Lower Colorado River, Texas
Instream Flow Guidelines

Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker

Prepared for

Lower Colorado River Authority

and San Antonio Water System

Prepared by

BIO-WEST, Inc.
1812 Central Commerce Court
Round Rock, Texas 78664

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EXECUTIVE SUMMARY

The lower Colorado River downstream of Austin has been impacted by human activity for more than 100 years and there are currently diversions, return flows, low water dams, agriculture up to the banks, and other structural and non-structural modifications. Nevertheless, the river continues to support a diverse aquatic and riparian environment. This environment relies on the quality, quantity, and timing of water moving through the lower Colorado River basin. A major alteration to the natural flow regime of the lower Colorado River occurred with the completion of Buchanan and Mansfield Dams (1937 and 1940, respectively). The LCRA-SAWS Water Project (LSWP) also has the potential to alter characteristics of the flow regime, and thus, the Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker Study was conducted. This study was developed to assess potential impacts or benefits resulting from the LSWP and address the environmental principles applied to the project.

Two of the environmental principles incorporated into the LSWP contract relate directly to the lower Colorado River aquatic and riparian environment. They specify that before LSWP implementation, studies must show that the project (1) "protects and benefits the lower Colorado River watershed and the Lower Colorado River Authority (LCRA) Service Area, including municipal, industrial, agricultural, recreational, and environmental interests"; and (2) "provides for instream flows no less protective than those included in the LCRA Water Management Plan (WMP) for the Lower Colorado River Basin, as approved by the Texas Commission on Environmental Quality." Additionally, the Texas Instream Flow Program (TIFP) has a legislative mandate (Senate Bill 2) to identify instream flow conditions that support a "sound ecological environment", which is described as "…a functioning ecosystem characterized by intact, natural processes, resilience, and a balanced, integrated, and adaptive community of organisms comparable to that of the natural habitat of a region." (TIFP Draft 2006). The respective resource agencies participating in the TIFP have participated in this study since its inception.

Streamflow acts as a "master" variable that directly and indirectly influences the full range of riverine resources and functions, including hydrology and hydraulics, biology (aquatic and riparian), geomorphology, and water quality. Intensive biological and physical data collection activities associated with these key study components were completed in 2004-2007. A detailed description of these activities can be found in BIO-WEST 2004, 2005, 2006, 2007. Chapter 2 provides an overview of each river study component while Chapters 3 and 4 document how study results were used to develop instream flow guidelines for the lower Colorado River.

In order to meet the environmental principles set forth for the LSWP and remain consistent with the TIFP objectives to conserve biodiversity and maintain biological integrity, the project team followed the recommendations of the NRC (2005) which has subsequently been endorsed by the TIFP (TIFP Draft 2006). The integration process involves four components of the hydrologic regime: subsistence flows, base flows, high flow pulses, and overbank flows. Hydraulic and habitat modeling, sediment transport analysis, and water quality modeling were used to support the development of subsistence and base flow guidelines. Pulse, channel maintenance and overbanking flow recommendations were based on sediment transport analysis conducted during this study and a hydrologic analysis of existing and pre-1940 flow regimes.

To establish instream flow guidelines, physical habitat times series were computed based on two flow scenarios. These included the existing condition (1975 to 2004) and pre-1940 (from 1898 at Austin and from 1916 at Columbus through 1939). The existing flow scenario was included in the habitat time series analysis because 1) the field data (physical and biological) used for the hydraulic and habitat models, sediment transport analysis, and baseline riparian conditions were all collected under the existing flow regime, and 2) the present day geomorphic conditions, riparian zone, water chemistry, aquatic habitat, and biological resources have all been imprinted by the existing flow regime. Additionally, the water quality and biological data collected by LCRA over the past decade reflect good water quality and diverse biological communities. Therefore, an examination of the existing flow regime was deemed necessary to evaluate the potential for maintaining similar conditions. The pre-1940 "natural" flow scenario was included to be consistent with the guidance of the TIFP and Natural Flow paradigm. Even though the data collected for this study was done under the existing flow regime, using natural flow conditions as a reference for comparison often provides insight into the ecological variability of riverine systems.

An evaluation of the hydrology, habitat time series modeling results, sediment transport analyses, and water quality results indicated that the pre-1940 flow regime is different from the existing flow regime. A detailed description of these differences is provided in Section 4.2.3. The TIFP (TIFP Draft 2006) proposes, "The goal of ensuring a 'sound ecological environment' has been equated to maintaining the ecological integrity and conserving the biological diversity of riverine ecosystems. In order to meet these goals, the Agencies recognize the importance of maintaining the natural habitat diversity, hydrologic character, and water quality of river systems." For the ecological advantages discussed in Section 4.2.3 and to be consistent with the goals of the TIFP, the pre-1940 time period was selected to be used for the development of instream flow guidelines. Hardy et al. (2006) states, "Utilizing the characteristics of the natural flow regime as a "template" is widely accepted and applied at the international level …."

Instream flow recommendations for five categories (subsistence, base, pulse, channel maintenance, and overbank flows) specific to the LSWP are recommended for the lower Colorado River (Table ES.1). The subsistence flow recommendations represent minimum conditions at which water quality is maintained at acceptable levels and aquatic habitats are expected to resemble those found during extreme conditions in a more natural setting. The base flow recommendations provide a range of suitable conditions with the goal of maintaining year to year variability and the ecological functions associated with this level of variability. Pulse flows provide a myriad of ecological functions including but not limited to nutrient and organic matter exchange, limited channel maintenance, flushing, vegetation scouring, and seed dispersal. Channel maintenance flows provide for the maintenance of channel capacity, while also flushing accumulated fine sediments from important gravel bar and riffle habitats, and scouring accumulated sediments from pool habitats. Overbank flows inundate low floodplain areas adjacent to the river providing for lateral floodplain and riparian connectivity, floodplain maintenance and nutrient deposition, and recruitment of organic material and woody debris.

Table ES.1. Instream Flow Guidelines for the lower Colorado River specific to the LSWP.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AUSTIN REACH												
Subsistence	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**
BASTROP REACH												
Subsistence	**208**	**274**	**274**	**184**	**275**	**202**	**137**	**123**	**123**	**127**	**180**	**186**
Base-DRY	**313**	**317**	**274**	**287**	**579**	**418**	**347**	**194**	**236**	**245**	**283**	**311**
Base-AVERAGE	**433**	**497**	**497**	**635**	**824**	**733**	**610**	**381**	**423**	**433**	**424**	**450**
COLUMBUS REACH												
Subsistence	**340**	**375**	**375**	**299**	**425**	**534**	**342**	**190**	**279**	**190**	**202**	**301**
Base-DRY	**487**	**590**	**525**	**554**	**966**	**967**	**570**	**310**	**405**	**356**	**480**	**464**
Base-AVERAGE	**828**	**895**	**1,020**	**977**	**1,316**	**1,440**	**895**	**516**	**610**	**741**	**755**	**737**
WHARTON REACH												
Subsistence	**315**	**303**	**204**	**270**	**304**	**371**	**212**	**107**	**188**	**147**	**173**	**202**
Base-DRY	**492**	**597**	**531**	**561**	**985**	**984**	**577**	**314**	**410**	**360**	**486**	**470**
Base-AVERAGE	**838**	**906**	**1,036**	**1,011**	**1,397**	**1,512**	**906**	**522**	**617**	**749**	**764**	**746**

COLORADO RIVER DOWNSTREAM OF AUSTIN	
PULSE FLOWS	
Base	**MAGNITUDE (2,000 to 3,000 cfs); FREQUENCY (8–10 times annually); DURATION (3–5 days)**
High	**MAGNITUDE (@ 8,000 cfs); FREQUENCY (2 Events in 3 year period); DURATION (2–3 days)**
CHANNEL MAINTENANCE	**MAGNITUDE (27,000 - 30,000 cfs); FREQUENCY (1 Event in 3 years); DURATION (3 days)**
OVERBANK	**MAGNITUDE (> 30,000 cfs); FREQUENCY and DURATION (Naturally Driven)**

As discussed in Chapter 4, the Austin Reach has a subsistence flow recommendation whereas the Bastrop, Columbus, and Wharton reaches have proposed monthly regimes for subsistence and two levels of base flow. Pulse flows, channel maintenance flows and overbanking flows are currently the same amongst reaches.

The LSWP instream flow recommendations represent an ecologically balanced approach that takes into account hydrology, biology, geomorphology, and water quality with the goal of supporting a sound ecological environment in the lower Colorado River. The project team concurs with the TIFP and acknowledges that a critical component of all recommendations for this project is a long-term monitoring program to evaluate the effectiveness of the LSWP instream flow guidelines. In conjunction with long-term monitoring, adaptive management will be a vital component to assist in ensuring the success of the environmental principles associated with the LSWP and goals of the TIFP.

1.0 INTRODUCTION

The lower Colorado River basin supports a diverse ecological community that relies on the quality, quantity, and timing of water moving through the system. The LCRA-SAWS Water Project (LSWP) has the potential to alter characteristics of the flow regime for the lower Colorado River, including the possibility of using instream structures to facilitate the removal of water to off-channel storage facilities (OCSF). Because of these potential changes, the Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker Study was developed to assess potential impacts or benefits on the aquatic resources of the lower Colorado River with and without implementation of the project. An additional study objective was to quantify the condition of the aquatic environment under different flow scenarios to satisfy federal and state permitting requirements and ensure compliance with the environmental principles set forth for this project.

Two of the environmental principles incorporated into the LSWP contract relate directly to this study and state that before project implementation, studies must show that the project (1) "protects and benefits the lower Colorado River watershed and the Lower Colorado River Authority (LCRA) Service Area, including municipal, industrial, agricultural, recreational, and environmental interests"; and (2) "provides for instream flows no less protective than those included in the LCRA Water Management Plan (WMP) for the Lower Colorado River Basin, as approved by the Texas Commission on Environmental Quality."

Separate, yet consistent with the description of LSWP environmental principles, has been the development of the Texas Instream Flow Program (TIFP) that has a legislative mandate (Senate Bill 2) to identify instream flow conditions that support a "sound ecological environment", which is described as "…a functioning ecosystem characterized by intact, natural processes, resilience, and a balanced, integrated, and adaptive community of organisms comparable to that of the natural habitat of a region." (TIFP Draft 2006).

This report documents the process by which the results of the LSWP studies were used to develop instream flow guidelines for the lower Colorado River specific to the LSWP. This report has integrated critical components (background and framework) of the TIFP (TIFP Draft 2006) and National Research Council (NRC 2005) to ensure compliance with all anticipated state-mandated requirements. The document is organized to first provide an overview of the LSWP relative to each of the four key instream flow technical components (hydrology and hydraulics, biology, geomorphology, and water quality), then to describe the integration of these study components, and finally, to provide recommendations for instream flow guidelines for the lower Colorado River specific to the LSWP.

This final report incorporates comments received from the LSWP project team, Science Review Panel, and Resource Agencies over the course of the one year review period. The comments received and study team responses are provided in Appendix A.

2.0 STUDY COMPONENTS

Rivers are complex, dynamic systems that support a myriad of important ecological functions. They transport water, sediment, organic matter, nutrients, and energy downstream, which support aquatic communities. This section includes background information, discussion and motivation behind major components of this LSWP study. Sections 3 and 4 describe study-specific activities in more detail.

Rivers and associated riparian habitats provide longitudinal movement corridors for terrestrial and avian wildlife. Natural riverine ecosystems also provide lateral transfer and cycling of water, sediment, nutrients, and energy between the stream channel and floodplain areas. Healthy floodplains store water during high flow events and release it back to the channel during low flow periods. Floodplains and associated riparian vegetation also help to filter contaminants and improve surface and ground water quality.

Streamflow acts as a "master" variable that directly and indirectly influences the full range of riverine resources and functions, including hydrology and hydraulics, biology (aquatic and riparian), geomorphology, and water quality. The individual riverine components also influence each other either directly or indirectly. Because of this interdependence among the various resource components and processes, the full range of flow regime components was evaluated in the LSWP aquatic habitat study.

2.1 Hydrology and Hydraulics

A natural streamflow regime, or river hydrology, is characterized by seasonal and inter-annual variability, and native aquatic and riparian biota are adapted to this variability. For example, seed dispersal by native riparian vegetation often coincides with the typical springtime high flow. Seasonal flow patterns may cue spawning for various native fish species including the blue sucker. Year-to-year hydrologic variability is also important. For example, wet periods characterized by large overbank floods create habitat complexity and promote lateral and longitudinal nutrient cycling. However, if major flooding occurred every year, the frequent disturbance would prevent riparian communities from becoming established and would compromise the stability of aquatic communities. Because different ecological functions are served by climatic conditions, inter-annual hydrologic variability was also considered in developing instream flow guidelines for the lower Colorado River.

On a smaller scale, the patterns of water movement inside the channel, or river hydraulics, can be as important to individual organisms as the overall flow regime. Water depth and velocity are not only useful for characterizing aquatic habitat but also play a vital role in river processes like erosion, deposition and overall formation of bedforms.

2.2 Biology

Native aquatic species have evolved such that their life history stages have adjusted to the variability and seasonal pattern of natural flow regimes. Hydraulic habitat (flow, depth, velocity, and substrate) is an important component of habitat for native aquatic species that is dependent upon the flow regime. Individual species may be adapted to spend all or a majority of their time in a particular hydraulic environment, such as backwaters or riffles. Other species may require a variety of hydraulic habitats for feeding, resting, and reproductive activities. Altered flow regimes can change the availability of important hydraulic habitats for certain species, resulting in shifts in aquatic community composition or diversity. Changes in channel morphology, such as reduced diversity in bed and bank topography, can also limit the availability and diversity of hydraulic habitat.

The streamflow regime, together with channel morphology, largely controls the composition, distribution, and extent of riparian vegetation on streambank and floodplain areas. Individual vegetation types have different inundation tolerances and water requirements. Grasses and other herbaceous species often occupy wet areas close to the channel, while species with lower inundation tolerances occupy higher-elevation surfaces. Because of these flow-specific requirements, changes in flood magnitude, timing, frequency, duration or recession rate all have the potential to compromise the native riparian community. Altered flow regimes may tend to favor nonnative riparian species. Low-flow characteristics are also important for riparian vegetation. The inundation width of the channel during the summer growing season will define the inward lateral extent of riparian vegetation. Vegetation will tend to encroach onto surfaces that remain dry during the growing season. In systems altered by artificially high summertime irrigation flow releases as observed in the lower Colorado River system, the inward extent of vegetation will be limited relative to rivers with naturally lower summertime flows. In systems where summertime base flows are reduced or eliminated by diversions, vegetation will tend to encroach inward into the active channel. If the encroaching vegetation is not scoured away by floods, channel capacity and aquatic habitat will be reduced over time. Therefore, the natural balance of edge vegetation growth and scouring is an important riverine component for many ecological processes.

2.3 Geomorphology

The morphology of river-floodplain systems is dynamic. Together with streamflow, the physical channel form provides important hydraulic habitat features such as pools, riffles, and backwaters. Geomorphic variables including channel width, depth, bed material characteristics, plan form, and slope are all potentially adjustable. They are controlled by the influx of water and sediment against the backdrop of a particular geologic/physiographic setting. Classic geomorphic theory suggests that streams tend toward a state of "dynamic equilibrium" in which channel size, shape, and slope adjust over a period of time to the dominant sediment and flow regime (Mackin 1948, Leopold et al. 1964). In a stream that is in equilibrium, features such as pools that are lost due to in-filling tend to be replaced by new pool features created by scour elsewhere in the system. Over time, the distribution of habitat features in an equilibrium channel is maintained.

When streamflow or sediment supply is changed by dams, diversions, or other alterations, channel equilibrium may be disturbed. A channel may begin to downcut, aggrade, or widen as it responds to changes in the flow and/or sediment regime (Williams and Wolman 1984, Schumm 1969). If an instream flow recommendation is developed based on an analysis of existing hydraulic habitat in a rapidly widening or incising river, habitat will not be effectively protected over the long term. Therefore, geomorphic trends in the lower Colorado River were considered when developing the instream flow guidelines.

Channel morphology and processes are a function of a wide spectrum of different flow regime parameters. Much attention is paid to the "bankfull channel", which empirical research has found to correspond to discharges with recurrence intervals between 1.2 and 4 years (Leopold et al. 1964). These moderate-magnitude bankfull floods are effective at flushing accumulated fine sediments from gravels, scouring pools, building riffles, removing vegetation from active channel areas, inundating bars, and maintaining channel capacity. Bankfull discharge has also been found to correspond to effective discharge, which is the flow that transports the largest amount of sediment when averaged over a long period of time (Wolman and Miller 1960, Andrews 1980, Leopold 1992, Andrews 1994).

Less frequent, higher magnitude floods that overtop the streambanks also perform important geomorphic functions. Overbank floods can create new side channels, form or erode islands, build log jams, cut off meander bends, and deposit fresh sediment and viable seeds on the floodplain. These processes maintain channel complexity and habitat diversity, as well as provide the disturbance needed for recruitment of certain riparian plants.

2.4 Water Quality

Streamflow directly influences water quality parameters including temperature, sediment and nutrient concentrations, dissolved oxygen, and pollutant concentrations. Dams and diversions that impound water and/or alter downstream flow release volumes can significantly alter water quality conditions, especially when point and non-point sources of pollution occur in downstream waters. Flow regime alterations that increase bank erosion rates can adversely affect water quality by increasing inputs of fine sediments and attached nutrients and contaminants. In general, water quality is a sensitive riverine component that responds to changes in land use, groundwater recharge, and channel morphology as well as instream flows.

3.0 STUDY RESULTS

Intensive data collection activities associated with the key study components were completed in 2004-2007 at the sites depicted in Figure 3.1. Detailed hydraulic and biological (aquatic and riparian) information was collected at each of the ten sites (BIO-WEST 2004, 2005, 2006, 2007). Geomorphologic data were collected at the La Grange and Columbus study sites as well as at the United States Geological Survey (USGS) gage locations at La Grange and Columbus. Water quality information from the entire lower Colorado River was provided by the LSWP Water Quality team and included in the analysis with segment designations corresponding to those used by that study team.

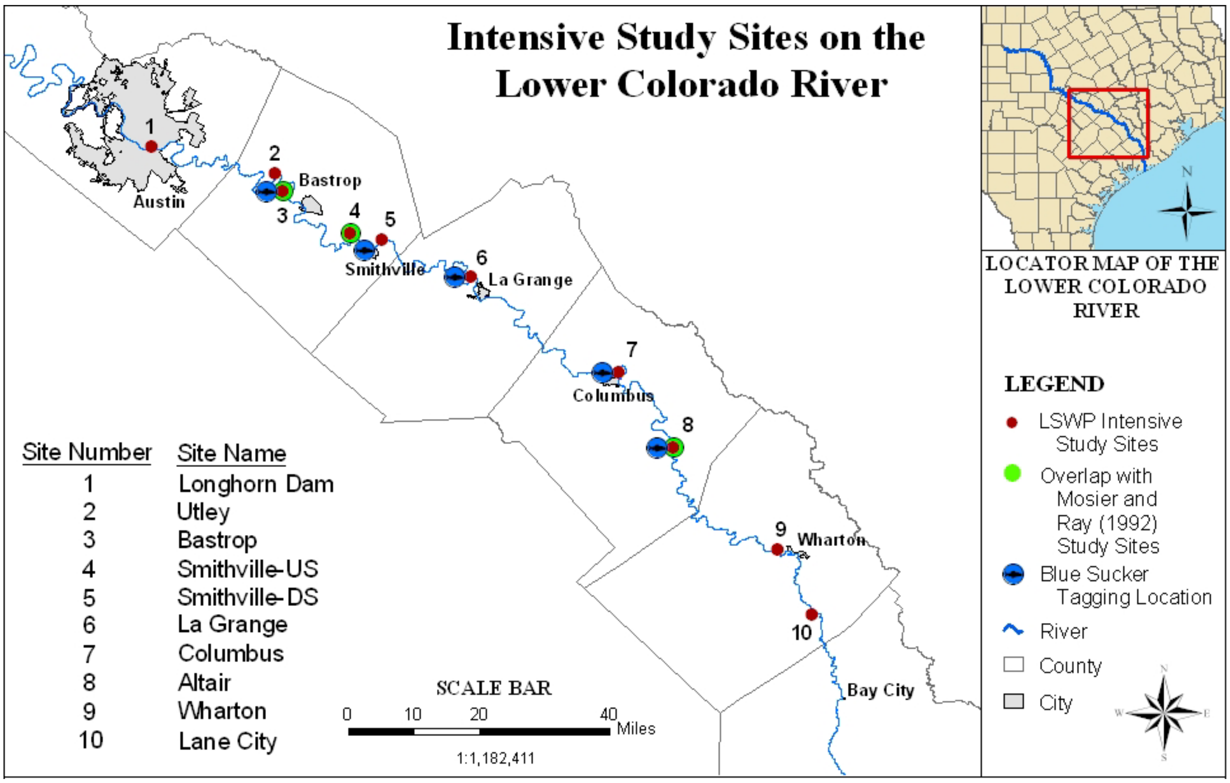


Figure 3.1. LSWP Intensive Study Sites

3.1 Hydrology and Hydraulics

3.1.1 Hydrology

Mosier and Ray (1992) provide a comprehensive overview of the major hydrological changes experienced on the lower Colorado River over the past century. For this study, additional detailed hydrologic evaluation of the historical flows in the Colorado River was conducted to aid in the development of instream flow guidelines. Statistical time-series software was used to assess current and pre-1940 (pre-Highland Lakes) conditions, quantify alteration of the quantity and timing of flows, and characterize the physical behavior of water in the system at an ecologically relevant scale. Although flows in the Colorado River downstream of Austin have been impacted by human activity for more than 100 years and there are currently diversions, return flows and low water dams, the major alteration to the natural flow regime occurred with the completion of Buchanan and Mansfield Dams (1937 and 1940, respectively) (Figure 3.2).

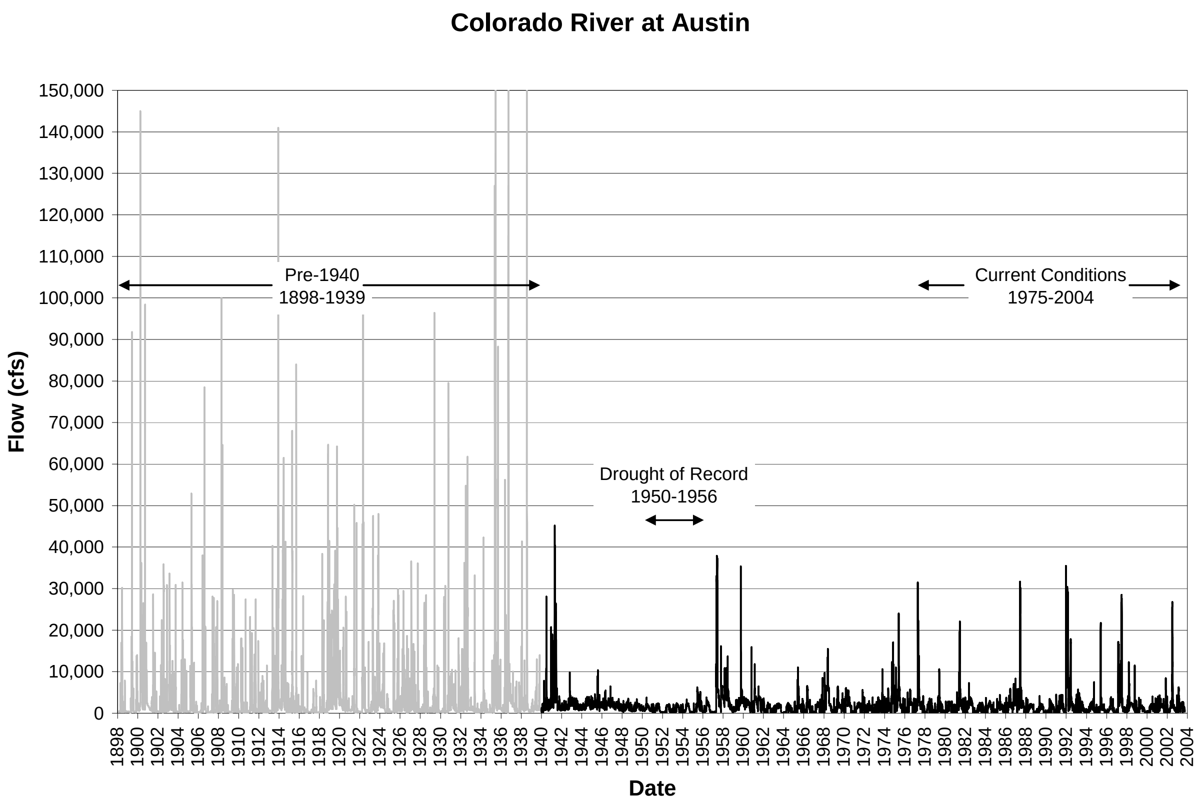


Figure 3.2. Lower Colorado River hydrograph (1898 to 2004).

For this analysis, the pre-1940 time period is used to represent "natural" conditions. Current (or "existing") conditions were evaluated using the 1975-2004 time period, since this time period was used by the LSWP Surface Water Availability Team to determine interim instream flow requirements based on the Lyon's method.

Neither the pre-1940 nor the current period includes the 1950-1956 drought of record. Flow in the lower Colorado River during the drought of record was reflective of the flow management that occurred downstream of recent, major development projects (Buchanan and Mansfield Dams); therefore, the Austin and Columbus historical records of daily flow during that period were not useful for developing instream flow recommendations. Although winter flows in the lower reaches were lower during the drought than in the pre-1940 and current time periods, summer base flows during the drought were higher than pre-1940 conditions due to releases for downstream uses. Therefore, based on available data, the operations of the system during the drought, and the approach taken in this report to develop instream flow recommendations, the drought of record was not included in flow guidelines development because it was not characterized by a daily flow regime that was either representative or extreme.

Figure 3.3 depicts a typical example of changes in the flow regime at Austin for pre-1940 and existing hydrographs using two years which had similar total annual flows. Differences in precipitation patterns aside, summer flows are elevated (irrigation releases) and winter flows somewhat depressed (recapturing storage) in the existing 1982 hydrograph relative to pre-1940 conditions.

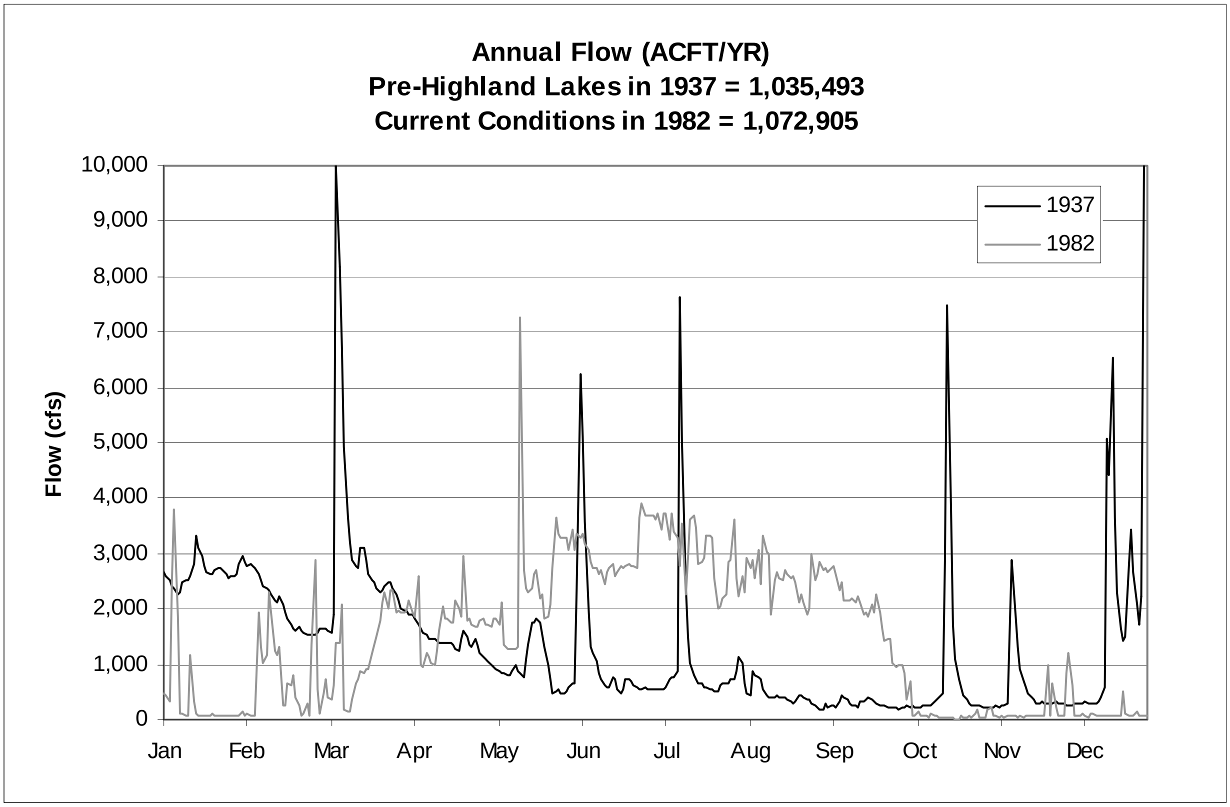
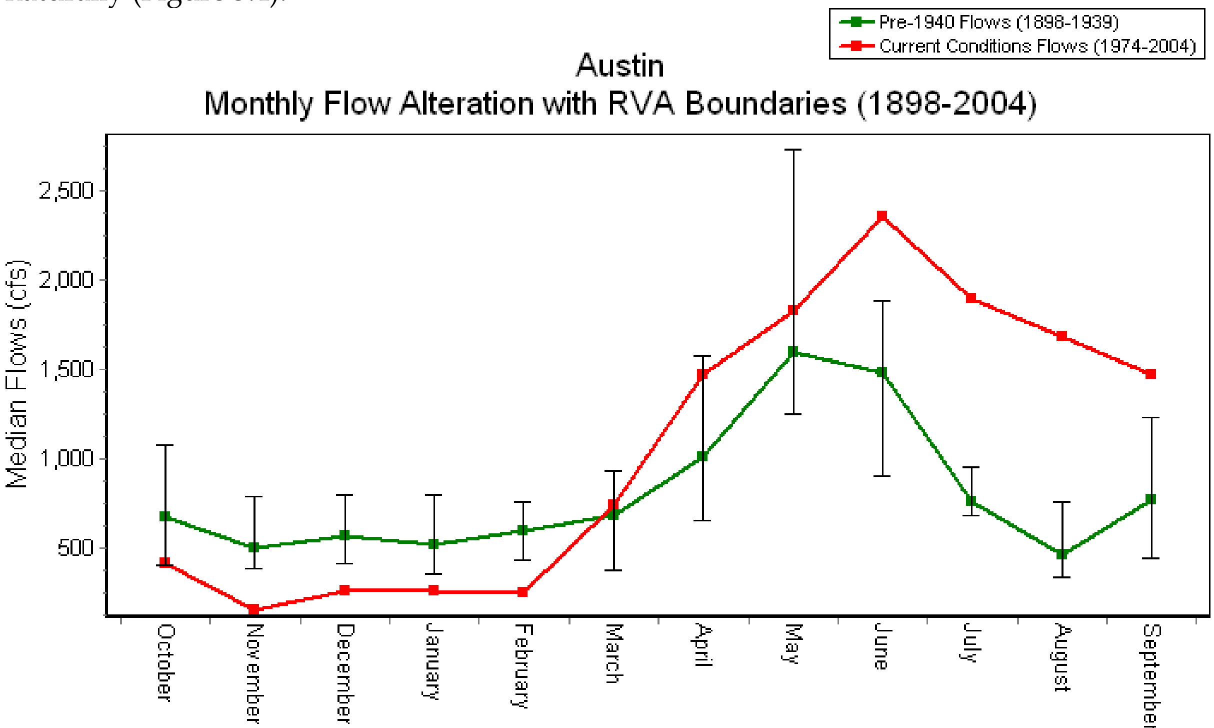


Figure 3.3. Pre-1940 and existing hydrographs for years which had similar total annual flows.

There are two USGS gages on the river with daily flow records that include data prior to 1940; 08158000 Colorado River at Austin (since 1898) and 08161000 Colorado River at Columbus (since 1916). The TIFP recommend using naturalized flows developed for the state's Water Availability Model (WAM) to characterize natural flow conditions. This analysis has not been performed as part of the present study for two reasons. First, because the long records of the Austin and Columbus gages can be used as an alternative to characterize the "natural" flow regime. Second, because a reference gage with records of an unmanaged period concurrent with the naturalized flow dataset (needed to confidently convert the monthly flows from the WAM to daily flows) is not available for this river segment downstream of Austin.

The Indicators of Hydrologic Alteration (IHA) software package was used to characterize changes in the flow regime at the Austin and Columbus gages. Range of Variability Analysis (RVA) (Richter et. al., 1997) indicates that flow conditions have been altered most in the summer (July and August), with existing conditions exhibiting higher flows than would have occurred naturally. Alteration is exhibited to a lesser extent in the fall, with November flows somewhat lower than would have occurred naturally (Figure 3.4).



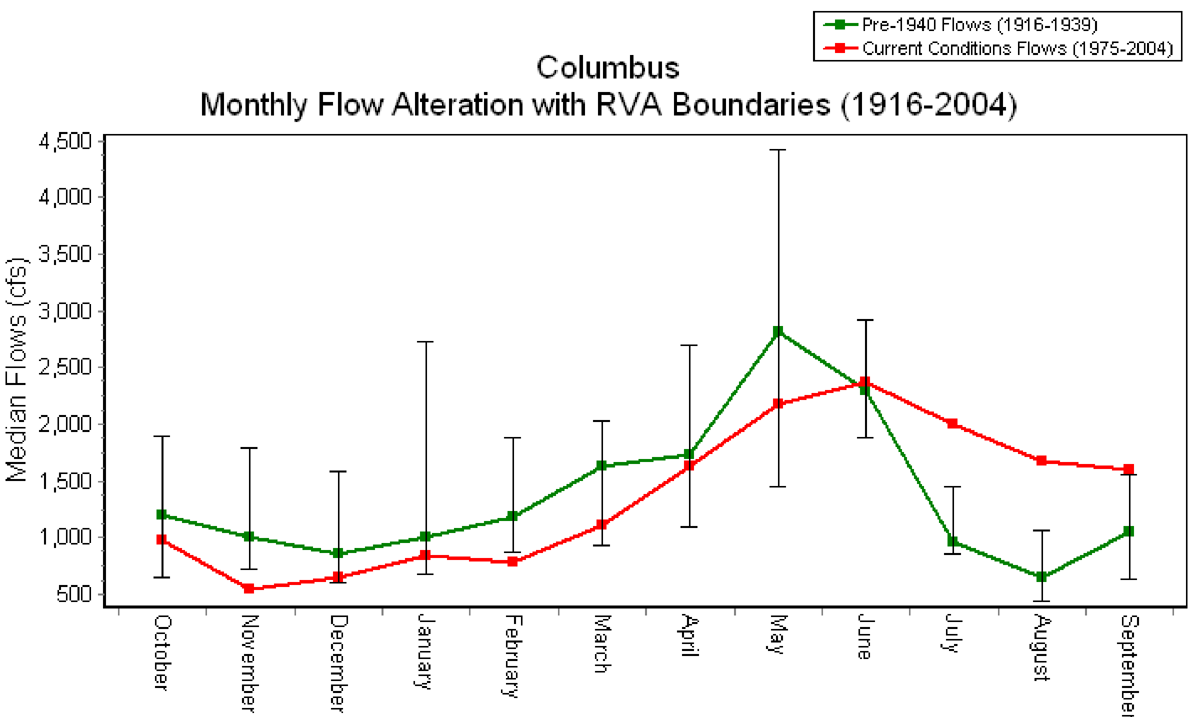


Figure 3.4. Pre-1940 versus existing comparison of median flows (range includes 25th and 75th percentiles).

The changes in median duration and frequency of extreme events have been most substantial at the higher flows, but are not significantly different (see discussion for Columbus gage below in Section 3.3.4). However, high flow magnitudes, at all durations evaluated with the IHA software, are now much lower than would have occurred naturally. The change in magnitude is to be expected since one of the purposes of the Highland Lakes is to provide flood control. The lack of change in duration and frequency of large events at the Columbus gage may be attributable to the contribution of flow from the lower-basin watershed, to management decisions related to storage of water in the highland lakes or to definition of pulse (particularly characteristics of post-flood receding limb of the hydrograph) in the IHA software.

3.2.1 Hydraulics

As outlined in the 2005 activities report (BIO-WEST 2005), the hydraulic model utilized for this project is 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 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); River2D is also reported to work well for stream restoration design (Schwartz 2003).

Work completed for this project in 2006 consisted of mesh refinement, application of substrate roughness, and calibration and validation of model output at all ten sites. Digital Terrain Models of each intensive site completed in 2005 are presented in Appendix J. Hydraulic model output was used to determine area of available habitat (see Section 4.0) for a range of flows between 150 cubic feet per second (cfs) and 8,000 cfs (Table 3.1).

Table 3.1 Modeled flow rates

Modeled flow rates (cfs)				
150	750	1,500	2,500	5,000
300	1,000	1,750	3,000	7,000
500	1,250	2,000	4,000	8,000

Model calibration was completed for at least three flow rates at each site, where one model fell generally within the range of the left column of Table 3.1, one within the center column, and one within the right column. At some sites one additional model was calibrated where field data were available. To model additional intermediate flow rates, rating curves relating flow rate to water surface elevation were developed at each site to determine boundary conditions.

A uniform, triangular, finite element mesh with 3-meter spacing between nodes (vertices) was used at each site (Figure 3.5). This node spacing allowed identification of habitat patches with surface areas as small as eight square meters. 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 ends. 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.

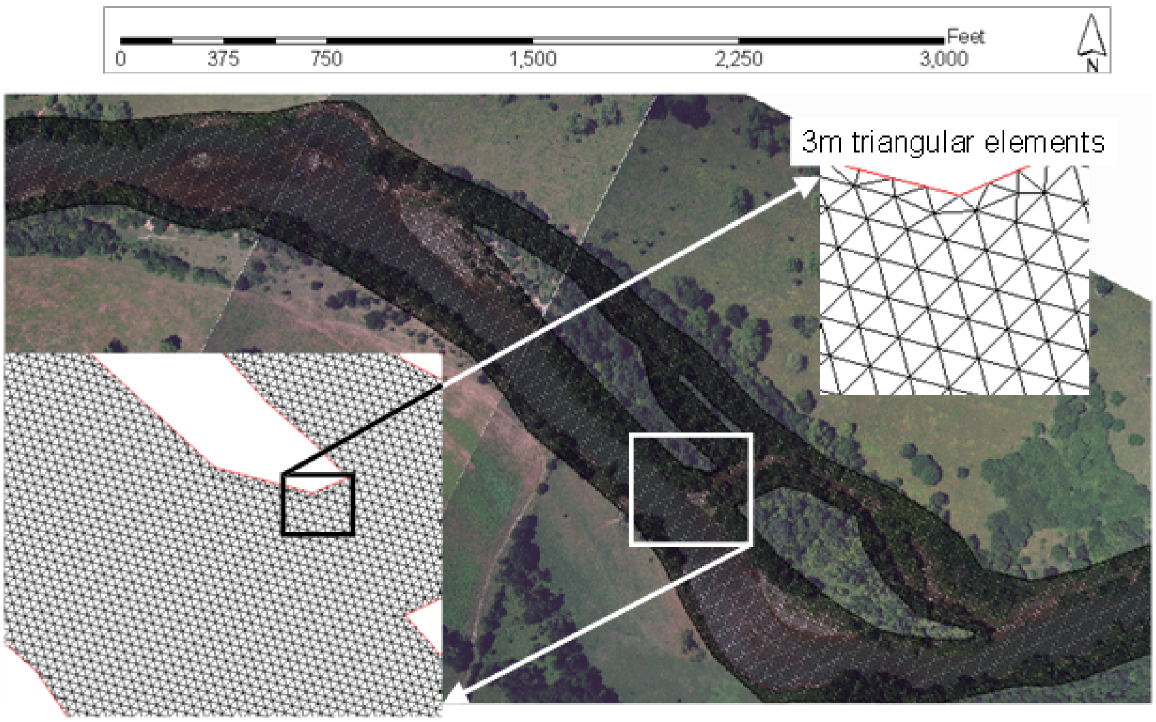


Figure 3.5 River2D model mesh with 3-meter triangular elements, Utley site (Site 2)

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 mapping and pebble counts. 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. While roughness differed at each site, roughness magnitude generally ranged from 0.004 meters (for silt), 0.06 meters for sand, and up to 1.0 meters for boulders and vegetated areas.

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 models the predicted water surface elevation profile matched observations within 2″ (5 cm) and many models matched observations within 3/4″ (2 cm). No calibrated model predicted water surface elevation more than 4″ (10 cm) higher or lower than field observations. Half of the depth and velocity field measurements were used for calibration as described above; the remaining half were compared to predictions made by calibrated models to assess accuracy. Additional validation measures include water surface elevation measurements at upstream and mid-reach locations, as well as field maps of water edge. Comparison of calibrated model predictions to validation data for the Utley site at 407 cfs (11.52 cms) and 1,930 cfs (54.65 cms) is shown in Figures 3.6-3.9.

Model validation is described in more detail in Appendix G. Across all sites where validation data is available, the mean difference between depth predictions and depth observations is -0.002 m and the r-squared is 0.826; the mean difference of velocity predictions and observations is 0.007 m/s and the r-squared is 0.741. The root mean square error (RMSE) for depth is 0.140 m and RMSE for velocity is 0.149 m/s. These validation metrics represent good correspondence between the model predictions and the field observations. A direct comparison of metrics in this study to metrics derived for other studies found in literature was difficult because a wide variety of methods have been used; however, the values from this study are comparable if not better than values presented in other studies.

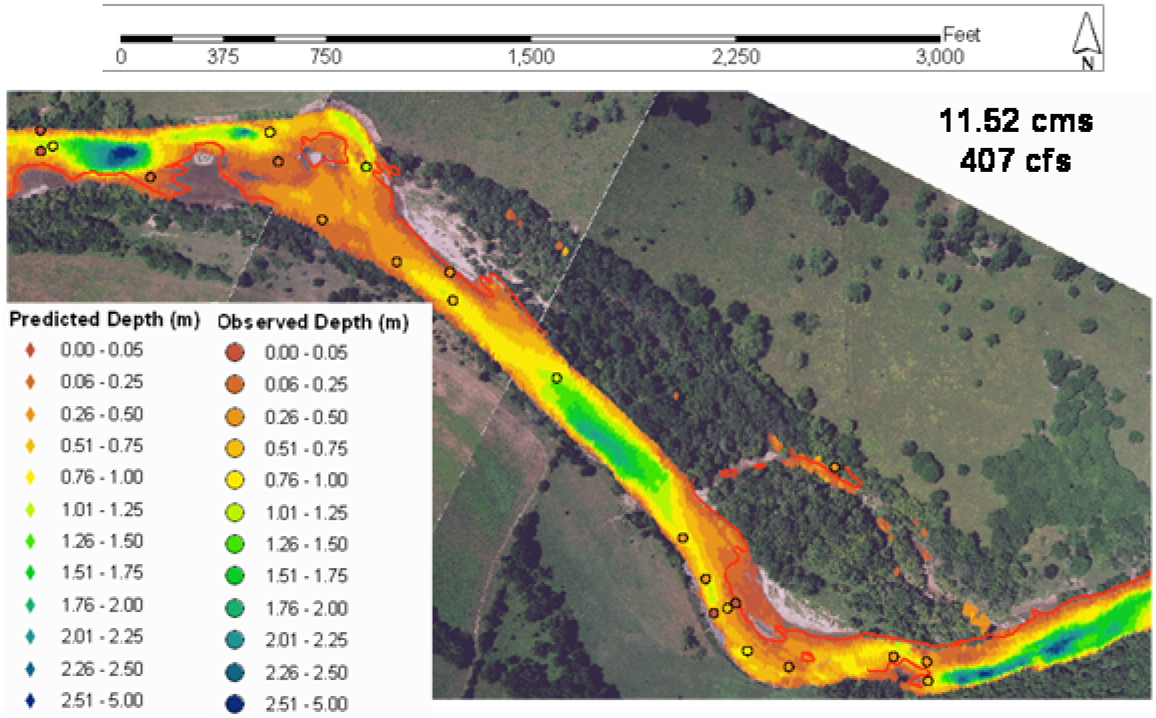


Figure 3.6 Utley, 407 cfs (11.52 cms) depth validation

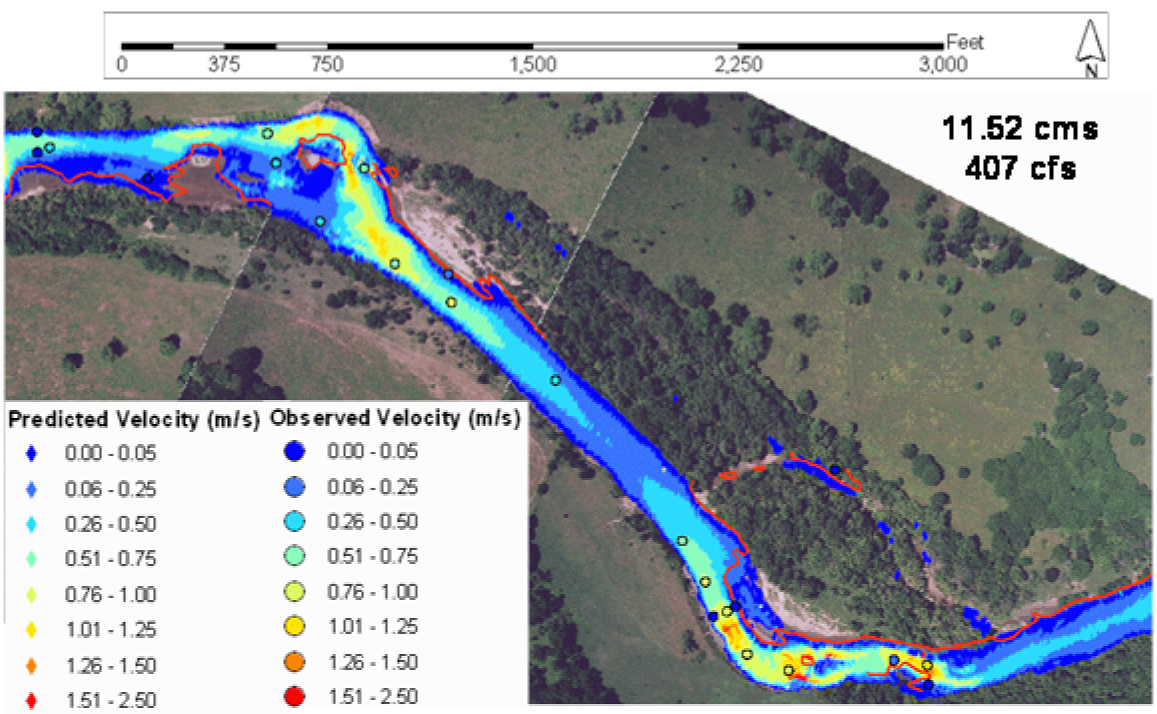


Figure 3.7 Utley, 407 cfs (11.52 cms) velocity validation

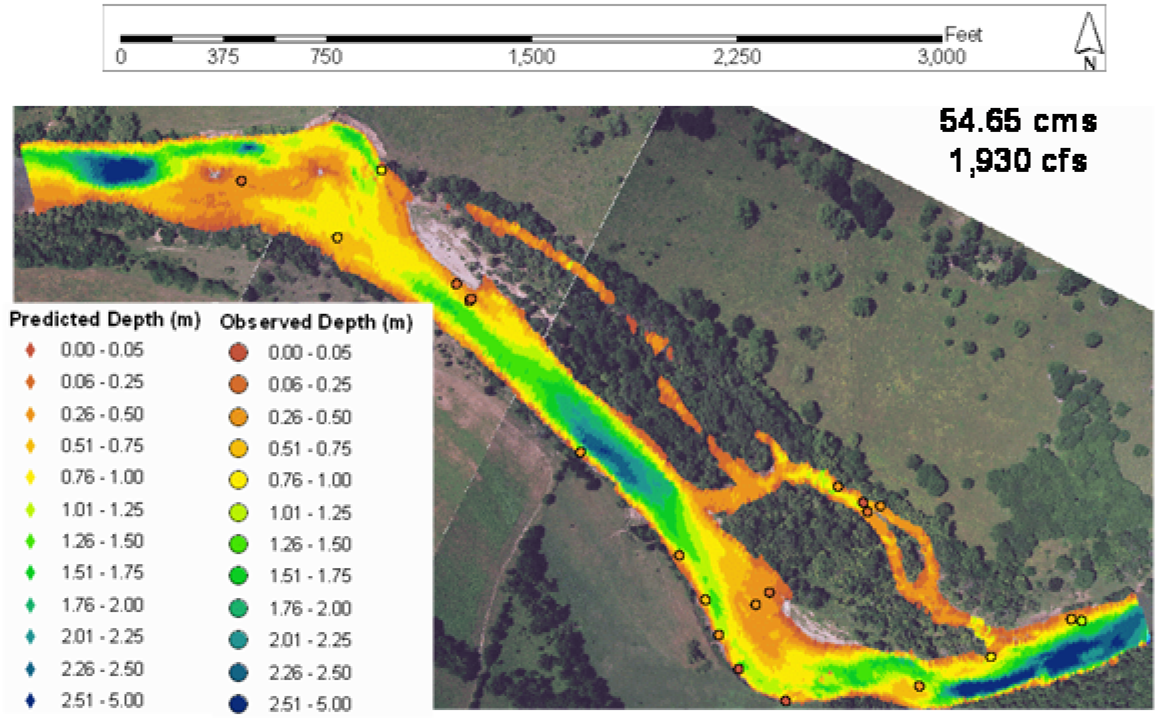


Figure 3.8 Utley, 1,930 cfs (54.64 cms) depth validation

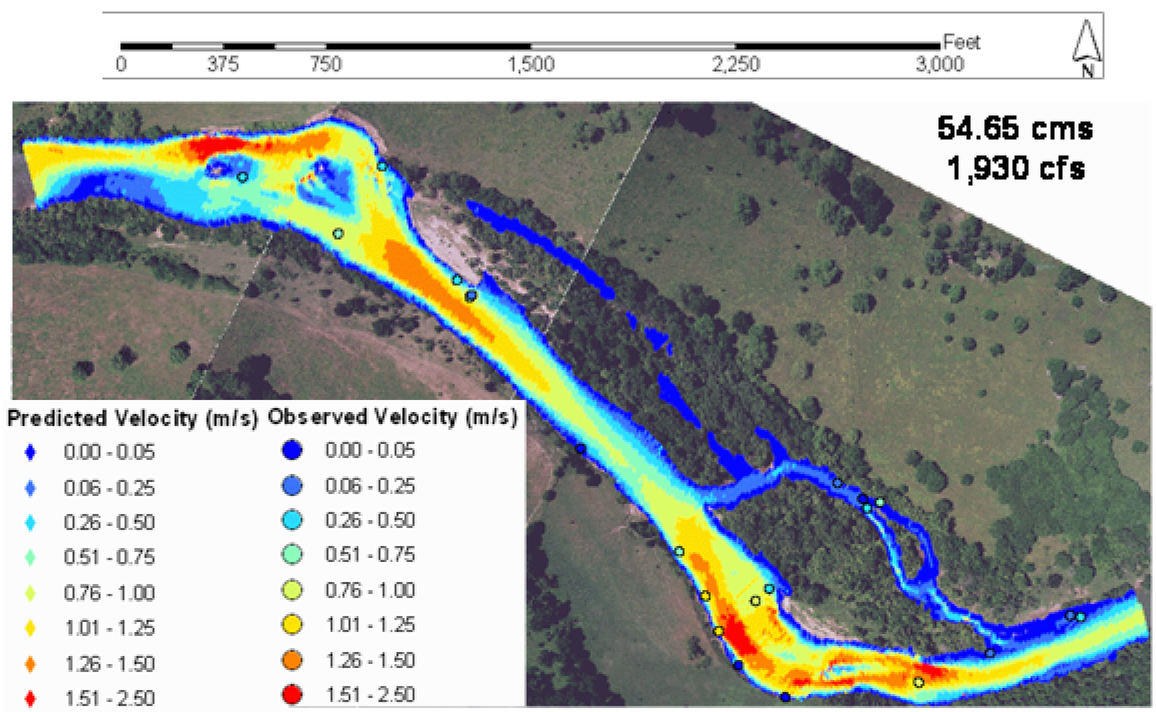


Figure 3.9 Utley, 1,930 cfs (54.65 cms) velocity validation

3.2 Biology

3.2.1 Aquatic Habitat

Habitat use data were collected in 2004-2007 using various fish sampling techniques including seining, backpack electrofishing, barge electrofishing, and boat electrofishing to provide effective coverage of a wide range of habitats. Often, a barge-mounted electrofisher with a hand-held wand was used to stun fishes in the sample area into a seine set at the downstream boundary of the sample area. During each sampling event a stratified random approach was used to sample each hydromorphologic unit (riffle, run, pool, etc.) in proportion to its relative availability. An attempt was made to sample fish from relatively small areas of approximately 3 meters x 3 meters with consistent depths, velocities, and substrates; however, exact size and dimensions were sometimes changed to facilitate sampling larger areas of relatively uniform habitat when fish densities were low. Once captured, fish were identified to species, counted, and released. Life stage (i.e., juvenile or adult) was determined based on size classifications used by Mosier and Ray (1992) for those species in which there was previous evidence of substantial ontogenetic changes in habitat use. Upon completion of fish sampling, velocity, depth, and substrate were characterized at five points representing each corner and the middle of the sampled area. Velocity and depth were measured using a Marsh-McBirney Flowmate Model 2000 portable flow meter and incremental wading rod. Dominant and subdominant substrates were classified as silt, sand, gravel, cobble, boulder, or bedrock following the standard Wentworth scale based on particle size.

During the study period, over 13,000 fish representing 15 families and 50 species were collected from various habitats of the lower Colorado River from Longhorn Dam to Wharton. Data was collected at discharges ranging from 188 to 2,030 cfs which includes much higher discharges than previously sampled by Mosier and Ray; however, these discharges are still within effective sampling conditions. Approximately 2/3 of the biological data was used for habitat guild and suitability criteria development, with the remaining 1/3 being used for biological validation. Initial habitat data collected at a range of flows during the first two years of the project were used for habitat guild and suitability criteria development. Information from additional habitat sampling conducted later, again across a range of flows, was specified for use as validation data. Validation data was not used to check habitat guild classification, rather habitat model results. However, life history information from the literature as well as observations from previous fish sampling experience fit well with guild classifications. Therefore, inclusion of validation data into habitat guild classification would likely change the outcome very little, if at all. As noted above, warmwater rivers such as the lower Colorado River maintain high species richness, and therefore, limiting habitat information to only one or two species limits the usefulness of model output. In certain cases, flows thought to protect the integrity of the river may actually be detrimental if based on needs of a few or individual species (Bain et al. 1988, Lobb and Orth 1991; Aadland 1993). Therefore, a habitat guild approach was taken in this study as a way to better represent the habitat needs of the lower Colorado River aquatic community. A habitat guild is defined as a group of species that use the same habitat types (Austen et al. 1994).

To create the habitat guilds, habitat conditions were characterized for each sample site (N=153) by averaging depth and velocity data at five individual points and converting substrate types into percent coverage within the sample site. Habitat data along with sample reach (i.e., Bastrop, Columbus, etc.) and abundance data from 29 ecological units (species or particular life stages of species) were then summarized in a Canonical Correspondence Analysis (CCA) (Figure 3.10). Ecological units with a sample size of less than 15 individuals were not included in the analysis. Since sample reach did not explain a significant portion of the variation in abundance of ecological units, it was excluded from further analysis. Based on the resulting CCA ordination plot, the 29 ecological units were grouped into five habitat guilds which were generally similar to those established by Mosier and Ray (1992). Although Mosier and Ray (1992) defined ten fundamental habitat groups, species groupings were strikingly similar to those used in the seven LSWP habitat guilds. The project team did not lump the Mosier and Ray (1992) data into the LSWP analysis. Instead, the Mosier and Ray information was used as an independent check on the LSWP guild development sampling. Depth, velocity, and substrate descriptions for each fundamental habitat group provided in Mosier and Ray (1992) (Figure V) corresponded well with habitat suitability criteria used in the LSWP study. In some instances, the LSWP suitability criteria encompassed greater depths and velocities for certain species groupings than Mosier and Ray (1992) summary data included; however, this was most likely a result of sampling under a greater variety of flow conditions including much higher flows. During development of the LSWP habitat guild classifications, the project team specifically met with Mr. Doyle Mosier (TPWD) to discuss sampling methods, flow ranges sampled, and results.

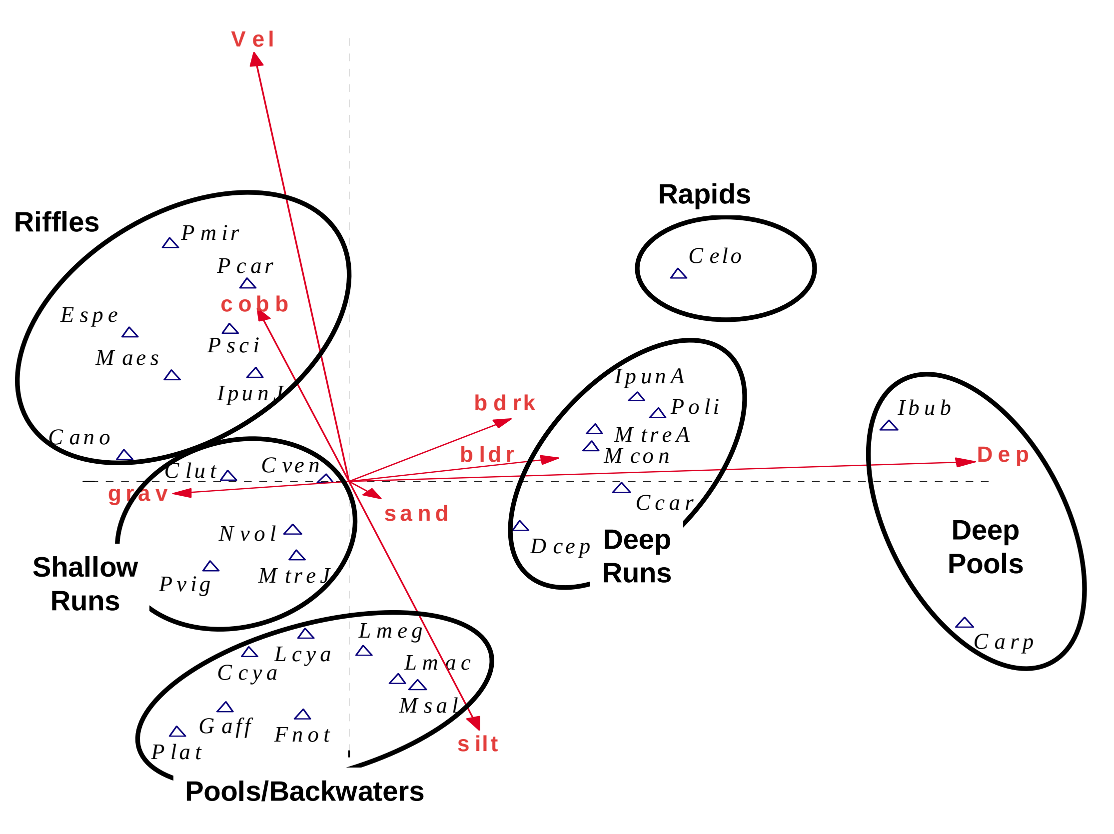


Figure 3.10. Multivariate ordination plot showing species associations among depth, velocity, and substrate gradients. Black circles designate habitat guilds.

As evident in Figure 3.10, occasionally species were located in close proximity to potential habitat guild boundaries. In these instances, life history information for those species was used to aid in final habitat guild assignment. Brief life history descriptions and observations specific to the lower Colorado River for each species used in the habitat modeling are provided in Appendix B. The species and number of fish collected in each of the defined habitat guilds are presented in Table 3.2.

Table 3.2. Habitat Guilds and blue sucker life stage categories derived from depth, velocity, and substrate use, as well as supplemental radio telemetry and spawning survey study results.

Habitat Guild	Species/Life Stage	Species/Life Stage Abbreviation	Number of Locations Where Observed	Total Number Observed
Riffles	*Percina sciera*	*Psci*	33	121
	Percina carbonaria	*Pcar*	30	95
	Ictalurus punctatus (juvenile, <180 mm)	*IpunJ*	44	640
	Phenacobius mirabilis	*Pmir*	8	65
	Etheostoma spectabile	*Espe*	13	27
	Campostoma anomalum	*Cano*	13	30
	Macrhybopsis spp.	*Maes*	21	280
Shallow Runs	*Cyprinella lutrensis*	*Clut*	66	1989
	Cyprinella venusta	*Cven*	71	1305
	Pimephales vigilax	*Pvig*	32	698
	Notropis volucellus	*Nvol*	40	516
	Micropterus treculii (juvenile, <170 mm)	*MtreJ*	31	91
Deep Runs	*Pylodictis olivaris*	*Poli*	40	107
	Ictalurus punctatus (adult, >180 mm)	*IpunA*	28	71
	Moxostoma congestum	*Mcon*	36	131
	Micropterus treculii (adult, >170 mm)	*MtreA*	13	23
	Carpiodes carpio	*Ccar*	35	215
	Dorosoma cepedianum	*Dcep*	29	451
Shallow Pools / Edge / Backwaters	*Micropterus salmoides*	*Msal*	9	19
	Lepomis megalotis	*Lmeg*	23	490
	Lepomis macrochirus	*Lmac*	21	115
	Lepomis cyanellus	*Lcya*	5	29
	Cichlasoma cyanoguttatum	*Ccya*	11	45
	Gambusia affinis	*Gaff*	14	92
	Poecilia latipinna	*Plat*	6	33
	Fundulus notatus	*Fnot*	6	15
Deep Pools	*Ictiobus bubalus*	*Ibub*	9	16
	Cyprinus carpio	*Carp*	9	18
Blue Sucker Life Stage				
Adult blue suckers / Rapids	*Cycleptus elongatus*	*Celo*	93*	102*
Spawning blue suckers	*Cycleptus elongatus*	*N/A*	10	**

*Data collected during fish sampling was supplemented with habitat data from the radio telemetry portion of the study. Each telemetry location was counted as one location and one fish observed.

**Habitat data collected at ten confirmed spawning locations, each with an aggregation of multiple fish, was used in constructing the spawning blue sucker habitat category.

For each habitat guild, suitability criteria for the continuous variables depth and velocity were created using nonparametric tolerance limits (NPTL) (Bovee 1986). The habitat criteria curves developed were based on the NPTL for the central 50%, 75%, 90% and 95% of the data. Five of the seven habitat categories were taken or interpolated from Somerville (1958) with a confidence level of 0.9. The remaining two categories were extrapolated from Somerville (1958) based on guidance provided by Dr. Thomas Hardy of the LSWP Science Review Panel. The tolerance limits for the central 50% were used as cutoffs for the most selected habitat and the range of data between these two points was given a suitability value of one. The tolerance limits for the central 75% were used to establish the range of data with a suitability value of 0.5. The tolerance limits for the central 90% were used to establish a suitability value of 0.2, and the data between the

95% tolerance limits was given a suitability value of 0.1. The range of data beyond the central 95% tolerance limit was given a value of zero and considered unsuitable. Criteria for the categorical data substrate were fitted using normalized frequencies.

Suitability criteria for all habitat guilds are presented in Appendix C. For a specific example, all habitat suitability criteria developed for the Riffle habitat guild are presented in Figures 3.11-3.13. To supplement the habitat guild approach, life-history information gathered for blue suckers was also used to develop specific habitat suitability criteria for adult and spawning habitat. Adult habitat data from the radio telemetry study was combined with biological collection data to develop the adult blue sucker habitat suitability curve. Based on the habitat guild analysis, adult blue suckers fell into a monospecific group labeled "Rapids." Therefore, this category will be referenced as adult blue sucker / rapids for this report. Finally, the habitat data collected in 2005 and 2006 at four locations with confirmed blue sucker spawning were used to create habitat suitability criteria specifically for spawning blue suckers. The habitat suitability criteria developed for the spawning blue sucker habitat category is presented in Figures 3.14-3.16 with adult blue sucker/rapids suitability criteria included in Appendix C.

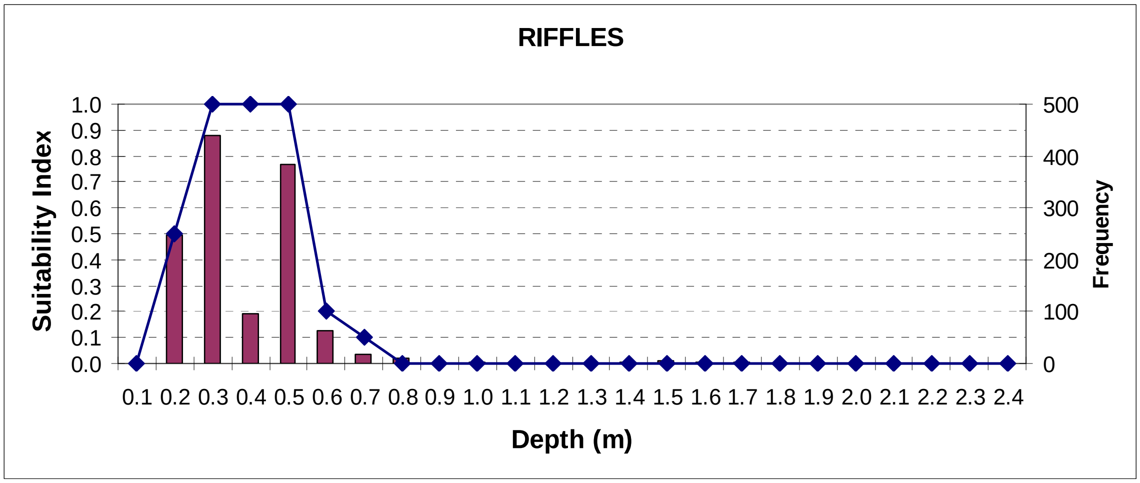


Figure 3.11 Frequency distribution and HSC values for Riffles Habitat Guild for depth in the lower Colorado River.

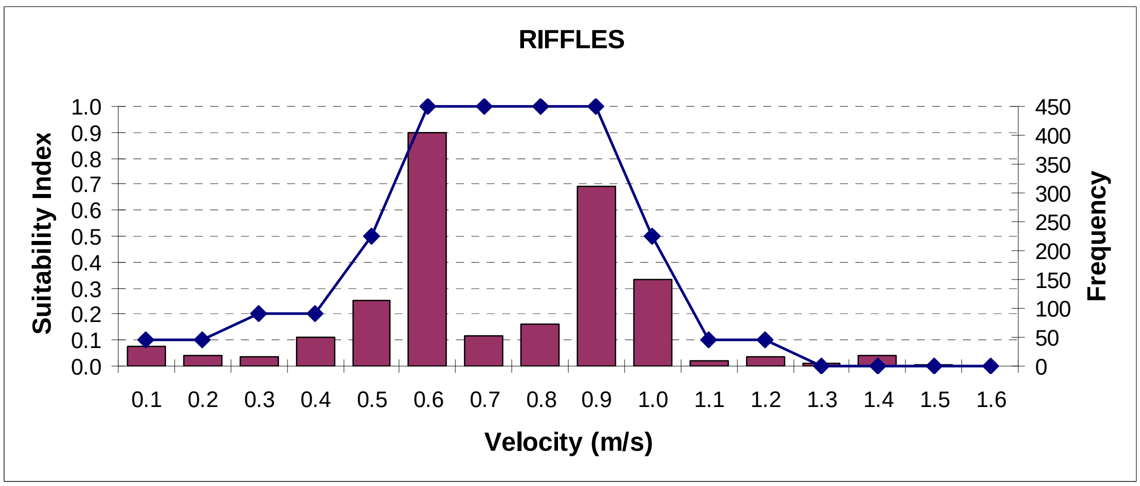


Figure 3.12 Frequency distribution and HSC values for Riffles Habitat Guild for velocity in the lower Colorado River.

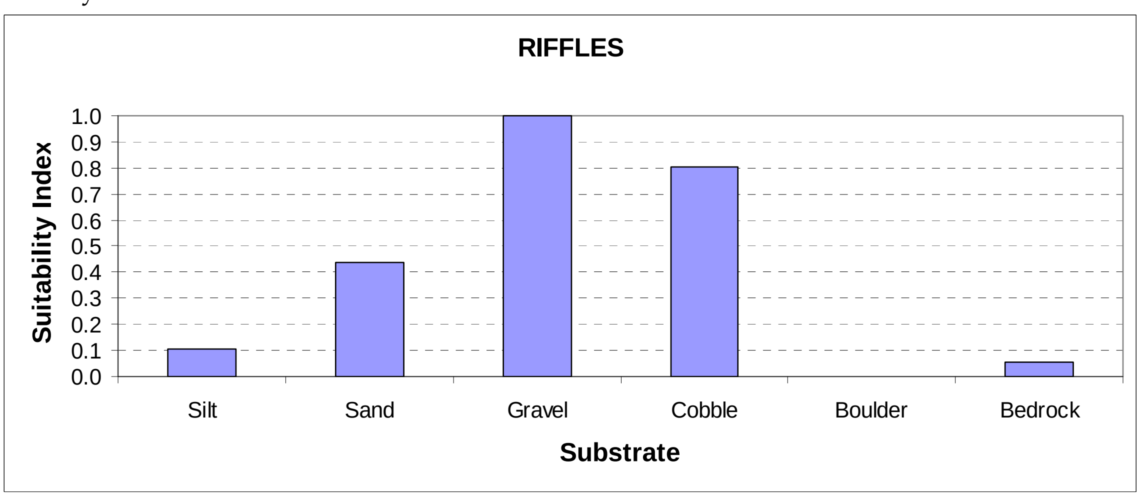


Figure 3.13 Frequency distribution and HSC values for Riffles Habitat Guild for substrate in the lower Colorado River.

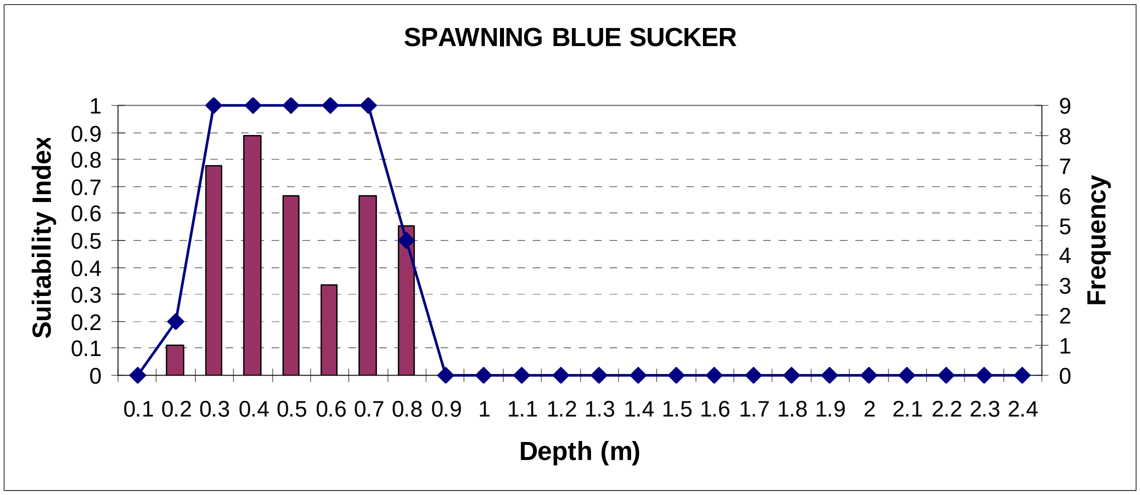


Figure 3.14 Frequency distribution and HSC values for Spawning Blue Sucker for depth in the lower Colorado River.

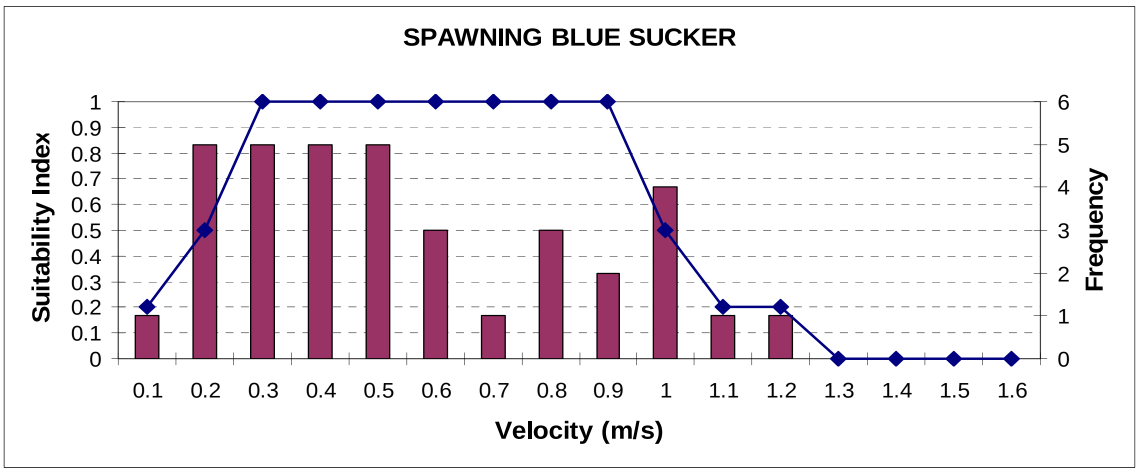


Figure 3.15 Frequency distribution and HSC values for Spawning Blue Sucker for velocity in the lower Colorado River.

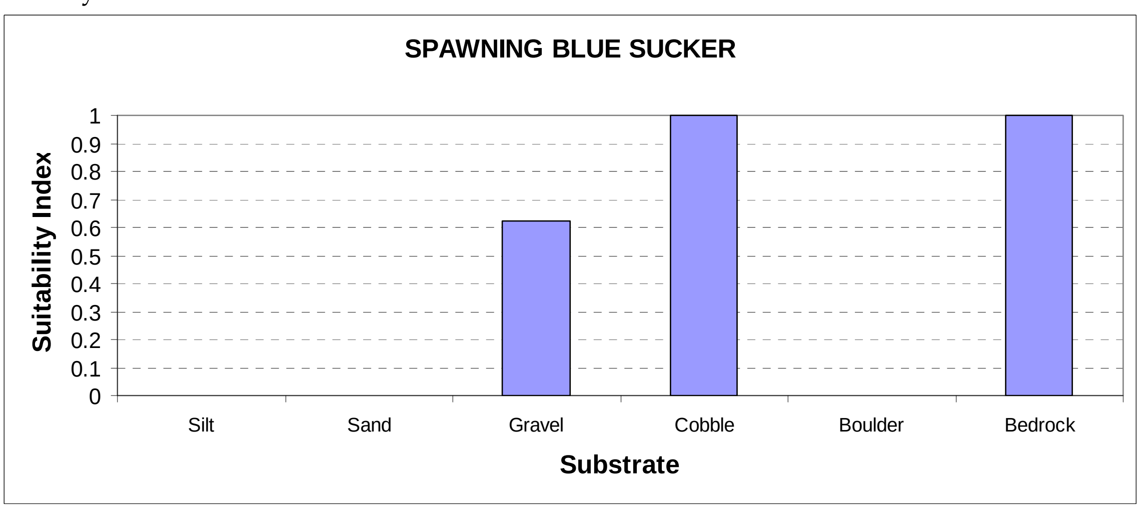


Figure 3.16 Frequency distribution and HSC values for Spawning Blue Sucker for substrate in the lower Colorado River.

Using the seven habitat categories (5 habitat guilds and 2 blue sucker life stages), the majority of the habitat types found in the lower Colorado River are represented. The one habitat type that is not represented is deep, extremely fast water. As shown in the habitat suitability curves in Appendix C, no depth is too deep for the deep run or deep pool habitat guilds (Appendix C, Figures C7 and C13) but there is a limit on velocity (Appendix C, Figures C8 and C14). No aquatic species were collected in this deep, extremely fast habitat type and therefore it was not deemed relevant for the aquatic habitat modeling portion of the study. The substrate criteria documents that the river is gravel dominated but the secondary substrates differ per habitat guild (i.e. higher silt and sand in shallow pools/edge/backwaters habitat guild [Appendix C, Figure C12]). Substrate maps for each intensive site are included in Appendix K.

3.2.2 Riparian Habitat

Detailed riparian baseline conditions were described within each of the ten intensive sites in the 2005 Activities Report (BIO-WEST 2005). Land use changes have had a strong influence on changes that have occurred in the riparian zone, with many areas being plowed for agriculture up to the river shoreline and other areas impacted by activities such as gravel mining. In addition, streamflow conditions within the lower Colorado River have been altered over the period of record, which has influenced characteristics of the riparian vegetation. The Highland Lakes have dampened the high magnitude, overbank floods that were prevalent during pre-1940 conditions, thus potentially limiting the outward lateral extent of riparian vegetation along the river corridor. However, the lateral extent of riparian vegetation is likely less influenced by water availability from the river in this region than the impacts associated with land use changes. Although the frequency of high magnitude flood events has been reduced, short-term hydrologic variability in areas near Austin has increased within the range of managed flow conditions because of hydropower peaking releases. Irrigation releases have resulted in higher-than-natural flows during the summer season and may have prevented normal inward migration of vegetation into the channel, and the associated stabilizing influence of such conditions.

As a result of land use practices and the altered hydraulic conditions since the completion of the Highland Lakes, the current riparian zone along the lower Colorado River consists of multiple terraces with varying degrees of connectivity to the river channel. The highest terrace (a part of the floodplain) has been highly altered, and the frequency of connectivity from the river channel has been greatly reduced by the man-made influences described above. Connectivity to the floodplain requires overbank flows that are controlled by climatic variability and are outside the influence of lower Colorado River operations. The lower terraces that support an active riparian zone are influenced by the hydrologic regime and geomorphic processes described in section 3.3. Summertime base flows, high flow pulses, and bankfull discharge are controlling the riparian community recruitment and establishment along the active floodplain (lower terraces) of the lower Colorado River.

Because of the importance of the hydrologic and geomorphologic conditions on riparian characteristics and the resources required to develop a suitable riparian zone model, the evaluation of hydrology and geomorphology was used to indirectly evaluate riparian conditions. The detailed riparian assessment documented in BIO-WEST (2005) will serve as a baseline starting point for long-term monitoring evaluations necessary to evaluate the effectiveness of instream flow guidelines. Riparian habitat maps from each intensive site are presented in Appendix L.

3.3 Geomorphology

On the lower Colorado River, streamflow and sediment transport dynamics shape and maintain sand and gravel bars, side channels and backwaters, riffle and pool habitats, river banks, and floodplain and terrace features. These geomorphic features provide important habitat for macroinvertebrates, fish, riparian plants, and other associated wildlife species. The flow regime associated with the proposed LSWP project has the potential to change the current timing, magnitude, and particle size distribution of sediment transport in the lower Colorado River. The changes in sediment transport, in turn, would have the potential to alter the geomorphic condition of the river and associated aquatic and riparian habitat.

A geomorphic field reconnaissance (by boat) of the lower Colorado River was conducted in February 2005 (BIO-WEST 2005). From that reconnaissance and subsequent interaction with reviewers, a sediment transport evaluation effort was implemented. The effort focused on completing a thorough geomorphic assessment to 1) appropriately divide the study area into distinct geomorphic reaches and then 2) analyze sediment transport rates and yields at select modeling transects within the intensive study sites and at nearby USGS gages.

Because no bedload data are available for the lower Colorado River and because field collection of bedload samples was beyond the scope of this project, our analysis approach relies on sediment transport modeling. Although reach-scale HEC-RAS hydraulics models have been developed for the lower Colorado River by LCRA, no sediment transport module is currently available for use in conjunction with HEC-RAS. Therefore, we opted to model transport at the four individual transects using the SAMwin Hydraulic Design Package (Thomas et al. 2002). The focus of the analysis was on the La Grange and Columbus river reaches because these reaches provide a diversity of aquatic and riparian habitat and are located immediately upstream from a potential additional instream structure that may be required should Off-Channel Storage Facilities (OCSF) be sited in Colorado County. In addition, both the La Grange and Columbus reaches have active USGS gages with good, consistent flow and discharge measurement records, and few/no changes in location or datum.

Four transects were selected for sediment transport modeling/analysis. The farthest-upstream transect is located at a bedrock riffle in the middle of the La Grange intensive study site (site 6). This transect is located approximately at River Mile 180.9, and will be referred to as “LA Site”. The next transect is located at the La Grange USGS gage (gage #08160400) at River Mile 177.9 and the new State Highway 71 bridge crossing. This transect is located in a sand-bedded “run” type habitat, and will be referred to as “LA

Gage". Continuing downstream, the third transect is located in a gravel riffle at the downstream end of the Columbus intensive study site (site 7). This transect is located approximately at River Mile 135, and will be referred to as "CO Site". The final transect is located at the Columbus USGS gage (gage #08161000) at River Mile 134 and the U.S. Highway 90 bridge crossing. This transect is located in a sand-bedded "run" type habitat, and will be referred to as "CO Gage".

<u>LA Site</u>

The project team surveyed the LA Site sediment transport modeling transect in Spring 2006 using a total station. A hand-held GPS was used to determine the real-world horizontal coordinates of the transect endpoints. A nearby benchmark established by the project team as part of the intensive study site modeling efforts (MDPIN06) was surveyed to determine the real-world elevation of the modeling transect. Flow at the nearby La Grange USGS gage at the time of the survey was approximately 500 cfs. Water surface elevations at the right and left edges of water as well as an approximate water surface slope were also surveyed.

The LA Site transect is located within a bedrock riffle. Because this bedrock is not mobile and does not characterize the size of sediment moved as bedload, we instead evaluated the size distribution of the material within a gravel bar spanned by the river-right portion of the transect (Figure 3.17). Surface material size distribution was determined by completing a pebble count (Wolman 1954) of 300 rocks on the bar. In addition, bulk sediment samples were collected at two locations on the bar. Separate surface and subsurface samples were collected at each site, for a total of four bulk samples (Figure 3.18). Samples were sieved and weighed at the Utah State University Soils Lab. The composite size distribution of the two subsurface bulk samples was used for sediment transport analysis.

Figure 3.17 Upstream view from LA Site gravel bar.

Figure 3.18 View of surface and subsurface material at one of the bulk sample sites on the LA Site gravel bar.

Cross section coordinates were input into the SAMwin hydraulic design package along with slope and roughness information to generate transect hydraulics (width, depth, velocity, shear stress, etc.) at ten flows of interest. Hydraulics were determined for flows between 170 cfs and 80,000 cfs using the "Normal Depth" and "Composite by Conveyance" options within SAMwin. Slope and roughness information were determined based on information from the River2D model for the La Grange intensive study site and from the LCRA's HEC-RAS model.

Once the LA Site hydraulics were modeled, the SAM.aid tool was used to select sediment transport equations appropriate for use at the site. The Ackers-White and Laursen (Madden) 1985 equations were used to generate transport rating curves in SAMwin. The default values in SAM were used for sediment density and water temperature (60 degrees F). A flow duration curve representing existing hydrologic conditions was developed using daily flows at the Bastrop USGS gage for the time period 1/1/75-9/30/04. This flow duration curve was input into the SAM package to generate sediment yield and effective discharge information under "existing conditions" (Figure 3.19). Data from the La Grange USGS gage were not used because of the short period of record with continuous data (1988-present).

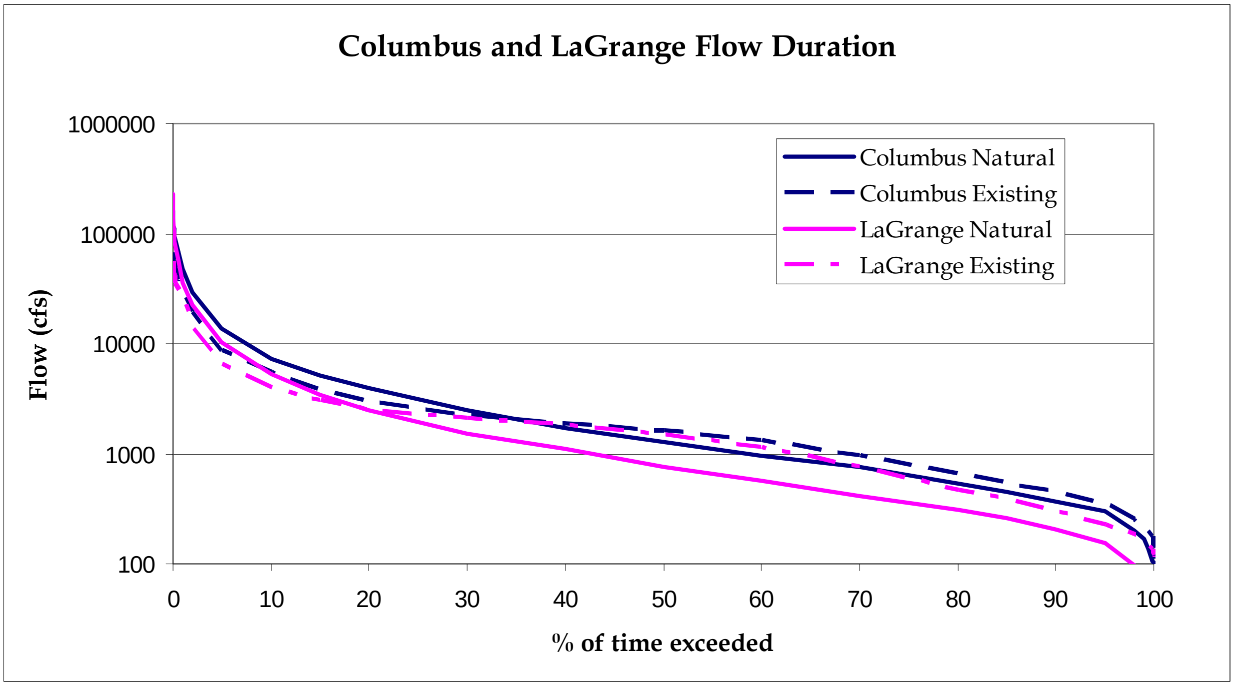


Figure 3.19. Flow duration curves used for sediment transport analysis. Data from the Austin and Bastrop USGS gages were used to develop the La Grange curves.

<u>LA Gage</u>
At the LA Gage sediment transport modeling transect, USGS discharge measurement data were used to develop hydraulic information (width, mean depth, velocity) at ten different flows. Slope data were obtained from the LCRA's Columbus Reach HEC-RAS model (which extends upstream to the La Grange USGS gage). The LA Gage transect is located in a sand-bedded, deep run habitat. Therefore, in order to characterize the substrate size distribution, bulk samples were collected from a boat using a pole-mounted sediment dredge sampler. Three evenly spaced samples were collected across the wetted portion of the channel. Samples were sieved and weighed at the Utah State University Soils Lab.

The LA Gage hydraulic data were used as inputs for the SAM.aid tool to select an appropriate set of sediment transport equations for the site. The Ackers-White, Laursen (Copeland), and Engelund-Hansen equations were used to generate transport rating curves in SAMwin. The same flow duration curve used to model sediment yield at the LA Site transect was also used to generate sediment yield and effective discharge information at the LA Gage transect.

CO Site

The project team surveyed the CO Site sediment transport modeling transect in Spring 2006 using a total station. One of the benchmarks established by the project team as part of the intensive study site modeling efforts (DSPIN07) was used as the left transect endpoint, and another established benchmark (MDPIN07) was used as a backsight to determine real-world horizontal and vertical coordinates. Flow at the nearby Columbus USGS gage at the time of the survey was approximately 416 cfs. Water surface elevations at the right and left edges of water were noted during the transect survey.

As with the LA Site, a combination of pebble counts and bulk samples were used to characterize the surface and subsurface particle sizes at the CO Site. A 300-rock pebble count was completed in the gravel riffle located in the central portion of the transect. In this same location, a bulk-sample of the subsurface material was also collected. Bulk samples of surface and sub-surface material were also collected from the sand/gravel bar spanned by the transect (Figure 3.20). Samples were sieved and weighed at the Utah State University Soils Lab. The composite size distribution of the two subsurface samples was used for sediment transport analysis.

Figure 3.20 View of surface and subsurface material at the bulk sample site on the CO Site bar.

Cross section coordinates were input into the SAMwin hydraulic design package along with slope and roughness information to generate transect hydraulics (width, depth, velocity, shear stress, etc.) at ten flows of interest. Hydraulics were determined for flows between 250 cfs and 69,000 cfs. Slope and roughness information were determined based on information from the River2D model for the Columbus intensive study site and from the LCRA's HEC-RAS model.

Once the CO Site hydraulics were modeled, the SAM.aid tool was used to select sediment transport equations appropriate for use at the site. The Ackers-White, Laursen (Madden) 1985, Laursen (Copeland), and Engelund-Hansen equations were used to generate transport rating curves in SAMwin. A flow duration curve developed using daily flows at the Columbus USGS gage for the time period 1/1/1975-9/30/2004 was input into the SAM package to generate sediment yield and effective discharge information under existing conditions (Figure 3.19).

<u>CO Gage</u>
At the CO Gage sediment transport modeling transect, USGS discharge measurement data were used to develop hydraulic information (width, mean depth, velocity) at ten different flows. Slope data were obtained from the LCRA's Garwood Reach HEC-RAS model (which extends upstream to the Columbus USGS gage). The CO Gage transect is located in a deep, sand-bedded run/pool habitat. Bulk substrate samples were collected at three points distributed across the wetted portion of the channel along the transect. Samples were sieved and weighed at the Utah State University Soils Lab. The composite size distribution of the three samples was used for preliminary sediment transport analysis.

The CO Gage hydraulic data were used as inputs for the SAM.aid tool to select an appropriate set of sediment transport equations for the site. The Ackers-White, Laursen (Copeland), and Engelund-Hansen equations were used to generate transport rating curves in SAMwin. The same flow duration curve used to model sediment yield at the CO Site transect was also used to generate sediment yield and effective discharge information at the CO Gage transect (Figure 3.19).

3.3.1 Hydraulics and Sediment Size

Hydraulic and sediment size characteristics are summarized in Table 3.3 for the 30,000 cfs discharge level. The LA Site is the highest gradient, shallowest and coarsest transect analyzed. The LA Gage and CO Gage transects are fairly similar hydraulically, and are much lower gradient and finer-grained than the LA Site. The CO Site is intermediate between the LA Site and the Gage sites.

Table 3.3. Comparison of particle size and hydraulic characteristics at the four sediment modeling transects.

Transect	Median (D50) particle size (mm)	Hydraulic Characteristics at 30,000 cfs			
		Velocity (ft/s)	Mean Depth (ft)	Top Width (ft)	Slope (ft/ft)
LA Site	38 (surface) 20 (subsurface)	5.20	13.36	432	0.0008
LA Gage	0.5	4.37	17.8	386	0.00024
CO Site	3 (surface at bar) 23 (surface in channel) 0.8 (subsurface)	3.74	15.6	513	0.0004
CO Gage	0.35	4.00	17.2	432	0.00017

3.3.2 Sediment Rating Curves

Rating curves for total sediment load at the four analysis transects are shown in Figures 3.21-3.24. Although the curves vary depending on the transport equation used, several trends are apparent when the results from a single equation (Ackers-White) are compared among the transects. The LA Site and CO Site have relatively flat curves, and transport sediment even at flows below 1,000 cfs. The LA Gage and CO Gage have steeper curves, and do not begin transporting "substantial amounts" (arbitrarily defined as 100 tons/day for the purposes of this discussion) of sediment until flows exceed 2,000 and 4,000 cfs, respectively. The steepness of these curves is partly due to the fact that these transects are located in areas where the water surface slope increases as flow increases, thus leading to greater transport rates. In addition, more fine-grained sediments are available for transport at the gage transects.

These same trends in rating curve steepness are apparent when the gravel (particles 2mm and greater) and sand (particles less than 2mm) fractions are plotted separately (Figures 3.25 and 3.26). At both the LA Site and CO Site, which are located in riffles, substantial sand transport occurs even at low flows of 500 cfs. At the LA and CO gage sites, sand transport does not become substantial until flows exceed about 2,000 and 4,000 cfs, respectively. However, at high flows, greater sand transport rates occur at the deeper gage transects than at the LA Site and CO Site riffle transects (Figure 3.25 and 3.26). Gravel transport rates are always significantly lower than sand transport rates at the modeled transects. For the purposes of this discussion, a "substantial amount" of gravel is arbitrarily defined as 1 ton/day. Substantial gravel transport occurs earliest at the high gradient LA Site transect (at about 1,300 cfs), followed by the CO Site (at about 8,000 cfs), then the LA Gage transect (at about 19,000 cfs) and finally the CO Gage transect (at about 28,000 cfs).

As discussed in Section 3.1, the pre-1940 flow regime exhibited lower summertime monthly flows than the existing (1975-2004) period. Although the rating curves provided in Figures 3.21-3.26 are not calibrated to field-measured values and there is substantial scatter in the data depending on the transport equation selected, it can be concluded that sand transport rates were lower under the pre-1940 flow regime than under existing hydrologic conditions. The difference between pre- and post-1940 summertime transport rates would be greatest at the LA Gage and CO Gage transects, which have steeper rating curves. At these gage sites, transport rates likely dropped to near zero during pre-1940 summertime flow conditions. Pre-1940 sand transport rates would also have been lower in riffle areas like the LA Site and CO Site transects.

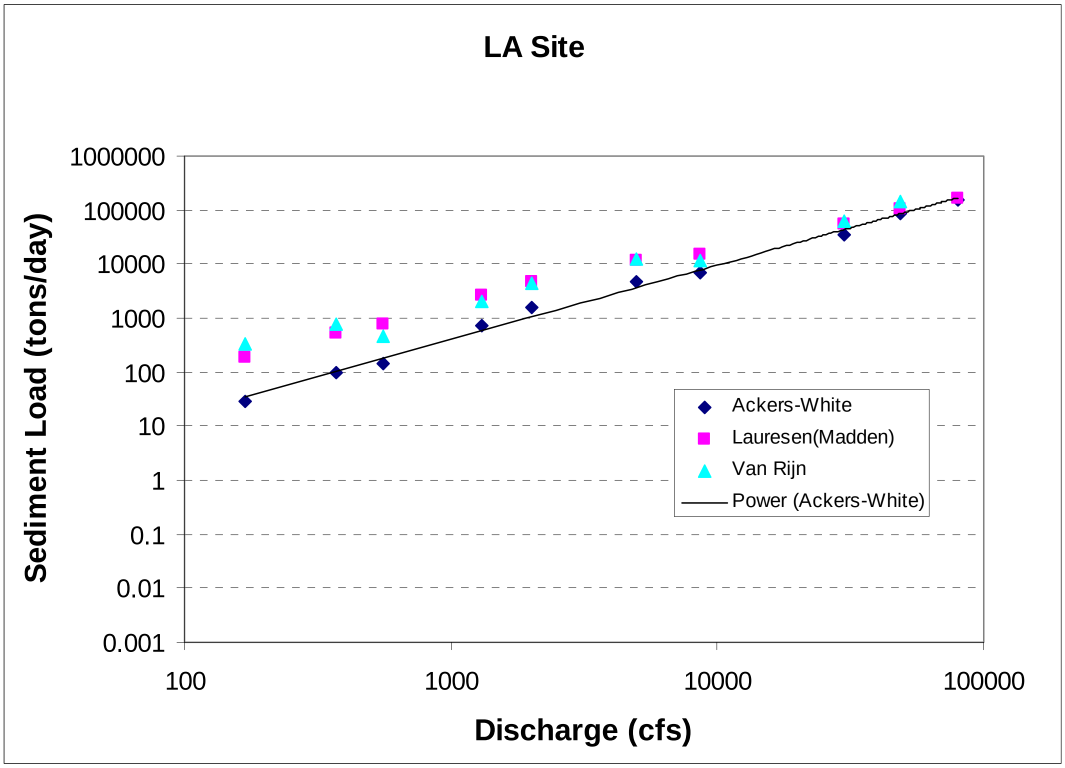


Figure 3.21. Sediment rating curves for LA Site.

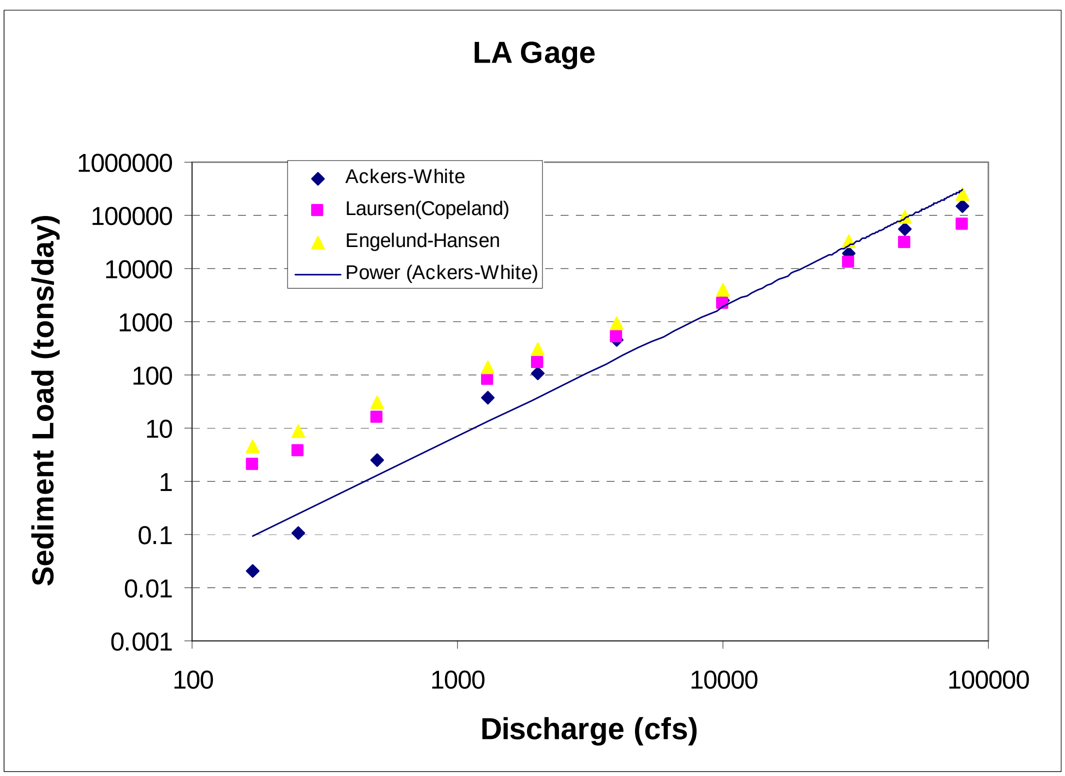


Figure 3.22. Sediment rating curves for LA Gage.

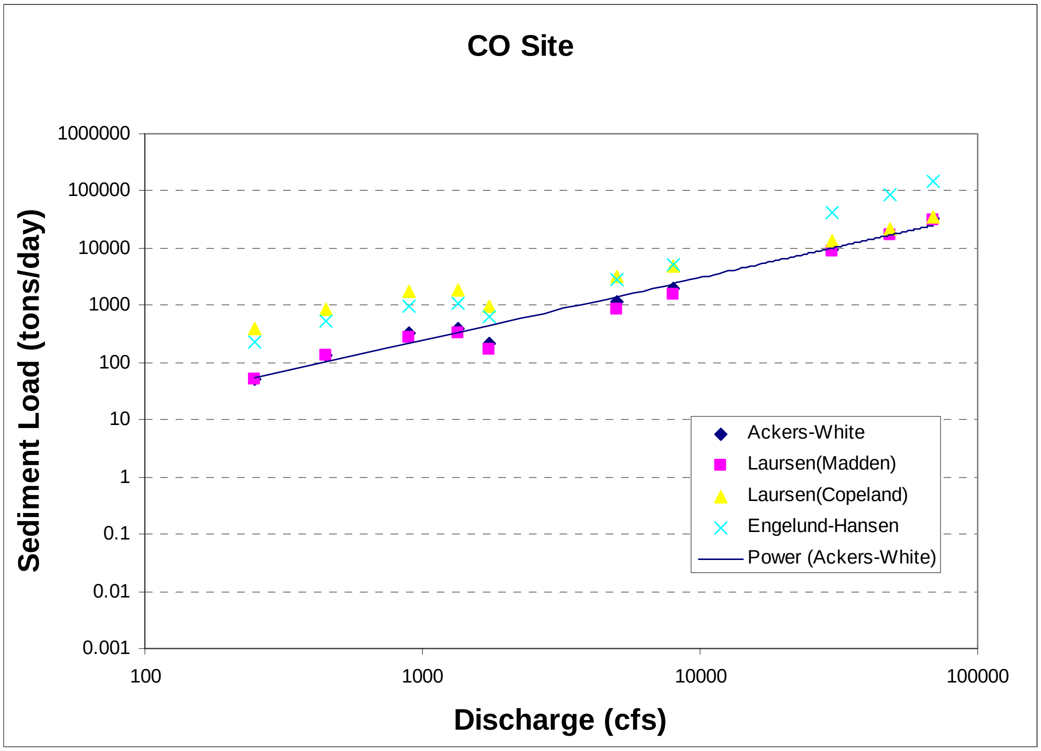


Figure 3.23. Sediment rating curves for CO Site.

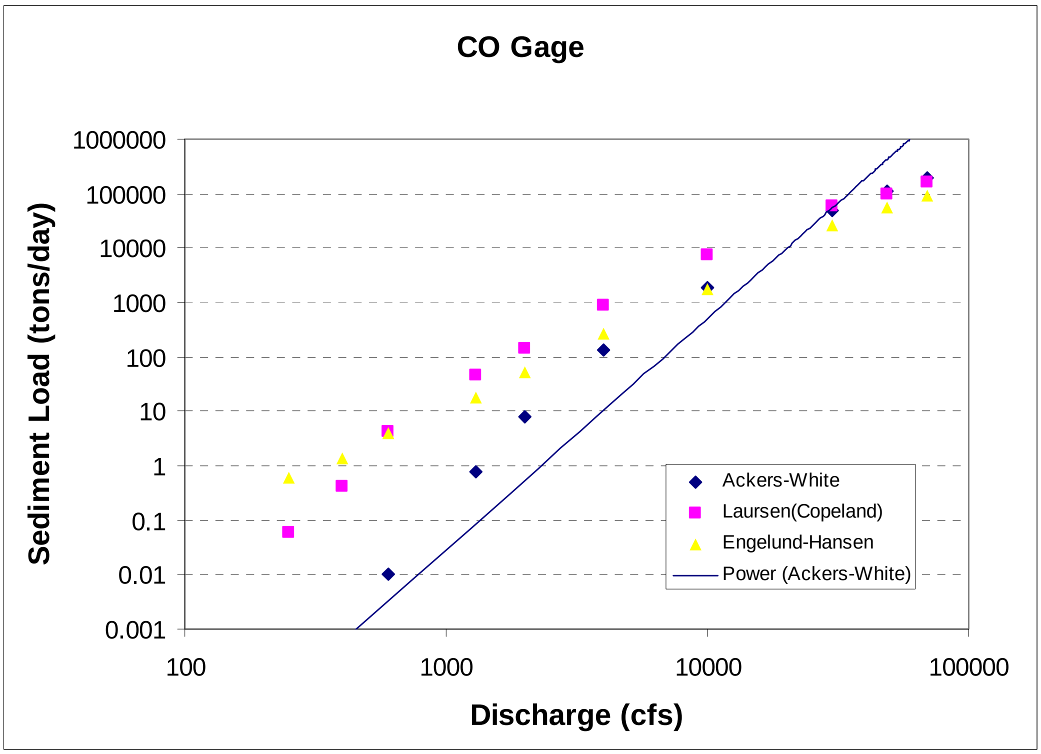


Figure 3.24. Sediment rating curves for CO Gage.

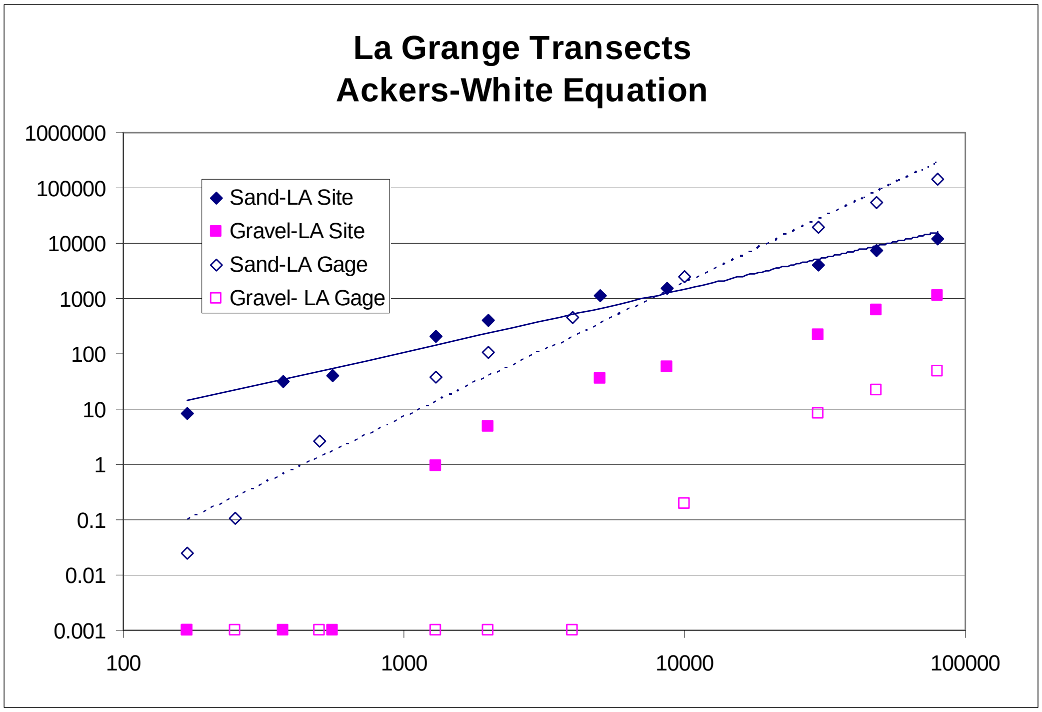


Figure 3.25. Sand and Gravel transport rating curves at La Grange sites.

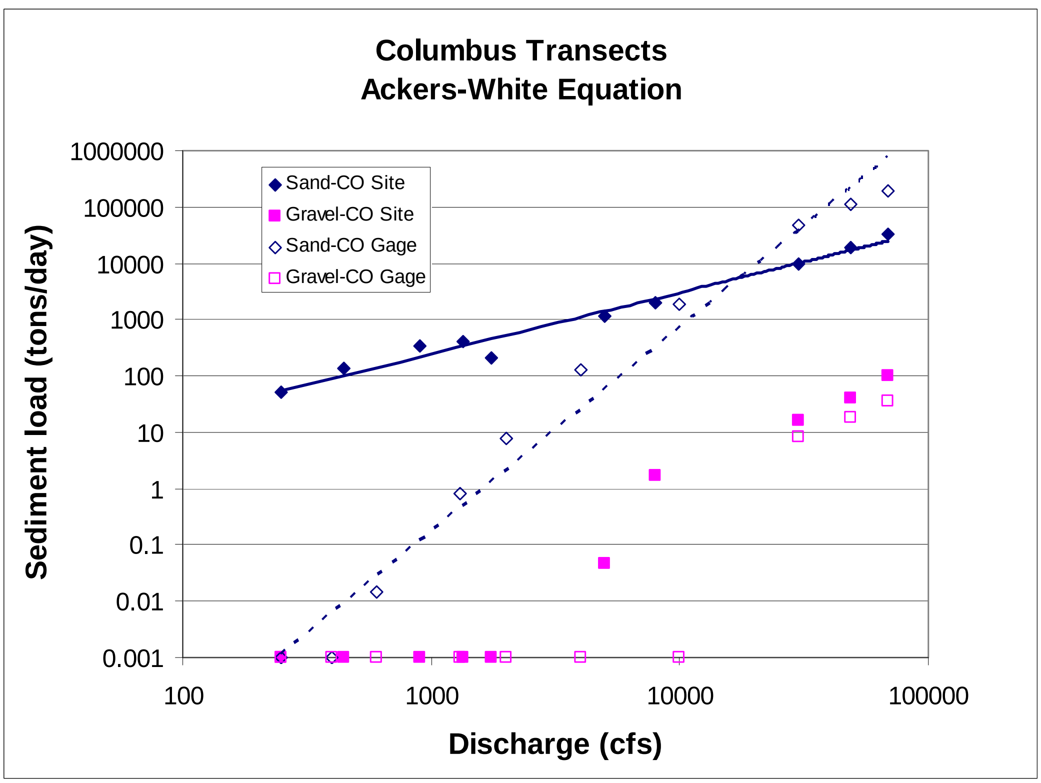


Figure 3.26. Sand and Gravel transport rating curves at Columbus sites.

Under existing summertime conditions where flows are typically held at approximately 1,000 - 2,000 cfs, a large portion of the streambed in the river is constantly in motion. Under these existing conditions, the sand moving through riffle and run areas most likely accumulates in the flattest-gradient, lowest-velocity pool and backwater areas of the river. In a more natural flow regime with reduced transport rates, sediment would tend to accumulate less rapidly in these low velocity habitats during summertime low flows, and they would be retained as deeper, more diverse habitat features. In addition, less winnowing/transport of sand would tend to occur along the channel margins. New shoreline sand deposits would potentially develop in areas that are not already dominated by sand, providing more gradually-sloping banks and bar features with greater near-bank topographic complexity. These shoreline sand deposits could also provide establishment sites for emergent and herbaceous riparian vegetation. This type of vegetation provides cover and shade for shallow, slackwater-type habitats, and serves as a source of nutrients and organic matter. This type of non-woody vegetation provides ecosystem benefits as long as it is periodically scoured by high flows so that stands do not reach densities that would have negative impacts in terms of reducing channel capacity.

Reduced baseflows could also lead to new deposits of fine gravel in steep riffle areas. A return to more natural summertime baseflow conditions would lead to less mobile summertime substrate conditions. Although our sediment transport analysis suggests that these would be the general geomorphic trends under altered hydrologic conditions, it is important to keep in mind that summertime sediment transport rates are only one variable affecting channel morphology. In some years, summertime high flow events will occur that could reset channel conditions (e.g., scour away new sand bars). The trend toward less mobile summertime substrate conditions and increased complexity of edge habitat and bar features would likely only be apparent as a long-term central tendency of the system. Nevertheless, such a trend would alter the disturbance regime of the lower Colorado River during the summer season. Under the existing summertime flow conditions, sand is constantly in transport across most of the streambed. This condition creates a situation of constant, chronic substrate disturbance, which can negatively affect macroinvertebrate populations.

3.3.3 Effective Discharge

Plots of the percentage of annual sediment load transported by different discharge increments are provided in Figure 3.27. These plots are the product of the sediment transport rating curve and the flow duration curve (discharge frequency curve). Although the highest-magnitude flood flows have the greatest sediment transport capacity, they occur very infrequently. Therefore, they are not typically the flows that transport the greatest amount of sediment over a long period of time. Typically, moderate-magnitude flood flows which occur more regularly (e.g., 1 or 2-yr recurrence interval floods) transport the greatest amount of sediment. This flow (the peak discharge increment on plots such as Figure 3.27) is known as the "effective discharge", and has been found to approximately equal the bankfull discharge (Andrews 1980, Leopold 1992, Andrews and Nankervis 1995).

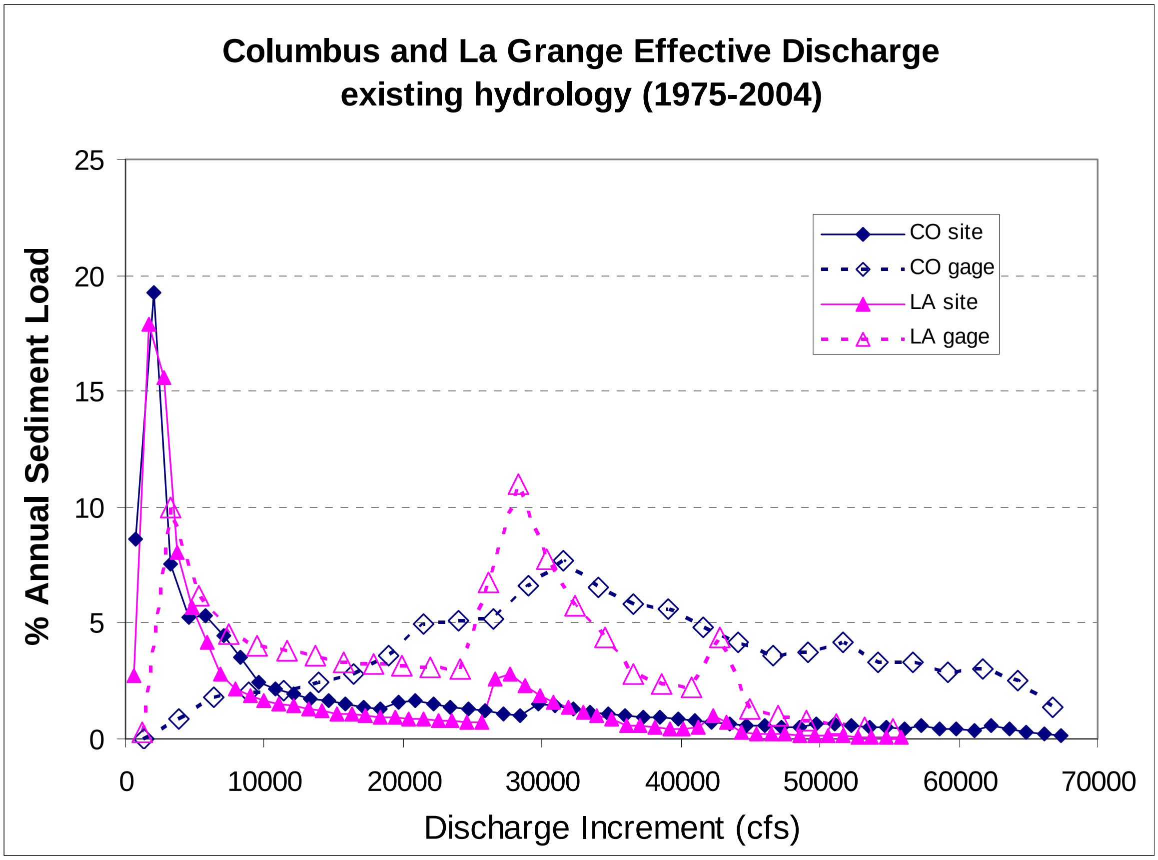


Figure 3.27. Effective discharge plots for Columbus and La Grange transects.

Several trends are apparent in the plots for the different analysis transects. At both the LA Site and CO Site, the greatest proportion of total sediment is transported by low flows. At the LA Site, the peak occurs at the discharge increment of about 1,700 cfs; at the CO Site, the peak occurs at the discharge increment of about 2,000 cfs. At these relatively low flow ranges, sand-sized particles are being transported while little to no gravel is mobile (Figures 3.25 and 3.26).

The curve for the LA Site has a strong secondary peak at the discharge increment between about 26,000- 29,000 cfs (Figure 3.27). This flow range is the effective discharge for gravel transport at the site. Minor secondary peaks can be seen in the CO Site curve at about 21,500 cfs and 31,500 cfs, when gravel would be in transport at the site. This gravel-based effective discharge is important for channel (and riffle) maintenance, and flows of this size reach the top of the banks at the CO Site and LA Site transects. Flows of this size are equaled or exceeded between 0.5-2% of the time (Figure 3.19). It is evident that the majority of gravel-sized sediment at these sites is transported by moderate-magnitude, commonly occurring flood flows.

The sediment yield plot for the LA Gage has its primary peak at a discharge of about 28,000 cfs, with a secondary peak at about 2,700 cfs. Although flows of 2,700 cfs do not transport sediment at a rapid rate (Figure 3.22), flows in this range occur frequently and over time transport a substantial volume of material (primarily sand in this case). The

CO Gage site does not exhibit the lower-flow peak seen in the plots for the other sites (Figure 3.27). This is because the CO gage is located in an area with a very flat water surface slope at low flow that is not able to transport significant quantities of sediment of any size until higher discharges. The CO gage peak occurs at a flow of about 31,500 cfs. Effective discharge for the gage transects (28,000-31,500 cfs) is essentially equivalent to the gravel-based effective discharge at the CO Site and LA Site transects.

3.3.4 Pulse Flow Hydrologic Evaluation

In addition to modeling sediment transport, hydrologic analyses were also completed to identify the characteristics of pulse flows on the lower Colorado under pre-1940 ("natural") and existing flow conditions. Specifically, the Indicators of Hydrologic Alteration (IHA) software program (TNC 2006) was used to generate a variety of hydrologic parameters using daily flow data at the Columbus USGS gage as input into the program. The Columbus gage was selected for IHA analysis because of its proximity to the sediment transport analysis transects and its long, continuous period of record. Water years 1917-1939 were analyzed as the "pre-impact" (i.e. natural/pre-1940) time period; water years 1975-2004 were analyzed as the "post-impact" (existing) time period. Pre- and post-impact are simply terms used in the IHA program.

Within IHA, a non-parametric analysis was completed using IHA default values to define hydrologic parameters and instream flow components. Version 7 of IHA defines high pulse flows in two different ways. The IHA parameter "high pulse" is defined as any flow that exceeds the pre-impact 75th percentile flow (using the default non-parametric threshold). The Environmental Flow Component (EFC) parameter "high flow pulse" has a more complex definition. Rising flows between the pre-impact 50th-75th percentile flows as well as any flows above the pre-impact 75th percentile flow are considered high flows (using the default non-parametric thresholds/definitions). However, the EFC algorithms classify "high flows" into three categories: high flow pulses, small floods (high flows with return intervals between 2 and 10 years), and large floods (high flows with return intervals of 10 years and greater). Therefore, the EFC "high flow pulses" exclude the larger-magnitude floods and more specifically define flow events that exceed average/ baseflow conditions but are not great enough to be considered actual "floods" (see TNC 2006 for more details regarding these parameter definitions). For the purposes of our analysis, we examined the magnitude, frequency, and duration of both the IHA "high pulse" and EFC "high flow pulse" outputs to help define recommendations for pulse flows on the lower Colorado River.

Results of the IHA high flow pulse analyses are summarized in Table 3.4. Flows classified as "IHA High Pulses" are flows above the pre-impact 75th percentile flow of 3,178 cfs. Flows classified as "EFC High Flow Pulses" include flows within the overall range of 1,300 cfs (the pre-impact 50th percentile flow) up to 43,600 cfs (the EFC small flood threshold); however, not all flows within the range are necessarily classified as EFC high flow pulses depending on their rising or falling trends (see TNC 2006 for details).

Table 3.4. Results of IHA analysis of lower Colorado River flows at the Columbus USGS gage.

	Pre-1940 (1917-1939)			Existing (1975-2004)		
Parameter	25% Value	Median Value	75% Value	25% Value	Median Value	75% Value
IHA High Pulse Count (events/yr)	6	10	13	4.75	8	13
IHA High Pulse Duration (days)	3	4	5.5	2	3	4.125
EFC High Flow Pulse Frequency (events/yr)	9	11	15	8	11.5	15
EFC High Flow Pulse Duration (days)	5	5	7	3.4	4.75	5
Annual 1-day Maximum Flow (cfs)	26,300	43,600	99,200	11,530	23,900	50,680
Annual 3-day Maximum Flow (cfs)	18,670	37,970	90,000	8,235	19,690	40,540

As seen in Table 3.4, existing high pulse characteristics remain quite similar to pre-1940 values for both the IHA and EFC parameters. This is because many of the lower-magnitude high flow events on the lower Colorado River are caused by rain storms that occur below the Lake Travis Watershed. These events are not affected by the Highland Lakes system. In contrast, the larger-magnitude high flow events (floods with frequencies of once per year or less) on the lower Colorado River have been substantially altered by the Highland Lakes. This is evident in the IHA results for annual 1-day and 3-day maximum flows (Table 3.4).

3.4 Water Quality

A steady state QUAL-TX model was developed and calibrated by the LSWP Water Quality team from Longhorn Dam to the Bay City Dam. For the instream flow guidelines development, six flow scenarios were originally run in this model to estimate the dissolved oxygen (DO) concentration in each model segment of the main stem of the Colorado River below Longhorn Dam. For these model runs, headwater flow (i.e., the flow at the Austin USGS gage, which was used to represent the flow passing Longhorn Dam) was reduced to the lowest possible amount. Each run used a flow balance based on results from the Water Availability Model (WAM) for future conditions in 2060 with Project (i.e., the 2006 PVA WAM run) and all diversions were set to flow demands in 2060 with Project (maximum demands predicted for 2060, as they are incorporated into the WAM). The following three scenarios were run for 2060 conditions in August and again for September (six total runs); these two months are those in which DO is predicted to be critical (because of diversions, high temperatures, and low flows):

- City of Austin (CoA) fully permitted discharge and concentration and all other dischargers at 100% permit limits

- CoA at current conditions (based on Discharge Monitoring Reports (DMRs) from 1999 – 2005) and all other dischargers at 75% permit limits
- CoA at potential future conditions (based on proposed return flow amounts and possible changes in their permits) and all other dischargers at 75% permit limits

The first is the worst case scenario, with CoA discharge and concentrations at maximum permitted. The second is based on recent CoA DMRs. The third is based on estimated CoA return flows (as provided from the WAM run) and potential concentrations (mainly from permit) in 2060. The results from QUAL-TX include the flow passing through each segment and each segment's predicted DO concentration.

Of the six scenarios, only the worst case scenario (CoA discharge and concentrations at maximum permitted during August) results in predicted DO concentrations below 4.0 mg/L. Under this worst case scenario, the minimum DO concentration predicted is 3.87 mg/L with concentrations under 4.0 mg/L occurring in less than 1% of the segments, concentrations under 5.0 mg/L occurring within 12% of the segments, and DO concentrations greater than 5.0 mg/L occurring within 87% of the segments. The predicted DO concentrations from this worst-case scenario are acceptable (described below) to meet the lower Colorado River aquatic community needs during low-flow periods. Therefore, a detailed evaluation of the other five scenarios (in which predicted DO concentrations were higher) was not conducted.

Although the predicted DO concentrations from the above analysis are acceptable to meet the aquatic community needs during low-flow periods, the river discharge used in all model runs described above are considerably greater than the current LCRA Water Management Plan critical flow requirements (120 cfs Bastrop) for the lower Colorado River and the projected subsistence flow recommendations from this study. Therefore, the LSWP water quality team conducted an additional model run evaluating predicted DO concentrations in the river at discharges less than or equal to 120 cfs. To make this discharge scenario possible, the following assumptions were placed on the model:

- Headwaters were set to 50 cfs,
- 50 cfs was added as return flows from the two major CoA Waste-Water Treatment Plants (WWTP) at fully permitted concentrations,
- Incremental flows were set to zero,
- Tributary flows were set to zero (including tributaries with WWTP dischargers),
- 13 main stem dischargers were set to fully permitted flows and concentrations.

The discharge passing through the lower Colorado River with these assumptions in place amounts to approximately 105 cfs near Bastrop, 115 cfs near Columbus, and 120 cfs near Wharton. The lowest predicted DO concentration in the lower Colorado River under this simulated low-flow condition is 4.98 mg/L. For this run, less than 2% of the segments show a DO concentration between 4.98 and 5.0 mg/L with all other segments maintaining DO concentrations of greater than 5.0 mg/L. The higher predicted DO concentrations under this simulated low-flow condition relative to the fully permitted

2060 with project run (at two to three times the discharge) is explained by the percentage of dilution flows from Longhorn dam. Under the simulated low-flow run, the dilution flows from Longhorn dam make up 40-50% of the flow in the river. Under the worst-case scenario 2060 with project condition modeled above, nearly 100% of the flow in the river is from downstream dischargers.

There is a level of conservatism built into both described conditions as flow will always be required to be passed through Longhorn Dam, projected CoA discharge concentrations are much less than the fully permitted concentrations run, and projected CoA return flows would not allow discharge in the river to get as low as the last simulated model run. However, even under these extreme conditions, LSWP water quality modeling predicts average DO concentrations in the river will only rarely fall below 5.0 mg/L and for only small segments of the river. The TCEQ assigns a "high" aquatic life use to stream segments with a 5.0 mg/L mean DO concentration and an "intermediate" aquatic life use to segments with a 4.0 mg/L mean DO concentration (30 TAC §307.7(b)(3)(A)(i)). The TCEQ "high" category which would be accomplished nearly all the time based on DO modeling, is described as including highly diverse habitat, high species diversity and richness, and a balanced to slightly imbalanced trophic structure. The TCEQ "intermediate" category, which would be in place very infrequently is described as including moderately diverse habitat, moderate species diversity and richness, and a moderately imbalanced trophic structure. As this would only occur during extreme conditions, the project team does not feel that DO concentrations as modeled pose a threat to the lower Colorado river aquatic community. As discussed in Section 6.0, long-term monitoring of water quality conditions especially during extreme low-flow conditions is recommended.

In consideration of subsistence flows and water quality, the Texas Instream Flow Program makes reference to low flow statistics such as the 7Q2, defined as the lowest average stream flow for seven consecutive days with a recurrence interval of two years, as statistically determined from historical data. Contrary to the approach taken in this study which relies on the natural flow paradigm, the 7Q2 statistic like the Lyons Method values, is based on analysis of the recent, altered flow regime. However, as modeling related to wastewater permits are based on these values, they are presented in Table 3.5 for reference. The site specific water quality modeling presented above is a more scientifically defensible approach for determining flows needed to maintain water quality needs.

Table 3.5. Lower Colorado River 7Q2 values from Figure 30 TAC §307.10(2) - Appendix B - Low-Flow Criteria

Segment	Name	Description	Gage Location	Gage	County	Period of Record		7Q2
1428	Colorado River Below Town Lake	from a point 100 meters (110 yards) upstream of FM 969 near Utley in Bastrop County to Longhorn Dam in Travis County	Austin	8158000	TRAVIS	1966	1996	71
			Bastrop	8159200	BASTROP	1966	1996	191
1434	Colorado River Above La Grange	from a point 100 meters (110 yards) downstream of SH 71 at La Grange in Fayette County to a point 100 meters (110 yards) upstream of FM 969 near Utley in Bastrop County						
1402	Colorado River Below La Grange	from a point 2.1 kilometers (1.3 miles) downstream of the Missouri-Pacific Railroad in Matagorda County to a point 100 meters (110 yards) downstream of SH 71 at La Grange in Fayette County	Columbus	8161000	COLORADO	1966	1996	300
			Wharton	8162000	WHARTON	1966	1996	391
			Bay City	8162500	MATAGORDA	1966	1996	205

4.0 INTEGRATION

In order to meet the environmental principles set forth for the LSWP and remain consistent with the TIFP objectives to conserve biodiversity and maintain biological integrity, the project team followed the recommendations of the NRC (2005) which has subsequently been endorsed by the TIFP (TIFP Draft 2006). The integration process involves 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 (2006) is presented in Table 4.1.

Table 4.1. Definitions and objectives of instream flow components (TIFP Draft 2006).

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.

A fifth component, channel maintenance flows, was subsequently included in this study to explicitly acknowledge the ecological benefit of very high, though in-channel flow events.

4.1 Flow Components Development and Integration

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. Table 4.2 provides an overview of the integration of analysis tools in the development of specific flow recommendations. Flow regime integration and preliminary recommendations are discussed in Sections 4.2 and 4.3.

Table 4.2. Analytical Component Integration Overview

	Hydrology and Hydraulics	Biology	Geomorphology	Water Quality
Subsistence Flows	Hydrologic analysis Hydraulic modeling	Habitat Modeling X^{th} percent exceedance level Base flows		Dissolved oxygen modeling
Base Flows	Hydrologic analysis Hydraulic modeling	Habitat Modeling X^{th} percent Habitat exceedance level(s) Base flows	Sediment transport modeling Base flow Particle movement	Dissolved oxygen modeling
High Flow Pulses	Hydrologic analysis Pulse Flows	Riparian assessment	Sediment transport modeling Particle movement Effective discharge	
Channel Maintenance	Hydrologic analysis Flood events	Riparian assessment	Sediment transport modeling Particle movement Effective discharge	
Overbank Flows	Hydrologic analysis Flood events	Riparian assessment Active floodplain connectivity		

4.2 Subsistence and Base Flow Development

Hydraulic and habitat modeling, sediment transport analysis, and water quality modeling were used to support the development of subsistence and base flow guidelines. The basic outline of that process is as follows: A) collect contemporary bathymetry, hydraulic, and biological data, B) develop Habitat Suitability Criteria and hydraulic model, C) determine habitat versus discharge relationships, D) develop historical habitat time series, E) select subsistence and base habitat flow values based on evaluation of historic habitat time series, and F) modify habitat-based flow recommendations to account for other considerations.

Figure 4.1 is a flowchart that describes the process for subsistence and base flow recommendations development. The numbers in the upper right hand corner of each task do not necessarily reflect the order of steps as several tasks are conducted simultaneously, but are included to serve as reference numbers for the discussion. Several of the tasks (Reference #s 1-5) in the top portion of the flowchart (Figure 4.1) have already been described in the results section (Section 3.0) or in the 2005 Activities Report (BIO-WEST 2005). This discussion will start with the habitat modeling activities (flow chart reference # 8). Although most of these steps are well established within instream flow science, there is no universally applied approach to select the Habitat Exceedence Levels (Step #11). Habitat time series data for both current and pre-1940 flows were analyzed to determine the varieties and relative proportions of various habitat types that would occur under these flow regimes.

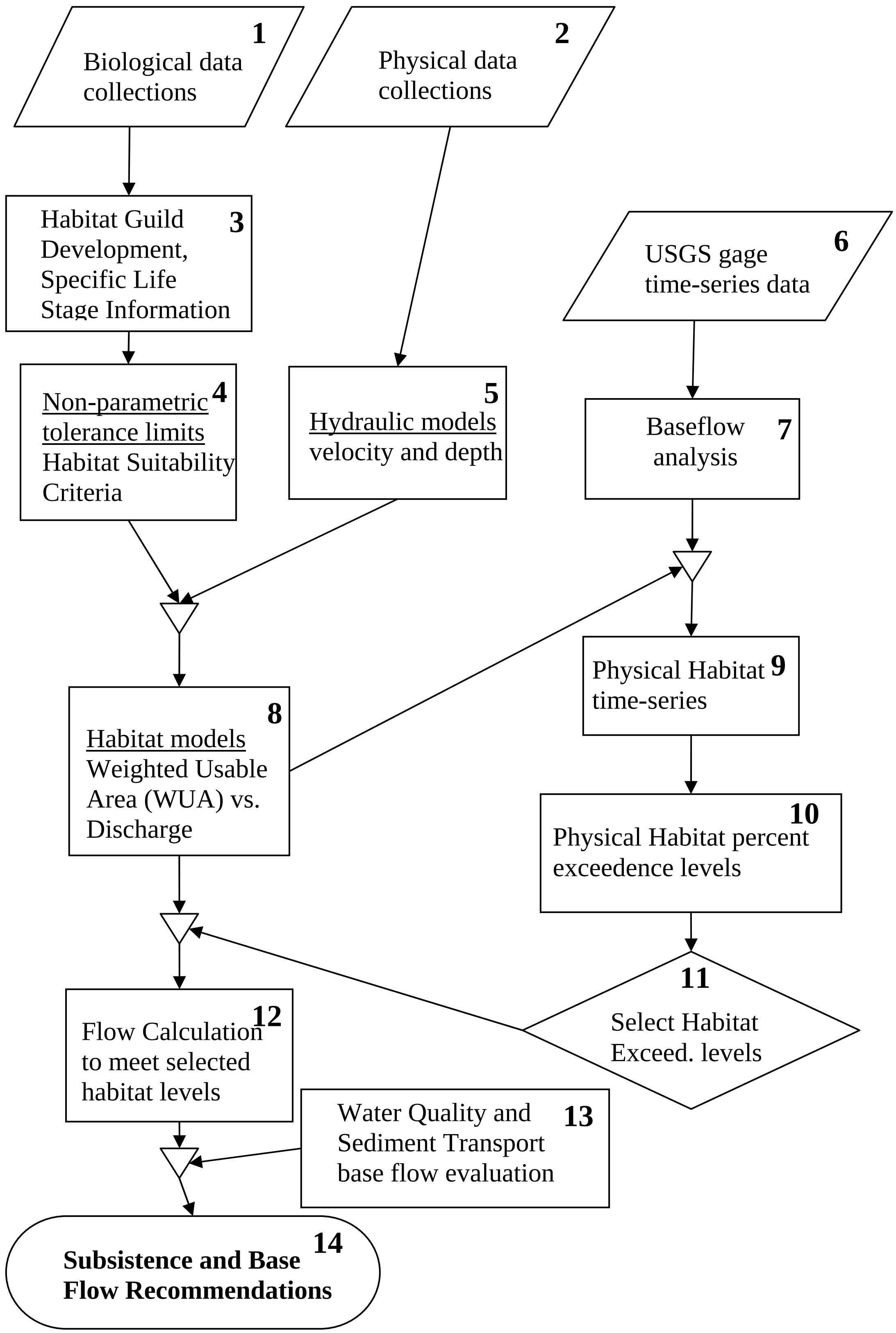


Figure 4.1. Subsistence and Base Flow Development Flowchart

4.2.1 Habitat Modeling

Habitat for the seven categories was computed on a node-by-node basis from the habitat suitability criteria (HSC) values for depth, velocity, and substrate (flowchart reference #8 [Figure 4.1]). The composite suitability index (CSI) for a given node was computed as the geometric mean of the individual velocity ($Velocity_{SI}$), depth ($Depth_{SI}$) and substrate ($Substrate_{SI}$) suitabilities (Hardy 2000):

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

Habitat simulations were computed for each of the seven habitat categories under each modeled flow rate at each intensive study site. Figure 4.2 shows a sample output of riffle habitat guild suitability at four flow rates at the Utley site. The simulated combined suitability at these flow rates were used to generate contours of suitable riffle habitat between 0 and 1.0 to visualize the spatial distribution of predicted habitat at the Utley site. Color contours are only shown for areas having suitability greater than 0. The color of the predicted habitat reflects the level of suitability for the riffle habitat guild with 1.0 being most selected and 0 being unsuitable.

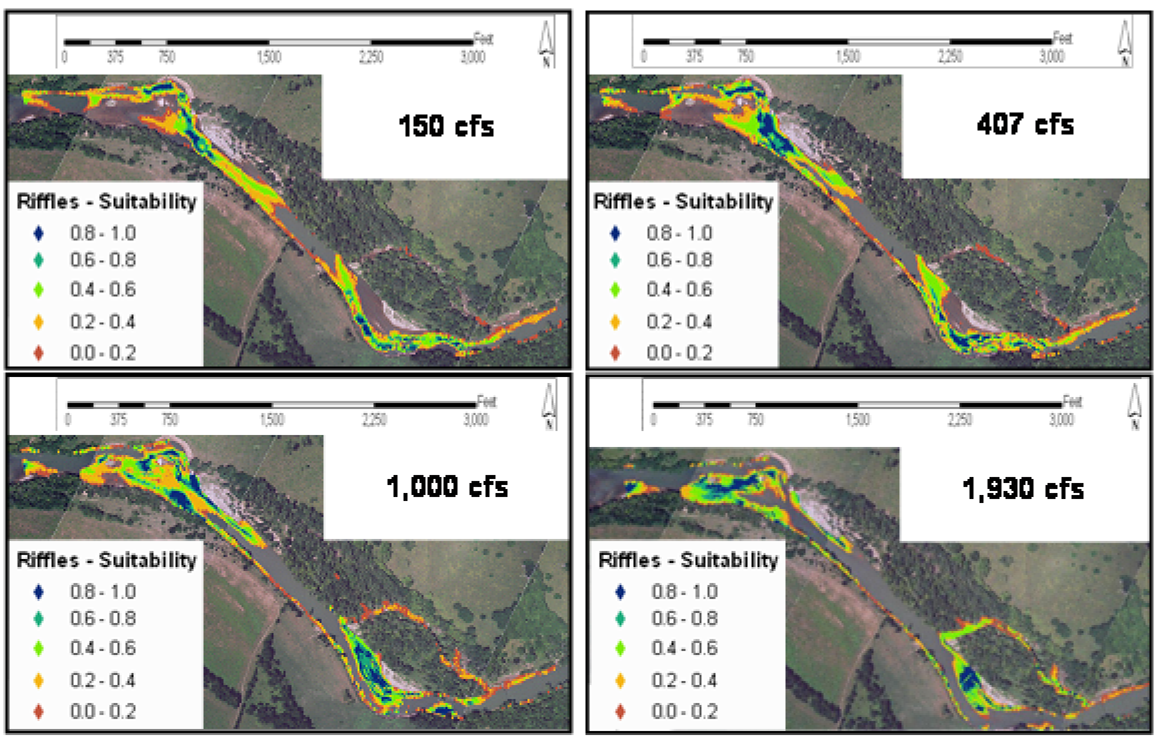


Figure 4.2. Simulated riffle habitat at Utley intensive study site (Site 2) at four modeled discharge rates.

Additionally, the habitat model output was compared back to habitat mapping at several sites at two different discharges. Figure 4.3 shows the simulated riffle habitat guild output at 300 cfs with an overlay of the field habitat mapping of riffles conducted at approximately 275 cfs. The simulated riffle habitat guild suitability extends out from the field mapped riffles area which is to be expected because of the slightly higher flows. Also, it is important to note the distinction between riffle habitat guild suitability and visual observations of "riffles" in the field. As they are not the exact same measure, they are not expected to be exact. Overall, the mapped "riffles" cover the majority of the higher suitability simulated riffle habitat guild. Additional field habitat mapping versus predicted habitat are presented in Appendix I.

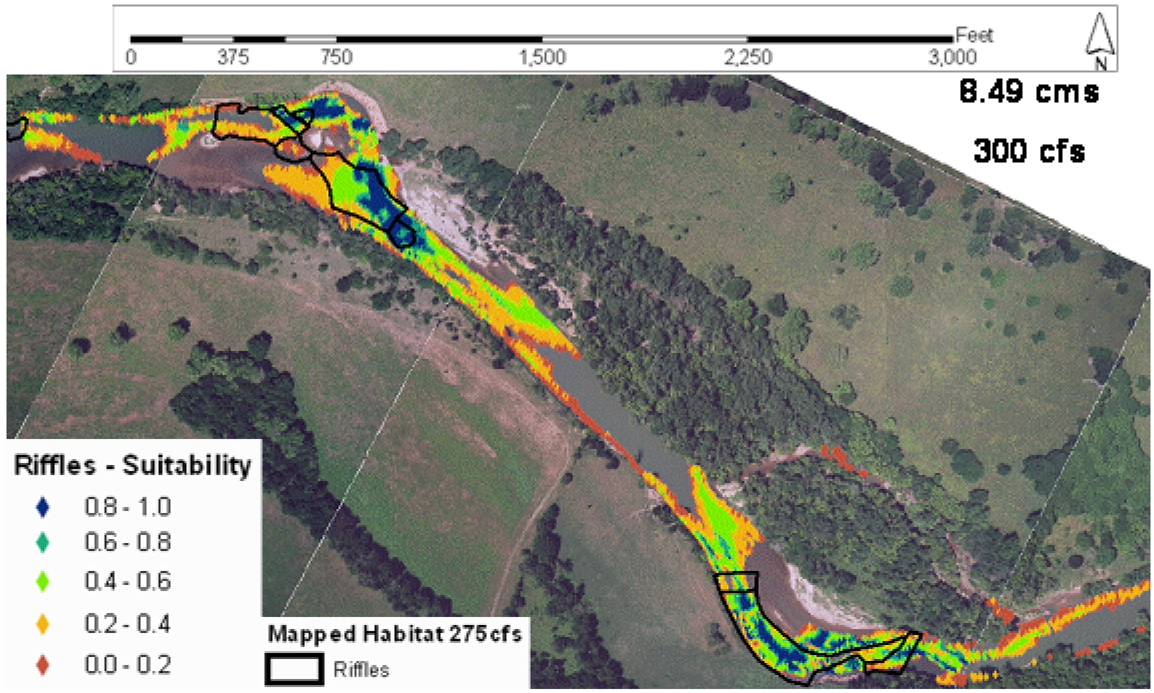


Figure 4.3. Utley, 300 cfs (8.495 cms) biological mapping validation; field mapping 11/28/2006 approx. 275 cfs

Biological validation data was collected at five sites (Utley, Smithville [downstream], La Grange, Altair, and Wharton) during intermediate flows (~ 1,300 to 2,000 cfs) and at all ten sites under lower flow (~ 300 to 700 cfs) conditions. Figure 4.4 shows the simulated combined suitability for the riffle habitat guild at Utley at 1,750 cfs along with the biological validation data collected at 1,690 cfs. Fish data collected at this flow rate are plotted relative to the abundance of riffle habitat guild species collected (Figure 4.4). A black x is placed on a sample site where no riffle habitat guild species were collected and the shapes (square, circle, triangle) represent a sample site where the appropriate species were collected. The shape represents the level of abundance as described in the legend. Additional biological validation maps versus predicted habitat are presented in Appendix I.

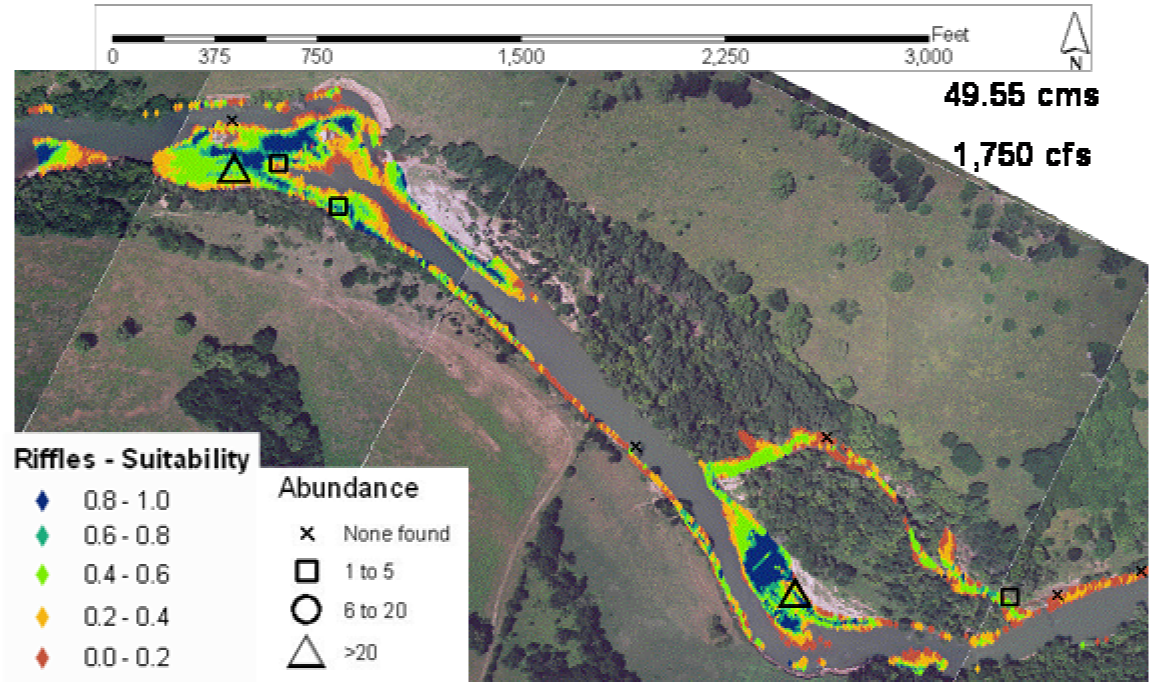


Figure 4.4. Utley, 1,750 cfs (49.55 cms) biological validation; field data 05/05/2005 at 1,690 cfs.

The biological validation data is included as a general, qualitative description of what is going on in the river. Several possible inclusions of error in this validation approach exist including positioning error (e.g., the mesh being +/- 2 m, the fish being collected +/- 2 m, etc). Therefore, the biological validation data is not expected to match exactly to predicted habitat suitability. Overall, biological validation data corresponds with predicted habitat suitability and provides further support of habitat modeling results.

Habitat simulation results were used to compute weighted usable area versus discharge relationships for each of the seven habitat categories at each of the ten sites. Area is calculated by summing the weighted usable area for each cell in the segment and reported as square feet per 1,000 linear feet along river centerline. Area is standardized per 1,000 linear feet to remove potential for influence of site size when combining sites into reaches. Figures 4.5 and 4.6 show this relationship and the corresponding percent of maximum habitat for the Utley (Site2) intensive study site. The relationships and corresponding percent of maximum habitat for all sites are included in Appendix D. The intensive study site results were grouped into five reaches as depicted in Figure 4.7.

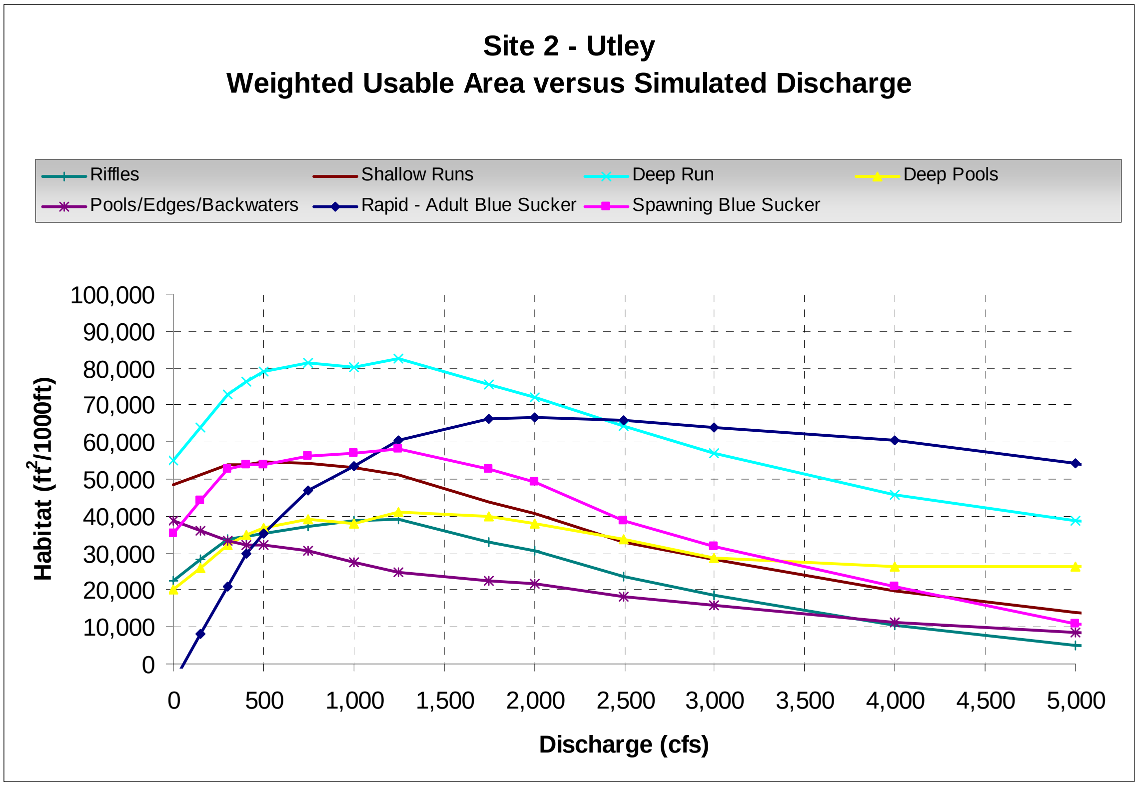


Figure 4.5. Weighted usable area versus simulated discharge at Utley (Site 2)

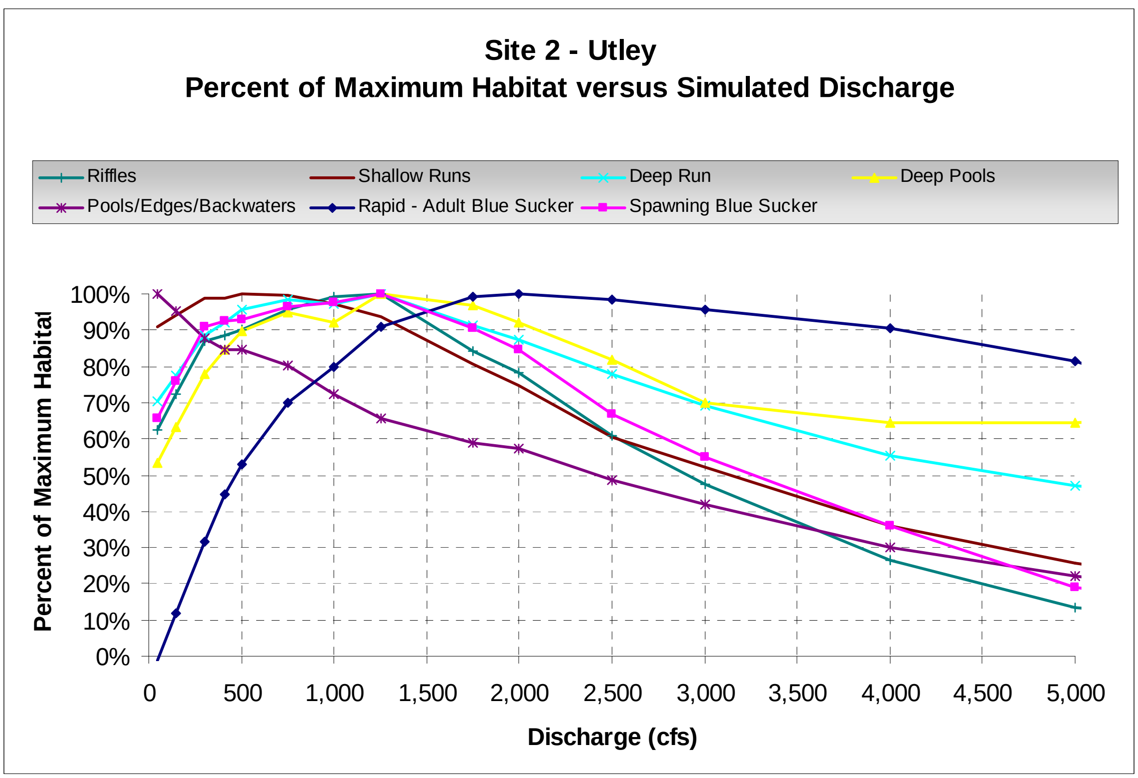


Figure 4.6. Percent of Maximum Habitat versus simulated discharge at Utley (Site 2)

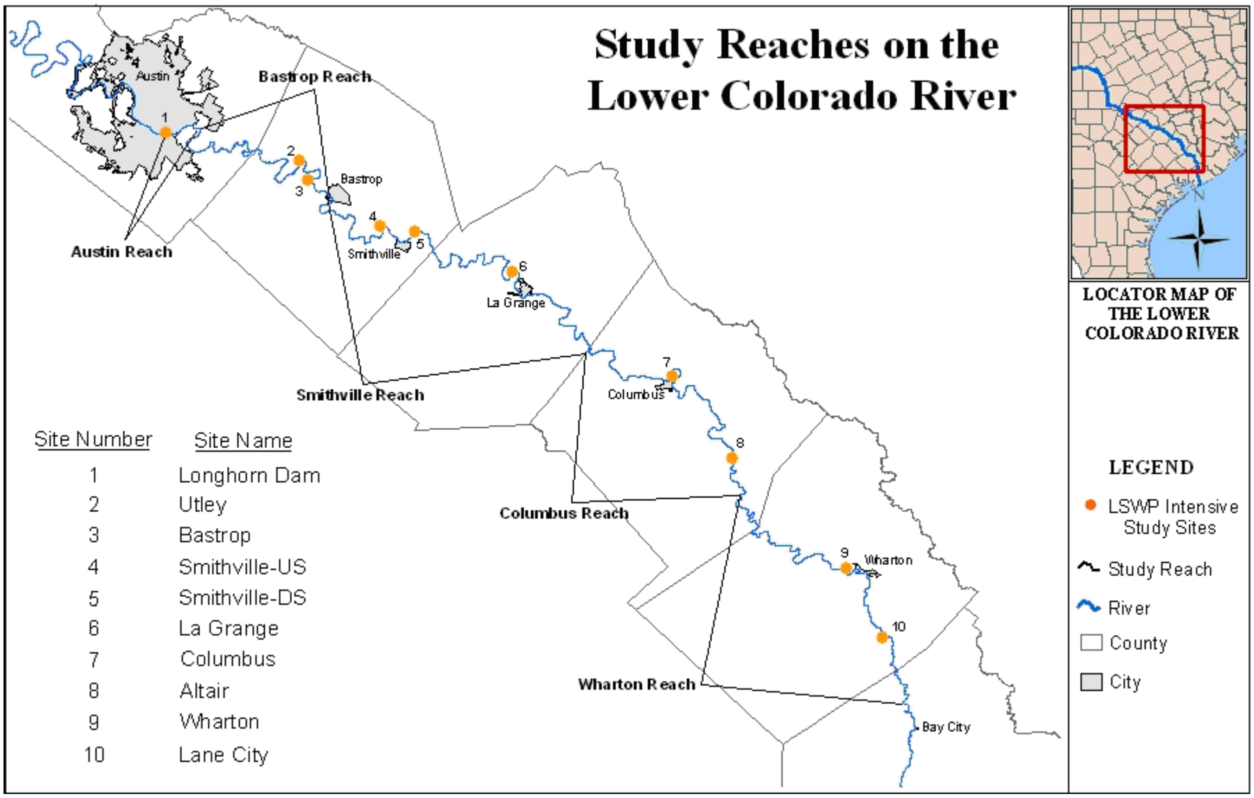


Figure 4.7. LSWP Reaches

4.2.2 Habitat Time Series Modeling

Physical habitat times series were computed based on two flow scenarios. These included the existing condition (1975 to 2004) and pre-1940 (1898/1916 – 1940). The existing flow scenario was included in the habitat time series analysis because 1) the field data (physical and biological) used for the hydraulic and habitat models, sediment transport analysis, and baseline riparian conditions were all collected under the existing flow regime, and 2) the present day geomorphic conditions, riparian zone, water chemistry, aquatic habitat, and biological resources have all been imprinted by the existing flow regime. Additionally, the water quality and biological data collected by LCRA over the past decade reflect high levels of quality and diverse biological communities. Therefore, an examination of the existing flow regime was deemed necessary to evaluate the potential for maintaining similar conditions.

The pre-1940 "natural" flow scenario was included to be consistent with the guidance of the TIFP and Natural Flow paradigm. Even though the data collected for this study was done under the existing flow regime, using natural flow conditions as a reference for comparison often provides insight into the ecological variability of riverine systems.

In order to compute the physical habitat time series (flowchart reference #9 [Figure 4.1]), a daily flow record is needed. For the existing conditions flow scenario, daily flow records from the USGS gages (flowchart reference #6 [Figure 4.1]) nearest to the study sites were used. For the pre-1940 scenario, the daily flow record for the upper reaches

(Austin, Bastrop [Utley and Bastrop sites], and Smithville [Smithville upstream and downstream, and La Grange sites]) were derived from the Austin gage and the lower reaches (Columbus [Columbus and Altair sites], and Wharton [Wharton and Lane City sites]) were derived from the Columbus gage.

Since the purpose of habitat time series analysis is development of subsistence and base flow (i.e., low flow) recommendations, it was necessary to place an upper limit on the range of flows over which the analysis would be performed. This is necessary because poor habitat conditions can result from flows that are both too high and too low. We found that including the entire range of flows resulted in percentile targets (the amount of time above which a certain amount of habitat is available) that were driven by high flow rather than low flow conditions. Because it does not make ecological sense to set low base and subsistence flow recommendations that are driven by poor habitat conditions resulting from extremely high flows, we set a maximum flow at which the weighted usable area versus discharge relationships would be applied. Analysis of the hydrologic time series using the U.S. Bureau of Reclamation BFI program for base flow separation (flowchart reference #7 [Figure 4.1]) suggested a base flow cut off at 5,838 cfs which is the 95th percentile flow from the base flow time series at the Columbus gage. By using the USGS time-series with high flow days (greater than 5,838 cfs) removed, base and subsistence flow habitat calculations would not be skewed by reduced habitat conditions during these high flow times. Filtering high flows removes 9% and 13% of flow days from the Austin and Columbus pre-1940 series, respectively. All discussion that follows in Section 4 relates to percent exceedence for the filtered subset.

Physical habitat time series were computed by applying the weighted usable area to discharge curves (flowchart reference #8 [Figure 4.1]) developed for each habitat category and reach to the daily flow record for each base flow adjusted scenario (flowchart reference #7 [Figure 4.1]). Comparative results in the form of Habitat Duration Curves (Austin and Wentzel 2001) for the shallow pools/edge/backwater habitat guild, riffle habitat guild, and adult blue sucker/rapids habitat category for all months at the Bastrop reach are presented in Figures 4.8-4.13, respectively. Habitat duration curves display the amount of time over the entire daily flow record that habitat is available. For example, Figure 4.13 shows that 80% of the time (existing time period [1975-2004]), adult blue sucker/rapids habitat for the Bastrop Reach in March was at least ~35,000 ft^2/1000ft or greater.

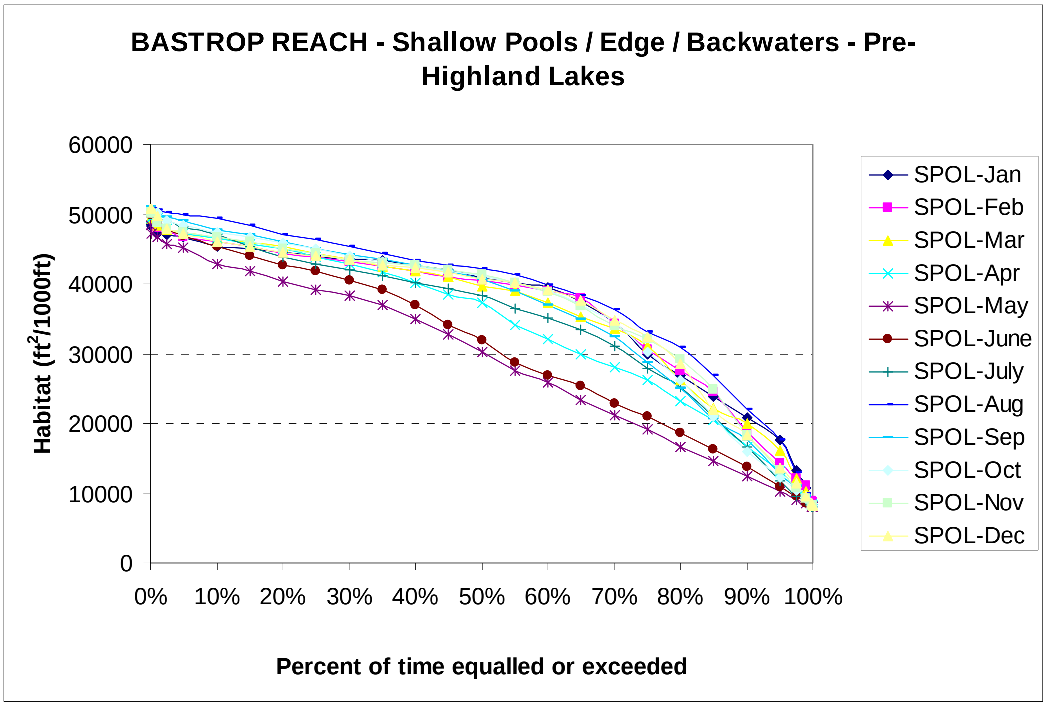


Figure 4.8. Habitat durations for shallow pools/edge/backwater for all months at the Bastrop Reach based on the pre-1940 flow regime.

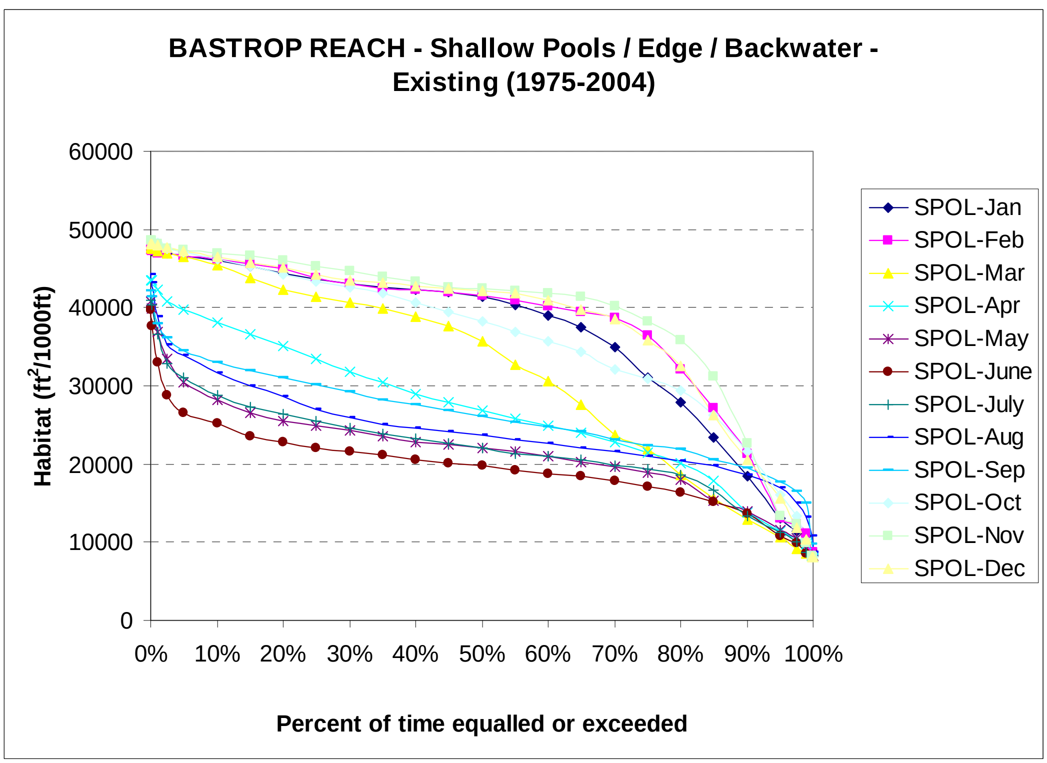


Figure 4.9. Habitat durations for shallow pools/edge/backwater for all months at the Bastrop Reach based on the existing flow regime.

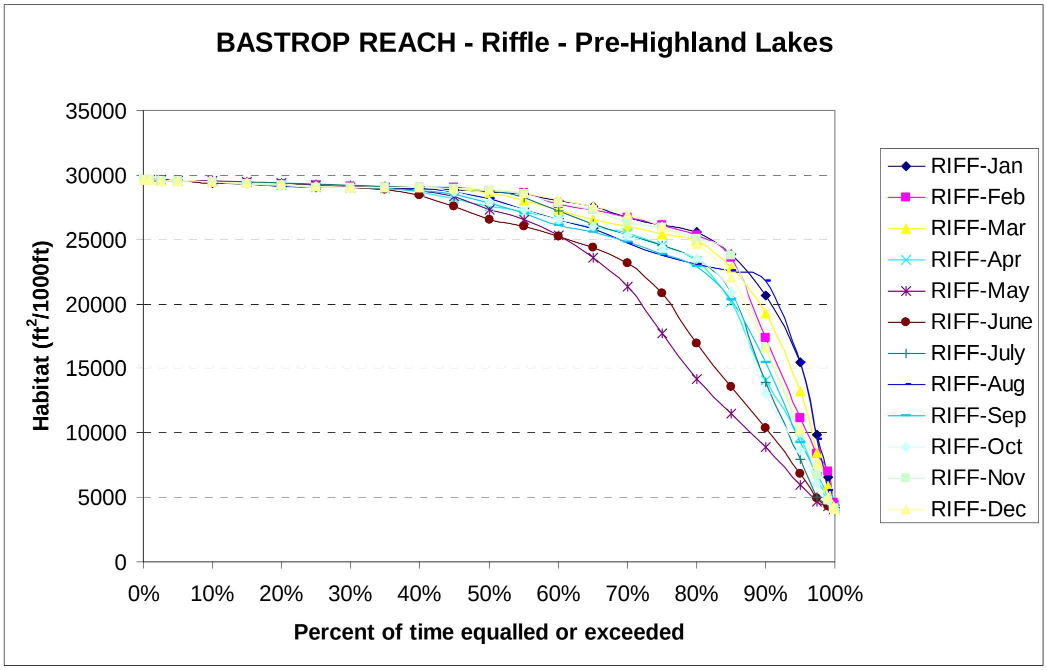


Figure 4.10. Habitat durations for riffles for all months at the Bastrop Reach based on the pre-1940 flow regime.

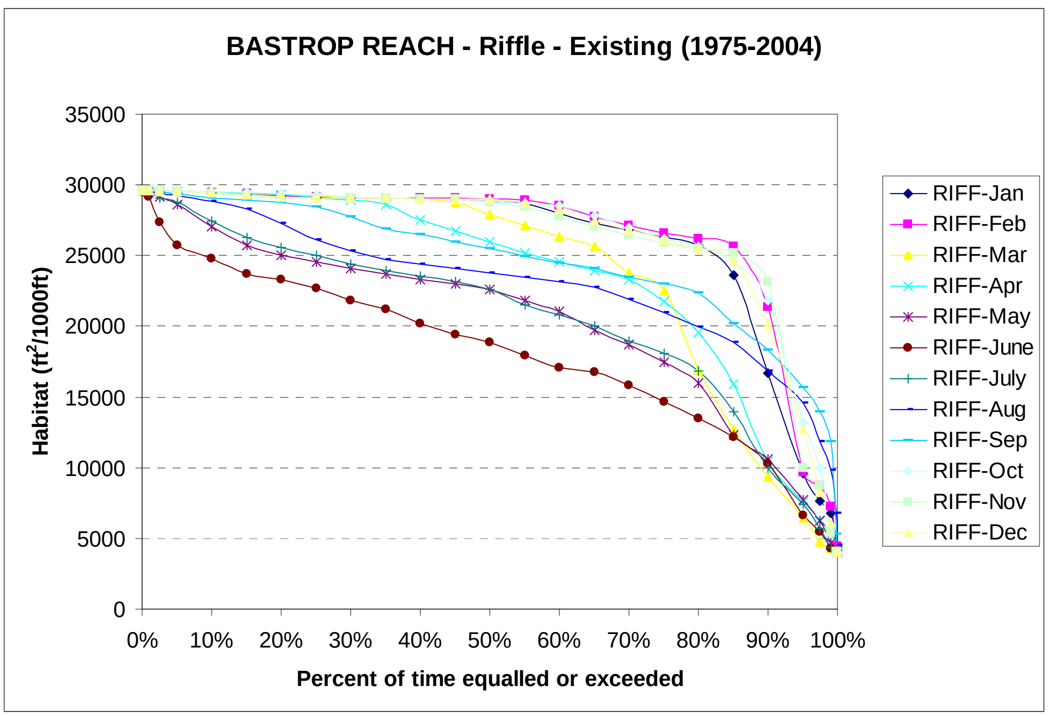


Figure 4.11. Habitat durations for riffles for all months at the Bastrop Reach based on the existing flow regime.

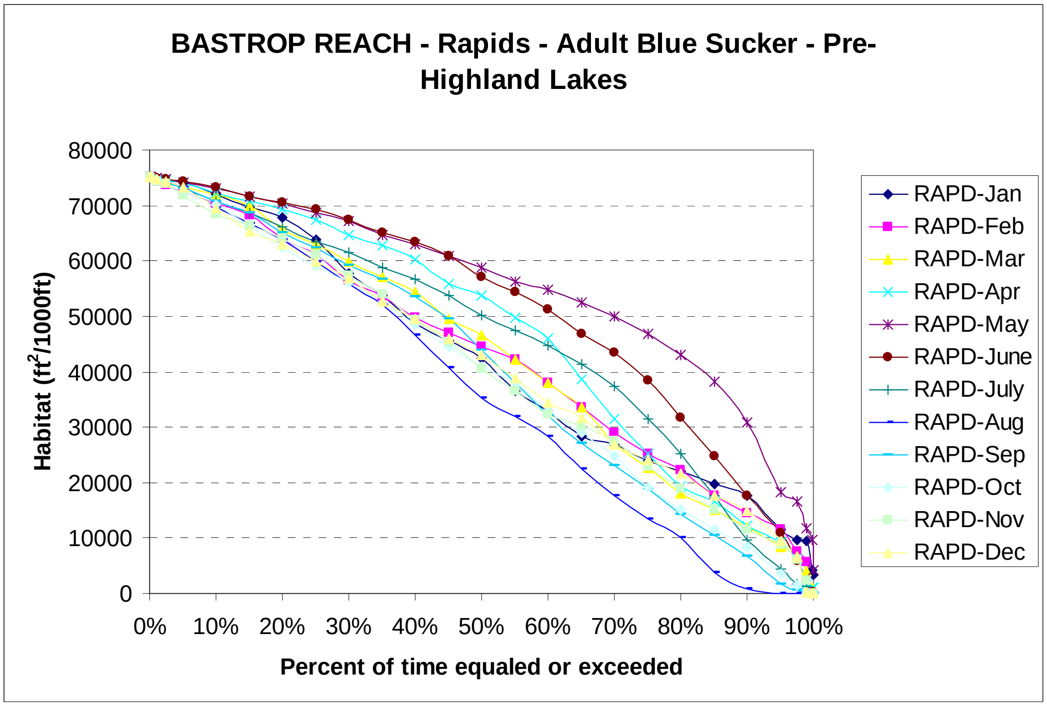


Figure 4.12. Habitat durations for rapids/adult blue sucker for all months at the Bastrop Reach based on the pre-1940 flow regime.

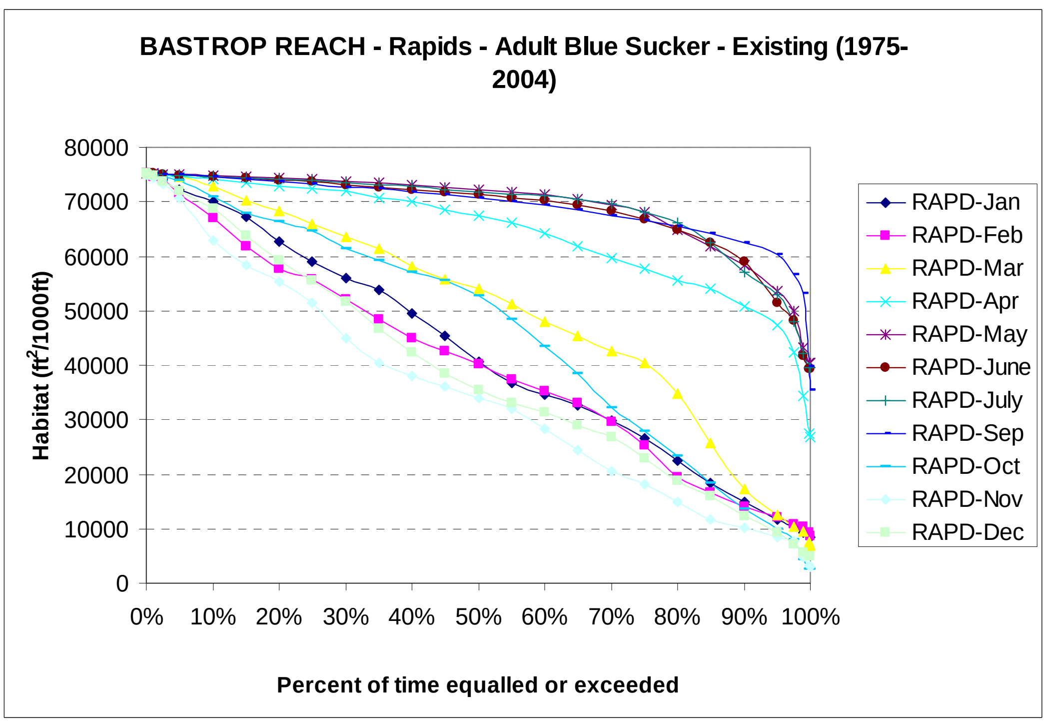


Figure 4.13. Habitat durations for rapids/adult blue sucker for all months at the Bastrop Reach based on the existing flow regime.

Habitat duration curves for each reach for each applicable habitat category per flow regime are included in Appendix F. Figures 4.8-4.13 and Appendix F figures for the Austin, Bastrop, Smithville, and Columbus reaches illustrate the differences in simulated habitat for both the existing and pre-1940 base flow conditions. The habitat time series modeling illustrates that both the existing and pre-1940 flow regimes provide all types of simulated habitat year round. The tighter fit lines for the Pre-1940 condition relates to a higher level of habitat diversity year round. The spread in the lines for the existing condition reflects greater amounts of habitat are available during certain times of the year and less year round habitat diversity is achieved.

Figures 4.14-4.16 were included to highlight the major differences in simulated habitat per flow regime during a winter (January) and summer (July) month at the Bastrop reach.

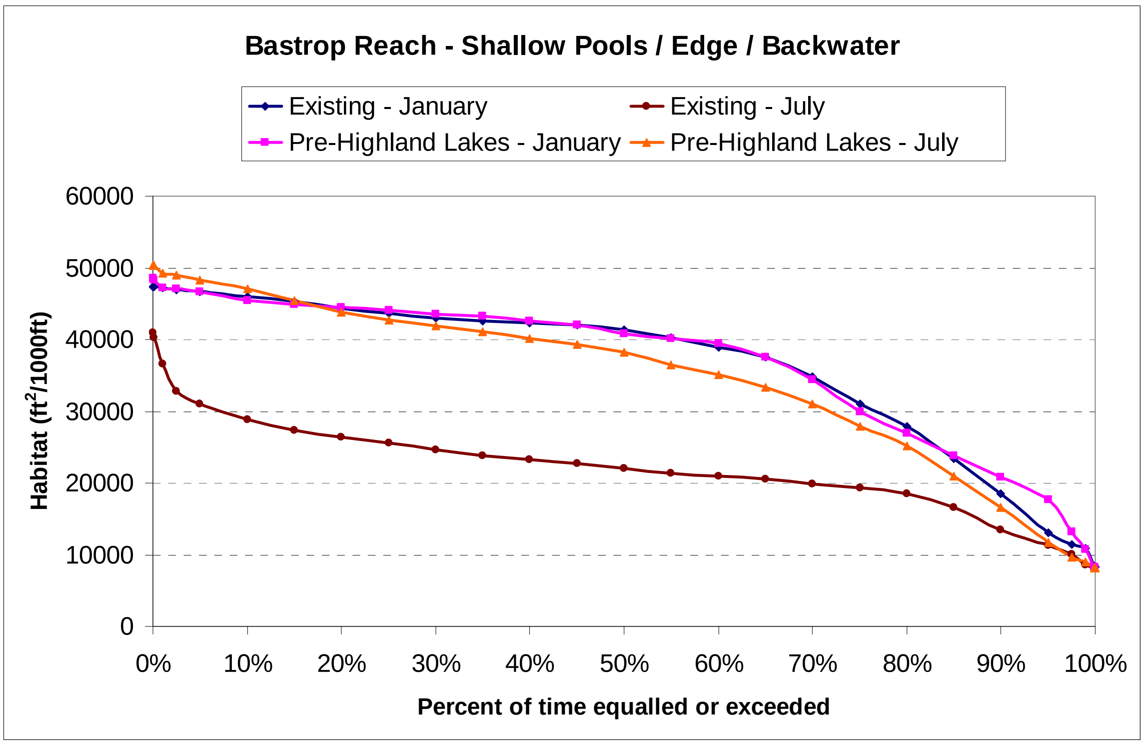


Figure 4.14. Habitat durations for shallow pools/edge/backwater for January and July at the Bastrop Reach for both flow regimes.

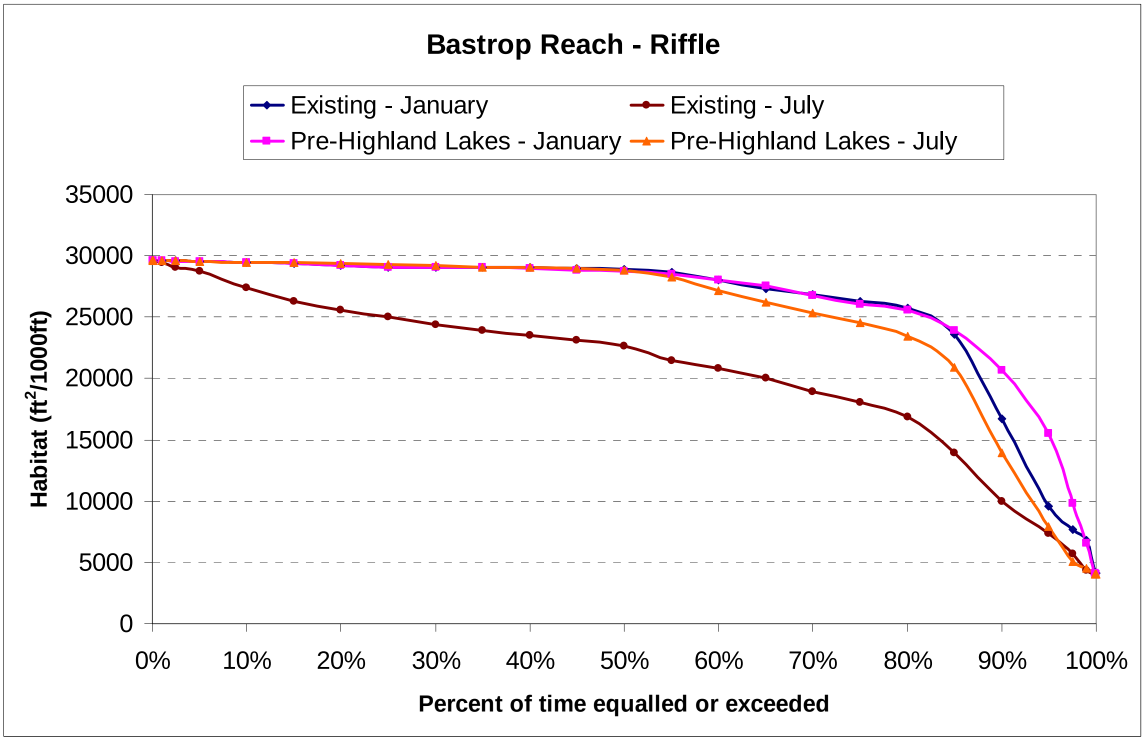


Figure 4.15. Habitat durations for riffles for January and July at the Bastrop Reach for both flow regimes.

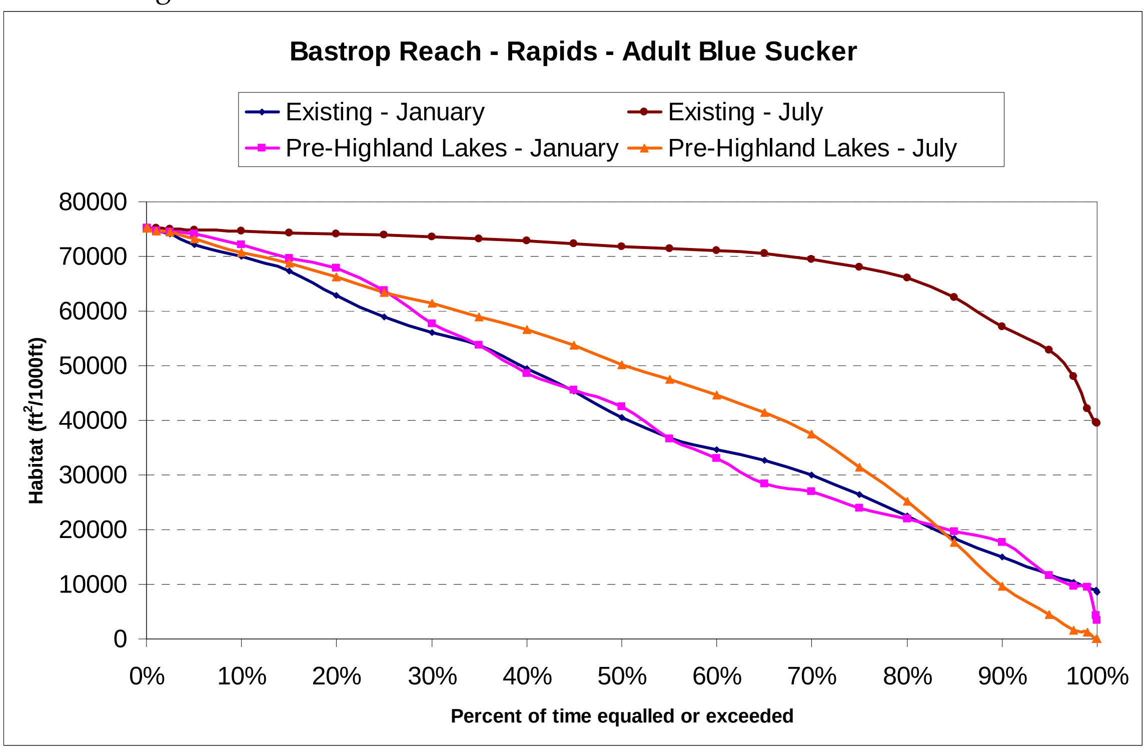


Figure 4.16. Habitat durations for rapids/adult blue sucker for January and July at the Bastrop Reach for both flow regimes.

The higher summer time flows under the existing regime fosters deeper and faster habitats (i.e Rapids, Figure 4.16) while decreasing shallow water habitats and riffles (Figures 4.14 and 4.15). Most of the time the winter conditions between the two regimes are similar. However, at the low flow extreme (>90th percent exceedence), the lower winter flows under the existing flow regime provide less shallow water and riffle habitat but the deeper and faster habitats remain similar.

The Wharton reach is the exception to the trends discussed above as withdrawals in this reach over the last 30 years have kept discharge conditions more similar to pre-1940 conditions than the other upstream reaches (Appendix F).

4.2.3 Natural Time Series Selection

An evaluation of the hydrology (Section 3.1), habitat time series modeling results (Section 4.2.2, Appendix F), sediment transport analysis (Section 3.3), and water quality results (Section 3.4) indicate that the pre-1940 flow regime does differ from the existing flow regime. The major differences between flow regimes are highlighted in Table 4.3.

Table 4.3. Summary of physical and biological differences predicted between the existing and pre-1940 flow regimes.

	FLOW REGIME	
Simulated Parameters	Existing (1975-2004)	Pre-1940 (Natural)
Habitat Diversity (see figures 4.8 – 4.16)	Less habitat diversity year round, particularly during summer irrigation releases	Habitat diversity present year round.
Larval / Juvenile Edge Habitat	Limited edge aquatic habitat during post-spawning months (May – July)	More simulated edge aquatic habitat than existing, but still reduced due to existing channel morphology.
Pre-Spawning migration – *Cycleptus elongatus*	Lower flows in Winter months reduce water depth thus causing more restriction to migration.	Higher flows in the Winter months cause greater water depths and thus, ease of migration.
Sediment Transport – Edge Habitat	Summer time base flows are high enough to provide constant sand transport, thus causing less edge aquatic habitat and adjacent riparian development.	Reduced summer time base flows mean greater potential for aquatic and riparian habitat diversity and river edge stabilization.
Sediment Transport - Deeper Habitats	More base flow sediment transport means more settling of materials in low-velocity habitats, thus reducing deep run/pool function.	Less sediment deposition into deep run/pools maintains this habitat function.
Sediment Transport - macroinvertebrate condition	More summertime base flow sediment transport causes continual disturbance, potentially affecting marcroinvertebrate communities in some areas.	Less summertime base flow sediment transport reduces continual disturbance, potentially benefiting macroinvertebrate communities in some areas.
Water Quality	Flow maintained at levels high enough to create high dissolved oxygen (>6.0 mg/L) even during the hot summer-time months.	Modeling demonstrates that lower summertime flows still produces good dissolved oxygen (>5.0 mg/L). Greater potential for occasional low DO events during summer.

In summary, simulated habitat conditions for the pre-1940 regime show a greater diversity of habitat conditions year round (i.e. a more equitable distribution of the variety of habitats available), an improvement in edge habitat, and better conditions for pre-spawning migration for adult blue suckers. Conversely, the pre-1940 regime provides considerably less deep, fast habitat in the summer months which could be critical relative to potential water quality impacts during these time periods. This is important from both a regulatory and ecological point of view. From a regulatory standpoint, water quality exceedences are to be avoided, thus making this scenario unfavorable. However, under a natural flow regime, these periods did occur, 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).

Other factors to be considered in the base flow determinations are the sediment transport characteristics and riparian recruitment. As discussed in Section 3.3, under existing summertime conditions where flows are typically held at approximately 1,000 - 2,000 cfs, a large portion of the streambed in the river is constantly in motion. Under these existing conditions, the sand moving through riffle and run areas most likely accumulates in the flattest-gradient, lowest-velocity pool and backwater areas of the river. In a more natural flow regime with reduced transport rates, sediment would accumulate less rapidly in these low velocity habitats, and they would be retained as deeper, more diverse habitat features. In addition, less winnowing/transport of sand would occur along the channel margins. New shoreline sand deposits would likely develop in areas that are not already dominated by sand, providing more gradually-sloping banks and greater near-bank topographic complexity. These shoreline sand deposits could also provide establishment sites for emergent and herbaceous riparian vegetation. This type of vegetation provides cover and shade for shallow, slackwater-type habitats, and serves as a source of nutrients and organic matter. This type of non-woody vegetation provides ecosystem benefits as long as it is periodically scoured by high flows so that stands do not reach densities that would have negative impacts in terms of reducing channel capacity. Reduced baseflows could also lead to new deposits of fine gravel in steep riffle areas. A return to more natural summertime baseflow conditions would likely lead to less constant, chronic substrate disturbance; a return could have positive implications for macroinvertebrate productivity and species richness.

The TIFP (Draft 2006) proposes, "The goal of ensuring a 'sound ecological environment' has been equated to maintaining the ecological integrity and conserving the biological diversity of riverine ecosystems. In order to meet these goals, the Agencies recognize the importance of maintaining the natural habitat diversity, hydrologic character, and water quality of river systems." The TIFP (Draft 2006) describes "sound ecological environment" as, "a functioning ecosystem characterized by intact natural processes, resilience, and a balanced, integrated, and adaptive community of organisms comparable to that of the natural habitat of a region."

For the ecological advantages discussed above and to be consistent with the goals of the TIFP, the pre-1940 time period was selected to be used for the development of instream flow guidelines. Hardy et al. (2006) states, "Utilizing the characteristics of the natural flow regime as a 'template' is widely accepted and applied at the international level as illustrated by work under the EU Water Framework Directive (Directive 2000/60/EC) by Hardy et al., (2006), Acreman et al., (2006) under EU Water Framework Directive (Directive 2005/48/EC), Dunbar et al., (1998), and Tharme and King (1998) in South Africa under river ecosystem protection legislative mandates." Therefore, the steps starting with the physical habitat time series (flowchart reference #10 [Figure 4.1]) and beyond focus on the pre-1940 flow regime, while considering modifications that may be necessary because of existing anthropogenic influences. Since the base flow component of the analysis will focus on this condition, so must the pulse flow component of the guidelines. This re-aggregation of base flow and pulse flow is important to maintain the ecological integrity of the lower Colorado River. As noted in the hydrologic discussion (Section 3.1) the magnitude of extreme flow events has been greatly reduced since the implementation of the Highland Lakes dams. Pre-1940 extreme events cannot be re-created as that magnitude of flow would flood many of the downstream cities along the river. Therefore, the overbanking flow guidelines development will focus on existing conditions.

4.2.4 Habitat Duration Curves

As described above, habitat duration curves were computed for each of the habitat categories at each reach (Appendix F). The information from these curves was then converted into habitat percent exceedence tables and evaluated based on habitat diversity, percent of maximum habitat, percent declines in habitat, and overall summaries of conditions. When evaluating the seven habitat categories, all habitat guilds and adult blue sucker/rapids habitat are applied with equal weighting per month. Spawning blue sucker habitat is also weighted equally but only applied during their spawning period from February through April. Additionally, no adult blue sucker/rapids habitat or spawning blue sucker habitat was applied to the Wharton Reach as this type of physical habitat does not currently exist in this reach due to substrate limitations nor have blue suckers been collected in this stretch of river.

Figure 4.17 and Tables 4.4 and 4.5 display the habitat duration curves, the percent of maximum habitat, and percent decline in each of the habitat categories in the Bastrop Reach in April, respectively. The percentage of maximum table (Table 4.4) shows the percent of maximum habitat available at each of the percent exceedence levels, whereas the percent decline table (Table 4.5) shows the percentage decline between percent exceedence levels from low to high. For example, there is 25% decline in rapids habitat area at the 0.95 percent exceedence level (Table 4.5) based upon percent of maximum habitat values (Table 4.4) of 16% and 12% at the 0.99 and 0.95 percent exceedence levels, respectively.

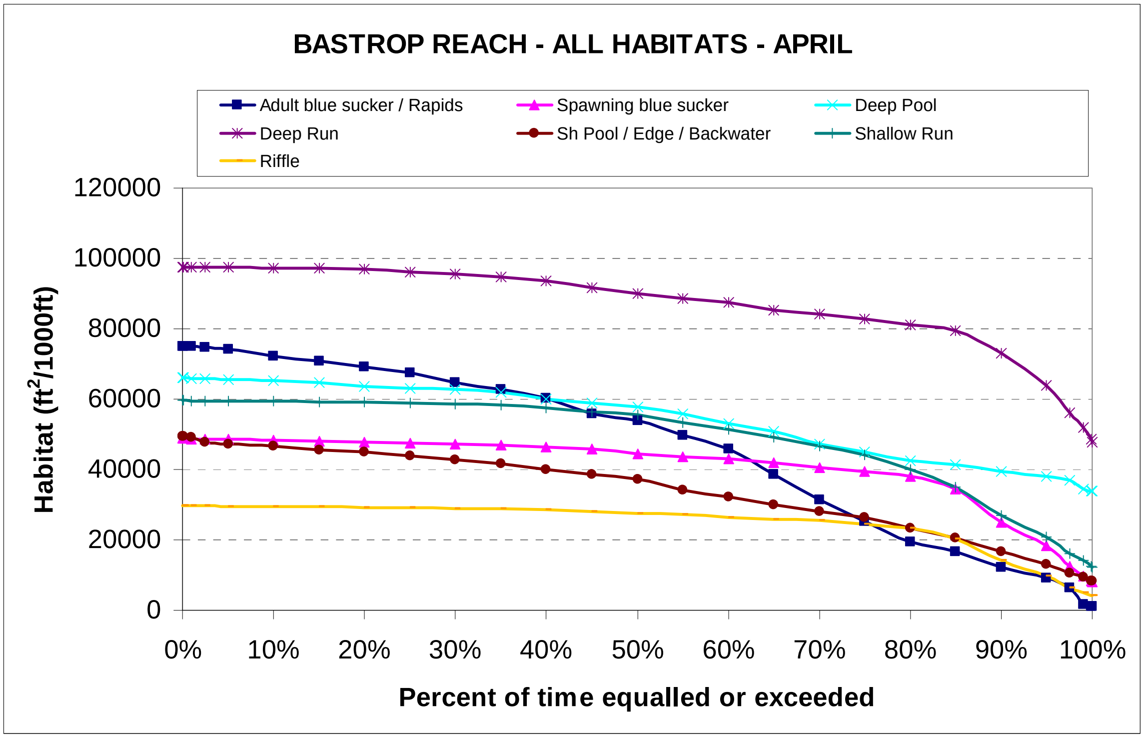


Figure 4.17. Habitat durations for all habitat types for April at the Bastrop Reach.

Table 4.4. Percentage of maximum available habitat at each percent exceedence level in April at the Bastrop Reach.

	Percentage of Maximum Available Habitat						
Percent Exceedance Level	Rapids / Adult blue sucker	Spawning blue sucker	Deep Pool	Deep Run	Shallow Pool / Edge / Backwater	Shallow Run	Riffle
0.99	2%	20%	52%	53%	19%	24%	17%
0.95	12%	38%	58%	66%	27%	35%	33%
0.90	16%	51%	60%	75%	34%	45%	48%
0.85	22%	71%	63%	81%	42%	59%	68%
0.80	26%	78%	64%	83%	47%	67%	79%
0.75	34%	81%	68%	85%	53%	74%	83%
0.70	42%	83%	72%	86%	57%	78%	86%
0.65	52%	86%	77%	87%	61%	82%	87%
0.60	61%	88%	80%	90%	65%	86%	90%
0.55	66%	89%	85%	91%	69%	89%	92%
0.50	72%	91%	88%	92%	76%	93%	93%
0.45	74%	94%	89%	94%	78%	95%	95%
0.40	80%	95%	91%	96%	81%	96%	97%
0.35	84%	96%	94%	97%	85%	98%	98%
0.30	86%	97%	95%	98%	87%	98%	98%
0.25	90%	97%	95%	99%	89%	99%	98%
0.20	92%	98%	97%	99%	91%	99%	99%
0.15	94%	99%	98%	99%	92%	99%	99%
0.10	96%	99%	99%	100%	94%	100%	99%
0.05	99%	100%	100%	100%	96%	100%	100%
0.01	99%	100%	100%	100%	97%	100%	100%

Table 4.5. Percent decline in maximum available habitat between percent exceedence levels in April at the Bastrop Reach.

	Percent Decline in Maximum Available Habitat						
Percent Exceedance Level	Rapids / Adult blue sucker	Spawning blue sucker	Deep Pool	Deep Run	Shallow Pool / Edge / Backwater	Shallow Run	Riffle
0.99	82%	47%	10%	19%	28%	32%	49%
0.95	25%	27%	3%	13%	21%	23%	31%
0.90	27%	28%	5%	8%	19%	23%	30%
0.85	14%	9%	3%	2%	11%	13%	13%
0.80	23%	4%	5%	2%	12%	9%	5%
0.75	20%	2%	5%	2%	7%	5%	4%
0.70	19%	3%	7%	1%	6%	5%	2%
0.65	16%	3%	4%	3%	7%	4%	2%
0.60	8%	1%	5%	1%	6%	4%	2%
0.55	8%	2%	3%	2%	8%	4%	1%
0.50	4%	3%	2%	2%	3%	2%	2%
0.45	7%	1%	2%	2%	4%	2%	2%
0.40	4%	1%	3%	1%	4%	1%	1%
0.35	3%	1%	1%	1%	2%	1%	0%
0.30	4%	1%	0%	1%	2%	0%	0%
0.25	3%	1%	1%	1%	3%	0%	0%
0.20	2%	1%	2%	0%	1%	0%	1%
0.15	2%	0%	1%	0%	2%	0%	0%
0.10	2%	0%	1%	0%	1%	0%	0%
0.05	1%	0%	0%	0%	4%	0%	0%

As there are five reaches and twelve months, a total of 60 tables were generated for each evaluation technique. As previously referenced, all the habitat duration curves are presented in Appendix F and the series of habitat percent exceedence tables for each reach are presented in Appendix E.

4.2.5 LSWP Subsistence Flow Recommendation

Selection of a habitat percent exceedence level, flowchart reference #11 (Figure 4.1), is needed to initiate flow recommendation development. Hardy et al. (2006) selected the 95% flow exceedence level for their ecological base flow determination citing several international studies that led to that recommendation. The ecological base flow category as defined by Hardy et al. (2006) is equivalent to the flow needed to provide the 95th percent habitat exceedence levels. Therefore, we initiated an evaluation of the 95th percent habitat exceedence level at each of our five reaches.

Table 4.6 displays a summary of the percent of maximum habitat area for each reach according to 55th-99th percent exceedence levels of habitat area. The count columns reflect how many habitat categories out of 75 possible (6 habitat categories * 12 months = 72 + spawning blue sucker habitat for 3 months = 75 total) for Austin, Bastrop, Smithville, and Columbus reaches have zero habitat area, <5% of maximum, <10% of maximum, etc. For Wharton, there are only 60 total as criteria for spawning blue sucker habitat and adult blue sucker/rapids habitat are not applied. The Annual Habitat Average columns show the twelve month average percent of maximum habitat (3 months [February-April] for spawning blue suckers) per habitat guild or life stage. The total column is an average of the seven habitat categories. It is important to recognize that this is a summary and the annual averages per habitat category can mask the intra-year variability. Therefore, a detailed evaluation of all the habitat duration curves and tables (presented in Appendices E and F) was conducted along with a visual evaluation of the simulated habitat output (Appendix H). Overall, viewing the count and annual averages together provides a good summary of habitat conditions.

Table 4.6. Summary of the 55^{th}-99^{th} percent exceedence levels of habitat area presented as percent of maximum habitat for each reach. Recommended Subsistence flow conditions highlighted.

							Percent of Maximum Habitat							
Reach	% Exc. level	Count [1]					Annual Habitat Average[2]							
		Zero	< 5%	< 10%	< 25%	< 50%	Rapids / Adult blue sucker	Spawn blue sucker	Deep Pool	Deep Run	Shallow Pool / Edge / Backwater	Shallow Run	Riffle	TOTAL
Austin	99	4	21	34	51	73	3%	7%	30%	45%	11%	11%	4%	17%
	95	1	5	15	41	64	7%	24%	33%	58%	22%	24%	14%	26%
	90	1	1	6	20	61	11%	45%	34%	65%	31%	38%	29%	35%
	85	0	1	3	14	50	14%	61%	36%	69%	38%	50%	43%	43%
	80	0	0	1	11	37	18%	68%	38%	73%	45%	61%	55%	49%
	75	0	0	0	9	31	22%	71%	40%	76%	53%	68%	62%	54%
	70	0	0	0	8	26	26%	76%	41%	79%	62%	74%	67%	59%
	65	0	0	0	5	23	31%	78%	43%	82%	69%	79%	72%	63%
	60	0	0	0	1	22	36%	82%	46%	85%	74%	83%	77%	67%
	55	0	0	0	0	18	41%	84%	49%	88%	79%	85%	81%	71%
Bastrop	99	3	8	10	46	55	4%	24%	53%	54%	19%	24%	18%	28%
	95	0	3	4	19	50	11%	43%	57%	66%	27%	36%	35%	39%
	90	0	1	2	11	35	17%	60%	60%	75%	35%	49%	53%	49%
	85	0	1	1	9	26	23%	76%	63%	79%	43%	61%	69%	57%
	80	0	0	0	4	18	29%	80%	66%	82%	51%	71%	77%	63%
	75	0	0	0	1	12	35%	83%	68%	84%	57%	78%	81%	68%
	70	0	0	0	1	12	40%	86%	71%	86%	63%	84%	85%	72%
	65	0	0	0	0	9	46%	88%	74%	88%	68%	88%	88%	76%
	60	0	0	0	0	6	52%	90%	77%	89%	72%	90%	91%	79%
	55	0	0	0	0	3	57%	92%	80%	91%	74%	92%	93%	82%
Smithville	99	5	23	49	51	66	2%	5%	53%	38%	6%	8%	3%	18%
	95	1	6	21	48	54	6%	18%	55%	56%	13%	21%	11%	27%
	90	1	2	8	28	50	11%	33%	58%	70%	22%	34%	24%	36%
	85	0	1	3	16	41	15%	49%	60%	77%	33%	48%	39%	45%
	80	0	0	1	13	25	19%	63%	62%	80%	44%	59%	52%	53%
	75	0	0	0	10	18	24%	69%	64%	83%	53%	67%	61%	59%
	70	0	0	0	7	16	29%	74%	66%	85%	61%	74%	68%	64%
	65	0	0	0	2	13	34%	77%	68%	87%	67%	80%	72%	68%
	60	0	0	0	0	12	39%	80%	71%	89%	72%	84%	76%	72%
	55	0	0	0	0	8	45%	83%	73%	90%	76%	87%	80%	76%
Columbus	99	0	4	8	51	53	8%	23%	53%	59%	16%	18%	14%	28%
	95	0	2	3	46	52	14%	30%	56%	67%	19%	22%	16%	32%
	90	0	0	2	33	51	22%	36%	60%	75%	24%	31%	19%	38%
	85	0	0	0	20	47	27%	44%	62%	80%	29%	40%	25%	44%
	80	0	0	0	10	38	33%	54%	65%	84%	36%	49%	35%	51%
	75	0	0	0	4	30	38%	64%	67%	87%	44%	58%	47%	57%
	70	0	0	0	3	19	45%	71%	70%	89%	51%	65%	58%	63%
	65	0	0	0	0	14	50%	77%	72%	90%	57%	70%	66%	68%
	60	0	0	0	0	8	56%	83%	75%	91%	63%	75%	74%	73%
	55	0	0	0	0	6	60%	87%	77%	93%	68%	79%	79%	76%
Wharton	99	0	0	0	31	48	N/A	N/A	35%	64%	24%	25%	13%	32%
	95	0	0	0	12	48	N/A	N/A	39%	72%	29%	32%	17%	38%
	90	0	0	0	10	45	N/A	N/A	44%	76%	35%	40%	22%	43%
	85	0	0	0	5	40	N/A	N/A	47%	79%	40%	49%	28%	49%
	80	0	0	0	2	28	N/A	N/A	50%	81%	47%	58%	37%	54%
	75	0	0	0	1	19	N/A	N/A	53%	82%	53%	66%	45%	60%
	70	0	0	0	0	10	N/A	N/A	57%	84%	58%	73%	53%	65%
	65	0	0	0	0	8	N/A	N/A	60%	86%	62%	77%	60%	69%
	60	0	0	0	0	3	N/A	N/A	64%	88%	66%	82%	68%	73%
	55	0	0	0	0	2	N/A	N/A	67%	89%	69%	85%	74%	77%

[1] ([Six habitat catagories * 12 months] + Spawning blue sucker habitat * 3 months = 75 Total) -- Wharton (60 possible - [Five habitat catagories * 12 months])

[2] February - April only for Spawning blue sucker

Subsistence Flow recommended habitat percent exceedence level

A review of the habitat duration curves, exceedence tables, and summary (Table 4.6) revealed that the 95th percent habitat exceedence level did appear to be an appropriate starting point for evaluating subsistence flow recommendations at the Austin, Bastrop, Smithville, and Columbus reaches. This level maintains very few instances where individual habitat categories during individual months (Count summary) go to zero or below 5%. Additionally, on average approximately 25% of the total maximum habitat is available for these reaches at that level (Table 4.6). At the Wharton Reach, the 99th percent exceedence level provides a comparable level of habitat to the other four reaches (Table 4.6). This happens because of the changing habitat conditions in this coastal plain reach of the lower Colorado River. Recall that rapids/adult blue sucker habitat and spawning blue sucker habitat categories are not found in the Wharton reach thus eliminating them from consideration. Mosier and Ray (1992) made a similar observation and adjustment for this lower reach, "The Egypt study reach lacked suitable habitat for *Cycleptus elongatus* adults…" Mosier and Ray (1992) went on to explain that "The disparity in base flows among the reaches is a direct result of differences in the quality of habitat available among the study reaches. Consequently, there are substantial differences in the structure of the fish community that may be found in each study reach." Ultimately Mosier and Ray (1992) recommended target flows for this lower reach that were lower than the upstream reaches "due to differences in physical habitat availability".

The values in Table 4.6 for Bastrop, Columbus, and Wharton are presented graphically in Figures 4.18 and 4.19. Figure 4.18 expands Table 4.6 to include all percent habitat exceedence levels. As shown in Figure 4.18, the 95th percent habitat exceedence level (Bastrop and Columbus) and 99th percent habitat exceedence level at Wharton are adequate to keep the amount of each habitat type above 10 percent of the maximum available habitat. Additionally, at both Bastrop and Columbus (Figure 4.19) a break is evident at the 95th percent habitat exceedence level with no instances of zero habitat, and very few instances where any given month falls below 10 percent of their maximum habitat availability. At Wharton, even at the 99th percent habitat exceedence level, there are no instances where any given month falls below 10 percent of the maximum habitat available. This again supports the decision made in Mosier and Ray (1992) and this study to treat Wharton differently relative to subsistence flow guidelines, with the goal to maintain similar ecological conditions as the more upstream locations.

Each habitat type was visually examined using the habitat model output at each reach. Figure 4.20 shows the available habitat (Rapids/Adult Blue Sucker and Riffle habitat guilds) at Utley for the 95th percent habitat exceedence level. Specifically, the Rapids and Riffles habitat guilds (along with shallow pool/edge/backwater) experienced the lowest percentage of maximum habitat at this level (Figure 4.18) and thus, visual evaluation was performed to examine their habitat distribution. As evident in Figure 4.20, there are contiguous segments of both habitat guild types and not just sporadic patches of habitat throughout the site. Optimal or high quality habitat is limited (blue color) for the Rapids habitat guild, but abundant for the Riffles habitat guild at this percent habitat exceedence level, both of which would be experienced naturally under this condition.

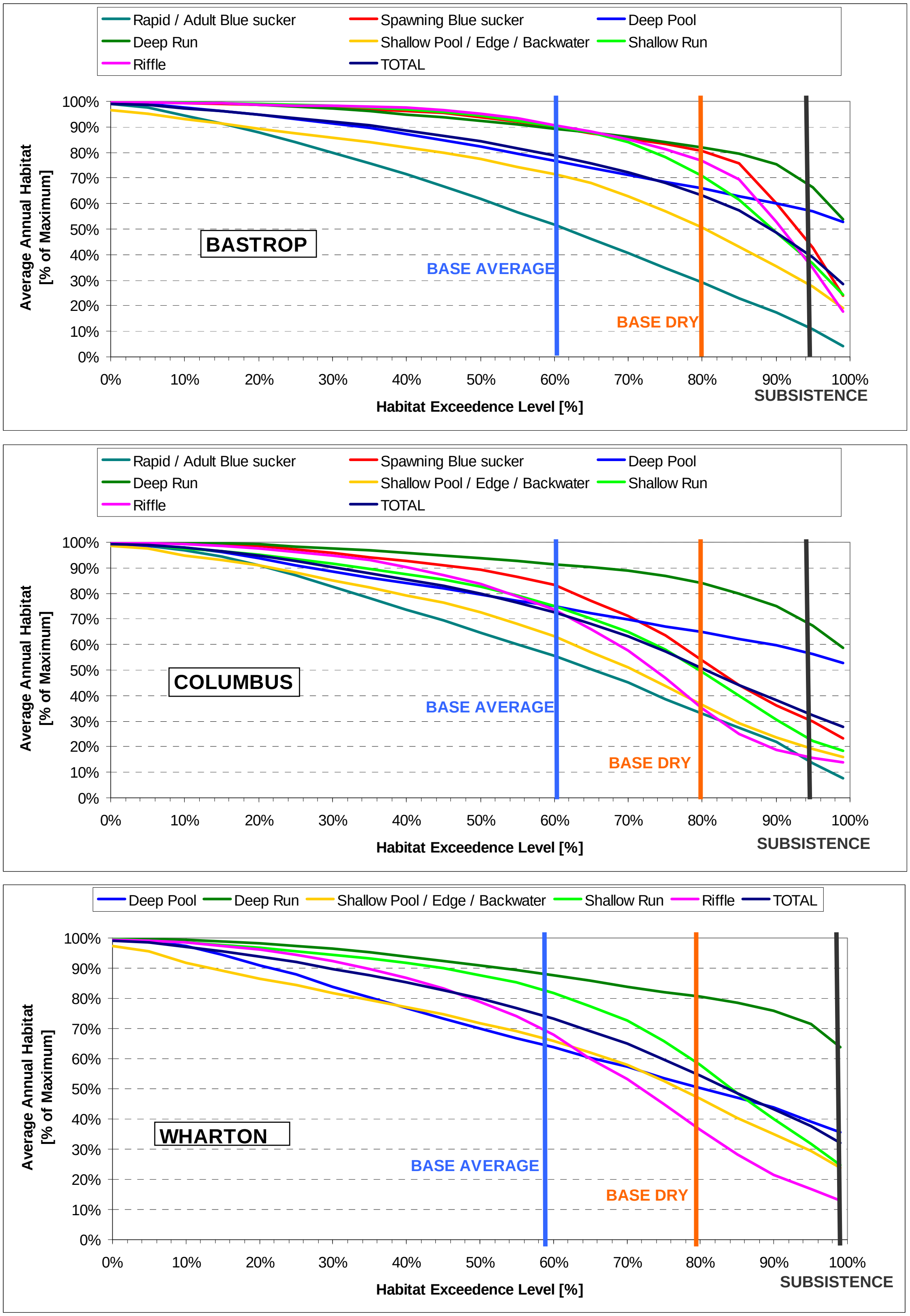


Figure 4.18. Average annual amount of habitat types (as percent of maximum) for various habitat exceedence levels.

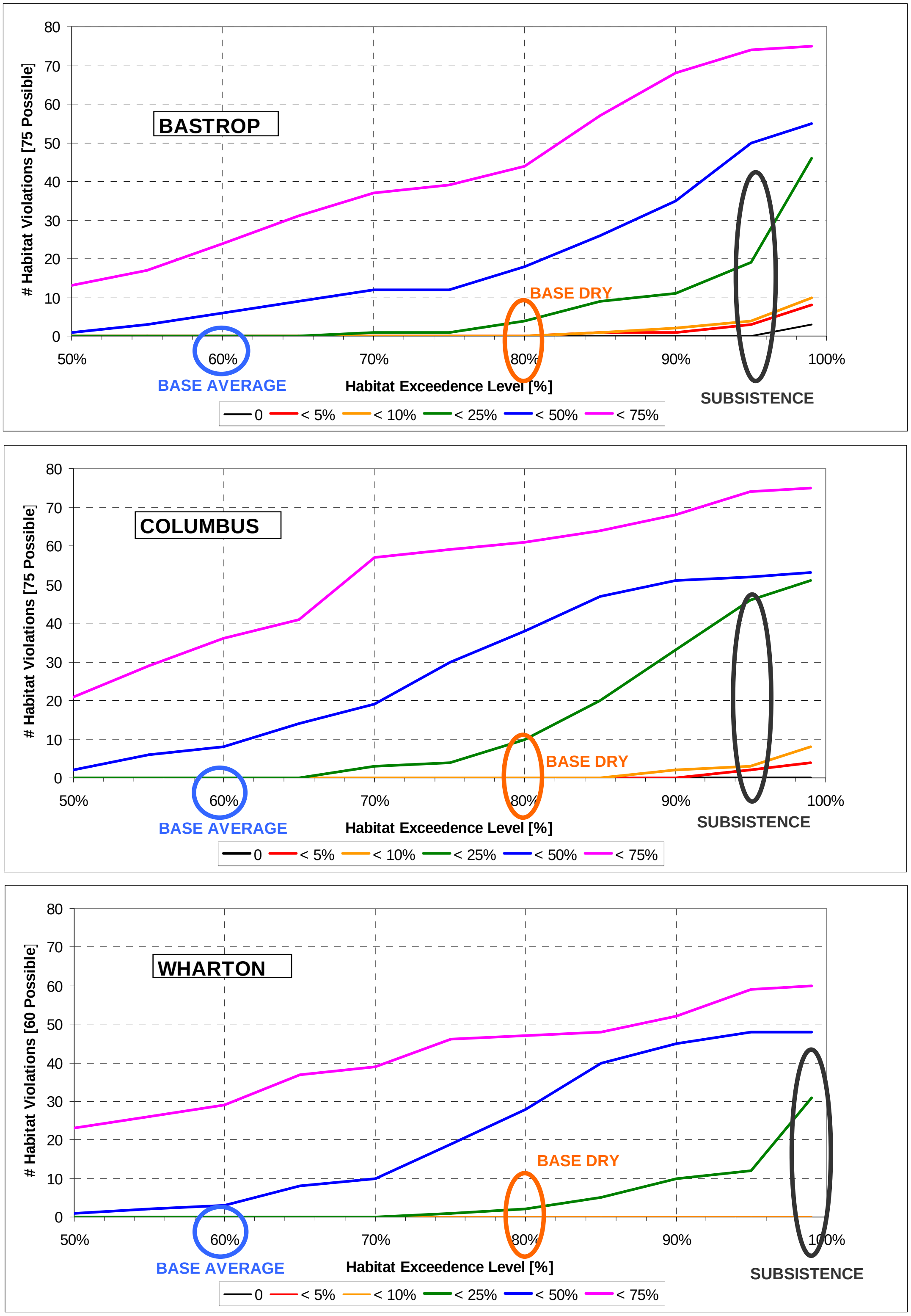


Figure 4.19. Number of times in year that monthly habitat is less than 0, 5, 10, 25, 50, or 75 percent of maximum for seven habitats (Blue sucker spawning habitat is only considered for three months of year). Rapids and blue sucker spawning not considered at Wharton.

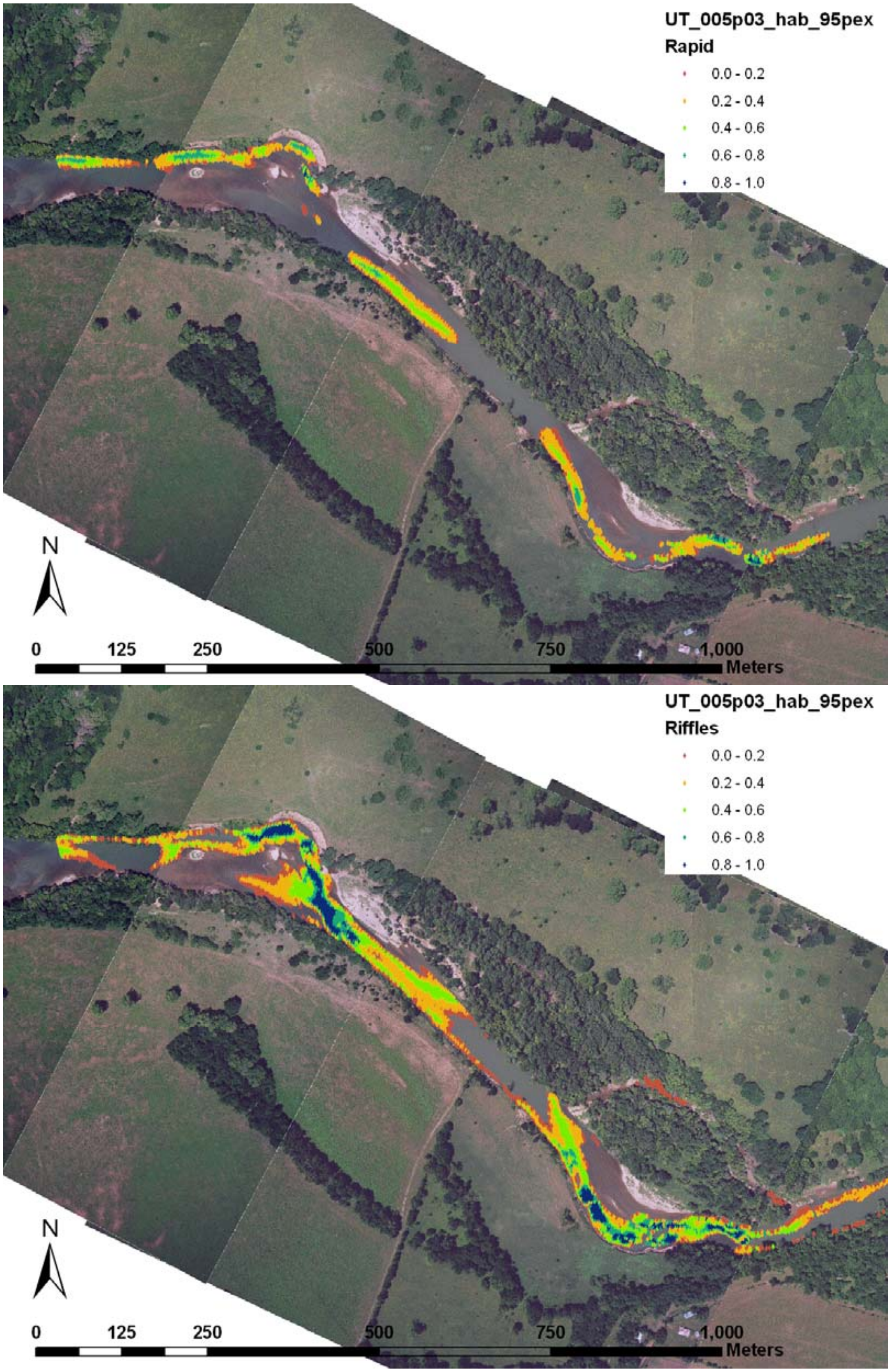


Figure 4.20. Available habitat for Rapids and Riffles habitat guilds at the Utley site at the 95th percent habitat exceedence level in April (177 cfs).

Upon complete evaluation, the 95th percent habitat exceedence level for the Austin, Bastrop, Smithville, and Columbus reaches and the 99th percent habitat exceedence level for the Wharton Reach was input into the flow calculation tool (flowchart reference #12 [Figure 4.1]). The flow calculation tool calculates the lowest and highest discharge that will meet all of the monthly habitat amounts generated per reach for that exceedence level (95th [four reaches] and 99th [Wharton] in this case). Table 4.7 presents the monthly flows (low end) necessary to meet the percent habitat exceedence level per reach.

Table 4.7. Calculated monthly flows to meet the selected subsistence flow habitat percent exceedence levels per reach.

Reach	Initially Calculated Monthly Flows (Instantaneous minimum [cfs])											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Austin	201	200	171	178	266	195	132	60	97	122	174	180
Bastrop	201	200	171	178	266	195	132	60	97	122	174	180
Smithville	201	200	171	178	266	195	132	60	97	122	174	180
Columbus	340	373	296	299	425	534	342	132	279	187	202	301
Wharton	311	299	202	267	301	367	209	106	186	145	171	200

On the low flow end the calculated flows were identical for reaches (Austin, Bastrop, and Smithville) using the same time series discharge data (Austin gage). Since the percentages of habitats created per these reaches at all flows were similar and the Bastrop reach is spatially located in the middle, it was chosen as the reach for which flow recommendations from this time series would be made.

The discharges presented in Table 4.7 were then evaluated for water quality and sediment transport implications. As discussed in Section 3.4, the predicted DO concentrations at low simulated discharges were consistently greater than 5.0 mg/L. The sediment transport analysis also confirms that these discharges would provide more natural sediment transport conditions.

Three flow modifications are proposed for incorporation into the subsistence flow recommendation. The first involves the addition of a specific water quality protective release for pass through at Longhorn Dam. The subsistence flow recommendation for pass though at Longhorn Dam is 50 cfs minimum. The Austin reach extends approximately 2.5 river miles before the first major CoA return flow which discharges greater than 100 cfs into the river. Under this scenario, the Decker lake diversion immediately downstream of the CoA WWTP withdraws approximately 40% of the discharge from the river, but less than 10 river miles downstream from this point, the second major CoA return flow of greater than 100 cfs is added to the river. Under the proposed 50 cfs subsistence flow release from Austin and projected CoA WWTP operating conditions, greater than 200 cfs would be present in the lower Colorado River before reaching the Utley intensive site. The water quality model predicts DO concentrations of greater than 5.0 mg/L for the entire Austin reach with the 50 cfs headwater flow. While it is recognized that the 50 cfs flow does not protect habitat in this 2.5 mile Austin reach to the same degree as the remaining 285 plus river miles, supplying the full amount of flow based on habitat modeling (Table 4.7) in the Austin reach results in subsistence flows at Bastrop and further downstream that are about 200 cfs greater than recommended, effectively removing the natural variability that maintains the health of the river. However, if future management alternatives remove or greatly decrease the return flows in this reach, flow requirements at Bastrop would need to be supplemented by additional flows that would pass through the Austin reach.

The second modification is an adjustment of the August and September monthly discharges for the Bastrop Reach and August and October monthly discharges at the Columbus Reach to account for current-period conditions. The 60 cfs and 97 cfs for August and September at Bastrop, respectively is replaced with a 123 cfs minimum discharge during these months. Using assumptions based upon a more current flow regime, the water quality modeling predicts greater than 5.0 mg/L through the entire Austin through Smithville reaches with the 50 cfs headwater flow requirement and a minimum of 100 cfs at Bastrop during August and September. The shift to 123 cfs is an attempt to address the higher nutrient concentrations in the river today by providing higher than habitat model predicted flows during the summer time months. The goal is to limit areas of stagnant water and warmer temperatures to avoid conditions favorable for excessive macrophyte growth. As no macrophyte model was developed for this project, the project team looked to existing conditions as a guide. The lowest discharge recorded at the Bastrop gage for the current (1975 to 2004) time period was 114 cfs. As discussed in Section 6, low summer time subsistence flow recommendations will need to be monitored closely relative to excess aquatic macrophyte growth, in particular exotics such as hydrilla. Secondly, the shift to 123 cfs at Bastrop for August and September and 190 cfs at Columbus for August and October provides for no less than 5 percent of the maximum available habitat for all guilds for all months.

The final modification addresses concerns specific to the lower Colorado River blue sucker recruitment. The inability to collect juvenile blue suckers in the lower Colorado River during the existing time period and again during intensive field activities in 2004-2007 leads to recruitment concerns for this species. As such, specific studies relative to long-term monitoring will be recommended in the long-term monitoring plan. However, in the interim, the project team recommends higher levels of blue sucker spawning habitat to be maintained during February and March for subsistence flow recommendations at the Bastrop reach. April was included in all blue sucker spawning habitat model runs, but was not included for adjustment since it does not represent the key time period observed for the lower Colorado River. An increase in the discharge to 274 cfs (Bastrop) and 375 cfs (Columbus) for February and March (Table 4.8) respectively, provides 90 percent of maximum spawning habitat available during these key months. The underlying assumption is that enhancement of spawning opportunities results in enhancement of recruitment. Clearly, many other factors are also important including maintaining available larval and juvenile habitat in subsequent months. Should this assumption be proven false during the completion of this project or long-term monitoring activities, adjustments to these modifications would be appropriate. This provides a glimpse into the importance of long-term monitoring and adaptive management discussed below. Table 4.8 presents the proposed monthly LSWP subsistence flow recommendations for the lower Colorado River.

To account for intervening flow between selected sites and the site with the long pre-1940 period of record (Long term records for Austin were used to develop flow recommendations at Bastrop and long term records at Columbus were used to develop recommendations at Wharton) a drainage area adjustment was applied. Bastrop recommendations were increased by 4% and Wharton recommendations were increased by 1%.

Table 4.8. LSWP Subsistence Flow recommendations per reach for the lower Colorado River.

Reach	LSWP Subsistence Flow Monthly Recommendations (Instantaneous Minimum [cfs])											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Austin	50	50	50	50	50	50	50	50	50	50	50	50
Bastrop	208	274	274	184	275	202	137	123	123	127	180	186
Columbus	340	375	375	299	425	534	342	190	279	190	202	301
Wharton	315	303	204	270	304	371	212	107	188	147	173	202

Table 4.9 shows the percent of maximum available habitat for the Subsistence Flow Recommendations per month per reach. It must be understood that Table 4.6 shows the percent of maximum habitat for the respective habitat percent exceedence levels, whereas Table 4.9 shows what actually is modeled to occur when the Subsistence Flow is applied. For instance, the annual average percent of maximum habitat for Riffles at the 95th percent habitat exceedence level for Bastrop is 35%, Columbus (16%) and Wharton (13%) (Table 4.6), whereas the annual average percent of maximum habitat for Riffles at the recommended subsistence flow recommendation for Bastrop is 87%, Columbus (95%) and Wharton (90%) (Table 4.9). An examination of Tables 4.6 and 4.9 reveal that the Rapids/Adult Blue Sucker habitat guild is the driving parameter for the Bastrop and Columbus reaches, with Deep Pools habitat being the driver for the Wharton Reach. As discussed above, the adjustments to February and March (key time period) for spawning blue suckers brings that habitat to greater than 90 percent of the maximum available during subsistence flows (Table 4.9). Also noted are the upward adjustments to August and September (Bastrop) and August and October (Columbus) to provide at least 5 percent of the maximum available habitat during those months (Table 4.9).

Table 4.9. Percent of maximum available habitat per month per reach for LSWP Subsistence Flow recommendations.

BASTROP REACH

Month	SUBSISTENCE Discharge (cfs)	Percent of Maximum Available Habitat: Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
January	**208**	16%	84%	60%	84%	91%	99%	89%
February	**274**	25%	91%	64%	88%	88%	100%	94%
March	**274**	25%	91%	64%	88%	88%	100%	94%
April	**184**	13%	82%	58%	83%	92%	99%	87%
May	**275**	26%	91%	64%	88%	88%	100%	94%
June	**202**	16%	N/A	59%	84%	91%	99%	88%
July	**137**	7%	N/A	55%	81%	94%	98%	83%
August	**123**	5%	N/A	54%	80%	95%	98%	81%
September	**123**	5%	N/A	54%	80%	95%	98%	81%
October	**127**	5%	N/A	54%	80%	94%	98%	82%
November	**180**	13%	N/A	58%	83%	92%	99%	86%
December	**186**	13%	N/A	58%	83%	92%	99%	87%
Annual Average		14%	88%	59%	83%	92%	99%	87%

COLUMBUS REACH

Month	SUBSISTENCE Discharge (cfs)	Percent of Maximum Available Habitat: Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
January	**340**	16%	88%	58%	89%	94%	99%	97%
February	**375**	19%	90%	59%	90%	93%	99%	98%
March	**375**	19%	90%	59%	90%	93%	99%	98%
April	**299**	12%	86%	56%	88%	95%	100%	96%
May	**425**	24%	93%	61%	91%	92%	98%	99%
June	**534**	33%	N/A	64%	93%	88%	96%	100%
July	**342**	16%	N/A	58%	89%	94%	99%	97%
August	**190**	5%	N/A	51%	82%	97%	99%	88%
September	**279**	10%	N/A	55%	87%	95%	100%	95%
October	**190**	5%	N/A	51%	82%	97%	99%	88%
November	**202**	5%	N/A	52%	83%	96%	99%	89%
December	**301**	12%	N/A	56%	88%	95%	100%	96%
Annual Average		14%	89%	57%	87%	94%	99%	95%

WHARTON REACH

Month	SUBSISTENCE Discharge (cfs)	Percent of Maximum Available Habitat: Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
January	**315**	N/A	N/A	40%	79%	91%	100%	96%
February	**303**	N/A	N/A	39%	78%	92%	100%	96%
March	**204**	N/A	N/A	34%	73%	96%	99%	88%
April	**270**	N/A	N/A	37%	77%	93%	100%	94%
May	**304**	N/A	N/A	39%	78%	92%	100%	96%
June	**371**	N/A	N/A	42%	80%	89%	99%	97%
July	**212**	N/A	N/A	35%	73%	96%	99%	89%
August	**107**	N/A	N/A	29%	66%	99%	97%	77%
September	**188**	N/A	N/A	34%	72%	97%	99%	87%
October	**147**	N/A	N/A	32%	70%	98%	98%	83%
November	**173**	N/A	N/A	33%	71%	97%	99%	86%
December	**202**	N/A	N/A	34%	73%	96%	99%	88%
Annual Average		N/A	N/A	36%	74%	95%	99%	90%

4.2.6 LSWP Base Flow Recommendation

The base flow recommendation development follows the same framework as subsistence but does not carry with it literature recommendations for what levels of habitat this recommendation should protect. Nor is specific guidance relative to different levels of base flows provided in the TIFP (2006). The goal of the following base flow recommendation is to assist in the year to year variability for periods outside of extreme drought. Therefore, an investigation of three base flow recommendations was initially pursued. A base flow greater than subsistence but still representative of dry weather conditions, a base flow more representative of average weather conditions (realizing there is really no average condition in Texas river hydrology), and a base flow representative of wet conditions in the basin.

A comprehensive evaluation of the habitat model results, duration curves, exceedence tables, and complementary water quality and sediment transport modeling led the project team to propose two base flow recommendations, rather than three as described in TIFP (2006). As discussed below, a conservative Base-DRY and Base-AVERAGE condition were selected because the project team is confident that they (along with the other LSWP flow regime recommendations) produce habitat conditions and year to year variability sufficient to maintain a sound ecological environment. A discussion on why a Base-WET condition at higher than the proposed Base-AVERAGE recommendation was not included is provided at the conclusion of this section.

When evaluating a Base-DRY guideline, Table 4.10 shows that at the 80th percent habitat exceedence level, there are only two instances when individual habitat categories in any month falls to less than 10 percent (once at Austin and at Smithville) of the maximum habitat. Also, natural habitat “diversity” is maintained. By habitat “diversity” we are not adhering strictly to the term diversity as defined in the Shannon’s or other biodiversity indices. Such indices of diversity would be maximized by maximizing evenness and richness of habitat types, i.e. all habitat types available in equal proportions. This is clearly not the goal of this study. Rather the goal is to maintain levels of habitats that would be expected under a more natural flow regime and to provide “the variety of physical habitats found within the river system” (TIFP Draft 2006). This diversity and equitability at the 80th percent habitat exceedence level is maintained by ensuring that the total annual average habitat is approximately equal to or greater than 50 percent of the maximum for each reach (Table 4.10).

The values in Table 4.10 for Bastrop, Columbus, and Wharton are presented in Figures 4.18 and 4.19. Figure 4.18 expands Table 4.10 to include all percent habitat exceedence levels. As shown in Figure 4.18, in general the 80th percent habitat exceedence level is conservative in that some breaks in the chart for certain habitats (i.e. riffles, spawning blue sucker, deep run at Bastrop) appear more towards the 85th, 90th, or 95th percent habitat exceedence levels. Additionally, Figure 4.19 shows that at the 80th percent habitat exceedence level (highlighted by the orange ovals), there are no instances where individual habitat categories at the three proposed criteria locations (Bastrop, Columbus, and Wharton) fall to less than 10 percent of the maximum habitat available. Of the three reaches, Columbus has the most months (10 months out of 75 possible [@13%]) where less than 25 percent of the maximum habitat available occurs in a given month based on habitat percent exceedence values.

During the review period, the question was raised whether the 90th percent habitat exceedence level might not be more suited for a Base-DRY recommendation since breaks in the duration curves are evident at this level. Figures 4.21 and 4.22 show the comparison of Rapids and Riffles habitat guild available habitat for each of these levels at the Utley site in April. Specifically, the Rapids (Bastrop/Columbus) and Riffles (Columbus/Wharton) habitat guilds (along with shallow pool/edge/backwater) experienced the lowest percentage of maximum habitat at the Base-DRY level (Figure 4.18) and thus, visual evaluation was performed to examine their habitat distribution. As evident in Figures 4.21 and 4.22, there are contiguous segments of both habitat guild types and not just sporadic patches of habitat throughout the site. Optimal or high quality habitat is limited (blue color) for the Rapids habitat guild for both habitat exceedence levels, but abundant for the Riffles habitat guild at both levels. Another way to evaluate differences is to look at how much available habitat is projected using Pre-1940 discharges at the 90th and 80th percent flow exceedence levels. Table 4.11 shows the modeled percentage of maximum habitat available at discharges associated with either the 90th or 80th flow exceedence level. As shown in Table 4.11, the 80th percent flow exceedence level provides nearly double the Rapids habitat and brings spawning blue sucker habitat to over 90 percent of maximum for the Bastrop reach and 95 percent of maximum for the Columbus reach. Although slight decreases are evident for shallow water habitats (Pools/ Edges/Backwaters and Shallow Runs) (Table 4.11), the increases for the remaining habitat guilds led the project team to select the 80th percent habitat exceedence level as the starting point for evaluating a conservative Base-DRY guideline at all reaches.

Following the same rationale, and again carefully examining the habitat model results, duration curves, and exceedence tables (Appendices E, F, and H), the 60th percent habitat exceedence level was selected as a conservative guideline for more “average” base flow conditions. The 60th percent habitat exceedence level exhibits only one case (Austin) where an individual habitat category in any month falls to less than 25 percent of maximum habitat (Table 4.10). At the 60th percent habitat exceedence level, the total annual average percent of maximum habitat is approximately equal to or greater than 70 percent of the maximum habitat per reach. Figure 4.18 shows how the percent of maximum habitat drops more rapidly after the 60th percent habitat exceedence level. Figure 4.19 reveals that at this level, there is not one month in the selected reaches that a given habitat type falls below 25 percent of the maximum habitat available, and less than 10 months at any given location (8 at Columbus) does a given habitat type fall below 50 percent of the maximum habitat available. As discussed for Subsistence and Base-DRY recommendations, visual evaluations of modeled habitat distribution was performed for the Base-AVERAGE recommendation. As evident in Figure 4.23, both the Rapids and the Riffles habitat guilds have considerable amounts of high quality habitat that extends throughout the site.

Table 4.10. Summary of the 55th-99th percent exceedence levels of habitat area presented as percent of maximum habitat for each reach. Recommended Base flow conditions highlighted.

		Percent of Maximum Habitat												
Reach	% Exc. level	Count [1]					Annual Habitat Average[2]							
		Zero	< 5%	< 10%	< 25%	< 50%	Rapids / Adult blue sucker	Spawn blue sucker	Deep Pool	Deep Run	Shallow Pool / Edge / Backwater	Shallow Run	Riffle	TOTAL
Austin	99	4	21	34	51	73	3%	7%	30%	45%	11%	11%	4%	17%
	95	1	5	15	41	64	7%	24%	33%	58%	22%	24%	14%	26%
	90	1	1	6	20	61	11%	45%	34%	65%	31%	38%	29%	35%
	85	0	1	3	14	50	14%	61%	36%	69%	38%	50%	43%	43%
	80	0	0	1	11	37	18%	68%	38%	73%	45%	61%	55%	49%
	75	0	0	0	9	31	22%	71%	40%	76%	53%	68%	62%	54%
	70	0	0	0	8	26	26%	76%	41%	79%	62%	74%	67%	59%
	65	0	0	0	5	23	31%	78%	43%	82%	69%	79%	72%	63%
	60	0	0	0	1	22	36%	82%	46%	85%	74%	83%	77%	67%
	55	0	0	0	0	18	41%	84%	49%	88%	79%	85%	81%	71%
Bastrop	99	3	8	10	46	55	4%	24%	53%	54%	19%	24%	18%	28%
	95	0	3	4	19	50	11%	43%	57%	66%	27%	36%	35%	39%
	90	0	1	2	11	35	17%	60%	60%	75%	35%	49%	53%	49%
	85	0	1	1	9	26	23%	76%	63%	79%	43%	61%	69%	57%
	80	0	0	0	4	18	29%	80%	66%	82%	51%	71%	77%	63%
	75	0	0	0	1	12	35%	83%	68%	84%	57%	78%	81%	68%
	70	0	0	0	1	12	40%	86%	71%	86%	63%	84%	85%	72%
	65	0	0	0	0	9	46%	88%	74%	88%	68%	88%	88%	76%
	60	0	0	0	0	6	52%	90%	77%	89%	72%	90%	91%	79%
	55	0	0	0	0	3	57%	92%	80%	91%	74%	92%	93%	82%
Smithville	99	5	23	49	51	66	2%	5%	53%	38%	6%	8%	3%	18%
	95	1	6	21	48	54	6%	18%	55%	56%	13%	21%	11%	27%
	90	1	2	8	28	50	11%	33%	58%	70%	22%	34%	24%	36%
	85	0	1	3	16	41	15%	49%	60%	77%	33%	48%	39%	45%
	80	0	0	1	13	25	19%	63%	62%	80%	44%	59%	52%	53%
	75	0	0	0	10	18	24%	69%	64%	83%	53%	67%	61%	59%
	70	0	0	0	7	16	29%	74%	66%	85%	61%	74%	68%	64%
	65	0	0	0	2	13	34%	77%	68%	87%	67%	80%	72%	68%
	60	0	0	0	0	12	39%	80%	71%	89%	72%	84%	76%	72%
	55	0	0	0	0	8	45%	83%	73%	90%	76%	87%	80%	76%
Columbus	99	0	4	8	51	53	8%	23%	53%	59%	16%	18%	14%	28%
	95	0	2	3	46	52	14%	30%	56%	67%	19%	22%	16%	32%
	90	0	0	2	33	51	22%	36%	60%	75%	24%	31%	19%	38%
	85	0	0	0	20	47	27%	44%	62%	80%	29%	40%	25%	44%
	80	0	0	0	10	38	33%	54%	65%	84%	36%	49%	35%	51%
	75	0	0	0	4	30	38%	64%	67%	87%	44%	58%	47%	57%
	70	0	0	0	3	19	45%	71%	70%	89%	51%	65%	58%	63%
	65	0	0	0	0	14	50%	77%	72%	90%	57%	70%	66%	68%
	60	0	0	0	0	8	56%	83%	75%	91%	63%	75%	74%	73%
	55	0	0	0	0	6	60%	87%	77%	93%	68%	79%	79%	76%
Wharton	99	0	0	0	31	48	N/A	N/A	35%	64%	24%	25%	13%	32%
	95	0	0	0	12	48	N/A	N/A	39%	72%	29%	32%	17%	38%
	90	0	0	0	10	45	N/A	N/A	44%	76%	35%	40%	22%	43%
	85	0	0	0	5	40	N/A	N/A	47%	79%	40%	49%	28%	49%
	80	0	0	0	2	28	N/A	N/A	50%	81%	47%	58%	37%	54%
	75	0	0	0	1	19	N/A	N/A	53%	82%	53%	66%	45%	60%
	70	0	0	0	0	10	N/A	N/A	57%	84%	58%	73%	53%	65%
	65	0	0	0	0	8	N/A	N/A	60%	86%	62%	77%	60%	69%
	60	0	0	0	0	3	N/A	N/A	64%	88%	66%	82%	68%	73%
	55	0	0	0	0	2	N/A	N/A	67%	89%	69%	85%	74%	77%

[1] ([Six habitat catagories * 12 months] + Spawning blue sucker habitat * 3 months = 75 Total) -- Wharton (60 possible - [Five habitat catagories * 12 months])

[2] February - April only for Spawning blue sucker

Base Flow - DRY (80) recommended habitat percent exceedence level

Base Flow - AVERAGE (60) recommended habitat percent exceedence level

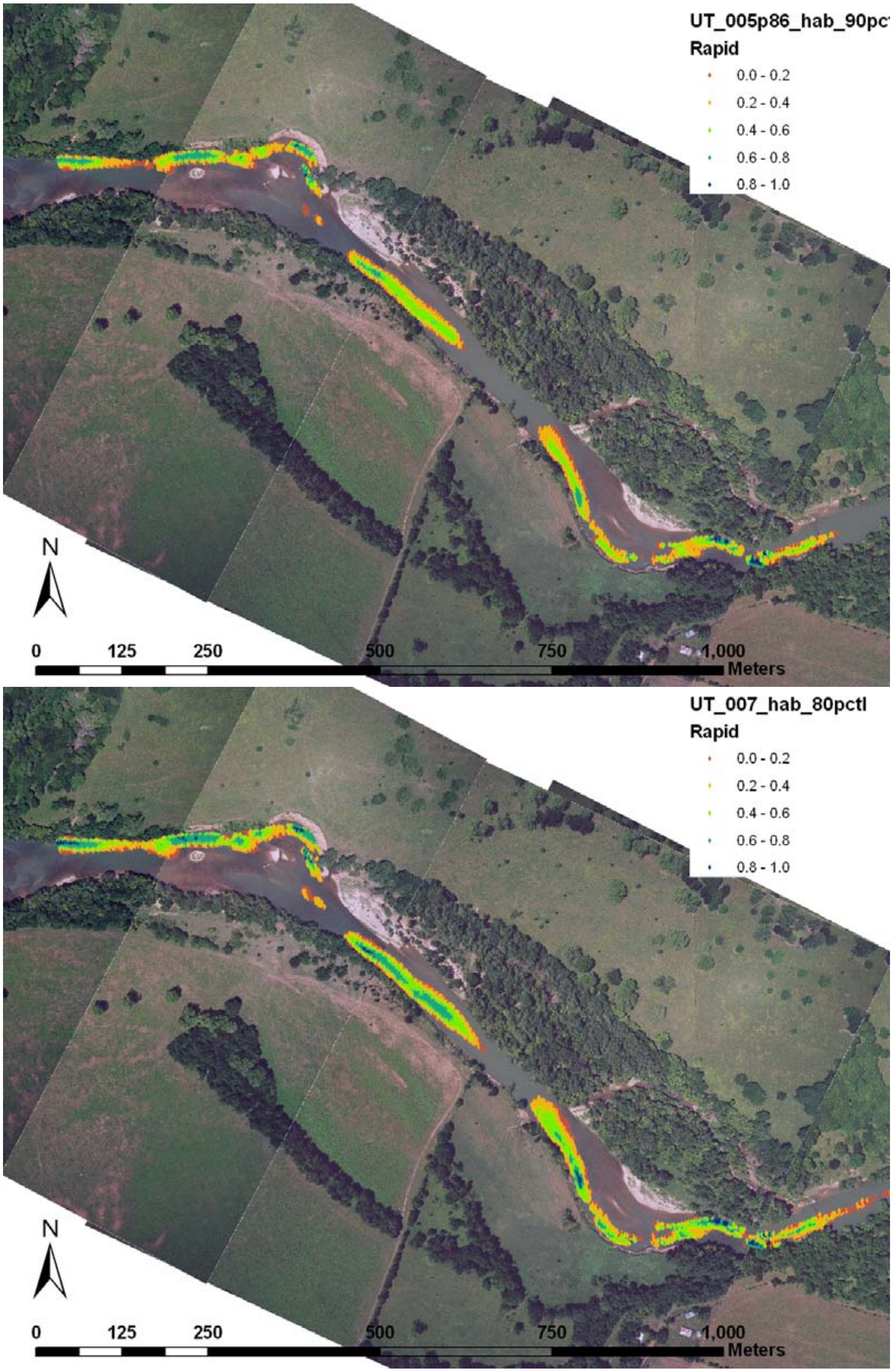
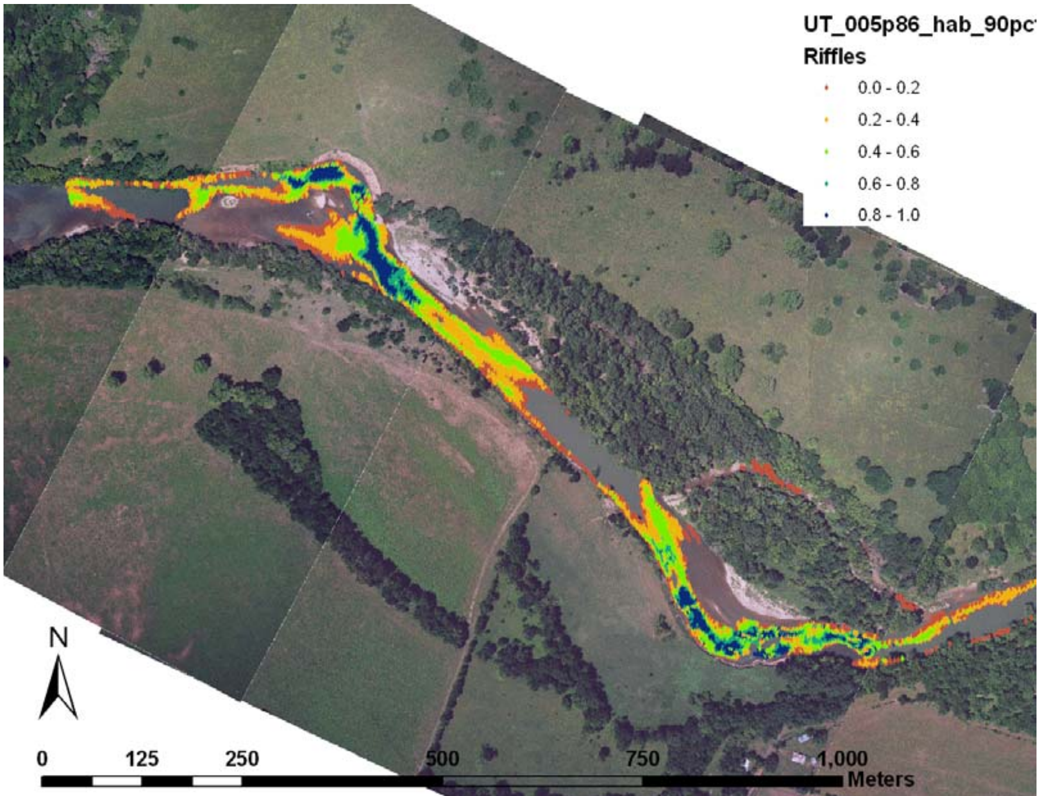


Figure 4.21. Available habitat for the Rapids/Adult Blue Sucker habitat guild at the Utley site at the 90th and 80th percent habitat exceedence level in April.



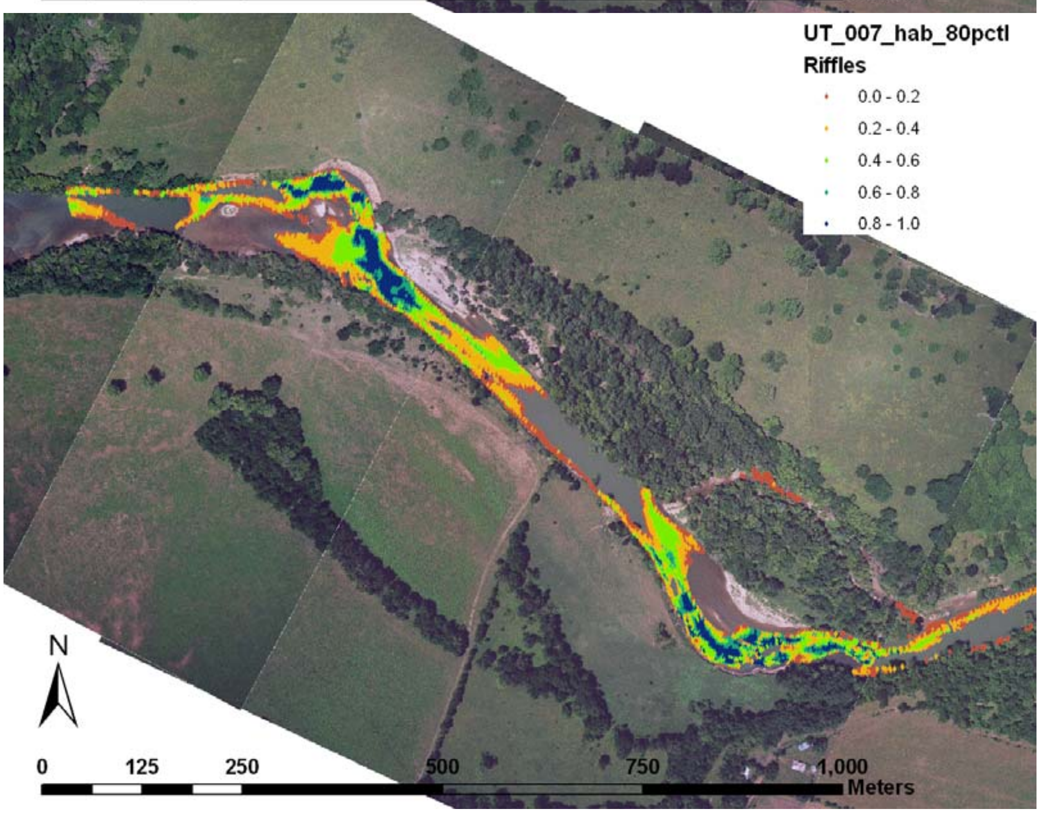


Figure 4.22. Available habitat for the Riffles habitat guild at the Utley site at the 90th and 80th percent habitat exceedence level in April.

Table 4.11. Percent of maximum available habitat per reach for Pre-1940 discharge associated with the 90th and 80th Percent Flow Exceedence levels.

BASE-DRY		Percent of Maximum Available Habitat						
	Discharge associated with (Pre-1940 - Flow Exceedence Level)	Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
Bastrop	**200 cfs (90th)**	15%	83%	59%	84%	91%	99%	88%
	283 cfs (80th)	27%	92%	65%	88%	88%	100%	95%
Columbus	**352 cfs (90th)**	17%	89%	58%	89%	93%	99%	98%
	489 cfs (80th)	29%	95%	63%	92%	90%	97%	100%
Wharton	**352 cfs (90th)**	N/A	N/A	41%	80%	90%	99%	97%
	489 cfs (80th)	N/A	N/A	48%	84%	84%	97%	100%

Table 4.12 presents the monthly flows necessary to meet these percent habitat exceedence levels at the same reaches as selected for subsistence flow recommendations, except for Austin for which only a subsistence flow recommendation was developed.

Table 4.12. **C**alculated monthly flows to meet the selected base flow habitat percent exceedence levels per reach.

Reach	**Initially Calculated Monthly Flows - Base DRY (80th) (Instantaneous minimum [cfs])**											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Bastrop	303	306	265	277	559	404	335	187	228	237	273	300
Columbus	487	590	525	554	966	967	570	310	405	356	480	464
Wharton	487	590	525	554	974	972	570	310	405	356	480	464
	Initially Calculated Monthly Flows - Base AVERAGE (60th) (Instantaneous minimum [cfs])											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Bastrop	418	480	480	613	796	708	590	368	409	418	410	435
Columbus	828	895	1020	977	1316	1440	895	516	610	741	755	737
Wharton	828	895	1024	999	1380	1495	895	516	610	741	755	737

The DO modeling and sediment transport analysis confirm that these discharges would be acceptable as base flow recommendations. These discharges also provide greater than 95 percent of the maximum available spawning blue sucker habitat and thus, further modifications during February and March were not proposed. Table 4.13 presents the proposed monthly LSWP base flow recommendations for the lower Colorado River, which includes the same drainage area adjustment as applied to the subsistence flow recommendations.

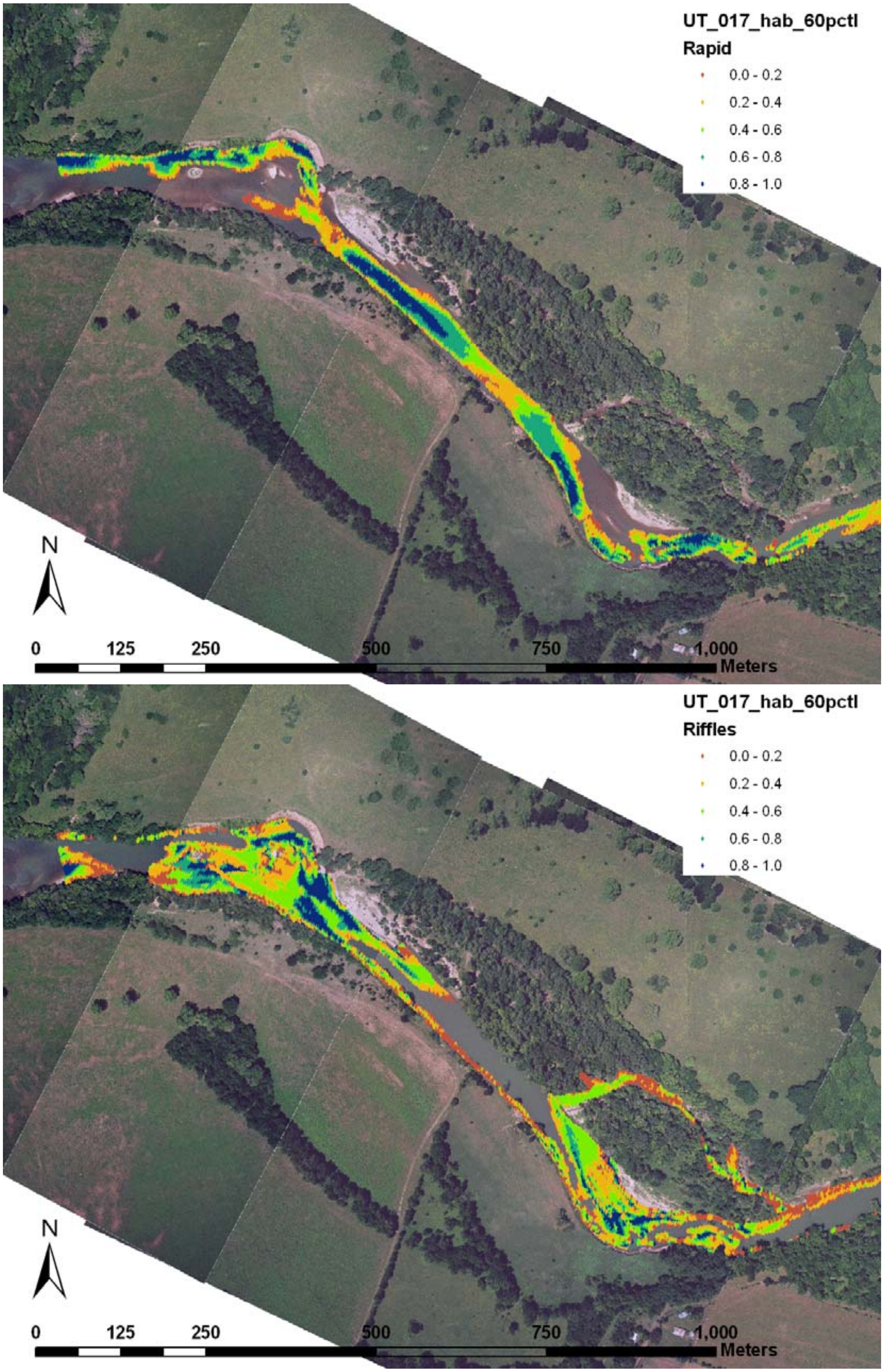


Figure 4.23. Available habitat for Rapids and Riffles habitat guilds at the Utley site at the 60th percent habitat exceedence level in April.

Table 4.13. LSWP Base Flow (DRY and AVERAGE) recommendations per reach for the lower Colorado River.

Reach	LSWP Base-DRY Monthly Flow Recommendations (Instantaneous Minimum [cfs])											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bastrop	313	317	274	287	579	418	347	194	236	245	283	311
Columbus	487	590	525	554	966	967	570	310	405	356	480	464
Wharton	492	597	531	561	985	984	577	314	410	360	486	470
	LSWP Base-AVERAGE Monthly Flow Recommendations (Instantaneous Minimum [cfs])											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bastrop	433	497	497	635	824	733	610	381	423	433	424	450
Columbus	828	895	1020	977	1316	1440	895	516	610	741	755	737
Wharton	838	906	1036	1011	1397	1512	906	522	617	749	764	746

Tables 4.14 and 4.15 show the percent of maximum available habitat for the Base-DRY and Base-AVERAGE Flow Recommendations per month for the Bastrop, Columbus, and Wharton reaches, respectively. Again, these values are the modeled output for the selected discharge, which is different than the habitat available for individual guilds at a certain habitat percent exceedence level. An examination of Tables 4.14 and 4.15 reveal that the Rapids/Adult Blue Sucker habitat guild is the driving parameter for the Bastrop and Columbus reaches, with Deep Pools habitat being the driver for the Wharton Reach.

One of the main goals of recommending a flow regime is to provide variability in habitat types, amounts, and distributions with the objective of maintaining a sound ecological environment. Tables 4.9, 4.14 and 4.15 highlight this variability. For instance, during the Subsistence Flow recommendation (Table 4.9), nearly maximum pools/edges/backwaters and shallow run habitat is maintained, and specific adjustments provide for over 90 percent of maximum spawning blue sucker habitat during February and March. As flows increase to Base-DRY (Table 4.14), nearly maximum habitat is available for shallow runs and riffles, with greater than 90 percent of maximum spawning blue sucker habitat throughout the entire spring. As flows increase to the Base-AVERAGE recommendations (Table 4.15), nearly maximum habitat is available for deep runs and spawning blue sucker habitat, with deep pools and rapids gaining considerable amounts of area. However, at the Base-AVERAGE flow recommendation, three (pools/edges/backwaters, shallow runs, and riffles) of the seven habitat guilds start to decrease.

The next logical step in this process was to evaluate what it would take to create near maximum conditions for deep pools and rapids habitat and call this recommendation Base-WET (a key item raised by resource agency professionals). However, as evident by the trends discussed above, a Base-WET recommendation would provide greater variability to the flow regime, but the modeling results show that increased flows benefit some habitat types while others are considerably reduced.

Table 4.14. Percent of maximum available habitat per month per reach for LSWP Base-DRY Flow recommendations.

BASTROP REACH

Month	BASE-DRY Discharge (cfs)	Percent of Maximum Available Habitat						
		Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
January	**313**	31%	94%	67%	90%	86%	100%	97%
February	**317**	31%	94%	67%	90%	86%	100%	97%
March	**274**	25%	91%	64%	88%	88%	100%	94%
April	**287**	27%	92%	65%	89%	87%	100%	95%
May	**579**	59%	99%	82%	97%	79%	97%	99%
June	**418**	44%	N/A	73%	93%	83%	99%	98%
July	**347**	35%	N/A	69%	91%	85%	100%	98%
August	**194**	14%	N/A	59%	84%	92%	99%	87%
September	**236**	20%	N/A	62%	86%	90%	99%	91%
October	**245**	21%	N/A	62%	86%	89%	99%	92%
November	**283**	27%	N/A	65%	88%	88%	100%	95%
December	**311**	30%	N/A	67%	90%	87%	100%	97%
Annual Average		30%	94%	67%	89%	87%	99%	95%

COLUMBUS REACH

Month	BASE-DRY Discharge (cfs)	Percent of Maximum Available Habitat						
		Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
January	**487**	29%	95%	63%	92%	90%	97%	100%
February	**590**	37%	98%	66%	94%	86%	95%	100%
March	**525**	32%	96%	64%	93%	89%	96%	100%
April	**554**	34%	97%	65%	93%	88%	95%	100%
May	**966**	63%	100%	78%	99%	77%	87%	92%
June	**967**	63%	N/A	78%	99%	77%	87%	92%
July	**570**	36%	N/A	65%	94%	87%	95%	100%
August	**310**	13%	N/A	56%	88%	94%	100%	97%
September	**405**	22%	N/A	60%	90%	92%	98%	99%
October	**356**	17%	N/A	58%	89%	93%	99%	98%
November	**480**	28%	N/A	62%	92%	90%	97%	100%
December	**464**	27%	N/A	62%	92%	90%	97%	100%
Annual Average		33%	97%	65%	93%	88%	95%	98%

WHARTON REACH

Month	BASE-DRY Discharge (cfs)	Percent of Maximum Available Habitat						
		Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
January	**492**	N/A	N/A	48%	84%	84%	97%	100%
February	**597**	N/A	N/A	52%	87%	81%	96%	99%
March	**531**	N/A	N/A	50%	85%	83%	97%	100%
April	**561**	N/A	N/A	51%	86%	82%	97%	99%
May	**985**	N/A	N/A	67%	97%	72%	92%	88%
June	**984**	N/A	N/A	67%	97%	72%	92%	88%
July	**577**	N/A	N/A	52%	86%	82%	97%	99%
August	**314**	N/A	N/A	39%	78%	91%	100%	96%
September	**410**	N/A	N/A	44%	81%	87%	99%	98%
October	**360**	N/A	N/A	42%	80%	89%	99%	97%
November	**486**	N/A	N/A	48%	84%	84%	97%	100%
December	**470**	N/A	N/A	47%	83%	85%	98%	99%
Annual Average		N/A	N/A	51%	86%	83%	97%	97%

Table 4.15. Percent of maximum available habitat per month per reach for LSWP Base-AVERAGE Flow recommendations.

BASTROP REACH

Month	BASE-AVERAGE Discharge (cfs)	Percent of Maximum Available Habitat						
		Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
January	**433**	46%	98%	74%	94%	83%	99%	98%
February	**497**	53%	99%	78%	96%	81%	98%	98%
March	**497**	53%	99%	78%	96%	81%	98%	98%
April	**635**	63%	99%	84%	98%	78%	96%	99%
May	**824**	74%	99%	90%	99%	73%	93%	100%
June	**733**	70%	N/A	88%	99%	75%	95%	100%
July	**610**	61%	N/A	83%	97%	79%	97%	99%
August	**381**	39%	N/A	71%	92%	84%	99%	98%
September	**423**	45%	N/A	74%	94%	83%	99%	98%
October	**433**	46%	N/A	74%	94%	83%	99%	98%
November	**424**	45%	N/A	74%	94%	83%	99%	98%
December	**450**	47%	N/A	75%	94%	82%	99%	98%
Annual Average		53%	99%	79%	96%	80%	98%	99%

COLUMBUS REACH

Month	BASE-AVERAGE Discharge (cfs)	Percent of Maximum Available Habitat						
		Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
January	**828**	55%	100%	74%	97%	80%	90%	97%
February	**895**	58%	100%	76%	98%	78%	89%	95%
March	**1,020**	66%	99%	80%	100%	75%	86%	91%
April	**977**	63%	100%	79%	100%	76%	87%	92%
May	**1,316**	80%	92%	84%	100%	63%	78%	81%
June	**1,440**	85%	N/A	86%	100%	58%	74%	75%
July	**895**	58%	N/A	76%	98%	78%	89%	95%
August	**516**	31%	N/A	64%	93%	89%	96%	100%
September	**610**	39%	N/A	67%	94%	86%	94%	100%
October	**741**	49%	N/A	71%	96%	82%	92%	100%
November	**755**	50%	N/A	71%	96%	82%	91%	100%
December	**737**	49%	N/A	71%	96%	82%	92%	100%
Annual Average		57%	98%	75%	97%	77%	88%	94%

WHARTON REACH

Month	BASE-AVERAGE Discharge (cfs)	Percent of Maximum Available Habitat						
		Rapid - Adult Blue Sucker	Spawning Blue Sucker	Deep Pools	Deep Run	Pools/Edges/ Backwaters	Shallow Runs	Riffles
January	**838**	N/A	N/A	62%	94%	76%	94%	94%
February	**906**	N/A	N/A	64%	95%	74%	93%	91%
March	**1,036**	N/A	N/A	69%	97%	71%	91%	86%
April	**1,011**	N/A	N/A	68%	97%	71%	91%	87%
May	**1,397**	N/A	N/A	79%	100%	64%	82%	66%
June	**1,512**	N/A	N/A	82%	100%	61%	79%	61%
July	**906**	N/A	N/A	64%	95%	74%	93%	91%
August	**522**	N/A	N/A	49%	85%	83%	97%	100%
September	**617**	N/A	N/A	53%	88%	81%	96%	99%
October	**749**	N/A	N/A	59%	92%	78%	95%	97%
November	**764**	N/A	N/A	60%	92%	77%	95%	96%
December	**746**	N/A	N/A	59%	92%	78%	95%	97%
Annual Average		N/A	N/A	64%	94%	74%	92%	89%

After extensive investigation the project team was unable to identify a higher wet flow condition that would show an overall benefit in terms of habitat specific to the lower Colorado River. Consideration was given to setting wet flow recommendation similar to other instream flow studies (e.g. Savanna Sustainable River Program) which set Base-WET recommendations at flows that are exceeded 25-30% of the time. Providing the 70th percentile flows (30th percent exceedence) based on pre-1940 conditions at the Columbus reach would result in increases in deep water habitats but also substantial decreases in shallow water habitats (Table 4.16).

Table 4.16. Percent change in habitat area from Base-AVERAGE to 70th percentile flows.

Rapid - Adult Blue Sucker	65%
Deep Pools	21%
Deep Run	-1%
Spawning Blue Sucker	-20%
Shallow Runs	-27%
Pools/Edges/Backwaters	-37%
Riffles	-39%

From a natural flows perspective these types of conditions did occur and, based on that paradigm, having some years with 65% more rapids habitat, 20% less spawning blue sucker habitat, and 39% less riffle habitat has an ecological benefit, however conditions within the lower Colorado River make this recommendation less feasible. The main factor is the reduction of riffle and spawning blue sucker habitat at these values. Due to the potential limited recruitment and genetic homogeneity of blue suckers in the lower Colorado River, a conscious effort has been made to recommend a flow regime that would be protective to the overall aquatic community but not unnecessarily harmful to the early life-stages of the blue sucker. Hence, the recommendation for higher subsistence flows during key blue sucker spawning periods. Following the same rationale, the recommendation during wet periods is to evaluate how additional water could be put to use by providing short term high flow pulses as described in Section 4.3, rather than increasing base flows for an entire month at the expense of shallow water habitats.

As such, the decision was made to go with more conservative percent habitat exceedence levels for Base-DRY and Base-AVERAGE (as described above) which encompass nearly maximum habitat conditions for five of the seven guilds, rather than including an additional Base-WET recommendation. As the long-term monitoring program is implemented, information on blue sucker recruitment may lead to the refinement in this thought process and ultimately a Base-WET recommendation.

4.3 Pulse Flow, Channel Maintenance and Overbanking Flow Development

Mosier and Ray (1992) stated that "Periodic spates of high flows are needed to prevent siltation and dense macrophyte growth." Mosier and Ray (1992) did not include any pulse flow recommendations in their report but did recommend that the frequency and duration of maintenance (pulse) flows should be evaluated based on historical flow data on the lower Colorado River. As limited data was available for sediment transport and ecological function of pulse flows on the lower Colorado River, the project team based the pulse, channel maintenance and overbanking flow recommendations on sediment transport analysis conducted during this study and a hydrologic (IHA) analysis of existing and pre-1940 flow regimes (Section 3.3).

4.3.1 LSWP Pulse Flow Recommendation

Two levels of pulse flows are recommended to support the ecological function of the river. These include base pulses and high flow pulses. The base pulse recommendation involves flows in the 2,000 to 3,000 cfs range. This magnitude of flow is recommended 8 to 10 times annually with a 3 to 5 day duration each. The ecological functions to be supported by these flows include 1) nutrient and organic matter exchange with streamside vegetation, 2) partial flushing of accumulated silt and sand material from riffles and gravel bars, 3) partial removal of herbaceous riparian vegetation on low elevation depositional features, limiting the encroachment of woody riparian vegetation on low elevation depositional features thus preventing the loss of channel capacity, and 4) relief from extended low flows during warm periods that can lead to elevated temperatures and critical dissolved oxygen concentrations.

Less frequent greater magnitude high flow pulses are also recommended. The high flow pulse magnitude recommended is approximately 8,000 cfs. A duration of 2 to 3 days for each pulse is recommended along with a frequency of two events within a three year period. These high flow pulses would mobilize the surface armor layer in steep riffle habitats such as the LA Site, mobilize smaller gravel (10mm diameter size) fractions in less-steep riffles such as CO Site, and mobilize significant volumes of sand in flat pool areas such as those similar to CO gage area. The ecological functions supported by these processes include:

- flushing of spawning areas (riffles and cobble bars);
- partial reworking of physical features (sand bars, cobble bars, etc.) to support habitat diversity;
- maintenance of deep habitat availability;
- providing nutrient and organics exchange both within the river and adjacent lower riparian tier;
- aquatic and riparian vegetation scouring
    - periodically scour herbaceous riparian vegetation to limit stand densities and help maintain channel capacity;
    - limiting the establishment of "high-strength", woody vegetation adjacent to low-flow channel;

- providing moisture to riparian plants;
- providing sediment deposition and seed dispersal to lower riparian tier.

Monitoring Recommendations

As limited cause and effect pulse flow data exist for the lower Colorado River, the project team recommends some additional monitoring to better define these ecological responses to the proposed pulse flow recommendations. One activity would be measuring bedload transport during lower-magnitude "base pulse" events to help determine whether the modeled sand and gravel transport thresholds are accurate. Because of the logistical challenges and cost of field-measuring total bedload transport on a large river such as the lower Colorado, we recommend focusing bedload transport measurements in specific habitats for specific size fractions, and that surrogate techniques such as painted rock studies and pre- and post-base pulse event transect surveys be investigated. These techniques would be helpful in determining the threshold flow for gravel transport in riffles and the effectiveness of specific flow events in scouring pool areas. Pre- and post- high flow event surveys and photography could also be used to help determine the flow magnitude that effectively scours aquatic and herbaceous/emergent riparian vegetation.

The results of these monitoring studies could be used to determine whether or not the proposed pulse flows recommendations are adequate to protect ecosystem resources, and, if not, guideline modifications may be required. This type of monitoring and potential response documents the linkage of recommendations and adaptive management. If logistically possible, monitoring studies that examine the effects of "test flow" dam releases of varying magnitudes, durations, and rising/falling limb rates could be used to help refine dam operations (within current operational and permitted constraints) to maximize the ecosystem benefits of high flow pulse events.

4.3.2 LSWP Channel Maintenance and Overbanking Flow Recommendations

Based on the results of the sediment transport analyses (Section 3.3), a flow rate of approximately 27,000 to 30,000 cfs was identified as the channel maintenance flow. Flows of this magnitude match the gravel-based effective discharge values calculated at the analysis transects, and based on hydraulic calculations would be able to mobilize the coarse armor layer at the transects (gravel particles between 20-40 mm in size). Flows in this range would provide for channel maintenance (i.e., maintenance of channel capacity) and would thoroughly flush accumulated fine sediments from important gravel bar and riffle habitats. This flow should also effectively scour accumulated sediments from pool habitats and periodically re-establish greater pool depths. Flows of this magnitude are recommended with a frequency of 1 in 3 years (i.e., with a 3-yr recurrence interval) and a minimum duration of three days. Flows greater than 30,000 cfs are proposed as the "overbank flow" recommendation, and would inundate low floodplain areas adjacent to the riffle transects analyzed, providing for lateral floodplain and riparian connectivity, floodplain maintenance/nutrient deposition, and recruitment of organic material and woody debris.

For comparison purposes Table 4.17 presents the various return period floods and the "Bankfull" and "Flood Condition" at the various gages. It also shows how the magnitude of the recommended pulse, channel maintenance and overbank flows compare with current conditions. Within the flood control context from which some of this information was taken, Bankfull is also termed "Action Stage" and described by the National Weather Service (NWS) as "flow exceeds low sections of the banks;" flood condition is described by NWS as "minor lowland flooding begins."

Table 4.17. Comparison of current hydrologic conditions and pulse and overbank flow recommendations.

		Reach		
		Bastrop	Columbus	Wharton
		Return Period [1:x years][1]		
Flow [cfs]	30,000	1:3.0	1:3.0	1:2.5
	27,000	1:2.6	1:2.0	1:2.2
	8,000	1:1.2	1:1.1	1:1.1
		Flow [cfs][1]		
Return Period	1:3 year	29,988	36,578	35,600
	1:1.5 year	14,059	19,174	17,400
	1:1 year	1,483	2,790	3,820
Flood Condition	Stage [feet][2]	23	34	39
	Flow [cfs][3]	34,461	43,040	47,412
Bankfull	Stage [feet][2]	14	30	20
	Flow [cfs][3]	15,218	31,340	9,682

[1] Calculated from peak flow data for USGS gages on Colorado River (1974-2004)
[2] From LCRA website – values are based on values reported by National Weather Service based on river levels at which minor and significant flooding of structures/developed areas occur
[3] Interpolated from recent measurement data for above USGS gages

<u>Monitoring Recommendations</u>

Although the sediment analysis transects were calibrated based on project team field measurements up to 8,000 cfs and using outputs from LCRA's HEC-RAS model, transect hydraulics were not able to be field-verified at channel maintenance or overbank flood flow levels as part of this effort. As field measurements of bedload transport were not made as part of this study, it is difficult to know exactly how long of a duration is required to fully mobilize the substrate armor layer and enter the "equal mobility" sediment transport phase. However, studies and bedload measurements on other rivers have found that multi-day durations of high flows are needed to fully mobilize the entire bed and allow for effective flushing/channel maintenance. Therefore, we recommend the long-term monitoring program include field visits, water surface elevation surveys, and bedload transport measurements in riffle and gravel bar areas at flows in the 27,000-30,000 range to confirm that surface/armor layer is in active transport, and recommended 3-day channel maintenance duration is adequate to achieve full mobilization of the coarser sediment fractions. Ideally, these studies should be conducted at several transects within each of the three river reaches for which guidelines were developed (Bastrop, Columbus, Wharton). This would be important for determining whether reach-specific channel maintenance flow recommendations are needed. Given the difference in "flood condition" and "bankfull" values reported by LCRA among the sites (Table 4.17), there may be important flood magnitude differences among the reaches. However, the reported "flood condition" and "bankfull" values are not based on specific ecological, geomorphic, or data; rather, they are indications of river levels at which flood damage to developed areas begins to occur. The field measurements and observations proposed here could be used to help refine the recommended channel maintenance flow magnitude, duration, and frequency to ensure that all relevant ecological processes are adequately protected.

4.4 LSWP Flow Regime Guidelines Summary

As described in Section 4.3, specific flow recommendations for five categories (subsistence flows, base flows, pulse flows, channel maintenance, and overbank flows) specific to the LSWP are recommended for the lower Colorado River. Figure 4.24 summarizes the integration of those recommendations into one proposed regime for the Bastrop, Columbus, and Wharton reaches of the lower Colorado River and provides an overview of ecological functions supported by each flow category.

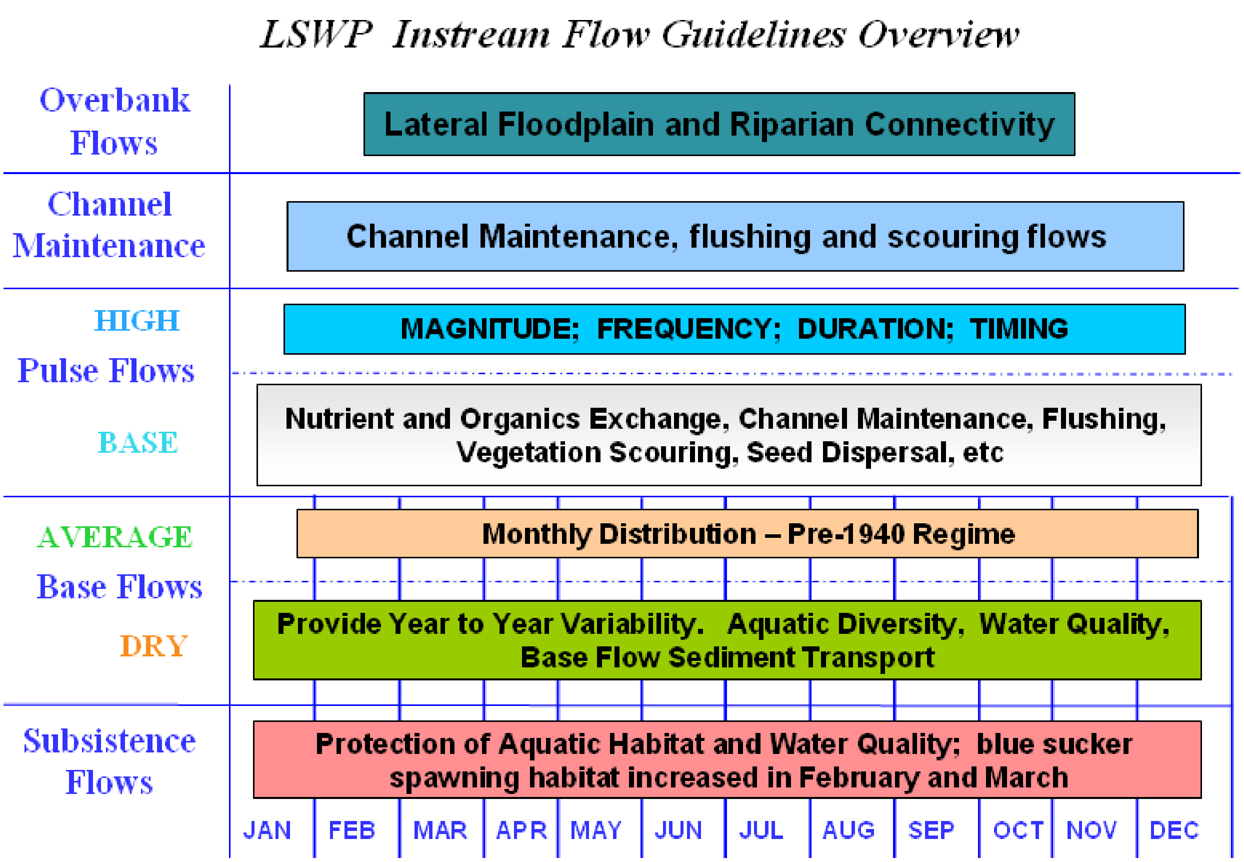


Figure 4.24. LSWP Instream Flow Guidelines Overview.

Table 4.18 shows the Instream Flow Guidelines for the lower Colorado River specific to the LSWP. As discussed in Section 4.2.5, the Austin Reach only has a subsistence flow recommendation. The Bastrop, Columbus, and Wharton reaches have proposed monthly regimes for subsistence and two levels of base flow. Pulse flows, channel maintenance flows and overbanking flows are currently the same amongst reaches.

Table 4.18. LSWP Instream Flow Guidelines

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AUSTIN REACH												
Subsistence	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**
BASTROP REACH												
Subsistence	**208**	**274**	**274**	**184**	**275**	**202**	**137**	**123**	**123**	**127**	**180**	**186**
Base-DRY	**313**	**317**	**274**	**287**	**579**	**418**	**347**	**194**	**236**	**245**	**283**	**311**
Base-AVERAGE	**433**	**497**	**497**	**635**	**824**	**733**	**610**	**381**	**423**	**433**	**424**	**450**
COLUMBUS REACH												
Subsistence	**340**	**375**	**375**	**299**	**425**	**534**	**342**	**190**	**279**	**190**	**202**	**301**
Base-DRY	**487**	**590**	**525**	**554**	**966**	**967**	**570**	**310**	**405**	**356**	**480**	**464**
Base-AVERAGE	**828**	**895**	**1,020**	**977**	**1,316**	**1,440**	**895**	**516**	**610**	**741**	**755**	**737**
WHARTON REACH												
Subsistence	**315**	**303**	**204**	**270**	**304**	**371**	**212**	**107**	**188**	**147**	**173**	**202**
Base-DRY	**492**	**597**	**531**	**561**	**985**	**984**	**577**	**314**	**410**	**360**	**486**	**470**
Base-AVERAGE	**838**	**906**	**1,036**	**1,011**	**1,397**	**1,512**	**906**	**522**	**617**	**749**	**764**	**746**

COLORADO RIVER DOWNSTREAM OF AUSTIN	
PULSE FLOWS	
Base	**MAGNITUDE (2,000 to 3,000 cfs); FREQUENCY (8–10 times annually); DURATION (3–5 days)**
High	**MAGNITUDE (@ 8,000 cfs); FREQUENCY (2 Events in 3 year period); DURATION (2–3 days)**
CHANNEL MAINTENANCE	**MAGNITUDE (27,000 - 30,000 cfs); FREQUENCY (1 Event in 3 years); DURATION (3 days)**
OVERBANK	**MAGNITUDE (> 30,000 cfs); FREQUENCY and DURATION (Naturally Driven)**

5.0 APPLICATION

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 (legislative mandate for the LSWP), etc. The following discussion focuses on the environmental considerations relative to the LSWP.

5.1 LSWP Subsistence Flow Guidelines

Modern scientific literature suggests that subsistence flows or ecological base flows are “hands off flows” (Hardy et al. 2006, Acreman et al. 2006). Therefore, the goal for the LSWP is that flows do not fall below the subsistence flow guidelines. This would be similar in application to the existing LCRA water management plan critical instream flow releases.

5.2 LSWP Base Flow Guidelines

The application of base flow recommendations in the literature is highly variable and river-specific in most cases. From a purely environmental consideration, the LSWP goal would be to achieve the base flow guidelines the equivalent percentage of time (80% for base-DRY, and 60% for base-AVERAGE). However, it is recognized that other considerations clearly need to be factored into this decision. An approach similar to the existing LCRA water management plan target flow releases application may be applicable. Under this approach, guidelines would be achieved when Highland Lakes conditions were met and pass through flows were available. The alternatives analysis of the project will analyze how closely the instream flow regime mimics natural patterns; those which provide flows with the durations and frequencies which most closely approximate pre-1940 occurrences will be evaluated higher than those which more significantly deviate from those occurrences.

5.3 LSWP Pulse, Channel Maintenance, and Overbanking Flow Guidelines

Pulse and overbanking flow recommendations are relatively new in the scheme of instream flow science although the concept has been around for many years. Mosier and Ray (1992) suggested that “maintenance flows” (equivalent to the proposed base pulses) be “provided by natural rainfall events but may occasionally require dam releases in excess of generation capacity for short periods.” The project team supports that description for base pulses and suggests water be stored to provide short term pulses during wet periods. Channel maintenance and overbanking flows will be provided by natural rainfall events and the recommendations in this report are included only so that evaluations over time can be conducted to assess the natural achievement of these recommendations. However, if additional studies indicate that the release pattern for channel maintenance flows could be adjusted somehow (again within the existing operational and permitting constraints) to increase the ecological benefit to the lower Colorado River without impacting other important interests, such adjustments should be considered in the adaptive management program.

6.0 MONITORING AND ADAPTIVE MANAGEMENT

The biggest omission from many instream flow studies has been an evaluation of the effectiveness of proposed recommendations. Recent studies in this field have immensely improved this component. The project team concurs with the TIFP and recognizes that a critical component of all recommendations for this project is a long-term monitoring program to evaluate the effectiveness of the recommended instream flow guidelines for the lower Colorado River. A comprehensive long-term monitoring plan is currently under development and review and will be submitted as a stand alone document in 2008.

A few specific examples of proposed activities were provided in the pulse, channel maintenance and overbanking flow sections. An additional consideration is the affect of the summertime subsistence flow recommendations on exotic aquatic vegetation establishment. Although low summertime flows would have been experienced under a more natural condition, the difference today is the additional nutrient load that the river carries. During future low-flow summertime conditions, clear warm water coupled with higher nutrient conditions may cause an increase in native aquatic plants and/or possibly invasive exotic plants such as hydrilla. In a natural flow regime, excessive vegetation growth is controlled by scouring during high flow pulses, channel maintenance flows and overbanking events. This supports the importance of multi-faceted instream flow recommendations as developed for the LSWP. Although the higher nutrient load did not affect the predicted dissolved oxygen concentrations by the water quality model at these lower summertime flows, aquatic macrophyte establishment should be monitored. Therefore, evaluating native and exotic aquatic plant responses in the future will be an important component of the long-term monitoring program.

In conjunction with the long-term monitoring, adaptive management will be a vital component to assist in ensuring the success of the environmental principles associated with the LSWP and goals of the TIFP. Brief examples of the linkage between monitoring and adaptive management were provided in the spawning blue sucker flow modification discussion and pulse flows section. However, a comprehensive adaptive management approach relative to the lower Colorado River is being developed and will be included as a section in the final LSWP Adaptive Management Report. This approach will address the difficulties inherent in whole ecosystem studies and will try to target specific areas of uncertainty while explicitly acknowledging variables that might confound results.

7.0 CONTINUED EVALUATION AND REFINEMENT

It is anticipated that the LSWP adaptive management framework will provide for implementation of the instream flow guidelines, followed by long-term monitoring, periodic review, modification, and future development.

7.1 Violated Assumption

One component of the project that has not proceeded as anticipated is the identification of selected habitat for juvenile blue suckers. The assumption that has been violated to date is, "*The ability to capture ecologically meaningful numbers of larval/juvenile blue suckers.*" Despite intensive efforts to locate this life stage, no juvenile individuals have been captured as of the preparation of this report. Previous sampling by LCRA, TPWD and others on the lower Colorado River, though not specifically targeting juveniles, also found only adults. This difficulty does not prevent development of instream flow guidelines, but it does provide some level of uncertainty relative to protecting *all* aquatic resources in the river. We believe that the juvenile blue suckers use habitat that is similar to adults, but because of the sampling methods and habitat conditions, are difficult to sample effectively. Individuals captured in the Rio Grande occupied cobble riffles in 1.5 to 2 feet depths (T. Bonner, Texas State University, personal communication). These types of habitats were targeted and sampled extensively in the lower Colorado River with no captures. Nevertheless, this type of habitat would fall within the selected habitat for the riffle habitat guild in the hydraulic and habitat model produced for this project. Although we believe that habitat for this life stage is covered by the existing habitat guilds, it would be valuable to identify the habitat preferences for juvenile blue suckers with field data. Therefore, specific activities relative to this concern will be recommended in the long-term monitoring program.

7.2 Matagorda Bay Freshwater Inflow Evaluation

This study has been conducted independent of the Matagorda Bay Health Evaluation (MBHE) for the LSWP. However, the project team understands the need to evaluate the instream flow recommendations for the lower Colorado River presented here in context with the freshwater inflow recommendations proposed by the MBHE team. The "natural" flow regime approach used in the river should lend itself well to the linkage of what Matagorda Bay requires for ecological health and productivity. This evaluation will be included in the final LSWP Adaptive Management Report.

7.3 Science Review Panel, Public Outreach Group, Stakeholders Review

This project has been subject to peer review at several milestone points during the project design, while in-progress and during development of recommendations. A Science Review Panel (SRP) of respected biologists, water quality experts, and instream flow modelers has interacted with the study team throughout the project. In addition, several Public Outreach Group meetings have been held at which this study was discussed. Additional meetings have been conducted with resource agency personnel during the course of the study to gather information and seek guidance in study methodology, data interpretation, and instream flow guidelines. Comments and responses received by the SRP and resource agencies on the draft instream flow document are provided in Appendix A.

The SRP and Public Outreach Group will remain actively involved in the LSWP. All interested parties will have an opportunity to review the findings of this study according to the LSWP stakeholder review process.

8.0 COMPARISON TO EXISTING CRITERIA

Table 8.1 displays the current release schedule as prescribed by the LCRA water management plan (WMP).

Table 8.1. LCRA WMP schedule of recommended releases.

Month	Subsistence/Critical Flows (cfs)		Target Flows (cfs)		
	Austin	Bastrop	Bastrop	Eagle Lake	Egypt
January	46[c]	120	370	300	240
February	46[c]	120	430	340	280
March	46[c]	500[b]	560	500[a]	360
April	46[c]	500[b]	600	500[a]	390
May	46[c]	500[b]	1030	820	670
June	46[c]	120	830	660	540
July	46[c]	120	370	300	240
August	46[c]	120	240	200	160
September	46[c]	120	400	320	260
October	46[c]	120	470	380	310
November	46[c]	120	370	290	240
December	46[c]	120	340	270	220

[a] Since Target flow at Eagle Lake (based on overall community habitat availability) were insufficient to meet Blue Sucker (Cycleptus elongatus) spawning requirements during March and April, target flows were superseded by critical recommendations for this reach.

[b] This flow should be maintained for a continuous period of not less than six weeks during these months. A flow of 120 cfs will be maintained on all days not within the six week period.

[c] LCRA will maintain a mean daily flow of 100 cfs at the Austin gage at all times, to the extent of inflows each day to the Highland Lakes as measured by upstream gages, until the combined storage of Lakes Buchanan and Travis reaches 1.1 million acre-feet of water. A mean daily flow of 75 cfs, to the extent of inflows each day to the Highland Lakes as measured by upstream gages, will then be maintained until the combined storage of Lakes Buchanan and Travis reaches 1.0 million acre-feet of water, then a subsistence/critical flow of 46 cfs will be maintained at all times, regardless of inflows.

In addition, if the subsistence/critical flow of 46 cfs should occur for an extended period of time, then operational releases Will be made by LCRA to temporarily alleviate the subsistence/critical flow conditions. Specifically, should the flow at the Austin gage be below a 65 cfs daily average for a period of 21 consecutive days, LCRA will make operational releases from storage sufficient to maintain daily average flow at the Austin gage of at least 200 cfs for two consecutive days. If this operational release conditions persists for three consecutive cycles (69 days), then a minimum average daily flow of at least 75 cfs will be maintained for the next 30 days.

Figures 8.1-8.3 provide a comparison of the LSWP instream flow guidelines (Table 4.18) for the Bastrop, Columbus, and Wharton reaches with the current LCRA WMP requirements (Table 8.1) and Lyon's method instream flow requirements originally used by the LSWP Surface Water Availability team. Lyon's method instream flow requirements are included only for reference and are not part of the LCRA WMP. Only the subsistence and base flow LSWP instream flow guidelines are included in the comparison as the LCRA WMP does not include pulse, channel maintenance or overbanking flow requirements. The subsistence flow recommendations represent minimum conditions at which water quality is maintained at acceptable levels and aquatic habitats are expected to resemble those found during extreme conditions in a more natural setting. The base flow recommendations provide a range of suitable conditions with the goal of maintaining year to year variability and the ecological functions associated with this level of variability.

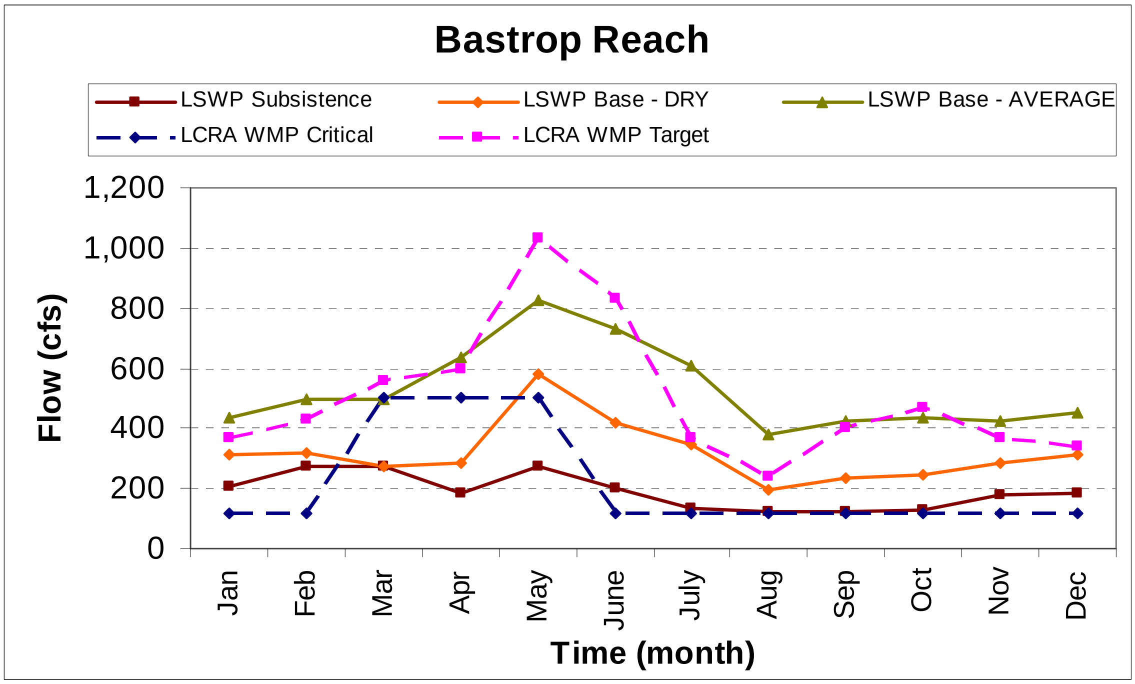


Figure 8.1. LSWP Instream Flow Guidelines for subsistence and base flow compared to the LCRA WMP critical and target instream flow requirements at Bastrop.

Upon review of Figure 8.1, the higher "critical" flows recommended by the LCRA WMP during March through May stand out. Please note the 500 cfs critical flow recommended in the LCRA WMP critical is implemented as noted in Table 8.1, "This flow should be maintained for a continuous period of not less than six weeks during these months. A flow of 120 cfs will be maintained on all days not within the six week period." This difference was also noted in the resource agency comments (Appendix A). The 500 cfs flow at Bastrop from Mosier and Ray (1992) was a number based on when they observed blue suckers spawning and likely some professional judgment. There is not a spawning blue sucker habitat category in Mosier and Ray (1992), nor was any modeling conducted. It coincidentally turns out (or more likely was good professional judgment by those authors) based on our modeling, that value does provide nearly 100 percent of the maximum available blue sucker spawning habitat. The authors of Mosier and Ray (1992) did not have any modeling to inform them that this flow value represented nearly the maximum amount of spawning habitat when they made this recommendation. Furthermore, Mosier and Ray (1992) state, "However, until more information on the flow requirements of the Blue Sucker (*Cycleptus elongatus*) during critical periods are available, it is recommended that flow be maintained at or above 500 cfs at Bastrop for a continuous period of not less than six weeks during the months of March, April, and May. Further studies on the life history of the Blue Sucker in the Colorado River are needed." The life history studies specific to the blue sucker developed for the LSWP (BIO-WEST 2007) in conjunction with the resource agencies through the Public Outreach Group process was designed and carried out to specifically address that request.

If the goal of maintaining aquatic health in a river is to provide optimal conditions (e.g. 100 percent of maximum available spawning blue sucker habitat) at subsistence flows, then you simply lose any low end variability that nature would have provided. Essentially, you dampen the extremes that nature is using to maintain and strengthen diversity. The more realistic historical values for blue sucker spawning habitat during periods of low-flow (i.e. subsistence conditions) would have been between 70 and 85 percent of maximum habitat. Clearly there is a scientific argument for leaving them at this level during these low-flow extremes to provide the natural variability once observed. However, we made the professional decision (as described in Section 4.2.5) to increase these amounts to 90 percent (274 cfs – Bastrop, 375 cfs – Columbus) of the maximum habitat during these periods because of the specific concern in the lower Colorado River regarding blue sucker recruitment.

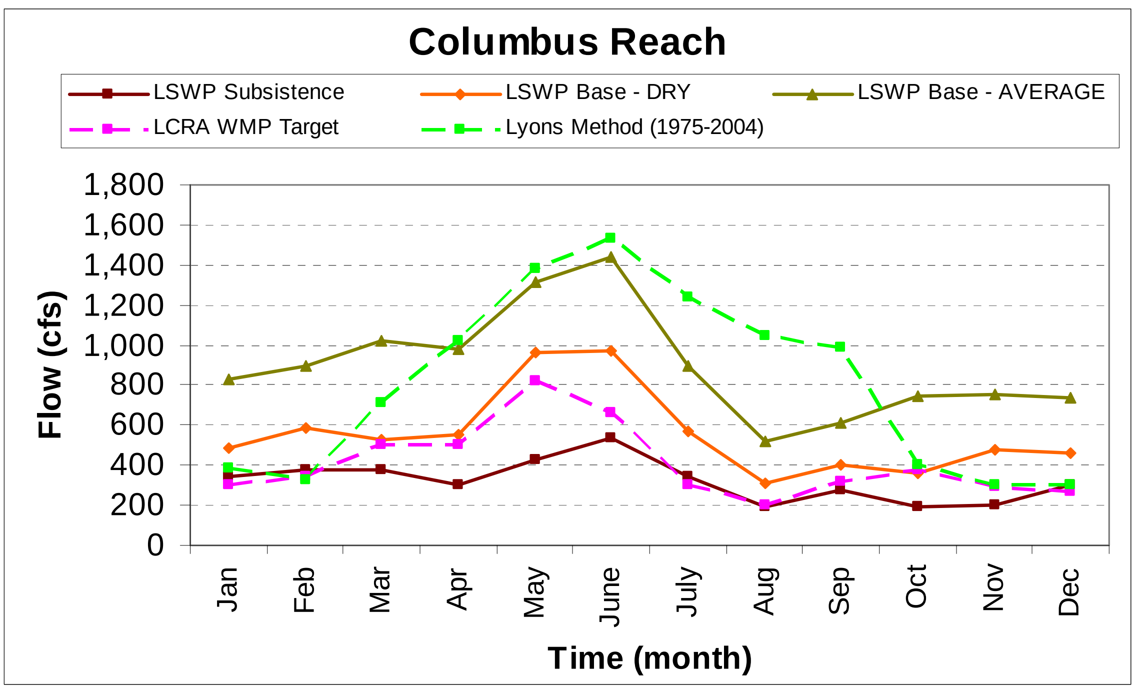


Figure 8.2. LSWP Instream Flow Guidelines for subsistence and base flow compared to the LCRA WMP target instream flow requirements and Lyons Method using existing (1975-2004) hydrology at Columbus. There is no LCRA WMP critical requirement at Columbus and Lyon's Method is not a part of LCRA WMP.

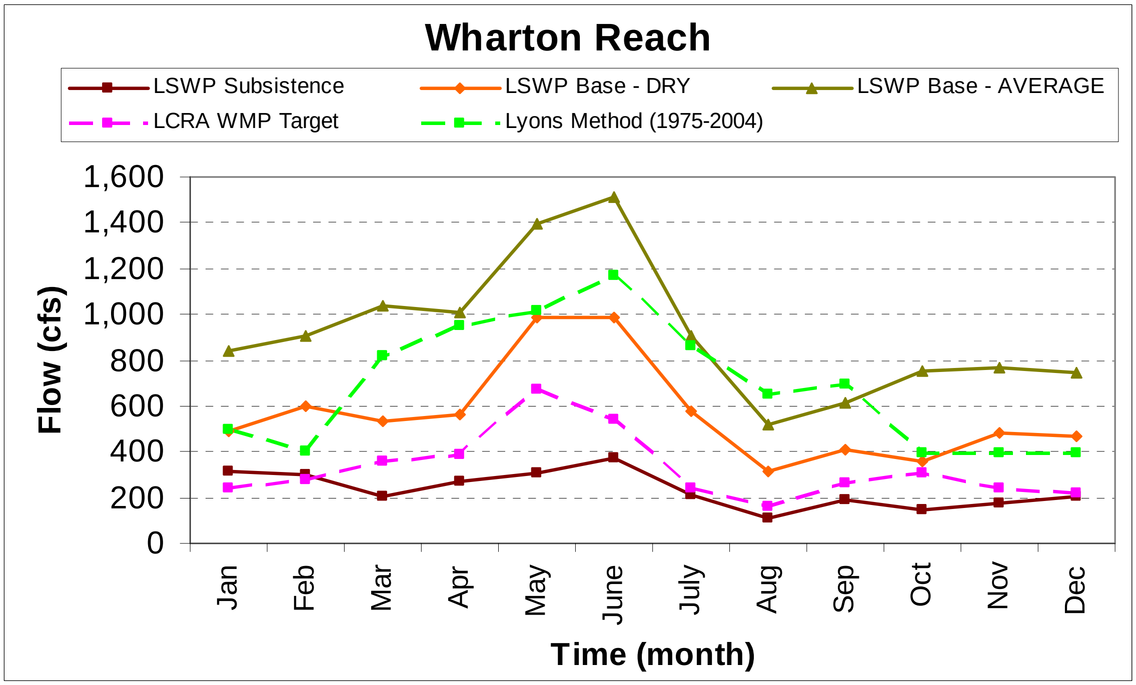


Figure 8.3. LSWP Instream Flow Guidelines for subsistence and base flow compared to the LCRA WMP target instream flow requirements and Lyons Method using existing (1975-2004) hydrology at Wharton. There is no LCRA WMP critical requirement at Wharton and Lyon's Method is not a part of LCRA WMP.

Other notable differences include the fact that the LSWP instream flow guidelines have subsistence requirements downstream of Bastrop (Columbus and Wharton), whereas the existing LCRA WMP does not. Additionally, both the Base-DRY and Base-AVERAGE LSWP instream guidelines exceed the current LCRA WMP target criteria in all months at Wharton and all but October during Base-DRY for Columbus.

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Appendix A – Science Review Panel and Resource Agency Comments and Responses

Science Review Panel Comments On:
Draft Instream Flow Guidelines Development Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker

Colorado River - Aquatic Habitat and Water Quality
Committee Chairs: Tom Arsuffi; Larry Hauck
Members: Khaled Bali, Thom Hardy, Doug Slack, Greg Stunz

April 25, 2007. Aquatic Habitat Team Response: The Aquatic Habitat team appreciates the review by the SRP of the Draft Instream Flow Guidelines Development Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker. Responses to specific comments/suggestions are inserted below.

The purpose of this interim report is to take the results-to-date of the LSWP studies and develop draft instream flow guidelines for the lower Colorado River specific to the LSWP. To do this, the report integrated critical components of the TIFP (TIFP DRAFT 2006) and National Research Council (NRC 2005) to ensure compliance with all anticipated state-mandated requirements. The document provides an overview of the LSWP status relative to each of the four key instream flow technical components (hydrology and hydraulics, biology, geomorphology, and water quality), describes the integration of the four study components, and provides preliminary recommendations for instream flow guidelines for the lower Colorado River specific to the LSWP.

This report did a good job of presenting the results of a variety of analyses associated with establishing several types of environmental flows for the Colorado River, the rationale for doing so, and effective visual and textual presentations of results. SRP appreciated inclusion of Appendices A-E, for a more detailed documentation of the life history summaries, habitat suitability criteria, etc.

Response: Thank you!

Below are SRP general and specific comments and review of this report.

Page 3. 2.0. Study Components & Hydrology and Hydraulics.

"Healthy floodplains act as "sponges" that store water during high flow events and release it back to the channel during low flow periods. This function serves to dampen downstream flood peaks (and associated flood damages) and helps ensure that adequate baseflows are available to aquatic communities during seasonal dry periods."

"For example, wet periods that are characterized by large overbank floods are important

for creating habitat complexity and promoting lateral and longitudinal nutrient cycling. However, if major flooding occurred every year, the frequent disturbance would prevent riparian communities from becoming established and would compromise the stability of aquatic communities."

The Colorado River does not have a flood plain that acts specifically in the way these statements imply. Instead it seems the statements better apply to tropical river systems that have predictable overbank flooding annually and flood plains are important structural and functional ecosystem components - life cycles of many organisms are keyed to use overbank inundated lands for reproductive and food resources. Tropical river systems have well developed riparian communities despite annual flooding. The "sponge" capacity of a watershed and flood plain is a function of topography, geomorphology, soil depth and composition and bedrock proximity to surface. The point here is how do these statements specifically relate to the Colorado River and the LSWP. As this report later shows, since the construction of the Highland Lakes, frequency and magnitude of floods has decreased such that the potential effect of flooding causing the proposed negative effect on the riparian communities of the Colorado River are reduced.

Response: Good Point. We will revise this section to apply more directly to the Colorado River floodplain.

Please clarify the meaning and usage of the term "hydrological cycling" in the context of the sentence, *"On a smaller scale, river hydraulics (the patterns of water movement inside the channel) can be as important as hydrologic cycling."*

Response: We propose to revise this statement as follows. "On a smaller scale, the patterns of water movement inside the channel (i.e., river hydraulics) can be as important to individual organisms as the overall flow regime."

Page 5. 2.3. Geomorphology.

The project team makes a good point that when streamflow or sediment supply is changed by dams, diversions, or other alterations, channel equilibrium may be disturbed and should be considered when developing the instream flow guidelines. They justify the point that habitat will not be effectively protected over the long term, if an instream flow recommendation is developed solely on an analysis of existing hydraulic habitat in a rapidly widening or incising river.

No response needed.

Page 10. Second Paragraph below Table 3.1, third sentence.

'… model edges.' It would be more correct to indicate you extended the upstream and downstream boundaries of the mesh to remove the influence of numerical goodies as suggested. However, the way it reads now, I could also justify the

interpretation that this occurred along the longitudinal boundaries on both sides of the channel but I do not think this is what is intended to be implied.

Response: The referenced sentence will be replaced as follows: 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 potential to occur at upstream and downstream ends. 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.

Page 10. Last sentence. What did you adjust and what specifically was carried forward? Was it the 'mesh', bed elevations, x-y locations, water surface elevations? Vague at best.

Response: To clarify what was adjusted, sentence will be revised as follows: 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.

Page 11. Paragraph below Figure 3.5. What model predictions were used to track what field observations? I assume you mean primarily the longitudinal water surface profile? Be specific please for those you are also educating. Second sentence: These are not mechanisms! Adjusting these parameters to match observations was the mechanism used to calibrate the model.

Response: Sentences will be changed to read: Calibration proceeded by adjusting model inputs so model predictions of water surface elevation tracked field observations. Roughness, bathymetry and the downstream water surface elevation boundary condition were the three model parameters adjusted to calibrate the models.

Page 11. 2nd Paragraph below Figure 3.5. You say 'bathymetric complexities were incorporated to match observed water surface profiles.' What does this mean? Did you modify the topography using professional judgment so that the induced topography in the mesh made the water surface match?

Response: We will revise to clarify intent: 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.

Page 18 top Paragraph. Did you only interpolate values from Somerville (1958) or did you also extrapolate? If you interpolated only no big deal, if not, big deal on how you extended the table values.

Response: For the draft report, 5 of the 7 habitat categories were interpolated. Of the remaining 2 that were extrapolated, only 1 had a sample size considerably greater than the largest sample size (1,000) in the Somerville (1958). We have worked directly with Dr. Hardy to address the extrapolation technique most appropriate for this specific situation and will revise in the final version.

Page 28. 3.3.2 Sediment Rating Curves

The discussion on this page is confusing and difficult to follow, in part because there are multiple "steepenings" and "increases" associated with water surface slopes and rating curves derived from equations.

Response: We will add text to help clarify this section in the final report.

Pages 27-32. 3.3.2 Sediment Rating Curves

Here, Colorado River flows and sediment rating curves under natural (pre 1940) and existing (post 1940) conditions are described. In particular, text suggests effects on shoreline, riparian, sediment deposition and movement, pools and other structure function river elements under higher (existing, 1,000 - 2,000 cfs) and lower (natural, < 500 cfs) summertime conditions. Although such contrasts appear plausible, given general trends on rivers due to higher versus lower flows, SRP suggests such conclusions may be too deterministic, given the large variability of stream ecosystems and the variety of "resetting" mechanisms such as floods that the project team discusses. For example, *"A return to more natural summertime baseflow conditions would likely lead to more stable (i.e., less mobile) substrate conditions, which could have positive implications for macroinvertebrate productivity and species richness."* Biodiversity of macroinvertebrates is a function of multiple factors operating on a variety of spatial and temporal scales. Rather than stability, macroinvertebrates are suggested to reach highest diversity at intermediate levels of disturbance. Our point is that we don't know if the difference between <500 cfs is biologically significant from 1000+ cfs on macroinvertebrate productivity and diversity. See Vinson & Hawkins 1998. (Annu. Rev. Entomol. 43:271–93. Biodiversity of stream insects). There is no mention of the effects of pre- versus post- flows on Colorado River structure and function and macroinvertebrates during other seasons, nor whether flows in other seasons could override proposed effects of summer flow seasonal patterns.

Response: We agree that as worded, substrate stability stands out as important to macroinvertebrates. What was meant by "lead to a more stable substrate condition…" was not complete stability but simply more than constant sand transport. We agree with the SRP that intermediate levels of disturbance create some of the highest levels of macroinvertebrate diversity. We will re-word to

include that statement and replace the discussion on stability with a description of how having constant sand transport at the higher flows creates a high level of disturbance, whereas reduced flows during the summer causes a lower level of disturbance. Yet, even with the lower base flows a level of intermediate disturbance does exist.

Page 34. Pulse flow Hydrologic Evaluation

SRP appreciated the inclusion of the Nature Conservancy's Index of Hydrologic Alteration in their analysis of the effects of the Highland Lakes on flow patterns in the Colorado River.

As seen in Table 3.4, existing high pulse characteristics remain quite similar to pre-1940 values for both the IHA and EFC parameters. This is because many of the lower magnitude high flow events on the lower Colorado River are caused by rainstorms that occur below the Lake Travis Watershed. These events are not affected by the Highland Lakes system. In contrast, the larger-magnitude high flow events (floods with frequencies of once per year or less) on the lower Colorado River have been substantially altered by the Highland Lakes. This is evident in the IHA results for annual 1-day and 3-day maximum flows (Table 3.4).

No response needed.

Pages 35-37. 3.4 Water Quality

The SRP review of the Water Quality Scenario Report observed that results (Table 2.2, including 2060 demands) showed DO levels are borderline compliant. Further, Appendix A Sensitivity Analysis (and Table A-1, effect of higher temperatures associated with global warming on DO concentrations) shows that a 1^{o}C increase takes DO below the 6 mg/l standard (although still in compliance because of error considerations), but out of compliance with 2 and 3 degree C increases in temperature. In contrast, this report concludes, "*However, even under these extreme conditions, LSWP water quality modeling predicts average and diel DO concentrations in the river will be acceptable to meet the needs of the lower Colorado River aquatic community.*" First, SRP was unaware that diel DO concentrations were modeled for future project conditions. Second, It would be helpful, provide consistency and prevent confusion, if these two reports were integrated with respect to water quality and DO concentrations with and without the project in different years. Presumably, the differences between the two reports are a result of using different flows or other inputs into the QualTX model.

Response: The subsistence and base flow instream flow guidelines are not based on the LSWP meeting the TCEQ water quality standard of 6.0 mg/L dissolved oxygen for "exceptional" aquatic life use. Therefore, the statement quoted above refers to water quality modeling showing that at these guideline flows dissolved oxygen would only rarely fall below 5.0 mg/L and for only small segments of the river. The project

team feels that during these periods of lower than average discharge, DO conditions in the river as modeled do not pose a threat to the lower Colorado River aquatic community. Specific references will be added to support this claim in the final report. It is correct that diel DO concentrations were not modeled for future project conditions. We will remove the phrase, "diel DO concentrations" from that sentence and discuss future conditions further with the LSWP water quality team.

As the WQ report is focused on TCEQ standards and the Instream Flow report on aquatic health it might be more confusing to completely integrate these efforts. However, more text will be added to explain these differences and that different scenarios were modeled for these studies.

Page 40. When I look at the habitat modeling and see small patches out among the trees I wonder if these were included in the total habitat areas over all ranges of flows?

Response: The Utley site has the most extensive set of side-channels of any site, and one of the reasons the site was chosen was to characterize this type of habitat. The only other site exhibiting similar features is the LaGrange site, and those channels are less extensive than at Utley. Side channel areas were included in the total habitat area for all flow rates, even at those flow rates where they are disconnected. The River2D model incorporates a crude groundwater flow component and that feature is the mechanism by which wetted area appears in disconnected areas. While that initially sounds like spurious model output, model predictions exhibit good agreement with on-site GPS measurements of water edge at 407 cfs where small pools are completely disconnected from the main channel (Figure 3.6).

Page 43. Figures 4.5, 4.6

Explain again how percent of maximum habitat per measured discharge can sum up to more than %100. SRP recalls this discussion at the October 2006 workshop, but several of us cannot recall how it was resolved. Also, because this will be a public document, it might be useful if the project team provided an explanation of the methodology relative to the construction of the figure. This would aid readers in understanding the figure and how it does not violate mathematical principles (summation > 100%) they were taught in school.

Response: In the percent of maximum habitat figure (Figure 4.6), the different habitat types at the same flow are not supposed to add up to 100%. The figure describes the percent of maximum habitat for each individual habitat type. For example in Figure 4.6, rapids – adult blue sucker habitat reaches its maximum (100% - Figure 4.5 [@67,000 ft2/1000ft]) at 2,000 cfs, while it only meets approximately 52% (Figure 4.5 [@35,000 ft2/1000ft]) of its maximum area at 500cfs. The figure title, legend, and report text will be modified to specify the percent of maximum habitat per individual habitat type.

Page 44 Last full paragraph. Are you suggesting that this all only applies to large river systems? Are small river systems exempt from such things?

Response: No and No. We will replace "large river" with "riverine"

Page 45. Section 4.2.2. All this logic is difficult to buy into. Your WUA curves all maximize well below 5000 cfs which is your cutoff level for the time series so as not to be influenced by poor habitat at high flows. Yet all your WUA relationships all have poor habitat at 3000, 4000, etc. Why not just say it makes sense to separate the base flow component, give it the record, get base flow out, and go on with the analyses. This all seems to make it read way more cooked than it is.

Response: This section will be revised to clarify our use of the base flow analysis.

Page 52. Table 4.3. Summary of physical and biological differences predicted between existing and pre-1940 flow regimes.

Table 4.3 is a very informative and useful summary table. That said, it would also be helpful and useful if TABLE 4.3 were supplemented with a summary table providing quantifiable analysis. For example, habitat diversity (1st row) comparing the 2 flow regimes states there is less habitat diversity in the period 1975-2004 than pre-1940. Can this result be presented as a mean plus or minus a measure of variation, so a reader can get a feel for the magnitude of the difference stated?

Response: Figures 4.8 – 4.16 were included to help describe the summary table. We will provide a reference in the table to refer to these figures.

Also, an SRP question. How is diversity being defined and used by the project team, there are several different uses in the ecological literature? For example, diversity simply is number of taxa occurring in an area. In other uses, diversity has 2 components, a variety component (# of different species/taxa) and an equitability components (# species and distribution of individuals collected). It is important that this report make clear what aspect of diversity was measured and reported. The variety and equitability components are usually reported as diversity indices such as Shannon-Wiener, Brillouins etc.

Response: For the discussion surrounding Table 4.3, habitat diversity is dealing with equitability of the different habitat types.

Row 6 (Sediment Transport - macroinvertebrate stability) of Table 4.3 states, *"More base flow sediment transport reduces substrate stability thus reducing marcroinvertebrate productivity and species richness. Less base flow sediment transport supports substrate stability and increases macroinvertebrate productivity and species richness."*

This is a much too definitive statement to make without justification in the form of Colorado River macroinvertebrate community structure information, biomass production, stability criteria (resistance, resilience), functional feeding group analysis, disturbance regime and literature review. From an empirical and theoretical perspective, stability is not always positively related to diversity. The Intermediate Diversity Hypothesis (IDH) predicts highest diversity at intermediate levels of disturbance and lower diversity when conditions are stable. IDH has been applied to stream ecosystems with variable success. SRP suggests that more speculative components of tables such as 4.3 be avoided unless derived from data of current studies and/or are clearly designated as hypotheses and justified by a literature review if that information for the Colorado River is unavailable.

Response: We agree with the comment that our reference to macroinvertebrate productivity and species richness goes beyond what Colorado River data can support. We will tone down this discussion and replace references of stability with description of disturbance level as discussed on Response to pages 27-32 above.

Page 55. Figure 4.17. Habitat durations for rapids/adult blue sucker for January and July at the Bastrop Reach for both flow regimes.

Figure 4.17 is unclear as the legend indicates the graph is for 2 times (January and July) at 2 flow regimes and there are 7 habitats evaluated. This suggests there should be 28 lines on the graph, yet there are only 7. This needs clarification.

Response: Figure 4.17 has the wrong legend. It should read, "Habitat durations for All Habitat Types for April at the Bastrop Reach." This will be changed in the text and list of figures.

General SRP comment. Overall the framework for picking the component flows for each component of the flow regime is good. What would help however, is show a hydrograph that identifies over what time period each of these flow components are in 'operation'.

Response: Thank you! We will include a hydrograph that identifies these time periods in the final report.

Page 63. 4.3 Pulse flow and Overbanking Flow Development

SRP concurs with the project team that base and high flow pulses are critical and needed elements of any instream flow recommendations for the Colorado River because of the many and varied multiple environmental benefits discussed in the report. The pulse flows should be implemented as much as possible.

No response needed.

Page 64. Monitoring recommendations.

SRP agrees with the project team that measuring bedload transport during lower-magnitude "base pulse" events would help determine whether the modeled sand and gravel transport thresholds are accurate and that surrogate techniques such as painted rock studies and pre- and post-base pulse event transect surveys can be effective and pre- and post- high flow event surveys and photography could also be used to help determine the flow magnitude that effectively scours aquatic and herbaceous/emergent riparian vegetation.

No response needed

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Page 72. Figure 8.1.

There may be a labeling mistake in this figure where LSWP Subsistence (purple) should be LSWP Base – Dry (red) and vice versa.

Response: The figure on the pdf is correct. This may be a color print issue?

ENERGY • WATER • COMMUNITY SERVICES

November 2, 2007

David Bradsby
Leader, Water Quality Program
Texas Parks and Wildlife Department
4200 Smith School Road
Austin, Texas 78744

RE: LCRA-SAWS Water Project - Letter dated September 11, 2007
Draft Instream Flow Guidelines Development: Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker April 23, 2007

Dear Mr. Bradsby:

Thank you for your letter to Ed Oborny with comments and suggestions following meetings on the LSWP Draft Instream Flow Guidelines Development and your review of the document. The input from you continues to be important and very helpful to us. Below, we have provided responses to your comments following the organization laid out in your letter.

General Comments

TPWD Comment:

Overall, the report integrates the flow components described in the Texas Instream Flow Program Draft Technical Overview (2006). Flow recommendations have been made for a flow regime consisting of subsistence, base habitat, pulse, and overbank flow components and the instream flow recommendations were developed in a remarkably short period of time. However, some questions remain as to the methodology, assumptions, and results used in determining the recommended flow regime.

LSWP Response: *We appreciate the thoughtfulness and thoroughness of TPWD's comments and thank you for your continued participation in this project.*

TPWD Comment:

Pages 15-16 - It is not clear how it was determined where samples for habitat use data would be collected. Was there an experimental design to ensure equal sampling across habitat types? If not, how was it ensured? How was it determined which proportion of data would be used for development of habitat guild and suitability criteria and which would be used for validation? How was the validation data used to check habitat guild classification? What were the results? For guilding, it may have been more appropriate to use all of the fish data. What were the results of the independent check of 2004-2006 sampling data with the Mosier and Ray (1992) data? If some of these questions are addressed in previous progress reports, the reports should be cited. Further, a scientific report does not seem to be the appropriate venue for documenting personal feelings. Consequently, the sentence stating how a member of TPWD staff was pleased should be removed.

LSWP Response: *During each sampling event a stratified random approach was used to sample each hydromorphologic unit (riffle, run, pool, etc.) in proportion to its relative availability. Initial habitat data collected at a range of flows during the first two years of the project were designated for habitat guild and suitability criteria development. Information from a separate sampling effort conducted later, again at a range of flows, was specified for use as validation data. Validation data was not used specifically to check habitat guild classification; however, life history information from the literature as well as observations from previous fish sampling experience fit well with guild classifications. In addition, habitat guilds were similar to previous guilds developed by Mosier and Ray (1992). Although Mosier and Ray (1992) defined ten fundamental habitat groups, species groupings were strikingly similar to those used in our seven habitat guilds. Depth, velocity, and substrate descriptions for each fundamental habitat group provided in Mosier and Ray (1992) (Figure V) also corresponded well with habitat suitability criteria used in the current study. In some instances, our suitability criteria encompassed greater depths and velocities for certain species groupings than Mosier and Ray (1992) summary data included; however, this was most likely a result of us sampling under a greater variety of flow conditions including much higher flows. The inclusion of validation data into habitat guild classification would change the outcome very little, if at all. The biological validation data set was used to confirm the habitat model predictions as discussed in the report. Text further clarifying the questions addressed above will be included in the final report, and the comment concerning TPWD personnel will be revised.*

TPWD Comment:

Page 16 - Figure 3.10 - It would be helpful and could help eliminate confusion if the abbreviated fish names were specifically related to full scientific or common names. This could be done in the figure caption or in Table 3.2. Explanations of other symbols used (A, J) should be made so that the figure can stand on its own. Likewise, species descriptions in Appendix 4 should include "adult" and "juvenile" designations in addition to the length criteria.

LSWP Response: *The figure caption and Table 3.2 will be modified to define species abbreviations. Adjustments will be made to Appendix A.*

TPWD Comment:

Page 17 - Table 3.2 - It would be informative to list species collected but not included in the analysis or habitat modeling. Further, while Table 3.2 reports the total number of each species collected, it would help to understand the robustness of the dataset if the number of samples for each species was reported. For example, how many sample events did it take to collect the 27 *Etheostoma spectabile*? If it was one sample event, should it be included in the CCA and in habitat modeling?

LSWP Response: *Table 3.2 will be modified to include species abbreviations from Figure 3.10, and number of samples where each species was present. An additional table will be added to list species which were not used in guild construction. Modified tables are presented below.*

Table 3.2. *Habitat guilds and blue sucker life stage categories derived from depth, velocity, and substrate use at 153 sample locations, as well as supplemental radio telemetry and spawning survey study results.*

Habitat Guild	Species/Life Stage	Species/Life Stage Abbreviation	Number of Locations Where Observed	Total Number Observed
Riffles	*Percina sciera*	*Psci*	33	121
	Percina carbonaria	*Pcar*	30	95
	Ictalurus punctatus (juvenile, <180 mm)	*IpunJ*	44	640
	Phenacobius mirabilis	*Pmir*	8	65
	Etheostoma spectabile	*Espe*	13	27
	Campostoma anomalum	*Cano*	13	30
	Macrhybopsis spp.	*Maes*	21	280
Shallow Runs	*Cyprinella lutrensis*	*Clut*	66	1989
	Cyprinella venusta	*Cven*	71	1305
	Pimephales vigilax	*Pvig*	32	698
	Notropis volucellus	*Nvol*	40	516
	Micropterus treculii (juvenile, <170 mm)	*MtreJ*	31	91
Deep Runs	*Pylodictis olivaris*	*Poli*	40	107
	Ictalurus punctatus (adult, >180 mm)	*IpunA*	28	71
	Moxostoma congestum	*Mcon*	36	131
	Micropterus treculii (adult, >170 mm)	*MtreA*	13	23
	Carpiodes carpio	*Ccar*	35	215
	Dorosoma cepedianum	*Dcep*	29	451
Shallow Pools / Edge / Backwaters	*Micropterus salmoides*	*Msal*	9	19
	Lepomis megalotis	*Lmeg*	23	490
	Lepomis macrochirus	*Lmac*	21	115
	Lepomis cyanellus	*Lcya*	5	29
	Cichlasoma cyanoguttatum	*Ccya*	11	45
	Gambusia affinis	*Gaff*	14	92
	Poecilia latipinna	*Plat*	6	33
	Fundulus notatus	*Fnot*	6	15
Deep Pools	*Ictiobus bubalus*	*Ibub*	9	16
	Cyprinus carpio	*Carp*	9	18
Blue Sucker Life Stage				
Adult blue suckers / Rapids	*Cycleptus elongatus*	*Celo*	93*	102*
Spawning blue suckers	*Cycleptus elongatus*	*N/A*	10	**

*Data collected during fish sampling was supplemented with habitat data from the radio telemetry portion of the study. Each telemetry location was counted as one location and one fish observed.

**Habitat data collected at ten confirmed spawning locations, each with an aggregation of multiple fish, was used in constructing the spawning blue sucker habitat category.

Table 3.3. *Species collected from the lower Colorado River during the course of the study, but not included in habitat guild development due to inadequate sample sizes.*

Common Name	Scientific Name	Total Number Collected
Mountain mullet	*Agonostomus monticola*	1
Yellow bullhead	*Ameiurus natalis*	1
Freshwater drum	*Aplodinotus grunniens*	3
Mexican tetra	*Astyanax mexicanus*	12
Grass carp	*Ctenopharyngodon idella*	1
Threadfin shad	*Dorosoma petenense*	2
Bluntnose darter	*Etheostoma chlorosomum*	1
Greenthroat darter	*Etheostoma lepidum*	2
Spotted gar	*Lepisosteus oculatus*	10
Longnose gar	*Lepisosteus osseus*	9
Redbreast sunfish	*Lepomis auritus*	3
Warmouth	*Lepomis gulosus*	13
Orangespotted sunfish	*Lepomis humilis*	3
Redear sunfish	*Lepomis microlophus*	4
Redspotted sunfish	*Lepomis miniatus*	7
Inland silverside	*Menidia beryllina*	6
Smallmouth bass	*Micropterus dolomieu*	1
Spotted bass	*Micropterus punctulatus*	4
White bass	*Morone chrysops*	1
Sand shiner	*Notropis stramineus*	1
Tadpole madtom	*Noturus gyrinus*	2
Fathead minnow	*Pimephales promelas*	2
White crappie	*Pomoxis annularis*	4

*Other species observed by the project team while sampling for juvenile blue suckers include American eel *Anguilla rostrata* , and pugnose minnow *Opsopoeodus emiliae*.

TPWD Comment:

Page 40 - Maps of suitability in Figure 4.2 do not match the maps provided to TPWD for review.

LSWP Response: *The maps provided to TPWD in July 2007 are the correct ones. In these maps the cells with zero habitat scores are not displayed. The maps in the final report will be replaced by the ones provided to TPWD.*

TPWD Comment:

Page 42 - Symbols used in biological validation map (Figure 4.4) need more contrast since they are difficult to discern.

LSWP Response: *The symbols will be improved.*

TPWD Comment:

Page 42-43 - It is not clear how weighted usable area (WUA) was calculated to generate Figure 4.5 and others like it and for use in subsequent steps. Was it only habitat areas with composite suitabilities greater than 0.1? Did it include only values of 0.6-1.0? This needs to be clarified because a review of the suitability maps across flows indicates that in some situations there appear to be large areas of low quality habitat (i.e. low composite suitabilities) that may be masking the contributions of high quality habitat (i.e. high composite suitabilities). Regardless, it would be informative to conduct a separate WUA-Q analysis using existing GIS output for 0.8-1.0 composite suitabilities which represent the most suitable or high quality habitat areas. Such an analysis would provide insight into how much WUA was attributed to "high quality" habitat rather than relatively large areas of low quality habitat. This could have large implications as this effect is propagated up through the WUA-Q, time series, and habitat duration analyses and is used in the evaluation of percent exceedence levels for proposing subsistence and base flow recommendations. It is difficult to develop an understanding of how much high quality habitat occurs at various flow rates without this information.

LSWP Response: *The weighted usable areas in Figure 4.5, 4.6 and in Appendix C are based on the sum total weighted usable habitat for all cells. Low suitability habitat cells were not filtered out of the analysis. Masking is probably not the correct term, though it is true that 10 cells with 0.1 suitability are equivalent, for the purposes of our evaluation, to one cell with 1.0 suitability. Assignment of 0.1 suitability does not mean habitat is unsuitable; it means that either (1) all components (velocity, depth and substrate) are marginally suitable, or (2) more likely that two components are suitable and one component is not ideal. Since some level of utilization is expected in habitats with lower suitability scores, these habitats were not excluded. There are a several acceptable approaches used in instream flow modeling to develop habitat suitability curves including binary and univariate formats. This study uses a univariate format whereby sub-optimal habitat is weighted lower than optimal habitat but is not, as would be the case with a binary format, set either to one (optimal) or zero (unsuitable). We believe that the univariate format is more realistic as species clearly use sub-optimal habitat at times. The univariate format also seems less arbitrary as all of the data is included in the analysis rather than selecting some percentage cut off at which to declare the habitat either optimal or unusable. At the October 2006 Science Review Panel (SRP) workshop, the SRP discouraged use of a binary approach and strongly recommended the univariate approach in which all of the data was included.*

The suggestion to filter the habitats that are used in the analysis after they have already been weighted seems inappropriate. The goal of this study was not to determine flows which produce optimal habitat areas-which may not be possible given that some habitats are optimal at low flows while others are optimal at high flows. The goal of this study is *to balance the various habitat types guided by the variability in flows that would be expected under a more natural flow regime.*

Although we employed a somewhat more sophisticated approach to defining the habitat suitability curve, the summation of all habitats (including relatively lower value cells) was identical to the method used in the TPWD instream flow study on the San Marcos River.

While it might be interesting to produce tables that filter out high and low quality habitat, we would expect it to support the current conclusions given a visual inspection of the habitat maps. However, in this instance, we do not lack for model output to include in the habitat analysis. If TPWD can provide some specific guidance as to how to filter out some of the less suitable habitats, we might consider an alternative approach; however, at this time, considering all of the data, with appropriate weightings, is the preferred approach.

TPWD Comment:

On a separate but related note, the key on the composite suitability maps combines unsuitable (0.0) and marginally suitable (up to 0.2) which doesn't make sense unless those combined areas are treated the same in the WUA calculations. Unsuitable habitat types (0.0) should be treated separately.

LSWP Response: *Maps will be revised to leave the unsuitable cells blank.*

TPWD Comment:

As discussed previously, habitat diversity appears to be a misused term. The spatially explicit habitat maps could be used to explore the relationship between discharge and hydraulic habitat diversity using a software package such as FragStats. It would also provide information on how contiguous habitat patch sizes change with flow, especially those considered high quality. What criteria were used to determine if habitat diversity/equitability was maintained? (see page 60-61)

LSWP Response: *You are correct that we are not using the term diversity in the traditional sense; equitability does not really work either. Our goal was not to maximize the traditional definition of diversity like the Shannon's Index, which incorporates richness and evenness of patch types. If it were, the highest ranked habitat distributions would be ones which included all of the habitat types in the most evenly distributed patches. What we are interested in is providing the distribution of habitats that would be expected under a natural flow regime. So if under natural conditions, 10% of the habitat area is riffle and 20% pools, then our recommendations are developed to maintain those relative distributions. Although TWDB has concerns about using the current bathymetry to estimate the distribution of habitats that would have occurred under natural conditions, modeling the response of the current channel to a natural flow regime provides a reasonable baseline condition to guide our selections of flow guidelines. This is then combined with the identification of breakpoints where the distribution of habitats abruptly changes or where some habitats disappear. We have combined both the natural* *flow paradigm and professional judgment to develop a reasonable distribution of habitat types for the current channel condition.*

TPWD Comment:

Page 54 - Table 4.2.4 - All habitat guilds were applied with equal weighting per month. What does this mean and how was this done? For what analyses does this statement apply? Why are they applied equally when it is clear that some habitats are more flow sensitive than others?

LSWP Response: *Stating that all habitat guilds were applied with equal weighting per month means that we did not give greater weight to one habitat type over another. Habitat analysis was done by calculating the area of weighted useable habitat per 1,000 feet of river segment at each modeled flow rate. It applies to the development of the habitat time series. They were applied equally because we considered all habitats important and the goal of this study was not to optimize some habitats at the expense of the others.*

TPWD Comment:

Table 4.18 does not provide monthly flows for the Austin gage which conflicts with the sentence on page 60, "Table 4.10 presents...." Information should be presented.

LSWP Response: *Base flow recommendations are to be implemented based on the gages at Bastrop, Columbus, and Wharton. Only subsistence flows apply to Austin. The text will be amended to represent this.*

TPWD Comment:

Page 58 - The project team used the Austin flow gage in lieu of Bastrop because of the older (i.e., pre-dam) data availability. Then the project team applied the Austin flows to Bastrop. TPWD believes that this introduces a bias because it neglects intervening contributions. Even during low flow conditions, larger tributaries such as Onion Creek and drainage from the Colorado River Alluvium will contribute some flow.

LSWP Response: *We will adjust the flows at sites without pre-1940 data to account for intervening flows based on a drainage area correction. This is the most straightforward approach; however, it does not account for different rainfall/runoff patterns within the basin. Another alternative that we considered was using unregulated daily flows developed by the USACOE as part of a flood flow study. However, upon discussions with Bob Brandes and the LSWP Surface Water Availability Team, it was determined that this data may not accurately represent the low flow conditions and thus, the drainage area correction was the best method to employ.*

TPWD Comment:

Page 72 - Comparison to Existing Criteria. - It would be helpful if a table of flow values from the LCRA Water Management Plan and their intended ecological value was included for comparison with proposed criteria. The proposed flow values for maintaining blue sucker spawning habitat at Bastrop (265 cfs) are considerably lower than those reported by Mosier and Ray (500 cfs). An explanation as to why recommended blue sucker spawning flows are nearly 50% less than previously reported should be included.

LSWP Response: *Many of the values in the LCRA Water Management Plan are in section 8.0 of the report, though we will add a table.*

The 500 cfs flow at Bastrop from Mosier and Ray (1992) was a number based on when they observed blue suckers spawning and likely some professional judgment. There is not a spawning blue sucker habitat category in Mosier and Ray (1992), nor was any modeling conducted. It coincidentally turns out (or more likely was good professional judgment by those authors) that based on our modeling, that value does provide nearly 100% of the available blue sucker spawning habitat. If the goal of maintaining aquatic health in a river is to provide optimal conditions (e.g. 100% spawning blue sucker habitat) at subsistence flows, then low end variability that nature would have provided is lost. Essentially, you dampen the extremes that nature is using to maintain and strengthen diversity. The more realistic historical values for blue sucker spawning habitat during periods of low-flow (i.e. subsistence conditions) would have been around 30%. Clearly there is a scientific argument for leaving them at this level during these low-flow extremes to provide natural variability. However, we made the professional decision to double those amounts from 30% to 60% during these periods (Page 59) because of our concern regarding recruitment.

Water Quality

TPWD Comment:

Future scenarios are based on Region K estimated future return flows and City of Austin agreed-to future treatment levels. These assumptions result in a substantially reduced load of oxygen-demanding substances than are permitted. If accepted by regulatory authorities, this may lead to a situation where water quality standards are violated and no-one accepts responsibility. For example, if the City of Austin treatment plants suffered a breakdown in the summer and discharged waste at their permitted concentration, the river may violate the dissolved oxygen standard. The City of Austin would, justly, not accept responsibility because they met their permit limits, even if they did not meet their verbal agreement with LCRA. Would LCRA accept responsibility for the violations and release additional water from the Highland Lakes to provide dilution until the treatment plants were fully functional? Who would enforce maintenance of water quality standards? TPWD believes that basing new wastewater discharge and/or water rights permits on assumptions that differ from existing permits is improper. The best solution is for the City of Austin to amend their permits to ensure that the assumed wastewater quantities and qualities will be achieved.

LSWP Response: *The LSWP environmental study that focuses on the water quality of the river has projected water quality using our best estimate of future conditions, given all available data, and conversations with the major discharger on the Colorado River below Austin (i.e., City of Austin). We feel that these scenarios are representative of potential future conditions in the river and given the conservative assumptions made in other areas of the modeling (i.e., 10th percentile flows, warm weather), ensure that our results will indicate whether or not the river will be protected with the implementation of the LSWP. This study assumes that the ongoing annual Basin Assessments and 305(b) reports will continue to be the mechanism to ensure the river remains within water quality standards. The TCEQ's enforcement of water quality standards and amendments to third parties' water quality permits is beyond the scope of this project.*

TPWD Comment:

Page 36 - The text states that "The predicted DO concentrations from this worst-case scenario are acceptable to meet the lower Colorado River aquatic community needs during low-flow periods." TPWD would appreciate justification for this statement. Recognizing that QUAL2E is a steady-state, 1-D model that is calibrated to current (i.e., oxic) conditions, how can the project team be confident that a prediction of 3.87 mg/L doesn't lead to significant ecological damage at critical locations and times, e.g., backwaters at dawn.

LSWP Response: *The recommendation in this report is not tied to a single parameter such as DO. Our recommendation incorporates the riverine components described in the TIFP and the fundamental concept that the prescribed flow regime should mimic critical* *components of the natural flow regime. This natural flow regime includes naturally occurring low flow conditions. The recommendations, however, are not a call for a return to pre-development flows. Therefore, we have made judgments in balancing the needs of providing enough water to assimilate wastewater return flows but not so much to eliminate the habitat benefits of low flow conditions. We are confident that the benefits to habitat outweigh the cost to water quality. This confidence is based on our understanding, from a review of the natural hydrology, that small scale (temporal and spatial) exceedances of regulatory water quality standards are part of a natural system. Although we are confident in our approach and understanding of natural hydrology, we also understand model uncertainty and have not witnessed the river at these discharge levels. Therefore, monitoring of dissolved oxygen along with other water quality parameters and aquatic macrophyte growth during subsistence flow conditions in the future to evaluate the applicability of these recommendations will be included in the long-term monitoring plan.*

TPWD Comment:

Page 59 - The 50 cfs minimum at Austin appears to have two implications. First, this flow is far lower than the subsistence flows based on habitat (Table 4.7), which suggests that the project team has consciously decided to not protect habitat in the 2.5 miles of river between Longhorn Dam and the Walnut Creek WWTP. Secondly, this flow is predicated on City of Austin return flows. TPWD believes that any flow recommendation predicated on return flows should explicitly require such return flows or provide the difference. Thus, TPWD believes that the flow recommendation should be explicitly presented as the values in Table 4.7 minus City of Austin return flows.

LSWP Response: *As described in the report, the 50 cfs recommendation at Austin is first based on maintaining water quality conditions which does not protect habitat in this 2.5 mile stretch to the same degree as the remaining 285 plus river miles. Obviously, some habitat in each of the categories is still protected as evident in Table4.6. Secondly, it is based on maintaining the natural low-flow variability in other portions of the river (the other 285+ miles). Finally, this decision is also based on our understanding of conditions of the system for the current and foreseeable future, namely that significant return flows are entering the river downstream of Austin. Although return flows are not required, if they stop, they would have to be supplemented with dam releases to meet subsistence criteria at Bastrop, thus including this 2.5 mile stretch below the dam. If we were to recommend a release on the order of 100-200 cfs from Austin during subsistence flow periods, the additional return flows would maintain 300-400 cfs at Bastrop during a natural drought, effectively removing natural low-flow variability. To maintain the natural flow regime for a greater portion of the river, the project team did consciously decide to protect the overall condition of the river to a greater extent than this small segment. This approach is not new. Indeed, the current LCRA Water Management Plan based on Mosier and Ray (1992) has 46 cfs as the critical flow at Austin (please see Executive Summary, page 1 [Mosier and Ray 1992]).*

Subsistence Flow Recommendations

TPWD Comment:

Pages 56-60 - Subsistence flows are based upon 95th percent habitat exceedence levels (Hab95) at Austin (initially), Bastrop, and Columbus and upon Hab99 at Wharton. The report (p. 56) states that Hardy et al. (2006) "selected the 95% habitat exceedence level for their ecological base flow [EBF] determination..." and thus lends support to the adoption of the Hab95 for setting subsistence flows, which was equated to EBF, in the present report. TPWD's review of Hardy et al. (2006) revealed that they adopted the "monthly 95 percent exceedence levels" or Q95 as the EBF citing several holistic approaches and some targeted research. According to the supporting rationale in Hardy et al. (2006) the concept of an ecological base flow (EBF) is effectively a minimum flow concept below which no further use of water is permitted: the EBF must be maintained. This raises several issues with the application of the EBF concept in the lower Colorado River. The report uses Hab95 instead of Q95. This may be fine if applied consistently as flow exceedences are related to each Hab95 and if the EBF concept is fully understood. However, at the Austin gage flow recommendations are adjusted down to 50 cfs which is less than the flow needed to maintain Hab95. And at the Wharton gage, flow recommendations are set to Hab99 instead of Hab95. Subsistence flow recommendations at the Austin and Wharton gages appear to violate the spirit of the EBF as defined by Hardy et al. (2006).

LSWP Response: *This is an excellent point. The project team focused a lot of effort on this specific topic. We will add text to expand this discussion in the final report per our response below.*

As stated, we used the EBF concept as a starting point for evaluation and not as the final answer, accepting that all rivers are unique and specific modifications may be necessary. Specific to the Hab95 vs. Q95 comment, upon our review we are confident that this technique is applicable for use with the EBF concept. As the TWDB comments also point out, the Hab95 turns out to require flows that are essentially the Q95 for this system, so this should further alleviate concerns regarding differences. As far as deviations from this approach, the comment is correct in that we did not fully honor the EBF concept at Austin and Wharton. We did this based on a comprehensive review of the hydraulic and habitat modeling, water quality modeling, and recommendations described in Mosier and Ray (1992).

The return flows associated with the stretch of river from Austin to Utley complicate the application of instream flow criteria to this stretch of river. As discussed in more detail in a response above, should the return flows go away, the subsistence criteria at Bastrop would still need to be met, meaning that the EBF (as used in this discussion) would be provided for the entire reach from Austin to Bastrop. Should the return flows remain constant, then the recommended 50 cfs would maintain water quality in the short stretch prior to the entry of returns flows further downstream but it would not honor the EBF *concept. Under these circumstances, releasing enough water to meet an EBF at Austin would double the amount of water at Bastrop, thus limiting the natural variability that was a major focus of these recommendations. Our recommendation is instead to protect the natural variability for the remaining, larger portion of the river.*

It was discussed in the text (pg 58) why the Hab99 was selected for the Wharton Reach. The first factor is the lack of adult blue sucker habitat in this reach. This was documented in Mosier and Ray (1992) and further confirmed in this study. Therefore, the adult blue sucker/rapids and spawning blue sucker habitat guilds were removed from consideration in the Wharton reach. These two categories heavily influenced the Hab95 recommendations at all other sites along with the distribution and remaining habitat amounts. With the removal of these two categories, the percent of maximum for all other habitats at Hab99 at Wharton are comparable to the same numbers for Hab95 at the other sites. Therefore, we continue to recommend use of Hab99 for the Wharton reach.

Finally, the authors of this document respect the work done by Mosier and Ray (1992). When additional information was collected and analyzed throughout this project, the project team used that updated information (i.e. spawning blue sucker modeling, blue sucker spawning window, sediment transport analysis, etc.). However, throughout our efforts we did not find anything to dispute the Mosier and Ray (1992) lower critical recommendation at Austin, or the decreased target flow recommendation at the Egypt reach due to differences in habitat quality. A review of Mosier and Ray (1992) will reveal a 46cfs requirement at Austin, and lower recommended target flows for every month at the Egypt reach (furthest downstream) compared to both the Eagle Lake and Bastrop reaches.

TPWD Comment:

Page 58 - The text states that "A review of the habitat duration curves, exceedence tables, and summary (Table 4.6) reveals that the 95th percent habitat exceedence level appears appropriate for a subsistence flow recommendation at the Austin, Bastrop, Smithville, and Columbus reaches." Please describe how this decision was made. Many of the habitat duration curves appear to have breakpoints in the 80%-90% exceedence range, which would suggest a little more water (i.e., from the 95% exceedence to the 90% exceedence) could provide substantial additional habitat.

LSWP Response: *These recommendations are based on extensive site specific collections of physical and biological data and analysis, state of the art habitat modeling and conformity with the dominate instream paradigm recognizing the importance of a natural flow regime. This analysis resulted in hundreds of tables and charts which were carefully reviewed. From all this analysis, an inflection point was evident at the 95th percent habitat exceedence level. As this level matched the EBF concept discussed in the literature, and as we were concerned about subsistence requirements, we selected that value.*

Other inflection points also are evident in the analysis. These breakpoints are most evident in the 80% to 90% exceedence range as noted in the comment. To be conservative we chose the 80% exceedence value for Base-Dry. Others have noted the inflection point at the 90% exceedence value as justification for that value to be included as the Base-Dry recommendation. While they have suggested that a lot of water could be saved for human use and still protect a "substantial" amount of habitat with the 90% exceedance, we continue to recommend the 80% exceedence value for our Base-Dry recommendation.

TPWD Comment:

Page 60 - Recommended subsistence flows are less than 7Q2 (191 cfs) in 7 of 12 months at Bastrop. Base-DRY flows are less than 7Q2 in 1 month. While TPWD recognizes that the flow recommendations in the Aquatic Habitat report are based on habitat, TPWD opposes the adoption of flow recommendations less than 7Q2 by the LCRA-SAWS Water Project. Wastewater dischargers have been issued permits based on the 7Q2 and TPWD believes that flows below this value will cause a deterioration of water quality.

LSWP Response: *Adjustments were made to our recommendations in consideration of water quality concerns. However, these adjustments were based on our judgment of the effects of water quality in the context of the ecological considerations.*

As stated in TAC §307.8(2) (a) (3) the 7Q2 flows are not intended to serve as minimum flow requirements.

"Low-flow criteria in Appendix B of §307.10 of this title are solely for the purpose of defining the flow conditions under which water quality standards apply to a given waterbody. Low-flow criteria listed in Appendix B of §307.10 of this title are not for the purpose of regulating flows in waterbodies in any manner or requiring that minimum flows be maintained in classified segments."

We understand that discharge permits have been issued based on the assumption for the 7Q2 flows for the purposes of water quality modeling. This is why we used the same water quality model to verify that providing the flow that we recommend will produce acceptable water quality conditions.

Finally, we note that one of the legislative mandates for the flow recommendations produced by this report require that they "provide for instream flows no less protective than those included in the LCRA Water Management Plan (LWMP) for the Lower Colorado River Basin, as approved by the Texas Commission on Environmental Quality." The subsistence/critical flow recommendations in the LWMP are 46 cfs at Austin and 120 cfs at Bastrop. These values are very much in line with our recommendations.

TPWD Comment:

Page 62 - TPWD agrees that subsistence flows should be adjusted in order to provide additional suitable habitat for blue sucker spawning in the months of February and March and suggests an extension of that adjustment to include April and May. For one, the species description states that spawning can occur in those later months and it is possible that blue suckers can spawn in April and May in Texas. On page 54, concerning habitat duration curves, the report states that blue sucker spawning habitat is only applied during February through April which indicates some inconsistency with the February and March adjustment. Until flow and habitat conditions suitable for blue sucker recruitment are identified and quantified, it seems best that a conservative approach to maximizing spawning potential is warranted to ensure the greatest chance of blue sucker persistence in the lower Colorado River. Further, the 50 cfs adjusted flow recommendation at Austin does not seem appropriate especially in light of recent observations of blue sucker spawning at Longhorn Dam. Lastly, the range of values for rapids/blue sucker adult habitat is from 6% to 14% of maximum across reaches. This range is perilously low. At those flow rates, will there be any high quality habitat (0.8-1.0 composite suitability) available to blue sucker adults anywhere in the river? Will there be suitable and exploitable high quality riffles in all reaches?

LSWP Response: *There were some inconsistencies in the text regarding application of spawning blue sucker criteria that we will correct. Spawning blue sucker criteria and related adjustments will be applied from Feb-April. Although the literature suggests that blue suckers may spawn as late as May (in areas farther north), results from intensive spawning surveys conducted as part of this study show that blue suckers in the lower Colorado River spawn from the beginning of February through March. This includes the spawning observations from Mosier and Ray (1992) in which spawning was observed in March, and four years (2004-2007) from the LSWP in which very different hydrologic and temperature regimes were witnessed and spawning did vary but was physically observed and documented from early February to mid-March. April is included just to be safe. The species description in Appendix A will be modified to include this information. One component of the immediate monitoring program is to identify this spawning window each year and thus, should spawning activities be observed in May in the future, the recommendations can be adjusted. In our opinion, it is more likely that during warm winters or due to effects of climate change, spawning may occur as early as late January.*

Spawning blue suckers have only been witnessed at Longhorn Dam during an extremely high flow year (2004) when high discharge eliminated spawning habitat from the majority of the river. Other factors likely contributed to this observation. The dam itself prevents further upstream migration. Further, the spawning was observed on a weekend when a rowing race on Town Lake had prompted short-term reductions in releases from Longhorn Dam. Our observations over the past three years have documented a wide range of hydrologic conditions and flow releases all of which have produced various *levels of available spawning habitat in the river. During each of these three years, no spawning activity has been documented below Longhorn Dam. Therefore, we do not consider the area immediately below Longhorn dam an important blue sucker spawning area.*

It is correct that at subsistence flows, the adult blue sucker rapids category supports between 6–14% on an annual average. We are interested to understand how TPWD supports the conclusion that this is "perilously low". For instance, at the 60% habitat exceedence level, there is only between 36-56 % of maximum across the reaches. This is simply a limited habitat type in the lower Colorado River. When not found in this preferred habitat type, adult blue suckers are predominantly found in deep runs. Deep runs maintain 56-67% (annual average) of maximum at the 95% habitat exceedence level across all reaches.

Base Flow Recommendations

TPWD Comment:

Base flow recommendations are made for dry and average climatic conditions at the Bastrop, Columbus, and Wharton reaches. TPWD supports the addition of a base flow recommendation for wet conditions that would tend towards maximizing habitat conditions. In combination with the Base-DRY and Base-AVERAGE, a Base-WET recommendation would more fully address year to year variability so that through time high quality habitat areas are available for all species in different reaches of the river.

LSWP Response: *A base flow recommendation for wet conditions would not tend towards maximizing habitat conditions. In considering inclusion of a base-wet recommendation, we found that, under such flows, habitat availability is decreased as the whole river becomes very deep and fast. Regardless, high flow variability and its associated functions are extremely important. Below, we have included our more detailed response to TCEQ and TWDB on the topic of Base-Wet.*

There are two basic assumptions within the agencies proposal that Base-Wet should be included in the flow recommendations. The first assumption is that Base-Wet can provide better habitat conditions ("additional habitat in years when additional water"). Second, it assumes that Base-Wet provides greater inter annual flow variability and this is beneficial, ("preserves more of the hydrologic variability of the system").

Based on the second assumption, we have been unable to identify a higher Base-wet flow condition that would show demonstrable benefits in terms of habitat. Increasing flow results in less of some types of habitats and more of others. As a result, we don't recommend a Base-Wet recommendation and instead have a simpler recommendation. We agree that inter annual variability is beneficial and are open to suggestions on how to select the wet period condition. We are concerned that picking an "arbitrary" flow percentile may result in insignificantly better or perhaps poorer overall habitat *conditions. The flow that is exceeded 25-30% of the time is a range that has been used in other studies. Providing the 70th percentile (30 percent exceedence) pre-1940 flows at Columbus would result in increases in deep water habitats but substantial decrease in shallow water habitats (Table 3). This is a quick annual analysis; a more complete analysis considering monthly patterns and base flow separation results in similar findings.*

Table 3. Percent change in habitat area from Base-Average to 70th percentile flows

Rapid - Adult Blue Sucker	74%
Deep Pools	26%
Deep Run	-10%
Spawning Blue Sucker	-37%
Shallow Runs	-45%
Pools/Edges/Backwaters	-54%
Riffles	-61%

From a natural flows perspective these types of conditions did occur and based on that paradigm having some years with 37% less Spawning Blue Sucker and 61% less riffle habitat has an ecological benefit. However, no clear pattern has emerged from the analysis to suggest how to set these Base-Wet targets. Rather than create a Base-Wet recommendation following the same approach that was used for dry and average years, we contend that additional water available during wet periods would be put to better use by providing high flow pulses.

TPWD Comment:

The rationale for adoption of the 80th and 60th exceedence levels should be documented more thoroughly as previously discussed. Specifically, supporting rationale should be better documented for how habitat diversity (equitability) is maintained at various flow levels including the criteria that were used and the habitat response; how dissolved oxygen and sediment transport were determined to be acceptable at those flow rates; and how the evaluation of habitat duration curves, tables, etc. led to the adoption of 80th and 60th exceedence levels.

LSWP Response: *As was noted at the June 26, 2007 meeting with the state agencies, this documentation will be supplemented in the final report.*

TPWD Comment:

Table 4.9 shows that the total annual average percent of maximum habitat is greater than 70% in Base-AVERAGE, but that some habitat categories, including blue sucker adult, in some reaches are fairly low for "average" conditions (i.e., less than 50% of maximum). As indicated by the individual reach counts of average percent of maximum habitat of less than 50%, all reaches in some months have some habitat less than 50% of maximum (Table 4.9). Further, only in two reaches does the proposed flow regime (Base-AVERAGE, Base-DRY and Subsistence) result in adult blue sucker habitat exceeding 50% of its maximum potential; in other reaches it is always less than 40% and substantially less under Base-DRY and Subsistence flows. Under Base-DRY conditions, riffle habitat potential is relatively low (less than 40%) in the downstream reaches. This is of concern since riffle habitats and their communities, which potentially includes blue sucker juveniles (see page 71), are considered particularly flow sensitive. TPWD believes that these issues lend further support for adjustments to the report's flow recommendations in order to address certain habitat "deficiencies" and for inclusion of a Base-WET flow recommendation.

LSWP Response: *Modeling demonstrates that under common historical flow conditions, blue sucker/rapids habitat was fairly limited because maximizing blue sucker habitat requires large amounts of water in the system. Maximum blue sucker habitat occurred at high flows, during which time most other habitats would be very limited. Again, our goal is not to maximize blue sucker habitat, but to provide a distribution of habitats similar to natural conditions. We agree that rapids and riffles are particularly flow sensitive, and are important habitats for maintaining species diversity; however, it is important to remember that they are both relatively uncommon compared to other habitat types (i.e., runs, pools) in the lower Colorado River.*

TPWD Comment:

It would be instructive to see additional count categories (e.g., <75%) and lower percentage exceedence levels (e.g. 50, 45, 40) in Table 4.9. Why are Utley and Altair not included in Table 4.9?

LSWP Response: *We will expand the table to show <75 count category and more percent exceedences. The table is for reaches not individual sites. Utley is in the Bastrop reach, and Altair is in the Columbus reach. See figure 4.7 page 44.*

Pulse Flow Recommendations

TPWD Comment:

Page 63 - Please describe how the two levels of pulse flows were selected including frequency, flow rate, and duration. No recommendations are made for the timing of high flow pulses, and there is no seasonal component. The report states that pulses will be driven by natural rainfall events. Perhaps no lines of evidence for the need for prescribed pulse flows revealed themselves during the study's evaluation of biology, fish life histories, riparian maintenance, and water quality but tools such as IHA can be helpful in guiding when pulse flows have historically occurred. Further, the report does not make reach-specific high flow pulse recommendations meaning that pulse volumes will not increase as they move lower in the basin. Higher downstream pulse flows will probably be required in order for predicted physical processes to be effective. The magnitude of high flow pulses and channel maintenance should be calibrated for each gauge.

LSWP Response: *Pulse flows were selected by examining IHA output as well as sediment transport analysis. Timing of high-flow pulses is fairly sporadic and no clear seasonal trends were evident. In order to incorporate more high-flow variability, base pulse-flow requirements are being explored. It is also acknowledged that high flow pulses could be managed or adjusted during times of reservoir releases and text will be added to the report to discuss. Inclusion of base flow pulse requirements will also add more high-flow variability to the existing recommendations, and thus, hopefully address other concerns regarding base-wet conditions without requiring long periods of high base flows which negatively impact habitat availability. Pulses should naturally increase in volume as they move downstream; however, requirements will be of proper magnitude to ensure effectiveness at all sites.*

Overall Recommendations

TPWD Comment:

Page 69 - The project team declined to recommend percentages of time in each flow category with the statement: "it is recognized that other considerations clearly need to be factored into this decision." That statement could just as easily be applied to the flow values themselves. The point is that "other considerations" will come to bear throughout the project, but this report is the appropriate location for the science to be heard. Clearly, it is not appropriate for flows to be no higher than the subsistence level 99% of the time. Similarly, it is not appropriate for flows to exceed the high flow pulse recommendation 99% of the time. TPWD strongly encourages the project team to provide scientific guidance regarding the percent of time it is appropriate to be in each category, the rational behind such guidance, and the potential environmental consequences from not meeting the specified percentages. A frequency and duration for each flow condition, including Base-WET, should be recommended as well as appropriate criteria to identify the transition from one flow condition to the next.

LSWP Response: *We recommend that subsistence flows would always be met, Base-Dry would be met 80% of the time and Base-Average would be met at least 60% of the time. The LSWP has not yet developed the trigger mechanism to determine how the system might be operated to achieve these goals. This will be developed in coordination with other study components. We have included our response to a similar comment posed by TCEQ.*

We agree that some discussion of the frequency and duration of the occurrence is appropriate. Flows should mimic, to some extent, the natural flow regime. This position is then augmented by a consideration of the existing conditions of the river (i.e. low flow recommendations should give some thought to the existing nutrient load, high flow recommendations to the current state of the riparian corridor and floodplain). Given this starting point the durations and frequencies of flows at or below our recommendations should not be significantly greater than has been experienced under a more natural flow regime. Table 1 shows the durations and frequencies of subsistence and base flow recommendations at Columbus with pre-1940 flows.

Table 1 Subsistence and Base Flow Frequency and Duration Statistics based on Columbus pre-1940 record

	Subsistence	Dry	Average
Jan	96%	82%	64%
Feb	86%	82%	63%
Mar	82%	82%	64%
Apr	95%	82%	67%
May	96%	86%	75%
Jun	97%	87%	75%
Jul	98%	86%	69%
Aug	92%	80%	60%
Sep	96%	86%	64%
Oct	96%	82%	67%
Nov	94%	82%	64%
Dec	93%	81%	61%
All	94%	83%	66%
Average Number of Events per year	3	5	8
Maximum Number of Events per year	13	18	14
Minimum Number of Events per year	0	0	1
Maximium Duration of Events	54	85	121
Average Maiximum Duration	10	22	43
Average Duration of Events	4	8	14

Events in this table are periods of days during which flows remained below the recommended flow. The event count is reset whenever flows go above the recommendation. Based on this analysis of the pre-1940 flow record subsistence, Base-Dry and Base-Average flows generally occurred with the same frequency as we recommend (i.e. subsistence flow are generally exceeded all the time, dry conditions about 80% of the time and average conditions about 60%). The percentages in the table are sometimes higher because the flow record includes pulse and flood flows whereas those flows were filtered out for the habitat analysis.

*In addressing the duration question one could ask what is the worst case scenario based on the most extremely literal interpretation of this report. That is, how often and for how long flows could be exactly at the subsistence level. Since the Base-Dry should be met 80% of the time, it could be construed that for 73 days in a row (365 days * 20%) in every year flows would exactly equal the subsistence flow recommendation. Such an interpretation is not the intent of our report. However, based on the historic record droughts have naturally occurred resulting in flows less than the Base-Dry recommendations for 85 days in a row and of these 54 days were less than the subsistence recommendation. Based on water quality concerns, we recommend that flows should never fall below the subsistence targets; however, the recommendations are not intended to completely remove drought from the system.*

This type of analysis will be used to help generate and evaluate various water management alternatives. Those that more closely mimic the natural pattern of low flow *duration and frequency will be evaluated more favorably than those that deviate from that pattern.*

TPWD Comment:

Page 70 - TPWD recommends that the entire LSWP team begin to develop a more explicit plan for adaptive management. The journal articles provided by TCEQ give useful information to consider when developing plans to incorporate the concept of adaptive management into a permitting or river management framework.

LSWP Response: *We agree and have begun constructing an adaptive management plan relative to the river that will be incorporated in the overall LSWP. We also appreciate the cautionary message of the Gregory articles provided by TCEQ and will develop an adaptive management plan which considers the value of adaptive management in comparison with other options for reducing uncertainty, as well as measures to ensure that results of this plan will be of highest value.*

We look forward to continuing discussions on the LCRA-SAWS Water Project. Please let me know if you would like a follow-up meeting to go over these responses and any lingering concerns or questions you may have. Please feel free to contact me at (512) 473-3589 or leah.manning@lcra.org or Ed Oborny at (512) 990-3954 or eoborny@bio-west.com .

Sincerely,

Leah Manning, P.E.
LSWP Program Manager

CC: Ed Oborny, Bio-West
Wendy Gordon, TCEQ
Mark Wentzel, TWDB
Gary Guy, SAWS

LCRA
ENERGY • WATER • COMMUNITY SERVICES

November 2, 2007

Wendy S. Gordon, Ph. D
Water Rights Permitting and Availability Section
Texas Commission on Environmental Quality
P. O. Box 13087
Austin, Texas 78711-3087

RE: LCRA-SAWS Water Project - Letter dated August 31, 2007
Draft Instream Flow Guidelines Development: Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker April 23, 2007

Dear Dr. Gordon:

Thank you for your letter to Ed Oborny with comments and suggestions following meetings on the LSWP Draft Instream Flow Guidelines Development and your review of the document. The input from you continues to be important and very helpful to us. Below, we have provided responses to your comments following the organization laid out in your letter.

1. I would question the assumption that the pre-1940 time period should be used for the development of instream flow guidelines. Selection of a reference period is clearly a challenging decision for a host of reasons. The hydrology and channel morphology of the Colorado River have been altered by the operation of the lakes. For example, low flows are now higher than they were pre-1940 (as you rightly point out). Hence, pre-1940 data should not be relied upon solely in the determination of instream flow recommendations. On the other hand, those same data can provide a window into the behavior of pulses.

   LSWP Response: *According to the Texas Instream Flow Program Draft Technical Overview (TO) document "Subsistence flows are naturally occurring low flow events." Developing subsistence flows based on artificially elevated low flows does not make sense from an ecological perspective, from the TO "..... some river systems may experience negative ecological impacts due to increased subsistence flows." The reason given in the TO is, "increased subsistence flows may allow exotic species to survive and dominate in areas previously hospitable only to highly-adapted native species." Extremes are dampened that nature is using to maintain and strengthen diversity.*

   This does not imply that results from models which consider pre-development flows should be blindly incorporated into the final recommendations, and they have not been in this study. We started with analysis of the current habitat conditions and then developed flow recommendations to restore important components of the flow regime that we believe existed prior to major water development in the basin. Within this process, current concerns related to water quality were considered and *subsistence flow recommendations were adjusted upward from those based on pre-development flows analysis to address these concerns. From an aquatic health perspective, we conservatively chose 5.0 mg/L as the dissolved oxygen goal to strive for. This level is still above what would have been experienced naturally, but with the addition of human influence, felt it an applicable goal.*

Dr. Thom Hardy (Utah State University) who is on the LSWP Science Review Panel responded to a similar comment on his recently completed report on the Klamath River. Dr. Hardy strongly disagreed with opposition to the natural flow paradigm and referred the commenter to several references [NRC (2005), Annear et al., (2002), Postel and Richter (2003), NRC (1996), NRC (2004)]. Dr. Hardy went on to discuss how the use of habitat modeling benchmarked against the natural flow regime is consistent with concepts put forward collectively in the references cited above. Dr. Hardy concluded by defending that the objectives of their study were satisfied by integrating physical habitat and hydrologic time series to develop flow recommendations within the context of the natural flow paradigm.

2. While maybe not entirely your purview, it is not sufficient to identify subsistence flow volumes without also specifying the frequency or duration of their occurrence. Also, as a point of reference, it would be helpful to include a table of current 7Q2 values for the applicable reaches. These are data I could provide.

   LSWP Response: *The "Instream Flow Guidelines Development" document is not intended to look specifically at how these flow recommendations will be implemented, and the mechanism whereby a trigger might be set to activate the various flow targets. We will be addressing this mechanism in a separate process in the near future. The Guidelines state that flows should mimic, to some extent, the natural flow regime. This position is then augmented by a consideration of the existing conditions of the river (i.e. low flow recommendations should give some thought to the existing nutrient load, high flow recommendations to the current state of the riparian corridor and floodplain). Given this starting point, the durations and frequencies of flows at or below our recommendations should not be significantly greater than has been experienced under a more natural flow regime. Table 1 shows the durations and frequencies of subsistence and base flow recommendations at Columbus with pre-1940 flows.*

Table 1 Subsistence and Base Flow Frequency and Duration Statistics based on Columbus pre-1940 record

	Subsistence	Dry	Average
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Jul	98%	86%	69%
Aug	92%	80%	60%
Sep	96%	86%	64%
Oct	96%	82%	67%
Nov	94%	82%	64%
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Average Duration of Events	4	8	14

Events in this table are periods of days during which flows remained below the recommended flow. The event count is reset whenever flows go above the recommendation. Based on this analysis of the pre-1940 flow record subsistence, Base-Dry and Base-Average flows generally occurred with the same frequency as we recommend i.e. subsistence flow are generally exceeded all the time, dry conditions about 80% of the time and average conditions about 60%. The percentages in the table are sometimes higher because the flow record includes pulse and flood flows whereas those flows were filtered out of our habitat analysis.

*In addressing the duration question one could ask what is the worst case scenario based on the most extremely literal interpretation of this report. That is, how often and for how long flows could be exactly at the subsistence level. Since the Base-Dry should be met 80% of the time, it could be construed that for 73 days in a row (365 days * 20%) in every year flows would exactly equal the subsistence flow recommendation. Such an interpretation is not the intent of our report, however based on the historic record droughts have naturally occurred resulting in flows less than the Base-Dry recommendations for 85 days in a row and of these 54 days were less than the subsistence recommendation. Based on water quality concerns, we recommend that flows should never fall below the subsistence targets, however the recommendations are not intended to completely remove drought from the system.*

This type of analysis will be used to help generate and evaluate various water management alternatives. Those that more closely mimic the natural pattern of low flow duration and frequency will be evaluated more favorably than those that deviate from that pattern.

Table 2 shows the published 7Q2 values from Figure 30 TAC §307.10(2) - Appendix B - Low-Flow Criteria. We will incorporate a discussion relative to 7Q2 values in the final report.

Table 2 Colorado Rive 7Q2 flows

Segment	Name	Description	Gage Location	Gage	County	Period of Record		7Q2
1428	Colorado River Below Town Lake	from a point 100 meters (110 yards) upstream of FM 969 near Utley in Bastrop County to Longhorn Dam in	Austin	8158000	TRAVIS	1966	1996	71
			Bastrop	8159200	BASTROP	1966	1996	191
1434	Colorado River Above La Grange	from a point 100 meters (110 yards) downstream of SH 71 at La Grange in Fayette County to a point 100 meters (110 yards) upstream of FM 969 near Utley in Bastrop County						
1402	Colorado River Below La Grange	from a point 2.1 kilometers (1.3 miles) downstream of the Missouri-Pacific Railroad in Matagorda County to a point 100 meters (110 yards) downstream of SH 71 at	Columbus	8161000	COLORADO	1966	1996	300
			Wharton	8162000	WHARTON	1966	1996	391
			Bay City	8162500	MATAGORDA	1966	1996	205

3. I am concerned about the "methodology" being invoked to determine base dry and base average flows. Without scientific justification for the thresholds being set, they are arbitrary choices. Do other studies back up the 60% or 80% habitat exceedence levels? How do these levels relate to climatologic or hydrologic conditions that we might associate with base dry or average flows? And, base wet flows are missing entirely from the report. Those should be identified as well.

LSWP Response: *As noted on page 69 of the report "The application of base flow recommendations in the literature is highly variable and river-specific in most cases." There is no magic number which says "these" flows must be met "this" percent of the time. These recommendations are not arbitrary but instead are based on extensive site specific collections of physical and biological data and analysis, state of the art habitat modeling and conformity with the dominant instream paradigm recognizing the importance of a natural flow regime. This analysis resulted in hundreds of tables and charts which were carefully reviewed. There is no simple way to summarize this process in a few sentences. The methodology is described briefly on p. 60 of the report. As was noted at the June 26, 2007 meeting with you, this documentation will be supplemented in the final report.*

As described in the TWDB and TPWD comment responses, there are two basic assumptions within the agencies proposal that Base-Wet should be included in the flow recommendations. The first assumption is that Base-Wet can provide better habitat conditions ("additional habitat in years when additional water"). Second, it assumes that Base-Wet provides greater inter annual flow variability and this is beneficial, ("preserves more of the hydrologic variability of the system").

Based on the second assumption, we have been unable to identify a higher Base-wet flow condition that would show demonstrable benefits in terms of habitat. Increasing flow results in less of some types of habitats and more of others. As a result, we don't recommend a Base-Wet recommendation and instead have a simpler recommendation. We agree that inter annual variability is beneficial and are open to suggestions on how to select the wet period condition. We are concerned that picking an "arbitrary" flow percentile may result in insignificantly better or perhaps poorer overall habitat conditions. The flow that is exceeded 25-30% of the *time is a range that has been used in other studies. Providing the 70th percentile (30 percent exceedence) pre-1940 flows at Columbus would result in increases in deep water habitats but substantial decrease in shallow water habitats (Table 3). This is a quick annual analysis; a more complete analysis considering monthly patterns and base flow separation results in similar findings.*

Table 3 Percent change in habitat area from Base-Average to 70th percentile flows

Rapid - Adult Blue Sucker	74%
Deep Pools	26%
Deep Run	-10%
Spawning Blue Sucker	-37%
Shallow Runs	-45%
Pools/Edges/Backwaters	-54%
Riffles	-61%

From a natural flows perspective these types of conditions did occur and based on that paradigm having some years with 37% less Spawning Blue Sucker or 61% less riffle habitat has an ecological benefit. However, no clear pattern has emerged from the analysis to suggest how to set these Base-Wet targets. Rather than create a Base-Wet recommendation following the same approach that was used dry and average years, we contend that additional water available during wet periods would be put to better use by providing high flow pulses.

4. With respect to high flow pulses, I think the report is remiss in not identifying a channel maintenance or bankfull pulse in the recommended flow tables 4.18-4.20. Recently, such a pulse at the Columbus gauge was recommended by our agency in the draft permit requested by LCRA to capture flood flows. As its name implies, channel maintenance flows (approximated by the 1.5- to 2-year recurrence interval of flow) serve important functions of sediment and bedload transport, clearing vegetation from the stream channel, and myriad other effects. The magnitude of channel maintenance flows would have to be calibrated for each gauge. Also, the seasonality in the distribution of high flow pulses has not been identified. From a biological standpoint, seasonality could be a critical factor (for example, serving as a spawning cue).

   LSWP Response: *Channel maintenance and overbank flows will be separated into two separate categories in the final report. Channel maintenance will be set at 27,000 cfs and overbanking will be defined as flows greater than 30,000 cfs. While rule of thumb estimates of peak flow recurrence intervals have provided useful starting points upon which to estimate these flow magnitudes, the substantial uncertainty in these estimates will be greatly reduced by monitoring the rivers response to naturally occurring high flow events over the next several years. While we expect that the magnitude of these flows may increase in the downstream direction or the river, we also understand that channel maintenance and overbanking flow rates are a function of in channel sediments, riparian corridor and floodplain gradient as well as peak flow recurrence rates. Given these factors and the fairly limited data collected, we do not believe that further refinements to these estimates are justified at this time.*

Although seasonality of high flow pulses is likely important, no clearly discernable trends from the initial and further IHA analysis are evident when examining timing of high flow pulses under natural conditions.

5. Though probably not what you intended, stating that "the goal is for the LSWP to meet the subsistence flow guidelines at all times," sounds as if that would be the year-round flow. I would suggest revising the wording. Page 69

   LSWP Response: *The language will be revised to read "Therefore, the goal for the LSWP is that flows do not fall below the subsistence flow guidelines."*

6. It is not clear that high flow pulses will only be the product of nature. LCRA may make reservoir management decisions in the future that could generate such pulses. Page 69

   LSWP Response: *This is a fair statement relative to base pulses. In order to incorporate more high-flow variability, base pulse-flow requirements are being explored. It is also acknowledged that high flow pulses could be managed or adjusted during times of reservoir releases and text will be added to the report to discuss. Inclusion of base flow pulse requirements could add more high-flow variability to the existing recommendations, and thus, hopefully address other concerns regarding base-wet conditions without requiring long periods of high base flows which negatively impact habitat availability.*

7. I would reiterate comments I have made previously that "adaptive management" be invoked with caution. Adaptive management may not be applicable to a situation such as the management of the Lower Colorado River given the many constraints and potentially confounding factors. At the least, goals would have to be made explicit in order to implement a successful adaptive management program. Some recognition of the challenges associated with adaptive management in the text would be welcome.

   LSWP Response: *We appreciate the cautionary message contained in the articles provided by TCEQ (Gregory 2005 and 2006) and will develop the adaptive management plan, which considers the value of adaptive management in comparison with other options for reducing uncertainty as well as measures to ensure that results are scientifically defensible. These papers emphasize the difficulty of designing experiments given the large temporal and spatial scales at play in ecological/river studies and these issues will be addressed in the comprehensive adaptive management approach that we will outline.*

We look forward to continuing discussions on the LCRA-SAWS Water Project. Please let me know if you would like a follow-up meeting to go over these responses and any lingering concerns or questions you may have. Please feel free to contact me at (512) 473-3589 or leah.manning@lcra.org or Ed Oborny at (512) 990-3954 or eoborny@bio-west.com .

Sincerely,

Leah Manning, P.E.
LSWP Program Manager

CC: Ed Oborny, Bio-West
David Bradsby, TPWD
Mark Wentzel, TWDB
Gary Guy, SAWS

November 2, 2007

Mark Wentzel
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711-3231

RE: LCRA-SAWS Water Project – Comments on Draft Instream Flow Guidelines Development: Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker April 23, 2007

Dear Mr. Wentzel:

Thank you for your comments to Ed Oborny following meetings on the LSWP Draft Instream Flow Guidelines Development and your review of the document. The input from you continues to be important and very helpful to us. Below, we have provided responses to your comments following the organization laid out in them.

TWDB Comment:
Overall, this document describes a good faith attempt to implement the type of instream flow analysis described in the Texas Instream Flow Program Draft Technical Overview (2006). Flow recommendations have been made for a flow regime, consisting of the following flow components: subsistence, base habitat, pulse, and overbank flows. Technical studies were completed to evaluate flows for each of these components. Factors related to the fields of hydrology, biology, geomorphology, and water quality have been considered. Bio-West appears to have conducted all the necessary studies and assembled the necessary data and tools to evaluate potential instream flow recommendations for the Lower Colorado River.

However, there appear to be several ways to improve the analysis and selection of flows. These include changes in the way habitat discharge relationships are used to develop subsistence and base flows, provision of a base habitat flow recommendation for wet conditions, additional analysis related to sediment transport, and additional hydrologic analysis for comparison to high pulse and overbank flow recommendations. I would also suggest presenting some of the results related to subsistence and base flows in graphical as well as tabular form. These changes are discussed in greater detail below. All of the necessary data and tools required to implement these changes seem to be readily available. With these changes, the Draft Instream Flow Guidelines should provide a guide for appropriate management for the Lower Colorado River.

Use of Habitat Discharge Relationships to Develop Subsistence and Base Flows

I am uncomfortable with the use of habitat modeling to develop subsistence and base habitat flow recommendations as described in the draft report. The basic outline of that process is as follows: 1) collect contemporary bathymetry, hydraulic, and biological data,

2) develop Habitat Suitability Criteria and hydraulic model of contemporary channel conditions, 3) determine habitat versus discharge relationships for contemporary channel conditions, 4) develop historical habitat time series data by merging historical hydrologic record and contemporary habitat versus discharge relationships, 5) select subsistence and base habitat flow values based on evaluation of historic habitat time series, 6) modify flow recommendations to account for other considerations.

The step that concerns me is step 4, where a "historical" habitat time series is developed using the pre-1940 hydrologic time series and the contemporary habitat versus discharge relationship. I believe it is unreasonable to expect that the current configuration of the channel is similar to the pre-1940 configuration. As pointed out by the report, the hydrologic conditions in the Lower Colorado have changed significantly from pre-1940 conditions. As shown in Figure 3.2 of the report, the number and magnitude of large flow events are reduced dramatically from the pre-1940 period to current conditions. These types of flows are particularly influential in shaping the channel. Sediment loadings to the river may also have changed during this extended time period due to land use changes, cultivation practices, and/or other factors. The net effect is probable, but unknown, changes in the shape of the channel and habitat versus discharge relationships.

Unfortunately, there is little data available to quantify changes in the shape of the channel of the Lower Colorado over the last 100 years. A review of historic USGS maps circa 1904, 1950, and 1981 and an aerial photograph from 1995 in the area of the Utley study site west of Bastrop, TX is shown in the figure below. This figure shows approximate changes in the planform configuration of the Colorado River over a period of almost 100 years. From this data, it appears that the planform shape of the river changed significantly from 1904 to 1950, but has not change significantly from 1950 to 1995. Without an appropriate historical data set, it's impossible to estimate the extent of changes within the channel itself. But it seems improbable that habitat versus discharge relationships developed for conditions in 2005 would accurately reflect conditions over the time period prior to

1940.

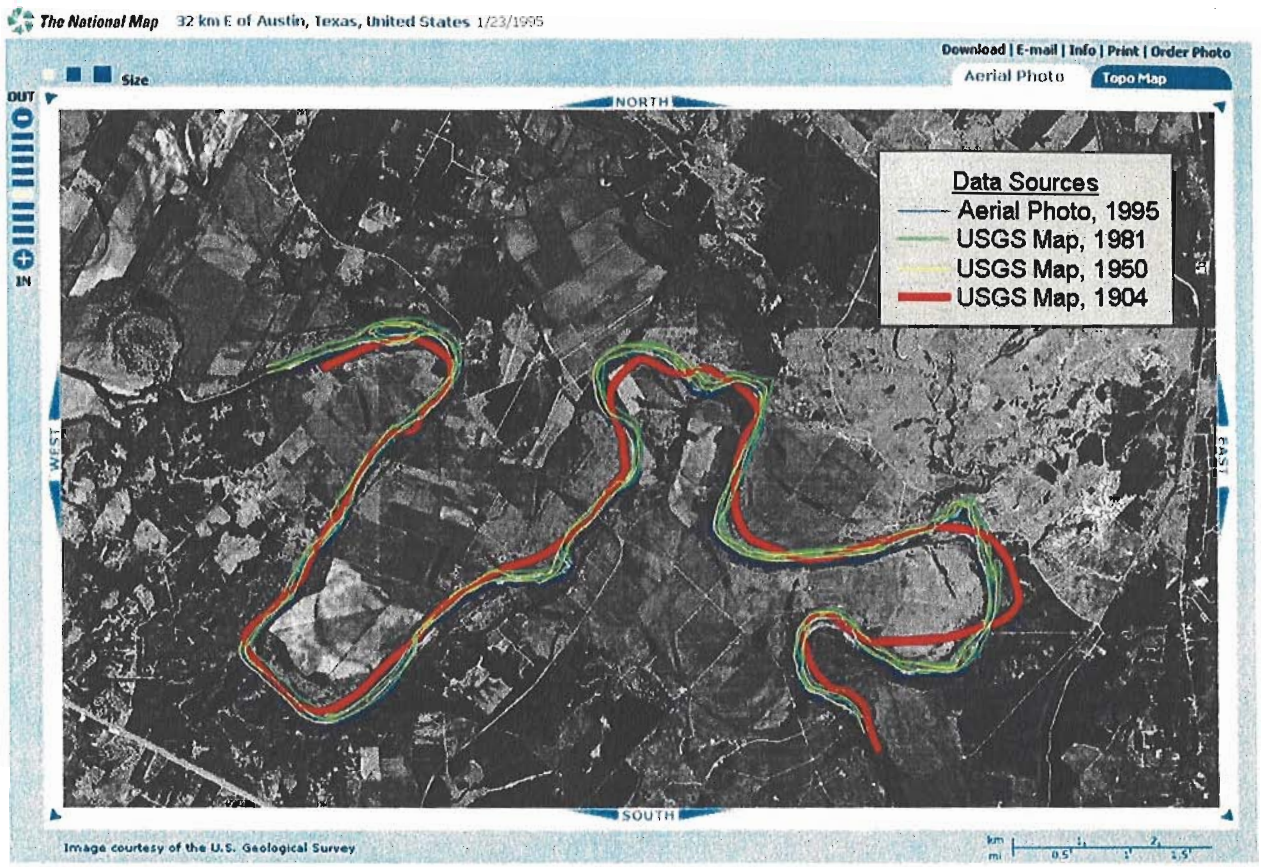

Figure 1. Planform channel changes in Lower Colorado River near Utley study site.

Despite my reservations regarding the "historical" time series, I do not have major concerns regarding the subsistence and base habitat flows derived from the analysis described in the report. In this case, selection of flows based on the criteria related to percentiles from the "historical" habitat time series wind up equivalent to flows that would be selected from criteria related to equivalent percentiles from the historical hydrologic time series. The two procedures are mathematically equivalent. To confirm this, I analyzed the pre-1940 hydrologic time series available for the USGS gage on the Colorado River at Austin, TX (gage #08158000). I calculated the 95, 80, and 60 percent exceedence levels for each month and compared to the flows presented in the report for equivalent habitat exceedence levels. Results are shown in Table 1. My analysis was completed without a baseflow separation, as was carried out by Bio-West on the hydrologic data they used to develop their "historical" habitat time series. Therefore, there are minor differences between the flows selected directly from the hydrologic data and those selected from the habitat data. Differences are greater for the 60 and 80% exceedence levels and months of April through June as these levels and months include a greater number of storm events (which would have been removed by the baseflow separation). I believe the use of a baseflow separation by Bio-West is entirely appropriate when developing subsistence and base habitat flow recommendations, but, for expediency, I did not include it in my analysis.

Table 1. Hydrologic and habitat percentiles for the Austin reach

	Flows [cfs]											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hydrology[1]												
60%	429	490	480	760	1352	1100	670	384	480	480	431	461
80%	306	306	276	317	710	465	359	200	260	253	290	301
95%	201	200	176	178	305	200	138	61	111	128	177	183
Habitat[2]												
60%	418	480	480	613	796	708	590	368	409	418	410	435
80%	303	306	265	277	559	404	335	187	228	237	273	300
95%	201	200	171	178	266	195	132	60	97	122	174	180

[1]Developed from pre-1940 daily stream flows for USGS gage #08158000 (Colorado River at Austin, TX)
[2]From BioWest (2006) Tables 4.7 and 4.10

The flow values from Table 1 show that using percentiles from the historic hydrologic data yields equivalent results to using percentiles from the "historic" habitat data. However, because of uncertainty that the historic habitat data actually reflects historical conditions, I think it is more straightforward and accurate to say that initial flow recommendations were selected based on hydrologic criteria alone. Given the lack of historical data related to channel shape, there is no accurate way to estimate historical habitat data.

If initial subsistence and base flow recommendations are made based strictly on historic hydrologic data, how should the habitat model be used? I believe the habitat model should be used to evaluate the implications of flow alternatives. The model should be used to answer questions such as "Given the current channel configuration, what habitat will be available if we operate the river according to a particular scenario?" Possible scenarios would include various percent exceedence levels from the historic hydrologic data and results would be very similar (if not identical) to those presented in Table 4.9. For comparison purposes, I would like to see additional scenarios evaluated and the results displayed in Table 4.9 (or a similar table). Scenarios should include percent exceedence levels from current hydrologic data (1975-2004) and other hydrologic criteria (say 7Q2 or Lyon's Method). Results should be used to select and modify scenarios as necessary.

LSWP Response: *In terms of the process that we used to develop these flow recommendations, the outline you provide may overlook important steps that we undertook to develop these recommendations. While it may appear that we developed these recommendations using the pre-1940 hydrologic time series and the contemporary habitat versus discharge relationship, we understood early on in this process that combining an existing conditions bathymetry with a natural flow regime can present problems of the kind you describe. The process we undertook, as described on page 44 of the April 23rd draft, was first to apply the existing flow regime to determine the habitats that we could expect under the existing operations. We then developed a habitat time series based on applying a pre-1940 time series to the models. We found that the later habitat time series produced a better diversity of habitats. Perhaps diversity is, as suggested by TPWD, a misused term. TPWD suggests using the term "equitability"* *which could bring other criticisms. Basing recommendations on natural flow regime results in better ecological conditions as defined on pages 52-54.*

The critical question became: "Can we use the habitat time series to develop flow recommendations and, if so, how?" In hindsight it appears, as you point out, that the flow percentile exceedence figures corresponded very closely with some of the habitats that are limiting at the flows we ultimately selected, however, the process of selecting these values was not arbitrary. Analysis of the habitat model output was critical. In some traditional instream flow studies, habitat models are used to maximize habitat for particular species, and in fact several of the comments that we have received seems to suggest that a goal of this study should be to maximize blue sucker spawning habitat. While we have given additional and careful consideration to the habitat needs of this state threatened species, a guiding principal of this study has been to identify instream flow conditions that support a "sound ecological environment", which has been described as "…a functioning ecosystem characterized by intact, natural processes, resilience, and a balanced, integrated, and adaptive community of organisms comparable to that of the natural habitat of a region" (TIFP Draft 2006). In order to do this we analyzed the response of all habitats to flows, and made a determination as to the best mix, diversity, balance, equality of habitats. We then determined the flows necessary to provide these habitats.

Following your suggestion that we select various flow percentiles, arbitrarily, and then see what habitats result might lead to the same recommendations, especially now that we have gone through this process and now know what to look for in terms of breakpoints, percents of maximums and counts of the times habitats fell below minimum thresholds; however, we contend that a more appropriate and scientifically defensible approach is to base our decision on the habitat needs and then determine what flow provides those habitats.

In response to the final paragraph in this section, we're not sure more information is better in this case. We have run the 1975-2004 flow regime through the models and believe the information requested would be similar to the information included in half of the figures in Appendix D. Current operations produce elevated summer and depressed winter flows, which results in conditions that are dominated by one or a few habitat types to the exclusion of the others. The Lyons and 7Q2 estimates reflect these alterations. The recommendations of the TIFP Technical Guidance document and the overwhelming majority of the scientific literature confirm that instream flow recommendations ought to be guided by the natural flow regime. We are not sure how demonstrating the inappropriateness of Lyons supports the primary aim of this study.

TWDB Comment:
Base habitat flow recommendation for "wet" conditions

The report makes recommendations for "dry" and "average" base flow conditions, but no recommendations are made for "wet" conditions. The Technical Overview (TIFP, 2006) describes a flow regime that includes base flow recommendations for "wet, normal, and dry conditions." The purpose of a base flow recommendation for wet conditions would be to provide additional habitat in years when additional water is available. Inclusion of all three components (wet, normal, and dry) preserves more of the hydrologic variability of the system. The analysis should be extended to include a base flow recommendation in wet years. The tools to complete this analysis seem to be available as the habitat versus discharge relationships extend up to flows as large as 5,000 cubic feet per second (see Figure 4.5 and 4.6).

LSWP Response: *There are two basic assumptions within the agencies proposal that Base-Wet should be included in the flow recommendations. The first assumption is that Base-Wet can provide better habitat conditions ("additional habitat in years when additional water"). Second, it assumes that Base-Wet provides greater inter annual flow variability and this is beneficial, ("preserves more of the hydrologic variability of the system").*

Based on the second assumption, we have been unable to identify a higher Base-wet flow condition that would show demonstrable benefits in terms of habitat. Increasing flow results in less of some types of habitats and more of others. As a result, we don't recommend a Base-Wet recommendation and instead have a simpler recommendation. We agree that inter annual variability is beneficial and are open to suggestions on how to select the wet period condition. We are concerned that picking an "arbitrary" flow percentile may result in insignificantly better or perhaps poorer overall habitat conditions. The flow that is exceeded 25-30% of the time is a range that has been used in other studies. Providing the 70th percentile (30 percent exceedence) pre-1940 flows at Columbus would result in increases in deep water habitats but substantial decrease in shallow water habitats (Table 3). This is a quick annual analysis; a more complete analysis considering monthly patterns and base flow separation results in similar findings.

Table 1 Percent change in habitat area from Base-Average to 70th percentile flows

Rapid - Adult Blue Sucker	74%
Deep Pools	26%
Deep Run	-10%
Spaw ning Blue Sucker	-37%
Shallow Runs	-45%
Pools/Edges/Backw aters	-54%
Riffles	-61%

From a natural flows perspective these types of conditions did occur and based on that paradigm having some years with 37% less Spawning Blue Sucker or 61% less riffle habitat has an ecological benefit however no clear pattern has emerged from the analysis to suggest how to set these Base-Wet targets. Rather than create a Base-Wet recommendation following the same approach that was used dry and average years, we contend that additional water available during wet periods would be put to better use by providing high flow pulses.

TWDB Comment:
Additional analysis related to sediment transport

It would be beneficial to complete some additional analysis with the sediment transport tools developed by Bio-West in order to more fully evaluate possible flow scenarios. For example, using the Ackers and White Equations for the four geomorphic study sites, it would be useful to know what amount of sediment (total sediment and sand and gravel separately) is moved by the current flow conditions. And, by comparison, what amount the proposed flow regime would move. This would give more confidence that the proposed flow regime would be capable of maintaining the current channel configuration (or even providing a better one).

LSWP Response: *With our tools, we can compare total average annual gravel and sediment loads for the different sites under current and proposed flow conditions. We have been hesitant to calculate annual loads because accuracy of the equation-based transport rating curves have not been field-verified (that is, however, recommended within the context of long-term investigations). Total annual load calculations can vary by orders of magnitude depending on the transport equation used or the sample data set used to develop an empirical equation. As such, we are somewhat reluctant to put estimated numbers "out there" for fear that they will be taken as real values and used for things not intended. That said, we certainly can run that calculation and make it very clear that the numbers are estimates and only valid as a tool to compare flow regimes. The trick will be to identify the appropriate "average annual" flow data set to use. We will use a real year's daily hydrology (for an example "normal" water year with approximately average total annual flow) rather than extracting a synthetic average or median daily flow regime statistically from a composite multi-year flow data set. Use of statistically-derived synthetic daily regimes can result in unrealistic day-to-day flow changes. We will proceed with this analysis and incorporate results into the final report.*

TWDB Comment:
Additional hydrologic analysis for comparison to high pulse and overbank flows

For comparison purposes, it would also be nice to know how the magnitude of the recommended pulse and overbank flows compare with current conditions, for example the various return period floods and the "Bankfull" and "Flood Stages" at the various gages. A table presenting data similar to that shown in Table 2 (next page) would be helpful. Note that this data was generated as a quick example and a different time period (say 1975-2004 for all gage locations) may be more appropriate. Also, a more accurate refinement of bankfull and flood stages may be available from field data collected at the sites.

LSWP Response: *We agree that a table like Table 2 does provide useful reference/context for our high pulse and overbank recommendations. We will incorporate/adapt such a table and associated text within the final report.*

TWDB Comment:
Display the results shown in Tables 4.6 and 4.9 in graphical form

Selection of the 95% habitat exceedence level (or 99% for the Wharton reach) for a subsistence flow and the 80 and 60% levels for base flows seems somewhat arbitrary. The benefit of these selections may be more obvious if the information in Tables 4.6 and 4.9 is presented in graphical form. Examples for the Austin reach are shown in Figures 2 and 3 on the following pages. I've taken the liberty of marking the x-axis as "Flow Exceedence Level [%]" as I believe the initial estimates of flow value should be characterized as selected based solely on historical hydrologic data. I believe these figures more clearly convey the idea that the 95% exceedence level is adequate to keep the amount of each habitat type above 10% of the maximum (Figure 2) and limit the number of months when various habitats are reduced to less than 5 or 10% of their maximum possible (Figure 3). Similarly, the value of the 80% exceedence flow is shown more clearly as percent of maximum habitat drops rapidly for larger values and the number of months a habitat type is less than 5 or 10% of its maximum is eliminated for smaller values.

LSWP Response: *We agree that the graphics provide helpful visuals and will produce similar graphs for the final report.*

We look forward to continuing discussions on the LCRA-SAWS Water Project. Please let me know if you would like a follow-up meeting to go over these responses and any lingering concerns or questions you may have. Please feel free to contact me at (512) 473-3589 or leah.manning@lcra.org or Ed Oborny at (512) 990-3954 or eoborny@bio-west.com .

Sincerely,

Leah Manning, P.E.
LSWP Program Manager

CC: Ed Oborny, Bio-West
David Bradsby, TPWD
Wendy Gordon, TCEQ
Gary Guy, SAWS

Appendix B – Life History Summaries

Life history summaries for species and life stages in the lower Colorado River, Texas included in the seven habitat categories used in aquatic habitat modeling.

RIFFLES

Percina sciera – dusky darter

The dusky darter is a fairly large darter (maximum size ≈ 110 mm) found in the Mississippi River drainage as far north as Illinois, Indiana, and Ohio, and in Gulf of Mexico drainages from the Mobile Bay system in Alabama south and west to the Guadalupe River in Texas. Dusky darters usually occur in riffles and raceways of moderate to large streams over gravel substrates, often associated with some type of cover such as boulders or logs (Miller and Robison 1973). They feed on a variety of aquatic insects, and spawn from February through June in the Colorado River over gravelly substrates. Eggs and larvae of dusky darters can survive at temperatures between 22 and 27°C (Hubbs 1961). Maximum life span is approximately four years (Page 1983, Robison and Buchanan 1988). Dusky darters are relatively abundant in riffle areas over gravel and cobble substrates throughout the Colorado River.

Percina carbonaria – Texas logperch

The Texas logperch is another relatively large darter (maximum size ≈ 112 mm) endemic to the Brazos, Colorado, Guadalupe, and San Antonio rivers of Texas. Due to its small native range, little life history information has been published on this species. However, they are assumed to be similar in habitat use and biology to the closely related and more widely distributed logperch *Percina caprodes*. Logperch inhabit rocky riffles, feed on a variety of aquatic insect larvae, and spawn demersal adhesive eggs in moderate current over gravel substrates (Boschung and Mayden 2003). Hubbs (1961) found that Texas logperch spawn from January through June in the Colorado River, and eggs and larvae can tolerate temperatures between 22 to 26°C. They are common in relatively deep fast riffles throughout the Colorado River over gravel and cobble substrates.

Ictalurus punctatus (<180 mm) – juvenile channel catfish

The channel catfish is native to the Mississippi River drainage as well as Gulf Slope drainages from Florida to Texas, including the Colorado River. Due to their popularity as a game and food fish, introductions of channel catfish into new areas have greatly expanded their range. This widely adaptable fish occupies a variety of habitats including rivers, reservoirs, and farm ponds. Channel catfish consume a wide variety of food, including small aquatic insects, crustaceans, mollusks, and some plant material. Fish generally becomes more important in their diet as they grow (Boschung and Mayden 2003). After fry leave the nest, they form tight schools for several weeks until they reach fingerling size (Robison and Buchanan 1988, Mettee et al. 1996). Such schools of juvenile channel catfish are abundant in riffle habitats over gravel and cobble substrates throughout the Colorado River in the late summer and fall. Conversely, adults are more common in deeper areas and were thus included in the Deep Run guild.

Phenacobius mirabilis – suckermouth minnow

The suckermouth minnow is a relatively large robust minnow (maximum size ≈ 102 mm) found throughout the Mississippi River drainage as well as Western Gulf slope drainages of Texas. Although it is found in a variety of habitats, the suckermouth minnow seems to prefer riffle areas of medium-sized prairie streams over gravel substrates. It is a bottom dwelling species that forages in the substrate to capture benthic invertebrates and also consumes some plant material (Robison and Buchanan 1988, Mettee et al. 1996). Suckermouth minnows spawn between April and August in Kansas (Cross 1967). Although suckermouth minnows are not particularly abundant in the Colorado River, when found, they are usually collected in swift riffle habitats over gravel and cobble substrates.

Etheostoma spectabile - orangethroat darter

The orangethroat darter is a small percid (maximum size ≈ 60 mm) that ranges from central Texas north as far as eastern Wyoming and east as far as central Ohio. They inhabit shallow, moderately-fast, gravel riffles where they feed on a variety of aquatic insects and fish eggs. Eggs are deposited in the gravel substrate, and spawning usually occurs from November through July in Texas (Page 1983, Hubbs 1985). Eggs ard larvae of orangethroat darters can survive temperatures of 10 to 27°C. In the Colorado River, orangethroat darters are fairly common on shallow gravel riffles from Austin downstream to Columbus. Their abundance decreases downstream most likely due to increased turbidity and decreasing amounts of gravel riffle habitat.

Campostoma anomalum - central stoneroller

The central stoneroller is a wide ranging herbivorous cyprinid that occurs throughout the Mississippi River drainage as well as several Gulf Coastal drainages including the Colorado River. Stonerollers are most abundant in small generally clear streams over gravel substrates where they use a special cartilaginous ridge on their lower lip to scrape algae and associated materials from the rocky substrate. Spawning occurs in riffle areas during spring at water temperatures of about 15C (Robison and Buchanan 1988). Males move small rocks and pebbles to create a nest and eggs are laid in the interstitial spaces between the rocks (Miller 1962). After hatching, small stonerollers occupy slow stream margins and backwaters until they reach larger sizes and move into the main flow. In the Colorado River, stonerollers were most commonly collected in shallow gravel riffles of moderate current from Austin downstream to Columbus. Similar to orangethroat darters, their abundance decreases downstream most likely as a result of increased turbidity and decreasing amounts of gravel riffle habitat.

Macrhybopsis spp. - shoal chub and burrhead chub

The species complex previously known as the speckled chub *Macrhybopsis aestivalis* is distributed throughout the Mississippi River drainage and Gulf Coastal drainages from the Choctawhatchee River in Florida to the Rio San Fernando in Mexico. However, recent analyses have split this complex into five species west of the Mississippi River, two of which (shoal chub *M. hyostoma* and burrhead chub *M. marconis*) occur in the lower Colorado River (Eisenhour 2004). However, because these two species were only recently differentiated, no attempt was made to distinguish them in field collections, and given that they occupy similar habitats they were grouped as one ecological unit for guild analysis. These fish inhabit moderate to swift flowing waters over sandy and gravelly substrates in large rivers. They use taste buds located on their head, body, fins, and small barbels to feed along the bottom of turbid rivers. Food consists of aquatic insects, small crustaceans, and some plant material. They spawn throughout the summer months and eggs develop as they drift in the current, hatching in about 25-28 hours. Maximum life span is approximately 1.5 years (Robison and Buchanan 1988). In the Colorado River, *Macrhybopsis spp*. are relatively abundant in shallow riffles over sand and small gravel throughout the river.

DEEP RUNS

Pylodictis olivaris – flathead catfish

The flathead catfish is a large long-lived catfish (maximum size ≈ 100 pounds, life span up to 20 years) native to the Mississippi River drainage as well as Western Gulf Slope drainages of Texas. It is most common in deeper areas of large turbid rivers around moderate current and heavy cover such as rocks, riprap, or submerged logs. It is a solitary species which feeds at night on live fish and crayfish. Spawning occurs in late June and July when parents construct a nest in a natural cavity. Females may lay up to 100,000 eggs which are guarded by the male. After hatching the young catfish form a compact school for a few days before dispersing (Robison and Buchanan 1988, Mettee et al. 1996). Flathead catfish are common throughout the Colorado River in deep runs and pools with slow to moderate currents often near large boulders or other dense cover.

Ictalurus punctatus (>180 mm) – adult channel catfish

The channel catfish is native to the Mississippi River drainage as well as Gulf Slope drainages from Florida to Texas, including the Colorado River. Due to their popularity as a game and food fish, introductions of channel catfish into new areas have greatly expanded their range. Channel catfish can live in a wide variety of habitats and can withstand temperatures from 6 to 39°C (Currie et al. 2004). In rivers adults usually occupy deep pools near cover and overhanging banks during the day and venture out to feed in shallower areas at night. Fish generally become increasingly important in the diet as they grow (Boschung and Mayden 2003). Spawning usually occurs from May to July in a cavernous nest dug out by the male along an undercut bank or under logs or other debris. The male guards the small fry until they leave the nest. In the Colorado River, adult channel catfish were collected from a variety of habitats; however, they were most abundant in deeper runs often near some type of cover.

Moxostoma congestum – gray redhorse

The gray redhorse is a large catostomid fish endemic to streams of the Edwards Plateau region of Texas including the Brazos, Colorado, Guadalupe, San Antonio, Nueces, and Rio Grande drainages. It is also found in extreme southeastern New Mexico, and a few coastal streams along the Gulf Coast of Mexico. Detailed life history studies are lacking for this species. However, gray redhorse have been found to consume a variety of aquatic insects, mainly dipteran and trichopteran larvae (Cowley and Sublette 1987). In central Texas, they spawn in small groups during late March and early April over shallow gravelly runs (Martin 1986). Gray redhorse are abundant in the Colorado River from Austin downstream to Columbus. Their abundance declines below Columbus where sand substrates are more common and river carpsuckers (*Carpiodes carpio*) become more abundant.

Micropterus treculii (>170 mm) – adult Guadalupe bass

The Guadalupe bass is endemic to the Edwards Plateau region of central Texas, including portions of the Brazos River, Colorado River, Guadalupe River, and San Antonio River basins (Hubbs et al. 1991). In 1989, the Guadalupe bass was recognized as the State Fish of Texas. These fish most commonly inhabit swift deep runs and pools below riffles where they prey on insects, crayfish, and small fish. Guadalupe bass spawn in spring over nests constructed by the male in shallow water. Edwards (1980) found that the females produce approximately 400 to 10,000 eggs depending on body size. They can live up to 6 years and reach sizes of approximately 3.5 lbs. Adult Guadalupe bass are common in deep flowing runs throughout the Lower Colorado River; however, they appear to be most abundant in the clearer upper reaches from Austin downstream to La Grange.

Carpiodes carpio – river carpsucker

River carpsuckers are native to the Mississippi River basin as well as Western Gulf Slope drainages in Texas. They are most common in medium to large rivers over sand and silt bottoms in slow current where they browse along the bottom feeding on attached algae, small crustaceans, molluscs, and small aquatic insects. Spawning occurs from May to August when adhesive eggs are broadcast over the substrate. River carpsuckers can live up to ten years and grow to sizes of approximately 10 pounds (Robison and Buchanan 1988, Mettee et al. 1996). They are abundant throughout the Colorado River, especially downstream of Columbus where sand is the predominant substrate.

Dorosoma cepedianum – Gizzard shad

Gizzard shad are common inhabitants of large rivers and reservoirs throughout the eastern United States. They are a pelagic schooling species usually found in deep calm water, although they are often found in strong currents as well. Gizzard shad use their long gill rakers to filter plankton from the water, and sometimes feed along the bottom ingesting detritus. Spawning occurs from April through June when adults congregate in open water and simultaneously release eggs and sperm. The adhesive eggs become attached to the substrate or float in the current for a few days until they hatch. Young gizzard shad provide an important food source for many predatory species. However, gizzard shad can live up to 6 years and grow to approximately 20 inches in length (Robison and Buchanan 1988, Mettee et al. 1996). Gizzard shad are abundant in deep runs and pools over a variety of substrates throughout the Colorado River.

SHALLOW RUNS

Cyprinella lutrensis – red shiner

The red shiner is a small cyprinid fish native to the Mississippi River drainage as well as Gulf slope drainages west of the Mississippi. Red shiners occupy a wide-range of habitats from sluggish backwaters to swift riffles over a variety of substrates. Their diet consists of aquatic and terrestrial invertebrates and algae. They are classified as crevice spawners that reproduce from April through September by attaching their adhesive eggs to crevices in rocks, wood, or onto submerged vegetation. They have also been known to broadcast their eggs over the nests of various sunfishes. Growth is fast and red shiners spawned early in the year can reproduce before the end of their first summer (Marsh-Matthews et al. 2002). They live approximately two years and reach a maximum size of about 75 mm (Robison and Buchanan 1988, Mettee et al. 1996). The red shiners ability to persist under a wide variety of habitats and environmental conditions as well as their high reproductive potential make them one of the most abundant species in many large rivers within their range. They are one of the most abundant species in the lower Colorado River and are collected in a wide variety of habitats over various substrates throughout the river. However, they are most abundant in shallow runs with moderate current. Their abundance increases in turbid downstream areas of the Colorado River where closely related blacktail shiners become less abundant.

Cyprinella venusta – blacktail shiner

The blacktail shiner occurs in Gulf Coast drainages from the Rio Grande in Texas to the Suwannee River, Florida, and as far north as the Ohio River. This species, which is a close relative of the red shiner, occurs in a variety of habitats over varied substrates from fast gravel riffles to silty reservoirs (Robison and Buchanan 1988, Mettee et al. 1996). Their diet fluctuates depending on food availability, and they consume a variety of aquatic and terrestrial invertebrates as well as algae (Hale 1962, Hambrick and Hibbs 1977). In central Texas they reproduce from April through September by expelling adhesive eggs into crevices in the substrate. Blacktail shiners can live up to four years (Ross 2001), and reach sizes of approximately 150 mm. They are one of the most abundant species in the Lower Colorado River, and occur in a variety of habitats; however, they seem to be most abundant in shallow runs with moderate current in the upper portion of the river from Austin downstream to La Grange. In the lower portion of the river they are usually less abundant than red shiners.

Pimephales vigilax – bullhead minnow

Bullhead minnows are a common inhabitant of large Gulf Slope streams and rivers from the Rio Grande basin of Texas north and east to the Mobile basin and north in the Mississippi drainage as far as Wisconsin. Although sometimes found in strong currents they are most common in sluggish currents over sand and silt substrates. Bullhead minnows feed in schools along the bottom on aquatic insects, snails, and plant material. Reproduction takes place in late spring and summer when eggs are laid on the undersides of rocks, logs, or other structures. Males guard the egg clusters and keep them clean and aerated by brushing against them with their fleshy backs. After hatching young bullhead minnows congregate in large schools over silt substrates feeding on bottom ooze and diatoms (Robison and Buchanan 1988, Johnston and Page 1992, Mettee et al. 1996). In the Colorado River, bullhead minnows are abundant throughout the river ranking third in overall abundance behind red and blacktail shiners. They are most commonly collected in shallow water over silt, sand, or gravel in slow to moderate currents.

Notropis volucellus – mimic shiner

The mimic shiner is commonly yet somewhat sporadically found in large Gulf slope streams and rivers from the Guadalupe River, Texas north and east to the Mobile basin, and north as far as Canada in the Mississippi River drainage. Mimic shiners are commonly collected in schools near the surface or midwater over sand and gravel substrates. They feed mainly on small crustaceans, aquatic insects, and algae (Black 1945). Spawning reportedly occurs between April and August (Robison and Buchanan 1988, Mettee et al. 1996). Mimic shiners are an abundant species throughout the Lower Colorado River, and are often found in shallow runs in association with blacktail shiners and red shiners.

Micropterus treculii (<180 mm) – juvenile Guadalupe bass

The Guadalupe bass is endemic to the Edwards Plateau region of central Texas, including portions of the Brazos River, Colorado River, Guadalupe River, and San Antonio River basins (Hubbs et al. 1991). These fish most commonly inhabit swift runs and pools below riffles where they prey on insects, crayfish, and small fish. In the Colorado River, young Guadalupe bass inhabited shallower and often somewhat slower areas than adults, which were placed in the deep run guild. Juvenile Guadalupe bass were most common in shallow runs over various substrates, and seem to be most abundant in the clearer upper reaches from Austin downstream to La Grange.

DEEP POOLS

Ictiobus bubalus – smallmouth buffalo

The smallmouth buffalo is a large catostomid fish native to large Gulf Coast drainages from the Rio Grande, Texas to the Mobile Bay drainage in Alabama. They are common in deep slow pools of rivers and reservoirs throughout their range, where they feed along the bottom on small aquatic insects, mollusks, algae, and detritus. Spawning occurs in early to middle spring when adhesive eggs are scattered over the substrate or onto submerged vegetation. Smallmouth buffalo are a large long-lived fish with a maximum life span of approximately 15 years and maximum size approaching 70 pounds (Robison and Buchanan 1988, Mettee et al. 1996, Boschung and Mayden 2003). They are common in deep slow pools and runs throughout the Colorado River.

Cyprinus carpio – common carp

The common carp is an exotic cyprinid fish first introduced into the United States in the 1870s. They are now common in a variety of habitats of small streams, large rivers, and reservoirs throughout the United States. Common carp feed along the bottom, especially in muddy areas, where they consume insect larvae, crustaceans, detritus, and plant material. They spawn in large groups in shallow water during spring and early summer. Small adhesive eggs, once fertilized, attach to aquatic vegetation or sink to the bottom. Common carp are extremely tolerant of pollution and siltation and are often one of the most abundant fish in large reservoirs. They are a large minnow that can live for several years and attain weights exceeding 50 pounds (Robison and Buchanan 1988, Mettee et al. 1996). Common carp are common in a variety of habitats throughout the Colorado River; however, they are most abundant in deep silty pools along with smallmouth buffalo.

SHALLOW POOLS / EDGE / BACKWATER

Micropterus salmoides – largemouth bass

Largemouth bass are native to eastern North America including most of Texas, and are arguably the most popular gamefish in the United States. This popularity as a sport fish has led to their introduction into many areas outside their native range. Although they are most abundant in reservoirs, lakes, and ponds, largemouth bass are also common in low velocity habitats of rivers such as pools and backwaters. They are a predatory species which feed on a variety of fish and invertebrates. Young largemouth bass consume zooplankton and aquatic insects, while adults feed mainly on smaller fish and crayfish. They spawn over nests excavated by the male bass in shallow still water during the spring, usually from February to May in Texas. Eggs and fry are protected by the male bass for several days after hatching. Largemouth bass commonly live 10+ years and can grow to sizes exceeding 20 pounds (Robison and Buchanan 1988, Mettee et al. 1996). They can withstand temperatures ranging from 7 to 37°C (Currie et al. 2004). In the Colorado River, largemouth bass are common in pool habitats over a variety of substrates throughout the river.

Lepomis megalotis – longear sunfish

The longear sunfish is a small centrarchid found throughout the Mississippi River drainage, as well as Gulf Coastal drainages from Florida to Mexico. They are common in pools of small streams and large rivers where they feed on a variety of aquatic invertebrates, terrestrial insects, and the occasional small fish. They spawn in late spring and summer in shallow slow-moving water where the male builds a small saucer shaped nest in the substrate. Spawning often takes place in colonies, with several nests located in close proximity to each other. Longear sunfish reach sizes of 5–7 inches over a maximum life span of about six years (Robison and Buchanan 1988, Mettee et al. 1996, Boschung and Mayden 2003). They are common in slow-moving shallow pools and backwaters throughout the Lower Colorado River.

Lepomis macrochirus – bluegill

Bluegill are common in rivers, lakes, and ponds throughout the eastern United States and south into Mexico. Since they provide an excellent forage species for the widely introduced largemouth bass, and are also popular with fishermen, bluegill have been extensively introduced outside their native range. In rivers, they are most commonly found in slow moving pools and backwaters where they feed on aquatic invertebrates and small fish. They reproduce during late spring and summer in shallow colonial nesting sites similar to other sunfish. Males guard the eggs, and fan them to discourage siltation until hatching. Growth of bluegill is highly variable depending on local conditions. However, they can live up to six years and grow to sizes of approximately 10 inches (Robison and Buchanan 1988, Mettee et al. 1996). Bluegill are common in shallow pools throughout the Colorado River, often in association with other *Lepomis* species.

Lepomis cyanellus – green sunfish

Green sunfish are native to the central United States from the Great Lakes south to the Gulf Coast; however, introductions have greatly expanded their range in North America. They are tolerant of a wide range of environmental conditions and are often found in stagnant creeks and ditches where other sunfish species cannot survive. In rivers and streams, they are most common in slow moving pools and backwaters where they feed on aquatic and terrestrial insects, small fish, and crayfish. Similar to other sunfish, they spawn in shallow saucer shaped nests during late spring and summer. Growth rates are faster than those of other sunfish, and green sunfish can quickly overpopulate small ponds and lakes. They can live 5-6 years and reach 8-10 inches in size (Robison and Buchanan 1988, Mettee et al. 1996, Boschung and Mayden 2003). Green sunfish are common in pools and backwaters throughout the Lower Colorado River, often in association with other sunfish species.

Cichlasoma cyanoguttatum – Rio Grande cichlid

The Rio Grande cichlid is the only member of the family Cichlidae native to the United States. Its native distribution was limited to the Rio Grande and Pecos River drainages of Texas and Northeastern Mexico (Hubbs et al. 1991); however, its range has been greatly expanded as a result of accidental and intentional introductions (Fuentes and Cashner 2002). The diet of Rio Grande cichlid has not been well studied. In central Texas, spawning has been documented in May when a monogamous pair defends a spawning territory usually established over rocky substrate. Both parents aggressively defend the eggs and fry for several days after hatching (Itzkowitz and Nyby 1982). Rio Grande cichlids are commonly collected in shallow pools and weedy backwaters throughout the

Lower Colorado River. Temperature is thought to be one factor limiting the distribution of this species in the Colorado River (Tilton 1961).

Gambusia affinis – western mosquitofish

The western mosquitofish is a small surface-dwelling fish which occurs in Gulf Coastal drainages from Alabama to Mexico, and in the Mississippi River drainage as far north as Illinois. They inhabit shallow areas of little to no current in streams, rivers, ponds, lakes, and swamps where they feed on small aquatic and terrestrial insects, fish larvae, and plant material. Mosquitofish can tolerate an extremely wide range of environmental conditions, often occurring in areas of low dissolved oxygen, elevated temperatures, and high salinities. Reproduction takes place throughout the summer, when females give birth to live young. Males have a modified anal fin that allows transfer of sperm to the female who can store it in her reproductive tract for several months. With a gestation period of 21-28 days, three to four broods of young can be produced by each female each summer. Females grow larger than males, and can reach sizes of approximately 70 mm (Robison and Buchanan 1988, Mettee et al. 1996). Western mosquitofish are abundant in shallow vegetated stream margins, pools, and backwaters throughout the Lower Colorado River.

Poecilia latipinna – sailfin molly

The sailfin molly is a surface-dwelling poeciliid fish distributed in brackish waters from Cape Fear, North Carolina to the Yucatan Peninsula of Mexico. Inland freshwater populations also exist in Texas, Louisiana, and Florida. The species gets its name from the large, elongate, and colorful dorsal fins present on males. Sailfin mollies, like mosquitofish, can tolerate a wide range of salinities and can occur in ditches and small pools with high temperatures and very little dissolved oxygen. They are often abundant in severely degraded habitats where other species cannot survive (Felley and Daniels 1992). Females give birth to live young after a gestation period of 23 to 27 days, usually producing 6 to 36 individuals. Sailfin mollies feed on algae, vascular plants, and small invertebrates; however, they become more herbivorous as they grow (Boschung and Mayden 2003). Although not particularly abundant in the Colorado River, sailfin mollies are common in shallow pools and weedy backwaters throughout the river.

Fundulus notatus – blackstripe topminnow

The blackstripe topminnow is a small surface-dwelling fish which occurs in Gulf Coast drainages from the San Antonio Bay drainage of Texas, north and east to the Tombigbee River drainage Alabama, and as far north in the Mississippi River drainage as southern Wisconsin. They prefer pools and margins of slow low-gradient streams and rivers. The majority of their diet is comprised of terrestrial insects taken from the surface, however, aquatic insects and crustaceans are also consumed. Spawning occurs in late spring and early summer when the female deposits 20-30 unguarded eggs on vegetation or detritus (Robison and Buchanan 1988, Mettee et al. 1996). Blackstripe topminnows occur in low abundance in shallow pools and backwaters throughout the Colorado River.

RAPIDS / ADULT BLUE SUCKER

Cycleptus elongatus - blue sucker

The blue sucker is a large long-lived catostomid native to large rivers of the Mississippi Basin and occurring sporadically in some Western Gulf Slope drainages of Texas as far south as the Rio Grande. A similar and closely-related species, the southeastern blue sucker *Cycleptus meridionalis,* was recently recognized from Eastern Gulf Slope drainages of Alabama, Mississippi, and Louisiana (Burr and Mayden 1999). Commercial harvest records from the Mississippi River indicate that the blue sucker was once abundant, however, they are now considered rare throughout most of their range and have been listed as threatened or endangered by several agencies including the Texas Parks and Wildlife Department. Blue suckers occupy deep high-velocity habitats over firm substrates (Rupprecht and Jahn 1980, Vokoun et al. 2003). They feed on aquatic insects, mainly Trichopteran and Dipteran larvae and pupae, and can grow to over 800 mm total length (Peterson et al. 1999, Moss et al. 1983, Cowley and Sublette 1987). Age and growth studies of blue suckers have yielded varying results. Previous studies using scale-aging have suggested that blue suckers live anywhere from 9-22 years (Moss et al. 1983, Rupprecht and Jahn 1980, Vokoun et al. 2003, Morey and Berry 2003). However, scale-aging is thought to underestimate the ages of large fish, and examination of annuli on opercular bones has suggested that southeastern blue suckers reach ages of 30+ years (Peterson et al. 1999, Burr and Mayden 1999). Reproduction occurs in early to late spring at temperatures of 12 – 20C when blue suckers migrate to spawning riffles where their adhesive eggs are deposited on the substrate (Moss et al. 1983, Semmens 1985, Peterson et al. 2000, Mettee et al. 2003, Vokoun et al. 2003). Eggs hatch in about 6 days (Semmens 1985). Although larval blue suckers have occasionally been collected in backwater and off-channel habitats (Fisher and Willis 2000, Adams et al. 2006), information on the ecology of young blue suckers is limited because juveniles are rarely collected (Morey and Berry 2003). In the Colorado River, adult blue suckers are fairly common in deep fast rapids over gravel, cobble, boulder, and bedrock substrates throughout the upper two-thirds of the river. Blue suckers were the only species collected in abundance in these deep high-velocity areas, and therefore, were the only species included in the rapids guild. Despite considerable effort, there have been no confirmed collections of juvenile blue suckers from the Lower Colorado River.

SPAWNING BLUE SUCKER

Cycleptus elongatus – blue sucker

Blue suckers reportedly spawn in deep riffles over cobble and bedrock from early February to May when water temperatures are between 10 and 23˚C (Moss et al. 1983, Boschung and Mayden 2003, Vokoun et al. 2003). Although spawning data from this study confirms spawning habitat described in other studies, blue suckers in the lower Colorado River spawn earlier than those from northern rivers. Several spawning locations have been documented on the lower

Colorado River - one site in early March 2005 below Longhorn Dam, three sites in February 2006 (near Altair, LaGrange, and Utley), and five sites in February 2007 (Altair, La Grange, Utley, Smithville, and Onion Creek). Habitat data from these confirmed spawning areas were used in constructing the spawning blue sucker habitat guild.

APPENDIX C – Habitat Suitability Criteria

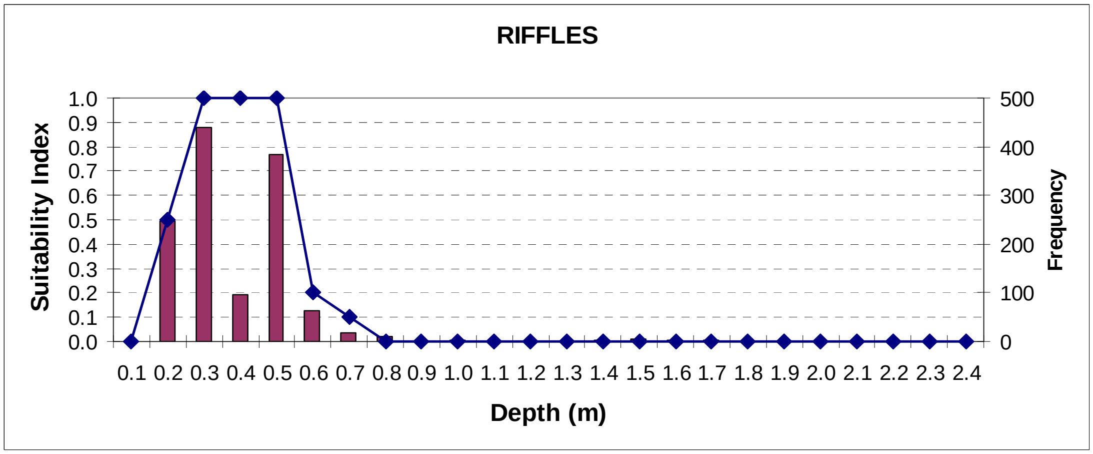

Figure C1. Frequency distribution and Habitat Suitability Criteria for depth in the Riffle Habitat Guild.

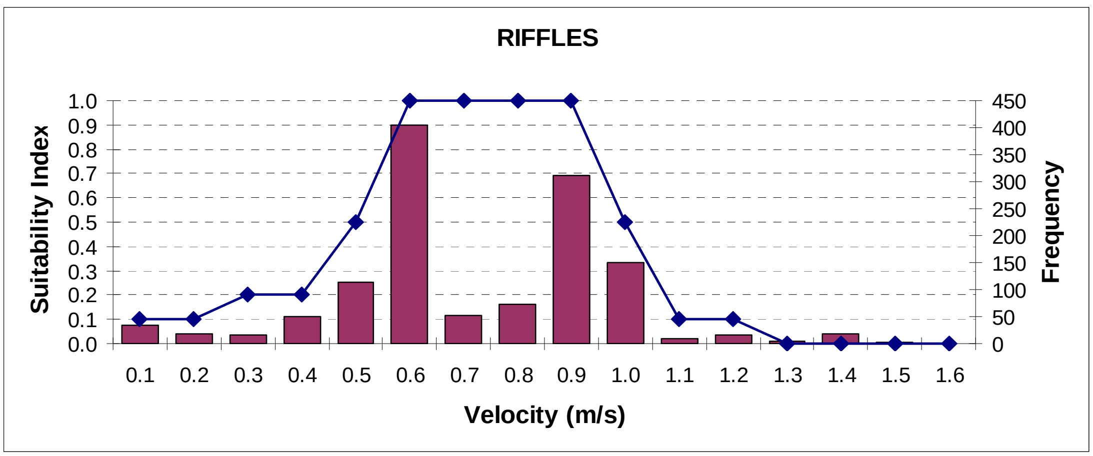

Figure C2. Frequency distribution and Habitat Suitability Criteria for velocity in the Riffle Habitat Guild.

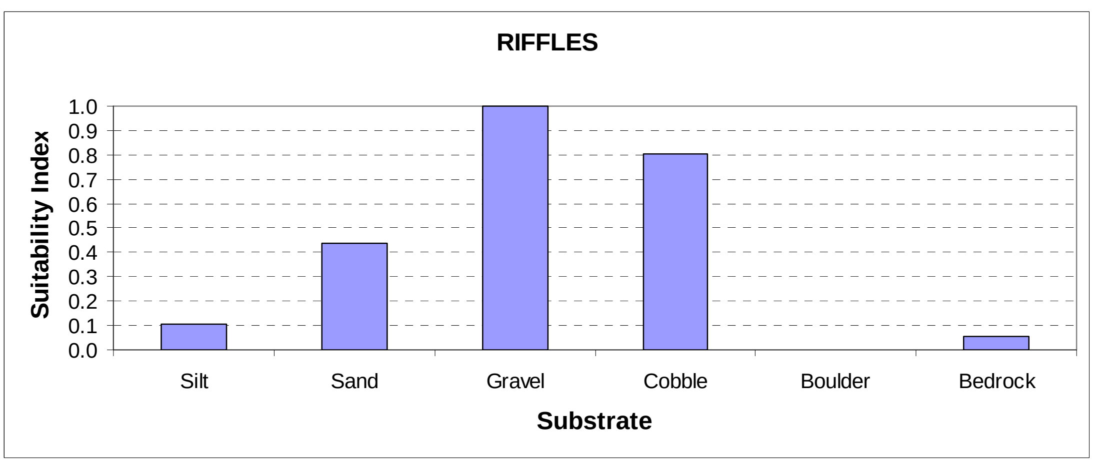

Figure C3. Normalized frequency distribution and Habitat Suitability Criteria for substrate in the Riffle Habitat Guild.

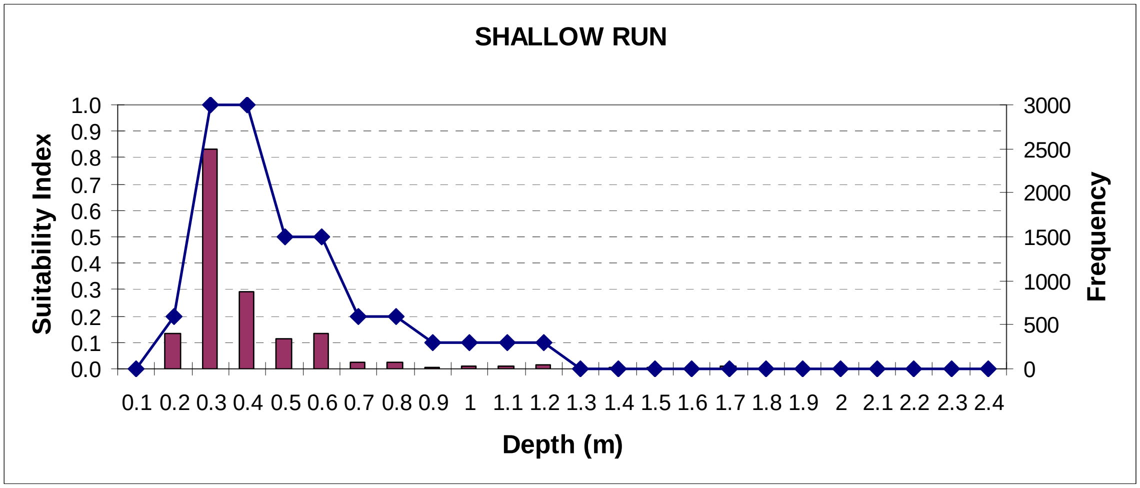

Figure C4. Frequency distribution and Habitat Suitability Criteria for depth in the Shallow Run Habitat Guild.

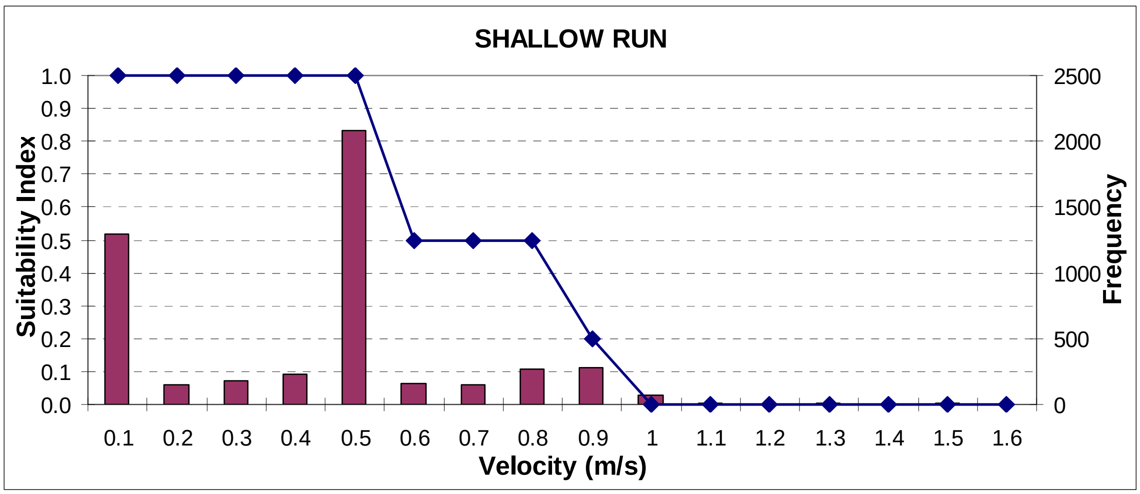

Figure C5. Frequency distribution and Habitat Suitability Criteria for velocity in the Shallow Run Habitat Guild.

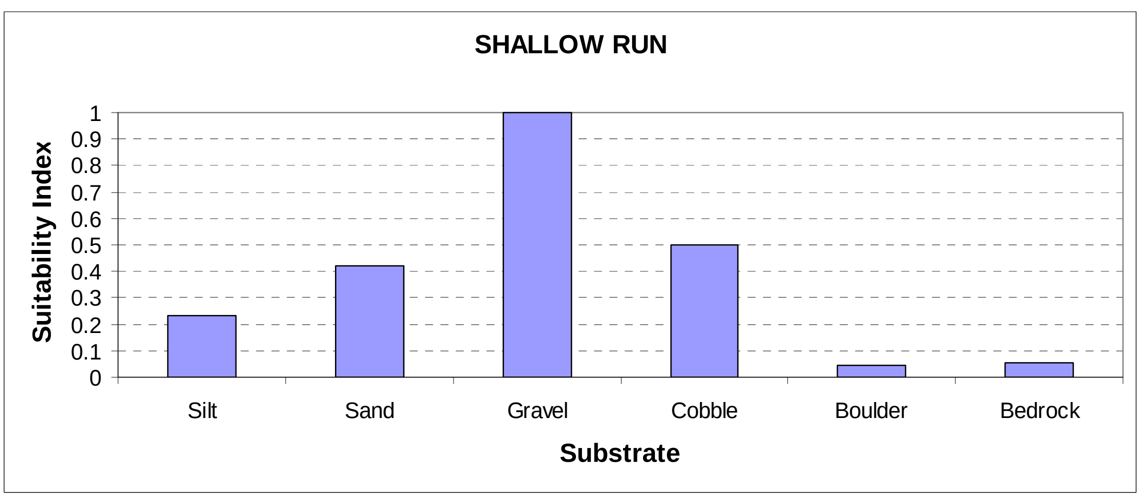

Figure C6. Normalized frequency distribution and Habitat Suitability Criteria for substrate in the Shallow Run Habitat Guild.

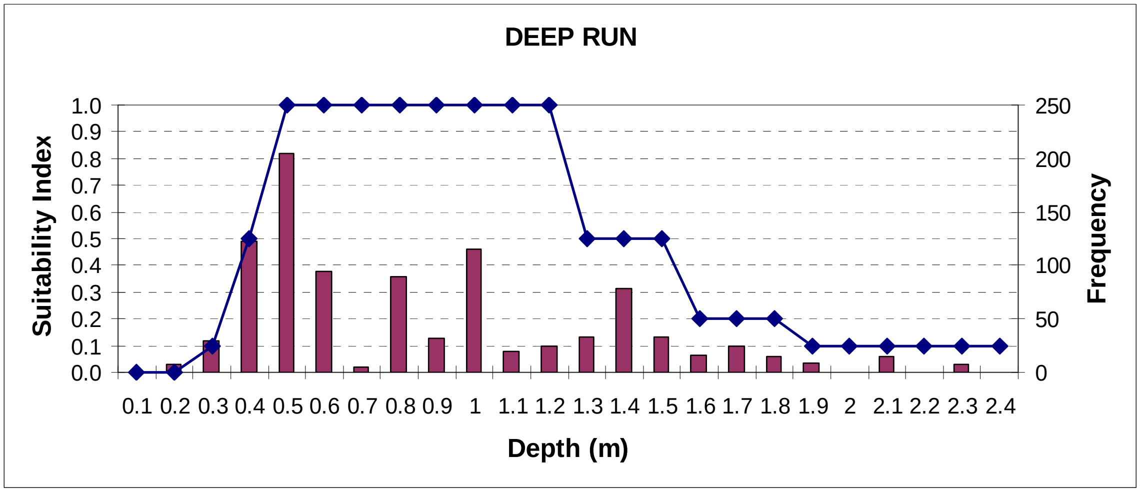

Figure C7. Frequency distribution and Habitat Suitability Criteria for depth in the Deep Run Habitat Guild.

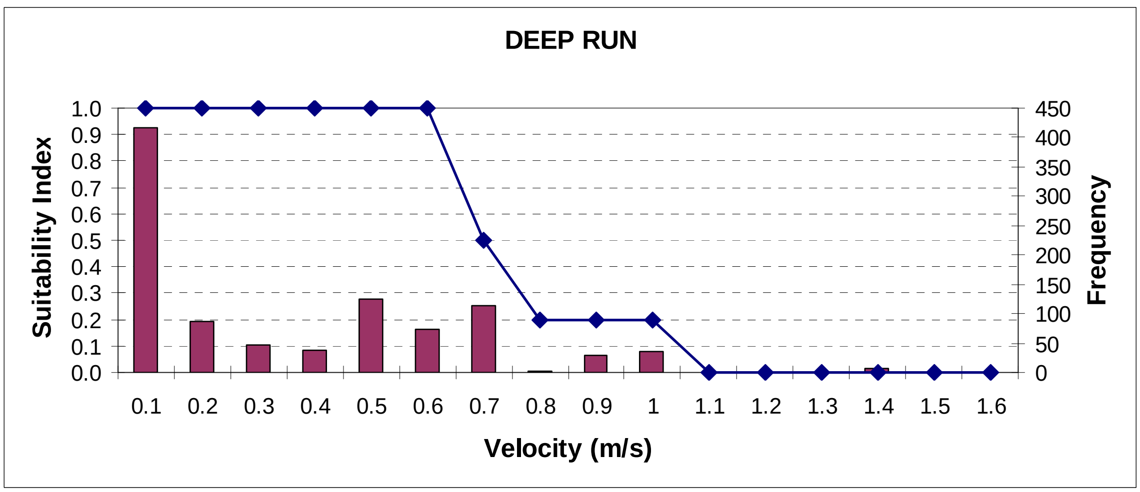

Figure C8. Frequency distribution and Habitat Suitability Criteria for velocity in the Deep Run Habitat Guild.

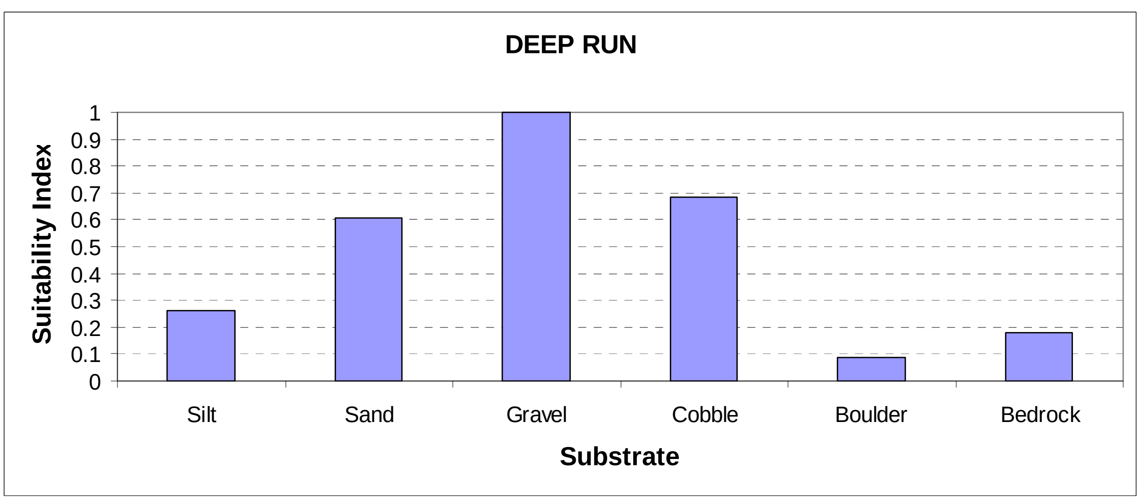

Figure C9. Normalized frequency distribution and Habitat Suitability Criteria for substrate in the Deep Run Habitat Guild.

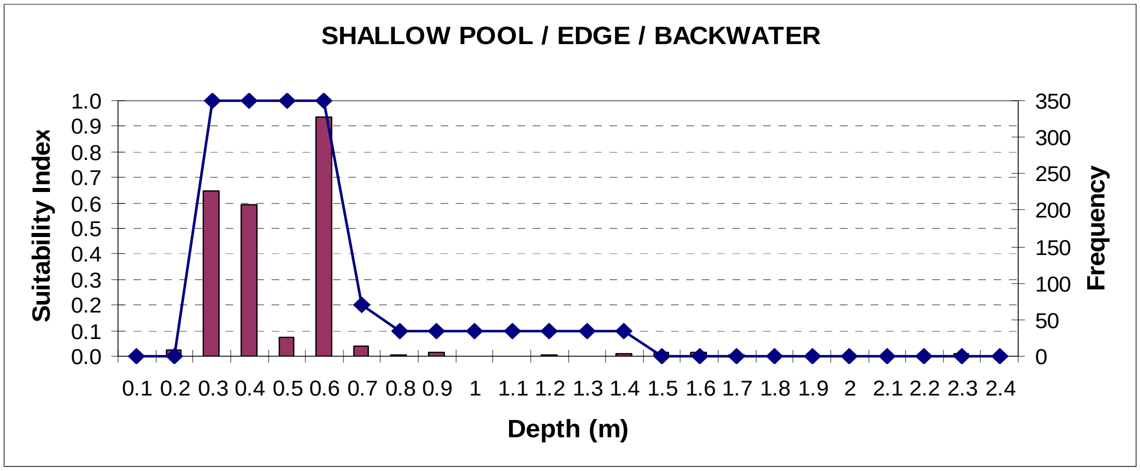

Figure C10. Frequency distribution and Habitat Suitability Criteria for depth in the Shallow Pool / Edge / Backwater Habitat Guild.

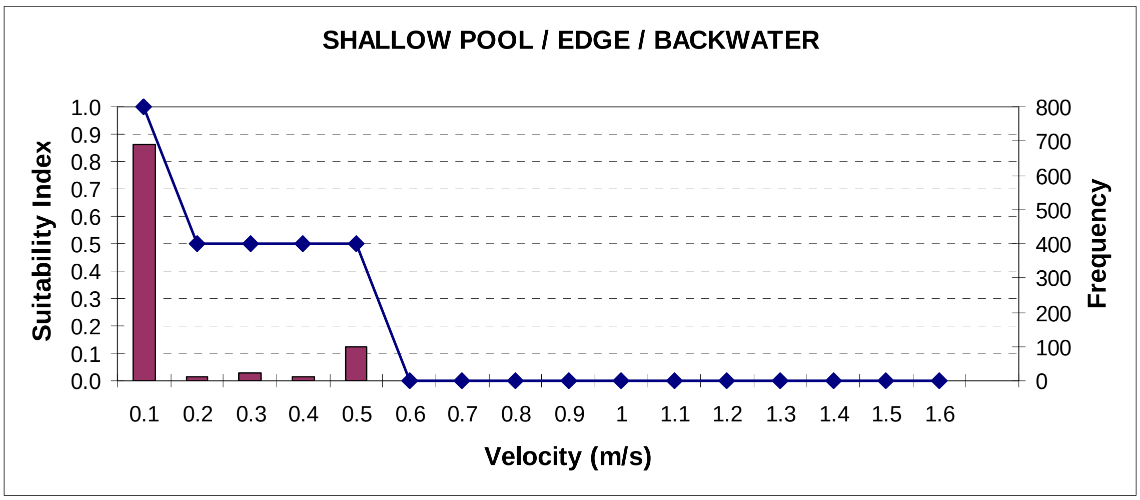

Figure C11. Frequency distribution and Habitat Suitability Criteria for velocity in the Shallow Pool / Edge / Backwater Habitat Guild.

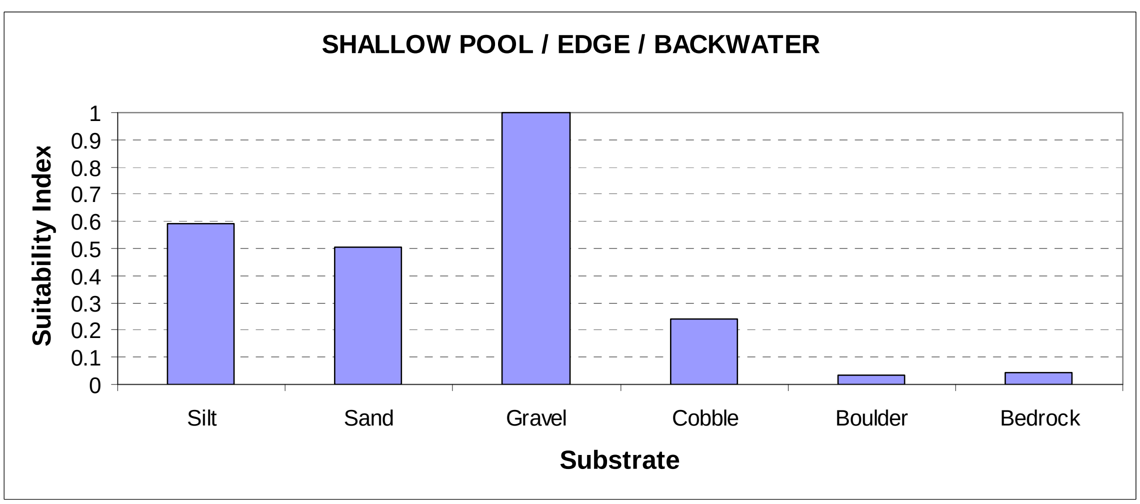

Figure C12. Normalized frequency distribution and Habitat Suitability Criteria for substrate in the Shallow Pool / Edge / Backwater Habitat Guild.

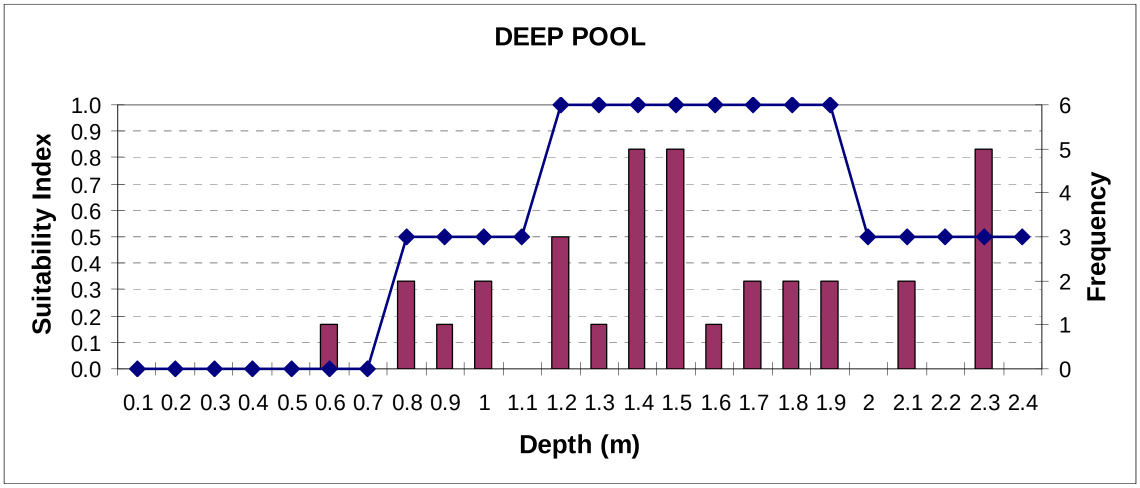

Figure C13. Frequency distribution and Habitat Suitability Criteria for depth in the Deep Pool Habitat Guild.

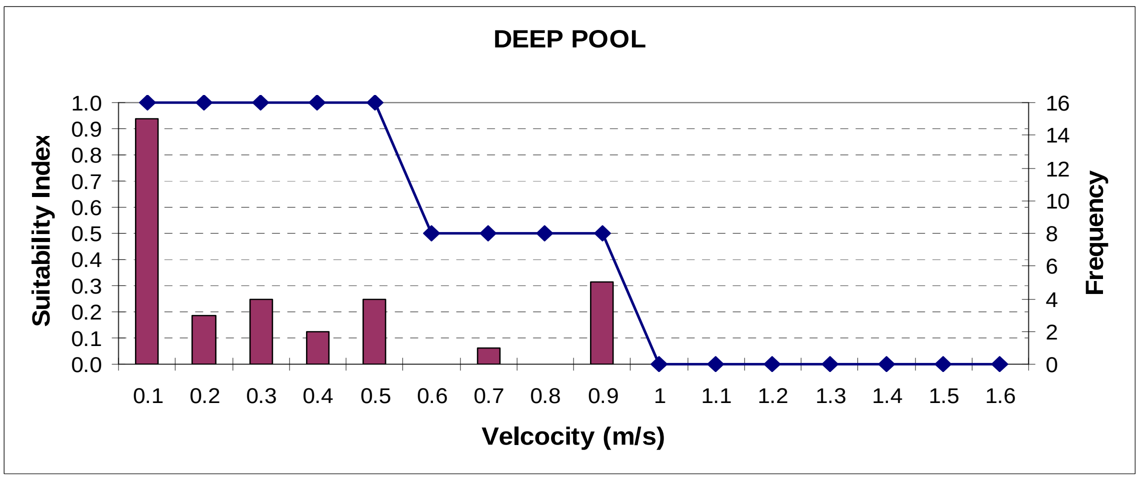

Figure C14. Frequency distribution and Habitat Suitability Criteria for velocity in the Deep Pool Habitat Guild.

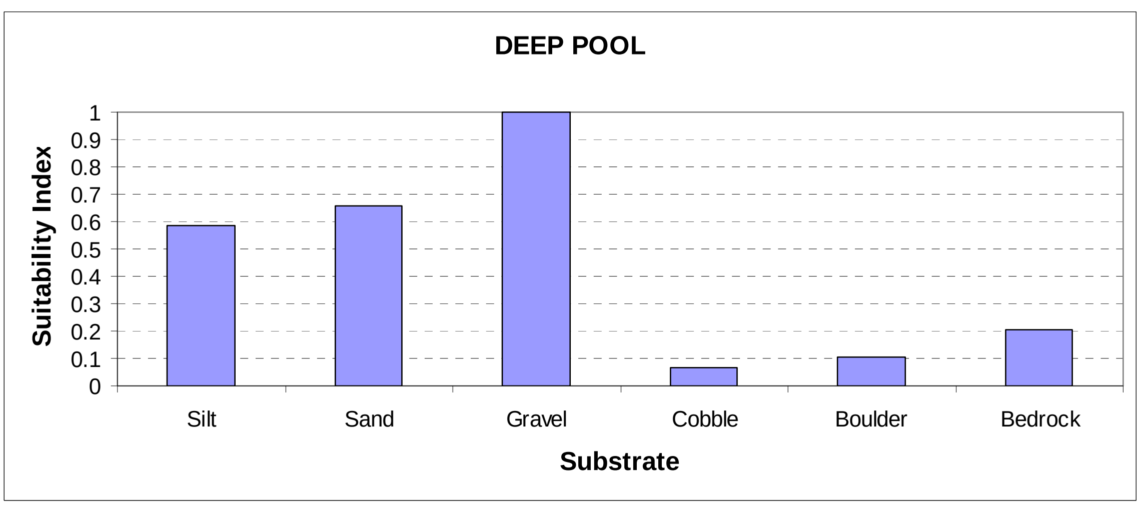

Figure C15. Normalized frequency distribution and Habitat Suitability Criteria for substrate in the Deep Pool Habitat Guild.

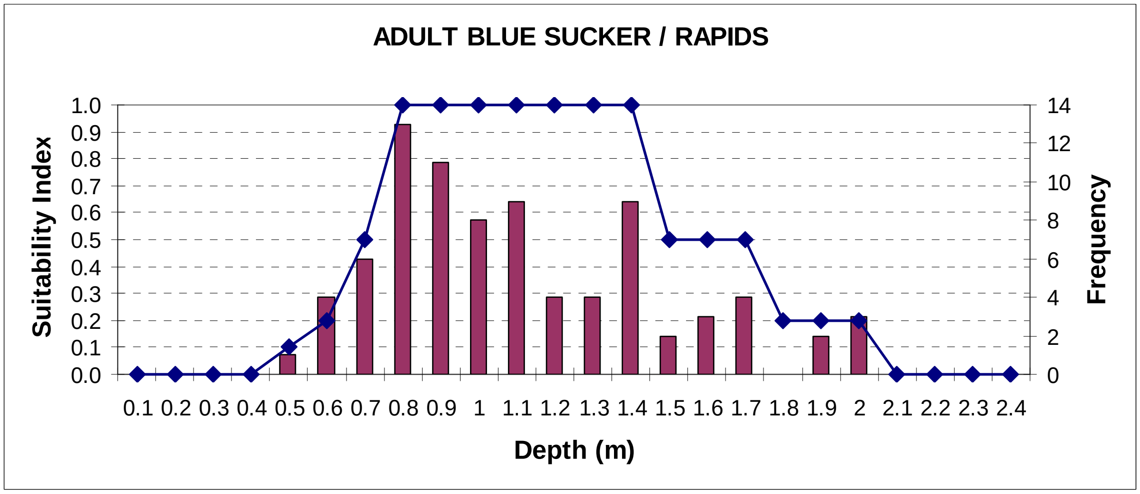

Figure C16. Frequency distribution and Habitat Suitability Criteria for depth in the Adult Blue Sucker / Rapids Habitat Guild.

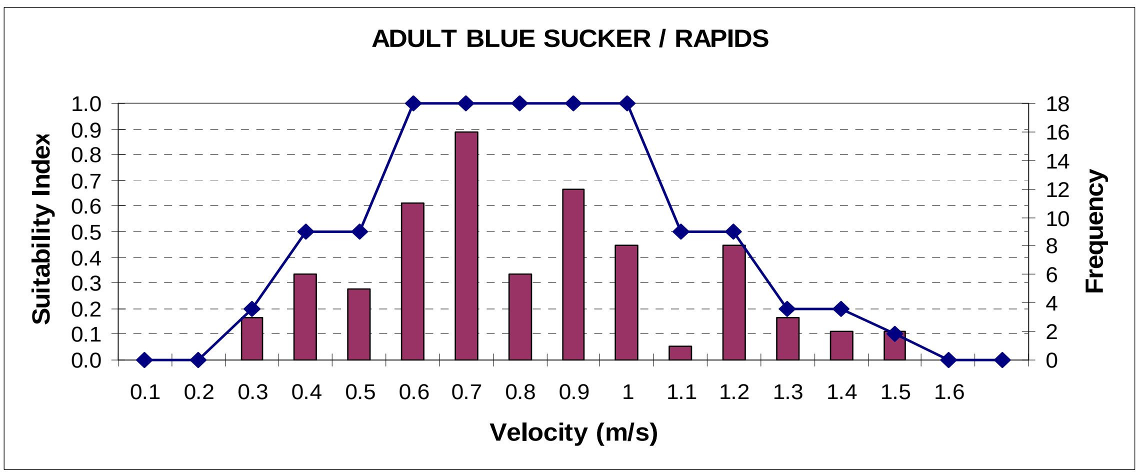

Figure C17. Frequency distribution and Habitat Suitability Criteria for velocity in the Adult Blue Sucker / Rapids Habitat Guild.

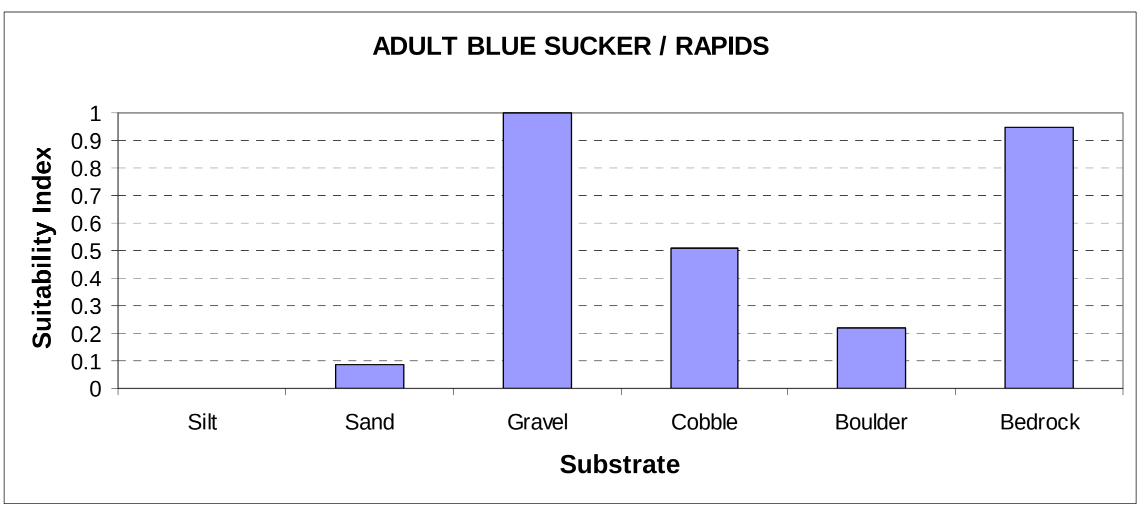

Figure C18. Normalized frequency distribution and Habitat Suitability Criteria for substrate in the Adult Blue Sucker / Rapids Habitat Guild.

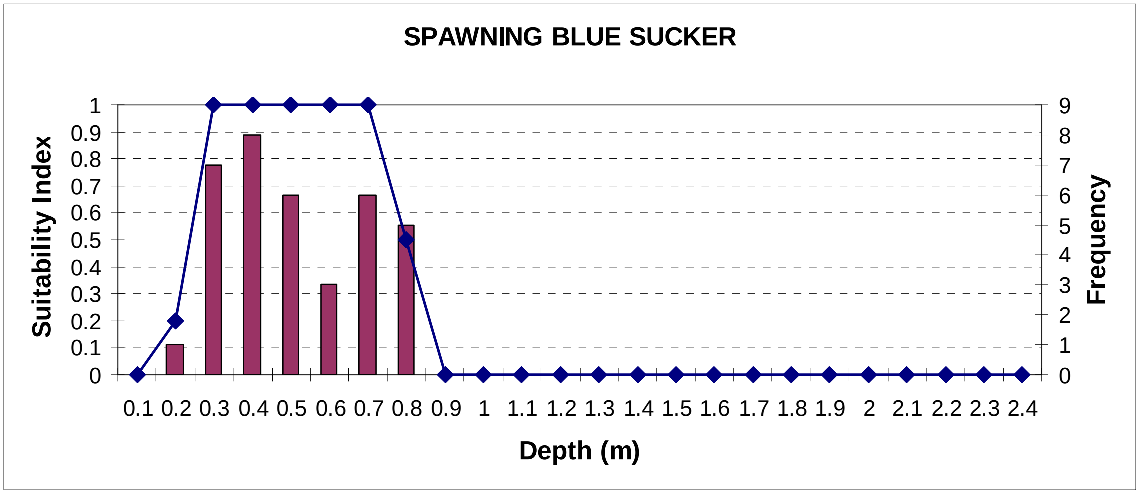

Figure C19. Frequency distribution and Habitat Suitability Criteria for depth in the Spawning Blue Sucker Habitat Guild.

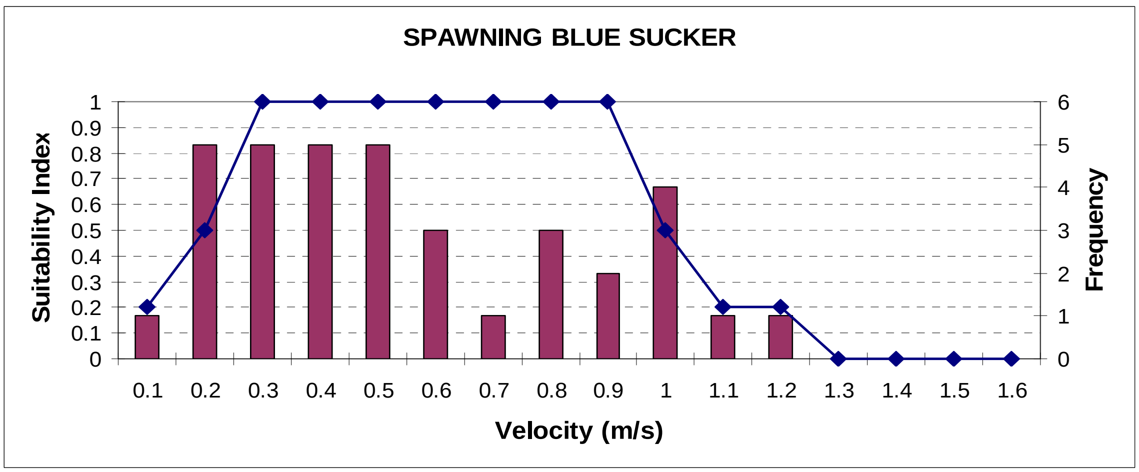

Figure C20. Frequency distribution and Habitat Suitability Criteria for velocity in the Spawning Blue Sucker Habitat Guild.

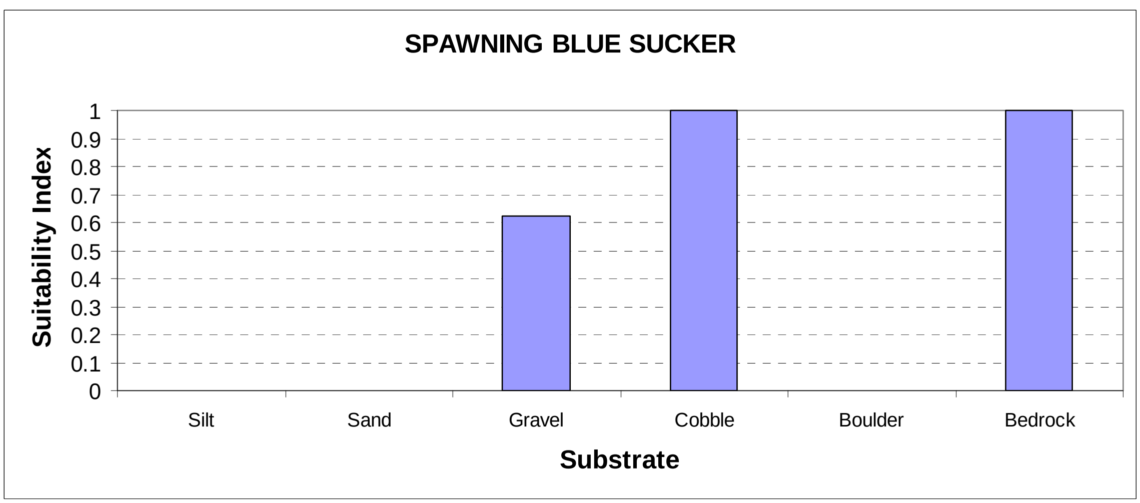

Figure C21. Normalized frequency distribution and Habitat Suitability Criteria for substrate in the Spawning Blue Sucker Habitat Guild.

APPENDIX D – WUA versus Discharge Relationships

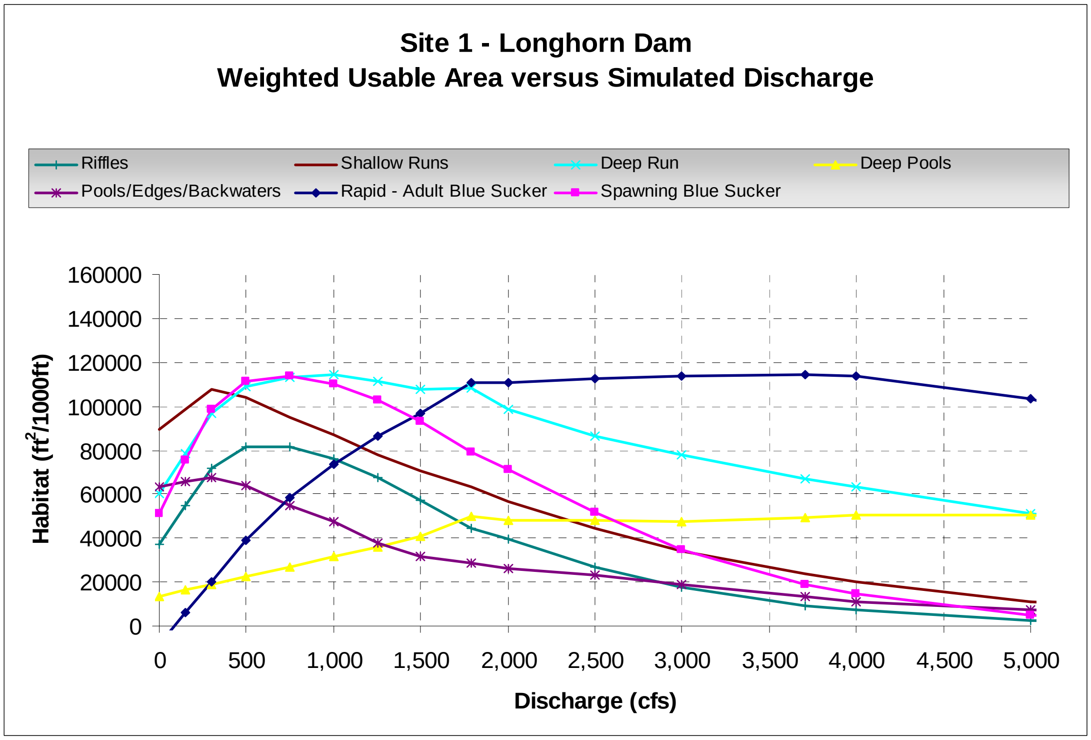

Figure D1. Weighted usable area vs. simulated discharge at Longhorn Dam (Site 1).

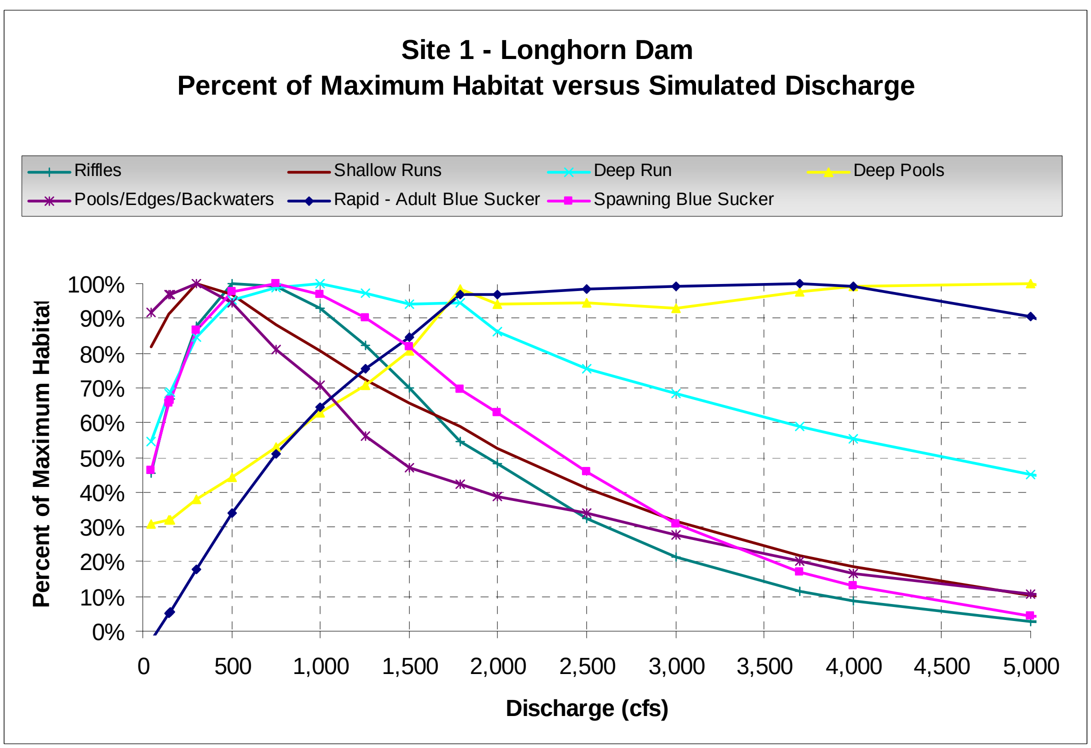

Figure D2. Percent of maximum habitat vs. simulated discharge at Longhorn Dam (Site 1).

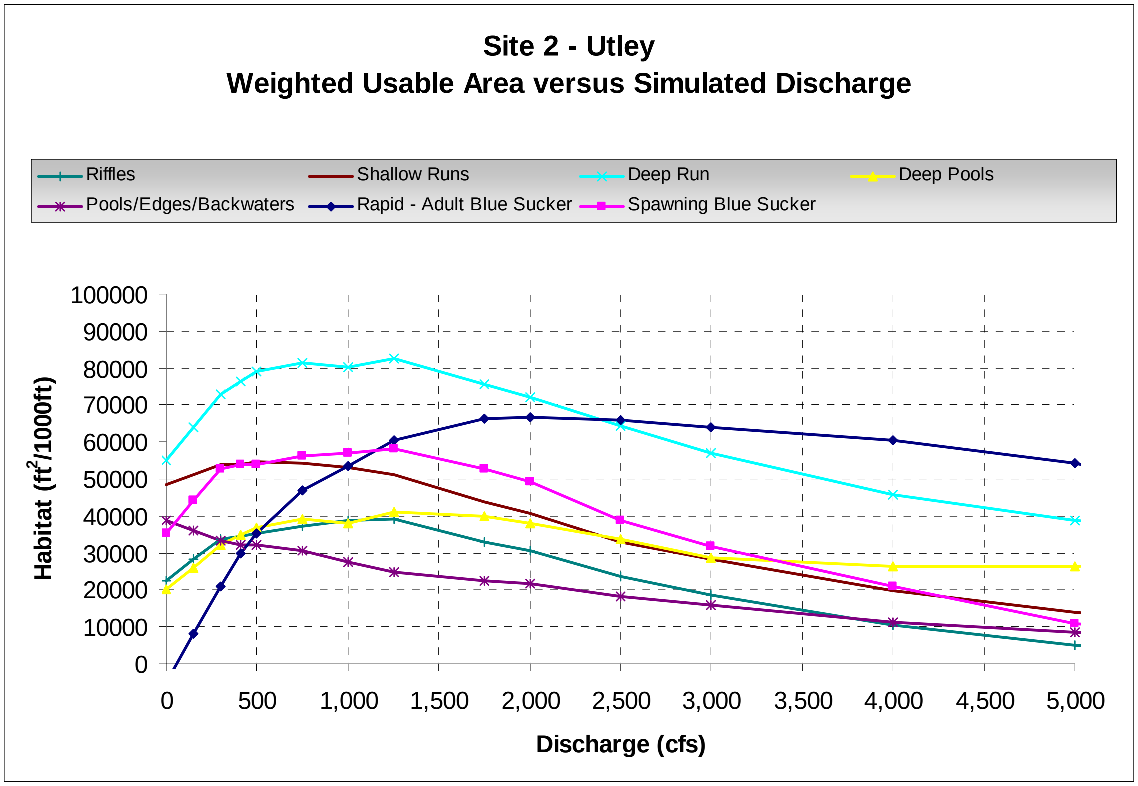

Figure D3. Weighted usable area versus simulated discharge at Utley (Site 2).

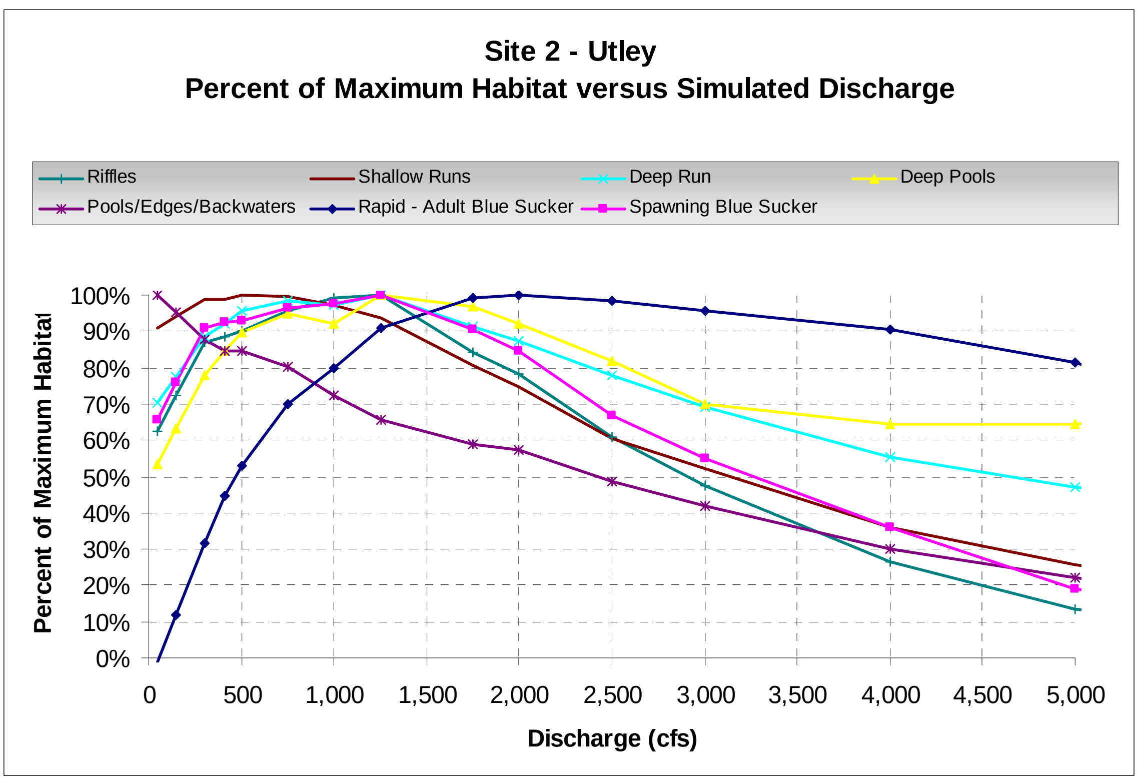

Figure D4. Percent of maximum habitat vs. simulated discharge at Utley (Site 2).

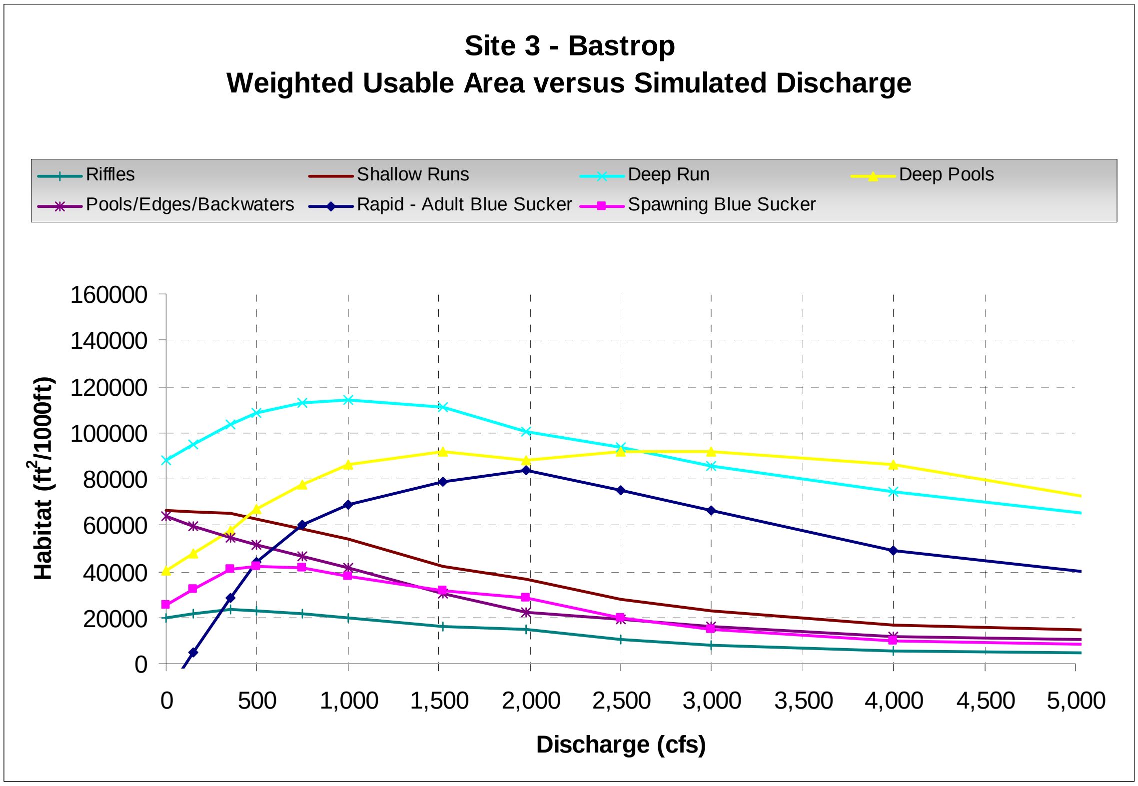

Figure D5. Weighted usable area versus simulated discharge at Bastrop (Site 3).

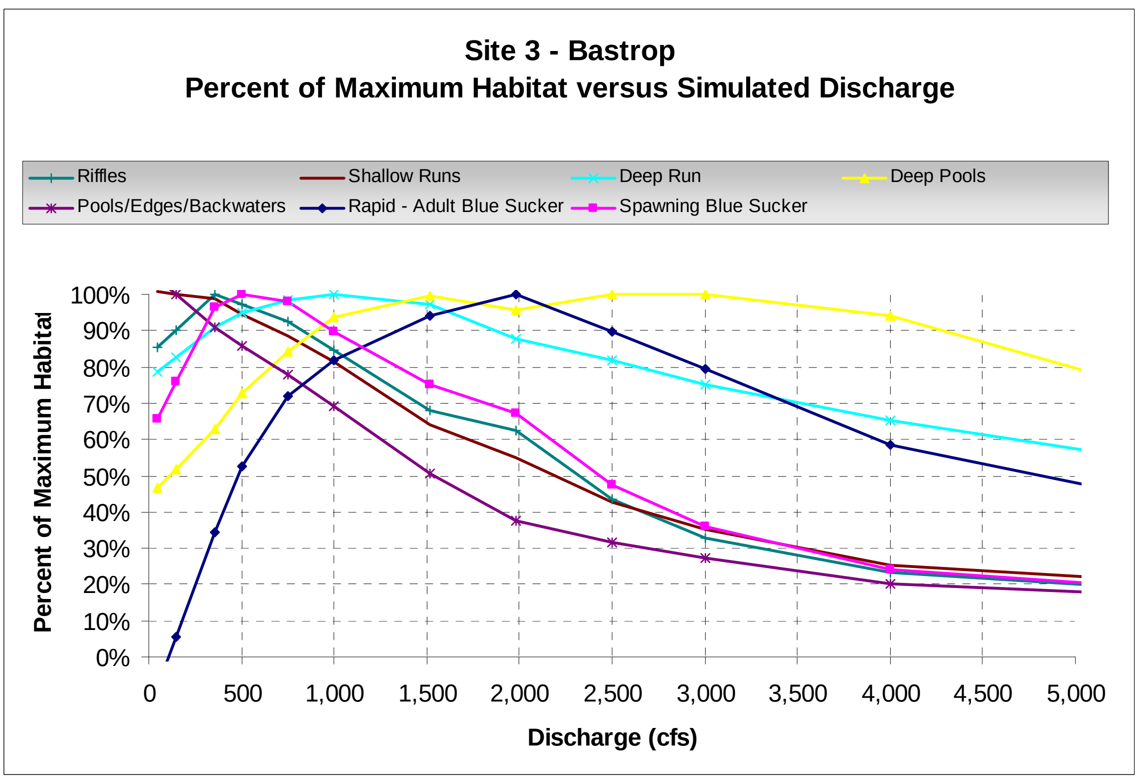

Figure D6. Percent of maximum habitat vs. simulated discharge at Bastrop (Site 3).

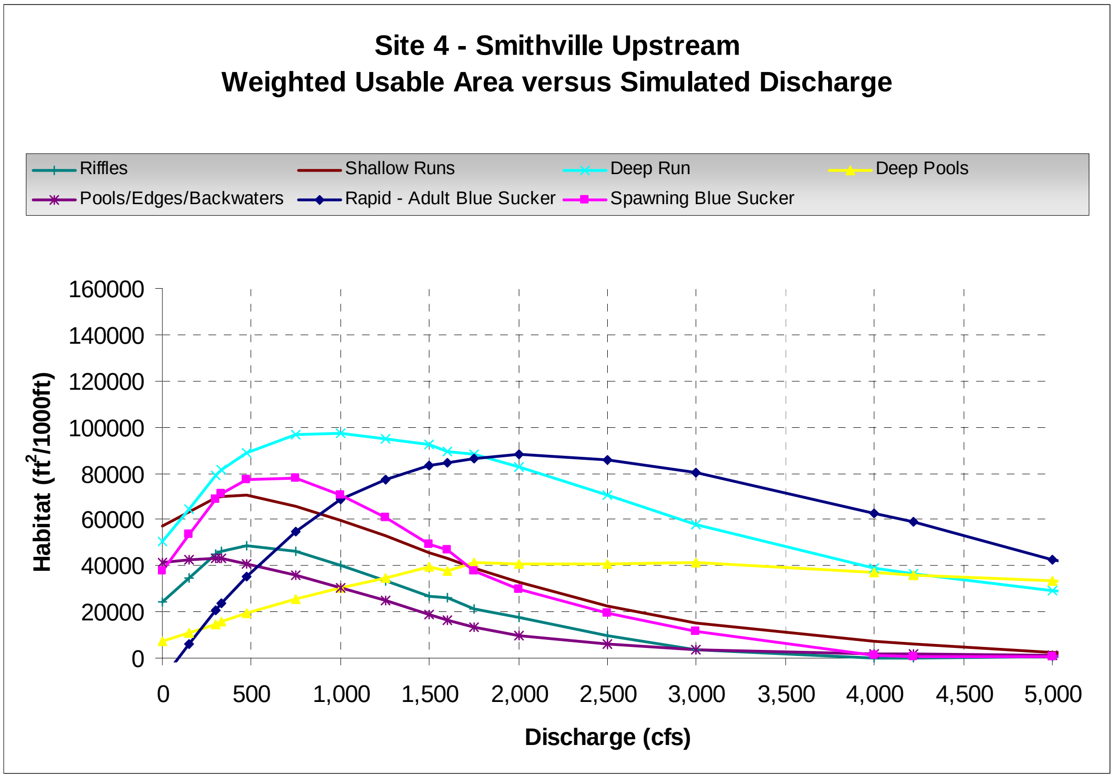

Figure D7. Weighted usable area versus simulated discharge at Smithville Upstream (Site 4).

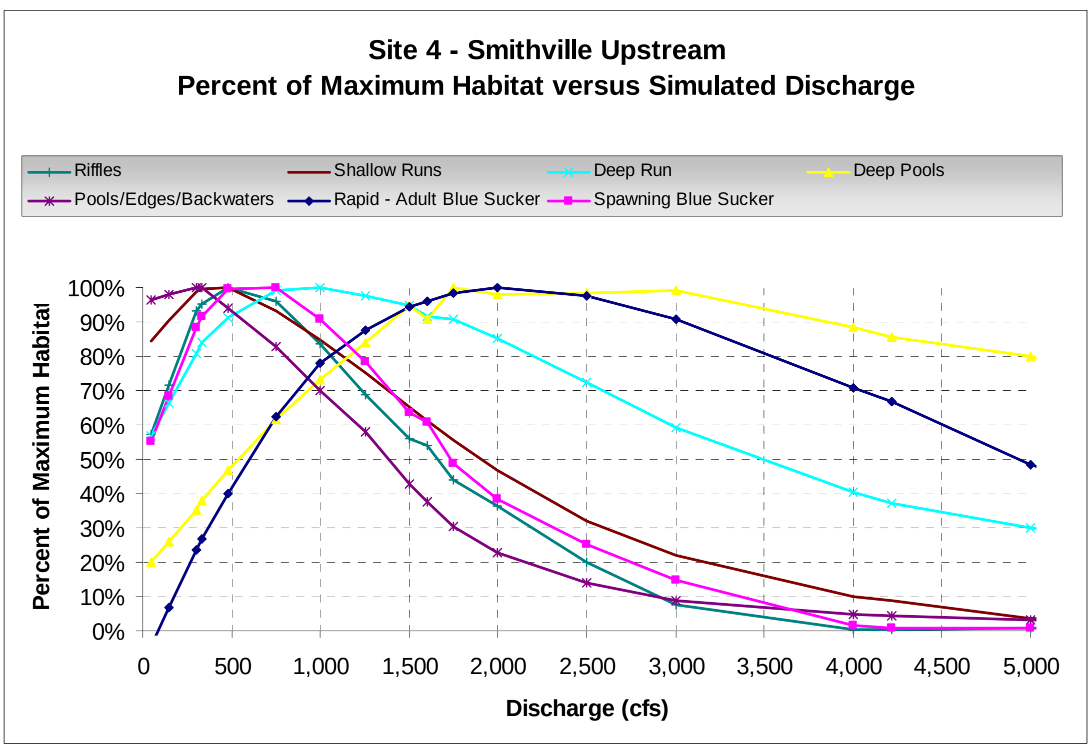

Figure D8. Percent of maximum habitat vs. simulated discharge at Smithville Upstream (Site 4).

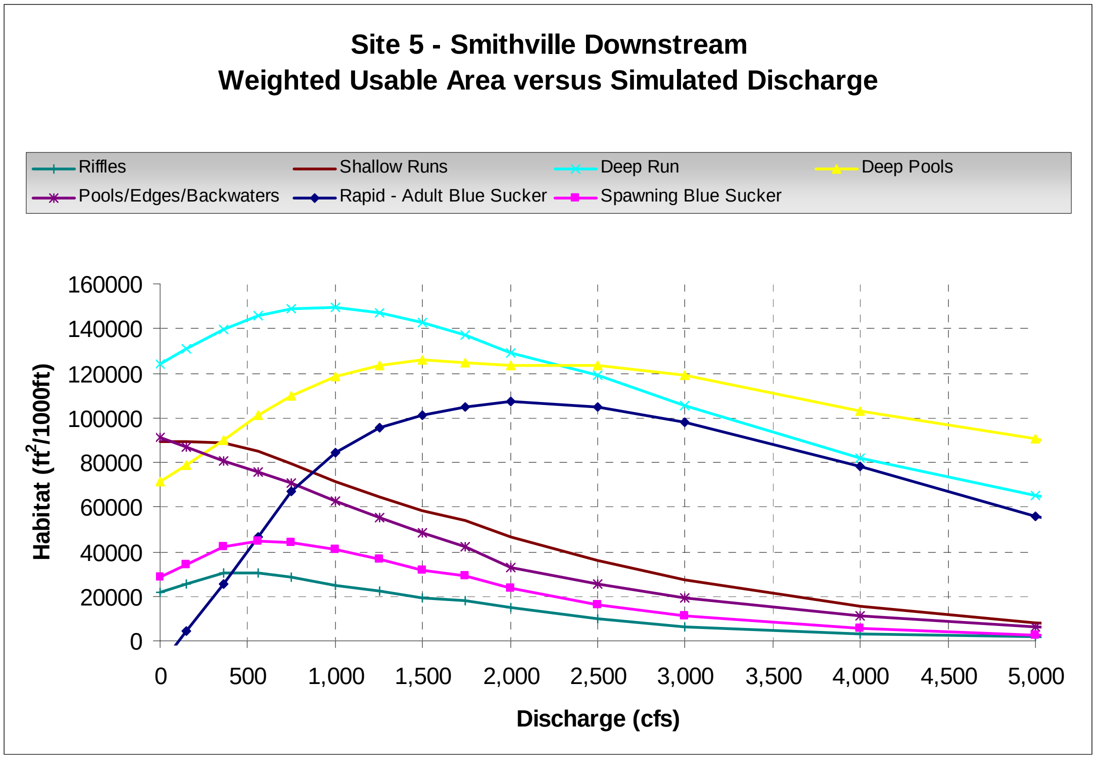

Figure D9. Weighted usable area versus simulated discharge at Smithville Down (Site 5).

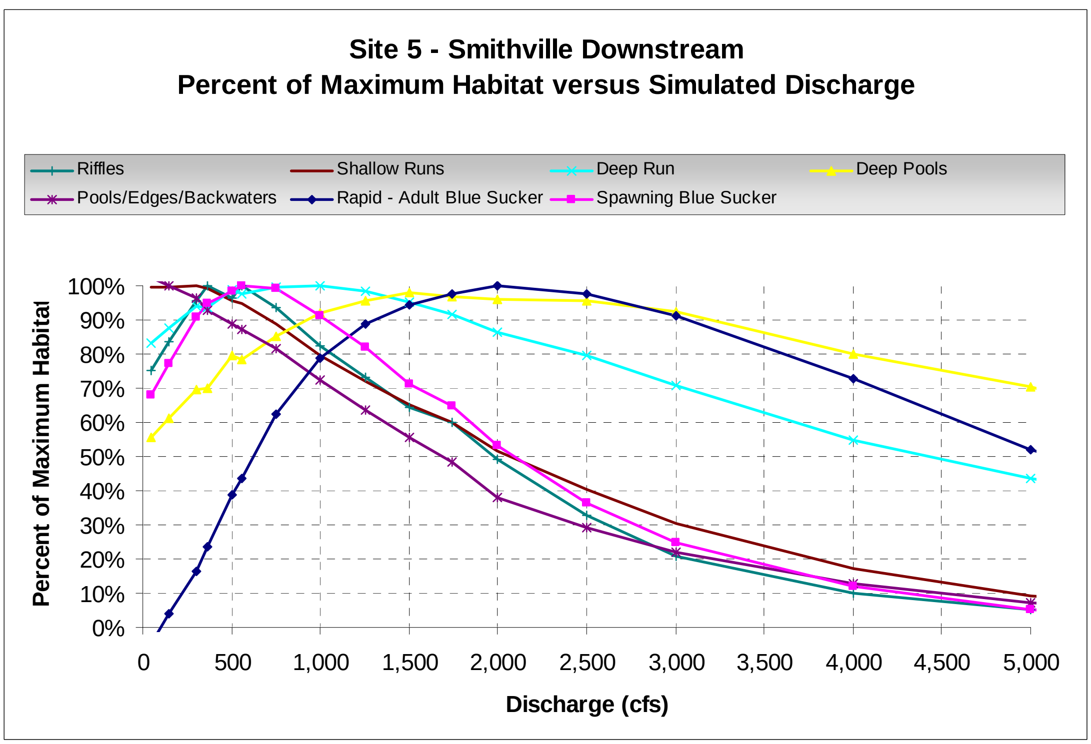

Figure D10. Percent of maximum habitat vs. simulated discharge at Smithville Down (Site 5).

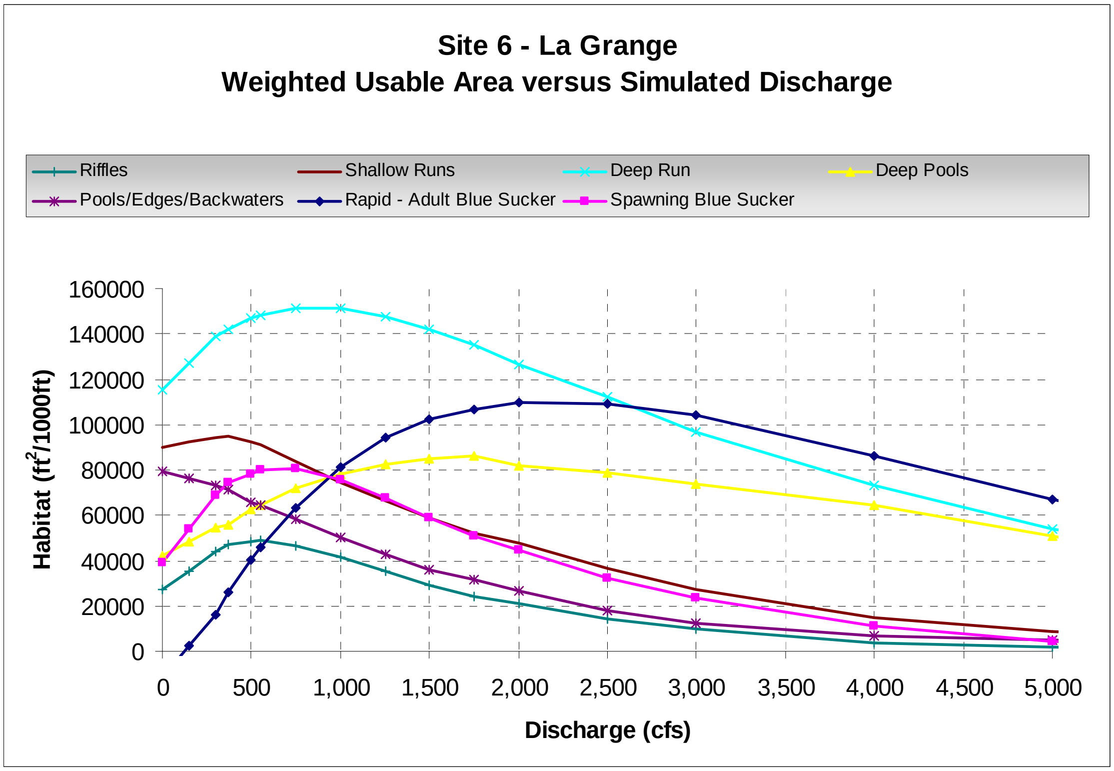

Figure D11. Weighted usable area versus simulated discharge at LaGrange (Site 6).

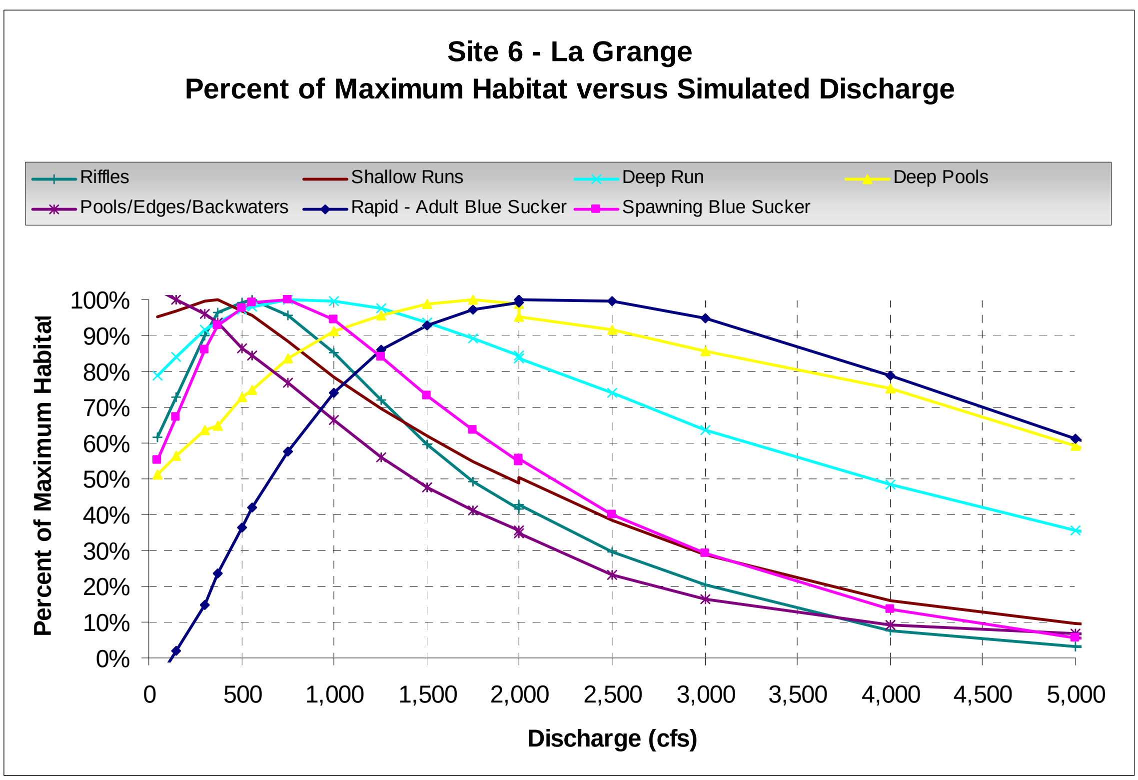

Figure D12. Percent of maximum habitat vs. simulated discharge at LaGrange (Site 6).

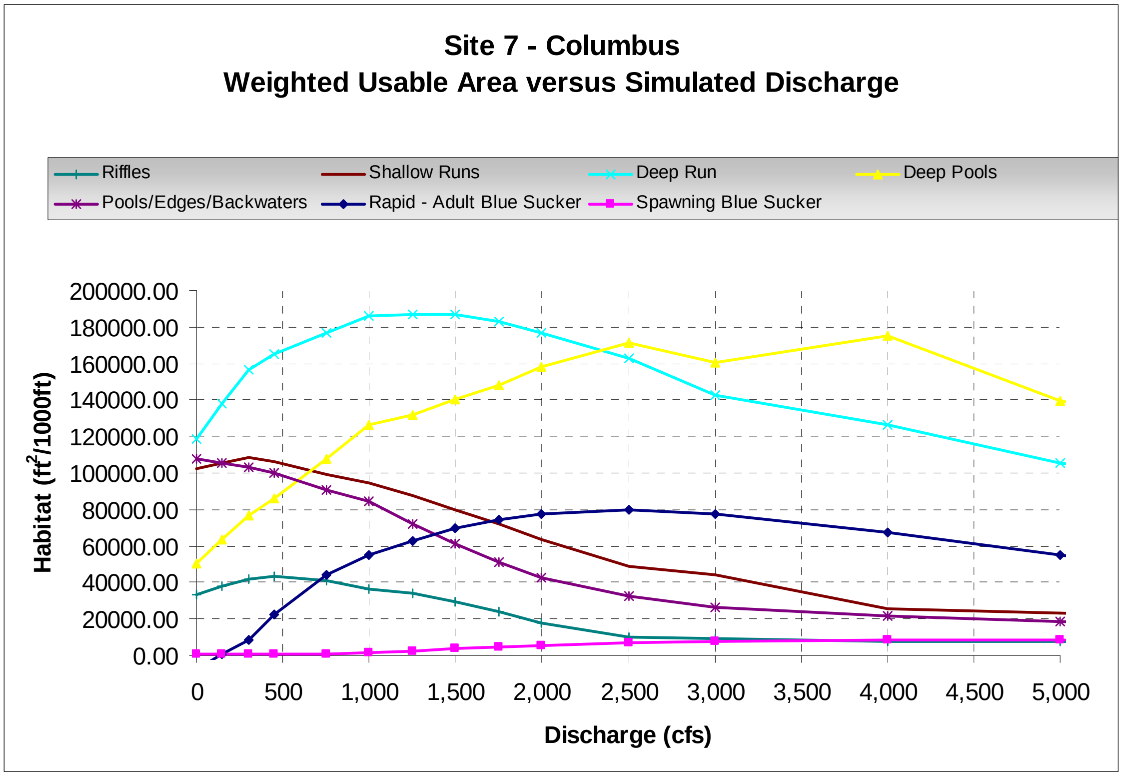

Figure D13. Weighted usable area versus simulated discharge at Columbus (Site 7).

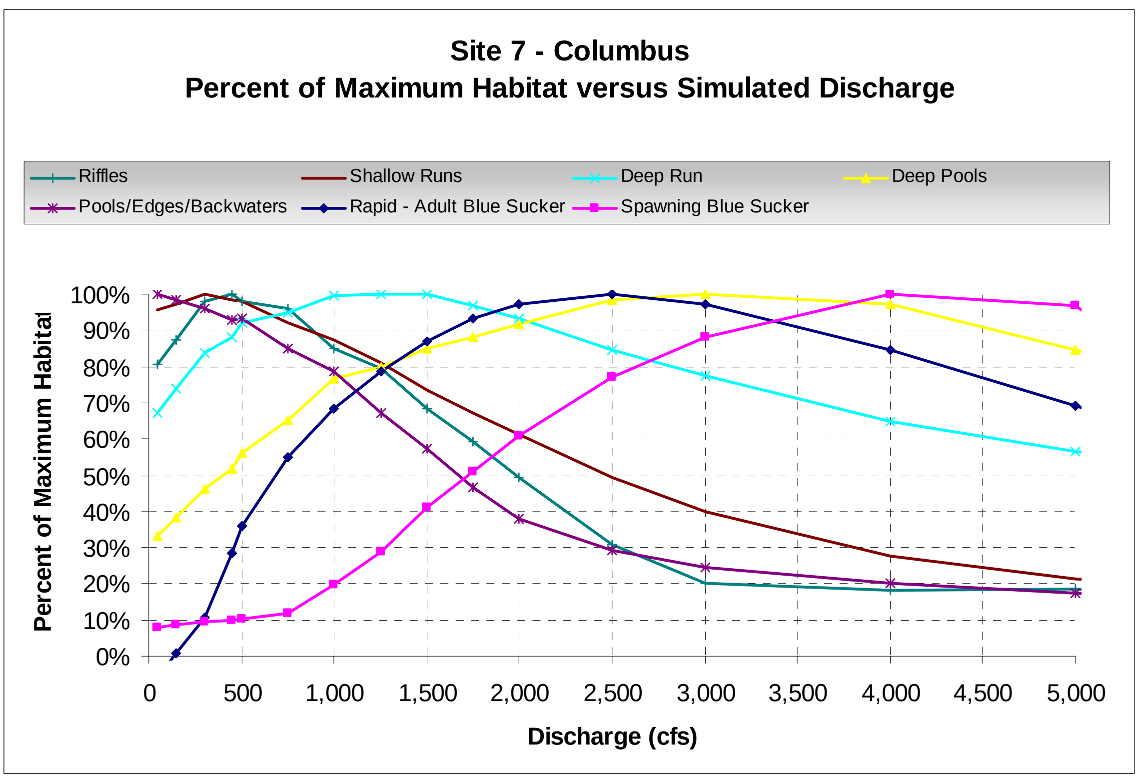

Figure D14. Percent of maximum habitat vs. simulated discharge at Columbus (Site 7).

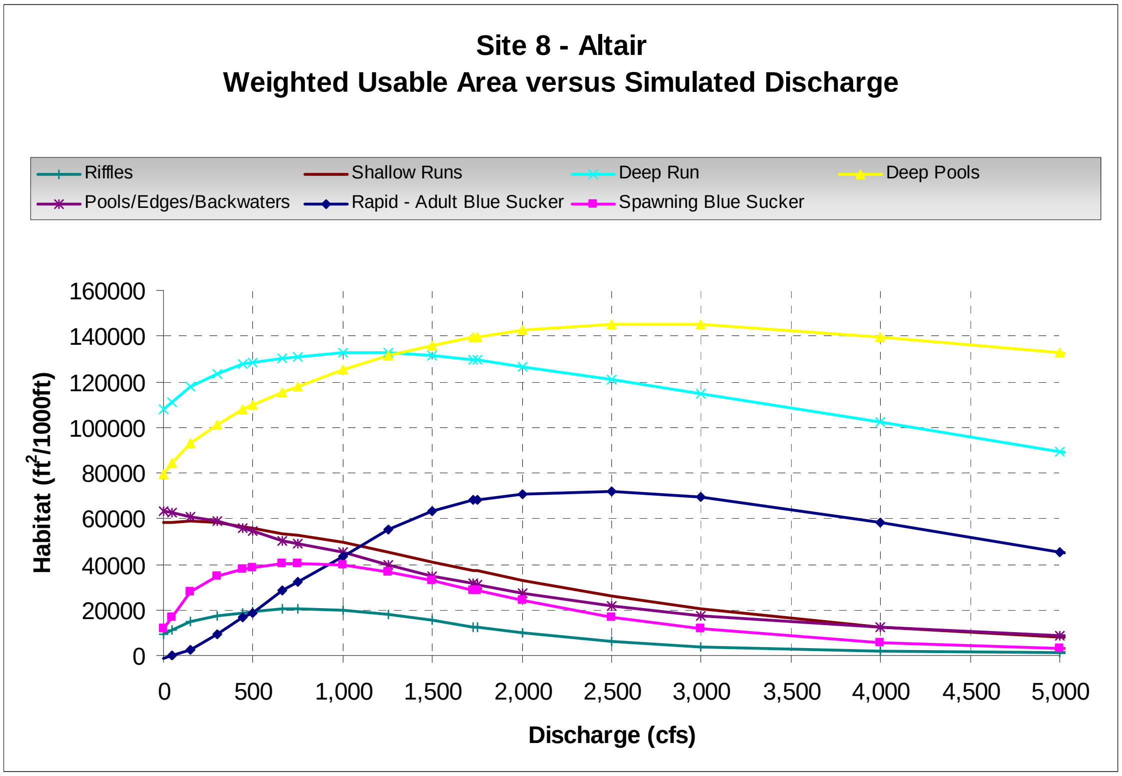

Figure D15. Weighted usable area versus simulated discharge at Altair (Site 8).

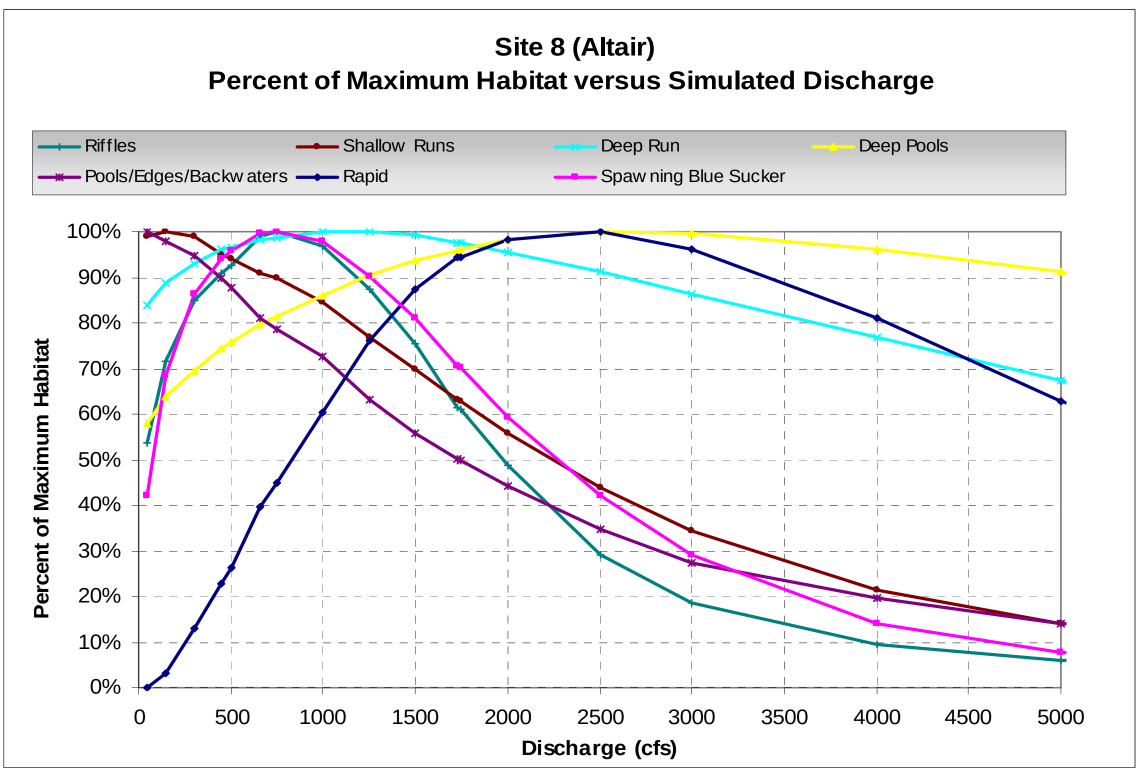

Figure D16. Percent of maximum habitat vs. simulated discharge at Altair (Site 8).

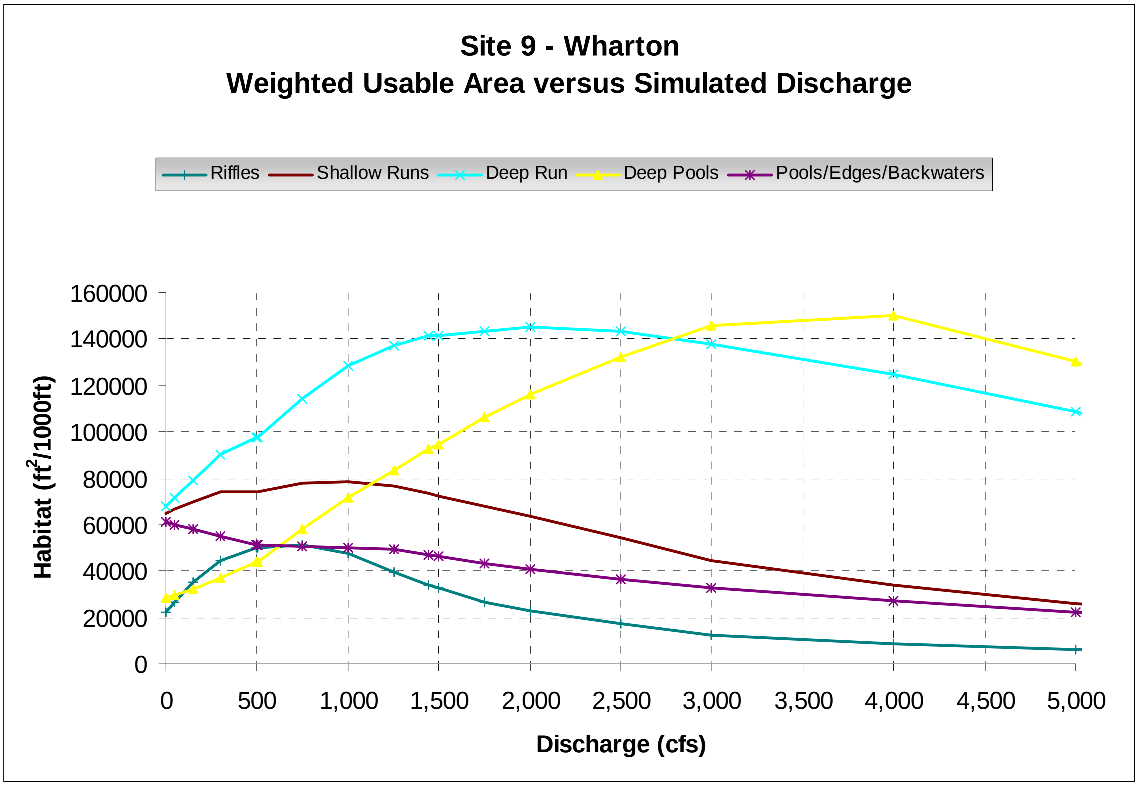

Figure D17. Weighted usable area versus simulated discharge at Wharton (Site 9).

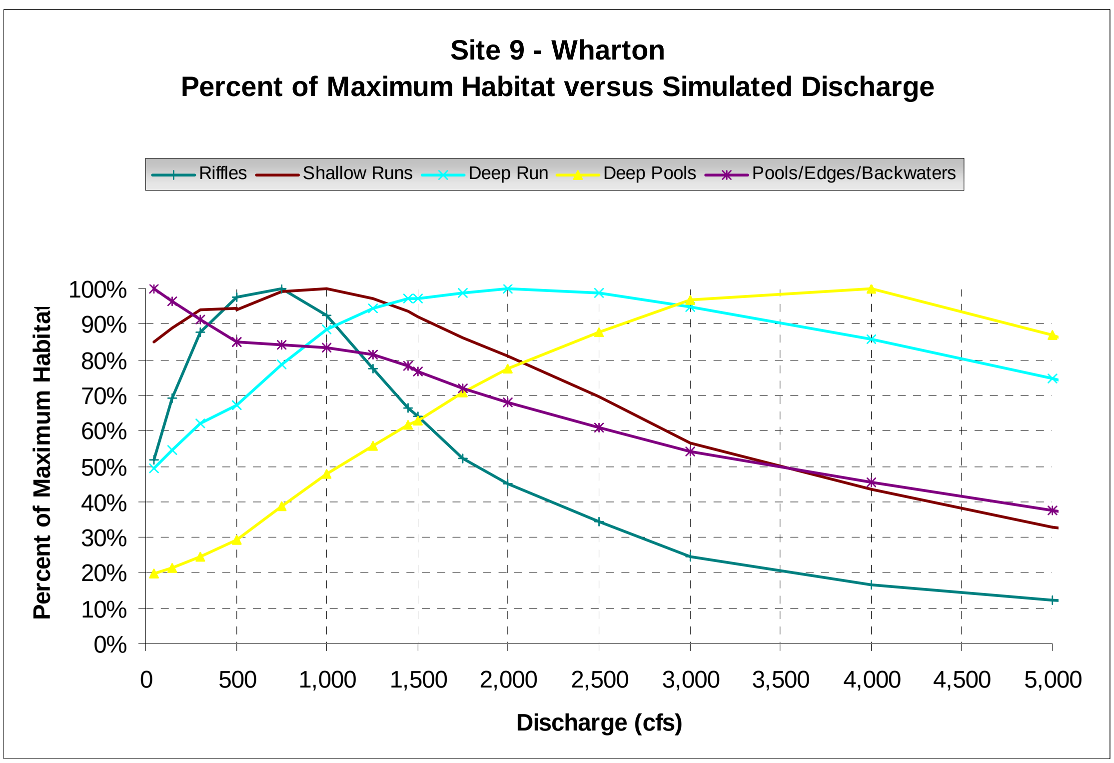

Figure D18. Percent of maximum habitat vs. simulated discharge at Wharton (Site 9).

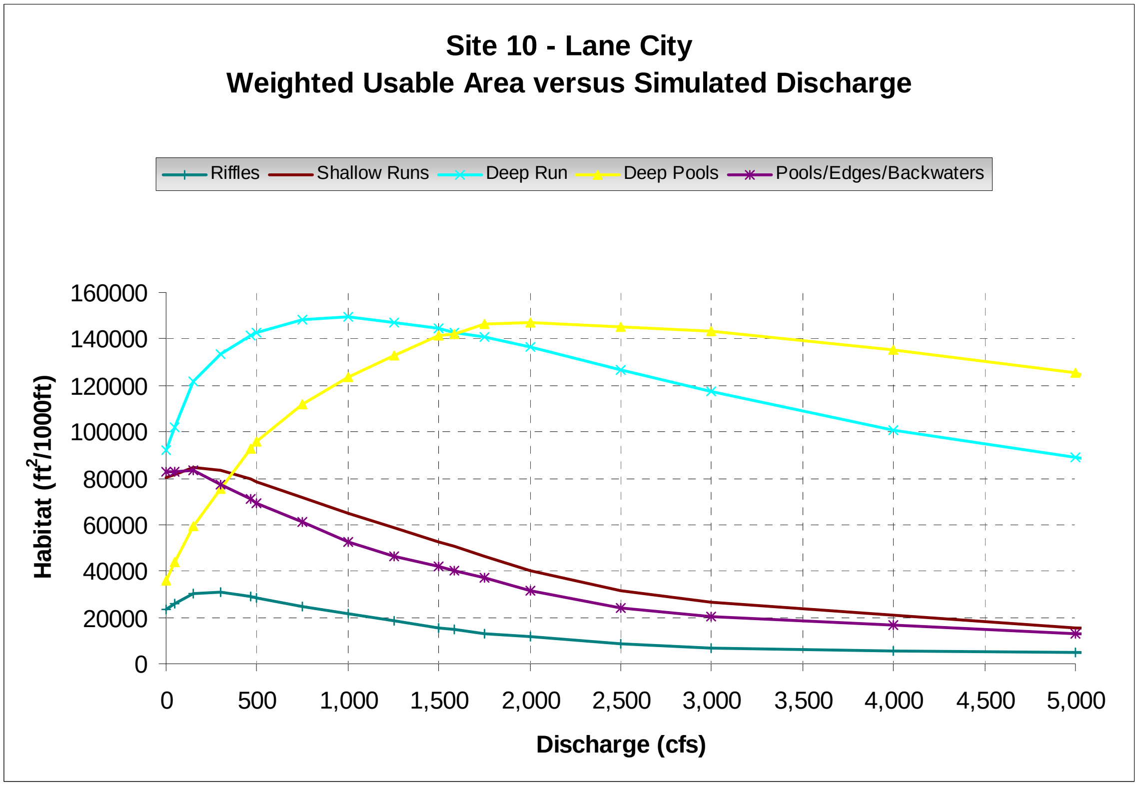

Figure D19. Weighted usable area versus simulated discharge at Lane City (Site 10).

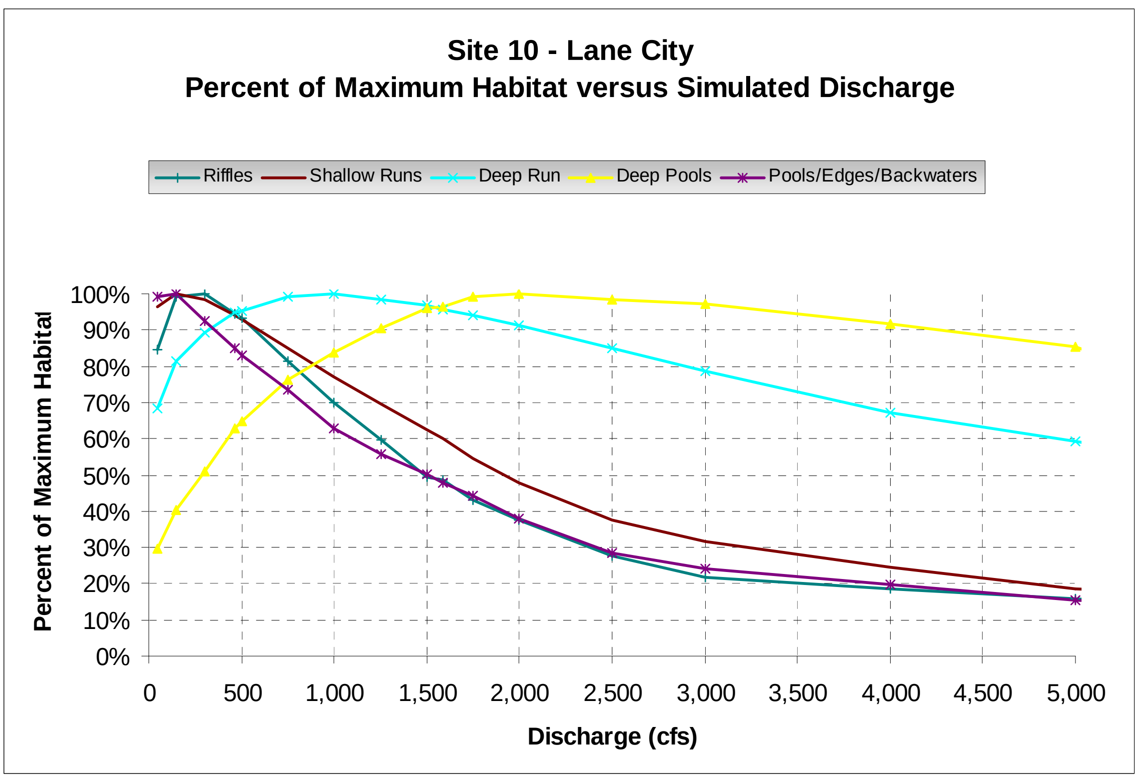

Figure D20. Percent of maximum habitat vs. simulated discharge at Lane City (Site 10).