Instream Flow Study of the Lower Sabine River

Draft Study Design

Prepared for

Lower Sabine River Sub-Basin Study Design Workgroup

Prepared by

TEXAS INSTREAM FLOW PROGRAM
AND SABINE RIVER AUTHORITY OF TEXAS

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1.0 INTRODUCTION

Beginning in northeast Texas, the Sabine River flows southeast and eventually forms the border between Texas and Louisiana before emptying into Sabine Lake. Formed by three main forks, the Cowleech, Caddo, and South forks, the river is 360 mi. long (BEG 1996a) and has the largest volume of water discharged (approximately 6,800,000 acre-feet) at its mouth of any river in Texas (TCEQ 2004). Rainfall varies from 41 in. near the headwaters to 59 in. at the Gulf of Mexico (SRA-Texas 2004). Total drainage area for the Sabine River basin is 9,756 square miles (BEG 1996a). The basin is characterized by low rolling, forested hills and wide, timbered floodplains. The upper watershed lies within the Blackland Prairies (BEG 1996b) and consists of predominately agricultural lands, oak forests and wetlands. However, the majority (88%) of the basin lies within the Gulf Coast Prairies and Marshes ecoregion and consists of mostly forested lands, agricultural lands and wetlands. Underlying the Sabine basin are two major aquifers: the Carrizo-Wilcox and the Queen City-Sparta; as well as the Gulf Coast aquifers: Jasper, Evangeline and Chicot (SRA-Texas 2004).

The lower Sabine River ecosystem has been influenced by the construction of large reservoirs, water development, and hydropower operations. Toledo Bend Reservoir, in Panola, Shelby, Sabine, and Newton counties and DeSoto and Sabine parishes, is the largest impoundment in Texas or Louisiana and controls the flow of the lower Sabine River. The Sabine River Authority of Texas (SRA-Texas) has water rights authorizing impoundment of 4,477,000 acre-feet and diversion and use of 750,000 acre-feet for municipal, industrial, and agricultural purposes. Lake Tawakoni in Hunt, Rains and Van Zandt counties, is a water storage reservoir and influences the upper portion of the river. A third major reservoir, Lake Fork, is also upstream of Toledo Bend. Smaller reservoirs include Greenville, Quitman, Holbrook, Hawkins, Winnsboro, Gladewater, Cherokee, Martin, Murvaul, Brandy Branch, Anacoco, and Vernon. Storage capacity in the Sabine basin reservoirs exceeds 6.0 million acre-feet (BEG 1996a). Demands to export more water from the basin are expected to increase given the surrounding population growth (e.g. DFW and Houston) and the abundant water resources and storage capacity in the Sabine basin. Population in the East Texas (Region I) water planning region is projected to grow 36 percent to 1,482,448 by 2060 (TWDB 2007). By 2060, the North East Texas (Region D) water planning region's population is projected to grow 57 percent to 1,213,095 (TWDB 2007). SRA-Texas has a water rights permit application pending at the Texas Commission on Environmental Quality (TCEQ) for an additional 293,300 acre-feet diversion from Toledo Bend Reservoir. Relicensing of the Toledo Bend Hydropower Project is underway given that the Federal Energy Regulatory Commission (FERC) license for the project expires in 2013.

Principal cities include Longview, Greenville, Kilgore, Marshall, Orange, Bridge City and Gladewater. Consisting of all or part of 21 counties, the Sabine River basin has approximately 650,000 in population according to U.S. 2000 Census figures[1]. Regional economies include petroleum and mineral production, timber, agriculture, manufacturing, shipping, recreation and tourism (SRA-Texas 2004). During the late 19th and early twentieth centuries the middle Sabine River basin was the site of intensive logging operations. The growth of the oil industry, in the last century, led to the development of the Beaumont-Port Arthur-Orange metropolitan area as a major site for oil refining, processing and shipping[2]. Total flow of wastewater discharge exceeds 1.6 MGD (SRA-Texas 1996).

The Sabine River has several major tributaries. The Cowleech Fork is located northeast of Lake Tawakoni in Hunt County and establishes the northern fork of the upper Sabine. Lake Fork Creek flows east to west from Lake Fork Reservoir into the Sabine River in central Wood County. Big Sandy Creek flows east along the northern corner of Wood County and enters the Sabine River in the southern corner of Upshur County. Bayou Anacoco flows southwest and enters downstream from Toledo Bend Reservoir between

[1] *Sabine River Authority of Texas*, http://www.sra.dst.tx.us/services/ecodev/default.asp (accessed March 16, 2010)
[2] *Handbook of Texas Online*, s.v. "Sabine River" http://www.tshaonline.org/handbook/online/articles/SS/rns3.html (accessed March 16, 2010).

Vernon and Beauregard parishes. Big Cow Creek also enters the Sabine downstream of Toledo Bend in Newton County.

The lower Sabine River is a valuable natural resource for the states of Texas and Louisiana and supports a diverse ecological community that relies on the quality, quantity, and timing of water moving through the system. Understanding the flow needs of ecosystems dependant on the river provides the rationale behind the Texas Instream Flow Program (TIFP) study of the lower Sabine River. Senate Bill 2, enacted in 2001 by the 77th Texas Legislature, established the TIFP. The purpose of the TIFP is to perform scientific studies to determine flow conditions necessary to support a sound ecological environment in the rivers and streams of Texas. With passage of Senate Bill 3 in 2007, the Texas Legislature restated the importance of maintaining the health and vitality of the State's aquatic resources and further created a stakeholder process that would result in science- and policy-based environmental flow regime recommendations to protect instream flows and freshwater inflows on a basin-by-basin basis.

Stakeholder involvement has been a key component of the TIFP's lower Sabine River sub-basin study. Through a series of TIFP sponsored meetings, stakeholders were briefed on the TIFP, informed about the available information and current conditions in the sub-basin, and provided a framework from which to define the study goal, objectives, and indicators (described in Section 2.0).

The focus of this Study Design document is to provide:

- an overview (Section 1.0) of
    - available information, results of preliminary analyses and reconnaissance surveys,
    - assessment of current conditions, and
    - a conceptual model of the lower Sabine River sub-basin;
- an overview of the stakeholder process and description of the study goal, objectives, and indicators developed with stakeholders (Section 2.0);
- a description of the proposed technical studies (Section 3.0), including
    - Study Site locations,
    - data collection methods and analysis, and
    - multidisciplinary coordination; and
- an overview of continued stakeholder involvement and future activities (Section 4.0).

Ultimately, the culmination of study efforts will be to characterize the flow-habitat and flow-ecology relationships within the riverine ecosystem supported by the lower Sabine River. Results will provide a means of assessing the relevant biological, chemical and physical factors associated with various flow regime components. A comprehensive tool will be generated from existing studies and field-gathered data that will provide predictive capabilities necessary to evaluate the ecological significance of the full range of flows on the riverine ecosystem of the lower Sabine River.

1.1 Summary of available information and results of preliminary analysis and reconnaissance surveys

A critical aspect in scoping an instream flow study is to identify existing literature and data and its geographical and temporal coverage, allowing researchers to evaluate data gaps as well as to develop a preliminary conceptual model of the system. Towards that end, Texas Water Development Board (TWDB) Research and Planning Funds were expended during FY04-05 to develop a geo-referenced database that identified historical information, literature and data in the areas of hydrology, biology, physical processes, water quality, and connectivity for the lower Sabine River sub-basin downstream of Toledo Bend (Figure 1). SRA-Texas (2005) identified more than 120 reports, and many sources of data and information related to the study area. Results were then summarized in a database and used to identify gaps in the data (either spatially or temporally). Identification of these gaps by the TIFP and SRA-Texas

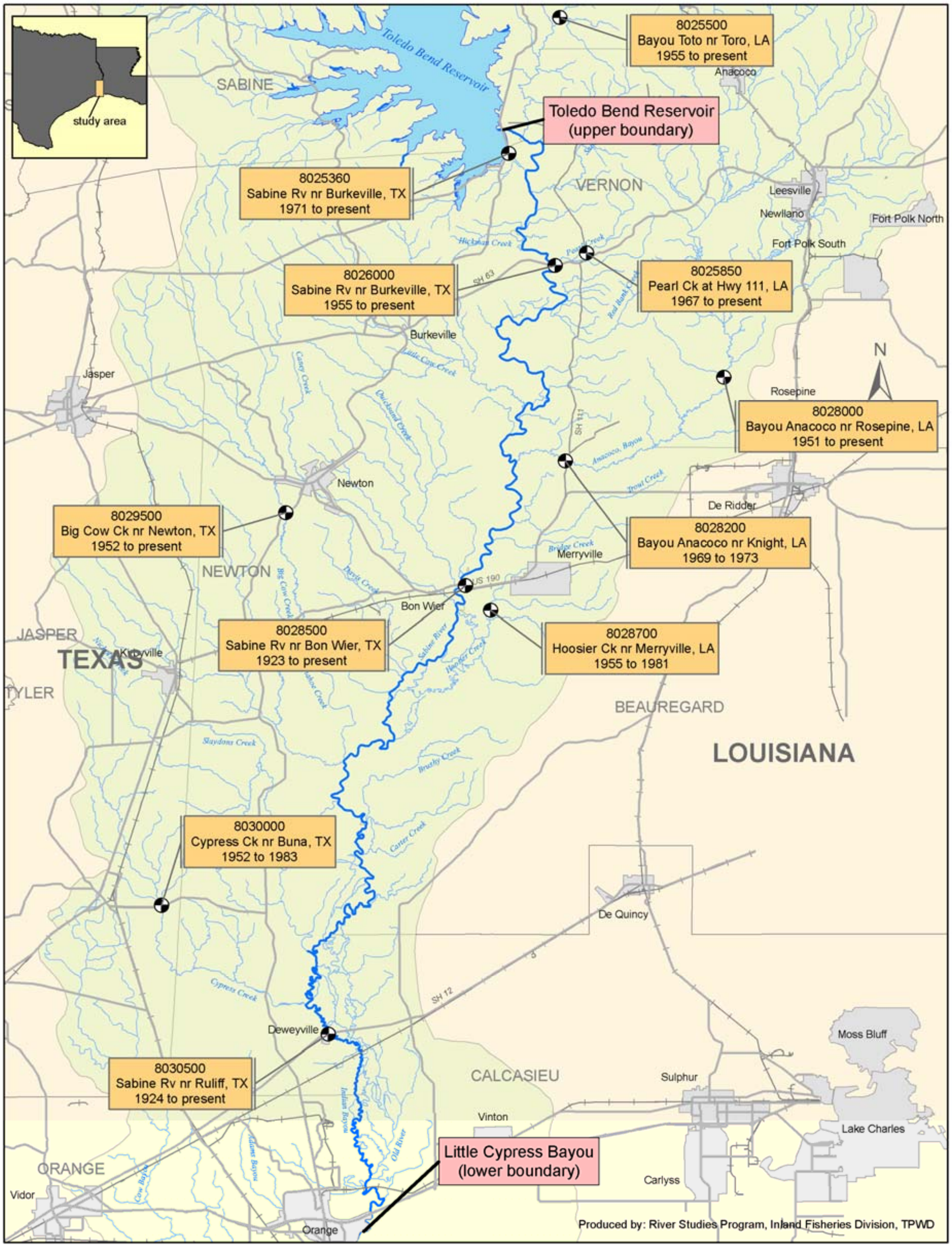

Figure 2. Study area and streamflow gages for the lower Sabine River instream flow study.

directed specific field surveys and preliminary analysis to better characterize the current condition of the river system. TIFP and SRA-Texas staff also conducted surveys of the river to familiarize themselves with conditions on the river, and evaluate locations for access and conducting baseline data collection. A representative example of available information and recent technical studies used to support the Study Design are presented in Table 1. Listing of a study in this table does not imply an endorsement by the TIFP of any conclusions documented in these reports. Rather, these studies are identified because they have collected valuable data related to riverine ecosystems in the lower Sabine River sub-basin. This data will be considered and incorporated along with data collected by TIFP in order to provide a better understanding of the study area.

Table 1. Studies of interest to the TIFP study of the lower Sabine River sub-basin.

Type of Study	Name of Study	Author/s	Year
All Disciplines	Lower Sabine River instream flow study – data summary evaluation and database	SRA-Texas	2005
Connectivity, Hydrology	Lower Sabine River bottomland connectivity study	Devine Tarbell & Associates, Inc.	2008
Connectivity, Hydrology	Results of streamflow gain-loss studies in Texas, with emphasis on gains from and losses to major and minor aquifers	Slade et al.	2002
Connectivity, Hydrology	Freshwater inflow recommendation for the Sabine Lake estuary of Texas and Louisiana	TPWD, TWDB	2005
Physical Processes	Geomorphic processes, controls, and transition zones in the lower Sabine River	Phillips	2007
Physical Processes	Geomorphic units of the lower Sabine River.	Phillips	2008
Physical Processes	Historical channel adjustment and estimates of selected hydraulic values in the lower Sabine River and lower Brazos River basins, Texas and Louisiana	Heitmuller & Greene	2009
Water Quality	Lower Sabine basin tidal study	SRA-Texas	2007
Water Quality	Sabine River basin summary report	SRA-Texas	2008
Biology	Fish assemblage changes in three western gulf slope drainages	Bonner & Runyan	2007
Biology	Baseline fish collections: lower Sabine River Priority Instream Flow Study	SRA-Texas, TIFP	2007
Biology	Extraction, analysis and summary of fish community data from the Sabine River system (Louisiana, Texas)	Bart	2008
Biology	Distributional survey and habitat utilization of freshwater mussels	Karatayev & Burlakova	2008
Biology	Distributional survey and habitat utilization of freshwater mussels (Family Unionidae) in the lower Brazos and Sabine River basins	Randklev et al.	2010

The following sections highlight key studies and preliminary results that describe existing hydrology, biology, geomorphology, water quality, and connectivity conditions in the lower Sabine River sub-basin. Please note that throughout this document the terms geomorphology and physical processes will be used interchangeably to refer to the science or field of study related to processes that shape the physical features and habitat of a river system.

1.1.1 Hydrology

USGS gage data and flow trends at representative gages

The U.S. Geological Survey (USGS) has maintained a network of streamflow gages in the lower Sabine River sub-basin since 1923 (Figure 1). Currently, the USGS operates nine gages in the sub-basin, including four on the mainstem of the lower Sabine River and five on tributaries. Some historical data is also available from an additional three tributary stream gages that are no longer maintained. Stream gages with daily streamflow data of interest to an instream flow study of the lower Sabine River are listed in Table 2.

Observation of the available gage data indicates that flow conditions in the lower Sabine River have changed over time. Figure 2 shows median flow for each day of the year for data collected from USGS gage #08030500, Sabine River near Ruliff, TX. The first data set, collected from 1925 to 1959, reflects hydrology at this location prior to the development of Toledo Bend Reservoir. The second data set, collected from 1970 to 2006, reflects conditions post development of Toledo Bend Reservoir. As shown in this figure, median flow in late spring (May) has been reduced while flows in summer (July, August, and September) have increased. Median flows in other months are little changed.

Table 2. USGS streamflow gages in the lower Sabine River sub-basin.

Gage No.	Gage Name	Earliest Record	Latest Record	Median Flow (cfs)	Drainage Area (mi^2)
08025360	Sabine Rv at Toledo Bd Res nr Burkeville, TX	1971	Present	3,660	7,178
08025500	Bayou Toro near Toro, LA	1955	Present	33	148
08025850	Pearl Creek at St. Hw. 111, at Burr Ferry, LA (peak flow only)	1965	Present	NA	9.66
08026000	Sabine Rv nr Burkeville, TX	1955	Present	2,750	7,482
08028000	Bayou Anacoco near Rosepine, LA	1951	Present	147	365
08028200	Bayou Anacoco near Knight, LA	1969	1973	235	425
08028500	Sabine Rv nr Bon Wier, TX	1923	Present	3,700	8,229
08028700	Hoosier Ck nr Merryville, LA	1955	1981	4.8	13.1
08029500	Big Cow Ck nr Newton, TX	1952	Present	66	128
08030000	Cypress Ck nr Buna, TX	1952	1983	2.6	69.2
08030500	Sabine Rv nr Ruliff, TX	1924	Present	4,780	9,329
08031000	Cow Bayou nr Mauriceville, TX	1952	Present	8.4	83.3

Figure 3 shows the daily gage data for these same time periods displayed as flow duration curves. From this figure, it can be seen that the occurrence of daily flows between 16,000 and 50,000 cfs have been reduced slightly from the earlier time period. Conversely, the magnitude of lower flows (those that are exceeded more than 40% of the time) has increased. The hydrologic changes shown in Figures 2 and 3 are typical for rivers that have been impounded in order to provide a more stable water supply.

Construction of dams and operation of reservoirs in the Sabine River basin have played a part in the hydrologic changes shown in Figures 2 and 3. Downstream of Toledo Bend Reservoir, there are no dams or reservoirs on the lower Sabine River, but several large reservoirs have been constructed in the upper sub-basin and one tributary in lower sub-basin (Table 3). Three reservoirs have original capacities greater than 500,000 acre-feet. The earliest of these was completed in 1960 and the latest in 1980.

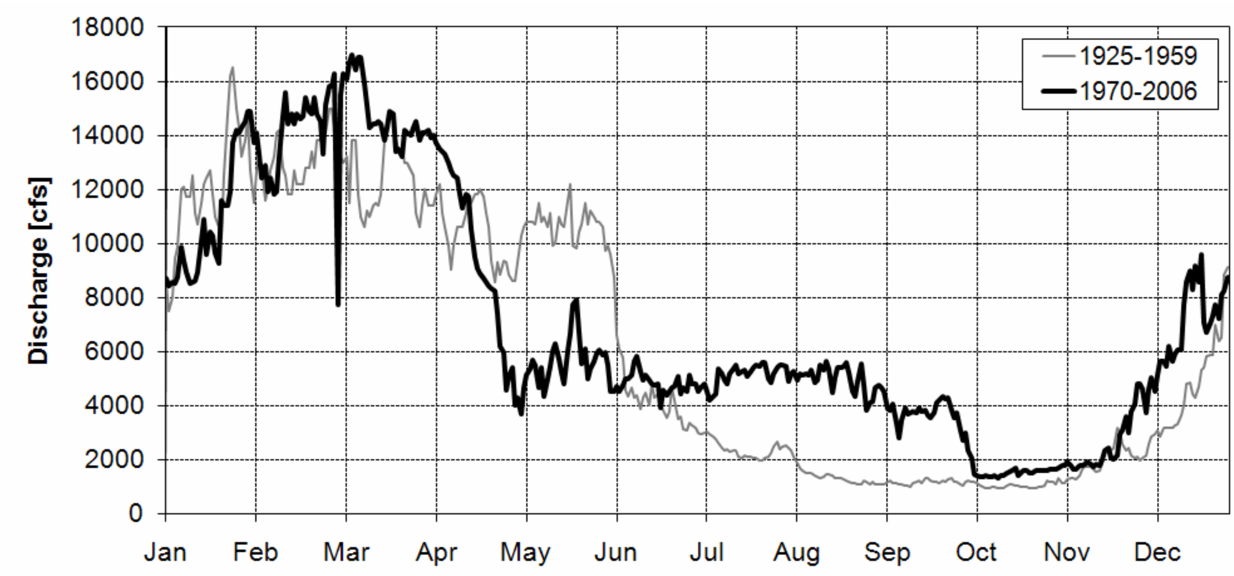

Figure 3. Median of daily streamflow values for USGS gage 08030500, Sabine River near Ruliff, TX.

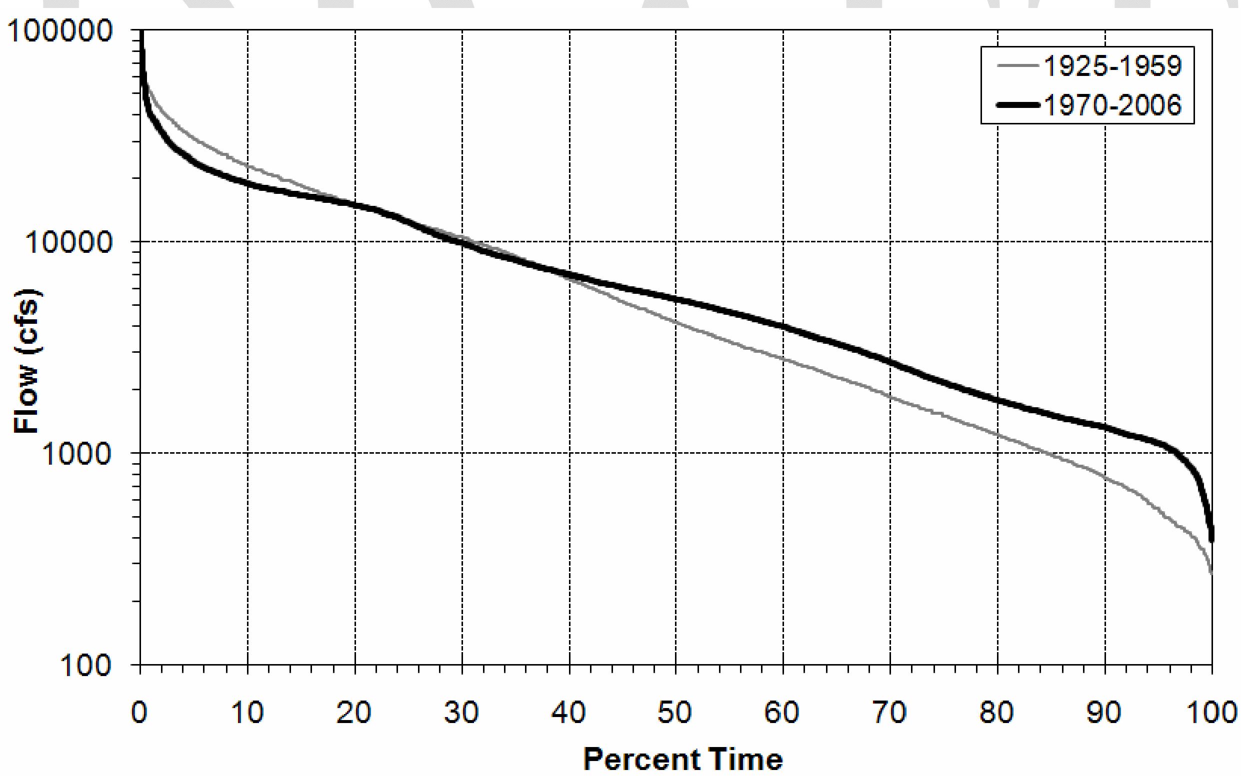

Figure 4. Flow duration curves for daily average flow at USGS gage 08030500, Sabine River near Ruliff, TX.

Table 3. Sabine River Basin reservoirs with original capacities greater than 50,000 acre-feet.

Location in Basin	Reservoir Name	Main Purposes	Storage Capacity † [acre-feet]	Year Completed
Upper Sub-basin	Lake Tawakoni	Municipal water supply	927,440	1960
Mainstem	Toledo Bend Reservoir	Water supply, hydroelectric, recreation	4,477,000	1969
Upper Sub-basin Tributaries	Lake Fork Reservoir	Municipal, industrial, & irrigation water supply	675,819	1980
	Martin Lake	Industrial	77,619	1974
Lower Sub-basin Tributaries	Vernon Lake (Upper Anacoco)	Water supply, recreation	57,000	1961

†These numbers represent original storage volumes with the reservoir filled to top of conservation pool. As a result of sedimentation, a reservoir's storage capacity decreases over time.

Because of its size and proximity, the reservoir with the greatest influence on the hydrology of the lower Sabine River is Toledo Bend Reservoir, which was completed in 1969. Toledo Bend is operated for water supply, hydroelectric, and recreational purposes.

During some periods of the year, discharge from Toledo Bend Reservoir is pulsed (referred to as "hydro-peaking") in order to facilitate hydropower generation. During hydro-peaking, discharge from the reservoir can vary significantly throughout the day or week. Figure 4 shows streamflows at USGS gages on the lower Sabine River measured at 15-minute increments during a period of hydro-peaking of flows from Toledo Bend Reservoir. USGS gage 08026000 at Burkeville is approximately 10 miles downstream of the reservoir, while gages 08028500 at Bon Weir and 08030500 at Ruliff are 50 miles and 105 miles downstream, respectively. As can be seen from the figure, the effects of hydro-peaking can be dramatic at the Burkeville gage, varying from 2,000 cfs or less to 10,000 cfs or more during the course of a day. Effects of hydro-peaking are attenuated further downstream. At the Bon Weir gage, the daily variation is less than 4,000 cfs. At Ruliff, the daily signal caused by hydro-peaking is no longer visible in the gage record. A weekly variation in the flow of about 3,000 cfs, however, can still be observed. The environmental effects of the Toledo Bend Hydropower Project are not completely understood and are the subject of ongoing studies as part of relicensing.

Changes in patterns of precipitation, temperature, human water use, and land use can also affect the hydrology of a sub-basin. The cumulative influence of these factors would be expected to affect the annual volume of water discharged from the sub-basin. In comparison to other sub-basins in the state, human water and land use changes have been relatively small in the lower Sabine. As shown in Figure 5, the annual volume of flow recorded at USGS gage 08030500 near Ruliff, TX (the lower most gage in the sub-basin) appears little changed over the period of record. The average flow over recent history (1970-2006) is 6.1 million acre-feet, essentially equivalent to the value during the early history of the gage (average of 6.4 million acre-feet per year from 1925 to 1959). This indicates that the cumulative impacts of changes in precipitation, temperature, human water use, and land use have been minimal. However, a complete hydrologic evaluation of the sub-basin would be required to investigate potential changes fully. Such an evaluation, described in Section 6.1 of the TIFP Technical Overview (TIFP 2008), will be completed as part of this study. The lower Sabine River is not reported to have a significant alluvium aquifer and interactions with deeper aquifers are believed to be limited (see section 1.1.5 for more details).

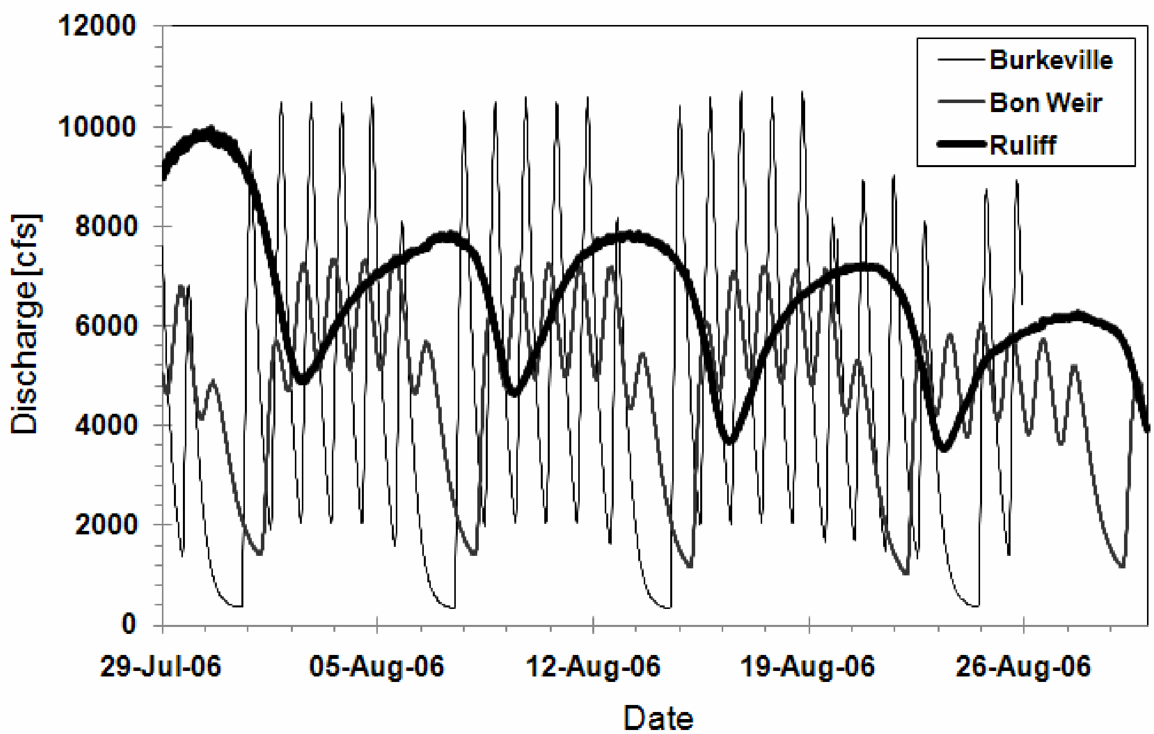

Figure 5. Lower Sabine River streamflow during a period of hydro-peaking.

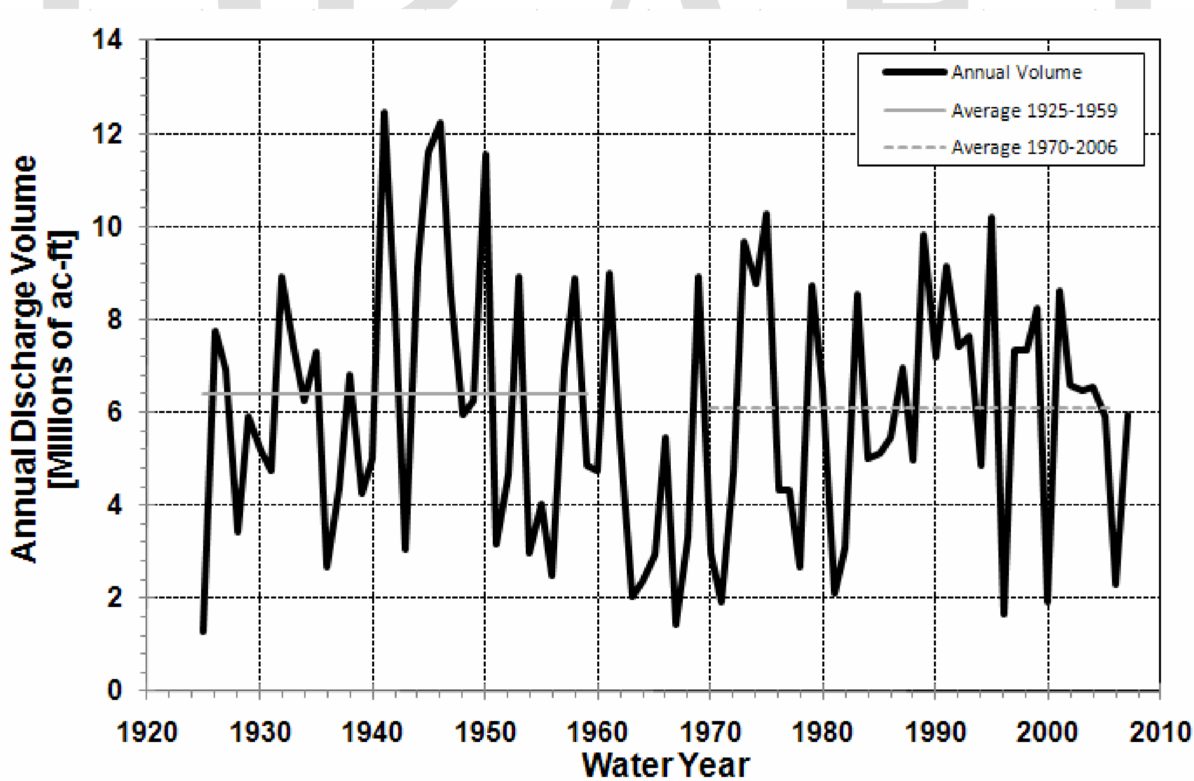

Figure 6. Annual discharge volume calculated for USGS gage 08030500, Sabine River at Ruliff, TX.

1.1.2 Biology

Fisheries data collection results summary

The Sabine River system has among the greatest fish species richness of the western Gulf Slope drainages (Conner and Suttkus 1986). Sites on the lower Sabine River, downstream of present day Toledo Bend Reservoir, and major tributaries were sampled extensively from the late 1950s through the early 1980s, mainly by Dr. Royal Suttkus and his students, records of which are found in the Tulane University fish collection. Conner and Suttkus (1986) considered the Sabine and Neches drainages to include 77 strictly freshwater species. The museum records document more than 200 collections in the lower Sabine River, greater than 90 in Bayou Anacoco, and approximately 15 in Big Cow Creek. Geographical coverage for collections in the Sabine River proper was fairly extensive from upstream of the confluence with Bayou Anacoco downriver to the Cypress Creek confluence, just upstream of Highway 12 near Deweyville. However, systematic collecting has been infrequent in recent years, creating temporal gaps in the record.

Bonner and Runyan (2007) evaluated data from a variety of sources, including the Tulane data, and found that samples from the main stem of the lower Sabine and two major tributaries, Big Cow Creek and Bayou Anacoco, included more than 90 species of fish, some of which are estuarine or marine. Analysis of the historic species relative abundance levels (Bonner and Runyan 2007) indicated that minnows comprised the most abundant fish family (93%), followed by sunfish (2.2%), livebearers (1.4%), and catfish (0.8%). Non-native fishes represented only a minor component of the lower Sabine River fish assemblage. Nine species had declining population trends whereas eight had increasing trends (Table 4). One formerly common species—red shiner—disappeared from the lower Sabine River by 1973 (Bonner and Runyan 2007). Bart (2008) concurred that minnows made up the largest proportion of historic collections, with red shiner *Cyprinella lutrensis* and ghost shiner *Notropis buchanani* disappearing and bullhead minnow *Pimephales vigilax* and shoal chub *Macrhybopsis hyostoma* decreasing. In his analysis, blacktail shiner *Cyprinella venusta*, Sabine shiner *Notropis sabinae,* weed shiner *Notropis texanus*, and mimic shiner *Notropis volucellus* have increased (Bart 2008).

Mussel data summary

Mussels represent one of the most rapidly declining faunal groups in North America. Life history traits related to their vulnerability include: sensitivity to toxic contaminants, low selectivity of feeding, long life span, size and mobility limitations, low fertilization rates, high juvenile mortality, irregular recruitment, and unique life cycle including an obligate parasitic larval stage (Fuller 1974; Downing et al. 1993; McMahon and Bogan 2001). Other anthropogenic impacts such as dam construction and altered flow regimes have been associated with mussel declines.

Historically, 32 mussel species are known to have occurred in the Sabine River basin (TPWD 2009). Historic mussel data was also obtained through joint efforts between SRA-Texas and Tulane University to recover, process, and identify archived samples from the Royal D. Suttkus collection at the Tulane University Museum of Natural History. Data represented collections from 22 sites on the lower Sabine River and Anacoco Bayou between July 1964 and September 1982. In total, 977 specimens were observed with 20 species being represented (Table 5). Although mussel distribution and life history information is limited throughout the state (Howells et al. 1996), recent mussel surveys conducted in the Sabine River basin by Karatayev and Burlakova (2008) and Randklev et al. (2010) have documented 12 live mussel species (Table 5). In addition, more recent mussel reconnaissance surveys on the lower Sabine River as part of the FERC relicensing process found two additional live species: giant floater *Pyganodon grandis* and tapered pondhorn *Uniomerus declivis* (Randklev et al. 2009).

Table 4. Fish species historically and recently collected in the lower Sabine River (from Bonner and Runyan [2007], Tulane University, and others) and their population trend.

Species	Common name	Population trend*	Historical Main River	2006 - 2007 Main River	2006 - 2007 Tributary
Alosa chrysochloris	skipjack herring	-	X	X	
Ameiurus melas	black bullhead	-	X		
Ameiurus natalis	yellow bullhead	-	X		
Amia calva	bowfin	S	X	X	
Ammocrypta clara	western sand darter	-	X		
Ammocrypta vivax	scaly sand darter	↑	X	X	X
Anchoa mitchilli	bay anchovy	-	X	X	
Anguilla rostrata	American eel		X	X	
Aphredoderus sayanus	pirate perch	↓	X		X
Aplodinotus grunniens	freshwater drum		X	X	
Ariopsis felis	hardhead catfish	-	X		
Atractosteus spatula	alligator gar	-	X	X	
Brevoortia patronus	Gulf menhaden	-	X	X	
Carpiodes carpio	river carpsucker	S	X	X	
Centrarchus macropterus	flier	-	X		
Citharichthys spilopterus	bay whiff			X	
Cycleptus elongates	blue sucker	-	X	X	
Cyprinella lutrensis	red shiner	↓	X		
Cyprinella lutrensis X venusta			X		
Cyprinella venusta	blacktail shiner	↑	X	X	X
Cyprinus carpio	common carp	-	X	X	
Dorosoma cepedianum	gizzard shad	S	X	X	
Dorosoma petenense	threadfin shad	S	X	X	
Elassoma zonatum	banded pygmy sunfish	-	X	X	
Elops saurus	ladyfish	-	X		
Erimyzon oblongus	creek chubsucker	-	X	X	
Erimyzon sucetta	lake chubsucker	-	X		
Esox americanus	redfin pickerel	-	X	X	
Etheostoma artesiae	redspot darter	-	X		
Etheostoma asprigene	mud darter	-	X		
Etheostoma chlorosoma	bluntnose darter	S	X		
Etheostoma gracile	slough darter	-	X		
Etheostoma histrio	harlequin darter	-	X	X	X
Etheostoma proeliare	cypress darter	-	X		
Fundulus chrysotus	golden topminnow	-	X	X	
Fundulus dispar	starhead topminnow			X	
Fundulus notatus	blackstripe topminnow	S	X	X	X
Fundulus olivaceus	blackspotted topminnow	↑	X	X	X
Gambusia affinis	western mosquitofish	↓	X	X	X
Hybognathus hayi	cypress minnow	-	X		
Hybognathus nuchalis	Miss. silvery minnow	↓	X	X	X
Hybopsis amnis	pallid shiner	S	X		X
Ichthyomyzon castaneus	chestnut lamprey	S	X		X
Ichthyomyzon gagei	southern brook lamprey	-	X		
Ictalurus furcatus	blue catfish	-	X	X	
Ictalurus punctatus	channel catfish	-	X	X	X
Ictiobus bubalus	smallmouth buffalo	-	X	X	
Labidesthes sicculus	brook silverside	S	X	X	X
Lagodon rhomboides	pinfish			X	

Species	Common name	Population trend*	Historical Main River	2006 - 2007	
				Main River	Tributary
Lepisosteus oculatus	spotted gar	S	X	X	X
Lepisosteus osseus	longnose gar	S	X	X	
Lepomis cyanellus	green sunfish	-	X		
Lepomis gulosus	warmouth	↓	X	X	X
Lepomis humilis	orangespotted sunfish	-	X	X	X
Lepomis macrochirus	bluegill	↑	X	X	X
Lepomis marginatus	dollar sunfish	-	X		
Lepomis megalotis	longear sunfish	↑	X	X	X
Lepomis microlophus	redear sunfish	S	X	X	X
Lepomis miniatus	redspotted sunfish	-	X	X	X
Lepomis symmetricus	bantam sunfish	-	X		
Lythrurus fumeus	ribbon shiner	S	X		X
Lythrurus umbratilis	redfin shiner	-	X		
Macrhybopsis hyostoma	shoal chub	↓	X	X	X
Menidia beryllina	inland silverside	↑	X	X	X
Micropterus punctulatus	spotted bass	↑	X	X	X
Micropterus salmoides	largemouth bass	S	X	X	X
Minytrema melanops	spotted sucker	S	X	X	X
Morone mississippiensis	yellow bass	-	X	X	
Morone saxatilis	striped bass		X		
Moxostoma poecilurum	blacktail redhorse	-	X	X	X
Mugil cephalus	striped mullet	S	X	X	
Mugil curema	white mullet	-	X		
Notemigonus crysoleucas	golden shiner	-	X		
Notropis atherinoides	emerald shiner	↓	X		
Notropis atrocaudalis	blackspot shiner	-	X		
Notropis blennius	river shiner	-	X		
Notropis buchanani	ghost shiner	↓	X		
Notropis sabinae	Sabine shiner	S	X	X	X
Notropis shumardi	silverband shiner	-	X		
Notropis texanus	weed shiner	S	X	X	X
Notropis volucellus	mimic shiner	S	X	X	X
Noturus gyrinus	tadpole madtom	-	X		
Noturus nocturnus	freckled madtom	-	X	X	X
Opsopoeodus emiliae	pugnose minnow	S	X	X	
Paralichthys lethostigma	southern flounder	-	X	X	
Percina caprodes	logperch	-	X		
Percina macrolepida	bigscale logperch	S	X		
Percina sciera	dusky darter	↑	X	X	X
Percina shumardi	river darter	-	X		
Phenacobius mirabilis	suckermouth minnow	S	X	X	
Pimephales vigilax	bullhead minnow	↓	X	X	X
Pomoxis annularis	white crappie	-	X	X	
Pomoxis nigromaculatus	black crappie	-	X	X	
Pylodictis olivaris	flathead catfish	-	X	X	X
Semotilus atromaculatus	creek chub	-	X		
Strongylura marina	Atlantic needlefish	-	X	X	
Trinectes maculates	hogchoker	S	X	X	

*Population trends after Bonner and Runyan (2007) and are indicated as increasing (↑), decreasing (↓), stable (S), and indeterminate (-). A blank indicates the species was not included in the analysis.

Table 5. Historical mussel species found in the Sabine River (TPWD 2009) compared to collections (1964-1982) by Dr. Royal D. Suttkus of Tulane University and recent collections (Karatayev and Burlakova 2008, Randklev et al. 2010) with current species status.

Historical Mussel Species	Suttkus Collections	Recent Collections	Status
Amblema plicata Threeridge	X	X	
Arcidens confragosus Rock Pocketbook	X		SC
Fusconaia askewi Texas Pigtoe	X	X	1,SC
Fusconaia flava Wabash Pigtoe			
*Fusconaia sp.**	X		
Glebula rotundata Round Pearshell			
Lampsilis hydiana Louisiana Fatmucket	X	X	
Lampsilis satura Sandbank Pocketbook	X	X	1, SC
Lampsilis teres Yellow Sandshell	X	X	
Leptodea fragilis Fragile Papershell	X	X	
Ligumia subrostrata Pond Mussel	X		
Megalonaias nervosa Washboard	X		
Obliquaria reflexa Threehorn Wartyback	X		
Obovaria jacksoniana Southern Hickorynut	X		1,SC
Plectomerus dombevanus Bankclimber	X	X	
Pleurobema riddellii Louisiana Pigtoe	X		1,SC
Potamilus amphichaenus Texas Heelsplitter	X		1,2,SC
Potamilus purpuratus Bleufer	X		
Pyganodon grandis Giant Floater			
Quadrula apiculata Southern Mapleleaf		X	
Quadrula mortoni Western Pimpleback	X	X	
Quadrula nobilis Gulf Mapleleaf	X	X	
Quadrula nodulata Wartyback			SC
Strophitus undulates Creeper			SC
Toxolasma parvus Lilliput			
Toxolasma texasiensis Texas Lilliput			
Tritogonia verrucosa Pistolgrip	X	X	
Truncilla donaciformis Fawnsfoot	X		SC
Truncilla truncate Deertoe			
Uniomerus declivis Tapered Pondhorn			
Uniomerus tetralasmus Pondhorn			
Utterbackia imbecillis Paper Pondshell			
Villosa lienosa Little Spectaclecase	X	X	

* Listed in the Suttkus historical collections only

SC = Species of Concern (TPWD 2005)
1 = State Threatened
2 = Proposed for Federal Listing

1.1.3 Physical Processes

Geomorphic processes create the channel characteristics and aquatic habitats of the lower Sabine River. The modern river system exhibits pronounced variability in four dimensions: lateral, vertical, longitudinal and temporal. The physical characteristics of the river channel vary by location as you move downstream as a result of both systematic changes (e.g. increased drainage area and runoff), as well as local effects (e.g. faults and bedrock outcroppings). As the modern channel meanders across the river valley, it is influenced by its geologic history. For example, in some locations, paleo-channels may affect the location and paleo-deposits of larger grained material may affect the composition of the river bed.

A complete understanding of the physical processes that have combined to form the entire length of the modern lower Sabine River is currently unavailable. Obtaining such an understanding would require extensive and lengthy study. What is known about the physical processes that maintain the modern channel is based on general concepts, a few broad scale studies, and a limited number of detailed studies carried out at select locations along the river.

Despite the occasional occurrence of minor amounts (less than 5% by mass composition of bed material) of gravel at some locations, the Sabine River is a predominantly sand bedded river and is not powerful enough to transport gravel size material significant distances. The slope of this portion of river is relatively modest, dropping less than 100 feet in the roughly 145 river miles from Toledo Bend Reservoir to the coast. Historic stream flows (since late 1920's) combined with this slope are too small to move gravel sized sediments significant distances. However, the ancient, Pleistocene Sabine River had higher flows and did succeeded in mobilizing gravel sized material and transporting, sorting, and depositing it in various locations in the river valley, most notable the Deweyville Terrace gravel formation. As the modern river meanders across the ancient river valley, bank erosion exposes these gravel deposits and adds this material to the bed of the modern Sabine River in a few locations. The geomorphic behavior of the river is believed to be relatively unaffected by this small amount of gravel.

TIFP has conducted a number of activities to segment the lower Sabine River based on geomorphic processes. These activities include work by Philips (2007) that segmented the lower Sabine River based on an adaptation of the River Styles classification scheme of Brierly and Fryirs (2005). This classification provides a useful tool to understand differences in physical processes and habitats along the river. The river was segmented into 6 major process zones based on channel and valley characteristics. A description of each zone was provided, including characteristic channel and floodplain features such as cutbanks, point bars, bedrock outcrops, meander cutoffs/oxbows, paleochannels, and sloughs. The geomorphic behavior of the most upstream zone (approximately 15 miles in length) was identified as being primarily controlled by operation of Toledo Bend Reservoir. Channel and floodplain features for each zone are described in further detail by Phillips (2008).

Heitmuller and Greene (2009) evaluated historical channel adjustment at USGS gage locations on the lower Sabine River (USGS gages 08026000 near Burkeville, TX; 08028500 near Bon Weir, TX; and 08030500 near Ruliff, TX). There are several factors that make it difficult to use observations from these specific sites to make inferences about the lower Sabine River in general. All three sites are highway crossings, introducing the possibility that channel characteristics may be influenced by localized impacts such as alteration of the channel during bridge construction, bank stabilization efforts, and localized scour due to the bridge. Nevertheless, field measurements at these sites began in the 1920's and provide the only historical channel cross section data in the sub-basin. Because the channel characteristics of sand bedded rivers such as the lower Sabine are naturally variable, long term data sets are preferable when evaluating their behavior. Heitmuller and Greene's analysis found minor channel incision (approximately 2.5 feet in 40 years) at the uppermost site (Burkeville), likely associated with sediment trapping in Toledo Bend Reservoir. Overall, they concluded that the lower Sabine River is relatively stable, but (like all sand bedded rivers) is subject to substantial temporary scour-and-fill processes during floods.

1.1.4 Water Quality

Clean Rivers program historical water quality trends

TCEQ in cooperation with SRA-Texas through the Clean Rivers Program produces the Sabine River Basin Summary Report every five years. The 2008 Basin Summary Report (SRA-Texas 2008) provides an overview of current monitoring and assessment activities in the Sabine River basin and presents a seven-year history summarizing the water quality concerns in 36 subwatersheds, including 15 classified waterbodies and 21 unclassified waterbodies. The lower Sabine comprises two major subwatersheds that are the primary focus of the TIFP study: the Sabine River Above Tidal (Segment 0502) and the Sabine

River Above Caney Creek (Segment 0503). Significant findings of the 2008 Basin Summary Report are listed below.

- **Bacteria -** No impairments due to bacteria were found for Segments 0502 and 0503. The unclassified tributaries Nichols Creek (Segment 0502A) and Caney Creek (Segment 0502B) were included in the 2008 Texas 303(d) List due to elevated bacteria. The summary report suggests that the elevated bacteria levels in Nichols Creek are characteristic of natural swamp conditions in the area and that levels in Caney Creek are due to nonpoint sources.
- **Total Dissolved Solids -** A trend analysis observed increasing values for chloride and sulfate in Segment 0503. However, in each case the values were below stream criteria.
- **Depressed Dissolved Oxygen -** Nichols Creek (Segment 0502A) was included in the 2008 303(d) List for depressed dissolved oxygen. The natural swamp conditions of the creek were again suggested as the cause for the failure to meet standards.

Water quality data in the lower Sabine River sub-basin is also collected and analyzed through several programs and agencies. Table 6 outlines the various sources of water quality data that may be utilized in this study. This table does not attempt to list all water quality data sources, only those that collect and analyze water quality data on a regular basis and make the data readily available and easily accessible.

Table 6. Water quality data information in the lower Sabine River.

Data Source	Types of Data	Frequency
Clean Rivers Program (TCEQ, SRA-Texas)	Chemical, Physical, Biological	Weekly, Monthly, Bimonthly, Quarterly, Annually, Continuous
Surface Water Quality Monitoring (TCEQ)	Chemical, Physical, Biological	Quarterly, Continuous
TMDL Implementation	Chemical, Physical, Biological	Specific Studies on the Brazos River
Use Attainability Analysis	Chemical, Physical, Biological	As needed
Receiving Water Assessments	Chemical, Physical, Biological	As needed
USGS	Chemical, Physical, Biological	Continuous

In order to assess current water quality conditions in the lower Sabine River sub-basin, multiple water quality related stations or locations will be used as data sources in this study. These locations include the following:

- Wastewater discharge locations – Discharges of pollutants to Texas surface water is regulated under the Texas Pollutant Discharge Elimination System program administered by the TCEQ. At the time of this writing there are nine major wastewater dischargers on the main stem of the lower Sabine River sub-basin (Figure 6). Major wastewater dischargers are defined as municipal facilities that are permitted to discharge more than 1 million gallons per day and industrial facilities that are permitted to discharge more than half a million gallons per day.
- Diversion locations – Water diversions from the lower Sabine River are permitted by the TCEQ through the issuance of water rights permits. Water is withdrawn from the river for domestic and

livestock use, irrigation, and various other uses. At the time of this writing there are approximately two permits to withdraw water on the main stem of the lower Sabine River (Figure 7).

- Surface water quality monitoring sites - The Surface Water Quality Monitoring (SWQM) Program has been evaluating biological, chemical, and physical characteristics of Texas' surface waters since 1967. The Clean Rivers Program and the SWQM program utilize the same monitoring sites to assess water quality data in the lower Sabine River sub-basin. At the time of this writing there are nine SWQM monitoring sites located on the main stem sub-basin (Figure 8).

Lower Sabine Basin Tidal Study

The Sabine River Authority in cooperation with the TCEQ under the authorization of the Texas Clean Rivers Act prepared the Lower Sabine Basin Tidal Study (SRA-Texas 2007). The study documented the extent of saltwater intrusion, the affects of tide on flow, the sediment and nutrient concentrations of freshwater flowing into Sabine Lake and attempted to better understand the dynamic nature of this complex river system. Sampling was conducted bimonthly from State Highway 12 near Ruliff, Texas to the mouth of the Sabine River at the northeast end of Sabine Lake.

The study area included sites in Adams and Cow Bayous in Texas and on the Gulf Intracoastal Waterway and Black Bayou in Louisiana. The most upstream intrusion of the saltwater wedge was on the Old River Channel near Nibletts Bluff, LA. Tidal saltwater flowed predominately upstream during low stream flow and during high tide conditions. Adams and Cow Bayous followed the general flow direction of the Sabine River; however this was not true of the flow in Black Bayou and the Gulf Intracoastal Waterway. The flow in Black Bayou was consistently counter to the tidal flow in the river and was most likely the result of hydrologic changes from the Gulf Intracoastal Waterway. There appeared to be no relationship between sediment, in the form of suspended solids, and flow. Nutrient concentrations were assessed using total Kjeldahl nitrogen (TKN) and total phosphorus (TP) and found to be fairly uniform across the stream profile and within ranges typical for the lower Sabine River (SRA-Texas 2007).

1.1.5 Connectivity

Extensive and diverse bottomland areas dependent on periodic hydrologic connectivity are present in the lower Sabine River sub-basin. DTA/HDR (2008) completed a survey of these areas and studied their connectivity to the river during hydropower operations. Bottomland areas along the river from Toledo Bend Reservoir to the Insterstate-10 Bridge in Orange County, TX were identified, classified, and characterized by vegetation species and community. Because it was focused on hydropower operations, the DTA study assessed the amount of connectivity between main channel and floodplain areas provided by flows of 7,000 to 14,000 cfs. Flows of this magnitude are typical in the lower Sabine River during the late spring, summer, and fall because of hydropower operation of Toledo Bend Reservoir. These flows were found to be too small to exceed the banks of the main channel and it appears that much larger overbank flows during the late winter and early spring (before hydroelectric operations begin) are required to provide connectivity between the main channel and floodplain areas.

Oxbow lakes and other floodplain habitats are believed to be an important component of the ecosystem supported by the lower Sabine River. Winemiller et al. (2004) completed a study of oxbow lakes along the Brazos River and concluded that oxbow lakes with a variety of age/connectivity characteristics increased overall fish diversity in that system. Similar studies have not been completed in the lower Sabine but connectivity with oxbow lakes is assumed to be important in this system as well.

The lower Sabine River exhibits little connectivity to underlying aquifers. The Gulf Coast Aquifer (GCA) is the primary aquifer beneath the area and is composed of Beaumont Clay with low permeability (PES 1999). A review by Slade et al. (2002) identified only one gain-loss study conducted along a

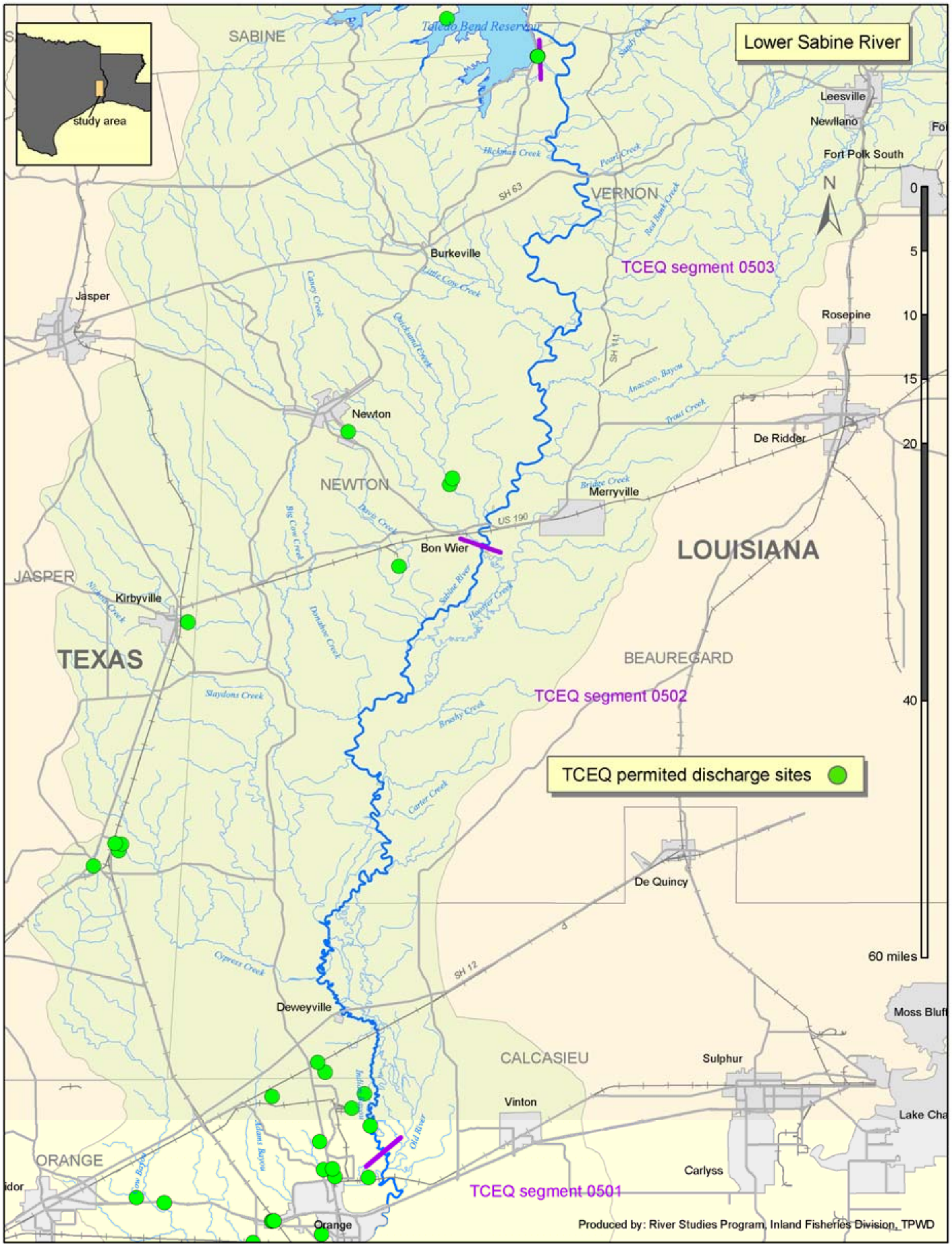

Figure 7. Major wastewater discharge locations in the lower Sabine River.

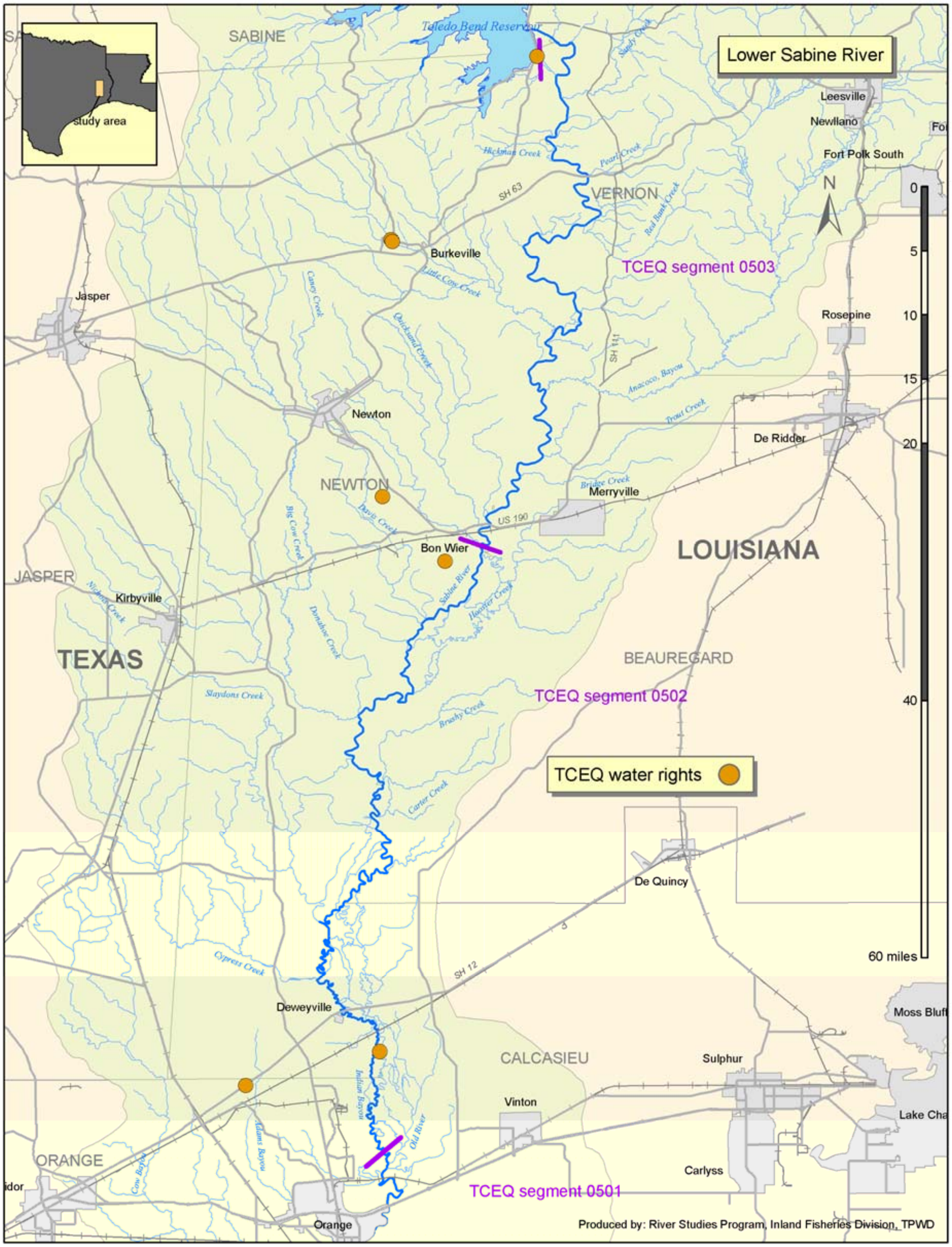

Figure 8. Water diversion points in the lower Sabine River.

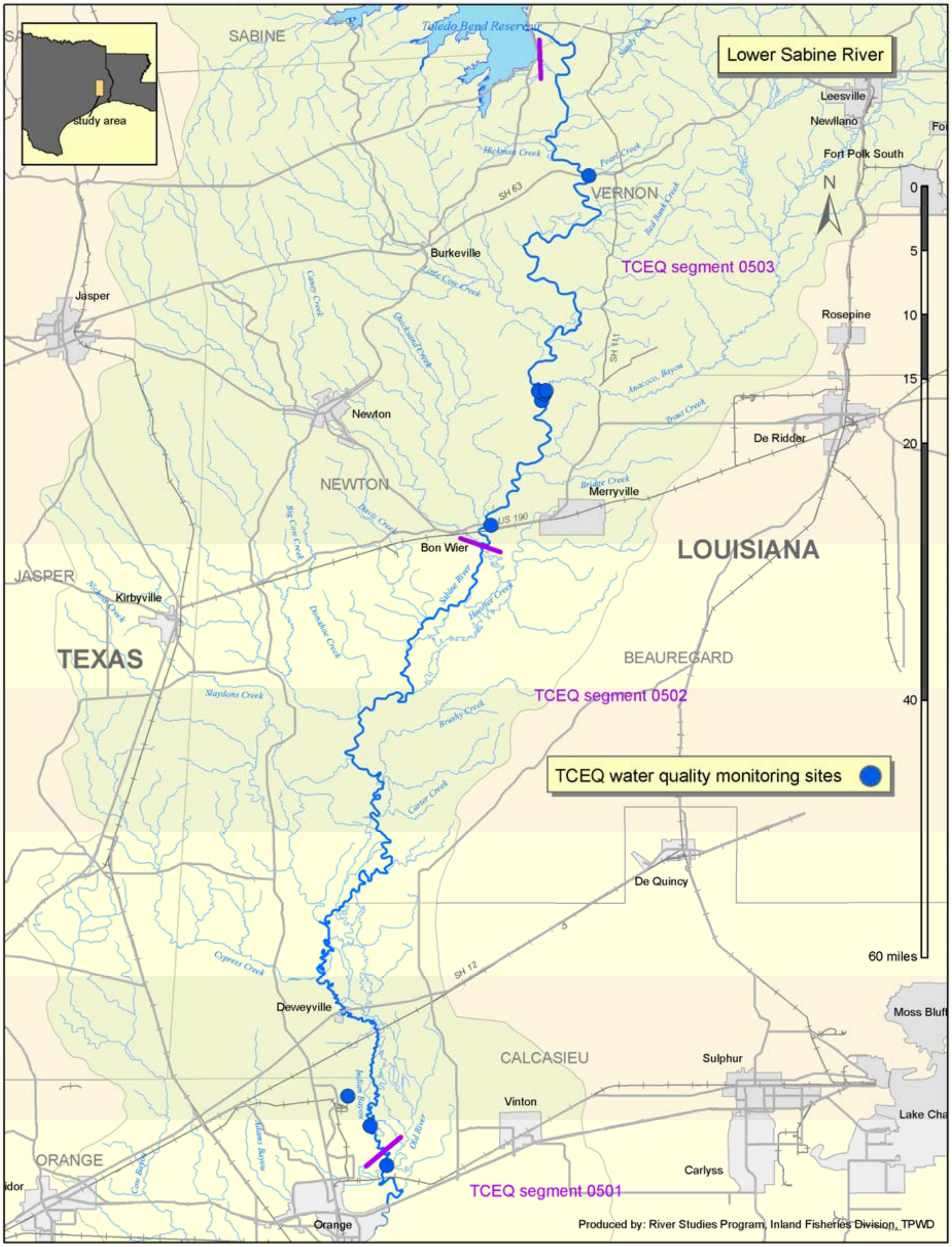

Figure 9. Surface Water Quality Monitoring Program sites in the lower Sabine River.

significant length of the lower Sabine River. Data for that study was collected in 1963 (before the construction of Toledo Bend Reservoir) along a 268 mile length of the river from Ruliff, TX (in the lower part of the lower Sabine sub-basin) to near Carthage, TX (well upstream of Toledo Bend Reservoir, the upper boundary of the lower Sabine sub-basin). That study, conducted during a period of relatively low flow (less than 500 cfs recorded for the daily average flows at USGS gage 08030500, Sabine River at Ruliff, TX) estimated a gain of less than 1 cfs per mile, indicating very little surface water/groundwater interaction.

The lower Sabine River is an important source of freshwater inflow to the Sabine Lake Estuary. A study completed by TPWD and TWDB (Kuhn and Chen 1998) identified monthly freshwater inflows recommended to maintain the estuarine ecosystem. These recommendations were developed based on a state methodology that has been applied to all of Texas' major estuaries.

1.1.6 FERC Relicensing Studies

SRA-Texas and Sabine River Authority, State of Louisiana jointly own and operate the Toledo Bend Hydropower Project. FERC relicensing is underway given the current license expires in 2013. The Authorities maintain a public website[3] for communication concerning the relicensing process. As part of the process, study plans were developed to address of number of resource issues including terrestrial and aquatic resources. The ongoing studies are planned to be completed by October 2010. The data from these studies will be used to evaluate potential project effects, but may also provide useful information related to instream flow needs.

1.1.7 Senate Bill 3: Environmental Flows Process

As part of the Environmental Flows Process, the Sabine and Neches Rivers and Sabine Lake Bay Basin Expert Science Team recently submitted an Environmental Flow Recommendations Report[4] to its respective Stakeholder Committee. Through that process, the Science Team compiled and assimilated extensive, existing information, performed multi-disciplinary analyses to identify and quantify flow-ecology relationships, where possible, and developed environmental flow regimes intended to support a sound ecological environment. Senate Bill 2 instream flow studies will provide a flow regime based on actual field investigations of flow-ecology relationships, which can be used as an adaptive management tool in the Senate Bill 3 process. Information from the Science Team's report may also be useful for focusing instream flow questions specific to the lower Sabine River and will provide existing basin-specific data.

1.2 *Assessment of Current Conditions*

To assess current conditions in the lower Sabine River sub-basin, available information was acquired and evaluated along with data from TIFP and SRA-Texas sampling efforts. Specific data layers included tributaries, human development (roads, bridges, towns, etc.), land use, aerial photography, USGS stream gages, discharge locations, withdrawal locations, water quality monitoring sites and data, historic and recent biological data collections, habitat evaluations (aquatic and riparian), and geomorphic data.

1.2.1 Hydrology

The largest tributaries of the lower Sabine River are Bayou Anacoco on the Louisiana side and Big Cow Creek on the Texas side. At their confluence, Bayou Anacoco has a median flow of less than 10% of that of the Sabine River. Big Cow Creek is smaller, with a median flow of less than 2% of that of the Sabine River at their confluence. Under base flow conditions, no other tributaries make as significant a contribution to the flow of the lower Sabine River. Flow patterns in the lower Sabine appear to be

[3] http://www.tbpjo.org/PublicRelicensing/default.aspx
[4] http://www.sratx.org/BBEST/RecommendationsReport/

affected by the operation of Toledo Bend Reservoir, which is located just upstream. The largest changes in flow patterns occur during hydro-peaking, when flows can vary by several thousand cfs during the course of a day. This effect is attenuated with distance from Toledo Bend. Operation of this reservoir also appears to slightly shift the pattern of flow during the year, decreasing flow in the late spring and increasing flows during the early summer. The total amount of flow in the sub-basin appears unaltered when viewed on a yearly time scale. The lower Sabine River exhibits relatively low connectivity with the Gulf Coast Aquifer. Flows within the lower sub-basin remain responsive to precipitation patterns and maintain much of their natural variability.

1.2.2 Biology

Starting in 2006, TIFP and SRA-Texas biologists conducted reconnaissance surveys and biological and habitat sampling throughout the lower Sabine River as well as in Bayou Anacoco and Big Cow Creek (Table 7). In selecting sampling locations, efforts were made to fill geographical data gaps as well as update collections at sites that have been little sampled in recent years. Eight sites were ultimately selected (Figure 9), with six spread longitudinally along the Sabine River, one on Bayou Anacoco, and one on Big Cow Creek. Extensive historical data was available for six sites—5030, 5040, 5050, 5060, 5070, and 5080. The most downstream sites—upstream of Indian Lake (5020) and at Blue Elbow (5010) were added to extend the geographical coverage of sampling, since historical data has not been identified for those reaches.

Data collected from these sampling efforts provided baseline habitat and fish assemblage data to fill information gaps within the lower Sabine River sub-basin. Collection methods included boat and backpack electrofishing and seining in as many habitat types as possible. Additionally, hoop and gill nets were occasionally utilized to supplement collections. Measurements of average habitat depth, dominant substrate, and current velocity were recorded within each habitat type. Individual biological collection efforts were segregated by habitat types from which the samples were collected. Photographs and global positioning system coordinates were recorded from the mid-point of each habitat type. The results from this study are presented in TIFP (2007).

A total of 64 species comprising more than 15,000 individuals was collected. One species is considered anadromous, American eel *Anguilla rostrata*, while 10 others are estuarine. Differences were observed between tributary assemblages and the main river, with 32 species found only in the Sabine River and four collected only in the tributaries. Those found only in the Sabine River included the estuarine species and large river species, whereas the tributary-only species included some that might be more commonly found in smaller systems and backwaters such as pirate perch *Aphredoderus sayanus*.

Table 7. Baseline fish assemblage sampling locations on the lower Sabine River 2006-2007.

Sample Site Number	Sample Site Description
5080	Sabine River at Burr Ferry
5070	Sabine River upstream of Bayou Anacoco
5060	Bayou Anacoco upstream from Sabine River confluence
5050	Sabine River at Highway 190 bridge 1.2 miles E of Bon Wier
5040	Big Cow Creek at State Highway 87
5030	Sabine River upstream of Deweyville between Nichols and Cypress creeks
5020	Sabine River upstream of Indian Lake
5010	Sabine River at Blue Elbow

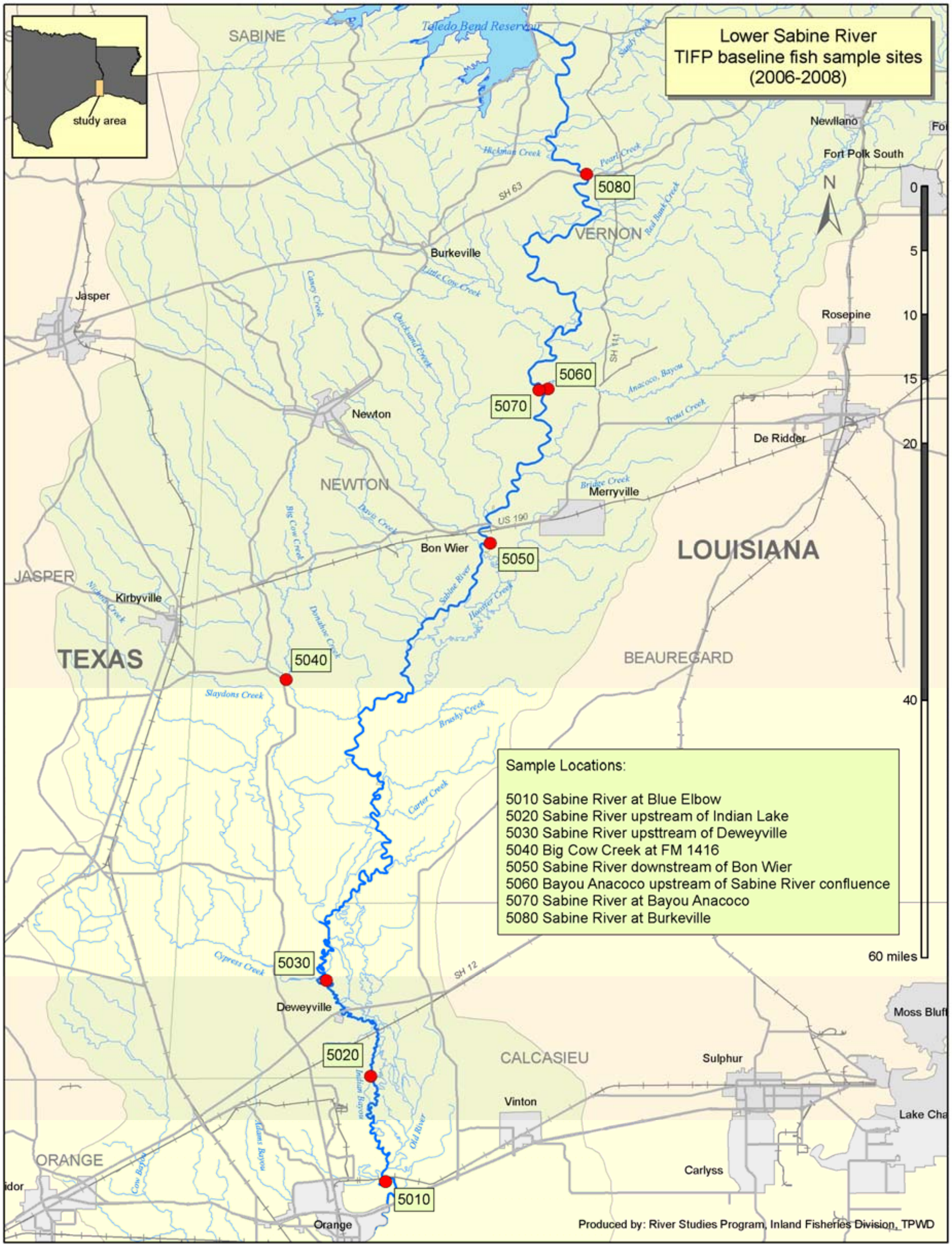

Figure 10. TIFP baseline fish sampling sites in the lower Sabine River.

Of the 32 mussel species known to occur in the Sabine River basin historically, only 14 live species have been recently documented in mussel distribution surveys (Karatayev and Bulakova 2008, Randklev et al. 2009, and Randklev et al. 2010). A main factor shown by Randklev et al. (2010) to affect mussel bed density and diversity in the lower Sabine River is bed stability. Currently, mussel beds have higher densities and diversity in more stable course sand substrates. Due to peaking hydropower operations in the lower Sabine River, mussels are being washed out from the less stable fine sand substrates (Randklev et al. 2010). There is also a general trend of increasing mussel abundance from Toledo Bend to downstream reaches (Randklev et al. 2009, 2010).

Nine of the 32 species that occurred historically (Table 5) in the basin are listed as species of concern (TPWD 2005). The American Fisheries Society considers three of these nine as mussel species of special concern – southern hickorynut *Obovaria jacksoniana*, Louisiana pigtoe *Pleurobema riddellii*, and Texas heelsplitter *Potamilus amphichaenus*. The Texas Parks and Wildlife Commission recently listed five mussels as threatened (Table 5) and the US Fish and Wildlife Service announced that the Texas heelsplitter is among nine species that may warrant federal protection as threatened or endangered.

1.2.3 Physical Processes

The lower Sabine River flows across geologic formations of Pleistocene age and eventually discharges into Sabine Lake, which connects to the Gulf of Mexico. Materials along the river's path consist mainly of clay, silt, and sand and overlay the Gulf Coast Aquifer, the major aquifer in the area. Unconsolidated material deposited by the river has created a valley containing Holocene alluvium, which provides a minor aquifer. The river is actively migrating across the valley and numerous oxbows occur along its length. The river is predominantly sand bedded, although in some areas, outcroppings of Pleistocene age gravel deposits provide some larger bed material for bars in the area. In a few isolated areas, the river crosses bedrock material. The presence of Toledo Bend Reservoir just upstream of the lower Sabine River sub-basin appears to have had some effect on the physical processes that shape the channel. Those effects decrease with distance from the reservoir.

1.2.4 Water Quality

The majority of the Sabine River basin supports the designated uses defined by the Texas Surface Water Quality Standards. The main stem of the lower Sabine River has no water quality issues according to the Sabine Basin Summary Report and the 2008 Texas Water Quality Inventory. Only two tributaries of the lower Sabine River (Nichols Creek and Caney Creek) have impairments, and the causes are likely due to nonpoint source pollution (SRA-Texas 2008). Continued monitoring of the impairments is recommended (SRA-Texas 2008).

1.2.5 Connectivity

The lower Sabine River is associated with a major estuary (Sabine Lake) and extensive riparian/wetland areas (bottomland hardwoods). These areas are sustained by periodic connectivity with the river. Species associated with oxbow lakes and other floodplain habitats also require periodic connectivity. The lower Sabine River does not have an extensive alluvium aquifer and its connection to groundwater may be limited. Connectivity of this portion of the river with upstream areas is restricted by the presence of Toledo Bend Dam.

1.3 *Conceptual Model*

As described in the Technical Overview (TIFP 2008), a conceptual model is useful to characterize the current understanding of the riverine ecosystem and develop study designs. A conceptual model incorporates much of the basic understanding of the system at the point of study initiation. As such, it represents a beginning point from which to develop flow-ecology relationships and direct studies to further refine understanding.

A general conceptual model of the lower Sabine River (Figure 10) has been adapted from a general model for an unconfined sand-bedded stream developed by Stillwater Sciences (2003). It has been tailored for the lower Sabine River by incorporating important findings from previous studies and local knowledge gained from participants during study design workgroup meetings. Because conditions vary along the river, various aspects of the general conceptual model are of lesser or greater importance depending on location. For example, the significance of riparian areas and floodplain habitats vary along the river. Although predominantly sand, the bed material of the channel also varies within the study area. There are limited areas with bed material including larger sediments and bedrock, depending on local conditions.

The expected relationships between flow components and various ecological processes of the lower Sabine River sub-basin are shown in Table 8. This table was adapted from the example flow-process relationships shown on page 14 of the Technical Overview (TIFP 2008). All four components of an environmental flow regime are provided in this table, as well as expected relationships to ecosystem processes. Although processes are categorized by primary discipline, each has linkages across disciplines and must be studied in a multi-disciplinary way.

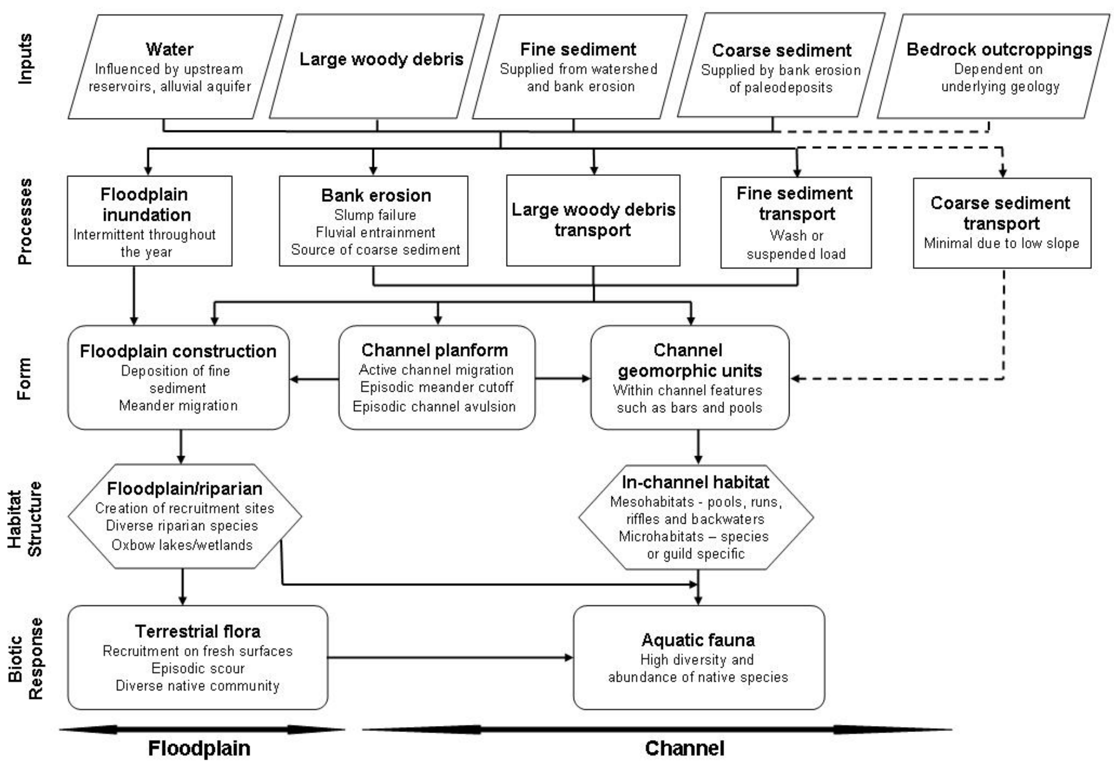

Figure 11. General conceptual model of the riverine ecosystem of the lower Sabine River.

Table 8. Ecological processes supported by instream flow components of the lower Sabine River.

Component	Hydrology	Geomorphology	Biology	Water Quality	Connectivity
Subsistence flows Infrequent, low flows (typically during summer)		Increase deposition of fine and organic particles	Provide limited aquatic habitat Maintain populations of organisms capable of repopulating system when favorable conditions return	Maintain adequate levels of dissolved oxygen, temperature, and constituent concentrations (particularly nutrients)	Provide limited connectivity along the length of the river May be affected by groundwater/ surface water interactions Maintain longitudinal connectivity
Base flows Average flow conditions, including variability	Influenced by reservoir operation, peaking hydropower, and land use changes Vary by season and year	Maintain soil moisture and groundwater table in riparian areas Maintain diversity of instream habitats	Provide suitable aquatic habitat for all life stages of native species	Provide suitable in-channel water quality	Provide connectivity along channel corridor May be affected by groundwater / surface water interactions
High flow pulses In-channel, short duration, high flows	Influenced by reservoir operations, peaking hydropower, and land use changes	Maintain channel and substrate characteristics Prevent encroachment of riparian vegetation Play an important role in recovery of channel after flood events	Provide migratory and spawning cues for organisms Transport semi-buoyant fish eggs	Restore in-channel water quality after prolonged low flow periods	Provide connectivity to near-channel water bodies (e.g. oxbows and distributary channels)
Overbank flows Infrequent, high flows that exceed the channel	Influenced by reservoir operation	Provide lateral channel movement, an important source of coarse material for channel Form new habitats Flush organic material woody debris into channel Transport nutrients and sediment to floodplain	Provide spawning cues for organisms Provide access to floodplain habitats Maintain diversity of riparian vegetation	Restore water quality in floodplain water bodies	Provide connectivity to floodplain Recharge alluvial aquifers Provide large volumes of freshwater to Sabine Lake

2.0 STAKEHOLDER INVOLVEMENT AND STUDY DESIGN DEVELOPMENT

2.1 *Stakeholder Involvement*

Stakeholder involvement has been a key component of the TIFP lower Sabine River study, beginning with initial meetings to gain historic and current perspectives on the basin to more recent meetings convened to develop goals and objectives to guide the development of the study design. Throughout the process, stakeholders provided a wealth of local knowledge, which complemented historical reports and data. This information was used to identify areas for reconnaissance activities. Preliminary analysis was performed on historical data as well as the data generated in the reconnaissance efforts and results were presented at basin update meetings. Stakeholders and agency personnel developed the study goal, objectives, and indicators at subsequent study design workgroup meetings. Section 4.0 describes the continued stakeholder involvement as the study progresses beyond the design and field sampling components.

2.2 *Study Goal, Objectives and Indicators*

The overall goal or vision agreed upon by the study design workgroup was for "a healthy, functioning Lower Sabine River Basin that has high quality water, sufficient flow, and a sustainable ecosystem to assure a dynamic balance between human needs and the environment." Because of the TIFP's mandate ("sound ecological environment"), expertise (environmental rather than economic and social), and resources (limited), objectives were geared towards the environmental aspects of this goal. Objectives for multiple disciplines (hydrology, biology, physical processes, water quality, and connectivity) were developed for this TIFP study with an overriding aim to determine the natural, historic, and current conditions related to each. As described in the Technical Overview (TIFP 2008), a list of practical indicators consistent with the study goal and objectives for the lower Sabine River sub-basin was provided to the study design workgroup. These indicators were then paired down to those ecologically significant indicators that were directly related to components of the flow regime. The following tables (Tables 9 through 13) present the final list of indicators as determined by the stakeholder process for hydrology, biology, physical processes, water quality, and connectivity.

Table 9. List of Hydrology indicators and their importance to the instream flow study.

<table>
<tr><th colspan="3">Hydrology</th></tr>
<tr><td colspan="3">Objective: Manage flow regimes which accommodate human needs while sustaining river and floodplain ecosystems.</td></tr>
<tr><td colspan="3">Indicators</td></tr>
<tr><td>Category</td><td>Indicator</td><td>Explanation</td></tr>
<tr><td rowspan="4">Flow regime components</td><td>Overbank flows (frequency, timing, duration, rate of change, and magnitude)</td><td>Infrequent, high magnitude flow events that enter the floodplain
Maintenance of healthy riparian areas
Transport of sediment and nutrients
Allow fish and other biota to utilize floodplain habitats during and after floods
Riparian and floodplain connectivity to the river channel</td></tr>
<tr><td>High pulse flows (frequency, timing, duration, rate of change, and magnitude)</td><td>Short duration, high magnitude within channel flow events
Maintain physical habitat features along the river channel
Provide longitudinal connectivity along the river corridor for many species (e.g., migratory fish)
Provide lateral connectivity (e.g., connects to oxbow lakes)</td></tr>
<tr><td>Base habitat flows (frequency, timing, duration, rate of change and magnitudes)</td><td>Range of average or “normal” flow conditions
Provide instream habitat quantity and quality needed to maintain the diversity of biological communities
Maintain water quality conditions
Recharge groundwater
Provide for recreational or other uses</td></tr>
<tr><td>Subsistence flows (frequency, timing, duration, rate of change, and magnitude)</td><td>Low flows maintained during times of very dry conditions
Maintain water quality standards
Prevent loss of aquatic organisms</td></tr>
<tr><td rowspan="2">Natural variability</td><td>Natural</td><td>Determination of the natural variability of the above indicators, based on the older portions of gage records, presumably less impacted by human activity. The exact time period may vary by gage site.</td></tr>
<tr><td>Current</td><td>Variability of the above indicators based on the last 20-25 years of gage records.</td></tr>
</table>

Table 10. List of Biology indicators and their importance to the instream flow study.

Biology		
Objectives: • Maintain and/or improve native biological communities/habitats • Control invasive and non-native species that threaten the function of the aquatic and terrestrial ecosystems		
Indicators		
Category	*Indicator*	*Explanation*
Instream Biological Communities	Native Richness	Richness, or the number of species or taxa, is a measure of community health, can be applied at a variety of scales (reach to basin to statewide), and can be related to modifications in flow. May also use proportions such as the proportion of native to non-native species.
	Relative Abundance	The number of organisms of a particular species as a percentage of the total community
	Fish • Flow sensitive species • Sportfish • Prey species • Imperiled species • Intolerant species	Fish are useful indicators because: • they occupy a range of habitats and have a variety of life histories that are generally known • their position at various levels of the aquatic food chain provides an integrative view of the watershed • they are useful for examining both direct toxicity and stressful conditions by looking at indicators such as missing species or depressed growth and reproduction • they are valued by the public There are many species of fish in the river and all of them cannot be studied individually. Those that may warrant study include: flow sensitive species, sportfishes, prey species, imperiled species, and intolerant species.
	Other aquatic organisms	Mussels and river and riparian plants may be appropriate as indicators.
Instream Habitat	Habitat Quality and Quantity for Key Species	Involves relating suitable habitat (microhabitat) and flow for key species. Habitat attributes may include current velocity, depth, substrate and cover; other attributes may be important for some species.
	Mesohabitat Area and Diversity	This indicator stems from the knowledge that diverse habitats support diverse communities. Mesohabitat analysis provides a quantifiable relationship between larger scale habitat (e.g. riffles, runs, pools) area and flow; habitat diversity can be derived from same data. Uses biological data for all species in a community (e.g., fish species) to define the attributes of each mesohabitat.

Table 10 (cont.). List of Biology indicators and their importance to the instream flow study.

Biology		
Indicators		
Category	*Indicator*	*Explanation*
Riparian Habitat	Vegetation • Age class distribution of riparian species • Riparian species richness and diversity • Density • % Canopy cover	These are key components in assessing the diversity, health, and functionality of riparian habitat and ensuring that adequate riparian species are present for recruitment and maintenance of the ecosystem. Riparian plants typically must maintain contact with the water table, so their presence and diversity is an important indicator of soil moisture (water table) characteristics. The listed vegetation parameters can be correlated with important riparian functions, such as stream bank stabilization, temperature dynamics, and nutrient cycling.
	Soils • Riparian soil types	In the absence of riparian vegetative indicators, soil characteristics identified by the soil survey database can be used to determine past or present hydrologic influence and hence historical riparian area extent.
	Hydrology • Gradient of inundation • Base flow levels	Periodic occurrence of flood (overbanking) flows, associated channel dynamics and the preservation of base flows capable of sustaining high floodplain water tables are essential to maintaining the health of riparian ecosystems. Groundwater depths can be sampled and coupled with surface water data to produce a probability of inundation curve. Overbanking flow requirements can be modeled.

The following species or groups are proposed as possible key species based on their historic and current abundance in the lower Sabine River, habitat use, life history, sensitivity to change (hydrologic and water quality), and/or sport fish value. Some may be dropped or combined with others to form mesohabitat guilds. Other species may be added as information is obtained from ongoing sampling efforts.

- Blue sucker *Cycleptus elongatus* – state threatened, large river fish; long-lived; adults utilize swift water habitats; migrate to spawning grounds.
- Paddlefish *Polyodon spathula* – state threatened, large river fish; long-lived species; utilize backwaters for feeding and gravel bars with swift current for spawning; may use the main river for moving between seasonal habitats.
- Scaly sand darter *Ammocrypta vivax* –shallow run mesohabitats.
- Dusky darter *Percina sciera* –shallow sandy runs/ riffles.
- Pallid shiner *Hybopsis amnis* – declining abundance, historically found in tributaries and the main river; generally intolerant of siltation, prefers quiet water often at the ends of bars.
- Shoal chub *Macrhybopsis hyostoma* – riffle / shallow run habitat, declining abundance; broadcast spawners whose reproduction is tied to flow events, allowing maturation of eggs and larvae.
- Sabine shiner *Notropis sabinae* – species of concern (TPWD 2005)*;* abundant in both river and tributary habitats, use shallow runs; prefers fine, silt-free sand substrates; reproduction tied to flow events, allowing maturation of eggs and larvae.
- Spotted bass *Micropterus punctulatus* – nest spawner, sport fish, habitat use varies by life stage;
- Floodplain dependent fishes –fishes that utilize the main river but are reliant upon floodplain habitats for some life stage (e.g., spawning or development).
- Mussel species of concern

Table 11. List of Physical Processes indicators and their importance to the instream flow study.

Physical Processes		
Objective: Protect/enhance current fluvial geomorphic processes that create natural habitat.		
Indicators		
Category	*Indicators*	*Explanation*
Bank stability	Rate of lateral channel migration	Rate of lateral movement of channel across valley. Some migration of the channel is crucial to support diverse riparian habitats and a healthy ecosystem.
	Rate of channel avulsion	Rate of creation of channel cut-offs. Cut-offs, in the form of oxbow lakes, backwater areas, and abandoned channels, provide distinct and important habitats.
	Rate of bank erosion	The rate at which flows erode the sides of channels. This will vary by bank material and condition of the banks (vegetated, saturated, etc.).
Channel maintenance	In-channel bars (area, configuration, sediment size)	Sediment bars are an important in-channel bed form. Flow across these features provides a diversity of hydraulic conditions. Bar formation, in combination with opposite-bank erosion, is the driving process behind channel migration. As bars age, they gradually create new areas of floodplain and riparian habitat.
	Meander pools (depth)	Meander pools are another important in-channel bed form. Deep pools provide diverse hydraulic conditions and cover for some species. They also provide refuge habitat for many species during low flow periods.
Flood impacts	Stage (at USGS gage locations)	The National Weather Service provides flood impact summaries for most USGS streamflow gage sites, based on water surface elevation or "stage." These summaries provide an estimate of negative impacts of overbank flows.

Table 12. List of Water Quality indicators and their importance to the instream flow study.

Water Quality		
Objective: Maintain/improve the water quality for the benefit of biological communities and human needs.		
Indicators		
Category	*Indicator*	*Explanation*
Nutrients	Nitrogen Organic Nitrate + Nitrite, Ammonia, Total Phosphorus Orthophosphate Total	Nutrient – any substance used by living things to promote growth. In water, the term generally applies to nitrogen and phosphorus. Nitrate-Nitrogen – A nitrogen containing compound that can exist as a dissolved solid in water. Excessive amounts (>10 mg/L) can have harmful effects on humans and animals. Nitrite-Nitrogen – An intermediate oxidation state of the nitrification process (ammonia, nitrite, nitrate). Ammonia-Nitrogen – Ammonia, naturally occurring in surface and wastewaters, is produced by the breakdown of compounds containing organic nitrogen. Orthophosphate – The most important form of inorganic phosphorus, making up 90% of the total. The only form of soluble inorganic phosphorus that can be directly used, it is the least abundant of any nutrient and is commonly the limiting factor. Total Phosphorus – A measure of all forms of phosphorus in water, including soluble and particulate phosphorus.
Oxygen	Dissolved Oxygen	Oxygen is essential for both plans and animals. There is often a relationship between discharge and dissolved oxygen concentrations. Decreased dissolved oxygen can be harmful to fish and other aquatic organisms. Nonpoint source pollution as well as decomposition of leaf litter, grass clippings, sewage, and funoff can decrease the amount of dissolved oxygen in the water.
Temperature	Temperature	The temperature of water is an important factor in an aquatic ecosystem because it controls biological activities and chemical processes. Stream systems exhibit *diel* (daily) temperature variations. Most aquatic organisms depend upon the environment to regulate metabolic rates and have adapted to temperature ranges that occur in their habitat. However, alteration of habitat, especially by human activities, can cause temperatures to exceed these ranges.
Water clarity	Total Suspended Solids (TSS)	A measure of the total suspended solids in water, both organic and inorganic.
Salinity	Salinity Specific Conductance	The amount of dissolved salts in water, generally expressed in parts per thousand (ppt). Specific conductance is a measure of salinity in water. Salty water has high specific conductance.
Recreational health (Contact Recreation)	Bacteria	*E.coli* (freshwater) and enterococci (saline waters) are used as indicators of potential waterborne pathogens.

Table 13. List of Connectivity indicators and their importance to the instream flow study.

Connectivity		
Objectives: • Maintain/improve hydrologic connectivity needed to sustain floodplain and wetlands area (e.g., bottomland hardwoods, swamps, emergent marsh, oxbows, yazoos) • Ensure that studies are not conducted in a vacuum that ignores other needs such as bays and estuaries		
Indicators		
Category	*Indicator*	*Explanation*
Riparian zone	Total area inundated	The amount of out of channel area inundated by an overbank flow of a particular magnitude.
	Habitat area inundated	The amount of habitat area of a particular type that is inundated by an overbank flow of a particular magnitude.
Lateral connectivity	Connection to river (frequency, duration, timing)	Periodic connectivity of the river with oxbow lakes, backwaters, and other floodplain habitats is important to maintain the health of these areas and the organisms that depend on them.
Freshwater inflows to estuary	Volume of flow (monthly and yearly totals) at USGS gage #8030500, Sabine River at Ruliff, TX	Freshwater inflow requirements for the Sabine Lake Estuary have been studied by other state programs. Recommendations have been made in the form of yearly and monthly volumes of freshwater inflow. The Sabine River is an important source of inflow for Sabine Lake. Determining the total volume of flow (yearly and monthly) provided at this gage will allow evaluation of the impact of instream flow recommendations on estuary freshwater inflows.
Longitudinal connectivity	No proposed indicator at this time	The movement and dispersal of nutrients, sediment, fish, seeds, and other material along the length of a river is important to maintain the health of the system. Toledo Bend Reservoir, upstream of the study area, restricts longitudinal connectivity with upstream areas. In keeping with statewide TIFP objectives, longitudinal connectivity issues identified during the course of studies will be evaluated and documented.

3.0 DESCRIPTION OF TECHNICAL STUDIES

In keeping with it's statewide mandate, the TIFP will conduct technical studies of the lower Sabine River in order to determine flow conditions necessary to support "a sound ecological environment" in that system. The goal and objectives developed by the study design workgroup (described in section 2.2) were used to develop study indicators (described in section 2.3). The technical studies will investigate how the flow regime may influence these indicators.

The description of technical studies is divided into two main sections. The first section (3.1) provides the locations (Study Segments, Reaches, and Sites) for proposed activities and the rationale for their selection. The second section (3.2) provides an overview of the studies (essentially, the "What" and "Why") and how the activities address specific objectives and indicators. This section also provides the description of data collection methods, data analysis and modeling, and multidisciplinary coordination. This is essentially "How" the data will be collected and analyzed. The Technical Overview (TIFP 2008) provides substantial detail regarding many of these activities, and thus will be referenced where appropriate.

3.1 *Study Site Selection*

In order to plan study activities, the lower Sabine River was divided into Study Areas, Reaches, and Sites. Throughout the remainder of this document, these specific divisions of the sub-basin will be referred to as "Study Areas," "Study Reaches," and "Study Sites." The more general terms "area," "reach," and "site" will be used to refer to general lengths of river. While broader studies may be conducted across an entire Study Area, other studies will be conducted at particular Study Sites. Localized studies may have a single purpose (e.g., sediment data collection) or may address multiple indicators and involve multiple disciplines (e.g., hydraulic and habitat modeling site).

A three-tier evaluation was used to identify proposed Study Sites on the lower Sabine River. The Tier 1 evaluation was high-level and based on geomorphic principles and significant hydrologic influences. This resulted in the designation of three large-scale Study Areas. In Tier 2, the Study Areas were further divided into Study Reaches. Tier 2 was more detailed and focused on geomorphic features, hydrologic influences, and biological resources. This evaluation also determined which activities are recommended within the proposed study reaches. Tier 3 evaluation will examine in finer detail actual Study Sites that are representative of the Study Areas and Reaches and be of a practical size for the project's resources.

For study planning purposes, the lower Sabine River was defined as the main river from the Sabine Lake confluence upstream to Toledo Bend Dam. Study Areas, Reaches, and Sites are numbered from downstream to upstream to be consistent with other TIFP studies.

<u>**Tier 1 Segmentation – Study Areas**</u>

The three study areas are designated in Figure 11. The three basic geomorphic zones of any river are the headwater, transfer, and deposition zones, (which describe whether the reach functions as a sediment source, sediment transfer area or sediment deposition area). The lower Sabine River includes part of the sediment transfer and the entire deposition zone. Shoats Creek marks the transition from transfer zone (upstream) to deposition zone (downstream) (Phillips 2007). The Lake Charles Geologic Quadrangle (LGS 2002) reveals multiple channels and associated alluvial deposits, confirming that the river becomes distributary (braided and flowing away from the main river) near this location. For these reasons, the Sabine River downstream of Shoats Creek was designated Study Area 1 (Figure 11). Though the river upstream of Shoats Creek represents the transfer zone, it was split into two study areas, with the upper (Study Area 3) representing the portion most directly influenced by Toledo Bend hydropower peaking operations. Thus, Study Area 3 was designated from Toledo Bend Dam down to Burr Ferry (TX SH 63 bridge east of Burkeville) and Study Area 2 from Burr Ferry to Shoats Creek (Figure 11).

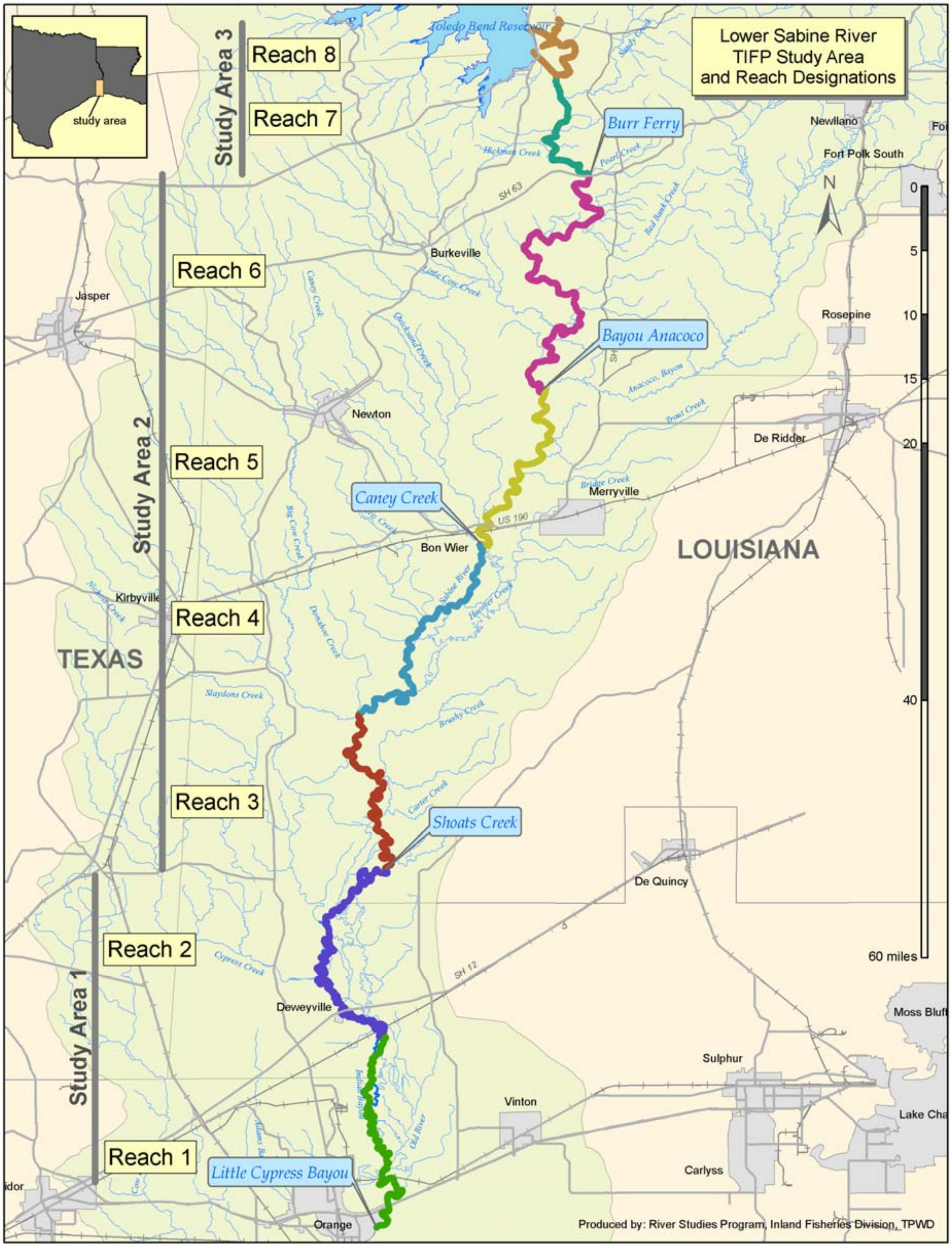

Figure 12. Proposed TIFP Study Areas and Reaches in the lower Sabine River sub-basin.

Tier 2 Segmentation – Study Reaches

Based on geomorphic, hydrologic, and biological differences, the three Study Areas developed in Tier 1 were further segmented into Study Reaches. A total of eight Study Reaches were designated numerically from 1 to 8 in an upstream direction (Figure 11). These Study Reaches and proposed study elements are also outlined in Table 14.

A significant contribution to the understanding of the geomorphic features of the lower Sabine River is the work of Phillips (2007). He divided the lower Sabine River into six geomorphic reaches (Figure 12) that were used as a starting point for segmenting the Study Areas into Study Reaches. Major tributaries were also evaluated to determine if additional reaches needed to be identified to account for substantial streamflow inputs.

Study Area 1—Distributary Area

Reaches 1 and 2 correspond with Phillips' two most downstream reaches (5 and 6). No additional reaches were needed to account for tributary inputs. However, the lower boundary of the reach (and of the entire study) was set to the Sabine River's confluence with the natural (non-channelized) portion of Little Cypress Bayou. This location corresponds to a break in vegetation type with the area upstream being Bald Cypress-Water Tupelo Swamp (predominantly freshwater) and the area downstream coastal (saltwater) marsh. The area downstream of Little Cypress Bayou was removed from the scope of this study because that area is heavily influenced by conditions along the coast including tidal influences. This area would be better characterized by a study focused on coastal marshes rather than an instream flow study focused on riverine conditions.

Study Area 2—Transfer Area

Reaches 3 and 4 correspond to Phillips' major reaches 4 and 3, respectively, though the upstream boundary of study reach 4 was moved to the confluence with Caney Creek. This location also corresponds with the boundary of Texas Commission on Environmental Quality Water Quality Segments 502 and 503.

Phillips' reach 2 was divided into two Study Reaches, upstream and downstream of the confluence with Bayou Anacoco, which is the largest tributary to the Sabine River downstream of Toledo Bend. Study reach 5 was defined as the portion of the river between the confluence with Caney Creek upstream to the confluence with Bayou Anacoco. Study Reach 6 was defined as upstream of the confluence with Bayou Anacoco to Burr Ferry.

Study Area 3—Major Hydropower Influence

Phillips' uppermost reach was divided into two Study Reaches. Study Reach 7 was defined to be the river from Burr Ferry upstream to the confluence of the hydroelectric and natural river (spillway) channels. Study Reach 8 was defined as the natural river (spillway) channel from the confluence with the hydroelectric channel to just downstream of the Toledo Bend Dam.

This segmentation of the river was developed by the TIFP state agencies, Sabine River Authorities of Texas and Louisiana, as well other stakeholders. This framework was subsequently adopted by the Aquatic Resource Work Group related to the FERC relicensing of the Toledo Bend Hydropower Project. Variation in biological resources (primarily riparian, mussel and fish assemblages) in relation to these Study Areas and Reaches was discussed to evaluate the type of studies needed in each reach.

Biological Resources

To maintain data collection efficiency, it was agreed that co-location of fish and mussel study sites would be preferred. Co-location of riparian study sites with mussel and fish sites was also preferred, for the

Table 14. Geomorphic reaches of the lower Sabine River (Phillips 2007) and proposed Study Areas, Reaches, and elements for lower Sabine River Priority Instream Flow Study.

River Mileage Geomorphic Reaches	Geomorphic Reaches (Phillips 2007)	Downstream Boundary	Upstream Boundary	Study Area	River Mileage Study Reaches	Study Reach	Riparian Study Element	Mussel Study Element	Fish Study Element*
131-146	1	Tailrace Channel	Spillway	3	141-146	8		X	BL
		Burr Ferry	Tailrace Channel		131-141	7			BL
91-131	2	Bayou Anacoco	Burr Ferry	2	105-131	6			FH
		Caney Creek	Bayou Anacoco		89-105	5			
70-91	3	Big Cow Creek	Caney Creek		70-89	4		X	FH
54-70	4	Shoats Creek	Big Cow Creek		54-70	3	X		BL
29-54	5	Cutoff Bayou	Shoats Creek	1	29-54	2		X	FH
0-29	6	Little Cypress Bayou	Cutoff Bayou		10-29	1	X		

*BL=Baseline fish data collection; FH=Fish habitat study.

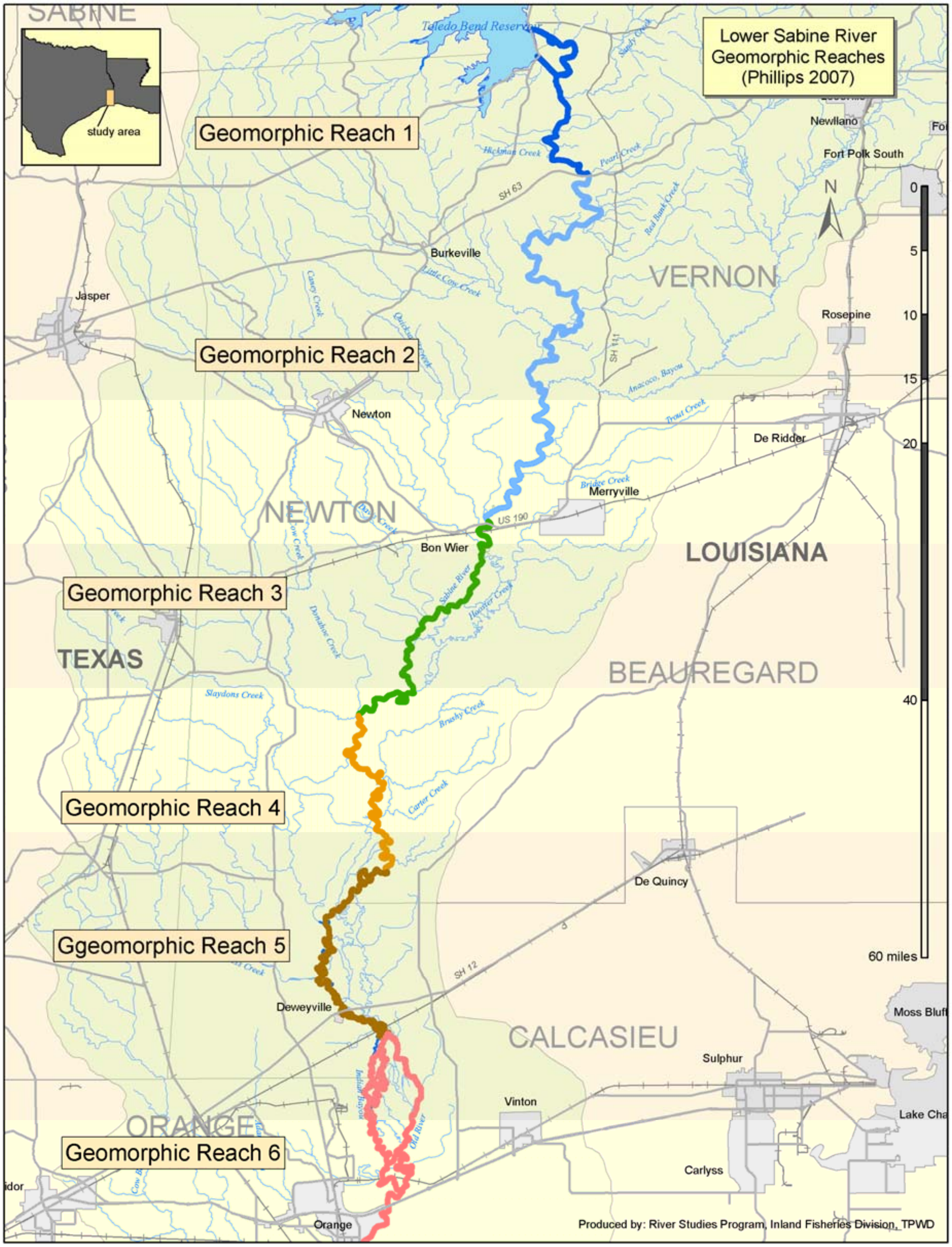

Figure 13. Geomorphic reaches described by Phillips (2007).

same reason, though riparian resources occupy a much larger spatial scale and will require larger study sites than those employed for fish and mussel studies. Proposed study elements for each reach are outlined in Table 14.

Riparian Resources
According to the statewide map of vegetation types (TPWD 1984), riparian areas in Study Reach 1 are composed of Bald Cypress-Water Tupelo Swamp and riparian areas in Study Reaches 2 through 8 are Willow Oak-Water Oak-Blackgum Forest. The lateral extent of riparian areas changes significantly at the boundary between Study Reaches 4 and 5, with Reaches below this point exhibiting "high floodplain/channel connectivity" (Phillips 2007). Riparian transect studies located in this area were completed by DTA/HDR (2008) as part of the FERC relicensing process and confirm the change in riparian extent at this location.Study Reach 1 contains two complete bottomland hardwood areas identified by USFWS (1985) as priority candidates for conservation (North Orange County Bottoms and Blue Elbow Swamp) and portions of another (Black Marsh). Study Reaches 2 through 4 contain portions of one area (Black Marsh) and two other areas in their entirety (Devil's Pocket and Big Cow Creek). There were no priority riparian areas identified in Study Reaches 5 through 8. Therefore, a riparian study site is proposed in Study Reach 1 and a second site somewhere within Study Reaches 2 through 4. Identifying flow conditions necessary for these two riparian study sites should support a healthy riparian condition along the length of the lower Sabine River. Further, a riparian study in Study Reaches 5 through 8 was deemed a low priority at this time.

Mussel Data
The University of North Texas(UNT) sampled mussels at four locations on the lower Sabine River, with three of the sites located in Study Reach 2 and one in Reach 4 (Randclev et al. 2010). Subsequently, UNT completed an additional reconnaissance survey in Study Reaches 5 through 8 as part of the FERC relicensing process (Randclev et al. 2009). A total of 446 individuals of 19 species from 42 sites were collected during the most recent work. Based on the results, 14 sites were selected as possible candidates for qualitative surveys pending review.

During the site selection meetings, it was proposed to place mussel habitat study sites in Reaches 2 and 4 and to evaluate mussel habitat at other sites for future consideration. The location of additional mussel habitat sites may be identified from recent data.

Fish Data
TPWD analyzed fish assemblage similarities for three data sets from the lower Sabine River: collections made by TPWD in 1955, Tulane University from 1968 through 1982, and TIFP in 2006 and 2007. Sampling locations vary among these efforts but several trends are evident. Study Reach 1 has a distinct assemblage due to the presence of estuarine species. There are probably at least two different assemblages along the length of Study Reaches 2 through 8. The TIFP data showed a unique assemblage in Study Reach 2 and another in Reaches 5 and 6. However, the sampling locations of that study were not adequate to determine if the assemblage in Study Reaches 3 and 4 is similar to (as shown in the Tulane data) or different from (as shown in the 1955 TPWD data) the assemblage in Reach 2. Additionally, the assemblage in Study Reach 7 and 8 was not sampled by the TIFP study. At the present time, it appears that there are at least three distinct fish assemblages along the length of the lower Sabine River. Fish habitat study sites are proposed in Study Reaches 2, 4, and 6, with baseline sampling in Study Reaches 3, 7, and 8 to evaluate the need for additional fish habitat or other studies. Data collected as part of the FERC relicensing evaluation may also be useful in analyzing fish assemblage patterns and the need for other studies.

<u>Tier 3—Study Site Delineation</u>

The aforementioned tiers provide a means for identifying reaches in which sampling for different study indicators needs to occur, and just as not every reach will be sampled for every component, entire reaches will not be sampled, but instead, sites that are representative of those reaches. Among the criteria for selecting sites will be characteristic mesohabitats, biological indicators, and property access. Although much of the work will occur within the river channel, control points/targets for surveying will be located away from the channel. Additionally, riparian assessments may need access to areas away from the river channel. Determining the suitability of those potential sites will require site visits and input from local stakeholders.

3.2 *Study Components*

The Technical Overview (TIFP 2008) outlines four major study components including hydrology and hydraulics, biology, physical processes, and water quality (TIFP 2008; Chapters 6, 7, 8, and 9). Additionally, the Technical Overview (TIFP 2008) discusses connectivity, dimension, and scale in stream systems (TIFP 2008; Section 3.3). As such, specific objectives and indicators for connectivity were developed during the series of stakeholder workshops (Section 2.2). This section describes the proposed study activities, proposed locations, and methods for each of the five components relative to the indicator categories established by the stakeholder process. The multi-disciplinary roles necessary to perform an instream flow study inherently cause overlap when presenting methods for the five major study components. However, to remain consistent with the Technical Overview and previous sections, each of the five components will again be discussed by section with interactions between components highlighted.

3.2.1 Hydrology and Hydraulics

The ecosystems dependant upon the lower Sabine River have evolved in response to the inter- and intra-annual variability in flow that includes cycles of overbank flows, high flow pulses and subsistence flows with intervening periods of base flows. This variability in the cycling of flow is typically referred to as the flow regime. An evaluation of the flow regime will address several of the hydrological indicators including characteristics of flow components and natural and current variability of those characteristics. A number of long-term streamflow gaging stations exist in the basin (Table 2) allowing characterization of flow variability, i.e., how the flow regime changes spatially (moving downstream towards the coast) and temporally (comparing early periods to later periods).

Natural variability / flow regime components

Natural variability includes typical fluctuations in base flow, limited periods of very low or subsistence flow, and high flows including within-channel pulse events and overbank flow events. The long period of stream flow records (beginning in the 1920's at some locations) allow comparisons between early periods that may represent a more natural condition to later periods reflecting reservoir operations, current land use, water usage, and other conditions affected by human's use of water and the landscape. Statistics derived from a hydrologic evaluation (described in section 6.1 of the Technical Overview) will be used to characterize the flow record and evaluate ranges for the four main instream flow components: subsistence flow, base flow, high flow pulses, and overbank flow. Existing flow analysis tools may be used to evaluate these components (e.g., Indicators of Hydrological Assessment [IHA], Hydrology-based Environmental Flow Regime [HEFR], Texas Hydrological Analysis Tools [TxHAT]) or alternatively, standard statistical methods may be used including non-parametric statistics (e.g., 5th percentile flow). Any statistical characterization of flows will be complementary to field studies and physical assessments that identify flow levels beneficial to the ecology of the lower Sabine River.

Hydraulic and habitat models

In addition to statistical analysis of the flow record at existing gages, site-specific field studies will focus on development of two-dimensional (2D) hydraulic and habitat models. A 2D hydraulic model provides simulated flow conditions for a given stretch of river (habitat study site). The simulated flow conditions are then run through a GIS-based physical habitat model to predict habitat conditions within that habitat study site. For each simulated flow, the spatial availability of suitable habitat can then be queried using habitat suitability criteria for habitat guilds and key species. For each guild and key species, streamflow to habitat relationships are developed. The general process of hydraulic modeling in support of habitat modeling is described in sections 6.2, 7.3, and 10.2 of the Technical Overview.

For the TIFP study of the lower Sabine River, 2D hydraulic and habitat models will be developed to evaluate changes in habitat across a range of flow rates. This analysis will specifically aid the development of subsistence and base flow components and will therefore focus on flow rates from about the median to the 10 percentile flow as described in section 6.1.3 of the Technical Overview (TIFP 2008). Hydraulic and habitat modeling will be conducted within Reaches 2, 4, and 6 on the lower Sabine (Figure 11) and additional reaches may be added as ongoing biological surveys are completed. These models will characterize existing habitat conditions across a range of flow rates. Specific habitat types will be characterized based upon habitat utilization data recorded in the lower Sabine River sub-basin relevant to the aquatic organisms present in the area. The collection of the biological data is described in the Biological Section (Section 3.2.2) below. Identifying breakpoints or sharp changes in habitat availability provides insight into flow rates relevant to river ecology. Relevant flow ranges identified by the habitat modeling will be compared to the frequency of those flows exhibited in historical and current flow records. Instream flow guidelines for achievement of particular flows may be recommended on the basis of both physical habitat requirements and upon historical frequency of occurrence. Other analyses, including development of a habitat time series, may be conducted to consider both habitat and flow frequency.

Development of hydraulic and habitat models is one of the more resource intensive tasks involved in a typical instream flow study. Model development represents a multi-stage, multi-disciplinary process that includes (1) biological data collection to characterize relevant habitat, (2) physical data collection to characterize the river channel, (3) data processing to integrate points into a cohesive map of the river system, (4) hydraulic model development, calibration and validation, (5) habitat model development, including the integration of habitat utilization data, (6) analysis of habitat model results and, finally, (7) evaluation of results leading to development of flow guidelines.

To characterize velocity and depth patterns at a level suitable for use in evaluating microhabitat, the model developed at each habitat Study Site needs input data at a sufficiently high resolution. In particular, detailed maps of bathymetry (elevation of the channel bed) and substrate (materials comprising the channel bed) are required as well as water surface elevation data. At the same time, flow rate, depth and velocity will be collected.

At each model Study Site, complete channel and near-channel floodplain Digital Terrain Models (DTMs) will be created using a combination of survey-grade GPS equipment and conventional surveying equipment coupled with hydro-acoustic depth/velocity sounding data. Survey data will be reviewed for completeness (missing data, holes in the topography, etc.) and supplementary topographic surveying will be conducted to ensure complete coverage of each intensive Study Site.

Model calibration, validation and sensitivity analysis

Calibration is the process whereby a model's input parameters are tuned to maximize measures of model performance using measured field data. To assess the ability of the model to predict real-world conditions, the model is then validated against additional field data using the calibrated ("tuned") parameter values.

The minimum calibration data required for hydraulic modeling consists of a stage-discharge relationship at the upstream and downstream end of each habitat Study Site. Development of a stage-discharge relationship requires a minimum of three flow measurements, during high, medium, and low flow conditions. Additional calibration data will be collected in the form or water surface elevations measured throughout the Site during the same flow conditions (high, medium, and low). Water surface elevations will be measured with survey grade GPS (centimeter accuracy) or conventional surveying equipment to adequately characterize changes in edge of water and water surface slope throughout the Site. During data collection, a temporary staff gage or pressure transducer will be installed at the downstream end of the Study Site to document any changes in stage.

Each time stage-discharge data for the development of rating curves is collected (a minimum of 3 flows at each Site), additional depth/velocity point measurements for calibration and validation will be collected. Velocity data (consisting of average column velocity and direction) will be collected using acoustic doppler profilers or other velocity measurement devices. Elevation contour maps and a random point generator will be used to produce a quasi-random set of calibration/validation point locations. Half of the velocity and depth data will be used to calibrate the roughness and viscosity parameters in the 2D hydraulic model and the other half to validate the model results and report uncertainty. Additional data to validate the accuracy of 2D hydraulic models will be collected and will consist of the length and width of any large recirculation zones observed during high, medium, and low flow conditions.

Substrate roughness and eddy viscosity are two parameters commonly used to calibrate a hydraulic models. The 2D hydraulic model will be calibrated to at least three measured water surfaces (high, medium, and low flow) by adjusting substrate roughness and eddy viscosity parameters. To adjust substrate roughness, substrate maps at each Study Site will include an estimated hydraulic roughness height based on the size of the largest particle in each substrate category. During the calibration phase of the hydraulic modeling, the roughness heights across all substrate types will be increased or decreased by a constant percentage until the modeled water surface matches the measured water surface. This will first be done at the moderate calibration flow. A check that the calibrated roughness performs accurately at the high and low calibration flows will be performed. If necessary an equivalent roughness height modifier regression will be used to scale roughness height over the range of modeled flows. A similar procedure will be used to calibrate the viscosity parameters, which are used by the model to calculate viscosity at each node based upon local velocity. Since viscosity parameters are assigned as constants for all areas of the model, a modifier regression may be used to scale the parameters over the range of flows. When roughness height and viscosity adjustments are obtained that generate accurate modeled water surface elevations for all three flows, the hydraulics model will be assumed to be calibrated. All subsequent hydraulics modeling of the various flows for habitat modeling will be completed using calibrated channel roughness heights and viscosity parameter adjustments. A range of flows will be modeled at each Study Site. This flow range covers the majority of median monthly flows in the historical range including temporary pulse flow events, but not including flood flow conditions. The focus of this range is in-channel aquatic habitat conditions.

Uncertainty in environmental models exists and can, to some degree, be characterized. A riverine model uses generalized parameters to describe and simulate the physical characteristics of the river. These generalized parameters have uncertainty bounds associated with them, which leads to model uncertainty. Calibration of a hydraulic model aids in reducing but not totally eliminating model uncertainty. The sensitivity of hydraulic model results to changes in calibrated parameters will be investigated. If the model is found to be highly sensitive to a parameter, efforts will be made to reduce the parameter uncertainty through further data analysis, calibration and/or acquisition of additional data.

3.2.2 Biology

Detailed biological studies at representative reaches of the lower Sabine River are required in order to understand the relationship between biology and flow conditions and address the overall biological objectives to:

- Maintain and/or improve sustainable native biological communities/habitats
- Control invasive and non-native species that threaten the function of aquatic and terrestrial ecosystems

Instream biological community and species level indicators will be used to measure how the study methodologies discussed below will address the biological objective. Biological surveys, riparian assessments and models, and instream habitat models will play a substantial role in identifying flow conditions needed to meet the goal and objectives set forth for the lower Sabine River. Many of the methods and analyses described in this section correspond directly with guidance provided in Chapter 7 of the Technical Overview (TIFP 2008).

Reach scale habitat mapping

Information collected during the aerial reconnaissance in combination with existing information and data layers (geomorphic reaches, aerial photos, geology, etc.), and meso-scale physical habitat types will be mapped in GIS using the following characteristics:

- Pool - flat surface, slow current; usually relatively deep
- Backwater - flat surface, very slow or no current
- Run/Glide - low slope, smooth, unbroken surface
- Riffle - moderate slope, broken surface
- Rapid - moderate to high slope, very turbulent (e.g. boulder field)
- Chute - very high velocities in confined channel

Ground truthing will be conducted by boat, kayak, and/or walking depending on specific conditions of the river or stream; these surveys should be performed when flows are at or below median conditions when habitat features are relatively easy to evaluate. Field notes and drawings will be digitized and incorporated into a GIS layer that can be used to query the amount and location of various habitat types. Riparian vegetation categories will also be delineated on the photos, digitized and incorporated into a GIS layer. This information can be used to determine appropriate Study Sites within select Reaches that represent habitat found in larger areas. The channel reach maps may also be used to evaluate how modeled habitat at a Study Site scales up to total habitat available within a Reach or Study Area, if necessary, and to assist in designing stratified sampling protocols.

Instream biological communities - fish and mussel surveys

Assessing the current condition of fish and mussel communities and their relationship to instream flows is an important step in focusing detailed studies (e.g., microhabitat use), evaluating and validating models developed from those studies and in long-term monitoring programs. As discussed in Section 1.1.2, baseline fish sampling throughout the lower Sabine River has been performed between 2006 and 2008 with the goal of collecting representative samples of fish species present in their relative abundance. Recent baseline mussel surveys (Karatayev and Burlakova 2008; Randklev et al. 2010) provide a picture of present species richness and distribution. Given the level of detail performed during these sampling efforts (see baseline fish survey methodology), baseline data will be useful in evaluating and validating the models developed from the detailed microhabitat studies. Baseline fish sampling will also be used to help address the indicators of species richness and relative abundance of flow sensitive species, sportfish, prey species, imperiled species, and intolerant species in the lower Sabine River.

Fish surveys

Fish will be collected in each identifiable mesohabitat within a Study Site (consisting of a length of river or stream 40 times the mean wetted width or one full meander wavelength) using multiple gear types (seines and electrofishers). If unable to employ multiple gear types, the reason will be indicated and effort increased with the gear type able to be utilized at that mesohabitat. Physical measurements will be made in association with each sampling event (e.g., each seine haul) and will include current velocity, depth, substrate composition and embeddedness, and instream cover (large woody debris, boulders, undercut banks, macrophytes, velocity shelters, etc.). Notes on climatic conditions and mesohabitat typing will also be recorded. Released fish will be identified, measured, photo-documented, and examined for disease and other anomalies. Voucher specimens will be preserved in 10% formalin. In all cases, fish sampling will continue as long as additional species are being collected.

Electrofishing (900 seconds minimum total combined trigger time) will be conducted using either boat or backpack electrofishing dependent on the habitats being sampled. Boat electrofishing will occur in habitats too deep or swift for effective backpack or seine sampling (e.g., pools, fast runs), and backpack electrofishing will focus on areas shallow enough for effective sampling by wading (e.g., riffles, shallow runs). Seines may be placed downstream of the areas sampled by the backpack electrofishing crew to assist in fish collection, if necessary. After a particular habitat type has been thoroughly sampled, collected fishes will be processed independently and fish abundance, electrofishing time, site information, personnel, and output settings can be recorded for each sampling event.

Seining (minimum 10 effective seine hauls) will be conducted in various habitats using a variety of seines sizes and seining techniques (e.g., riffles kicks) in order to complement electrofishing efforts. It should be noted that a seine haul where zero fish are collected is considered an effective seine haul if the haul was not impeded (i.e. snagged), allowing fish to escape. Examples of commonly used seines include a 9.1 m x 1.8 m x 7.6 cm (30’ x 6’ x 1/4”) mesh seine for sampling pools and open runs and a 4.6 m x 1.8 m x 5.7 cm (15’ x 6’ x 3/16”) mesh seine for sampling riffles, runs, and small pools. All seines will be constructed of delta weave mesh with double lead weights on the bottom line. Seine size used, seine haul length, site information, and personnel will be recorded. Fishes collected from each seine haul will be processed independently.

Mussel surveys

To determine abundance, distribution, and habitat utilization of mussels within Study Sites, a systematic sampling approach will be employed (Strayer and Smith 2003). In this method, a sampling area consisting of a length of channel two times the wetted width of each identifiable mesohabitat within the Study Site will be sampled. Using a 0.25 m^2 quadrat, a minimum of 20 samples will be collected, each spaced equidistance from at least three random starting points. Strayer and Smith (2003) provide a formula to calculate distance between systematically selected units:

$$d = \sqrt{\frac{L \cdot W}{n / k}}$$

Where d is the distance between units, L and W are the length and width of the sampling area, n is the total number of quadrats, and k is the number of random starts. Given that a 0.25 m^2 quadrat will be employed, distance between sampling units calculated using the formula can be rounded down to the nearest half meter. In each of the sample quadrats, mussel species will be identified and enumerated. Physical measurements such as depth, current velocity, and substrate type will be recorded for each sample for use in habitat suitability criteria development. Pooler and Smith (2005) found systematic sampling approaches with greater than two random starts more accurate at estimating abundance than simple random sampling, 0.25 m^2 quadrats more accurate and precise in estimating abundance than 1 m^2 quadrats, and systematic sampling estimates more accurate when distance between sampling units across the stream are less than or equal to the distance between sampling units along the stream (hence the two times the wetted width sampling area). Hydraulic data in mussel beds will be collected following Morales et al. (2006) and Randklev et al. (2010).

Instream habitat surveys and habitat modeling

For several flow regime components, instream flow recommendations depend on assessments of how instream habitat changes with variations in streamflow. This study will address these habitat-flow relationships using two complementary approaches. The first is an assessment of the area and diversity of intermediate scale habitats, referred to as mesohabitats (e.g., riffles, runs, and pools) in relationship to streamflow. Habitat diversity is a primary factor affecting the richness and abundance of fishes and other aquatic organisms and can be assessed by using mesohabitat criteria. Those criteria can be derived either from biological (habitat guild approach) or hydraulic variable data coupled with a hydraulic model that describes the distribution and magnitudes of depth and current velocity at different streamflow rates. This approach addresses the indicator of mesohabitat area and mesohabitat diversity and is a valuable approach in species-rich ecosystems such as the lower Sabine River.

The second layer of assessment addresses the habitat quality and quantity for key species (microhabitat) to ensure that their habitat and life history needs are specifically addressed. In this approach, habitat suitability criteria for the life stage of a particular species are developed and used in the habitat model (as above) to develop microhabitat-flow relationships. Specific sampling strategies may need to be developed to ensure adequate sampling of particular species (e.g. blue sucker).

For each Study Site where habitat modeling will be conducted, GPS units will be used to delineate mesohabitats. If the mesohabitat can be further discriminated, it will be assigned a qualifier for relative current speed and depth using 'fast' or 'slow' for current velocity and 'shallow' or 'deep' for depth. Notes on location and density of woody debris and other instream cover, unique habitat features (e.g., a unique outcrop) and substrate composition will be taken. Measurements of current velocity and depth will be taken to facilitate development of objective criteria to define mesohabitat types in the lower Sabine River. These mesohabitat surveys should be performed when flows are at or below median conditions when habitat features are relatively easy to evaluate. Standardized field guides and sampling protocols will be provided to field crews in order to maximize the accuracy and repeatability of habitat data collection.

Fish microhabitat utilization and biological validation surveys

Because native fish and mussel communities in the lower Sabine River have evolved life history strategies and patterns of habitat utilization that correspond to natural flow regimes, they represent ideal taxa to assess the relationship between biology and streamflow conditions. Detailed studies on fish and mussel habitat use will be needed to develop habitat suitability criteria. Potential key species (described in Section 2.3), anticipated for microhabitat modeling include blue sucker, paddlefish, scaly sand darter, dusky darter, pallid shiner, shoal chub, Sabine shiner, spotted bass, floodplain dependent fishes, as well as mussel species of concern. Some of the aforementioned species and others may be grouped in mesohabitat guilds to facilitate evaluating habitat utilization. Those criteria can then be used in conjunction with instream habitat modeling (discussed below) to develop an index of suitable habitat (e.g. weighted usable area [WUA]) to support fish and mussel populations at various flow levels. These types of studies will help identify flow requirements necessary to conserve flow-sensitive, intolerant, and imperiled fish and mussel species, as well as key aquatic habitats that support those species.

Determining habitat utilization for use in developing habitat suitability criteria (HSC) will be done by sampling fishes using a stratified random design consisting of mesohabitat and substrate categories.

Given these combinations and the total number of sites and flow rates to be sampled, the minimum number of samples can be determined. It is important to recognize that the primary role of these categories in fish sampling is as an analog for depth and velocity; pools tend to be slow and deep and riffles tend to be fast and shallow, for example. Stratifying sample locations by mesohabitat helps ensure a wide range of depths and velocities are sampled. Further, each site will be sampled four times from low to high base flow conditions, but only when diverse habitat conditions exist and sampling efficiency is not compromised. A minimum number of HSC samples will be collected from each combination of mesohabitat and substrate categories at each study site under each of the four flow rates. This minimum number may be as low as three but will be calculated once the total number of combinations at each study site is determined. For example, three samples per strata/site/flow were used on the Lower San Antonio River Instream Flow Study which had five habitat categories, eight substrate categories, five sites, and four flow rates.

The first step is to generate substrate and mesohabitat maps so that the number of combinations can be determined. To map substrate, cross-sections will be established every 10–20 meters throughout each study site. Shorter cross-section intervals may be needed to map sites that have complex substrate patches while longer intervals can be used at downstream sites that exhibit fairly homongeneous distributions of fine substrates (such as sand). At each transect, 3-10 evenly spaced substrate grabs will be made across the width of the river and classified using the modified Wentworth Scale (TIFP 2008). A greater number of substrate grabs may be needed in sites or habitats with complex combinations of substrate. Where differences among substrate grabs are noted, more detailed sampling will be conducted to establish exact location of substrate changes. GPS receivers capable of sub-meter accuracy will then be used to map polygon areas of similar substrate. Coordinate data will be processed to create detailed maps of substrate for each study site. Substrate/cover data may be grouped into fewer categories in order to facilitate distribution of samples in the stratified-random design.

Based on the reach scale maps (see *Reach scale habitat mapping* above) of mesohabitats and the substrate maps generated at each site; an initial allocation of sample points can be made across the combinations of mesohabitat and substrate, study sites and flow rates. This initial allocation may need to be adjusted (using detailed site maps described below) to ensure all habitat types can be sampled to meet design criteria. Although substrate conditions are typically assumed to be constant in instream flow modeling (and thus, will be mapped only once), hydraulic habitat conditions (depth and velocity) change considerably with flow rate. Therefore, more detailed habitat mapping will be conducted immediately prior to, and at a similar flow rate to, each HSC-related fish sampling event.

To create detailed mesohabitat site maps, the river will be divided into mesohabitat categories (as defined above). Current velocity and depth will be measured to guide the mapping. A GPS unit will then be used to delineate each mesohabitat, with detailed site maps being generated. The detailed mesohabitat site map and substrate map will be merged to form one map and then used to spatially locate the allocated random samples at a given site for a given flow rate. The sampling locations generated are simply meant as a general guide to aid field biologists in selection of appropriate areas. They are not meant to identify exact sampling locations, but rather, to approximate general areas of interest. Field biologists are responsible for picking an area near the suggested sample point of sufficient size to capture resident fish, with relatively consistent depths and velocities. For example, points that fall along or within transition zones (where conditions begin to change) will be dropped and the next random point located. This will ensure that data accurately describe instream conditions for each mesohabitat type.

Once a location is found in the field, a sampling area consistent in depth, velocity, and substrate characteristics will be delineated. The size of the sampling area will depend on considerations such as mesohabitat type and gear limitations. Although effective size of the sampled area will vary among mesohabitat types, an effort will be made to establish an approximate effective size for each type. Additionally, variation in size of sampling areas can be accounted for by determining the size of each sample area and using fish density (# fish/m^2) instead of raw abundance during calculation of habitat suitability. At the sampling area, fish will be collected using seines, backpack and/or boat electrofishers or combinations thereof, as appropriate. Collected fish will be identified, enumerated and measured prior to release or preservation. Voucher specimens will be kept and large specimens photographed following TIFP protocols. Mesohabitat fish sampling may include both day and night time efforts to properly identify diurnal differences in habitat use by species and age class.

Physical characteristics of the sampled area will also be measured. Parameters will include current velocity, water depth, substrate types (dominant and subdominant) and cover characteristics. These characteristics will be used to develop habitat suitability indices for modeling purposes. Further, instantaneous water quality readings (DO, pH, temperature and conductivity) will be measured from the sampled area. Similar sampling procedures have been used in development of fish habitat use data for instream flow assessments in Texas (BIO-WEST 2008).

Biological data analysis

The goal of analyzing biological data is to develop a conceptual model of biological assemblage dynamics and health and habitat utilization. By evaluating and modeling habitat use over a range of hydrologic conditions, we can develop quantitative instream flow recommendations that support the study objectives as well as the overall objective of a sound ecological environment. Among the goals for analysis are to evaluate temporal and longitudinal trends in assemblage structure and seek to relate those trends to broad-scale habitat conditions within the system. That may include both in-channel and riparian influences as well as tributary and other inputs. This approach will undoubtedly include using multivariate statistics (e.g. detrended correspondence analysis or other tools) to examine such trends and the effects of physicochemical variables. Diversity, richness, and relative abundance along with other derived information such as biotic integrity indices will also be assessed to provide indicators of ecosystem condition.

To determine the relationship between biology and streamflow conditions, habitat utilization data for fishes and mussels will be developed to evaluate a variety of habitat factors such as depth, substrate, mean column velocity, bed velocity, cover, etc. That information will result in habitat suitability criteria, which can then be integrated with simulations of instream habitat modeling (see 2D hydraulic models above) to develop an index of habitat availability for various flow conditions. The development of habitat suitability criteria for fishes in the lower Sabine River may require the approach of grouping fishes into guilds (e.g. habitat guilds) using multivariate techniques in conjunction with supplemental life history information. A guild approach would simplify assessments (more than 90 species historically (Bonner and Runyan 2007) and more than 60 species identified in baseline sampling), but maintain an assemblage-based approach for addressing instream flow requirements and can be used in a complementary assessment of habitat suitability for individual key species. A GIS-based physical habitat model will be used to assess habitat versus flow relationships, including mesohabitat diversity.

Across a range of flow rates, habitat models will be used to characterize suitability of aquatic habitat for key species or groups of species. The biological validation data collected will be used during habitat modeling to validate or to modify the habitat modeling procedures. Flow ranges, typically at the subsistence and base flow levels, will then be identified that are appropriate to maintain the health and function of the aquatic ecosystem.

Riparian habitat - baseline surveys and evaluation

The health of riparian ecosystems is linked to the periodic occurrence of overbank high flow pulses, associated channel dynamics, and the preservation of base flows capable of sustaining high floodplain water tables (Busch and Scott 1995). Because of the importance of maintaining connectivity of riparian vegetation to hydrology, assessing the condition of riparian vegetative communities is an important component in determining ecosystem health. In order to determine baseline riparian vegetative conditions, detailed studies that characterize the riparian habitat will be conducted within representative study areas. Key riparian vegetative indicators to be assessed are: age class distribution, richness and diversity, density, and % canopy cover. This information will then be linked back to overbanking and base flow requirements for the maintenance of a healthy riparian ecosystem.

The purpose of characterizing riparian habitat within the study area is to identify the extent and condition of existing riparian habitats as well as the surrounding land use. Extent and distribution of riparian communities will assessed using the TPWD/NatureServe Vegetation Classification System database, which utilizes vegetation types, soils, and topography parameters. To verify accuracy, classify small changes to the TPWD/NatureServe Classification System, and gather specific riparian community composition and structure data, riparian habitats within the habitat modeling study sites will be assessed during field visits being conducted for physical or biological data collection.

Riparian habitat will be characterized by establishing 50m transects in a stratified random approach at the physical and biological data collection sites along the lower Sabine River. In general, transects will be typically be placed perpendicular to the river channel, and the number of transects run will be determined by the size of the study site selected. Information will be collected to determine density, dominance, and frequency of riparian plant species, land use, and adjacent land use.

Tree strata will be sampled with a 10m x 50m area whose center line corresponds to the 50 m line transect established. All single trunked, woody, perennial vegetation (trees) with a diameter at breast height (dbh) of greater than 5 cm within the sample area will be measured and recorded by species into one of the following size class categories: 5-15cm, 16-25 cm, 26-35 cm, 36-45cm, 46-55cm, 56-65cm, 66-75cm, 76-85 cm, 86-95 cm and greater than 95cm. Measurement will be to closest cm, rounded as appropriate. Canopy closure will be estimated using spherical densiometers at the 10m, 20m, 30m and 40m intervals on center transect line. The mean of the 4 densiometer measurements will be calculated.

Shrub composition and relative abundance will be calculated using a line intercept method. Shrubs are all multi-trunked, woody perennial vegetation and also all single trunked woody perennial vegetation less than 5cm dbh. The linear distance, to the nearest cm, that each species intersects the line will be recorded. Percent coverage of each species will be calculated by dividing the total linear distance of each species by 5000cm. Overlapping canopy of different species will be recorded according to distance each species intersects the line transect. Total distance with no shrub canopy will also be recorded. Total percent shrub canopy cover will be calculated according to the following formula: 1 – (no shrub linear intercept distance / 5000).

Herbaceous vegetation composition will be determined using a line point intercept methodology. A 1 meter long 1/8 inch diameter "pin" will be set vertically every 1 meter along the 50 meter line, starting at 0. All species of herbaceous vegetation, woody vines and woody seedlings that touch the pin will be recorded. Relative abundance of each species will be calculated using the formula: # pins touched by species / 51.

Data obtained from transect surveys will be assumed to be representative of the entire stand of vegetation. Measurements collected during the first sampling effort will be used to establish existing, or baseline, conditions within the riparian zone. Measurements collected in subsequent sampling events can be used to compare against baseline conditions to assess changes in species composition and structure over time.

The recurrence interval of inundation is important to riparian and wetland areas. Water surface elevations will be combined with Digital Elevation Model data to evaluate how different riparian areas are affected by overbank flows, and how riparian areas may transition (spatially) according to differences in wetting and drying characteristics. Results of overbanking studies will include quantifiable area (acres) inundated for each riparian area. Overlaying inundation areas with existing land use maps (National Land Cover Dataset) or with interpreted riparian area maps allows assessments of frequency of habitat inundation. For further description of the use of DEM models to evaluate overbank flows, please see Section 3.2.5.

3.2.3 Physical Processes

The objective of the physical processes component is to identify the interrelationships between flows and bank stability, channel maintenance, and flood impacts. Geomorphic activities will focus on four areas: (1) analysis of available aerial photographs as a source of historical geomorphic data, (2) evaluation of sediment dynamics in active channel areas, (3) detailed mapping of geomorphic features, and (4) evaluation of the impacts of high flow pulse and overbank flows. The first activity will be carried out along the length of the lower Sabine River following methods previously suggested by Gillespie and Giardino (1997) on the Brazos River. The second will be carried out at the scale of the length of the lower Sabine River and select field sites in order to evaluate processes that operate at these different scales. The third activity will be carried out only at select field study sites. The fourth will rely on sediment and cross section data from USGS gage locations and select sites on the lower Sabine River.

Analysis of aerial photos

Available aerial photographs will be analyzed and historical rates of bank erosion, lateral channel migration, and channel avulsion will be estimated. Analysis will be completed following a methodology suggested by Gillespie and Giardino (1997). Available photo coverage for the lower Sabine River begins as early as the 1930's. By comparing changes over time, estimates will be made for historical decadal rates of bank erosion, lateral channel migration, and channel avulsion development. The possibility of estimating flow thresholds necessary to initiate these processes by comparing changes in aerial photos with hydrologic flow records will be explored.

Evaluation of sediment dynamics

Sediment dynamics in the study area will be evaluated based on a combination of sediment budgeting for active channel and floodplain areas. Sediment budgeting is the analysis of particular matter, organic or mineral, which is depositing and moving through the fluvial system. Sediment budgeting will be completed at two scales: (1) across the length of large sections of river with relatively uniform sediment carrying capacity and (2) select sites (segments of river equivalent to one or more meander wavelengths.

At the first scale, the entire lower Sabine River will be segmented based on USGS gage locations and network connection points. The purpose of the segmentation is to identify sections of the river with relatively uniform sediment carrying capacity (a function of flow, slope, channel shape, and sediment characteristics). Sediment budgets for the active channel and floodplain areas of each segment will be completed, including estimates of sediment input to the segment from the upstream channel, tributaries, and banks and outputs to downstream sections of the river and floodplain. At the second scale, sediment budgets will be completed to describe the deposition and transport processes within and between segments of the river. The stability of deposit and residence time of particles will be determined for specific size classes of material (for example, sand between 0.1 and 2 millimeters in diameter or gravel between 4 to 10 millimeters in diameter).

In order to support the objective of evaluating sediment dynamics, sediment modeling will be conducted at two scales. At the first scale, sections of river (equivalent to a few meander wavelengths) representative of the variety of different morphology and sediment characteristics in the study area will be selected. A sediment transport model will be coupled with a standard one-dimensional hydraulic model (such as HEC-RAS) to estimate the magnitude of flows that perform various geomorphic processes within each reach, such as floodplain deposition, meander migration, or bar maintenance. The models will be modified to incorporate several mechanisms, including bimodal surface particle transport and river morphodynamics. Stream power patterns will be analyzed in order to understand specific fluvial process such as the movement of particular sediment sizes through the reach, deposition on the floodplain, and bed aggradation or degradation. Field data will be collected in order to compare with model results.

At the second scale, a sediment transport model will be coupled with the two-dimensional hydraulic developed for habitat modeling (see Section 3.2.1). We will investigate the utility of using the coupled sediment transport/hydraulic model to evaluate finer scale processes at work in pools or bars of interest. Sites for this analysis will correspond to habitat modeling sites described in Section 3.2.1 and will be approximately one meander wavelength in length. Processes such as deposition patterns on bar surfaces and maintenance of pool depths will be modeled and compared with field observations. Stream power patterns and sediment movement thresholds required to accomplish channel scale process goals will be estimated and compared to independent empirical data.

Mapping of geomorphic features

Geomorphic mapping of channel scale morphology will be completed at field study sites, including habitat modeling Sites. As part of this mapping, channel morphology features (such as thalweg location, bank shape, and bar size) will be mapped. Geomorphic mapping will extend up the banks to the beginning of the active flood plain (approximately the area inundated by the 2-year return interval flood). Bed and bank sediment material, as well as large woody debris, will also be mapped. Sediment material will be sieved in order to determine grain sizes and sorting pattern. Work will be conducted in a manner consistent with finer scales associated with River Styles (Brierley and Fryirs 2005), which includes mapping of channel and hydraulic units. The detailed geomorphic map will be of value for determining substrate material, associated roughness for hydraulic modeling, and the physical features of biological habitat. The data collected during the detailed geomorphic mapping will be in a format allowing the extraction of more general mesohabitat and substrate maps for analysis of fish habitat utilization (see Section 3.2.2).

Overbank flows

The range of overbank flows of interest to the TIFP study of the lower Sabine River will range from events that have historically occurred more than once per year to those that occur only once every few years. The impacts of such flows can be estimated based on flood impact summaries provided by the National Weather Service for most USGS streamflow gage sites. In addition, Digital Elevation Models described in Section 3.2.5 will provide an estimation of the extent of area inundated by overbank flows, providing another measure of their impact.

3.2.4 Water Quality

Maintaining adequate water quality is an essential part of managing a river ecosystem. Evaluating water quality along with hydrology, biology, and physical processes is an important component of the lower Sabine River study. To a large degree, appropriate water quality is monitored and regulated through the EPA and the TCEQ in processes like the CRP, National Pollutant Discharge Elimination System, Total Maximum Daily Load (TMDL) program and others. SRA-Texas actively participates in and manages portions of these processes. Generally, existing water quality programs (e.g., CRP) will be used to evaluate water quality. Any new data will be collected according to water quality protocols that already exist for those programs. Water quality issues will be evaluated and will consider results of ongoing or completed SRA-Texas studies (basin nutrient loading study, bacteria Watershed Protection Plans, previous water quality models, etc.) and state-wide efforts (nutrient criteria development). However, existing studies do not provide sufficient detail to assist in the development of instream flow recommendations that address water quality concerns. In particular, dissolved oxygen (DO) is a primary parameter of concern since low levels can have detrimental effect on aquatic organisms. Unfortunately, relationships between flow, nutrients, and DO in the lower Sabine sub-basin are not well quantified at this time.

Nutrients, dissolved oxygen, and temperature

Despite the somewhat comprehensive set of water quality programs already in place, the tools used in those programs to promote good water quality have thus far been applied for specific programmatic purposes. The tools may not yet have been applied for a range of scenarios necessary to evaluate instream flows. At least one of these tools, the QualTX water quality model, is developed for some reaches within the lower Sabine River sub-basin. However, it is anticipated that updates and revisions to the existing QualTX models or development of new models will be necessary to analyze effects relative to various flow regimes. Currently, QualTX can be used to evaluate steady-state water quality conditions across a range of low to moderate flows. The primary output is DO concentration based upon inputs including flow, nutrient concentration, temperature, and other physical and kinematic parameters.

Refinements or development of these models will require data accumulation and manipulation. Data needs include but are not limited to current: (1) water balance (volume and location of inflows, discharges, and diversions), (2) loading from tributaries and contributing watersheds, (3) treatment plant discharges (both volume and loading), (4) literature values for modeling parameters and/or (5) collection of additional field data (travel time, diurnal variations, etc.). Interaction with SRA-Texas and other entities will be necessary, particularly as related to understanding the lower Sabine River sub-basin and development of modeling scenarios. Calibration of model parameters will be conducted, as will model sensitivity analyses. The calibrated model will be validated using a set of known conditions if sufficient data is available. Once calibrated and validated, the model will be a useful tool for understanding and estimating water quality impacts for different instream flow scenarios. The model will also be useful for understanding potential future conditions.

Rather than use the model as a starting place to identify flows, the model will be used to check and adjust flow rates determined to be beneficial to the river ecology. It is anticipated that if QualTX is used, it will be to evaluate low flows, consistent with the subsistence or base flow levels. Generally, the greatest potential for low DO to occur is during low-flow, high-temperature conditions, when potential for aeration is reduced and DO saturation is low. If, however, low flows regularly occur during seasons with more moderate temperatures, it would be appropriate to model both the low flows with moderate temperatures and the higher flows with high temperatures to ensure that the critical period is evaluated.

In addition, it may also be important to understand how the DO concentration in creeks and rivers can be affected by an influx of organic matter from the watershed following rain events. Since this represents a more dynamic process, analysis tools in addition to the steady-state QualTX model may need to be developed. Assessing water quality is complex. The concentration of DO depends on a number of factors including temperature, nutrient concentration, organic matter, organisms present, and rates of decay. Each of those factors needs to be quantified in a way that is relevant to each flow scenario to be evaluated.

A number of flow scenarios will be evaluated and compared. The baseline for comparison will need to be agreed upon and could either be representative of current conditions or could be the TCEQ's current model that evaluates the water body's capacity to assimilate all permitted discharges. Potential scenarios to compare include the current level of discharges with lower base flows, fully permitted discharges with lower base flows, a reduced discharge level (coinciding to a reuse scenario) against lower base flows, or other potential future conditions.

At most study sites, measurements of the standard water quality parameters will be made during each site visit. Standard parameters include temperature, conductivity, pH, and DO. These measurements are complementary to existing programs (e.g., CRP) where these parameters and others continue to be measured and recorded at regular intervals at regular stations for long periods of time. Water quality data, specifically temperature and dissolved oxygen, collected as part of the FERC relicensing evaluation may also be useful in analyzing water quality trends in relation to instream flow.

3.2.5 Connectivity

The objective of the Connectivity component is to identify the interrelationships between flow and connectivity between the main channel and other ecosystems supported by the lower Sabine River. The primary focus of activities related to this discipline will be on understanding connectivity between the river and riparian areas and floodplain habitats. A broad scale model will be developed to estimate the extent of inundation caused by high flow pulses and overbank flows. Select oxbow lakes will be instrumented in order to determine their connectivity to the main stem of the lower Sabine River.

Estimating inundation area

The extent of inundation (both total area and area of various habitat types) associated with overbank flows will be calculated for select riparian areas. In other parts of the state, TIFP has proposed modifying existing one-dimensional hydraulic models to complete this calculation, but this approach is not deemed feasible for the lower Sabine River. The existing one-dimensional floodplain models used by the Federal Emergency Management Agency (FEMA) to develop Flood Insurance Rate Maps (FIRM) for this area were developed with a minimal number of cross sections. For example, the model used to develop the most recent FIRMs for Newton County, Texas (Effective Date: September 21, 1998) employees 28 cross sections along roughly 120 miles of the Sabine River directly downstream of Toledo Bend Reservoir (about 4 miles between cross sections). The model used to develop the most recent FIRMs (Effective Date: June 8, 1998) for Calcasieu Parish, Louisiana, has 29 cross sections along the roughly 42 miles of river in that parish (roughly 1.5 miles between cross sections). The resources required to refine these models in order to accurately model the extent of inundation associated with frequent return period overbank flows (1 in 1 year to 1 in 10 year events), would be considerable.

As an alternative, TIFP will use a Geographic Information System and available data (supplemented by some measured data) in order to estimate inundation area associated with overbank flows at riparian Study Sites. Water surface elevations for overbank flows will be developed from three sources: USGS gage data, data from pressure transducers deployed at Study Sites, and aerial photos taken during overbank events. Data from these sources will be used to develop steady-state water surfaces for overbank flow events. Water surfaces will be linearly interpolated between data points with known water surface elevation. Estimates of the extent of inundation will then be made by draping water surfaces over Digital Elevation Models (DEM) for each Study Site. Currently, DEMs with 5 meter grid spacing are available for the Louisiana side of the lower Sabine River and some portions of the Texas side. The Texas side of the river is covered by DEMs with 30 meter grid spacing.

To determine inundated area for overbank flows, water surface elevations will be subtracted from the DEM topography in a manner similar to that employed by Osting, et al (2004). The inundated areas will then be used as a mask for habitat data layers in order to determine the area of each type of habitat inundated. The habitat data layer used for this analysis will be an interpreted riparian area map or other data layer such as the National Land Cover Dataset (see Section 3.2.2).

Inundation modeling at the broad scale described above is ineffective for evaluating connectivity between the river and oxbow lakes. Relatively fine scale topographic features control connectivity with these off-channel water bodies, making direct measurements a more accurate means of evaluation. These measurements will be made by locating pressure transducers in the target water bodies and nearby river segment in order to determine water levels when connectivity occurs. Lakes of varying age and connectivity frequency in Study Reaches 2 through 4 along the Sabine River will be targeted for these measurements.

Freshwater inflows

Evaluating freshwater inflow requirements for Sabine Lake is beyond the scope of an instream flow study for the lower Sabine River sub-basin. However, as a result of this study, recommendations for instream flow components (subsistence, base, high flow pulse, and overbank) will be made for USGS gage 08030500, Sabine River at Ruliff, TX. This is the most downstream gage on main stem of the Sabine River and as such is used to measure freshwater inflows to Sabine Lake Estuary. At this location, monthly and annual volumes of flow provided by instream flow recommendations will be calculated in order to allow comparison with freshwater inflow requirements based on the same USGS gage.

4.0 CONTINUED STAKEHOLDER INVOLVMENT AND FUTURE ACTIVITIES

Stakeholder involvement has been and will continue to be an integral part of the entire TIFP process (Figure 13). This study design document will be reviewed by the study design workgroup and subsequently submitted for peer review. Annual presentations will be made to the stakeholder group in order to provide technical updates of study progress, including data collection, analysis, and modeling activities. As the instream flow study moves forward as briefly outlined below, stakeholder input will continue to be vital for successful completion and implementation.

As described in the Technical Overview (TIFP 2008; Chapter 10), data integration to generate flow recommendations is an integral component of the overall study. Descriptions of flow recommendations will include four components of the hydrologic regime: subsistence flows, base flows, high flow pulses, and overbank flows (Table 10-1, TIFP 2008).

- **Subsistence Flows** - The primary objective of subsistence flow recommendations will be to maintain water quality criteria. Secondary objectives for the lower Sabine River will include providing habitat that ensures a population is able to recolonize the river system once normal, base flow rates return.
- **Base Flows** - The primary objective of base flow recommendations will be to ensure adequate habitat conditions, including variability, to support the natural biological community of the lower Sabine River sub-basin. These habitat conditions are expected to vary from day to day, seasons to season, and year to year. This variability is essential in order to balance the distinct habitat requirements of the various key species of the sub-basin.
- **High Flow Pulses** – The primary objectives of high flow pulse recommendations will be to maintain important physical habitat features and longitudinal connectivity along the river channel. Many physical features of the lower Sabine River provide important habitat during base flow conditions that cannot be maintained without suitable high flow pulses.
- **Overbank Flows** – The primary objectives of overbank flow recommendations will be to maintain riparian areas, provide lateral connectivity between the river channel and active floodplains. Secondary objectives for overbank flows are to move organic debris to the main channel, provide life cycle cues for various species, and maintain the balance of species in aquatic and riparian communities.

Chapter 11 of the Technical Overview (TIFP 2008) documents several steps that need to be performed after Study Design development and multidisciplinary data collection and evaluation for the lower Sabine River study. In conjunction with continued stakeholder involvement, these major steps include the preparation of Draft and Final Study Reports and Implementation, Monitoring, and Adaptive Management. As outlined above, and discussed in Chapter 11 (TIFP 2008), the product of Senate Bill 2 is a series of instream flow recommendations that will achieve a sound ecological environment, in this case for the lower Sabine River.

After study reports are completed, the additional steps (Implementation, Monitoring, and Adaptive Management) will be necessary to translate recommendations into action. Following up on Senate Bill 2, Senate Bill 3 creates a process to generate regulatory environmental flow standards based on the "the best available science." That legislation ensures that the development of management strategies to meet instream flow recommendations will be ongoing and adaptive and will consider and address local issues. Management strategies will outline steps or policies requiring adoption by state agencies, stakeholders, and possibly the legislature to implement new flow regimes. The strategies will also include recommendations related to monitoring and adaptively managing the aquatic environment through periodic review and refinement of flow recommendations.

Specifics regarding these activities are not described in this document but will be presented as the study progresses. However, these activities are important to note to best put this Study Design document into context within the overall lower Sabine River study and directives from Senate Bills 2 and 3.

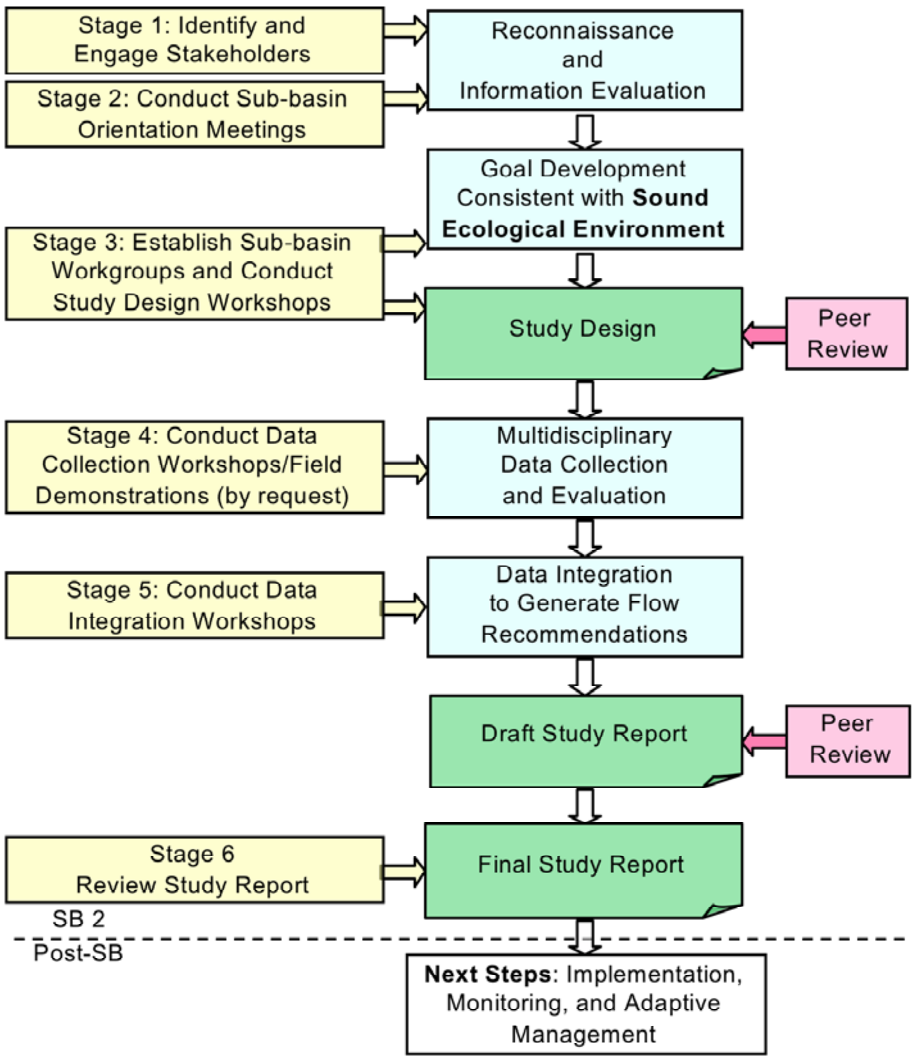

Figure 14. Stages of stakeholder participation in the TIFP study of the lower Sabine River.

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