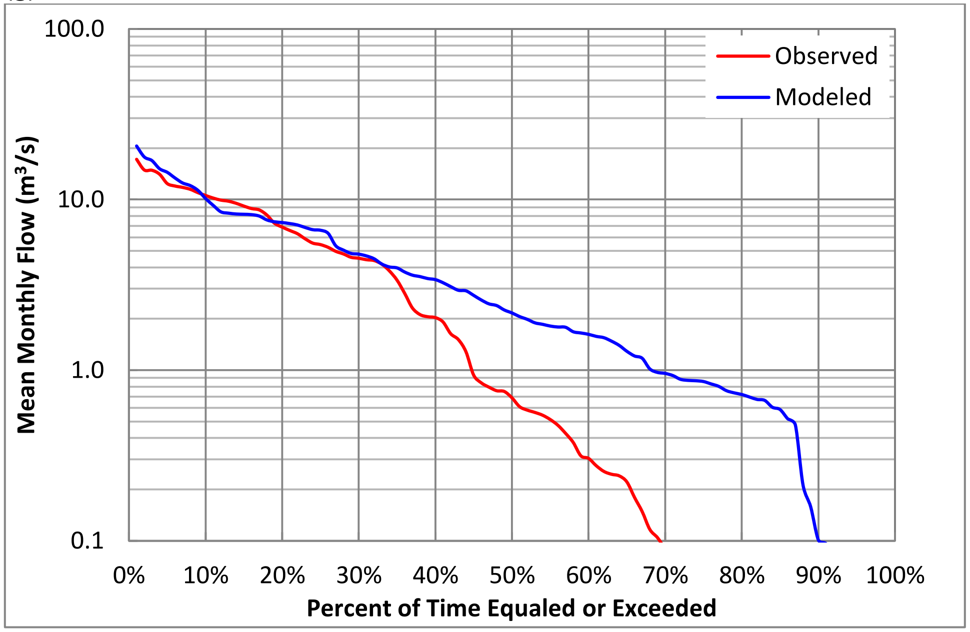
(e) calibration at 07342480 – subbasin 21



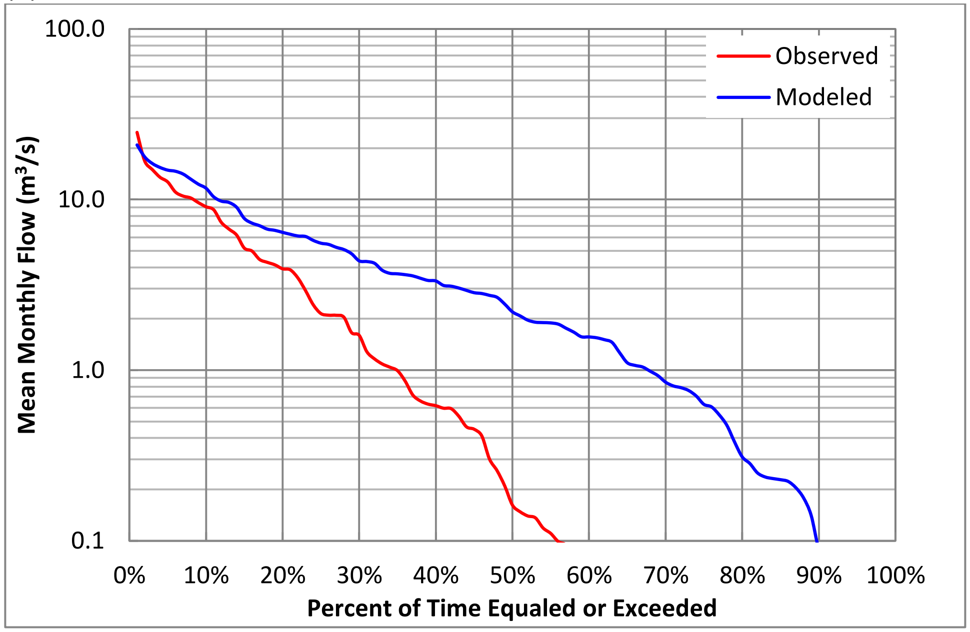
(f) validation at 07342480 – subbasin 21



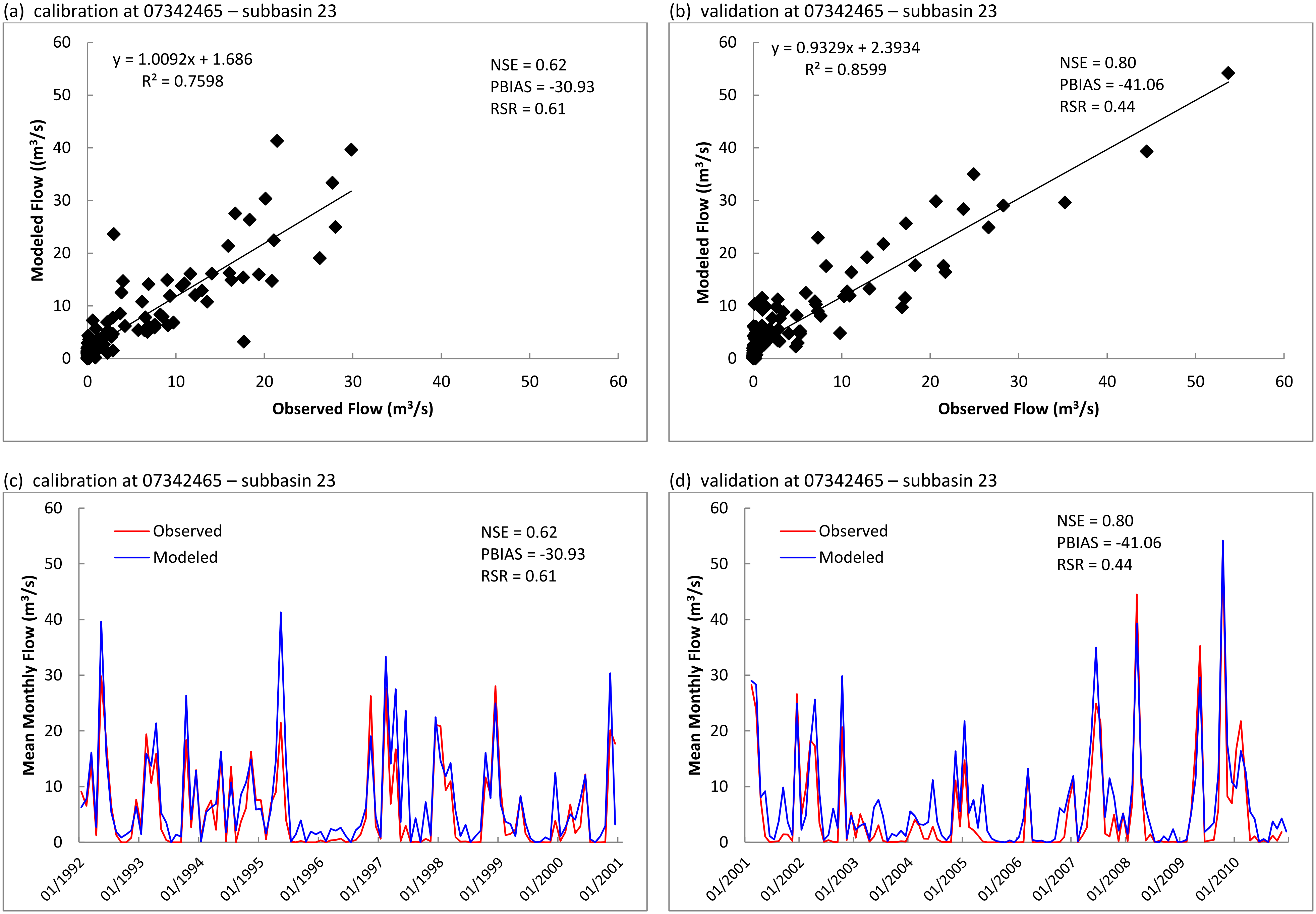
(g) calibration at 07342480 – subbasin 21



(h) validation at 07342480 – subbasin 21

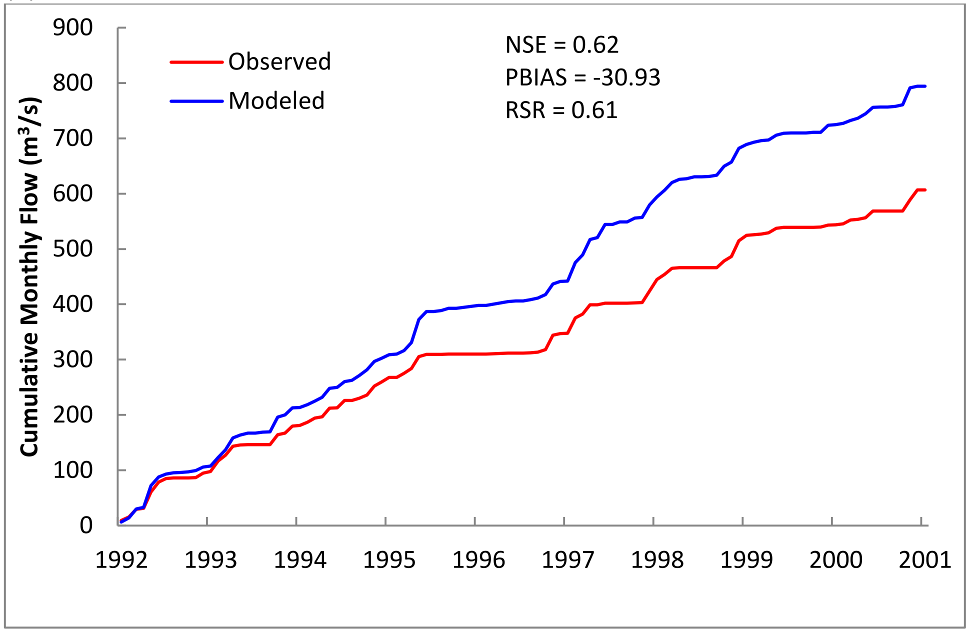


Calibration and validation at USGS streamgage 07342465 – subbasin 23

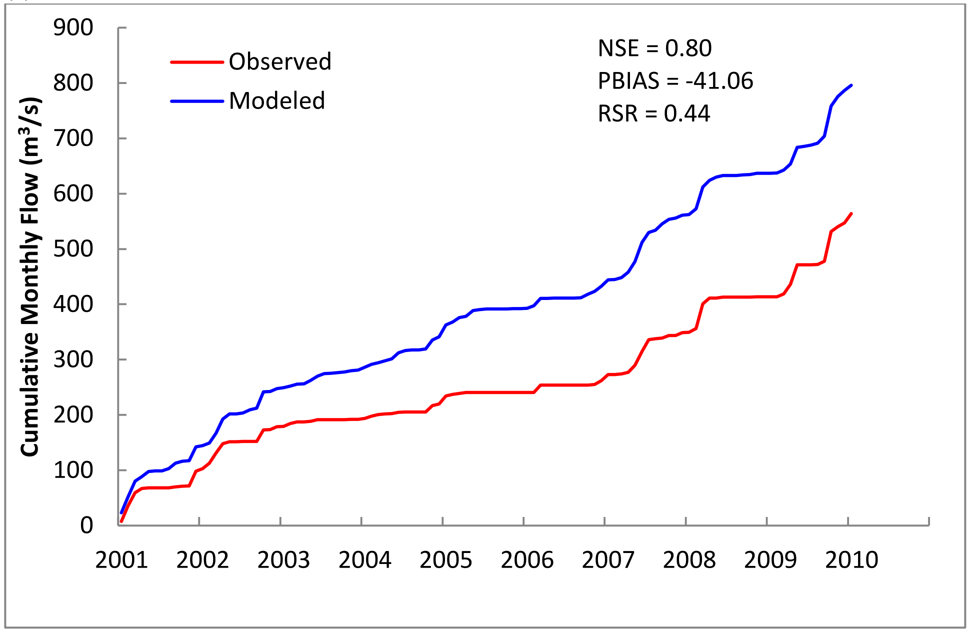


Calibration and validation at USGS streamgage 07342465 – subbasin 23 (cont.)

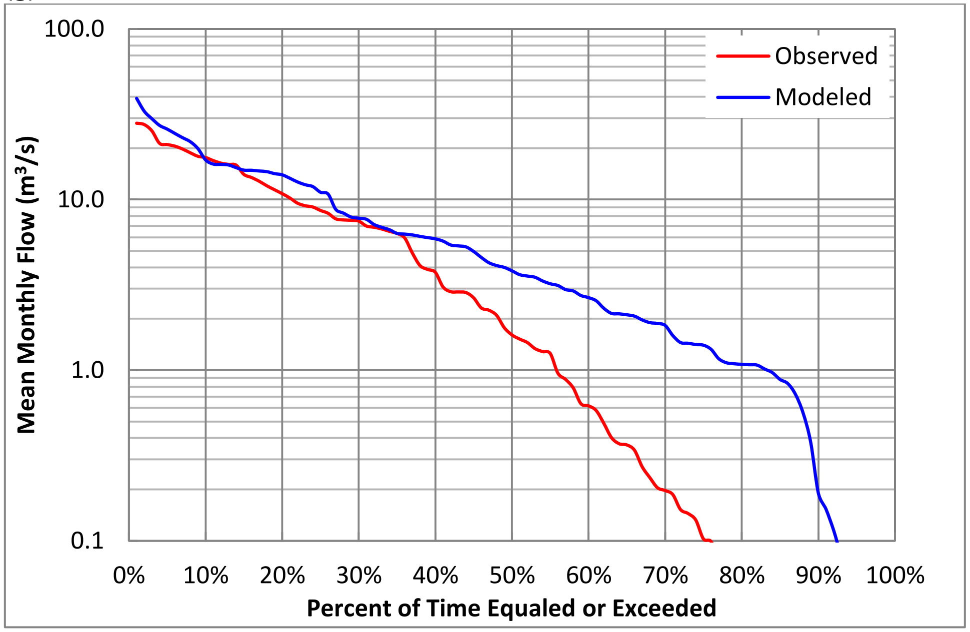
(e) calibration at 07342465 – subbasin 23



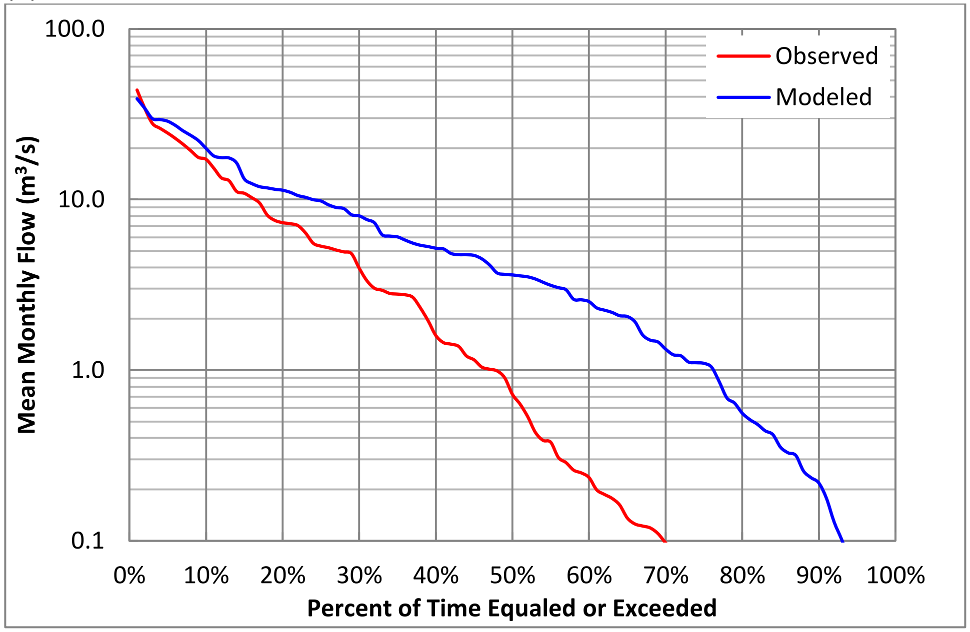
(f) validation at 07342465 – subbasin 23



(g) calibration at 07342465 – subbasin 23

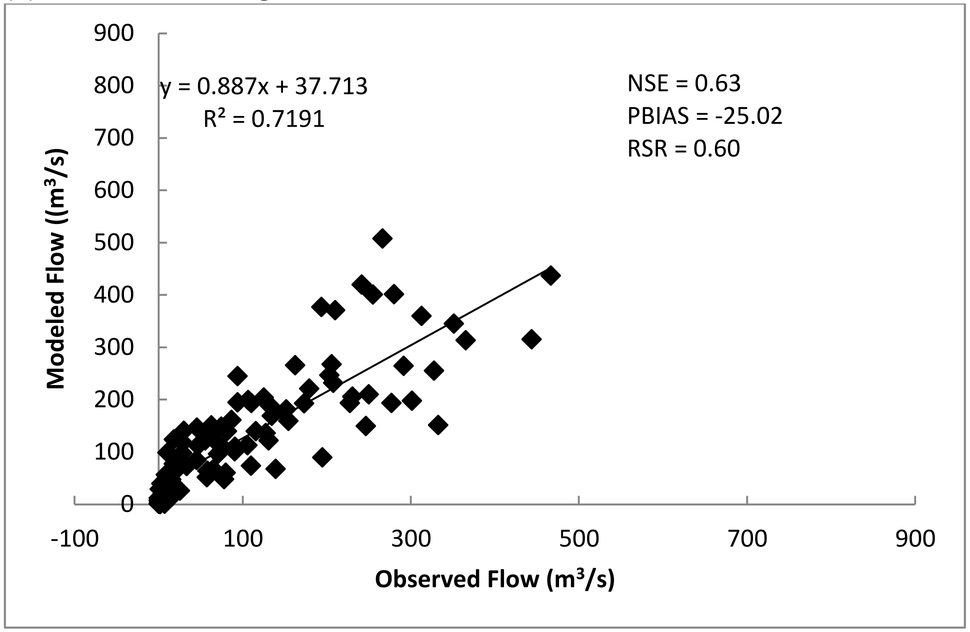


(h) validation at 07342465 – subbasin 23

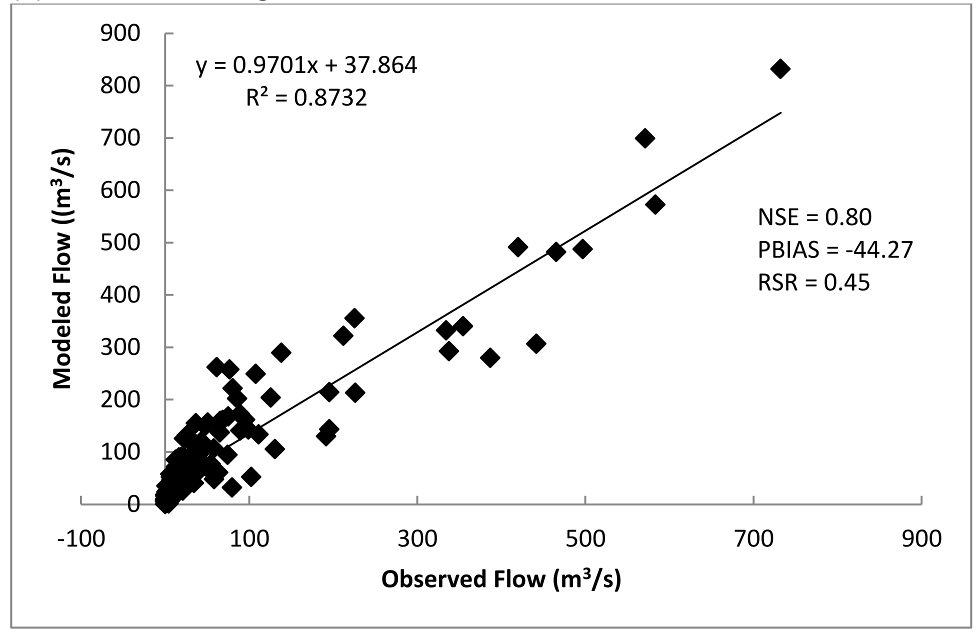


Calibration and validation at Wright Patman Lake – subbasin 12

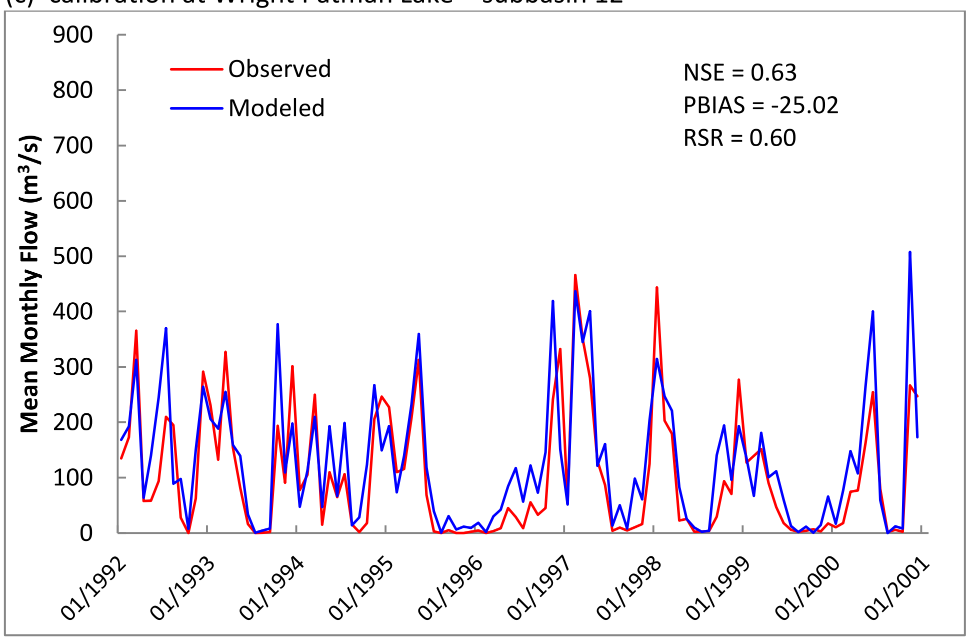
(a) calibration at Wright Patman Lake – subbasin 12



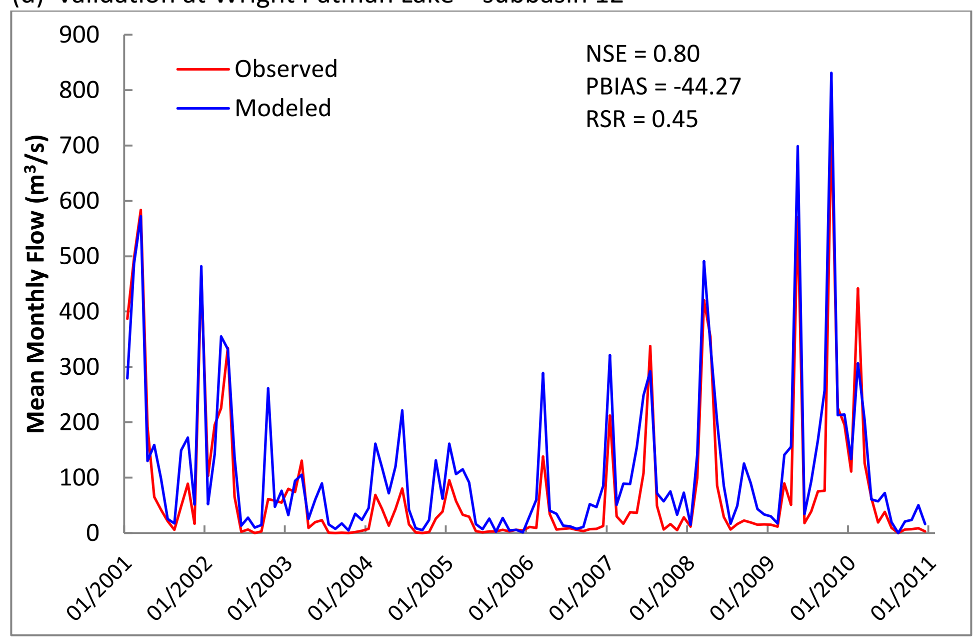
(b) validation at Wright Patman Lake – subbasin 12



(c) calibration at Wright Patman Lake – subbasin 12

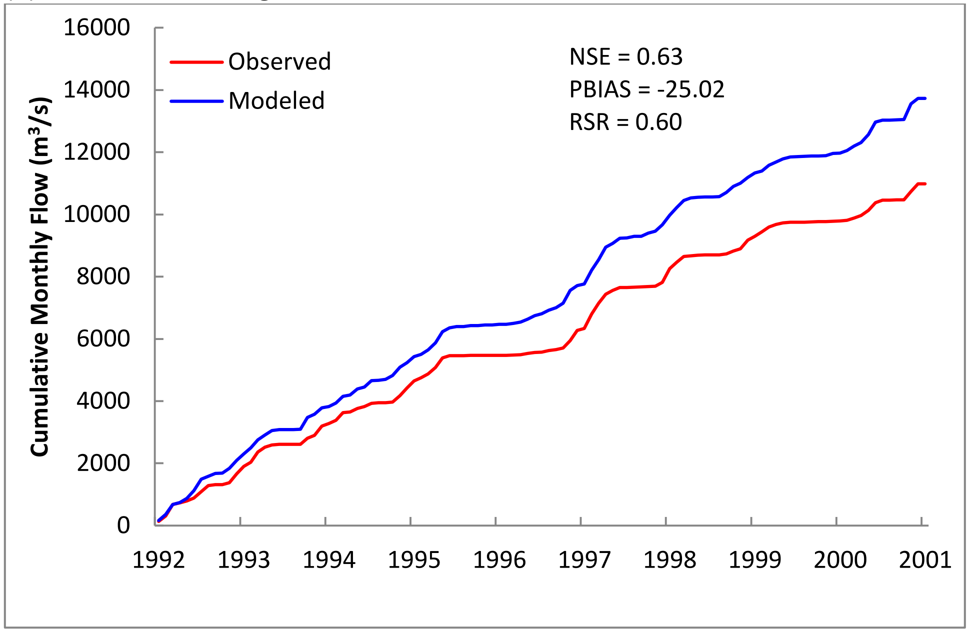


(d) validation at Wright Patman Lake – subbasin 12

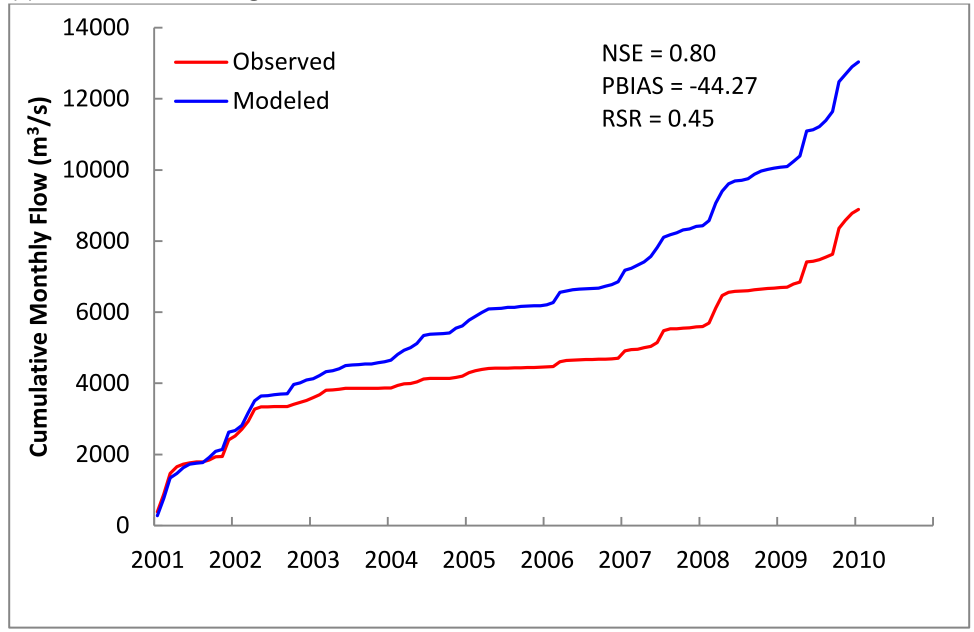


Calibration and validation at Wright Patman Lake – subbasin 12 (cont.)

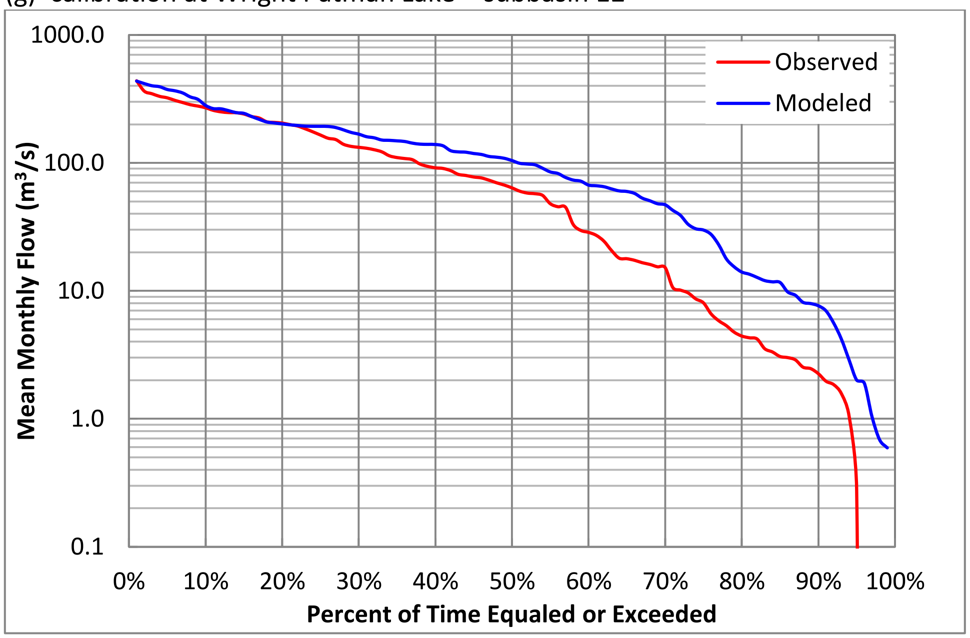
(e) calibration at Wright Patman Lake – subbasin 12



(f) validation at Wright Patman Lake – subbasin 12



(g) calibration at Wright Patman Lake – subbasin 12



(h) validation at Wright Patman Lake – subbasin 12