Sulphur River Basin Instream Flow Study

FINAL REPORT

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Sulphur River Basin Instream Flow Study
Final Report

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Commonly Used Acronyms & Abbreviations

BBASC	Basin and Bay Area Stakeholder Committee
BBEST	Basin and Bay Expert Science Team
E-Flow	Environmental Flow
EFAG	Environmental Flows Advisory Group
FNI	Freese and Nichols, Inc.
JCPD	Joint Committee on Project Development
HEFR	Hydrology-Based Environmental Flow Regime Tool
HFP	High Flow Pulse
IHA	Indicators of Hydrologic Alteration
MBFIT	Modified Base Flow Index Threshold Tool
Run 3	WAM Full Authorized Permit, No Return Flow Scenario
SAC	SB 3 Environmental Flows Science Advisory Committee
SB 2	Senate Bill 2
SB 3	Senate Bill 3
SBG	Sulphur Basin Group
SRBA	Sulphur River Basin Authority
SWQM	Surface Water Quality Monitoring
TCEQ	Texas Commission on Environmental Quality
TIFP	Texas Instream Flow Program
TPWD	Texas Parks and Wildlife Department
TWC	Texas Water Code
TWDB	Texas Water Development Board
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WAM	Water Availability Model
WRAP	Water Rights Analysis Package

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Executive Summary

The Sulphur River Basin Authority (SRBA), in coordination with the Tarrant Regional Water District (TRWD), North Texas Municipal Water District (NTMWD), Upper Trinity Regional Water District (UTRWD), City of Irving, and City of Dallas, comprise the Joint Committee on Project Development (JCPD) undertaking a process to evaluate the potential development of surface water resources in the Sulphur River Basin. This process may be broadly characterized as the Sulphur River Basin Feasibility Study, whereby a suite of varying water supply alternatives have been analyzed and evaluated to determine a preferred water supply project (or projects) when considering socio-economic, political, and environmental concerns.

The present effort, documented herein, comprises a single element of this study; namely, the consideration of the environmental flow needs of the Sulphur River Basin. In recognition of the importance that the ecological soundness of riverine systems has on the economy, health, and well-being of the State of Texas, the 80th Texas Legislature, 2007, passed into law the landmark omnibus Senate Bill 3 (SB 3). SB 3, enacted through modifications of the Texas Water Code (TWC), requires the Texas Commission on Environmental Quality (TCEQ) to adopt by rule appropriate environmental flow standards for each river basin and bay system in the state.

Environmental flow standards developed according to the SB 3 process have been adopted for the Sabine, Neches, Trinity, San Jacinto, Colorado, Lavaca, Guadalupe, San Antonio, Mission, Aransas, Nueces, Brazos, and Rio Grande River basins. These environmental flow standards are found in Chapter 298 of the Texas Administrative Code – Environmental Flow Standards for Surface Water Subchapters A-H. The adoption and effective dates of these regulations have varied in dates ranging from 2011 to 2014 depending on the river basin. The adoption schedule, as amended, requires the legislatively established committee known as the Environmental Flows Advisory Group (EFAG) to eventually establish a schedule for a process to develop such environmental flow standards for the Sulphur River Basin. At present, no such schedule has yet been established, nor have the adopted standards been modified to date.

Senate Bill 2 (SB 2), established by the Texas Legislature in 2001, created the Texas Instream Flow Program (TIFP), establishing that the Texas Parks and Wildlife Department (TPWD), Texas Water Development Board (TWDB), and TCEQ conduct studies to determine appropriate methodologies for determining flow conditions in the State's rivers and streams necessary to support a sound ecological environment, focusing upon these multiple facets of riverine ecology. At present, no such SB 2 study is scheduled for the Sulphur River Basin. Such a study could be scheduled by the three agencies, under the direction of the Texas Legislature.

Technically, as there are no adopted environmental standards for the Sulphur River Basin, nor any schedule to do so, the default methodology presently in place is the utilization of criteria developed by the Lyon's approach, a statistical characterization of seasonal variation resulting in a monthly pattern of instream flow requirements. Although consideration has been previously given to such requirements, it is nevertheless appropriate to consider those flows necessary to maintain a sound ecological environment in the Sulphur River Basin that may be identified through a more rigorous development and implementation of an environmental flow regime based on previous recent precedents established by the TCEQ. It is thus necessary for the present effort to develop and incorporate such considerations into the assessment of the alternative water supply scenarios under evaluation.

The present effort has been performed with the objective to develop an environmental flow regime consistent with the Senate Bill 2 (SB 2) and SB 3 framework, and highlight important decision points throughout the development and analysis of the data. Information learned from such analyses may inform and refine the comprehension of decisions and assumptions utilized in the consideration of such environmental flow guidelines.

It is important to note that such an effort is not intended to pre-empt a SB 3 process for the Sulphur River Basin. Rather, it is an attempt to identify potential environmental flow guidelines in order to maintain the sound ecological environment of the Sulphur River Basin and ultimately assess the potential impact of such guidelines upon various water supply alternatives under consideration in the Sulphur Basin Feasibility Study. Lastly, as no estuary is reliant upon flows from the Sulphur River Basin, no estuarine freshwater inflow requirements have been considered herein.

Summary of Methodological Approach

The guiding objective applied to the analyses and associated methodological approaches utilized herein has been the maintenance of a "sound ecological environment", which emphasizes the importance of the natural flow regime and the dynamic processes that occur over a range of flows that maintain the physical, biological, chemical, and ecological integrity of river systems (Poff, et. al., 1997). The importance of natural flow regimes for the maintenance of ecological processes in flowing water systems is well recognized (Sparks 1995; Poff and Allan 1995; Poff et al. 1997; Bunn and Arthington 2002; Bowen et al. 2003). The Instream Flow Council (IFC), an organization of state and provincial agencies in the United States and Canada dedicated to improving the effectiveness of instream flow programs, has adopted this principle as a cornerstone of river resource stewardship (Annear et al. 2004; Locke et al. 2008).

Although the goal is the maintenance of a sound ecological environment, in some cases the existence of an anthropogenic impact, such as a reservoir, may have substantially modified a downstream natural flow regime, but the downstream environment may still be ecologically sound. In either case, the objective herein has been to identify, to the extent possible, representations of the dynamic components comprising the flow regime for a given location intended to maintain a sound ecological environment and highlight, where lacking, those data gaps that might necessitate the development of data that might inform upon environmental needs.

Such a flow regime has several critical components of flow that are hypothesized to regulate ecological processes in river ecosystems: magnitude, frequency, duration, timing, and rate of change in flow (Poff and Ward, 1989; Richter, et. al., 1996; Walker, et. al., 1995; Annear et al. 2004; NRC 2005; Locke et al. 2008). These components represent attributes of the entire range of both flood and low flow conditions. Along with the physical characteristics of each river, the flow regime is the driving variable in controlling physical, biologic, and chemical processes. Such processes are interrelated, each having effects on the other and the river system.

The Scientific Advisory Committee (SAC), virtually all of the SB 3 Basin and Bay Expert Science Teams (i.e., BBESTs), and the Texas Instream Flow Program (TIFP 2008) have followed the IFC's recommendations in adopting the natural flow regime as the conceptual foundation for their proposed technical approaches. Based largely on the recommendation of the NRC (2005), the SAC (2009b) supported the development of the Hydrology-Based Environmental Flow Regime (HEFR) Methodology.

Statistical approaches to describe the instream flow regime using historical streamflow gauge records have been summarized (SAC 2009a) and employed in multiple river basins during the SB 3 process. A useful set of initial steps in the flow guideline development process utilized in the present effort may be described as (step 1) the identification of which flow components are relevant to the stream segment of interest; (step 2) levels of data, analyses and/or expert judgment acceptable in characterization in each flow component; (step 3) the identification of clear purposes or goals for each flow component; and (step 4) an indication of when and/or how often each flow component is relevant.

HEFR is a software tool that employs statistical calculations based on historic mean daily flows that relies on a framework that quantifies key attributes of four components of the flow regime. These instream flow regime components can be characterized as: subsistence, base flows, high flow pulses, and overbank flows. HEFR has been developed by the Texas Parks and Wildlife Department (TPWD) to utilize historic hydrologic data to characterize the attributes of these flow regime components in terms of magnitude, volume, duration, timing, and frequency. The application of HEFR has not been peer reviewed, although some of its underpinnings (e.g. the Indicators of Hydrologic Alteration, IHA, software) have been employed successfully elsewhere in the nation.

A wide range of purposes, ecological roles and evaluation approaches have been proposed for the four flow components (subsistence flow, base flow, high flow pulses, and overbank flows). Description excerpts from the Hydrologic Methods document (SAC 2009a) for each regime component are provided in Table-ES 1.

Table-ES 1: Generalized flow components

Overbank Flows	Overbank flows are infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. A primary objective is to maintain riparian areas associated with riverine systems, eg, transport sediments and nutrients to riparian areas, recharge floodplain aquifers, and provide suitable conditions for seedlings.											
High Flow Pulses	High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events. They serve to maintain important physical habitat features and connectivity along a stream channel.											
Base Flows	Base flows represent the range of "average" or "normal" flow conditions in the absence of significant precipitation or runoff events. Base flows provide instream habitat conditions needed to maintain the diversity of biological communities in streams and rivers.											
Subsistence Flows	An atypical, short-duration (days to weeks) low flow event											
	Maintain water quality conditions											
Month	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Season	**Winter**			**Spring**			**Summer**			**Fall**		

The environmental flow analyses performed in the present effort follow a logical progression established in SAC guidance through which: a) hydrology-based tools are evaluated and applied to extract descriptive statistics of flows and flow regime components at the selected locations relevant to the water supply alternatives under consideration; and b) biological, water quality, hydraulic, and geomorphology information are applied to confirm or refine the hydrology-based statistics. The statistically derived flow regime components are evaluated and can be modified in terms of their effectiveness in maintaining a sound ecological environment of the study reaches via a series of what are referred to as *overlays*. Such overlays are analyses of likely relations to water quality, aquatic and riparian biota, and the geomorphological and sediment dynamics that maintain habitats over the long term. The conclusion of this logical progression is the set of identified environmental flow regime guidelines.

As determined from review of the available literature, the stream segments for which environmental flow analyses have been performed herein have experienced a wide range of scientific attention varying from little to no scientific work concerning some ecosystem processes, and extensive work concerning other processes. There have generally been few, if any, scientific investigations or monitoring efforts designed to comprehensively relate physical or biological processes to the flow regime. Although the best scientific data available have been employed herein, it must again be noted that the limited levels of data and the varying levels of available information are significantly disparate and are difficult to justify employing, other than in the broadest sense, towards adjustment of the statistically derived amounts identified by HEFR.

Only limited quantitative data or analysis has been discovered to identify appropriate instream flow values on the basis of habitat utilization. The data and analyses discovered and evaluated to date lack sufficient detail to characterize specific flow rates or flow ranges that provide specific habitat conditions. In addition, quantitative measures defining bounds of habitat conditions (e.g., range of suitable velocities) are not well quantified for all species and/or guilds. Therefore, consideration is not given to the inter-relation of habitat suitability amongst the full population. Lastly, relationships are not available to characterize how habitat conditions change with changing flow.

Gage and Period of Record Selection

The historical daily observations from two locations (Table-ES 2) have been used to develop the flow time series from which instream flow guidelines are evaluated. Missing data or time periods of import to the analysis, such as representation of the drought of record, have been supplemented by either historical reservoir releases or the calculation of synthetic flow data derived from nearby gauge stations via areal relation.

Table-ES 2: USGS Gauge Selection for Estimation of Environmental Flow Guidelines

Project	Description of Hydrology to be Employed
Wright Patman	Historical releases from Wright Patman Reservoir, as reported by the USACE for the period 1979 – 2014
	Translation from USGS Sulphur River near Talco gauge (No. 07343200) to the Wright Patman dam location
Marvin Nichols IA	Utilize synthesized flow for USGS Sulphur River near Talco gauge (No.

	07343200) adjusted to dam site location with drainage area ratio
	Flow synthesis based on multivariate regression of daily measured flow at 07343200 with daily measured flow at upstream gauges 07342500 and 07343000 for 1957 – 2011
	Total period of resulting synthetic flow data set 1950-2014

Seasonality

Based upon the hydrologic, water quality, climatological, and biologic work performed in the present effort, a four-season specification has been identified as being generally applicable to the individual project locations in the Sulphur River Basin (Table-ES 3).

Table-ES 3: Seasonal identification

Season	Months
Winter (light blue)	December through March
Spring (green)	April through June
Summer (tan)	July through August
Fall (orange)	September through November

Identification of Flow Components

Flow data relevant to each of the potential project sites have been analyzed both with Indicators of Hydrologic Alteration (IHA) and the Hydrology-based Environmental Flow Regime (HEFR) software. The IHA analysis was performed to identify pulse and base flow conditions. The HEFR software was employed to characterize historic hydrologic conditions at the various locations under consideration. The flow statistics provide the fundamental basis for the identified environmental flow guidelines.

Similar to evaluations in other river basins during the SB 3 process, the analysis of available water quality data and standards in the basin has not yielded statistically significant, quantifiable relations to flow. Thus, in order to characterize a subsistence flow, the median of extreme low flow values generated via IHA was initially assumed to be representative of atypical, low flow conditions. This percentile has frequently been employed in other river basins during the SB 3 process, and has been assumed to be representative of such conditions herein. The calculated minimum 7-day, 2-year flow amount (7Q2) was then used as an overlay for the consideration of subsistence flow guidelines.

The lack of quantifiable relations between flow and ecologic functions within the Sulphur River Basin limits the extent to which ecological overlay information may be used to modify the resultant historic statistics on hydrology. The most comprehensive evaluation to date was performed by the Texas Water Development Board (Osting et. al. 2004). As is noted by TWDB, there appears to be significant uncertainty in the relations between velocity, depth, and observed mesohabitat.

While this uncertainty may preclude the identification of a specific flow magnitude (or magnitudes), the information developed by TWDB does appear sufficient to warrant a need for multiple levels of base flow, a conclusion based largely on the observations from the available literature. Although specific relations may be uncertain, the observed mesohabitats from the Gelwick and Morgan (2000) and Gelwick and Burgess (2002) studies suggest at least one shift as velocity and depth vary. At present, the available information is insufficient to quantify how much of a given mesohabitat might be produced at various flow velocities and depths. Furthermore, the available information base only lends to a general characterization of the habitat requirements of the indicator organisms considered. It is thus not presently defensible to identify specific flow thresholds at which biologically critical mesohabitats would be produced. It has thus been concluded herein that two base flow components should be identified (high and low), in order to capture a range of base flow conditions, recognizing the observed variation in mesohabitat conditions as flows vary.

The statistical characterization of the historic hydrology has been employed to identify seasonal base flows that approximate the orders of magnitude at low and high flows in order to potentially mimic the historical variations in observed mesohabitat characteristics in the watersheds of interest. High base flows are characterized as those flows subsequent to the significant rainfall events observed in the Sulphur River Basin, while lower base flows are intended to be more representative of typical base flow conditions in the system.

A significant assumption employed for the present planning effort is that any proposed water supply strategy which may alter the hydrology of the system must also be designed to operate in a manner that protects life and property downstream of the proposed project.

Recognizing the legal precedent associated with flooding and the potential assignment of legal liability to owners of water rights, specific overbanking components including pulses with peaks that may result in flows in excess of bank-full capacity (overbank flows) have not been included in the identified environmental flow guidelines herein. Pulse flow guidelines identified in the present effort were selected based on not exceeding the overbank flow amount at the measurement point and the capability of implementation in the Water Availability Modeling (WAM).

Identification of Environmental Flows

Having compiled and evaluated the available data and statistics regarding hydrology, biology, ecology, and climate; environmental flow guidelines have been identified. Implementation of such guidelines is an equally important consideration, and is thus broadly described below. The identified environmental flow guidelines for each alternative water supply location under consideration are then summarized. The locations of the identified environmental flow guidelines relevant to each potential water supply alternative are depicted in Figure-ES 1.

Implementation (General)

An essential component of the specification of environmental flow guidelines is delineating how such numerical elements might be applied to new surface water appropriations, particularly as they relate to WAM, as WAM is the tool utilized herein to determine priority flows (consisting of pass through amounts for senior water rights and environmental flows) that feed forward into subsequent analyses of firm supply available from the alternative water supply projects under consideration. (Model implementation is described later in this section.)

General Consideration

Flows passed for senior water rights count toward satisfaction of any specified subsistence, base, and pulse flow rates and volumes. Further, the identified components comprise a flow regime, and should not be implemented individually.

Subsistence Flow

Ecological functions of subsistence flows include provision for aquatic habitat, longitudinal connectivity, dissolved oxygen, and temperature sufficient to ensure survival of aquatic species through low flow periods to the extent possible while recognizing that the stream segments in the Sulphur River Basin are significantly variable. The translation of seasonal subsistence flows into potential special conditions should not result in a more frequent occurrence of flows less than the identified seasonal subsistence guidelines as a result of a new surface water project. In those instances where subsistence flows are specified that result in a value lower than 1 cfs, the subsistence guideline has been set at 1 cfs. If inflow is less than the seasonal subsistence value, then all inflow should be passed and none impounded or diverted.

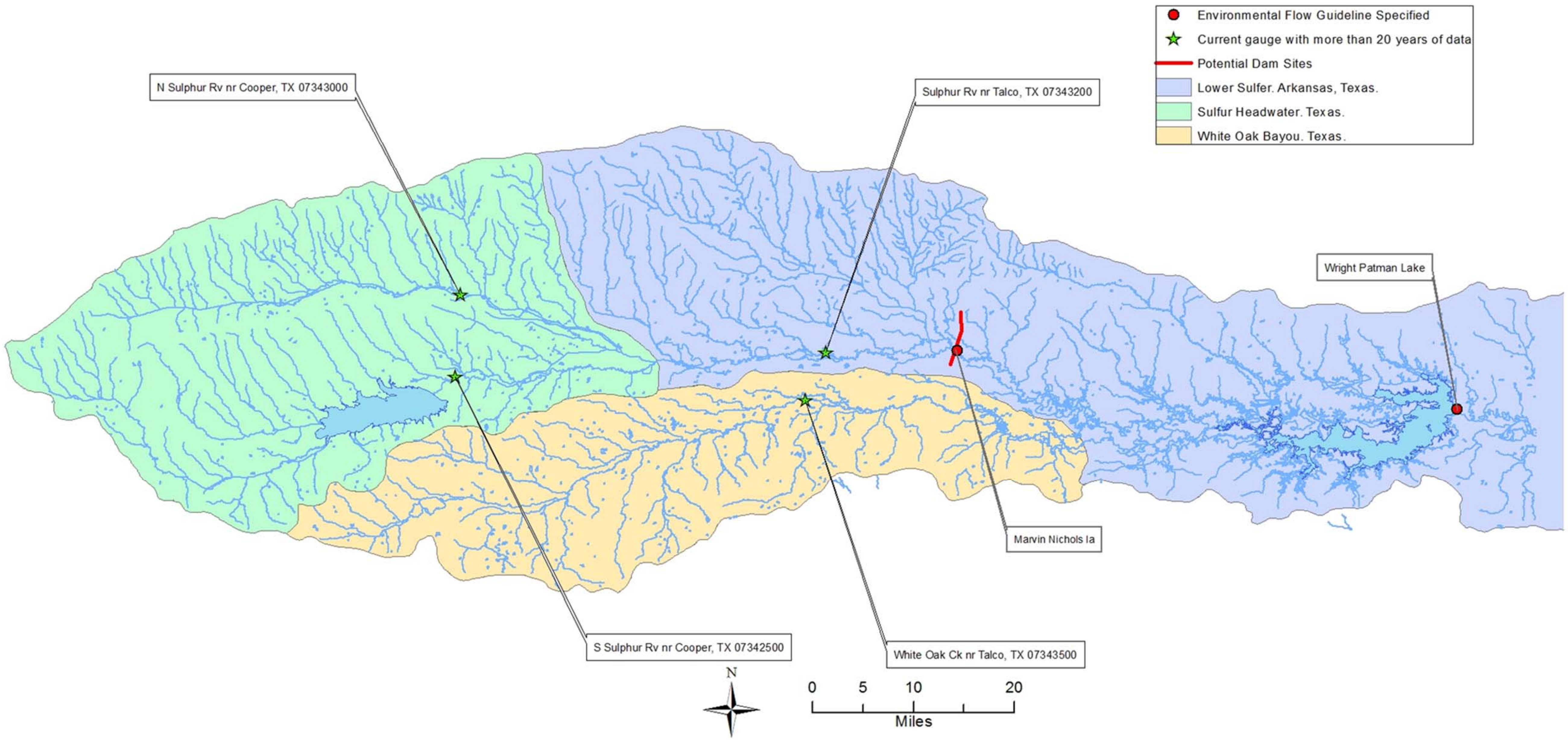

Figure-ES 1: Environmental Flow Guideline Locations

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Base Flow and 50% Rule

Base flows provide variable flow conditions, suitable and diverse aquatic habitat, longitudinal connectivity, soil moisture, and water quality sufficient to sustain aquatic species and proximate riparian vegetation for extended periods. As simply stated in SAC guidance, “base flows provide instream habitat conditions needed to maintain the diversity of biological communities in streams and rivers (SAC, August 31, 2009).” To remain generally consistent with approaches utilized by TCEQ during the SB 3 process in other basins in Texas, specific implementation guidelines regarding application of the base flow component are summarized as follows:

a. If inflow is less than the lowest seasonal base value and greater than the seasonal subsistence value, then the seasonal subsistence flow plus 50 percent of the difference between inflow and the seasonal subsistence value should be passed, and the balance may be impounded or diverted to the extent available, subject to senior water rights. This “50% Rule” is identified for each of the identified locations.

b. If inflow is less than the highest base flow value and greater than the lowest base value, then that the lowest seasonal base value must be passed, and the balance may be impounded or diverted to the extent available, subject to senior water rights.

c. If inflow is less than the lowest applicable pulse peak value and greater than the highest seasonal base value, then that highest seasonal base value must be passed, and the balance may be impounded or diverted to the extent available, subject to senior water rights.

High Flow Pulses

Generally, high flow pulses provide elevated in-channel flows of short duration, recruitment events for organisms, lateral connectivity, channel and substrate maintenance, limitation of riparian vegetation encroachment, and in-channel water quality restoration after prolonged low flow periods as necessary for long-term support of a sound ecological environment. Guidelines regarding application of the high flow pulse components are summarized as follows:

a. Applicable high flow pulses for a new surface water appropriation are to be determined in accordance with the Pulse Exemption Rule as described below.

b. If inflow is greater than a specified peak flow (Qp), and all applicable pulse recommendations have not been satisfied, then all inflow up to the peak flow must be passed until either the recommended volume or duration has passed, and the balance of inflow may be impounded or diverted to the extent available, subject to senior water rights.

c. If all applicable pulse recommendations have been satisfied and inflow is greater than the seasonal base value, then that seasonal base value must be passed, and the balance may be impounded or diverted to the extent available, subject to senior water rights.

d. Pulse events are identified upon occurrence of specified trigger flow, counted in the season or year in which they begin, and assumed to continue into the following season or year as necessary to meet specified volumes or durations. Once a pulse event has been identified, volumes passed during the event, but prior to exceeding the specified trigger flow (equivalent to Qp in the environmental flow guidelines), may be credited towards the specified volume requirement.

e. One pulse counts towards the specified achievement frequency, and resets at the season or return period end.

f. Each return period (i.e., season, series of months, one-year, two-years, or five-years) is independent of the preceding and subsequent return period with respect to high flow pulse attainment frequency.

Environmental Flow Guidelines

The numerical elements of the identified Sulphur River Basin environmental flow guidelines, and a summary discussion on their derivation, is provided below.

Marvin Nichols

Environmental flow guidelines identified for the Marvin Nichols Project location are presented in Table-ES 4. The estimated flow guidelines have been developed utilizing the hydrologic characteristics of the USGS Sulphur River near Talco gauge (No. 07343200), in conjunction with the general biological and ecological flow needs identified in the literature review.

The subsistence flow is the 7Q2 flow amount calculated at USGS Sulphur River near Talco gauge (No. 07343200) from 1950-2014, translated to the project location using a drainage area ratio.

As noted previously, two levels of base flow have been identified to maintain the historical seasonal variation of a range of flows spanning the two broad levels of the mesohabitat characteristics identified within Osting et. al. (2004). The high base flow is characterized from the historical statistics by the 75th percentile of seasonal flows (as characterized with the present application of IHA). In addition, the 25th percentile of seasonal flows best represents the low base flow level.

The pulse guideline identified herein is the translated pulse peak flow from the Sulphur River near Talco that would not result in overbanking of the channel at the measurement location. Seasonal pulses have been identified wherein the identified frequency does not exceed the number of months in the season, allowing for implementation within WAM consistent with previous TCEQ approaches for representing pulse frequency.

Table-ES 4: Marvin Nichols Project Location Environmental Flow Guidelines

Season	Subsistence	Base Low	Base High	Pulse
Winter	1.5 cfs	17 cfs	241 cfs	4 per season
				Trigger: 3,789 cfs
				Volume: 23,136 af
				Duration: 7 days
Spring	1.5 cfs	20 cfs	168 cfs	3 per season
				Trigger: 3,789 cfs
				Volume: 21,162 af
				Duration: 6 days
Summer	1.5 cfs	5.6 cfs	23 cfs	2 per season
				Trigger: 168 cfs
				Volume: 1,001 af
				Duration: 5 days
Fall	1.5 cfs	6.1 cfs	48 cfs	2 per season
				Trigger: 2,975 cfs
				Volume: 16,940 af
				Duration: 7 days

Wright Patman

Environmental flow guidelines estimated at Wright Patman are presented in Table-ES 5. The estimated environmental flow guidelines have been developed based upon the environmental flow guidelines identified at the Sulphur River near Talco, which have been translated downstream to Wright Patman using the TCEQ's pulse translation methodology. Little other specific information regarding biological needs or water quality is available; thus, base and high flow conditions have been derived using the same statistics as used to develop guidelines at the USGS Sulphur River near Talco gauge (No. 07343200). The translation method has been used in order to develop a more natural representation of hydrologic conditions unaffected by historical Wright Patman releases.

The subsistence flow is the calculated 7Q2 flow value at USGS Sulphur River near Talco gauge (No. 07343200) over the 1950-2014 time period, translated to the project location using a drainage area ratio. The high and low base flow levels are the 75th and 25th percentiles, respectively, of seasonal flow at the USGS Sulphur River near Talco gauge (No. 07343200), translated to the project location using a drainage area ratio.

Seasonal pulses at Wright Patman are the seasonal pulses identified at USGS Sulphur River near Talco gauge (No. 07343200), translated to the project location using TCEQ's pulse translation methodology.

Table-ES 5: Wright Patman Location Environmental Flow Guidelines (Translated)

Season	Subsistence	Base Low	Base High	Pulse
Winter	2.7 cfs	32 cfs	435 cfs	4 per season
				Trigger: 6,823 cfs
				Volume: 44,310 af
				Duration: 7 days
Spring	2.7 cfs	36 cfs	304 cfs	3 per season
				Trigger: 6,823 cfs
				Volume: 40,530 af
				Duration: 7 days
Summer	2.7 cfs	10 cfs	41 cfs	2 per season
				Trigger: 303 cfs
				Volume: 1,916 af
				Duration: 6 days
Fall	2.7 cfs	11 cfs	87 cfs	2 per season
				Trigger: 5,357 cfs
				Volume: 32,444 af
				Duration: 8 days

Model Implementation

Evaluations implementing the identified environmental flow guidelines in a modeling context have been performed, and the results reported herein. The objective of the present effort is to develop the environmental flow guidelines and implement them in a WAM context to determine a revised set of priority releases representing not only releases for senior water rights, but also releases for the pass-through of environmental flows. These revised priority releases (represented as a monthly time series) are the functional deliverable of the present effort, as they are then to be incorporated by SBG in subsequent evaluations of alternative project firm yields.

SBG has adopted the RiverWare platform to evaluate potential project firm yields. To explicitly determine priority releases (i.e., required releases for senior water rights or to potentially meet environmental flow requirements), SBG developed a simplified WAM referred to hereafter as the "Mini-WAM." This "Mini-WAM" uses the RiverWare hydrology developed by USACE in a WAM to determine priority releases from Ralph Hall, Chapman, and Marvin Nichols projects for Lake Wright Patman. Other water rights are not explicitly modeled in the "Mini-WAM", although the impact of the historical operation of these other water rights is contained in the hydrology used in the model. Use of the USACE hydrology allows for a model period of record from 1938-2014, which includes the identified new potential drought of record. The "Mini-WAM" is also modified to include Lake Ralph Hall, a proposed but at present unbuilt reservoir.

The objective of the present effort is thus the incorporation of new information and data regarding the aforementioned recent hydrologic conditions of drought in the Sulphur River Basin, and the identification and implementation of alternative potential environmental guidelines representative of a more comprehensive environmental flow regime with a framework consistent with instream standards adopted in other Texas river basins through the SB 3 process.

The "Mini-WAM" of the Sulphur Basin was obtained from SBG on March 28, 2016, and has been utilized to implement alternative potential environmental flow guidelines in a manner consistent with TCEQ's implementation in other river basins. Output from this "Mini-WAM" are time series of priority flows at all control points reflecting senior water rights and pass-throughs of flow needed to achieve downstream environmental flow guidelines developed as part of this effort.

The present effort has been performed to develop and employ environmental flow guidelines consistent with the SB 3 framework, highlight important decision points throughout their development, and implement them in a WAM context for SBG's subsequent assessment of their potential impacts on various potential water supply alternatives in the Sulphur River Basin.

This study has consisted of three work elements: (1) a comprehensive literature review compiling and organizing existing historical information on the hydrology, biology, physical habitat, physical processes (geomorphology), and water quality of the study area, (2) hydrologic analyses of streamflow at relevant and available gauge locations for development of hydrology-based environmental flow guidelines, and (3) an initial implementation of the guidelines in a WAM context for subsequent evaluation of their impacts on modeled firm yields of alternative projects.

The available data related to hydrologic, biologic, physical habitat, geomorphologic, and water quality conditions have been utilized herein to broadly identify a range of base flow conditions.

While there are substantial data available with regard to water quality, direct relations to flow magnitude were not identifiable. Recognizing that SAC guidance recommends that a comprehensive flow regime include atypical, low flow conditions, subsistence flow metrics have been developed solely utilizing statistics from the historical hydrology, namely 7Q2.

Recognizing the legal precedent associated with flooding and the potential assignment of legal liability to owners of water rights, specific overbanking components including pulses with peaks that may result in flows in excess of bank-full capacity (overbank flows) have not been included in the identified environmental flow guidelines herein. Rather, that information has been utilized to establish a maximum magnitude of pulse flow at the measurement location (consistent with TCEQ's methodology in other river basins), allowing for the specification of high flow pulses again utilizing statistics from the historical hydrology. While literature sources were used to identify potential ecological indicators and their general ecological requirements, this general information was used largely to support that pulse flows are a necessary component of the flow regime.

The resultant environmental flow guidelines have then been implemented within the SBG Sulphur Basin "Mini-WAM" to ultimately ascertain their potential impacts on water supply alternatives presently under consideration. A significant complication in such an endeavor is that, at present, there is no final formal documentation of how TCEQ intends to implement environmental flow standards. The only indications available are those provided within WAM models where environmental standards have been adopted, and a Draft guidance document currently under development by TCEQ. Nevertheless, it remains unclear whether such implementations are the TCEQ staff’s final position on the matter. Given this uncertainty, it has been necessary to employ representations of the environmental flow guidelines that are consistent with previous TCEQ implementations and assumptions.

Consistent with the SB 3 process in other basins, no releases from storage are required to produce achievement of a given environmental flow criterion. Rather, the evaluation is made as to whether inflow conditions trigger the requirement of an environmental flow guideline. Said differently, if the flows are present they must be passed, but if the flows are not present, they do not have to be produced.

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1 Introduction

The Sulphur River Basin Authority (SRBA), in coordination with the Tarrant Regional Water District (TRWD), North Texas Municipal Water District (NTMWD), Upper Trinity Regional Water District (UTRWD), City of Irving, and City of Dallas, comprise the Joint Committee on Project Development (JCPD) undertaking a process to evaluate the potential development of surface water resources in the Sulphur River Basin. This process may be broadly characterized as the Sulphur River Basin Feasibility Study, whereby a suite of varying water supply alternatives have been analyzed and evaluated to determine a preferred water supply project (or projects) when considering socio-economic, political, and environmental concerns.

The present effort, documented herein, comprises a single element of this study; namely, the consideration of the environmental flow needs of the Sulphur River Basin. In recognition of the importance that the ecological soundness of riverine systems has on the economy, health, and well-being of the State of Texas, the 80th Texas Legislature, 2007, passed into law the landmark omnibus Senate Bill 3 (SB 3). SB 3, enacted through modifications of the Texas Water Code (TWC), requires the Texas Commission on Environmental Quality (TCEQ) to adopt by rule appropriate environmental flow standards for each river basin and bay system in the state.

Environmental flow standards developed according to the SB 3 process have been adopted for the Sabine, Neches, Trinity, San Jacinto, Colorado, Lavaca, Guadalupe, San Antonio, Mission, Aransas, Nueces, Brazos, and Rio Grande River basins. These environmental flow standards are found in Chapter 298 of the Texas Administrative Code – Environmental Flow Standards for Surface Water Subchapters A-H. The adoption and effective dates of these regulations have varied in dates ranging from 2011 to 2014 depending on the river basin. The adoption schedule, as amended, requires the legislatively established committee known as the Environmental Flows Advisory Group (EFAG) to eventually establish a schedule for a process to develop such environmental flow standards for the Sulphur River Basin. At present, no such schedule has yet been established, nor have the adopted standards been modified to date.

Technically, as there are no adopted environmental standards for the Sulphur River Basin, nor any schedule to do so, the default methodology presently in place is the utilization of criteria developed by the Lyon's approach, a statistical characterization of seasonal variation resulting in a monthly pattern of instream flow requirements. Although consideration has been previously given to such requirements, it is nevertheless appropriate to consider those flows necessary to maintain a sound ecological environment in the Sulphur River Basin that may be identified through a more rigorous development and implementation of an environmental flow regime based on previous recent precedents established by the TCEQ. It is thus necessary for the present effort to develop and incorporate such considerations into the assessment of the alternative water supply scenarios under evaluation. The principal mandates set forth by SB 3 require the development of "environmental flow analyses" and an "environmental flow regime…"

An "environmental flow regime" is defined by SB 3 as:

> "*a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies.*"

Many considerations contribute to the establishment of an environmental flow regime, including chemical processes (water quality, aquatic life uses), sediment transport, biology, hydrology, hydraulics, habitat quantity and quality, and other physical processes (geomorphology). Senate Bill 2 (SB 2), established by the Texas Legislature in 2001, created the Texas Instream Flow Program (TIFP), establishing that the Texas Parks and Wildlife Department (TPWD), Texas Water Development Board (TWDB), and TCEQ conduct studies to determine appropriate methodologies for determining flow conditions in the State's rivers and streams necessary to support a sound ecological environment, focusing upon these multiple facets of riverine ecology. At present, no such SB 2 study is scheduled for the Sulphur River Basin. Such a study could be scheduled by the three agencies, under the direction of the Texas Legislature.

However, since the SB 3 schedule has typically occurred at a faster pace than that of the SB 2 schedule, SB 3 processes have attempted to focus upon the use of the "best available science," with a desire to fashion initial environmental flow recommendations consistent with the environmental flow regime framework established through the TIFP studies. This has namely been through the identification and study of four components of a flow regime: subsistence, base flow, pulse flow, and overbank flows.

The present effort has been performed with the objective to develop an environmental flow regime consistent with the SB 2 and SB 3 framework, and highlight important decision points throughout the development and analysis of the data. Information learned from such analyses may inform and refine the comprehension of decisions and assumptions utilized in the consideration of such environmental flow guidelines.

It is important to note that such an effort is not intended to pre-empt a SB 3 process for the Sulphur River Basin. Rather, it is an attempt to identify potential environmental flow guidelines in order to maintain the sound ecological environment of the Sulphur River Basin and ultimately assess the potential impact of such guidelines upon various water supply alternatives under consideration in the Sulphur Basin Feasibility Study. Lastly, as no estuary is reliant upon flows from the Sulphur River Basin, no estuarine freshwater inflow requirements have been considered herein.

This study consists of three work elements, specifically (1) a comprehensive literature review compiling and organizing existing historical information on the hydrology, biology, physical habitat, physical processes (geomorphology), and water quality of the study area, (2) hydrologic analyses of streamflows at relevant and available gauge locations for development of hydrology-based instream flow guidelines, and (3) the implementation of these guidelines in a Water Availability Modeling context to be utilized in the determination of the potential impacts of the identified guidelines on the projected firm yields of alternative project scenarios.

The report is organized broadly into these three components, respectively. A discussion is first provided on the literature review (Chapter 2), assessing the available information base. Several discussions are then provided detailing the methodological approaches utilized in the development of the hydrology-based potential environmental flow regimes, including: the selection of potential environmental flow guidelines relevant to the water supply alternatives and seasonal characterizations (Chapters 3 – 10).

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2 Literature Review

Development of environmental flow guidelines should involve characterization of indicators or ecological processes that respond to changes in flow or the flow regime. In a process where detailed studies may not be available, the guideline development process necessarily relies upon existing information and studies. Indeed, the SB 3 effort presently underway in many of the river basins of Texas has progressed in just such a fashion, as detailed studies have not yet been completed to evaluate the specific effects of changes to components of a flow regime on many of the rivers and bay systems in Texas. Therefore, only limited amounts of information are available to identify particular flow rates or flow patterns for specific beneficial ecological processes. The main challenge, in this regard, is thus in attempting to use small point data sets to characterize the natural spatial and temporal variability of surface water bodies.

The present effort documented within this section aims to extract data or information from existing studies on the Sulphur River Basin (depicted in Figure 1) that may provide some guidance, or informed development, of flow guidelines, until such time as more detailed studies or information are available. A statistical characterization of historical hydrology may be informed by this literature review effort to the degree of confidence attributable to the existing information. Ultimately over the long term, detailed site-specific data throughout a system is necessary to characterize habitat or ecological response to changes in flow regime.

The information discovered and presented herein concentrates upon the Sulphur River Basin, including a discussion of focal fish and mussel species, a characterization of least-impacted reaches, the status of biota, nitrogen budgets, hydrologic assessments and water quality assessments. The majority of the information has been identified and developed for the main stem of the Sulphur River, with some information on the North Sulphur, South Sulphur, White Oak Creek and other tributaries in lesser amounts.

2.1 Background

Specific work items include the summary of relationships developed and reported in previous efforts. Relationships of particular interest include those between flow and biological variables, geomorphologic parameters, water quality or nutrient/sediment transport. The generic term “flow” encompasses a variety of concepts including river flow regime and flow velocity.

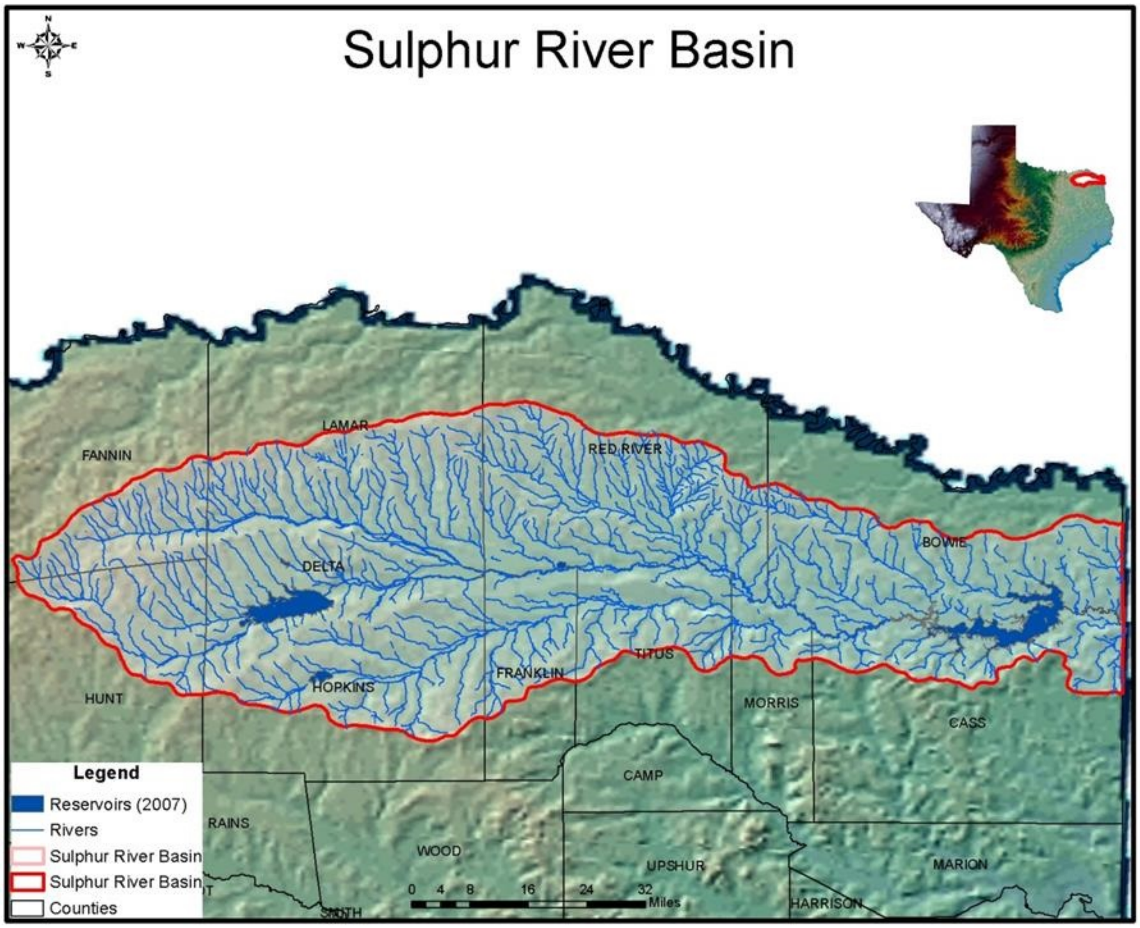

Figure 1: Sulphur River Basin over terrain map

As a result of coordination with the Sulphur River Basin Authority (SRBA), Tarrant Regional Water District (TRWD), the Sulphur Basin Group (SBG), and the U.S. Army Corps of Engineers (USACE), work was initially focused on areas near specifically identified potential water supply project locations (Table 1 and Figure 2).

Table 1: Measurement points identified as data sources for potential instream flow guidelines

USGS Gage	Site Name
7344000	Sulphur Rv nr Darden, TX
7343200	Sulphur Rv nr Talco, TX
7343500	White Oak Ck nr Talco, TX
7343000	N Sulphur Rv nr Cooper, TX
7342500	S Sulphur Rv nr Cooper, TX
	Wright Patman Releases

Relevant publications were discovered for this project by searching specific sources, as listed in Appendix A. The resulting reports were reviewed for pertinent information. Additional material was gathered through electronic data searches, and communicating with various State agency staff involved with the Texas Instream Flow Program. Literature sources are cited where relevant in this report.

2.1.1 Basin Setting

As described in Osting, et. al. (2004):

> Located in North-east Texas, the Sulphur River Basin (depicted in Figure 1 and Figure 2) has a drainage area of approximately 9,211 square kilometers (3,558 square miles). White Oak Creek is the only major tributary of the Sulphur River, and its confluence is upstream of Wright Patman Reservoir, downstream of the proposed Marvin Nichols I project. Water flows into the Red River within the State of Arkansas. The main channel of the Sulphur River is made up of three smaller channels: the North Sulphur River, the Middle Sulphur River, and the South Sulphur River. The headwaters of all three streams are located in Fannin County and all flow approximately 80 km (50 miles) before their confluence. The North Sulphur River drains eastward along the Delta and Lamar County line to the confluence with the South Sulphur River. The Middle Sulphur River drains southward approximately 37 km (23 miles) through Hunt County then turns east through Delta County to its confluence with the South Sulphur River. The South Sulphur River drains southward approximately 57 km (35 miles) through Hunt County then east along the Hopkins and Delta County line, passing through Jim Chapman Lake, to its confluence with the Middle Sulphur River. Continuing along the same county line, the South Sulphur River traverses an additional 40 km (25 miles) east to its confluence with the North Sulphur River. (all distance above are approximate river miles).
>
> The Sulphur River and tributaries flow through two distinctly different land resource areas (based on NRCS classification). The upper reaches, encompassing the proposed Marvin Nichols I and George Parkhouse I Reservoir sites, are within the Blackland Prairie area, while the lower reaches downstream of the proposed reservoir sites lie within the West Gulf Coastal Plain area. Soils of the Blackland Prairie are predominantly silty clay and clay, topography is generally flat, and the region is used primarily for agriculture (Bureau of Economic Geology 1992). Different from the Blackland Prairie, soils within the West Gulf Coastal Plain are predominantly sandy clay soils associated with the Wilcox formation, topography is characterized by gentle rolling hills, and forestry is the major land use.
>
> The river basin lies within three geological regions that are sedimentary in origin primarily characterized by the Navarro and Taylor Groups within the northwestern part of the basin and the Claiborne Group within the southeastern part of the basin (Figure 4).
>
> Ewing (1991) described the tectonic features of Texas, including the Sulphur River Basin, and the accompanying tectonic map of Texas (northeast quadrant) shows that the Talco Fault Zone clearly crosses the Sulphur River about where the Blackland Prairie and West Gulf Coastal Plain land resource areas separate. During field reconnaissance of the Sulphur River Basin, we noted a change from the silty clay to sandy clay substrate composition below the proposed Marvin Nichols Reservoir site on the Sulphur River. Fault zones frequently result in changes in slope, where coarser sediments collect (GregMalstaff, eomorphologist with the TWDB, personal communication). It is important

to tie in as many features as possible in the soil, geology, vegetation, and land use characteristics of a river basin in order to understand the resulting ecological functions.

The Sulphur River also flows through two of the seven biotic provinces of Texas based on those established by Blair (1950), including the Texan (George Parkhouse I site), and Austroriparian (Marvin Nichols I site). The classification of aquatic habitats within the state is based on these biotic provinces (Edwards et al. 1989). There exist a number of ecosystem classifications that relate to the different ecosystems that the Sulphur River flows through. For instance, Gould (1960) classified the Sulphur River Basin into three major ecological regions, which are from west to east the Black Prairies, Post Oak Savannah, and Pineywoods; TPWD (http://www.tpwd.state.tx.us/images/tx-eco95.gif) describes 11 ecoregions of Texas, three of which are within the Sulphur River Basin, including the Blackland Prairie, Oak Woods & Prairies, and Piney Woods; and McMahan et al. (1984) describe several vegetation types within the Sulphur River Basin. The ecosystem type delineations are generally based on physiognomic designations and vegetative cover (an EPA level III ecoregion map is provided; Figure 3)

Instream uses of the Sulphur River near the confluence of the South Sulphur and North Sulphur Rivers include aquatic life, contact recreation and fish consumption. Instream uses of the Sulphur River in the vicinity of the proposed Marvin Nichols I Reservoir project include contact recreation, aquatic life, and fish consumption. There are no stateparks located in the vicinity of the proposed reservoir; however, the White Oak Creek Wildlife Management Area is located near the confluence of White Oak Creek and the Sulphur River just upstream of Wright Patman Lake. Steep riverbanks limit access to the river for recreational boating. The river has a high turbidity level due to the highly erodeable soils in the watershed.

Located more than 200 river miles from the coast, the Sulphur River does not have a legally binding inflow requirement. The river flows into Wright Patman Reservoir downstream of the proposed reservoir site, and then flows into the Red River in Arkansas, turning south into Louisiana, and eventually flows into the Mississippi River.

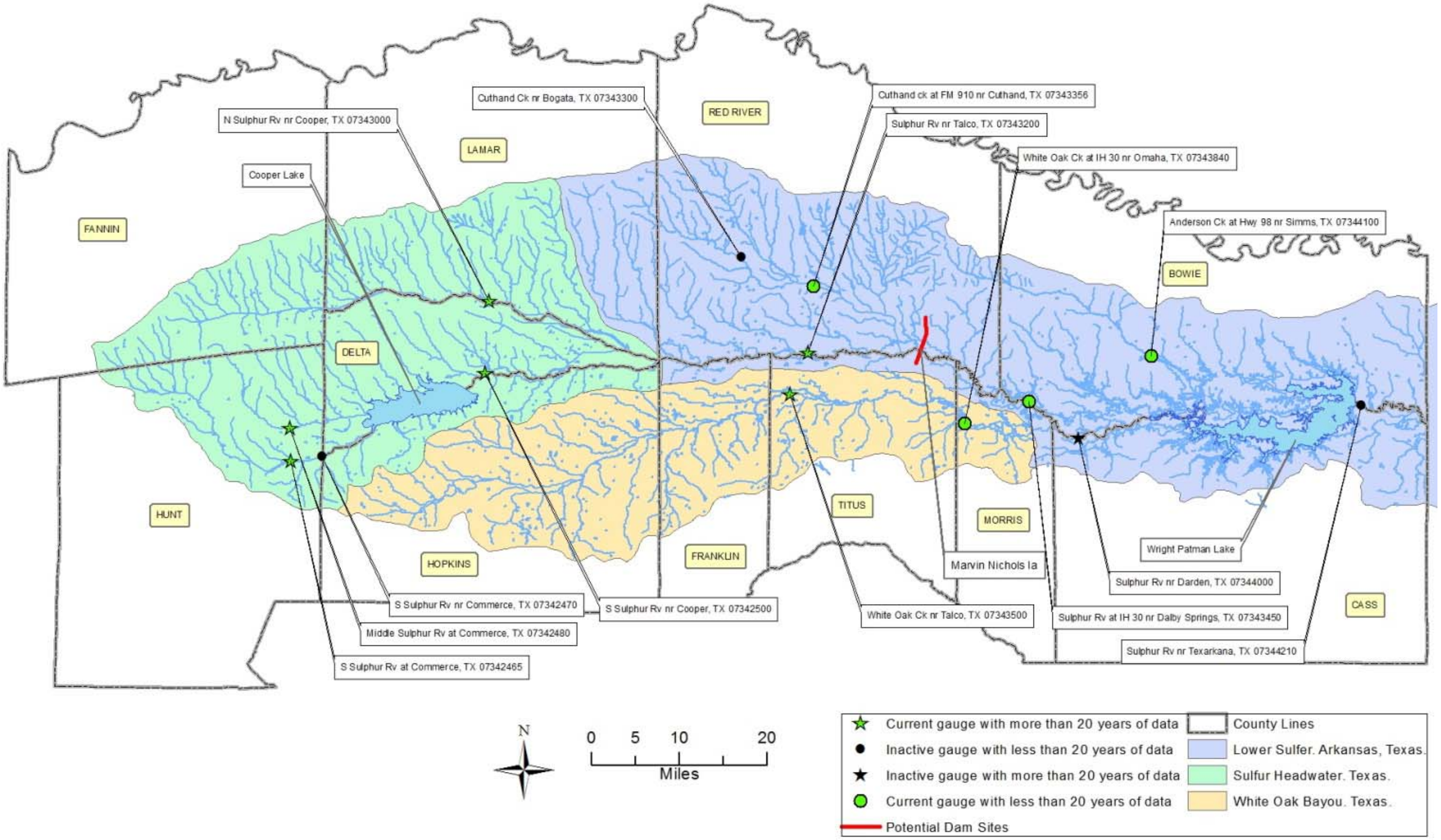

Figure 2: Sulphur River Basin Hydrologic Record Map

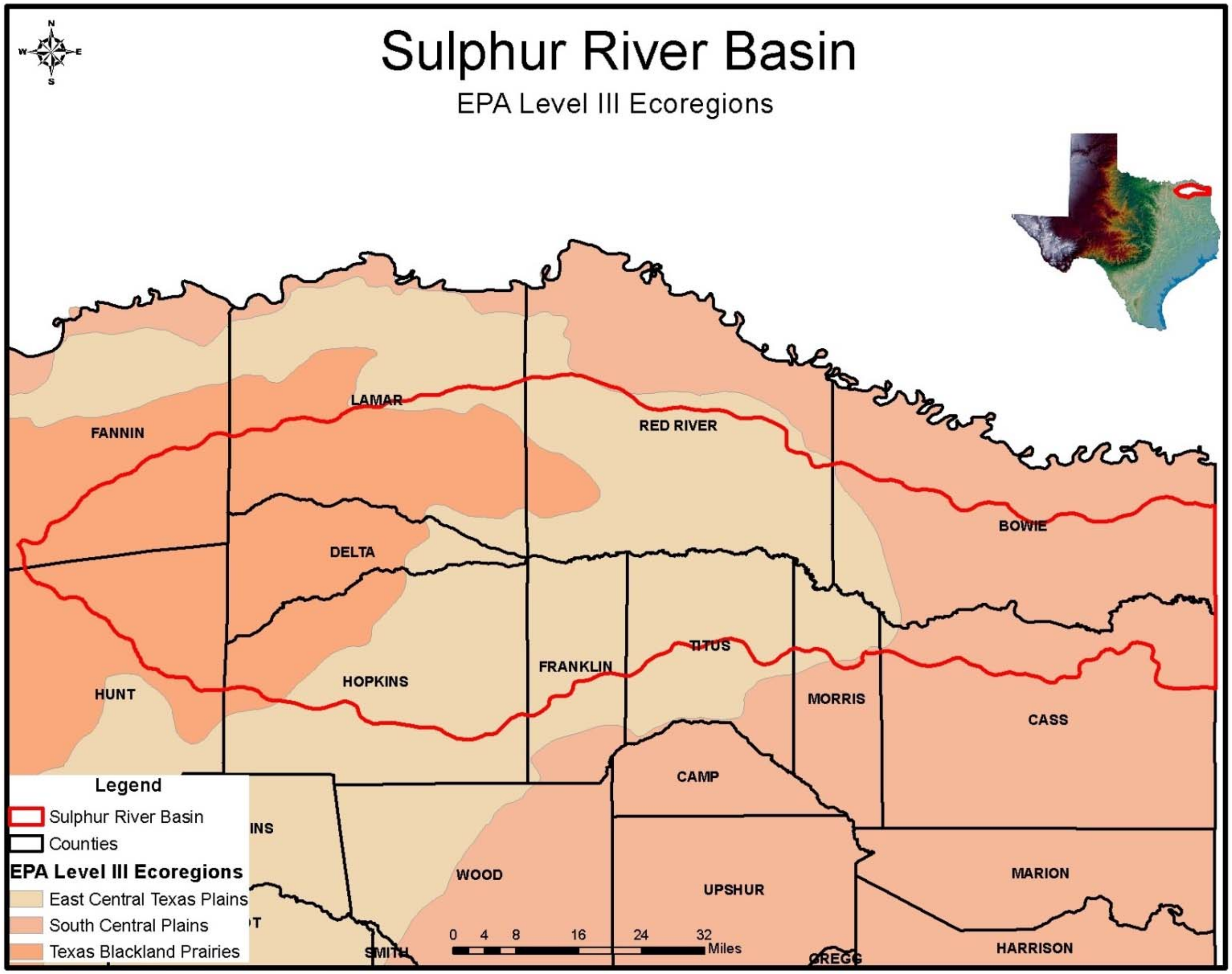

Figure 3: EPA Level III Ecoregions

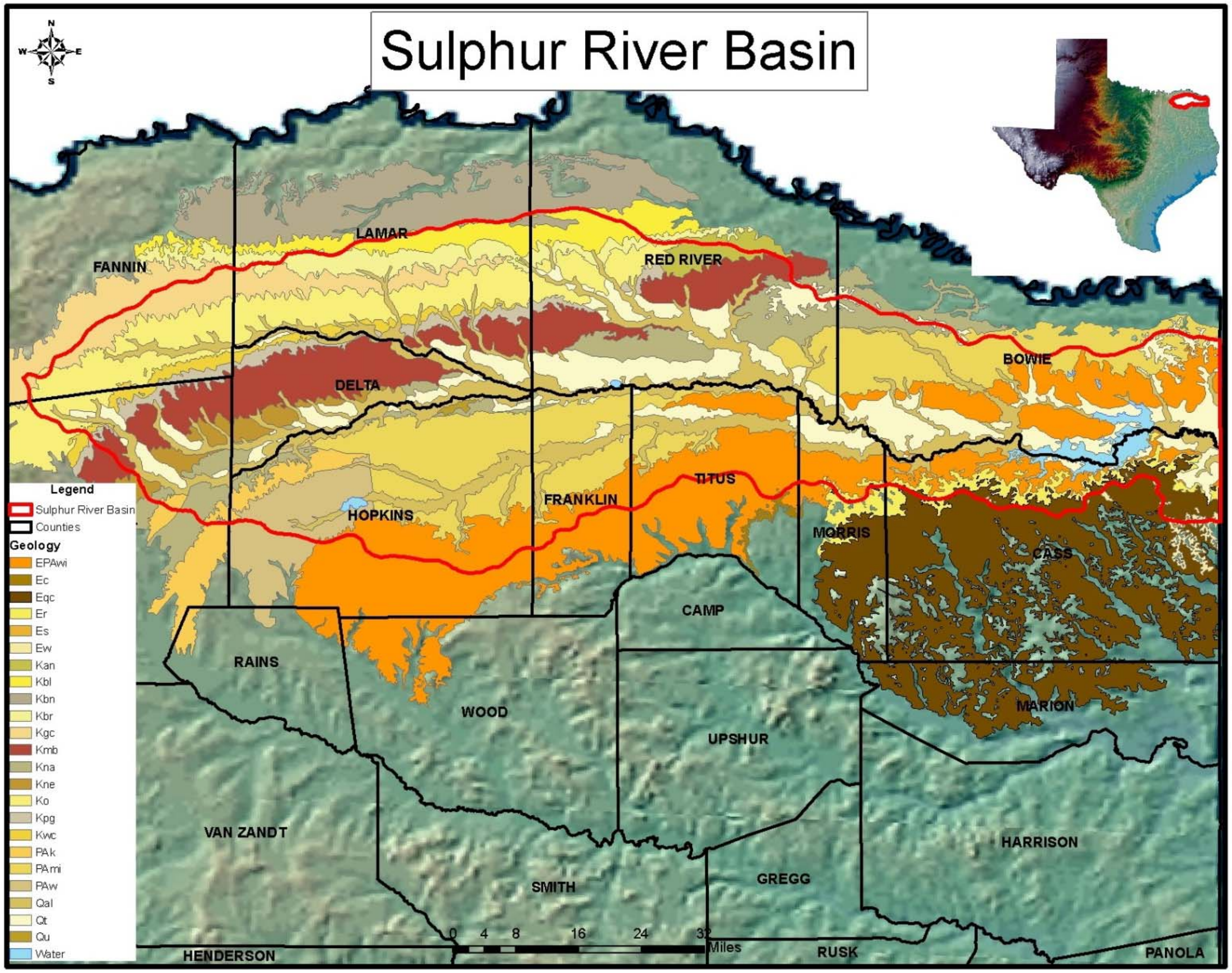

Figure 4: Sulphur River Basin Geology

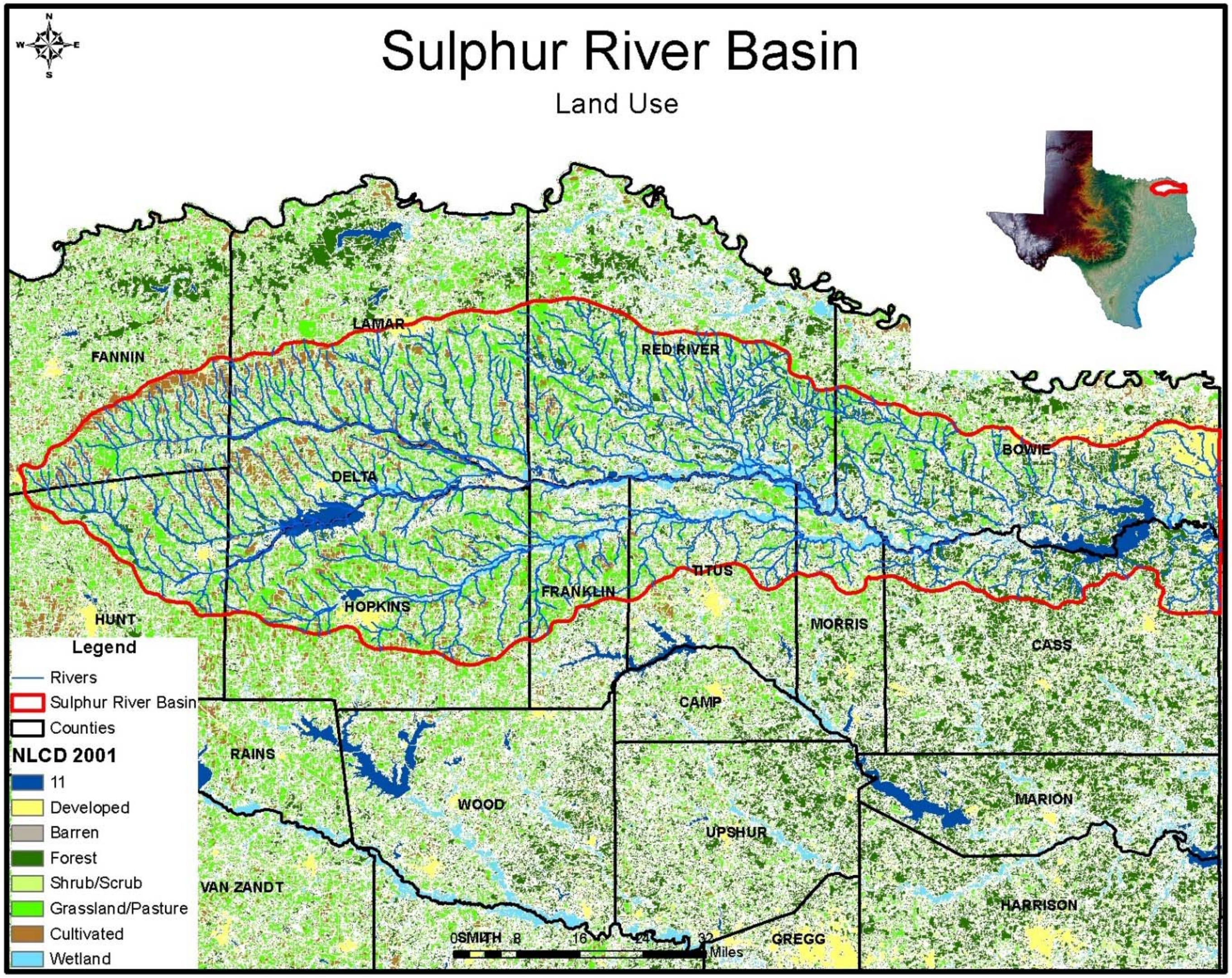

Figure 5: Sulphur River Basin NLCD 2001 Land Use

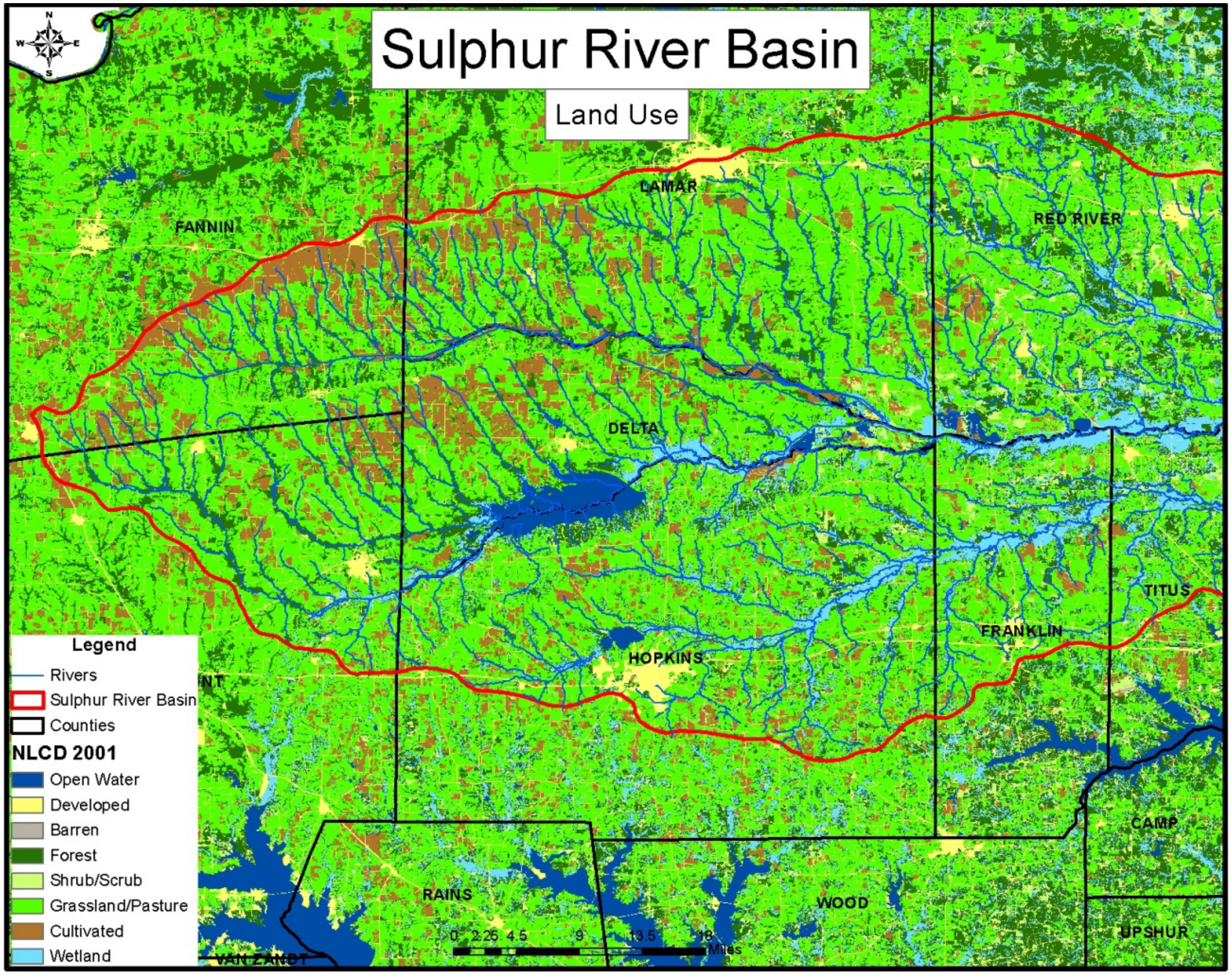

Figure 6: Sulphur River sub basin NLCD 2001 Land Use, Part I

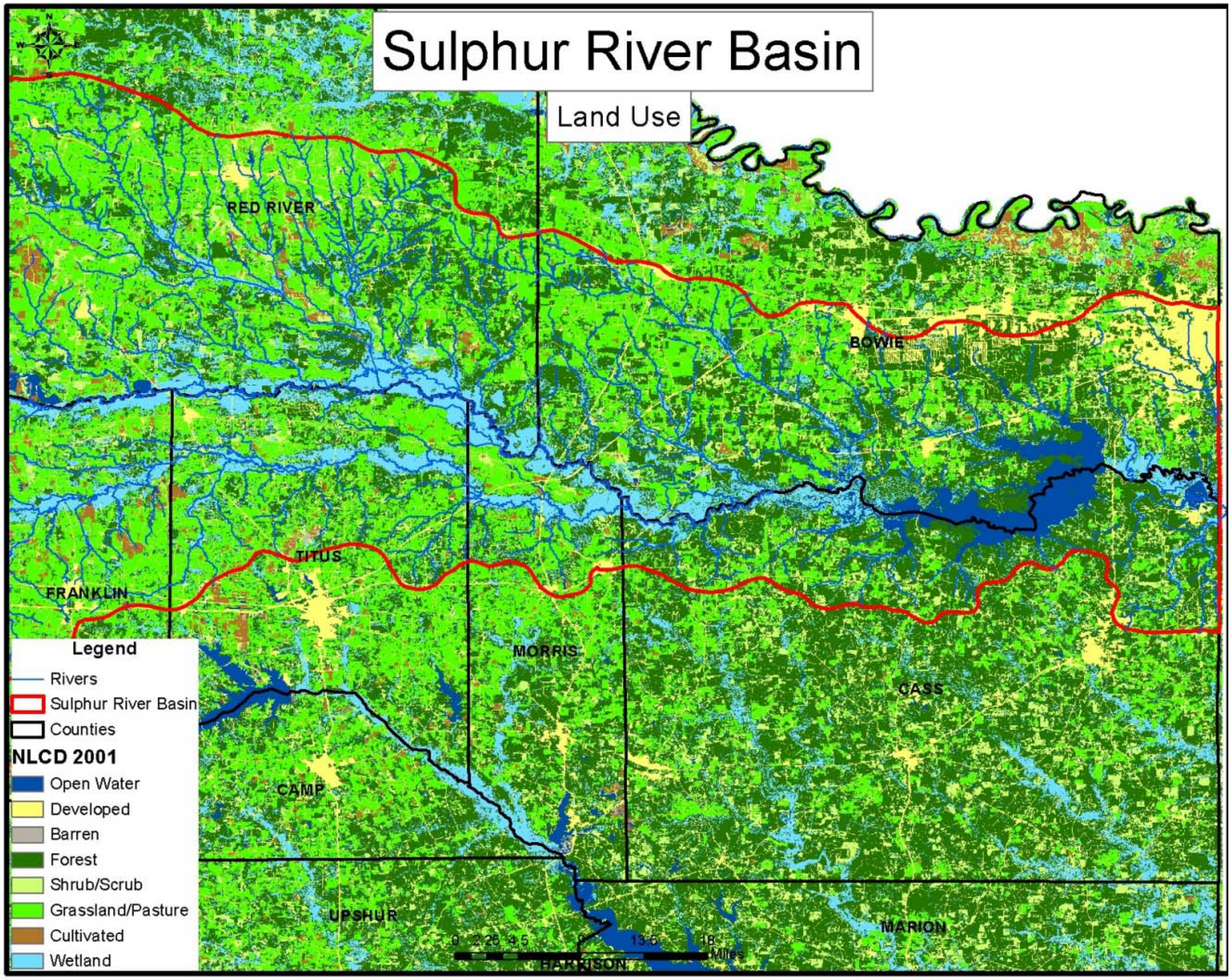

Figure 7: Sulphur River sub basin NLCD 2001 Land Use, Part II

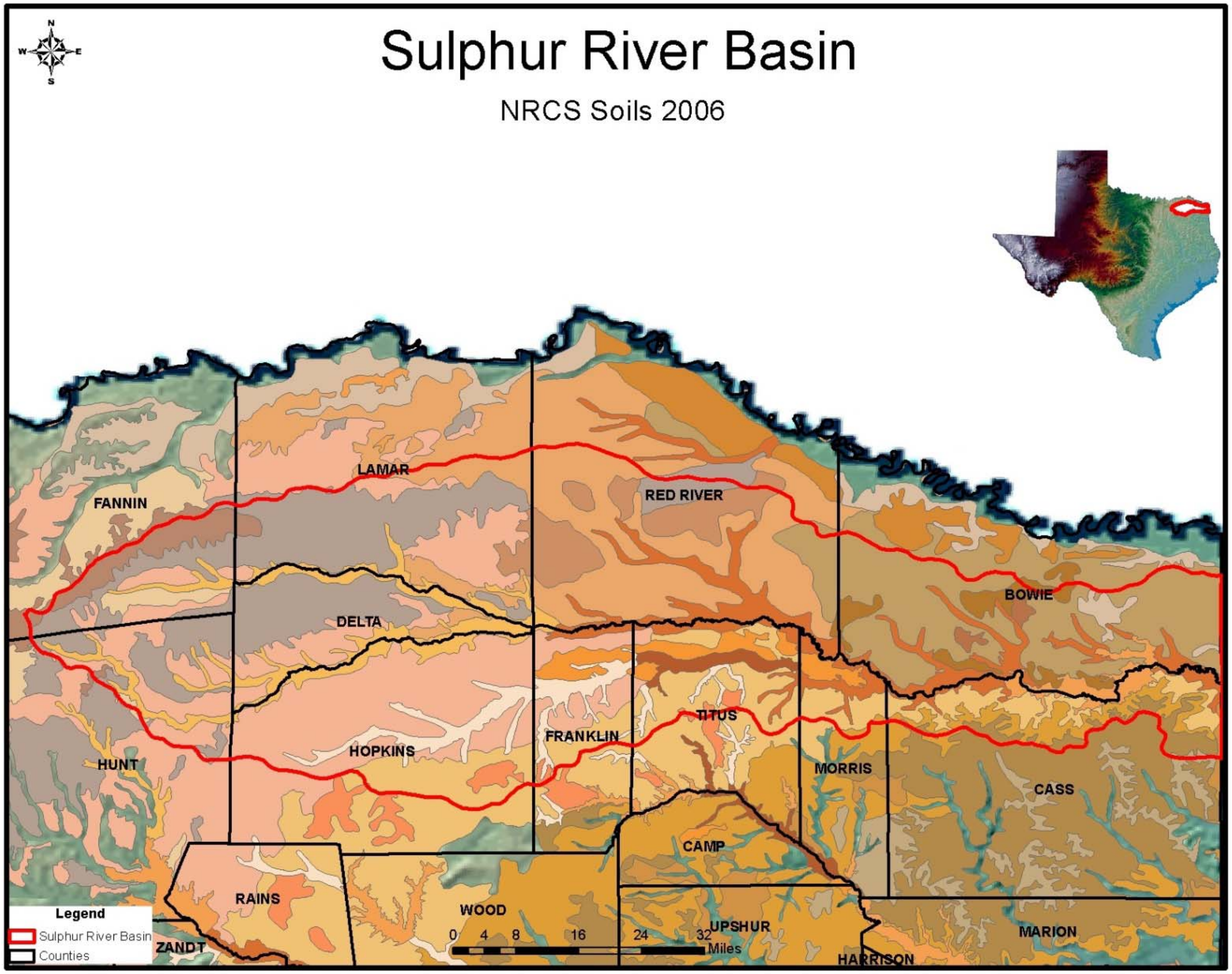

Figure 8: NRCS STATSGO 2006 soil map..

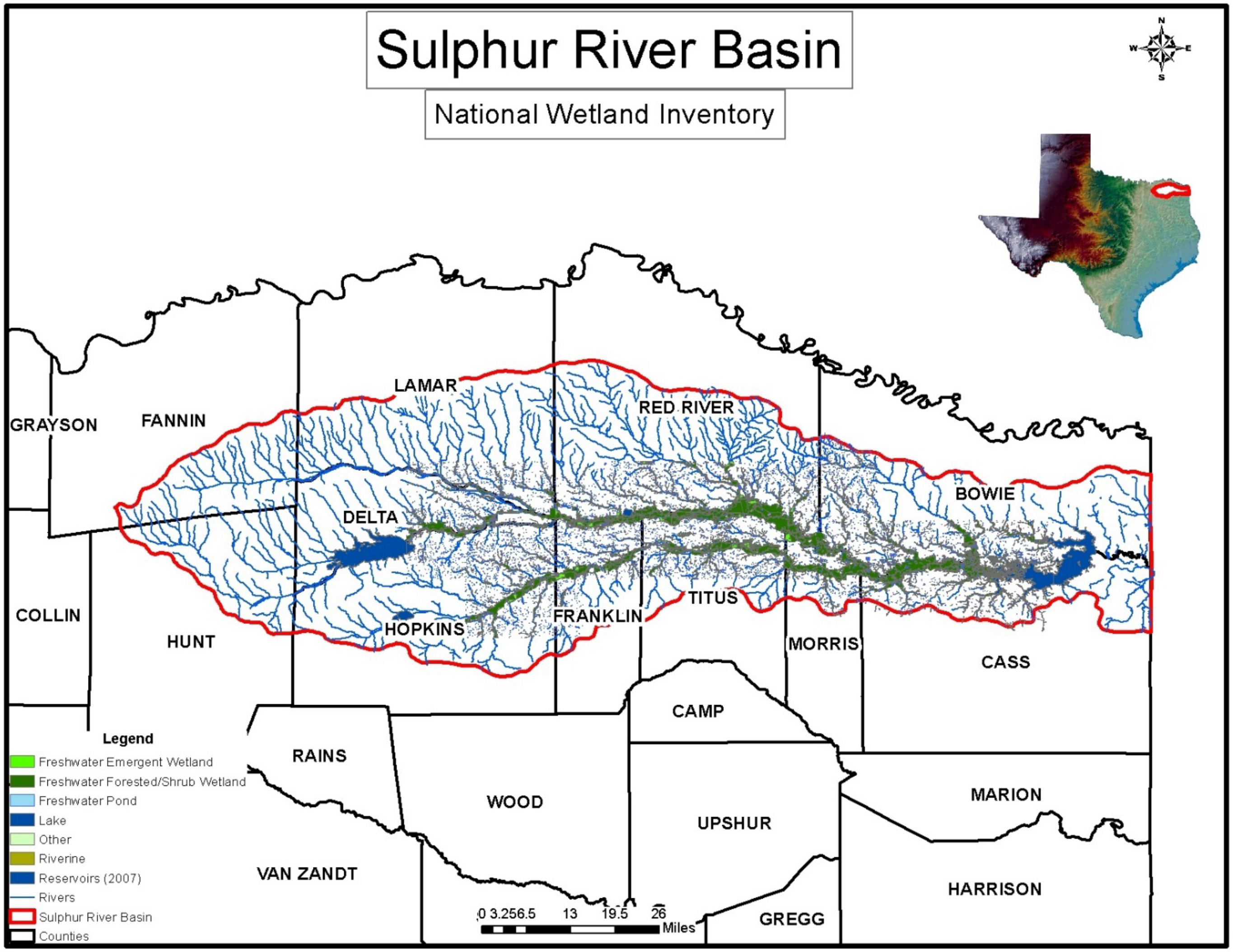

Figure 9: Sulphur River Basin National Wetland Inventory

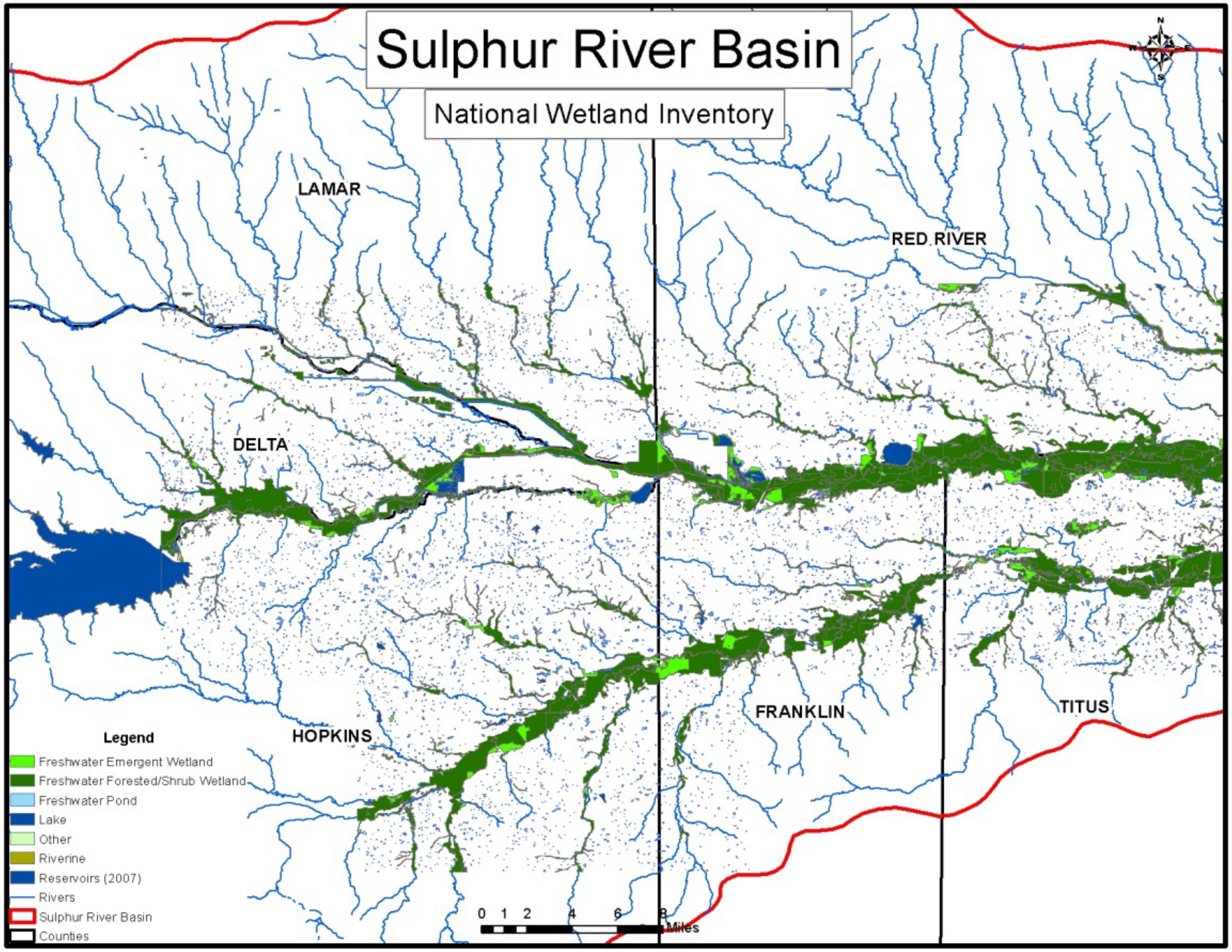

Figure 10: Sulphur River sub basin National Wetland Inventory, Part I

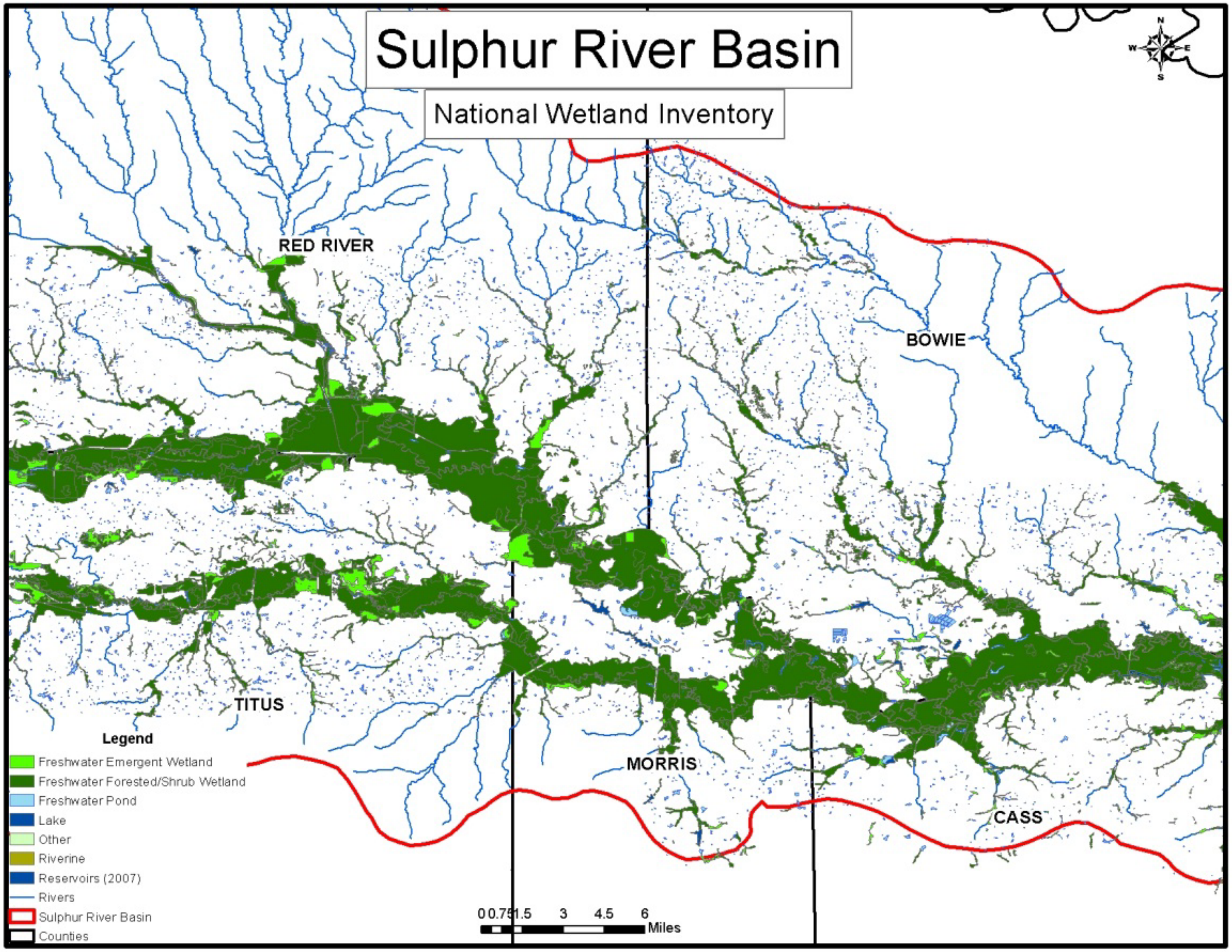

Figure 11: Sulphur River sub basin National Wetland Inventory, Part II

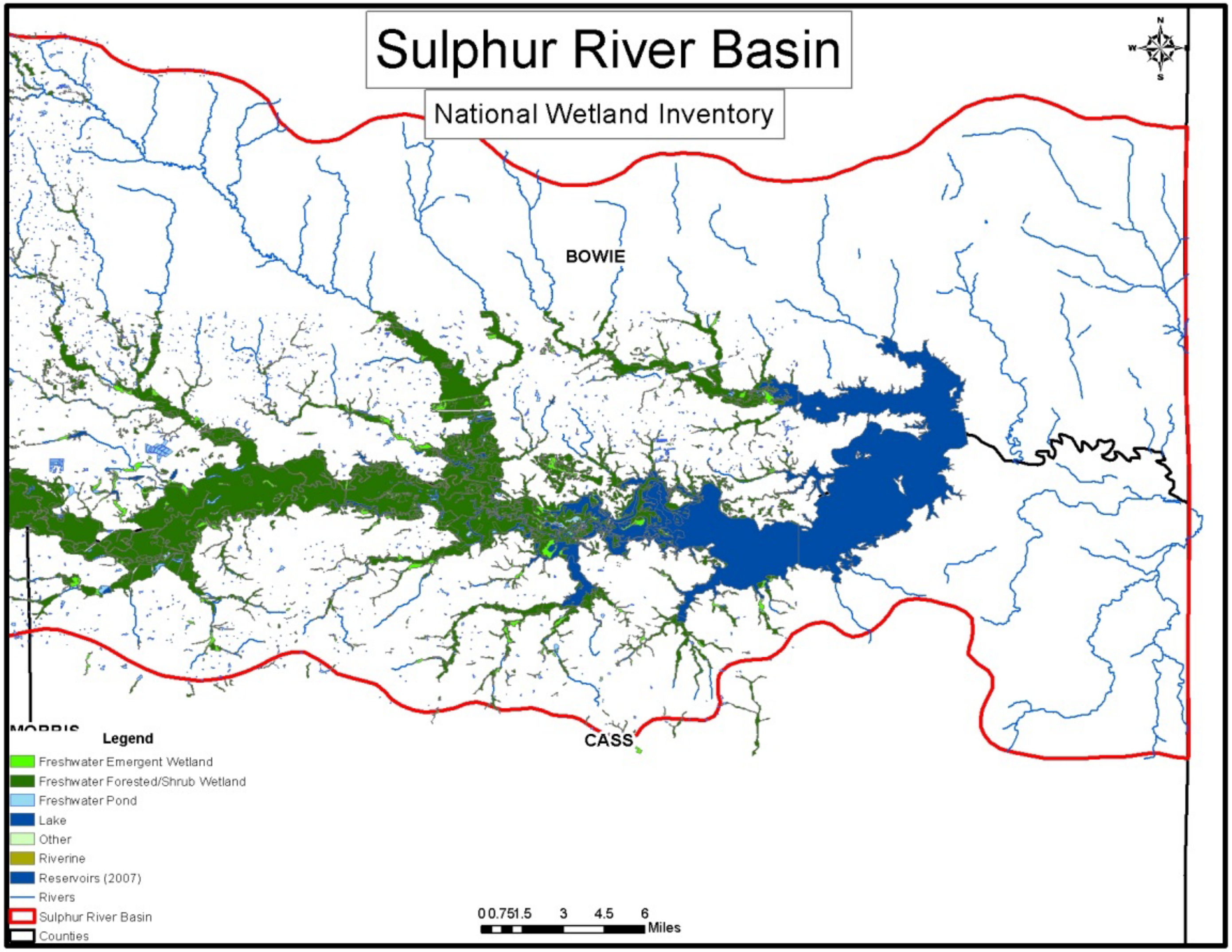

Figure 12: Sulphur River sub basin National Wetland Inventory, Part III

2.2 Previous General Studies of the Sulphur River Basin

Limited historic information relating ecological conditions to specific flow metrics exist in the Sulphur River Basin. Several studies provide a general overview of the Sulphur River: sediment (Mirabal 1974), water quality (Leifeste 1968), and surface water/groundwater interaction (Parsons Engineering Science, Inc. 1999). In 1985 the United States Fish and Wildlife Service (USFWS) designated approximately 92,000 acres of Bottom Land Hardwood Forest (BHF) west of Wright Patman Reservoir. In 1997, the TPWD and the TWDB initiated studies of three BHFs approximate to the Marvin Nichols I and George Parkhouse I sites, with the third site located in the Red River Basin. Fisheries reservoir management reports for Cooper Reservoir (Jubar and Storey 2008) and for Wright Patman Reservoir (Brice and Bister 2009) provide insight on the overall water quality, shoreline habitat and game species found in these reservoirs.

Summaries of water quality data and geologic information of the proposed Parkhouse I and II and Marvin Nichols Reservoirs were developed by FNI and Alan Plummer Associates Inc. (2000).

There have been numerous Water Availability analyses conducted on the Sulphur River Basin using Water Availability Models (WAM) developed by the TCEQ (formerly TNRCC). FNI (1996) conducted a water supply analysis specifically evaluating five potential reservoir sites: New Bonham Reservoir on Bois d'Arc creek, George Parkhouse North Reservoir on the North Sulphur River, George Parkhouse South Reservoir on the South Sulphur River, both George Parkhouse Reservoirs combined, and Marvin Nichols Reservoir. Previous studies (Regional Water Plan 1990, New Bonham Reservoir 1984) on the five additional water supply sources already existed; however, FNI revised the previous methodologies to include a longer period of record, changes to existing water rights and inclusion of the draft Environmental Water Needs Criteria.

HDR (2007) conducted a reservoir yield analysis on the proposed George Parkhouse I, George Parkhouse II, and Marvin Nichols reservoirs. This effort considered environmental flow needs, based upon calculations employing Consensus Criteria for Environmental Flow Needs (TWDB 1997). This analysis also utilized the Sulphur Basin WAM obtained from the TCEQ.

A system operation assessment of Lake Wright Patman and Lake Jim Chapman (FNI 2003) was conducted to determine the possibility and magnitude of potential gains in supply from alternative operations at both reservoirs. The assessment included the "development of a computer model capable of simulating a variety of operational policies to evaluate overall yield of the two reservoirs."

Hydrologic and hydraulic flood models were developed and calibrated (FNI 2008) on the Sulphur River from Jim Chapman Lake (on the South Sulphur River) and the proposed Ralph Hall Lake (on the North Sulphur River), downstream to Wright Patman Dam. The study used HEC-RAS for river channel floodway re-routing. Cross sections were gathered from a 2006 LIDAR survey. The model was calibrated based on historical floods registered by the USGS stream flow gages and lake levels on Wright Patman Lake.

Osting, et. al. (2004) completed an instream flow study on the Sulphur River; however, there were limitations to this study as well. This study encompassed multiple disciplines and involved several agencies and universities including the Texas Water Development Board, Texas Parks and Wildlife, Texas State University-San Marcos, Texas A&M University and various other individuals. The primary focus of this effort was to characterize regional physical properties and biological communities of the Sulphur River. This study attempted to address potential impacts from several water development projects including proposed main-channel reservoirs. Difficulties arose during this study as data collection efforts progressed. Fish sampling efficiency was observed to be inadequate for the determination of species-flow relationships. This inadequacy was due to study design, specifically gear sampling efficiency and lack of geo-referenced and flow data collected at each habitat type. However, the study does provide essential population assemblage data for the Sulphur River and useful information regarding flow characteristics and general habitat conditions.

An RMA-2, two-dimensional, hydrodynamic model was developed (Osting, et. al. 2004) to characterize both lateral and longitudinal velocity variations at two study sites. The model results included depth and velocity data points spaced 7 meters apart. The model was executed for different steady state flow rates.

On the South Sulphur River, near the George Parkhouse I Reservoir, Gelwick and Burgess (2002) conducted fish assemblage and mesohabitat utilization studies under different flows. Fish studies conducted below the Proposed Marvin Nichols I Reservoir looked at fish habitat-low flow relationships (Gelwick and Morgan 2000) as well as two additional studies by Morgan (2002) and Burgess (2003). These studies all concluded weak habitat specialization by the fish communities in the Sulphur River. Burgess (2003) concluded weak or no differences between channelized and unchannelized portions of the Sulphur River.

Complications with the habitat and biological data collected during the fisheries studies precluded any strong relationships to be made between fish and habitat specialization. Because of this a mesohabitat model (Wentzel 2001) was developed to reclassify field collected observations. The model was then used to provide some basic insight to habitat specialization for fish communities collected in the different sections of the Sulphur River.

Osting, et. al. (2004) performed an inundation analysis using field collected in-channel bathymetry, extrapolated cross sections (calculated from DEMs), USGS gauge data and gridded vegetation data (provided by TPWD). This analysis specifically evaluated potential impacts from proposed water development projects on the periodic inundation of low lying areas. There was significant importance to quantify the flooded area for reoccurring floods because of native species utilization of flood areas during specific stages in their life history.

2.2.1 Ecologically Unique River Segments

Ecologically unique river segments by definition (Texas Senate Bill 1, 31 TAC § 357.8) possess unique attributes for biological function or hydrologic function; for riparian conservations; for areas with high water quality, exceptional aquatic life, and/or high aesthetic value; and for threatened or endangered species/unique communities (Osting, et. al. 2004).

The Texas Parks and Wildlife Department (TPWD) recommended, Norris and Linam (2000), fifteen (15) segments in the Region D water planning area of northeast Texas, which includes the Sulphur River Basin. This included a segment 0.9 miles downstream of Bassett Creek in Bowie/Cass County upstream to IH 30 in Bowie/Morris County. The boundary of this segment includes the upper reaches of existing Wright Patman Lake, half way to the proposed dam for the Marvin Nichols I Reservoir project, just past the confluence of the Sulphur River and White Oak Creek (Osting, et. al. 2004)

As previously mentioned, the U.S. Fish and Wildlife Service (USFWS) has identified 94,252 acres of bottomland along the Sulphur River west of Wright Patman Reservoir as being priority bottomland hardwood forest. The area has a favorable hydrologic regime with numerous sloughs and documented frequent flooding. This flow regime provides refugia and enhances the value of the habitat for numerous terrestrial and aquatic species including migratory birds (Osting, et. al. 2004).

This section of the Sulphur River is also within the target recovery area set by the TPWD for the state threatened paddlefish, due to the sluggish, fertile waters found above Wright Patman Reservoir that provides excellent paddlefish feeding habitat (Pitman 1991). The candidate segment is located downstream of the proposed dam site for Marvin Nichols I reservoir, and thus would be affected by the alterations in riverine flow (Osting, et. al. 2004).

2.2.2 Threatened and Endangered Species

As describe by Osting, et. al. (2004):

> The proposed Marvin Nichols I reservoir site in Red River and Titus Counties, Texas, is within the range of several threatened and endangered species. The construction and operation of the reservoir will impact the diverse bottomland forest community in the proposed reservoir project area. The bottomland hardwoods and associated wetlands of eastern Texas represent major and valuable habitat to waterfowl in Texas. The riparian wetlands support substantial wintering populations of a number of waterfowl species, principally mallards, but also breeding and wintering wood ducks.
>
> Bottomland forest in eastern Texas, including that encompassed by the proposed Nichols reservoir site, supports a large number of plant and other animal species including over 100 species of special concern because of rarity (Neal 1989). Some of the threatened and endangered migratory species are expected to lose habitat within their range as a result of the reservoir construction and operation; however, their usage of this area is not well understood at this time. The bald eagle may benefit by the proposed reservoir because of increased availability of lake habitat.
>
> The range of the state-listed, endangered Paddlefish previously included habitats within the proposed Marvin Nichols I reservoir site. The TPWD has a recovery program for this species (Pitman 1991), which includes the area of the proposed reservoir site. The state threatened creek chubsucker is also reported in the proposed reservoir site area.
>
> Natural plant communities reportedly present in George Parkhouse I and II reservoir sites, and thus by close proximity likely present in the proposed Marvin Nichols reservoir area, include the Silveanus dropseed series and the Sugarberry-Elm series. The Silveanus dropseed series is listed by TPWD as imperiled and very rare globally and in Texas (Bauer et al. 1991). Other protected species are listed in the area, including Bachman's sparrow, alligator snapping turtle, paddlefish, interior least tern, bald eagle, American swallow-tailed kite, timber rattlesnake, and southeastern myotis. A total of 48 rare plant species of special concern are found in bottomland hardwoods and associated wetlands (Texas Organization for Endangered Species 1983, Poole 1984, USFWS 1985).
>
> The ironcolor shiner, *Notropis chihuahua*, and the Tailgate shiner, *Notropis maculatus*, are listed respectively as watch-list and threatened species by the Texas Organization for Endangered Species-TOES (1995). Each species ranges within the Sulphur River drainage; however, these species have not been collected in the contract studies. Other listed species include the mole salamander, *Ambystoma talpoideum*, TOES watch-listed; alligator snapping turtle, *Macroclemys temminckii*, a state threatened species; Louisiana pine snake, *Pituophis melanoleucus ruthveni*, a state and federally listed endangered species; the Texas garter snake, *Thamnophis sirtalis annectens*, a federal candidate species; and the Cerulean warbler, *Dendroica cerulea*, a federal

candidate species in northeast Texas bottomland hardwoods (Texas Organization for Endangered Species 1995).

2.3 Focal Fish and Mussel Species and Flow Component Considerations

Available literature, data, and professional judgment have been used to generate fish and mussel occurrence matrices. The fish occurrence data includes a total of 70 species within 12 Families of fish (Gelwick and Morgan 2000; Gelwick and Burgess 2002; Carroll et. al 1977; Fish collections data archived at the University of Texas - Texas Natural History Collections (UTTNHC) website: Hubbs et al. 1953; Bowles et al. 2000; Thorton and Blair 1950; Mecham and Macewan 1950; Crandal and Dries 1994). Fish collected by Gelwick and Morgan (2000), Gelwick and Burgess (2002) and Carroll et. al (1977) did not provide supplemental gps coordinates, therefore best professional judgment was used to determine sample sites.

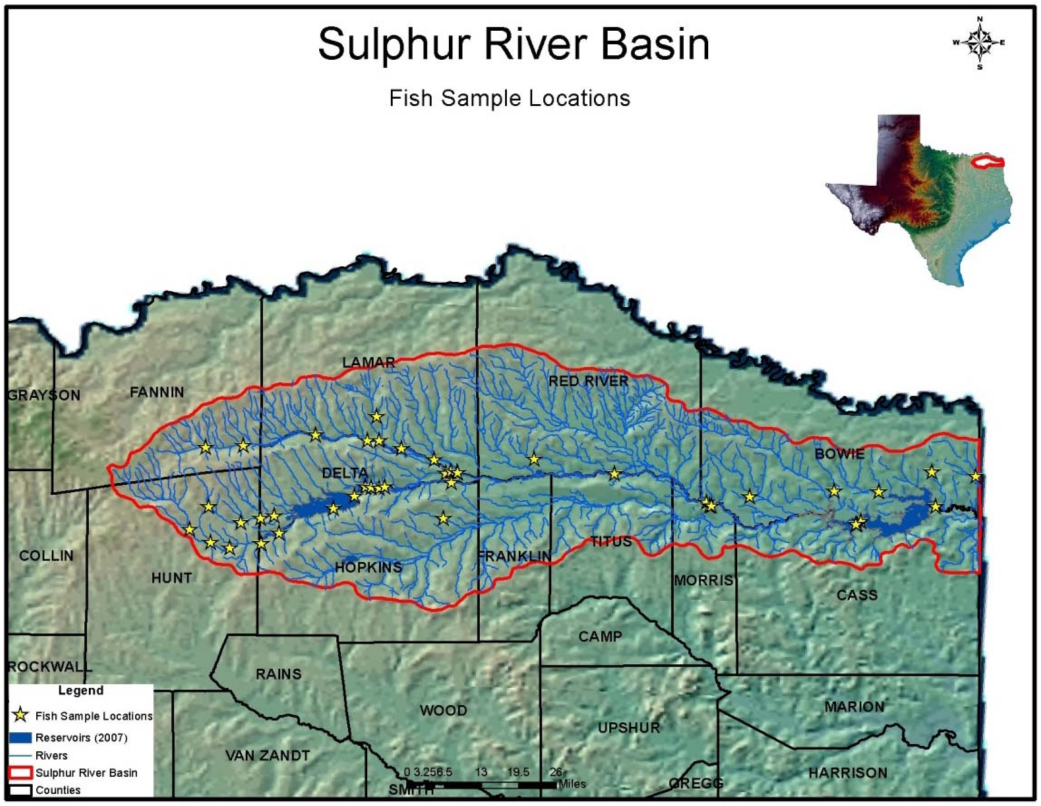

Figure 13: Fish sample location within the Sulphur River Basin

Mussel collections conducted in the Sulphur Basin reported a total of 1 Family of mussels with a total of 23 species (Karatayev and Burlakova 2007; Marsha May, unpublished data 2007; Howells 1995; 2004; Mr. Cheatwood; Howells, Neck and Murray 1996). No effort has been made in the present effort to verify reported values.

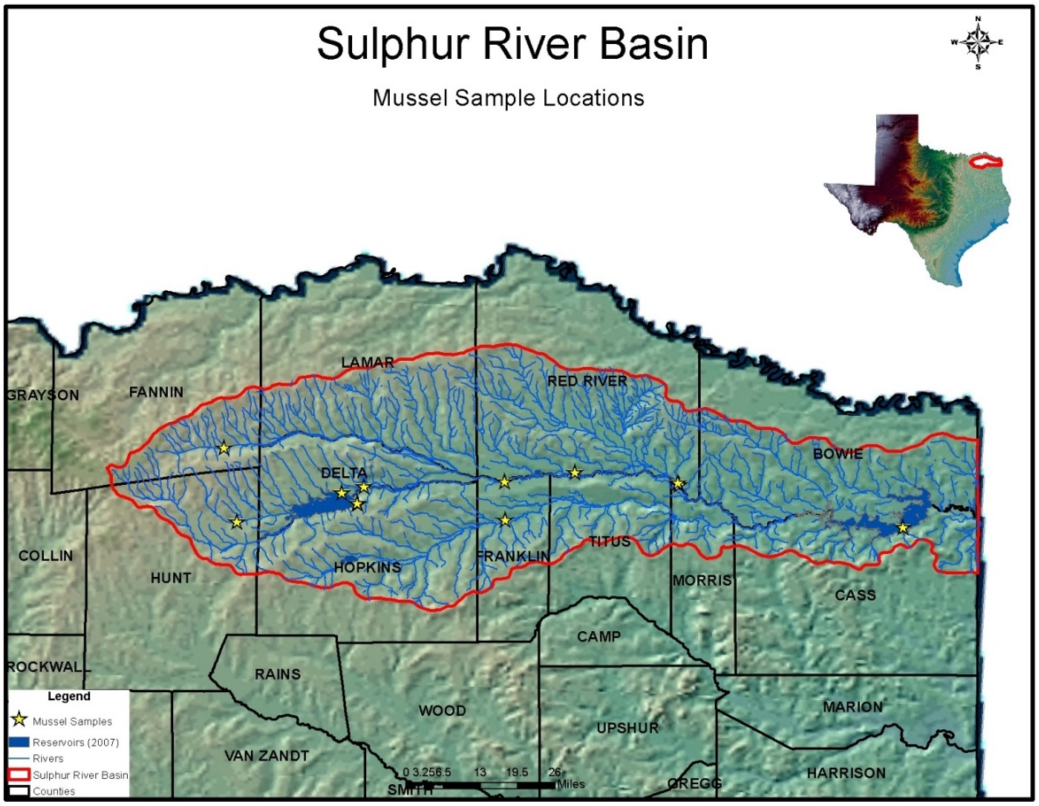

Figure 14: Mussel sample locations within the Sulphur River Basin

The ultimate goal of this effort is to develop ecological information to support the development of environmental flow guidelines. Published and unpublished reports, journal articles and agency reports have been reviewed for specific relationship information which includes fish and mussel occurrences related to stream velocity, stream discharge, water quality, salinity, sediment loading, turbidity, etc. Relevant species-specific information or characteristics for Sulphur River Basin species have been incorporated where possible.

2.3.1 Focal Freshwater Species Short List

A short list of focal species is presented based on their occurrence in the Sulphur basin, tolerance limits, observed habitat requirements or other parameters discovered in the literature. The rationale for their utilization is summarized below with information on how the species requirements may be related to flow. The principal sources of information are (1) the Texas Freshwater Fishes website maintained by Dr. Tim Bonner at Texas State University (Hassan-Williams and Bonner 2009) and (2) the Fishes of Texas project overseen by Dr. Dean Hendrickson at University of Texas – Texas Natural History Collections (UTTNHC) and the Fishes of Alabama (Bouschung and Maydem 2004). Mapping and spatial distribution information derived from the UTTNHC data is provisional at present. A map of fish collections in the Sulphur Basin is provided in Figure 13.

Noturus nocturnus (freckled madtom)

Fuvial specialists found in medium to large turbid streams with permanent flow (Rhode 1980; Boschung and Mayden 2004). This species will inhabit riffle areas with moderate to gentle flows, undercut banks, instream cover (submerged logs, root masses, beer bottles etc.), silty or mud bottomed pools and backwaters (Boschung and Mayden 2004). In the South Sulphur River this species is found in higher velocities and shallower depths (Morgan 2002), and occurs more frequently in unchannelized reaches (Burgess 2003).

Spawning season in southeast Missouri, spring-early summer spawning season (Pflieger 1975); in Mississippi, summer (Clark 1978); in southern Illinois, June – July when water temperatures are around 25^{o}c (Boschung and Mayden 2004). Nests located where there is some current in water depth 10-15 cm (Burrr and Mayden 1982) and eggs incubated at 25oc in a laboratory hatch (Boschung and Mayden 2004).

Seasonality: spring to early summer spawning. (when water temperatures are around 25^{o}c in southern Illinois).

Baseflows: maintain riffle areas; found in higher velocities and shallower depths; nests located in some current at depth 10 to 15 cm (eggs incubated in a laboratory at 25^{o}c)

Notropus volucellus (mimic shiner)

Fluvial specialist (Morgan 2002; Burgess 2002) found near riffles or in flowing pools over substrates of gravel or rubble with clear water (Bouschung and Mayden 2004). In large rivers found along shorelines over sand, mud and gravel in moderate flows (Hrabik 1996). Most frequent near riffles in current (Gilbert and Burgess 1980) and schooling in mid-water or at the surface (Edwards 1997).

Spawning season: in the Cahaba River mid-April to early August with peak spawning occurs early May to mid-June (Bouschung and Mayden 2004); May to August in Minnesota and Wisconsin (Moyle 1973; Becker 1983); mid-April to August in Alabama (Oliver 1986). Spawning strategy locations has not been documented for streams (Bouschung and Mayden 2004).

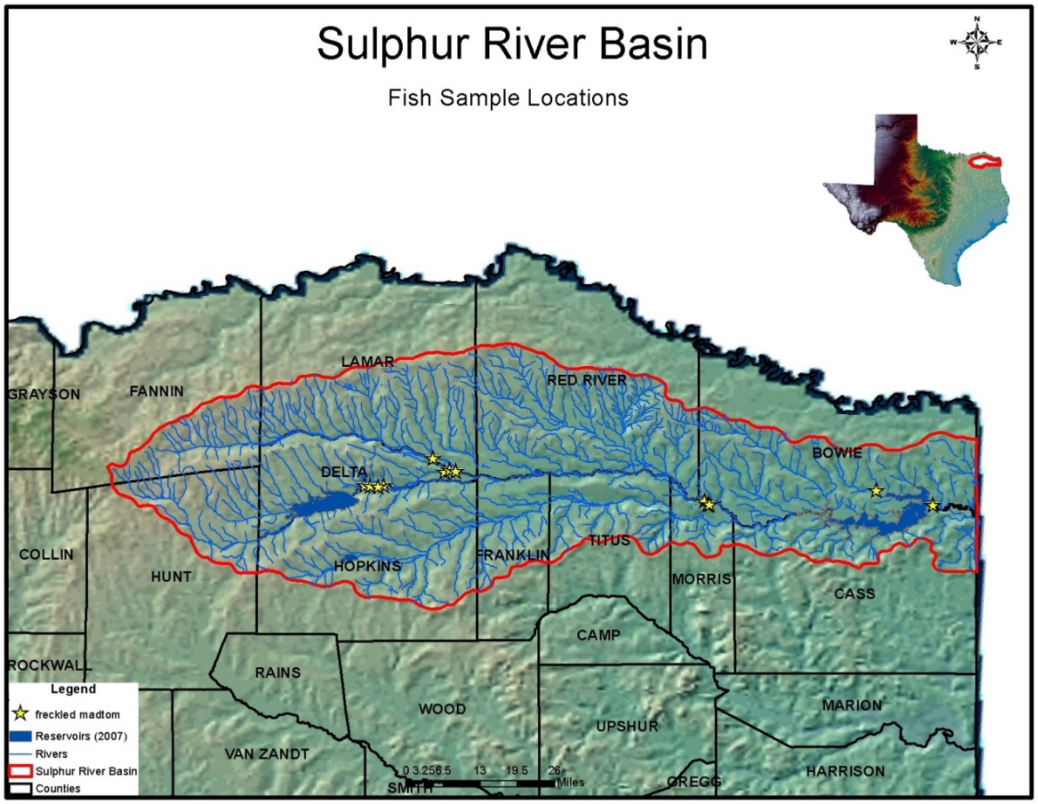

Figure 15: Freckled madtom samples in the Sulphur River Basin

Seasonality: Spawning from mid-April to early August with a peak early May to mid-June.

Baseflows: maintain riffle areas; found most frequent near riffles in current and schooling in mid-water or at the surface.

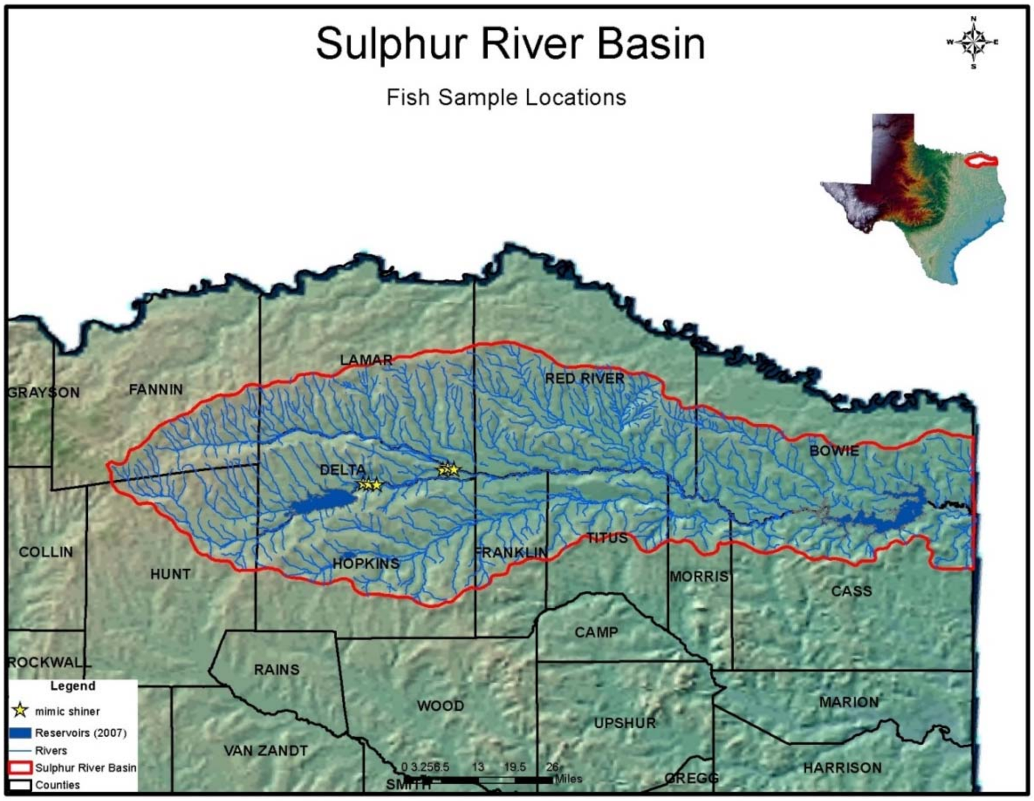

Figure 16: Mimic shiner samples in the Sulphur River Basin

Pylodictis olivaris (flathead catfish)

Found in deep pools around instream cover (large woody debris) (Bouschung and Mayden 2004; Cowley and Sublette 1987). Fluvial specialist young, usually to 2 to 4 inches in length (Minckley and Deacon 1959) are found in riffle and run areas over rock, cobble and gravel (Bouschung and Mayden 2004).

Spawning season: in Texas occurs in late June and July (Hubbs et al. 1953; Minkley and Deacon 1959); in Alabama, June and July (Bouschung and Mayden 2004); when temperatures reach 23.8°C to 26.6°C (TPWD website accessed 08/14/2012).

Seasonality: Spawning from June to July (when temperatures reach 23.8°C to 26.6°C).

Baseflows: Maintain riffle areas; juveniles found most frequent near riffles in current. Also, need to maintain instream habitat especially large woody debris.

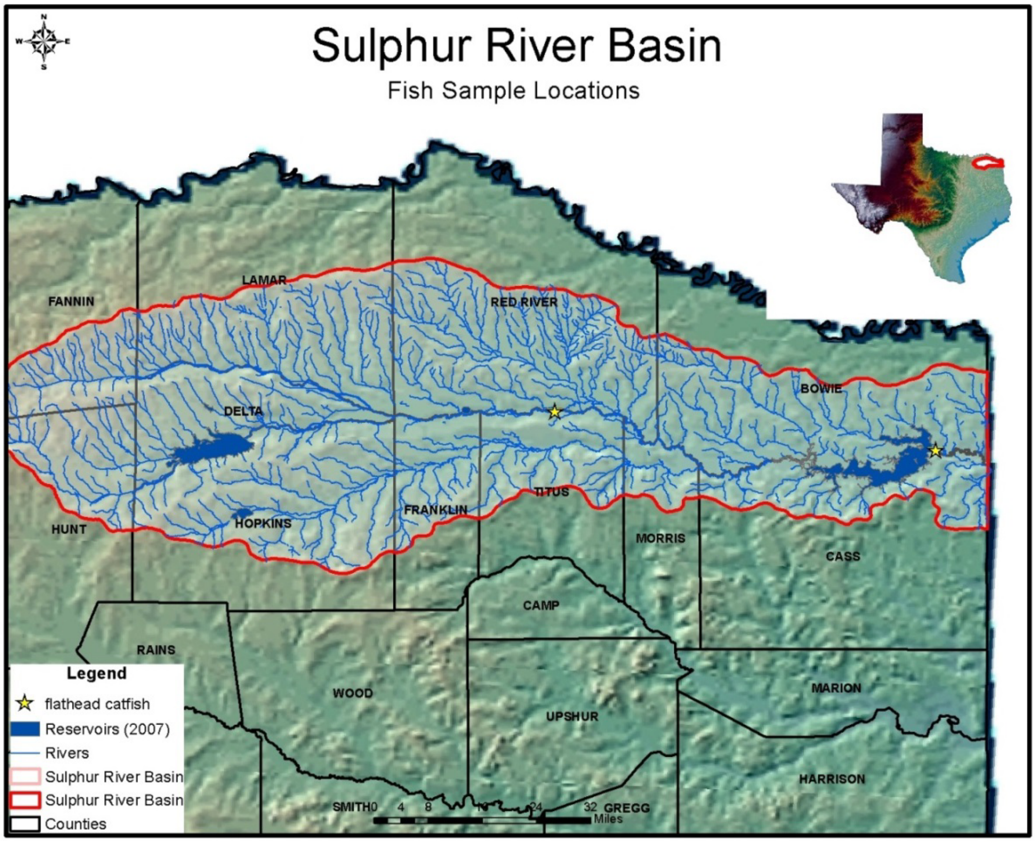

Figure 17: Flathead catfish samples in the Sulphur River Basin

Micropterus salmoides (largemouth bass)

This species is found in a variety of macro and meso habitats. Found in still pools of rivers and streams (Williams 1983; Chilton 1997; Ross 2001) usually in areas with aquatic vegetation or instream cover (Bouschung and Myaden 2004).

Spawning season: occurs in late winter or early spring as temperatures range from 15^{o}C to 24^{o}C (coutant 1975). In Tennessee, late March to mid-May (Miranda and Muncy 1987). In Alabama, from mid-April to mid-June (bouschung and Myaden).

Seasonality: Spawning in late winter through spring (when temperatures range from 15^{o}C to 24^{o}C).

Baseflows: Need to maintain instream cover (e.g. aquatic vegetation).

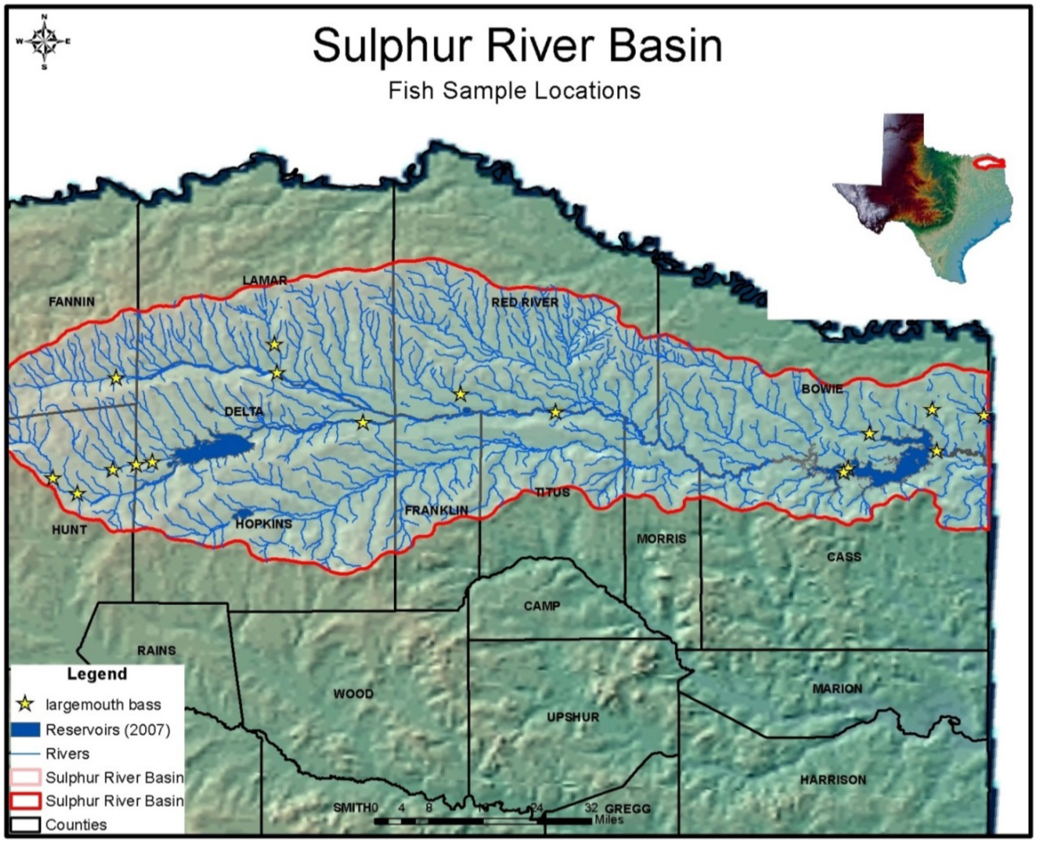

Figure 18: Largemouth bass samples in the Sulphur River Basin

Etheostoma spectabile (Orange throated darter)

Found in shallow riffle areas over gravel (Page 1983). Also found in slow to moderate flows usually around vegetated banks and/or undercut banks (Etnier and Starnes 1993). Males are found in riffles throughout the year while females tend to be below riffles in pools. During the winter months migrations between the two occur (Simon 2006).

Spawning season: in Texas, occurs from mid-October through July (Hubbs and Armstrong 1962; Marsh 1980; Hubbs 1985).

Most recently collected in 2000 by TPWD staff in the central part of the basin.

Seasonality: Spawning from mid-October to July.

Baseflows: Maintain riffle areas and connectivity to pools during spawning periods (and possibly winter migrations).

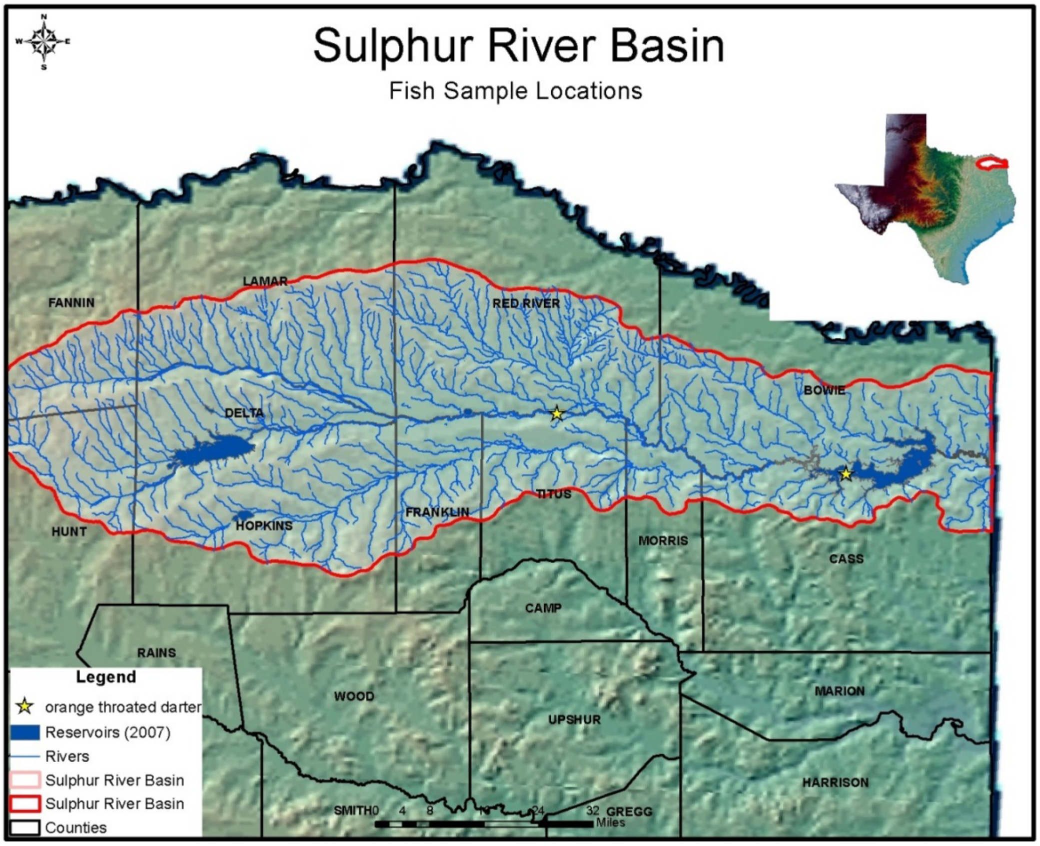

Figure 19: Orange throated darter samples in the Sulphur River Basin

Lepisosteus osseus (longnose gar)

Most common gar found in Texas. Found in large rivers, reservoirs, oxbow lakes (Etnier and Starnes 1993). Are sometimes found in oxbow lakes after floods and return as waters recede (Winemiller et al. 2004). This species has been found in water temperatures as high as 33.9oC (Becker 1993).

Spawning season: in the spring when water temperatures are 17.8 to 21.1°C (Dean 1895; Netsch and Witt 1962), but has been documented as late as August depending on geographic location (Carlander 1969; Wiley 1980). Spawning takes place over submerged structure such a Large Wood Debris (LWD) or other aquatic vegetation (Simon 1999; Balon 1981), in gravel shoal areas among rocks (Dean 1895; Yeager and Bryan 1983) and in shallow riffle areas.

Seasonality: Spawning in the spring (when temperatures reach 17.8°C to 21.1°C).

Baseflows: Maintain instream habitat, especially large woody debris. Also, maintain lateral connectivity with the floodplain (this species is known to in habitat oxbow lakes).

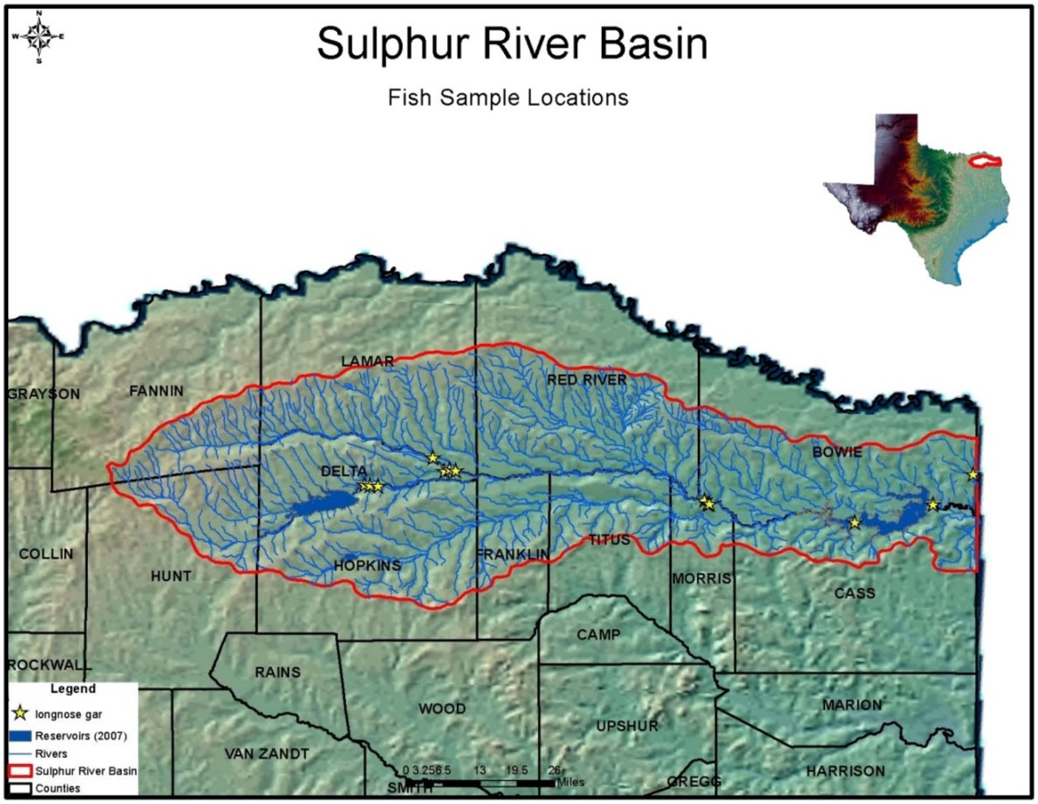

Figure 20: Longnose gar samples in the Sulphur River Basin

2.3.2 Focal Mussel and Invertebrate Species Short List

Mussels have limited mobility although the parasitic stage of the unionid glochidial stage and flood flows are thought to be significant contributors to species distribution (Howells, Neck and Murray 1996). Glochidia cannot swim or crawl and are dependent solely on water currents for distribution (Buchanan 1980; Oesch 1984).

Mussels in general prefer mud, sand gravel and cobble substrate usually behind a velocity break (e.g. fallen tree, sand/gravel bars, etc.). Deep shifting sand and soft silt are some of the most inhospitable substrate types for mussels as well as bedrock and boulder (Howells, Neck and Murray 1996).

Water quality can directly influence mussel abundance and distribution. Mussels are highly sensitive to low dissolved oxygen levels. Ellis (1937) and Ingram (1957) reported dissolved oxygen below 20% saturation could stress mussel populations; however some species can survive low oxygen levels for brief periods (Howells, Neck and Murray 1996). Imlay (1971) documented Ablema plicata in conditions of no dissolved oxygen for 10 weeks.

Mussels identified by TPWD and by USFWS (for the Sulphur River Basin Ecological Overlay) are provided below.

Pleurobema riddelli (Louisiana pigtoe)

Although little is documented about Pleurobema riddelli, it is currently under ESA status review.

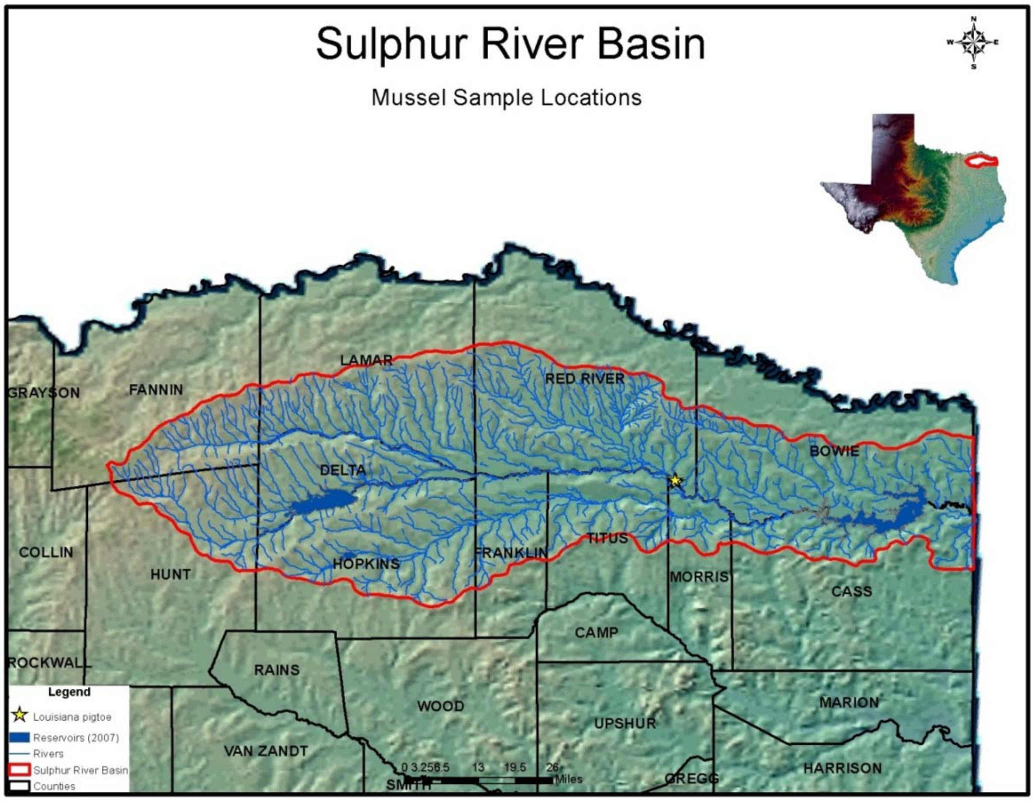

Figure 21: Louisiana pigtoe sample in the Sulphur River Basin

Tritogonia verruscosa (Pistolgrip)

Found on a variety of stable substrates and at a wide range of velocities (Howells, Neck and Murray 1996). This species has been associated with oxygen rich riffles and runs (Stansbery 1965).

Spawning season: tachytictic occurring from spring to end of summer. In central Texas, August (Littleton 1979), April through June in West Virginia.

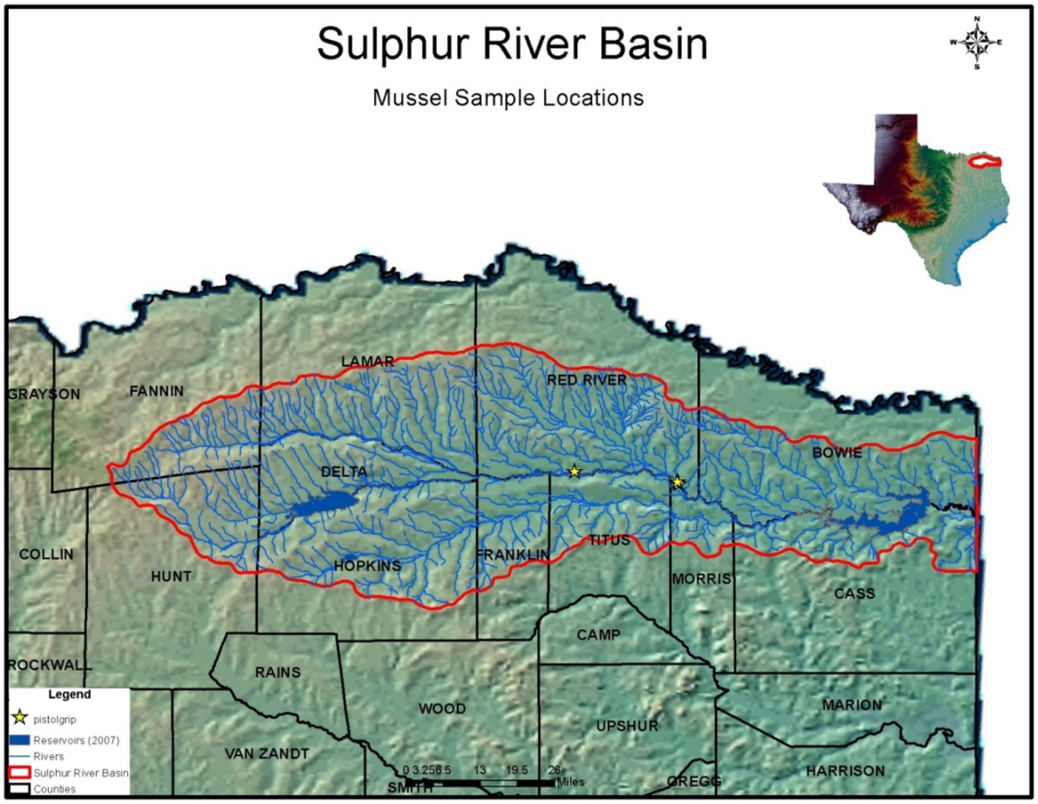

Figure 22: Pistolgrip samples in the Sulphur River Basin

Lampsilis teres (yellow sandshell)

Found on a variety of substrates but avoids deep shifting sands (Howells, Neck and Murray 1996). Coker et al. (1921) described this species as one which could move into inundated areas during flood conditions and return as water receded. Lampsilis teres has also been described as intolerant to drought and dewatering (Strecker 1931).

Spawning season: In Texas from June to August (Littleton 1979), in central Texas May to July [RGH].

Glochidia host fish include gars, sunfishes, black basses, etc.

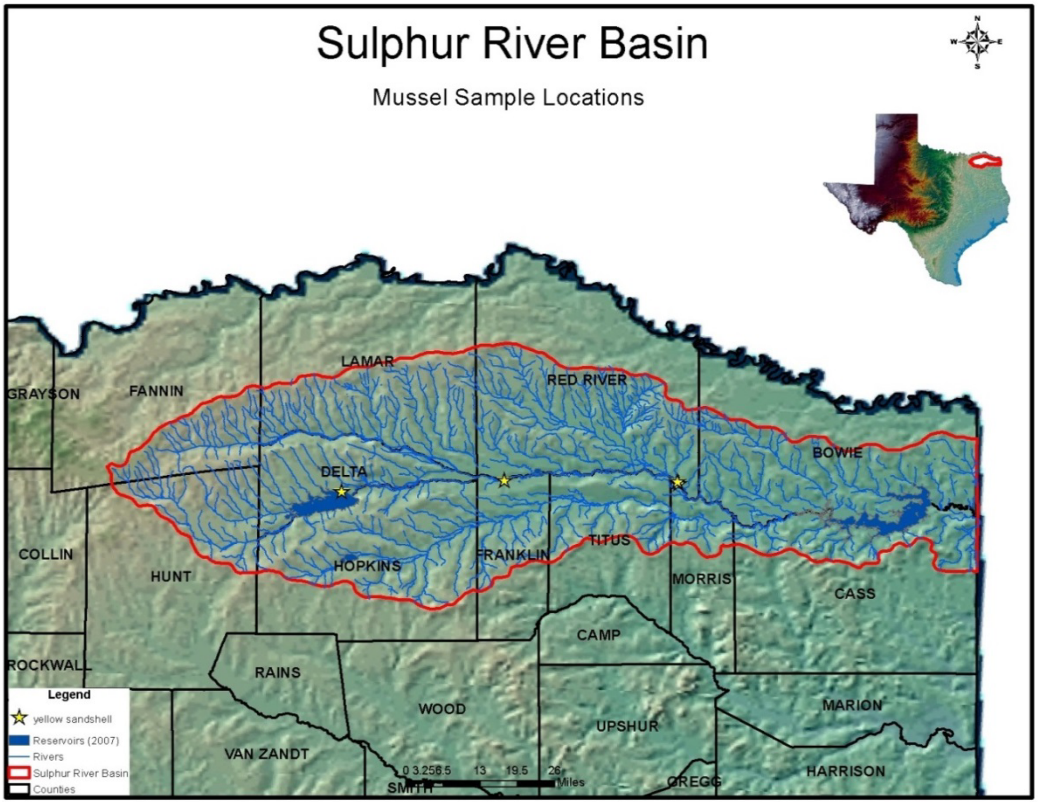

Figure 23: Yellow sandshell samples in the Sulphur River Basin

Quadrula apiculata (southern mapleleaf)

Found in a variety of habitat types ranging from reservoirs to flowing waters in rivers and streams. Also, found on mud, sand, gravel and cobble substrates.

Spawning season: In Texas early May to mid-June (Howells, Neck and Murray 1996).

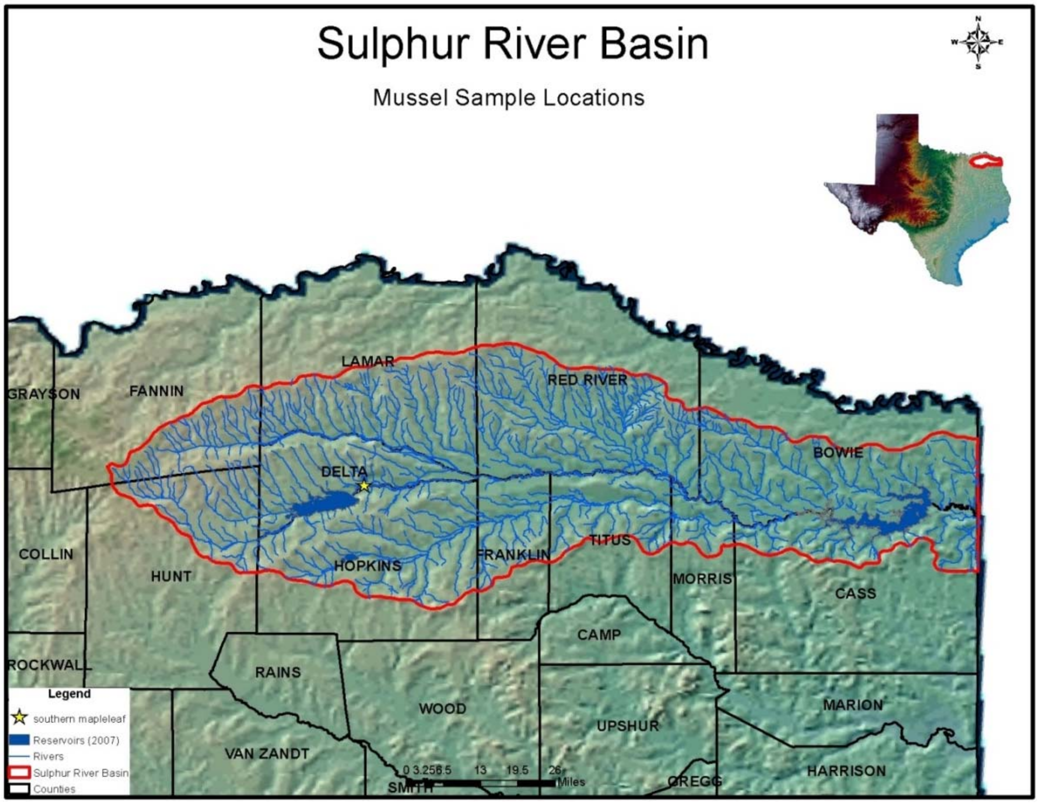

Figure 24: Southern mapleleaf sample in the Sulphur River Basin

2.4 Flow Components

Statistical approaches to describe the instream flow regime using historical streamflow gauge records have been summarized by the SB 3 Science Advisory Committee (SAC, 2009a) and employed in multiple river basins during the SB 3 process. A degree of uncertainty exists on the purposes of specific flow components for a given river or stream. Greater uncertainty exists on the use or application of flow regime statistics based upon mimicking historical (or more natural) conditions towards the development of environmental flow guidelines.

A useful set of initial steps in the flow guideline development process may be (step 1) the identification of which flow components are relevant to the stream segment of interest; (step 2) levels of data, analyses and/or expert judgment acceptable in the characterization in each flow component; (step 3) the identification of clear purposes or goals for each flow component; and (step 4) an indication of when and/or how often each flow component is relevant.

A wide range of purposes, ecological roles and evaluation approaches are proposed for four flow components (as previously used in the SB3 and SB2 processes), namely subsistence flow, base flow, high flow pulses, and overbank flows. Description excerpts from the Hydrologic Methods document (SAC 2009a) for each regime component are provided in Table 2.

Table 2: Generalized flow components

<table>
<tr><td>Overbank Flows</td><td colspan="12">Overbank flows are infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. A primary objective is to maintain riparian areas associated with riverine systems, eg, transport sediments and nutrients to riparian areas, recharge floodplain aquifers, and provide suitable conditions for seedlings.</td></tr>
<tr><td>High Flow Pulses</td><td colspan="12">High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events. They serve to maintain important physical habitat features and connectivity along a stream channel.</td></tr>
<tr><td>Base Flows</td><td colspan="12">Base flows represent the range of "average" or "normal" flow conditions in the absence of significant precipitation or runoff events. Base flows provide instream habitat conditions needed to maintain the diversity of biological communities in streams and rivers.</td></tr>
<tr><td rowspan="2">Subsistence Flows</td><td colspan="12">An atypical, short-duration (days to weeks) low flow event</td></tr>
<tr><td colspan="12">Maintain water quality conditions</td></tr>
<tr><td>Month</td><td>Dec</td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td><td>Nov</td></tr>
<tr><td>Season</td><td colspan="3">Winter</td><td colspan="3">Spring</td><td colspan="3">Summer</td><td colspan="3">Fall</td></tr>
</table>

2.4.1 Sulphur River Basin Flow Components

Only limited quantitative data or analysis has been discovered to identify appropriate instream flow values on the basis of habitat utilization. The data and analyses discovered and evaluated to date lack sufficient detail to characterize specific flow rates or flow ranges that provide specific habitat conditions. In addition, quantitative measures defining bounds of habitat conditions (e.g., range of suitable velocities) are not well quantified for all species and/or guilds. Therefore, consideration is not given to the inter-relation of habitat suitability amongst the full population. Lastly, relationships are not available to characterize how habitat conditions change with changing flow. Each of these factors should be evaluated quantitatively in the future to increase confidence in any flow guideline or recommendation.

2.4.2 Previous Sulphur Flow Regime Characterization

The 2016 North East Texas Regional Water Plan (Region D) identifies a study entitled "Sulphur River Environmental Flow Regime and Analysis Recommendation Report" prepared by Trungale Engineering & Science (Trungale, 2015). As noted in the 2016 Region D Plan, the flows identified in Trungale (2015) are not presented as requirements to be implemented on regional water management strategies. The regime has not been subject to review and revision by stakeholders for balancing in order to determine the extent of this flow regime that is needed to maintain the ecological health of the fish and wildlife habitat and the economic and other values currently provided. The 2016 Region D Plan notes that this flow regime serves as "only a first attempt at identifying voluntary instream flow goals for the Sulphur River Basin." There is insufficient detail identifying the derivation of the flow regime components for the Trungale (2015) flow regime, as specifics regarding the parameterization of the flow separation analysis are not reported.

2.5 Biologic Information

As noted previously, the United States Fish and Wildlife Service (USFWS) (1985) identified approximately 94,000 acres of priority bottomland hardwood forest along the Sulphur River west of Wright Patman Reservoir. Bottomland forests in eastern Texas, which are found within the Sulphur River Basin, support a large number of sensitive plant and animal species including over a 100 species of special concern (Neal 1989). Such species include: wood ducks and mallards, paddlefish, ironcolor shiner and tailgate shiner, Silveanus dropseed series, Sugarberry-Elm series, Bachmans's sparrow, alligator snapping turtle, interior least tern, bald eagle, American swallow-tailed kite, timber rattlesnake, and southeastern myotis (Osting et al. 2004).

Most historic biological studies conducted within the Sulphur River are limited both spatially and temporally. Osting et al. (2004) conducted a multi-year instream flow study in the upper basin of the Sulphur River which is the most comprehensive study conducted on the Sulphur River to date. This study encompassed biological (fish) and hydraulic samples sites. These sites were located just downstream of the Proposed George Parkhouse II reservoir site and just downstream of Cooper Lake (also known as Jim Chapman Lake). Biological studies (Gelwick and Burgess 2002; Gelwick and Morgan 2000) were focused on fish habitat utilization at different flows and seasons (Osting et al. 2004) as well as habitat and assemblage differences between channelized and unchannelized reaches. Fish assemblage data collected during Gelwick and Burgess (2002) and Gelwick and Morgan (2000) were similar to a taxonomic survey of fishes in the Sulphur River Basin from its headwaters to Wright Patman Reservoir (Turner 1978).

Large Woody Debris (LWD) was the dominant habitat found in pools during low flow conditions and in some instances provided false riffle habitat. LWD was incorporated into habitat maps (Gelwick and Burgess 2002; Gelwick and Morgan 2000) and the habitat modeling (Osting et al. 2004). In most sampled areas, LWD appeared to be the most significant in-channel habitat structure. This could be due to anthropogenic impacts to the river channel.

Sites on the South Sulphur River downstream of Cooper Lake were considered unchannelized . The river channel consisted mainly of pool habitat at lower flows and run habitat at higher flows (Gelwick and Burgess 2002; Osting et al. 2004). Sites on the South Sulphur River near the confluence with the North Sulphur River had been channelized. The river channel was straighter and had a uniform depth and habitat characteristics (Gelwick and Burgess 2002).

Sites on the main stem of the Sulphur River downstream of the confluence with the North and South branches were channelized. The river channel consisted of steep banks and levees and had similar habitat to the channelized sites on the South Sulphur River (Gelwick and Morgan 2000). Sites on the main stem Sulphur River downstream of the proposed Marvin Nichols Reservoir and upstream of the existing Wright Patman Reservoir were not channelized. The river channel had steep banks, higher quality habitat with meanders and cutoff channels and was considered more pristine than unchannelized sites in the upper basin (Osting et al. 2004). This was supported with a greater diversity of fish at these sites (Gelwick and Morgan 2000).

Gelwick and Burgess (2002) report 34 species collected during the study. Species richness was consistent across all sites or flow ranges. Several species were considered rare because of infrequent capture during sampling efforts: alligator gar (Atractosteus spatula), shortnose gar (Lepisosteus platostomus), emerald shiner (Notropis atherinoides), black stripetopminnow (Fundulus notatus), pirate perch (Aphredoderus sayanus), brook silverside (Labidesthes sicculus), striped bass (Morone saxatilis), green sunfish (Lepomis cyanellus) and black crappie (Pomoxis nigromaculatus). However, sampling methods and gear types used were not adequately effective during the study (Morgan 2002). Therefore, these species may have been under represented because of sampling inefficiencies.

Gelwick and Morgan (2000) reported 36 species encompassing 12 families during the study. Red shiners (Cyprinella lutrensis), Mississippi silvery minnow (Hybognatuhus nuchalis) and mosquito fish (Gambusia affinis) represent approximately 66% of the specimens collected (although sampling effectiveness was cited as an issue, Morgan 2002). Results from Morgan (2002) showed four species were indicators of back water habitat: mosquitofish (Gambusia affinis), orangespotted sunfish (Lepomis humilis), Mississippi silvery minnow (Hybonathus nuchalis) and white crappie (Poxomis annularis). Three species were indicators of riffle (fast water) habitat: red shiner (Cyprinella lutrensis), freckled madtom (Noturus nocturnus) and juvenile channel catfish (Ictalurus punctatus). Freckled madtom (Noturus nocturnus) and red shiner (Cyprinella lutrensis) were collected almost entirely in riffle habitat (Morgan 2002).

A fish survey of the North Sulphur River, Middle Sulphur River and the South Sulphur River was conducted by Carroll et al. (1977). A total of 30 species were collected during this survey with most minnow comprising approximately 72% of the fishes collected. However, fishes were collected using minnow seines and bag seines which select for these types of fish species. Larger more mobile fish are rarely captured using this gear type.

Mussel data was limited in the Sulphur River Basin prior to 2005. Recent Mussel studies Marsha May (TPWD 2005) and Karatayev and Burlakova (2007) have been conducted. Karatayev and Burlakova (2007) East Texas survey was conducted in areas which were previously sampled by Marsha May (TPWD 2005). These sites included the mainstem of the Sulphur River, Wright Patman Reservoir and Coopers Reservoir. However, this survey was conducted at slightly higher flows than previous collections and following severe drought conditions which extended from 2005-2006 (Karatayev and Burlakova 2007).

At one site, Shumake property (33.36549°N, 94.80084°W), approximately one third of the total number of individuals found previously (2005) were collected in 2007. Seven species including four found alive in 2005 were collected in 2007. These species included: sandbank pocketbook, Louisiana pigtoe, fragile papershell, giant floater, tapered pondhorn and western pimpleback. As noted by Osting et. al. 2004,

> "Both Morgan (2002) and Burgess (2002) made concluding comments in their respective thesis that effective management of the Sulphur River should include identification of fluvial specialist, in addition to the ones they identified (freckled madtom and mimic shiner) and maintenance of habitat suitability requirements for those species. Fluvial specialists have a greater sensitivity to altered flow regimes (Petts 1984), and thus targeting these species for maintenance flow requirements is probably prudent."

3 Streamflow Gauge Locations

Generally, two potential water supply alternatives are currently under evaluation for the Sulphur Basin Feasibility Study, namely:

1. Reallocation of Wright Patman Reservoir, and
2. Marvin Nichols Reservoir IA.

Review of United States Geological Survey (USGS) streamflow gaging stations in the Sulphur River Basin has identified historical streamflow data, of varying periods of record, for fourteen (14) separate locations. Figure 25 depicts the locations of these streamflow gaging stations, while a graphical depiction of each gauge's available period of record is provided in Figure 26. Of the gauges identified, four gauges (USGS Gauge ID's: South Sulphur River near Cooper, Texas (No. 07342500); North Sulphur River near Cooper, Texas (No. 07343000); White Oak Creek near Talco, Texas (No. 07343500); and Sulphur River near Darden, Texas (No. 07344000)) have streamflow data spanning the historical drought of record in the 1950's (the first three of these gauges remain active). Each of these gauges contain at least a 20 year period of record, which has been assumed herein to represent a sufficiently variable range of streamflow conditions within a watershed (Table 3).

The critical gauge of importance to the two identified potential project alternatives enumerated above is located at the Sulphur River near Talco, Texas 07343200, which has greater than 20 years of streamflow data and remains actively monitored; however, the gauge was not activated until October 1956, near the end of the drought of record identified within the TCEQ's current Water Availability Model for the Sulphur River Basin. Furthermore, the location of this gauge was physically moved slightly downstream in October 1997. Thus, this gauge and the Wright Patman location were preliminarily selected for instream flow analysis locations, due to their sufficiency of data and locations proximate to the initially identified water supply alternatives under evaluation. The remaining gauge locations have been utilized to inform upon the instream flow analysis and characterization of the basin.

Table 3: Measurement points identified as data sources for potential environmental flow guidelines

USGS Gage	Site Name
7344000	Sulphur Rv nr Darden, TX
7343200	Sulphur Rv nr Talco, TX
7343500	White Oak Ck nr Talco, TX
7343000	N Sulphur Rv nr Cooper, TX
7342500	S Sulphur Rv nr Cooper, TX
	Wright Patman Releases

A review of the watersheds represented by the selected locations is warranted, specifically as to how the data from each location may be employed in the subsequent development of environmental flow criteria specific to a potential water supply alternative.

As noted previously, the focus of this effort is to develop instream flow guidelines for subsequent evaluations of their impact to alternative water supply strategies. To facilitate the development of these guidelines, USGS gauge data and (in the case of Wright Patman) USACE release data have been utilized. The present effort is not intended to pre-empt a Senate Bill 3 process. As such, rather than develop a comprehensive suite of environmental flow guidelines representative of the entirety of the Sulphur River Basin, the focus has been on the development of project-specific environmental flow guidelines. Such a focus affords the opportunity to develop instream flow guidelines not at USGS streamflow gauging stations, but rather at the location of the potential water supply alternative. This allows for the development of environmental flow guidelines explicit to the water supply alternative, and avoids the operational complexity of a downstream environmental flow guideline that may include uncertainties due to attenuation and contributions of flows from intervening tributaries. This further increases the importance of the identified hydrologic relations between the location of a specific water supply alternative and the relevant USGS gauge.

It should be noted that at present the TCEQ's methodology for relating pulse flows between two given points in a watershed is currently in a "draft" state, but has been used herein as the best available information on TCEQ's preferred approach for such translations in a SB 3 context.

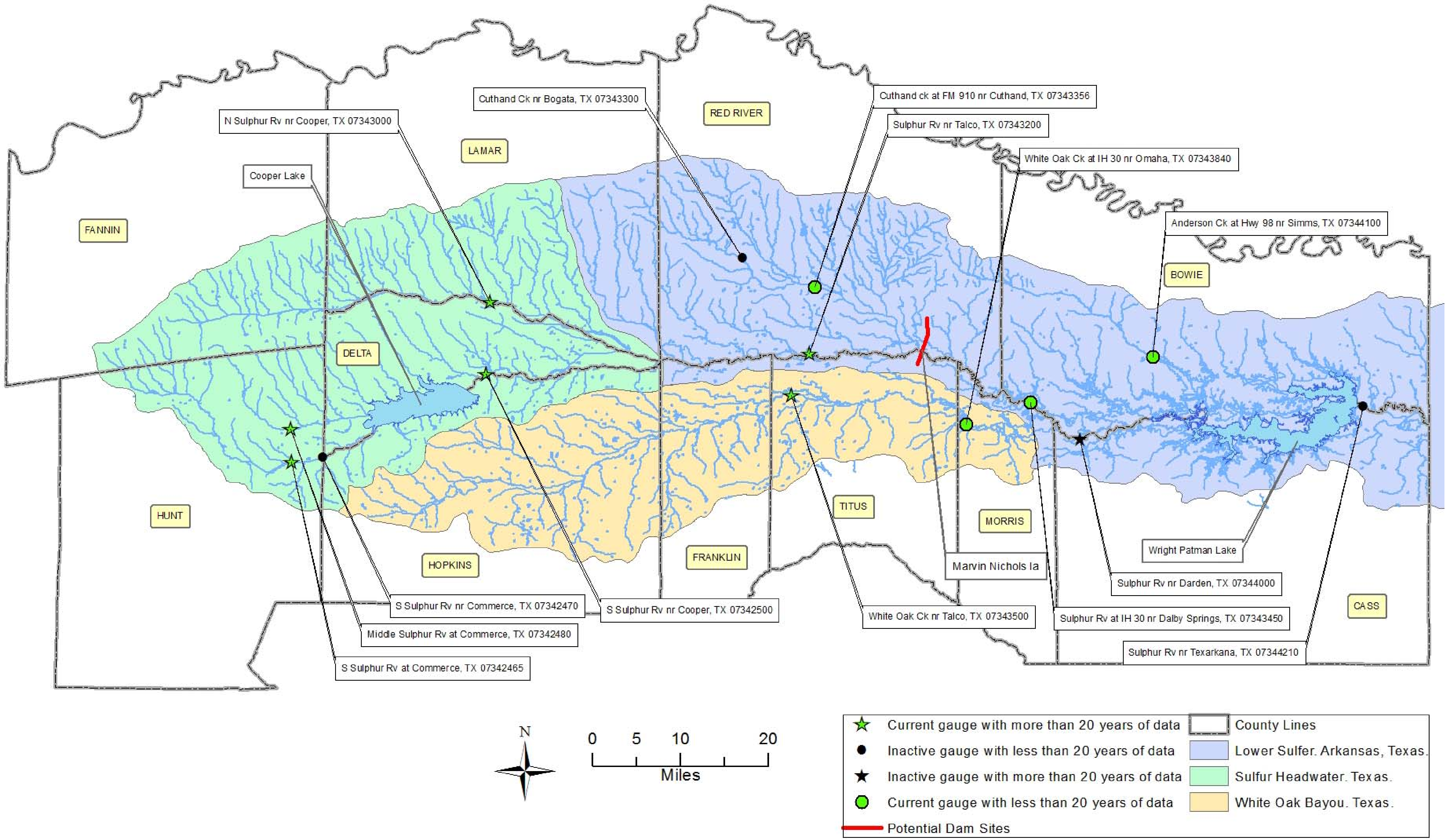

Figure 25: Sulphur River Basin Hydrologic Record Map.

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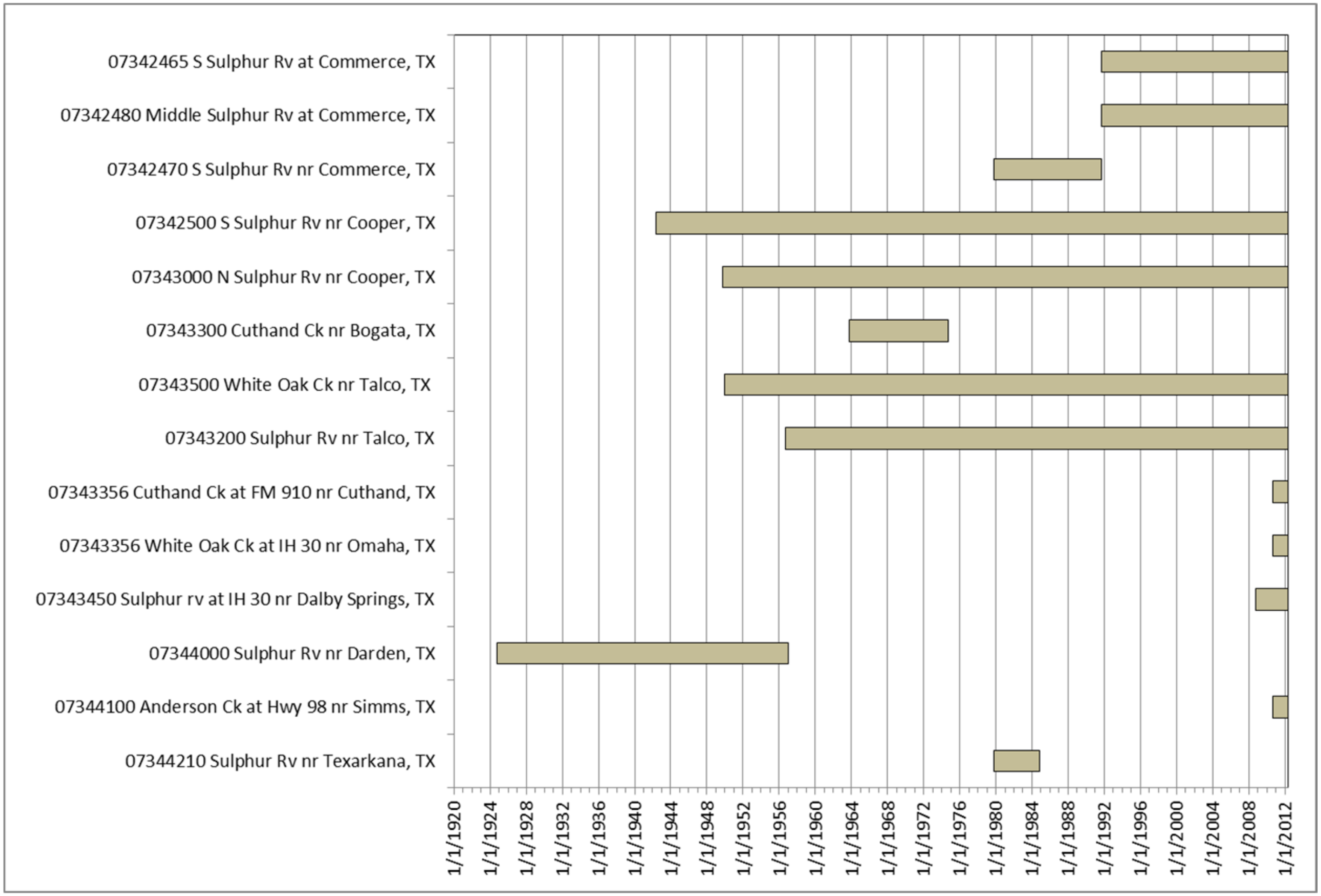

Figure 26: Sulphur River Basin USGS Gauge Periods of Record.

3.1 Wright Patman Reservoir

The USGS gauge preliminarily identified for use in the development of instream flow guidelines is located upstream of Wright Patman Reservoir. Instream flow guidelines developed and implemented at this location would thus only potentially impact inflows to Wright Patman Reservoir. No actively monitored USGS gauge is readily available that could be employed to quantitatively evaluate streamflows downstream of Wright Patman. However, several alternatives have been considered for the development of environmental flow guidelines downstream of Wright Patman.

Brandes (1999) presents the results of the development of the Water Availability Model (WAM) for the Sulphur River Basin. Within Brandes (1999), there is reported a USGS Gauge 07344200, Wright Patman Lake near Texarkana, located downstream of Wright Patman Reservoir, with a period of record of July 1953 to September 1997. Data from this gauge were employed in the streamflow naturalization process (Brandes 1999). However, a recent query of the USGS National Water Information System (NWIS) resulted in only reservoir elevation data for October 2007 to present. Further investigation of the flow naturalization process downstream of Wright Patman suggests that USGS 07344200 was used only as a control point specifying the location of Lake Wright Patman.

Reported release data from the United States Army Corps of Engineers (USACE) for Wright Patman Reservoir are available for October 1979 through present on a daily time step. These data are reported as gated flows as an average daily flow rate in cfs, and could be considered for utilization of instream flow criteria downstream of the reservoir. The data set is missing flow data for Jan 1981 – Oct 1981. Additionally, the data set has steady release events of 96 – 115 cfs. It is understood that USACE will cease the 96 – 115 cfs releases in the future, performing only the contractually required 10 cfs releases in future operations. To simulate this future condition of reservoir operations and to represent reservoir operation contractual requirements, the historical release data has thus been modified to convert all steady release amounts which are 115 cfs or less, for a duration of one day or more, to the contractually required 10 cfs.

A statistical characterization of the flow regime based on historical releases from Lake Wright Patman is based on the assumption that ecological processes downstream of the reservoir have developed based upon the releases from Wright Patman. The objective of an instream flow guideline based on this assumption would be to maintain the current ecological conditions of the reach downstream of Wright Patman, rather than the maintenance of the reach of natural flow conditions. Such an objective would substantively differ from the established precedent in other Texas river basins to identify the natural flow regime. Nevertheless, such a characterization is informative for comparison with alternative, more natural flow regime characterizations.

Available streamflow data from the USACE for discharges from Wright Patman (1979-2014) have thus been utilized for such a comparative characterization.

In order to characterize a more natural flow regime downstream of Wright Patman, an analysis was performed to simulate natural flow conditions prior to the impoundment of Wright Patman. This simulation is based upon the translation of environmental flow guidelines representing a more natural flow regime from an upstream gauge to the Wright Patman location. For this alternative, the identified potential environmental flow guideline at the Sulphur River near Talco gauge location was developed, then translated to Wright Patman using a drainage area ratio for the translation of seasonal subsistence and base flow amounts and the TCEQ adopted pulse flow translation methodology to translate high flow pulse amounts.

3.2 Marvin Nichols

As depicted in Figure 25, the proposed Marvin Nichols IA dam site is located on the Sulphur River between USGS Sulphur River near Talco gauge (No. 07343200) and Sulphur River near Darden, Texas (No. 07344000). As noted previously, 07343200 and 07344000 each have more than 20 years of available streamflow data; however, only 07343200 is currently active.

There are several issues regarding the use of data from the USGS Sulphur River near Talco gauge (No. 07343200). First, the gauge was relocated near the end of 1997. If the gauge is to be utilized as a potential environmental flow measurement location (where criteria would be evaluated), then first the full period of record of available data (1956 – present) would need to be synthesized at the present gauge location. Additionally, the period of record for USGS Sulphur River near Talco gauge (No. 07343200) does not span the drought of record identified in the TCEQ's official WAM for the Sulphur River Basin, while the Sulphur River near Darden gauge (No. 07344000), located further downstream, does span this period. As the drought of record in the WAM is a significant event which is generally the limiting factor of all Texas water supply projects when evaluated in a state permitting context, and is representative of an extreme, infrequent (i.e., subsistence) instream flow event, a means of further synthesizing the flows during the drought period at this location is necessary.

To normalize the USGS Sulphur River near Talco gauge's (No. 07343200) period of record the reported daily average flow values for the gauge's original location (drainage area 1365 sq-mi) have been adjusted to the current location (drainage area 1405 sq-mi). According to USGS documentation, the gauge was moved approximately 2.3 miles downstream, with the reporting of data for the relocated gauge beginning in October 1997 (USGS 1999). Thus, for the period December 1956 to September 1997, reported data for USGS Sulphur River near Talco gauge (No. 07343200) have been adjusted to the present gauge location using a derived drainage area ratio:

$\frac{1405mi^2}{1365mi^2} = 1.0293.$

Data from October 1997 to present require no such modification or estimation at the gauge site.

Several alternatives for synthesizing flow data for the early-1950's period have been considered. One alternative for synthesizing flow data for USGS Sulphur River near Talco gauge (No. 07343200) is to utilize the area relationships developed during the development of the Sulphur River Basin WAM. When the naturalized flows for the Sulphur WAM were developed, relationships relating naturalized gauge flow data to other ungauged watersheds or gauged watersheds with periods of missing data were developed and reported in Table 3-2 of Brandes (1999).

Three correlation relationships with surrounding gauged watersheds were identified for potentially estimating naturalized flows at USGS Sulphur River near Talco gauge (No. 07343200). However, it is important to note that this methodology of developing synthesized flows was focused on calculating monthly naturalized flow data from naturalized gauged flow records. The present effort is not concerned with monthly naturalized flows and thus would be required to develop new relations for daily data utilizing reported daily streamflow amounts. Hence, this alternative was deemed not acceptable.

A second alternative considered was to estimate the early portion of the period of record for the USGS Sulphur River near Talco gauge (No. 07343200) through the development of a flow relationship with the nearest upstream gauges during the overlapping period of record. Two flow relationships could be developed for the USGS Sulphur River near Talco gauge (No. 07343200): the first between 07343200 and the upstream Sulphur River gauges South Sulphur River near Cooper, Texas (No. 07342500) and the North Sulphur River near Cooper, Texas (No. 07343000). The second flow relationship which could potentially be developed is between the USGS Sulphur River near Talco gauge (No. 07343200) and the White Oak Creek near Talco, Texas gauge (No. 07343500). A comparative analysis of the two flow relationships was then performed to identify the relationship that best represents flows at USGS Sulphur River near Talco gauge (No. 07343200) (via the greatest amount of explained variance in the prediction). The drainage area relationship that provides the best approximation will be used to estimate the missing period of record prior to, and through, the drought of record at the USGS Sulphur River near Talco gauge (No. 07343200) location. Analysis of flows at 07344000 coupled with drainage area ratios are then used to check flow estimations at 07343200 during the drought of record.

The method ultimately utilized for synthesizing flow data for the early period of flow at the USGS Sulphur River near Talco gauge (No. 07343200) is a regression of the daily streamflow data. The sum of the daily measured streamflow at the South Sulphur River near Cooper, Texas gauge (No. 07342500) and the North Sulphur River near Cooper, Texas gauge (No. 07343000) is regressed with the drainage area corrected and daily measured streamflow for the USGS Sulphur River near Talco gauge (No. 07343200, at its present location) over the period of 1957 to 2011. The resultant regression is then utilized to synthesize flow at the current location of 07343200 for the period of October 1949 to 1957 using the reported streamflow data from 07342500 and 07343000. The resulting synthesized flow data period of October 1949 to 2011 are translated to the Marvin Nichols dam location using the drainage area ratio method. Measured streamflow downstream of the Marvin Nichols dam site are considered for validation of the synthesized flow data developed for the Marvin Nichols dam site. The gauges used for validation are 07344000 Sulphur River near Darden, in conjunction with the 07343500 White Oak Creek near Talco USGS gauge. Further consideration is given to 07343300 Cuthand Creek near Bogata, and 07343450 Sulphur River near Dalby Springs.

The development of relationships between the daily average flow data at USGS South Sulphur River near Cooper (No. 07342500), and North Sulphur River near Cooper (No. 07343000) gauges with USGS Sulphur River near Talco gauge (No. 07343200) have been developed using differing relational methods in order to comparatively assess the methods' accuracy. A drainage area ratio relation between the sum of the one day lagged daily average flow at USGS 07342500 and 07343000 and daily flow at 07343200 resulted in an explained variance of 0.75. A multivariate regression relating the one day lagged daily average flow at 07342500 and 07343000 to daily flow at 07343200 resulted in an explained variance of 0.79. Finally, a univariate regression relating the sum of the one day lagged daily average flow at 07342500 and 07343000 to daily average flow at 07343200 resulted in an explained variance of 0.77.

However, these relations are all based upon the daily average flows for the period of record December 1956 – 2011, yet the purpose of relating the upstream gauges is the estimation of low flows during the Texas drought of the 1950's. Since the goal is to develop a best representation of low flows during the 1950's period, a comparative analysis of the ogives for historical daily average flow at USGS gauges 07342500 and 07343000, 1943-2011 and 1950-2011 respectively, has been performed. Daily flow data for the available period of record at a particular gauge has been plotted, along with the daily average flow from the period 1950 – 1957. Direct comparison of these flow distribution curves allows for the identification of the range of flows experienced during the drought of record. These comparative curves of flow frequency for the USGS gauges 07342500 and 07343000 are presented in Figure 27 and Figure 28. As is evidenced in the figures, the full range of flows observed historically also largely occur during the 1950's drought. This suggests that the preliminary regression relationships developed represent the best estimate of flow at the downstream USGS Sulphur River near Talco gauge (No. 07343200) during the 1950's. Had only a small range of the frequency distribution represented the flow range of the drought of record, then employing an alternative relationship representing that flow range would likely provide a better representation of low flows for estimation of flows during the 1950's at 07343200.

Since the flow range of the 1950's drought spans the historical flow frequency distribution in its entirety, the best regression from the preliminary derivations is identified as the relationship of choice for synthesizing 1950's flow data for USGS Sulphur River near Talco gauge (No. 07343200).

Thus, the average daily flow at USGS Sulphur River near Talco gauge (No. 07343200) for the 1950's has been estimated as:

$$Q_{1_i} = 1.8398 * Q_{2_{i-1}} + 1.1898 * \ Q_{3_{i-1}}$$

Where,
$Q_1 \ = 07343200\ Average\ daily\ flow,$
$Q_2 \ = 07342500\ Average\ daily\ flow$,and
$Q_3 \ = 07343000\ Average\ daily\ flow.$

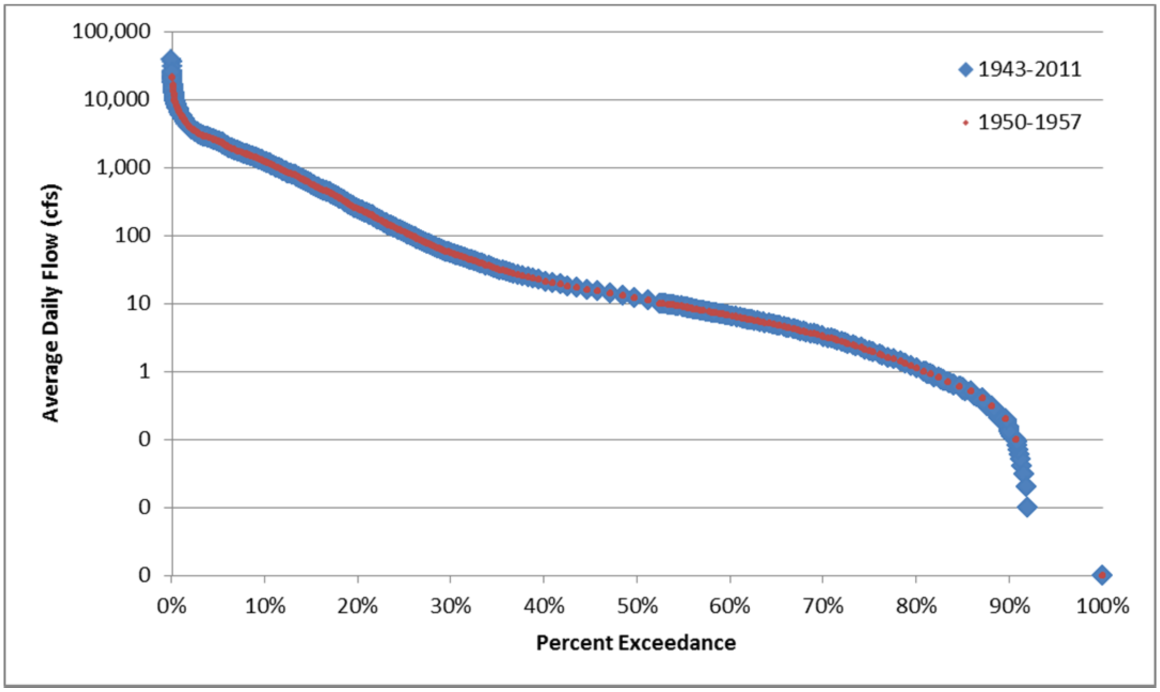

Figure 27: Comparison of flow frequency distribution for USGS 07342500 South Sulphur River near Cooper Texas between alternative time periods.

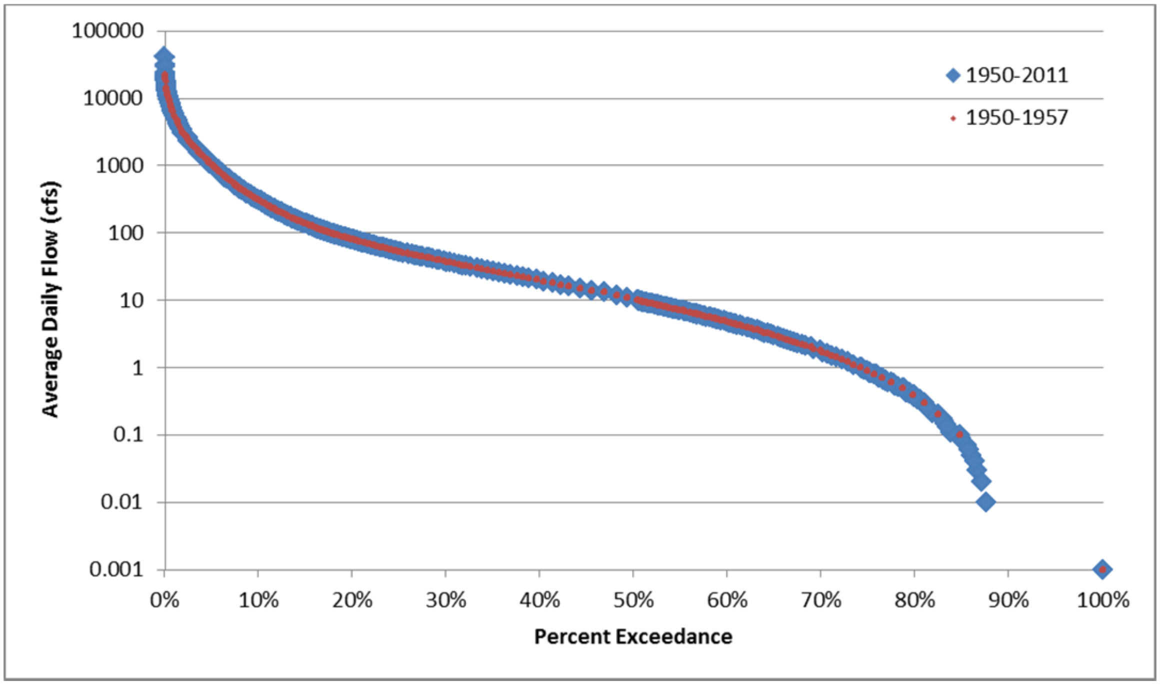

Figure 28: Comparison of flow frequency distribution for USGS 07343000 North Sulphur River near Cooper Texas between alternative time periods.

Additional gauges have been utilized to validate flow estimates at the Marvin Nichols site derived above. USGS gauges Sulphur River near Darden (No. 07344000), and White Oak Creek near Talco (No. 07343500) have been utilized as a means of validation of flow estimates at USGS Sulphur River near Talco gauge (No. 07343200) for the 1950 – 1956 period. The sum of the daily regression estimated flow at 07343200 and reported flow at 07343500 have been compared to the daily reported flow at 07344000 lagged three days. A linear regression of these data results in an explained variance of 0.72, which suggests that the relation is valid, though there is still uncertainty introduced by the intervening drainage area between the source gauges. Furthermore, a validation of the later period of record (Late 2008 – 2011) has been performed utilizing USGS Sulphur River near Dalby Springs, Texas (No. 07343450) lagged by two days. A linear regression of these data results in an explained variance of 0.85, which suggests that the relation is valid.

Thus, instream flow targets have been developed for the Marvin Nichols project site using a synthetic flow period of 1950-2014 derived as:

- 1950-Nov 1956:
  $Q_{1_i} = 1.8398 * Q_{2_{i-1}} + 1.1898 * Q_{3_{i-1}}$,
- Dec 1956-September 1997:
  $Q_{1_i} = 1.0293 * Q_{1_i}$

- October 1997 – 2014:
  Q_{1_i}.

Where:

$Q_1 = 07343200\ Average\ daily\ flow$,

$Q_2 = 07342500\ Average\ daily\ flow$, and

$Q_3 = 07343000\ Average\ daily\ flow$.

3.3 Gauge Selection Summary

For each water supply alternative considered herein, the time series of flow data have been developed as shown in Table 4:

Table 4: Location Selection for Estimation of Environmental Flow Regime Characterization

Project	Description of Hydrology to be Employed
Wright Patman	Historical releases from Wright Patman Reservoir, as reported by the USACE for the period 1979 – 2014
	Translation from USGS Sulphur River near Talco gauge (No. 07343200) to the Wright Patman dam location
Marvin Nichols IA	Utilize synthesized flow for USGS Sulphur River near Talco gauge (No. 07343200) adjusted to dam site location with drainage area ratio
	Flow synthesis based on multivariate regression of daily measured flow at 07343200 with daily measured flow at upstream gauges 07342500 and 07343000 for 1957 – 2011
	Total period of resulting synthetic flow data set 1950-2014

4 Seasonal Analyses

The seasonal analyses presented herein focus upon the six measurement points previously identified in Section 3, as it is assumed these locations provide a sufficient geographic distribution to assess both spatial and temporal seasonal characteristics of streamflow. Two of the six locations utilized for seasonal analyses correspond to those gauges utilized for estimating streamflow at the potential water supply project locations.

Average daily and monthly flows have been statistically evaluated to assess what seasonal characteristics, if any, may be identified. Such information has been utilized, along with biologic, ecologic, and climatological analyses to inform upon the proper delineation of seasonal components of the hydrologic flow regime. Characterizations of various parameters are seasonally evaluated, then compared. These comparisons are then utilized to identify patterns of consistent seasonal variations at various locations, and are reported herein.

4.1 Methodology

Historic average daily flow data for the available periods of record have been compiled from the USGS for each measurement point identified in Table 3. Monthly flows are then calculated and tabulated for subsequent analyses. A flow duration curve (FDC) based upon the unseparated historic hydrologic data (as reported by USGS) is developed, depicting both the annual and monthly distributions of average daily flows recorded at the measurement point under consideration.

Distributions of monthly flow amounts have then been developed and analyzed to determine if comparisons of means are statistically appropriate. These characterizations of monthly distributions further provide a comparative metric of monthly variation for the assessment of seasonal characteristics of streamflow. A One-Sample Kolmogorov-Smirnov (K-S) Test procedure is performed to compare the observed cumulative distribution function for monthly flow with alternative theoretical distributions: normal, Poisson, or exponential. The K-S Z-statistic is computed from the largest difference (in absolute value) between the observed and theoretical cumulative distribution functions, testing the probability that the specified distribution is a good fit at the 95% confidence level ($\alpha = 0.05$). Statistically significant results for this analysis, unlike much statistical tests, suggest the specified distribution is not appropriate.

A One-Way ANOVA analysis (utilizing Levene's test statistic) for homogeneity of variance is then performed at the 95% confidence level ($\alpha = 0.05$). When monthly variances are determined to be non-homogeneous, a Tamhane's T2 multiple comparison test is performed. This analysis is a conservative post-hoc comparison of means at the 95% confidence level (α =

0.05) based on a t test. (Conservative in the sense that variances are assumed to be unequal). This test is performed to assess which means are statistically different. Broad comparisons assessing spatial similarities and differences are presented subsequently.

4.2 Summary of Seasonality

Seasonal analyses based upon hydrology, water quality and biology work summarized in this report, a four-season specification has been proposed as generally applicable to the individual project locations and the Sulphur basin (Table 5 and Figure 29 - Figure 31). Statistically similar months have been similarly colored to differentiate between seasonalities.

Table 5: Seasonal identification

Season	Months
Winter (light blue)	December through March
Spring (green)	April through June
Summer (tan)	July through August
Fall (orange)	September through November

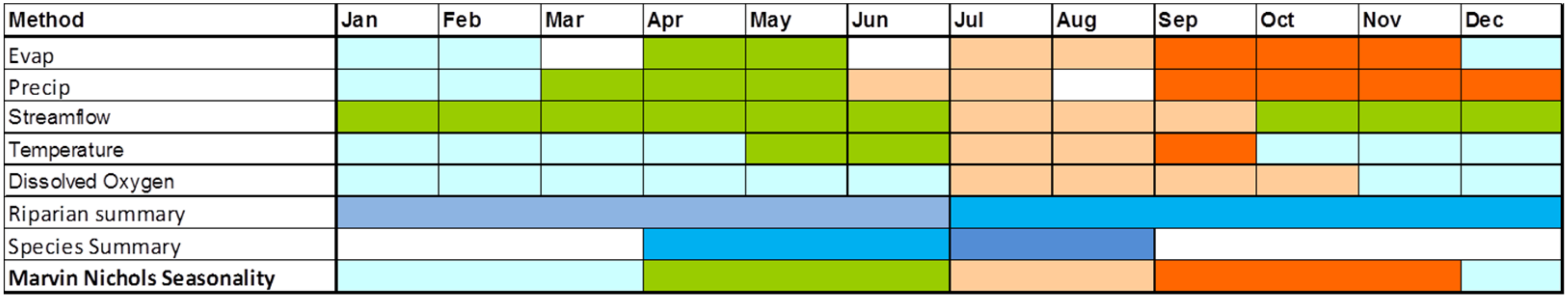

Figure 29: Seasonal summary for Marvin Nichols IA project site – 4 seasons

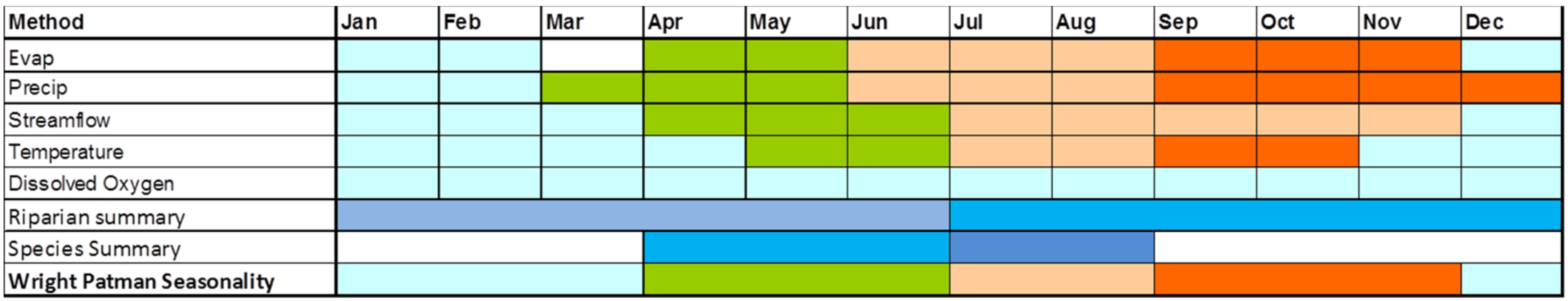

Figure 30: Seasonal summary for Wright Patman – 4 seasons

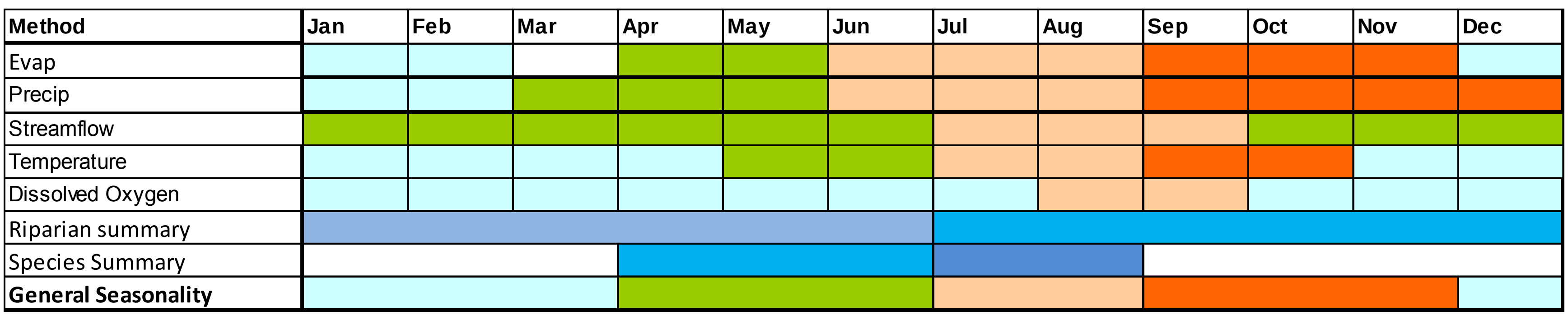

Figure 31: Seasonal summary for Sulphur basin – 4 seasons

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5 Flow Separation Analyses

The guiding objective applied to the analyses and associated methodological approaches herein is the maintenance of a "sound ecological environment", which emphasizes the importance of the natural flow regime and the dynamic processes that occur over a range of flows that maintain the physical, biological, chemical, and ecological integrity of river systems (Poff, et. al., 1997). The importance of natural flow regimes for the maintenance of ecological processes in flowing water systems is well recognized (Sparks 1995; Poff and Allan 1995; Poff et al. 1997; Bunn and Arthington 2002; Bowen et al. 2003). The Instream Flow Council (IFC), an organization of state and provincial agencies in the United States and Canada dedicated to improving the effectiveness of instream flow programs, has adopted this principle as a cornerstone of river resource stewardship (Annear et al. 2004; Locke et al. 2008).

Although the goal is the maintenance of a sound ecological environment, in some cases the existence of an anthropogenic impact, such as a reservoir, may have substantially modified a downstream natural flow regime, but the downstream environment may still be ecologically sound. In either case, the objective herein has been to identify to the extent possible representations of the dynamic components comprising the flow regime for a given location intended to maintain a natural flow regime and sound ecological environment and highlight, where lacking, those data gaps that might necessitate the development of data that might inform upon environmental needs.

Such a flow regime has several critical components of flow that are hypothesized to regulate ecological processes in river ecosystems: magnitude, frequency, duration, timing, and rate of change in flow (Poff and Ward, 1989; Richter, et. al., 1996; Walker, et. al., 1995; Annear et al. 2004; NRC 2005; Locke et al. 2008). These components represent attributes of the entire range of both flood and low flow conditions. Along with the physical characteristics of each river, the flow regime is the driving variable in controlling physical, biologic, and chemical processes. Such processes are interrelated, each having effects on the other and the river system.

The Scientific Advisory Committee (SAC), virtually all of the SB 3 Basin and Bay Expert Science Teams (i.e., BBESTs), and the Texas Instream Flow Program (TIFP 2008) have followed the IFC's recommendations in adopting the natural flow regime as the conceptual foundation for their proposed technical approaches. Established under SB 2, the TIFP's scientific program was reviewed by an expert committee assembled by the National Academy of Science's National Research Council (NRC 2005). The NRC committee supported use of the natural flow regime as the scientific basis for the Texas program's objective of determining instream flow needs. Based largely on the recommendation of the NRC (2005), the SAC (2009b) supported the development of the Hydrology-Based Environmental Flow Regime (HEFR) methodology.

HEFR is a software tool that employs statistical calculations based on historic mean daily flows that relies on a framework that quantifies key attributes of four components of the flow regime. Additional information, in the form of ecological overlays, allows for the identification of those flow components intended to support a sound ecological environment. These instream flow regime components can be characterized as: subsistence, base flows, high flow pulses, and overbank flows. HEFR has been developed by the Texas Parks and Wildlife Department (TPWD) to utilize historic hydrologic data to characterize the attributes of these flow regime components in terms of magnitude, volume, duration, timing, and frequency. The application of HEFR has not been peer reviewed, although some of its underpinnings (e.g. the Indicators of Hydrologic Alteration, IHA, software) have been employed successfully elsewhere in the nation.

The SAC has acknowledged that there is no single measure that can be employed to test or determine the soundness of ecological systems under alternative environmental flow regimes. However, many methods and individual measures may be employed to assess components of a sound ecological environment. Such measures can include water quality standards; habitat suitability and availability for indicator species or functional groups of species; indices of biologic integrity; sediment transport; and patterns of occurrence, abundance, and diversity of aquatic and riparian species.

As noted previously, statistically derived flow regime components can be evaluated and modified in terms of their effectiveness in maintaining a sound ecological environment of riverine reaches via a series of what are referred to as *overlays*. Such overlays are analyses of likely relations to water quality, aquatic and riparian biota, and the geomorphological and sediment dynamics that maintain habitats over the long term.

Presented within the next few sections of this report is a description of the environmental flow analyses performed. These sections of the report follow a logical progression established in SAC guidance through which: a) hydrology-based tools are evaluated and applied to extract descriptive statistics of flows and flow regime components at the selected locations relevant to the water supply alternatives under consideration; and b) biological, water quality, hydraulic, and geomorphology overlays are applied to confirm or refine the hydrology-based statistics. The conclusion of this logical progression is the set of identified environmental flow regime guidelines.

5.1 Methodology

For the determination of potential environmental flow guidelines, approaches have been utilized that are consistent with the recommendations of the SAC (SAC 2009 a-e) and precedents established previously by the TCEQ in the adoption of environmental flow standards in other Texas river basins, involving the identification of subsistence flows, base flows, and larger high flow pulses. A brief outline of these approaches, including SAC guidance and descriptions of the analyses leading to the identification of the environmental flow guidelines, is presented here.

1) Parameterize the flow regime hydrological analysis using seasonal, and limited ecological and biological data. The initial parameterization of flow regime components to populate a HEFR flow regime matrix has been based upon the evaluation of multiple alternatives, with the goal being to capture broad-scale patterns of the flow regime for each location. The objective was to identify and characterize those aspects of the historical flow regime most critical for maintenance of a sound ecological environment.

2) Establish clear, operational objectives for support of a sound ecological environment and maintenance of the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies. As described previously, a sound ecological environment is as defined by the SAC.

3) Compile and evaluate readily available biological information and identify a list of focal species. Available information for ecosystems and important species in the Sulphur River Basin has been reviewed. In addition to reviewing fish and mussel species distribution and abundance records, a list of focal species has been identified for evaluation of ecological needs in relation to flows. Research reporting species life history information and reliance on general habitat suitability criteria based on studies conducted within and outside the basin, where appropriate, has been utilized.

4) Obtain and evaluate geographically oriented biological data in support of a flow regime analysis. Reports have been obtained for studies of historical records of fishes and mussels in the Sulphur River Basin. A particular focus was made to determine what, if any, research findings are available for population and community-level responses of aquatic organisms to variations in flow. Available information on the ecology and current status of riparian vegetation communities in the study area was limited.

5) Evaluate and refine the initial flow matrix. The flow regime matrices produced by HEFR have been evaluated with respect to the identifiable general needs of major biological components of the fluvial ecosystems, water quality requirements, and geomorphic processes that maintain habitats for species.

As noted within the literature review, the stream segments for which environmental flow analyses have been performed herein have experienced a wide range of scientific attention varying from little to no scientific work concerning some ecosystem processes, and extensive work concerning other processes. There have generally been few, if any, scientific investigations or monitoring efforts designed to comprehensively relate physical or biological processes to the flow regime. Although the best scientific data available have been employed herein, it must again be noted that the limited levels of data and the varying levels of available information are significantly disparate and are difficult to justify employing, other than in the broadest sense, towards adjustment of the statistically derived amounts identified by application of IHA (described herein) and HEFR.

The most straightforward analytical component is the hydrologic evaluation, which is discussed below, but the ecological justification of such amounts is limited. The relevant ecological overlay information, described later herein, is then incorporated where possible to build upon and modify the identified environmental flow regime matrices.

5.2 Comparison of Alternative Flow Separation Approaches

A number of approaches exist to statistically characterize historical streamflow data. Some stepwise approaches have been used to characterize instream flow regimes involving (1) parsing a hydrograph into two or more subsets (e.g., flow pulses and steady, low flows) then (2) evaluating select characteristics of each subset. The SAC has provided some information related to the characterization of hydrological statistics relevant to an instream flow regime, particularly through the use of Indicators of Hydrologic Alteration (IHA), Modified Base Flow Indicator Threshold (MBFIT), and HEFR (SAC 2009a) software.

After parsing low- (Group 1) and high pulse (Group 2) flows with a tool like MBFIT or IHA, the HEFR software (presently at v3.0) calculates non-parametric statistics on the Group 1 dataset to characterize base flow levels (defaulting to low, medium, and high, formerly identified as dry, average, and wet) using default 25-, 50-, and 75-percent exceedances (values that can be customized), respectively, within each season or month (SAC 2009a).

For high flow pulses, two alternatives are available when executing HEFR: (1) a similar utilization of non-parametric statistics for determining percentiles of peak flow, volume, and duration; and (2) a frequency-based approach for episodic events, wherein the historical distribution of the magnitudes of peak flow events are characterized (annually and seasonally) and associated statistics of pulse volume and duration are derived. It is important to note that with the frequency based alternative, the characterizations represent those magnitudes met or exceeded at some historical frequency (e.g., “one per year”). HEFR further offers the capability to investigate the actual frequencies of occurrence of a given hydrologic event (e.g., the annual frequency of two “one per year” events) based on either the number of events equal or exceeding the specified peak flow, or the number of events equal or exceeding the peak flow, volume, and duration amounts specified (Memorandum RE: HEFR Enhancements, TPWD 2010).

Both IHA and MBFIT offer alternative means of characterizing days as predominantly base (Group 1) or pulse (Group 2) flow driven. Generally, IHA characterizes the rate of change in flow conditions through parameters of percentage day-to-day increases and decreases in flow magnitude {% increase on rise, % decrease on fall}.

From this point in the flow separation process, the prosecution of either IHA and MBFIT is similar. Magnitude thresholds which automatically classify high and low flows are specified. Threshold amounts for extreme low flows, small, and large floods are also specified.

For high flow pulses and overbank flows, it must be noted that these flows are statistically treated as events. For example, for overbank flows there will be some days within each event in which flows do not exceed the bank full condition. This fact manifests in the resultant statistics for overbank, and pulse, flows. The individual parameterizations of IHA and MBFIT can be adjusted to address this fact, if an issue is apparent.

IHA and MBFIT are sensitive to changes in flows (i.e., a modest flow change triggers the identification of a pulse event). At locations downstream of reservoir facilities, extended periods of increased flow due to flood control reservoir releases, as shown later in Figure 34, have been identified in the IHA and MBFIT analyses. These extended periods of flow are considered base flows during wet conditions, as quantifying them as pulses would result in month long pulse flow events. Presented below in Figure 32 - Figure 34, are comparisons of the application of each of these tools at flow measurement locations downstream of existing reservoirs. Inspection of Figure 32 - Figure 34 allows for the evaluation of the IHA and MBFIT tools.

For the identification of overbank pulses, HEC-RAS model output (FNI 2008) was evaluated and National Weather Service (NWS) action stages (where available) have been utilized as indicators of bank full/flood threshold conditions. Subsistence flow guidelines have been characterized via selection of the calculated minimum 7-day, 2-year flow amount (7Q2), although the initial characterization is based on the median of extreme low flow values generated via the hydrographic separation algorithm. Alternative representations, such as the Q-95 (e.g., the 5th-percentile of flows binned by season, regardless of hydrographic separation), represents another arbitrary statistic that was considered. While this issue is addressed later within the document, for the initial evaluations the median extreme low flow value is utilized, with the acknowledgement that the resultant subsistence guideline may differ.

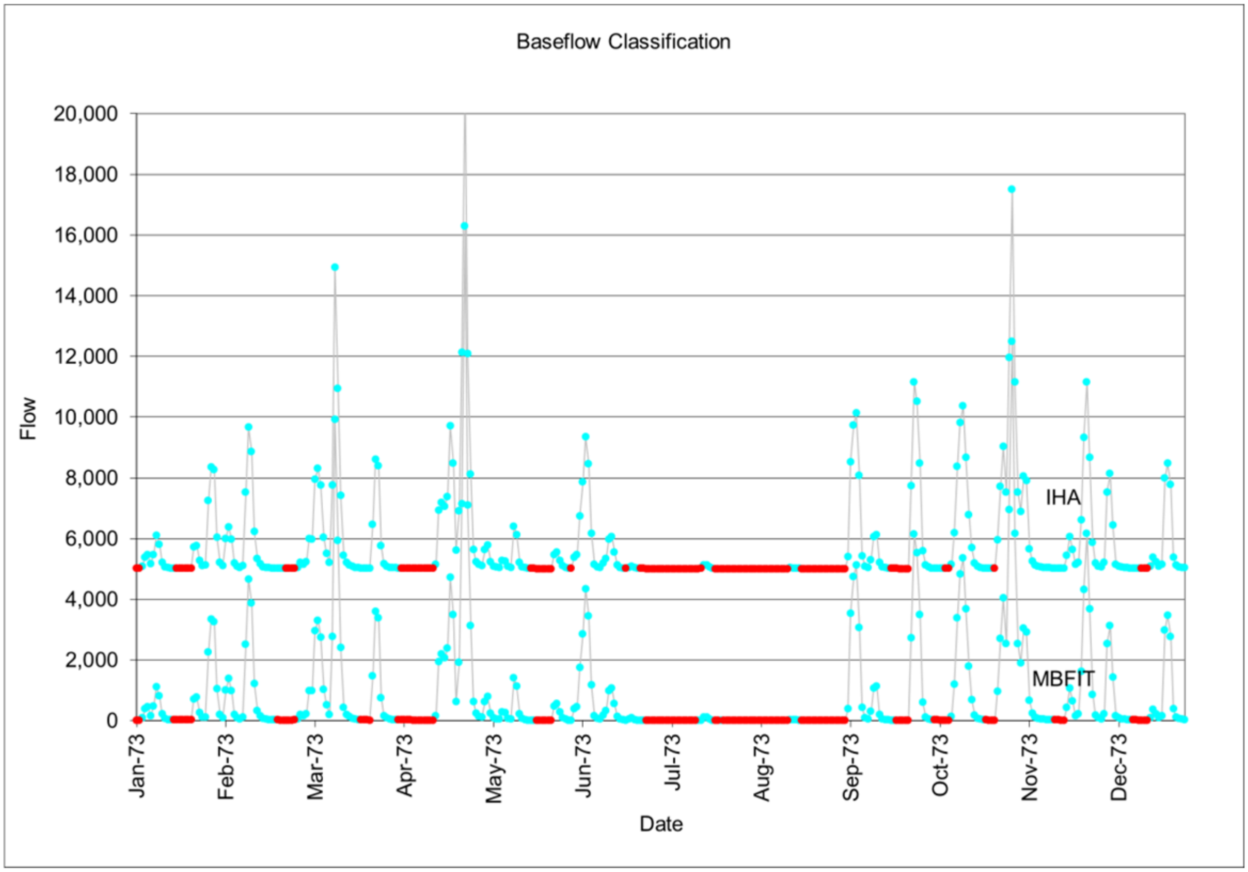

Figure 32: Time series comparison of base and high pulse flow parsing at South Sulphur near Cooper measurement point (1943-2011) with alternative IHA and MBFIT tools without averaging of flows, focus on 1973 flows.

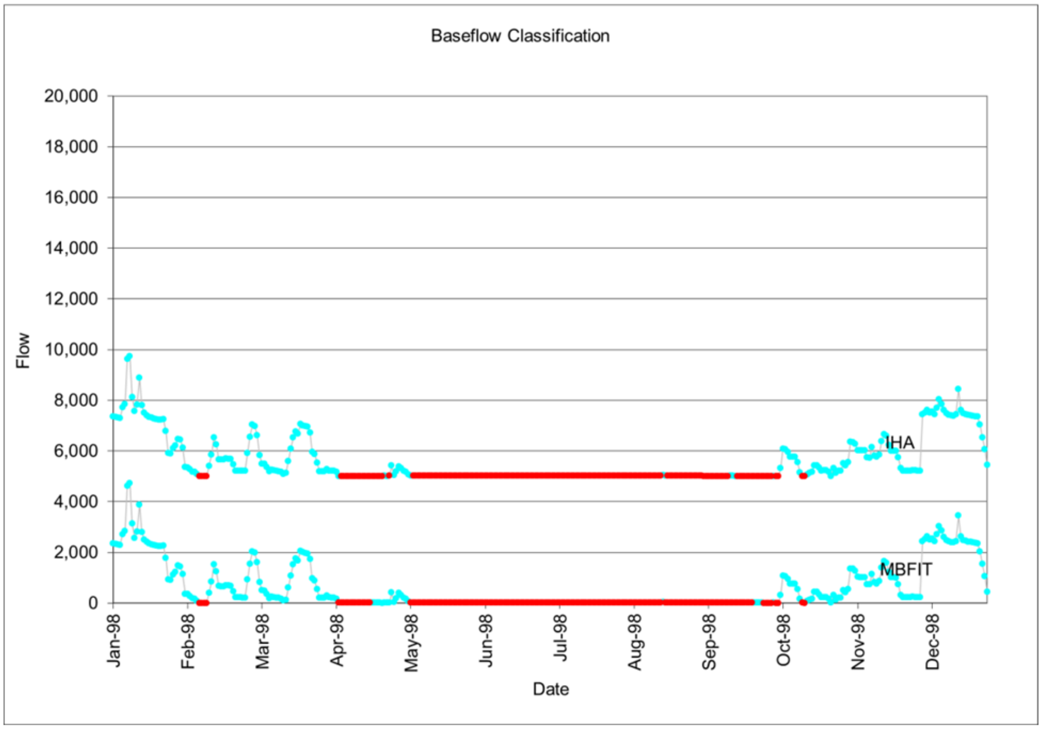

Figure 33: Time series comparison of base and high pulse flow parsing at South Sulphur near Cooper measurement point (1943-2011) with alternative IHA and MBFIT tools without averaging of flows, focus on 1998 flows.

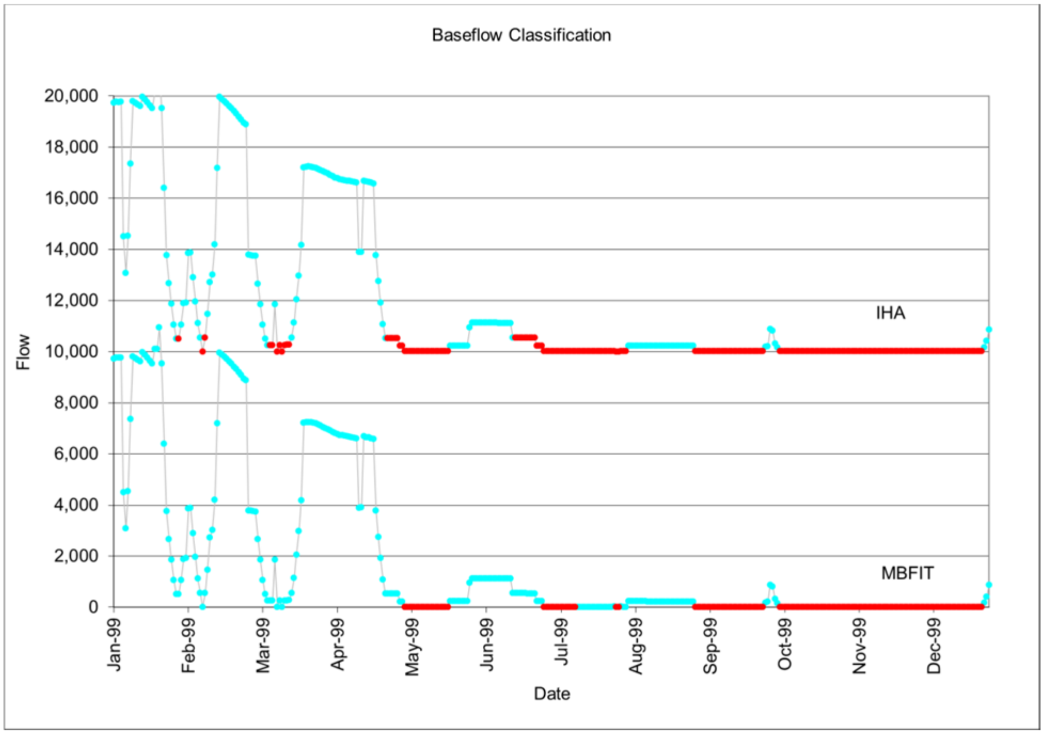

Figure 34: Time series comparison of base and high pulse flow parsing at Wright Patman measurement point (1982-2011) with alternative IHA and MBFIT tools, focus on 1999 flows.

Not surprisingly, Figure 32 - Figure 34 suggest the significance of the methodology is not necessarily the tool employed (IHA or MBFIT), but rather the particular parameterization selected. The identification of the onset of pulses is relatively straightforward. However, identification of the cessation of pulses via the descending (receding) limbs of storm events is of critical importance, and must be carefully considered. SAC (2009b) notes, "…the primary consideration is what flow transitions from primarily high flow pulse ecological functions such as mobilizing sediments to base flow ecological functions such as instream habitat." Said another way, a significant question regarding the parameterization employed is the determination of whether such receding limbs of storm events are included in the pulse or base flow dataset. The impact of incorporating these receding limbs is manifested in the resultant statistical characterizations of base and pulse flows. The characterization of the receding limbs of storm events as base flows results in greater base flow magnitudes (and lower frequencies), as well as manifesting in a variation of statistics on pulse volume and duration.

The identification of breakpoints in an un-separated flow duration curve has been employed to allow for a refined specification of the threshold parameters. Given that the receding limbs of storm events are, by definition, driven by meteorology, an initial characterization of these receding limbs as pulse events appears reasonable.

The present MBFIT and IHA analyses employed herein allow for these thresholds to vary from site to site, allowing for greater sensitivity to specific hydrologic aspects of the individual watersheds, as shown in. Fluctuation in the difference in upper and lower thresholds allows the analysis to be tailored to the hydrologic characteristics of the watershed. The greater the difference in thresholds, the greater the fraction of the hydrograph assigned based on either the rate of change parameters of IHA or the runoff fraction turning point evaluation in MBFIT. Indeed, this fact manifests in the significant variations of the percentages of base and pulse days identified when comparing MBFIT and IHA results.

Table 6: Upper and Lower High Flow thresholds by location

Project Location	Initial High Flow(cfs)	Initial Low Flow (cfs)
Wright Patman	10000	115
Sulphur River near Talco	14000	10
White Oak Creek near Talco	2500	11
South Sulphur River near Cooper	4000	30
North Sulphur River near Cooper	1000	10

Preliminary parameterization of the hydrology at each of the locations analyzed was performed utilizing IHA. Parameters representing the daily rate of change in streamflow have been developed to identify the start of a pulse event and when a pulse event returns to a base flow condition. However, the limited capability to adjust the parameterization of IHA and the highly variable (i.e., flashy) nature of the Sulphur River Basin resulted in identifiable, infrequent anomalies wherein an identified base flow between two pulse events is greater in magnitude than the flow rate from the last day of the previous pulse. (An example can be found in January 1994 in Figure 35 at the Sulphur River near Talco gauge.)

Thus, flow data for each of the project sites analyzed with IHA were also analyzed using MBFIT. This analysis was performed to identify if the parameterization of MBFIT could separate base flows from pulses without anomalies wherein a base flow is higher than the tail of a pulse. Analysis of MBFIT results demonstrated that the MBFIT parameterization could not identify base versus pulse flow without also occasionally identifying a base flow with a flow higher than the tail of the previous pulse. Additionally, it appears that the turning point factor and the n-day sliding window result in situations where a part of the descending limb of a pulse would be classified as a base flow with a pulse flow in the middle of the base flow portion of the descent.

Having concluded that both IHA and MBFIT results exhibit similar infrequent anomalies with regard to identified base flows higher than the tail of a pulse, the appearance of an additional anomalous pulse flows in the MBFIT output, and the additional complexity of the MBFIT parameterization, it was concluded to proceed with analyses using the IHA software. The significance of the effects of the anomaly was monitored throughout the parsing of hydrology and analysis of base flows to ensure such anomalies did not significantly affect the resultant statistical characterizations.

5.2.1 Parsing of Hydrology using IHA

IHA's advanced calibration parameters allow the definition of high and low flow thresholds as well as the specification of rate-of-change criteria for triggering the start and end of pulses between the flow thresholds. Discussed herein are the considerations and analyses contributing to the development of such parameters relevant to each water supply alternative.

5.2.1.1 Marvin Nichols (1950-2014)

The calculated daily flows at USGS Sulphur River near Talco gauge (No. 07343200) for the period of 1950 – 2014 have been iteratively processed in IHA to identify best fit parameters for identifying high flow pulses. Again, the hydrology of the system is flashy, dominated by rapid rises in flow with rainfall events followed by rapid declines in streamflow. Figure 35 presents the depiction of base and pulse flow events, again with red dots representing base flow and blue dots representing pulses.

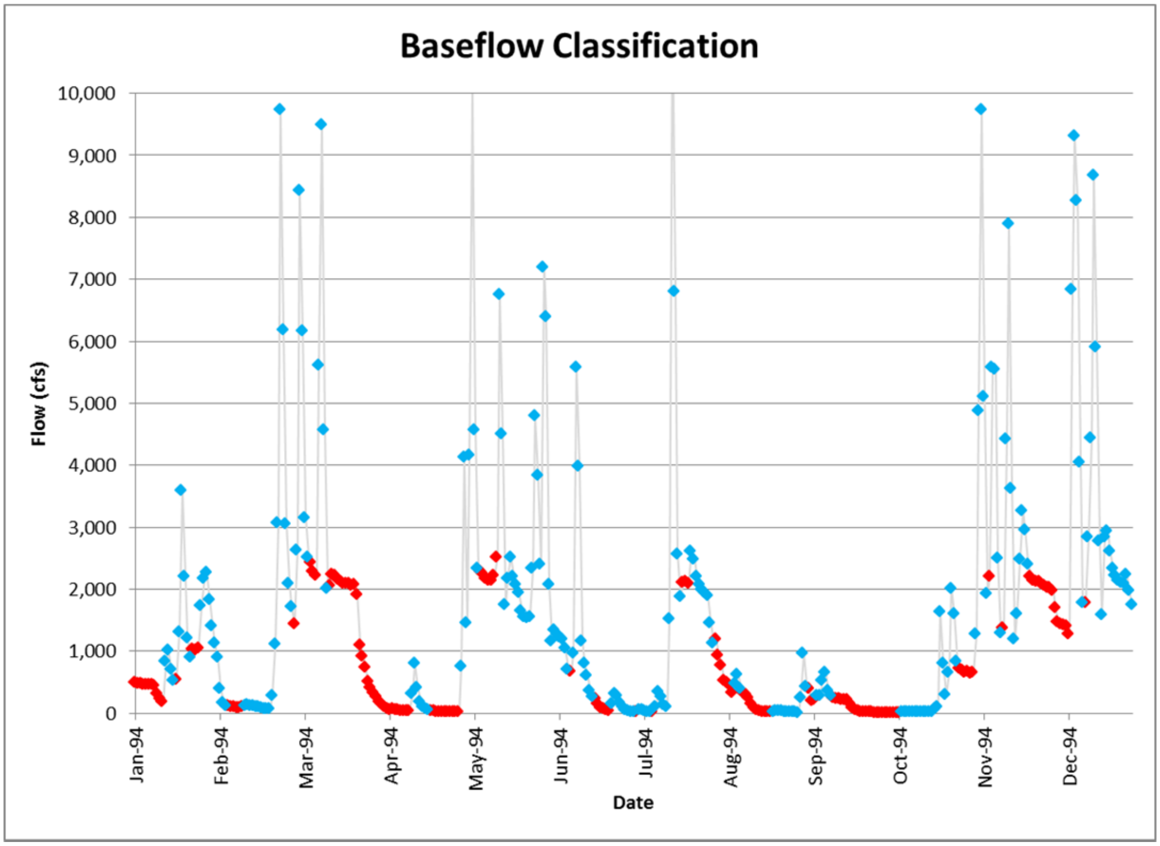

Figure 35: USGS Sulphur River near Talco gauge (No. 07343200) flow parsed using IHA

5.2.1.2 Wright Patman (1982-2014)

USACE reported daily gated flows from Wright Patman have been iteratively processed in IHA to identify best fit parameters for identifying high flow pulses. Analysis of time series data of estimated inflows to Wright Patman relative to the reported releases shows that the majority of release events are rainfall derived, thus in IHA the rainfall derived releases from Wright Patman are considered as pulses in this context. Figure 36 presents the depiction of base and pulse flow events at this location.

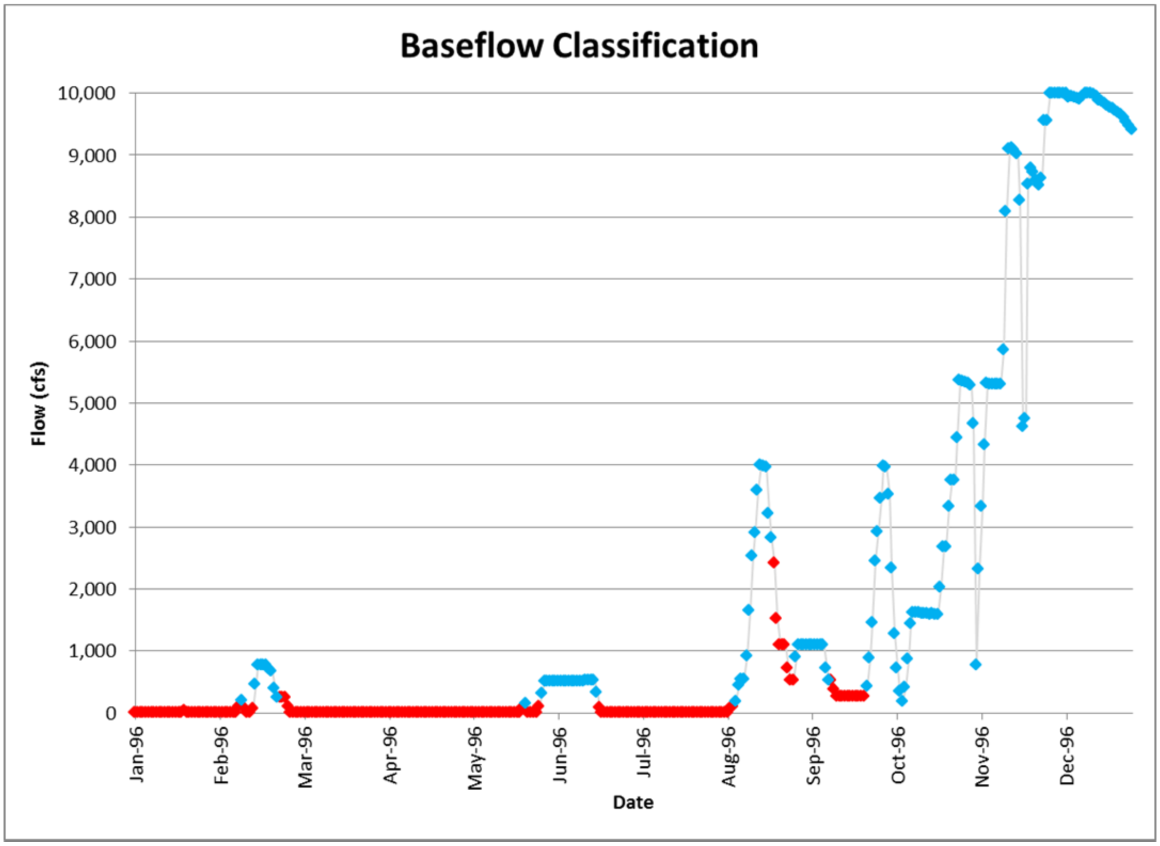

Figure 36: Wright Patman flow parsed using IHA

5.2.2 Parameterization

5.2.2.1 IHA Parameterization

Based on the results of both the IHA and MBFIT analyses on the flow data at each location, a set of preliminary parameterizations using IHA to identify pulse and base flows were identified, with consideration given to the anomalies noted during the IHA analysis. These IHA parameterizations are displayed in Table 7.

Table 7: IHA Parameters

Project Location	Initial High Flow(cfs)	Initial Low Flow (cfs)	High Flow Trigger (rate of change)	Pulse End (rate of change)	Small Flood	Large Flood	Extreme Low Flow
Wright Patman	2500	115	9%	19%	2	10	11 (cfs)
Sulphur River near Talco	14000	10	15%	18%	2	10	10%
White Oak Creek near Talco	2500	11	24%	18%	2	10	6.20%
South Sulphur River near Cooper	4000	30	13%	15%	2	10	10%
North Sulphur River near Cooper	1000	10	18%	22%	2	10	10%

Note: The extreme low flow values are generally represented as a lowest percentile of historical low flow, with the exception of Wright Patman, as historical flow data is derived from reservoir release data.

5.2.2.2 Persistence Analysis

An alternative analytic approach (hereafter referred to as a Persistence Analysis) has been utilized herein that provides a different means of characterizing base flows. This approach is presented herein merely as an additional means of evaluating intra-annual variation through the evaluation of a range of associated "typical" base flows that are not impacted by antecedent pulses and not part of a long, steady, low-flow event. This information aids in the characterization of these "typical" base flow conditions, as well as the identification of "atypical" events, and are provided for future consideration as more information is developed for the Sulphur River Basin.

Using the output from the parsing of the hydrologic dataset (herein developed from IHA, although MBFIT could be utilized similarly), each low-flow (Group 1) day is assigned a value corresponding to the number of days since the initiation of the low-flow event (alternatively, since the cessation of the antecedent pulse, Group 2, event). The daily dataset of points considered in this persistence investigation thus becomes {Flow (cfs), Days since end of pulse}, as presented in Figure 37.

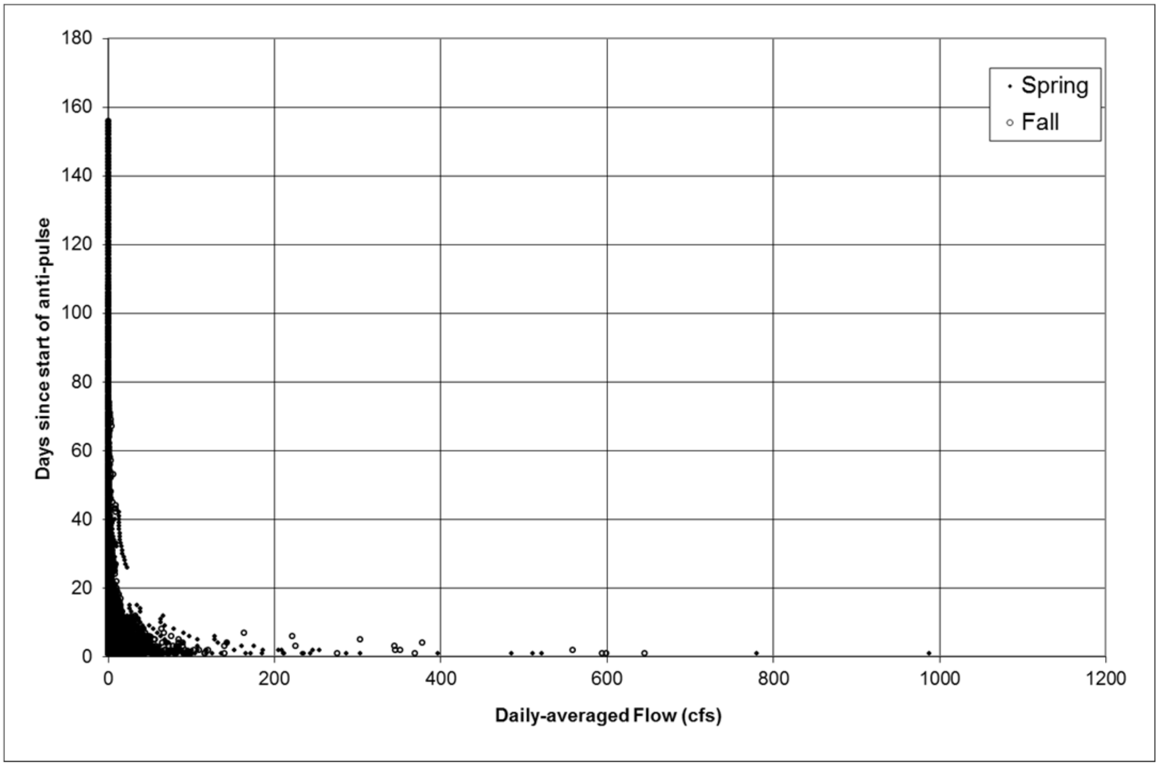

Figure 37: Example plot of persistence vs. flow magnitude.

A histogram of the number of days since the start of the low-flow event is informative in evaluating the historical occurrence of these Group 1 events (Figure 38). For example, at the North Sulphur River near Cooper measurement point for 1950-2011, 75% of the days in Group 1, low-flow, events occur more than 4 days following the end of a pulse, and 25% of the days are more than 25 days following a pulse. Identifying a range of days, e.g., between the 75% and 25% exceedance levels (in this example 4 and 25 days), may be useful in evaluating a range of associated “typical” base flows that are not impacted by antecedent pulses and not part of a long, steady, low-flow event. The selection of a range of days lower than the 25% exceedance level (greater than 25 days in this example) may be useful in evaluating “atypical” subsistence flow events.

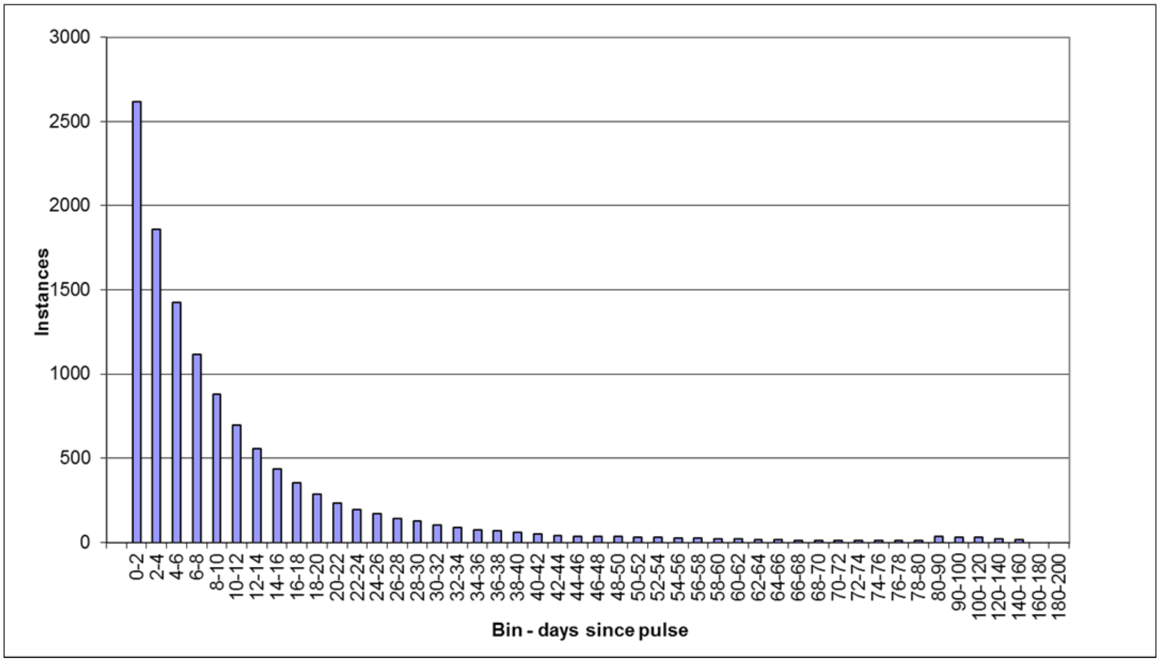

Figure 38: Example histogram of the number of days since the cessation of a pulse.

One must note that the number of days since the end of a pulse is not the same as the duration of a low-flow event. Indeed, a complete low-flow event may have a duration of 40 days, suggesting the length of time from the end of one pulse to the beginning of the next was 40 days, yet the event has persisted through 1-, 2-, 3-days, etc. Said another way, a base flow event with a total duration of 40 days persisted through 26 days as well. Thus, the fundamental question addressed by Figure 38 is: “how many times has the river been this many days from the end of a pulse?”

Across the entire range of “days since end of pulse,” historical occurrence of typically persistent base flow magnitudes and atypically persistent subsistence flow magnitudes may be investigated. Figure 39 below presents the non-parametric distribution of flow magnitudes, organized by days since the end of a pulse. This representation[1] allows for the evaluation of the historical distribution in flow magnitudes following the end of a pulse. A persistence analysis similar to that described above has been performed at each location assessed in the present effort utilizing the preliminary parameterizations from IHA. The non-parametric distribution of historical flow magnitudes by number of days since a pulse event provides additional insight into the effectiveness of the preliminary parameterization, allowing for consideration of the length of time hydrologic conditions persist in the river.

[1] Such a depiction can in essence be characterized as a series of box plots, wherein at each given number of days since the end of a pulse the distribution of historic flows is plotted utilizing non-parametric statistics (e.g. 25-, 50-, 75-percentiles).

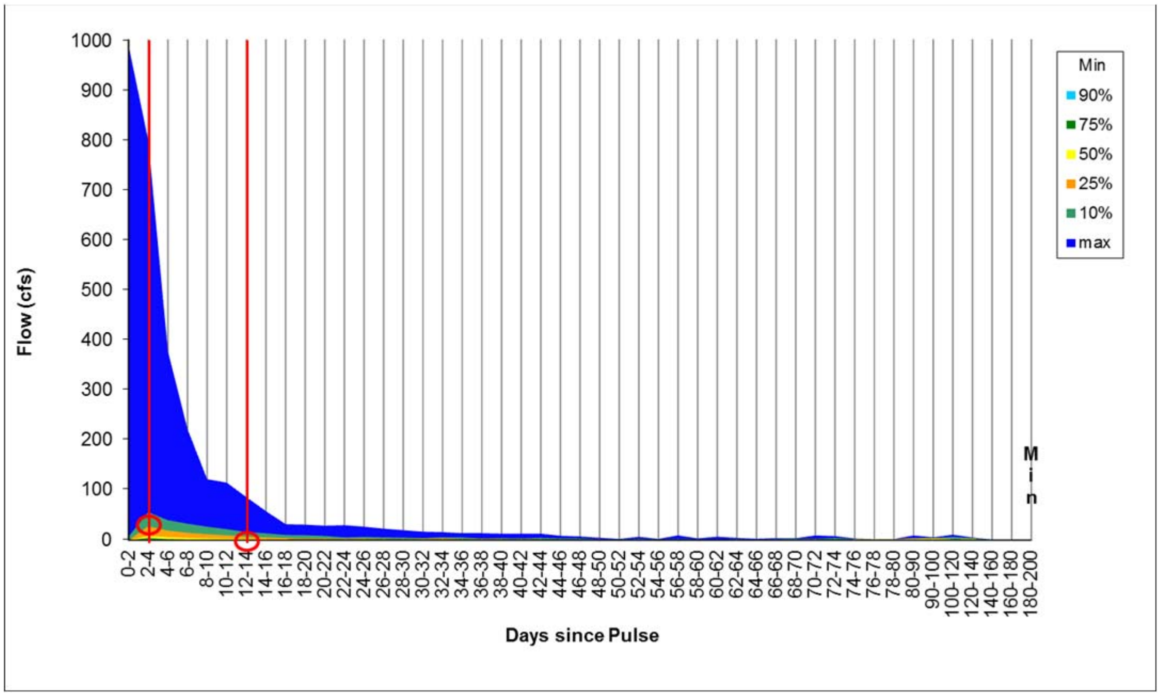

Figure 39: Example non-parametric distributions of historical flow magnitudes by number of days since

A persistence analysis has been performed at locations relevant to each of the two water supply project alternatives considered, utilizing the revised parameterizations from IHA to identify low flow conditions. Table 8 presents the statistical range of base flows that have historically occurred at various locations over the range of days since the end of a pulse.

Table 8: Base flow ranges over range of days since pulse

Measurement Location	Season	25% exceedance flow (cfs) at 75% days	90% exceedance flow (cfs) at 25% days	75% exceedance flow (cfs) at 5% days
South Sulphur	Winter	426.0	3.0	0.4
	Spring	97.8	1.3	7.6
	Summer	15.0	0.7	2.9
	Fall	15.0	3.0	0.7
North Sulphur	Winter	50.0	0.9	0.5
	Spring	26.0	0.2	0.4
	Summer	6.8	0.1	0.2
	Fall	9.5	0.1	0.3
Sulphur at Talco	Winter	479.7	4.1	2.0
	Spring	345.1	2.4	3.0
	Summer	24.7	0.0	0.0
	Fall	51.5	0.0	0.0
White Oak Cr	Winter	142.0	2.5	1.2
	Spring	82.0	2.8	2.5
	Summer	17.0	0.2	0.1
	Fall	10.0	0.3	0.7
Wright Patman	Winter	479.3	10.0	10.0
	Spring	348.0	10.0	10.0
	Summer	228.0	10.0	10.0
	Fall	516.0	10.0	10.0

6 Hydrologic Characterization

The primary uncertainty related to the identification of specific environmental flow guidelines in the Sulphur River Basin is the degree of environmental protection afforded by the specific levels and values (i.e. magnitudes, peak flows, volume, duration, and frequency) identified. Such values have been derived based upon statistical evaluations of the historical hydrology.

As described previously, subsistence flows have been defined as the low flows that occur during times of drought or under very dry, atypical, conditions. Base flows represent the range of “average” or “normal” flow conditions in the absence of significant precipitation or runoff events. Base flows are intended to provide instream habitat conditions necessary to maintain the diversity of biological communities in streams and rivers. Pulse events have been incorporated as an acknowledgement that, in general, a varying flow regime that includes cycles of low and high flows is beneficial to maintaining a riverine environment. It is anticipated that future efforts will need to further define the specific environmental benefits provided by base and pulse flows.

Focusing first on pulse flows, a number of uncertainties exist related to accounting and forecasting of pulse metrics, arising primarily because of the timing and distribution of precipitation patterns across the basin. At present, forecasting of pulses is not explicitly incorporated into operations related to the alternative water supply projects under consideration. Existing protocols related to dam operation, flood control (if appropriate), and requirements of surface water permits continue to govern the storage and release of storm event flood flows. It is anticipated that the default operational strategy for any of these projects will be to capture storm pulses entering a reservoir and monitor incoming flows. When applicable, storm pulses may be passed for achievement of a required environmental flow guideline. It is anticipated that short-term forecasting may be necessary to coordinate an operation release pattern with current downstream flows. Consideration will need to be given to travel time, pulse attenuation, and intervening flows, among other factors.

A key factor meriting consideration in the identification of episodic pulse events is the application of the Multipeaks-Multiplier within HEFR. There have historically been storm events in the Sulphur River Basin whereby multiple pulses, with individual peak flow amounts, occur within a short time period in the watershed. A key question then is if such events should be aggregated, or treated as separate individual pulses.

The IHA software only disaggregates the individual pulses if there is at least one base flow day occurring between the end of a pulse and the start of a subsequent pulse. Because of the importance of statistical calculations on high flow pulses in HEFR outputs, the HEFR software allows for the application of a "Multipeaks-Multiplier" to split high flow pulses with multiple individual peaks (i.e., caused by distinct storm events). Given that it does not appear from the analyses performed herein that such multi-peak storm events are due to single storms across tributaries with different travel times, but are likely multiple discrete storms, the Multipeaks-Multiplier was employed for all subsequent hydrologic analyses reported herein.

To quantify episodic event (i.e., pulse and overbank) volumes and durations, HEFR generates regression equations relating: (1) episodic event volume and peak flow; and (2) episodic event duration and peak flow. Two regression forms are available in HEFR: (1) natural logarithms - ln/ln; and (2) quadratic. Because of the natural variability and the imprecision of dissecting flow patterns into flow components (and associated ecological functions), there is scatter in the data within these regressions. Example plots resulting from the evaluation of episodic event data and the regressions generated by HEFR are shown in Figure 40 - Figure 43.

Past experience has suggested that the ln/ln regression often provides a reasonable fit and rarely provides an unacceptable fit, whereas the quadratic equation often provides a reasonable fit, but also can generate results that are far removed from the data in the vicinity of a particular peak flow recommendation. Accordingly, HEFR was run using the ln/ln regression form for both volume and duration. Each regression (2 sites × 1 period of record × 5 events × 2 regressions (volume and duration) = 20 regressions) was examined with the intent of identifying any regressions where the best-fit line is outside of the range of the data in the vicinity of each peak flow recommendation. No unacceptable regressions were identified.

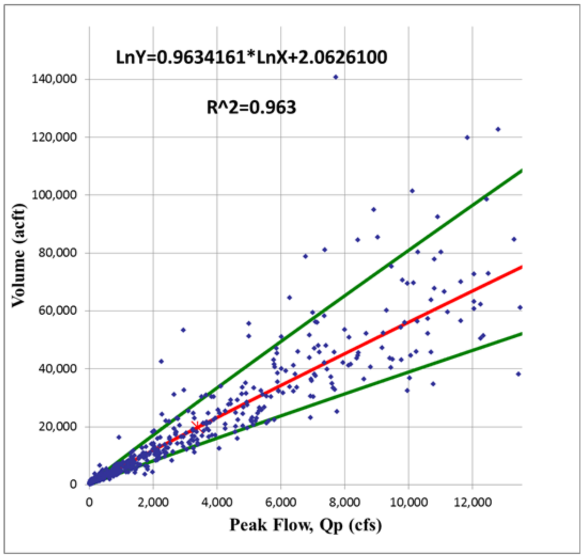

Figure 40: ln/ln regression plot of episodic event volume vs peak flow

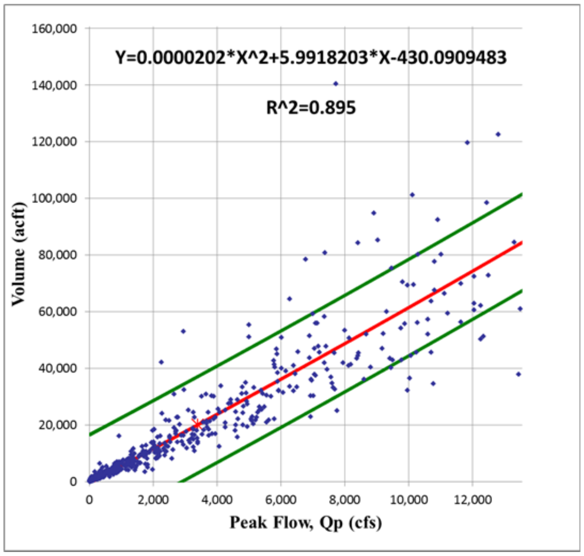

Figure 42: Quadratic regression plot of episodic event volume vs peak flow

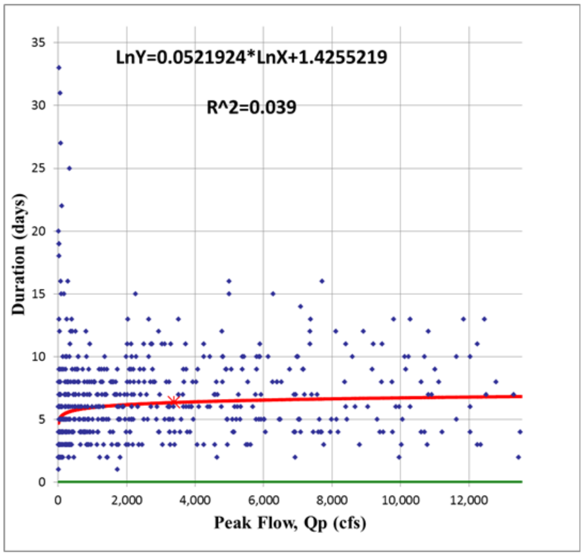

Figure 41: ln/ln regression plot of episodic event duration vs peak flow

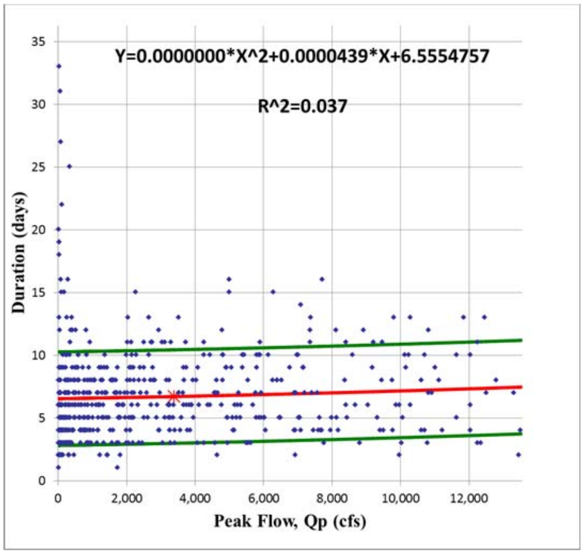

Figure 43: Quadratic regression plot of episodic event duration vs peak flow

Presented below for each water supply alternative project location are results of these statistical characterizations. IHA was utilized to perform the hydrographic separation of base and pulse flows, initially characterizing the receding limbs of storm events as rainfall derived, pulse flows. Along with the period of record analyzed, NWS action stage flow levels, where available, are reported to represent overbank flow magnitudes. Statistics on the persistence of base flow conditions are presented as well, such that assessments may be made as to the historic periods of time the river has experienced "typical" base flows not impacted by antecedent pulses and not part of a long, steady, low-flow events. The statistically identified flow regimes relevant to the project sites of the alternative water supply projects are summarized in Table 9 and Table 10.

6.1 Hydrologic Characteristics by Flow Component, Sulphur River at USGS 07343200 near Talco.

The identified hydrologic flow regime statistics for the USGS Sulphur River near Talco gauge (No. 07343200) from the application of HEFR are shown in Table 9. The base flows identified by HEFR range between 4 – 180 cfs, with subsistence flows ranging between 0 cfs and 5 cfs. The base flow range identified in the persistence analysis is 0.0 – 130 cfs, as shown in Table 8. The Q_{95} flow for the 1950-2014 analysis period is 0.2 cfs. The calculated 7Q2 for the 1950-2014 analysis period is 1.1 cfs. The median low flow for the same period is 12 cfs. The flow regime depicted in Table 9 represents a more comprehensive flow regime, with arbitrarily selected frequencies of occurrence of high flow pulses. Generally, moderate levels of overbanking would be expected to occur during wetter seasons with high flow pulses at the lower frequencies of seasonal occurrence. In the below HEFR results, the identified pulses which are shaded blue represent potential overbank events at the given measurement point (discussed further in Chapter 9).

Figure 44 presents the frequency distribution of seasonal and annual high flow pulses by peak flow for the USGS Sulphur River near Talco gauge (No. 07343200). The summer season has the lowest frequency and magnitude of pulses, while winter has the highest frequency. Figure 45 - Figure 48 present the non-parametric distributions of historical flow magnitudes by number of days since a pulse by project location for all data and by season. The seasonal distribution of base flows is presented in Figure 49. It can be seen that there is nearly a 100 cfs variation in flows between the winter and spring seasons versus the summer and fall seasons. Where the summer and fall seasons experience the lowest base flows, and appear to drive the annual base flow, while the winter and spring seasons experience higher base flows.

Table 9: USGS Sulphur River near Talco gauge (No. 07343200) Preliminarily Identified Flow Regime

	Winter	Spring	Summer	Fall
Overbank Events	Qp: 23,570 cfs with Average Frequency 1 per year Regressed Volume is 81,506 to 188,328 (123,895) Regressed Duration is 4 to 12 (7)			
Overbank Events	Qp: 16,060 cfs with Average Frequency 2 per year Regressed Volume is 56,116 to 129,645 (85,295) Regressed Duration is 4 to 12 (7)			
High Flow Pulses	Qp: 14,620 cfs with Average Frequency 1 per season Regressed Volume is 56,140 to 116,800 (80,976) Regressed Duration is 4 to 11 (7)	Qp: 12,350 cfs with Average Frequency 1 per season Regressed Volume is 44,809 to 94,309 (65,007) Regressed Duration is 4 to 11 (7)	Qp: 839 cfs with Average Frequency 1 per season Regressed Volume is 2,651 to 7,571 (4,480) Regressed Duration is 3 to 12 (6)	Qp: 6,608 cfs with Average Frequency 1 per season Regressed Volume is 21,340 to 56,429 (34,701) Regressed Duration is 4 to 13 (7)
High Flow Pulses	Qp: 9,192 cfs with Average Frequency 2 per season Regressed Volume is 35,906 to 74,682 (51,784) Regressed Duration is 4 to 11 (7)	Qp: 6,454 cfs with Average Frequency 2 per season Regressed Volume is 23,659 to 49,771 (34,315) Regressed Duration is 4 to 11 (6)	Qp: 120 cfs with Average Frequency 2 per season Regressed Volume is 407 to 1,163 (688) Regressed Duration is 3 to 9 (5)	Qp: 2,120 cfs with Average Frequency 2 per season Regressed Volume is 7,167 to 18,932 (11,648) Regressed Duration is 4 to 12 (7)
High Flow Pulses	Qp: 5,620 cfs with Average Frequency 3 per season Regressed Volume is 22,354 to 46,485 (32,236) Regressed Duration is 4 to 11 (7)	Qp: 3,020 cfs with Average Frequency 3 per season Regressed Volume is 11,204 to 23,560 (16,247) Regressed Duration is 4 to 10 (6)	Qp: 16 cfs with Average Frequency 3 per season Regressed Volume is 59 to 170 (100) Regressed Duration is 2 to 7 (4)	Qp: 618 cfs with Average Frequency 3 per season Regressed Volume is 2,194 to 5,793 (3,565) Regressed Duration is 3 to 11 (6)
High Flow Pulses	Qp: 3,386 cfs with Average Frequency 4 per season Regressed Volume is 13,721 to 28,528 (19,785) Regressed Duration is 4 to 10 (6)	Qp: 1,482 cfs with Average Frequency 4 per season Regressed Volume is 5,559 to 11,689 (8,061) Regressed Duration is 3 to 10 (6)		Qp: 145 cfs with Average Frequency 4 per season Regressed Volume is 546 to 1,442 (887) Regressed Duration is 3 to 10 (6)
Base Flows (cfs)	179 (47.8%)	125 (50.4%)	17 (42.2%)	36 (39.9%)
Base Flows (cfs)	54 (67.4%)	40 (71.5%)	8.3 (56.7%)	10 (62.1%)
Base Flows (cfs)	13 (85.7%)	15 (87.3%)	4.2 (67.0%)	4.5 (71.4%)
Subsistence Flows (cfs)	3.8 (95.0%)	4.9 (95.0%)	0 (100.0%)	0 (100.0%)
	Dec Jan Feb Mar	Apr May Jun	Jul Aug	Sep Oct Nov
	Winter	Spring	Summer	Fall

Base Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)

Pulse volumes are in units of acre-feet and durations are in days.

Period of record used : 1/1/1950 to 12/31/2014.

Q95 calculation used for subsistence flows. Annual Q95 value is 0.1544 cfs.

Period of Record: 1950-2014

Overbank Flow: 2,700 cfs.

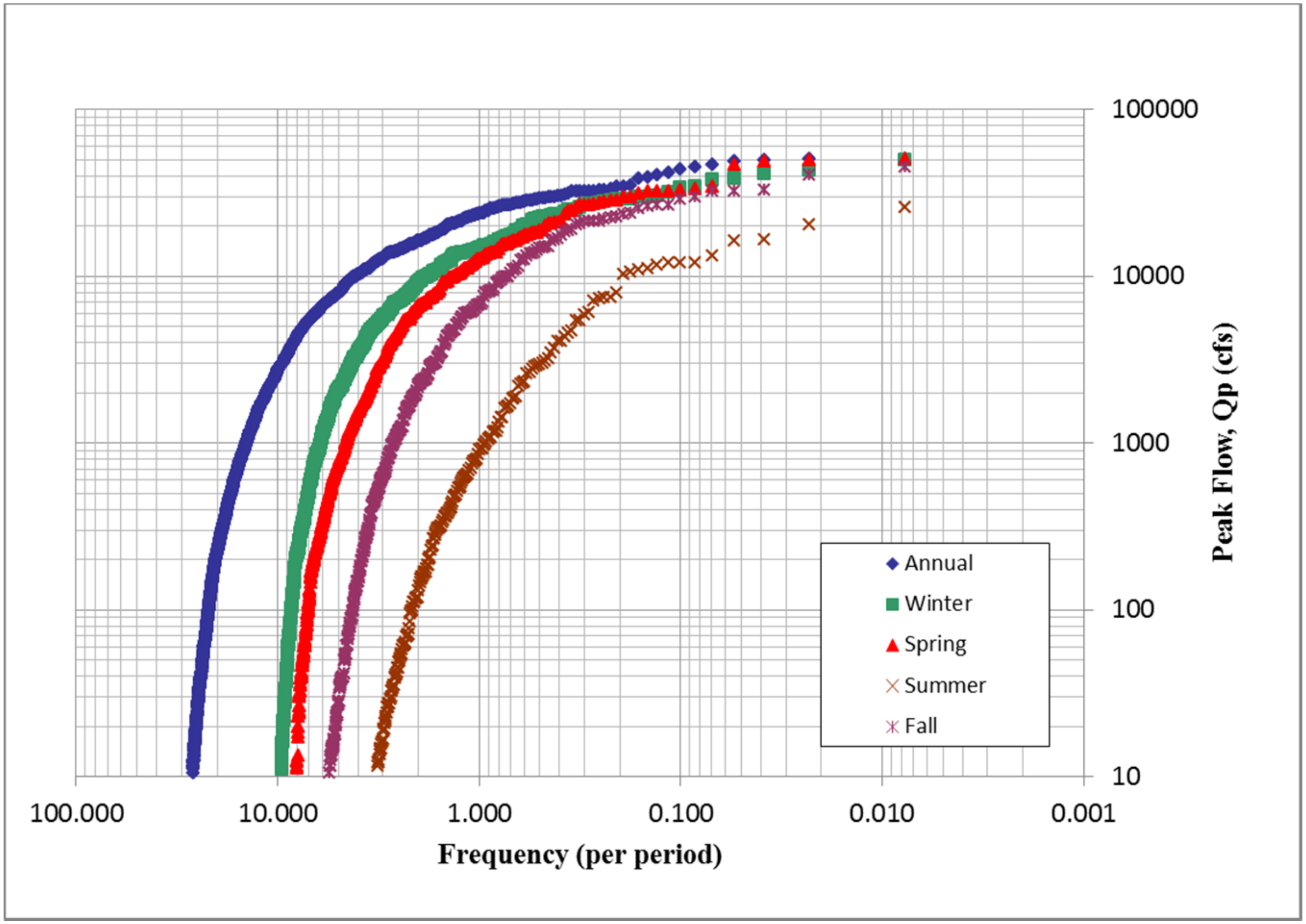

Figure 44: Seasonal and Annual High Flow Pulse Frequency Distributions by Peak Flow (USGS Sulphur River near Talco gauge No. 07343200)

Base Flow Persistence Characteristics:
25th Percentile = 3 days
75th Percentile = 13 days

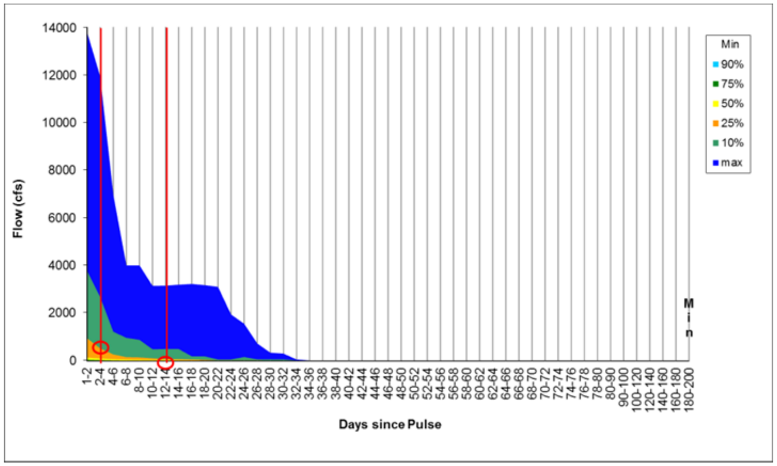

Figure 45: USGS 07343200 1950-2014 Winter

25th Percentile = 5 days
75th Percentile = 29 days

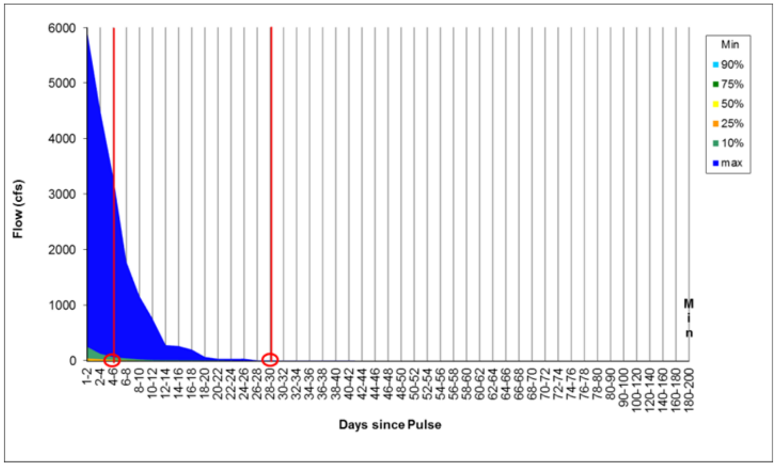

Figure 46: USGS 07343200 1950-2014 Summer

Base Flow Persistence Characteristics:
25th Percentile = 3 days
75th Percentile = 12 days

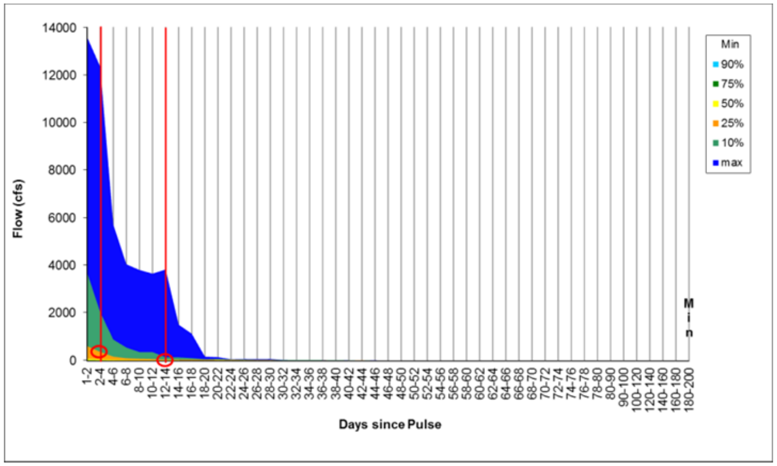

Figure 47: USGS 07343200 1950-2014 Spring

25th Percentile = 5 days
75th Percentile = 42 days

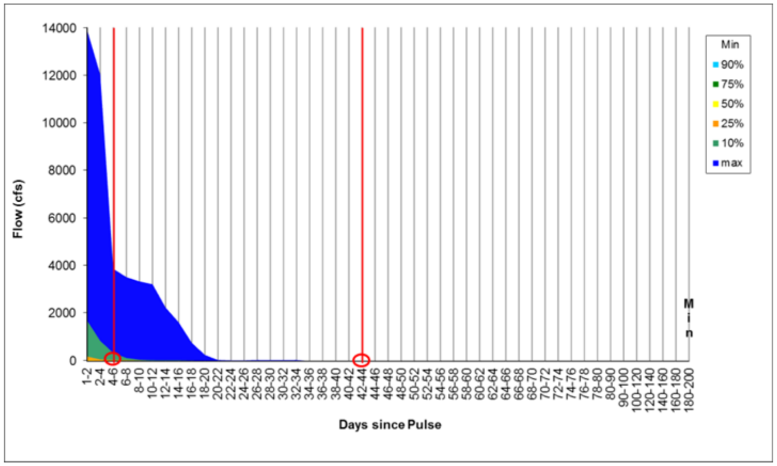

Figure 48: USGS 07343200 1950-2014 Fall

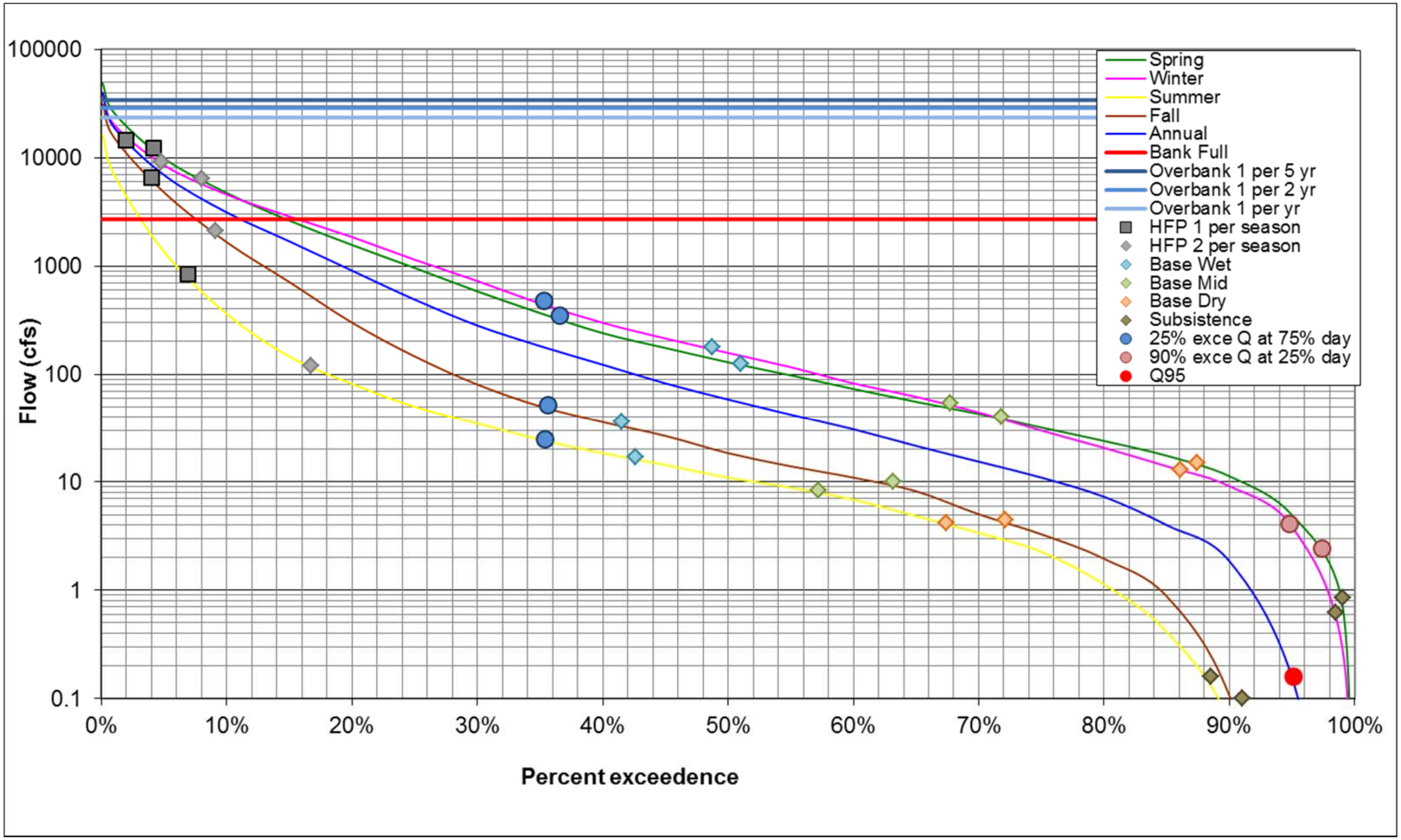

Figure 49: Comparison of seasonal and annual flow distributions identified at USGS Sulphur River near Talco gauge (No. 07343200)

6.2 Hydrologic Characteristics by Flow Component, Sulphur River downstream of Wright Patman (Gated Releases).

The identified hydrologic flow regime statistics for the Sulphur River downstream of Wright Patman based on historical releases from Wright Patman[2] are shown in Table 10. The base flows identified by HEFR range between 200 – 1,050 cfs, with subsistence flows of 10 cfs. The base flow range identified in the persistence analysis is 10 – 2,500 cfs, as shown in Table 8, while the $Q_{95,}$ 7Q2, and median low flows for the 1982-2014 analysis period is 10 cfs. As would be expected, the operational releases of 10 cfs significantly affect the statistical characterization of the lower flows in this context.

The flow regime depicted in Table 10 represents a more comprehensive flow regime, with arbitrarily selected frequencies of occurrence of high flow pulses. Generally, moderate levels of overbanking would be expected to occur/increase starting during wetter seasons with high flow pulses at the lower frequencies of annual occurrence.

Figure 50 presents the frequency distribution of seasonal and annual high flow pulses by peak flow for the Sulphur River downstream of Wright Patman. Figure 51 - Figure 54 present the non-parametric distributions of historical flow magnitudes by number of days since a pulse by project location for all data and by season. The seasonal distribution of flows is presented in Figure 55. It can be seen that there is a wide variation in base flows from season to season, with the summer and fall seasons experiencing the lowest base flows, less than 100 cfs 73 to 79% of the time, respectively, and base flows greater than 100 cfs 20 to 26% of the time for the fall and summer seasons respectively. Most notably, the winter and spring seasons experience base flows of less than 100 cfs approximately 72% of the time.

[2] The hydrologic characteristics presented within this section pertain to historical gated releases from Wright Patman. No such analysis has been performed on the translated guidelines, as the translation is based upon the TCEQ methodology for translating an environmental flow guideline.

Table 10: Wright Patman Flow Regime Characterization (Based on Historical Gated Releases, modified from 96-115 cfs to 10 cfs)

	Winter (Dec, Jan, Feb, Mar)	Spring (Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Events	Qp: 10,310 cfs with Average Frequency 1 per 5 years Regressed Volume is 189,625 to 1,210,813 (479,166) Regressed Duration is 16 to 89 (38)			
Overbank Events	Qp: 10,030 cfs with Average Frequency 1 per 2 years Regressed Volume is 182,299 to 1,163,745 (460,597) Regressed Duration is 16 to 88 (37)			
Overbank Events	Qp: 9,966 cfs with Average Frequency 1 per year Regressed Volume is 180,637 to 1,153,068 (456,384) Regressed Duration is 16 to 88 (37)			
Overbank Events	Qp: 6,128 cfs with Average Frequency 2 per year Regressed Volume is 90,037 to 572,675 (227,073) Regressed Duration is 12 to 68 (29)			
High Flow Pulses	Qp: 6,764 cfs with Average Frequency 1 per season Regressed Volume is 125,497 to 679,315 (291,980) Regressed Duration is 15 to 74 (34)	Qp: 2,784 cfs with Average Frequency 1 per season Regressed Volume is 27,852 to 214,673 (77,324) Regressed Duration is 8 to 50 (20)		Qp: 1,096 cfs with Average Frequency 1 per season Regressed Volume is 8,306 to 45,440 (19,428) Regressed Duration is 6 to 26 (12)
High Flow Pulses	Qp: 524 cfs with Average Frequency 2 per season Regressed Volume is 1,759 to 9,898 (4,173) Regressed Duration is 2 to 12 (5)			
Base Flows (cfs)	992 (61.7%)	744 (51.0%)	544 (28.1%)	1033 (28.0%)
Base Flows (cfs)	478 (70.1%)	496 (57.7%)	230 (34.8%)	516 (38.9%)
Base Flows (cfs)	208 (75.7%)	228 (65.0%)	227 (40.5%)	221 (47.9%)
Subsistence Flows (cfs)	10 (99.9%)	10 (99.8%)	10 (99.6%)	10 (100.0%)

Base Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)

Pulse volumes are in units of acre-feet and durations are in days.
Period of record used : 1/1/1982 to 12/31/2014.
Q95 calculation used for subsistence flows. Annual Q95 value is 10 cfs.

Period of Record: 1982-2014

Overbank Flow: 3,000 cfs.

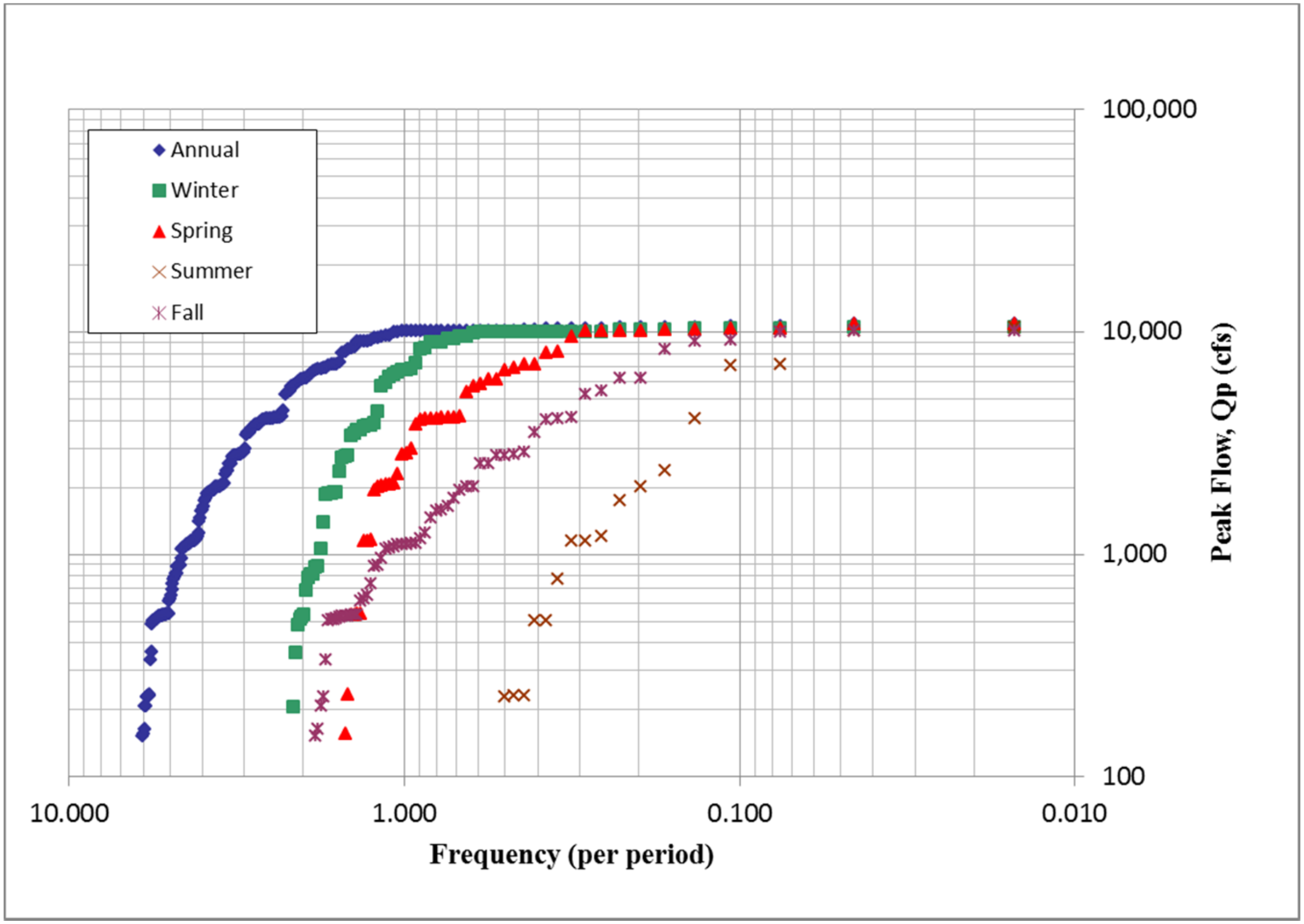

Figure 50: Seasonal and Annual High Flow Pulse Frequency Distributions by Peak Flow (Wright Patman)

Base Flow Persistence Characteristics:

25th Percentile = 8 days

75th Percentile = 57 days

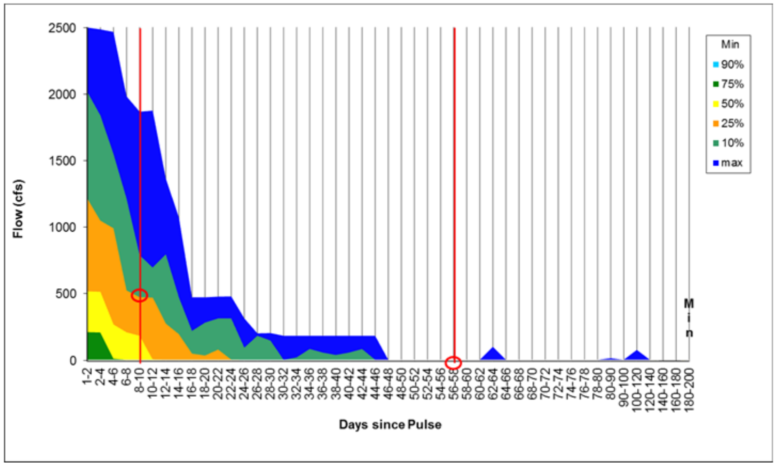

Figure 51: Wright Patman 1982-2014 Winter

25th Percentile = 17 days

75th Percentile = 86 days

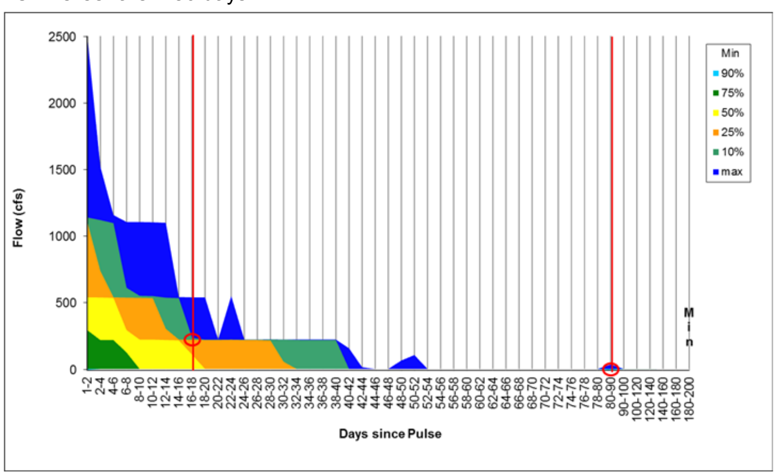

Figure 52: Wright Patman 1982-2014 Summer

Base Flow Persistence Characteristics:

25th Percentile = 10 days

75th Percentile = 53 days

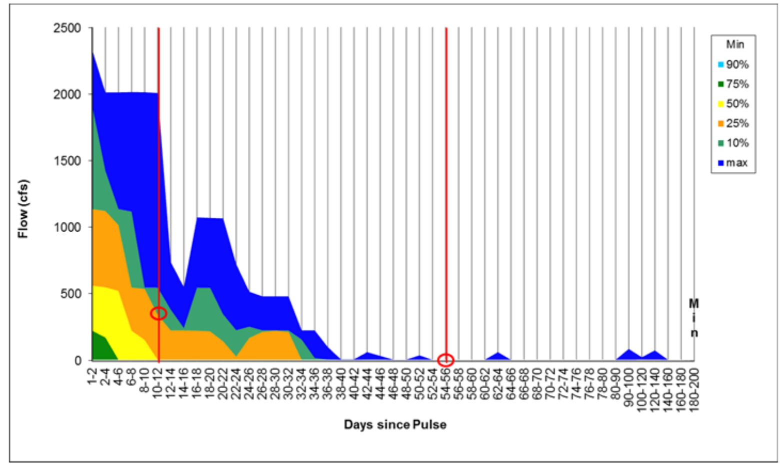

Figure 53: Wright Patman 1982-2014 Spring

25th Percentile = 12 days

75th Percentile = 97 days

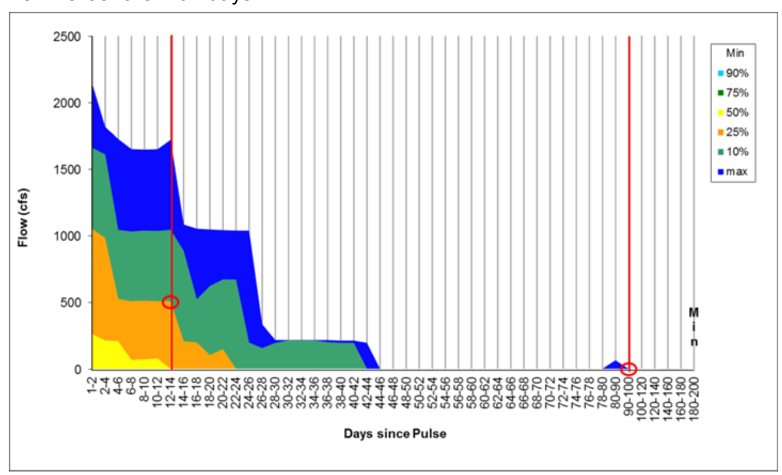

Figure 54: Wright Patman 1982-2014 Fall

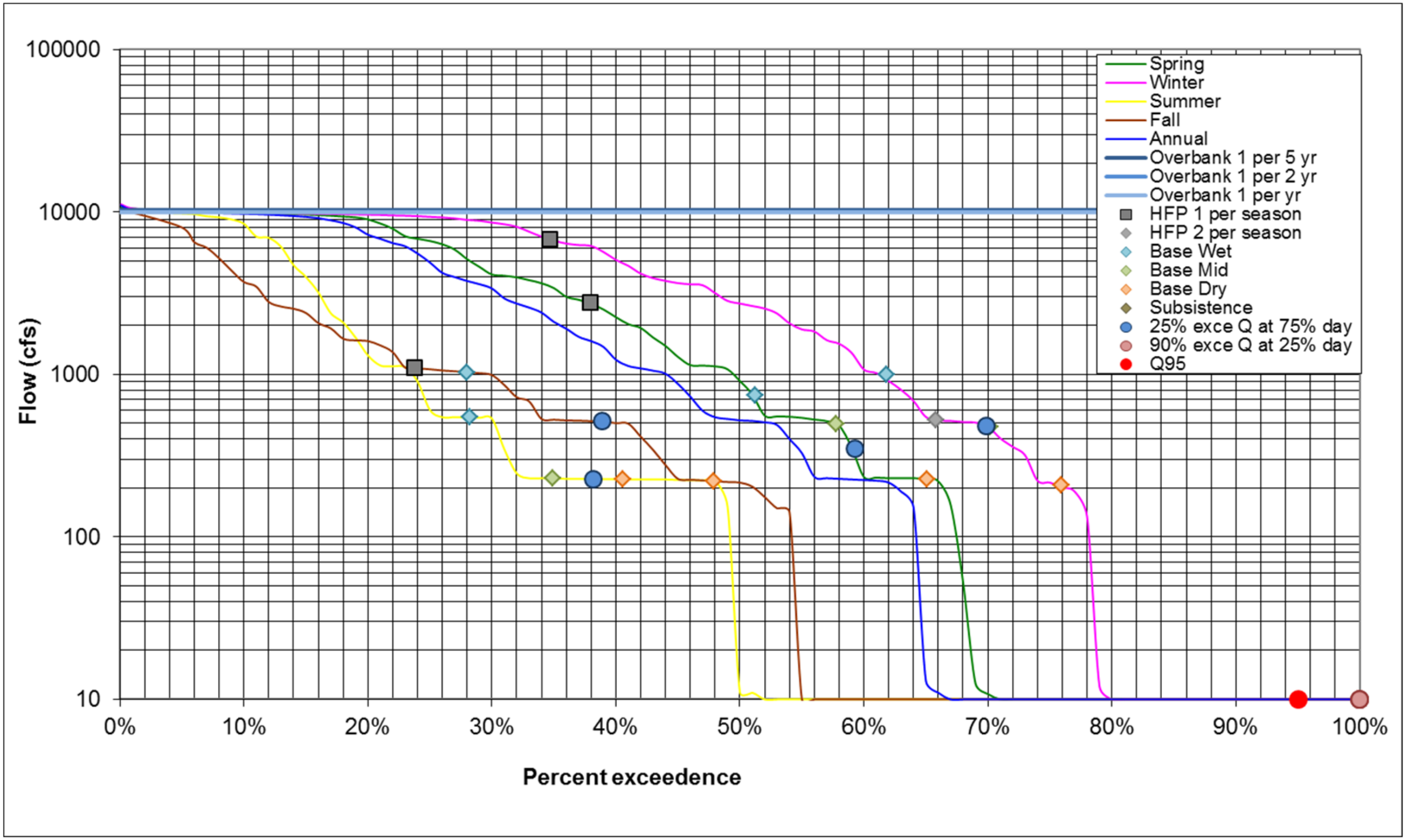

Figure 55: Comparison of seasonal and annual flow distributions identified from adjusted Wright Patman releases

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7 Water Quality Analysis

An assessment of the existing condition of the river system has been performed through a review of historical water quality data. The TCEQ has identified water quality goals and standards for the Sulphur River Basin. In an effort to identify ranges of flow which are shown to degrade water quality, historically reported water quality data have been compared to TCEQ water quality standards identified for the stream segments of the Sulphur River. The objective of water quality goals can be characterized as being:

- To maintain day-to-day conditions that are not anticipated to cause adverse effects on native aquatic species.
- To maintain water quality conditions that satisfy current state water quality standards, as determined by the surface water quality standards.

7.1 Water Quality Goals

To assess historical achievement of water quality goals, indicator parameters have been prioritized according to potential instream flow needs and impacts on aquatic habitat. Instream flow water quality goals are presented for TCEQ segments 0301, 0303 and 0305 in Table 11-Table 13.

Table 11: Water Quality Goals for Sulphur River below Wright Patman Lake (TCEQ segment 0301)

Sulphur River Below Wright Patman Lake	
0301	
Parameter	**Instream Flow Goals (Values)**
DO (2010a)	>= 5.0 mg/L daily average >= 3.0 mg/L minimum for <= 8 hours For Spring Condition: >= 5.5 mg/L daily average >= 4.5 mg/L minimum for <= 8 hours
Temperature (2010a)	<= 90 'F
E. Coli (2010a)	<= 126 org/100mL geometric mean
Total Phosphorus (2010b)	<= 0.69 mg/L
Orthophosphate (2010b)	<= 0.37 mg/L
NOx (2004)	<= 2.76 mg/L
Ammonia (2010b)	<= 0.33 mg/L
Salinity (2010b)	<= 2 ppt
2nd tier instream flow goals for additional indicators	
Nitrate (2010b)	<= 1.95 mg/L
Chlorophyll-a (2010b)	<= 14.1 ug/L
Chloride (2010a)	<= 120 mg/L
Sulfate (2010a)	<= 100 mg/L
pH (2010a)	6-8.5
TDS (2010a)	<= 500 mg/L
TSS (2010c)	<= 10 mg/L

Table 12: Water Quality Goals for Sulphur River and South Sulphur River (TCEQ segment 0303)

Sulphur River / South Sulphur River	
0303	
Parameter	**Instream Flow Goals (Values)**
DO (2010a)	>= 5.0 mg/L daily average >= 3.0 mg/L minimum for <= 8 hours For Spring Condition: >= 5.5 mg/L daily average >= 4.5 mg/L minimum for <= 8 hours
Temperature (2010a)	<= 93 'F
E. Coli (2010a)	<= 126 org/100mL geometric mean
Total Phosphorus (2010b)	<= 0.69 mg/L
Orthophosphate (2010b)	<= 0.37 mg/L
NOx (2004)	<= 2.76 mg/L
Ammonia (2010b)	<= 0.33 mg/L
Salinity (2010b)	<= 2 ppt
2nd tier instream flow goals for additional indicators	
Nitrate (2010b)	<= 1.95 mg/L
Chlorophyll-a (2010b)	<= 14.1 ug/L
Chloride (2010a)	<= 80 mg/L
Sulfate (2010a)	<= 180 mg/L
pH (2010a)	6-8.5
TDS (2010a)	<= 600 mg/L
TSS (2010c)	<= 22 mg/L

Table 13: Water Quality goals for North Sulphur River (TCEQ segment 0305)

North Sulphur River	
0305	
Parameter	**Instream Flow Goals (Values)**
DO (2010a)	>= 4.0 mg/L daily average >= 3.0 mg/L minimum for <= 8 hours For Spring Condition: >= 5.0 mg/L daily average >= 4.0 mg/L minimum for <= 8 hours
Temperature (2010a)	<= 93 'F
E. Coli (2010a)	<= 126 org/100mL geometric mean
Total Phosphorus (2010b)	<= 0.69 mg/L
Orthophosphate (2010b)	<= 0.37 mg/L
NOx (2004)	<= 2.76 mg/L
Ammonia (2010b)	<= 0.33 mg/L
Salinity (2010b)	<= 2 ppt
2nd tier instream flow goals for additional indicators	
Nitrate (2010b)	<= 1.95 mg/L
Chlorophyll-a (2010b)	<= 14.1 ug/L
Chloride (2010a)	<= 190 mg/L
Sulfate (2010a)	<= 475 mg/L
pH (2010a)	6-8.5
TDS (2010a)	<= 1320 mg/L
TSS (2010c)	<= 5.6 mg/L

7.2 Water Quality Goal Achievement

Evaluation of water quality goal achievement at the project locations within the Sulphur River Basin is based on available data from the Surface Water Quality Monitoring (SWQM) Database.

7.2.1 Sulphur River near Marvin Nichols Project Location

Figure 56 - Figure 61 show identified water quality parameters versus flow rate at the time of collection, with the water quality goals also plotted for reference and identification of achievement.

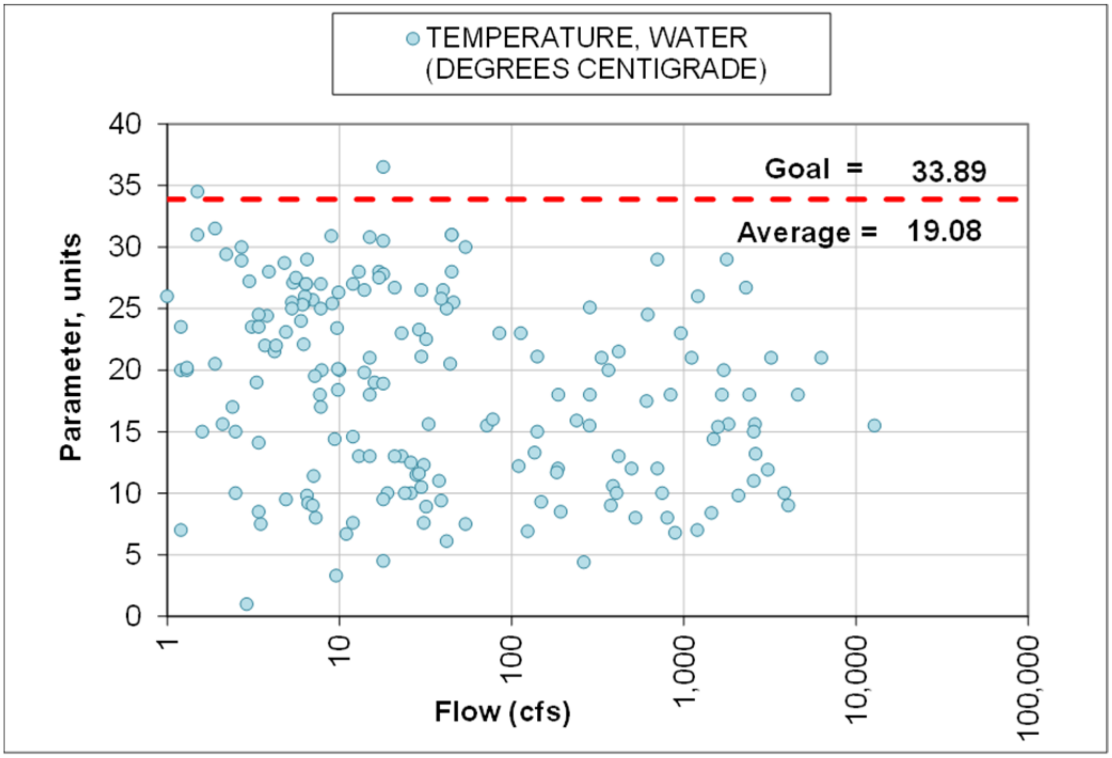

Figure 56: SWQM reported temperature versus flow - Sulphur River Marvin Nichols project location

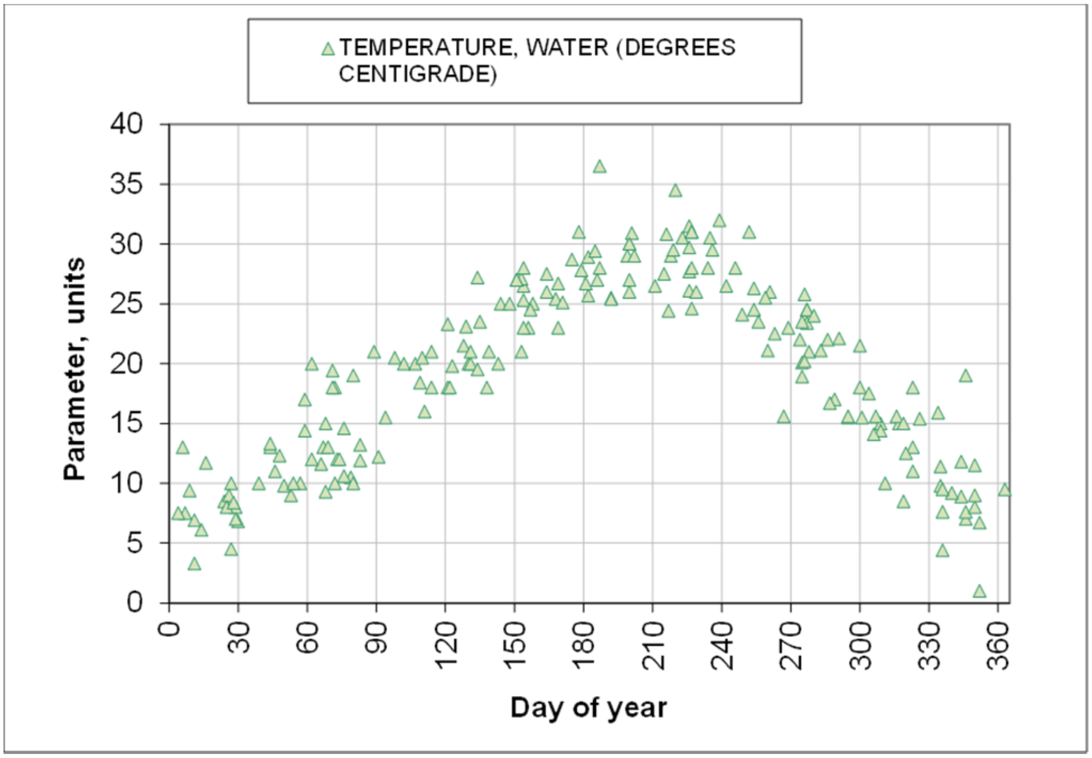

Figure 57: SWQM reported temperature versus day of year - Sulphur River Marvin Nichols project location

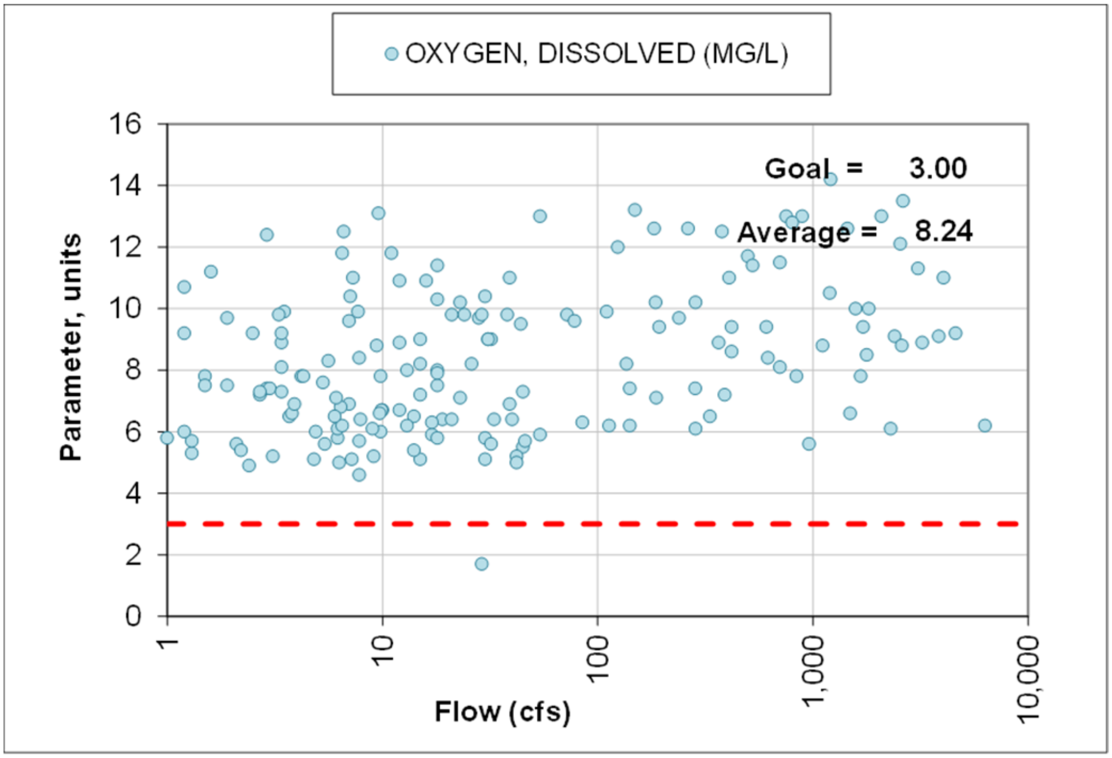

Figure 58: SWQM reported dissolved oxygen versus flow - Sulphur River Marvin Nichols project location

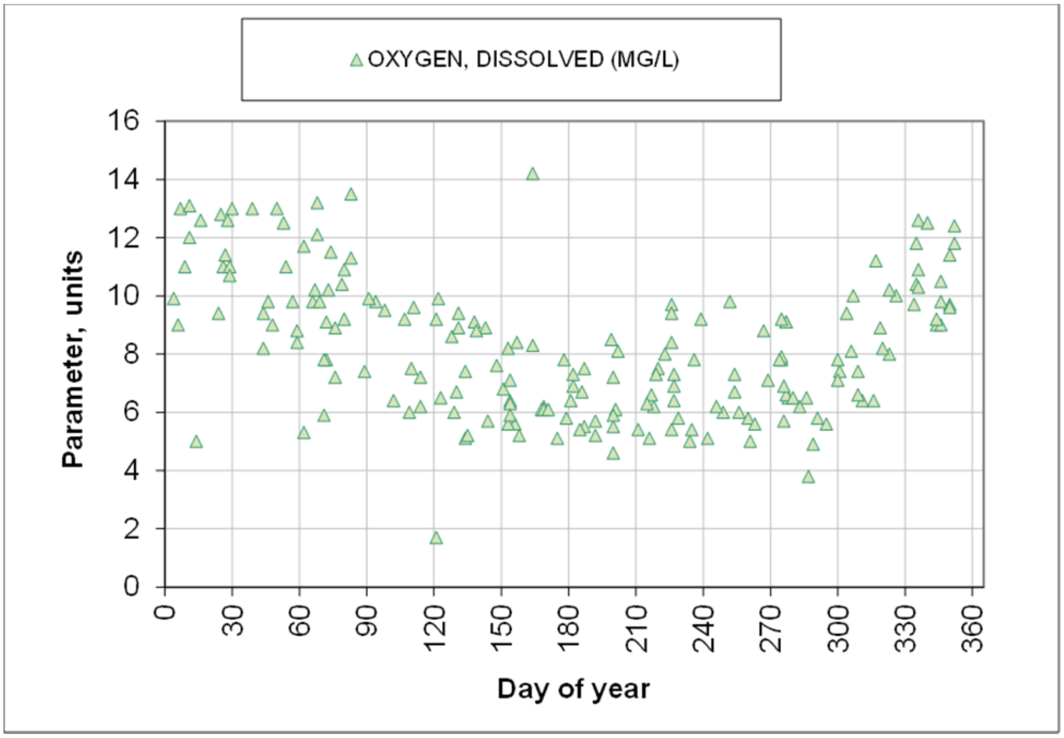

Figure 59: SWQM reported dissolved oxygen versus day of year - Sulphur River Marvin Nichols project location

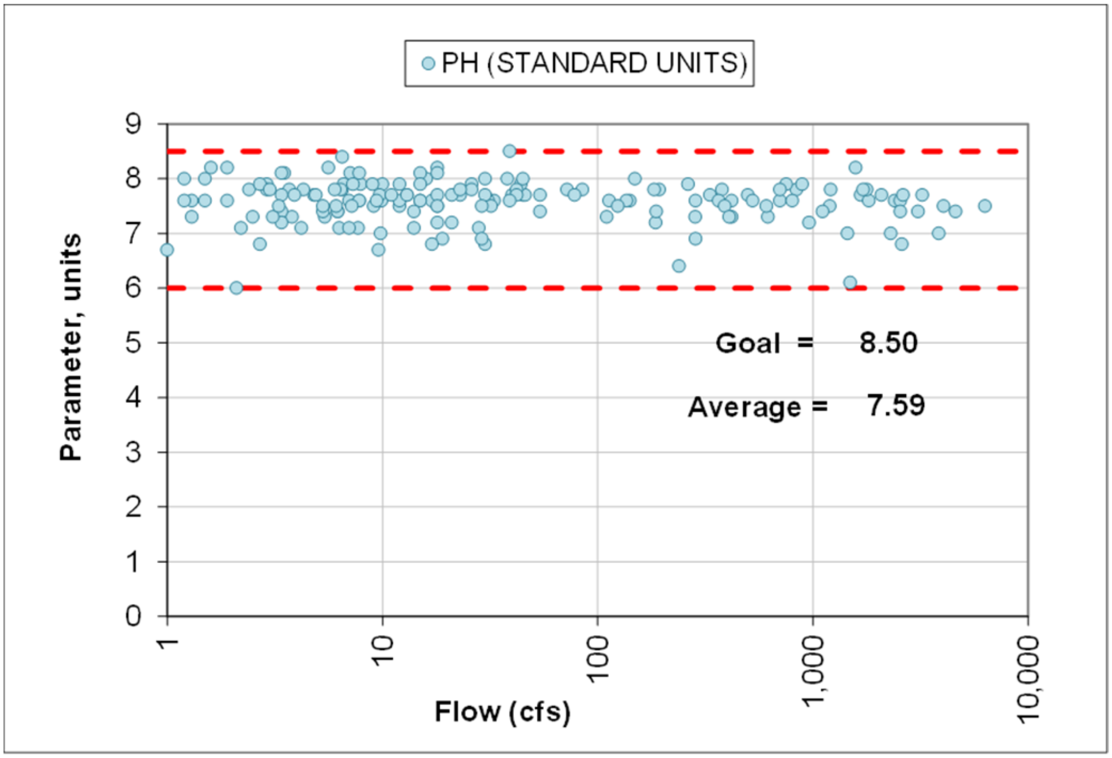

Figure 60: SWQM reported pH versus flow - Sulphur River Marvin Nichols project location

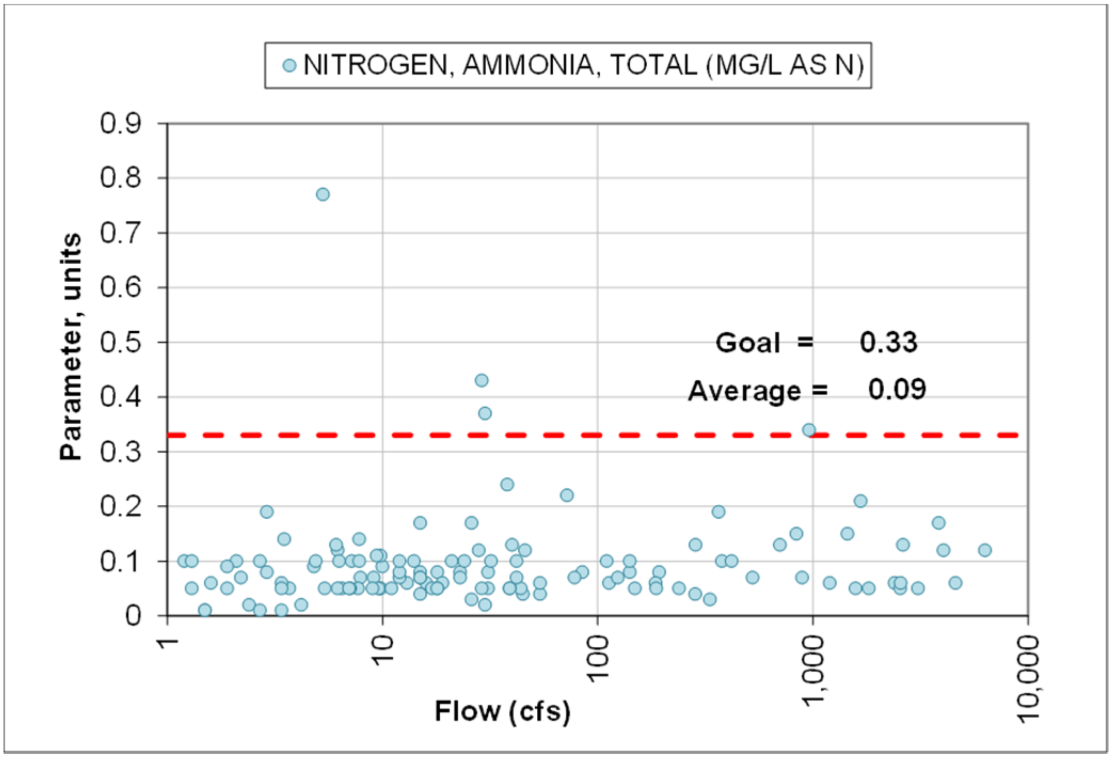

Figure 61: SWQM reported ammonia versus flow - Sulphur River Marvin Nichols project location

The water quality is generally good with respect to the identified instream flow goals. Most parameters achieved the water quality goals under all flow conditions with limited or no observations (depending on the parameter) not meeting the screening levels. Parameters meeting instream flow goals at this stage are given a preliminary assessment of goal achievement (pGA). If concentration goals were not met, the parameter assessment was goal non-achievement (pGNA). Goal achievement and goal non-achievement conditions were identified and shown in Table 14 - Table 17 for different preliminary flow condition and different seasons, in an attempt to inform upon the identification of base flow criteria. However at the Marvin Nichols project location, water quality parameters do not suggest an obvious criteria violation flow range. Thus, flow criteria at Marvin Nichols have been based solely on hydrology and general biologic considerations, but not water quality properties.

Table 14: Water Quality Goal Achievement – Fall - Marvin Nichols Project Location

Marvin Nichols	Fall	<0.6	0.6-5.4	5.4-12	12 —36	36 - 185	185 - 400	400-600	600-800	>800
10219		**Low flow steady conditions**				**Episodic events**				
Parameters	**all-preliminary**	**Subsistence**	**Baseflow-low**	**Baseflow-mid**	**Baseflow-high**	**LHFP**	**MHFP**	**HHFP**	**?**	**Overbank**
DO (2010a)	pGA, 1 below standard @ 16cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Temperature (2010a)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
E. Coli (2010a)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Total Phosphorus (2010b)	pGA, 1 above standard @ 1170cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Orthophosphate (2010b)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
NOx (2004)	pGA, 1 above standard @ 3340cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Ammonia (2010b)	pGA, 1 above standard @ 56cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Salinity (2010b)	no data	no data	no data	no data	no data	no data	no data	no data		no data
Secondary priority parameters										
Nitrate (2010b)	pGA, 1 above standard @ 123cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Chlorophyll-a (2010b)	pGNA	no data	pGA, 1 above standard	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Chloride (2010a)	pGA, 2 above standard @ 2.3cfs, 21cfs	no data	pGA, 1 above standard	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Sulfate (2010a)	pGA, 3 above standard @ 13cfs, 21cfs, 152cfs	no data	pGA	pGA	pGA, 1 above standard	pGA, 1 above standard	pGA	pGA	pGA	pGA
pH (2010a)	pNA??? 3 above standard @100, 1670, 4900	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TDS (2010a)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TSS (2010c)	pGNA	no data	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Field codes:	GA - goal achievement	pGA - prelim assessment of goal achievement								
	GNA - goal non-achievement	pGNA - prelim goal non-achievement								
	NGN - no goal necessary									
	ND - no data									

Table 15: Water Quality Goal Achievement –Summer - Marvin Nichols Project Location

Marvin Nichols	Summer	<0.55	0.55-5.4	5.4-10	10—21	21-155	155-430	430-680	680-800	>800
10219		Low flow steady conditions				Episodic events				
Parameters	**all-preliminary**	**Subsistence**	**Baseflow-low**	**Baseflow-mid**	**Baseflow-high**	**LHFP**	**MHFP**	**HHFP**	**?**	**Overbank**
DO (2010a)	pGA, 1 below standard @ 16cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Temperature (2010a)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
E. Coli (2010a)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Total Phosphorus (2010b)	pGA, 1 above standard @ 1170cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Orthophosphate (2010b)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
NOx (2004)	pGA, 1 above standard @ 3340cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA, 1 above standard
Ammonia (2010b)	pGA, 1 above standard @ 56cfs	no data	pGA	pGA	pGA	pGA, 1 above standard	pGA	pGA	pGA	pGA
Salinity (2010b)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Secondary priority parameters										
Nitrate (2010b)	pGA, 1 above standard @ 123cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Chlorophyll-a (2010b)	pGNA	no data	pGA	pGA	pGNA	pGNA	pGNA	no data	no data	no data
Chloride (2010a)	pGA, 2 above standard @ 2.3cfs, 21cfs	no data	pGA	pGA	pGA, 1 above standard	pGA	pGA	pGA	pGA	pGA
Sulfate (2010a)	pGA, 3 above standard @ 13cfs, 21cfs, 152cfs	no data	pGA	pGA	pGA, 1 above standard	pGA	pGA	pGA	pGA	pGA
pH (2010a)	pNA??? 3 above standard @100, 1670, 4900	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TDS (2010a)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TSS (2010c)	pGNA	no data	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Field codes:	GA - goal achievement	pGA - prelim assessment of goal achievement								
	GNA - goal non-achievement	pGNA - prelim goal non-achievement								
	NGN - no goal necessary									
	ND - no data									

Table 16: Water Quality Goal Achievement – Spring - Marvin Nichols Project Location

Marvin Nichols	Spring	<1.6	1.6-15	15-36	36-80	80-135	135-400	400-790	790-800	>800
10219		Low flow steady conditions				Episodic events				
Parameters	all-preliminary	Subsistence	Baseflow-low	Baseflow-mid	Baseflow-high	LHFP	MHFP	HHFP	?	Overbank
DO (2010a)	pGA, 1 belowstandard @ 16cfs	no data	pGA	pGA, 1 below standard	pGA	pGA	pGA	pGA	pGA	pGA
Temperature (2010a)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
E. Coli (2010a)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Total Phosphorus (2010b)	pGA, 1 above standard @ 1170cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Orthophosphate (2010b)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
NOx (2004)	pGA, 1 above standard @ 3340cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Ammonia (2010b)	pGA, 1 above standard @ 56cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Salinity (2010b)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Secondary priority parameters										
Nitrate (2010b)	pGA, 1 above standard @ 123cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Chlorophyll-a (2010b)	pGNA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA, 1 above standard
Chloride (2010a)	pGA, 2 above standard @ 2.3cfs, 21cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Sulfate (2010a)	pGA, 3 above standard @ 13cfs, 21cfs, 152cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
pH (2010a)	pNA??? 3 above standard @100, 1670, 4900	no data	pGA	pGA	pGA	pGA, 1 above standard	pGA	pGA	pGA	pGA, 1 above standard
TDS (2010a)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TSS (2010c)	pGNA	no data	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Field codes:	GA - goal achievement	pGA - prelim assessment of goal achievement								
	GNA - goal non-achievement	pGNA - prelim goal non-achievement								
	NGN - no goal necessary									
	ND - no data									

Table 17: Water Quality Goal Achievement –Winter - Marvin Nichols Project Location

Marvin Nichols	Winter	<1.1	1.1-14	14-44	44-102	102-155	155-460	460-630	630-800	>800
10219		Low flow steady conditions				Episodic events				
Parameters	all-preliminary	Subsistence	Baseflow-low	Baseflow-mid	Baseflow-high	LHFP	MHFP	HHFP	?	Overbank
DO (2010a)	pGA, 1 belowstandard @ 16cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Temperature (2010a)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
E. Coli (2010a)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Total Phosphorus (2010b)	pGA, 1 above standard @ 1170cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA, 1 above standard
Orthophosphate (2010b)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
NOx (2004)	pGA, 1 above standard @ 3340cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Ammonia (2010b)	pGA, 1 above standard @ 56cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Salinity (2010b)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Secondary priority parameters										
Nitrate (2010b)	pGA, 1 above standard @ 123cfs	no data	pGA	pGA	pGA	pGA, 1 above standard	pGA	pGA	pGA	pGA
Chlorophyll-a (2010b)	pGNA	no data	pGA, 1 above standard	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Chloride (2010a)	pGA, 2 above standard @ 2.3cfs, 21cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Sulfate (2010a)	pGA, 3 above standard @ 13cfs, 21cfs, 152cfs	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
pH (2010a)	pNA??? 3 above standard @100, 1670, 4900	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA, 1 above standard
TDS (2010a)	pGA	no data	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TSS (2010c)	pGNA	no data	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Field codes:	GA - goal achievement	pGA - prelim assessment of goal achievement								
	GNA - goal non-achievement	pGNA - prelim goal non-achievement								
	NGN - no goal necessary									
	ND - no data									

7.2.2 Wright Patman

Evaluation of the area just downstream of Wright Patman for water quality goal achievement has been performed based on available SWQM data near Wright Patman. Goal achievement and goal non-achievement conditions were identified and shown in Table 18 - Table 21 for different preliminary flow conditions and different seasons relevant to the Wright Patman location.

Table 18: Water Quality Goal Achievement – Fall – Wright Patman

Wright Patman	Fall	<0.6	0.6-5.4	5.4-12	12 ---36	36 - 185	185 - 400	400-600	600-800	>800
10212				**Low flow steady conditions**				**Episodic events**		
Parameters	**all-preliminary**	**Subsistence**	**Baseflow-low**	**Baseflow-mid**	**Baseflow-high**	**LHFP**	**MHFP**	**HHFP**	**?**	**Overbank**
DO (2010a)	pGA, 1 below standard @ 2.9cfs	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Temperature (2010a)	pGA, 1 above standard @ 2.5cfs	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
E. Coli (2010a)	pGA (Geomean < Standard)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Total Phosphorus (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Orthophosphate (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
NOx (2004)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Ammonia (2010b)	pGNA, data above standard in the range of 1.8-223cfs	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Salinity (2010b)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Secondary priority parameters										
Nitrate (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Chlorophyll-a (2010b)	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Chloride (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Sulfate (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
pH (2010a)	pGNA??? Multiple above standard, 1 below standard @ 10(	pGA	pGA, 1 above standard	pGA	pGA	pGA, 1 above standard	pGA	pGA	pGA	pGA
TDS (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TSS (2010c)	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Field codes:	GA - goal achievement	pGA - prelim assessment of goal achievement								
	GNA - goal non-achievement	pGNA - prelim goal non-achievement								
	NGN - no goal necessary									
	ND - no data									

Table 19: Water Quality Goal Achievement – Summer – Wright Patman

Wright Patman	Summer	<0.55	0.55-5.4	5.4-10	10---21	21-155	155-430	430-680	680-800	>800
10212				Low flow steady conditions				Episodic events		
Parameters	all-preliminary	Subsistence	Baseflow-low	Baseflow-mid	Baseflow-high	LHFP	MHFP	HHFP	?	Overbank
DO (2010a)	pGA, 1 below standard @ 2.9cfs	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Temperature (2010a)	pGA, 1 above standard @ 2.5cfs	pGA	pGA, 1 above standard	pGA	pGA	pGA	pGA	pGA	pGA	pGA
E. Coli (2010a)	pGA (Geomean < Standard)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Total Phosphorus (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Orthophosphate (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
NOx (2004)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Ammonia (2010b)	pGNA, data above standard in the range of 1.8-223cfs	no data	pGNA?? 1 above standard	pGNA?? 2 above standard	pGA	pGA	pGNA?? 1 above standard	pGA	pGA	pGA
Salinity (2010b)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Secondary priority parameters										
Nitrate (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Chlorophyll-a (2010b)	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Chloride (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA		pGA
Sulfate (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
pH (2010a)	pGNA??? Multiple above standard, 1 below standard @ 10(	pGA	pGA, 1 above standard	pGA	pGA	pGA, 1 above standard	pGA, 2 above standard	pGA	pGA	pGA
TDS (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TSS (2010c)	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Field codes:	GA - goal achievement	pGA - prelim assessment of goal achievement								
	GNA - goal non-achievement	pGNA - prelim goal non-achievement								
	NGN - no goal necessary									
	ND - no data									

Table 20: Water Quality Goal Achievement – Spring – Wright Patman

Wright Patman	Spring	<1.6	1.6-15	15-36	36-80	80-135	135-400	400-790	790-800	>800
10212		Low flow steady conditions				Episodic events				
Parameters	all-preliminary	Subsistence	Baseflow-low	Baseflow-mid	Baseflow-high	LHFP	MHFP	HHFP	?	Overbank
DO (2010a)	pGA, 1 below standard @ 2.9cfs	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Temperature (2010a)	pGA, 1 above standard @ 2.5cfs	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
E. Coli (2010a)	pGA (Geomean < Standard)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Total Phosphorus (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Orthophosphate (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
NOx (2004)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Ammonia (2010b)	pGNA, data above standard in the range of 1.8-223cfs	pGA	pGA, 1 above standard	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Salinity (2010b)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Secondary priority parameters										
Nitrate (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Chlorophyll-a (2010b)	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Chloride (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Sulfate (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
pH (2010a)	pGNA??? Multiple above standard, 1 below standard @ 10	pGA	pGA	pGA	pGA, 1 above standard	pGA, 1 above standard	pGA	pGA	pGA	pGA, 1 below standard
TDS (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TSS (2010c)	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Field codes:	GA - goal achievement	pGA - prelim assessment of goal achievement								
	GNA - goal non-achievement	pGNA - prelim goal non-achievement								
	NGN - no goal necessary									
	ND - no data									

Table 21: Water Quality Goal Achievement – Winter – Wright Patman

Wright Patman	Winter	<1.1	1.1-14	14-44	44-102	102-155	155-460	460-630	630-800	>800
10212		Low flow steady conditions				Episodic events				
Parameters	all-preliminary	Subsistence	Baseflow-low	Baseflow-mid	Baseflow-high	LHFP	MHFP	HHFP	?	Overbank
DO (2010a)	pGA, 1 below standard @ 2.9cfs	pGA	pGA, 1 below standard	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Temperature (2010a)	pGA, 1 above standard @ 2.5cfs	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
E. Coli (2010a)	pGA (Geomean < Standard)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Total Phosphorus (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Orthophosphate (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
NOx (2004)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Ammonia (2010b)	pGNA, data above standard in the range of 1.8-223cfs	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Salinity (2010b)	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Secondary priority parameters										
Nitrate (2010b)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
Chlorophyll-a (2010b)	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Chloride (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA		pGA
Sulfate (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
pH (2010a)	pGNA??? Multiple above standard, 1 below standard @ 10	pGA	pGA	pGA	pGA	pGA, 1 above standard	pGA	pGA	pGA	pGA
TDS (2010a)	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA	pGA
TSS (2010c)	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA	pGNA
Field codes:	GA - goal achievement	pGA - prelim assessment of goal achievement								
	GNA - goal non-achievement	pGNA - prelim goal non-achievement								
	NGN - no goal necessary									
	ND - no data									

8 Base Flow Characterization

Previously collected biological, hydrologic and habitat data, as well as model outputs, have been considered in the present effort; specifically, information utilized in the development of the mesohabitat model and inundation analyses from Osting, et. al. (2004).

As noted in Osting et. al. (2004), TWDB used the Gelwick and Morgan (2000) and Gelwick and Burgess (2002) fish habitat utilization datasets to evaluate habitat utilization for the four areas for which data were collected: the unchannelized South Sulphur River, the channelized South Sulphur River, the channelized Sulphur River and the unchannelized Sulphur River. Two additional studies considered by TWDB used datasets limited to summer low-flow conditions to investigate fish habitat utilization based upon mesohabitat and structural habitat (Morgan 2002), and based upon habitat heterogeneity (Burgess 2003).

None of those four studies evaluated the individual study areas; thus, TWDB developed a spatial (GIS) model at the aforementioned Sites (1) and (2) to quantify as best as possible the area of mesohabitat and area of structural habitat, then used the depth and velocity data reported for each habitat sample by Gelwick and Morgan (2000) and Gelwick and Burgess (2002) to develop hydraulic mesohabitat classifications. TWDB analyzed field data and structural habitat descriptions presented in those same studies to define structural habitat with each hydraulic mesohabitat. Each sample was reclassified by TWDB based on the new mesohabitat and structural habitat classifications.

A broad, in-channel evaluation may be made utilizing the TWDB derived observation data, wherein focal fish species are utilized as the main source for determining necessary base flow components of the flow regime. Although the "riffle" mesohabitat is almost nonexistent in the Sulphur River and has not been observed during previous data collection efforts, artificial riffle areas composed of submerged wood debris, were observed (Osting et. al. 2004) and designated as riffle areas because of the observed water velocity and depth characteristics. This conclusion was supported by biological data collected during the TWDB study, as. riffle species were collected at observed artificial riffle areas. While specific flow magnitudes might be characterized from the relations derived by Osting et. al. 2004, two facts emerge:

(1) there is significant uncertainty in the mesohabitat relations to flow velocity and depth; and

(2) specification of individual magnitudes of flow appears problematic given the uncertainty and the need for seasonal variation in the hydrologic flow regime.

As is noted by TWDB, there appears to be significant uncertainty in the relations between velocity, depth, and observed mesohabitat. This uncertainty is reflected in the TWDB methodology both as a percent likelihood (i.e., 50%) of an observable mesohabitat at a given velocity and depth, and the spread of observations relative to TWDB's identified mesohabitat threshold criteria.

While this uncertainty may preclude the identification of a specific flow magnitude (or magnitudes), the information developed by TWDB appears sufficient to warrant a need for multiple levels of base flow. Although the specific relations specified by TWDB may be uncertain, the observed mesohabitats from the Gelwick and Morgan (2000) and Gelwick and Burgess (2002) studies suggest at least one shift as velocity and depth vary. At present, the available information is insufficient to quantify how much of a given mesohabitat might be produced at various flow velocities and depths. Furthermore, the available information base only lends to a general characterization of the habitat requirements of the indicator organisms considered. It is thus not presently defensible to identify specific flow thresholds at which biologically critical mesohabitats would be produced. It has been concluded herein that two base flow components should be preliminarily identified (high and low), in order to capture a range of base flow conditions, recognizing the observed variation (i.e., gradient) in mesohabitat conditions as flows vary.

The statistical characterization of the historic hydrology has been employed to identify seasonal base flows that approximate the orders of magnitude at low and high flows in order to potentially mimic the historical variations in observed mesohabitat characteristics in the watersheds of interest. High base flows are characterized as those flows subsequent to the significant rainfall events observed in the Sulphur River Basin, while lower base flows are intended to be more representative of typical base flow conditions in the system.

9 Analysis of Episodic Events related to Potential Overbanking

A significant assumption employed for the present planning effort is that any proposed water supply strategy which may alter the hydrology of the system must also be designed to operate in a manner that protects life and property downstream of the proposed project.

The processes of developing and adopting environmental flow requirements in other basins have similarly considered overbanking flows. Citing concerns over potential legal liabilities, Stakeholder Committees in the SB 3 process have acknowledged during their balancing of BBEST recommendations the importance of overbanking flows, but avoided recommending their explicit adoption. To date, TCEQ has not adopted environmental flow standards that include overbanking flows at the measurement point.

Recognizing the legal precedent associated with flooding and the potential assignment of legal liability to owners of water rights, specific overbanking components including pulses with peaks that may result in flows in excess of bank-full capacity (overbank flows) have not been included in the identified environmental flow guidelines herein. Thus, to identify high flow pulse conditions that would likely be beneficial to the system, yet remain within the river channel, an estimate of the full flow capacity of the river system has been performed utilizing a HEC-RAS model of the Sulphur River Basin as developed by FNI and data where available.

9.1 Identification of Overbank Flow

To assess characterizing the main-stem channel geometry, a HEC-RAS model representation of the Sulphur River Basin was obtained from FNI (2008). The HEC-RAS model of the Sulphur River Basin was developed by FNI for Federal Emergency Management Association (FEMA) flood plain modeling in 2007 and 2008. The HEC-RAS model utilizes cross sections developed from land surfaces created from a 2006 LIDAR survey of the river basin. In addition to the LIDAR survey, seven road cross sections were surveyed to verify LIDAR accuracy and to adjust channel inverts of the cross sections used in the HEC-RAS model (FNI 2008).

Prior to employing HEC-RAS model output, comparison of the modeled river cross section versus observed river cross sections was performed for six of the seven cross sections surveyed in 2006. These locations are shown as red lines in Figure 62. The survey data are then compared to a HEC-RAS model cross section corresponding to a nearby location. This comparison has been performed to assess how well the model provides an approximation to the observed channel geometry. Figure 63 – Figure 68 present the comparisons of the observed and modeled cross sections.

To estimate the overbanking flow rate of the river system, a series of steady state flow scenarios at multiple river cross sections have been modeled, and the model output used to identify a flow range when the river enters an overbank condition at a cross section. For this analysis, overbank flow is considered the flow rate at which the water surface elevation at a cross section rises above the elevation of the right or left bank of the river channel and water flows into the floodplain. The modeled water surface elevations at varying flow rates are compared to the modeled left and right bank elevations of the river channel. The first flow rate scenario which has a modeled water surface elevation above the left or right bank elevation is considered as overbanking at a particular cross section.

Select cross sections in each reach of the Sulphur River Basin were utilized for estimation of overbank flow. Highly channelized reaches had fewer cross sections selected for overbank estimation, while the cross sections representing the river reach approaching the proposed Marvin Nichols project location and downstream were evaluated with a higher number of cross-sections (See Figure 69). The analysis described above has been performed for the selected cross sections on the North Sulphur River, South Sulphur River, Sulphur River, and White Oak Creek. Representations of the estimated overbank flow rates from upstream to downstream of each reach are shown in Figure 69.

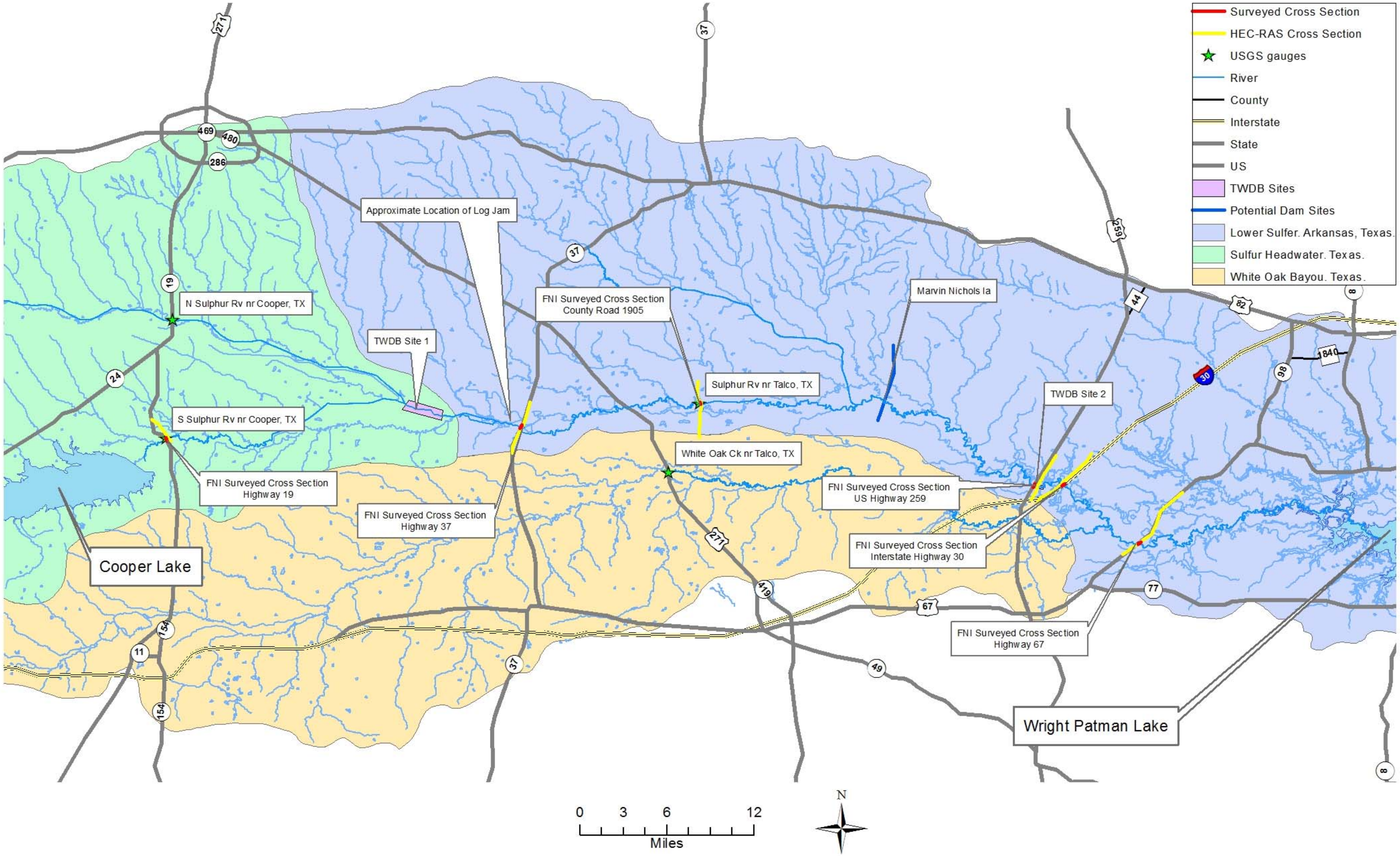

Figure 62: Map of Project locations relative to physically surveyed channel cross sections

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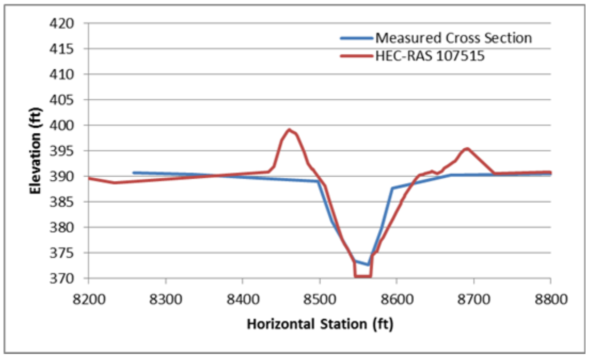

Figure 63: South Sulphur River at Highway 19 (South Sulphur River at Cooper USGS gauge site).

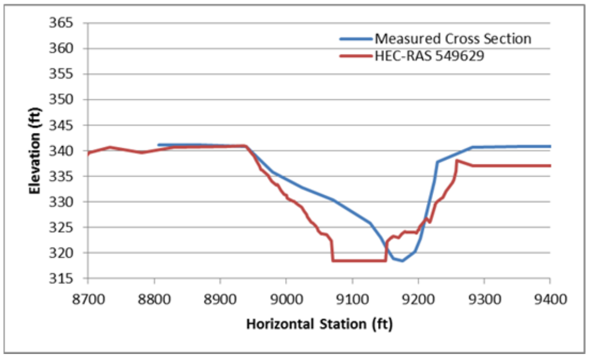

Figure 64: Sulphur River at Highway 37.

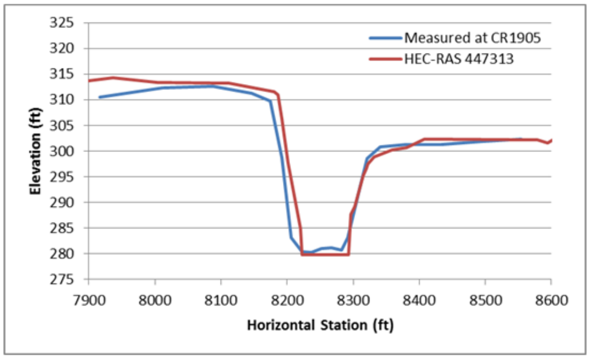

Figure 65: Sulphur River at county Road 1905 (Sulphur River near Talco gauge site).

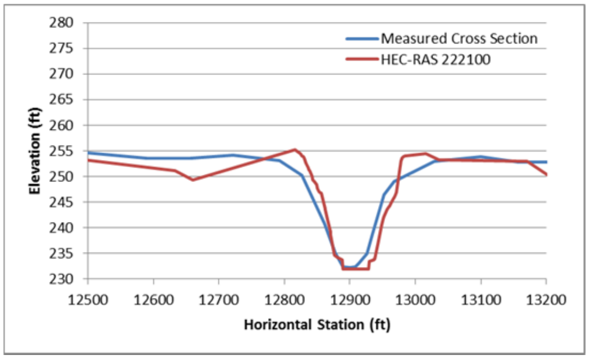

Figure 66: Sulphur River at US 259.

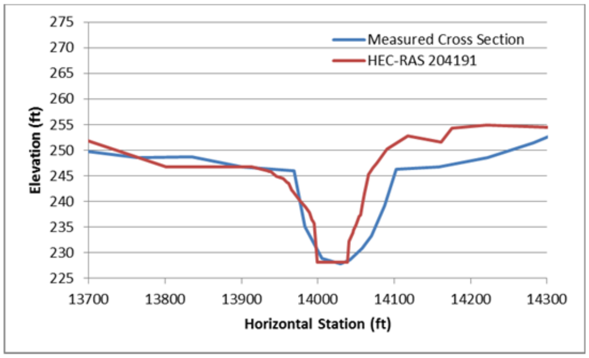

Figure 67: Sulphur River at Interstate 30.

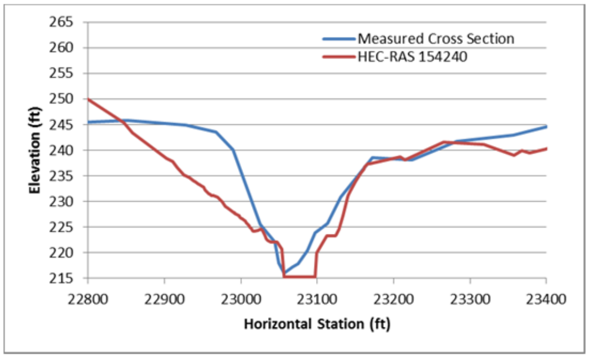

Figure 68: Sulphur River at Highway 67.

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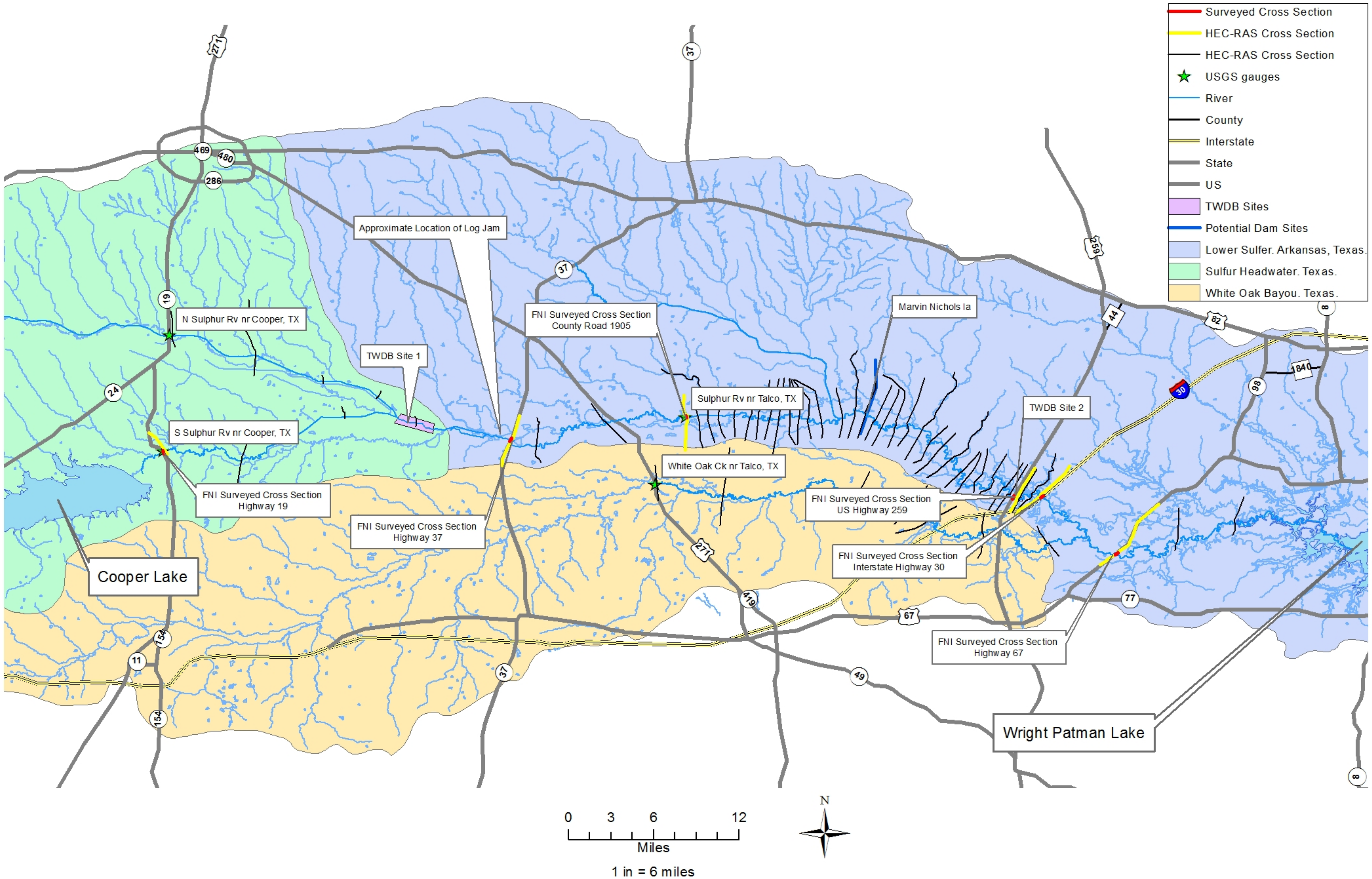

Figure 69: HEC-RAS model cross sections employed for potential overbank flow rate calculations.

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All of the manually surveyed cross sections occur on transects lying between the HEC-RAS cross sections, explaining some of the inconsistencies. As seen in Figure 63, Figure 65, and Figure 66, half of the observed cross sections appear generally consistent with their model representations. The remaining cross sections (Figure 64, Figure 67, and Figure 68) generally match one side of the channel well, with the other bank of the channel having varying shape. While these variations demonstrate a margin of error, it must be considered that the channel shape constantly changes along the reach, and variation of this magnitude is possible.

In order to avoid the likelihood of flooding of low-lying areas, first the minimum peak flow rate at which an overbank event occurs must be identified. HEC-RAS modeled overbank flows along the North Sulphur River suggest this reach is highly channelized (as expected), with the lowest overbank flow at approximately 30,000 cfs. The modeled overbank flow of the South Sulphur River declines from approximately 50,000 cfs to approximately 10,000 cfs. The modeled overbank flow along the main channel Sulphur River varies from greater than 90,000 cfs to approximately 2,700 cfs, making this lower magnitude the most restrictive in terms of overbank flows along the mainstem Sulphur River. Modeled overbank flows along White Oak Creek are more restrictive; however, these restrictions impact only White Oak Creek. The estimated overbank flow range along White Oak Creek ranges from approximately 7,000 cfs to approximately 280 cfs at the downstream end of the watershed. The spatial relation of these modeled overbanking flow magnitudes is portrayed in Figure 70.

Observations are available at the TWDB study site located downstream of the proposed Marvin Nichols IA dam site. Osting et. al. (2004) reports approximately 830 cfs of flow in the Sulphur River raises the water surface level to an elevation which leaves the main flow channel and reconnects cutoff channels. The TWDB also recorded an overbank flow rate of nearly 3,500 cfs, reporting that at the observed flow rate much of the flood plain was also inundated (Osting et. al. 2004). National Weather Service (NWS) action stages for selected USGS gauge stations were reviewed to get estimated flow rates at the action stage. Comparison of the NWS Action stage flow rates to the HEC-RAS overbank flows are presented in Table 22.

Table 22: NWS Action stage values with estimated flows for USGS sites versus modeled and observed overbank flows.

USGS Gauge	NWS Action Stage (cfs)	HEC-RAS Characterization (cfs)	TWDB measurement (cfs)
North Sulphur Near Cooper	39,000	70,000	
South Sulphur Near Cooper	2,500	50,000	
Sulphur River Near Talco	2,700	9,000	3,500*
White Oak Creek near Talco	1,900	3,000	

*At a location several miles downstream of USGS gauge. Similar region in HEC-RAS model estimated at 4000 cfs.

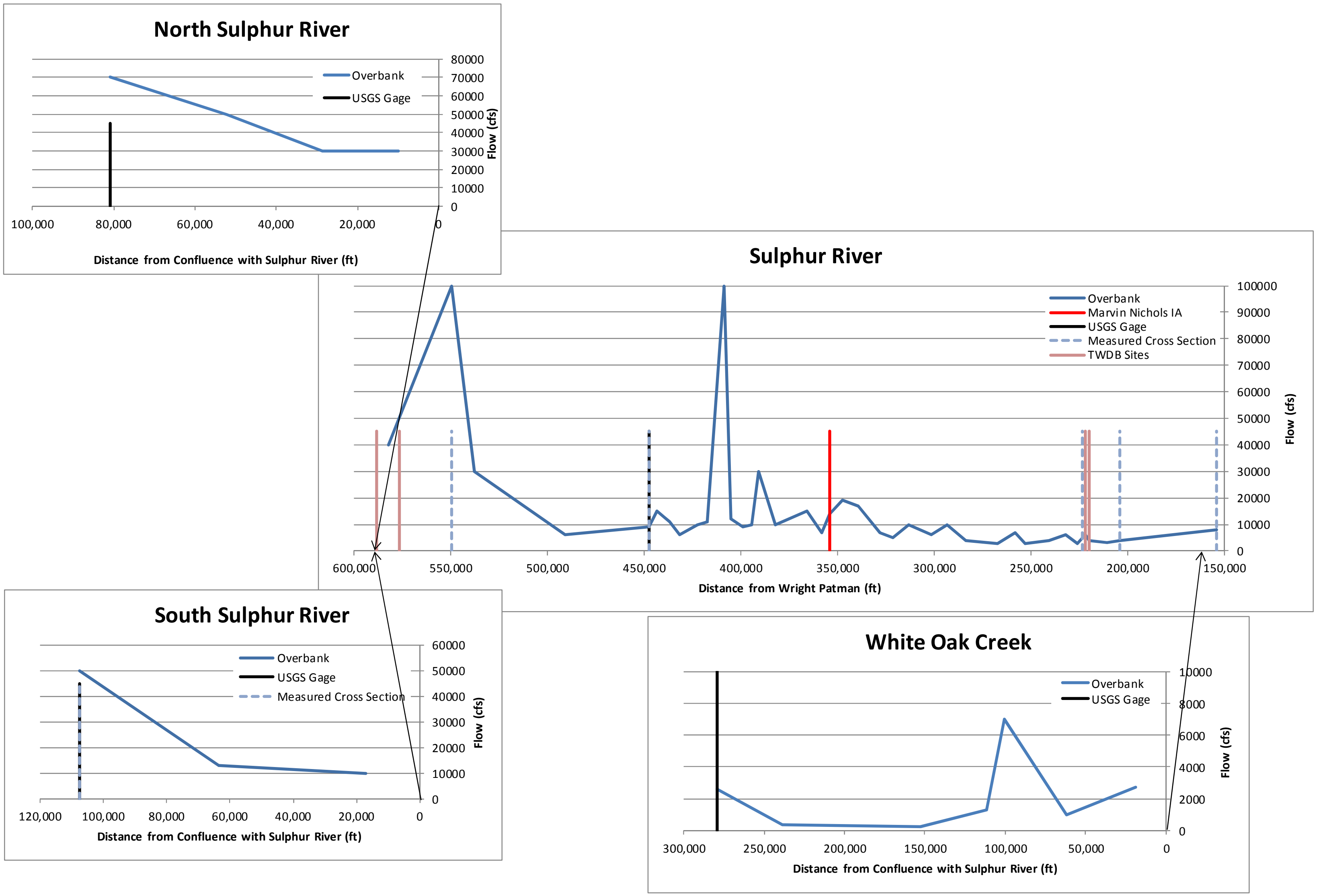

Figure 70: HEC-RAS model predicted overbank flows along Sulphur River Basin, oriented to approximate spatial layout of the watershed.

The observed discrepancy between the overbank flow values estimated using the HEC-RAS model versus the NWS action stage and USGS rating curve could result from several factors. The primary reason for the differences is the one dimensional nature of the HEC-RAS model and the cross-section data. For example, some cross sections in the HEC-RAS model span not only the main channel of the river, but may also include smaller tributary channels. The HEC-RAS model considers the entire length of a cross section when performing flow calculations, thus if a tributary happens to be included in the cross section and that tributary conveys flow prior to the model water surface elevation reaching the overbank elevation, then its flow also contributes to the total flow rate modeled through the cross section.

Another possible explanation for the difference in values could be what the NWS flow targets represent. For example, an interpretation of overbank flow could be the flow at which water begins to leave the main channel but remains within the banks of the old river channel, cutoff channels and oxbows. While another interpretation of overbank flow could be the flow at which water enters the flood plain. These values can vary widely depending on the surrounding terrain and movement of the river. An example of this wide flow range is present at TWDB's study site 2 downstream of the proposed Marvin Nichols IA reservoir, where TWDB reports that short circuiting of flow occurs at around 830 cfs as the cutoff channels begin to convey water (overbank of the main channel), while overbank of the river into the flood plain does not occur until nearly 3,500 cfs.

For the present effort high flow pulses were identified as an overbank event based on a magnitude of 2,700 cfs, the NWS action stage for the measurement point at the USGS Sulphur River near Talco gauge. This approach is consistent with previous precedents for the identification of overbank flows in the SB 3 process in other river basins.

9.2 Translation Methods

To develop guidelines at the project location, each component of the flow regime must be spatially translated from the flow magnitudes identified at a gauge location or a location at which a known flow is desired. For the derivation of pulse guidelines (in terms of peak flow, volume, duration, and frequency), analyses of historic episodic events at USGS gauges approximate to a given water supply alternative project location are first performed utilizing HEFR. Once seasonal and annual pulse criteria are derived at the gauge location, these criteria are translated to the water supply project location using a TCEQ Pulse Translation Methodology. The TCEQ Pulse Translation Methodology has been utilized herein to translate pulses from upstream gauged locations to downstream ungauged locations. Base and subsistence flows at a USGS gauge location are translated to alternative locations using a straightforward drainage area ratio.

9.2.1 TCEQ Pulse Translation

The TCEQ Pulse Translation methodology can be based on the National Hydrography Dataset (NHDPlus) or TCEQ WAM hydrology for the applicable basin. The TCEQ translation methodology uses mean annual naturalized[3] flow at an upstream location and at a downstream location to develop a ratio to be applied for translation of a pulse flows peak flow rate, volume, and duration.

9.3 Overbank Limitation of Pulse Flow

Given the aforementioned precedent, environmental flow pulse peak amounts should not result in an overbank event at the measurement location. As discussed in the previous section, overbank flows in channelized sections of the river are much higher in volume and in the resultant water surface elevation than the overbank flows in non-channelized portions of the river.

The TWDB study identifies an overbank flow rate of approximately 3,200 cfs downstream of the proposed Marvin Nichols reservoir site, while the HEC-RAS model representation of the area suggests that overbank occurs at approximately 4,000 cfs at an elevation of 254 feet mean sea level at the TWDB study site. Furthermore, the elevation of the top of flood control pool of Wright Patman Lake is reported as 259.5 feet above mean sea level (USACE). This suggests that overbank conditions upstream of Wright Patman can occur upstream of the TWDB study site and US Highway 259 when Wright Patman nears its flood control volume. When Wright Patman is not at flood capacity, the HEC-RAS model estimated channel capacity of the Sulphur River downstream of Marvin Nichols to the head waters of Wright Patman ranges from approximately 2,700 to 19,000 cfs before beginning to overbank.

In their adoption of SB3 environmental flow standards in other Texas river basins, the TCEQ has previously considered the conditions at the measurement point of the criteria. It is not apparent if consideration of the potential for downstream overbanking due to a pulse flow requirement at a given location has been given. For the analysis herein the overbank limitation at the USGS Sulphur River near Talco gauge (No. 07343200) has been identified as 2,700 cfs.

[3] "Naturalized", in this context, is not to be confused with the flow naturalization process used by TCEQ in the development and prosecution of Texas Water Availability Models (WAM's). The naturalized flows described here can also be developed through a separate process by the USGS and USEPA (McKay, et. al., 2012).

This overbank amount is based on the NWS action stage at this measurement point, presented in Figure 71. Thus, the maximum environmental pulse flow guidelines identified for each of the potential water supply alternatives have been specified as those peak flows that contribute to no more than a maximum 2,700 cfs pulse peak flow in the Sulphur River near Talco.

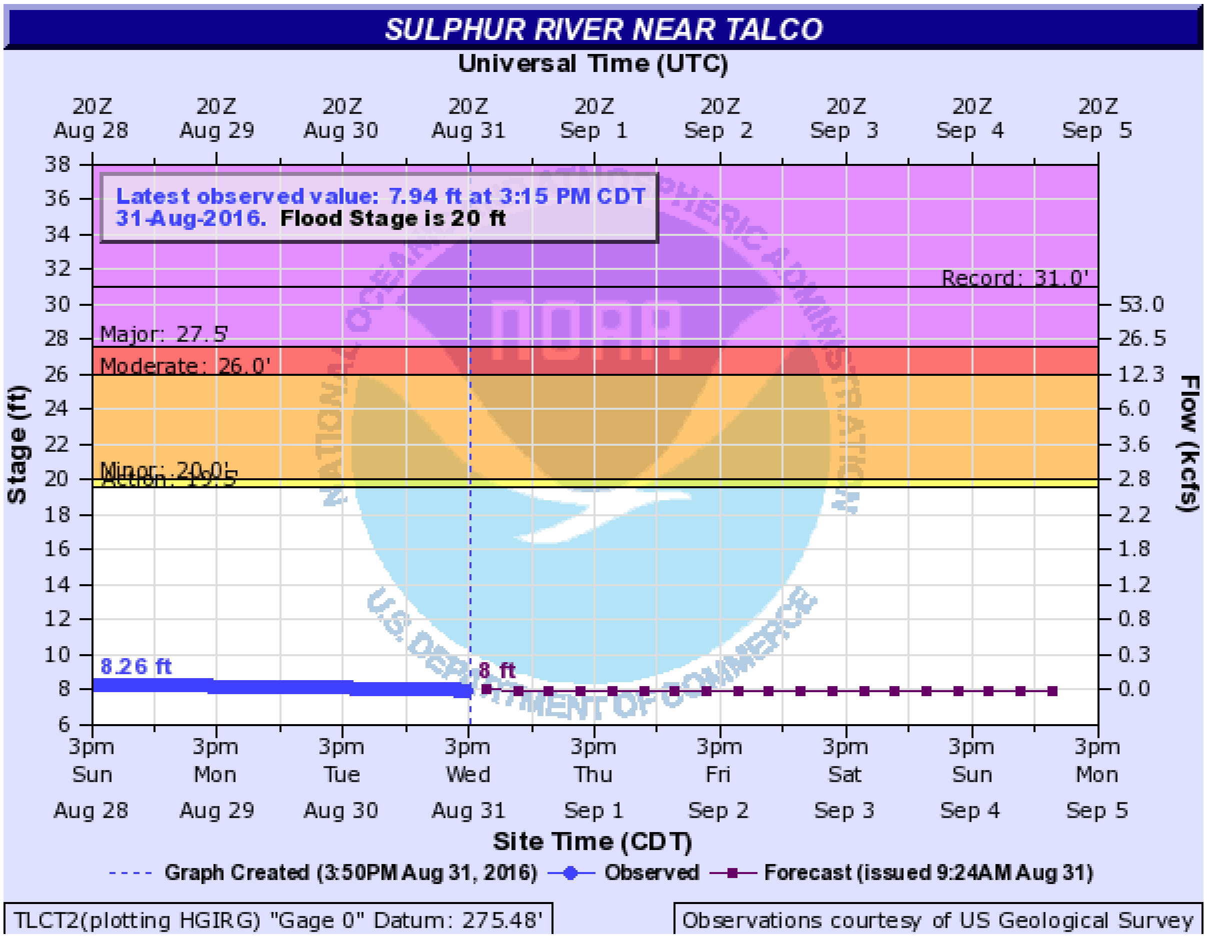

Figure 71: NWS Action Stage chart for Sulphur River near Talco

9.4 WAM Implementation Considerations

Having developed preliminary flow guidelines, implementation into the Water Availability Model (WAM) must be taken into consideration. With preliminary peak flow triggers for seasonal and annual pulses developed, the historical frequency of occurrence of these pulses is identified. Depictions of the seasonal frequency distribution of peak flow plots, similar to the one shown in Figure 72, were developed through application of HEFR, and are utilized to identify the historic frequency of occurrence of various peak flow rates. For example, at the USGS Sulphur River near Talco gauge (No. 07343200) a small winter pulse with a peak flow is 2,500 cfs is found to have historically occurred at an average frequency of 5 pulses per season.

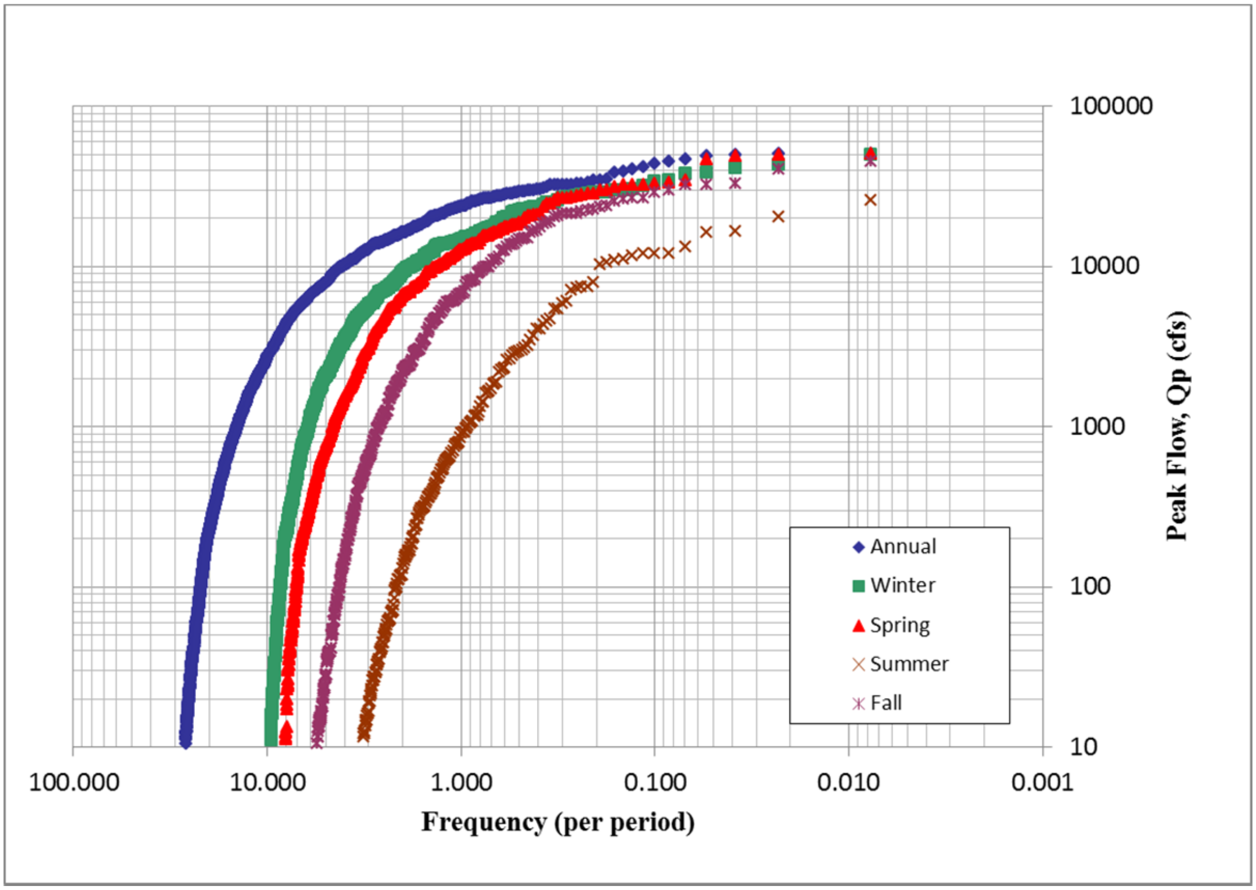

Figure 72: Seasonal and Annual Pulse Flow Frequency Distributions by Peak Flow (USGS Sulphur River near Talco gauge No. 07343200)

Past implementations of seasonal pulse flow criteria in the WAM by TCEQ has not exceeded the number of months in a single season. At present, for the river basins in which riverine environmental flow standards have been adopted via the Senate Bill 3 process, only one to four pulse flow events per season have been implemented. Currently, the TCEQ implements seasonal pulse criteria in the WAM by checking for one pulse a month, which affords a maximum number of pulses per season equal to the number of months in the season. Said another way, under the TCEQ implementation of pulse flow criteria in the WAM, a spring season defined as being three months long only has a maximum of three pulses identified, and these pulses are accounted individually by counting a single pulse volume per month in the season up to a maximum of four pulses (in a 4-month season).

10 Environmental Flow Guidelines

Having compiled and evaluated the available data and statistics regarding hydrology, biology, ecology, and climate, environmental flow guidelines have been identified. Implementation of such guidelines is an equally important consideration, and is thus discussed in Section 11.1 below. The identified environmental flow guidelines for each water supply alternative under consideration are summarized in Sections 10.2.1 and 10.2.3 below. The locations of the identified environmental flow guidelines relevant to each potential water supply alternative are depicted in Figure 73.

10.1 General Implementation

An essential component of the specification of environmental flow guidelines is delineating how such numerical elements might be applied to new surface water appropriations, particularly as they relate to Water Availability Modeling (WAM), as WAM is the tool utilized herein to determine priority flows (consisting of pass through amounts for senior water rights and environmental flows) that feed forward into subsequent analyses of firm supply available from the alternative water supply projects under consideration. Thus, some general information regarding each component of the flow regime, and the potential application (or implementation) of these components is summarized in this section, progressing from low- to high-flow components. (Model implementation is discussed later in this report in Section 11).

10.1.1 General Consideration

Flows passed for senior water rights count toward satisfaction of any specified subsistence, base, and pulse flow rates and volumes. Further, the identified components comprise a flow regime, and should not be implemented individually.

10.1.2 Subsistence Flow

Ecological functions of subsistence flows include provision for aquatic habitat, longitudinal connectivity, dissolved oxygen, and temperature sufficient to ensure survival of aquatic species through low flow periods to the extent possible while recognizing that the stream segments in the Sulphur River Basin are significantly variable. The translation of seasonal subsistence flows into potential special conditions should not result in a more frequent occurrence of flows less than the identified seasonal subsistence guidelines as a result of a new surface water project. In those instances where subsistence flows are specified that result in a value lower than 1 cfs, the subsistence guideline has been set at 1 cfs. If inflow is less than the seasonal subsistence value, then all inflow should be passed and none impounded or diverted.

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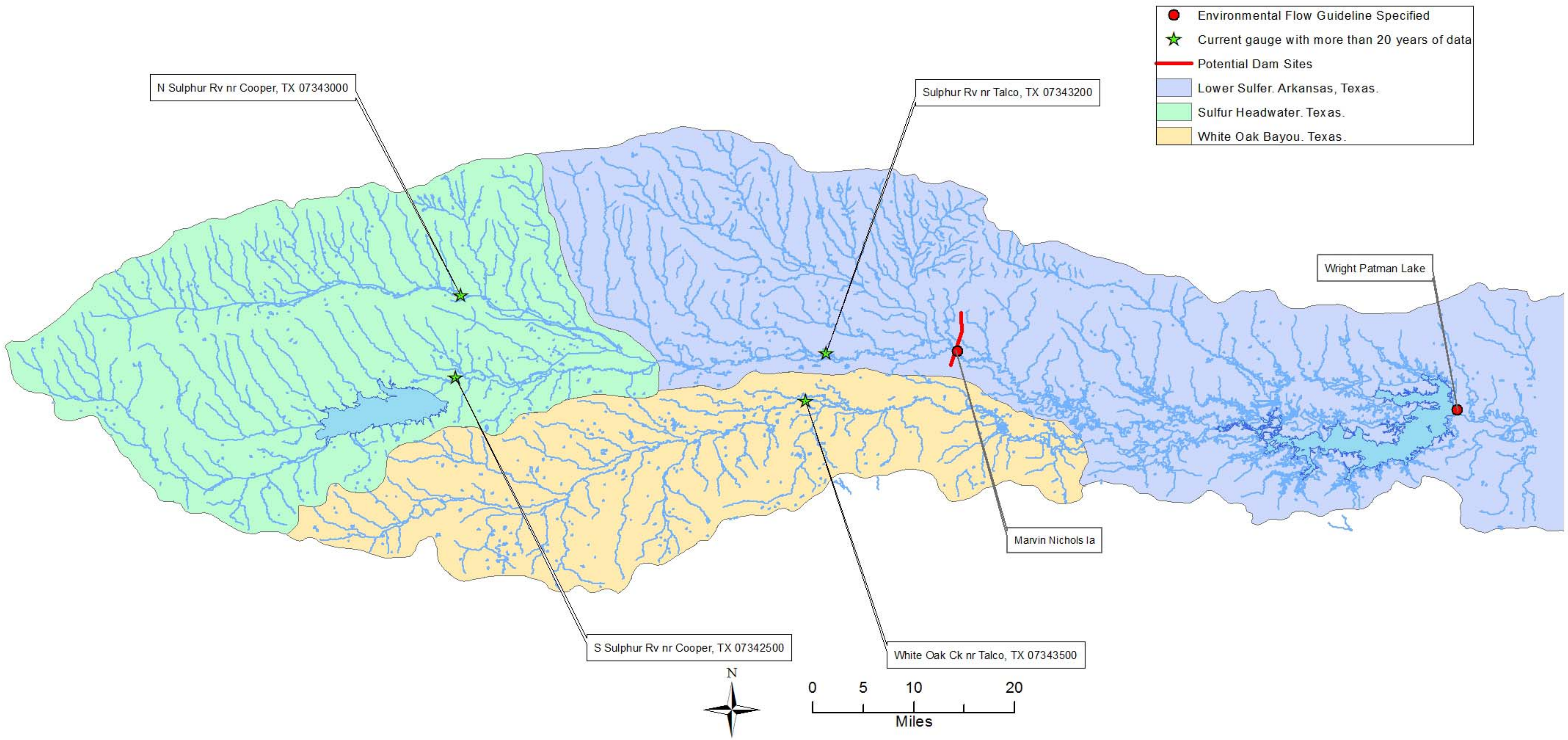

Figure 73: Environmental Flow Guideline Locations

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10.1.3 Base Flow and 50% Rule

Base flows provide variable flow conditions, suitable and diverse aquatic habitat, longitudinal connectivity, soil moisture, and water quality sufficient to sustain aquatic species and proximate riparian vegetation for extended periods. As simply stated in SAC guidance, “base flows provide instream habitat conditions needed to maintain the diversity of biological communities in streams and rivers (SAC, August 31, 2009).” To remain generally consistent with approaches utilized by TCEQ during the SB 3 process in other basins in Texas, specific implementation guidelines regarding application of the base flow component are summarized as follows:

a. If inflow is less than the lowest seasonal base value and greater than the seasonal subsistence value, then the seasonal subsistence flow plus 50 percent of the difference between inflow and the seasonal subsistence value should be passed, and the balance may be impounded or diverted to the extent available, subject to senior water rights. This “50% Rule” is identified for each of the identified locations.

b. If inflow is less than the highest base flow value and greater than the lowest base value, then that the lowest seasonal base value must be passed, and the balance may be impounded or diverted to the extent available, subject to senior water rights.

c. If inflow is less than the lowest applicable pulse peak value and greater than the highest seasonal base value, then that highest seasonal base value must be passed, and the balance may be impounded or diverted to the extent available, subject to senior water rights.

10.1.4 High Flow Pulses

Generally, high flow pulses provide elevated in-channel flows of short duration, recruitment events for organisms, lateral connectivity, channel and substrate maintenance, limitation of riparian vegetation encroachment, and in-channel water quality restoration after prolonged low flow periods as necessary for long-term support of a sound ecological environment. Guidelines regarding application of the high flow pulse components are summarized as follows:

a. Applicable high flow pulses for a new surface water appropriation are to be determined in accordance with the Pulse Exemption Rule as described below.

b. If inflow is greater than a specified peak flow (Qp), and all applicable pulse recommendations have not been satisfied, then all inflow up to the peak flow must be passed until either the recommended volume or duration has passed, and the balance of inflow may be impounded or diverted to the extent available, subject to senior water rights.

c. If all applicable pulse recommendations have been satisfied and inflow is greater than the seasonal base value, then that seasonal base value must be passed, and the balance may be impounded or diverted to the extent available, subject to senior water rights.

d. Pulse events are identified upon occurrence of specified trigger flow, counted in the season or year in which they begin, and assumed to continue into the following season or year as necessary to meet specified volumes or durations. Once a pulse event has been identified, volumes passed during the event, but prior to exceeding the specified trigger flow (equivalent to Qp in the environmental flow guidelines), may be credited towards the specified volume requirement.

e. One pulse counts towards the specified achievement frequency, and resets at the season or return period end.

f. Each return period (i.e., season, series of months, one-year, two-years, or five-years) is independent of the preceding and subsequent return period with respect to high flow pulse attainment frequency.

10.1.5 Potential Adjustment

The adopted SB 3 standards contemplate the potential impacts, both positive and negative, from future adjustments to adopted environmental flow conditions. Texas Administrative Code (TAC) §298.25(h) provides specific instruction regarding the process for adjusting environmental flow conditions in certain permits as follows:

> *"(h) The environmental flow adjustment, in combination with any previous adjustments made under this section may not increase the amount of the environmental flow pass-through or release requirement for a water right permit by more than 12.5% of the annualized total of that requirement contained in the permit as issued or of that requirement contained in the amended water right and applicable only to the increase in the amount of water authorized to be stored, taken, or diverted under the amended water right permit. Any new permit conditions must be consistent with the environmental flow standards to the maximum extent practicable.*

10.2 Identified Environmental Flow Guidelines

The following sub-sections provide the numerical elements of the identified Sulphur River Basin environmental flow guidelines, and a summary discussion on their derivation.

10.2.1 Marvin Nichols

Environmental flow guidelines identified for the Marvin Nichols Project location are presented in Table 23. The estimated flow guidelines are developed utilizing the hydrologic characteristics of USGS Sulphur River near Talco gauge (No. 07343200) as discussed in Section 6.1, in conjunction with the general biological and ecological flow needs identified in the literature review.

Table 23: Marvin Nichols Project Location Environmental Flow Guidelines

Season	Subsistence	Base Low	Base High	Pulse
Winter	1.5 cfs	17 cfs	241 cfs	4 per season
				Trigger: 3,789 cfs
				Volume: 23,136 af
				Duration: 7 days
Spring	1.5 cfs	20 cfs	168 cfs	3 per season
				Trigger: 3,789 cfs
				Volume: 21,162 af
				Duration: 6 days
Summer	1.5 cfs	5.6 cfs	23 cfs	2 per season
				Trigger: 168 cfs
				Volume: 1,001 af
				Duration: 5 days
Fall	1.5 cfs	6.1 cfs	48 cfs	2 per season
				Trigger: 2,975 cfs
				Volume: 16,940 af
				Duration: 7 days

The subsistence flow is the calculated 7Q2 flow value at USGS Sulphur River near Talco gauge (No. 07343200) over the 1950-2014 time period, translated to the project location using a drainage area ratio. As presented in Section 9, two levels of base flow have been identified based on the TWDB's analysis of available mesohabitat across multiple ranges of stream flow along a 0.85 river mile reach of the Sulphur River located west of US-259 and north of IH-30. These two levels of base flow have been identified to maintain the historical seasonal variation of a range of flows spanning the two broad levels of the mesohabitat characteristics. The high base flow is characterized from the historical statistics by the 75th percentile of seasonal flows (as characterized with the present application of IHA). In addition, the 25th percentile of seasonal flows best represents the low base flow level.

The pulse guideline identified herein is the translated pulse peak flow from the Sulphur River near Talco gauge location that would not result in overbanking of the channel at the measurement location. Seasonal pulses have been identified wherein the identified frequency does not exceed the number of months in the season, allowing for implementation within WAM consistent with previous TCEQ approaches for representing pulse frequency.

10.2.2 Wright Patman (Translated)

Environmental flow guidelines estimated at Wright Patman are presented Table 24. The estimated flow guidelines have been developed based upon the environmental flow guidelines identified at the Sulphur River near Talco, which have been translated downstream to Wright Patman using the TCEQ's pulse translation methodology. Little other specific information regarding biological needs or water quality is available; thus, base and high flow conditions have been derived using the same statistics as used to develop guidelines at the USGS Sulphur River near Talco gauge (No. 07343200). The translation method has been used in order to develop a more natural representation of hydrologic conditions unaffected by historical Wright Patman releases.

The subsistence flow is the calculated 7Q2 flow amount at USGS Sulphur River near Talco gauge (No. 07343200) over the 1950-2014 time period, translated to the project location using a drainage area ratio. The high and low base flow levels are the 75th and 25th percentiles, respectively, of seasonal flow at the USGS Sulphur River near Talco gauge (07343200), translated to the project location using a drainage area ratio.

Seasonal pulses at Wright Patman are the seasonal pulses identified at USGS Sulphur River near Talco gauge (No. 07343200), translated to the project location using TCEQ's pulse translation methodology.

Table 24: Wright Patman Location Environmental Flow Guidelines (Translated)

Season	Subsistence	Base Low	Base High	Pulse
Winter	2.7 cfs	32 cfs	435 cfs	4 per season
				Trigger: 6,823 cfs
				Volume: 44,310 af
				Duration: 7 days
Spring	2.7 cfs	36 cfs	304 cfs	3 per season
				Trigger: 6,823 cfs
				Volume: 40,530 af
				Duration: 7 days
Summer	2.7 cfs	10 cfs	41 cfs	2 per season
				Trigger: 303 cfs
				Volume: 1,916 af
				Duration: 6 days
Fall	2.7 cfs	11 cfs	87 cfs	2 per season
				Trigger: 5,357 cfs
				Volume: 32,444 af
				Duration: 8 days

10.2.3 Wright Patman (Releases)

Calculated environmental flow guidelines estimated at Wright Patman based on adjusted historical releases are presented in Table 25. These estimated flow guidelines have been developed utilizing the hydrologic characteristics of adjusted historic releases from Wright Patman as discussed in Section 6.2 for comparative purposes to the more natural, translated guidelines. Little other information regarding biological needs or water quality is available; thus, base and high flow conditions have been derived using the same statistics as used to develop guidelines at the Sulphur River near Talco USGS gauge.

The subsistence flow is the 7Q2 flow value based on the analyzed historical discharge data (1982-2014) and reflects the USACE contractual release rate of 10 cfs. Two levels of base flow have been identified. The high base flow is characterized from the historical statistics by the 75th percentile of seasonal flows (as characterized with the present application of IHA), which reflects a seasonal distribution of the historical releases from Wright Patman. The low base flow is characterized by the 25th percentile of seasonal flows, reflecting lower magnitudes of releases that have been consistently observed. Due to a lack of additional data characterizing the river downstream of Wright Patman, a single pulse level has been identified similar to those identified for Marvin Nichols. Seasonal pulses with an average historical frequency of 1 per season have been utilized for implementation within the WAM in a manner consistent with previous TCEQ implementations of environmental flows.

Table 25: Wright Patman Location Environmental Flow Guidelines

Season	Subsistence	Base Low	Base High	Pulse
Winter	10 cfs	208 cfs	992 cfs	1 per season Trigger: 6,764 cfs Volume: 291,980 af Duration: 34 days
Spring	10 cfs	228 cfs	744 cfs	1 per season Trigger: 2,784 cfs Volume: 77,324 af Duration: 20 days
Summer	10 cfs	227 cfs	544 cfs	
Fall	10 cfs	221 cfs	1,033 cfs	1 per season Trigger: 1,096 cfs Volume: 19,428 af Duration: 12 days

11 Conclusions

11.1 Summary of Results

The present effort has been performed to develop and employ potential environmental flow guidelines consistent with the SB 3 framework, highlight important decision points throughout their development, and implement them in a WAM context for SBG's subsequent assessment of their impacts on various water supply alternatives under current consideration in the Sulphur River Basin. It is important to note that such an effort is not intended to pre-empt a SB 3 process for the Sulphur River Basin. Indeed, there are many variables to consider when anticipating the results of a Senate Bill 3 process, the most significant of which are the potential balancing processes to be applied by both stakeholders and TCEQ prior to the development of an environmental flow standard, and their subsequent implementation by TCEQ.

This study has generally consisted of three work elements: (1) a comprehensive literature review compiling and organizing existing historical information on the hydrology, biology, physical habitat, physical processes (geomorphology), and water quality of the study area, (2) hydrologic analyses of streamflow at relevant and available gauge locations for development of hydrology-based environmental flow guidelines, and (3) an initial implementation of the guidelines in a WAM context for subsequent evaluation of their impacts on modeled firm yields of alternative projects.

A significant finding of this study, in terms of the available science, is that at present there appears to be little information that quantifies a direct relation between instream flow and metrics of ecological health. While there is broad consensus that flows are a key component for the maintenance of a sound ecological environment, the best science available specific to the Sulphur River Basin offers data and modeling on flows and their relation to the presence of mesohabitat and sub-mesohabitat conditions for two sites in the watershed. The available data related to these conditions have been utilized herein to broadly identify a range of base flow conditions.

While there are substantial data available with regard to water quality, direct relations to flow magnitude were not identifiable. Recognizing that SAC guidance recommends that a comprehensive flow regime include atypical, low flow conditions, subsistence flow metrics have been developed solely utilizing statistics from the historical hydrology, namely 7Q2.

Recognizing the legal precedent associated with flooding and the potential assignment of legal liability to owners of water rights, specific overbanking components including pulses with peaks that may result in flows in excess of bank-full capacity (overbank flows) have not been included in the identified environmental flow guidelines herein. Rather, that information has been utilized to establish a maximum magnitude of pulse flow at the measurement location (consistent with TCEQ's methodology in other river basins), allowing for the specification of high flow pulses again utilizing statistics from the historical hydrology. While literature sources were used to identify potential ecological indicators and their general ecological requirements, this general information was used largely to support that pulse flows are a necessary component of the flow regime. Information identifying the specific magnitude, timing, and frequency of such pulses necessary to maintain a sound ecological environment in the Sulphur River Basin has not been identified.

The resultant environmental flow guidelines will be implemented within the SBG Sulphur Basin "Mini-WAM" to identify priority releases recognizing water right priorities and potential application of environmental flow guidelines. These modeled priority releases will ultimately be used to ascertain potential impacts on water supply alternatives presently under consideration.

Consistent with the SB 3 process in other basins, no releases from storage are required to produce achievement of a given environmental flow criterion. Rather, the evaluation is made as to whether inflow conditions trigger the requirement of an environmental flow guideline. Said differently, if the flows are present they must be passed, but if the flows are not present, they do not have to be produced.

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Appendix A - Publications Found During Literature Review

Appendix A
Publications Found During Literature Review

Literature Review			
Type of Study	**Name of Study**	**Author/s**	**Year**
Everything	Sulphur River Basin Highlights Report, FYs 2009-2010	SRBA	2009
Everything	Analysis of Instream Flows for the Sulphur River: Hydrology, Hydraulics & Fish Habitat	Osting, Mathews, Austin	2004
Biology, Physical Habitat	2008 Survey Report Wright Patman Reservoir	Brice, Bister	2008
Biology, Physical Habitat	2007 Survey Report Cooper Reservoir	Jubar, Storey	2008
Biology, Physical Habitat	Summer fish assemblages in channelized and unchannelized reaches of the South Sul	Christine Conner Burgess	2003
Biology, Habitat	An analysis of bottomland hardwood areas at three proposed reservoir sites in northeast Texas	TPWD	1997
Biology, Habitat	Texas bottomland hardwood preservation program	USFWS	1985
Biology, Habitat	Aquatic Studies at the proposed George Parkhouse I Reservor site on the South Sulphur River in Northeast Texas (TR-244)	Gelwick and Burgess	2002
Biology, Habitat	Microhabitat use and community structure of fishes downstream of the proposed George Parkhouse I and Marvin Nichols I reservoir sites on the Sulphur River, TX	Gelwick and Morgan	2000
Biology, Habitat	Habitat associations of fish assemblages in the Sulphur River, Texas	Morgan	2002
Biology	Distribution and species diversity of summer fish populations in two channelized rivers in Northeast Texas	Carrol, Ingold and Bradley	1977
Hydrology, Water Quality	Reconnaissance of the Chemical Quality of Surface Waters of the Sulphur River and Cypress Creek Basins, Texas	Leifeste	1968
Hydrology, Physical Habitat	Surface Water/ Groundwater Interaction Evaluation for 22 Texas River Basins	Parsons Engineering Science,	1999
Hydrology	Reservoir Site Protection Study	R.J Brandes Company, HDR, Freese & Nichols	2007
Water Quality	Sulphur River Basin Reservoir Report	Freese and Nichols and Alan Plummer and Associates	2000
Water Quality	Surface Water Quality Monitoring (SWQM) datat	TCEQ	
Hydrology	Hydrologic and hydraulic Models	Freese and Nichols	2008
Suspended Sediment Load	Suspended-sediment load of Texas streams	James Mirabal	1971
Water Supply	Preliminary study of sources of additonal water supply	Freese and Nicols	1996
Sys Ops	Systerm operation assessment of Lake Wright Patman and Lake Jim Chapman vol I and II	Freese and Nichols	2003