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

NOVEMBER 2009

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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 and physical 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. Listing of a study in this table does not imply an endorsement by the TIFP of any conclusions documented in these reports. Rather, these studies are identified because they have collected valuable data related to riverine ecosystems in the lower San Antonio River sub-basin. This data will be considered and incorporated along with data collected by TIFP in order to provide a better understanding of the study area.

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.

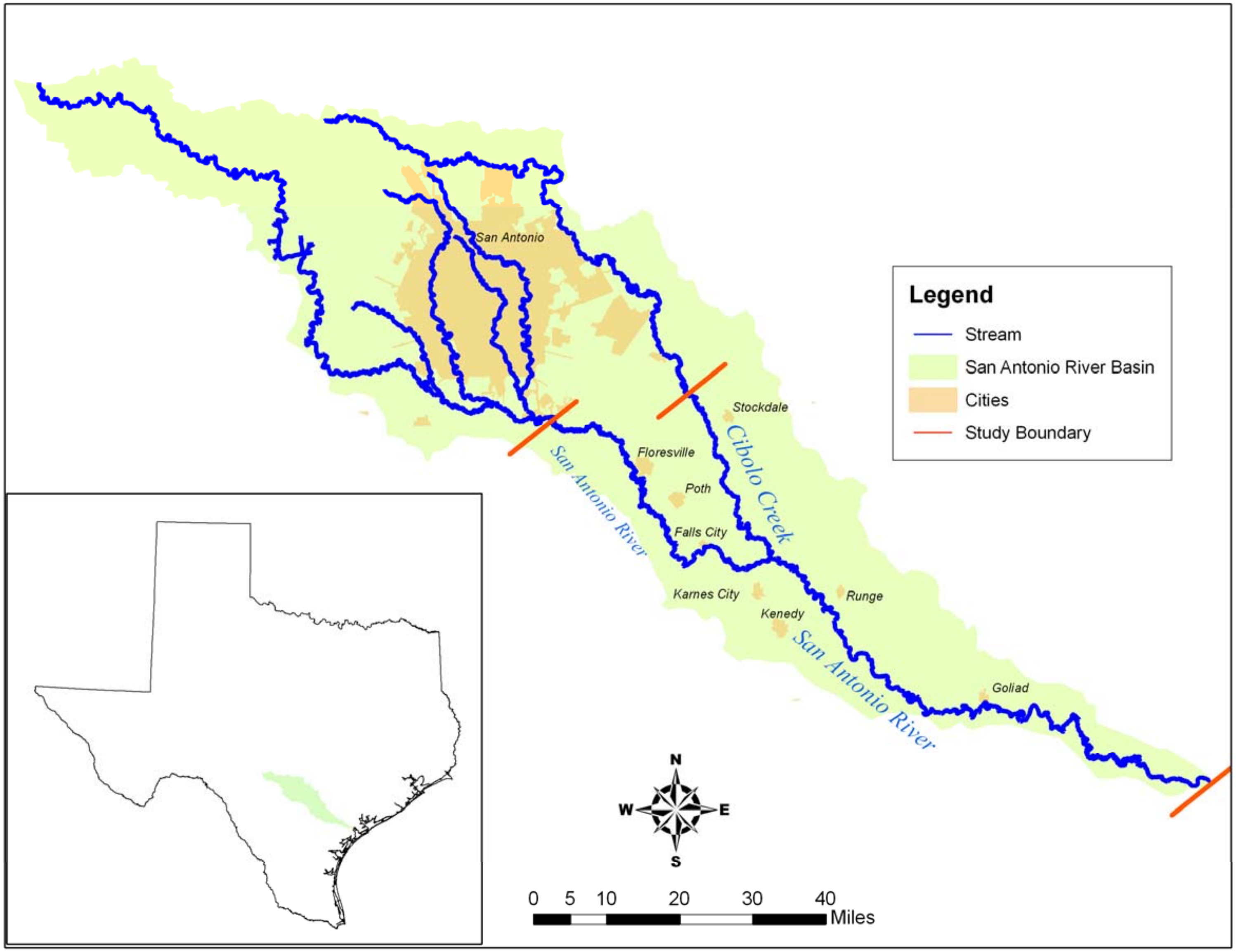

Figure 1. Map of the San Antonio River basin and lower San Antonio River sub-basin (study boundary) depicted.

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. 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 makes 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.

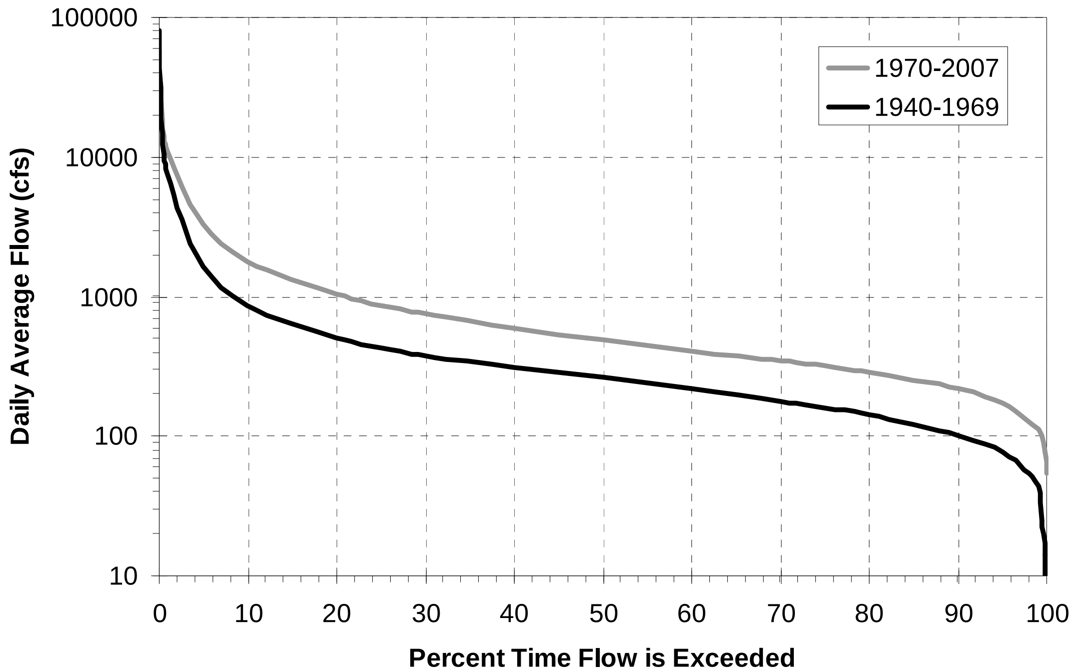

Figure 3. Flow duration curves for daily average flow at USGS gage 08188500, San Antonio River at Goliad.

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. A hydrologic evaluation of the sub-basin, as described in Section 6.1 of the TIFP Technical Overview (TIFP 2008), will be required in order to investigate changes in flow in the lower San Antonio River sub-basin.

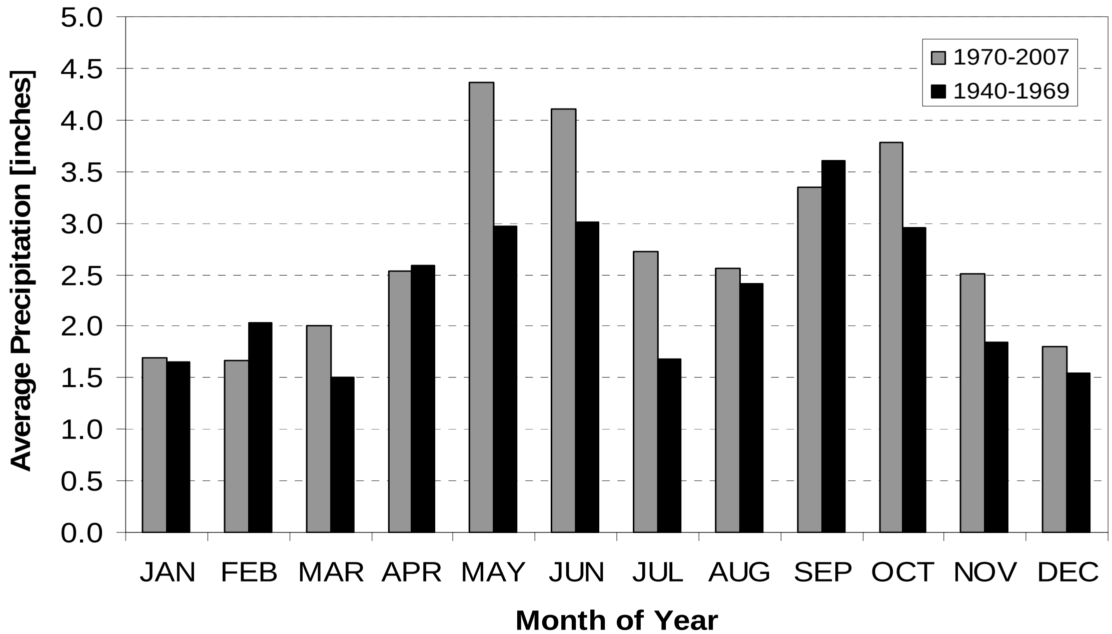

Figure 4. Average monthly precipitation for San Antonio, Texas for the periods 1940 to 1969 and 1970 to 2007 (National Weather Service data).

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. Data and results from this USGS study will assist the TIFP in understanding how conditions in the study area are affected by conditions in the upper 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. Flow regimes within the lower San Antonio

River sub-basin have a significant impact on freshwater inflows to the Guadalupe Estuary. The TIFP will present study results as annual volumes and seasonal patterns that can be compared to freshwater inflow recommendations for the estuary.

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 sub-basin. Collection methods included boat and backpack electrofishing and seining. 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). Available fish data has been used to inform selection of indicator species and Study Site locations for the TIFP study.

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

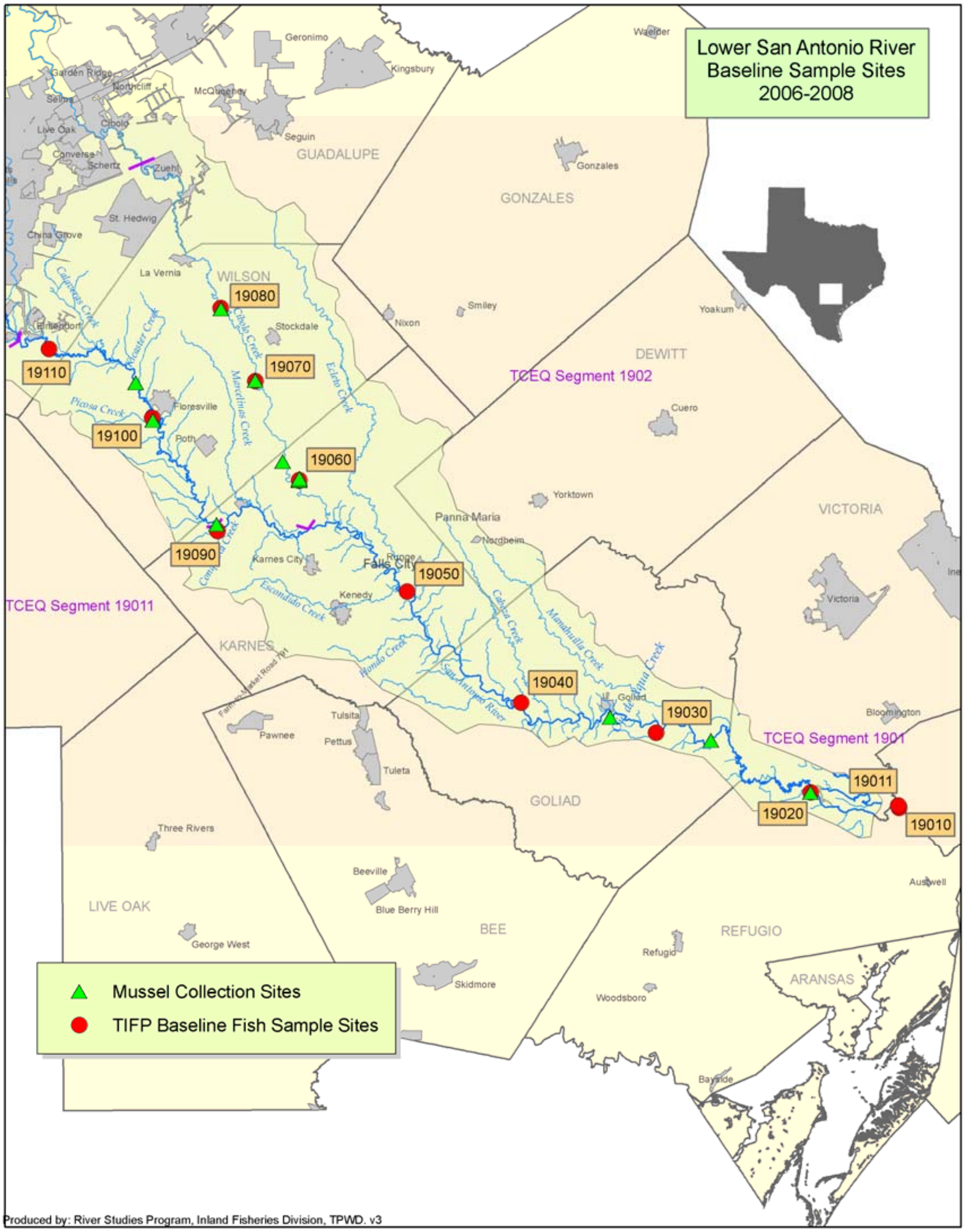

Figure 5. TIFP baseline fish sample sites and mussel collection sites on the lower San Antonio River and Cibolo Creek.

Mussel 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, 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). Available mussel data has been used to inform selection of indicator species and Study Site locations for the TIFP study.

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. Results of these geomorphic studies will be used by the TIFP to evaluate conditions in the lower sub-basin and their influence on flow/ecology relationships.

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 will 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, analyze, and disseminate water quality data on a regular basis.

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. Within the study area, there are approximately 88 water rights to withdraw water on the San Antonio River and 26 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.

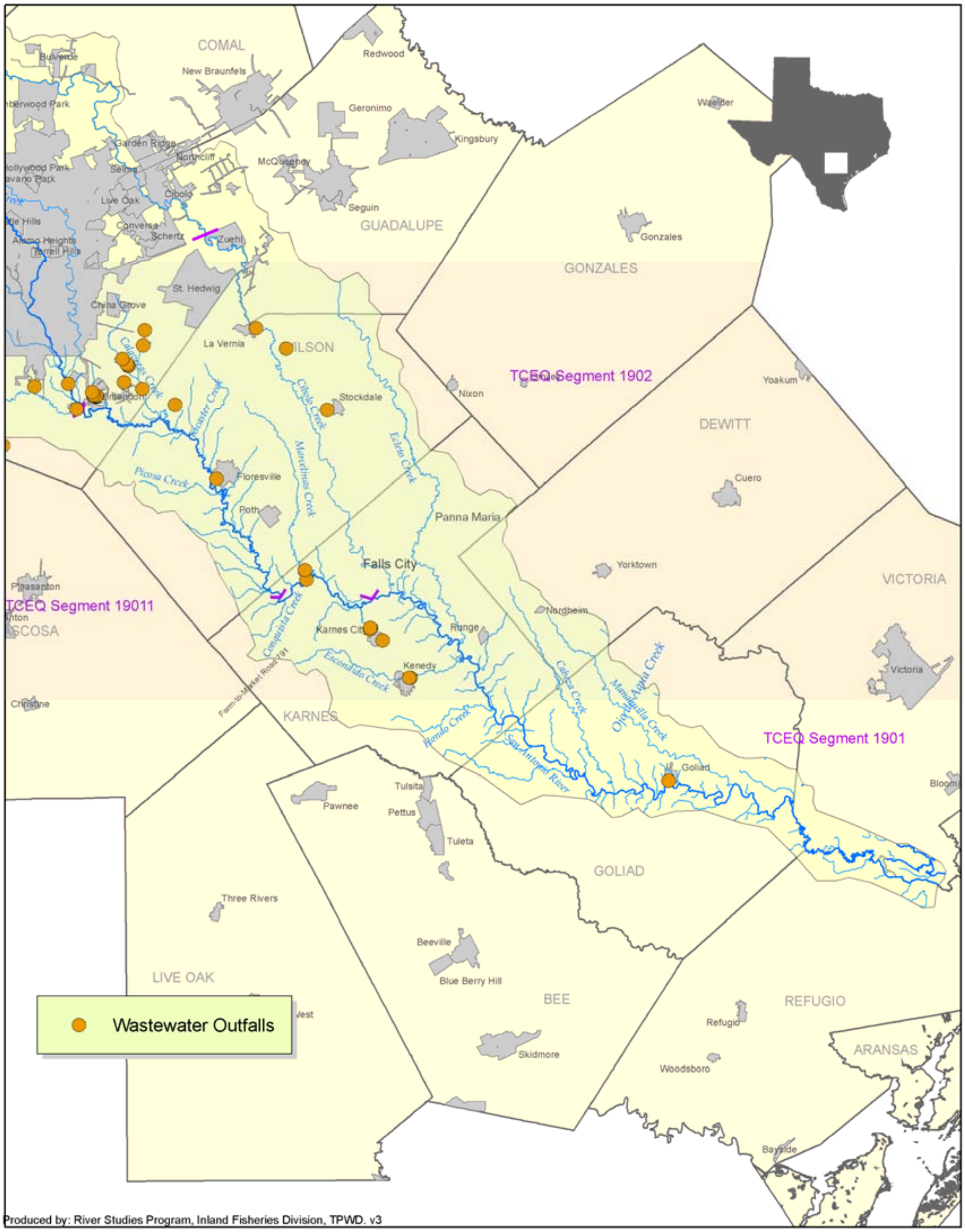

Figure 6. Wastewater discharge locations on the lower San Antonio River and Cibolo Creek.

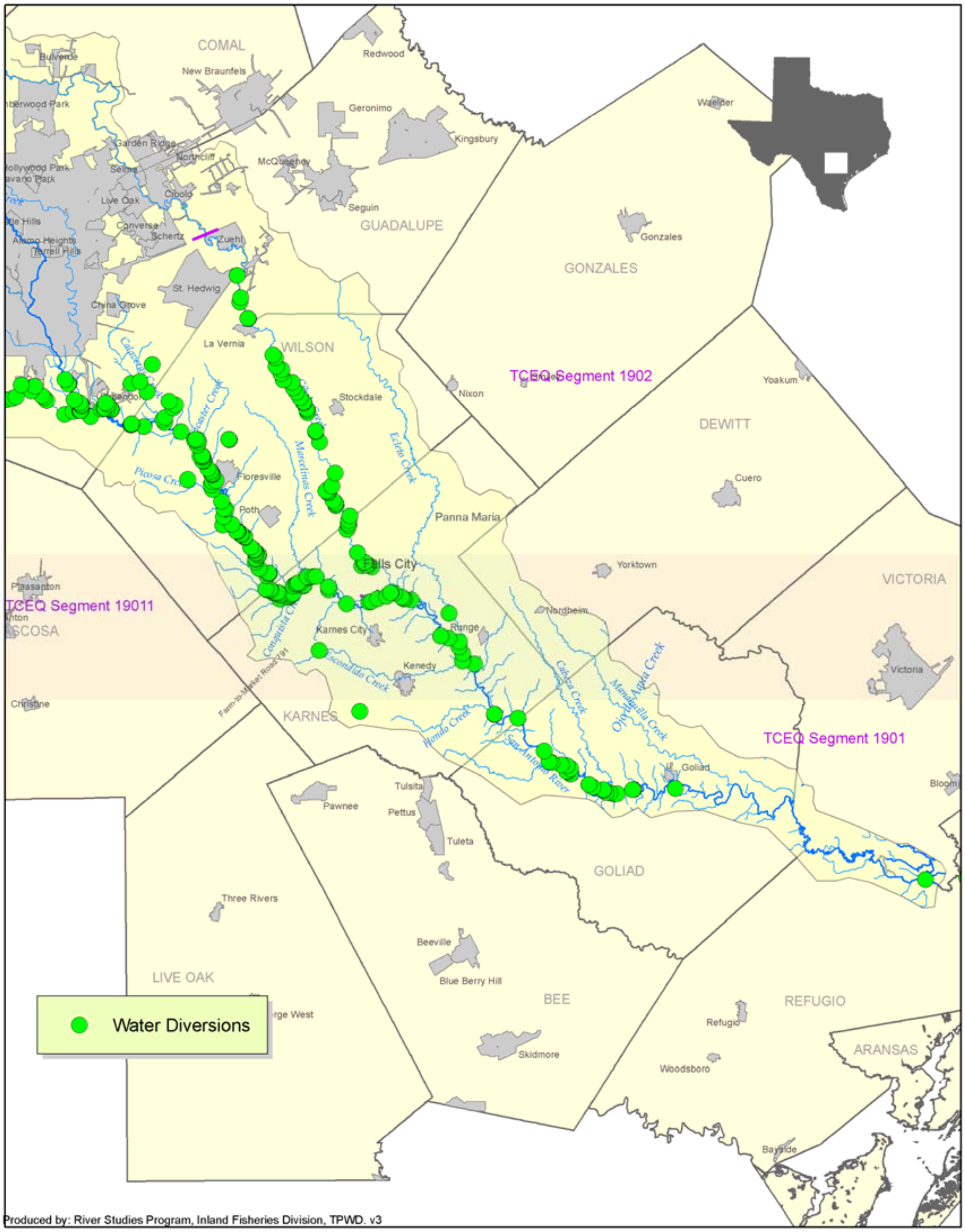

Figure 7. Water diversion points on the lower San Antonio River and Cibolo Creek.

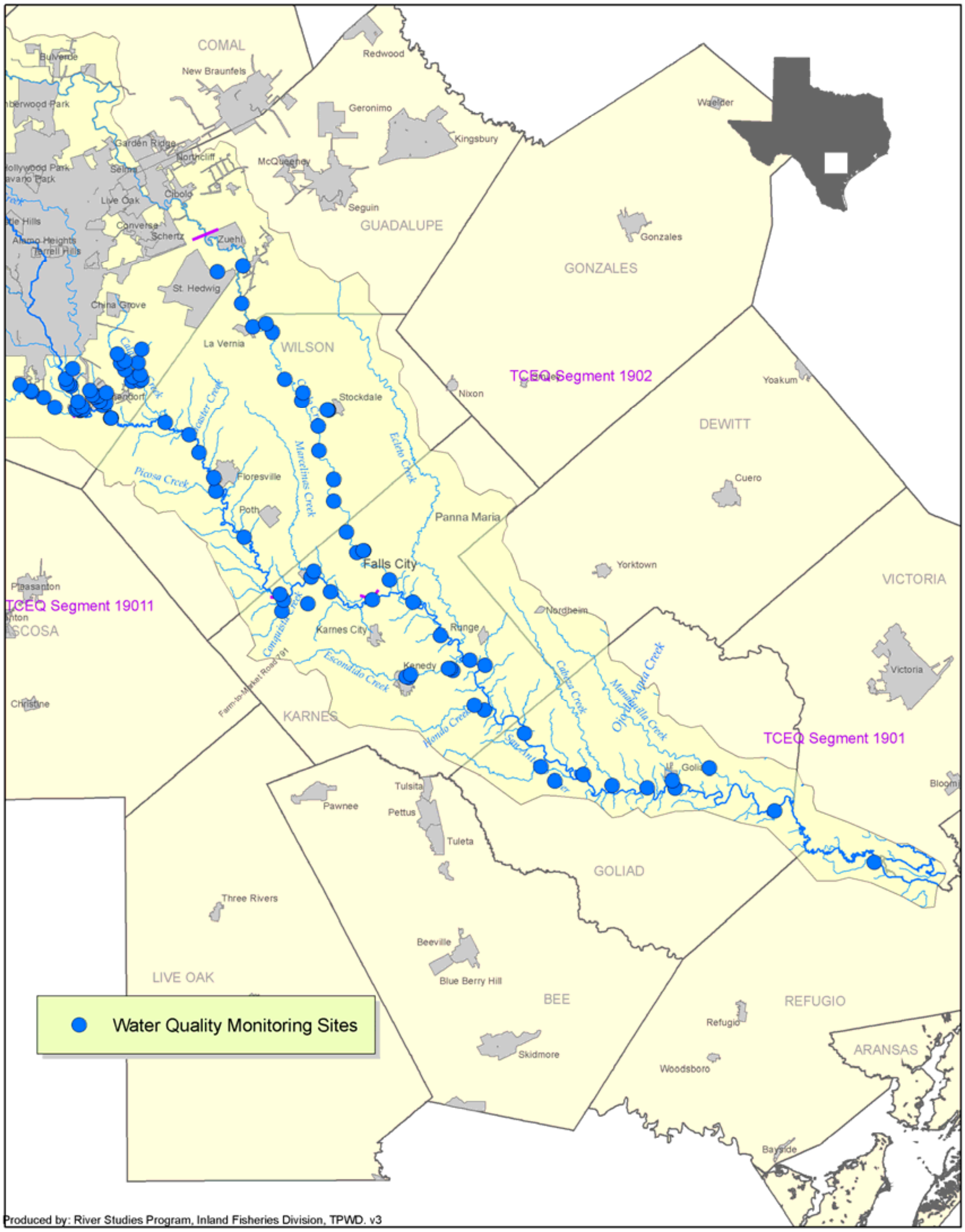

Figure 8. SWQM monitoring sites on the lower San Antonio River and Cibolo Creek.

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. As mentioned previously, data from this USGS study will assist the TIFP in understanding how conditions in the study area are affected by conditions in the upper 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. This study provides an additional set of data that can be incorporated along with TIFP collected data to provide a greater understanding of the study area during low-flow conditions.

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. 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. TIFP will incorporate data from this study to provide an understanding of surface water/groundwater interactions in the study area.

1.2 *Assessment of Current Conditions*

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

1.2.1 Hydrology

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 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 9. 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.

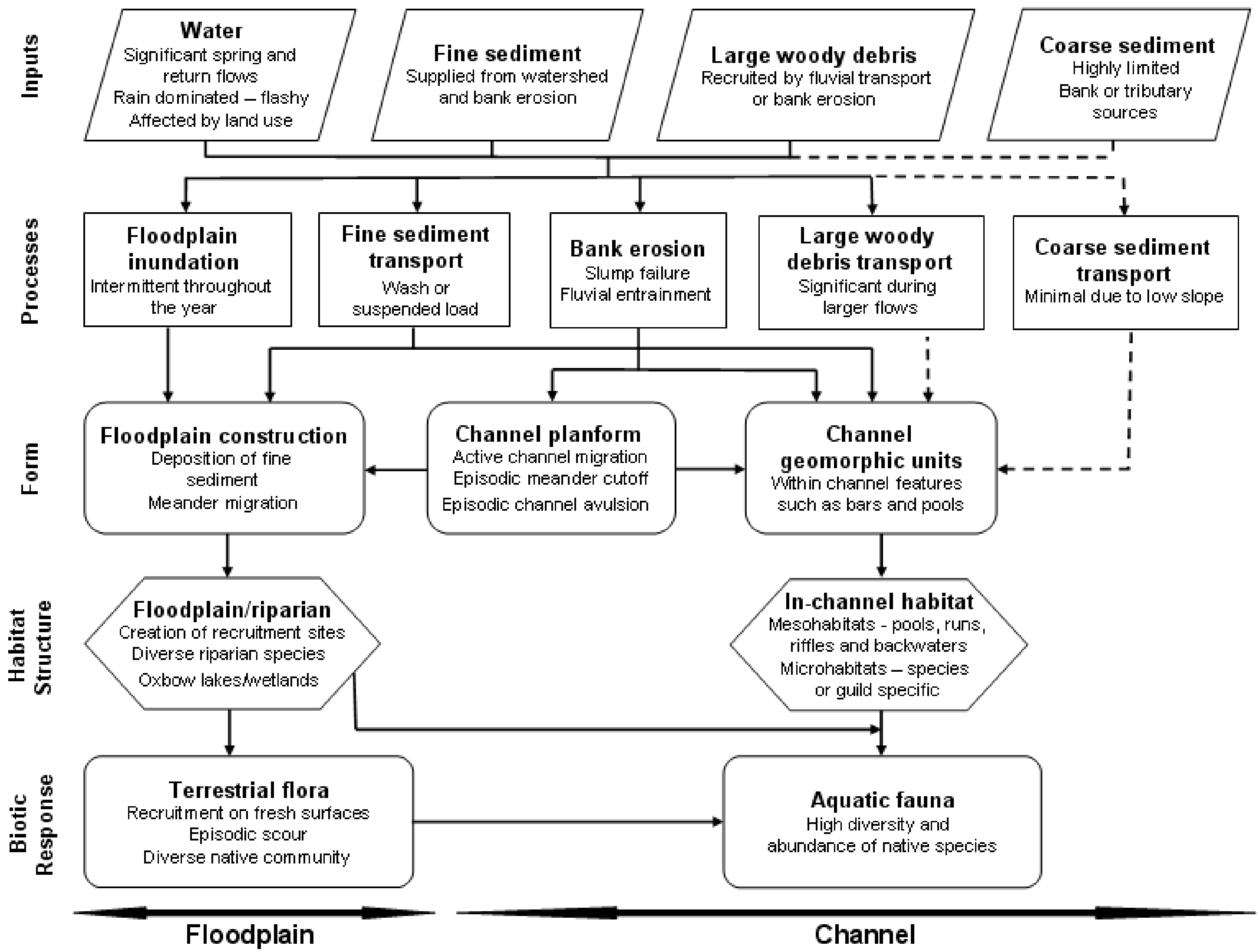

Figure 9. General conceptual model of the riverine ecosystem, lower San Antonio River sub-basin.

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, may be 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 through 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 gage 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.

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

Table 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 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).

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), baseline sampling indicated a reduced distribution in the San Antonio River Basin (Karatayev and Burlakova 2008), and because the American Fisheries Society considers this species one of special concern (Williams et al. 1993).

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

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

The description of technical studies is divided into two main sections. The first section (3.1) provides the locations (Study Segments, Reaches, and Sites) for proposed activities and the rationale for their selection. The second section (3.2) provides an overview of the 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*

In order to plan study activities, the lower San Antonio River sub-basin was divided into Study Segments, Reaches, and Sites. Through out the remainder of the Study Design, these specific divisions of the sub-basin will be referred to as "Study Segments," "Study Reaches," and "Study Sites." The more general terms "segment," "reach," and "site" will be used to refer to general lengths of river or stream. While broader studies may be conducted across an entire Segment, other studies will be conducted at particular Study Sites. Localized studies may have a single purpose (e.g., sediment data collection) or may address multiple indicators and involve multiple disciplines (e.g., hydraulic and habitat modeling site). 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, valley shape, and Texas ecoregions, resulting in the designation of large-scale Study 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 (Study 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 10). 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 10). Figure 10 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 11 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 10 and 11).

Each study Segment was then further evaluated based on hydrology, biology, geomorphology, and water quality components. From this assessment, eight Study 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 12). River miles are calculated for this study based upon the USGS National Hydrography Dataset (NHD) flow lines. Distance on the San Antonio River is measured traveling upstream from mile 0.0 at its confluence with the Guadalupe River. On Cibolo Creek, distance is measured traveling upstream from mile 0.0 at its confluence with the San Antonio 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.

The selection of candidate Reaches for habitat modeling efforts was aided by an analysis of recent fish assemblage data collected in the study area. That analysis compared the similarity of fish assemblage data from various locations on the San Antonio River and Cibolo Creek collected by TPWD and fellow TIFP partners in 2006 and 2008; SARA between 2000 and 2007; and Southwest Texas State University between 1992 and 1997. Results are shown in Figure 13. The diagrams show the location where data was collected, approximate river mileage, and the site identification number assigned to each sample location. Dots with different colors indicate a significant difference in fish assemblage data for these sites. Dots with the same color indicate that the fish assemblage at these sites was relatively similar. To eliminate variation caused by different sampling methods and/or gear, comparisons were limited to data collected within the same study.

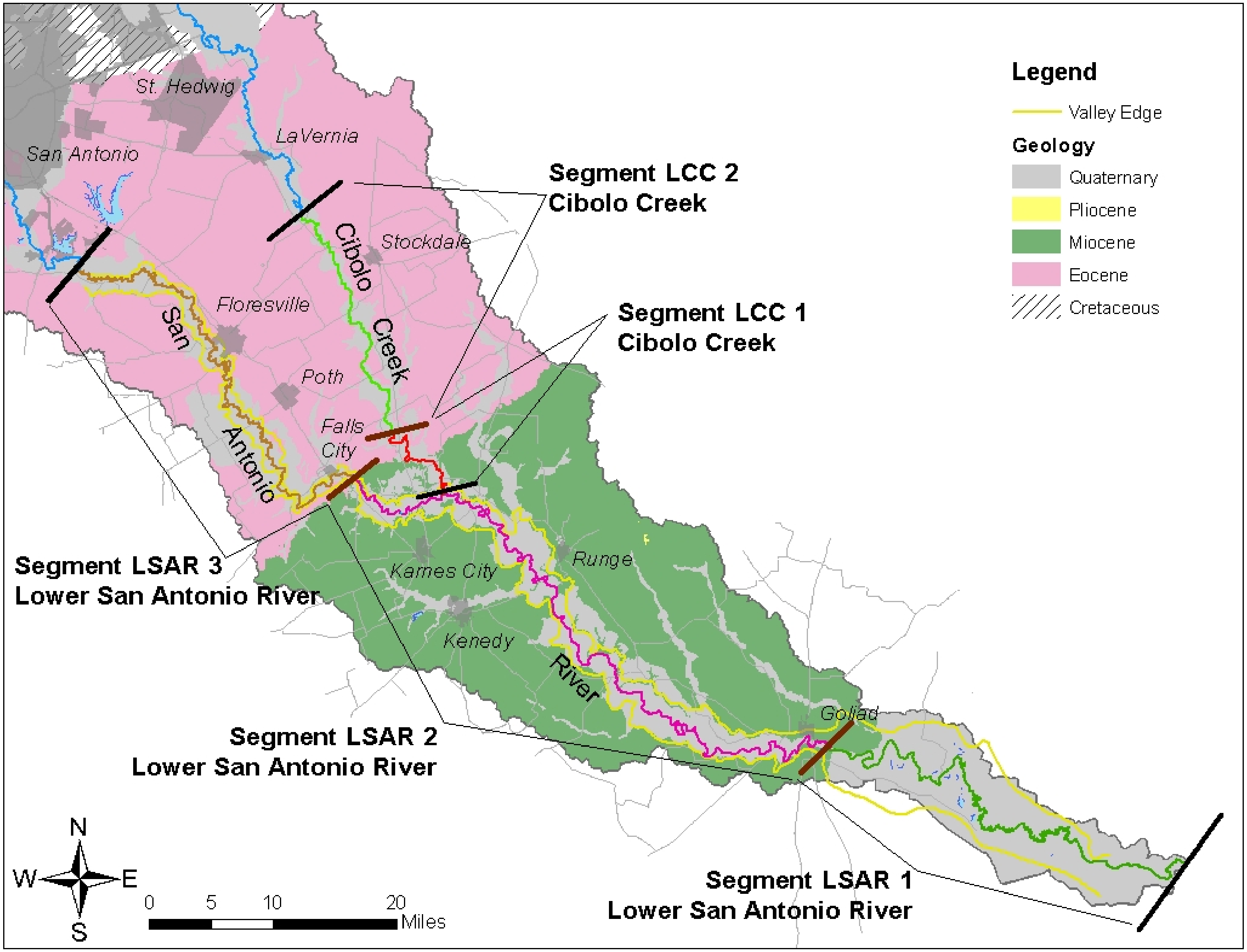

Figure 10. Map of Tier 1 Study Segments, regional geology (Brown et al. 2000) and valley edge (Engel and Curran 2008).

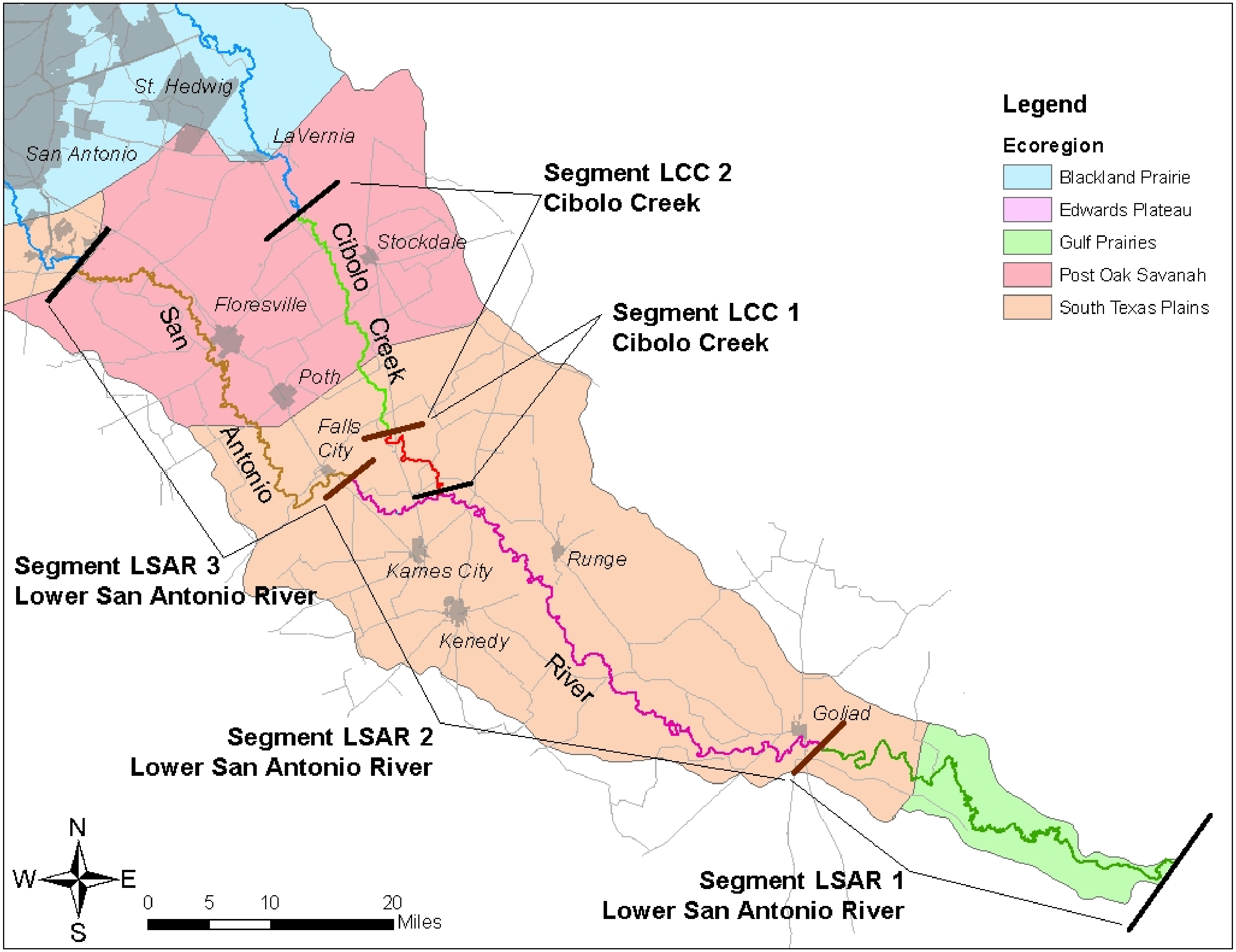

Figure 11. Map of the Tier 1 Study Segments and the Gould Ecoregions of Texas (Gould et al. 1960).

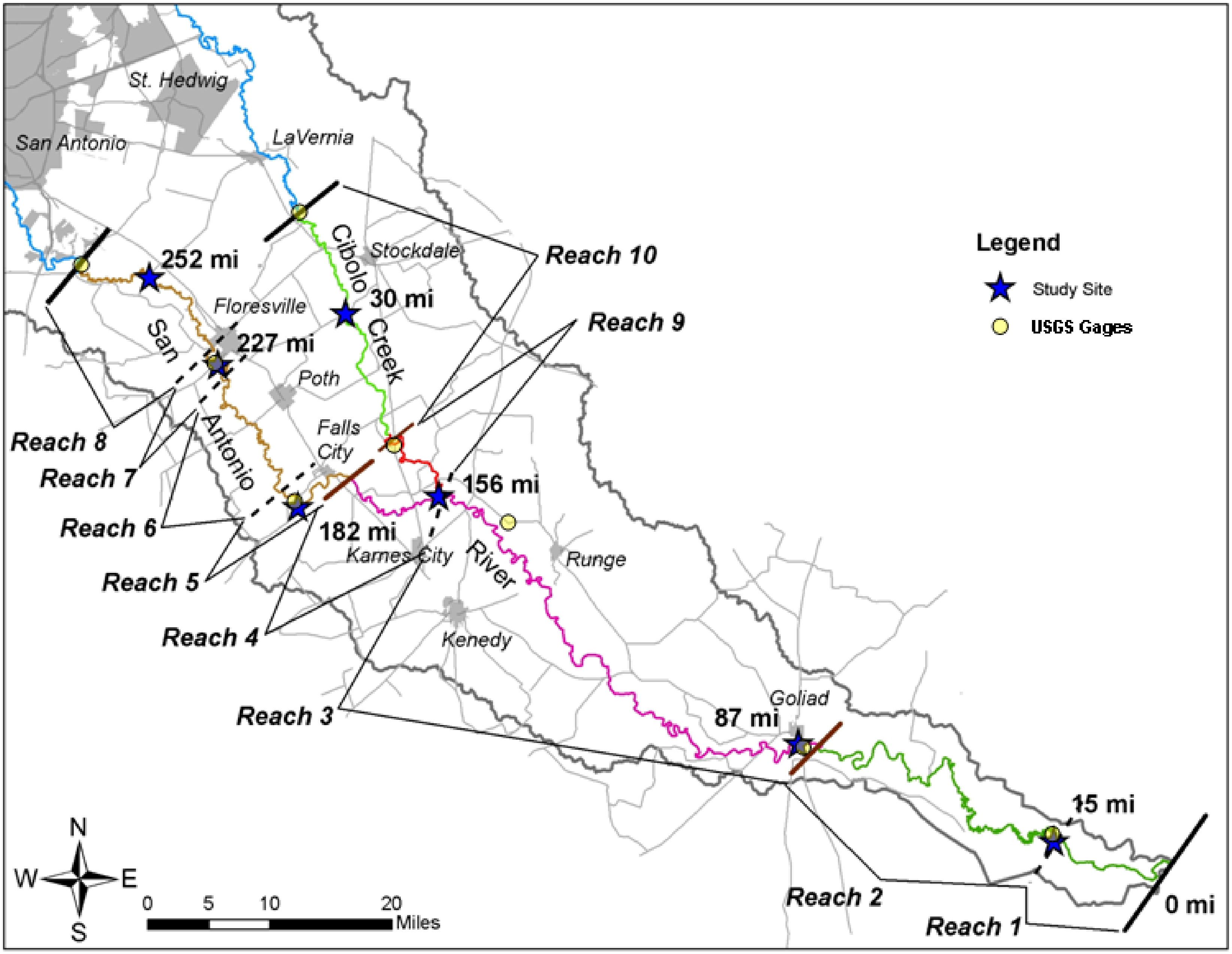

Figure 12. Proposed Study Reaches and Sites (with river miles from downstream confluence noted).

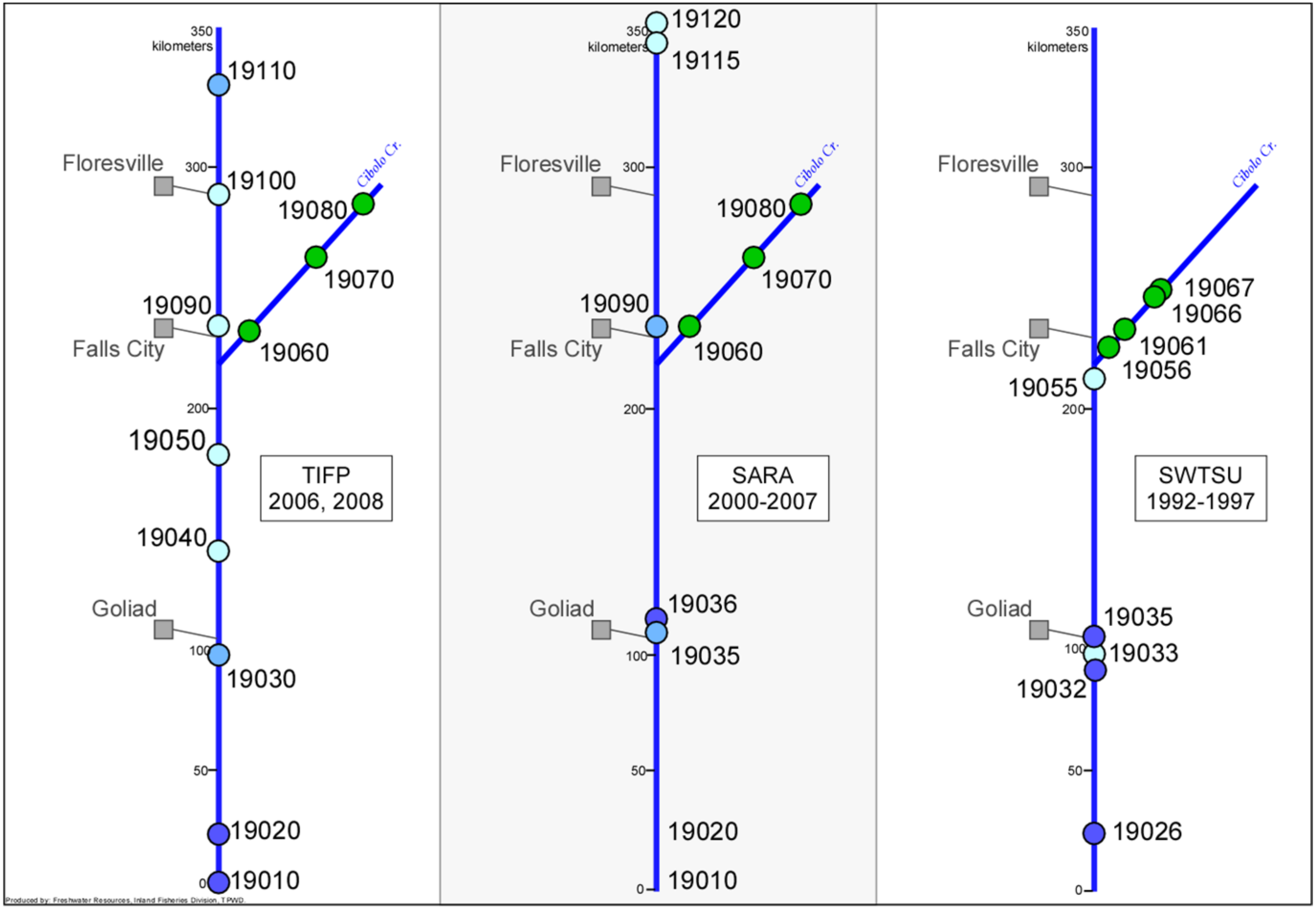

Figure 13. Fish assemblage similarity within the study area from data collected by Texas Instream Flow Program (2006 and 2008), San Antonio River Authority (2000-2007), and Southwest Texas State University (1992-1997).

The proposed Reaches, a summary of key characteristics, and Reach specific study activities 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 with the potential for both tidal influences and channel avulsion, considerably adding to the complexity of habitat models. Therefore, activities for this Reach will be limited to an investigation of channel avulsion processes and the contribution of large woody debris to those processes.
    - Reach 2 – Hwy 77 to Goliad (RM 15 to RM 82)
      - Of the two Reaches in LSAR Segment 1, this Reach has more existing biologic information and is also listed as water quality impaired (bacteria). Hydraulic and habitat modeling, baseline riparian assessment, and associated instream flow sampling activities are proposed for this Reach.

  - **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. Hydraulic and habitat modeling, baseline riparian assessment, and associated instream flow sampling activities are proposed upstream of Goliad.
      - A fisheries habitat and geomorphology assessment is also proposed for an area immediately downstream of the Cibolo Creek confluence.
    - Reach 4 – Cibolo Creek confluence to Falls City (RM 156 to RM 173)
      - The physical characteristics of this Reach are similar to those of Reach 3 and recent biological sampling indicates a similar fish assemblage. Therefore, at this time, no Reach specific activities are proposed.

  - **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, 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 Reach specific activities are proposed.

- 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 is the most representative of the segment relative to instream and riparian habitat. Therefore, hydraulic and habitat modeling, 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 those of Reach 10. Therefore, at this time, no Reach specific activities are proposed.

  - **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, baseline riparian assessment, and associated instream flow sampling activities are proposed for this Reach.

TIER 3

It is not economically feasible to conduct intensive study activities such as hydraulic and habitat modeling and riparian assessment for entire Study Reaches. Therefore, representative Study Sites were selected within Reaches selected for these types of activities. Tier 3 assessment was done to locate representative Study Sites within selected Reaches. 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. The fish assemblage data presented in Figure 13 aided the selection of Sites for instream habitat modeling. 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 12. 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.

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 overbank flows, high flow pulses and subsistence flows with intervening periods of base flows. This variability in the cycling of flow is typically referred to as the flow regime. An evaluation of the flow regime will address several of the hydrological indicators including 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 flow 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 derived from a hydrologic evaluation (described in section 6.1 of the Technical Overview) will be used to characterize the flow record and evaluate ranges for the four main instream flow components: subsistence flow, base flow, high flow pulses, and overbank flow. 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. The general process of hydraulic modeling in support of habitat modeling is described in sections 6.2, 7.3, and 10.2 of the Technical Overview.

For the TIFP study of the lower San Antonio River sub-basin, 2D hydraulic and habitat models will be developed to evaluate changes in microhabitat across a range of flow rates. This analysis will specifically aid the development of subsistence and base flow components and will therefore focus on flow rates from about the median to the 10 percentile flow as described in section 6.1.3 of the Technical Overview (TIFP 2008). Hydraulic and habitat modeling will be conducted within Reaches 2, 3, 5, and 8 on the lower San Antonio River and Reach 10 on lower Cibolo Creek (Figure 12, 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 river ecology. Relevant flow ranges identified by the habitat modeling will be compared to the frequency of those flows exhibited in historical and current flow records. Instream flow guidelines for achievement of particular flows may be recommended on the basis of both physical habitat requirements and upon historical frequency of occurrence. Other analyses, including development of a habitat time series, may be conducted to consider both habitat and flow frequency.

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

To characterize velocity and depth patterns at a level suitable for use in 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 Study 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 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 2D hydraulic model results 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 of average column velocity and direction will be collected by acoustic doppler profilers or other velocity measurement devices.

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

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

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

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

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

Mussel surveys

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

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

Where d is the distance between units, L and W are the length and width of the sampling area, n is the total number of quadrats, and k is the number of random starts.

Given that a 0.25 m^2 quadrat will be employed, distance between sampling units calculated using the formula can be rounded down to the nearest half meter. In each of the sample quadrats, mussel species will be identified and enumerated. Physical measurements such as depth, current velocity, and substrate type will be recorded for each sample for use in habitat suitability criteria development. Pooler and Smith (2005) found systematic sampling approaches with greater than two random starts more accurate at estimating abundance than simple random sampling, 0.25 m^2 quadrats more accurate and precise in estimating abundance than 1 m^2 quadrats, and systematic sampling estimates more accurate when distance between sampling units across the stream are less than or equal to the distance between sampling units along the stream (hence the two times the wetted width sampling area). Hydraulic data in mussel beds will be collected following Morales et al. (2006) and Randklev 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 study areas. Key riparian vegetative indicators to be assessed are: age class distribution, richness and diversity, density, and % canopy cover. This information will then be linked back to overbanking and base flow requirements for the maintenance of a healthy riparian ecosystem.

The purpose of characterizing riparian habitat within the study area is to identify the extent and condition of existing riparian habitats as well as the surrounding land use. Extent and distribution of riparian communities will 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 Study 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 (National Land Cover Dataset) 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 gage 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 sub-basin. 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 Clean Rivers Program (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), (4) literature values for modeling parameters and/or (5) 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.

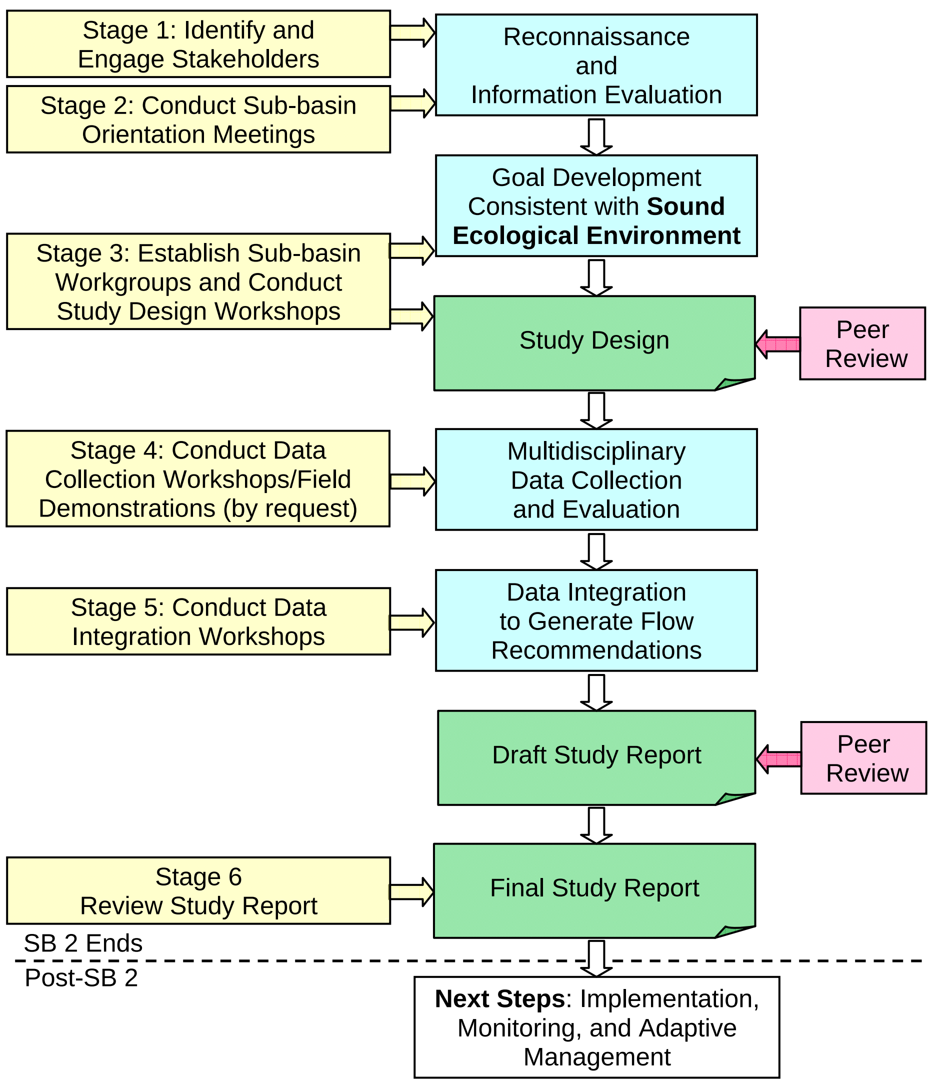

Figure 14. Stages of stakeholder participation in lower San Antonio River sub-basin study.

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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6.0 APPENDIX

Stakeholder comments and responses related to draft Study Design

Comment 1 - The degree to which flows in the lower San Antonio River changed before and after 1970 is somewhat misleading by the data and information presented in the report. For example, the two curves plotted in Figure 2 and in Figure 3 do not represent an equal number of years of flow data (38 versus 30), with almost a third of the shorter pre-1970 period encompassing the 1950s drought of record. Based solely on these facts, it is not surprising that the pre-1970 flows are substantially lower than the post-1970 flows, particularly when the report clearly acknowledges with the bar chart in Figure 4 that there was significantly less rainfall during this earlier period than the latter period. What needs to be presented are the data that truly substantiate why there is more base flow in the lower San Antonio River now than in the past, that is, the historical wastewater return flow data. This would clearly make the point. If a river flow plot is to be used for this purpose, then it has to be based on historical flow data for periods of equal duration and very similar rainfall conditions; otherwise, the flow changes due to varying climatic conditions overshadow the effects of the increased wastewater return flows or whatever else (i.e., increased impervious cover in San Antonio) may have impacted historical flows along the lower San Antonio River.

Response 1 - The information in Section 1.1.1 and Figures 2, 3, and 4 is presented to insure readers (stakeholders or scientific peer reviewers) are familiar with some of the hydrologic considerations related to the lower San Antonio River sub-basin. The main point is that "flow conditions in the lower San Antonio River sub-basin have been changing over time." The information is presented as an example of the degree of hydrologic change in the basin, not an attempt to determine the causes of that change. As part of the study, a hydrologic evaluation of changes in the sub-basin will conducted (please see Section 3.2.1 of the Study Design).

Comment 2 - With regard to San Antonio Bay, it should be noted that the freshwater inflow recommendations from the studies conducted by the TPWD and the TWDB utilizing the state methodology have not been adopted by the TCEQ for water rights permitting or any other purpose. Furthermore, it is important to recognize that the Texas Environmental Flows Science Advisory Committee in its draft Freshwater Inflow Regime report has not fully endorsed the TPWD/TWDB freshwater inflow studies or the inflow recommendations for any of the Texas bays and estuaries because of technical and scientific concerns regarding the procedures employed. Requirements for freshwater inflows to San Antonio Bay will not become official until completion of the TCEQ rulemaking process for the San Antonio/Guadalupe Basin and the Guadalupe Estuary system as required under Senate Bill 3.

Response 2 - Listing of a report in Table 1 and further description within the study design does not imply that the conclusions presented by that report will be accepted wholly or in part by the TIFP. Descriptions of these reports are meant to highlight efforts that have been completed or are underway within the study area. The TIFP will investigate these studies and incorporate any data that may be relevant. General statements describing how TIFP plans to incorporate data and/or results from the studies listed in Table 1 have been added to study descriptions. If appropriate, reviewer's comments about the study reports listed in Table 1 have been forwarded to the authors of the reports themselves.

TIFP is not in a position to endorse or critique the freshwater inflow recommendations in TPWD and TWDB (1998). The report is described merely to acknowledge that a previous study has addressed connectivity between the river and estuary, at least in terms of freshwater inflow recommendations. TIFP will not study the estuary, but instead will be focusing on determining the instream flow requirements for the lower San Antonio River sub-basin. However, in consultation with the Study Design Workgroup, a connectivity indicator related to freshwater inflows to the estuary was chosen. That indicator, the volume of flow (calculated both monthly and yearly) resulting at USGS gage 08188500 on the San Antonio River at Goliad, will allow the comparison of recommendations of instream flow for the river and freshwater inflow for the estuary. This indicator should prove of interest regardless of which set of freshwater inflow requirements for the estuary are eventually adopted.

Comment 3 - The discussion of the geomorphology of the lower San Antonio River sub-basin in Section 1.1.3 notes that "flashy" streams such as those in central Texas behave differently with regard to their geomorphic processes and characteristics, but it is not clear that the San Antonio River, which lies generally below the base of the Hill Country and generally flows across the relatively flat Coastal Plain, exhibits these unique hydrologic or geomorphic traits. Indeed, the meandering nature of the lower San Antonio River is mentioned in Section 1.2.3, and the decrease in the "flashiness" of the river from its upper to lower portions is noted in Section 1.3. Further explanation would be helpful.

Response 3 - The article by Baker refers to a more comprehensive report by Beard (Beard 1975) which provides a mapping of a "Flash Flood Magnitude Index " (FFMI) for the entire continental United States. FFMI values of greater than 0.65 are considered to be high and correspond to systems where the shape of the river channel is in constant change (response and recovery) due to flood damage (Hennessy and Jones 1999). Beard's mapping indicates the upper areas of the lower San Antonio River sub-basin (both the mainstem San Antonio River and Cibolo Creek) have relatively high FFMI. As part of this study, FFMI will be calculated at streamflow gage locations throughout the sub-basin. This will allow the potential impact of "flashiness" on study methods to be estimated and addressed, if necessary.

Beard, L. 1975. Generalized evaluation of flash flood potential. Center for Research in Water Resources, Austin ,Texas. Report CRWR-124.

Hennessy KJ, Jones RN. 1999. Climate change impacts in the Hunter Valley: stakeholder workshop report. Aspendale, Victoria: CSIRO Atmospheric Research. p.26.

Comment 4 - The number of water rights located on and authorized to withdraw water from the San Antonio River is closer to 100 than 211 as noted on page 18 of the report. The 41 water rights noted on Cibolo Creek also may be questionable.

Response 4 - The study design was corrected to reflect 88 water rights to withdraw water on the San Antonio River and 26 water right diversion locations on Cibolo Creek.

Comment 5 - With regard to surface water/groundwater interactions, it is not clear how the study being conducted by the U. S. Geological Survey for the lower San Antonio River will utilize the Hydrological Simulation Program to provide meaningful estimates of groundwater recharge to the Carrizo and Gulf Coast aquifers unless data are available to quantify these flow quantities to start with. If such data are available, then it is not clear as to why it needs to be modeled to assess surface water gains and losses. It is likely that the results from the synoptic gain/loss field surveys, the extensive base flow measurements, and the water chemistry analyses will provide the most useful information.

Response 5 -After the USGS study is completed, TIFP will examine the report and incorporate any suitable data and improved understanding of the sub-basin. The synoptic gain/loss field surveys, base flow measurements, and water chemistry analyses may indeed provide useful information. The possible benefit of the HSPF model to the instream flow study of the sub-basin will also be evaluated. The model, if properly calibrated and validated, could provide estimates of surface water/groundwater connectivity at many more points within the sub-basin than it would be practical to investigate with direct measurements.

Comment 6 - It is not clear as to exactly what the Conceptual Model described in Section 1.3 and depicted in Figure 10 (*Ed. changed to Figure 9*) is supposed to represent. Is it the riverine ecosystem? The diagram seems to be missing some important elements, such as wastewater return flows that are discharged into the San Antonio River under Inputs, a water quality function linked to other components of the ecosystem, and riparian habitat and connectivity with the stream channel. It is not clear how this representation "incorporates much of the basic understanding of the system at the point of study initiation" or "represents a beginning point from which to develop flow/ecology relationships and direct studies to further refine understanding".

Response 6 - The caption has been modified to more directly specify that the figure refers to the riverine ecosystem of the sub-basin. The contribution of return flows to water input to the system has also been noted in the Inputs/Water portion of the figure. Potential linkages between water quality and flow regime components are shown in Table 6. These linkages will be the focus of TIFP studies. Possible linkages between ecosystem components and water quality can be inferred from Figure 9. For example, healthy floodplain/riparian habitats may provide suitable stream temperature conditions (due to shading), exerting a positive impact on the suitability of in-channel habitat for aquatic fauna. However, these interactions are not as directly related to flow and therefore, are not slated to be investigated as part of this study. If these interactions are found to be significant, they could be addressed by future studies. “Floodplain/riparian” habitats are a specific component in Figure 9. Connectivity between floodplain and channel processes, forms, habitats, and biota are also shown in the figure.

Comment 7 - Do we really know that the magnitude and frequency of high flow pulses may have increased as a result of increased development in the basin? This statement is made, but it is likely based only on conjecture.

Response 7 - It’s fairly well established that urbanization of a watershed may result in an increase in runoff, particularly during pulse or peak flow events. For example, please see ASCE (1975), Olivera and DeFee (2005), USEPA (2008), and many others. As part of this study, a hydrologic analysis of available gage data will be conducted to determine if significant changes in the flow regime have occurred (please see Section 3.2.1 of the Study Design).

ASCE Task Committee on the Effects of Urbanization on Low Flow, Total Runoff, Infiltration, and Ground-Water Recharge of the Committee on Surface-Water Hydrology of the Hydraulics Division. 1975. Aspects of hydrological effects of urbanization. Journal of the Hydraulics Division, ASCE, Vol. 101, No. HY5, pp. 449-68.

Olivera, F, and B. DeFee. 2005. Urbanization and runoff in the Whiteoak Bayou watershed. Watershed Update, Vol. 3, No. 4. http://www.awra.org/committees/ techcom/watershed/pdfs/0304WU.pdf

US EPA. 2008. Urbanization and streams: studies of hydrologic impacts, available on the http://www.epa.gov/OWOW/nps/urbanize/report.html#03

Comment 8 - In Section 2.2.1, obvious questions arise with regard to which portions of gage records will be considered to represent "natural variability" and the role of water losses and gains in the overall process of establishing appropriate flow regime components. The definition of the natural variability gage period again involves issues dealing with the length of the records used (the pre-1970 30-year period versus post-1970 38-year period) and the influence of the drought of record during the 1950s. How these periods are selected can make a lot of difference in the results. With regard to indicators for water losses and gains, the question is how will these quantities be determined. Normal practice is to perform a water balance for a stream segment using synoptic measured upstream and downstream river or tributary flows at gages, measured river flow diversions, measured wastewater discharges, and an estimate of surface evaporation losses during relatively dry periods to arrive at an estimate of the loss/gain amount. The problem is that the resultant loss/gain amount does not necessarily represent only the interaction or exchange between surface water and groundwater. It also includes unreported and illegal diversions, diversions for domestic and livestock use, evapotranspiration uptake, and any ungaged surface runoff. It is not clear as to the utility of such an uncertain and indefinite estimate of losses and gains in the context of developing recommendations for environmental flow requirements. These issues regarding estimates of water losses and gains also applies to the discussion of Connectivity in Section 2.2.5 in which it is suggested that the loss/gain values would be representative of indicators for surface water/groundwater interaction.

Response 8 – A hydrologic analysis will be required in order to determine the natural variability of flow component characteristics. The time period that will be used to establish “natural” conditions will be selected based on the development history of the sub-basin and review of at least some preliminary results of the hydrologic analysis. As noted in Response 1, Figures 2 through 4 serve only to demonstrate that “flow conditions in the lower San Antonio River sub-basin have been changing over time.” These figures do not imply that conditions prior to 1970 have been established as the pattern for natural variability.

The study design workgroup and TIFP agreed to use stream gain/loss characteristics as both an indicator of hydrologic conditions and connectivity. As described in the draft Study Design, a soon to be completed study by the USGS will provide improved understanding of the surface water/groundwater relationships in the lower San Antonio River sub-basin. The USGS has completed four synoptic surface water gain/loss surveys as part of that study. Rather than being "uncertain and indefinite," such surveys are the most direct and accurate way to measure streamflow gain and loss. Standard practice is to conduct these surveys during periods of little or no rainfall and to measure both tributary streamflow (gaged or ungaged) and other return flows. In addition, any diversions (legal or illegal) are noted and, if at all possible, measured. To neglect the information regarding streamflow gains/losses provided by the USGS study would not serve the interests of an accurate instream flow study.

Comment 9 - In Table 7, the title suggests that the "importance" of the Hydrology study indicators is provided under the Explanation column, but it would seem more appropriate to label this information as the "Function" of the various indicators. Also, for the Base Habitat Flows and the Subsistence Flows, the "frequency, timing, duration, and rate of change" would seem to be relatively unimportant compared to "magnitude". Are these just carry-overs from the indicator descriptions for the Overbank and High Pulse Flows? Again, in this table, the indicator for Losses/Gains is described as the "Difference in the amount of water entering and leaving a specific section of the river channel." As noted above, this may not be representative of indicators for surface water/groundwater interaction, if that is the intention.

Response 9 - The "function" carried out by a particular flow regime component (or other indicator) does generally establish it's "importance" to the riverine environment, (and therefore the instream flow study). The explanation of some of the other indicators (including those in Tables 8 through 11) is not so readily related to "function." It was therefore decided to continue to use the more general term "Explanation" to describe the information in this column of the tables.

Frequency (how often they occur), timing (what time of year they occur), duration (number of days they occur), and rate of change (how quickly the system transitions between conditions) are important characteristics of subsistence flows. They are of at least some importance to base habitat flows as well. As part of this study, the relative importance of these characteristics will be investigated.

In regards to the indicator related to gains or losses, please see Response 8.

Comment 10 - From a layman's point of view with regard to biology, it seems unlikely that typical stakeholders would select the five species listed on page 33 as the important key species for consideration in a study to establish environmental flow recommendations. Maybe more explanation as to exactly how these species were selected would be helpful and would make the selections seem more credible. From a practical standpoint, it would seem that using at least some more common fish species that most people are familiar with would help in this regard.

Response 10 - At the December 9, 2008 study design workgroup meeting, participants agreed that fish were a suitable indicator for instream biological communities. The fish community as a whole will be studied in terms of the indicators "Native Richness" and

"Relative Abundance." The workgroup also agreed to study a few key species in detail, as it is not practical to study all of the species present in the sub-basin. The Technical Overview (TIFP 2008) defines a key species as one that is directly related to study objectives or is particularly flow sensitive. After some discussion, the group agreed to allow TIFP technical staff to select the particular key species to be studied. This list of key species proposed by TIFP was presented to the study design workgroup on June 30, 2009 and will also be reviewed by scientific peers. An explanation for the selection of each of the four key fish species is included in the study design. An additional paragraph describing why golden orb was selected as a key mussel species has been added. Unfortunately, many of the common species that members of the public may be familiar with are not suitable for consideration as key species because they are not particularly flow sensitive.

Comment 11 - Why are High Pulse Flows not listed in Table 9 as an Indicator Category considering their important role with respect to connectivity and riparian habitat areas? Is it because Habitat Features are addressed in Table 11 with respect to connectivity? It seems like High Flow Pulse might be considered in both tables.

Response 11 - Overbank flows (mentioned in Table 7 with indicators frequency, timing, duration, rate of change, and magnitude) are mentioned again in Table 9 because different indicators are suggested (total area inundated, habitat area inundated, and stage at USGS gage locations). High pulse flows do provide a lot of the physical power required for channel migration, woody debris transport, and shaping of channel characteristics (all categories of indicators listed in Table 9). However, no new indicators related to high flow pulses (beyond frequency, timing, duration, rate of change, and magnitude, which are already mentioned in Table 7) were identified during study design workgroup deliberations.

Comment 12 - Looking at the maps of regional geology in Figure 11 (*Ed. changed to Figure 10*) and ecoregions in Figure 12 (*Ed. changed to Figure 11*), it appears that only the regional geology was considered when delineating Tier 1 study segments, even though at the bottom of page 38 both are indicated to have been examined.

Response 12 - As stated in the Study Design, "geological properties, valley shape, and Texas Ecoregions" were used to delineate Tier 1 Study Segments. Each of these criteria were considered during the selection of Study Reaches, keeping in mind that both the regional geology (shown in Figure 10) and ecoregions (shown in Figure 11) represent overall conditions across a large extent of area, not necessarily precisely at the stream channel.

The downstream boundary of the study area was previously fixed as the confluence of the San Antonio River with the Guadalupe River. Moving upstream from this location, the upstream boundary of Segment 1 of the lower San Antonio River was selected to be just downstream of Goliad. This location coincides with a significant change in valley width and regional geology. Further downstream, there is a transition of the channel's surrounding land area (ecoregion) from South Texas Plains to Gulf Prairies Ecoregion. In considering these three criteria, TIFP staff felt the large change in valley width was most significant and placed the upstream boundary of the Segment at the location downstream of Goliad.

A change in valley width also played a significant part in the selection of the upstream boundary of Segment 2 of the lower San Antonio River. In this case, there is a transition of the channel's surrounding land area (ecoregion) from Post Oak Savannah to South Texas Plains near Poth. There is a change in the regional geology and significant widening of the valley near Falls City. The upstream boundary of this Segment was again chosen to coincide with the change in valley width.

The segmentation of Cibolo Creek represented a compromise between the location of transitions in regional geology and ecoregion. The regional geology changes a short distance upstream of the confluence with the San Antonio River. At a greater distance upstream, there is a transition of the surrounding ecoregion. There does not appear to be a significant change in valley width to further guide segmentation of the stream. The location selected for the boundary between the two Reaches therefore represents a compromise between the two criteria of regional geology and ecoregion.

Comment 13 - Also in Section 3.2.1, it would be meaningful to know what level of resolution in terms of grid size or element length expressed in feet will likely be used to construct the 2-D hydraulic model. Also, it is not clear as to whether this will be a steady-state model or a dynamic model. If dynamic, some discussion of periods to be simulated would be helpful. Has a modeling platform been selected? If so, it should be noted and generally described.

Response 13 - As noted in the study design, 2-D hydraulic modeling to assist in habitat modeling will be conducted in a manner similar to that described in the Technical Overview, Sections 6.2, 7.3, and 10.2 (TIFP 2008). As noted in the Technical Overview, mesh sizes of approximately 20 to 55 square feet are suitable for fish habitat analysis. We anticipate similar mesh sizes for habitat modeling efforts in the lower San Antonio River sub-basin. We have not selected a particular hydraulic model for this instream flow study, but a general description of available models and the criteria for their selection is provided in the Technical Overview (Section 6.2.3). Dynamic habitat modeling is typically reserved for situations with rapid changes in base flows, such as experienced in close proximity to some dams operated for hydropower generation. It is not anticipated that dynamic modeling will be required to evaluate instream habitat for this sub-basin.

Comment 14 - With regard to the substrate and instream cover mapping, is it possible that these features could change with flow conditions in the river over the range of flow levels being considered for the hydraulic and habitat modeling and analyses? Does this present problems with using the substrate and instream cover mapping to characterize conditions in the river segments for the proposed studies? This should be explained further in the report.

Response 14 - The Technical Overview, sub-section *Substrate, roughness, and moving beds* in Section 6.2.3 (TIFP 2008), provides a description of this consideration. Overall, changes in channel shape, substrate characteristics, and cover should be small for the range of flows considered for habitat modeling (daily median to 10 percentile flows). High flow pulses and overbank flows are expected to influence channel characteristics (such as substrate and cover), but their impact will be the emphasis of studies other than habitat modeling.

Comment 15 - On page 47, with regard to calibration/validation of the 2-D hydraulic model, what does using "half" of the velocity and depth data mean? Half of the sampling periods or half of the actual measurements or what? Can the parameter used to describe substrate roughness in the model be related to some common bottom roughness coefficient such as Mannings "n" or a "C" factor? The final distribution of substrate roughness parameters at a given site should be examined for reasonableness with regard to the actual distribution of substrate types. What action will be taken if the 2-D hydraulic models cannot be adequately calibrated using normally accepted values of the model input parameters?

Response 15 - It is general practice to use one set of data to calibrate a computer model and a different set of data to validate the accuracy of the model. For a 2-D hydraulic model, calibration and validation data is in the form of flow depth and average column velocity data collected at a constant flow rate at specific field locations within the boundaries of the modeled area. The study design proposes to collect calibration and validation data at the same time (i.e. the same field effort) and therefore the same flow rate. Data from half of the field locations will be used to calibrate the model for a particular flow rate. Data from the other field locations will be compared against model output for that flow rate in order to validate the accuracy of the model. Calibration and validation data will be collected at three different flow rates within the range of flows of interest to habitat modeling (roughly daily median to 10 percentile flows).

The Technical Overview, sub-section *Substrate, roughness, and moving beds* in Section 6.2.3, (TIFP 2008) provides a description of bed roughness parameters employed by 2-D hydraulic models. In general, they are analogous to roughness coefficients such as Manning's "n" or the Chezy coefficient "C" used in 1-D hydraulic models. As described in the Technical Overview, 2-D roughness parameters are selected based on the substrate type, so mesh nodes with the same substrate type have the same roughness. It may be necessary to increase the roughness of nodes where there are obstructions (such as boulders or debris). Please see the Technical Overview for further description.

2-D hydraulic models have an established record of providing accurate estimates of flow depths and average column velocities. If models developed for the lower San Antonio River sub-basin cannot be adequately calibrated, reasons for this situation will be investigated. The collection of additional data to refine substrate or bathymetric maps may be necessary. Ultimately, if a 2-D hydraulic model cannot be adequately calibrated or validated, it will be discarded.

Comment 16 - The importance of performing model sensitivity analyses cannot be overstated. Results from these analyses will either provide confidence in the overall modeling process or identify modeling deficiencies that must be addressed. The sensitivity procedures and results need to be fully documented in the Study report.

Response 16 - TIFP generally agrees with these comments. However, validation data also provides a measure of the accuracy of the hydraulic model. If the hydraulic model results compare well with the validation data, this also provides confidence in the modeling process. The proposed sensitivity analysis would further increase that confidence. Procedures and results of the sensitivity analysis will be fully documented in the study report.

Comment 17 - With regard to the high flow pulse and overbank flow assessment using HEC-RAS models, is there LiDAR topographic data already available or are these data going to be acquired during and as part of the Study? Some indication of the resolution to be incorporated into the HEC-RAS modeling in terms of the distance spacing between model sections would be helpful in understanding the modeling application.

Response 17 - Due to limited funding resources, the TIFP is not proposing to pay for additional LiDAR topographic data collection or significant improvements of existing HEC-RAS models. LiDAR data available for the entire study area includes data flown for the San Antonio River Authority in 2004. This data set provides information on 2′ contour lines. Additional LiDAR data with similar resolution is available for Wilson, Refugio, and Victoria Counties from the Texas Natural Resources Information System. The existing HEC-RAS models for the lower San Antonio River sub-basin were developed to aid in flood plane delineation. The model for the San Antonio River contains 709 cross sections in the study area with an approximate distance between cross sections of 2,000 feet. On Cibolo Creek, the model includes 220 cross sections in the study area or about 1,000 feet between cross sections. These models were most recently updated in 2007.

Comment 18 - No discussion is provided either at the end of Section 3.0 or in Section 4.0 regarding the procedures and process by which instream flow recommendations for the different study reaches and sites will be established. This is the crux of the study output and is a substantial omission from the Study Design. The concept of data integration is mentioned in Section 4.0 and shown on the diagram in Figure 14 dealing with stakeholder participation, but no where is there an in-depth description of how these recommended environmental flow regimes are to be developed.

Response 18 - The process for developing flow recommendations to maintain a sound ecological environment in the lower San Antonio sub-basin based on scientific studies is currently being developed. The first step in that process is completing the scientific studies themselves so that we understand the environmental consequences of various flow regimes. The technical field studies described in this Study Design are intended to accomplish that step. The multi-year TIFP instream flow study will answer questions regarding the impact of instream flows on habitat for key species, water quality parameters, riparian areas, and other indicators. After completion of the technical activities, TIFP will conduct workshops to present and explain the results to sub-basin stakeholders. The information gained about the response of various parts of the ecosystem to flow will then be integrated to develop instream flow recommendations for the sub-basin. This process will include input from the public and local stakeholders in a manner generally described in Chapters 4 and 10 of the Technical Overview (TIFP 2008). The exact method of carrying out that integration has not been developed but will accomplish tasks similar to those carried out by the Ecosystem Functions Model (HEC-EFM) developed by the Corps of Engineers (HEC 2008).

Hydrologic Engineering Center, 2008. HEC-EFM: Ecosystem Functions Model, Quick Start Guide. US Army Corps of Engineers. http://www.hec.usace.army.mil/software/hec-efm/documentation/HEC-EFM_Quick_Start_Guide.pdf

Comment 19 - The importance of stakeholder participation, input and buy-in cannot be overemphasized. It is not clear from the discussion in Section 4.0 or the diagram in

Figure 14 how this is to be accomplished for the Study. Annual presentations seem too infrequent to allow for useful input from the stakeholders.

Response 19 - As documented in Chapter 4 of the Technical Overview (TIFP 2008), TIFP is committed to working collaboratively with the public to carry out instream flow studies. A basin specific goal for the lower San Antonio River sub-basin that reflects local stakeholder's vision of the statewide goal of a "sound ecological environment" was developed in collaboration with the Study Design Workgroup. That collaboration also developed objectives and indicators that have formed the basis for the proposed technical activities described in the Study Design. The TIFP will continue to implement the stages of the stakeholder process described in the Technical Overview. During the execution of field study and data collection efforts, stakeholders will be invited to view study activities. Stakeholders will also be invited to participate in the integration of study results into a flow recommendation for the sub-basin (see Response 18). TIFP will keep the public, stakeholders, and other interested parties informed of study activities by our electronic newsletter, website updates, and periodic meetings.

Comment 20 - Finally, and again to reemphasize, on page 61 the statement is made that the descriptions of the flow recommendations "will" include four flow components of the hydrologic regime: subsistence flows, base flows, high flow pulses and overbank flows, but it would be more appropriate to say they "may" include four such flow components depending on local or regional site-specific conditions.

Response 20 - The flow recommendation will include various flow components required to maintain a sound ecological environment in the lower San Antonio River sub-basin. It is anticipated that those components will include the four components listed. If studies indicate a fewer (or greater) number of components are required, the necessary adjustments will be made.

Comment 21 - Page 2: The document indicates that the study results will provide a means to assess "social impacts/benefits" of various flow regimes. From what we have read in the Study Plan, the results are only focused on ecological values.

Response 21 – The text was corrected to omit "social."

Comment 22 - Page 2: The document indicates that the goal of the study is to develop a "comprehensive tool" to "provide predictive capabilities" to "evaluate ecological significance." Ecological significance is a vague and value-laden term. It is also unclear what "tool" will allow this to be assessed. The studies outlined in the Study Plan are scientific and, as such, the results can only be used to inform the decision process for recommending instream flows, not to "evaluate ecological significance."

Response 22 - As mandated by legislation, the goal of TIFP is to determine instream flows required to support a "sound ecological environment." The term "ecological significance" used in the Study Design identifies impacts of consequence to the ecology; literally, impacts that change the riverine ecosystem. This is a value and science laden term that has been defined for the lower San Antonio River sub-basin based on the goal, objectives, and indicators developed during the Study Design Workshops. The "comprehensive tool" will be built up from the results of individual technical studies whose results describe how instream flows affect the various indicators (such as habitat area for key species, water quality parameters, and inundation of riparian areas).

Recommendations for the various flow components will be made based on their "ecological significance."

Comment 23 - Page 5. In Section 1.1.1 Hydrology: the text describes the changes in flow that have occurred in the San Antonio River since 1970. Sources of the change are noted as wastewater discharges (+), changes in precipitation (+), storm water (+ and - seasonal), and various withdrawals (-). Increased urbanization in San Antonio and adjacent communities which corresponds with the increase in impervious cover, may also be a contributing factor. Figure 2 indicates about a 60% increase in median flow over this period. Figure 4 indicates an increase in average precipitation of about 18%. It would be useful to have a better understanding of how much each of these factors has contributed to the total flow change. When trying to comply with minimum flow requirements or looking for flow-related opportunities to enhance ecological values in the stream, it would be important to have a better quantitative understanding of the sources of flow gains and losses. The Study Plan (p 29) notes a hydrology objective of "evaluating water losses and gains" but it is not clear whether it is intended to separately quantify each source (or category) of change. It is suggested that each source of flow change should be separately quantified.

Response 23 – The main focus of TIFP activities is quantifying the instream flows required to maintain a sound ecological environment in the sub-basin. It will be important to understand changes in the flow regime (both in the past and potential future changes) and possible causes of those changes. TIFP agrees that a detailed understanding of the sources of changes and their individual impacts on the flow regime would be particularly helpful "when trying to comply with minimum flow requirements or looking for flow-related opportunities to enhance ecological values." Unfortunately, due to limited resources, it will not be possible to conduct extensive studies to separately quantify each source of flow change at this time.

Comment 24 - Page 29 Goals and Objectives (Section. 2.2): The stated goal is to have a "sustainable ecosystem that supports a **balance** of ecological and **economic**, recreational, and educational uses." Yet the Study Plan focuses entirely on ecological values. The flow chart (Fig 14 on page 60) includes a step entitled "Data Integration to Generate Flow Recommendations." The box above that states "Multidisciplinary Data" input. Does this mean that non-ecological values, many of which may conflict with ecological values, will be considered or "balanced" in the final recommendations? This approach is not apparent from what is stated many times elsewhere in the Study Plan. If the goal of the Study is to exclusively recommend flows for ecological values then it should be clearly stated so as to not disillusion some stakeholders who may believe, by virtue of their involvement in the study plan, that the final flow recommendations will involve tradeoffs and balancing of instream and out-of-stream water-use values.

Response 24 - The goal of TIFP is to determine instream flows required to support a "sound ecological environment." In the context of the TIFP, "multidisciplinary" refers to the disciplines of Hydrology, Biology, Water Quality, Geomorphology, and Connectivity, all related to the riverine ecosystem. Throughout the Study Design Workgroup process, TIFP has communicated to participants that TIFP has staff, resources, and a legislative mandate to study the ecological aspects of instream flow in the sub-basin. At the second workgroup meeting, objectives were developed for the five scientific disciplines of Hydrology, Biology, Water Quality, Geomorphology, and Connectivity. Objectives related to economic, recreational, and educational uses were not developed (see meeting notes at: http://www.twdb.state.tx.us/instreamflows/pdfs/Notes2ndSanAntonioWorkgroup.pdf).

As described in Section 3.2.1 of the Study Design, TIFP will evaluate the impact of instream flows on recreation. This will not require a substantial commitment of resources, however, as TIFP will utilizing recreation suitability criteria from the literature and 2-D hydraulic models developed to evaluate habitat versus flow relationships. Flow recommendations developed for the lower San Antonio River sub-basin by TIFP will be based on the requirements for a "sound ecological environment." Thanks to recreation modeling, TIFP will also be able to describe how those recommendations may affect recreation in the sub-basin.

As described in Chapter 11 of the Technical Overview (TIFP 2008), implementation of instream flow recommendations will be carried out as part of the Environmental Flows process created by Senate Bill 3. During the Environmental Flows process, instream and out-of-stream water-use values will be balanced before environmental flow standards are adopted or altered by the Texas Commission on Environmental Quality.

Comment 25 - Page 29 (Hydrology): Based on typical scopes for these studies, it is expected that the objective of the Hydrology studies would be to "identify flow regimes that sustain ecological processes", not to "develop" them. Developing an ecological flow regime involves the integration of results of multiple studies, as is stated elsewhere.

Response 25 - In this context, there doesn't appear to be a large semantic difference between the use of the word "develop" or "identify." However, if the word "develop" implies incorporating information from other disciplines beyond simply hydrology, then it is the correct term to use here. During a thorough instream flow study, it is impossible to segregate study activities strictly by predominant discipline. For most study activities, there are linkages between and within disciplines. As noted by the Technical Overview (TIFP 2008), "a river's hydrologic flow regime is recognized as a 'master variable' that drives variation in other components of the river ecosystem. As a result, evaluations of a river's hydrology and hydraulics play a key role in developing instream flow components." Completion of a hydrologic analysis will necessitate the incorporation of information from other disciplines. Initial hydrologic analysis can identify the basic flow characteristics of the lower San Antonio sub-basin, but biologic and geomorphic studies will need to be completed in order to identify flow characteristics important to ecological processes. Once these characteristics are identified, a more refined hydrologic analysis will be conducted to investigate the frequency of occurrence of such characteristics.

Comment 26 - Page 33 (Key Species): Doing an instream flow study, especially one that quantifies fish habitat versus flow, in a stream that supports many species of fish, each with multiple life stages, is a major challenge. Habitat for each species and life stage responds differently to flow. The common approach to this situation is to group the species into habitat guilds (ranging from slow-shallow to fast-deep) and/or to focus only on "key" species. This study plan proposes both. It is also useful if the key species reasonably represent the range of guilds (and are "key" for other reasons too). However, the key fish species chosen for this study, except for burrhead chub, are those that prefer "moderate-to-swift' or "moderate-to-strong" current. If the results of the habitat-flow models for these species are to be used in a major way for recommending instream flows, then it must be acknowledged that the flows will be biased toward the high end.

Response 26 - TIFP does not expect the development of an environmental flow regime to be unduly biased toward "key" species. The Study Design does propose to determine the effect of instream flows on the habitat of both guilds of species and individual "key" species. As discussed in Section 2.3, key species were selected because of concerns related to their populations or because they are flow sensitive. However, flow recommendations will not be developed simply to maximize the habitat of "key" species. Using habitat models, it will be possible to estimate the historical occurrence of various habitats. Final flow recommendations will consider habitat for both guilds and key species and historical occurrence of those habitats.

Comment 27 - Page 38 (Study Site Selection): This section does an excellent job of describing the importance of study site selection and presents a logical approach. The authors need to be clear and consistent on the use of terminology. On page 38, the distinction is made between stream segment (long), reach (mid-length), and site (small). Elsewhere in the Study Plan, the terms (and others) are used interchangeably.

Response 27 - A general length of river or stream is often referred to as a "segment" or "reach," while a particular location on the river or stream is referred to as a "site." In order to avoid confusion with these more general terms, when referring to the specific lengths of river and stream designated during the site selection process, the Study Design will capitalize the first letter of each term, e.g. "Study Segment," "Reach," and "Site."

Comment 28 - Page 42 (The Study Plan): The Plan indicates that the study sites will be representative of the study reach. This is a critical requirement of an instream flow study and one that is often violated. It is usually very difficult or impossible to find a truly "representative" site. Therefore, it has become common practice in instream flow studies to do what is called "habitat mapping." This involves quantifying meso-habitat ratios in the larger study reach and then applying those ratios as "weighting factors" to similarly defined sub-areas of the study site. This is simple to apply with one dimensional (1-D) models (containing individual transects) but is challenging with two-dimensional (2-D) models. On page 49, it is stated that habitat mapping will be used to determine if the study sites are representative, but does not indicate what might be done if the sites are not found to be representative. Several options are available to address this potential concern, and the Study Plan should not overlook this need.

Response 28 - It can be very difficult to find representative Study Sites if the criteria for selection are needlessly restrictive. For example, it is very difficult to select Study Sites so that the proportions of various mesohabitats (pools, riffles, runs, etc) within the Site are identical to the proportions of these habitats in the entire Reach. However, this is not necessary in order to "scale up" results from the Site to the Reach scale. Instead, it is sufficient for mesohabitats in the Study Reach to be represented in the Study Site. Habitat mapping of the Study Reach and Site, as described in Section 3.2.2, can then be used to determine the appropriate ratios for scaling up results from the Study Site to the Reach. If a candidate Study Site does not include an important habitat type found in the

Study Reach, the Site boundaries can be extended upstream or downstream to include such habitat or the entire Site can be moved to a more suitable location.

Comment 29 - Page 45 (Hydraulic Models): Is the 2-D hydraulic model that is discussed the same as a 2-D hydrodynamic model, such as River 2-D? Either term is acceptable but it should be noted if these are one and the same or not. Also, has the use of 1-D models been excluded? Often the 1-D- and 2-D models provide similar results, but the 2-D is much more expensive to implement. The advantages of 2-D include an ability to better model eddies and side channels and to generate more informative graphs. If funds are limited or could be applied to other studies, the option of a 1-D model should not be ruled out in the Study Plan.

Response 29 – For purposes of instream flow studies, the terms "hydraulic model" and "hydrodynamic model" are equivalent. Chapter 6 of the Technical Overview (TIFP 2008) provides a general description of the merits of 1, 2, and 3D hydraulic models as applied to instream flow studies. The Study Design proposes using a combination of 1D and 2D hydraulic models as part of technical studies for the lower San Antonio River sub-basin. A 1D model will be used to support studies of riparian area (Section 3.2.2) and sediment transport (Section 3.2.3). Because of their better characterization of habitat conditions within the channel, 2D models will be used for habitat modeling (Section 3.2.2). The TIFP has the necessary resources to carry out this level of modeling effort.

Comment 30 - Page 51: This section indicates that a meso-habitat-flow relationship will be developed. However, meso-habitats are defined primarily by physical features such as slope, hydraulic controls, and substrate, and not by flow (although high flows help create these features). Also, a decision as to when a certain meso-habitat (e.g. pool) might turn into another type (e.g. run) is highly subjective. Most habitat surveys are done at low-to-moderate flow so that the habitat distinctions and defining physical features can readily be observed. There is little value in attempting to develop a meso-habitat-flow relationship.

Response 30 - Mesohabitats can be differentiated based on flow characteristics such as depth and average column velocity, making it possible to use hydraulic models to evaluate mesohabitat versus flow relationships (see for example, Jowett 1993, Vadas and Orth 1998, Panfil and Jacobson 1999, and Parasiewicz 2007). After hydraulic models have been developed to identify species specific habitat versus flow relationships, there is relatively little additional effort required to develop mesohabitat versus flow relationships. There is value in knowing the relationship between instream flow and both species specific habitats and more general mesohabitats. Mesohabitat versus flow relationships provide an overall picture of habitat conditions that may not be captured by looking only at habitat related to a few key species.

Jowett, I.G., 1993, A method for objectively identifying pool, run, and riffle habitats from physical measurements: New Zealand Journal of Marine and Freshwater Research, v. 27, p. 241-248.

Panfil, M. S. and Jacobson, R.B. 1999. Hydraulic modeling of in-channel habitats in the Ozark Highlands of Missouri: Assessment of physical habitat sensitivity to environmental Change: online document, URL: http://www.cerc.usgs.gov/rss/rfmodel/

Parasiewicz, P., 2007, The MesoHABSIM model revisited: River Research and Applications, v. 23, i. 8, p. 893-903.

Vadas, R.L., Jr., and Orth, D.J., 1998, Use of physical variables to discriminate visually determined mesohabitat types in North American streams: Rivers, v. 6, p. 143–159.

Comment 31 - Since it is stated that water quality has improved and quantity has increased, the focus has been on including historical and natural conditions which are echoed in the Statewide and Basin Goals, these include:

- "natural processes"
- "comparable to that of the natural habitat"
- "naturally functioning"
- and most importantly, " supports a balance of ecological benefits and economic, recreational, and educational uses"

Have historical data been the center point for evaluating these factors? A more definitive comparison of aquatic ecosystems, species and abundance should reflect what historical flows have been and not focusing on modifications of base flows (see page 6, Figure 2).

Response 31 - It is certainly not the intention of TIFP to limit the instream flow study to modifications of base flows. As stated in Response 1, the purpose of Figure 2 is simply to point out that flow conditions in the sub-basin have changed over time. The figure does not in any way imply that analysis will be limited to median flows or separation of the data around the year 1970.

Comment 32 - 1.2.4, Water Quality: the Report should have a detailed description of the current Total Maximum Daily Loads (TMDL) activities within the basin. There are currently three TMDL development projects in the San Antonio River Basin. The project titles are:

- Salado Creek (Dissolved Oxygen),
- San Antonio River Basin and Leon River (Bacteria), and
- South Central Texas (Bacteria and Dissolved Oxygen).

Also, reference should be provided on the existence of the draft Best Management Practices (BMP) Assessment Report, dated February 17, 2009. This report's objective is to identify and assess potential sources of bacteria, and to evaluate Best Management Practices (BMPs) that can be used to control those sources.

Response 32 – The focus of the TIFP study is to determine instream flows necessary to support a "sound ecological environment" and the effects of instream flow on water quality within the study area will be studied. However, as stated in the Technical Overview (TIFP 2008), water quality may be affected by many factors other than instream flow, such as point source discharges and nonpoint source runoff. These factors are not flow related and cannot be addressed by the choice of an appropriate instream flow regime. There are existing programs (such as TMDL and BMP projects) to address these types of non-flow related factors. TIPF is aware of the TMDL and BMP projects in the lower San Antonio River sub-basin. These projects are not focused on and have not provided substantial information about flow related water quality issues in the study area. Therefore, descriptions of these projects have not been included in the Study Design.

Comment 33 - There needs to be some reference to the significant value of precipitation and the contribution of rain events to overall flow and especially high pulse flows. Also, any flow values for spring discharges which include the Edwards Aquifer, could be drastically reduced or even to no flow if another significant drought occurs.

Response 33 - The Technical Overview (TIFP 2008) recognizes that "most streamflows are directly related to episodic rainfall-runoff events." The Technical Overview also states that "base flows of some Texas rivers and streams are groundwater dependent (spring-fed)" and "other stream segments are dominated by wastewater return flows from municipal areas." The Technical Overview defines high flow pulses as "short-duration, in-channel, high flow events following storm events." In the Study Design, the conceptual model (Figure 10 - *Ed. Changed to Figure 9*) identifies springflow, return flows, and rainfall as the primary sources of water in the sub-basin. Section 1.1.3 of the Study Design describes the unique precipitation patterns of central Texas and related "flashiness" of area streams. The Study Design for the lower San Antonio River sub-basin is probably not the place to speculate about the potential impacts of future droughts on springs. After completion of a hydrologic analysis, the final Study Report will provide a description of historic flow patterns (and trends, if appropriate) in the sub-basin during wet, average, and dry conditions.

Comment 34 - The Pugnose minnow is now being proposed as a potential target species. SAWS believe that any inclusion of a target species needs to be evaluated by the stakeholders as to the river life cycle and preferred aquatic habitat requirements of this particular species.

Response 34 - See Response 10 related to how key species were selected.

Comment 35 - The Report proposes new water quality indicators:

- Nutrients - Organic and total Nitrogen indicator omitted and the explanation changed to TCEQ definitions.
- Filterable reactive and total phosphorus indicator changed to total phosphorus and orthophosphate. Explanation changed to TCEQ definitions.
- Dissolved Oxygen - Explanation changed to TCEQ definitions.
- Temperature - Explanation changed to TCEQ definitions.
- Bacteria - Bacteria indicator as a function of contact recreation. Explanation changed to TCEQ definitions.

Any modification such as water quality indicators should comply with the decisions we accomplished together as stakeholders during the study design workgroup meetings. These include but are not limited to:

- Determine natural, historic, and current parameters of water quality of the river system.
- Maintain flow in order to sustain water quality to support:
  - Biodiversity, Economic uses, and Recreational uses
- The workgroup also noted the following as possible water quality indicators:
  - Dissolved oxygen levels, Purity, Sensitive or intolerant species, Contact recreation, Low bacterial count, Edible fish, Salinity

Will there be a "matrix" or benchmarking table that will weigh these factors to aid in prioritizing them?

Response 35 - Water quality indicators selected by the Study Design Workgroup at their third meeting were Nitrogen, Phosphorus, Dissolved Oxygen, Temperature, and Bacteria (see meeting notes: http://www.twdb.state.tx.us/instreamflows/pdfs/Notes-ThirdSAworkgroup.pdf). This list is identical to those provided in Table 10 of the Study Design. Table 10, however, does change the explanations of these indicators and proposed method of measuring some of the indicators. These changes were necessary to exactly match the explanations for these indicators and measurement methods currently being used in the TCEQ Surface Water Quality Monitoring Procedures. For example, as shown in Table 10, Nitrogen will now be measured in two ways; as "Nitrate plus Nitrite" and "Ammonia." TIFP had previously communicated to the workgroup that Nitrogen would be measured in four ways; Organic, Nitrate plus Nitrite, Ammonia, and Total. TIFP does not believe these changes will significantly affect the way that studies will be conducted in the sub-basin. The changes were necessary, however, in order maintain strict compatibility with existing state programs and thereby reduce confusion, allow comparison of study results, and eliminate unnecessary costs. The list of water quality indicators and explanations shown in Table 10 was provided to the Study Design Workgroup member on May 29, 2009, along with a request to provide comments or concerns (if any) by June 10, 2009. No comments or concerns were expressed by workgroup members at that time.

When weighing factors (including various water quality indicators) in order to make instream flow recommendations for the sub-basin, we anticipate using a tool such as HEC-EFM (see Response 18).

Comment 36 - The freshwater now in the lower basin south and east of the USGS Elmendorf gage is tremendously influenced by activity and urbanization north and west of the Elmendorf gage. This fact is briefly discussed on page 7 of the draft study design and basically ignored during the rest of the study. In the TCEQ staff presentation on June 30, 2009, there was one statement about all water rights and Texas Pollution Discharge Elimination System (TPDES) permits for entities above the Elmendorf gage would be examined to determine impact of these water rights and industrial permits on the lower basin. The San Antonio River Basin operates as one entire system and it seems that artificially separating the system at the Elmendorf gage does not provide a complete understanding of the system dynamics. How does staff intend to account for the upper basin contributions to the lower basin?

Response 36 – The location of the USGS streamflow gage at Elmendorf was intentionally chosen as the upstream boundary of the study area in order to readily relate conditions in the study area with conditions upstream. The daily flow data available at this location (September 1962 to present) provides a direct measure of the hydrologic influence of the upper basin on the lower San Antonio River sub-basin. The USGS has also maintained continuous water quality monitoring at this location since 1987, providing a direct measure of the impact of the upper basin in terms of water temperature, specific conductance, dissolved oxygen and pH. Other water quality parameters, including nutrients such as nitrogen and phosphorous, have been measured at this location on a less frequent basis. As mentioned in Section 1.1, a recent USGS study (Ockerman and McNamara 2002) has further expanded the understanding of the upper basins' influence on the lower basin. That study was able to provide estimates of the contribution of various components of the upper basin to both flow quantity and quality at the Elmendorf gage location. Using the available data and previously published reports, TIFP believes that it is possible to adequately describe the influence of the upper basin on the lower San Antonio River sub-basin.

Comment 37 - There has been some discussion in stakeholder meetings about restricting the study to the area within the normal stream bed or the area between the normal high water marks. USGS defines this as their area of responsibility and one stakeholder and staff indicated that this study should be restricted to this narrow area. River systems are really the sum of all areas that drain into the river as well as the area covered by the water flowing in the river. Will staff be viewing the San Antonio River Basin as a holistic system or confine the study to the area below the normal high water mark?

Response 37 – As documented in the Technical Overview (TIFP 2008), TIFP studies will not be restricted to within channel flows. The indicators for this study were developed in collaboration with the Study Design Workgroup and include an overbank flow component, which would certainly exceed the normal stream channel. Such flows are important to riverine ecosystems because they move sediment, connect the river to the floodplain, maintain riparian habitats, serve as biological cues, and provide other important functions. The list of indicators documented in the Study Design includes many dependent on overbank flows, such as "total area inundated by overbank flows" and "richness and diversity of riparian vegetation." In order to address these indicators and meet study objectives, TIFP will be studying overbank flows in the sub-basin.

Comment 38 - River flows are influenced by several different things. Section 1.1.3 does a good job of describing the physical processes that influence variability in stream flows. The 2008 Bio-West study divided flow records into two periods using 1972 as the dividing year. Staff seems to support this scheme. The flow after 1972 has been greatly influenced by urbanization in Bexar County and increased population in the San Antonio region as well as higher than normal rainfall through much of the period. Population in San Antonio has increased from approximately 500,000 in 1950 to approximately 1.7 million in 2009 and the area covered by urbanization has increased over 350% since 1950. The San Antonio region is projected to continue to grow at approximately 3% per year and this growth will continue to contribute to changes in river flows. The San Antonio River existed before the city of San Antonio and the native flora and fauna developed long before Europeans settled in the region. It would be incorrect to look at the history of known flows as represented by the USGS record to develop a true understanding of the natural flow regimes and restricting the study to the last 40 years ,as suggested in the Bio-West study would skew the result. Central Texas is prone to great variability in rainfall and stream flow as shown in the record and recommendations of minimum and subsistence flows, as defined in the draft study design, should take the entire historic record and even the prehistoric record into consideration. How does staff intend to deal with the historic record of stream flows?

Response 38 – Daily gaged streamflow data in the basin goes back as far as 1924, well before significant influence from human impacts such as urbanization in Bexar County. TIFP proposes to use this data to conduct hydrologic analysis to determine "natural conditions" (see Response 8). It is possible to infer annual flow volumes or even seasonal flow conditions based on tree ring data, thereby extending historical flow records to periods prior to stream gaging. However, it is impossible to infer daily flow conditions from such efforts, significantly reducing their value for the determination of instream flows. TIFP is unaware of any accepted methods to extend daily flow records to periods prior to historical streamflow gaging. We will, however, continue to monitor the science and literature for techniques that hold promise for improving future studies.

Comment 39 - Figure 10 (*Ed. changed to Figure 9*) on page 26 shows a graphic representation of the conceptual model for the San Antonio Basin study. In the biotic response row aquatic flora is omitted. The draft study design discusses determining critical habitat for aquatic fauna at the defined flow regimes. Aquatic habitats consists of many and dynamic elements. Aquatic flora, in many aquatic systems, is both a diverse biotic community and a vital element of habitat for aquatic fauna. Staff should add aquatic flora to the list of biotic communities studied.

Response 39 – TIFP agrees that aquatic flora (or river plants) is (are) an important component of some riverine ecosystems. River plants were proposed as a biological indicator during the third Study Design Workgroup meeting. However, at that time, none of the workgroup participants or TIFP staff could identify any concerns related to river plants in the sub-basin. Review of the available literature has also failed to identify any concerns in the study area related to river plants. In the event that concerns come to light during initial study efforts, it was decided to keep "river plants" as an indicator. This indicator is listed in Table 8 of the Study Design and flow requirements for aquatic flora of concern will be identified if/when they are discovered. Aquatic flora was not included in Figure 9 because their significance in the Lower San Antonio River sub-basin is unknown.

Comment 40 - One of the themes expressed throughout the research design is the need to develop an understanding of the impact of varying flow regimes. It is important that this study examines overbank flow as well as subsistence flow, stream migration, stream capture, and sedimentation caused by overbank flows. At the stakeholder meeting on June 30, 2009, Mr. Walter Womack expressed concern that river segment 1, defined by staff as the lower area of the study region near the confluence with the Guadalupe River, was being excluded from the study design. Mr. Womack reminded staff that there is extensive sedimentation and active stream migration and capture taking place on his property. Staff stated that they had omitted segment 1 from the study due to the complexity of understanding the processes at work in the deltaic region of the river. Mr. Womack's concerns seem very valid and the offer of such an active depositional area with active stream capture for study by staff seems to be a very valuable asset to the study. Understanding this region would develop a better understanding of the dynamics of the entire river basin. Staff should reconsider omitting Segment 1 from the study. Segment 1 offers staff access to what staff defined as objectives of the study; understanding sediment transport, woody debris transport, stream migration and stream capture.

Response 40 – In Segment 1, the mainstem of the San Antonio River is in the deltaic portion of the river system. In this unique portion, channel and valley slopes are much lower, connectivity to out of channel areas is much higher, and channel changes may occur much more rapidly than in other parts of the system. In contrast to the rest of the system, dominant processes in this portion of the river basin are depositional and complex geomorphic processes (such as channel avulsion) are much more likely to occur. Thoroughly investigating such processes would be very resource and time intensive. Moreover, many of the conditions and processes in Segment 1 are unique to this Segment and studying these processes does not provide better understanding of conditions in the upper portions of the study area. For these reasons, TIFP did not propose any studies in Segment 1.

Nevertheless, after considering comments from the Study Design Workgroup, TIFP has agreed to conduct some qualitative study of large woody debris dynamics and channel avulsion processes in Segment 1 of the study area. These activities will provide some general understanding of the significance of these processes in Segment 1 and may provide insight on how to study these processes in greater detail in the future.

Comment 41 - The draft study design discusses the goal of understanding various flow regimes. The assumption is that staff would make recommendations to the legislature about required environmental flows and that the legislature would authorize the readjustment of water rights to assure adequate flows in the river to support biotic communities. Water rights in the San Antonio basin have priority dates all the way back into the 1700's. Many of the larger water rights are in the area above the Elmendorf gage. Staff is proposing that decisions be made in the lower basin that will influence water rights in the upper basin. All water rights holders and interests in the upper basin are not represented in the stakeholder group. All political subdivisions in the upper basin have not been involved in this process and may not have even heard about the potential impact of decisions made as a result of this process. The suggestion that water rights could be ultimately be amended and property rights and property values impacted by this process should be considered very carefully. How does staff intend to communicate the science and environmental flow regimes developed by this process and how this process will impact property rights and political subdivisions to the hundreds of water rights holders and the dozens of cities that could be impacted by decisions made about required flow rates downstream?

Response 41 – Existing water rights will not be impacted by the results of TIFP studies or the Senate Bill 3 environmental flows process. The goal of TIFP studies is to determine flow conditions that support a sound ecological environment in specific sub-basins. The determination of required flow conditions will be made based on scientific studies of the systems involved. For each sub-basin, the definition of a sound ecological environment is being refined based on goals, objectives, and indicators developed with local stakeholders. After the completion of studies, local stakeholders will again assist in the process of integrating results in order to develop a recommended flow regime (see Response 18). A final study report will document the recommended flow regime, as well as the scientific studies on which it was based.

As described in Chapter 11 of the Technical Overview (TIFP 2008), implementation of instream flow recommendations will be carried out as part of the environmental flows process created by Senate Bill 3. During that process, instream and out-of-stream water-use values will be balanced before environmental flow standards are adopted or altered by the Texas Commission on Environmental Quality. Once enacted, environmental flow standards will limit future water rights permits and amendments, but will not impact existing water rights.

Comment 42 - The Lower San Antonio River is a large geographic region. The study design breaks the basin into 8 reaches on the San Antonio River and 2 on the Lower Cibolo Creek. Staff stated that the study sites were selected primarily for convenience of access. The study segments are long and study sites selected for subjective reasons or convenience as stated on page 41 and 42 of the study design seem to reduce the objectivity of the study. Segment 3 for example is 69 miles long and the study site is near the bottom of the segment. The study site was chosen because of a specific mussel habitat and population that is not represented in the rest of the study segment. Selecting a study site specifically because it is different does not seem to be the best way to determine study results that can be generalized to the entire segment. The lack of randomness in site selection will skew the result of the scientific analysis. How will staff account for this sampling error and report results with any degree of confidence?

Response 42 – Access was an important, but not the only, criteria in selection of Study Sites. As described in Section 3, Study Segments and Reaches were selected based on geological properties, valley shape, ecoregions, and major hydrologic and geomorphic conditions (see also Response 12). Activities to be completed in each Study Reach were selected based on the current understanding of hydrology, biology, physical processes, and water quality within the sub-basin. This understanding is based on previous studies, many of which are described in Section 1.1. Current understanding of the system also aided in the selection of specific locations within each Study Reach where study activities will be carried out (Study Sites).

Access to the lower San Antonio River or Cibolo Creek was an important consideration in Study Site selection. There are a limited number of options for access to the river or creek within the study area. Study activities outside the channel (e.g., evaluation of riparian areas) require a cooperative land owner. Logistics for activities within the channel (e.g., habitat modeling) are aided by access from at least one bank. However, if criteria are not needlessly restrictive, there are a large number of potential Study Sites that would be representative of each Study Reach (see Response 28). In this case, it is more efficient to confirm the suitability of locations with known access rather than to contact landowners of all potential sites to determine if access can be obtained. If a potential Study Site is found to be unsuitable during field visits, an alternative site will be selected. TIFP does not believe that access has limited (or will limit, if alternate sites are necessary) Study Site selection in a manner that will skew results.

In regards to the intensive Study Site (hydraulic and habitat modeling, baseline riparian assessment) chosen for Study Reach 3: Please note that although the Reach is 74 miles long; geological properties, valley shape, ecoregions, and major hydrologic and geomorphic conditions are relatively similar along this entire length of river. Data from recent collections also indicates the assemblage of fish species present is very similar along this length of river (please see additional material added to Section 3.1). In consultation with the Study Design Workgroup, golden orb was selected as a key species indicator (see Section 2.3). This freshwater mussel has been found recently at the proposed Study Site, but given the similarity of conditions, should be present at many other locations within Reach 3. In addition, the Study Site has excellent access and there is a long history of biological data collection at or near this location (making it possible to readily compare current and historical conditions). All of these factors contributed to the decision to select this location as a proposed Study Site.