Instream Flow Study of the Lower San Antonio River and Lower Cibolo Creek

Draft Study Design

Prepared for

Lower San Antonio River Sub-Basin Study Design Workgroup

Prepared by

TEXAS INSTREAM FLOW PROGRAM
AND SAN ANTONIO RIVER AUTHORITY

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1.0 INTRODUCTION

The lower San Antonio River sub-basin is located in portions of 7 counties in south, central Texas and supports a diverse ecological community that relies on the quality, quantity, and timing of water moving through the system. The San Antonio River basin (particularly Bexar County) has undergone rapid transformation over the past several decades due to development. Historically, the majority of the San Antonio River base flow was from area springs, but over the past several decades the river has experienced an evolution from a system driven predominantly by springflow to a system highly influenced by year-round wastewater treatment plant discharges, intermittent diversions, and a mix of various urban and rural land uses. The hydrology of the lower San Antonio River (portion below USGS gage 08181800 near Elmendorf) continues to be variable with the seasons, driven by precipitation patterns, and supported by springflow. However, in the more recent past, flow in the river has been augmented by treated municipal effluent. The treated effluent is composed primarily of return flows from groundwater pumped from the Edwards Aquifer for municipal use.

In recent history, the increased use of groundwater to sustain rapid development in the basin has resulted in increasing base flows in the San Antonio River. This trend in base flows may continue if population growth in the basin is supported by additional groundwater usage or surface water transfers from outside the basin. However, lower river base flows may also result should management strategies such as reuse be employed. In any event, there is the potential to affect physical, biological, and social resources in the lower San Antonio River sub-basin which provides the rationale behind the Texas Instream Flow Program (TIFP) lower San Antonio River sub-basin study.

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 surface-water 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 lower San Antonio 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 San Antonio River basin;

- an overview of the stakeholder process and description of the study goal, objectives, and indicators developed with stakeholders (Section 2.0), and
- a description of the proposed technical studies (Section 3.0)
    - study site locations,
    - data collection methods and analysis, and
    - multidisciplinary coordination.
- 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-ecological relationships within the lower San Antonio River sub-basin (lower San Antonio River and lower Cibolo Creek from just downstream of the city of San Antonio to the confluence with the Guadalupe River) and its riverine ecosystem. Results will provide a means of assessing biological, physical, and social impacts/benefits of various flow regimes. 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 (from low, to moderate, to high throughout the annual hydrologic cycle) on the riverine ecosystem of the lower San Antonio River sub-basin.

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

The lower San Antonio River sub-basin is shown in Figure 1. An inventory of available data and study reports related to the hydrologic, biologic, geomorphic, water quality, and connectivity features of the lower San Antonio River sub-basin was completed by SARA in 2006. This effort identified more than 100 reports or sources of data or 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 SARA directed specific field surveys and preliminary analysis to better characterize the current condition of the river system. TIFP and SARA staff also conducted surveys of the river in order 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.

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

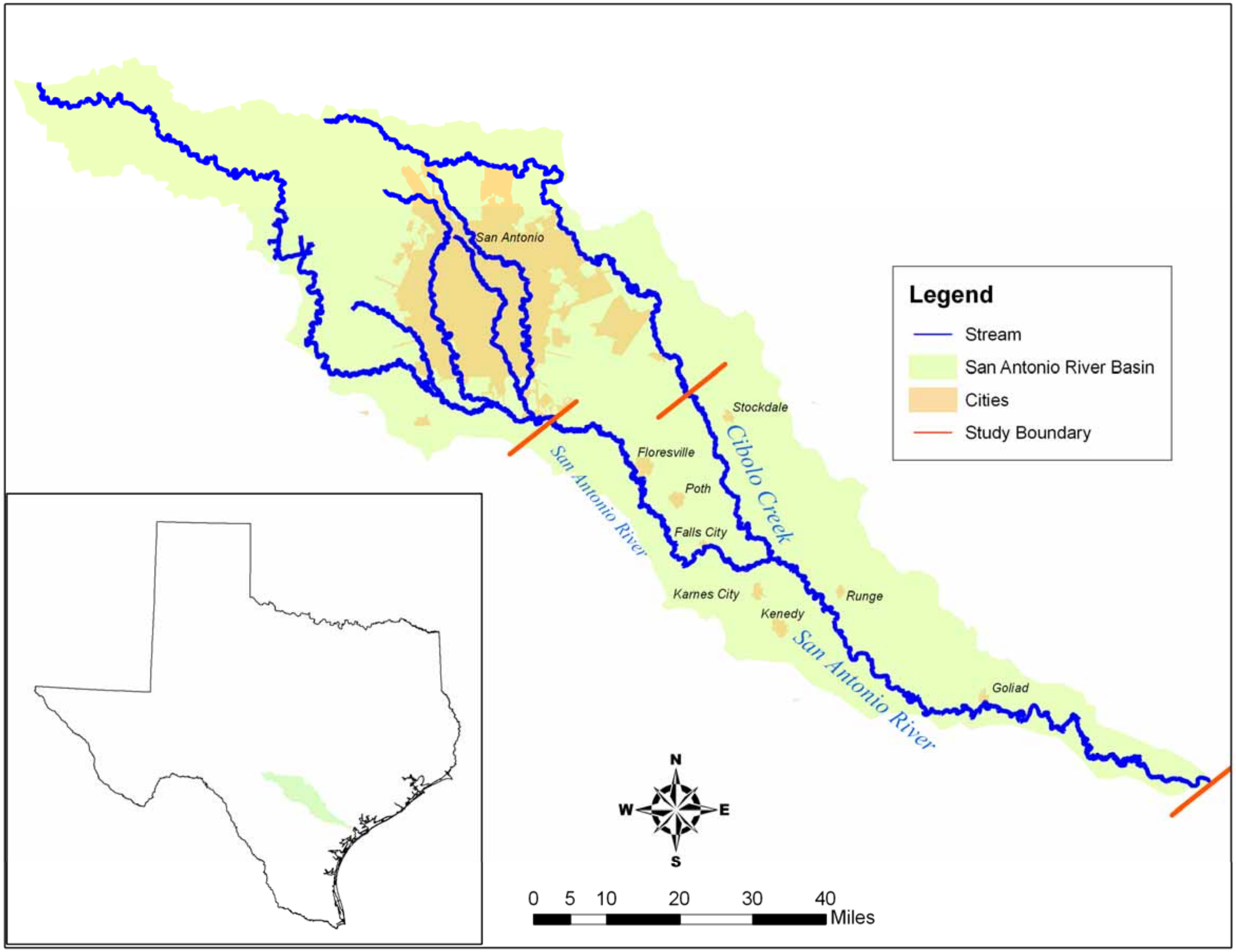

Figure 1. Map of the San Antonio River basin and lower San Antonio River sub-basin (study boundary) depicted.

Table 1. Studies of interest to the instream flow study of the lower San Antonio River sub-basin.

Type of Study	Name of Study	Author/s	Year Completed
Hydrology, Geomorphology	Stream channel response to floods, with examples from central Texas	Baker	1977
Hydrology, Connectivity	Freshwater inflow recommendations for the Guadalupe Estuary of Texas	TPWD & TWDB	1998
Hydrology, Water Quality	Simulation of streamflow and estimation of streamflow constituent loads in the San Antonio River watershed, Bexar County, Texas, 1997-2001	Ockerman & McNamara	2002
All Disciplines	Lower San Antonio River instream flow study – data summary evaluation and database	SARA	2006
Biology	Lower San Antonio River watershed instream flows study biological collection summary report	SARA	2006
Geomorphology	Logjam characterization, distribution and stability on the San Antonio River, Texas	Cawthon	2007
Hydrology, Biology, Water Quality	Preliminary instream flow assessment for the lower San Antonio River (Interim subsistence and base-dry instream flow guidelines development)	BIO-WEST	2008
Geomorphology	Geomorphic classification of the lower San Antonio River, Texas	Engel & Curran	2008
Geomorphology	Channel change on the San Antonio River	Cawthon & Curran	2008
Water Quality	San Antonio River basin summary report	SARA	2008
Biology	Fish population changes in three western gulf slope drainages	Bonner & Runyan	2008
Biology	Distributional survey and habitat utilization of freshwater mussels	Karatayev & Burlakova	2008
Hydrology, Connectivity	Surface water – groundwater interaction in the lower San Antonio River watershed	USGS	Ongoing

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 San Antonio River sub-basin since the 1920's. Currently, 12 gages are operational in the sub-basin, including five on the mainstem of the San Antonio River and five on Cibolo Creek. Some historical data is available from an additional five stream gages that are no longer being maintained in the sub-basin. Data from all of these gages including median flow in cubic feet per second (cfs) are listed in Table 2.

Table 2. Historical and current USGS stream gages in the lower San Antonio River sub-basin.

Gage #	Gage Name	Earliest Record	Latest Record	Median Flow (cfs)	Drainage Area (mi^2)
08181800	San Antonio Rv nr Elmendorf , TX	1962	Present	326	1,743
08182500	Calaveras Ck nr Elmendorf, TX	1954	1971	0	77.2
08183200	San Antonio Rv nr Floresville, TX	2006	Present	NA	1,964
08183000	San Antonio Rv at Calaveras, TX	1918	1925	NA	1,786
08183500	San Antonio Rv nr Falls City, TX	1925	Present	262	2,113
08183890	Cibolo Ck at CNC nr Boerne, TX	2005	Present	NA	56.3
08183900	Cibolo Ck nr Boerne, TX	1962	1997	7.5	68.4
08184000	Cibolo Ck nr Bulverde, TX	1946	1965	0	198
08185000	Cibolo Ck at Selma, TX	1946	Present	27.9	274
08185065	Cibolo Ck nr Saint Hedwig, TX	2005	Present	NA	306
08185100	Martinez Ck nr Saint Hedwig	2005	Present	NA	81.1
08185500	Cibolo Ck at Sutherland Springs, TX	1924-29, 2005	Present	NA	665
08186000	Cibolo Ck nr Falls City, TX	1930	Present	29	827
08186500	Ecleto Ck nr Runge, TX	1962	Present	0.48	239
08187500	Escondido Ck at Kenedy, TX	1954	1973	0	72.4
08188500	San Antonio Rv at Goliad, TX	1924-29, 1939	Present	358	3,921
08188570	San Antonio Rv nr McFaddin, TX	2005	Present	NA	4,134

The median flow of Cibolo Creek near Falls City (approximately 10 miles upstream of its confluence with the mainstem of the San Antonio River) over the period from 1930 to 2007 is approximately 29 cfs. In comparison, the median flow in the San Antonio River near Falls City (approximately 20 miles upstream of its confluence with Cibolo Creek) over the period from 1925 to 2007 is 262 cfs. It appears that at their confluence, the flow of Cibolo Creek is approximately 10 percent of the flow of the mainstem of the San Antonio River. No other tributary of the lower San Antonio River appears to make as significant a contribution to its flow.

Observation of the available gage data indicates that flow conditions in the lower San Antonio River sub-basin have been changing over time. If the available gage data is divided into two groups based on whether it was collected before or after January 1, 1970, an interesting trend appears. Flows in the lower sub-basin have increased dramatically. For example, Figure 2 compares the median flow for each day of the year for data collected from USGS gage number 08188500, San Antonio River at Goliad. From this figure, it can be seen that median flows for the period 1970 through 2007 have increased substantially from median flows for the earlier period, 1940 through 1969. As shown in Figure 3, a flow duration curve for data from this gage divided into the two periods, an increase can be observed across the entire range of flows. Similar results can be seen at other long term streamflow gages within the sub-basin, such as USGS gages 08183500, San Antonio River near Falls City, and 08186000, Cibolo Creek near Falls City.

Figure 2. Median of daily streamflow values for USGS gage 08188500, San Antonio River at Goliad.

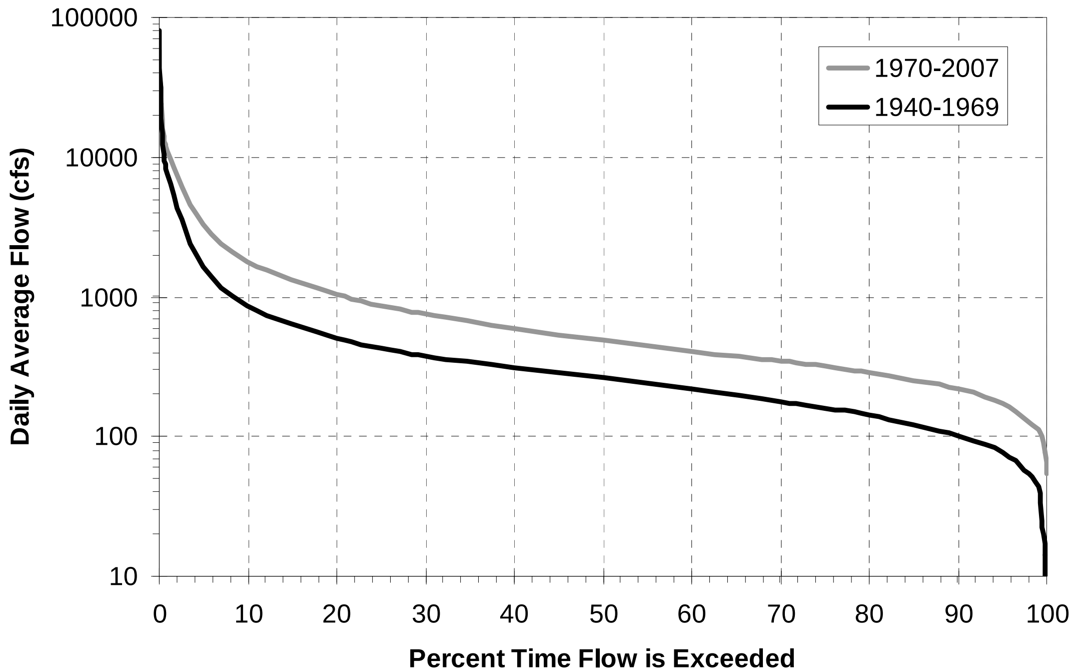

Figure 3. Flow duration curves for daily average flow at USGS gage 08188500, San Antonio River at Goliad.

Changes in flows in the lower sub-basin are likely due to a number of factors, including changes in precipitation, urban growth, and groundwater pumping and return flows. As shown in Figure 4, average monthly precipitation for San Antonio, Texas has been greater since 1970, relative to the three decades before this time. Urbanization in the upper basin may also have played a role in changes in flow in the lower San Antonio River. The city of San Antonio is located along the banks of the San Antonio River about 20 miles upstream of the upper boundary of the lower San Antonio River as defined by this study. According to U.S. Census data, the population of the city has increased from about 250,000 in 1940 to more than 650,000 in 1970 and more than 1.3 million in 2007. Growth and expansion of the city of San Antonio has resulted in changes in water withdrawals and return flows, as well as patterns of runoff from the land surface. Much of the water demand in the city of San Antonio and surrounding areas is met by groundwater pumping from the Edwards Aquifer. Pumping from this aquifer increased from about 120,000 acre-feet a year in 1940 to a yearly maximum value of 542,000 acre-feet in 1989 (EAA 2008). Since that maximum, annual pumping has averaged 401,300 acre-feet per year (1990-2007). The median estimated well production for the 10-year period 1998-2007 is 379,900 acre-feet (EAA 2008). The relationship between levels of groundwater in aquifers and flows in the lower San Antonio River sub-basin is complicated. Increased groundwater pumping can increase flows in some portions by increasing return flows to the river, while lowered groundwater tables can reduce spring flows in other areas.

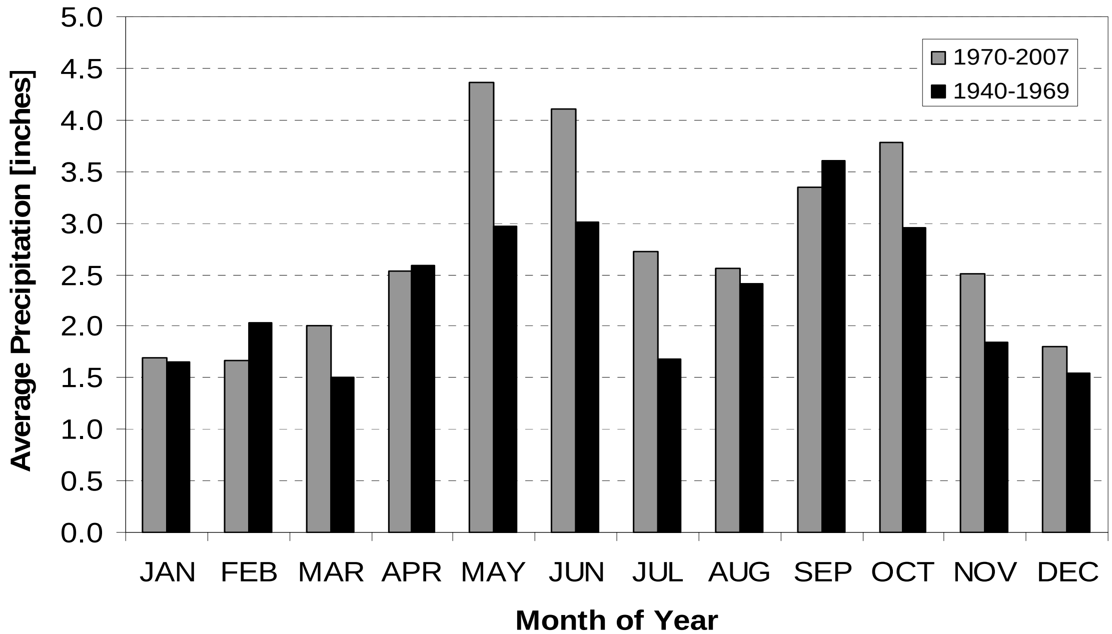

Figure 4. Average monthly precipitation for San Antonio, Texas for the periods 1940 to 1969 and 1970 to 2007 (National Weather Service data).

Conditions in upper portions of the river basin have a significant influence on flows in the lower San Antonio River. A USGS study (Ockerman and McNamara, 2002) evaluated the linkage between the upper and lower portions of the San Antonio River Basin. Watershed models (Hydrologic Simulation Program-FORTRAN) were developed for the San Antonio River watershed area upstream of USGS gage 08181800, San Antonio River near Elmendorf. Models were calibrated and then used to simulate daily flow conditions (water quantity and quality) for the years 1997 to 2001. During this time period, the four largest contributors to flow at the Elmendorf gage were found to be stormwater runoff in Bexar County (33 percent), the Medina River upstream of Bexar County (22 percent), wastewater discharge (20 percent), and groundwater inflow (18 percent). The Elmendorf gage is located at the upper boundary of this study of the lower San Antonio River sub-basin.

The lower San Antonio River is an important source of freshwater inflow to the Guadalupe Estuary (San Antonio Bay). A study completed by TPWD and TWDB (1998) determined that an annual inflow of between 1.03 million and 1.29 million acre-feet of water is required each year to maintain the biological health and productivity of the estuary. An annual inflow of 1.15 million acre-feet was found to provide the maximum fisheries harvest. Seasonal timing of inflows is important and recommendations were provided as total volumes of flow for each month of the year. These recommendations were developed based on a state methodology that has been applied to all of Texas' major estuaries. According to Longley (1994), the contribution of the San Antonio River (as measured at USGS gage 08188500 at Goliad) to freshwater inflow to the estuary is approximately 23% of the total amount.

1.1.2 Biology

Fisheries data collection results summary

Sixty fish species have been reported from the mainstem of the San Antonio River from collections dating back to 1950 (Table 3). Life history and population information for these species are also provided in Table 3 and are based upon scientific studies (Balon 1975, Balon 1981, Bonner and Runyan 2007, Hildebrand and Cable 1938, Hubbs et al. 1991, Linam and Kleinsasser 1998, Simon 1999, Warren et al. 2000, Williams et al. 1989). Cyprinidae was the most abundant family, followed by families Poeciliidae, Ictaluridae, Centrarchidae, and Cichlidae. Three native fish species – central stoneroller (*Campostoma anomalum*), green sunfish (*Lepomis cyanellus*), and longear sunfish (*Lepomis megalotis*) - have increased in abundance since the earliest collection records; whereas, pugnose minnow (*Opsopoeodus emiliae*) and western mosquitofish (*Gambusia affinis*) have significantly declined (Bonner and Runyan 2007). Seventeen species showed stable populations while the rest had indeterminable changes. Only five non-native species were reported in the earliest records; whereas, now there are 17.

The diversity of fish species reported from the river include representatives from each of the major trophic guilds (piscivore, invertivore, omnivore, and herbivore) and include hardy species such as gar, mosquitofish, and mollies as well as a number of species intolerant of degraded water quality such as Texas logperch (*Percina carbonaria*), Guadalupe bass (*Micropterus treculii*), and mimic shiner (*Notropis volucellus*) (Linam and Kleinsasser 1998). A rich variety of reproductive strategies are also represented within the fish assemblage, including three species with marine spawning requirements. These species are the striped mullet (*Mugil cephalus*) which spawn offshore, hogchoker (*Trinectes maculatus*) which reproduce in estuaries, and American eel (*Anguilla rostrata*) which spawn in the Sargasso Sea. In addition, the big claw river shrimp (*Macrobrachium carcinus*) is another catadromous species known to occur in the San Antonio River.

Starting in 2006, TIFP and SARA biologists conducted reconnaissance, and biological and habitat sampling throughout the lower San Antonio River and lower Cibolo Creek. Evaluations of the fish community and habitat assessments were conducted at eight sites on the lower San Antonio River, three sites on the lower Cibolo Creek, and one site on Elm Bayou (Table 4; Figure 5). Data collected from these sampling efforts provided baseline habitat and fish assemblage data to fill information gaps within the lower San Antonio River sub-basin. Collection methods included boat and backpack electrofishing and seine netting in as many habitat types as possible. 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 SARA (2006).

Table 3. Life history and population information on fish species collected in the lower San Antonio River sub-basin.

Species	Population Trend (San Antonio River)	Species Status	Resident Status	Trophic Guild	Primary Reproductive Guild	Secondary Reproductive Guild	Tolerance
Atractosteus spatula	-	Vulnerable	N	P	Open substrate	Phytophil	T
Lepisoteus oculatus	-	Stable	N	P	Open substrate	Phytophil	T
Lepisoteus osseus	-	Stable	N	P	Open substrate	Phytolithophil	T
*Anguilla rostrata**	-	Secure	N	P	Catadromous		-
Dorosoma cepedianum	S	Stable	N	O	Open substrate	Lithopelagophil	T
Dorosoma petenense	-	Stable	N	O	Open substrate	Phytophil	-
Campostoma anomalum	↑	Secure	N	H	Brood hider	Lithophil	-
Cyprinella lutrensis	S	Stable	N	IF	Brood hider	Speleophil	T
Cyprinella venusta	-	Stable	N	IF	Brood hider	Speleophil	-
Cyprinus carpio	S		I	O	Open substrate	Phytolithophil	T
Macrhybopsis marconis	S	Special concern	N	IF	Open substrate	Pelagophil	-
Notropis amabilis	-	Stable	N	IF	Open substrate	Pelagophil	-
Notropis buchanani	-	Stable	N	IF	Open substrate	Pelagophil	-
Notropis stramineus	-	Stable	N	IF	Open substrate	Lithophil	-
Notropis volucellus	S	Stable	N	IF	Open substrate	Phytophil	I
Opsopoeodus emiliae	↓	Secure	N	IF	Nest spawner	Speleophil	-
Pimephales promelas	S		I	O	Nest spawner	Speleophil	T
Pimephales vigilax	S	Secure	N	IF	Nest spawner	Speleophil	-
Carpiodes carpio	-	Secure	N	O	Open substrate	Lithopelagophil	T
Ictiobus bubalus	S	Secure	N	O	Open substrate	Lithopelagophil	-

Population trend (↑ - increasing, S - stable, - - indeterminable, ↓ - decreasing), species status, resident status (N – native to basin, I – introduced to basin), trophic guild (H - herbivore, O - omnivore, IF - invertivore, P - piscivore), reproductive guild, and tolerance (I – intolerant, - - intermediate, T – tolerant) of fishes reported from the lower San Antonio River basin.

* Collected in Cibolo Creek

Table 3 (continued). Life history and population information on fish species collected in the lower San Antonio River sub-basin.

Species	Population Trend (San Antonio River)	Species Status	Resident Status	Trophic Guild	Primary Reproductive Guild	Secondary Reproductive Guild	Tolerance
Ictiobus niger	-	Secure	N	O	Open substrate	Lithopelagophil	-
Moxostoma congestum	S	Special concern	N	IF	Open substrate	Lithophil	-
Astyanax mexicanus	S		I	IF	Open substrate	Pelagophil	-
Ameiurus melas	-	Stable	N	O	Nest spawner	Speleophil	T
Ameiurus natalis	-	Secure	N	O	Nest spawner	Speleophil	-
Ictalurus furcatus	-	Stable	N	P	Nest spawner	Speleophil	-
Ictalurus punctatus	S	Secure	N	O	Nest spawner	Speleophil	T
Noturus gyrinus	-	Secure	N	IF	Nest spawner	Speleophil	I
Noturus nocturnus	-		I	IF	Nest spawner	Speleophil	I
Pylodictis olivaris	-	Stable	N	P	Nest spawner	Speleophil	-
Hypostomus plecostomus	-		I	H	Nest spawner	Speleophil	-
Pterygophlichthys multiradiatus	-		I	H	Nest spawner	Speleophil	-
Fundulus notatus	-	Stable	N	IF	Open substrate	Phytophil	-
Gambusia affinis	↓	Stable	N	IF	Bearer	Viviparous	T
Poecillia formosa	S		I	O	Bearer	Viviparous	-
Poecilia latipinna	S		I	O	Bearer	Viviparous	T
Xiphophorus helleri	-		I	IF	Bearer	Viviparous	T
Menidia beryllina	-	Stable	N	IF	Open substrate	Phytophil	-
Morone sp.	-		I	P	Open substrate	Phytolithophil	-

Population trend (↑ - increasing, S - stable, - - indeterminable, ↓ - decreasing), species status, resident status (N – native to basin, I – introduced to basin), trophic guild (H - herbivore, O - omnivore, IF - invertivore, P - piscivore), reproductive guild, and tolerance (I – intolerant, - - intermediate, T – tolerant) of fishes reported from the lower San Antonio River basin.

* Collected in Cibolo Creek

Table 3 (continued). Life history and population information on fish species collected in the lower San Antonio River sub-basin.

Species	Population Trend (San Antonio River)	Species Status	Resident Status	Trophic Guild	Primary Reproductive Guild	Secondary Reproductive Guild	Tolerance
Lepomis auritus	S		I	IF	Nest spawner	Polyphil	-
Lepomis cyanellus	↑	Secure	N	P	Nest spawner	Polyphil	T
Lepomis gulosus	S	Secure	N	P	Nest spawner	Lithophil	T
Lepomis humilis	-		I	IF	Nest spawner	Lithophil	-
Lepomis macrochirus	S	Secure	N	IF	Nest spawner	Polyphil	T
Lepomis marginatus	-		I	IF	Nest spawner	Polyphil	-
Lepomis megalotis	↑	Secure	N	IF	Nest spawner	Polyphil	-
Lepomis microlophus	-	Secure	N	IF	Nest spawner	Polyphil	-
Lepomis miniatus	-	Stable	N	IF	Nest spawner	Polyphil	-
Micropterus dolomieu	-		I	P	Nest spawner	Polyphil	I
Micropterus punctulatus	-	Secure	N	P	Nest spawner	Polyphil	-
Micropterus salmoides	S	Secure	N	P	Nest spawner	Polyphil	-
Micropterus treculi	-	Special concern	N	P	Nest spawner	Polyphil	I
Pomoxis annularis	-	Secure	N	P	Nest spawner	Phytophil	-
Percina carbonaria	-	Stable	N	IF	Brood hider	Lithophil	I
*Percina shumardi**	-	Secure	N	IF	Brood hider	Lithophil	-
Aplodinotus grunniens	-	Stable	N	IF	Open substrate	Pelagophil	T
Cichlasoma cyanoguttatum	S		I	IF	Substratum chooser	Lithophil	-
Oreochromis aureus	-		I	O	Bearer	Mouth brooder	T

Population trend (↑ - increasing, S - stable, - - indeterminable, ↓ - decreasing), species status, resident status (N – native to basin, I – introduced to basin), trophic guild (H - herbivore, O - omnivore, IF - invertivore, P - piscivore), reproductive guild, and tolerance (I – intolerant, - - intermediate, T – tolerant) of fishes reported from the lower San Antonio River basin.

* Collected in Cibolo Creek

Table 3 (continued). Life history and population information on fish species collected in the lower San Antonio River sub-basin.

Species	Population Trend (San Antonio River)	Species Status	Resident Status	Trophic Guild	Primary Reproductive Guild	Secondary Reproductive Guild	Tolerance
Oreochromis mossambica	-		I	O	Bearer	Mouth brooder	-
Tilapia zilli	-		I	O	Nest spawner	Lithophil	-
Mugil cephalus	-	Secure	N	O	Catadromous		-
Trinectes maculatus	-	Secure	N	IF	Catadromous		-

Population trend (↑ - increasing, S - stable, - - indeterminable, ↓ - decreasing), species status, resident status (N – native to basin, I – introduced to basin), trophic guild (H - herbivore, O - omnivore, IF - invertivore, P - piscivore), reproductive guild, and tolerance (I – intolerant, - - intermediate, T – tolerant) of fishes reported from the lower San Antonio River basin.

* Collected in Cibolo Creek

Table 4. Biological and habitat sample site locations within the lower San Antonio River and lower Cibolo Creek.

Sample Site Number	Sample Site Description
19010	San Antonio River mouth, Refugio County
19011	Elm Bayou mouth, Refugio County
19020	San Antonio River at US 77, Refugio County
19030	San Antonio River about 9 miles downstream of Goliad, Goliad County
19040	San Antonio River at Riverdale Road, Goliad County
19050	San Antonio River at SH 72, Karnes County
19060	Cibolo Creek at FM 389, Karnes County
19070	Cibolo Creek at FM 537, Wilson County
19080	Cibolo Creek at FM 539, Wilson County
19090	San Antonio River at Conquista Crossing, Karnes County
19100	San Antonio River at Floresville City Park, Wilson County
19110	San Antonio River at Loop 1604 near Elmendorf, Bexar County

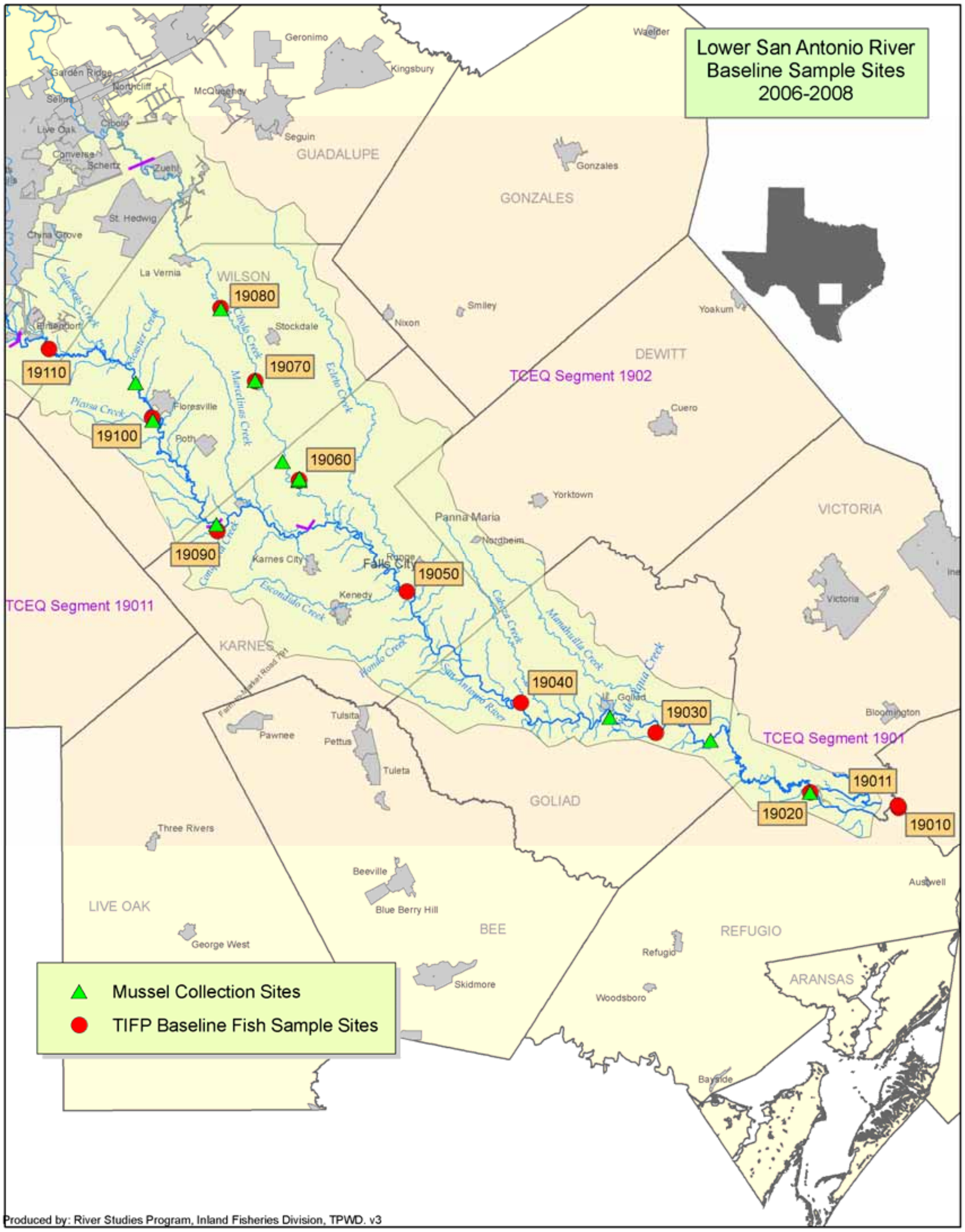

Figure 5. TIFP baseline fish sample sites and mussel collection sites on the lower San Antonio River and Cibolo Creek.

Mussels data collection results summary

Four live mussel species were collected during baseline sampling efforts in 2006 and 2007 (Karatayev and Burlakova 2008). These mussels included threeridge (*Ablema plicata*), Tampico pearlymussel (*Cyrtonaias tampicoensis*), yellow sandshell (*Lampsilis teres*), and golden orb (*Quadrula aurea*). Mussels represent one of the most rapidly declining faunal groups in North America. A variety of life history traits related to their vulnerability include: sensitivity to toxic contaminants in the water, 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). Large quantities of dead shells of the Texas endemic golden orb were found in the upper reaches of the lower San Antonio River during the aforementioned baseline mussel sampling. At some sites it was apparently the dominant species; however, live individuals were only found at two sites (located in the middle and lower reaches). Golden orb was selected as a potential target species since statewide sampling by TPWD suggests this mussel species may be declining (Howells et al. 1996) and because the American Fisheries Society considers this species one of special concern (Williams et al. 1993).

1.1.3 Physical Processes

The geomorphology of the lower San Antonio River sub-basin is influenced by the unique climatic and physiographic setting of central Texas. Weather conditions in central Texas include convective thunderstorms and tropical disturbances that produce intense precipitation. In addition, many physical features of the Edwards Plateau (steep slopes, sparse vegetative cover, thin soils, and underlying geology) contribute to high runoff rates. As a result, peak flow rates for watersheds in this region generally exceed those for similar sized watersheds in other parts of the world (Baker 1977). Central Texas streams are “flashy,” tending to carry a large percentage of their annual flow volume in large, infrequent events.

Baker (1977) suggests that “flashiness” causes central Texas streams to behave differently in terms of their geomorphic processes and characteristics. General principles of geomorphology assume that relatively frequent, modest sized flow events transport the greatest amount of sediment over time and are therefore responsible for the characteristic shape of a stream channel. After the disturbance caused by a large flood event, modest sized flow events rework the channel and allow a relatively rapid recovery of the characteristic shape of the channel. This assumption of the relationship of the geomorphic significance of large flood and modest flow events appears to be valid in many parts of the world. However, for flashy streams, extremely large scale sediment transport and channel modification may occur during large flood events. Under these conditions, modest sized flow events may not occur often enough to rework the channel significantly before the next large flood. In these systems, the channel shape remains in a state of recovery from the disturbance caused by the last large flood event and may not recover a shape characteristic of channels in other parts of the world.

The characteristics, distribution and stability of log jams were investigated by Cawthon (2007) within an approximate 35-mile reach centered on Floresville. The reach extends between CR 125 (Wilson County, south of San Antonio) to FM 541 near Poth. This study presents an overview of log jam characterization methods and a series of metrics that are used to quantify location, degree and configuration of log jams observed in the San Antonio River. Field observations are reported for the period November 2006 though February 2007, and are related to log jams evident on December 7, 2003, as interpreted from high-resolution aerial imagery. Log jams are found to be mobile, only 10% of those identified in 2003 still existed in 2007; none of the full-channel jams identified in 2003 still existed in 2007. Six high-flow events (between 5,000 and 20,000 cfs) occurred between December 2003 and January 2005. The high mobility of log jams are attributed to these events considering high stream power caused by narrow incised banks. Based on the field efforts (2006-2007), spacing between log jams decreased moving downstream, with a notable lack of jams within 6 miles downstream of the CR 117 low-water crossing where debris removal typically occurs. (In 2008 this low-water crossing was removed and replaced with a clear span bridge.) The number of "in-channel obstruction" jams increases in the lower half of the study reach, but percent of lateral coverage of log jams (percent of the channel width obstructed by a log jam) is relatively uniform throughout the reach.

A geomorphic classification of the lower San Antonio River was completed by Engel and Curran (2008). This classification provides a useful tool to understand differences in physical processes and habitats along the river. The river was segmented into 25 reaches based on channel and valley characteristics. A description of each reach was provided, including characteristic channel and floodplain features such as point bars, large woody debris dams, cobble riffles, oxbow lakes, and backwater swamps.

Cawthon and Curran (2008) examined channel change on the lower San Antonio River and found that the river has widened over a 68-year period, primarily due to floods. The study examined channel migration, widening, erosion, and deposition by analyzing aerial photos of the river from Wilson to Victoria counties taken from 1938 to 2004. The 1946 flood had the greatest impact on the channel in the upper portion of the river (above central Karnes County) while the 1967 flood caused the greatest amount of change in the lower portion. Conditions prior to the 1946 flood (oversteepened banks saturated by an extended period of rainfall) probably contributed to the severity of changes due to this event. The effectiveness of large floods is reduced in the lower portion of the study area, where the valley becomes wider and the channel is less confined.

1.1.4 Water Quality

Clean Rivers program historical water quality trends

TCEQ in cooperation with SARA through the Clean Rivers Program produce the San Antonio River Basin Summary Report every five years. The 2008 Basin Summary Report provides an overview of monitoring and assessment activities in the San Antonio River basin. The report was prepared by SARA staff in coordination with the TCEQ and in accordance with the State's guidelines. The report presents a ten-year history of the levels of bacteria, nutrients, aquatic life use, and other water quality parameters at over 40 sites throughout six watersheds in the basin, covering the period January 1997 through August 2007. Significant findings of the basin summary report as related to this draft study design are listed below.

- **Bacteria**

  Portions of the San Antonio River and Cibolo Creek are not meeting the contact recreation standard due to *E. coli* bacteria. Generally, there is a relationship between high flows and increased levels of bacteria indicating a non-point source of bacterial pollution. The actual source of the pollution (whether wildlife, livestock or human origin) is difficult to determine. Several studies are ongoing in the upper San Antonio River basin. Please see the Watershed Protection Plan for further details at: www.sara-tx.org/site/water_quality/water_qual_mon/Projects_and_Studies.php.

  TCEQ, SARA, City of San Antonio, San Antonio Water Systems, and Bexar County are working together to abate the bacterial pollution by implementing the Watershed Protection Plan for the urban portion of the upper San Antonio River watershed. An implementation plan for the entire upper San Antonio River watershed (includes Bexar, Wilson and northern Karnes counties) and Salado Creek has been started.

- **Nutrients**

  Nutrients are a concern in portions of the San Antonio River and Cibolo Creek. Currently there are no numerical standards for nutrients, only screening criteria. High nutrient levels may cause algal blooms and consequently low dissolved oxygen levels. At this time, no segments on the San Antonio River and Cibolo Creek are identified as impaired by the TCEQ for low dissolved oxygen levels. The sources of the nutrients are varied and depend on the sampling location. Elevated nutrient levels are typically found downstream of wastewater discharge points, but nutrients can also enter the stream system from storm water runoff, discharge of groundwater polluted with nutrients, through natural and manmade sources, and even through the atmosphere. SARA has begun a nutrient study in the basin to better understand the sources and effects of nutrients in the basin. Historical Basin Summary Reports are available on the SARA website at: http://www.sara-tx.org/site/water_quality/water_qual_mon/clean_rivers/.

Water quality data in the lower San Antonio River sub-basin is also collected and analyzed through several other programs and agencies. Table 5 outlines the various sources of water quality data that may be utilized in this study on the lower San Antonio River and lower Cibolo Creek. 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 5. Water quality data information on the lower San Antonio River and lower Cibolo Creek.

Data Source	Types of Data	Frequency
Clean Rivers Program (TCEQ, SARA)	Chemical, Physical, Biological	Weekly, Monthly, Bimonthly, Quarterly, Annually, Continuous
Surface Water Quality Monitoring	Chemical, Physical, Biological	Quarterly, Continuous
TMDL Implementation	Chemical, Physical, Biological	Specific Studies on the San Antonio 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 San Antonio River sub-basin, multiple water quality related stations or locations will be used as data points in this study. These locations include the following:

- Wastewater discharge locations – Municipal or industrial wastewater treatment plant discharges to the lower San Antonio River and lower Cibolo Creek are regulated under the Texas Pollutant Discharge Elimination System program administered by the TCEQ. There are approximately 35 wastewater discharge locations on the San Antonio River and three discharge locations on Cibolo Creek. Discharge locations in the study area are shown in Figure 6.
- Diversion locations – Water diversions from the lower San Antonio River and lower Cibolo Creek are permitted by the TCEQ through the issuance of a water rights permit. Water is withdrawn from the river for domestic and livestock use, irrigation, impoundments, and various other uses. There are approximately 211 water rights to withdraw water on the San Antonio River and 41 water rights diversion locations on Cibolo Creek. Water diversion points in the study area are show in 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 San Antonio River and lower Cibolo Creek. There are approximately 79 SWQM monitoring sites on the San Antonio River and 21 sites on Cibolo Creek. SWQM monitoring sites in the study area are shown in Figure 8.

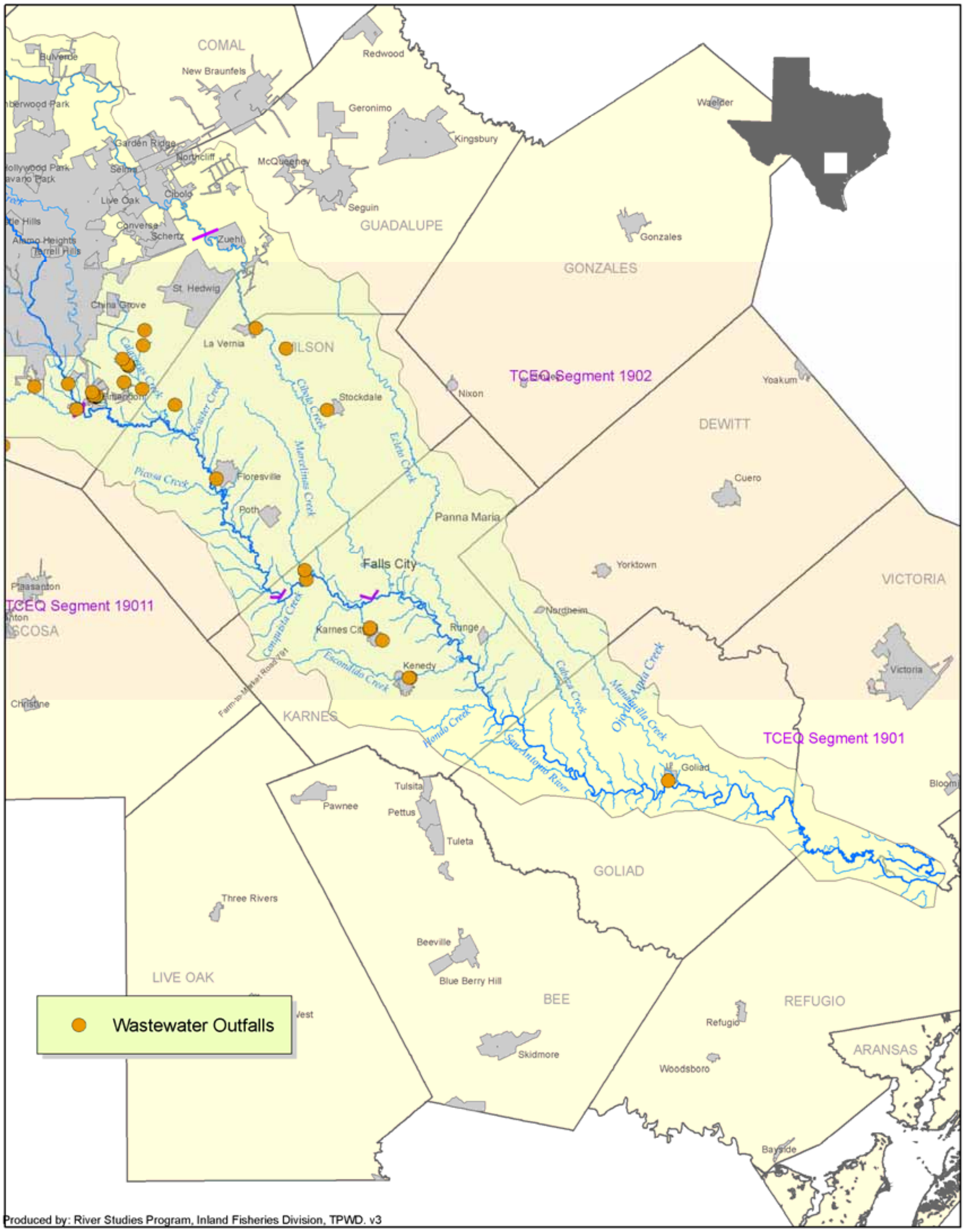

Figure 6. Wastewater discharge locations on the lower San Antonio River and Cibolo Creek.

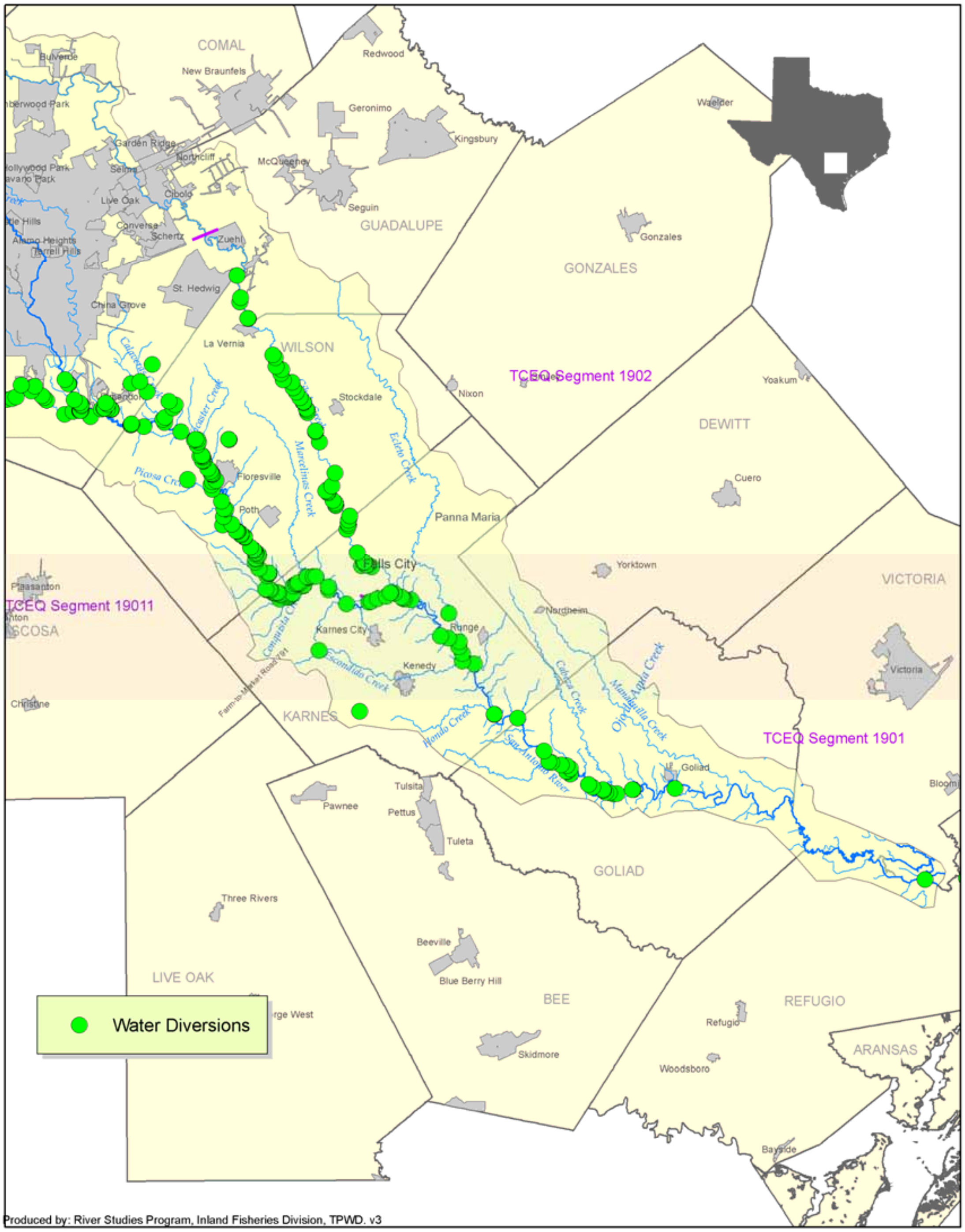

Figure 7. Water diversion points on the lower San Antonio River and Cibolo Creek.

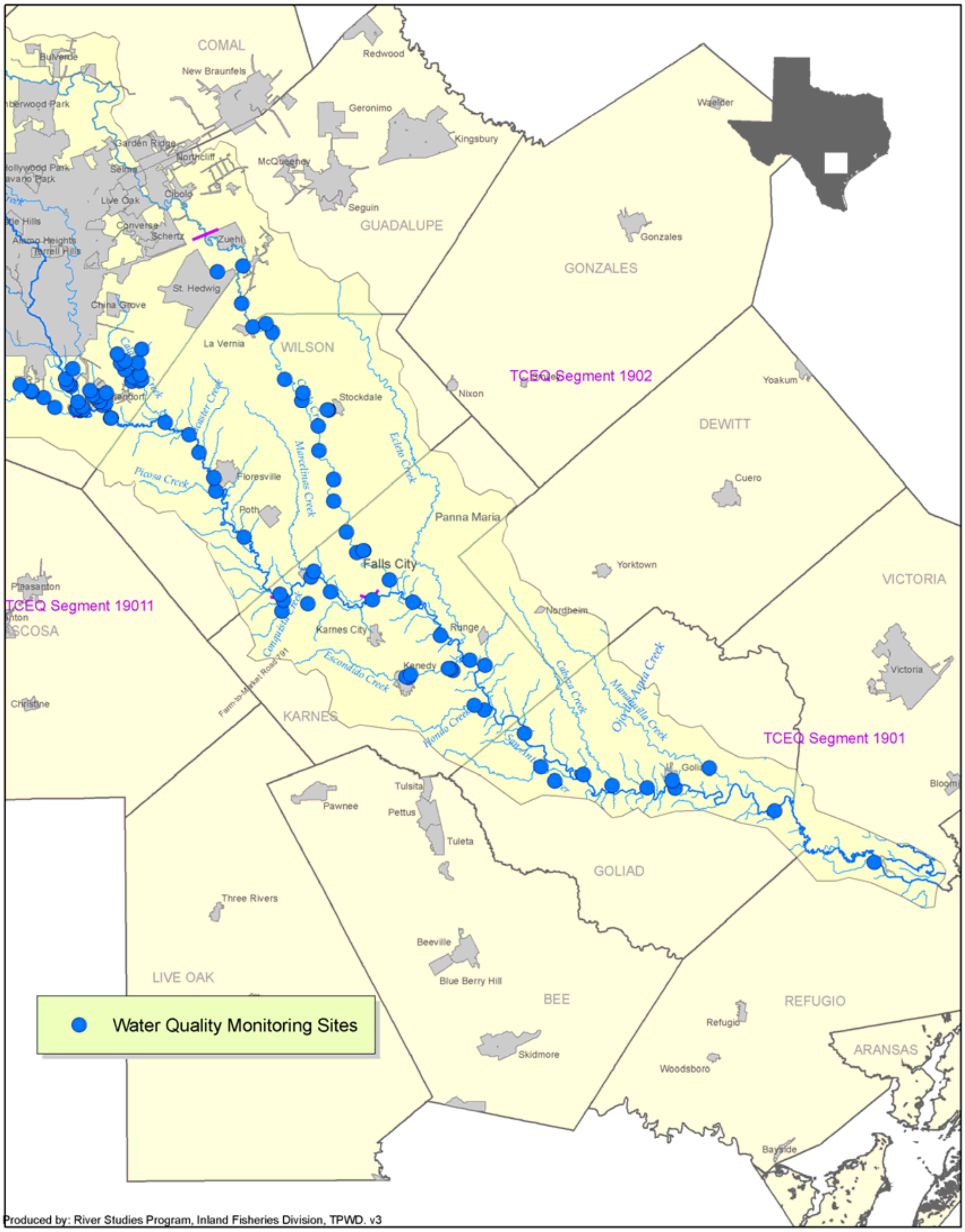

Figure 8. SWQM monitoring sites on the lower San Antonio River and Cibolo Creek.

Water quality in the lower San Antonio River is influenced by conditions in the upper portion of the basin. A USGS study evaluated the water quality linkage between the upper and lower portions of the San Antonio River Basin (Ockerman and McNamara, 2002). The sources of various water quality constituents at USGS gage 08181800 on the San Antonio River near Elmendorf were evaluated for the years 1997 to 2001. Flows from recycled wastewater, the upper Medina River upstream of Bexar County, and shallow groundwater were found to be the largest contributors to nitrogen (nitrate plus nitrite) measured at the Elmendorf gage. These contributions were 66, 21, and 6.6 percent respectively. The Elmendorf gage is located at the upper boundary of this study of the Lower San Antonio River sub-basin.

1.1.5 SARA Preliminary Instream Flow Assessment Summary

For this preliminary assessment, extensive biological and physical data collection activities associated with portions of TIFP study components were completed along the lower San Antonio River near Falls City and Goliad in 2007-2008. The final document (BIO-WEST 2008a) provides an overview of each river study component, and documents existing conditions and methods associated with data collection activities. Preliminary assessment results were integrated among disciplines considered. The focus of this preliminary instream flow assessment was on the development of preliminary dry weather guidelines to provide a glimpse at the river's responses to lower flow conditions. Additionally, this preliminary assessment was designed specifically to be consistent with the goals and objectives of the TIFP and assist in Study Design development for the full-scale TIFP instream flow study.

1.1.6 Surface Water / Groundwater Interaction Study

SARA along with the Evergreen Underground Water Conservation District and the Goliad County Groundwater Conservation District are sponsoring a Surface Water – Groundwater Interaction Study through the USGS. The study focuses on the Carrizo and Gulf Coast aquifers in the San Antonio River basin. The objective is to obtain a better understanding of the interaction between surface water and groundwater based on streamflows, groundwater levels, and water chemistry. USGS is developing a Hydrological Simulation Program – FORTRAN (HSPF) model to simulate streamflow and estimate ground water recharge to the Carrizo and Gulf Coast aquifers in the lower San Antonio River basin. Through this model, local agencies will achieve a better understanding of the relationship between surface water and groundwater in the lower San Antonio River basin. Information about water quality as well as water quantity will be generated through the modeling exercise. This model also will assist local agencies develop and implement appropriate natural resource management strategies to ensure the long term availability and quality of water resources. The study is scheduled to be completed by the end of 2009.

To date, USGS has installed five new continuous streamflow stations located at Cibolo Creek near Saint Hedwig (gage 08185065); Martinez Creek near Saint Hedwig (gage 08185100); Cibolo Creek at Sutherland Springs (gage 08185500); San Antonio River near Floresville (gage 08183200); and San Antonio River near McFaddin (gage 08188570). USGS also installed five new groundwater monitoring sites, two in the Carrizo outcrop, one in the Wilcox, and two in the Gulf Coast aquifer. USGS completed four synoptic surface water gain/loss surveys, conducted measurements during base flow conditions at thirty sites including the gaging stations, and performed water chemistry/isotope samples at the surface water and groundwater sites.

1.2 *Assessment of Current Conditions*

To assess the current conditions in the lower San Antonio River sub-basin, the available information acquired and evaluated along with the specific TIFP and SARA sampling efforts data and analyses were compiled. 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

Major tributaries of the lower San Antonio River include Cibolo Creek, Escondido Creek and Ojo de Agua Creek. Under base flow conditions, flow from Cibolo Creek is approximately 10 percent of that of the mainstem of the San Antonio River, while the other tributaries do not make as significant a contribution. As discussed in Section 1.1.1, observation of the available gage data indicates that base flow conditions in the lower San Antonio River sub-basin have increased dramatically over time. These changes in base flows in the lower sub-basin are likely due to a number of factors, including changes in precipitation, urban growth, and groundwater pumping and return flows. The relationship between levels of groundwater in aquifers and flows in the lower San Antonio River sub-basin continues to be complicated. Increased groundwater pumping can increase flows in some portions by increasing return flows to the river, while lowered groundwater tables can reduce spring flows in other areas.

1.2.2 Biology

In recent TIFP fish collections (2006-2008), over 40 species of fish were collected in the lower San Antonio River sub-basin. The diversity of fish species recently collected include representatives from each of the major trophic guilds (piscivore, invertivore, omnivore, and herbivore). Fish species representing several habitat categories (riffle, shallow run, deep run, deep pool, shallow pool, edge, and backwater) have been observed. Riffle species included Texas logperch, central stoneroller (*Campostoma anomalum*), and burrhead chub. Species collected that are representative of deep run habitat included flathead catfish (*Pylodictis olivaris*), gray redhorse *(Moxostoma congestum*), and gizzard shad (*Dorosoma cepedianum*). A variety of the sunfish species collected are reported to be representative of shallow pool, edge, and backwater habitat; whereas, several minnow species are listed as potential representatives of shallow runs. Smallmouth buffalo (*Ictiobus bubalus*) may serve as a representative of deep pool habitat. Four live mussel species were collected during baseline sampling conducted between 2006 and 2007 (Karatayev and Burlakova 2008). These mussels included threeridge, Tampico pearlymussel, yellow sandshell, and golden orb.

Much of the lower San Antonio River floodplain has been cleared up to or near the banks for agricultural and ranching purposes leaving isolated patches of brushy riparian habitat scattered throughout the basin. Riparian habitats vary in width from a few meters to greater than fifty or sixty meters in undisturbed areas. There are some areas adjacent to the lower San Antonio River covered by dense hardwood canopies limiting the growth of underlying vegetation. Riparian vegetation along the lower Cibolo Creek is confined to the immediate bank in urban areas, whereas the rural areas possess wide dense hardwood riparian corridors. Stream canopy ranges from open canopies in urban areas to partially and completely closed canopies. Macrophytes have a limited distribution in the lower San Antonio River but are abundant in the lower Cibolo Creek and occur in greater numbers in areas of the stream that are open to direct sunlight and reduced flow.

1.2.3 Physical Processes

Characteristics of the lower San Antonio River are influenced by geological formations associated with the Gulf Coastal Plains Province. These formations consist primarily of sand, sandstone, silt, clay and gravel. Two other formations influencing the lower San Antonio River are the Grayson Shale and Wills Point formation which consist largely of clay, maryl, limestone, and sandstone. A series of falls formed by an outcropping of lignite and limestone are located between FM 791 and FM 81 near Falls City. The lower San Antonio River is deep, wide and meandering and the stream bed is composed of deep layers of sand and silt throughout most of the river. In many places, stream banks along the lower San Antonio River are entrenched by high, steep, muddy banks and are undercut particularly along outer bends of the river. Log jams are common and can vary on the order of feet to several hundred feet across. The river is dominated by runs and glides. Turbidity increases longitudinally downstream due to an increase in suspended particles from the surrounding geological formations and an increase in planktonic algae due to increased nutrient concentrations.

The lower Cibolo Creek flows southeastward as it makes its way to the confluence with the San Antonio River near Panna Maria in Karnes County. The banks of the lower Cibolo Creek are steep and undercut. The upper reaches of this segment are characterized by shallow, fairly uniform channels with alternating riffle and pooled areas. The lower reaches are primarily pools and glides. Substrates consist of gravel, silt and sand. Turbidity is influenced by substrate composition and associated geological formations. Log jams and sand bars are common in the narrower portions of the stream.

1.2.4 Water Quality

Water quality in the San Antonio River basin continues to improve (SARA 2008); however, water quality concerns are still experienced throughout the basin for particular constituents. Portions of the lower San Antonio River and lower Cibolo Creek are not meeting the contact recreation standard due to *E. coli* bacteria. Generally, there is a relationship between high flows and increased levels of bacteria indicating a non-point source of bacterial pollution. The actual source of the pollution (whether wildlife, livestock or human origin) is difficult to determine. Nutrients are also a concern in portions of the lower San Antonio River and lower Cibolo Creek. The sources of the nutrients are varied and depend on the sampling location. Elevated nutrient levels are typically found below wastewater discharge points, but nutrients can also enter the stream system from runoff, discharge of groundwater polluted with nutrients, through natural and manmade sources, and even through the atmosphere. At this time, no segments are identified as impaired by the TCEQ for low dissolved oxygen levels. The sources of the nutrients are varied and depend on the sampling location.

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 San Antonio River sub-basin is shown in Figure 10. This model 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 San Antonio River sub-basin by incorporating important findings from previous studies and local knowledge gained from participants during study design workgroup meetings. Because conditions vary within the sub-basin, various aspects of the general conceptual model are of lesser or greater importance depending on location. For example, “flashiness” decreases significantly from the upper to the lower portions of the study area. This is due to an increase in contributing watershed (which acts to decrease flashiness) and a significant change in climate, geography, and geology (from the Edwards Plateau / Balcones Escarpment to the Coastal Plain). Similarly, riparian areas and floodplain habitats vary from minimal to significant from the upper to the lower portions of the study area. Groundwater/surface water interactions vary depending on the underlying aquifers. Although predominantly sand, the bed material of the channel also varies within the study area. In the upper portions, there are limited areas with bed material including larger sediments and bedrock.

The expected relationships between flow components and various ecological process of the lower San Antonio River sub-basin are shown in Table 6. 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 multidisciplinary way.

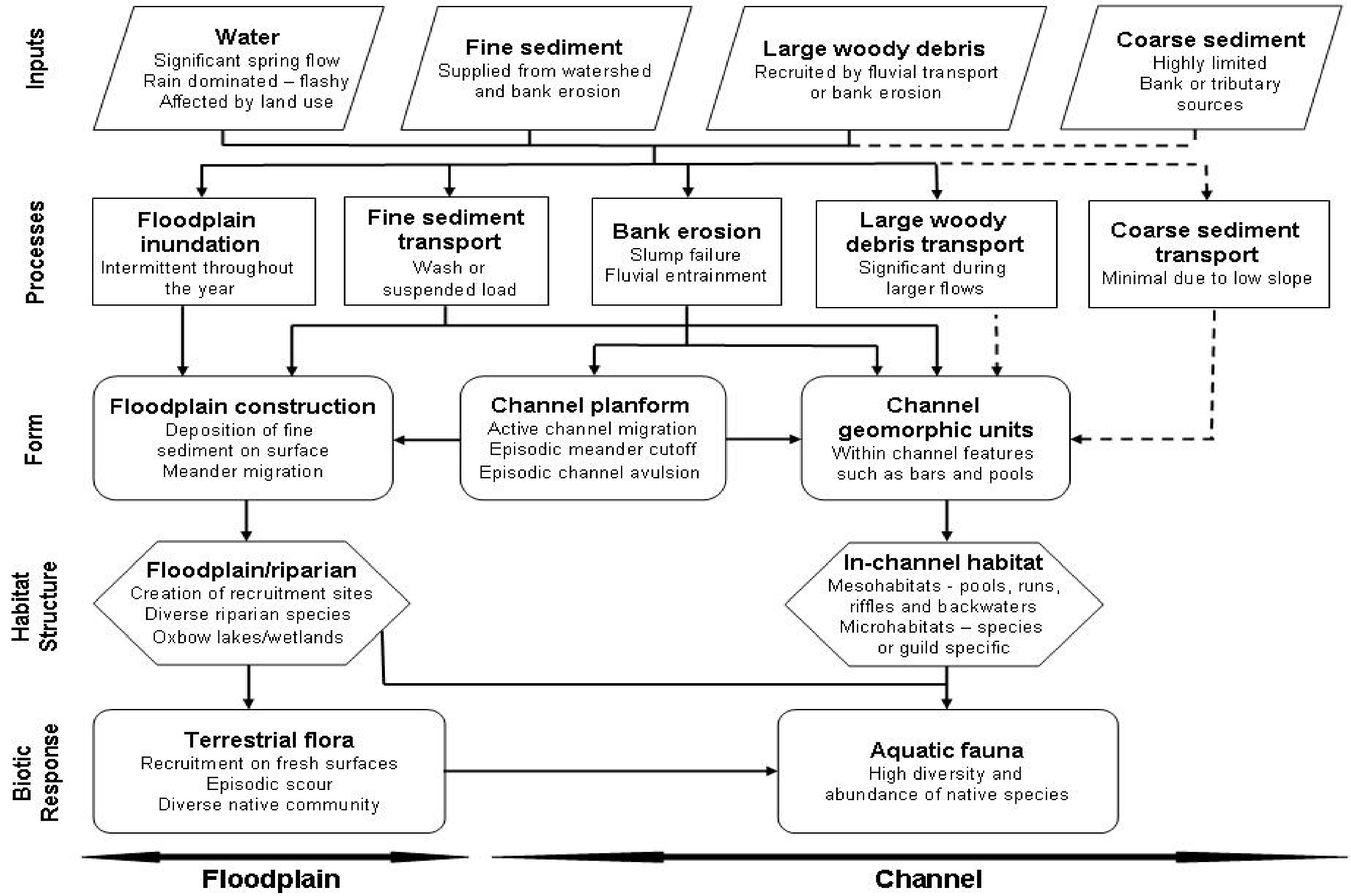

Figure 10. General conceptual model of lower San Antonio River sub-basin.

Table 6. Ecological processes supported by instream flow components of the lower San Antonio River sub-basin.

Component	Hydrology	Geomorphology	Biology	Water Quality	Connectivity
Subsistence flows Infrequent, low flows (typically during summer)	Spring flow (especially from the Edwards Aquifer) and return flows (such as wastewater discharge) make up a large portion of flow	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 lateral connectivity along the length of the river Affected by groundwater/ surface water interactions Maintain longitudinal connectivity
Base flows Average flow conditions, including variability.	Elevated in recent years partially due to increased groundwater use (with return flow) in the basin May vary by season and year	Maintain soil moisture and groundwater table in riparian areas Maintain a diversity of habitats	Provide suitable aquatic habitat for all life stages of native species	Provide suitable in-channel water quality Edwards Aquifer spring flow contributes to nitrate levels	Provide connectivity along channel corridor Groundwater / surface water connectivity plays an important role.
High flow pulses In-channel, short duration, high flows	Increased development in the basin (increasing impervious cover) may have increased the magnitude and frequency of these events	Maintain channel and substrate characteristics Flush sediment Prevent encroachment of riparian vegetation Play an important role in recovery of channel after extreme flood events	Provide spawning cues for organisms	Restore in-channel water quality after prolonged low flow periods	Provide connectivity to near-channel water bodies

Table 6 (continued). Ecological processes supported by instream flow components of the lower San Antonio River sub-basin.

Component	Hydrology	Geomorphology	Biology	Water Quality	Connectivity
Overbank flows Infrequent, high flows that exceed the channel	Occur frequently due to natural climate, geography, and geology of the Hill Country	Provide lateral channel movement and floodplain maintenance Form new habitats Flush organic material into channel Recruit and transport large woody debris Deposit nutrients in floodplain	Provide spawning cues for organisms Maintain diversity of riparian vegetation	Restore water quality in floodplain water bodies	Provide connectivity to floodplain Provide large volumes of freshwater to San Antonio Bay

2.0 STAKEHOLDER INVOLVEMENT AND STUDY DESIGN DEVELOPMENT

2.1 *Stakeholder Involvement*

Stakeholder involvement has been a key component of the TIFP lower San Antonio River sub-basin study, beginning with initial meetings to gain historic and current perspectives on the basin to more recent meetings convened to develop study specific 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 and Objectives*

The overall goal or vision agreed upon by the stakeholders was for the lower San Antonio River sub-basin to be *"a naturally functioning and sustainable ecosystem that supports a balance of ecological benefits and economic, recreational, and educational uses"*. Objectives were developed for multiple disciplines, including hydrology, biology, physical processes, water quality, and connectivity with an overriding aim to determine the natural, historic, and current conditions of each. To evaluate the progress made toward meeting the goal and objectives, a set of indicators were selected for each objective and summarized below with more details provided in Section 2.3.

2.2.1 Hydrology

The objective for hydrology is to develop a flow regime that sustains ecological processes throughout the system. Three parts of this objective include: determining the components of the flow regime and their characteristics that support study objectives of the aforementioned disciplines; determining the natural variability of flow component characteristics; and, evaluating water losses and gains throughout the system. Indicators selected to evaluate flow regime components are frequency, timing, duration, rate of change, and magnitude of overbanking, high pulse, base habitat, and subsistence flows. Natural variability will be based upon the above indicators from the older portions of gage records; whereas, current variability will be limited to the last 20 to 25 years of flow records. Indicators for water losses and gains are strictly the difference in the amount of water entering and leaving specific sections of the river channel.

2.2.2 Biology

The biological objective is to determine and maintain flows necessary to support key aquatic habitats and native species and biological communities known to occur in the river and riparian zones. Biology was split into three categories for evaluation purposes:

instream biological communities, instream habitat, and riparian habitat. Indicators of instream biological communities include native species richness, relative abundance of target species, fish (flow sensitive species, sportfish, prey species, imperiled species, and intolerant species), and other aquatic organisms (such as mussels). Instream habitat indicators are habitat quality and quantity for key species and mesohabitat area and diversity. Riparian habitat indicators include vegetation (age class, richness, diversity, density, and canopy cover), soils, and hydrology (gradient of inundation and base flow levels).

2.2.3 Physical Processes

The geomorphological objective is to determine and balance the effects of different flows on factors such as channel migration and woody debris dynamics and to examine the positive and negative effects of overbanking flows. Indicators chosen for channel migration evaluation are rate of lateral channel migration, channel avulsion, and bank erosion. Overbanking flow indicators are total area inundated, habitat area inundated, and stage at USGS gage locations. Indicators related to woody debris dynamics will be volume, transport rate, and recruitment rate. Channel shape will also be evaluated using characteristics of in-channel bars and meander pools as indicators.

2.2.4 Water Quality

The water quality objective is to maintain flow in order to sustain water quality to support biodiversity, economic uses, and recreational uses. Indicators include nitrogen, phosphorus, dissolved oxygen, temperature, and bacteria concentrations.

2.2.5 Connectivity

Objectives for connectivity include identifying the interaction of groundwater and surface water and evaluating the relationship of important habitat features of the river and riparian zone that support the basin goal. Connectivity categories selected for evaluation are groundwater/surface water interaction, habitat features, and freshwater inflows to the estuary. Gain or loss in specific sections of the river will be used as the indicator for groundwater/surface water interaction. Frequency, duration, and timing of connection of riparian areas to the river will serve as the indicator for habitat features. Volume of flow at USGS gage 08188500 at Goliad will serve as the indicator of freshwater inflows to the estuary.

2.3 *Study Indicators*

As described in the Technical Overview (TIFP 2008), a list of all practical indicators consistent with the study goal and objectives was provided to the stakeholders for the lower San Antonio River sub-basin. 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 7-11) present the final list of indicators as determined by the stakeholder process for hydrology, biology, physical processes, water quality, and connectivity.

Table 7. List of the Hydrology study indicators and their importance to the instream flow study.

Hydrology		
Indicators		
Category	*Indicator*	*Explanation*
Flow regime components	Overbank flows (frequency, timing, duration, rate of change, and magnitude)	Infrequent, high magnitude flow events that enter the floodplain • Maintenance of riparian areas • Transport of sediment and nutrients • Allow fish and other biota to utilize floodplain habitat during and after floods • Riparian and floodplain connectivity to the river channel
	High pulse flows (frequency, timing, duration, rate of change, and magnitude)	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., connections to oxbow lakes)
	Base habitat flows (frequency, timing, duration, rate of change and magnitude)	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 • Provides for recreational or other uses
	Subsistence flows (frequency, timing, duration, rate of change, and magnitude)	Low flows maintained during times of very dry conditions • Maintain water quality standards • Prevent loss of aquatic organisms
Natural variability	Natural	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 site
	Current	Variability of the above indicators based on the last 20-25 years of gage records
Losses/gains	Gain or loss in section of river	Difference in the amount of water entering and leaving a specific section of the river channel. Sources of gains include inflow from tributaries, alluvial and deeper aquifers, and discharges to the river. Sources of losses include evaporation, evapo-transpiration from riparian areas, diversions, and recharge of alluvial and deeper aquifers. Indicator may be influenced by shallow groundwater surface elevation and hydraulic head of deeper aquifers.

Table 8. List of the Biology study indicators and their importance to the instream flow study.

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<tr><th colspan="3">Biology</th></tr>
<tr><td colspan="3">Indicators</td></tr>
<tr><td>Category</td><td>Indicator</td><td>Explanation</td></tr>
<tr><td rowspan="4">Instream Biological Communities</td><td>Native Richness</td><td>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</td></tr>
<tr><td>Relative Abundance</td><td>The number of organisms of a particular species as a percentage of the total community</td></tr>
<tr><td>Fish
• Flow sensitive species
• Sportfish
• Prey species
• Imperiled species
• Intolerant species</td><td>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</td></tr>
<tr><td>Other Aquatic Organisms
• Mussels
• River plants, if any</td><td>Mussels and river plants (if present) may be appropriate indicators</td></tr>
<tr><td rowspan="2">Instream Habitat</td><td>Habitat Quality and Quantity for Key Species</td><td>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.</td></tr>
<tr><td>Mesohabitat Area and Diversity</td><td>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.</td></tr>
</table>

Table 8 (continued). List of the Biology study indicators and their importance to the instream flow study.

Biology		
Indicators		
Category	*Indicator*	*Explanation*
Riparian Habitat	Vegetation • Age class • 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 at each study reach and coupled with surface water data to produce a probability of inundation curve. Overbanking flow requirements can be modeled.

Key species identified during a series of stakeholder meetings based upon their abundance and sensitivity to water quality and flow include:

- burrhead chub
- American eel
- pugnose minnow
- all darter species
- golden orb (a freshwater mussel)

Burrhead chub is considered a flow sensitive species which inhabits moderate to swift flowing waters over sand and gravel substrates in large rivers. They use taste buds located on their head, body, fins, and small barbels to feed along the bottom of turbid rivers. Food consists of aquatic insects, small crustaceans, and some plant material. They spawn throughout the summer months and eggs develop as they drift in the current, hatching in about 25-28 hours. Maximum life span is about 1.5 years (Robison and Buchanan 1988).

American eel was not reported from the San Antonio River in any of the historical collections reviewed; however, historical collections and recent communications with stakeholders report them as occurring in Cibolo Creek, meaning they must also occur, at least at times, in the mainstem of the lower San Antonio River. American eel were selected as a target species because of their migratory habits and recent nationwide concern that their numbers may be declining. Habitat and range for this species have been reduced by the construction of dams (Thomas et al. 2007). American eel are secretive, hiding by day beneath rocks, submerged logs, or other cover, moving actively about only at night. Their food consists entirely of animal material, either living or dead (Pflieger 1975). Breeding occurs from late winter to early summer near the Sargasso Sea (Robison and Buchanan 1988). Flows that ensure movement between upstream foraging habitats and the ocean in early spring appear to be very important for this species (Meyer et al. 2003).

Due to a significant decline in pugnose minnow abundance, this species was also selected as a potential target species. Pugnose minnow is reported to inhabit quiet regions of streams and oxbow lakes over mud and sand or debris substrates in or near vegetation (Robison and Buchanan 1988). Foods eaten by this midwater-feeding species include chironomid larvae, filamentous algae, fish eggs, and microcrustaceans (Gilbert and Bailey 1972).

As a group, darters are typically indicators of clean, flowing water. Their diet consists mostly of insect larvae. Two species, Texas logperch *(Percina carbonaria)* and river darter (*Percina shumardi*) have been reported in the lower San Antonio River. Darters of the genus *Percina* are egg-burying spawners (Page 1983). During spawning the female will work her body partially below the surface of the substrate and expel her eggs with the male mounted on her back. The substrates usually utilized are loose gravel, sand, or mixed gravel and sand. Texas logperch is reported to prefer moderate to strong current and are typically found in riffles over gravel, rubble, or sand substrate (Robison and Buchanan 1988). River darter is also mostly found in riffles and runs (Thomas et al. 2007). These two species and orangethroat darter (*Etheostoma spectabile*) have been reported in Cibolo Creek. Orangethroat darter prefers small headwater creeks and spring runs where they are found in shallow riffles of slow to moderate current over a gravel or rubble substrate (Robison and Buchanan 1988). Spawning in Texas occurs from mid-October through July (Hubbs and Armstrong 1962; Marsh 1980; Hubbs 1985) within and downstream of shallow gravel riffles with moderate flows, where the eggs are buried in the substrate (Edwards 1997).

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

Physical Processes		
Indicators		
Category	*Indicators*	*Explanation*
Channel migration	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.).
Overbank flows	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 a particular magnitude of overbank flow.
	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.
Woody debris	Volume	The volume of woody debris in a section of river. A certain amount of woody debris is necessary to provide food and/or shelter for various organisms.
	Transport rate	The rate at which woody debris moves past a specific point along the river.
	Recruitment rate	The rate that woody debris enters a section of river. Wood may be supplied by upstream sections of the river, tributaries, tree fall from the banks, or washed into the river during flood events.
Channel shape characteristics	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.

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

Water Quality		
Indicators		
Category	*Indicator*	*Explanation*
Nutrients	Nitrogen Nitrate + Nitrite, Ammonia 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	The oxygen freely available in water. Dissolved oxygen is vital to fish and other aquatic life. Traditionally, the level of dissolved oxygen has been accepted as the single most important indicator of a water body's ability to support a desirable aquatic life.
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.
Recreational health (Contact Recreation)	Bacteria	*E.coli* (freshwater) and enterococci (saline waters) are used as indicators of potential waterborne pathogens.

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

Connectivity		
Indicators		
Category	*Indicator*	*Explanation*
Groundwater/ surface water interaction	Gain or loss in section of river	Difference in the amount of water entering and leaving a specific section of the river channel. Sources of gains include inflow from tributaries, alluvial and deeper aquifers, and discharges to the river. Sources of losses include evaporation, evapo-transpiration from riparian areas, diversions, and recharge of alluvial and deeper aquifers. Indicator may be influenced by shallow groundwater surface elevation and hydraulic head of deeper aquifers.
Habitat features	Connection to river (frequency, duration, and timing)	Periodic connectivity between riparian areas and the river 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 08188500 at Goliad	Freshwater inflow requirements for the Guadalupe Estuary (San Antonio Bay) have been studied by other state programs. Recommendations have been made in the form of yearly and monthly volumes of freshwater inflow. The San Antonio River is an important source of inflow for the Guadalupe Estuary. 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.

3.0 DESCRIPTION OF TECHNICAL STUDIES

The description of technical studies is divided into two main sections. The first section (3.1) provides the locations (segments, reaches, sites, etc.) for proposed activities and the rationale for selecting these areas. The second section (3.2) provides an overview of the proposed studies (essentially, the "What" and "Why") and how the proposed 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*

While broader studies may be conducted across an entire segment, other studies will be conducted at particular study sites. The 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). Study sites were selected in cooperation with the stakeholder group following the process described below. Details like the specific length of each site will be determined in the field and be dependant upon availability, distribution and abundance of habitat types, as well as upon availability of study resources.

The TIFP used a three-tier evaluation to identify proposed study sites on the lower San Antonio River and a tributary, lower Cibolo Creek. Tier 1 evaluation was high-level and based primarily on basin geology and Texas ecoregions, resulting in the designation of large-scale segments for both the lower San Antonio River and lower Cibolo Creek. These segments were further divided into potential study reaches based primarily on major hydrological and geomorphological features and conditions. Tier 2 evaluation was more detailed and focused on specific parameters relative to the hydrology, biology, physical processes, and water quality supported within those reaches. This detailed evaluation determined which activities are recommended within the proposed study reaches. Tier 3 evaluation examined in finer detail shorter stretches of the river (sites) that would represent the reach in general and be of a practical size for the resources available for this study.

TIER 1

The uppermost boundaries for the lower San Antonio River and lower Cibolo Creek instream flow study are the USGS streamflow gages at Elmendorf and Sutherland Springs, respectively (Figure 11). The downstream boundary for lower Cibolo Creek is the confluence with the lower San Antonio River, and the downstream boundary for the lower San Antonio River is the confluence with the Guadalupe River (Figure 11). Figure 11 also shows the major geologic formations and transition zones that occur within the lower San Antonio River sub-basin and the valley edge that was described by Engel and Curran (2008). Figure 12 highlights the Gould Ecoregions of Texas (Gould et. al 1960) associated with the lower San Antonio River sub-basin. The upper portion of the study area occurs in the Post Oak Savannah ecoregion, the central portion in South Texas Plains, and the lower portion in Gulf Prairies. From an assessment of the geological properties, valley shape, and Texas Ecoregions, boundaries for the three study segments on the lower San Antonio River (LSAR) and two study segments on lower Cibolo Creek (LCC) were delineated (shown on both Figures 11 and 12).

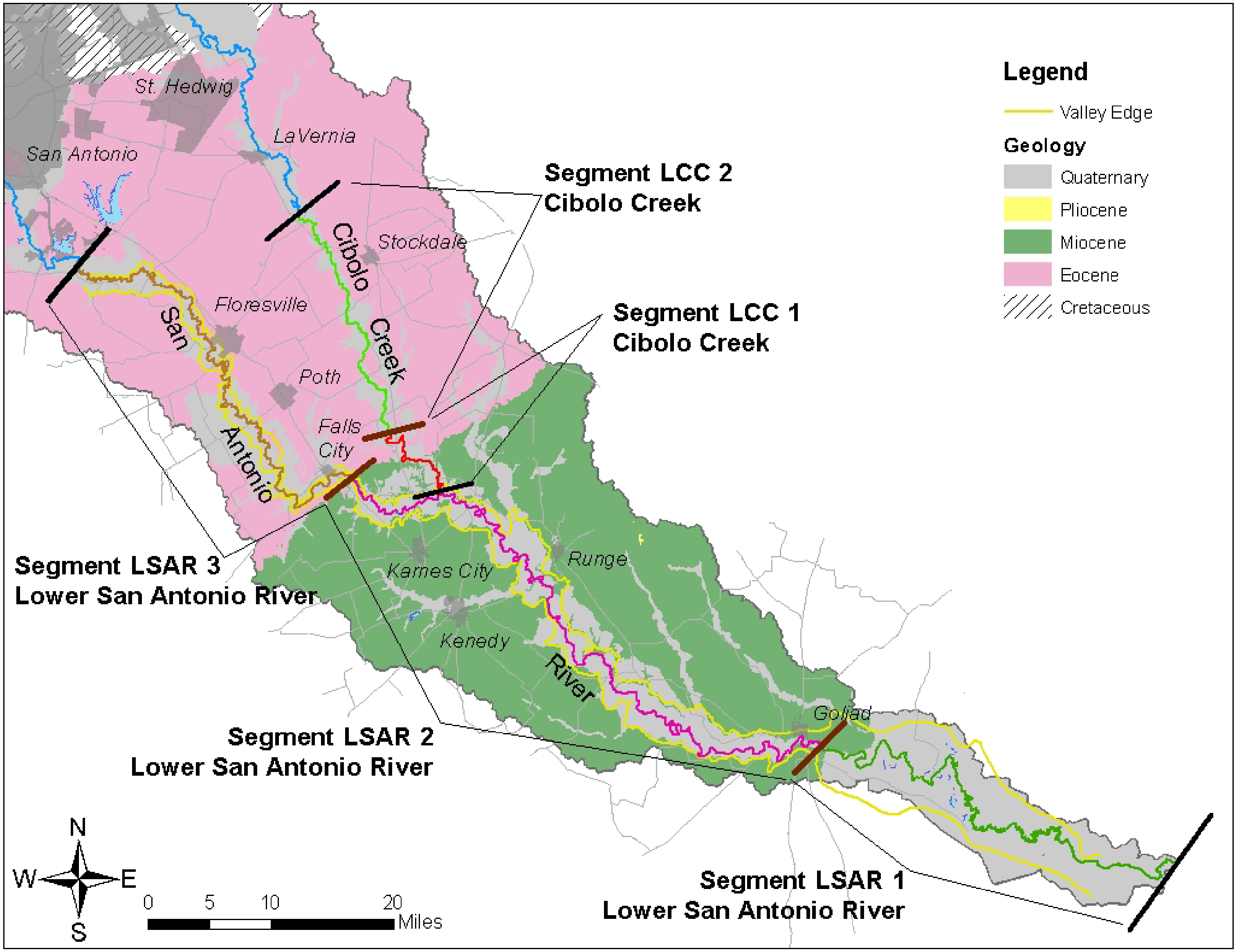

Figure 11. Map of the Tier 1 study segments, regional geology (Brown et al. 2000) and valley edge (Engel and Curran 2008).

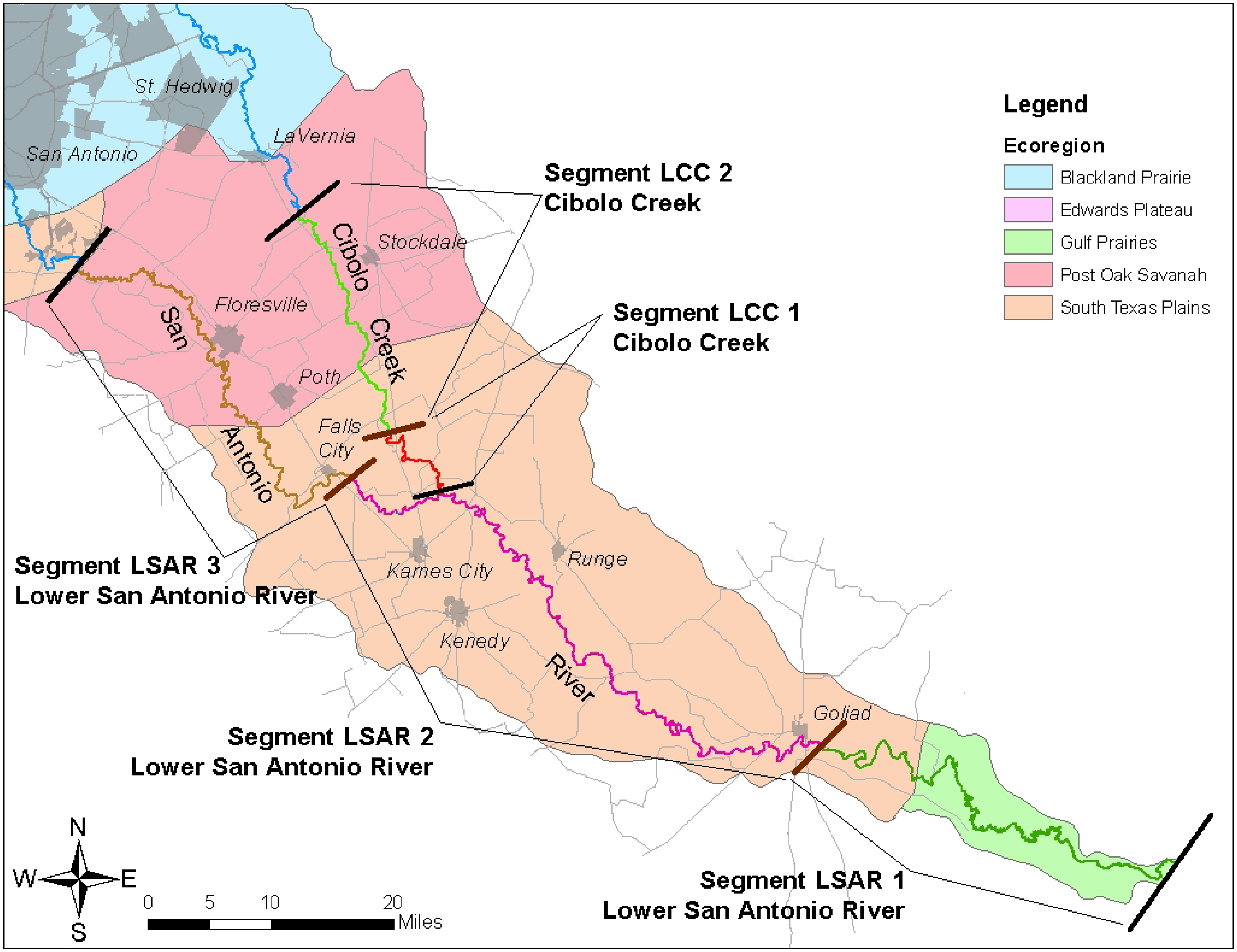

Figure 12. Map of the Tier 1 study segments and the Gould Ecoregions of Texas (Gould et al. 1960).

Each study segment was then further evaluated based on hydrology, biology, geomorphology, and water quality components. From this assessment, eight reaches were selected within the three segments on the lower San Antonio River, and each of the two segments on lower Cibolo Creek were also designated as reaches (Figure 13). River miles are calculated for this study based upon the USGS National Hydrography Dataset (NHD) flow lines; distance is measured traveling upstream from mile 0.0 at San Antonio River's confluence with the Guadalupe River.

TIER 2

Tier 2 involved evaluating each of the potential study reaches in more detail to determine what activities should be conducted within each reach. To accomplish this task, existing data (USGS gage locations, diversions, previous instream flow data, fish data, mussel data, aerial photography, geomorphologic data, water quality sampling stations, recreational areas, etc.) was compiled and uploaded into separate GIS data layers for evaluation. A comprehensive data table was created (1) to better describe each of the study reaches, and (2) to assist with the determination of activities within a reach. The proposed reaches and a summary of key characteristics and study activities proposed for each reach are provided below:

- **Lower San Antonio River (LSAR)**
  - **LSAR TIFP Segment 1**
    - Reach 1 – Guadalupe River confluence to Hwy 77 (river mile [RM] 0 to RM 15.
      - This reach encompasses an expanded floodplain and the potential for tidal influences both of which considerably add to the complexity of instream flow models. Therefore, at this time, <u>no activities are proposed for this reach</u>.
    - Reach 2 – Hwy 77 to Goliad (RM 15 to RM 82)
      - Of the two proposed reaches in LSAR Segment 1, this reach has more existing information and is also listed as water quality impaired (bacteria). <u>Hydraulic and habitat modeling, a baseline riparian assessment, and associated instream flow sampling activities are proposed for this reach.</u>

  - **LSAR TIFP Segment 2**
    - Reach 3 – Goliad to Cibolo Creek confluence (RM 82 to RM 156)
      - This reach is representative of LSAR Segment 2, and has a wealth of hydrological and biological information and known populations of a special status mussel species. Activities are proposed for two sites. <u>Hydraulic and habitat modeling, a baseline riparian assessment, and associated instream flow sampling activities are proposed upstream of Goliad.</u>
      - <u>A fisheries habitat and geomorphology assessment is also proposed for an area immediately downstream of the Cibolo Creek confluence.</u>
    - Reach 4 – Cibolo Creek confluence to Falls City (RM 156 to RM 173)
      - This reach is similar to Reach 3 but was separated at the confluence with Cibolo Creek. Therefore, at this time, <u>no activities are proposed for this reach.</u>

  - **LSAR TIFP Segment 3**
    - Reach 5 – Falls City to Hwy 791 (RM 173 to RM 185)
      - The unique geological features in this reach and the availability of recent hydrological and biological information led this reach to be

proposed for hydraulic and habitat modeling, a baseline riparian assessment, and associated instream flow sampling activities.

- Reach 6 – Hwy 791 to downstream of oxbow (RM 185 to RM 208)
  - This reach is similar to Reach 8 but has more pool habitat resulting from the hydraulic control in Reach 5. Because pool habitats are less sensitive to flow and other habitats are similar to those in Reach 8, no activities are proposed for this reach.
- Reach 7 – Downstream of oxbow to Floresville (RM 208 to RM 227)
  - This reach was selected for a specific geomorphological assessment because of the unique physical processes that have created an oxbow at the downstream edge of the reach.
- Reach 8 - Floresville to Hwy 1604 (RM 227 to RM 261)
  - Of the three upstream most reaches in LSAR Segment 3, this reach was the most representative of the segment relative to instream and riparian habitat. Therefore, hydraulic and habitat modeling, a baseline riparian assessment, and associated instream flow sampling activities are proposed for this reach.

- **Lower Cibolo Creek (LCC)**
  - **LCC TIFP Segment 1**
    - Reach 9 – San Antonio River confluence to Hwy 123 (RM 0 to RM 16)
      - The instream, biological, and riparian habitat characteristics of this reach are similar to Reach 10. Therefore, at this time, no activities are proposed for this reach.

  - **LCC TIFP Segment 2**
    - Reach 10 – Hwy 123 to Sutherland Springs (RM 16 to RM 43)
      - This reach is representative of lower Cibolo Creek and therefore, hydraulic and habitat modeling, a baseline riparian assessment, and associated instream flow sampling activities are proposed for this reach.

TIER 3

As it is not economically feasible to study the entire study reach, representative study sites within reaches are selected. Tier 3 assessment was done to locate representative study sites within each selected reach. These sites typically range from 0.5 to 2 river miles in length with a goal of being representative of the study reach overall. Instream and riparian habitats were evaluated based on the aerial photography and data presented in the Tier 2 assessment. An important additional criterion was property access. Although the majority of work will take place within the river channel, control points/targets for surveying will need to be located at distances away from the channel. Additionally, the riparian assessment will need to be performed while traversing the banks. The TIFP and study partners were able to identify the general location of candidate study sites, as shown in Figure 13. These sites appear suitable for study purposes and are areas where we have access to the river, either through proximity to public road crossings or cooperative land owners. Determining the suitability of specific sites for the proposed activities and finalizing the upstream and downstream boundaries will require visits to each location.

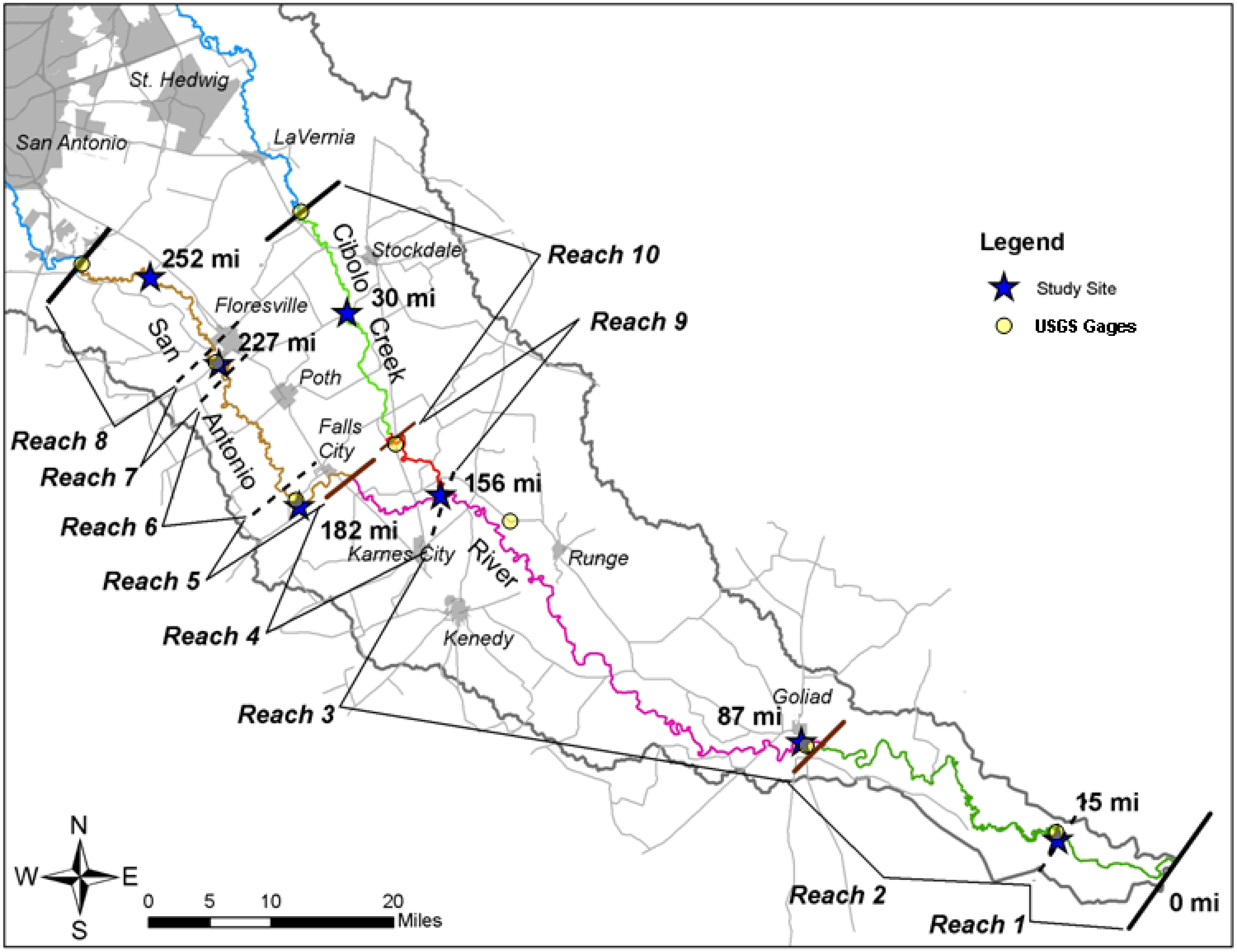

Figure 13. Proposed study reaches and study sites, with river miles (from downstream confluence) noted at each study site.

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 2.3). However, upon evaluation of the indicators developed for the lower San Antonio River sub-basin, it was determined that the Connectivity indicators could be incorporated into the hydrology and biology study components (i.e. groundwater/surface water and freshwater inflows to hydrology, and habitat features to biology). This section describes the proposed study activities, proposed locations, and methods for each of the four 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 four major study components. However, to remain consistent with the Technical Overview and previous sections, each of the four components will again be discussed by section with interactions between components highlighted.

3.2.1 Hydrology and Hydraulics

The lower San Antonio River and lower Cibolo Creek ecosystem has evolved in response to the inter- and intra-annual variability in flow that includes cycles of floods, pulses and low 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 natural variability, current variability, and gain or loss in river flow. A number of long-term flow 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 flood events. Since the time of the earliest flow records (early 1900's), a significant increase in base flow is exhibited at all gages as a result of factors such as increased wastewater return flows from the San Antonio metropolitan area. The long period of record allows comparisons between early periods that may represent a more natural condition to later periods reflecting current land use, water usage, and other conditions affected by human's use of water and the landscape.

Statistics 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 floods. Pre-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 existing natural ecology of the lower San Antonio River sub-basin.

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.

Specific to the lower San Antonio River sub-basin, the 2D hydraulic and habitat models will be developed to evaluate changes in microhabitat across a range of flow rates. This analysis will specifically address the subsistence and base flow hydrological indicators and is described in some detail in Sections 6.2, 7.3, and 10.2 of the Technical Overview (TIFP 2008). It is proposed that 2D hydraulic and habitat modeling be conducted within Reaches 2, 3, 5, and 8 on the lower San Antonio River and Reach 10 on lower Cibolo Creek (Figure 13, Section 3.1). 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 San Antonio 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 the river ecology. Relevant flow ranges identified by the habitat modeling task 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 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.

Topography, water surface elevation and discharge

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.) on a daily basis using ArcView software, and supplementary topographic surveying will be conducted to ensure complete coverage of each intensive site.

Once the model study sites are established, low-altitude, high-resolution color aerial photography will be flown at each of the five habitat modeling study sites at relatively low flows. Capturing images of the terrain at low flows will help to increase the amount of channel topography that can be generated from the aerial photos. The film negative from the flight mission will be handled and stored to meet National Map Accuracy Standards (NMAS). All negatives will be scanned. Scanned images will be manually georeferenced using distinct features in common with available black and white imagery. The aerial photography will be used to the degree practicable to fill in potential gaps in difficult to survey areas for the completion of the DTM. The DTM will be used to characterize the channel in both the 2D hydraulic and habitat models. The color aerial photography will also be used to assist in substrate mapping, riparian mapping, water's edge description, mesohabitat mapping, and woody debris assessment. Finally, the high resolution photography will provide the background imagery for model development.

Calibration data for hydraulic modeling consists of a stage-discharge relationship at the upstream and downstream end of each habitat study site. Water surface elevations will also be measured throughout the site at a minimum of three different discharges. Detailed water surface elevations will be measured with the survey grade GPS (centimeter accuracy) or conventional surveying equipment at a minimum of three flows--high, medium, and low flow 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. Data to validate the accuracy of the two-dimensional hydraulic model results will be measured. Validation data will be collected during high, medium , and low flow conditions and will consist of the length and width of any large recirculation zones in addition to velocity data. Velocity data consisting on average column velocity and direction will be collected by acoustic doppler profilers or more conventional methods.

Substrate and instream cover mapping

Substrate will be mapped based on dominant and subdominant particle sizes. In areas too deep for visual characterization, sampling with a pole Ekman dredge (or equivalent sediment sampler) or sounding will be used to characterize the substrate. Classification will be based on a modified Wentworth scale. Instream cover such as aquatic macrophytes, woody debris, etc. will also be mapped.

Aerial photographs from each model site will be printed and laminated to be used in the field for delineating substrates. Dominant substrates will be identified by walking or kayaking each site and measuring the substrate and placing it in a class represented by a code number. One or two dominant substrate types will be assigned for each delineated polygon. Hand-drawn delineations will be digitized using ArcView GIS software by scanning each field map, georeferencing the scanned images back onto the original aerial photos and digitizing the polygons into the GIS. Attributes to be recorded include dominant substrate type, subdominant substrate, and instream cover.

Pebble counts will be performed within selected polygons from the substrate mapping. For each polygon, 100 pebbles will be systematically chosen, measured, and categorized to validate dominance. In addition, pictures of each pebble count site will be taken to verify site characteristics.

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 the additional field data using the calibrated ("tuned") parameter values.

Substrate roughness and eddy viscosity are two calibration parameters commonly used in this process. Each time stage-discharge data for the development of rating curves is collected (each site at a minimum of 3 flows), additional depth/velocity point measurements for calibration will be collected. 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.

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 intensive 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.

Recreation modeling

Recreational activities including swimming, fishing, boating, kayaking, and canoeing will be modeled using existing suitability criteria for these activities. Recreation modeling will consist of using the final 2D hydraulic models at each study site coupled with suitability criteria for recreational activities (swimming, fishing, boating, kayaking, and canoeing). Recreational suitability criteria will be compiled from existing literature including peer reviewed articles, technical reports, and published books (e.g., Hyra 1978, Nestler et al. 1986).

High flow pulse and overbank assessment

Using HEC-RAS models and high-resolution LIDAR topography, extent of inundation will be evaluated along the longer sections of the river for a series of high flow pulses or small floods. This analysis will be valuable in assessing the hydrologic indictors of overbanking and high flow pulses. Differences in interval between inundation events will be evaluated spatially along the length of the river to identify breakpoints or to identify areas where frequent inundation has significant ecological impact.

The range of flows to be evaluated will have recurrence intervals ranging from less than a year (high pulse flows) to 10 years (overbank flows). Given the small magnitude of some of these flows, i.e., much lower magnitude than typically analyzed for flood studies (e.g., 100-year flood), the in-channel bathymetry will become an important factor. Detailed cross-sectional information may need to be developed for select reaches of the river where it is not currently known. This information may be developed from a combination of new survey data and statistical relationships that result in synthetic in-channel cross-sections.

Losses / gains

To assess interaction of surface water and groundwater in adjacent aquifers, the USGS is currently conducting a gain/loss study for the San Antonio River and Cibolo Creek as described in Section 1.1.6. The TIFP will continue to monitor the results of this study to assess their relevance to objectives related to groundwater/ surface water interaction.

3.2.2 Biology

Detailed biological studies in representative reaches of the lower San Antonio River sub-basin are required in order to understand the relationship between biology and flow conditions and address the overall biological objective to: "Determine and maintain flows necessary to support: 1) Native species and biological communities known to occur in the river and riparian zones; and 2) Key aquatic habitats." Instream biological community 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 San Antonio River sub-basin. 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 (run, pool, riffle, etc.) will be mapped in GIS. Ground truthing will be conducted by boat, kayak, and/or walking depending on specific reaches of river. 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 will be used initially 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 segment.

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 1.1.3, baseline fish sampling throughout the lower San Antonio River and lower Cibolo Creek has been underway since March 2006 with the goal of collecting representative samples of fish species present in their current relative abundance. Baseline mussel surveys were conducted between 2006 and 2007 in order to determine present and historical species richness and distribution (Karatayev and Burlakova 2008). 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. The baseline fish sampling will also be used to help address the indicators of species richness and relative abundance of native, sport, and prey fishes throughout the lower San Antonio River sub-basin.

Fish surveys

Fish will be collected in each identifiable mesohabitat within a sample reach length of 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 site. 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 the study reaches, a systematic sampling approach will be employed (Strayer and Smith 2003). In this method, a study site of two times the wetted width of each identifiable mesohabitat within the study reach 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 study site, 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 and Kennedy (2009).

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 diversity and is a valuable approach in species-rich ecosystems such as the lower San Antonio River sub-basin. The second layer of assessment addresses the habitat quality and quantity for key species 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.

For each study site where habitat modeling will be conducted, GPS units will be used to delineate mesohabitats according to 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

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 San Antonio River sub-basin.

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 San Antonio River sub-basin 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. Key species (described in Section 2.3) anticipated for microhabitat modeling include burrhead chub, pugnose minnow, darters, and golden orb. 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 microhabitat utilization for use in habitat suitability criteria development will be done by sampling fishes using a stratified random sampling technique, where each mesohabitat within the study reach is sampled in proportion to its relative availability. The same technique will be used for the collection of biological data for use in habitat model validation. For either application, fish sampling will be conducted using the most appropriate gear type, and an attempt will be made to sample fishes from homogeneous patches of microhabitat in relatively small areas. For each sample, fishes will be identified, enumerated, and measured (for determination of life history stage). Within each sample area, depth, mean column velocity, substrate composition (using TPWD protocol [modified Wentworth scale]), instream cover, habitat type, and location (using position averaging GPS) will be recorded, and it may be necessary to average multiple measurements within sample units to accurately characterize microhabitat conditions. Similar sampling procedures have been used in development of fish habitat use data for instream flow assessments in Texas (BIO-WEST 2008b).

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 San Antonio River sub-basin 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 (over 60 species historically and over 40 species currently in the lower San Antonio River sub-basin), 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. For mussels, a grouping method may not be necessary since only four species have been collected recently (although 17 species are listed for the lower San Antonio River sub-basin within the last 30 years [TPWD 2005]). For both taxa, a GIS-based physical habitat model will be used to assess habitat versus flow relationships, including 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 reaches. 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 be 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 five 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 San Antonio River or lower Cibolo Creek. In general, transects will 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 within 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.

The line intercept for shrubs is along center transect line. Point line intercept for herbaceous vegetation is at 1 meter intervals along the center 50-meter transect. All trees within 5 meters on either side of the 50-meter line are recorded in 10-cm size categories.

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. HEC-RAS models and LIDAR data will be used to evaluate how different riparian areas are affected by high flow pulses and overbank flows, and how riparian areas may transition (spatially) according to differences in wetting and drying characteristics. Results of

HEC-RAS overbanking studies will include quantifiable area (acres) inundated for each reach. Overlaying inundation areas with existing land use maps (NLCD) or with interpreted riparian area maps allows assessments of frequency of habitat inundation. As with flow information, the most comprehensive source of river stage information is from the USGS gauging station network. Changes in flow-stage rating curves over time can be evaluated and the stage data will be used to validate HEC-RAS overbanking models.

3.2.3 Physical Processes

The objective of the Physical Processes component is to determine and balance the geomorphic effects of different flows. Geomorphic activities related to this study will focus on three 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 overbank flows. The first activity will be carried out for the length of the lower San Antonio River and build on work already completed by Cawthon and Curran (2008). The second will be carried out at the scale of the length of the lower San Antonio River and at select field sites to evaluate processes that operate at these different levels. The third activity will be carried out only at select field study sites.

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. Available photo coverage for the lower San Antonio River sub-basin begins as early as the 1930's (Cawthon and Curran, 2008). 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) sediment sampling at USGS sites: (Example: to identify size of material being moved) and 2) sediment budgeting at select sites: (Example: to identify source of coarse sediment found in a particular bar).

At the first scale, the entire lower San Antonio River will be segmented based on USGS gage locations. Sediment budgets for the active channel area of each segment will be completed, including estimates of sediment input to the segment from the upstream channel, tributaries, and banks. At the second scale, mineral and organic (large woody debris) sediment budgets will be studied to see how the deposition and transport processes work and differ between sections 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 large woody debris between 8 to 12 inches in diameter).

In order to support the objective of evaluating sediment dynamics, sediment modeling will be conducted at two scales. First, a one-dimensional model will be used to investigate sediment dynamics through different reaches of interest within the Lower San Antonio River. Reaches will be selected to represent the variety of different morphology and sediment characteristics in the study area and will be the equivalent of a few meander wavelengths. 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.

Second, two-dimensional hydraulic and sediment transport models will be used to estimate finer scale processes at work in pools or bars of interest. A number of sites representing the range of different morphologies, facies patterns, and fluvial characteristics on the lower San Antonio River will be modeled. Sites will be approximately one meander wavelength in length, but the reaction at each bar and pool will be of interest. Processes such as deposition patterns on bar surfaces and maintenance of pool depths will be modeled, as well as the impact of woody debris on morphological patterns. Stream power patterns and sediment movement thresholds required to accomplish channel scale process goals will be estimated and compared to independent empirical data. Note that this is an area of active research for the TIFP with ongoing research being conducted by Judy Haschenburger of the University of Texas San Antonio and Matthew McBroom of Stephen F. Austin State University.

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 2000), 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.

Overbank flows

As discussed in Section 3.2.1, a series of HEC-RAS models and high-resolution LIDAR topography will be used to characterize the extent of inundation along the longer sections of the river for a series of small floods. Differences in interval between inundation events will be evaluated spatially along the length of the river to identify breakpoints or to identify areas where frequent inundation has significant geomorphic impact. The magnitude of flows to be evaluated will have recurrence intervals around 10 years or less. Given the small magnitude of some of these flows, i.e., much lower magnitude than typically analyzed for flood studies (e.g., 100-year flood), the in-channel bathymetry will become an important factor. Detailed cross-sectional information may need to be developed for select reaches of the river where it is not currently known. This information may be developed from a combination of new survey data and statistical relationships that result in synthetic in-channel cross-sections.

3.2.4 Water Quality

Maintaining adequate water quality is an essential part of managing a river ecosystem, so evaluating water quality along with hydrology, biology and physical processes is an essential part of the lower San Antonio River sub-basin study. To a large degree, appropriate water quality is monitored and regulated through the EPA and TCEQ in processes like the CRP, National Pollutant Discharge Elimination System (NPDES), Total Maximum Daily Load (TMDL) program and others. SARA 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 on-going or completed SARA studies (basin nutrient loading study, bacteria WPPs, previous water quality models, etc.) and state-wide efforts (nutrient criteria development). However, at this stage no existing studies have been identified that provide sufficient detail and the final instream flow recommendations need to ensure water quality concerns are addressed. In particular, dissolved oxygen (DO) is a primary parameter of concern since low levels can have detrimental effect on aquatic organisms. Relationships between flow, nutrients, and DO concentration are not well quantified in the lower San Antonio River sub-basin 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 most reaches within the lower San Antonio River sub-basin. However, it is anticipated 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 watershed, (3) treatment plant discharges (both volume and loading),

(3) literature values for modeling parameters and/or (4) collection of additional field data (travel time, diurnal variations, etc.). Interaction with SARA and other entities will be necessary, particularly as related to understanding the lower San Antonio 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, during summertime conditions. 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. However, following rain events DO concentration in creeks and rivers can be affected by an influx of organic matter from the watershed, so understanding the response to these events may also be important. 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.

Recreational health

Due to excessive concentrations of bacteria, portions of the lower San Antonio River have been placed on the EPA 303(d) list of impaired water bodies. The TCEQ has performed Total Maximum Daily Load (TMDL) assessments on the impaired reaches of the lower San Antonio River (TCEQ 2008) to determine the desired bacterial load reductions that may be required to bring the San Antonio River in compliance with State surface water quality standards. In response to the TCEQ TMDL reports, SARA initiated the development of a series of Watershed Protection Plans (WPPs) designed to address water quality impairments and attain load reductions determined by TCEQ TMDL studies. In addition to the WPPs, the TCEQ has contracted with SARA to develop Implementation Plans (IP) that will provide a detailed list of identified Best Management Practices (BMPs) and a schedule for their implementation. SARA will initiate the development of a WPP for the lower San Antonio River when funds become available.

Additionally, in an effort to monitor water quality, flow and bacterial levels in the San Antonio River for recreational purposes, SARA has initiated a River Recreation Monitoring Program. Under the program the San Antonio River is monitored for e-coli at four locations weekly. The results are posted on SARA's river recreational web site (www.riverrec.org) where current results and results from the previous 10 weeks are posted. In addition to bacterial levels, the geometric mean, compliance with water quality standards, river flow, weather and other information important to recreation enthusiasts are also available.

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 14). This study design document will be reviewed by the stakeholders 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.

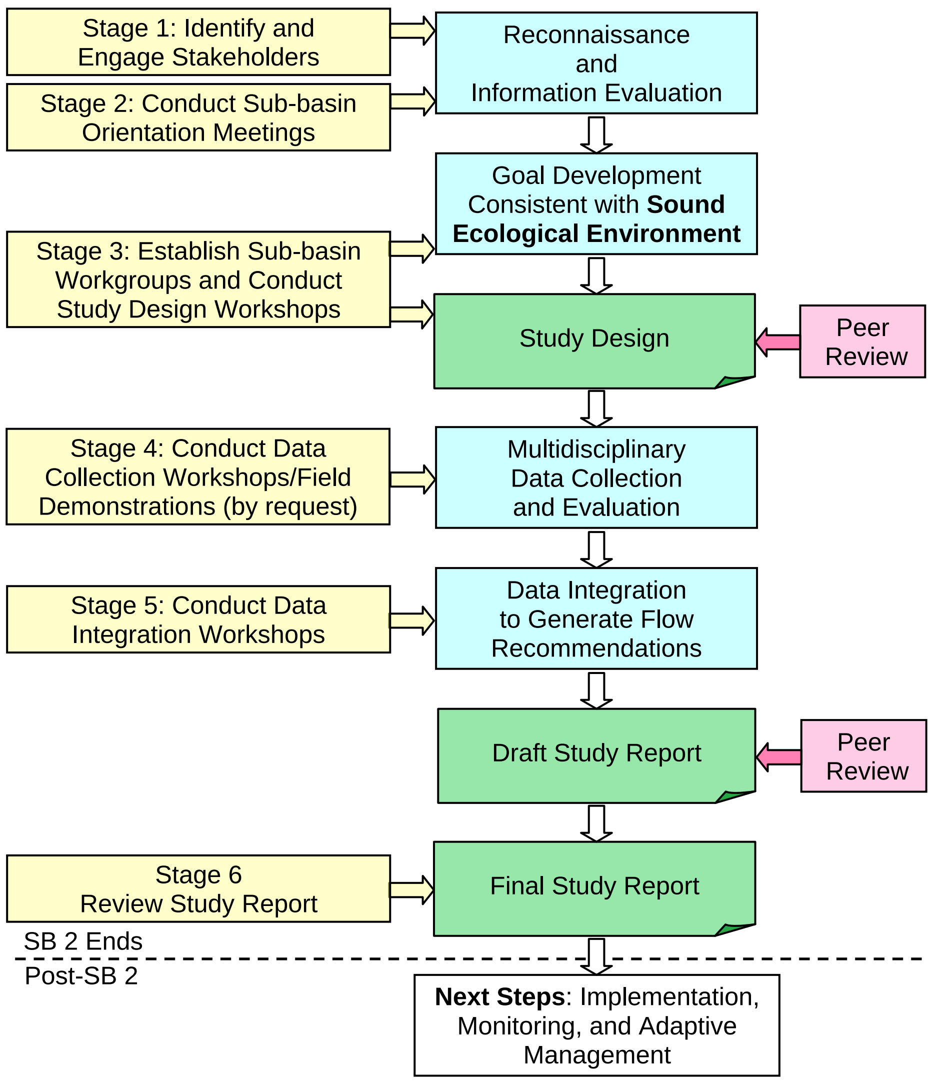

Figure 14. Stages of stakeholder participation in lower San Antonio River sub-basin study.

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 San Antonio River sub-basin 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 San Antonio 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 San Antonio River sub-basin provide important habitat during base flow conditions that cannot be maintained without suitable high flow pulses. Secondary objectives for high flow pulses include improving recruitment for riparian plant species.
- **Overbank Flows –** The primary objectives of overbank flow recommendations will be to maintain riparian areas and provide lateral connectivity between the river channel and active floodplains. Secondary objectives for overbank flows are to move organic debris to the main channel, providing life cycle cues for various species, and maintaining 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 San Antonio River sub-basin 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 San Antonio River and lower Cibolo Creek.

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 Study Design 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 San Antonio River sub-basin study and directives from Senate Bills 2 and 3.

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