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Development and Application of an Instream Flow Assessment Framework for the Fountain Darter (*Etheostoma fonticola)* and Texas Wild-Rice (*Zizania texana*) in Spring Lake and the San Marcos River System

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EXECUTIVE SUMMARY

INSE and USFWS mapped the San Marcos River channel in 1997 and developed a hydraulic and habitat assessment model for Fountain Darter and Texas Wild-Rice. Habitat was quantified for flows from 15 cfs (roughly one third the historical low) to 170 cfs (roughly the median flow). A large flow event modified the channel of the San Marcos River in October 1998 and led to the failure or Thornton's (Cape's) Dam. In 2001, INSE and USFWS remapped the portion of the channel downstream of the Spring Lake Dam to the Cape's Dam. In addition the Texas Parks and Wildlife Department updated the curves for habitat suitability indices (SI) for Fountain Darter. Available habitat was analyzed for the changes in existing geometry and hypothetical removal of Thornton's Dam. In addition to the flows examined in 1997, two new flows at 190 and 200 (roughly the bankfull discharge) were modeled. Generally the channel changes had little impact (10% or less) on changes in habitat for the range of flows (135-200 cfs) near the median. For Fountain Darter temperature impacts at low flow had larger impacts on available habitat than changing flow hydraulics. Additionally vegetation is a significant limiter on available Fountain Darter habitat, as it reduces suitable area by as much as 60%. Analysis for the removal of the Thornton Dam shows improved habitat for Wildrice at lower flows (less than or equal to 100 cfs) and limited impact at greater flows. However, for Fountain Darter the loss of the dam results in a reduction of habitat by approximately two thirds at all flows for the modified geometry and existing vegetation distribution.

Please see pages 17-18 for data charts and their graphs which back-up the assertion that there is "a reduction of habitat by approximately two-thirds at all flows" when removing Cape's Dam.

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Background

The San Marcos River in central Texas is home to three endangered species - Texas Wild-rice (*Zizania texana*), Fountain Darter (*Etheostoma fonticola*), and Sam Marcos Gambusia (*Gambusia georgei*) – and one threatened species - San Marcos Salamander (*Eurycea nana*). In addition the San Marcos River is listed as critical habitat in part or in whole depending on the species (50CFR17). The river is impacted by withdrawals from the Edwards Aquifer and recreational uses inside the City of San Marcos (Saunders, et al. 2001).

In the fall of 1997 personnel from the Institute of Natural Systems Engineering (INSE) at Utah State University gathered global positioning system (GPS) and sonar data on the San Marcos River in order to construct a habitat model for the native endangered Wild-rice and Fountain Darters. This project was undertaken in cooperation with and funded by the U.S. Fish and Wildlife Service (USFWS) in order to better understand the habitat and river flow requirements of the endangered species in the San Marcos River. The habitat model consists of habitat equations for the selected species, hydraulic modeling, water quality modeling and inclusion of vegetation maps for the entire system. The habitat model was completed in 1999. The model divided the San Marcos River into eight self-contained sections from Spring Lake to the confluence with the Blanco River.

On October 17th and 18th 1998, torrential rains dropped 22.5 inches of rain on the San Marcos, Texas area resulting in what could be the 500-year flood on the San Marcos River. Actual flood discharge is unknown, as the flood rendered the USGS San Marcos gage inoperable. Damages in San Marcos exceeded twelve million dollars.

The 1998 flood greatly affected the vegetation and morphometry of the San Marcos River. Whole stands of vegetation were torn up from the river bottom during the flood. Stands of Wild-rice in particular disappeared from the stretch of river near the state fish hatchery and downstream thereof. Deposition and removal of bed material occurred throughout the system including new gravel deposits above the University Drive Bridge in an area near Wild-rice stands.

*

Additionally, Cape's (Thornton's) Dam failed in December 1999. Temporary repairs of bags of concrete reinforced with rebar were made to the dam. These changes to both the channel geometry and vegetation distribution make any analysis from the existing model problematic. In April 2001 personnel from INSE and the Ecological Services Office of the USFWS collected cross-section information at select locations in the Rio Vista section (Spring Lake dam to Rio Vista dam) and the Cape's Dam section (Rio Vista dam to Cape's or Thornton's dam). Looking at the cross section just upstream of the I-35 overpass (Figure 1) deposition is evident in the center left channel (right side of the graph). The right hand side of the channel (left hand side of the graph) as the channel was too deep for wading. Based on these cross sections INSE and USFWS judged the channel change impacts on the model significant enough to require remapping.

* See Attachment I, pgs 39-42, for a copy of "Breached: Wildlife officials rescue wild rice after dam fails," published Jan 7, 2000. "The breach lowered the river level all the way up stream to Rio Vista Dam... Although the breach lowered the water level only inches, Power said that was enough to threaten the [Texas Wild Rice] plants survival.... After the breach widened Wednesday, the upstream water level dropped another two inches..."

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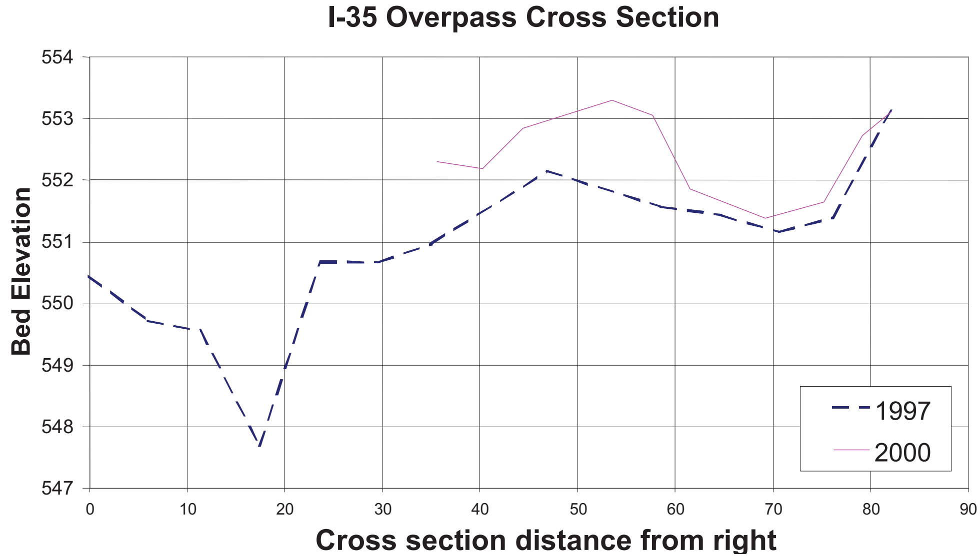

Figure 1: Cross-section upstream of I-35 Overpass.

San Marcos River System

The San Marcos River originates from San Marcos Springs in Spring Lake, San Marcos, Hays County, Texas. The river flows 4.6 miles downstream to a confluence with the Blanco River and continues for another 71.5 miles where it joins the Guadalupe River. The 1997 model was developed for the first 4.6 miles of river. The headwaters in Spring Lake initiates from the San Marcos Springs fault as a complex of more than 200 springs (W.F. Guyton and Assoc. 1979).

The two sections of the river for which bathymetric data was collected and the model updated are shown in Figure (2). These sections are bounded by the three most upstream dams in the system; Spring Lake, Rio Vista, and Cape's Dams. The hydrological record begins in May 1956. For the period of record to Sep 30, 2003, the minimum daily flow was 46 cubic feet per second (cfs) in August 1956, and estimated maximum flood flows at up to 21,500 cfs in October 1998 (Slade and Persky 1999). A graphical summary of statistical information for daily flows is displayed in Figure (3). Data is for flows from May 26, 1956 to September 30, 2003. As a spring fed system flows don't show great variability as shown by typical coefficients of variance for daily flows around 0.4 (range of 0.29 to 0.56). In the nearby Guadalupe River this value is around 1.5 (range of 0.68 to 4.74). The median daily flow in the San Marcos is 162 cfs.

The dams create a system dominated by pools and slow runs except for the area immediately downstream of the dams were the flow more closely represents the historical shallow faster run (Saunders et al., 2001). For additional descriptive information regarding the San Marcos see Bartsch et al., 1999, or Saunders et al., 2001.

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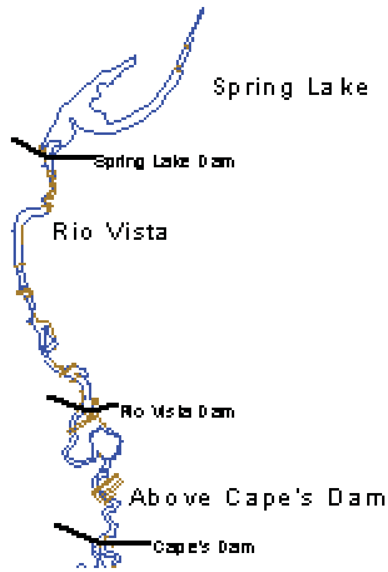

Figure 2: Rio Vista and Cape's Dam sections of the San Marcos River, Texas (from Bartsch et al., 1999)

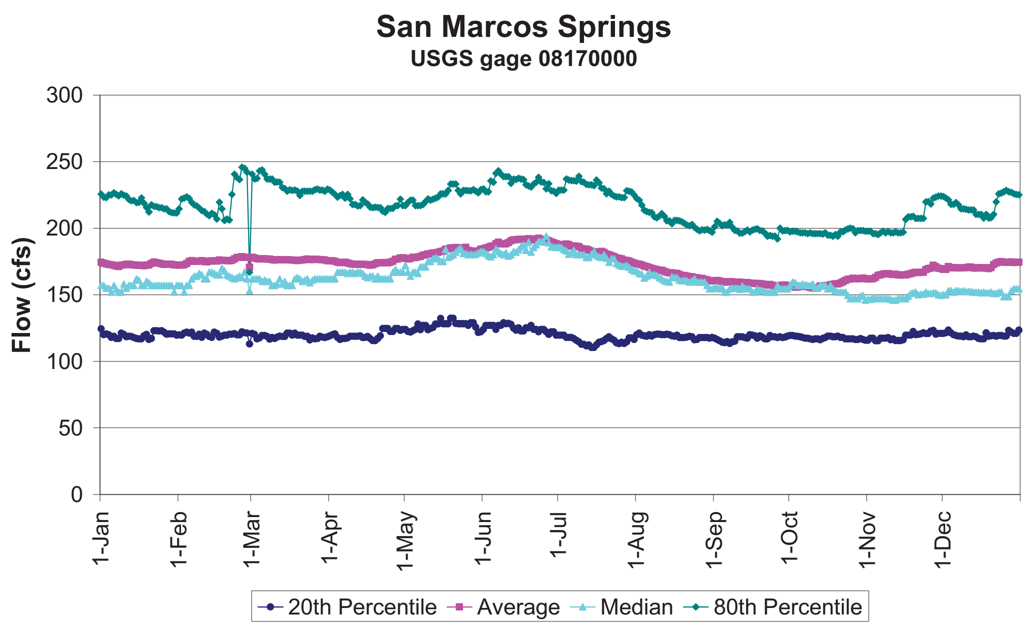

Figure 3: Daily flow statistics at San Marcos Springs (USGS gage 8170000).

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Generation of Updated Geometry

Data Collection and Preprocessing

Field data was collected from June 7, 2001 to June 23, 2001 using two technologies for generation of the new geometry mesh. The first technology used a Trimble GPS 4770 Total Station couple with an Odom Hydrotrac echo sounder. The GPS Total Station collected 3-D positional information to 1 cm resolution. The echo sounder determined the water depth with both units floated in a canoe down the length of the Rio Vista and Cape's Dam river sections. The GPS and sonar data were fed to a laptop computer to be time tagged and logged for post processing with INSE proprietary software. The data was pre-processed to eliminate problems caused by such errors such as null depths, low sonar signal-to-noise (SNR) data, high GPS dilution of precision (DOP), and poor GPS satellite coverage. The data was reprojected from the WGS-84 datum to the Texas State Plane South Central (NAD-83).

* Some portions of the channel were either too shallow for the sonar (depth less than approximately two feet) or had a channel bottom occluded by vegetation, especially in the Rio Vista section. In these areas the bathymetry was supplemented with spot elevations collected using a laser based total station owned by the USFWS Ecological Services Office. These points were referenced to the Wild-rice monuments previously established by surveyors with Texas Parks and Wildlife (TPWD). The monuments are in the Texas State Plane South Central coordinate system. Some data files were erroneously referenced to the wrong monument and the positions had to be adjusted with INSE in house software using techniques from Wolf and Ghilani (1997).

Model Geometry Mesh Generation

The mesh from the 2-D hydraulic model developed in 1996/1997 (Bartsch et al., 1999) was updated to reflect changes in channel geometry as measured by the 2001 data. The raw data files were combined and refined using the Trimble Terramodel™ software (http://www.trimble.com). Here they were visually examined for any gross error not found in previous QA/QC check. Next the new elevations were brought into the Surface Modeling System (SMS, from Boss International http://www.bossintl.com) as scatter points. SMS provides a graphical interface to format input files and model parameters for the U.S. Federal Highway Administration's FESWMS Flo2DH model.

Elevations from the 1997 mesh were updated with the 2001 measurements by a linear interpolation of the field collected point elevations. This allowed use of the 1997 modeling results to 'hot start' the hydraulic model calibration. Additionally it allowed the direct comparison of the meshes for elevation changes.

As with the 1997 mesh, the updated geometry mesh for the Rio Vista section contained 26200 elevation nodes yielding 8803 elements. The computational mesh for the Above Cape's section was extended slightly into the Mill Race from the extent of the 1997 mesh and resulted in slightly more nodes, 17747 nodes versus 17657 nodes (both with 5760 model elements). Figure (4) presents a histogram of the elevation differences. Values for each curve are calculated as

* See Attachment I, page 30 where Hardy & Raphelt declare: "A careful examination of Figures 12, 13, and 14 show the expected depths of water at flow rates of 45, 100, and 173 cfs under [all dam scenarios] maintain adequate areas with sufficient depths (>2 feet) to support all forms of contact recreation **throughout the river channel**."

$$Count\_of\left(Z_i^{2001} - Z_i^{1997}\right)_j \Big/ \sum_{j=0.2}^{5.0} Count\_of\left(Z_i^{2001} - Z_i^{1997}\right)_j$$

where i is each mesh node, N is the number of nodes in the mesh and the counts, j, are binned such that elevations are rounded up to the next 0.1 foot. One fact seen in the graph is that both sections appeared to deepen slightly as the negative elevation differences almost uniformly out number the positive elevation differences.

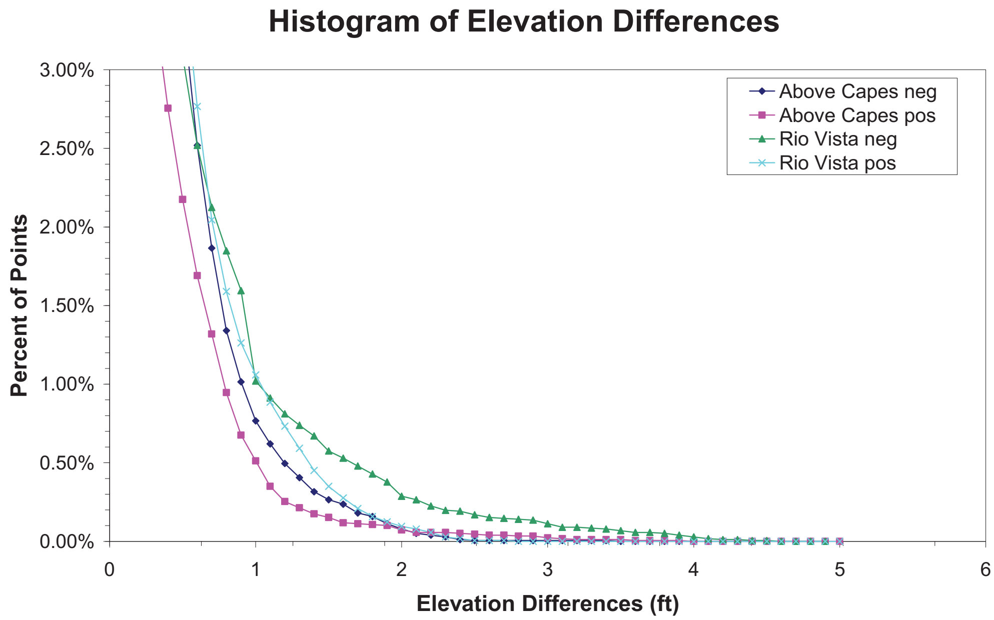


Figure 4: Histogram of elevation change between 1997 and 2001 computational geometry meshes. Percentages for points with elevations differences equal to or less than 0.1 foot are not included.

Vegetation Distribution

An annual San Marcos River macrophyte survey was completed in 2001 by Dr. Robert Doyle, Biologist, Baylor University. The exception being the distribution of the elephant ears, which were not resurveyed, but had their polygons updated from the 2001 field notes. The survey contains the elevations of the various species and their geographic distribution within the river. Figure (5) shows the changes in elephant ear distribution in the vicinity of Snake Island (Rio Vista section). A full set of figures for vegetation distribution for the San Marcos is presented in Appendix 1.

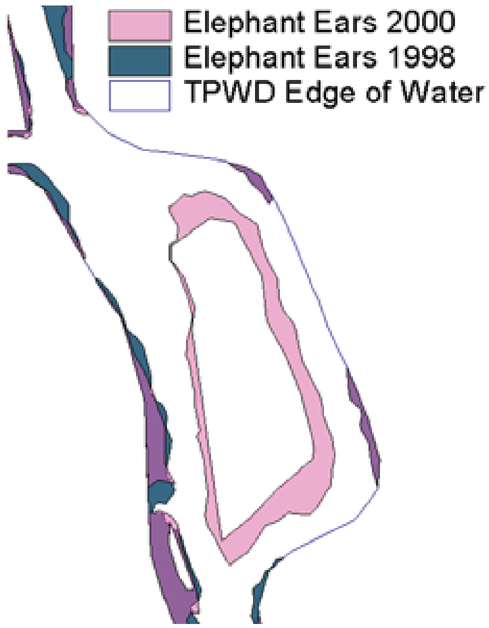


Figure 5: Comparison of Elephant Ear distribution at Snake Island in the San Marcos River, Texas

Habitat Suitability Indices

Figures (6) shows the velocity and depth SI curves for the Fountain Darter used in both the 1997 analysis and for the current analysis. Figure (7) shows the curves for Wild-rice with the curves labeled USFWS-USU were developed for the 1997 work and the current curves labeled TPWD. The TPWD curves were provided by the USFWS Ecological Services Office for this work and greatly increase the area provided by low velocity habitat while reducing the habitat quality provided by deeper water. This has dramatic implication for the Weighted Usable Area (WUA) calculations discussed in the next section.

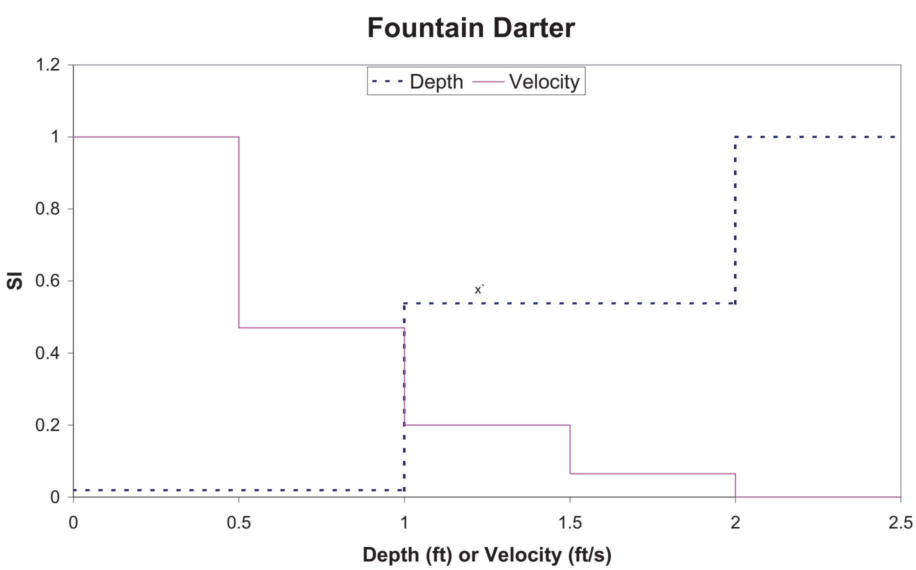
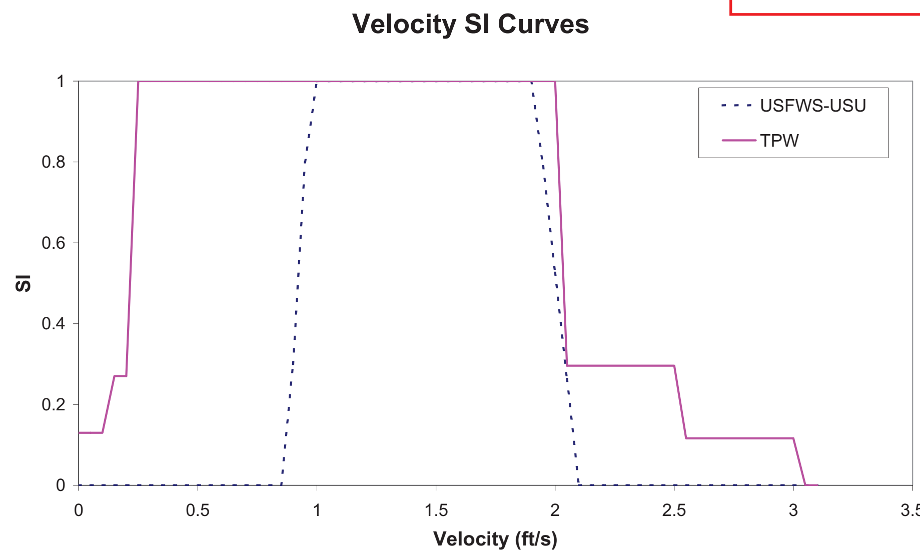


Figure 6: Velocity and Depth SI curves for Fountain Darter (*Etheostoma fonticola)*



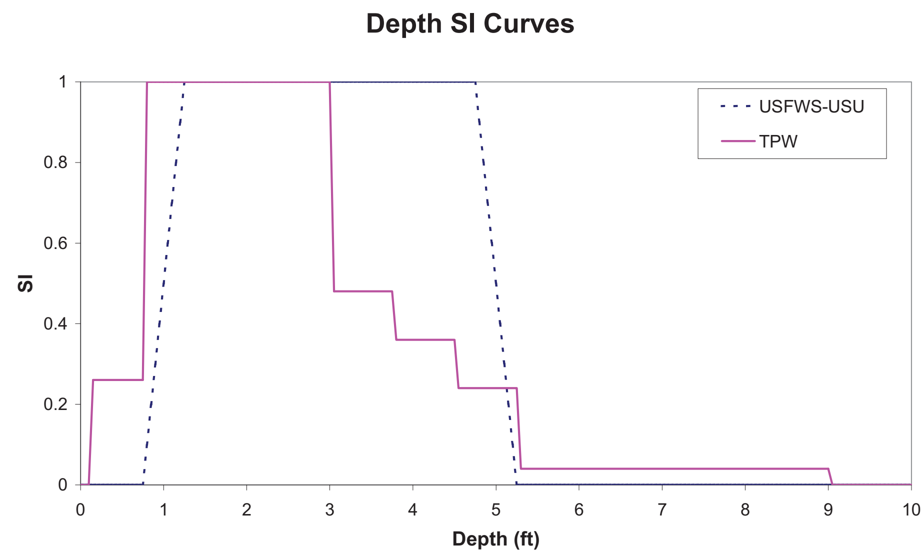


Figure 7: Velocity and Depth SI curves for Texas Wild-rice (*Texania Zizania*)

ANALYSIS

Hydraulic modeling

The 2-D hydraulic model developed in 1996/1997 (Bartsch et al., 1999) was updated to reflect changes in channel geometry as measured by the 2001 data. As with the previous study the U.S. Federal Highway Administration's FESWMS model was used. This model assumes negligible vertical water velocities and determines a flow field varying in the x and y directions. The updated vegetation maps were used to update the material type assignments for the mesh. These material types serve as the basis for the hydraulic roughness values (Bartsch 1999). From the 1997 analysis six flows were analyzed as in the 1997 data (15, 30, 65, 100, 135, and 170 cfs) with the addition of two new flows (190 and 200 cfs). The Rio Vista dam served as the

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downstream boundary for both the 1997 and 2001 models. As this geometry remained unchanged from the 1997 flows the model was calibrated using the 1997 discharge curve. Cape's dam was restored to a geometry that closely matched that from 1997 while flow to the millrace was restricted by the addition of a berm. Lacking downstream water surface elevations at flows other than those around 200 cfs the 1997 discharge curve was used here as well.

Alternate Scenario

The model was also calibrated for an alternative scenario in the Cape's Dam section. Specifically the model was calibrated for the absence of Cape's Dam. The 2001 mesh geometry was altered using Terramodel to reflect the removal of the dam and the channel upstream of the dam was modified for approximately 100 feet to a roughly trapezoidal shape. Due to the heavy sediment deposition in this part of the channel the resulting geometry should only be considered hypothetical. From the resulting channel cross section the HEC-RAS software was used to develop a discharge curve. The model was calibrated to the eight flows above and the downstream water surface elevations predicted by the curve (Figure 8).

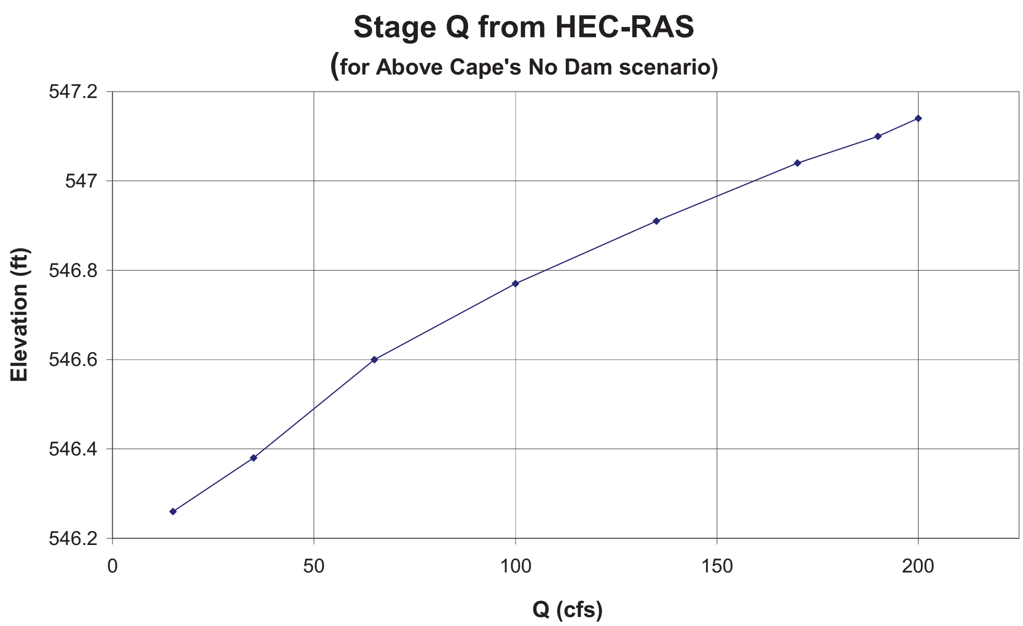

Figure 8: Stage discharge relationship from HEC-RAS used to calibrate the Above Cape's section No Dam scenario

Habitat modeling

For the 1997 analysis a C++ program, INSE Habitat Analyzer, was created to allow the GIS analysis of the habitat available for a specific model flow file. The original program had the SI values for the curves hard coded in the software. The program was modified to allow user specified SI curves to give greater flexibility. The program calculates and outputs three files. The first is a summary file with the total mesh area and the WUA for the mean column and 15cm velocities. In addition two files provide habitat information for each of the mesh model elements for both the mean column and 15cm velocities. For each element the files contain location (x and y), velocity, depth, element area, material type, depth WUA factor, vegetation WUA factor, velocity WUA factor, and suitable area.

RESULTS/CONCLUSIONS

Rio Vista

Tables (1) and (2) contain the WUA values for each of the modeled flows for Wild-rice and Fountain Darter respectively. As with the 1997 geometry WUA's generally increase as flow approaches the system mean or median flows. A comparison of Figures (9) and (11) for 30 cfs and Figures(10) and (12) for 170 cfs indicates how the change in channel geometry impacts the depth-velocity combinations. At both 30 and 170 cfs the 1997 geometry the depth-velocity histograms shows that depth-velocity combinations are in a narrower zone with a higher peak than that seen in the 2001 geometry.

Table (1) indicates a significant increase in WUA for Wild-rice when compared to the original 1997 values (Bartsch et al., 1999). This increase is an artifact of the changes made in the SI curves. As seen in SI contour overlays in Figures (10) and (11) the area of habitat marginally suitable for Wild-rice (SI less than 0.5) has increased greatly with the new SI curves. It now encompasses many more of the depth-velocity combinations seen in the channel for all the flows modeled. When the TPWD curve is used for both the 1997 and 2001 model results WUA's decrease as flow increases. The impact is highest at 30 cfs with a 30% reduction. For 15, 60, and 100 cfs the reduction is ~10% and decreases as flow increases to 135 (5% reduction in WUA) and 170 (2% reduction in WUA).

As in 1997, the Rio Vista section had the highest vegetation coverage and diversity according to the vegetation survey conducted by Baylor University. As observed previously in Bartsch, et al. (1999) this results in a higher proportion of the total wetted area being habitat suitable for the Fountain Darter. For example at 200 cfs (2001 geometry), the WUA is 62% of the wetted mesh while for the Above Capes section at 200 cfs (2001 geometry), the WUA is 47% of the wetted mesh.

The output of the 1997 Qual2E analysis was used to adjust Fountain Darter WUA's for temperature effects. This reduces available habitat by approximately 48% at 15 cfs, 28% at 30 cfs, 7% at 60 cfs, and 4% at 100 cfs. As flow approaches 170 cfs temperature in the Rio Vista section remains below 75.2°F throughout its length and thus at 170 cfs (and higher flows) temperature has no impact on Fountain Darter WUA.

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Above Capes

As with the Rio Vista section, habitat was not corrected for temperature modeling from the 1997 Qual2EU results. This section saw minimal impact on WUA's for temperature effects. One possibility for this is greater shading in this section. Again, WUA's are indicative of impacts on habitat by changing channel geometry and flow velocities.

WUA's for the Above Capes section are also in Tables (1) and (2) for Wild-rice and Fountain Darter. As with the Rio Vista section WUA's are at or near a maximum for flows around the system mean or median flow. This is true for all three modeled geometries; 1997, 2001, and No-dam. Figures (13) and (15) for 30 cfs and Figures(14) and (16) for 170 cfs show histograms for depth-velocity combinations for the 1997 and 2001 geometries. Figures (17) and (18) show the depth-velocity histograms for the No-dam geometry.

Wild-rice WUA's in Table (1) indicate an increase between 1997 and 2001, which again is due to the change in the SI curve. When comparing the geometries using the TWPD SI curve there is a slight decrease (6-9%) in WUA's at higher flows (135 and 170 cfs). At lower flows (30, 65, and 100 cfs) the reductions are higher (15-32%). A significant portion of the Above Cape's section is impacted by the backwater effect due to the presence of the dam. So in the No-dam scenario WUA's are higher (10-45%) at lower flows (30 and 65 cfs) due to the increase in the amount of shallower area with corresponding higher velocities. At higher flows this increase in WUA's changes to a decrease due to the reduction in the amount of wetted channel area.

*

As with the Rio Vista section the 1997 Qual2E analysis was used to adjust Fountain Darter WUA's for temperature. Overall temperatures are slightly higher in the Above Cape's section than the Rio Vista section. Habitat reduction effects are also slightly greater, approximately 54% at 15 cfs, 43% at 30 cfs, 20% at 60 cfs, 15% at 100 cfs, and 10% at 135 cfs. As flow approaches 170 cfs temperature in the Rio Vista section drops to 75.19°F, slightly below the critical 75.2°F point. At 170 cfs (and higher flows) temperature has no impact on Fountain Darter WUA.

See our clarification on pages 17-18.

*

For the No-dam scenario the decrease in the WUA's at all modeled flows is a quite dramatic 35-40%. The dominance of this section by *hydrilla* in the lower portions and bare substrate in the upper sections. Prior to actual dam removal it is recommended that changes in Fountain Darter WUA's due to changing vegetation distribution be carefully considered. Changes in vegetation distribution could either amplify or mitigate changes in Fountain Darter WUA caused by changes in depth-velocity distributions due to dam removal.

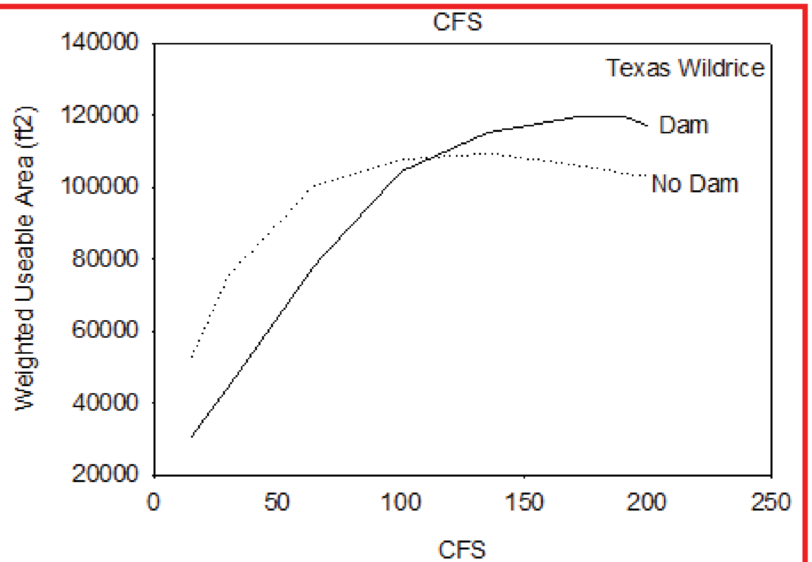
*

How is the results presented to the City of San Marcos in Hardy's October 2015 report that there would be an increase in suitable habitat for Fountain Darter at all flow rates for all dam scenarios (full dam, half-dam, no dam), when this report, dated August 2004 shows a "quite dramatic" decrease in Fountain Darter habitat for all flow rates, without a dam? Please see Table 2 on page 12 of this report for data.

Table 1: Modeled Texas Wild-rice (*Zizania texana*) Weighted Useable Area (WUA) by total San Marcos Springs flow rate. Data in the columns "from 1997 analysis" used the USFWS-USU SI curve. All other data used the TPWD SI curve.

Flow rate (cfs)	WUA (ft^2)										
	Rio Vista Section					Above Cape's Dam Section						
	Past Geometry (1997)			Current Geometry (2001)		Past Geometry (1997)			Current Geometry (2001)		No Dam Geometry (2001)	
	From 1997 analysis[1]	15 cm (0.49 ft)	Mean column	15cm (0.49 ft)	Mean column	From 1997 analysis[1]	15 cm (0.49 ft)	Mean column	15cm (0.49 ft)	Mean column	15cm (0.49 ft)	Mean column
15	283	123,570	118,740	109,550	108,040	105	38,740	36,310	33,150	30,570	55,020	52,610
30	1,624	261,190	249,710	182,570	178,320	1,251	69,010	64,650	46,830	44,380	76,110	75,550
65	3,905	351,080	341,190	307,490	297,490	11,068	110,400	106,350	81,720	78,370	98,840	100,580
100	10,524	392,580	381,260	360,360	353,260	25,584	125,480	124,220	105,910	104,330	105,350	107,680
135	17,191	393,250	388,950	374,390	371,030	44,043	128,360	128,300	115,990	115,160	105,670	109,370
170	25,922	383,960	380,650	374,810	372,750	56,100	126,990	128,490	118,770	119,370	102,050	106,280
190	-	-	-	350,830	349,330	-	-	-	118,920	119,880	99,980	103,910
200	-	-	-	339,580	338,490	-	-	-	115,840	116,950	99,090	103,030
Total Mesh Area	546,100					244,300			247,300			

Note 1: From Table 8, Bartsch et al. (1997)



This graph (left) was produced based upon the data shown in Table 1 (above) and graphically displays what the numbers show: Texas Wild Rice has a higher WUA (Weighted Usable Area) with Cape's Dam in place.

WR	2001	no dam	% change
15	30,570	52,610	72.1
30	44,380	75,550	70.2
65	78,370	100,580	28.3
100	104,330	107,680	3.2
135	115,160	109,370	-5.0
170	119,370	106,280	-11.0
190	119,880	103,910	-13.3
200	116,950	103,030	-11.9

An examination of Hard's data, and this graph produced from Hardy's data, demonstrates rice habitat with a dam is favored at about 100 cfs or greater, which occurs about 90% of the time. Therefore Cape's Dam would provide *more* habitat for rice *more often* than the benefits of no dam during low flows, which occurs infrequently.

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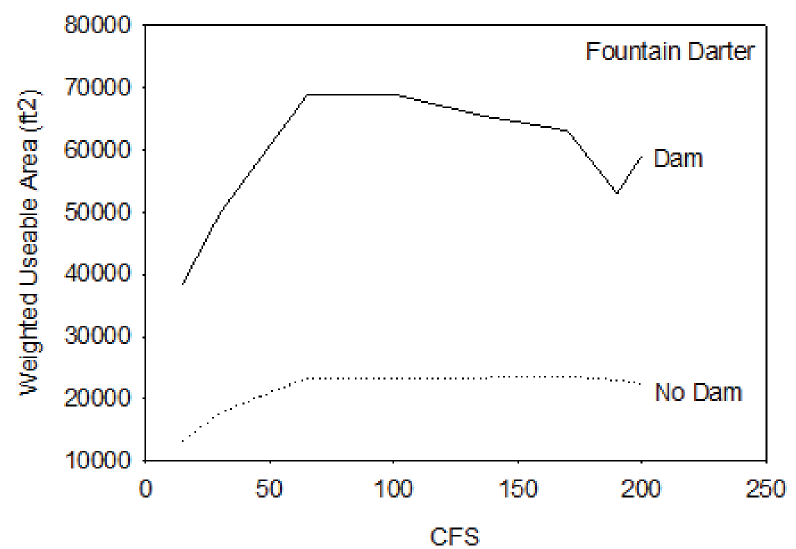
Table 2: Modeled Fountain Darter (*Etheostoma fonticola*) Weighted Useable Area by total San Marcos Springs flow rate.

Flow rate (cfs)	WUA (ft^2)											
	Rio Vista Section					Above Cape's Dam Section						
	Past Geometry (1997)			Current Geometry (2001)		Past Geometry (1997)			Current Geometry (2001)		No Dam Geometry (2001)	
	From 1997 analysis[1]	15cm	Mean column	15cm	Mean column	From 1997 analysis[1]	15cm	Mean column	15cm	Mean column	15cm	Mean column
15	20685	48420	48470	50700	50690	8397	38720	38720	38480	38480	13250	13320
30	77633	89830	90440	89170	90160	46335	47640	47740	49870	49890	17460	17840
65	151422	174210	178480	156020	158450	54197	64930	65330	68520	68820	22750	23360
100	185614	188410	195070	179710	183830	60143	65870	66710	68620	68980	22610	23330
135	220996	197270	207960	183320	188700	56240	64280	65250	64910	65590	22480	23410
170	229134	188300	194610	174840	180320	51181	63220	63930	62350	63150	22940	23720
190	-	-	-	179060	183320	-	-	-	52800	53020	22180	22990
200	-	-	-	179060	183450	-	-	-	58760	59190	21760	22420
Total Mesh Area	546,100					244,300			247,300			

Note 1: From Table 7, Bartsch et al. (1997)



This graph (left) was produced based upon the data shown in Table 1 (above) and graphically displays what the numbers show: Fountain Darter has a substantially higher WUA (Weighted Usable Area) at ALL flow rates with Cape's Dam in place.

FD	2001	No dam	% change
15	38480	13320	-65.4
30	49890	17840	-64.2
65	68820	23360	-66.1
100	68980	23330	-66.2
135	65590	23410	-64.3
170	63150	23720	-62.4
190	53020	22990	-56.6
200	59190	22420	-62.1

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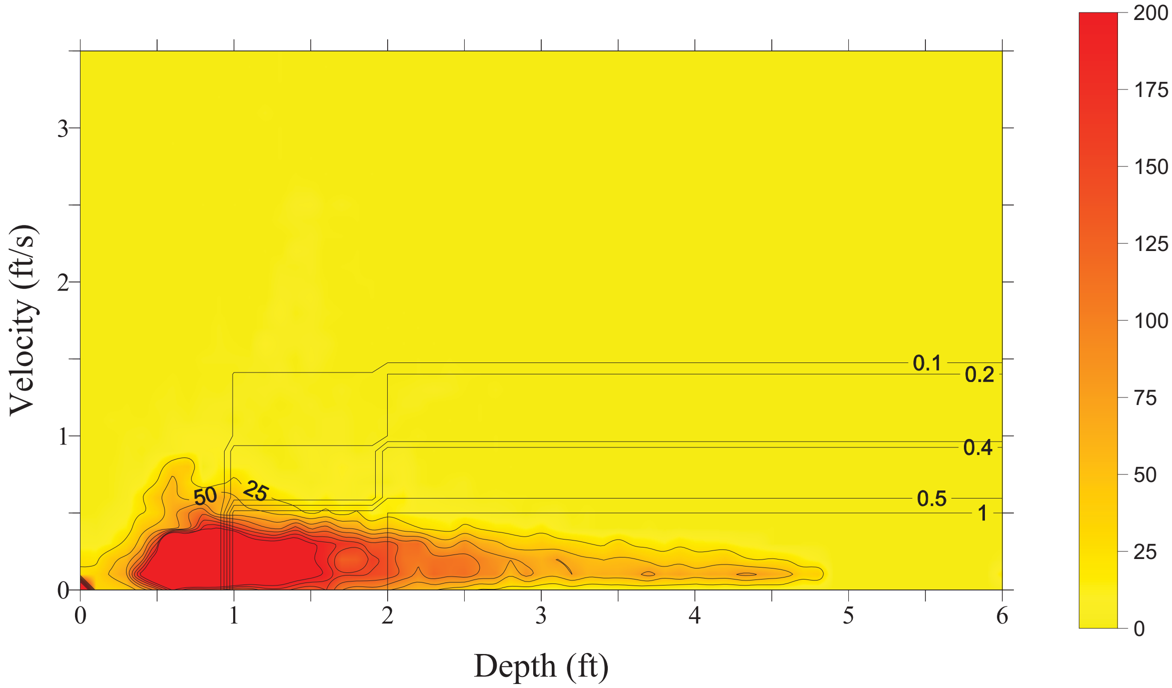

Figure 9: Velocity versus Depth histogram at 30 cfs for the 1997 geometry in the Rio Vista Section overlain with Fountain Darter SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

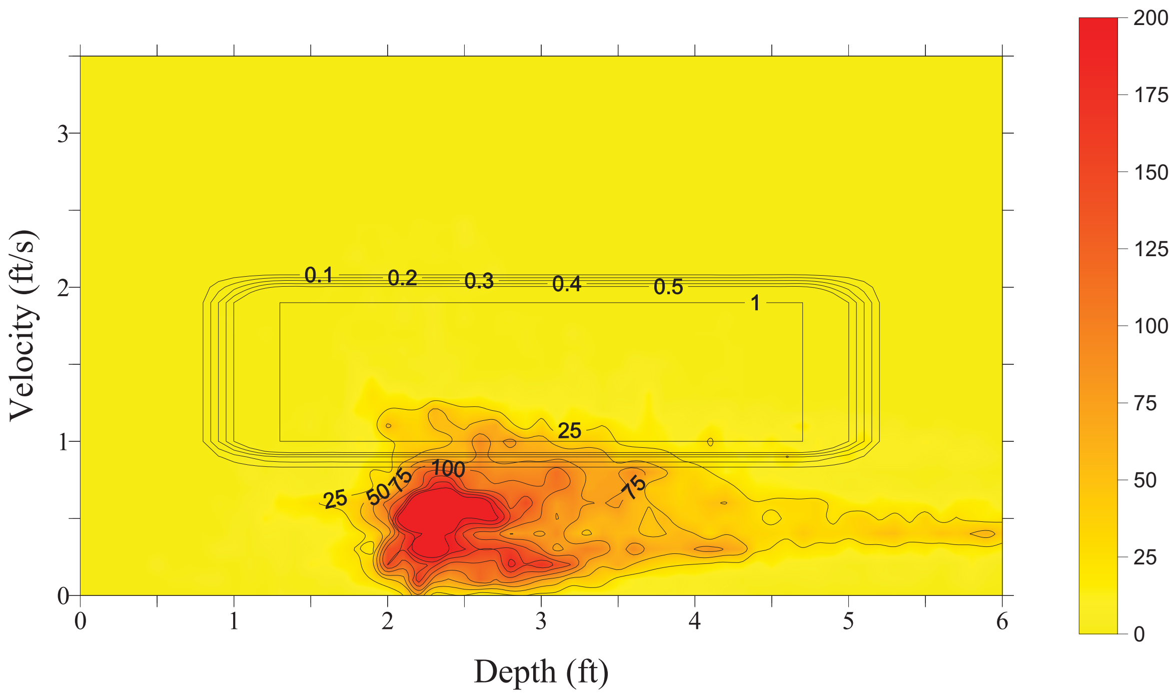

Figure 10: Velocity versus Depth histogram at 170 cfs for the 1997 geometry in the Rio Vista Section overlain with USFWS-USU Texas Wild-rice SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

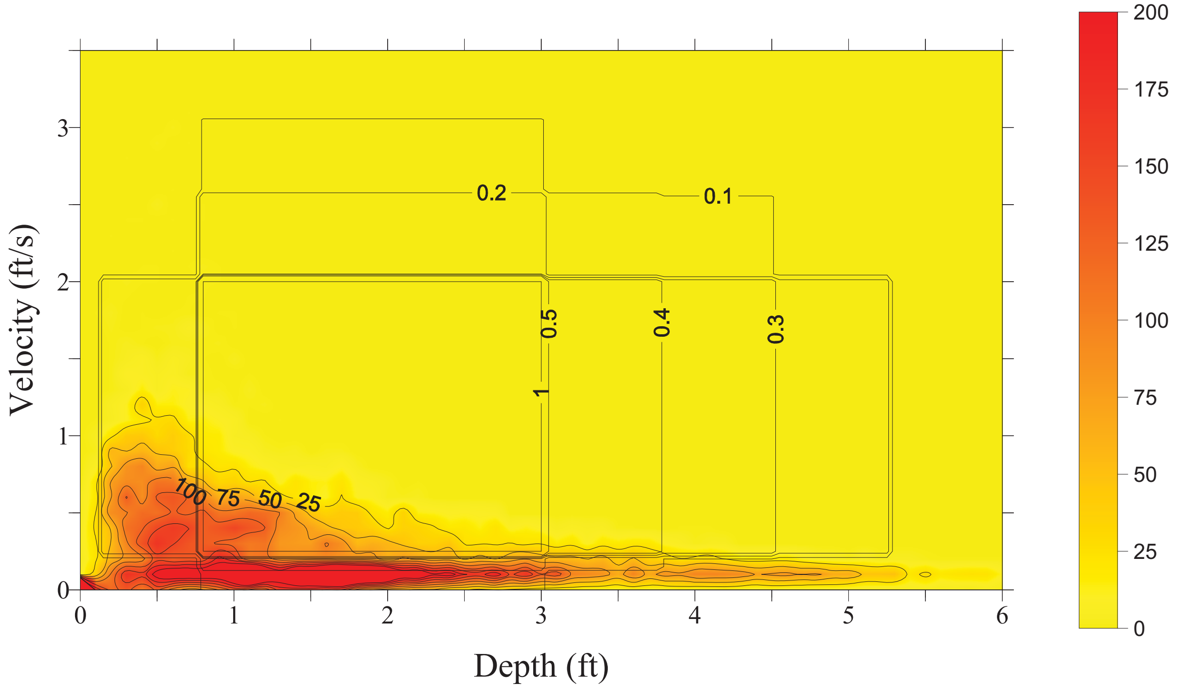

Figure 11: Velocity versus Depth histogram at 30 cfs for the 2001 geometry in the Rio Vista Section overlain with TPWD Texas Wild-rice SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

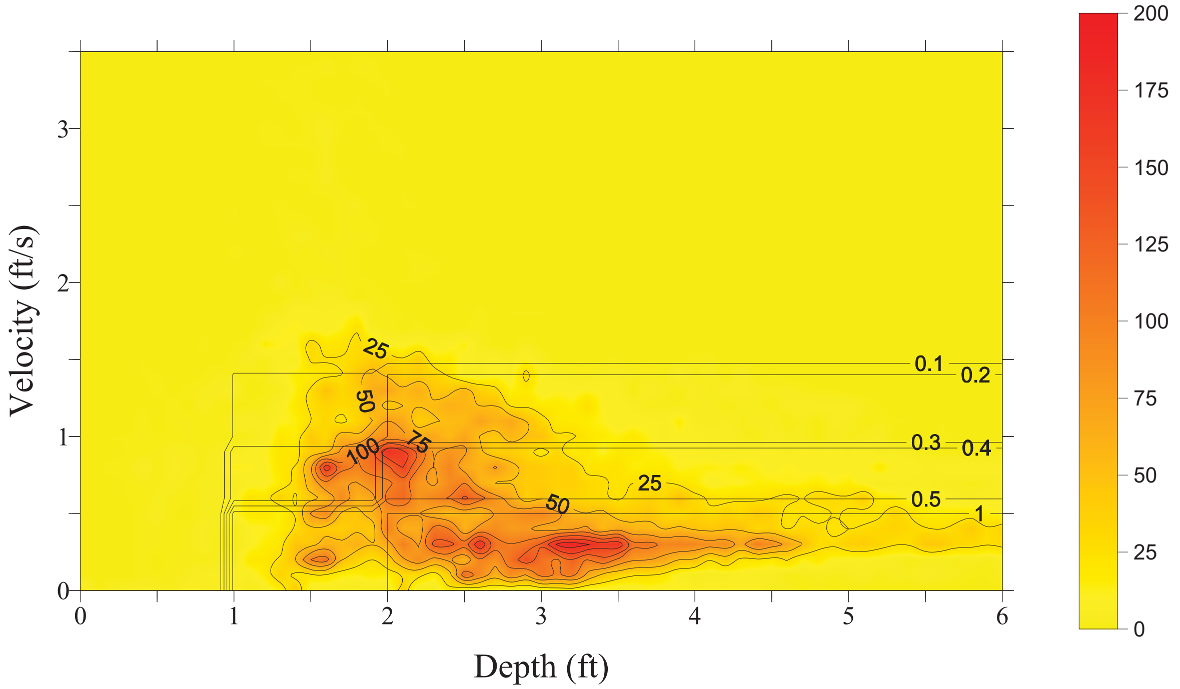

Figure 12: Velocity versus Depth histogram at 170 cfs for the 2001 geometry in the Rio Vista Section overlain with USFWS-USU Texas Wild-rice SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

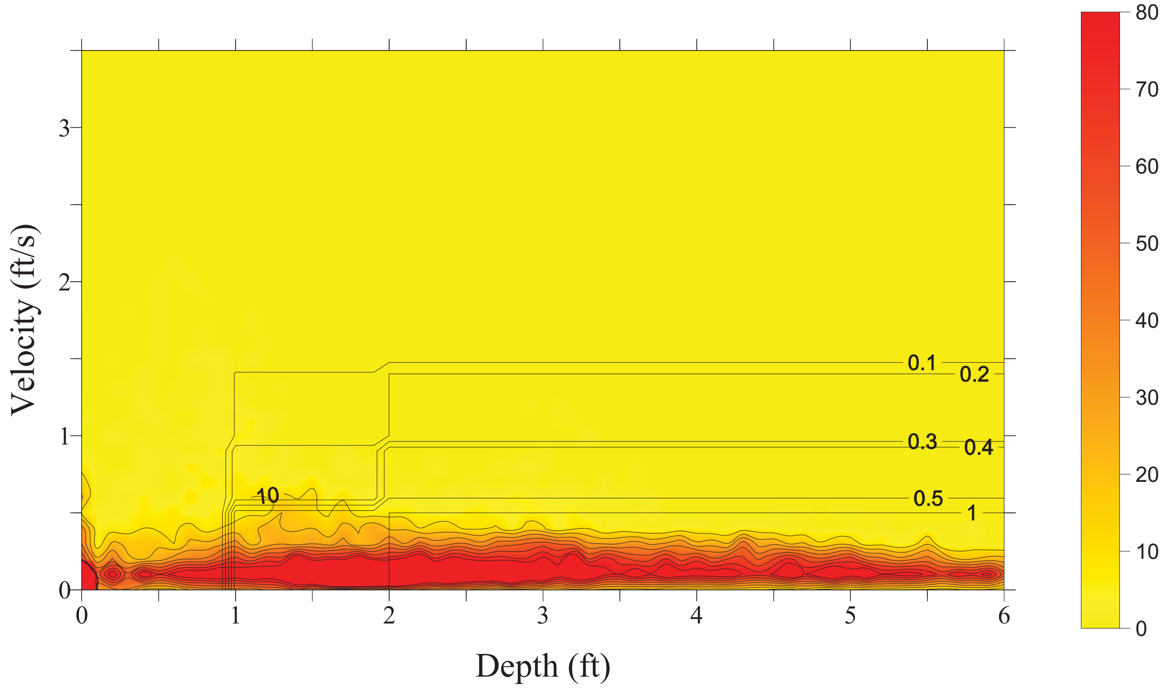

Figure 13: Velocity versus Depth histogram at 030 cfs for Above Capes Section (1997 geometry) overlain with Fountain Darter SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

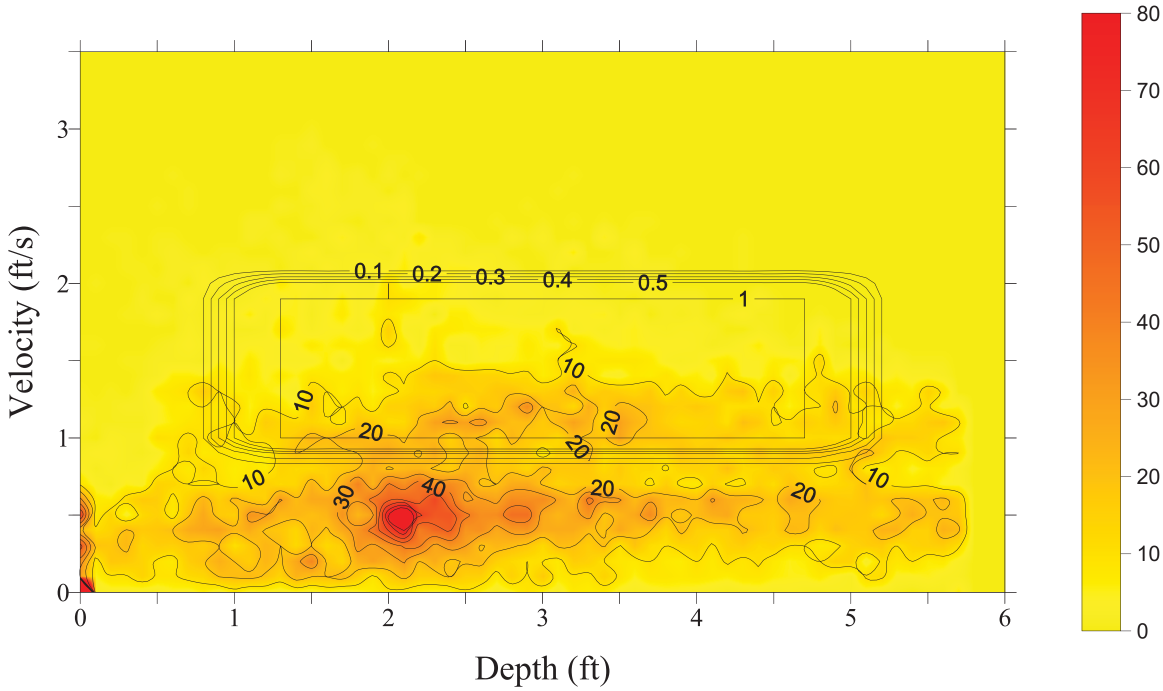

Figure 14: Velocity versus Depth histogram at 170 cfs for Above Capes Section (1997 geometry) overlain with USFWS-USU Texas Wild-rice SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

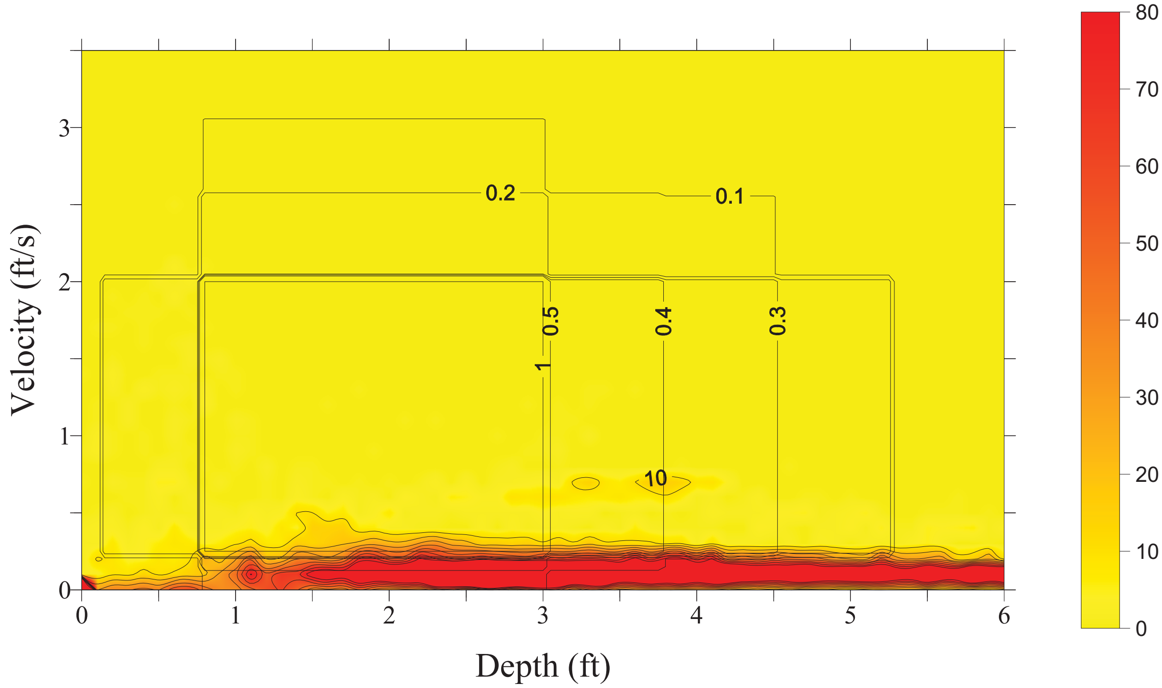

Figure 15: Velocity versus Depth histogram at 030 cfs for Above Capes Section (Current geometry) overlain with TPWD Texas Wild-rice SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

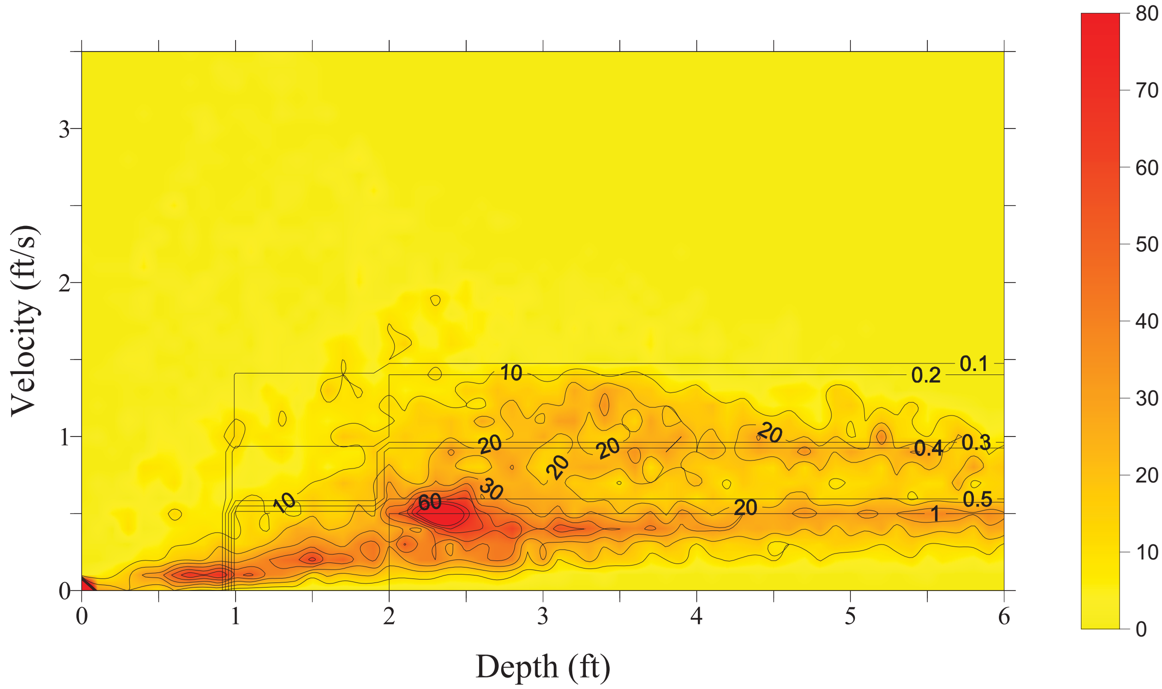

Figure 16: Velocity versus Depth histogram at 170 cfs for Above Capes Section (Current geometry) overlain with Fountain Darter SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

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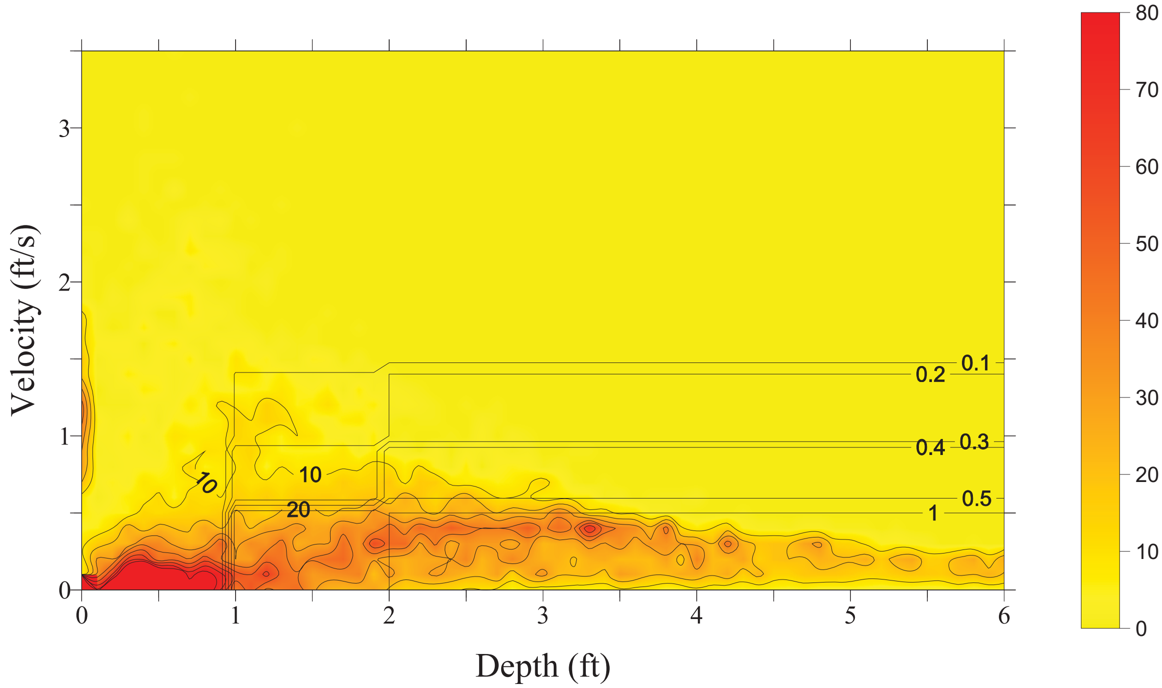

Figure 17: Velocity versus Depth histogram at 30 cfs for Above Capes Section (No Dam geometry) overlain with Fountain Darter SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

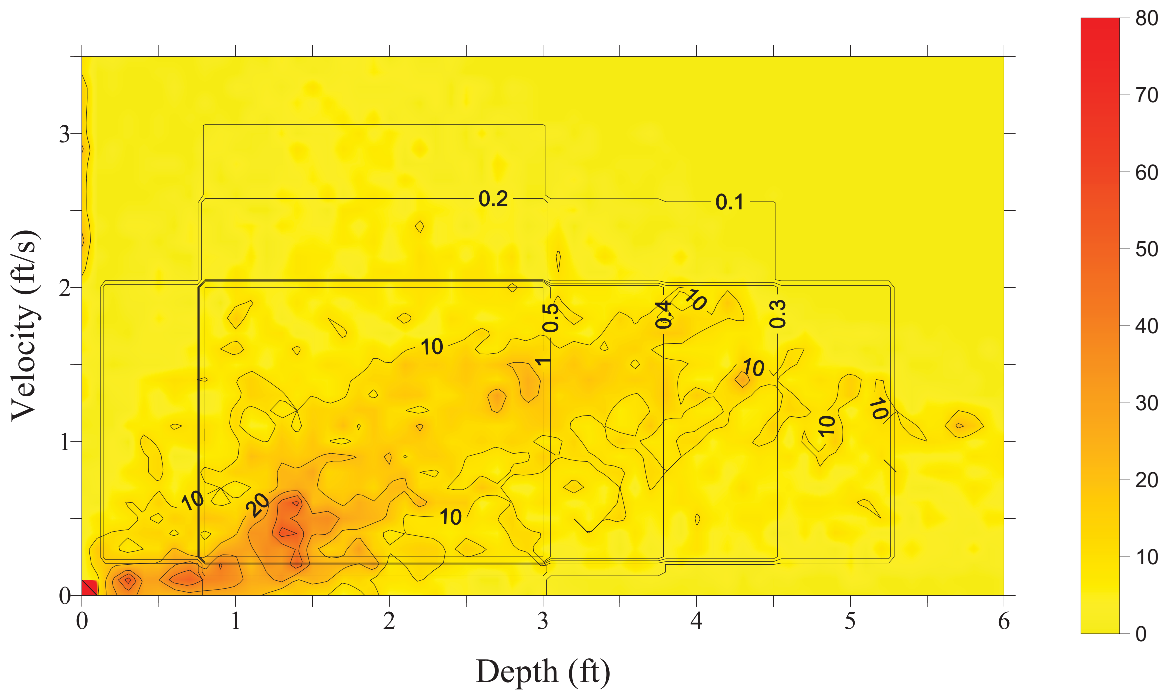

Figure 18: Velocity versus Depth histogram at 170 cfs for Above Capes Section (No Dam geometry) overlain with TPWD Texas Wild-rice SI contours. The color shading with contours is the histogram for Velocity & Depth combinations. SI curves at a 0.1 interval (0.1, 0.2, 0.3, 0.4, 0.5, & 1.0 labeled).

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