Instream Flow-Habitat Relationships in the Nueces River Basin

Prepared for:

Senate Bill 3
Nueces River and Corpus Christi and Baffin Bays Basin and Bay Expert Science Team

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and

River Systems Institute
Texas State University
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ACKNOWLEDGEMENTS

The authors wish to express their gratitude for the support of a number of individuals and entities without whom this work would not have been possible. The Dooley and Bledsoe Ranches and Garner State Park graciously proved river access to conduct the data collection. The Nueces River Authority and especial the operators at Choke Canyon Dam provided the experimental releases for the Three River site. Members of the BBEST coordinated this work and provided expert guidance and feedback, particularly on the habitat suitability analysis. Finally, agency personal from Texas Parks and Wildlife and the Texas Water Development Board including John Botros, Karim Aziz, Steve Boles, Clint Dawson (TPWD) and Michael Vielleux and David Flores (TWDB) who spent several long days in the field collecting all this data.

INTRODUCTION

Trungale Engineering & Science (TES) and the River Systems Institute (RSI) are pleased to present this report in support of the efforts of the Nueces River and Corpus Christi and Baffin Bays Basin and Bay Expert Science Team (Nueces BBEST) in the development of Instream Flow-Habitat relationships supporting flow regime recommendations. This report documents the data collection and analysis performed to develop predictive relationships that describe the response instream available habitat over a range of flows. These relationships can be used to evaluate the flows that may be recommended by the BBEST as part of their charge under Senate Bill 3. The approach taken in this study employs a well establish methodology whereby site specific physical habitat data is collected at river cross sections and used to produce a one-dimensional physical habitat model. Species specific habitat suitability criteria were applied to the results of the physical habitat model to estimate the weighted usable area for each species over a range of flows at all cross sections.

1. Study site selection and reconnaissance.

Relationships between flow and instream habitat for focal species have been developed at 3 sites near U.S. Geological Survey gages for which the Nueces BBEST is developing recommended flow regimes. These sites are shown in Figure 1.

Figure 1 Map of Study Sites.

Prior to field data collection, site access permission was obtained from landowners. A reconnaissance trip was made on May 14-15, 2011 to identify specific study site locations. Table 1 identifies study site locations and associated USGS gages.

Table 1 Study Sites.

USGS Number	USGS Name	Lat	Lon	Study Site	Lat	Lon	Proximity
08195000	Frio Rv at Concan	29.49	-99.70	Garner State Park	29.59	-99.74	site is about 10 mile upstream of USGS gage
08190000	Nueces Rv at Laguna	29.43	-100.00	Dooley Ranch	29.42	-100.00	USGS gage is approximately at cross section 9
08210000	Nueces Rv nr Three Rivers	28.43	-98.18	Bledsoe Ranch	28.44	-98.11	site is approximately 5 miles downstream of USGS gage

At each site, 7 to 9 cross sections including replicates of riffles, runs and pools were identified. Figure 2 through Figure 4 show the layout of the cross sections at each study site. Note that Laguna cross sections were numbered in the opposite order (upstream to downstream) versus cross section numbering at the other two sites, which are from downstream to upstream. At the Concan site, the cross sections were grouped into three sub-sites (upper 1-3, middle 4-6 and lower 7-9) and are treated in the modeling as three independent sites. This was done because large boulders, small chutes and other instream features are present within the site that cannot be properly simulated by the one dimensional hydrodynamic model as is used in this study.

At each cross section photographs were taken across the channel from the right and left banks and from the upstream and downstream ends of the mesohabitat feature towards the cross sections. These photos were georeferenced by TPWD and are included as part of the project deliverable on the Nueces BBEST ftp site in a Google Earth project file.

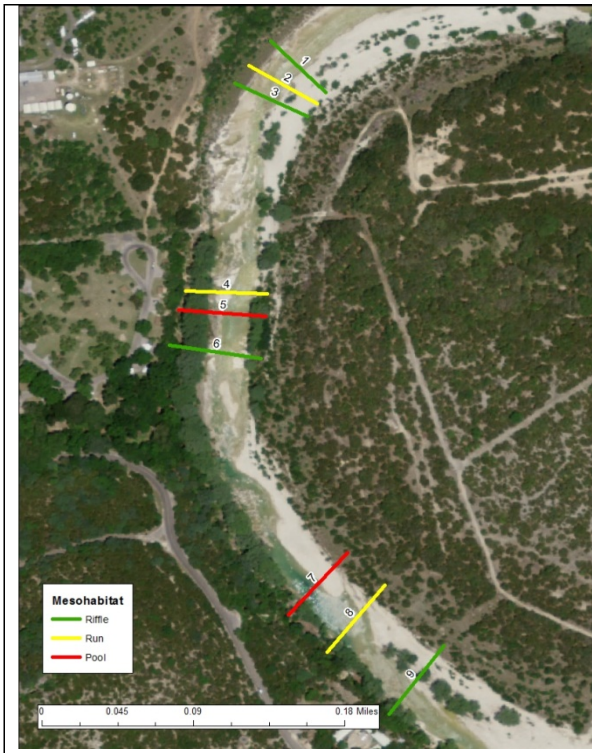


Figure 2 Concan Cross Sections.

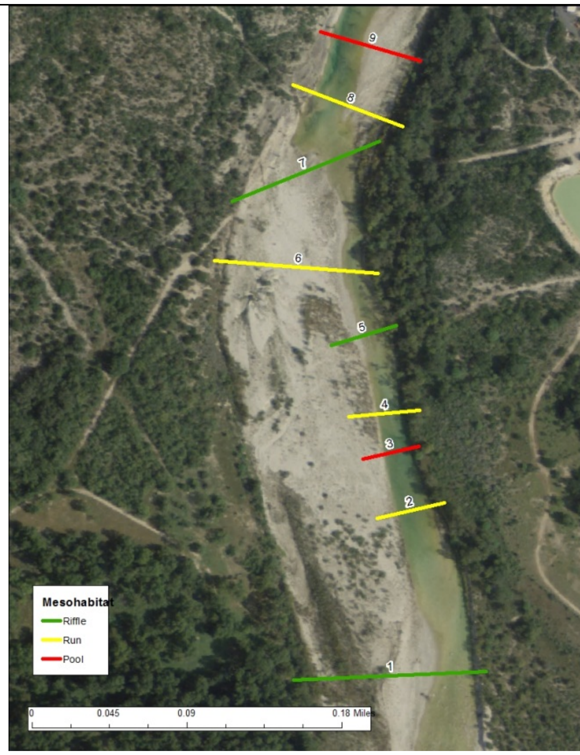


Figure 3 Laguna Cross Sections.

Figure 4 Three Rivers Cross Sections.

2. Cross-section profiles, depth, velocity, substrate type, and field discharge measurements.

Physical habitat data, collected at each of the study sites at 7 to 9 cross sections, included water surface elevations (WSE), channel bathymetry, velocity and dominate substrate type. It is important to point out that these measurements were made during low flow conditions and in some cases a significant portion of the base flow channel was dry. Recognizing the possibility that subsequent data may be desired as part of future adaptive management studies, benchmark monuments were established at each site using survey grade GPS. Headpins (river left facing downstream) and tailpins (river right facing downstream) were placed at each cross section by hammering two foot long rebar into the ground away from the channel and above the top of the bank. The elevations of these pins were tied to the benchmark via level surveying. GPS readings and sketches with distance and bearing to large trees or other fixed landmarks were made to facilitate location of these pins should they be needed as part of future adaptive management studies.

Within each study site, the cross-sections were established to describe physical and hydraulic conditions of individual mesohabitat types generally including at least three replicates for each mesohabitat type of interest (e.g., riffle, run and pool). The upper and lower boundaries of mesohabitat types were identified and the total stream length distances measured. The water surface elevation at the top and bottom of each mesohabitat unit was also measured in order to calculate the slope of each mesohabitat feature. Figure 5 provides a generalized schematic of cross sections located within a study site.

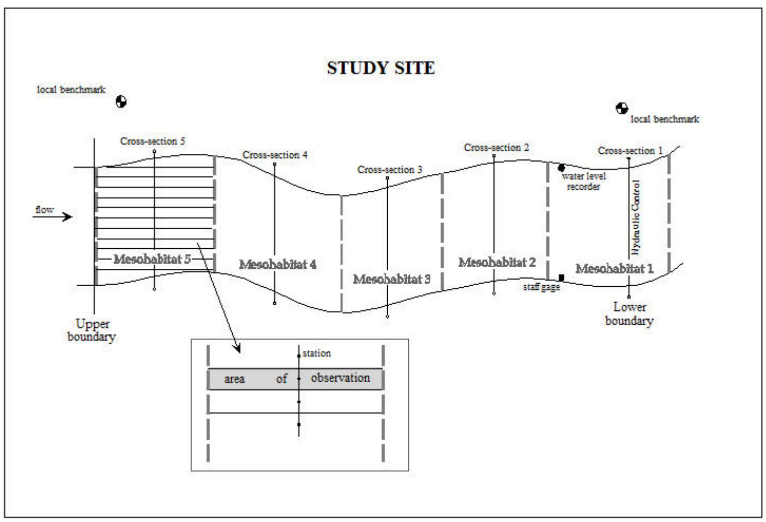


Figure 5 Generalized study site map.

Taglines were placed across the river, perpendicular to the channel, with zero located at the headpin. Measurements were taken at horizontal stations at breaks in topography (minimum of 20 stations in water) that, primarily, describe the streambed profile of the channel. The streambed profile was surveyed at each station from headpin to tailpin, with the horizontal distance of the right and left edge of water designated. Water surface elevations were surveyed at the right and left edge of water. A critical data point on the streambed profile is the deepest point on the cross-section, which is input as the stage of zero flow in the hydraulic models. Current velocity and depth were measured at each station within the wetted channel. Current velocity was measured at appropriate depths according to USGS protocol. At each station, primary substrate types were characterized according to a modified Wentworth substrate scale (Table 2).

Table 2 Modified Wentworth substrate scale.

Code	Classification	Size (mm)
1	Organics/Grass	organic debris
2	Clay/Silt	0 - 0.062
3	Sand	0.062 – 2
4	Fine Gravel	2 – 8
5	Course Gravel	8 – 32
6	Cobble/Rubble	32 – 256
7	Boulder	> 256
8	Bedrock	Solid substrate
9	Aquatic Vegitation	

All field data including pdf scans of field book notes and TWDB's GPS readings for benchmarks and pins are included as part of the project deliverable on the Nueces BBEST ftp site.

3. Hydraulic Modeling.

Hydraulic models were developed to predict depths and velocities at each station across cross sections. The depths were calculated by subtracting measured channel bathymetry elevations from predicted water surface elevation (WSE) at each flow. Discharge measurements were made following USGS methods for each data set collected. Ideally water surface elevation (WSE) stage - discharge (Q) measurement dataset would have been collected at three flow levels that encompass the full range of base flows and from this a site specific rating curve could have been developed to predict WSE over the range of flows. The limited time frame for this project coinciding with current drought in the Nueces Basin did not allow for this, as a full range of flows did not occur within the time window available. For the site near Three Rivers, data was collected at two flow rates. This was possible because the Nueces River Authority, which operates Choke Canyon Reservoir, was able to provide requested releases for several days when data collections were being made, including releases of approximately 20 cfs and 150 cfs. The two WSE-Q data points for cross sections at this site were then compared to the WSE-Q data measured at the Three Rivers Gage (Figure 6). As they compared favorably, a log-log rating curve was developed from the Three Rivers USGS gage data and applied to all of the cross sections at this site. It is worth noting that these models are used to evaluated base flow conditions which for this site are generally less than about 200 cfs and for this range of flows the USGS appears to predict WSE well. The tools developed as part of this project could be used to preform sensitivity analysis to evaluate how change in the shape of this regression curve affect final habitat results or the regression could be updated with additional measurement collected as part of a future adaptive management program.

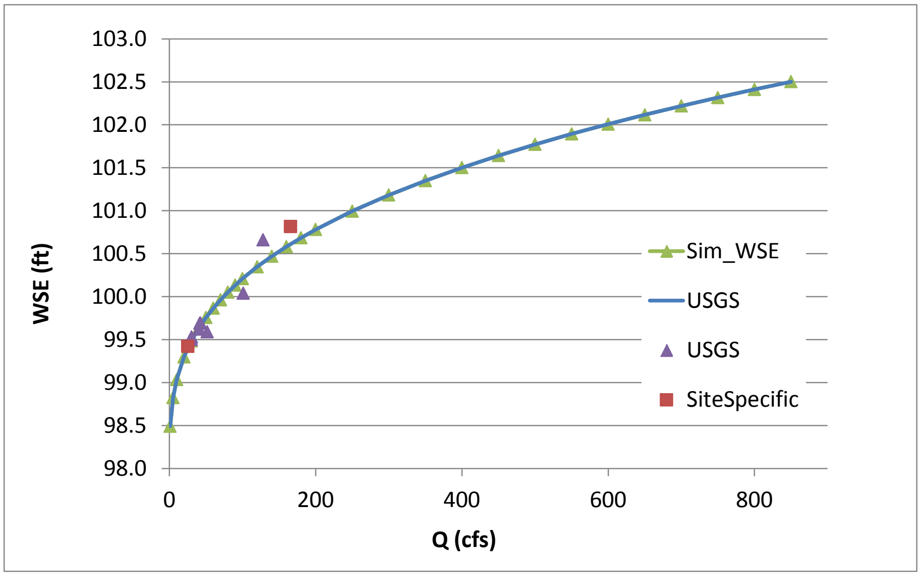


Figure 6 Rating Curve used for Three River Cross Sections.

Only one discharge measurement was available at the two Edwards Plateau sites (Frio River at Concan and Nueces River at Laguna). Although several hydraulic modeling approaches were attempted to develop stage discharge relationships for these sites, however due the lack of additional calibration data and the fact that the modeling had to extrapolate up from such low flows this effort proved unsuccessful and the same log-log regression of USGS data approach was applied at these two sites. (Figure 7and Figure 8)

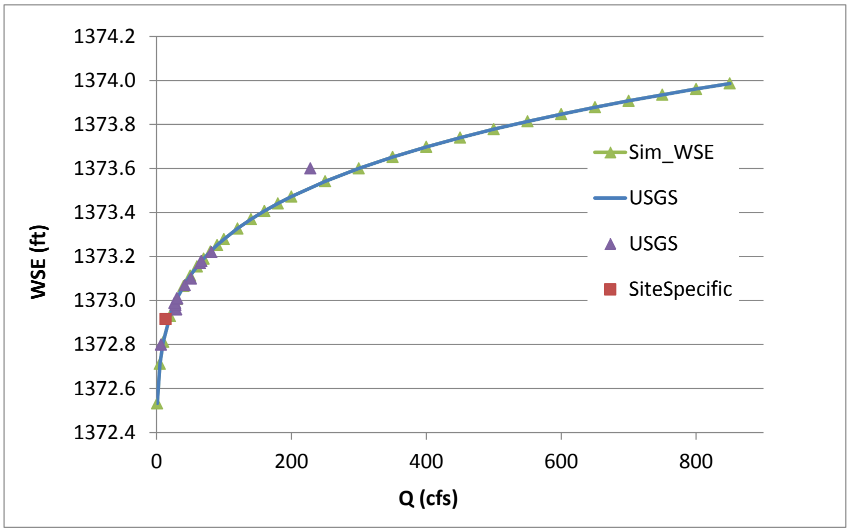


Figure 7 Rating Curve used for Concan Cross Sections.

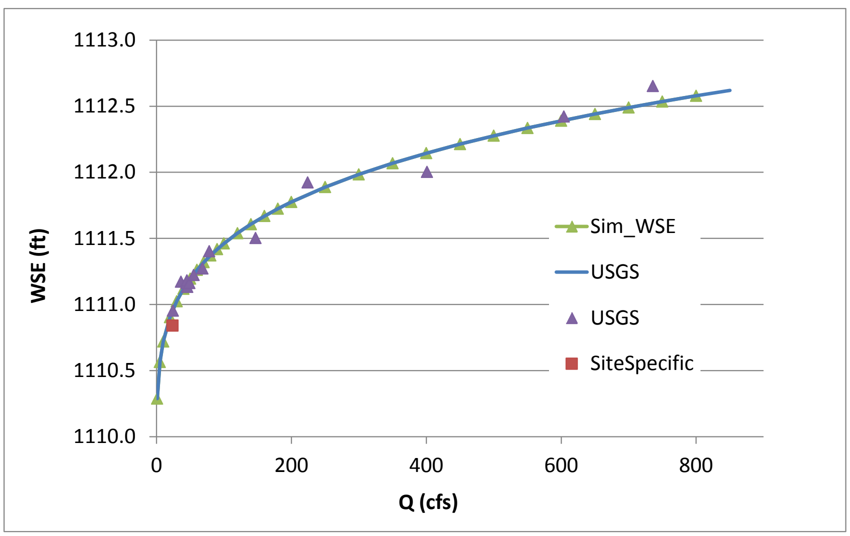


Figure 8 Rating Curve used for Laguna Cross Sections.

While the lack of additional data points for these curves does introduce grater uncertainty, the data used to develop these curves is from nearby USGS sites and presumably those locations share similar channel slopes, banks and substrates such that the transfer is reasonable.

Velocities were predicted by applying Manning equation to back calculate a velocity distribution parameters (N) based on the measured data. During the velocity calibration, Manning's N was adjusted at each vertical until the measured versus predicted velocities were no greater than 0.1 feet/second. At the Three Rivers site, the second measured velocity set was used for calibration. The lowest velocity calibration set was applied from low to intermediate flows while the higher calibrated velocity set was used for intermediate and all higher discharges. As with WSE discussed above, the availability of a single velocity calibration data set is a limitation on the level of certainty that can be associated with these predictions when simulations are extended over much higher discharges. For all sites, velocity simulations at flow higher than what were measured were reviewed and an adjustment to the velocity distributions values were made to ensure that unrealistic velocity spikes were not produced. Velocity spikes can occur in one-dimensional models particularly when extrapolating up from distributions based on data collected at very low flows. Figure 9 shows some of the WSE and velocity results from the hydraulic model for cross section 1 at Three Rivers. For this site, data was collected at two flow rates (Q1 = 23 cfs, Q2= 165 cfs) which are highlighted in red and green respectively. In the bottom panel the difference between the red lines (thick dashed indicate measured values) provide some insight as to the uncertainty that is associated with this model.

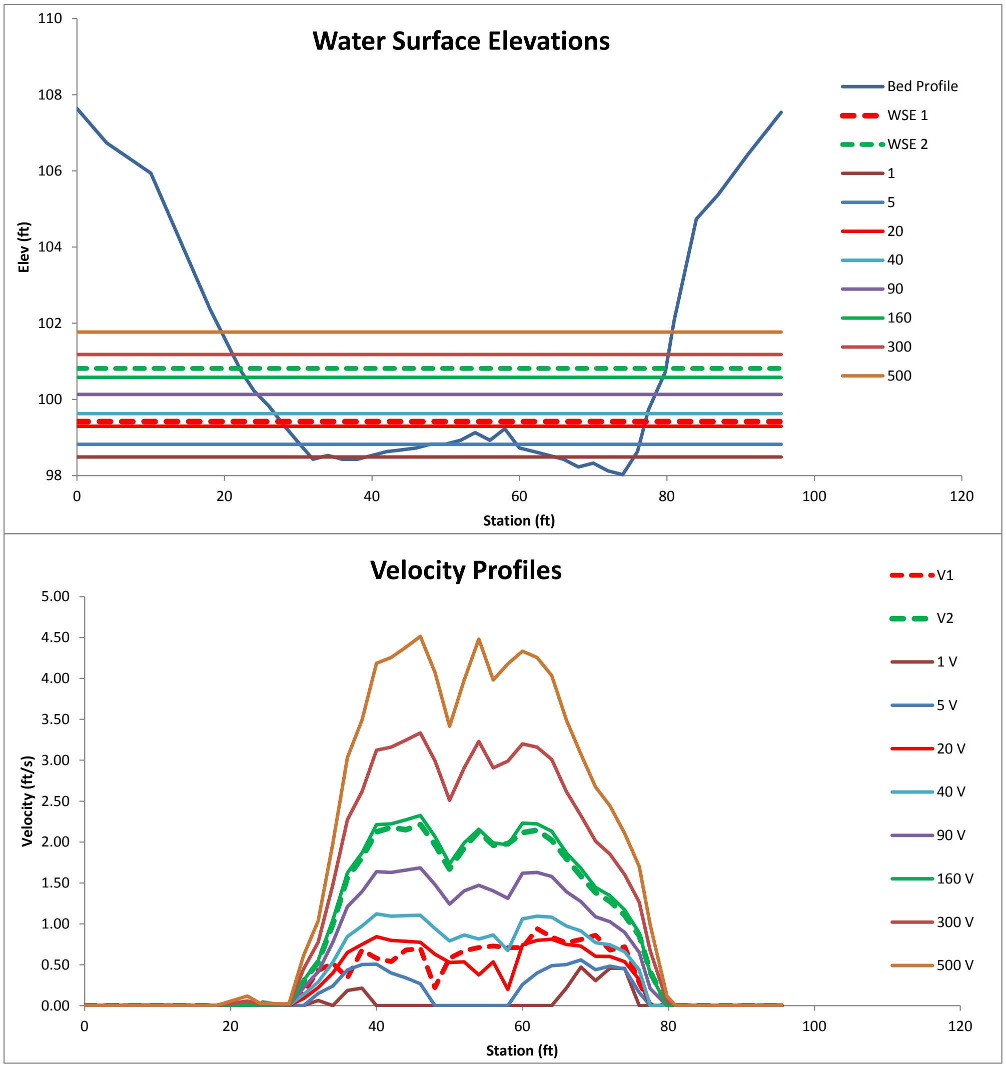


Figure 9 WSE and Velocities predicted by hydraulic model for Cross Section 1 (Riffle) at Three Rivers.

4. Habitat suitability curves.

Available habitat suitability curves were reviewed and modified by the Nueces BBEST biology subcommittee. Curves were selected for the 8 species for the Edwards Plateau sites (Concan and Laguna) and 13 species for the South Texas Brush site (Three Rivers) shown in Table 3.

Table 3 Species for which Habitat Suitability Curves were developed for use in the Physical Habitat Model.

Edwards Plateau	South Texas Brush/ Coastal Plain
Greenthroat darter	Channel catfish, juvenile
Central stoneroller	Red shiner
Texas shiner	Weed shiner
Guadalupe bass	Bullhead minnow
Gray redhorse	Smallmouth buffalo
Channel catfish, adult	Blue catfish
Longear sunfish	Channel catfish, adult
Largemouth bass	Flathead catfish, juvenile
	Freshwater drum
	River carpsucker
	Longear sunfish
	Spotted gar
	Largemouth bass

Habitat suitability curves describe suitability of hydrologic habitat parameters for specific species including depth, velocity and substrate. Figure 10 presents an example of these curves. The x-axis is the habitat parameter, velocity depth or substrate (substrate codes correspond to values in Table 2) and the y-axis is the corresponding suitability index where 1 is most suitable and zero is unsuitable.

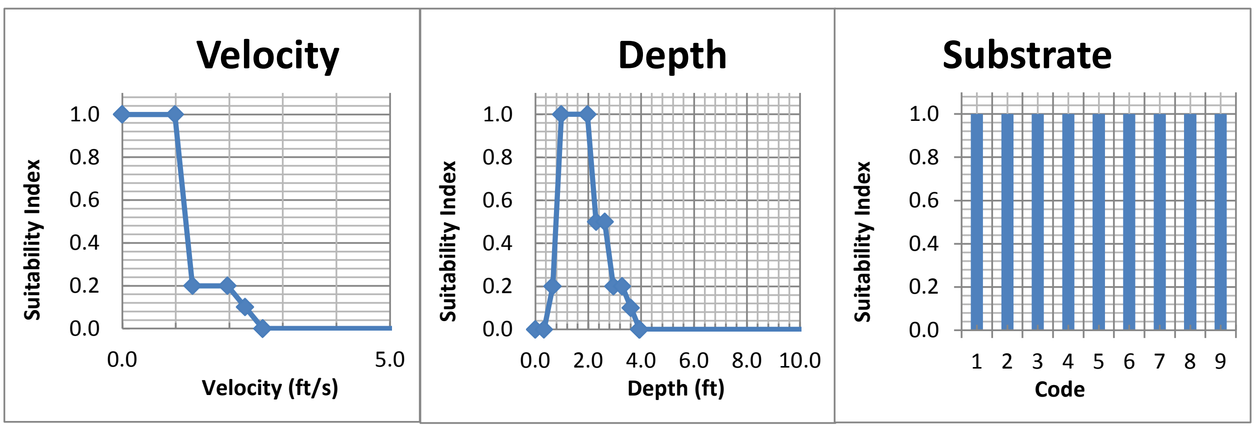


Figure 10 Habitat Suitability Indices for Bullhead minnow.

The final habitat suitability curves for all species evaluated in this study are available in a file entitled Nueces_HSC.xlsm included as part of the project deliverable on the Nueces BBEST ftp site.

5. Physical Habitat Model.

The calibrated hydraulic simulation models at each site were integrated with the habitat suitability criteria to generate available habitat as a function of discharge for each target species. Physical habitat is reported as Weighted Usable Area (WUA) and is derived by the combined suitability for depth, velocity and substrate based on the habitat suitability functions for each species times the area of the cell. The default combined suitability computation was based on the geometric mean of the component depth, velocity, and substrate suitability. Habitat results (WUA versus discharge) are provided for each species at each cross section, combined mesohabitat types, and for the reach level results that incorporate all mesohabitat types. These WUA curves include the full range of base flows and show the response of available habitat to different flow rates for each species. An Excel spreadsheet tool was developed for these analyses and permits detailed examination of each species, cross section, mesohabitats, and reach level results in terms of depth, velocity and substrate suitability, and combined suitability. In addition to the total quantity of available habitat (WUA) relationships, the analysis tool permits the evaluation of habitat quality by constraining the computed habitat area based on exceeding a combined suitability threshold value.

5.1. Microhabitat Scale Analysis (Point Depth and Velocity Habitat Values).

An example of the WUA (total quantity) versus discharge relationships for target species at Cross Section 3 at the Three Rivers study site is illustrated in Figure 11. In Figure 11, the available habitat for Bullhead minnow starts low, increases with flow to about 50 cfs, after which it gradually declines. The highest quantity of habitat for this species is produced by flows that result in depths between 1 and 2 feet and velocities less than 1 foot per second based on the habitat suitability curves (see Figure 10 above). This species is not associated any particular substrate thus all substrate codes equal one and substrate is not a factor in the habitat suitability analysis.

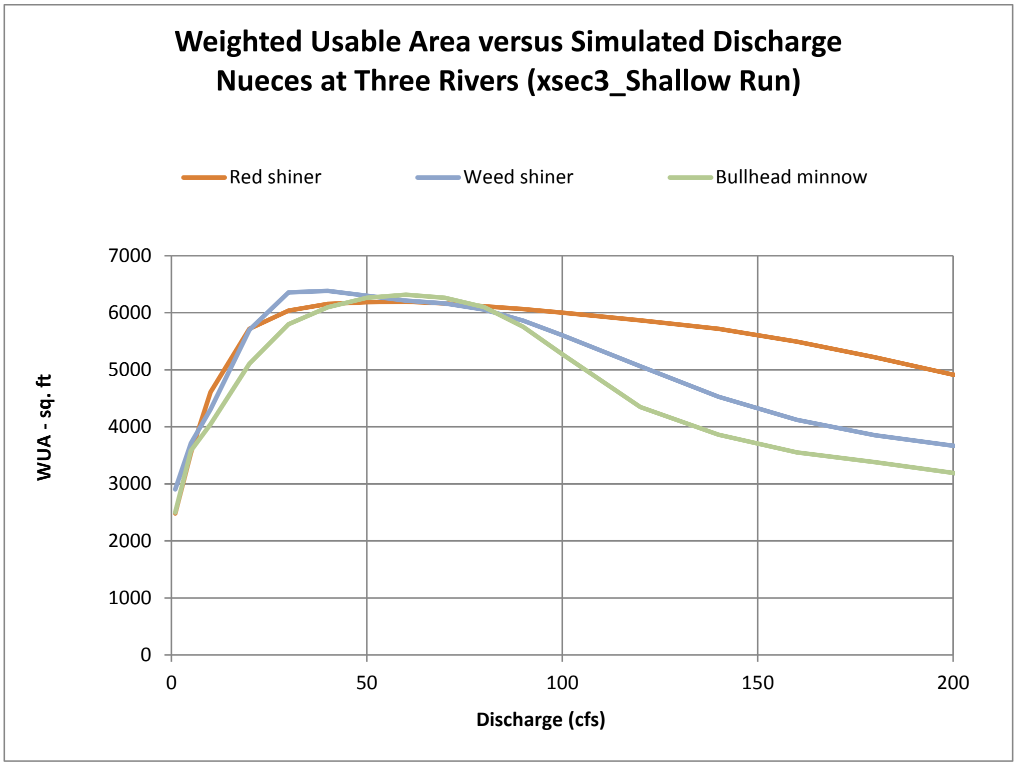


Figure 11 Flow versus Weighted Usable Area Curve (WUA) for Cross Section 1 (Riffle) at Three Rivers.

This mesohabitat level response can be explained by examining the hydrologic habitat parameters (depth, velocity and substrate) at the microhabitat level of points across the channel. At subsistence level flows (based on preliminary HEFR runs subsistence flows are estimated at about 5 cfs) habitat conditions are poor primarily because much of the channel is dry or simply too shallow even for this small fish (Figure 12).

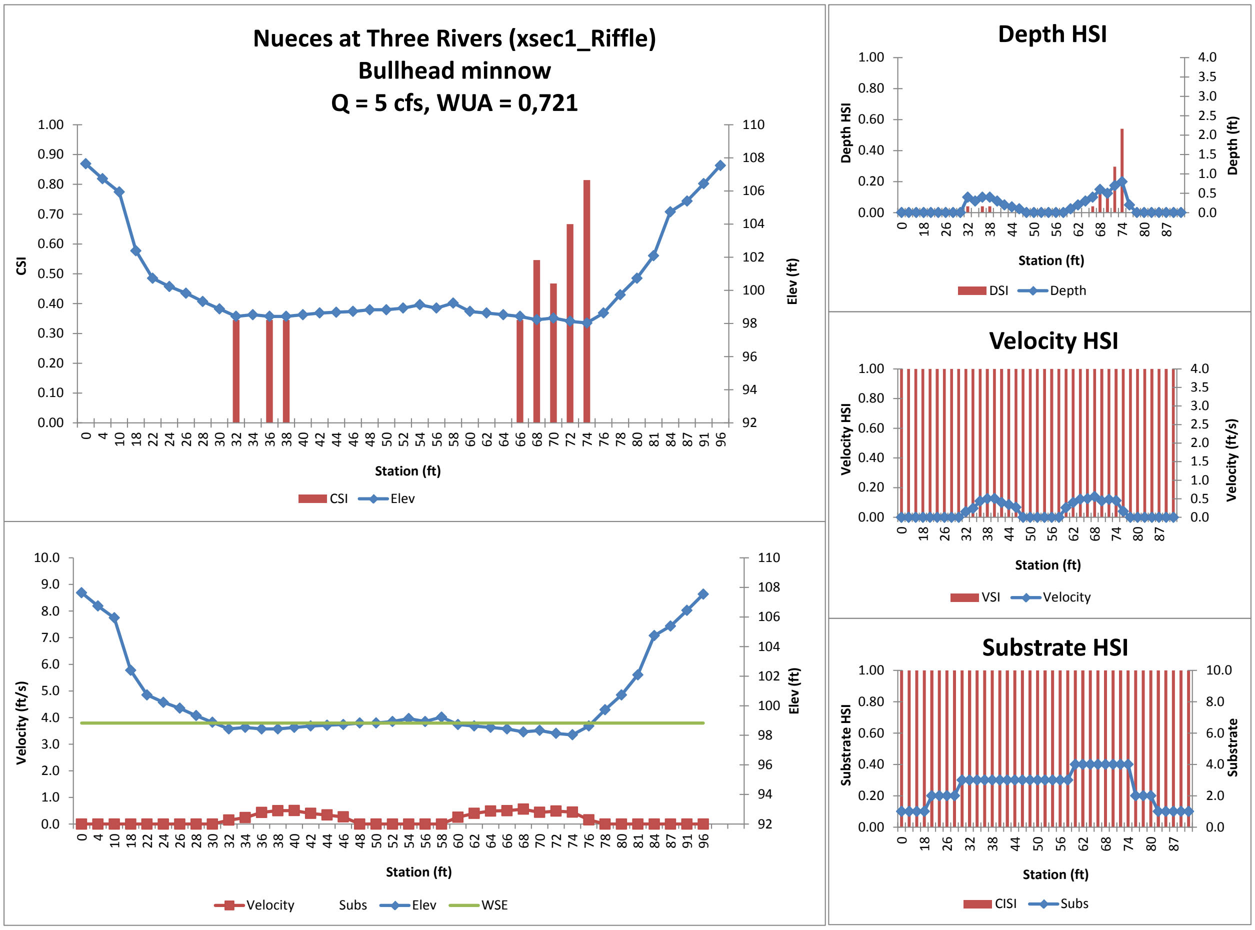


Figure 12 Bullhead minnow habitat at 5 cfs at Cross Section 1 (Riffle) at Three Rivers.

As flows increase to 50 cfs (in the range of medium base flows), even though velocities become too fast, making some parts of the channel less suitable, significant portions of the edges are highly suitable for this species (Figure 13).

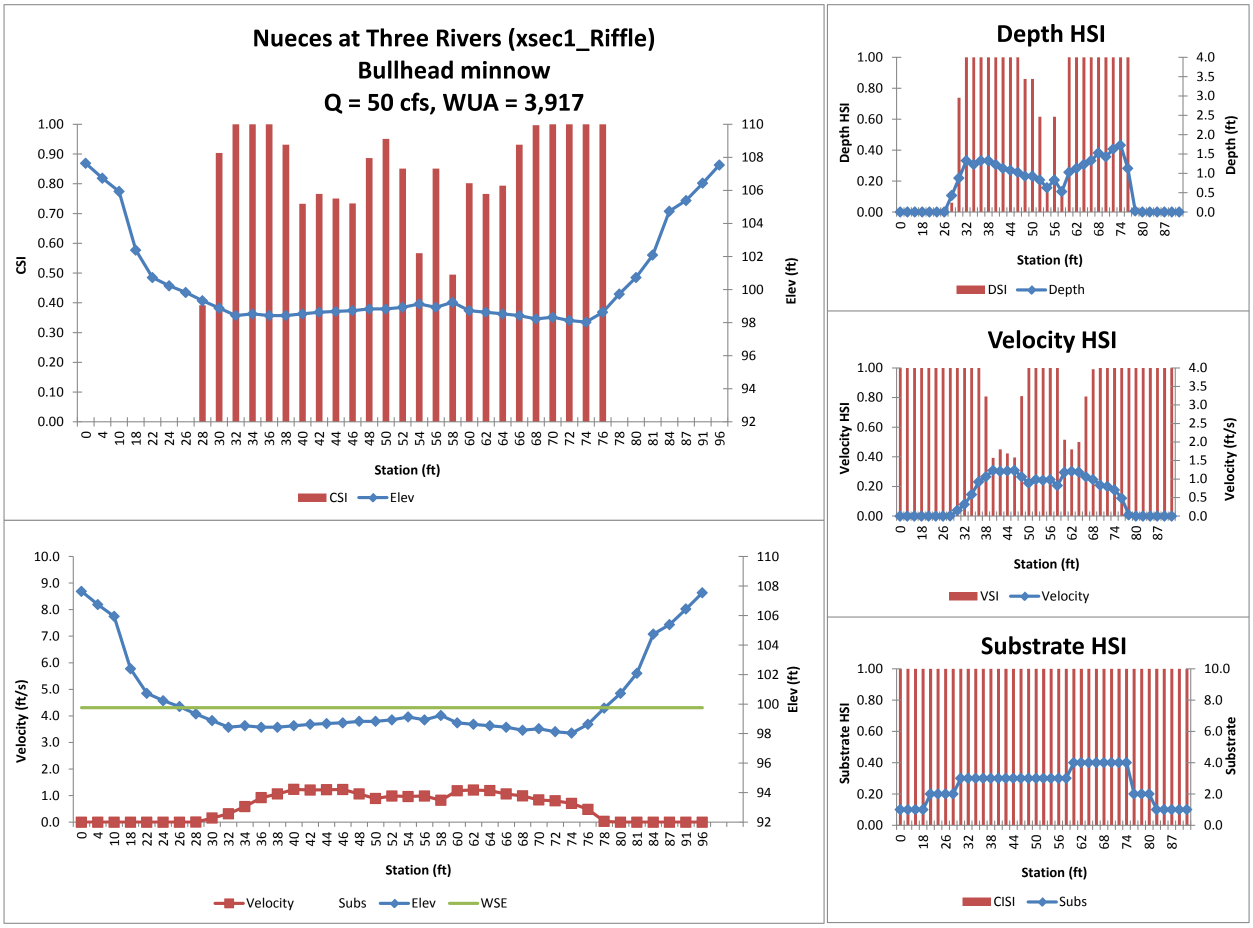


Figure 13 Bullhead minnow habitat at 50 cfs at Cross Section 1 (Riffle) at Three Rivers.

Although somewhat higher than what would be considered for base flow recommendations, once the flow reaches 140 cfs at this cross section, velocities cause much of the middle of the channel to be poorer quality habitat for this species (Figure 14)

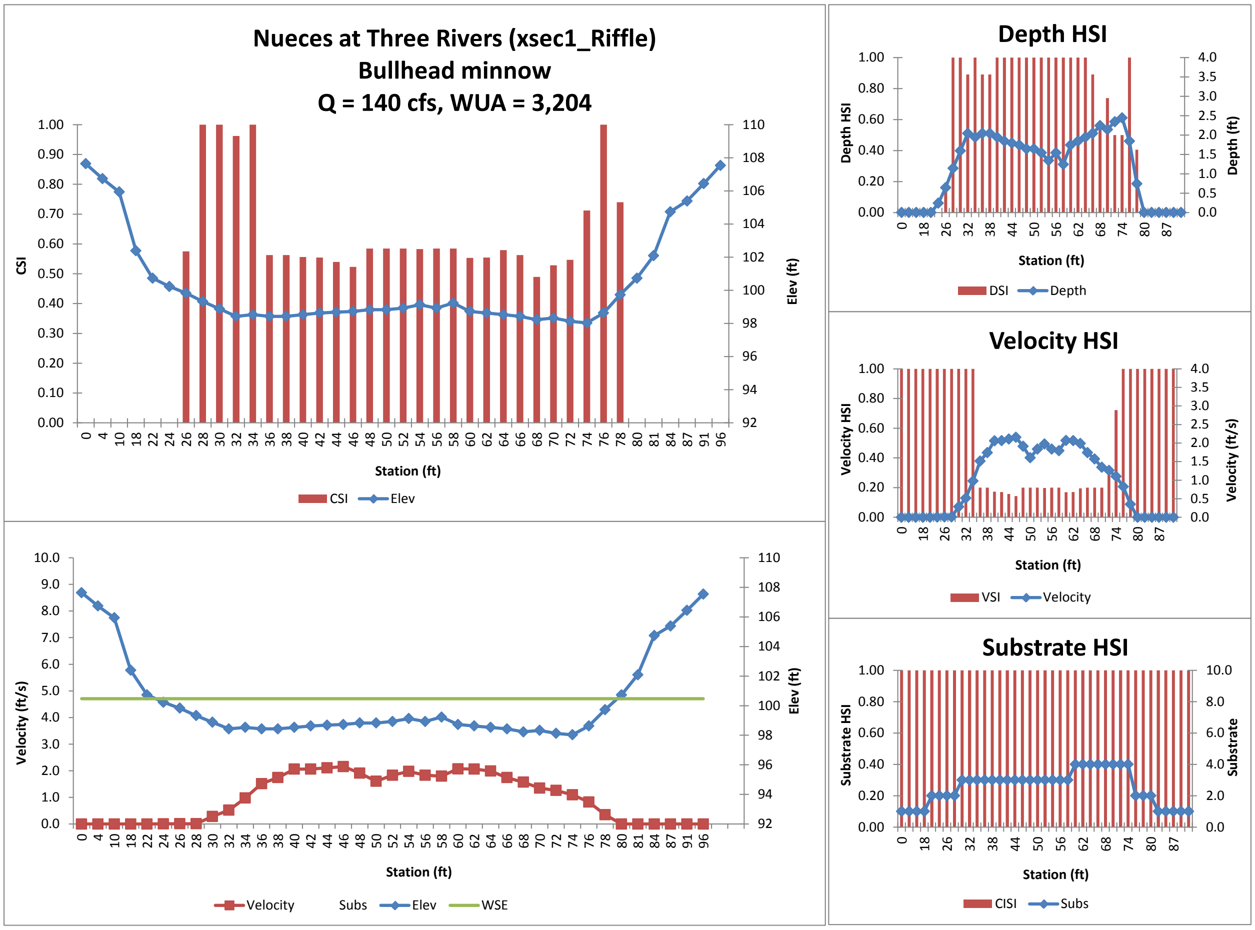


Figure 14 Bullhead minnow habitat at 140 cfs at Cross Section 1 (Riffle) at Three Rivers.

The proceeding example demonstrates how the tool can be used to better understand how habitat conditions change with flows. It is not intended to make a recommendation for one flow rate over another, in fact this species at this cross section was selected because it shows a clear modal response over the range of base flows being considered, many of the species examined suggest less dramatic responses, especially when integrated over the entire study site and viewed at the reach scale. Typically habitat area increases with increased flows as more edge area is inundated and, for some species, higher flows produce unsuitable depths and velocities in the middle of the channel. This highlights the importance of evaluating spatial issues. Suitable habitat for all species being limited to channel edges may suggest increased competition within that limited space. The analysis also highlights the importance of habitat quality. A cursory look at the upper left chart in Figure 14 might suggest that much of the cross section provides suitable habitat and the over overall weighted usable area value (3,204 square feet) may not seem significantly different from the weighted usable area value at 50 cfs (3,917 square feet). However, the majority of the area in this cross section at 140 cfs provides rather poor velocity conditions for the Bullhead minnow. The spreadsheet tool provides an option for excluding low quality habitat below a user defined value. Values used in other studies have been in the range of 0.7 and 0.8, would indicate that a flow rate of 140 cfs produces very little high quality habitat for Bullhead minnow. The issue of habitat quality, at the reach level, is addressed in more detail in Section 5.3 below.

5.2. Mesohabitat Scale Analysis (Cross Section Weighted Usable Area).

Moving from the microhabitat scale of the cross section to the mesohabitat scale of runs, riffles and pools represented by the different cross sections, the analysis conducted in this project provide outputs that allow for a direct evaluation of the WUA produced at user defined flow rates. In the spreadsheet HEFR[1] derived values from analysis of these gages are used as defaults. Figure 15 is a repeat of Figure 11 but includes points that indicate the HEFR flow magnitudes. In this example, the HEFR values are based on the full period of record although there are user inputs within the spreadsheet that allow for the display of early or late period values. The points should be read by drawing vertical lines to see where they intercept with the WUA curves[2]. In this example base high value, in the summer (the season with the lowest flows) are approximately 60 cfs and produce about 4,500 square feet of Red Shiner WUA, 4,250 square feet of Weed Shiner WUA and 3,750 square feet of Bull Minnow WUA. Similarly, the season with the highest base high HEFR number has a flow of about 100 cfs and produces about 4,600 square feet of Red Shiner WUA, 3,500 square feet of Weed Shiner WUA and 3,400 square feet of Bull Minnow WUA. Figure like this one are available within the spreadsheet for all cross sections individually, grouped by mesohabitat type and overall total for the study site. In addition to Figure 15 which display the total WUA these figures are also available base on percent of maximum and per 1000 foot of river length.

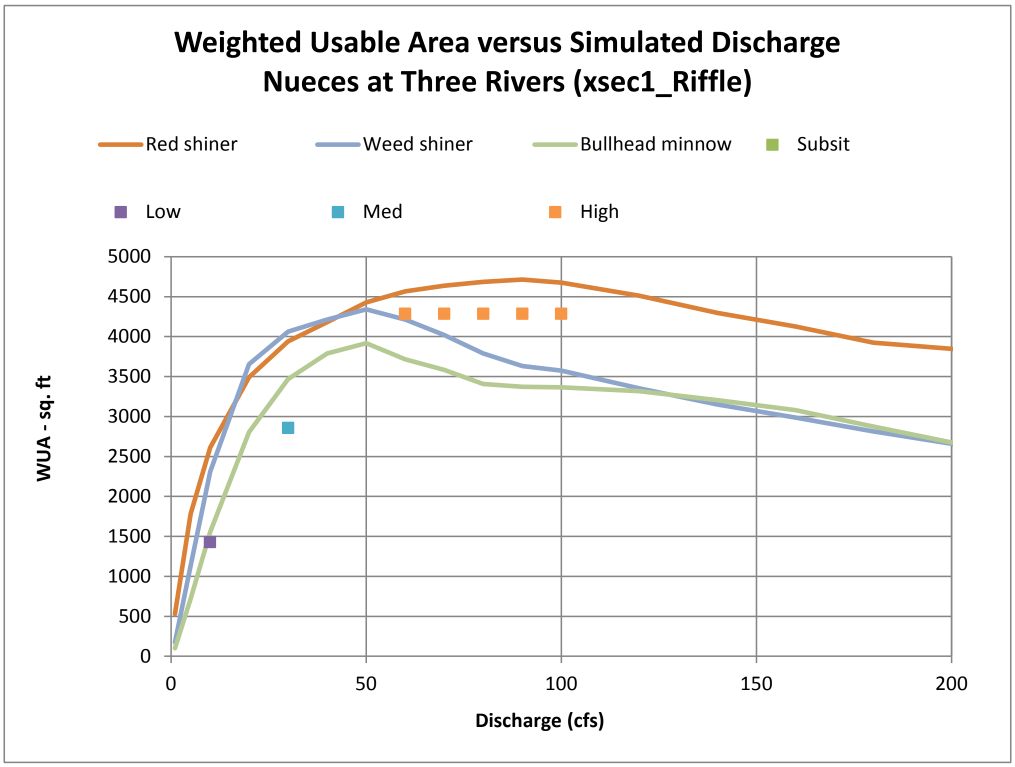


Figure 15 HEFR values overlain on Flow versus Weighted Usable Area Curve (WUA) for Cross Section 1 (Riffle) at Three Rivers.

[1] HEFR stands for Hydrology-Based Environmental Flow Regime. It is a methodology for analyzing historical flow data to develop preliminary environmental flow recommendations.

[2] The y-axis values for the HEFR points have no real values. A convention was adopted simply for display to show them at different levels on the chart. The range of flows on the x-axis indicate the highest and lowest values for that base flow level which typically vary by season. Figure 16 through Figure 18 near the end of the report include a perhaps more intuitive way of displaying these magnitudes, with vertical lines, unfortunately time constraints have not allowed for amendment of all of the spreadsheet to display in that manor thus the existing display is described here.

This information can also be viewed in tabular formats. Table 4 presents an example that could be used to compare the WUA produce by HEFR estimates derived from alternative periods of record. The values in the lower portion of this table (under Full) provide the same information presented in Figure 15. In the table, some cells are colored based on the percent of the maximum habitat produced over the entire HEFR range (from zero to the maximum HEFR flow value plus 10 percent). Green indicates that the WUA produced at this flow rate is greater than 90 percent of that maximum, blue is greater than 75 percent, red greater than 50 percent and white is less than 50 percent. These thresholds are arbitrary are solely to aid in display. The thresholds can be modified in the spreadsheet and the tables will update accordingly.

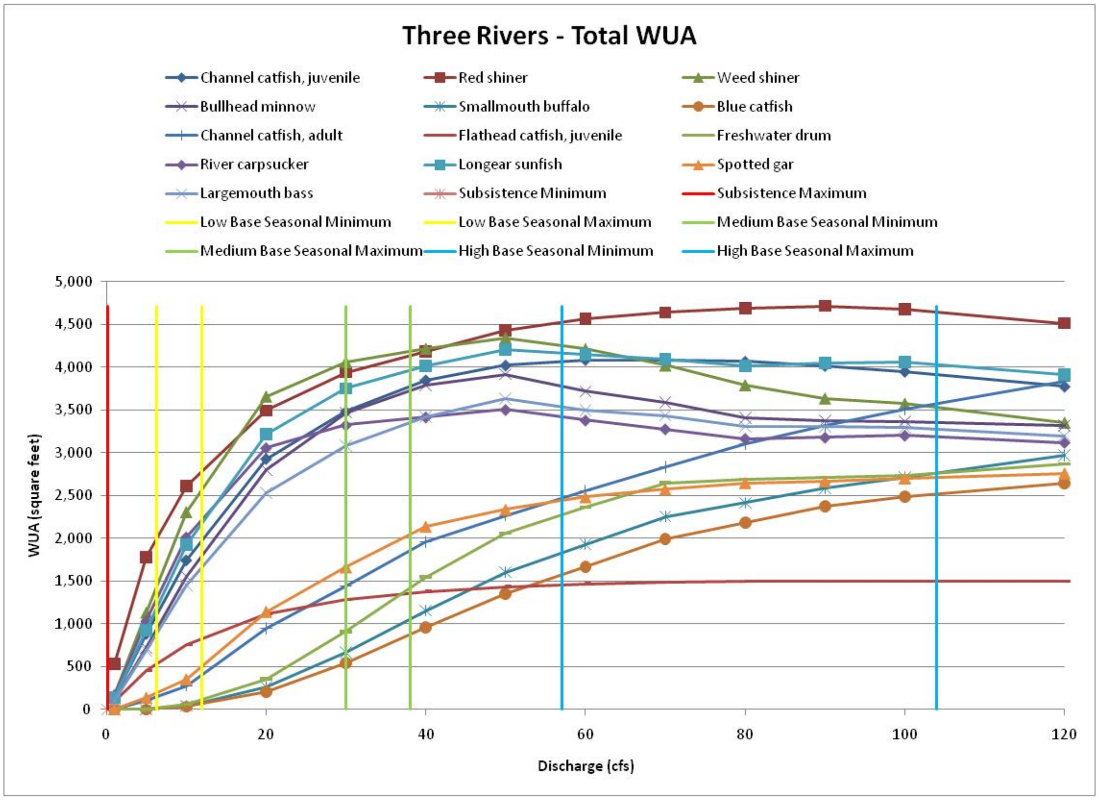
Table 4 Flow versus Weighted Usable Area (WUA) for Cross Section 1 (Riffle) at Three Rivers at HEFR flows derived from alternative periods of record.

Species			MaxH	MaxHQ
Bullhead minnow			3,917	50
Early	Subsit	Low	Med	High
Winter	0	9	20	66
Spring	0	5.5	18	52
Summer	0	3.1	8.2	39
Fall	0	4	12	44
WUA	Subsit	Low	Med	High
Winter	#N/A	1,389	2,802	3,636
Spring	#N/A	805	2,553	3,877
Summer	#N/A	427	1,255	3,758
Fall	#N/A	566	1,805	3,841
% MAX	Subsit	Low	Med	High
Winter	#N/A	35%	72%	93%
Spring	#N/A	21%	65%	99%
Summer	#N/A	11%	32%	96%
Fall	#N/A	14%	46%	98%
Late	Subsit	Low	Med	High
Winter	9.5	42	83	162
Spring	5.1	35	55	127
Summer	3.1	32	40	79
Fall	1.5	39	50	99
WUA	Subsit	Low	Med	High
Winter	1,472	3,815	3,396	3,059
Spring	738	3,629	3,817	3,278
Summer	427	3,532	3,790	3,424
Fall	179	3,758	3,917	3,366
% MAX	Subsit	Low	Med	High
Winter	38%	97%	87%	78%
Spring	19%	93%	97%	84%
Summer	11%	90%	97%	87%
Fall	5%	96%	100%	86%
Full	Subsit	Low	Med	High
Winter	0.1	12	38	104
Spring	0.1	10	36	83
Summer	0.1	6.3	30	57
Fall	0.2	9	37	68
WUA	Subsit	Low	Med	High
Winter	#N/A	1,805	3,726	3,356
Spring	#N/A	1,556	3,661	3,396
Summer	#N/A	938	3,468	3,777
Fall	#N/A	1,389	3,693	3,610
% MAX	Subsit	Low	Med	High
Winter	#N/A	46%	95%	86%
Spring	#N/A	40%	93%	87%
Summer	#N/A	24%	89%	96%
Fall	#N/A	35%	94%	92%

5.3. Assessing Quantity versus Quality Habitat at Reach level.

One component in the evaluation of any instream flow regime is a consideration of the quantity versus quality aspects of available habitat. It is clear from simple observations across a wide array of aquatic species that individuals will occupy less than ideal habitats due to a variety of factors such as competition, linear dominance, community density, community structure (predator versus prey), etc. It is also known that if a more suitable location is made available, species will move to that 'higher preferred" habitat location. This directly points out the subtle difference between pure quantities versus quality habitat in habitat selection by species. The analysis presented in this report is an estimate of the available habitat at each discharge but does not consider these behavioral factors or species interactions. It is simply an estimated potential of locations having depth, velocity and substrate conditions that the biologist considers useable by the each target species. Given the type of habitat suitability criteria being employed in these studies, the calculation of physical habitat availability based on combinations of depth, velocity and substrate imply that over some combination of their ranges, the combined suitability will range between 0.0 (totally unsuitable) to 1.0 (assumed to be ideal). What is assumed however, is that any potential location having non-zero combined suitability is potentially inhabitable by the target species and that a location having a combined suitability of 0.0 would not be occupied. The calculation of available habitat at any discharge is therefore the sum of all locations (cell areas) weighted by the combined suitability at each location. Clearly, if every location in the stream at given discharge had a combined suitability of 1.0 then the computed available habitat (Weighted Usable Area) would equal the stream surface area. Inherent in these calculations of total available habitat is that two identical values of available habitat at some discharge can be composed of two entirely different conditions of absolute suitability. If the river at some discharge contained 10 cells, each 1 square foot, and the combined suitability of each cell was 0.1 (poor quality) the total WUA would be estimated as 1 square foot. However, given this same discharge and 10 cells in which 9 cells had a 0.0 suitability and 1 cell had perfect suitability (i.e., 1.0) then the computed WUA would still be 1 square foot. At issue for the biologists then is making an informed decision between different flow rate ranges where one might be maximizing the total habitat area which may be composed mostly of poor quality suitability versus an alternative discharge in which more proportional area is composed of higher quality habitat areas.

In order to inform the BBEST, we have provided the capability in the assessment spreadsheets to examine both total quantity as well as quality of habitat available as a function of discharge. These results can be explored on a species by species basis at individual cross sections, by mesohabitat types derived from the replicate cross sections is these mesohabitat types, or at the reach level which integrates all habitat availability across all mesohabitat types. To further explore the implications of quantity versus quality, Figure 16 shows the relationships between total available habitat and discharge (top) versus only "high" quality habitat versus discharge (bottom) over the ranges of subsistence, low, medium and high base flow ranges. High quality habitat was assumed to be where the combined suitability for component depth, velocity, and substrate suitability were >= 0.80. The analysis tool can be used to set any arbitrary threshold for screen out "poor" habitat and the threshold of 0.80 was selected based on previous work by the TPWD and discussions with the Biology Subcommittee.



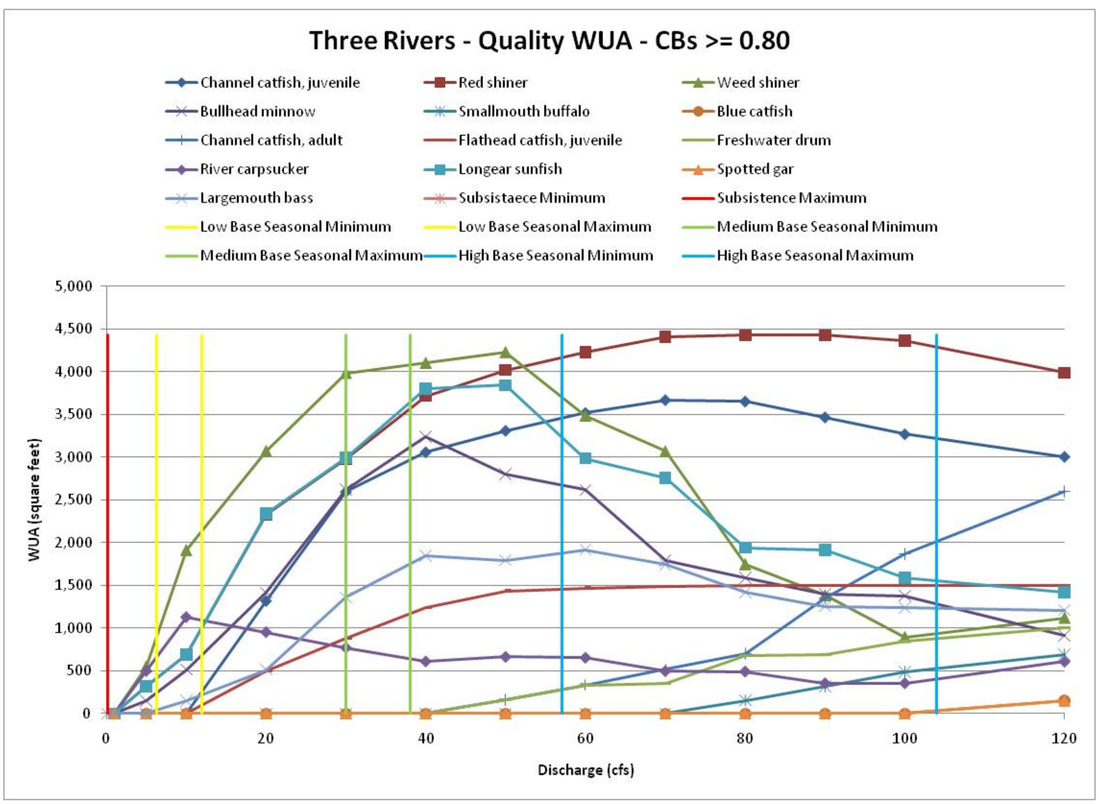
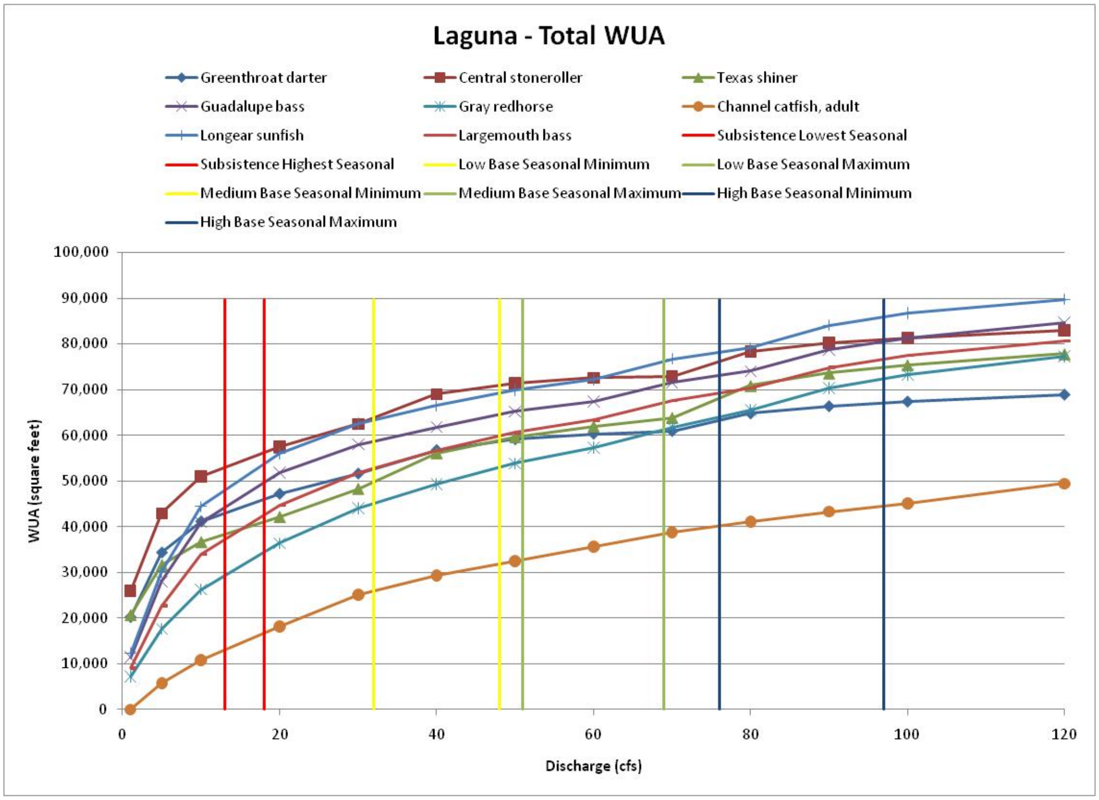


Figure 16 Quantity versus quality of available habitat at the Three Rivers study site.

What is evident in Figure 16 is that the total quantity of habitat (top) increases over all ranges of discharge within the subsistence to high base flow range. The results also suggest that the total quantity of available habitat within the medium to high base flow seasonal range in discharge for the seven species grouped at the top are somewhat insensitive to amount of available habitat. However, when examining the contribution of high quality habitat (bottom) a very different pattern emerges. Three of the species reach the maximum of high quality habitat within the medium base flow range while three species only have high quality habitat at middle to upper ranges of the high base flow seasonal discharges. It is also clear that some species have no quality habitat (or extremely low) within the seasonal subsistence flow ranges but have proportionally higher amounts within the seasonal low base flow ranges of discharge. It is also evident that the amount of quality habitat is very sensitive to flows within the medium and high base flow seasonal discharge ranges not evident when only considering total habitat available. In some sense, these results underscore the recommendations of the Texas Instream Flow Program and SAC guidance where three levels of base flow regimes are considered 'ideal' for protecting the aquatic resources as embodied in the natural flow paradigm. Clearly, these results imply that the only way that different target species can experience periods of high quality habitat availability would be an environmental flow regime that provided for periods of flow within the low, medium and high base flow regimes. Figure 17 and Figure 18 provide similar examples from the Laguna and Concan study sites for comparison.



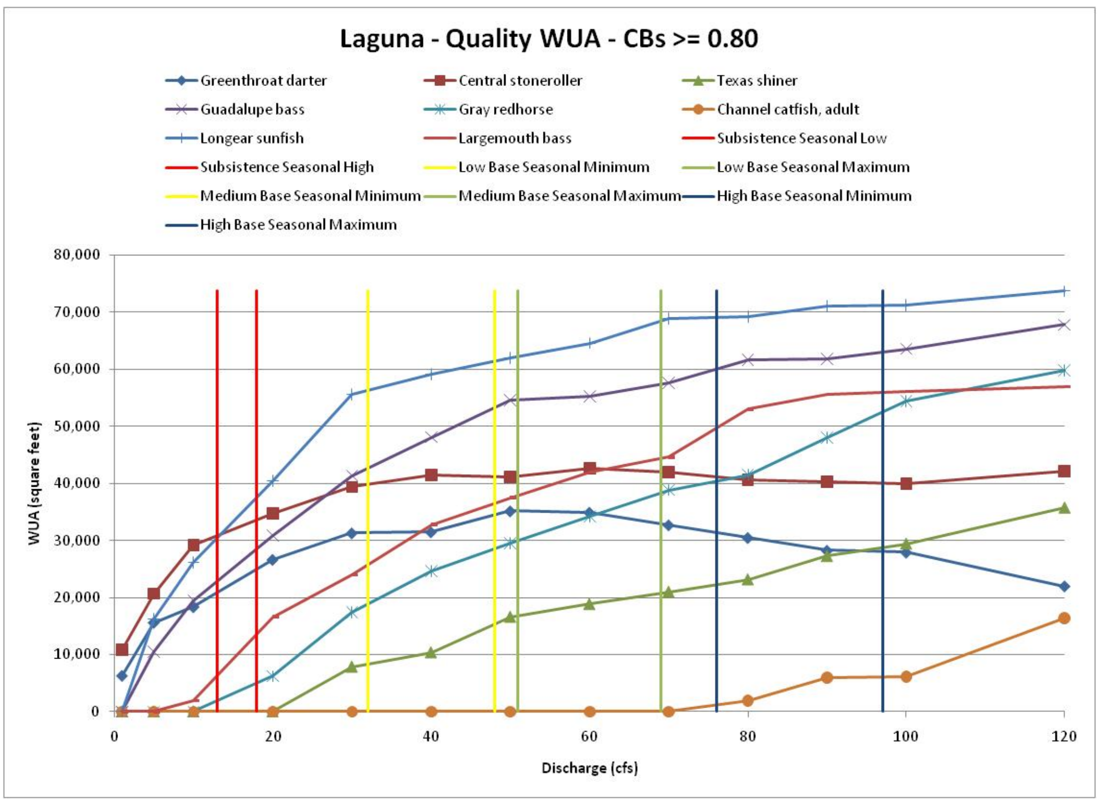
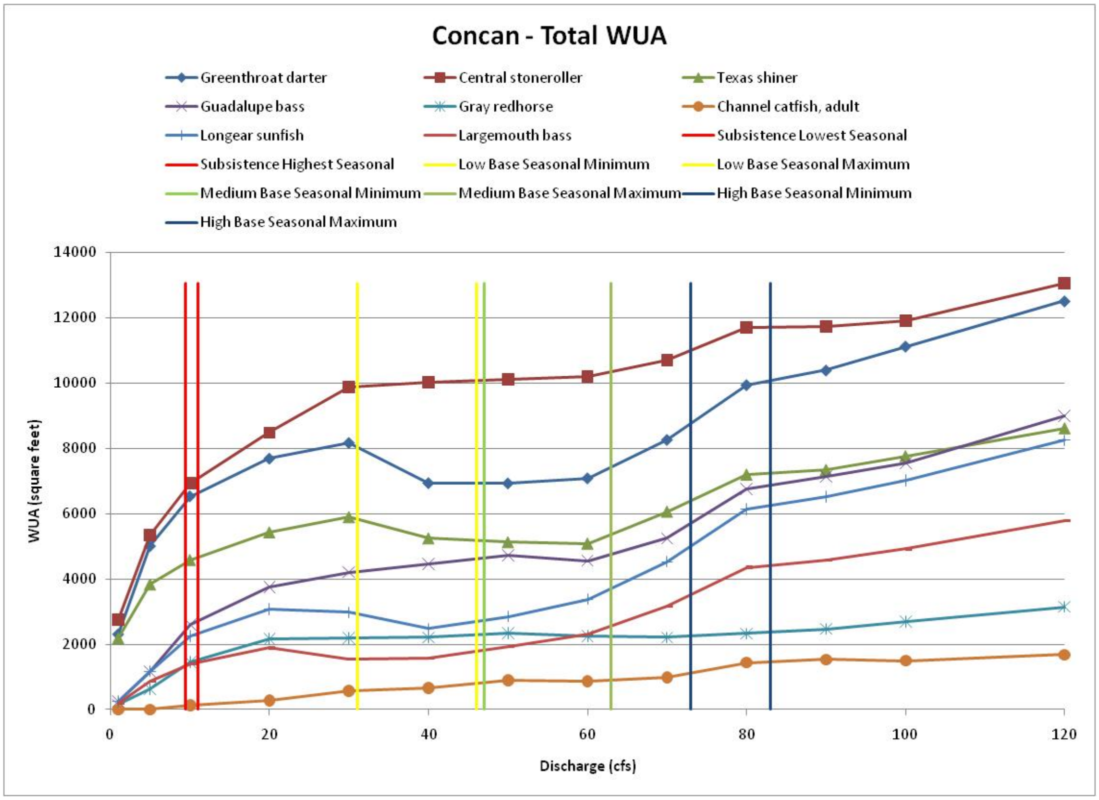


Figure 17 Quantity versus quality of available habitat at the Laguna study site.



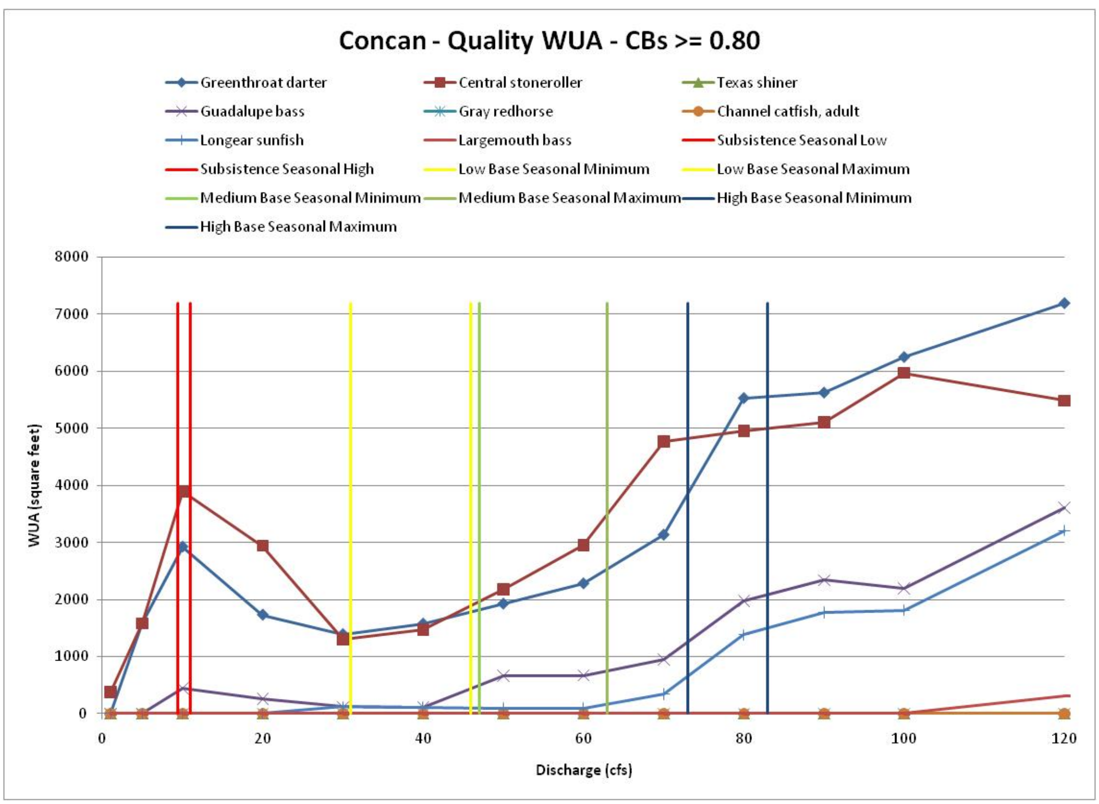


Figure 18 Quantity versus quality of available habitat at the Concan study site.

6. Conclusions.

The authors of this report recognize the task facing the BBEST, namely to develop scientifically defensible flow recommendations to maintain a sound environment. A paucity of data, incomplete understanding of biological responses and time and resource constraints make this a particularly daunting task. The information developed as part of this project are intended to assist in the evaluation of the instream habitat response to different flow levels and support the decision process for recommended instream flow regimes. We wish to stress that physical habitat is a necessary but not sufficient component of the stream ecosystems and the analysis does not consider water quality, sediment transport, or direct consequences of competition and predation.

Appendix Spreadsheet Details.

The report provides several examples of the how the results from the tools developed as part of this study may be used to support the BBEST in the development of Instream Flow-Habitat relationships supporting flow regime recommendations. This report does not include, nor did it intended to include, a flow recommendation, rather the project provides a flexible and adaptable approach to predicting the instream habitat response to different base flows and displaying these response in a format that that can be useful to the BBEST in their deliberations to develop flow recommendations to maintain a sound environment.

The approach is flexible in that it provides many options to evaluate alternative scenarios and display results[3]. It is adaptable in that it may be improved if additional data or better understanding of the habitat response of species to hydraulic habitat conditions is developed. Unfortunately a flexible and adaptable tool carries a certain level of complexity. While not a comprehensive user's manual, the following describes how the excel spreadsheet program works and provides guidance should modifications be desired as part of future studies.

The products produced as part of this project are three sets of Excel spreadsheets. The first set, in the PHAB folder contain files with the suffix "_PHAB", contain the complete hydraulic habitat models for each site. The other spreadsheets discussed below, contain results extract from the "_PHAB" files. The PHAB spreadsheets incorporate the programming approach originally developed by the Fort Collins Instream flow group called PHABSIM (Physical HABitat model SIMulation) and subsequently updated into the MS windows platform. The spreadsheet does not include all of the options available in the PHABSIM/PHABWIN software but has the benefit displaying results in a manor more accessible to a wider range of users. The main PHAB spreadsheets include a number of sheets. In general, the sheets "FieldData", "RatingCurve" and "Site_xsecs" (possibly "Criteria", which contains the habitat suitability criteria for the species included in this analysis) should be view as places to input data to the spreadsheet. "Calibration" and "Simulation" are for developing and executing the hydrodynamic part of the program and "Habitat" applies the habitat suitability to the hydrodynamic results to calculate weighted useable area. The "Control" sheet allows user input to evaluate alternative for the hydraulic and habitat simulations, several cells in the sheet contain comments viewable when hoover the mouse over these cells. The models are executed using a Visual Basic macro tilted "Results" and there are several additional macros for producing and viewing intermediate results. Table 5provides a quick reference to the sheets and macros included in this spreadsheet.

During the course of this project the full PHAB model spreadsheets had become large and time consuming to execute. To facilitate analysis different scales, portions of the main program were extracted. The files in the folder "WUA_result_only" include files that are intended to facilitate analysis at the mesohabitat or cross section level. The folder contains one file for each study site and the out puts from these files include WUA figures and tables similar to Figure 15 and Table 4. The files in the folder "xsec_hab_only" include a file for each cross section; 25 total (9 at Concan, 9 at Laguna and 7 at Three Rivers). These spreadsheets are intended allow for an analysis at the microhabitat level i.e. point velocities and depths and their corresponding habitat values at each station across the channel similar to Figure 12 through Figure 14.

During the process of completing project, superfluous calculations have been removed from the main PHAB models and the spreadsheets are now smaller and more manageable than some of the intermediated versions. As a result the need to extract outputs to other spreadsheet is less pressing. For the most part what is available in the extracted spreadsheets can be accomplished in the main PHAB spreadsheets. On the other hand if the BBEST chooses to develop other ways to analyze and display results the main program will continue to grow, and it might be prudent to amend to the extracted outputs. For example "xsec_hab_only" files do not presently contain anything that is not in the main model, however if the BBEST is interested in evaluating species completion by displaying habitat scores for more than one species e.g. a figure like Figure 13 but with two sets of bars, one for each species, it may make sense to develop this analysis in the extracted "xsec_hab_only" spreadsheets rather than in the full model. Some examples of this kind of add-on have been developed for the other extracted

[3] Tip - cells within the spreadsheets that are outlined and highlighted yellow are intended as user inputs and in many cases include drop down menus to guild the user, however it is recommended that a backup file be saved before attempting to modify these values

spreadsheets "WUA_reuslts_only" which include additional figures not in the main model to display WUA per 1000 feet and to create the tabular results presented in Table 4. Should the BBEST decide to develop a habitat time series analysis it may be more efficient to start with the "WUA_reuslts_only" extracted spreadsheet rather than to add this to the full PHAB spreadsheet.

Table 5 Summary of spreadsheet sheets and macros.

Sheets	
Control	User Inputs for simulation alternatives
Site_xsecs	Summary Information for each cross section including GIS locations, cell lengths, WSE and Q, Thalweg and Stage of zero flow elevations which are used by other sheets.
RatingCurve	Rating curve for converting flow to WSE. Includes placeholders for developing log-log regressions based on USGS or site specifc data. WSE-Q pairs may also be imported from other sources such as PHABWIN hydraulic model which includes more sophisicated appraoches such as WSP step backwater model.
Calibration	Part 1 of the Hydrologic model designed to aid in processing and evaluating the field data and refining calibration parameters, primarily the velocity distribution coeffienct (N) and the choice of whether to use a velocity adjustment factor.
Simulation	Part 2 of the Hydraulic model applies the calibration parameter to predict velocityies and depths at all stations for the range of flows simulated.
Habitat	Applies habitat criteria to results of hydraulic model to calculate weighted usable area for range of flows modeled.
Criteria	Habitat suitablity criteria for depth, velocity and substrate. This sheet was developed based on data provided by the BBEST with support of TPWD which is included in the spreadsheet Nueces_HSC.xlsm.
FieldData	Cross section field data. Depth, velocity and substrate foor each station.
PHABWIN_SIM	Cross section outputs from calibrated PHABWIN model
WUA	Weighted usable area results includes options for displaying HERF flow estimates on curves and percent of maximum habitat at these flows.
Results	Weighted usable area results for all species and flows simulated.
BySubstrate	Optional sheet to examine the amount of weighted usable area over each substrate type. Currently the macro to calculate these estimates for all flows and species has beren deactivated and reactivating it might require addtioanl modifications.

Macros	
UpdateCharts	Updates x-axis scales for charts on hydraulics and habitates sheets (does not work for velocity simualtions chart on habitat sheet). (control-p)
ChartsStep	Automates visualization of cross section station charts on Habitat sheet (starting about row 72). Steps through the range of flow simulated. Currently set to display every other flow. (control-i)
UpdateHAB	Produces WUA results for one cross section for all flows and species only saves results on Habitat sheet. (control-u)
Results	Produces WUA results for all cross sections for a all species at all flows and saves them to Results sheet. (control-k)
SubstrateCalcs	Calucates WUA over each substrate type (currently disabled as part of Results macro and may require modification if it is to be used in the future)
InsertCells	Utiltility macro not used in producing model results