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

Interim Progress Report and Instream Flow Recommendations

Prepared for

Lower San Antonio River Sub-Basin Workgroup

Prepared by

TEXAS INSTREAM FLOW PROGRAM
AND SAN ANTONIO RIVER AUTHORITY

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1.0 INTRODUCTION

The lower San Antonio River sub-basin is located in portions of 7 counties in south-central Texas and supports a diverse ecological community that relies on the quality, quantity, and timing of water moving through the system. The San Antonio River basin 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, the increased use of groundwater to sustain rapid development in the basin has resulted in increasing base flows in the San Antonio River. This trend in base flows may continue if population growth in the basin is supported by additional groundwater usage or surface water transfers from outside the basin. However, lower river base flows may also result should water management strategies such as reuse be increased. In any event, there is the potential to affect physical, biological, and social resources in the lower San Antonio River sub-basin which provides the rationale behind the Texas Instream Flow Program (TIFP) lower San Antonio River sub-basin study.

Senate Bill 2 (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.

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 2010). This Study Design was peer reviewed by the U.S. Geological Survey (USGS) and subsequently modified based on comments received.

Approximately two years later, a wealth of hydrological, biological, geomorphological, and water quality information has been collected and analyzed in support of the SB2 instream flow study. This information has been condensed and compiled to generate this Interim Progress Report.

The focus of this Interim Progress Report is to provide 1) an update of study progress to the Stakeholders and 2) Interim Instream Flow recommendations for the lower San Antonio River and lower Cibolo Creek. The recommendations are termed "Interim" as ongoing SB2-sponsored efforts and future SB2 studies/activities implemented in relation to long-term monitoring and adaptive management will provide additional information that may result in modifications or revisions to the Interim recommendations. Final recommendations will be developed after meeting with sub-basin workgroups and obtaining their input related to integrating data and generating instream flow recommendations, as described in the Technical Overview (TIFP 2008).

The Interim Progress Report provides:

- an overview of the Study Design document and associated references;
- a description of the methods and analysis performed for technical studies;
- a discussion on integration of study results to formulate Interim instream flow recommendations; and
- a summary of continued stakeholder involvement and future activities.

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

The lower San Antonio River sub-basin is shown in Figure 1. As previously stated, stakeholder involvement was integral in the development of the Study Design for the TIFP lower San Antonio River sub-basin study. This involvement started with initial 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 2010) 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, and
- 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.

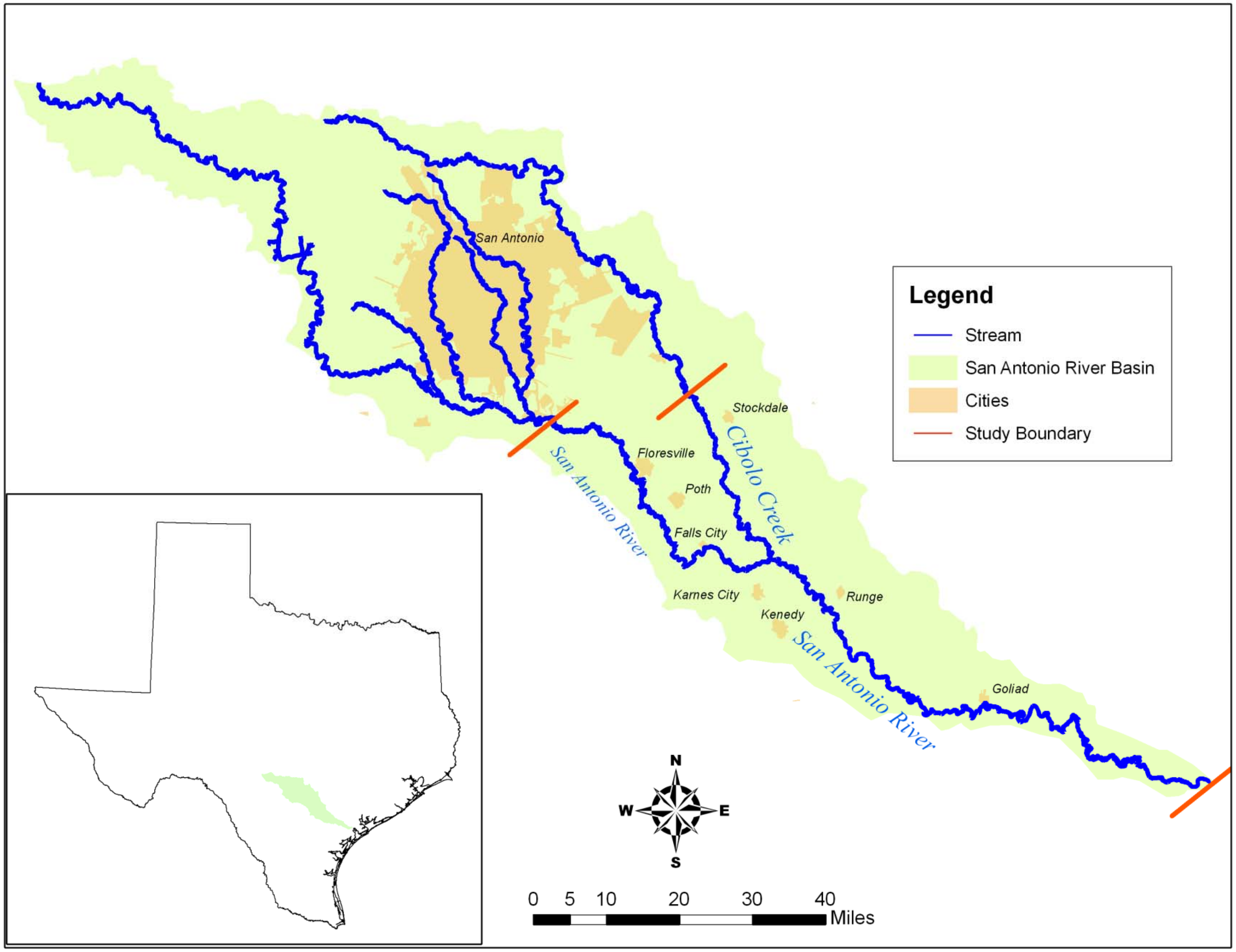


Figure 1. Map of the San Antonio River basin and lower San Antonio River sub-basin (study boundary) depicted.

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 2010).

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. A refined set of parameter-specifc water quality goals have been developed and evaluated as part of this project (Section 3.0 and EC 2010b). The refined goals are based upon greater understanding of the river system's aquatic conditions found over the course of this study.
- **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.

Within the biological indicator suite, several key species were identified during a series of stakeholder meetings based upon their abundance and sensitivity to water quality and flow. These include:

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

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. Additional studies for key species with limited information are proposed and discussed in Section 4.0.

2.0 METHODS AND ANALYSIS

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 were conducted across an entire Segment (e.g. water quality models), other studies were conducted at particular Study Sites (e.g. hydraulic and habitat modeling). As described in the Study Design (TIFP 2010), a three-tier approach was employed for the final selection of specific study sites (Figure 2).

The Technical Overview (TIFP 2008) and Study Design (TIFP 2010) outlines four major study components including hydrology and hydraulics, biology, physical processes, and water quality. Sections 2.2 through 2.4 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.

2.2 *Hydrology and Hydraulics*

The lower San Antonio River and lower Cibolo Creek ecosystem has evolved in response to the inter- and intra-annual variability in flow that includes cycles of overbank flows, high flow pulses, and subsistence flows with intervening periods of base flows. This variability in flow is typically referred to as the flow regime. An evaluation of the flow regime was conducted to assess the hydrological indicators including natural variability, current variability, and gain or loss in river flow. The USGS has maintained a network of streamflow gages in the lower San Antonio River sub-basin since the 1920's. Currently, 12 gages are operational in the sub-basin, including five on the mainstem of the San Antonio River and five on Cibolo Creek. This network allows for a characterization of flow variability, i.e., how the flow regime changes spatially (moving downstream towards the coast) and temporally (comparing early periods to later periods).

Since the time of the earliest flow records (early 1900's), a significant increase in base flow is exhibited at all gages as a result of factors such as increased wastewater return flows from the San Antonio metropolitan area. The long period of record allows comparisons between early periods that may represent a more natural condition to later periods reflecting current land use, water usage, and other conditions affected by human's use of water and the landscape. A discussion of these changes is presented in the Study Design (TIFP 2010).

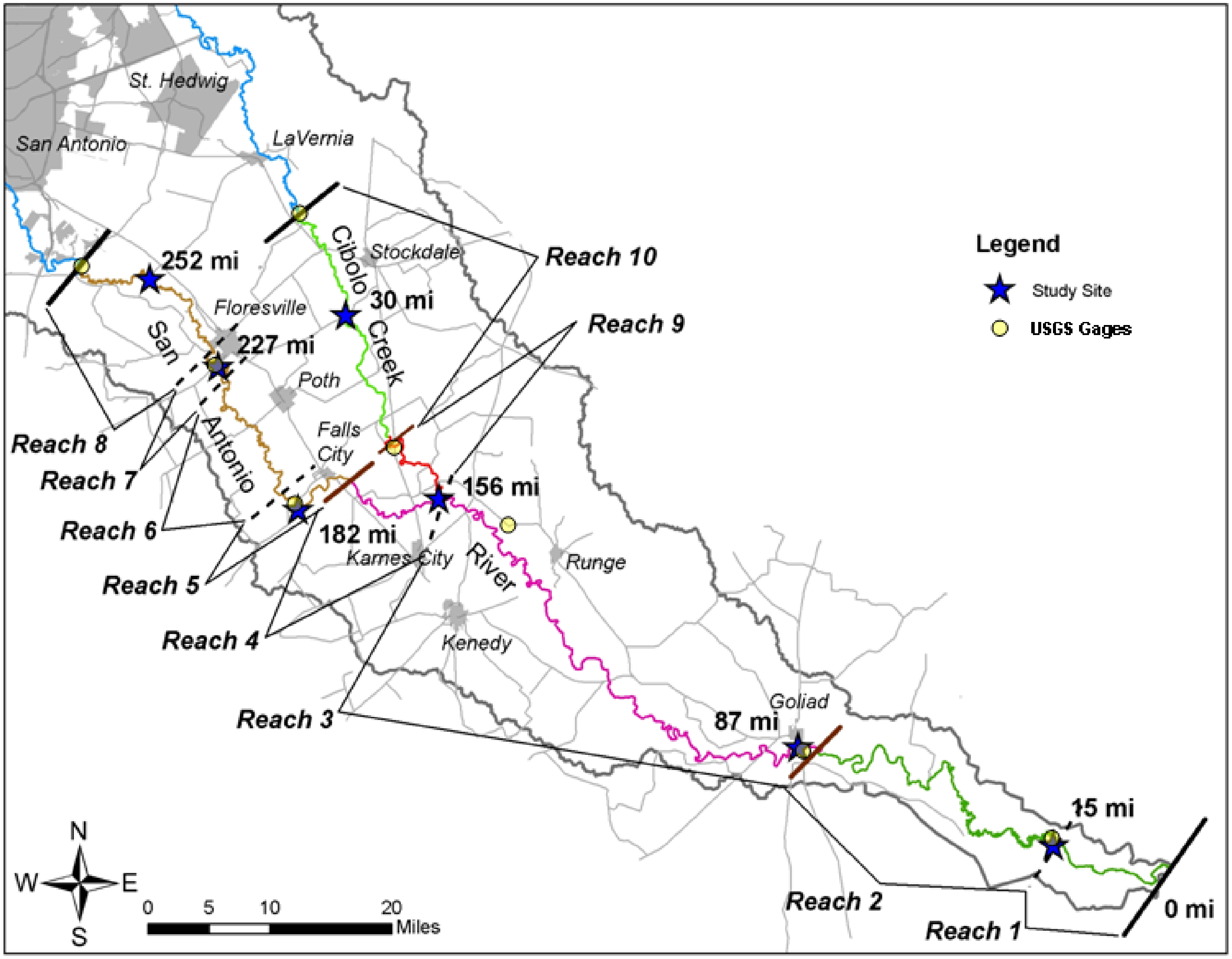


Figure 2. Study Reaches and Study Sites, with river miles (from downstream confluence) noted at each Study Site.

Statistics derived from a hydrologic evaluation were used to characterize the flow record and evaluate ranges for the four main instream flow components: subsistence flow, base flow, high flow pulses, and overbank flow. These statistical evaluations were used primarily to determine approximate flow levels at which to conduct field studies, physical assessments, and initiate model evaluations. Additionally, these flow statistics were incorporated into the integration of hydrology and habitat via the time series analysis conducted to develop Interim instream flow recommendations. Finally, these statistics and flow patterns were used as an overlay to determine whether proposed flow recommendations based on biological (aquatic and riparian) sampling and analysis were historically observed within the lower San Antonio River sub-basin.

2.2.1 *Hydraulic and habitat models*

In addition to statistical analysis of the flow record at existing gages, site-specific field studies focused on the development of two-dimensional (2D) hydraulic and habitat models for base flow conditions at each of the five modeling sites. Additional 1D hydraulic modeling was performed for the entire study area for a range of flows higher than baseflows but lower than overbank flows. The 1D modeling is described in further detail in the High Flow Pulse and Overbank Assessment section.

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 2008a), 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 include the following:

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

At each model Study Site, complete channel and near-channel floodplain Digital Terrain Models (DTMs) were created using a combination of conventional equipment and survey-grade GPS equipment coupled with hydro-acoustic depth sounding data. Survey data was reviewed for completeness (missing data, holes in the topography, spikes, etc.) on a daily basis using custom software (Osting 2009), ArcView software, Trimble software and 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 habitat 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 a 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 and subdominant particle sizes (Figure 3). In areas too deep for visual characterization, sampling with a pole Ekman dredge (or equivalent sediment sampler) 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 4).

Figure 3. Substrate characterization at the Falls City Study Site.

Digital terrain models (DTMs) were generated for each Study Site using all available topographic and elevation data (e.g., Figure 5). 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.

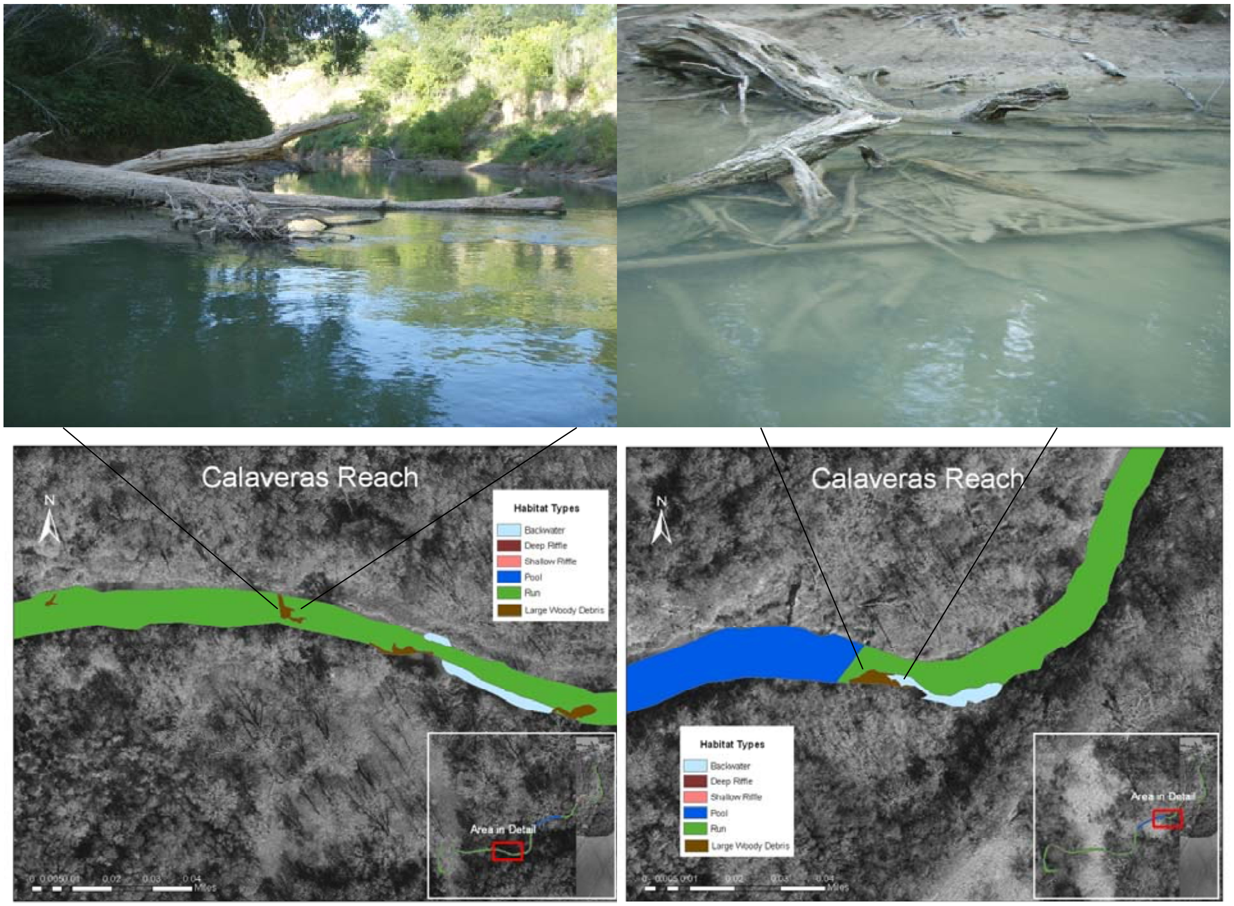


Figure 4. Instream cover (large woody debris) characterization at the Calaveras Study Site.

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 cubic feet per second (cfs) and 150 cfs for lower Cibolo Creek, between 15 cfs and 1,000 cfs for the Calaveras Study Site, and between 30 cfs and 1,500 cfs for the Falls City and Goliad study sites.

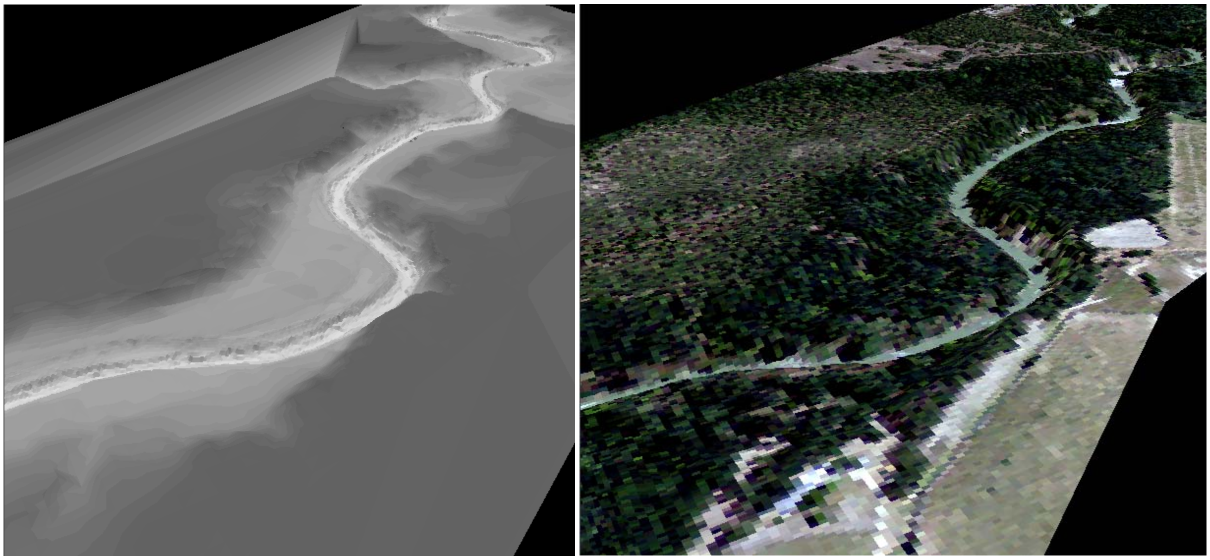


Figure 5. Digital Terrain Model (DTM) for the Calaveras Study Site.

Model calibration was completed for at least three flow rates at each site; the range of calibrated flows covered the low, moderate, and higher flow conditions relative to the range of all flows desired to be evaluated. To model additional intermediate 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-feet (1.5- to 3-meter) spacing between nodes (vertices) was used at each site (Figure 6). 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.

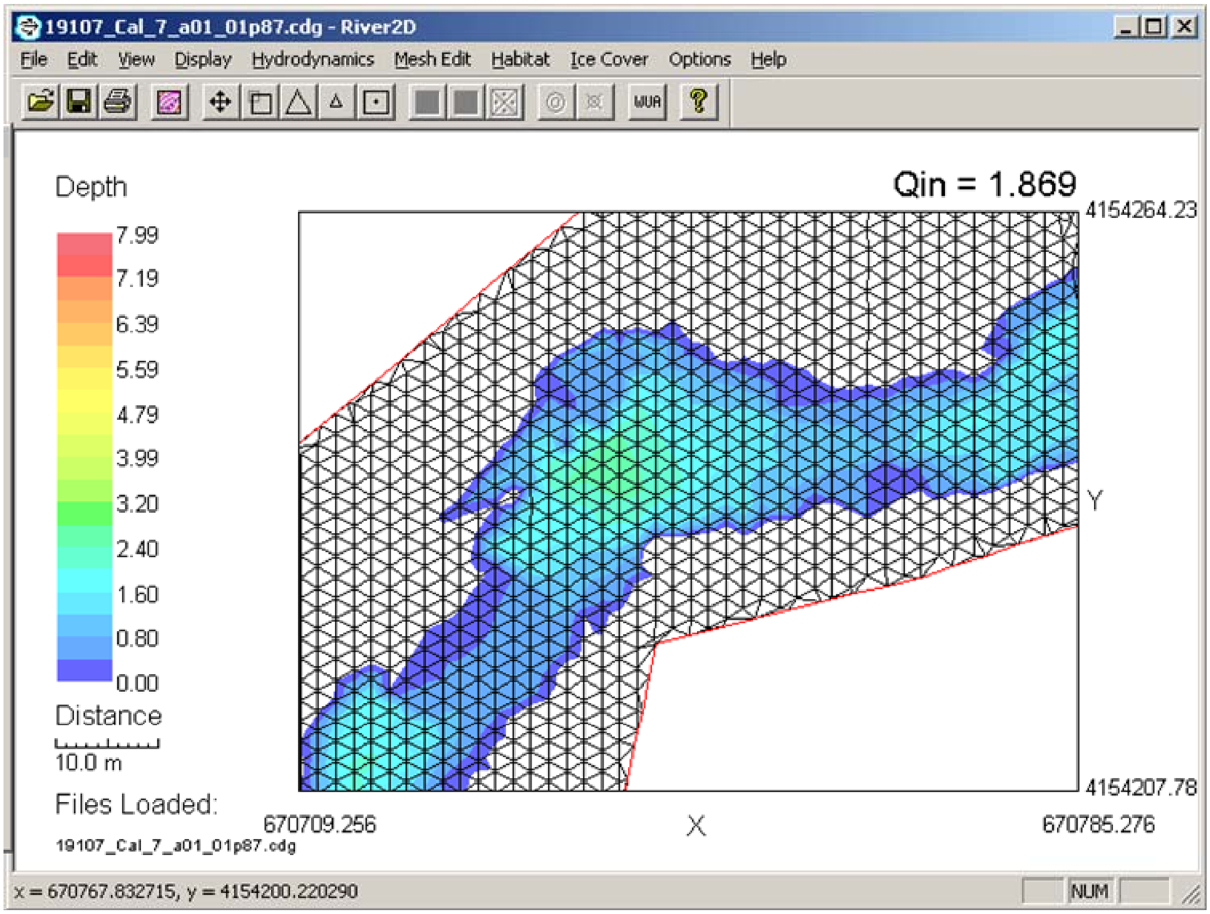


Figure 6. River2D model mesh for the Calaveras Study Site.

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. A Chezy roughness height equivalent to the maximum diameter of each size class was applied; however, a multiplier was applied to each size class during calibration.

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 was 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.

For most calibrated models the predicted water surface elevation profile matched observations within 2″ (5 cm) and many models matched observations within 3/4″ (2 cm). Validation measures include 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.

2.2.2 *High flow pulse and overbank 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 indictors of these flow components relative to riparian communities. The range of flows evaluated had recurrence intervals ranging from less than a year (high pulse flows) to 10 years (overbank flows). Given the small magnitude of some of these flows, i.e., much lower magnitude than typically analyzed for flood studies (e.g., 100-year flood), the in-channel bathymetry 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 also provided in the Study Design and are based upon scientific studies (Balon 1975, Balon 1981, Bonner and Runyan 2007, Hildebrand and Cable 1938, Hubbs et al. 1991, Linam and Kleinsasser 1998, Simon 1999, Warren et al. 2000, Williams et al. 1989). Cyprinidae was the most abundant family, followed by families Poeciliidae, Ictaluridae, Centrarchidae, and Cichlidae. Three native fish species – central stoneroller (*Campostoma anomalum*), green sunfish (*Lepomis cyanellus*), and longear sunfish (*Lepomis megalotis*) - have increased in abundance since the earliest collection records; whereas, pugnose minnow (*Opsopoeodus emiliae*) and western mosquitofish (*Gambusia affinis*) have significantly declined (Bonner and Runyan 2007). Seventeen species showed stable populations while the rest had indeterminable changes. Only five non-native species were reported in the earliest records; whereas, now there are 17. In recent TIFP fish collections (2006-2008), over 40 species of fish were collected in the lower San Antonio River sub-basin. 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*).

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

2.3.1 *Fisheries*

Fish habitat utilization data were collected during August 2009–August 2010 (Table 1). To ensure coverage of a wide range of base flow conditions, collections were made whenever the flows were near predetermined target levels which represented low, moderate, and high base flows based on hydrological statistics. As of the deadline for report preparation, low flow fish habitat utilization sampling at the Goliad and Hwy 77 sites had not been conducted due to conditions not being available. However, sampling during these low flow conditions did occur during August 2011 and will be analyzed for inclusion in the next edition of the instream flow recommendations report to be prepared by the TIFP in the future.

Table 1. Date and discharge from the nearest USGS gage for each fish habitat utilization sampling trip at each site during each target flow level.

Target Flow Range	Site	Date	Discharge (cfs)
LOW	Cibolo Creek	8/27/2009	10
	Calaveras	8/11/2009	95
	Falls City	9/1/2009	75
	Goliad		
	Hwy. 77		
MODERATE	Cibolo Creek	8/26/2010	23
	Calaveras	6/22/2010	254
	Falls City	8/3/2010	250
	Goliad	8/5/2010	300
	Hwy. 77	8/12/2010	320
HIGH	Cibolo Creek	11/12/2009	66
	Calaveras	3/30/2010	421
	Falls City	3/10/2010	475
	Goliad	3/31/2010	558
	Hwy. 77	4/7/2010	591

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 approximately one meter) boat electrofishing was typically used. Seining was typically employed to most effectively sample shallower 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 2-3 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.

During each sampling event, a stratified random sampling approach was used to sample each hydromorphological unit (HMU) and substrate combination in proportion to its relative availability. To capture a snapshot of HMU distribution within each study site at the time of sampling, GPS-based HMU maps (Figure 7) 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.

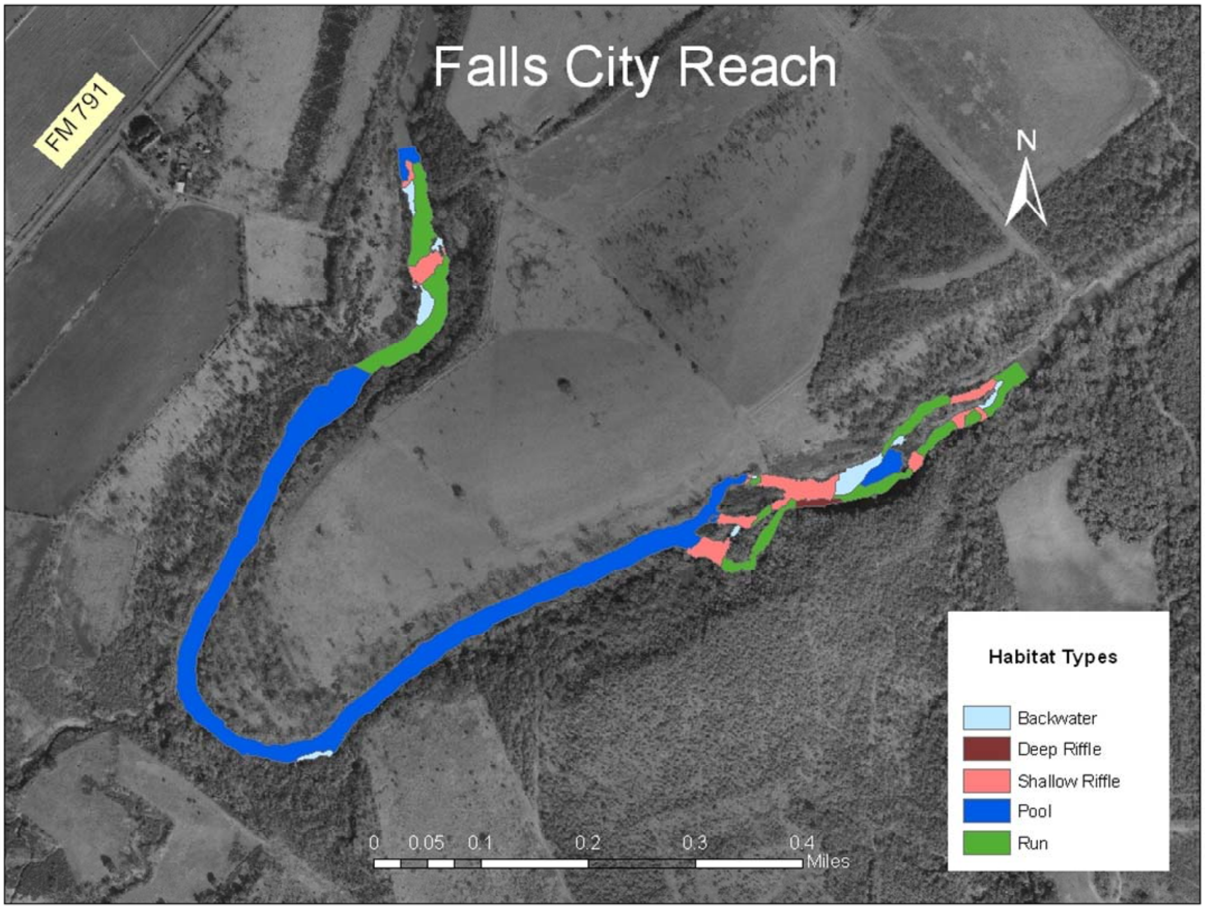


Figure 7. Mesohabitat map for the Falls City Study Site.

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 which 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 onto a GPS unit which was used to locate sampling areas in the field. After sampling areas were located with GPS, estimates of depth, velocity, and substrate were taken 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 redistribute 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.

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

Upon completion of fish sampling, velocity (ft/s), depth (ft), 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. Physicochemical water quality field parameters 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 (HSC) Development

Fishes were collected at 249 separate sample areas distributed among multiple HMU-substrate combinations at five study sites across a wide range of base flow conditions. This resulted in capture of 23,722 individual fish representing 15 families and 43 species (Table 2).

Eight 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 *Poecilia formosa*, Rio Grande cichlid *Cichlasoma cyanoguttatum*, and blue tilapia *Oreochromis aureus*) were considered introduced or exotic 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 5 or more individuals were included in the analysis. This excluded six additional species: freshwater drum (*Aplodinotus grunniens)*, redear sunfish (*Lepomis microlophus)*, white crappie (*Pomoxis annularis)*, American eel (*Anguilla rostrata)*, threadfin shad (*Dorosoma petenense)*, and golden shiner (*Notemigonus crysoleucas)*. One exception was made for pugnose minnow (*Opsopoeodus emiliae)*, which was represented by eight individuals at three sample areas, but was included in the analysis since it was labeled as a key indicator species for the study (TIFP 2010). American eel was also identified as an indicator species, but only one individual was collected and thus, not applicable for this analysis.

Table 2. Number (#) and relative abundance (%) of fishes collected from five sites during the Lower San Antonio River and Lower Cibolo Creek Instream Flow Study.

Family	Common Name	Scientific Name	Calaveras		Cibolo Creek		Falls City		Goliad		Hwy 77		Total	
			#	%	#	%	#	%	#	%	#	%	#	%
Anguillidae	American eel	*Anguilla rostrata*							1	**0.0**			1	**0.0**
Lepisosteidae	Spotted gar	*Lepisosteus oculatus*	3	**0.1**	5	**0.2**	1	**0.0**	2	**0.0**	1	**0.1**	12	**0.1**
	Longnose gar	*Lepisosteus osseus*	9	**0.4**	1	**0.0**	3	**0.0**	4	**0.1**	5	**0.4**	22	**0.1**
Clupeidae	Gizzard shad	*Dorosoma cepedianum*	6	**0.3**	11	**0.4**	14	**0.1**	33	**0.8**	1	**0.1**	65	**0.3**
	Threadfin shad	*Dorosoma petenense*							5	**0.1**			5	**0.0**
Cyprinidae	Central stoneroller	*Campostoma anomalum*	41	**1.7**			4	**0.0**					45	**0.2**
	Red shiner	*Cyprinella lutrensis*	957	**40.8**	968	**34.8**	6277	**48.0**	2947	**70.5**	1067	**79.6**	12216	**51.5**
	Blacktail shiner	*Cyprinella venusta*	758	**32.3**			37	**0.3**					795	**3.4**
	Common carp	*Cyprinus carpio*	3	**0.1**									3	**0.0**
	Burrhead chub	*Macrhybopsis marconis*	9	**0.4**			94	**0.7**	58	**1.4**	2	**0.1**	163	**0.7**
	Golden shiner	*Notemigonus crysoleucas*									3	**0.2**	3	**0.0**
	Ghost shiner	*Notropis buchanani*					221	**1.7**	46	**1.1**	25	**1.9**	292	**1.2**
	Mimic shiner	*Notropis volucellus*			406	**14.6**	26	**0.2**					432	**1.8**
	Pugnose minnow	*Opsopoeodus emiliae*							2	**0.0**	6	**0.4**	8	**0.0**
	Bullhead minnow	*Pimephales vigilax*	88	**3.8**	24	**0.9**	4128	**31.6**	729	**17.4**	43	**3.2**	5012	**21.1**
Catostomidae	Smallmouth buffalo	*Ictiobus bubalus*	2	**0.1**			1	**0.0**	8	**0.2**	5	**0.4**	16	**0.1**
	Gray redhorse	*Moxostoma congestum*	3	**0.1**	20	**0.7**					1	**0.1**	24	**0.1**
Characidae	Mexican tetra	*Astyanax mexicanus*	1	**0.0**	15	**0.5**	31	**0.2**	10	**0.2**	4	**0.3**	61	**0.3**
Ictaluridae	Blue catfish	*Ictalurus furcatus*					4	**0.0**	3	**0.1**	38	**2.8**	45	**0.2**
	Channel catfish	*Ictalurus punctatus*	120	**5.1**	123	**4.4**	356	**2.7**	26	**0.6**	9	**0.7**	634	**2.7**
	Tadpole madtom	*Noturus gyrinus*	2	**0.1**	2	**0.1**	1	**0.0**					5	**0.0**
	Flathead catfish	*Pylodictis olivaris*	9	**0.4**	4	**0.1**	32	**0.2**	25	**0.6**	18	**1.3**	88	**0.4**
Loricariidae	Armadillo del rio	*Hypostomus plecostomus*	6	**0.3**			3	**0.0**					9	**0.0**
	Suckermouth armored catfish	*Pterygoplichthys anisitsi*	60	**2.6**			25	**0.2**					85	**0.4**
Mugilidae	Striped mullet	*Mugil cephalus*							7	**0.2**	13	**1.0**	20	**0.1**
Atherinopsidae	Inland silverside	*Menidia beryllina*					8	**0.1**	1	**0.0**			9	**0.0**
Poeciliidae	Western mosquitofish	*Gambusia affinis*	23	**1.0**	289	**10.4**	745	**5.7**	73	**1.7**	37	**2.8**	1167	**4.9**
	Amazon molly	*Poecilia formosa*					651	**5.0**	12	**0.3**			663	**2.8**
	Sailfin molly	*Poecilia latipinna*	9	**0.4**	56	**2.0**	124	**0.9**	3	**0.1**	1	**0.1**	193	**0.8**
Centrarchidae	Green sunfish	*Lepomis cyanellus*	8	**0.3**	25	**0.9**	8	**0.1**	7	**0.2**			48	**0.2**
	Warmouth	*Lepomis gulosus*	2	**0.1**			3	**0.0**			3	**0.2**	8	**0.0**
	Orangespotted sunfish	*Lepomis humilis*							36	**0.9**	4	**0.3**	40	**0.2**
	Bluegill	*Lepomis macrochirus*	30	**1.3**	85	**3.1**	10	**0.1**	21	**0.5**	7	**0.5**	153	**0.6**
	Longear sunfish	*Lepomis megalotis*	97	**4.1**	612	**22.0**	115	**0.9**	85	**2.0**	43	**3.2**	952	**4.0**
	Redear sunfish	*Lepomis microlophus*							2	**0.0**			2	**0.0**
	Spotted bass	*Micropterus punctulatus*	28	**1.2**	21	**0.8**	9	**0.1**	8	**0.2**			66	**0.3**
	Largemouth bass	*Micropterus salmoides*	2	**0.1**	5	**0.2**	1	**0.0**	9	**0.2**			17	**0.1**
	White crappie	*Pomoxis annularis*							2	**0.0**	3	**0.2**	5	**0.0**
Percidae	Texas logperch	*Percina carbonaria*	7	**0.3**	16	**0.6**							23	**0.1**
	River darter	*Percina shumardi*			28	**1.0**			15	**0.4**			43	**0.2**
Scianidae	Freshwater drum	*Aplodinotus grunniens*							1	**0.0**	2	**0.1**	3	**0.0**
Cichlidae	Rio Grande cichlid	*Cichlasoma cyanoguttatum*	63	**2.7**	65	**2.3**	137	**1.0**					265	**1.1**
	Blue tilapia	*Oreochromis aureus*					4	**0.0**					4	**0.0**
	Total		**2346**		**2781**		**13073**		**4181**		**1341**		**23722**	
	Species Richness		**27**		**21**		**30**		**30**		**24**		**43**	

Many species of fish are thought to change 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 (Figure 8). This analysis demonstrated that individuals of all species less than 20 mm in total length tended to inhabit shallow slow-velocity habitats. Individuals in this category were typically post-larval and early-juvenile, and likely did not possess the swimming abilities required to occupy higher velocity habitats. Therefore, a Larval/Early Juvenile category was created to include all fish less than 20 mm in total length, regardless of species. Excluding all fish less than 20 mm, nine species (gizzard shad *Dorosoma cepedianum*, red shiner *Cyprinella lutrensis*, spotted bass *Micropterus punctulatus*, gray redhorse *Moxostoma congestum*, blacktail shiner *Cyprinella venusta*, flathead catfish *Pylodictis olivaris*, burrhead chub *Macrhybopsis marconis*, bullhead minnow *Pimephales vigilax*, and channel catfish *Ictalurus punctatus*) exhibited size-dependent changes in habitat use, and were thus split into two additional size classes for further analysis. Data from two of these species (burrhead chub and bullhead minnow) were later recombined when both life stages fell into the same habitat utilization guilds. Best professional judgment was used to develop juvenile/adult breaks for depth/velocity utilization, as illustrated in Figure 8. Appendix A contains similar graphs for every species examined. After eight exotic species were excluded, six rare species removed, and eight new life stage categories defined, 22,420 fishes were grouped into 37 species/life stage categories and used in habitat guild analysis.

Generating habitat suitability criteria (HSC) for 37 individual species/life stage categories would complicate interpretation of study results, yet basing flow recommendations on the needs of a few key species may be 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 is 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, simplifies 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 2008a).

To create the guilds, habitat conditions were characterized for each sample area (N=249) by calculating the mean of the depth and velocity data for the five individual measurements taken at each sampling area. Mean depth and velocity, along with dominant surficial substrate, Froude number, Edge or Mid-Channel, and presence/absence of large woody debris (LWD), were combined with abundance data from each species/life stage and summarized in a Canonical Correspondence Analysis (CCA). Based on the resulting CCA ordination plot the 37 species/life stage categories were visually grouped into six habitat guilds (Figure 9). 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, BIO-WEST) were used to make final guild determination. The species/life stage categories and number of each collected within each of the resulting habitat guilds are presented in Table 3.

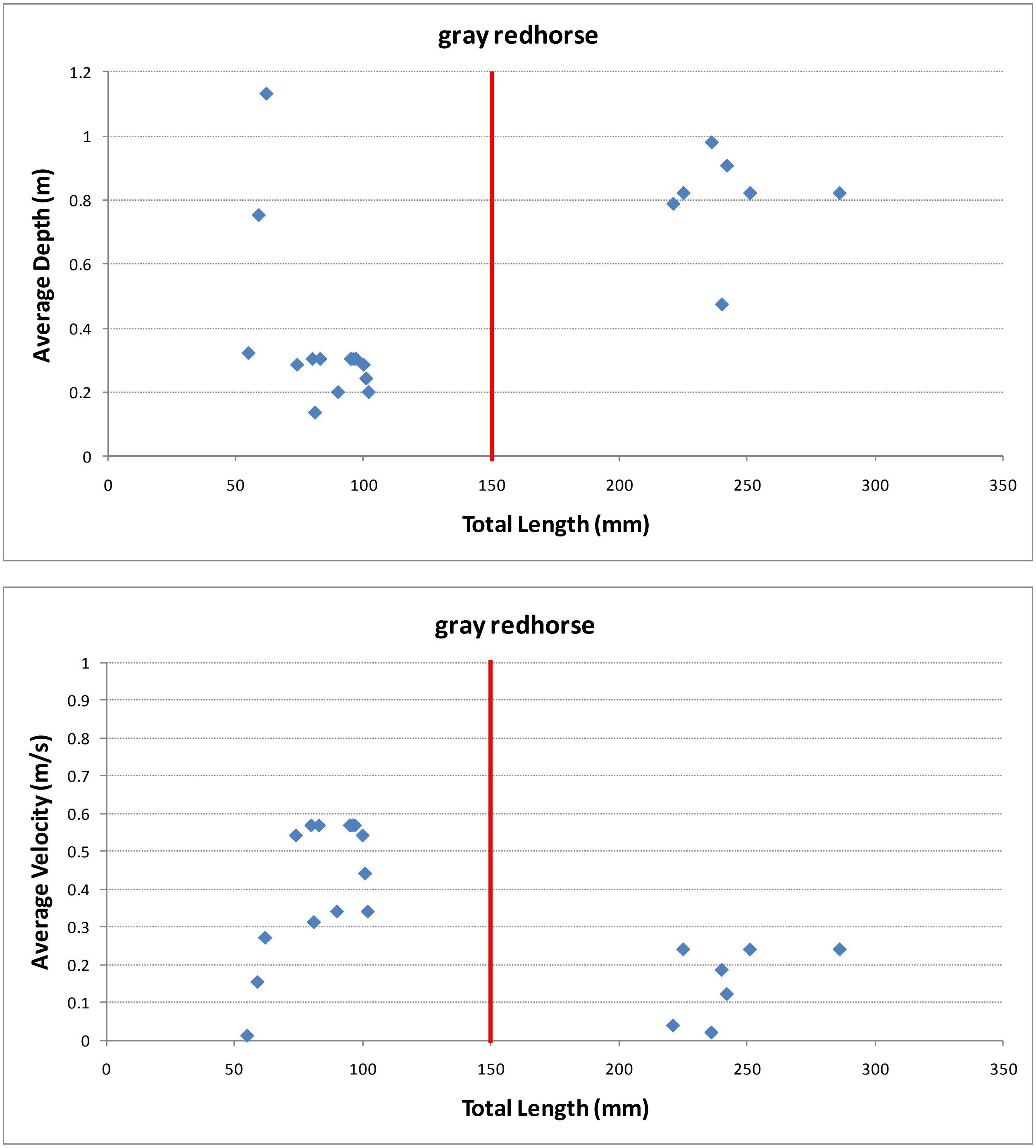


Figure 8. Example of size-dependent habitat utilization analysis for gray redhorse. The red line indicates the resulting boundary between juvenile and adult life stage categories.

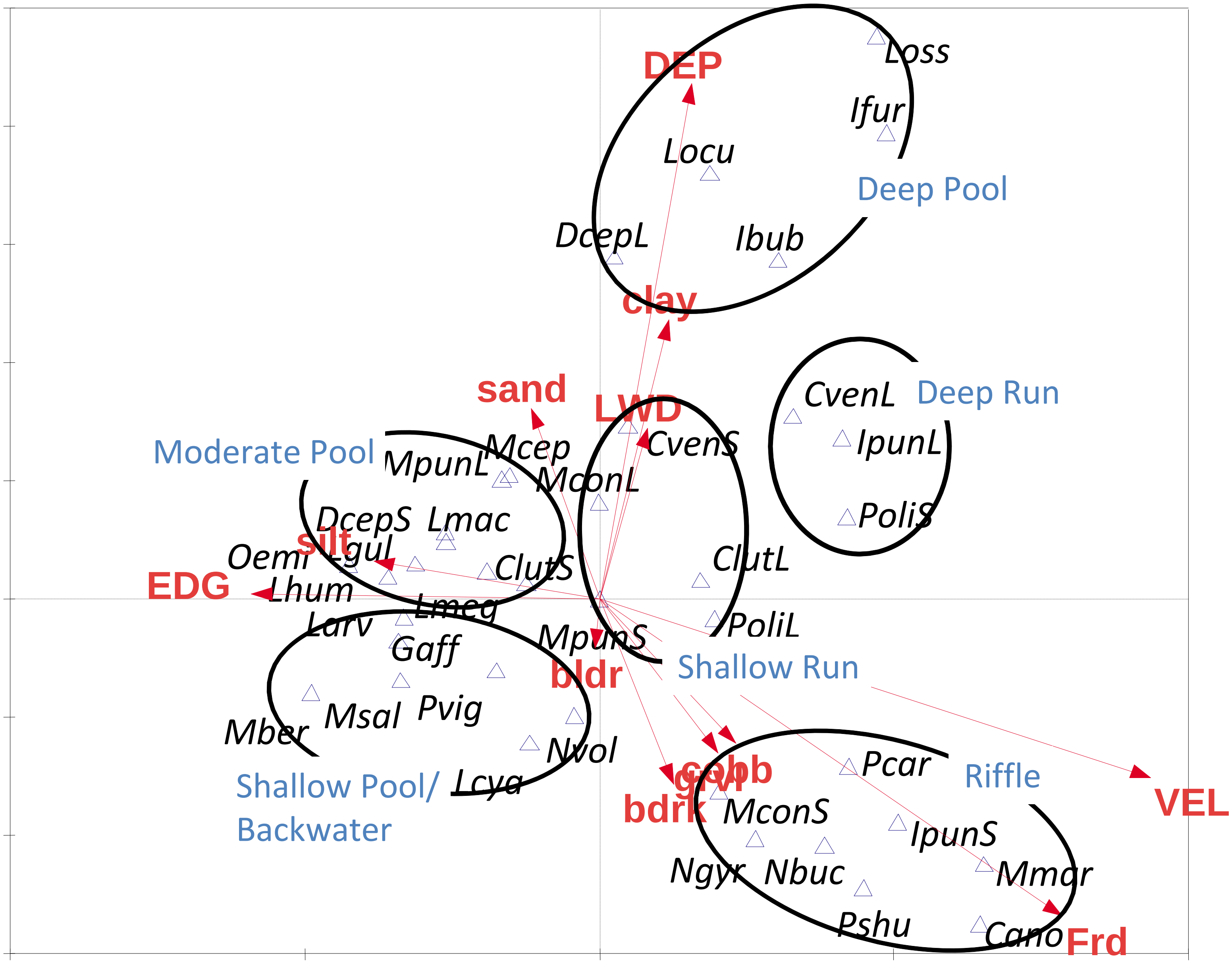


Figure 9. Multivariate ordination plot showing species associations among gradients of depth, velocity, substrate, edge, Froude number, and large woody debris (LWD). Black circles encompass habitat guilds. Species/life stage abbreviations are provided in Table 3.

Table 3. Number of locations observed and total number of individuals observed for each habitat guild and their component species/life stage categories.

Habitat Guild	Species/Life Stage		Species/Life Stage Abbreviation	Number of Locations Observed	Total Number Observed
Deep Pool	Spotted gar	*Lepisosteus oculatus*	*Locu*	11	12
	Longnose gar	*Lepisosteus osseus*	*Loss*	16	22
	Blue catfish	*Ictalurus furcatus*	*Ifur*	17	45
	Smallmouth buffalo	*Ictiobus bubalus*	*Ibub*	13	16
	Gizzard shad (adult)	*Dorosoma cepedianum* (>200 mm)	*DcepL*	15	33
	Guild Total			**57**	**128**
Moderate Pool	Red shiner (juvenile)	*Cyprinella lutrensis* (21-30 mm)	*ClutS*	109	4438
	Gizzard shad (juvenile)	*Dorosoma cepedianum* (21-200 mm)	*DcepS*	9	32
	Striped mullet	*Mugil cephalus*	*Mcep*	7	20
	Spotted bass (adult)	*Micropterus punctulatus* (>125 mm)	*MpunL*	15	19
	Longear sunfish	*Lepomis megalotis*	*Lmeg*	140	940
	Warmouth	*Lepomis gulosus*	*Lgul*	8	8
	Orangespotted sunfish	*Lepomis humilis*	*Lhum*	13	40
	Bluegill	*Lepomis macrochirus*	*Lmac*	59	150
	Pugnose minnow	*Opsopoeodus emiliae*	*Oemi*	3	8
	Guild Total			**192**	**5655**
Shallow Pool/Backwater	Western mosquitofish	*Gambusia affinis*	*Gaff*	61	765
	Inland silverside	*Menidia beryllina*	*Mber*	5	8
	Bullhead minnow	*Pimephales vigilax*	*Pvig*	100	4618
	Largemouth bass	*Micropterus salmoides*	*Msal*	11	17
	Green sunfish	*Lepomis cyanellus*	*Lcya*	22	48
	Mimic shiner	*Notropis volucellus*	*Nvol*	16	397
	Larval/Early Juvenile	All species (<20 mm)	*Larv*	56	2816
	Guild Total			**149**	**8669**
Shallow Run	Gray redhorse (adult)	*Moxostoma congestum* (>150 mm)	*MconL*	5	7
	Spotted bass (juvenile)	*Micropterus punctulatus* (21-125 mm)	*MpunS*	30	47
	Red shiner (adult)	*Cyprinella lutrensis* (>30 mm)	*ClutL*	176	5876
	Blacktail shiner (juvenile)	*Cyprinella venusta* (21-30 mm)	*CvenS*	23	219
	Flathead catfish (adult)	*Pylodictis olivaris* (>300 mm)	*PoliL*	7	8
	Guild Total			**195**	**6157**
Deep Run	Blacktail shiner (adult)	*Cyprinella venusta* (>30 mm)	*CvenL*	68	515
	Channel catfish (adult)	*Ictalurus punctatus* (>180 mm)	*IpunL*	18	21
	Flathead catfish (juvenile)	*Pylodictis olivaris* (21-300 mm)	*PoliS*	43	80
	Guild Total			**111**	**616**
Riffle	Gray redhorse (juvenile)	*Moxostoma congestum* (21-150 mm)	*MconS*	7	17
	Burrhead chub	*Macrhybopsis marconis*	*Mmar*	33	163
	Tadpole madtom	*Noturus gyrinus*	*Ngyr*	5	5
	Central stoneroller	*Campostoma anomalum*	*Cano*	6	45
	River darter	*Percina shumardi*	*Pshu*	10	43
	Texas logperch	*Percina carbonaria*	*Pcar*	8	23
	Channel catfish (juvenile)	*Ictalurus punctatus* (21-180 mm)	*IpunS*	50	607
	Ghost shiner	*Notropis buchanani*	*Nbuc*	20	292
	Guild Total			**86**	**1195**

Habitat data from all species/life stage categories within a particular guild were combined to generate frequency histograms for the continuous variables depth and velocity. Data were binned using 0.1 meter (m) increments for depth and 0.1 meter/second (m/s) increments for velocity. Suitability criteria were then created using nonparametric tolerance limits (NPTL) based on the central 50%, 75%, 90%, and 95% of the data (Bovee 1986). Values for NPTL were interpolated or extrapolated from the table provided in Somerville (1958) using a 0.95 confidence level. 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.

Habitat suitability criteria 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.

Initial depth, velocity, and substrate HSC were developed for each habitat guild and were reviewed by study team biologists (fisheries biologists from TPWD, TCEQ, and BIO-WEST). As a result of this review, several HSC modifications were made based on the professional judgment and previous experience of study team biologists. First, minimum depth criteria of approximately one inch (0.025 meters) were established for all guilds with non-zero suitability at depths less than 0.1 meters (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 (gar, blue catfish *Ictalurus furcatus*, smallmouth buffalo *Ictiobus bubalus*, 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 Pools was modified to exhibit a suitability of 1.0 for all depths of approximately 2.95 feet (0.9 m) or greater (Figure 10). Similarly, to account for sampling limitations, the tail of the Deep Run HSC curve was also extended (Figure 11).

Additionally, the data-generated HSC values for substrate in the Riffle guild were modified by the study team biologists based on professional judgment. Fish habitat utilization data used to generate Riffle guild HSC were dominated by a large number of burrhead chub and juvenile channel catfish captured in shallow bedrock riffles at the Falls City site. As a result, initial HSC values for substrate in the Riffle guild showed high utilization of bedrock (suitability of 1.0) and rather low utilization of gravel and cobble substrates (0.71 and 0.34, respectively). Since gravel and cobble substrates were known to be highly important to darter species within the guild (river darter *Percina shumardi* and Texas logperch *Percina carbonaria*), the suitability of these substrates was raised to 1.0. Similarly, life history data and previous experience with darters in this guild suggested an avoidance of silt habitats, and therefore, the suitability of silt was dropped from 0.14 to 0.0 (Figure 12).

Study team biologists felt that HSC modifications described above more accurately represented the utilization patterns of each habitat guild, and these modifications were accepted by group consensus. Figures 10-15 demonstrate final HSC curves for depth and velocity, as well as final HSC values for substrate categories per fish habitat guild. Original curves/values are noted wherever modifications were made.

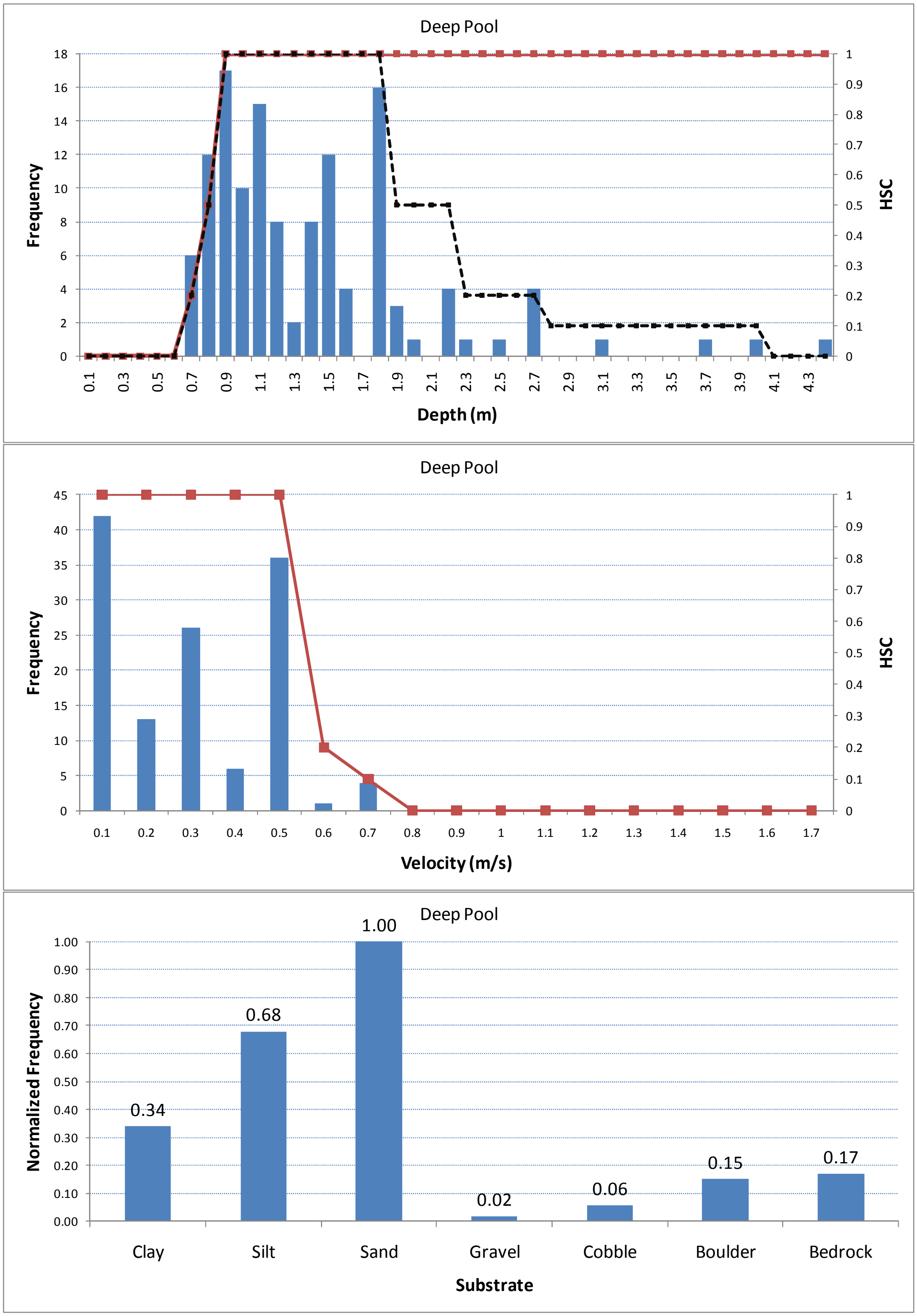


Figure 10. Frequency distribution and resulting HSC values for the Deep Pool Fish Habitat Guild. Dotted black line indicates original depth HSC curve, whereas solid red line indicates final modified curve.

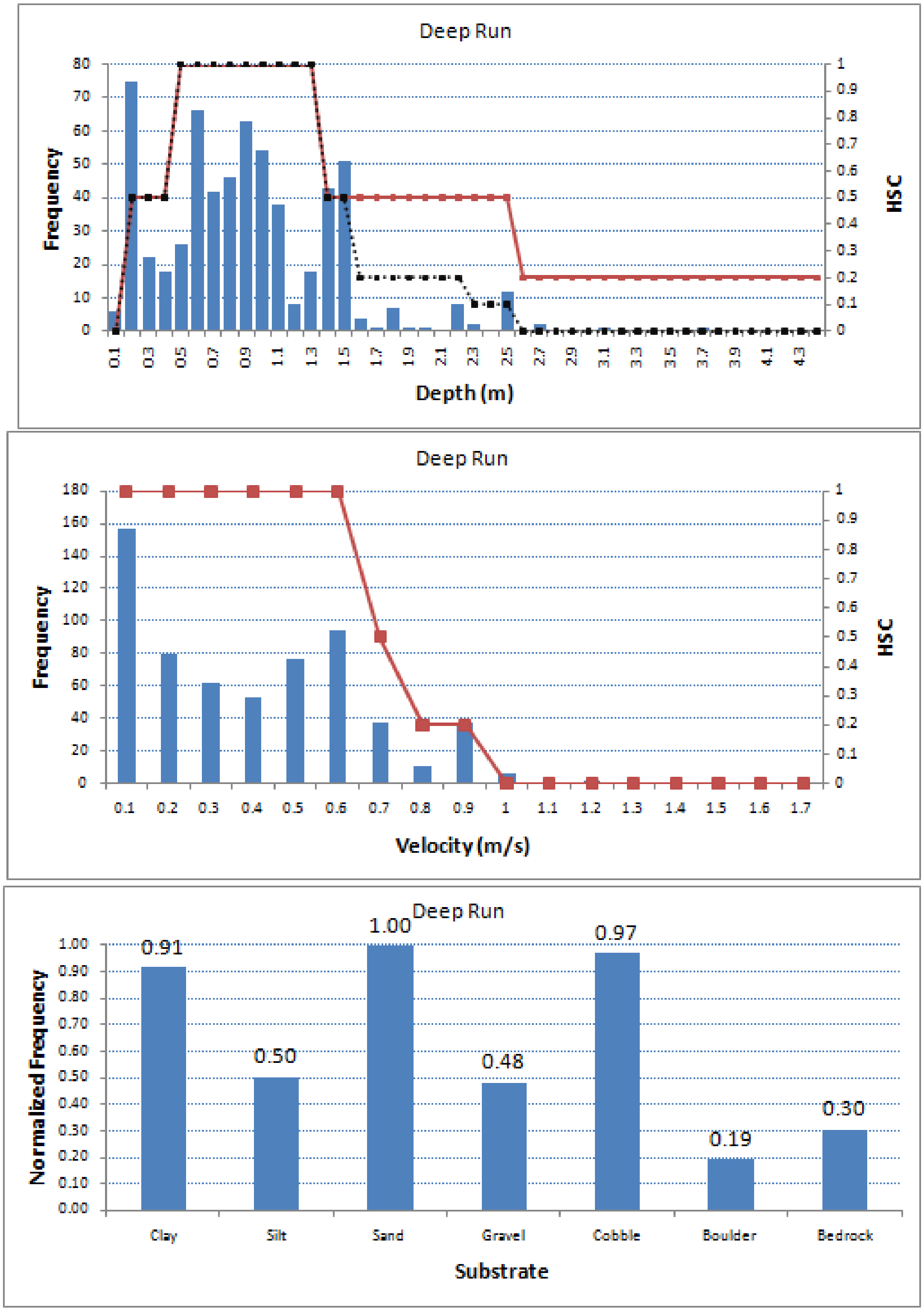


Figure 11. Frequency distribution and resulting HSC for the Deep Run Fish Habitat Guild. Dotted black line indicates original depth HSC curve, whereas solid red line indicates final modified curve.

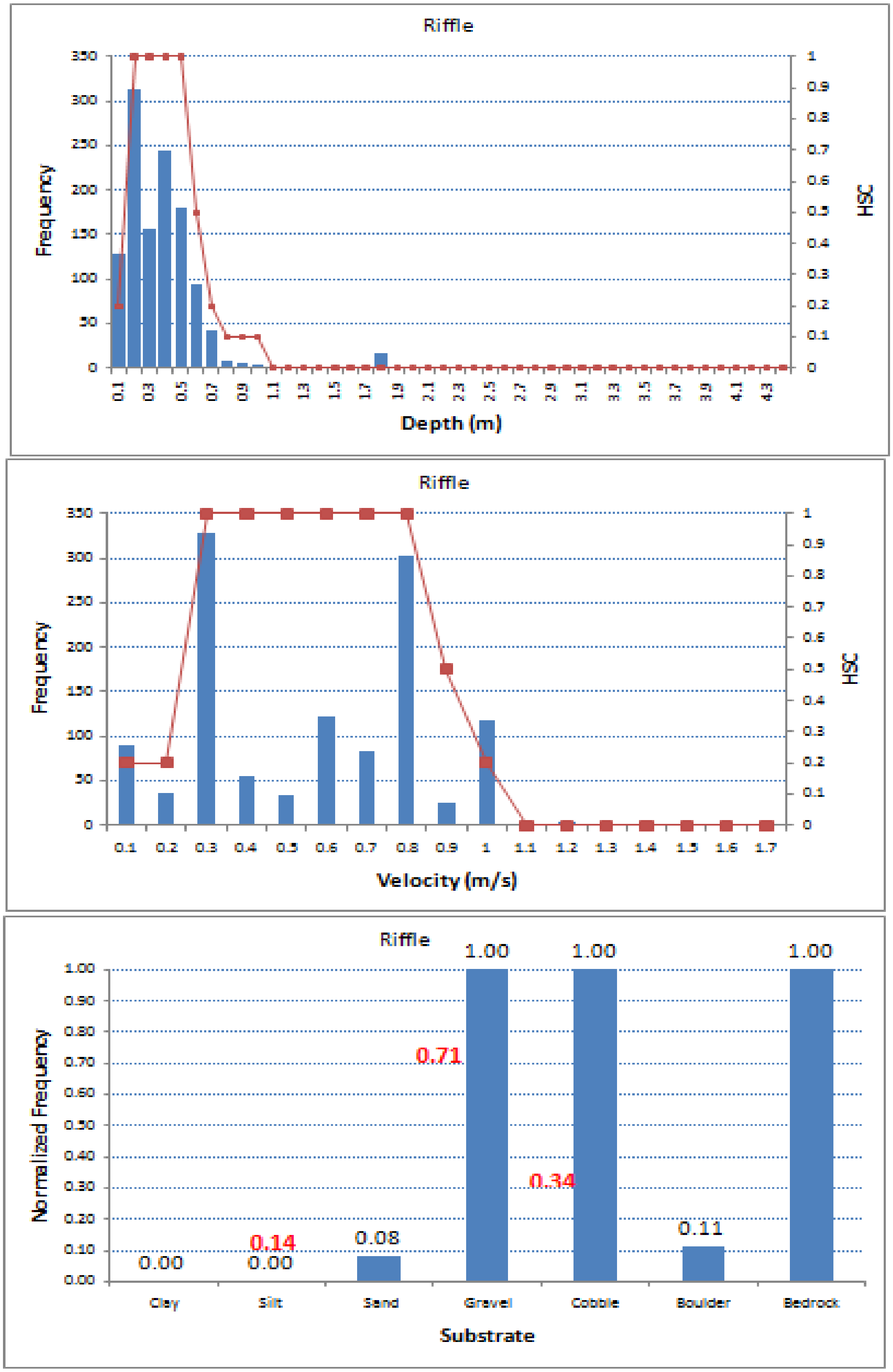


Figure 12. Frequency distribution and resulting HSC for the Riffle Fish Habitat Guild. Original substrate HSC values indicated in red.

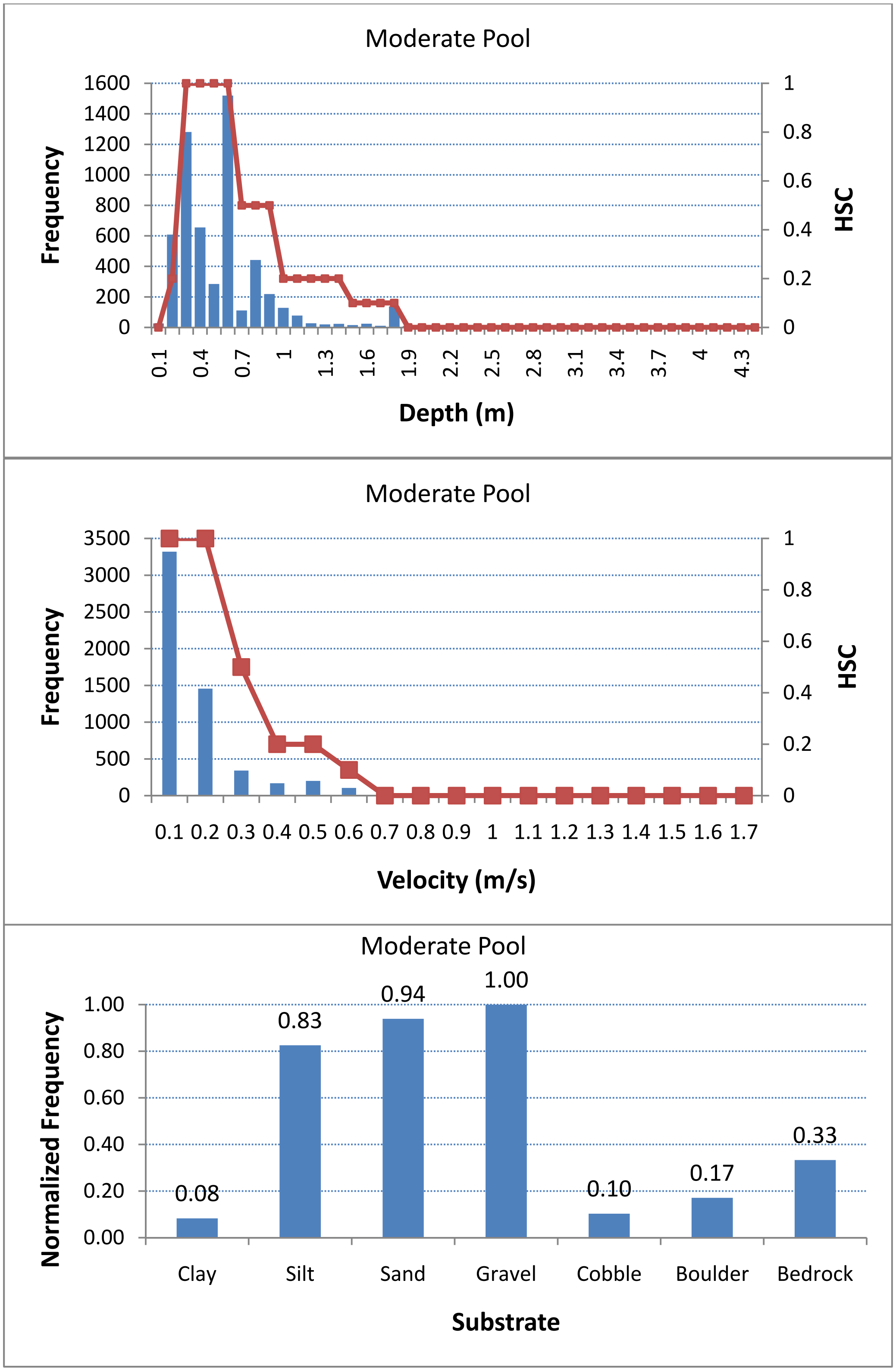


Figure 13. Frequency distribution and resulting HSC values for the Moderate Pool Fish Habitat Guild.

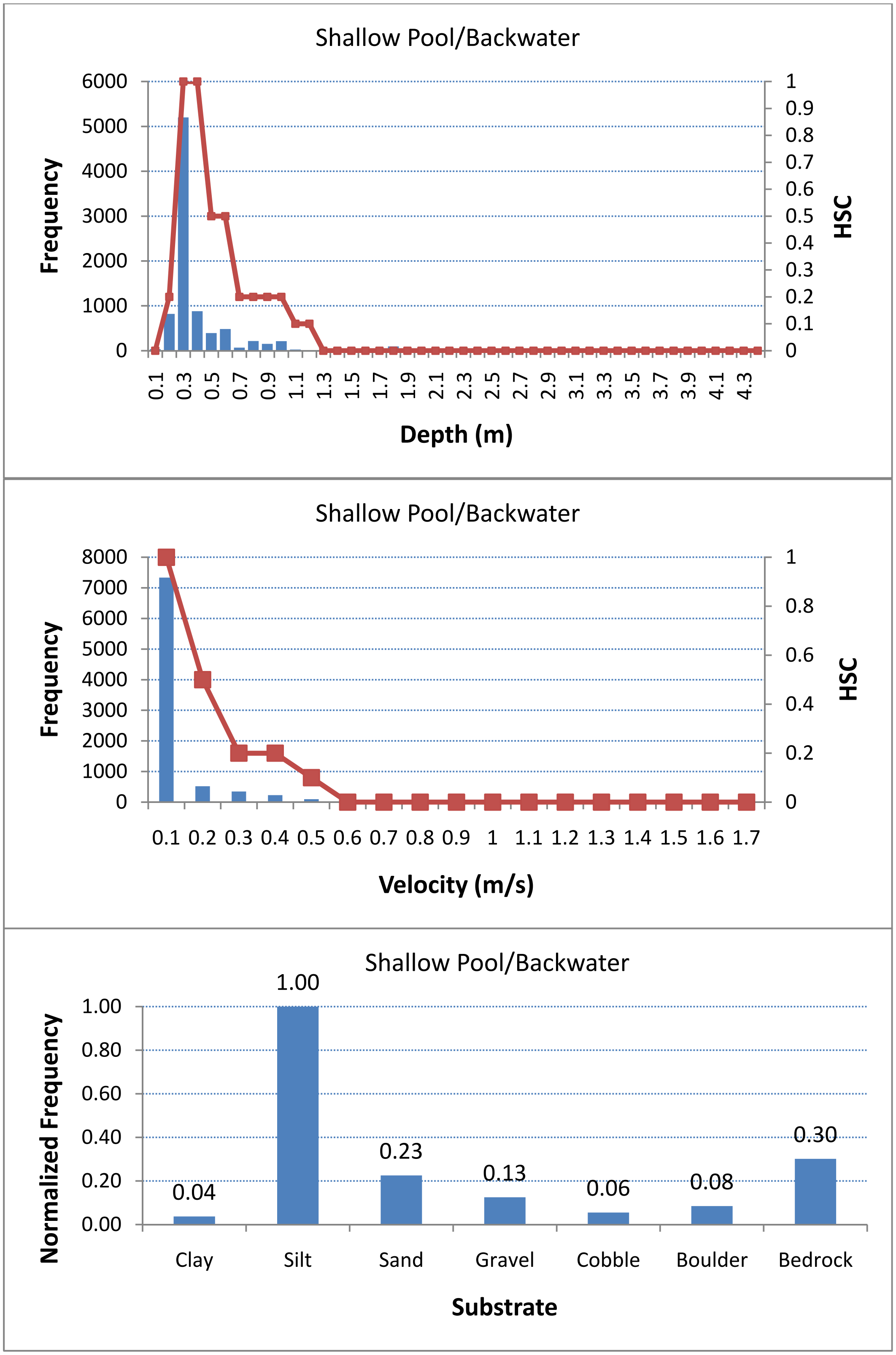


Figure 14. Frequency distribution and resulting HSC values for the Shallow Pool/Backwater Fish Habitat Guild.

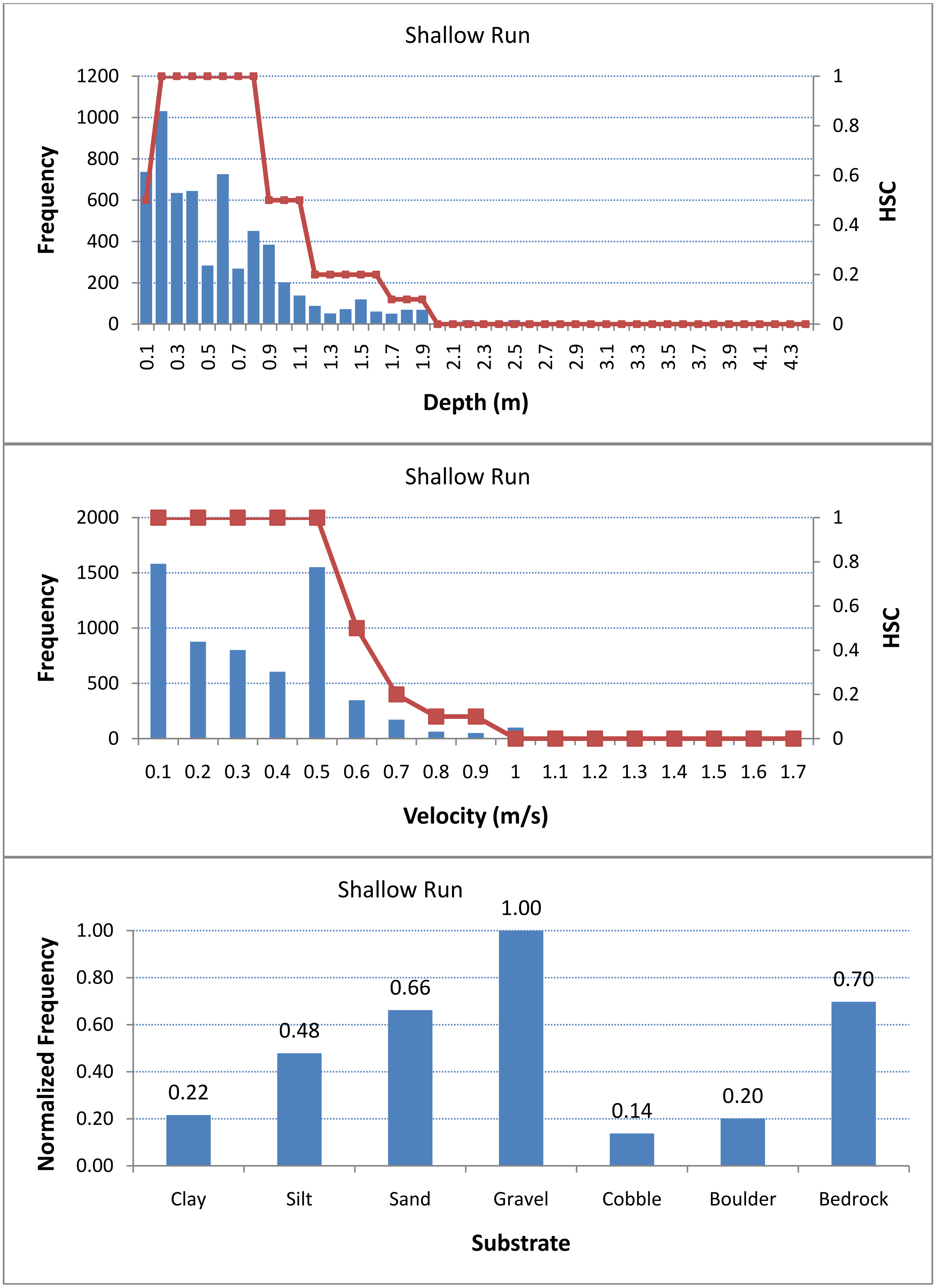


Figure 15. Frequency distribution and resulting HSC for the Shallow Run Fish Habitat Guild.

Calculating Weighted Usable Area

Final HSC curves for each habitat guild were then applied to hydraulic model output to generate Weighted Usable Area (WUA) to 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 for 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 to discharge curves (Figure 16).

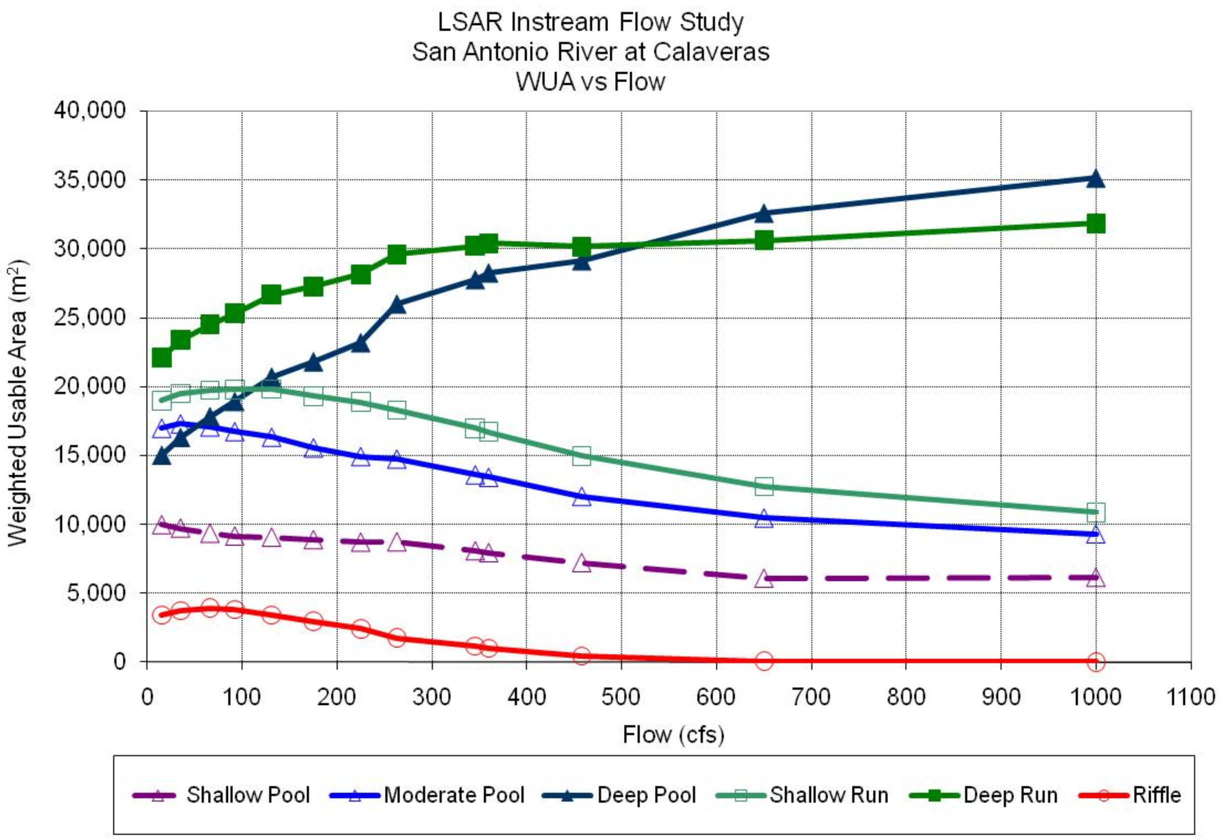


Figure 16. Weighted Usuable Area versus simulated discharge at Calaveras Study Site.

One drawback to the above graph is that changes in Deep Run habitat are of much greater magnitude than changes in Riffle habitat. As a result, 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 17).

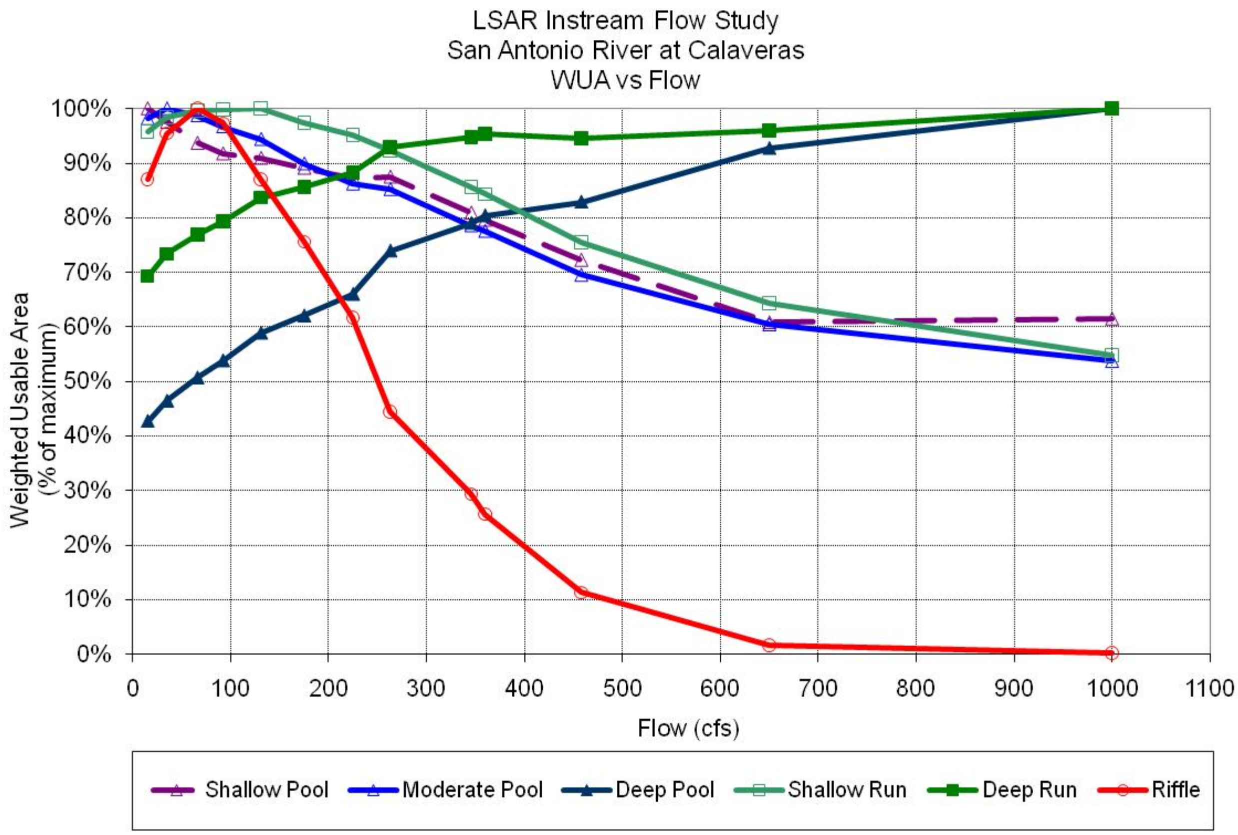


Figure 17. Percent of Maximum Habitat versus simulated discharge at Calaveras Study Site.

Another consideration when examining WUA results is habitat quality. The graphs above examine total WUA. However, it is possible that large amounts of low-quality habitat contribute substantially, and little high-quality habitat exists. To examine changes in habitat quality, 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 18 shows this analysis for each guild at the Calaveras study site. All WUA curves and displays are presented for all Study Sites in Appendix B.

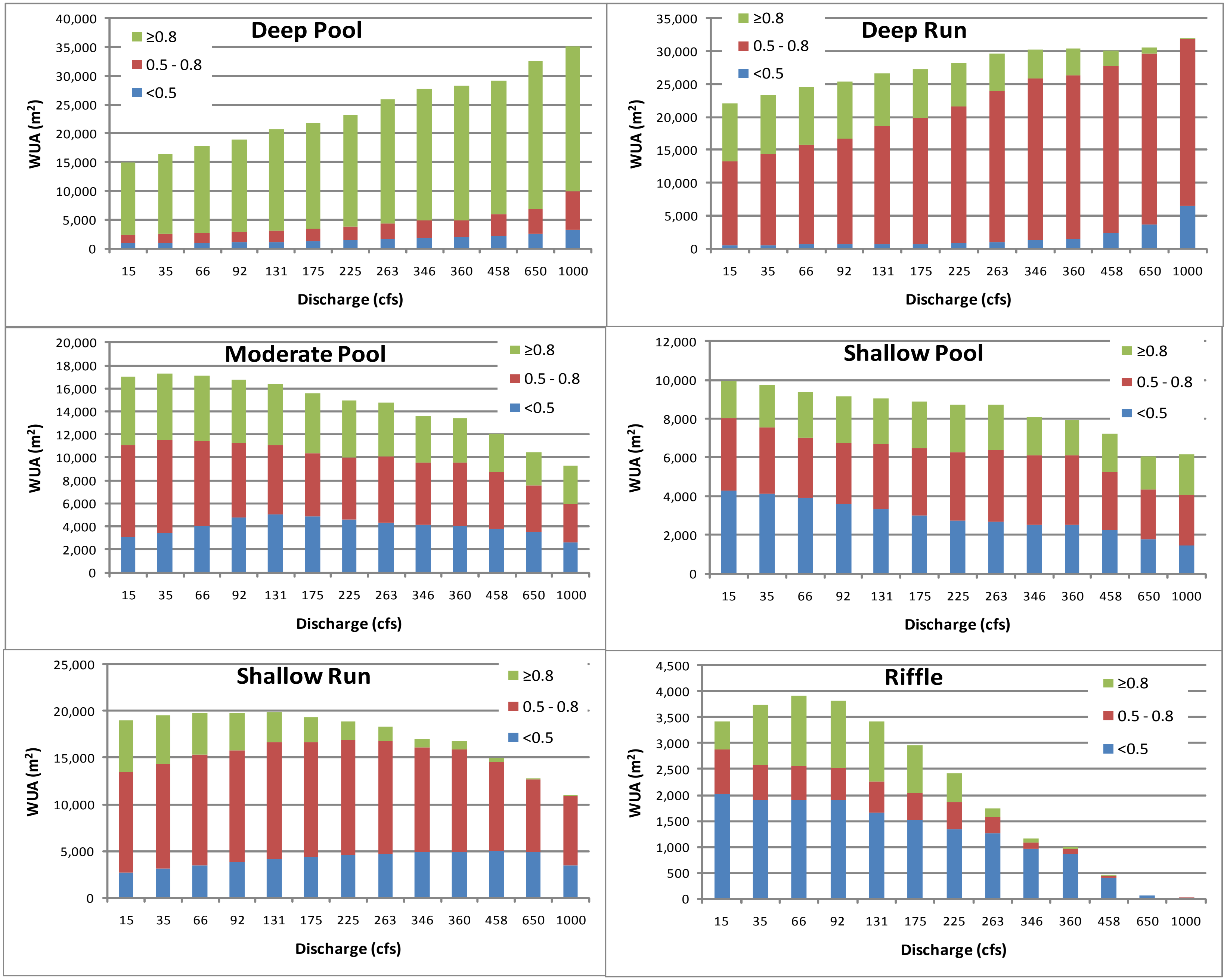


Figure 18. Habitat quality breakout of Weighted Usable Area (WUA) versus simulated discharge at the Calaveras Study Site.

Habitat Time Series

Following the natural flow paradigm, one way to provide context to habitat conditions is to examine how often they occurred in the past. To accomplish this, total WUA to discharge relationships described above were applied to the hydrologic record. The amount of habitat for each habitat guild was calculated using the mean daily flow for each day in the period of record. A resulting habitat time series was constructed for the entire period of record, the pre-1970 period of record, and the post-1970 period of record using the closest USGS gage to each study site. For the Calaveras study site, the flows at the Elmendorf USGS gage only went back to 1962. Therefore, mean daily flows from 1926 – 1962 were estimated for this site via a correction factor following a comparison of the flows from 1962 – 2009 for the Elmendorf and Falls City gages which had an R^2 of 0.89. A one-day offset for travel time was also incorporated in the estimate.

As highlighted for Goliad in Figure 19, obvious differences existed in the pre-1970 and post-1970 hydrology datasets for the lower San Antonio River. Higher flows in the post-1970 period were attributed to much wetter climactic conditions observed over this period, as well as increased base flows resulting from wastewater return flows (TIFP 2010). However, in order to capture the entire variation in flows that the system has experienced, the entire period of record was used for all subsequent habitat time series analysis.

Figure 19. Median of daily streamflow values for USGS gage 08188500, San Antonio River at Goliad.

Habitat time series information was summarized in percentile tables such as Table 4 for the Calaveras study site. Once habitat percentiles were available, the next step was to calculate the flow conditions necessary to meet various habitat percentiles for all guilds simultaneously. These flows were back-calculated using previously-discussed WUA to discharge curves and are provided on the far right in Table 4. Since high amounts of Deep Pool habitat are created during high flow conditions, and high amounts of shallow habitat types like Riffle and Shallow Run are created during low flow conditions, the 50th percentile and above of all habitat types could not be met with one flow. These conditions are labeled "unattainable" in the table. However, the 49^{th} percentile of all habitat guilds could be met or exceeded with a flow of 221 cfs. Similarly, the 20^{th} percentile of all habitat guilds could be met or exceeded with flows ranging from 116 to 401 cfs. As percentiles decrease, habitat thresholds become easier to meet, and thus can be accomplished by a wider range of flow conditions.

Based on this habitat time series analysis for the entire period of record at the Calaveras study site, a flow of 221 cfs provides the highest habitat percentile for all guilds that can be created simultaneously. This diverse habitat condition was used to approximate a base average flow target level, whereas base dry conditions would benefit shallow habitats (Riffle) more and base wet conditions would benefit deeper habitats (Deep Pool) more. Additional details on this analysis are provided in Section 3.0, with similar tables for all sites provided in Appendix C.

Spatial Output

Spatial output of habitat model results was also analyzed to assess habitat conditions at particular areas of interest and evaluate habitat connectivity. Maps of Riffle habitat under two different flow rates at the upper portion of the Calaveras study site are presented in Figure 20 as an example.

Table 4. Habitat Time Series results for Calaveras Study Site (WUA – top table, Percent of Maximum WUA – lower table).

Percentile	Percent Exceedance	Calaveras - Weighted Usable Area (m^2)						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	17,305	35,146	31,863	9,937	19,820	3,922	unattainable*	
0.999	0.1	17,304	35,131	31,856	9,826	19,820	3,922	unattainable*	
0.99	1	17,240	34,625	31,607	9,616	19,818	3,911	unattainable*	
0.975	2.5	17,168	33,921	31,260	9,492	19,815	3,899	unattainable*	
0.95	5	17,067	33,024	30,819	9,329	19,810	3,875	unattainable*	
0.925	7.5	16,946	32,017	30,532	9,263	19,807	3,847	unattainable*	
0.9	10	16,839	30,847	30,390	9,204	19,803	3,823	unattainable*	
0.8	20	16,498	28,628	30,259	9,103	19,749	3,572	unattainable*	
0.75	25	16,275	28,261	30,194	9,055	19,667	3,376	unattainable*	
0.7	30	15,977	27,364	30,075	8,985	19,549	3,203	unattainable*	
0.6	40	15,433	26,142	29,653	8,850	19,207	2,848	unattainable*	
0.5	50	14,935	23,202	28,146	8,727	18,873	2,420	unattainable*	
0.49	51	14,916	23,088	28,075	8,726	18,812	2,349	221	221
0.4	60	14,663	22,111	27,468	8,674	18,188	1,695	186	270
0.3	70	13,873	21,222	26,964	8,221	17,275	1,287	152	327
0.25	75	13,431	20,792	26,733	7,941	16,719	1,007	135	360
0.2	80	12,852	20,007	26,147	7,636	15,990	771	116	401
0.1	90	11,270	18,616	25,088	6,649	13,873	257	85	553
0.05	95	10,281	17,897	24,575	6,117	12,432	56	68	642
0.025	97.5	9,875	17,233	24,081	6,091	11,776	36	54	832
0.01	99	9,555	16,750	23,720	6,080	11,260	20	44	928
0.001	99.9	9,326	15,792	22,869	6,074	10,890	8	27	998
0.0001	99.99	9,319	15,203	22,277	6,074	10,879	8	18	1000

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

Percentile	Percent Exceedance	Calaveras - Percent of Maximum WUA						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	100%	100%	100%	100%	100%	100%	unattainable*	
0.999	0.1	100%	100%	100%	99%	100%	100%	unattainable*	
0.99	1	100%	99%	99%	97%	100%	100%	unattainable*	
0.975	2.5	99%	97%	98%	96%	100%	99%	unattainable*	
0.95	5	99%	94%	97%	94%	100%	99%	unattainable*	
0.925	7.5	98%	91%	96%	93%	100%	98%	unattainable*	
0.9	10	97%	88%	95%	93%	100%	97%	unattainable*	
0.8	20	95%	81%	95%	92%	100%	91%	unattainable*	
0.75	25	94%	80%	95%	91%	99%	86%	unattainable*	
0.7	30	92%	78%	94%	90%	99%	82%	unattainable*	
0.6	40	89%	74%	93%	89%	97%	73%	unattainable*	
0.5	50	86%	66%	88%	88%	95%	62%	unattainable*	
0.49	51	86%	66%	88%	88%	95%	60%	221	221
0.4	60	85%	63%	86%	87%	92%	43%	186	270
0.3	70	80%	60%	85%	83%	87%	33%	152	327
0.25	75	78%	59%	84%	80%	84%	26%	135	360
0.2	80	74%	57%	82%	77%	81%	20%	116	401
0.1	90	65%	53%	79%	67%	70%	7%	85	553
0.05	95	59%	51%	77%	62%	63%	1%	68	642
0.025	97.5	57%	49%	76%	61%	59%	1%	54	832
0.01	99	55%	48%	74%	61%	57%	0%	44	928
0.001	99.9	54%	45%	72%	61%	55%	0%	27	998
0.0001	99.99	54%	43%	70%	61%	55%	0%	18	1000

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

Figure 20. Spatial output of Riffle habitat quality at two simulated flows for the Calaveras Study Site.

2.3.2 *Mussels*

As discussed in the Study Design (TIFP 2010), baseline mussel surveys were conducted between 2006 and 2007 in order to determine present and historical species richness and distribution (Karatayev and Burlakova 2008). Although these recent surveys have been conducted at a few sporadic locations within the basin, little is known about the abundance and distribution of freshwater mussels in the lower San Antonio River. Therefore, the TIFP commissioned a special study designated at assessing habitat suitability for mussel species in the lower San Antonio River near Goliad. The study was contracted to researchers at the University of North Texas (UNT) and is presently in the process of being initiated. The original goal was to wait for the completion of this focused study prior to any additional TIFP mussel activities in the sub-basin. However, due to contracting delays, it became apparent that the UNT study would not be initiated prior to summer 2011. As such, the TIFP initiated preliminary mussel surveys during fall 2010 to assess the species composition and general abundance within each of the study sites.

Preliminary mussel surveys consisted of personnel doing timed searches throughout each study site. Considerable 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 pulled by a jon boat (Figure 21) 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 was recorded. Details of each preliminary mussel survey are provided below.

Figure 21. Small dredge used for mussel sampling in deep areas.

Calaveras
The Calaveras preliminary mussel survey was conducted on February 23, 2011 from 09:00-12:00. Biologists from TPWD, SARA, and BIO-WEST conducted the survey. Mean daily discharge at the USGS gage on the San Antonio River near Elmendorf (# 08181800) was 218 cfs. A total of 1 live golden orb and 1 live yellow sandshell were found. No mussels were collected using the dredge at this site. Both live mussels were found in the same riffle in gravel/sand substrate. A total of 15 man-hours of searching was conducted resulting in a capture rate of 0.07 mussels/man-hour for both golden orb and yellow sandshell.

Falls City
The preliminary mussel survey at the Falls City site was conducted on February 22, 2011 from 09:30-15:30. Biologists from TPWD, SARA, and BIO-WEST conducted the survey. Mean daily discharge at the USGS gage on the San Antonio River near Falls City (# 08183500) was approximately 249 cfs. A total of 9 live golden orbs and 8 live yellow sandshells 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 man-hours of searching was conducted resulting in a 0.30 mussels/man-hour capture rate for golden orb and 0.27 mussels/man-hour for yellow sandshell.

Goliad
The Goliad preliminary mussel survey was conducted on March 2, 2011 from 11:00-16:00. Biologists from TPWD and BIO-WEST conducted the survey. Mean daily discharge at the USGS gage on the San Antonio River near Goliad (# 08188500) was 316 cfs. A total of 7 live golden orbs, 2 live yellow sandshells, and 2 live threeridges (*Amblema plicata*) were found. No mussels were collected using the dredge at this site. All live mussels were found in gravel/sand substrate in riffles or near woody debris in gravel/sand. A total of 25 man-hours of searching was conducted resulting in a 0.28 mussels/man-hour capture rate for golden orb and 0.08 mussels/man-hour capture rate for both threeridge and yellow sandshell.

Hwy. 77
The Hwy 77 preliminary mussel survey was conducted on March 3, 2011 from 10:00-15:30. Biologists from TPWD and BIO-WEST conducted the survey. Mean daily discharge at the USGS gage on the San Antonio River near McFaddin (# 08188570) was 439 cfs. A total of 8 live golden orbs and 53 live yellow sandshells were found. No mussels were collected using the dredge at this site. All live mussels were found in sand substrate along inside bends or near woody debris. A total of 27.5 man-hours of searching was conducted resulting in a 0.29 mussels/man-hour capture rate for golden orb and a 1.93 mussels/man-hour capture rate for yellow sandshell.

Cibolo Creek
The preliminary mussel survey at the Cibolo Creek site was conducted on August 27, 2010 from 09:00-15:00. Biologists from TPWD, BIO-WEST, and U.S. Fish and Wildlife Service (USFWS) conducted the survey. Mean daily discharge at the USGS gage on Cibolo Creek near Falls City (# 08186000) was 42 cfs. Approximately 12 live golden orbs and 1 live yellow sandshell were found. No mussels were collected with the dredge at this site. All live mussels were found in gravel substrate in and around riffle areas. Approximately 42 man-

hours of searching were conducted resulting in a capture rate of 0.29 mussels/man-hour for golden orb and 0.02 mussels/man-hour for yellow sandshell.

Preliminary Mussel Survey Summary
Table 5 summarizes the number of mussels of each species captured at each site, along with collection rates in mussels/man-hour. Overall, the Hwy. 77 site had the highest number of live mussels (61 individuals) due to high abundance of yellow sandshell (53) at this site. Yellow sandshells were also relatively abundant at the Falls City site (8), but were represented by only one or two individuals at all other sites. The highest abundance of golden orbs was found in Cibolo Creek (12). Excluding the Calaveras site where only one golden orb was found, the collection rate for golden orbs was relatively consistent at all sites (0.28-0.30). Threeridges were rare in our preliminary collections, and were documented only at the Goliad study site.

Table 5. Number of mussels and collection rates (mussels/man-hour) for three species of mussels collected during preliminary mussel surveys at five sites in the lower San Antonio River basin during 2010 - 2011.

Site	Golden Orb		Yellow Sandshell		Threeridge	
	Number Collected	Mussels/ Man-Hour	Number Collected	Mussels/ Man-Hour	Number Collected	Mussels/ Man-Hour
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. However, this habitat type (gravel riffles) does not exist at the Hwy. 77 site. Here, mussels were found in shallow areas along the inside of bends usually in sand or silt substrate. In their recent mussel surveys on the lower San Antonio River, Burlakova and Karatayev (2008) found two species that were not captured during this preliminary survey. They documented washboard (*Megalonaias nervosa)* and pistolgrip (*Quadrula verrucosa)* in close proximity to the Goliad site. However, both species were relatively rare in their collections.

The preliminary surveys were designed to be followed by more detailed studies of mussel density and habitat utilization as described in the Study Design. However, at present, the project team feels that the completion of the UNT study is imperative before extensive quantification of mussels in the lower San Antonio River is undertaken. As such, when completed, the UNT study results will be used to formulate additional SB2 sponsored studies to assess the flow-habitat relationships of mussels in the lower San Antonio sub-basin.

2.3.3 *Riparian Communities*

The riparian assessment aims to investigate the diversity, health, and functionality of riparian habitat on the lower San Antonio River and lower Cibolo Creek systems. Vegetation communities within the riparian zone are typically characterized by hydrophilic plants along the banks of the river, and occur in many forms including grassland, woodland, wetland, or even non-vegetative. These 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 between 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 riparian hardwood forest community dominated by species including green ash, box elder, cottonwood, American elm, cedar elm, and hackberry (scientific names of woody species observed in the sub-basin are provided in Table 8). 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 natural development of riparian communities. However, it is assumed that the flow recommendations developed as part of 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, a field effort 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 core study to identify the magnitude of environmental flows that are important to riparian communities at the five study sites. The methodology of each of these tasks is described in the following sections, and the results are presented in summary for each study site.

Riparian and Floodplain Vegetation Community Maps

Texas Parks and Wildlife Department is conducting an ecological mapping effort in Texas called the Texas Ecological Systems Classification Program (TESCP) that makes vegetation community information available to the public (German et al. 2009). To accomplish this effort, TPWD is coordinating with private, state, and federal partners to produce a new land classification map for Texas, based on the NatureServe Ecological System Classification System as described by Comer (2003). The data are being developed in phases covering different parts of the state, and over a period of several years. Phases 1, 2, and 3 of the project are complete and cover 80,168,327 acres or 47% of Texas land area.

Phase 1 generally covers eastern Texas, Phase 2 covers central and parts of North Texas, and Phase 3 covers the middle Texas coast. There are 73 Ecological Systems mapped in phases 1 thru 3 and 288 mapping subsystems. Improved thematic and spatial resolution provided by this data was achieved by using advanced remote sensing techniques and spatial analysis of existing digital data related to ecoregions, soils, elevation models, aerial and satellite imagery, and hydrology, among other ecosystem variables. ESRI products were used for spatial modeling, and Earth Resource Data Analysis System (ERDAS) Imagine software was used to perform remote sensing analysis and to produce the final ArcGIS compatible gridded data generated at 10-meter resolution.

The TIFP used vegetation community map information from Phase 3 of the TESCP to identify the broad community types at each of the study sites. Typically, 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 effort was then designed to measure species information along transects sampled within the dominant vegetation map communities at each of the study sites. 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 pulse and overbank flows, as well as the small scale patterns of inundation that affect specific species in the riparian zone.

The TESCP-mapped riparian communities at the Calaveras, Falls City, Goliad, and Cibolo Creeks sites were dominated by the "Central Texas: Floodplain Hardwood Forest", while the Highway 77 site was dominated by "Coastal Bend: Floodplain Hardwood Forest". While both of these communities include some of the same dominant woody species (green ash, cedar elm, pecan, American elm, sugar hackberry, live oak), the "Coastal Bend" type has two additional dominant species: black willow and bur oak.

<u>Field-Collected Riparian Data</u>

Information on riparian tree, shrub, and herbaceous plants was collected at all five study sites. Riparian data were collected using a transect method that measured trees and shrubs within a 10 meter wide plot along a 50 meter 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 meter 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 measured using a line-intercept method along the center of the 50 meter long transect.

Data was collected during summer 2010 (May-September), 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. The number of transects sampled at each site is shown in Table 6 and depicted in figures 22-26. Each transect was surveyed relative to 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 6. Number of riparian transects sampled at each study site.

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

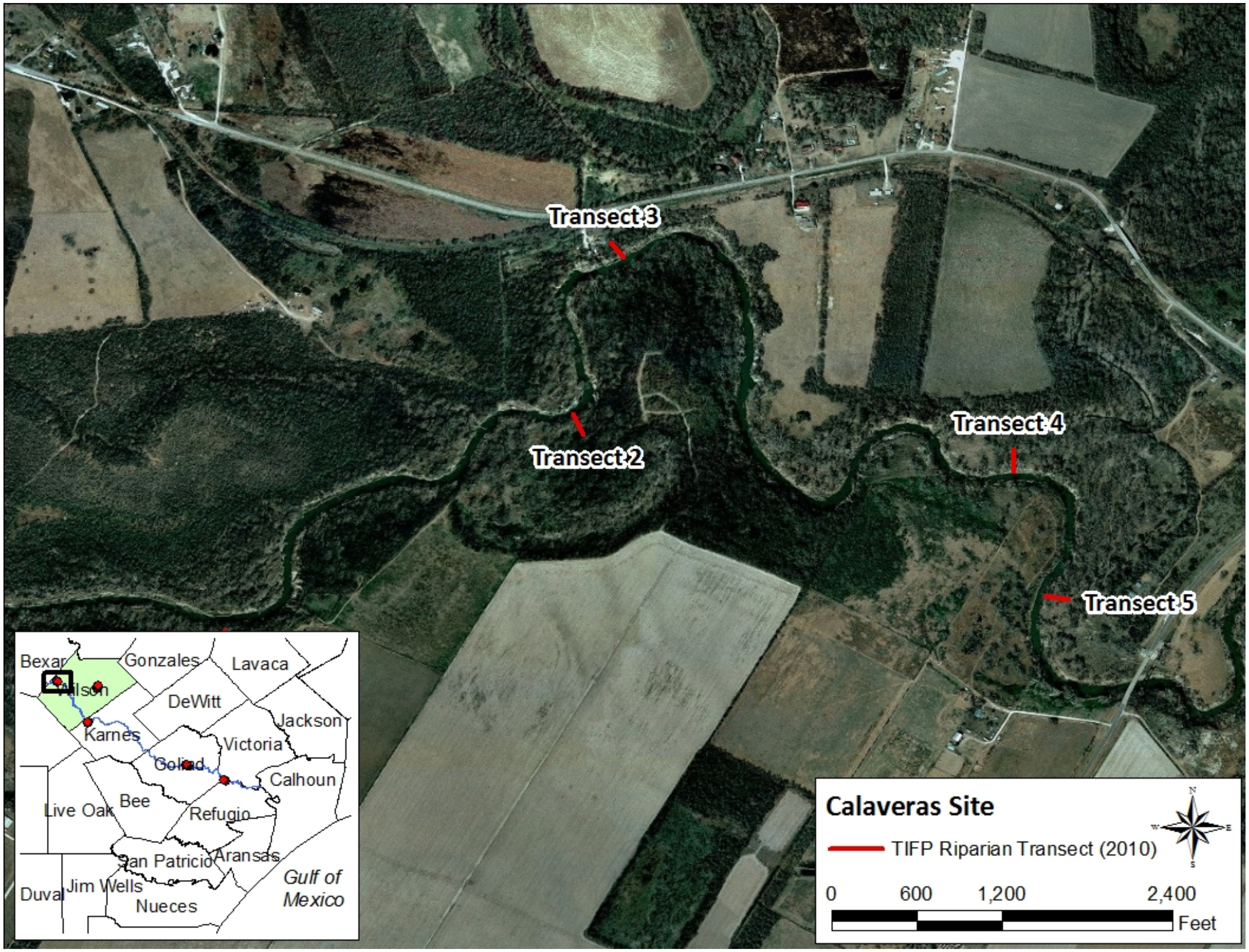


Figure 22. Riparian transects at Calaveras Study Site.

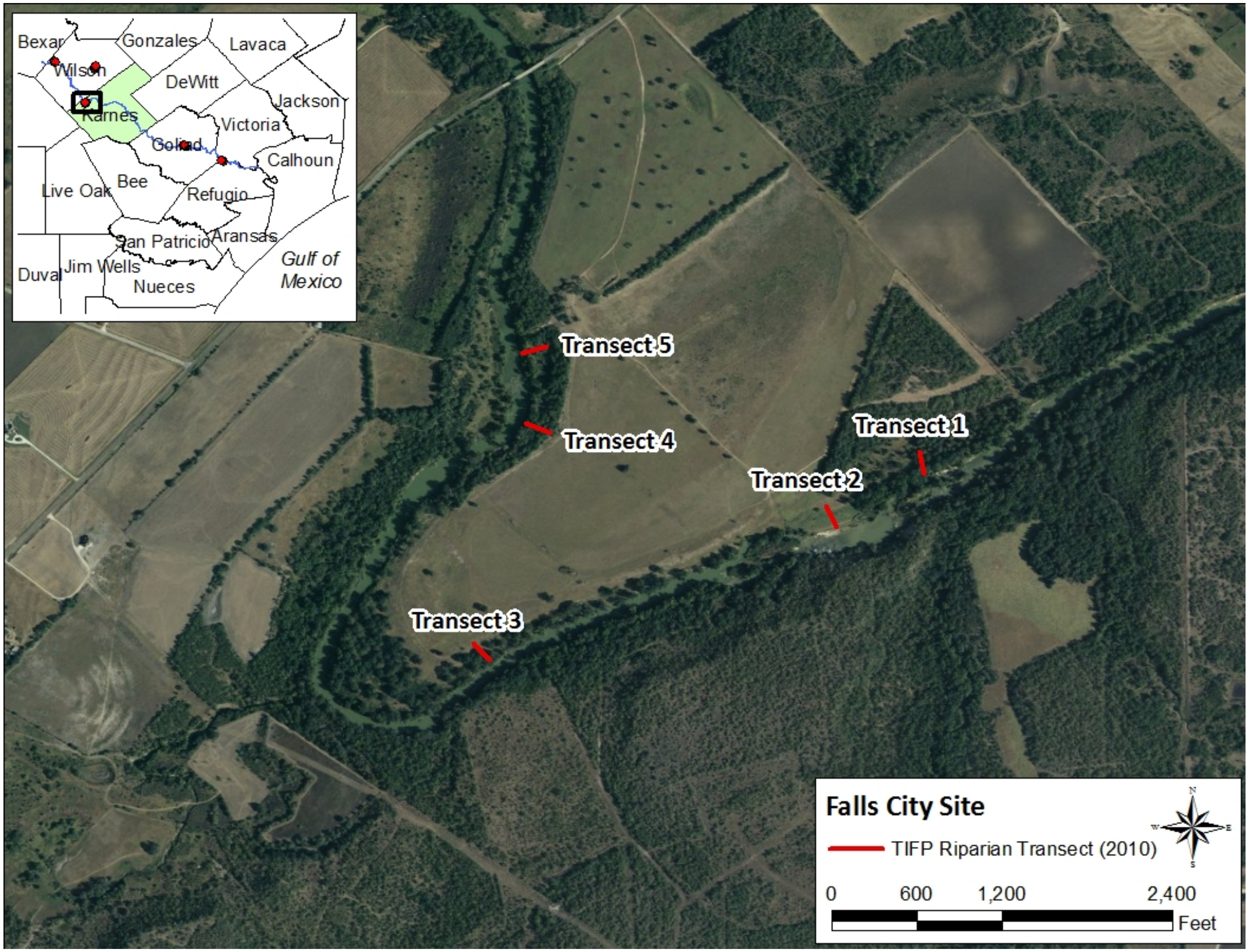


Figure 23. Riparian transects at Falls City Study Site.

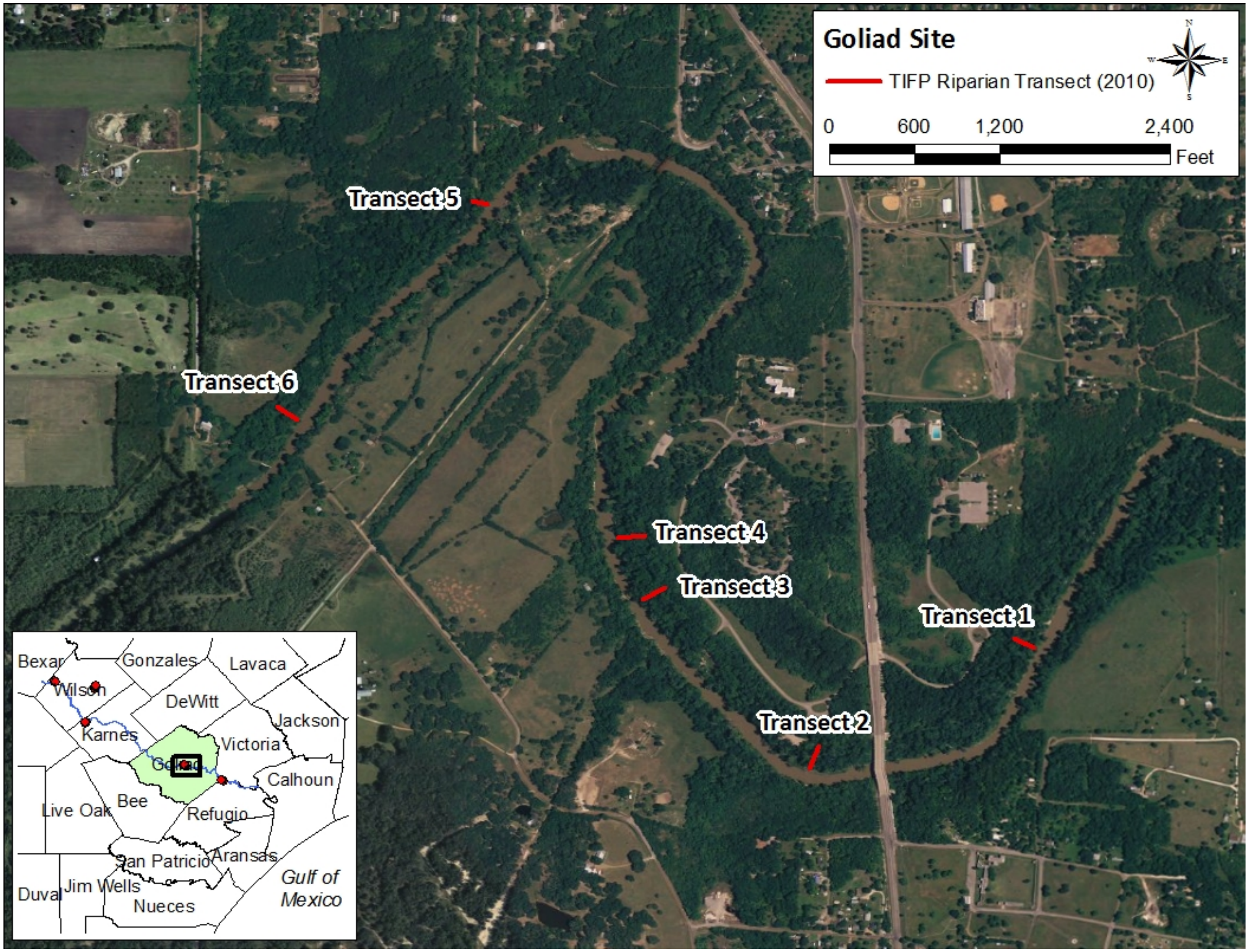


Figure 24. Riparian transects at Goliad Study Site.

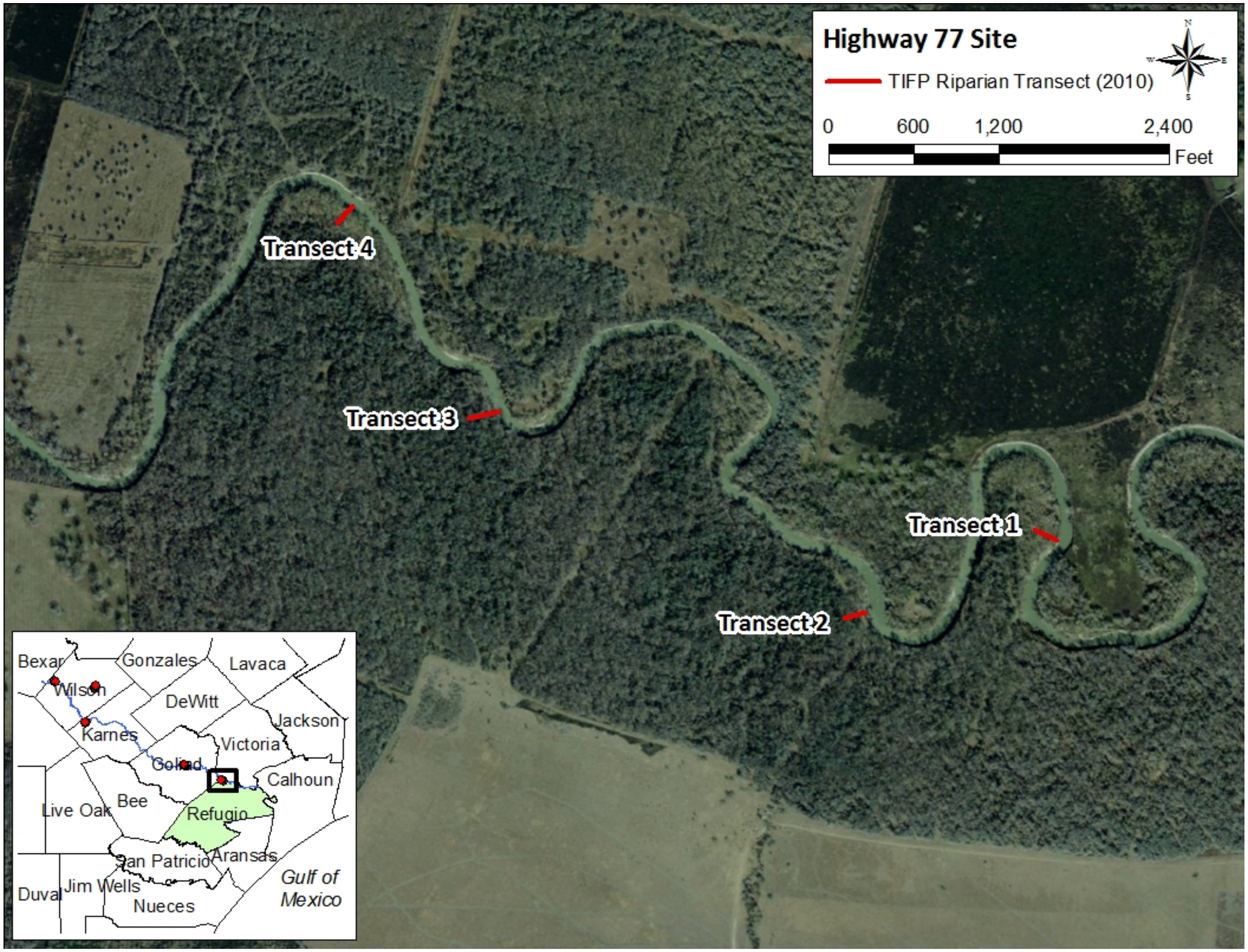


Figure 25. Riparian transects at Highway 77 Study Site.

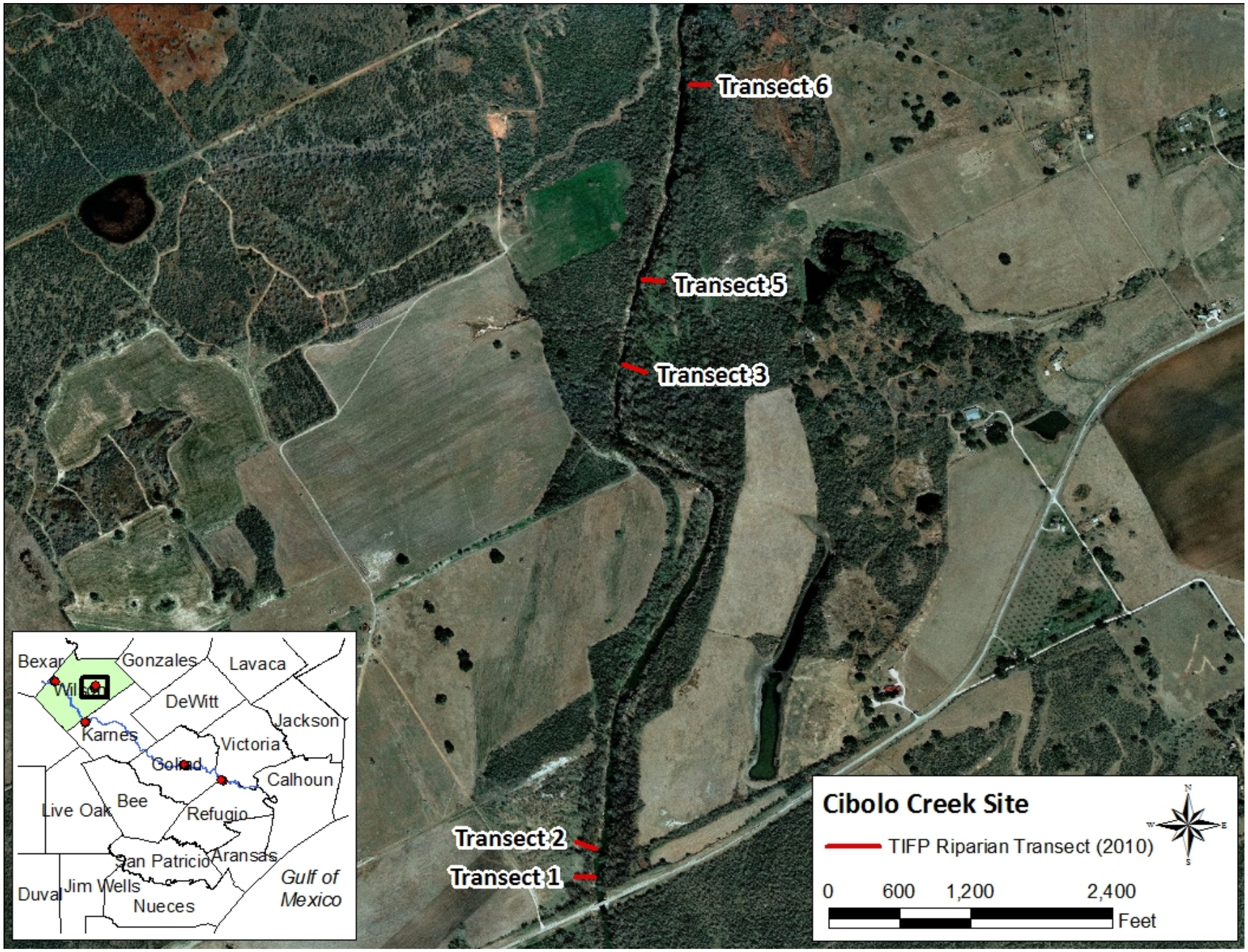


Figure 26. Riparian transects at Cibolo Study Site.

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 D and the transect profile plots in Appendix E.

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. While the level of effort would significantly increase, 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.

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 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 occurs 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, *Platanus occidentalis* (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, *Ulmus americana* (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, *Salix nigra* (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 hours, 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, *Acer negundo* (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, *Populus deltoides* (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, cottonwood 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, *Fraxinus pennsylvanica* (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, *Baccharis neglecta* (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 Pulse Flow 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 pulse and overbank flows. The HEC-RAS model projected water's edge for a series of modeled flow events based on the topography at each study site. Table 7 presents the flow events modeled for each site. 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 in graph format 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 pulse flows were evaluated based on the species that occur in them (based on TESCP descriptions), at which flows they became inundated, and the acreage that was inundated. To focus the analysis on vegetation communities with wetland species, the TESCP 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 7. Flow values (cfs) for each 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 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 Highway 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 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.

Site-specific recommendations of environmental flows for good riparian growth found in this study 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-ft
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-ft
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-ft

These recommendations are important since they incorporate the hydrology that the current riparian community has developed under, and there is currently documented recruitment of riparian species in these communities. While the recommendation is at an annual scale, it does present the variation in flow that is healthy for a natural riparian zone.

Summary of Results

The field collection of riparian species information from four sites on the lower San Antonio River (Calaveras, Falls City, Goliad, Highway 77) and one site on the lower Cibolo Creek

(Cibolo Creek) enabled the TIFP to assess the environmental flow needs of riparian communities within the watershed.

Figures 27, 28, and 29 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 D. Based on the field data, Falls City appeared to have the highest diversity of species (Figure 30), while the highest density of trees and saplings occurred at Cibolo Creek (Figure 31), and Goliad had the highest density of seedlings observed (Figure 32). Several factors lead 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.

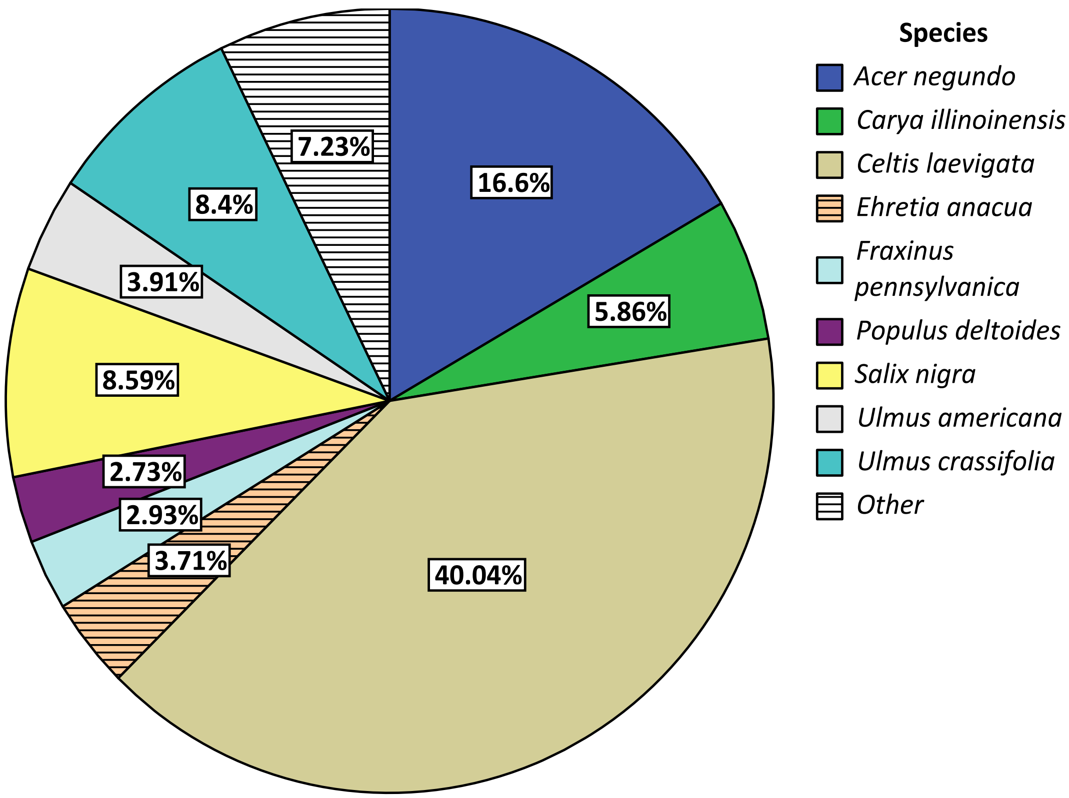


Figure 27. Riparian – Overall Tree Species Composition (common names presented in Table 8)

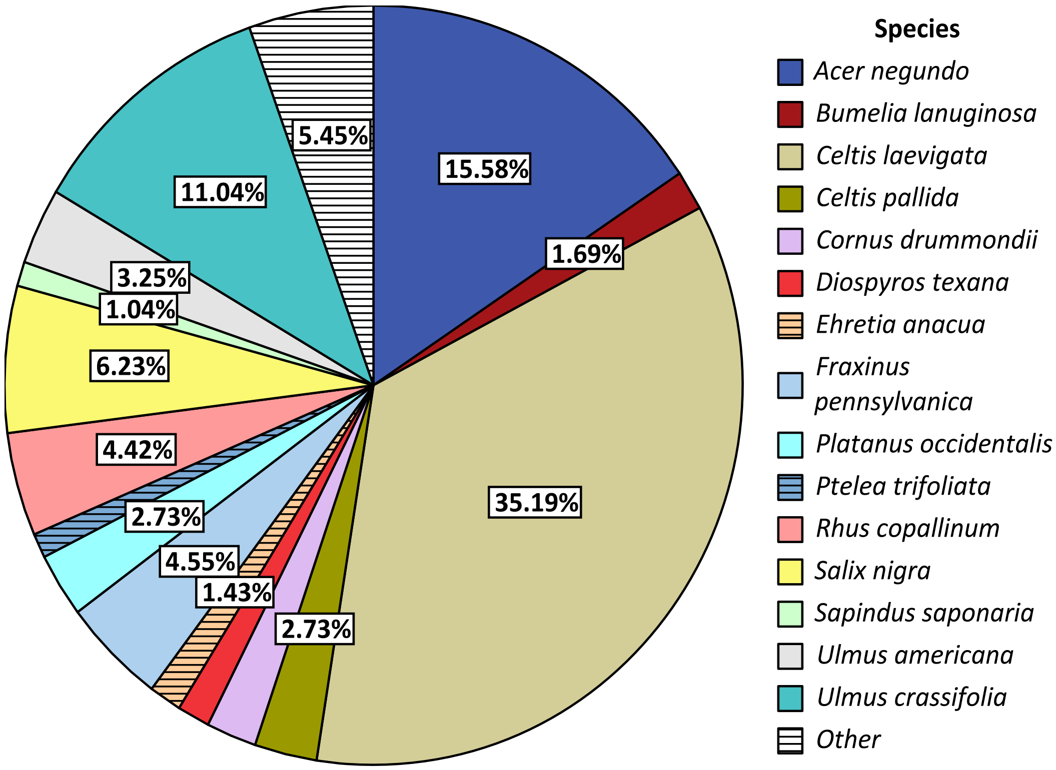


Figure 28. Riparian – Overall Sapling Composition (common names presented in Table 8)

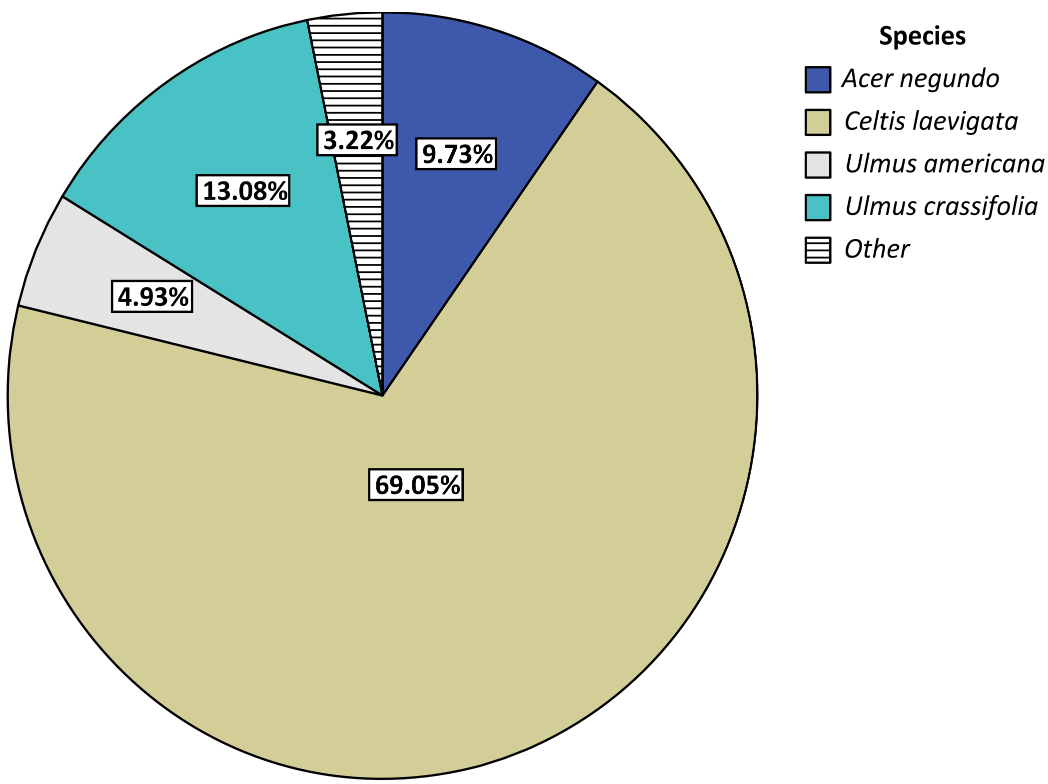


Figure 29. Riparian – Overall Seedling Composition (common names presented in Table 8)

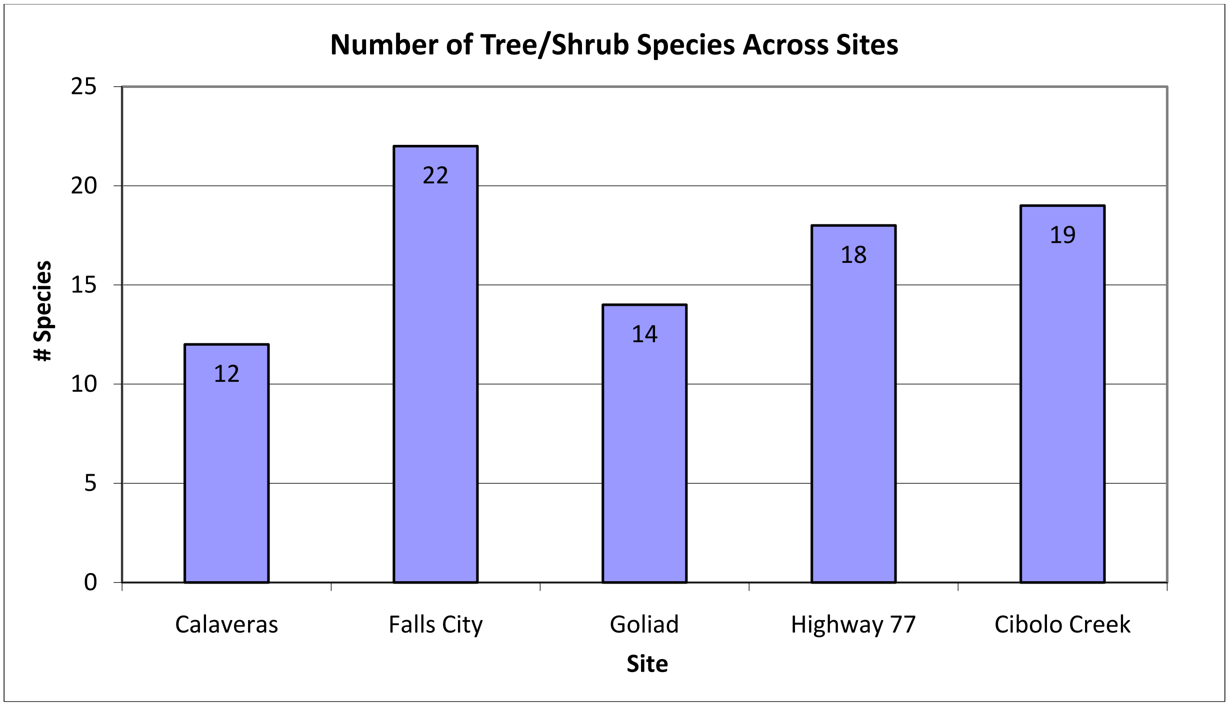


Figure 30. Number of tree and shrub species across the five sites (standard error).

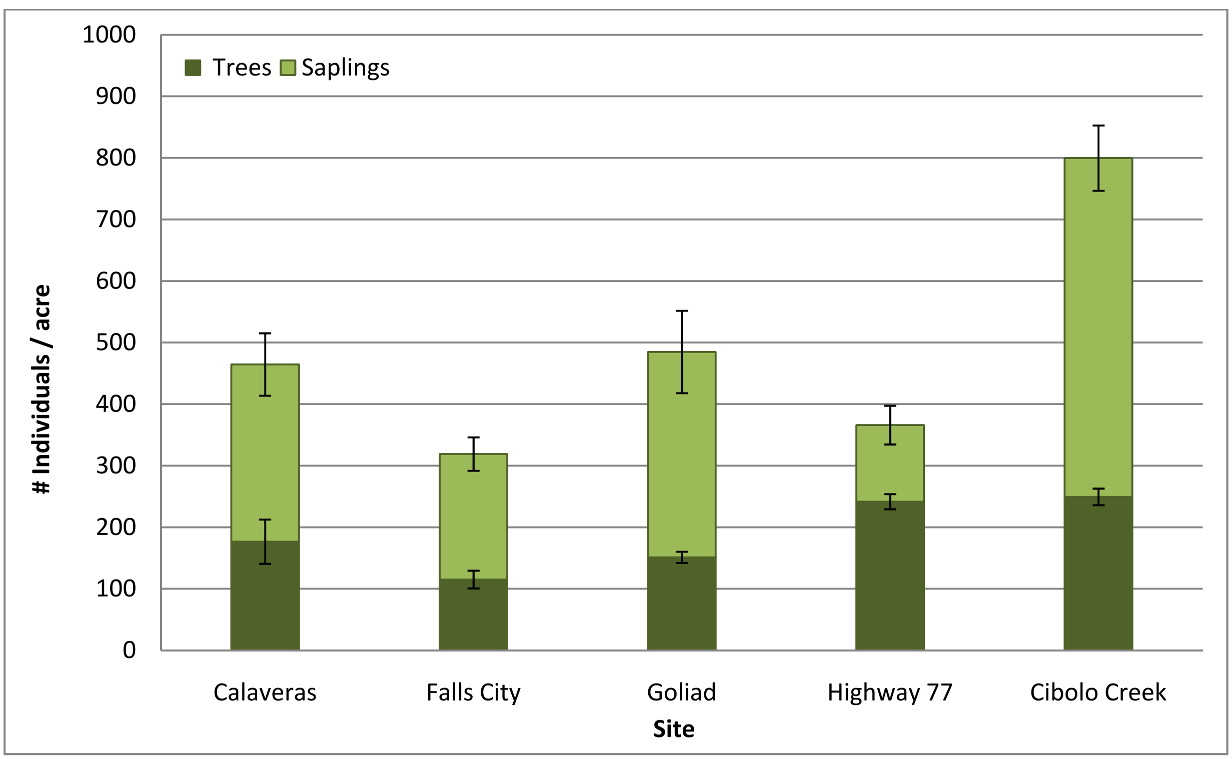


Figure 31. Average tree and sapling density estimates across the five sites (standard error).

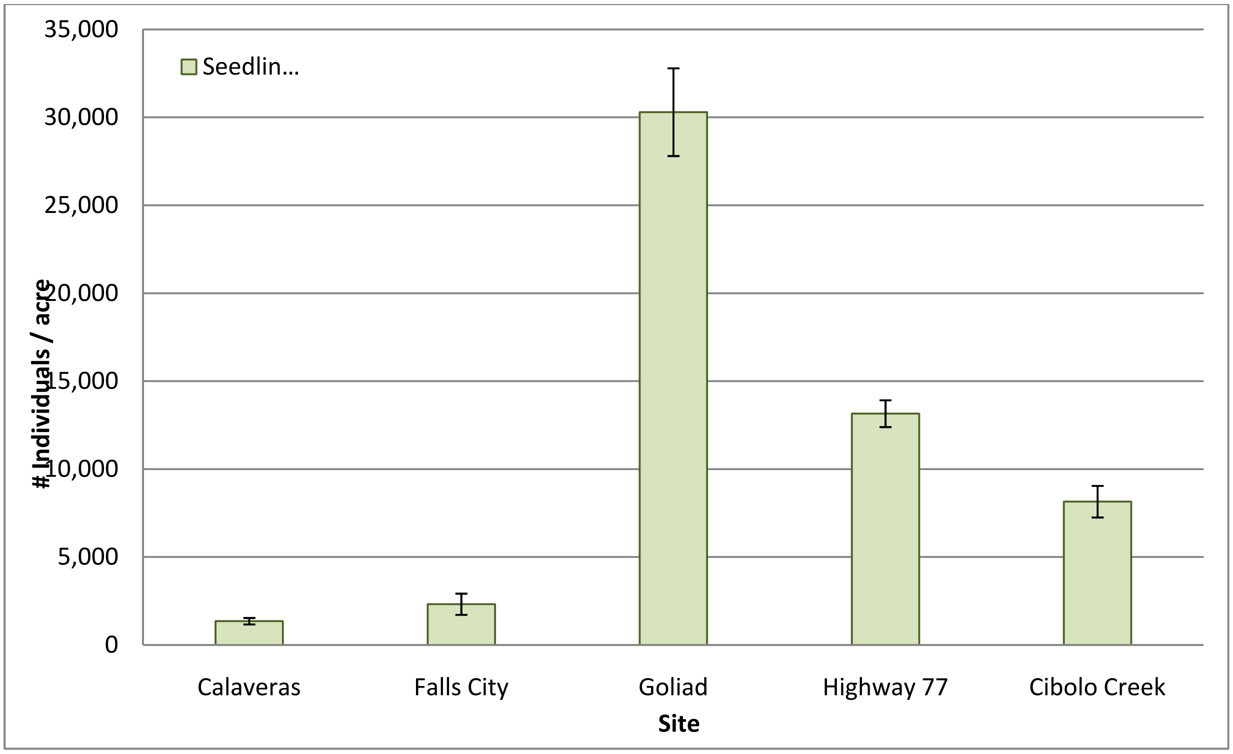


Figure 32. Seedling density estimates across the five sites (standard error).

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 8). 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 D). 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 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 8. List of woody species observed in transects across the five sites in 2010.

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

Riparian transect survey data was used to plot the bank profile of each transect relative to the water's edge present on the day of the riparian data collection (example, Figure 33). A series of plots illustrating the bank profile and corresponding tree location data for each transect individually are presented in Appendix E. 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 E. The distance from the water's edge (0 meter location on transect) to the extent of inundation of a range of pulse flows 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 buttonbush and American sycamore, where present) occurs closest to the water's edge. Somewhat 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 pulse flows 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.

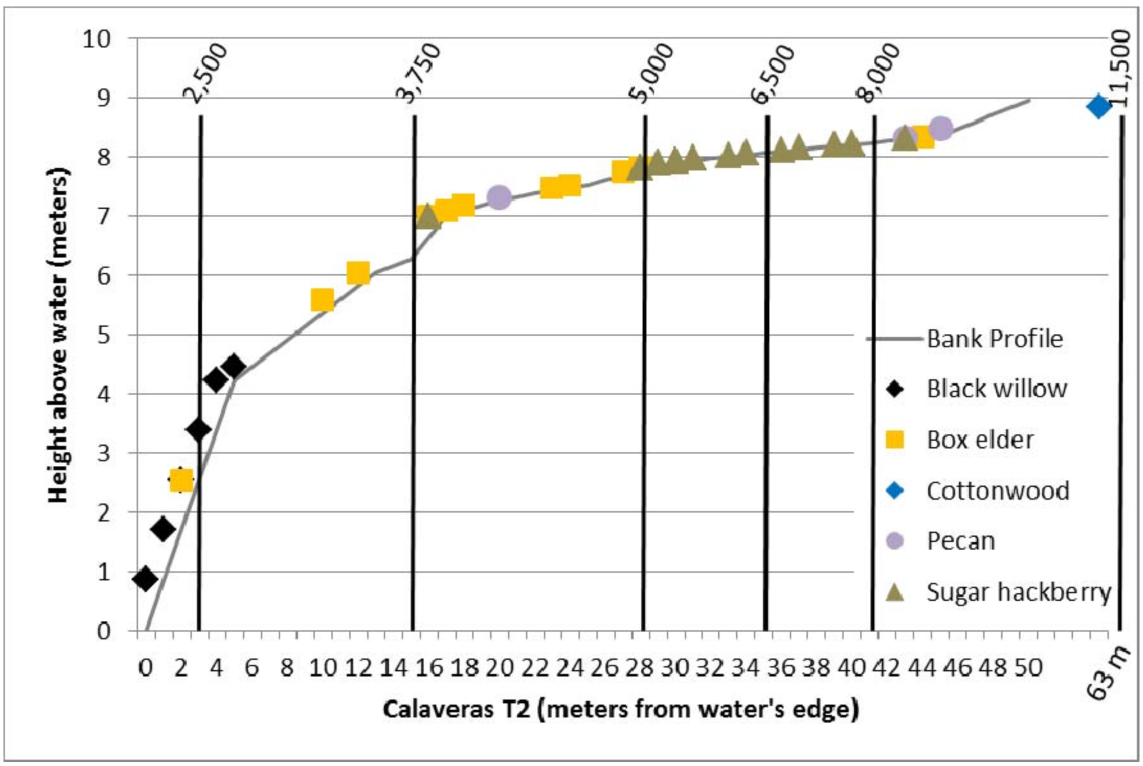


Figure 33. Riparian transect survey data for trees at Calaveras transect 2.

As discussed above vegetation communities inundated at modeled pulse flows were evaluated based on the species that occur in them, at which flows they became inundated, and the acreage that was inundated. Areas of inundation for the entire hardwood communities were selected as presented in the recommendation tables in Section 3.0 to maintain the riparian corridor which includes both the protection of native species and protection against non-native species intrusion.

2.4 *Physical Processes*

Three reaches were selected for sediment transport evaluations based on field reconnaissance of the lower San Antonio River from the Elmendorf area to south of the Goliad area. The overriding selection criterion was diverse channel morphology sufficient to capture the range of possible geomorphic responses likely to occur along the lower San Antonio River and, secondarily, land access to the reach. A geomorphic classification of the lower San Antonio River (Engel and Curran 2008) was used to guide reach selection. The three reaches are identified as Floresville, Charco, and Goliad. Note that sediment sampling for the Charco reach is displaced upstream and identified as Kennedy. Cross-sectional survey data per site along with boundary sediment conditions, bedload, and suspended sediment data was collected.

The hydrological forcing responsible for sediment transport can be quantified by the streamflow observations. Additionally, observations of suspended sediment concentration have been collected by the USGS, from which suspended loads are estimated. Suspended sediment information is available for the Elmendorf, Falls City, and Goliad gauging stations. The Elmendorf suspended concentration rating curve shows the most pronounced difference among the USGS data as well as the observations collected as part of this study at Floresville and Goliad.

As part of the TIFP study of the lower San Antonio River, TWDB has a contract with University of Texas – San Antonio (UTSA) to conduct two types of analysis at the Floresville, Charco, and Goliad sites. First, a 1D hydraulic model with sediment transport modeling capacity (HEC-RAS) is being developed. That effort will identify flow magnitudes that cause adjustment in the streambed elevation through deposition of material (aggradation) or erosion of material (degradation). This model will also allow evaluation of the relative depth of floodplain accretion expected with various overbank flow rates. Cross section and other input data required for development of the model was collected for all three reaches in January 2010. Cross sections were resurveyed in March 2010 to provide data to compare to model results for calibration and validation purposes. During the time from January to March 2010, peak average daily flow was 6,650 cfs in the Floresville reach and 9,850 cfs in the Charco and Goliad reaches. Additional time will be required to complete this investigation in order to refine the model and collect data across the range of high pulse and overbank flows of interest at these locations.

The second type of analysis that is being conducted by UTSA is investigating effects of finer scale sediment transport processes within the same three study reaches (Falls City, Charco, and Goliad). This effort is making use of a 2D hydraulic model (River2D), which is being coupled with a 2D sediment transport model (River2D-Morphology – R2DM) to predict how the characteristics of in-channel features such as pools and bars may be affected by high flow pulse and overbank flows, as well as prolonged periods of base flow. This effort will make use of the 2D hydraulic models (River2D) developed for habitat investigations at the Falls City and Goliad sites. A new River2D model is being developed for the Charco site. Working R2DM models are not yet available for any of the reaches.

Field observations and analysis

Although not yet complete, the sediment transport efforts being completed by UTSA have yielded significant data for analysis of the physical processes that are active in the lower San Antonio River. This includes cross-sectional survey, boundary material, and bed and suspended load samples.

Cross-sectional survey

Each reach was characterized by a minimum of 5 cross sections. Stream-wise spacing was set to meet minimum requirements for the HEC-RAS model and achieve a relatively consistent study reach length in terms of multiple channel widths. Cross-sectional survey focused on capturing major breaks in slope along the cross section. Latitude and longitude coordinates for the survey data were established by collecting and differentially correcting observations from a GPS unit. Where land access was not possible, survey of the flow channel was extended to the floodplain using available LiDAR coverage.

Boundary materials

Sediment samples were collected along the cross sections. All samples were collected by a grab technique and therefore represent near surface sediments. In general, characteristics of sediments are based on between 4 to 10 samples of streambed sediments depending on channel bed width, 6 samples of bank sediments (three per bank), and 6 samples of floodplain sediments where possible (three per surface). All sediments were wet sieved to remove fines (<0.0025 inches or 0.0625mm) that aggregate and therefore bias the grain size distribution. All coarser sediments were dry sieved. Size fractions were characterized by 0.5 phi increments. The grain size distribution for a given depositional environment was calculated as a weighted mean to represent the boundary materials of the cross-section.

Bedload sampling

Bedload observations were collected by deploying a 3 inch (7.6 cm) orifice Helley-Smith bedload sampler with a 0.008 inch (0.2 mm) mesh collection bag from the nearest workable bridge. The orifice size was sufficiently large relative to the largest grain sizes present locally to permit capture of all potentially mobile grain sizes. Collection proceeded using a fixed width interval strategy along the cross section aiming for 20 samples. Although bedload transport is expected to be most significant during large flow events, early in the sampling program, 10 sample efforts were completed to ensure at least some observations given the unpredictability of floods. The Helley-Smith sampler rested on the bed from 1 minute to 25 minutes, depending on the sampling site and flow conditions. Bedload samples were wet sieved to remove suspended sediment collected as the sampler moved through the water column and any aggregates of clay and silt. Sediment larger than 0.0025 inches (0.0625 mm) was dry sieved into 0.5 phi size increments. Only sediment larger than the size of the mesh of the collection bag is considered in rates and grain size distributions. Reported values are representative of the sampling cross section. Rating curves were fitted using linear regression.

Suspended load sampling

Suspended sediment observations were collected by deploying a DH-76 suspended sediment sampler, which is a depth-integrating sampler. Collection proceeded using a fixed width interval along the cross section aiming for 20 samples. Again, 10 sample efforts were completed early in the field program to ensure at least some observations given the unpredictability of floods, with the remaining effort reserved for larger flow events. Sampling suspended sediment was a lower priority given the availability of USGS observations, so it followed bedload sampling throughout most of the field program. For a given sampling, transit rates for the DH-76 were determined for the specific flow condition and then held constant. Sediment concentrations were determined in the laboratory by quantifying the mass of both water and sediment. Suspended sediment loads are the product of the average cross-sectional suspended sediment concentration and mean flow discharge over the sampling period. Reported values are representative of the sampling cross section. Rating curves were fitted using linear regression and are provided in the digital data. No grain size analysis was undertaken for suspended sediments.

Results

Results of the 1D and 2D modeling efforts being undertaken by UTSA are not yet available. In lieu of those results, TWDB has completed preliminary analysis to evaluate sediment transport at USGS Gage Number 08188500 on the San Antonio River at Goliad. That analysis made use of suspended sediment data for the site available from USGS and cross section, bed material samples, and bed and suspended sediment data collected as part of the UTSA studies described above. The analysis method followed procedures described by SAC (2009) and GSA-BBEST (2011) to estimate and compare average annual sediment load at the site for various flow conditions. Results from baseline flow conditions were compared to results for flow regimes based on environmental flow recommendations in order to provide a preliminary evaluation of high flow pulses and overbank flows (see Section 3.3).

2.5 *Water Quality*

Water quality in the San Antonio River basin continues to improve (SARA 2008); however, water quality concerns are still experienced throughout the sub-basin for particular constituents (TIFP 2010). The TIFP water quality evaluation focused on three reaches within the Lower San Antonio River sub-basin as follows:

- LSAR – Upper = San Antonio River, Falls City upstream to Loop 1604
- LSAR – Lower = San Antonio River, Guadalupe River confluence upstream to Falls City
- Cibolo = Cibolo Creek, San Antonio River confluence upstream to Sutherland Springs

For the water quality assessment, the TCEQ commissioned a special TIFP study to evaluate water quality modeling techniques for statewide application with a case-study on the lower San Antonio River (Espey Consultants 2010a; 2010b). The first step was to refine water quality goals by identifying water quality screening criteria for which to compare existing data and future model runs to. The goals for the study are presented in Table 9.

Table 9. Water Quality Screening Criteria established for Instream Flow Study

San Antonio River, downstream of Loop 1604 to Guadalupe River confluence

Parameter	Instream Flow Goals (Values)	
Tier 1 - Primary priority		
DO* (EC 2010a; EC 2011)	<= 12 hours below 3 mg/L <= 2 hours below 2 mg/L >1.5 mg/L	
Temperature* (EC 2010a)	<= 35' C (95 'F)	Critical Thermal Maximum water temperature for some San Antonio River species
Tier 2 - Secondary priority		
DO* (2010a)	>= 5.0 mg/L daily average >= 3.0 mg/L minimum for <= 8 hours For Spring Condition: >= 5.5 mg/L daily average >= 4.5 mg/L minimum for <= 8 hours	
Temperature* (EC 2011)	<= 27` C (80.6`F) Jan - May	Spawning fish water temperature criteria
Temperature* (TCEQ 2010a)	<= 32.2`C (90`F)	
Nitrate (TCEQ 2010b)	<= 1.95 mg/L	
Ammonia* (TCEQ 2010b)	<= 0.33 mg/L	
Orthophosphate* (TCEQ 2010b)	<= 0.37 mg/L	
Tier 3 - additional parameters		
E. Coli* (TCEQ 2010a)	<= 126 org/100mL geometric mean	
Total Nitrogen*	no value	
NOx* (TCEQ 2004)	<= 2.76 mg/L	
Organic Nitrogen*	no value	
Total Phosphorus* (TCEQ 2010b)	<= 0.69 mg/L	
pH (TCEQ 2010a)	6.5 - 9.0	

Notes:
* = Preliminary indicator identified by SB2 TIFP stakeholders

References:

[TCEQ] Texas Commission on Environmental Quality. 2004. Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data, 2004. August 15, 2003.
[TCEQ] Texas Commission on Environmental Quality. 2010a. Texas Surface Water Quality Standards. July 22, 2010.
[TCEQ] Texas Commission on Environmental Quality. 2010b. 2010 Guidance for Assessing and Reporting Surface Water Quality in Texas. June 6, 2009.
[EC] Espey Consultants, Inc. 2010a. Water quality evaluation needs for the Texas Instream Flow Program: Identification of needs and statewide approach. October 2010.
[EC] Espey Consultants, Inc. 2011. Brazos River Iinstream FLow Program (BRIFP) Instream Flow Water Quality Evaluation, Volume 1 - Brazos River downstream of Waco, TX, Rev v1-06.

The goals were centered on the basin-specific water quality indicators recommended by the SB2 stakeholder group (TIFP 2010) and were used to assess current status relative to historical trends and relative to water quality standards. Suitability of water quality conditions were evaluated using the indicators and assessed at a wide range of flow levels to assist in the development of instream flow recommendations.

Primary priority parameters (dissolved oxygen [DO] and water temperature) are afforded more severe levels than the respective TCEQ stream standards for those parameters (Table 9). The rationale behind this decision is that "subsistence" flow should only be a temporary condition and as such is represented by extreme conditions that will maintain survival of aquatic organisms, but will not always provide optimal or even suitable water quality conditions throughout the entire water body. From a planning standpoint, long-term strategies should be identified that avoid or minimize water quality conditions that do not achieve the instream flow goals. However, under a natural flow regime, these periods did occur for limited periods, thus crafting the ecological makeup of the river system. The ecology of a river system is defined by extreme events on both the high-flow and low-flow end of the spectrum, and having occasional extremes supports populations of native species who have evolved life history strategies in response to the natural flow regime (Poff and Allan 1997, Bunn and Arthington 2002).

Distribution and abundance of fish species are influenced by both biotic (predation, competition, etc.) and abiotic factors (physical/chemical environmental conditions). Abiotic factors which influence fish distributions include physical habitat parameters such as depth, velocity, and substrate, (discussed in Section 2.2) as well as chemical water quality parameters such as temperature, DO, turbidity, pH, and salinity/conductivity. Water quality parameters can affect fish survival directly when conditions become lethal to a species, or indirectly through influences on reproduction and growth rates. The influence of water quality parameters on distribution and abundance of fish is species-specific, and is difficult to quantify since these parameters are constantly changing in natural systems. Due to the dynamic nature of water quality variables, most studies focus on identifying the minimum or maximum values which a particular species can withstand.

The most common studies in the literature which examine the effect of water quality variables on fish deal with the effects of temperature. Fish are poikilotherms - their body temperature is in direct relationship to the surrounding water temperature. At temperature equilibrium the body temperature of a fish is usually about 0.1-1.0ºC above water temperature (Beitinger et al. 2000). Critical Thermal Maximum (CTM) is a number used to estimate a fish's ability to survive extreme temperatures (Matthews and Zimmerman 1990). The CTM is defined as 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 35ºC. It is important to note that CTM values can fluctuate between two populations of the same species, and are highly dependent on the conditions which the fish are initially acclimated to (Beitinger et al. 2000).

Currently, water temperatures in portions of the San Antonio River basin routinely exceed 32ºC during the late summer during the hottest parts of the day. This temperature already encroaches on the temperature maximums reported for some species such as river carpsuckers (*Carpiodes carpio*) and smallmouth buffalo. However, these values were calculated using the fish and temperature database matching system (FTDMS), which may underestimate the tolerance of some warm water species (Eaton and Scheller 1996). Both of these species are common in large rivers of Texas where temperatures commonly exceed their published CTM values. In general, literature values for fish from the lower San Antonio River basin suggest that most species have an upper temperature limit somewhere around 35 ºC. It is acknowledged that sub-lethal effects will be occurring prior to reaching these water temperature criteria, and thus, understanding the duration and frequency of subsistence flow conditions becomes critical when developing instream flow recommendations. During this study, water temperature observations rarely exceed 35ºC, and were only found to do so for short periods representing the hottest part of a diurnal cycle. Evening and morning hours of those same days exhibit lower temperatures.

Temperature also influences DO concentrations. The amount of DO that water can hold (saturation concentration) decreases as temperature increases. Levels of DO below 3 mg/L are considered stressful (and ultimately lethal over extended periods) to most fish. However, certain species are more tolerant of low DO levels than others. Red shiners can survive DO values of 1.5 mg/L (Matthews and Hill 1977), and when acclimated gradually, bluegill can tolerate DO concentrations below 1.0 mg/L (Moss and Scott 1961). For this assessment, a goal was established such that at no time should DO be allowed to fall below 1.5 mg/L, but it can fall below 2 mg/L for up to 2 hours on a diurnal pattern, and below 3 mg/L for up to 12 hours on a diurnal pattern.

To understand how water quality relates to instream flow components, the team used the hydrological statistics described in Section 2.1 to understand what specific ranges of flow were relevant for the assessment. Specifically, the hydrological assessment was used for identifying what ranges of flows constituted subsistence, base, high pulse and overbank flows. A detailed description of the hydrologic assessment, evaluation of existing data, and subsequent preliminary water quality modeling is presented in Espey Consultants (2010b). Overall, the findings of the existing data evaluation and preliminary water quality modeling showed water quality conditions meet the instream flow screening criteria and goals.

At this point, the water quality modeling evaluation focused on subsistence level flows that might cause an exceedence of the primary priority (Table 9) parameters (dissolved oxygen and water temperature). Steady-state modeling of DO was conducted for low flows under maximum permitted wastewater discharge concentrations and non-contributing headwater and watershed flow conditions. The modeling indicates worst-case DO conditions occur at 100 cfs (Figure 34). There were no non-achievement observed in DO concentration. Additional model runs were conducted and described in Espey Consultants (2010b) with the ultimate conclusion that down to 10 cfs, DO was not going to be a concern within the lower San Antonio River TIFP study area based on primary priority parameters.

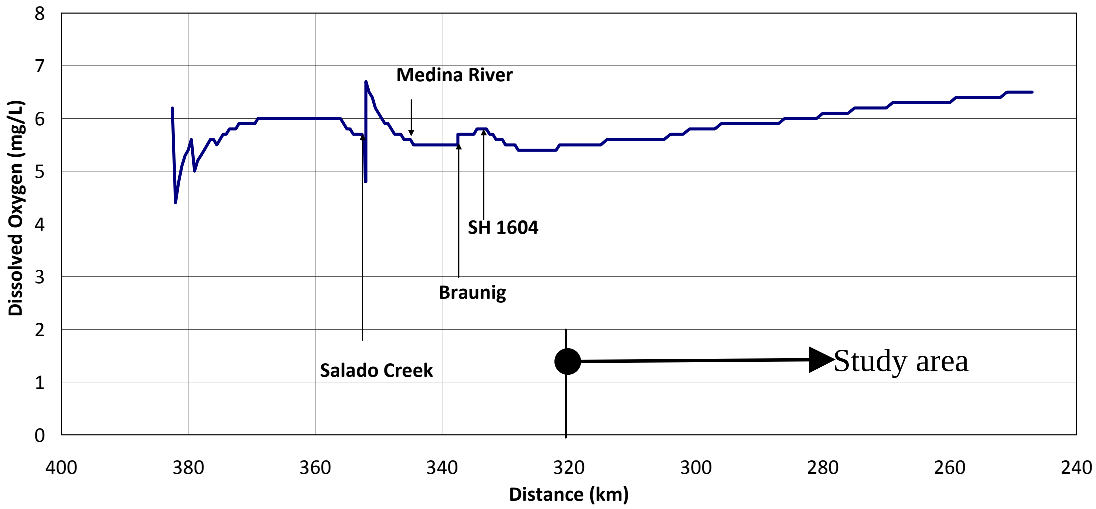


Figure 34. Dissolved Oxygen longitudinal profile - LSAR upper segment with 100 cfs flow after diversion at Braunig, with zero headwater flows and water temperature of 33.2 °C.

Additionally, modeling conducted in 1998 for the Trans-Texas project (HDR & PPA 1998) indicated flows as low as 3 cfs could support DO water quality under steady conditions. The model scenarios included fully-permitted wastewater discharges (achieving highest permitted nutrient concentrations) and a diversion resulting in low-flows near Goliad. The steady-state scenarios were not anticipated to result in DO lower than 5 mg/L. For the TIFP, steady-state modeling of DO was also conducted for lower Cibolo Creek with similar results pertaining to extremely low-flow conditions. Model runs indicated that down to 2.5 cfs, DO was not going to cause an exceedence in lower Cibolo Creek.

As steady-state modeling had water temperature approaching the screening criteria, additional modeling was then conducted to evaluate diurnal temperature variation for low flows. Figures 35 and 36 show the results for the upper and lower segments of the lower San Antonio River, respectively.

Under extreme summer ambient temperature conditions (daily high air temperature exceeding 102°F), the daily average water temperature is approximately 32°C. Depending on flow, the daily variation around that average fluctuates, with greater variation resulting from low flows where shallow waters are more susceptible to heating throughout the water column. In both the upper and lower segments, diurnal fluctuations start to exceed the 35°C primary priority temperature goal around 80 cfs. In comparison at 60 cfs river flow, the 75 percentile summer and 75 percentile spring high ambient air temperatures were used, resulting in an average daily water temperature of approximately 29°C and 26°C, respectively.

Examination of observed diurnal DO trends revealed periodic afternoon supersaturation conditions. While under observed nutrient loading and observed conditions the DO did not decrease below the DO goal, the diurnal pattern should be more closely examined under future projects under future scenarios.

Additionally, observed DO following small pulse events exhibited short time-frames (less than 12 hours) where DO dropped below 3 mg/L. Time-series DO modeling for potential future condition (higher) nutrient loading revealed an indication that DO could remain below

3 mg/L for increased time. Additional data sets are recommended to more appropriately calibrate and evaluate water quality model results.

Based on the examination of existing data and steady-state modeling results, no further diurnal water temperature modeling was conducted for Cibolo Creek (TCEQ 2011). As future specific projects are planned, this more-detailed water temperature and/or DO modeling should be conducted.

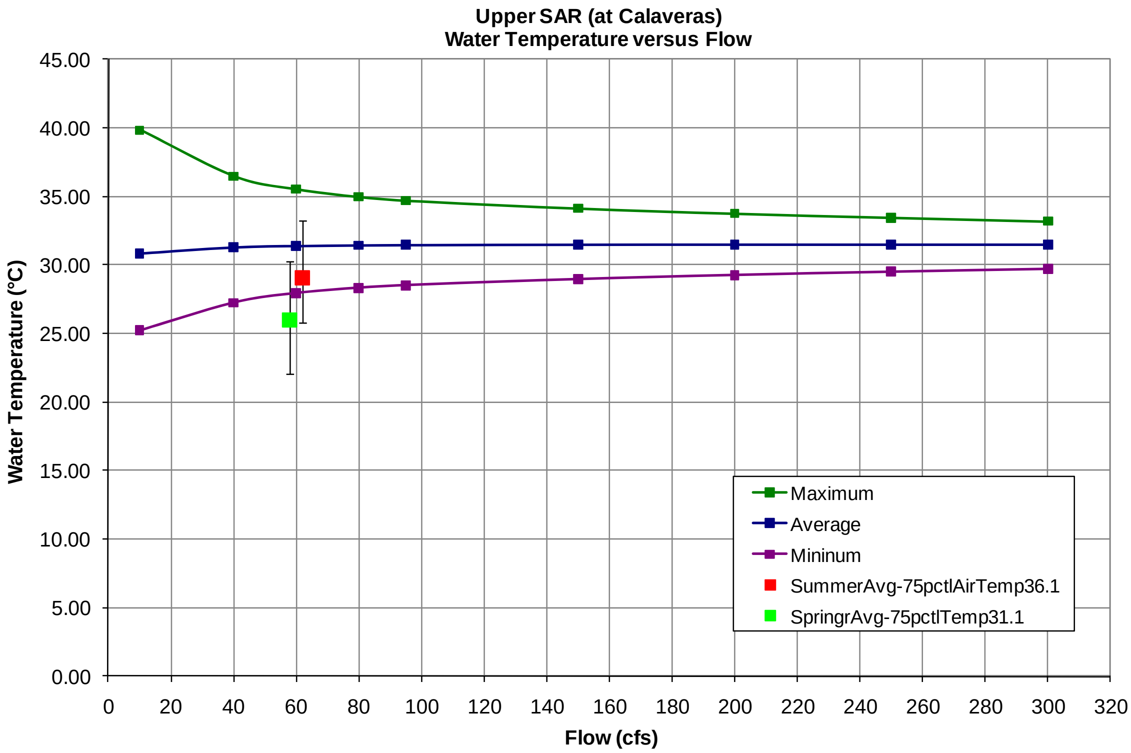


Figure 35. Temperature plot versus discharge for San Antonio River - Upper segment

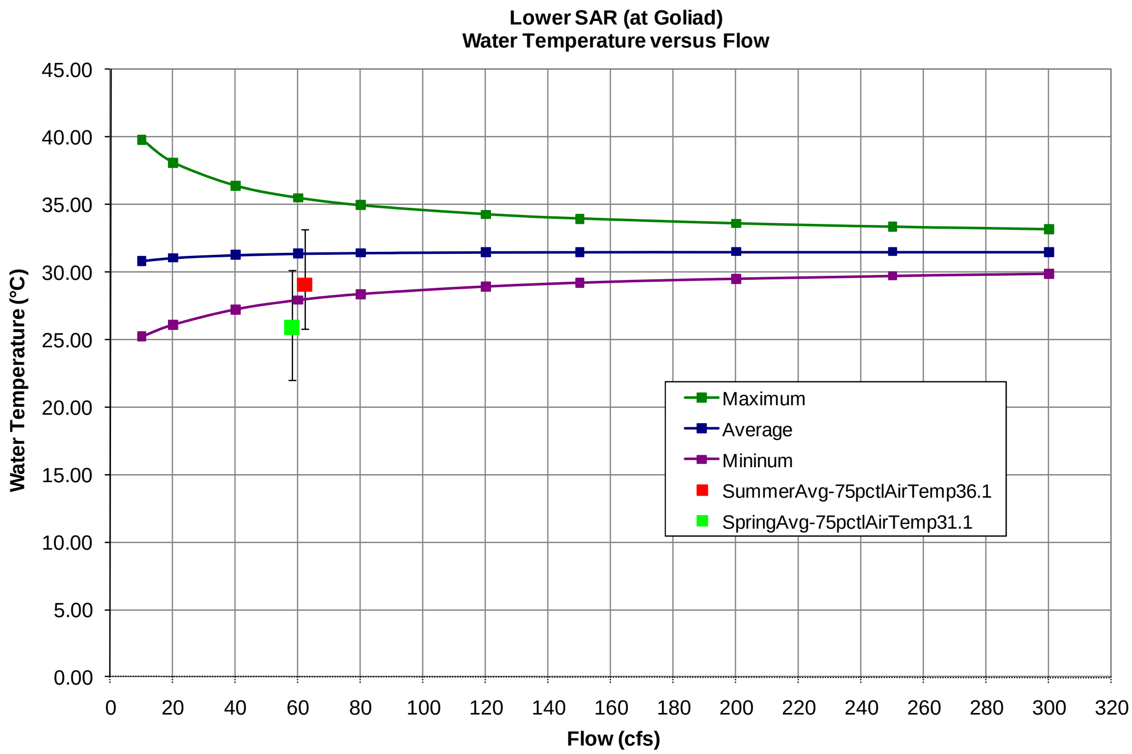


Figure 36. Temperature plot versus discharge for San Antonio River - Lower segment

3.0 INTEGRATION OF STUDY RESULTS

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 (i.e. subsistence flow, base flow, etc.). Once the 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 goals established.

The 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 centered on 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 10.

Table 10. 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 Pulse Flows	
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.

3.1 *Subsistence Flow*

During the data collection period for this study, the project team was fortunate to observe low-flow conditions (summer 2009) throughout much of the lower San Antonio River sub-basin. This allowed for data collection opportunities at flows near 10 cfs on lower Cibolo Creek and from 60 to 100 cfs on the lower San Antonio River. This provided the project team with firsthand experience of conditions in the subsistence and low base-flow range for these respective rivers. Additionally, this data collection opportunity greatly assisted the project team in water quality and aquatic habitat model calibration. This is important in that both water quality modeling and aquatic habitat modeling were primarily used in evaluating subsistence flow recommendations.

As the primary objective of subsistence flows according to TIFP (2008) is to "maintain water quality criteria", the subsistence flow evaluation first focused on observed water quality conditions and water quality modeling. As discussed in Section 2.5, existing water quality data and water quality modeling results showed that modeled parameters met TIFP established water quality goals at most flows modeled. As discussed, the one exception was modeled water temperature at extreme ambient summer air temperatures. Under extreme summer air temperatures (39˚C or 102˚F), modeled maximum daily temperatures exceeded the previously established 35°C water temperature goal at approximately 80 cfs in both the upper (Calaveras and Falls City, Figure 35) and lower (Goliad and Hwy 77, Figure 36) segments of the study area (Figure 37, repeat of Figure 35 with 80 cfs highlighted).

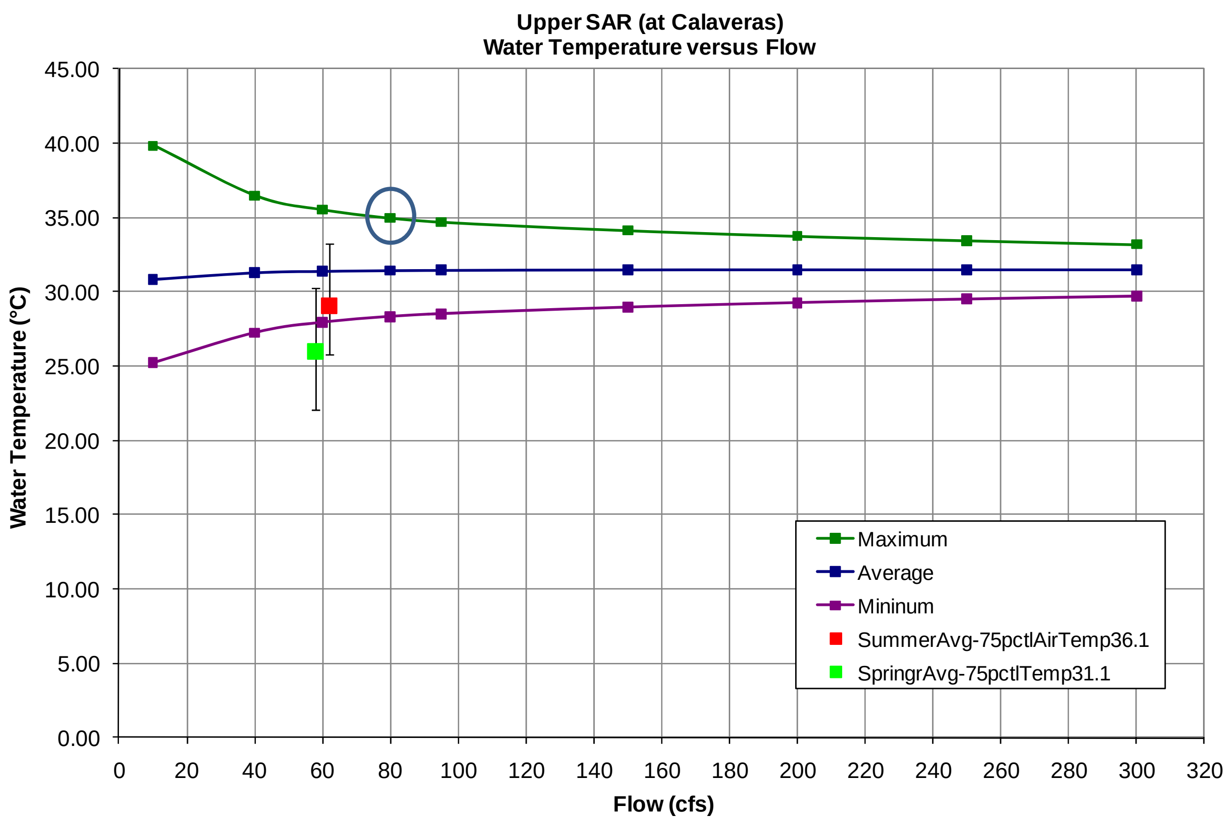


Figure 37. Temperature plot versus discharge for San Antonio River - Upper segment – 80 cfs intersection of maximum daily temperature circled.

This threshold was established because it has the potential to directly alter an ecological response of aquatic organisms. As discussed in Section 2.5, the 35°C value was selected because it approaches (or in some instances exceeds) the reported Critical Thermal Maximum for fish species occurring in the lower San Antonio River. It is anticipated that water temperatures approaching this threshold will already be causing sublethal effects for certain aquatic organisms, but water temperatures at or above this value could have potential lethal effects. It is also important to note that the water quality criteria (Table 9) were established in advance of any modeling activities. To maintain the water quality criteria of 35˚C, 80 cfs was proposed as a subsistence flow throughout the lower San Antonio River.

At this point a detailed assessment of the aquatic habitat modeling results near 80 cfs was conducted for each of the lower San Antonio River study sites. This detailed assessment included 1) an evaluation of the WUA results for each level of habitat quality, 2) evaluation of spatial outputs to examine habitat connectivity, and 3) an evaluation of the habitat time series results examining both the pre-1970 and full period of record hydrological data sets. In every instance, suitable aquatic habitat was available to aquatic organisms at 80 cfs. Additionally, wetted area at 80 cfs was examined in relation to known mussel locations observed during the 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. As such, neither the aquatic habitat modeling results nor preliminary mussel assessment resulted in any adjustments to the lower San Antonio River Interim subsistence recommendation.

The project team had extensive discussions regarding the selection of the maximum instantaneous daily temperature during extreme hot summer conditions, but determined that at this time it is unknown whether 10 minutes, 2 hours, or 2 weeks at these water temperatures would cause lethal conditions. As such, a conservative approach was adopted and this topic is highlighted for additional monitoring during extremely hot, low-flow conditions. Flows less than 80 cfs have been observed on several occasions since the inception of the instream flow study. This first occurred during June 2009 and 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. A second, more recent time period when flows were consistently below 80 cfs on a daily basis was June 2011. During this time period, ambient air temperatures did exceed 100°F for several days to a week. During this time period, data from the USGS Elmendorf gage reported a daily average temperature of approximately 31.5°C with a range up to approximately 33°C. As experienced in 2009, the low-flow observations in 2011 were in early summer, rather than extreme conditions during the intense July/August time period.

As extreme summer time air temperatures are rare or non-existent during non-summer months, subsistence recommendations could theoretically be lowered during the cooler months of the year, as aquatic habitat is still predicted to be sufficient. However, the project team felt this would result in recommendations which conflict with the natural hydrologic pattern observed in the lower San Antonio River of higher flows in spring and fall and lower flows in summer. Rather than propose Interim subsistence recommendations which conflict with the natural hydrologic pattern, the decision was made to maintain one subsistence value year round and to monitor these low-flow conditions for both water temperature and aquatic response when they occur in the future.

For lower Cibolo Creek, existing water quality data and steady-state water quality modeling did not show exceedence of any water quality goal at any flow level modeled. As discussed, there was not a detailed temperature model created for lower Cibolo Creek that evaluated diurnal fluctuations, as the existing data and water quality modeling conducted by TCEQ did not raise concerns, and the potential to presently have large diurnal swings in hydrology in lower Cibolo Creek does not exist as it does in the lower San Antonio River. Therefore, aquatic habitat modeling was the driver for setting Interim subsistence recommendations for lower Cibolo Creek. As previously mentioned, the 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. Aquatic habitat modeling predicts that high quality riffle habitat (CSI≥0.8) is lost as flows dropped from 10 cfs to 6 cfs (Figure 38).

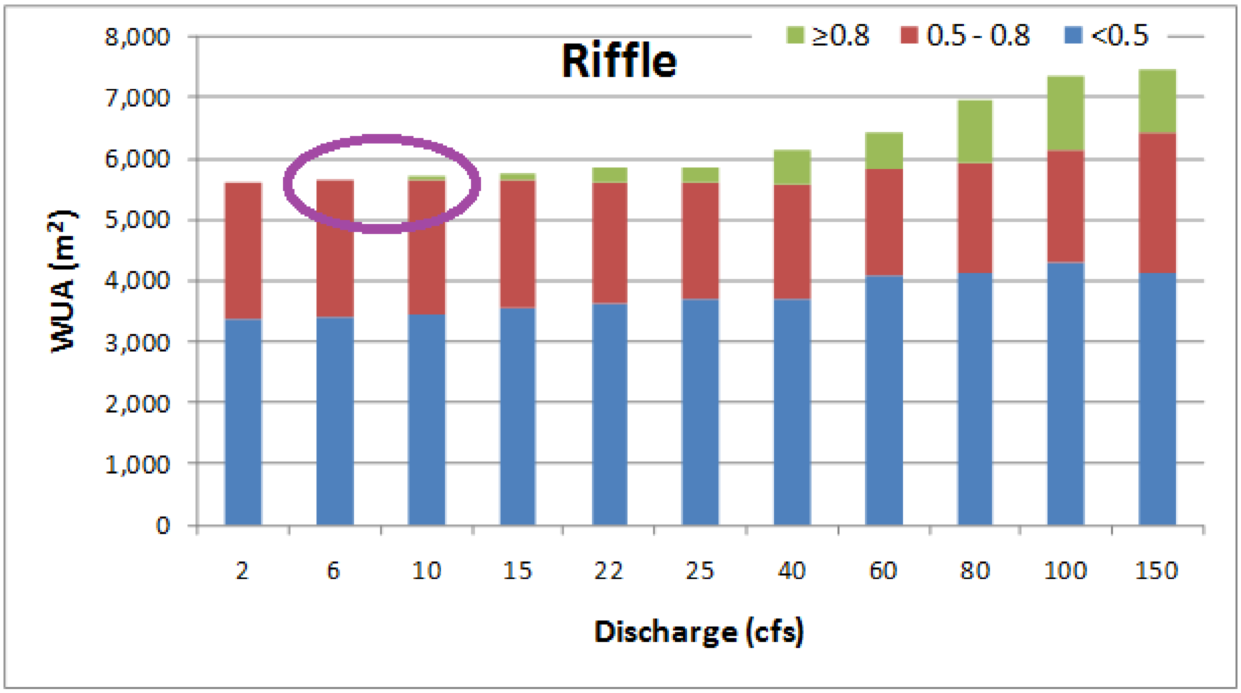


Figure 38. WUA versus simulated discharge for high, moderate, and low quality Riffle guild habitat.

Since Riffle guild species such as river darter and Texas logperch as well as state threatened golden orb mussels were abundant at lower Cibolo Creek, it was desired to maintain at least a minimal amount of high quality habitat at this lowest threshold. Spatial model output confirms that below 6 cfs, habitat connectivity also starts to degrade. As such, an Interim subsistence recommendation was set at 7.5 cfs for lower Cibolo Creek. Since 7.5 cfs was identified as a minimum flow to maintain adequate habitat under subsistence conditions, this number was applied year round. As for the lower San Antonio River, monitoring of both the flow level, and applicability of a year-round application will be part of the long-term monitoring program recommendations in Section 4.0.

Final TIFP recommendations for susbsistence flow in the lower San Antonio River and lower Cibolo Creek sub-basin may be adjusted in response to the results of ongoing studies investigating mussel habitat versus flow relationships and consultations with the sub-basin workgroup.

3.2 *Base Flow*

For both the lower San Antonio River and lower Cibolo Creek, existing water quality data and water quality modeling results showed that modeled parameters met established water quality criteria within projected base flow ranges. Therefore, base flow recommendations were focused on maintaining a desirable range of aquatic habitat conditions. To ensure inter-annual variability in base flow conditions, recommendations were made for dry, average/normal, and wet conditions as proposed in TIFP Technical Overview (TIFP 2008). Total WUA to flow relationships were examined to identify flows which provided sufficient and diverse habitat under each hydrologic condition (Appendix B). Emphasis was placed on maintaining adequate amounts of high quality habitat (CSI≥0.8). Additionally, spatial projections of habitat were viewed to ensure adequate connectivity between habitat patches, and to identify flows where key habitats were available. Habitat time series and habitat duration curves were used to put habitat conditions into historical context. Once habitat conditions of interest were identified from this analysis, existing WUA to discharge relationships were used to back-calculate the flows needed to create such conditions.

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 11, with justification provided in the following text.

Table 11. Base Flow Levels Identified by Aquatic Modeling Results Evaluation

Study Site	Target Base Flow Levels (cfs)		
	Dry	Average	Wet
Calaveras	100	225	350
Falls City	130	250	450
Goliad	170	290	500
Cibolo Creek	15	25	40

3.2.1 *Calaveras*

At the Calaveras Study Site, total WUA for Shallow Pool, Shallow Run, Riffle, and Moderate Pool all peak at or below approximately 66 cfs (Figure 39). In contrast, total WUA for Deep Run and Deep Pool continue to increase until the highest modeled flow of 1,000 cfs. Given the diverse habitat conditions at flows below 80 cfs, base dry recommendations based solely on habitat could theoretically fall below previously established subsistence recommendations. However, to provide a buffer over subsistence recommendations, and thus stay well away from critical temperatures at a base flow condition, the target level for base dry at Calaveras was set to 100 cfs.

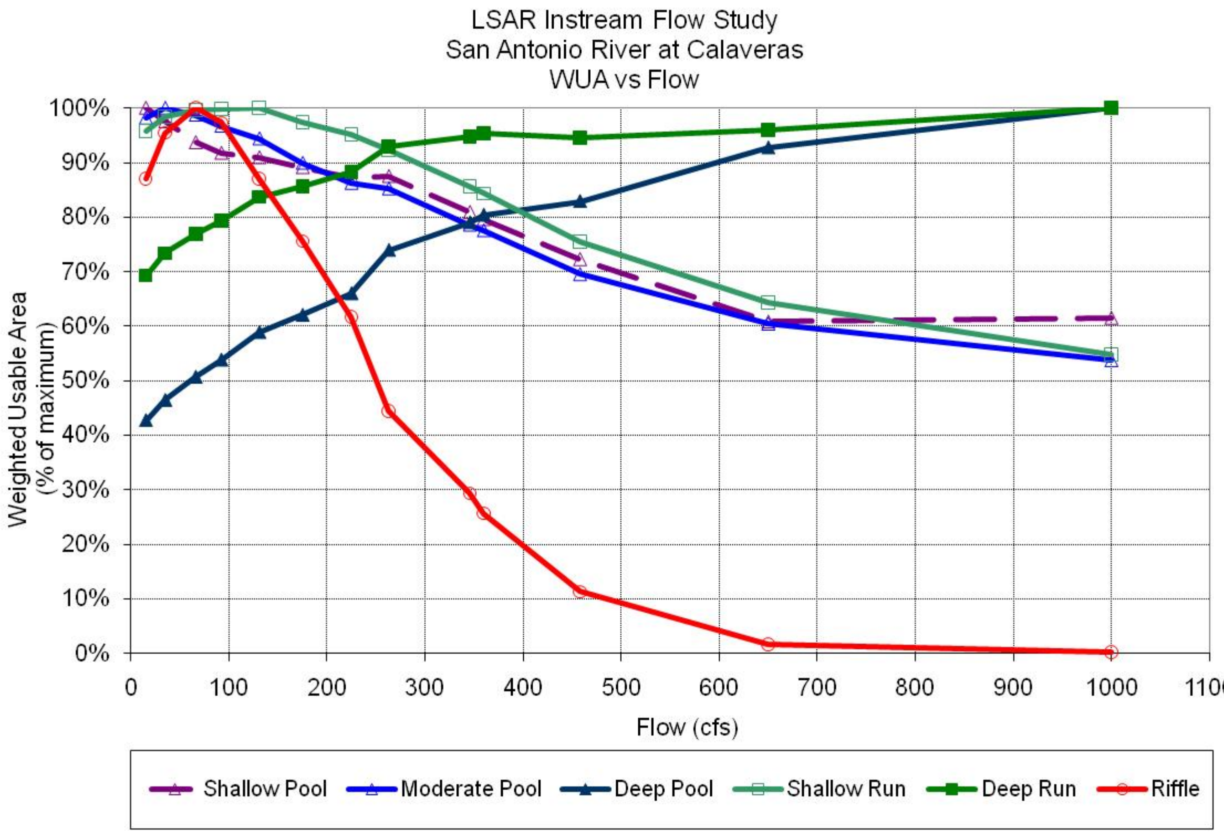


Figure 39. Percent of Maximum Habitat versus simulated discharge at Calaveras Study Site.

The habitat time series for the entire period of record was summarized by calculating various percentiles of total WUA for each habitat guild (Table 12). For example, from Table 12 we see that, over the entire period of record, the median amount of Deep Pool habitat observed (50th percentile) was 23,202 m^2. The median amount of Riffle habitat observed was 2,420 m^2. The next step was to determine what flow condition could maintain the highest percentile of habitat in all habitat guilds simultaneously. In this instance, the historical median amount of habitat in each guild could not be maintained with a single flow. This results from the fact that higher flows create more Deep Pool and Deep Run habitat, whereas lower flows create more WUA in most other guilds. Since the 50th percentile and above is unattainable with a single flow, this data is labeled "unattainable" in the table. However, analysis showed that the 49th percentile habitat in each guild could be maintained with a minimum flow of 221 cfs. Therefore, based on the amount of habitat that was seen over the entire period of record, a flow of 221 cfs provides the most diverse conditions (highest evenness) across all guilds. Based on this analysis, and the diversity of high quality habitat available at the modeled flow of 225 cfs (Figure 18, Section 2.3.1 and Appendix B), the target level for base average at Calaveras was set to 225 cfs. An evaluation of the spatial output created by these modeled flows shows diverse habitat conditions with lateral and longitudinal connectivity.

Table 12. Habitat Time Series results for Calaveras Study Site - WUA.

Percentile	Percent Exceedance	Calaveras - Weighted Usable Area (m^2)						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	17,305	35,146	31,863	9,937	19,820	3,922	unattainable*	
0.999	0.1	17,304	35,131	31,856	9,826	19,820	3,922	unattainable*	
0.99	1	17,240	34,625	31,607	9,616	19,818	3,911	unattainable*	
0.975	2.5	17,168	33,921	31,260	9,492	19,815	3,899	unattainable*	
0.95	5	17,067	33,024	30,819	9,329	19,810	3,875	unattainable*	
0.925	7.5	16,946	32,017	30,532	9,263	19,807	3,847	unattainable*	
0.9	10	16,839	30,847	30,390	9,204	19,803	3,823	unattainable*	
0.8	20	16,498	28,628	30,259	9,103	19,749	3,572	unattainable*	
0.75	25	16,275	28,261	30,194	9,055	19,667	3,376	unattainable*	
0.7	30	15,977	27,364	30,075	8,985	19,549	3,203	unattainable*	
0.6	40	15,433	26,142	29,653	8,850	19,207	2,848	unattainable*	
0.5	50	14,935	23,202	28,146	8,727	18,873	2,420	unattainable*	
0.49	51	14,916	23,088	28,075	8,726	18,812	2,349	221	221
0.4	60	14,663	22,111	27,468	8,674	18,188	1,695	186	270
0.3	70	13,873	21,222	26,964	8,221	17,275	1,287	152	327
0.25	75	13,431	20,792	26,733	7,941	16,719	1,007	135	360
0.2	80	12,852	20,007	26,147	7,636	15,990	771	116	401
0.1	90	11,270	18,616	25,088	6,649	13,873	257	85	553
0.05	95	10,281	17,897	24,575	6,117	12,432	56	68	642
0.025	97.5	9,875	17,233	24,081	6,091	11,776	36	54	832
0.01	99	9,555	16,750	23,720	6,080	11,260	20	44	928
0.001	99.9	9,326	15,792	22,869	6,074	10,890	8	27	998
0.0001	99.99	9,319	15,203	22,277	6,074	10,879	8	18	1000

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

The target level for base wet at the Calaveras Study Site was set at 350 cfs based on several breakpoints in WUA at this flow level: 1) above this flow, high quality Riffle habitat is minimal or non-existent; 2) Shallow Run habitat becomes limited at flows above 350 cfs; and 3) total Deep Run WUA hits a plateau at this level, with increasing flows contributing minimal amounts of additional habitat (Figure 18, Section 2.3.1 and Appendix B). An evaluation of the spatial output created by these modeled flows shows no problems with habitat connectivity.

3.2.2 *Falls City*

Due to the unique hydraulic conditions at the Falls City study site, total WUA for Deep Run and Deep Pool guilds change little with flow and remain at or above 90% of maximum for all modeled flows (Figure 40). However, changes in WUA for the other four habitat guilds are more significant. Habitat for these guilds is maximized under lower flow conditions, and Shallow Pool habitat begins to decline between approximately 100 and 200 cfs. Therefore, this range was examined further for setting a base dry target level. Using habitat time series analysis similar to that described for the Calaveras site, it was determined that 130 cfs is the minimum flow that would provide greater than the 20th percentile amount of habitat for each guild based on the entire period of record. Based on this analysis coupled with the diversity of habitats predicted (Figure 40) and the connectivity observed in spatial outputs of modeled data, 130 cfs was selected as the base dry target flow level.

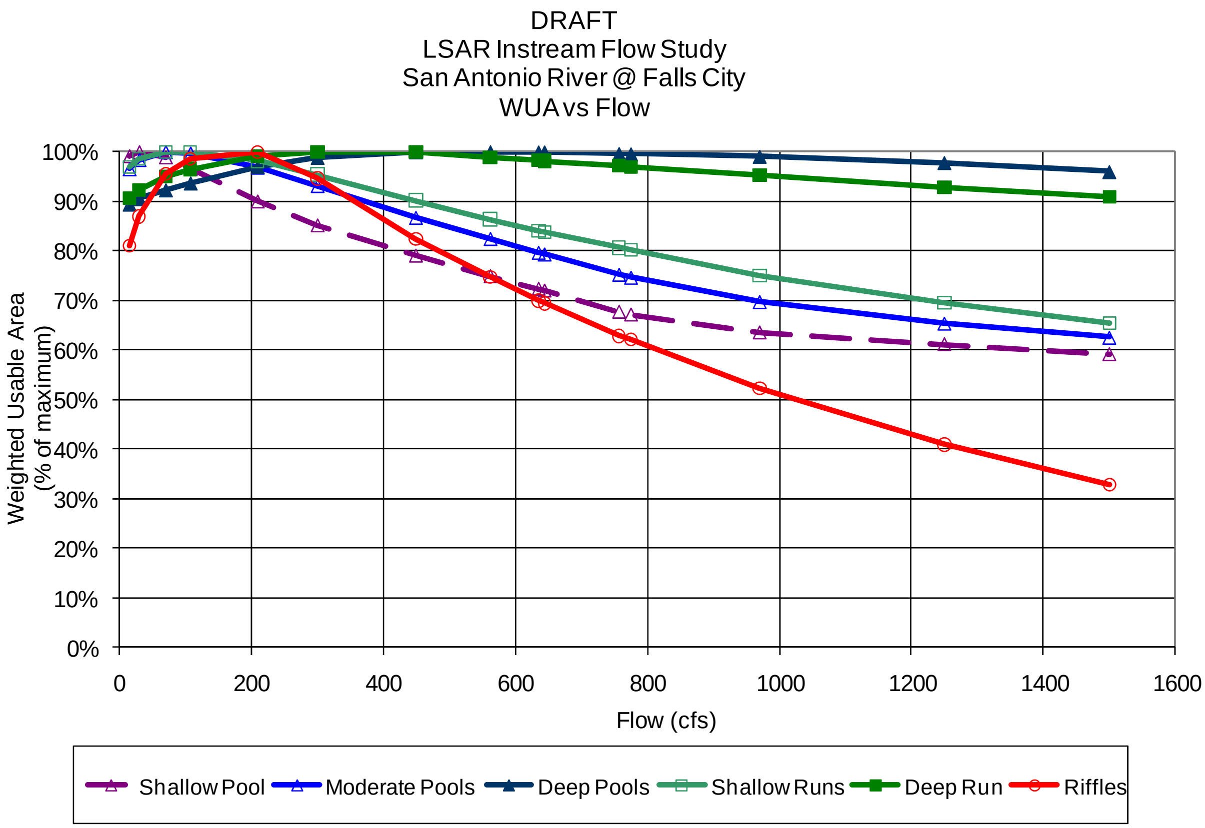


Figure 40. Percent of Maximum Habitat versus simulated discharge at Falls City Study Site.

Similar to the Calaveras study site, a target base average flow level was evaluated by examining the percentiles of WUA for each habitat guild based on the entire period of record, and then calculating the flow necessary to reach the highest percentile for all habitat guilds simultaneously. This analysis showed that the median amount (50th percentile) of habitat for each guild could be created with a flow of approximately 250 cfs (247-253 cfs) (Appendix C). Since this condition provided diverse amounts of high quality habitat for all guilds (Appendix B), and was near the peak in high quality Riffle habitat (Figure 40), the base average target flow level at Falls City was set at 250 cfs.

The base wet target flow level at Falls City was set based on analysis of total WUA, as well as analysis of spatial output for key shallow pool/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 Shallow Pool. Therefore, from a strictly habitat perspective, base flows above 450 cfs have little benefit. An evaluation of spatial output shows that flows in the 450 cfs range create additional critical shallow pool/backwater habitat at the area around and immediately downstream from Conquista Crossing (Figure 41). These habitats are particularly important since they provide considerable habitat for larval fish in close proximity to Riffle habitat at Conquista Crossing. The shallow riffles in this area are used as spawning habitat by several species. Based on the information above, the base wet target level at Falls City was set at 450 cfs.

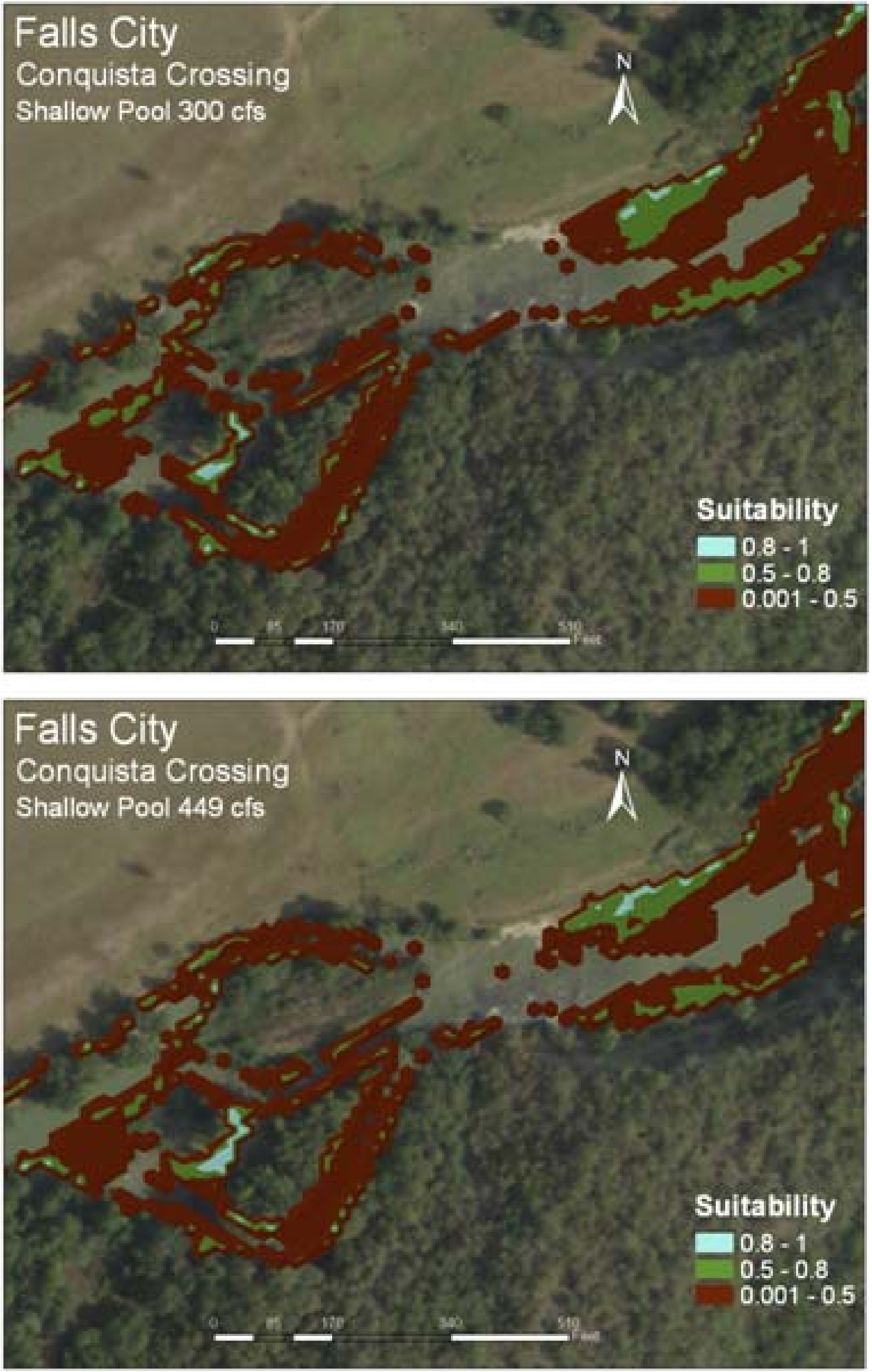


Figure 41. Spatial output of Shallow pool/backwater WUA depicted for three levels of habitat quality at Falls City Study Site. Note the increase in high suitability (0.8-1) habitat at 449 cfs (bottom picture).

3.2.3 *Goliad*

Shallow water habitat guilds at the Goliad Study Site begin to decline between 100 and 200 cfs, whereas, Deep Pool and Deep Run peak at flows of 300-400 cfs (Figure 42). Therefore, the range of flows between 100 and 200 cfs were examined for setting a base dry target flow level. Habitat time series analysis showed that 170 cfs was the minimum flow that maintained greater than the 20th percentile amount of habitat for each guild based on the entire period of record (Appendix C). Additionally, based on spatial output of model flows and previous mesohabitat mapping efforts (BIO-WEST 2008b), 170 cfs is the approximate flow to connect the downstream end of a critical deep backwater habitat to the main river channel (Figure 43 and 44). Therefore, 170 cfs was set as the base dry target flow level.

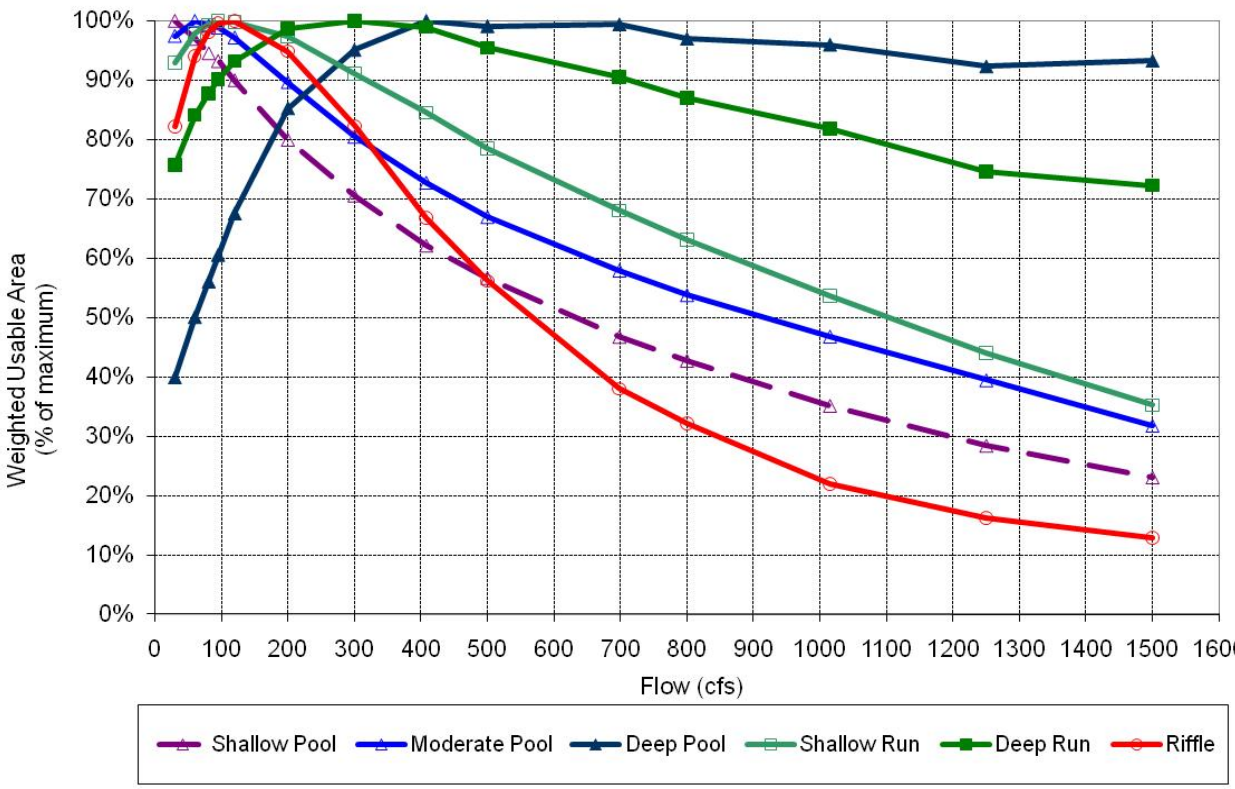


Figure 42. Percent of Maximum Habitat versus simulated discharge at Goliad Study Site.

A flow of 290 cfs provides for greater than 70 percent of maximum for all habitat types (Figure 42) and high quality habitat is available for all habitat types (Appendix B). As a result, 290 cfs was set as the base average target flow level.

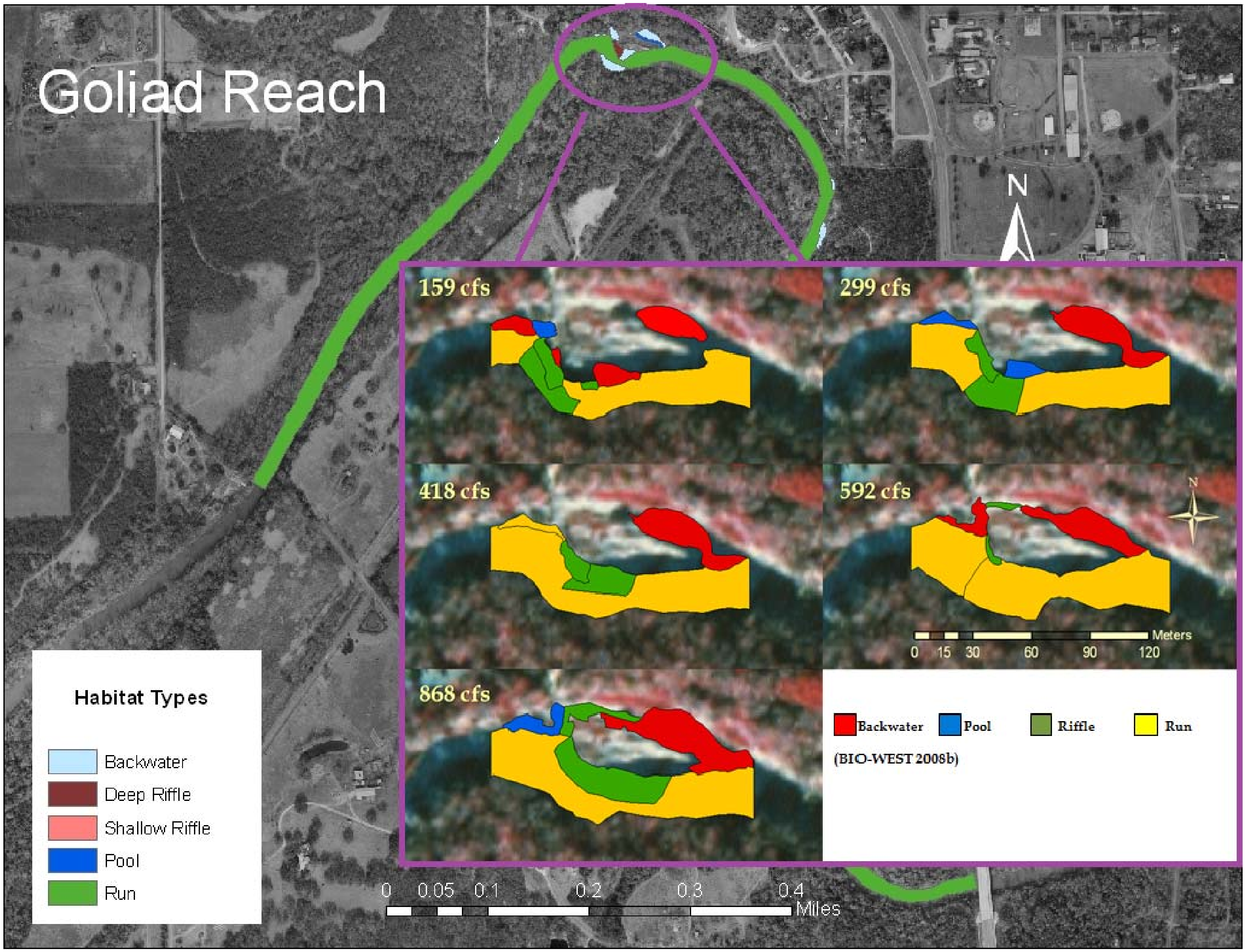


Figure 43. Goliad Riffle Complex – Insert of mesohabitat mapping data collected during preliminary assessment in 2008 (BIO-WEST 2008b).

An evaluation of all previously described aquatic habitat modeling tools and spatial output suggested a fairly wide range of potential base-wet flow conditions. WUA curves and evaluations of high quality habitat (Figure 42 above and Appendix B) suggest that flows from 350 to 650 cfs would still provide greater than 40 percent of the maximum of each habitat type and allow for high quality habitat of each type. However, the Goliad study site contains a unique habitat feature that assisted in this determination. The riffle complex at the upper end of the study site (Figure 43) creates a diversity of habitat at differing flows. It was already mentioned that at approximately 170 cfs, the deep backwater on river left is connected to the main river channel on the downstream end. For the base wet target flow level assessment, connectivity of the river left side channel that connects the previously described backwater habitat on the upstream end and creates a secondary channel was an important factor. At this area under high base flows, water spills over the river-left side of the gravel bar, and creates an island. Flow through this river-left channel was viewed as important for maintaining good habitat conditions in a unique deep backwater at this location which can become stagnant under lower flow conditions. In fact, under subsistence conditions, this habitat is completely separated from the main river channel (Figure 43 and Figure 44).

According to mesohabitat mapping and model predictions of wetted area, the dry base flow of 170 cfs approximates the flow at which the downstream end of this backwater connects to the main channel (Figure 44). Mesohabitat mapping conducted during a preliminary study in 2008 (BIO-WEST 2008b) showed the upstream connection to this channel began flowing somewhere between 418 and 592 cfs (Figure 43). However, mesohabitat mapping conducted during the current study could not refine this number since it was only conducted at flows of 408 and 1,050 cfs. Model predictions of wetted area demonstrated that this connection was complete somewhere between 800 and 1,015 cfs (Figure 44). The possibility certainly exists that the river bed morphology changed due to large floods between the preliminary data collected in 2008 and the modeling done in 2010. However, given uncertainty in the model, and the fact that the connection was witnessed to occur in the 500 cfs range, 500 cfs was set as the base wet target flow level at Goliad.

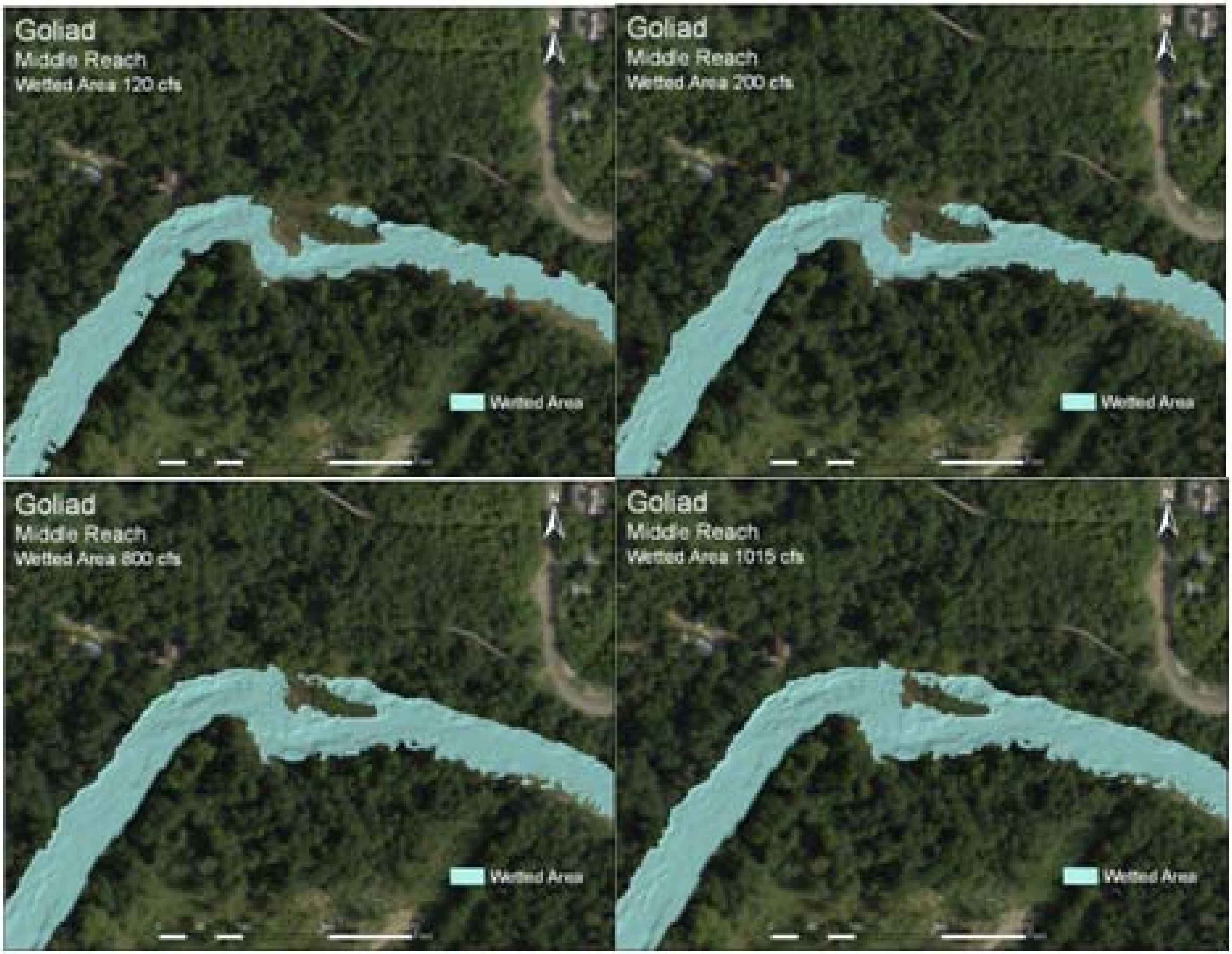


Figure 44. Model predictions of wetted area at four flows around the Goliad riffle complex. Notice isolated backwater at 120 cfs, and complete side channel formation at 1,015 cfs.

3.2.4 *Cibolo Creek*

Weighted Usable Area to discharge relationships at Cibolo Creek were rather unique when compared to relationships observed in the lower San Antonio River. Except for Shallow Pool/Backwater, all habitat guilds were maximized at the highest flow rate (Figure 45). Moderate Pool habitat showed little change with flow, remaining above 90% of maximum regardless of flow, while Deep Pool showed the highest variation with flow, dipping below 50% of maximum at a flow of 2 cfs (Figure 45).

WUA to discharge curves observed 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, 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.

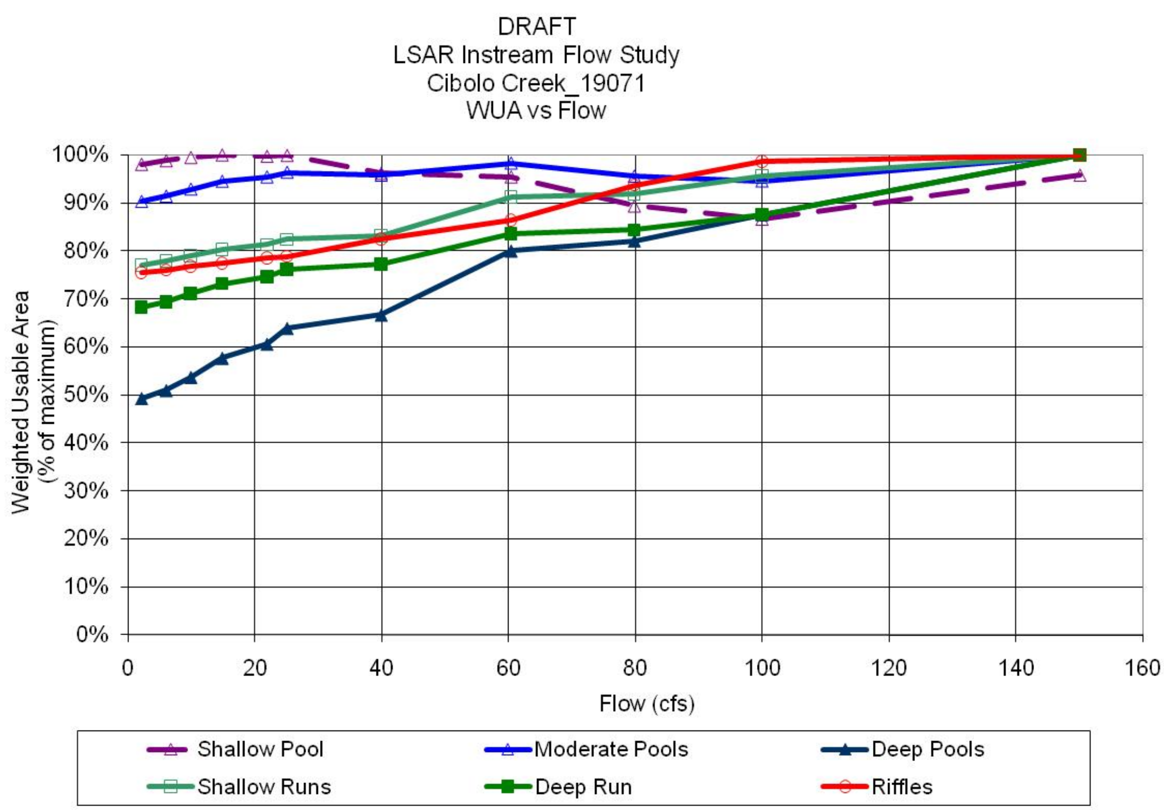


Figure 45. Percent of Maximum Habitat versus simulated discharge at Cibolo Study Site.

High quality (CSI≥0.8) habitat was present for all habitat guilds at all flow rates modeled, except for Riffle at flows of 2 and 6 cfs (Figure 38 above, and Appendix B). Therefore, in an attempt to maintain high-quality habitat for all guilds, subsistence recommendations were set at 7.5 cfs (Section 3.1). However, this maintains only very minor amounts of high quality Riffle habitat. A flow of 15 cfs maintains 124 m^2 of high quality Riffle habitat, which was deemed a more appropriate level within our study reach for a base flow condition. At other sites, base dry target flow levels approximated the minimum flow that would maintain the 20th percentile of all habitat guilds based on the entire period of record. At Cibolo Creek, this value was 14 cfs. Since this approximated the previously identified target level based on adequate amounts of high-quality Riffle habitat, the base dry target flow level at Cibolo Creek was set at 15 cfs.

Habitat time series analysis at Cibolo Creek revealed that the 53rd percentile of each habitat guild could be maintained with a flow of 28 cfs (Appendix C). This represents the most diverse habitat condition at this site, based on the entire period of record. WUA results for the nearest modeled flow rate of 25 cfs showed sufficient amounts of high-quality habitat. Spatial output revealed good habitat connectivity in this flow range as well. Therefore, the base average target flow level was set to 25 cfs.

The base wet target flow level at Cibolo Creek was set primarily on analysis of spatial model output. In the middle reach of the Cibolo Creek site are three key riffle areas where most of the darter species were caught. At flows of 25 cfs, high-quality Riffle habitat exists at only one of these areas. However, at a flow of 40 cfs, high-quality Riffle habitat was observed at all three areas (Figure 46). To provide this key habitat condition in multiple areas of the site, the base wet target flow level was set at 40 cfs.

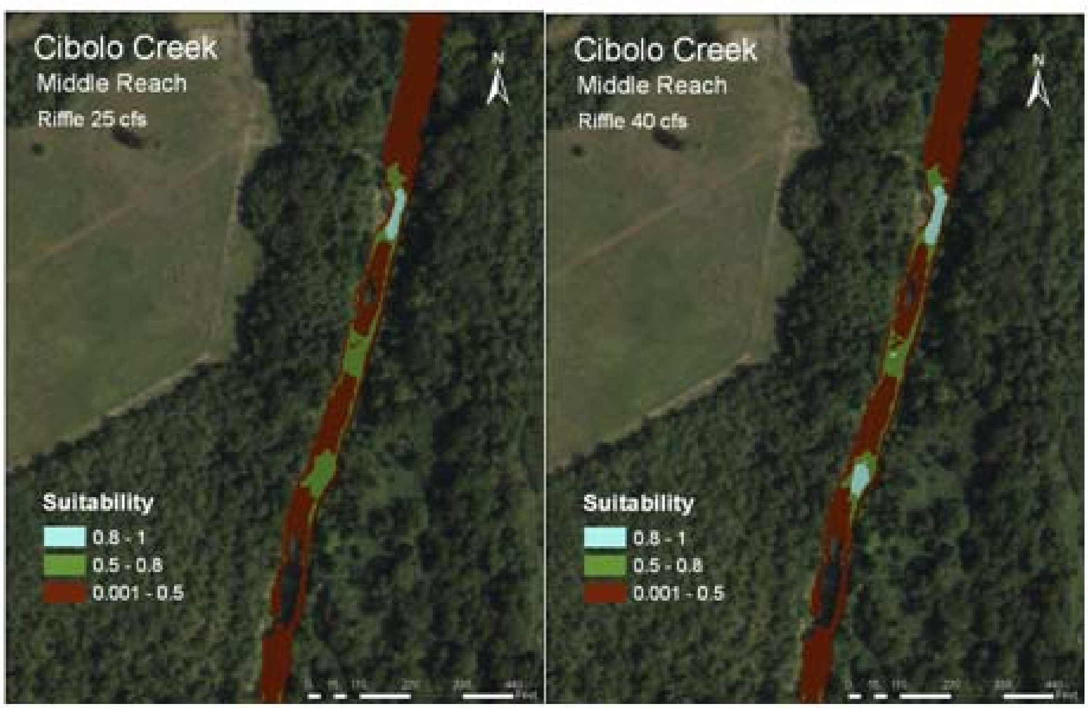


Figure 46. Riffle guild habitat suitability at the middle reach of the Cibolo Creek site under 25 and 40 cfs. Note expansion of high-quality habitat (light blue) into multiple areas at 40 cfs.

3.2.5 *Establishing Intra-annual Variability*

Once base flow target levels were established for each site, the next step in recommendations development was to develop monthly recommendations which followed a natural hydrologic pattern and thus provided intra-annual variability. To do this, the entire hydrologic record at the nearest USGS gage to each site was divided into Dry, Average, and Wet years based on Total Annual Volume (TAV). Total Annual Volume was calculated for each year in the record by summing the mean daily flow and converting from cfs to acre-feet. Years which had a TAV less than the 25th percentile were classified as Dry. Years that had a TAV which fell between the 25th percentile and the 75th percentile were classified as Average. Finally, years with a TAV greater than the 75th percentile were classified as wet.

The average monthly base flow for each month was then calculated for all years which fell in a given hydrologic condition. This resulted in a monthly distribution for each hydrologic condition. The mean of the 12 average monthly flows for each hydrologic condition was then calculated to get a yearly average. The percent difference was then calculated between the yearly average and each monthly average. This percent difference for each month was then multiplied by the previously identified target base flow levels to generate a monthly distribution around each target flow level which would reflect the natural hydrologic pattern observed during Dry, Average, and Wet years. The Dry Year monthly distribution at Calaveras resulted in flows which approached or fell below Subsistence levels during July, August, and October. To provide a buffer over Subsistence recommendations, flows in these months were adjusted to 90 cfs. The resulting monthly base flow recommendations for each site are presented in Section 4.0 within the Interim Recommendations figures.

Final TIFP recommendations for base flow in the lower San Antonio River and lower Cibolo Creek sub-basin may be adjusted in response to the results of ongoing studies (mussel habitat versus flow relationships and seasonal patterns of fish habitat utilization) and consultations with the sub-basin workgroup.

3.3 *High Flow Pulses and Overbank Flows*

For high flow pulses and overbank flow recommendations development, the project team used field-collected riparian data, TESCP-mapped community data, HEC-RAS model data, and the results from a tree core study to identify flow events that are important to riparian vegetation at the five study sites. Life history information from the literature review was used to identify potentially important time periods when those pulse flows would be necessary to the dominant bottomland forest tree species present at the sites (Table 13).

The riparian transect data and bank profiles found that black willow, sycamore, and buttonbush are riparian species typically found at the water's edge and on the stream banks. HEC-RAS model results identified the flow events that would inundate these species in the riparian zone. The transect data also found that box elder, green ash and cottonwood trees were typically found higher up on the stream banks and on up into the riparian zone, where they are inundated less frequently than the black willow community. Based on a literature review, seeding and germination periods were identified for several dominant tree species in the riparian community. This timing for individual species' recruitment is reflected in Table 14 for each site. An estimate for the frequency (# 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 (Table 14).

Based on the life history information, the modeled extent of pulse flows in the riparian zone, and the overall area of inundation of riparian communities, the flows specified in Table 14 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 pulse from April to June for black willow seed dispersal and germination, and soil moisture for seedlings and sapling growth.
- 1,000 cfs high flow pulse from July to October for soil moisture to buttonbush during the flowering and seeding period.
- 2,500 cfs high flow pulse from July to November to provide for soil moisture and seedling dispersal and recruitment.
- 5,000 and 8,000 cfs overbank flow during the growing season to inundate the larger riparian zone for soil moisture and inundation to prevent intrusion of upland species.

Table 13. Summary of literature review information regarding life history of riparian indicator species.

Species	Life history needs for environmental flows
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
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
Buttonbush (*Cephalanthus occidentalis*)	- Seeds disperse September to October
Box elder (*Acer negundo*)	- Seeds disperse Sept 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 - Larger 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 seed/saps - Need scoured sites (periodic high floods) to establish - Susceptible to desiccation from too rapid soil moisture subsidence, or prolonged inundation

Table 14. High Flow Pulses and Overbank Flow Evaluation for Riparian Community at each Study Site.

STUDY SITE	PULSE (cfs)	TIMING	FREQ./ year	DURATION	BENEFIT
Calaveras	3,000	Apr-Jun	1-3	2-5 days	Inundates most of the **black willow** habitat
	4,000	May-Jun	1-2	2-3 days	Inundates a young **cottonwood** stand and most of the box elder/green ash habitat
	4,000	Jul-Nov	1-2	2-3 days	Inundates a young cottonwood stand and most of the **box elder/green ash** habitat
	8,000	Feb-Oct	1	2 days	Inundates 75% of TESCP-mapped floodplain hardwood forest and riparian **hardwood forest communities**
	11,500	Feb-Oct	1	2 days	Inundates 90% of TESCP-mapped floodplain hardwood forest and riparian **hardwood forest communities**
Falls City	4,000	Feb-Apr	1-2	2-5 days	Inundates most of the black willow and **sycamore** habitat
	4,000	Apr-Jun	1-3	2-5 days	Inundates most of the **black willow** and sycamore habitat
	6,500	Jul-Nov	1-2	2-3 days	Inundates a majority of the **box elder/green ash** trees and saplings
	8,000	Feb-Oct	1	2 days	Inundates almost all of the box elder/green ash habitat; Inundates 80% of TESCP-mapped floodplain **hardwood forest community**
	11,500	Feb-Oct	1	2 days	Inundates most of the facultative wetland species habitat; Inundates over 90% of TESCP-mapped floodplain **hardwood forest community**
Goliad	4,000	Feb-Apr	1-2	2-5 days	Inundates most of the black willow and **sycamore** habitat
	4,000	Apr-Jun	1-3	2-5 days	Inundates most of the **black willow** and sycamore habitat
	8,000	Jul-Nov	1-2	2-3 days	Inundates a portion of the **box elder/green ash** habitat; serves as a break-point in the community where many facultative species begin to occur
	11,500	Feb-Oct	1	2 days	Inundates almost all of the box elder/green ash habitat; Inundates 65% of TESCP-mapped floodplain **hardwood forest community**
	14,000	Feb-Oct	1	2 days	Inundates most of the facultative wetland species habitat; Inundates 90% of TESCP-mapped floodplain **hardwood forest community**

Table 14. High Flow Pulses and Overbank Flow Evaluation for Riparian Community at each Study Site (continued).

STUDY SITE	PULSE (cfs)	TIMING	FREQ./ year	DURATION	BENEFIT
Highway 77	4,000	Feb-Apr	1-3	2-5 days	Inundates most of the black willow and **sycamore** habitat
	4,000	Apr-Jun	1-3	2-5 days	Inundates most of the **black willow** and sycamore habitat
	8,000	Jul-Nov	1-2	2-3 days	Inundates the lower riparian portion including the **box elder/green ash** habitat
	10,000	Feb-Oct	1	2 days	Inundates most box elder/green ash habitat; Inundates 70% of TESCP-mapped floodplain **hardwood forest community**
Cibolo	1,000	Apr-Jun	1-3	2-5 days	Inundates the existing **black willow** trees and buttonbush shrubs
	1,000	Jul-Oct	1-2	2-3 days	Inundates the existing black willow trees and **buttonbush** shrubs
	2,500	Jul-Nov	1-2	2-3 days	Inundates a large portion of **box elder/green ash** habitat
	5,000	Feb-Oct	1	2 days	Inundates most box elder/green ash habitat; Inundates 75% of TESCP-mapped floodplain **hardwood forest community**
	8,000	Feb-Oct	1	2 days	Inundates over 90% of TESCP-mapped floodplain **hardwood forest community**

As discussed in Section 2.3.3, a TIFP sponsored tree-ring coring 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 (TAV) ranges at which riparian growth was good. Therefore, the project team used those TAV recommendations as an overlay to assess the proposed flow magnitudes, frequencies, and durations described in Table 14.

For this riparian overlay assessment, three different scenarios building on subsistence (Section 3.1) and base (Section 3.2) Interim recommendations and including the high flow pulses and overbank flows (Table 14) are presented that bracket the potential for the least to greatest amount of TAV with strict interpretation of the Interim recommendations. The scenarios are as follows:

- Subsistence Flow
  - Alone
  - Including 3 high flow pulses with minimum duration
  - Including all 5 high flow pulses with maximum duration
- Base-Dry
  - Alone
  - Including 3 high flow pulses with minimum duration
  - Including all 5 high flow pulses with maximum duration
- Base-Average
  - Alone
  - Including 3 high flow pulses with minimum duration
  - Including all 5 high flow pulses with maximum duration
- Base-Wet
  - Alone
  - Including 3 high flow pulses with minimum duration
  - Including all 5 high flow pulses with maximum duration

Tables 15-18 show the TAV (acre-feet) range recommended by Duke (2011) followed by TAV for a bracketed range of scenarios. Strict interpretation of the Interim instream flow recommendations means that all water in the system beyond the Interim Recommendation in place at any given time is removed from the system, and thus, not counted in the calculation. During implementation, it is likely that some additional flow above the recommendations would be provided, in the form of larger events that could not be captured and removed from the system, deliveries of water to downstream water right holders, and other factors. At the same time, actual flows may be reduced somewhat as environmental flows are not expected to be supplemented by releases. For example, during dry conditions, flows may drop below base dry or even subsistence levels. No diversions will be allowed for water rights subject to environmental flow recommendations, but no water would be available to bring flows up to subsistence or base dry conditions. Therefore, actual flow in the river may occasionally be lower than the environmental flow recommendations. Nevertheless, Tables 15-18 provide insight regarding the annual flow volumes that would be associated with the recommended environmental flow recommendations at each location.

Table 15. Total Annual Volume scenarios for Calaveras Study Site.

CALAVERAS - (Recommendation 198,400 - 1,190,000)	
Condition	**Total Annual Volume (acre-feet)**
Subsistence all year, no pulses	57,933
Subsistence all year, 3 pulses for 2 days	100,628
Subsistence all year with max pulses	314,900
Base dry all year, no pulses	74,477
Base dry all year, 3 pulses for 2 days	116,798
Base dry all year, max pulses	330,092
Base Avg all year, no pulses	162,712
Base Avg all year, 3 pulses for 2 days	203,398
Base Avg all year, max pulses	410,700
Base Wet all year, no pulses	253,301
Base Wet all year, 3 pulses for 2 days	292,715
Base Wet all year, max pulses	489,306

Table 16. Total Annual Volume scenarios for Falls City Study Site.

FALLS CITY - (Recommendation 215,000 - 1,285,000)	
Condition	**Total Annual Volume (acre-feet)**
Subsistence all year, no pulses	57,933
Subsistence all year, 3 pulses for 2 days	114,516
Subsistence all year with max pulses	405,530
Base dry all year, no pulses	93,960
Base dry all year, 3 pulses for 2 days	149,806
Base dry all year, max pulses	437,867
Base Avg all year, no pulses	180,905
Base Avg all year, 3 pulses for 2 days	235,382
Base Avg all year, max pulses	516,396
Base Wet all year, no pulses	325,731
Base Wet all year, 3 pulses for 2 days	378,041
Base Wet all year, max pulses	647,353

Table 17. Total Annual Volume scenarios for Goliad Study Site.

GOLIAD - (Recommendation 297,500 - 1,587,000)	
Condition	**Total Annual Volume (acre-feet)**
Subsistence all year, no pulses	57,933
Subsistence all year, 3 pulses for 2 days	120,468
Subsistence all year with max pulses	447,194
Base dry all year, no pulses	122,972
Base dry all year, 3 pulses for 2 days	184,234
Base dry all year, max pulses	505,061
Base Avg all year, no pulses	209,826
Base Avg all year, 3 pulses for 2 days	269,850
Base Avg all year, max pulses	584,246
Base Wet all year, no pulses	361,971
Base Wet all year, 3 pulses for 2 days	419,685
Base Wet all year, max pulses	722,821

Table 18. Total Annual Volume scenarios for Cibolo Study Site.

CIBOLO CREEK - (Recommendation 39,000 - 317,100)	
Condition	**Total Annual Volume (acre-feet)**
Subsistence all year, no pulses	5,431
Subsistence all year, 3 pulses for 2 days	23,198
Subsistence all year with max pulses	127,978
Base dry all year, no pulses	10,718
Base dry all year, 3 pulses for 2 days	28,361
Base dry all year, max pulses	132,865
Base Avg all year, no pulses	18,086
Base Avg all year, 3 pulses for 2 days	35,611
Base Avg all year, max pulses	139,495
Base Wet all year, no pulses	28,954
Base Wet all year, 3 pulses for 2 days	46,313
Base Wet all year, max pulses	149,379

In general, the TAV range for riparian productivity is not met for the Subsistence, Base-Dry or Base-Average alone scenarios (Tables 15-18). A series of varying pulses are required during Subsistence, Base-Dry, and Base-Average to meet the TAV criteria, whereas the criteria are almost always met during the Base-Wet condition. This overlay confirmed to the project team that the riparian pulse and overbank levels (Table 14) coupled with subsistence and base levels proposed in Sections 3.1 and 3.2, respectively would be protective of riparian productivity for the following reasons:

- the Duke (2011) criteria are based on the parameter of suppressed growth outside this range, rather than mortality;
- suppressed growth is typically experienced during dryer conditions as part of the natural process;
- the Interim recommendations meet the criteria most of the time during Wet-Base conditions and with varying pulses during other hydrologic conditions; and
- the assumption of all water being removed from the calculation above said criteria is extremely conservative.

As the UTSA studies related to sediment transport versus flow condition are not complete at this time, a full evaluation of the TAV to sediment transport and channel adjustment was not conducted. Preliminary assessment of sediment transport associated with interim environmental flow recommendations was made for one site, the location of USGS Gage Number 08188500 on the San Antonio River at Goliad. That 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. Baseline flow conditions investigated included daily flow values from 1940 to 1969 (historic gaged values selected to be representative of conditions prior to substantial alteration of hydrologic conditions in the basin) and 1970 to 2010 (historic gauged values selected to be representative of conditions after substantial human alterations within the basin).

Two possible future flow conditions were investigated. In the first scenario, flows were limited to the interim flow recommendations only (shown in Figure 50). This analysis did take into account the historical occurrence of flows for the period from 1970 to 2010 in that flow values were set to the lower of two values, either the historical daily flow or the interim recommendations. The analysis did not take into account the effect of senior downstream water rights, which, on a particular day, may act to keep more water in the channel than would be prescribed by the interim flow recommendations themselves. The analysis of sediment transport associated with these flows does give a general idea of the sediment transport characteristics associated with the interim recommendations exclusively.

A second future flow condition, which included all of the criteria of the first plus a maximum diversion rate of 1,500 cfs, was also investigated. In this scenario, flow at the site was limited to the historical gaged flow for the period from 1970 to 2010 if the gauged flow was less than the interim recommended flow. If gauged flow was greater than the flow recommendations, flow was set to the greater of the following two values, either the environmental flow recommendations or the gauged flow minus the maximum diversion rate.

An example hydrograph for 2004 is shown in Figure 47. In this figure, the green area represents daily gauged flow data from 2004. The blue area shows flows that would result from both implementation of the interim flow recommendations and a maximum diversion rate of 1,500 cfs. The purple area shows the interim flow recommendations themselves.

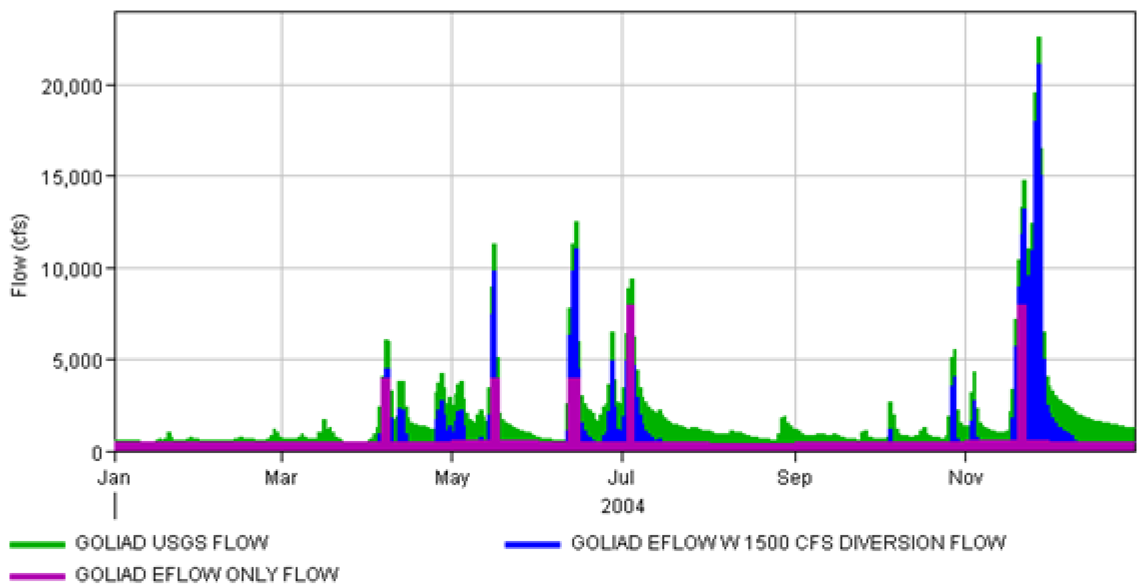


Figure 47. Daily flows for 2004 for historical conditions, interim flow recommendations for Goliad with maximum diversion rate, and interim flow recommendations only.

Results of the sediment transport analysis at Goliad are shown in Table 19. Note that the average annual water yield has increased about 40 percent from the gauged flow in the 1940 to 1969 time period to the 1970 to 2010 time period. Average annual sediment yield increased about 28 percent between these time periods. The interim flow recommendations only scenario results in a drop in water and sediment yields of approximately 30 percent and 70 percent, respectively from 1940 to 1969 baseline conditions (Table 19). Such a change would be expected to result in a river with a smaller channel at Goliad than existed during the 1940 to 1969 baseline period. When a maximum diversion rate of 1,500 cfs is included with the interim flow recommendations, average annual water and sediment yields are within 10 percent of their values for the 1940 to 1969 baseline condition. With this flow scenario, the river would be expected to retract from the current size (as reflected by 1970 to 2010 conditions) and eventually take on a shape similar to that experienced in the 1940 to 1969 time period. If the interim recommendations with a maximum diversion rate were implemented on the lower San Antonio River, it is likely that the channel would migrate towards what the channel historically looked like prior to the 1970's when there was less total annual volume in the river.

Table 19. Results of preliminary sediment transport analysis for the San Antonio River at Goliad.

Flow Scenario	Average Annual Water Yield [acre-feet/year]	Average Annual Sediment Yield [cubic yards/year]	Effective Discharge [cfs]
Gauged 1940-1969	446,264	103,376	8,472
Gauged 1970-2010	749,064	132,158	5,629
Interim Flow Recommendations Only 1970-2010	302,601	29,774	4,098
Interim Flow Recommendations with a Maximum Diversion Rate 1970-2010	483,126	98,837	7,912

Final TIFP recommendations for high flow pulse and overbank flows in the lower San Antonio River and lower Cibolo Creek sub-basin may be adjusted in response to the results of ongoing studies (sediment transport versus flow relationships) and consultations with the sub-basin workgroup.

4.0 INSTREAM FLOW INTERIM RECOMMENDATIONS

As described in Section 3.0, specific instream flow Interim recommendations for four categories (subsistence flows, base flows, high flow pulses, and overbank flows) have been established for the lower San Antonio River and lower Cibolo Creek. Figures 48-51 summarize the integration of those Interim recommendations into one flow regime for all study sites excepting HWY 77 and provide an overview of ecological functions supported by each flow category. Analysis and modeling for the HWY 77 site is in the process of being completed and results and recommendations will be incorporated into the final report.

The recommendations are termed "Interim" as ongoing SB2-sponsored efforts and future SB2 studies/activities in addition to long-term monitoring and adaptive management will provide additional information that may result in modifications or revisions to the Interim recommendations. Potential data gaps within the Interim recommendations flow-regime will be evaluated with additional analysis of existing TIFP data and ongoing and future TIFP research. From this work, additional flow regime components may be developed. TIFP will consult with the sub-basin workgroup before making final recommendations. As highlighted in each recommendations section (3.1, 3.2, and 3.3), final TIFP recommendations for the lower San Antonio River and lower Cibolo Creek sub-basin may be adjusted in response to the results of ongoing studies and consultations with the sub-basin workgroup.

Often, the most difficult parts of an instream flow study are the decisions regarding application and implementation. These decisions involve environmental considerations, operational constraints, social implications (human needs), political implications, etc. This is very evident by the SB2 stakeholders goal 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".*** Senate Bill 2 studies were not mandated to develop implementation strategies. However, the project team feels that an overview is necessary for the reader to understand the context under which the recommendations were developed.

Modern scientific literature suggests that subsistence flows or ecological base flows are "hands off flows" (BIO-WEST 2008a, Hardy et al. 2006, Acreman et al. 2006). Therefore, the goal for Subsistence is that flows below the subsistence flow recommendation should remain in the river. The application of base flow recommendations in the literature is highly variable and river-specific in most cases. The project team developed the base flow recommendations under the assumption that a hydrologic condition would be associated with each flow level. This might involve a climatological index or predictor (e.g. Palmer drought index), operational strategy (e.g. lake level), assessment of river flow upstream with some duration component (e.g. 6 month rolling average river flow), or other management strategy that would constitute the establishment of hydrological conditions for base flow recommendations.

CALAVERAS

Overbank Flow

[February – October]
Magnitude = 11,500 cfs
Frequency = 1 event
Duration = 2 days
Key Indicators:
Riparian: Inundates approx. 90% of hardwood forest community
Sediment transport: Channel maintenance

[February – October]
Magnitude = 8,000 cfs
Frequency = 1 event
Duration = 2 days
Key Indicators:
Riparian: Inundates approx. 75% of hardwood forest community
Sediment transport: Channel maintenance

High Flow Pulses

[May – June]
Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 2-3 days
Key Indicators: Cottonwood

[July – November]
Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 2-3 days
Key Indicators:
Riparian: Green Ash / Box Elder

[April – June]
Magnitude = 3,000 cfs
Frequency = 3 events
Duration = 2-5 days
Key Indicators: Riparian - Black Willow

MONTH	January	February	March	April	May	June	July	August	September	October	November	December
BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability) Key Indicators: Aquatic Habitat, Water Quality												
Base Wet	319	336	329	338	372	382	384	303	336	357	390	355
Base Average	264	268	256	235	259	216	177	160	195	220	226	225
Base Dry	119	113	114	109	113	98	90	90	107	90	91	101
SUBSISTENCE FLOWS (cfs) - Water quality protection and maintainence of limited aquatic habitat Key Indicators: Water Quality, Aquatic Habitat												
Subsistence	80	80	80	80	80	80	80	80	80	80	80	80

Figure 48. Interim Instream Flow Recommendations for the Calaveras Study Site.

FALLS CITY

Overbank Flow

Magnitude = 11,500 cfs
Frequency = 1 event
Duration = 2 days

Key Indicators:
Riparian: Inundates approx. 90% of hardwood forest community
Sediment transport: Channel maintenance

Magnitude = 8,000 cfs
Frequency = 1 event
Duration = 2 days

Key Indicators:
Riparian: Inundates approx. 80% of hardwood forest community
Sediment transport: Channel maintenance

High Flow Pulses

Magnitude = 6,500 cfs
Frequency = 2 events
Duration = 2-3 days

Key Indicators:
Riparian: Green Ash / Box Elder

Key Indicators: Riparian - Sycamore
Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 2-5 days

Magnitude = 4,000 cfs
Frequency = 3 events
Duration = 2-5 days
Key Indicators: Riparian - Black Willow

BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability)								**Key Indicators: Aquatic Habitat, Water Quality**				
Base Wet	429	429	413	427	487	489	489	380	422	459	511	466
Base Average	292	296	288	261	281	249	200	177	218	242	244	251
Base Dry	152	158	147	142	145	125	103	96	141	105	119	127
SUBSISTENCE FLOWS (cfs) - Water quality protection and maintainence of limited aquatic habitat								**Key Indicators: Water Quality, Aquatic Habitat**				
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

Figure 49. Interim Instream Flow Recommendations for the Falls City Study Site.

GOLIAD

Overbank Flow

Magnitude = 14,000 cfs
Frequency = 1 event
Duration = 2 days

Key Indicators:
Riparian: Inundates approx. 90% of hardwood forest community
Sediment transport: Channel maintenance

Magnitude = 11,500 cfs
Frequency = 1 event
Duration = 2 days

Key Indicators:
Riparian: Inundates approx. 65% of hardwood forest community
Sediment transport: Channel maintenance

High Flow Pulses

Magnitude = 8,000 cfs
Frequency = 2 events
Duration = 2-3 days

Key Indicators:
Riparian: Green Ash / Box Elder

Key Indicators: Riparian - Sycamore
Magnitude = 4,000 cfs
Frequency = 2 events
Duration = 2-5 days

Magnitude = 4,000 cfs
Frequency = 3 events
Duration = 2-5 days
Key Indicators: Riparian - Black Willow

BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability)								**Key Indicators: Aquatic Habitat, Water Quality**				
Base Wet	475	460	471	470	538	498	503	434	507	531	579	535
Base Average	325	340	323	305	326	308	248	212	252	272	287	282
Base Dry	200	203	197	178	190	154	121	111	186	155	169	176
SUBSISTENCE FLOWS (cfs) - Water quality protection and maintainence of limited aquatic habitat									**Key Indicators: Water Quality, Aquatic Habitat**			
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

Figure 50. Interim Instream Flow Recommendations for the Goliad Study Site.

CIBOLO CREEK	January	February	March	April	May	June	July	August	September	October	November	December
Overbank Flow		Magnitude = 8,000 cfs Frequency = 1 event Duration = 2 days *Key Indicators:* *Riparian: Inundates approx. 90% of hardwood forest community* *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*										
High Flow Pulses							Magnitude = 2,500 cfs Frequency = 2 events Duration = 2-3 days *Key Indicators:* *Riparian: Green Ash / Box Elder*					
				Magnitude = 1,000 cfs Frequency = 3 events Duration = 2-5 days *Key Indicators: Riparian - Black Willow*			Magnitude = 1,000 cfs Frequency = 2 events Duration = 2-3 days *Key Indictors: Riparian - Buttonbush*					
BASE FLOWS (cfs) - Aquatic Habitat protection (intra- and interannual variability) Key Indicators: Aquatic Habitat, Water Quality												
Base Wet	39	41	38	38	48	45	44	31	35	35	43	42
Base Average	29	28	27	26	29	28	21	17	20	23	25	25
Base Dry	19	20	19	18	17	14	11	9	12	13	13	15
SUBSISTENCE FLOWS (cfs) - Water quality protection and maintainence of limited aquatic habitat Key Indicators: Water Quality, Aquatic Habitat												
Subsistence	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
MONTH	January	February	March	April	May	June	July	August	September	October	November	December

Figure 51. Interim Instream Flow Recommendations for the Cibolo Creek Study Site.

Pulse and overbanking flow recommendations are relatively new in the scheme of instream flow science although the concept has been around for many years. The project team realizes that high flow pulses and overbank flows will be provided by natural rainfall events since no dams/structures are in place which can regulate flows to this extent. The high flow pulse and overbank flow recommendations were also designed to be independent of hydrological conditions. Therefore, if a pulse or overbank flow occurs, it is allowed to pass regardless of which hydrological base condition is currently engaged. For both the high flow pulse frequency and duration criteria a range was determined (Table 14). For the frequency category, the TIFP chose the upper end of that range for all recommendations, with the understanding that if multiple events occur they should be allowed to pass. Therefore, the recommendation is to pass the upper number of high flow pulse events recommended even during a dry year if they occur, realizing that the probability of that is extremely low as it is a dry year. The TIFP expects that over time this would likely balance the fact that there is no guarantee that a wet year will provide the upper recommendation for high flow pulse events. The range presented for duration is interpreted as follows: a duration of 2-5 days means that 2 days at flows above the recommended magnitude may be sufficient to meet the requirement under most conditions, but an upper boundary of 5 days of flows above the recommended magnitude was included to cover uncertainty embedded in the estimate. Therefore, the goal for implementation of the high flow pulse duration recommendation is to be within that range.

Implementation of high flow pulse and overbanking flow recommendations will need to be carefully examined relative to future projects. There are an infinite number of scenarios of pulses and overbank flows that could occur in the lower San Antonio River and lower Cibolo Creek. Following are a couple of examples aimed at explaining the context in which these recommendations were developed. Figure 51 shows the high flow pulse and overbank flow recommendations for Cibolo Creek. One example could be the following events have occurred for a given year up to September and the permit holder was curious if all recommendations have been met:

- 1 event of magnitude 1,050 cfs in April (duration 3 days);
- 1 event of magnitude 1,050 cfs in May (duration 3 days);
- 1 event of magnitude 1,050 cfs in June (duration 3 days);
- 1 event of magnitude 3,000 cfs in July (duration 3 days); and
- 1 event of magnitude 3,000 cfs in August (duration 3 days).

Under this scenario, all the high flow pulse requirements have been met, but the overbank flows of 5,000 cfs or 8,000 cfs would need to be passed if they are projected to occur. A second example through September is as follows:

- 1 event of magnitude 1,050 cfs in April (duration 3 days);
- 2 separate events of magnitude 1,050 cfs in May (duration 2 and 4 days);
- 1 event of magnitude 8,050 cfs in August (duration 3 days); and
- 1 event of magnitude 2,500 cfs in September (duration 3 days).

Under this second example, all high flow pulse and overbank flow requirements would have been met, as higher volume events trump the lower requirements if they meet the ecological requirements of the lower recommendations.

4.1 *Ongoing TIFP Applied Research, Monitoring and Adaptive Management*

As previously described, several TIFP sponsored SB2 studies in the lower San Antonio sub-basin are still in progress. These include:

- UTSA Sediment Transport Evaluations and R2DM modeling
- Stephen F. Austin Large Woody Debris Evaluation
- UNT Golden orb mussel Study

Additionally, several applied research efforts have been identified during this study that may improve the ecological understanding of the aquatic and riparian communities and their relationship to flow. These studies include:

- High flow pulse effects on riparian communities
  - 2012-2014 – first year funding approved, subsequent years to be determined
- Development of a mechanistic ecosystem model of ecological interactions of high flow pulses and riparian communities
  - 2012-2014 – pending funding approval
- Longitudinal Mussel Survey – Lower San Antonio River
  - 2012 – funding approved
- Seasonal fish habitat sampling
  - 2013-2014 – pending funding approval
- Life history research on focal species
- Macroinvertebrate community / substrate disturbance evaluation
- Water temperature modeling for Cibolo Creek

The primary goal of the applied research and adaptive management efforts will be to first collect the data necessary to fill any data gaps identified by the TIFP or stakeholders during this study. This will include but not be limited to 1) collecting information on the ecological function and potential need for intermediate pulse recommendations, 2) seasonal fish habitat sampling and potential need for more refined seasonal subsistence or base-flow recommendations, and 3) life history studies for focal species and potential need for species-specific recommendations. A secondary goal for these studies will be to further describe and/or define flow to ecological relationships to better inform potential future modifications to the Interim recommendations.

The biggest omission from many instream flow studies has been an evaluation of the effectiveness of proposed recommendations. The project team concurs with the TIFP Technical Overview document and National Research Council guidance and recognizes that a critical component of all recommendations for this study is a long-term monitoring program to evaluate the effectiveness of the recommended instream flow recommendations. Specific monitoring and long-term monitoring is recommended as follows:

- Specific (flow/temperature driven) monitoring to evaluate water temperature conditions, habitat, and aquatic ecology during flows near or below the 80 cfs and 7.5 cfs subsistence flow Interim recommendations for the lower San Antonio River and lower Cibolo Creek, respectively.
- Specific low-flow monitoring near Base-Dry recommendations to evaluate potential impacts to mussel communities.
- Long-term annual monitoring to assess fisheries communities at each Study Site.
- Long-term annual monitoring of select riparian transects.
- Long-term (every five years) select channel cross-sections within study sites to assess potential changes in channel configuration.
- Long-term (every 10 year) limited tree-ring coring analysis to assess riparian productivity relative to TAV.

In conjunction with short-term and long-term monitoring, adaptive management will be a vital component to assist in ensuring the effectiveness of the Interim recommendations. Upon completion of on-going TIFP sponsored studies and short-term focused monitoring efforts, the TIFP in conjunction with stakeholder involvement will evaluate study results and revise Interim recommendations, if necessary. As future SB2 studies are completed, the TIFP will evaluate those results and in conjunction with stakeholder involvement publish a Final Study Report by 2016 per SB2 legislation. It is anticipated that the final report and recommendations will include a framework for continued long-term monitoring, periodic review, modification, and on-going adaptive management.

4.2 *Continued Stakeholder Involvement*

This project has been subject to stakeholder and peer review during the project design, and periodic updates during study activities and development of Interim recommendations. Stakeholder involvement has been and will continue to be an integral part of the TIFP process. This Interim Progress Report will be submitted to the SB2 stakeholder group for review. As future TIFP studies and both short- and long-term monitoring activities are developed, stakeholder input will be solicited and participation encouraged. Additionally, as on-going TIPF studies, future studies, and short-term and long-term monitoring results become available periodic stakeholder review will be requested.

5.0 REFERENCES

Acreman, M.C., M.J. Dunbar, J. Hannaford, O.M. Bragg, A.R. Black, and J.S. Rowan. 2006. Development of environmental standards (water resources). Stage 3: environmental standards. Project WFD48. Scotland and Northern Ireland Forum for Environmental Research, Edinburgh, Scotland.

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.

[BIO-WEST] BIO-WEST, Inc. 2008a. 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. 2008b. Preliminary instream flow assessment for the lower San Antonio River (interim subsistence and base-dry instream flow guidelines development). Report to the San Antonio River Authority. BIO-WEST, Inc., Round Rock, 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.

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

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.

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(5):1109-1115.

Engel, F.L. and J.C. Curran. 2008. Geomorphic classification of the lower San Antonio River, Texas. Report to the Texas Water Development Board, Project No. 0604830637. www.twdb.state.tx.us/RWPG/rpgm rpts/0604830637 LowerSanAntonioRiver.pdf

[EC] Espey Consultants, Inc. 2010a. 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.

[EC] Espey Consultants, Inc. 2010b. 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.

[EC] Espey Consultants, Inc. 2011. Brazos River instream flow program (BRIFP) instream flow water quality evaluation, volume 1 - Brazos River downstream of Waco, TX, Rev v1-06. Prepared for Texas Commission on Environmental Quality and Brazos River Authority. Revision 1-06.

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

German, D., D.D. Diamond, L.F. Elliott, A. Treuer-Kuehn, K. Ludeke, and J. Scott. 2009. Texas Ecological Systems Project Phase I Interpretive Booklet. Accompanies Ecological Systems GIS Data-Layer. Texas Parks and Wildlife Department, Austin, Texas (internal document).

[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

[HDR & PPA] HDR Engineering, Inc. and Paul Price and Associates. 1998. Trans-Texas Water Program west central study area, phase II: Guadalupe-San Antonio River Basin environmental criteria refinement. Report to the Texas Water Development Board.

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.

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., R.C. Addley, and E. Saraeva. 2006. Evaluation of instream flow needs in the lower Klamath River. Phase II, Final Report. Institute for Natural Systems Engineering, Utah State University, Logan, Utah. http://www.neng.usu.edu/uwrl/inse/klamath/FinalReport/PhaseII_Final_Report_Revised_Oct_16_2006.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.

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.

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.

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

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.

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(6):26-32.

Matthews, W.J. and L.G. Hill. 1977. Tolerance of the red shiner, *Notropis lutrensis* (Cyprinidae) to environmental parameters. The Southwestern Naturalist 22(1): 89-98.

Moss, D.D. and D.C. Scott. 1961. Dissolved-oxygen requirements of three species of fish. Transactions of the American Fisheries Society 90(4): 377-393.

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

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.

Poff, N.L. and J.D. Allan. 1997. The natural flow regime. Bioscience 47(11):769-785.

[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. http://www.tceq.texas.gov/assets/public/permitting/watersupply/water_rights/eflows/sac_2009_04_sedtransport.pdf

[SARA] San Antonio River Authority. 2008. San Antonio River Basin summary report. San Antonio River Authority, San Antonio, Texas. http://www.sara-tx.org/site/water_quality/water_qual_mon/clean_rivers/assessment_report.html

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

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.

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].

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.

[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] Texas Instream Flow Program. 2010. Instream flow study of the lower San Antonio River and lower Cibolo Creek. Study design. Texas Instream Flow Program and San Antonio River Authority.

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

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

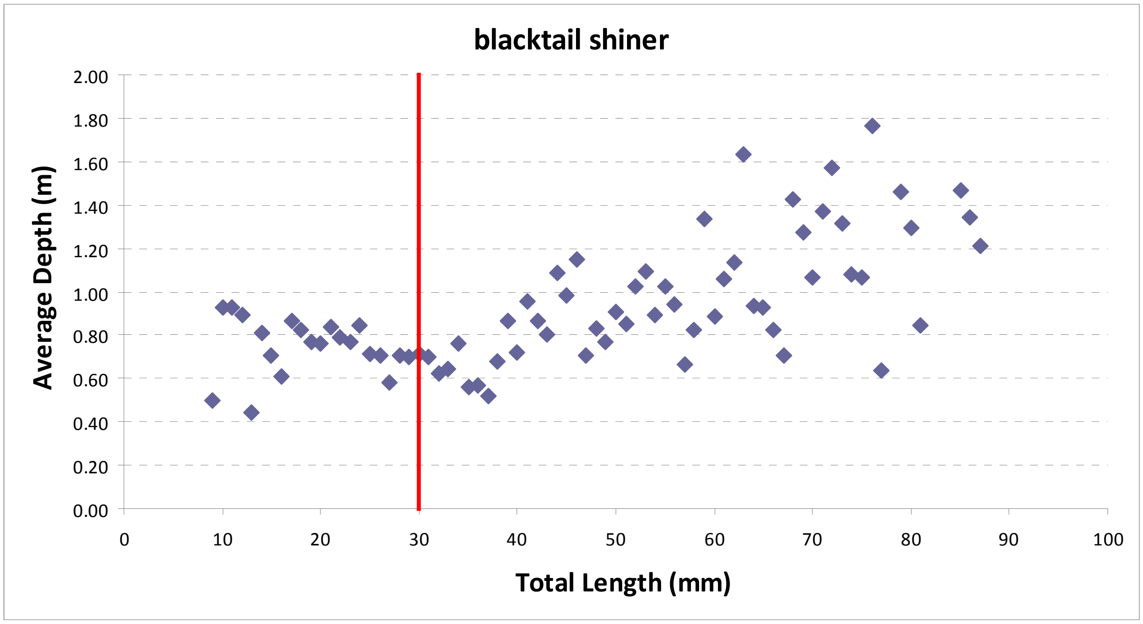
[NRCS] Natural Resources Conservation Service. 2004. Plant fact sheet: common buttonbush, *Cephalanthus occidentalis*. http://plants.usda.gov/factsheet/pdf/fs_ceoc2.pdf

[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

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.

APPENDIX A
FISHERIES SIZE CLASS FIGURES



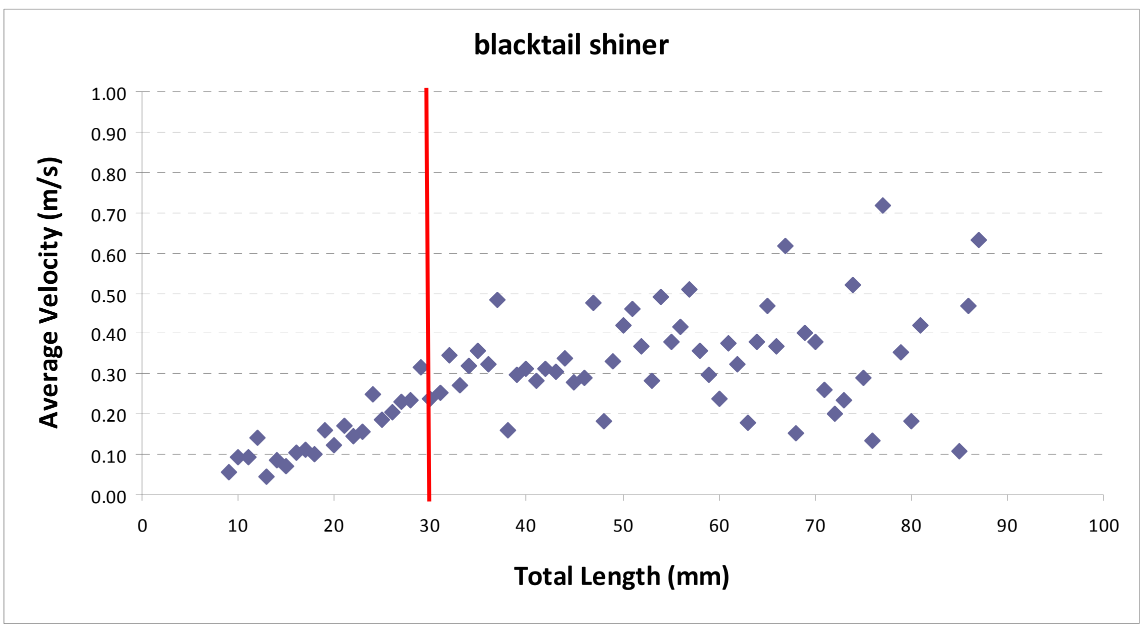
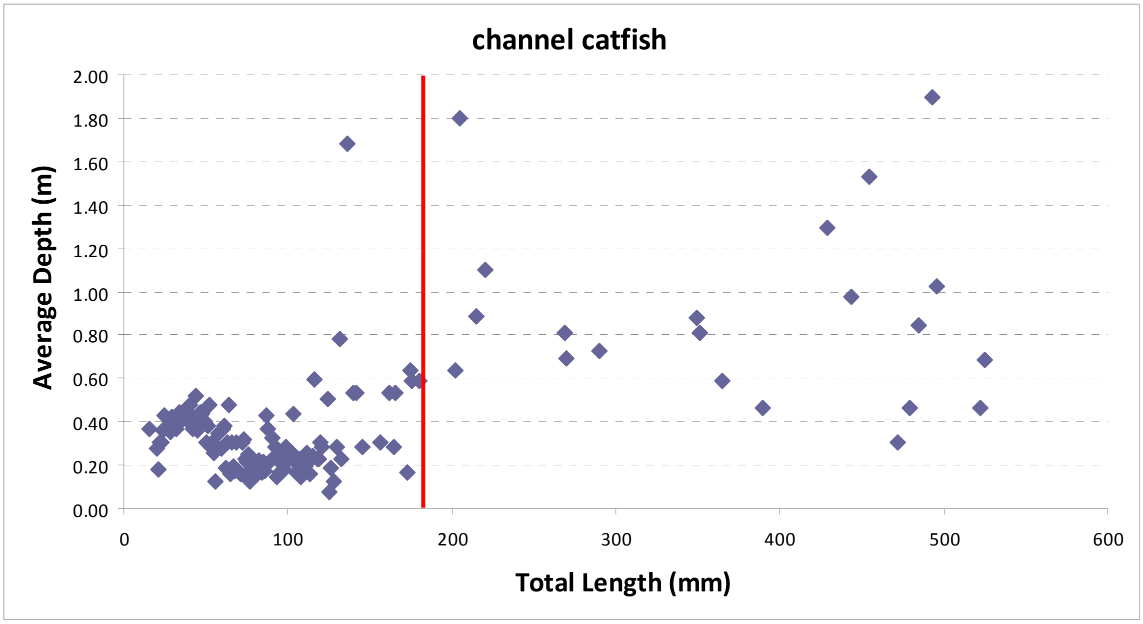


Figure A-1. Average depth and average velocity versus total length for blacktail shiner *Cyprinella venusta*. The red line indicates the resulting boundary between juvenile and adult life stage categories.



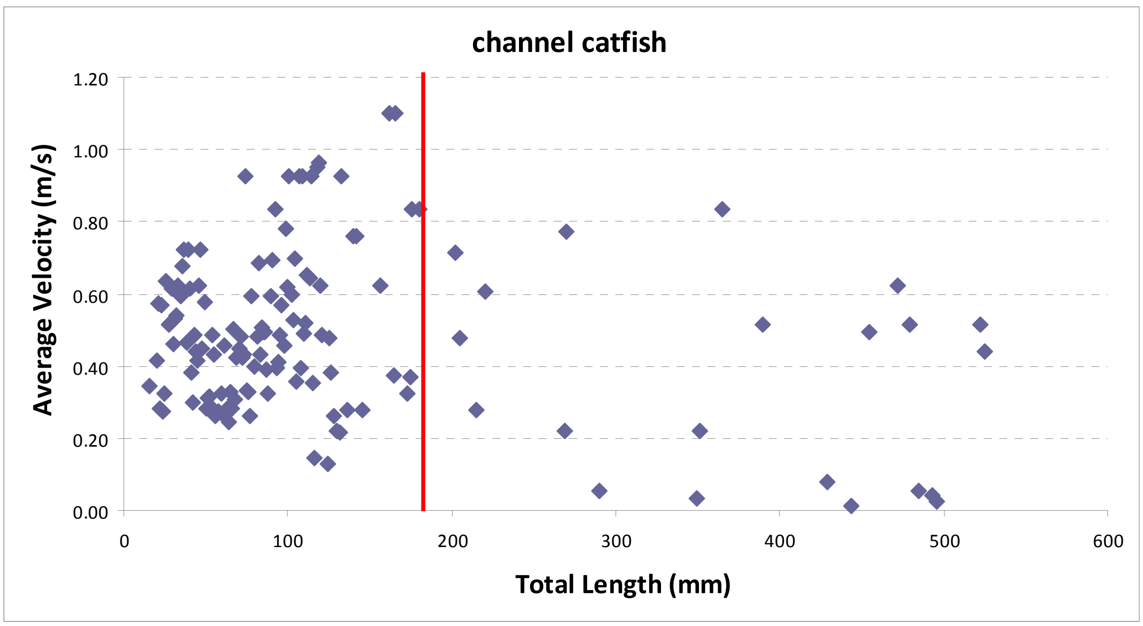
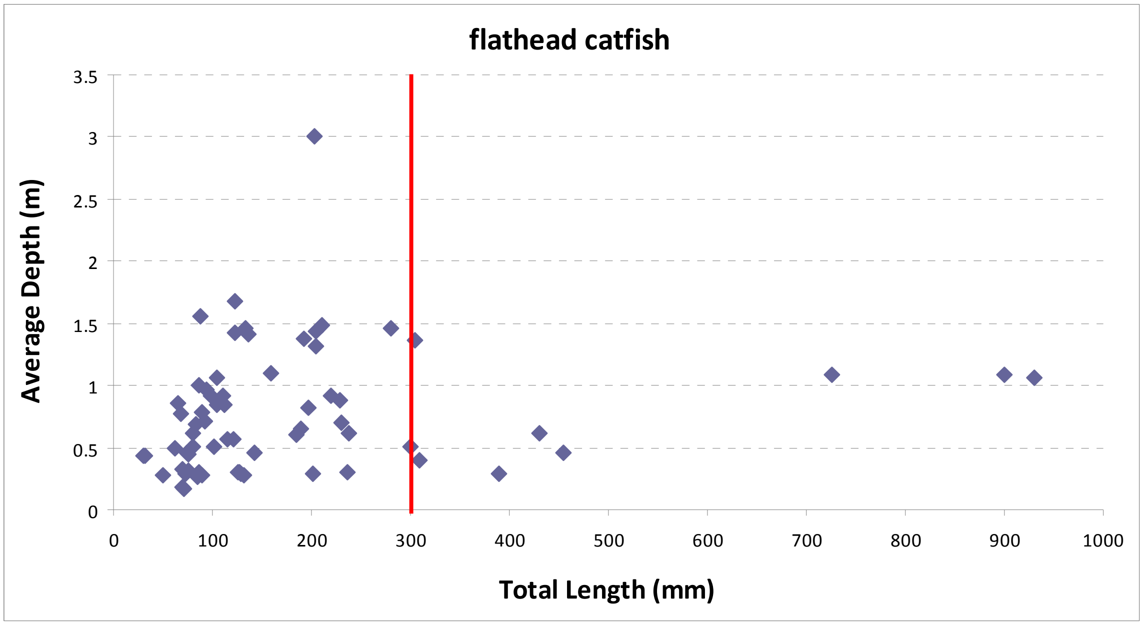


Figure A-2. Average depth and average velocity versus total length for channel catfish *Ictalurus punctatus*. The red line indicates the resulting boundary between juvenile and adult life stage categories.



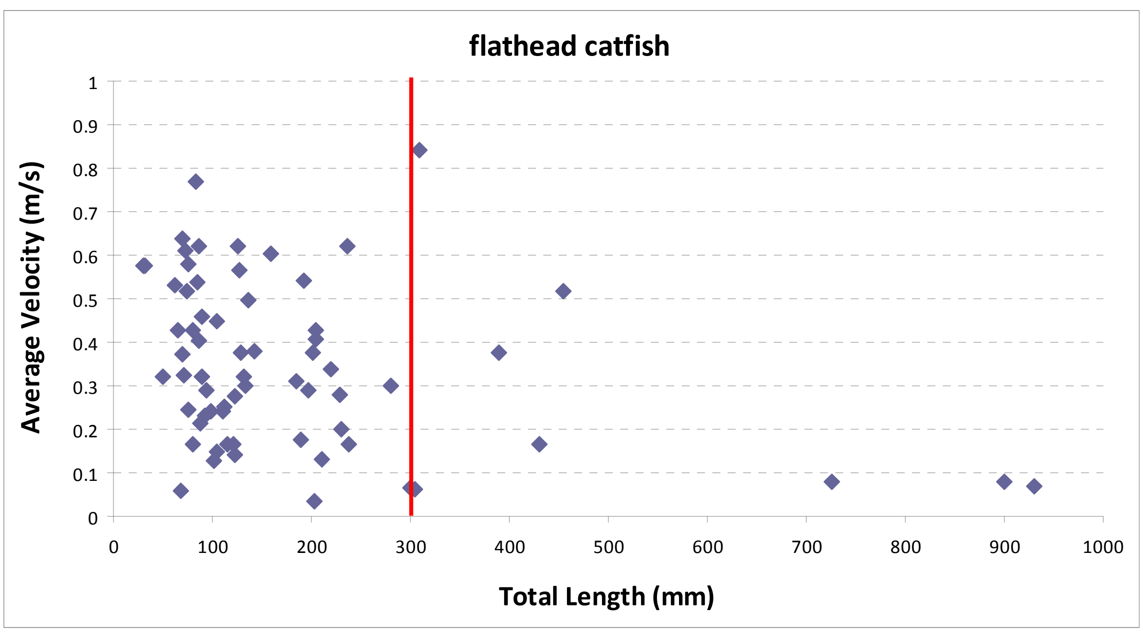
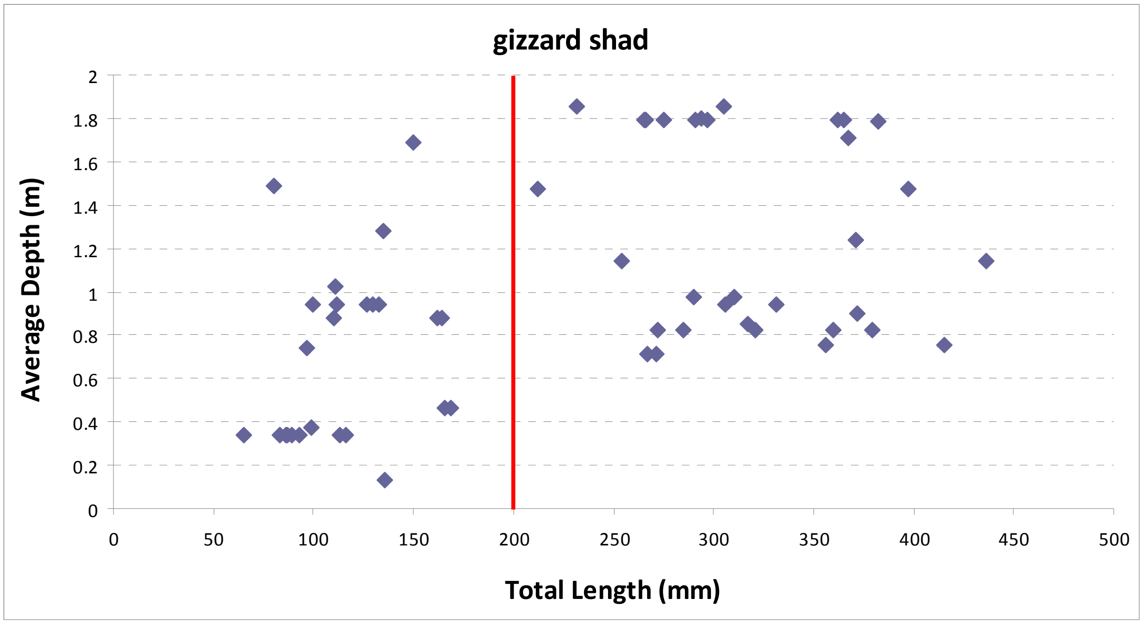


Figure A-3. Average depth and average velocity versus total length for flathead catfish *Pylodictis olivaris*. The red line indicates the resulting boundary between juvenile and adult life stage categories.



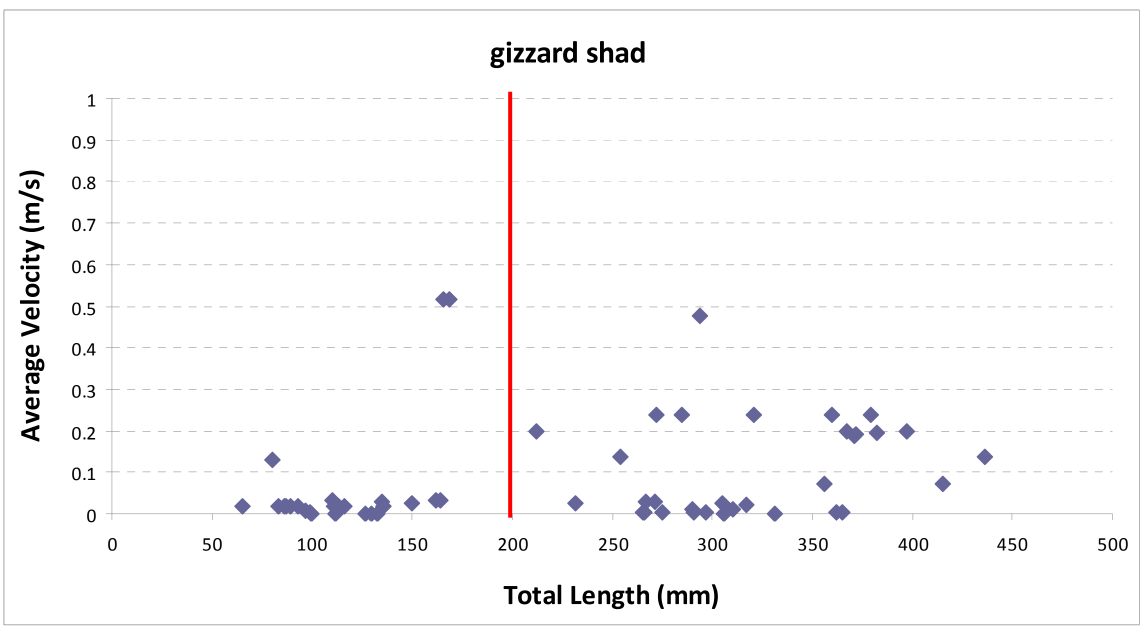
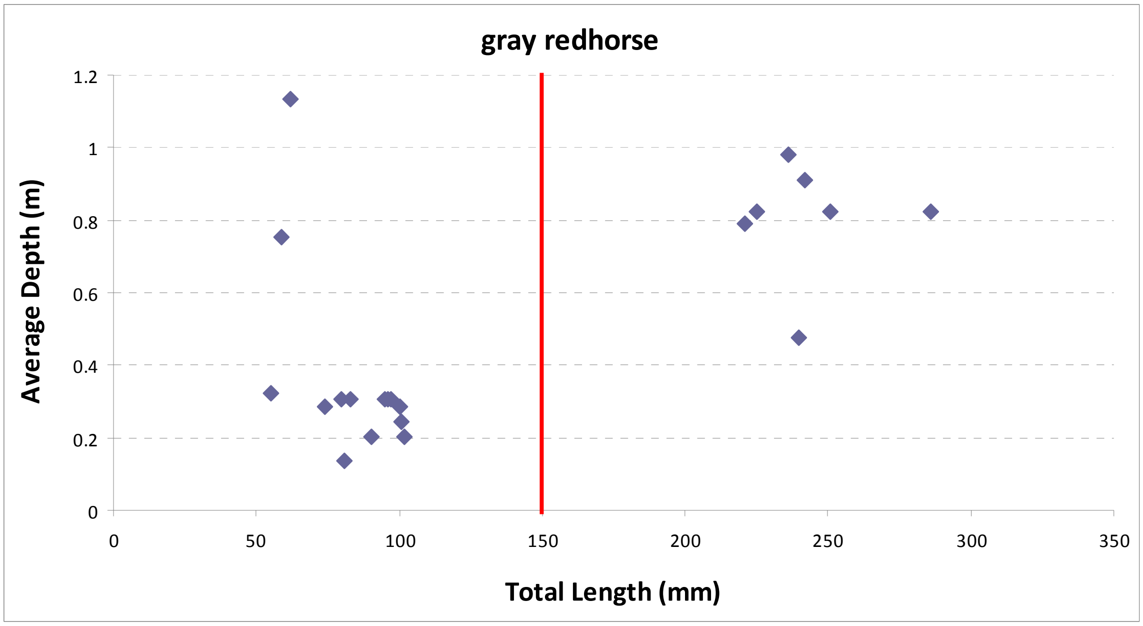


Figure A-4. Average depth and average velocity versus total length for gizzard shad *Dorosoma cepedianum*. The red line indicates the resulting boundary between juvenile and adult life stage categories.



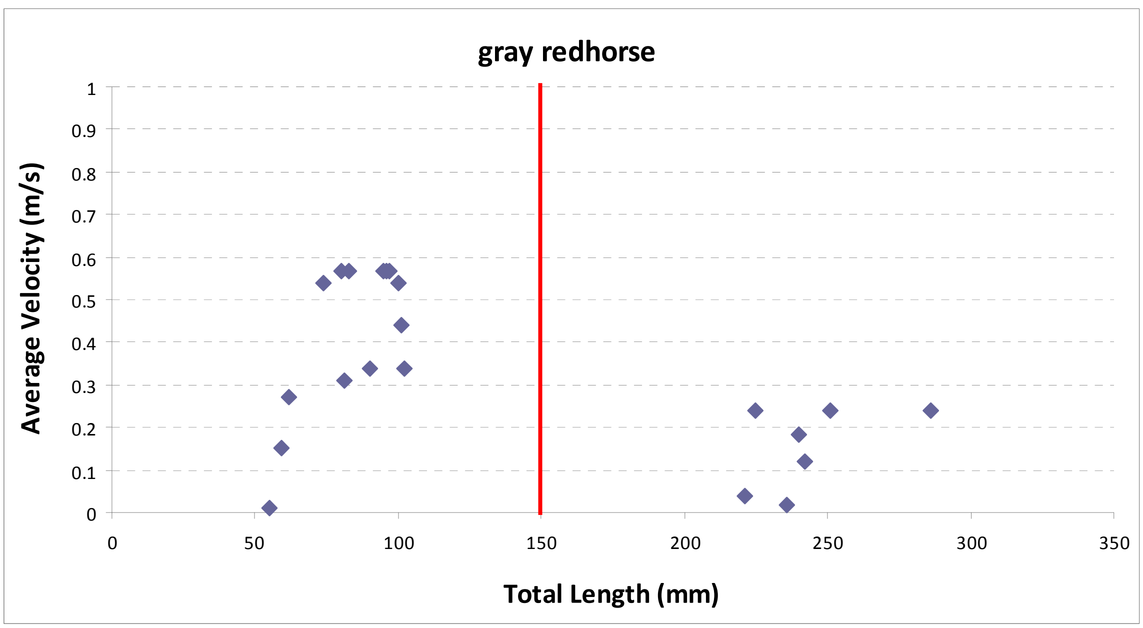
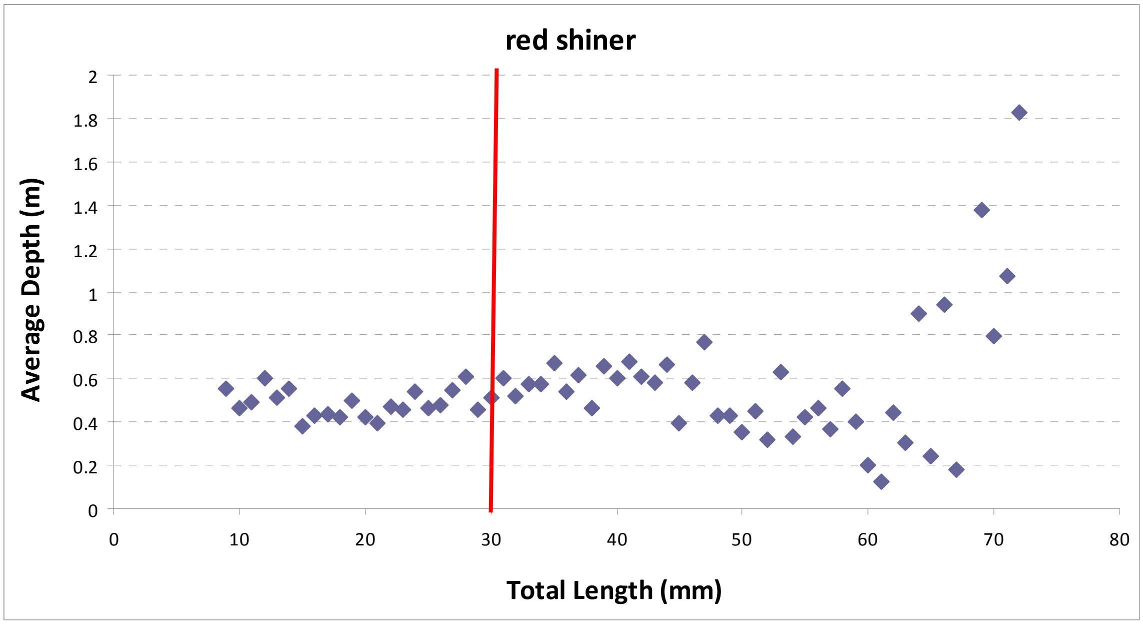


Figure A-5. Average depth and average velocity versus total length for gray redhorse *Moxostoma congestum*. The red line indicates the resulting boundary between juvenile and adult life stage categories. 3



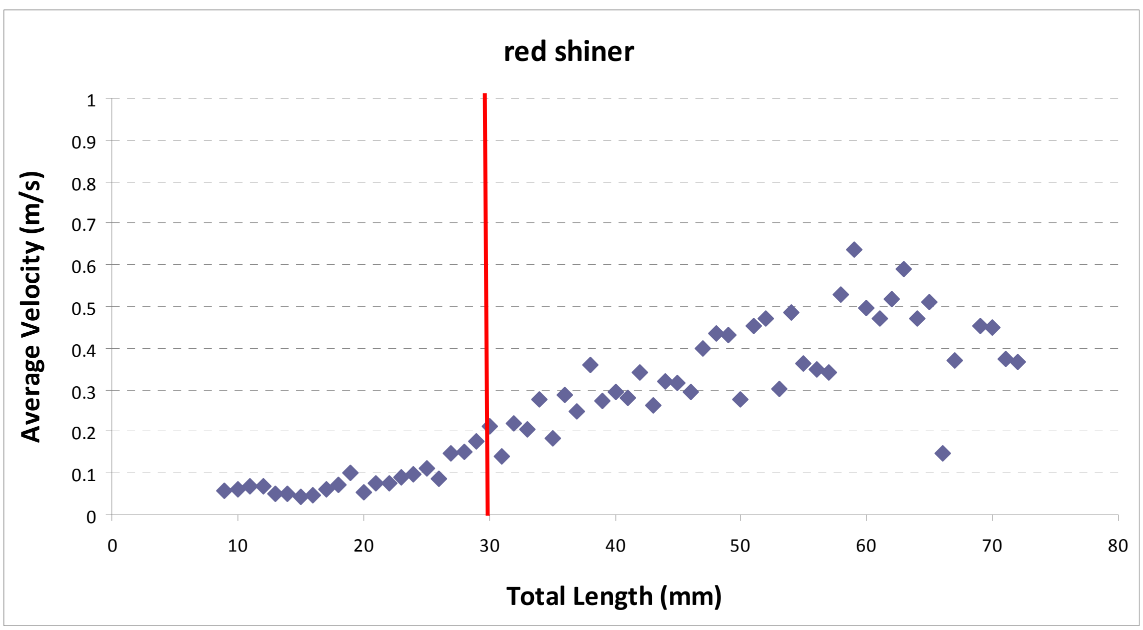
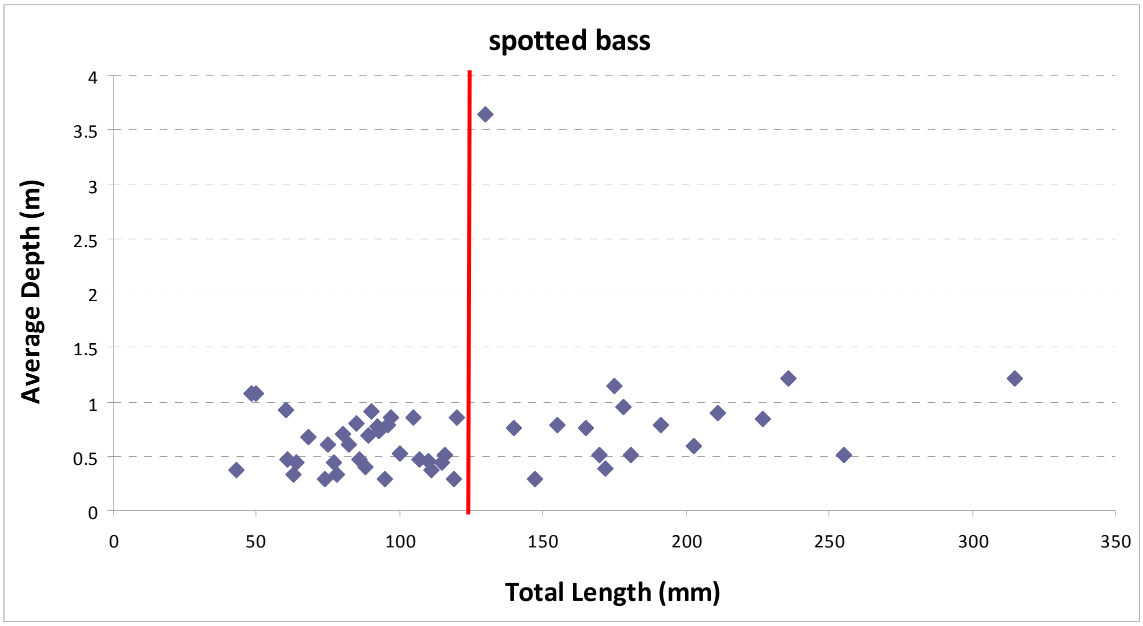


Figure A-6. Average depth and average velocity versus total length for red shiner *Cyprinella lutrensis*. The red line indicates the resulting boundary between juvenile and adult life stage categories.



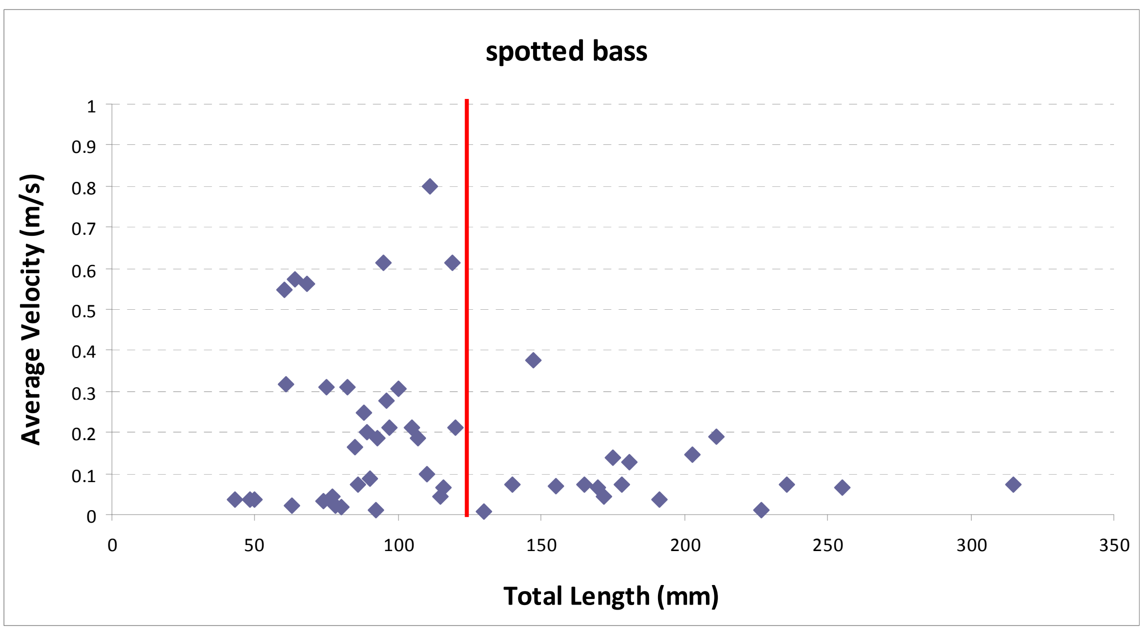
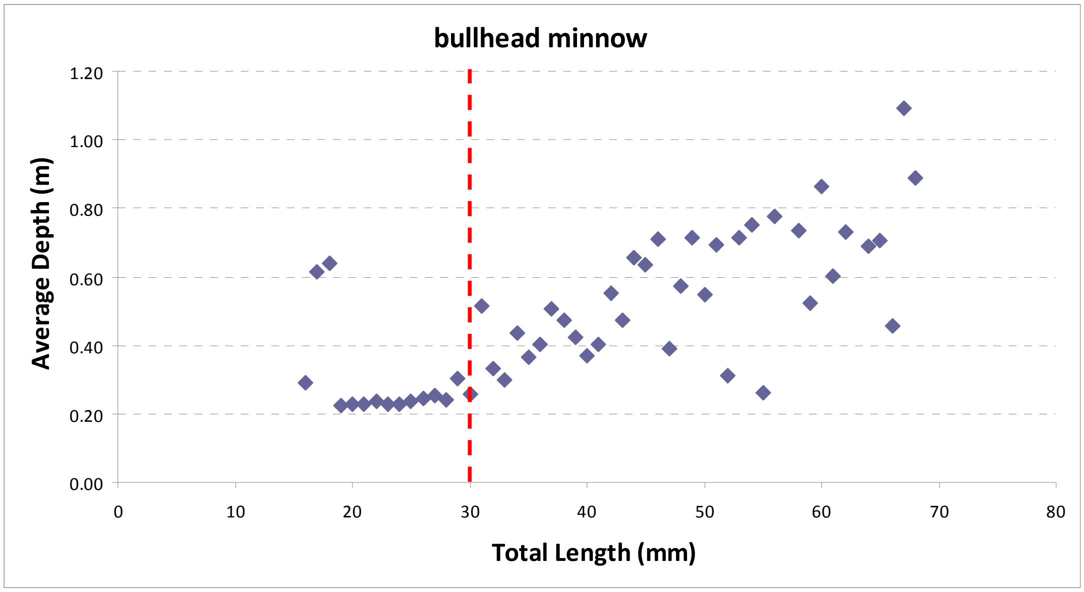


Figure A-7. Average depth and average velocity versus total length for spotted bass *Micropterus punctulatus*. The red line indicates the resulting boundary between juvenile and adult life stage categories.



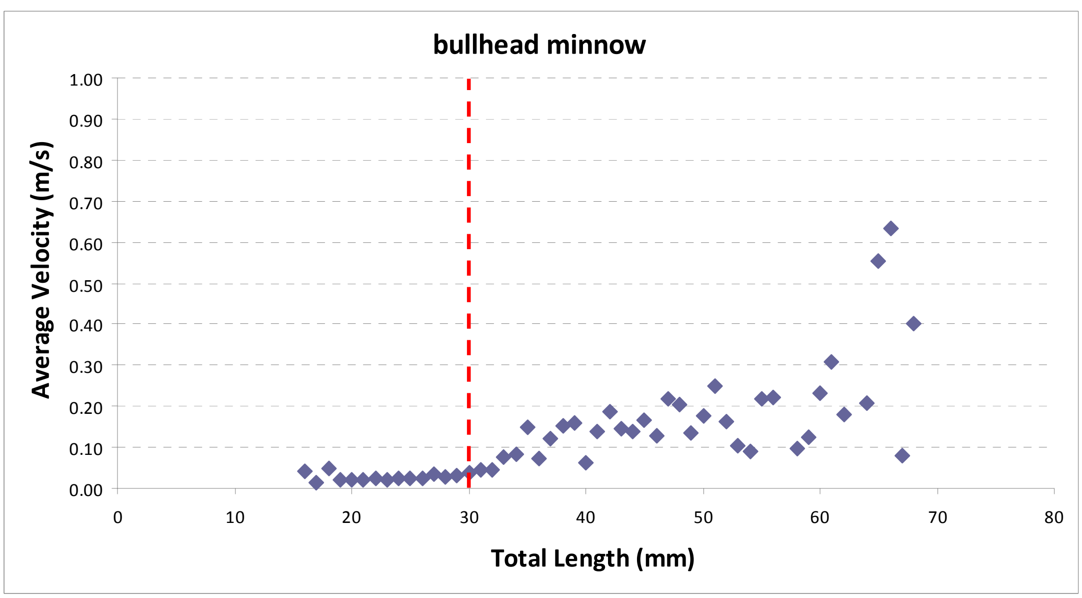
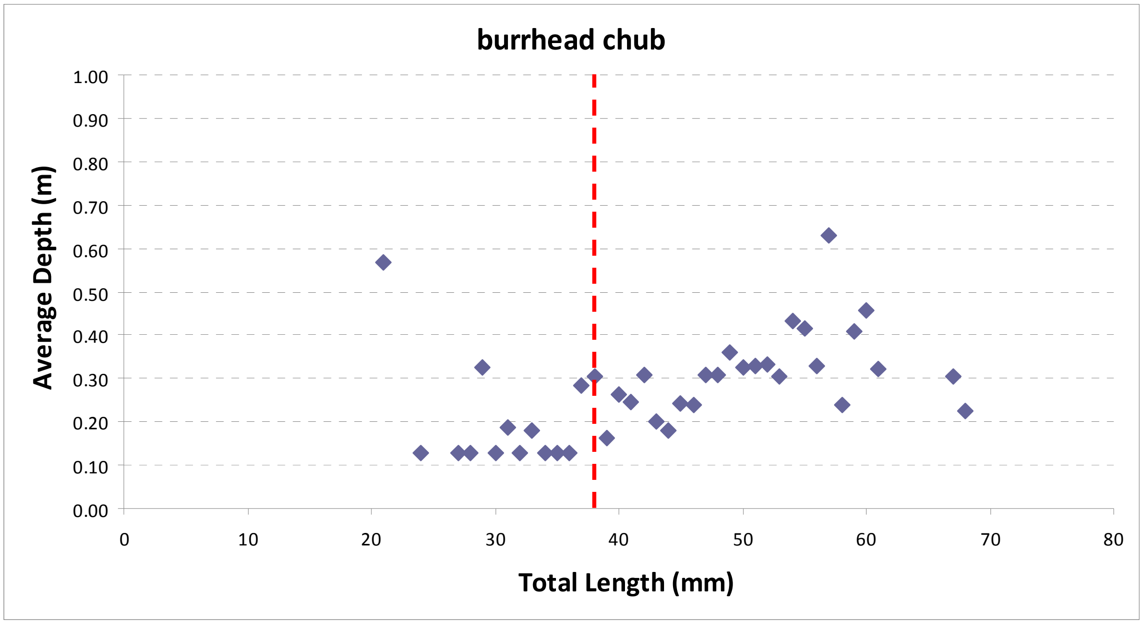


Figure A-8. Average depth and average velocity versus total length for bullhead minnow *Pimephales vigilax*. The dotted red line indicates the original boundary between juvenile and adult life stage categories. However, these life stages were later recombined when they fell into the same habitat guild.



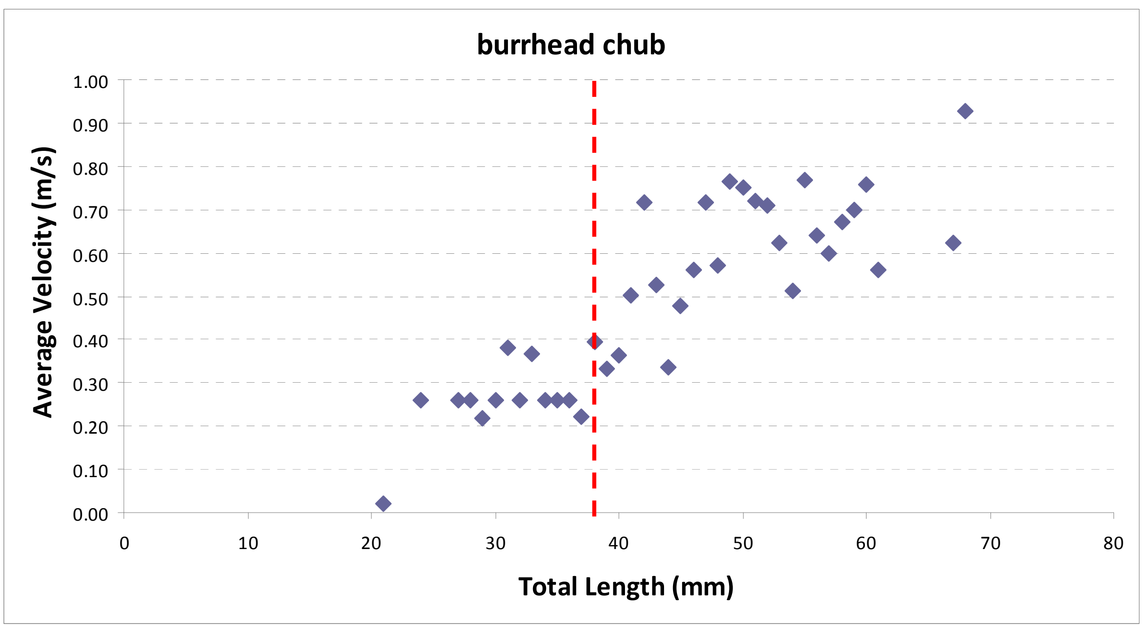
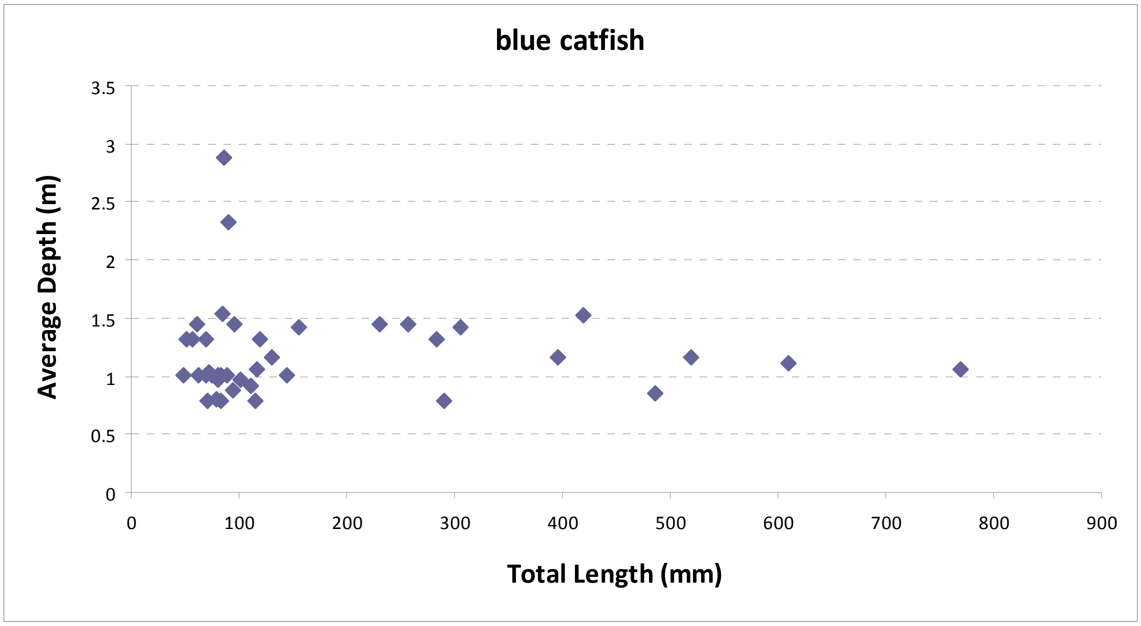


Figure A-9. Average depth and average velocity versus total length for burrhead chub *Macrhybopsis marconis*. The dotted red line indicates the original boundary between juvenile and adult life stage categories. However, these life stages were later recombined when they fell into the same habitat guild.



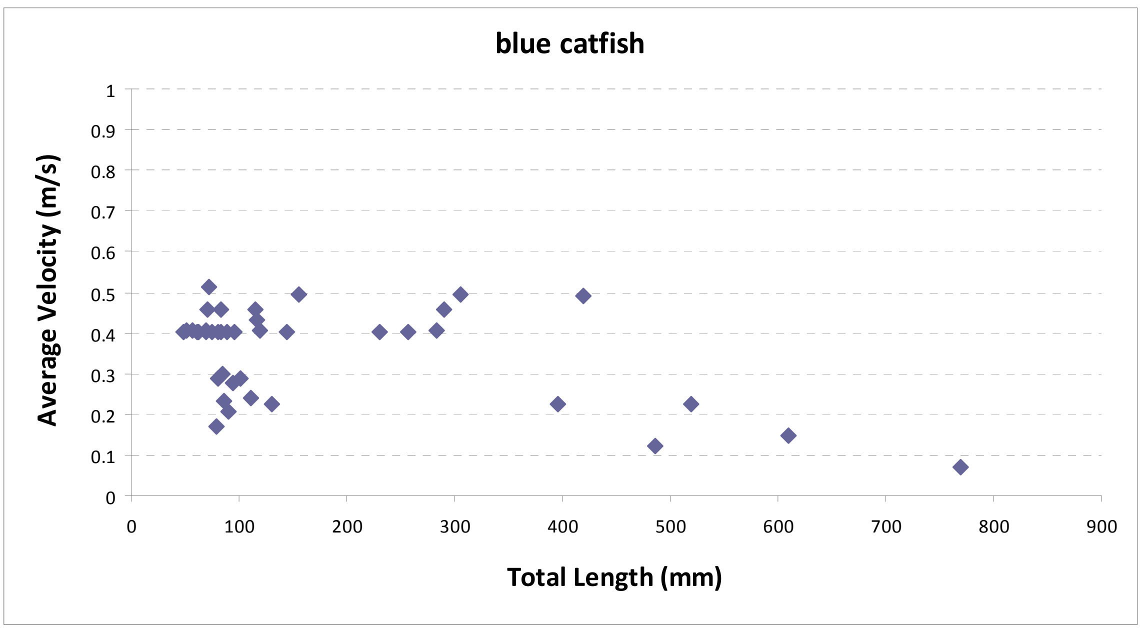
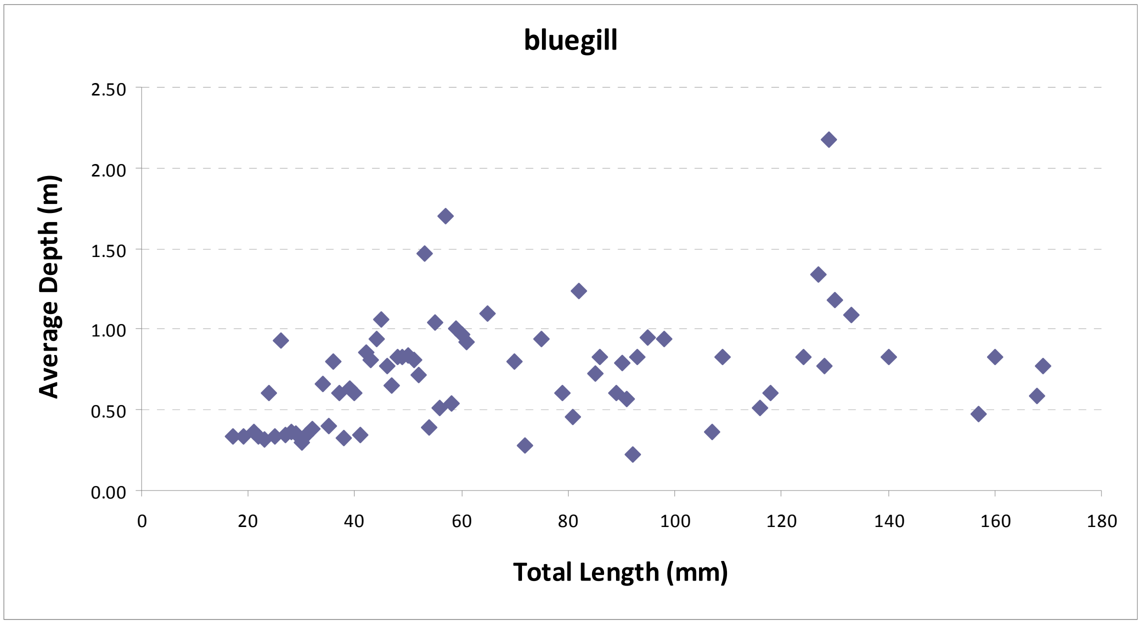


Figure A-10. Average depth and average velocity versus total length for blue catfish *Ictalurus furcatus*.



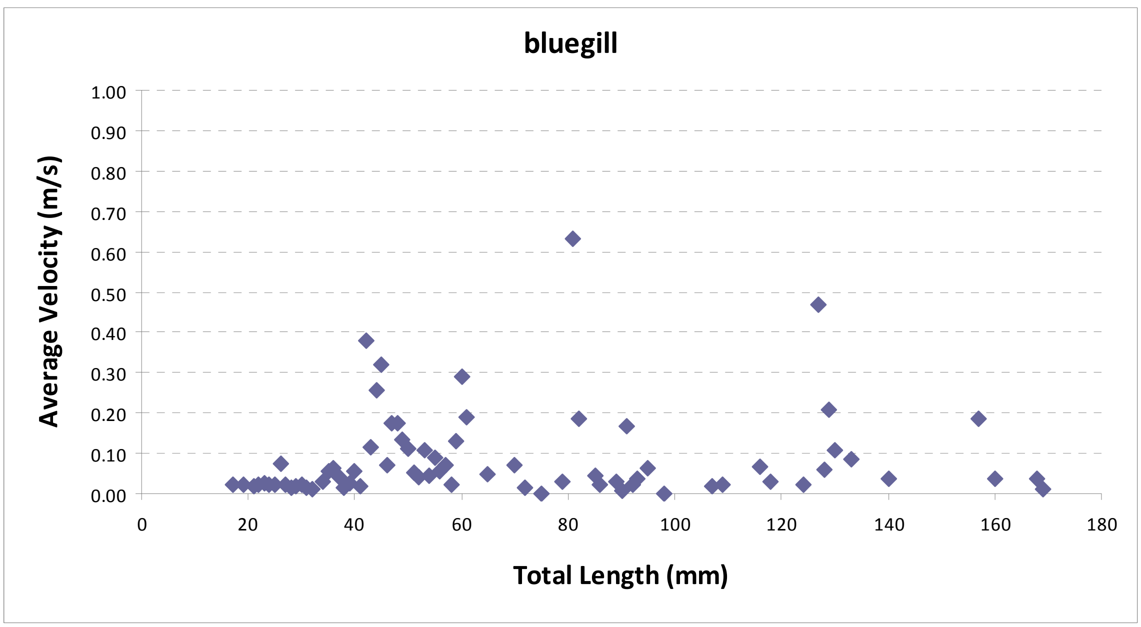
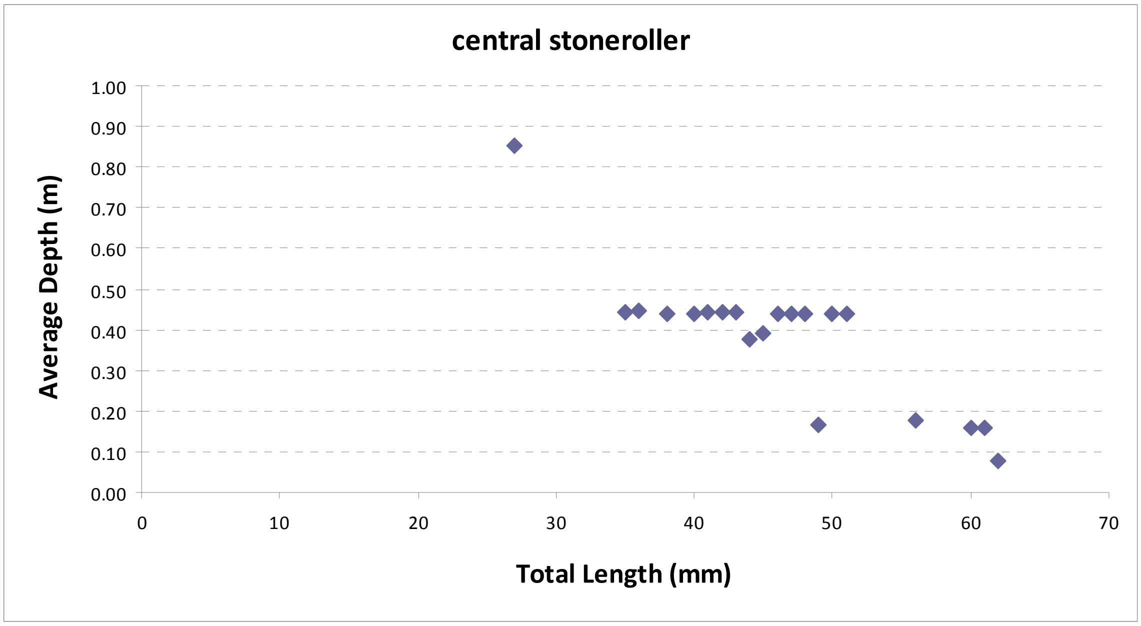


Figure A-11. Average depth and average velocity versus total length for bluegill *Lepomis macrochirus*.



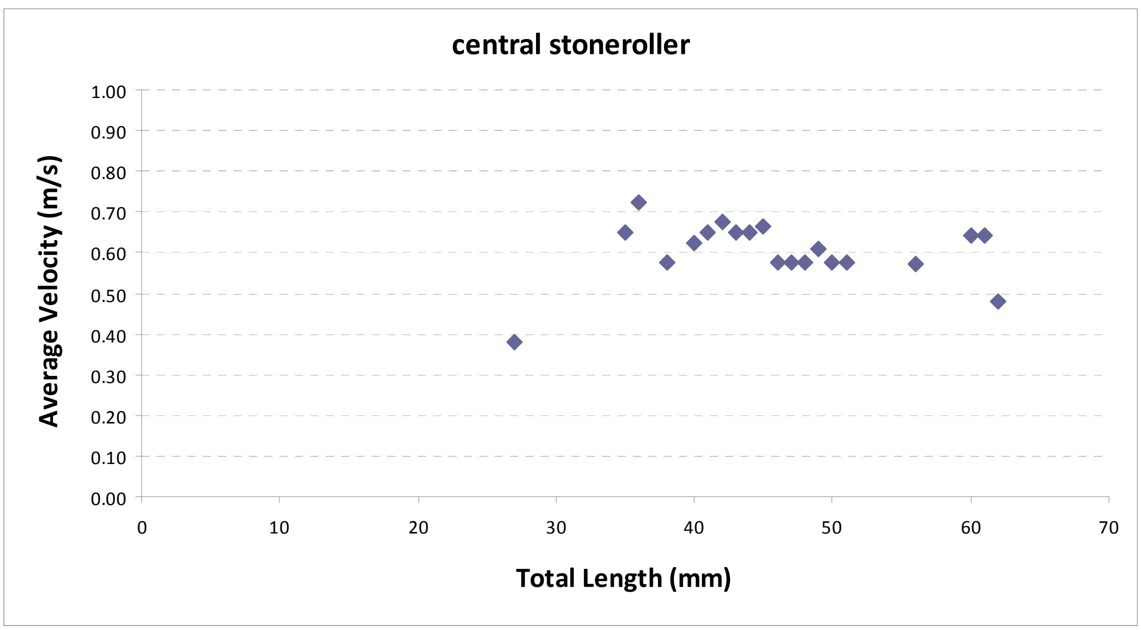


Figure A-12. Average depth and average velocity versus total length for central stoneroller *Campostoma anomalum*.

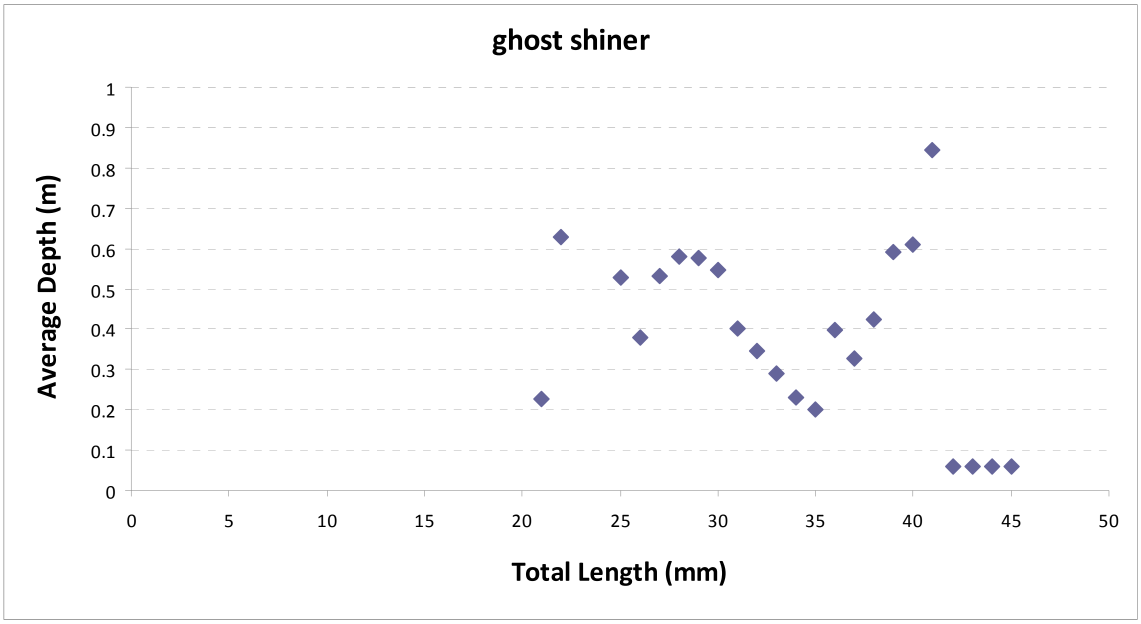
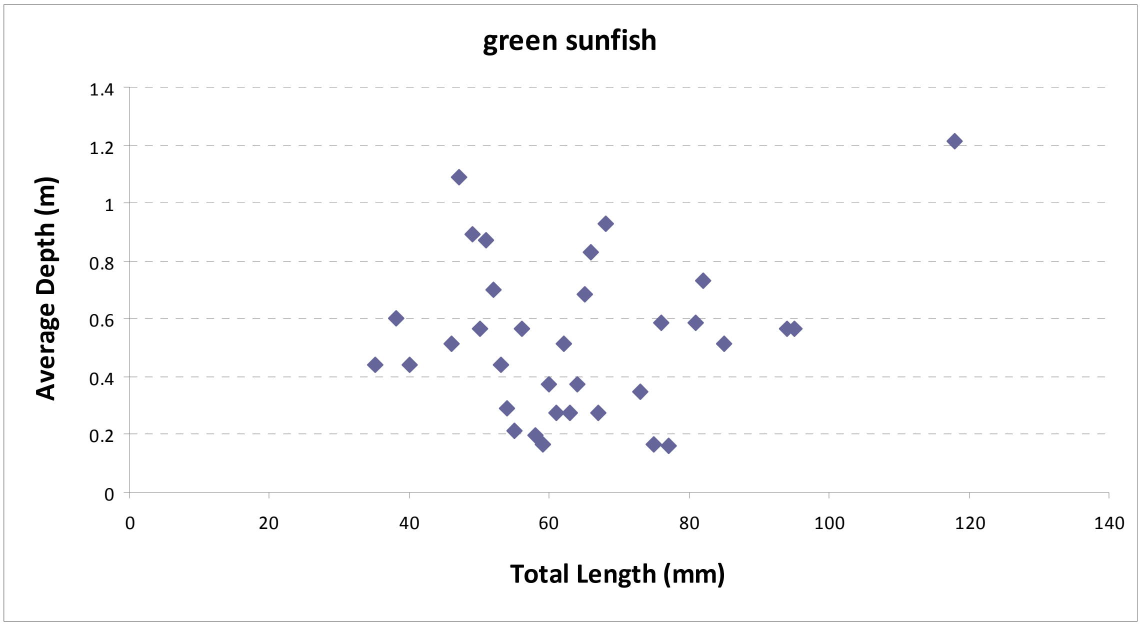


Figure A-13. Average depth and average velocity versus total length for ghost shiner *Notropis buchanani*.



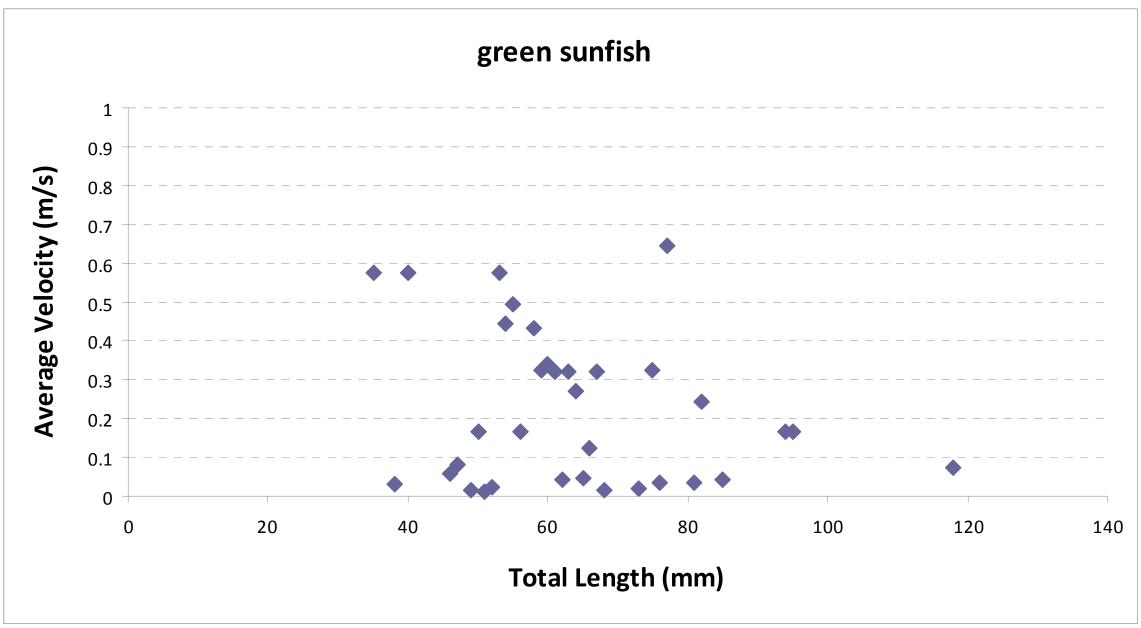
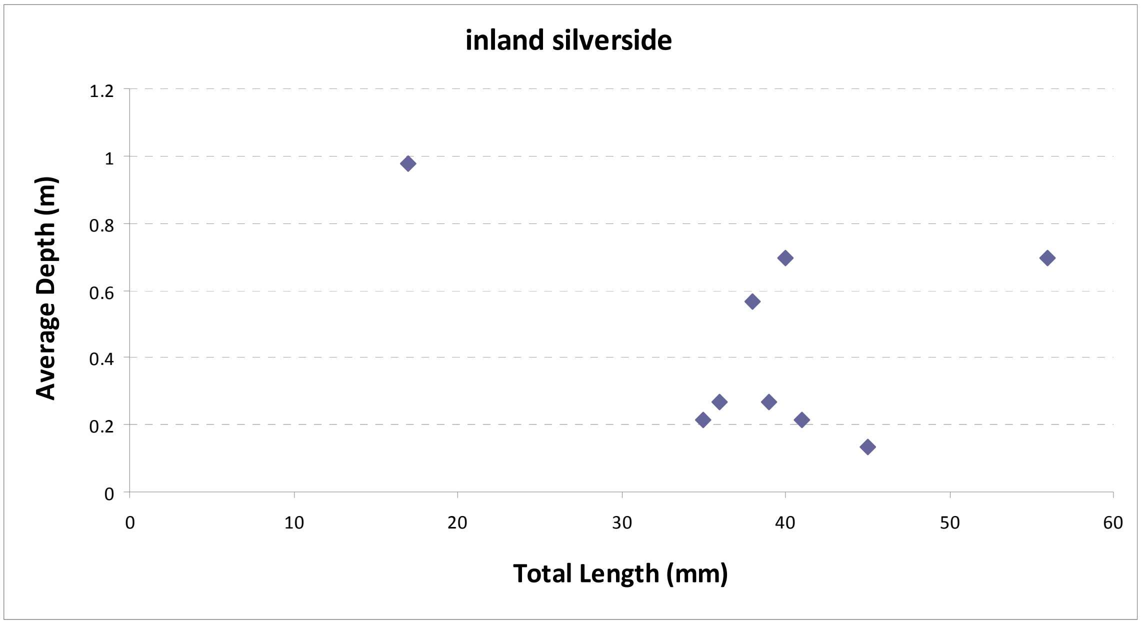


Figure A-14. Average depth and average velocity versus total length for green sunfish *Lepomis cyanellus*.



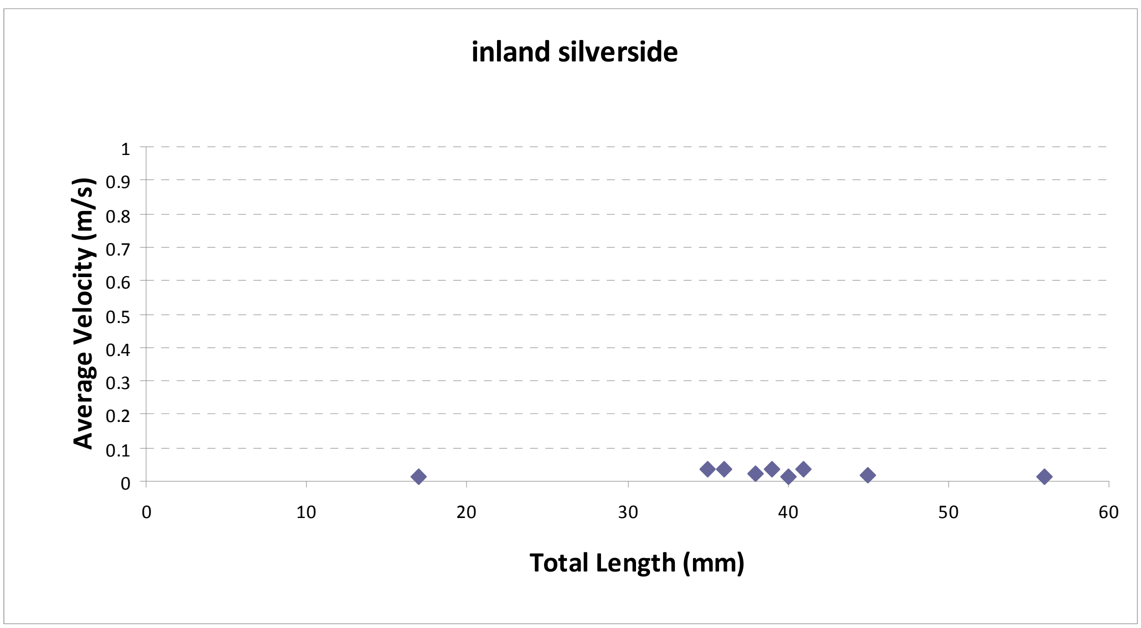
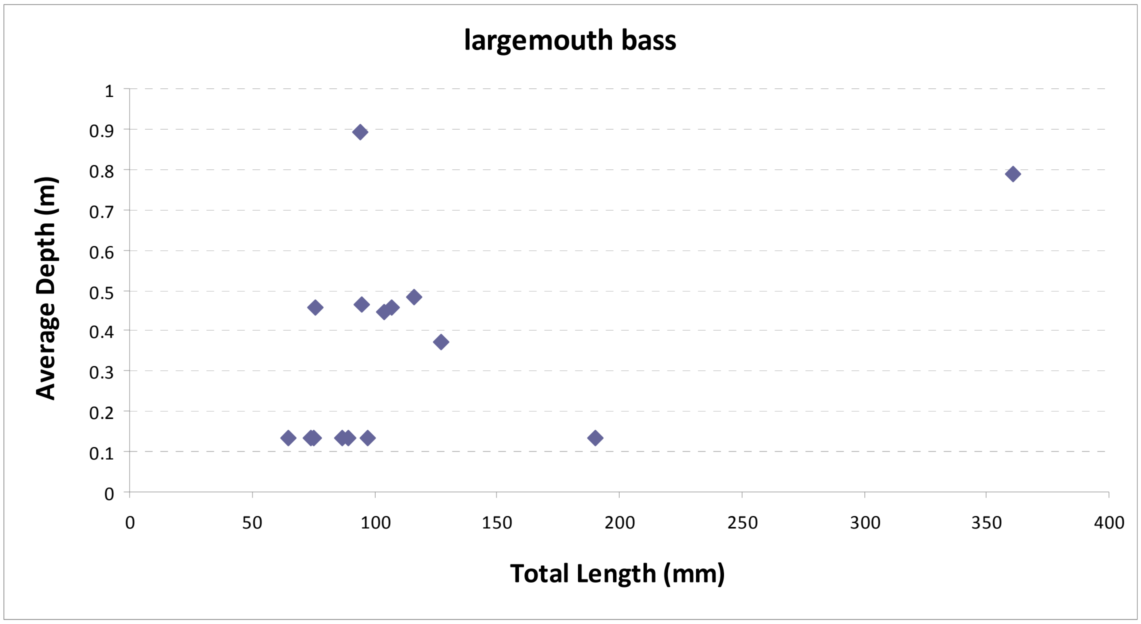


Figure A-15. Average depth and average velocity versus total length for inland silverside *Menidia beryllina*.



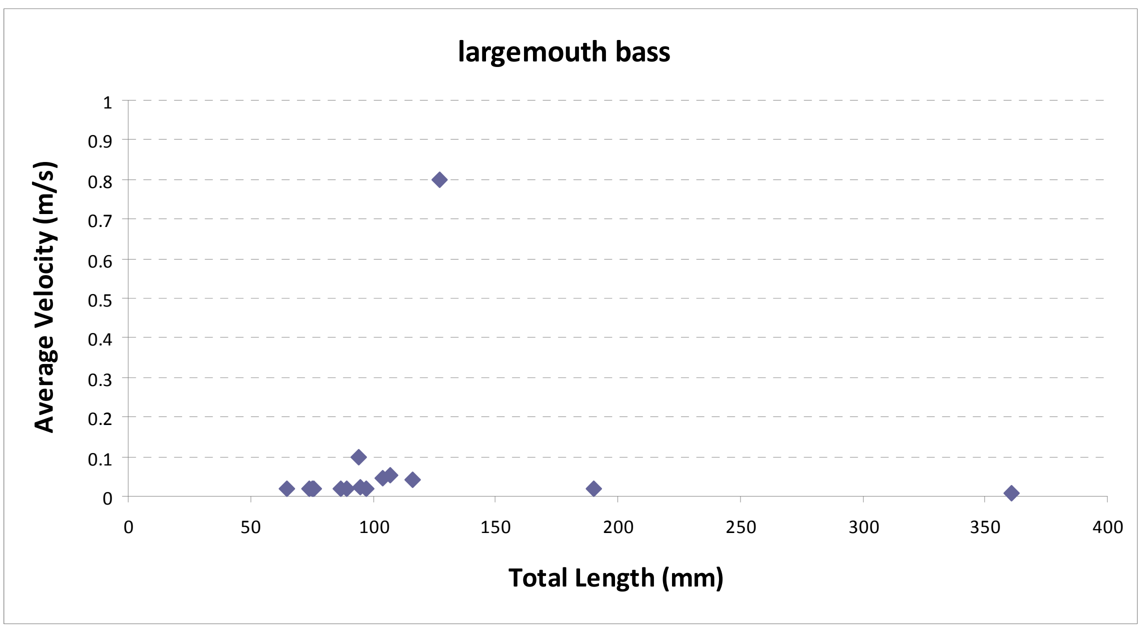
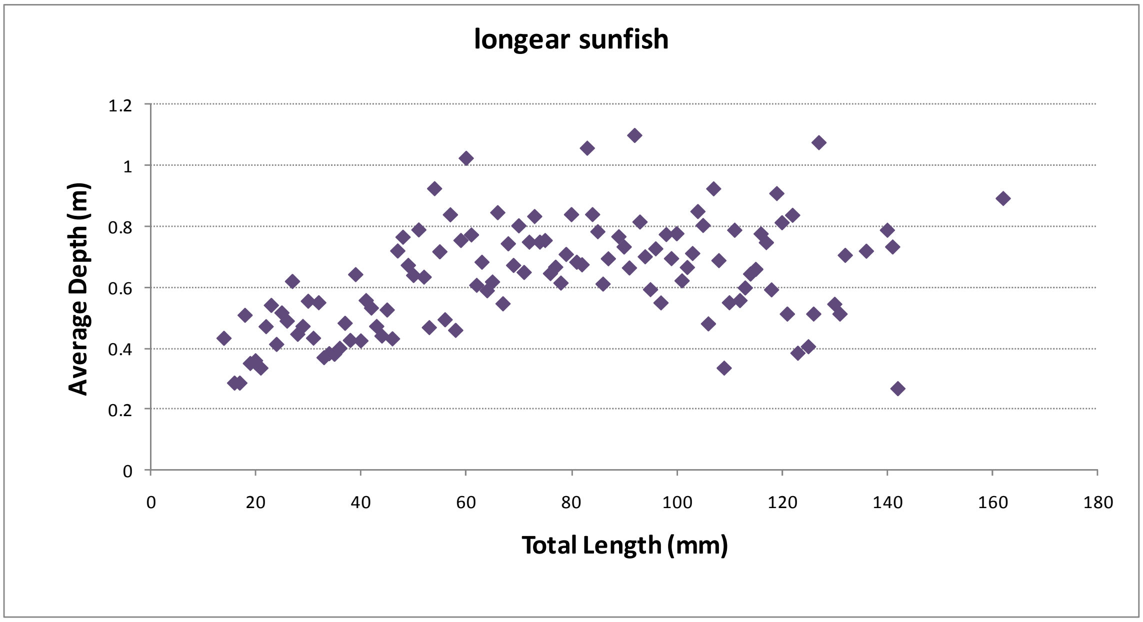


Figure A-16. Average depth and average velocity versus total length for largemouth bass *Micropterus salmoides*.



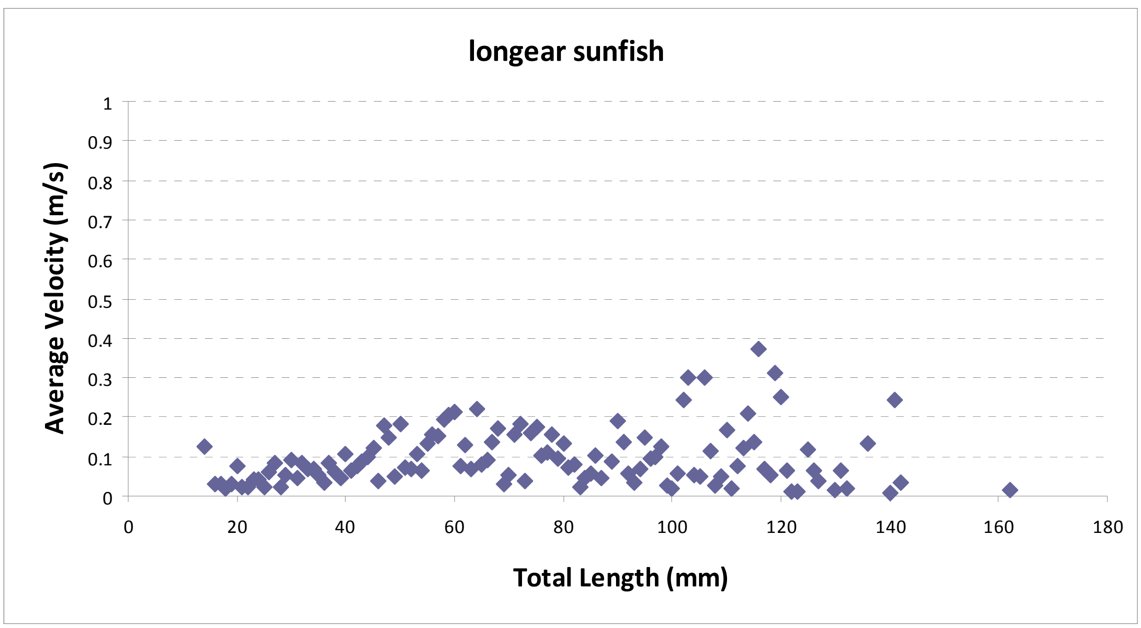
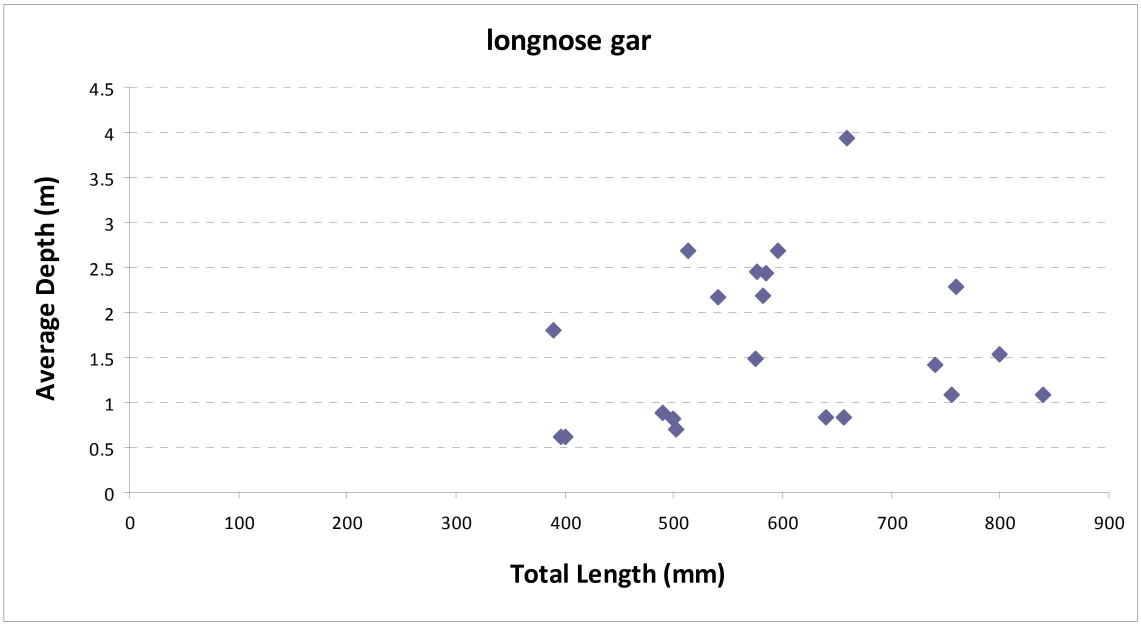


Figure A-17. Average depth and average velocity versus total length for longear sunfish *Lepomis megalotis*.



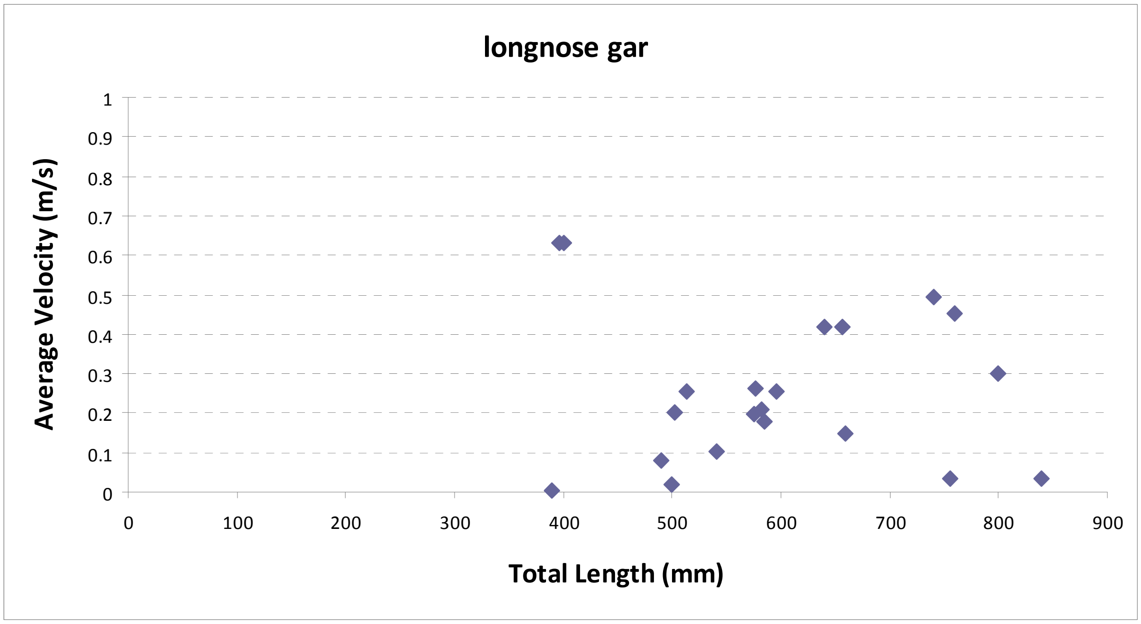
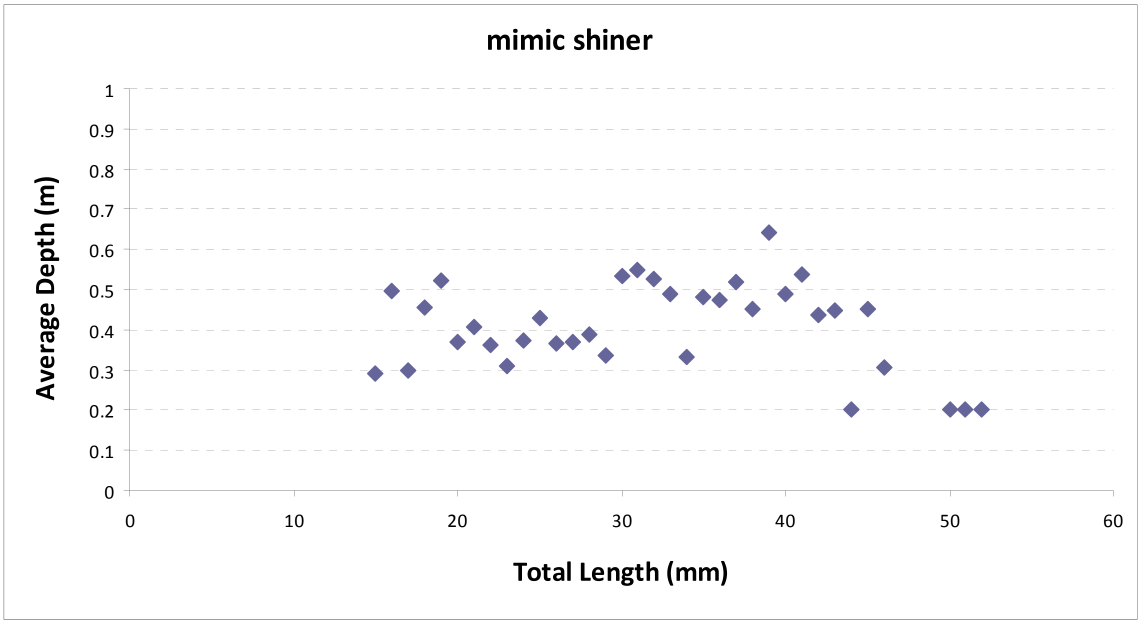


Figure A-18. Average depth and average velocity versus total length for longnose gar *Lepisosteus osseus*.



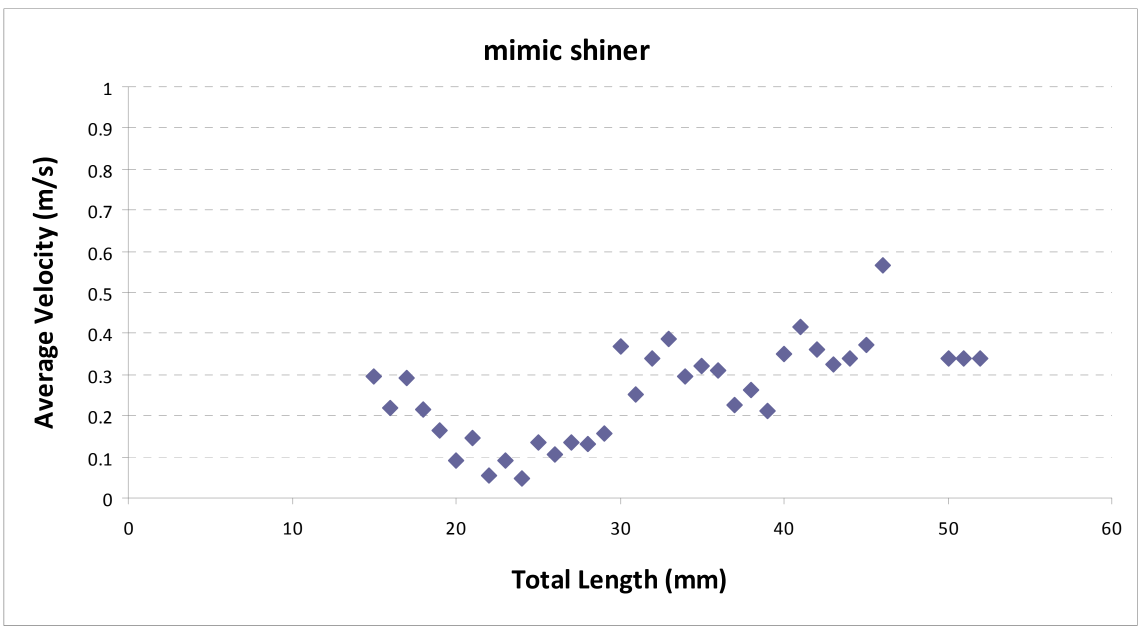
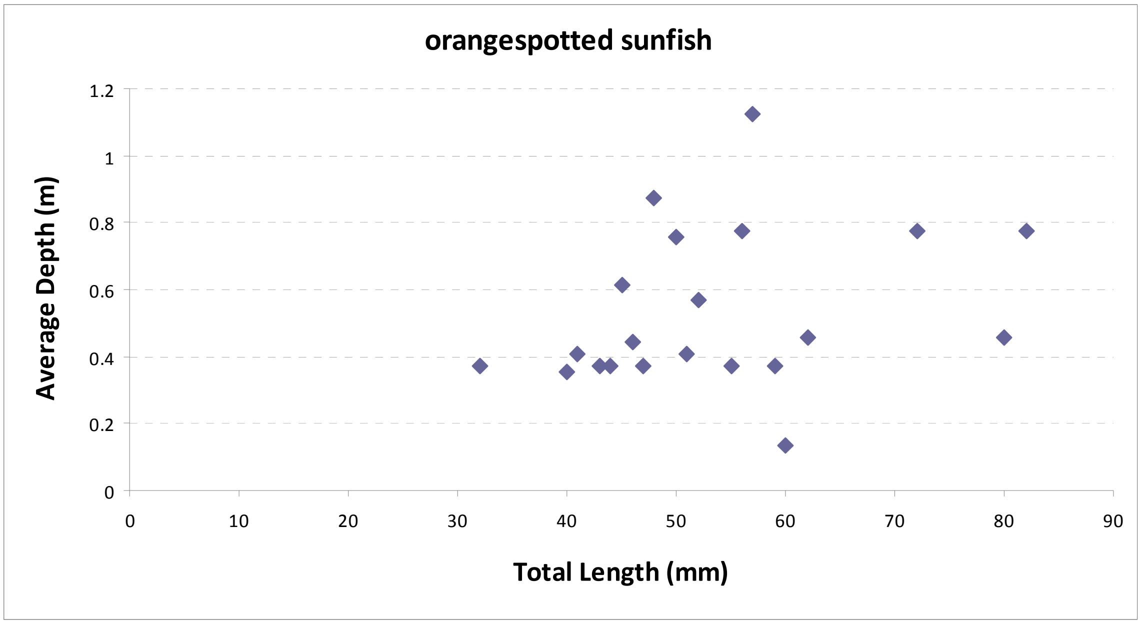


Figure A-19. Average depth and average velocity versus total length for mimic shiner *Notropis volucellus*.



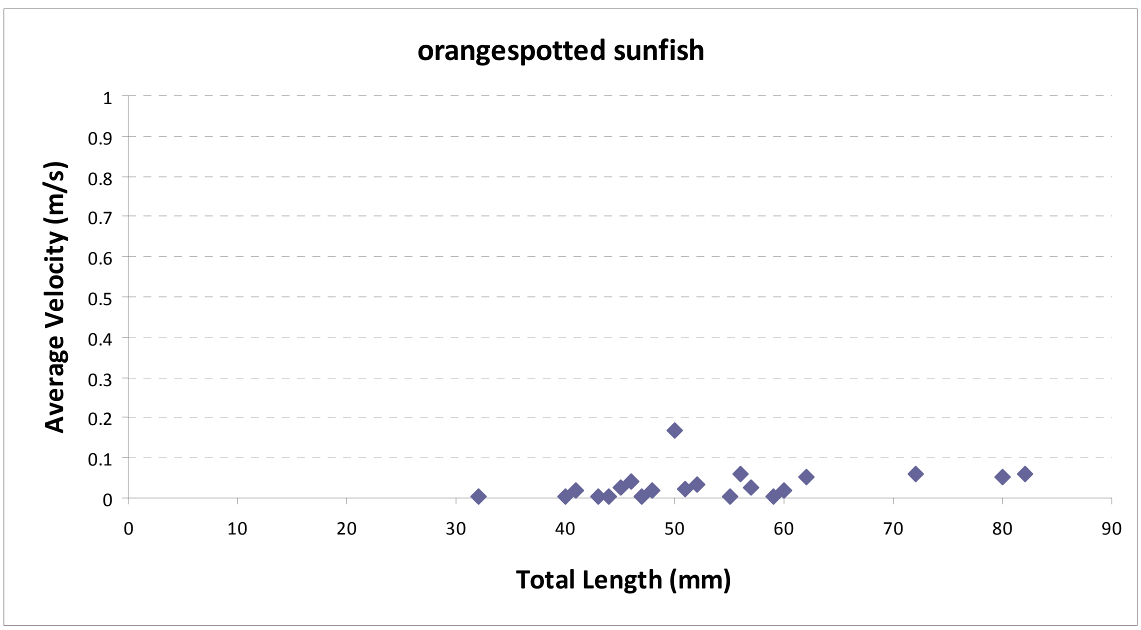
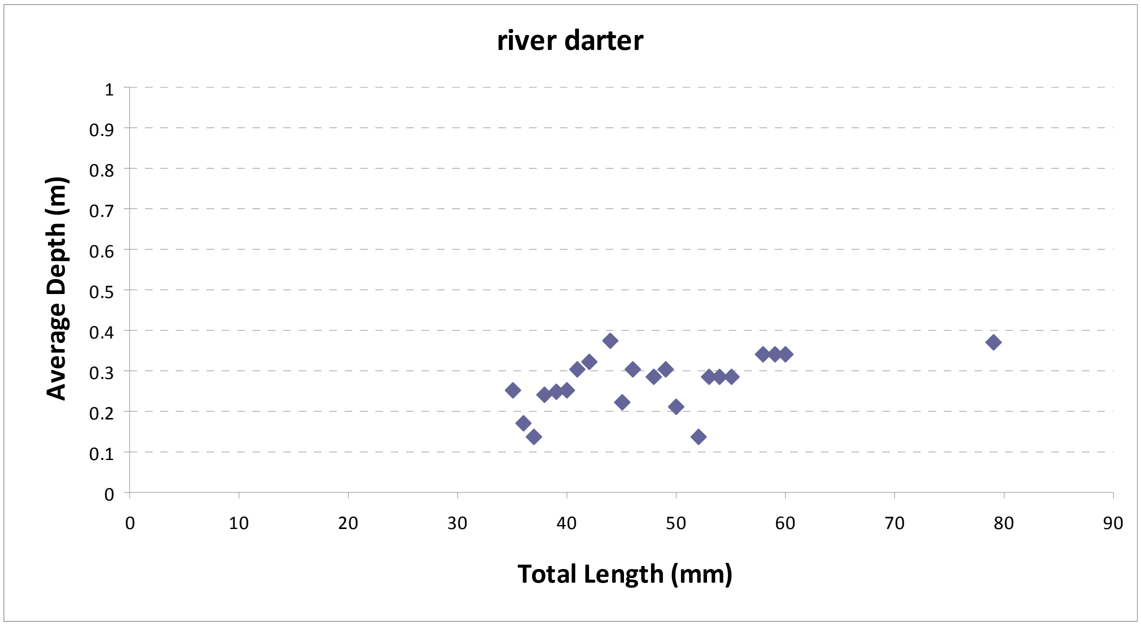


Figure A-20. Average depth and average velocity versus total length for orangespotted sunfish *Lepomis humilis*.



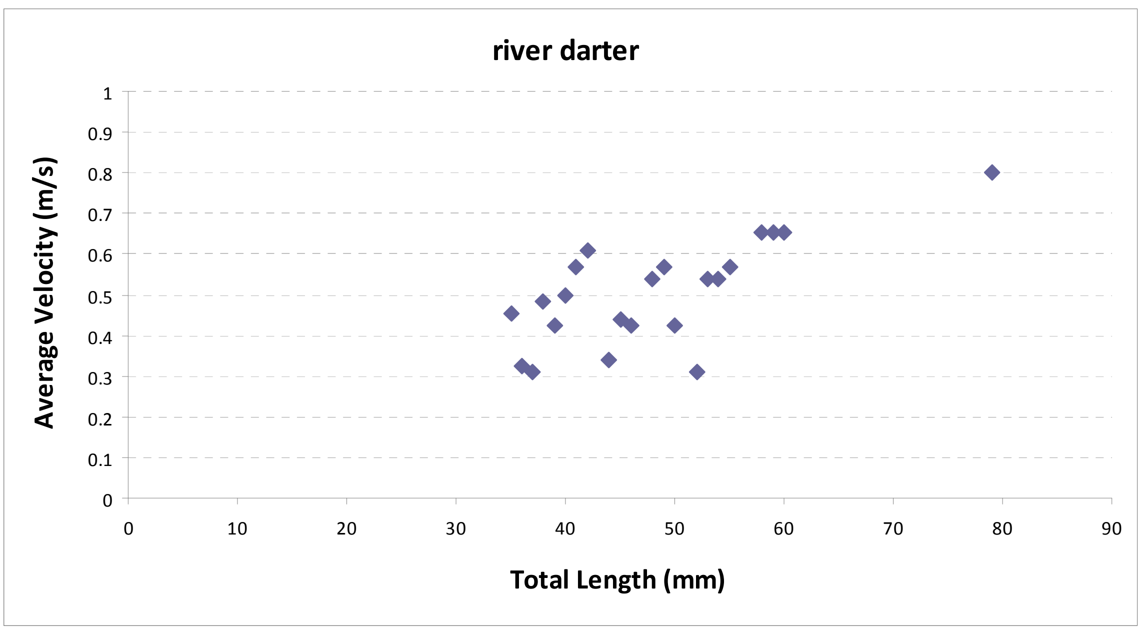
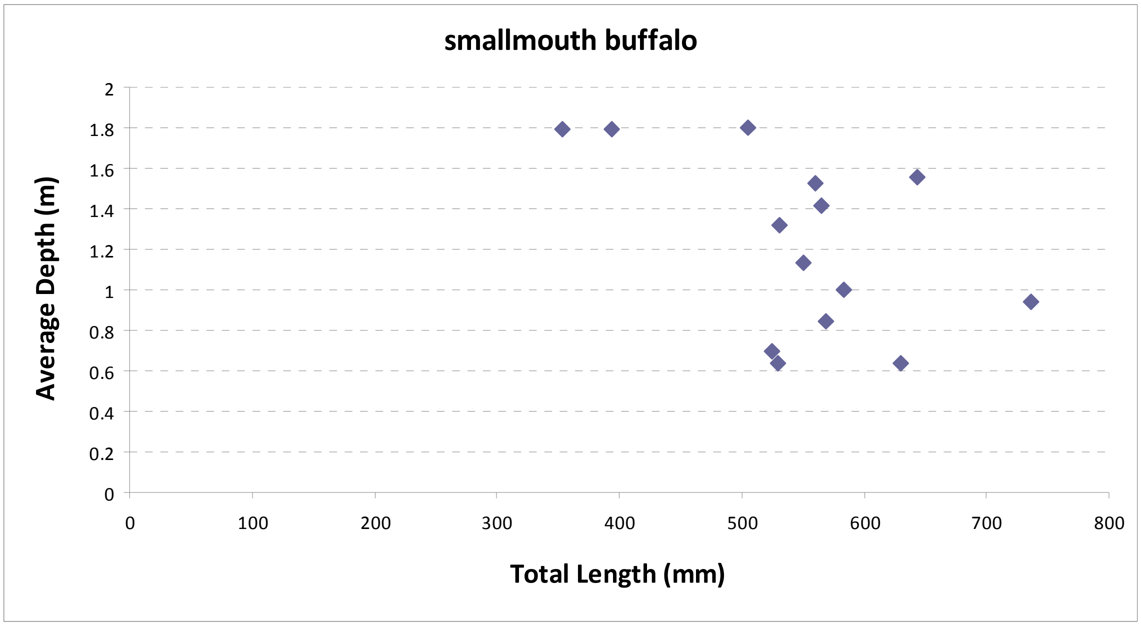


Figure A-21. Average depth and average velocity versus total length for river darter *Percina shumardi*.



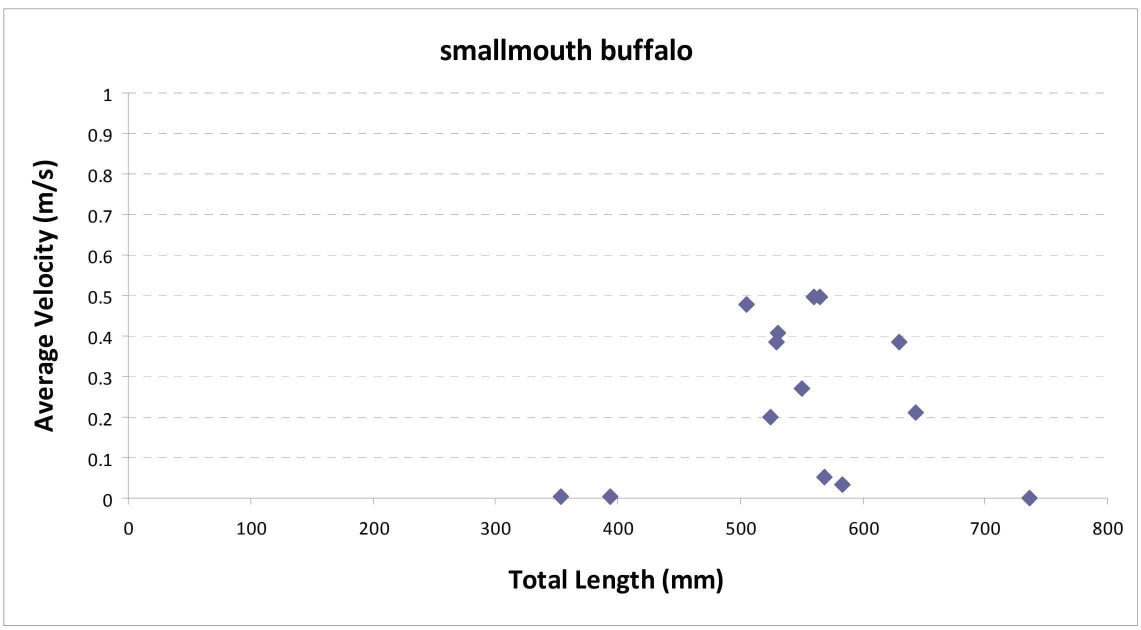
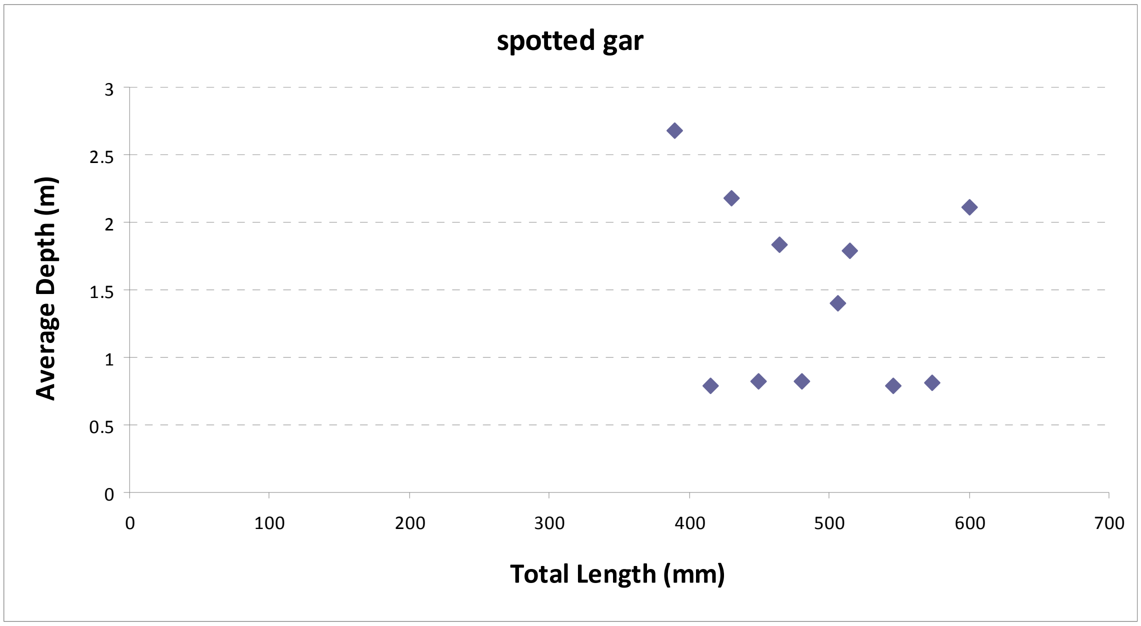


Figure A-22. Average depth and average velocity versus total length for smallmouth buffalo *Ictiobus bubalus*.



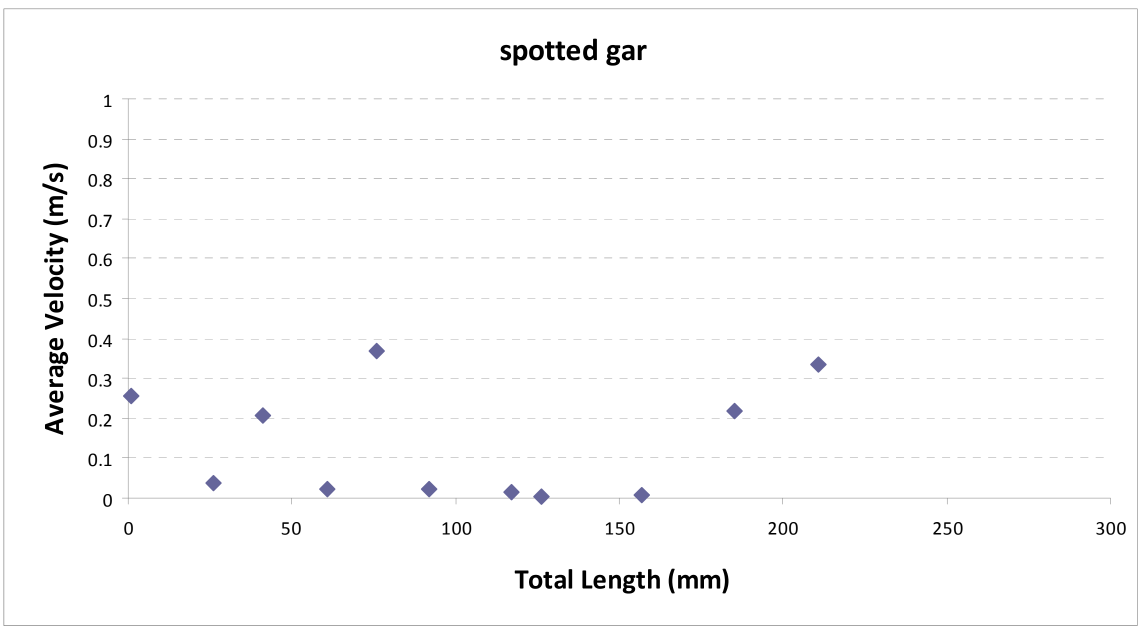
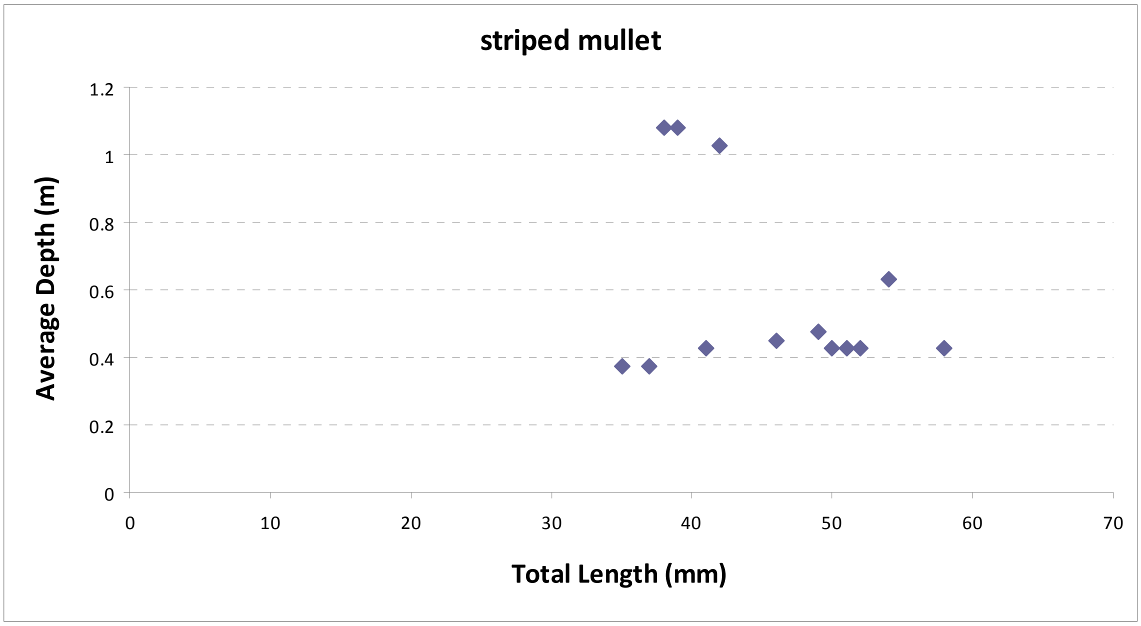


Figure A-23. Average depth and average velocity versus total length for spotted gar *Lepisosteus oculatus*.



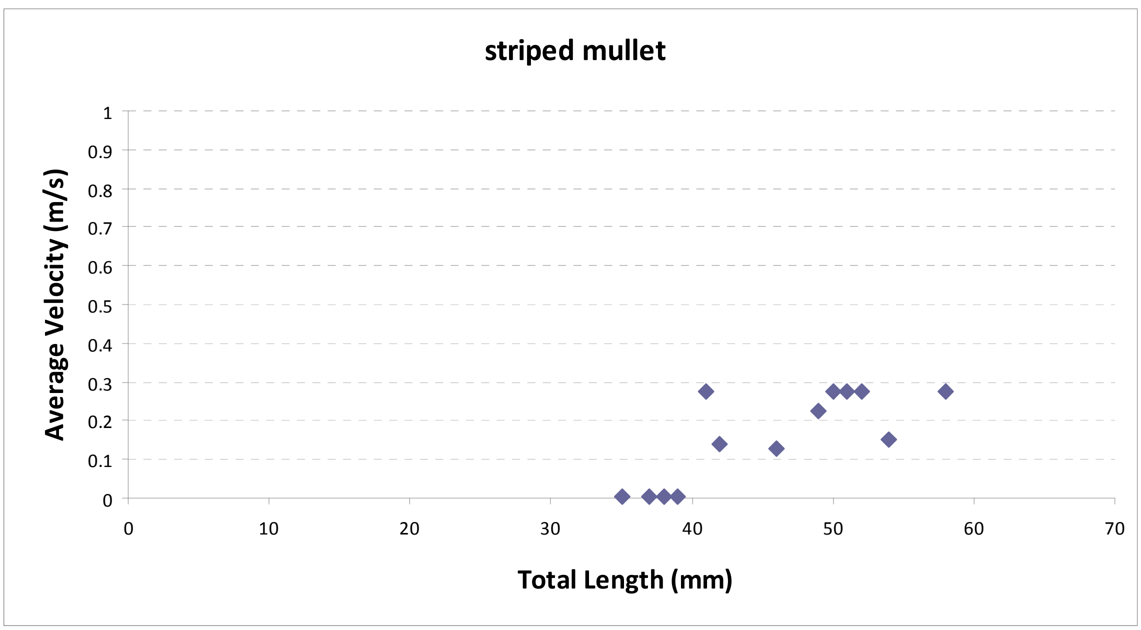
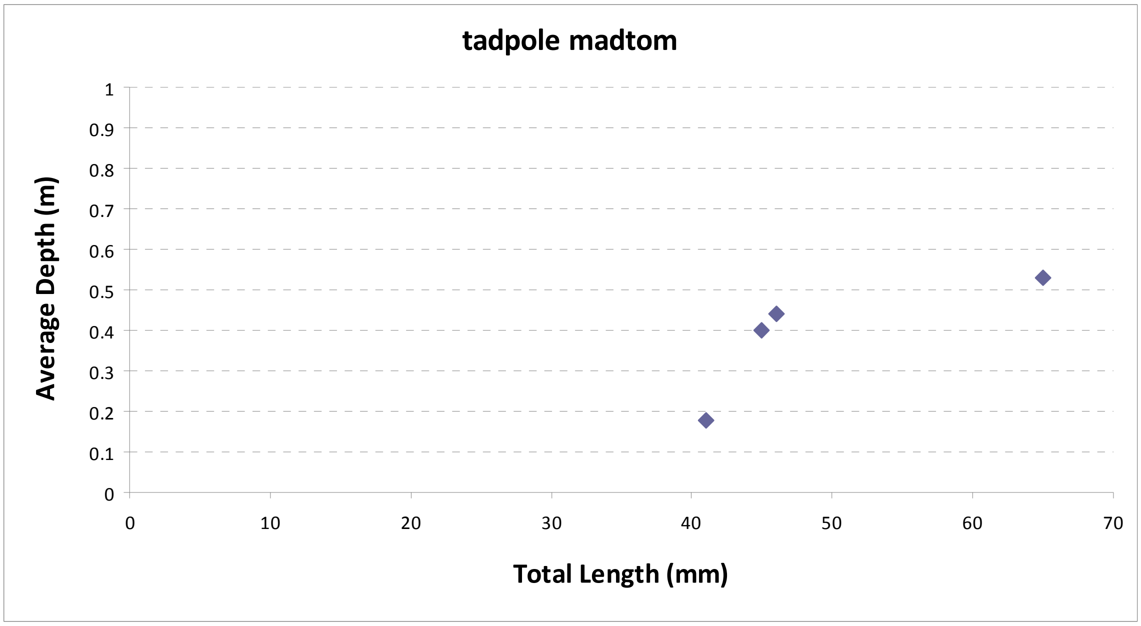


Figure A-24. Average depth and average velocity versus total length for striped mullet *Mugil cephalus*.



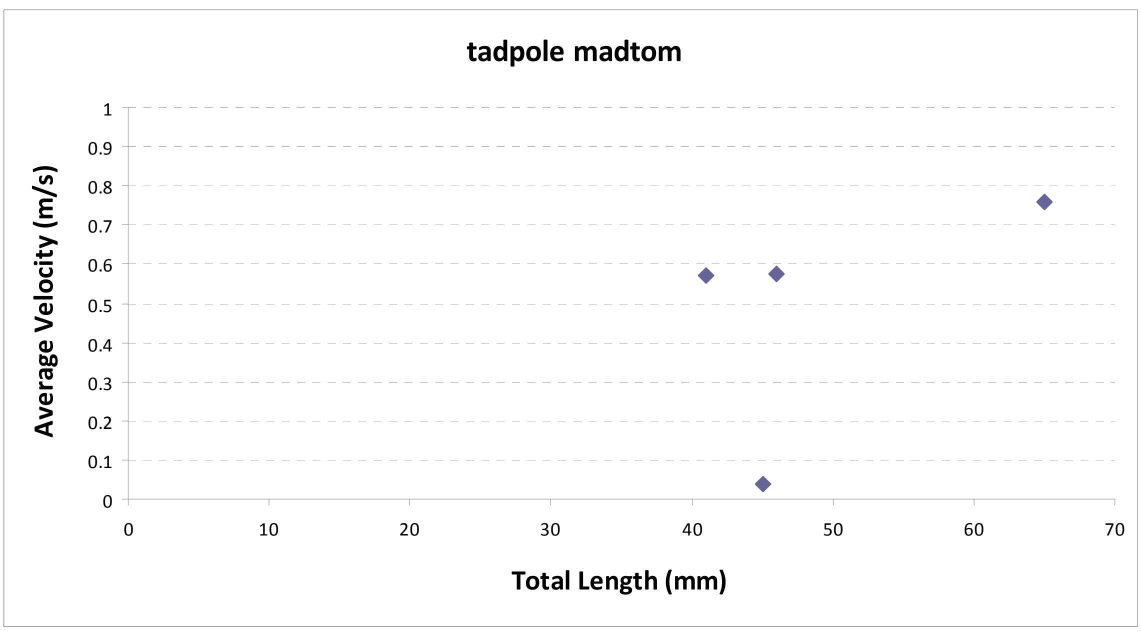


Figure A-25. Average depth and average velocity versus total length for tadpole madtom *Noturus gyrinus*.

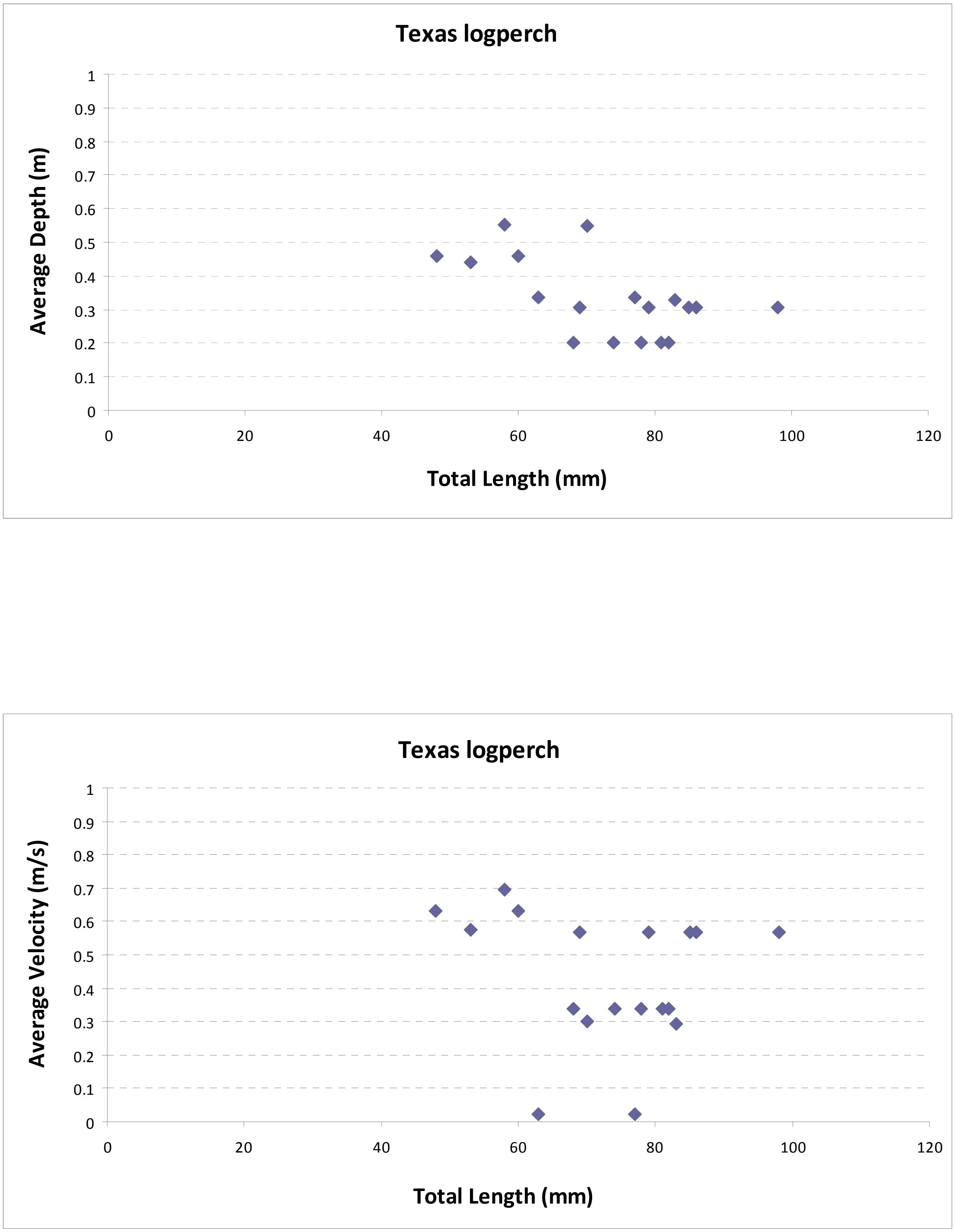
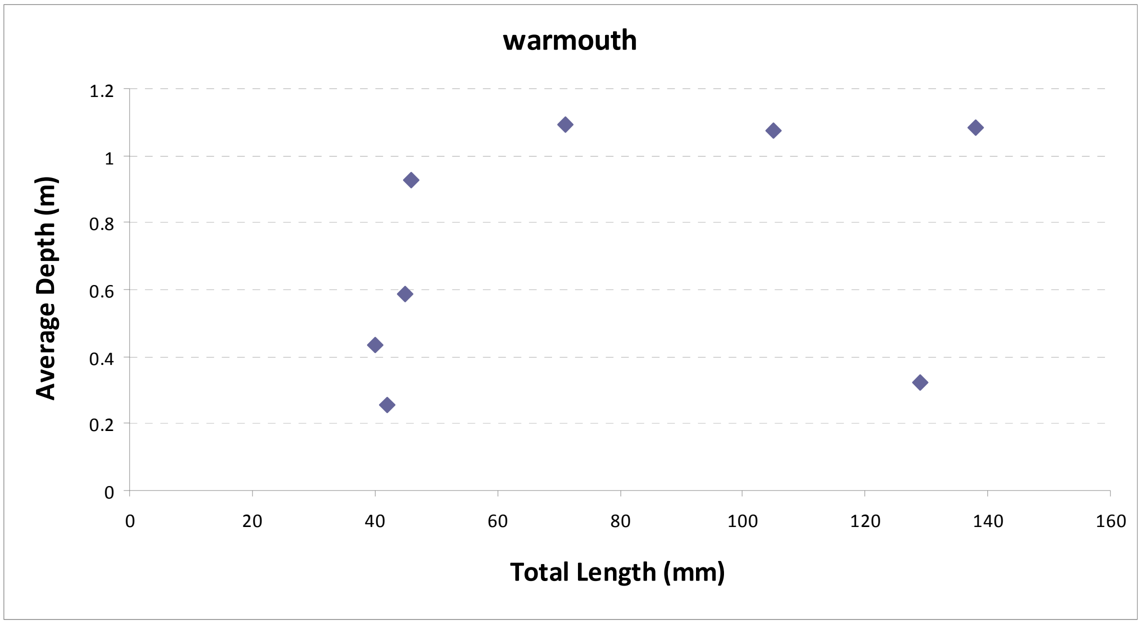


Figure A-26. Average depth and average velocity versus total length for Texas logperch *Percina carbonaria*.



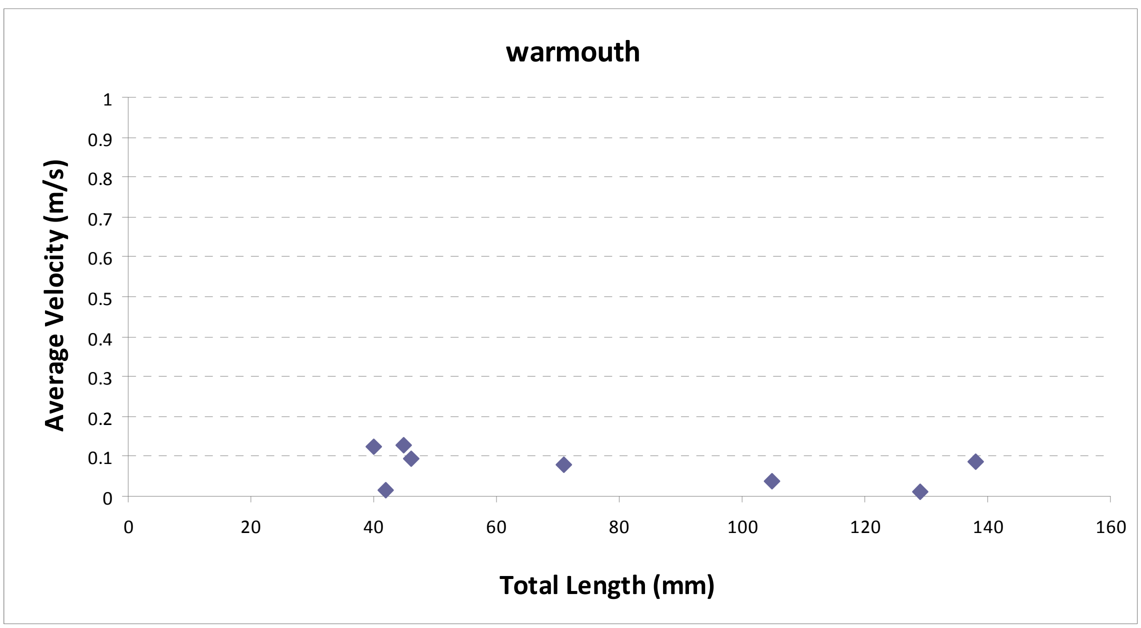
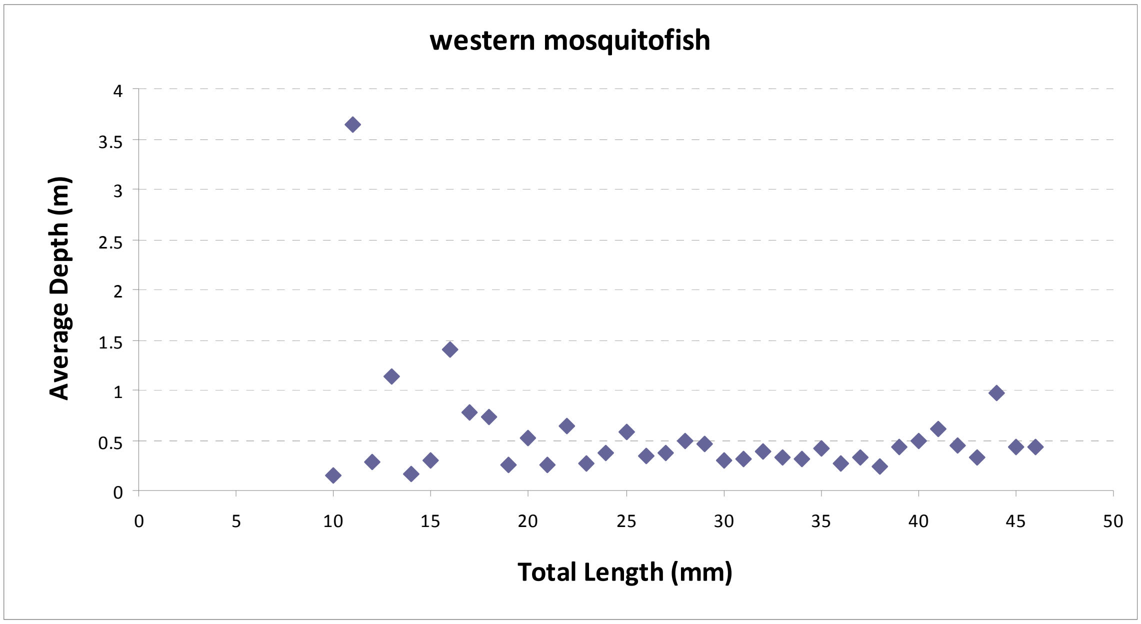


Figure A-27. Average depth and average velocity versus total length for warmouth *Lepomis gulosus*.



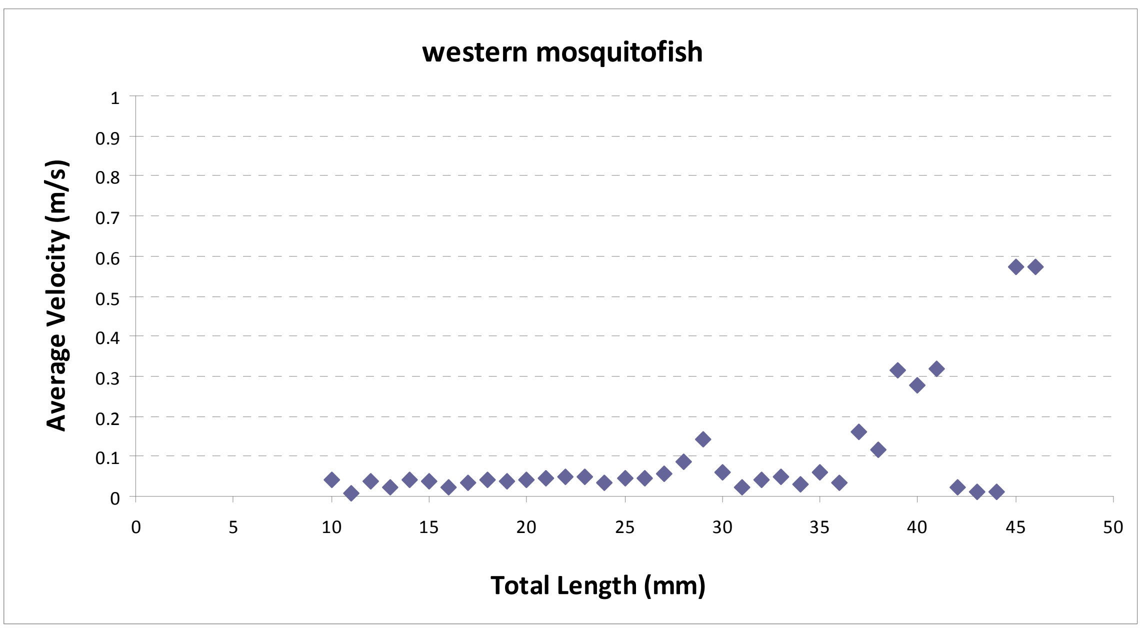
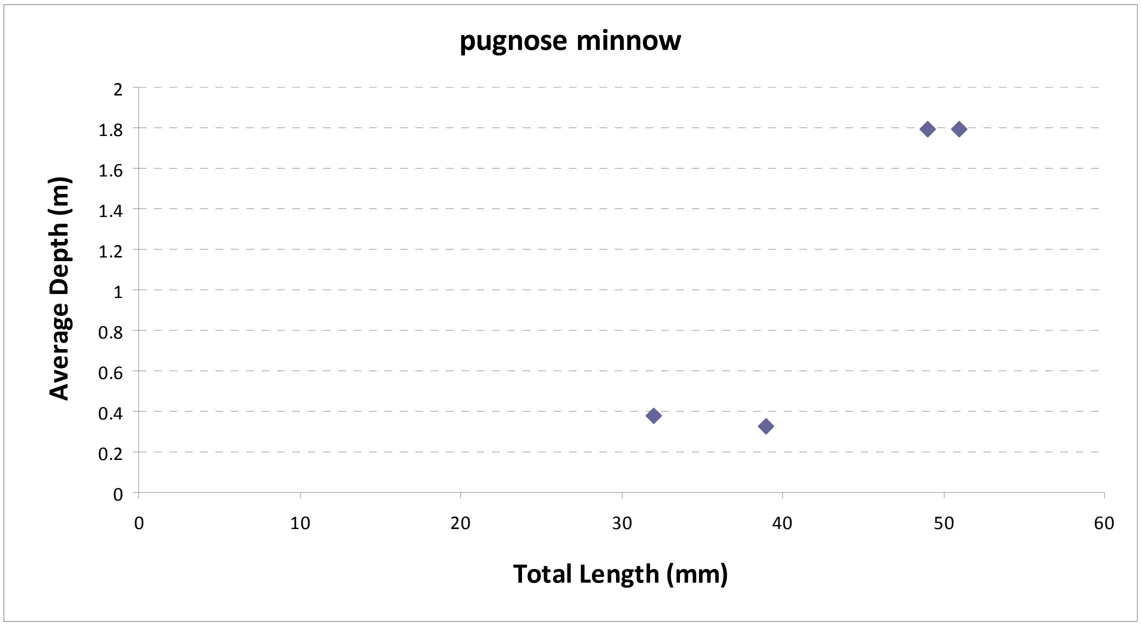


Figure A-28. Average depth and average velocity versus total length for western mosquitofish *Gambusia affinis*.



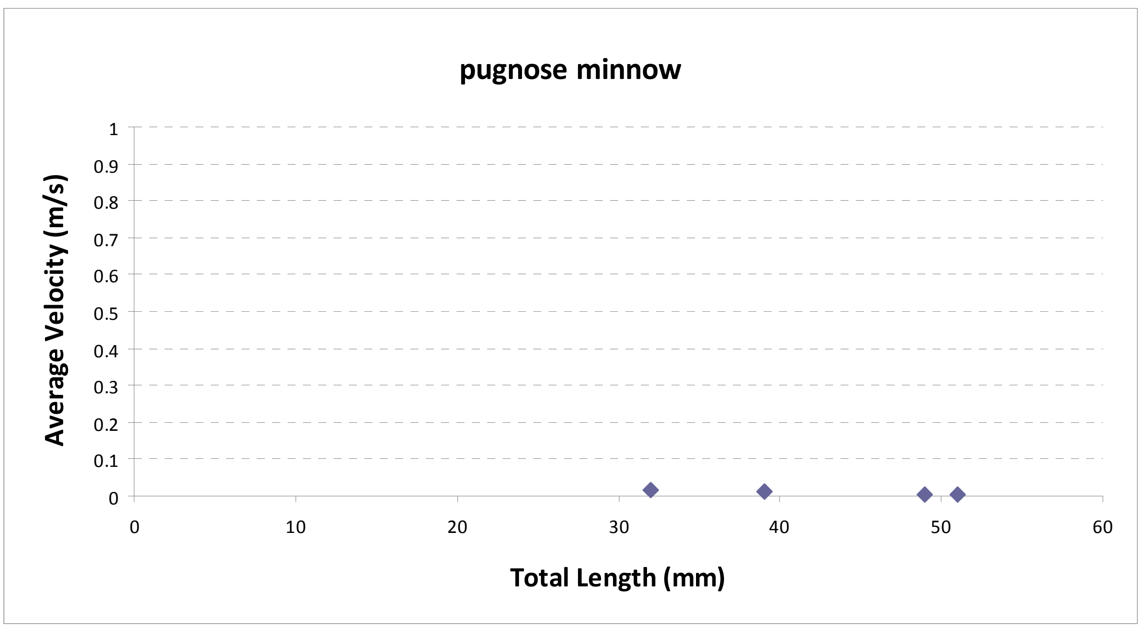


Figure A-29. Average depth and average velocity versus total length for pugnose minnow *Opsopoeodus emiliae*.

APPENDIX B
WEIGHTED USABLE AREA FIGURES

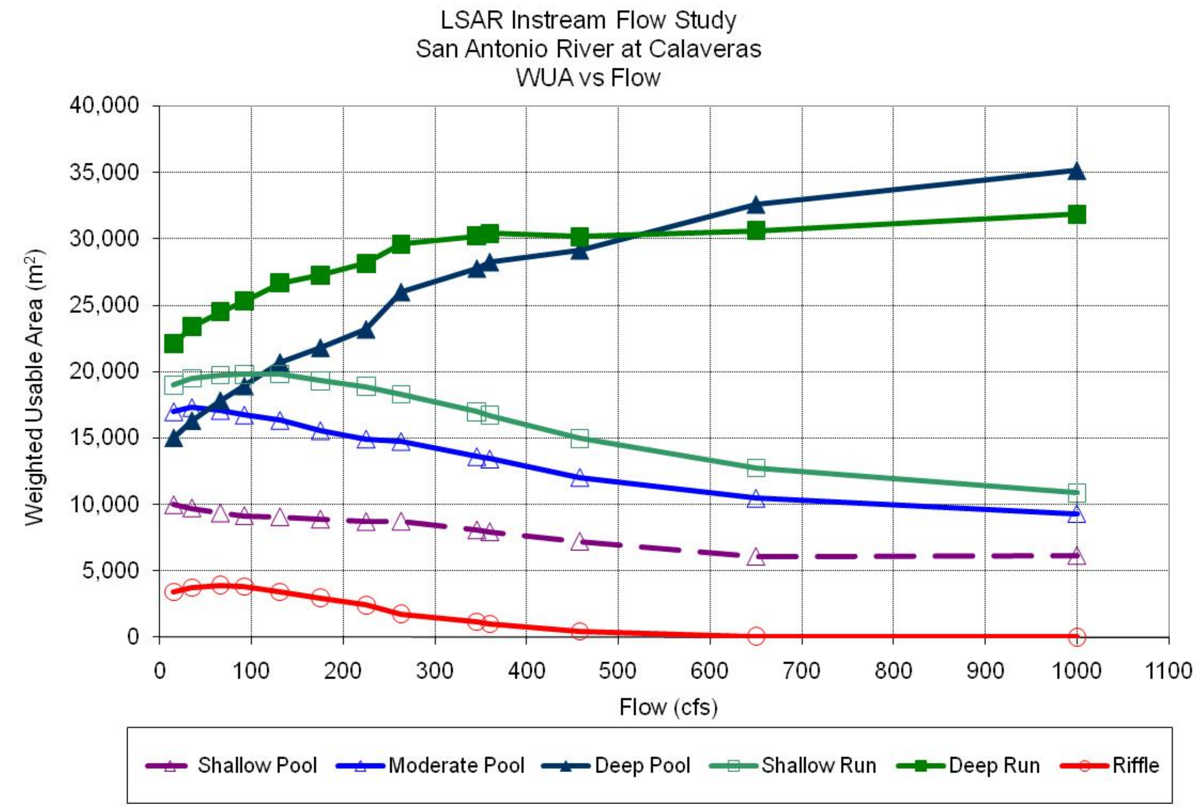


Figure B-1. Weighted Usuable Area versus simulated discharge at Calavers Study Site.

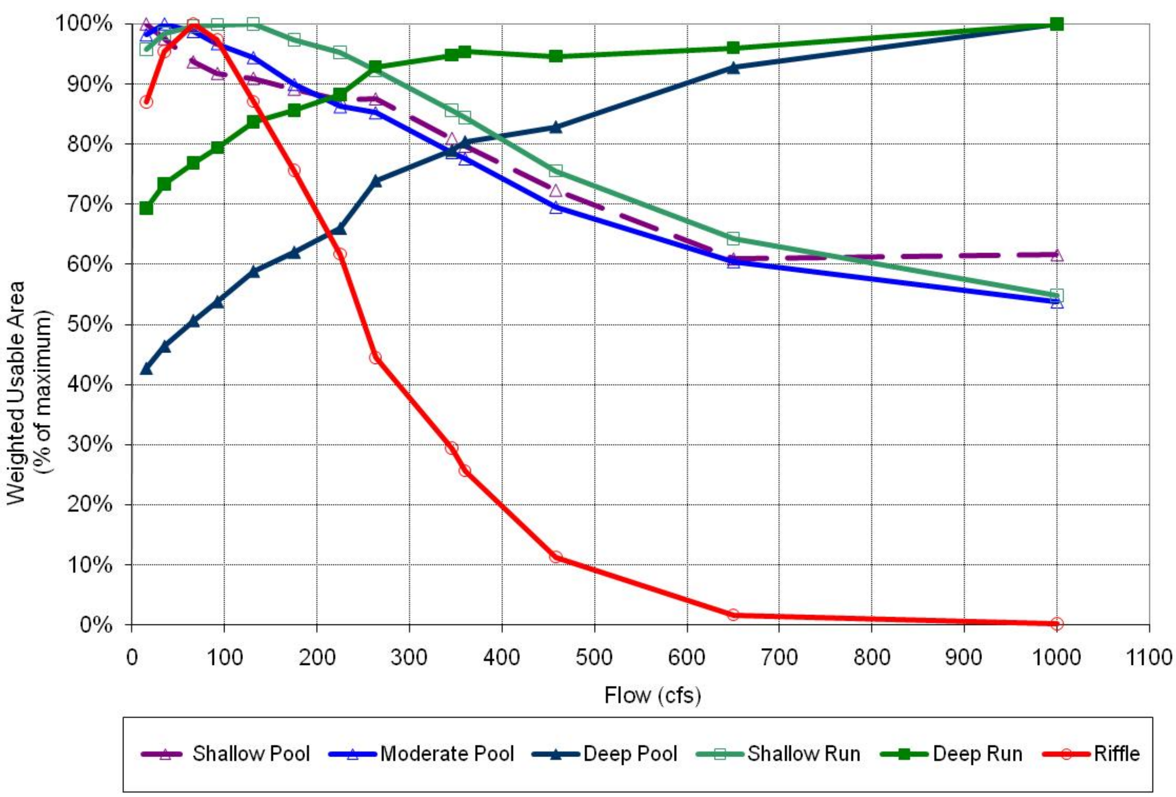


Figure B-2. Percent of Maximum Habitat versus simulated discharge at Calavers Study Site

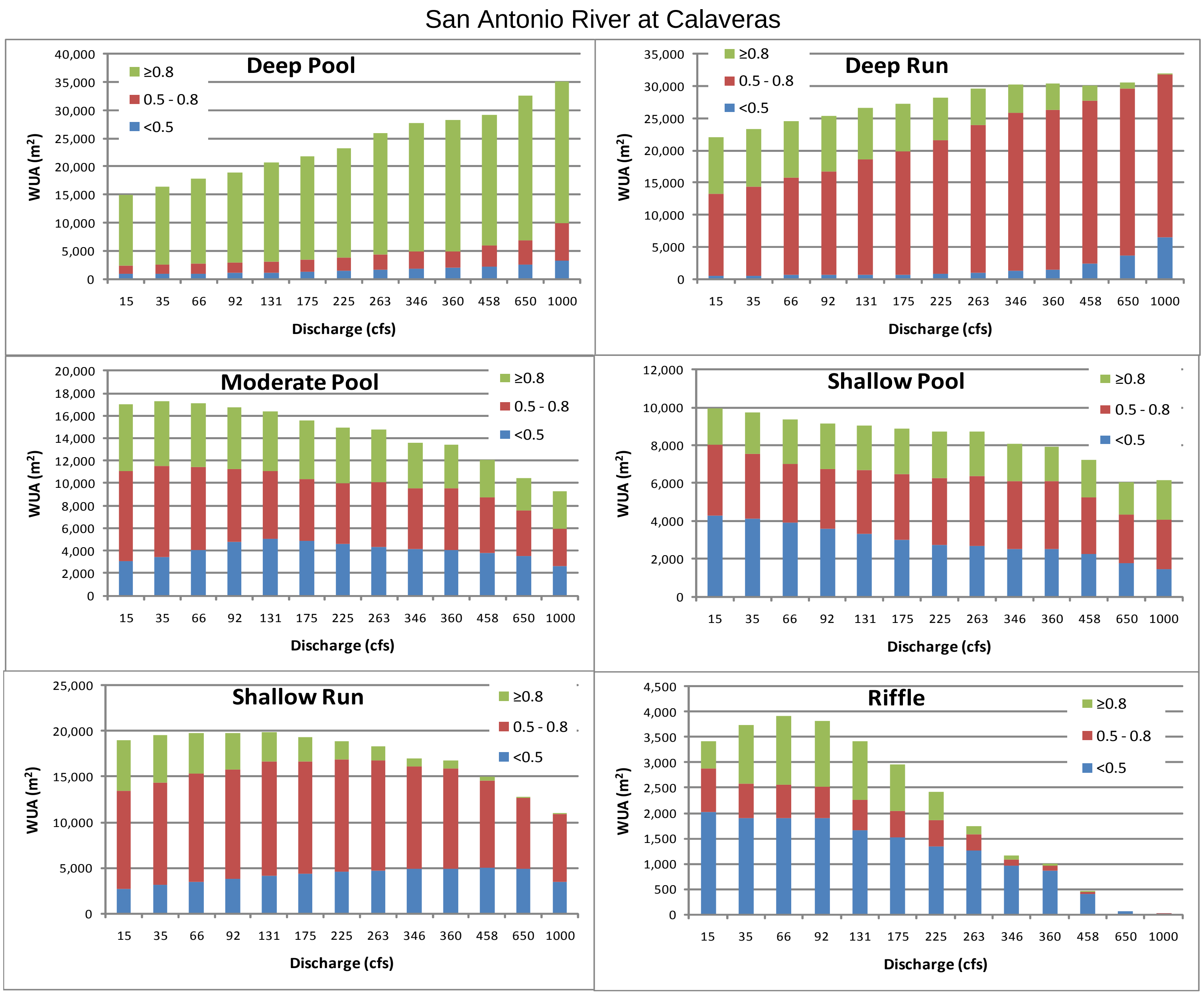


Figure B-3. Habitat quality breakout of Weighted Usable Area (WUA) versus simulated discharge at the Calavers Study Site.

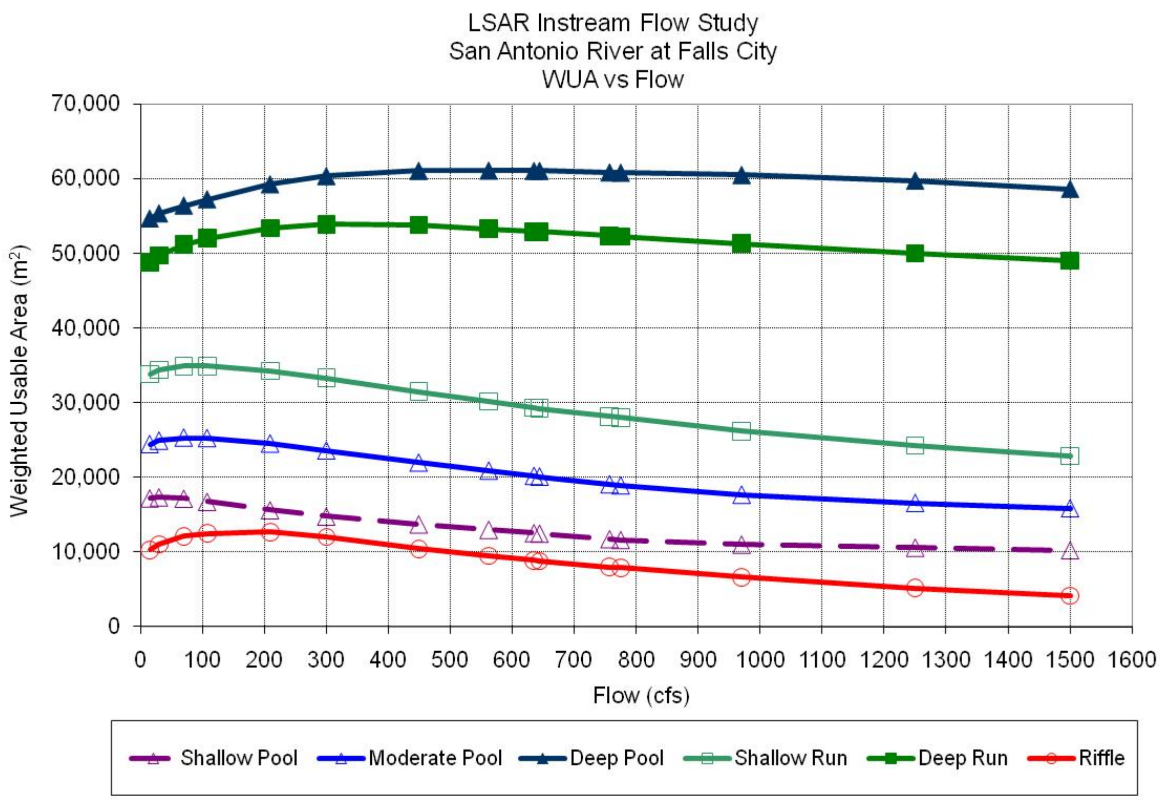


Figure B-4. Weighted Usuable Area versus simulated discharge at Falls City Study Site.

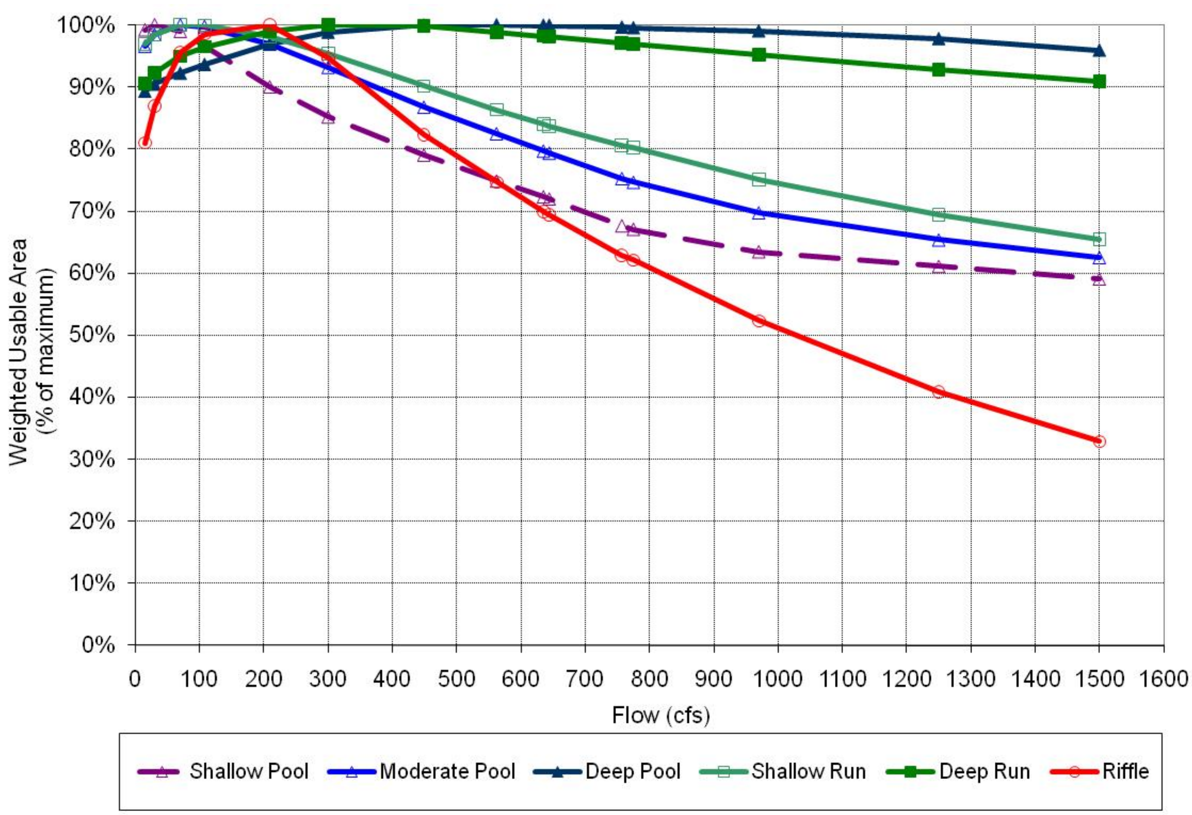


Figure B-5. Percent of Maximum Habitat versus simulated discharge at Falls City Study Site

San Antonio River at Falls City

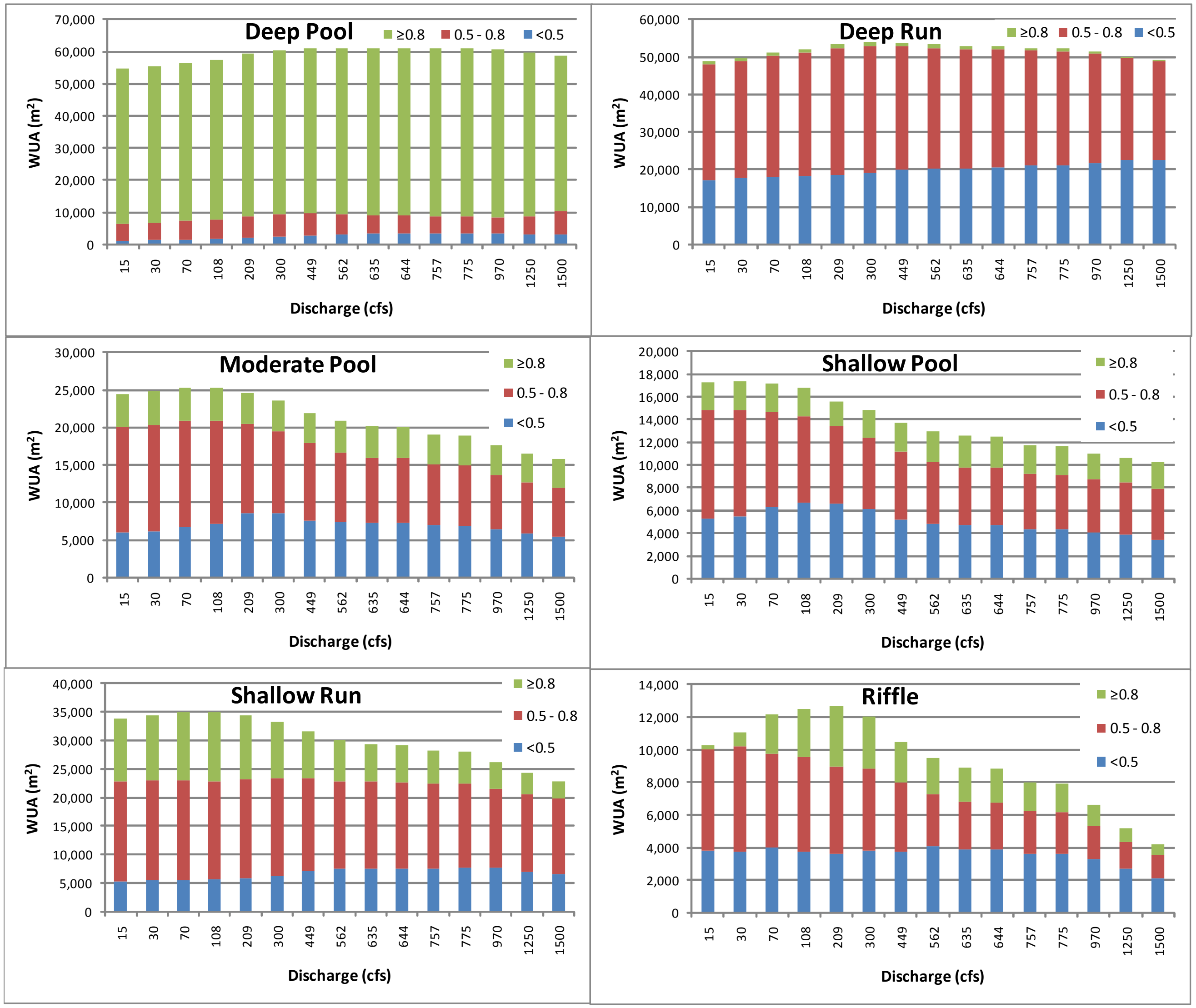


Figure B-6. Habitat quality breakout of Weighted Usable Area (WUA) versus simulated discharge at the Falls City Study Site.

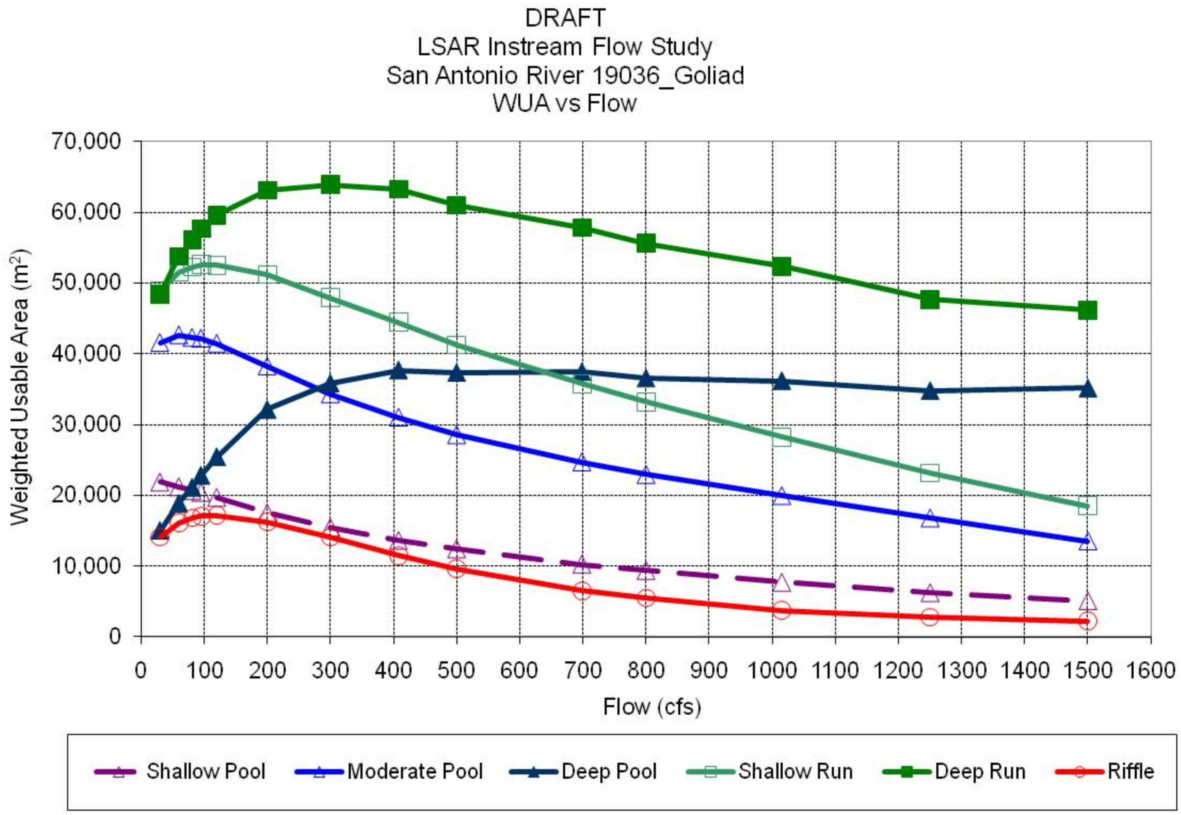


Figure B-7. Weighted Usuable Area versus simulated discharge at Goliad Study Site.

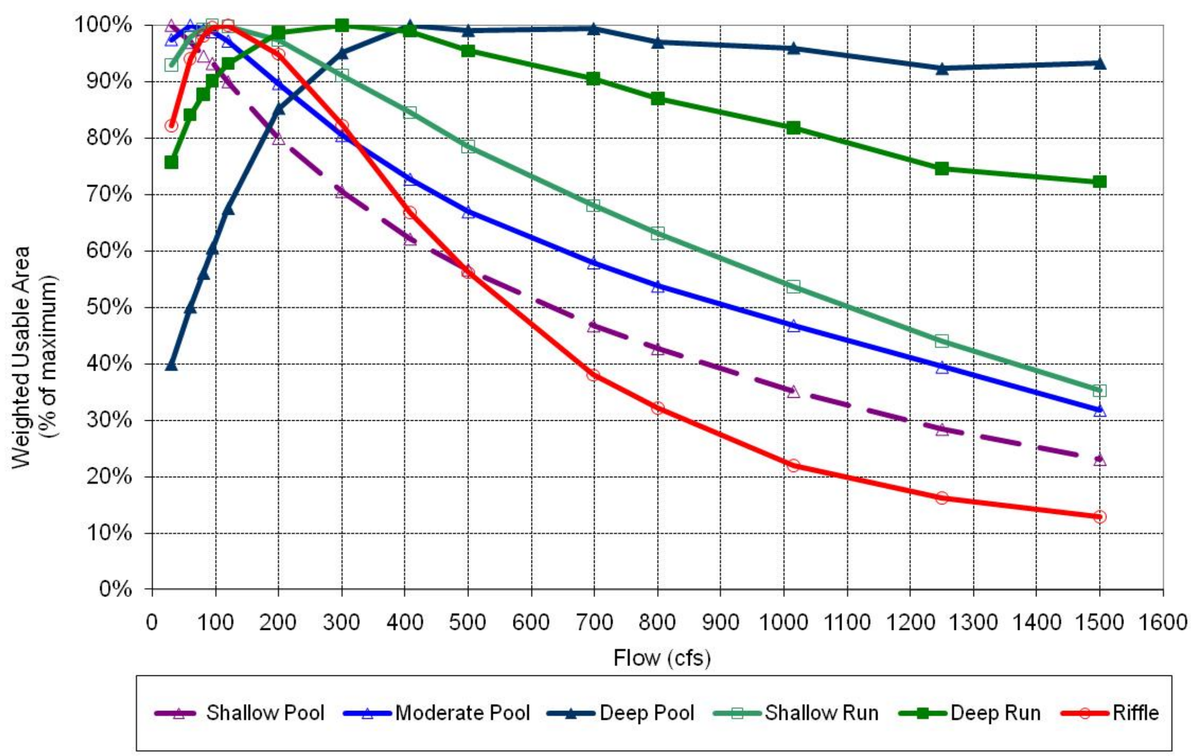


Figure B-8. Percent of Maximum Habitat versus simulated discharge at Goliad Study Site

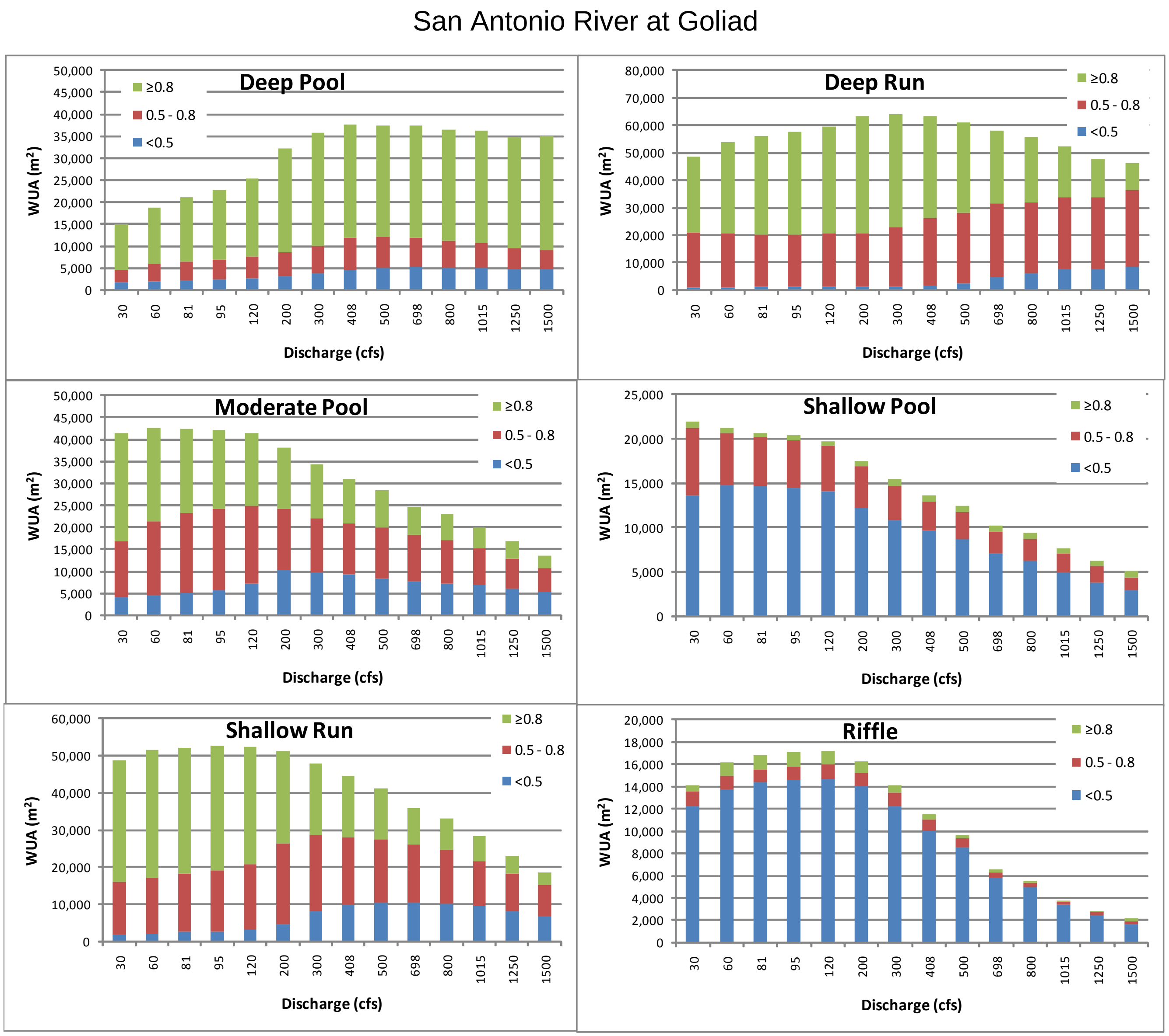


Figure B-9. Habitat quality breakout of Weighted Usable Area (WUA) versus simulated discharge at the Goliad Study Site.

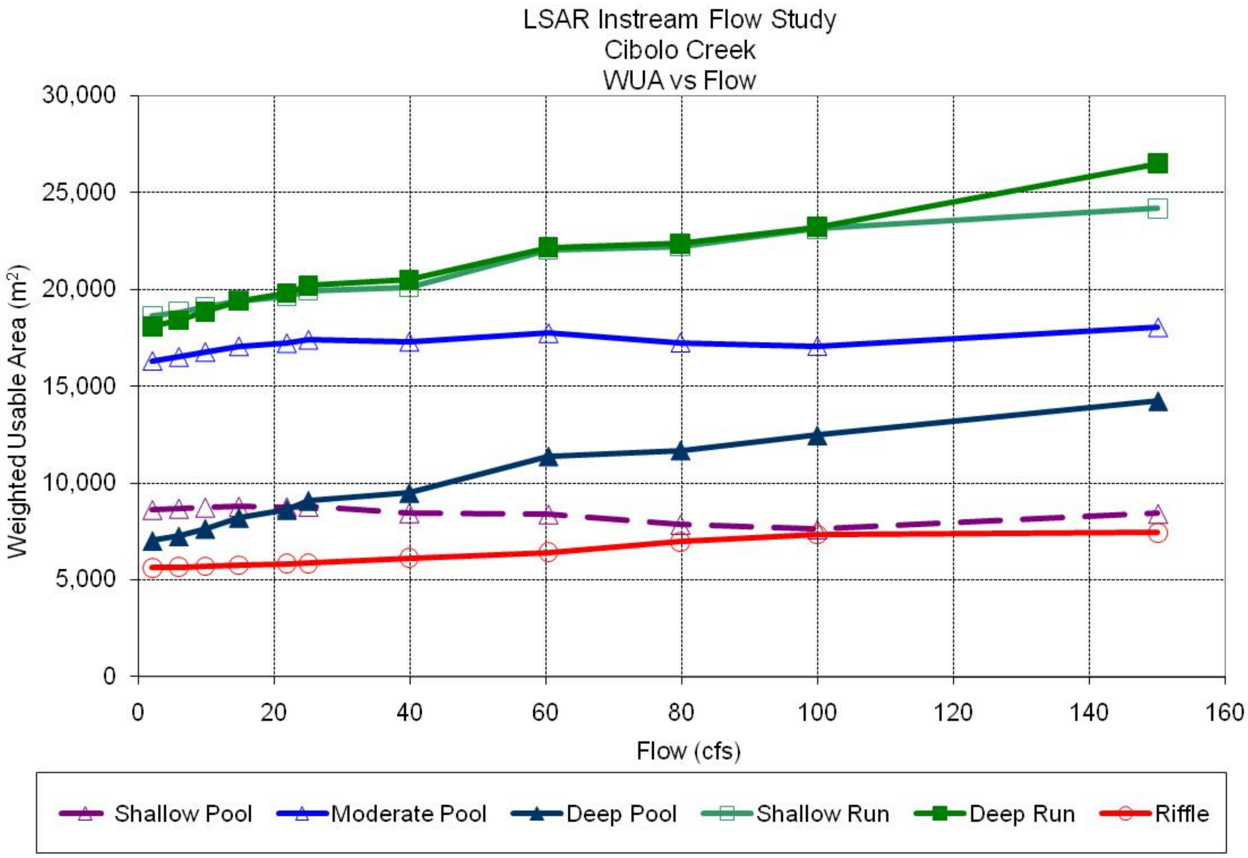


Figure B-10. Weighted Usuable Area versus simulated discharge at Cibilo Creek Study Site.

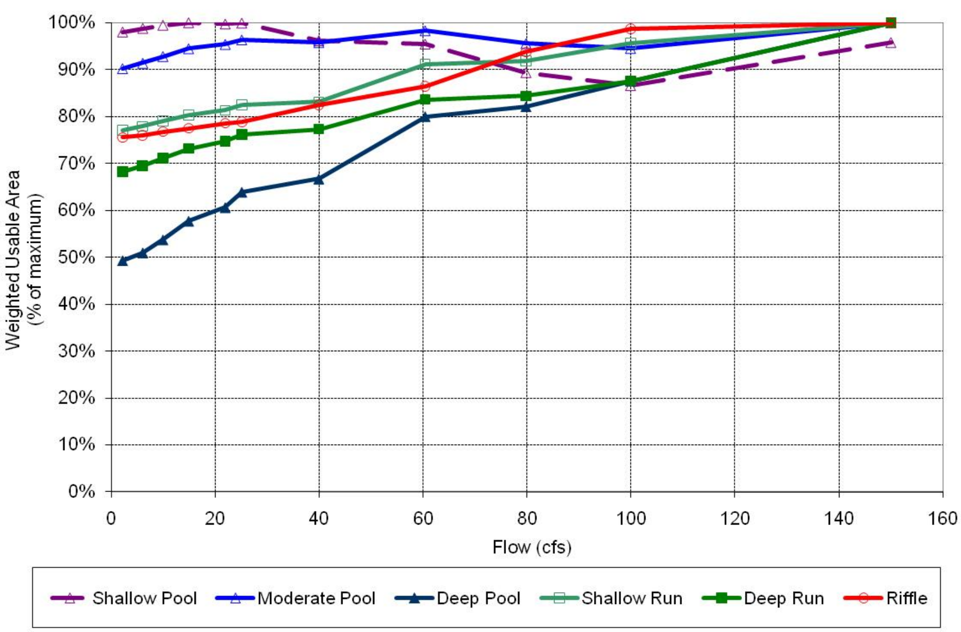


Figure B-11. Percent of Maximum Habitat versus simulated discharge at Cibilo Creek Study Site

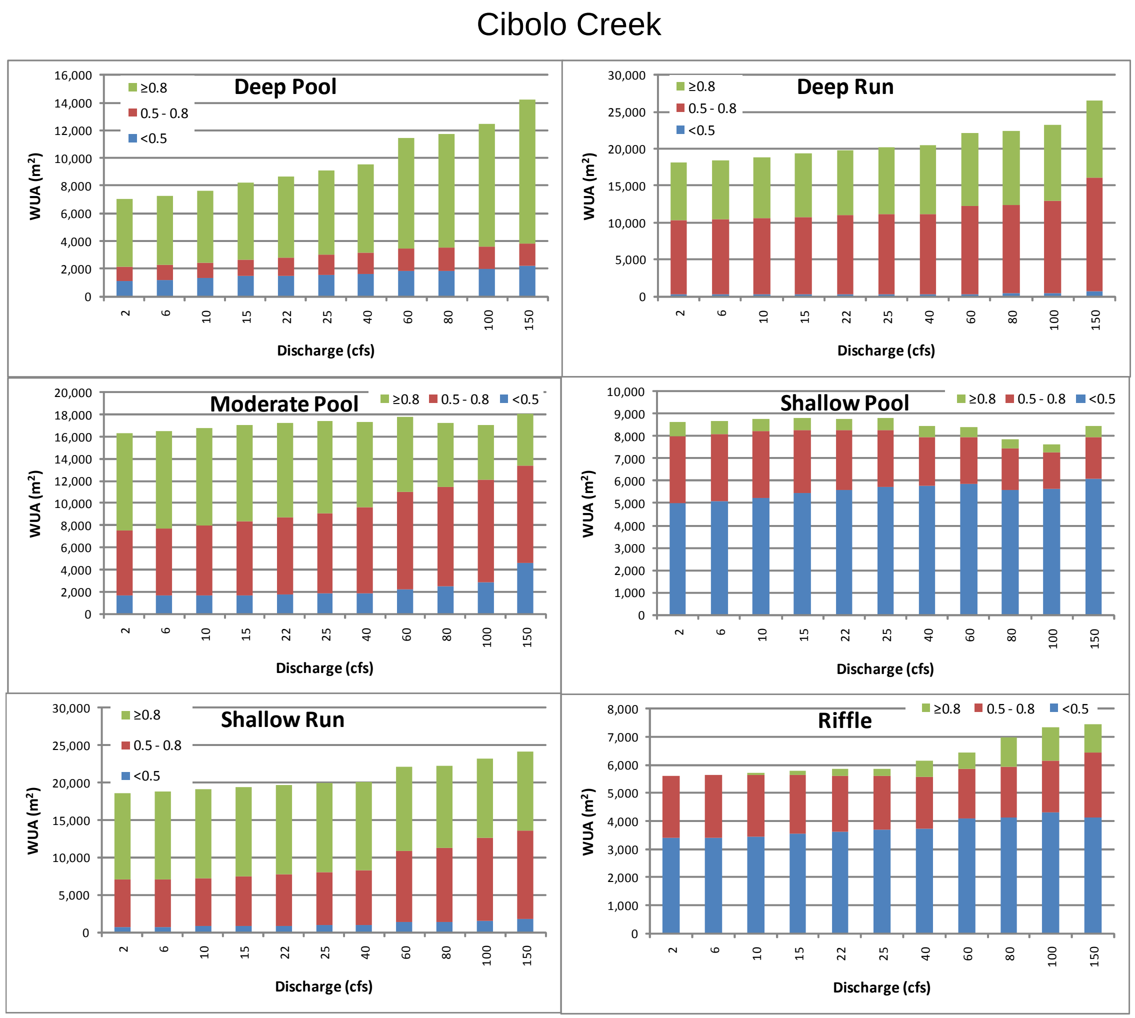


Figure B-12. Habitat quality breakout of Weighted Usable Area (WUA) versus simulated discharge at the Cibilo Creek Study Site.

APPENDIX C
HABITAT TIME SERIES TABLES

Table C-1. Habitat Time Series results for Calaveras Study Site (WUA – top table, Percent of Maximum WUA – lower table).

Percentile	Percent Exceedance	Calaveras - Weighted Usable Area (m^2)						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	17,305	35,146	31,863	9,937	19,820	3,922	unattainable*	
0.999	0.1	17,304	35,131	31,856	9,826	19,820	3,922	unattainable*	
0.99	1	17,240	34,625	31,607	9,616	19,818	3,911	unattainable*	
0.975	2.5	17,168	33,921	31,260	9,492	19,815	3,899	unattainable*	
0.95	5	17,067	33,024	30,819	9,329	19,810	3,875	unattainable*	
0.925	7.5	16,946	32,017	30,532	9,263	19,807	3,847	unattainable*	
0.9	10	16,839	30,847	30,390	9,204	19,803	3,823	unattainable*	
0.8	20	16,498	28,628	30,259	9,103	19,749	3,572	unattainable*	
0.75	25	16,275	28,261	30,194	9,055	19,667	3,376	unattainable*	
0.7	30	15,977	27,364	30,075	8,985	19,549	3,203	unattainable*	
0.6	40	15,433	26,142	29,653	8,850	19,207	2,848	unattainable*	
0.5	50	14,935	23,202	28,146	8,727	18,873	2,420	unattainable*	
0.49	51	14,916	23,088	28,075	8,726	18,812	2,349	221	221
0.4	60	14,663	22,111	27,468	8,674	18,188	1,695	186	270
0.3	70	13,873	21,222	26,964	8,221	17,275	1,287	152	327
0.25	75	13,431	20,792	26,733	7,941	16,719	1,007	135	360
0.2	80	12,852	20,007	26,147	7,636	15,990	771	116	401
0.1	90	11,270	18,616	25,088	6,649	13,873	257	85	553
0.05	95	10,281	17,897	24,575	6,117	12,432	56	68	642
0.025	97.5	9,875	17,233	24,081	6,091	11,776	36	54	832
0.01	99	9,555	16,750	23,720	6,080	11,260	20	44	928
0.001	99.9	9,326	15,792	22,869	6,074	10,890	8	27	998
0.0001	99.99	9,319	15,203	22,277	6,074	10,879	8	18	1000

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

Percentile	Percent Exceedance	Calaveras - Percent of Maximum WUA						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	100%	100%	100%	100%	100%	100%	unattainable*	
0.999	0.1	100%	100%	100%	99%	100%	100%	unattainable*	
0.99	1	100%	99%	99%	97%	100%	100%	unattainable*	
0.975	2.5	99%	97%	98%	96%	100%	99%	unattainable*	
0.95	5	99%	94%	97%	94%	100%	99%	unattainable*	
0.925	7.5	98%	91%	96%	93%	100%	98%	unattainable*	
0.9	10	97%	88%	95%	93%	100%	97%	unattainable*	
0.8	20	95%	81%	95%	92%	100%	91%	unattainable*	
0.75	25	94%	80%	95%	91%	99%	86%	unattainable*	
0.7	30	92%	78%	94%	90%	99%	82%	unattainable*	
0.6	40	89%	74%	93%	89%	97%	73%	unattainable*	
0.5	50	86%	66%	88%	88%	95%	62%	unattainable*	
0.49	51	86%	66%	88%	88%	95%	60%	221	221
0.4	60	85%	63%	86%	87%	92%	43%	186	270
0.3	70	80%	60%	85%	83%	87%	33%	152	327
0.25	75	78%	59%	84%	80%	84%	26%	135	360
0.2	80	74%	57%	82%	77%	81%	20%	116	401
0.1	90	65%	53%	79%	67%	70%	7%	85	553
0.05	95	59%	51%	77%	62%	63%	1%	68	642
0.025	97.5	57%	49%	76%	61%	59%	1%	54	832
0.01	99	55%	48%	74%	61%	57%	0%	44	928
0.001	99.9	54%	45%	72%	61%	55%	0%	27	998
0.0001	99.99	54%	43%	70%	61%	55%	0%	18	1000

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

Table C-2. Habitat Time Series results for Falls City Study Site (WUA – top table, Percent of Maximum WUA – lower table).

Percentile	Percent Exceedance	Falls City - Weighted Usable Area (m^2)						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	25,309	61,122	53,914	17,362	34,921	12,694	unattainable*	
0.999	0.1	25,309	61,121	53,914	17,343	34,921	12,694	unattainable*	
0.99	1	25,302	61,120	53,911	17,270	34,920	12,688	unattainable*	
0.975	2.5	25,290	61,118	53,906	17,220	34,919	12,680	unattainable*	
0.95	5	25,277	61,115	53,897	17,111	34,917	12,665	unattainable*	
0.925	7.5	25,264	61,113	53,890	17,011	34,915	12,650	unattainable*	
0.9	10	25,248	61,091	53,880	16,899	34,913	12,635	unattainable*	
0.8	20	25,068	60,830	53,837	16,520	34,736	12,579	unattainable*	
0.75	25	24,941	60,702	53,769	16,298	34,630	12,547	unattainable*	
0.7	30	24,813	60,579	53,674	16,086	34,531	12,522	unattainable*	
0.6	40	24,531	60,246	53,481	15,641	34,288	12,373	unattainable*	
0.5	50	24,068	59,754	53,187	15,222	33,811	12,185	247	253
0.4	60	23,548	59,202	52,805	14,765	33,271	11,845	205	303
0.3	70	22,818	58,466	52,397	14,286	32,452	11,259	168	370
0.25	75	22,350	58,088	52,179	13,978	31,927	10,830	149	413
0.2	80	21,758	57,689	51,989	13,586	31,240	10,273	129	470
0.1	90	19,659	56,981	51,382	12,181	28,790	8,466	95	691
0.05	95	17,903	56,555	50,774	11,140	26,564	6,883	76	932
0.025	97.5	16,992	56,177	50,276	10,768	25,028	5,762	61	1140
0.01	99	16,332	55,881	49,650	10,495	23,821	4,872	50	1320
0.001	99.9	15,896	55,341	49,129	10,283	22,978	4,254	30	1480
0.0001	99.99	15,839	54,883	49,050	10,255	22,867	4,172	20	1500

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

Percentile	Percent Exceedance	Falls City - Percent of Maximum WUA						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	100%	100%	100%	100%	100%	100%	unattainable*	
0.999	0.1	100%	100%	100%	100%	100%	100%	unattainable*	
0.99	1	100%	100%	100%	99%	100%	100%	unattainable*	
0.975	2.5	100%	100%	100%	99%	100%	100%	unattainable*	
0.95	5	100%	100%	100%	99%	100%	100%	unattainable*	
0.925	7.5	100%	100%	100%	98%	100%	100%	unattainable*	
0.9	10	100%	100%	100%	97%	100%	100%	unattainable*	
0.8	20	99%	100%	100%	95%	99%	99%	unattainable*	
0.75	25	99%	99%	100%	94%	99%	99%	unattainable*	
0.7	30	98%	99%	100%	93%	99%	99%	unattainable*	
0.6	40	97%	99%	99%	90%	98%	97%	unattainable*	
0.5	50	95%	98%	99%	88%	97%	96%	247	253
0.4	60	93%	97%	98%	85%	95%	93%	205	303
0.3	70	90%	96%	97%	82%	93%	89%	168	370
0.25	75	88%	95%	97%	81%	91%	85%	149	413
0.2	80	86%	94%	96%	78%	89%	81%	129	470
0.1	90	78%	93%	95%	70%	82%	67%	95	691
0.05	95	71%	93%	94%	64%	76%	54%	76	932
0.025	97.5	67%	92%	93%	62%	72%	45%	61	1140
0.01	99	65%	91%	92%	60%	68%	38%	50	1320
0.001	99.9	63%	91%	91%	59%	66%	34%	30	1480
0.0001	99.99	63%	90%	91%	59%	65%	33%	20	1500

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

Table C-3. Habitat Time Series results for Goliad Study Site (WUA – top table, Percent of Maximum WUA – lower table).

Percentile	Percent Exceedance	Goliad - Weighted Usable Area (m^2)						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	42,643	37,689	63,915	21,809	52,593	17,152	unattainable*	
0.999	0.1	42,626	37,689	63,915	21,676	52,593	17,152	unattainable*	
0.99	1	42,499	37,667	63,899	21,321	52,568	17,141	unattainable*	
0.975	2.5	42,290	37,630	63,865	20,828	52,543	17,127	unattainable*	
0.95	5	42,101	37,559	63,818	20,415	52,503	17,096	unattainable*	
0.925	7.5	41,732	37,495	63,772	19,990	52,344	17,009	unattainable*	
0.9	10	41,328	37,450	63,728	19,625	52,187	16,905	unattainable*	
0.8	20	39,286	37,381	63,526	18,226	51,474	16,426	unattainable*	
0.75	25	38,166	37,355	63,429	17,472	50,980	16,100	unattainable*	
0.7	30	37,144	37,057	63,330	16,936	50,236	15,604	unattainable*	
0.6	40	35,178	36,439	62,884	15,907	48,649	14,590	unattainable*	
0.52	48	33,733	36,030	61,915	15,130	47,323	13,650	311	319
0.5	50	33,382	35,895	61,738	14,933	46,951	13,368	303	330
0.4	60	31,414	34,845	60,632	13,829	44,869	11,786	274	395
0.3	70	28,985	33,169	59,481	12,624	41,807	9,953	228	483
0.25	75	27,841	32,204	58,660	12,012	40,230	9,053	202	537
0.2	80	26,448	29,957	57,655	11,223	38,245	7,924	174	608
0.1	90	22,355	25,696	54,091	9,031	32,192	5,171	123	842
0.05	95	19,237	22,818	51,043	7,355	27,043	3,538	95	1070
0.025	97.5	16,834	20,585	47,672	6,225	23,132	2,792	76	1250
0.01	99	15,004	18,357	46,838	5,572	20,556	2,468	56	1390
0.001	99.9	13,697	16,309	46,243	5,106	18,715	2,237	40	1490
0.0001	99.99	13,566	15,541	46,183	5,059	18,531	2,214	34	1500

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

Percentile	Percent Exceedance	Goliad - Percent of Maximum WUA						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	100%	100%	100%	100%	100%	100%	unattainable*	
0.999	0.1	100%	100%	100%	99%	100%	100%	unattainable*	
0.99	1	100%	100%	100%	98%	100%	100%	unattainable*	
0.975	2.5	99%	100%	100%	95%	100%	100%	unattainable*	
0.95	5	99%	100%	100%	94%	100%	100%	unattainable*	
0.925	7.5	98%	99%	100%	92%	100%	99%	unattainable*	
0.9	10	97%	99%	100%	90%	99%	99%	unattainable*	
0.8	20	92%	99%	99%	84%	98%	96%	unattainable*	
0.75	25	90%	99%	99%	80%	97%	94%	unattainable*	
0.7	30	87%	98%	99%	78%	96%	91%	unattainable*	
0.6	40	82%	97%	98%	73%	93%	85%	unattainable*	
0.52	48	79%	96%	97%	69%	90%	80%	311	319
0.5	50	78%	95%	97%	68%	89%	78%	303	330
0.4	60	74%	92%	95%	63%	85%	69%	274	395
0.3	70	68%	88%	93%	58%	79%	58%	228	483
0.25	75	65%	85%	92%	55%	76%	53%	202	537
0.2	80	62%	79%	90%	51%	73%	46%	174	608
0.1	90	52%	68%	85%	41%	61%	30%	123	842
0.05	95	45%	61%	80%	34%	51%	21%	95	1070
0.025	97.5	39%	55%	75%	29%	44%	16%	76	1250
0.01	99	35%	49%	73%	26%	39%	14%	56	1390
0.001	99.9	32%	43%	72%	23%	36%	13%	40	1490
0.0001	99.99	32%	41%	72%	23%	35%	13%	34	1500

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

Table C-4. Habitat Time Series results for Cibolo Creek Study Site (WUA – top table, Percent of Maximum WUA – lower table).

Percentile	Percent Exceedance	Cibolo Creek - Weighted Usable Area (m^2)						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	18,057	14,251	26,502	8,798	24,178	7,443	unattainable*	
0.999	0.1	18,037	14,216	26,437	8,798	24,157	7,441	unattainable*	
0.99	1	17,783	13,758	25,586	8,798	23,887	7,417	unattainable*	
0.975	2.5	17,702	13,124	24,408	8,794	23,514	7,382	unattainable*	
0.95	5	17,613	12,451	23,186	8,791	23,095	7,331	unattainable*	
0.925	7.5	17,546	11,946	22,636	8,791	22,494	7,093	unattainable*	
0.9	10	17,480	11,430	22,145	8,791	21,945	6,903	unattainable*	
0.8	20	17,392	10,538	21,327	8,784	20,971	6,302	unattainable*	
0.75	25	17,377	9,890	20,836	8,781	20,493	6,202	unattainable*	
0.7	30	17,363	9,486	20,483	8,775	20,091	6,127	unattainable*	
0.6	40	17,327	9,297	20,341	8,752	20,012	5,999	unattainable*	
0.53	47	17,292	9,189	20,260	8,727	19,967	5,926	28	28
0.5	50	17,242	9,162	20,240	8,709	19,956	5,907	27	28
0.4	60	17,187	8,659	19,818	8,638	19,674	5,852	22	32
0.3	70	17,118	8,416	19,585	8,484	19,535	5,807	18	39
0.25	75	17,095	8,299	19,471	8,451	19,468	5,784	16	44
0.2	80	17,018	8,135	19,312	8,428	19,376	5,762	14	51
0.1	90	16,776	7,676	18,863	7,927	19,127	5,718	10	150
0.05	95	16,630	7,452	18,615	7,827	18,971	5,686	7.8	150
0.025	97.5	16,510	7,269	18,411	7,731	18,842	5,661	6	150
0.01	99	16,410	7,155	18,261	7,671	18,747	5,643	4.2	150
0.001	99.9	16,324	7,057	18,134	7,624	18,665	5,628	2.5	150
0.0001	99.99	16,309	7,039	18,110	7,624	18,650	5,625	2.2	150

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

Percentile	Percent Exceedance	Cibolo Creek - Percent of Maximum WUA						Flows Required	
		Moderate Pool	Deep Pool	Deep Run	Shallow Pool	Shallow Run	Riffle	Min	Max
0.9999	0.01	100%	100%	100%	100%	100%	100%	unattainable*	
0.999	0.1	100%	100%	100%	100%	100%	100%	unattainable*	
0.99	1	98%	97%	97%	100%	99%	100%	unattainable*	
0.975	2.5	98%	92%	92%	100%	97%	99%	unattainable*	
0.95	5	98%	87%	87%	100%	96%	98%	unattainable*	
0.925	7.5	97%	84%	85%	100%	93%	95%	unattainable*	
0.9	10	97%	80%	84%	100%	91%	93%	unattainable*	
0.8	20	96%	74%	80%	100%	87%	85%	unattainable*	
0.75	25	96%	69%	79%	100%	85%	83%	unattainable*	
0.7	30	96%	67%	77%	100%	83%	82%	unattainable*	
0.6	40	96%	65%	77%	99%	83%	81%	unattainable*	
0.53	47	96%	64%	76%	99%	83%	80%	28	28
0.5	50	95%	64%	76%	99%	83%	79%	27	28
0.4	60	95%	61%	75%	98%	81%	79%	22	32
0.3	70	95%	59%	74%	96%	81%	78%	18	39
0.25	75	95%	58%	73%	96%	81%	78%	16	44
0.2	80	94%	57%	73%	96%	80%	77%	14	51
0.1	90	93%	54%	71%	90%	79%	77%	10	150
0.05	95	92%	52%	70%	89%	78%	76%	7.8	150
0.025	97.5	91%	51%	69%	88%	78%	76%	6	150
0.01	99	91%	50%	69%	87%	78%	76%	4.2	150
0.001	99.9	90%	50%	68%	87%	77%	76%	2.5	150
0.0001	99.99	90%	49%	68%	87%	77%	76%	2.2	150

*Conditions labeled as unattainable cannot be met or exceeded for all habitat guilds simultaneously.

APPENDIX D
RIPARIAN SPECIES COMMUNITY DATA

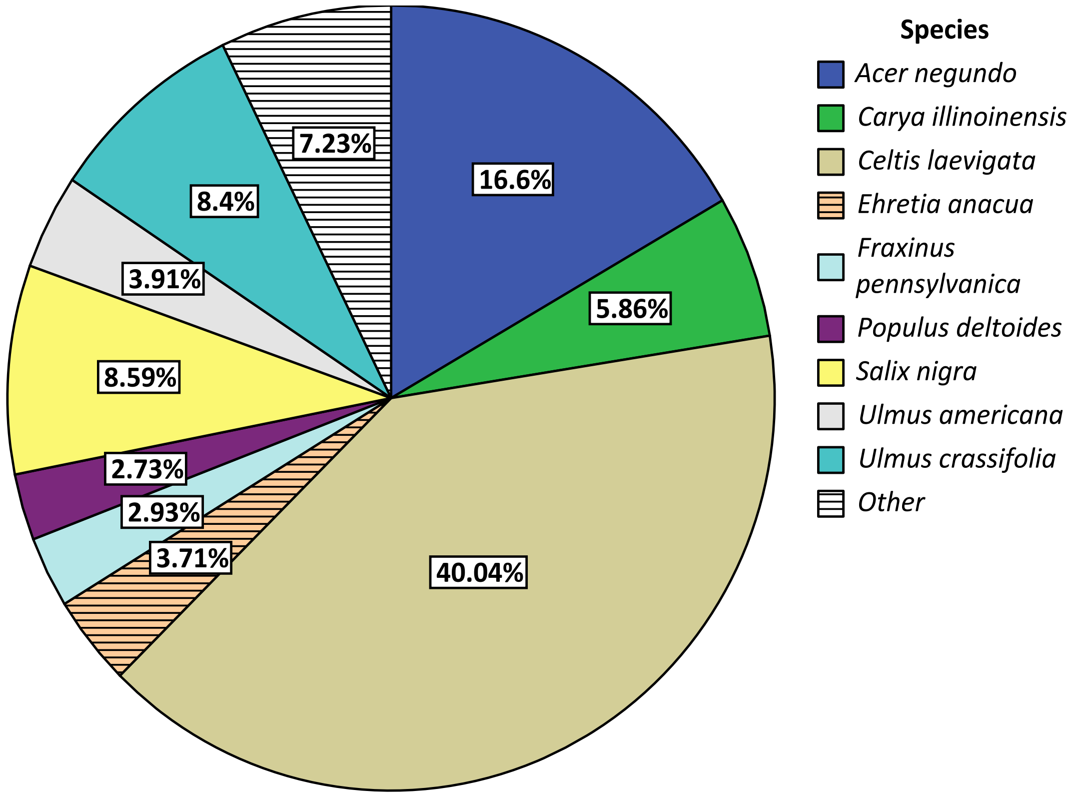


Figure D-1. Overall Tree Species Composition

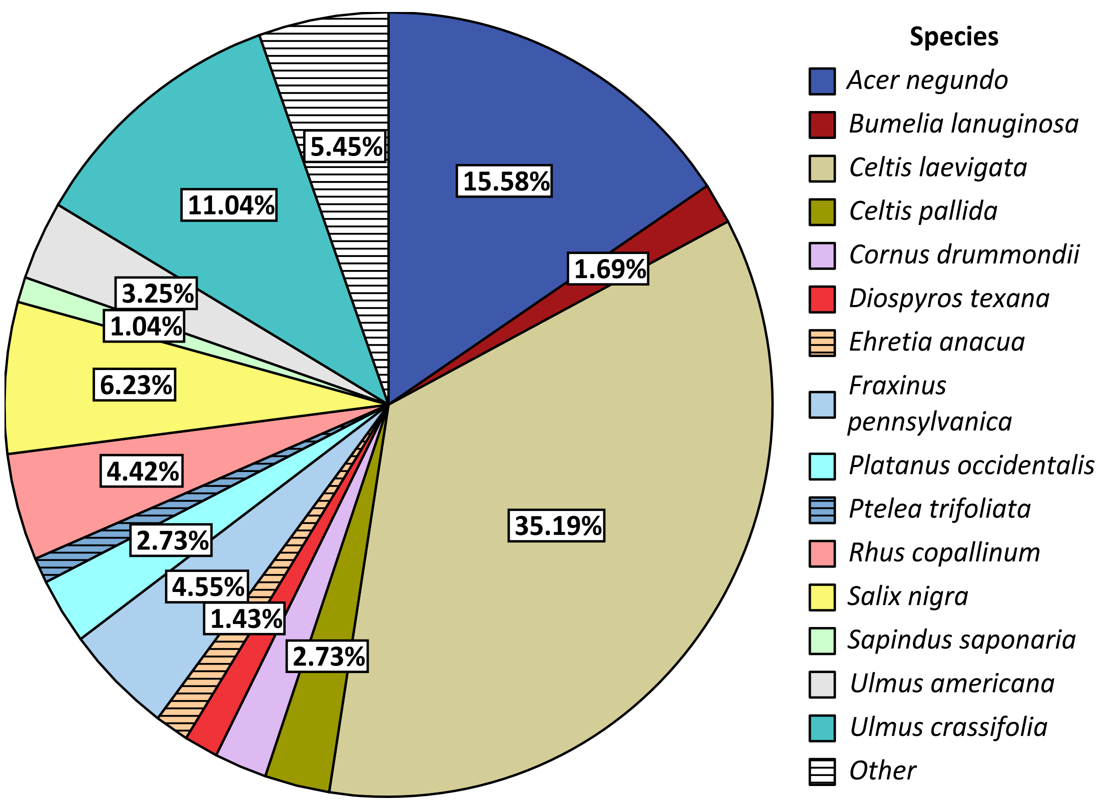


Figure D-2. Overall Sapling Species Composition

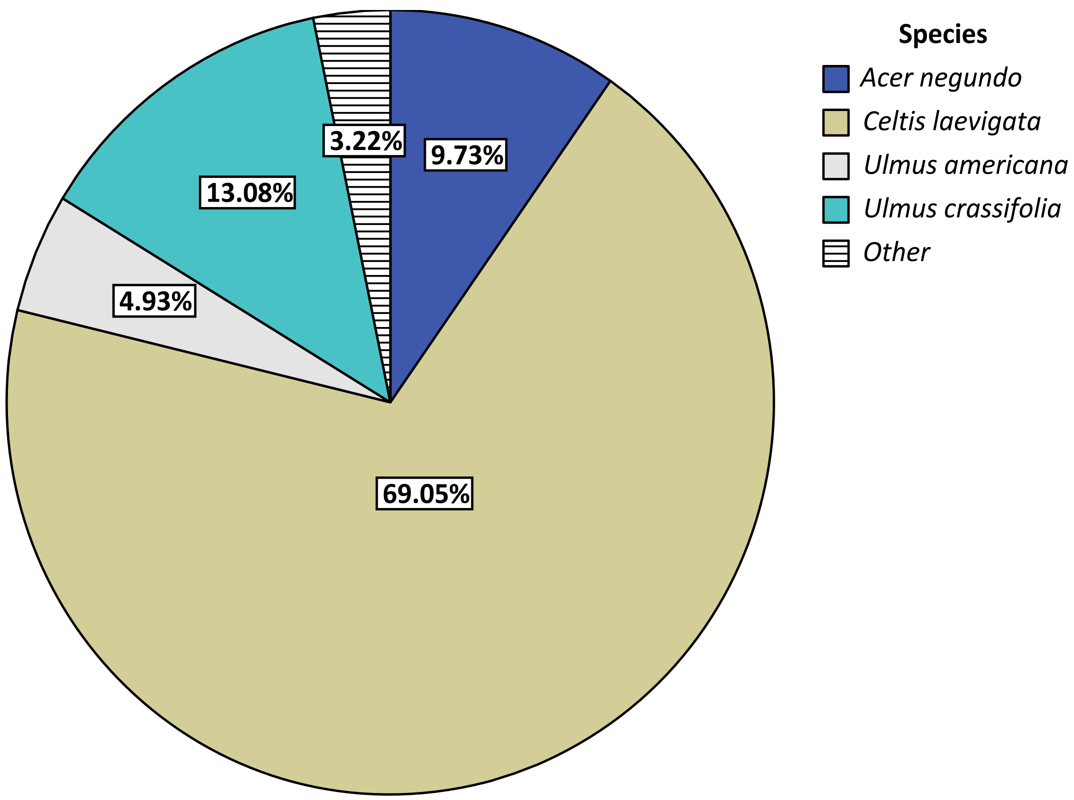


Figure D-3. Overall Seedling Species Composition

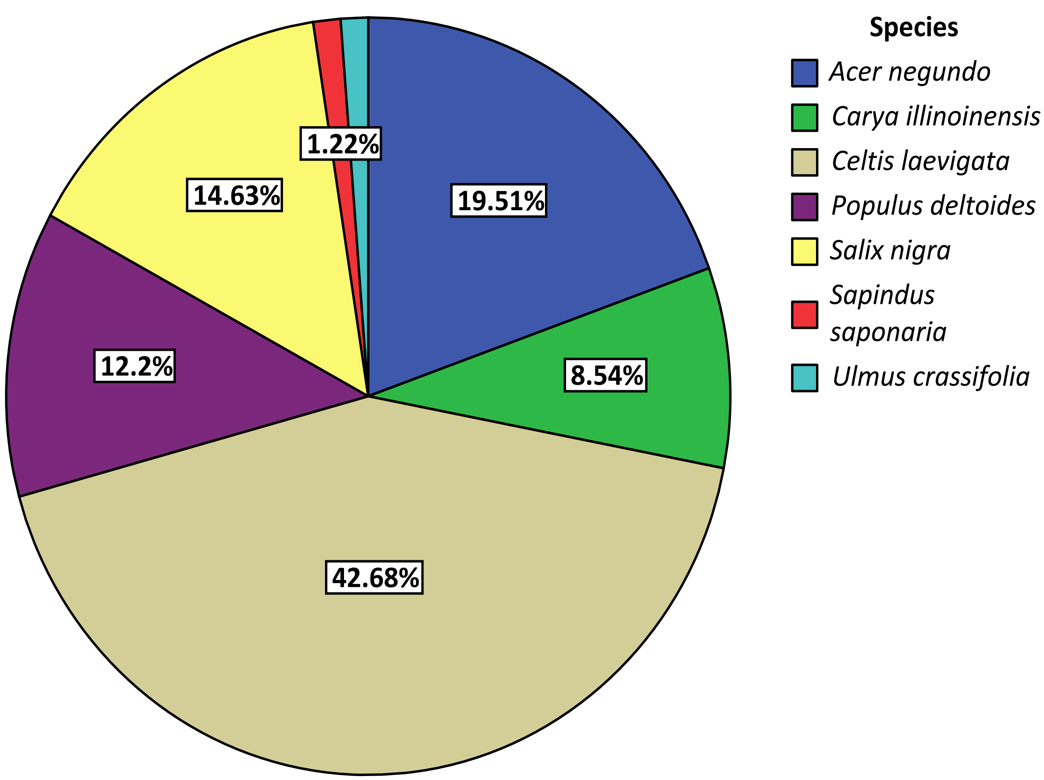


Figure D-4. Calaveras Tree Species Composition

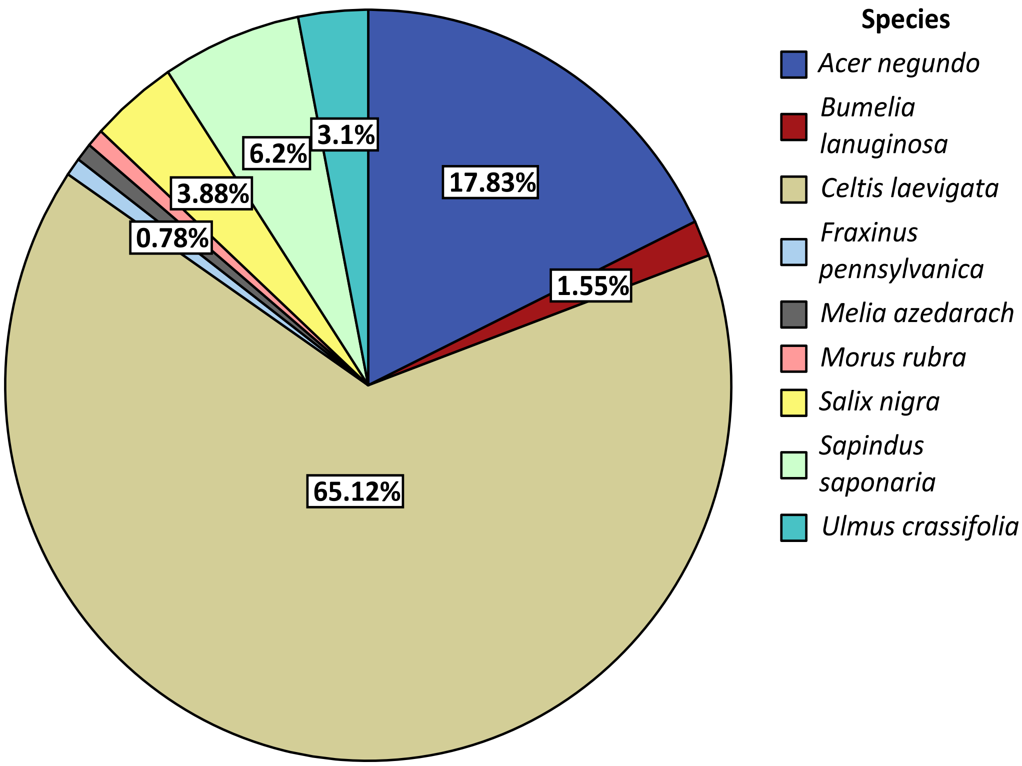


Figure D-5. Calaveras Sapling Species Composition

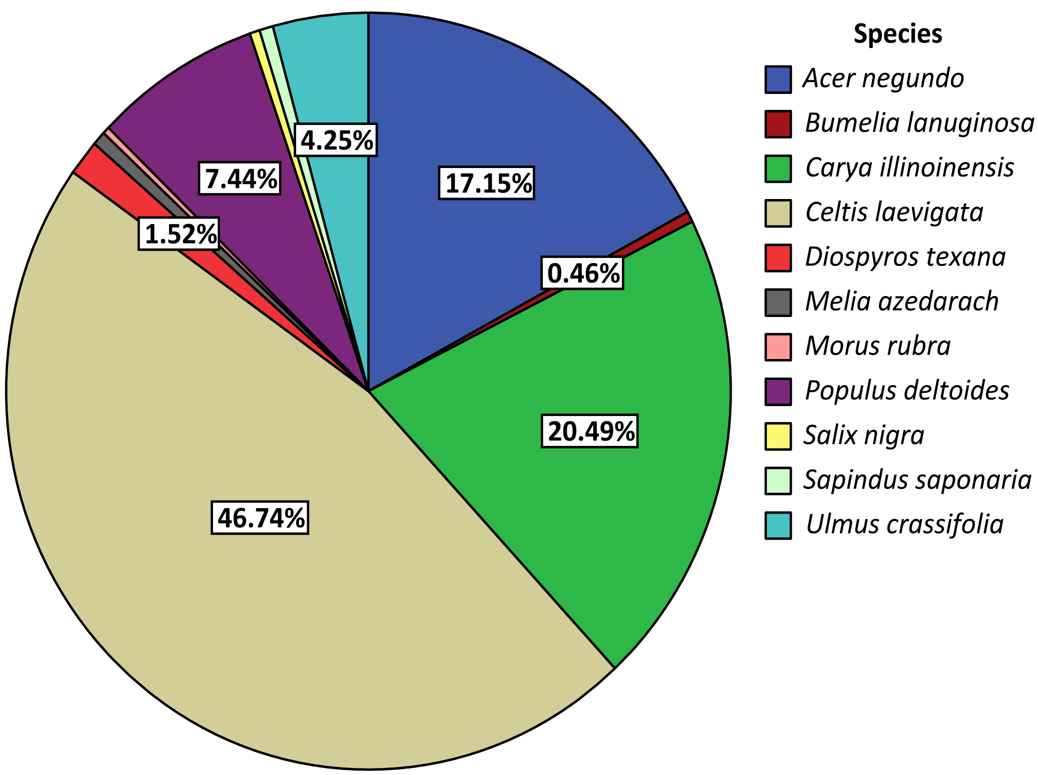


Figure D-6. Calaveras Seedling Species Composition

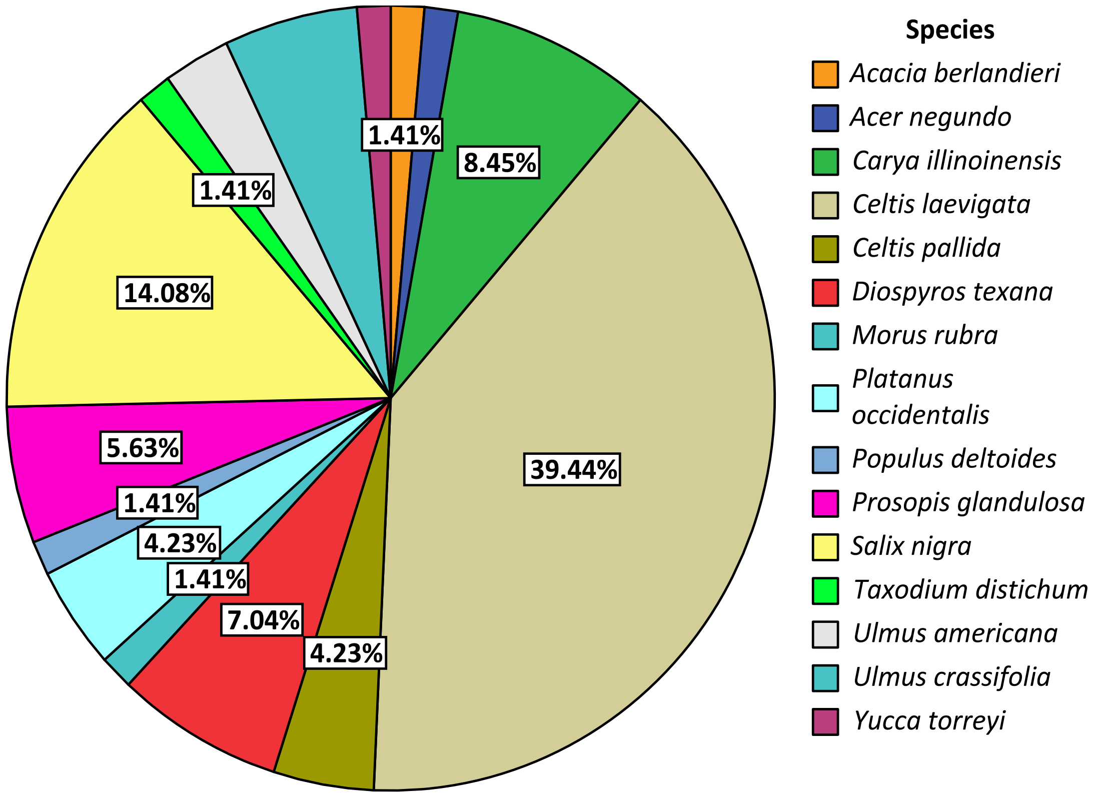


Figure D-7. Falls City Tree Species Composition

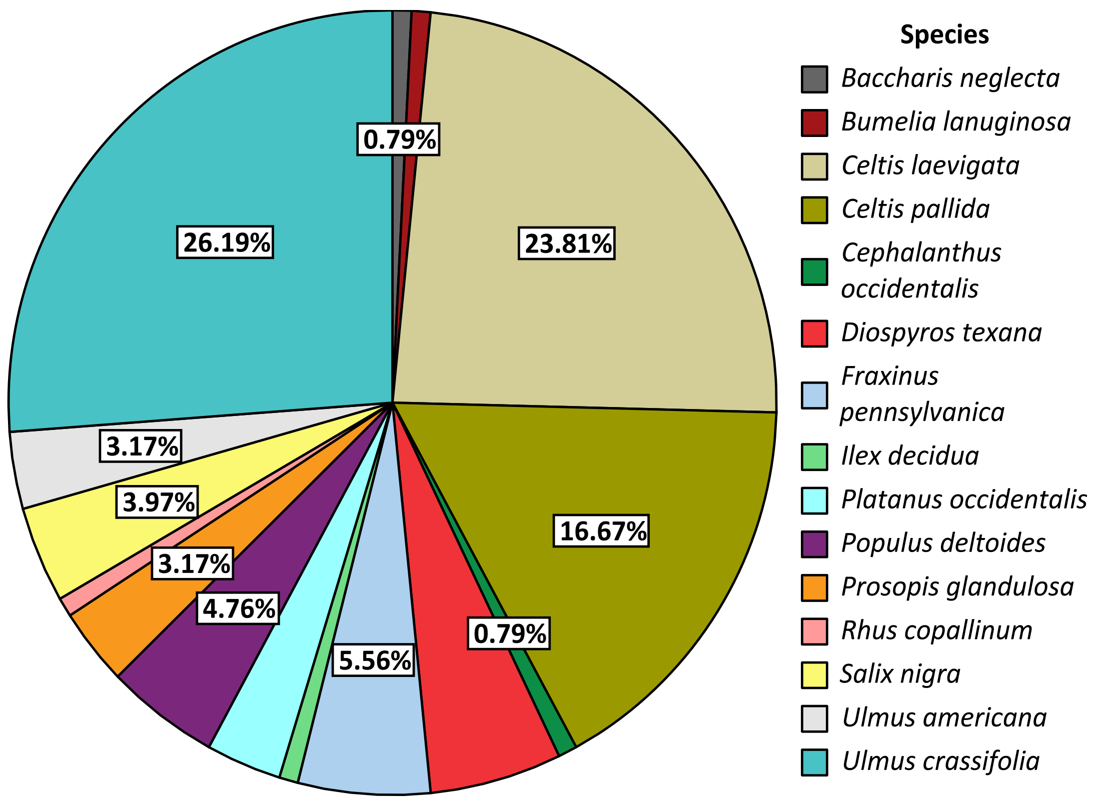


Figure D-8. Falls City Sapling Species Composition

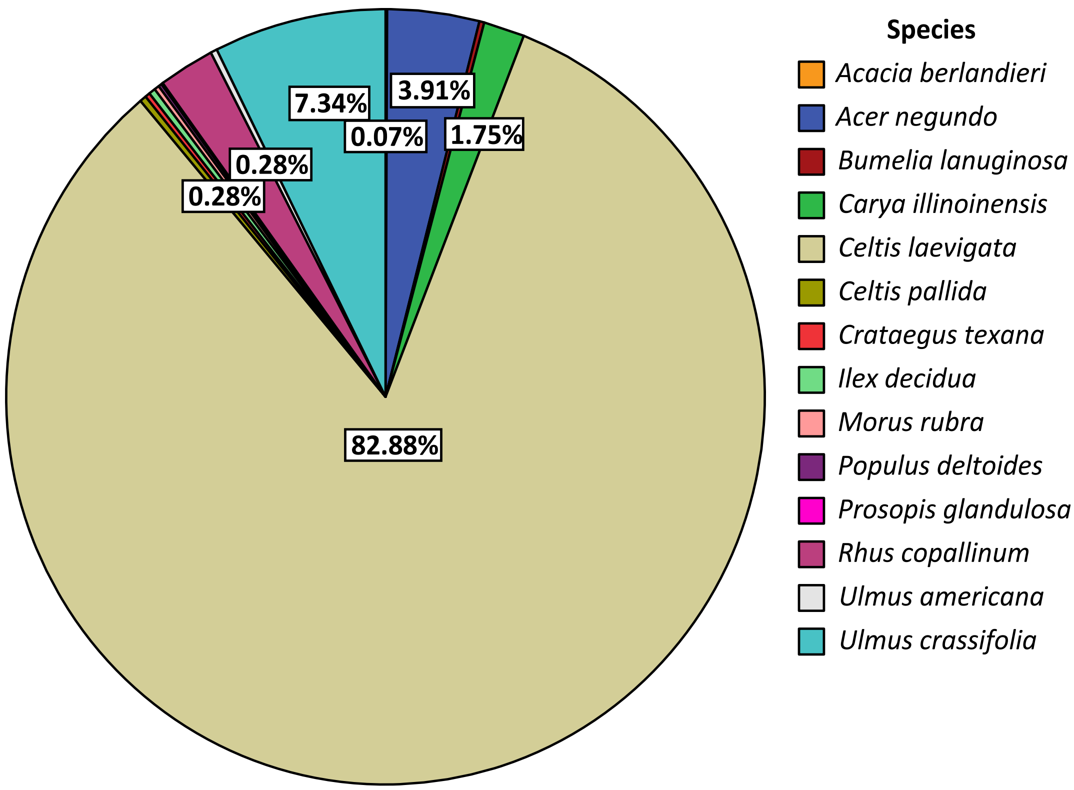


Figure D-9. Falls City Seedling Species Composition

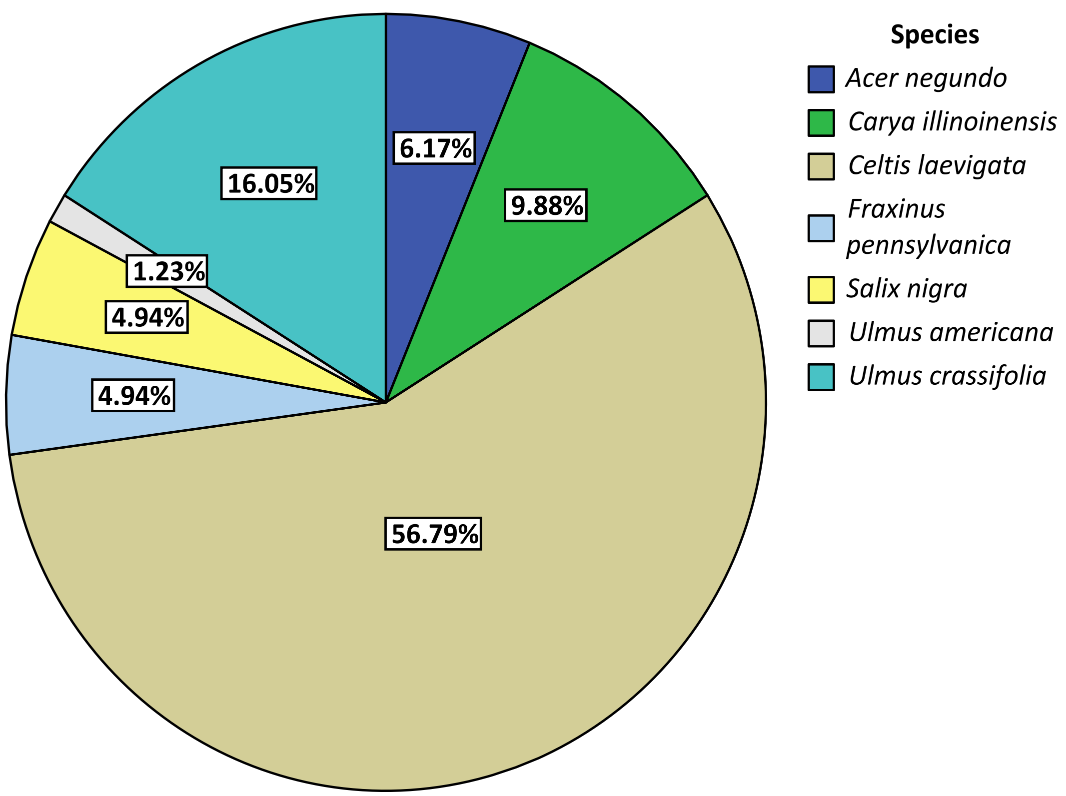


Figure D-10. Goliad Tree Species Composition

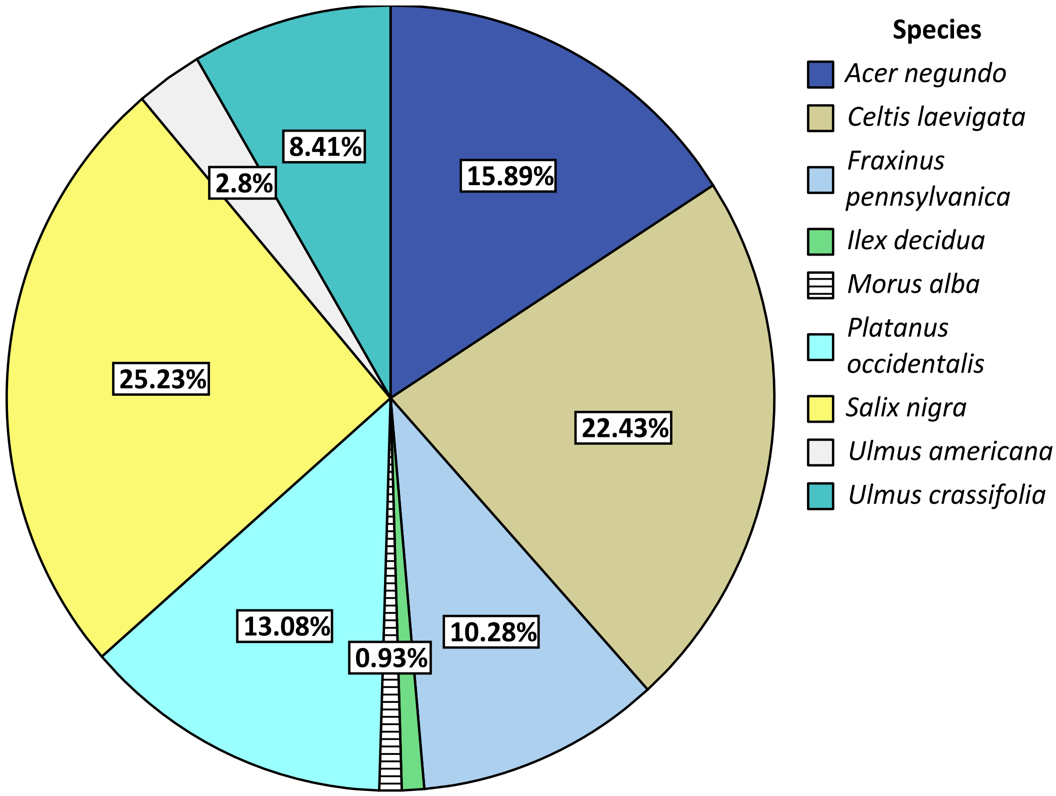


Figure D-11. Goliad Sapling Species Composition

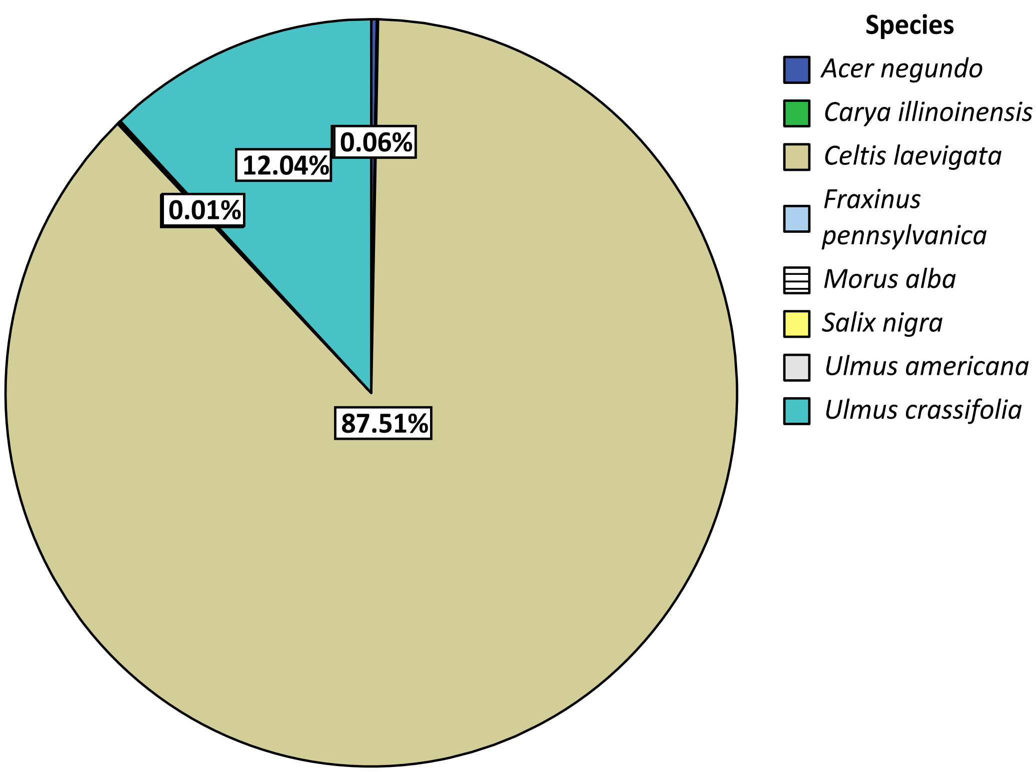


Figure D-12. Goliad Seedling Species Composition

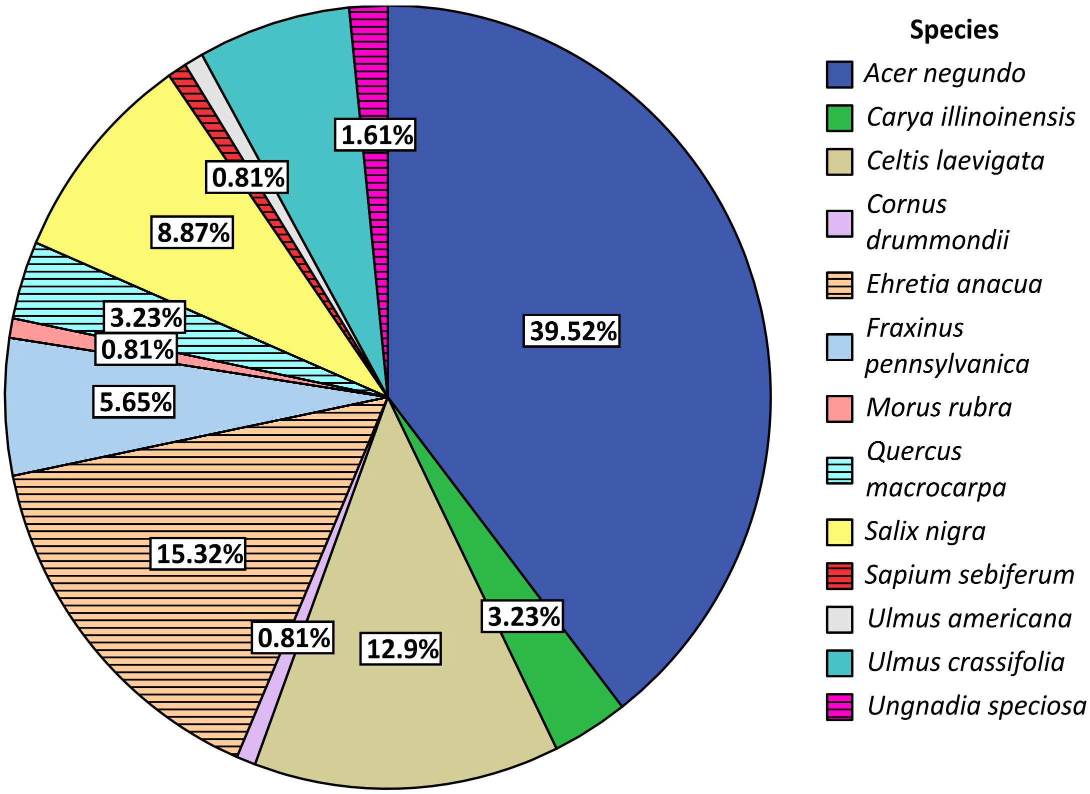


Figure D-13. Highway 77 Tree Species Composition

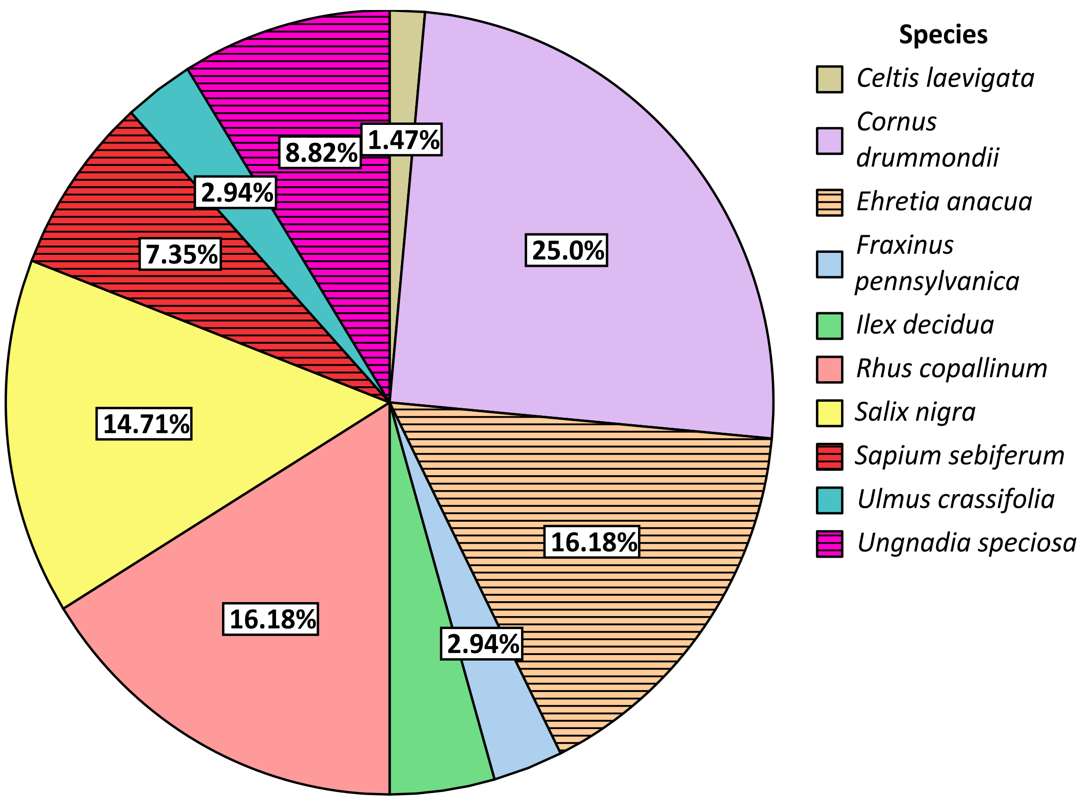


Figure D-14. Highway 77 Sapling Species Composition

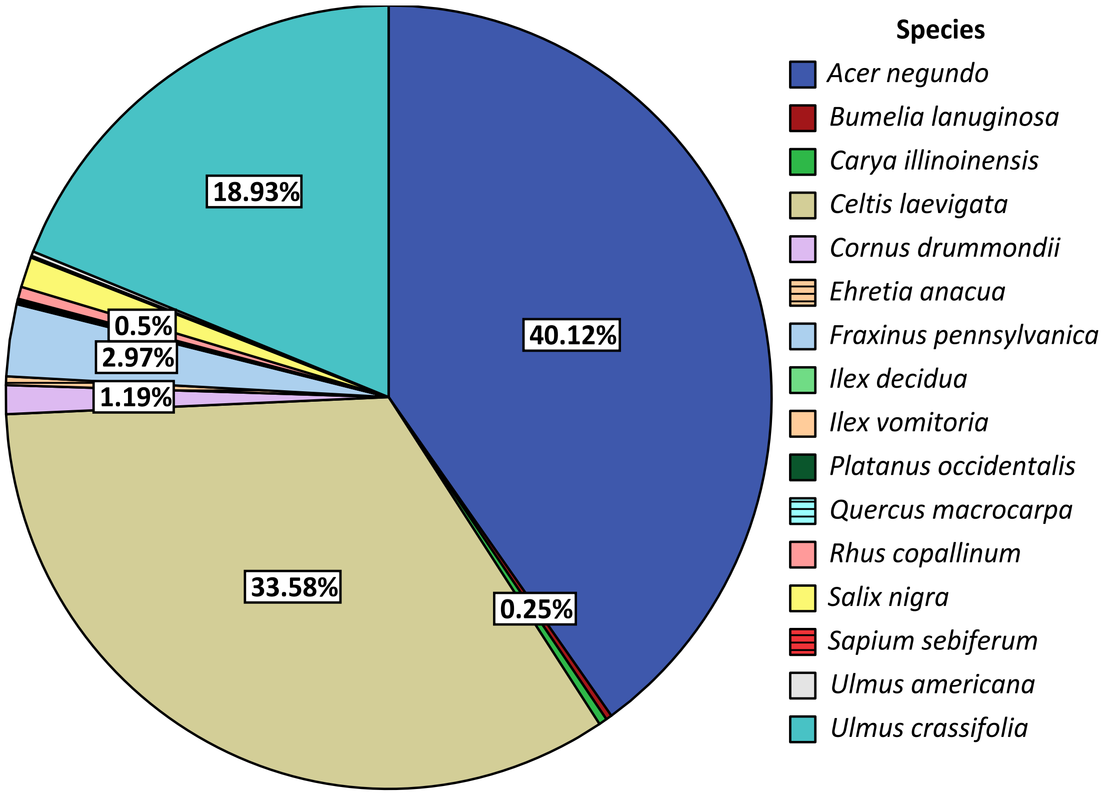


Figure D-15. Highway 77 Seedling Species Composition

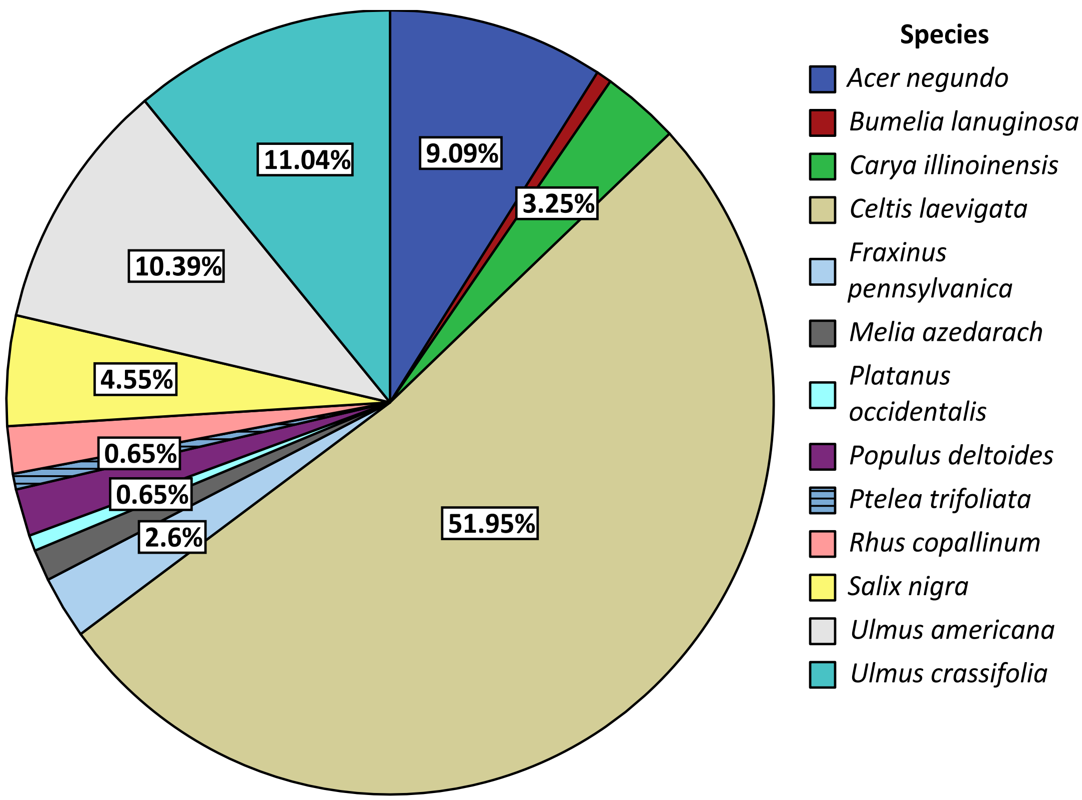


Figure D-16. Cibolo Creek Tree Species Composition

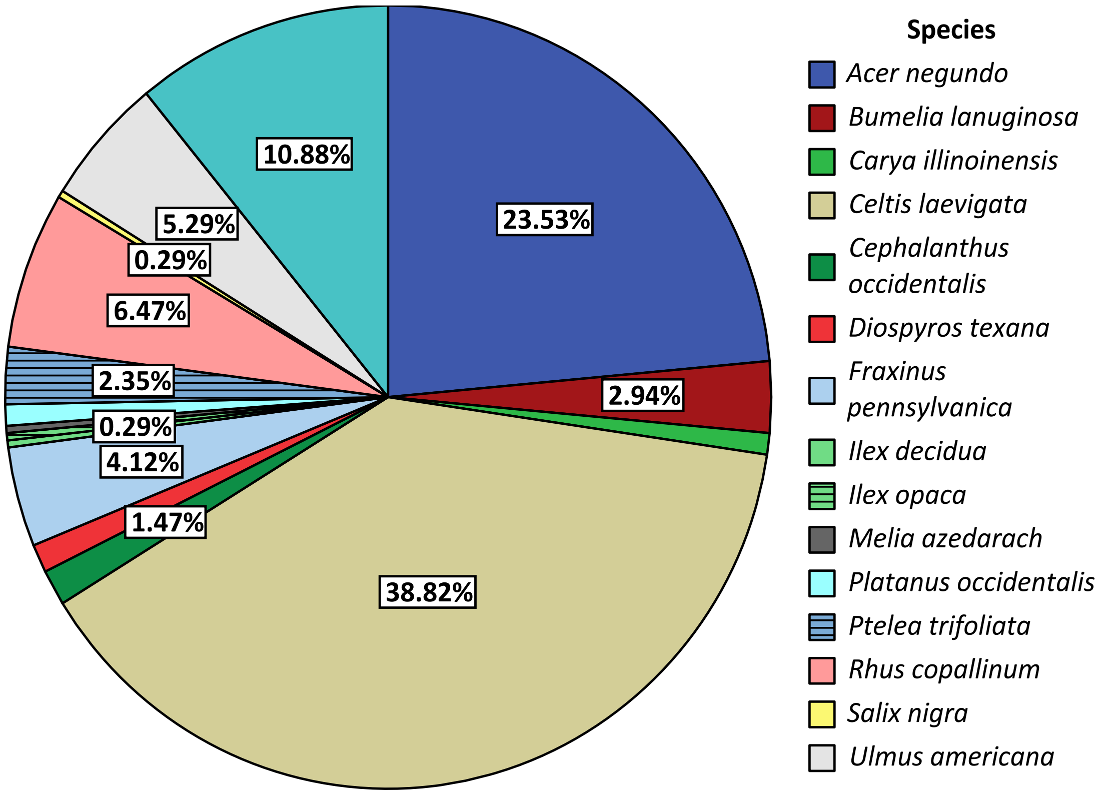


Figure D-17. Cibolo Creek Sapling Species Composition

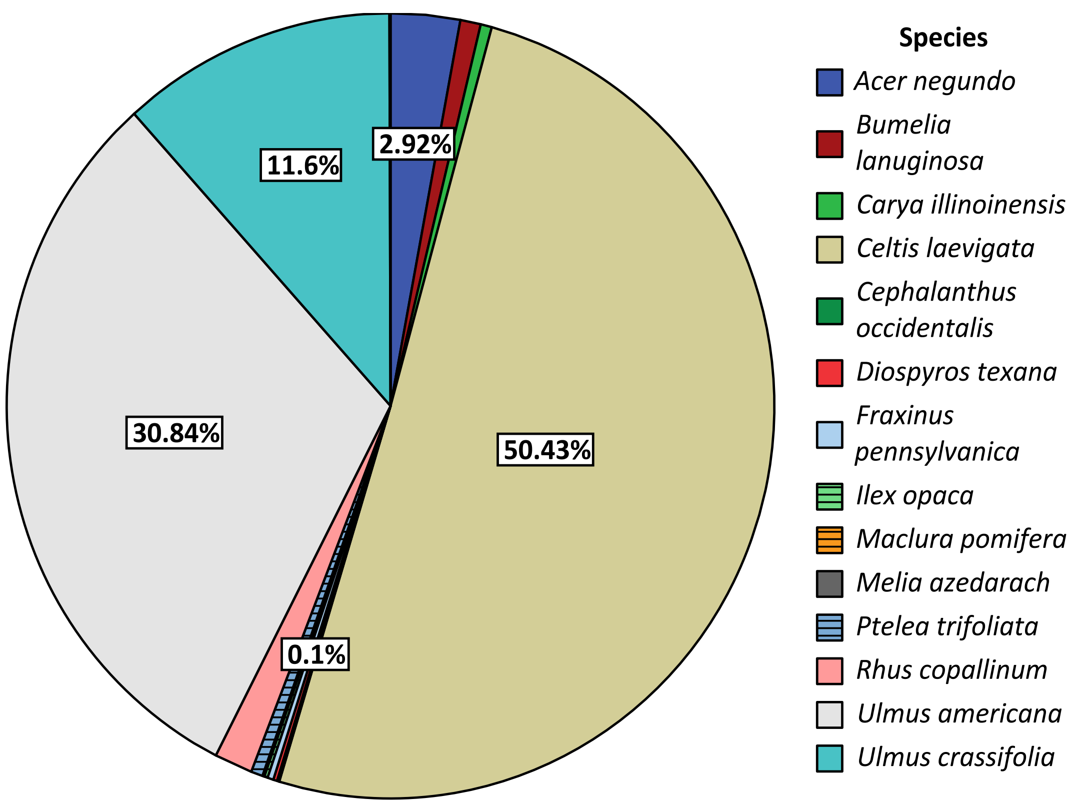


Figure D-18. Cibolo Creek Seedling Species Composition

APPENDIX E
RIPARIAN TRANSECT DATA

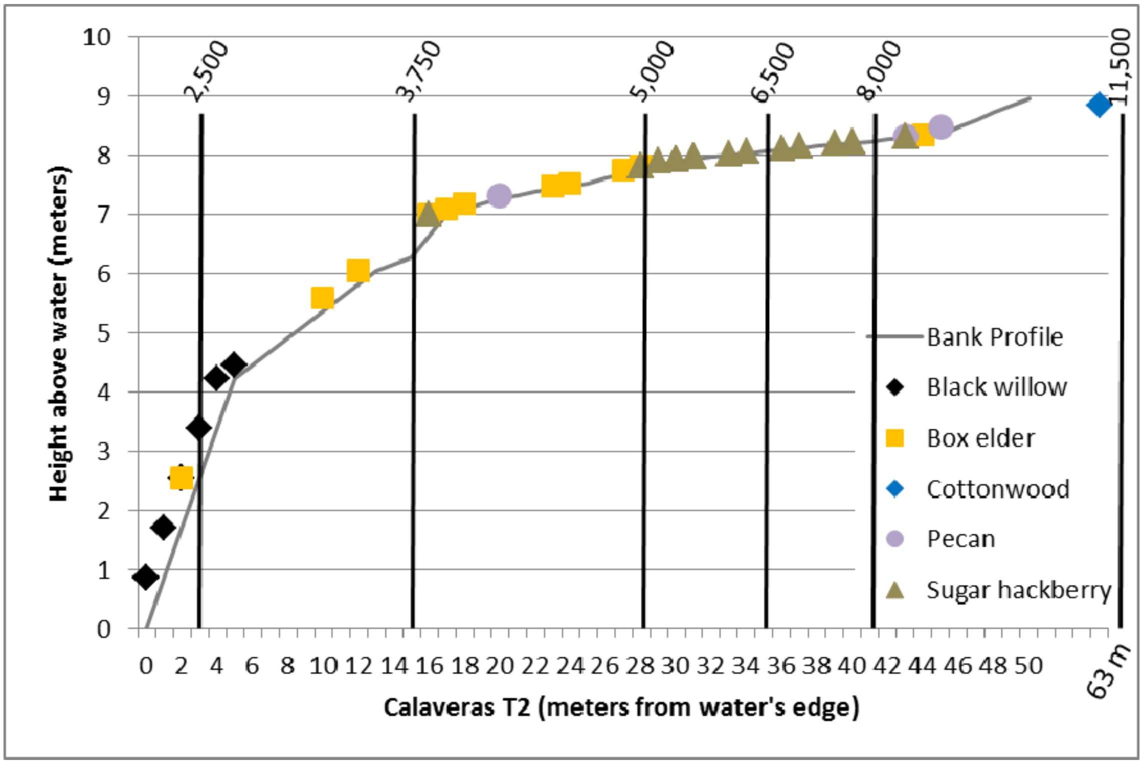


Figure E-1. Tree data from Calaveras site along Transect 2.

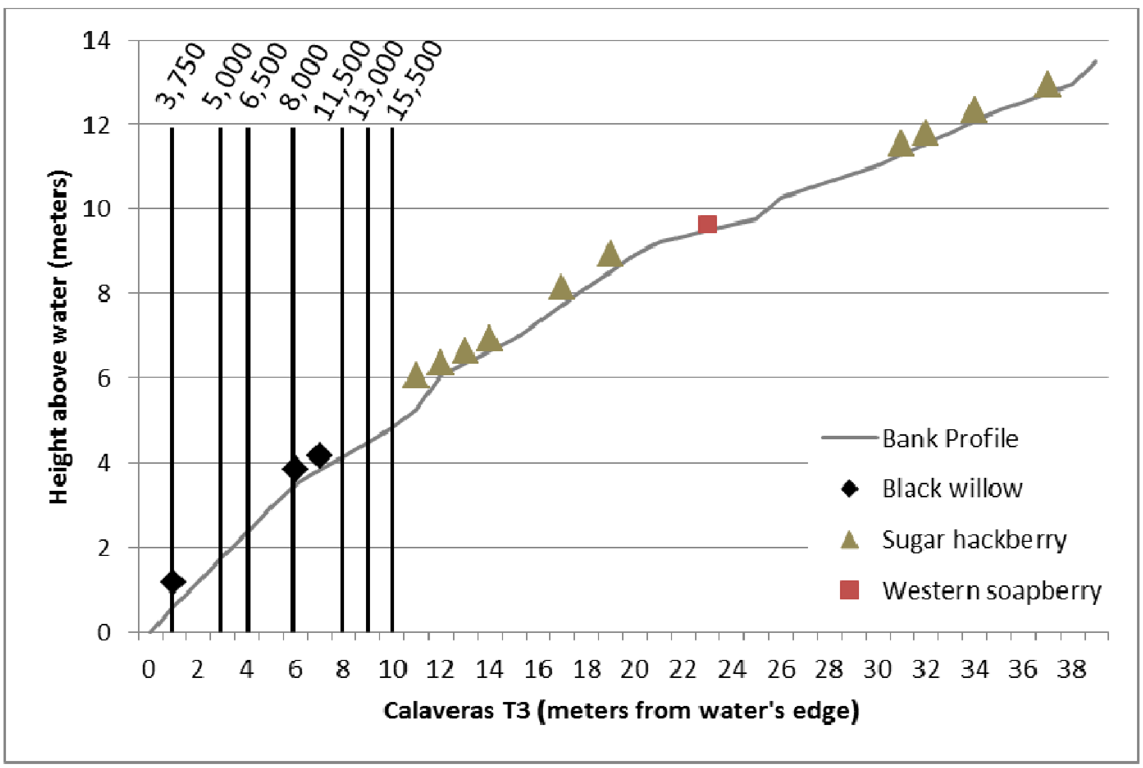


Figure E-2. Tree data from Calaveras site along Transect 3.

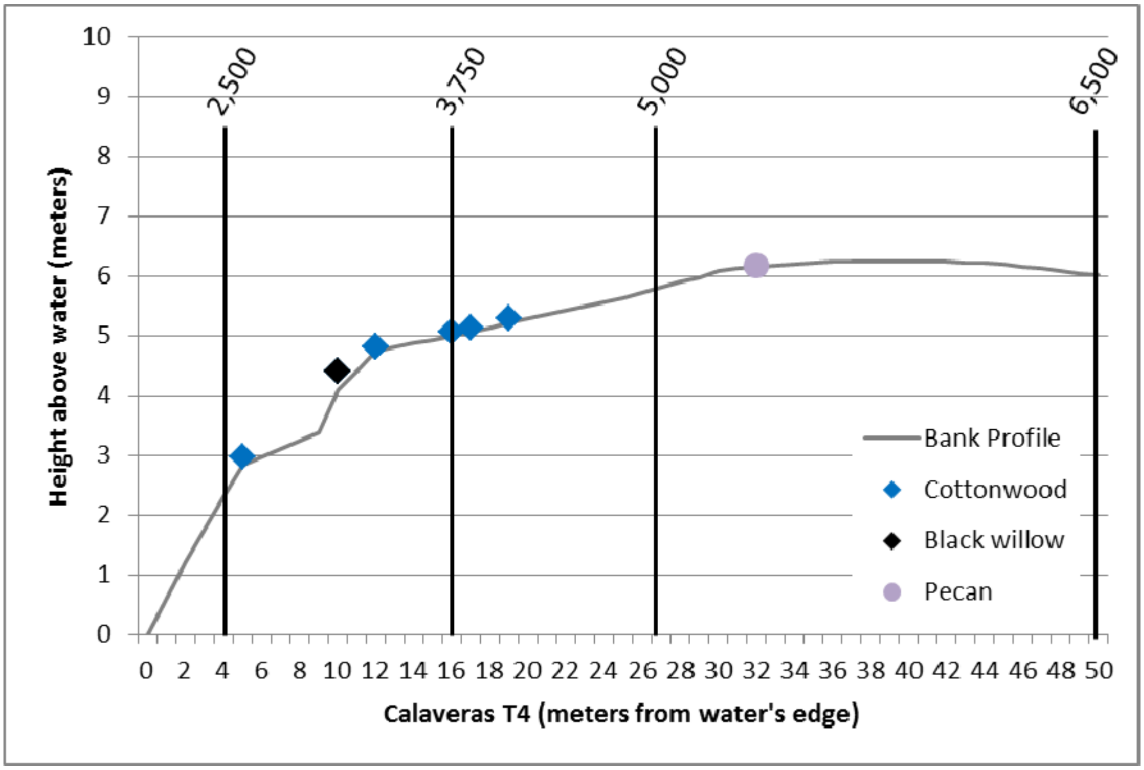


Figure E-3. Tree data from Calaveras site along Transect 4.

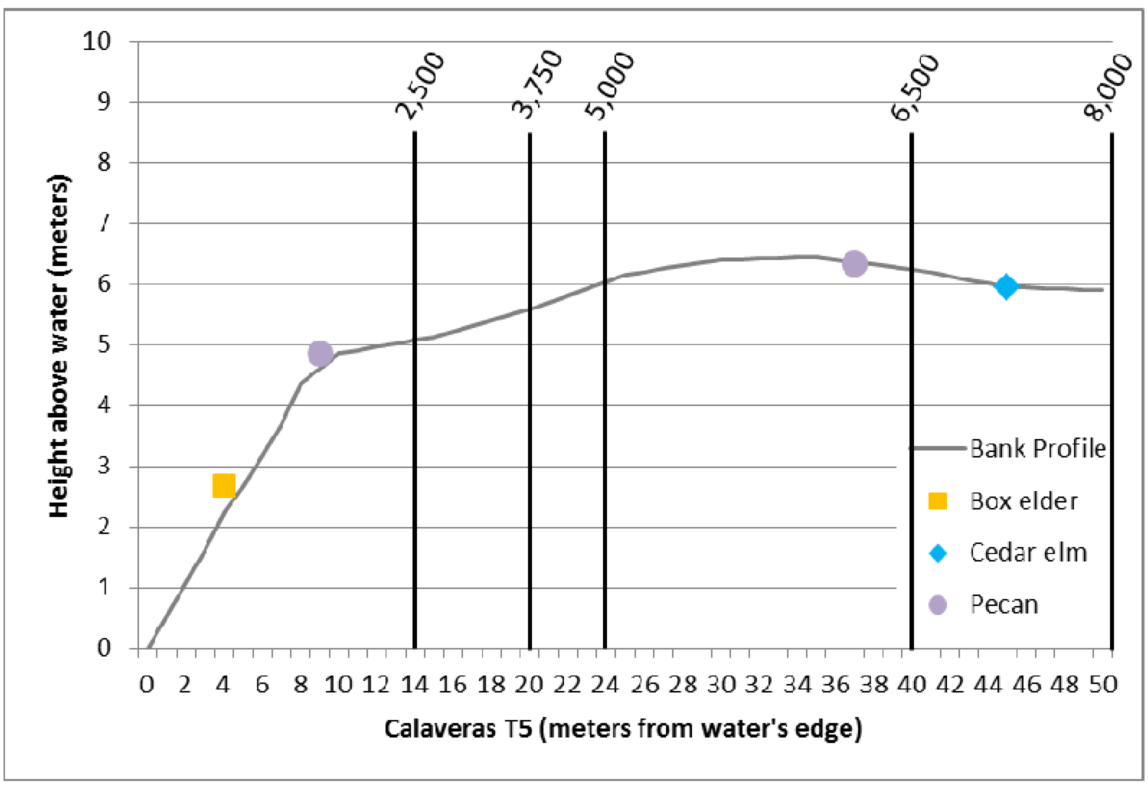


Figure E-4. Tree data from Calaveras site along Transect 5.

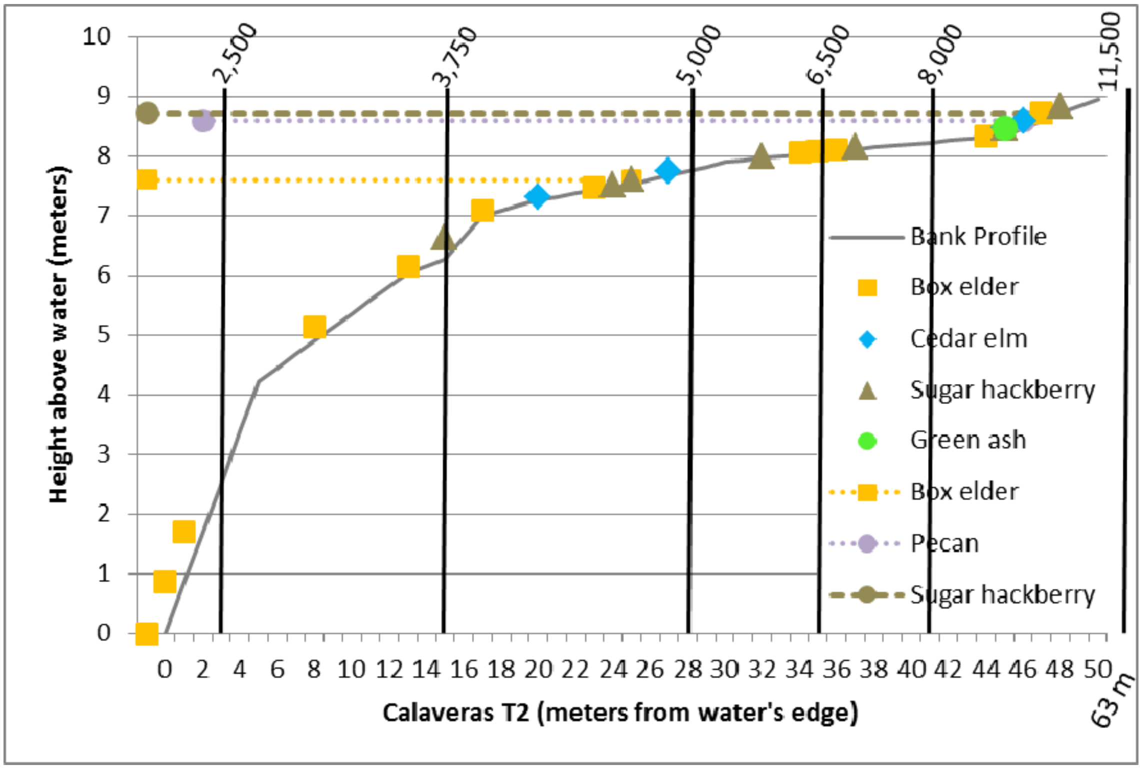


Figure E-5. Sapling (point) and seedling range (line) data from Calaveras site along Transect 2.

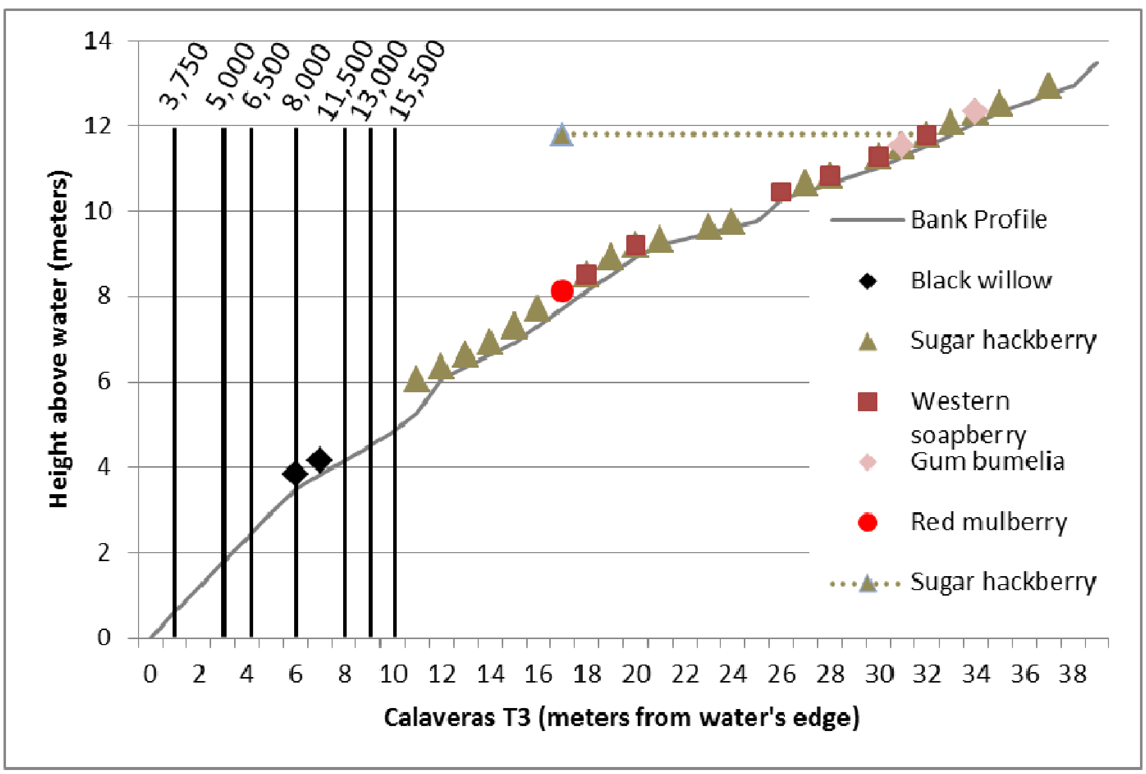


Figure E-6. Sapling (point) and seedling range (line) data from Calaveras site along Transect 3.

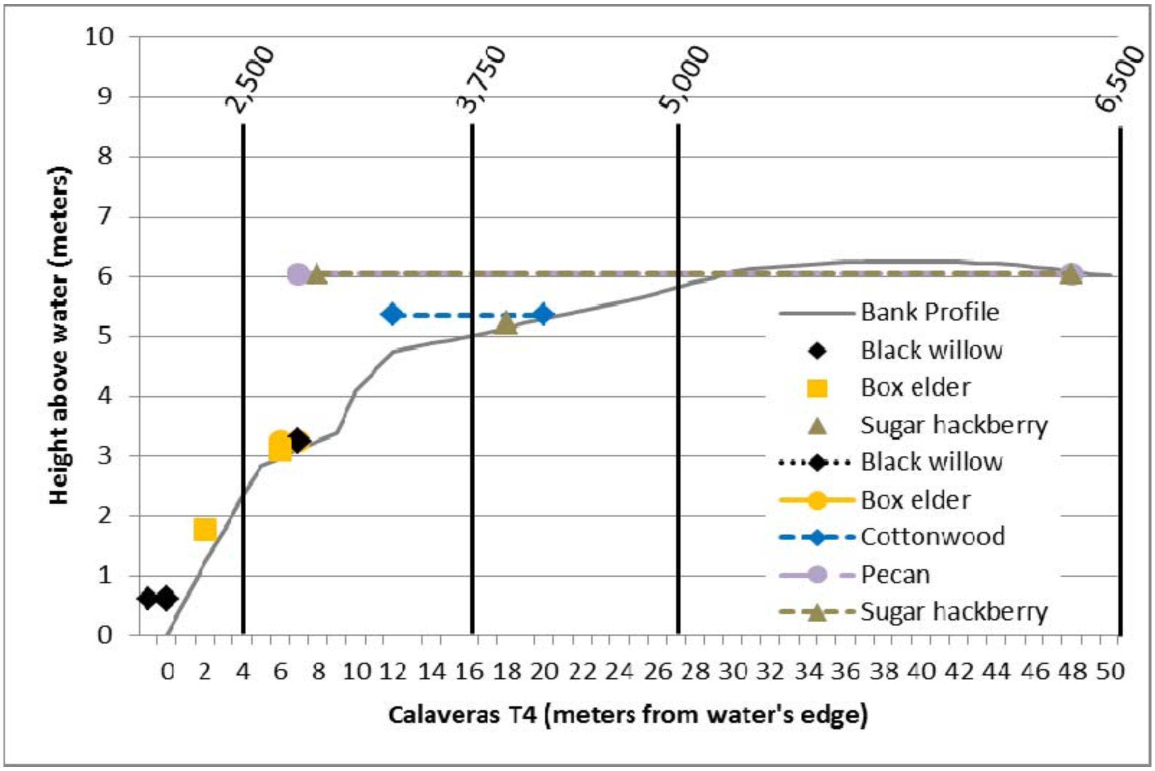


Figure E-7. Sapling (point) and seedling range (line) data from Calaveras site along Transect 4.

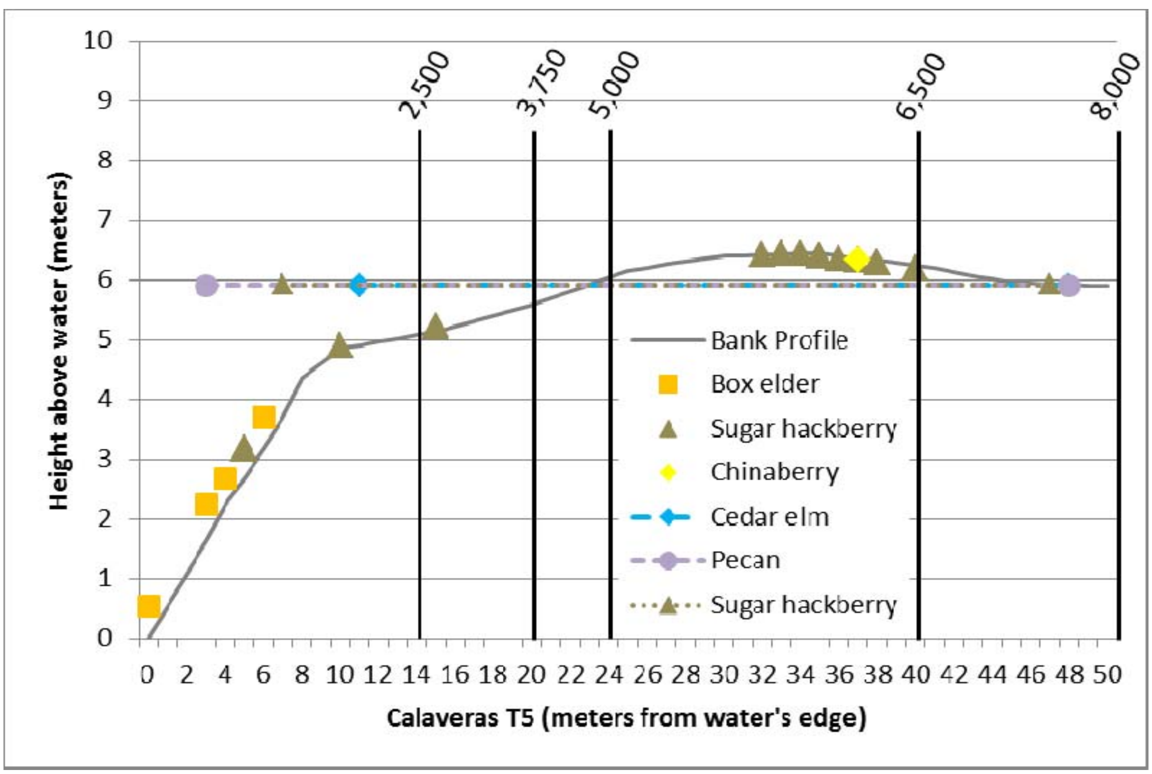


Figure E-8. Sapling (point) and seedling range (line) data from Calaveras site along Transect 5.

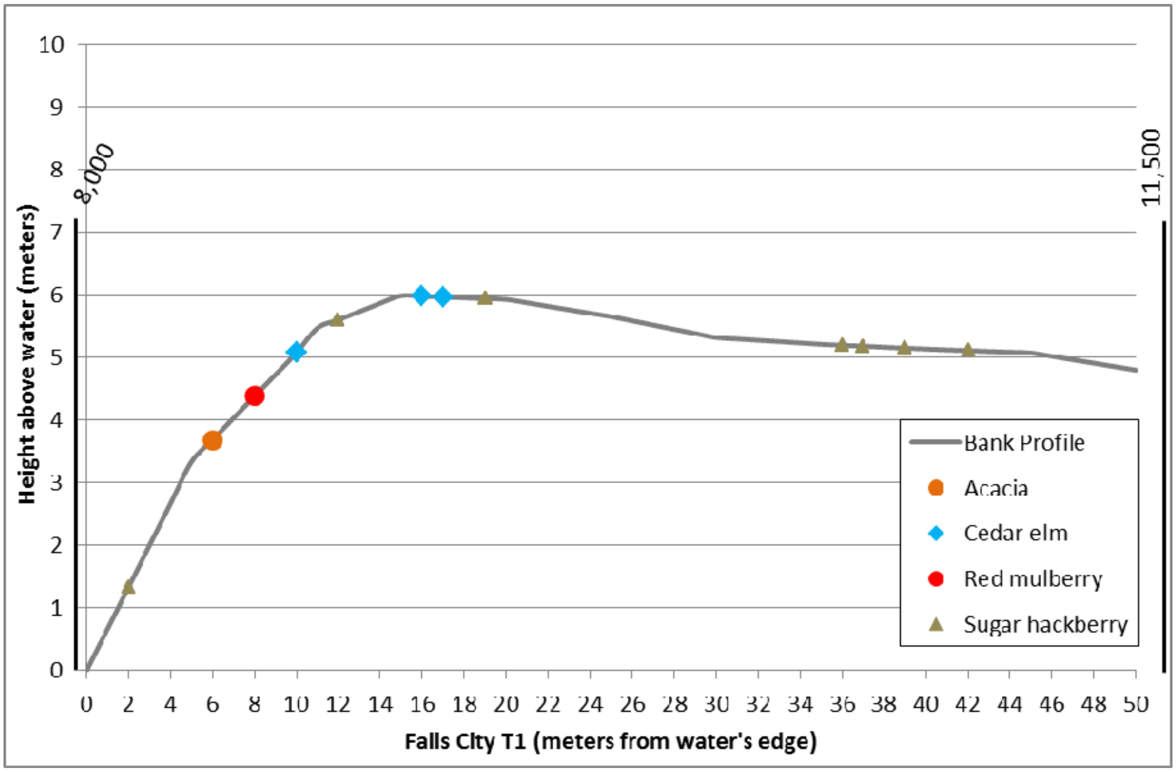


Figure E-9. Tree data from Falls City site along Transect 1.

No Trees observed along Transect 2 at Falls City site.

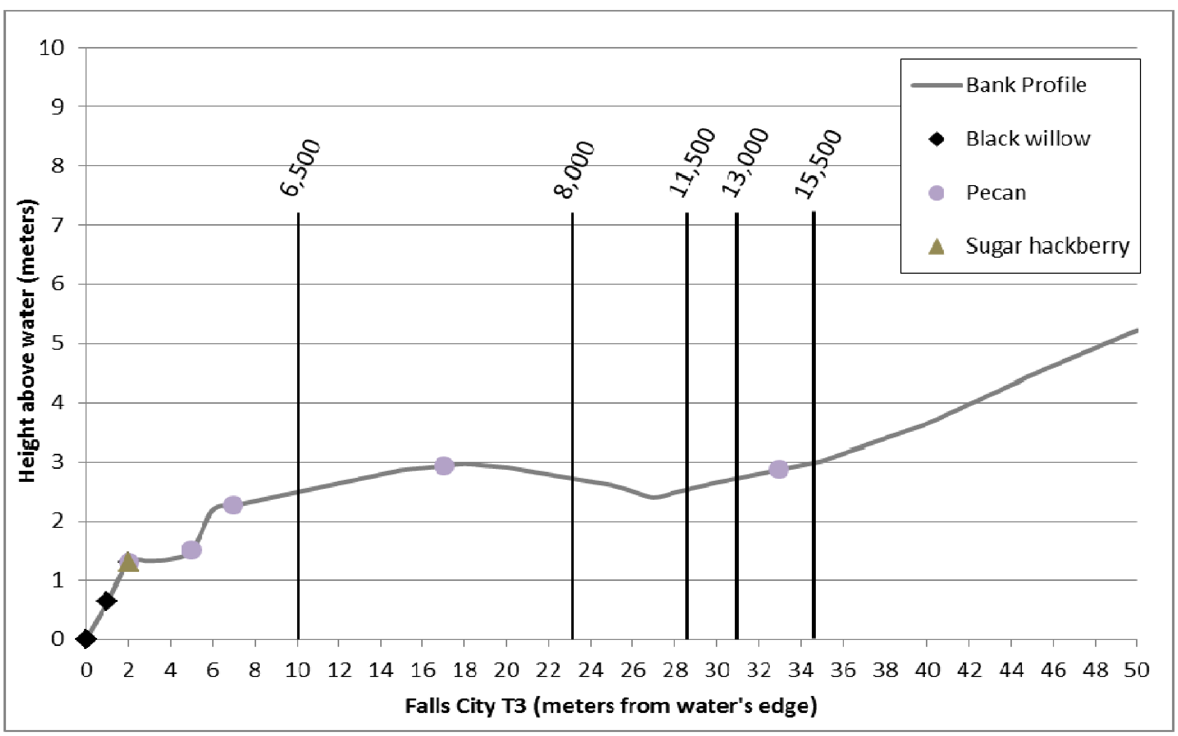


Figure E-10. Tree data from Falls City site along Transect 3.

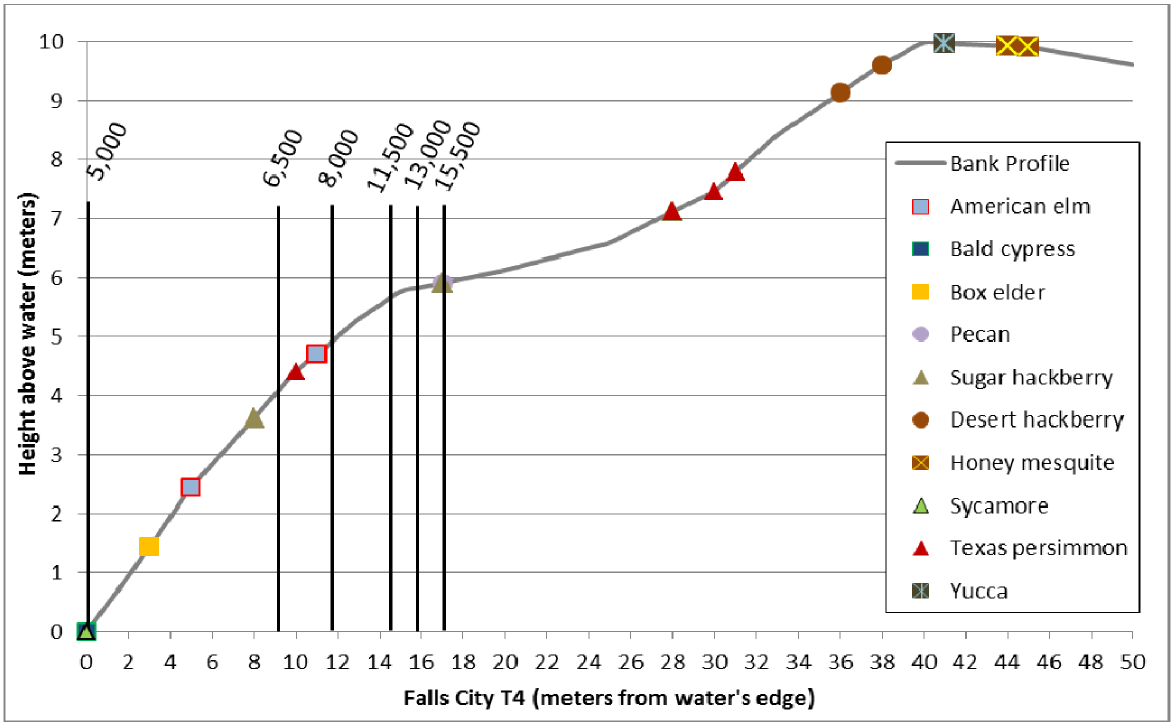


Figure E-11. Tree data from Falls City site along Transect 4.

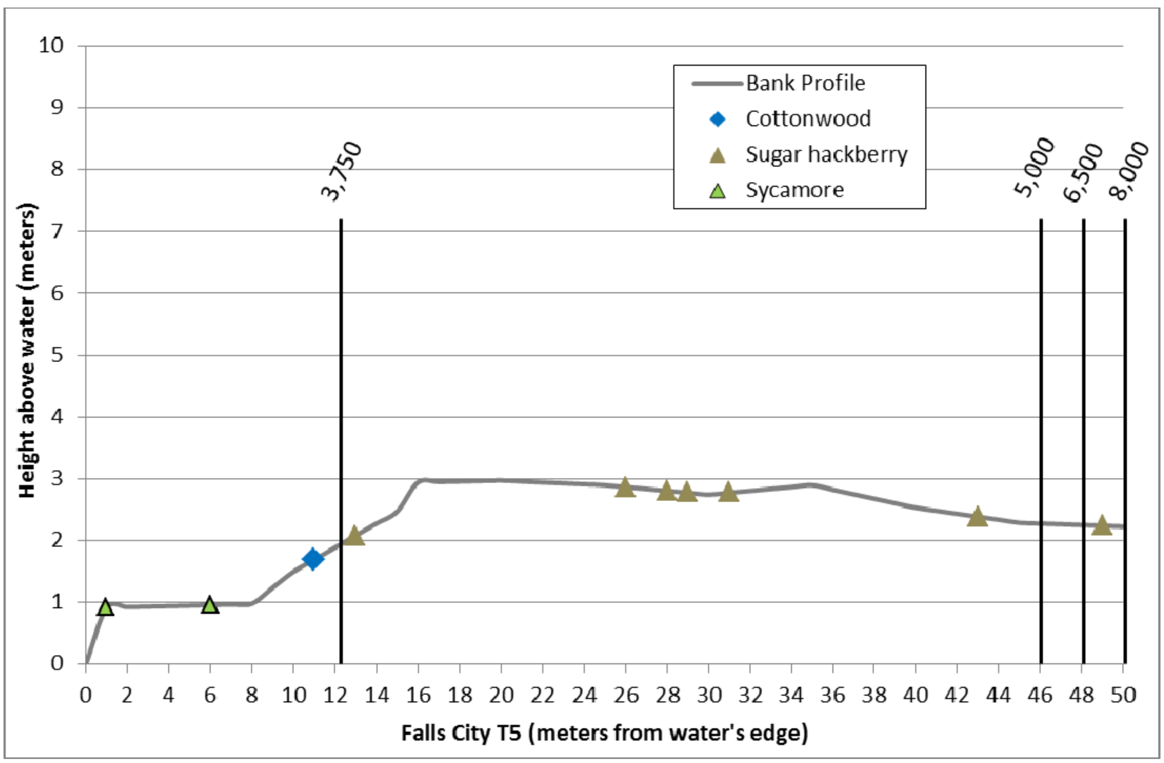


Figure E-12. Tree data from Falls City site along Transect 5.

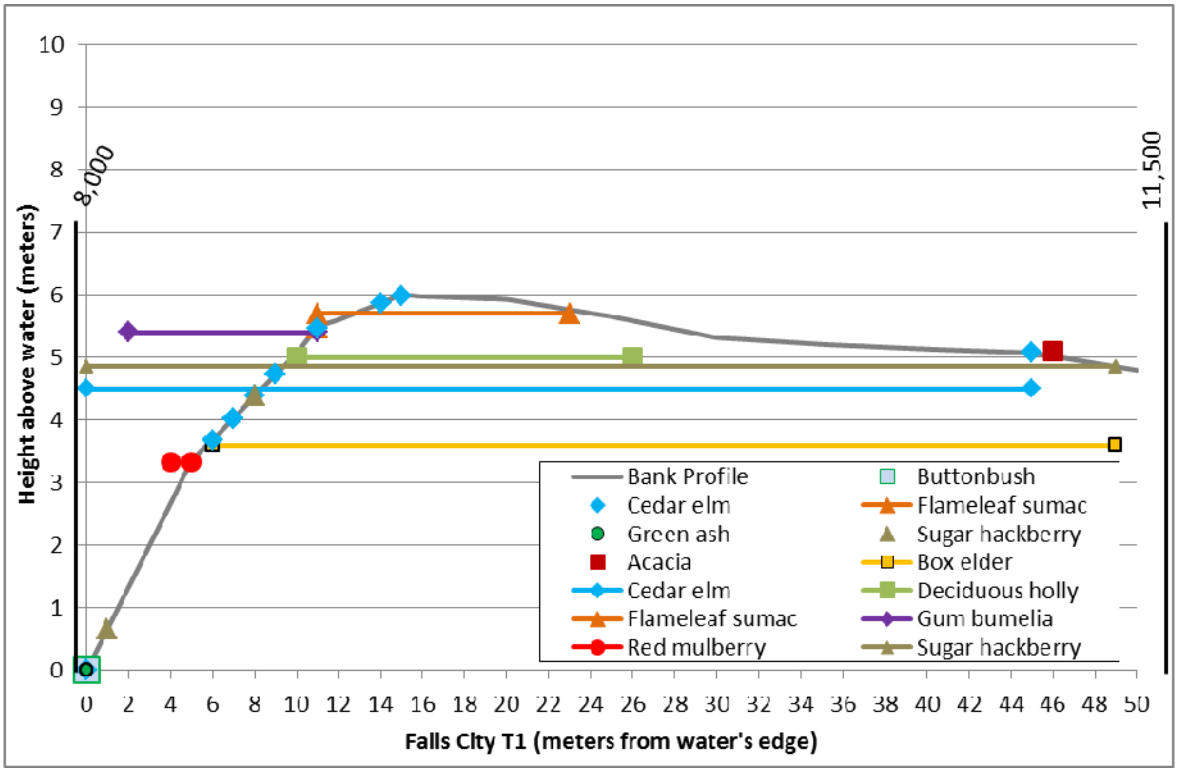


Figure E-13. Sapling (point) and seedling range (line) data from Falls City site along Transect 1.

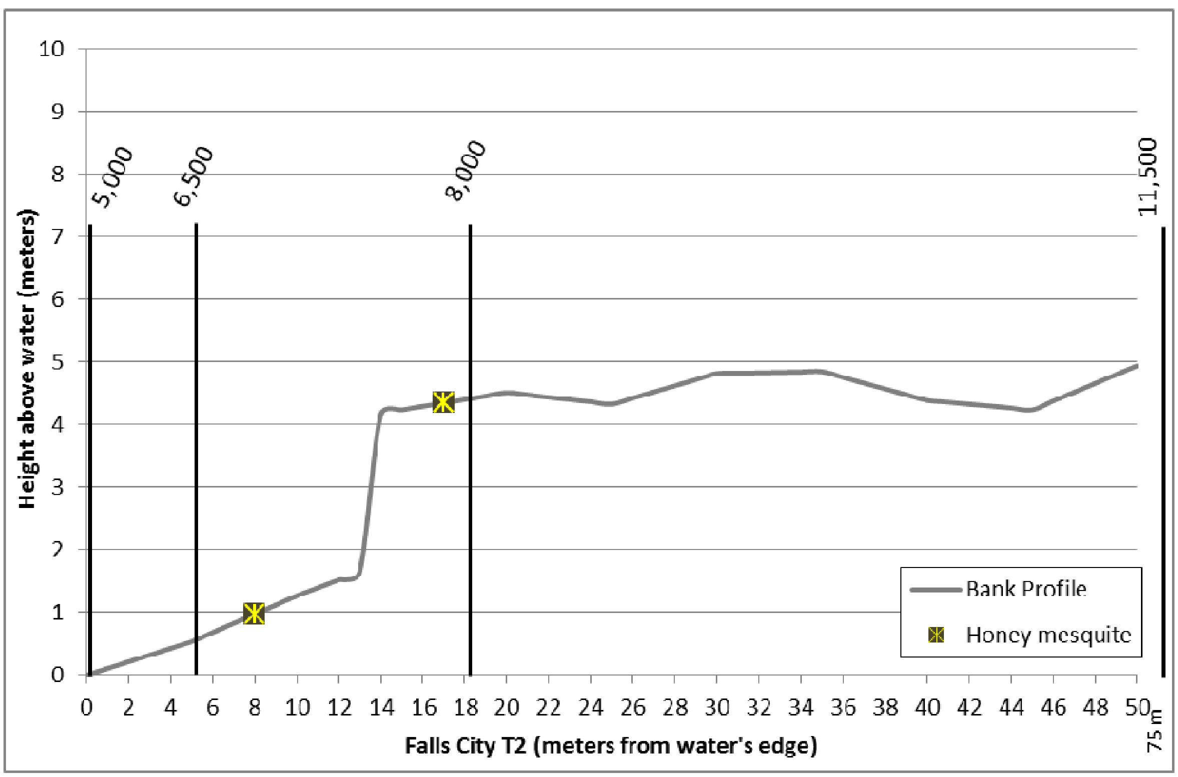


Figure E-14. Sapling (point) and seedling range (line) data from Falls City site along Transect 2.

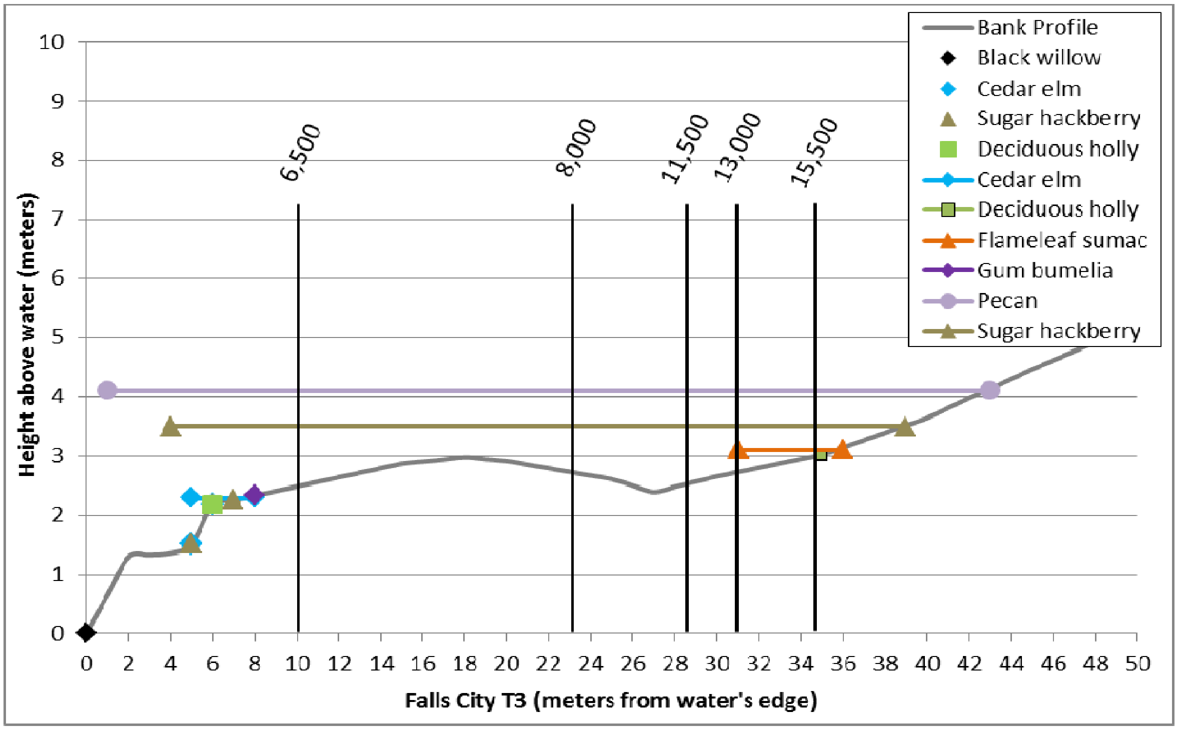


Figure E-15. Sapling (point) and seedling range (line) data from Falls City site along Transect 3.

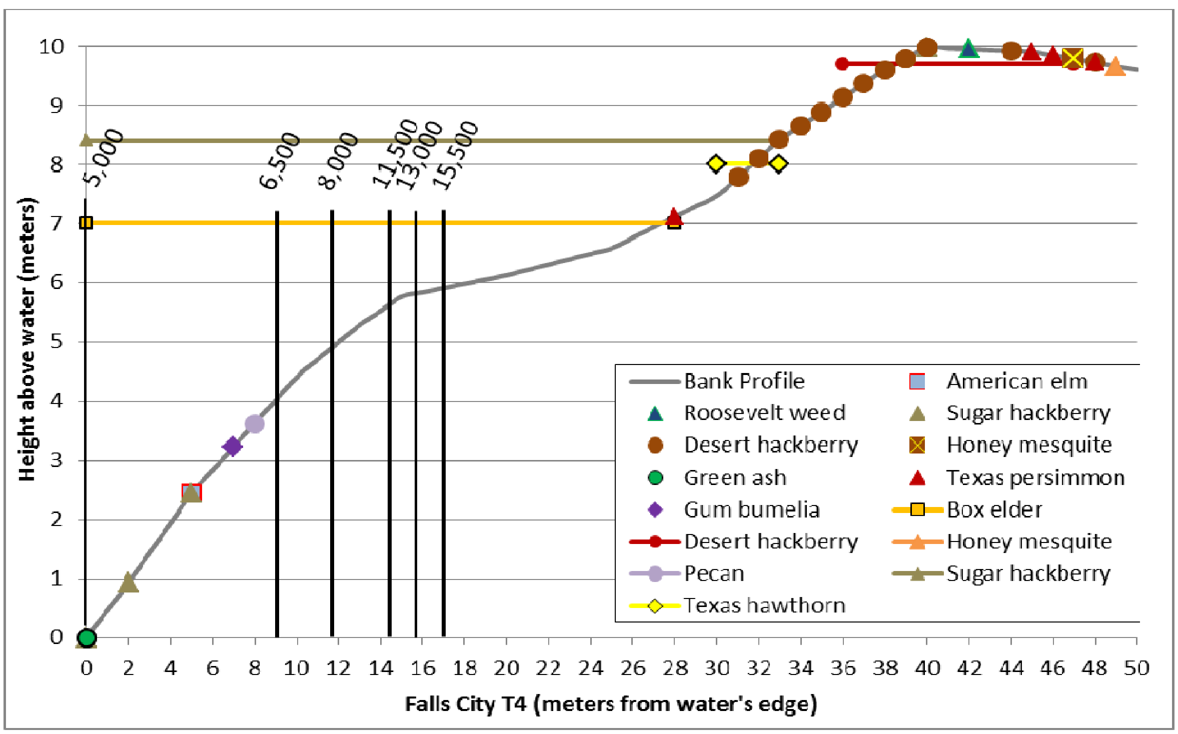


Figure E-16. Sapling (point) and seedling range (line) data from Falls City site along Transect 4.

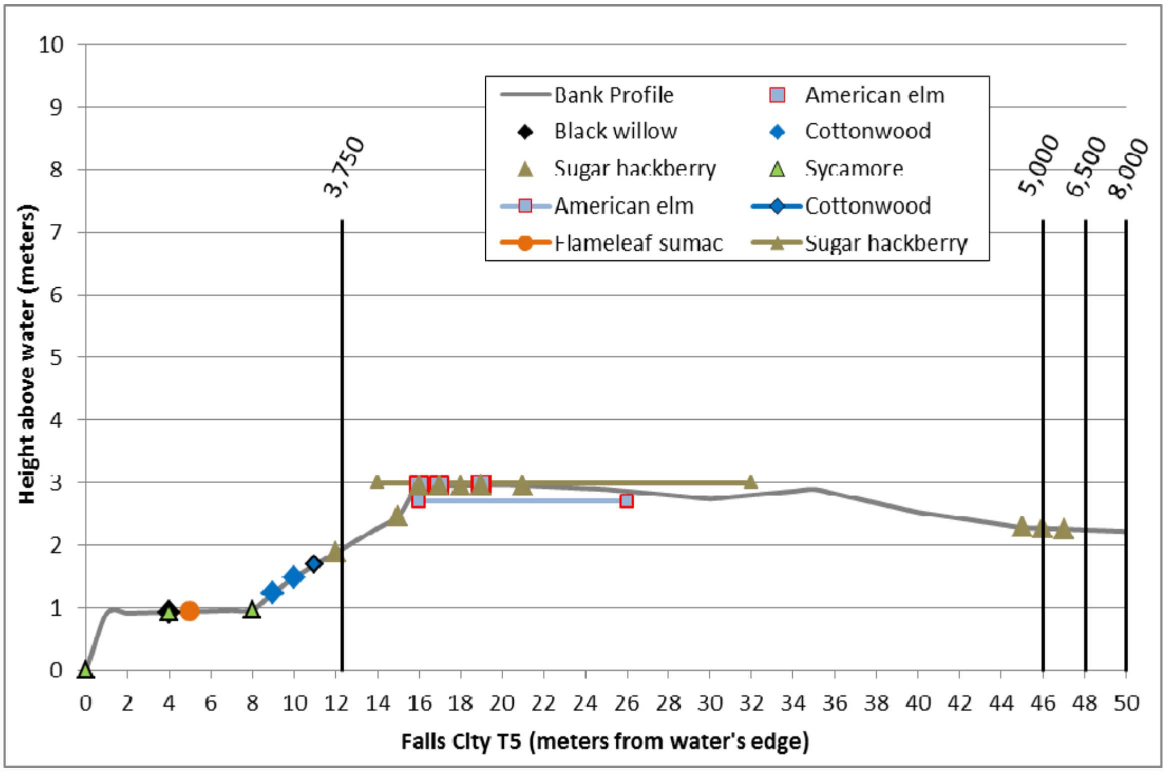


Figure E-17. Sapling (point) and seedling range (line) data from Falls City site along Transect 5.

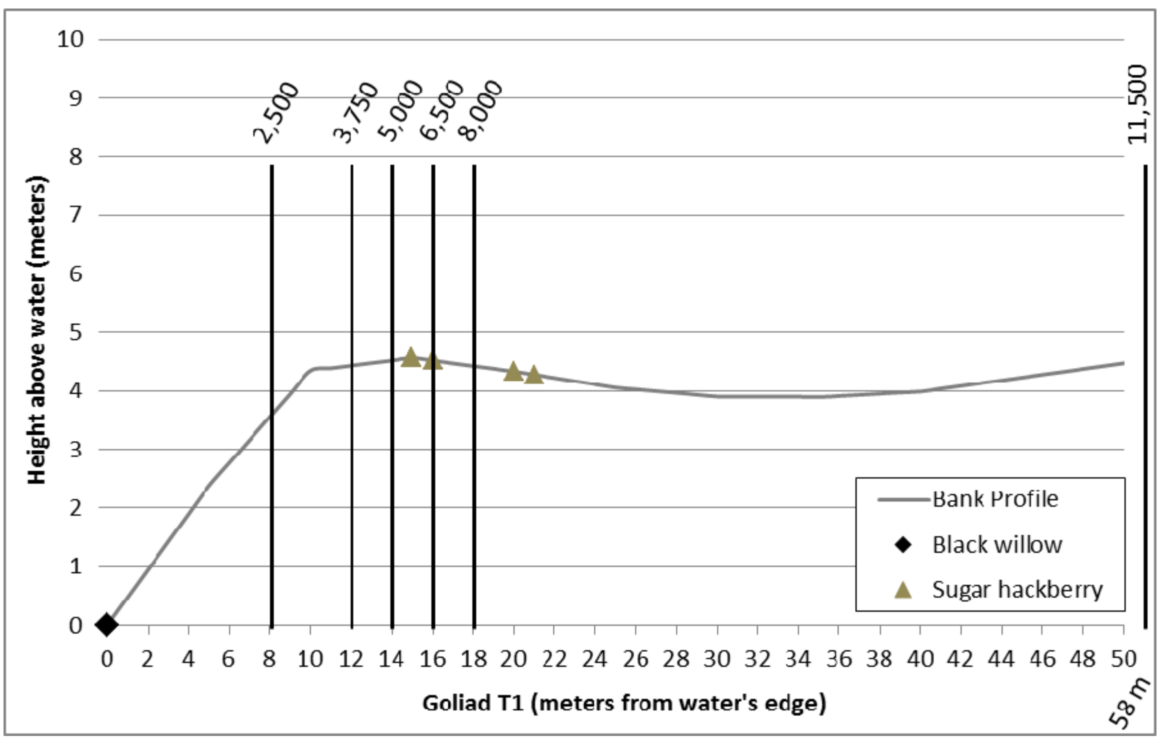


Figure E-18. Tree data from Goliad site along Transect 1.

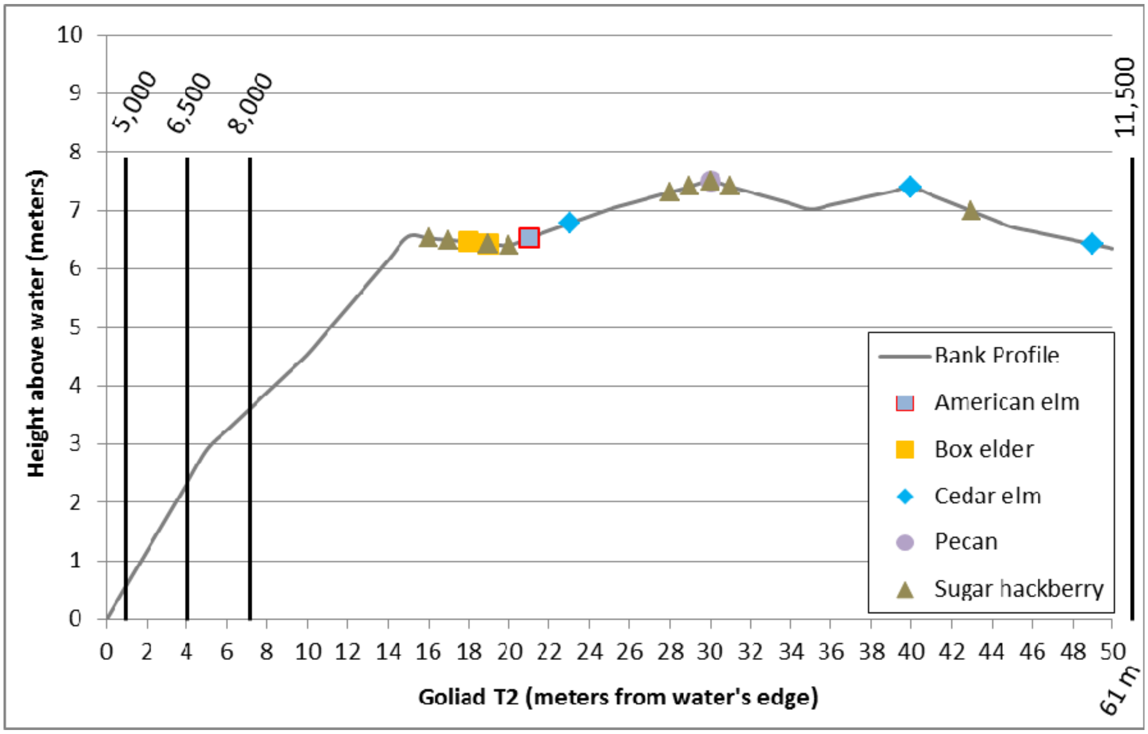


Figure E-19. Tree data from Goliad site along Transect 2.

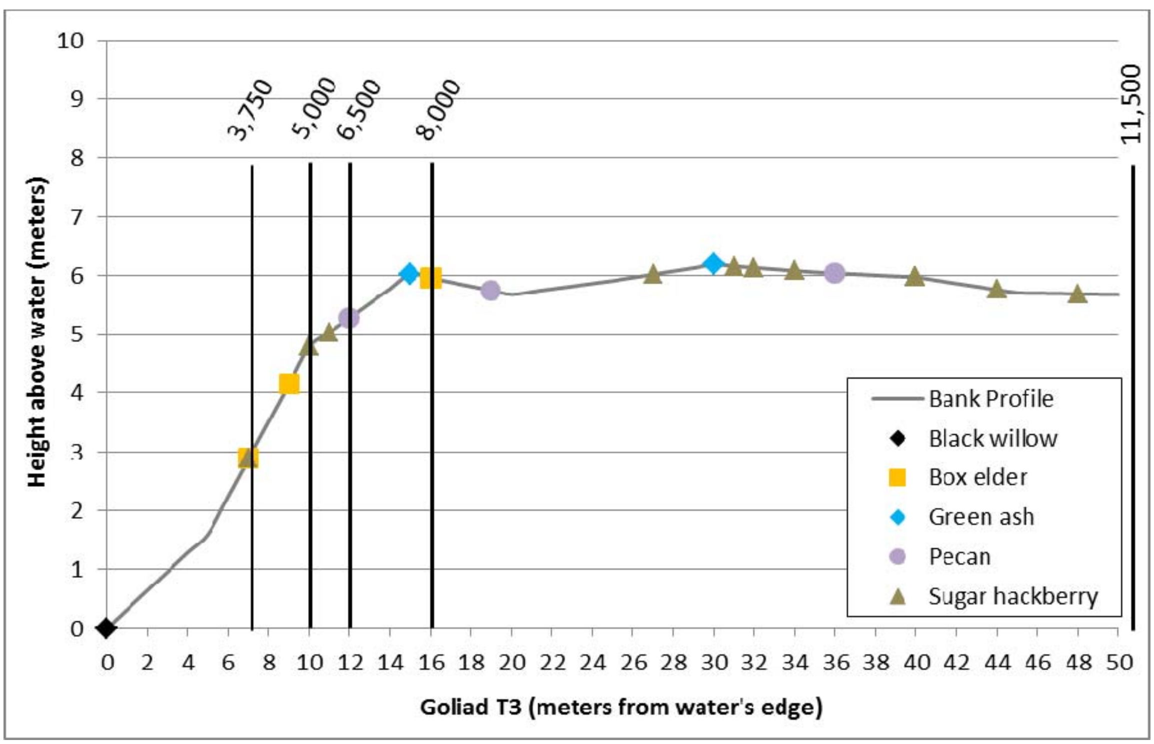


Figure E-20. Tree data from Goliad site along Transect 3.

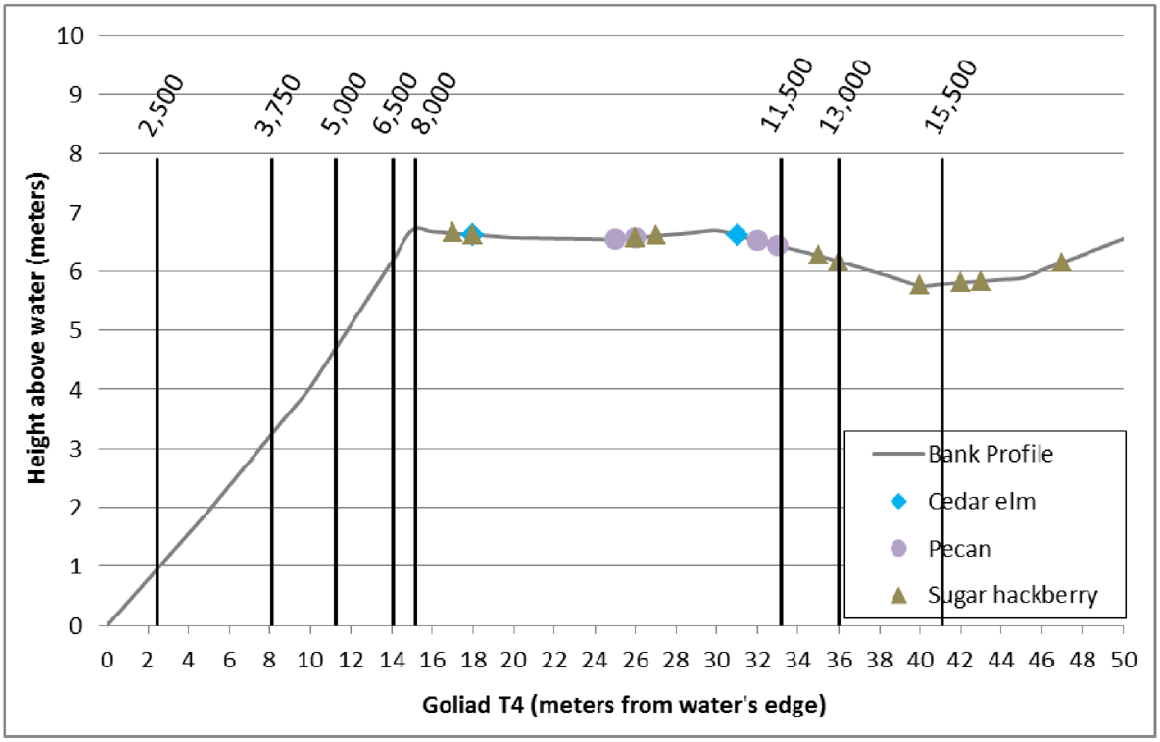


Figure E-21. Tree data from Goliad site along Transect 4.

Bank profile survey for Transect 5 from Goliad site not available.

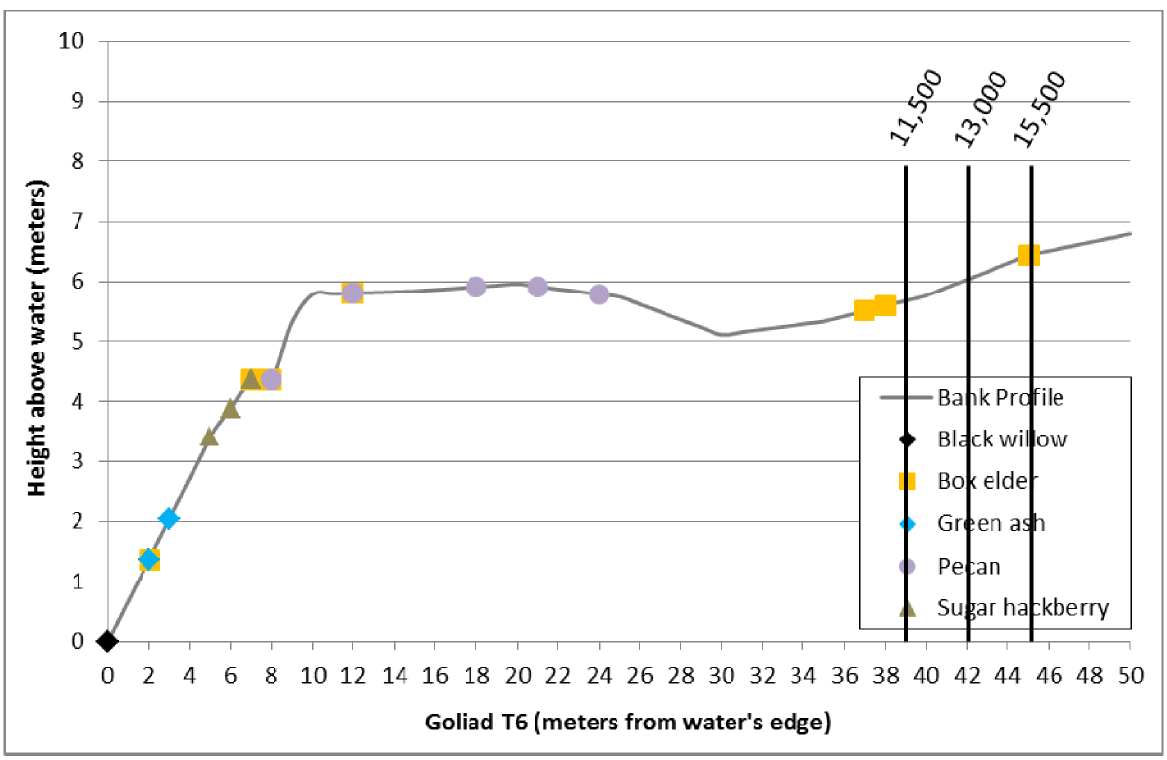


Figure E-22. Tree data from Goliad site along Transect 6.

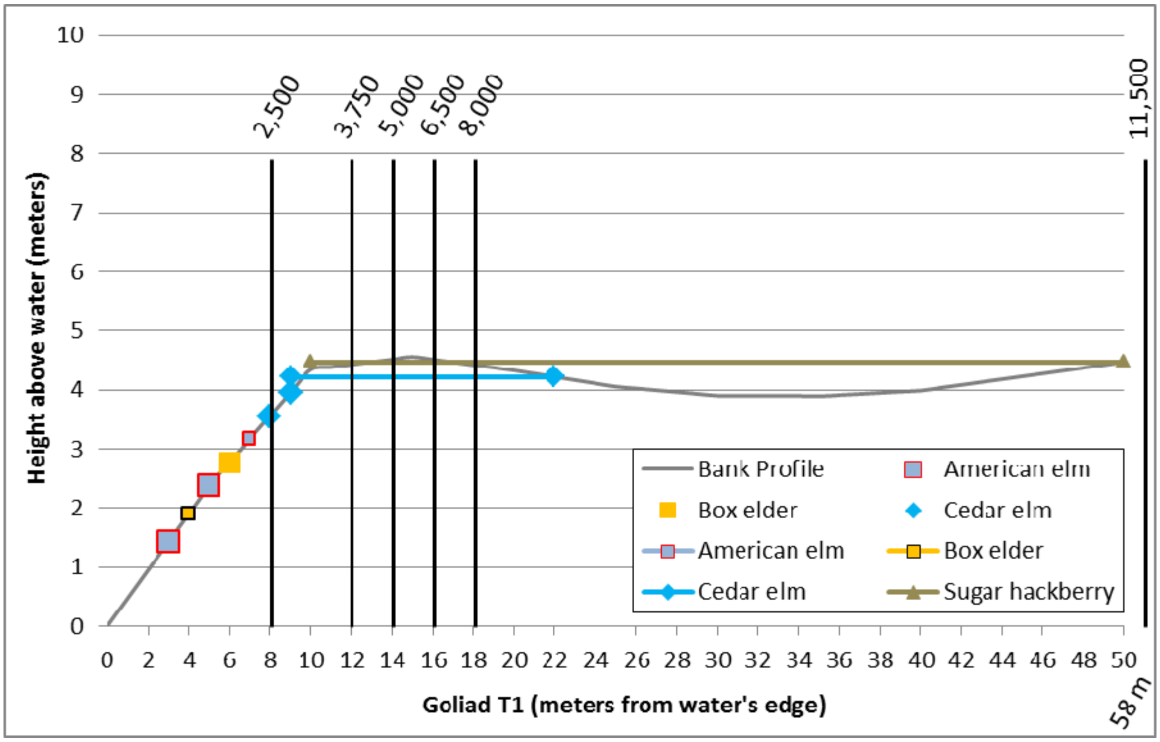


Figure E-23. Sapling (point) and seedling range (line) data from Goliad site along Transect 1.

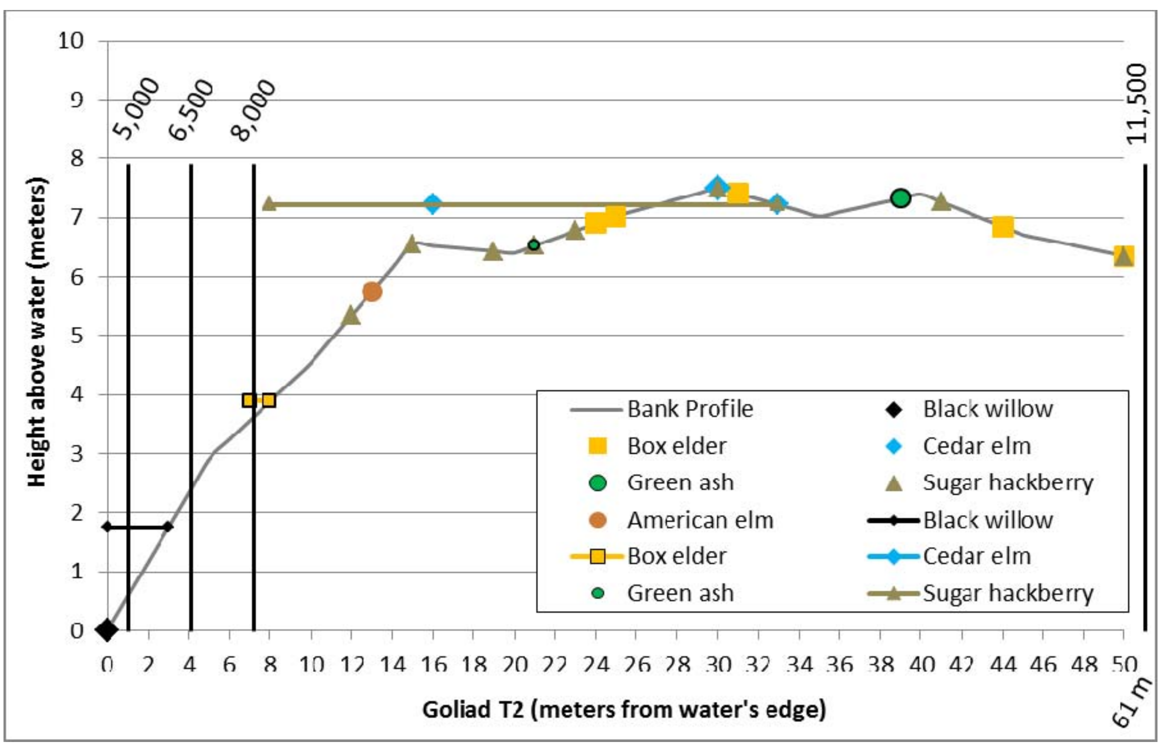


Figure E-24. Sapling (point) and seedling range (line) data from Goliad site along Transect 2.

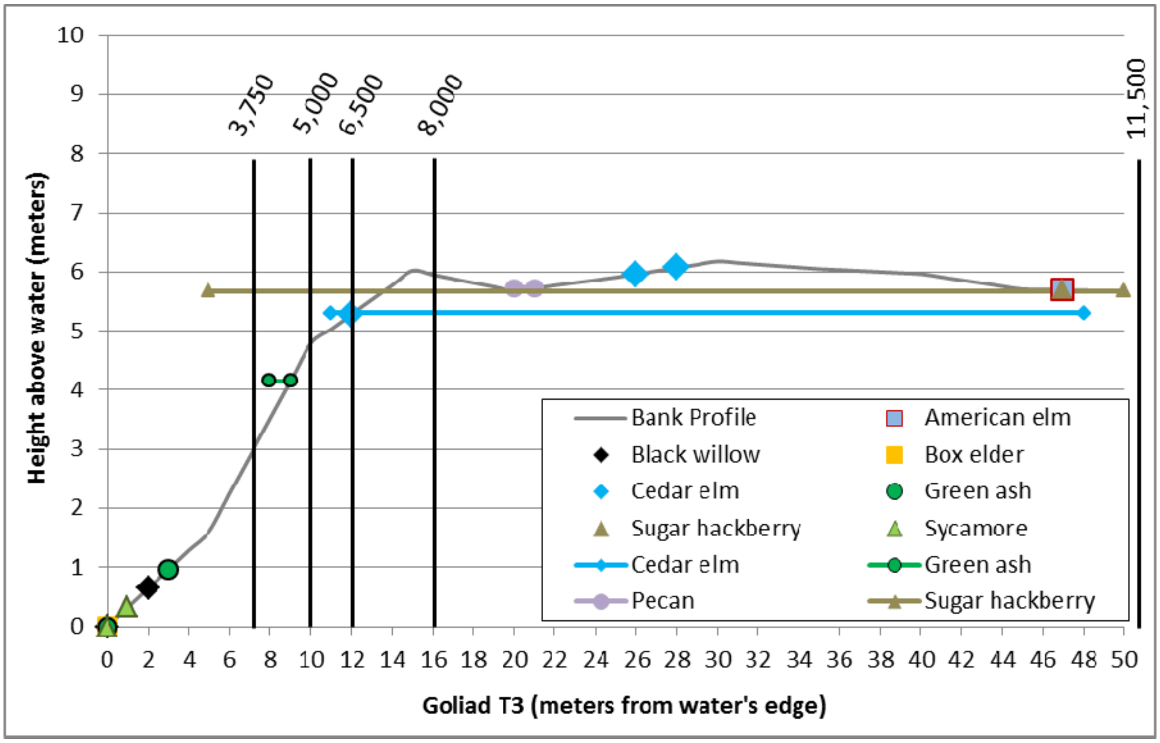


Figure E-25. Sapling (point) and seedling range (line) data from Goliad site along Transect 3.

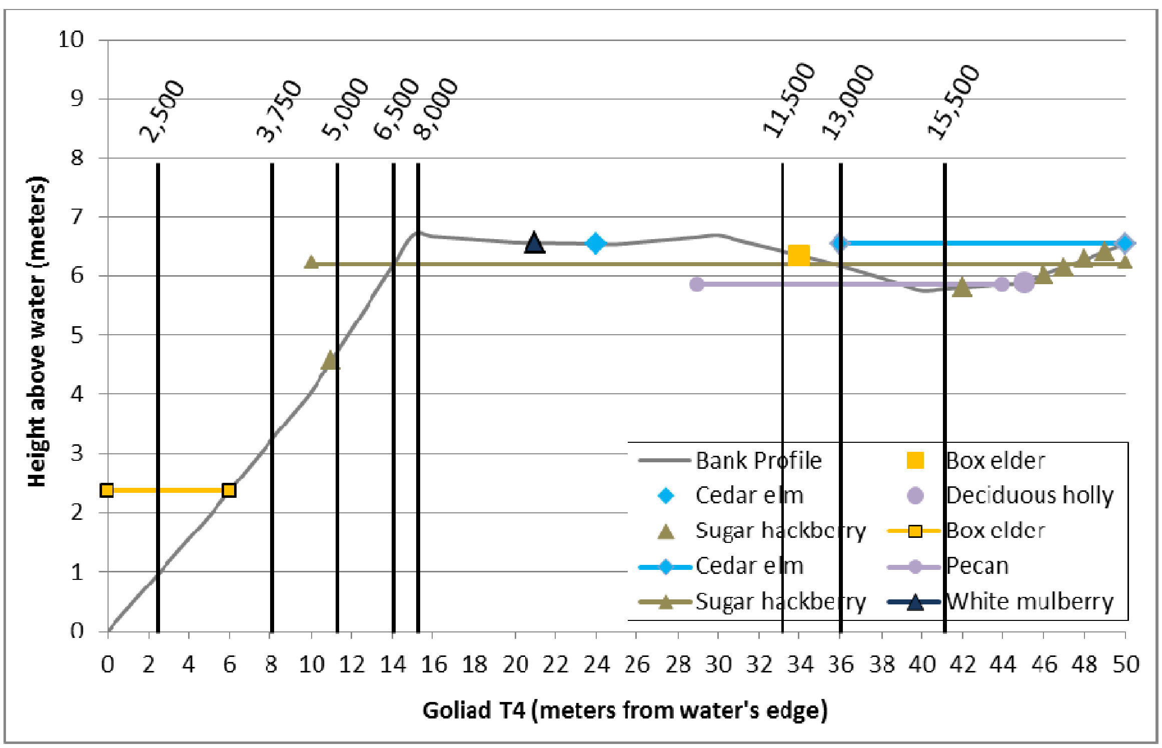


Figure E-26. Sapling (point) and seedling range (line) data from Goliad site along Transect 4.

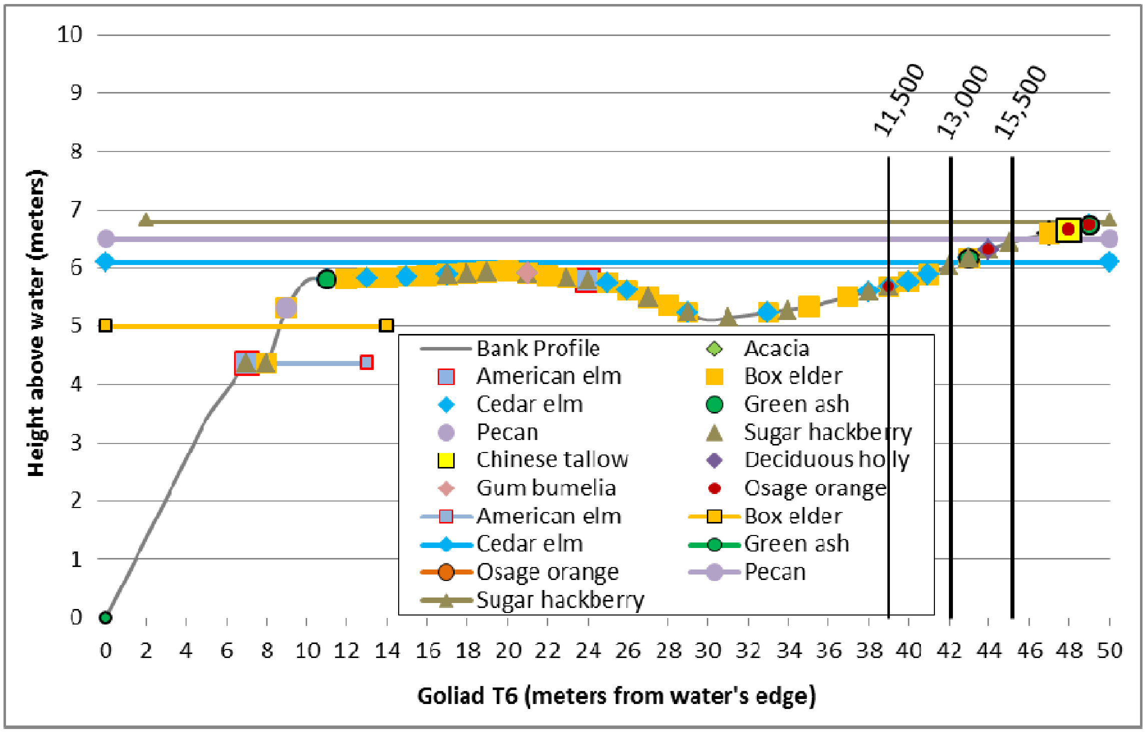


Figure E-27. Sapling (point) and seedling range (line) data from Goliad site along Transect 6.

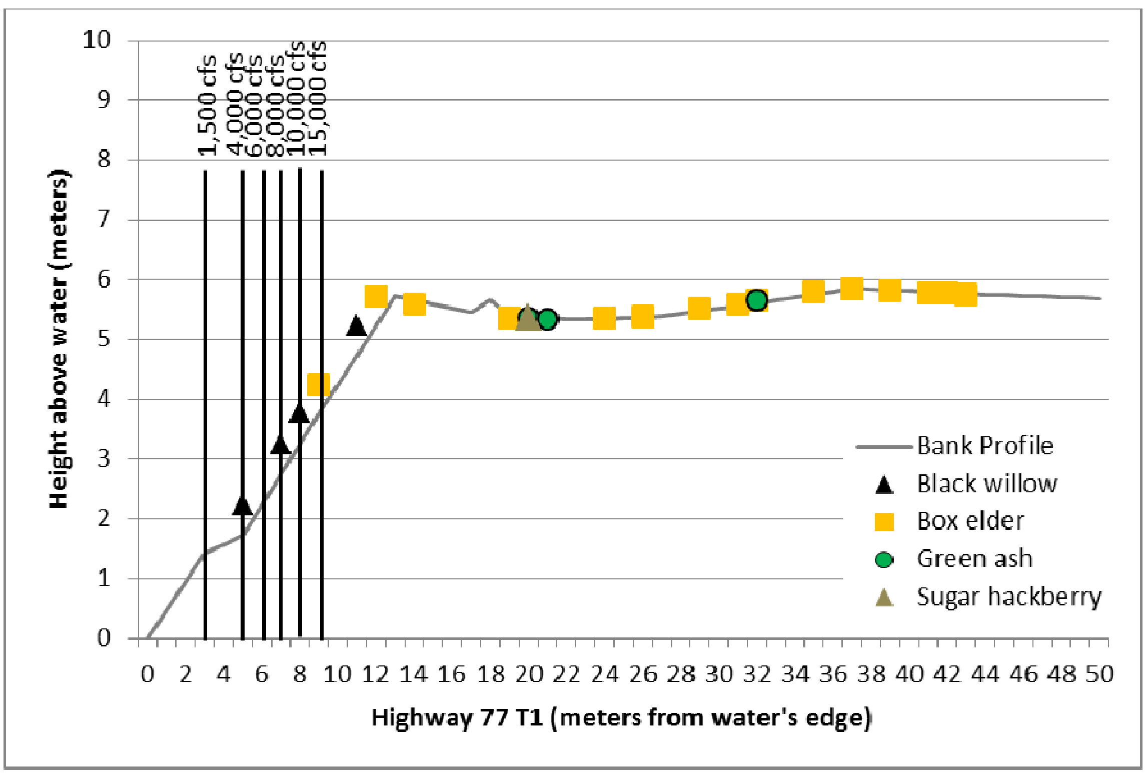


Figure E-28. Tree data from Highway 77 site along Transect 1.

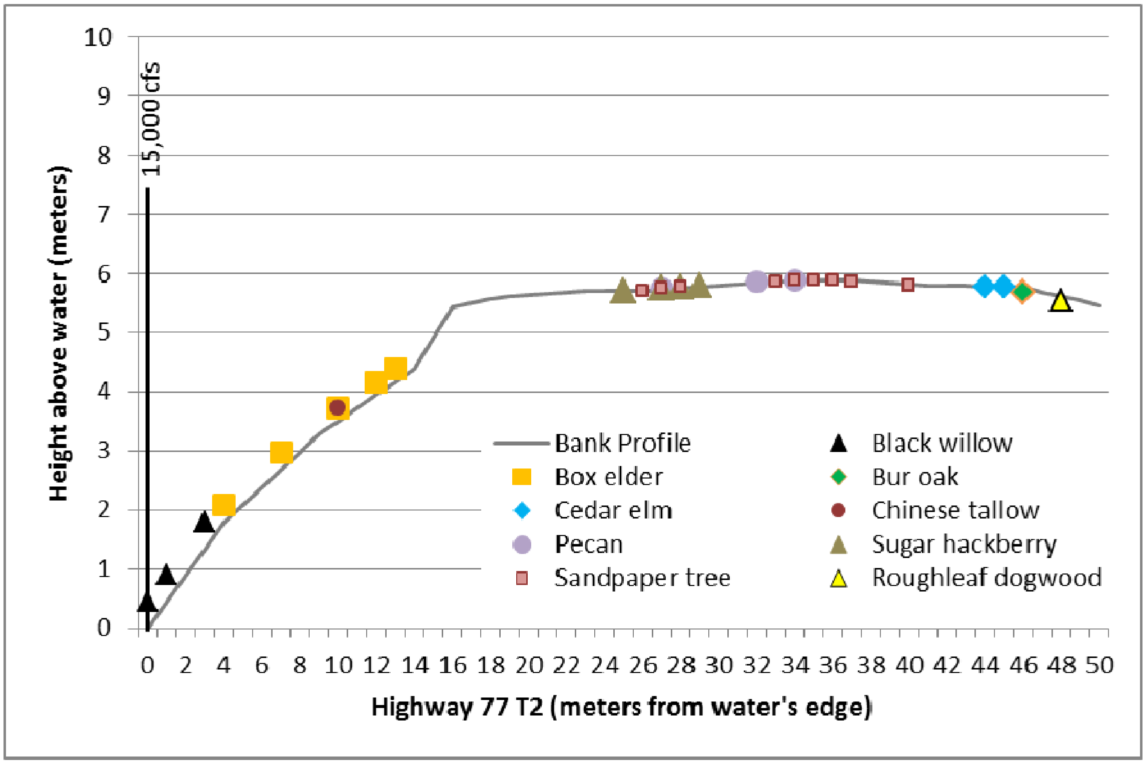


Figure E-29. Tree data from Highway 77 site along Transect 2.

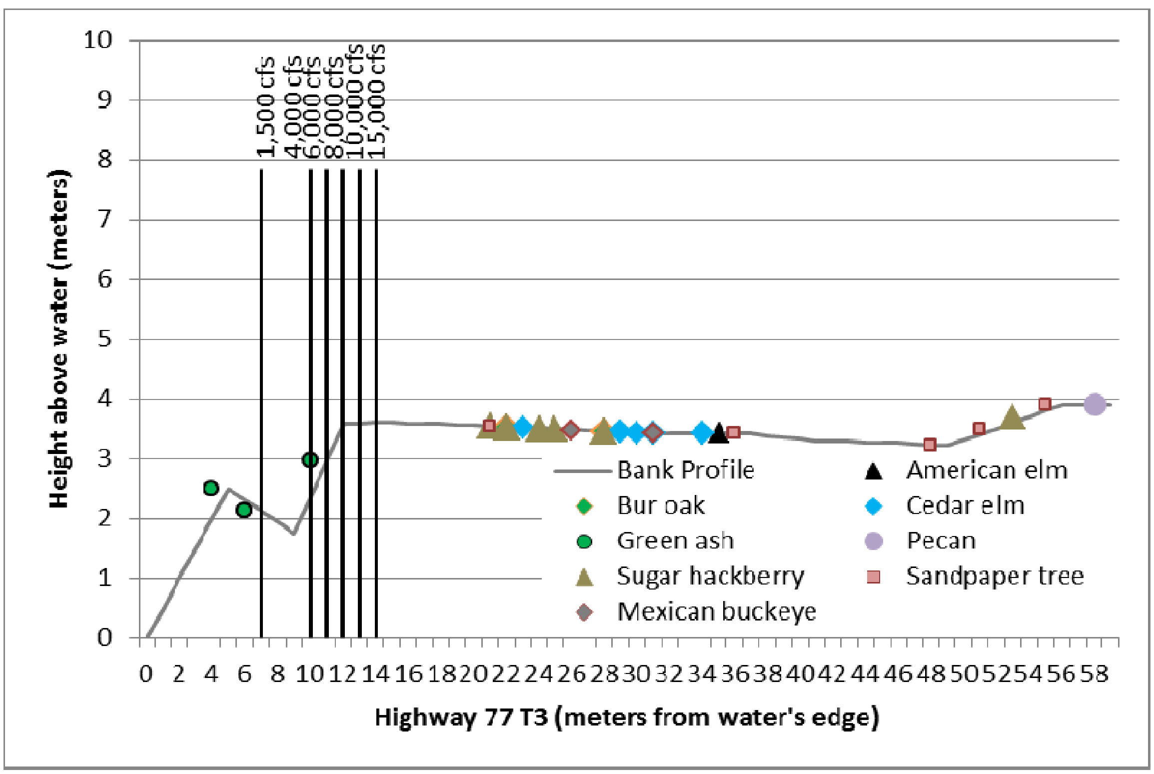


Figure E-30. Tree data from Highway 77 site along Transect 3.

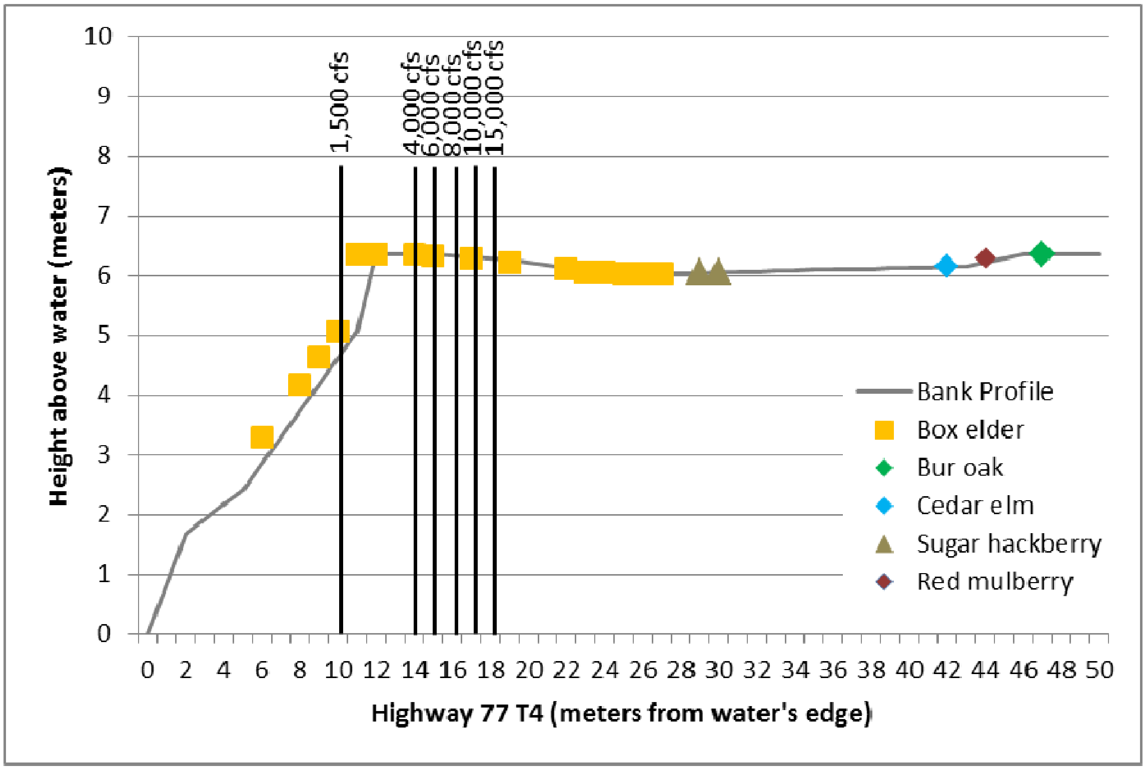


Figure E-31. Tree data from Highway 77 site along Transect 4.

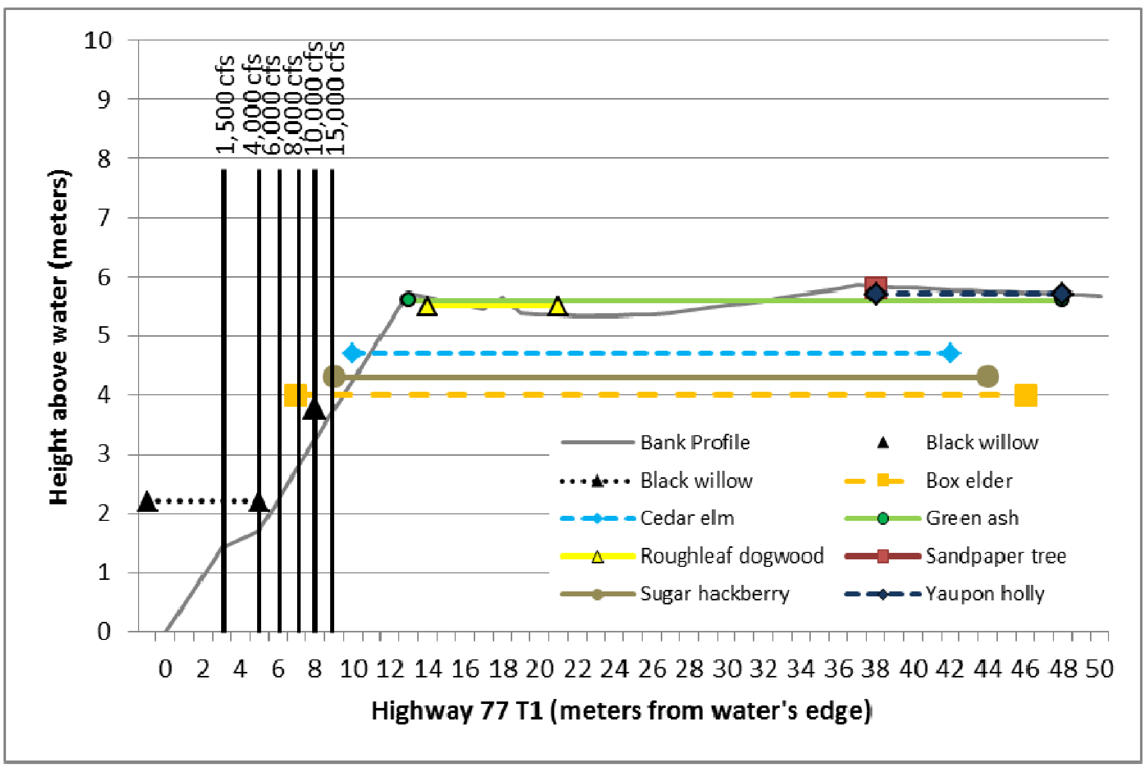


Figure E-32. Sapling (point) and seedling range (line) data from Highway 77 site along Transect 1.

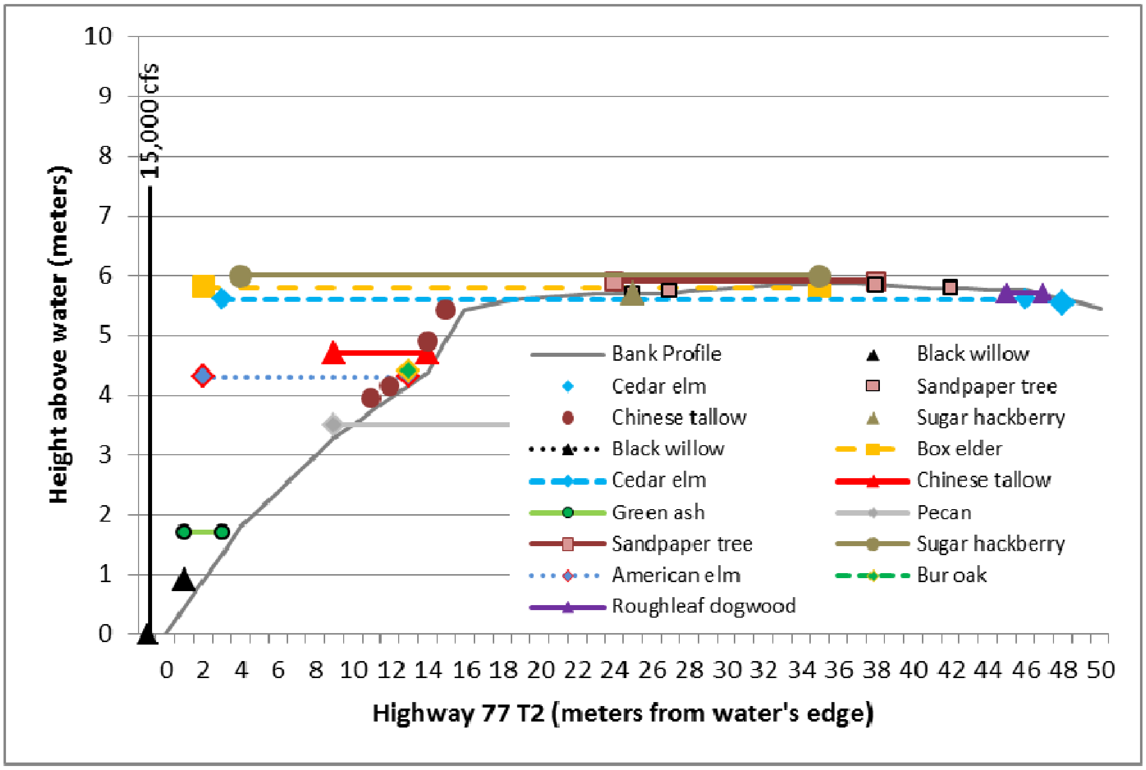


Figure E-33. Sapling (point) and seedling range (line) data from Highway 77 site along Transect 2.

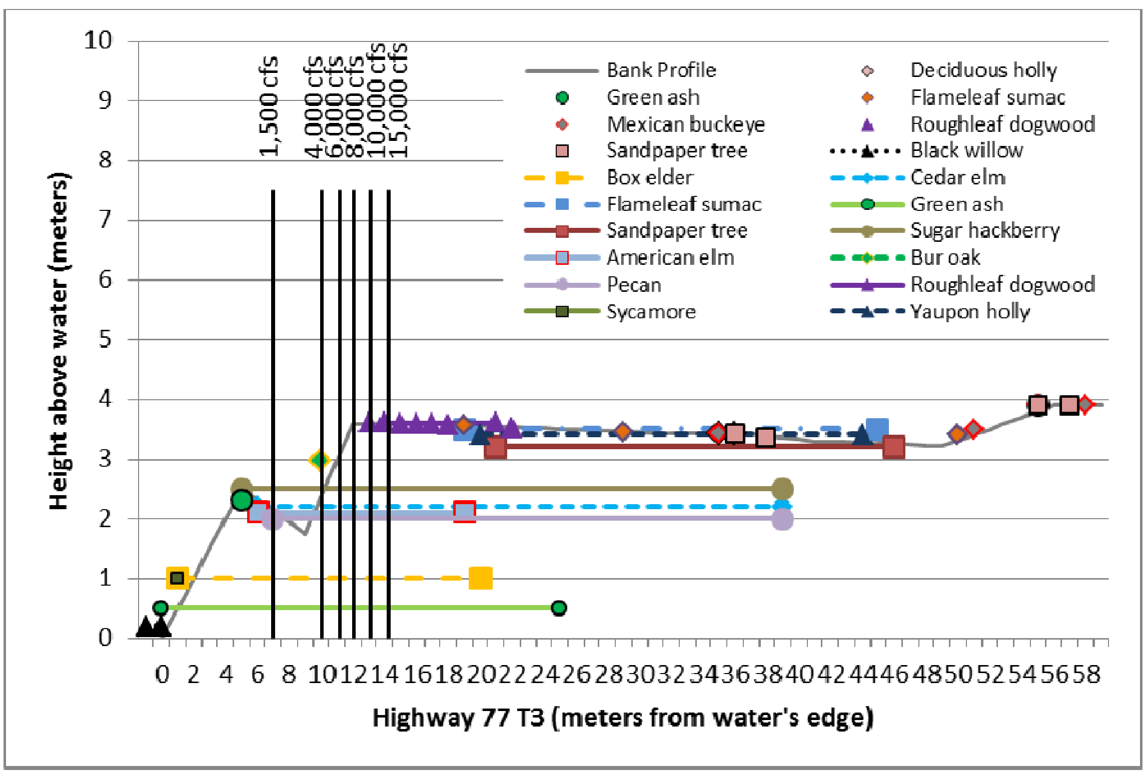


Figure E-34. Sapling (point) and seedling range (line) data from Highway 77 site along Transect 3.

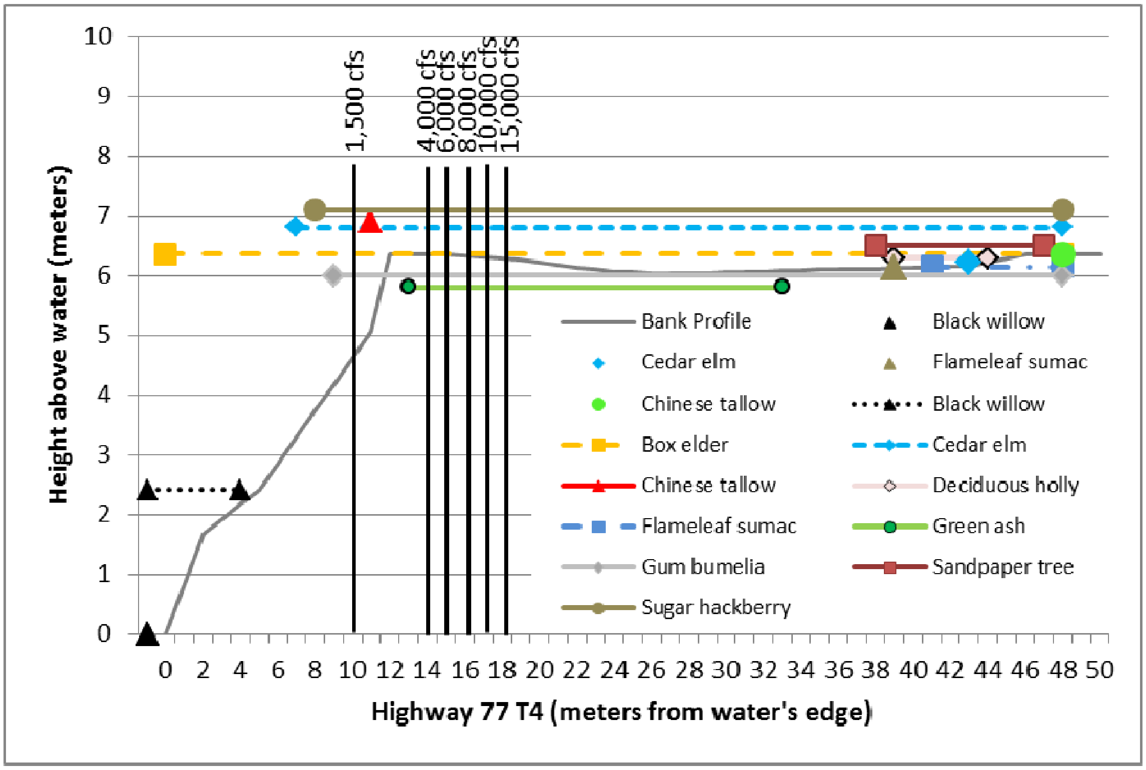


Figure E-35. Sapling (point) and seedling range (line) data from Highway 77 site along Transect 4.

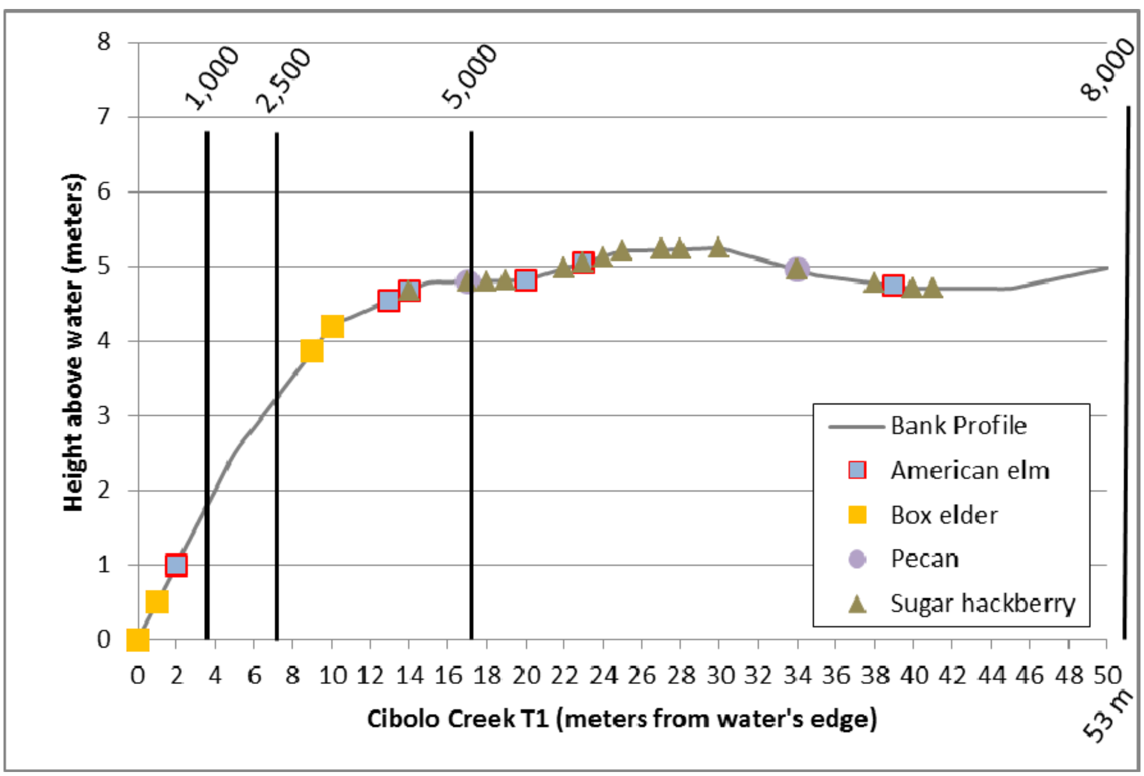


Figure E-36. Tree data from Cibolo Creek site along Transect 1.

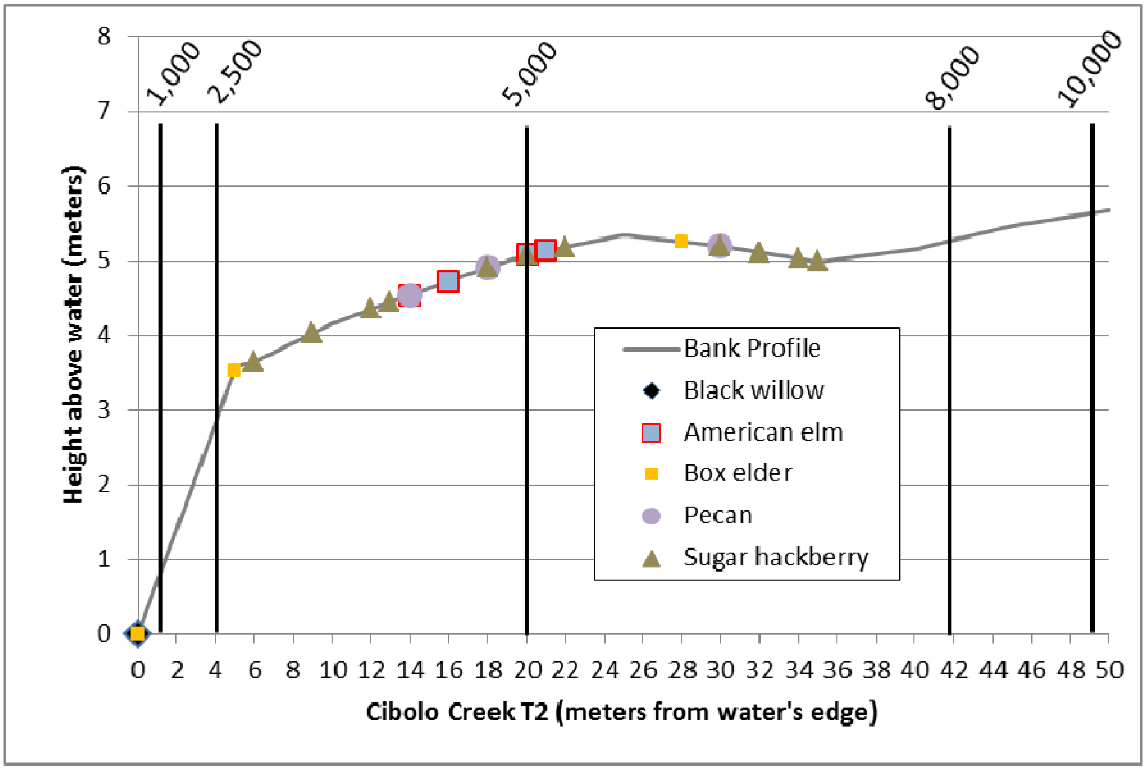


Figure E-37. Tree data from Cibolo Creek site along Transect 2.

Bank profile survey for Transect 3 at Cibolo Creek site not available.

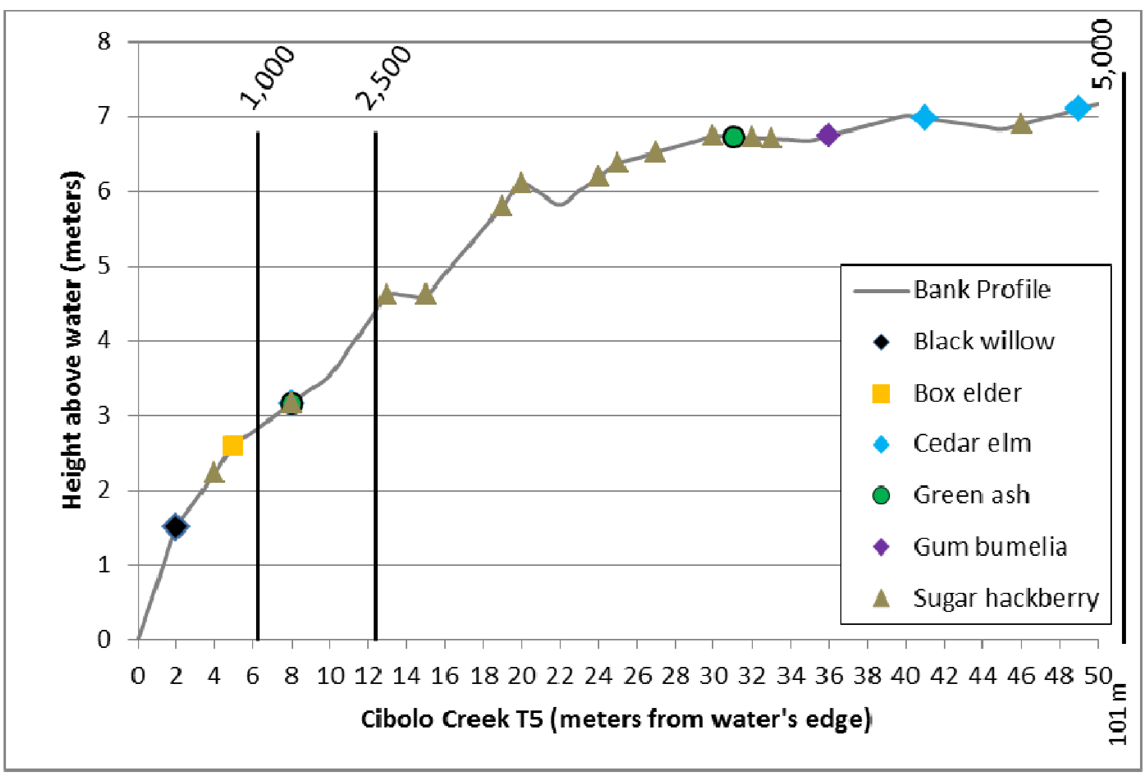


Figure E-38. Tree data from Cibolo Creek site along Transect 5.

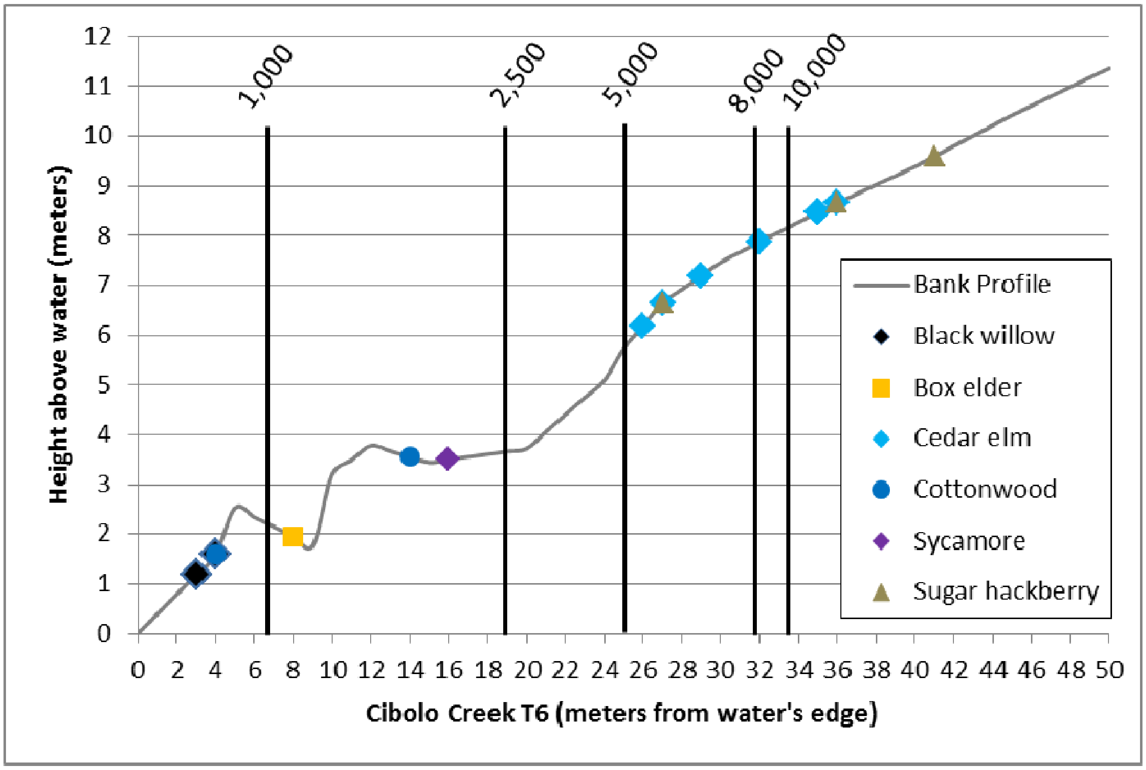


Figure E-39. Tree data from Cibolo Creek site along Transect 6.

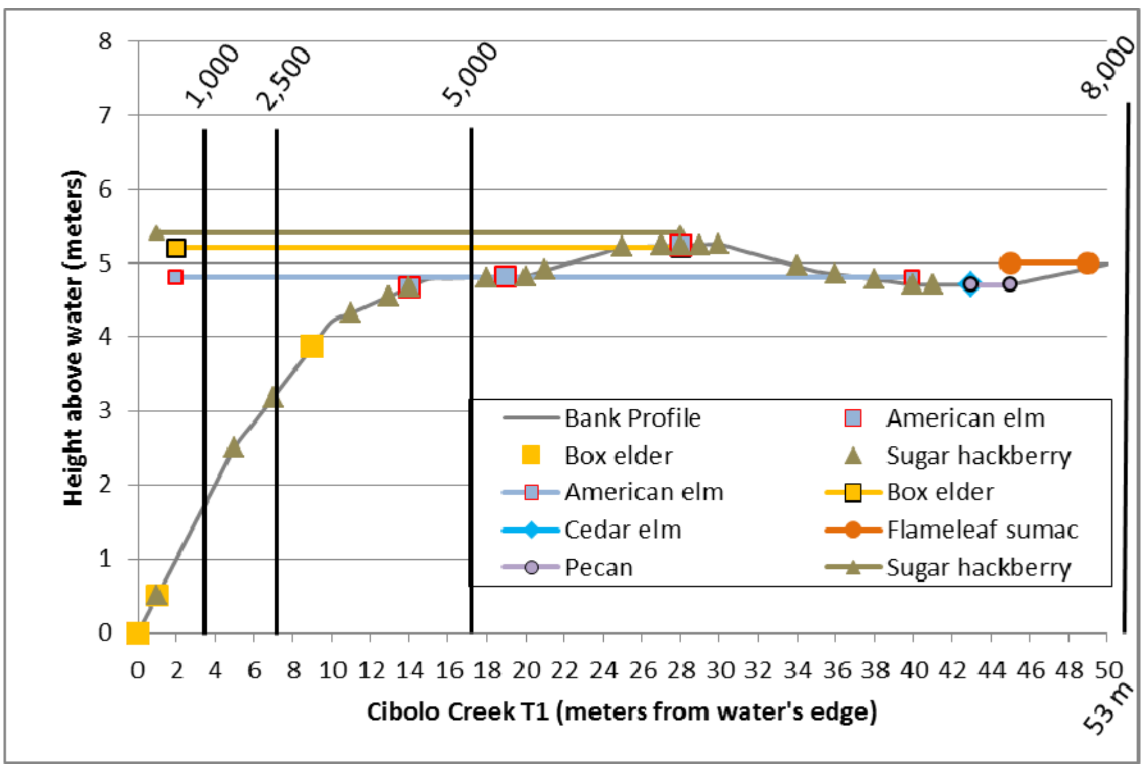


Figure E-40. Sapling (point) and seedling range (line) data from Cibolo Creek site along Transect 1.

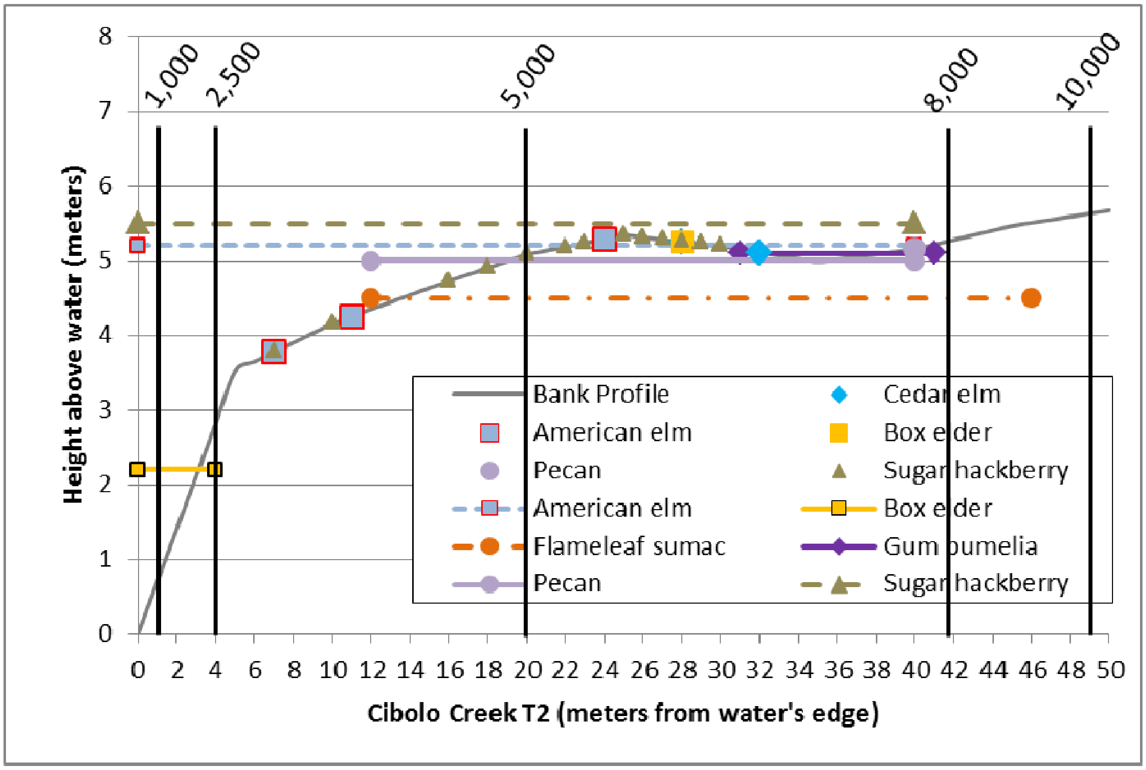


Figure E-41. Sapling (point) and seedling range (line) data from Cibolo Creek site along Transect 2.

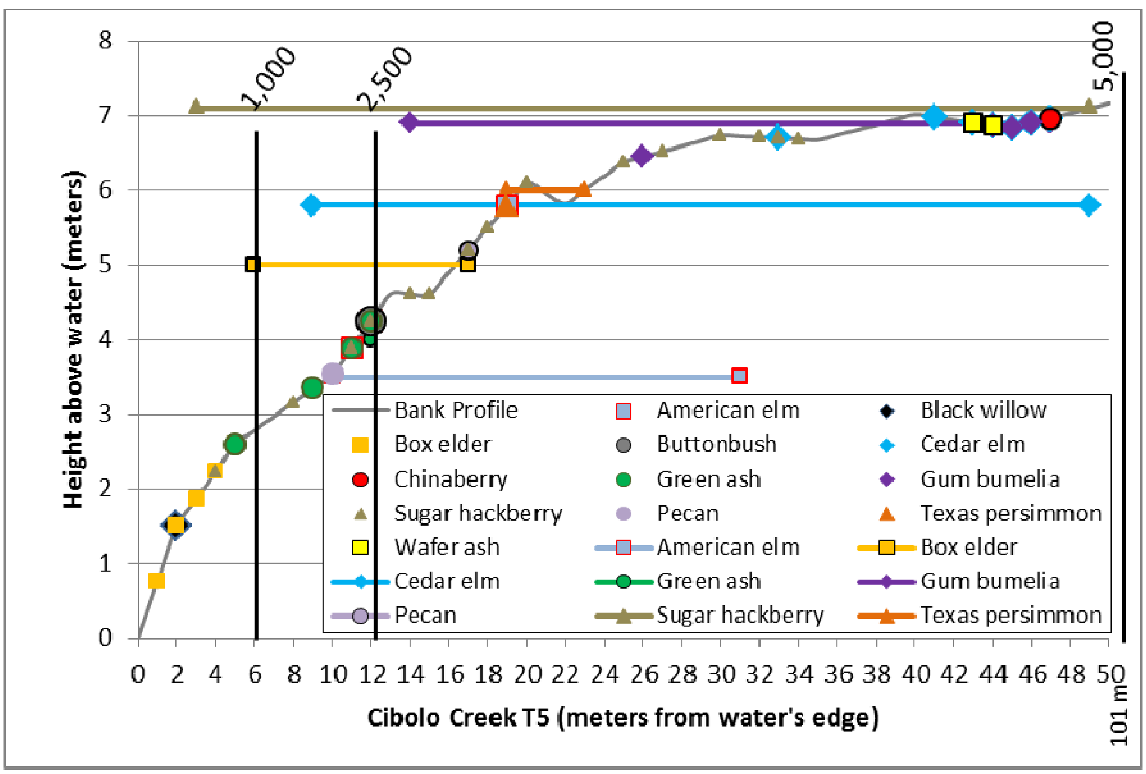


Figure E-42. Sapling (point) and seedling range (line) data from Cibolo Creek site along Transect 5.

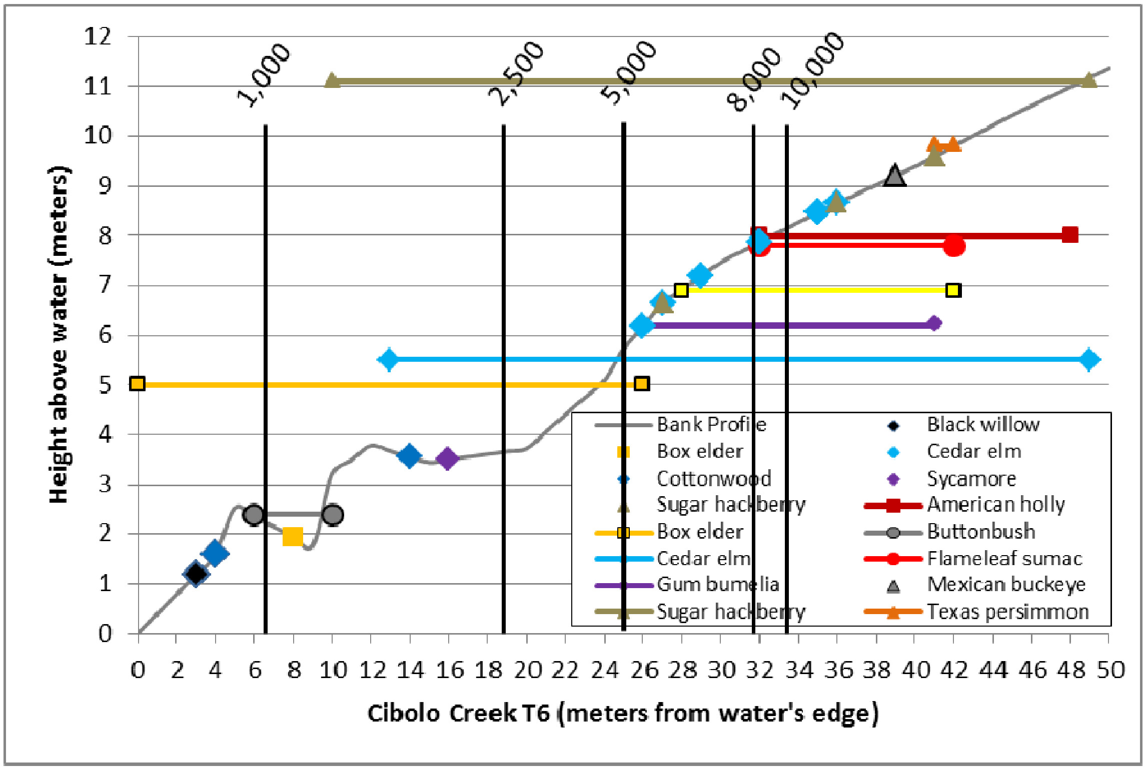


Figure E-43. Sapling (point) and seedling range (line) data from Cibolo Creek site along Transect 6.