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

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Executive Summary

The lower San Antonio River sub-basin, including lower Cibolo Creek, is located in portions of seven 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. Senate Bill 2, enacted in 2001 by the 77th Texas Legislature, established the Texas Instream Flow Program (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. The TIFP study of the lower San Antonio River sub-basin was completed with the assistance of a local study partner, the San Antonio River Authority. Stakeholder involvement was integral from the planning of the TIFP study through the review of the final report. The overall goal or vision agreed upon by stakeholders was for the sub-basin to be ***"a naturally functioning and sustainable ecosystem that supports a balance of ecological benefits and economic, recreational, and educational uses".*** Through a series of public meetings, the TIFP developed study specific objectives, indicators, and a study design.

The TIFP study of the lower San Antonio River sub-basin includes activities related to five major disciplines: hydrology and hydraulics, biology, physical processes, water quality, and connectivity. Study activities were carried out in order to identify flow-ecology relationships related to a flow regime (including subsistence flows, base flows, high flow pulses, and overbank flows) supportive of the ecological environment. Results from completed and ongoing study and data collection efforts related to the lower San Antonio River sub-basin were utilized to the extent possible. Base flow recommendations were based on aquatic habitat versus flow relationships developed from six intensive study sites (five on the lower San Antonio River and one on lower Cibolo Creek). Subsistence flow recommendations were based on water quality versus flow relationships developed from data collected as part of the existing Clean Rivers Program and data and modeling work completed by the TIFP. Aquatic habitat versus flow relationships also played a role in the selection of subsistence flows. High flow pulse and overbank flow recommendations were based on riparian flow ecology relationships identified at five field sites (four on the lower San Antonio River and one on lower Cibolo Creek). Timing and duration of high flow pulse and overbank flow recommendations were also informed by life history requirements of focal riparian species. Flow recommendations were adjusted to provide a sediment transport rate capable of maintaining the current channel and habitats based on analysis at one site (lower San Antonio River).

Final flow recommendations are provided for five sites, four on the lower San Antonio River and one on lower Cibolo Creek (Tables 22-26). A monitoring program is recommended to evaluate the effectiveness of these recommendations. Such a program may provide additional information that could result in modifications or revisions to these recommendations.

1.0 INTRODUCTION

The lower San Antonio River sub-basin is located in portions of seven 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 has undergone significant transformation over the past several decades due to urban development in and around Bexar County and changing agricultural practices in the rural portion of the basin. 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 derived primarily from groundwater pumped from the Edwards Aquifer for municipal use, diversions, and runoff from a changing mix of various urban and rural land uses.

In recent history, use of groundwater to sustain rapid development in the basin has resulted in increasing base flows in the San Antonio River resulting from discharged groundwater-based return flows. This trend in increasing 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 water management strategies such as reuse, both direct and indirect, be increased. In any event, there is the potential to change the current 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 (SB2), 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 (SB3) 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. Instream flow studies function to provide available scientific information that can be utilized during the adaptive management process within SB3 to inform environmental flow recommendations.

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. From that foundation, a study design document was prepared in 2009 for the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study (TIFP and SARA 2012). This Study Design was peer reviewed by the U.S. Geological Survey (USGS) and subsequently modified based on comments received.

A wealth of hydrological, biological, geomorphological, and water quality information was collected and analyzed in support of the SB2 instream flow study. This information has been condensed and compiled to generate this report. As will be evident throughout this report, the culmination of study efforts to date have resulted in a characterization of the flow-habitat and flow-ecological relationships associated with the riverine environment 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).

1.1 Stakeholder Involvement and Study Design

Stakeholder involvement was integral in the development of the Study Design for the TIFP lower San Antonio River sub-basin study (Figure 1). This involvement started with meetings to acquire historic and current perspectives on the basin, which then led to a series of meetings designed to develop study specific goals and objectives to guide the development of the study design. Throughout the study design process, stakeholders provided a wealth of local and technical knowledge, which complemented historical reports and available data. The Study Design (TIFP and SARA 2012) focused on:

- Available information, results of preliminary analyses, and reconnaissance surveys
- Assessment of current conditions
- A conceptual model of the lower San Antonio River Basin
- An overview of the stakeholder process
- A description of the study goal, objectives, and indicators developed with stakeholders
- A description of the proposed technical studies
- Study Site locations
- Data collection methods and analysis
- Multidisciplinary coordination

The contents of the Study Design document will not be repeated in this document but are referenced as they constitute a wealth of background information regarding historical and current-day perspective and study activities.

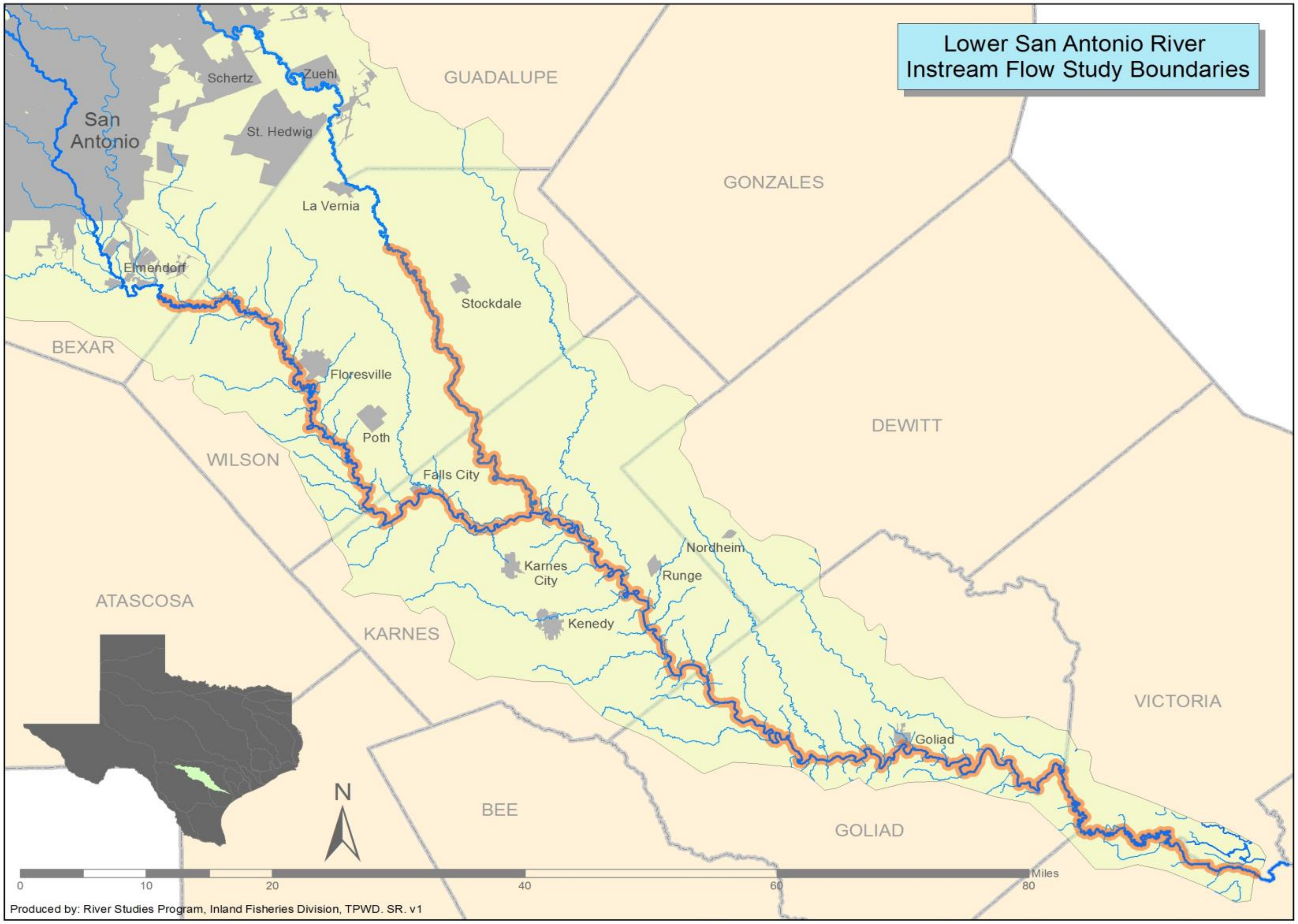


Figure 1. Map of the San Antonio River Basin and lower San Antonio River sub-basin (study boundary depicted).

1.2 Study Goals 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 as described in the Study Design (TIFP and SARA 2012). Sampling effort was expended to assess each of the key indicators to the degree practicable for the Study Design as described in Section 2.0.

The objective for each component was defined as follows:

- **Hydrology:** to develop a flow regime that sustains ecological processes throughout the system.
- **Biology:** 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.
- **Physical Processes:** 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.
- **Water Quality:** to maintain flow in order to sustain water quality to support biodiversity, economic uses, and recreational uses.
- **Connectivity:** identify the interaction of groundwater and surface water and evaluate the relationship of important habitat features of the river and riparian zone that support the basin goal.

While this report thoroughly addresses the ecological aspect, it does not directly address the economic, recreational, and educational uses of the river. The San Antonio River provides a variety of recreational opportunities. Sections of it have been developed into designated paddling trails, the river flows through a number of local and state parks, and the river supports an assortment of sportfish. These recreational activities provide economic and societal benefits. Economic benefits are also reaped by municipalities that discharge wastewater into the river, as well as water right permit holders who draw water from it. Both depend upon there being sufficient flow and water quality present to allow them to continue using the river for these purposes. Future studies could specifically address these uses.

2.0 METHODS AND ANALYSIS

The development of instream flow recommendations requires the integration of multiple disciplines at several key stages in the process. During the analysis phase, integration of the analytical results is necessary to develop specific flow recommendations (subsistence flow, base flow, etc.). Once specific flow recommendations are developed, an integration of those flow recommendations into a proposed flow regime is required. Once a proposed flow regime is generated, a myriad of testing and overlays are employed to assess if the recommendations are meeting the established goals and objectives.

The overall goal established by the stakeholders is 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".*** Additionally, the TIFP has internal objectives to conserve biodiversity and maintain biological integrity. To accomplish these goals and objectives, the integration process involves the development of a flow regime comprised of four components of the hydrologic regime: subsistence flows, base flows, high flow pulses, and overbank flows. A brief overview of the definitions and objectives of the instream flow components as presented in TIFP (2008) is presented in Table 1.

Table 1. Definitions and objectives of instream flow components (adapted from TIFP 2008).

Subsistence Flows	
Definition:	Infrequent, seasonal periods of low flow.
Objectives:	Primary objective is to maintain water quality criteria. Secondary objectives to provide important low flow life cycle cues or refugia habitat.
Base Flows	
Definition:	Normal flow conditions between storm events.
Objectives:	Ensure adequate habitat conditions, including variability, to support the natural biological community.
High Flow Pulses	
Definition:	Short duration, within channel, high flow events following storm events.
Objectives:	Maintain important physical habitat features. Provide longitudinal connectivity along the river channel.
Overbank Flows	
Definition:	Infrequent, high flow events that exceed the normal channel.
Objectives:	Maintain riparian areas. Provide lateral connectivity between the river channel and active floodplain

2.1 *Study Site Selection and Study Components*

In order to plan study activities, the lower San Antonio River sub-basin was divided into Study Segments, Reaches, and Sites. Throughout this document, 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 (e.g., water quality models) were conducted across an entire Study Segment, other studies (e.g., hydraulic and habitat modeling) were conducted at particular Study Sites. As described in the Study Design (TIFP and SARA 2012), a three-tier approach was employed for the final selection of specific Study Sites (Table 2 and Figure 2). 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. 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.

Table 2. Coordinates of upper and lower boundaries for each Study Site. Note: Floresville Study Site only used for seasonal Habitat Suitability Criteria sampling.

Site	County	Study Site Number	Upper Boundary		Lower Boundary	
			X	Y	X	Y
Calaveras	Wilson	19110	29.214663	-98.284636	29.223174	-98.271837
Cibolo Ck.	Wilson	19070	29.192445	-97.992604	29.179781	-97.992301
Floresville	Wilson	19100	29.110436	-98.174248	29.109258	-98.166738
Falls City	Karnes	19090	28.948614	-98.064521	28.944383	-98.055024
Goliad	Goliad	19030	28.655284	-97.396803	28.649949	-97.384149
Hwy 77	Victoria	19020	28.553471	-97.138444	28.545281	-97.123046

The Technical Overview (TIFP 2008) and Study Design (TIFP and SARA 2012) outline four major study components: hydrology and hydraulics, biology, physical processes, and water quality. A fifth study component, connectivity, was also included in the Study Design for the lower San Antonio River sub-basin. Sections 2.2 through 2.6 provide a brief overview of existing conditions and data collected, and then describe the study activities, locations, and methods for each of the four components relative to the indicator categories established by the stakeholder process.

Figure 2. Study Reaches and Study Sites used during the Texas Instream Flow Program (TIFP) study on the lower San Antonio River (LSAR) and lower Cibolo Creek (LCC).

2.2 *Hydrology and Hydraulics*

The lower San Antonio River and lower Cibolo Creek ecosystems have evolved in response to the inter- and intra-annual variability in flow that includes cycles of overbank flows, high flow pulses, and subsistence flows with intervening periods of base flows. This variability in flow is typically referred to as the flow regime. An analysis of available flow data was conducted to assess hydrological indicators including natural variability, current variability, and gain or loss in river flow. The current hydrology, as represented by gaged date from 1996-2015, was chosen as the baseline hydrologic condition for purposes of this study. To support development of relationships between base flow values and fish and mussel habitat two-dimensional (2D) hydraulic and habitat modeling was performed at select sites. To support development of relationships of higher flows to riparian areas, one-dimensional (1D) hydraulic modeling was performed for the entire study area.

2.2.1 *Hydrologic Analysis*

The USGS has maintained a network of streamflow gages in the lower San Antonio River sub-basin since the 1920s. Currently, 16 gages are operational in the sub-basin, including six on the mainstem of the San Antonio River and seven on Cibolo Creek. This network allows characterization of flow regime changes spatially (moving downstream towards the coast); however, the ability to characterize how the flow regime has changed temporally (from early periods to later periods) is limited as only six of these gages have continuous records going back at least 20 years.

Since before the time of the earliest flow records (early 1900s), the hydrology of the lower San Antonio River sub-basin has been influenced by human activities, including reservoir construction, urbanization of the upper watershed, diversions and return flows, and reductions in spring flows due to groundwater pumping. The cumulative impact of these factors is not completely understood. An accurate and accepted estimate of what daily flows in the basin would look like without human influences (referred to as daily "naturalized flows") is currently under development. The monthly Water Availability Model for the combined Guadalupe-San Antonio River Basin includes monthly naturalized flow volumes, but monthly flow volumes are of limited value for an instream flow study, which relies on daily stream flows. A Water Availability Model for the Guadalupe-San Antonio River Basin with approximate daily naturalized flow is available (Wurbs et al. 2014), but is considered to still be under development (Wurbs 2015) and was therefore not considered for analysis as part of this study. Still, there are clues in the historical data collected from long term stream gages in the basin and data compiled as part of the state's water planning process. Each of these data sources can contribute to an estimate of the alteration of natural hydrology in the lower San Antonio River sub-basin.

Data from three gages in the lower San Antonio River sub-basin with long term flow records (Table 3) were analyzed in order to evaluate human impacts on the hydrology of the sub-basin. For each of these gages, we can make comparisons between flows over the last twenty years (1996-2015) and the earliest twenty years of flow records common to all three gages (March 1939 to February 1959). The hydrology of the lower San Antonio River Basin during the early time period was already affected by human activity in the basin. Nevertheless, it is representative of less human activity than occurred during the latest time period. Results for USGS Gage No. 08183500 San Antonio River near Falls City are presented in this section. Results for the other two gages are provided in Appendix A.

Table 3. United States Geological Survey stream gages in the lower San Antonio River with long periods of record.

Gage No.	Gage Name	Continuous Record Begins	River Mile	Drainage Area (mi²)
08183500	San Antonio River near Falls City	May 1925	150.5[1]	2,113
08186000	Cibolo Creek near Falls City	Oct. 1930	10.4[2]	827
08188500	San Antonio River at Goliad	March 1939	66.5[1]	3,921

[1]River mileage measured from confluence with the Guadalupe River
[2]River mileage measured from confluence with the San Antonio River

Both of these time periods have included severe droughts and extreme wet conditions. Using a 20-year time period dampens some of the effect of including extremely wet or dry years in the analysis; however, the comparison is less than ideal because some of the change in flow statistics may be due to natural differences in meteorology between the two time periods.

Annual precipitation for the South Central Texas climate region, which includes most of the San Antonio River Basin, are shown in Figure 3. During calendar years 1939 to 1958 and 1996 to 2015, precipitation averaged 32.3 and 34.0 inches per year, respectively, each within 3% of the average for the entire period of record (1895 to 2015) of 33.2 inches per year. The earlier period includes a 7-year period (1950-1956) when rainfall was well below average (24.1 inches per year). Though not as severe, the later time period also includes a 7-year period (2008-2014) when rainfall was well below average (27.6 inches per year). The later period does include 2011 when total precipitation was only 16.8 inches for the year, the lowest annual total since 1917 (when total rainfall was only 14.4 inches).

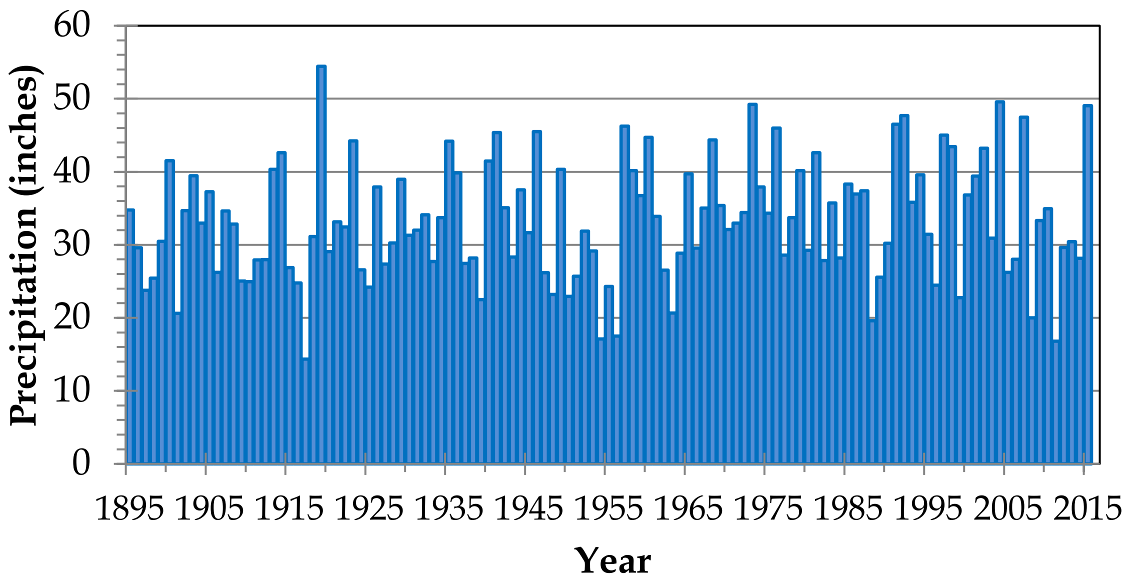


Figure 3. Annual precipitation for the South Central Texas climate region (data from National Oceanic and Atmospheric Administration 2016).

There are few reservoirs in the basin large enough to significantly impact flows in the lower San Antonio River sub-basin (Table 4). The largest reservoir in the basin is Medina Lake with a capacity of 254,823 acre-feet. Medina Lake is located on the Medina River 72 river miles upstream of the confluence with the San Antonio River, which is in turn 11 river miles upstream of the upstream boundary of this study. Average annual flow volume for the Medina River near Pipe Creek (USGS Gage No. 08179000, active from 1924 to 1982, about 15 miles upstream from Medina Lake dam) was 107,000 acre-feet. Because Medina Lake was constructed in 1913, well before stream gaging began in the lower San Antonio River sub-basin, any impacts of Medina Lake on the hydrology of the lower San Antonio River sub-basin have been embedded in the flow records of the region since gaging began. Large dams, such as at Medina Lake, have the potential to cause changes in downstream hydrology, including reduction of peak flows and changes in the distribution of flows within the year. That potential decreases with increasing distance downstream from the dam as more uncontrolled area contributes to flow. Gage data from both time periods include impacts from Medina Lake and Olmos Reservoir.

Table 4. Largest reservoirs in the San Antonio River Basin.

Location	Name	Storage (acre-feet)	Year Completed
Upper Sub-basin	Medina Lake	254,823	1913
	Olmos Reservoir	15,500	1926
Lower Sub-basin Tributaries	Calaveras Lake	63,200	1969
	Victor Braunig Lake	26,500	1964

Diversions from the river basin have the potential to impact the hydrology of the lower San Antonio River sub-basin. Authorized diversions for consumptive use in the San Antonio River basin total 198,558 acre-feet per year (TCEQ 2016). In comparison, the average annual flow volume for the San Antonio River at Falls City is 356,000 acre-feet per year for water years 1925-2015; however, not all authorized diversions in the basin are currently exercised. Surface water diversions from the San Antonio River Basin have averaged 76,900 acre-feet per year for the last ten years (TCEQ 2016). Not all water diverted from surface waters for human use is completely removed from the lower basin. Depending on the use associated with the diversion, some of the diverted water will return to the river network via "return flows". Return flows occur when water diverted for human use is not entirely consumed and a portion drains back to surface water in the basin. The rate of consumption differs by type of water use. For example, USGS (1988) found that consumptive use rates in Texas for diversions for irrigation and livestock, manufacturing and mining, municipal, and steam electric power uses were 83.4%, 45.2%, 36%, and 3%, respectively. Because of return flows, the impact of upper basin diversions on hydrology in the lower basin is less than the actual volume of the diversions.

The City of San Antonio is the largest developed area in the basin, covering 412 square miles in the upper portion of the San Antonio River Basin. The lower San Antonio River sub-basin, as defined by this study, begins just downstream of the City of San Antonio at the location of USGS Gage No. 08181800 San Antonio River at Elmendorf (river mile 202). In 1970, the City of San Antonio had a population of just over 650,000 (World Population Review 2016). The population grew to 1.2 million in 2005 and 1.4 million in 2013 (World Population Review 2016).

One of the ways urbanization alters the hydrology of a watershed is by increasing the amount of impervious cover. Runoff volumes from storm events increase due to reduced infiltration. Peak flows increase due to increased runoff volumes and reduced travel time through storm drainage systems. Contributions to base flow are reduced with the decrease in infiltration during rain events. The net result can be increased flashiness of the hydrology in downstream areas, that is, increasing peak flows while decreasing base flows. Impervious cover causes a greater percentage increase in peak flows associated with smaller, more frequent storm events and a lesser percentage increase on larger, less frequent storm events (Hollis 1975).

A second way that urbanization alters hydrology is from return flows from water imported to the area for human use (Bhaskar et al. 2016). When human population in a watershed increases, human demand for water typically increases as well. Meeting those demands often requires moving additional water to developed areas, either from surface water outside the watershed or from groundwater. Not all of the “new” water brought into the watershed for human use is consumed, leading to return flows to the watershed. Depending on the magnitude of return flows, they can partially or completely overcome the reduction in base flows associated with increased impervious cover. As a result of the interplay of these two factors - impervious cover and return flows- urbanization may result in decreasing, stable, or reduced base flows (Bhaskar et al. 2016, Brandes et al. 2005) while flow pulses are increased.

For the lower San Antonio River Basin, the relationship between hydrology and increased return flows due to urbanization is complicated. The City of San Antonio has historically relied on groundwater pumped from the Edwards Aquifer to meet the majority of the demands of its growing population. That aquifer is also the source of naturally occurring spring flow that contributes to the hydrology of the lower San Antonio River Basin. Tapping the aquifer to meet the needs of the growing population has increased return flows to the river network, but as aquifer levels are lowered, it has also reduced naturally occurring spring flow.

Estimated discharge from the Edwards Aquifer in Bexar County in the form of both pumping and spring flow has increased from earlier decades (Figure 4). Spring flow in Bexar County averaged almost 34,000 acre-feet per year in the period 1999 to 2014 (Edwards Aquifer Authority 2015), but is suspected to have been larger in earlier time periods. Average annual discharge from the Edwards Aquifer in Bexar County increased more than 100,000 acre-feet per year from 1939-1958 to 1996-2014 (Figure 4) due to a large increase in pumping. Municipal supply is the largest user of groundwater in Bexar County, accounting for about 86% (224,000 acre-feet per year) of pumping from the Edwards Aquifer in Bexar County from 1996-2014 (Edwards Aquifer Authority 2015). Return flows from municipal use are treated at wastewater treatment plants to meet surface water quality standards before the water is returned to the San Antonio River.

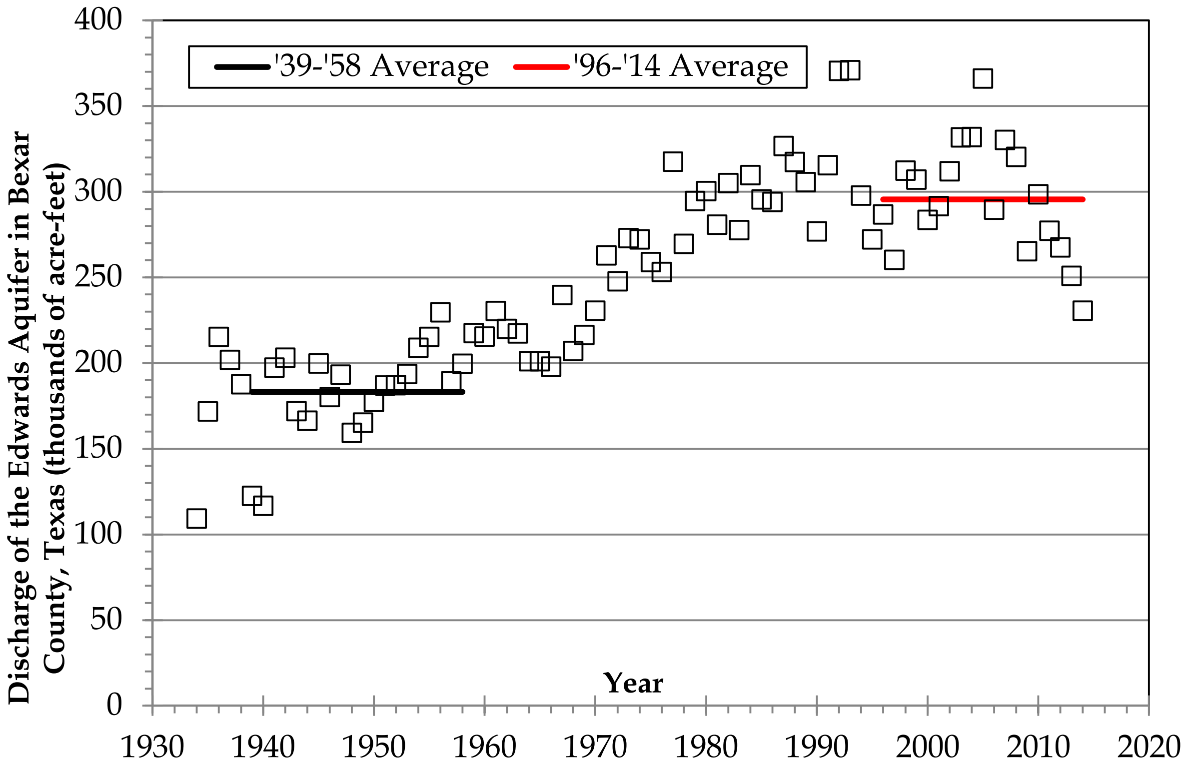


Figure 4. Annual discharge of the Edwards Aquifer in Bexar County, Texas due to pumping and spring flow (data from the Edwards Aquifer Authority 2015).

The amount of wastewater treated by the San Antonio Water System has grown steadily from about 20,000 acre-feet per year in 1940 to almost 150,000 acre-feet per year in 1980 (Clouse 2010). From 1940 to 1960, treated wastewater averaged about 50,000 acre-feet per year. Since 1980, the volume of treated wastewater has averaged close to 150,000 acre-feet per year. Some of the wastewater treated each year is reused to meet needs for landscape watering and industrial processes in and around the City of San Antonio. From 1996-2009, wastewater return flows from the City of San Antonio have contributed an average of about 110,000 acre-feet per year to the annual flow volume at USGS Gage No. 08183500 San Antonio River near Falls City (Clouse 2010).

An examination of annual peak flows for USGS Gage No. 08183500 San Antonio River near Falls City (Figure 5) does not show any significant changes over time. Annual peak flows for this gage are highly variable but do not show a strong trend over time. Application of a Kruskal-Wallis test (Helsel and Hirsch 2002) does not confirm a change in annual peak flows from the early time period (March 1939-February 1959) compared to the most recent time period (1996-2015).Peak annual flows at this location do not appear to be effected by upstream urbanization.

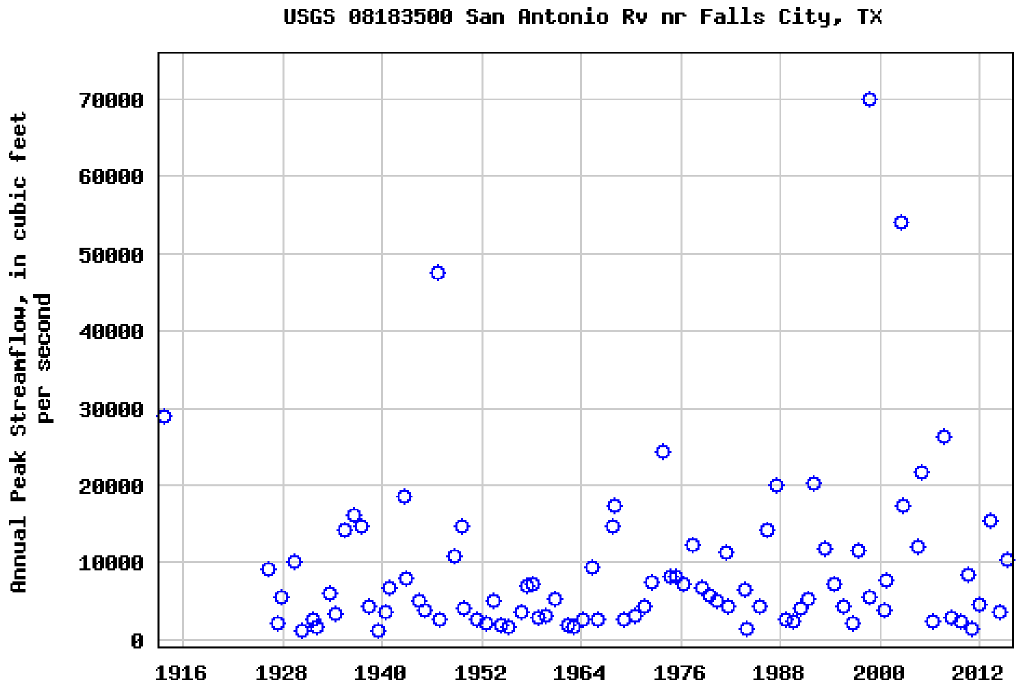


Figure 5. Annual peak streamflow at USGS Gage No. 08183500 San Antonio River near Falls City, Texas.

Examination of flows smaller than annual peak flows show evidence of change over time. Flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City are significantly different for the early time period (March 1939-February 1959) compared to the most recent time period (1996-2015) (Figure 6 and Table 5). Recent low flows (exceeded 95% or more of the time) have been elevated 40 cfs from the earlier time period (about a 70% increase)(Table 5). At median flows, the recent gaged data are elevated about 65% from the earlier time period. Flows exceeded 10% of the time are more than double what they were in the earlier time period. Flows exceeded 1% of the time are about 80% more than in the earlier time period. Application of a Kruskal-Wallis test (Helsel and Hirsch 2002) to the daily flow data confirms that the data are from two different distributions.

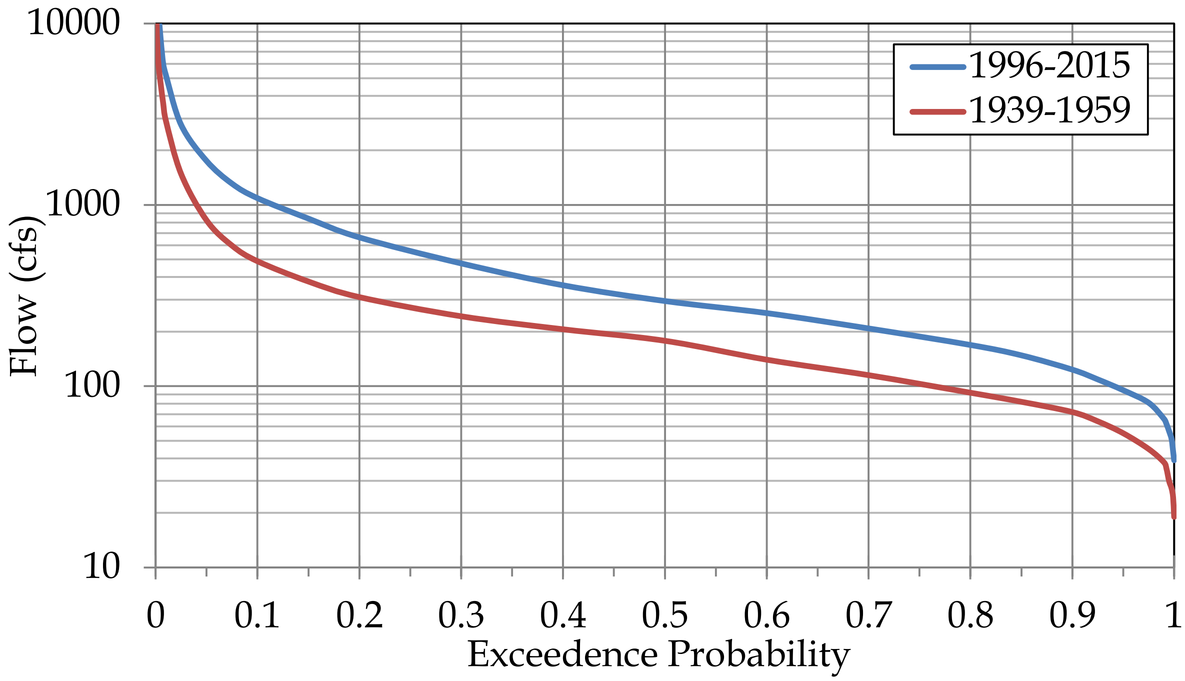


Figure 6. Flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for an early (March 1939-February 1959) and late (1996-2015) time period.

The comparison of data from USGS Gage No. 08183500 San Antonio River near Falls City for the two time periods (March 1939 to February 1959 and January 1996 to December 2015) reveals some interesting clues about how recent human activity has impacted the hydrology of the lower San Antonio River basin. First, annual peak flows are not significantly different for the two time periods. Falls City appears to be far enough downstream that effects of urbanization upstream do not show up in annual peak flows. Second, the two large reservoirs that were constructed between these time periods (Calaveras and Victor Braunig lakes) also don't appear to have any impact on peak flows at this location. That is not too surprising because these reservoirs are cooling lakes for power plants on tributaries of the San Antonio River and have no flood storage.

The average annual flow of the San Antonio River at Falls City increased from 225,000 acre-feet per year in the earlier time period (March 1939 to February 1959) to 440,000 acre-feet in the recent time period (1996-2015). That is an increase in average flow volume of about 215,000 acre-feet, or about 97% of the average annual volume of the earlier time period. As mentioned previously, annual precipitation was about 7% more in the later time period than in the earlier time period, accounting for more than 15,000 acre-feet per year of difference. As described by Clouse (2010), return flows from the City of San Antonio account for about 100,000 acre-feet per year of difference. That leaves about 100,000 acre-feet per year of flow difference between the two time periods. Urbanization in the upper basin, particularly increased impervious cover, is the most likely cause for the remaining increase in flow.

In the case of the lower San Antonio River, both high flows and low flows have increased during a period of rapid urbanization upstream. Increased impervious cover is most likely the mechanism that has increased higher flows. At the same time, increased return flows from groundwater pumping is most likely the mechanism that has increased low flows.

Table 5. Flow exceedance statistics for USGS Gage No. 08183500 San Antonio River near Falls City for an early (March 1939-February 1959) and late (1996-2015) time period.

Exceedence Probability (-)	Time Period 3/1/1939 to 2/28/1959 (cfs)	1/1/1996 to 12/31/2015 (cfs)
0.00	42,200	53,800
0.01	10,309	24,740
0.25	6,290	12,692
0.50	4,644	8,179
0.75	3,620	5,970
1.00	2,928	5,227
2.50	1,484	2,768
5.00	823	1,750
7.50	596	1,310
10.00	489	1,090
15.00	378	841
20.00	310	662
30.00	243	476
40.00	206	360
50.00	178	295
60.00	140	253
70.00	115	208
80.00	92	169
85.00	82	148
90.00	72	123
92.50	64	109
95.00	55	95
97.50	45	81
99.00	38	66
99.25	35	62
99.50	30	57
99.75	27	51
99.90	24	44
100.00	19	39

Although there is evidence that the hydrology of the lower San Antonio River sub-basin has changed from the early (March 1939-February 1959) to the recent (1996-2015) time period, the recent time period (1996-2015) was chosen as the base line hydrology for this study. Literature review, interaction with stakeholders, and biological assessments carried out during this study confirm that the lower San Antonio River sub-basin remains a funcitioning and sustainable ecosystem that meets the expectations of stakeholders, state agencies, and the public. The current condition of the system has been most greatly influenced by the hydrology of the most recent time period (1996-2015). The hydrology of the recent time period (1996-2015) includes sufficient inter- and intra-annual variability to sustain the current environmental conditions of the river sub-basin. Therefore, the hydrology of the recent time period (1996-2015) was chosen as the basin line for analysis of flow-ecology relationships (e.g. fish and mussel habitat, riparian inunndation, and sediment transport) and the context for instream flow recommendations. Preserving important features of the recent hydrology (1996-2015) was deemed adequate to support the current condition of the riverine ecosystem.

2.2.2 *Hydraulic and Habitat Models*

The 2D hydraulic model utilized for this project was River2D, a two-dimensional, depth-averaged, finite element, hydrodynamic code developed at the University of Alberta (Steffler and Blackburn 2002). River2D predicts water depth and velocity based upon observed inputs including flow rate, elevation and bathymetry data. Recent projects using River2D for aquatic habitat modeling include the lower Colorado River, Texas (BIO-WEST 2008), Green and Yampa Rivers (Bowen et al. 2001), the Yellowstone River (Bowen et al. 2003), Canadian prairie rivers (Katapodis 2003), and the Columbia River (Hanrahan et al. 2004).

Field data necessary for the model included the following:

- Topography/bathymetry
- Water surface elevations
- Discharge
- Substrate
- Instream Cover

At each intensive Study Site, complete channel and near-channel floodplain Digital Terrain Models were created using a combination of conventional equipment and survey-grade GPS equipment coupled with hydro-acoustic depth sounding data. Survey data were reviewed for completeness (missing data, holes in the topography, spikes, etc.) using custom software (Osting 2009), ArcView software, and Trimble software. Supplementary topographic surveying was conducted to ensure sufficient coverage of each intensive Study Site.

Calibration data for 2D hydraulic modeling consisted of measurements to develop a stage-discharge relationship at the upstream and downstream end of each Study Site. Water surface elevations were measured throughout the site at a minimum of three different discharges. Detailed water surface elevations were measured with survey grade GPS (centimeter accuracy) and/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 and pressure transducer was installed at the upstream and downstream end of the Study Site to document any changes in stage. Water level measurements were referenced to onsite benchmarks installed at site boundaries (upstream and downstream) and at intermediate transition points (mid-site or at grade controls). Elevation for each benchmark was referenced using post-processed survey-grade GPS to established nearest available NGS elevation bench marks.

Substrate was mapped based on dominant particle size (Figure 7). In areas too deep for visual characterization, sampling with a pole Ekman dredge, scoop on a pole, or sounding was used to characterize the substrate. Classification was based on a modified Wentworth scale. Instream cover such as aquatic macrophytes, woody debris, etc., were also mapped and considered during calibration of roughness (Figure 8).

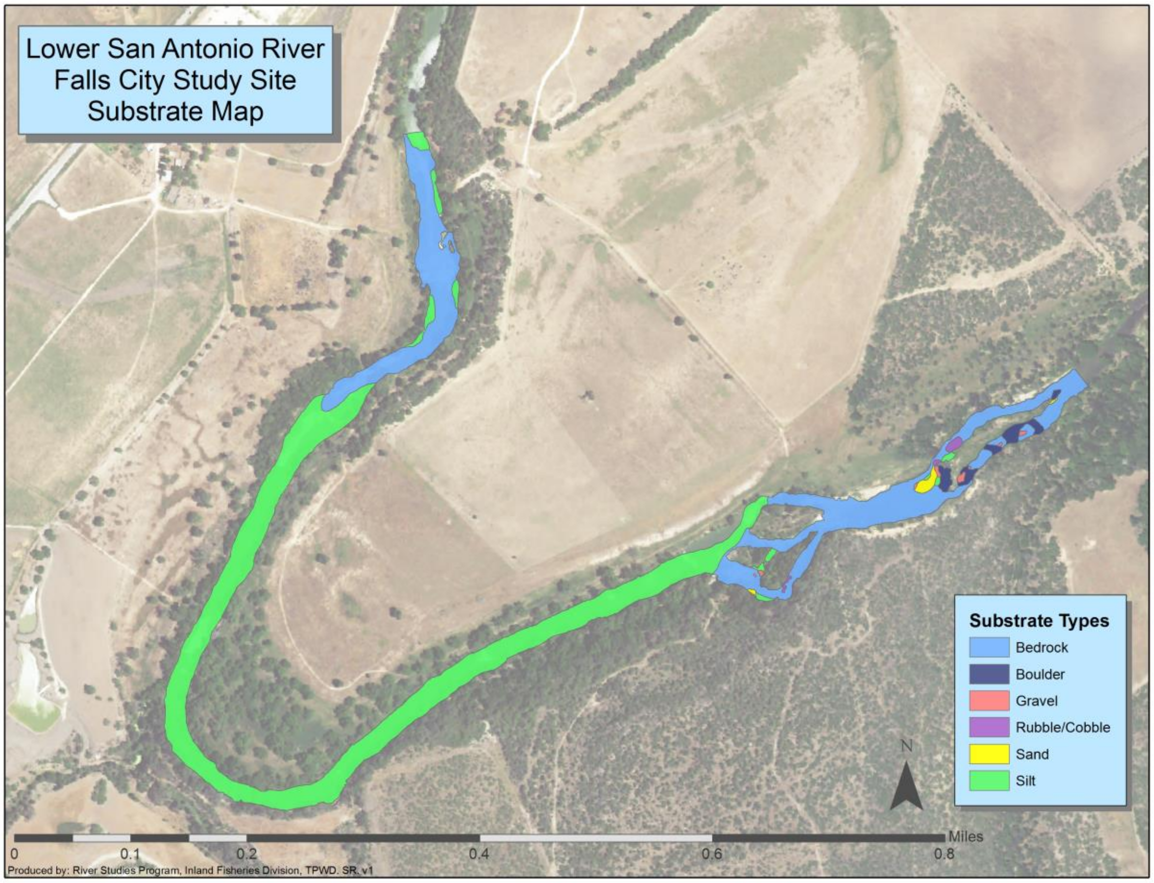


Figure 7. Substrate characterization at the San Antonio River Falls City Study Site.

Digital terrain models (e.g., Figure 9) were generated for each Study Site using all available topographic and elevation data. The hydraulic model mesh geometry was created from the DTM and mesh refinement involved localized geometry refinement and application of substrate roughness. Calibration of model output at all Study Sites considered available elevation, flow, velocity, and depth measurements.

Spatially-explicit 2D hydraulic model output was used to determine area of available habitat (see Section 2.3) for a range of flows between 2 cfs and 150 cfs for lower Cibolo Creek, between 15 cfs and 1,000 cfs for the Calaveras Study Site, between 30 cfs and 1,500 cfs for the Falls City and Goliad Study Sites, and 100 and 1,500 cfs for the Hwy 77 Study Site. These flow ranges span the flows of interest to habitat analysis at these sites. Lower flows are encountered less than 2.5% of the time and flows above these ranges occured less than 15% of the times at any of the sites as measured at the nearest USGS gage for the period 1996-2015.

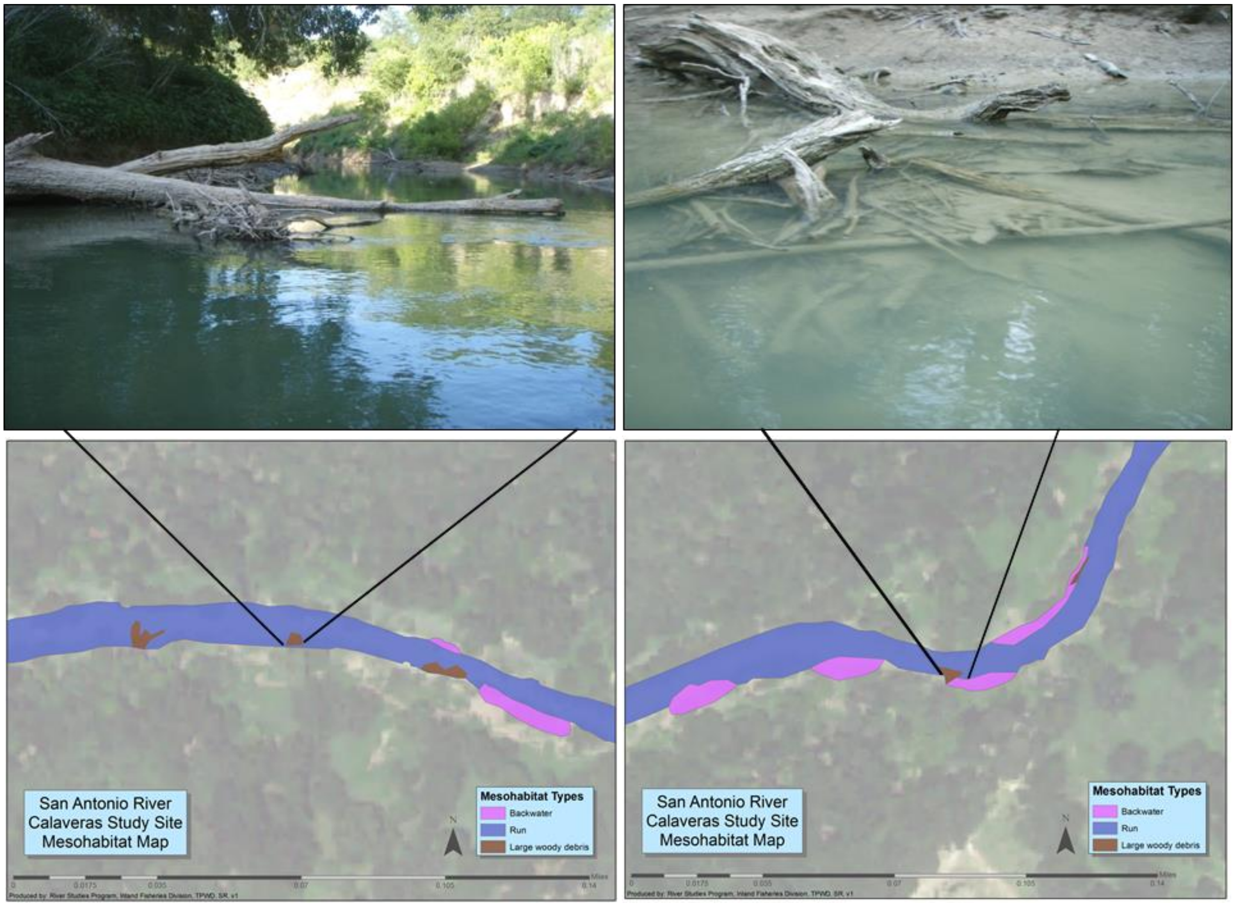


Figure 8. Instream cover (large woody debris) characterization at the San Antonio River Calaveras Study Site.

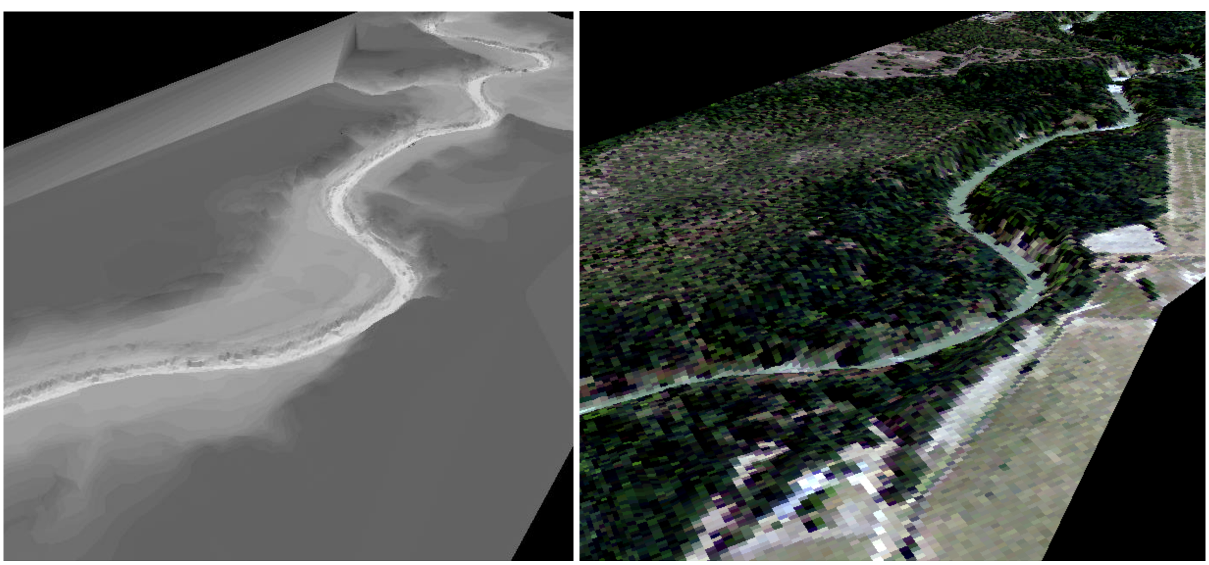


Figure 9. Digital Terrain Model for the San Antonio River Calaveras Study Site.

Model calibration was completed based on field data collected for at least three flow rates at each site. To model additional flow rates, rating curves relating flow rate to water surface elevation were developed at each site to determine boundary conditions. Depending on site geometry, a uniform, triangular, finite element mesh with approximately 5 to 10 ft (1.5 to 3 m) spacing between nodes (vertices) was used at each site (Figure 10). Based upon field data, the model mesh included channel areas both upstream and downstream of site boundaries. Habitat was not considered in these "extra" upstream and downstream areas located outside the site boundaries. The model included these extra areas to ensure depth and velocity fields inside the site boundaries were not influenced by spurious numerical effects that have the potential to occur at upstream and downstream boundaries. Similarly, the model mesh included near-channel floodplain area on both sides of the channel to ensure wetted water edges along the banks did not touch model edges. At each site, the same geometric mesh was used for all modeled flow rates; adjustments to the bed elevations and x-y locations made at a particular steady-state flow rate were carried through to each of the other flow rates at the same site.

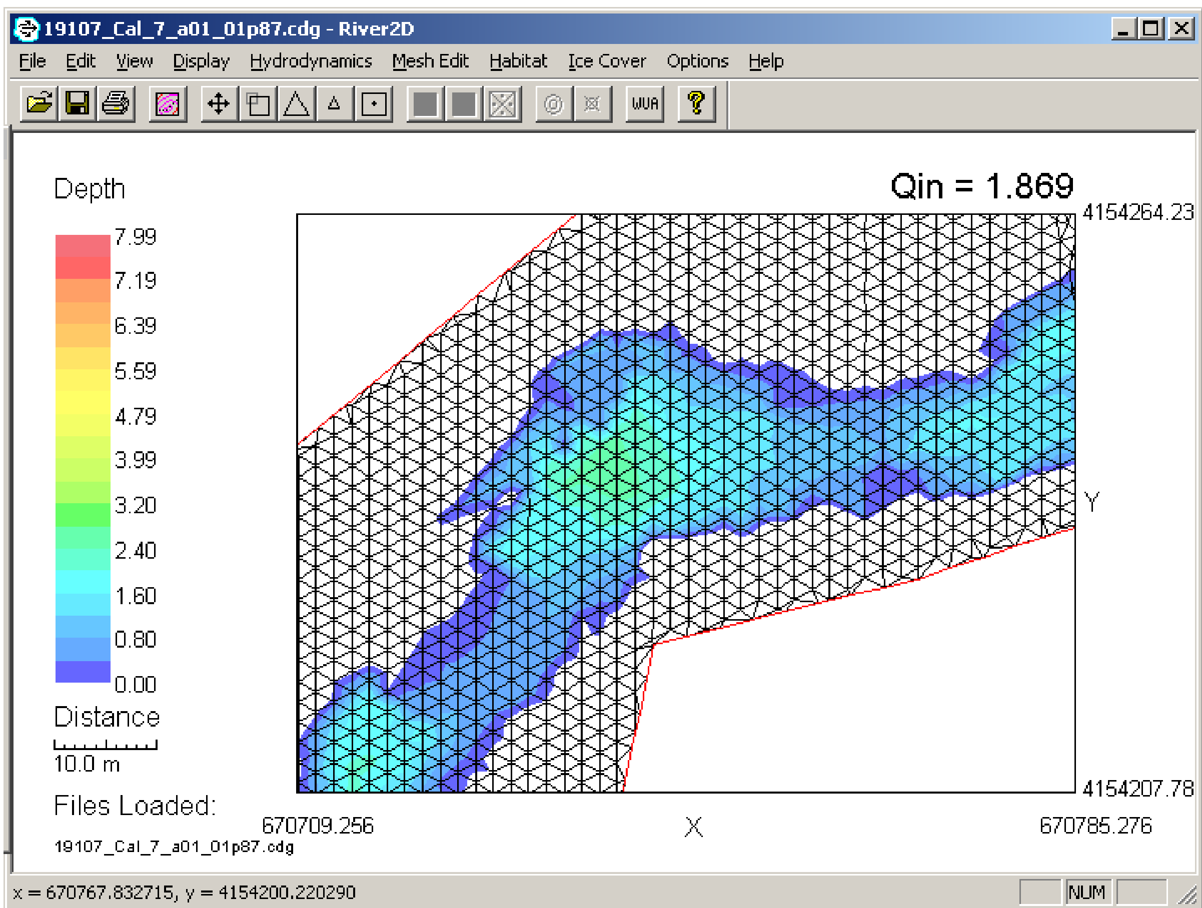


Figure 10. River2D model mesh for the San Antonio River Calaveras Study Site.

Calibration proceeded by adjusting model inputs so that model predictions of water surface elevation tracked field observations. Roughness, and to lesser extents bathymetry and the downstream water surface elevation boundary condition, were the three model parameters adjusted to calibrate the models. Spatially-varying roughness, input at each model node, was based upon substrate and instream cover mapping. Chezy roughness height for each node was initially set to the maximum diameter of each size class associated with the node. During calibration, a multiplier was applied to the initial roughness estimate for each node with a similar size class.

Water surface elevation was the primary indicator used for calibration; point measurements of depth and velocity were supplementary. Adjustments to model inputs were made until model predictions for water surface elevation matched field data near the downstream benchmark, near the upstream benchmark, and at intermediate locations where field data were available. Predicted depth and velocity were matched as nearly as possible at discrete points where observations were available. In limited areas exhibiting abrupt, localized changes in water surface elevation, bathymetric complexities (e.g., areas with rock outcrops or ridges forming water surface steps) were incorporated into the mesh where bathymetric, photographic, and/or water surface elevation data were available. Based upon professional judgment, additional changes to bathymetry were made in localized areas (e.g., within secondary channels or within constricted areas of the main channel during very low flow) to ensure predicted flow rate, wetted width, water edge, and/or water surface elevations match observations.

Calibrated models adequately reproduced the hydraulic charateristics of flow at each intensive Study Site. For most flow rates, the predicted water surface elevation profile matched observations within 2 inches (5 cm) and many modeled results matched observations within ¾ inches (2 cm). Validation measures included water surface elevation measurements at upstream and mid-reach locations, field maps of water edge, and comparison to velocity and depth point measurements. The River2D model results are presented in Section 2.3 with the habitat modeling assessment.

2.2.3 *High Flow Pulse and Overbank Flow Assessment*

Using HEC-RAS models and high-resolution LIDAR topography, extent of inundation was evaluated along the length of the river for a series of high flow pulses and overbanking flows. This analysis was valuable in assessing the hydrologic indicators of these flow components relative to riparian communities. The range of flows evaluated had recurrence intervals ranging from less than a year (high flow pulses) to 10 years (overbank flows). Given the small magnitudes of these flows relative to the large magnitudes typically analyzed for flood studies (e.g., 100-year flood), the in-channel bathymetry was an important factor when examining the intersection of flow and riparian transect data. The HEC-RAS model results are presented in Section 2.3 with the riparian community analysis.

2.3 *Biology*

Sixty fish species have been reported from the mainstem of the San Antonio River from collections dating back to 1950. Life history and population information for these species are provided in the Study Design and are based upon scientific studies (Bonner and Runyan 2007, Warren et al. 2000, Simon 1999, Linam and Kleinsasser 1998, Hubbs et al. 1991, Williams et al. 1989, Balon 1981, Balon 1975, Hildebrand and Cable 1938,). 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

L. 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. 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*.

Several species were identified as indicator species during a series of stakeholder meetings based upon their abundance and sensitivity to water quality and flow. These included Burrhead Chub *Macrhybopsis marconis*, American Eel *Anguilla rostrata*, Pugnose Minnow, all darter species, 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 50 or 60 m 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.

2.3.1 *Fisheries*

Fish habitat utilization data were collected over two separate time periods. To ensure coverage of a wide range of base flow conditions, collections were made between August 2009 and July 2011 whenever the flows were near predetermined target levels that represented low, moderate, and high base flows based on hydrological statistics (Tables 6 and 7). Additional data were collected between May 2012 and February 2014. These data were collected on a seasonal basis rather than being driven by target flow levels (Table 8). As a consequence all but four seasonal samples were collected under moderate target base flow levels. Three seasonal samples were collected in high target base flows (Falls City, Fall 2012; Cibolo Creek, Winter 2013 and 2014). Only one seasonal sample was collected within low target base flow levels (Falls City, Summer 2012) even though most of this time period was beset with severe drought conditions. The drought did not appear to significantly affect the fish assemblage, based on a comparison of Aquatic Life Uses calculated using fish data collected before and after the drought, thus combining this seasonally collected data with that collected earlier was deemed appropriate.

During each sampling event targeted at a specific base flow condition, a stratified random sampling approach was used to sample each hydromorphological unit (HMU) and substrate combination in proportion to its relative abundance. To capture a snapshot of HMU distribution within each Study Site at the time of sampling, GPS-based HMU maps (Figure 11) were developed immediately prior to, and at a similar flow rate to, each fish sampling event using a Trimble GPS unit capable of sub-meter accuracy mounted on a kayak. HMUs encountered and sampled as part of this study include pools, backwaters, runs, and riffles. A description of the characteristics of each respective HMU is reported in TIFP (2008).

Table 6. Date and mean daily discharge from the nearest USGS gage for each fish habitat utilization sampling trip at each Study Site during each target flow level.

Target Flow	Site	Sampling Date	Mean Daily Discharge (cfs)
Low	Cibolo Creek	08/27/09	10
	Calaveras	08/11/09	88
	Falls City	09/01/09	77
	Goliad	07/28/11	79
	Hwy 77	07/27/11	145
Moderate	Cibolo Creek	08/26/10	23
	Calaveras	06/22/10	255
	Falls City	08/03/10	243
	Goliad	08/05/10	311
	Hwy 77	08/12/10	320
High	Cibolo Creek	11/12/09	57
	Calaveras	03/30/10	345
	Falls City	03/10/10	562
	Goliad	03/31/10	559
	Hwy 77	04/07/10	528

Table 7. Discharge values associated with target flow levels at each Study Site based upon the nearest USGS gage.

Target Flow	Site	USGS Gage No.	Discharge (cfs)
Low	Cibolo Creek	08186000	<10
	Calaveras	08181800	<110
	Falls City	08183500	<110
	Goliad	08188500	<150
	Hwy 77	08188570	<150
Moderate	Cibolo Creek	08186000	10 - 25
	Calaveras	08181800	110 - 275
	Falls City	08183500	110 - 275
	Goliad	08188500	150 - 325
	Hwy 77	08188570	150 - 325
High	Cibolo Creek	08186000	>25 - <55
	Calaveras	08181800	>275 - <475
	Falls City	08183500	>275 - <475
	Goliad	08188500	>150 - <750
	Hwy 77	08188570	>150 - <750

Table 8. Date and mean daily discharge from the nearest USGS gage for each seasonal fish habitat utilization sampling trip at each Study Site.

Target Season	Site	Sampling Dates		Discharge (cfs)	
		Event 1	Event 2	Event 1	Event 2
Spring	Cibolo Creek	04/17/13	04/02/14	21	25
	Calaveras	04/16/13	04/01/14	217	147
	Floresville	05/01/12	04/23/13	177	143
	Falls City	05/07/12	04/22/13	214	167
	Goliad	–	04/25/13	–	171
	Hwy 77	04/15/13	03/31/14	245	199
Summer	Cibolo Creek	06/25/13	08/07/13	20	10
	Calaveras	06/26/13	08/12/13	110	112
	Floresville	08/01/12	07/22/13	101	175
	Falls City	08/02/12	07/23/13	101	176
	Goliad	07/30/12	07/25/13	183	239
	Hwy 77	06/24/13	08/05/13	266	160
Fall	Cibolo Creek	11/12/12	11/20/13	24	27
	Calaveras	11/14/12	11/19/13	127	194
	Floresville	11/19/12	10/22/13	137	220
	Falls City	11/05/12	10/21/13	388	220
	Goliad	11/20/12	10/24/13	212	272
	Hwy 77	11/13/12	11/18/13	293	177
Winter	Cibolo Creek	01/31/13	01/15/14	25	27
	Calaveras	01/30/13	01/14/14	184	161
	Floresville	01/30/13	02/03/14	201	161
	Falls City	01/29/13	01/22/14	178	191
	Goliad	01/31/13	01/27/14	255	215
	Hwy 77	02/12/13	01/13/14	314	308

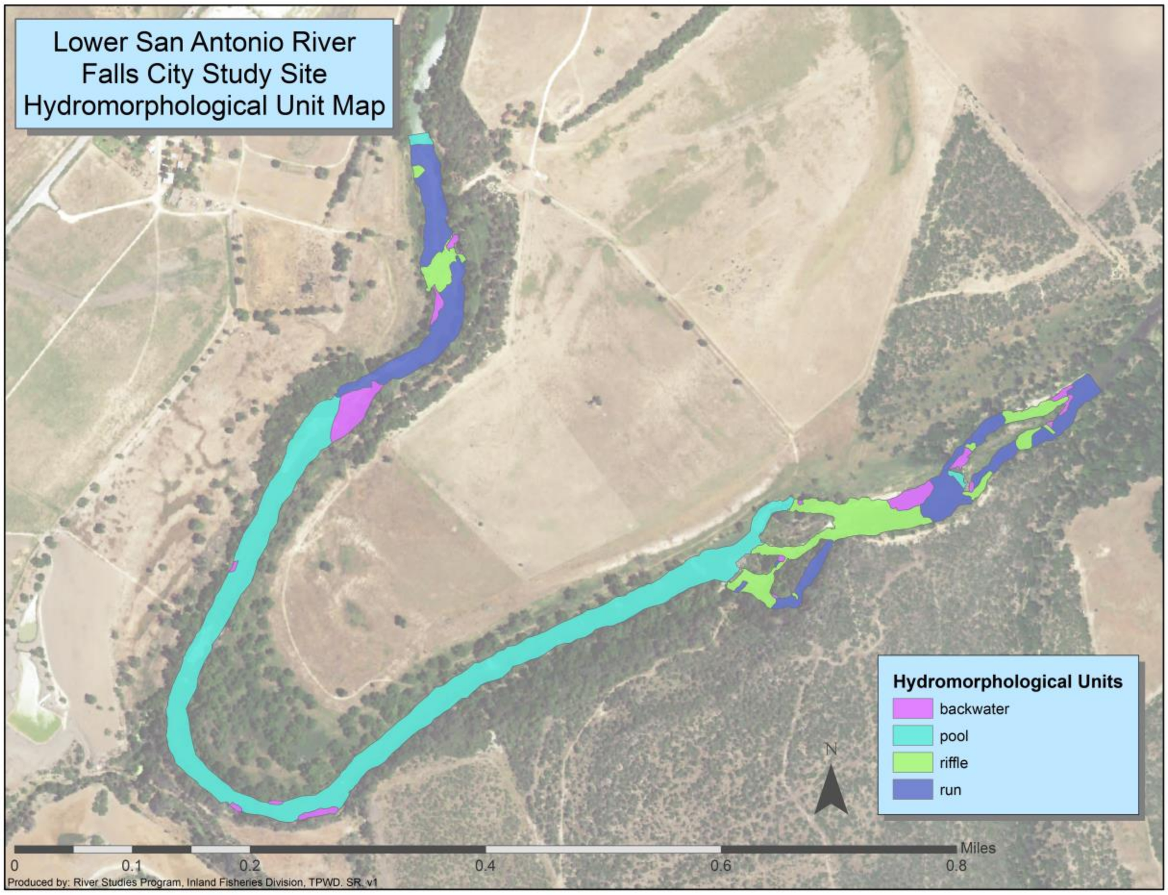


Figure 11. Hydromorphological unit map for the Falls City Study Site.

Using ArcMap, these maps were overlaid on the previously collected substrate layers from each site, and sample areas were randomly selected within each appropriate HMU-substrate category. Backup points were also selected for each HMU-substrate category in the event that primary points were deemed inappropriate in the field. Randomly selected points that fell within approximately 6.5 ft (2 m) of the river's edge were designated as "Edge", whereas those that fell away from the edge were designated as "Mid-Channel". These randomly selected points were then labeled with their appropriate HMU-substrate-edge designation (e.g., Run Sand Mid-Channel or Pool Silt Edge) and loaded into a GPS unit that was used to locate sampling areas in the field. After sampling areas were located, depth, velocity, and substrate were appraised to ensure selection of an area with relatively uniform habitat. Once areas of uniform habitat were identified around each randomly selected point, flagging or small weighted buoys were used to mark the corners/edges of the area. The sample area was then left undisturbed for at least 30 minutes to allow fish to recolonize before being sampled. Typically, sample areas were selected and marked early in the morning, with fish sampling occurring later that afternoon.

Exact dimensions of sampling areas were variable, depending on uniformity of habitat variables. Sample areas identified as Edge were typically long and rectangular with sampling only conducted within 6.5 ft (2 m) of the river's edge. Sample areas identified as Mid-Channel were typically square in shape and sampling was not conducted near the river's edge. Mid-Channel sample areas were typically larger than Edge sample areas due to the lower density of fish in Mid-Channel areas.

GPS-based HMU maps were not employed during seasonal sampling. Instead, researchers attempted to collect fishes from each representative habitat complex (HMU and substrate combination) in relative proportion to the habitat's abundance based upon visual inspection of the sample reach. An additional sample location was added during seasonal sampling (Floresville) to address concerns raised about possible water quality issues in that area.

Fish sampling was conducted with boat electrofishing, barge electrofishing, and seining to provide effective coverage of a wide range of habitats. In deeper areas (over about 1 m) boat electrofishing was typically used. Seining was typically employed to most effectively sample shallow, wadeable areas of slow to moderate velocity. In wadeable areas with large woody debris or coarse substrates that made seining difficult, barge-style electrofishing with a hand-held wand and two to three netters was used. In shallow, high-velocity riffles and runs a barge electrofisher with hand-held wand was used with a seine set at the downstream boundary of the discrete sampling area (see below for designation of sampling area). Sampling techniques were selected based on which would be most effective at capturing fish at each particular sampling area given the depth, velocity, substrate, and cover conditions present.

Once captured, large fish were identified to species, measured (total length in mm), and released. Smaller specimens were often fixed in 10% formalin for later identification, enumeration, and measurement in the laboratory. For voucher specimens, at least one individual of smaller species (e.g., minnows and darters) was retained, whereas digital photographs were used to document larger fish.

Upon completion of fish sampling, velocity, depth, and substrate were characterized at five points representing each corner and the middle of the sample area. Velocity and depth were measured using a Marsh-McBirney Flowmate Model 2000 portable flow meter and incremental wading rod. Dominant surficial substrates were classified as silt, sand, gravel, cobble, boulder, or bedrock following the standard Wentworth scale based on particle size. Dissolved oxygen, water temperature, pH, and specific conductivity were also measured in each sample area with a calibrated multiprobe instrument. Although these data were not used in development of Habitat Suitability Criteria (HSC), they provide quantitative spatially-explicit water quality conditions present at the time of sampling, which were subsequently used to verify the water quality models developed.

Fisheries Sampling Results and Habitat Suitability Criteria Development

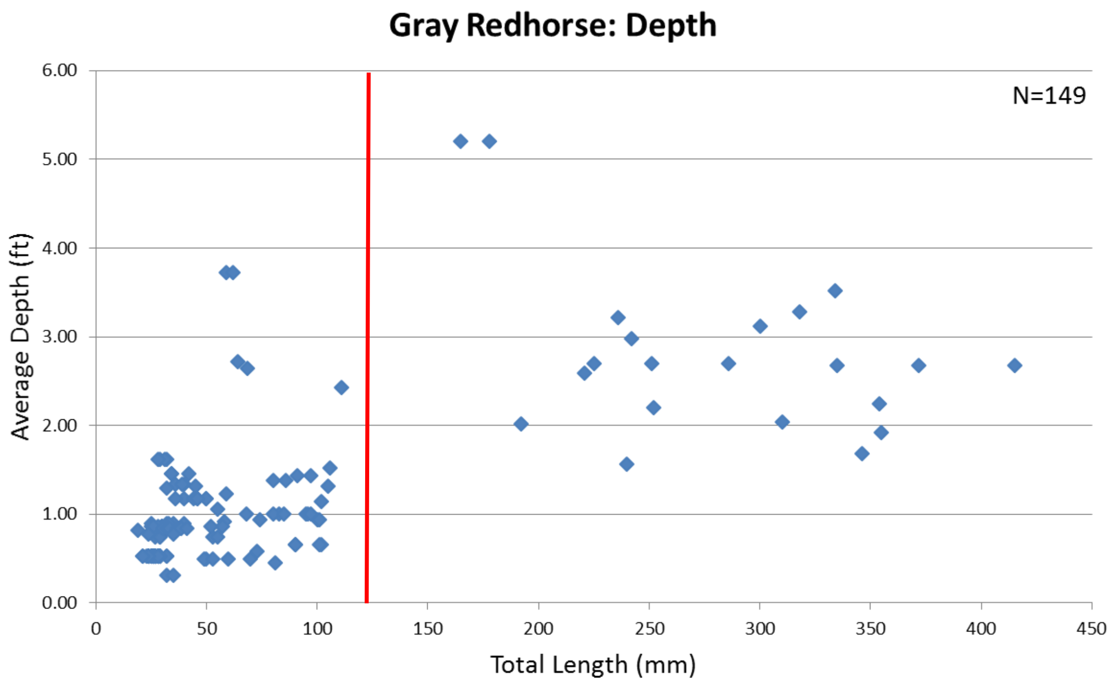
Fishes were collected in 1147 separate sample areas distributed among multiple HMU-substrate combinations at five Study Sites and Floresville across a wide range of base flow conditions. This resulted in the capture of 74,071 individual fish representing 16 families and 49 species (Table 9).

Table 9. Number (#) and relative abundance (%) of fishes collected from five Study Sites and Floresville during the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study. Species are listed in phylogenetic order.

		Cibolo Creek		Calaveras		Floresville		Falls City		Goliad		Hwy 77		Grand Total	
Common Name	**Scientific Name**	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Alligator Gar	*Atractosteus spatula*									1	0.0	1	0.01	2	0.0
Spotted Gar	*Lepisosteus oculatus*	10	0.1	11	0.2	1	0.0	2	0.0	7	0.0	5	0.03	36	0.0
Longnose Gar	*Lepisosteus osseus*	11	0.1	13	0.2	9	0.2	10	0.0	18	0.1	17	0.10	78	0.1
American Eel	*Anguilla rostrata*							1	0.0	1	0.0			2	0.0
Gizzard Shad	*Dorosoma cepedianum*	72	0.8	25	0.4	54	1.2	21	0.1	49	0.3	6	0.04	227	0.3
Threadfin Shad	*Dorosoma petenense*					1	0.0	2	0.0	6	0.0			9	0.0
Central Stoneroller	*Campostoma anomalum*			74	1.3			7	0.0					81	0.1
Red Shiner	*Cyprinella lutrensis*	2507	27.2	2047	35.6	1688	38.6	10972	50.2	8705	54.6	13298	78.49	39217	52.9
Blacktail Shiner	*Cyprinella venusta*	1	0.0	1,114	19.4	9	0.2	47	0.2					1171	1.6
Red x Blacktail Shiner hybrid	*C. lutrensis* x *C. venusta*					9	0.2	23	0.1					32	0.0
Common Carp	*Cyprinus carpio*	1	0.0	7	0.1	5	0.1	9	0.0	12	0.1	1	0.01	35	0.0
Burrhead Chub	*Machrybopsis marconis*			567	9.9	25	0.6	248	1.1	99	0.6	7	0.04	946	1.3
Golden Shiner	*Notemigonus crysoleucas*											3	0.02	3	0.0
Ghost Shiner	*Notropis buchanani*	7	0.1			16	0.4	593	2.7	388	2.4	27	0.16	1031	1.4
Mimic Shiner	*Notropis volucellus*	2516	27.3	115	2.0			26	0.1			105	0.62	2762	3.7
Pugnose Minnow	*Opsopoeodus emiliae*									3	0.0	6	0.04	9	0.0
Fathead Minnow	*Pimephales promelas*							4	0.0					4	0.0
Bullhead Minnow	*Pimephales vigilax*	900	9.8	377	6.6	1872	42.8	5599	25.6	4540	28.5	1575	9.30	14863	20.1
Smallmouth Buffalo	*Ictiobus bubalus*	3	0.0	6	0.1	5	0.1	19	0.1	28	0.2	12	0.07	73	0.1
Gray Redhorse	*Moxostoma congestum*	110	1.2	21	0.4	4	0.1	4	0.0	11	0.1	1	0.01	151	0.2
Mexican Tetra	*Astyanax mexicanus*	36	0.4	3	0.1	2	0.0	47	0.2	20	0.1	25	0.15	133	0.2
Yellow Bullhead	*Ameiurus natalis*	3	0.0	2	0.0							1	0.01	6	0.0
Blue Catfish	*Ictalurus furcatus*			1	0.0			4	0.0	12	0.1	112	0.66	129	0.2
Channel Catfish	*Ictalurus punctatus*	139	1.5	334	5.8	56	1.3	444	2.0	116	0.7	66	0.39	1155	1.6
Tadpole Madtom	*Noturus gyrinus*	5	0.1	45	0.8			2	0.0	5	0.0	2	0.01	59	0.1
Flathead Catfish	*Pylodictis olivaris*	10	0.1	19	0.3	18	0.4	39	0.2	56	0.4	88	0.52	230	0.3
Armadillo Del Rio	*Hypostomus plecostomus*			27	0.5			3	0.0					30	0.0
Suckermouth Armored Catfish	*Pterygoplichthys anisitsi*			84	1.5	8	0.2	61	0.3	4	0.0			157	0.2
Striped Mullet	*Mugil cephalus*									7	0.0	13	0.08	20	0.0
Inland Silverside	*Menidia beryllina*							8	0.0	1	0.0			9	0.0
Western Mosquitofish	*Gambusi affinis*	835	9.1	225	3.9	149	3.4	1326	6.1	517	3.2	1265	7.47	4317	5.8
Amazon Molly	*Poecilia formosa*			22	0.4	153	3.5	1098	5.0	244	1.5	56	0.33	1573	2.1
Sailfin Molly	*Poecilia latipinna*	202	2.2	44	0.8	24	0.5	178	0.8	464	2.9	50	0.30	962	1.3
Sheepshead Minnow	*Cyprinodon variegatus*			1	0.0			27	0.1					28	0.0
Redbreast Sunfish	*Lepomis auritus*	2	0.0											2	0.0
Green Sunfish	*Lepomis cyanellus*	39	0.4	15	0.3	1	0.0	10	0.0	9	0.1			74	0.1
Warmouth	*Lepomis gulosus*	29	0.3	6	0.1	6	0.1	4	0.0	3	0.0	4	0.02	52	0.1
Orangespotted Sunfish	*Lepomis humilus*	52	0.6	14	0.2	1	0.0	9	0.0	70	0.4	15	0.09	161	0.2
Bluegill	*Lepomis macrochirus*	212	2.3	41	0.7	13	0.3	34	0.2	22	0.1	11	0.06	333	0.4
Longear Sunfish	*Lepomis megalotis*	1131	12.3	228	4.0	162	3.7	259	1.2	355	2.2	140	0.83	2275	3.1
Redear Sunfish	*Lepomis microlophus*	1	0.0							2	0.0			3	0.0
Sunfish sp. (juvenile)	*Lepomis* sp.	23	0.2	15	0.3							8	0.05	46	0.1
Spotted Bass	*Micropterus punctulatus*	65	0.7	55	1.0	9	0.2	35	0.2	64	0.4			228	0.3
Largemouth Bass	*Micropterus salmoides*	41	0.4	26	0.5	14	0.3	19	0.1	12	0.1	9	0.05	121	0.2
White Crappie	*Pomoxis annularis*			4	0.1	1	0.0			2	0.0	3	0.02	10	0.0
Black Crappie	*Pomoxis nigromaculatus*	1	0.0											1	0.0
Texas Logperch	*Percina carbonaria*	90	1.0	20	0.3			2	0.0	3	0.0			115	0.2
River Darter	*Percina shumardi*	43	0.5							22	0.1			65	0.1
Freshwater Drum	*Aplodinotus grunniens*									8	0.1	3	0.02	11	0.0
Rio Grande Cichlid	*Herichthys cyanoguttatus*	109	1.2	143	2.5	39	0.9	620	2.8	55	0.3	6	0.04	972	1.3
Blue Tilapia	*Oreochromis aureus*			4	0.1	19	0.4	37	0.2			2	0.01	62	0.1
Total		9206		5755		4373		21853		15941		16943		74071	
Species Richness		31		35		29		38		38		33		49	

Nine species (Common Carp *Cyprinus carpio*, Mexican Tetra *Astyanax mexicanus*, Suckermouth Armored Catfish *Pterygoplichthys anisitsi*, Armadillo Del Rio *Hypostomus plecostomus*, Sailfin Molly *Poecilia latipinna*, Amazon Molly *P. formosa*, Redbreast Sunfish *L. auritus,* Rio Grande Cichlid *Herichthys cyanoguttatus*, and Blue Tilapia *Oreochromis aureus*) were considered introduced or exotic to the river basin and were therefore not considered in further analysis. Several other species were relatively rare and were captured at only a few locations. To exclude species for which there were insufficient data, only species collected in five or more sample areas with five or more individuals were included in the analysis. This excluded eight additional species: Alligator Gar *Atractosteus spatula*, Sheepshead Minnow *Cyprinodon variegatus*, Redear Sunfish *L. microlophus*, Black Crappie *Pomoxis nigromaculatus*, Yellow Bullhead *Ameiurus natalis*, American Eel, Fathead Minnow *Pimephales promelas*, and Golden Shiner *Notemigonus crysoleucas*. One exception was made for Pugnose Minnow, which was represented by nine individuals at four sample areas, but was included in the analysis since it was labeled a key indicator species for the study (TIFP and SARA 2012). American Eel was also identified as an indicator species, but only two individuals were collected and thus, not applicable for this analysis.

Many species of fish are thought to undergo ontogenetic changes in their habitat preferences as they grow and mature. For example, small juveniles of a species may occupy different habitats than mature adults. To examine such size-dependent changes in habitat use, average depth and average velocity were plotted against total length for each species with sufficient data (e.g., Figure 12). Thirteen species (Gizzard Shad *Dorosoma cepedianum*, Red Shiner *Cyprinella lutrensis*, Spotted Bass *Micropterus punctulatus*, Warmouth *L. gulosus*, Longear Sunfish, Gray Redhorse *Moxostoma congestum*, Smallmouth Buffalo *Ictiobus bubalus*, Blacktail Shiner *C. venusta*, Flathead Catfish *Pylodictis olivaris*, Burrhead Chub, Central Stoneroller, Texas Logperch *Percina carbonaria*, and Channel Catfish *Ictalurus punctatus*) exhibited size-dependent changes in habitat use, and were thus split into two additional size classes for further analysis. Best professional judgment was used to develop juvenile/adult breaks for depth/velocity utilization (e.g., Figure 12). Appendix B contains similar graphs for every species examined. After nine exotic species were excluded, seven rare species removed, 1 hybrid cyprinid removed, unidentified juvenile sunfish removed, and thirteen new life stage categories defined, 69,539 fishes were grouped into 45 species/life stage categories and used in habitat guild analysis. Generating HSC for 45 individual species/life stage categories would have complicated interpretation of study results, yet basing flow recommendations on the needs of a few key species might have been detrimental to other species; therefore, a habitat guild approach was used to best represent the habitat needs of the entire fish community. A habitat guild was defined as a group of species that use similar habitat. Grouping species based on similar habitat use, and creating HSC for each resulting habitat guild, simplified interpretation of study results while still representing the flow requirements of the entire fish community. The habitat guild approach is often used for instream flow studies on warmwater rivers with high species richness such as the lower San Antonio River (Persinger et al. 2010, BIO-WEST 2008).



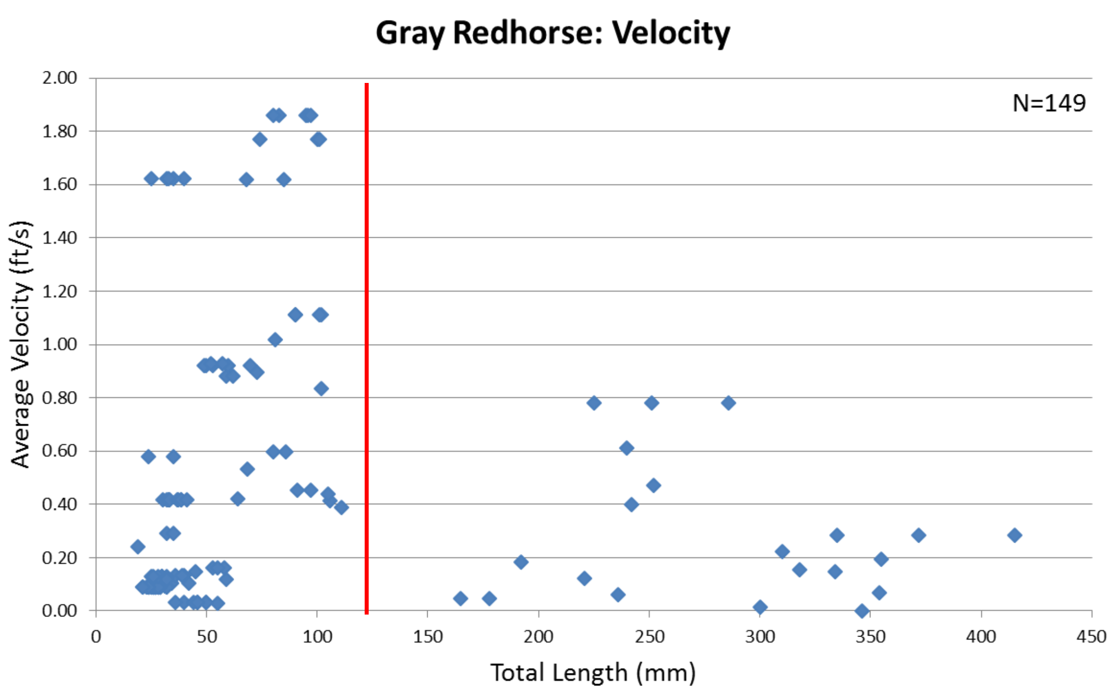


Figure 12. Example of size-dependent habitat utilization analysis for Gray Redhorse. The red line indicates the resulting boundary between juvenile and adult life stage categories (125 mm).

Based on the resulting CCA ordination plot the 45 species/life stage categories for each season and overall (Appendix C) were visually grouped into habitat guilds, such as those shown in Figure 13. Where a particular species/life stage category fell in close proximity to guild boundaries, habitat descriptions from the literature, and professional experience of the study team biologists (TPWD, TCEQ, and BIO-WEST) were used to make the final guild determination.

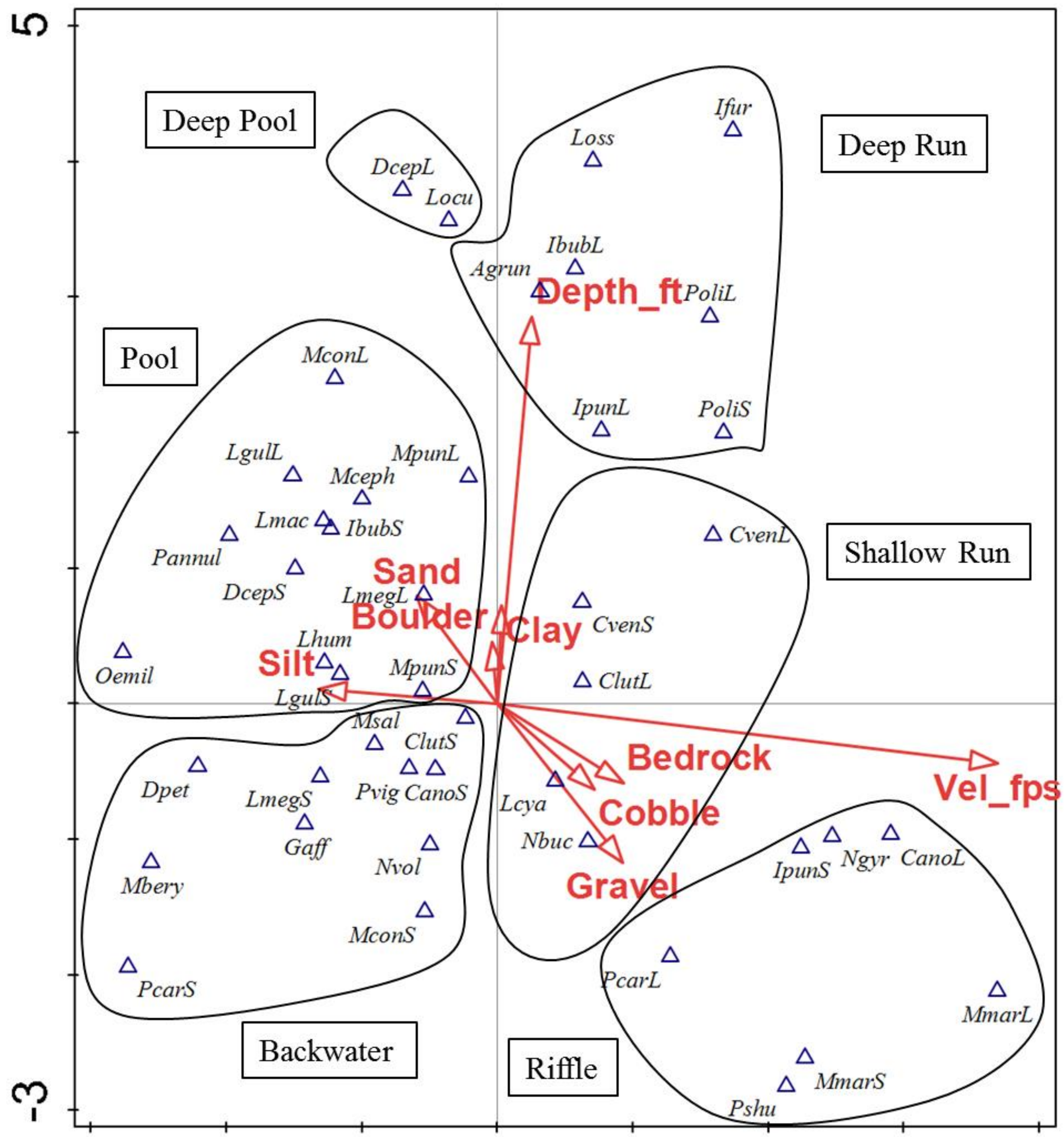


Figure 13. Multivariate ordination plot showing species associations among gradients of depth, velocity, and substrate in the San Antonio River Basin. Black circles encompass habitat guilds (guild names located in boxes). Species/life stage abbreviations are provided in Table 9.

The resulting CCA analysis of the seasonal fish habitat data (Appendix C) and seasonal guild determinations were then analyzied to determine if habitat utilization (depth and velocity) differed significantly ($p \leq 0.05$) among the seasonal guilds, that is, do fish in the same guilds utilize significantly different depths and velocities across seasons. To assess for these differences, a multiple analysis of variance (MANOVA) was performed for each guild across all seasons and the combined overall fish data. The MANOVA results showed there were significant differences ($p \leq 0.05$) among seasons for each guild. A pairwise analysis of variance and Tukey test of significance were then conducted to determine which seasons were significantly different for each guild (Appendix C). Although there were some significant differences between seasons and the overall fish data for some guilds in depth and velocity utilization, the overall distribution of depths and velocities utilized compared to the seasonal depth and velocity utilized were very similar. Although significant differences were observed in the raw depth and velocity utilization by season for some guilds, the next step was to assess if those differences translated to differences in HSC.

To assess if there were differences in seasonal HSC for each guild, habitat data from all species/life stage categories within a particular guild were combined to generate frequency data for the continuous variables depth and velocity for each guild seasonally and for the overall combined fish data. These combined data for each guild were then imported into the HSC Development Tool (Hardy 2015) where it was binned for further analysis. HSC were then created using nonparametric tolerance limits (NPTL) based on the central 50%, 75%, 90%, and 95% of the data (Bovee 1986) using a 0.95 confidence level (Appendix C). Tolerance limits for the central 50% of the data were used as boundaries for the most selected habitat and the range of data between these two points was assigned a suitability of 1.0. Data between the 50% tolerance limits and the 75% tolerance limits were assigned a suitability of 0.5. Data between the 75% tolerance limits and the 90% tolerance limits were assigned a suitability of 0.2; and the data between the 90% tolerance limits and the 95% tolerance limits received a suitability of 0.1. The data beyond the 95% tolerance limits were considered unsuitable and given a suitability of zero.

HSC for the categorical variable substrate were developed using normalized frequencies. The substrate with the highest frequency (most utilized) received a suitability value of 1.0. All other substrates received a lower suitability dependent on their relative frequency.

All seasonal HSC developed utilizing the HSC Development Tool (Hardy 2015) for each guild, season, and all fish data combined are presented in Appendix C. Upon review of the HSC curves for each guild by season and all fish data combined, it was determined by the study team (fisheries biologists) that the seasonal curves did not appear to be very different from the overall fish curves for each of the habitat guilds, so it was decided that the overall fish HSC curves derived from the total fish data guilds (Figure 13) should be sufficient to encompass the seasonal ranges of habitat utilization for each guild. The species/life stage categories and number of each collected within each of the resulting habitat guilds derived from the overall fish collections and utilized for fish habitat modeling are presented in Table 10.

Table 10. Number of locations observed and total number of individuals observed within the San Antonio River Basin for each habitat guild and their component species/life stage categories.

Habitat Guild	Species/Life Stage		Species/Life Stage Abbreviation	Locations Observed	Number Observed
	Spotted Gar	*Lepisosteus oculatus*	*Locu*	34	36
Deep Pool	Gizzard Shad (adult)	*Dorosoma cepedianum* (≥150 mm)	*DcepL*	59	116
	Guild Total			**93**	**152**
	Gizzard Shad (juvenile)	*Dorosoma cepedianum* (<150 mm)	*DcepS*	32	111
	Pugnose Minnow	*Opsopoeodus emiliae*	*Oemil*	4	9
	Smallmouth Buffalo (juvenile)	*Ictiobus bubalus* (<150 mm)	*IbubS*	3	18
	Gray Redhorse (adult)	*Moxostoma congestum* (≥125 mm)	*MconL*	16	21
	Striped Mullet	*Mugil cephalus*	*Mceph*	7	20
	Warmouth (adult)	*Lepomis gulosus* (≥65 mm)	*LgulL*	19	32
Pool	Warmouth (juvenile)	*Lepomis gulosus* (<65 mm)	*LgulS*	8	20
	Orangespotted Sunfish	*Lepomis humilus*	*Lhum*	67	161
	Bluegill	*Lepomis macrochirus*	*Lmac*	131	333
	Longear Sunfish (adult)	*Lepomis megalotis* (≥45 mm)	*LmegL*	435	1414
	Spotted Bass (adult)	*Micropterus punctulatus* (≥125 mm)	*MpunL*	37	44
	Spotted Bass (juvenile)	*Micropterus punctulatus* (<125 mm)	*MpunS*	100	184
	White Crappie	*Pomoxis annularis*	*Pannul*	7	10
	Guild Total			**866**	**2377**
	Threadfin Shad	*Dorosoma petenense*	*Dpet*	5	9
	Central Stoneroller (juvenile)	*Campostoma anomalum* (<35 mm)	*CanoS*	5	21
	Red Shiner (juvenile)	*Cyprinella lutrensis* (<35 mm)	*ClutS*	632	26434
	Mimic Shiner	*Notropis volucellus*	*Nvol*	121	2762
	Bullhead Minnow	*Pimephales vigilax*	*Pvig*	507	14863
Backwater	Gray Redhorse (juvenile)	*Moxostoma congestum* (<125 mm)	*MconS*	35	128
	Inland Silverside	*Menidia beryllina*	*Mbery*	6	9
	Western Mosquitofish	*Gambusia affinis*	*Gaff*	321	4317
	Longear Sunfish (juvenile)	*Lepomis megalotis* (<45 mm)	*LmegS*	196	861
	Largemouth Bass	*Micropterus salmoides*	*Msal*	75	121
	Texas Logperch (juvenile)	*Percina carbonaria* (<40 mm)	*PcarS*	6	32
	Guild Total			**1909**	**49557**
	Longnose Gar	*Lepisosteus osseus*	*Loss*	54	78
	Smallmouth Buffalo (adult)	*Ictiobus bubalus* (≥150 mm)	*IbubL*	44	55
	Blue Catfish	*Ictalurus furcatus*	*Ifur*	44	129
Deep Run	Channel Catfish (adult)	*Ictalurus punctatus* (≥200 mm)	*IpunL*	73	87
	Flathead Catfish (adult)	*Pylodictis olivaris* (≥300 mm)	*PoliL*	33	37
	Flathead Catfish (juvenile)	*Pylodictis olivaris* (<300 mm)	*PoliS*	173	193
	Freshwater Drum	*Aplodinotus grunniens*	*Agrun*	11	11
	Guild Total			**432**	**590**
	Red Shiner (adult)	*Cyprinella lutrensis* (≥35 mm)	*ClutL*	747	12306
	Blacktail Shiner (adult)	*Cyprinella venusta* (≥35 mm)	*CvenL*	160	752
Shallow Run	Blacktail Shiner (juvenile)	*Cyprinella venusta* (<35 mm)	*CvenS*	53	419
	Ghost Shiner	*Notropis buchanani*	*Nbuc*	83	1031
	Green Sunfish	*Lepomis cyanellus*	*Lcya*	42	74
	Guild Total			**1085**	**14582**
	Central Stoneroller (adult)	*Campostoma anomalum* (≥35 mm)	*CanoL*	10	60
	Burrhead Chub (adult)	*Macrhybopsis marconis* (≥35 mm)	*MmarL*	113	864
	Burrhead Chub (juvenile)	*Macrhybopsis marconis* (<35 mm)	*MmarS*	26	82
Riffle	Channel Catfish (juvenile)	*Ictalurus punctatus* (<200 mm)	*IpunS*	165	1068
	Tadpole Madtom	*Noturus gyrinus*	*Ngyr*	26	59
	Texas Logperch (adult)	*Percina carbonaria* (≥40 mm)	*PcarL*	30	83
	River Darter	*Percina shumardi*	*Pshu*	22	65
	Guild Total			**392**	**2281**

Depth, velocity, and substrate HSC developed for the fish habitat guilds were reviewed by study team biologists and several HSC modifications were made based on their input. First, minimum depth criteria of approximately one inch (0.025 m) were established for all guilds with non-zero suitability at depths less than 0.1 m (Riffle and Shallow Run). Habitats shallower than one inch (0.025 m) were considered unsuitable. Second, given the known reduction in electrofishing capture efficiency at depths greater than approximately 6 feet (1.8 m), it was suggested that reductions in suitability for the Deep Pool and Deep Run guilds at depths greater than approximately 6 feet (1.8 m) were more likely a result of sampling limitations rather than a pattern in habitat utilization. Fishes of the Deep Pool guild (Spotted Gar and adult Gizzard Shad) are known to commonly inhabit areas considerably deeper than those from which they were captured in this study. As a result, the depth HSC curve for Deep Pool was modified to exhibit a suitability of 1.0 for all depths of approximately 2.3 feet (0.7 m) or greater (Figure 14). Similarly, to account for sampling limitations, the tail of the Deep Run and Pool HSC curves were also extended at a suitability of 0.5 (Figures 15 and 16).

Additionally, the data-generated HSC values for substrate in the Riffle guild were modified by the study team biologists. Initial HSC showed the highest utilization in gravel and bedrock (suitabilities of 1.0 and 0.53, respectively). Since boulder and cobble substrates are also known to be suitable substrate for Riffle habitat and are highly important to species within the guild, the suitability of these substrates (as well as bedrock) was raised to 1.0. Similarly, life history data and previous experience with darters in this guild suggested an avoidance of silt and clay habitats, and therefore, the suitability of silt and clay was dropped from 0.08 and 0.06 to 0.0, respectively. (Figure 17).

Study team biologists believed the HSC modifications described above more accurately represented the utilization patterns of each habitat guild, and these modifications were accepted by TIFP consensus. Figures 14-19 demonstrate final HSC curves for depth and velocity, as well as final HSC values of substrate categories per fish habitat guild. Original curves/values are noted wherever modifications were made.

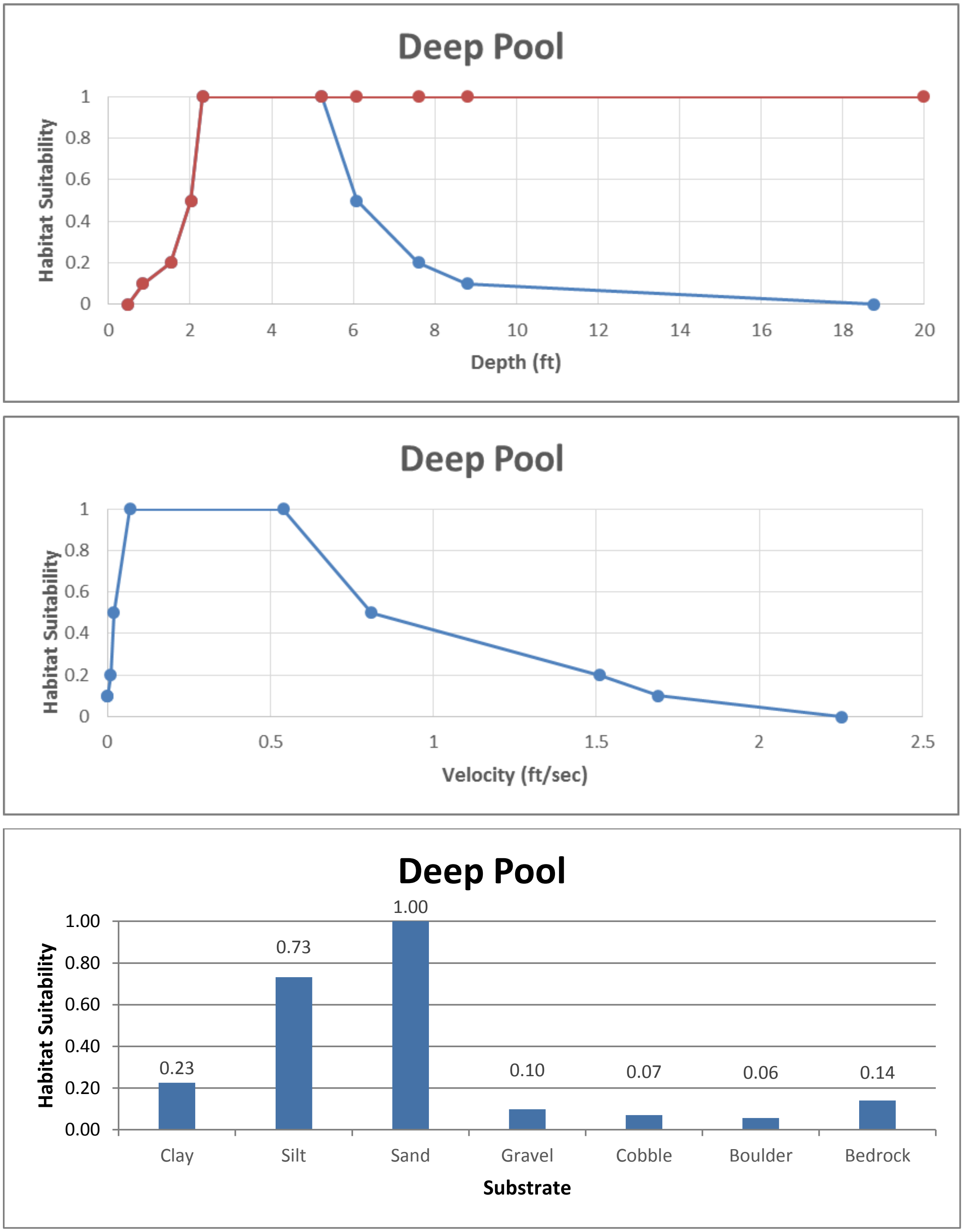


Figure 14. Habitat Suitability Criteria (HSC) for the Deep Pool Fish Habitat Guild. Blue line indicates original depth HSC curve, whereas the red line indicates the final modified curve.

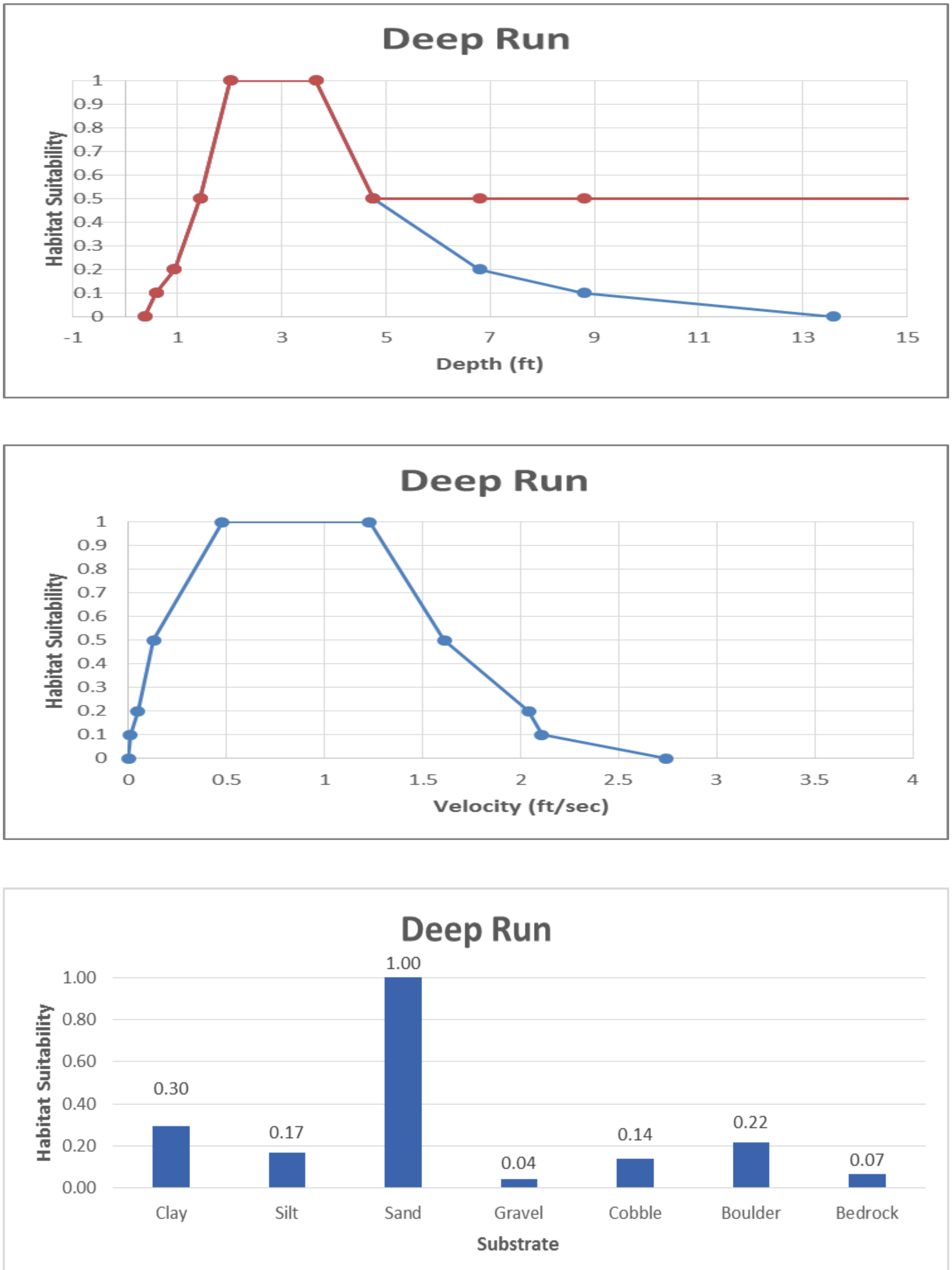


Figure 15. Habitat Suitability Criteria (HSC) for the Deep Run Fish Habitat Guild. Blue line indicates original depth HSC curve, whereas the red line indicates the final modified curve.

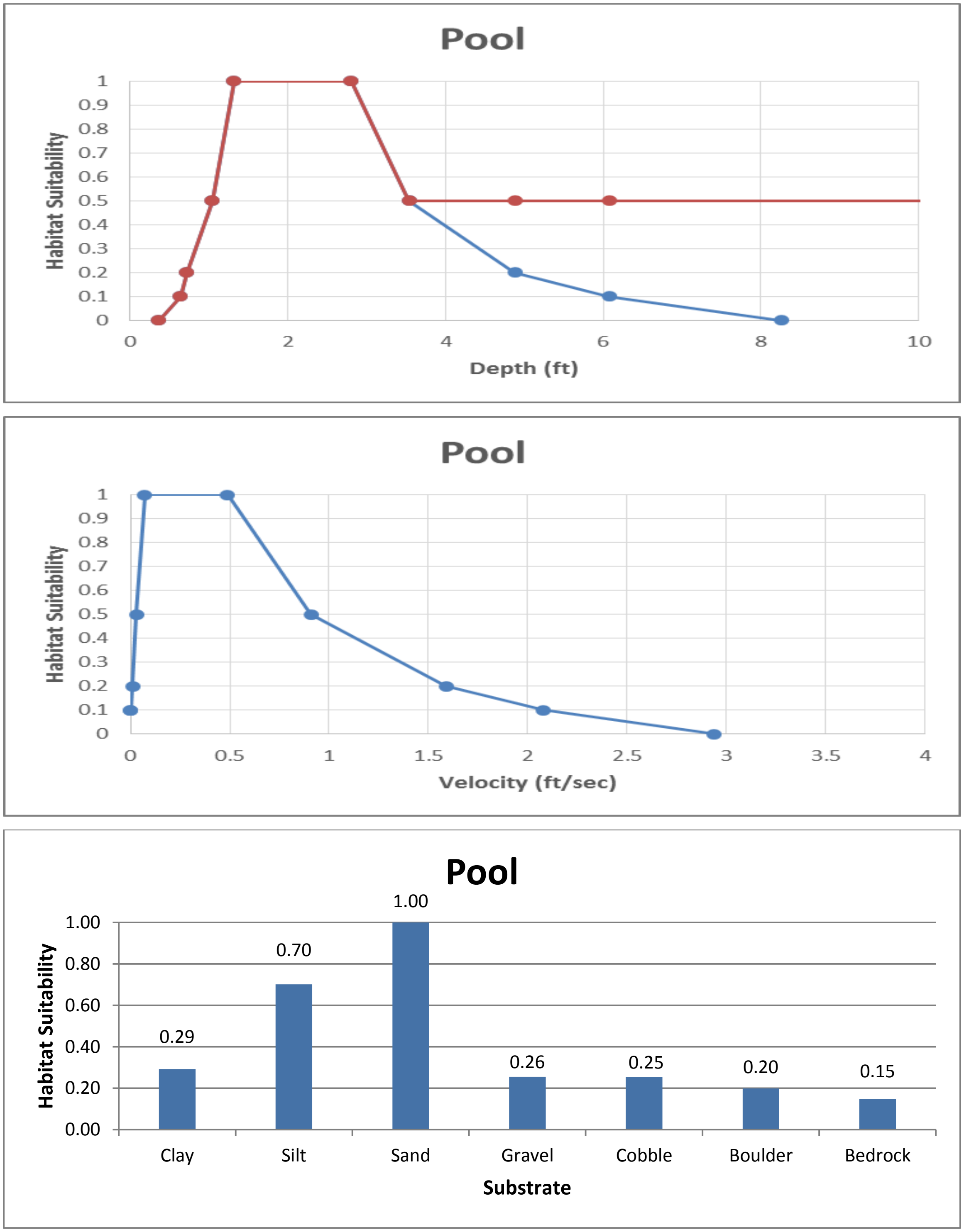
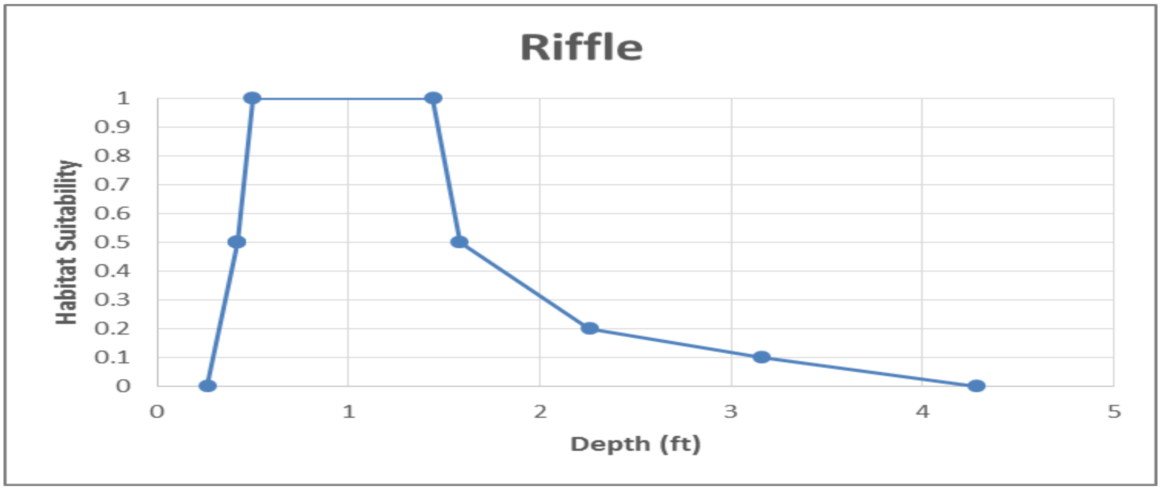
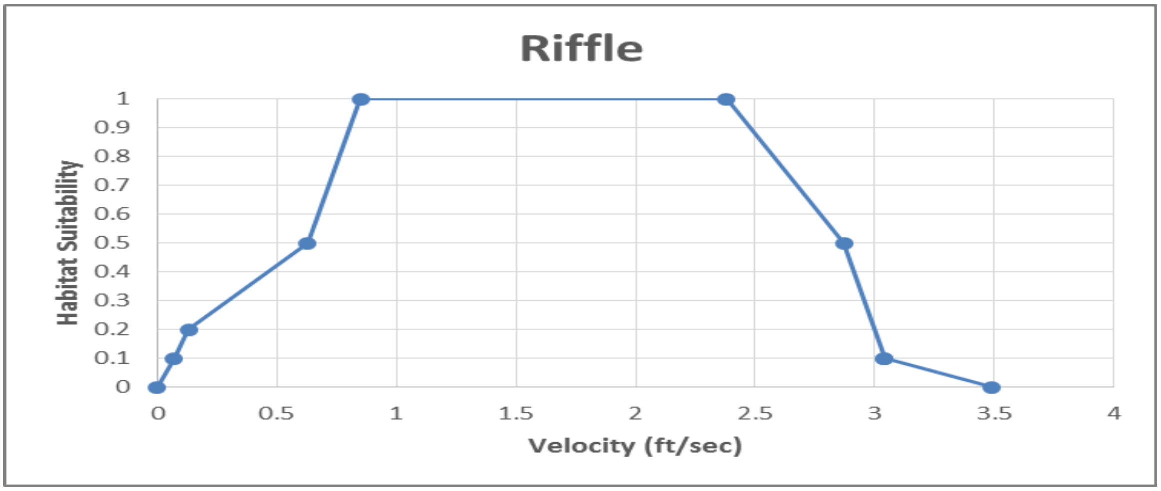


Figure 16. Habitat Suitability Criteria (HSC) for the Pool Fish Habitat Guild. Blue line indicates original depth HSC curve, whereas the red line indicates the final modified curve.





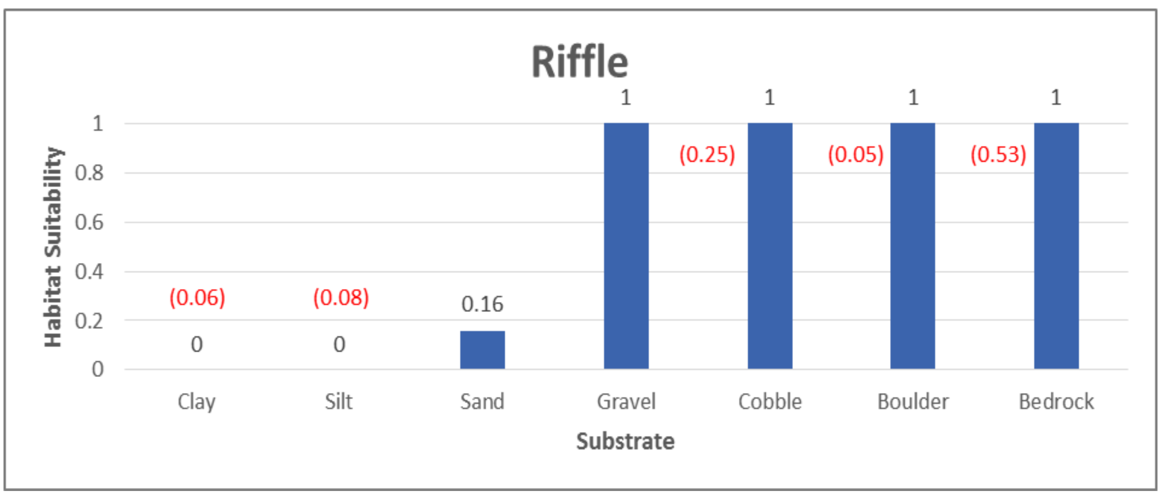
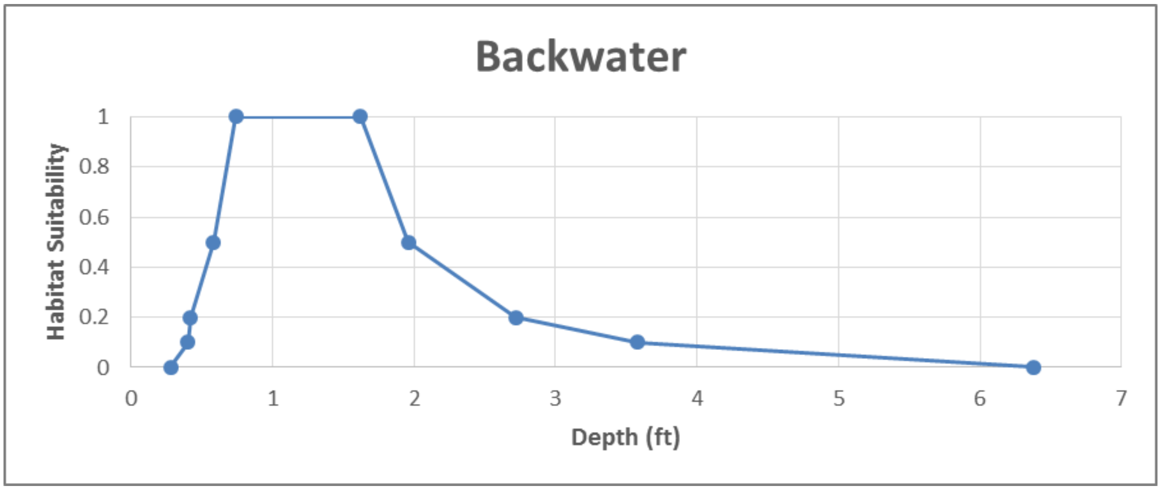
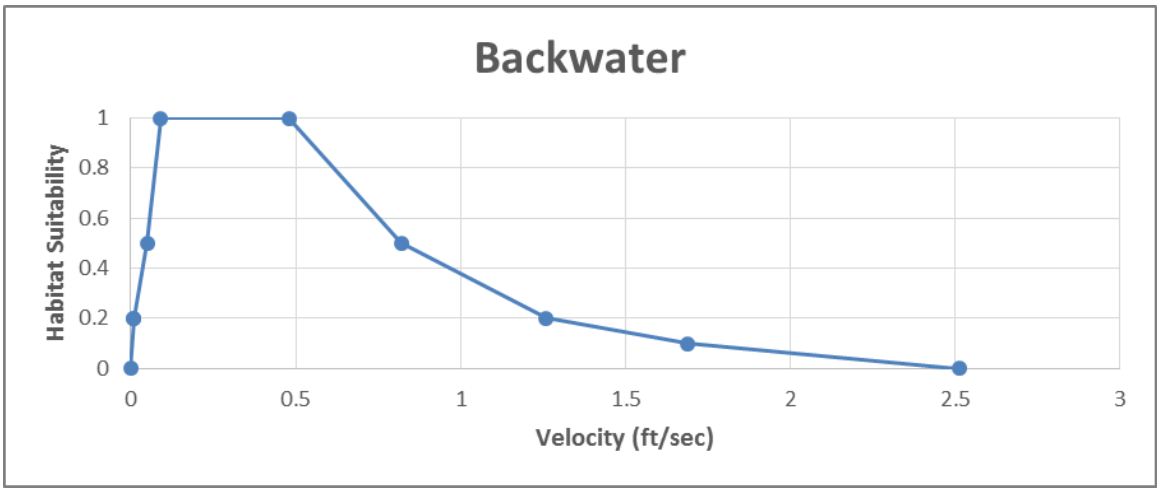


Figure 17. Habitat Suitability Criteria (HSC) for the Riffle Fish Habitat Guild. Original substrate HSC values indicated in parentheses.





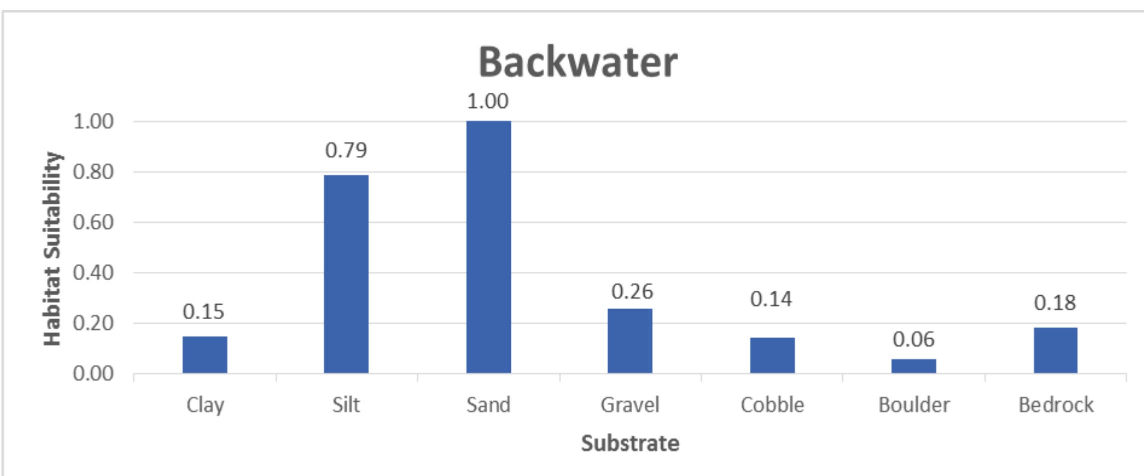


Figure 18. Habitat Suitability Criteria (HSC) for the Backwater Fish Habitat Guild.

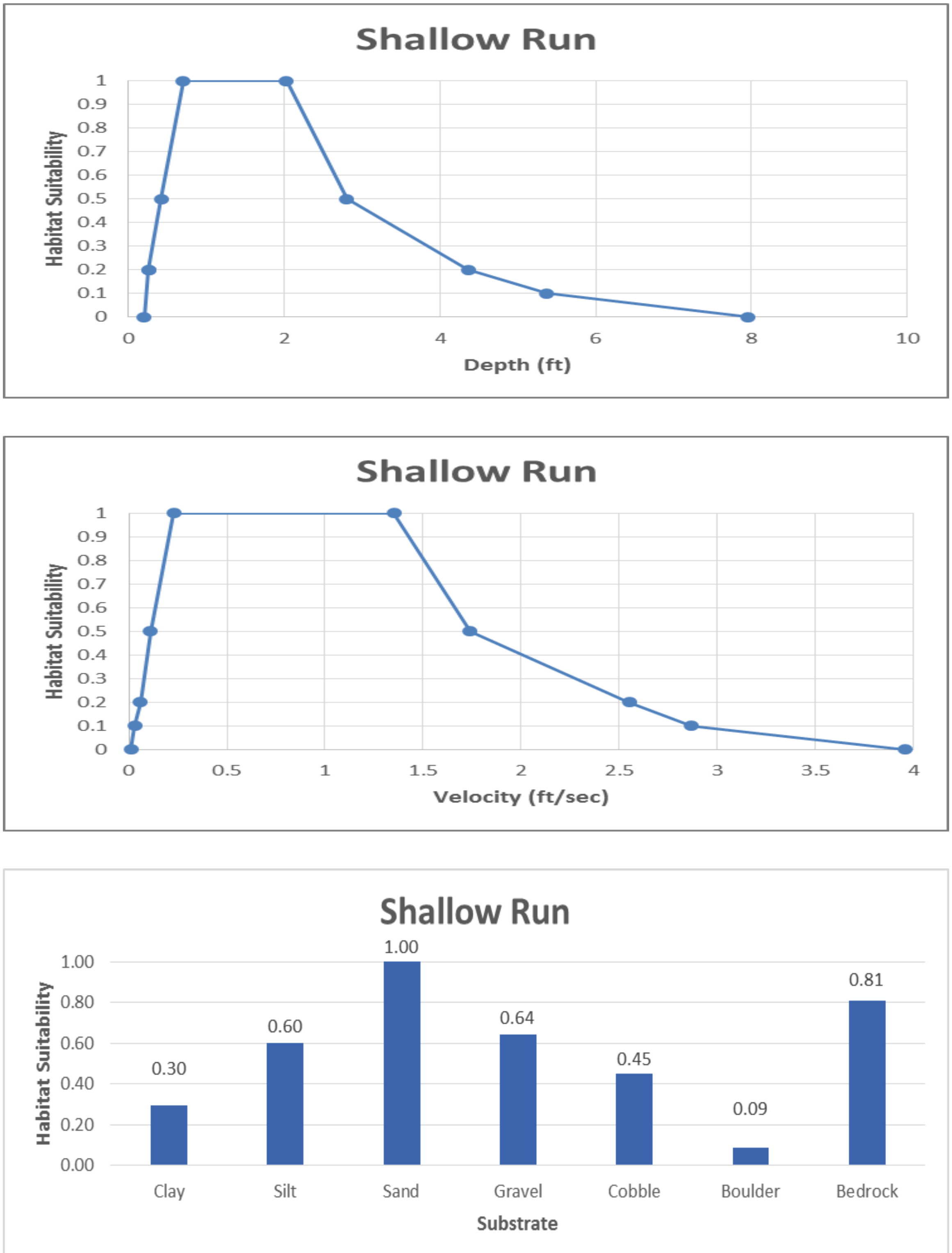


Figure 19. Habitat Suitability Criteria (HSC) for the Shallow Run Fish Habitat Guild.

Calculating Weighted Usable Area

Final HSC curves for each habitat guild were then applied to hydraulic model output to generate Weighted Usable Area (WUA) versus discharge curves. To do this, a Composite Suitability Index (CSI) was calculated for each habitat guild at each node in a given hydraulic model run. The CSI was calculated by taking the geometric mean of the suitability for depth ($Depth_{SI}$), velocity ($Velocity_{SI}$), and substrate ($Substrate_{SI}$) as follows:

$$CSI = (Velocity_{SI} * Depth_{SI} * Substrate_{SI})^{1/3}$$

The CSI of each node was then multiplied by the area of that node to generate a WUA, and these values were summed for each habitat guild. The total WUAs for each habitat guild at each modeled flow rate were then compiled to create WUA versus discharge curves (Figure 20).

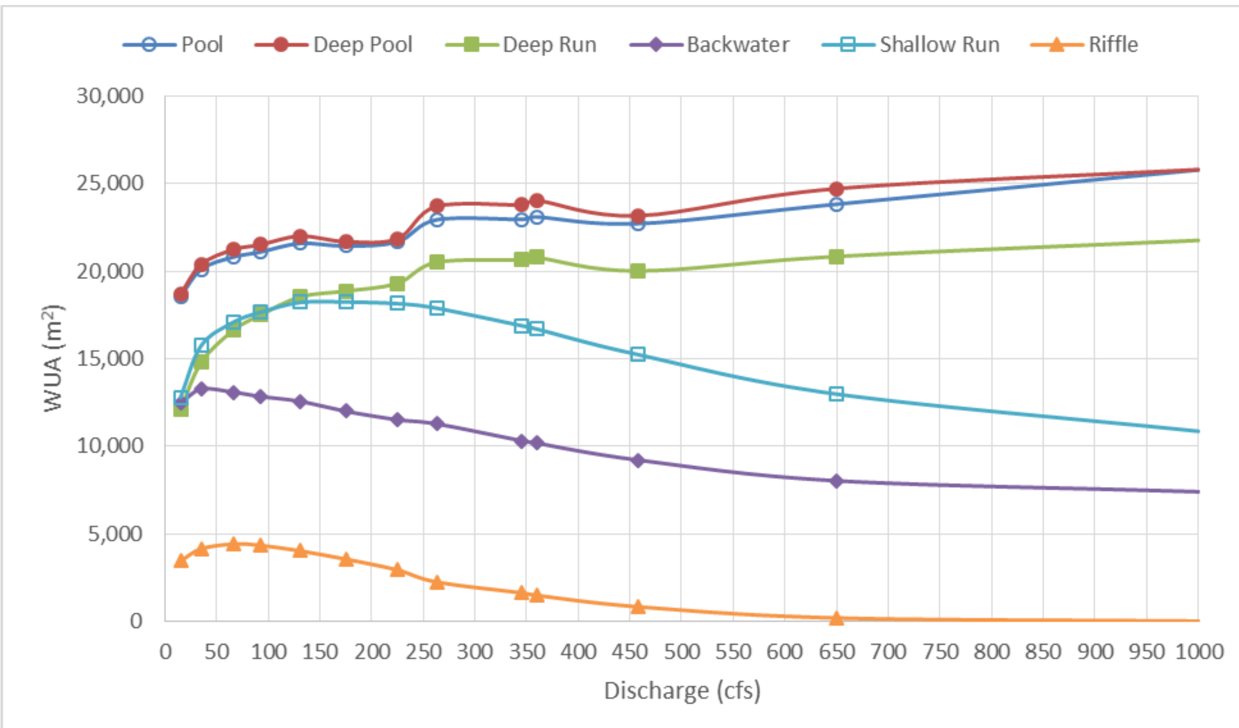


Figure 20. Weighted Usable Area (WUA) versus simulated discharge at the San Antonio River Calaveras Study Site.

One drawback to the above graph is that changes in rare habitat types such as Riffle can be masked by changes in common habitat types. Therefore, in an attempt to assess all habitat types equally, graphs were created to depict percent of maximum WUA versus discharge for each habitat guild (Figure 21).

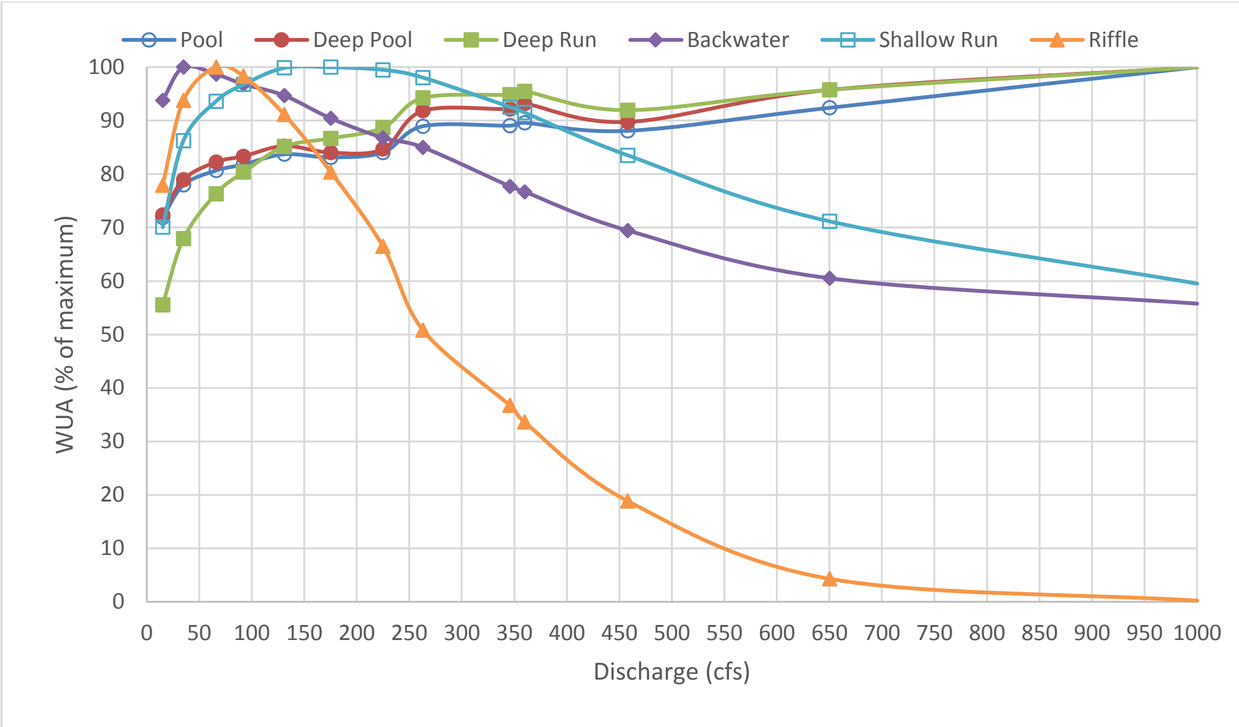


Figure 21. Percent of Maximum Weighted Usable Area (WUA) versus simulated discharge at the San Antonio River Calaveras Study Site.

Another consideration when examining WUA results is habitat quality. So far, we have generated total WUA; however, it is possible that large amounts of low quality habitat contribute substantially, and little high quality habitat exists. The contribution of high quality (CSI ≥0.8), moderate quality (CSI = 0.5-0.79), and low quality (CSI <0.5) habitat to overall WUA was examined for each habitat guild at each modeled flow rate. The levels of quality (high, moderate, and low) for this assessment were based on professional judgment of and consensus by the study team. Figure 22 shows this analysis for each guild at the Calaveras Study Site. All WUA curves and displays are presented for all Study Sites in Appendix D.

Spatial Output

Spatial output of habitat model results was also analyzed to assess habitat conditions at each site and evaluate habitat connectivity at different flow rates. Maps of Riffle habitat under two different flow rates at the upper portion of the Calaveras Study Site are presented in Figure 23 as an example.

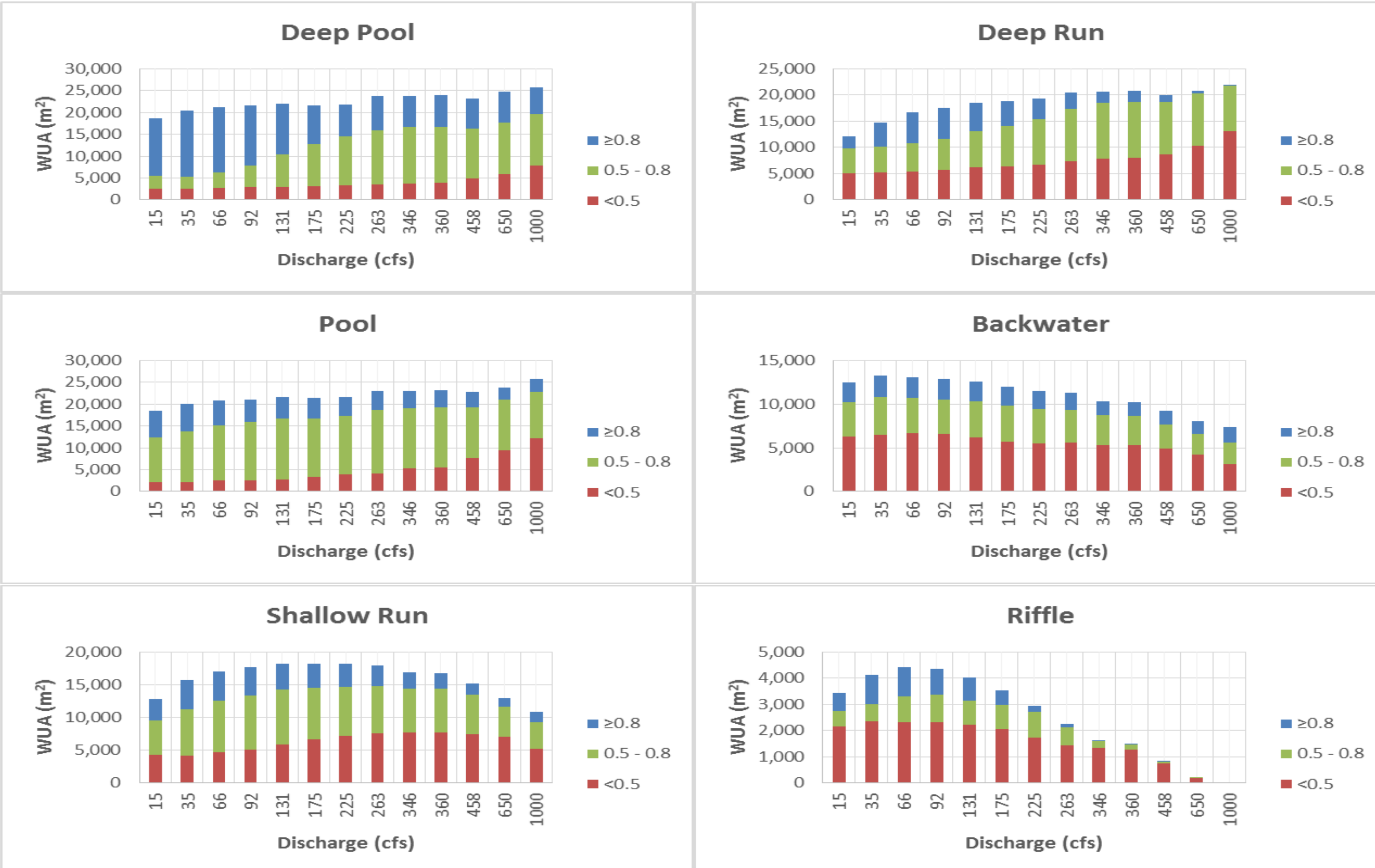


Figure 22. Habitat quality breakout (0.5 low; 0.5-0.8 moderate; ≥0.8 high) of Weighted Usable Area (WUA) versus simulated discharge at the San Antonio River Calaveras Study Site.

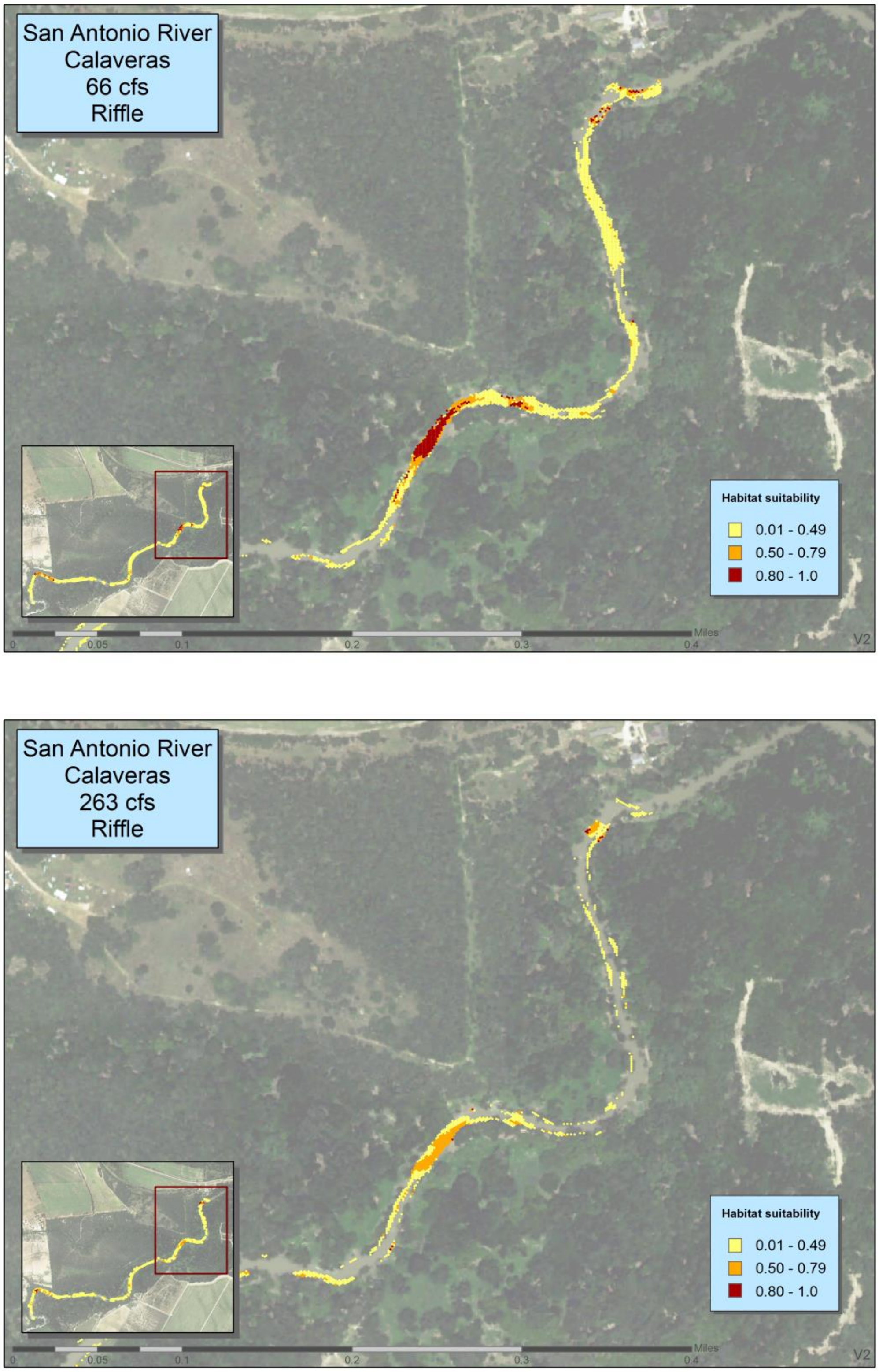


Figure 23. Spatial output of Riffle habitat quality at two simulated flows for the San Antonio River Calaveras Study Site.

2.3.2 *Mussels*

As discussed in the Study Design (TIFP and SARA 2012), mussel surveys were contracted to university researchers between 2006 and 2007 in order to determine mussel species richness and distribution within the San Antonio River Basin (Karatayev and Burlakova 2008). To supplement these surveys, which were only conducted at a few locations within the basin, the TIFP initiated baseline mussel surveys during fall 2010 to assess the species composition and general abundance within each of the Study Sites. The TIFP also commissioned a special study designed to assess habitat suitability for mussel species in the lower San Antonio River near Goliad (Hammontree et al. 2012).

Baseline mussel surveys consisted of personnel doing timed searches throughout each Study Site. Effort was focused in areas likely to contain mussels such as gravel riffles and shallow runs. When necessary because of depth, SCUBA and/or a small dredge towed by a boat were used for surveys. A GPS waypoint was recorded wherever native freshwater mussels were documented. Digital photographs were taken of most mussels collected, and length data were recorded. Details of each baseline mussel survey are provided below.

Calaveras

The Calaveras baseline mussel survey was conducted on February 23, 2011. Mean daily discharge at USGS Gage No. 08181800 (San Antonio River near Elmendorf) was 218 cfs. A total of one live Golden Orb and one live Yellow Sandshell were found. Both live mussels were found in the same riffle in gravel/sand substrate. A total of 15 person-hours of searching was conducted resulting in a catch per unit effort (CPUE) of 0.07 mussels/hr for both Golden Orb and Yellow Sandshell.

Falls City

The baseline mussel survey at the Falls City site was conducted on February 22, 2011. Mean daily discharge at USGS Gage No. 08183500 (San Antonio River near Falls City) was approximately 249 cfs. A total of nine live Golden Orb and eight live Yellow Sandshell were found. One Golden Orb was collected using the small dredge in a Deep Pool area. All other live mussels were found in gravel or sand substrate in a variety of habitats. A total of 30 person-hours of searching was conducted resulting in a 0.30 mussels/hr CPUE for Golden Orb and 0.27 mussels/hr CPUE for Yellow Sandshell.

Goliad

The Goliad baseline mussel survey was conducted on March 2, 2011. Mean daily discharge at USGS Gage No. 08188500 (San Antonio River at Goliad) was 316 cfs. A total of seven live Golden Orb, two live Yellow Sandshell, and two live Threeridge were found. All live mussels were found in gravel/sand substrate in riffles or near woody debris in gravel/sand. A total of 25 person-hours of searching was conducted resulting in a 0.28 mussels/hr CPUE for Golden Orb and 0.08 mussels/hr CPUE for both Threeridge and Yellow Sandshell.

Hwy 77

The Hwy 77 baseline mussel survey was conducted on March 3, 2011. Mean daily discharge at USGS Gage No. 08188570 (San Antonio River near McFaddin) was 439 cfs. A total of eight live Golden Orb and 53 live Yellow Sandshell were found. All live mussels were found in sand substrate along inside bends or near woody debris. A total of 27.5 person-hours of searching was conducted resulting in a 0.29 mussels/hr CPUE for Golden Orb and a 1.93 mussels/hr CPUE for Yellow Sandshell.

Cibolo Creek

The baseline mussel survey at the Cibolo Creek site was conducted on August 27, 2010. Mean daily discharge at USGS Gage No. 08186000 (Cibolo Creek near Falls City) was 42 cfs. A total of 12 live Golden Orb and one live Yellow Sandshell were found. All live mussels were found in gravel substrate in and around riffle areas. Approximately 42 person-hours of searching were conducted resulting in a CPUE of 0.29 mussels/hr for Golden Orb and 0.02 mussels/hr for Yellow Sandshell.

Baseline Mussel Survey Summary

Overall, the lower Study Sites (Falls City, Goliad, and Hwy 77) had the highest abundances of mussels with the Hwy 77 Study Site having the highest number of live mussels (61 individuals) due to high numbers of Yellow Sandshell (53)(Table 11). Yellow Sandshell were also relatively abundant at the Falls City Study Site (8), but were represented by only one or two individuals at all other sites. The highest number of Golden Orb was found in Cibolo Creek (12). Excluding the Calaveras Study Site where only one Golden Orb was found, the CPUE for Golden Orb was relatively consistent at all sites (0.28-0.30 mussels/hr). Threeridge were rare in our baseline collections and documented only at the Goliad Study Site, resulting in this Study Site having the highest species diversity (three species).

Table 11. Number of mussels and catch per unit effort (CPUE, mussels/hr) for three species of mussels collected during baseline mussel surveys at five Study Sites in the lower San Antonio River Basin during 2010-2011.

Site	Golden Orb		Yellow Sandshell		Threeridge	
	Number Collected	CPUE	Number Collected	CPUE	Number Collected	CPUE
Cibolo Creek	12	0.29	1	0.02		
Calaveras	1	0.07	1	0.07		
Falls City	9	0.30	8	0.27		
Goliad	7	0.28	2	0.08	2	0.08
Hwy. 77	8	0.29	53	1.93		

At most sites, mussels appeared to be most common in shallow areas of gravel substrate, usually near riffles. This habitat type (gravel riffles) does not exist at the Hwy 77 Study Site. Here, mussels were found in shallow areas along the inside of bends usually in sand or silt substrate. In earlier mussel surveys on the lower San Antonio River, Burlakova and Karatayev (2008) found two species that were not captured during this baseline survey. They documented Washboard *Megalonaias nervosa* and Pistolgrip *Quadrula verrucosa* in close proximity to the Goliad Study Site; however, both species were relatively rare in their collections.

In addition to the five live mussel species collected as part of the other surveys, Rock Pocketbook *Arcidens confragosus* was added to the list of species collected during a longitudinal qualitative survey of ten separate reaches from Elmendorf to Goliad (BIO-WEST, Inc. 2014). Ten sites were surveyed from a total of 74.7 river miles within an estimated 200 man hours of search time collecting a total of 930 live mussels.

Mussel Habitat Suitability

As stated in the Study Design (TIFP and SARA 2012), the goal of conducting quantitative mussel sampling is to develop HSC for mussels. Hammontree et al. (2012) conducted quantitative mussel sampling at the Goliad Study Site in order to determine the habitat requirements of Golden Orb. Although their results did not include the development of HSC for Golden Orb (because sampling was only conducted in known mussel locations), their results were invaluable in understanding the habitat needs of this species. Hammontree et al. (2012) found that Golden Orb density was highly correlated with complex hydraulic variables such as shear stress (FST hemisphere density) and relative substrate stability (RSS). These results indicate that suitable Golden Orb habitat is indicative of hydraulically stable patches within the stream bed.

The TIFP and SARA added the sampling approach outlined in Maloney et al. (2012), which utilizes modeled persistent habitat patches suitable for Golden Orb, to conduct stratified random sampling to assess the validity of the Hammontree et al. (2012) findings and to develop HSC for Golden Orb. Persistent habitat patches are defined as areas within the stream bed that provide suitable habitat (RSS values less than 1.0, indicative of stable substrates) for Golden Orb at all modeled flows. Persistent habitat patches were developed for the Calaveras, Goliad, and Cibolo Creek Study Sites. Two hundred 0.25 m^2 quadrats were identified for sampling at each site (100 in persistent habitat patches and 100 in non-persistent habitat patches) for a total of 600 samples. Sampling began in May 2014. In total, 143 quadrats were sampled (Figure 24) at Cibolo Creek (only four mussels collected), 31 quadrats at Calaveras (only five mussels collected), and 116 quadrats at Goliad (80 mussels collected). A large flood event (which altered the substrate distribution from what had been previously mapped, thus preventing the modeling of RSS values at precise locations for sample selection) and persistent high flows precluded completion of sampling.

Figure 24. Mussel sampling at the San Antonio River Goliad Study Site.

Although sampling was not completed, data that were collected at the Goliad Study Site showed RSS values that appeared to be representative of suitable Golden Orb habitat given that 83% of total mussels collected were located in persistent mussel habitat patches (stable substrates), and with the majority of mussels collected in non-persistent habitat patches being located adjacent to persistent habitat patches (within perceived modeling error). Even though sample size was insufficient to develop HSC for Golden Orb, our preliminary data suggest persistent habitat patches do reflect suitable Golden Orb habitat and that areas of suitable mussel habitat are apparently unoccupied and available for additional mussel colonization (Figure 25).

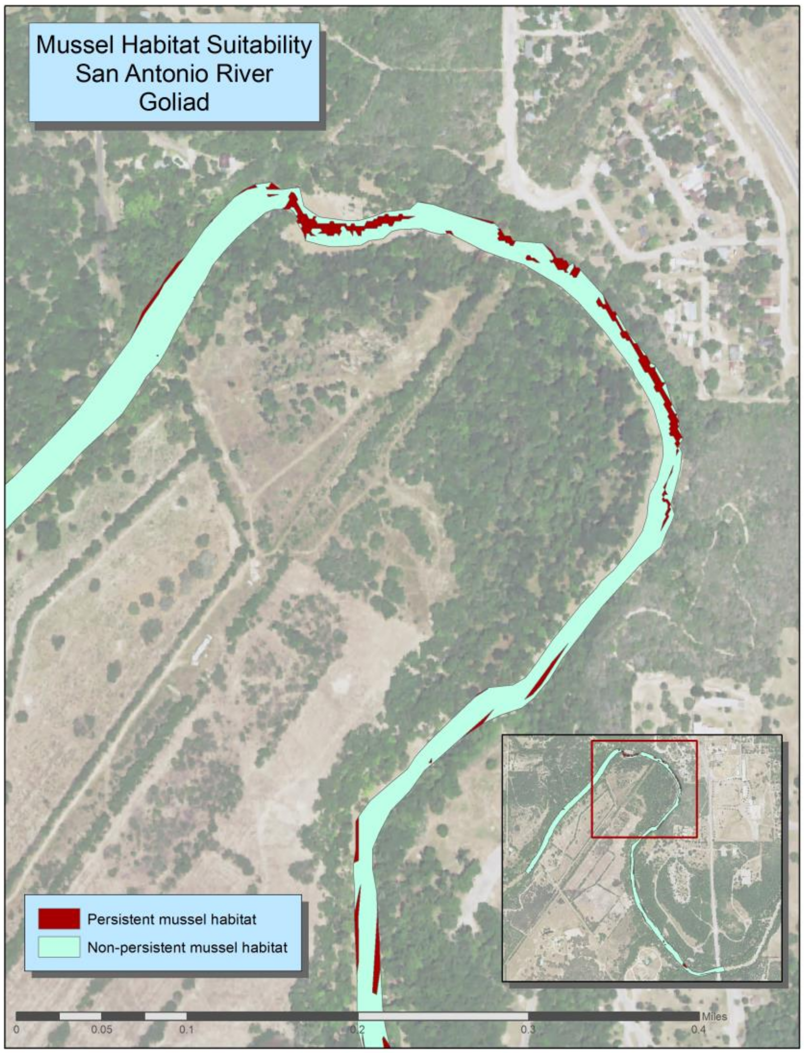


Figure 25. Modeled persistent and non-persistent mussel habitat at the San Antonio River Goliad Study Site.

2.3.3 *Riparian Communities*

Riparian zones are important natural biofilters, protecting aquatic environments from excessive sedimentation, polluted surface runoff, and erosion. They also supply shelter and food for many aquatic and terrestrial animals, and shade that is an important part of stream temperature regulation.

Due to hydrological variation of water levels among base, pulse, and overbank flows, the plant species that grow in the lower San Antonio River and Cibolo Creek riparian zones are adapted to a disturbance regime. Riparian plants in the region have adaptations to enable them to either withstand periods of inundation or to seed and recolonize following high flow conditions. The hydrologic regime, coupled with other environmental variables, produces riparian vegetation of herbaceous, shrub, and forest type communities that segregate spatially across the floodplain.

On the lower San Antonio River and Cibolo Creek, a shrub zone dominated by species of black willow *Salix nigra*, American sycamore *Platanus occidentalis*, and Roosevelt weed *Baccharis neglecta* typically develops along the water's edge. These plants are able to spread by seed and rhizomes, rapidly colonizing exposed sand or gravel bars. Higher up the banks, the riparian zone typically develops a hardwood forest community dominated by species including green ash *Fraxinus pennsylvanica*, box elder *Acer negundo*, cottonwood *Populus deltoides*, American elm *Ulmus americana*, cedar elm *U. crassifolia*, and hackberry.

The riparian analysis was specifically designed to evaluate the environmental flow needs of these San Antonio River and Cibolo Creek riparian communities. In addition to environmental flows, largely anthropogenic factors such as land use change and introduction of invasive species may influence the development of riparian communities; however, it is assumed that the flow recommendations resulting from the TIFP will provide for the environmental flow needs of the riparian zone under current environmental conditions.

The riparian analysis involved a review of vegetation community maps, field efforts to collect site-specific riparian community data, a literature review to identify life history information of dominant riparian plant species, analysis of HEC-RAS modeled water's edge data, and results from a tree-ring core study to identify the magnitude of environmental flows that are important to riparian communities at the five study sites. The methodologies associated with these tasks are described in the following sections, and the results are presented in summary for each Study Site.

The banks of the lower San Antonio River and Cibolo Creek were dominated by riparian and floodplain vegetation communities and the broad regional types of these communities varied between upstream and downstream sites in correlation with the ecoregions in Texas. The riparian field data collection efforts were then designed to measure species information along transects sampled within the dominant vegetation map communities at each of the Study Sites (and at one additional site, County Road 125, located about five miles downstream of FM 1604 in Wilson County). The combination of assessing broad vegetation types and collecting site-specific species information allowed the TIFP to address the large-scale patterns of inundation from high flow pulses and overbank flows, as well as the small scale patterns of inundation that affect specific species in the riparian zone.

Field-Collected Riparian Data

Information on riparian tree, shrub, and herbaceous plants was collected as part of two separate studies. In the first collection effort (May-September 2010), riparian data were collected at all five Study Sites using a transect method that measured trees and shrubs within a 10 m wide plot along a 50 m long transect, positioned perpendicular to the river channel. All trees and shrubs within the transect grid were identified to species, and the diameter at breast height (dbh) to the nearest 1 cm and distance to water's edge (in 1 m increments) for each individual was recorded. Seedlings were classified as having a dbh less than 1 cm. Saplings were classified as having a dbh of 1 to 5 cm. Herbaceous plants were catalogued using a line-intercept method along the center of the 50 m long transect.

Data were collected from 4-6 transects at each site within vegetation communities that were observed to be representative of the dominant riparian communities present within the reach (Table 12; Figures 26-30). Each transect was surveyed starting from the water's edge on the date of riparian sampling and the transect location was recorded with Trimble GPS equipment with sub-meter accuracy.

Table 12. Number of riparian transects sampled at each San Antonio River Study Site.

Site	Number of Transects
Calaveras	4
Falls City	5
Goliad	6
Hwy 77	4
Cibolo Creek	5

Following the completion of field data collection, each riparian transect was plotted using Microsoft Excel graphing software. The riparian transect profile (depicting the relative change in elevation from water's edge to 50 m into the riparian zone) was plotted along with tree, sapling, and seedling data individually for each transect. These plots were reviewed to identify any potential breaks in the riparian community as distance away or above water's edge increased. The riparian species information collected at each site is presented in Appendix E and the transect profile plots in Appendix F.

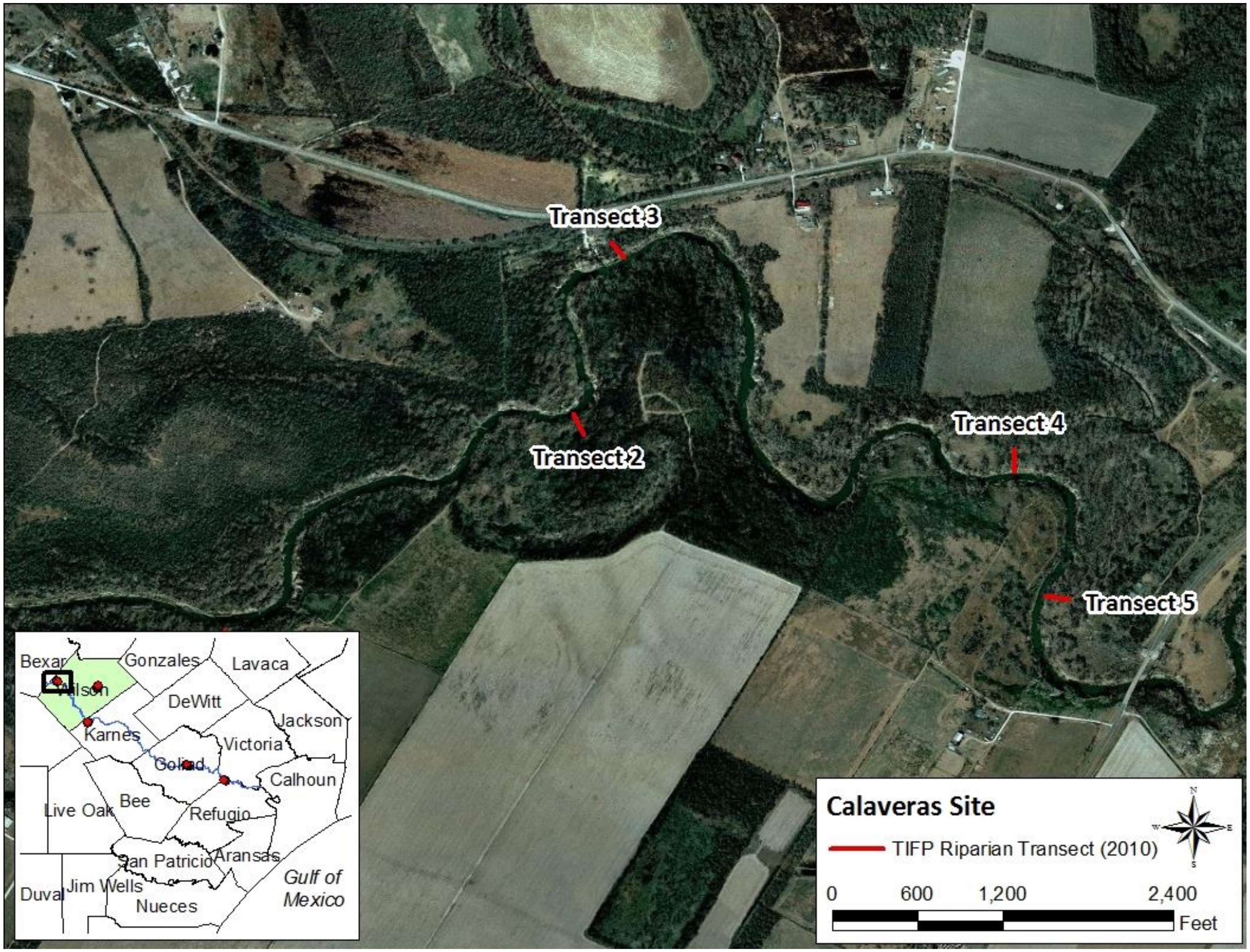


Figure 26. Riparian transects at the San Antonio River Calaveras Study Site (no data were collected from Transect 1).

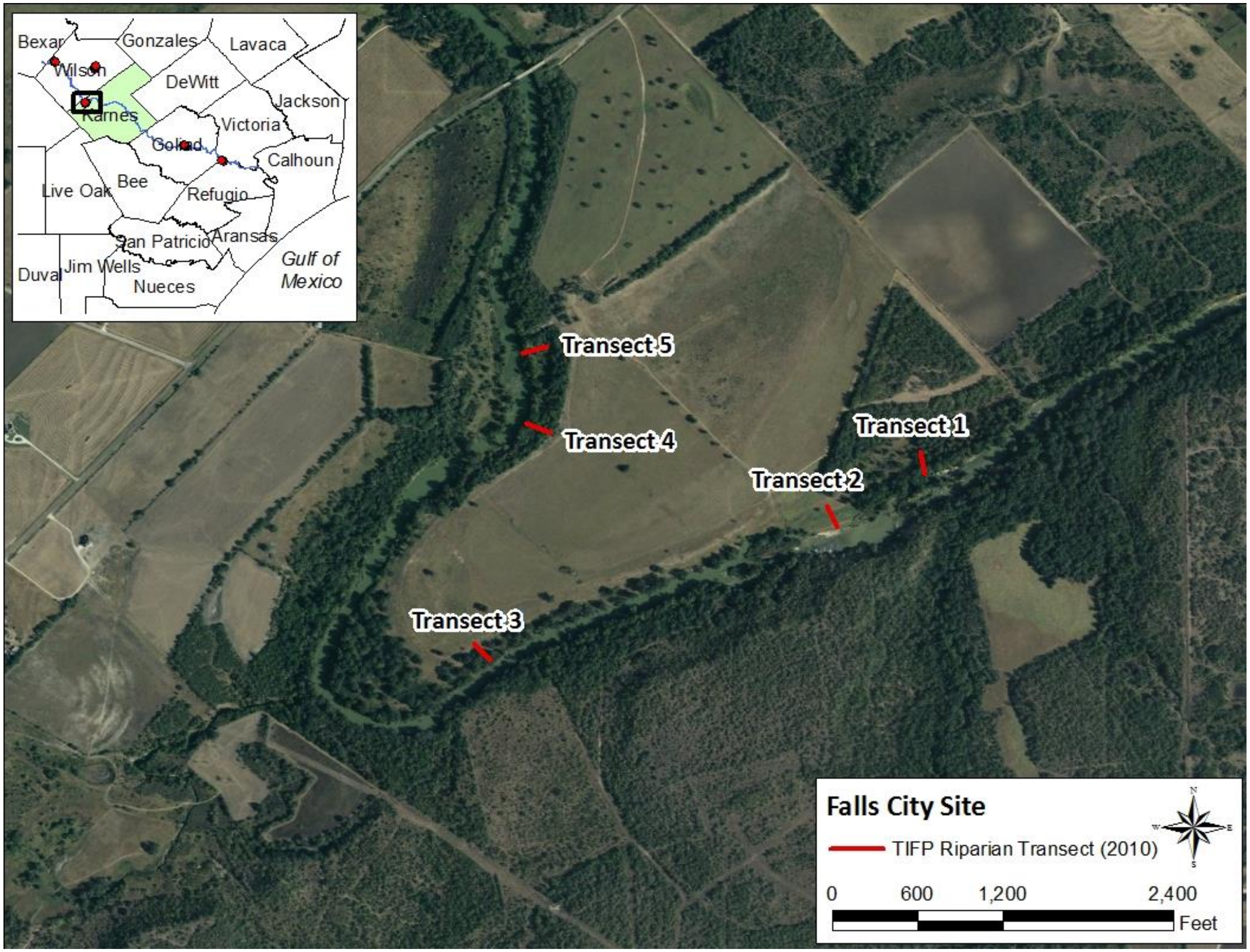


Figure 27. Riparian transects at the San Antonio River Falls City Study Site.

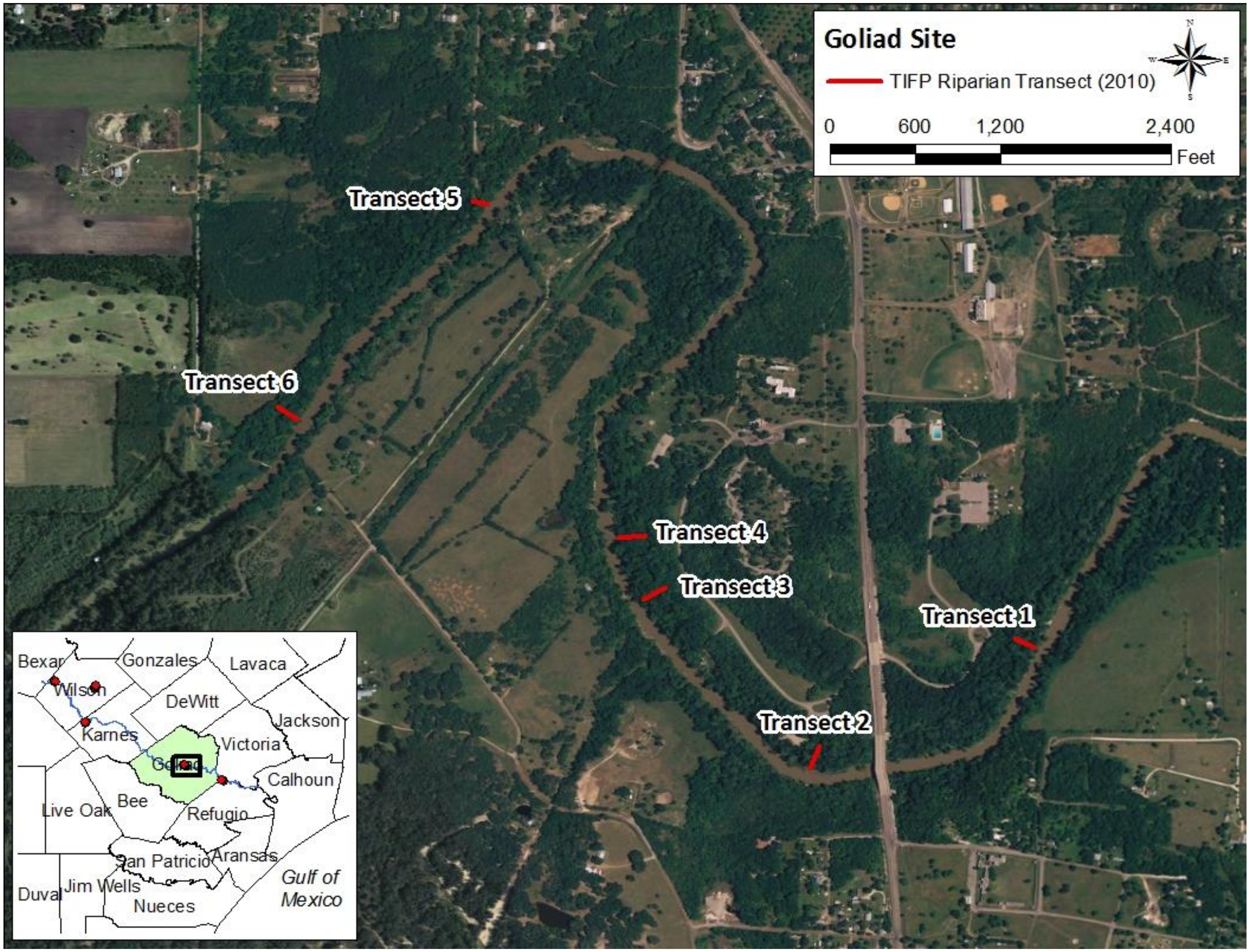


Figure 28. Riparian transects at the San Antonio River Goliad Study Site.

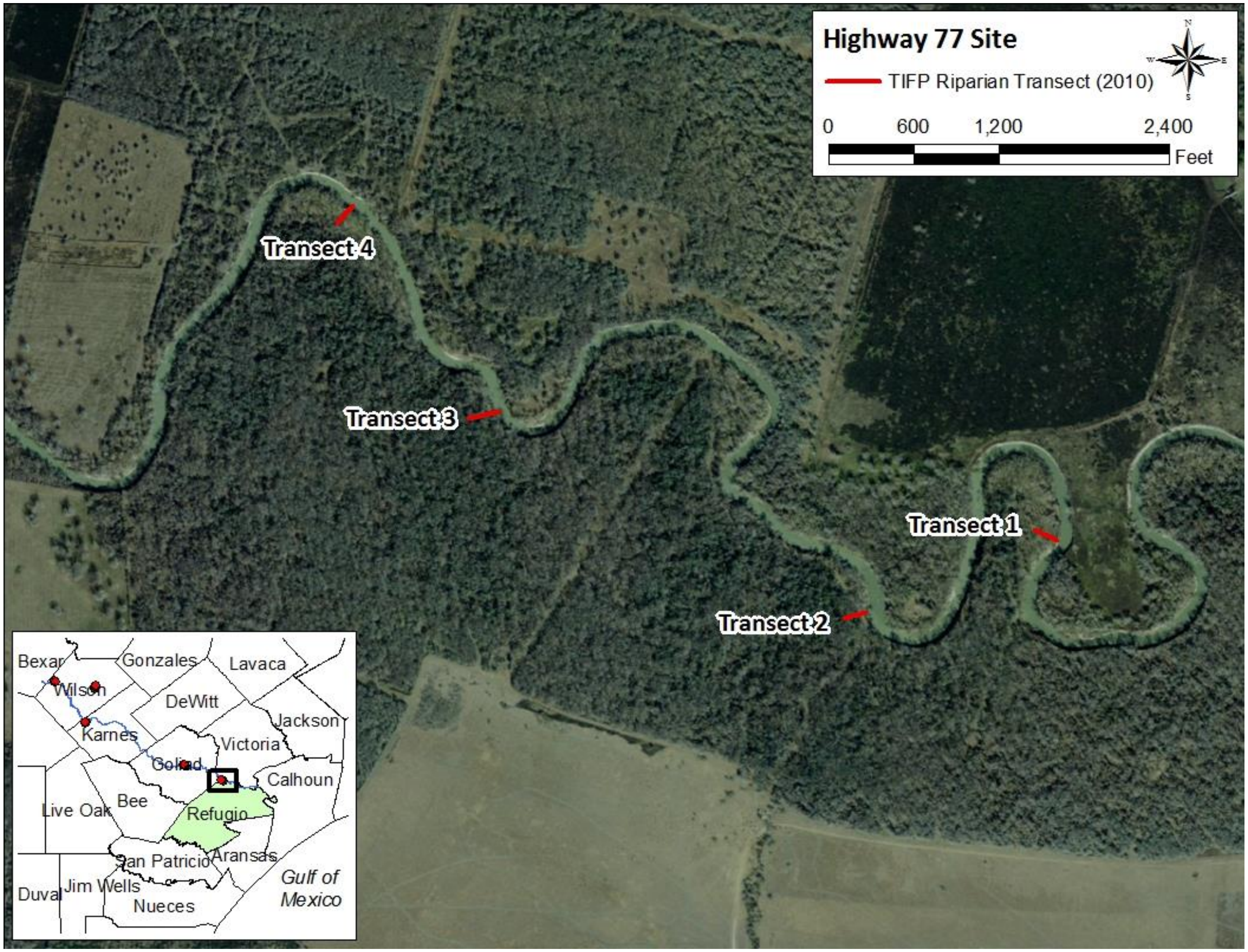


Figure 29. Riparian transects at the San Antonio River Hwy 77 Study Site.

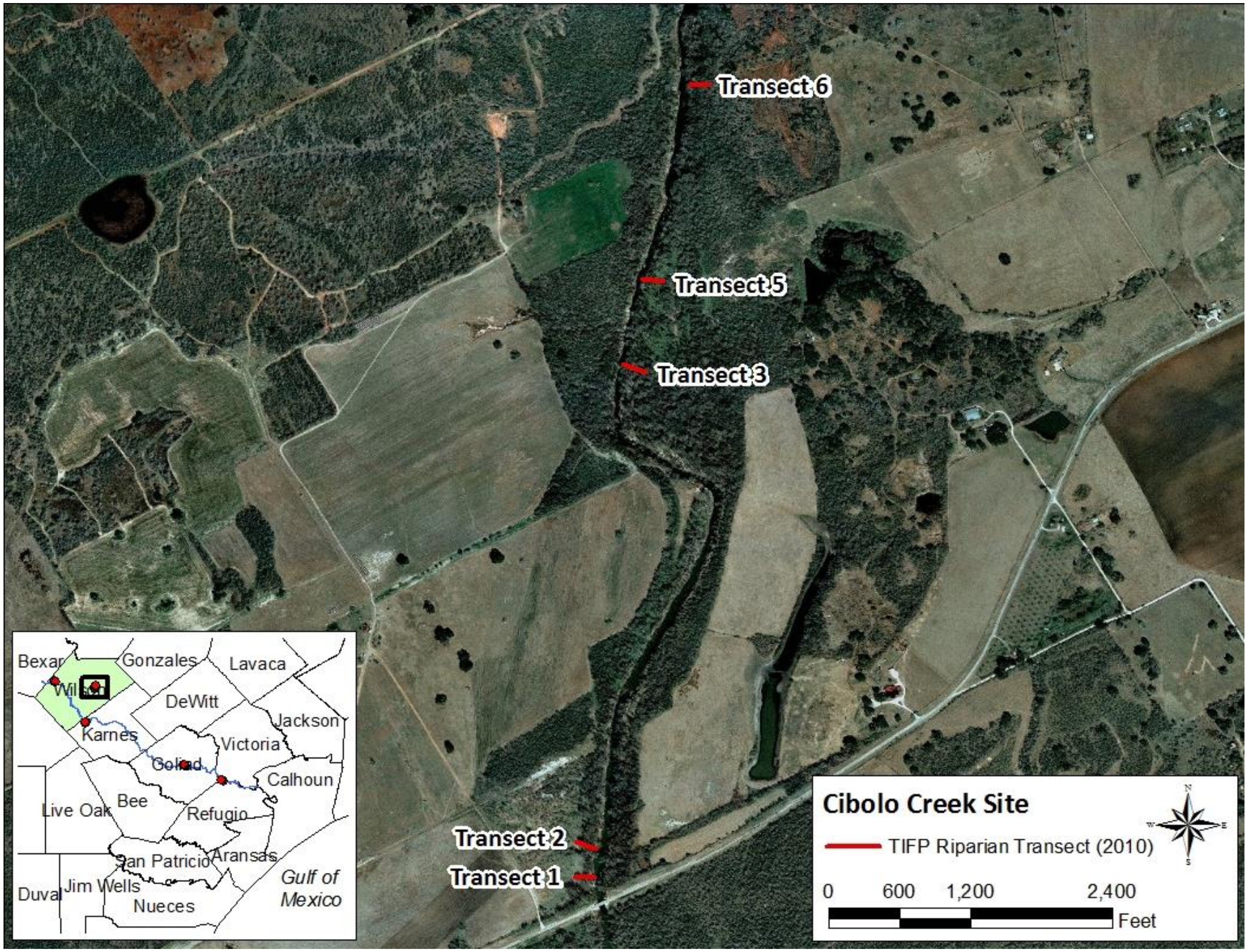


Figure 30. Riparian transects at the Cibolo Creek Study Site (no data were collected from Transect 4).

Although this analysis was able to capture detailed species-specific information, it is important to note a few of the limitations: 1) the 50 m long riparian transects did not always span the entire width of the riparian zone that was present at the site, 2) data from 4-6 transects at a site did not always capture all of the riparian species that were present within the study reaches, and 3) not all of the transect profiles had a linear increase in elevation with distance. Including more transects that span the entire riparian width would allow more detailed analysis of the encroachment of upland species into the riparian zone and increasing the number of transects at each site would enable a more robust correlation between species and their location in the landscape. Since not all of the transects that were measured have a linear increase in elevation, it is also apparent that topographic changes in the riparian zone may allow flooding from a direction other than from directly up the bank of the channel.

The second riparian study utilized a random, permanent transect survey method to monitor seedling recruitment at two sites on the San Antonio River to determine the influence of environmental flows on germination and survival (BIO-WEST 2014). In order to enhance the earlier riparian study, this additional study was designed to monitor recruitment at one of the existing TIFP Study Sites (Goliad) in the lower river basin and at a new site (County Road 125) at the upstream end of the lower river. The extent of inundation of the riparian zone by high flow pulses and overbank flows, in addition to microhabitat characteristics, were assessed in relation to recruitment areas and seedling survival between spring 2012 and spring 2014. Physical environmental variables including river level, discharge, rainfall, groundwater level, soil moisture, canopy closure, and ground cover were also measured.

Literature Review

Life history information of dominant plant species in the riparian zone of the lower San Antonio River and Cibolo Creek Study Sites was researched during a literature review of relevant scientific publications and field guides. Hydroperiod and light have been identified as the principal factors that influence population dynamics and species composition in bottomland hardwood forest communities (Streng et al. 1989, Hall and Harcombe 1998, Battaglia et al. 2000, Lin et al. 2004, Battaglia and Sharitz 2006). Life history strategies, especially the timing and modes of seed dispersal, germination requirements, and seedling growth rates, are also important mechanisms maintaining riparian vegetation communities. While mature trees may be tolerant of varying degrees of inundation and drought, seedlings are susceptible to desiccation under dry conditions, uprooting during high flow pulses, and anoxic soil conditions during prolonged periods of inundation.

A general understanding of plant species' relationships to water is available through USFWS (1988) data and definitions for wetland plant indicator categories. These plant categories were developed to identify plants commonly associated with wetland hydrology (Tiner 1993).

- Obligate Wetland (OBL) species occur almost always (estimated probability 99%) under natural conditions in wetlands
- Facultative Wetland (FACW) species usually occur in wetlands (estimated probability 67%–99%), but occasionally found in non-wetlands
- Facultative (FAC) species are equally likely to occur in wetlands or non-wetlands (estimated probability 34%–66%)

Relationships between these riparian species and environmental flow needs were also explored by reviewing currently available instream flow studies that included riparian analysis. Further, the TIFP expanded the link between life history strategy information, seedling dispersal mechanisms, germination requirements, and the location of facultative and obligate wetland plant species' in the riparian landscape to develop recommendations of environmental flows important to maintaining these riparian communities.

It is largely understood that many factors influence the recruitment of seedlings and saplings into the riparian environment. Also, due to differences in germination timing and requirements, species may not recruit every year. Additionally, only a small percentage of emerging seedlings will ultimately survive to grow into maturity. Summaries of the life history information of dominant plant species found at the Study Sites are provided below.

Tree Layer

American sycamore (Burns and Honkala 1990)

- Classified as a facultative (FAC) species
- Can grow in river bottoms saturated for 2–4 months
- Seed production starts when trees are 25 years, with optimum production between 50–200 years and good seed crops every 1 or 2 years
- Seeds are dispersed primarily by wind and water from February–May
- Germination will not occur where litter layer is more than 2 inches deep
- Seedlings require direct light
- Can live more than 250 years

American elm (Burns and Honkala 1990)

- Classified as a facultative (FAC) species
- Can withstand flooding in the dormant season, but not if the flooding is prolonged in the growing season
- Intermediately tolerant to complete inundation
- Seed production starts when trees are at least 15 years of age, but seldom abundant before age 40
- Seed fall occurs in early spring and is usually complete by mid-March in the south
- Seed dispersal is by wind and wildlife (birds)
- Germination occurs within 6-12 days, although some seeds may remain dormant until the spring
- Seedlings that develop in saturated soils are stunted

Bald cypress, *Taxodium distichum* (Langdon 1958)

- Classified as an obligate wetland (OBL) species
- Seeding occurs annually, with good seed crops approximately every 3 years
- Seeds fall from October to November
- Water is necessary for seed dispersal (few seeds are disseminated by animals)
- Germination occurs after 1–3 months in saturated or wet, organic, or peaty soils
- Can live to 1200 years

Black willow (Burns and Honkala 1990)

- Classified as a facultative wetland (FACW) species
- Seed production starts when trees are approximately 10 years old, and occurs annually

- Seeds are distributed by water and wind, and must reach a seedbed within 12–24 hrs, unless floating in water
- Very moist, almost flooded mineral soil is best for germination and development
- Seedlings grow best when there is abundant moisture available throughout the growing season
- Can survive more than 30 days of inundation
- Tends to be shallow rooted
- Not drought tolerant

Box elder (Friedman and Auble 1999)

- Classified as a facultative wetland (FACW) species
- Seed production starts when trees are 8–11 years of age, and occurs annually
- Seeds are wind distributed continuously from fall until spring on a variety of seedbeds
- Saplings can be killed if inundated for more than 85 days during the growing season
- Usually develops a shallow, fibrous root system
- Mature trees can survive being inundated for an entire growing season
- Tolerant to some extent of drought
- Can live 60–100 years

Cottonwood (Burns and Honkala 1990)

- Classified as a facultative (FAC) species
- Seed production starts when trees are 5–10 years of age, and occurs annually
- Seed dispersal occurs from May to mid-July in the southeast U.S.
- Unless floating or immersed, seeds must reach a suitable germination site within 1–2 weeks to avoid desiccation
- Late spring high flows generate bare, moist, mineral substrate and silt deposits where cottonwood normally become established
- Seedlings are delicate for the first few weeks when root growth is slow
- Cottonwood is a shade intolerant, pioneer species and relies on a disturbance regime to regenerate
- In addition to regeneration from seed, it sprouts readily from roots
- The best sites have water tables from 24 to 72 inches below ground
- May be stressed by wetter than normal summer soil conditions (Dudek et al. 1998)
- Can live 100–200 years

Green ash (Burns & Honkala 1990, NRCS 2002)

- Classified as a facultative wetland (FACW) species
- Grows best on moist, fertile, well drained soils
- Tolerant of seasonal flooding, up to 40% of the growing season
- Intolerant of shading from surrounding trees

Shrub Layer

Common buttonbush, *Cephalanthus occidentalis* (NRCS 2004)

- Classified as an obligate wetland (OBL) species
- A tall shrub common along the borders of ponds and streams and in shrub-scrub wetlands
- Prefers medium to wet soils and is intolerant of dry soils
- Fruits in September–October
- Seeds germinate in moist soils

Deciduous holly, *Ilex decidua* (Sullivan 1993)

- Classified as a facultative wetland (FACW) species
- Usually found on moist soils of floodplains, low woodlands, wet thickets, and along streams
- Moderately tolerant of periodic flooding, with mature trees able to withstand flooding up to 35% of the growing season
- Produces seeds that are dispersed by animals from September to spring
- Seedlings grow slowly
- Tolerant of drought and shade tolerant

Roosevelt weed (Texas Agrilife Extension Service 2011)

- Classified as a facultative (FAC) species
- Tall shrub that occurs in wet or dry sites
- Extremely drought tolerant
- Prolific seed producer

HEC-RAS High Flow Pulse Analysis

The recurrence interval of inundation is important to riparian and wetland areas. LiDAR data and HEC-RAS models were used to evaluate how different riparian communities are affected by flow pulses and overbank flows. The HEC-RAS model projected water's edge for a series of high modeled flow events based on the topography at each Study Site (Table 13). A digital shapefile for the water's edge from each modeled flow value was overlaid on the vegetation community map at each site. The total area of inundation of each vegetation community type at each flow value was calculated and plotted graphically to depict the increase in community inundation with increase in flow. With the understanding that the largest modeled flow value at each site is an extremely rare flow event, the inundation values were also plotted as a percentage increase in inundation with flow (to a maximum of the area inundated by the highest modeled flow).

Vegetation communities inundated at modeled high flow pulses were evaluated based on the species that occur in them (based on TPWD Ecological Mapping Systems descriptions), at which flows they became inundated, and the acreage that was inundated. To focus the analysis on vegetation communities with wetland species, the TPWD Ecological Mapping Systems subsystem communities were identified as tree, shrub, or herbaceous communities and grouped if they had the same dominant species and significantly overlapping common species.

Table 13. Flow values (cfs) for each San Antonio River Study Site used in HEC-RAS modeling.

Calaveras (San Antonio River)	Falls City (San Antonio River)	Goliad (San Antonio River)	Highway 77 (San Antonio River)	Cibolo Creek
2,500	2,500	2,500	1,500	1,000
3,750	3,750	3,750	4,000	2,500
5,000	5,000	5,000	6,000	5,000
6,500	6,500	6,500	8,000	8,000
8,000	8,000	8,000	10,000	10,000
11,500	11,500	11,500	15,000	
13,000	13,000	13,000		
15,500	15,500	15,500		

Tree-ring Core Study

A concurrent study to evaluate tree growth in relationship to flow on the San Antonio River and Brazos River was conducted by scientists at Baylor University (Duke 2011). Tree-ring analyses were used to evaluate annual tree basal growth as measured from tree cores of a variety of riparian tree species at three sites on the San Antonio River (Calaveras, Goliad, and Hwy 77) and one site on Cibolo Creek. The detailed findings of this study were presented to the Texas Water Development Board (Duke 2011) and were used to supplement the riparian analyses and environmental flow recommendations as part of the TIFP.

Several important findings of the tree-ring core study include: 1) seed dispersal along the San Antonio River appears to be adequately maintained, 2) some riparian species exhibit suppression of growth by very high annual flow volumes (box elder and green ash), while others do not (black willow), 3) there is not an "optimum" flow for riparian health and variability in flow likely maintains diversity, and 4) tree-ring analysis can be used to correlate annual growth response with annual flow volumes.

Annual flow volumes identified in Duke (2011) for good riparian growth are:

1) Total annual flow volume at the Calaveras site (based on the San Antonio River at Elmendorf gage) should vary between 198,400-1,190,000 acre-feet
2) Total annual flow volume at the Goliad site (based on the San Antonio River at Goliad gage) should vary between 297,500–1,587,000 acre-feet
3) Total annual flow volume at the Cibolo Creek site (based on the Cibolo Creek near Falls City gage) should vary 39,800–317,100 acre-feet

Total annual flow volumes are important measures since they incorporate the hydrology that the current riparian community has developed under and since there is currently documented recruitment of riparian species in these communities.

Summary of Results

The field collection of riparian species information from five sites on the lower San Antonio River and one site on the lower Cibolo Creek enabled the TIFP to assess the environmental flow needs of riparian communities within the watershed.

Figures 31, 32, and 33 show the overall species composition of tree, sapling, and seedling layers, while figures for each Study Site (based on pooled transect data) are presented in Appendix E.

Falls City had the highest species richness (Figure 34), while the highest density of trees and saplings occurred at Cibolo Creek (Figure 35). Goliad had the highest density of seedlings observed (Figure 36). Several factors led to the species diversity of the Falls City site, including that it had a unique bald cypress community, and included a transect with a steep bank profile that extended from the water's edge up through a narrow bottomland hardwood forest community and into an elevated sandy hilltop with upland species. However, species data could vary based on the number of transects sampled at each site and the bank profile of the transect.

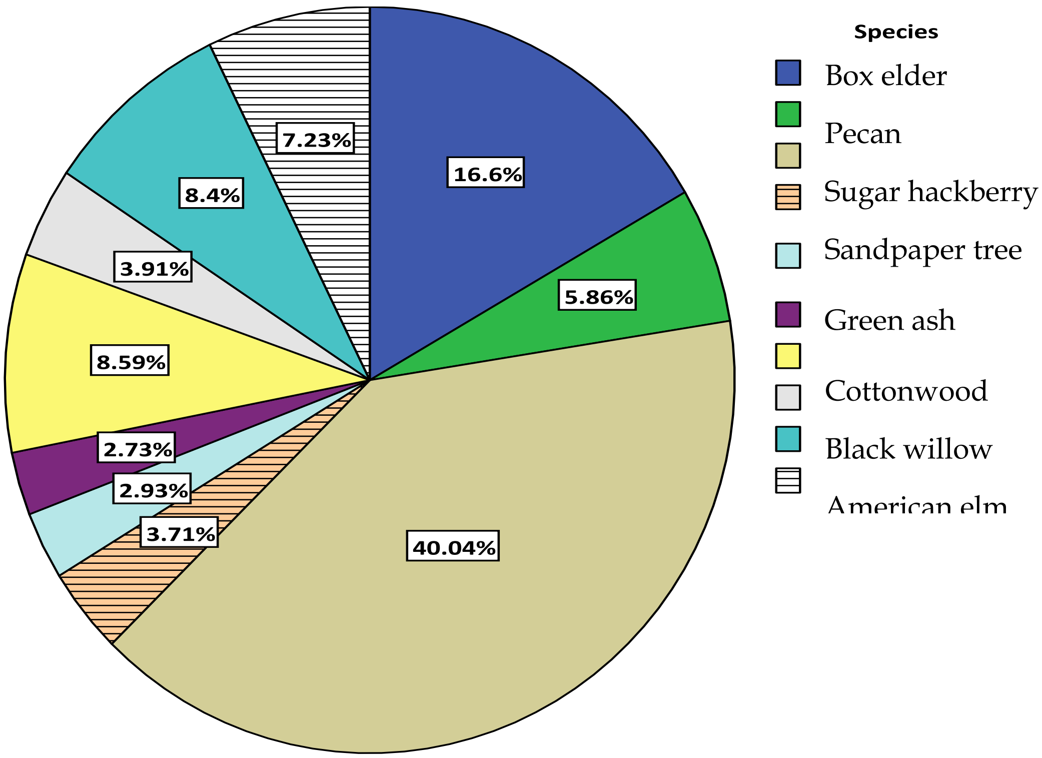


Figure 31. Overall tree species composition identified during the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study.

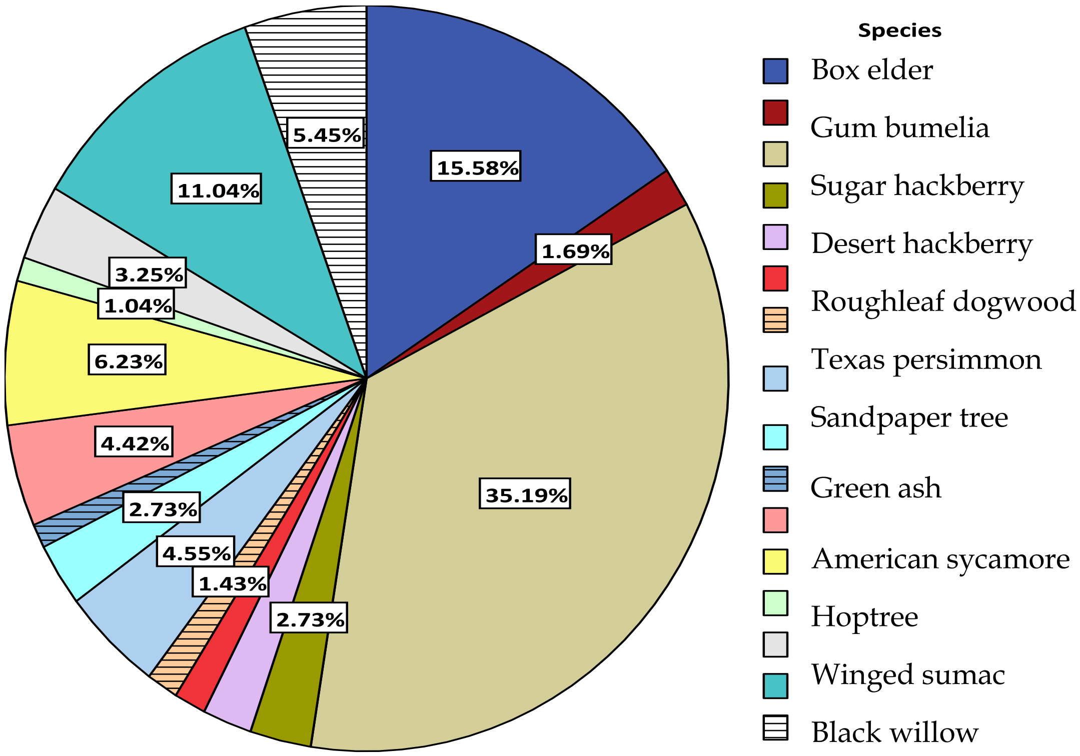


Figure 32. Overall riparian sapling composition identified during the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study.

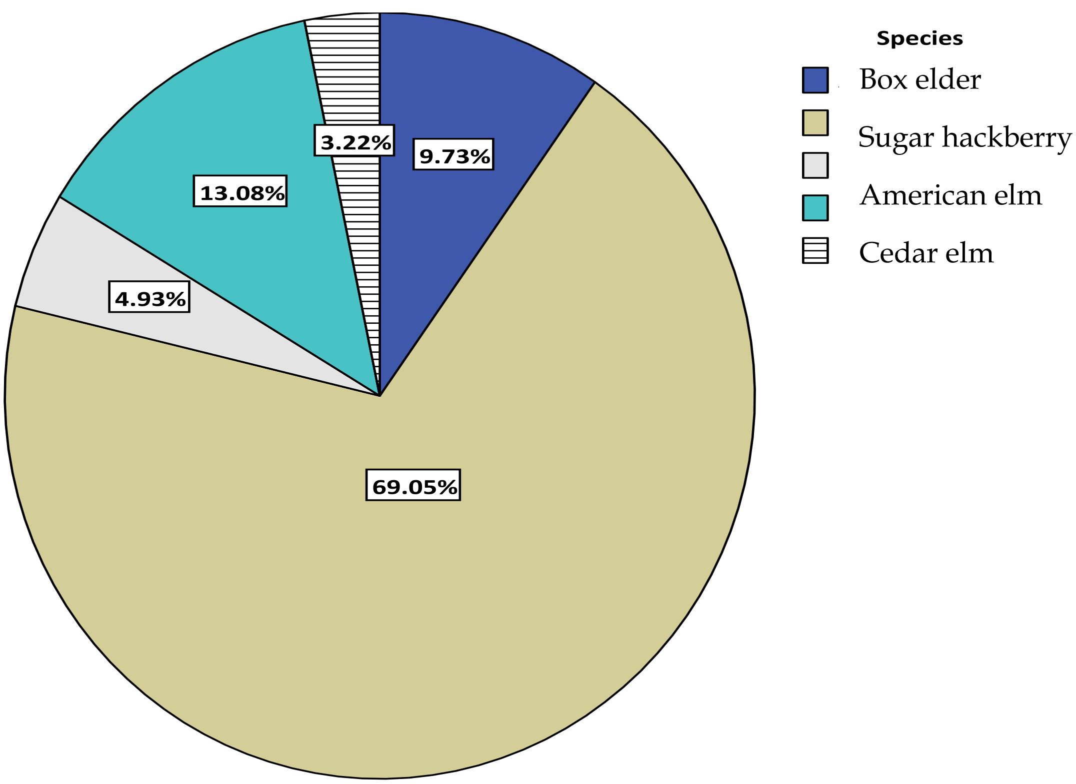


Figure 33. Overall riparian seedling composition identified during the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study.

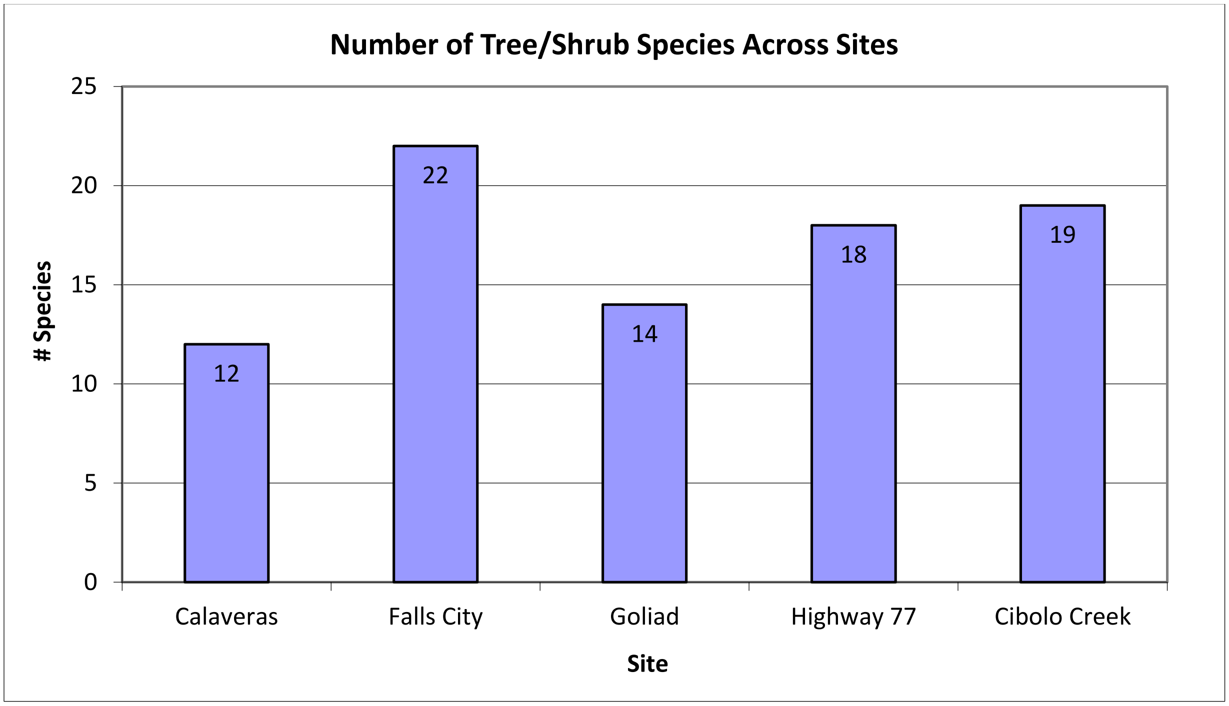


Figure 34. Number of tree and shrub species across the five San Antonio River Study Sites.

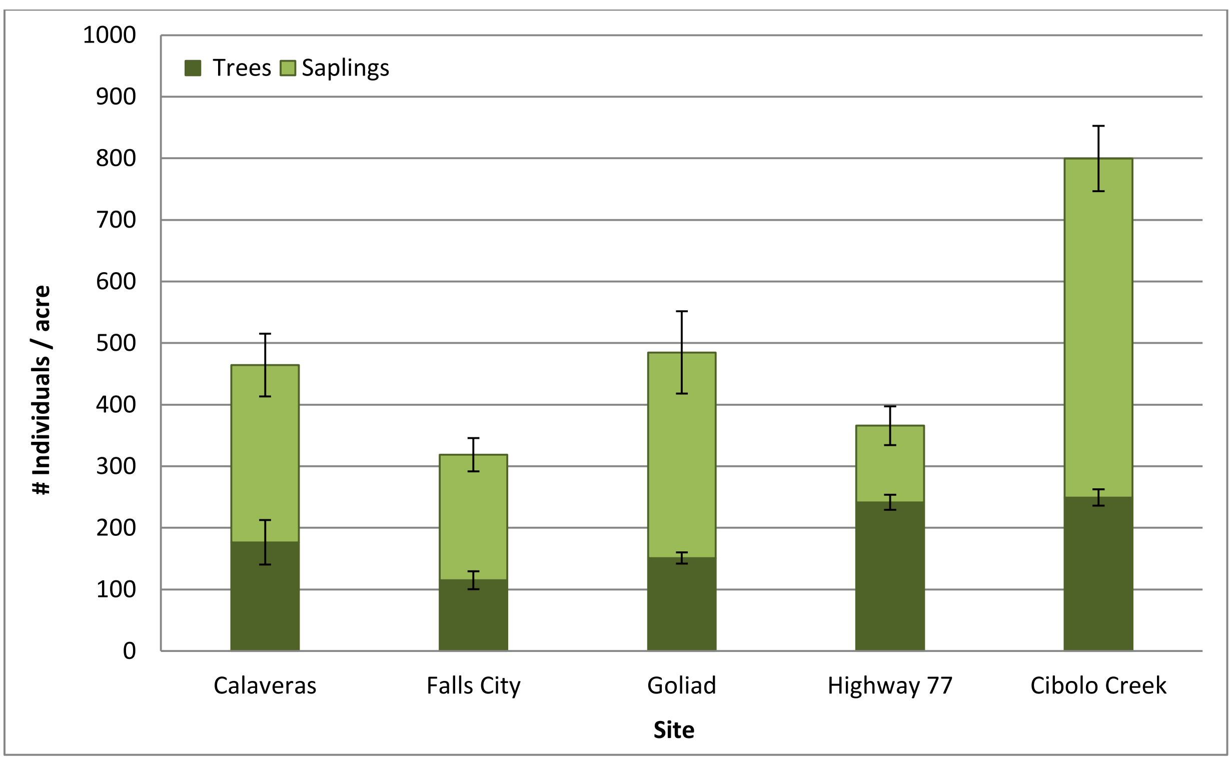


Figure 35. Average tree and sapling density estimates (with standard error) across the five San Antonio River Study Sites.

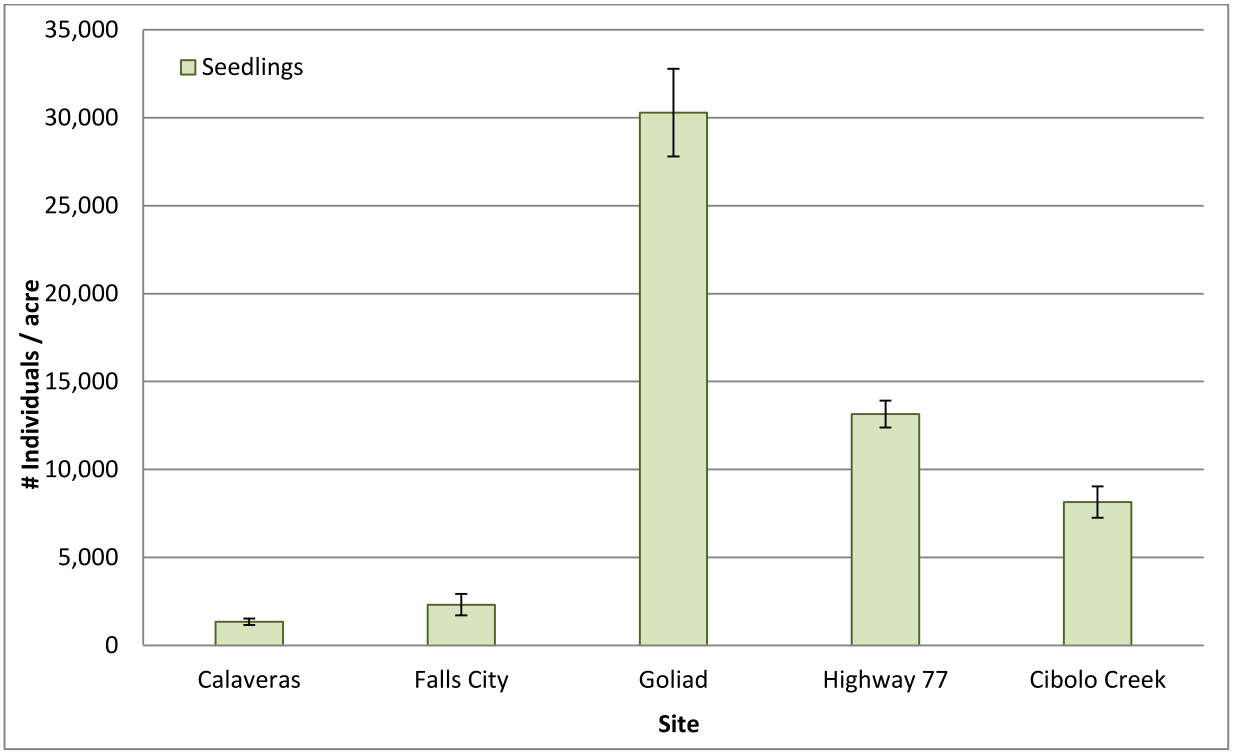


Figure 36. Seedling density estimates (with standard error) across the five San Antonio River Study Sites.

The riparian analysis focused on the woody species in the riparian vegetation communities since they are longer lived than annual and perennial herbaceous plants and represent the dominant strata of the climax riparian community that exists along major watercourses in Texas: bottomland hardwood forests. A total of 34 woody plant species were observed in riparian transects across all sites (Table 14). Woody plant species were compared across sites and dominant obligate wetland (OBL), facultative wetland (FACW), and facultative (FAC) species were identified based on the number of individuals in the tree, sapling, and seedling layers of the riparian transect communities (Appendix E). Several species were chosen as indicator species based upon each being a main component of the riparian community with life stages dependent upon environmental flows. These riparian indicator species include black willow, box elder, green ash, cottonwood, American sycamore, and common buttonbush. Pecan trees were also present at several sites, but it was unclear whether they occurred naturally or only in areas planted as pecan groves. Additional surveys or study of recruitment in these areas would clarify the role of pecan trees within these riparian communities. Additionally, sugar hackberry trees were prevalent at many sites, although it is not considered a wetland species.

Table 14. List of woody species observed in transects across the five San Antonio River Study Sites in 2010. OBL-obligate wetland species; FACW-facultative wetland species; FAC-facultative species; FACU-facultative upland species; UPL-upland species. Status classification based on Lichvar et al. (2016).

Species name	Common name	Status	Calaveras	Falls City	Goliad	Hwy 77	Cibolo Creek
Cephalanthus occidentalis	Common buttonbush	OBL		X			X
Taxodium distichum	Bald cypress	OBL		X			
Acer negundo	Box elder	FACW	X	X	X	X	X
Fraxinus pennsylvanica	Green ash	FACW	X	X	X	X	X
Ilex decidua	Deciduous holly	FACW		X	X	X	X
Salix nigra	Black willow	FACW	X	X	X	X	X
Baccharis neglecta	Roosevelt weed	FAC		X			
Carya illinoinensis	Pecan	FAC	X	X	X	X	X
Cornus drummondii	Roughleaf dogwood	FAC				X	
Crataegus texana	Texas hawthorn	FAC		X			
Ilex vomitoria	Yaupon	FAC				X	
Platanus occidentalis	American sycamore	FAC		X	X	X	X
Populus deltoides	Cottonwood	FAC	X	X			X
Ptelea trifoliata	Hoptree	FAC					X
Quercus macrocarpa	Bur oak	FAC				X	
Ulmus americana	American elm	FAC		X	X	X	X
Ulmus crassifolia	Cedar elm	FAC	X	X	X	X	X
Acacia berlandieri	Guajillo	UPL		X	X		
Bumelia lanuginosa	Gum bumelia	UPL	X	X	X	X	X
Celtis laevigata	Sugar hackberry	FAC	X	X	X	X	X
Celtis pallida	Desert hackberry	UPL		X			
Diospyros texana	Texas persimmon	UPL	X	X			X
Ehretia anacua	Sandpaper tree	UPL				X	
Maclura pomifera	Osage orange	FACU			X		X
Melia azedarach	Chinaberry	UPL	X				X
Prosopis glandulosa	Honey mesquite	FACU		X			
Rhus copallinum	Winged sumac	UPL		X		X	X
Ungnadia speciosa	Mexican buckeye	UPL				X	X
Yucca torreyi	Yucca	UPL		X			
Ilex opaca	American holly	FACU					X
Morus alba	White mulberry	FACU			X		
Morus rubra	Red mulberry	FACU	X	X		X	
Sapindus saponaria	Western soapberry	FACU	X				
Sapium sebiferum	Chinese tallow	FACU			X	X	
Total # Species = 34	**# Species by site:**		**12**	**22**	**14**	**18**	**19**

Riparian transect survey data were used to plot the bank profile of each transect relative to the water's edge present on the day of the riparian data collection (e.g., Figure 37). A series of plots illustrating the bank profile and corresponding tree location data for each transect individually are presented in Appendix F. Similarly, a series of plots illustrating the bank profile and corresponding sapling and seedling range data for each transect individually are also presented in Appendix F. The distance from the water's edge (0 m location on transect) to the extent of inundation of a range of high flow pulses modeled in HEC-RAS (thick, vertical lines with an associated flow rate in units of cfs) are also presented on the riparian transect plots. In most of the plots, it is apparent that a community of black willow (and common buttonbush and American sycamore, where present) occurs closest to the water's edge. Further away from water's edge, but still typically on the lower portion of the bank, box elder, cottonwood, and green ash can be found. Modeled high flow pulses that inundate the range of each of these species, either individually or in groups where they occur together, were identified based on these transect plots. Each of these identified pulses are presented in the recommendation tables in Section 3.0.

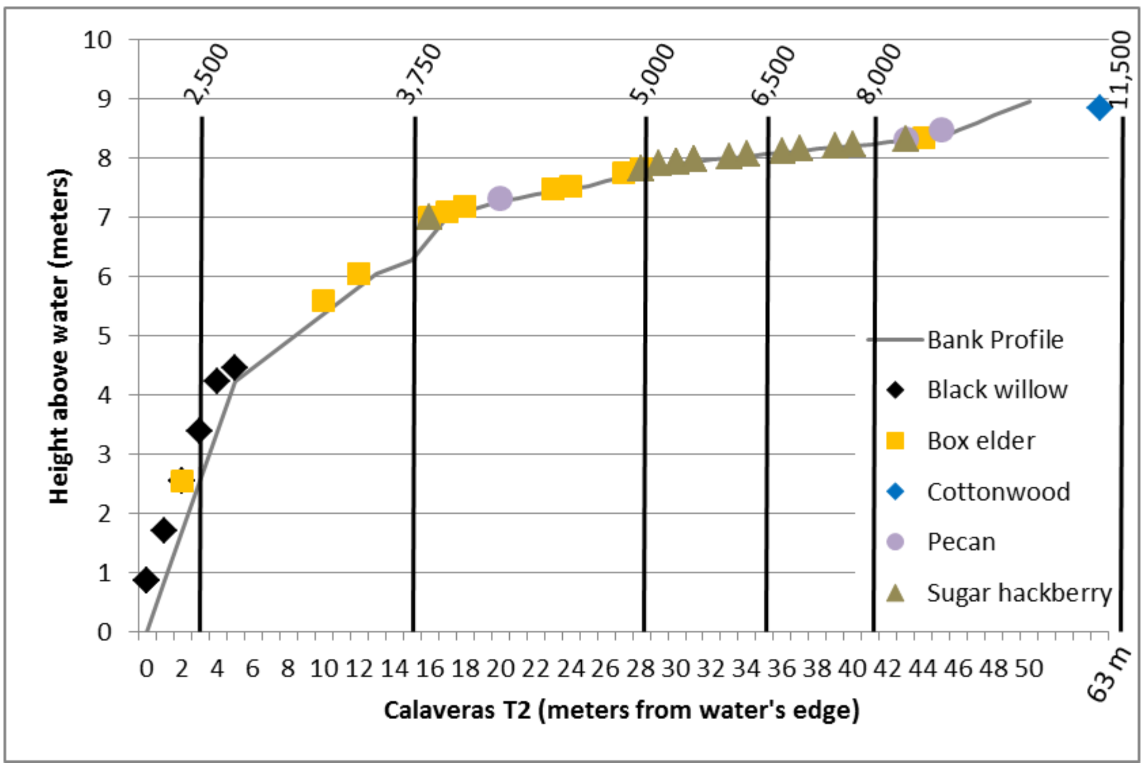


Figure 37. Riparian transect survey data for trees at the San Antonio River Calaveras Study Site along Transect 2.

As discussed above vegetation communities inundated at modeled high flow pulses were evaluated based on the species that occur in them, at which flows they became inundated, and the acreage that was inundated. Flow recommendations that inundate the entire hardwood communities were selected and are presented in the recommendation tables in Section 3.0. These recommendations are intended to maintain the riparian corridor, which includes protection of native species and protection against non-native species intrusion.

2.4 *Physical Processes*

The channel shape (geometry or bathymetry) of an alluvial river adjusts in response to the range of flows that mobilize the boundary sediments. A stable channel shape is important because it maintains habitat conditions that support biological resources both within the channel and in near channel riparian areas. Flow recommendations will only be successful if they support the long term creation and maintenance of desired aquatic and riparian habitats. Changes in the flow regime of a stable channel can cause unstable conditions due to changes in the rate of erosion, sediment transport, and/or sediment deposition.

While channel shape is always adjusting to sediment and flow conditions, a stable channel exhibits what river engineers call "dynamic equilibrium." A channel in dynamic equilibrium exhibits relatively stable average channel geometry (width, depth, width-depth ratio, sinuosity, and slope) over time. Once dynamic equilibrium is disrupted, the channel will be unstable while the flow and sediment regimes interact to reestablish equilibrium by changing the channel geometry (Schumm 1969). Such changes in channel geometry have the potential to alter the amount and nature of aquatic and riparian habitats and therefore biological communities.

At least some of the reported impacts on biological communities due to flow alterations are probably due to changes in river geomorphology (and therefore habitat). An examination of published instream flow data found that a 50% change or greater in flow magnitudes (including peak, total or mean, base or hourly discharge) had a negative impact on fish communities (Poff and Zimmerman 2010). Flow alterations of this magnitude are likely to impact sediment transport rates and channel geometry. Examination of data from 237 sites across the United States found that a 60% decrease in the mean annual maximum flow was likely to lead to degraded fish communities (Carlisle et al. 2010). In most systems, mean annual maximum flows significantly affect the channel's shape or morphology. The impact on fish communities related to changes in mean annual maximum flow may be directly related to changes in habitat, though disruptions to spawning cues, access to floodplain habitats, or other factors may also play a role.

There is growing recognition that geomorphic processes must be considered in order to protect biological resources. Failure to protect flows required to maintain geomorphic processes and river geometry is credited with the failure of implemented instream flows to protect biological resources in alluvial rivers (Trush et al. 2000). Environmental standards implemented in the United Kingdom were developed with consideration of geomorphic processes and biological resources (Acreman et al. 2010). Those standards allow diversion of from 7.5 to 30% of flow, depending on geomorphology, flow conditions, and desired ecological status. The U.S. Army Corps of Engineers has developed guidance for maintaining dynamic stability in river channels (Biedenharn et al. 2000). According to that guidance, channels should remain dynamically stable if they are currently stable and the sediment transport capacity of a reach is maintained within 10% of the sediment supplied to the reach.

As described in Section 2.2, the hydrology of the lower San Antonio River sub-basin has been altered by rapid urbanization just upstream of the study area. Changes in hydrology also impact the amount of sediment transported by the river, which, over time, can lead to changes in channel shape and associated habitats. Channel enlargement is a typical geomorphic response to urbanization (Brierely and Fryirs 2005; Cawthon and Curran 2008;, and, O'Driscoll et al. 2010).

In their evaluation of channel change along the lower San Antonio River, Cawthon and Curran (2008) evaluated historical and contemporary cross sections taken at two locations (FM 775 bridge near Floresville and FM 791 bridge near Falls City). At both locations, the analysis found evidence of channel enlargement. The FM 791 site corresponds to the location of USGS Gage No. 08183500, San Antonio River near Falls City. Changes in the hydrology at this gage site are discussed in detail in Section 2.2. Data from the FM 791 site near Falls City show channel widening of about 40 feet from 1950 to 2007, along with an increase in channel cross-sectional area of almost 50% (Figure 38). Cawthon and Curran (2008) attributed channel widening in this portion of the lower San Antonio River basin to an increase in the 80^{th} to 99^{th} percentile flows during the 1950 to 2007 time period and attributed this change to a combination of increased runoff due to increased urbanization in and around the City of San Antonio and increased precipitation.

Another typical response of the channel to upstream urbanization is development of a more homogeneous or simplified channel shape (Pizzuto et al. 2000, Hession 2001, O'Driscoll et al. 2010). As part of that process of homogenization of channel shape, pools become shallower and bars become lower, resulting in less varied in-channel habitat versus unaltered conditions (Figure 39). Unfortunately, there are not enough historical data available for the lower San Antonio River to confirm whether such impacts have occurred or are occurring as a result of upstream urbanization.

Channel responses to urbanization can be greatly influenced by local conditions such as geological setting, riparian conditions, and other factors (Pizzuto et al. 2000 and O'Driscoll et al. 2010). In general, however, effects of urbanization in the lower San Antonio River sub-basin are expected to be less pronounced with greater distance downstream from the City of San Antonio as the landscape becomes more rural .

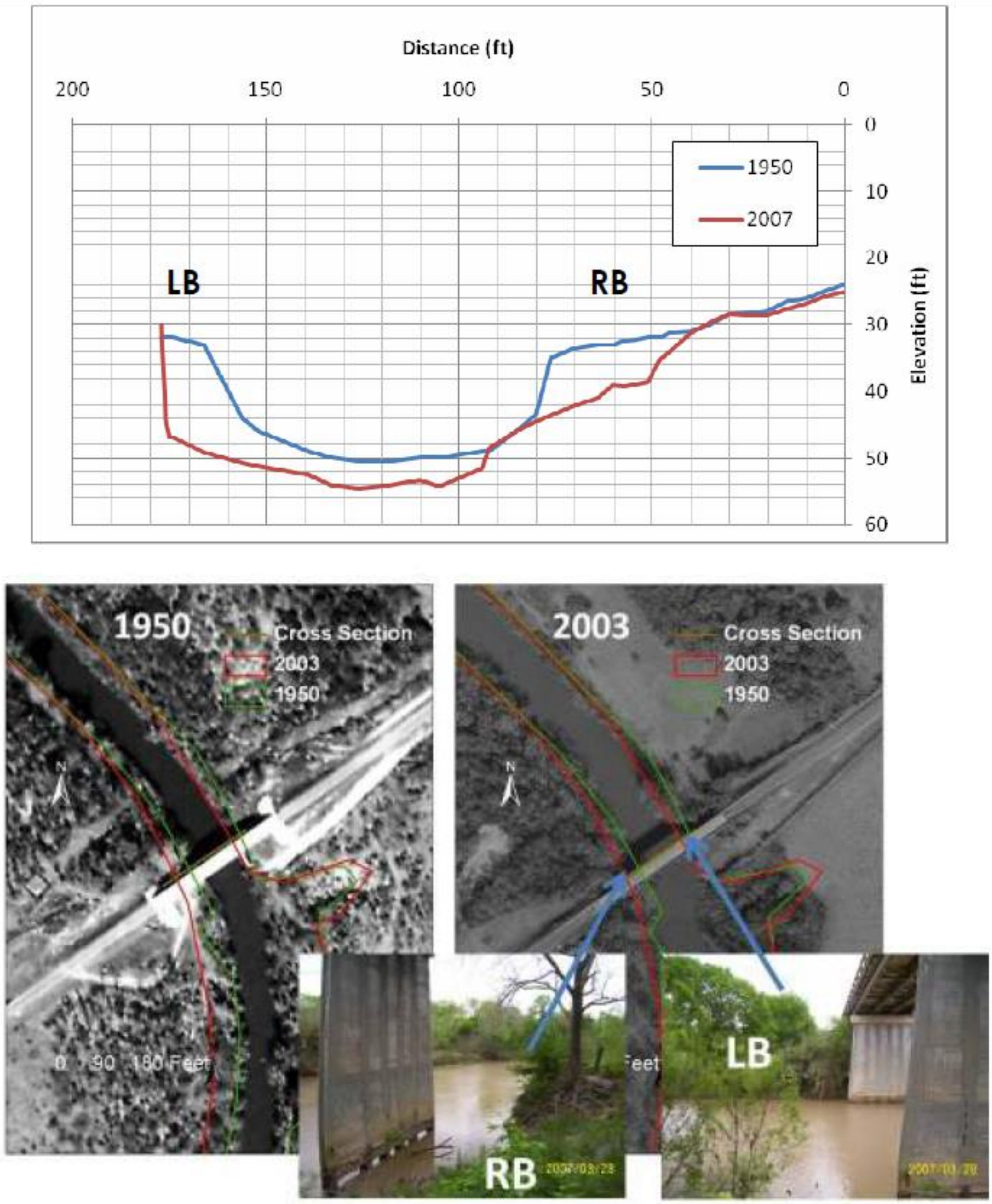


Figure 38. Cross sections and aerial and ground based photos of the San Antonio River at FM 791 bridge near Falls City, Texas (from Cawthon and Curran 2008). RB – right bank; LB – left bank.

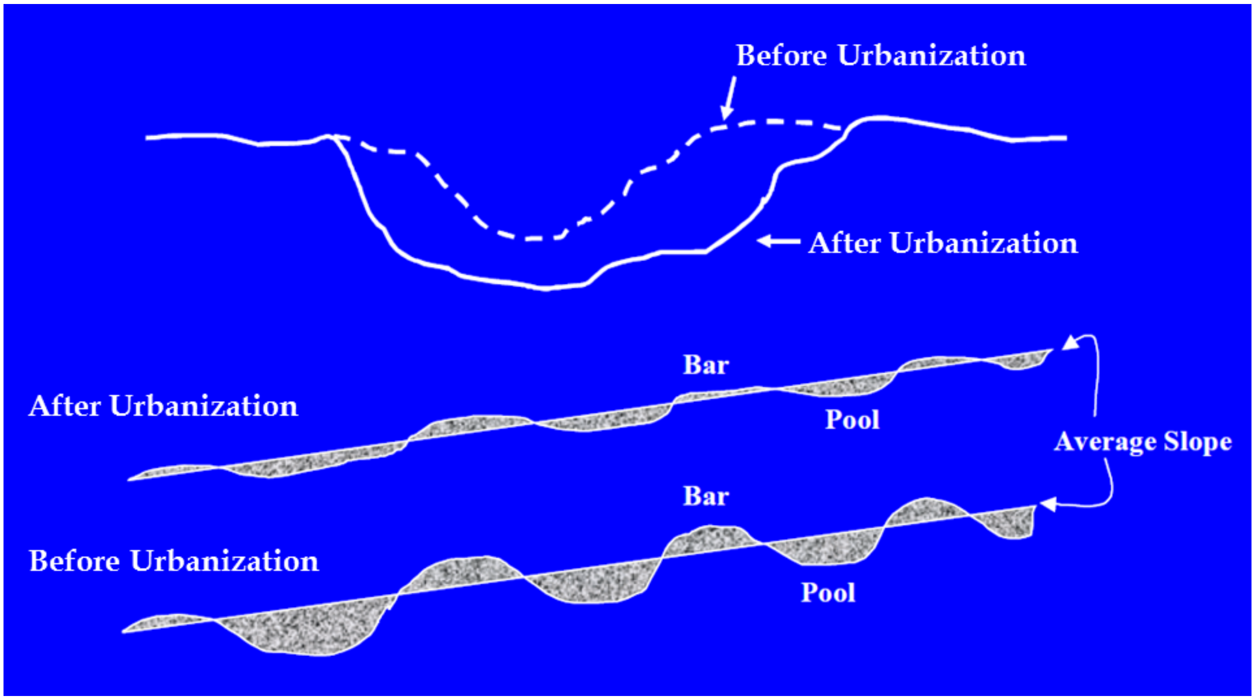


Figure 39. Typical stream cross section and longitudinal profile before and after upstream urbanization (modified from Hession 2001).

Data collected during the completion of this study made it possible to estimate how sediment transport in the lower San Antonio River has varied historically and could vary in the future based on various flow regimes. As described in the Interim Report, efforts to develop and calibrate 1D and 2D models to predict channel and reach scale geomorphic changes in response to individual high flow pulse or overbank flow events proved to be ineffective (Haschenburger 2012, Haschenburger and Curran 2012). Nevertheless, data such as channel cross-section, slope, bed material, and bed and suspended sediment data collected by Haschenburger and Curran (2012) and sediment rating curves developed with that data (Figure 40) proved valuable for evaluating sediment transport associated with alternative flow regimes. Analysis followed procedures described by SAC (2009) and GSA-BBEST (2011) to estimate and compare average annual sediment load at the Goliad gage site for various flow regimes rather than individual flow events. Results from the analysis are summarized in Section 3.3. Methods are described in more detail in Appendix G.

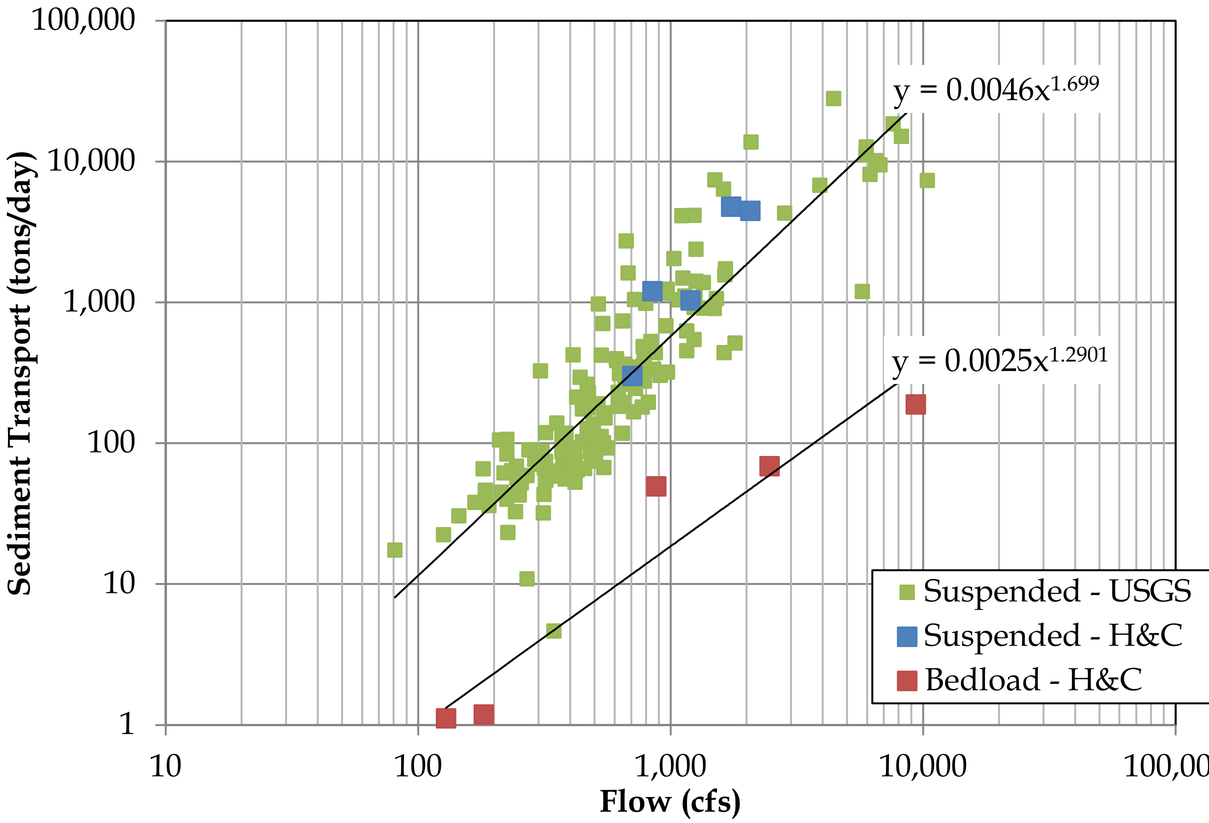


Figure 40. Suspended and bedload sediment transport data and trend lines for the San Antonio River at Goliad, Texas developed with data from the U.S. Geological Survey (USGS) and Haschenburger and Curran (2012) (H&C).

2.5 *Water Quality*

The TIFP water quality and subsistence flow evaluation focused on three reaches within the lower San Antonio River sub-basin as follows:

- Upper San Antonio River, Falls City upstream to Loop 1604. This reach includes TIFP Study Sites 19110 (Calaveras), 19100 (Floresville), and 19090 (Falls City).
- Lower San Antonio River, Guadalupe River confluence upstream to Falls City. This reach includes TIFP Study Sites 19030 (Goliad) and 19020 (Hwy 77).
- Cibolo Creek, San Antonio River confluence upstream to Sutherland Springs. This reach includes TIFP Study Site 19070 (Cibolo Creek).

The TIFP developed water quality goals, objectives, and indicators (Section 1.2) associated with the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study and in collaboration with the stakeholder workgroup (TIFP and SARA 2012). These were utilized to develop water quality goals to assess current water quality conditions relative to historical trends and water quality standards (Espey Consultants 2010a and 2010b, TIFP and SARA 2011). Water quality goals for the lower San Antonio River sub-basin study are presented in Table 15 and were reviewed and accepted by the stakeholder workgroup. Parameters with asteriks are preliminary water quality indicators identified within the Study Design. Additional criteria, beyond those identified in the Study Design, were evaluated to provide a thorough analysis of water quality and determine study goal attainment. These goals are considered by TIFP to be adequate to provide for a sound ecological environment for the lower San Antonio River and lower Cibolo Creek. Temperature and DO are considered by the TIFP as parameters of primary concern and will be the focus of additional analysis, as detailed below.

Table 15. Water quality goals established for the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study (adapted from TIFP and SARA 2011).

Parameter	**Instream Flow Goals (Values)**
Tier 1 – Primary Priority	
Dissolved Oxygen	≤12 hrs below 3 mg/L ≤2 hrs below 2 mg/L >1.5 mg/L
Temperature	≤35°C (95°F)[1]
Tier 2 – Secondary Priority	
Dissolved Oxygen	≥5.0 mg/L daily average ≥3.0 mg/L daily average for ≤ 8 hrs Spring Condition ≥5.5 mg/L daily average ≥4.5 mg/L daily average for ≤ 8 hrs
Temperature	≤27.0°C (80.6°F) Jan – May[2]
Temperature	≤32.2°C (90.0°F)
Nitrate	≤1.95 mg/L
Ammonia	≤0.33 mg/L
Orthophosphate	≤0.37 mg/L
Tier 2 – Additional Parameters	
E. coli	≤126 or/100 mL geometric mean
Total Nitrogen	No value
NO_x	≤2.76 mg/L
Organic Nitrogen	No value
Total Phosphorous	≤0.69 mg/L
pH	6.5 – 9.0

[1] - Critical thermal maximum water temperature for some San Antonio River species
[2] - Spawning fish water temperature criteria

Subsistence flows are naturally occurring low flow events that can be seasonal in nature. These episodic low flow events can be represented by extreme conditions that still maintain survival of aquatic organisms although may not always provide for suitable or even optimal water quality conditions at varying spatiotemporal scales. The ecology of river systems are influenced by extreme events on both the high and low flow ends of the spectrum. Having occasional extremes supports populations of native species that have evolved life history strategies in response to the natural flow regime (Poff et al. 1997; Bunn and Arthington 2002). The data and analyses used to determine subsistence flow recommendations are discussed in the following sections.

Surface Water Quality Monitoring Program

To assess historical water quality the TIFP evaluated existing surface water quality monitoring data from TCEQs Surface Water Quality Monitoring (SWQM) Program. The SWQM Program monitors and evaluates physical, chemical, and biological characteristics of aquatic systems. The SWQM Program coordinates the collection of physical, chemical, and biological samples from more than 1,800 surface water sites statewide, including surface water sites within the Lower San Antonio TIFP study area. Water quality goals in Table 15 were used to determine study goal attainment for historical water quality conditions.

Currently, portions of Lower San Antonio River (TCEQ Segment No. 1901) and Upper San Antonio River (TCEQ Segment No. 1911) are listed in the 2014 303(d) list for impaired fish communities (TCEQ 2014a). Portions of Lower Cibolo Creek (TCEQ Segment No. 1902) are not meeting the contact recreation standard due to *E. coli*. Water quality impairments related to bacteria and impaired fish communities are currently addressed by other water management strategies outside the scope of the TIFP and were not considered further by the TIFP in developing subsistence flow recommendations.

The TIFP related analysis of SWQM water quality data at various flows determined that water quality was generally good for the Upper San Antonio River study reach and Cibolo Creek. Evaluation of historical water quality and determination of study goal attainment was not conducted for the Lower San Antonio River study reach.

Water Quality Modeling

The TIFP contracted with Epsey Consultants to develop a statewide approach for generating water quality recommendations for the TIFP (Espey Consultants 2010b). Espey Consultants used information from the statewide approach to evaluate issues specific to the San Antonio River Basin (Espey Consultants 2010a). The Espey Consultants study evaluated different water quality modeling techniques to aid in selecting an appropriate model for the Lower San Antonio River Study (Espey Consultants 2010a). Models were used to evaluate temperature and DO under various scenarios. Based on the findings from Espey Consultants (2010a), the TIFP water quality workgroup selected Run B, a steady state subsistence flow model, to aide in developing subsistence flow recommendations for the Lower San Antonio River. Additional details of the Run B model scenario are contained in Espey Consultants (2010a).

The TIFP also selected EPD Riv-1 to model DO within the mainstem of the San Antonio River and QUAL-TX for DO on the mainstem of Cibolo Creek. For temperature QUAL-2K was selected for the mainstem of the San Antonio River. There was not a detailed temperature model created for Cibolo Creek.

Water Quality Modeling Results

To determine flow conditions necessary to protect water quality and provide for a sound ecological environment, modeling was performed for temperature and DO. The water quality modeling evaluation focused on identifying subsistence level flows that might cause an exceedance of DO and water temperature. These model results provided the information to support water quality based subsistence flow recommendations. QUAL-TX was also used to evaluate DO for Cibolo Creek. Results for water quality modeling are detailed in the following paragraphs.

Dissolved Oxygen

EPD-Riv 1 was used to model DO for the lower San Antonio River and QUAL-TX was used to model DO for Cibolo Creek. Available DO data and modeling results indicate that current DO levels within the study area are protective of a sound ecological environment because the water quality goals for DO were achieved.

Water Temperature

QUAL-2K was used to model water temperature in order to evaluate diurnal variability at different locations for low flows. Figures 41 and 42 show the results for the upper and lower San Antonio River, respectively. Depending on flow, the daily variation of water temperature fluctuates, with greater variation resulting from low flows where shallow waters are more susceptible to heating throughout the water column. Based on study results water temperature was identified as the parameter of concern for the mainstem of the San Antonio River. In both the upper and lower reaches of the San Antonio River, diurnal fluctuations start to exceed the 35°C primary priority temperature goal around 80 cfs.

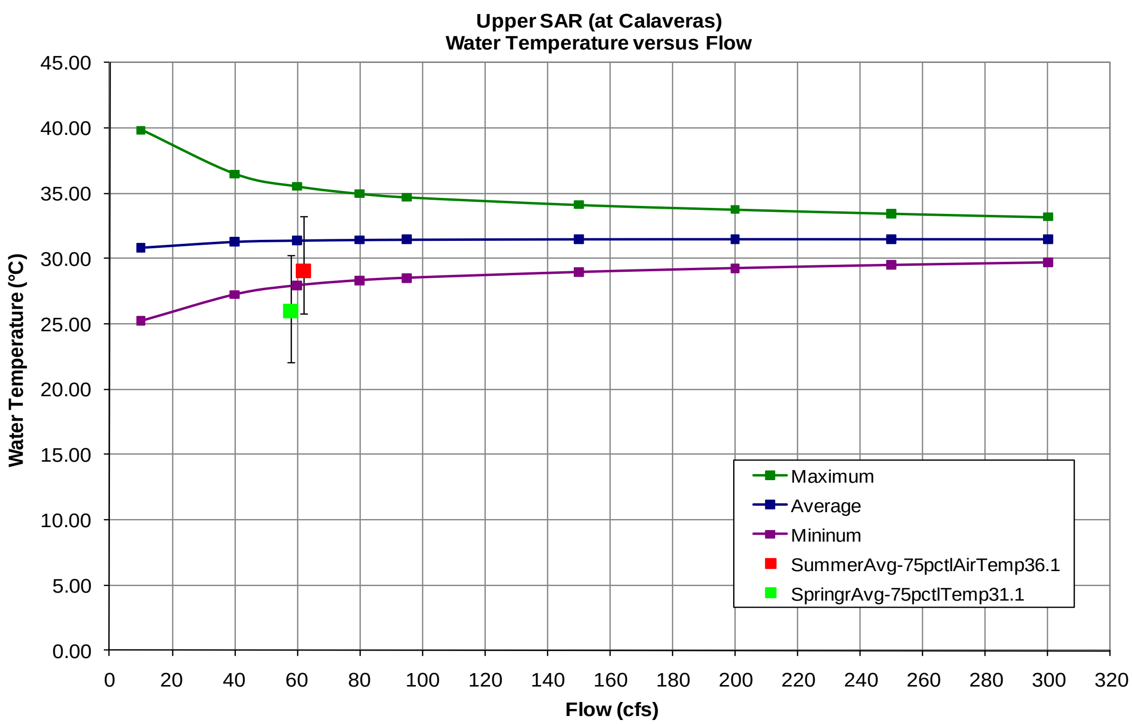


Figure 41. Modeled water temperature versus discharge for the upper study reach of the San Antonio River (TIFP and SARA 2011).

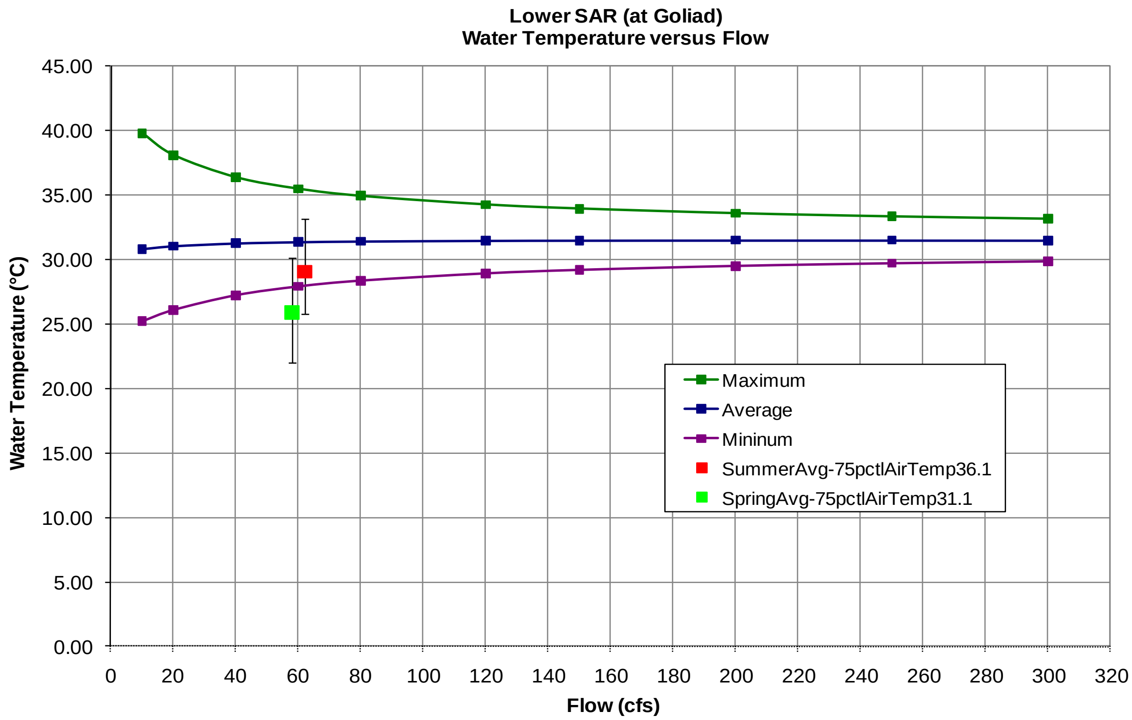


Figure 42. Modeled water temperature versus discharge for the lower study reach of the San Antonio River (TIFP and SARA 2011).

For the Cibolo Creek study area, examination of historical SWQM data revealed that water temperature is maintained below the secondary priority temperature of 32.2°C (Figure 43) under low flow conditions (<5th percentile flows). Additionally, TIFP collected diurnal sonde data in September 2009 under low flow conditions (6th percentile flow) and temperatures did not exceed 30°C (Figure 44). Based on these findings no diurnal water temperature modeling was conducted for Cibolo Creek (TCEQ 2011).

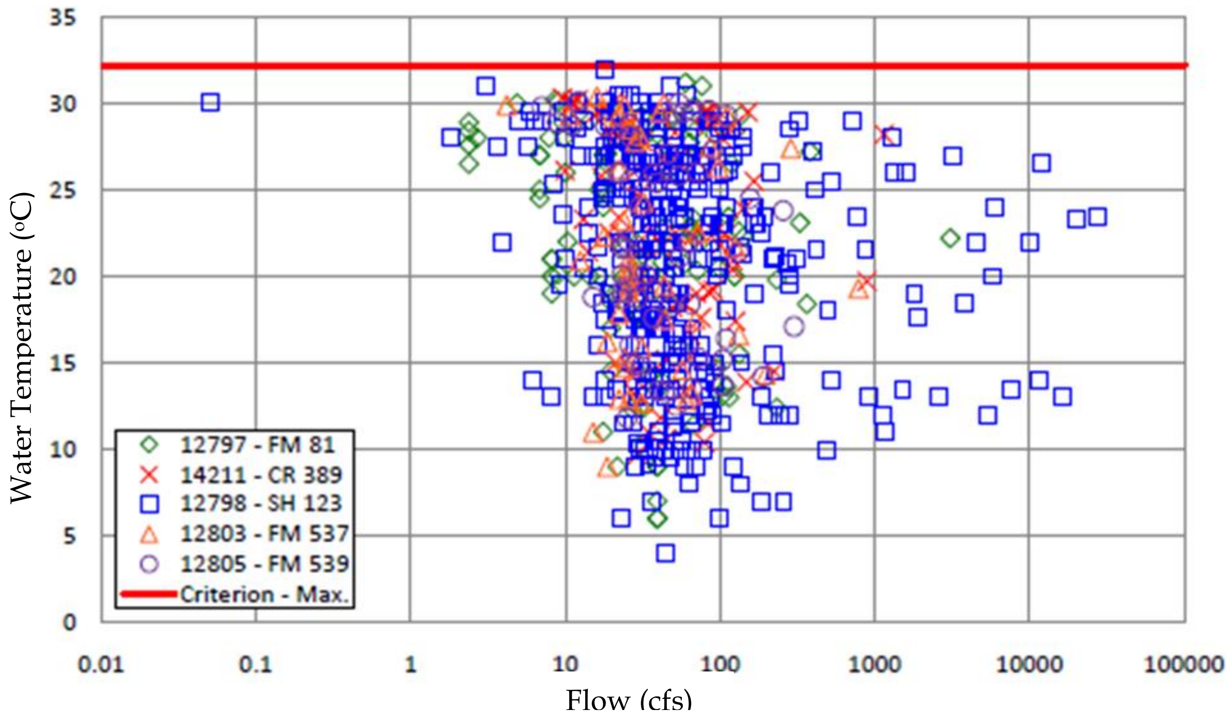


Figure 43. Water temperature data for SWQM Station Nos. 12797, 14211, 12798, 12803, and 12805 on Cibolo Creek (TCEQ 2011).

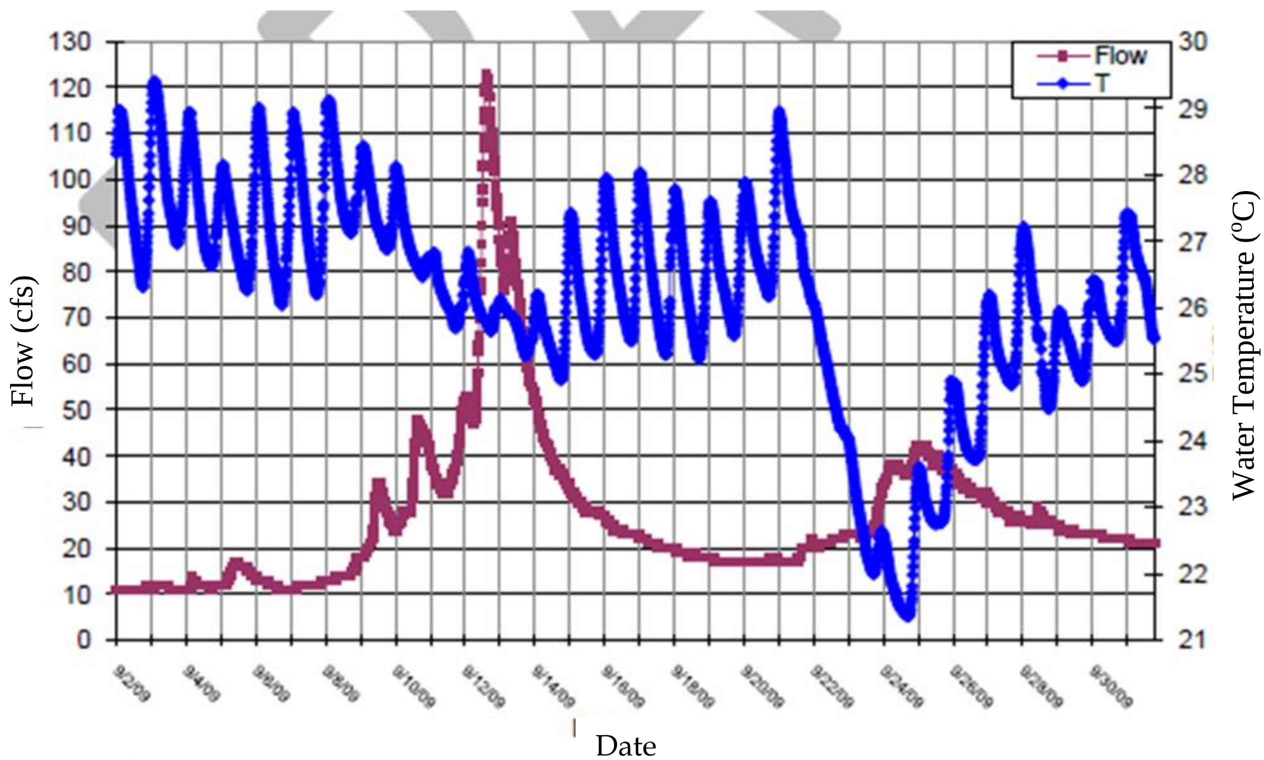


Figure 44. Water temperature data collected at the Cibolo Creek Study Site from September 2, 2009 through October 1, 2009 (TCEQ 2011).

Interim Recommendations

To aid the Guadalupe and San Antonio River Basins Senate Bill 3 process the TIFP, in consultation with Biowest, developed interim flow recommendations. During multiple TIFP workshops in April and May of 2011, the TIFP reviewed available scientific information to develop subsistence flow recommendations. The TIFP workgroup determined that the 35˚C primary priority goal started to exceed during extreme summer air temperatures at approximately 80 cfs for the Upper San Antonio River and Lower San Antonio River study reaches (TIFP and SARA 2011). The TIFP determined that these subsistence flow values should be applied year-round (TIFP and SARA 2011).

Based on available water quality data and modeling results, the TIFP workgroup determined that water quality was currently supported within the Cibolo Creek study reach. Therefore, the TIFP workgroup utilized other discipline specific information to develop a subsistence flow recommendation of 7.5 cfs for this study reach (TIFP and SARA 2011).

Final Recommendations

During the data collection period of this study, the TIFP project team was able to conduct water quality and fish sampling during low flow summer conditions (summers 2009, 2012, and 2013) throughout much of the lower San Antonio River sub-basin (Linam et al. 2014). The data was collected at flows near 10 cfs on lower Cibolo Creek and from 40 to 100 cfs on the lower San Antonio River. Observed maximum temperatures during summer months did not indicate concern for water quality modeling results or previous recommendations.

The water quality data and analyses indicate that primary priority goals are supported at flows lower than 80 cfs for the lower San Antonio River and at 7.5 cfs for lower Cibolo Creek. Other factors were considered in developing the final subsistence flow recommendations (see Section 3.1).

2.6 *Connectivity*

As identified in the study design (TIFP 2009), objectives related to connectivity focused on three areas: interaction of groundwater and surface water, riparian zone, and freshwater inflows to the estuary. Results from the flow recommendations made at USGS Gage No. 08188500 San Antonio River at Goliad, can readily be compared to freshwater inflow studies that make use of this same gage. Lateral connectivity with riparian habitats has been addressed by recommending high flow pulses and overbank flows with suitable characteristics to meet the needs of riparian areas (see Section 3.3).

Based upon habitat analysis, longitudinal connectivity is maintained under the instream flow recommendations included in this report. Depth criteria was used in modelling to ensure adequate depth (≥ 1 inch) for fish movement between habitat types. In addition, there are no dams to prevent fish movement.

During the course of this study, the USGS and local cooperators completed a gain loss study of the lower San Antonio River watershed (Lizarraga and Wehmeyer 2012). Results have been used to evaluate the interaction of groundwater and surface water in the sub-basin. Lizarraga and Wehmeyer (2012) analyzed stream flow data from active USGS gages from 2006 to 2010 and found that the lower San Antonio River and lower Cibolo Creek generally gain streamflow in the downstream direction. The average gain from groundwater for the San Antonio River from the location of USGS Gage No. 08181800 at Elemendorf to the location of USGS Gage No. 08188570 at McFaddin during 2006 to 2010 was estimated to be 155 cfs (0.8 cfs per river mile), about 16% of the average daily flow of the San Antonio River at McFaddin over the same time period. Cibolo Creek from the location of USGS Gage No. 08185000 at Selma to the location of USGS Gage No. 08183500 near Falls City was found to have an average gain of 88.5 cfs (1.1 cfs per stream mile) during 2006 to 2010. That gain would represent about 56% of the average daily flow of Cibolo Creek near Falls City over the same time period.

Lizarraga and Wehmeyer (2012) also conducted four synoptic surveys of the river sub-basin during different seasons and flow conditions in 2006 and 2007. During synoptic measurements, total gain to the San Antonio River from groundwater from Elmendorf to McFaddin was found to range from about 25 to 350 cfs (15 to 29% of average flow at McFaddin during the measurements). Total gain to Cibolo Creek from groundwater from Selma to near Falls City varied from 2 to 50 cfs (16 to 50% of average flow near Falls City during the measurements).

Results of the study by Lizarraga and Wehmeyer (2012) confirm that groundwater and surface water are connected in the lower San Antonio River sub-basin. Development of groundwater resources therefore has the potential to impact instream flows in the sub-basin. In Texas, groundwater is managed separately from surface water; however, as charged by Texas Water Code §36.1071(a), the groundwater management plans of groundwater conservation districts in the area address natural resource issues which are impacted by the use of groundwater (Edwards Underground Water Conservation District 2016, Edwards Aquifer Authority 2011). The groundwater management plan of the Edwards Aquifer Authority recognizes instream flows as an important environmental water use in areas downstream of the Edwards Aquifer (Edwards Aquifer Authority 2011). Continued investigation of groundwater/surface water interaction will be necessary to assess the impacts on instream flows.

3.0 INTEGRATION OF STUDY RESULTS

The development and integration of instream flow recommendations requires all riverine components be addressed as thoroughly as possible and that all interests be part of the decision making process from the initial study design through to the final recommendations.

3.1 *Subsistence Flow*

The primary objective of subsistence flows according to TIFP (2008) is to "maintain water quality criteria". Therefore, the subsistence flow evaluation initially focused on water quality conditions and water quality modeling as described in Section 2.5. The TIFP identified 80 cfs as a water quality based subsistence flow recommendation for the Upper San Antonio River and Lower San Antonio River study areas. Based on water quality modeling results and water quality data, water quality based subsistence flow recommendations were not developed for Cibolo Creek. Once water quality based considerations were identified, the TIFP study team utilized biological study results to integrate habitat considerations into the final subsistence flow recommendations at each Study Site.

As stated in Section 2.5, the TIFP water quality analysis indicated the primary priority goals for water quality were supported at the water quality based subsistence flow recommendations. Following the 2011 interim flow recommendations (TIFP and SARA 2011) additional fish habitat utilization data was collected at each study site. The TIFP study team utilized this data to update fish guilds, HSC curves, and recalculate WUA. The updated results were utilized to reevaluate habitat modeling results for integration into subsistence flow recommendations as detailed below.

A detailed assessment of aquatic habitat modeling results near 80 cfs was conducted for each of the lower San Antonio River Study Sites. This included an evaluation of the WUA results for each level of habitat quality and an evaluation of spatial outputs to examine habitat connectivity. In every instance, suitable aquatic habitat was available to aquatic organisms at 80 cfs. It should also be noted that WUA results indicated that high quality habitat was also available at flows less than 80 cfs with adequate habitat connectivity (Appendices D and H). Next, wetted surface area at 80 cfs was examined in relation to known mussel locations observed during preliminary surveys. This assessment documented that at 80 cfs, wetted area was available for the mussels, but some of the beds were at or near the predicted water's edge.

A water temperature goal of 35°C was established by the TIFP due to the potential of temperatures greater than this directly altering ecological responses of aquatic organisms and potentially having lethal effects. It is anticipated that water temperatures approaching this threshold may already be causing sublethal effects for certain aquatic organisms.

Water quality can affect fish survival directly when conditions become lethal or indirectly through influences on reproduction and growth rates. Much research has been performed examining the effects of water quality on aquatic species. Critical Thermal Maximum (CTM) is a number used to estimate a fish's ability to survive extreme temperatures (Matthews and Zimmerman 1990). It is the temperature where a fish loses locomotory movement, and therefore, the ability to escape from conditions that will ultimately lead to its death. In general, most warm water fish have a CTM around 35°C (Beitinger et al. 2000).

Other fauna, such as freshwater mussels, are also sensitive to high water temperatures. Adult freshwater mussels can experience species-specific, sub-lethal stress when exposed to high water temperatures, generally greater than 35°C, but lower for some species (Spooner et al. 2005, Ganser et al. 2015). In addition, research has shown that juvenile and glochidial stages of freshwater mussels were more sensitive to high water temperatures than adults as the LT50 (temperature at which mortality occurs in 50% of the exposed population) was lower than the 35°C thermal maxima for adult mussels (Pandolfo et al. 2010, Archambault 2012). These high water temperatures can eventually lead to death, which is of particular concern given the substantial number of Golden Orb documented in the Goliad area (Hammontree et al. 2012). Golden Orb are designated as state threatened and are currently a candidate for placement on the federal endangered species list.

During the data collection period of this study, the TIFP project team was able to conduct water quality and fish sampling during low flow conditions (summers 2009, 2012, and 2013) throughout much of the lower San Antonio River sub-basin. This allowed for data collection at flows near 10 cfs on lower Cibolo Creek and from 40 to 100 cfs on the lower San Antonio River. These data greatly assisted the TIFP project team in water quality modeling validation for use in the reevaluation of habitat modeling results for integration into subsistence flow recommendations.

Flows less than 80 cfs were observed on several occasions throughout the instream flow study. This first occurred during June 2009. Sampling was conducted during this time period. Ambient air temperatures were not at extreme summer time conditions and subsequently, water temperature in the river did not approach 35°C. It is important to note that habitat conditions (as the modeling predicts) were suitable for aquatic organisms during this period of low flow. Flows were also less than 80 cfs on a daily basis in June 2011. During this time period, ambient air temperatures did exceed 37˚C for several days to a week; however, data from the USGS Elmendorf gage reported a daily average water temperature of approximately 31.5°C with a range up to approximately 33°C. Data from the USGS Runge gage indicated maximum daily water temperature did not exceed 35˚C. As experienced in 2009, low flow observations in 2011 were in early summer, rather than extreme conditions during the intense July/August time period.

More recently, continuous water quality data were collected at multiple sites during seasonal sampling throughout the summers of 2012 and 2013 (Linam et al. 2014). Water temperatures greater than the 32.2°C secondary priority goal were recorded during both summers; however, water temperatures never reached the 35°C primary priority goal. The two highest values recorded by a deployed data sonde (34.1°C and 33.5°C) were recorded at Goliad during the summers of 2013 and 2012, respectively. During both events stream discharge was near 250 cfs. Discharge continued to drop during both summers to 100 cfs or less with water temperatures staying about the same. During the summer of 2013 at Goliad, water temperatures exceeded 32.2°C an average of 4.75 hrs/day during 18 of the 27 days the water quality sonde was deployed. During the summer of 2012, temperature exceedances (average of 6 hrs/day) occurred all five days at Goliad that the sonde collected data. At Floresville, water temperatures began to exceed the 32.2°C secondary priority goal at discharges approaching 80 cfs. Exceedances were documented on 13 of the 20 days readings were captured during the summer of 2012 and 8 of 29 days during the summer of 2013. These high values occurred an average of 5 hrs/day in 2012 and 2.5 hrs/day in 2013. The highest instantaneous value (34.9°C) was recorded in a backwater at Falls City during the summer of 2012 while conducting fish sampling. Water temperatures recorded during the course of these studies support those predicted by the model (Linam et al. 2014).

Since habitat quantity and quality was determined to be adequate at flows less than 80 cfs and since extreme summer time air temperatures are rare or non-existent during non-summer months, TIFP recommends a subsistence flow recommendation of 60 cfs for the months of October through May for each San Antonio River Study Site. This 60 cfs recommendation ensures that optimal high quality habitat is maintained, with habitat connectivity, during periods when temperature is not the primary concern. A subsistence flow recommendation of 80 cfs is proposed for the remaining months, June through September. These recommended subsistence flows are largely based on keeping temperatures below the 35°C CTM previously discussed, but also consider habitat quantity and quality for fish and mussels. Currently, water temperatures in portions of the San Antonio River Basin routinely exceed 32°C in late summer during the hottest parts of the day. This temperature (32°C) already exceeds or encroaches on the temperature maximums reported for several species such as Spotted Bass, River Carpsucker *Carpiodes carpio*, and Smallmouth Buffalo (Eaton and Scheller 1996). In addition, based upon DO point measurements taken at each specific HMU sampled, long-term deployed data sondes, and model simulations, the recommended subsistence flow recommendations are expected to support DO criteria.

For lower Cibolo Creek, water quality data analyses indicate that the potential does not exist to have large diurnal swings in hydrology there as it does in the lower San Antonio River. Therefore, aquatic habitat modeling was the driver for setting subsistence recommendations for lower Cibolo Creek. As previously mentioned, the TIFP project team had the opportunity to sample Cibolo Creek at 10 cfs, at which time sufficient water quality and aquatic habitat conditions existed to support subsistence flow objectives; however, based on WUA and CSI, predicted high quality riffle habitat starts to disappear as flows drop below 10 cfs (Figure 45).

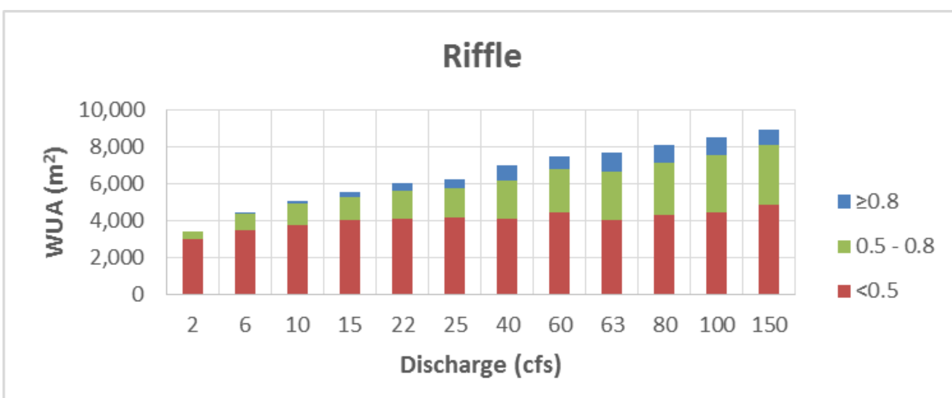


Figure 45. Habitat quality breakout (<0.5 low; 0.5-0.8 moderate; ≥0.8 high) of Weighted Usable Area (WUA) versus simulated discharge at the Cibolo Creek Study Site.

Since Riffle guild species such as River Darter and Texas Logperch (both focal species) were abundant in lower Cibolo Creek, TIFP recommended that at least a minimal amount of high quality habitat be maintained at the lowest threshold. As such, the subsistence flow recommendation was set at 10 cfs for lower Cibolo Creek. Since 10 cfs was identified as a minimum flow to maintain high quality habitat under subsistence conditions, this number was applied year round. Spatial model outputs indicate habitat connectivity is not hindered at 10 cfs (Appendix H).

3.2 *Base Flow*

Base flows are the normal flow conditions between storm events and naturally vary in discharge depending upon ambient climatological conditions. Base flow recommendations in this report are intended to provide high relative percentages of moderate to high quality habitat for each fish guild (as well as mussels). Inter- and intra-annual variability in flow are also built into the recommendations. Base flow recommendations are parsed out into three hydrologic categories: dry, average, and wet. These hydrologic conditions are intended to occur at frequencies of 25% for dry and wet base and 50% for average base. Variability is critical to ecosystem function and native biodiversity (Poff et al. 1997). Variation in flow drives processes that periodically reset physical, chemical, and biological functions essential to the ecosystem (Annear et al. 2004). Some species do well in wet years and other species do well in dry years. For example, availability of riffle habitat is typically maximized at lower flows associated with dry base flow conditions that support focal species such as darters and Burrhead Chub, whereas pool and deep run habitats are typically maximized at wet base flow and support species such as Spotted Bass, Flathead Catfish, Blue Catfish Ictalurus furcatus, and Channel Catfish. Likewise, habitat quality and availability among the sites varies by base flow condition. Intra-annual (monthly to seasonal) and inter-annual variability in baseflow conditions (dry, average, and wet years) are necessary to ensure that each Study Site supports a full complement of fish guilds through time.

Base flows also serve an important role in structuring riparian communities. Both low and high base flows can limit encroachment of invasive species and maintain high species diversity (Stromberg et al. 2007). Maintaining healthy and diverse riparian zones provides many benefits to the river, such as buffering thermal effects of high temperatures, increasing habitat structure, and influencing food web structure (Pusey and Arthington 2011). High base flow conditions also correlate with higher groundwater tables within the riparian zone and support increased riparian productivity (Duke 2011), especially in species such as black willow that play an important role in food web dynamics (Zeug and Winemiller 2008). For these reasons, providing a single flow value or base flow regime cannot simultaneously meet the requirements ofr all species or maintain a fishery.

WUA to flow relationships were used to set base flow recommendations (Appendix D). Emphasis was placed on maintaining high quality habitat (habitat quality $\geq$0.5) while still protecting water quality. The flow range providing the maximum amount of each high quality habitat type was identified and then divided into three flow levels (dry, average, and wet) to ensure inter-annual variability as proposed in the TIFP Technical Overview (TIFP 2008). Additionally, spatial projections of habitat were reviewed to ensure adequate connectivity between habitat patches and to identify flows where key habitats were available. Adjustments were made in consideration of water quality.

Using the techniques described above, three base flow target levels (dry, average, wet) were identified at each Study Site. Base flow levels are presented in Table 16, with justification provided in the following text. See 3.2.6 for a discussion of methods on monthly scaling factors used to convert target base flow levels to monthly flow recommendations.

Table 16. Base flow levels identified using the relationship of Weighted Usable Area (WUA) and flow. The dry base flow value for Goliad was adjusted up in consideration of water quality and subsistence flow recommendations.

		Target Base Flow Ranges (cfs)		
Study Site		**Dry**	**Average**	**Wet**
Calaveras	WUA vs Discharge	60-105	105-175	175-260
Falls City	WUA vs Discharge	100-200	200-300	300-600
Goliad	WUA vs Discharge	40-60	80-200	200-300
Goliad	Water Quality Adjusted	**60-80**		
Hwy 77	WUA vs Discharge	80-100	100-250	250-500
Cibolo Creek	WUA vs Discharge	15-25	25-40	40-60

3.2.1 *Calaveras*

At the Calaveras Study Site, total WUA (habitat quality >0.5) for Shallow Run, Riffle, and Backwater all peak at or below approximately 66 cfs (Figure 46). In contrast, total WUA for Deep Run and Deep Pool continue to increase until the modeled flow of about 350 cfs. Given the high percentage of maximum WUA of all habitat types at flows less than 80 cfs, dry base recommendations based solely on habitat could theoretically fall below the previously established subsistence recommendation of 100 cfs during the summer months; therefore, a minimum dry base recommendation of 100 cfs was established for the months of June through September (i.e. any dry base flows calculated to be less than 100 cfs using monthly scaling factors as outlined in 3.2.6 were set to 100 cfs) in order to avoid increasing the frequency at which subsistence flow values would occur, and thus stay well away from critical temperatures ($\geq$35°C) at a base flow condition.

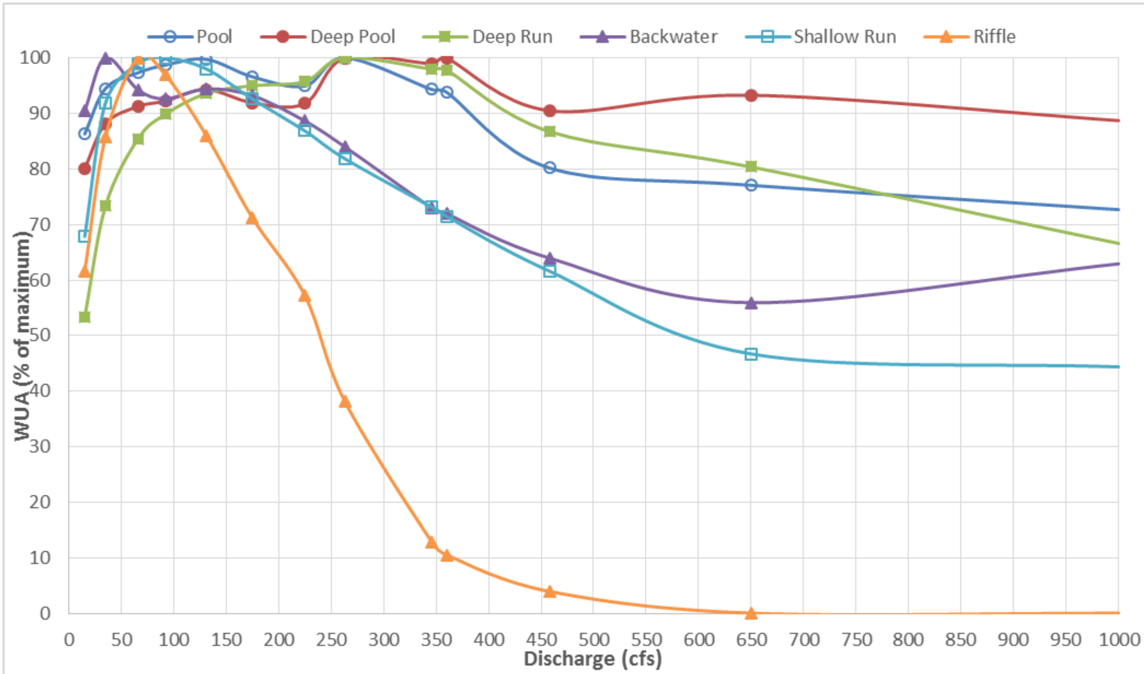


Figure 46. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Calaveras Study Site.

The target range for wet base at the Calaveras Study Site was set at 175-260 cfs based on several breakpoints in WUA. Above this flow, high quality Riffle habitat is greatly reduced and Deep Run and Deep Pool WUA hit a plateau. Additional flows contribute minimal amounts of additional habitat (Figure 44). An evaluation of the spatial output generated by these modeled flows shows no problems with habitat connectivity.

Flows falling between the wet and dry base recommendations (105-175 cfs) make up the average base target range. Pool habitat peaked within this range. As was done for dry base, a 100 cfs minimum average base flow recommendation was implemented for the summer months of June through September.

3.2.2 *Falls City*

Due to the unique hydraulic conditions at the Falls City Study Site, WUA (habitat quality >0.5) for Deep Pool and Pool guilds change little with flow and remain at or above 90% of maximum for flows between 100-1000 cfs (Figure 47). Changes in WUA for the other four habitat guilds are more significant. Habitat for these guilds is maximized under lower flow conditions (100-300 cfs range). Based on WUA analysis coupled with the diversity of habitats predicted (Figure 45) and the connectivity observed in spatial outputs, 100-200 cfs was selected as the base dry target flow range. As was done at Calaveras for dry base, a 100 cfs minimum dry base flow recommendation was established for the summer months of June through September in order to avoid increasing the frequency at which subsistence flows would occur, and thus stay well away from critical temperatures at the base flow condition.

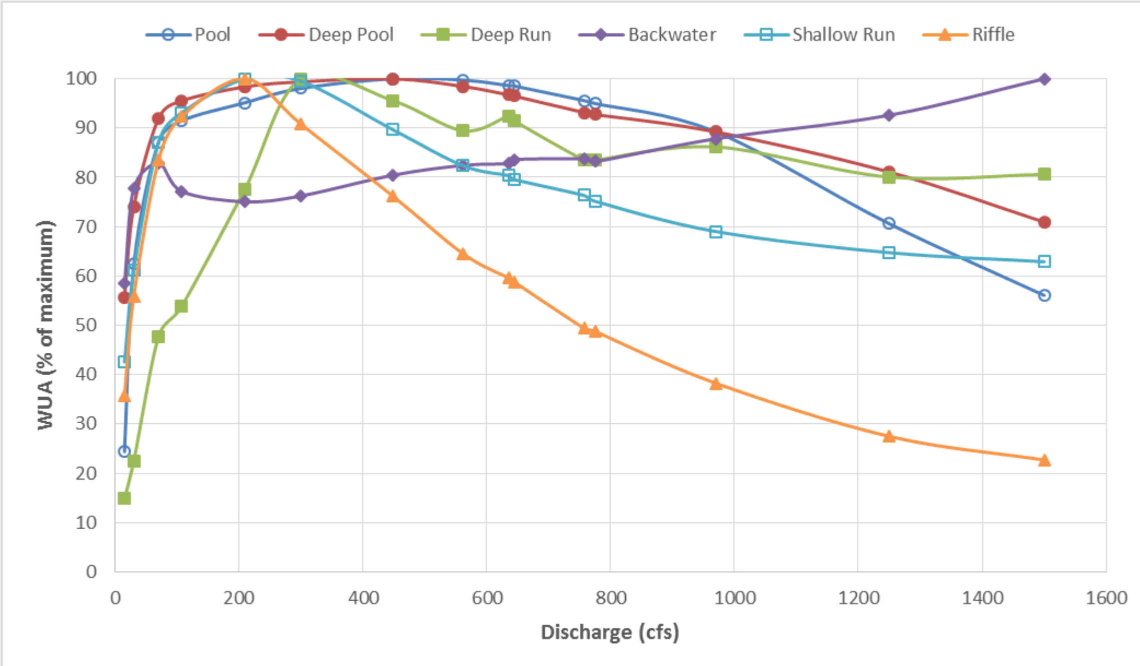


Figure 47. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Falls City Study Site.

The wet base target flow level at Falls City was set based on analysis of total WUA (habitat quality >0.5), as well as analysis of spatial output for key Backwater areas. Both Deep Pool and Deep Run habitat reach a plateau at approximately 450 cfs. Higher flows result in no substantial increase in these deeper habitats, but continue to drive down shallow guilds such as Riffle and Pool. Therefore, from a strictly habitat perspective, base flows above 450 cfs offer little benefit. An evaluation of spatial output shows that flows in the 450 cfs range create additional critical Backwater habitat in and near where the river splits into three channels (Figure 48). Backwater habitat is particularly important here as it provides considerable habitat for larval fish in close proximity to the Riffle habitat which comprises most of the proximate area. The shallow riffles in this area are used as spawning habitat by several species. Based on the information above, the base wet target range at Falls City was set at 300 to 600 cfs.

Flows falling between the dry and wet base recommendations (200-300 cfs) make up the average base target range and maintain greater than 75 percent of the high quality habitat for all guilds. Riffle and Pool habitat peaked within this range.

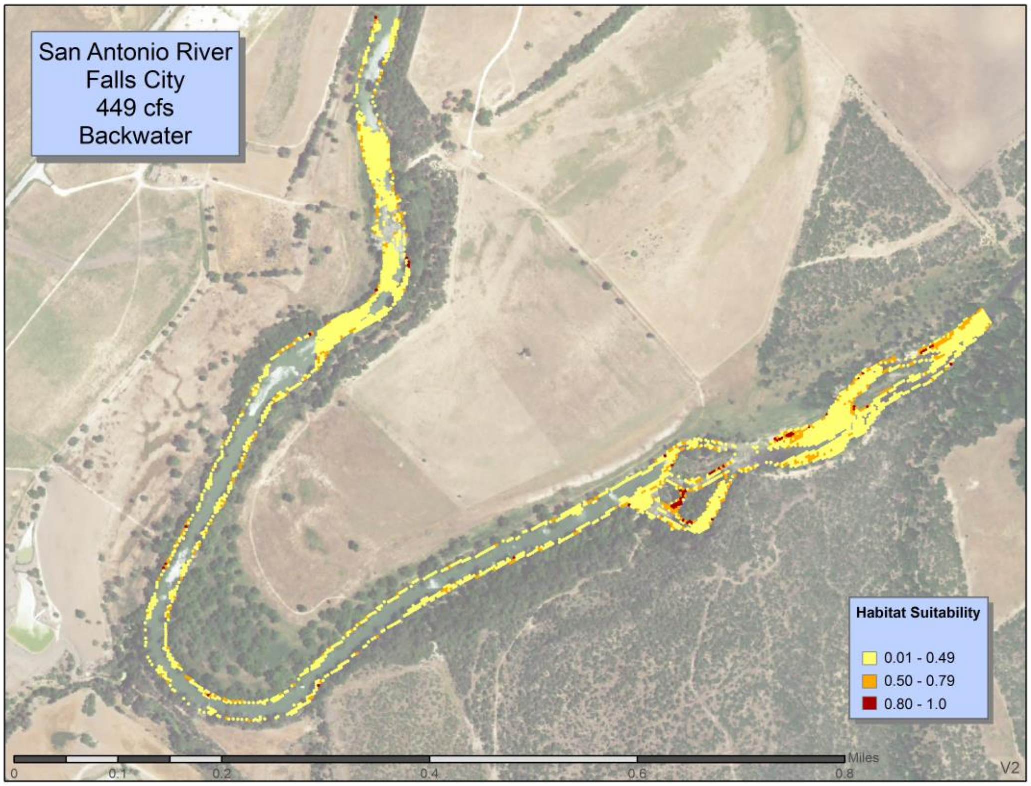


Figure 48. Spatial output of Backwater Weighted Usable Area (habitat quality >0.5) at the San Antonio River Falls City Study Site at a flow of 449 cfs.

3.2.3 *Goliad*

Total WUA (habitat quality >0.5) for most habitat types peaked at or below approximately 100 cfs (Figure 49). Given the diverse habitat conditions at flows less than 60 cfs, dry base recommendations based solely on habitat would fall below previously established subsistence recommendations throughout the year (i.e., 60-80 cfs); therefore, target dry base was adjusted to 80 cfs (Table 16). As was done at Calaveras, a minimum dry base recommendation of 100 cfs was established for the months of June through September in order to avoid increasing the frequency at which subsistence flow values would occur, and thus stay well away from critical temperatures at the base flow condition.

The target range for wet base was set at 200-300 cfs based on several breakpoints in WUA. Above this flow, most habitat types were greatly reduced (Figure 49). Flows up to 250 cfs provided for greater than 50% of maximum for all habitat types.

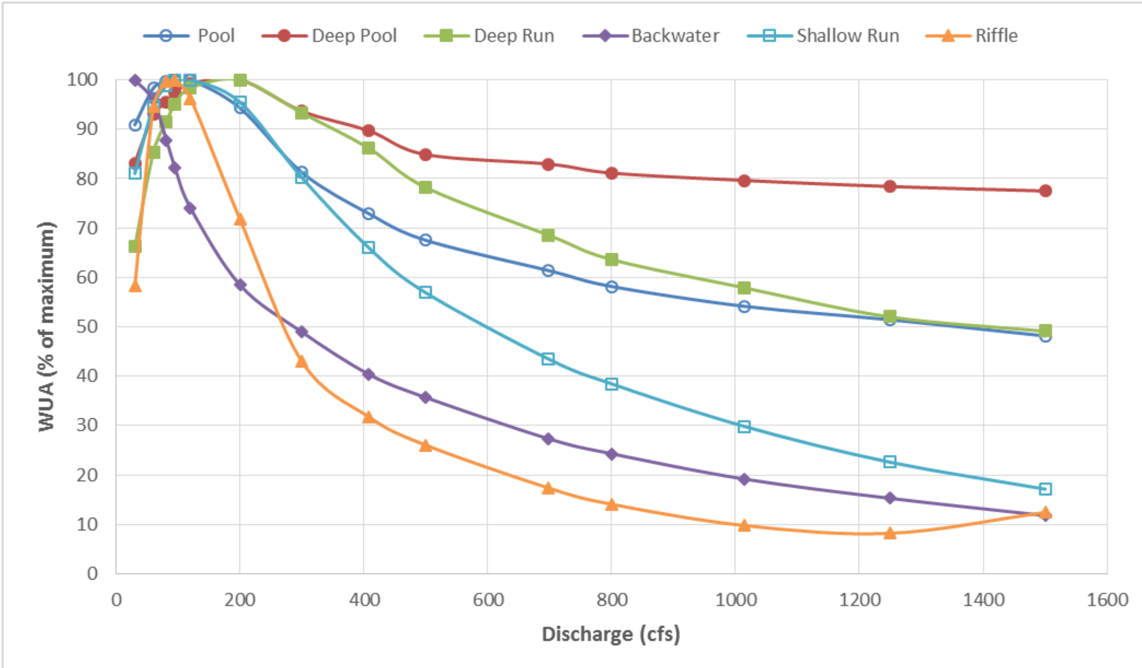


Figure 49. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Goliad Study Site.

Flows falling between the wet and dry base recommendations (80-200 cfs) make up the average base target range and provide diverse amounts of high quality habitat for all guilds. Deep Run habitat peaked within this range. Additionally, based on spatial output of model flows and previous HMU mapping efforts, 170 cfs is the flow necessary to connect the downstream end of a critical deep Backwater habitat to the main river channel (Figure 50). As was done for dry base, a 100 cfs minimum base flow flow recommendation was implemented for the summer months of June through September.

Base flow recommendations for the Goliad Study Site are lower than those made for the Falls City Study Site located upstream. Riffle habitat is reduced to 50% at a flow of about 250 cfs at the Goliad Study Site, compared to 750 cfs at the Fall City Study Site.

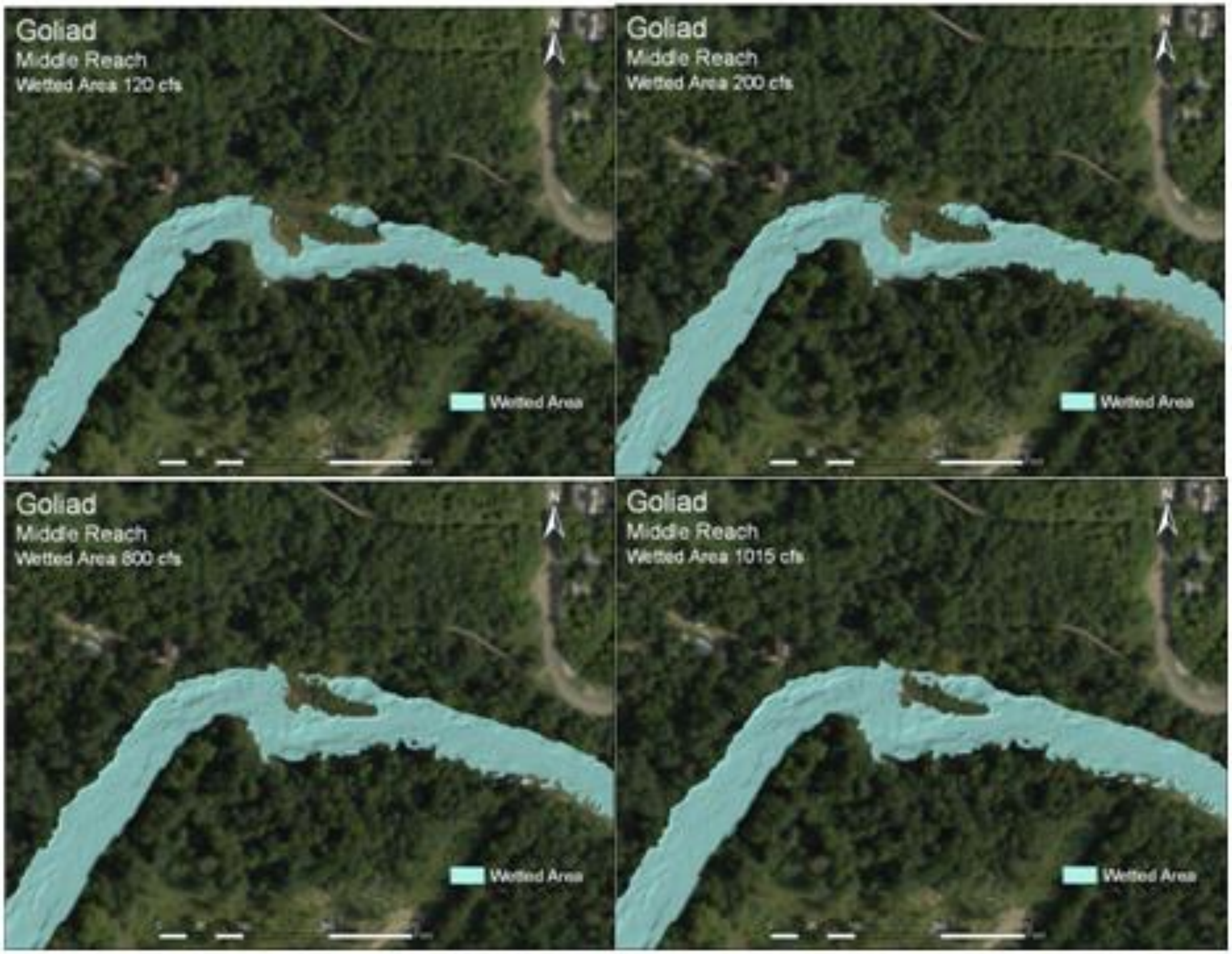


Figure 50. Model predictions of wetted area at four flows around the San Antonio River Goliad Riffle Complex. Notice isolated Backwater at 120 cfs and nearly complete side channel formation at 1,015 cfs.

3.2.4 *Hwy 77*

WUA was not calculated for flows less than 100 cfs but likely followed patterns similar to those at the other Study Sites, which had similar channel morphology and maintained diverse habitat conditions at flows below 80 cfs (Figure 51). Given the diverse habitat conditions at 100 cfs, dry base recommendations based solely on habitat could theoretically fall below previously established subsistence recommendations during the summer months; therefore, as was done at Calaveras a minimum dry base recommendation of 100 cfs was established for the months of June through September in order to avoid increasing the frequency at which subsistence flow values would occur, and thus stay well away from critical temperatures at the base flow condition.

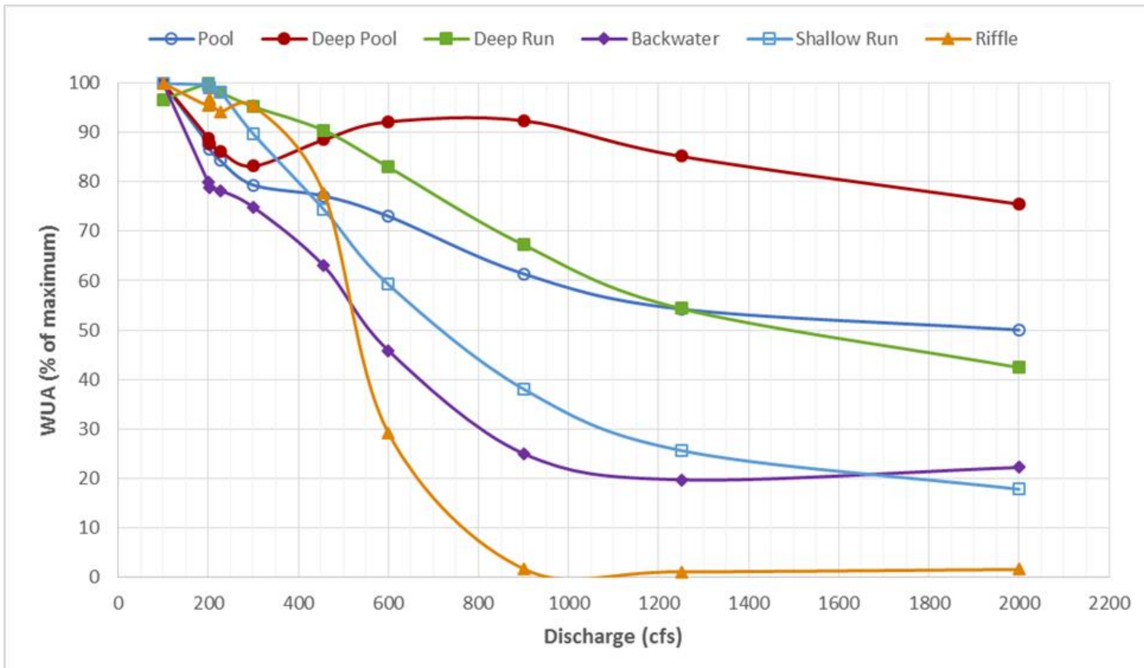


Figure 51. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Hwy 77 Study Site.

The target range for wet base was set at 250-500 cfs based on several breakpoints in WUA. Above this flow, many habitat types were greatly reduced (Figure 51). Flows up to 500 cfs provided for greater than 50% of maximum for all habitat types.

Flows falling between the wet and dry base recommendations (100-250 cfs) make up the average base target range and provide diverse amounts of high quality habitat for all guilds. Total WUA (habitat quality >0.5) for most habitat types peaked within this range.

3.2.5 *Cibolo Creek*

WUA to discharge relationships at Cibolo Creek were unique when compared to relationships observed in the lower San Antonio River. Deep Run, Shallow Run, and Riffle were maximized at the highest modeled flow rate (Figure 52).

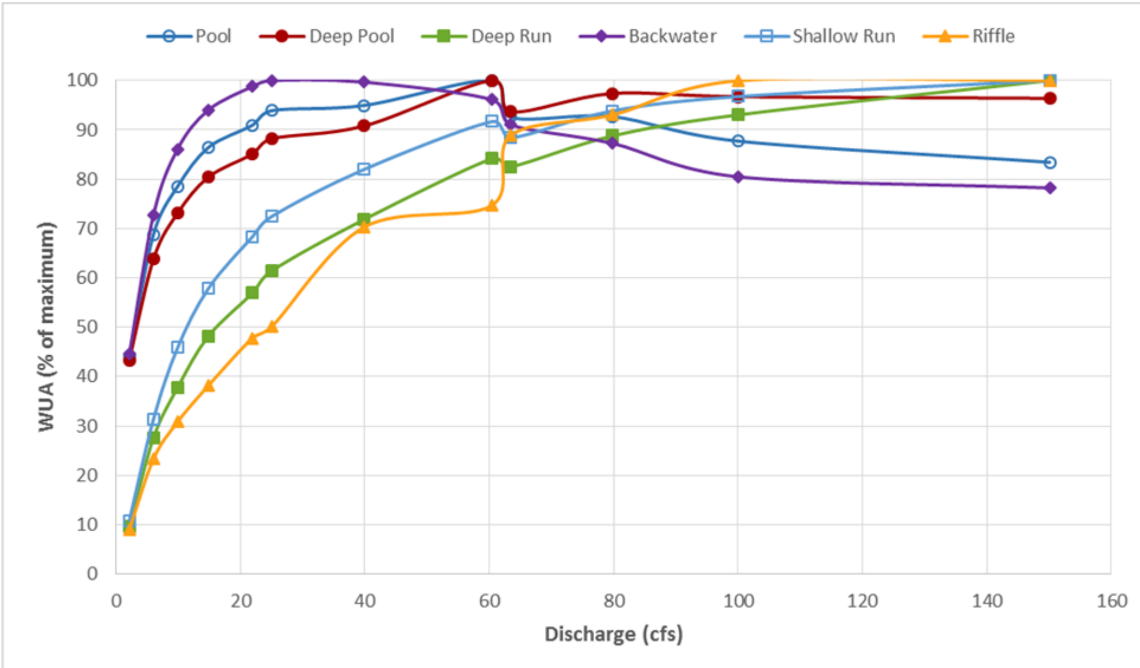


Figure 52. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the Cibolo Creek Study Site.

WUA to discharge curves modeled at Cibolo Creek are likely a result of the wider, less incised channel of this system relative to the lower San Antonio River. Therefore, as flows increase, water tops the banks and the channel spreads laterally creating additional shallow water habitat. As a result of this widening of the wetted area, shallow water habitats are not "blown out" as quickly as in the lower San Antonio River; however, it should be noted that although depth, velocity, and substrate may be suitable for fish in a given area, if that area has not been wetted in a long period, then food resources (benthic invertebrates, attached algae, etc.) may be limiting. Thus, flows over the 80th percentile (70 cfs), which are only wetted 20% of the time, were not considered when setting base flow target levels, despite having higher WUA.

In an attempt to maintain high-quality habitat for all guilds, subsistence recommendations were set at 10 cfs (Section 3.1); however, this maintains only very minor amounts of high quality Riffle habitat. A flow of 15 cfs maintains about 30% of the maximum high quality Riffle habitat, which was deemed a more appropriate level within our study reach for a base flow condition.

WUA results for the modeled flow rate of 25 cfs showed that at least 50% of the maximum of all habitat types were maintained. Spatial output revealed good habitat connectivity in this flow range as well. Given the above, the dry base range was set at 15-25 cfs and the average base at 25-40 cfs.

The wet base target flow level at Cibolo Creek was set primarily on analysis of spatial model output. In the middle reach of the Cibolo Creek Study Site are three key riffle areas where most of the darter species were caught. The spatial extant of high quality riffle habitat is spatially restricted at 25 cfs compared to 40 cfs. (Figure 53). To provide more of this key habitat and to stay below 70 cfs for reasons described above, the wet base target flow range was set at 40-60 cfs.

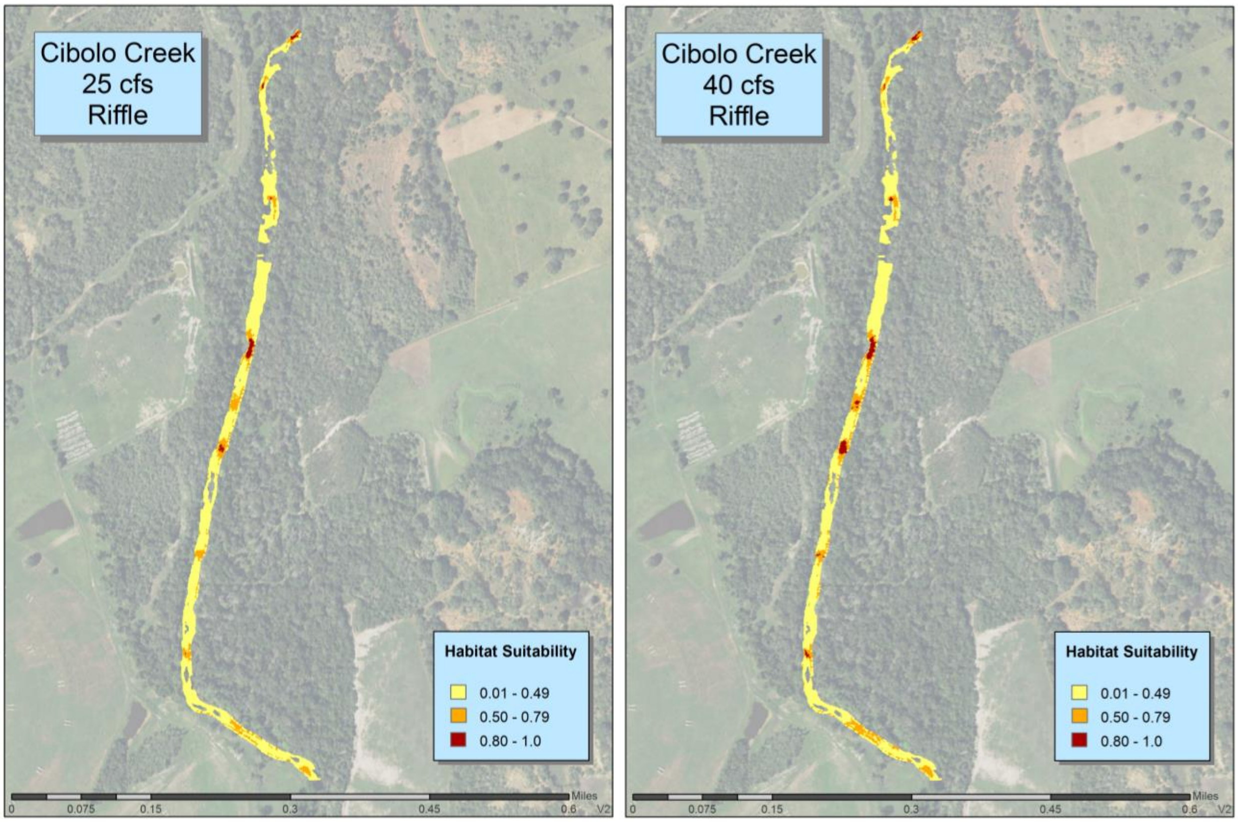


Figure 53. Riffle guild habitat suitability at the middle reach of the Cibolo Creek site under 25 and 40 cfs. Note expansion of high-quality habitat (red) into multiple areas at 40 cfs.

3.2.6 *Establishing Intra-annual Variability*

Once base flow target ranges were established for each site, the next step in recommendation development was to develop monthly recommendations that followed a natural hydrologic pattern and thus provided intra-annual variability. To develop this pattern, daily flow data from the USGS gage nearest each site were used to calculate median monthly flow for the years 1990-2015 (Table 17). Data from USGS gages on the San Antonio River near Elmendorf, Falls City, and at Goliad were used to establish a monthly variability pattern at the Calaveras, Falls City, and Goliad Study Sites, respectively. Although it is closer to the Hwy 77 Study Site, the USGS gage on the San Antonio River at McFaddin has only been in operation since 2005; therefore, data from the USGS gage for the San Antonio River at Goliad were used to establish variability for the Hwy 77 Study Site. Daily flow data are not available for the USGS gage at Cibolo Creek for the time period from October 1990 to September 1991. The available data between 1990 and 2015 for this site were used to establish variability for the Cibolo Study Site. For all other gage sites, complete records for the period from 1990-2015 were available.

Table 17. Median monthly flows for USGS gages near San Antonio River and Cibolo Creek Study Sites.

USGS Gage	Median Flow (cfs)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
San Antonio River near Elmendorf	331	340	345	350	365	290	239	179	287	280	310	306
San Antonio River near Falls City	357	369	357	365	380	332	262	196	308	287	311	303
San Antonio River at Goliad	474	476	487	503	533	434	359	250	373	376	426	408
Cibolo Creek near Falls City	49	47	49	42	50	42	36	25	30	33	39	47

Median monthly flow values were used to develop monthly scaling factors for base flow recommendations for each Study Site (Table 18). This was accomplished by dividing the monthly median flow by the average of the 12 monthly median flows for each site.

Table 18. Monthly scaling factors for base flow recommendations for San Antonio River and Cibolo Creek Study Sites.

Study Site	Monthly Base Flow Scaling Factors											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Calaveras	1.10	1.13	1.14	1.16	1.21	0.96	0.79	0.59	0.95	0.93	1.03	1.01
Falls City	1.12	1.16	1.12	1.14	1.19	1.04	0.82	0.62	0.97	0.90	0.98	0.95
Goliad	1.12	1.12	1.15	1.18	1.25	1.02	0.85	0.59	0.88	0.89	1.00	0.96
Hwy 77	1.12	1.12	1.15	1.18	1.25	1.02	0.85	0.59	0.88	0.89	1.00	0.96
Cibolo	1.20	1.14	1.20	1.03	1.23	1.03	0.88	0.61	0.74	0.81	0.96	1.15

The monthly base flow scaling factor for each month was then multiplied by the mid-point of the target base flow ranges (dry, average, and wet) to generate a monthly distribution around each target flow level that would reflect the natural hydrologic pattern. Monthly distributions at Calaveras resulted in flows which fell below the lower end of the target range during July and August for all base flows. This also occurred at Falls City (all base flows in August), Goliad (dry base from July through October, average and wet base in August), Hwy 77 (dry base from July through October, average and wet base in August), and Cibolo Creek (dry base in August, average and wet base in August and September). Flows in these months were adjusted to the low end value of each respective base flow range. The resulting monthly base flow recommendations for each site are presented in Section 4.0 within the recommendation figures.

3.3 *High Flow Pulses and Overbank Flows*

Pulse and overbanking flow recommendations are important components of an instream flow regime designed to maintain a sound ecological environment. Specific recommendations for flow magnitude, frequency, duration, and time of year were developed for each Study Site. Sufficient data on flow-ecology relationships to rate of change characteristics were not available. Each of these prescription components are important for maintaining the health of existing riparian communities and for sediment transport and subsequent channel and habitat maintenance. High flow pulses are also necessary for the successful reproduction and recruitment of broadcast spawning fishes, which rely upon flow conditions that are capable of keeping their eggs suspended within the water column for several days while they develop and subsequently hatch (Durham and Wilde 2009). Broadcast spawning is the predominant reproductive mode among North American cyprinids (Johnston and Page 1992). Because most small cyprinid species are short-lived with only a two- to three-year maximum life span (Bonner 2000, Winemiller and Rose 1992), a single year without successful reproduction could result in a significant decrease in population abundance or even result in extirpation if recruitment does not occur for two or three consecutive years. Pulse and overbanking flows also provide connectivity to backwaters and floodplain lakes which serve as important reproductive habitat and nursery grounds for many fish species (Shaeffer 1984).

3.3.1 *Riparian*

The project team used field-collected riparian data, TPWD Ecological Mapping Systems-community data, HEC-RAS model values, and the results from a tree-ring core study to identify flow levels that were important to riparian vegetation at the five Study Sites. Life history information from the literature review was used to identify potentially important times of the year when high flow pulses are particularly critical to the dominant bottomland forest tree species present at the sites (Table 19).

The riparian transect data and bank profiles found that black willow, American sycamore, and common buttonbush are riparian species typically found at the water's edge and on stream banks (Appendix F). HEC-RAS model results identified flow events that would inundate these species in the riparian zone. Transect data also found that box elder, green ash and cottonwood trees were typically found higher up on the stream banks and further into the riparian zone, where they are inundated less frequently than black willow. Based on a literature review, seeding and germination periods were identified for several dominant tree species in the riparian community (Table 19). An estimate of the frequency (number times per year) and duration (days) of these pulses is also provided, based on the need for providing soil moisture for seedling and sapling growth and for seed dispersal at each Study Site (Table 20).

Table 19. Summary of literature review regarding life history of riparian indicator species.

Species	Life history traits and environmental flow needs
Black willow (*Salix nigra*)	- Seeds ripen 45 to 60 days after pollination - Seeds do not go dormant - Very moist, bare soil best for germination and early development - Not damaged by flooding or silting - Trees may survive >30 days of complete inundation - Intolerant of dry soil - Flowering February to June - Seeds fall in April to July
American sycamore (*Platanus occidentalis*)	- Seeds are dispersed February to May - Good seed crops only every 1 or 2 years - Germination "window" with spring floods in May to July
Common buttonbush (*Cephalanthus occidentalis*)	- Seeds disperse September to October
Box elder (*Acer negundo*)	- Seeds disperse September to March - Germinate when soil is moist and following disturbance - Need shallow soil moisture to establish - Prefer well-drained soils
Green ash (*Fraxinus pennsylvanica*)	- Germination in spring/overwinter , live 1-3 years - Moisture content of seeds influenced by late fall precipitation - Tolerant of flooding up to 50% of growing season
Cottonwood (*Populus deltoids*)	- Germination "window" with spring floods in May to July - Flooding should be most intense in the beginning, tapering off - Large flood pulses in spring to disperse seeds outside of active flood channel - Lower pulses later to not remove them - Fall pulses to provide adequate soil moisture to seeds/saplings - Need scoured sites (periodic high floods) to establish - Susceptible to desiccation from too rapid soil moisture subsidenceand to prolonged inundation

Table 20. High flow pulse and overbank flow evaluation for the riparian community at each Study Site.

STUDY SITE	PULSE (cfs)	TIMING	FREQ./ year	DURATION	BENEFIT
Calaveras	2,000	Mar-May	3	4 days	Inundates most of the black willow habitat
	2,000	Jun-Aug	2	4 days	Inundates most of the black willow habitat
	2,000	Sep-Nov	2	4 days	Inundates most of the black willow habitat
	4,000	Feb-Apr	2	3 days	Inundates American sycamore and most of the box elder habitat
	4,000	May-Jun	2	3 days	Inundates most of the green ash habitat
	4,000	Jul-Nov	2	3 days	Inundates American sycamore and most of the box elder/green ash habitat
	6,500	Feb-May	1	3 days	Inundates about 75% of the hardwood forest communities
	6,500	Jun-Oct	1	3 days	Inundates about 75% of the hardwood forest communities
	11,500	Feb-Oct	1	3 days	Inundates about 90% of the hardwood forest communities and reduces upland vegetation encroachment
Falls City	2,000	Mar-May	3	4 days	Inundates most of the black willow habitat
	2,000	Jun-Aug	2	4 days	Inundates most of the black willow habitat
	2,000	Sep-Nov	2	4 days	Inundates most of the black willow habitat
	4,000	Feb-Apr	2	3 days	Inundates box elder and most of the American sycamore habitat
	4,000	May-Jun	2	3 days	Inundates green ash habitat
	6,500	Jul-Nov	2	3 days	Inundates a majority of the green ash/box elder/American sycamore trees and samplings
	8,000	Feb-May	1	3 days	Inundates almost all of the green ash habitat and about 80% of the other hardwood forest community
	8,000	Jun-Oct	1	3 days	Inundates almost all of the green ash habitat and about 80% of the other hardwood forest community
	11,500	Feb-Oct	1	2 days	Inundates most of the facultative wetland species habitat, about 90% of the hardwood forest community, and reduces upland vegetation encroachment

Table 20. High flow pulse and overbank flow evaluation for riparian community at each Study Site (continued).

STUDY SITE	PULSE (cfs)	TIMING	FREQ./ year	DURATION	BENEFIT
Goliad	2,000	Mar-May	3	4 days	Inundates most of the black willow habitat
	2,000	Jun-Aug	2	4 days	Inundates most of the black willow habitat
	2,000	Sep-Nov	2	4 days	Inundates most of the black willow habitat
	4,000	Feb-Apr	2	4 days	Inundates box elder and most of the American sycamore habitat
	7,000	May-Jun	1	3 days	Inundates a portion of the green ash habitat
	7,000	Jul-Nov	1	3 days	Inundates a portion of the box elder/green ash/American sycamore habitat
	8,500	Feb-May	1	3 days	Inundates cottonwood/box elder habitat and about 65% of the other floodplain hardwood forest community
	8,500	Jun-Oct	1	3 days	Inundates cottonwood/box elder habitat and about 65% of the other floodplain hardwood forest community
	14,000	Feb-Oct	1	3 days	Inundates cottonwood habitat, most of the facultative wetland species habitat, about 90% of the other floodplain hardwood forest community, and reduces upland vegetation encroachment
Hwy 77	2,000	Mar-May	3	4 days	Inundates most of the black willow habitat
	2,000	Jun-Aug	2	4 days	Inundates most of the black willow habitat
	2,000	Sep-Nov	2	4 days	Inundates most of the black willow habitat
	4,000	Feb-Apr	2	4 days	Inundates box elder and most of the American sycamore habitat
	7,000	May-Jun	1	3 days	Inundates a portion of the green ash habitat
	7,000	Jul-Nov	1	3 days	Inundates a portion of the box elder/green ash/American sycamore habitat
	8,500	Feb-May	1	3 days	Inundates box elder habitat
	8,500	Jun-Oct	1	3 days	Inundates box elder habitat
	10,000	Feb-Oct	1	2 days	Inundates about 70% of the floodplain hardwood forest community and reduces upland vegetation encroachment

Table 20. High flow pulse and overbank flow evaluation for riparian community at each Study Site (continued).

STUDY SITE	PULSE (cfs)	TIMING	FREQ./ year	DURATION	BENEFIT
Cibolo	1,000	Mar-May	3	4 days	Inundates the existing black willow trees
	1,000	Jun-Aug	2	4 days	Inundates the existing black willow trees and common buttonbush shrubs
	1,000	Sep-Nov	2	4 days	Inundates the existing black willow trees and common buttonbush shrubs
	2,500	Feb-Apr	2	3 days	Inundates a large portion of the box elder habitat
	2,500	May-Jun	2	3 days	Inundates a large portion of the green ash habitat
	2,500	Jul-Nov	2	3 days	Inundates a large portion of the green ash/box elder habitat
	5,000	Feb-Oct	1	2 days	Inundates most of the box elder/green ash habitat and about 75% of the hardwood forest community
	8,000	Feb-Oct	1	2 days	Inundates about 90% of the hardwood forest community and reduces upland vegetation encroachment

Based on the life history information, the modeled extent of high flow pulses in the riparian zone, and the overall area of inundation of riparian communities, the flows specified in Table 20 were considered appropriate to maintain the health of existing riparian communities on the lower San Antonio River and Cibolo Creek. The integration of life history of key indicator species, riparian transect data, and modeling (elevation and inundation) can be summarized for the Cibolo Creek Study Site as follows:

- 1,000 cfs high flow pulses from March to November for black willow seed dispersal and germination, and to provide soil moisture for seedlings and sapling growth
- 1,000 cfs high flow pulses from June to November to provide soil moisture to common buttonbush during the flowering and seeding period
- 2,500 cfs high flow pulses from February to November to provide soil moisture and for seedling dispersal and recruitment
- 5,000 and 8,000 cfs overbank flows during the growing season to inundate the larger riparian zone for soil moisture and inundation to prevent intrusion of upland species

As discussed in Section 2.3.3, a TIFP sponsored tree-ring core study on the lower San Antonio River and lower Cibolo Creek was conducted by Baylor University (Duke 2011). The results from that study were integral in establishing key riparian indicators species, aiding in the evaluation of riparian (life-stage) transect data relative to flood stage, and in establishing timing, frequency, and duration estimates for associated flow levels. Additionally, Duke (2011) provided recommendations for total annual volume ranges at which riparian growth was good.

3.3.2 *Sediment Transport*

Sediment transport analyses were also incorporated to evaluate high flow pulses and overbank flows for consideration in setting recommendations. Assessment of sediment transport associated with the environmental flow recommendations was made for one site, the location of USGS Gage No. 08188500, on the San Antonio River at Goliad. This assessment was carried out to determine the likelihood that flow recommendations would be adequate to maintain the current channel configuration or if some channel changes could be expected. Analysis made use of the software package SAMWin following procedures described by SAC (2009) and GSA-BBEST (2011) and made use of available geomorphic data.

Flow conditions investigated included daily gaged flow values from March 1939 to February 1959 (Scenario 1 in Table 21). This scenario was selected to be representative of more natural conditions in the basin. During this time period, flows may already have been impacted by some human activities (groundwater pumping, irrigation diversions, etc.) in the basin; however, it was prior to significant urbanization in the upper basin. This time period includes a severe drought period (1950-1956). Another flow regime investigated was daily gaged flow values from 1996 to 2015 (Scenario 2 in Table 21). This scenario was selected to be representative of the flows most responsible for the current channel shape and associated flow-ecology relationships. This period also includes a severe drought period (2011-2015). Examination of these two flow regimes provide an estimate of how flow and sediment transport have varied through time for the San Antonio River at the Goliad Study Site.

A flow regime with no consideration for sediment transport was also investigated (Scenario 3 in Table 21). This flow regime was derived from daily gaged data from 1996 to 2015 by reducing the gaged flow to the values protected by subsistence flows, base flows, high flow pulses, and overbank flows in Table 24. This analysis took into account the historical occurrence of flows for the period from 1996 to 2015 in that flow values were set to the lower of two values, either the historical daily flow or the recommendations. The analysis did not take into account the effect of senior downstream water rights, which, on any particular day, may act to keep more water in the channel than would be prescribed by the flow recommendations themselves. The analysis also assumed no limitations on the capacity to divert or impound flows in excess of flow recommendations. The analysis of sediment transport described here gives an idea of the sediment transport characteristics associated with each flow scenario but does not consider how flow recommendations would operate in consort with existing water rights.

Table 21. Results of sediment transport analysis by flow scenario.

Flow Scenario	Average Water Volume (ac-ft/yr)	Average Sediment Transported (tons/yr)	Effective Discharge (cfs)	Percent of 1939-1959 Sediment Yield	Percent of 1996-2015 Sediment Yield
1. 1939-1959 Gaged	431,419	99,559	5,450	100%	56%
2. 1996-2015 Gaged	736,316	177,084	6,900	178%	100%
3. Flow Recommendation Without Sediment Transport Consideration	169,621	20,970	10,300	21%	12%
4. Flow Scenario 3 + 75% of Flow >2,000 cfs	395,122	119,213	5,200	120%	67%
5. Flow Scenario 3 + 85% of Flow >2,000 cfs	427,632	138,374	5,800	139%	78%
6. Flow Scenario 3 + 90% of Flow >2,000 cfs	445,876	149,172	6,200	150%	84%
7. Flow Scenario 3 + 92% of Flow >2,000 cfs	453,399	153,551	6,300	154%	87%
8. Flow Scenario 3 + 95% of Flow >2,000 cfs	464,724	160,169	6,500	161%	90%
9. Flow Scenario 3 + 95% of Flow >1,000 cfs	556,552	163,771	6,500	164%	92%

Other flow scenarios (Scenarios 4-9 in Table 21) were developed by providing additional water for sediment transport to Scenario 3. In these scenarios, in addition to the high flow pulses specified in Table 24, a percentage of all flows in the gaged record above a flow threshold were reserved for sediment transport and channel maintenance. In other words, after the flow threshold was achieved, only a limited percentage of water could be diverted from the river, with the remainder reserved in the channel to carry out sediment transport and channel maintenance. Again, these scenarios did not consider existing water rights. An example hydrograph for June 19, 1997 to July 5, 1997 is shown in Figure 54. In this figure, the green area represents daily gaged flow data. The purple area shows the flows associated with recommendations that do not consider sediment transport (Scenario 3 in Table 21). This scenario includes subsistence and base flows similar to those recommended in Section 4 for the Goliad Study Site. It also includes the specific high flow pulses and overbank flows. Two additional scenarios are also shown in Figure 54. The blue line corresponds to Scenario 4 from Table 21. This scenario protects all the flow protected by Scenario 3 and also protects 75% of flows above 2,000 cfs that are not already protected by one of the specific pulse or overbank flow recommendations made in Section 4. The red line corresponds to Scenario 8 from Table 21, which protects 95% of flows above 2,000 cfs that are not already protected by one of the specific pulse or overbank flow recommendations made in Section 4. Note that Scenarios 4 and 8 protect more of the rising and receding limbs of the high flow pulses than Scenario 3.

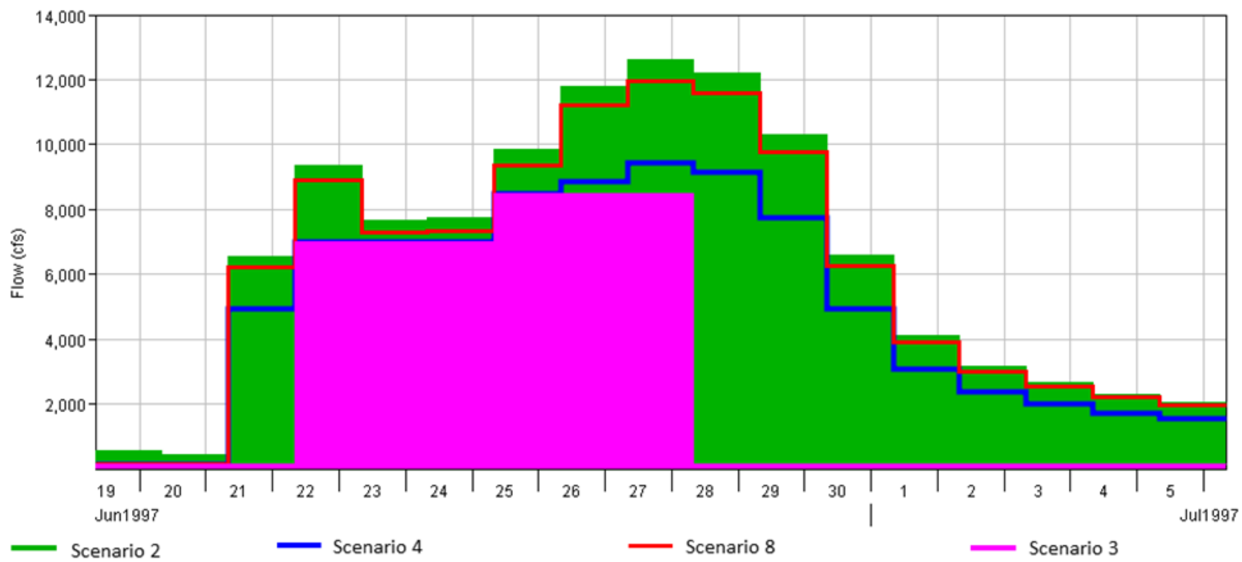


Figure 54. Gaged and modeled daily flows for June 19, 1997 to July 5, 1997 for Scenarios 2, 3, 4, and 8 (from Table 21) for the San Antonio River at Goliad, Texas.

Note that flow recommendation scenarios (Scenarios 3 through 9) are always less than the historical gaged flow. The flow recommendations are intended to provide for a sound ecological environment; however, recommendations do not require that flow be augmented to meet flow recommendations if suitable flow conditions are not already present in the gaged record. In some cases, existing water rights and infrastructure in the basin may dictate higher flows than those calculated for Scenarios 3 through 9. This is a result of several factors. First, at certain times, downstream senior water rights may require flows in excess of flow recommendations be left in the river. This may result in flows in excess of subsistence or base flow recommendations remaining in the channel. Part or all of some unprotected pulse events may also be required to meet downstream water rights. Another factor that may contribute to flows in excess of flow recommendations remaining in the river is limited infrastructure to impound or divert water upstream of Goliad. This limited capacity to impound or divert water that is not protected by flow recommendations may result in flows greater than the flow recommendations being provided at Goliad; however, if flows in excess of the flow recommendations occur, their existence would be attributable to other factors, not the flow recommendations themselves. For this analysis, we considered only the effects of the flow recommendations themselves and not the combination of flow recommendations, downstream water rights, and upstream infrastructure limitations.

Flow duration curves for several of the flow scenarios are shown in Figure 55, including gaged data from the periods March 1939 to February 1959 (Scenario 1) and 1996-2015 (Scenario 2). Also shown in this figure are flow duration curves for Scenarios 3, 4, and 8 (derived from the 1996-2015 gaged data). Note that the flow duration curves for Scenarios 3, 4, and 8 are below the curve for gaged flow from 1996-2015. Also note that for flows less than 2,000 cfs, the curves for

Scenarios 4 and 8 are identical. Above 2,000 cfs, the curve for Scenario 8 is closer to the curve for the 1996-2015 gaged data, while the curve for Scenario 4 is farther below. In this same flow range, the curve for Scenario 3 is below the other scenarios, including historical flows from March 1939 to February 1959 (Scenario 1). The 80th and higher percentile flows for Scenarios 3, 4, and 8 are similar to or greater than those for the gaged data from March 1939 to February 1959. For both Scenario 4 and 8, flows between the highest monthly base flow for wet conditions (about 300 cfs) and the threshold flow (2,000 cfs) were not protected and are therefore missing from the flow duration curves.

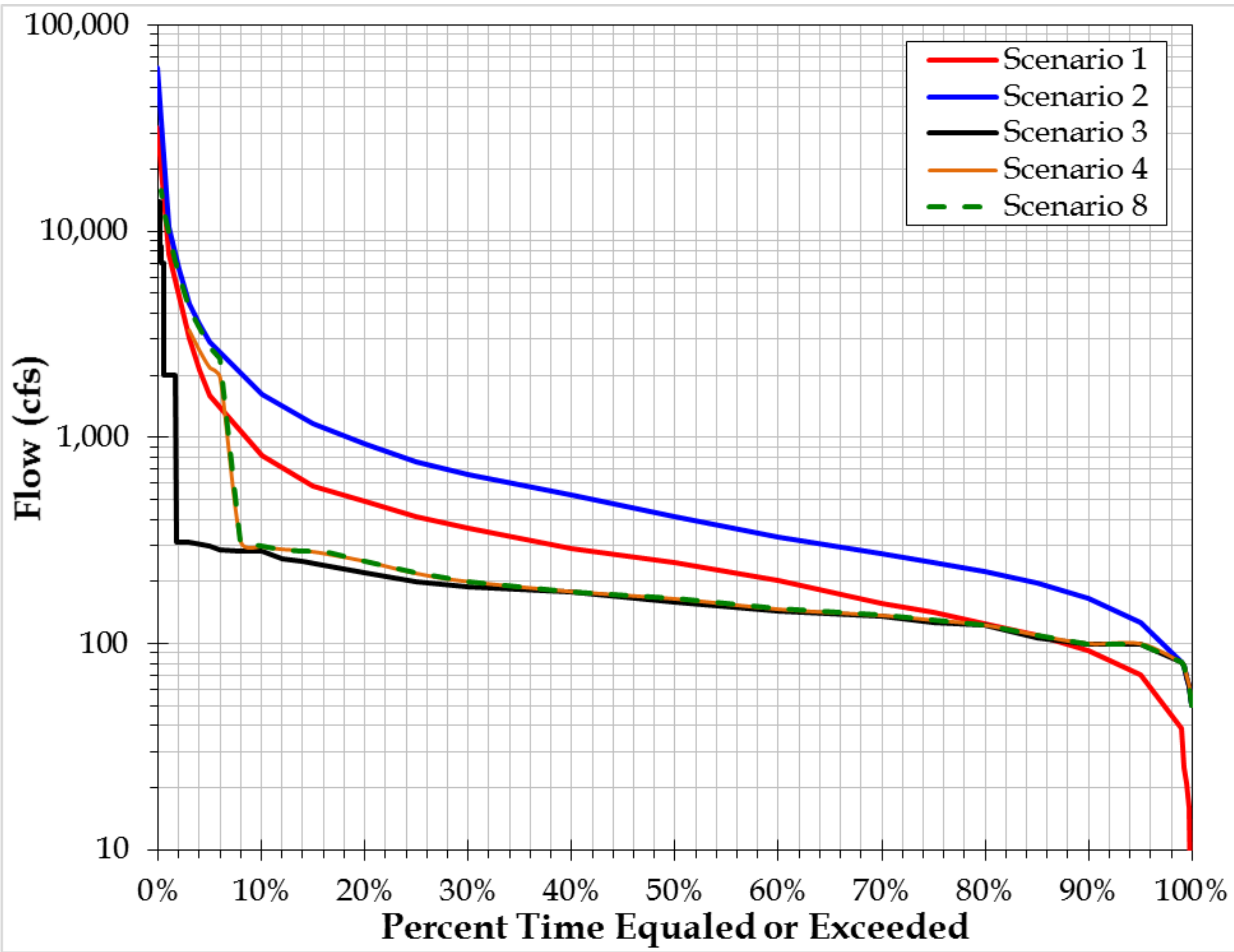


Figure 55. Flow duration curves for Scenarios 1, 2, 3, 4, and 8 (from Table 21) for the San Antonio River at Goliad, Texas.

Results of the sediment transport analysis for the San Antonio River at Goliad are shown in the right hand columns of Table 21. Note that the average annual water yield increased about 70% from the gaged flow in the 1939 to 1959 time period to the 1996 to 2015 time period. Average annual sediment yield increased about 73% between these time periods as well. Scenario 3(no sediment transport consideration), which was developed from 1996 to 2015 gaged data, results in a drop in water and sediment yields of approximately 77 and 88%, respectively from 1996 to 2015 conditions. Note also that the water and sediment yields of this scenario are also reduced approximately 60 and 79%, respectively from March 1939 to February 1959 baseline conditions. Providing such a flow regime for an extended period of time would result in a river with a smaller channel at Goliad than existed during the 1939 to 1959 baseline period. With this flow scenario, the river would be expected to retract from the current size (as reflected by 1996 to 2015 conditions) and eventually take on a shape even smaller than that experienced in the 1939 to 1959 time period. Without specifically including flows for sediment transport, the channel will most likely begin to aggrade. Sediment deposition could negatively affect the river in a number of ways including the degradation of habitat quality and reduction in quantity of specific habitat types. Sullivan and Watzin (2009) reported all fish in their study of aggraded environments lost condition over time, indicating that streams and rivers with extensive sediment aggradation are unlikely to support healthy fish assemblages.

Sediment analysis indicates additional flow in excess of that provided by Scenario 3, which includes high flow pulse and overbanking flow recommendations, would be required to maintain sediment transport at a rate similar to that experienced during either of the historical time periods analyzed (1939-1959 or 1996-2015). Although significantly less sediment was transported in the 1939-1959 time period (less than 60% of the sediment moved in the 1996-2015 time period), Scenario 3 moves even less (12% of the sediment moved in the 1996-2015 time period). Movement of this amount of sediment would not be sufficient to maintain the shape of the channel or associated habitats required for a sound ecological environment.

Several options for increasing flow recommendations in order to maintain a desired sediment transport rate and channel shape are explored in Scenarios 4-9 in Table 21. Each of these scenarios adds flow to that provided by Scenario 3 by reserving a percentage of flow above a certain flow threshold for sediment transport and channel maintenance. In Scenarios 4 through 8, the flow threshold is set to 2,000 cfs and the percentage of flow retained for sediment transport and channel maintenance is varied from 75 to 95%. For Scenario 9, the flow threshold is reduced to 1,000 cfs and the percentage of flow retained is 95%.

According to Biedenharn et al. (2000), maintaining 90 to 110% of the current sediment transport rate will maintain a channel that has adjusted to its flow and sediment regime. Results of the sediment transport analysis indicate that both Scenarios 8 and 9 in Table 21 result in a sediment transport rate capable of maintaining the current channel shape at the Goliad Study Site. Over the 1996 to 2015 time period, Scenarios 8 and 9, respectively would have required approximately 63 and 76% of the water to remain in the river. In other words, at this location and over this time period we could have removed as much as 37% of the flow from the river and still maintained the existing channel.

Sediment transport rates associated with Scenarios 4 through 7 are reduced to less than 90% of the rate associated with gaged flows for 1996 through 2015. At the same time, they exceeded 110% of the sediment transport associated with the March 1939 to February 1959 gaged flows. Moving to a flow regime similar to Scenarios 4 through 7 would cause the channel to move toward a shape intermediate to the 1939-1959 and 1996-2015 conditions.

Please note, not all geomorphic changes are reversible merely by changing flow conditions. For example, when streams degrade and become disconnected from historical riparian areas, restoration of the original high flow pulses and overbank flows will not be sufficient to ensure that appropriate flows reach the desired areas. In most cases, channel restoration work requires physical reshaping of the channel (by means such as reshaping cross section and planform, installation of bank protection, and construction of control structures) along with restoration of important flow components. This analysis should not be used to imply that channel conditions similar to those that existed in 1939-1959 could be achieved exclusively by means of matching flows to a particular flow scenario. An almost complete lack of data describing the physical shape of the channel in the 1939-1959 time period makes it even more difficult to surmise the actions required to return to such a channel. Therefore, a flow regime based on Scenario 8, which maintains 90% of the sediment transported by the current flow regime (1996-2015), is recommended in order to maintain the existing sound ecological environment. These flows are identified as 95% of any flow greater than 2,000 cfs in the San Antonio River and greater than 1,000 cfs in Cibolo Creek.

A detailed geomorphic study of the lower San Antonio River is recommended. The response of channels to large changes in flow and sediment transport can be difficult to predict with simple geomorphic models. For similar reasons, an ongoing monitoring program for the lower San Antonio River should coincide with a significant change in flow regime from what prevailed from 1996 to 2015. Such a change has the capacity to impact sediment transport and trigger changes in channel shape. Flow-ecology relationships related to fish habitat and riparian conditions measured and identified by this study are dependent on the current channel configuration. If the channel begins to change, flow-ecology relationships may change in significant ways.

4.0 INSTREAM FLOW RECOMMENDATIONS

Instream flow recommendations for four categories (subsistence flows, base flows, high flow pulses, and overbank flows) were developed for the lower San Antonio River and lower Cibolo Creek and specific sediment flow recommendations (beyond those part of the high flow pulse and overbanking flow recommendations) were also developed (summarized in Tables 22-26). As mentioned previously, subsistence flows are typically infrequent and seasonal in nature. These low flow events have been characterized by the Q95, or the 95% exccedance flow (Smakhtin 2001, Laaha and Blöschel 2005) where these low flow events should not occur more frequently than 5% of the time. The subsistence flow values recommended in this report are dependent upon that and are not intended to be suitable for maintaining a sound ecological environment if experienced more frequently or for extended periods. Increasing the frequency and or duration of these low flow events could affect the structure and function of the river (Rolls et al. 2012), and more importantly have been shown to adversely impact fish and macroinvertebrate communities (Lake 2003, Jowett et al. 2005, Walters and Post 2011).

An overview of ecological functions supported by each flow category are also provided. Future long term monitoring and adaptive management may provide additional information that could result in modifications or revisions to these recommendations.

Table 22. Instream flow recommendations for the San Antonio River Calaveras Study Site.

<table>
<tr><td rowspan="2">Overbank Flow</td><td></td><td colspan="9">Magnitude = 11,500 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Inundates approx. 90% of hardwood forest community
Reduces upland vegetation encroachment
Sediment transport: Channel maintenance</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Magnitude = 6,500 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Inundates approx. 75% of hardwood forest community
Cottonwood/Green Ash
Sediment transport: Channel maintenance</td><td colspan="5">Magnitude = 6,500 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Inundates approx. 75% of hardwood forest community
Cottonwood/Green Ash
Sediment transport: Channel maintenance</td><td></td><td></td></tr>
<tr><td rowspan="2">Flow Pulses</td><td></td><td colspan="3">Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 3 days
Key Indicator:
Riparian: Sycamore/Box Elder</td><td colspan="2">Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 3 days
Key Indicator:
Riparian: Green Ash</td><td colspan="5">Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 3 days
Key Indicator:
Riparian: Green Ash/Box Elder/Sycamore</td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 3 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td></td></tr>
<tr><td>Sediment Flow</td><td colspan="12">95% of any flow > 2,000 cfs left in river
Key indicator:
Sediment transport: Channel maintenance</td></tr>
<tr><td colspan="9">BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability)</td><td colspan="4">Key Indicators: Aquatic Habitat, Water Quality</td></tr>
<tr><td>Base Wet</td><td>239</td><td>246</td><td>248</td><td>252</td><td>263</td><td>209</td><td>172</td><td>128</td><td>207</td><td>202</td><td>224</td><td>220</td></tr>
<tr><td>Base Average</td><td>154</td><td>158</td><td>160</td><td>162</td><td>169</td><td>134</td><td>111</td><td>100</td><td>133</td><td>130</td><td>144</td><td>142</td></tr>
<tr><td>Base Dry</td><td>94</td><td>93</td><td>94</td><td>96</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>77</td><td>85</td><td>83</td></tr>
<tr><td colspan="9">SUBSISTENCE FLOWS (cfs) - Water quality protection and maintenance of limited aquatic habitat</td><td colspan="4">Key Indicators: Aquatic Habitat, Water Quality</td></tr>
<tr><td>Subsistence</td><td>60</td><td>60</td><td>60</td><td>60</td><td>60</td><td>80</td><td>80</td><td>80</td><td>80</td><td>60</td><td>60</td><td>60</td></tr>
<tr><td>MONTH</td><td>January</td><td>February</td><td>March</td><td>April</td><td>May</td><td>June</td><td>July</td><td>August</td><td>September</td><td>October</td><td>November</td><td>December</td></tr>
</table>

Table 23. Instream flow recommendations for the San Antonio River Falls City Study Site.

<table>
<tr><td rowspan="2">Overbank Flow</td><td></td><td colspan="9">Magnitude = 11,500 cfs
Frequency = 1 event
Duration = 2 days
Key Indicators:
Riparian: Inundates approx. 90% of hardwood forest community
Reduces upland vegetation encroachment
Sediment transport: Channel maintenance</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Magnitude = 8,000 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Inundates approx. 80% of hardwood forest community
Green Ash
Sediment transport: Channel maintenance</td><td colspan="5">Magnitude = 8,000 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Inundates approx. 80% of hardwood forest community
Green Ash
Sediment transport: Channel maintenance</td><td></td><td></td></tr>
<tr><td rowspan="2">Flow Pulses</td><td></td><td colspan="3">Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 3 days
Key Indicator:
Riparian: Box Elder/Sycamore</td><td colspan="2">Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 3 days
Key Indicator:
Riparian: Green Ash</td><td colspan="5">Magnitude = 6,500 cfs
Frequency = 2 events
Duration = 3 days
Key Indicator:
Riparian: Green Ash/Box Elder /Sycamore</td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 3 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td></td></tr>
<tr><td>Sediment Flow</td><td colspan="12">95% of any flow > 2,000 cfs left in river
Key indicator:
Sediment transport: Channel maintenance</td></tr>
<tr><td colspan="9">BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability)</td><td colspan="4">Key Indicators: Aquatic Habitat, Water Quality</td></tr>
<tr><td>Base Wet</td><td>504</td><td>522</td><td>504</td><td>513</td><td>536</td><td>468</td><td>369</td><td>279</td><td>437</td><td>405</td><td>441</td><td>428</td></tr>
<tr><td>Base Average</td><td>280</td><td>290</td><td>280</td><td>285</td><td>298</td><td>260</td><td>205</td><td>155</td><td>243</td><td>225</td><td>245</td><td>238</td></tr>
<tr><td>Base Dry</td><td>168</td><td>174</td><td>168</td><td>171</td><td>179</td><td>156</td><td>123</td><td>100</td><td>146</td><td>135</td><td>147</td><td>143</td></tr>
<tr><td colspan="9">SUBSISTENCE FLOWS (cfs) - Water quality protection and maintenance of limited aquatic habitat</td><td colspan="4">Key Indicators: Aquatic Habitat, Water Quality</td></tr>
<tr><td>Subsistence</td><td>60</td><td>60</td><td>60</td><td>60</td><td>60</td><td>80</td><td>80</td><td>80</td><td>80</td><td>60</td><td>60</td><td>60</td></tr>
<tr><td>MONTH</td><td>January</td><td>February</td><td>March</td><td>April</td><td>May</td><td>June</td><td>July</td><td>August</td><td>September</td><td>October</td><td>November</td><td>December</td></tr>
</table>

Table 24. Instream flow recommendations for the San Antonio River Goliad Study Site.

<table>
<tr><td rowspan="2">**Overbank Flow**</td><td></td><td colspan="9">Magnitude = 14,000 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Inundates approx. 90% of hardwood forest community
Reduces upland vegetation encroachment
Cottonwood
Sediment transport: Channel maintenance</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Magnitude = 8,500 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Inundates approx. 65% of hardwood forest community
Cottonwood/Box Elder
Sediment transport: Channel maintenance</td><td colspan="5">Magnitude = 8,500 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Inundates approx. 65% of hardwood forest community
Cottonwood/Box Elder
Sediment transport: Channel maintenance</td><td></td><td></td></tr>
<tr><td rowspan="2">**Flow Pulses**</td><td></td><td colspan="3">Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Box Elder/Sycamore</td><td>Magnitude = 7,000 cfs
Frequency = 1 event
Duration = 3 days
Key Indicator:
Riparian: Green Ash</td><td colspan="6">Magnitude = 7,000 cfs
Frequency = 1 event
Duration = 3 days
Key Indicator:
Riparian: Green Ash/Box Elder/Sycamore</td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 3 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td></td></tr>
<tr><td>**Sediment Flow**</td><td colspan="12">95% of any flow > 2,000 cfs left in river
Key indicator:
Sediment transport: Channel maintenance</td></tr>
<tr><td colspan="9">**BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability)**</td><td colspan="4">**Key Indicators: Aquatic Habitat, Water Quality**</td></tr>
<tr><td>**Base Wet**</td><td>280</td><td>280</td><td>288</td><td>295</td><td>313</td><td>255</td><td>213</td><td>148</td><td>220</td><td>223</td><td>250</td><td>240</td></tr>
<tr><td>**Base Average**</td><td>157</td><td>157</td><td>161</td><td>165</td><td>175</td><td>143</td><td>119</td><td>100</td><td>123</td><td>125</td><td>140</td><td>134</td></tr>
<tr><td>**Base Dry**</td><td>90</td><td>90</td><td>92</td><td>94</td><td>100</td><td>100</td><td>100</td><td>100</td><td>100</td><td>71</td><td>80</td><td>77</td></tr>
<tr><td colspan="9">**SUBSISTENCE FLOWS (cfs) - Water quality protection and maintenance of limited aquatic habitat**</td><td colspan="4">**Key Indicators: Aquatic Habitat, Water Quality**</td></tr>
<tr><td>**Subsistence**</td><td>60</td><td>60</td><td>60</td><td>60</td><td>60</td><td>80</td><td>80</td><td>80</td><td>80</td><td>60</td><td>60</td><td>60</td></tr>
<tr><td>**MONTH**</td><td>January</td><td>February</td><td>March</td><td>April</td><td>May</td><td>June</td><td>July</td><td>August</td><td>September</td><td>October</td><td>November</td><td>December</td></tr>
</table>

Table 25. Instream flow recommendations for the San Antonio River Hwy 77 Study Site.

<table>
<tr><td rowspan="2">Overbank Flow</td><td></td><td colspan="9">Magnitude = 10,000 cfs
Frequency = 1 event
Duration = 2 days
Key Indicators:
Riparian: Inundates approx. 70% of hardwood forest community
Reduces upland vegetation encroachment
Sediment transport: Channel maintenance</td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Magnitude = 8,500 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Box Elder
Sediment transport: Channel maintenance</td><td colspan="5">Magnitude = 8,500 cfs
Frequency = 1 event
Duration = 3 days
Key Indicators:
Riparian: Box Elder
Sediment transport: Channel maintenance</td><td></td><td></td></tr>
<tr><td rowspan="2">Flow Pulses</td><td></td><td colspan="3">Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Box Elder/Sycamore</td><td colspan="2">Magnitude = 7,000 cfs
Frequency = 1 event
Duration = 3 days
Key Indicator:
Riparian: Green Ash</td><td colspan="5">Magnitude = 7,000 cfs
Frequency = 1 event
Duration = 3 days
Key Indicator:
Riparian: Green Ash/Box Elder/Sycamore</td><td></td></tr>
<tr><td></td><td></td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 3 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td colspan="3">Magnitude = 2,000 cfs
Frequency = 2 events
Duration = 4 days
Key Indicator:
Riparian: Black Willow</td><td></td></tr>
<tr><td>Sediment Flow</td><td colspan="12">95% of any flow > 2,000 cfs left in river
Key indicator:
Sediment transport: Channel maintenance</td></tr>
<tr><td colspan="9">BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability)</td><td colspan="4">Key Indicators: Aquatic Habitat, Water Quality</td></tr>
<tr><td>Base Wet</td><td>420</td><td>420</td><td>431</td><td>443</td><td>469</td><td>383</td><td>319</td><td>221</td><td>330</td><td>334</td><td>375</td><td>360</td></tr>
<tr><td>Base Average</td><td>196</td><td>196</td><td>201</td><td>207</td><td>219</td><td>179</td><td>149</td><td>103</td><td>154</td><td>156</td><td>175</td><td>168</td></tr>
<tr><td>Base Dry</td><td>101</td><td>101</td><td>104</td><td>106</td><td>113</td><td>100</td><td>100</td><td>100</td><td>100</td><td>80</td><td>90</td><td>86</td></tr>
<tr><td colspan="9">SUBSISTENCE FLOWS (cfs) - Water quality protection and maintenance of limited aquatic habitat</td><td colspan="4">Key Indicators: Aquatic Habitat, Water Quality</td></tr>
<tr><td>Subsistence</td><td>60</td><td>60</td><td>60</td><td>60</td><td>60</td><td>80</td><td>80</td><td>80</td><td>80</td><td>60</td><td>60</td><td>60</td></tr>
<tr><td>MONTH</td><td>January</td><td>February</td><td>March</td><td>April</td><td>May</td><td>June</td><td>July</td><td>August</td><td>September</td><td>October</td><td>November</td><td>December</td></tr>
</table>

Table 26. Instream flow recommendations for the Cibolo Creek Study Site.

Overbank Flow		Magnitude = 8,000 cfs Frequency = 1 event Duration = 2 days *Key Indicators:* *Riparian: Inundates approx. 90% of hardwood forest community* *Reduces upland vegetation encroachment* *Sediment transport: Channel maintenance*										
		Magnitude = 5,000 cfs Frequency = 1 event Duration = 2 days *Key Indicators:* *Riparian: Inundates approx. 75% of hardwood forest community* *Sediment transport: Channel maintenance*										
Flow Pulses		Magnitude = 2,500 cfs Frequency = 2 events Duration = 3 days *Key Indicator:* *Riparian: Box Elder*			Magnitude = 2,500 cfs Frequency = 2 events Duration = 3 days *Key Indicator:* *Riparian: Green Ash*		Magnitude = 2,500 cfs Frequency = 2 events Duration = 3 days *Key Indicator:* *Riparian: Green Ash/Box Elder*					
			Magnitude = 1,000 cfs Frequency = 3 events Duration = 4 days *Key Indicator:* *Riparian: Black Willow*			Magnitude = 1,000 cfs Frequency = 2 events Duration = 4 days *Key Indicator:* *Riparian: Black Willow/Buttonbush*			Magnitude = 1,000 cfs Frequency = 2 events Duration = 4 days *Key Indicator:* *Riparian: Black Willow/Buttonbush*			
Sediment Flow	95% of any flow > 1,000 cfs left in river *Key indicator:* *Sediment transport: Channel maintenance*											
BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability)									**Key Indicators: Aquatic Habitat, Water Quality**			
Base Wet	60	57	60	52	62	52	44	31	37	41	48	58
Base Average	39	37	39	33	40	33	29	20	24	26	31	37
Base Dry	24	23	24	21	25	21	18	12	14	16	19	23
SUBSISTENCE FLOWS (cfs) - Water quality protection and maintainence of limited aquatic habitat									**Key Indicators: Aquatic Habitat, Water Quality**			
Subsistence	10	10	10	10	10	10	10	10	10	10	10	10
MONTH	January	February	March	April	May	June	July	August	September	October	November	December

4.1 *Monitoring and Adaptive Management*

Future monitoring and adaptive management is a critical component of this study and may provide additional information that could result in modifications or revisions to these recommendations. A monitoring program should evaluate the effectiveness of the instream flow recommendations and to what extent objectives were met for those recommendations (Higgins et al. 2011). Monitoring is recommended for water quality, fish, mussels, riparian vegetation, and channel morphology.

Temperature was identified as the water quality component of greatest concern; therefore, specific monitoring to evaluate water temperature conditions during flows approaching and less than subsistence flow recommendations are especially important. Data sondes should be deployed for extended periods during dry base and subsistence flow conditions in order to collect continuous water quality data at a maximum of an hourly time step. Water quality data will be important for linking to the following biological monitoring components and updating parameters in water quality models. Additional studies to understand the linkage between water temperature and ecological processes (e.g., mussel and fish survivability and recruitment) are also needed.

Annual fish assemblage monitoring, following TCEQ (2014b) sampling procedures, should be conducted at each Study Site. These sampling procedures will allow the calculation of the Index of Biotic Integrity (Linam et al. 2002), which can be tracked over time to determine changes to the fish assemblage based upon a series of biological metrics. Data and IBI calculations reported from past years as part of the TIFP baseline collections and Clean Rivers Program can be used as reference. Changes in occurrence, distribution, density, and relative abundance of broadcast spawners and focal species (Burrhead Chub, American Eel, Pugnose Minnow, and darters) should also be monitored.

Quantitative mussel sampling should be conducted annually at each Study Site in order to monitor changes in species richness and density, detect recruitment, and document microhabitat use. Density and size class structure of species encountered should be calculated. Ideally this work should be performed when flows are near dry base flow conditions.

Annual monitoring of select riparian transects should be performed at each Study Site in order to monitor changes in percent composition of facultative to obligate wetland riparian species as well as changes in spatial extent and density of seedling germination of native plants. Tree-ring analysis to assess riparian productivity relative to inter-annual flood pulses should be conducted every 10 years to refine flood pulse specifications relative to riparian productivity.

Monitoring of select channel cross-sections at each Study Site should be conducted yearly to assess potential changes in channel configuration. Bed material should be collected annually at each Study Site and nearby USGS gage. A preliminary analysis and monitoring report should be prepared annually with a more extensive analysis and report prepared at five-year intervals. Leaf off aerial imagery should be gathered and analyzed for changes in plan form and channel top width, updating the work started by Cawthon and Curran (2008). The availability of long term channel monitoring data from other agencies and programs should be investigated and analyzed if available. Examples include bridge cross sections collected by the Texas Department of Transportation similar to those used by Cawthon and Curran (2008) at two sites on the San Antonio River and cross sections at USGS gages similar to those used by Hietmuller and Greene (2009) for analysis of geomorphic change on the Brazos and Sabine rivers.

In conjunction with this monitoring, the Technical Overview document also ascribes the importance of adaptive management in order to address the uncertainty of management outcomes that arise from the complexity of the natural environment (TIFP 2008). Through systematic testing of management assumptions, recommended strategies can be modified to ensure that goals are achieved. It should be expected that various aspects of the program, from instream flow study design to integration of multidisciplinary information to the establishment of monitoring programs, will be modified as new techniques and ideas are formulated and experience and knowledge are gained.

4.2 *Continued Stakeholder Involvement*

This project has been subject to stakeholder and peer review during the project design, study activities, and the development of flow recommendations. Stakeholder involvement has been and will continue to be an integral part of the TIFP process. As future TIFP studies and monitoring activities are developed, stakeholder input will be solicited and participation encouraged. Periodic stakeholder review will also be requested as on-going TIFP studies, future studies, and monitoring results become available.

5.0 REFERENCES

Acreman, M., M. Dunbar, J. Hannaford, O. Mountford, P. Wood, N. Holmes, I. Cowx, R. Noble, C. Extence, J. Aldrick, J. King, A. Black, and D. Crookall. 2010. Developing environmental standards for abstractions from UK rivers to implement the EU Water Framework Directive. Hydrological Sciences Journal 53: 1105-1120.

Annear, T., I. Chisholm, H. Beecher, A. Locke, and 12 other authors. 2004. Instream flows for riverine resource stewardship, revised edition. Instream Flow Council, Cheyenne, Wyoming.

Archambault, J.M. 2012. Thermal sensitivity of freshwater mussels: incorporating benthic ecology into laboratory mesocosm experiments. Master of Science Thesis. North Carolina State University, Raleigh, North Carolina.

Balon, E.K. 1975. Reproductive guilds of fishes: a proposal and definition. Journal of the Fisheries Research Board of Canada 32: 821-864.

Balon, E.K. 1981. Additions and amendments to the classification of reproductive styles in fishes. Environmental Biology of Fishes. 6: 377-389.

Battaglia, L.L., S.A. Fore, and R.R. Sharitz. 2000. Seedling emergence, survival and size in relationship to light and water availability in two bottomland hardwood species. Journal of Ecology 88: 1041-1050.

Battaglia, L.L. and R.R. Sharitz. 2006. Responses of floodplain forest species to spatially condensed gradients: a test of the flood-shade tolerance tradeoff hypothesis. Oecologia 147: 108-118.

Beitinger, L.T., W.A. Bennett, and R.W. McCauley. 2000. Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. Environmental Biology of fishes 58: 237-275.

Bhaskar, A.S., L. Beesley, M.J. Bruns, T.D. Fletcher, P. Hamel, C.E. Oldham, and A.H. Roy. 2016. Will it rise or will it fall? Managing the complex effects of urbanization on base flow. Freshwater Science 35: 293-310.

Biedenharn, D.S., R.R. Copeland, C.R. Thorne, P.J. Soar, R.D. Hey, and C.C. Watson. 2000. Effective discharge calculation: a practical guide. Report No. ERDC/CHL TR-00-15. U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, Mississippi. www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA383261&Location=U2&doc=GetTRDoc.pdf

[BIO-WEST] BIO-WEST, Inc. 2008. Lower Colorado River, Texas instream flow guidelines, Colorado River flow relationships to aquatic habitat and state threatened species: Blue Sucker. BIO-WEST, Inc., Round Rock, Texas. www.lcra.org/library/media/public/docs/lswp/findings/BIO_LSWP_IFguidelines_FINAL.pdf

[BIO-WEST] BIO-WEST, Inc. 2014. Instream flow assessment monitoring and special studies of the lower San Antonio River Basin (2011-2014). BIO-WEST, Inc., Round Rock, Texas.

Bonner, T.H. 2000. Life history and reproductive ecology of the Arkansas River shiner and peppered chub in the Canadian River, Texas and New Mexico. Ph.D. dissertation. Texas Tech University, Lubbock, Texas.

Bonner, T. and D.T. Runyan. 2007. Fish assemblage changes in three western Gulf slope drainages. Final Project Report 2005-483-033. Report to the Texas Water Development Board. www.twdb.state.tx.us/RWPG/rpgm_rpts/2005483033_fish.pdf

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. Instream Flow Information Paper 21. Biological Report 86(7). U.S. Fish and Wildlife Service, Washington, D.C.

Bowen, Z., K.D. Bovee, T. Waddle, T. Modde, and C. Kitcheyan. 2001. Habitat measurement and modeling in the Green and Yampa rivers. Project Report to the Natural Resources Preservation Program. U.S. Geological Survey, Fort Collins, Colorado.

Bowen, Z., K.D. Bovee, and T. Waddle. 2003. Effects of channel modification on fish habitat in the Upper Yellowstone River. Open File Report 03-476. U.S. Geological Survey, Washington, D.C.

Brandes, D., G.J. Cavallo, and M.L. Nilson. 2005. Base flow trends in urbanizing watersheds of the Delaware River Basin. Journal of the American Water Works Association 41: 1377-1391.

Brierely, G.J. and K. Fryirs. 2005. Geomorphology and river management: applications of the river styles framework. Blackwell Publishing, Malden, Massachusetts.

Bunn, S.E. and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30(4):492-507.

Burns, R.M. and B.H. Honkala, tech. cords. 1990. Silvics of North America, volume 2: hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, D.C. 877 pp. http://www.na.fs.fed.us/spfo/pubs/silvics_manual/table_of_contents.htm

Carlisle, D.M., D.M. Wolock, and M.R. Meador. 2010. Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment. Frontiers in ecology and the environment 2010. doi:10.1890/100053. water.usgs.gov/nawqa/pubs/Carlisleetal_FLowAlterationUS.pdf

Cawthon, T.M. and J.C. Curran. 2008. Channel change on the San Antonio River. Texas Water Development Board Project No. 0604830368. Austin, Texas. www.twdb.texas.gov/publications/reports/contracted_reports/doc/0604830638_channelchange.pdf

Clouse, S. 2010. Overview of water in the San Antonio area. Presentation to the Guadalupe, San Antonio, Mission and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Stakeholder Committee. San Antonio, Texas. www.tceq.texas.gov/assets/public/permitting/watersupply/water_rights/eflows/20100301gsabbasc_sawsppt.pdf

Duke, J.R. 2011. Riparian productivity in relation to stream dynamics along two rivers: San Antonio and Brazos, in Central/South Texas. Prepared for the Texas Water Development Board, Contract No. 1000011020.

Durham, B.W. and G.R. Wilde. 2009. Effects of streamflow and intermittency on the reproductive success of two broadcast-spawning cyprinid fishes. Copeia 2009(1): 21–28.

Eaton, J.G. and R.M Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. Limnology and Oceanography 41: 1109-1115.

Espey Consultants, Inc. 2010a. Water quality evaluation needs for the Texas Instream Flow Program: volume 2: San Antonio River case study. Prepared for the Texas Commission on Environmental Quality and San Antonio River Authority, Rev6 2010-10-27.

Espey Consultants, Inc. 2010b. Water quality evaluation needs for the Texas Instream Flow Program: volume 1: identification of needs and statewide approach. Prepared for the Texas Commission on Environmental Quality and San Antonio River Authority, Rev6 2010-10-12.

Edwards Aquifer Authority. 2015. Hydrologic data report for 2014. Report No. 15-01. Edwards Aquifer Authority, San Antonio, Texas.

Edwards Aquifer Authority. 2011. Groundwater management plan, 2010-2015. Approved by Texas Water Development Board January 5, 2011.

Evergreen Underground Water Conservation District. 2016. Groundwater management plan, 2016. Approved by the Texas Water Development Board.

Friedman, J.M. and G.T. Auble. 1999. Mortality of riparian box elder from sediment mobilization and extended inundation. Regulated Rivers 15: 463-476.

Ganser, A.M., T.J. Newton, and R.J. Haro. 2015. Effects of elevated water temperature on physiological responses in adult freshwater mussels. Freshwater Biology 60: 1705-1716.

[GSA-BBEST] Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Expert Science Team. 2011. Environmental flows recommendations report. Texas Commission on Environmental Quality, Austin, Texas. http://www.tceq.state.tx.us/assets/public/permitting/watersupply/water_rights/eflows/20110301guadbbest_transmission.pdf

Hall, R.B.W. and P.A. Harcombe. 1998. Chronic understory disturbance and crown disturbance interact to determine spatial and temporal patterns of sapling occurrence and recruitment. Ecology 79: 847-855.

Hammontree, S.E., J.A. Mabe, and J.H. Kennedy. 2012. Habitat requirements of the Golden Orb. Contract No. 0904830970. Texas Water Development Board, Austin, Texas.

Hanrahan, T.P., D.D. Dauble, and D.R. Geist. 2004. An estimate of Chinook salmon (*Oncorhynchus tshawytscha*) spawning habitat and redd capacity upstream of a migration barrier in the upper Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 61: 23-33.

Hardy, T.B. 2015. HSC development tool. Texas State University, San Marcos, Texas.

Haschenburger, J.K. 2012. Sediment transport modeling of channel scale geomorphic processes. Final Report for TWDB Contract No. 1004831127. Austin, Texas. http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/1004831127_transport.pdf

Haschenburger, J.K. and J. Curran. 2012. Sediment transport modeling of reach scale geomorphic processes. Final Report for TWDB Contract No. 0904830899. Austin, Texas. http://www.twdb.texas.gov/publications/reports/contracted_reports/doc/0904830899_sediment%20transport.pdf

Helsel, D.R. and R.M. Hirsch. 2002. Statistical methods in water resources techniques of water-resources investigations, Book 4, Chapter A3. U.S. Geological Survey, Washington, D.C. http://pubs.usgs.gov/twri/twri4a3/

Hession, W.C. 2001. Riparian forest and urban hydrology influences on stream channel morphology: implications for restoration. In D. Phelps and G. Shelke (eds.). Bridging the gap: meeting the world's water and environmental resources challeges. American Society of Civil Engineers, Reston, Virginia.

Higgins, J.V., C.P. Konrad, A. Warner, and J.T. Hickey. 2011. A framework for monitoring, reporting and managing dam operations for environmental flows at sustainable rivers project sites. Version 1.0. Sustainable Rivers Project Measures Working Group. https://www.conservationgateway.org/Documents/SRP%20Monitoring%20Document%20-%202011-02-11.pdf

Hildebrand, S.F. and L.E. Cable. 1938. Further notes on the development and life histories of some teleosts at Beaufort, North Carolina. Fishery Bulletin 48(24): 505-642.

Hollis, G.E. 1975. The effect of urbanization on floods of different recurrence interval. Water Resources Research 11: 431-435. http://srnr.arizona.edu/rnr/wsm462/Readings/hollis_1975_urban.pdf

Hubbs, C., R.J. Edwards, and G.P. Garrett. 1991. An annotated checklist of the freshwater fishes of Texas, with keys to identification of species. Texas Journal of Science, Supplement 43(4): 1-56.

Johnston, C.E. and L.M. Page. 1992. The evolution of complex reproductive strategies in North American minnows (Cyprinidae). Pages 600–621 in R.L. Mayden (ed.). Systematics, historical ecology, and North American freshwater fishes. Stanford University Press, Stanford, California.

Jowett, I.G., J. Richardson, and M.L. Bonnett. 2005. Relationship between flow regime and fish abundances in a gravel-bed river, New Zealand. Journal of Fish Biology 66: 1419-1436.

Karatayev, A.Y. and L.E. Burlakova. 2008. Distributional survey and habitat utilization of freshwater mussels. Prepared for the Texas Water Development Board, Contract No. 0604830631. . http://www.twdb.state.tx.us/RWPG/rpgm_rpts/0604830631FreshwaterMussels.pdf

Katapodis, C. 2003. Case studies of instream flow modeling for fish habitat in Canadian prairie rivers. Canadian Water Resources Journal 28(2): 199-216.

Laaha, G. and G. Blöschl. 2005. A comparison of low flow regionalization methods-catchment grouping. Journal of Hydrology 323: 193-214.

Lake, P.S. 2003. Ecological effects of perturbation by drought in flowing waters. Freshwater Biology 48: 1161-1172.

Langdon, O.G. 1958. Silvical characteristics of bald cypress. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina.

Lichvar, R.W., D.L. Banks, W.N. Kirchner, and N.C. Melvin. 2016. The national wetland plant list: 2016 wetland ratings. Phytoneuron 2016-30: 1-17. http://wetland-plants.usace.army.mil/nwpl_static/data/DOC/lists_2016/National/National_2016v2.pdf

Lin, J., P.A. Harcombe, M.R. Fulton, and R.W. Hall. 2004. Sapling growth and survivorship as affected by light and flooding in a river floodplain forest of southeast Texas. Oecologia 132: 428-435.

Linam, G.W. and L.J. Kleinsasser. 1998. Classification of Texas freshwater fishes into trophic and tolerance groups. River Studies Report No. 14. Texas Parks and Wildlife Department, Austin, Texas. http://tpwd.texas.gov/publications/pwdpubs/media/pwd_rp_t3200_1694.pdf

Linam, G.W., L.J. Kleinsasser, and K.B. Mayes. 2002. Regionalization of the index of biotic integrity for Texas streams. River Studies Report No. 17. Texas Parks and Wildlife Department, Austin, Texas. http://tpwd.texas.gov/publications/pwdpubs/media/pwd_rp_t3200_1086.pdf

Linam, G.W., S. Robertson, K. Sablan, R. Burke, L. Larralde, and S. Donovan. 2014. Fish assemblage and water quality in the San Antonio River, Texas, between Floresville and Goliad. River Studies Report No. 22. Texas Parks and Wildlife Department, Austin, Texas. http://tpwd.texas.gov/publications/pwdpubs/media/pwd_rp_t3200_1804.pdf

Lizarraga, J.S. and L.L. Wehmeyer. 2012. Estimation of streamflow gains and losses in the lower San Antonio River watershed, south-central Texas, 2009-2010. Scientific Investigations Report 2012-5073. U.S. Geological Survey, Reston, Virginia.

Maloney, K.O., W.A. Lellis, R.M. Bennett, and T.J. Waddle. 2012. Habitat persistence for sedentary organisms in managed rivers: the case for the federally endangered Dwarf Wedgemussel (*Alasmidonta heterodon*) in the Delaware River. Freshwater Biology 57: 1315-1327.

Matthews, W.J. and E.G. Zimmerman. 1990. Potential effects of global warming on native fishes of the southern Great Plains and the southwest. Fisheries 15: 26-32.

National Oceanic and Atmospheric Administration. 2016. National Centers for Environmental Information web page. https://www.ncdc.noaa.gov/cag/time-series/us/41/7/pcp/ytd/12/1895-2016?base_prd=true&firstbaseyear=1901&lastbaseyear=2000

[NRCS] Natural Resources Conservation Service. 2002. Plant fact sheet: green ash, *Fraxinus pennsylvanicus*. http://plants.usda.gov/factsheet/pdf/fs_frpe.pdf

[NRCS] Natural Resources Conservation Service. 2004. Plant fact sheet: common buttonbush, *Cephalanthus occidentalis*. http://plants.usda.gov/factsheet/pdf/fs_ceoc2.pdf

O'Driscoll, M., S. Clinton, A. Jefferson, A. Manda, and S. McMillian. 2010. Urbanization effects on watershed hydrology and in-stream processes in the southern United States. Water 2: 605-648.

Osting, T.D. 2009. Expanded method for filtering submerged objects in echosounder data. Proceedings EWRI 2009 conference, Kansas City, Missouri.

Pandolfo, T.J., W.G. Cope, C. Arellano, R.B. Bringolf, M.C. Barnhart, and E. Hammer. 2010. Upper thermal tolerances of early life stages of freshwater mussels. Journal of the North American Benthological Society 29: 959-969.

Persinger, J.W., D.J. Orth, and A.W. Averett. 2010. Using habitat guilds to develop habitat suitability criteria for a warmwater stream fish assemblage. River Research and Applications.

Pizzuto, J.E., W.C. Hession, and M. McBride. Comparing gravel-bed rivers in paired urban and rural catchments of southeastern Pennsylvania. Geology 28: 79-82.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, and others. 1997. The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47: 769-785.

Poff, N.L. and J.K.H. Zimmerman. 2010. Ecological responses to altered flow regimes – a literature review to inform the science and management of environmental flows. Freshwater Biology 55: 194-205. rydberg.biology.colostate.edu/~poff/Public/poffpubs/Poff_Zimmerman_2010_FWB.pdf

Pusey, B.J. and A.H. Arthington. 2003. Importance of the riparian zone to the conservation and management of freshwater fish: a review. Marine and Freshwater Research 54: 1-16.

Rolls, R.J., C. Leigh, and F. Sheldon. 2012. Mechanistic effects of low-flow hydrology on riverine ecosystems: ecological principles and consequences of alteration. Freshwater Science 31: 1163-1186.

[SAC] Science Advisory Committee. 2009. Fluvial sediment transport as an overlay to instream flow recommendations for the environmental flows allocation process. Report No. SAC-2009-04. Texas Commission on Environmental Quality, Austin, Texas. http://www.tceq.texas.gov/assets/public/permitting/watersupply/water_rights/eflows/sac_2009_04_sedtransport.pdf

Schumm, S.A. 1969. River metamorphosis. ASCE Journal of the Hydraulics Division 95(HY1): 255–273.

Shaeffer, W.A. 1984. Importance of backwater area confluences to the fishes and macroinvertebrates of the Upper Mississippi River, pool 13. Master of Science thesis. Iowa State University, Ames, Iowa.

Simon, T.P. 1999. Assessment of Balon's reproductive guilds with application to midwestern North American freshwater fishes. Pages 97-121 in T.L. Simon (ed.). Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton, Florida. 671 pp.

Smakhtin, V.U. 2001. Low flow hydrology: a review. Journal of Hydrology 240: 147-186.

Spooner, D.E., C.C. Vaughn, and H.S. Galbraith. 2005. Physiological determination of mussel sensitivity to water management practices in the Kiamichi River and review and summarization of literature pertaining to mussels of the Kiamichi and Little River watersheds, Oklahoma. Final Report submitted to Oklahoma Department of Wildlife Conservation. Project No: T-10-P. Oklahoma Biological Survey and Department of Zoology. University of Oklahoma, Norman, Oklahoma.

Steffler, P. and J. Blackburn. 2002. Introduction to depth averaged modeling and user's manual. University of Alberta. http://www.river2d.ualberta.ca/

Streng, D.R., J.S. Glitzenstein, and P.A. Harcombe. 1989. Woody seedling dynamics of an east Texas floodplain forest. Ecological Monographs 59: 177-204.

Stromberg, J.C., V.B. Beauchamp, M.D. Dixon, S.J. Lite, and C. Paradzick. 2007. Importance of low-flow and high-flow characteristics to restoration of riparian vegetation along rivers in arid south-western United States. Freshwater Biology 52: 651-679.

Sullivan, J. 1993. Ilex decidua. In: Fire Effects Information System, [online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). http://www.fs.fed.us/database/feis/ [2011, August 25].

Sullivan, S.M.P and M.C. Watzin. 2009. Towards a functional understanding of the effects of sediment aggradation on stream fish condition. River Research and Applications 26: 1298-1314.

Texas Agrilife Extension Service. Accessed 2011. Online plant database information for Roosevelt willow, *Baccharis neglecta*. http://rangeweb.tamu.edu/plants/PlantPDF/118_rooseveltwillow.pdf.

[TCEQ] Texas Commission on Environmental Quality. 2011. Preliminary results of water quality analysis of Cibolo Creek for the Texas Instream Flow Program. Prepared for the Water Supply Division of the Texas Commission on Environmental Quality. Rev. 4.

[TCEQ] Texas Commission on Environmental Quality. 2014a. Texas integrated report of surface water quality. Texas Commission on Environmental Quality, Austin, Texas.

[TCEQ] Texas Commission on Environmental Quality. 2014b. Surface water quality monitoring procedures, volume 2: methods for collecting and analyzing biological assemblage and habitat data. Texas Commission on Environmental Quality, Austin, Texas. https://www.tceq.texas.gov/assets/public/comm_exec/pubs/rg/rg416/rg-416.pdf

[TCEQ] Texas Commission on Environmental Quality. 2016. Texas Commission on Environmental Quality records. Texas Commission on Environmental Quality, Austin, Texas.

[TIFP] Texas Instream Flow Program. 2008. Texas instream flow studies: technical overview. Report No. 369. Texas Water Development Board, Austin, Texas. http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R369_InstreamFlows.pdf

[TIFP and SARA] Texas Instream Flow Program and San Antonio River Authority. 2011. Instream flow study of the lower San Antonio River and lower Cibolo Creek – interim progress report and instream flow recommendations. Texas Instream Flow Program and San Antonio River Authority.

[TIFP and SARA] Texas Instream Flow Program and San Antonio River Authority. 2012. Instream flow study of the lower San Antonio River and lower Cibolo Creek. Study design. Texas Instream Flow Program and San Antonio River Authority. http://www.twdb.texas.gov/surfacewater/flows/instream/lower_san_antonio/doc/LSAR_Study_Design_March12.pdf?d=1509554166821

Tiner, R.W. 1993. Using plants as indicators of wetland. Proceedings of the Academy of Natural Sciences of Philadelphia 144: 240-253. http://www.fws.gov/northeast/wetlands/publications/113_using_plants_as_indicators.pdf

Trush, W.J., S.M. McBain, and L.B. Leopold. 2000. Attributes of an alluvial river and their relation to water policy and management. Proceedings of the National Academy of Sciences 97: 11858-11863. http://www.pnas.org/content/97/22/11858.full.pdf

[USFWS] U.S. Fish and Wildlife Service. 1988. National list of plant species that occur in wetlands: 1988 national summary. Biological Report 88(24). 254 pp. http://www.fws.gov/pacific/ecoservices/habcon/pdf/National%20List%20of%20Plant%20Species%201988.pdf

[USGS] United States Geological Survey. 1988. National water summary 1987 – hydrologic events and water supply and use. Water-Supply Paper 2350. U.S. Geological Survey, Denver, Colorado. http://pubs.usgs.gov/wsp/2350/report.pdf

Walters, A.W. and D.M. Post. 2011. How low can you go? Impacts of low-flow disturbance on aquatic insect communities. Ecological Applications 21: 163-174.

Warren, M.L., Jr., B.M. Burr, S.J. Walsh, H.L. Bart, Jr., R.C. Cashner, D.A. Etnier, B.J. Freeman, B.R. Kuhajda, R.L. Mayden, H.W. Robison, S.T. Ross, and W.C. Starnes. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. Fisheries 25(10): 7-29.

Williams, J.E., J.E. Johnson, D.A. Hendrickson, S. Contreras-Balderas, J.D. Williams, M. Navarro-Mendoza, D.E. McAllister, and J.E. Deacon. 1989. Fishes of North America endangered, threatened, or of special concern: 1989. Fisheries 14(6): 2-20.

Winemiller, K.O. and K.A. Rose. 1992. Patterns of lifehistory diversification in North American fishes: implications for population regulation. Canadian Journal of Fisheries and Aquatic Sciences 49: 2196–2218.

World Population Review. 2016. San Antonio population. Retrieved September 6th, 2017, from http://worldpopulationreview.com/us-cities/san-antonio-population/

Wurbs, R. 2015. Daily water availability models. Texas A&M University for Texas Commission on Environmental Quality. College Station, Texas. https://ceprofs.civil.tamu.edu/rwurbs/wrap.htm

Wurbs, R., M. Ryu, M. Pauls, and R. Hoffpauir. 2014. Daily water availability model for the Guadalupe and San Antonio River basins. Texas Commission on Environmental Quality. Available at: https://ceprofs.civil.tamu.edu/rwurbs/ wrap.htm

Zeug, S.C. and K.O. Winemiller. 2008. Evidence supporting the importance of terrestrial carbon in a large-river food web. Ecology 89: 1733-1743.

APPENDIX A
HYDROLOGIC AND HYDRAULIC DATA

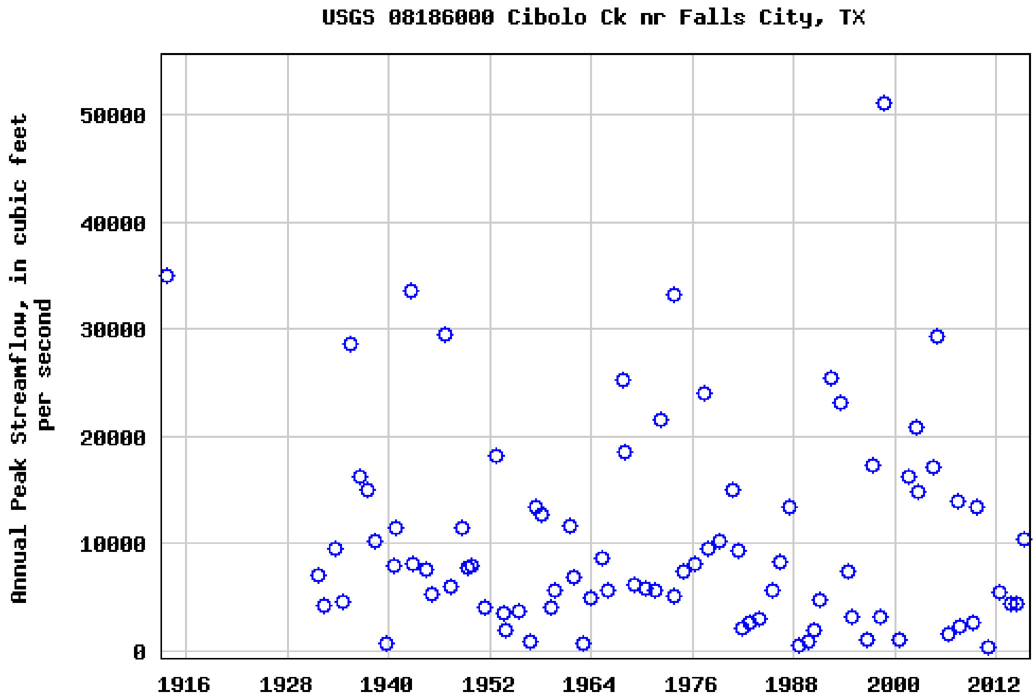


Figure A-1. Annual peak streamflow at USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas.

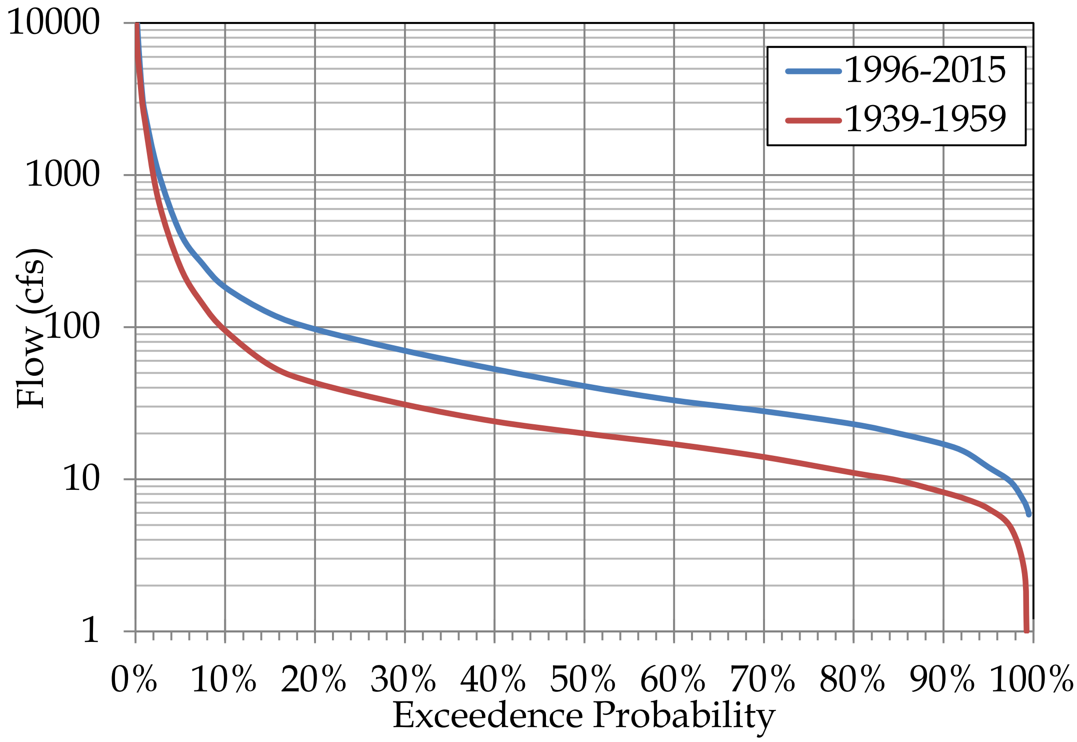


Figure A-2. Flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for an early (March 1939-February 1959) and late (1996-2015) time period.

Table A-1. Flow exceedance statistics for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for an early (March 1939-February 1959) and late (1996-2015) time period.

Exceedence Probability (%)	Time Period 3/1/1939 to 2/28/1959 (cfs)	1/1/1996 to 12/31/2015 (cfs)
0.00	20,900	45,000
0.01	9,784	13,709
0.25	6,230	8,695
0.50	4,368	5,190
0.75	3,018	3,432
1.00	2,370	2,659
2.50	706	1,070
5.00	249	416
7.50	141	259
10.00	95	183
15.00	56	123
20.00	43	97
30.00	31	70
40.00	24	53
50.00	20	41
60.00	17	33
70.00	14	28
80.00	11	23
85.00	10	20
90.00	8	17
92.50	7	15
95.00	6	12
97.50	5	10
99.00	3	7
99.25	1	7
99.50	0	6
99.75	0	3
99.90	0	0
100.00	0	0

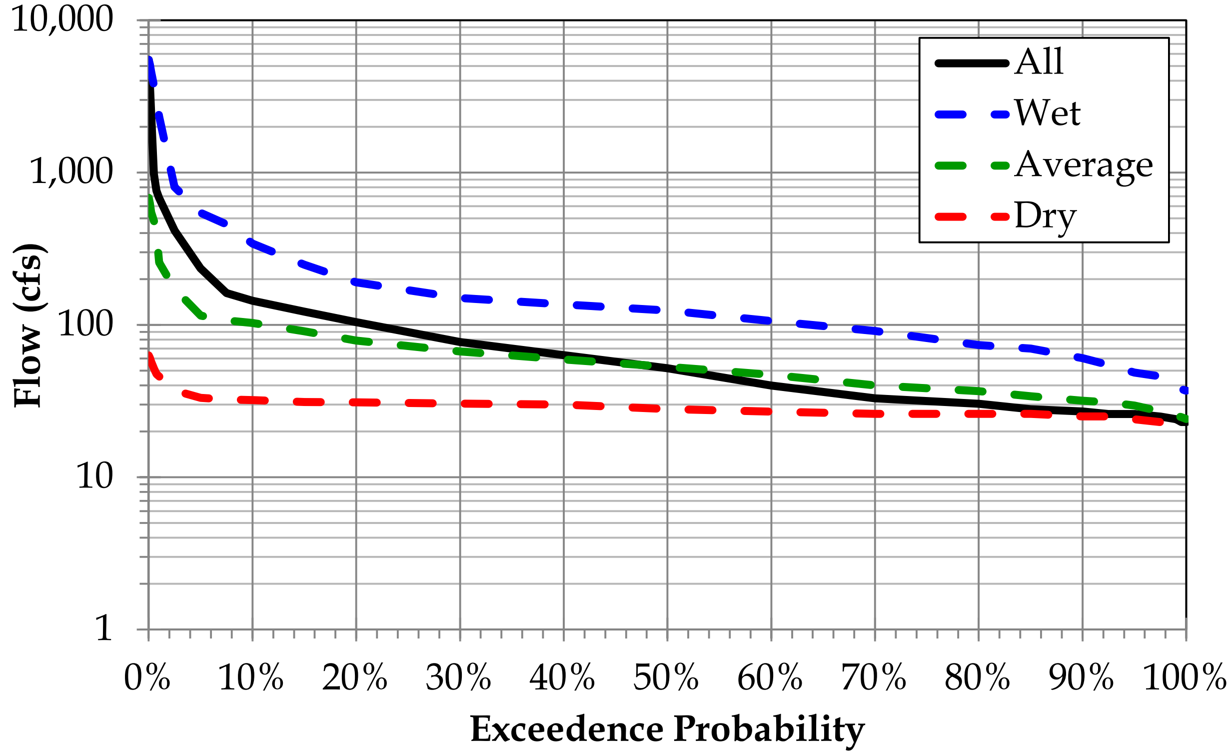


Figure A-3. January flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

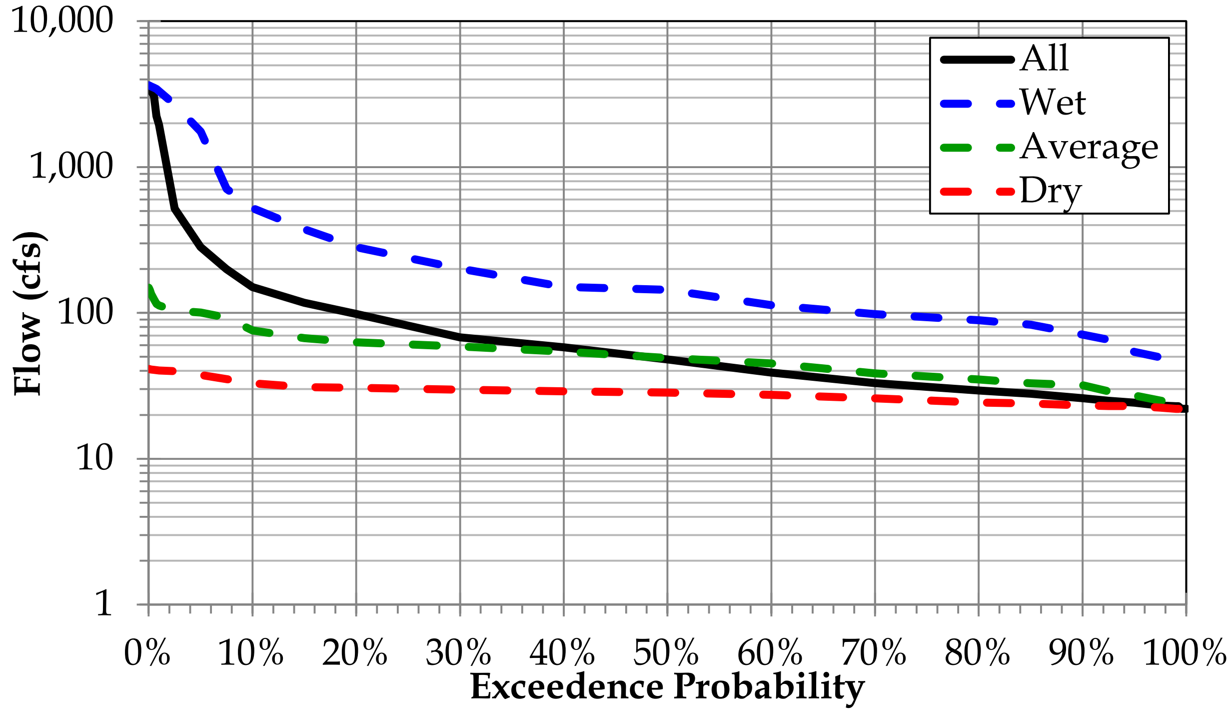


Figure A-4. February flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

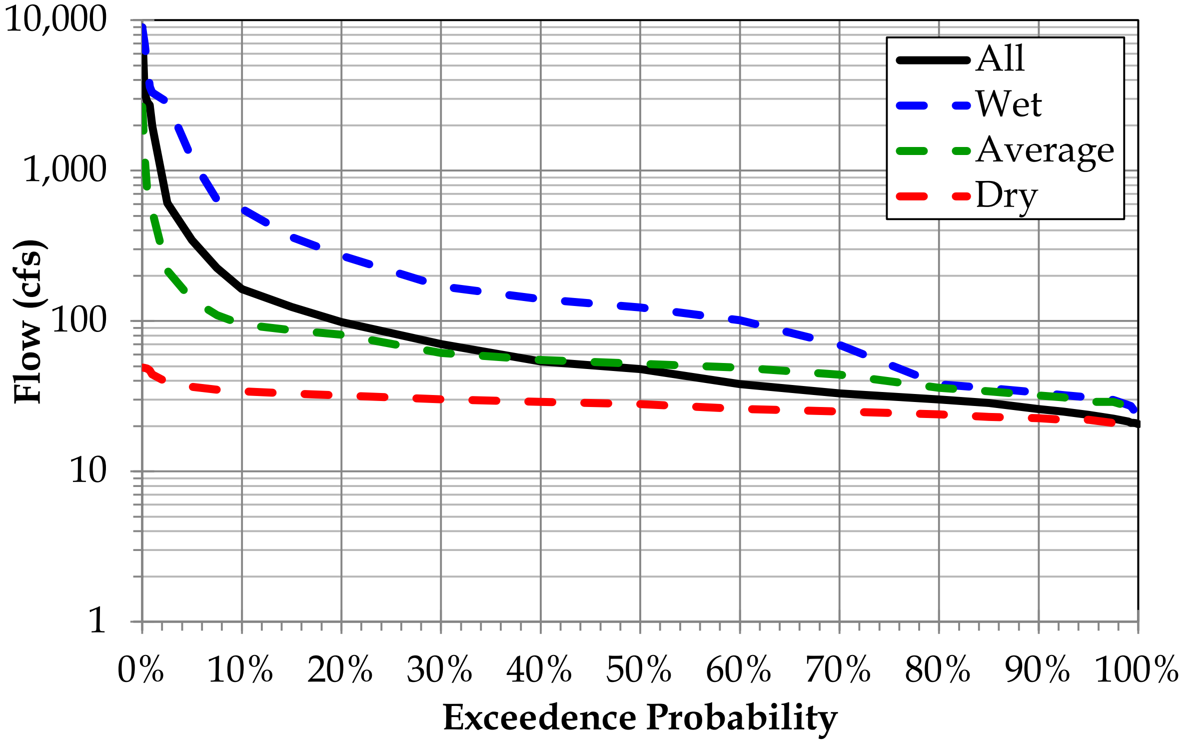


Figure A-5. March flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

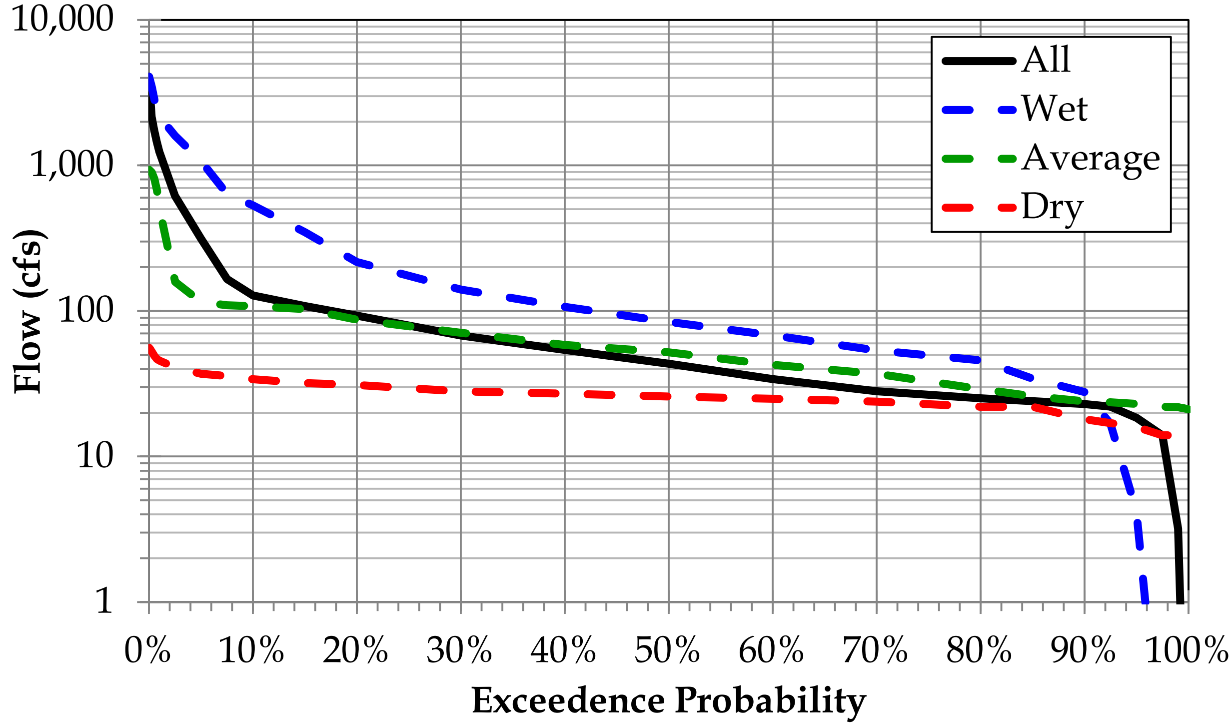


Figure A-6. April flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

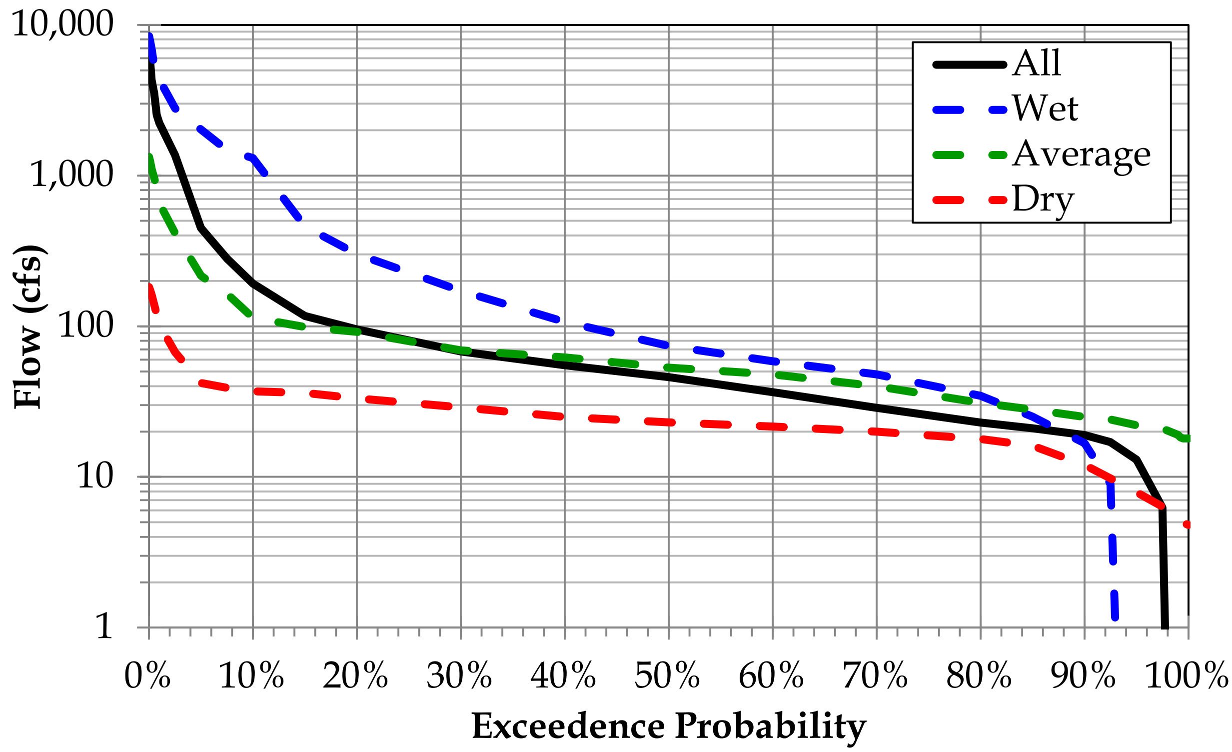


Figure A-7. May flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

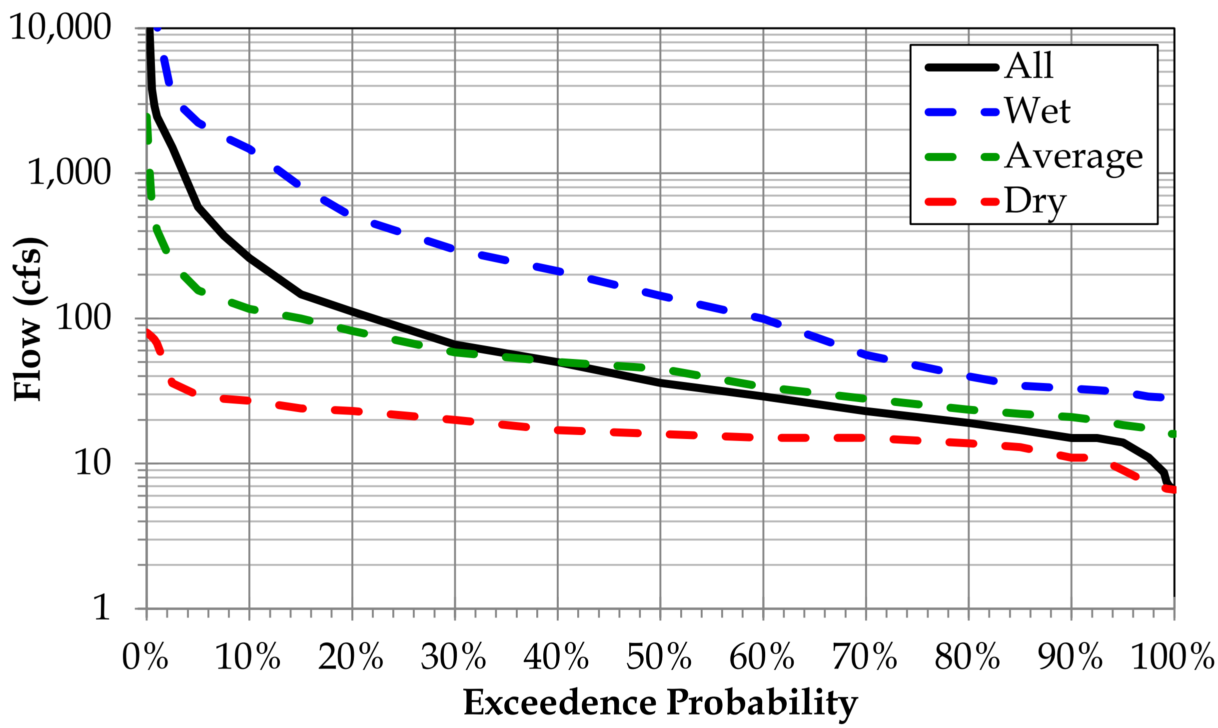


Figure A-8. June flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

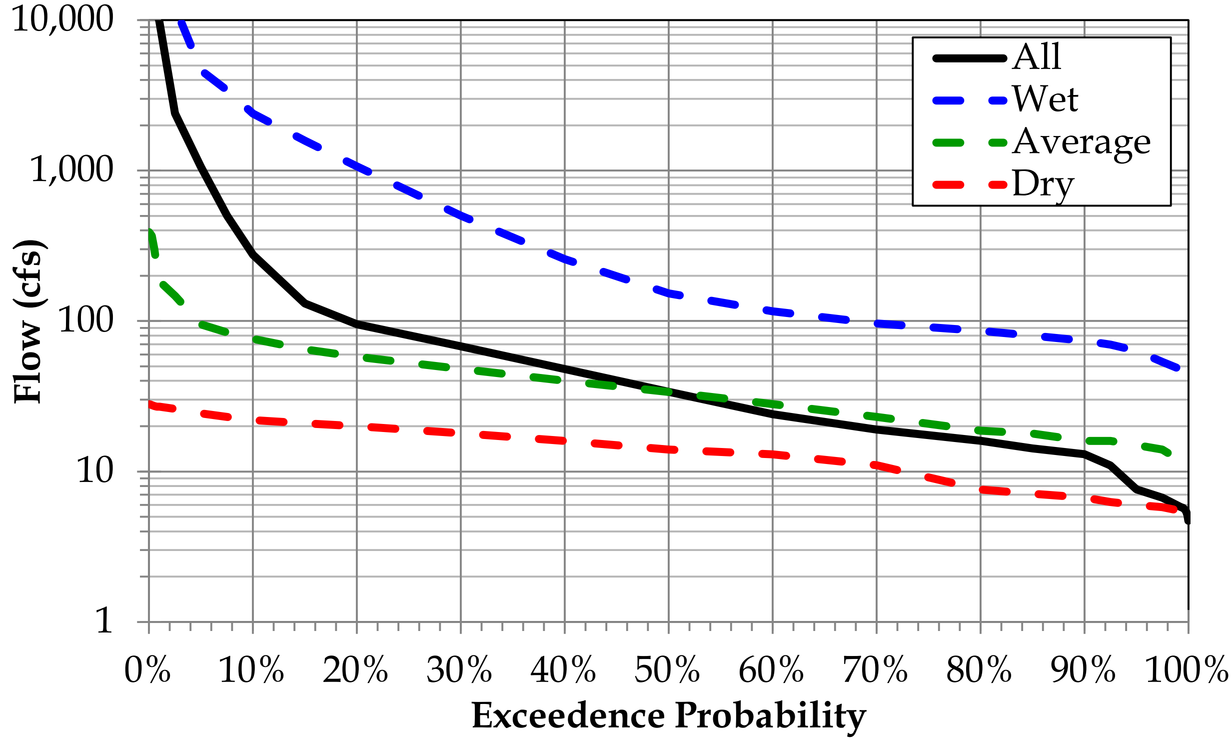


Figure A-9. July flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

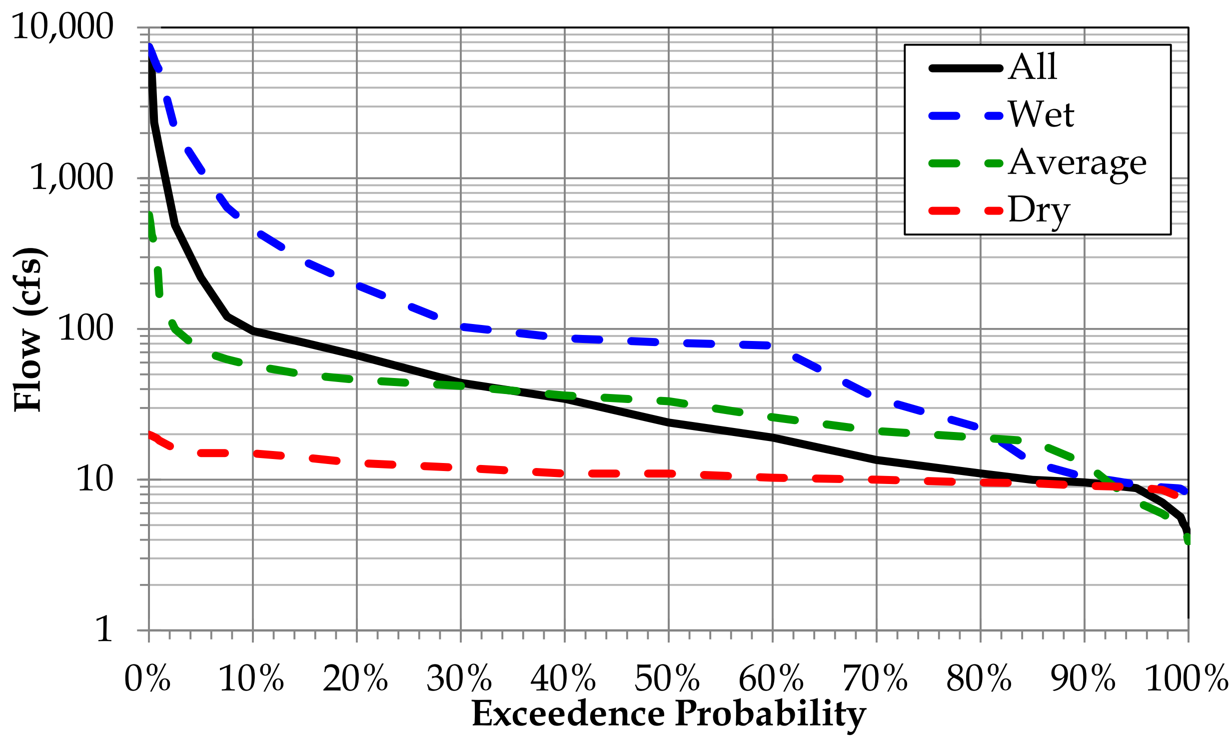


Figure A-10. August flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

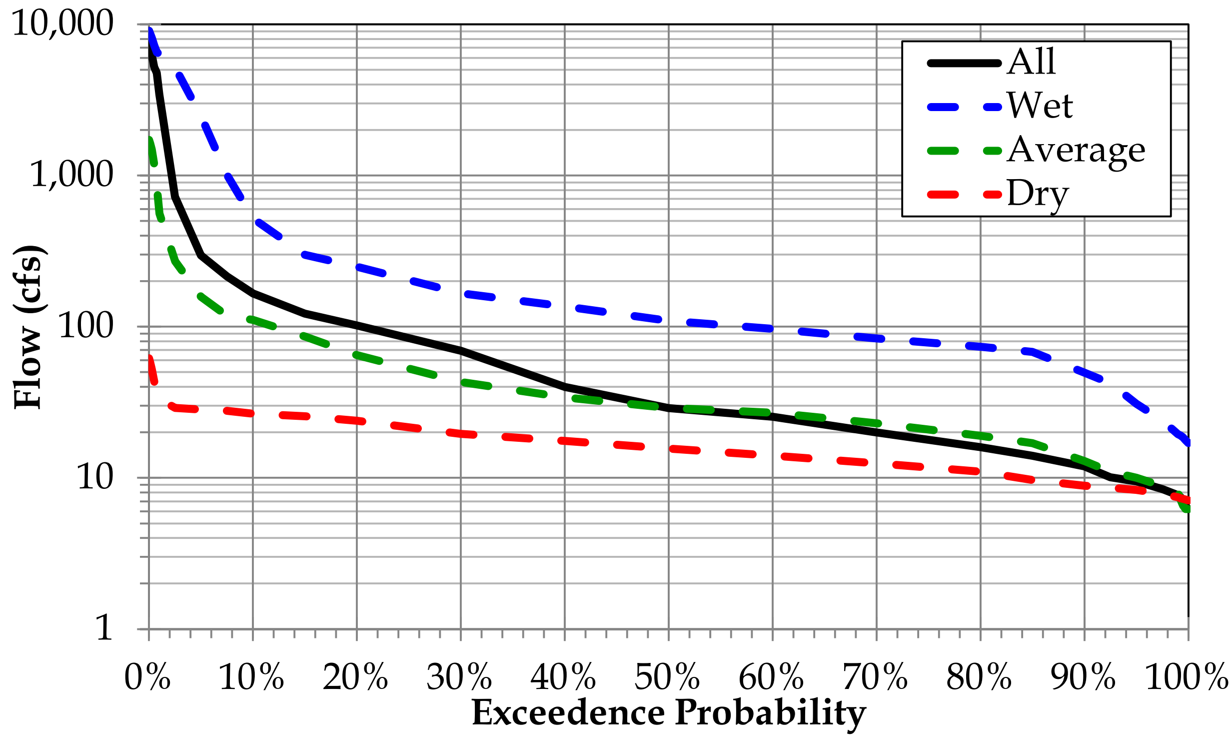


Figure A-11. September flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

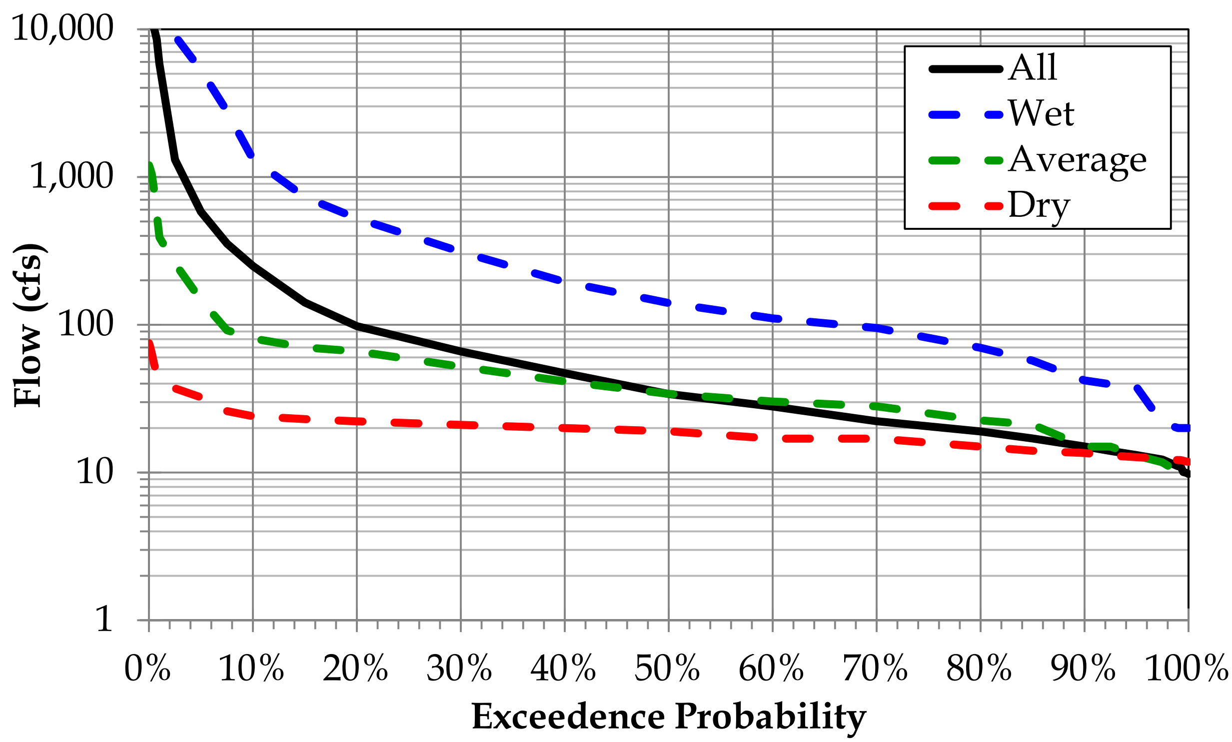


Figure A-12. October flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

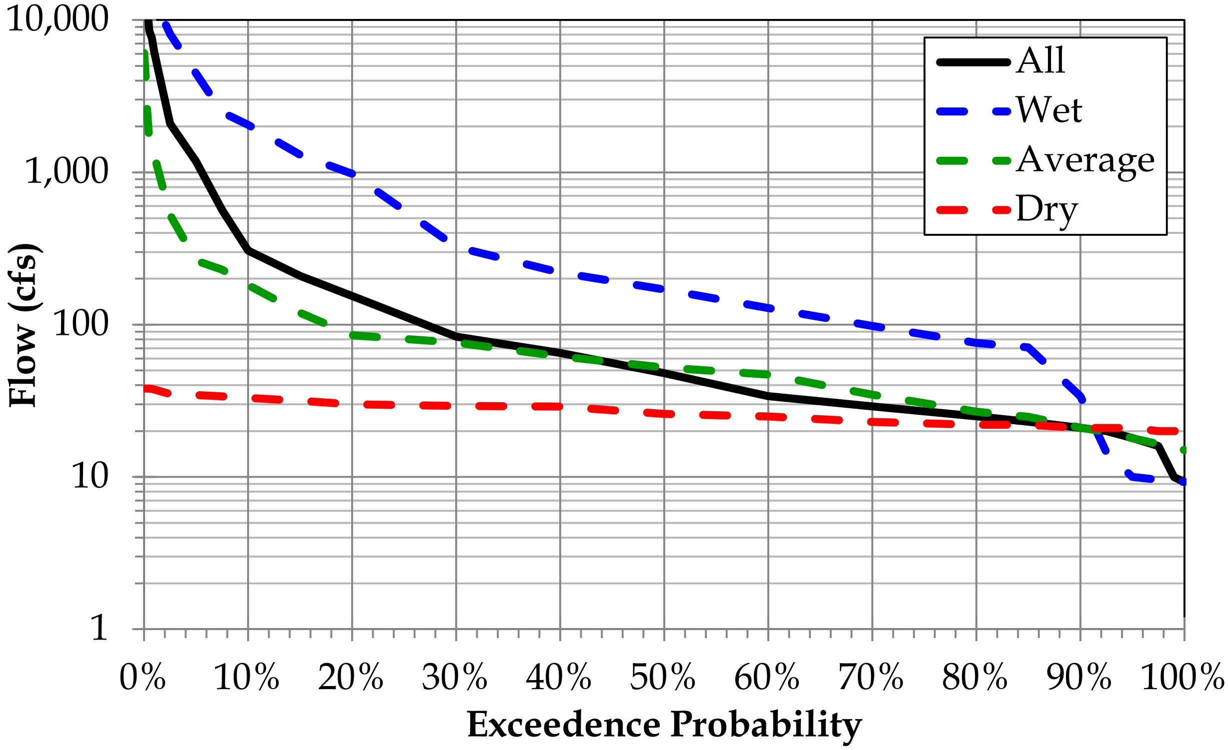


Figure A-13. November flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

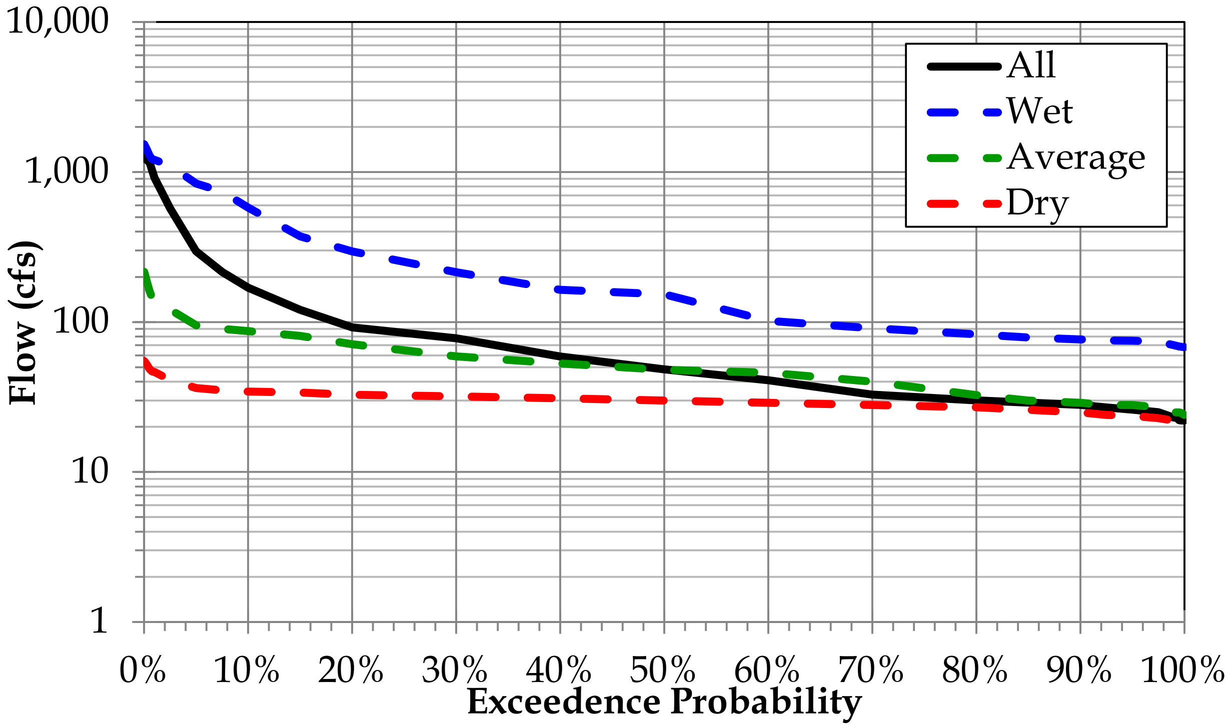


Figure A-14. December flow duration curves for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Table A-2. Monthly flow exceedance statistics for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	January*				February**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	5,490	63	682	5,490	3,640	41	149	3,640
0.01	4,042	61	628	5,130	3,527	41	143	3,612
0.25	2,323	57	548	4,589	3,309	41	135	3,570
0.50	978	51	480	3,688	3,104	41	124	3,500
0.75	761	47	393	2,916	2,236	40	116	3,424
1.00	684	46	257	2,335	1,956	40	113	3,312
2.50	416	37	173	805	518	40	104	2,690
5.00	235	33	115	543	283	38	101	1,750
7.50	162	32	107	457	200	35	93	709
10.00	144	32	103	341	151	33	76	523
15.00	122	31	91	249	117	31	67	374
20.00	104	31	79	190	98	31	63	283
30.00	77	30	67	150	68	30	59	201
40.00	63	30	59	136	58	29	54	151
50.00	52	28	53	124	48	28	49	144
60.00	40	27	47	106	39	28	45	113
70.00	33	26	40	91	33	26	39	98
80.00	30	26	37	74	29	24	35	89
85.00	28	26	34	70	28	24	33	83
90.00	27	25	32	60	26	23	32	71
92.50	26	25	31	55	25	23	29	66
95.00	26	24	30	49	24	23	27	54
97.50	25	23	27	46	23	22	25	50
99.00	24	23	25	39	23	22	24	45
99.25	24	23	25	38	23	22	24	44
99.50	23	23	25	38	22	22	24	44
99.75	23	23	24	37	22	22	24	43
99.90	23	23	24	37	22	22	23	43
100.00	23	23	24	37	22	22	23	43

*For January at this gage, Dry years were 1996, 1997, 2000, 2009 and 2014. Wet years were 2001, 2003, 2005, 2007, and 2010.

** For February at this gage, Dry years were 1996, 2009, 2013, 2014, and 2015. Wet years were 1998, 2003, 2005, 2010, and 2012.

Table A-2 (continued). Monthly flow exceedance statistics for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	March*				April**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	8,970	49	2,660	8,970	4,070	56	935	4,070
0.01	5,720	49	2,079	8,162	3,088	55	920	3,826
0.25	3,309	49	1,208	6,949	2,156	53	898	3,459
0.50	2,859	48	721	4,927	1,741	49	811	2,848
0.75	2,728	47	629	3,604	1,456	47	679	2,365
1.00	1,973	44	540	3,315	1,241	46	506	2,160
2.50	608	39	218	2,852	617	41	159	1,595
5.00	345	37	138	1,187	315	37	115	1,070
7.50	225	35	109	638	165	36	110	639
10.00	163	34	95	557	128	34	108	532
15.00	124	33	87	361	108	32	103	348
20.00	98	32	81	272	93	31	87	217
30.00	70	30	61	170	68	28	71	140
40.00	54	29	55	139	54	27	58	107
50.00	48	28	52	123	44	26	52	84
60.00	38	26	49	101	34	25	43	68
70.00	33	25	44	69	28	24	37	54
80.00	30	24	36	38	25	22	29	46
85.00	29	23	34	36	24	22	26	34
90.00	26	23	32	33	23	18	24	28
92.50	25	22	31	32	22	17	24	17
95.00	24	22	29	31	18	16	23	4
97.50	22	21	29	30	14	14	22	0
99.00	21	21	27	28	3	14	22	0
99.25	21	21	26	27	1	14	22	0
99.50	21	21	26	26	0	14	21	0
99.75	21	21	26	24	0	14	21	0
99.90	21	21	25	22	0	14	21	0
100.00	21	21	25	21	0	14	21	0

*For March at this gage, Dry years were 1996, 1997, 2009, 2013, and 2014. Wet years were 1998, 2003, 2005, 2007, and 2015.

** For April at this gage, Dry years were 1996, 1998, 2006, 2011, and 2014. Wet years were 1997, 2002, 2004, 2007, and 2015.

Table A-2 (continued). Monthly flow exceedance statistics for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	May*				June**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	8,410	182	1,330	8,410	13,500	80	2,450	13,500
0.01	5,866	173	1,237	7,777	13,380	79	1,926	13,470
0.25	4,300	160	1,098	6,828	10,444	77	1,140	13,426
0.50	3,509	138	955	5,245	3,799	75	616	13,351
0.75	2,524	118	820	4,300	2,893	72	502	12,626
1.00	2,232	102	651	4,300	2,452	68	408	10,487
2.50	1,367	67	414	2,784	1,503	36	236	3,302
5.00	448	42	216	2,018	585	30	156	2,228
7.50	281	39	164	1,477	371	28	134	1,790
10.00	191	37	114	1,308	260	27	116	1,473
15.00	117	36	99	458	147	24	100	810
20.00	95	33	92	302	111	23	82	502
30.00	68	29	69	172	66	20	58	298
40.00	55	25	62	107	50	17	50	212
50.00	46	23	53	74	36	16	45	144
60.00	37	22	48	59	29	15	34	99
70.00	29	20	40	48	23	15	28	56
80.00	23	18	31	35	19	14	24	40
85.00	21	16	28	25	17	13	22	34
90.00	19	12	25	17	15	11	21	33
92.50	17	10	24	9	15	11	20	32
95.00	13	8	22	0	14	9	18	31
97.50	6	6	21	0	11	7	17	29
99.00	0	5	19	0	9	7	17	28
99.25	0	5	18	0	8	7	17	28
99.50	0	5	18	0	7	7	16	28
99.75	0	5	18	0	7	7	16	28
99.90	0	5	18	0	7	7	16	28
100.00	0	5	18	0	7	7	16	28

*For May at this gage, Dry years were 1996, 1998, 2000, 2008, and 2011. Wet years were 2004, 2007, 2012, 2014, and 2015.

** For June at this gage, Dry years were 1996, 1998, 2009, 2011, and 2012. Wet years were 1997, 1999, 2004, 2007, and 2015.

Table A-2 (continued). Monthly flow exceedance statistics for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	July*				August**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	18,900	28	390	18,900	7,450	20	571	7,450
0.01	17,414	28	381	18,530	6,367	20	511	7,181
0.25	16,062	28	368	17,976	5,207	20	422	6,776
0.50	13,619	27	300	17,052	2,339	19	375	6,102
0.75	11,386	27	228	16,376	1,924	19	307	5,561
1.00	9,813	27	184	16,068	1,571	18	164	5,214
2.50	2,395	26	147	12,185	490	16	100	2,090
5.00	1,062	24	95	4,644	219	15	72	1,131
7.50	501	23	84	3,425	121	15	63	643
10.00	276	22	76	2,396	97	15	57	459
15.00	131	21	65	1,578	81	14	50	279
20.00	95	20	58	1,066	67	13	46	196
30.00	68	18	48	503	44	12	42	104
40.00	48	16	40	257	34	11	36	87
50.00	34	14	34	153	24	11	33	81
60.00	24	13	28	116	19	10	26	78
70.00	19	11	23	96	13	10	21	35
80.00	16	8	19	86	11	10	19	22
85.00	14	7	18	80	10	10	18	13
90.00	13	7	16	74	10	9	13	10
92.50	11	6	16	70	9	9	9	10
95.00	8	6	15	63	9	9	7	9
97.50	7	6	14	53	7	9	6	9
99.00	6	6	12	49	6	8	5	9
99.25	6	5	12	48	6	8	5	9
99.50	6	5	12	47	5	7	5	9
99.75	6	5	12	46	5	7	5	8
99.90	5	5	12	45	4	7	4	8
100.00	5	5	12	45	4	7	4	8

*For July at this gage, Dry years were 1996, 1998, 2000, 2009, and 2011. Wet years were 1997, 2002, 2003, 2004, and 2007.

** For August at this gage, Dry years were 2000, 2006, 2009, 2011, and 2013. Wet years were 2001, 2002, 2003, 2007, and 2008.

Table A-2 (continued). Monthly flow exceedance statistics for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	September*				October**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	9,060	62	1,720	9,060	45,000	75	1,200	45,000
0.01	7,568	58	1,627	8,689	34,167	71	1,138	42,305
0.25	6,386	52	1,488	8,132	18,466	64	1,045	38,263
0.50	5,205	43	1,170	7,205	10,065	53	794	31,525
0.75	4,776	36	836	6,527	8,523	47	550	24,943
1.00	3,439	33	560	6,389	5,882	45	389	18,590
2.50	725	29	271	5,171	1,310	37	259	8,993
5.00	296	28	157	2,470	582	32	147	5,268
7.50	215	28	118	1,009	353	26	92	2,792
10.00	166	27	111	520	249	24	81	1,318
15.00	122	26	86	299	141	23	70	729
20.00	102	24	65	249	98	22	66	526
30.00	69	20	43	167	66	21	52	312
40.00	40	18	34	136	47	20	41	194
50.00	29	16	29	110	34	19	34	140
60.00	25	14	27	97	28	17	30	111
70.00	20	12	23	84	22	17	28	95
80.00	16	11	19	74	19	15	23	70
85.00	14	10	17	68	17	14	21	57
90.00	12	9	13	50	15	14	15	42
92.50	10	9	11	42	14	13	15	40
95.00	9	8	10	31	13	13	13	38
97.50	8	8	9	24	12	12	12	22
99.00	8	7	8	19	11	12	10	20
99.25	7	7	7	19	11	12	10	20
99.50	7	7	7	18	10	12	10	20
99.75	7	7	6	18	10	12	10	20
99.90	6	7	6	17	10	12	10	20
100.00	6	7	6	17	10	12	10	20

*For September at this gage, Dry years were 1999, 2000, 2011, 2014, and 2015. Wet years were 2001, 2002, 2003, 2007, and 2010.

** For October at this gage, Dry years were 1996, 1999, 2008, 2011, and 2014. Wet years were 1998, 2002, 2003, 2004, and 2009.

Table A-2 (continued). Monthly flow exceedance statistics for USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	November*				December**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	20,200	38	6,070	20,200	1,530	55	216	1,530
0.01	17,085	38	4,722	19,425	1,338	54	204	1,482
0.25	13,358	38	2,699	18,263	1,204	52	185	1,411
0.50	8,466	38	1,525	16,326	1,171	49	161	1,291
0.75	7,610	38	1,434	14,612	1,039	47	145	1,215
1.00	6,082	38	1,262	13,383	917	46	136	1,204
2.50	2,091	35	523	8,059	573	41	121	1,104
5.00	1,181	35	263	4,441	296	36	95	839
7.50	563	34	229	2,480	216	35	90	742
10.00	306	33	182	2,054	169	34	87	579
15.00	208	32	119	1,302	120	34	81	373
20.00	154	30	85	979	92	33	71	296
30.00	83	29	76	323	78	32	59	215
40.00	65	29	62	220	59	31	53	164
50.00	48	26	52	170	48	30	48	153
60.00	34	25	47	128	41	29	46	102
70.00	29	23	35	98	33	28	40	91
80.00	25	22	27	76	30	27	33	83
85.00	23	22	25	71	29	26	30	79
90.00	21	21	21	34	28	25	29	76
92.50	20	21	20	15	27	24	28	76
95.00	18	21	18	10	26	24	28	75
97.50	16	20	16	10	25	23	27	74
99.00	10	20	16	9	23	22	25	70
99.25	10	20	16	9	23	22	25	69
99.50	10	20	15	9	22	22	25	69
99.75	9	20	15	9	22	22	25	68
99.90	9	20	15	9	22	22	24	68
100.00	9	20	15	9	22	22	24	68

*For November at this gage, Dry years were 1999, 2005, 2006, 2008, and 2012. Wet years were 2000, 2001, 2002, 2004, and 2009.

** For December at this gage, Dry years were 1996, 1999, 2008, 2012, and 2013. Wet years were 1998, 2001, 2002, 2004, and 2009.

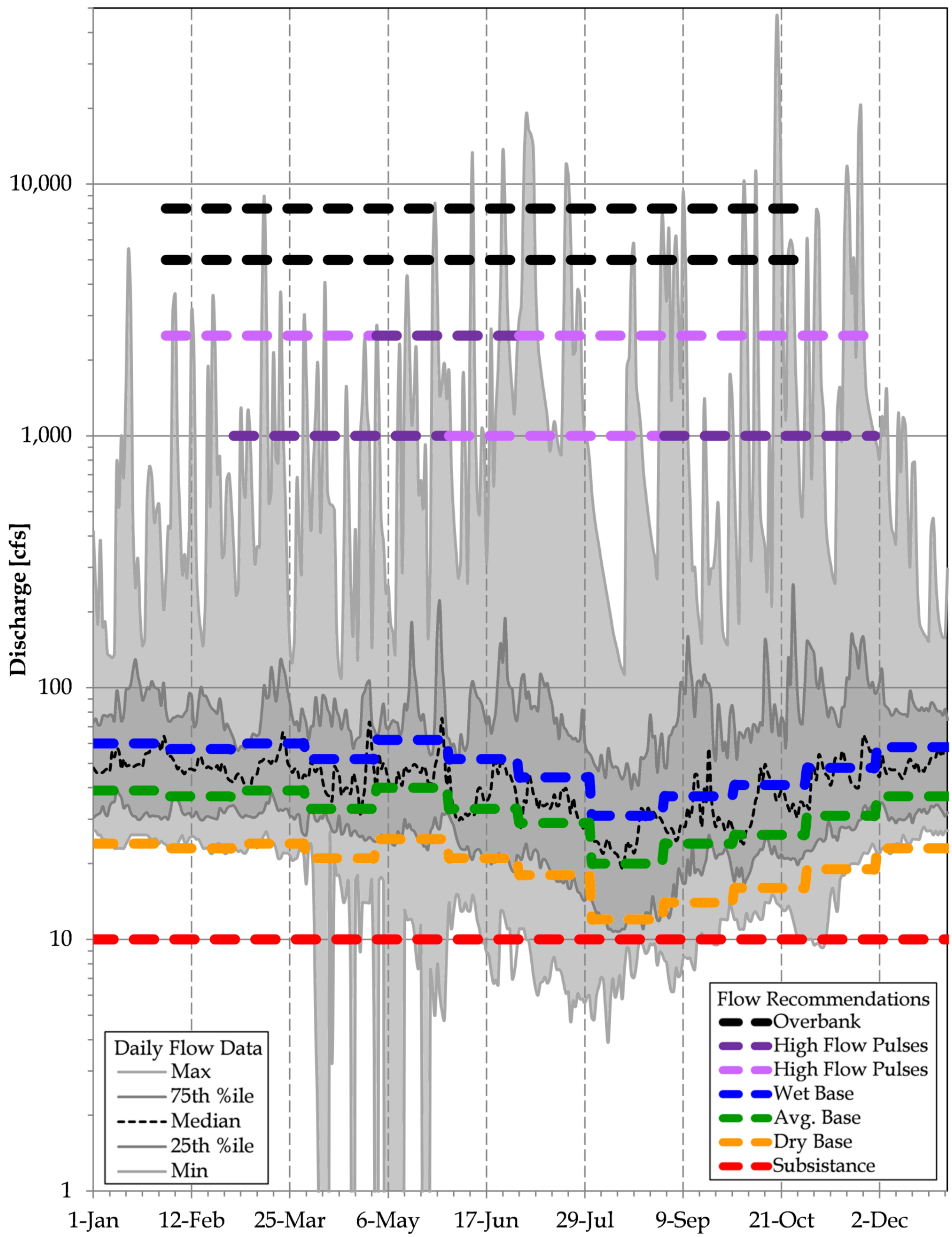


Figure A-15. Instream flow recommendations for the Cibolo Creek Study Site versus flow data from USGS Gage No. 08186000 Cibolo Creek near Falls City, Texas for 1996 to 2015.

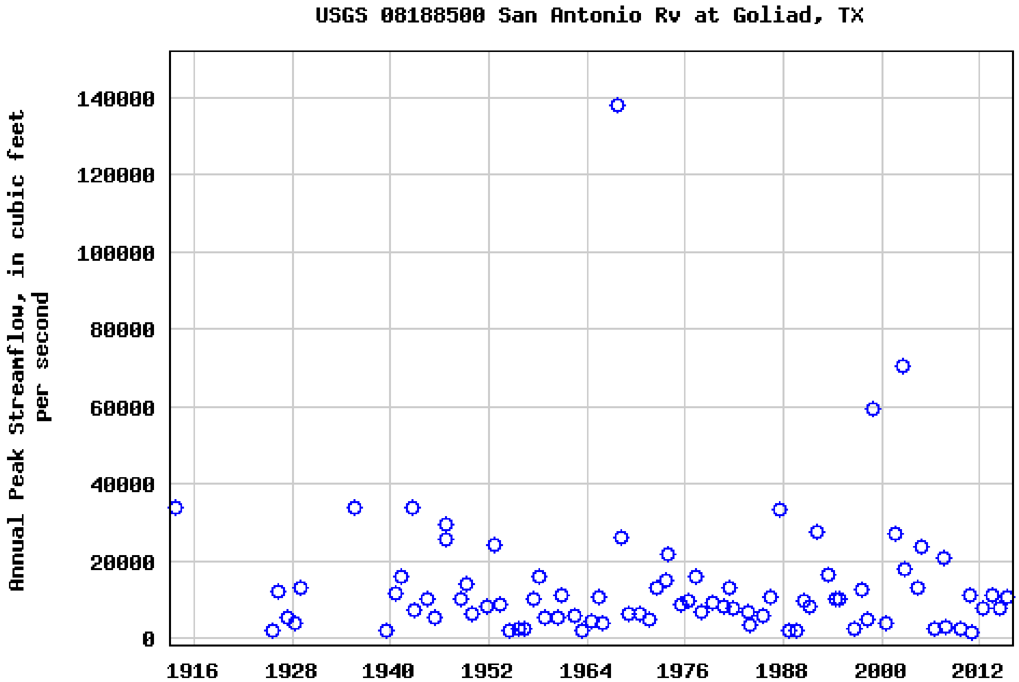


Figure A-16. Annual peak streamflow at USGS Gage No. 08188500 San Antonio River at Goliad, Texas.

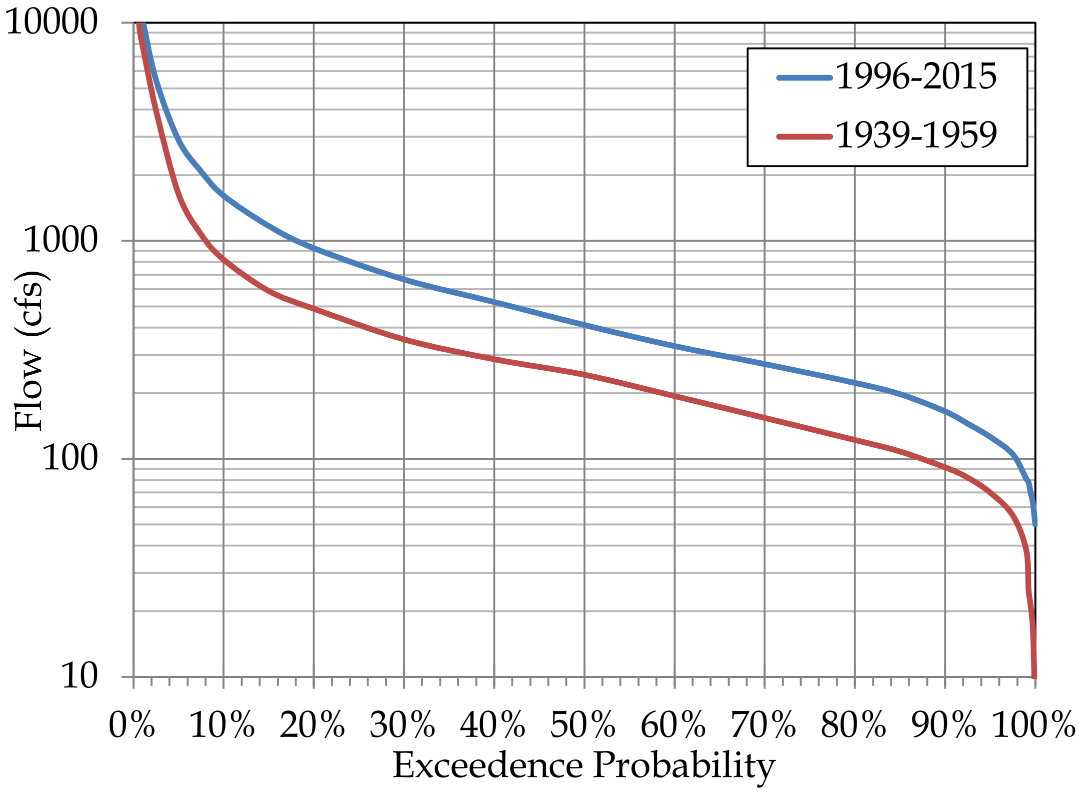


Figure A-17. Flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for an early (March 1939-February 1959) and late (1996-2015) time period.

Table A-3. Flow exceedance statistics for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for an early (March 1939-February 1959) and late (1996-2015) time period.

Exceedence Probability (%)	Time Period 3/1/1939 to 2/28/1959 (cfs)	1/1/1996 to 12/31/2015 (cfs)
0.00	32,000	62,000
0.01	23,339	32,702
0.25	14,900	17,074
0.50	10,992	14,148
0.75	8,891	11,822
1.00	7,886	10,396
2.50	3,968	5,470
5.00	1,640	2,900
7.50	1,070	2,080
10.00	820	1,610
15.00	589	1,170
20.00	488	925
30.00	353	665
40.00	286	524
50.00	243	411
60.00	194	329
70.00	154	272
80.00	122	223
85.00	108	198
90.00	91	165
92.50	82	145
95.00	70	126
97.50	55	105
99.00	38	81
99.25	25	78
99.50	21	70
99.75	16	62
99.90	9	54
100.00	2	50

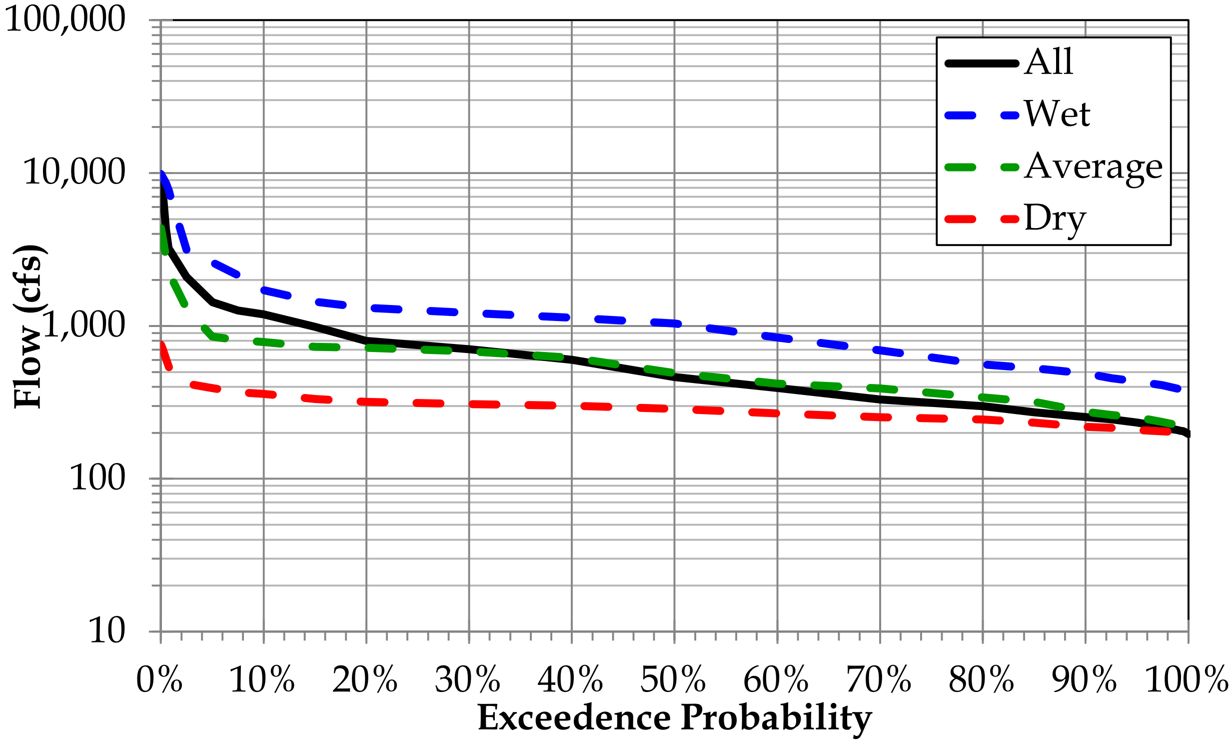


Figure A-18. January flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

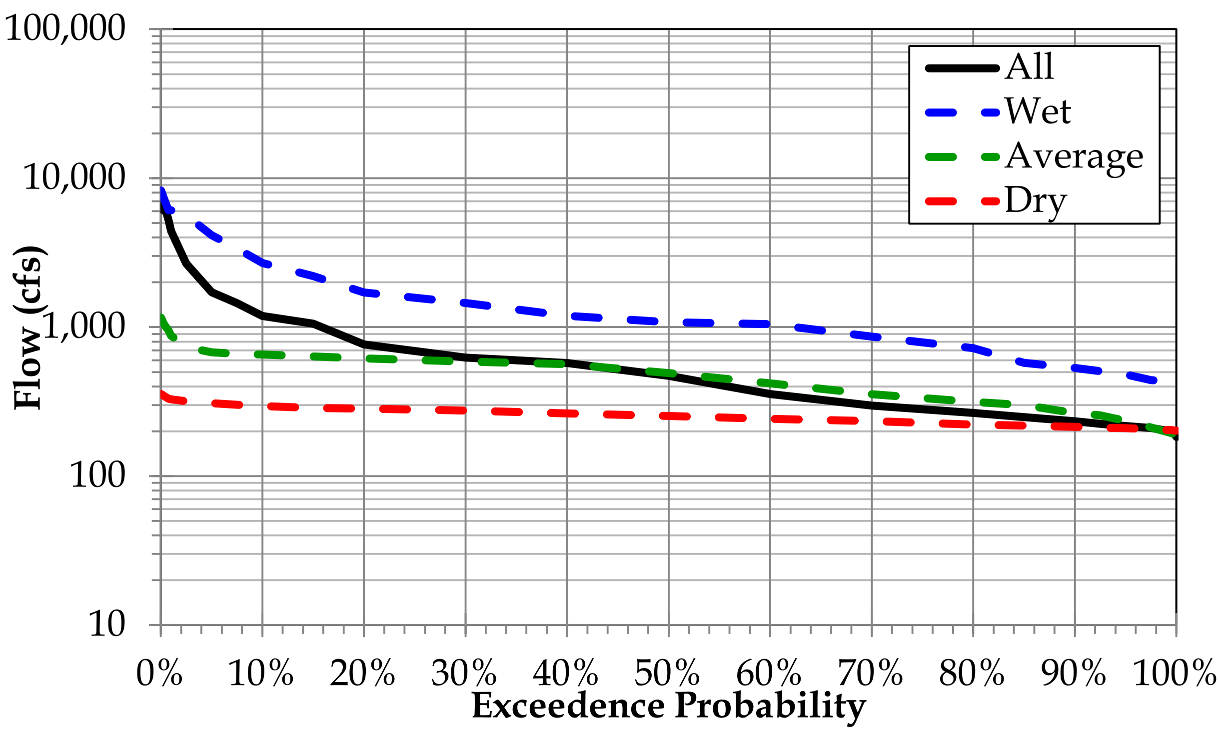


Figure A-19. February flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

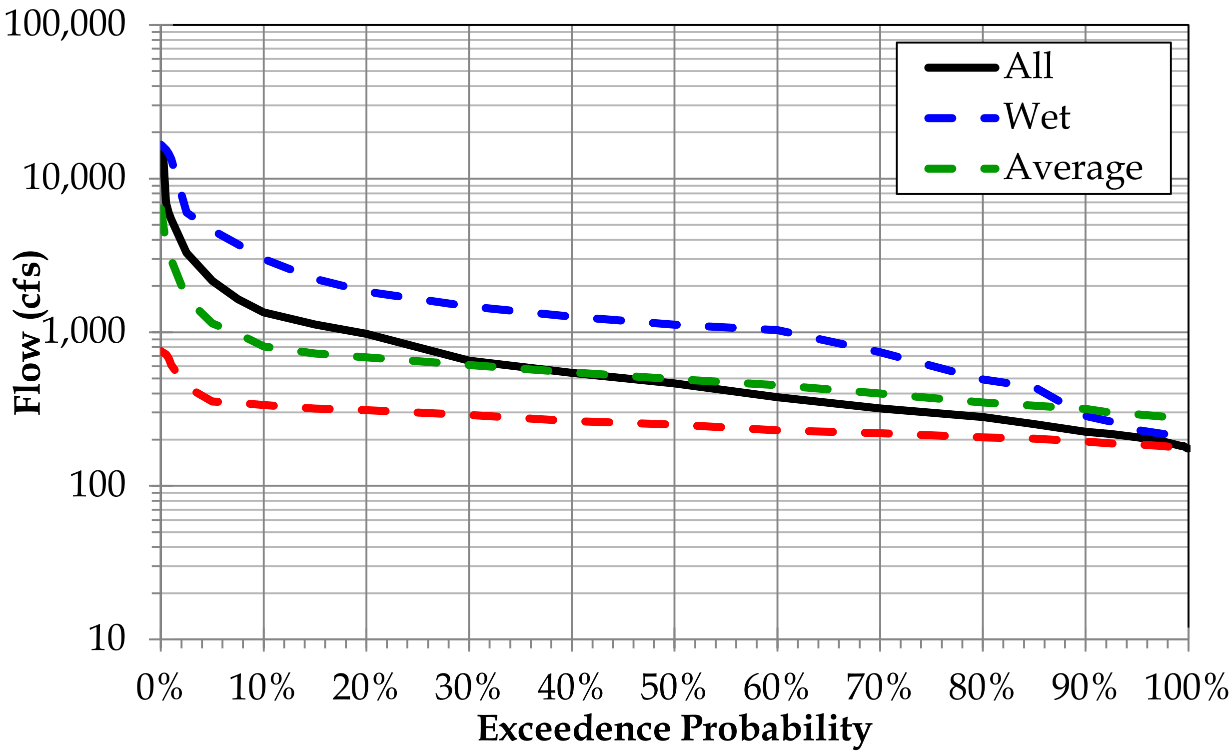


Figure A-20. March flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. “Wet” data from five wettest, “Average” data from ten central tendency, and “Dry” data from five driest months by volume.

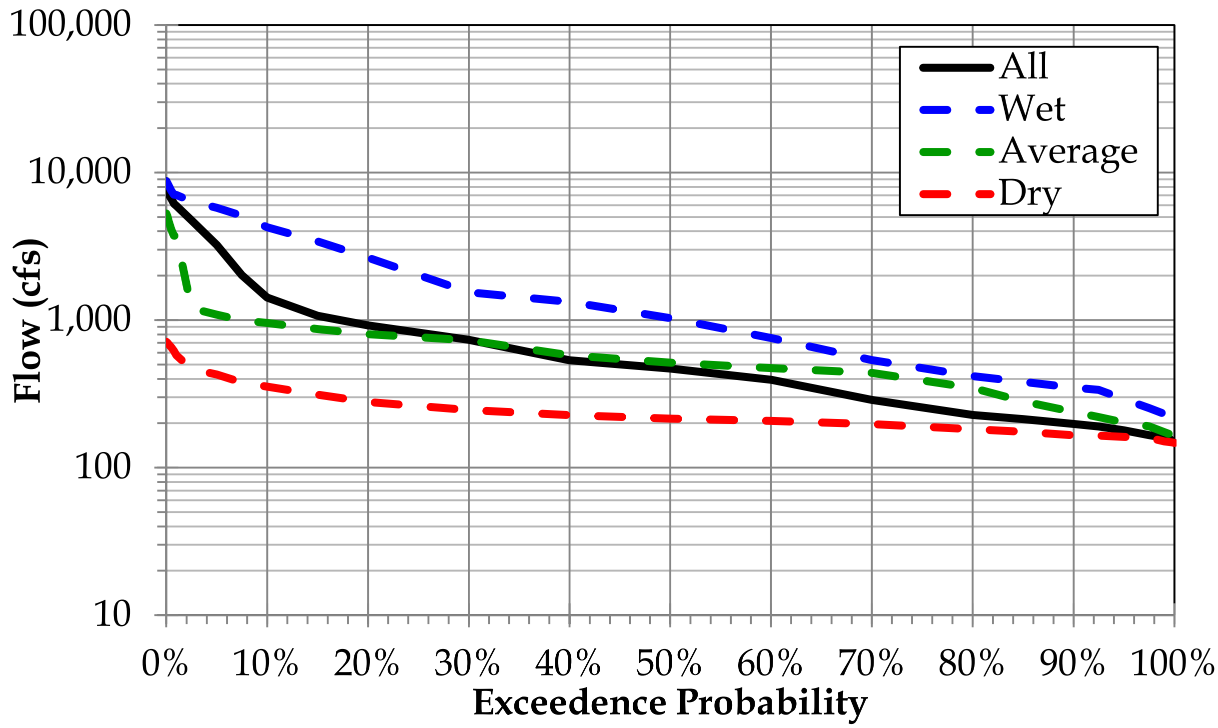


Figure A-21. April flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. “Wet” data from five wettest, “Average” data from ten central tendency, and “Dry” data from five driest months by volume.

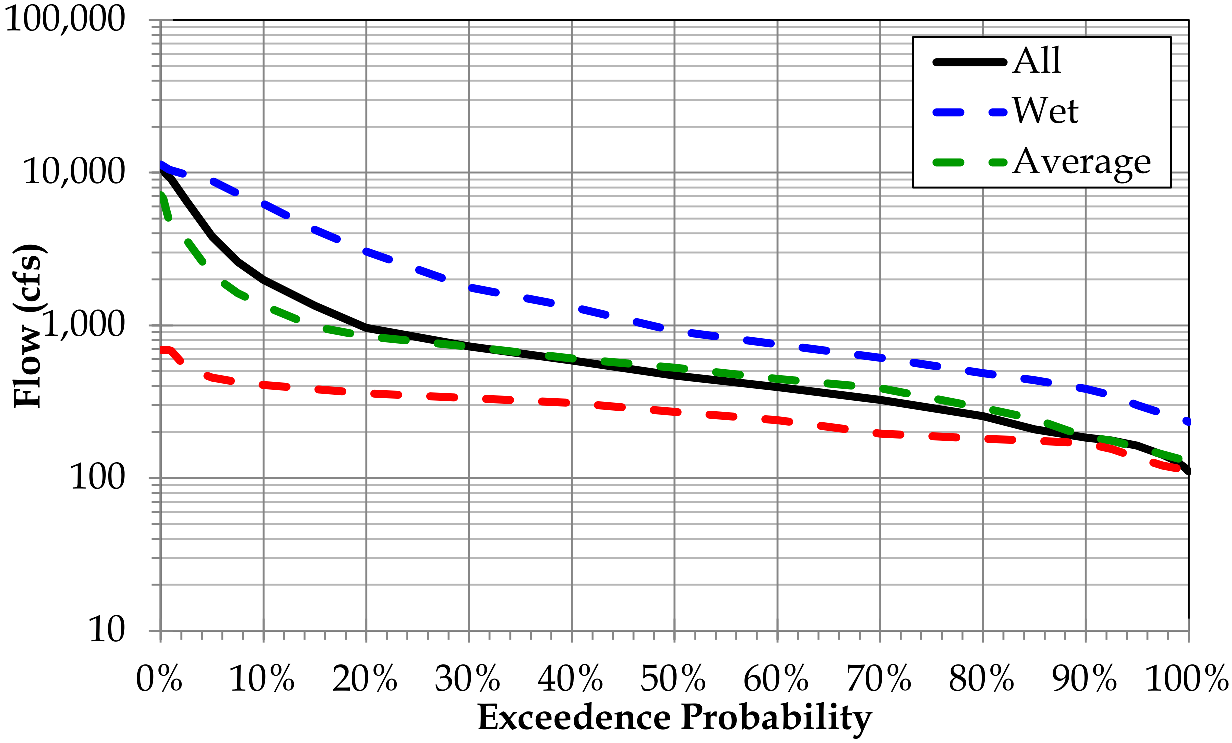


Figure A-22. May flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

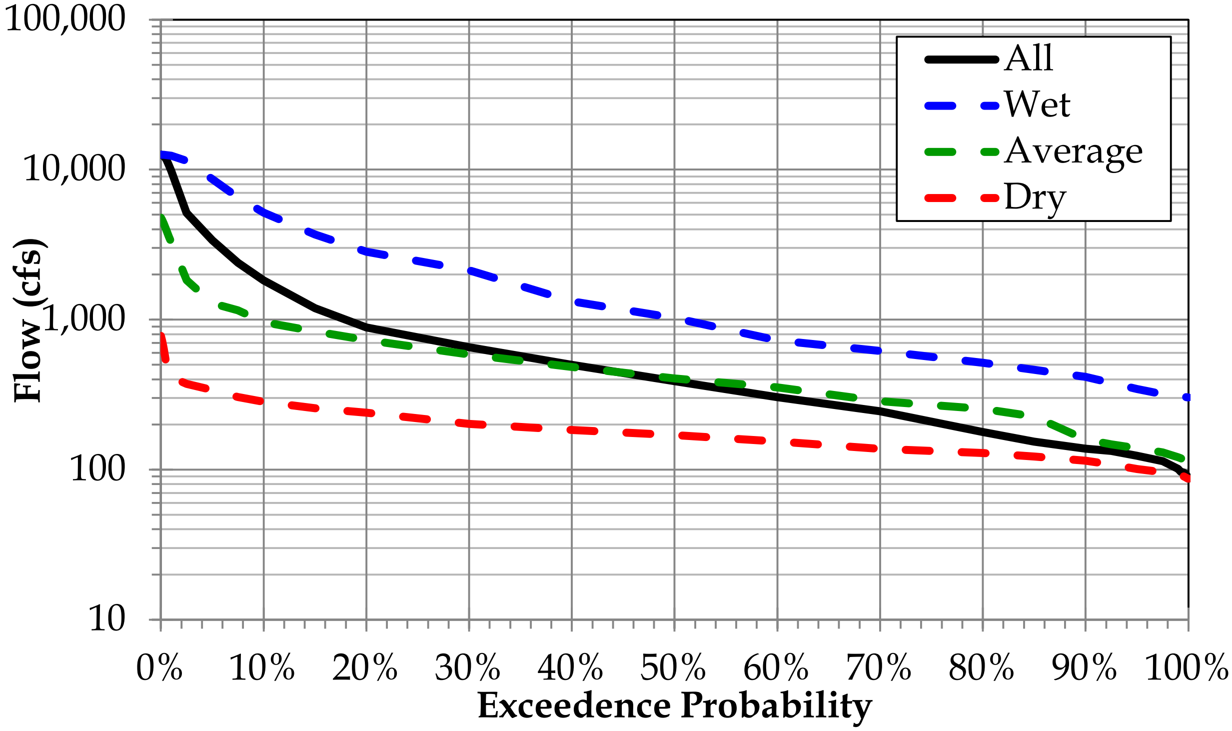


Figure A-23. June flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

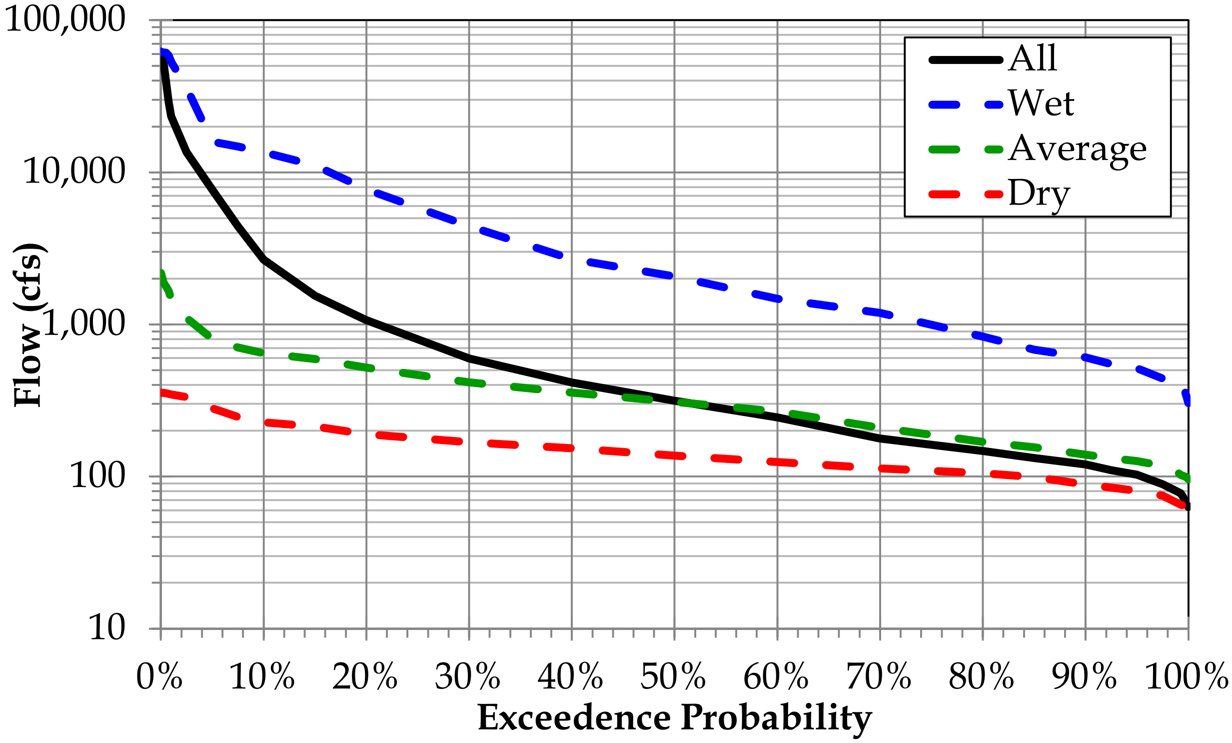


Figure A-24. July flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

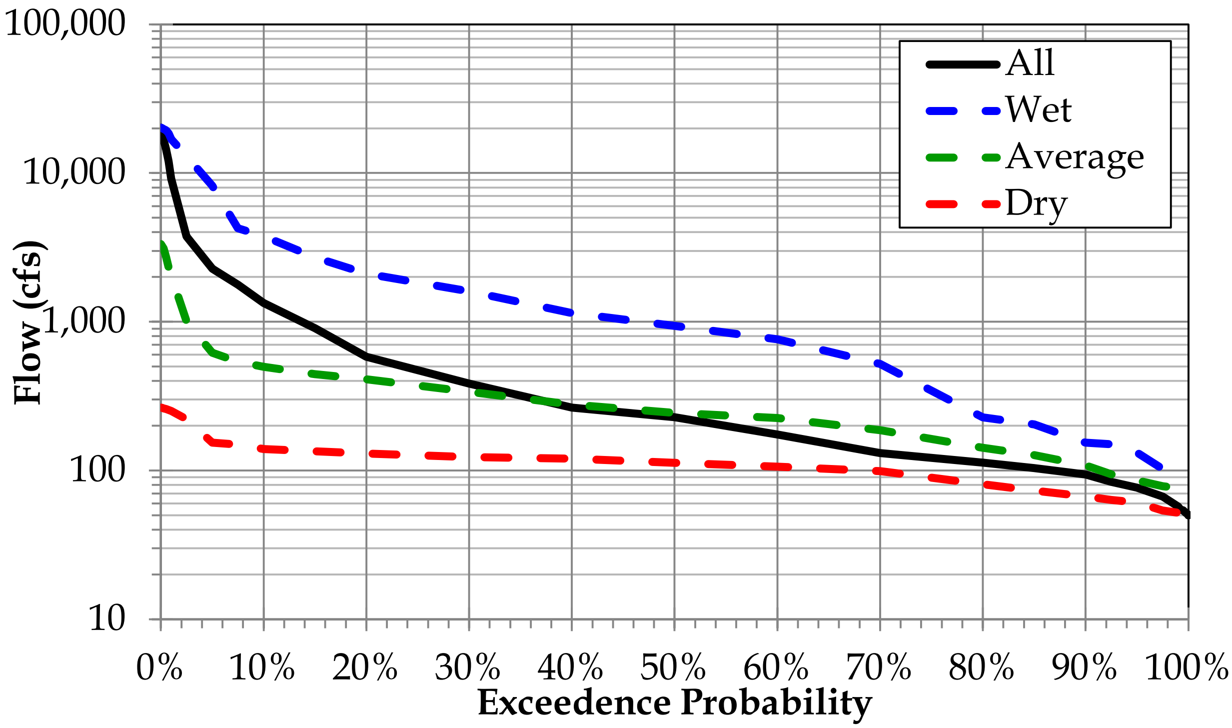


Figure A-25. August flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

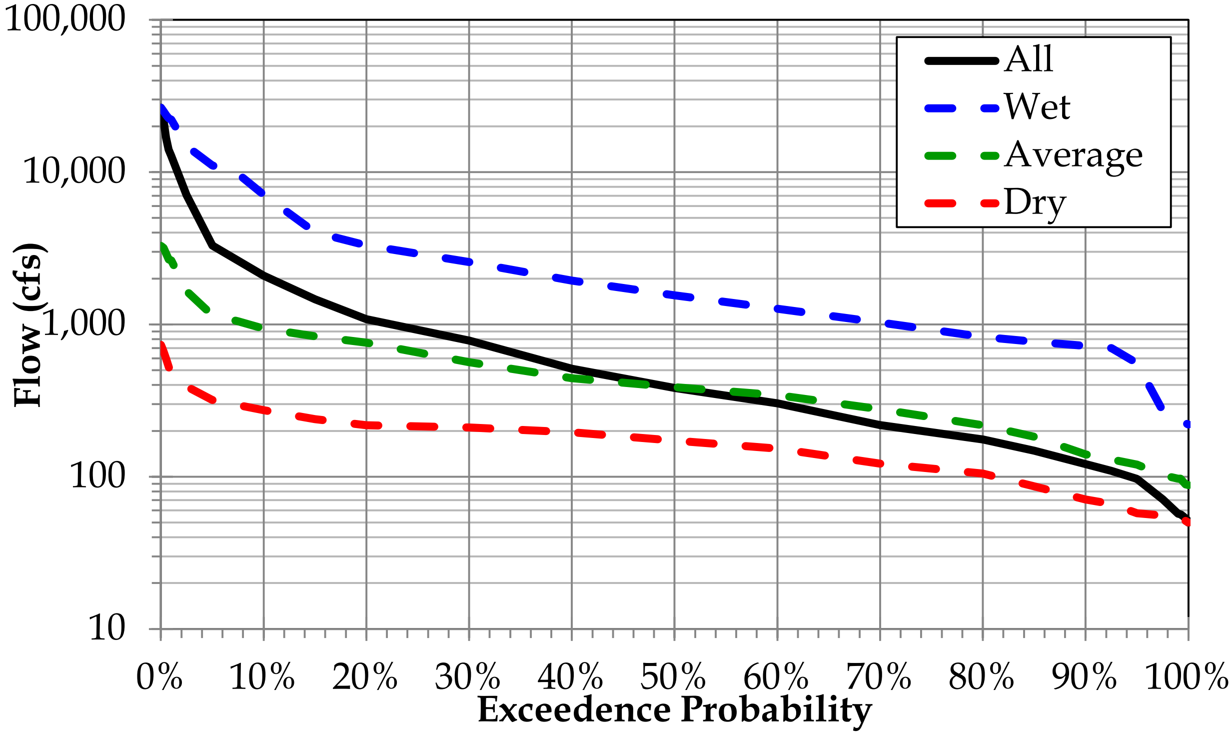


Figure A-26. September flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

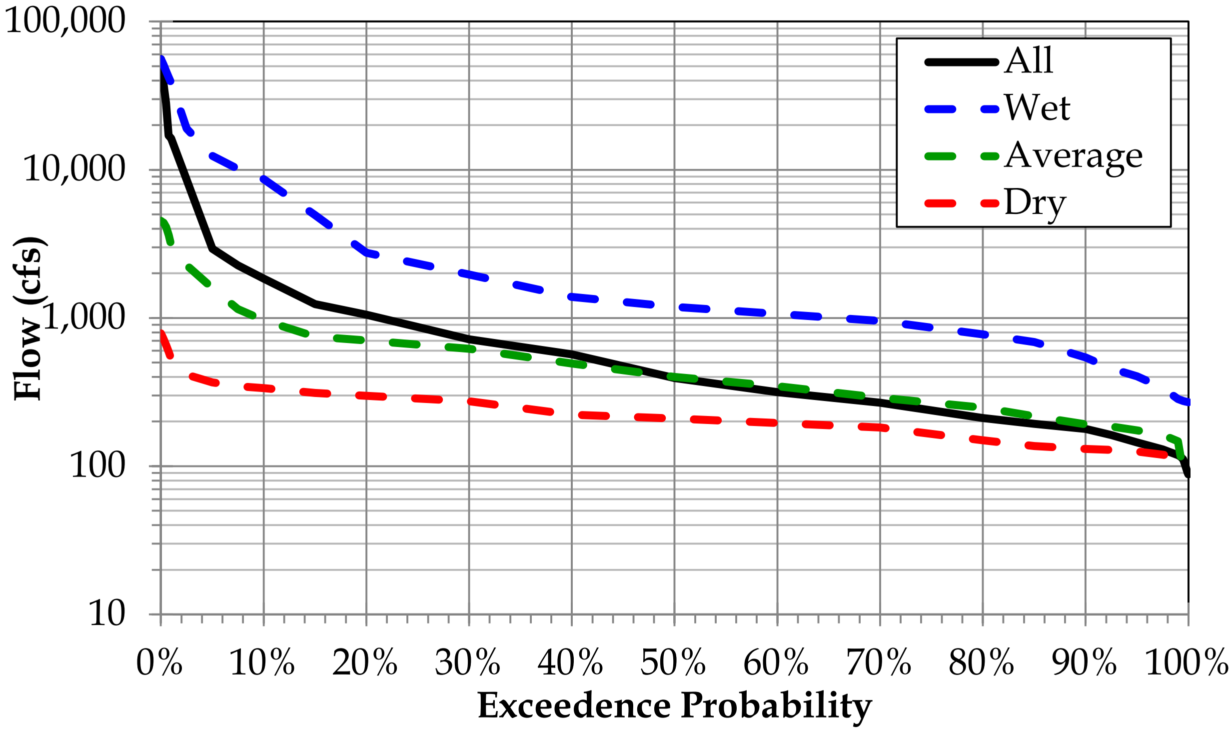


Figure A-27. October flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

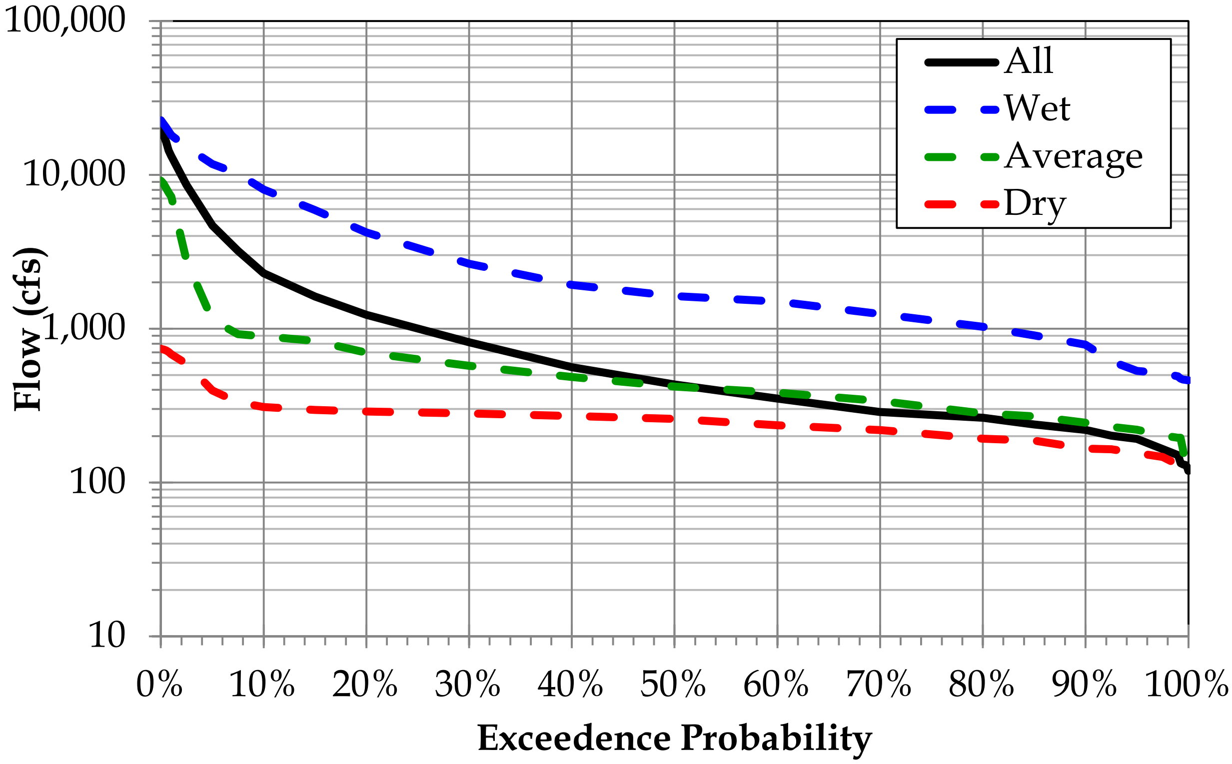


Figure A-28. November flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

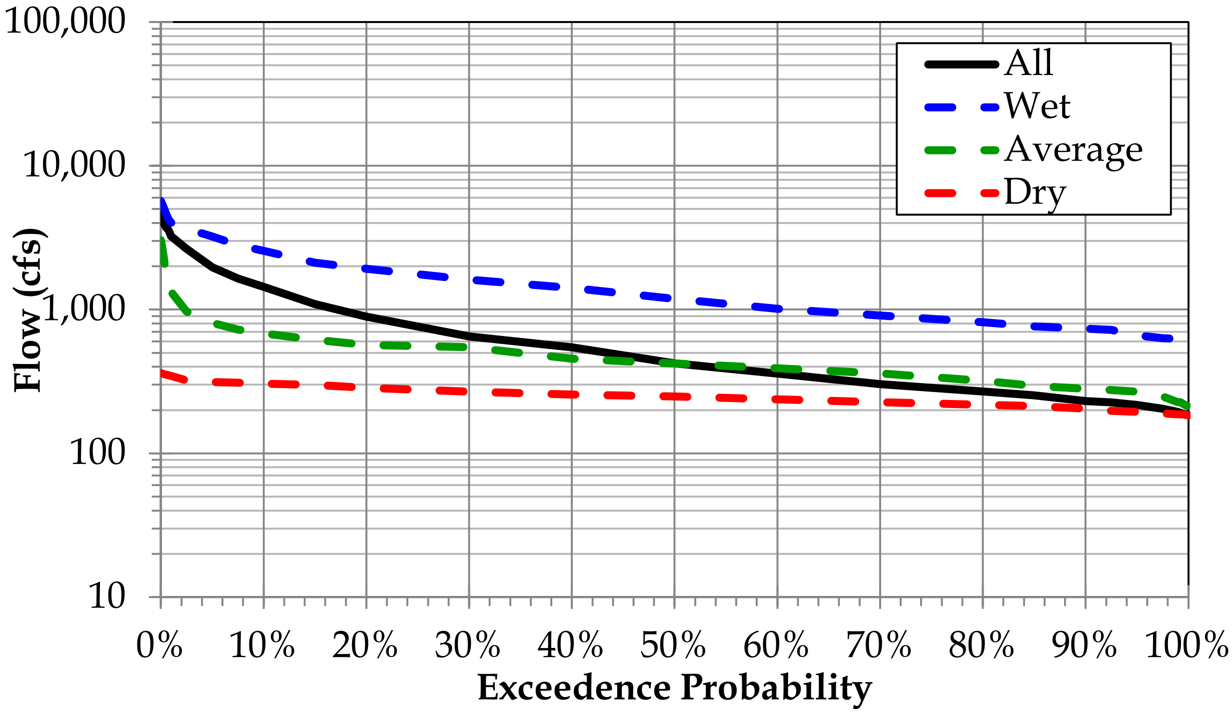


Figure A-29. December flow duration curves for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Table A-4. Monthly flow exceedance statistics for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	January*				February**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	9,850	755	4,360	9,850	8,270	356	1,160	8,270
0.01	8,779	725	4,008	9,584	7,046	353	1,123	7,966
0.25	6,669	680	3,479	9,184	6,084	348	1,068	7,511
0.50	4,252	605	2,773	8,518	5,978	339	1,003	6,751
0.75	3,207	540	2,298	7,709	5,215	332	952	6,098
1.00	3,036	491	2,066	6,689	4,408	328	876	6,084
2.50	2,091	420	1,294	3,132	2,670	318	733	5,645
5.00	1,431	391	853	2,603	1,710	309	677	4,150
7.50	1,260	367	808	2,150	1,447	301	661	3,375
10.00	1,190	360	786	1,716	1,186	295	654	2,690
15.00	988	333	732	1,439	1,054	287	636	2,200
20.00	797	319	719	1,312	764	284	616	1,710
30.00	704	309	681	1,216	624	276	587	1,450
40.00	602	301	620	1,130	573	263	565	1,190
50.00	464	287	492	1,040	471	253	491	1,080
60.00	394	268	419	840	356	242	419	1,050
70.00	331	253	390	694	297	234	354	862
80.00	299	244	341	561	265	222	315	724
85.00	273	234	319	528	249	218	299	575
90.00	253	218	275	491	234	214	265	531
92.50	245	216	262	456	224	212	256	506
95.00	234	209	253	433	217	210	235	481
97.50	218	205	235	410	210	207	212	440
99.00	208	201	224	389	202	204	199	434
99.25	206	200	223	388	200	204	197	433
99.50	205	198	223	385	199	203	195	429
99.75	201	197	223	383	195	203	190	424
99.90	198	196	222	381	189	202	186	421
100.00	196	196	222	380	183	202	183	419

*For January at this gage, Dry years were 1996, 1997, 2000, 2009 and 2014. Wet years were 2001, 2003, 2005, 2007, and 2010.

** For February at this gage, Dry years were 1996, 2006, 2009, 2013, and 2014. Wet years were 1998, 2003, 2005, 2010, and 2012.

Table A-4 (continued). Monthly flow exceedance statistics for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	March*				April**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	16600	754	6370	16600	8740	713	5280	8740
0.01	15610	746	5746	16354	7758	701	5035	8496
0.25	13358	735	4810	15984	7065	683	4667	8129
0.50	6958	716	3756	15368	6612	653	4114	7518
0.75	6029	677	3177	14535	6157	620	3748	7092
1.00	5449	612	2950	13380	5941	577	3711	7066
2.50	3292	442	1658	6017	4731	466	1206	6385
5.00	2161	354	1140	4606	3221	427	1091	5782
7.50	1637	347	979	3729	2020	377	997	5108
10.00	1350	336	806	2996	1423	355	955	4262
15.00	1122	318	727	2226	1072	313	870	3415
20.00	978	311	686	1838	922	279	802	2646
30.00	653	290	611	1472	736	246	730	1543
40.00	543	264	548	1260	534	227	576	1328
50.00	464	250	495	1120	469	215	516	1030
60.00	377	230	453	1030	394	207	474	757
70.00	319	220	399	742	288	197	439	537
80.00	280	207	349	494	228	183	347	417
85.00	252	203	333	438	213	175	281	382
90.00	225	194	317	285	198	166	239	349
92.50	217	189	300	262	190	165	220	336
95.00	207	186	292	231	179	161	203	291
97.50	194	182	283	218	166	159	191	253
99.00	184	178	268	214	160	150	174	231
99.25	182	176	265	214	159	150	172	231
99.50	182	176	262	213	159	149	169	230
99.75	178	175	260	212	150	148	166	229
99.90	176	175	259	211	149	147	166	228
100.00	175	175	259	210	147	147	165	228

*For March at this gage, Dry years were 1996, 2009, 2011, 2013, and 2014. Wet years were 1998, 2003, 2005, 2007, and 2015.

** For April at this gage, Dry years were 1996, 2006, 2011, 2012, and 2014. Wet years were 1997, 2004, 2007, 2010, and 2015.

Table A-4 (continued). Monthly flow exceedance statistics for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	May*				June**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	11300	692	7120	11300	12600	779	4780	12600
0.01	10867	691	6962	11192	12540	726	4625	12585
0.25	10381	690	6726	11031	12351	646	4391	12563
0.50	9823	689	5749	10761	11802	514	3983	12526
0.75	9448	687	5011	10538	10808	421	3596	12465
1.00	9116	683	4906	10384	9864	413	3274	12353
2.50	6548	526	3628	9687	5137	373	1830	11438
5.00	3804	455	2143	8853	3377	339	1284	8639
7.50	2603	425	1621	7304	2391	304	1156	6539
10.00	1983	406	1343	6240	1830	283	963	5157
15.00	1340	382	979	4222	1190	257	836	3692
20.00	964	358	847	3046	888	240	732	2836
30.00	728	334	725	1776	655	202	586	2133
40.00	588	310	607	1322	498	184	484	1322
50.00	470	271	528	919	389	170	406	1025
60.00	393	239	446	749	304	154	353	726
70.00	325	195	388	613	244	138	286	618
80.00	254	181	288	485	178	129	255	517
85.00	208	176	244	437	154	122	226	463
90.00	184	169	186	384	138	115	158	416
92.50	176	155	175	348	133	108	147	378
95.00	163	136	159	300	124	101	139	345
97.50	141	121	143	265	114	96	130	318
99.00	127	115	134	249	101	93	121	309
99.25	122	113	133	247	97	92	119	307
99.50	119	112	132	243	96	91	117	305
99.75	115	111	131	238	93	89	114	304
99.90	112	111	130	235	90	88	114	303
100.00	111	111	129	233	87	87	113	303

*For May at this gage, Dry years were 1996, 1998, 2002, 2008, and 2011. Wet years were 2004, 2007, 2010, 2013, and 2015.

** For June at this gage, Dry years were 1996, 1998, 2008, 2009, and 2012. Wet years were 1997, 1999, 2004, 2007, and 2015.

Table A-4 (continued). Monthly flow exceedance statistics for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	July*				August**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	62000	356	2180	62000	20200	265	3330	20200
0.01	61257	355	2059	61815	19519	264	3247	20031
0.25	52861	354	1879	61538	16855	262	3121	19777
0.50	39625	352	1768	61076	14510	259	2711	19353
0.75	29253	350	1658	58553	11993	255	2303	18465
1.00	23385	347	1459	52970	9191	251	2031	16886
2.50	13553	332	1104	35850	3743	221	999	13000
5.00	7675	281	806	15870	2274	154	620	8211
7.50	4422	246	707	14745	1776	149	539	4254
10.00	2668	227	647	13560	1337	140	499	3752
15.00	1543	213	593	11100	907	135	444	2717
20.00	1066	190	519	7722	583	130	411	2102
30.00	596	168	415	4426	384	123	339	1600
40.00	415	153	355	2692	265	120	278	1146
50.00	315	137	309	2070	228	113	244	937
60.00	245	125	268	1470	175	106	226	764
70.00	178	113	209	1192	131	99	187	520
80.00	147	105	169	830	113	81	142	228
85.00	132	99	155	681	104	73	127	204
90.00	120	89	139	608	94	67	108	154
92.50	110	85	132	549	84	64	94	151
95.00	103	81	126	516	77	61	86	132
97.50	89	75	118	441	67	54	79	103
99.00	79	67	106	428	57	52	76	101
99.25	78	65	103	426	55	52	73	100
99.50	73	65	101	397	54	52	71	100
99.75	67	64	100	351	52	51	69	100
99.90	64	63	98	323	51	50	68	100
100.00	63	63	96	304	50	50	67	100

*For July at this gage, Dry years were 1996, 1998, 2000, 2009, and 2011. Wet years were 1997, 2002, 2003, 2004, and 2007.

** For August at this gage, Dry years were 2000, 2009, 2011, 2013 and 2014. Wet years were 2001, 2002, 2003, 2007, and 2008.

Table A-4 (continued). Monthly flow exceedance statistics for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	September*				October**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	26500	734	3280	26500	55800	787	4520	55800
0.01	24224	706	3238	25934	48062	760	4467	53875
0.25	22103	663	3175	25085	38263	720	4389	50988
0.50	16824	592	2912	23669	28322	653	4088	46175
0.75	14051	526	2668	22559	17036	588	3616	41874
1.00	12812	473	2631	22112	16292	527	3064	38332
2.50	7079	391	1656	14843	8616	415	2263	18960
5.00	3301	319	1152	11055	2924	367	1596	12440
7.50	2631	296	1050	9771	2266	347	1147	10145
10.00	2090	273	939	7105	1845	335	965	8620
15.00	1462	239	835	4025	1242	312	750	4953
20.00	1082	217	757	3304	1050	298	707	2752
30.00	784	211	566	2566	716	275	619	1962
40.00	512	195	443	1942	567	223	493	1388
50.00	384	173	387	1550	393	210	401	1190
60.00	304	153	343	1268	315	195	347	1066
70.00	218	122	277	1027	268	182	290	956
80.00	176	105	218	828	211	150	248	773
85.00	148	86	183	769	193	137	217	689
90.00	121	71	140	721	178	131	192	542
92.50	109	66	130	698	162	129	185	454
95.00	97	57	120	556	145	126	174	405
97.50	71	56	102	273	129	120	162	337
99.00	57	53	97	234	118	116	147	284
99.25	56	53	97	233	116	115	117	280
99.50	55	52	93	230	111	114	98	276
99.75	53	51	89	225	98	113	92	273
99.90	52	50	88	222	91	112	90	271
100.00	50	50	88	220	88	111	88	270

*For September at this gage, Dry years were 1999, 2000, 2011, 2014, and 2015. Wet years were 2001, 2002, 2003, 2007, and 2010.

** For October at this gage, Dry years were 1996, 1999, 2006, 2008, and 2014. Wet years were 1998, 2002, 2004, 2007, and 2009.

Table A-4 (continued). Monthly flow exceedance statistics for USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	November*				December**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	22600	741	9160	22600	5670	361	3040	5670
0.01	20743	737	8990	22138	4816	359	2765	5457
0.25	18057	731	8734	21445	4016	356	2352	5139
0.50	16501	721	8189	20291	3738	352	1719	4607
0.75	14454	706	7644	19159	3562	348	1350	4213
1.00	13309	681	7226	18079	3240	345	1322	4020
2.50	8593	591	2746	15195	2647	321	969	3640
5.00	4681	398	1141	11770	1971	313	809	3219
7.50	3212	333	922	10180	1646	309	724	2809
10.00	2291	310	892	8037	1441	306	681	2560
15.00	1620	297	835	5898	1092	300	617	2117
20.00	1232	290	698	4222	893	285	569	1926
30.00	817	281	575	2645	649	269	547	1618
40.00	561	270	484	1922	547	257	455	1414
50.00	434	259	420	1630	422	249	422	1190
60.00	351	236	384	1500	360	237	390	1012
70.00	287	219	338	1247	304	226	359	911
80.00	264	193	281	1028	269	218	320	816
85.00	238	187	269	906	253	213	295	765
90.00	220	166	245	785	231	204	281	736
92.50	202	164	229	614	226	198	276	721
95.00	192	155	220	531	217	195	268	662
97.50	165	147	202	514	204	190	249	632
99.00	151	131	195	490	194	187	227	625
99.25	133	131	195	473	191	187	226	624
99.50	131	130	163	466	187	186	221	623
99.75	130	130	128	464	187	185	216	622
99.90	125	129	123	463	186	184	215	621
100.00	119	129	119	462	184	184	214	621

*For November at this gage, Dry years were 1996, 1999, 2006, 2008, and 2011. Wet years were 1998, 2000, 2001, 2002, and 2004.

** For December at this gage, Dry years were 1999, 2008, 2012, 2013, and 2014. Wet years were 1998, 2001, 2002, 2004, and 2007.

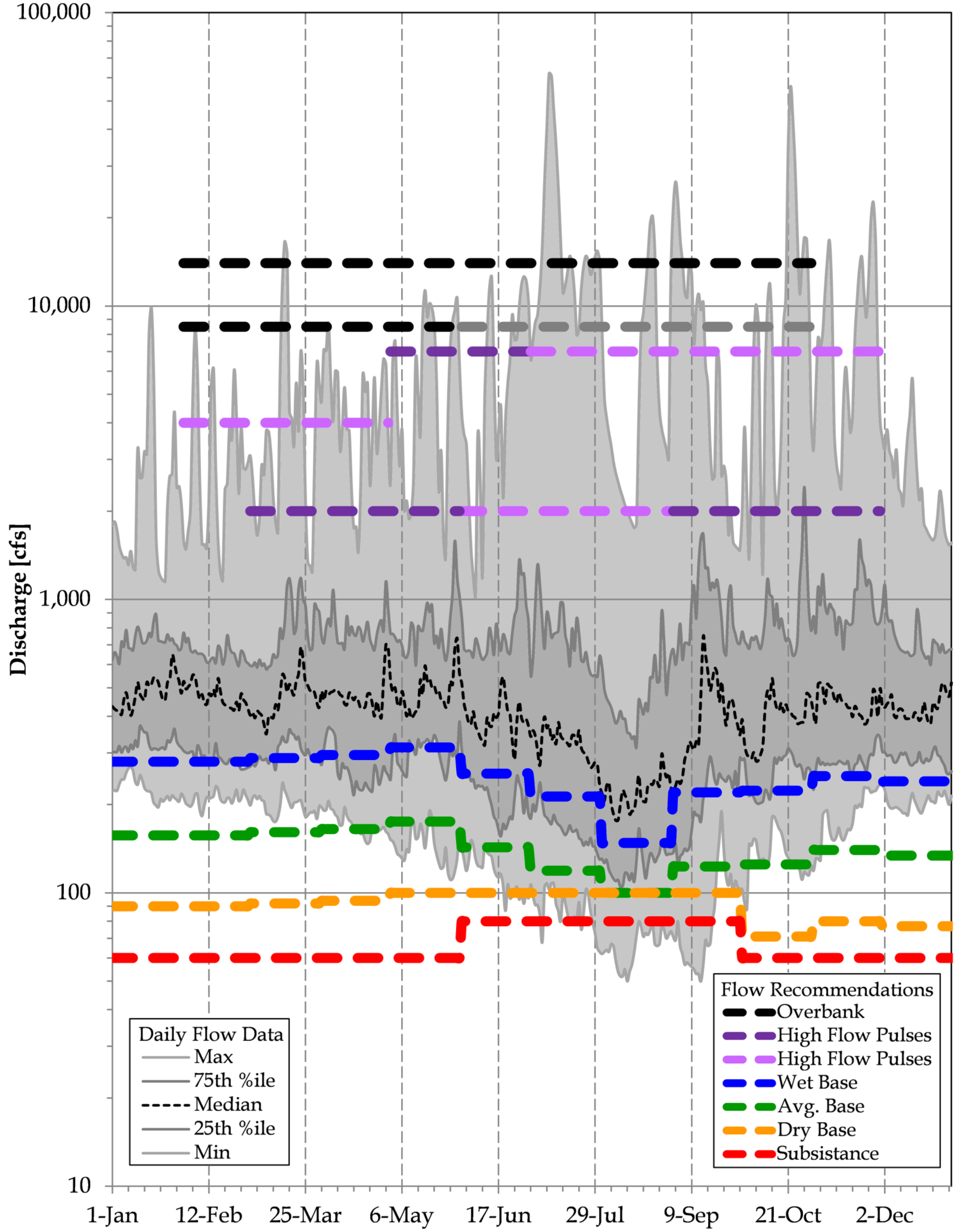


Figure A-30. Instream flow recommendations for the Goliad Study Site versus flow data from USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015.

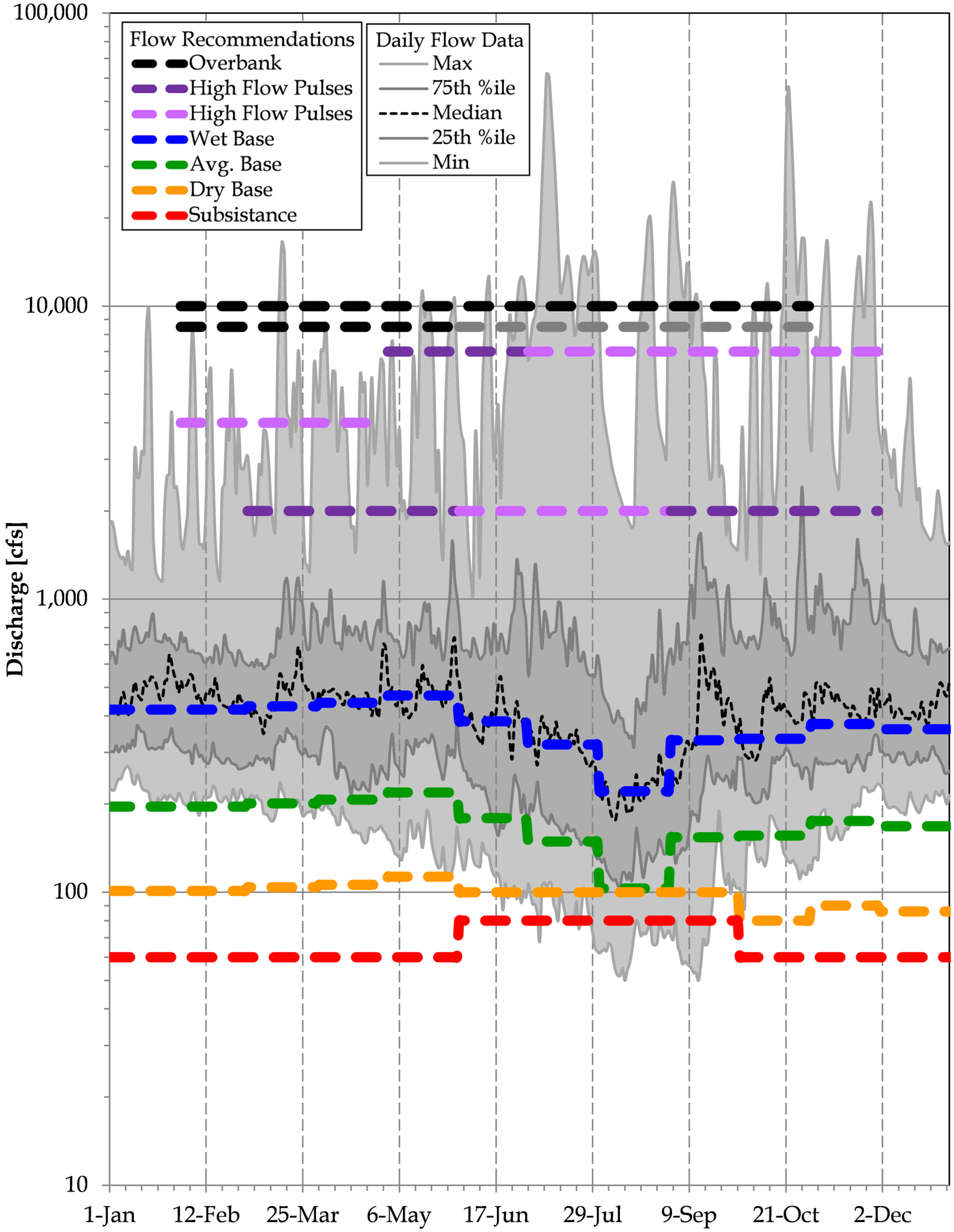


Figure A-31. Instream flow recommendations for the Highway 77 Study Site versus flow data from USGS Gage No. 08188500 San Antonio River at Goliad, Texas for 1996 to 2015.

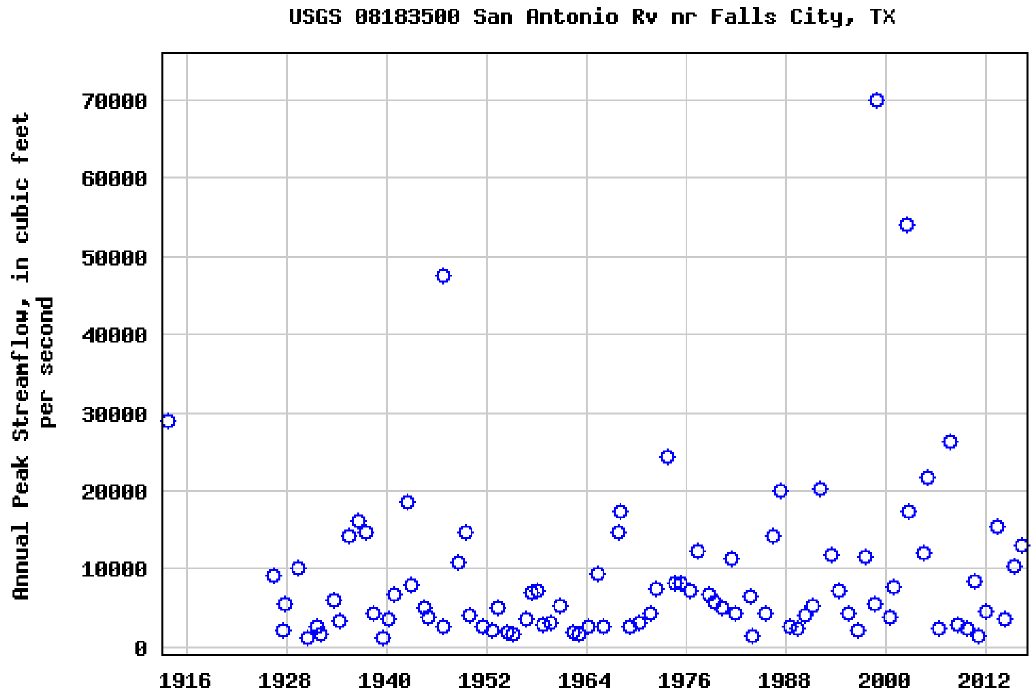


Figure A-32. Annual peak streamflow at USGS Gage No. 08183500 San Antonio River near Falls City, Texas.

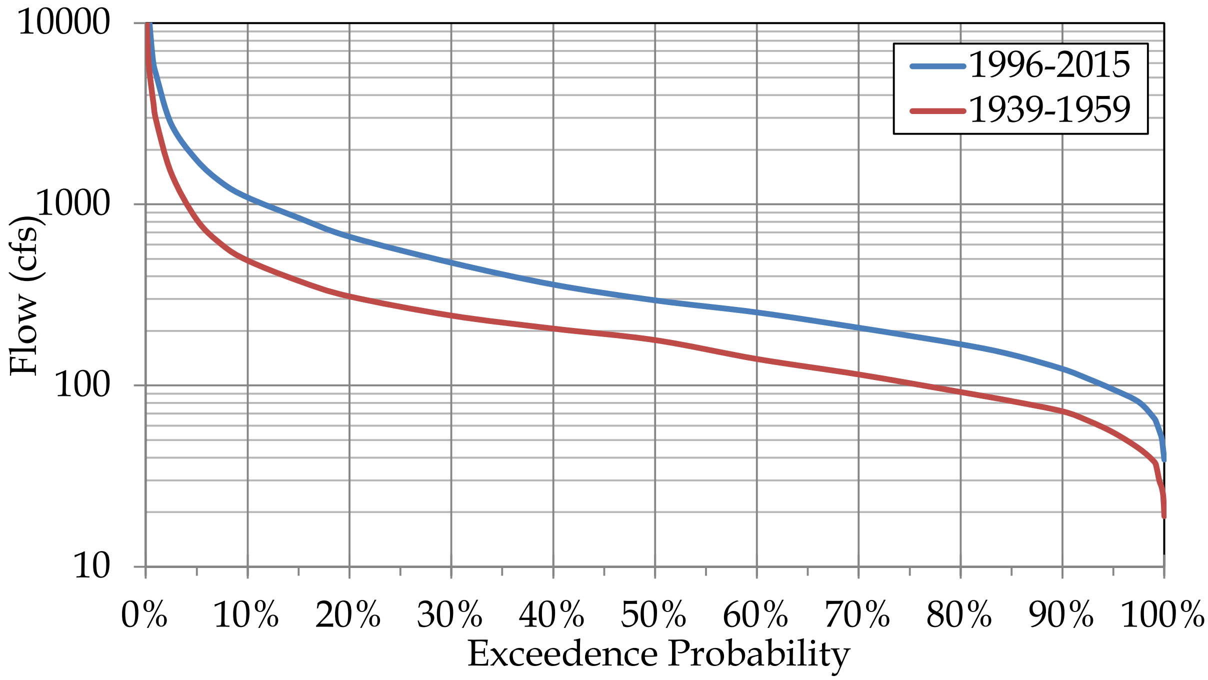


Figure A-33. Flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for an early (March 1939-February 1959) and late (1996-2015) time period.

Table A-5. Flow exceedance statistics for USGS Gage No. 08183500 San Antonio River near Falls City for an early (March 1939-February 1959) and late (1996-2015) time period.

Exceedence Probability (%)	Time Period 3/1/1939 to 2/28/1959 (cfs)	1/1/1996 to 12/31/2015 (cfs)
0.00	42,200	53,800
0.01	10,309	24,740
0.25	6,290	12,692
0.50	4,644	8,179
0.75	3,620	5,970
1.00	2,928	5,227
2.50	1,484	2,768
5.00	823	1,750
7.50	596	1,310
10.00	489	1,090
15.00	378	841
20.00	310	662
30.00	243	476
40.00	206	360
50.00	178	295
60.00	140	253
70.00	115	208
80.00	92	169
85.00	82	148
90.00	72	123
92.50	64	109
95.00	55	95
97.50	45	81
99.00	38	66
99.25	35	62
99.50	30	57
99.75	27	51
99.90	24	44
100.00	19	39

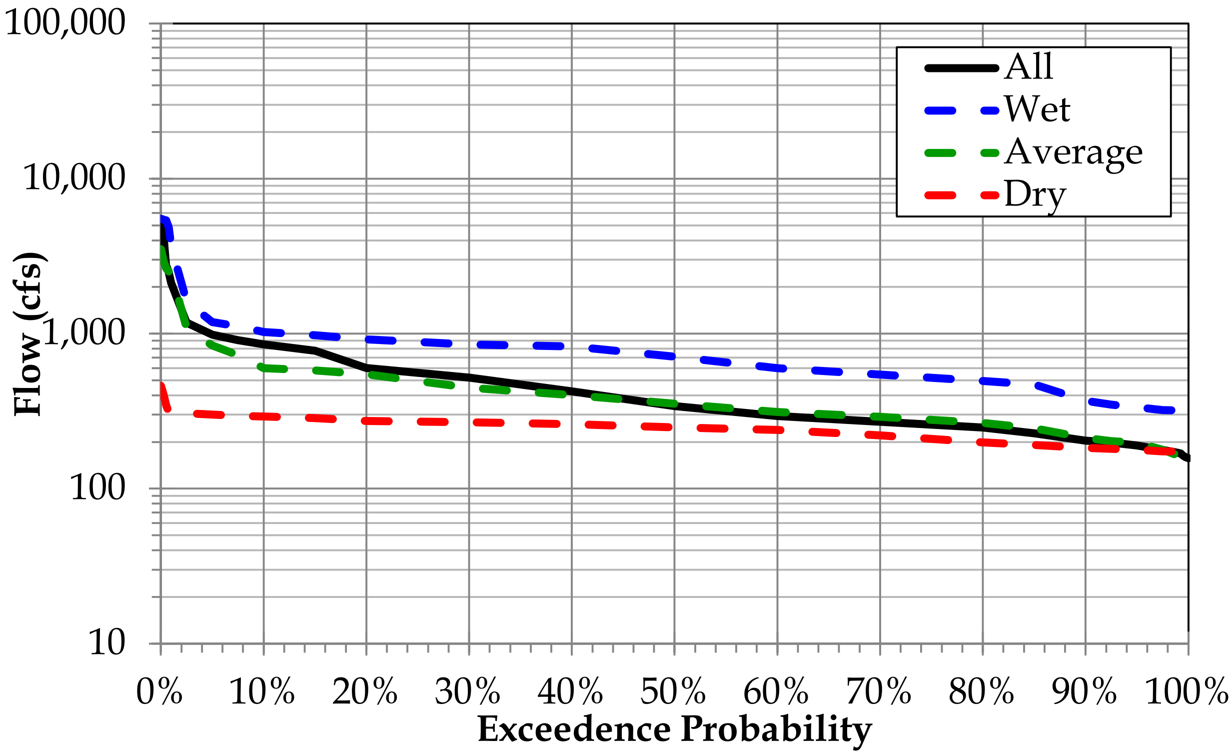


Figure A-34. January flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

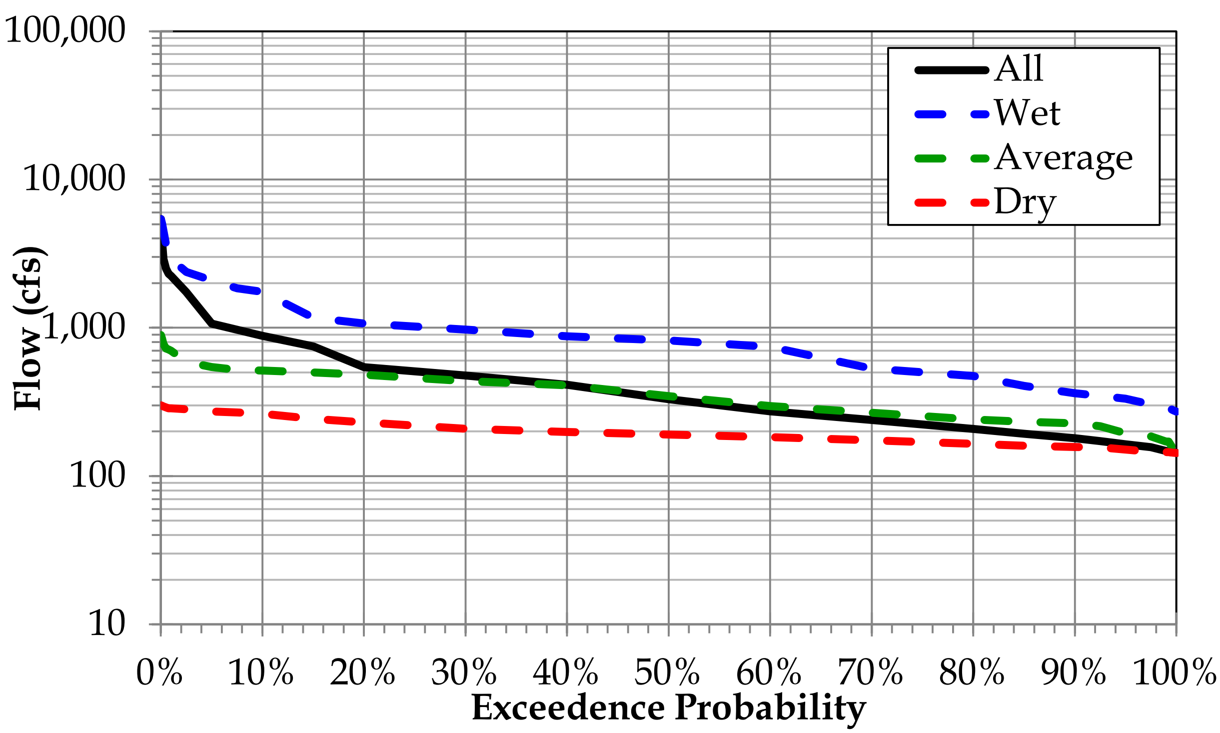


Figure A-35. February flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

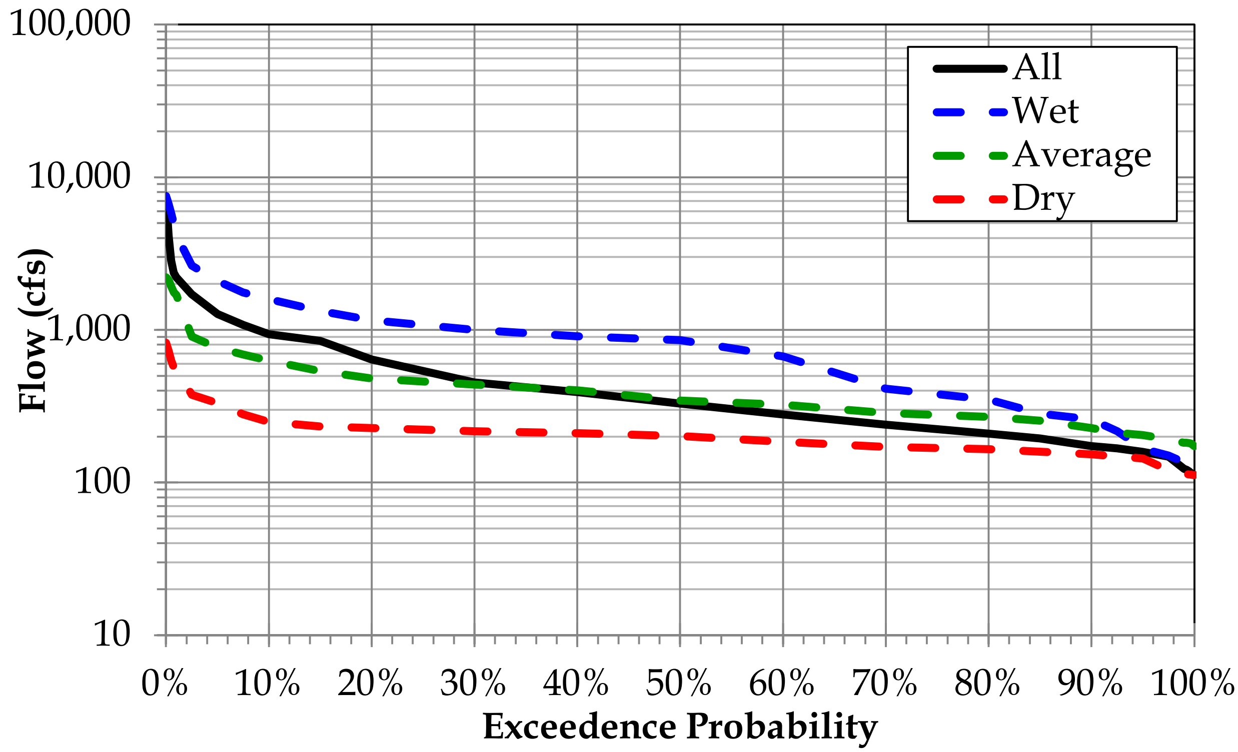


Figure A-36. March flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

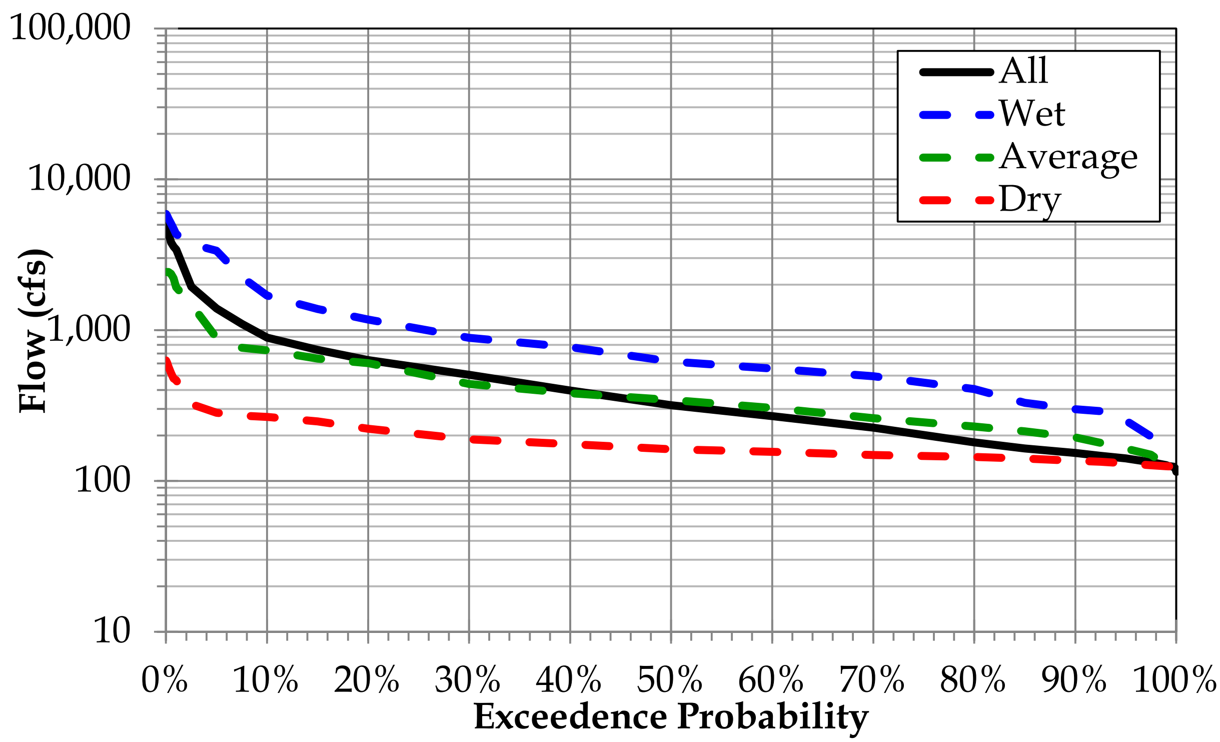


Figure A-37. April flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

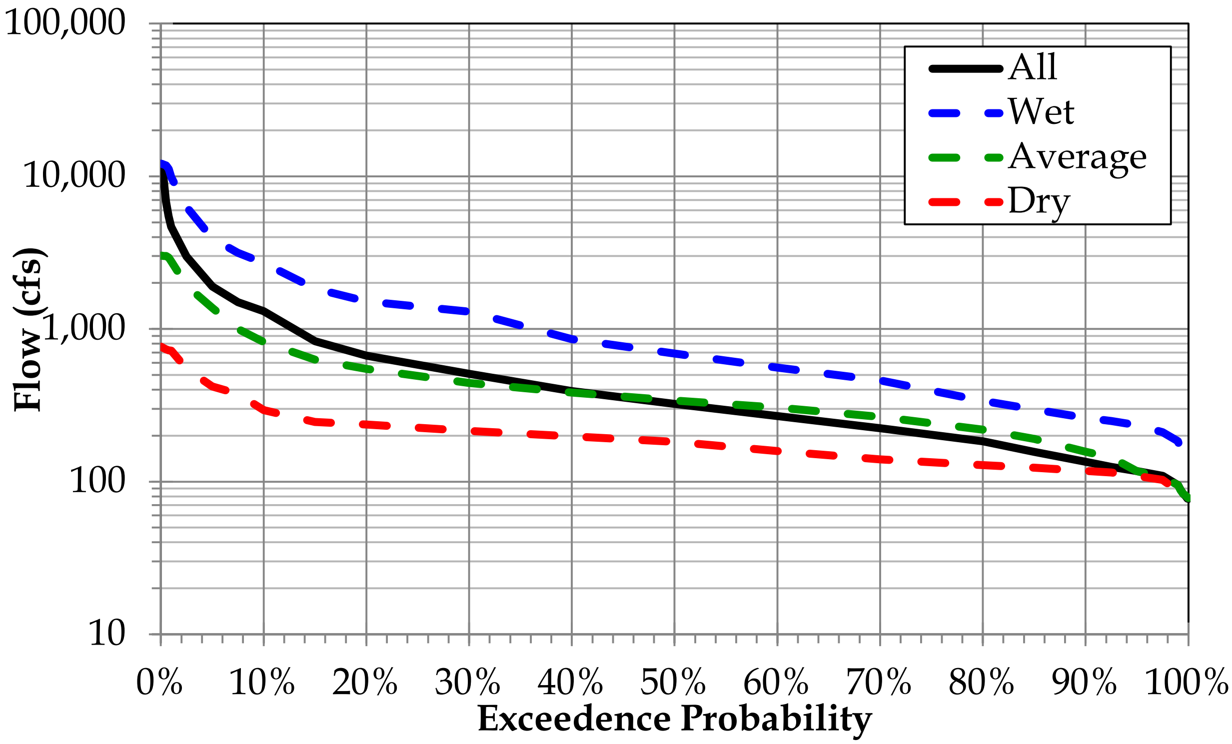


Figure A-38. May flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

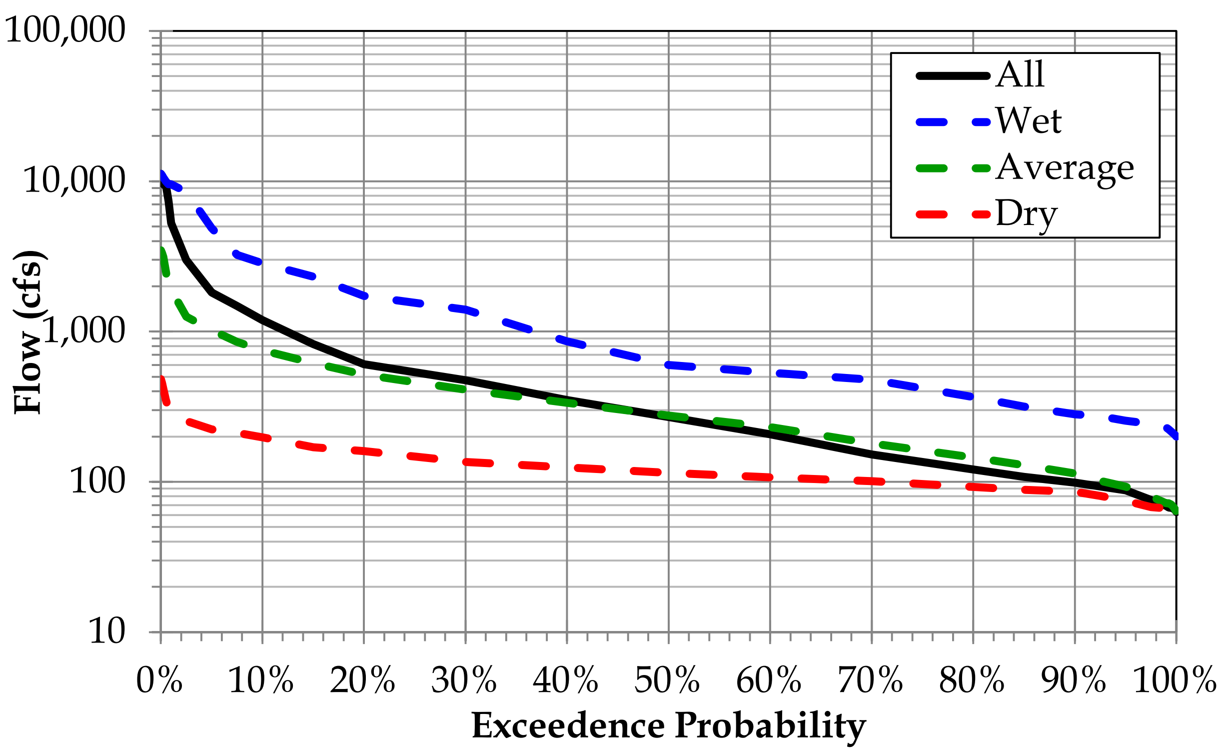


Figure A-39. June flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

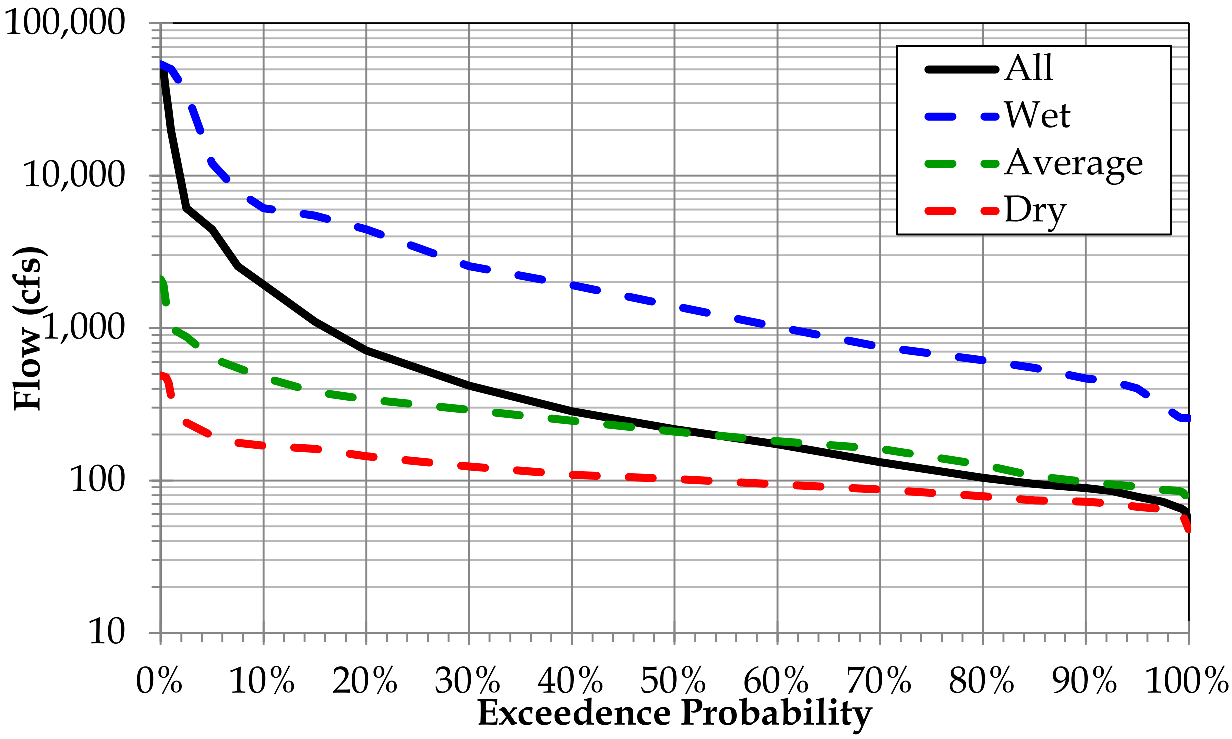


Figure A-40. July flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

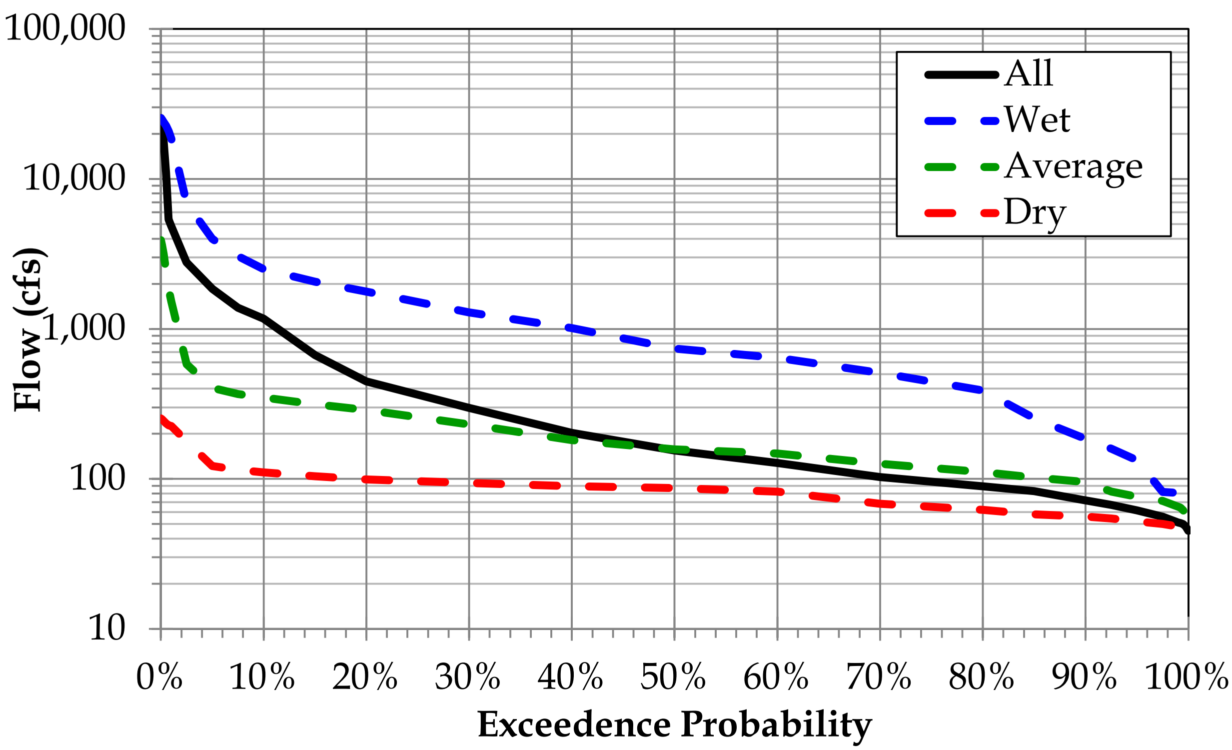


Figure A-41. August flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

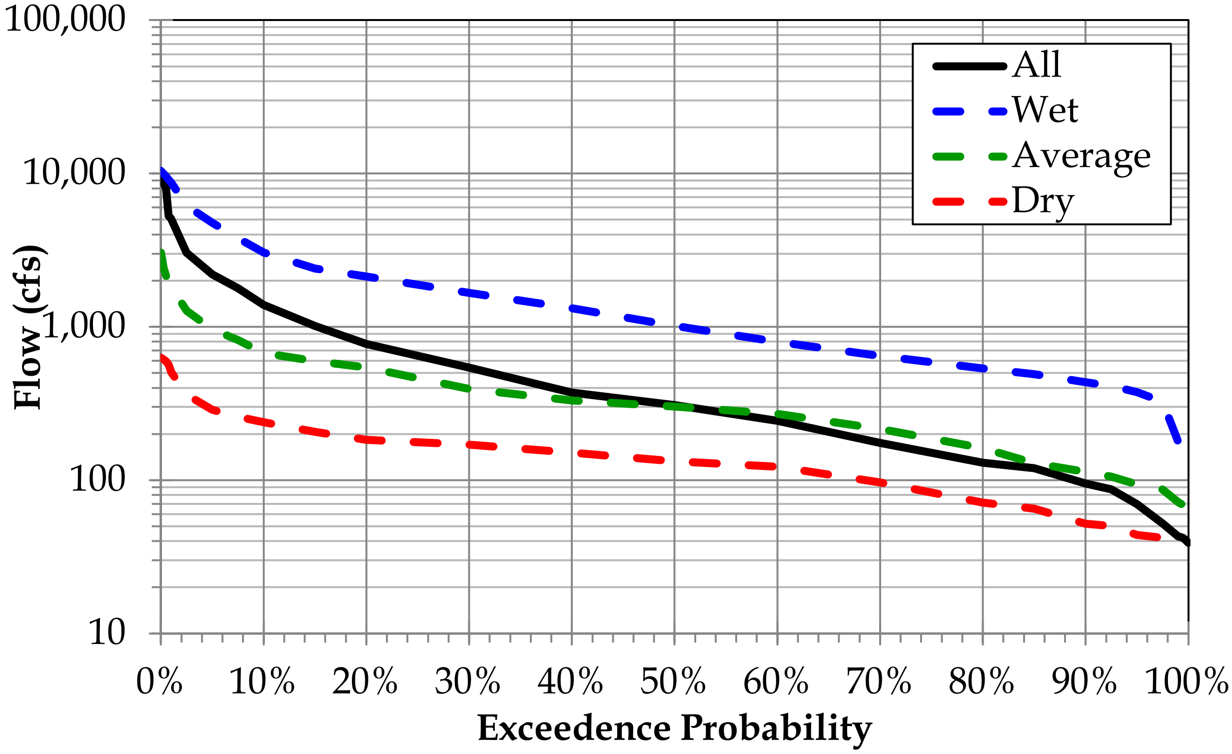


Figure A-42. September flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

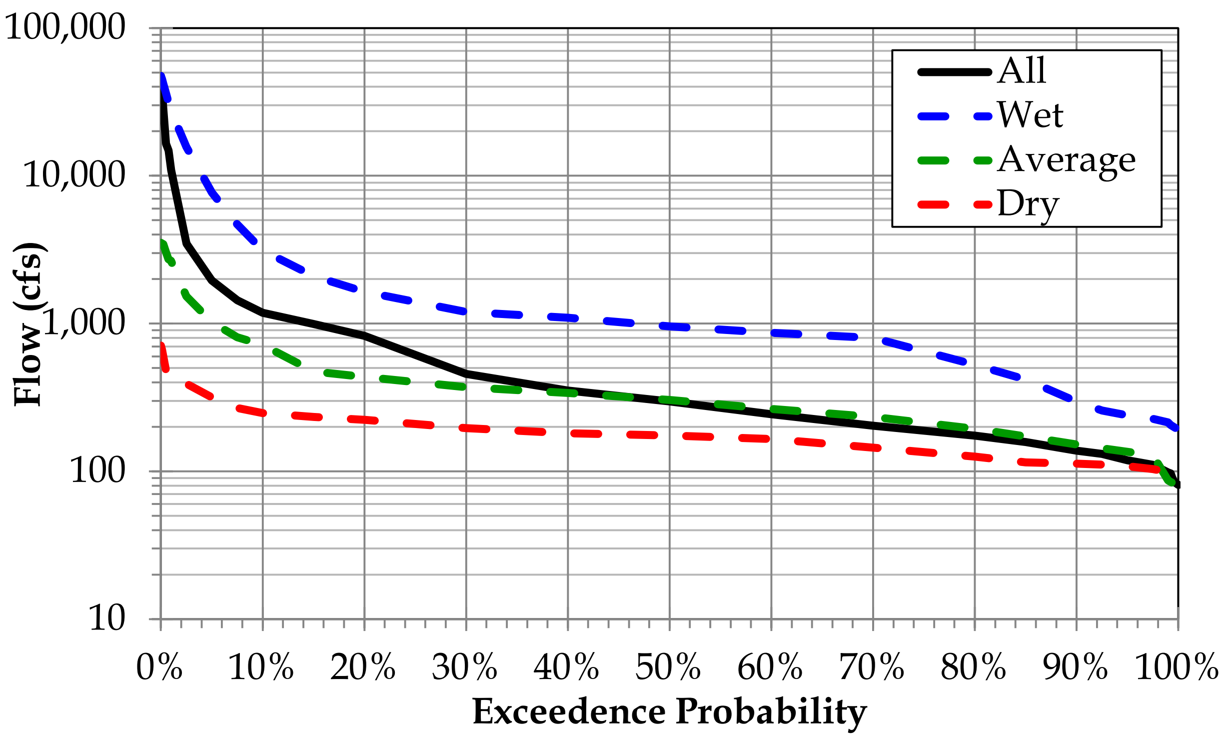


Figure A-43. October flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

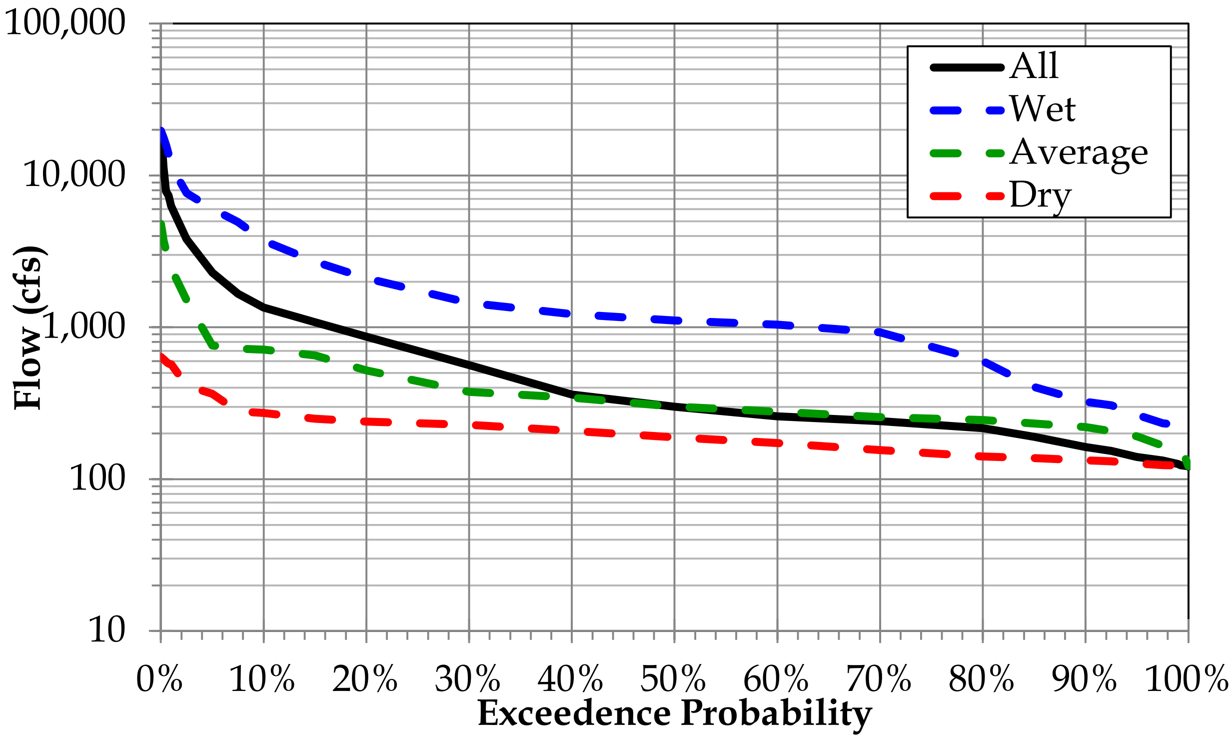


Figure A-44. November flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

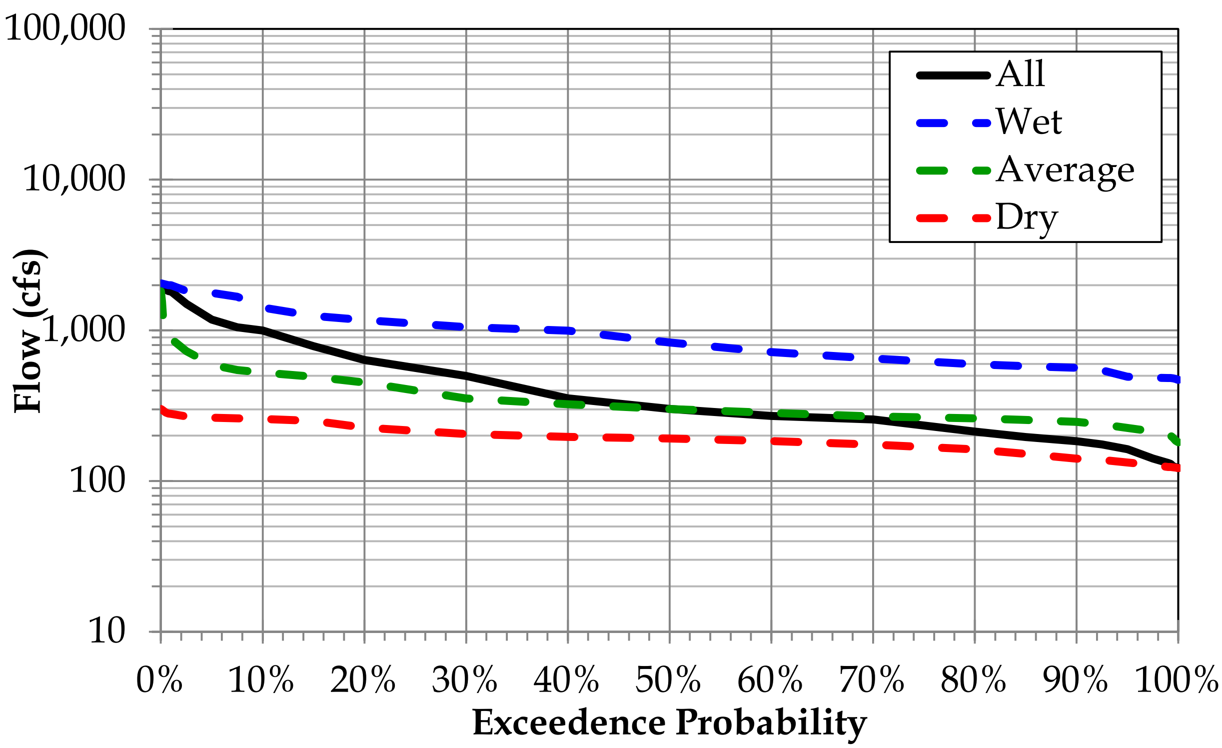


Figure A-45. December flow duration curves for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Table A-6. Monthly flow exceedance statistics for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	January*				February**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	5,500	461	3,510	5,500	5,410	300	893	5,410
0.01	5,407	438	3,284	5,477	4,028	298	848	5,067
0.25	4,343	403	2,946	5,442	2,911	295	781	4,553
0.50	2,755	345	2,638	5,385	2,512	291	727	3,695
0.75	2,514	311	2,517	4,856	2,318	287	714	2,954
1.00	2,130	310	2,464	3,627	2,240	286	702	2,912
2.50	1,180	306	1,084	1,606	1,746	283	589	2,380
5.00	982	300	839	1,189	1,066	272	543	2,090
7.50	908	295	728	1,118	968	268	521	1,850
10.00	852	293	600	1,026	884	263	514	1,750
15.00	777	285	580	975	749	243	500	1,170
20.00	600	273	547	917	541	230	482	1,070
30.00	520	268	448	852	478	208	437	974
40.00	423	261	401	828	413	198	409	876
50.00	341	249	353	711	330	191	346	821
60.00	295	239	311	599	273	183	297	744
70.00	270	220	290	544	239	174	267	530
80.00	248	199	266	496	207	165	241	473
85.00	227	191	245	470	193	160	233	406
90.00	204	183	213	369	180	157	227	362
92.50	198	181	202	349	172	156	217	348
95.00	190	178	198	335	164	151	194	332
97.50	177	174	178	322	157	146	185	305
99.00	171	174	163	320	147	145	171	287
99.25	168	173	161	319	145	145	171	286
99.50	163	172	160	310	145	144	160	282
99.75	160	171	159	294	145	144	151	277
99.90	158	170	158	285	144	143	147	274
100.00	157	169	157	279	143	143	145	272

*For January at this gage, Dry years were 1996, 1997, 2006, 2009 and 2014. Wet years were 1999, 2001, 2003, 2005, and 2010.

** For February at this gage, Dry years were 1996, 2006, 2009, 2014, and 2015. Wet years were 1998, 2003, 2005, 2010, and 2012.

Table A-6 (continued). Monthly flow exceedance statistics for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	March*				April**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	7,520	823	2,210	7,520	5,880	629	2430	5,880
0.01	6,102	783	2,170	7,167	5,257	607	2430	5,725
0.25	4,157	724	2,110	6,638	4,323	573	2430	5,493
0.50	2,844	625	1,917	5,757	3,800	518	2366	5,105
0.75	2,362	565	1,761	4,926	3,567	477	2208	4,718
1.00	2,206	561	1,694	4,172	3,420	467	1924	4,330
2.50	1,711	376	903	2,641	1,939	323	1485	3,720
5.00	1,272	332	764	2,096	1,391	283	889	3,366
7.50	1,076	280	691	1,754	1,102	271	764	2,252
10.00	938	249	631	1,588	891	266	736	1,695
15.00	848	233	536	1,327	738	248	647	1,383
20.00	640	227	479	1,154	633	221	603	1,174
30.00	451	217	437	999	505	189	440	887
40.00	391	210	401	910	397	175	382	771
50.00	329	202	345	856	318	163	344	621
60.00	279	185	323	669	269	156	304	555
70.00	239	171	285	412	225	149	260	494
80.00	209	165	269	349	180	144	230	406
85.00	195	159	254	283	164	140	213	330
90.00	173	153	228	259	153	136	194	299
92.50	167	148	211	216	147	134	179	290
95.00	159	144	204	166	141	130	164	252
97.50	148	121	192	150	133	127	149	197
99.00	123	114	182	136	127	125	127	186
99.25	121	113	182	129	125	125	127	183
99.50	118	113	182	126	125	122	126	181
99.75	114	112	179	123	124	119	125	181
99.90	113	112	175	122	120	116	124	180
100.00	112	112	173	121	115	115	124	180

*For March at this gage, Dry years were 1996, 2009, 2011, 2013 and 2014. Wet years were 1998, 2003, 2005, 2007, and 2015.

** For April at this gage, Dry years were 1996, 2006, 2009, 2011, and 2014. Wet years were 2004, 2005, 2007, 2010, and 2015.

Table A-6 (continued). Monthly flow exceedance statistics for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	May*				June**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	12,100	766	3,020	12,100	11,200	482	3,470	11,200
0.01	11,852	760	3,017	12,038	10,230	456	3,335	10,959
0.25	9,806	750	3,012	11,946	9,545	417	3,134	10,597
0.50	6,815	734	3,010	11,792	9,281	352	2,515	9,993
0.75	5,487	724	2,937	11,164	7,358	307	1,976	9,572
1.00	4,663	722	2,770	9,832	5,272	307	1,901	9,546
2.50	2,986	546	1,916	6,302	3,001	253	1,256	8,497
5.00	1,901	421	1,377	3,911	1,814	223	1,021	4,889
7.50	1,496	377	1,001	3,148	1,480	211	853	3,228
10.00	1,310	294	820	2,710	1,191	197	752	2,841
15.00	831	246	629	1,842	826	170	615	2,320
20.00	671	236	548	1,516	605	160	516	1,730
30.00	509	215	444	1,296	475	135	410	1,396
40.00	392	198	383	857	349	124	336	860
50.00	324	182	340	692	270	115	276	600
60.00	269	159	306	558	207	107	231	532
70.00	224	140	266	461	152	101	180	479
80.00	184	128	219	338	121	93	145	367
85.00	157	123	191	297	108	88	129	316
90.00	135	117	157	262	99	86	114	281
92.50	125	115	144	250	93	81	101	273
95.00	117	109	117	235	88	75	93	254
97.50	109	103	107	211	76	68	80	243
99.00	95	87	95	184	69	66	72	230
99.25	88	84	88	163	67	66	72	224
99.50	83	82	84	153	67	66	70	216
99.75	80	79	81	151	66	66	67	208
99.90	78	78	79	150	65	66	65	203
100.00	77	77	78	149	63	66	63	200

*For May at this gage, Dry years were 1996, 1998, 2002, 2009 and 2011. Wet years were 2004, 2007, 2010, 2013, and 2015.

** For June at this gage, Dry years were 1998, 2006, 2008, 2009, and 2012. Wet years were 1997, 2004, 2007, 2010, and 2015.

Table A-6 (continued). Monthly flow exceedance statistics for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	July*				August**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	53,800	489	2,090	53,800	25,500	253	3,910	25,500
0.01	52,252	486	2,025	53,415	23,148	249	3,613	24,915
0.25	50,260	482	1,928	52,838	18,524	244	3,168	24,037
0.50	36,267	476	1,460	51,875	11,072	235	2,421	22,574
0.75	27,290	439	1,075	51,006	5,385	228	1,840	20,801
1.00	19,866	359	999	50,274	4,858	225	1,523	18,568
2.50	6,126	239	876	35,210	2,787	178	582	6,874
5.00	4,443	196	634	12,060	1,852	122	405	3,997
7.50	2,542	176	547	7,908	1,386	115	368	3,067
10.00	1,932	169	474	6,128	1,171	111	348	2,508
15.00	1,102	161	382	5,482	669	104	315	2,062
20.00	713	144	340	4,452	447	99	289	1,770
30.00	419	124	291	2,546	297	94	231	1,288
40.00	285	109	246	1,918	202	89	182	1,012
50.00	217	102	209	1,390	155	87	157	739
60.00	173	94	181	1,016	128	82	148	642
70.00	132	87	161	753	103	68	126	510
80.00	104	79	127	616	89	62	111	388
85.00	95	74	107	547	83	58	102	253
90.00	89	72	98	466	72	56	95	185
92.50	85	71	94	448	67	54	82	159
95.00	78	67	91	401	62	52	76	133
97.50	72	65	87	309	56	50	71	82
99.00	66	62	86	263	51	48	65	81
99.25	66	61	85	258	51	47	64	80
99.50	64	58	83	256	50	47	62	79
99.75	62	53	79	256	48	46	59	77
99.90	56	50	75	256	46	45	59	76
100.00	48	48	73	256	45	45	59	75

*For July at this gage, Dry years were 1996, 2000, 2001, 2009 and 2011. Wet years were 1997, 2002, 2003, 2004, and 2007.

** For August at this gage, Dry years were 2000, 2009, 2011, 2013, and 2014. Wet years were 1998, 2002, 2004, 2007, and 2008.

Table A-6 (continued). Monthly flow exceedance statistics for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	September*				October**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	10,400	629	3,050	10,400	47,400	709	3,520	47,400
0.01	9,693	622	2,799	10,224	38,610	664	3,489	45,213
0.25	8,693	611	2,422	9,960	27,506	597	3,443	41,933
0.50	8,011	594	2,141	9,521	16,496	486	3,055	36,466
0.75	5,293	564	2,007	9,095	14,858	418	2,725	31,588
1.00	5,061	506	1,813	8,701	10,962	416	2,655	27,584
2.50	3,051	361	1,271	6,161	3,473	391	1,530	15,665
5.00	2,191	288	961	4,764	1,962	316	1,021	7,692
7.50	1,782	259	823	3,795	1,433	268	806	4,706
10.00	1,392	239	676	3,046	1,180	248	716	3,112
15.00	1,012	207	597	2,396	993	233	474	2,089
20.00	772	183	543	2,130	826	223	436	1,636
30.00	542	170	394	1,666	456	196	371	1,198
40.00	372	151	330	1,322	353	181	338	1,094
50.00	309	133	302	1,015	297	175	304	958
60.00	244	122	271	799	243	165	264	864
70.00	175	96	216	644	203	144	233	801
80.00	130	71	161	534	174	126	194	526
85.00	120	65	129	491	158	115	172	419
90.00	95	52	113	435	138	112	152	296
92.50	87	50	105	411	131	111	143	258
95.00	70	44	94	375	119	108	135	240
97.50	52	42	87	325	110	104	128	227
99.00	43	40	72	180	98	99	87	214
99.25	42	40	70	176	97	98	85	206
99.50	42	40	69	172	87	97	83	200
99.75	40	39	68	167	83	96	82	196
99.90	40	39	68	165	82	96	81	194
100.00	39	39	68	163	81	95	81	192

*For September at this gage, Dry years were 1999, 2000, 2011, 2014 and 2015. Wet years were 2001, 2002, 2003, 2007, and 2010.

** For October at this gage, Dry years were 1996, 1999, 2008, 2013, and 2014. Wet years were 1998, 2002, 2004, 2007, and 2009.

Table A-6 (continued). Monthly flow exceedance statistics for USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	November*				December**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	19,700	639	4,800	19,700	2,050	301	1,820	2,050
0.01	16,525	630	4,363	18,910	2,019	298	1,551	2,042
0.25	11,450	617	3,709	17,726	1,995	293	1,146	2,031
0.50	7,863	594	3,177	15,752	1,856	286	917	2,012
0.75	7,393	577	2,869	13,703	1,820	281	889	1,998
1.00	6,289	570	2,436	11,494	1,818	280	880	1,995
2.50	3,824	412	1,509	7,672	1,499	268	730	1,826
5.00	2,292	365	760	6,036	1,180	263	589	1,775
7.50	1,662	280	723	4,954	1,050	261	547	1,675
10.00	1,354	273	712	3,721	998	259	524	1,420
15.00	1,080	251	654	2,705	784	251	492	1,249
20.00	867	240	520	2,102	636	227	451	1,172
30.00	564	228	376	1,446	500	205	354	1,050
40.00	361	208	344	1,224	354	197	324	995
50.00	300	189	301	1,110	302	192	301	833
60.00	260	173	279	1,040	271	184	284	719
70.00	242	156	257	928	256	175	269	652
80.00	217	141	245	599	213	163	261	597
85.00	190	138	233	405	196	151	255	578
90.00	163	133	221	324	184	141	248	564
92.50	154	131	207	307	175	138	238	544
95.00	140	127	192	266	163	133	225	494
97.50	133	124	166	234	141	128	214	486
99.00	126	123	154	226	132	124	201	484
99.25	123	123	148	225	130	124	200	484
99.50	123	122	143	225	125	124	194	481
99.75	122	122	136	224	124	123	186	475
99.90	122	121	128	224	123	122	183	472
100.00	121	121	122	224	122	122	181	470

*For November at this gage, Dry years were 2005, 2008, 2011, 2012 and 2013. Wet years were 1998, 2000, 2002, 2004, and 2015.

** For December at this gage, Dry years were 1999, 2008, 2012, 2013, and 2014. Wet years were 1998, 2001, 2002, 2004, and 2007.

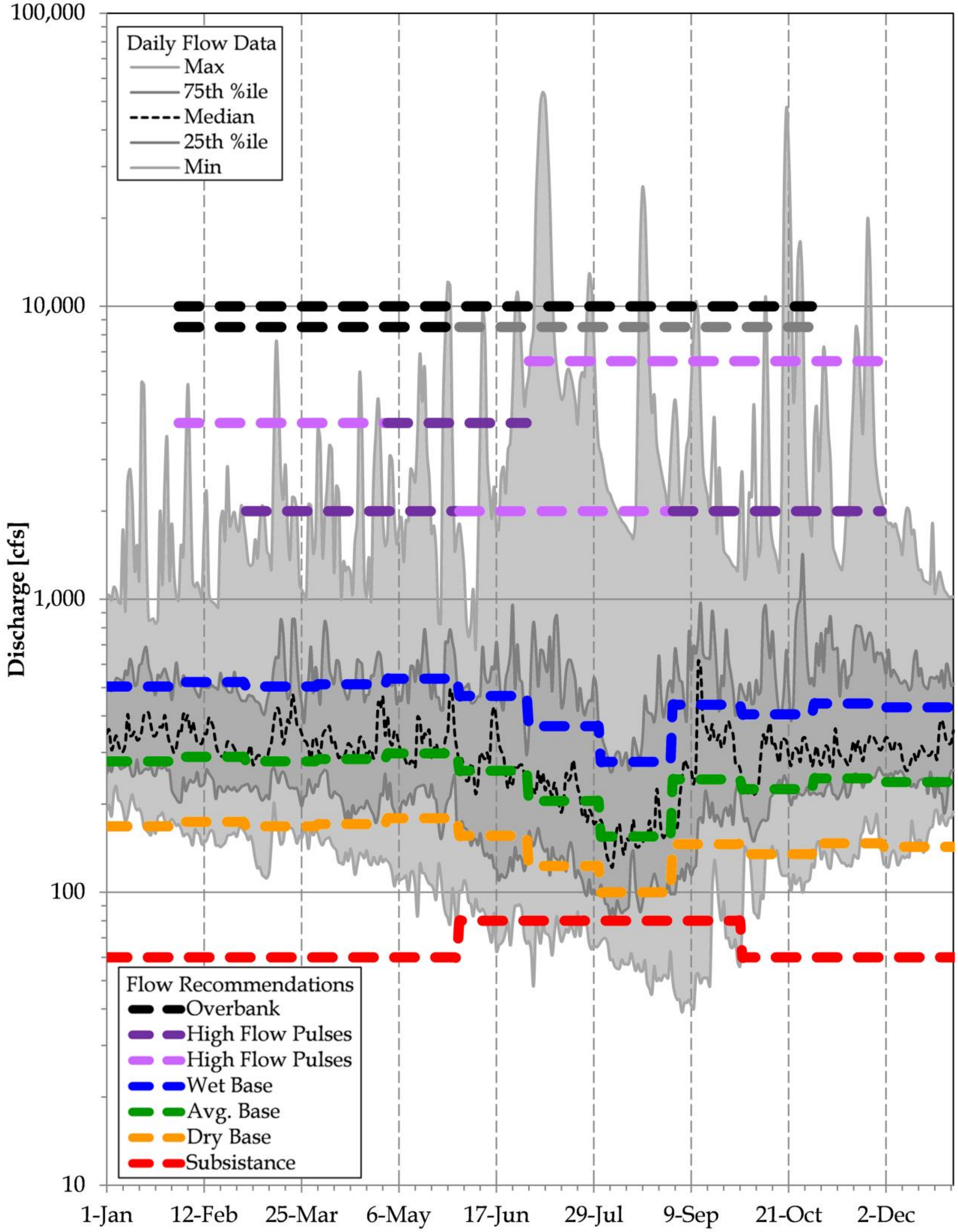


Figure A-46. Instream flow recommendations for the Falls City Study Site versus flow data from USGS Gage No. 08183500 San Antonio River near Falls City, Texas for 1996 to 2015.

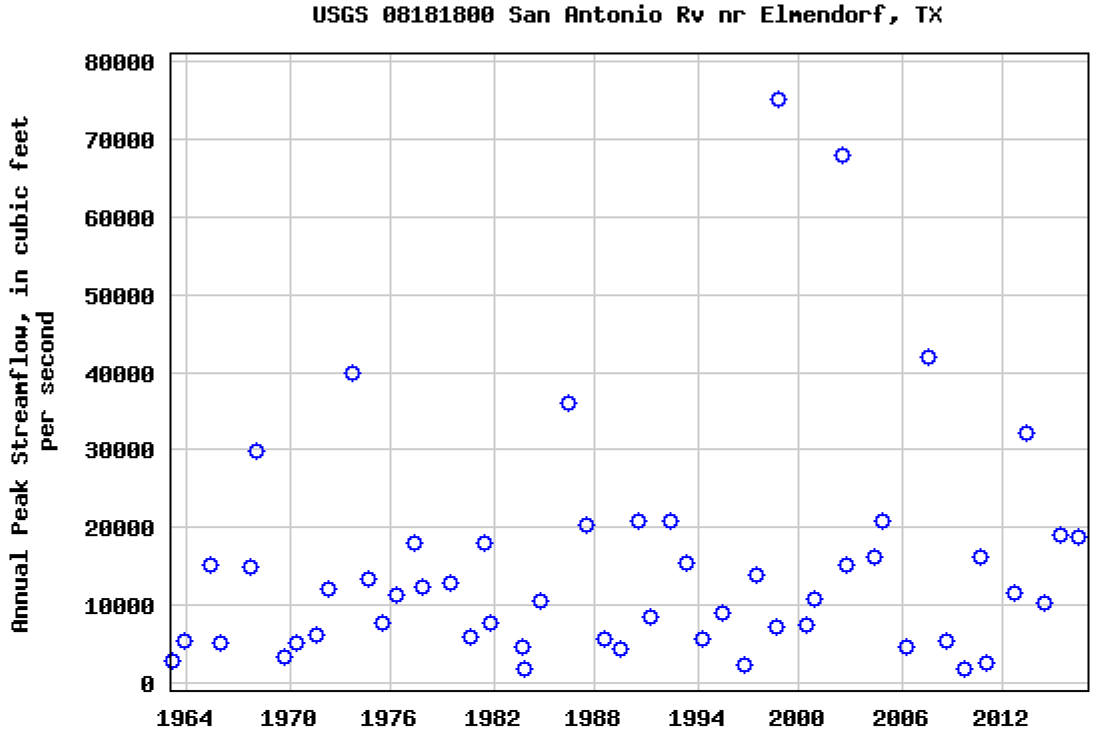


Figure A-47. Annual peak streamflow at USGS Gage No. 8181800 San Antonio River near Elmendorf, Texas.

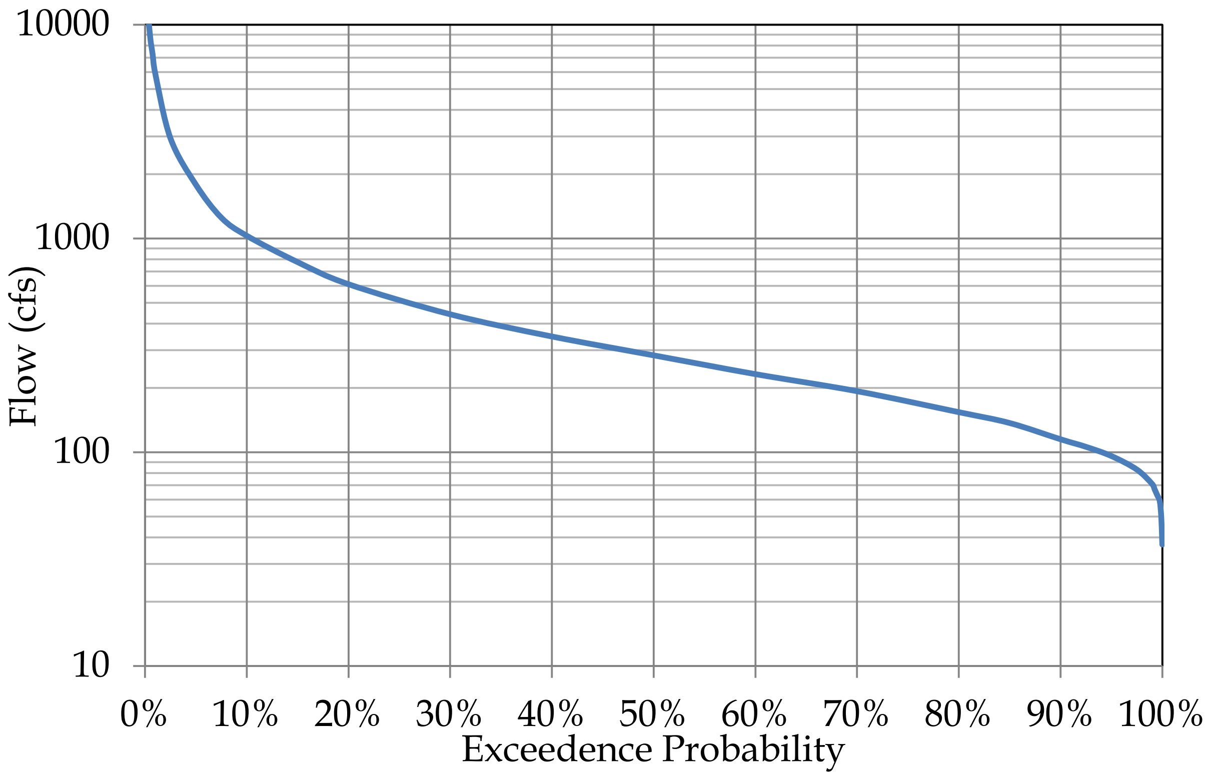


Figure A-48. Flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996-2015.

Table A-7. Flow exceedance statistics for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996-2015.

Exceedence Probability (%)	Flow (cfs)
0.00	62,400
0.01	24,318
0.25	12,722
0.50	8,841
0.75	7,254
1.00	5,938
2.50	2,944
5.00	1,786
7.50	1,252
10.00	1,030
15.00	775
20.00	611
30.00	442
40.00	348
50.00	284
60.00	232
70.00	193
80.00	154
85.00	137
90.00	115
92.50	106
95.00	96
97.50	83
99.00	71
99.25	67
99.50	63
99.75	59
99.90	50
100.00	37

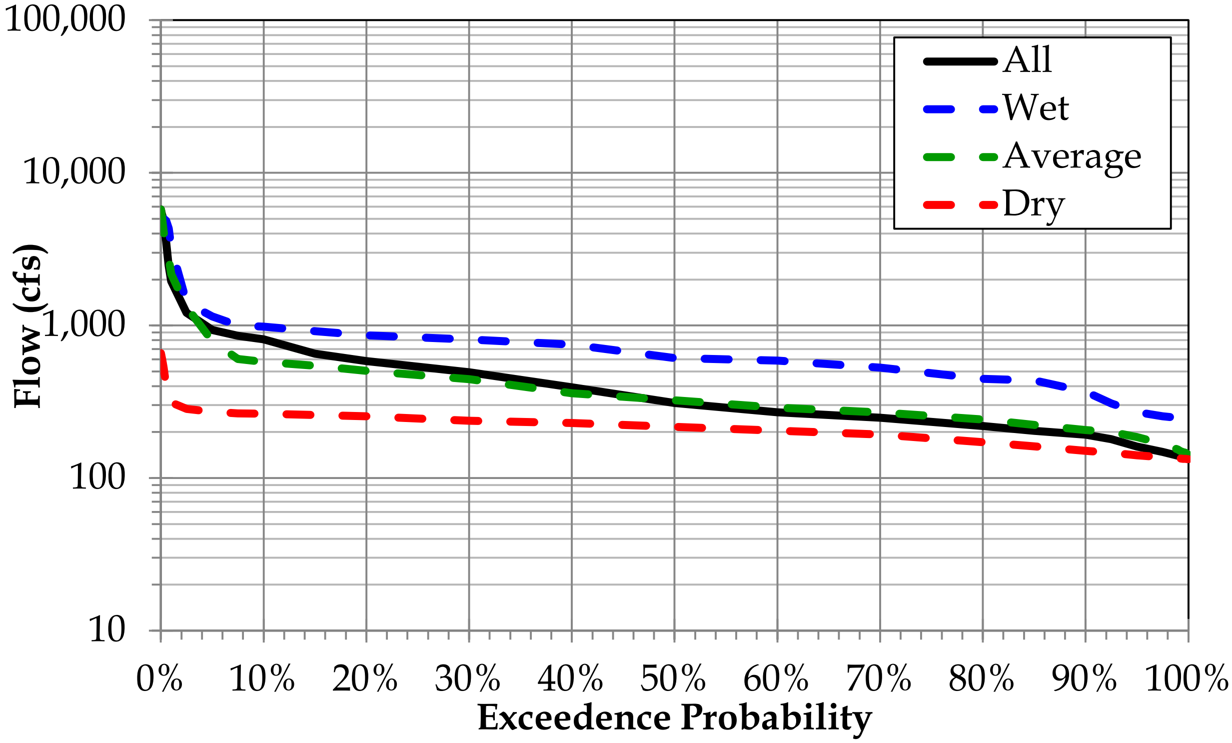


Figure A-49. January flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

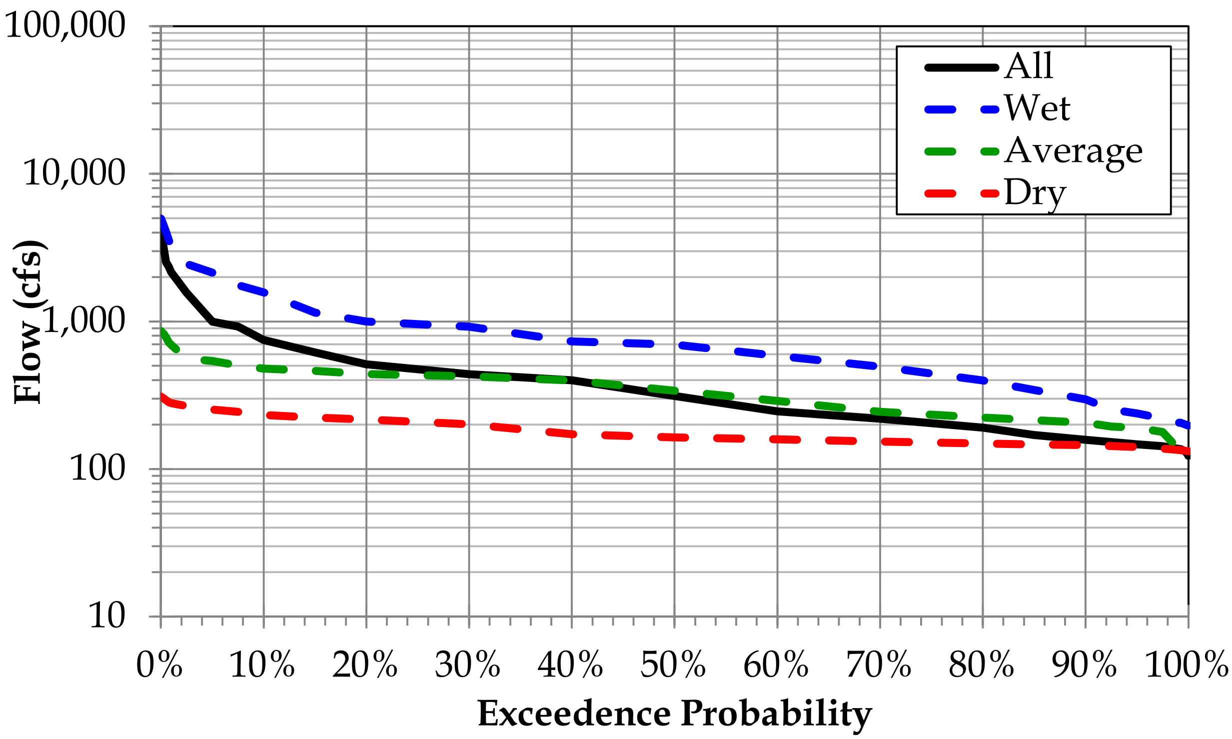


Figure A-50. February flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

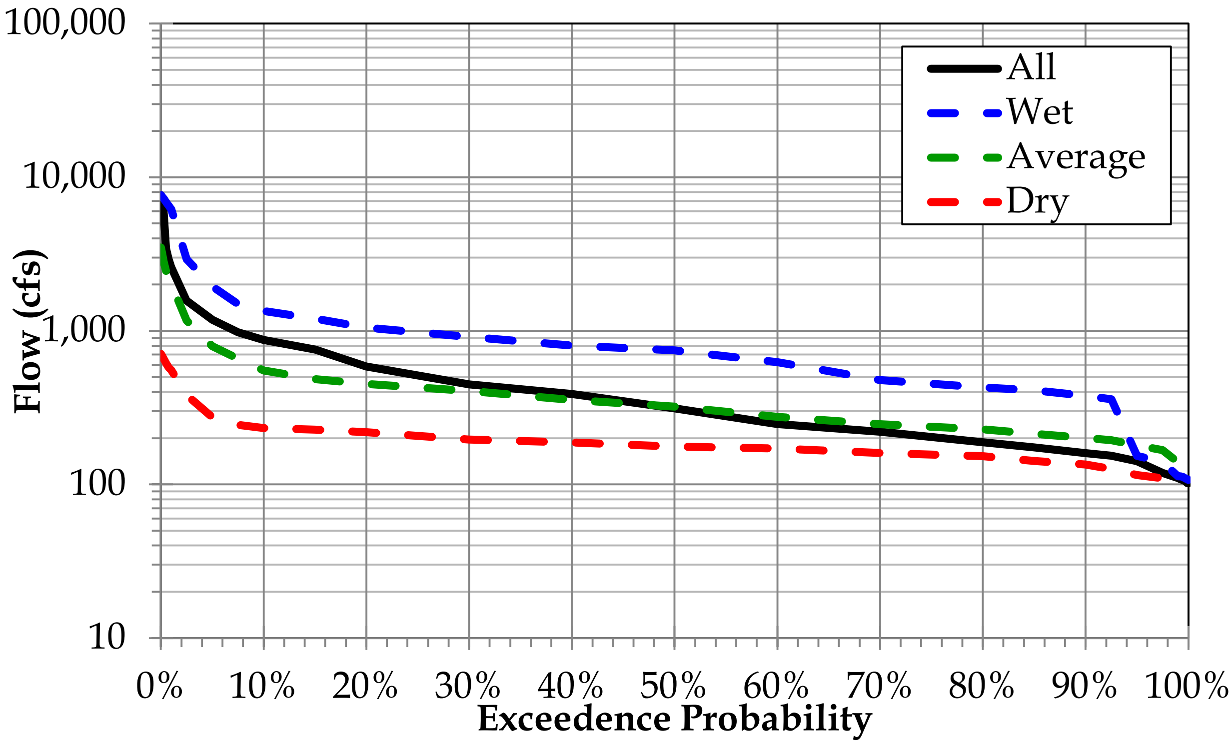


Figure A-51. March flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

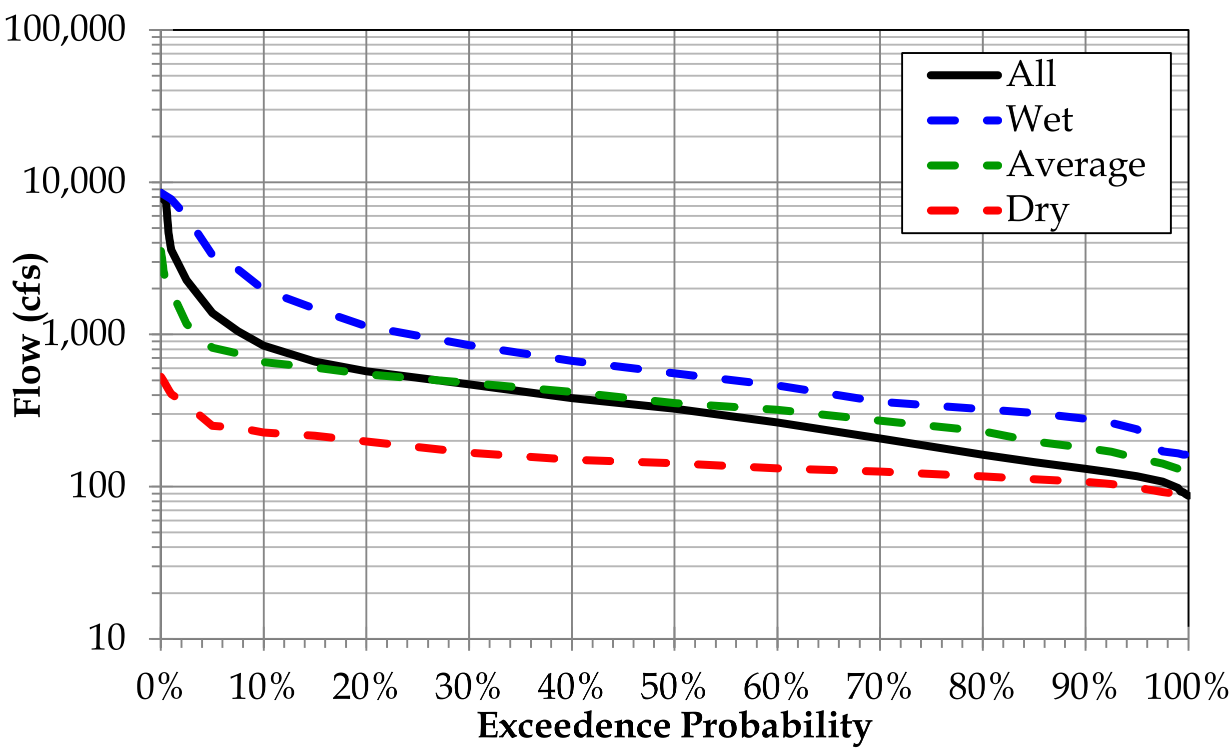


Figure A-52. April flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

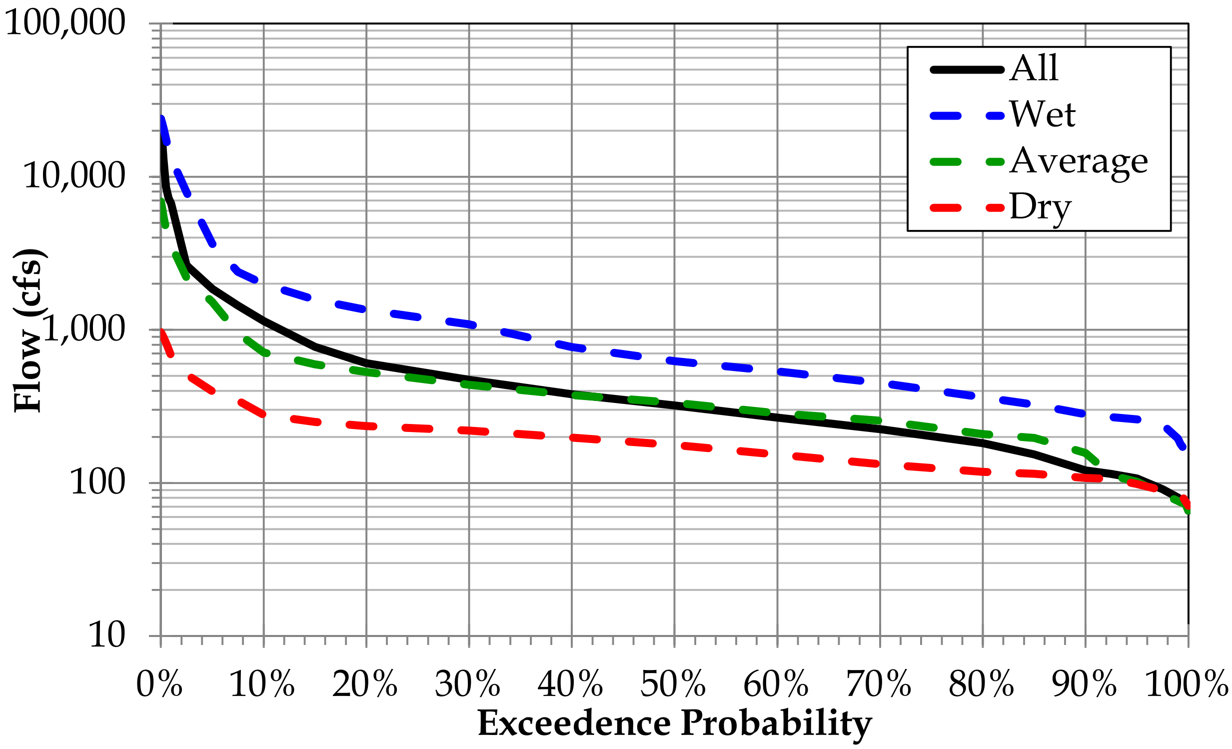


Figure A-53. May flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

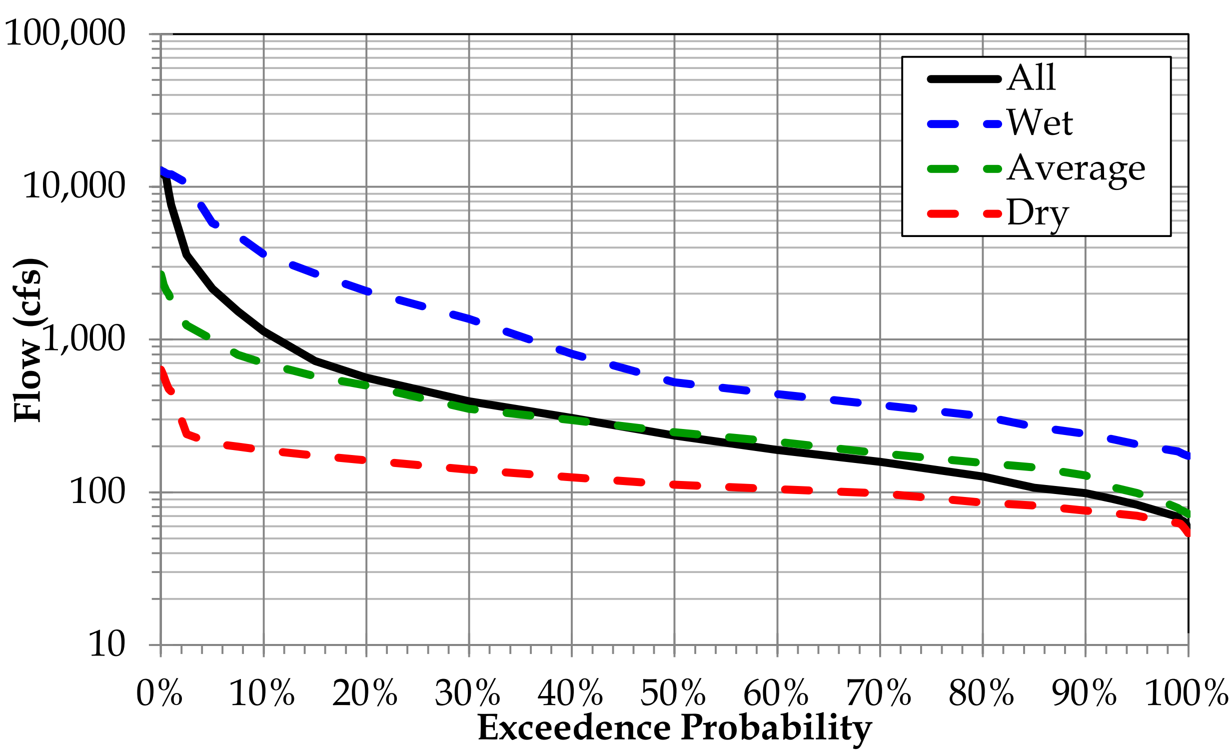


Figure A-54. June flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

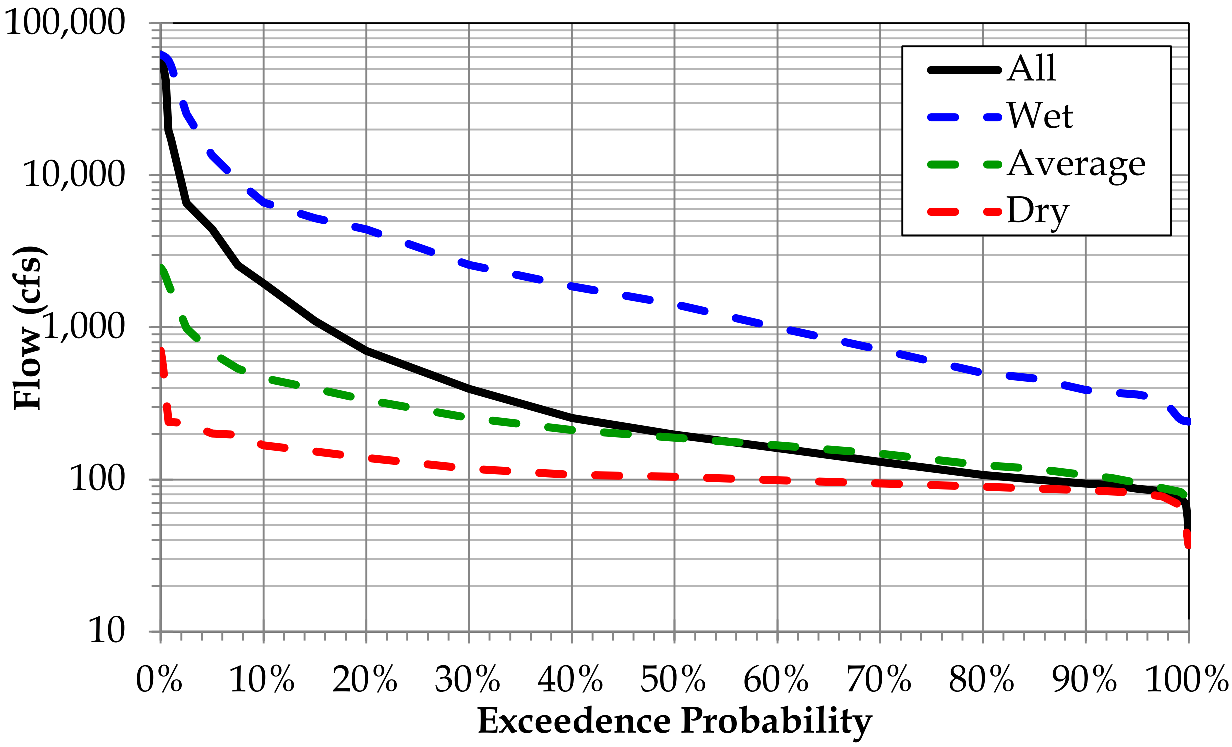


Figure A-55. July flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

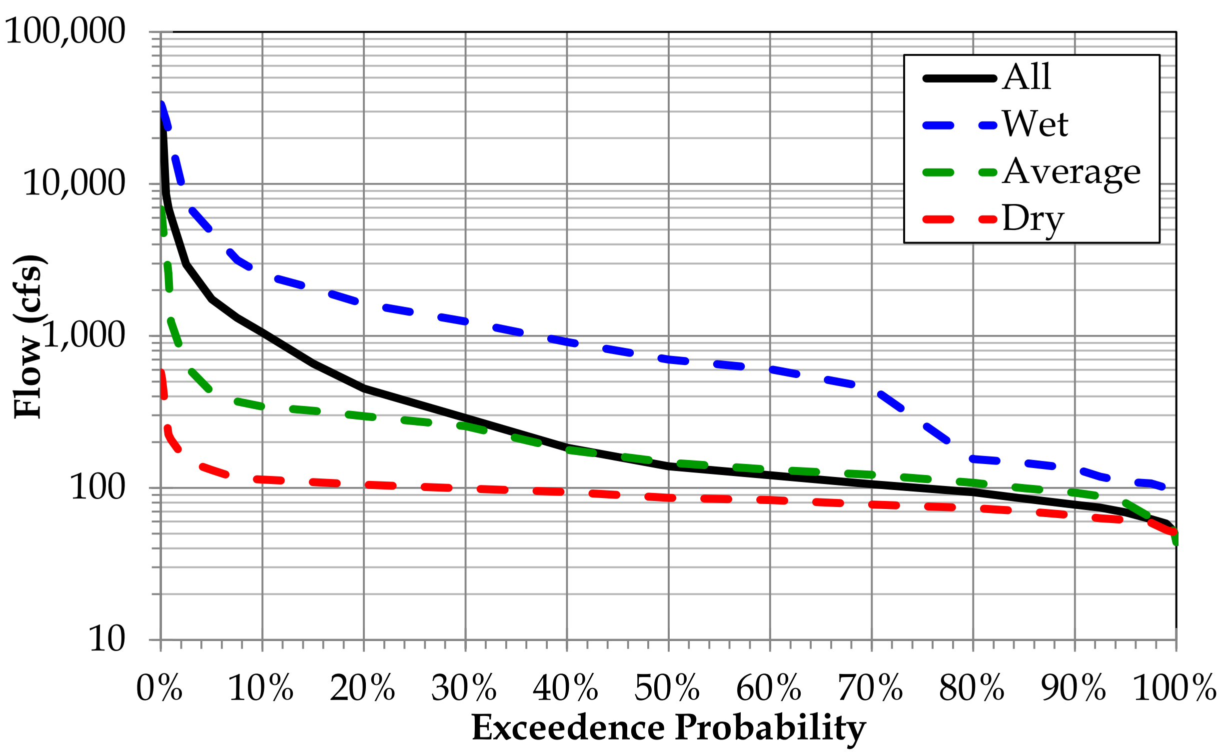


Figure A-56. August flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

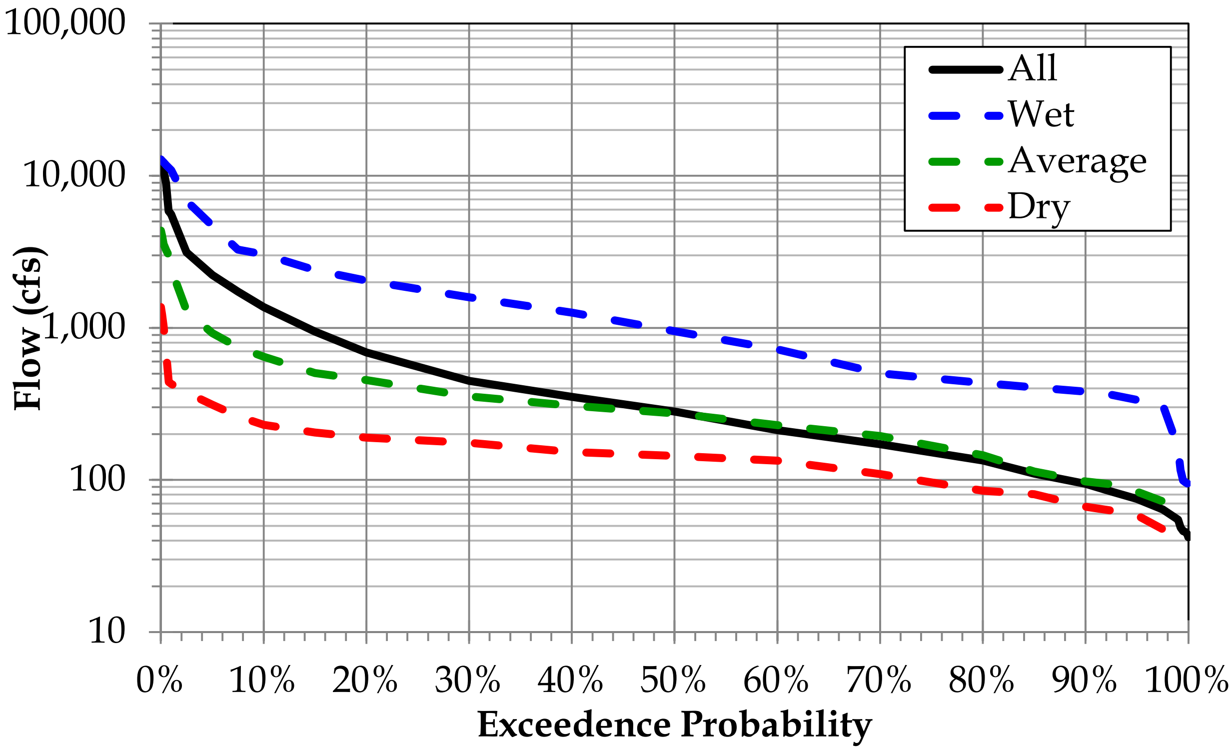


Figure A-57. September flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

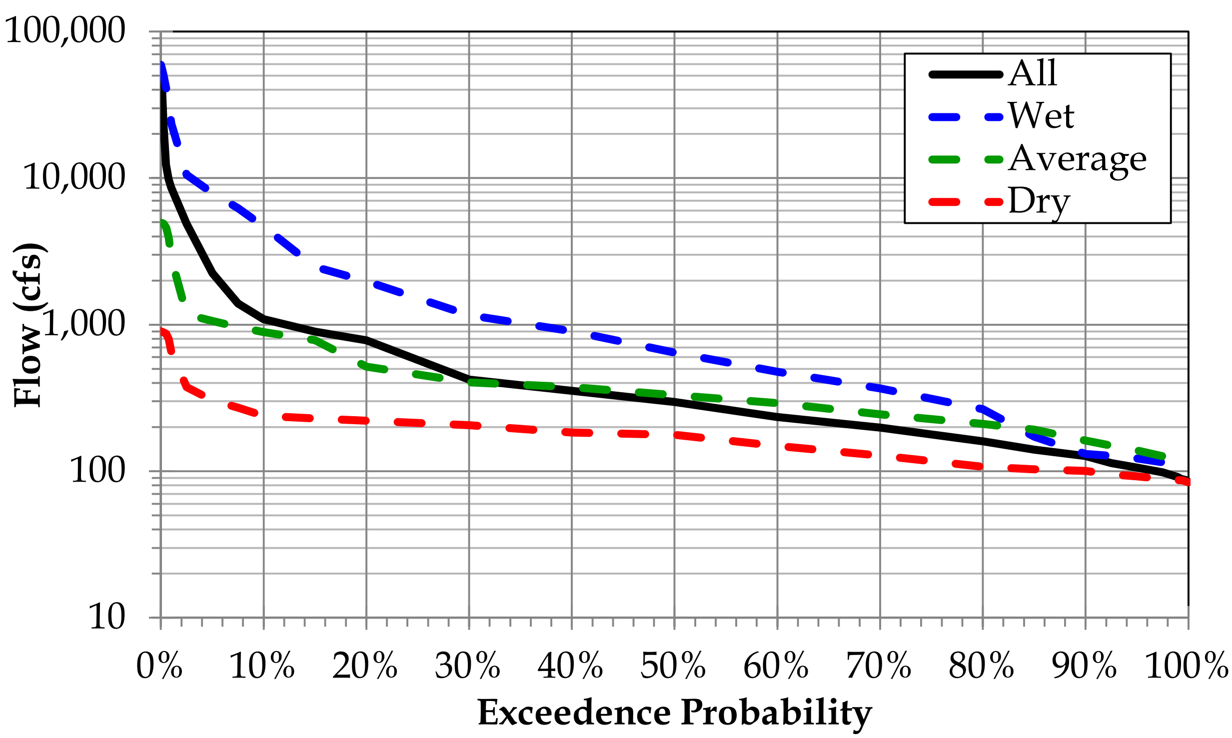


Figure A-58. October flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

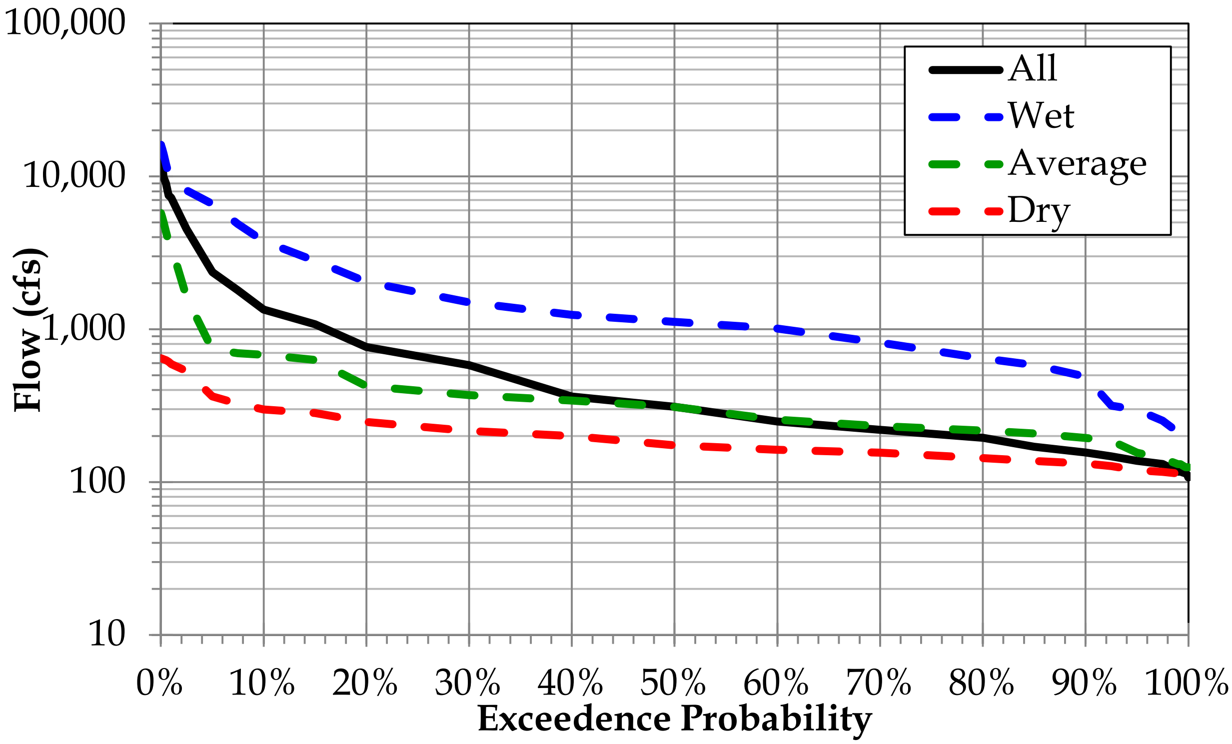


Figure A-59. November flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

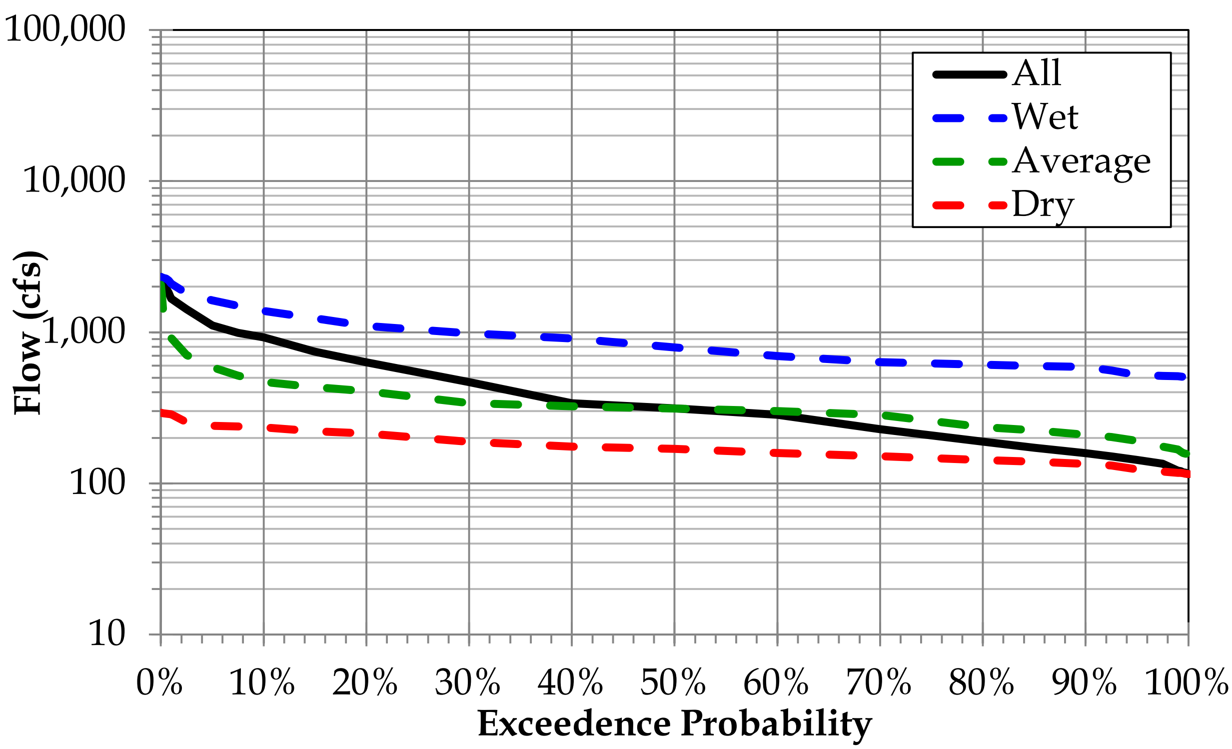


Figure A-60. December flow duration curves for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Table A-8. Monthly flow exceedance statistics for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	January*				February**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	5,750	658	5,750	5,160	4,970	310	861	4,970
0.01	5,385	607	5,101	5,100	4,203	306	847	4,780
0.25	4,946	530	4,128	5,010	3,225	301	827	4,494
0.50	3,586	402	3,285	4,860	2,514	292	776	4,018
0.75	2,472	322	2,729	4,324	2,363	283	720	3,563
1.00	1,955	313	2,170	3,215	2,157	279	692	3,234
2.50	1,211	283	1,315	1,409	1,564	268	560	2,450
5.00	933	271	790	1,143	998	253	539	2,140
7.50	856	265	602	1,000	922	245	504	1,765
10.00	810	264	576	980	748	232	480	1,570
15.00	654	259	546	919	616	223	463	1,150
20.00	584	254	503	863	512	216	440	1,000
30.00	493	238	445	809	438	201	424	923
40.00	392	229	360	748	398	172	399	734
50.00	310	217	323	612	313	164	340	697
60.00	270	204	289	589	246	159	289	586
70.00	248	193	270	528	219	154	244	493
80.00	219	171	242	447	191	149	224	398
85.00	204	161	222	435	170	147	214	343
90.00	192	150	206	369	158	145	206	297
92.50	179	146	200	308	152	143	194	253
95.00	161	141	185	271	147	141	190	238
97.50	148	137	168	254	143	137	178	220
99.00	140	135	154	248	137	135	138	206
99.25	138	134	150	248	136	134	137	206
99.50	136	134	148	246	134	133	132	203
99.75	135	133	147	242	130	133	127	200
99.90	134	133	144	240	126	132	125	198
100.00	133	133	142	238	123	132	123	197

*For January at this gage, Dry years were 1996, 1997, 2000, 2009 and 2014. Wet years were 2001, 2003, 2005, 2008, and 2010.

** For February at this gage, Dry years were 2006, 2007, 2009, 2014, and 2015. Wet years were 1998, 2003, 2005, 2010, and 2012.

Table A-8 (continued). Monthly flow exceedance statistics for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	March*				April**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	7,650	708	3,490	7,650	8,520	527	3,530	8,520
0.01	7,031	689	3,224	7,496	8,197	514	3,156	8,440
0.25	6,163	660	2,826	7,265	7,726	495	2,596	8,319
0.50	3,441	613	2,423	6,880	7,440	462	2,176	8,118
0.75	2,938	576	2,190	6,512	4,622	432	2,036	7,920
1.00	2,605	555	2,021	6,169	3,612	406	1,931	7,730
2.50	1,573	382	1,166	2,928	2,283	348	1,170	5,961
5.00	1,181	273	796	1,950	1,383	251	819	3,322
7.50	981	244	658	1,499	1,051	243	748	2,675
10.00	874	233	551	1,346	843	227	658	1,968
15.00	757	227	486	1,198	662	216	606	1,473
20.00	587	219	451	1,050	573	198	547	1,130
30.00	447	196	406	914	471	167	480	852
40.00	388	188	355	802	382	150	419	670
50.00	313	176	321	745	326	143	354	555
60.00	247	171	275	624	265	132	320	461
70.00	221	160	247	477	207	126	271	361
80.00	188	153	228	428	162	117	231	323
85.00	174	142	214	410	145	112	198	305
90.00	160	135	201	377	131	108	180	280
92.50	154	126	194	358	124	104	169	262
95.00	142	115	179	153	117	98	154	238
97.50	118	110	167	140	108	92	141	171
99.00	110	107	140	113	98	89	131	166
99.25	108	106	122	113	93	89	125	164
99.50	107	105	113	112	92	88	122	163
99.75	104	104	109	109	89	88	121	162
99.90	102	103	105	108	88	87	119	162
100.00	102	102	102	107	87	87	118	162

*For March at this gage, Dry years were 1996, 2009, 2011, 2013 and 2014. Wet years were 1998, 2003, 2004, 2005, and 2007.

** For April at this gage, Dry years were 1996, 2006, 2011, 2012, and 2014. Wet years were 2001, 2004, 2007, 2010, and 2015.

Table A-8 (continued). Monthly flow exceedance statistics for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	May*				June**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	23,900	966	6,890	23,900	12,800	635	2,670	12,800
0.01	18,700	936	6,309	22,606	12,381	612	2,515	12,696
0.25	13,146	891	5,438	20,666	12,050	578	2,281	12,539
0.50	8,530	817	4,519	17,432	11,702	520	2,096	12,279
0.75	7,243	743	3,948	14,834	9,289	475	1,982	12,088
1.00	6,685	672	3,571	13,178	7,607	456	1,802	12,051
2.50	2,638	511	2,189	7,896	3,587	240	1,236	10,613
5.00	1,850	397	1,520	3,651	2,150	209	1,003	5,796
7.50	1,437	346	951	2,397	1,532	199	795	4,793
10.00	1,143	279	712	1,994	1,132	189	702	3,610
15.00	773	250	594	1,578	725	174	576	2,711
20.00	605	235	530	1,348	563	162	499	2,074
30.00	473	220	438	1,088	395	141	351	1,366
40.00	379	198	374	773	307	125	297	805
50.00	321	177	334	624	235	112	248	524
60.00	267	154	286	535	189	105	214	438
70.00	225	132	255	450	158	99	180	373
80.00	182	118	209	363	127	86	156	315
85.00	154	115	197	325	107	82	146	268
90.00	121	108	157	281	99	76	129	242
92.50	114	106	112	269	91	73	108	224
95.00	107	98	102	260	83	70	99	206
97.50	91	90	85	241	74	65	87	193
99.00	80	85	76	195	69	63	79	185
99.25	77	84	75	179	65	62	77	181
99.50	74	80	74	170	65	60	75	178
99.75	73	76	72	166	63	57	74	176
99.90	69	73	68	163	59	55	73	174
100.00	66	71	66	161	54	54	72	173

*For May at this gage, Dry years were 1996, 1998, 2002, 2009 and 2011. Wet years were 2004, 2007, 2010, 2013, and 2015.

** For June at this gage, Dry years were 1996, 2006, 2008, 2009, and 2012. Wet years were 1997, 2000, 2004, 2007, and 2015.

Table A-8 (continued). Monthly flow exceedance statistics for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	July*				August**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	62,400	703	2,470	62,400	33,400	575	6,820	33,400
0.01	60,172	632	2,414	61,846	27,891	522	6,057	32,029
0.25	52,449	524	2,331	61,014	19,080	443	4,912	29,974
0.50	41,919	346	2,121	59,628	8,586	310	3,723	26,547
0.75	19,851	239	1,907	57,002	6,927	224	2,581	22,966
1.00	17,377	239	1,738	52,536	6,057	208	1,237	19,154
2.50	6,605	234	988	25,385	2,959	150	630	7,363
5.00	4,422	201	679	13,550	1,745	131	427	4,827
7.50	2,562	196	537	9,224	1,316	115	371	3,153
10.00	1,950	167	464	6,652	1,051	114	343	2,528
15.00	1,103	153	396	5,246	657	109	322	2,054
20.00	704	139	333	4,428	450	105	296	1,624
30.00	394	118	255	2,582	288	99	255	1,248
40.00	253	107	212	1,862	183	94	178	914
50.00	197	104	189	1,420	139	86	147	699
60.00	161	99	168	996	121	83	132	605
70.00	131	94	147	712	106	78	122	454
80.00	107	90	124	502	94	74	108	155
85.00	100	87	118	461	85	70	100	146
90.00	94	85	107	387	78	66	93	134
92.50	92	84	102	373	74	63	88	119
95.00	87	82	95	362	69	62	79	110
97.50	84	77	87	339	62	59	64	107
99.00	78	69	84	255	58	53	60	100
99.25	76	67	83	248	56	52	58	100
99.50	72	60	80	244	54	52	56	100
99.75	69	49	76	242	52	51	52	99
99.90	56	42	74	241	48	51	47	99
100.00	37	37	73	240	44	51	44	99

*For July at this gage, Dry years were 1996, 2001, 2006, 2009 and 2011. Wet years were 1997, 2002, 2003, 2004, and 2007.

** For August at this gage, Dry years were 2006, 2009, 2011, 2013, and 2014. Wet years were 1998, 2001, 2002, 2004, and 2007.

Table A-8 (continued). Monthly flow exceedance statistics for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	September*				October**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	12,800	1,370	4,360	12,800	59,100	900	4,950	59,100
0.01	11,961	1,232	4,037	12,591	44,492	893	4,919	55,466
0.25	10,853	1,025	3,553	12,279	23,345	883	4,873	50,014
0.50	8,957	680	3,235	11,757	12,281	866	4,599	40,928
0.75	5,857	440	3,001	11,271	9,847	797	3,920	32,059
1.00	5,571	428	2,418	10,861	8,621	651	2,843	23,512
2.50	3,141	375	1,291	6,826	4,903	374	1,170	10,545
5.00	2,231	313	923	4,703	2,252	305	1,060	7,903
7.50	1,731	263	747	3,272	1,392	272	965	6,240
10.00	1,370	230	646	3,034	1,091	239	890	4,662
15.00	947	205	504	2,397	897	229	784	2,479
20.00	689	189	454	2,044	781	221	518	1,974
30.00	448	175	354	1,589	422	206	404	1,160
40.00	352	152	308	1,262	354	184	374	904
50.00	282	144	275	953	296	177	331	646
60.00	213	134	230	723	235	149	292	477
70.00	172	109	195	503	199	128	244	367
80.00	134	85	145	435	160	107	210	265
85.00	110	81	114	406	140	103	192	172
90.00	94	67	98	382	127	100	162	131
92.50	84	63	94	364	113	95	149	127
95.00	75	58	84	337	106	92	138	122
97.50	64	47	72	313	98	89	127	115
99.00	55	45	67	165	91	87	107	112
99.25	48	45	67	116	89	87	105	111
99.50	46	44	65	99	88	86	101	110
99.75	45	43	62	97	87	85	97	109
99.90	44	42	62	95	86	84	97	108
100.00	42	42	61	94	84	84	97	108

*For September at this gage, Dry years were 1999, 2000, 2011, 2014 and 2015. Wet years were 2001, 2002, 2003, 2007, and 2010.

** For October at this gage, Dry years were 1996, 1999, 2006, 2008, and 2014. Wet years were 1998, 2002, 2004, 2009, and 2015.

Table A-8 (continued). Monthly flow exceedance statistics for USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996-2015. "Wet" data from five wettest, "Average" data from ten central tendency, and "Dry" data from five driest months by volume.

Exceedence Probability (%)	Time Period 1996-2015							
	November*				December**			
	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)	All (cfs)	Dry (cfs)	Average (cfs)	Wet (cfs)
0.00	16,100	646	5,760	16,100	2,320	293	2,060	2,320
0.01	12,746	642	5,461	15,266	2,270	292	1,739	2,308
0.25	9,928	636	5,013	14,014	2,141	291	1,257	2,289
0.50	8,992	626	4,280	11,928	1,963	289	1,015	2,258
0.75	7,529	612	3,712	10,365	1,829	288	983	2,198
1.00	7,250	591	3,473	9,936	1,672	286	915	2,094
2.50	4,536	533	1,613	8,106	1,421	254	705	1,807
5.00	2,362	364	739	6,624	1,111	241	586	1,623
7.50	1,800	325	697	4,876	991	237	518	1,497
10.00	1,343	298	680	3,764	925	234	468	1,380
15.00	1,080	283	631	2,806	743	221	433	1,238
20.00	764	247	423	2,042	632	214	406	1,102
30.00	581	216	371	1,499	468	188	339	982
40.00	363	200	341	1,240	339	175	324	910
50.00	311	174	310	1,115	313	169	313	793
60.00	250	163	255	1,010	285	159	300	695
70.00	220	156	232	816	228	151	284	634
80.00	195	144	217	644	189	143	236	610
85.00	170	137	208	584	172	139	224	597
90.00	156	132	194	490	158	134	210	588
92.50	147	127	186	316	151	131	202	559
95.00	138	119	156	297	143	124	191	522
97.50	131	116	142	252	134	120	175	515
99.00	117	114	131	212	121	118	167	510
99.25	117	114	131	207	121	117	162	508
99.50	115	112	128	200	118	117	159	507
99.75	114	110	125	193	118	116	157	506
99.90	111	108	125	189	116	115	157	505
100.00	107	107	125	186	115	115	157	505

*For November at this gage, Dry years were 2005, 2008, 2011, 2012 and 2013. Wet years were 1998, 2000, 2001, 2002, and 2004.

** For December at this gage, Dry years were 1999, 2008, 2012, 2013, and 2014. Wet years were 1998, 2001, 2002, 2004, and 2007.

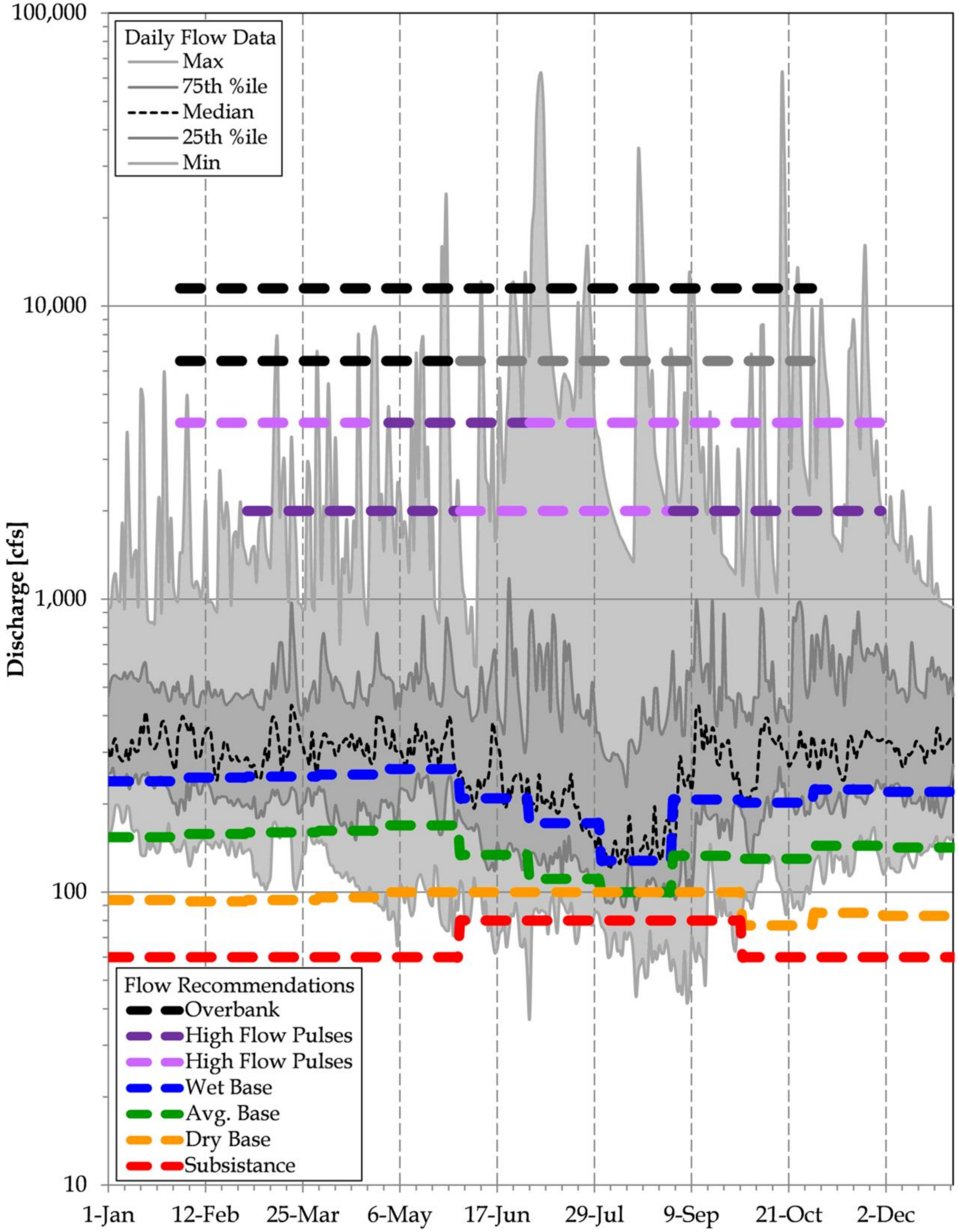


Figure A-61. Instream flow recommendations for the Calaveras Study Site versus flow data from USGS Gage No. 08181800 San Antonio River near Elmendorf, Texas for 1996 to 2015.

Table A-9. Average triangular mesh properties for River2D models.

Study Site	Base (meters)	Height (meters)	Area (m^2)	Base (feet)	Height (feet)	Area (ft^2)
Calaveras	2.0	1.7	1.7	6.6	5.7	18.8
Falls City	4.0	3.5	7.0	13.1	11.5	75.3
Goliad	2.6	2.3	3.0	8.5	7.5	31.9
Hwy 77	2.6	2.3	3.0	8.5	7.5	31.9
Cibolo Creek	1.7	1.5	1.3	5.6	4.9	13.7

Table A-10. Viscosity parameters used for calibrated River2D models.

Study Site	Minimum Depth ε_1	Bed Shear ε_2	Horizontal Shear ε_3
Calaveras	0.001	0.3	0.1
Falls City	0.001	0.3	0.1
Goliad	0.000	0.5	0.0
Hwy 77	0.001	0.3	0.1
Cibolo Creek	0.001	0.3	0.1

Note: Default values for ε_1, ε_2, and ε_3 are 0, 0.5, and 0, respectively. Vales of ε_2 from 0.2 to 1.0 are considered reasonable (Steffler and Blackburn 2002).

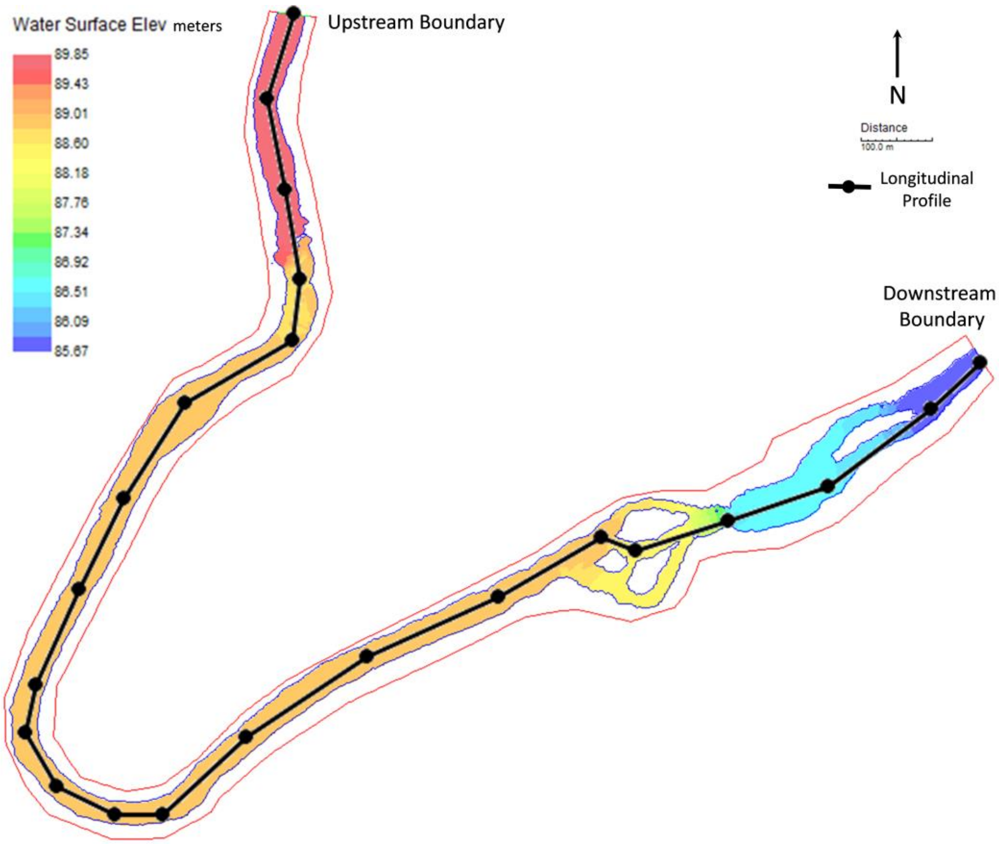


Figure A-62. Modeled water surface elevation for flow of 757 cfs and longitudinal transect location for Falls City Study Site.

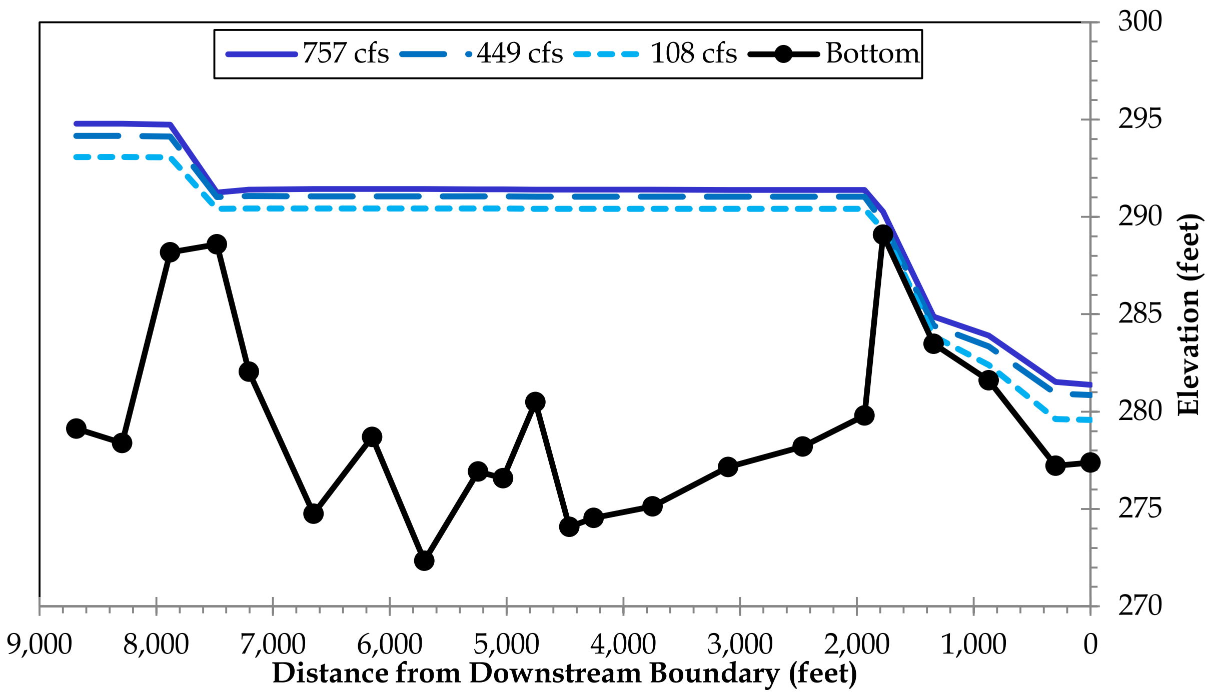


Figure A-63. Longitudinal profile and modeled water surface elevation for select flows for Falls City Study Site.

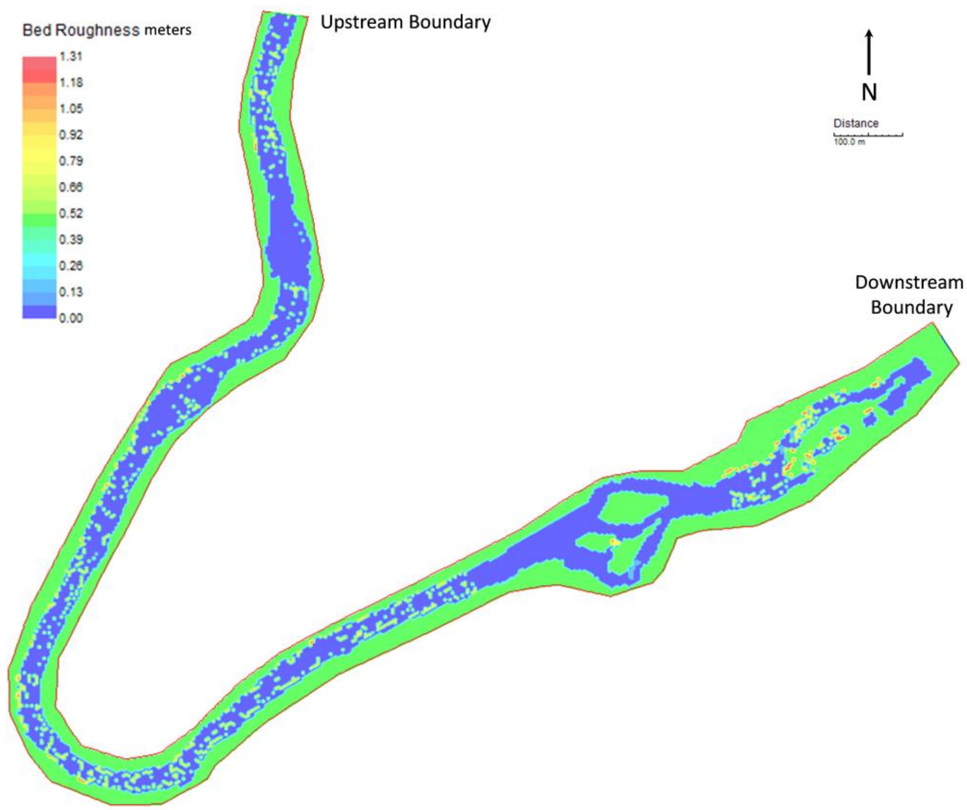


Figure A-64. Bed roughness values for calibrated River2D model of Falls City Study Site.

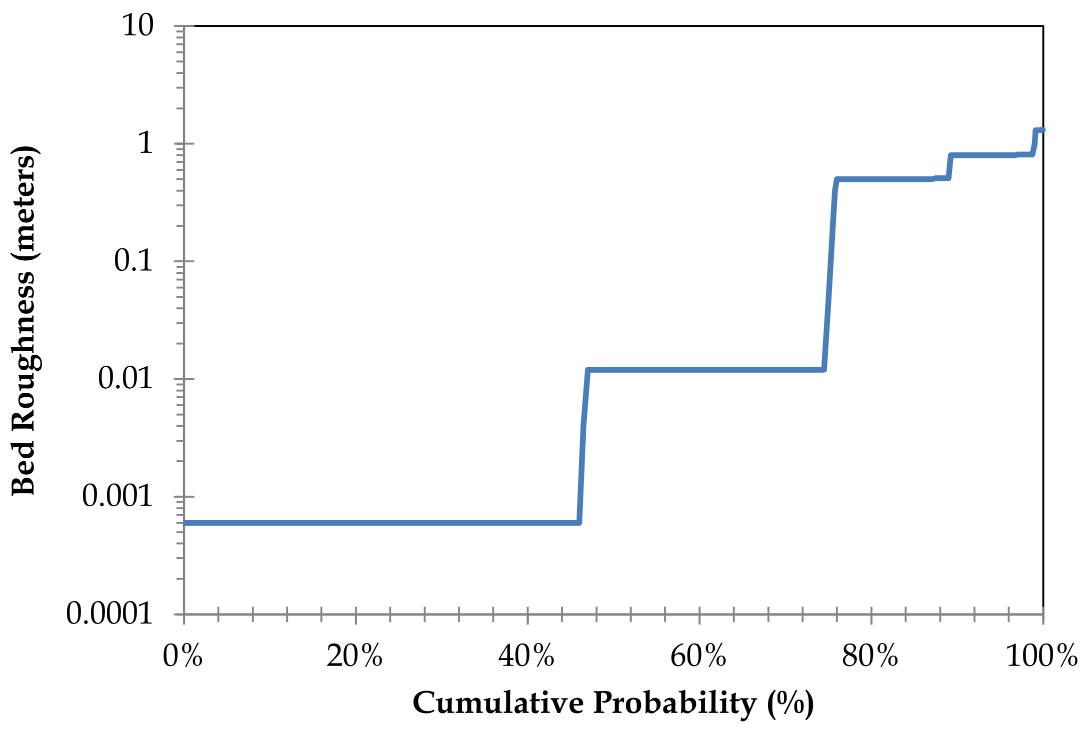


Figure A-65. Cumulative distribution of bed roughness values for wetted area of calibrated River2D model of Falls City Study Site at a flow rate of 757 cfs.

Table A-11. Cumulative distribution of bed roughness values for wetted area of calibrated River2D model of Falls City Study Site at a flow rate of 757 cfs.

Cumulative Probability (%)	Bed Roughness (meters)
0%	0.0006
5%	0.0006
10%	0.0006
15%	0.0006
20%	0.0006
25%	0.0006
30%	0.0006
35%	0.0006
40%	0.0006
45%	0.0006
50%	0.0120
55%	0.0120
60%	0.0120
65%	0.0120
70%	0.0120
75%	0.0480
80%	0.5000
85%	0.5000
90%	0.8006
95%	0.8006
100%	1.3100

Note: Typical values of bed roughness range from one to three times substrate diameter (Stefflar and Blackburn 2002).

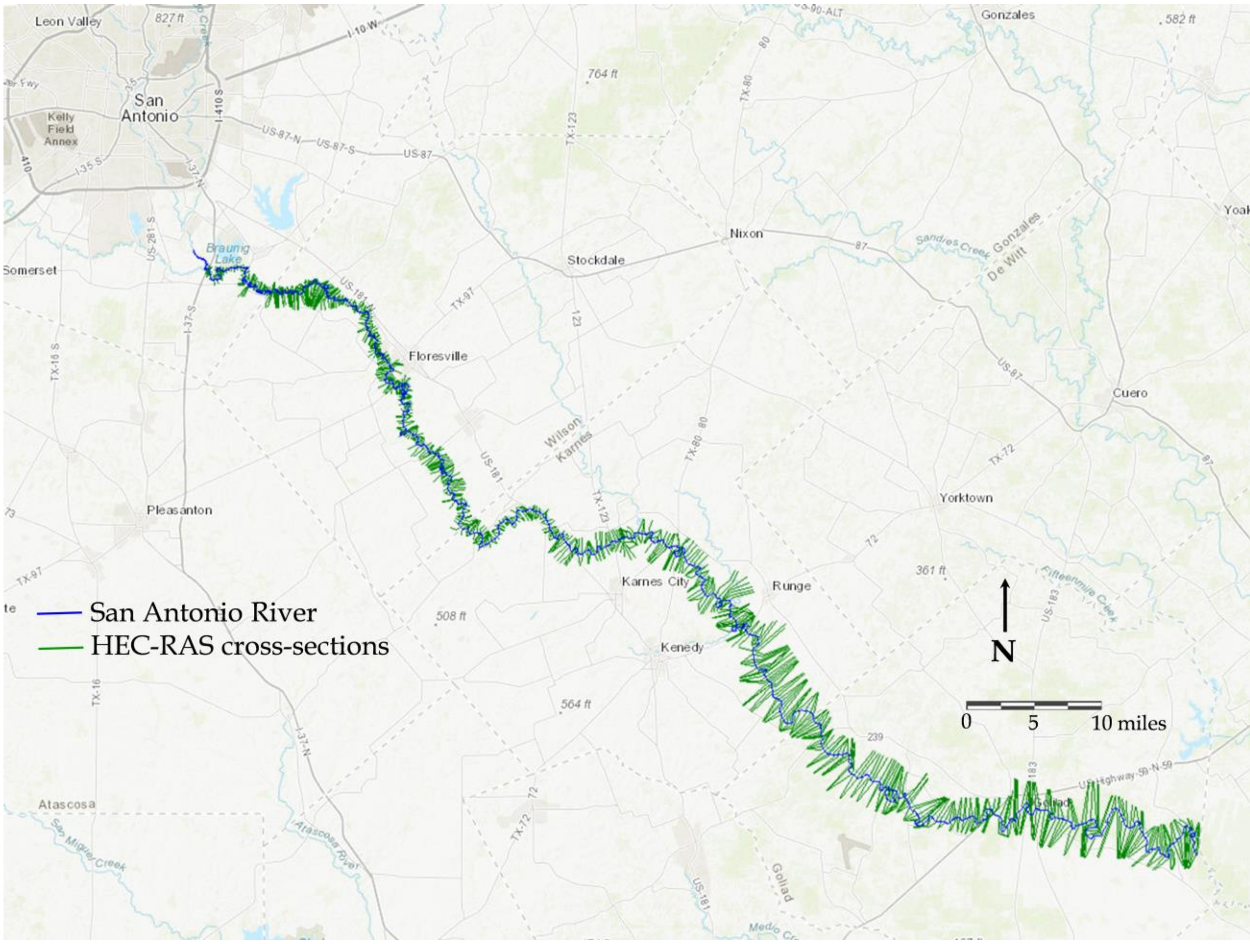


Figure A-66. Approximatel location of 717 cross-sections used in HEC-RAS model of San Antonio River from river mile 43.8 to river mile 218.8.

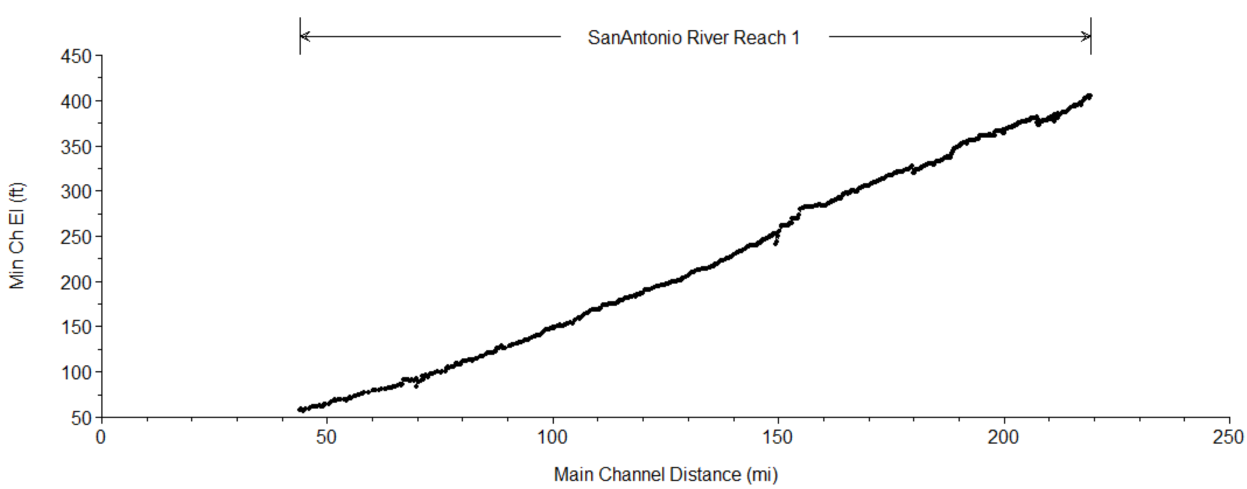


Figure A-67. Longitudinal profile of minimum channel elevation of HEC-RAS model of San Antonio River.

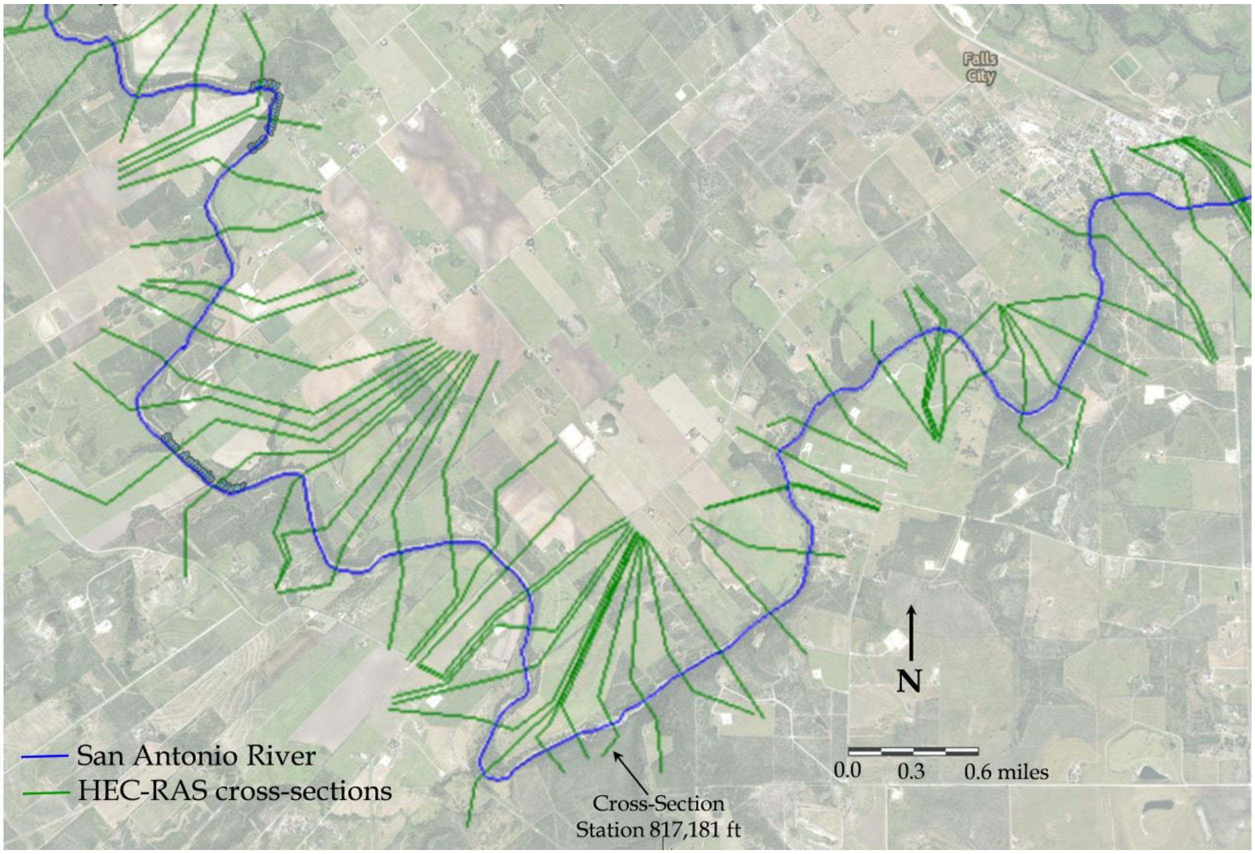


Figure A-68. Longitudinal profile of minimum channel elevation of HEC-RAS model of San Antonio River.

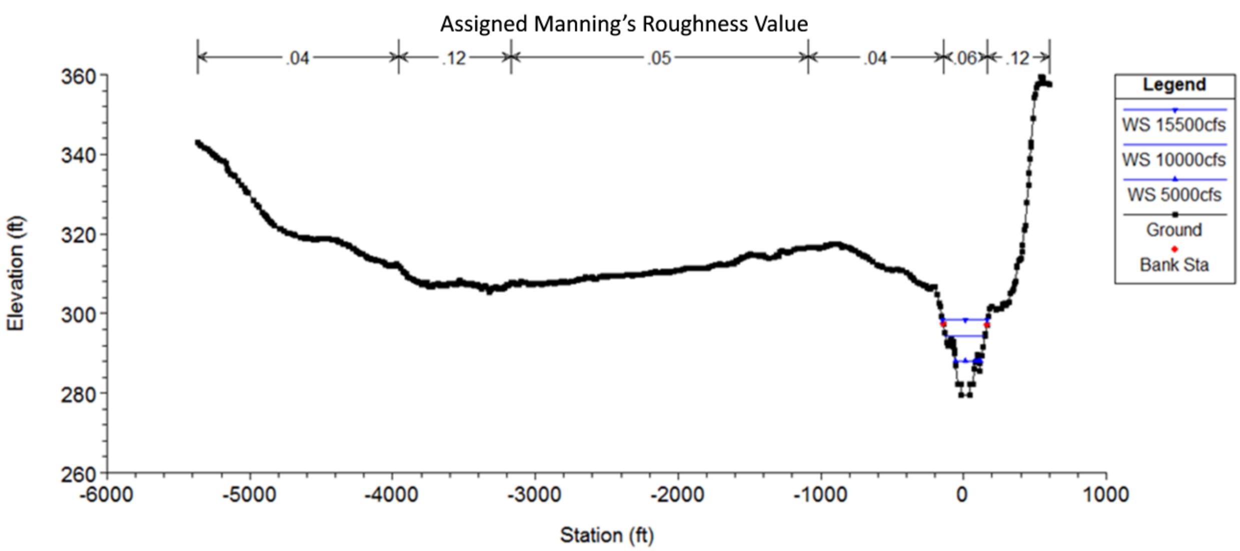


Figure A-69. Valley cross-section at Station 817,181 feet with assigned roughness values and water surface elevations for select flow rates.

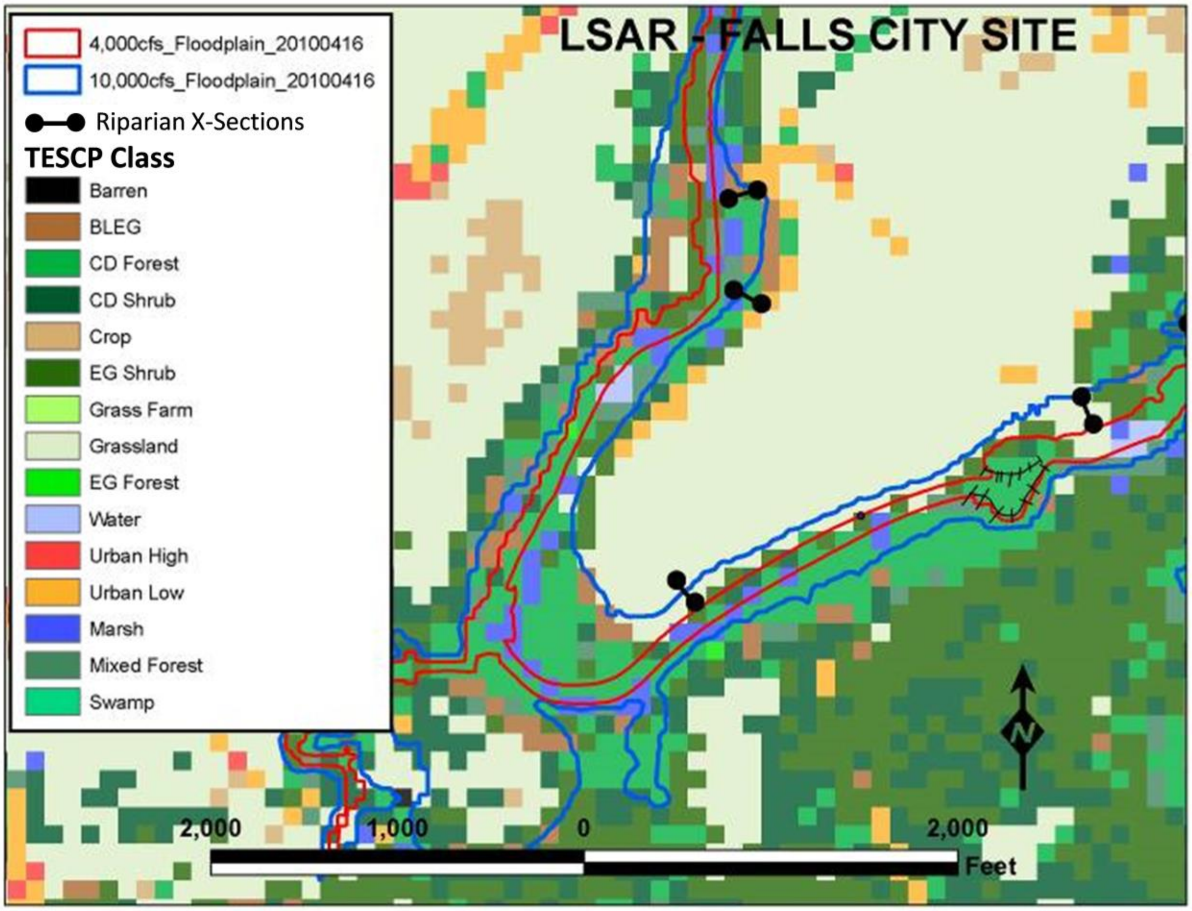
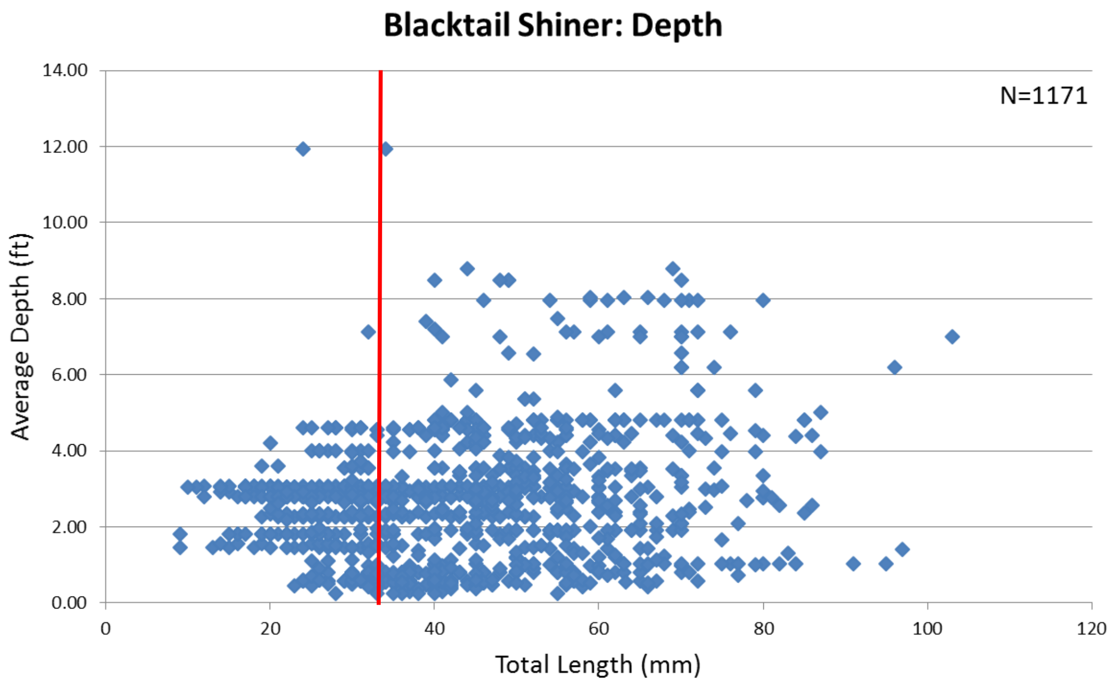


Figure A-70. Modeled floodplain inundation and Texas Ecological Systems Classification Project land classification for Falls City Study Site (from a presentation given by T. Osting on October 15, 2010 to the TIFP lower San Antonio River study partners).

APPENDIX B
FISHERIES SIZE CLASS FIGURES



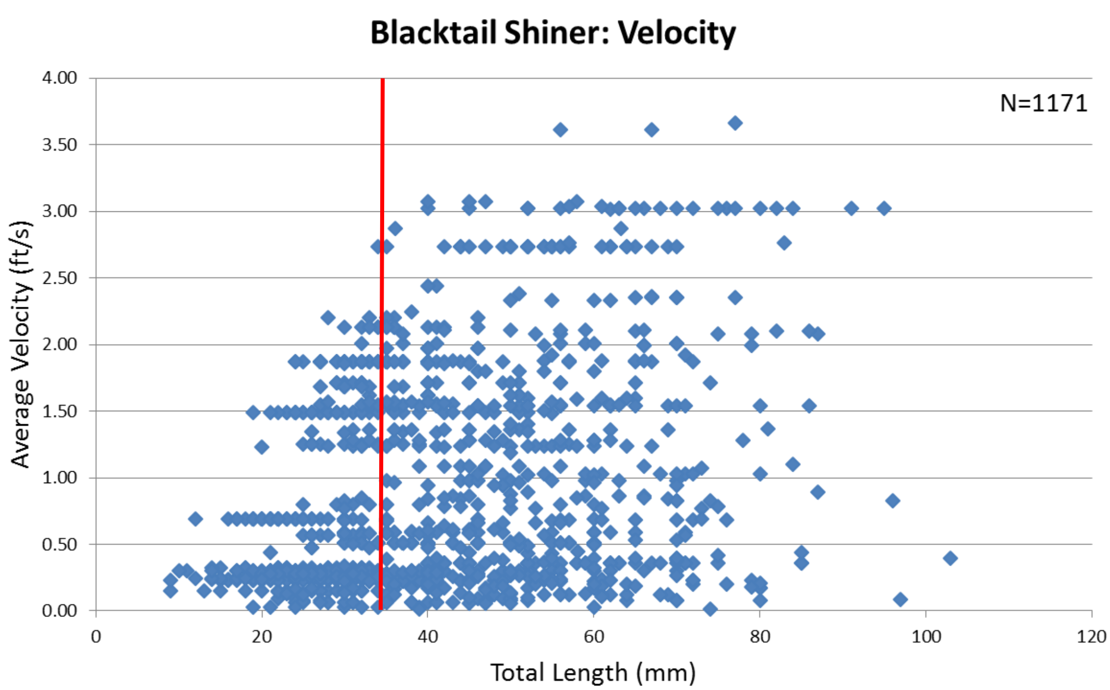
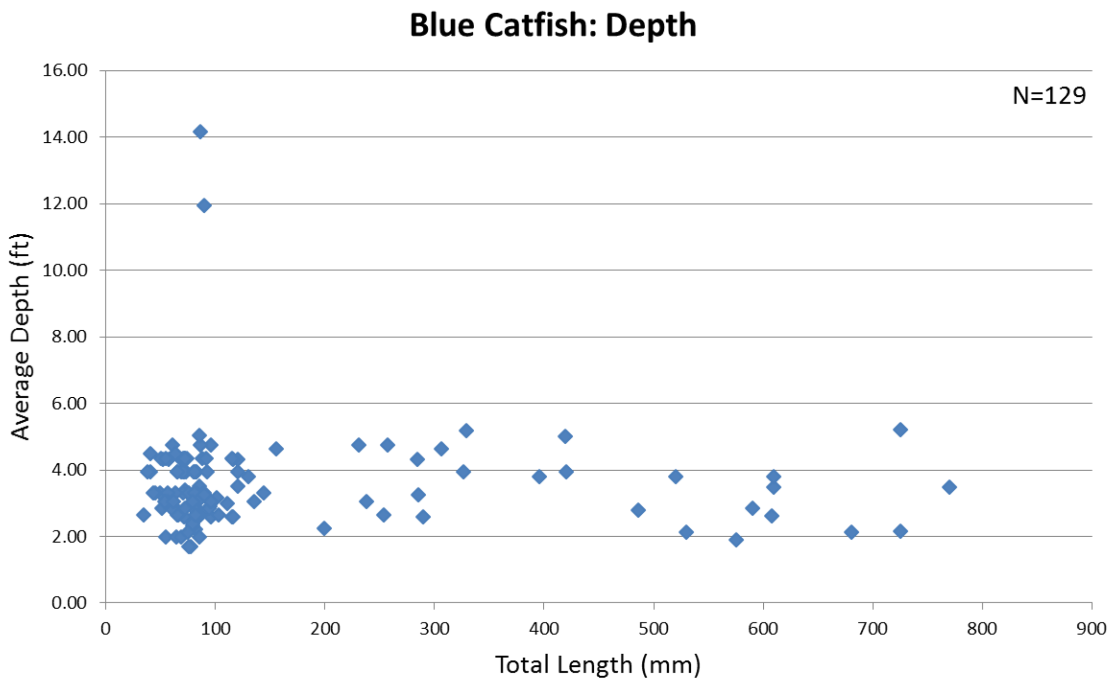


Figure B-1. Average depth and average velocity versus total length for Blacktail Shiner *Cyprinella venusta*. The red line indicates the resulting boundary between juvenile and adult life stage categories (35 mm).



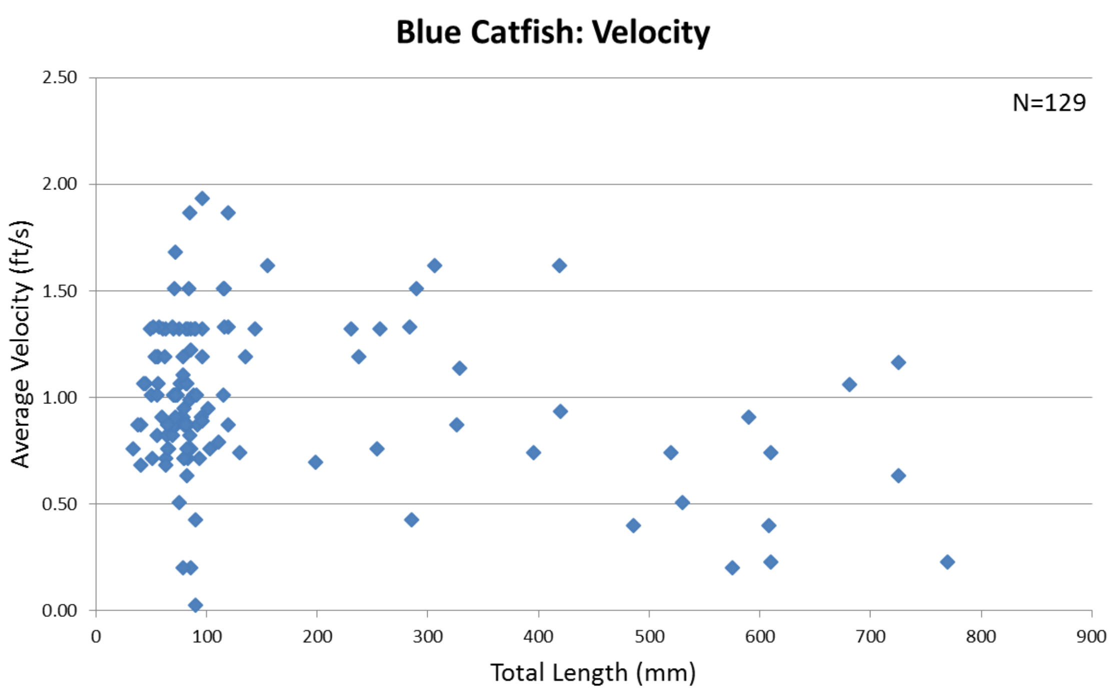


Figure B-2. Average depth and average velocity versus total length for Blue Catfish *Ictalurus furcatus*.

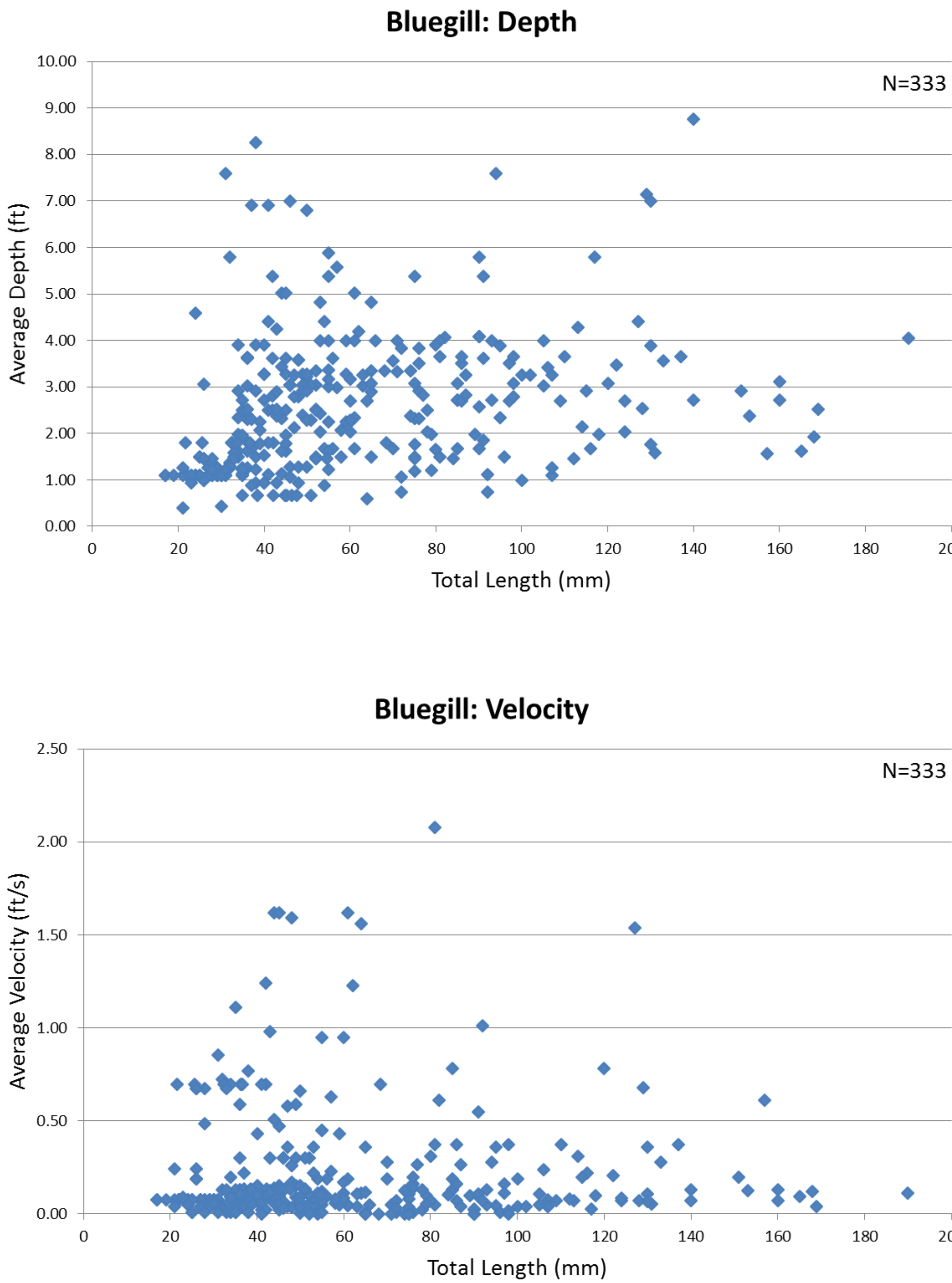
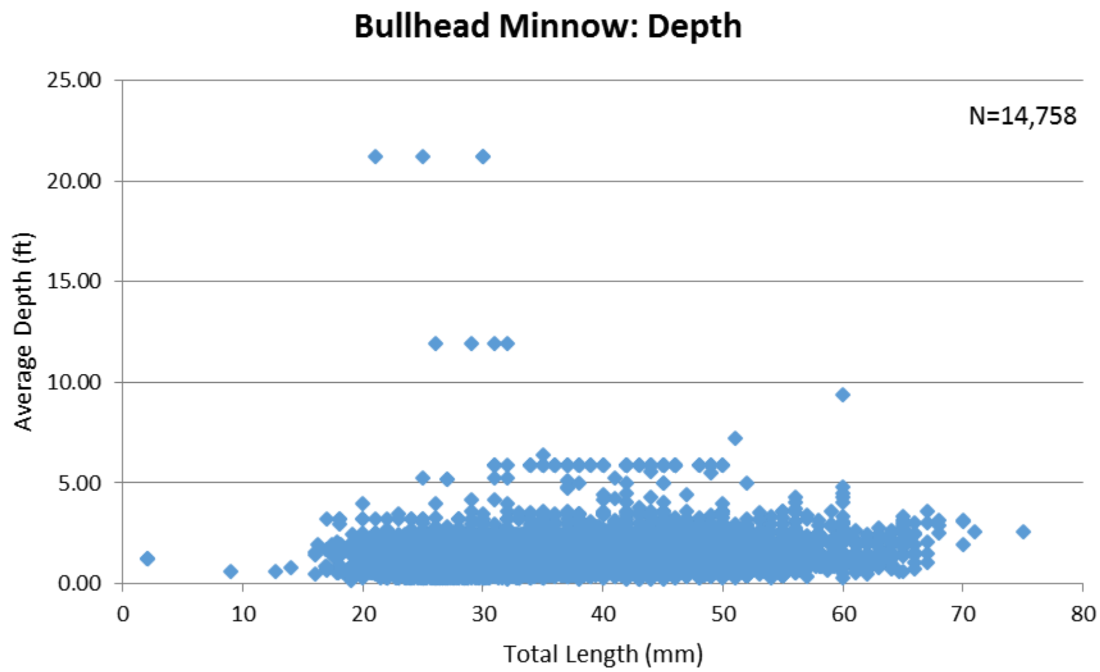


Figure B-3. Average depth and average velocity versus total length for Bluegill *Lepomis macrochirus*.



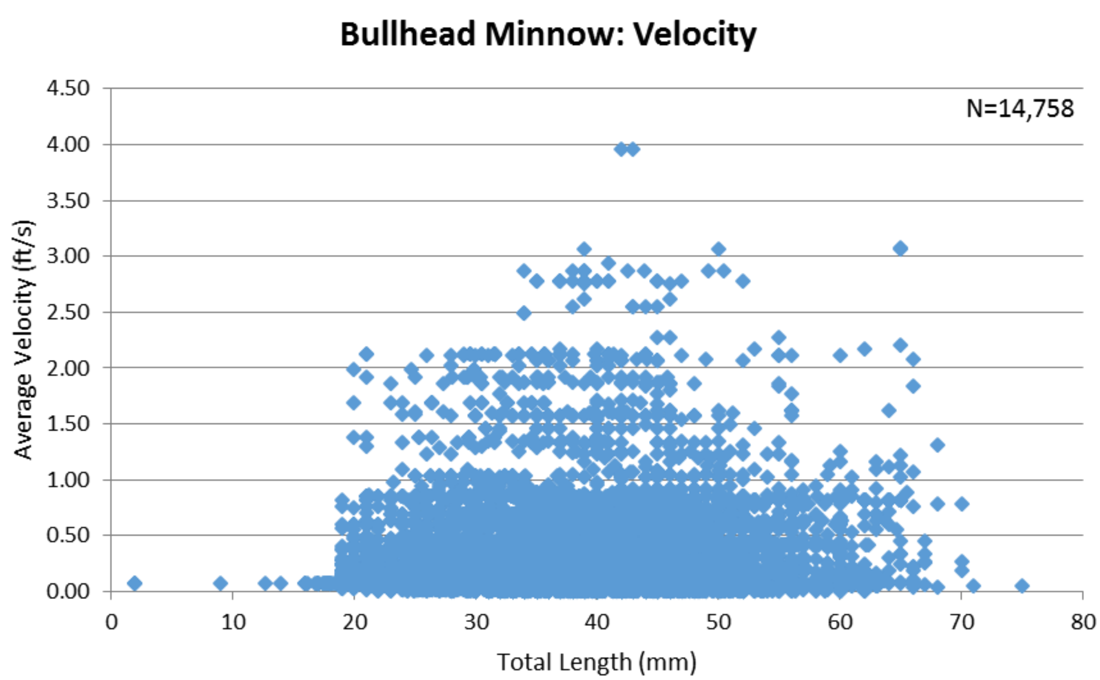
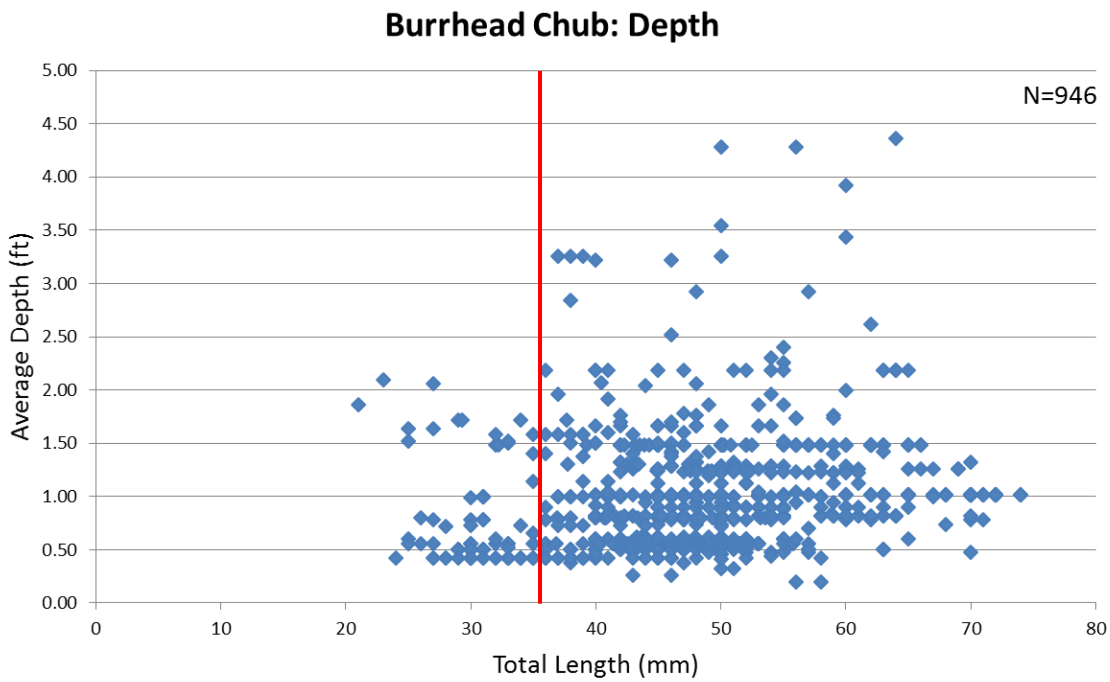


Figure B-4. Average depth and average velocity versus total length for Bullhead Minnow *Pimephales vigilax*.



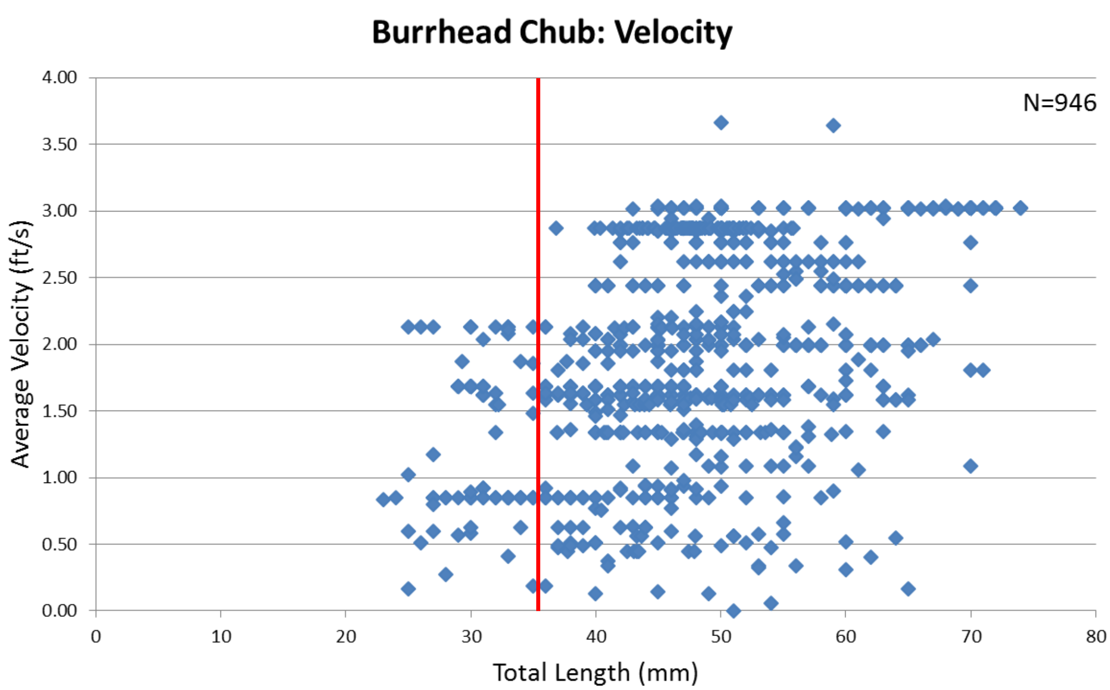
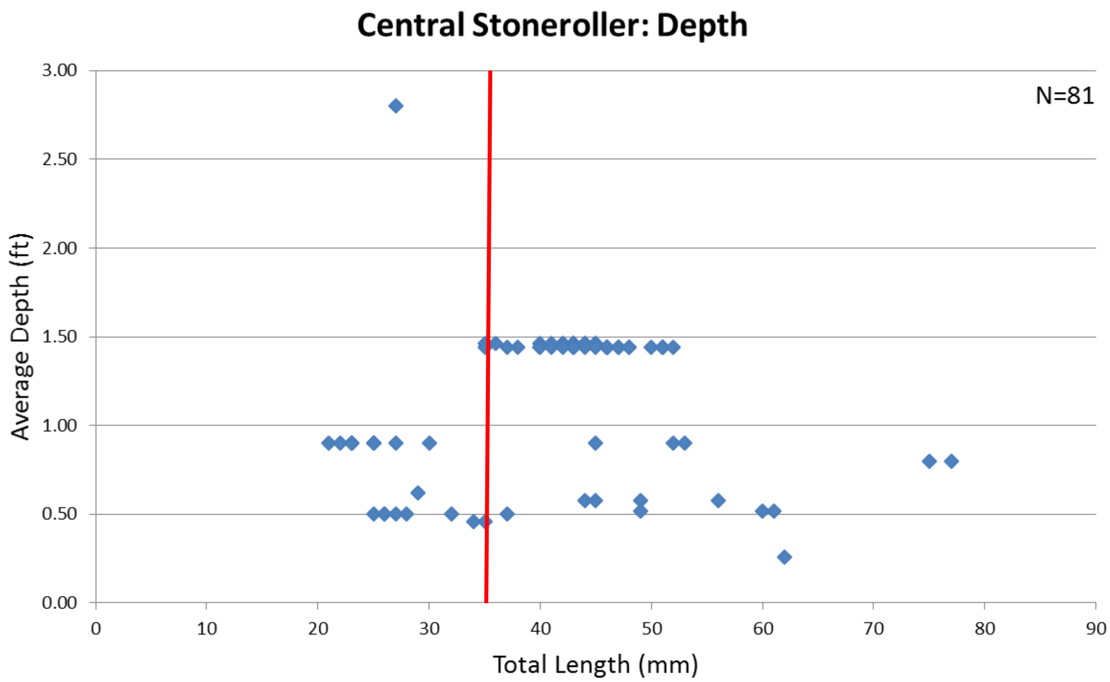


Figure B-5. Average depth and average velocity versus total length for Burrhead Chub *Macrhybopsis marconis*. The red line indicates the boundary between juvenile and adult life stage categories (35 mm).



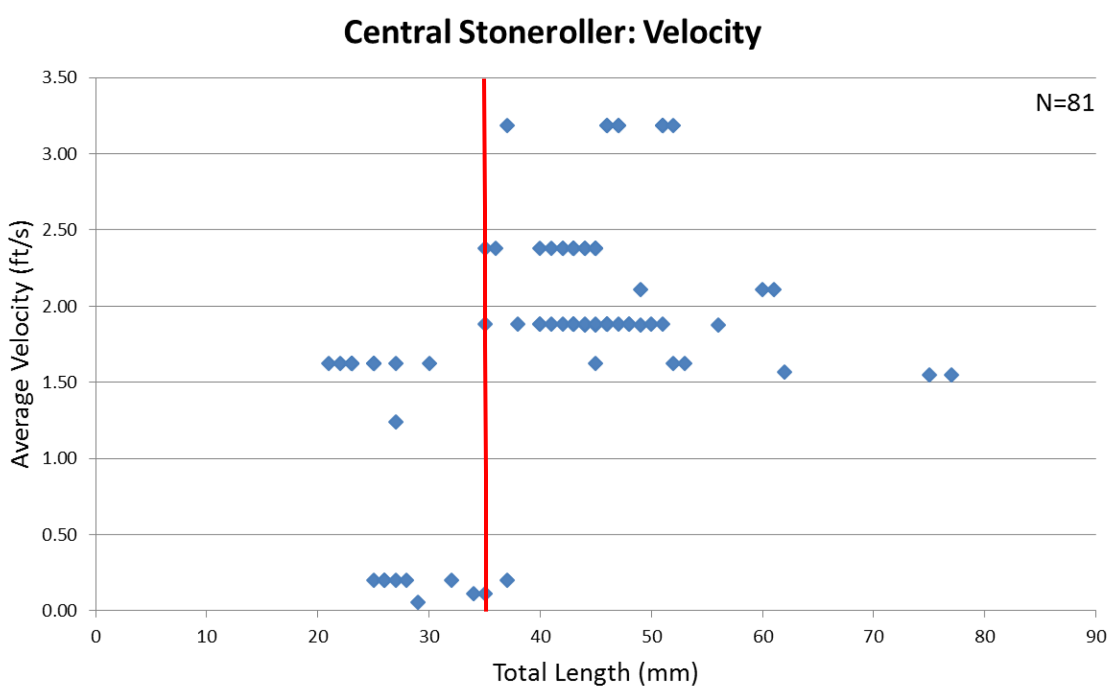
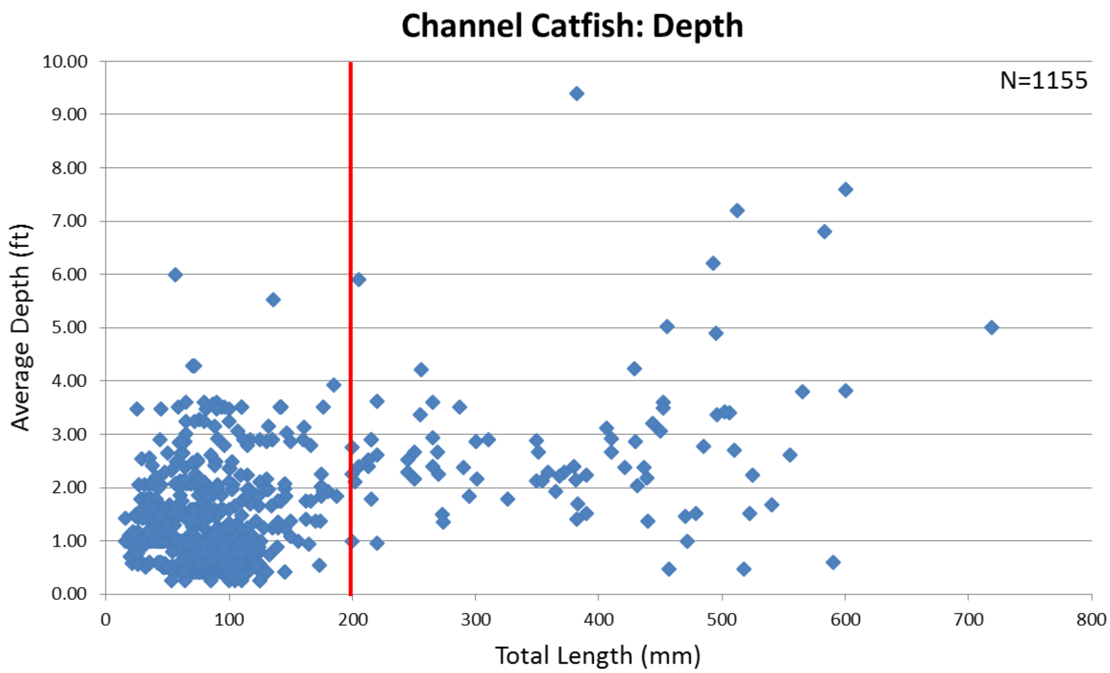


Figure B-6. Average depth and average velocity versus total length for Central Stoneroller *Campostoma anomalum*. The red line indicates the resulting boundary between juvenile and adult life stage categories (35 mm).



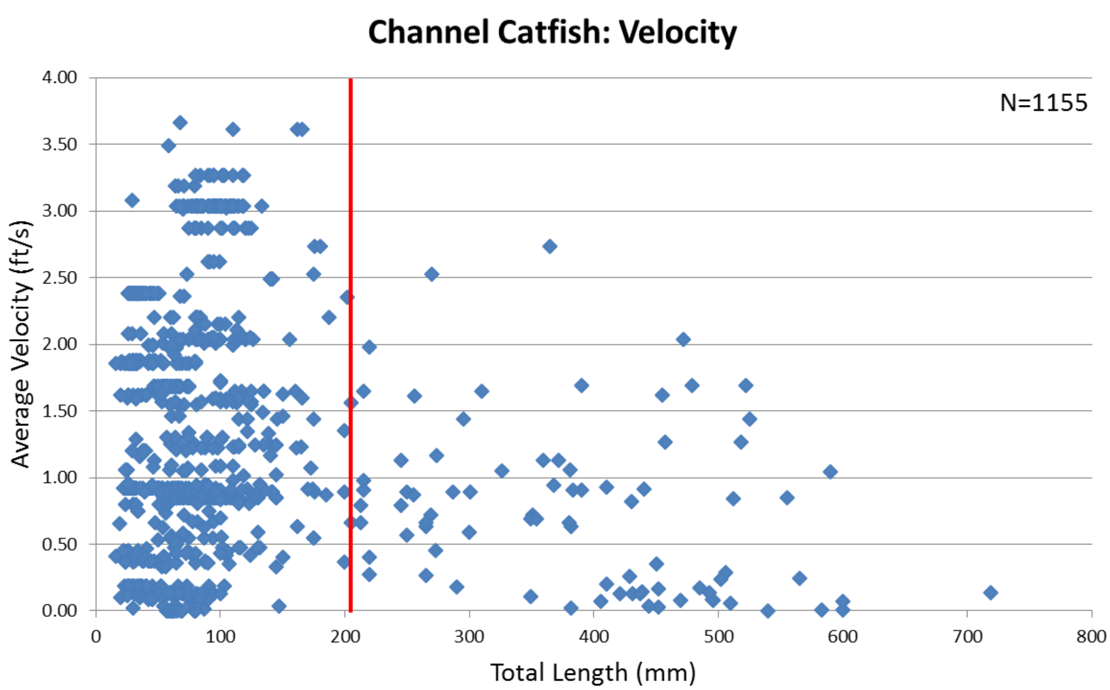
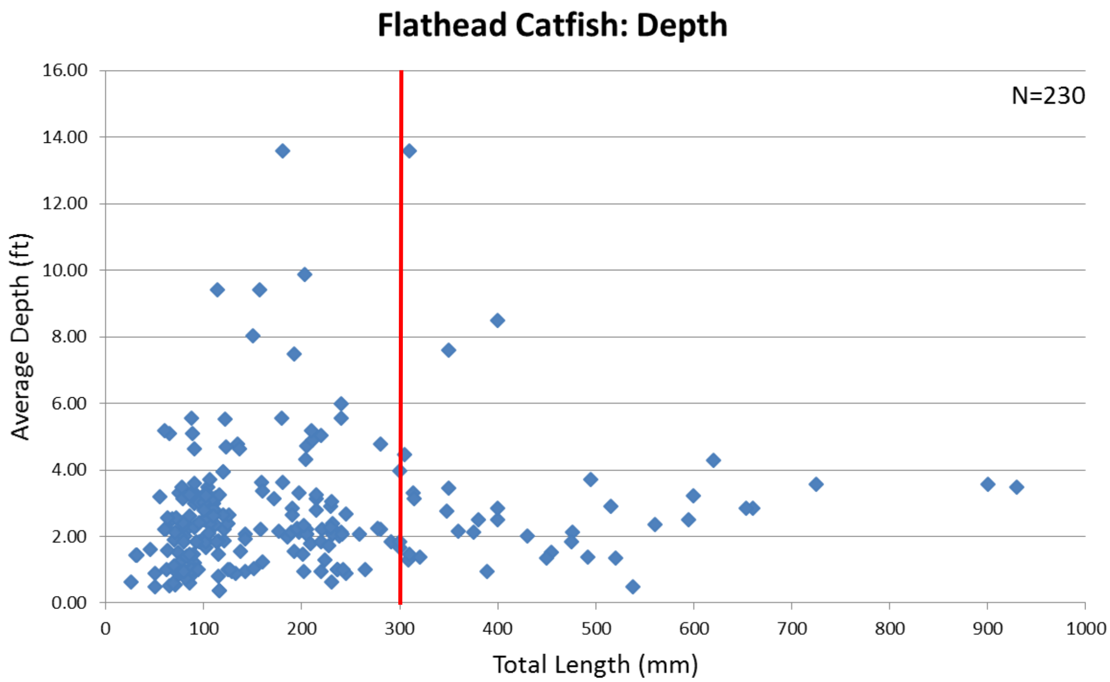


Figure B-7. Average depth and average velocity versus total length for Channel Catfish *Ictalurus punctatus*. The red line indicates the resulting boundary between juvenile and adult life stage categories (200 mm).



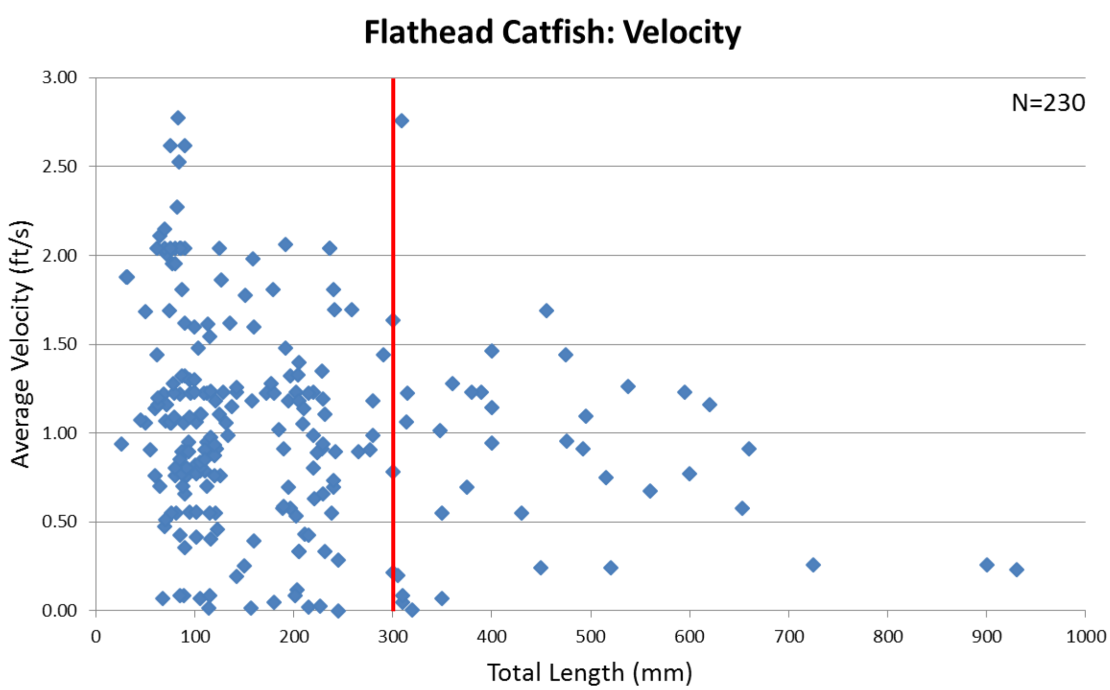
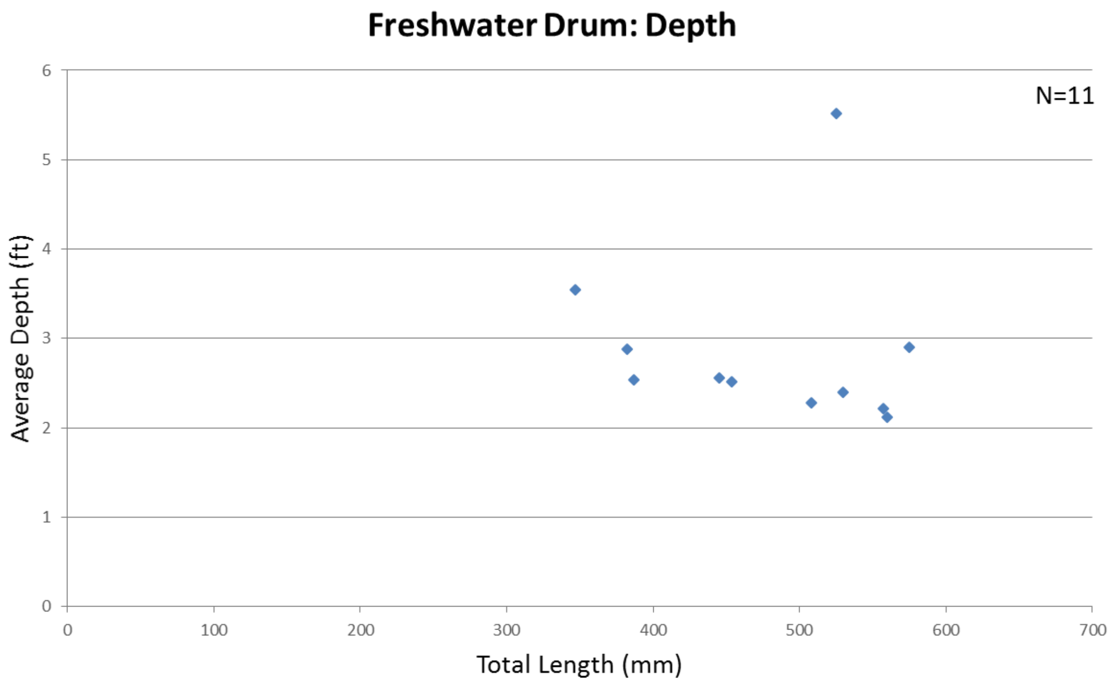


Figure B-8. Average depth and average velocity versus total length for Flathead Catfish *Pylodictis olivaris*. The red line indicates the resulting boundary between juvenile and adult life stage categories (300 mm).



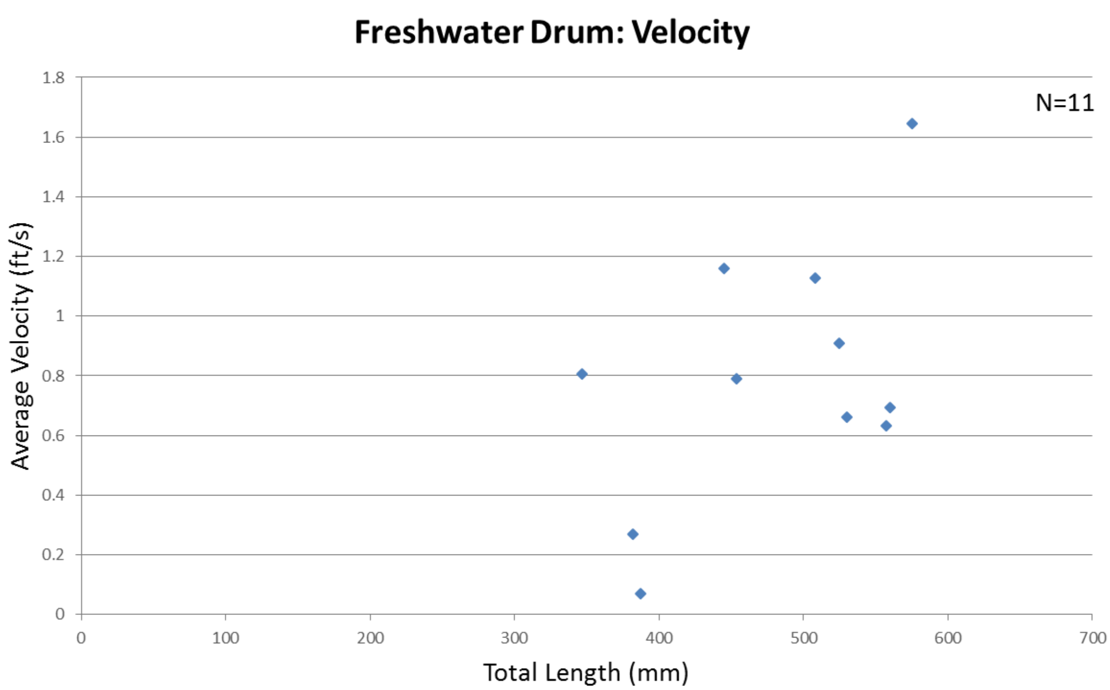
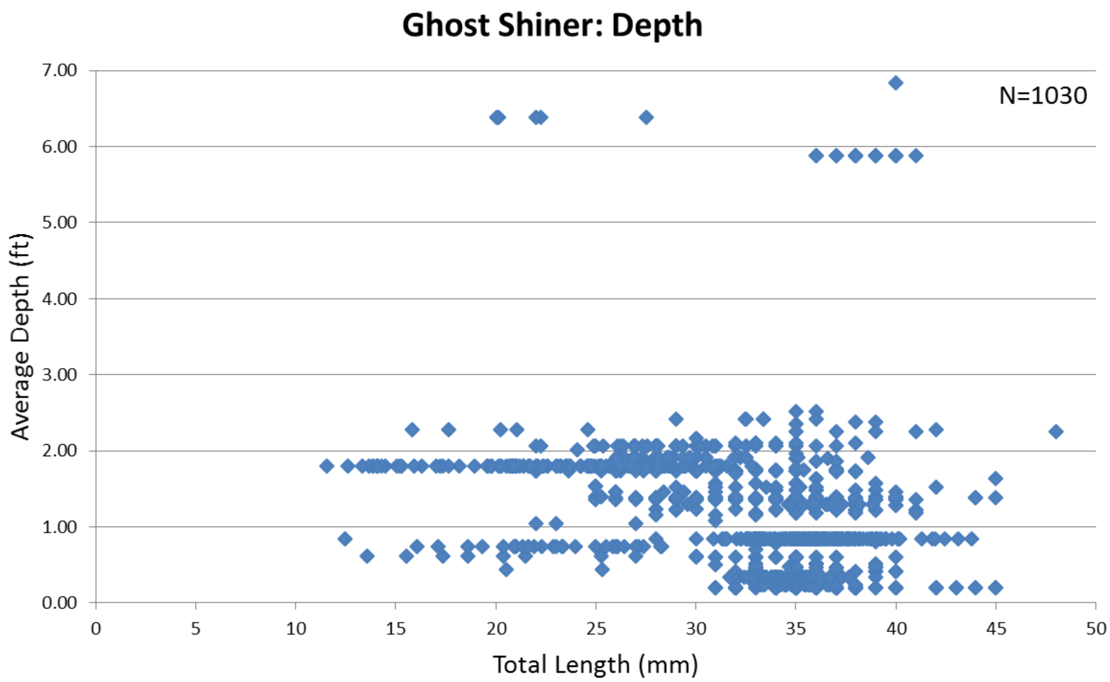


Figure B-9. Average depth and average velocity versus total length for Freshwater Drum *Aplodinotus grunniens*.



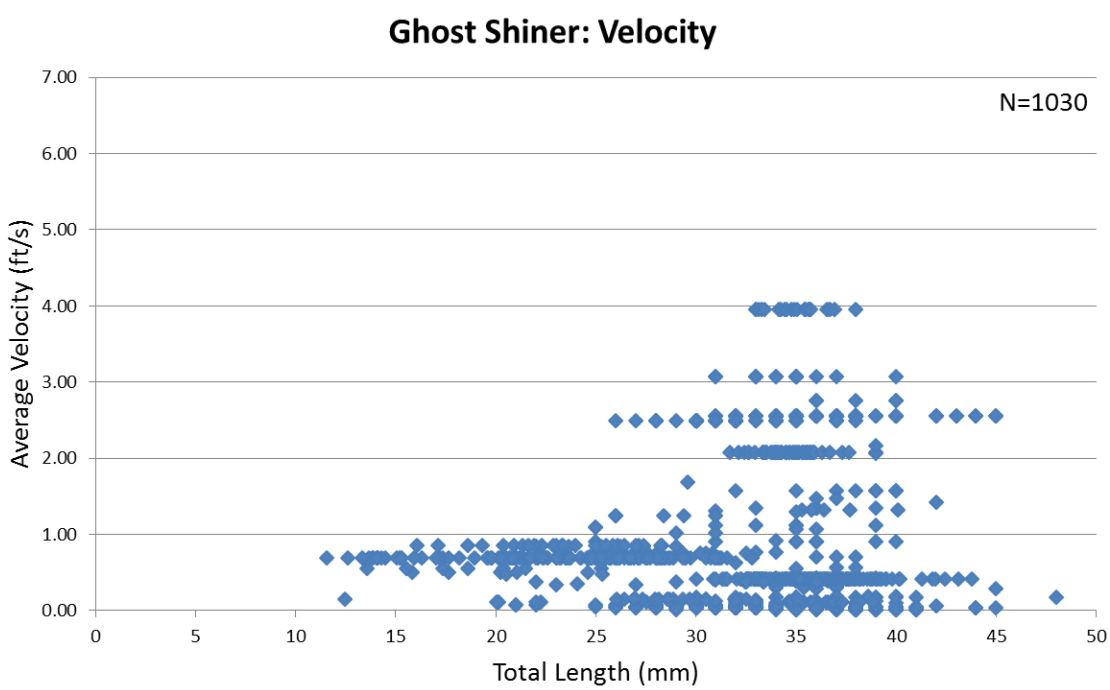


Figure B-10. Average depth and average velocity versus total length for Ghost Shiner *Notropis buchanani*.

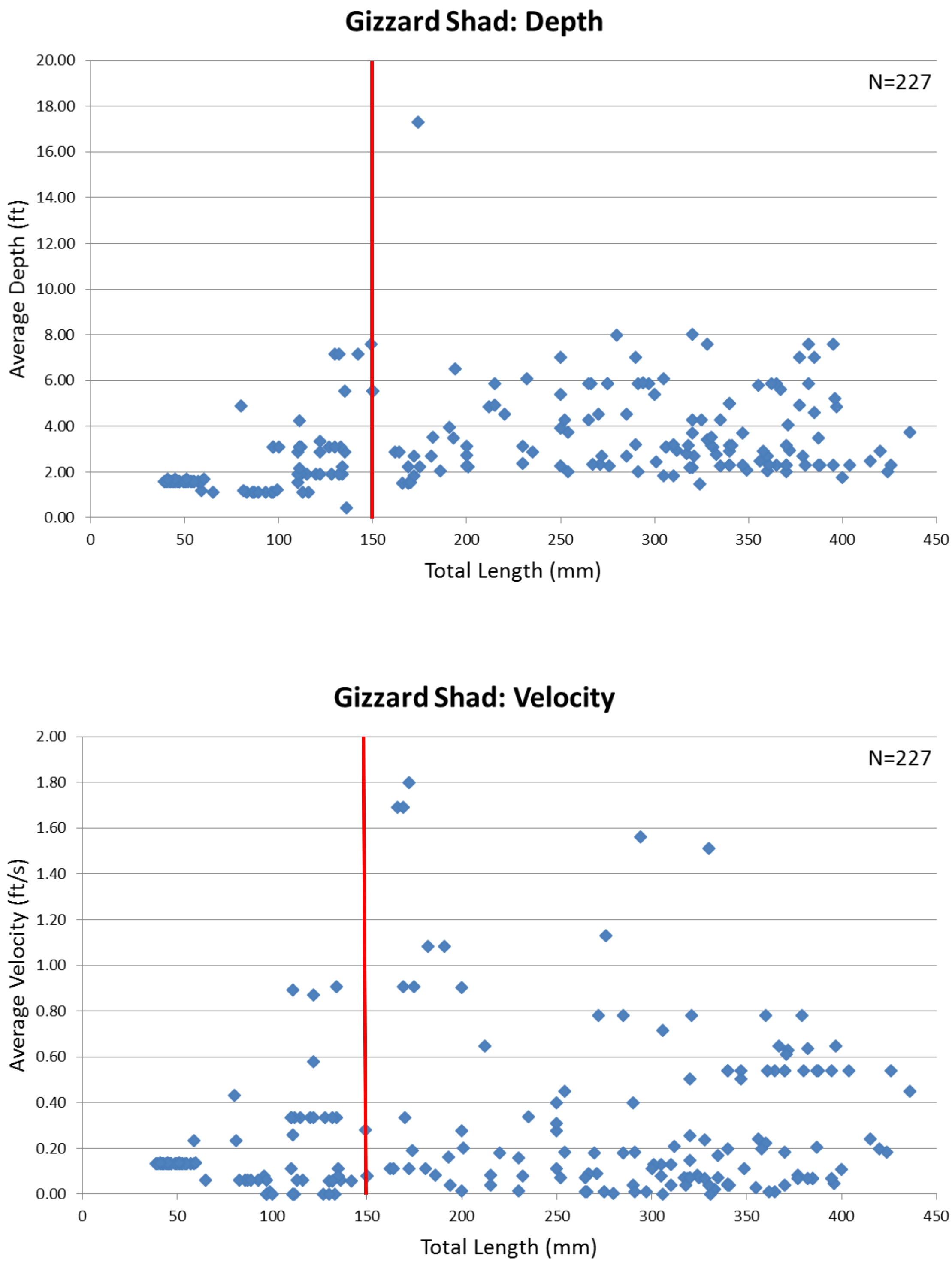
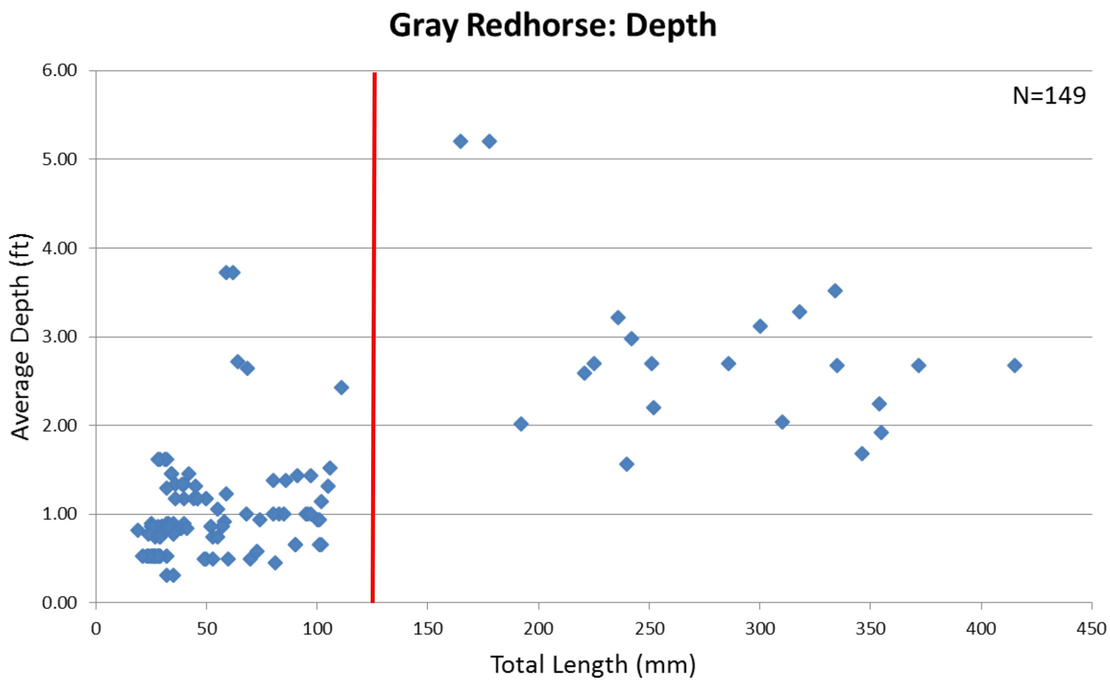


Figure B-11. Average depth and average velocity versus total length for Gizzard Shad *Dorosoma cepedianum*. The red line indicates the resulting boundary between juvenile and adult life stage categories (150 mm).



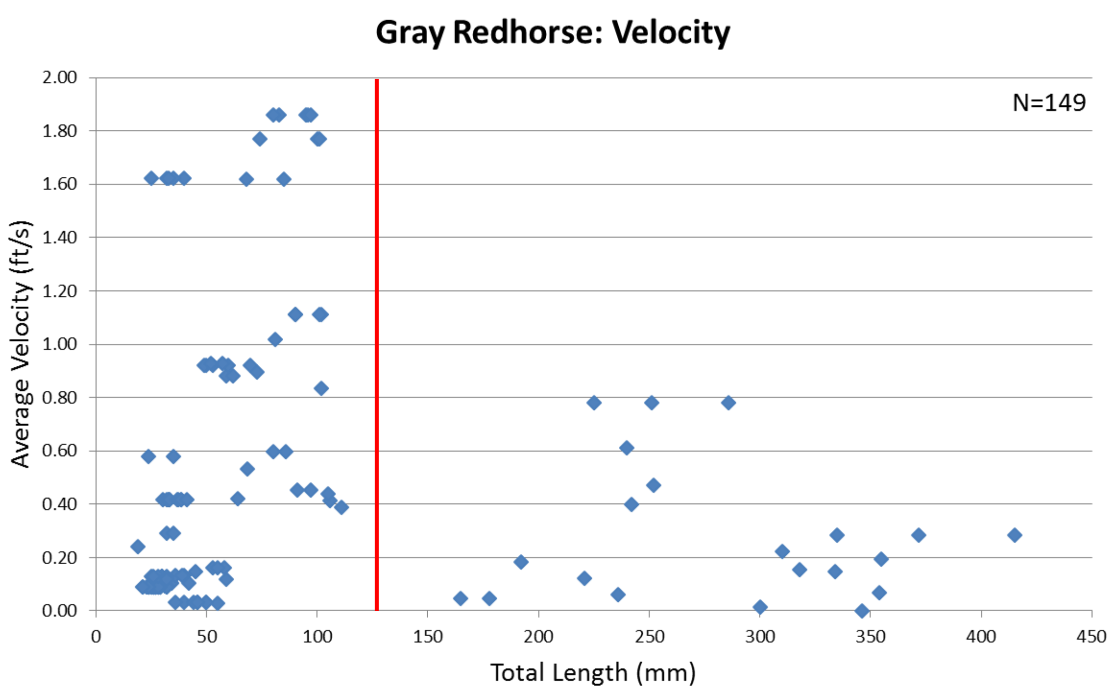
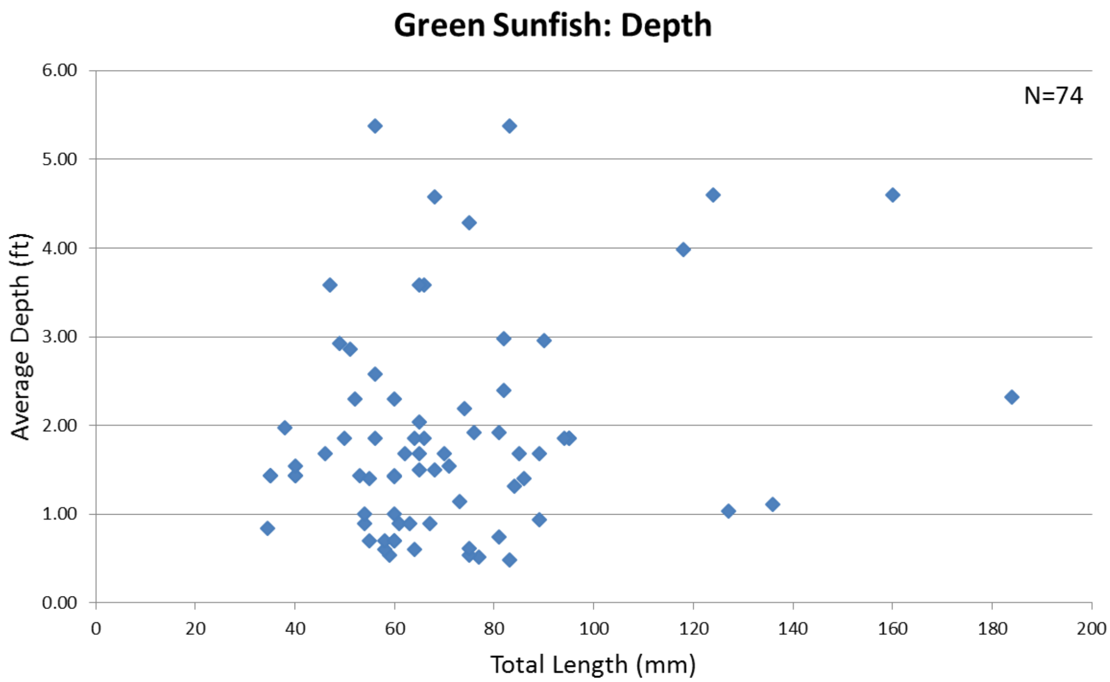


Figure B-12. Average depth and average velocity versus total length for Gray Redhorse *Moxostoma congestum*. The red line indicates the resulting boundary between juvenile and adult life stage categories (125 mm).



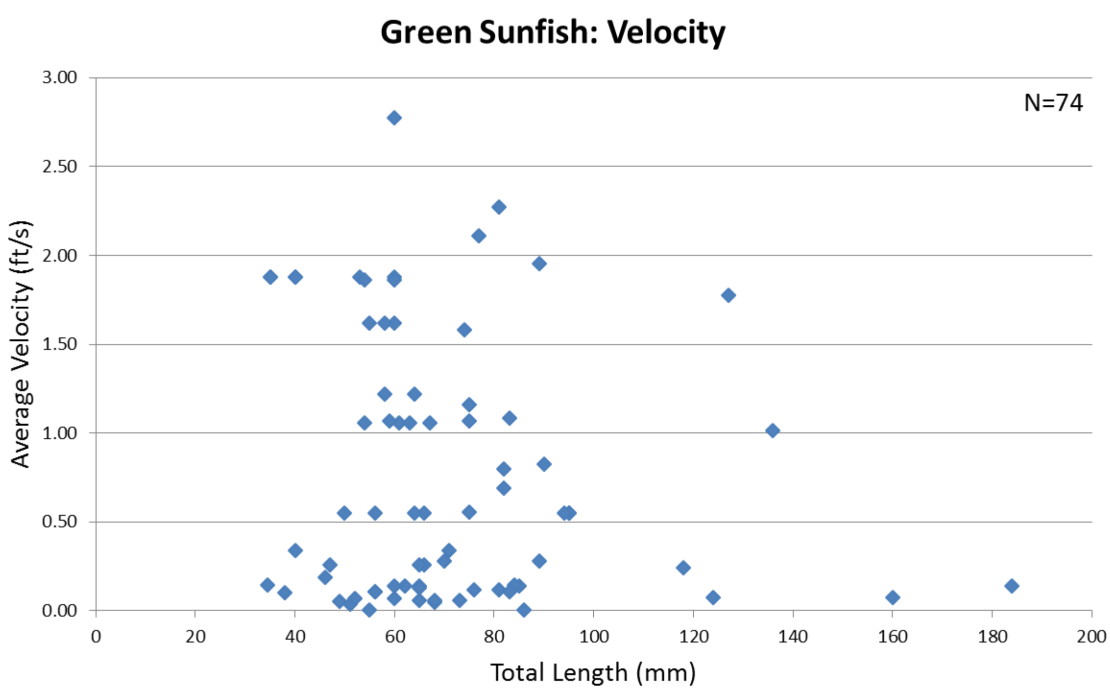
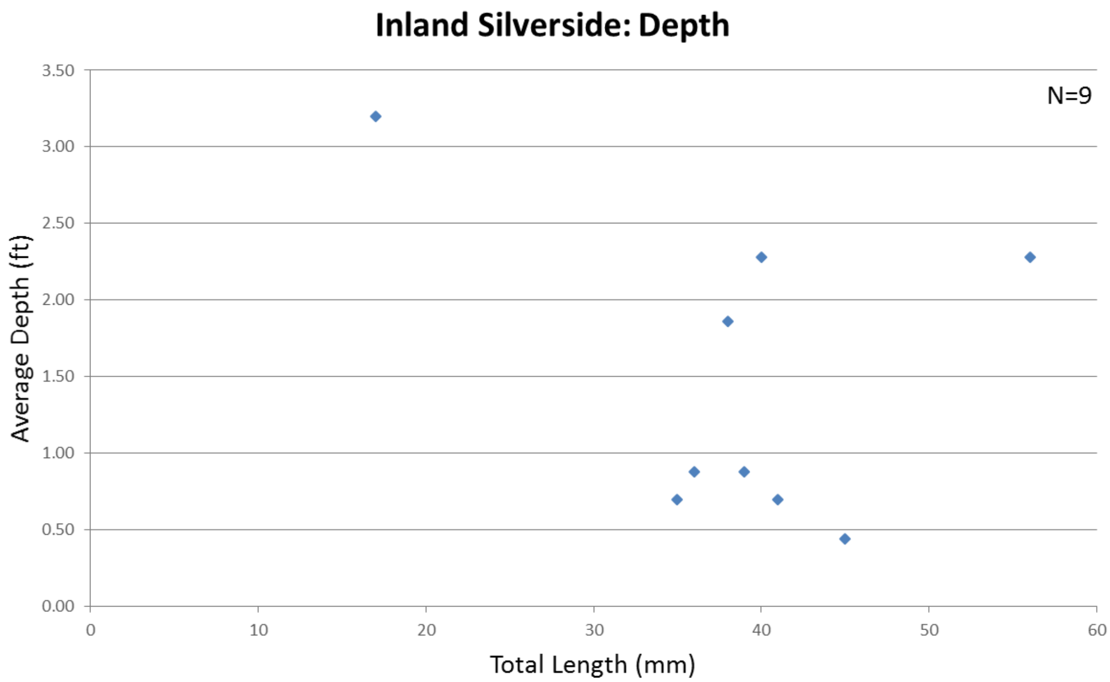


Figure B-13. Average depth and average velocity versus total length for Green Sunfish *Lepomis cyanellus*.



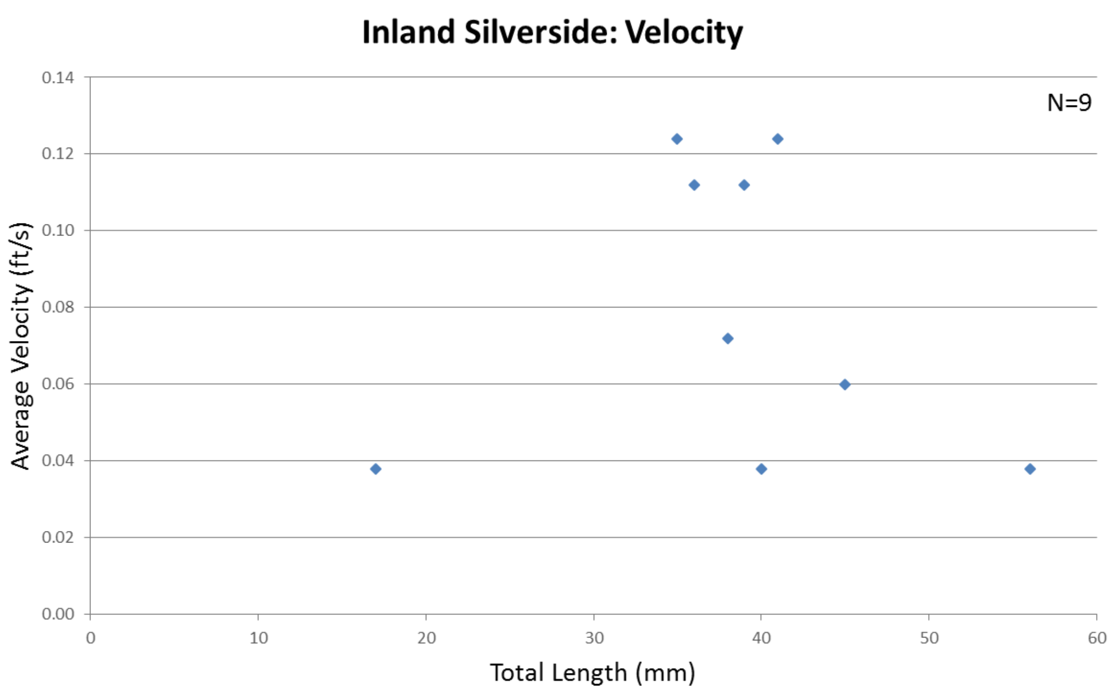
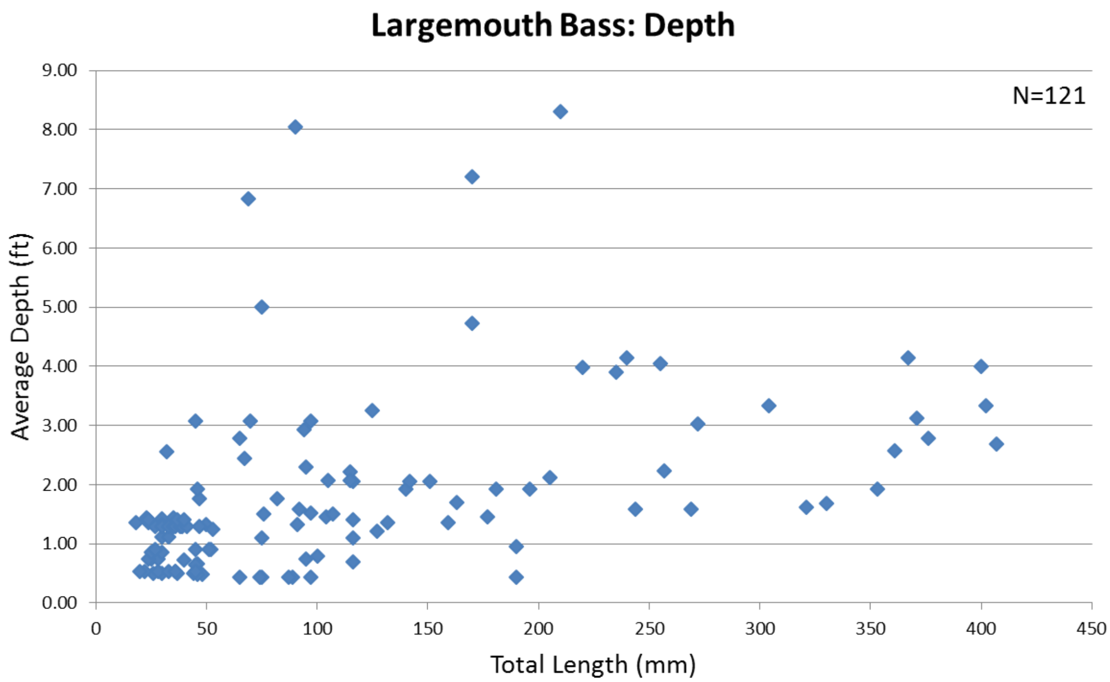


Figure B-14. Average depth and average velocity versus total length for Inland Silverside *Menidia beryllina*.



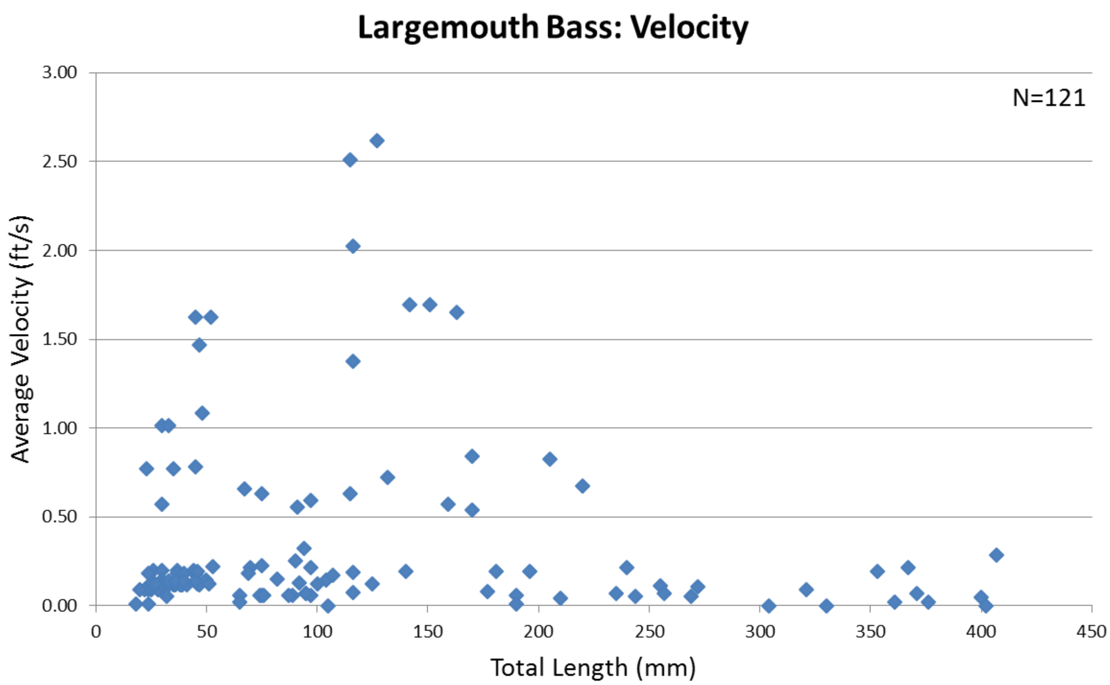
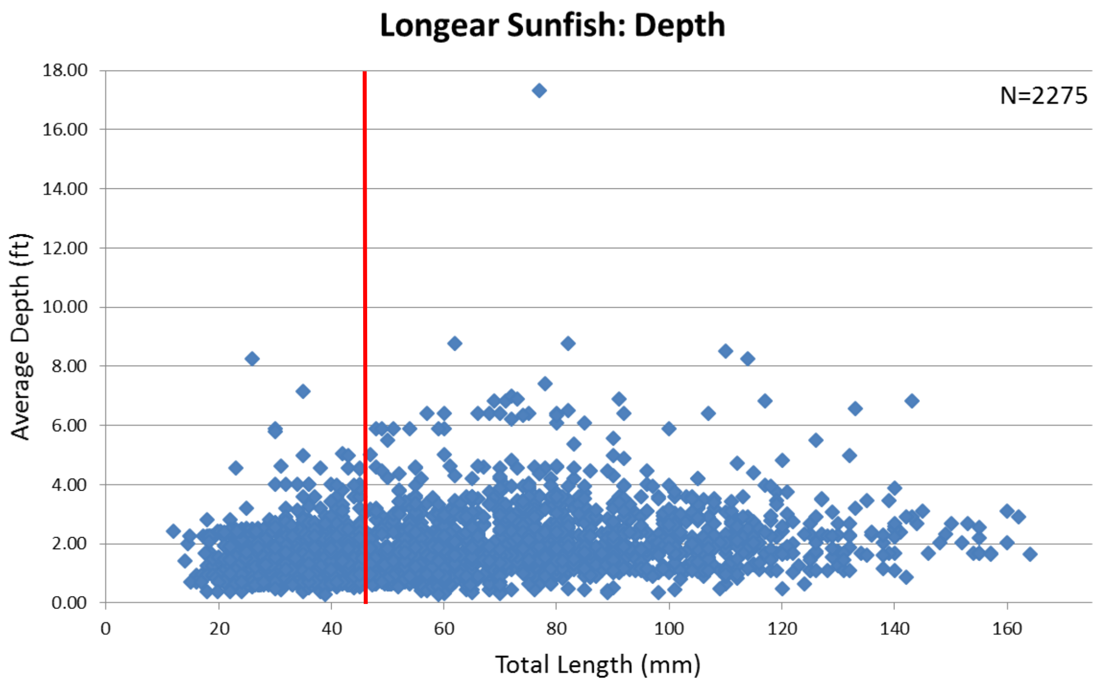


Figure B-15. Average depth and average velocity versus total length for Largemouth Bass *Micropterus salmoides*.



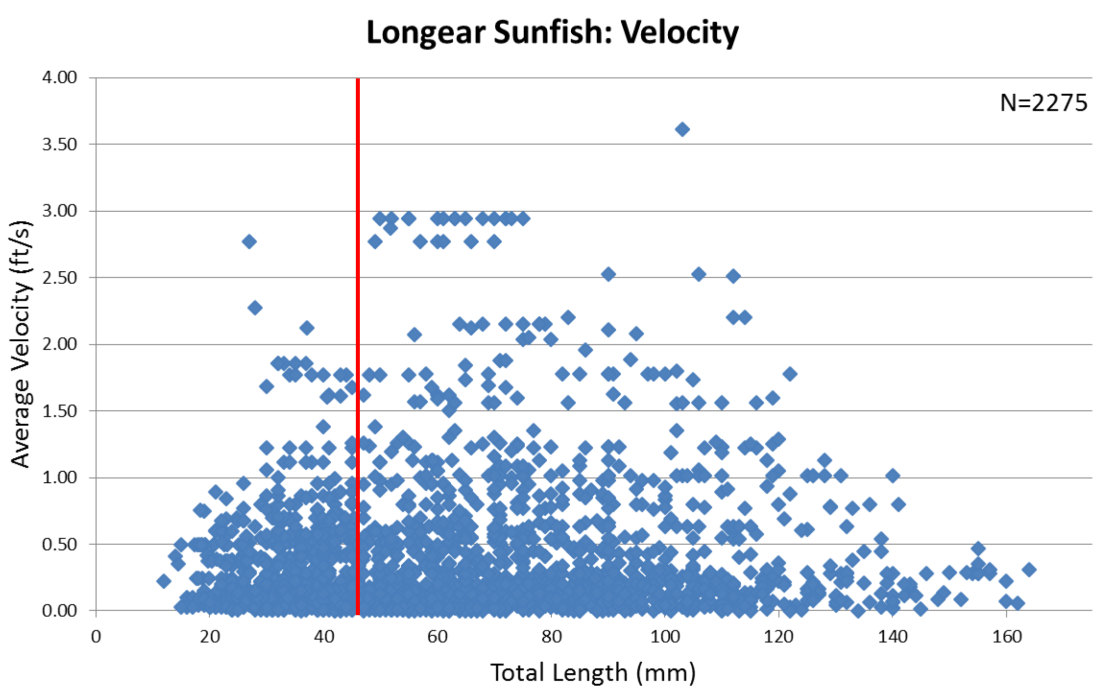
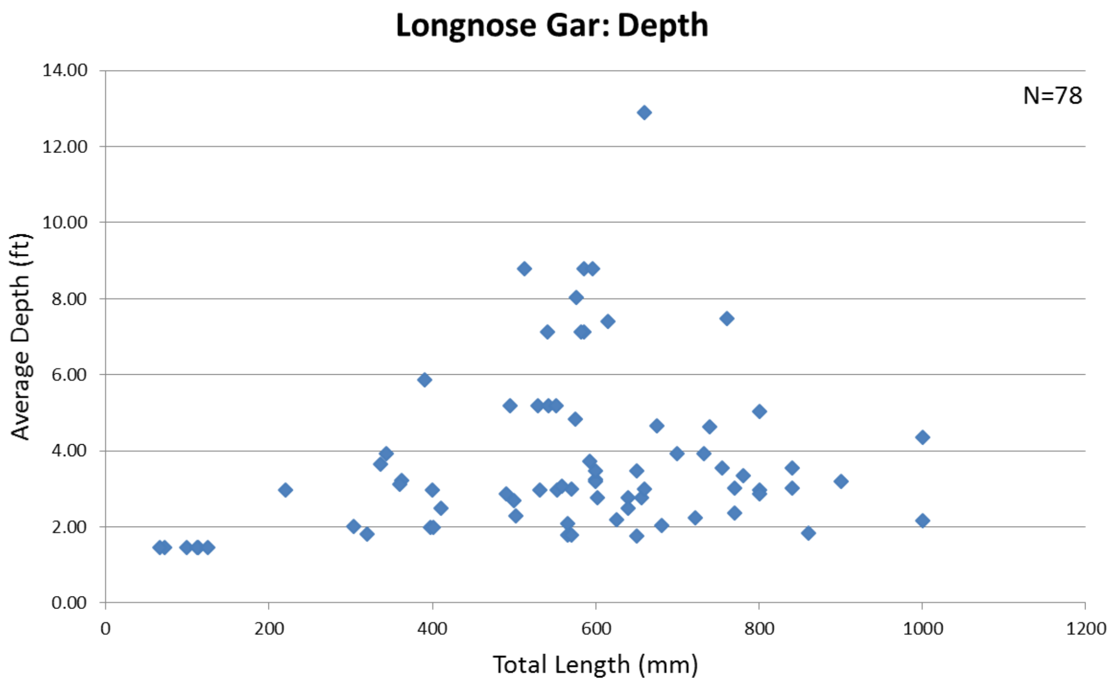


Figure B-16. Average depth and average velocity versus total length for Longear Sunfish *Lepomis megalotis*. The red line indicates the resulting boundary between juvenile and adult life stage categories (45 mm).



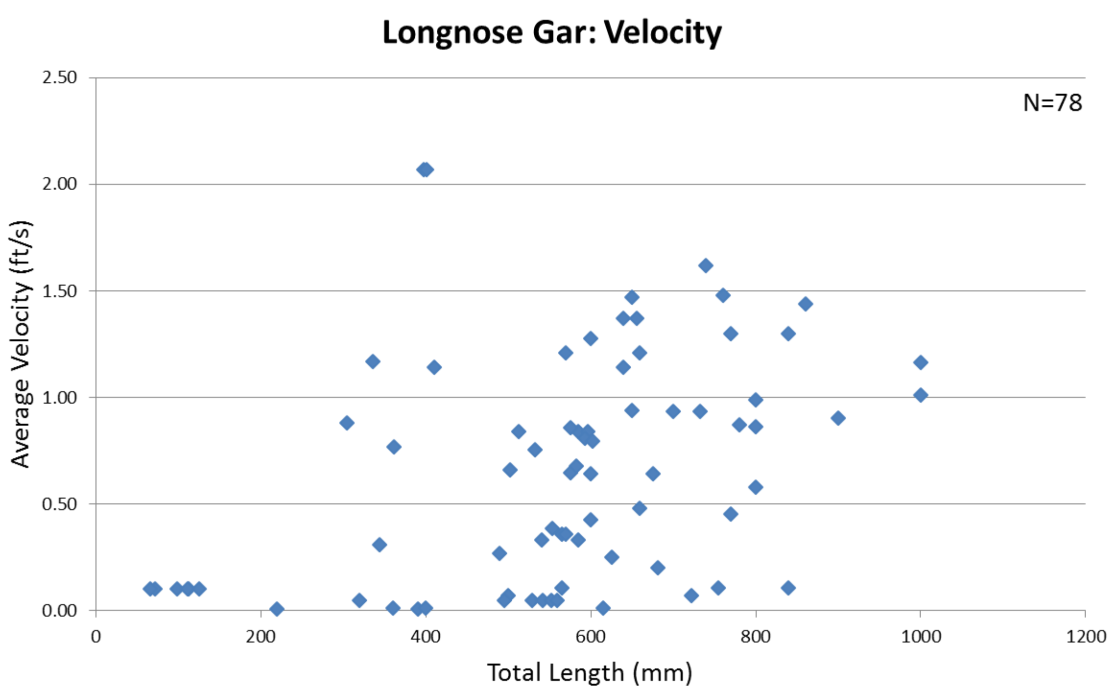
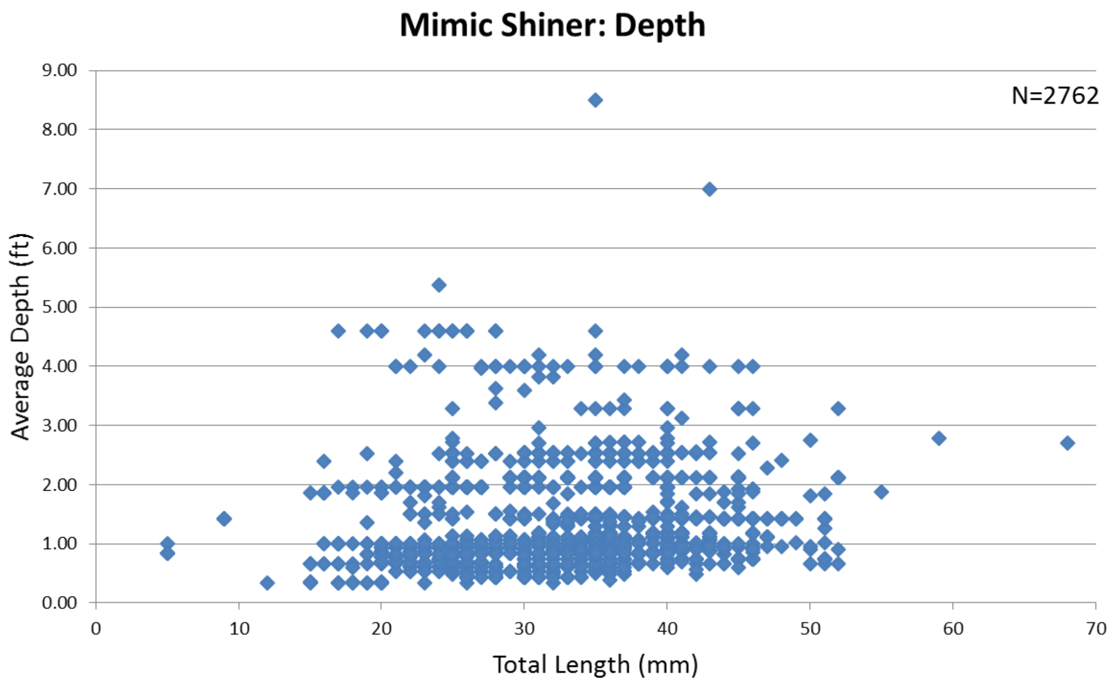


Figure B-17. Average depth and average velocity versus total length for Longnose Gar *Lepisosteus osseus*.



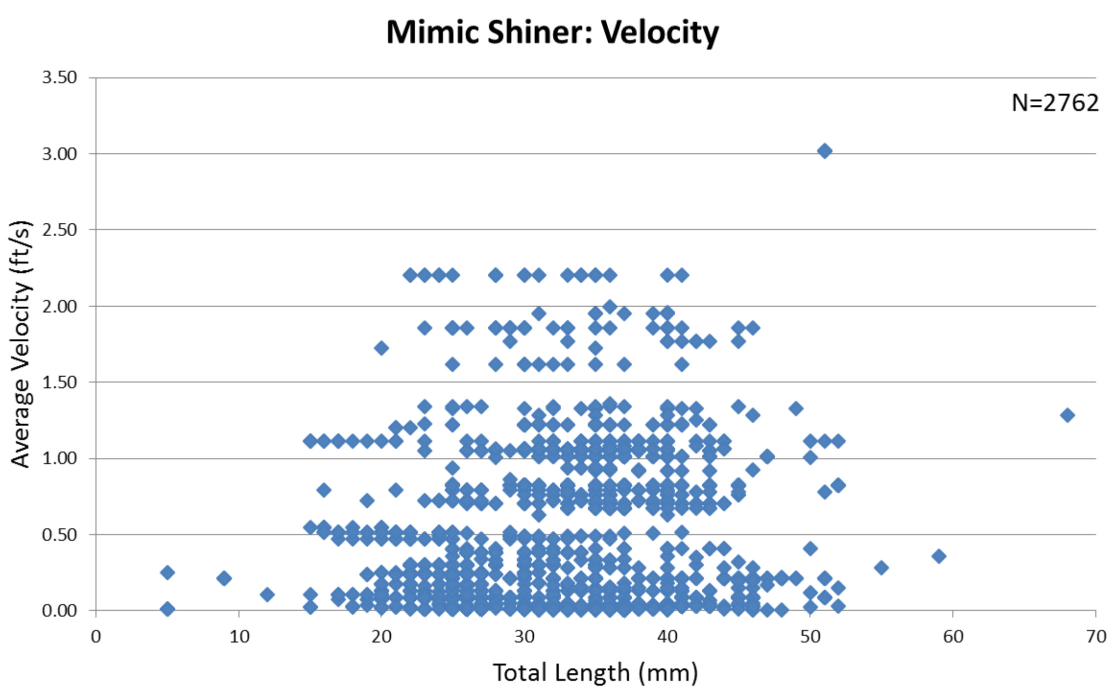
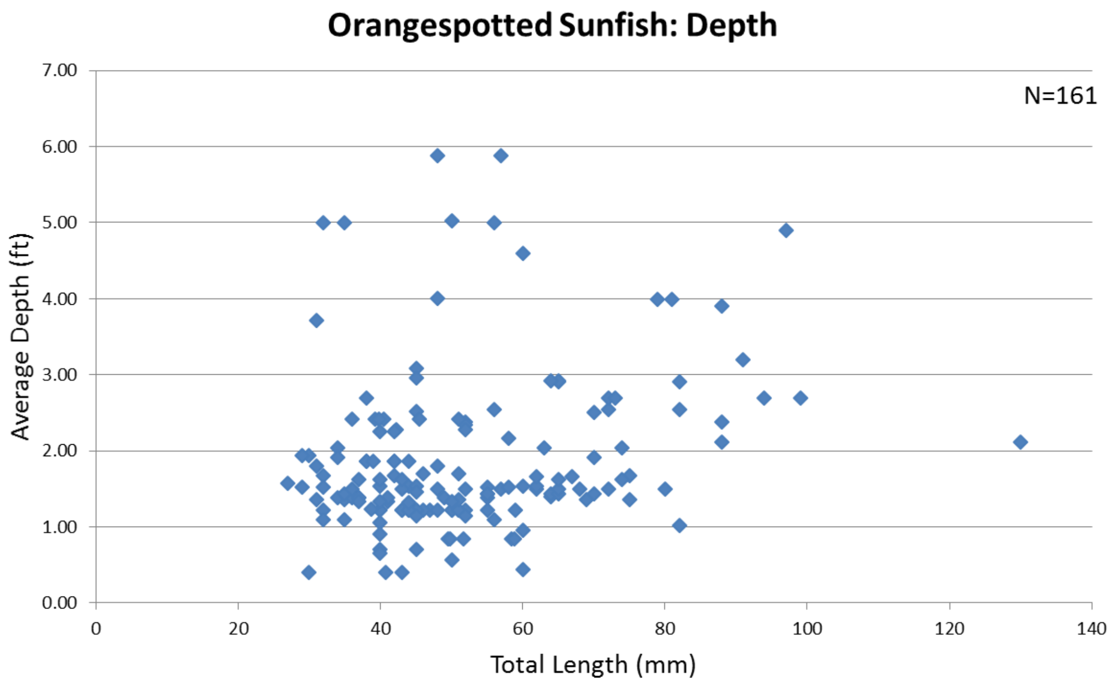


Figure B-18. Average depth and average velocity versus total length for Mimic Shiner *Notropis volucellus*.



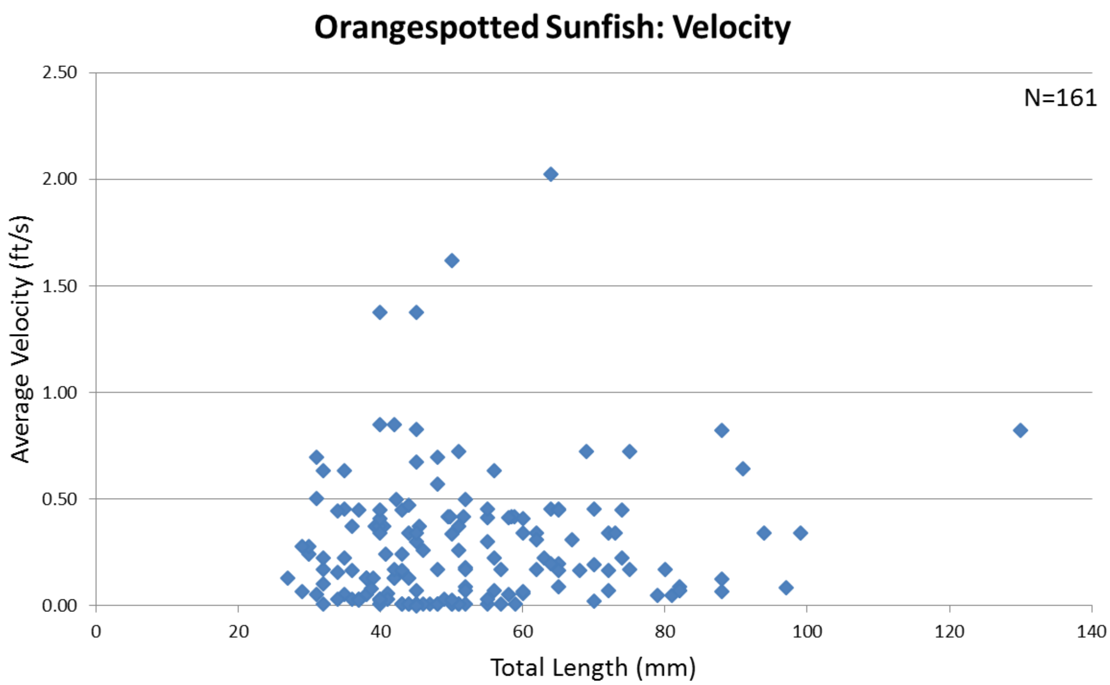
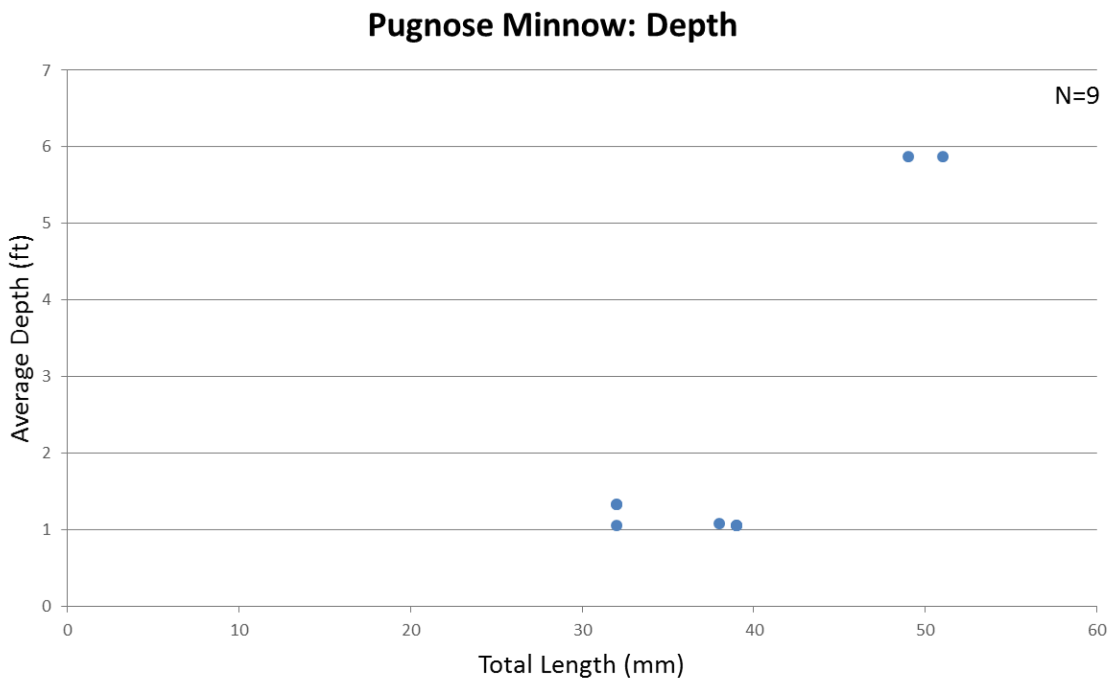


Figure B-19. Average depth and average velocity versus total length for Orangespotted Sunfish *Lepomis humilis*.



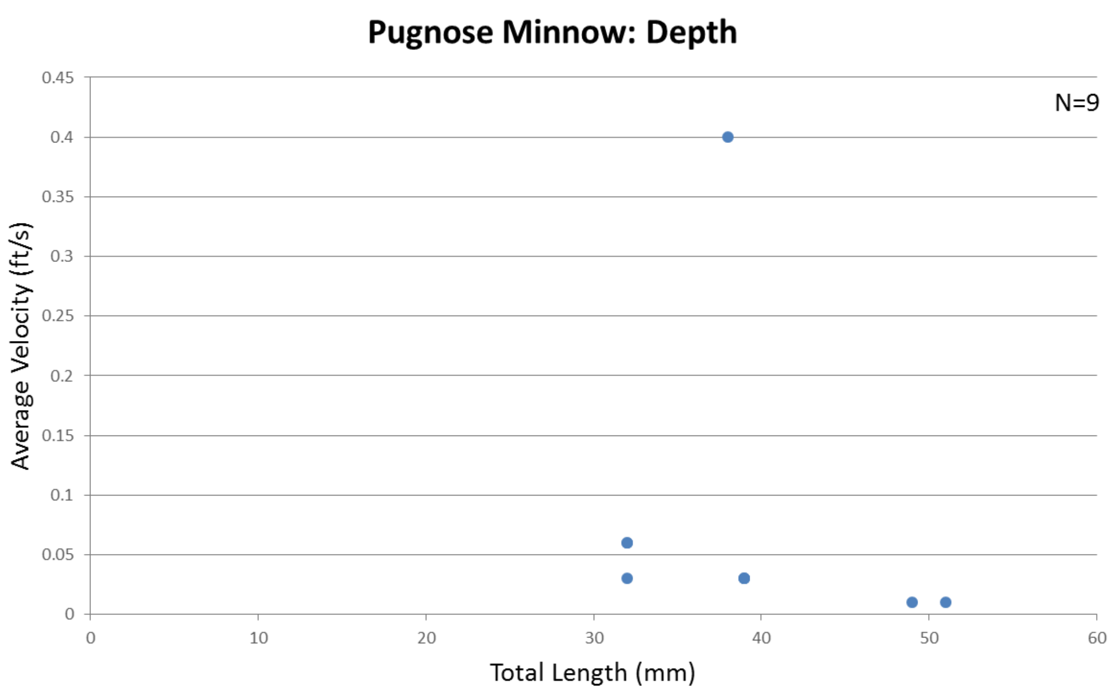
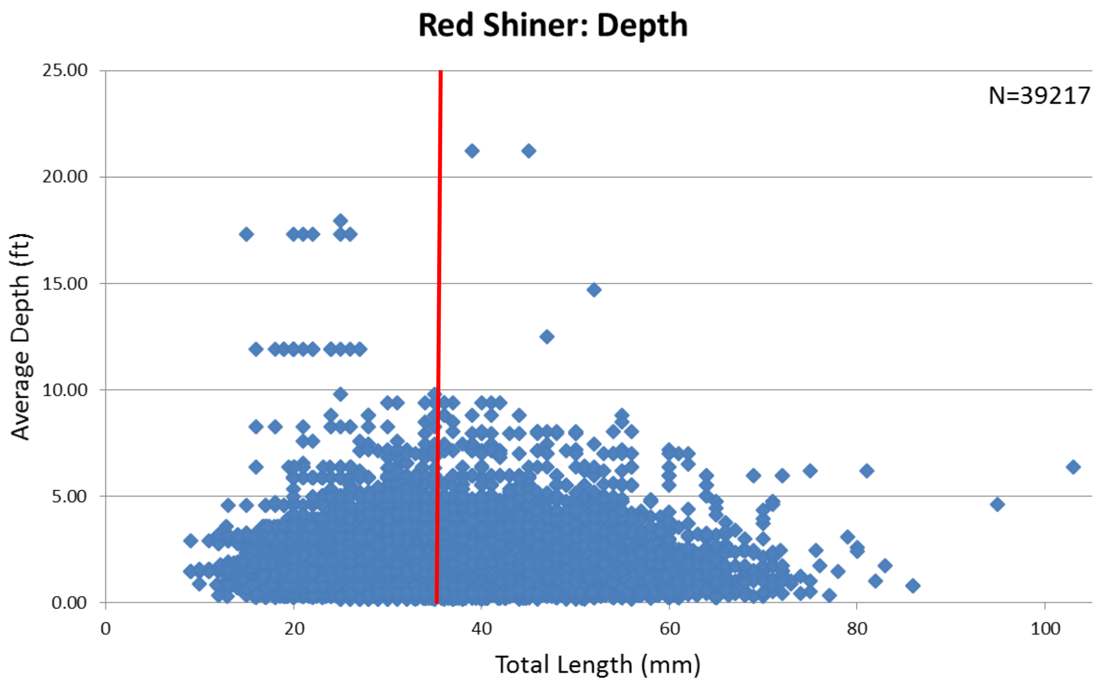


Figure B-20. Average depth and average velocity versus total length for Pugnose Minnow *Opsopoeodus emiliae*.



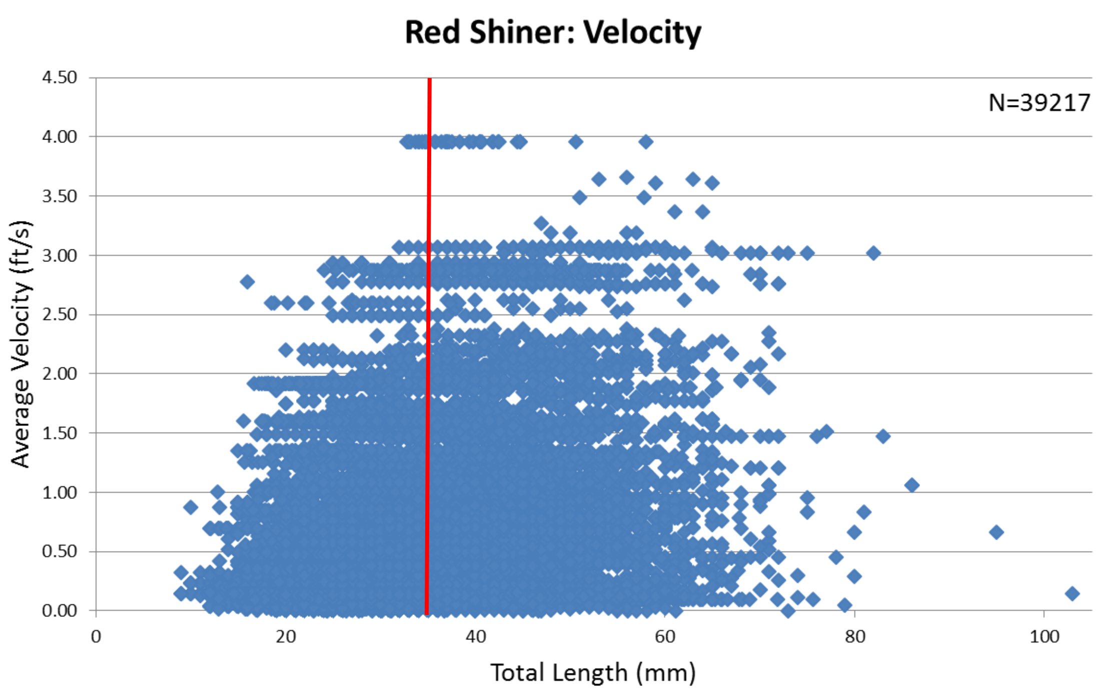
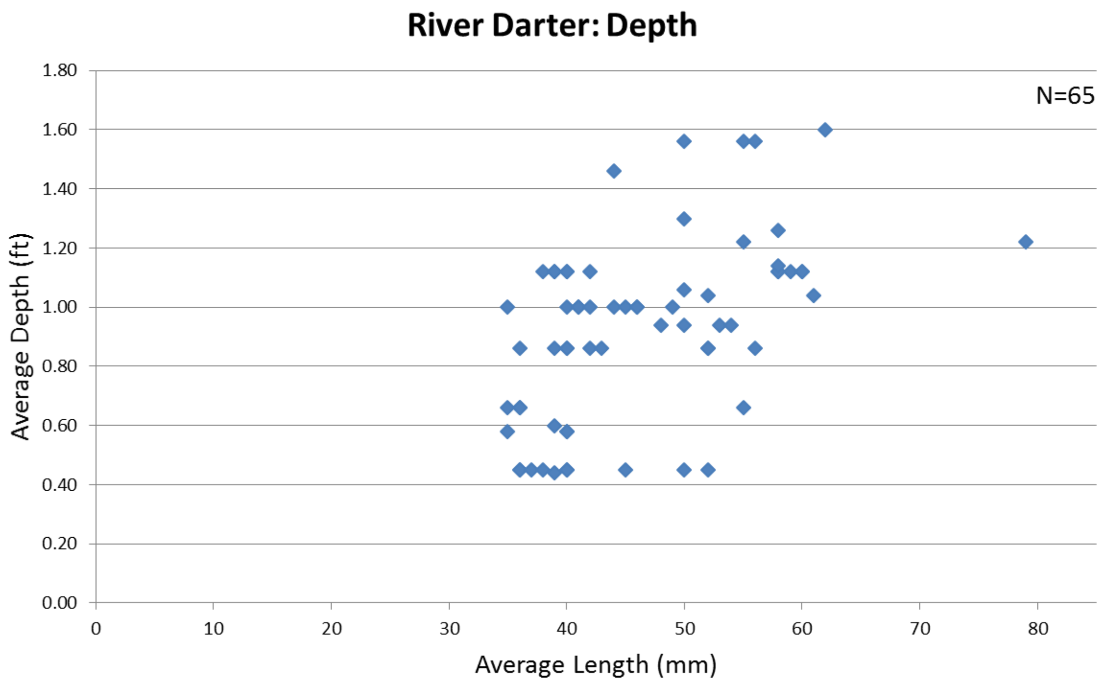


Figure B-21. Average depth and average velocity versus total length for Red Shiner *Cyprinella lutrensis*. The red line indicates the resulting boundary between juvenile and adult life stage categories (35 mm).



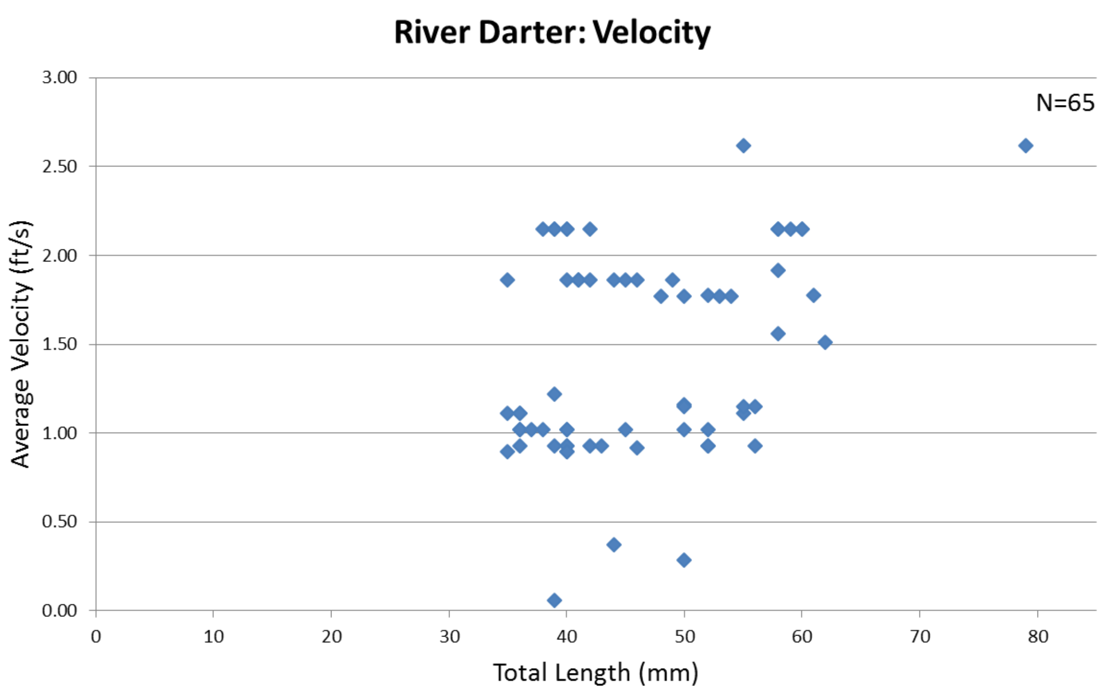
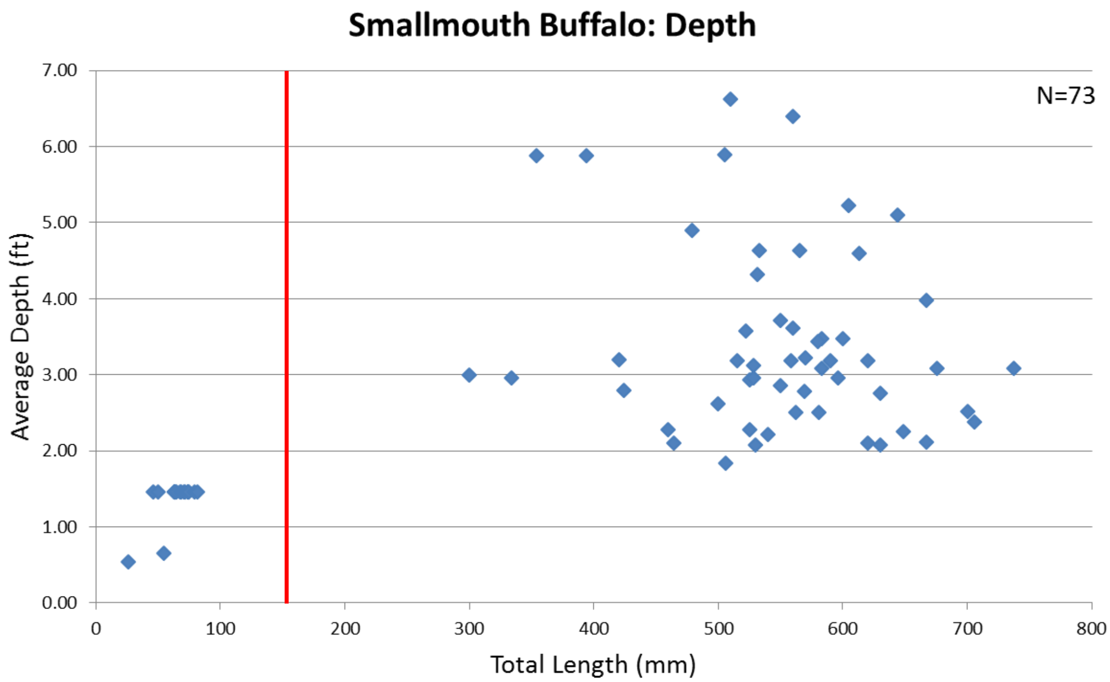


Figure B-22. Average depth and average velocity versus total length for River Darter *Percina shumardi*.



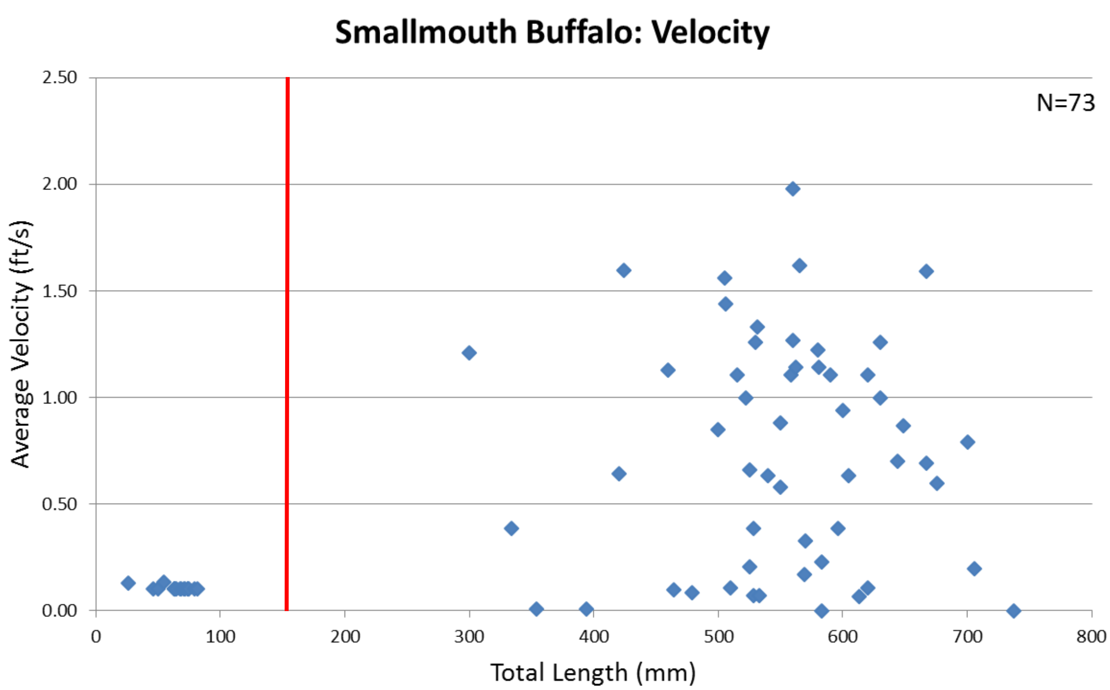
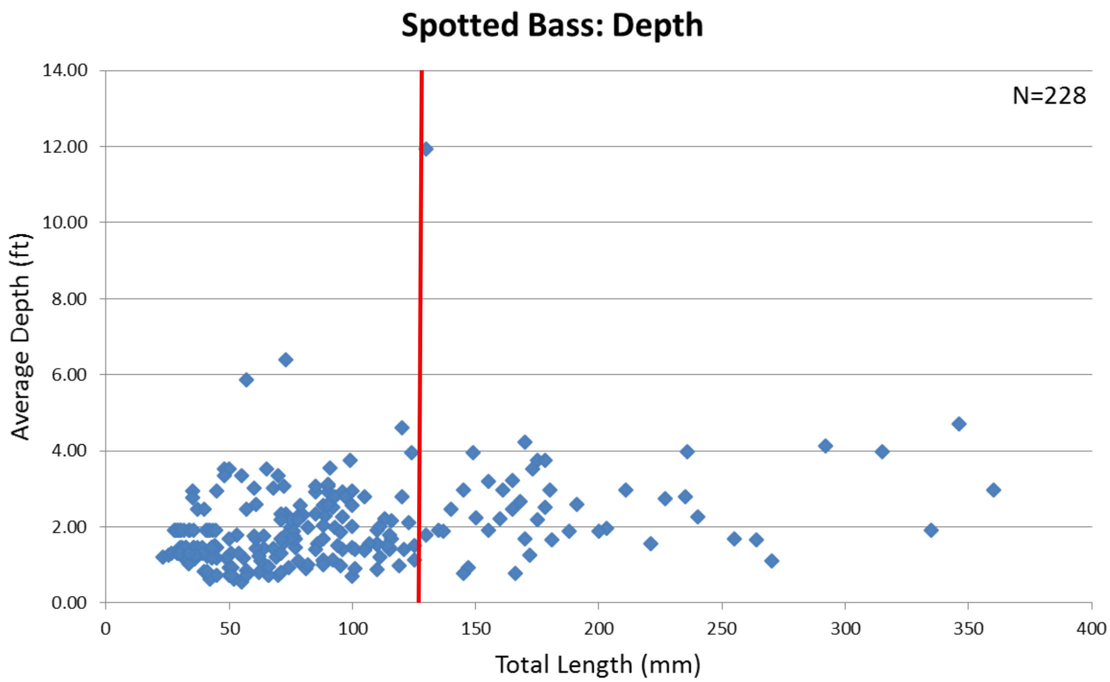


Figure B-23. Average depth and average velocity versus total length for Smallmouth Buffalo *Ictiobus bubalus*. The red line indicates the resulting boundary between juvenile and adult life stage categories (150 mm).



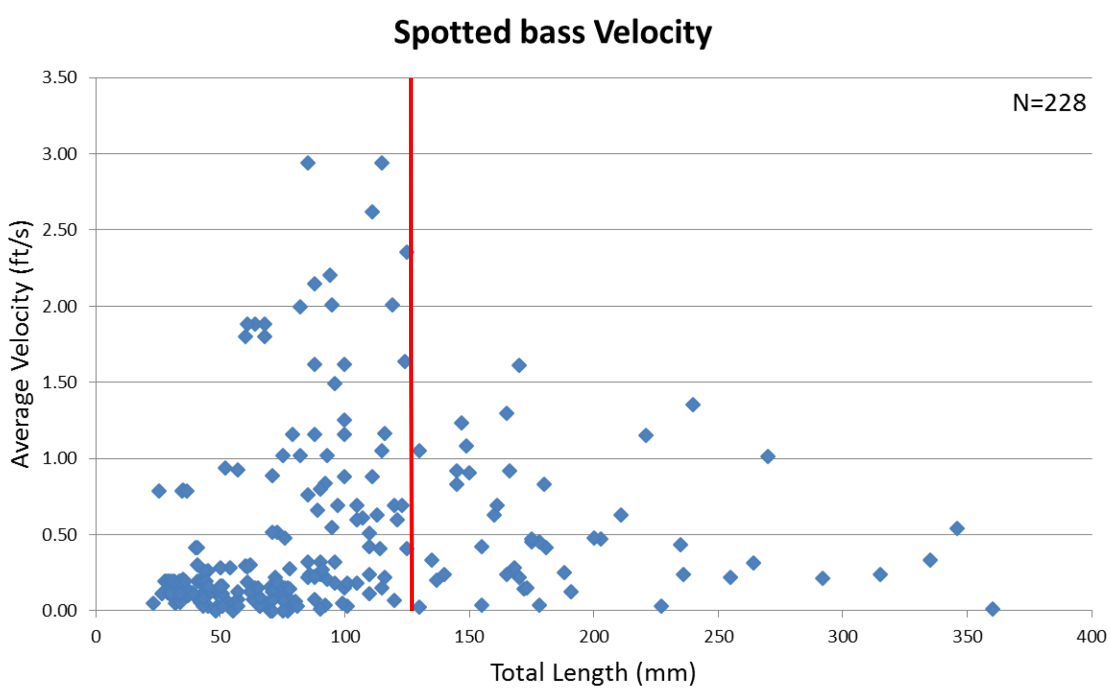
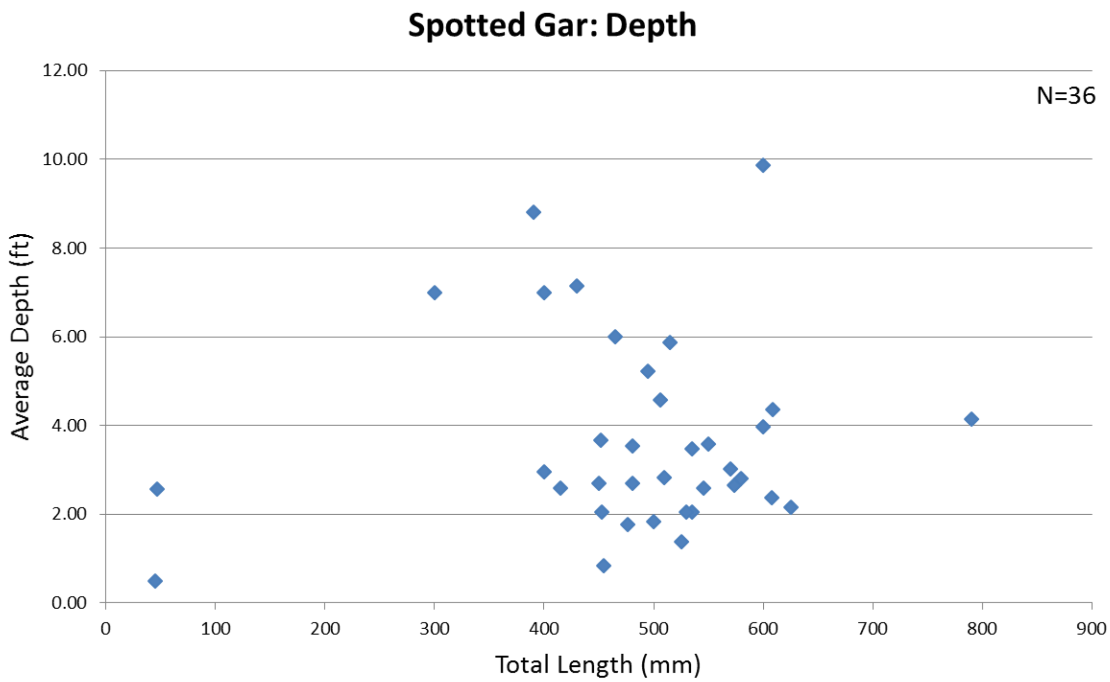


Figure B-24. Average depth and average velocity versus total length for Spotted Bass *Micropterus punctulatus*. The red line indicates the resulting boundary between juvenile and adult life stage categories (125 mm).



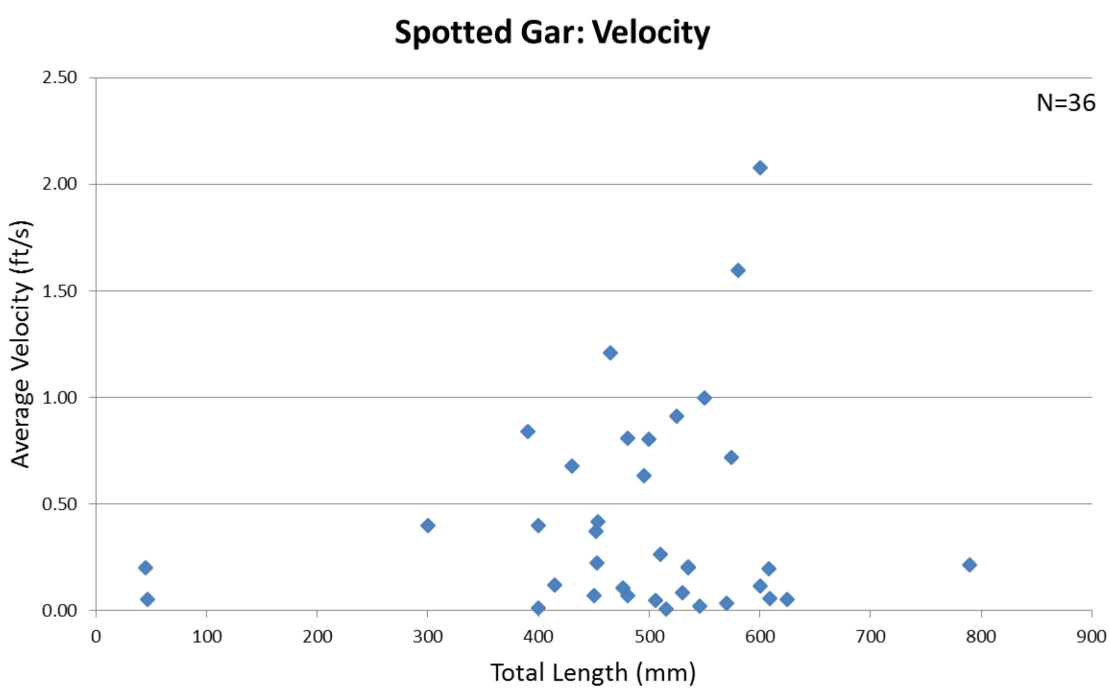
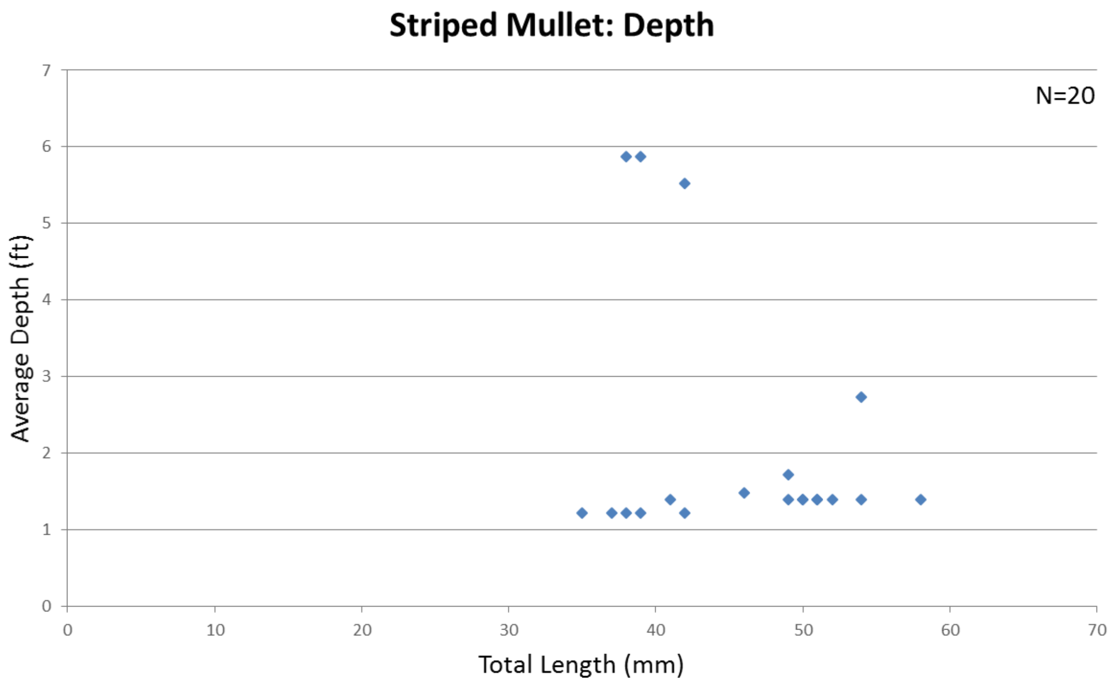


Figure B-25. Average depth and average velocity versus total length for Spotted Gar *Lepisosteus oculatus*.



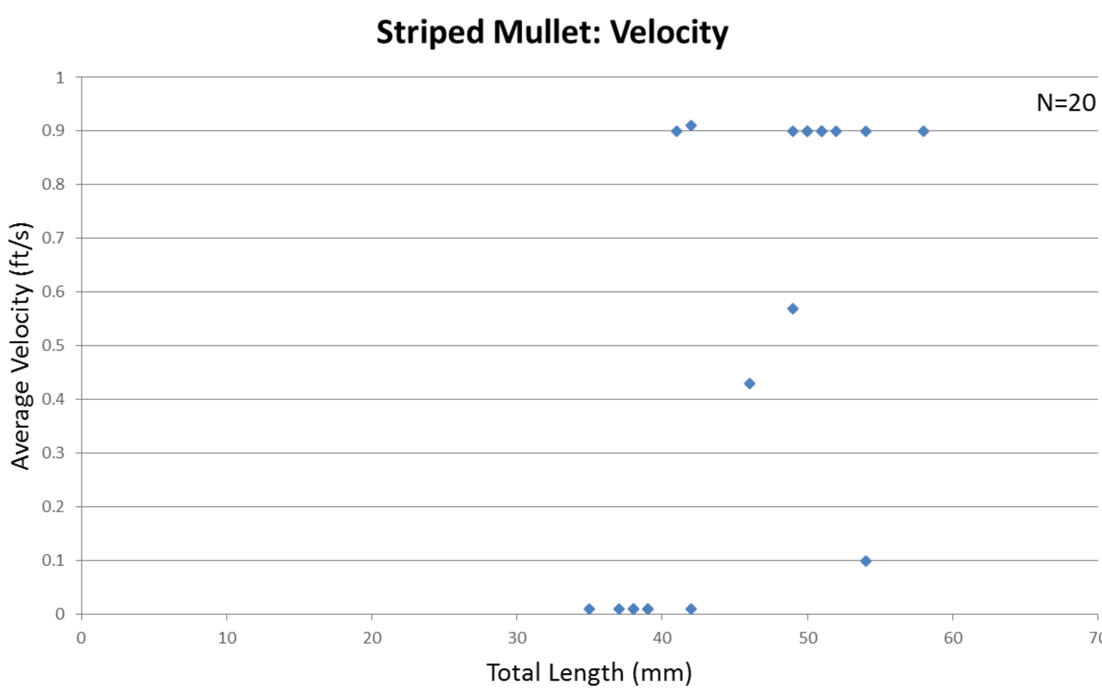
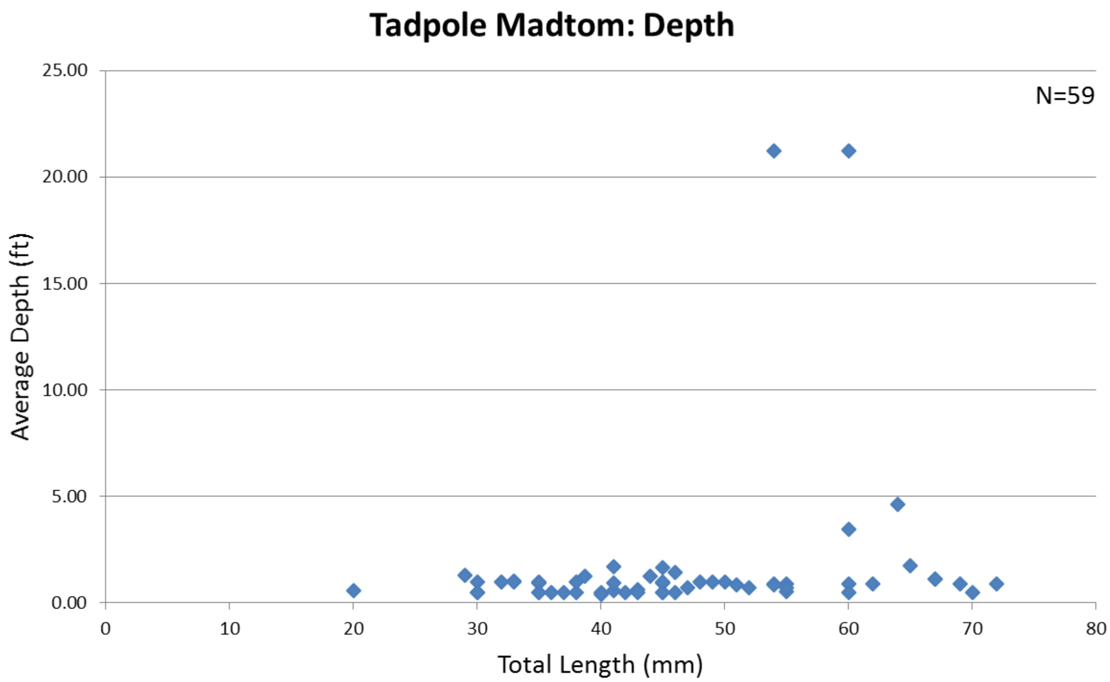


Figure B-26. Average depth and average velocity versus total length for Striped Mullet *Mugil cephalus*.



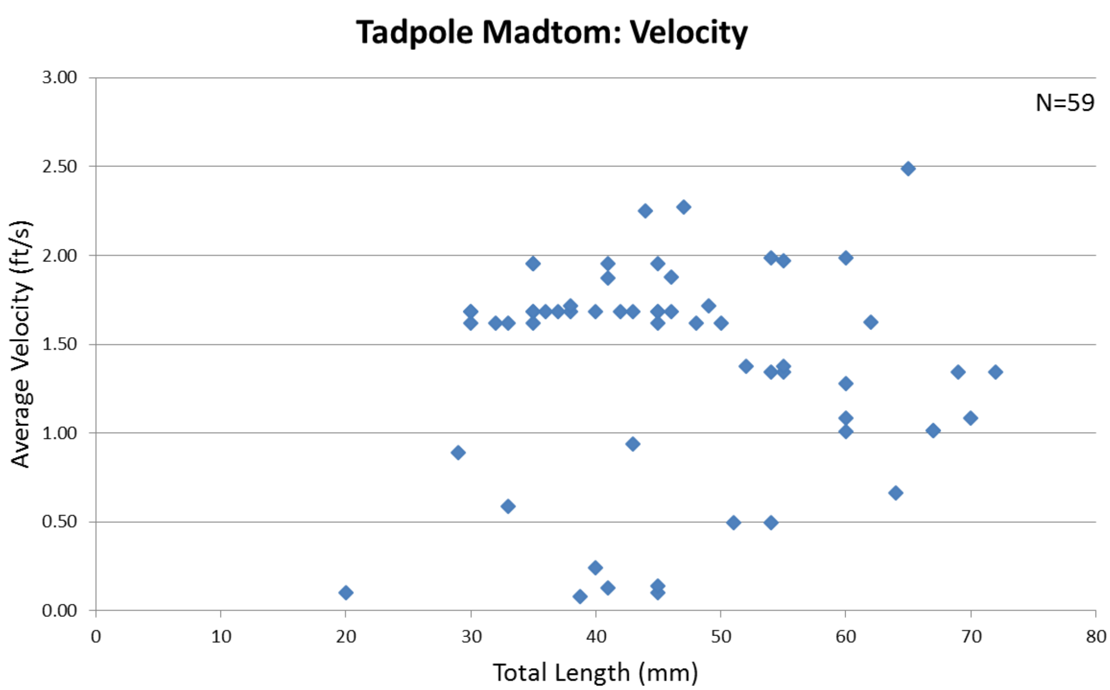


Figure B-27. Average depth and average velocity versus total length for Tadpole Madtom *Noturus gyrinus*.

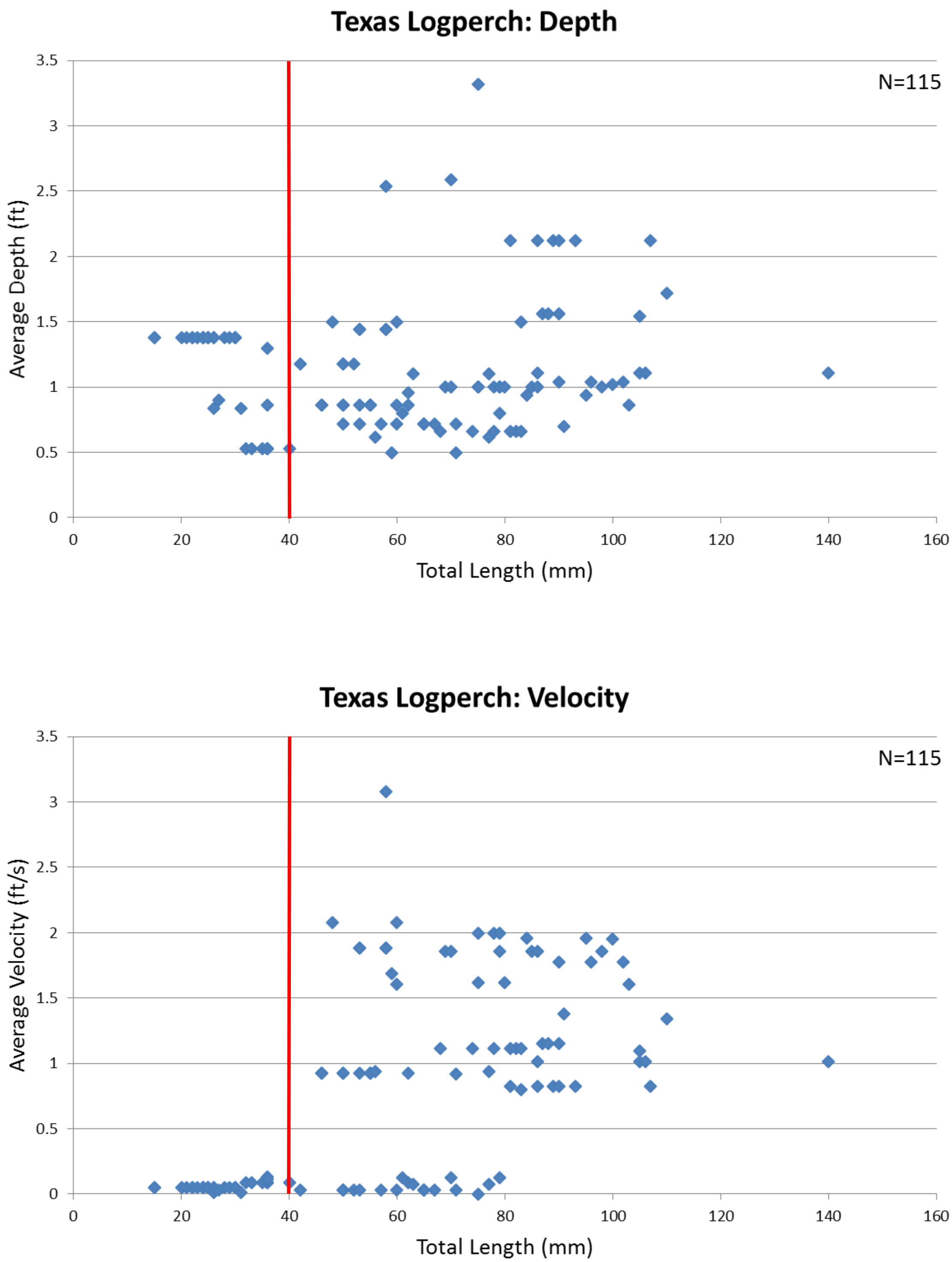
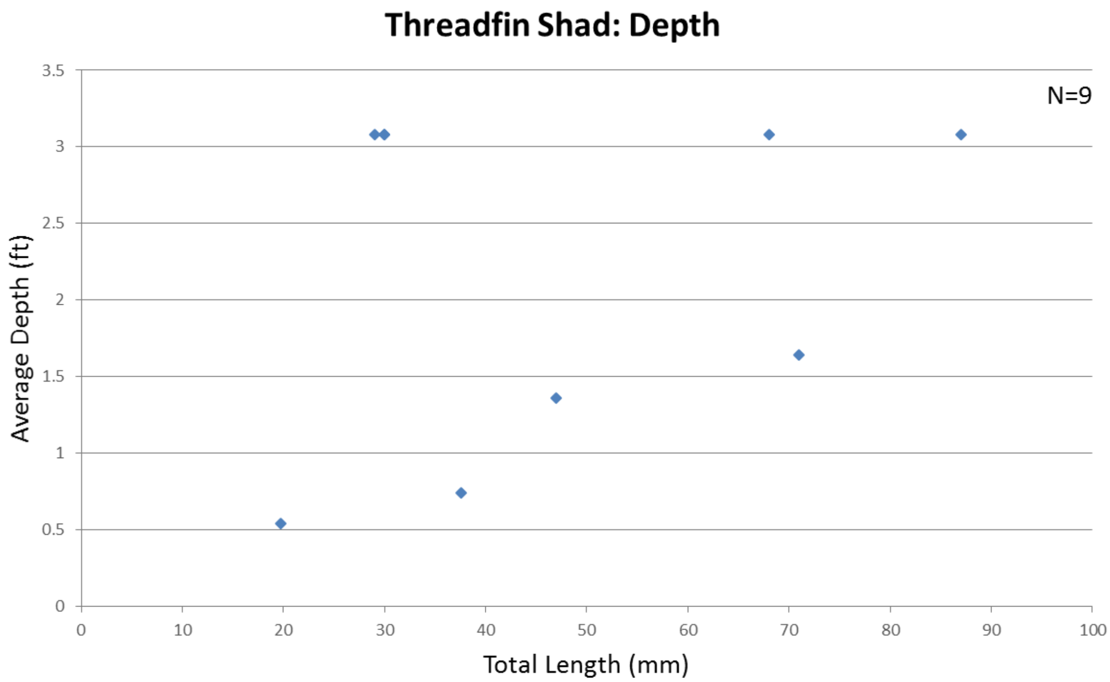


Figure B-28. Average depth and average velocity versus total length for Texas Logperch *Percina carbonaria*. The red line indicates the resulting boundary between juvenile and adult life stage categories (40 mm).



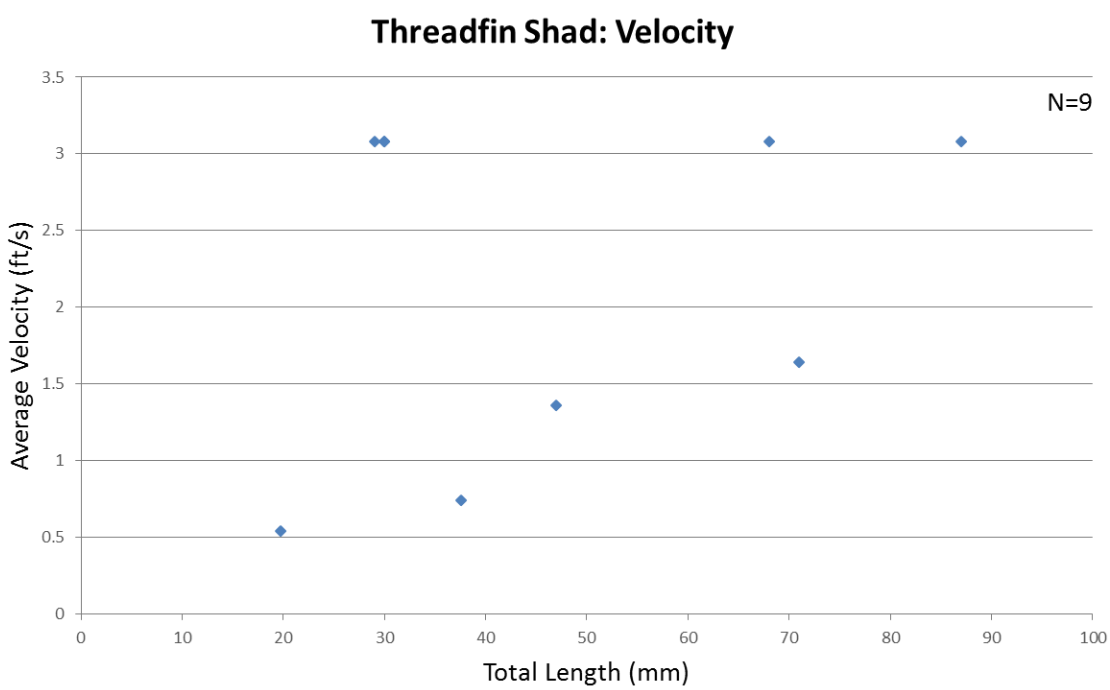
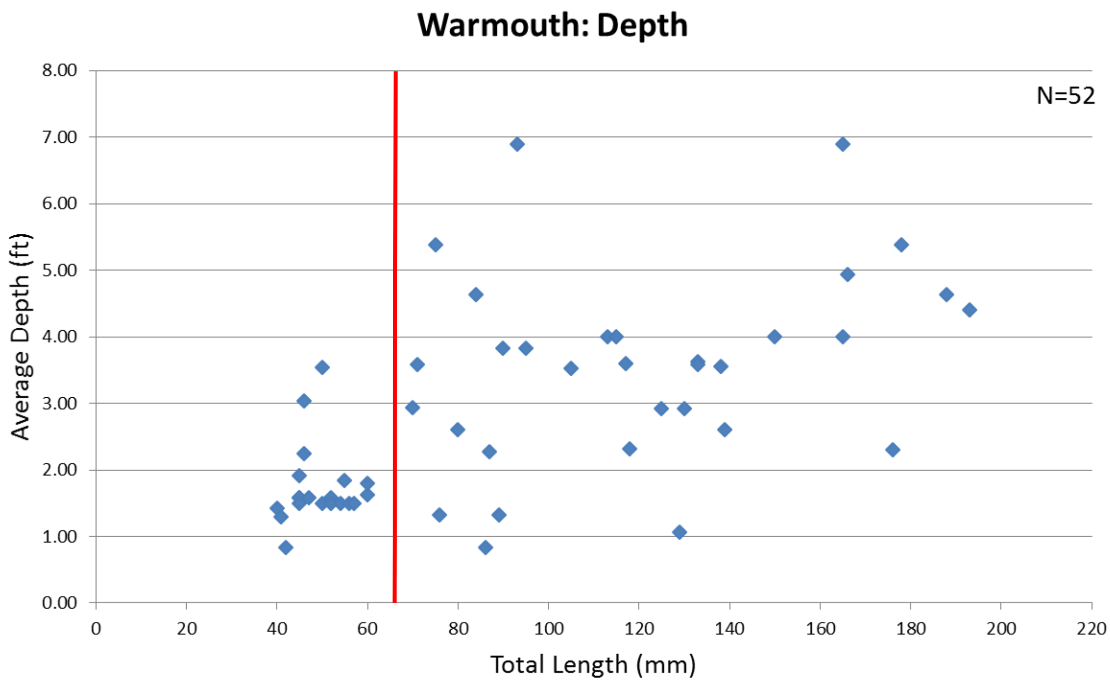


Figure B-29. Average depth and average velocity versus total length for Threadfin Shad *Dorosoma petenense*.



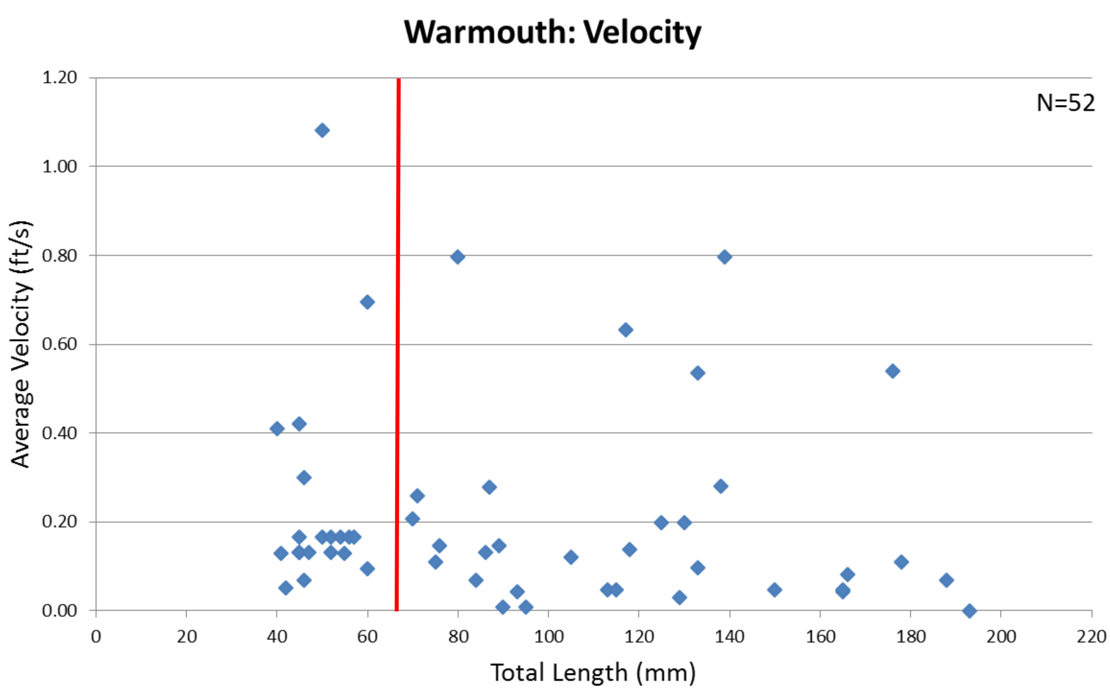
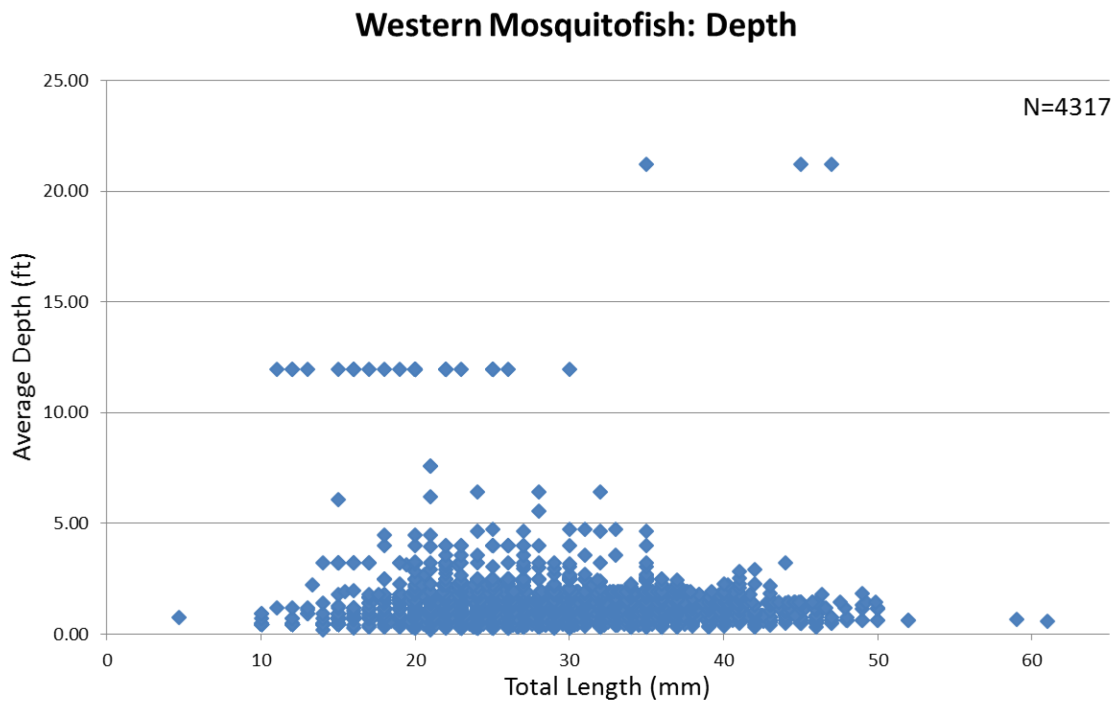


Figure B-30. Average depth and average velocity versus total length for Warmouth *Lepomis gulosus*. The red line indicates the resulting boundary between juvenile and adult life stage categories (65 mm).



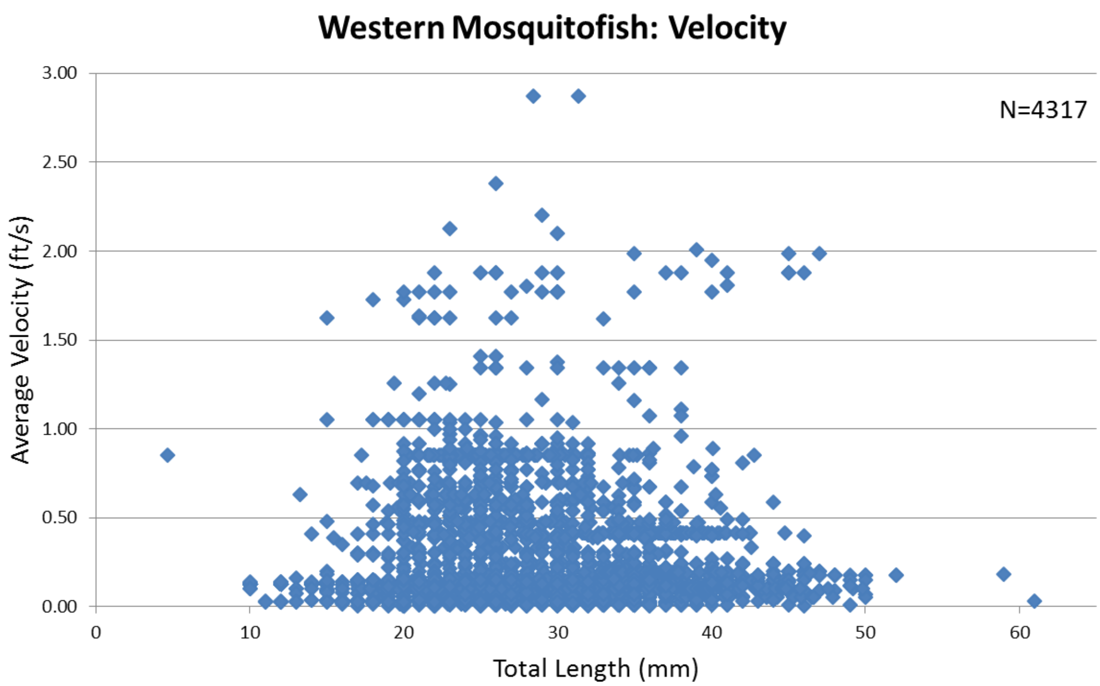
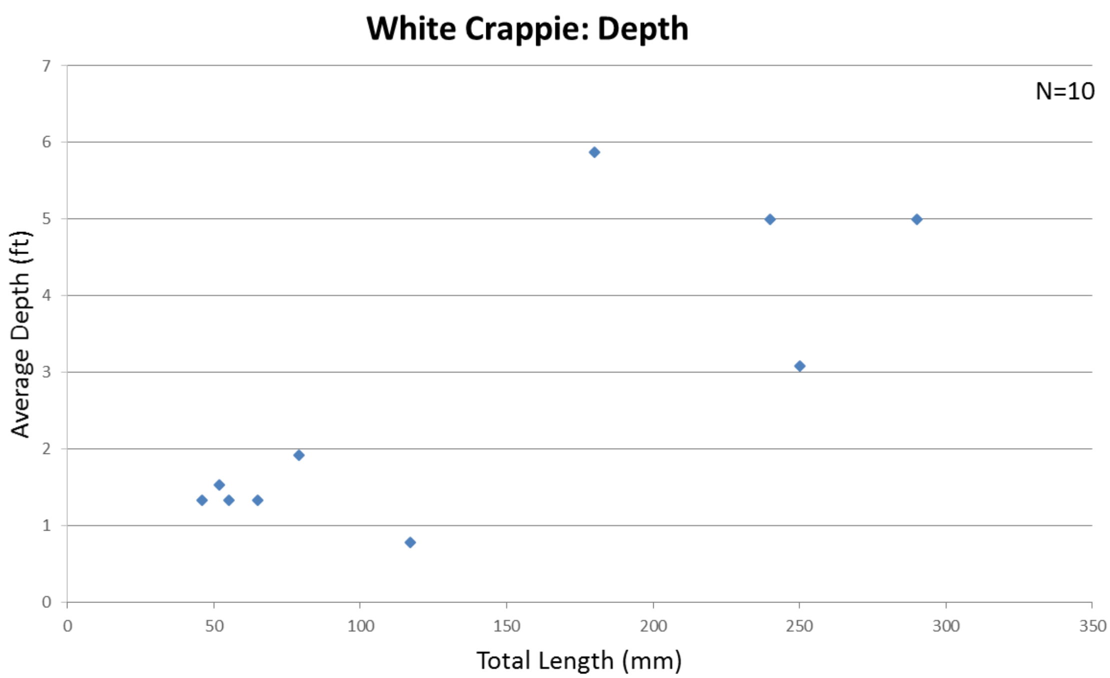


Figure B-31. Average depth and average velocity versus total length for Western Mosquitofish *Gambusia affinis*.



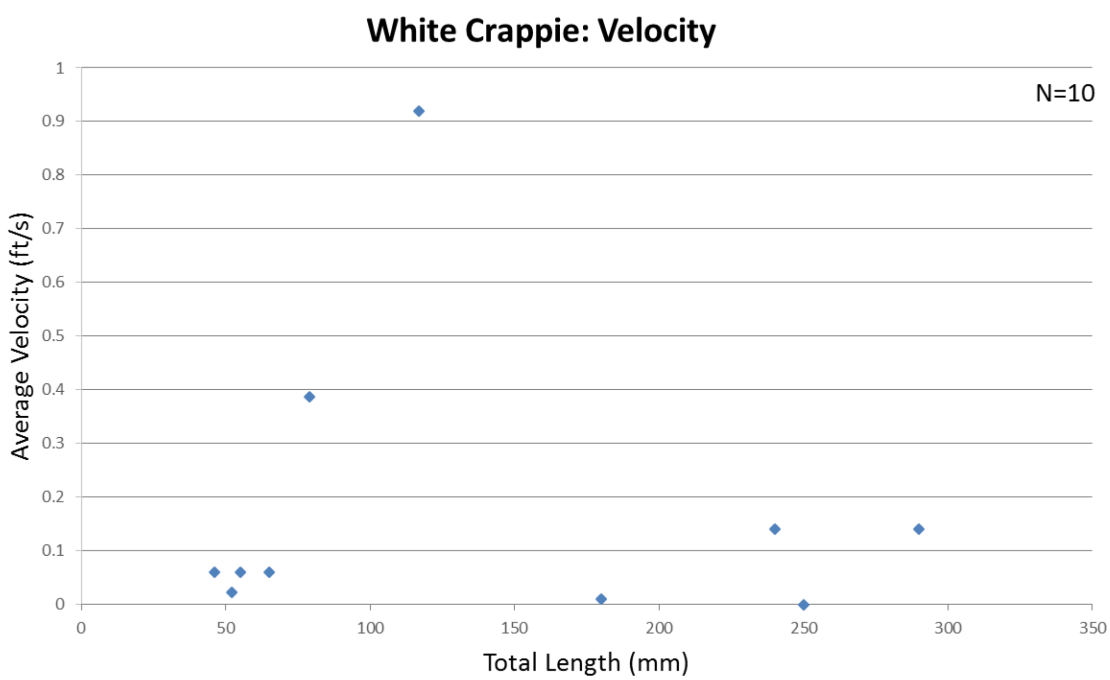


Figure B-32. Average depth and average velocity versus total length for White Crappie *Pomoxis annularis*.

APPENDIX C

SEASONAL FISH HABITAT UTILIZATION FIGURES

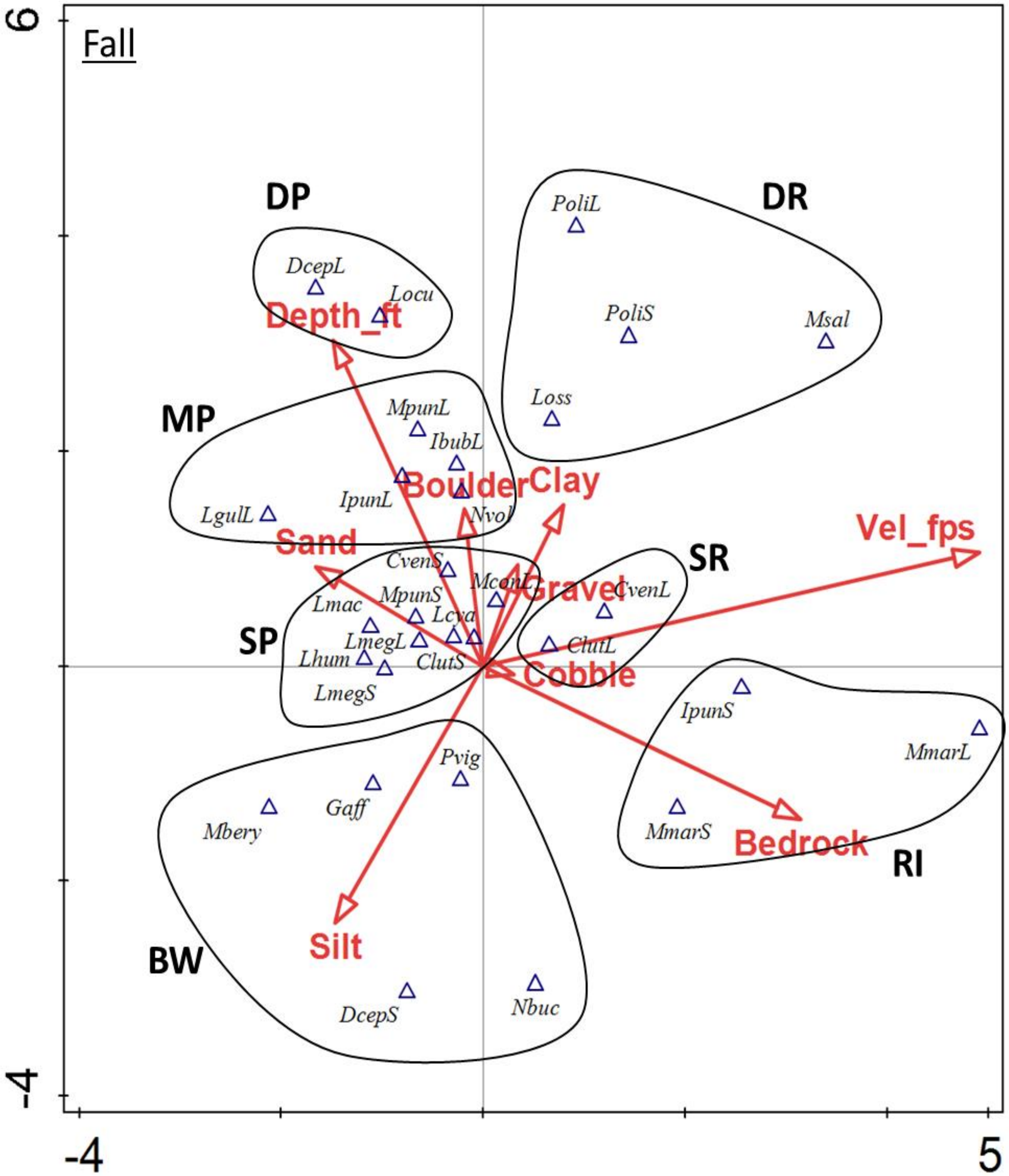


Figure C-1. Canonical correspondence analysis plot showing species associations among gradients of depth, velocity, and substrate for fall season samples. Red circles encompass habitat guilds (DP – Deep Pool, DR – Deep Run, MP – Moderate Pool, SP – Shallow Pool, BW – Backwater, RI – Riffle, SR – Shallow Run). Species/life stage abbreviations are provided in Table 9.

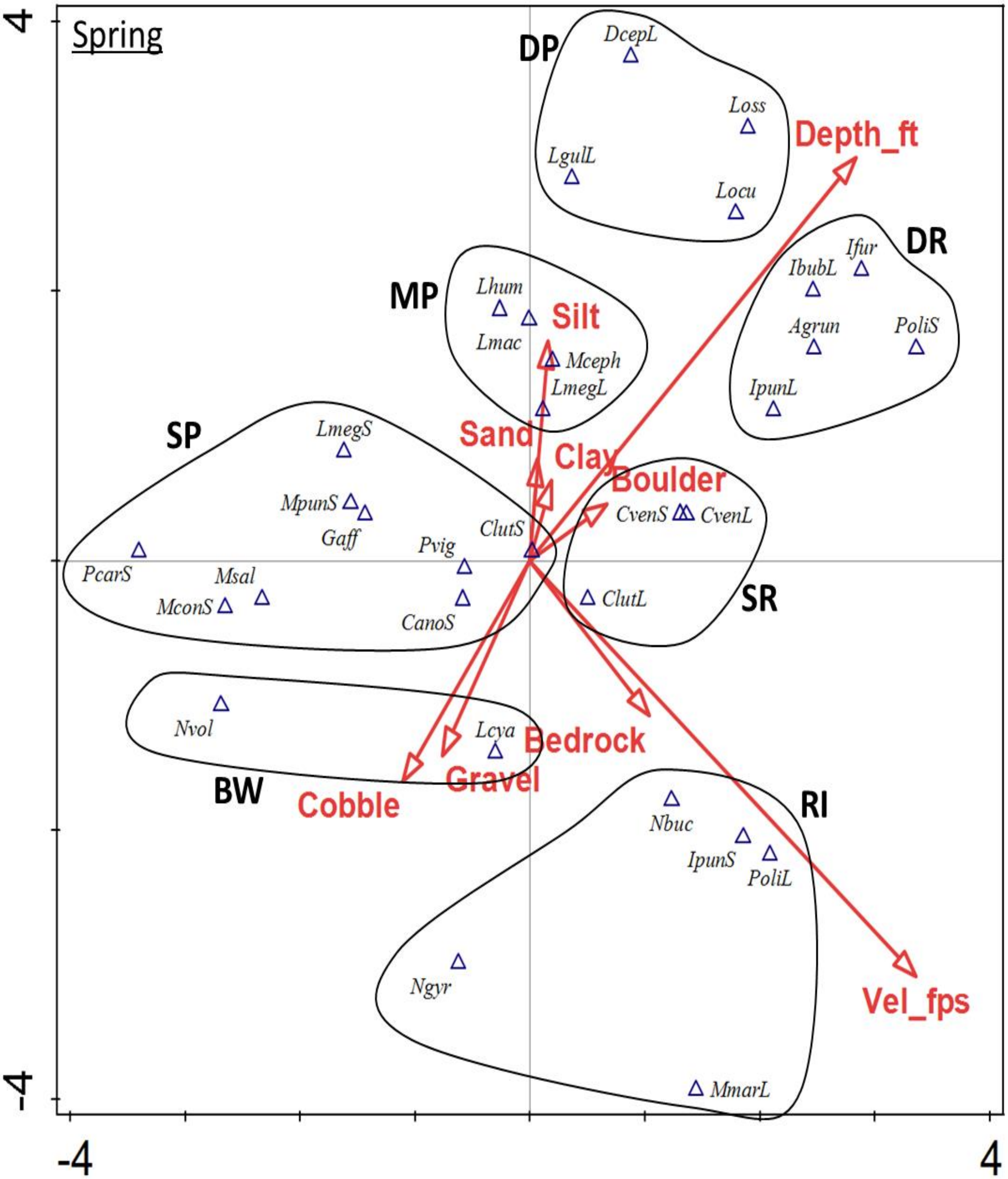


Figure C-2. Canonical correspondence analysis plot showing species associations among gradients of depth, velocity, and substrate for spring season samples. Red circles encompass habitat guilds (DP – Deep Pool, DR – Deep Run, MP – Moderate Pool, SP – Shallow Pool, BW – Backwater, RI – Riffle, SR – Shallow Run). Species/life stage abbreviations are provided in Table 9.

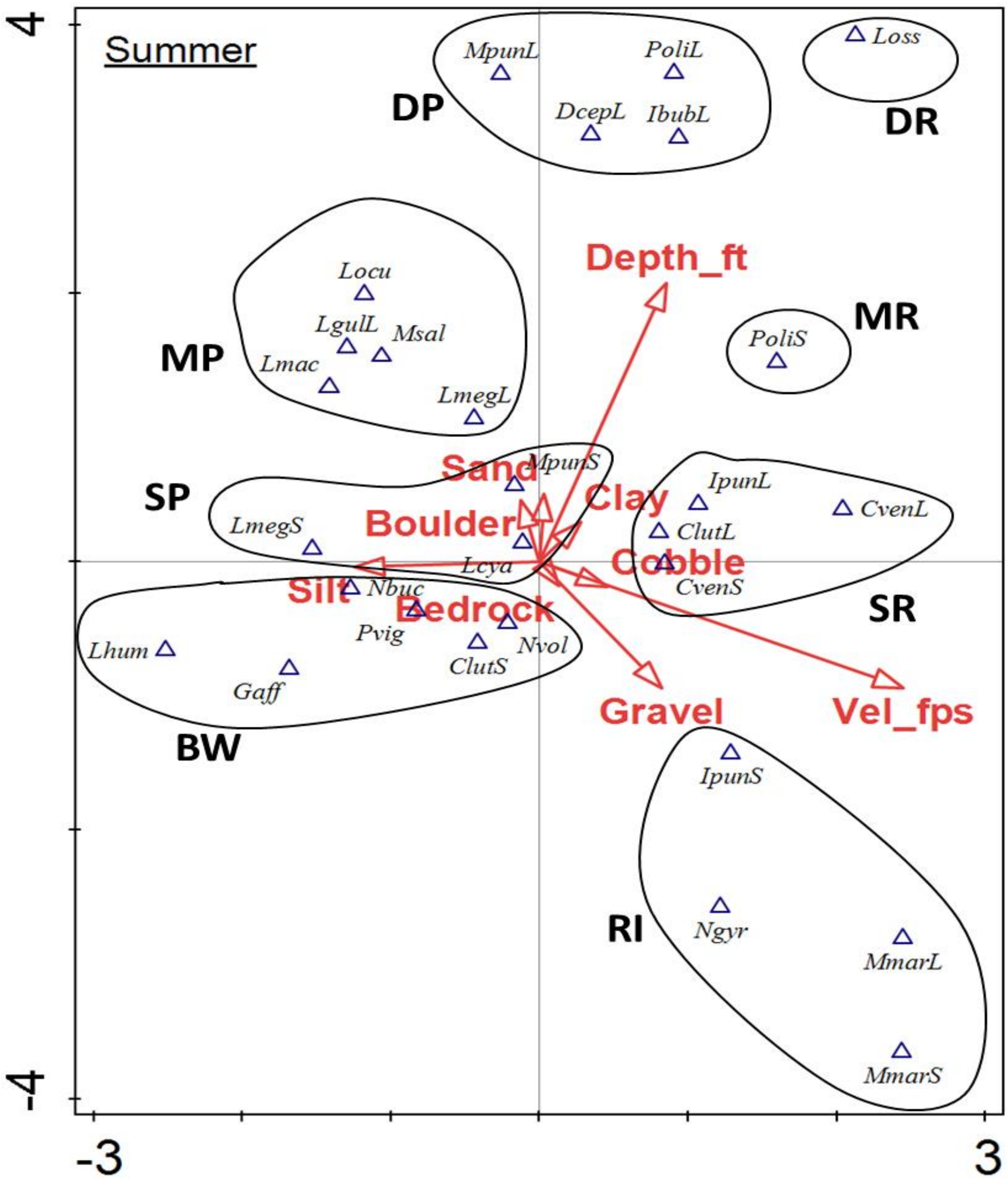


Figure C-3. Canonical correspondence analysis plot showing species associations among gradients of depth, velocity, and substrate for summer season samples. Red circles encompass habitat guilds (DP – Deep Pool, DR – Deep Run, MP – Moderate Pool, SP – Shallow Pool, BW – Backwater, RI – Riffle, SR – Shallow Run). Species/life stage abbreviations are provided in Table 9.

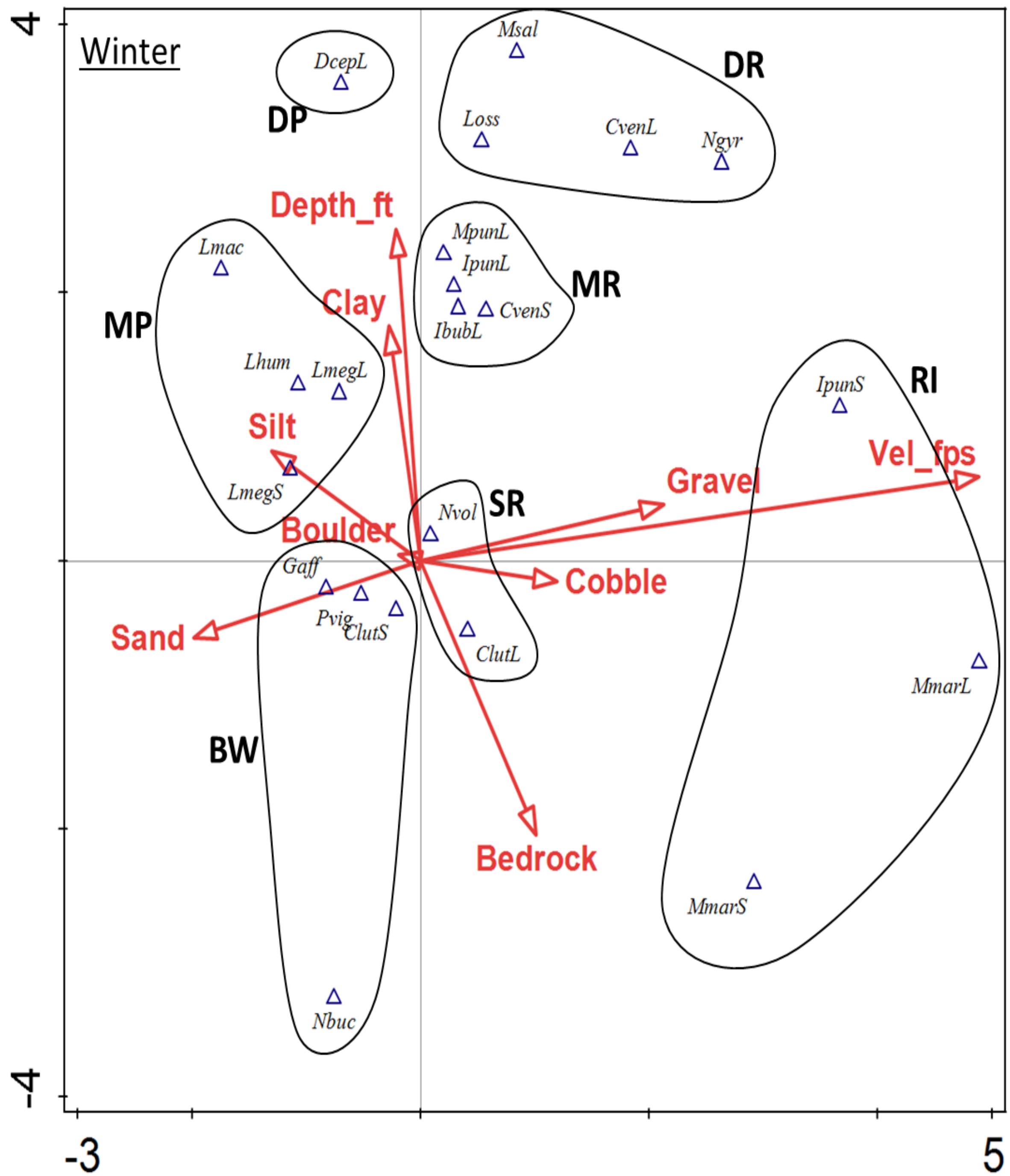


Figure C-4. Canonical correspondence analysis plot showing species associations among gradients of depth, velocity, and substrate for winter season samples. Red circles encompass habitat guilds (DP – Deep Pool, DR – Deep Run, MP – Moderate Pool, SP – Shallow Pool, BW – Backwater, RI – Riffle, SR – Shallow Run). Species/life stage abbreviations are provided in Table 9.

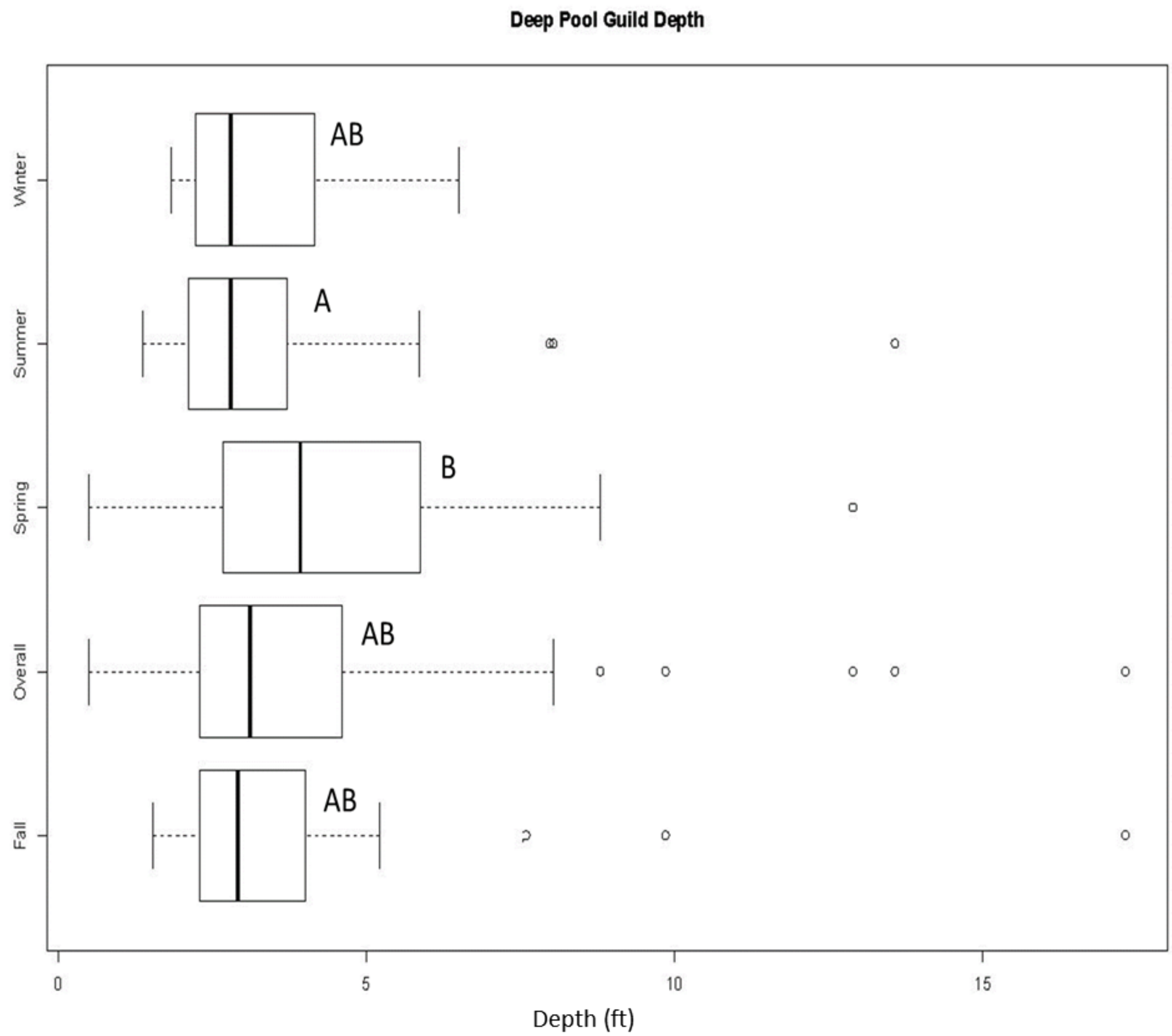


Figure C-5. Seasonal and overall depth (ft) utilization boxplots by Deep Pool guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

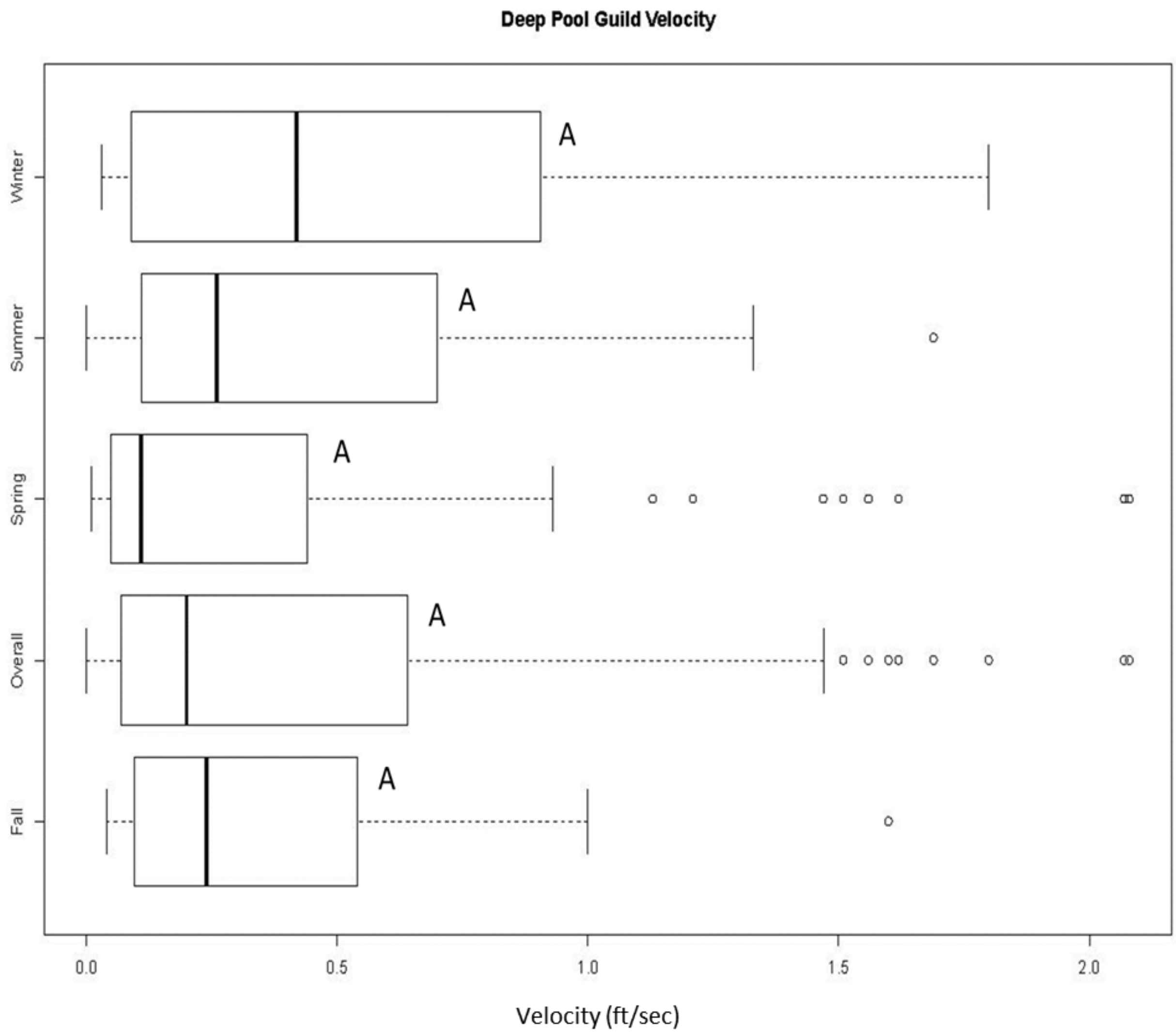


Figure C-6. Seasonal and overall velocity (ft/sec) utilization boxplots by Deep Pool guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

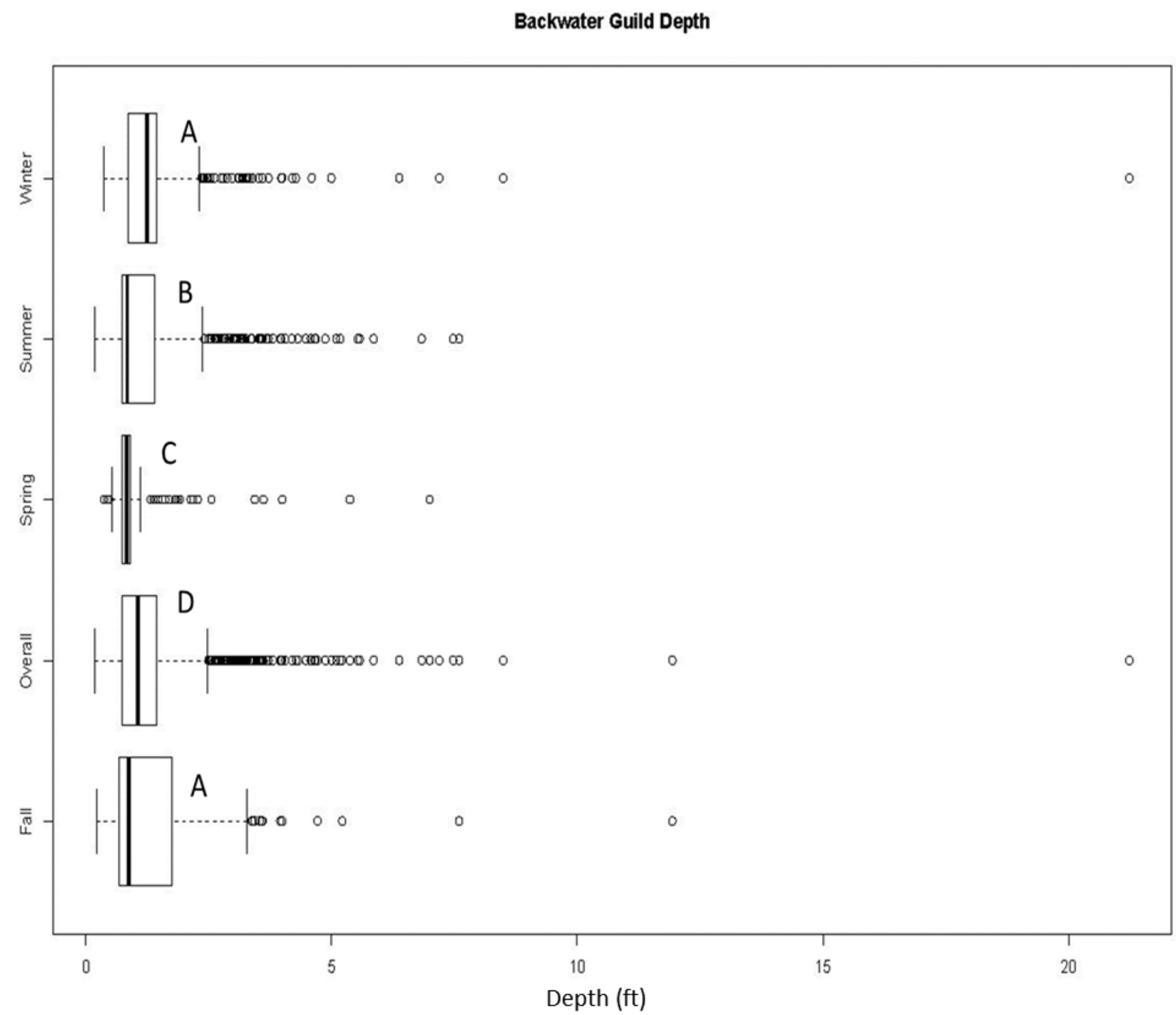


Figure C-7. Seasonal and overall depth (ft) utilization boxplots by Backwater guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

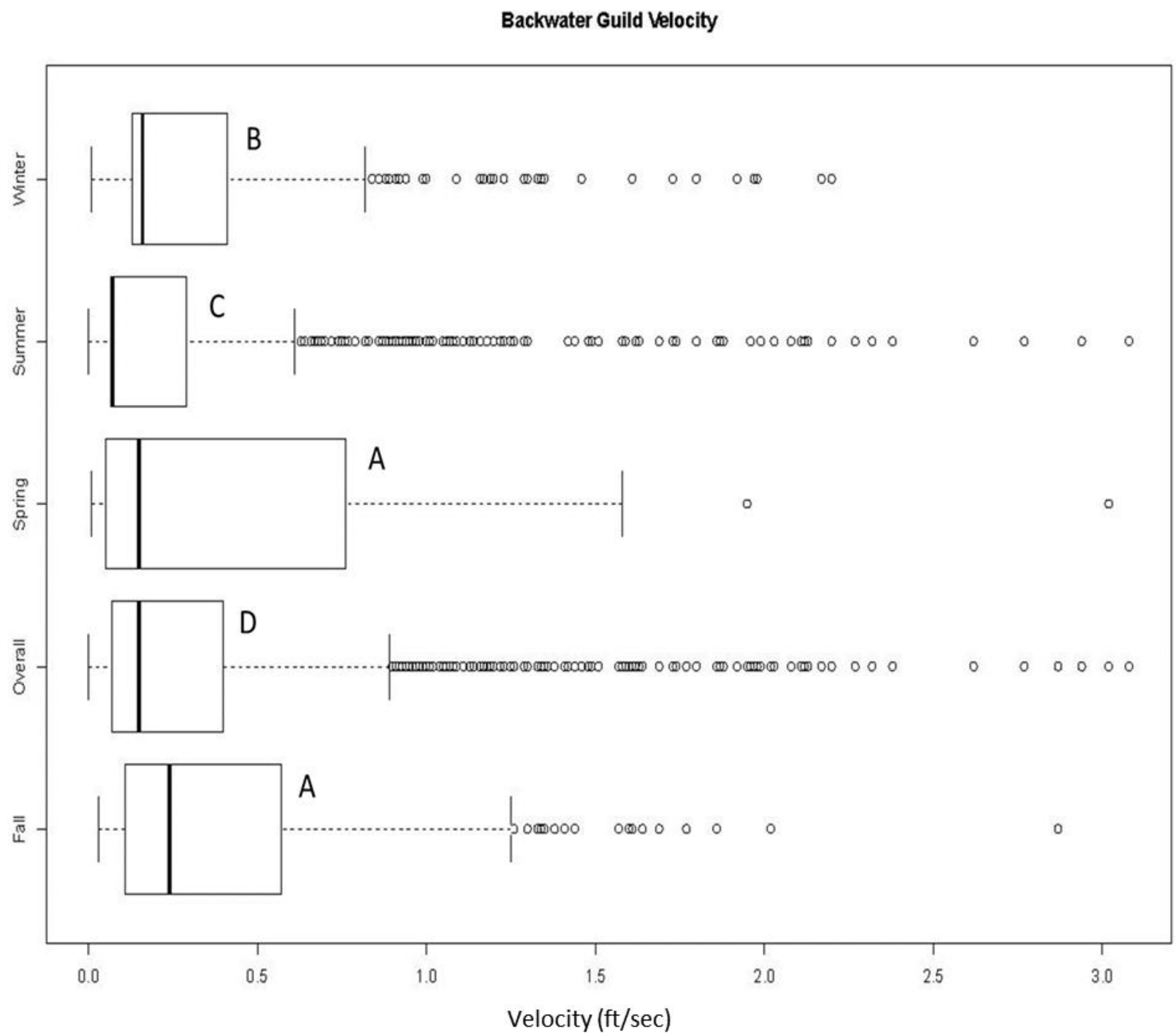


Figure C-8. Seasonal and overall velocity (ft/sec) utilization boxplots by Backwater guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

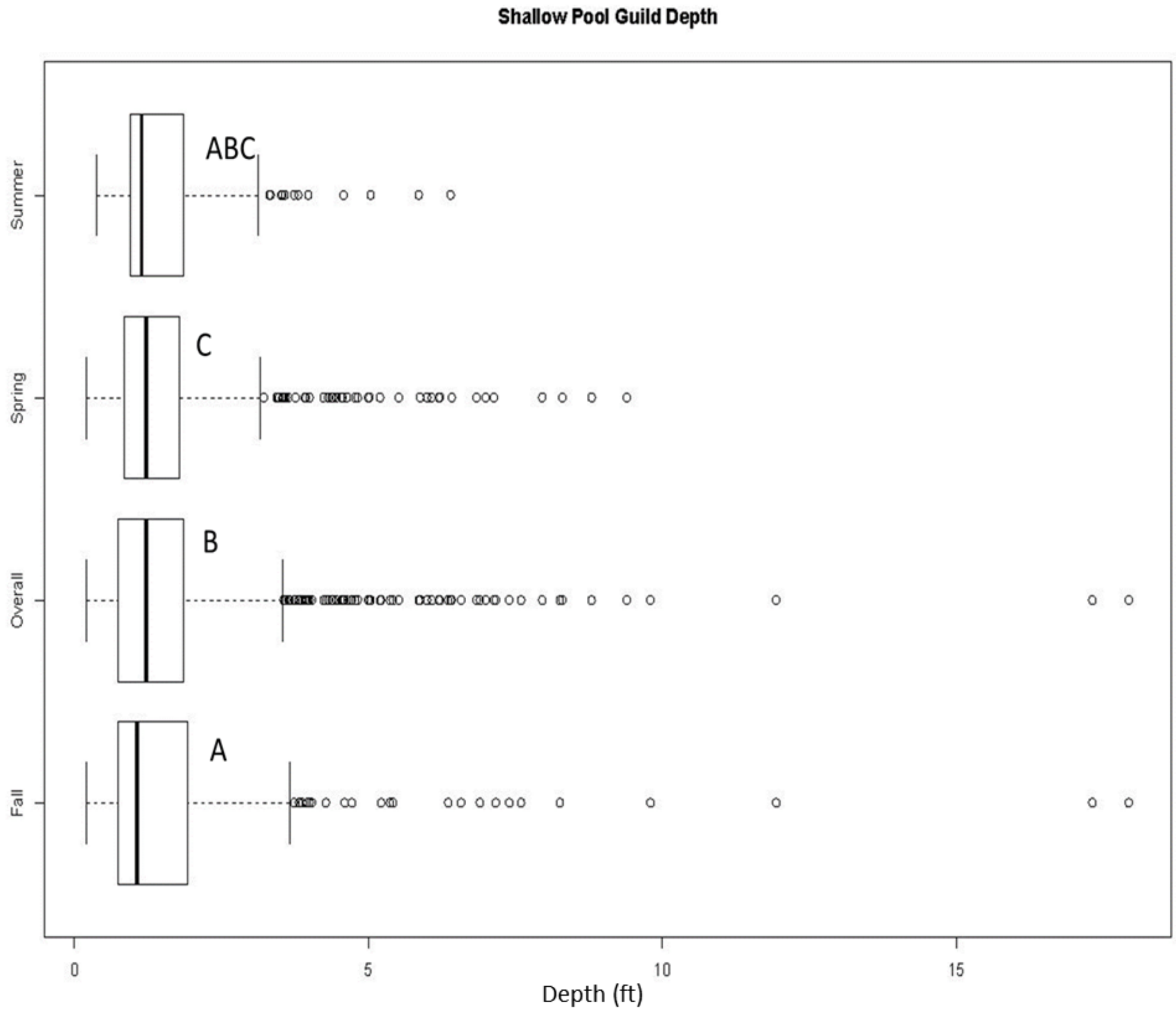


Figure C-9. Seasonal and overall depth (ft) utilization boxplots by Shallow Pool guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

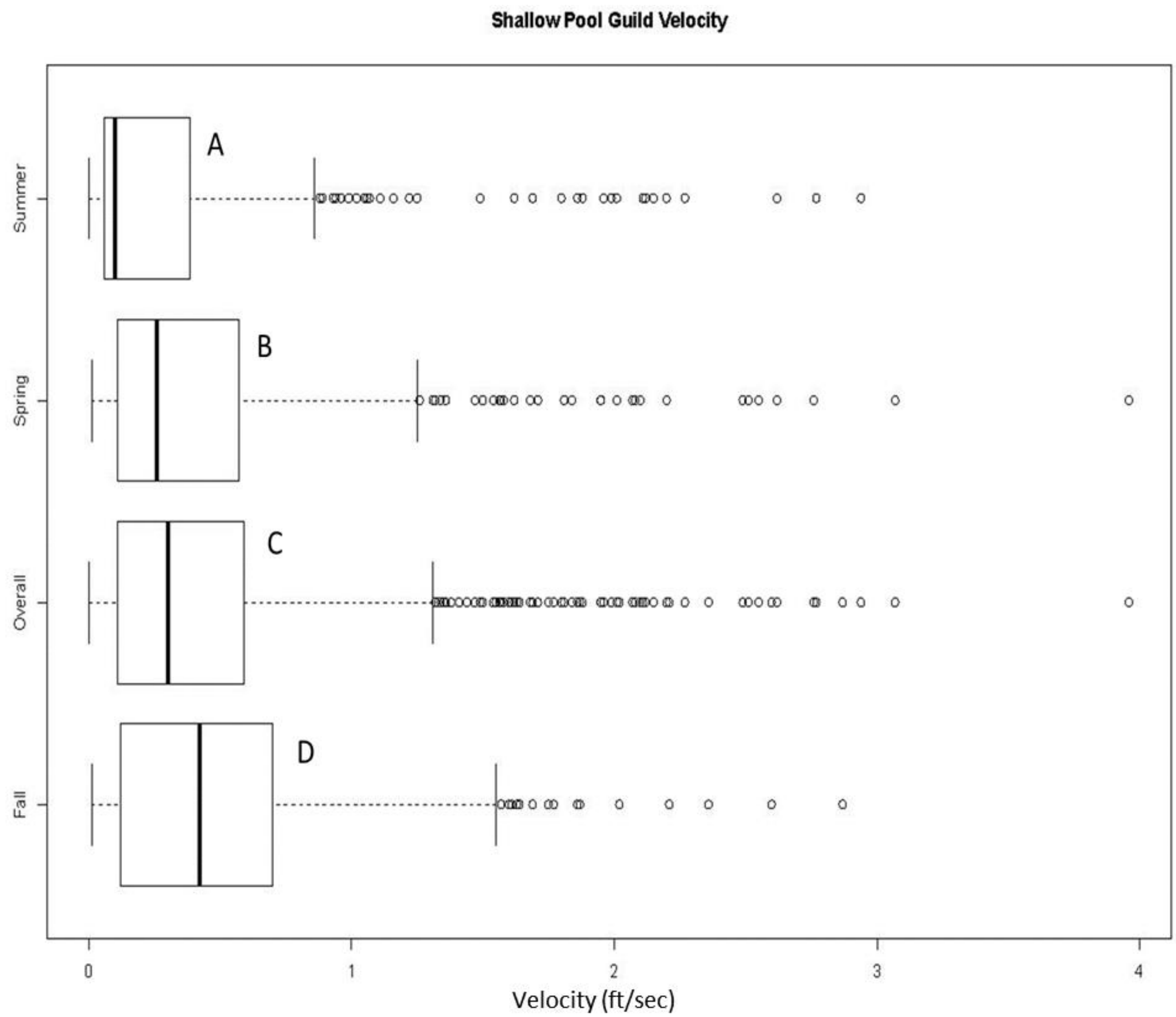


Figure C-10. Seasonal and overall velocity (ft/sec) utilization boxplots by Shallow Pool guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

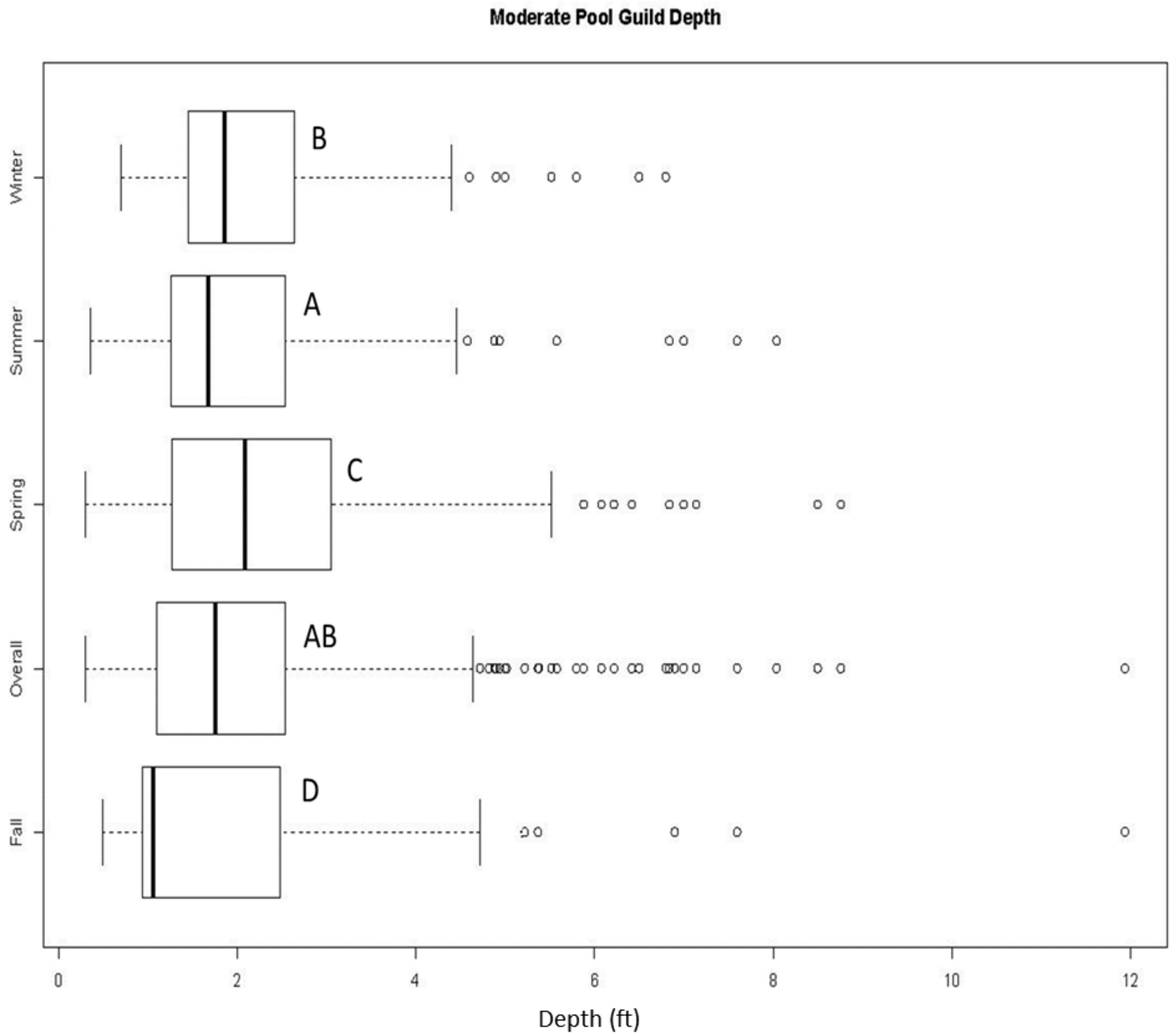


Figure C-11. Seasonal and overall depth (ft) utilization boxplots by Moderate Pool guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

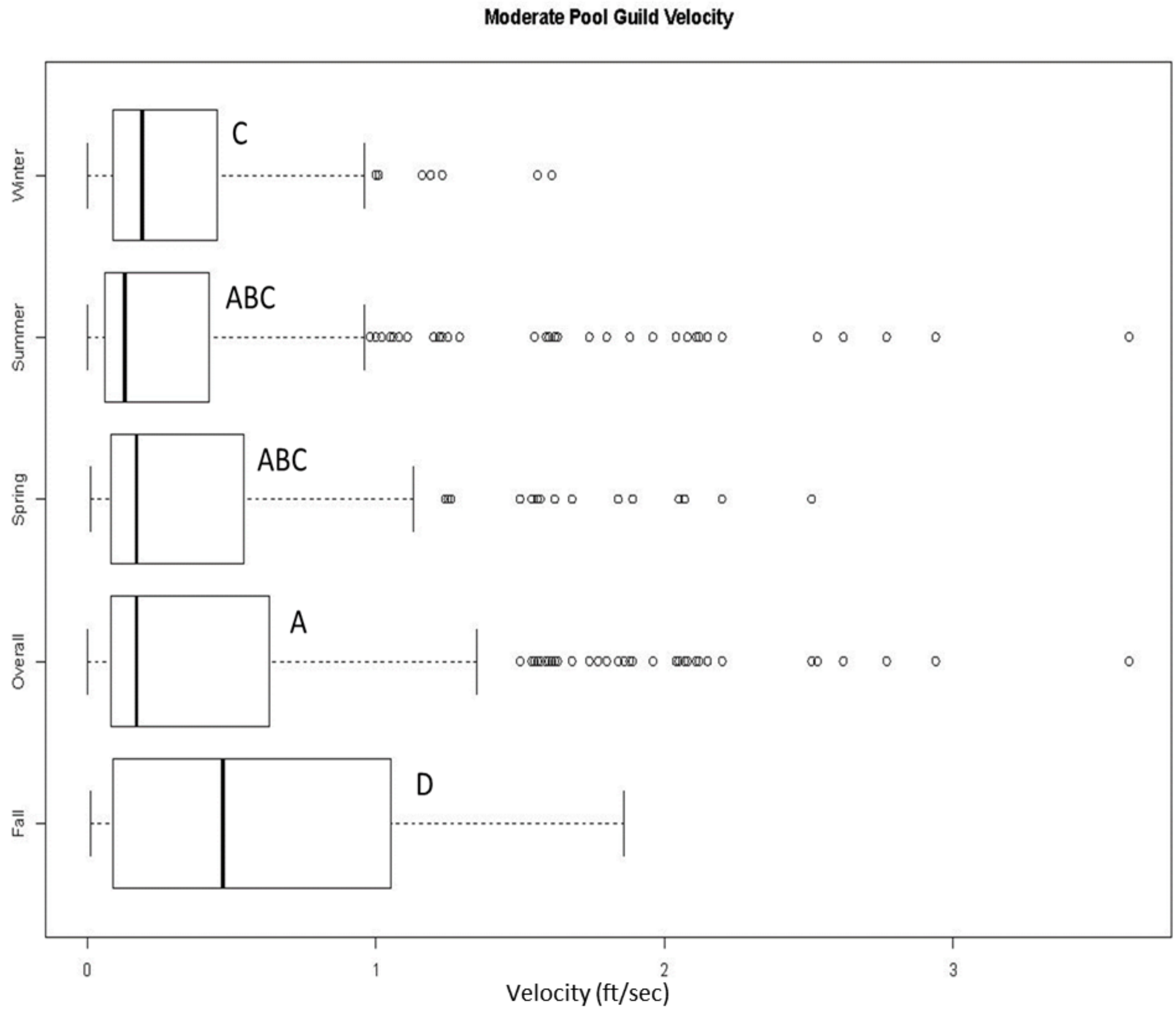


Figure C-12. Seasonal and overall velocity (ft/sec) utilization boxplots by Moderate Pool guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

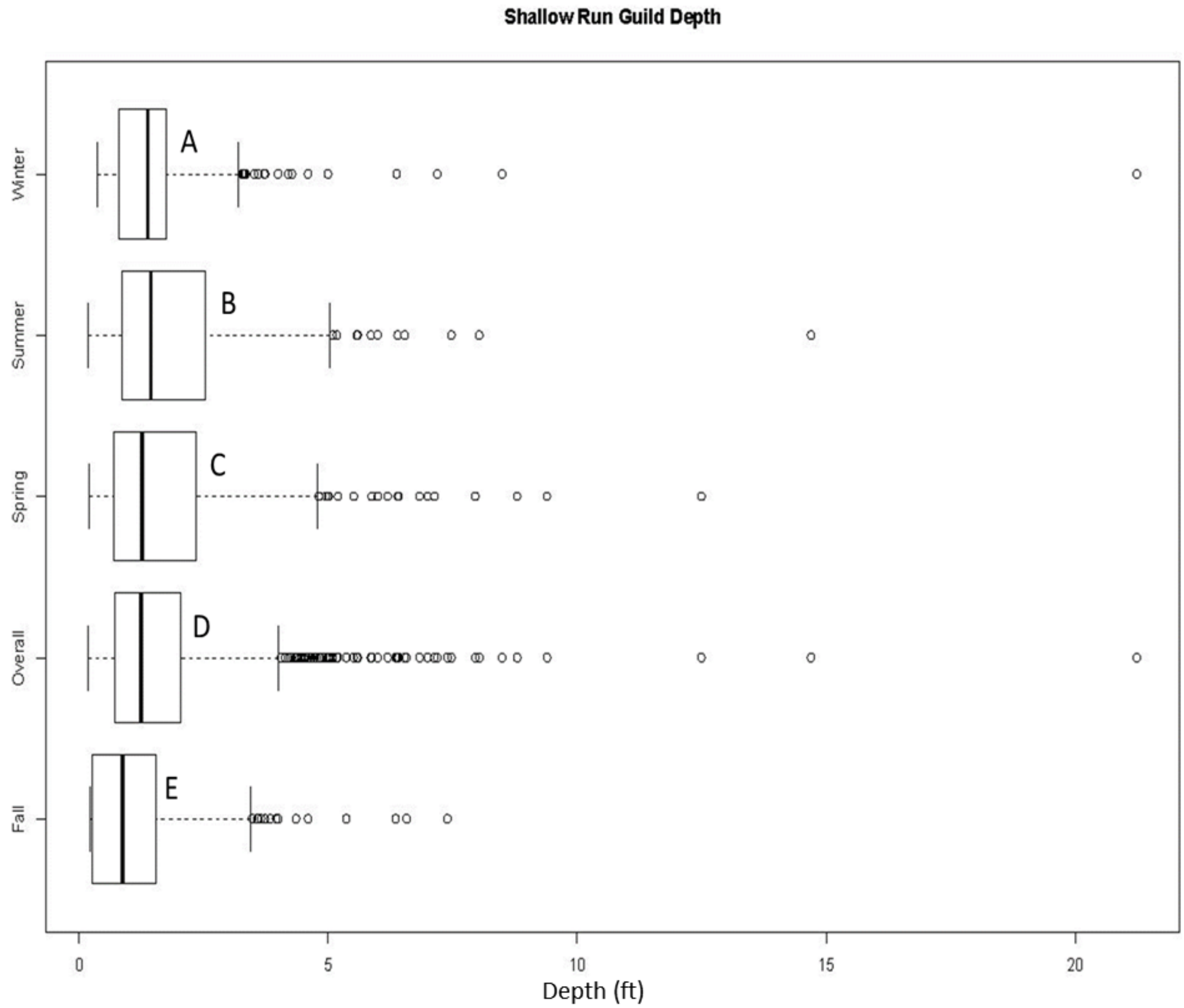


Figure C-13. Seasonal and overall depth (ft) utilization boxplots by Shallow Run guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

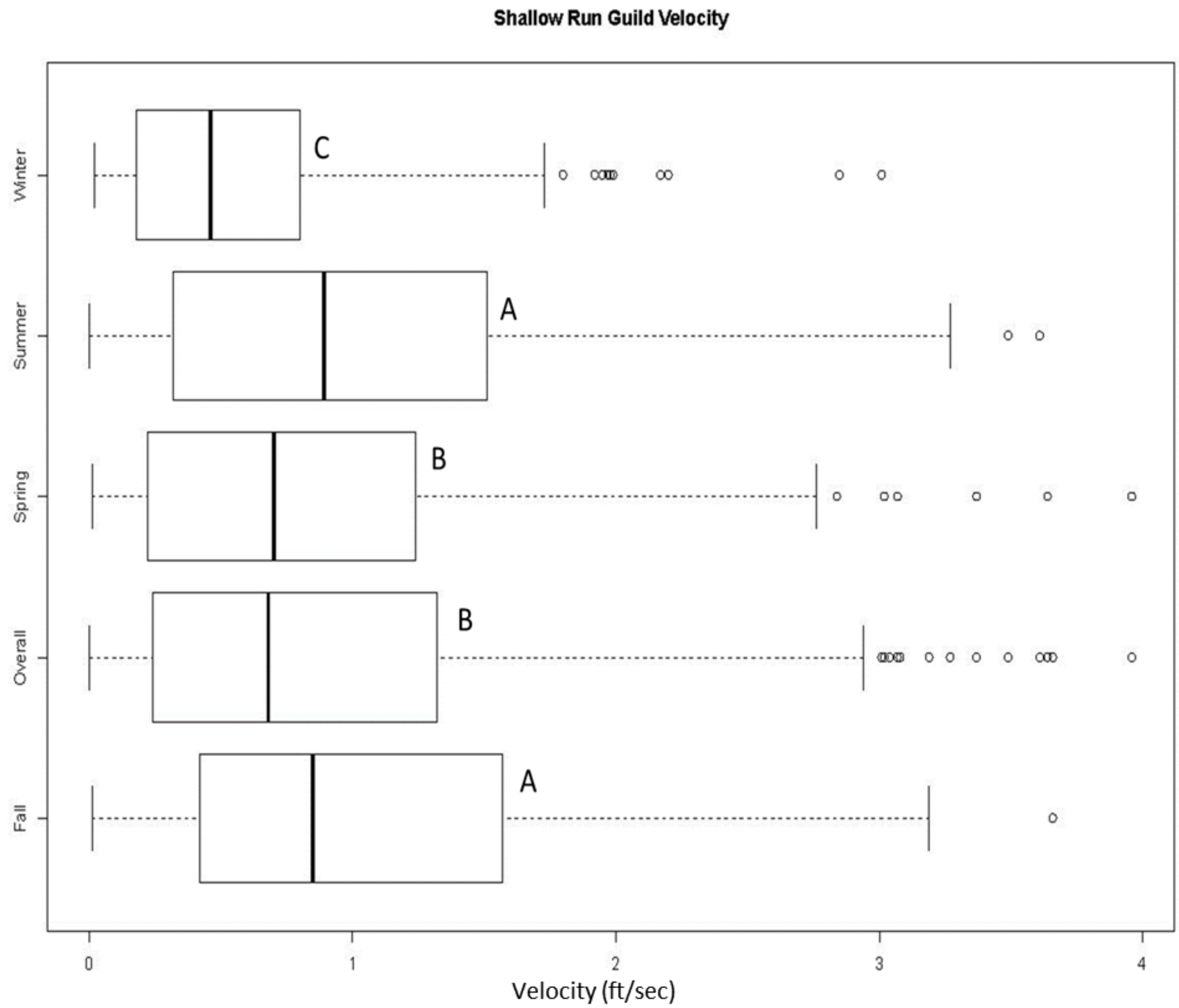


Figure C-14. Seasonal and overall velocity (ft/sec) utilization boxplots by Shallow Run guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

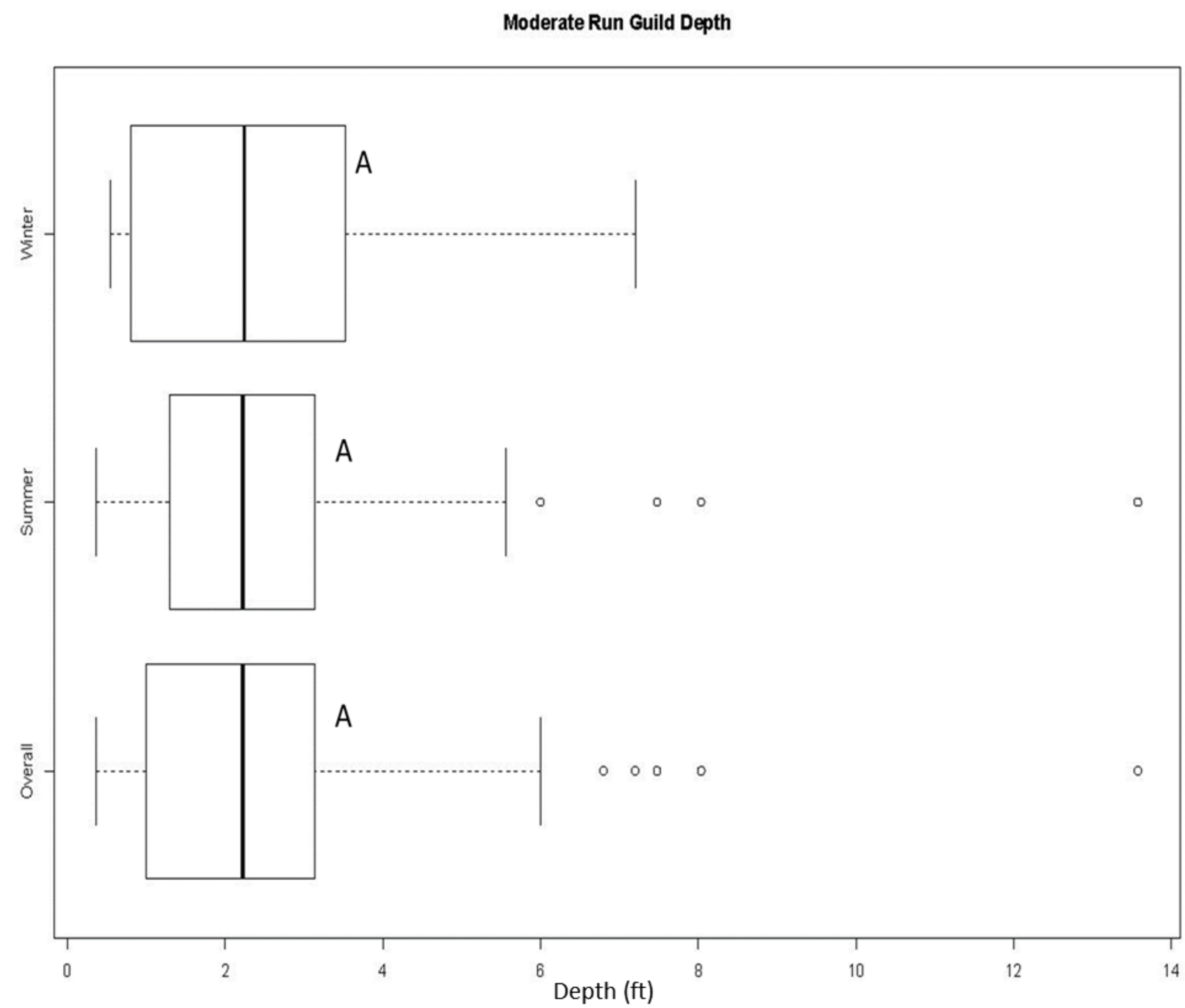


Figure C-15. Seasonal and overall depth (ft) utilization boxplots by Moderate Run guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

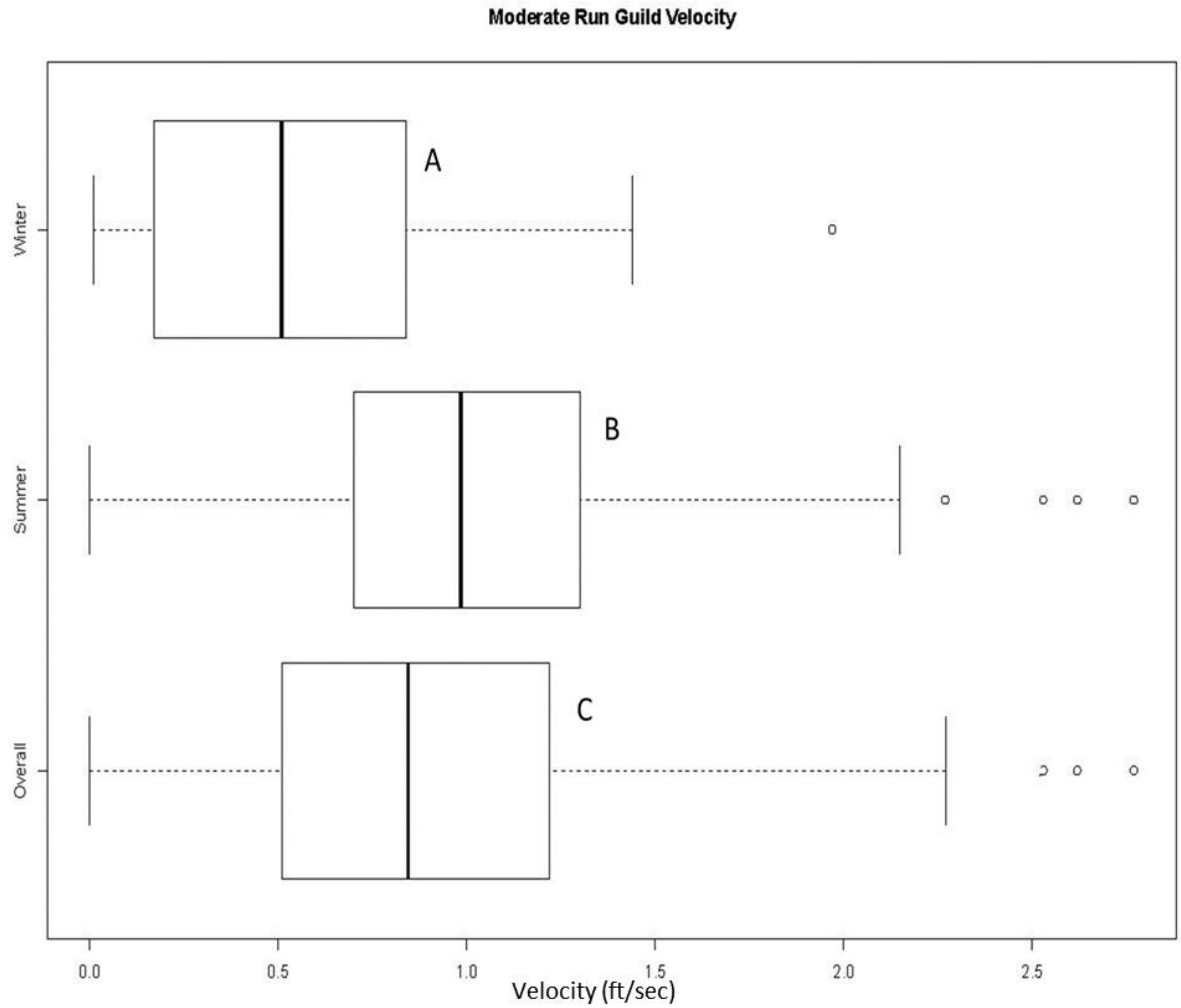


Figure C-16. Seasonal and overall velocity (ft/sec) utilization boxplots by Moderate Run guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

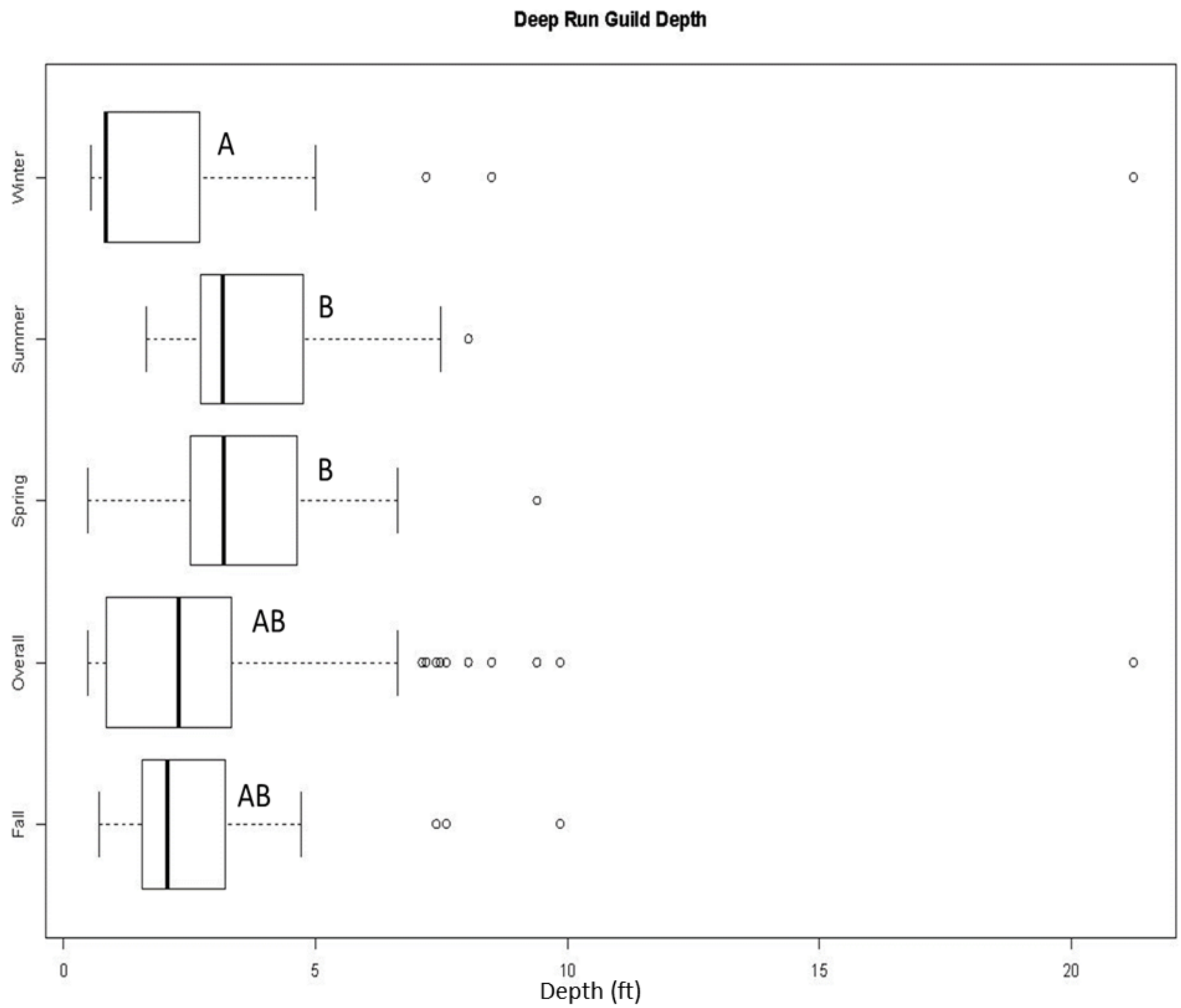


Figure C-17. Seasonal and overall detph (ft) utilization boxplots by Deep Run guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

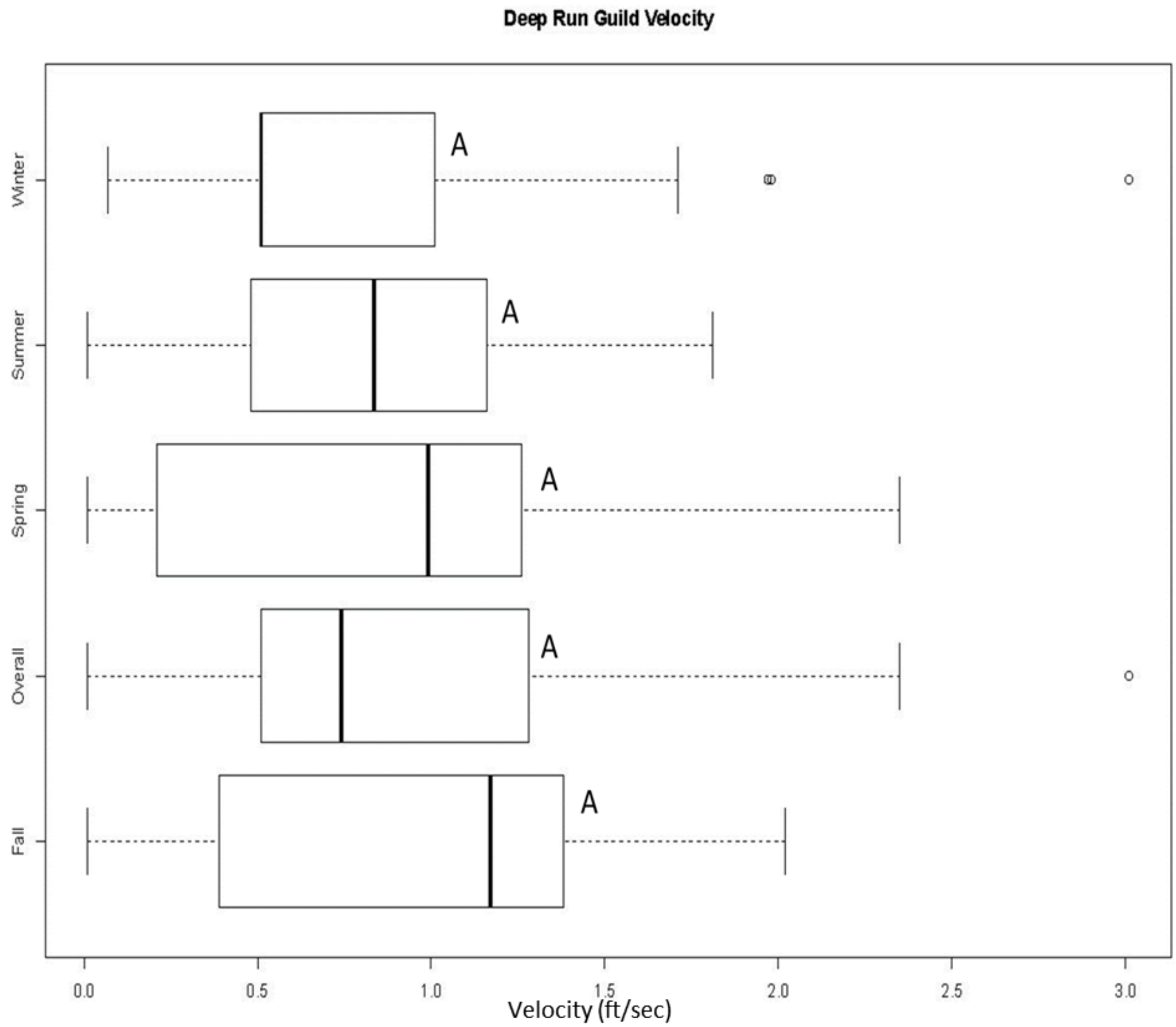


Figure C-18. Seasonal and overall velocity (ft/sec) utilization boxplots by Deep Run guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

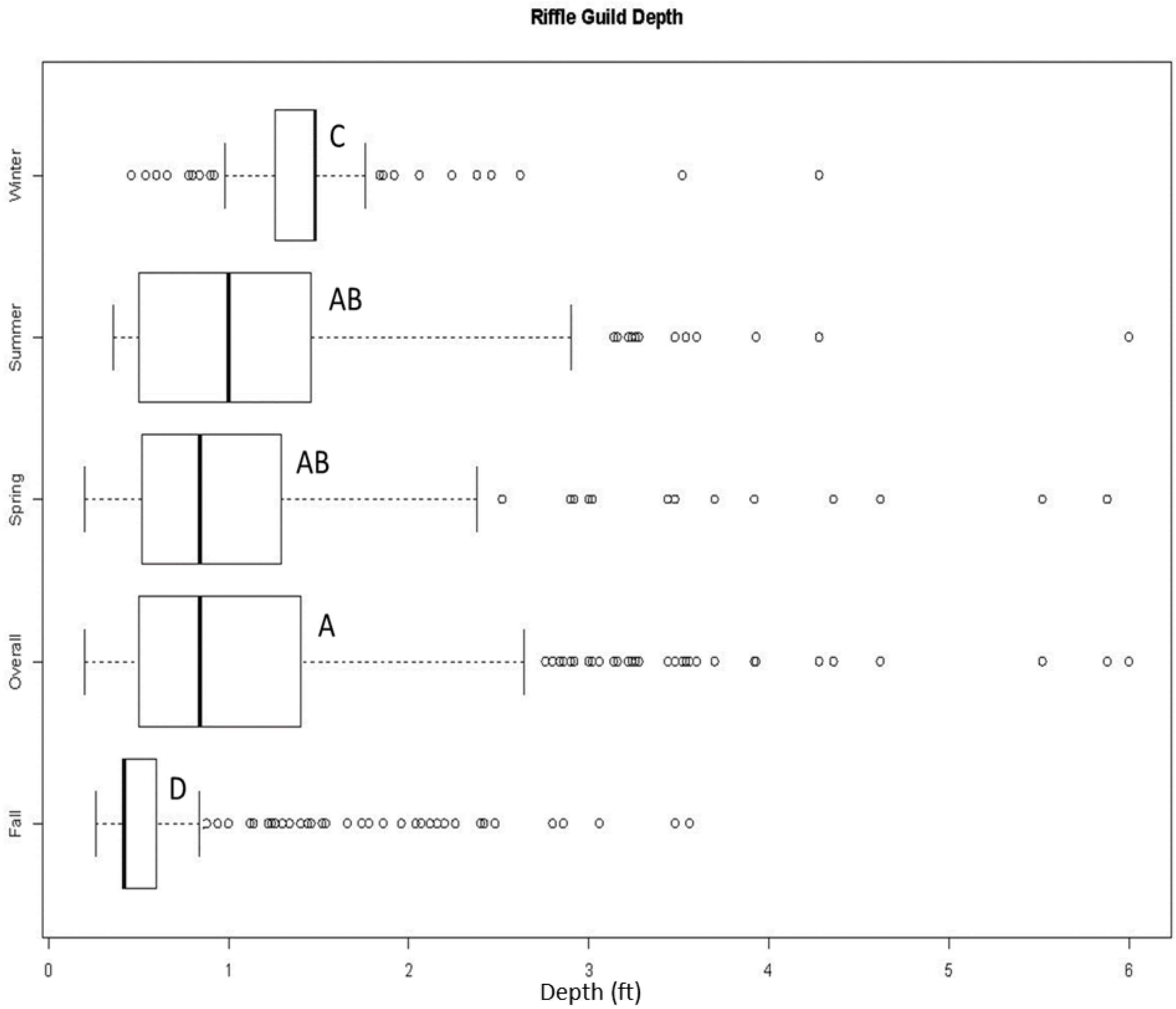


Figure C-19. Seasonal and overall depth (ft) utilization boxplots by Riffle guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.

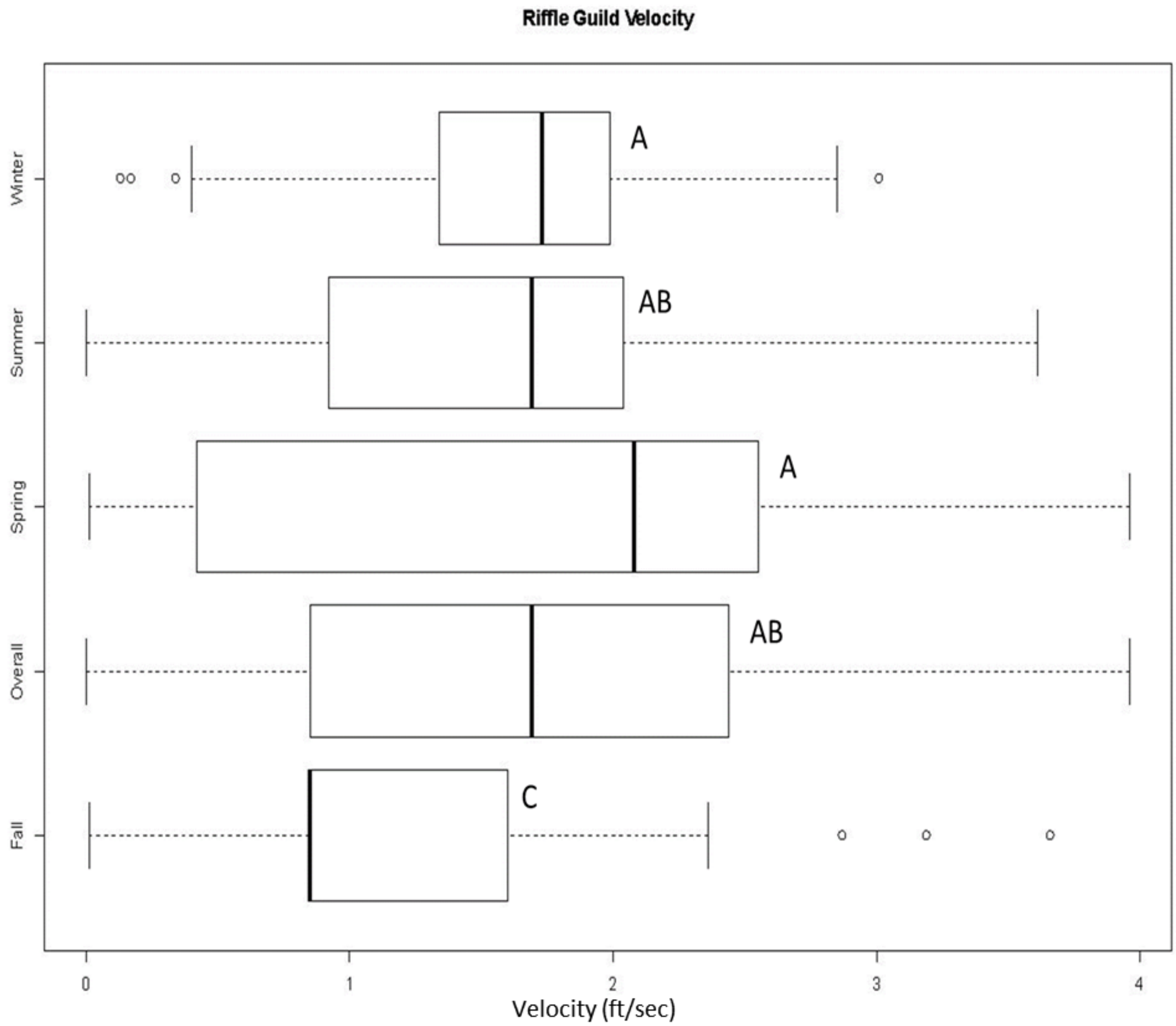
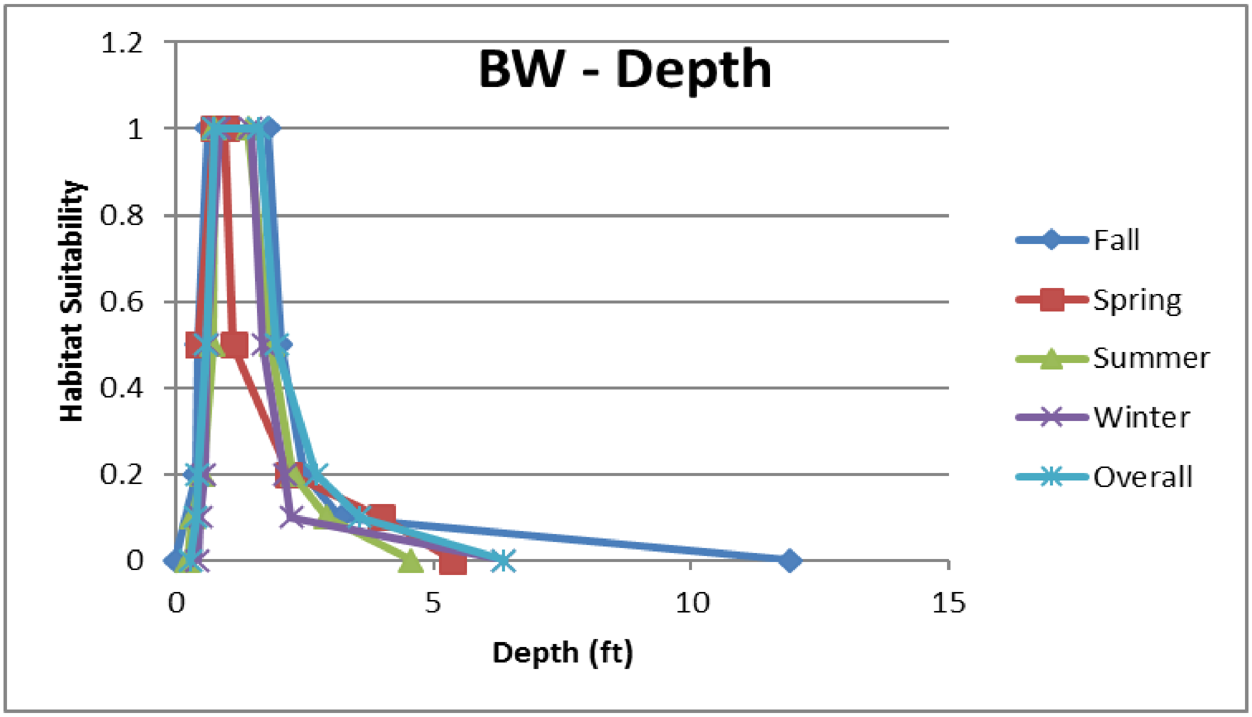


Figure C-20. Seasonal and overall velocity (ft/sec) utilization boxplots by Riffle guild species. Letters indicate significant differences ($p \leq 0.05$), with same letters being non-significant and different letters being significantly different.



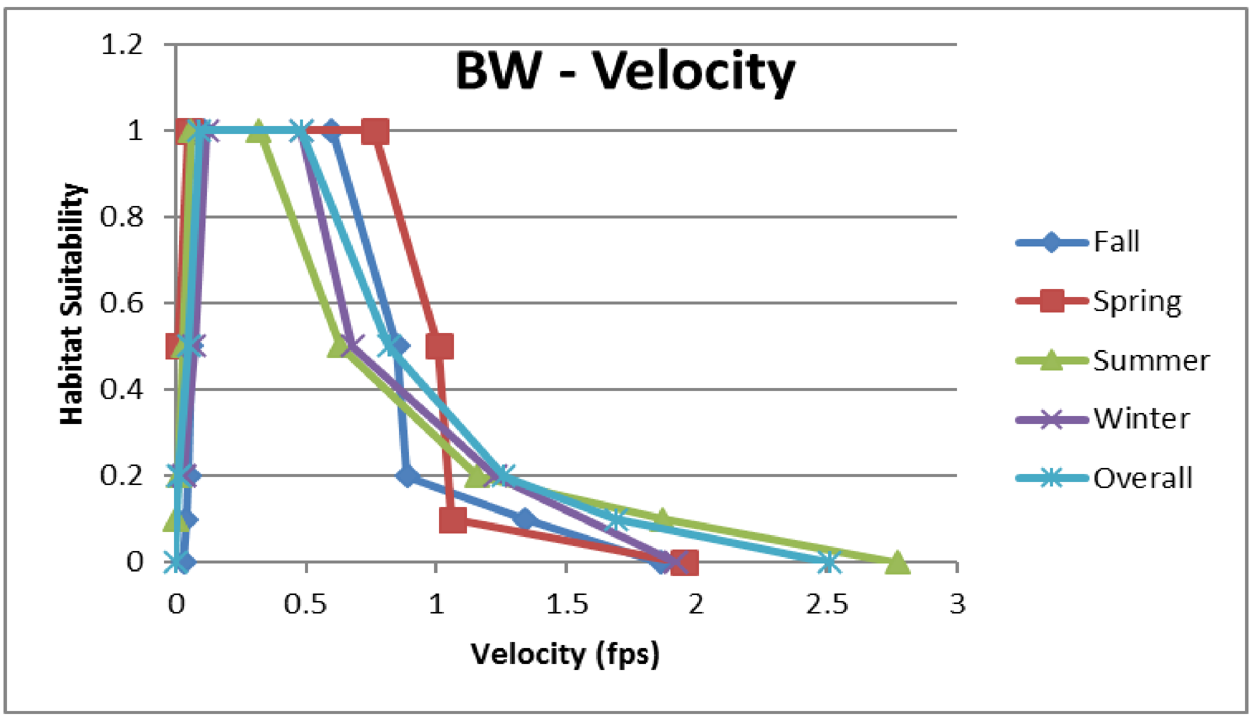
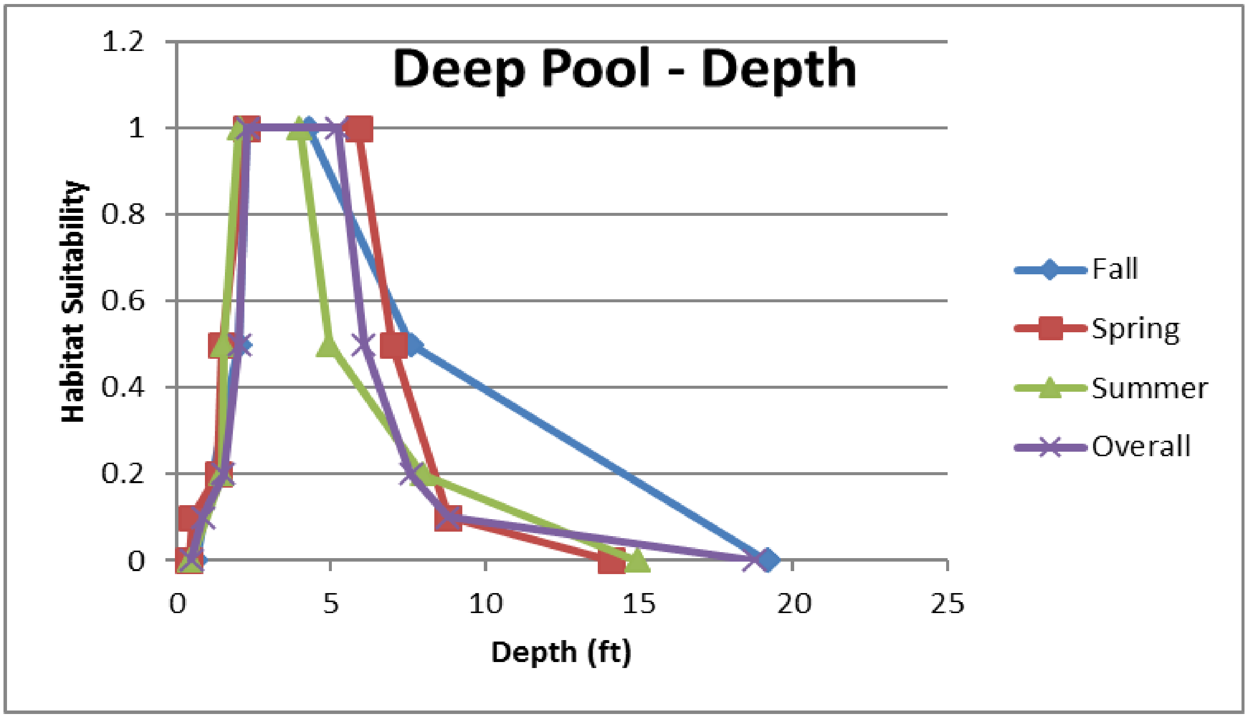


Figure C-21. Seasonal and overall depth and velocity habitat suitability curves for Backwater guild species.



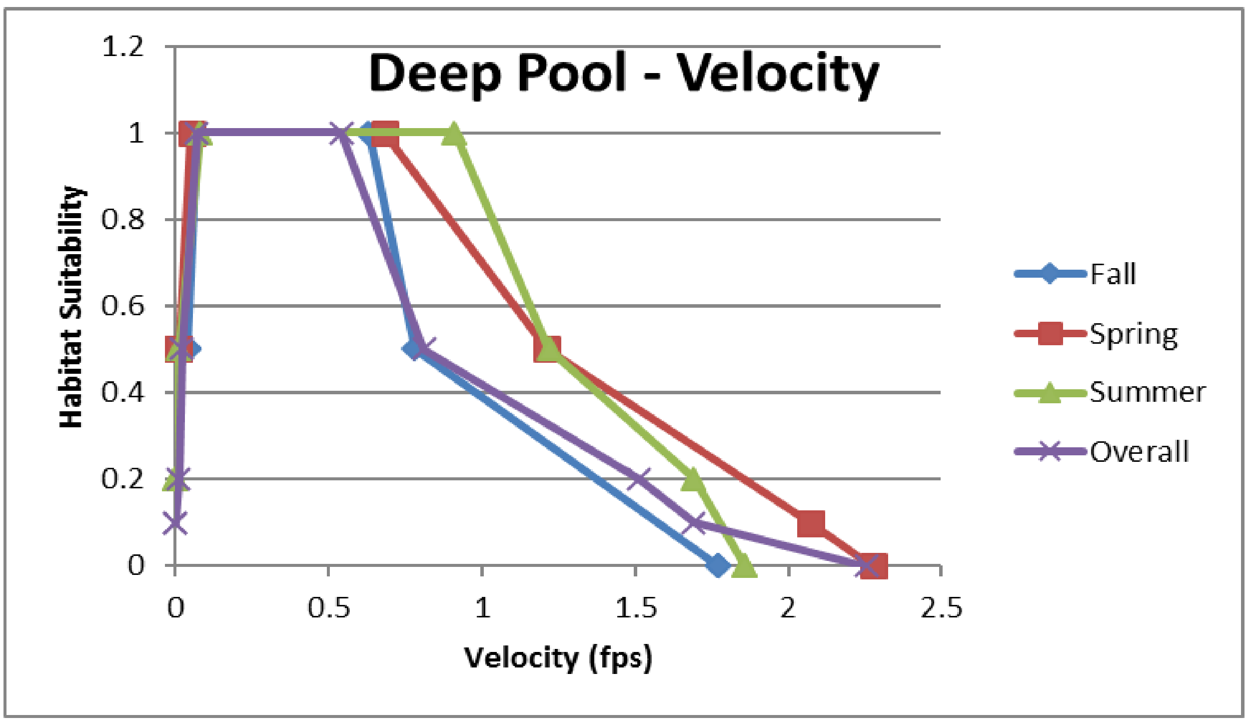


Figure C-22. Seasonal and overall depth and velocity habitat suitability curves for Deep Pool guild species.

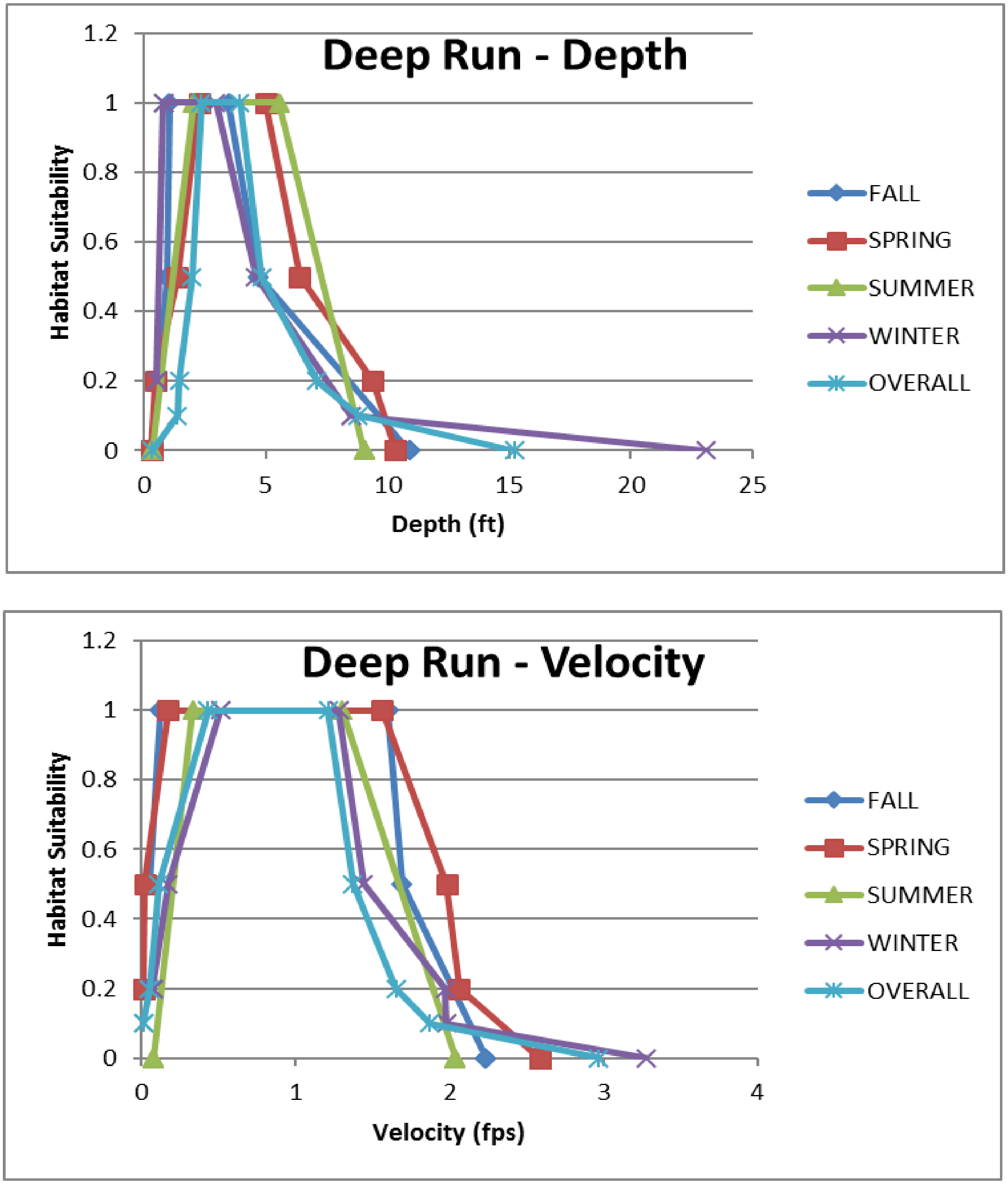
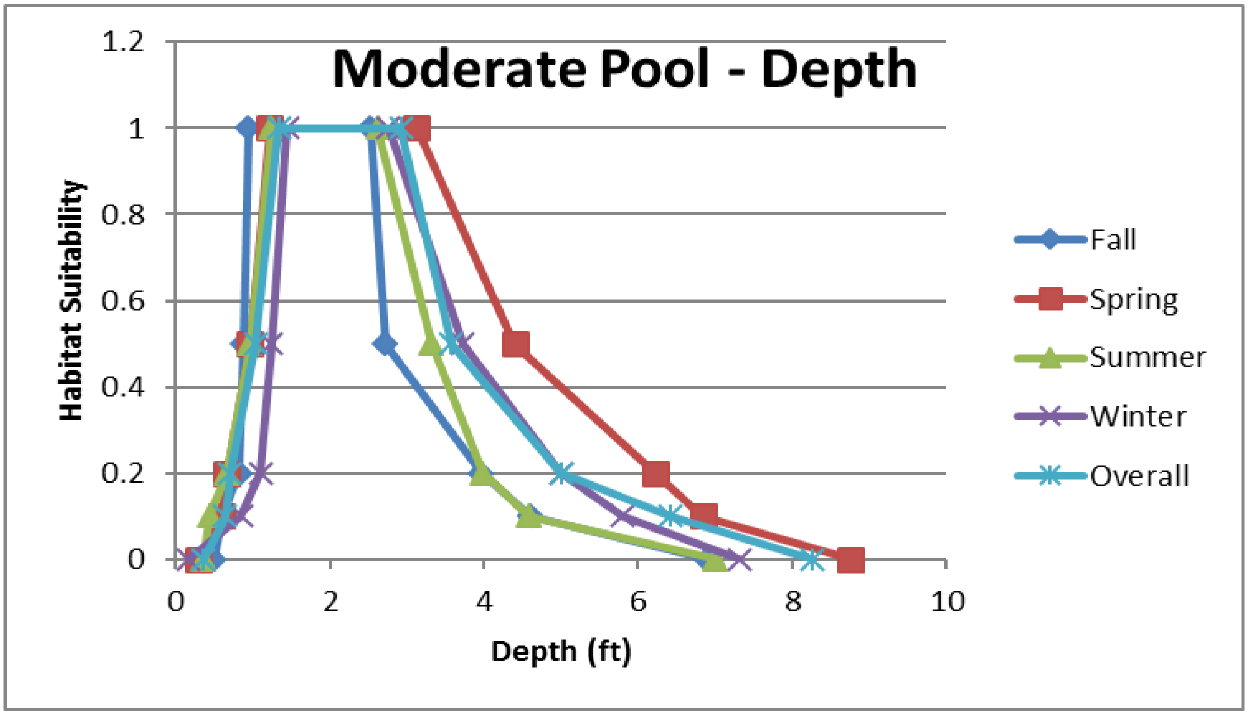


Figure C-23. Seasonal and overall depth and velocity habitat suitability curves for Deep Run guild species.



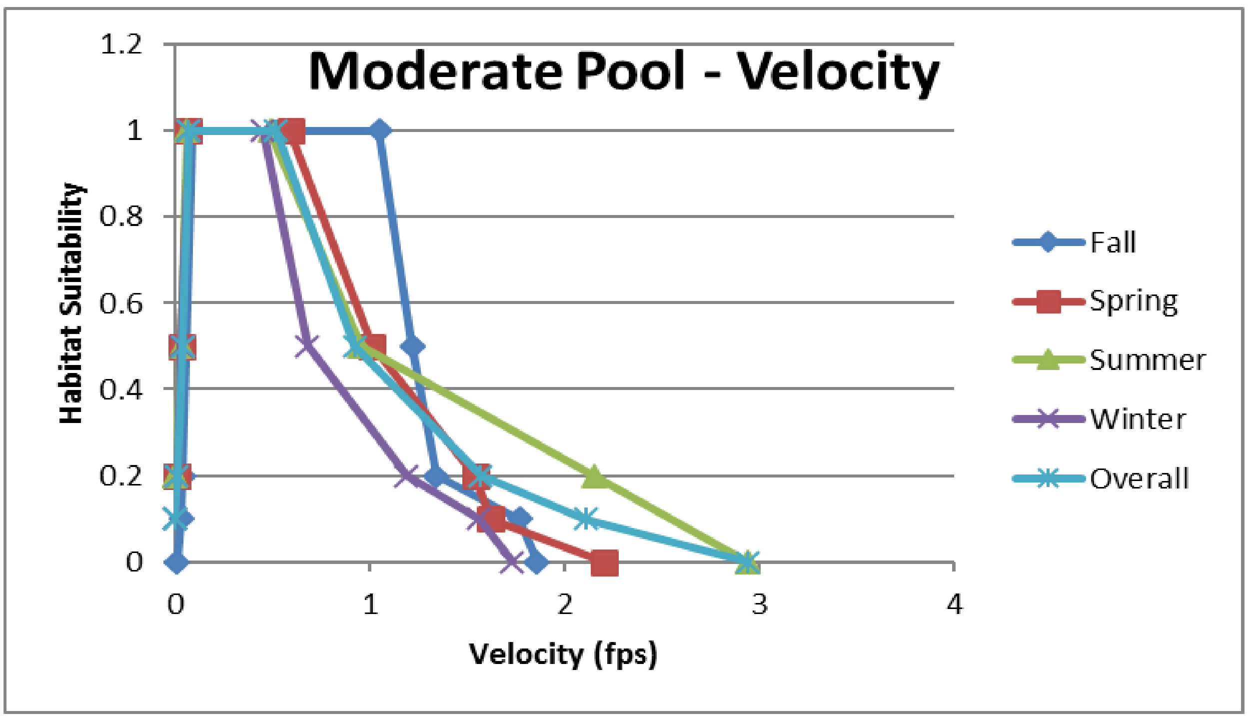
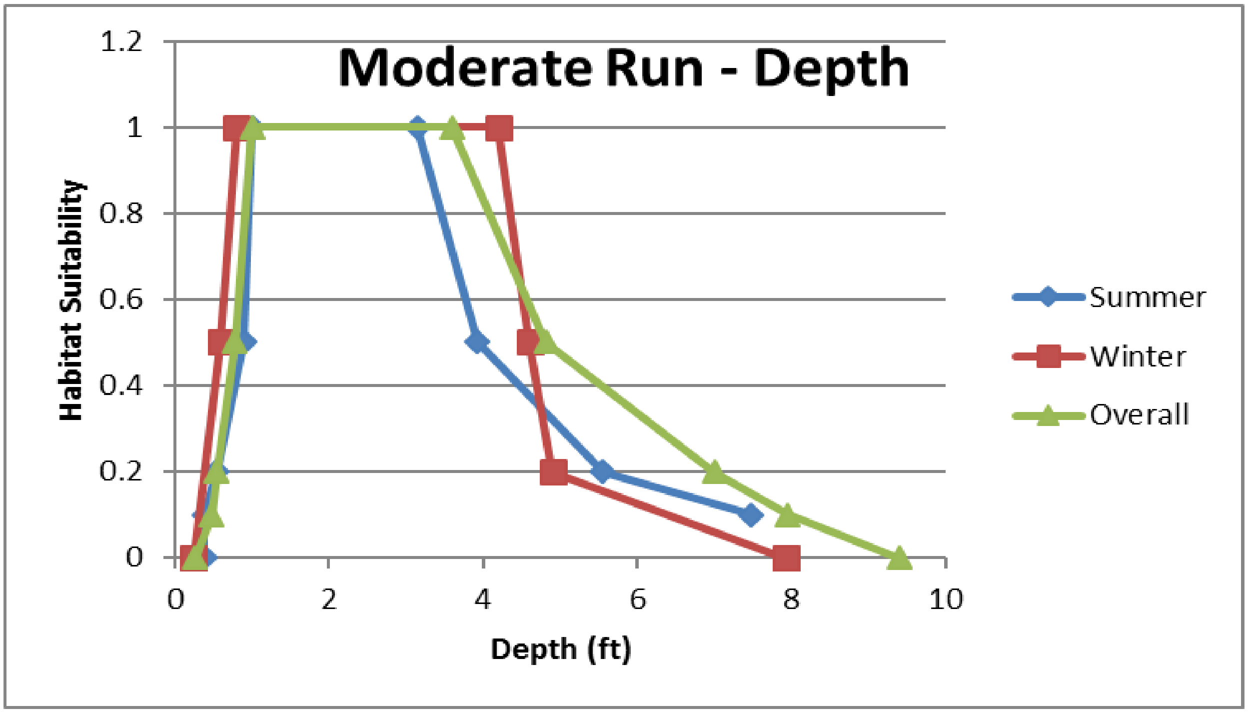


Figure C-24. Seasonal and overall depth and velocity habitat suitability curves for Moderate Pool guild species.



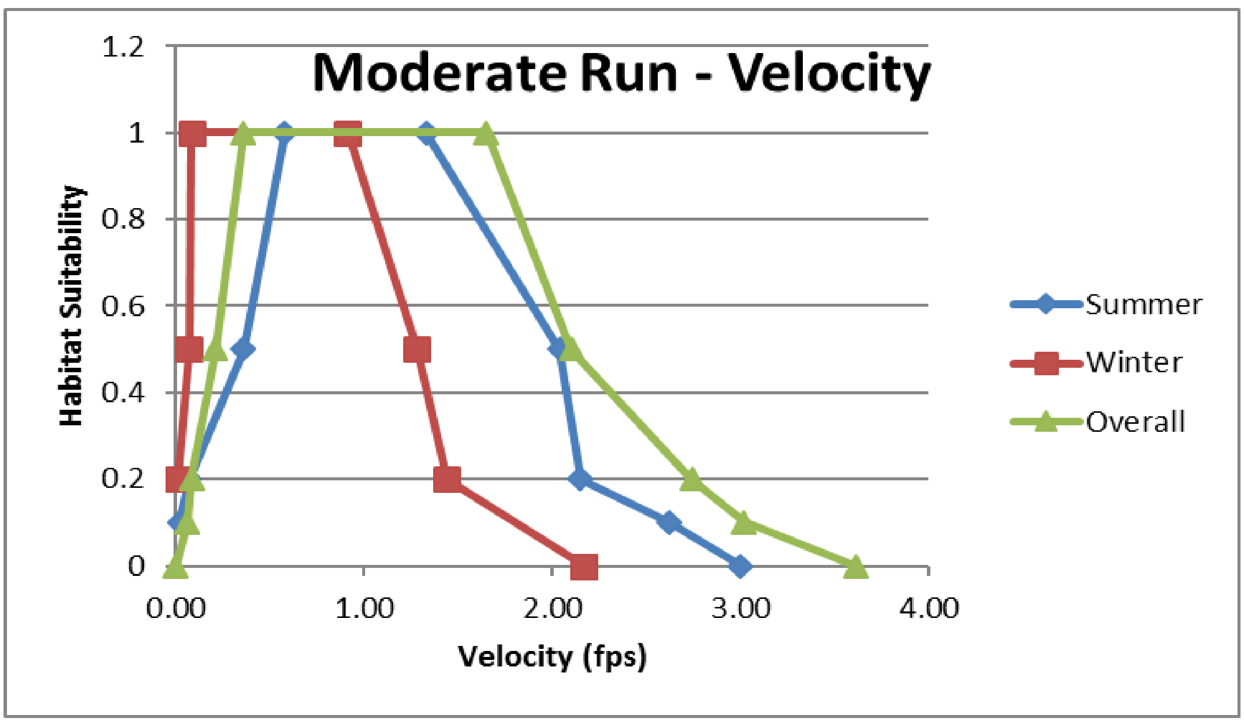


Figure C-25. Seasonal and overall depth and velocity habitat suitability curves for Moderate Run guild species.

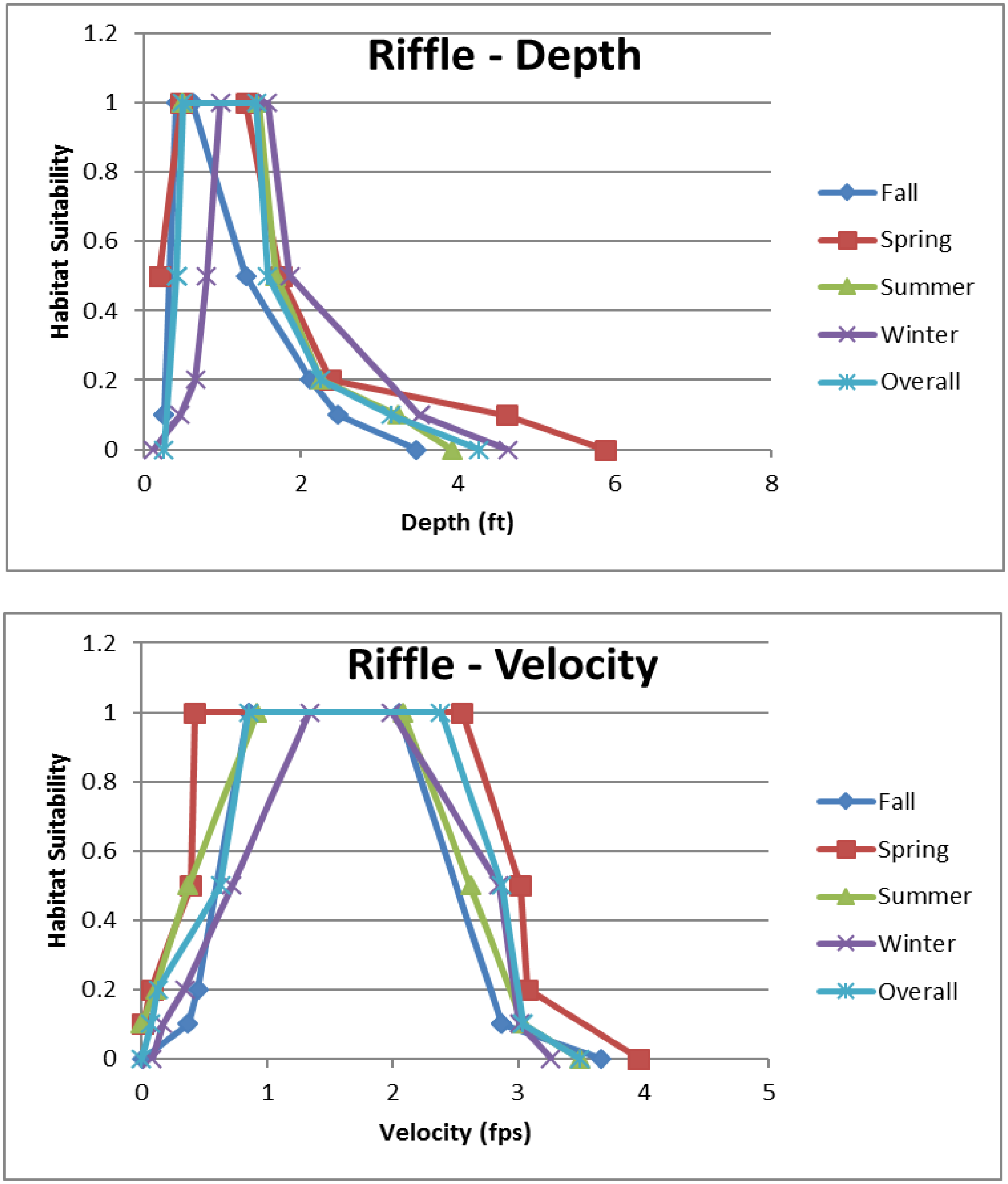
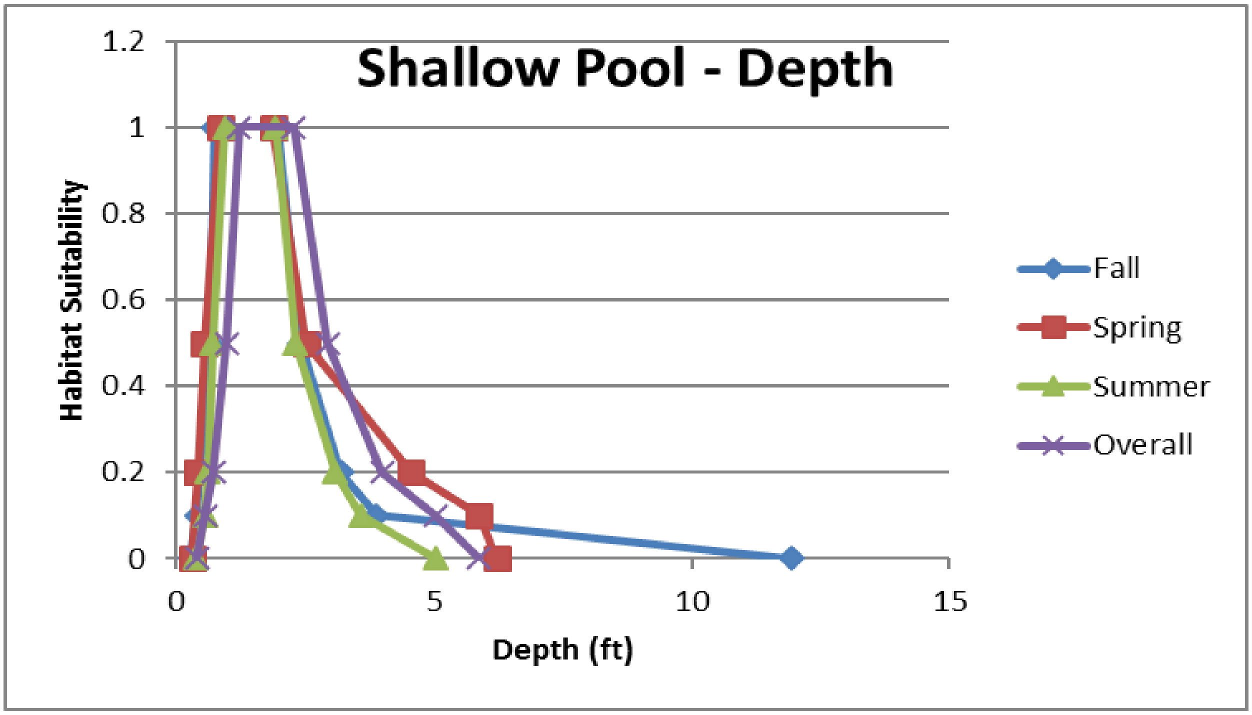


Figure C-26. Seasonal and overall depth and velocity habitat suitability curves for Riffle guild species.



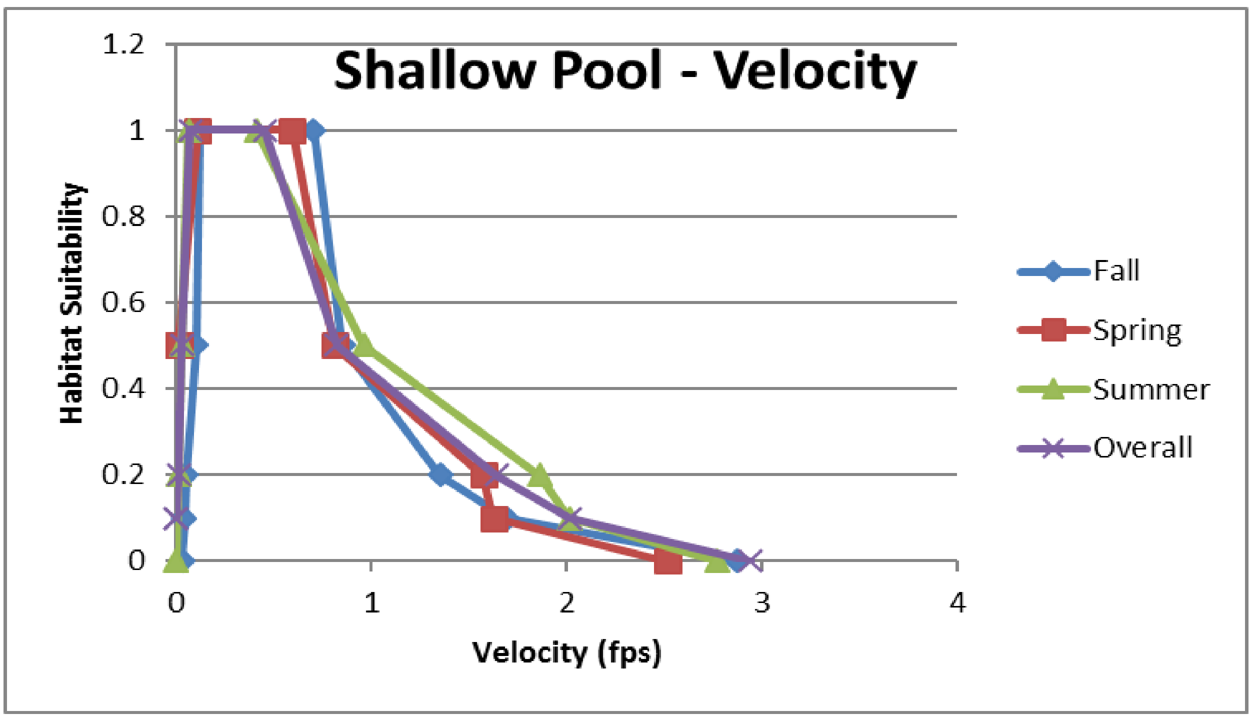
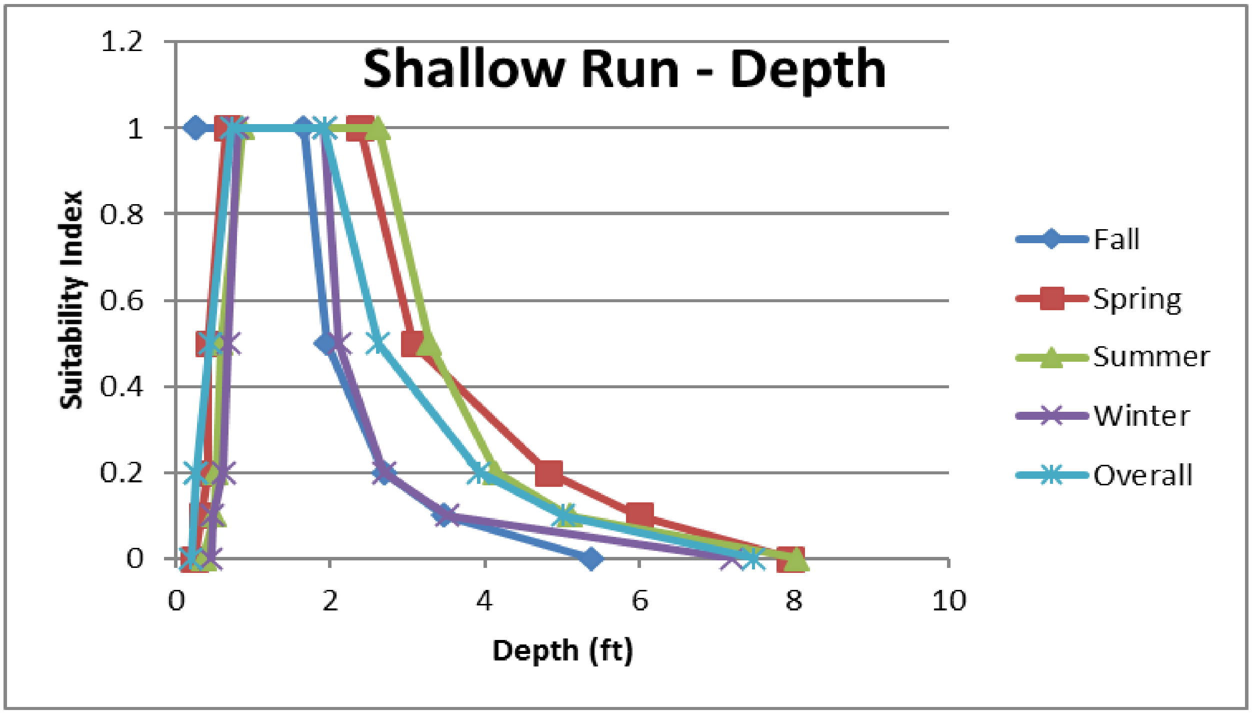


Figure C-27. Seasonal and overall depth and velocity habitat suitability curves for Shallow Pool guild species.



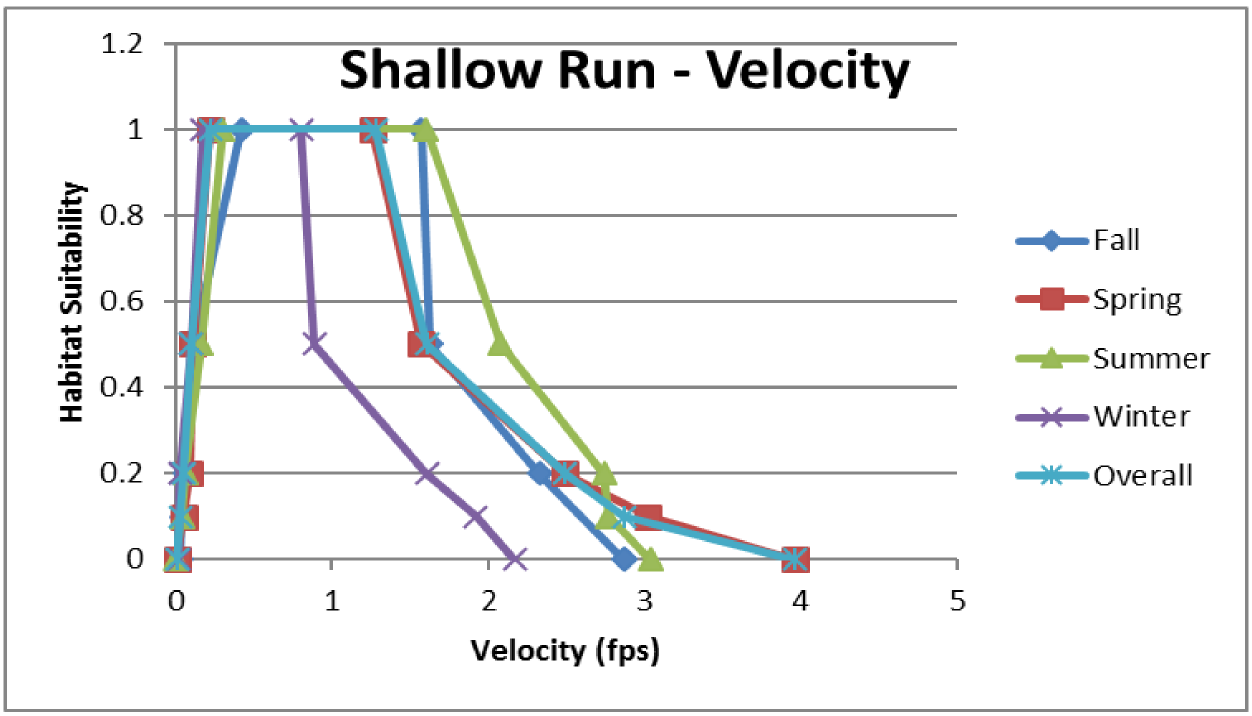


Figure C-28. Seasonal and overall depth and velocity habitat suitability curves for Shallow Run guild species.

APPENDIX D
WEIGHTED USABLE AREA FIGURES

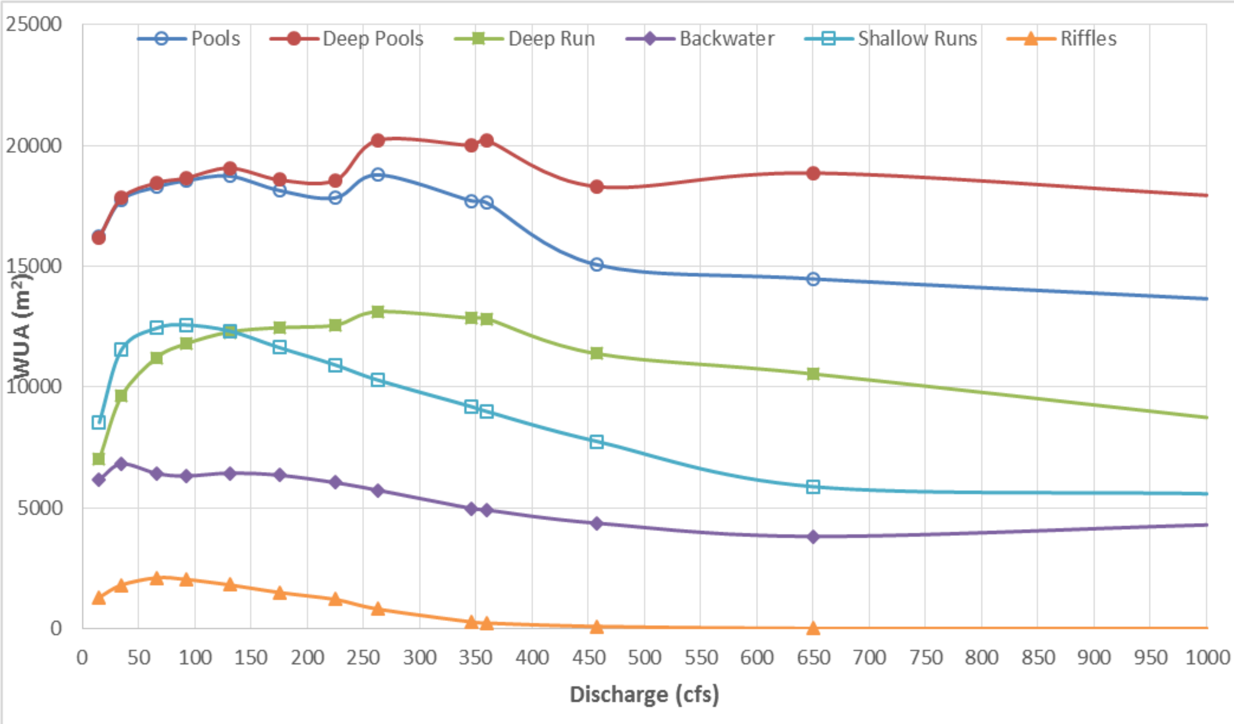


Figure D-1. Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Calaveras Study Site.

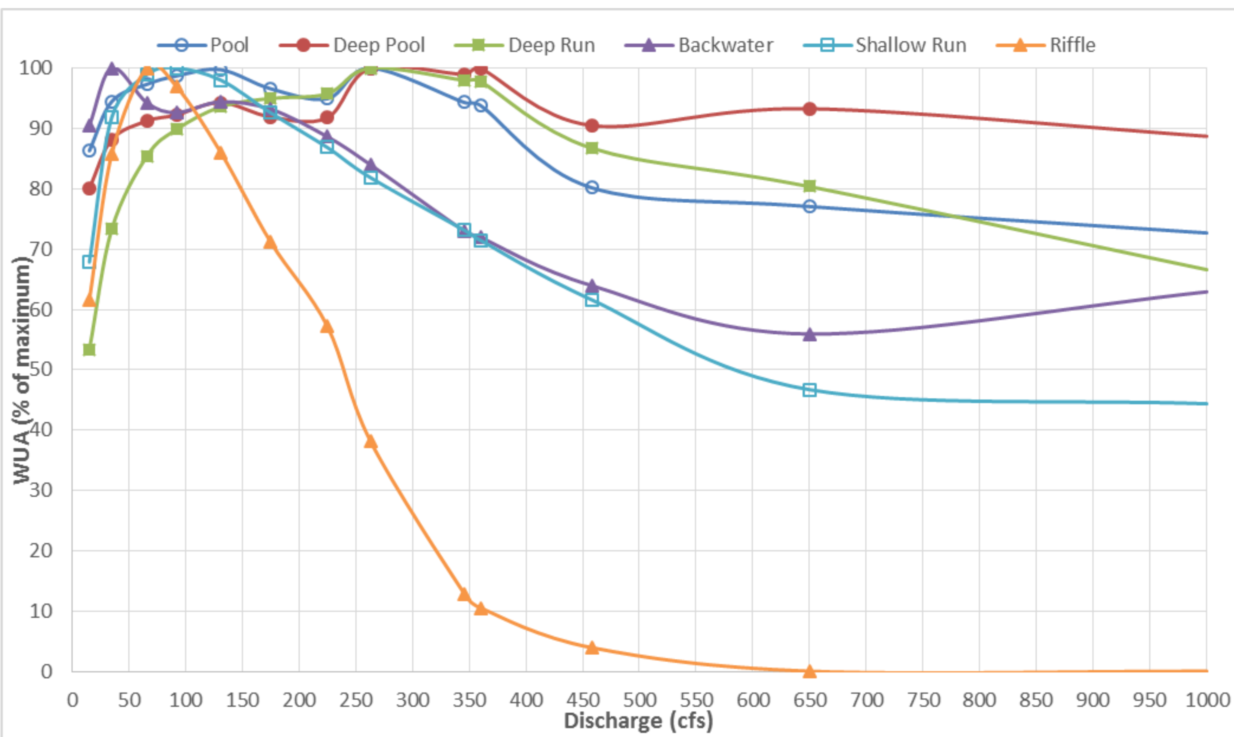


Figure D-2. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Calaveras Study Site.

San Antonio River at Calaveras

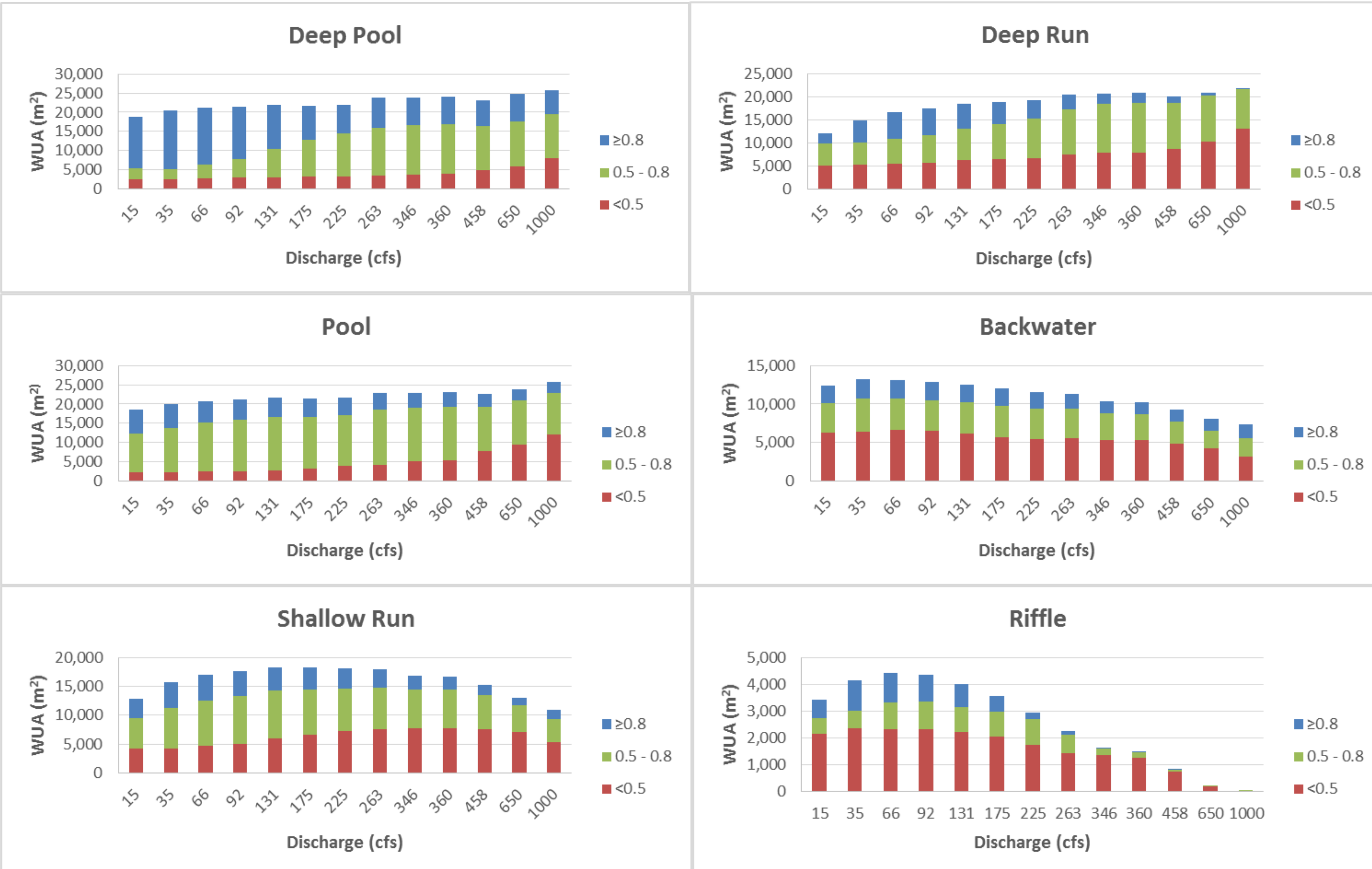


Figure D-3. Habitat quality breakout (0.5 low; 0.5-0.8 moderate; ≥0.8 high) of Weighted Usable Area (WUA) versus simulated discharge at the San Antonio River Calaveras Study Site.

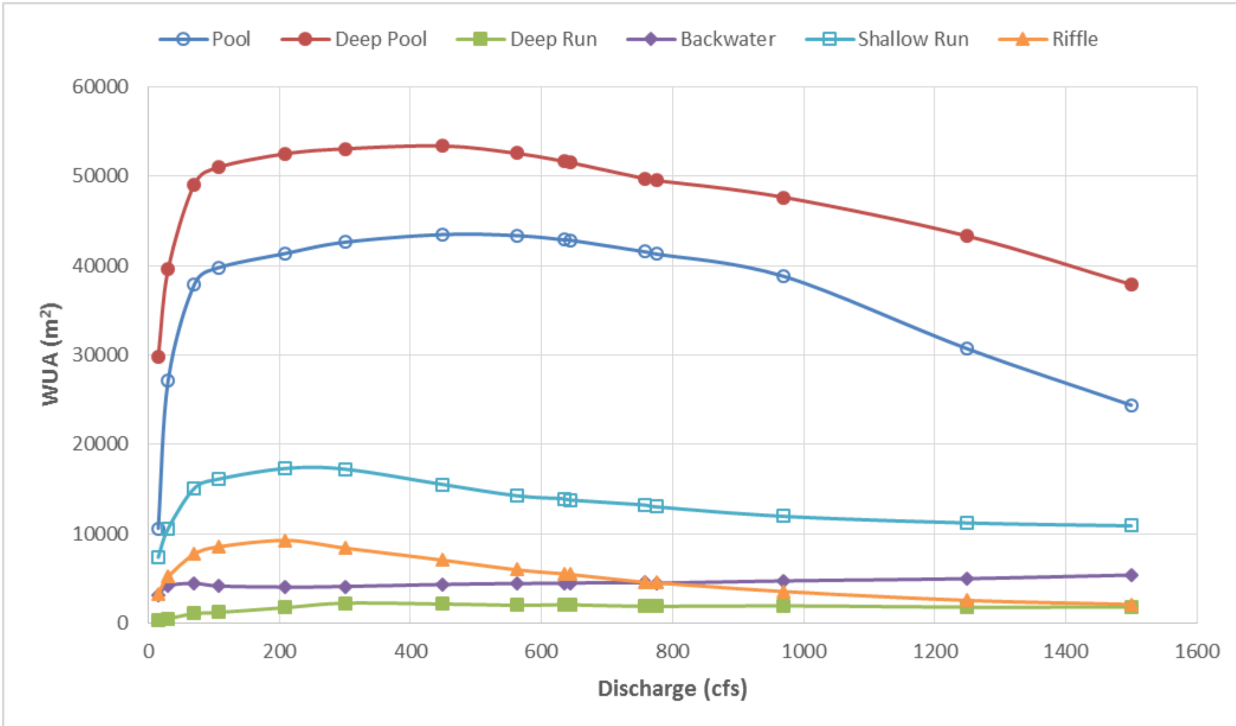


Figure D-4. Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Falls City Study Site.

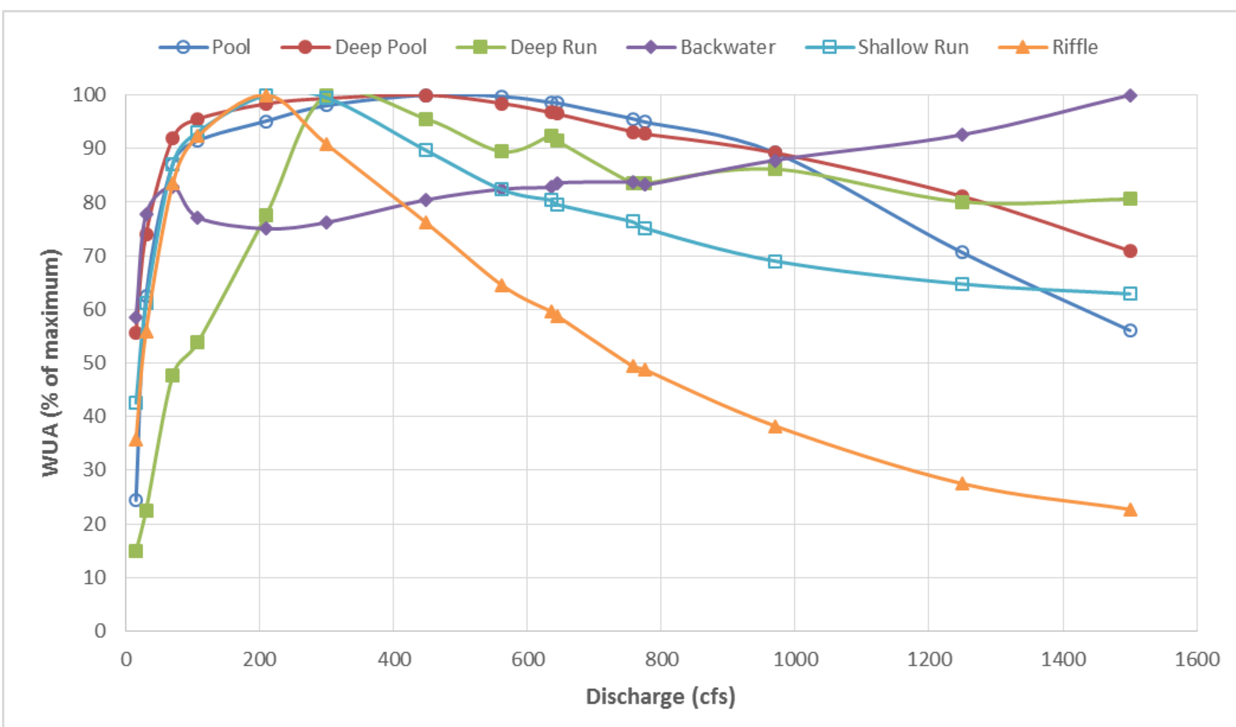


Figure D-5. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Falls City Study Site.

San Antonio River at Falls City

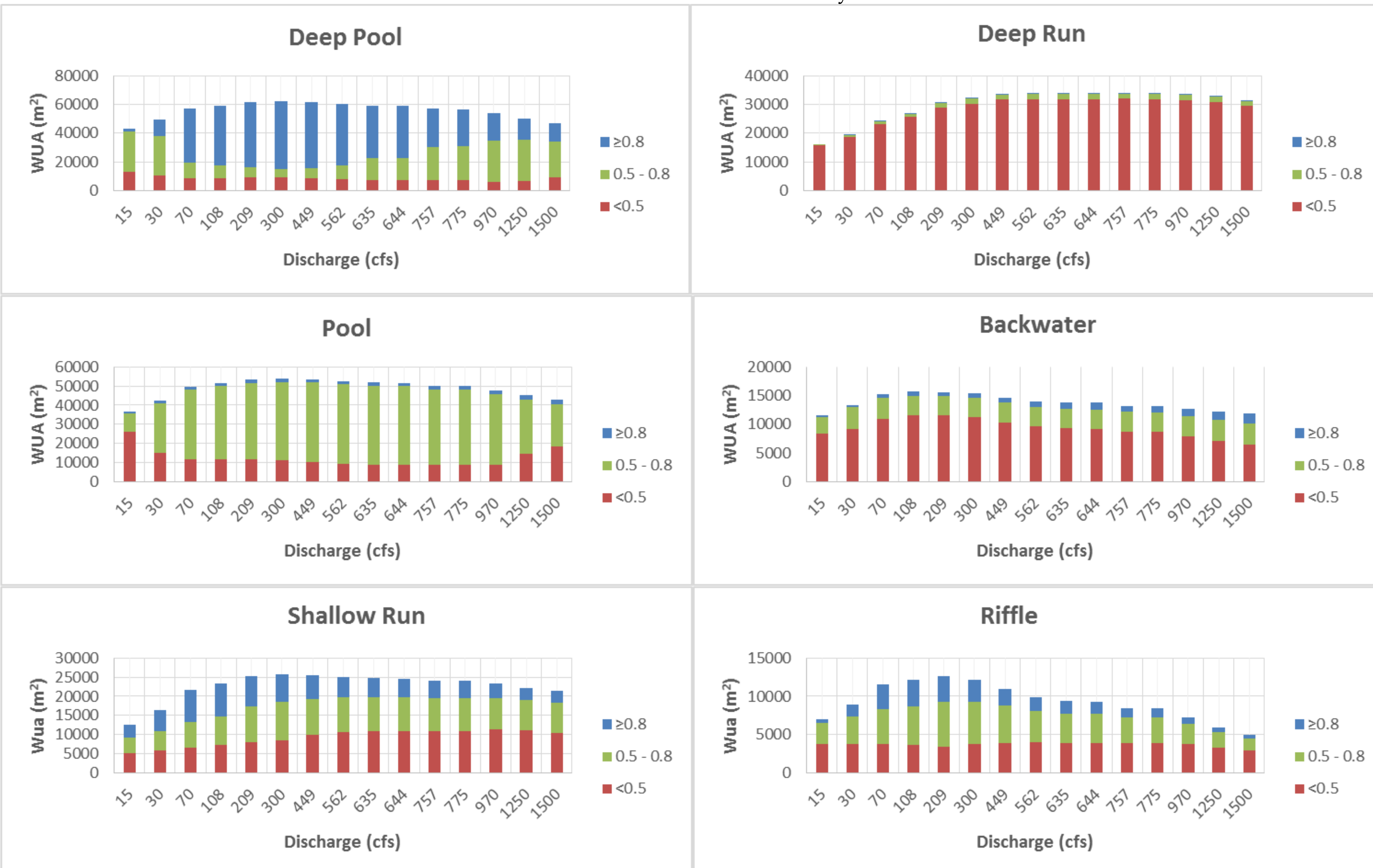


Figure D-6. Habitat quality breakout (0.5 low; 0.5-0.8 moderate; ≥0.8 high) of Weighted Usable Area (WUA) versus simulated discharge at the San Antonio River Falls City Study Site.

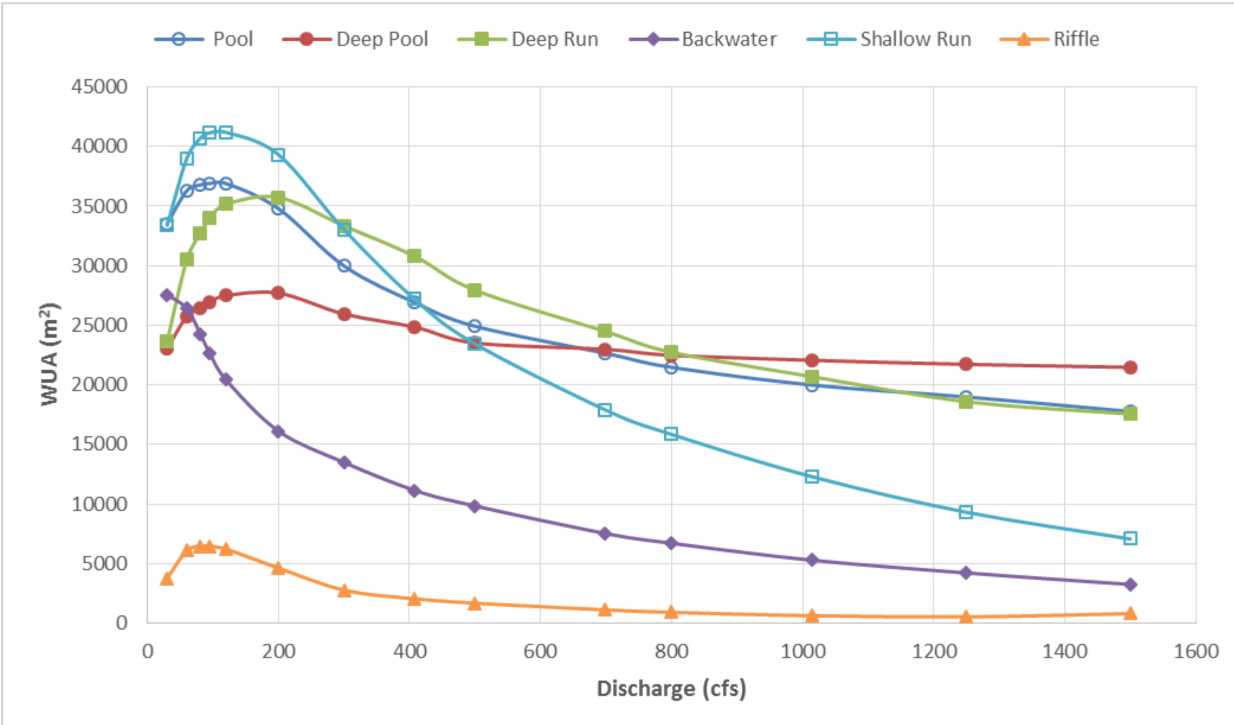


Figure D-7. Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Goliad Study Site.

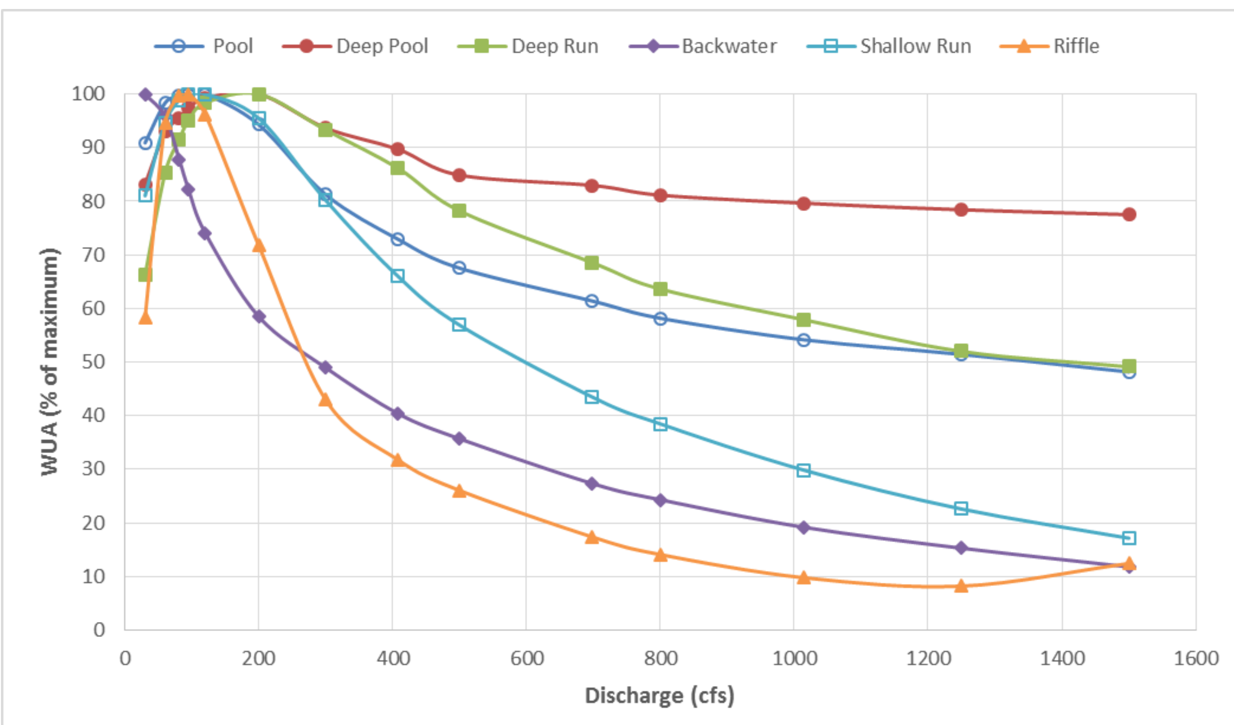


Figure D-8. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Goliad Study Site.

San Antonio River at Goliad

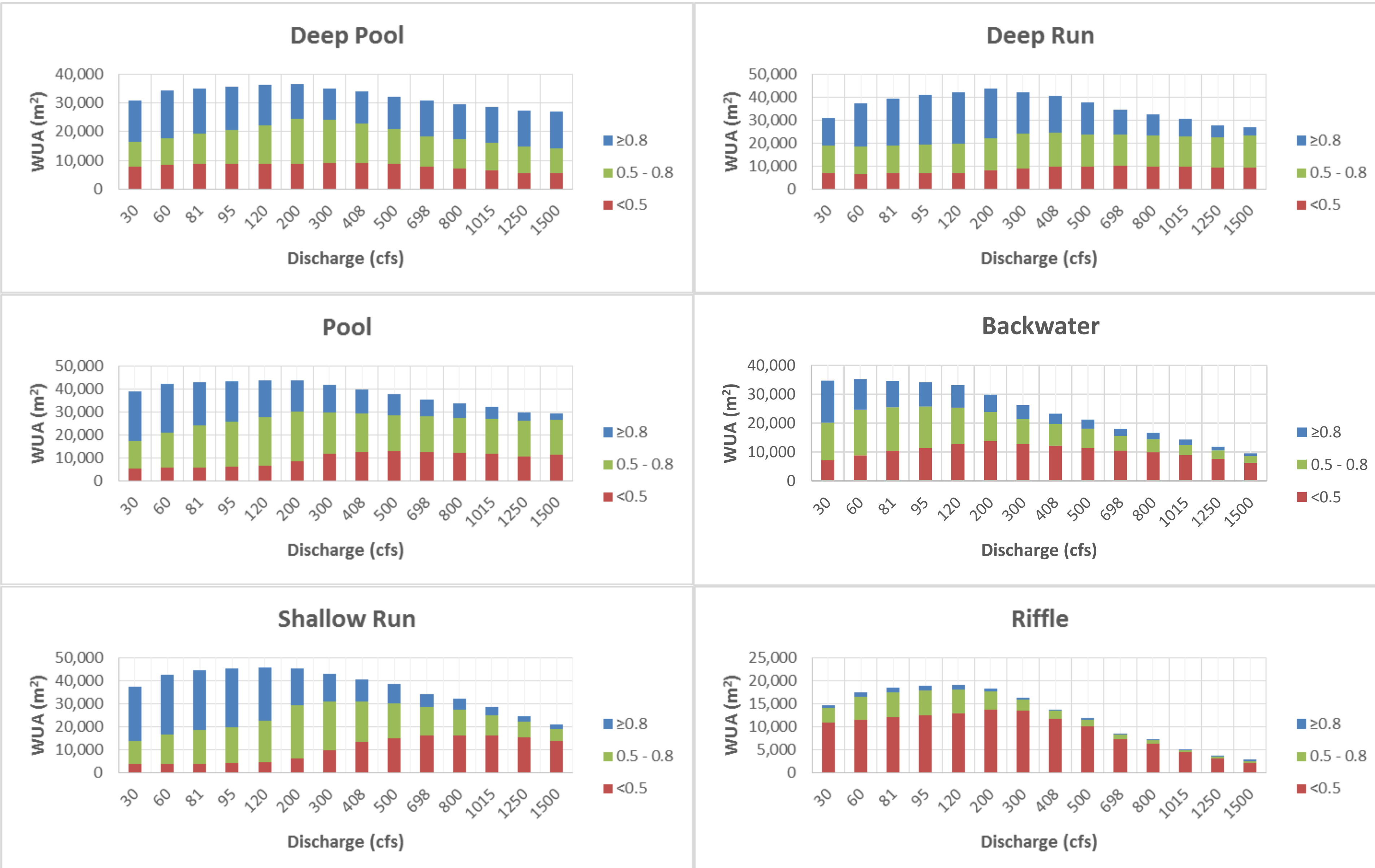


Figure D-9. Habitat quality breakout (0.5 low; 0.5-0.8 moderate; ≥0.8 high) of Weighted Usable Area (WUA) versus simulated discharge at the San Antonio River Goliad Study Site.

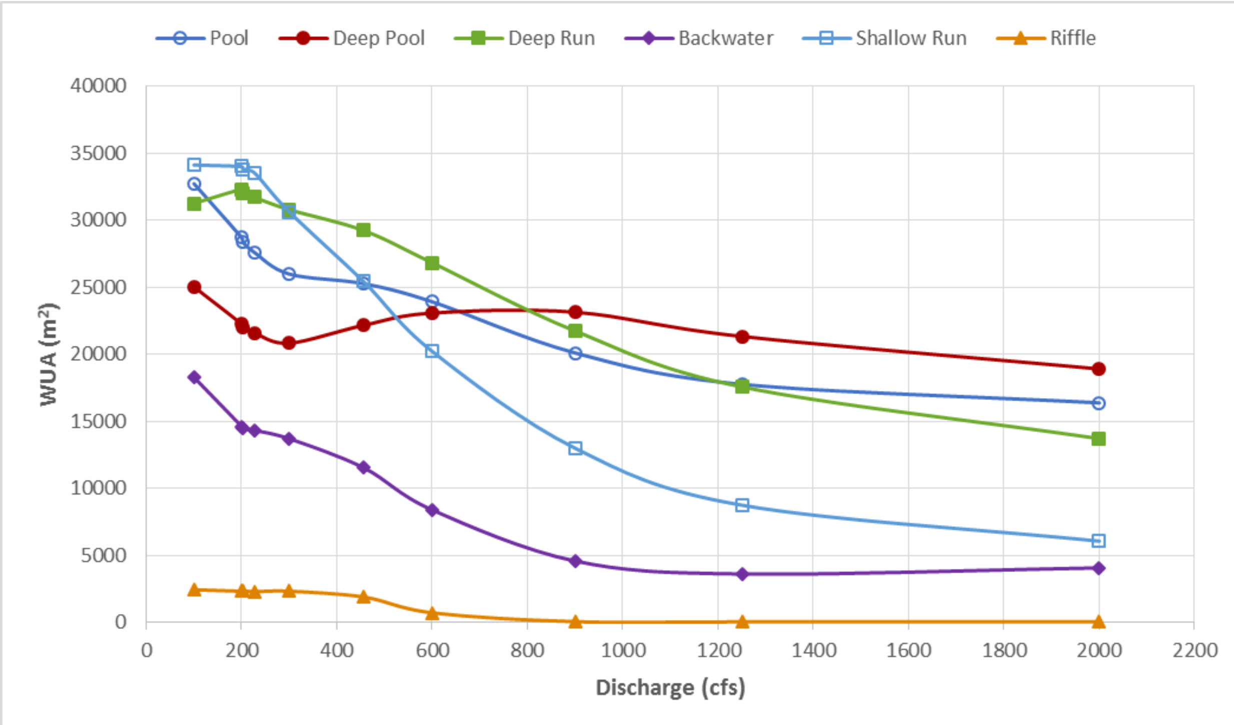


Figure D-10. Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Hwy 77 Study Site.

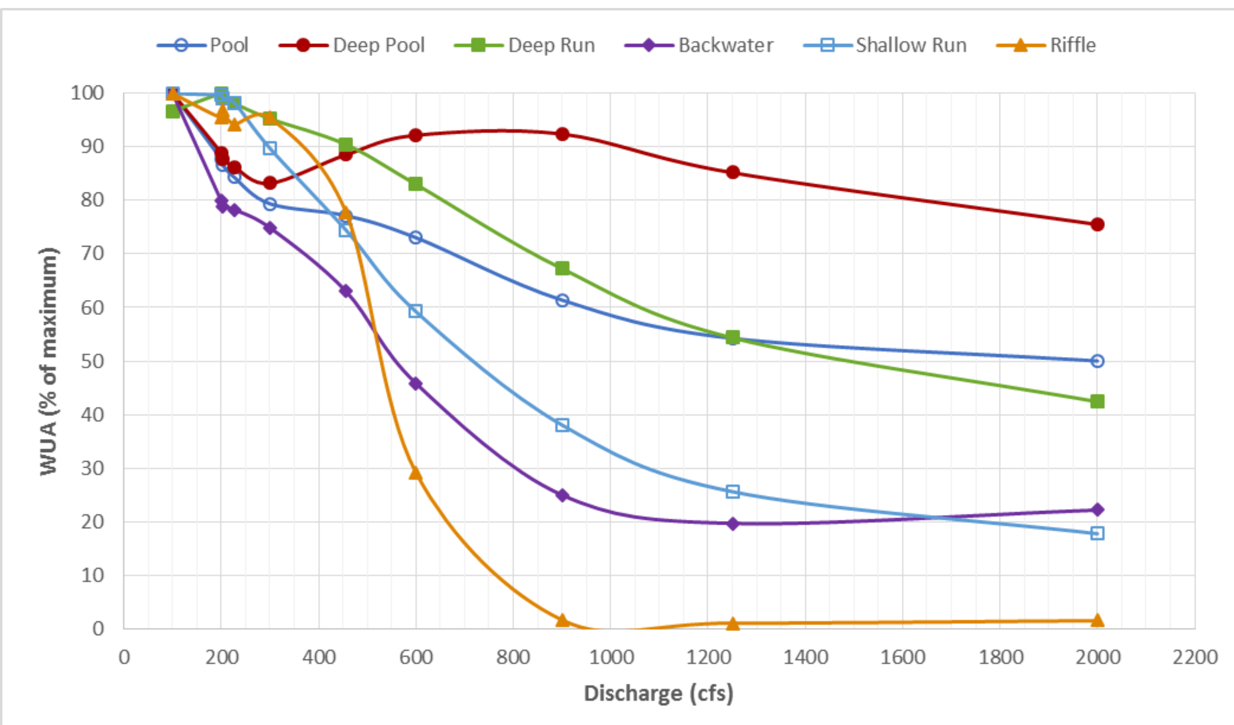


Figure D-11. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the San Antonio River Hwy 77 Study Site.

San Antonio River at Hwy 77

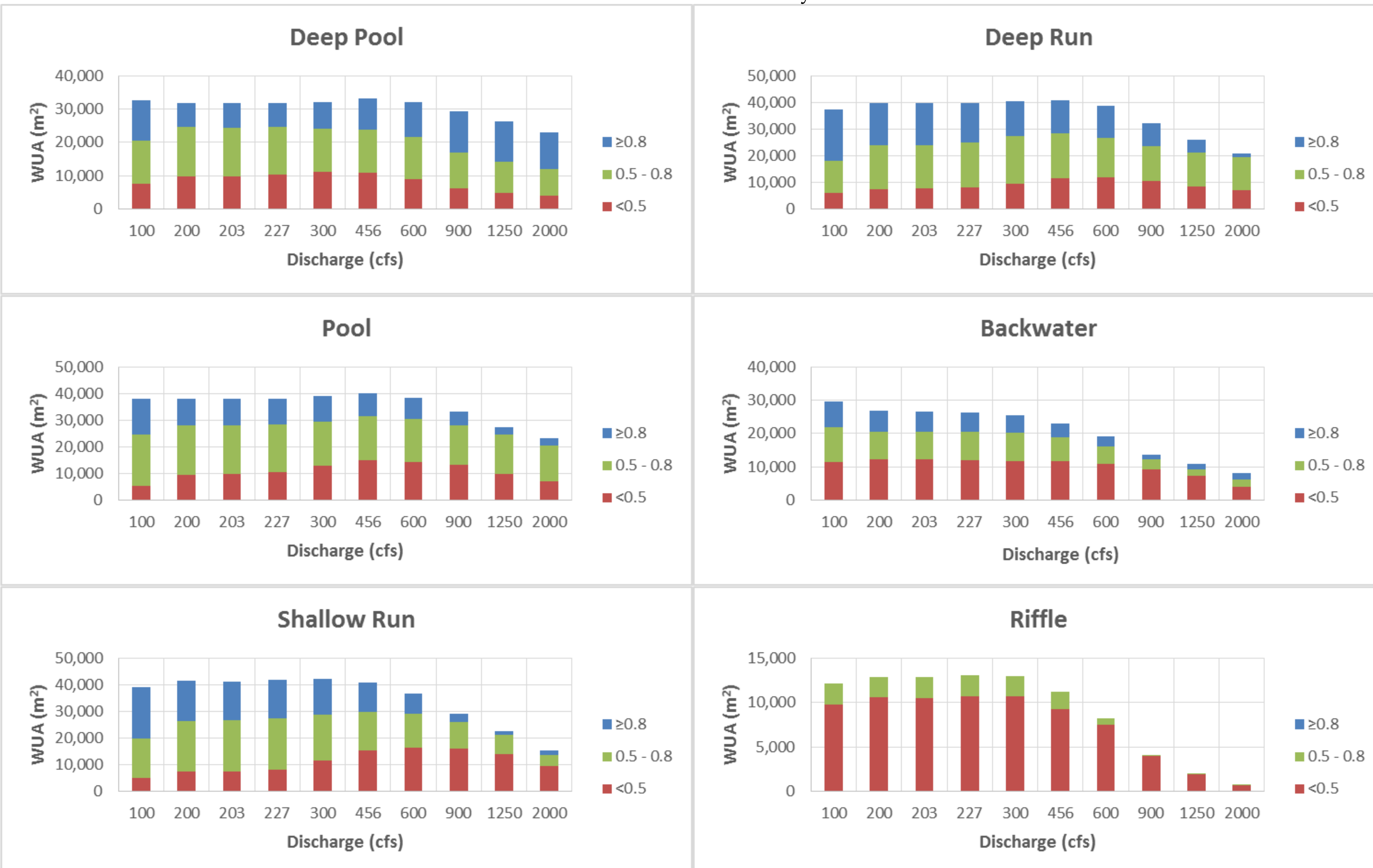


Figure D-12. Habitat quality breakout (0.5 low; 0.5-0.8 moderate; ≥0.8 high) of Weighted Usable Area (WUA) versus simulated discharge at the San Antonio River Hwy 77 Study Site.

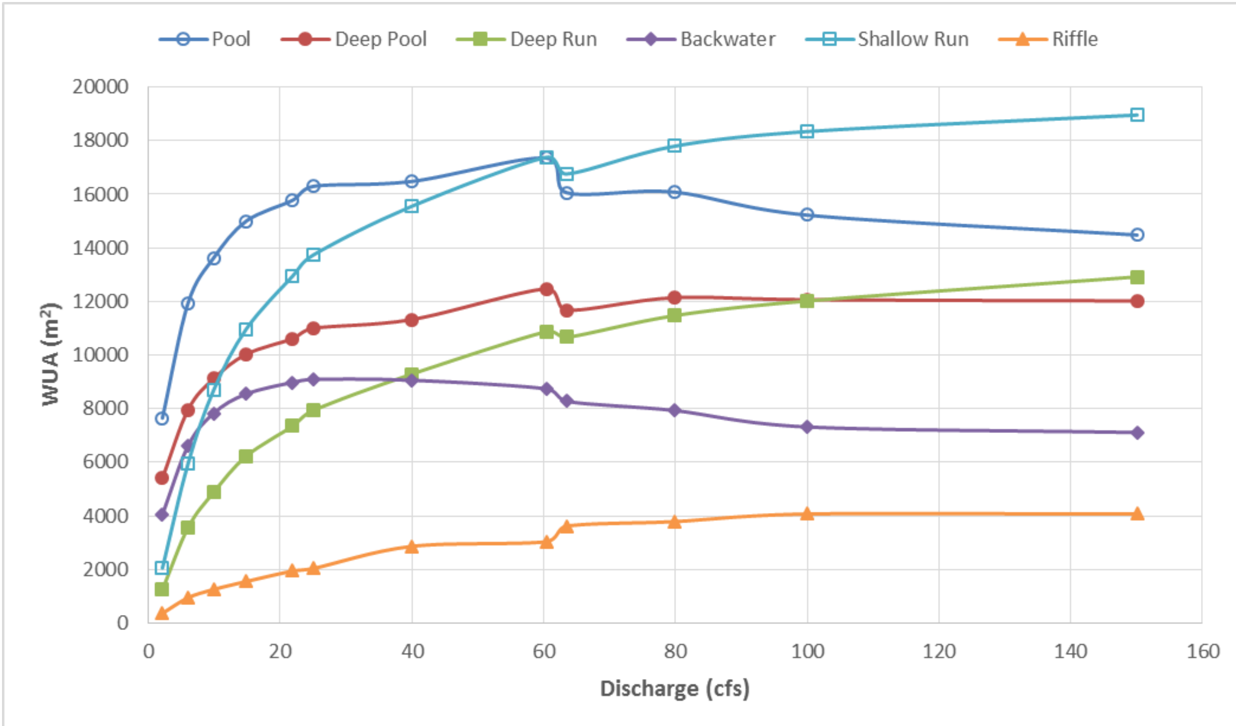


Figure D-13. Weighted Usable Area(WUA-habitat quality >0.5) versus simulated discharge at the Cibolo Creek Study Site.

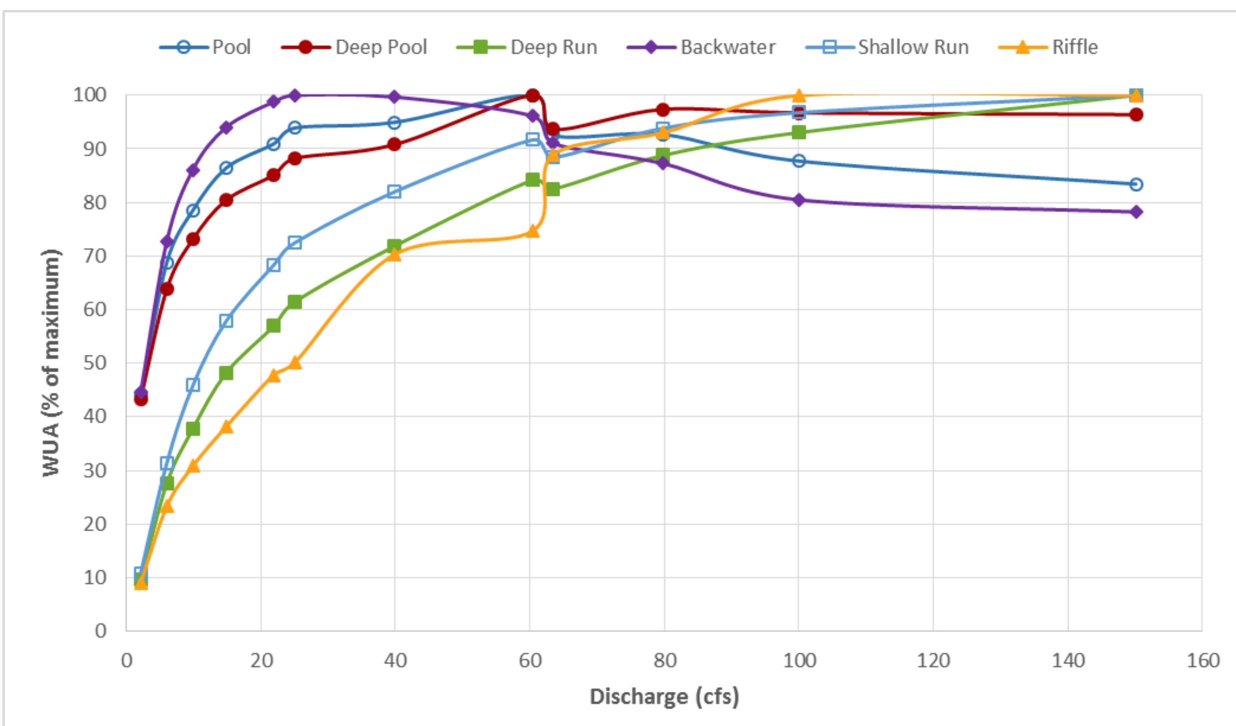


Figure D-14. Percent of Maximum Weighted Usable Area (WUA-habitat quality >0.5) versus simulated discharge at the Cibolo Creek Study Site.

Cibolo Creek

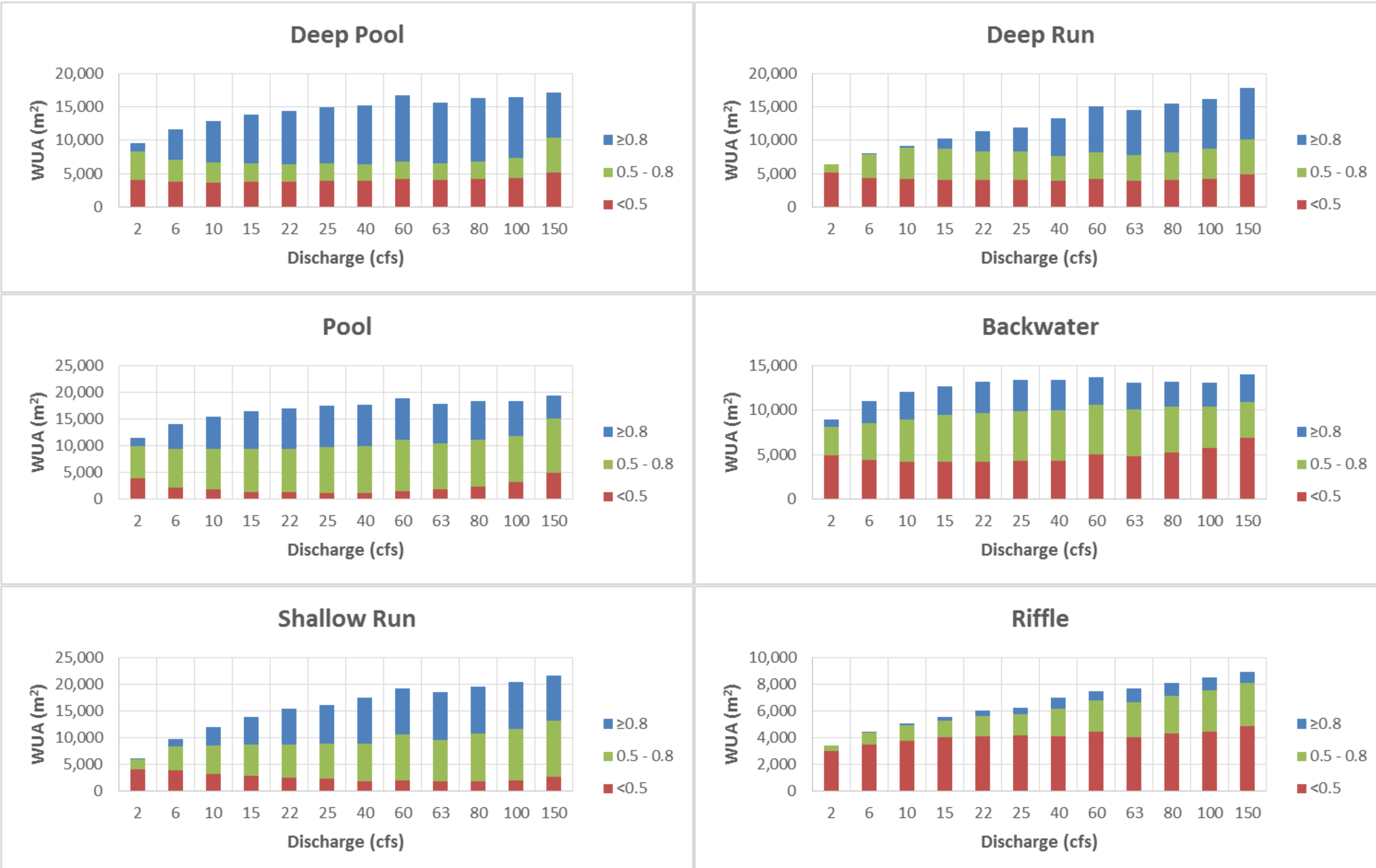


Figure D-15. Habitat quality breakout (0.5 low; 0.5-0.8 moderate; >0.8 high) of Weighted Usable Area (WUA) versus simulated discharge at the Cibolo Creek Study Site.

APPENDIX E
RIPARIAN SPECIES COMMUNITY DATA

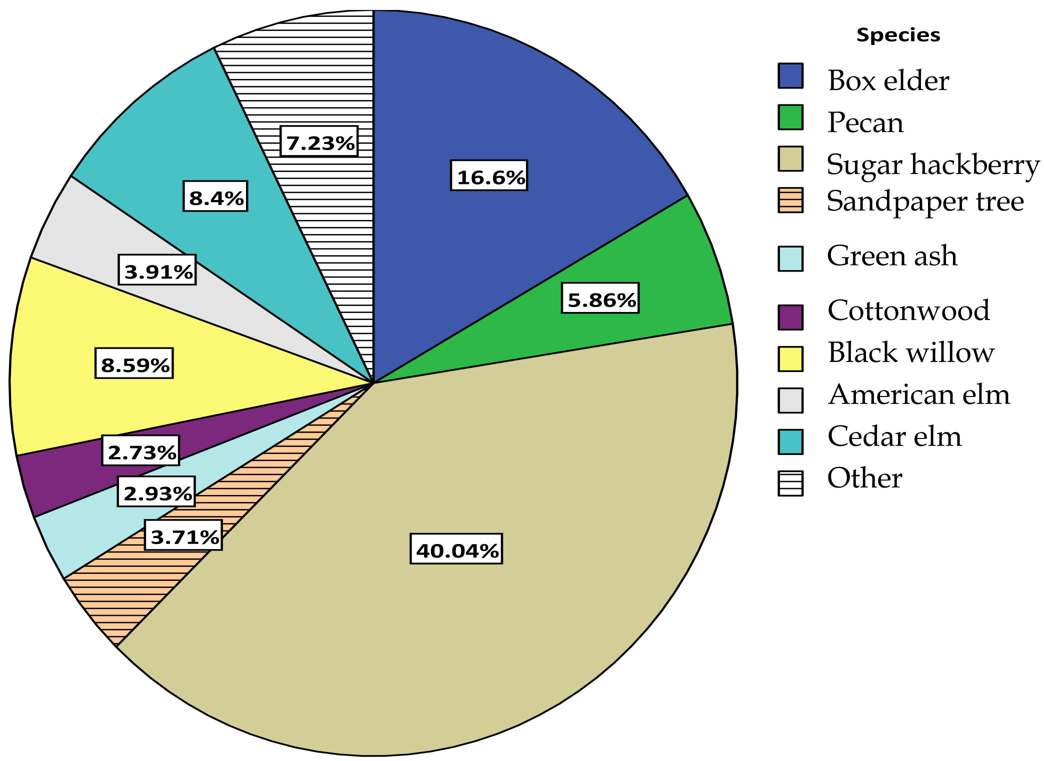


Figure E-1. Overall tree species composition identified during the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study.

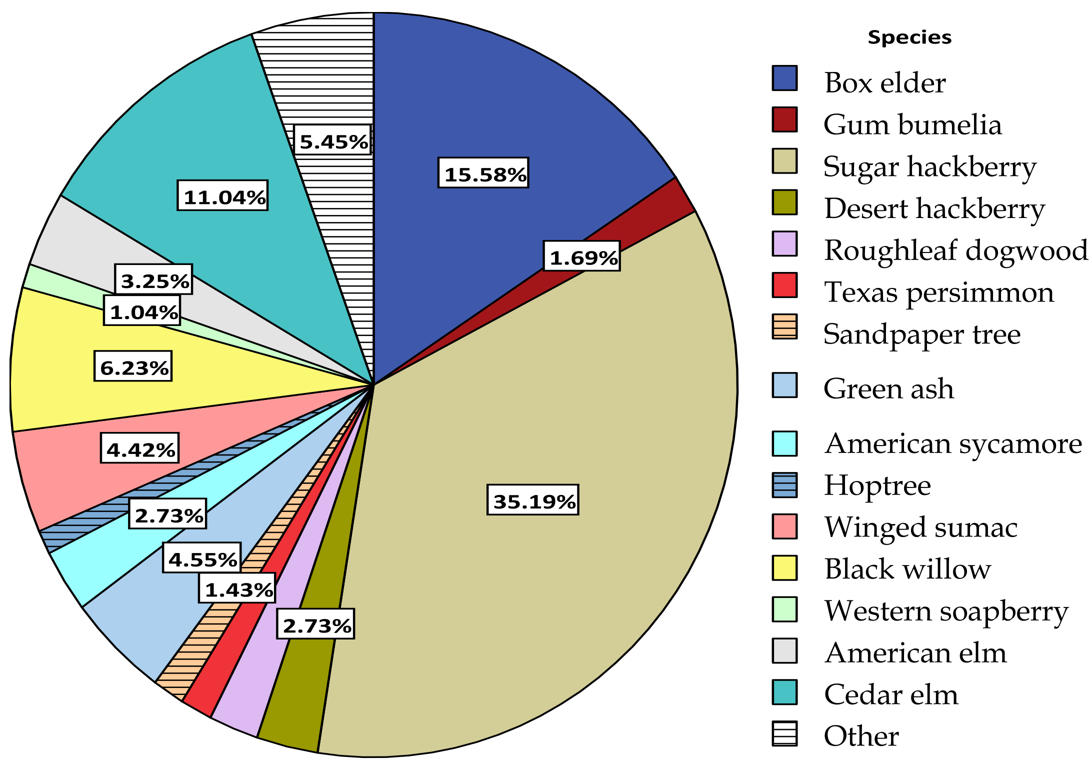


Figure E-2. Overall sapling species composition identified during the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study.

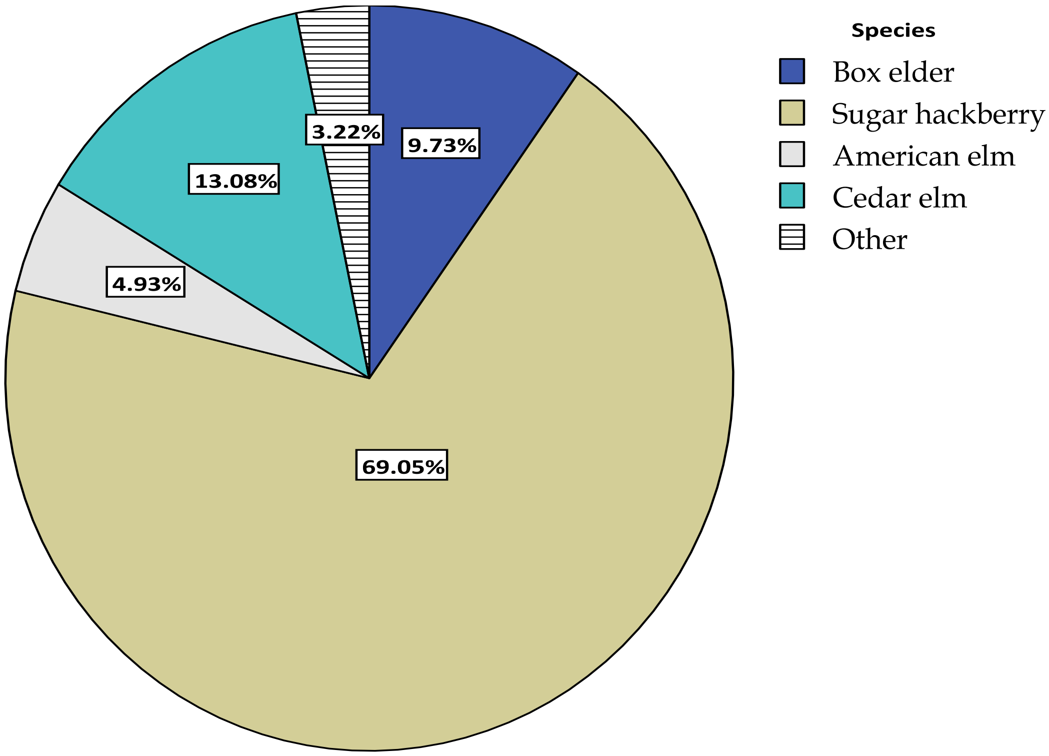


Figure E-3. Overall seedling species composition identified during the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study.

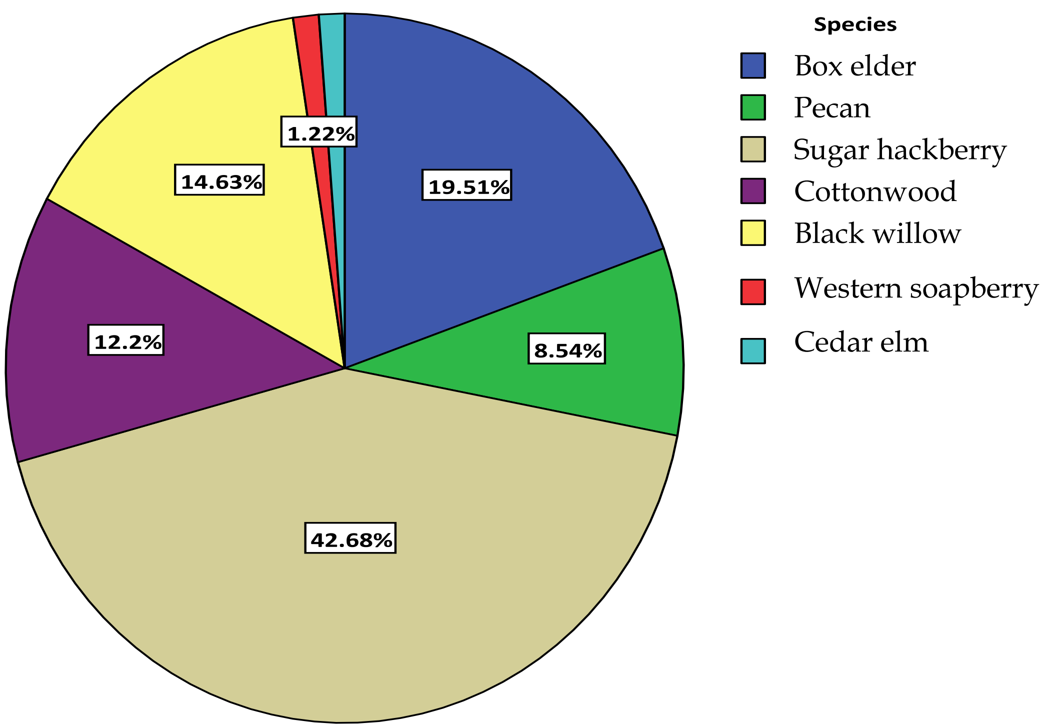


Figure E-4. Tree species composition identified at the San Antonio River Calaveras Study Site.

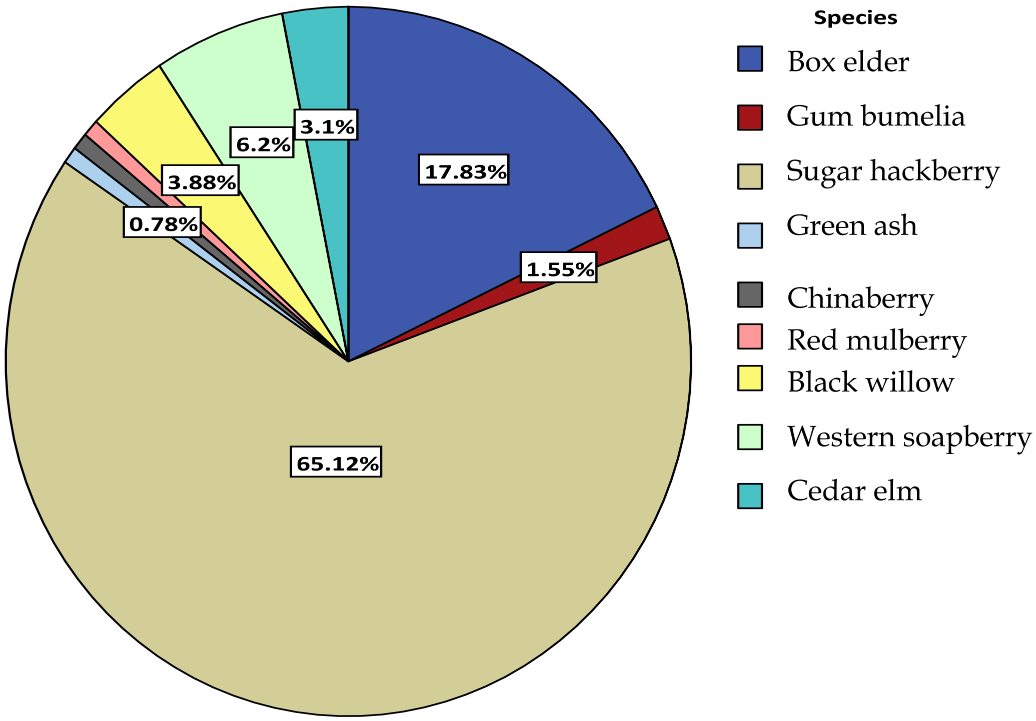


Figure E-5. Sapling species composition identified at the San Antonio River Calaveras Study Site.

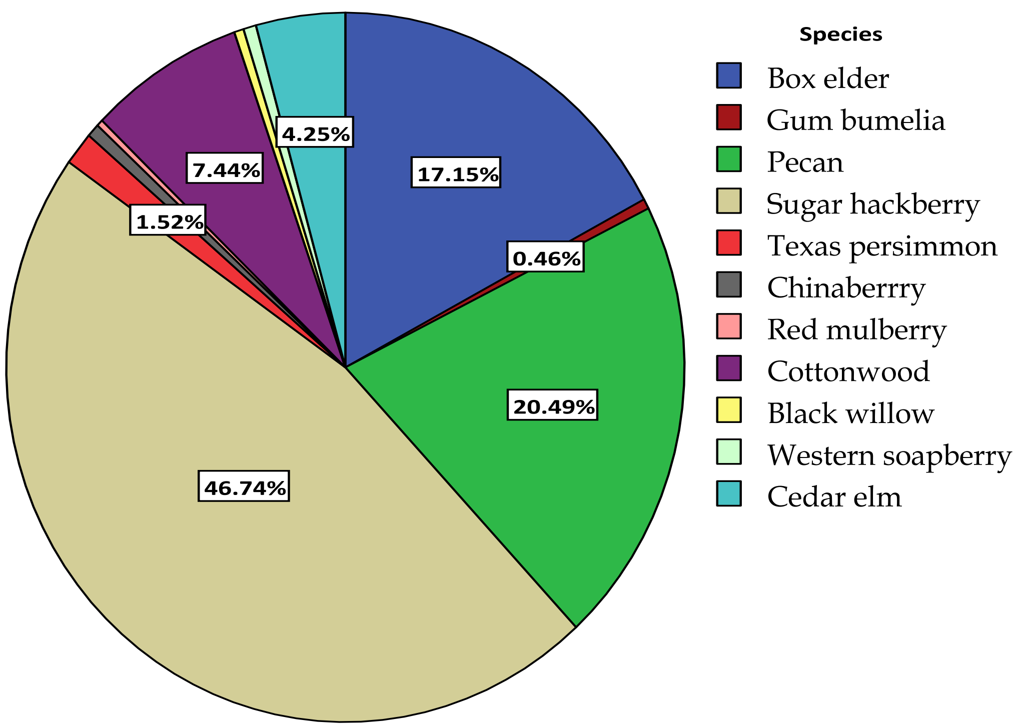


Figure E-6. Seedling species composition identified at the San Antonio River Calaveras Study Site.

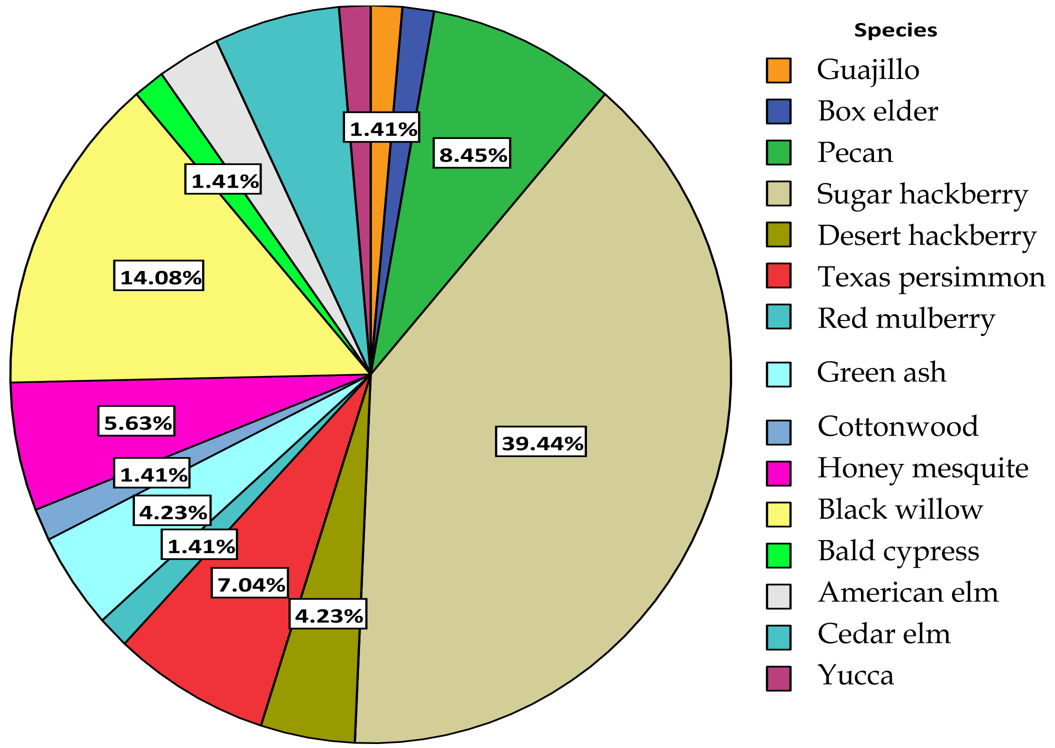


Figure E-7. Tree species composition identified at the San Antonio River Falls City Study Site.

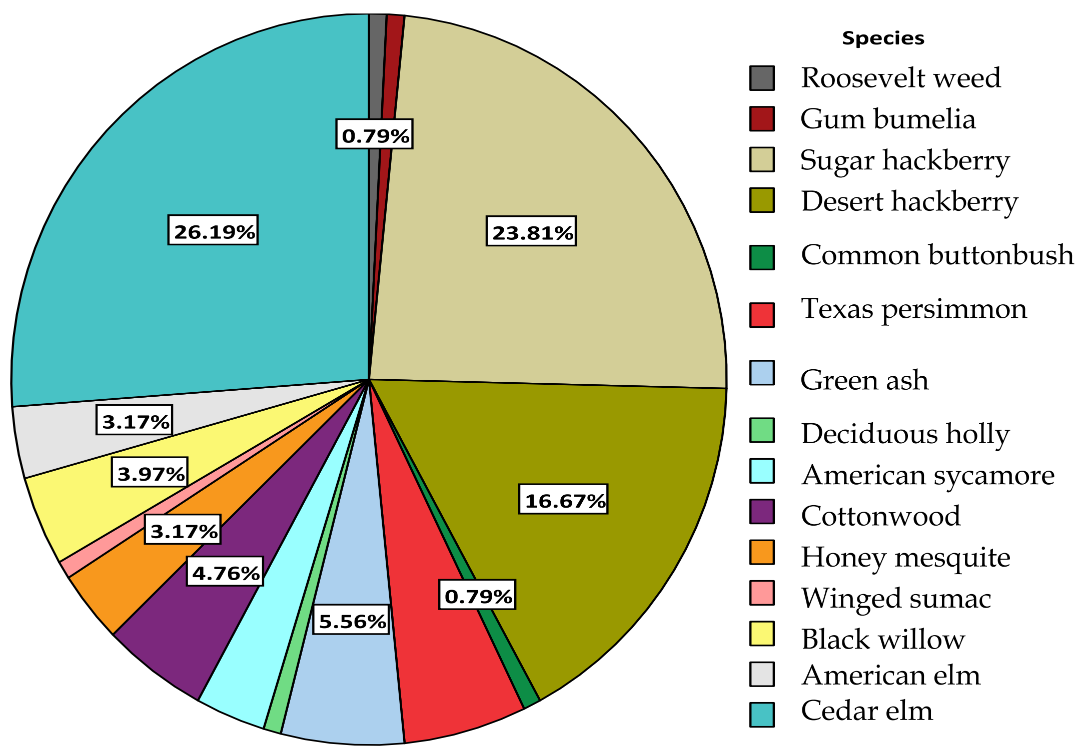


Figure E-8. Sapling species composition identified at the San Antonio River Falls City Study Site.

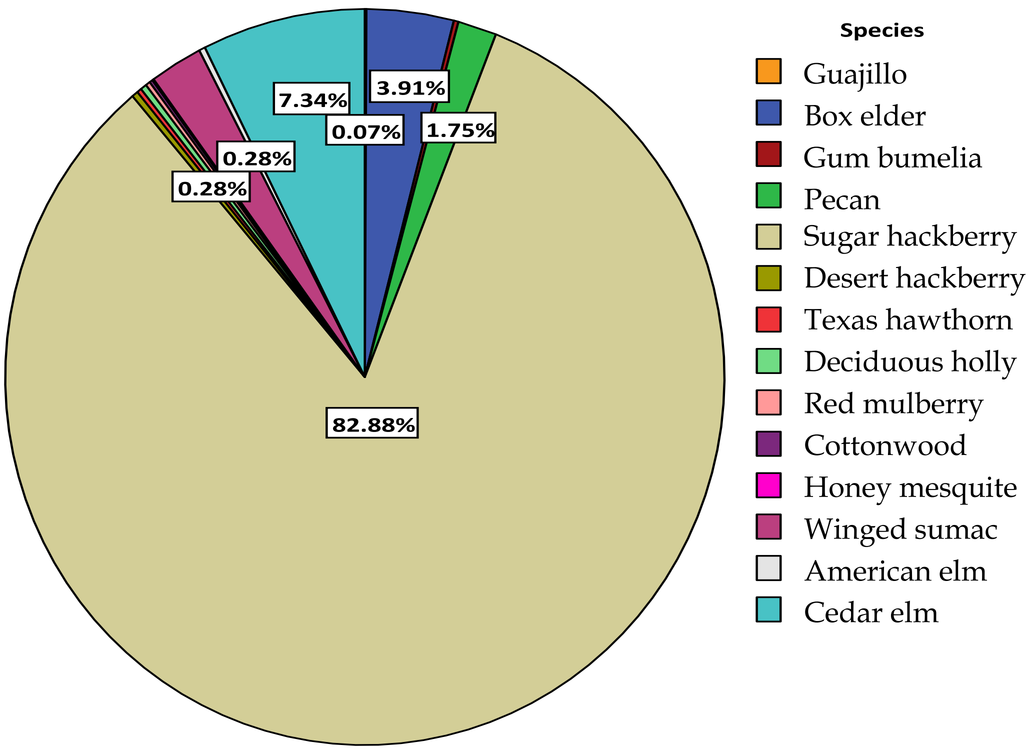


Figure E-9. Seedling species composition identified at the San Antonio River Falls City Study Site.

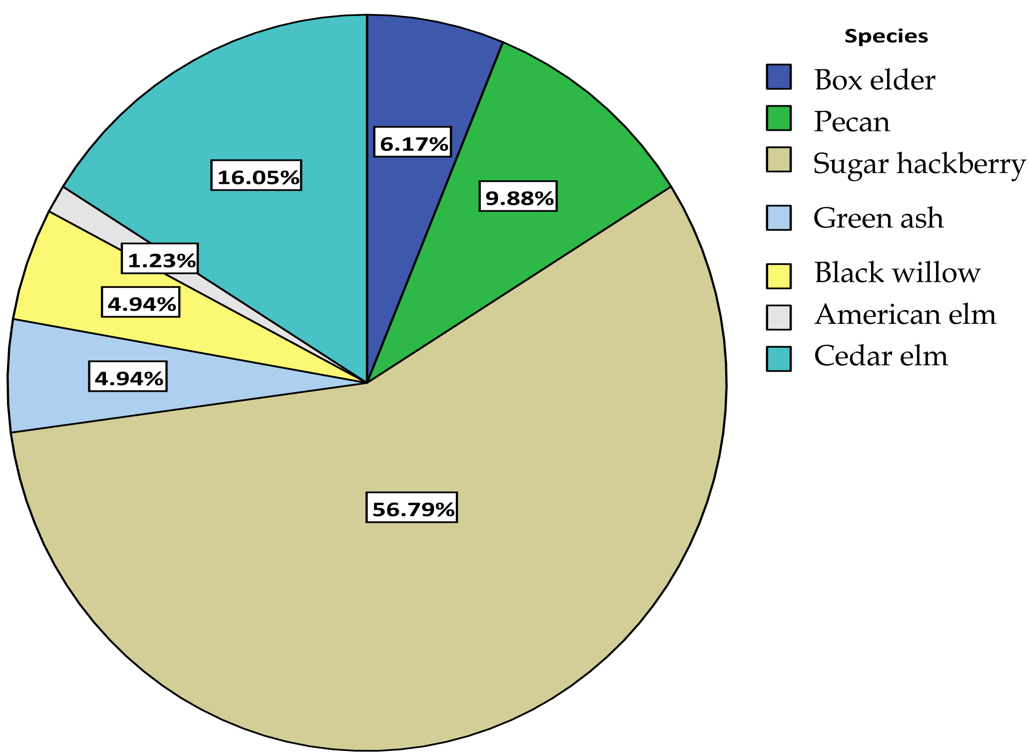


Figure E-10. Tree species composition identified at the San Antonio River Goliad Study Site.

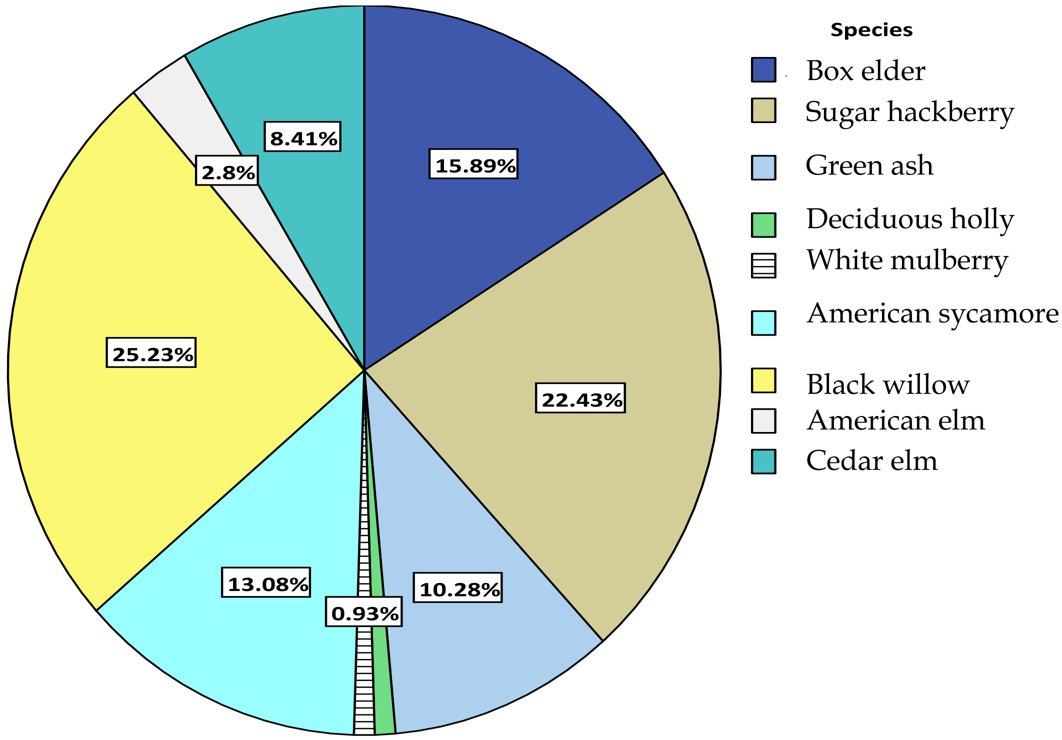


Figure E-11. Sapling species composition identified at the San Antonio River Goliad Study Site.

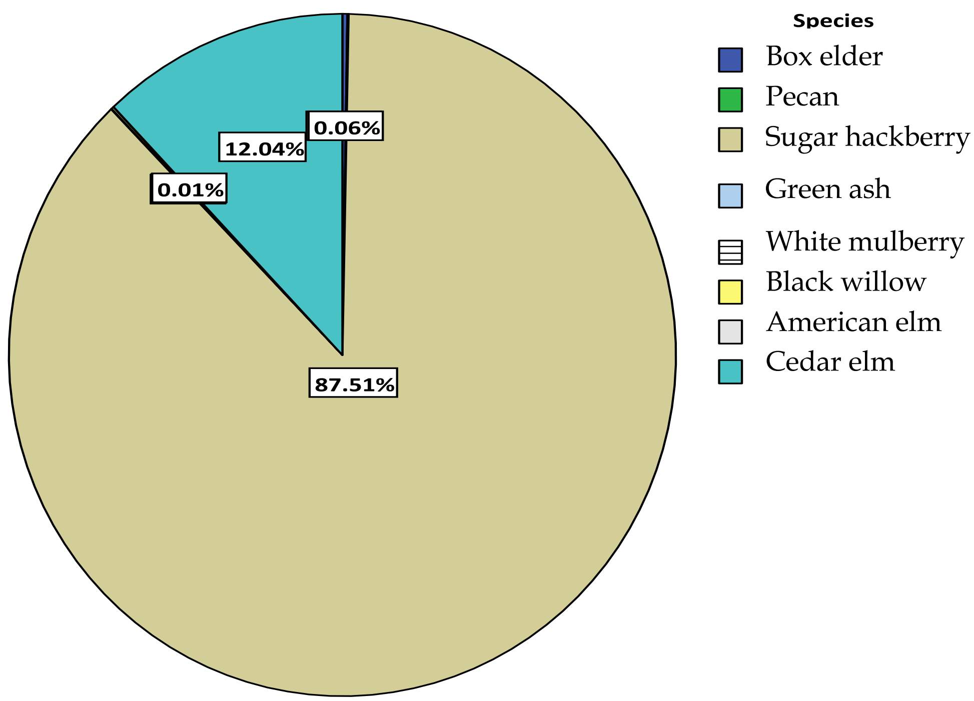


Figure E-12. Seedling species composition identified at the San Antonio River Goliad Study Site.

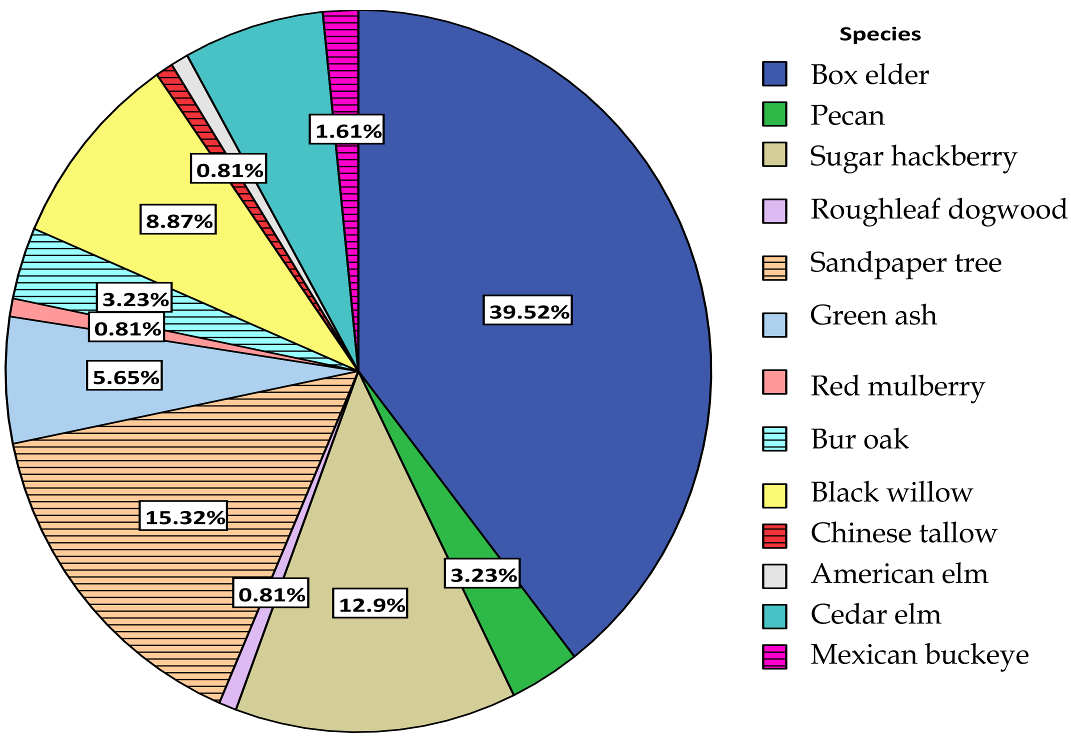


Figure E-13. Tree species composition identified at the San Antonio River Hwy 77 Study Site.

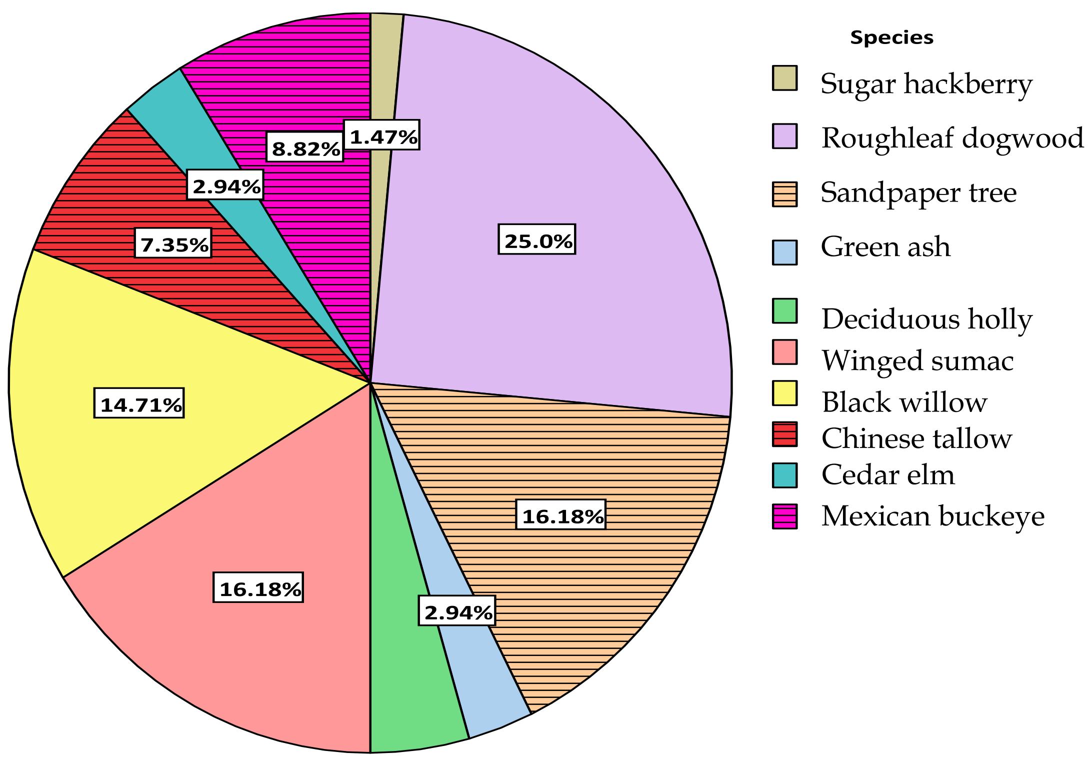


Figure E-14. Sapling species composition identified at the San Antonio River Hwy 77 Study Site.

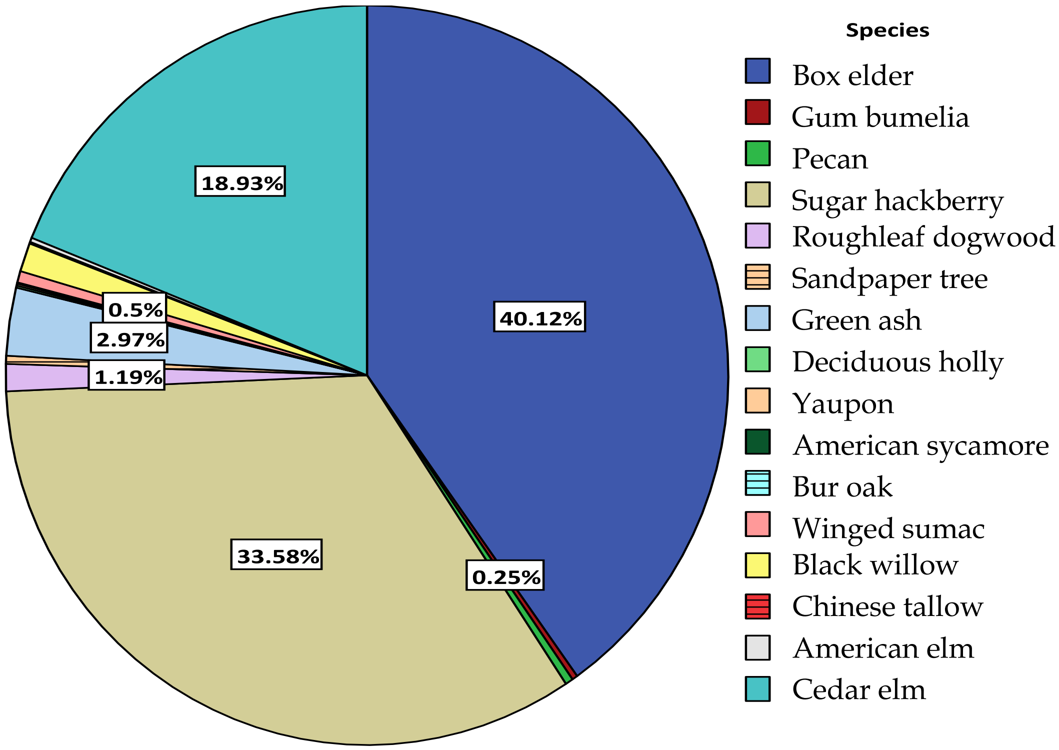


Figure E-15. Seedling species composition identified at the San Antonio River Hwy 77 Study Site.

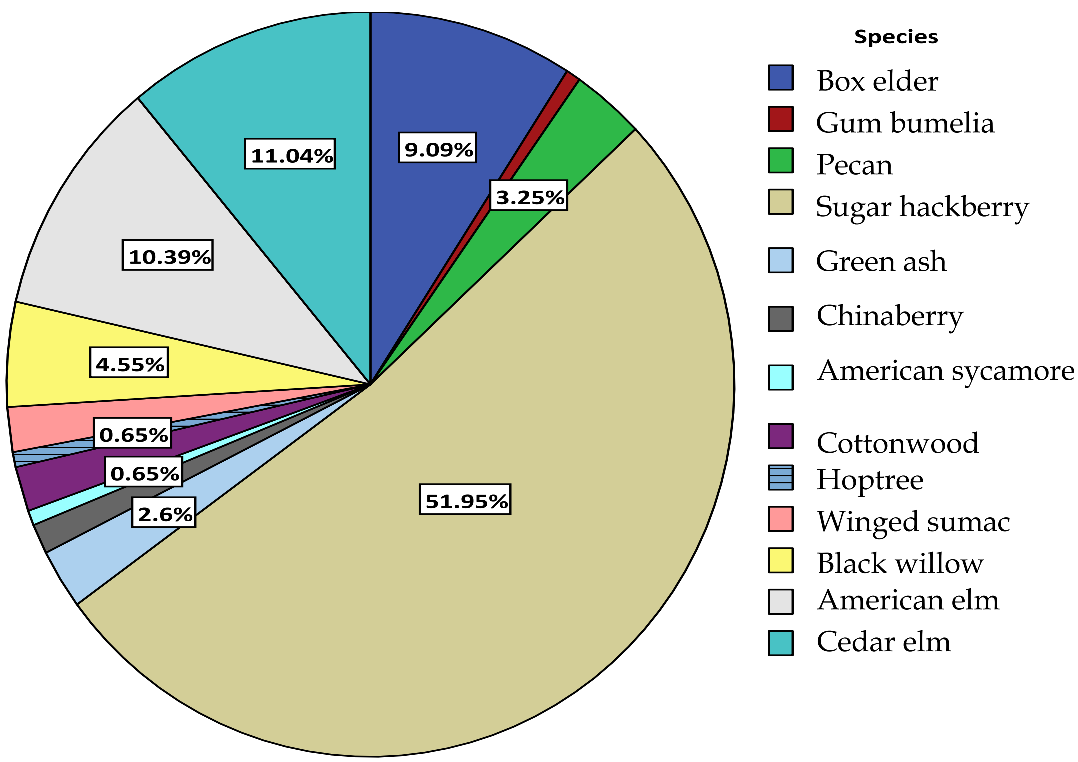


Figure E-16. Tree species composition identified at the Cibolo Creek Study Site.

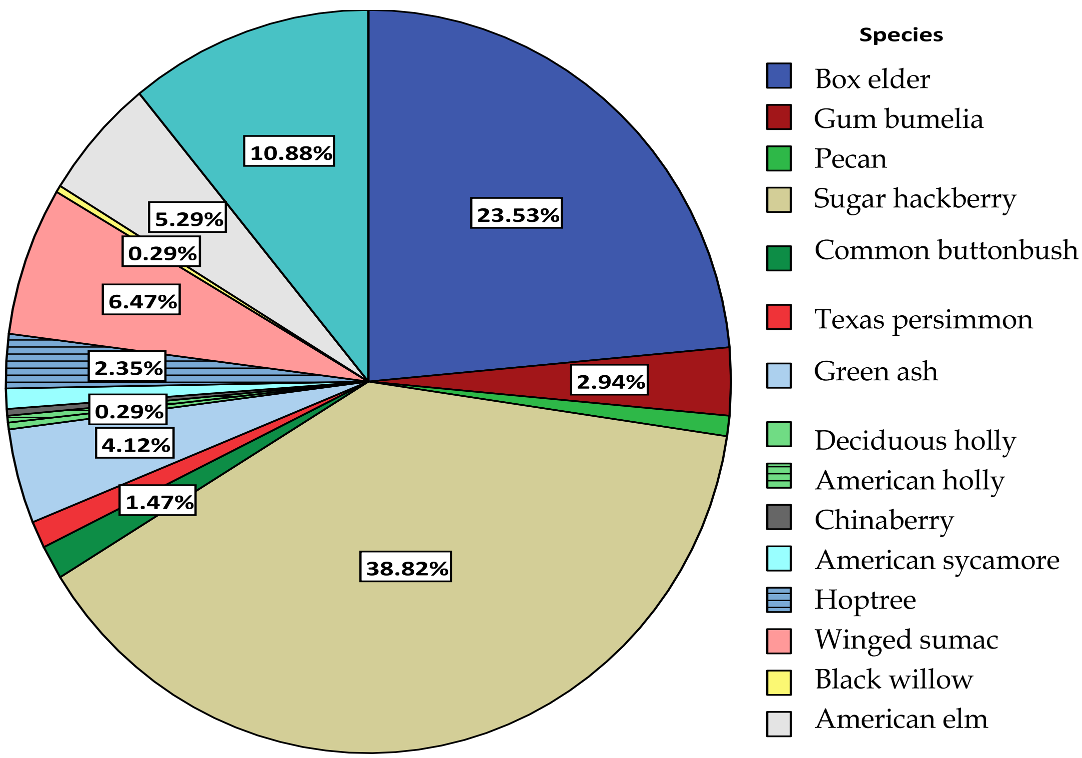


Figure E-17. Sapling species composition identified at the Cibolo Creek Study Site.

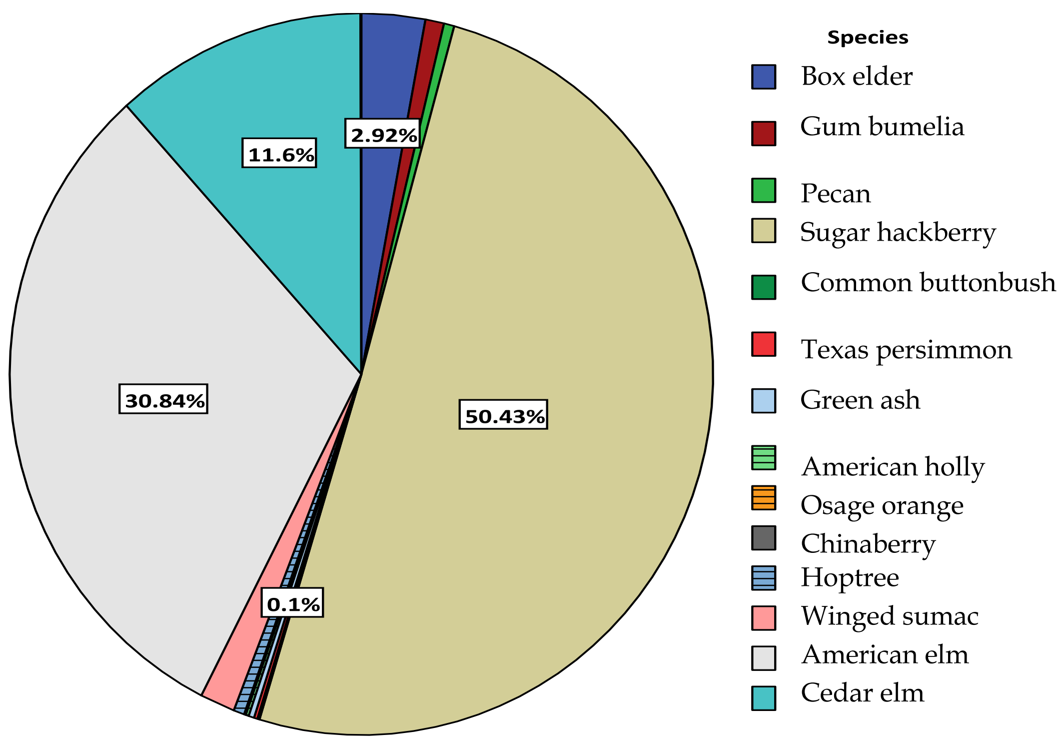


Figure E-18. Seedling species composition identified at the Cibolo Creek Study Site.

APPENDIX F
RIPARIAN TRANSECT DATA

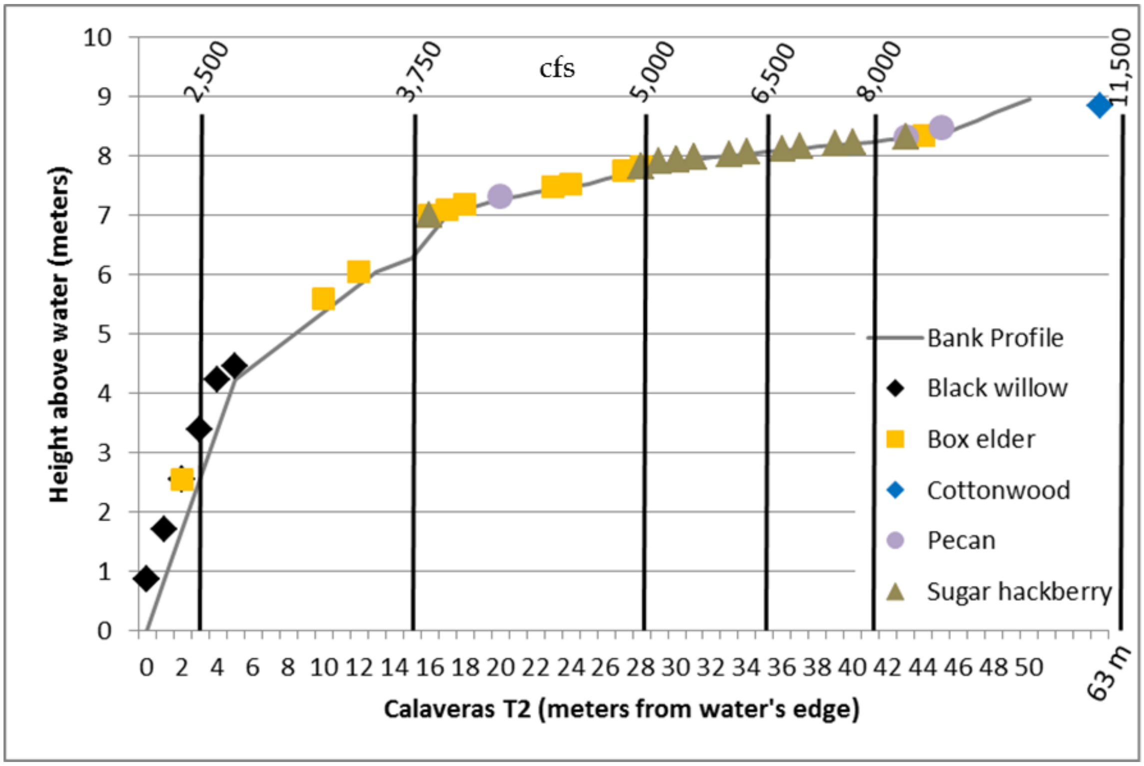


Figure F-1. Tree data from the San Antonio River Calaveras Study Site along Transect 2.

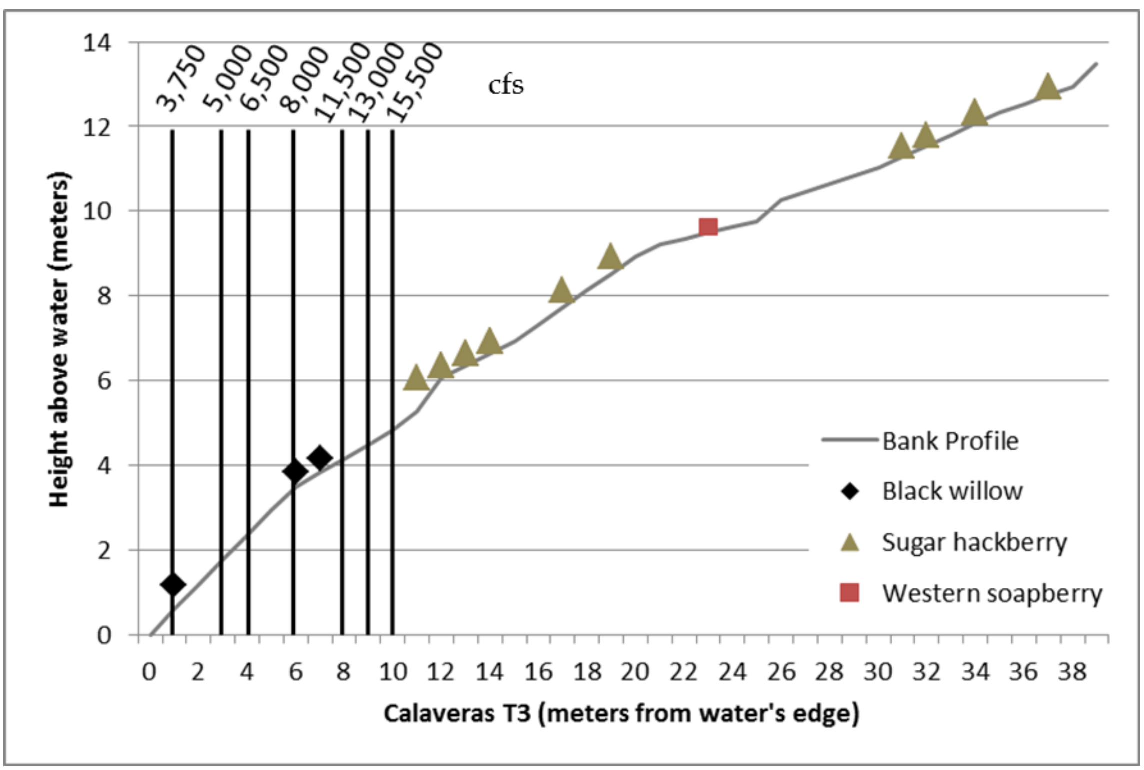


Figure F-2. Tree data from the San Antonio River Calaveras Study Site along Transect 3.

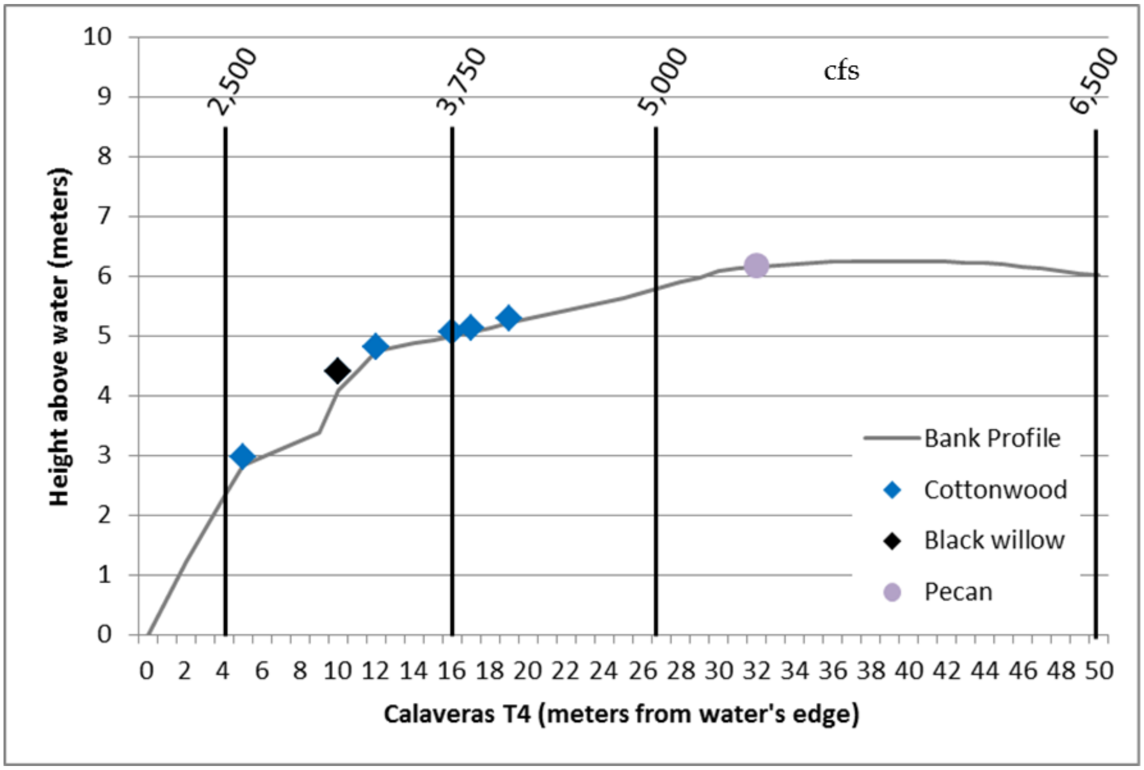


Figure F-3. Tree data from the San Antonio River Calaveras Study Site along Transect 4.

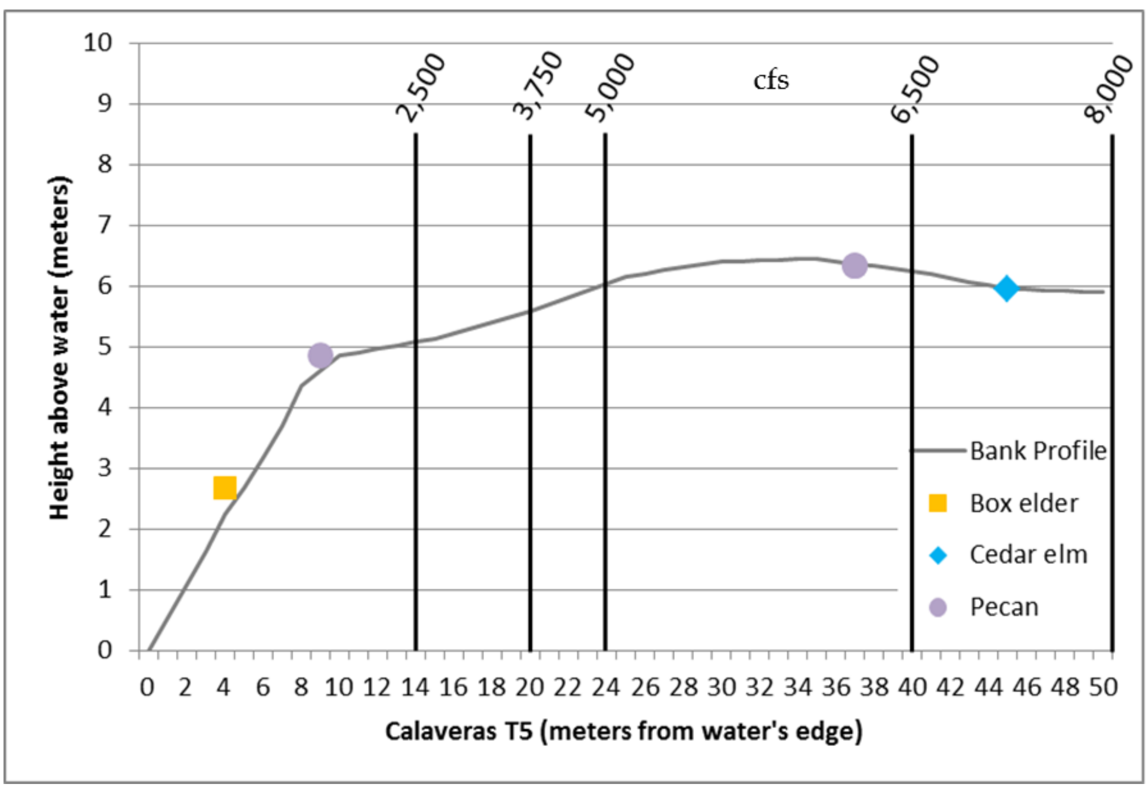


Figure F-4. Tree data from the San Antonio River Calaveras Study Site along Transect 5.

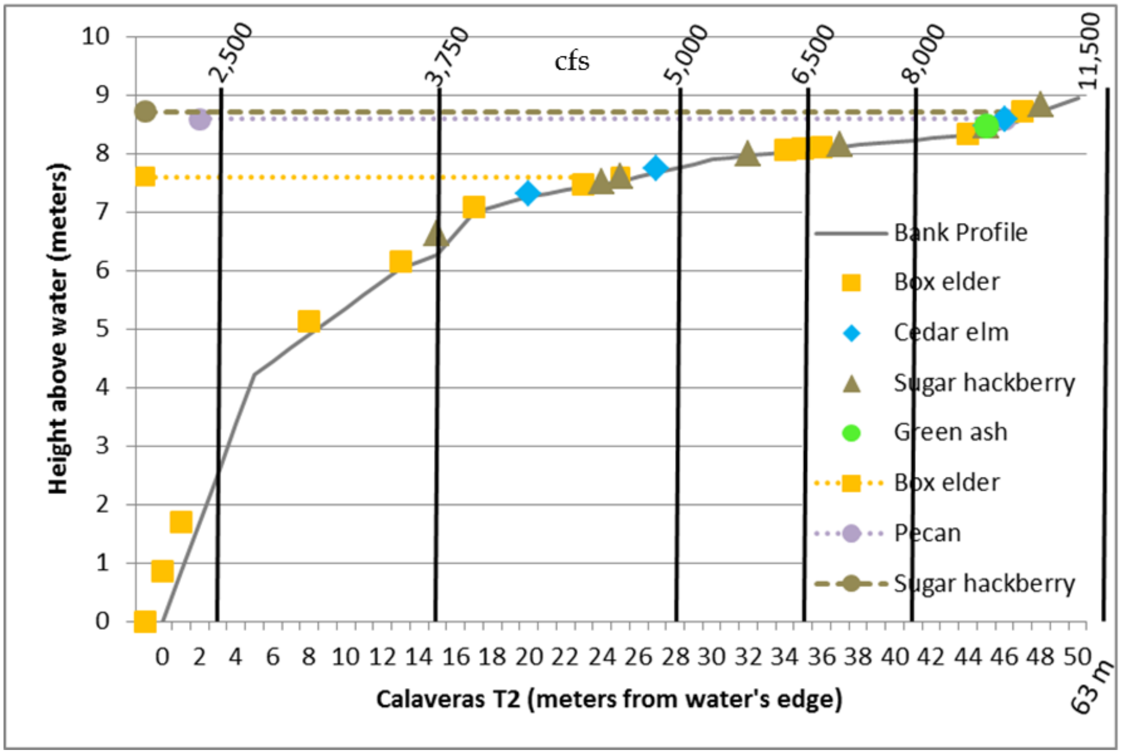


Figure F-5. Sapling (point) and seedling range (line) data from the San Antonio River Calaveras Study Site along Transect 2.

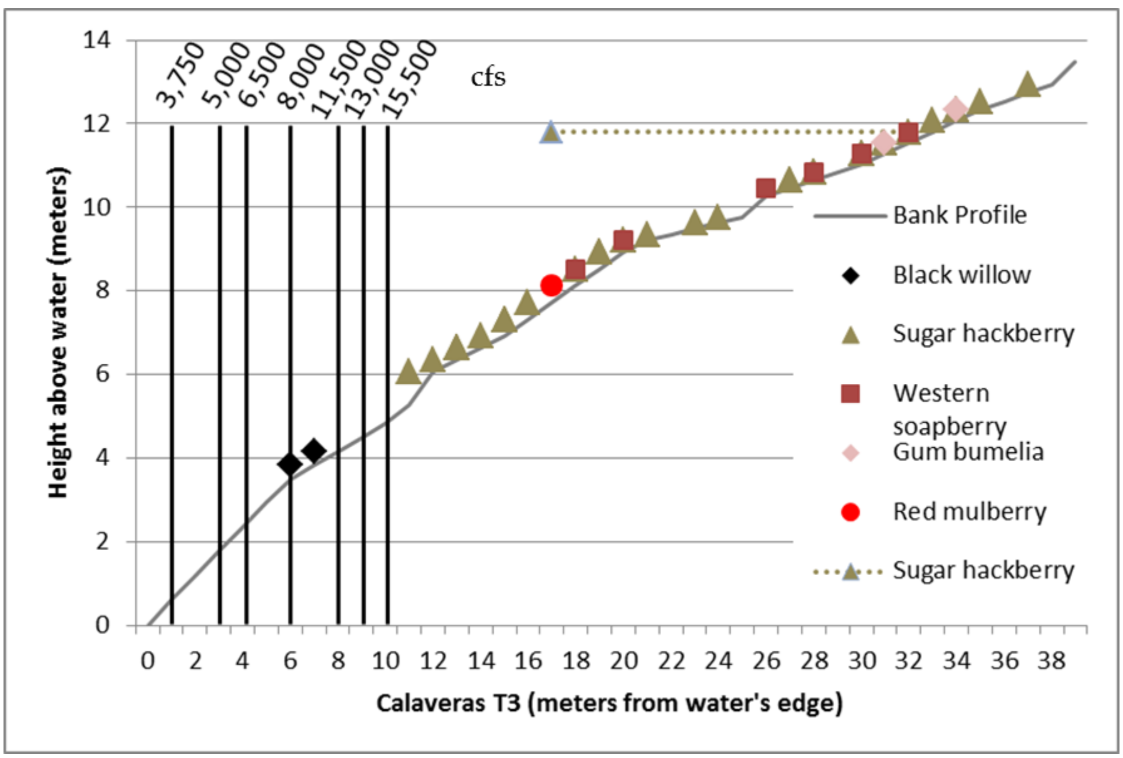


Figure F-6. Sapling (point) and seedling range (line) data from the San Antonio River Calaveras Study Site along Transect 3.

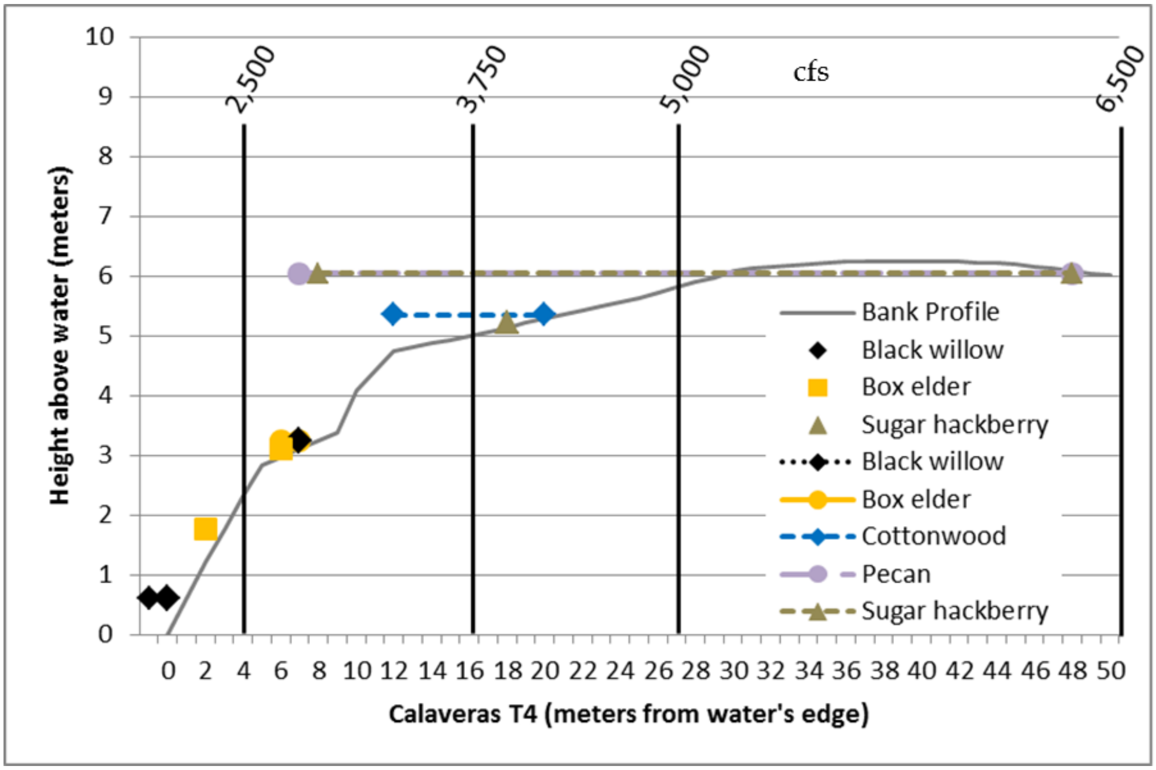


Figure F-7. Sapling (point) and seedling range (line) data from the San Antonio River Calaveras Study Site along Transect 4.

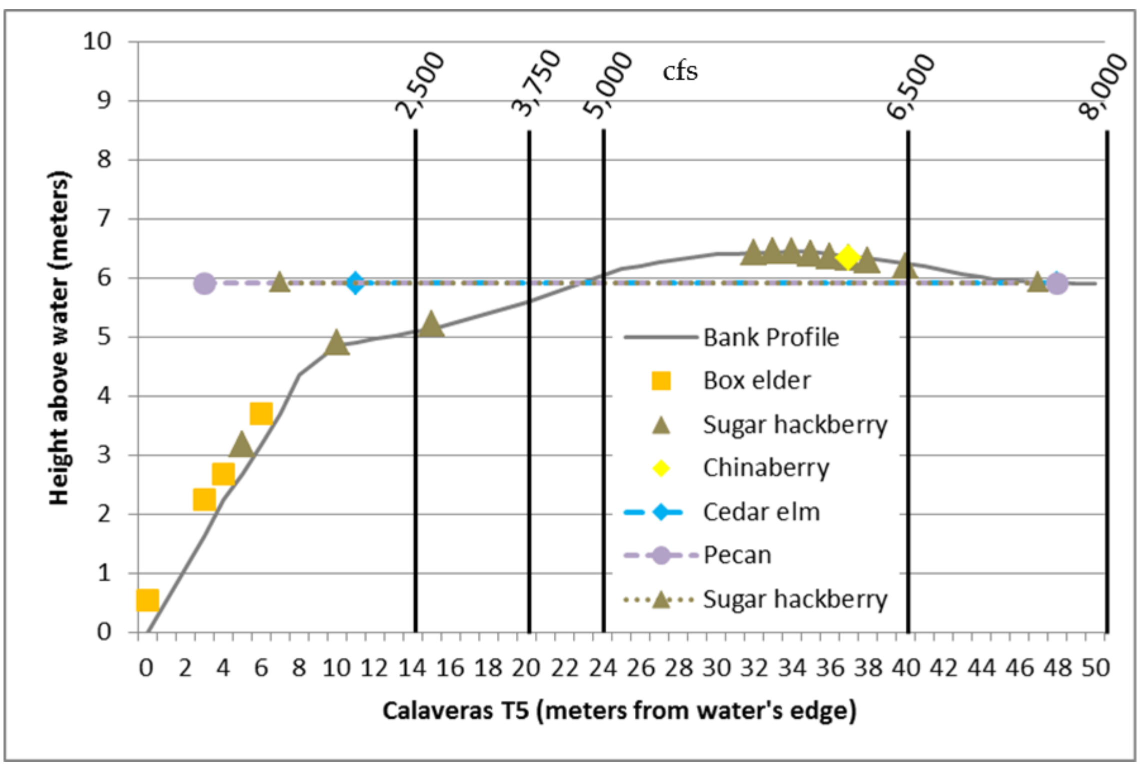


Figure F-8. Sapling (point) and seedling range (line) data from the San Antonio River Calaveras Study Site along Transect 5.

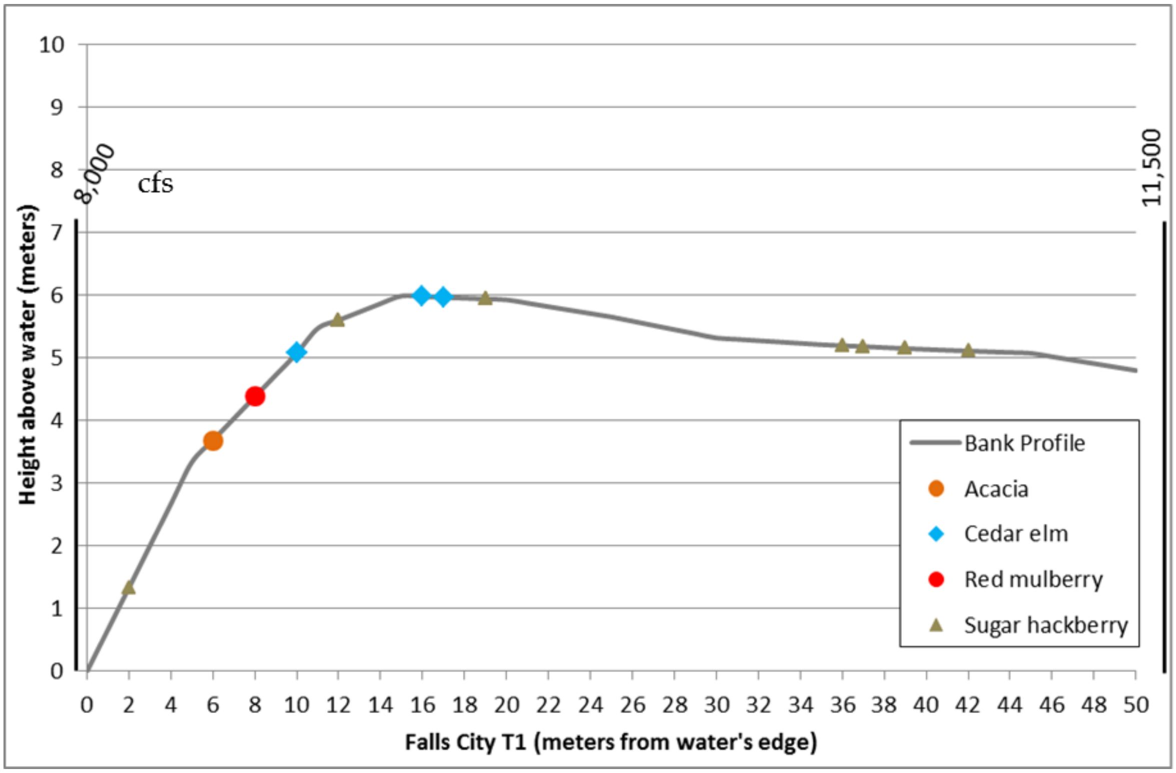


Figure F-9. Tree data from the San Antonio River Falls City Study Site along Transect 1.

No trees observed along Transect 2 at the San Antonio River Falls City Study Site.

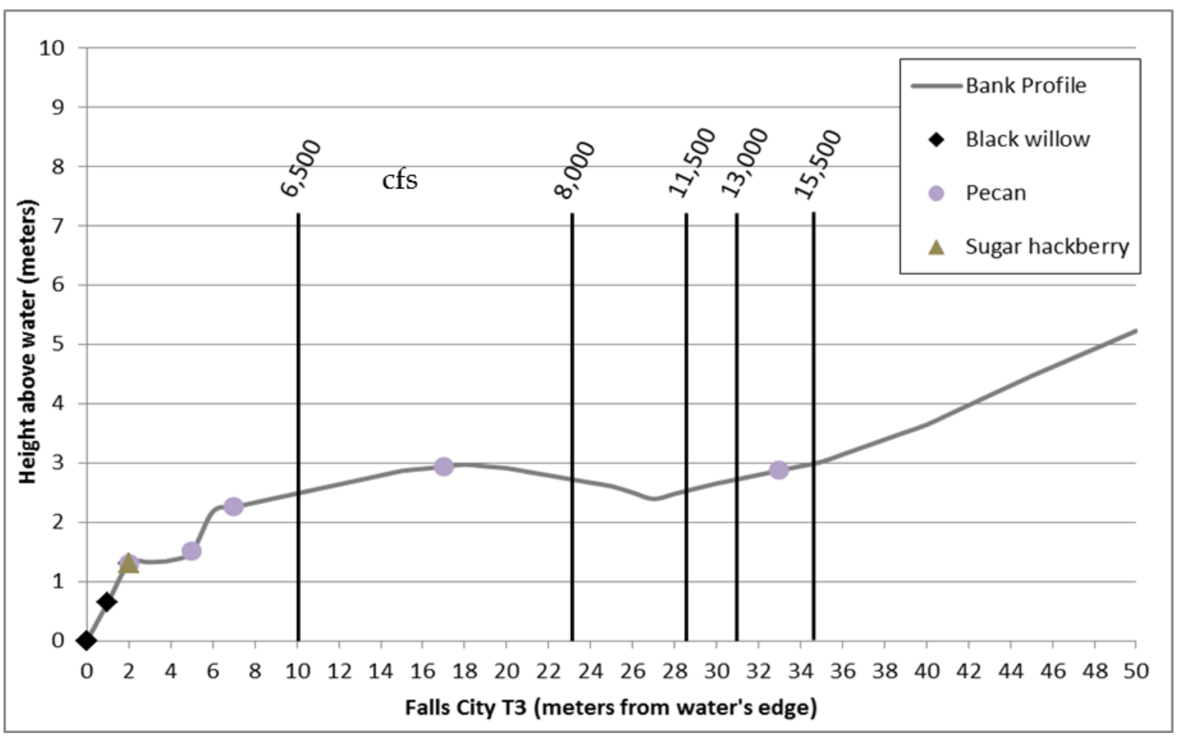


Figure F-10. Tree data from the San Antonio River Falls City Study Site along Transect 3.

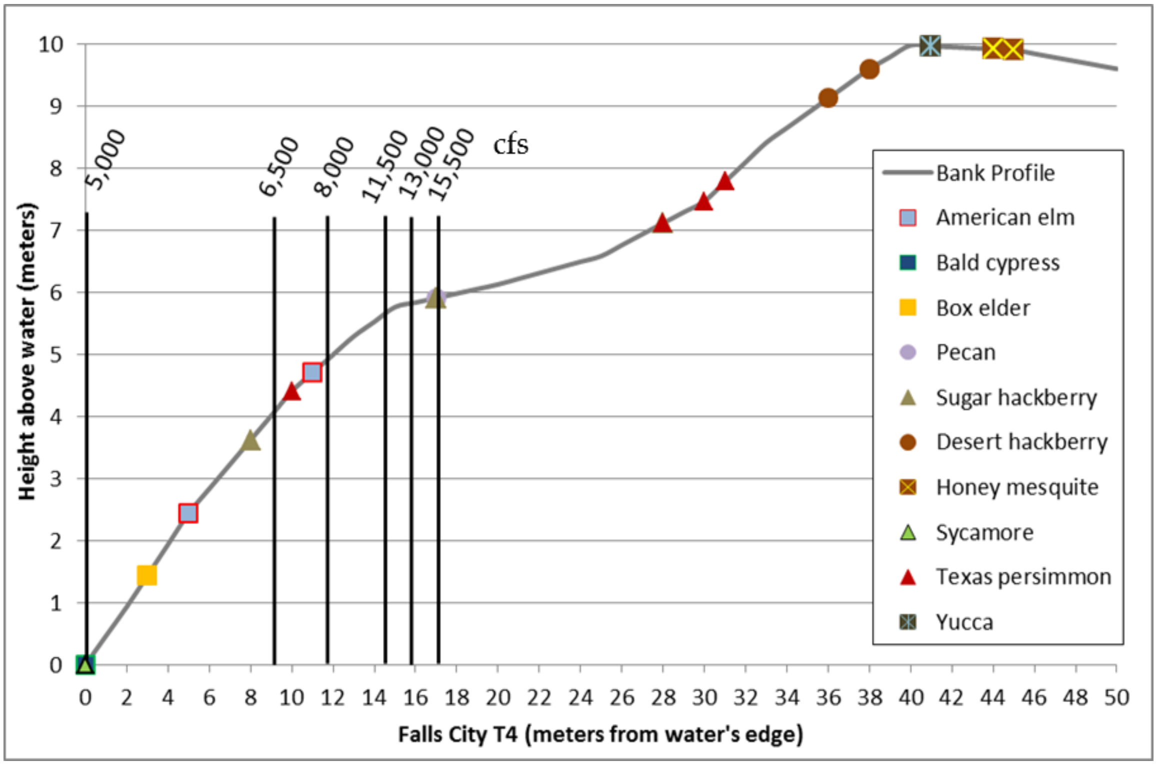


Figure F-11. Tree data from the San Antonio River Falls City Study Site along Transect 4.

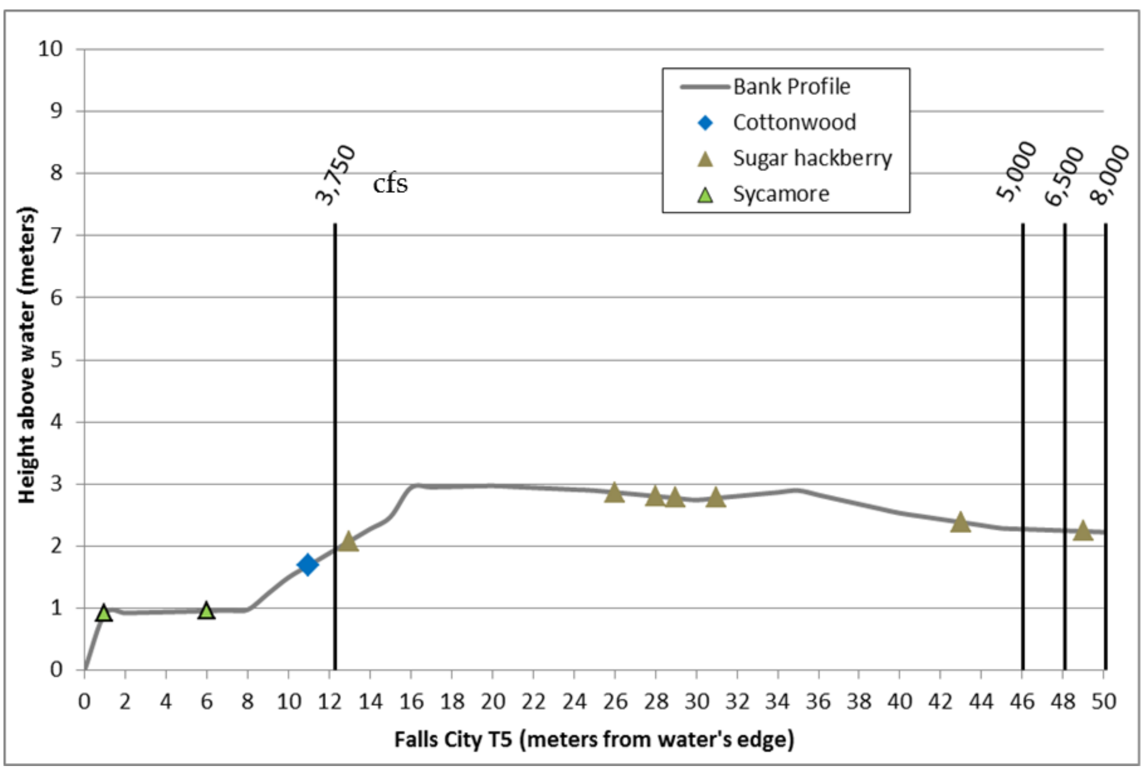


Figure F-12. Tree data from the San Antonio River Falls City Study Site along Transect 5.

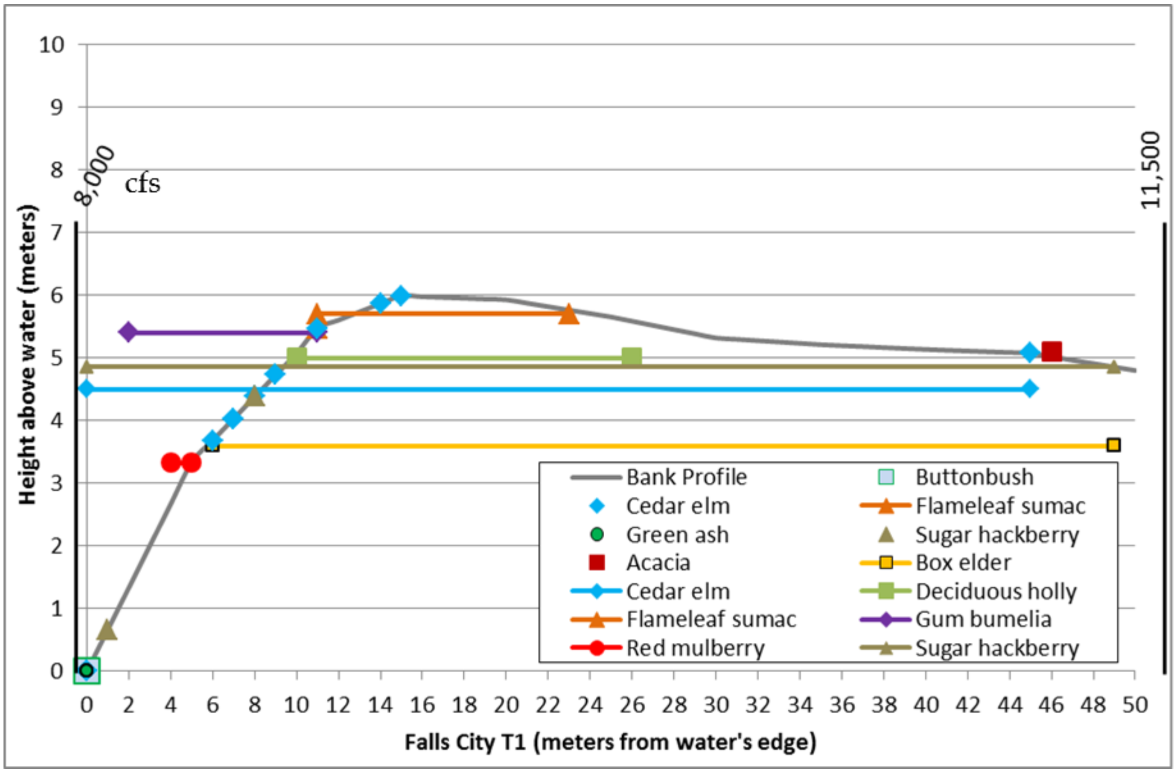


Figure F-13. Sapling (point) and seedling range (line) data from the San Antonio River Falls City Study Site along Transect 1.

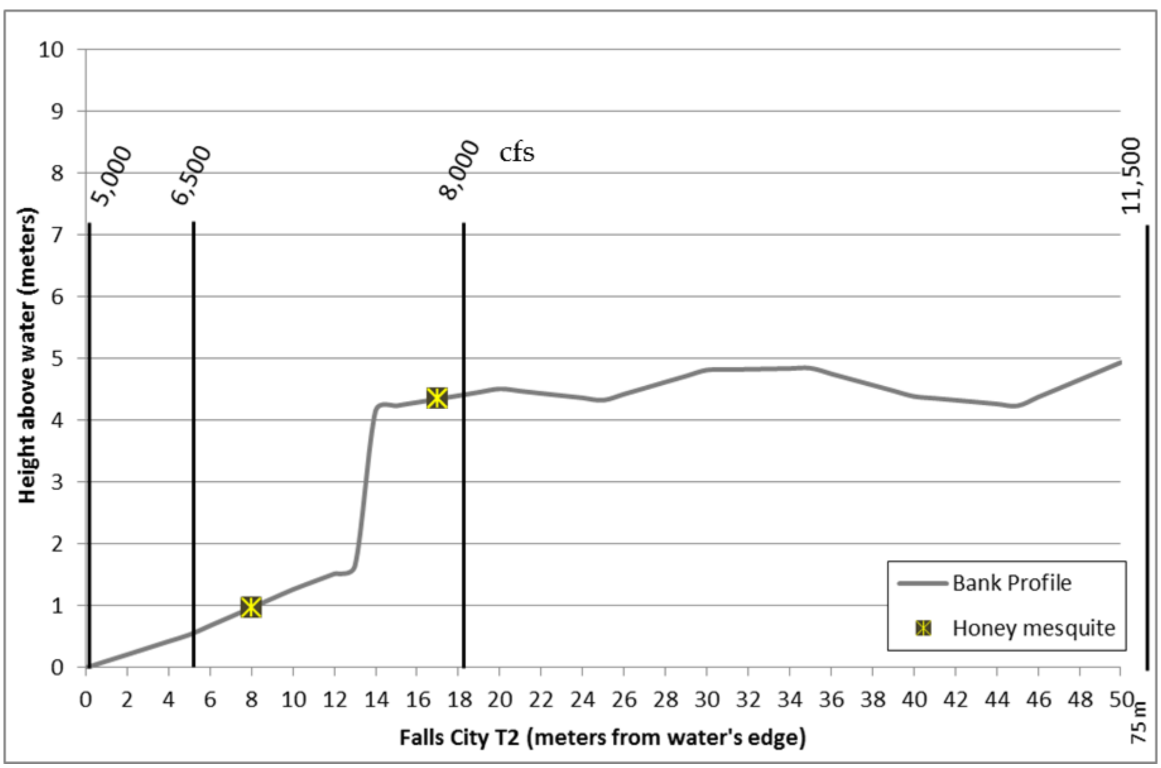


Figure F-14. Sapling (point) and seedling range (line) data from the San Antonio River Falls City Study Site along Transect 2.

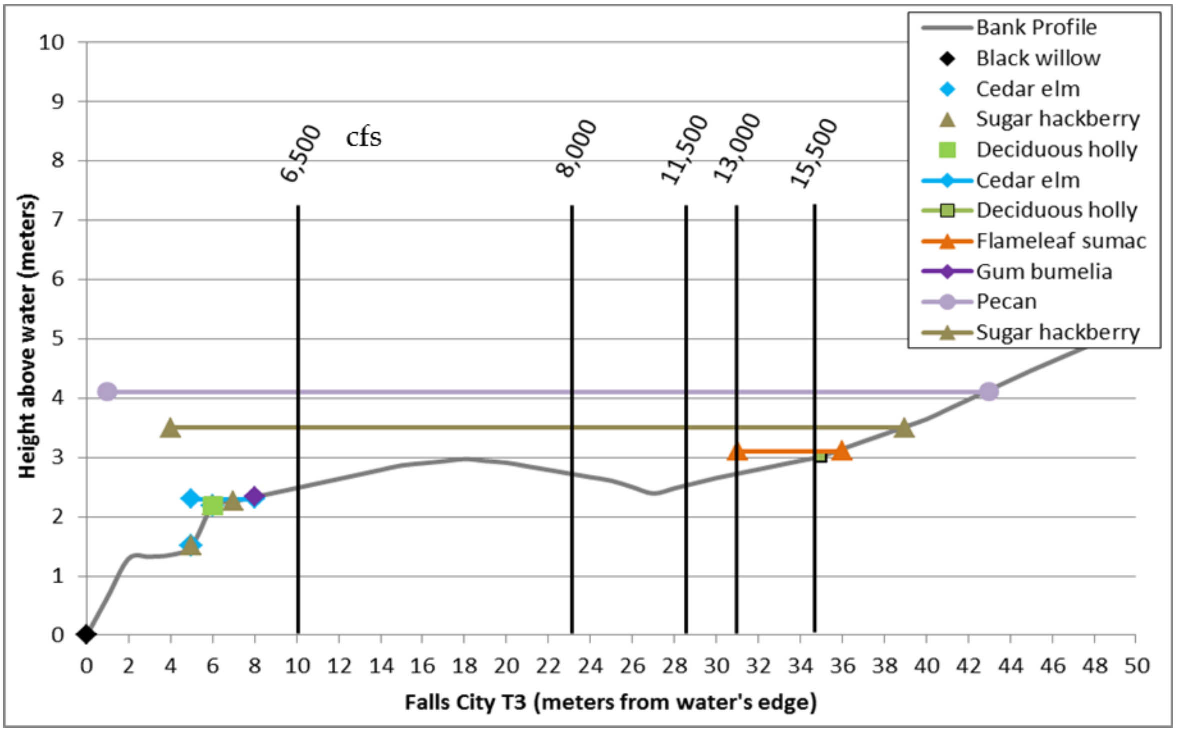


Figure F-15. Sapling (point) and seedling range (line) data from the San Antonio River Falls City Study Site along Transect 3.

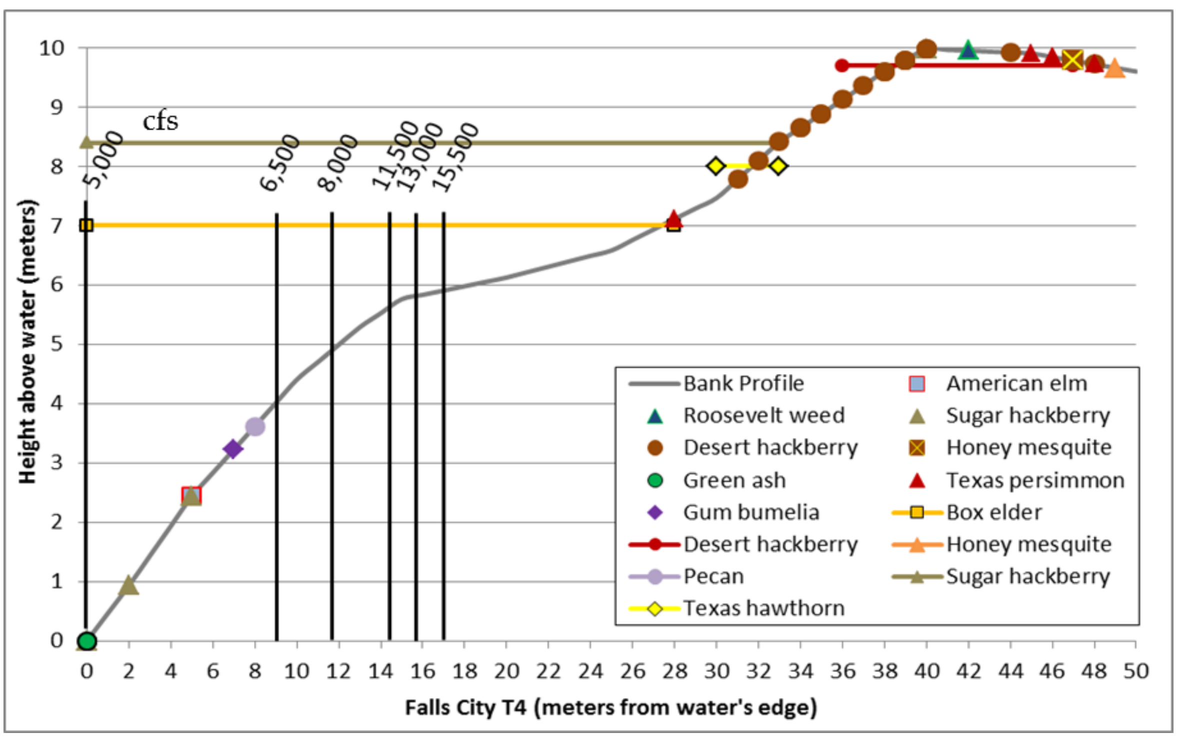


Figure F-16. Sapling (point) and seedling range (line) data from the San Antonio River Falls City Study Site along Transect 4.

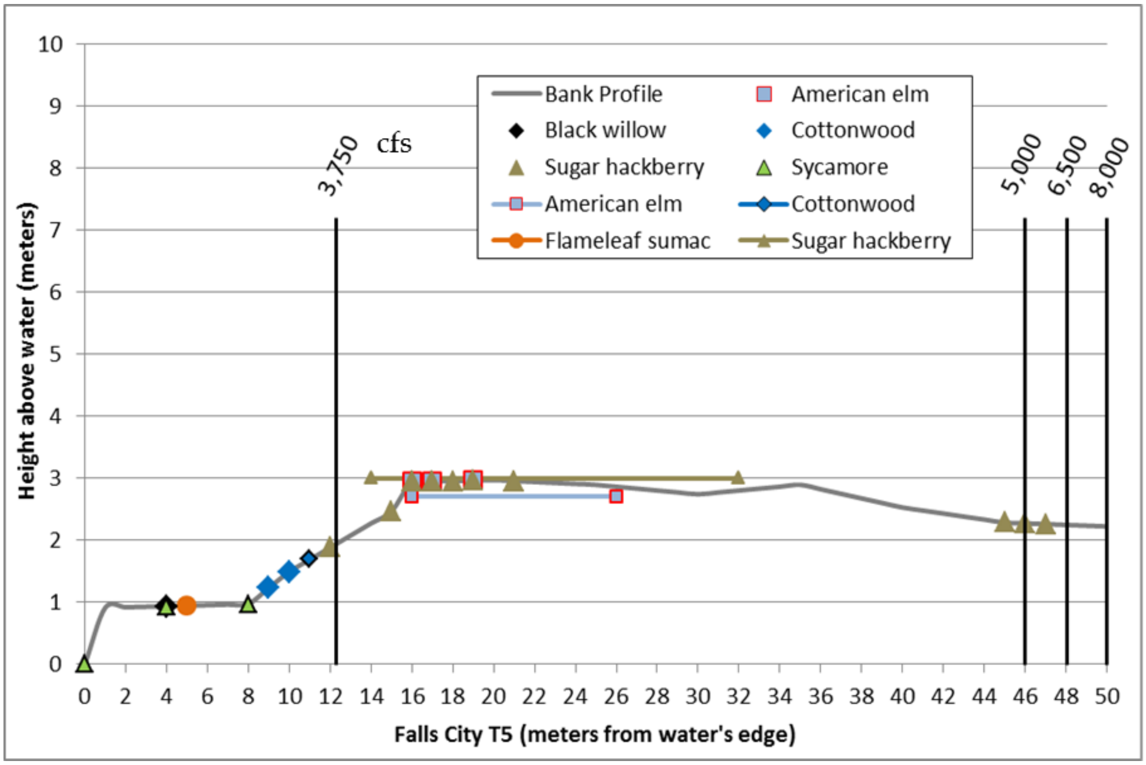


Figure F-17. Sapling (point) and seedling range (line) data from the San Antonio River Falls City Study Site along Transect 5.

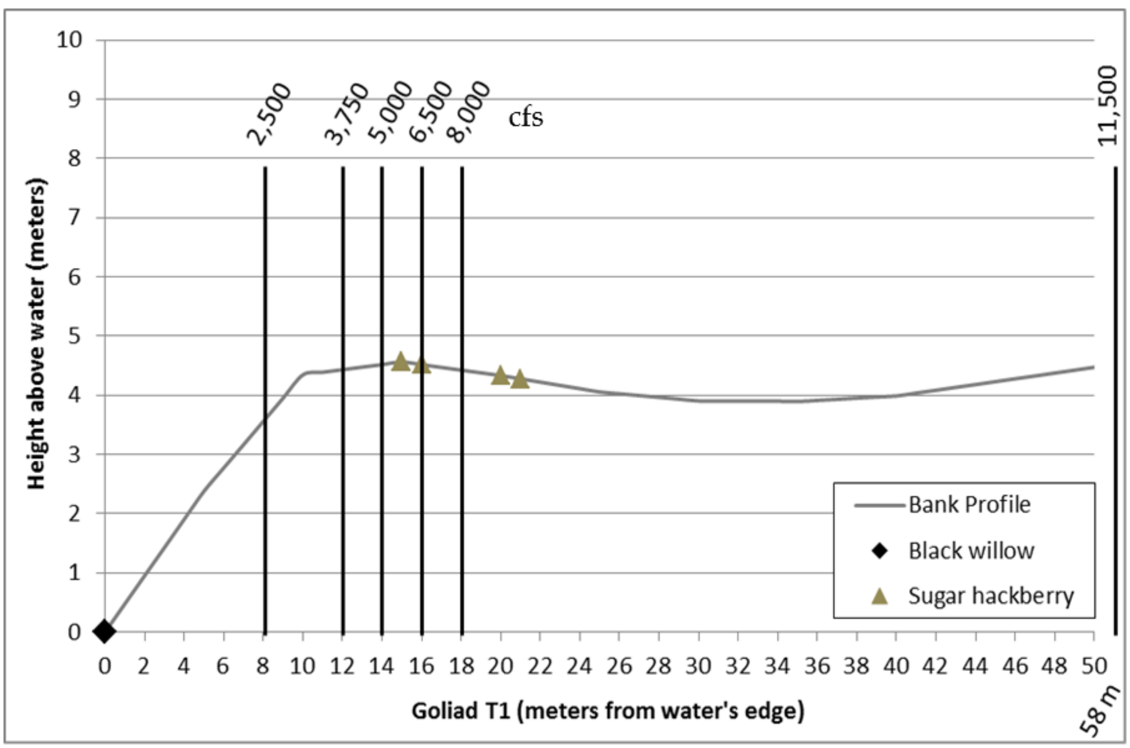


Figure F-18. Tree data from the San Antonio River Goliad Study Site along Transect 1.

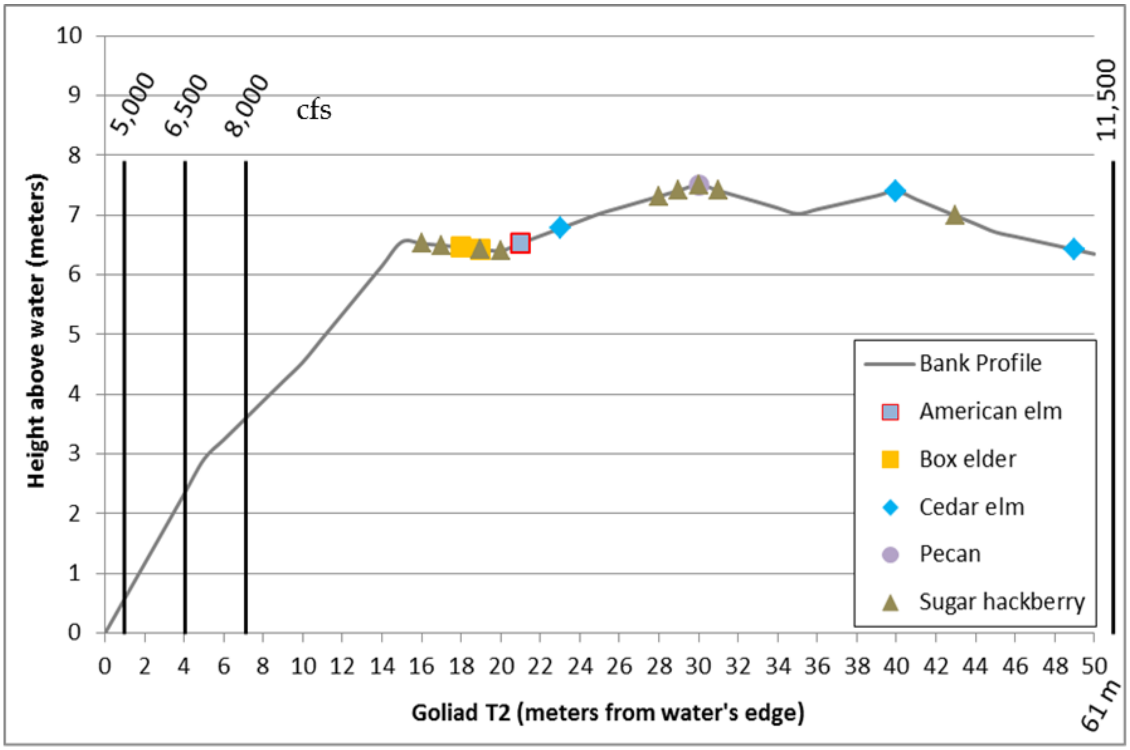


Figure F-19. Tree data from the San Antonio River Goliad Study Site along Transect 2.

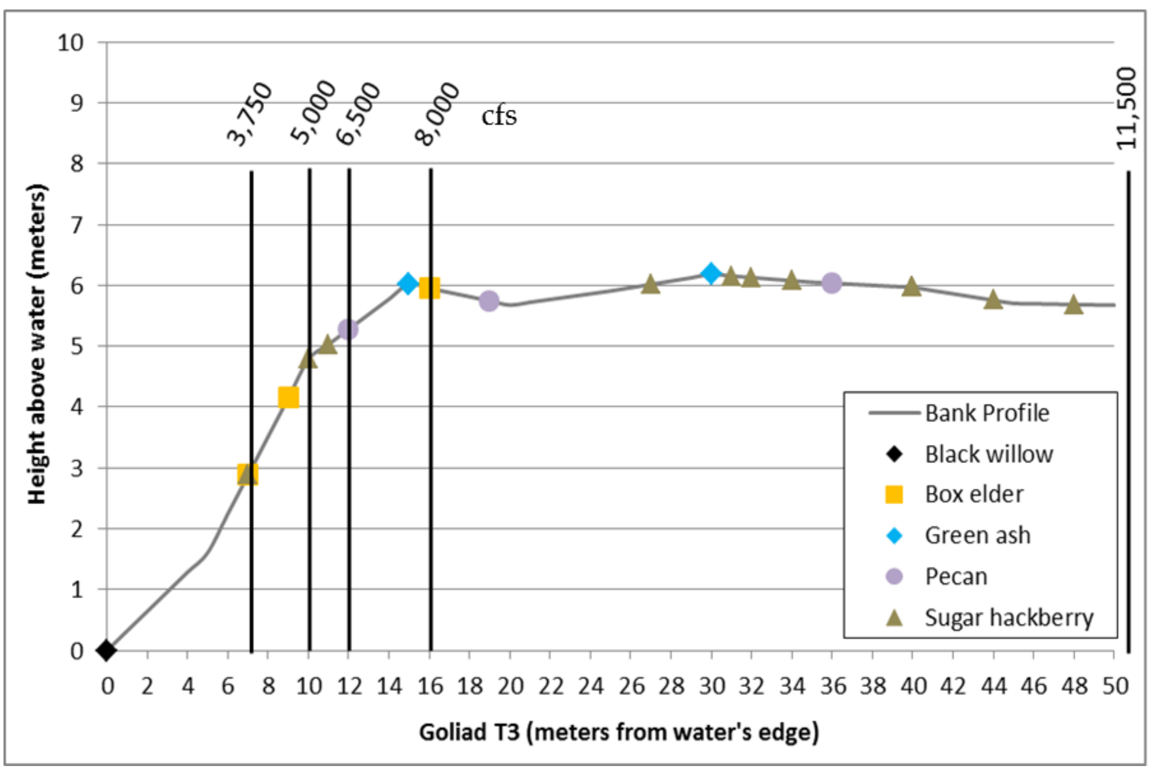


Figure F-20. Tree data from the San Antonio River Goliad Study Site along Transect 3.

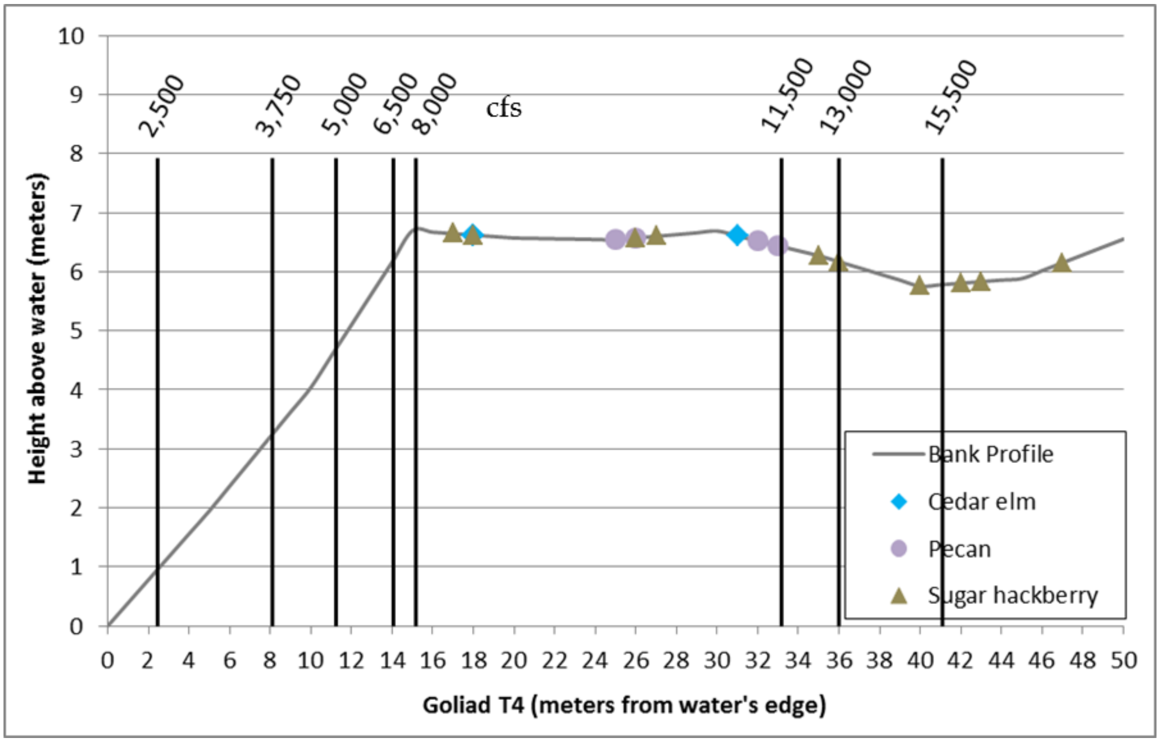


Figure F-21. Tree data from the San Antonio River Goliad Study Site along Transect 4.

Bank profile survey for Transect 5 from the San Antonio River Goliad Study Site not available.

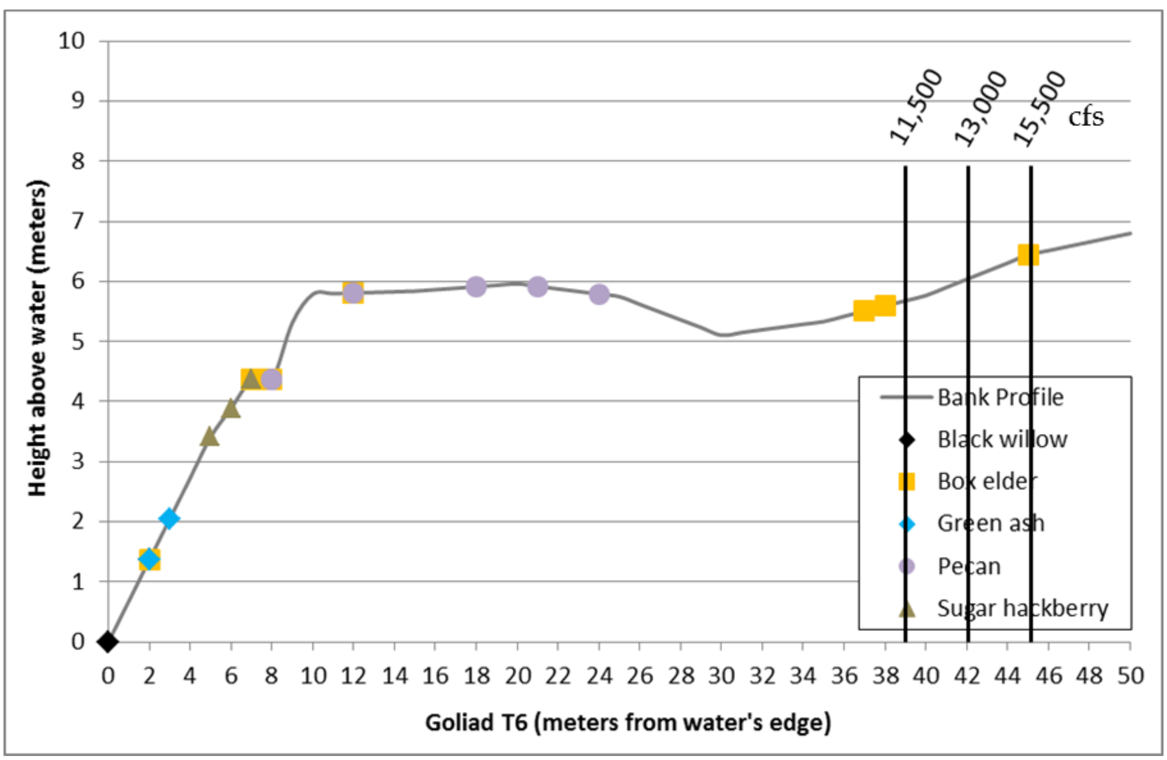


Figure F-22. Tree data from the San Antonio River Goliad Study Site along Transect 6.

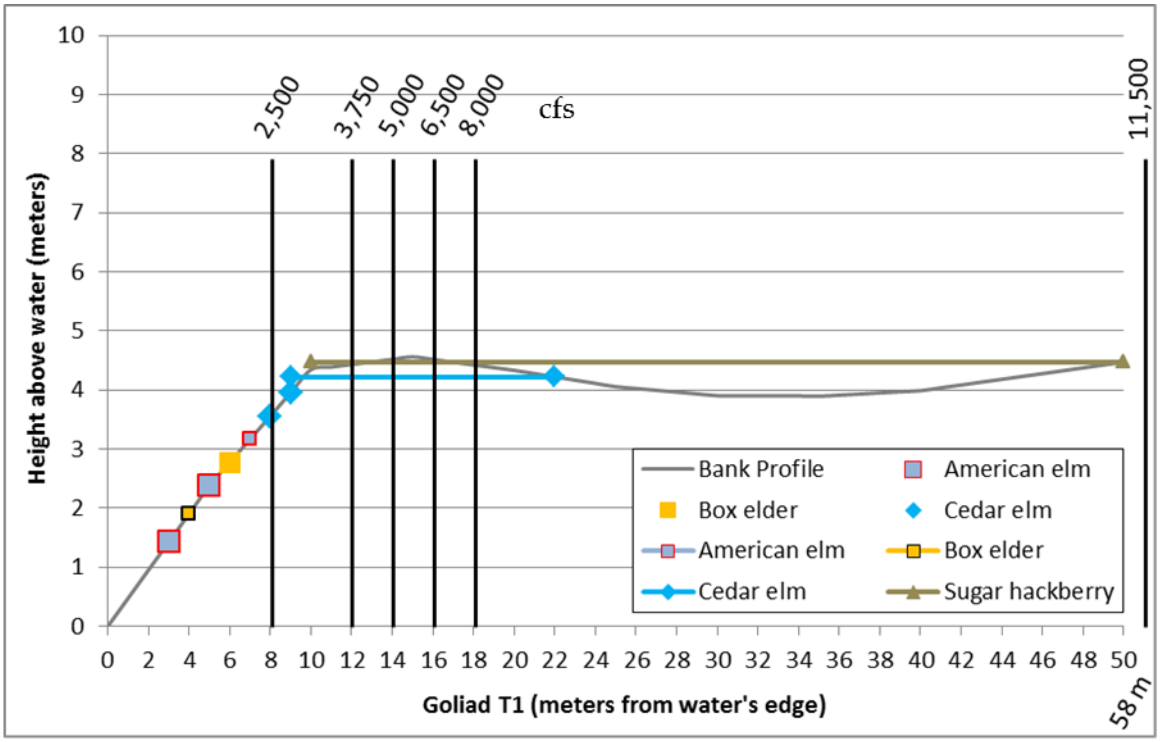


Figure F-23. Sapling (point) and seedling range (line) data from the San Antonio River Goliad Study Site along Transect 1.

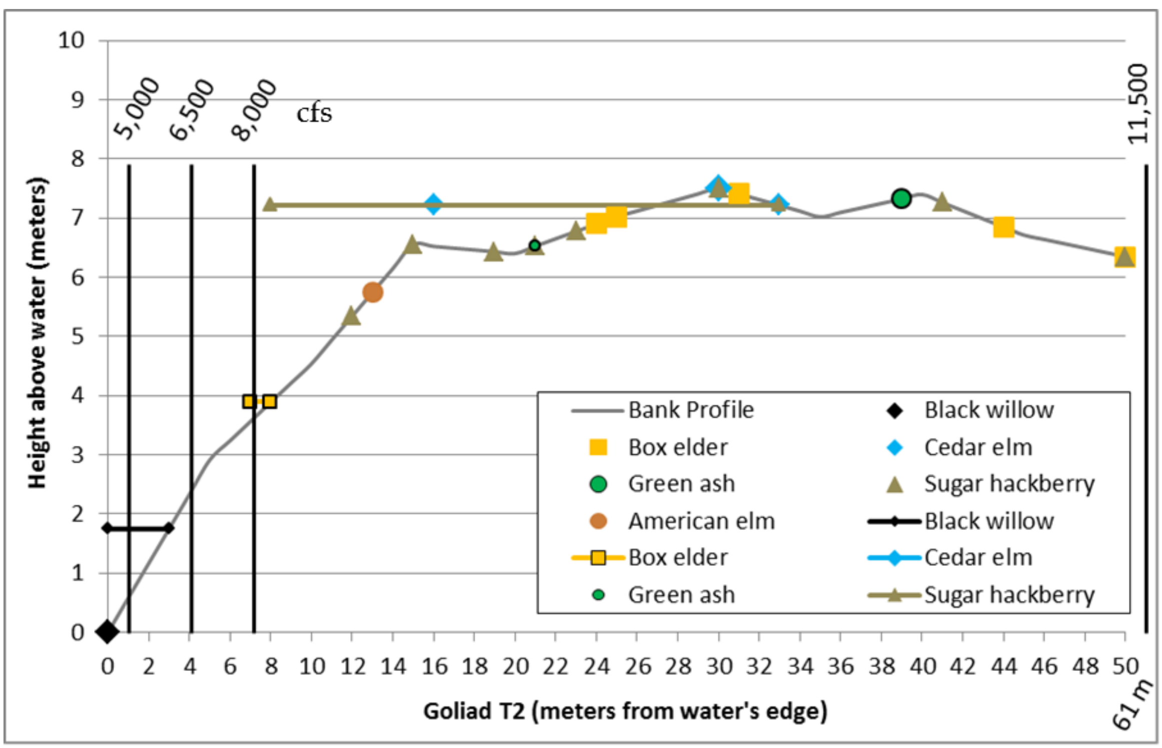


Figure F-24. Sapling (point) and seedling range (line) data from the San Antonio River Goliad Study Site along Transect 2.

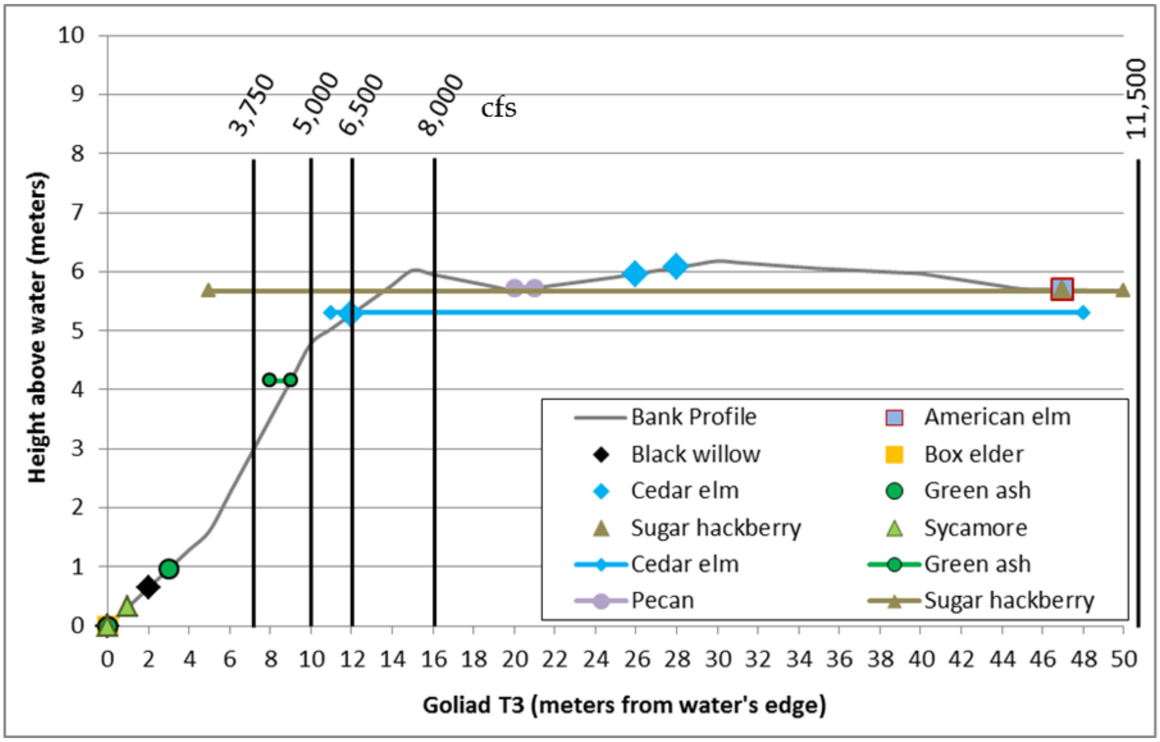


Figure F-25. Sapling (point) and seedling range (line) data from the San Antonio River Goliad Study Site along Transect 3.

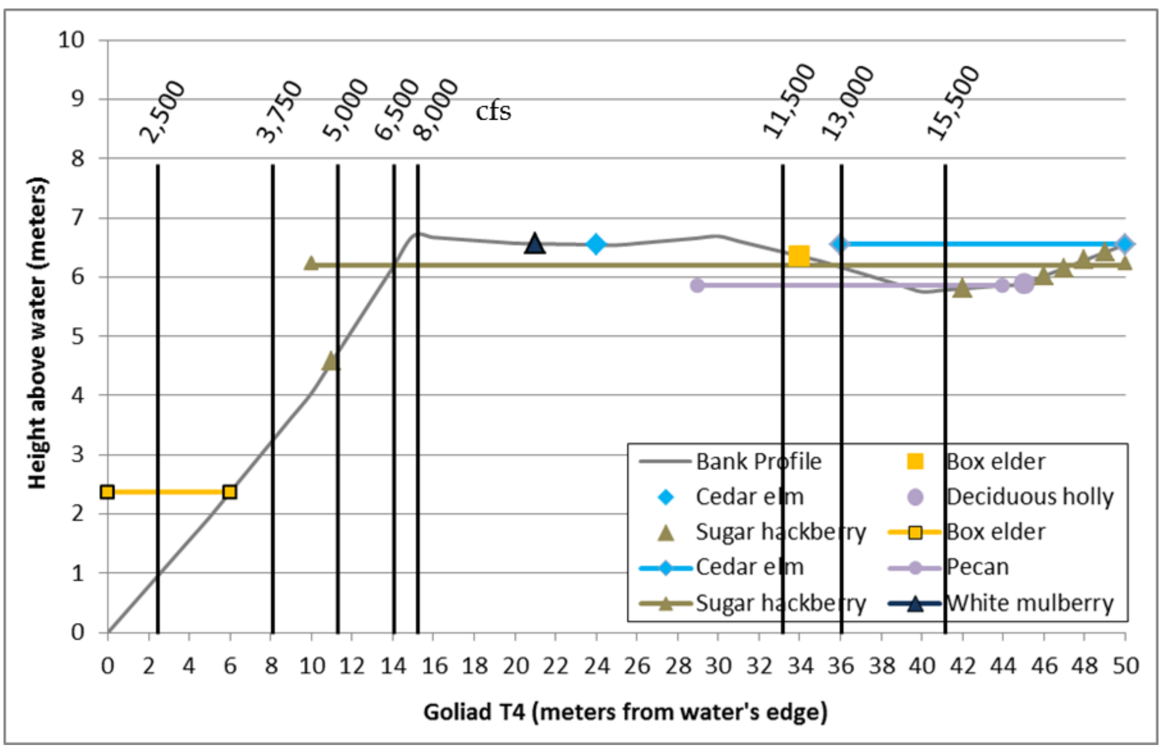


Figure F-26. Sapling (point) and seedling range (line) data from the San Antonio River Goliad Study Site along Transect 4.

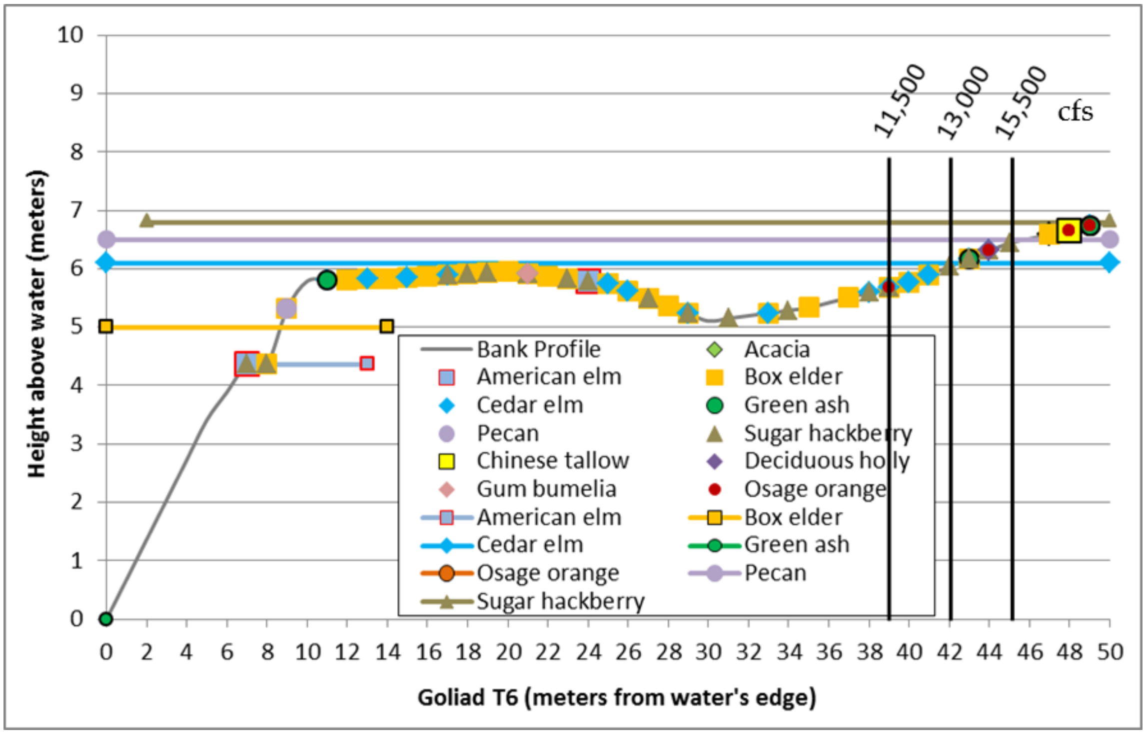


Figure F-27. Sapling (point) and seedling range (line) data from the San Antonio River Goliad Study Site along Transect 6.

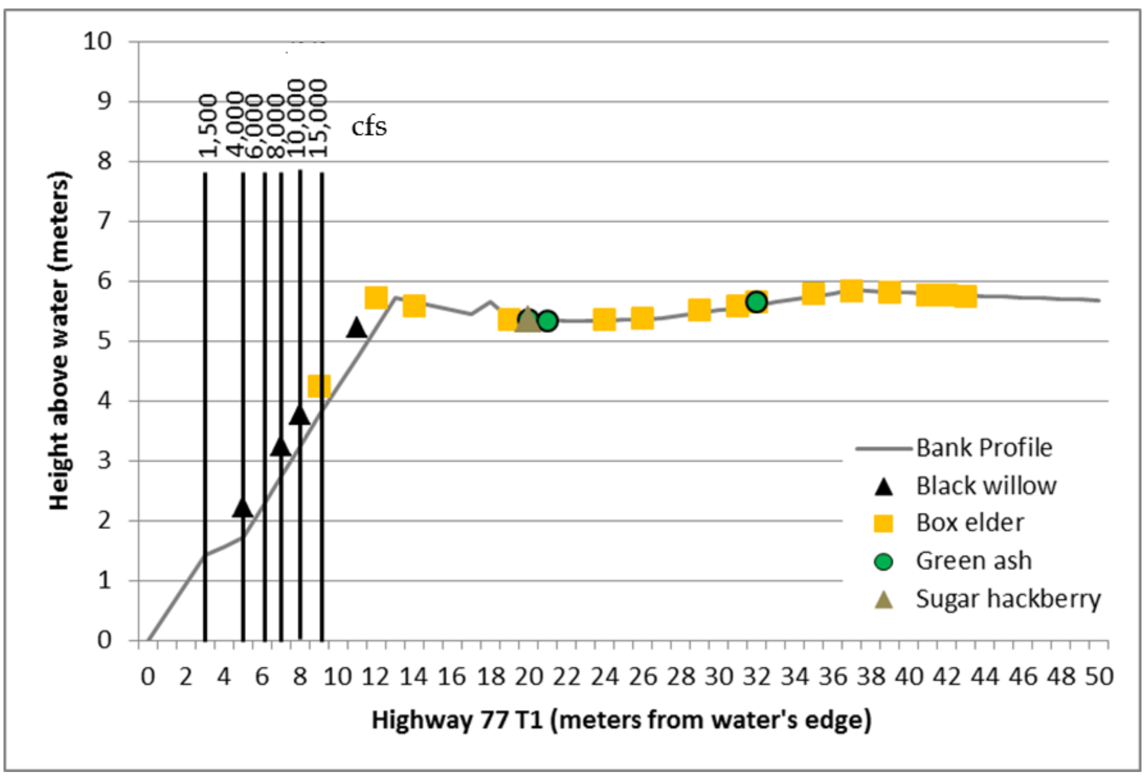


Figure F-28. Tree data from the San Antonio River Hwy 77 Study Site along Transect 1.

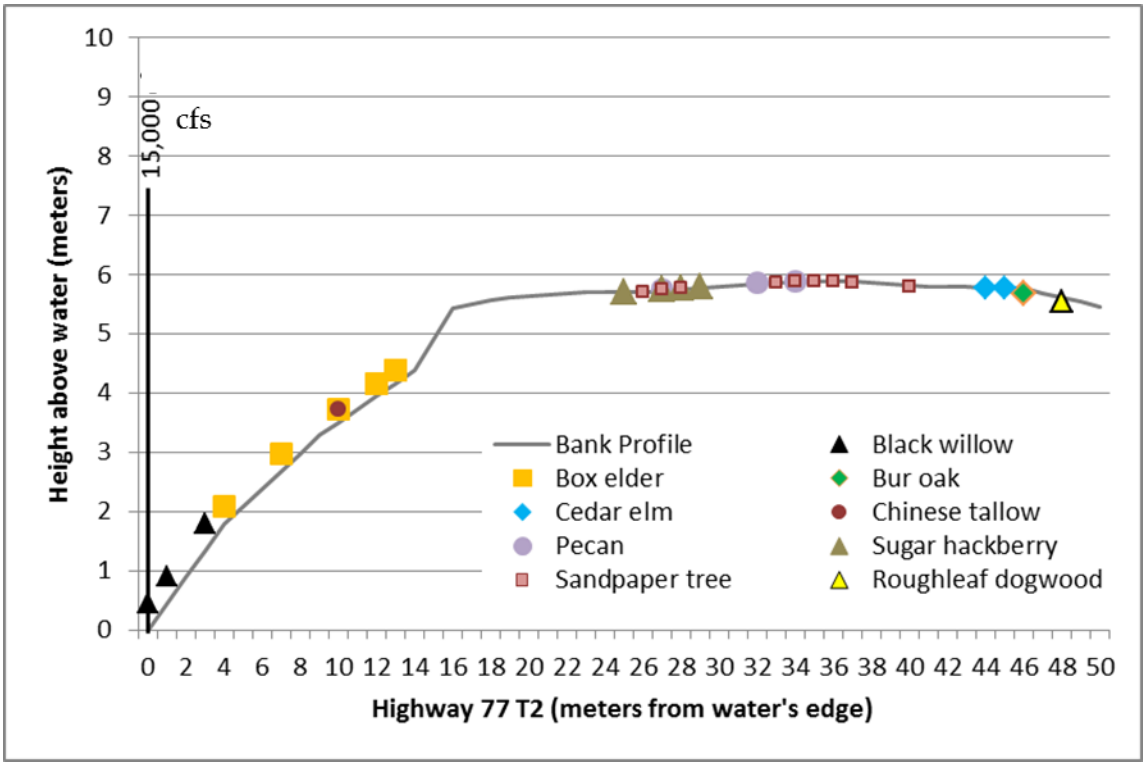


Figure F-29. Tree data from the San Antonio River Hwy 77 Study Site along Transect 2.

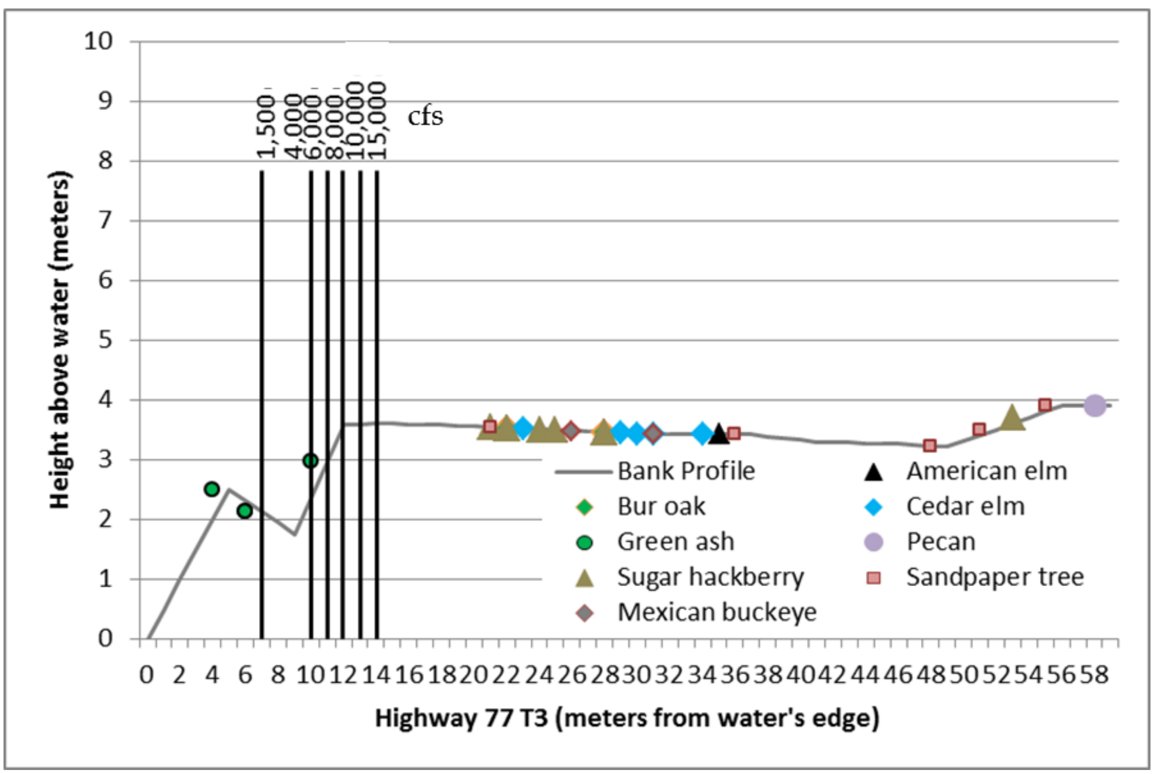


Figure F-30. Tree data from the San Antonio River Hwy 77 Study Site along Transect 3.

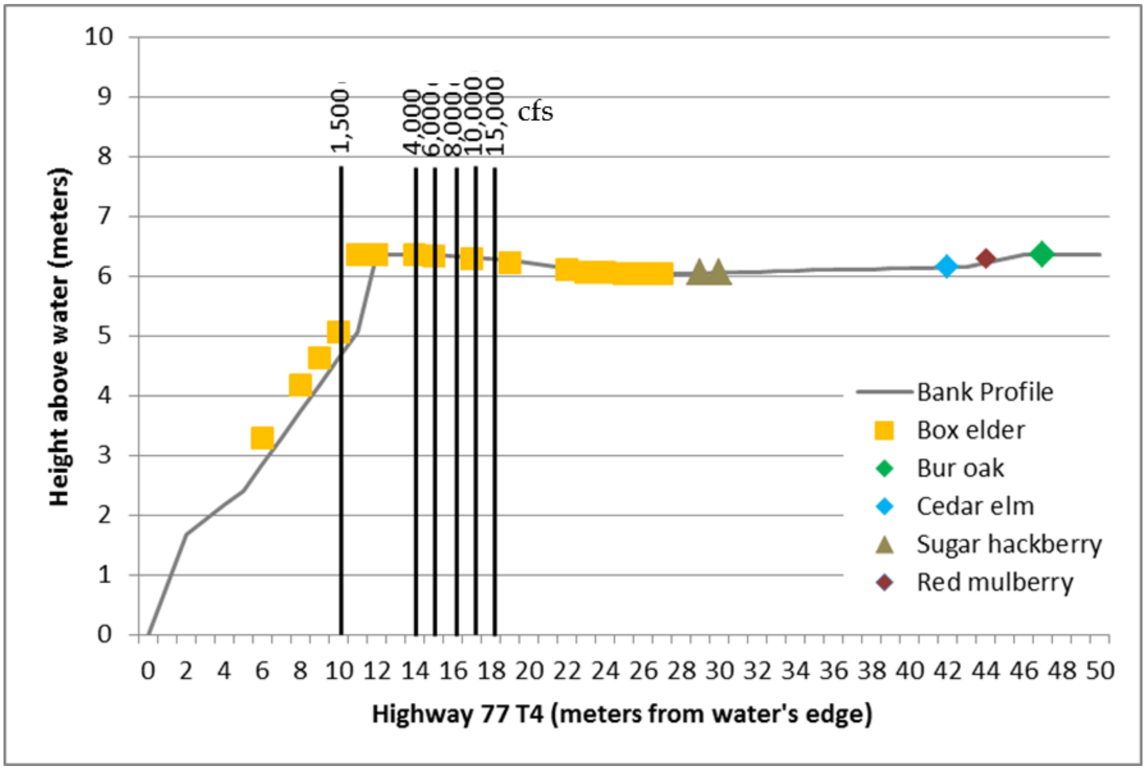


Figure F-31. Tree data from the San Antonio River Hwy 77 Study Site along Transect 4.

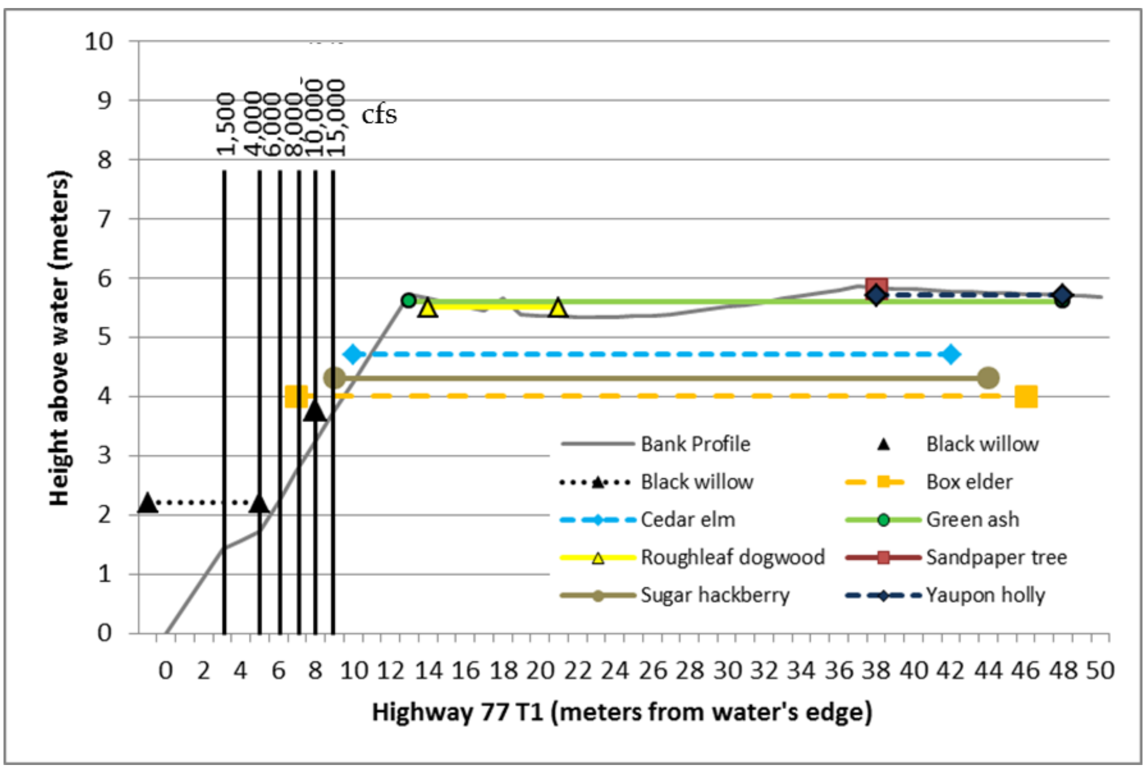


Figure F-32. Sapling (point) and seedling range (line) data from the San Antonio River Hwy 77 Study Site along Transect 1.

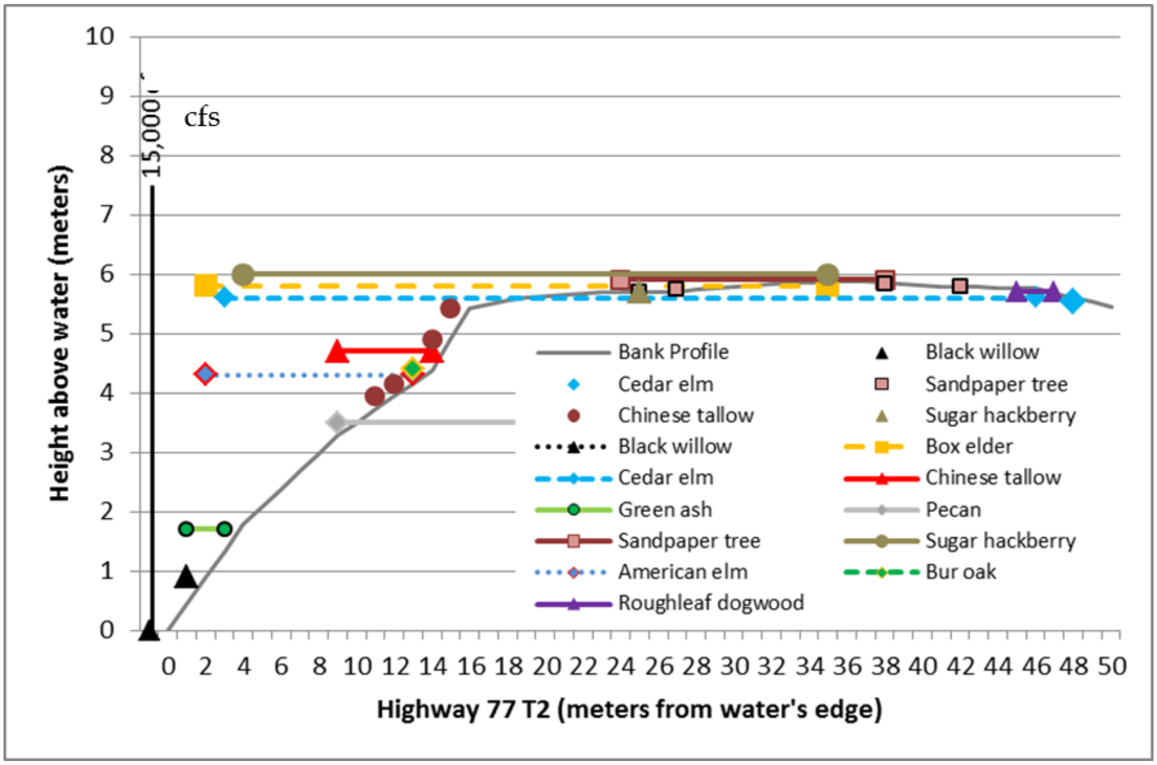


Figure F-33. Sapling (point) and seedling range (line) data from the San Antonio River Hwy 77 Study Site along Transect 2.

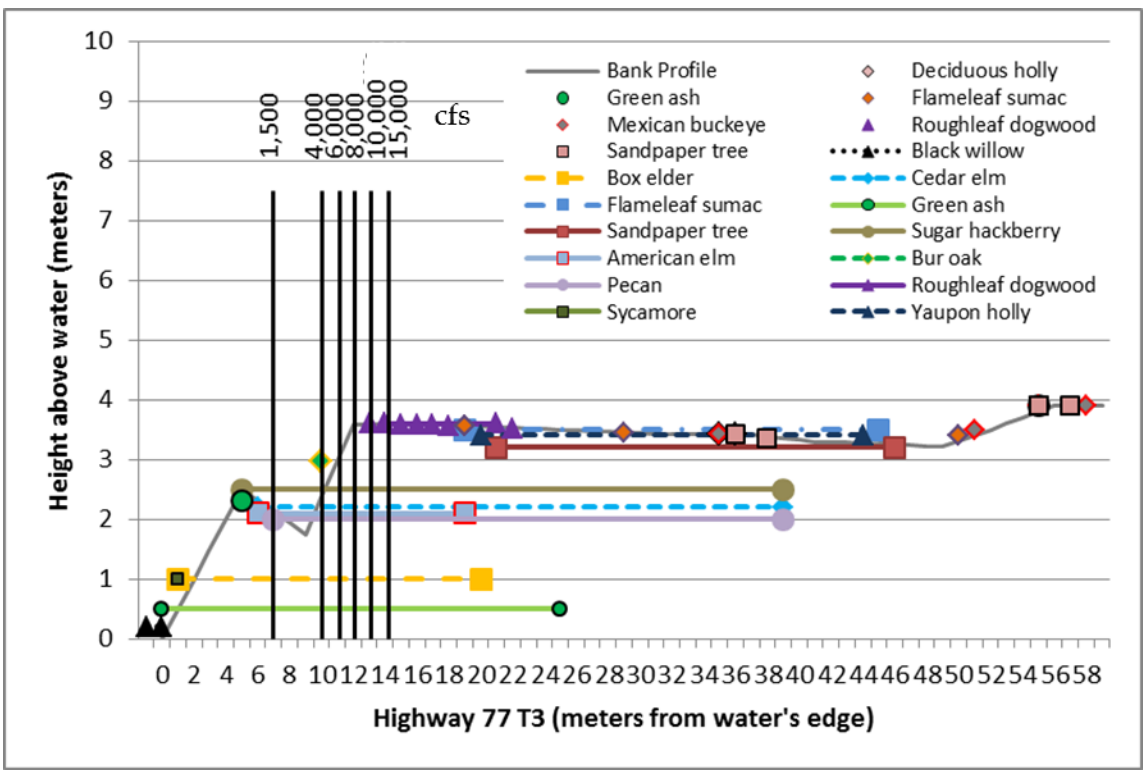


Figure F-34. Sapling (point) and seedling range (line) data from the San Antonio River Hwy 77 Study Site along Transect 3.

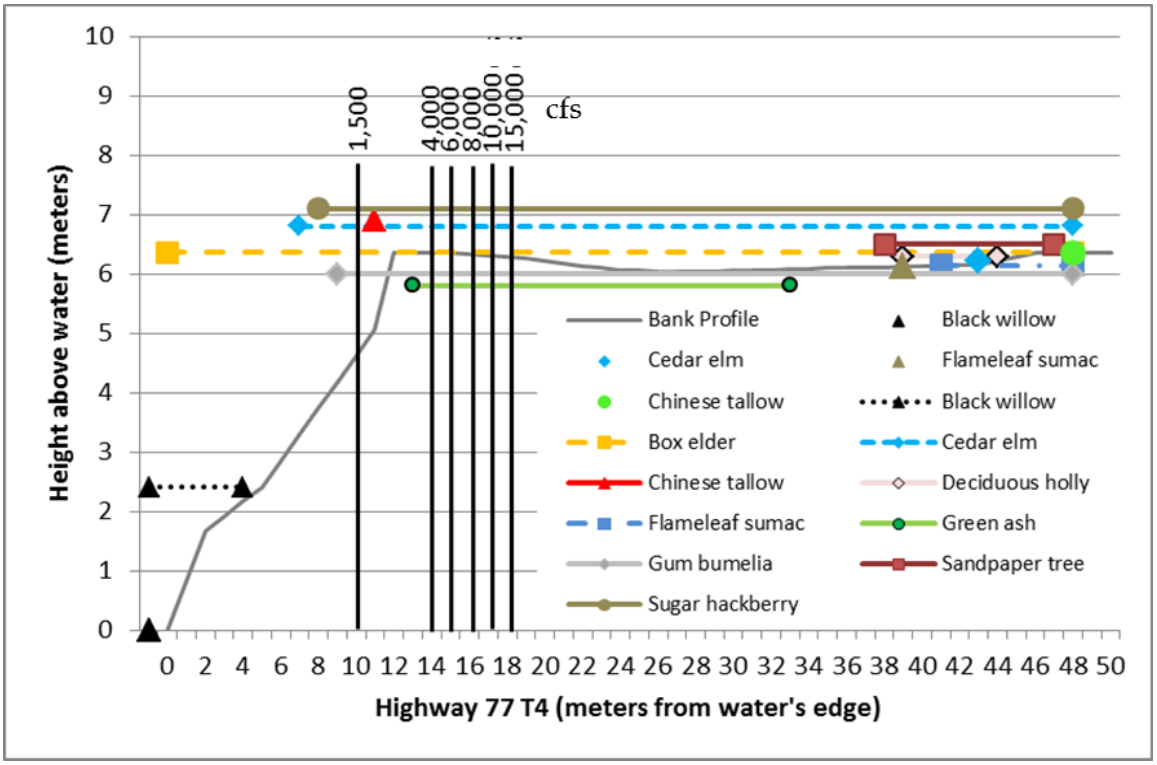


Figure F-35. Sapling (point) and seedling range (line) data from the San Antonio River Hwy 77 Study Site along Transect 4.

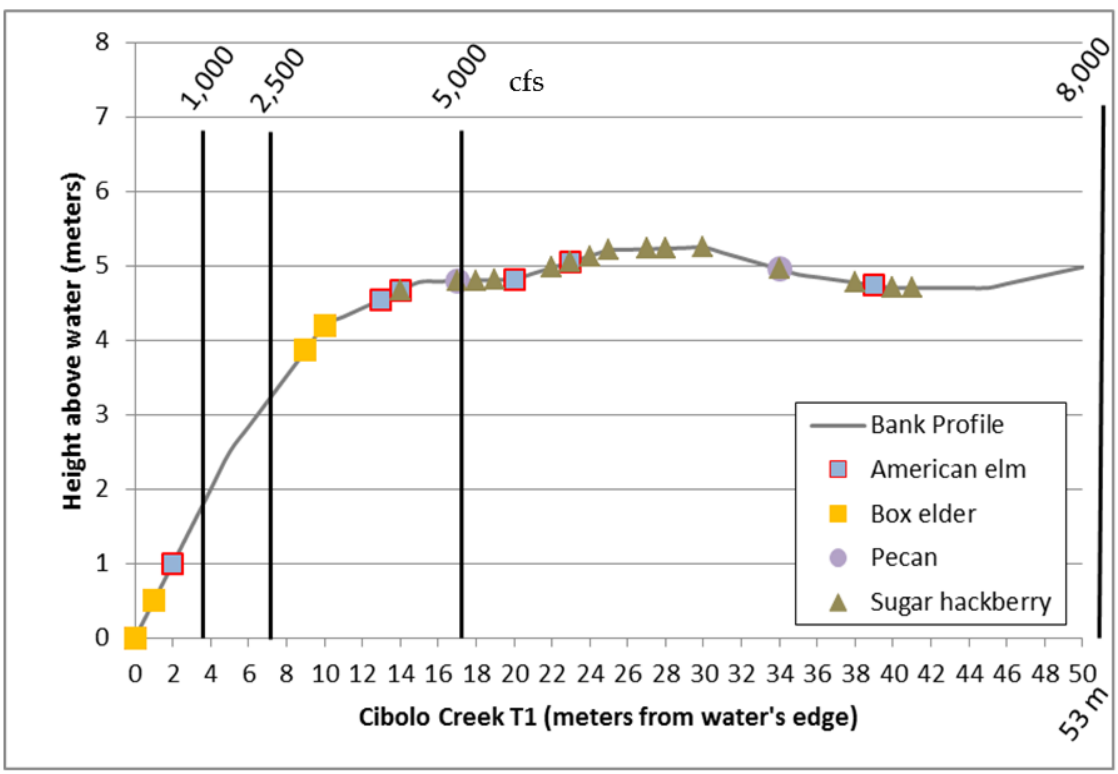


Figure F-36. Tree data from the Cibolo Creek Study Site along Transect 1.

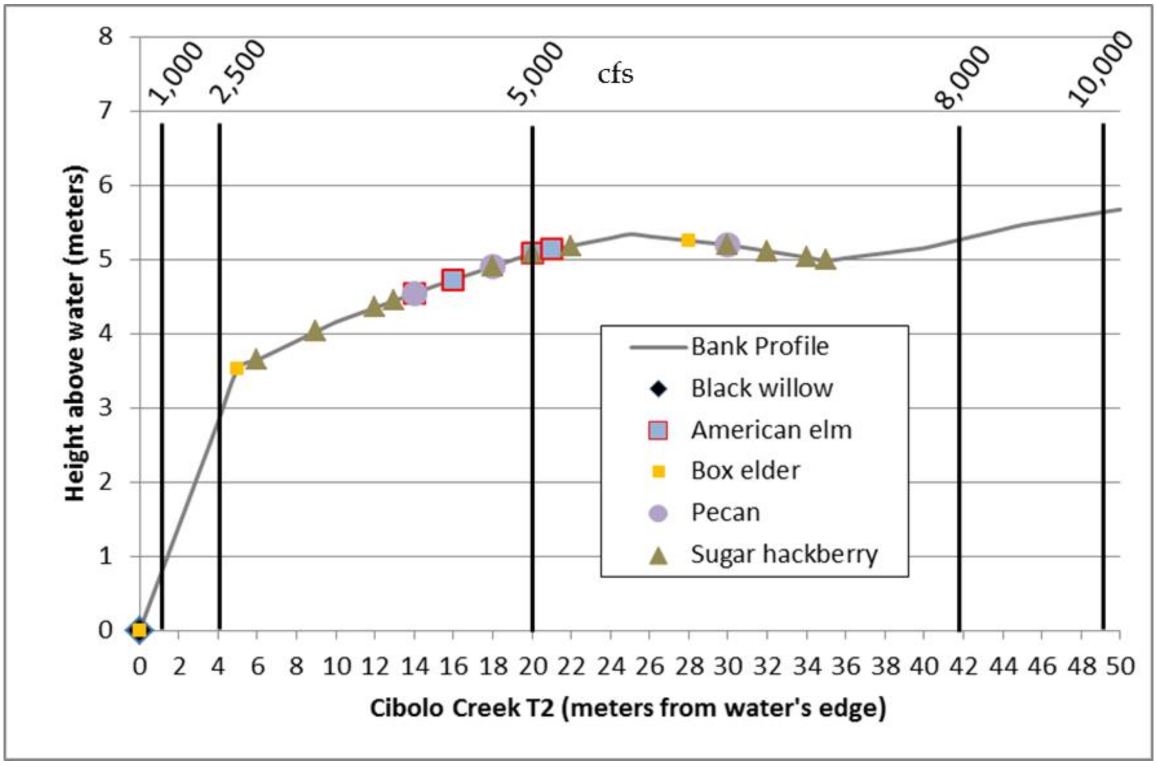


Figure F-37. Tree data from the Cibolo Creek Study Site along Transect 2.

Bank profile survey for Transect 3 at the Cibolo Creek Study Site not available.

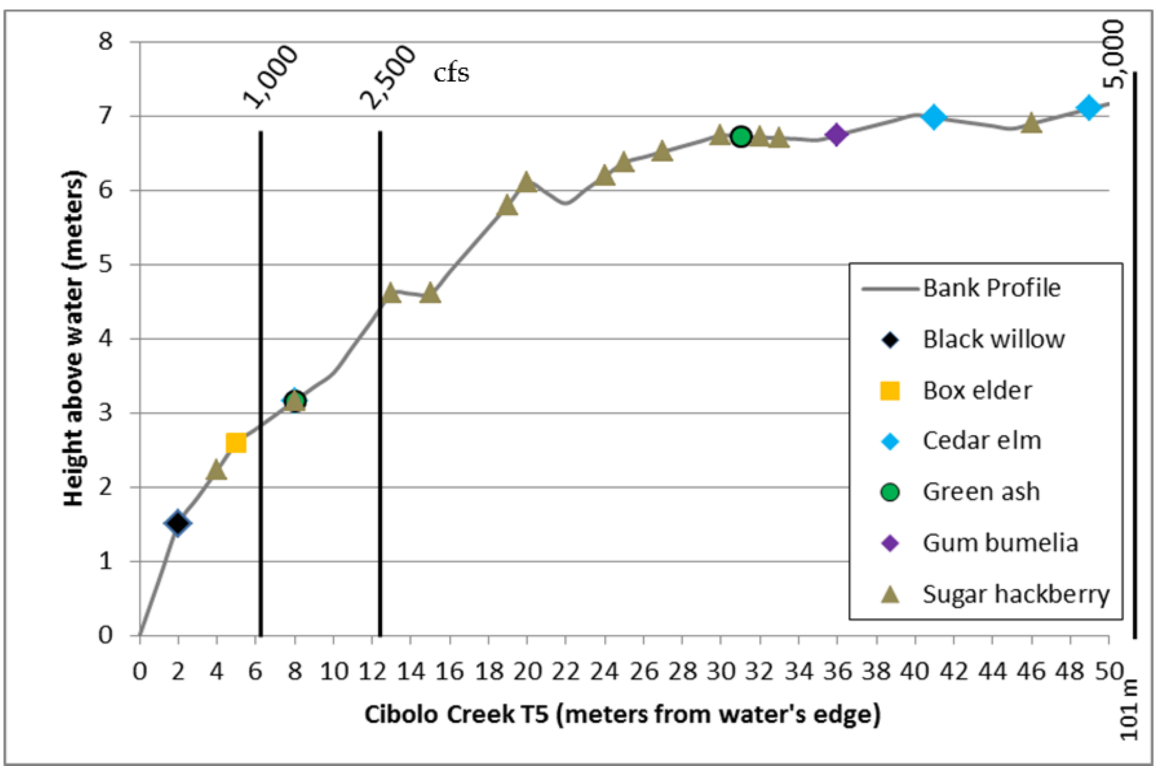


Figure F-38. Tree data from the Cibolo Creek Study Site along Transect 5.

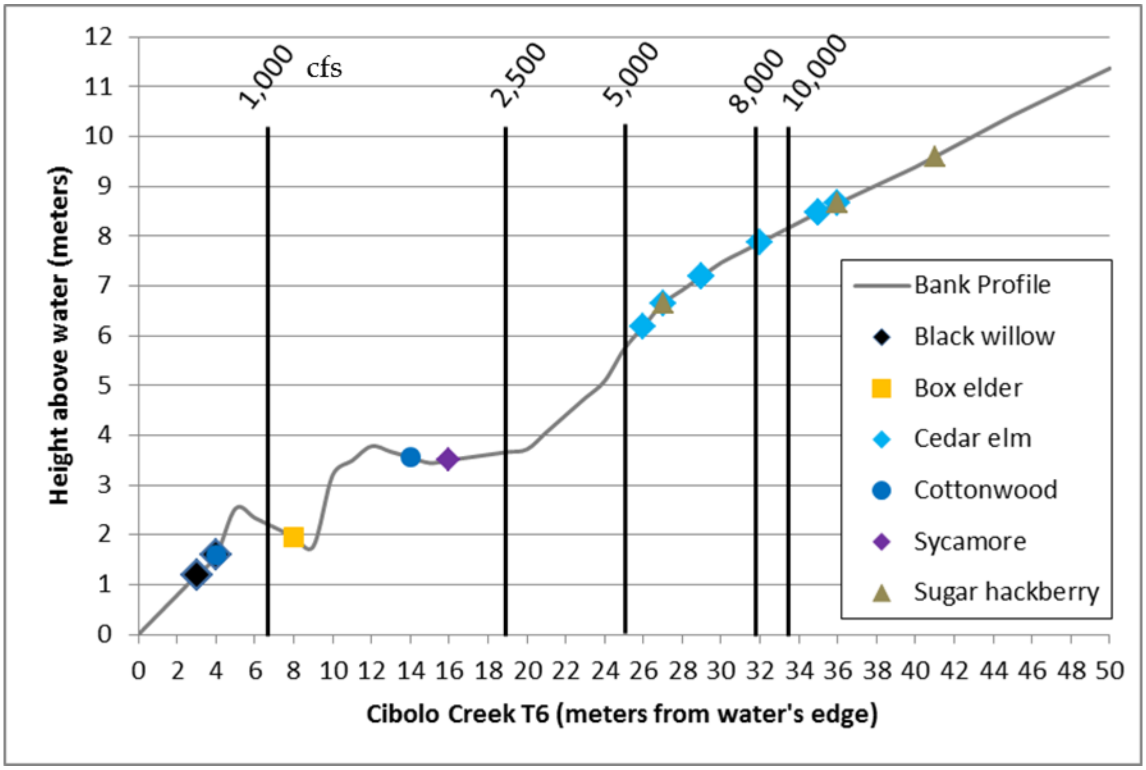


Figure F-39. Tree data from the Cibolo Creek Study Site along Transect 6.

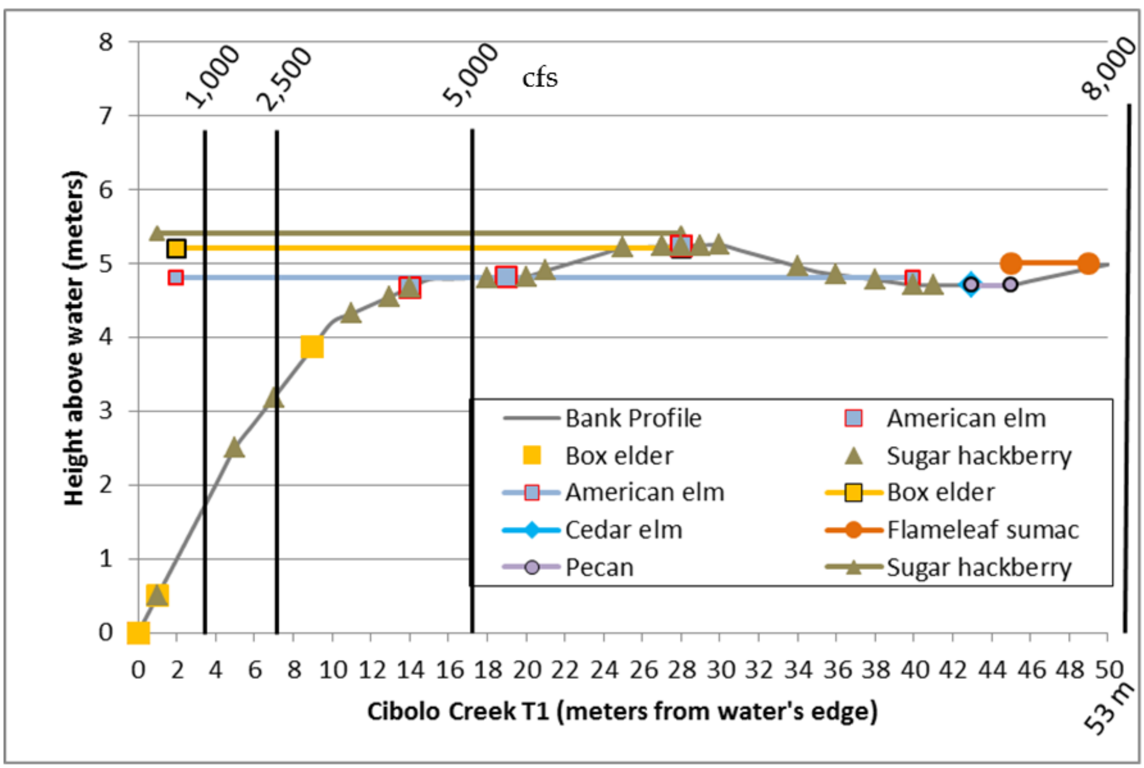


Figure F-40. Sapling (point) and seedling range (line) data from the Cibolo Creek Study Site along Transect 1.

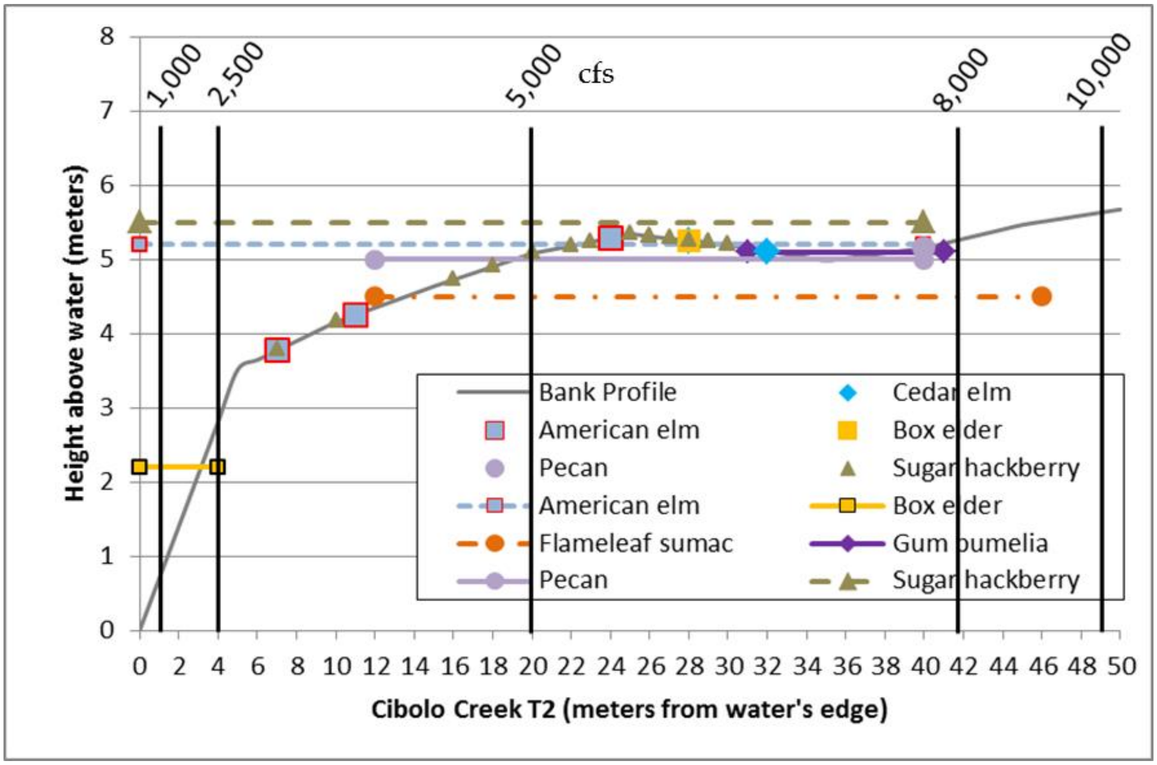


Figure F-41. Sapling (point) and seedling range (line) data from the Cibolo Creek Study Site along Transect 2.

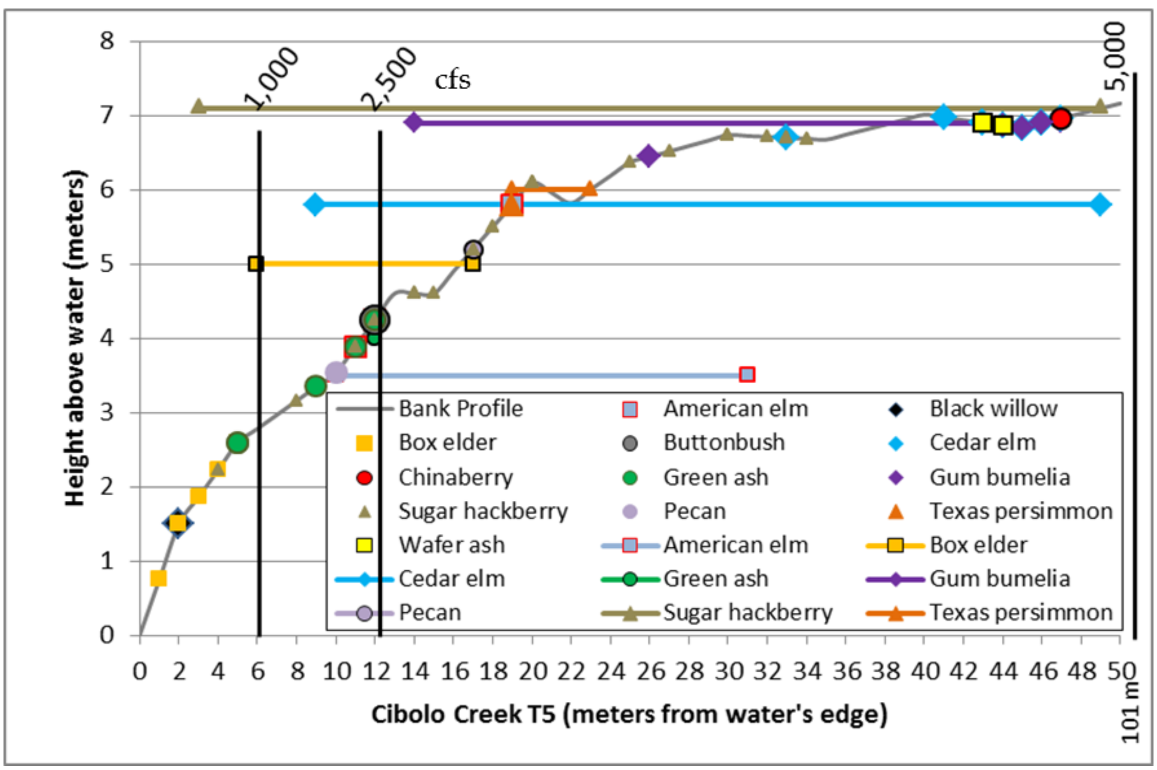


Figure F-42. Sapling (point) and seedling range (line) data from the Cibolo Creek Study Site along Transect 5.

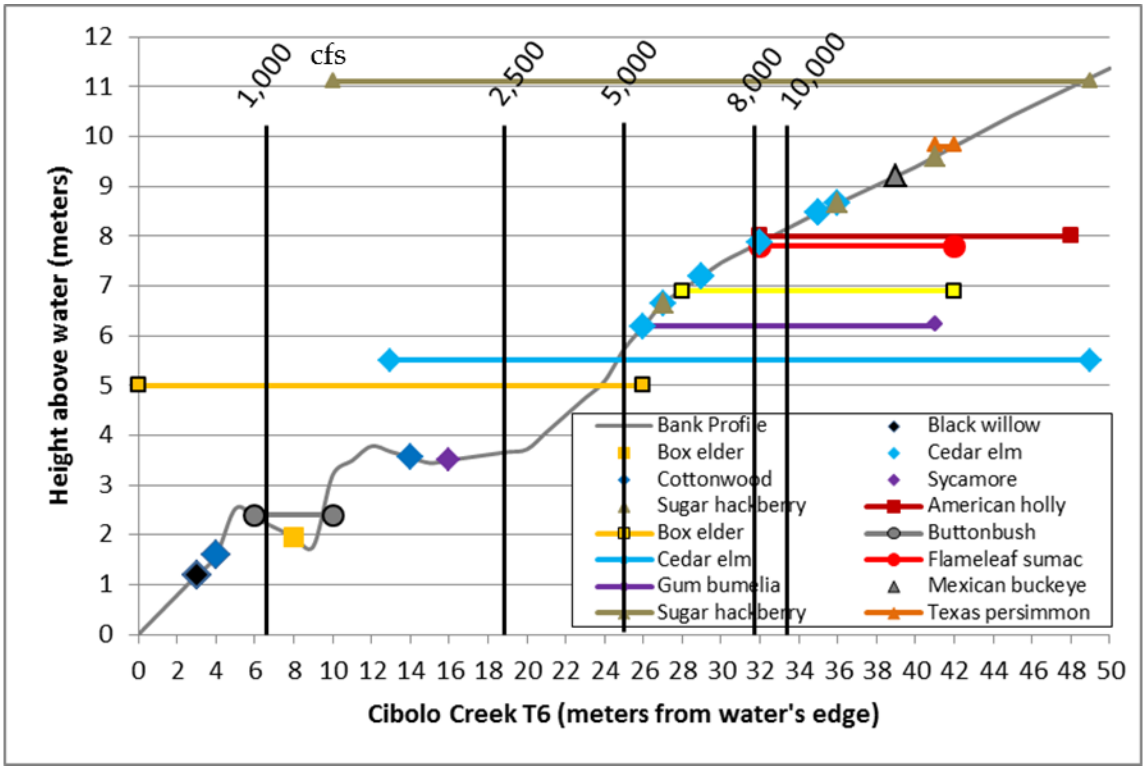


Figure F-43. Sapling (point) and seedling range (line) data from the Cibolo Creek Study Site along Transect 6.

APPENDIX G
SEDIMENT TRANSPORT ANALYSIS

Summary Points

1. Stream channel shape (geometry or bathymetry) is determined by the movement of bed material (sediment) by flow. Substantial, long-term, changes in flow will change stream channel shape and consequently change existing habitat conditions for aquatic life.
2. The existing channel at the San Antonio River Goliad Study Site appears to be stable with the hydrologic regime observed over the last 20 years.
3. The flow recommendations for the San Antonio River Goliad Study Site are considered adequate to support the biology of the system (fish habitat, riparian maintenance, etc.) but are not sufficient to maintain the stream channel shape (and therefore aquatic habitats) at the site. The recommended flows by themselves provide only 39% of the average annual flow volume and 21% of the average annual sediment transport as compared to historic gaged flow data (1939 to 1959). Compared to the most recent flow conditions in the river (1996 to 2015), the flow recommendations provide only 23% of the average annual flow volume and only 12% of the average annual sediment transport.
4. As shown in this analysis, sediment transport associated with the flow recommendations only are not adequate to maintain the channel shape and therefore the aquatic habitats that support the current ecological environment.
5. More detailed geomorphic analysis and study at the site would be needed to determine how the channel would adjust to a 77% reduction in flow and an 88% reduction in sediment transport rate relative to current (1996 to 2015) conditions. The flow change would likely occur faster than any change in the inflowing sediment load, resulting in channel aggradation, increased meandering, and significant channel bank caving. Because the exact geomorphic outcomes of large changes in flow and sediment regimes can be very diffluent to predict with simple geomorphic models and outcomes can include significant loss of land and infrastructure, a detailed geomorphic study of the lower San Antonio River is recommended before a regime change of the magnitude represented by the flow recommendations only scenario is adopted.
6. The exact nature of the flow and sediment regime that would be created due to implementation of the flow recommendations is unclear. The method of implementing flow recommendations would impact the flow and sediment regimes that would occur. Also, limitations on infrastructure to divert and impound flows in excess of the flow recommendations and downstream water rights that may require flows in excess of the flow recommendations would act to increase the resulting flow and sediment regimes. It is unclear if these factors would be sufficient to produce a flow and sediment regime suitable for maintaining the channel relative to either historical (1939 to 1959) or current (1996 to 2015) conditions.

Introduction

The channel shape (geometry or bathymetry) of an alluvial river adjusts in response to the range of flows that mobilize the boundary sediments. It has been observed that in many rivers, a single representative discharge from the range of flows that have occurred historically can be used to determine a stable channel shape. A stable channel shape is important because it maintains habitat conditions that support biological resources both within the channel and in near channel riparian areas. Flow recommendations will only be successful if they support the long term creation and maintenance of desired aquatic and riparian habitats. Changes in the flow regime of a stable channel can cause unstable conditions due to changes in the rate of:

- Erosion
- Sediment transport
- Sediment deposition

While these processes are at work in any river, and channel shape is always adjusting somewhat, a stable channel exhibits what river engineers call "dynamic equilibrium". Once dynamic equilibrium is disrupted, the channel will be unstable while these processes work to reestablish equilibrium by changing the channel geometry (width, depth), width-depth ratio, sinuosity, and slope (Schumm 1969). Such changes in channel geometry have the potential to alter the amount and nature of aquatic and riparian habitats and, therefore, biological communities.

There are some indications in the scientific literature regarding the flows required to maintain the physical characteristics/habitats of river systems. Biedenharn et al. (2000) report that channels should remain dynamically stable if the sediment transport capacity of a reach is within 10% of the sediment supplied to the reach. Acreman et al. (2010) report that environmental standards implemented in the United Kingdom were developed with consideration of biology (macro-invertebrates, fish, and macrophytes) and geomorphology. Those standards allow diversion of from 7.5 to 30%, depending on geomorphology, flow conditions, and desired ecological status. In addition, at least some of the reported impacts on biological communities due to flow alterations are probably due to changes in river geomorphology (and therefore habitat). Poff and Zimmerman (2010) found that a 50% change or greater in flow magnitudes (including peak, total or mean, base or hourly discharge) had a negative impact on fish communities. They could not precisely identify the level of flow alteration when fish were likely to be impacted, however, because of limited data related to systems with flow alterations in the range of 0 to 50%. Carlisle et al. (2010) found that a 60% decrease in the mean annual maximum flow was likely to lead to degraded fish communities. In most systems, mean annual maximum flows significantly affect the channel's shape or morphology. The impact on fish communities related to changes in mean annual maximum flow may be directly related to changes in habitat, though disruptions to spawning cues, access to floodplain habitats, or other factors may also play a role.

When significant changes to a river's flow regime are proposed, a geomorphic analysis should be conducted to determine if the proposed regime can be expected to maintain the current channel shape. The need for performing such a geomorphic analysis is discussed in a guidance document prepared by the Science Advisory Committee (SAC 2009). The foundation of the SAC guidance is the use of effective discharge as a means of estimating if a future hydrologic regime is capable of maintaining the existing channel shape. Effective discharge is the (relatively narrow) range of flows from the entire range of flows associated with some hydrologic condition that transports the most sediment over time. Effective discharge incorporates the principles prescribed by

Wolman and Miller (1960) that channel-forming discharge is a function of both the magnitude of an event and its frequency of occurrence. The analysis performed for the lower San Antonio River was performed as outlined in SAC (2009).

Study Location

The San Antonio River at Goliad (USGS Gage No. 08188500) was selected as the study site for this sediment transport analysis. The data necessary to perform this type of analysis are not readily available at all five sites in the lower San Antonio River sub-basin where flow recommendations were developed. Because flow recommendations at all five sites were developed using the same methodology, lessons learned from the results of sediment transport analysis at this site are generally applicable to the remaining sites.

Frequency Curves

An understanding of the basic hydrology of a stream is necessary when performing geomorphic studies. The basic assumption of the effective discharge approach is that channel shape is a function of the flow in the channel. The stability of a channel in a study reach can also be judged by the frequency of occurrence of the effective discharge. The effective discharge of a stable alluvial channel is usually associated with peak flows that occur every one to three years (Biedenharn et al. 1999). In the reaches where the channel bed is composed of material larger than sand (gravel, cobble, and/or bedrock), effective discharges are expected to occur less often. For the Llano River at Llano, Heitmuller (2009) found that floods with return periods ranging from about 10 to 40 years play an important role in shaping the channel. The Llano River at Llano is a bedrock channel with sands and gravels found in the overbank areas. Because the channel of the lower San Antonio is composed principally of sand and gravel sized material, an effective discharge with a return period of one to three years is expected for a stable channel condition at the Goliad Study Site.

Annual frequency curves were developed using the U.S. Army Corps of Engineers Hydrologic Engineering Center Statistical Software Package (HEC-SSP). This software allows the user to perform a variety of statistical analyses of hydrologic data. The current version of HEC-SSP (Version 1.1, May 5, 2009) can perform flood flow frequency analysis based on "Bulletin 17B - Guidelines for Determining Flood Flow Frequency" (Interagency Advisory Committee on Water Data 1982), a generalized frequency analysis on not only flow data but other hydrologic data as well, and a volume-duration frequency analysis on high and low flows. HEC-SSP uses annual peak flows to develop the flood frequency curves. Langbein (1949) showed that the annual flood flow frequency analysis underestimates the return interval of flows by about 0.5 years, which is important on the lower end of the frequency analysis. The annual series flood frequency calculated a one-year event can be expected to occur about every six months. Frequency curves for the gaged historical flow for the San Antonio River at Goliad for the periods 1939 to 1959 and 1996 to 2015 are shown in Figures G-1 and G-2, respectively. Figure G-3 is a frequency curve for the San Antonio River at Goliad when all flow not protected by the flow recommendations has been withdrawn. The gaged data from 1996 to 2015 was used to develop this "recommended flows only" regime. Table G-1 shows annual flood frequency calculations and the frequency when adjusted as recommended by Langbein (1949) for the three flow scenarios.

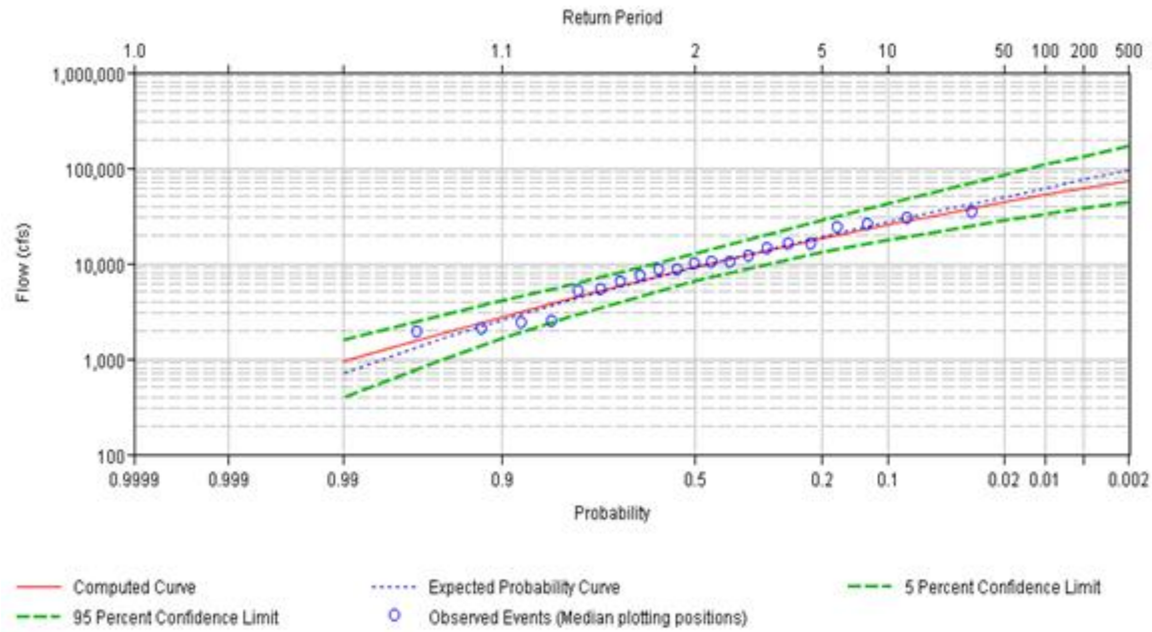


Figure G-1. Annual flow frequency curve of gaged flow of San Antonio River at Goliad from 1939 to 1959.

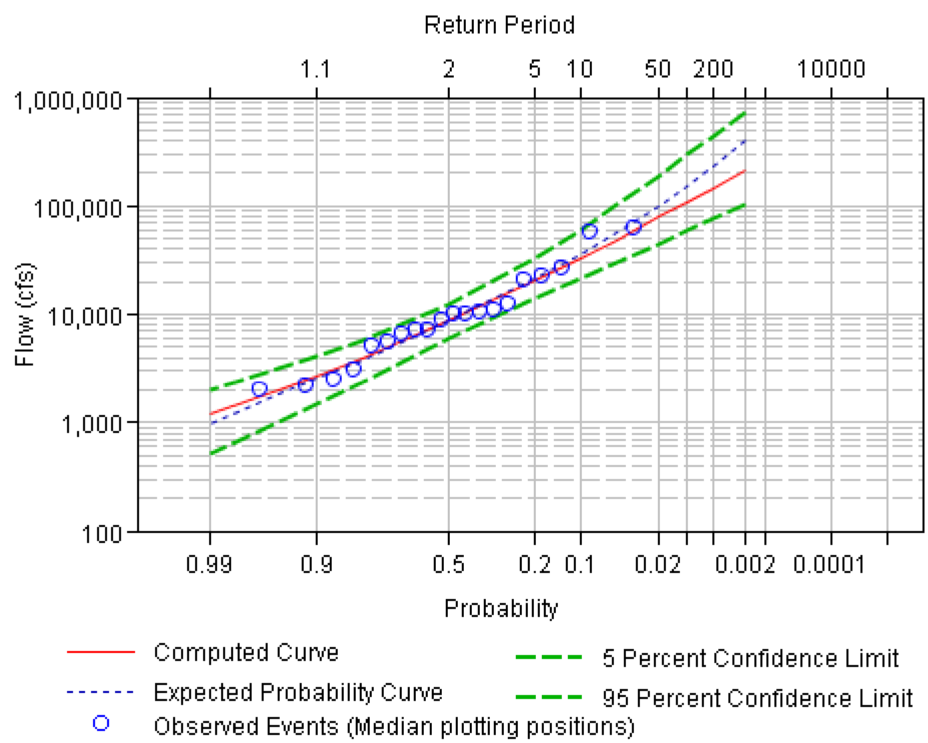


Figure G-2. Annual flow frequency curve of gaged flow of San Antonio River at Goliad from 1996 to 2015.

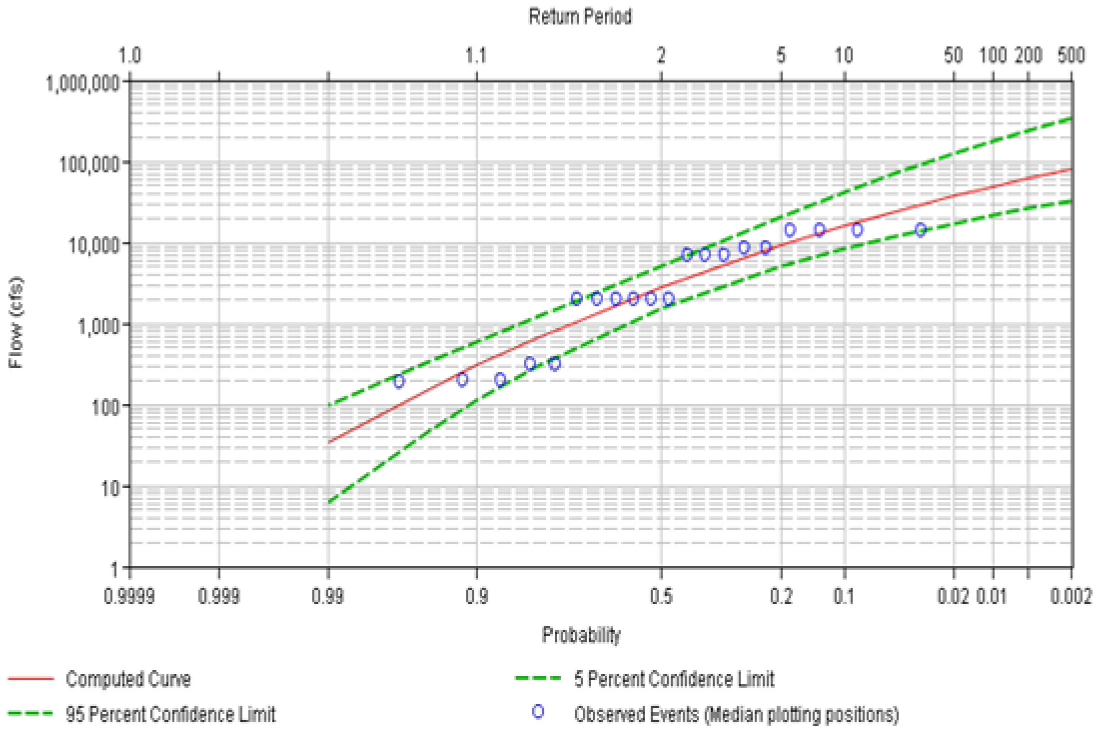


Figure G-3. Annual flow frequency curve for San Antonio River at Goliad based on modeling for specific recommended flows only.

Table G-1. Selected flow frequencies for San Antonio River at Goliad for three flow scenarios.

Corresponding Return Period in Years for Annual and Partial Series (Langbein 1949)							
Partial Series	0.5	1	1.45	2	5	10	50
Annual Series	1.16	1.58	2	2.54	5.52	10.5	50.5

Annual Return Period in Years	10	5	2	1.25	1.11
Estimate Partial Return Periods in Years		4.5	1.5	0.7	0.5
Percent Chance of Exceedance in 1 Year	10	20	50	80	90

Scenario	Time Period	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
Gaged	1939-1959	26,870	18,750	9,120	4,100	2,580
Gaged	1996-2015	40,450	23,440	8,860	3,500	2,150
Recommendations Only	1996-2015	16,000	9,220	2,780	685	300

Discharge Rating Curves

The existing channel should be analyzed to insure it is stable and has adjusted to its existing hydrologic regime. This can result in a meaningful effective discharge calculation, which in turn can provide guidance in how a future hydrologic regime might affect channel stability. One relatively simple and quick way to do this is to analyze how the long term stage-discharge curve (also known as the "rating curve") has changed overtime. For USGS Gage No. 08188500 San Antonio River at Goliad, the USGS has collected field measurements for an extended period of record to analyze for channel stability. A rating curve that remains stable over time is one indication that the channel in a particular reach is stable. An alluvial channel that is either degrading or aggrading will show a distinct change in the stage-discharge relationship over time. Incising (degrading) channels will exhibit a decreasing gage height for the same discharge while the gage height for an aggrading channel will exhibit an increase in gage height for the same discharge.

The channel of the San Antonio River at Goliad has remained relatively stable across the range of flows measured (or recorded) from 1939 to 1979 (Figure G-4) The river, however, appears to exhibit some stream incision or degradation has occurred since 1979 (Figure G-5). The river shows approximately one to two feet of incision for flows above about 3500 cfs. This is a relatively small amount of degradation over 70 years of record and could be within the normal fluctuation expected of a stable channel. Also note that the data from 1980 until 2011 do not seem to change as compared to the small change relative to the earliest data (1939 to 1949). This indicates that the river may have adjusted to existing hydrologic conditions and, therefore, the effective discharge analysis will provide useful information regarding how the channel will react to future changes from the current hydrologic regime.

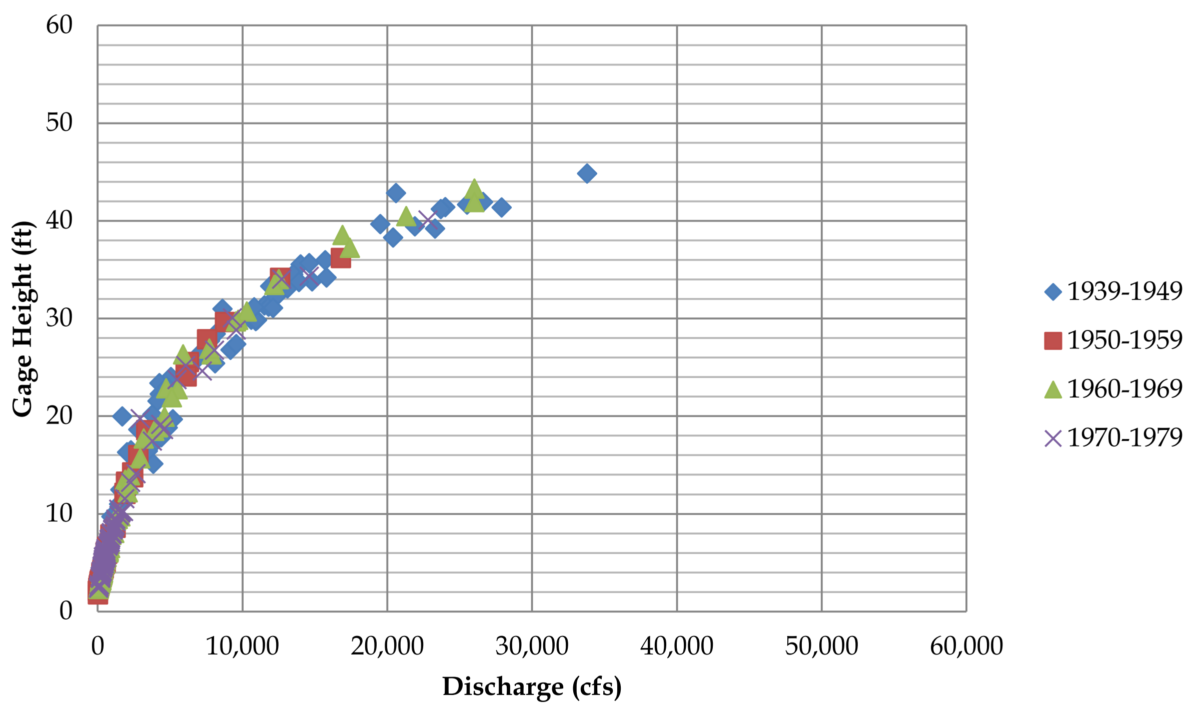


Figure G-4. Discharge rating curve for the San Antonio River at Goliad from 1939 to 1979.

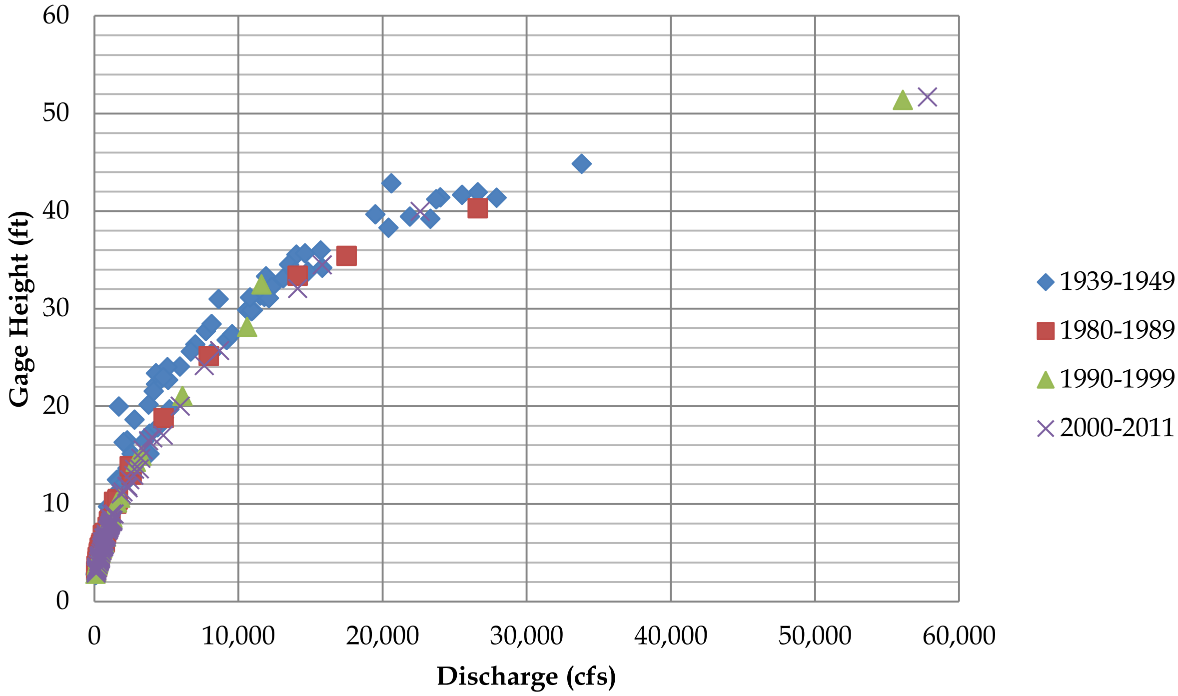


Figure G-5. Discharge rating curve for the San Antonio River at Goliad from 1939 to 1949 and 1980 to 2011.

To definitively determine if channel degradation is occurring at this site would require additional studies, including but not limited to looking at how gages upstream and downstream of this gage have changed during this same time period, examining changes in cross sections and channel shape in this reach of the San Antonio River, and consulting with the USGS to determine if changes in field measurement techniques or locations may be causing the gage to appear to be reflecting lower stages for the same discharge.

Sediment Rating Curves

Sediment rating curves estimate the amount of sediment moved by flows of various sizes. A hybrid approach using both measured and computer modeled sediment-discharge data were used to develop a sediment rating curve at the study site. Bed material sediment data for the San Antonio River at Goliad collected by Haschenburger (2012) were used in the computer program SAMWin to compute the sediment rating curve.

Channel parameters (velocity, discharge, channel width, channel depth, computed energy slopes, and bed gradation) at the gage site were input into SAMWin in order to compute a sediment rating curve. A number of different sediment functions were applied and the function that fit the measured data most closely was chosen as a guide for developing the sediment rating curve used in the effective discharge calculation. The Laursen–Madden sediment function worked best for the San Antonio River at Goliad because the bed material gradation was relatively large, ranging from sands to large gravels (Figure G-6). Note the extreme non-linearity of the relationship between discharge and sediment load, which is typical for river systems. Because of this non-linearity, large flows have a more significant role in moving sediment than lower flows. For example, we see that a flow of 1,000 cfs for one day would move about 75 tons of bed material. In contrast, a flow of 200 cfs for five days would only move a total of about 5 tons of bed sediments.

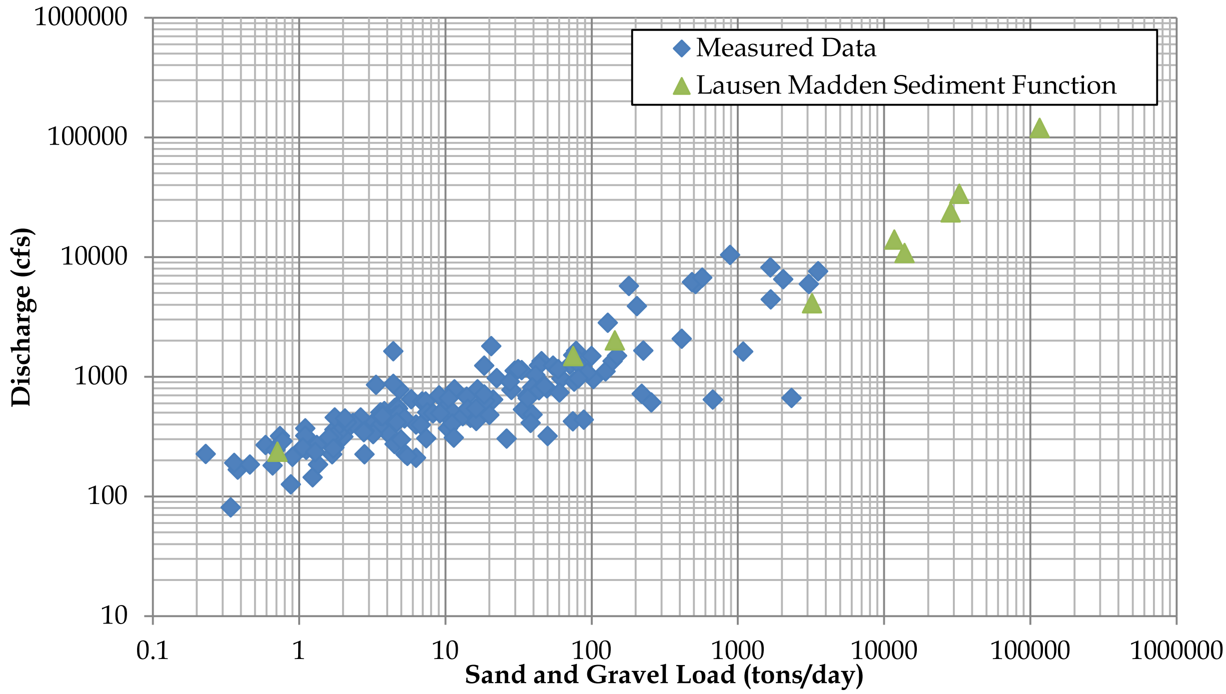


Figure G-6. Sediment rating curve for the San Antonio River at Goliad.

Hydrology

In addition to the sediment rating curves discussed in the previous section, a flow duration curve developed from a time series of flow values is required in order to compute effective discharge. The hydrologic time series can be daily, hourly, 15 minute, etc., depending on flow characteristics of the stream. Daily time step data were available for the San Antonio River at Goliad and flow characteristics of the stream are such that the daily flow is a fairly accurate description of the flow regime. Smaller time steps are required when flow events rise and fall within a short time span and are not accurately reflected in the average daily flow computation.

Three hydrologic scenarios were used for this sediment analysis. Scenario 1 was the gaged or observed flow that occurred from March 1, 1939 to February 28, 1959. This scenario was chosen because it represents a flow regime that occurred prior to extensive human development in the basin.

Scenario 2 was the gaged or observed flow that occurred from January 1, 1996 to December 31, 2015. This scenario represents current conditions and was the regime most responsible for sculpting the shape of the current San Antonio River channel.

Scenario 3 is based on gaged daily flows (1996 to 2015) reduced to the minimum values protected by subsistence flows, base flows, high flow pulses, and overbank flows similar to those described in Sections 3.1 and 3.2 and shown in Table G-2. This scenario does not consider sediment transport.

Table G-2. Specific flow recommendations for the San Antonio River Goliad Study Site.

	January	February	March	April	May	June	July	August	September	October	November	December
Overbank Flow		Magnitude = 14,000 cfs Frequency = 1 event Duration = 3 days *Key Indicators:* *Riparian: Inundates approx. 90% of hardwood forest community* *Reduces upland vegetation encroachment* *Cottonwood* *Sediment transport: Channel maintenance*										
Overbank Flow		Magnitude = 8,500 cfs Frequency = 1 event Duration = 3 days *Key Indicators:* *Riparian: Inundates approx. 65% of hardwood forest community* *Cottonwood/Box Elder* *Sediment transport: Channel maintenance*				Magnitude = 8,500 cfs Frequency = 1 event Duration = 3 days *Key Indicators:* *Riparian: Inundates approx. 65% of hardwood forest community* *Cottonwood/Box Elder* *Sediment transport: Channel maintenance*						
High Flow Pulses					Magnitude = 7,000 cfs Frequency = 1 event Duration = 3 days *Key Indicator:* *Riparian: Green Ash*		Magnitude = 7,000 cfs Frequency = 1 event Duration = 3 days *Key Indicator:* *Riparian: Green Ash/Box Elder/Sycamore*					
High Flow Pulses		Magnitude = 4,000 cfs Frequency = 2 events Duration = 4 days *Key Indicator:* *Riparian: Box Elder/Sycamore*										
High Flow Pulses			Magnitude = 2,000 cfs Frequency = 3 events Duration = 4 days *Key Indicator:* *Riparian: Black Willow*			Magnitude = 2,000 cfs Frequency = 2 events Duration = 4 days *Key Indicator:* *Riparian: Black Willow*			Magnitude = 2,000 cfs Frequency = 2 events Duration = 4 days *Key Indicator:* *Riparian: Black Willow*			
BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability)									Key Indicators: Aquatic Habitat, Water Quality			
Base Wet	279	280	287	296	312	257	211	147	220	219	251	241
Base Average	178	179	183	189	200	165	135	100	141	140	160	154
Base Dry	123	123	126	130	137	113	100	100	100	100	110	106
SUBSISTENCE FLOWS (cfs) - Water quality protection and maintainence of limited aquatic habitat									Key Indicators: Aquatic Habitat, Water Quality			
Subsistence	80	80	80	80	80	80	80	80	80	80	80	80
MONTH	January	February	March	April	May	June	July	August	September	October	November	December

Flow duration curves associated with the three flow regimes evaluated in this analysis are shown in Figure G-7.

Figure G-8 and Table G-3 show annual flow volumes for observed gage flows and the flow recommendations only for 1996 to 2015. The total volume of gaged flow from 1996 to 2015 was 6.8 million day second-feet (dsf). A day second-foot is equivalent to the volume provided by a flow of one cubic foot per second for one day (equal to 1.98 acre-feet). The total volume of the flow recommendations only for 1996 to 2015 is 1.8 million dsf, or about 26% of the observed flows for the same time period.

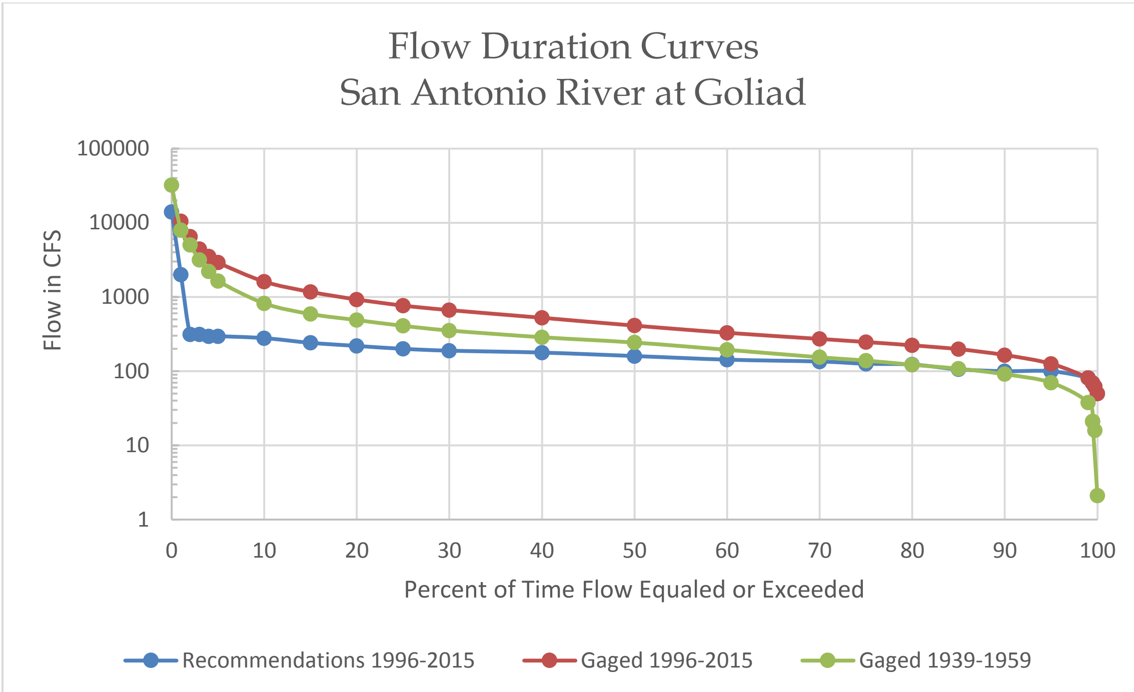


Figure G-7. Flow duration curves for the San Antonio River at Goliad.

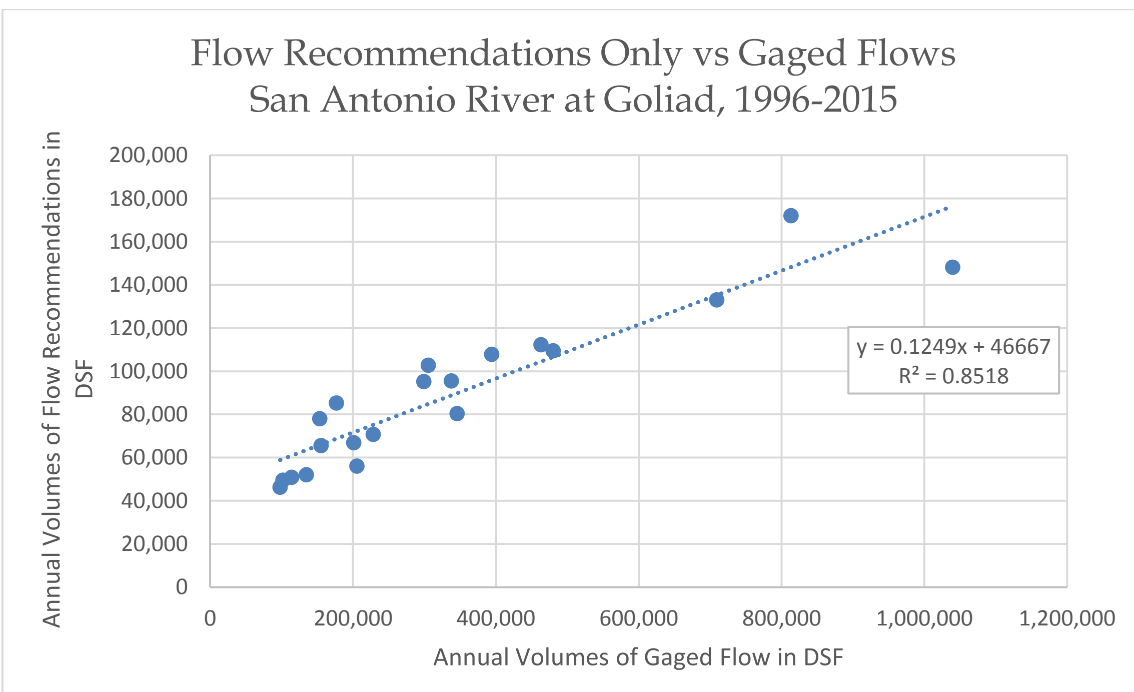


Figure G-8. Annual flow volumes (day second-feet) for gaged flow and the flow recommendations only for the San Antonio River at Goliad, 1996 to 2015.

Table G-3. Annual flow volumes (day second-feet) for gaged flow and flow recommendations only for 1996 to 2015.

Annual Flow Volumes for San Antonio River at Goliad (1996-2015)			
Year	Flow Recommendations Only (DSF)	Gaged Flow (DSF)	Flow Recommendations Only as a Percentage of Gaged Flow
1996	46,239	97,898	47.23%
2011	49,462	102,057	48.47%
2006	50,902	113,965	44.67%
2014	51,997	134,674	38.61%
2008	78,028	153,763	50.75%
2013	65,529	155,634	42.10%
1999	85,209	176,924	48.16%
2009	66,848	201,228	33.22%
2012	56,040	205,408	27.28%
2000	70,733	228,485	30.96%
2005	95,200	299,276	31.81%
1997	102,716	305,763	33.59%
2003	95,492	337,936	28.26%
2010	80,332	346,154	23.21%
2015	107,773	394,155	27.34%
2001	112,240	463,597	24.21%
1998	109,491	480,344	22.79%
2004	133,057	709,750	18.75%
2007	171,951	813,471	21.14%
2002	148,176	1,040,032	14.25%
Total	1,777,415	6,760,516	26.29%

Effective Discharge Calculations

SAMWin calculates the annual sediment yield by integrating the flow duration and sediment rating curves discussed in previous sections. The effective discharge is determined from analyzing the results of the "bin" computations created by SAMWin, which are generated during computation of the annual sediment yield. The effective discharge is the mid-point flow of the bin (also called class or interval) that transports the largest sediment load. The following example describes how bin size is determined. If the minimum flow for the hydrologic period of record is 0 cfs, the maximum is 100,000 cfs, and 50 bins are chosen for the analysis, each bin would be 2,000 cfs. Bin one would bracket flows from 0 to 2,000 cfs, bin two from 2,000 to 4,000 cfs, and so forth until bin 50, which would encompass the range from 98,000 to 100,000 cfs. There are no definite rules for selecting the bin size (or interval) to be used in the effective discharge computation (Biedenharn et al. 2000). In rivers with a high incidence of very low flows, a large number of bins (thus small intervals) can bias the computed effective discharge towards the lowest discharge class (bin) (Hey 1997). In channels where the effective discharge corresponds relatively closely to the bankfull flow, 25 bins produced a continuous flow frequency distribution with a smooth sediment load histogram while using more than 25 bins produced inconsistent results (Hey 1997). Experience has shown that in some cases, 25 bins produce unsatisfactory results and that up to 250 bins may be required (Biedenharn et al. 2000).

There is no standard method to validate or check the results of an effective discharge calculation. As a first step, the bed material load histogram can be analyzed to insure that the computed effective discharge does not occur in the first bin (the bin with the lowest discharge class). An effective discharge taken from the lowest discharge bin is most likely erroneous according to Biedenharn et al. (2000).

Review of the return period of the computed value may also provide information about the reasonableness of the computed effective discharge. Effective discharge return periods are normally in the one to three year return frequencies (Biedenharn et al. 2000, Hey 1997, Hey 1994). Discharges outside the one to three year return frequency range should be queried (Biedenharn et al. 2000).

Effective Discharge Results

Results of the SAMWin computations for all hydrologic scenarios investigated are shown in Table G-4. SAMWin computations were completed for the following hydrologic scenarios:

1. Historical gaged flow (1939 to 1959)
2. Historical gaged flow (1996 to 2015)
3. Flow recommendations only (1996 to 2015) (see Table G-2)

Table G-4. Results of sediment analysis for three flow scenarios in the San Antonio River at Goliad.

Flow Scenario	Average Annual Water Volume (ac-ft/year)	Average Annual Sediment Transport Rate (tons/year)	Effective Discharge (cfs)	Sediment Load in Effective Discharge Bin (tons/year)	Annual Frequency of Effective Discharge (years)	Partial Duration Frequency of Effective Discharge (years)
Gaged 1939-1959	434,377	102,235	5,450	5,603	1.4	.9
Gaged 1996-2015	736,316	177,084	6,900	11,572	1.7	1.2
Flow Recommendations Only	169,621	20,970	10,300	1,285	5.0	5.0

The effective discharges calculated for the historical data all fall within the expected return period frequency range of one to three years. None of the effective discharges fall within the lowest discharge bin. All of the effective discharges calculated are below the National Weather Service's flood stage for the San Antonio River at Goliad, which is 8,200 cfs. Having an effective discharge greater than flood stage is not unexpected for a natural system. Although flood flows occur less frequently then other flows, they have the capacity to move higher concentrations of bed material sediments.

The flow recommendations only scenario does not provide the variability or magnitude of flows needed to maintain the current channel shape. According to Biedenharn et al. (2000), a 10% or less reduction in sediment transport should not cause instability and rapid changes in channel configuration. Sediment transport provided by the flow recommendations only scenario is reduced by more than 10% from that provided by either gaged period (1939 to 1959 or 1996 to 2015). The limited number of high flow pulses and overbank events provided by the flow recommendations only scenario are not sufficient to move a significant fraction of the sediment moved by the historical flows. For gaged flows from 1939 to 1959, 50% of the bed material sediment is moved by flows greater than 12,000 cfs. The flow recommendations include only one flow event in this flow range. For gaged flows from 1995-2015, 50% of the bed material sediment is moved at flows greater than 18,000 cfs. The flow recommendations do not include any flow events in this flow range.

If the flow recommendations only scenario were implemented, it would result in major channel instabilities including incision in some areas and aggradation in others and the likely narrowing of the entire channel. Incision could cause bank failure due to over steepening of banks. Increased rates of channel meandering could occur in other areas where channel aggradation occurs. The current aquatic habitats and flow ecology relationships would not be maintained.

Conclusions

The effective discharge computations show:

1. Over 70 years, the San Antonio River at Goliad appears to have experienced some bank caving, channel deposition, and erosion but these are occurring in a manageable and somewhat predictable manner. The rating curve at the San Antonio River at Goliad shows degradation over several decades, but seems to stabilize after 1980.
2. The specific flow recommendations only scenario will not provide the variability and magnitude of flows needed to maintain the current channel shape (bathymetry). This flow regime would result in major channel instabilities including incision in some areas and aggradation in others. Incision could cause bank failure due to over steepening of banks. Increased rates of channel meandering could occur in other areas where channel aggradation occurs. The current channel shape, aquatic habitats and flow-ecology relationship would not be maintained.

The effective discharge and desktop computational methods provide a means of rapidly comparing the geomorphic impacts of current and proposed flow regimes. As noted by Shafroth et al. (2009), approaches that account for geomorphic processes (including models of sediment transport, channel migration, and sediment budgets) hold great potential for advancing efforts to link changes in flow regimes to changes in channel geometry, aquatic habitats, and biotic responses, thereby strengthening the scientific basis of environmental flow assessments and implementation strategies. The development of basin-wide sediment transport models in the future should be considered in order to more accurately account for geomorphic processes.

To be able to accurately model the effect of future flow regimes on the physical characteristics of a channelrequires accurate information about how those flows will occur; however, the details of how environmental flow recommendations will be implemented are unknown at this time. Those details may greatly influence the flow regimes (particularly the high flow pulse and overbank flow components) that are actually achieved at locations within the basin and, therefore, the extent to which channel change may or may not occur.

References

Acreman, M., M. Dunbar, J. Hannaford, O. Mountford, P. Wood, N. Holmes, I. Cowx, R. Noble, C. Extence, J. Aldrick, J. King, A. Black, and D. Crookall. 2010. Developing environmental standards for abstractions from UK rivers to implement the EU Water Framework Directive. Hydrological Sciences Journal 53: 1105-1120.

Biedenharn, D.S., R.R. Copeland, C.R. Thorne, P.J. Soar, R.D. Hey, and C.C. Watson. 2000. Effective discharge calculation: a practical guide. Report No. ERDC/CHL TR-00-15. U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, Mississippi. http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA383261&Location=U2&doc=GetTRDoc.pdf

Biedenharn, D.S., C.D. Little, and C.R. Thorne. 1999. Magnitude-frequency analysis of sediment transport in the Lower Mississippi River. Miscellaneous paper CHL–99–2. U.S. Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, Mississippi.

Carlisle, D.M., D.M. Wolock, and M.R. Meador. 2010. Alteration of streamflow magnitudes and potential ecological consequences – a multiregional assessment: frontiers in ecology and environment 2010. doi:10.1890/100053. http://water.usgs.gov/nawqa/pubs/Carlisleetal_FLowAlterationUS.pdf

Haschenburger, J.K. 2012. Sediment transport modeling of channel scale geomorphic processes. Final report for TWDB contract no. 1004831127. Austin, Texas. www.twdb.texas.gov/publications/reports/contracted_reports/doc/1004831127_transport.pdf

Heitmuller, F.T. 2009. Downstream trends of alluvial sediment composition and channel adjustment in the Llano River watershed, Central Texas, USA: the roles of a highly variable flow regime and a complex lithology. Ph.D. dissertation. University of Texas, Austin, Texas. http://repositories.lib.utexas.edu/handle/2152/6900

Hey, R.D. 1994. Channel response and channel forming discharge: literature review and interpretation. First interim report for U.S. Army contract no. R&D 6871-EN-01.

Hey, R.D. 1997. Channel response and channel forming discharge: literature review and interpretation. Final report for U.S. Army contract no. R&D 6871-EN-01.

Interagency Advisory Committee on Water Data. 1982. Guidelines for determining flood flow frequency. Bulletin No. 17B. U.S. Geological Survey, Reston, Virginia. http://water.usgs.gov/osw/bulletin17b/dl_flow.pdf

Langbein, W.B. 1949. Annual floods and the partial duration series. Transactions, American Geophysical Union 30: 879.

Poff, N.L. and J.K.H. Zimmerman. 2010. Ecological responses to altered flow regimes – a literature review to inform the science and management of environmental flows. Freshwater Biology 55: 194-205.

http://rydberg.biology.colostate.edu/~poff/Public/poffpubs/Poff_Zimmerman_2010_FWB.pdf

[SAC] Science Advisory Committee. 2009. Fluvial sediment transport as an overlay to instream flow recommendations for the environmental flows allocation process. Report No. SAC-2009-04. Texas Commission on Environmental Quality, Austin, Texas. http://www.tceq.texas.gov/assets/public/permitting/watersupply/water_rights/eflows/sac_2009_04_sedtransport.pdf

Schumm, S.A. 1969. River metamorphosis. ASCE Journal of the Hydraulics Division 95(HY1): 255–273.

Shafroth, P.B., A.C. Wilcox, D.A. Lytle, J.T Hickey, D.C. Andersen, V.B. Beauchamp, A. Hautzinger, L.E. McMullen, and A. Warner. 2009. Ecosystem effects of environmental flows - modeling and experimental floods in a dryland river. Freshwater Biology 55: 68-85. http://www.fort.usgs.gov/Products/Publications/pub_abstract.asp?PubId=22264

Wolman, M.G. and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology 68: 54–74.

APPENDIX H

SPATIAL OUTPUT OF LONGITUDINAL CONNECTIVITY

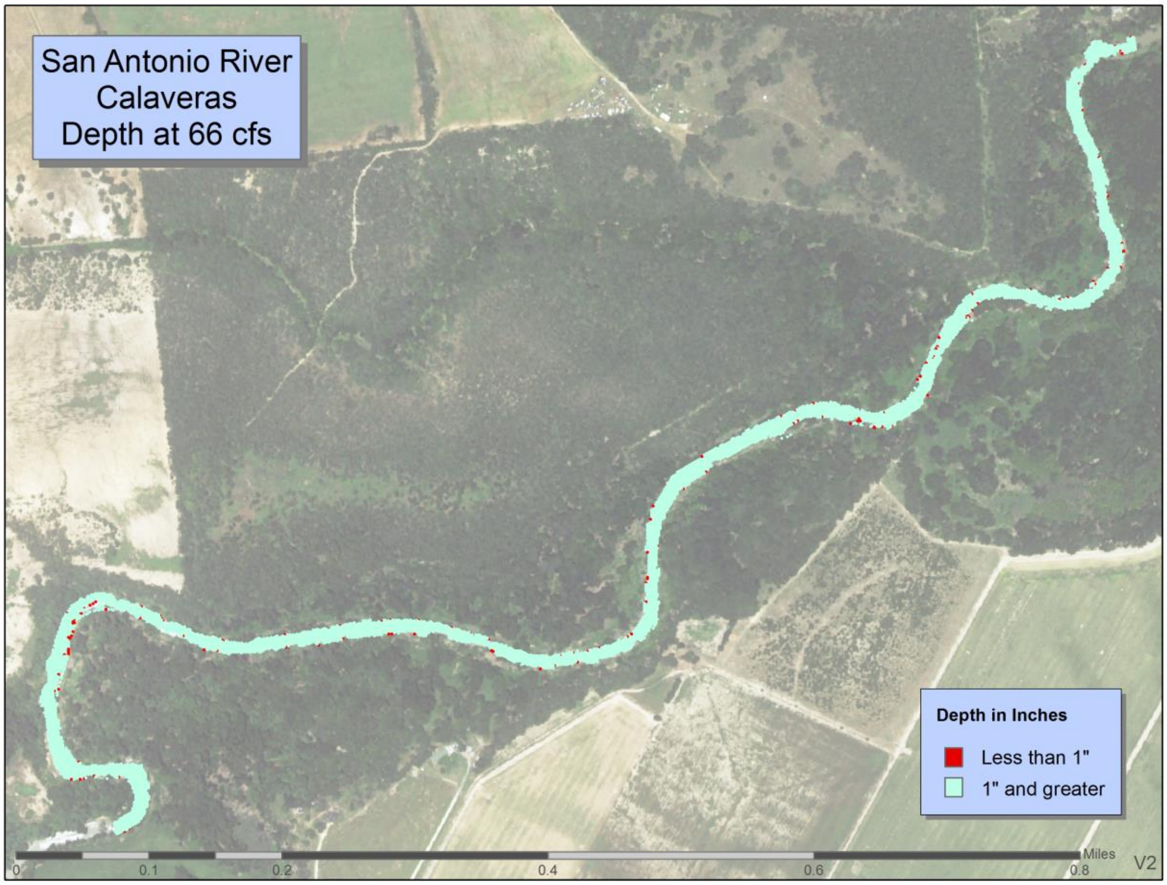


Figure H-1. Spatial output of longitudinal connectivity at the simulated flow of 66 cfs for the San Antonio River Calaveras Study Site.

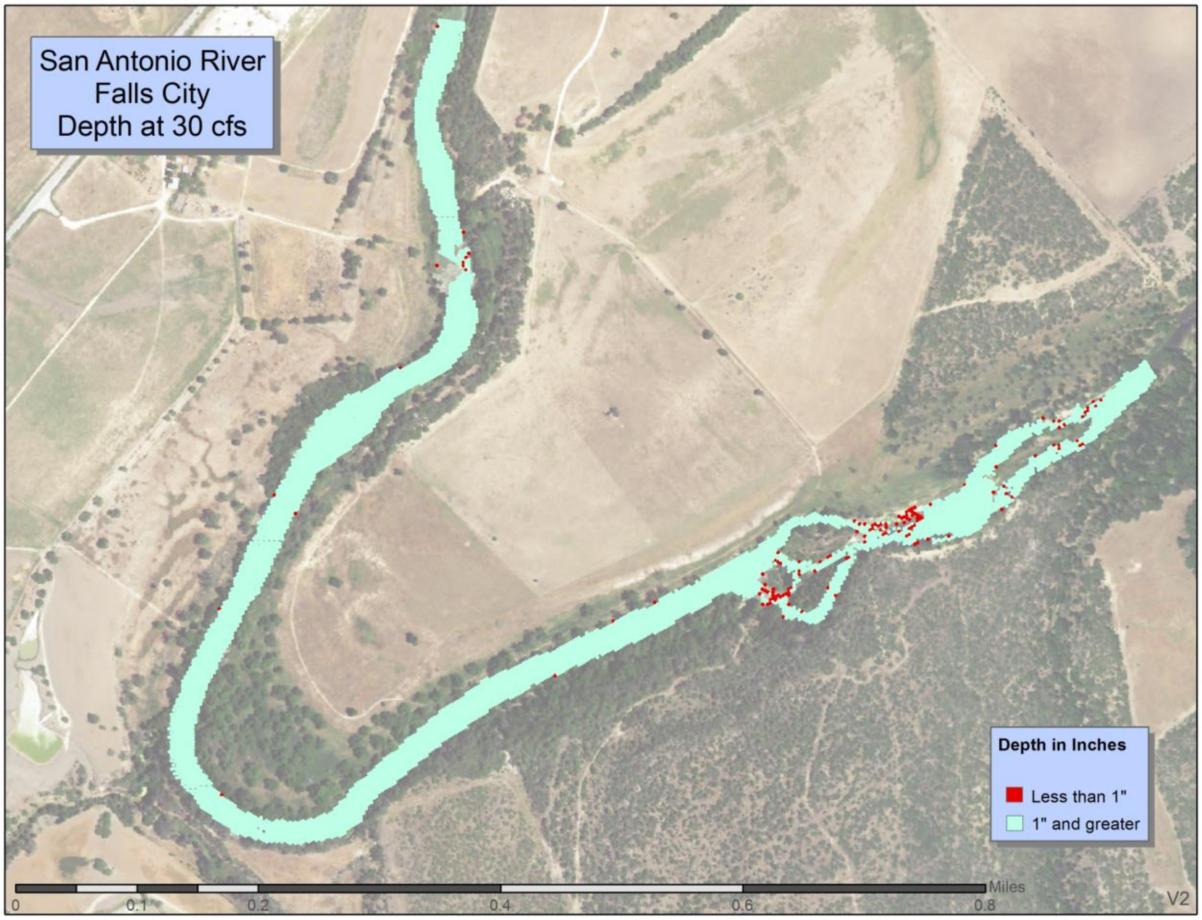


Figure H-2. Spatial output of longitudinal connectivity at the simulated flow of 30 cfs for the San Antonio River Falls City Study Site.

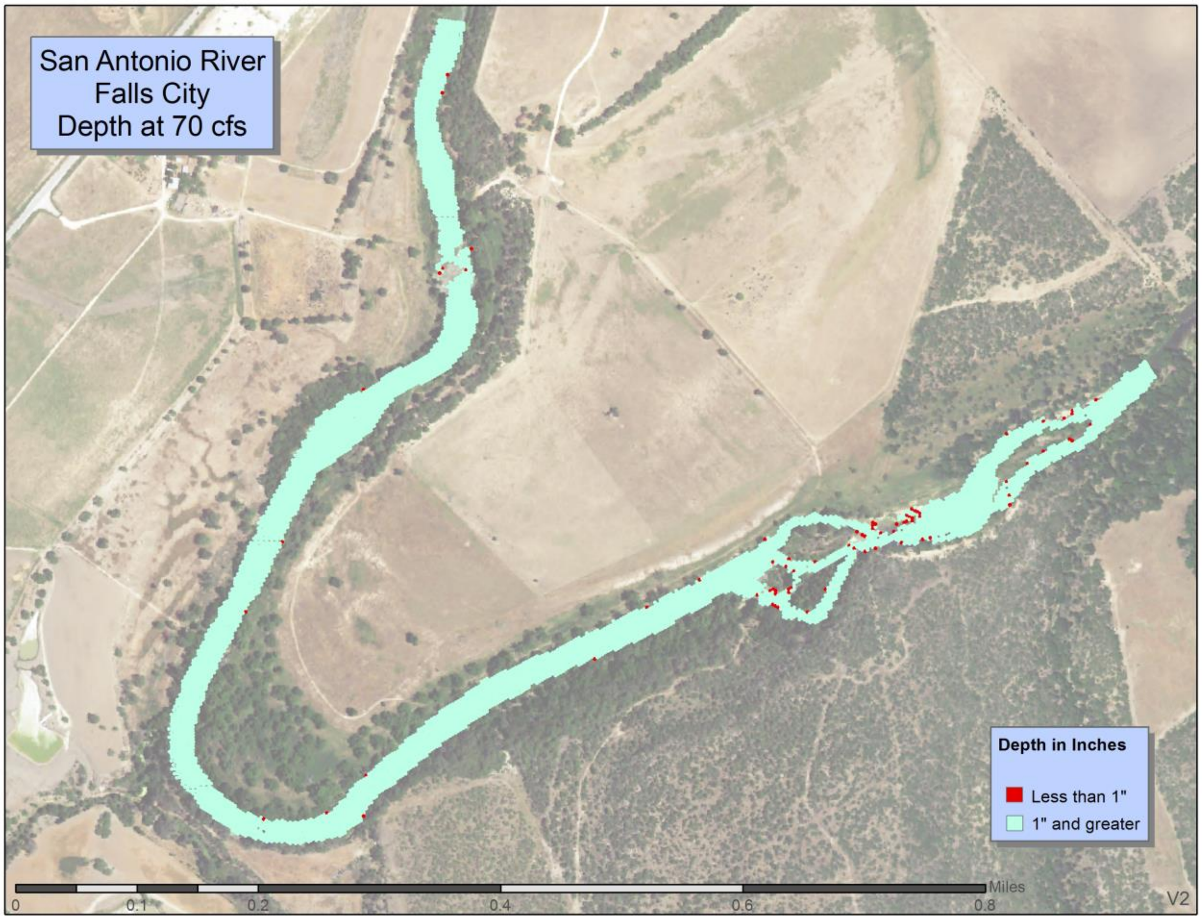


Figure H-3. Spatial output of longitudinal connectivity at the simulated flow of 70 cfs for the San Antonio River Falls City Study Site.

Figure H-4. Spatial output of longitudinal connectivity at the simulated flow of 60 cfs for the San Antonio River Goliad Study Site.

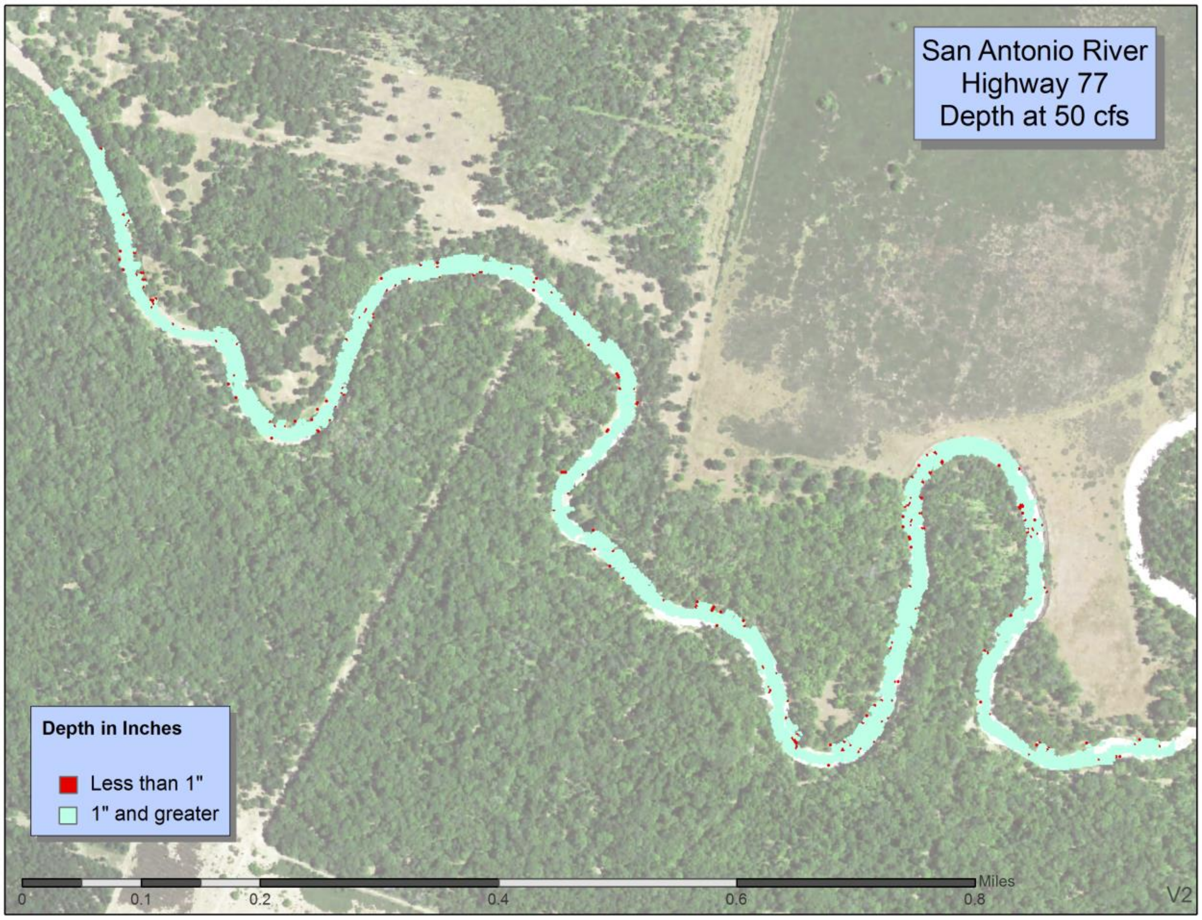


Figure H-5. Spatial output of longitudinal connectivity at the simulated flow of 50 cfs for the San Antonio River Hwy 77 Study Site.

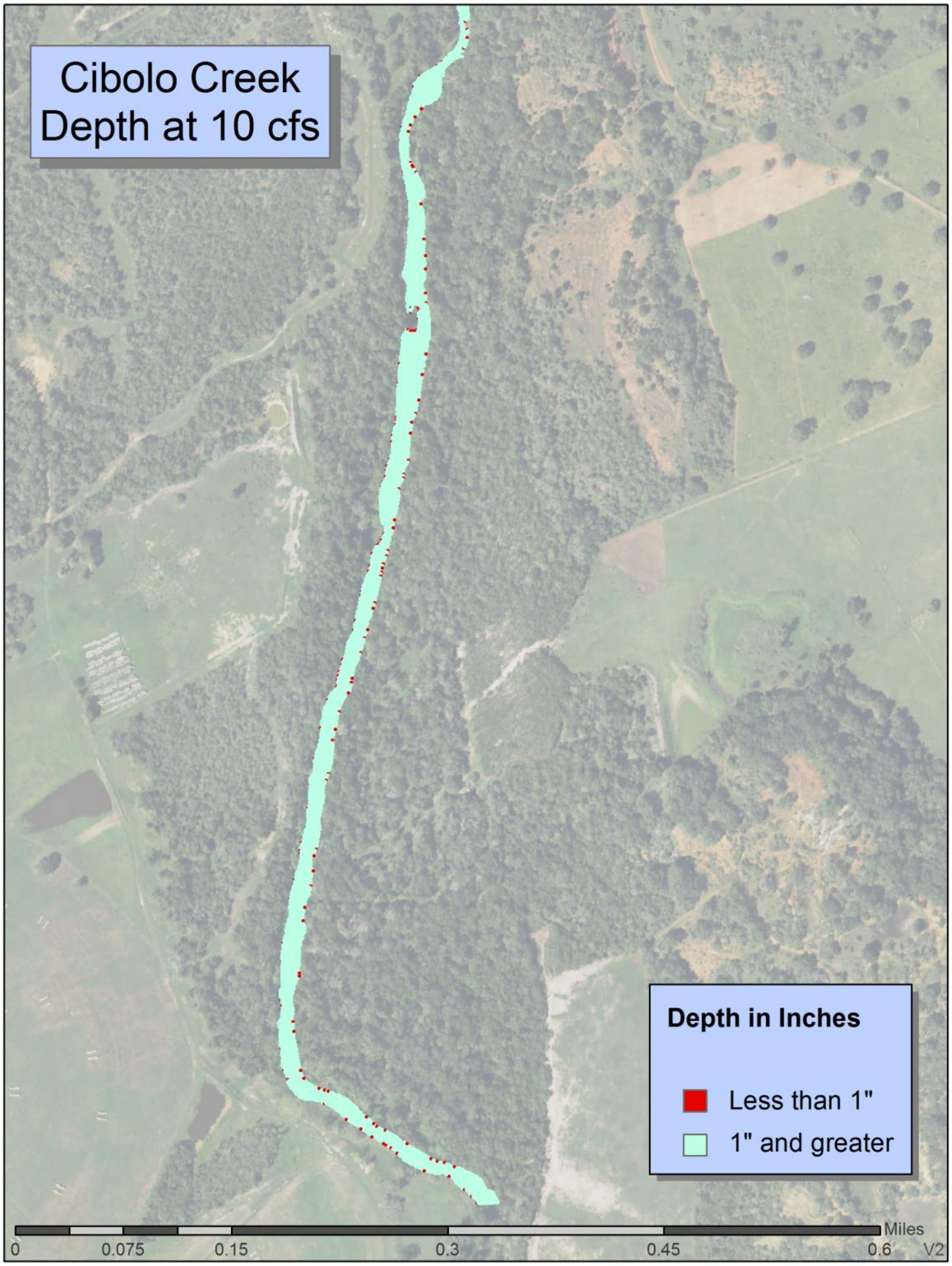


Figure H-6. Spatial output of longitudinal connectivity at the simulated flow of 10 cfs for the Cibolo Creek Study Site.

APPENDIX I

TIFP RESPONSES TO STAKEHOLDER COMMENTS

Stakeholder Comments on the Draft Report

and the Lower San Antonio River Workgroup Responses

<u>San Antonio Water System Comments:</u>

- Page 1 Paragraph 2 - Introduction: ***In recent history, use of groundwater to sustain rapid development in the basin has resulted in increasing base flows in the San Antonio River resulting from discharged groundwater-based return flows.*** This is not really true and not a good way to begin report. I have been talking with Mark Wentzel about the observed flow increases and he developed some flow-frequency curves that demonstrate return flows alone cannot account for the observed increases at the low-flow end of the spectrum. Would request that you ask Mark to provide some better and more accurate language to replace this.

  Response: Agree that the increased base flows are due to more factors that just increased return flows. Statement has been modified to reflect contribution of impervious cover as well.

- Page 6 Study Reaches and Study Sites: It would be helpful to the reader to identify the five sites by name instead of number, or perhaps use both.

  Response: The figure has been modified as recommended.

<u>San Antonio River Authority General Comments:</u>

- The introduction of the 95% rule in the waning stage of the TIFP gives SARA great concern that the relationship of sediment transport to the ecological health of the San Antonio River has not been adequately addressed so that we can rely on it for the basis of a flow recommendation.

  Response: Because it is dependent on an associated flow regime, sediment transport analysis is inherently one of the last study elements completed. Sediment transport rates associated with final flow recommendations could only be completed after flows that met objectives for water quality, base fish habitat, and riparian maintenance were developed. This order of the analysis was anticipated throughout the TIFP process. Though the final sediment transport analysis was not completed until the last stages of the study, it followed the same procedures used in the Interim Progress Report and those utilized by the Guadalupe-San Antonio Basin and Bay Expect Science Team (GSA-BBEST 2011). During scientific peer review, all aspects of the study, including sediment transport analysis, will be evaluated in terms of their adequacy to form the basis for flow recommendations.

- A review of data indicates that temperatures didn't reach 35°C during extreme air temperatures and low flows. Data from the Elmendorf gage (USGS 08181800: 10/01/2007 – 02/22/2017) which included the 2011 Drought and SH 72 gage (USGS 08188060: 07/27/2011-02/22/2017) never reached 35°C.

Response: The highest water temperature recorded during the course of this study (34.9°C) was taken in a backwater at the Falls City Study Site during the summer of 2012. This temperature was recorded at 2:18 p.m. in a non-shaded backwater. It is quite possible that water temperature exceeded 35°C in that backwater (and other similar backwaters) later that afternoon when the daily high air temperature reached 39°C.

- Sampling conducted during low flow conditions didn't find stressed fish. Since the 80 cfs recommendation is based on modeled worst case scenario, and data collected indicate that the worst case scenario may never be realized, SARA supports the BBASC recommendation of 60 cfs.

  Response: Worst case scenario, as defined in the report, is extreme summer ambient temperature conditions (daily high air temperature exceeding 39°C) combined with low flow. Low flow can occur at any time of the year; however, based upon a review of historical air temperature data recorded from Floresville and Victoria, air temperatures have not reached or exceeded 39°C except during the months of June, July, August, and September. Therefore, we have lowered subsistence flow values in the lower San Antonio River from 80 cfs to 60 cfs for the other eight months of the year, but maintain a subsistence flow value of 80 cfs for the aforementioned summer months.

- An Executive Summary would be a great addition for most Stakeholders.

  Response: An Executive Summary has been added as recommended.

<u>San Antonio River Authority Detailed Comments:</u>

- Page 1, Paragraph 3: This paragraph holds the only two references to Senate Bill 3 in the entire document. We understand TCEQ's hesitancy to discuss SB3, but the TIFP Technical Guidance document (2008) does. That is the focus of Chapter 11 of that document and it seems that, at this point in time, the sole purpose of this SB2 report is to "be utilized during the adaptive management process within SB3 to inform environmental flow recommendations" as stated in the last sentence of this paragraph. To assist stakeholders in their understanding of the purpose of this document, more discussion of how this SB2 could be used (i.e., the process) should be considered in an Executive Summary and again in the recommendations section.

  Response: SB3 envisions an adaptive management process for revisiting the environmental flow standards adopted by the TCEQ through rulemaking. Additional data, information, and studies will be necessary for the SB3 stakeholders to make informed decisions regarding any future recommendations for changes to the adopted standards. During the SB3 process there was limited scientific information available to enable the groups to directly relate recommendations to the ecological needs of aquatic and aquatic-dependent species. The purpose of SB2 studies is to provide additional scientific information that can be used by SB3 science teams and stakeholders to develop recommendations in future SB3 rulemakings. This concept is noted in the document. Specifics on how the SB2 information would be used by the SB3 groups would be decided by the SB3 groups during their future deliberations related to adaptive management.

- Page 12, Figure 6 and text following: This is an extremely important figure and discussion. Essentially it describes how much the system has changed over time with increasing flows (nearly doubled) and how much is assumed to be from increased return flows (≈100,000 acre-feet) from the aquifer. Yet later in the document, the sediment flow recommendations are specifically implemented to support the channel formed by these artificially high flows. And somehow that is now necessary to support a sound ecological environment?

  Response: The goal of the TIFP is not to restore rivers to pre-human impact conditions. Some modification of modern river ecosystems in Texas is expected and, in many cases, may still be considered ecologically sound. As long as a sound ecological condition currently exists, TIFP efforts will generally be focused on identifying flows required to maintain those conditions (not a return to pre-development conditions). During examination of existing data, literature review, and interactions with study partners and stakeholders, no parties expressed the opinion that the lower San Antonio River and lower Cibolo Creek are not environmentally sound and restoration efforts are therefore necessary. The study team therefore made a conscious decision to focus on maintaining the current ecosystem conditions and channel configuration.

  There are several hindrances to making flow recommendations intended to restore the channel to historical conditions. First, channel restoration is rarely (if ever) accomplished simply by adjusting flows. Once a channel has incised and widened in response to larger flows, reducing flows will not restore the channel to the pre-alteration condition. Channel restoration work typically involves physical reconstruction of the channel, with associated costs that can reach millions to tens of millions of dollars per mile of channel restored. Second, all of the flow ecology relationships identified in this study (water quality, fish habitat, connectivity to riparian areas, and sediment transport) are dependent on the current channel configuration. For example, flows identified by this study that maximize riffle habitat are dependent on the current channel geometry. There is no assurance that the same flows would maximize riffle habitat for a significantly different channel configuration.

  Bexar County, the City of San Antonio, U.S. Army Corps of Engineers, San Antonio River Foundation, and San Antonio River Authority recently initiated channel restoration on several miles of the upper San Antonio River (upstream of the upper boundary of this study area). A similar effort to restore the lower San Antonio River and/or lower Cibolo Creek to an earlier, historical condition would require careful planning before undertaking any necessary physical reconfiguration of the channel, as well as alteration of the current flows entering the system. Buy-in from the public, stakeholders, impacted parties, and funding agencies would also be required.

- Page 18, Section 2.3 Biology: The statement on mussels should be updated. A lot of mussel information has been collected since the interim report in 2012 and this is same statement used in that report referencing Karatayev and Brulakova 2008.

Response: This section is intended to represent the baseline information on mussels that was available the time this study was originally initiated. The additional studies that have been completed since the initiation of this project are highlighted in the results section of this report.

- Page 27, Figure 13: Title says Figure 133. Also, could the circles be drawn in a way to look more professional?

  Response: The figure has been modified as recommended. Similar figures in Appendix B were also modified.

- Section 2.3.3 Riparian Communities (17 pages) – vs. Section 2.4 Physical Processes (5 pages). Might consider moving some of the riparian baseline and literature review to an appendix, like was done for the sediment transport work.

  Response: Comment noted.

- Section 2.4. Page 65, Figure 39. This is a really good figure to point out how pre-urbanization channels typically support more habitat diversity. However, Figure 39 could be easily misinterpreted relative to the LSAR. It highlights the greater diversity of habitat that a channel has before urbanization, which is correct. This is also supported by the LSAR habitat modeling which shows lower base discharges create more diverse habitat, including more riffle habitat. Figure 38 in fact confirms this is how the LSAR used to look in the earlier periods (at least at that 1 cross-section). The assumption implied later (and somewhat misleading in Figure 39) is that the current channel shape today is solely due to urbanization. Thus, more water coming down this channel (like seen in recent times) is needed to support this channel because we can't do anything about urbanization. However, as referenced on page 12, at least half of in the increased water is return flows, which could be managed via reuse. Not advocating anything here other that pointing out that this figure can be a bit misleading without some additional text fully pointing out what's going on in the LSAR. OR at least referencing back to the discussion on page 12.

  Response: As pointed out in the text, there is little historical data available to confirm or deny that the channel of the lower San Antonio River has experienced channel changes considered typical for urbanized streams. The lack of historical channel data also makes it difficult to speculate whether particular flow rates would result in more or less habitat diversity in the historical channel than provided by those flow rates in the current channel. The focus of the flow recommendations is preserving the current sound ecological condition and channel configuration. These flow recommendations do not preclude removal of some water from the system. As shown in Table 21, the flow recommendations (Scenario 8) would allow a reduction of approximately 270,000 acre-feet per year in flow at the Goliad gage over the time period from 1996 to 2015.

- Page 65, last paragraph. First reference to the Goliad 10% rule for sediment transport that was highly controversial in the SB3 process.

Response: The sediment transport analysis completed for this study followed the same procedures used in the Interim Progress Report and those utilized by the Guadalupe-San Antonio Basin and Bay Expect Science Team (GSA-BBEST 2011). Section 2.4 seems the most appropriate location in the report to reiterate this concept. In the opinion of the TIFP agencies, the guidance by Biedenharn et al. (2000) that channels should remain dynamically stable if the sediment transport capacity is maintained within 10% of sediment supplied to the reach is reasonable and not out of line with scientific consensus regarding the behavior of rivers and streams. During scientific peer review, all aspects of the study, including sediment transport analysis, will be evaluated in terms of their adequacy to form the basis for flow recommendations.

One purpose of SB2 studies is to provide additional scientific information. The SB3 stakeholders can use that information to develop their recommendations based on the factors outlined in Texas Water Code §11.02362(o), which include considerations other than just the science. The fact that these types of recommendations were controversial in the SB3 process is not relevant to SB2.

- Page 68, first paragraph. Hard to reference the Natural Flow Paradigm and the sentence, "Having occasional extremes supports populations of native species that have evolved life history strategies in response to the natural flow regime (Poff et al. 1997, Bunn and Arthington 2002)" and then subsequently adjust the subsistence flow recommendations later on in the report considerably above where any harm might occur. This NFP sentence just said some harm is necessary for nature to do what nature does. The subsistence recommendations later in this report remove this by padding them to prevent harm.

  Response: Comment noted.

- Page 73, initial partial paragraph. Using the modeled "maximum" daily temperature is an ultra-conservative approach for subsistence flows. Using the modeled "average" temperature under extreme summer ambient temperature conditions seem more appropriate when considering subsistence flows in the context of the natural flow paradigm. We understand using the "maximum" as a conservative approach in the Interim report back in 2012 because at that time, there was no field data to support ecological conditions at low flows, high temps, etc. We now have quite a bit of that data and in our opinion, none of that temperature or biological data supports staying with the "maximum" modeled value.

  Response: The focus of the review was on sensitivity analysis and modeling assumptions. Adding more data would not change the output of the model.

- Page 73, third full paragraph. The discussion on mussels to justify 80 cfs falls short of being consistent with the natural flow paradigm. To summarize - at 80 cfs, wetted area was available, but some areas were close to being in trouble. The natural flow paradigm suggests that at times, trouble happens, not just getting close to trouble. Again the 35-degree value was a modeled "maximum" temperature under extreme summer time conditions and maximum loadings/reuse. That water temperature was not experienced during extreme summer time conditions in the river during the drought at lower flows than 80 cfs (experienced in 2013 and 2014). Seems like real data on current conditions should outweigh model results conducted on conditions that may never be realized.

Response: While we agree with the characterization of the natural flow paradigm and personally observed flows below 80 cfs occurring naturally in the lower San Antonio River in recent years, the 80 cfs subsistence flow recommendation (for June through September) is based on the modeled worst case scenario which takes into account longer term conditions. While we acknowledge that water temperature data at flows less than 80 cfs during 2013 and 2014 did not exceed 35°C, these data represent a small snapshot and conditions during which they were collected could have potentially influenced them (e.g., a water temperature of 34.9°C was recorded at 2:18 p.m. in a non-shaded backwater at the Falls City Study Site during fish sampling in the summer of 2012). It is quite possible that water temperature exceeded 35°C later that afternoon when the daily high air temperature reached 39°C. The TIFP workgroup established that exceedances above 35°C were not acceptable. The 35°C temperature limit was set by the TIFP workgroup to reflect the upper thermal tolerance limit for many fish and mussel species as discussed in Section 4.0 paragraphs 2 and 3. In addition, because Golden Orb were specifically identified by the stakeholder workgroup as a focal species, flow values were specifically selected that would be protective of them. As the 35°C criteria was established for adult Golden Orb mussels based on surrogate species, the thermal sensitivity of juvenile and glochidia mussels are generally less than that of adults. This point has been elaborated upon in this section.

- Page 73 last paragraph and page 74 first paragraph lay out the real data nicely. In fact, the last sentence of the first paragraph on page 74 states, "Cumulatively, the results for site specific water quality monitoring indicate that the primary priority temperature thresholds can be supported at flows lower than 80 cfs under current conditions." Yet, the decision was still to go with the modeled maximum. We understand this was the collective decision of the TIFP based on professional judgement, but in our opinion it is extremely conservative and counter to the natural flow paradigm which one could easily contend SB2 was founded on by the TIFP.

  Response: Subsistence flow values have been lowered from 80 cfs to 60 cfs from October through May, but the original recommended subsistence flow value of 80 cfs is maintained from June to September.

- Page 74, last paragraph. Without a water quality model the subsistence flow for Cibolo was set at the point at which the habitat model showed that habitat modeling predicted, "high quality riffle habitat starts to become lost as flows drop below 10 cfs (Figure 43)". We don't have an issue with the Cibolo recommendation. However, it contradicts the LSAR recommendation (based on water quality modeling), in that riffle habitat in the LSAR is actually at its highest below 80 cfs. In Summary, 1) the real water quality data from the LSAR collected during drought, 2) the habitat modeling for riffles in the LSAR (for which the TIFP based their recommendation for Cibolo), and 3) wetted area for mussels all support a subsistence flow below 80 cfs, yet the decision was to bump it to 80 cfs.

Response: Subsistence flow values have been lowered from 80 cfs to 60 cfs from October through May, but the original recommended subsistence flow value of 80 cfs is maintained from June to September.

- Page 76, Table 16 and discussion on base flows. With subsistence being set at 80 cfs throughout the river and throughout the year (even during cold months), the TIFP was forced to bump up several Base flow recommendations. We disagree with this approach in that the water quality model "maximum" temperature during extreme conditions in the summer is now driving several recommendations, even base flows. A quick glance on the habitat based base recommendations in Table 16 (and corresponding WUA charts) shows that LSAR sites are forced to sacrifice high quality habitat throughout the entire year (as predicted by the habitat model) in order to support a "maximum" modeled summer time temperature. At a minimum, at least consider letting the habitat model be the driver for recommendations outside of summer months. It seems to us that having high quality habitat in the spring is more important than sacrificing it in order to keep more water in the river for a modeled maximum temperature requirement that was never exceeded (in the water quality modeling) outside of a summer extreme condition. In our opinion, habitat model results should drive the base recommendations, at least during all non-extreme, summer time conditions.

  Response: Subsistence flow values have been lowered from 80 cfs to 60 cfs from October through May, but the original recommended subsistence flow value of 80 cfs is maintained from June to September.

- Page 83, Section 3.2.6. These calculations are overkill in our opinion and could be simplified greatly by going to seasonal recommendations.

  Response: Comment noted.

- Page 89 and following. Sediment flow recommendation. A sediment transport recommendation that states, "95% of all flows over 2,000 cfs" in the lower San Antonio River are needed to maintain a sound ecological environment does not seem scientifically based for the LSAR. Especially when using the current time period to make this calculation. As we understand it, this number is calculated as the amount of water that maintains 90% of the sediment transported by the current flow regime (1996-2015). This remains a lingering artifact (10% rule) of the early rounds of SB3 and it was highly criticized then. The issue is that it simply tells you that what (or 90% of what) the river in its current condition has witnessed over the past 20 years from a sediment standpoint is necessary to maintain a sound ecological environment. Does a sound ecological environment really require maintaining the increased baseflows (from water use taken out of the aquifer that would naturally have went to the Guadalupe River) that are now impacting habitat diversity (which the habitat modeling clearly articulates)?
  Response: In the opinion of the TIFP agencies, the guidance by Biedenharn et al. (2000) that channels should remain dynamically stable if the sediment transport capacity is maintained within 10% of sediment supplied to the reach is reasonable and not out of line with scientific consensus regarding the behavior of rivers and streams. This guidance was not a "lingering artifact of the early rounds of SB3," but rather the outcome of an extensive study effort commissioned by the River Sedimentation Branch of the U.S. Army Engineer

Research and Development Center. During scientific peer review, all aspects of the study, including sediment transport analysis, will be evaluated in terms of their adequacy to form the basis for flow recommendations.

The focus of the flow recommendations from this study is preserving the current ecological condition and channel configuration. The flow recommendations from this study do not preclude removal of some water from the system. As shown in Table 21, the flow recommendations (Scenario 8) would allow a reduction of approximately 270,000 acre-feet per year in flow at the Goliad gage over the time period from 1996 to 2015.

For clarity, the habitat modeling completed in this study is related to the current channel configuration. There are insufficient data available to describe the historic channel or associated habitat conditions with certainty.

- Page 92, first full paragraph. It would be nice to see a 95% rule for "Scenario 1" plotted on Figure 52. "Scenario 1" is 56% of the current regime sediment yield based on Table 21.

  Response: Scenario 4 in Table 21 and Figure 52 requires specific flow recommendations plus 75% of flow greater than 2,000 cfs. The average annual sediment transport rate associated with this scenario is approximately 120% of the rate associated with Scenario 1. According to the guidance provided by Biedenharn et al. (2000) for maintaining dynamic stability, if the 1939 to 1959 channel received such a flow regime, the channel would likely be unstable because the change in sediment transport would exceed 10%. A flow scenario that maintained 110% of the sediment transport rate of Scenario 1 would require specific flow recommendations plus a slightly smaller percentage of flow greater than 2,000 cfs. Although such a scenario is not plotted on Figure 52, it would be only slightly reduced from Scenario 4.

- Page 94, second paragraph. Might a 95% of Scenario 1 option be a better recommendation to support high quality riffle habitat or more habitat diversity in general? The TIFP response stated in the report is, "This analysis should not be used to imply that channel conditions similar to those that existed in 1939-1959 could be achieved exclusively by means of matching flows to a particular flow scenario." Or in meetings, typically as "we don't know what the channel was and we can't go back in time." We agree that due to current entrenchment of the channel, returning to a historical hydrology/sediment load likely doesn't result in the same habitat conditions observed then. However, SB2 started in 2002, SB3 in 2007, the interim report was published in 2012, and we are now in 2017. The TIFP has had ample time to study sediment transport and come up with something more defined than simply maintaining 90% of the sediment load from "existing hydrology" based on literature. Especially, when it is not clear that that literature ever considered a system that has return flows (coming in from another river basin) that have doubled over the past 50 years creating an existing channel that is losing its habitat diversity.

  Response: Unfortunately, once a channel has incised and widened in response to larger flows, reducing flows typically will not restore the channel to the pre-alteration condition. Channel restoration work would most likely require physical reconstruction of the channel (by means such as reshaping cross section shape and planform, installation of bank

protection, and construction of control structures) in addition to manipulation of the flow regime. Restoring the flow regime of Scenario 1 (or an alternative that provides 110% of the sediment transport of Scenario 1) to the existing channel without carrying out sufficient physical reconstruction of the channel has the potential to create several problems over the next few decades including channel aggradation, increased meandering, significant channel bank caving, and associated loss of land and infrastructure.

In the opinion of the TIFP agencies, the guidance by Biedenharn et al. (2000) that channels should remain dynamically stable if the sediment transport capacity is maintained within 10% of sediment supplied to the reach is reasonable and not out of line with scientific consensus regarding the behavior of rivers and streams. This guidance was the outcome of an extensive study effort commissioned by the River Sedimentation Branch of the U.S. Army Engineer Research and Development Center. During scientific peer review, all aspects of the study, including sediment transport analysis, will be evaluated in terms of their adequacy to form the basis for flow recommendations.

- Page 94, last paragraph. We concur with further study, but would focus it on specific sections of the river to try and answer this specific question of channel change or recovery over time. What would happen if the channel started to go back to more historical conditions? Maybe a pilot restoration project to evaluate the importance of riffle habitat or more habitat diversity?

  Response: The additional geomorphic study recommended in this section would be focused on predicting the response of the current channel due to changes in the flow regime from what prevailed from 1996-2015. Such a study would benefit from analysis from additional sites within the lower San Antonio River sub-basin. If projects to reduce flows significantly in the lower San Antonio River are contemplated, more detailed studies specific to those projects may need to be carried out by the project sponsors rather than relying on the relatively generic analysis completed during this study.

  Bexar County, the City of San Antonio, U.S. Army Corps of Engineers, San Antonio River Foundation, and San Antonio River Authority recently initiated channel restoration on several miles of the upper San Antonio River (upstream of the upper boundary of this study area). Perhaps some portion of that project could serve as the pilot restoration project of interest to the commenter.

- Additionally, a sediment transport recommendation of "95% of all flows over 2,000 cfs" essentially overrides all the previous riparian based pulse flow recommendations. If the sediment transport rule is implemented, why are riparian pulse flow recommendations even included? Riparian pulse flow recommendations were based on intensive data collection within the LSAR, and are more scientifically defensible in our opinion than a 10% rule based on a literature review from studies done in other locations.

  Response: Maintaining the physical shape of the channel is an important, but not the exclusive, ecological goal of the flow recommendations. Each of the specific flow recommendations provides ecological benefit to some aspect of the riverine ecosystem. High flow pulse recommendations specific to riparian needs remain in the recommendations to accomplish such processes as seed dispersal and germination and sapling growth and development as seasonally necessary. It may be possible to develop

flow recommendations to maintain the physical channel but not the riparian areas, or vice versa. Neither of these would be sufficient to maintain the currently sound ecological environment of the lower San Antonio River and lower Cibolo Creek. During scientific peer review, all aspects of the study, including flow recommendations to maintain riparian areas and sediment transport analysis, will be evaluated.

- Page 102, Section 4.1. This would be the perfect place for a well thought out and articulated monitoring program. Being that this is the first SB2 report to be released, setting the precedent for items like monitoring to answer specific flow-ecological linkages seems relevant. At present, this section is a 1.5-page long overview of how to carry on with the status quo.

  Response: We agree in part and have refined the monitoring program, where appropriate, to provide additional specificity.

- Page 102, Section 4.1 title. "Adaptive Management" in the title and this section does not make sense. This report does not describe anything relative to implementation or interactions with SB3, or TCEQ standards. As such, what is there to "adaptively manage" relative to these recommendations? For there to be "adaptive management" there must first be implementation. We understand that these recommendations might change based on future monitoring, but that is not "management" but rather simply revising a recommendation in a SB2 report.

  Response: Texas Water Code §11.02362(p) sets out the adaptive management process for the refinement and validation of the adopted standards. One purpose of SB2 is to provide scientific information that can be used to support adaptive management under SB3. Under SB3, the stakeholders can consider additional scientific information developed through SB2 studies. Additional monitoring as discussed in the report can be used to develop and refine the recommendations in the report. The results of any refined SB2 recommendations can be provided to future SB3 groups to support the continued periodic review of the adopted standards as outlined in the SB3 statute. How specific recommendations are implemented in a regulatory framework is addressed through the SB3 process. This next step is laid out in the document. Discussion in the report beyond this next step would be speculative because specifics on how the SB2 information will be used by the SB3 groups will be decided by the SB3 groups during their future deliberations related to adaptive management.

- Chapter 11 of the TIFP guidance document (2008, page 110) states, "After study reports are completed, an additional process will be necessary to translate recommendations into action." Chapter 11 (TIFP 2008) includes Implementation, Monitoring, and Adaptive Management. With that note, maybe Section 4.1 and 4.2 of the existing report should be deleted and a Conclusion section be added to reiterate that point. That would provide the reader some clarity on what the next steps for this information actually are.

  Response: Texas Water Code §11.02362(p) sets out the adaptive management process for the refinement and validation of the adopted standards. One purpose of SB2 is to provide scientific information that can be used to support adaptive management under SB3. Under SB3, the stakeholders can consider additional scientific information developed through

SB2 studies. Additional monitoring as discussed in the report can be used to develop and refine the recommendations in the report. The results of any refined SB2 recommendations can be provided to future SB3 groups to support the continued periodic review of the adopted standards as outlined in the SB3 statute. How specific recommendations are implemented in a regulatory framework is addressed through the SB3 process. This next step is laid out in the document. Discussion in the report beyond this next step would be speculative because specifics on how the SB2 information will be used by the SB3 groups will be decided by the SB3 groups during their future deliberations related to adaptive management.