Effects of changing height of Cape's Dam on recreation, Texas wild rice and fountain darter habitat in the San Marcos River, Texas

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INTRODUCTION

Watershed Systems Group, INC was tasked to assist the City of San Marcos in the evaluation and the implications if Cape's Dam was rebuilt to full height, modified to half its existing height or was removed on impacts/benefits to recreation and the habitats for the endangered Texas wild rice (TWR) and fountain darters in the San Marcos River. The assessment relied upon existing data on river topography, empirical hydraulic and river sediment properties in conjunction with supplemental field data and habitat models developed at Texas State University (Hardy et al., 2012). Advanced hydrodynamic modeling was utilized to evaluate expected changes in river bed topography due to sediment transport and river bed evolution under full height, half height and full dam removal that was not considered in the previous modeling evaluations (Hardy et al., 2012). The resulting evolved river bed topography and associated hydraulic properties were utilized to model TWR and fountain darter habitat as well as modeling water based recreation under all three Capes Dam conditions. Habitat modeling for TWR and fountain darters followed the procedures developed by Hardy et al. (2012) and in the development of the Edwards Aquifer Habitat Conservation Plan for consistency.

METHODS

Study Area

Figure 1 shows the spatial extent of the assessment conducted in the San Marcos River. The study area includes the reach downstream from Rio Vista Dam downstream to the TPWD State Hatchery outflow. The reach of the river encompasses the spatial extent most likely to be affected by the proposed Cape's Dam scenarios and occupied habitat for the endangered TWR and fountain darters.

Figure 1. San Marcos River study area.

River Channel Topography, Hydraulic and Substrate/Vegetation Data

Topography (i.e., elevation), substrate, vegetation, and surface water elevation data were collected from September 2009 – April 2010. Standard survey equipment and GPS Trimble XH units were used to measure topography within the wetted portion of the stream using a systematic irregular sampling strategy that targets capturing all available heterogeneity within the stream channel topography. Data density was approximately 3000 data points per 100 meter of stream length. Latitude (x), longitude (y), depth, and substrate type were recorded at each point surveyed. Vegetation within the stream was delineated with polygons with the corresponding percentages of each vegetation or substrate type recorded for each polygon. Vegetation polygons were spatially joined with the hydrodynamic modeling grids to assign roughness values and vegetation class attributes for habitat modeling of fountain darters and Texas wild rice. Discharge and water surface elevation (WSE) longitudinal profiles were recorded each day during field measurements of channel topography. In addition, data collected by Dr. Paul Hudson from the University of Texas as part of the original modeling efforts in 2012 were utilized and consisted of penetrometer and substrate grab samples at 100 locations upstream of Capes Dam to estimate particle size distribution and depth of sediments. Lateral scour and bed evolution data were also obtained at fixed cross section locations associated with monitoring of channel changes post channel dredging in reaches below Capes Dam (Hudson, 2012).

Initial water surface elevations under existing conditions were obtained from the calibrated two-dimensional hydrodynamic models developed at Texas State University (Hardy et al., 2010). Table 1 documents the hydraulic model roughness heights (meters) for various substrate and vegetation types utilized in the modeling.

Table 1. Roughness (height in meters) of vegetation and substrate in the San Marcos River.

Substrate Type	Roughness (m)
Bedrock	0.027
Boulder/Cobble	0.050
Clay	0.030
Cobble	0.050
Concrete	0.050
Gravel	0.050
Gravel/Cobble	0.050
Gravel/Sand	0.040
Gravel/Sand/Silt	0.040
Large Boulder	0.050
Metal	0.050
Sand	0.030
Silt	0.030
Silt/Sand	0.030
Small Boulder	0.050
Vegetation	0.075

Computational Mesh from River Topography

The process of taking river bed topography to generate the computational mesh for use in the hydraulic modeling was accomplished using triangular irregular networks as illustrated graphically in Figure 2.

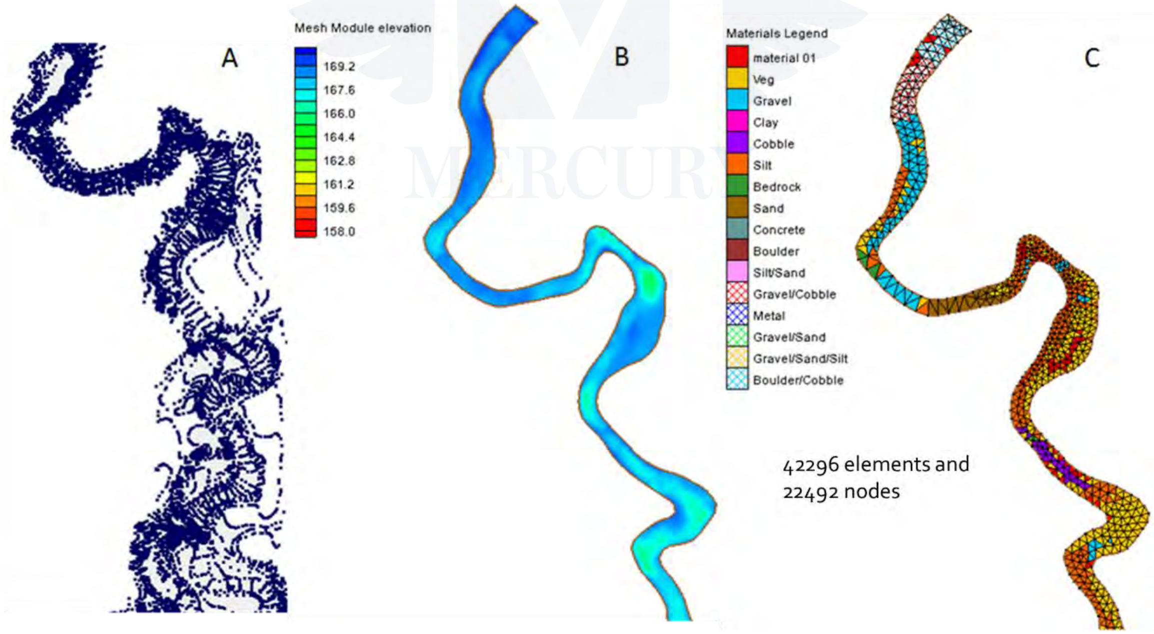

Figure 2. Example of field measured topography points (A) and computational mesh mapped onto elevation contours (B) and substrate (C).

Assumed Capes Dam Configurations for Full Height, Half Height and Complete Removal

The channel topography associated with full height at Capes Dam was taken from previous survey work conducted in 2009 as shown in Figure 3. These data were used to construct the full height computational mesh to reflect this topography as shown in Figure 4. The computational mesh in Figure 4 was lowered by 50 percent and then 100 percent to approximate the starting conditions for the hydrodynamic modeling as illustrated in Figures 5 and 6.

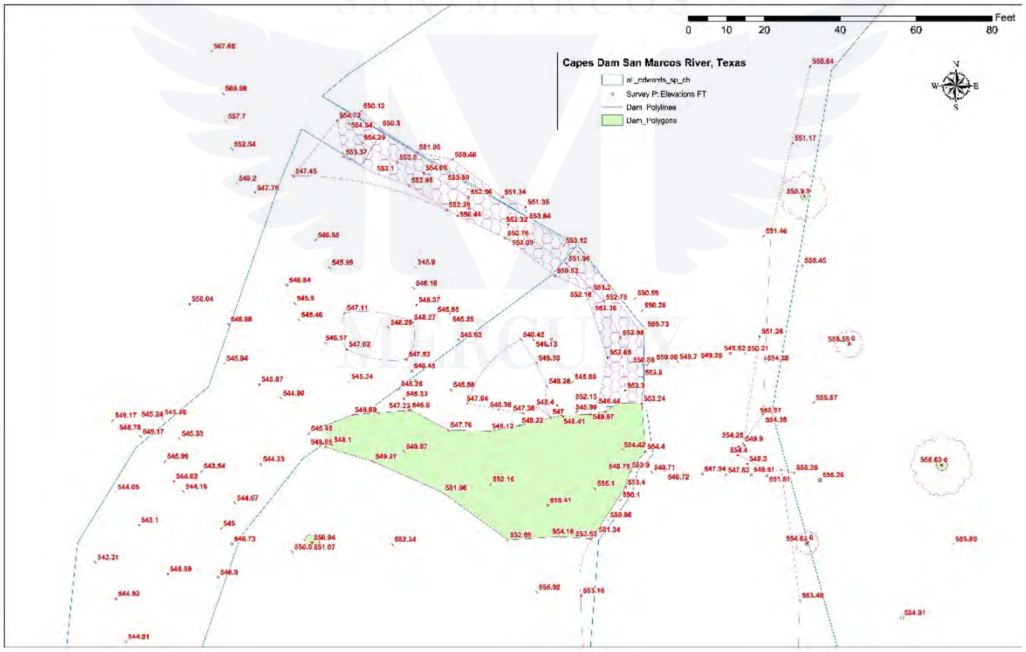

Figure 3. Survey data for full height Capes Dam.

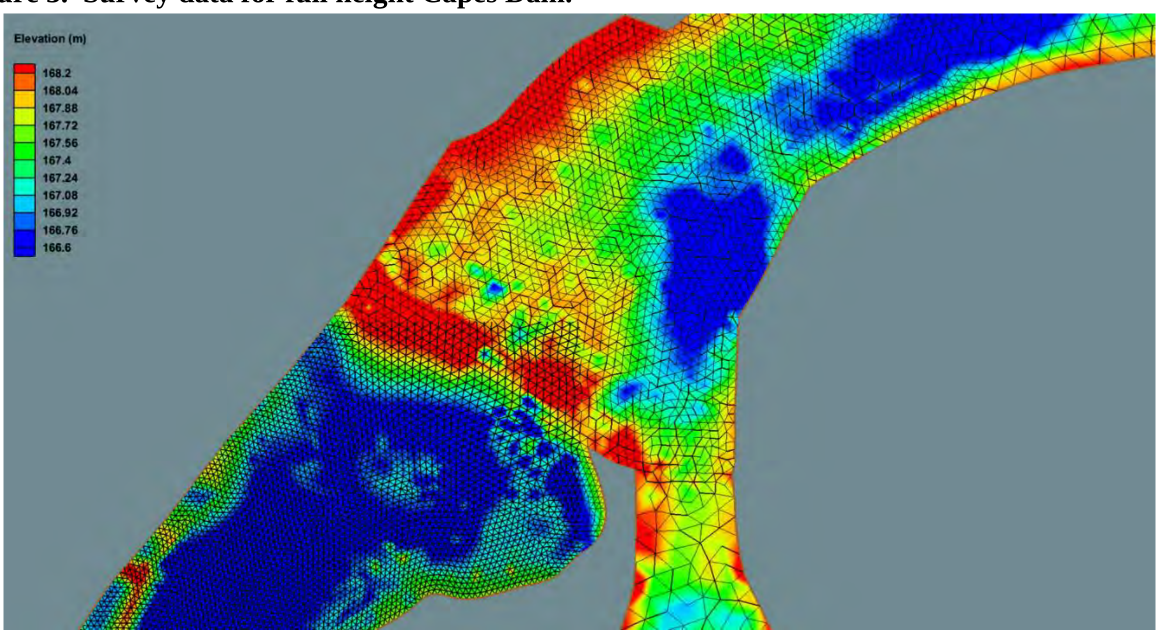

Figure 4. Assumed computation mesh for full height Capes Dam used in the hydrodynamic modeling.

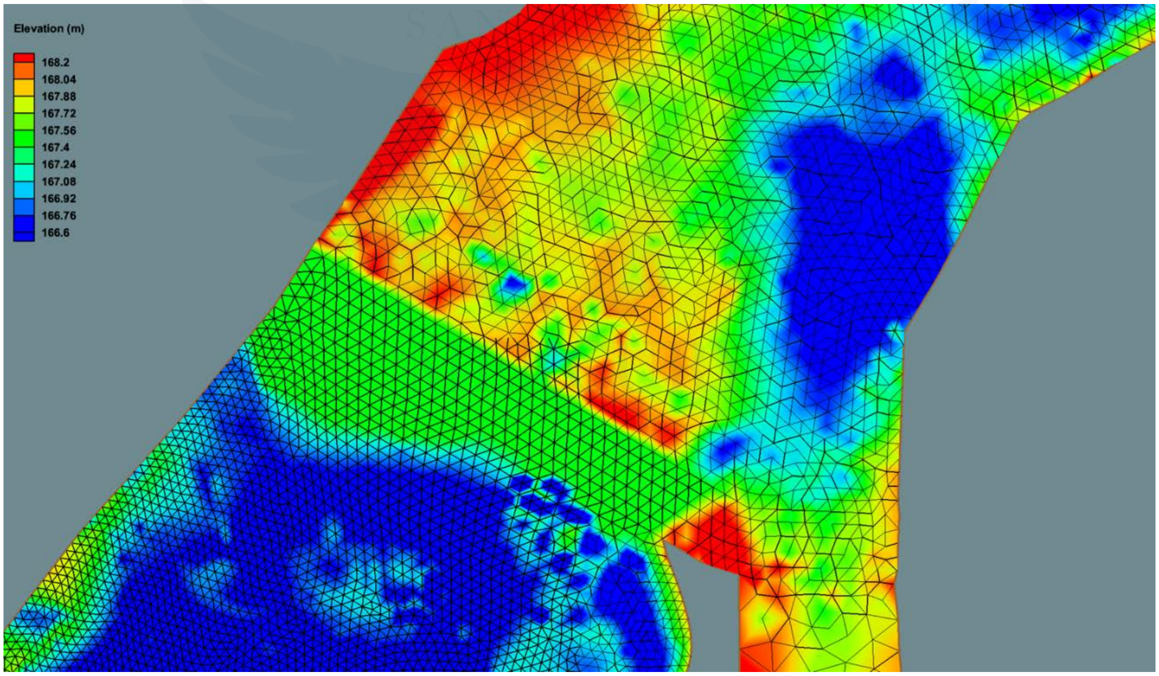

Figure 5. Assumed computation mesh for half height Capes Dam used in the hydrodynamic modeling.

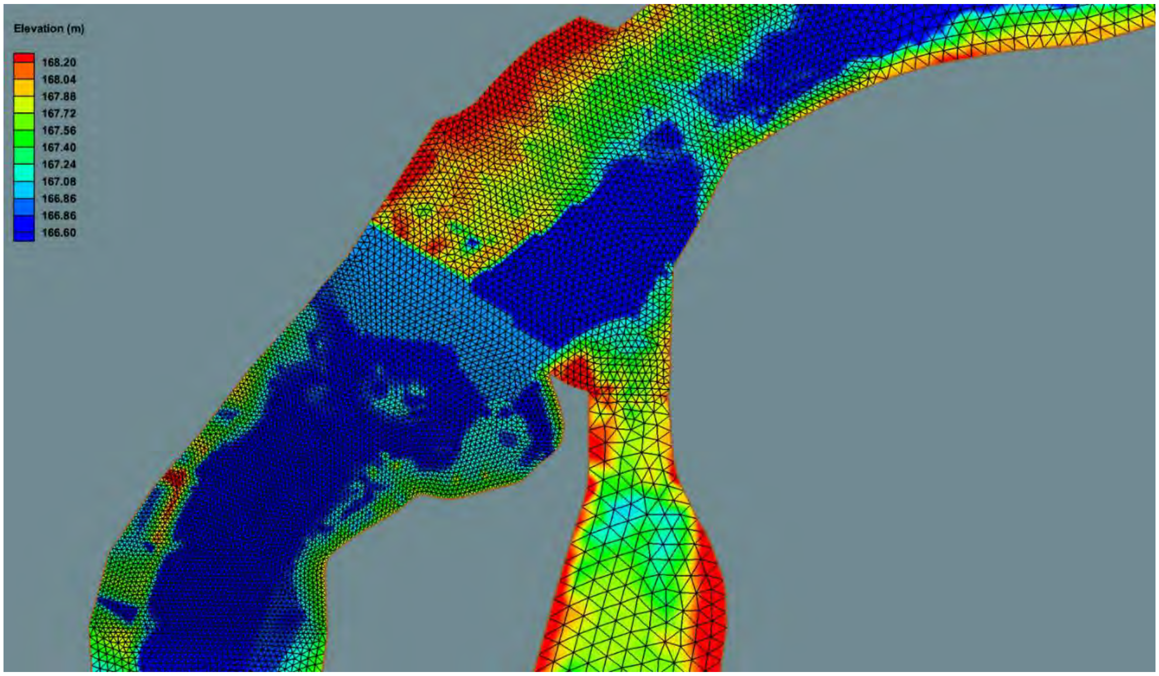

Figure 6. Assumed computation mesh for complete removal of Capes Dam used in the hydrodynamic modeling.

Sediment Characteristics

Surficial sediment polygons over the study area were mapped using GPS and spatially joined with the computational mesh using GIS as noted previously. However, to support the bed evolution modeling under full height, half height and complete removal, the data from Hudson (2012) was used to characterize the particle size distribution behind Capes Dam (Table 2) and then spatially interpolate sediment characteristics and sediment depth profiles as illustrated in and Figures 7 and 8. Based on these data, Hudson (2012) estimated that ~ 6,700+ cubic meters of fine sediment are trapped behind Capes Dam.

Table 2. Sediment particle size distributions behind Capes Dam (adapted from Hudson, 2012).

Reservoir bottom sediment samples of Capes Dam							
G=grab sample at bed with sediment sampler; Sh=shallow core sample (0-10 cm); Dp=deep core sample (20-30 cm)							
			Sediment size (mm)				
			D10	D50	D90	Sample type	Location
Sample ID #	X	Y	(10 % finer by weight)	(50% finer by weight, median size)	(90% finer by weight)		
SM-1	-	-	**-**	**-**	**-**	N/A	Thalweg
SM-2-G	N29º 52' 27.9	W097º 55' 52.2	**<0.001**	**0.7**	**>1**	Grab	Inside bend
SM-3-Sh	N29º 52' 27.3	W097º 55' 51.4	**<0.001**	**0.0035**	**0.4**	Core (Shallow)	Outside bend
SM-3-Dp			**<0.001**	**0.005**	**>1**	Core (Deep)	
SM-4-Sh	N29º 52' 27.3	W097º 55' 52.1	**<0.001**	**0.15**	**>1**	Core (Shallow)	Inside bend
SM-5-G	N29º 52' 27.1	W097º 55' 52.3	**<0.001**	**0.26**	**0.7**	Grab	Riffle
SM-6-G	N29º 52' 26.7	W097º 55' 52.8	**<0.001**	**0.16**	**0.5**	Grab	Pool
SM-7-Sh	N29º 52' 27.2	W097º 55' 53.5	**<0.001**	**0.0140**	**0.19**	Core (Shallow)	Outside bend
SM-7-Dp			**<0.001**	**0.0085**	**0.14**	Core (Deep)	
SM-8-Sh	N29º 52' 26.0	W097º 55' 53.4	**<0.001**	**0.0140**	**0.13**	Core (Shallow)	Outside bend
SM-8-Dp			**<0.001**	**0.0013**	**0.13**	Core (Deep)	
SM-9-Sh	N29º 52' 25.8	W097º 55' 52.6	**<0.001**	**0.0020**	**0.20**	Core (Shallow)	Inside bend
SM-9-Dp			**<0.001**	**0.0022**	**0.30**	Core (Deep)	
SM-10-G	N29º 52' 25.2	W097º 55' 53.1	**-**	**-**	**-**	Grab	Thalweg
SM-11-Sh	N29º 52' 24.9	W097º 55' 52.3	**<0.001**	**0.0042**	**0.18**	Core (Shallow)	Left bank
SM-11-Dp			**<0.001**	**0.0090**	**0.26**	Core (Deep)	
SM-12-G	N29º 52' 24.6	W097º 55' 52.5	**<0.001**	**0.31**	**>1**	Grab	Riffle
SM-13-Sh	N29º 52' 24.1	W097º 55' 52.7	**<0.001**	**0.0350**	**0.51**	Core (Shallow)	Inside bend
SM-13-Dp			**<0.001**	**0.0169**	**0.30**	Core (Deep)	
SM-14-Sh	N29º 52' 23.0	W097º 55' 53.5	**<0.001***	**>1**	**>1**	Core (Shallow)	Right bank
SM-14-Dp			**<0.001**	**0.2200**	**0.45**	Core (Deep)	
SM-15-Sh	N29º 52' 23.2	W097º 55' 53.3	**<0.002**	**0.0040**	**0.80**	Core (Shallow)	Left bank
SM-15-Dp			**<0.003**	**0.0035**	**1.00**	Core (Deep)	
SM-16-Sh	N29º 52' 23.3	W097º 55' 52.0	**<0.001**	**0.0025**	**0.11**	Core (Shallow)	Outside bend
SM-16-Dp			**<0.001**	**0.0029**	**0.13**	Core (Deep)	
SM-17-G	N29º 52' 23.1	W097º 55' 53.8	**<0.001**	**0.1300**	**0.45**	Grab	Thalweg
SM-18-G	N29º 52' 27.0	W097º 55' 53.0	**<0.001**	**0.2700**	**0.90**	Grab	Thalweg
SM-19-G	N29º 52' 28.0	W097º 55' 51.7	**<0.001**	**0.1700**	**0.99**	Grab	Thalweg
SM-20-Sh	N29º 52' 28.5	W097º 55' 52.1	**<0.001**	**0.0600**	**0.40**	Core (Shallow)	Left bank
SM-20-Dp			**<0.001**	**0.0300**	**0.33**	Core (Deep)	

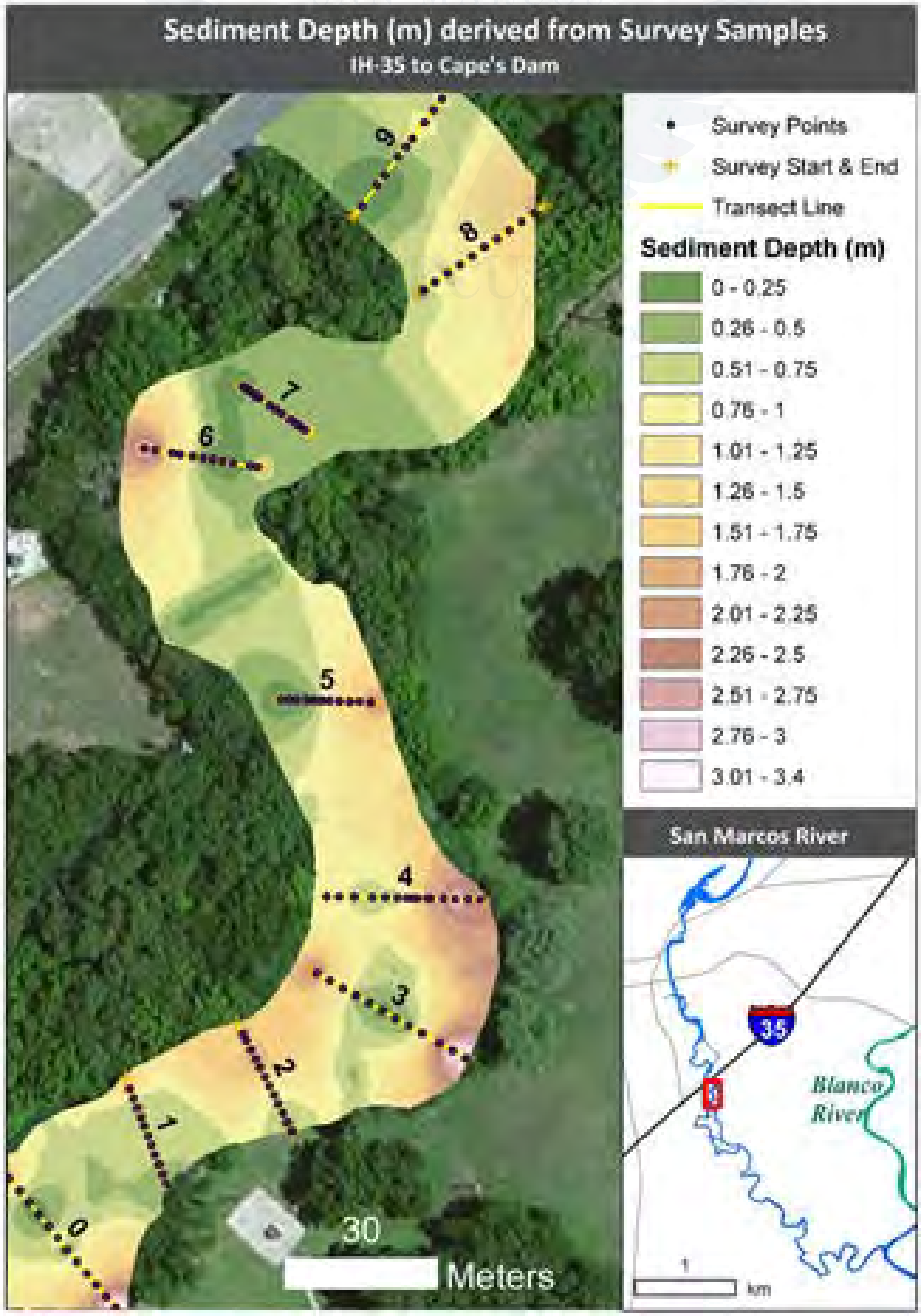

Figure 7. Location of field measurements of sediment behind Capes Dam and interpolated spatial distribution used in the hydrodynamic modeling (adapted from Hudson 2012).

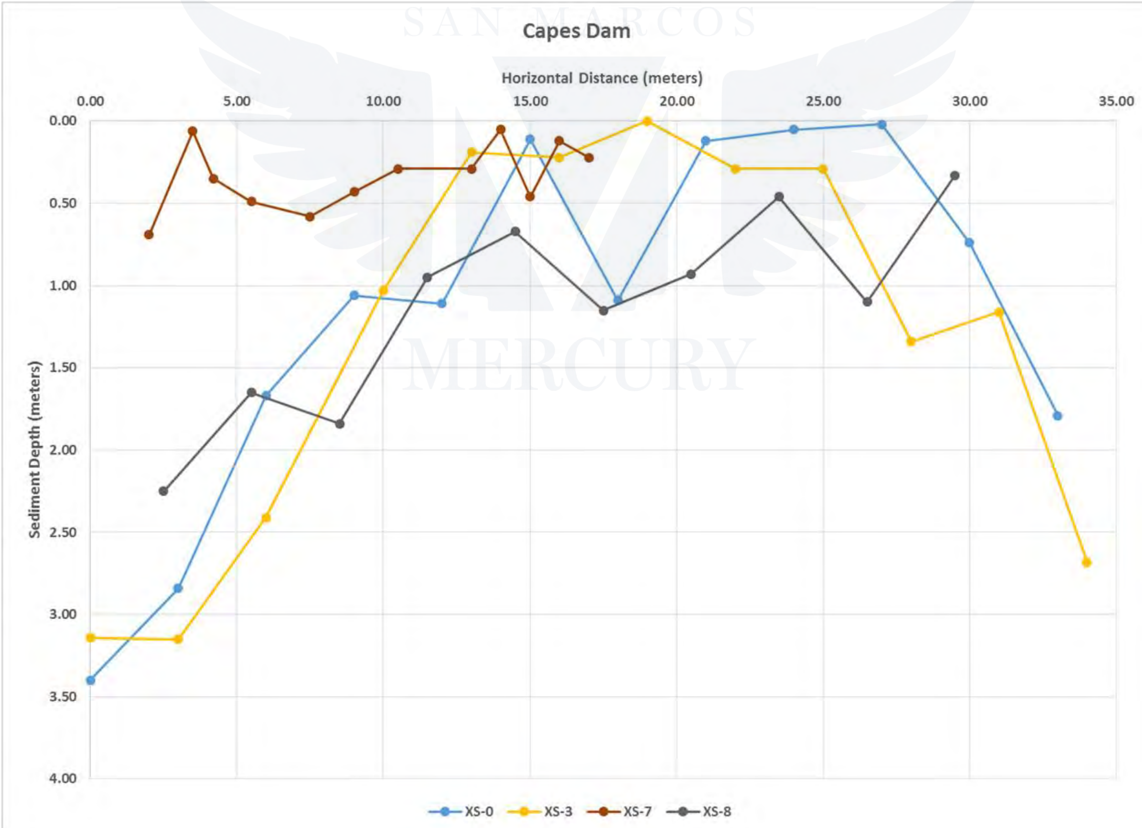

Figure 8. Sediment depth profiles for selection cross sections (see Figure 7 for location) behind Capes Dam (adapted from Hudson 2012).

Simulated Flows

Four different steady state flows were modeled for this the study; these flows, ranging from 45 to 300 cfs, are shown in Table 3. The 45 cfs flow was modeled as it represents the expected minimum flow under the proposed Edwards Aquifer Habitat Conservation Plan during a repeat of the drought of record. The 100 cfs flow was chosen as this flow is equaled or exceeded 90 percent of the time and similar to low flow conditions observed during the summer of 2009. The 173 cfs flow was chosen as it is approximately the long term median discharge of the San Marcos River. The 300 cfs discharge is equaled or exceeded approximately 10 percent of the time and as noted below, was utilized to evolve the river bed topography under sediment transport conditions.

Table 3. Modeled discharge and percent of time exceeded for the San Marcos River.

Discharge Cfs[1]	Discharge Cms[2]	Percentage of time flow equaled or exceed * (1995-2011)
45	1.27	Not Determined
100	2.83	90
173	4.9	50
300	8.5	10

* Flows Measured at USGS Gage 08170500 San Marcos River at San Marcos, Texas
1 = cubic feet per second
2 = cubic meters per second

Hydraulic Modeling

Adaptive Hydraulics (ADH) is an unstructured finite element package capable of modeling 2-dimensional and 3-dimensional shallow water equations, 3-dimensional Navier Stokes equations, groundwater equations and groundwater-surface water interaction. ADH solves the hydraulic and sediment transport equations while dynamically adapting the mesh so that a coarse mesh can give results as accurate as a mesh with finer resolution. (Berger et al., 2011) (See Figure 9).

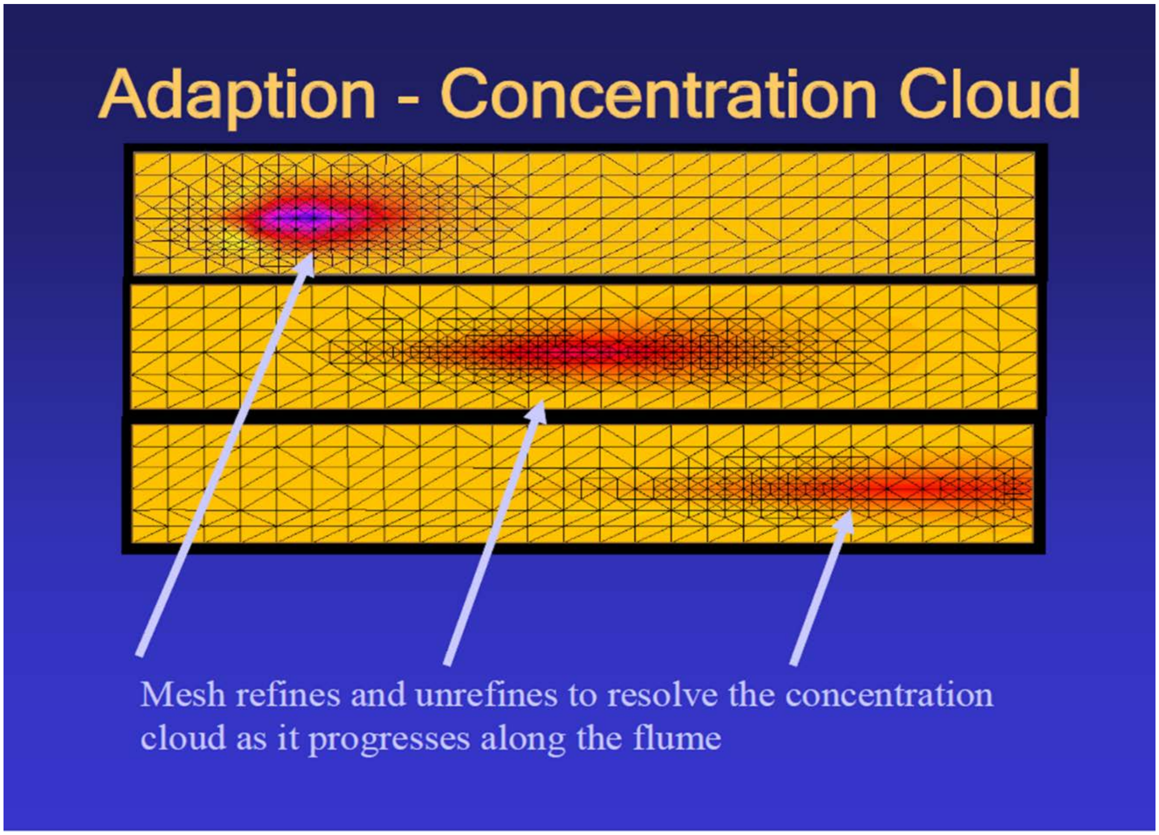

Figure 9. Example of dynamically adaptive mesh of ADH for refinement of sediment transport.

ADH contains other essential features such as wetting and drying, completely coupled cohesive and non-cohesive sediment transport. One of the major benefits of ADH is it also allows for the rapid convergence of flows to steady state solutions using parallel processing architecture. ADH contains other essential features such as completely coupled sediment transport. The User's Manual for Adaptive Hydraulics Modeling system provides additional information on the hydrodynamic modeling capabilities of ADH (Berger et al., 2011).

The 300 cfs flow was modeled for 30 days to approximate bed evolution under high flow conditions where sediment transport and scouring are known to occur. This approach is a pragmatic modeling compromise to approximate the long-term channel adjustments associated with intermittent 'storm events' by using a shorter simulation period with a sustained high flow given the intensive computational burden of the model. Simulations were carried out on a 64 node parallel processing architecture and each 30 day simulation required approximately 23 hours. Hydraulic model calibrations followed standard engineering practice by changing model parameters such as roughness and viscosity until agreement between predicted and observed water surface elevation profiles were achieved for each dam scenario.

Modeling Texas wild rice, Fountain Darters and Recreation

Both Texas wild rice and fountain darters were modeled by computing physical habitat based on habitat suitability curves for depth, velocity and substrate/vegetation cover using the approach in Hardy et al. (2012). At each computational node, given the simulated depth, velocity, etc, the suitability of the 'cell' was computed by the following equations:

Texas Wild Rice and Fountain Darters

The combined suitability for Texas wild rice was derived as the geometric mean of the component suitability's for depth and current velocity as follows:

$$\text{TWR Combined Suitability} = (\text{TWRdS} * \text{TWRcvS})^{1/2}$$

The combined suitability for fountain darters was derived as the geometric mean of the component suitability's for depth, velocity and substrate/vegetation as follows:

$$\text{Fountain Darter Combined Suitability} = (\text{FDdS} * \text{FDcvS} * \text{FDsubS})^{1/3}$$

The suitable area of the computational cell is then derived by multiplying the combined suitability by the area of the computational cell. The total suitable area for the reach at a given discharge is the sum of all computational cells weighted by the corresponding combined suitability in each cell. For example, if the combined suitability for depth and velocity in all computational cells for TWR were 1.0 then the amount of habitat for TWR would be equal to the surface area of the stream at that simulated discharge. For a given flow rate and dam scenario (i.e., full height, half height, or full removal), the total available habitat area for TWR or fountain darters were normalized by the total wetted surface area in the river at that simulated flow.

Recreation

Based on a review of the recreational literature (e.g., Mosley 1983; Shelby et al., 1992) and empirical experience, a simple 2 foot minimum depth was set as the criteria to permit water borne recreation in terms of kayaks, canoes, paddle boards, and tubing. Specifically, all locations that were over two feet deep were considered suitable for recreation. Therefore, the total area suitable for recreation is the total surface area of the stream at a given flow rate and dam scenario that is over two feet deep. As was the case for TWR and fountain darters, the recreational area was normalized by the total surface area at the specific flow rate/dam scenario evaluated.

Results and Discussion

Figure 10 shows the simulated bed sheer stress at 300 cfs under each of the three dam scenarios.

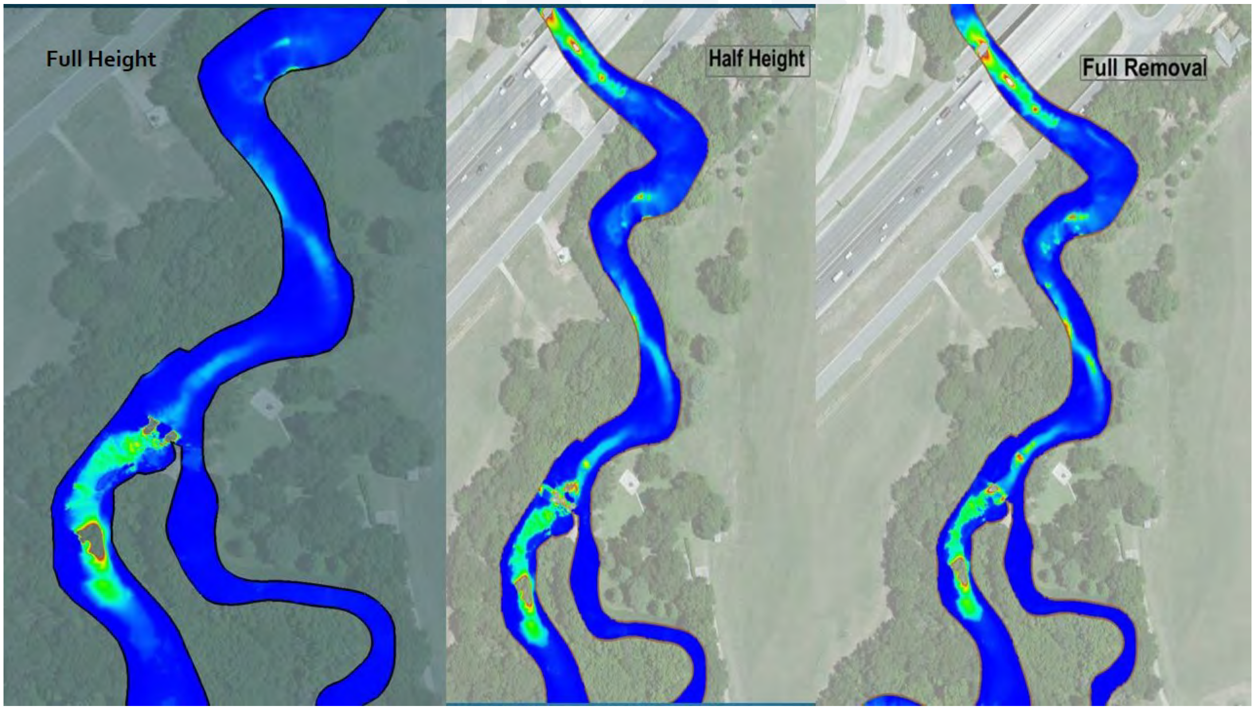

Figure 10. Computed bed sheer stress at 300 cfs for each of the dam scenarios.

What Figure 10 shows, is that under full height, the primary area of sheer stress and therefore highest potential for movement of sediments is located to the downstream plunge pool at the base of the dam. The existing topography of the river is consistent with the modeling results, with the deep hole on the downstream side of the dam and accumulation of fine sediments at the stream margins upstream of the dam (see Figure 8). Figure 10 also shows the expected increasing sheer stress along the thalweg (deepest part of the channel centerline) and expanding in spatial extant as the backwater effect of the dam is reduced at half height and then full removal. These areas of increasing sheer stress are the areas of greatest river channel changes.

Figure 11 shows the localized velocity magnitudes for each of the three dam scenarios at the 300 cfs simulated discharge.

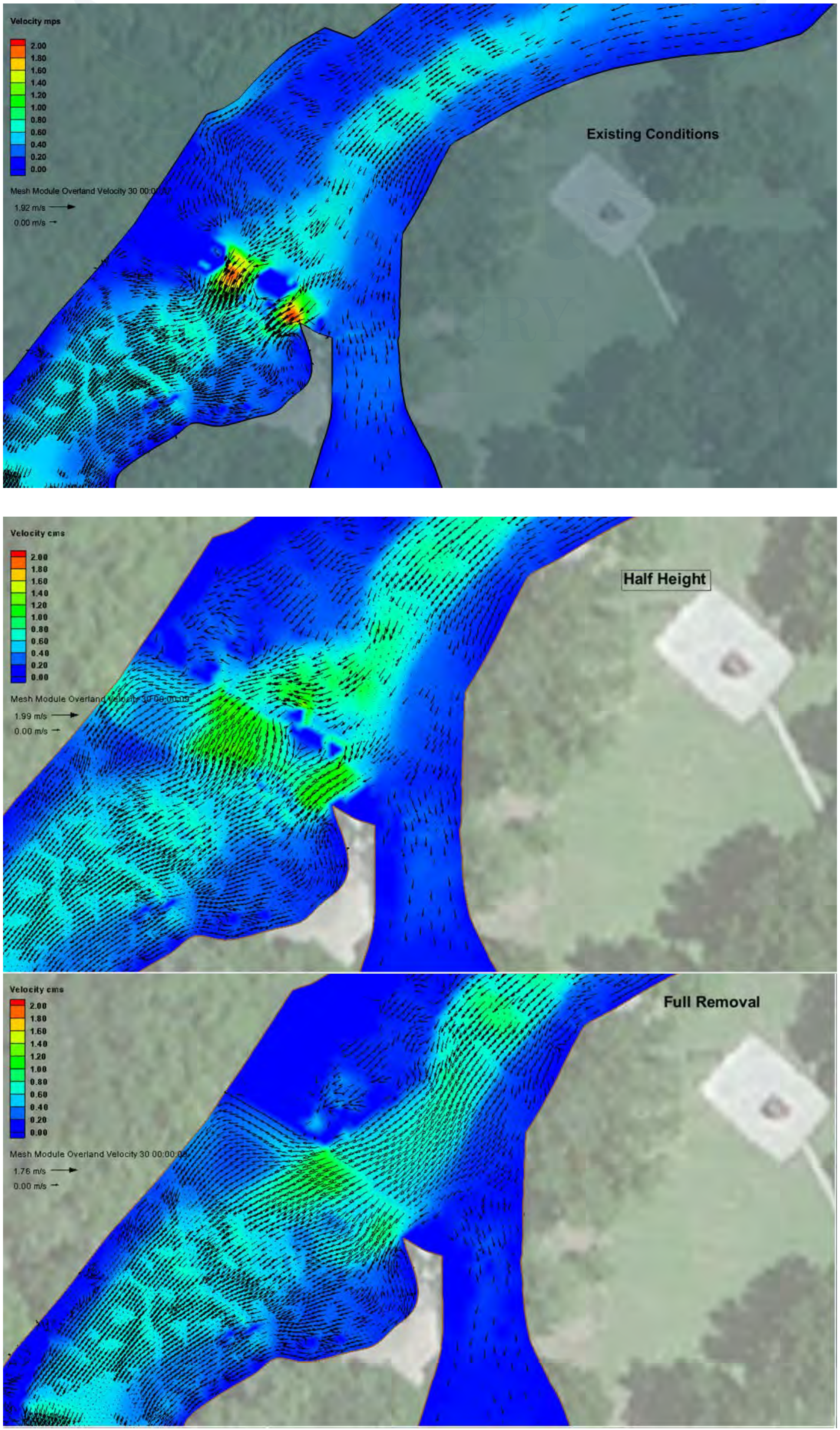

Figure 11. Velocity magnitude and directions at 300 cfs under full height, half height and full dam removal.

The simulation results in Figure 11 clearly show that the velocity fields are maintained within the center area or thalweg of the channel although the lateral extant is widened under half and full dam removal as would be expected. This pattern in the velocity distributions is maintained over all the simulated flows evaluated as would be expected from the fundamentals of hydraulics. This is important as will be illustrated below on the maintenance of the recreation corridor under half height and especially full dam removal.

Mobility of Fine Sediments

The relationship between sheer stress and the spatial area where mobility of fine sediments upstream of Capes Dam under the three modeled scenarios are shown in Figure 12.

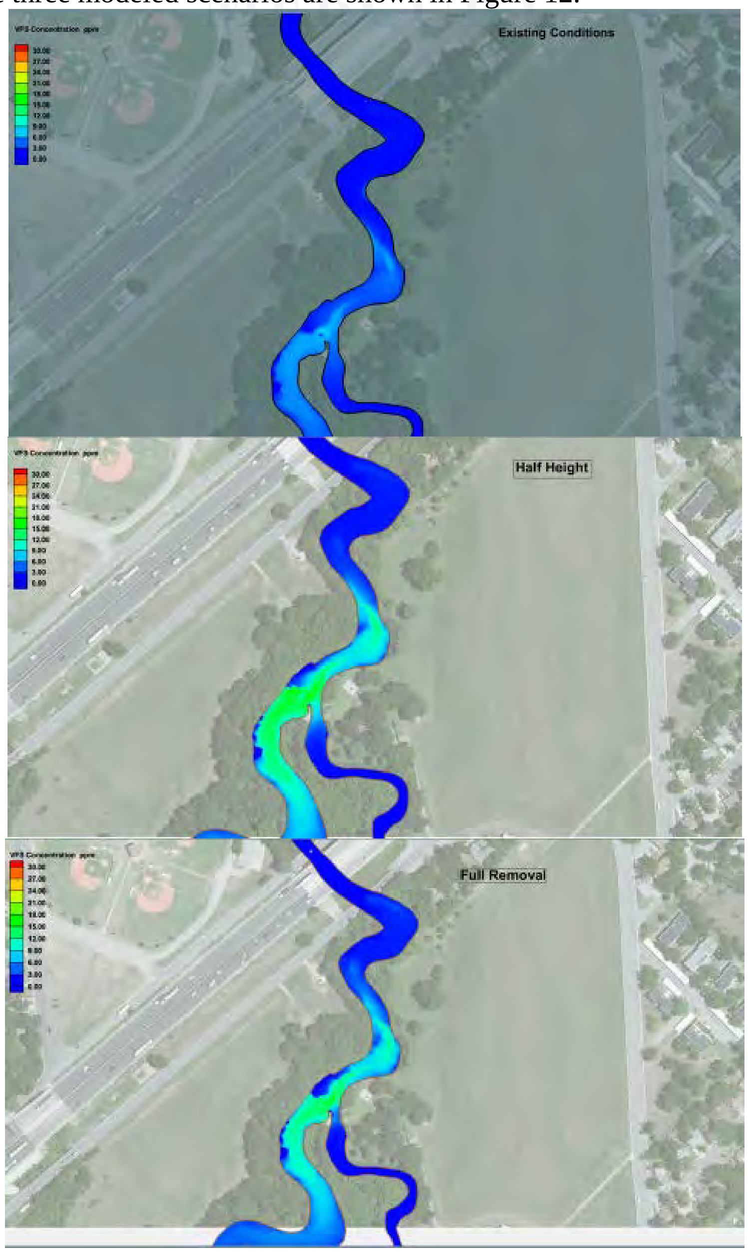

Figure 12. Mobility of fine sediments at 300 cfs under full, half height, and full removal of Capes Dam.

These simulation results again show where the largest channel changes are expected to occur due to the winnowing of fine sediments above Capes Dam and these areas are likely to become dominated by gravel type of substrates as is characterized by much of the existing San Marcos River channel where it is no impacted by backwater effects upstream of dam structures.

Bed and Bank Stability

The multi-year monitoring of river channel responses to dredging (Hudson 2012) clearly show that channel adjustment to dredging was mainly confined locally to individual cross-sections, and analysis of survey cross-sections and longitudinal profiles do not suggest that a knick point (erosion zone) migrated upstream into the non-dredged channel. This suggests very strongly that removal of Capes Dam will not result in any demonstrable head cutting. Additionally, bank erosion rates were ~1.8 inches per year along the channel, and did not spatially vary. The cohesive (clayey) bank material likely represents an inherent geomorphic buffer along the San Marcos River, thereby reducing the rivers sensitivity to erosion. These results strongly suggest that removal of Capes Dam will not result in any demonstrable bank failure or large scale changes in channel width and lateral scour.

The bed evolution results indicates that there will be some incremental reduction in channel width upstream of Capes Dam with dam removal as would be expected with the elimination of the backwater effect of the dam. Average changes in channel depths in pool like areas are estimated to be on the order of 6 to 7 inches at the 100 cfs simulated flow (remember, that flow is equaled or exceeded 90 percent of the time).

Texas wild rice and Fountain darter

Figure 13 shows a comparison of changes in normalized habitat area for Texas wild rice at different simulated flow rates under each of the dam scenarios evaluated.

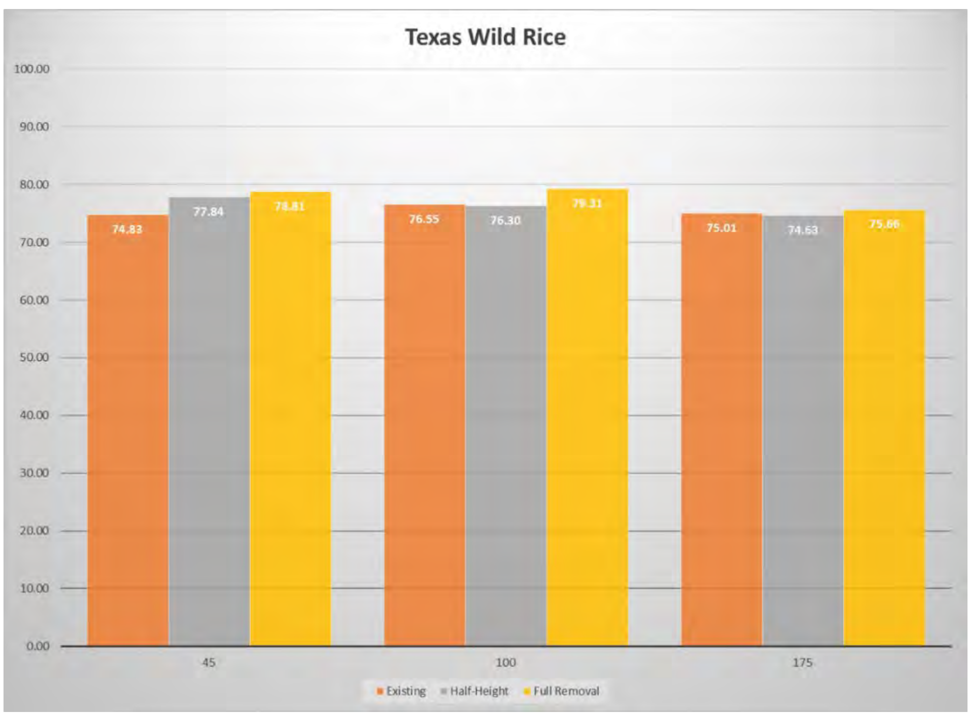

Figure 13. Area of normalized available habitat as a percent of the stream area for Texas wild rice for different flow rates and dam scenarios.

These simulation results show under the lower flow regimes (i.e, 100 and 45 cfs), full removal shows increased wild rice habitat. This is in part due to the increased velocity fields in the channel with removal of the dam which favor Texas wild rice (TWR does not favor zero velocity areas). Although not specifically modeled, the reduced depths are expected to result in better light penetration to more channel bed areas which in turn will promote both Texas wild rice but other aquatic vegetation propagation through this reach of the river. At the 175 cfs flow rate there is a small incremental improvement with full dam removal but essentially at this higher flow rate there is little differences between the three scenarios.

Figure 14 shows a comparison of changes in normalized habitat area for fountain darter at different simulated flow rates under each of the dam scenarios evaluated.

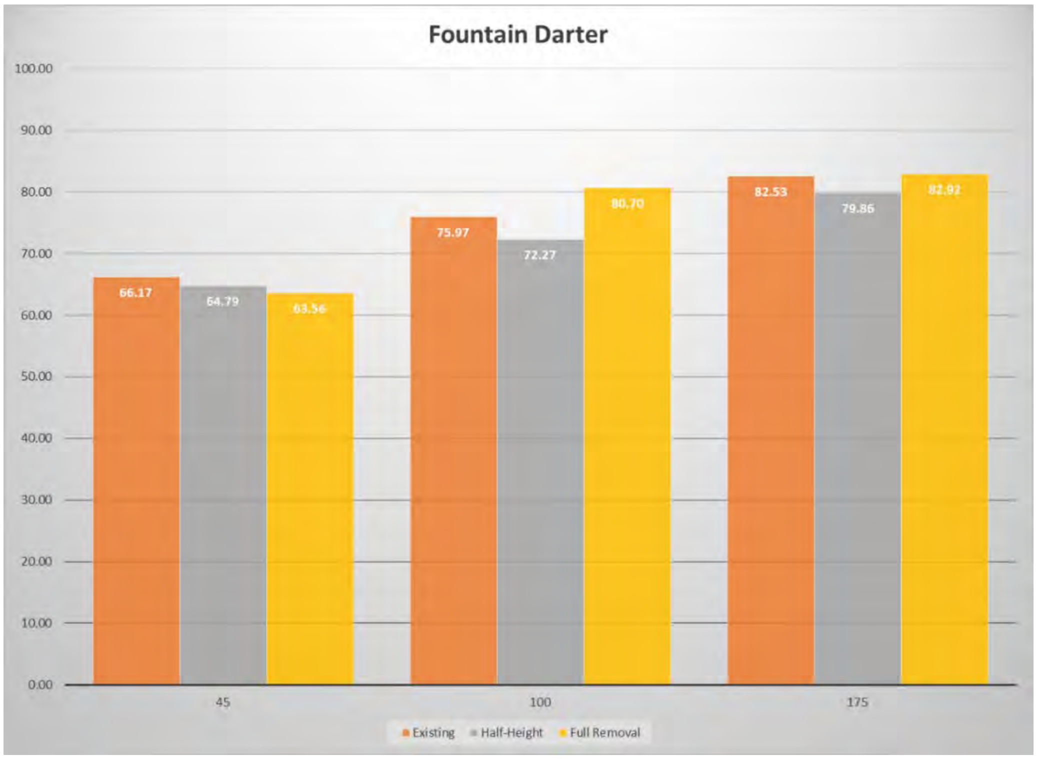

Figure 14. Area of normalized available habitat as a percent of the stream area for fountain darters for different flow rates and dam scenarios.

The simulation results for fountain darters show higher increased gains at the 100 and 175 cfs simulated flows for full dam removal compared to existing (full dam height) conditions. The results are intermediate for half height conditions and is related to the combined distributions of depth and velocity over the river channel. The incremental higher values for existing conditions compared to the half-height and full removal at 45 cfs is driven by the very shallow depths estimated at this extremely low flow. The simulations however, do not take into account the expected increase in aquatic vegetation due to improved light penetration. Fountain darters are associated with aquatic vegetation and the scenarios likely underestimate the improved habitat availability at all simulate flow rates for half height and full dam removal scenarios.

Figure 15 shows a comparison of changes in normalized habitat area for recreation at different simulated flow rates under each of the dam scenarios evaluated.

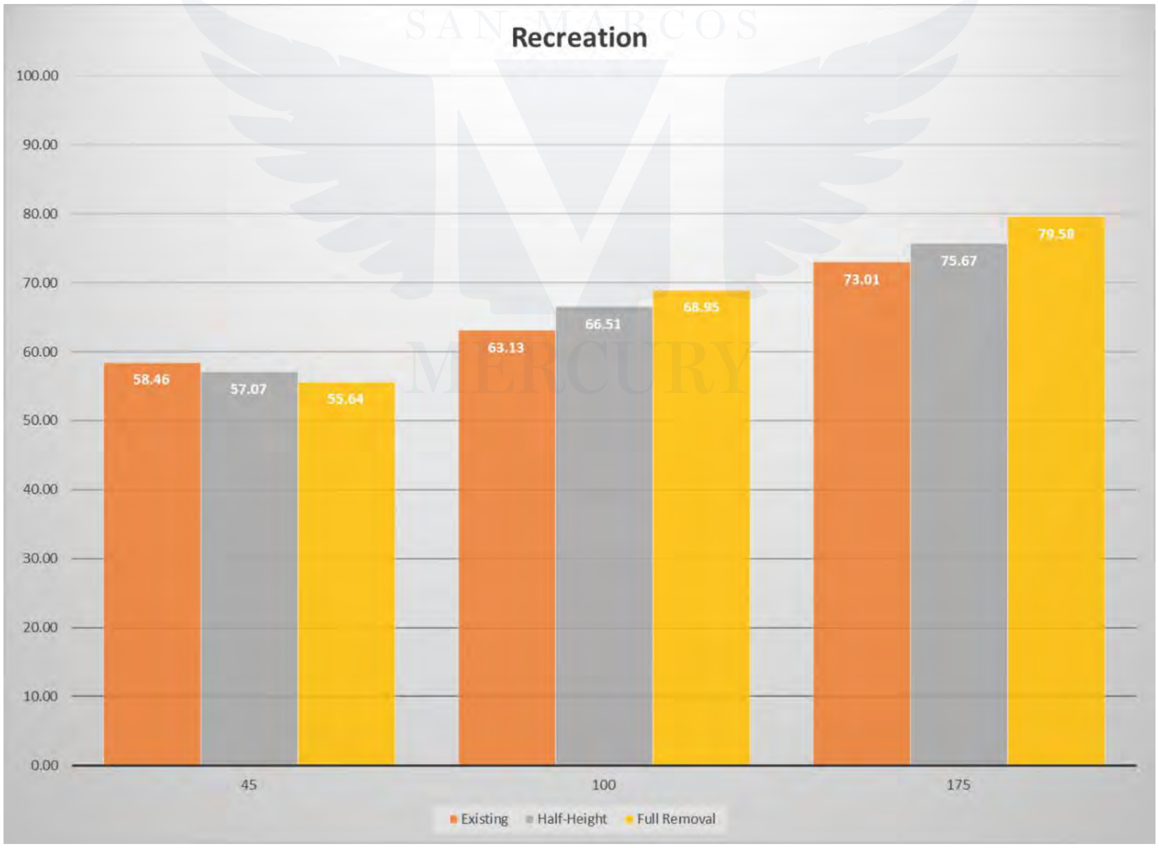

Figure 15. Area of normalized available habitat as a percent of the stream area for recreation for different flow rates and dam scenarios.

As noted previous, a simplified assessment of recreation was utilized that set a minimum threshold of water depth greater than two feet as necessary for contact water recreation (obviously wading will occur at shallower depths). The simulation results show that at 45 cfs the decreased back water effects within the channel will result in about a 3 percent reduction in normalized surface areas greater than two feet in depths. Remember that 45 cfs is approximately the single day lowest flow ever recorded during the 1950's drought of record. The simulation results at 100 and 175 cfs clearly show that the normalized areas of recreation increase for half height and full dam removal scenarios and reflect areas of channel adjustment (deeper areas) due to removal of areas of fine sediment. This is also illustrated in Figure 16, which shows a comparison of the 'recreation corridor' (blue areas) under each of the three dam scenarios at 100 cfs (flow equaled or exceeded 90 percent of the time). Clearly, removal of the dam will not result in negative impacts to the recreation corridor based on maintenance of river depths in excess of two feet.

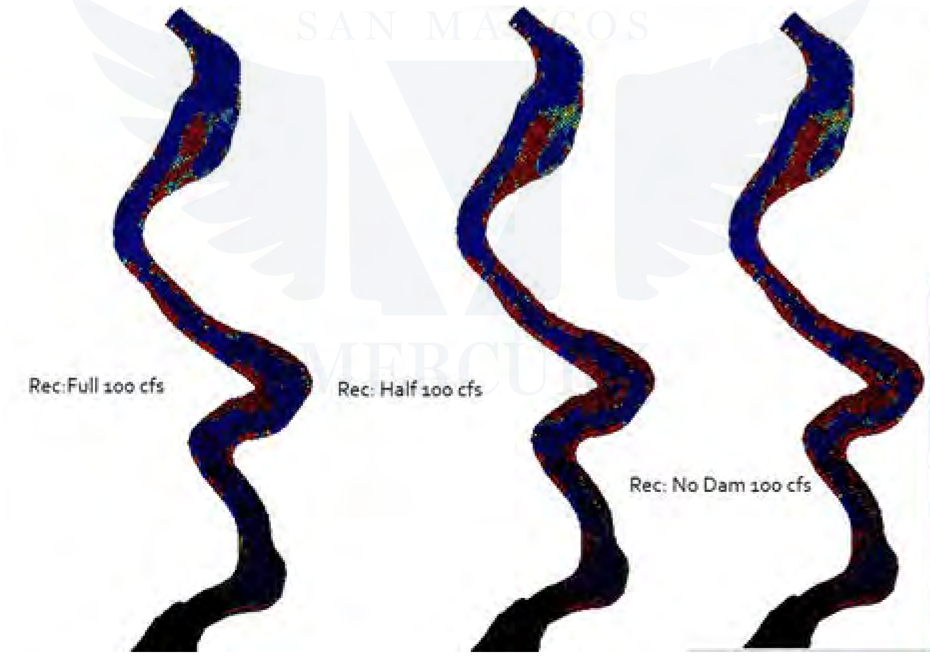

Figure 16. Recreation corridors (blue areas) at 100 cfs under existing, half height and full dam removal.

Conclusions

Modeling results suggest that TWR habitat upstream of Cape's Dam would marginally improve under half-height or complete dam removal when compared to existing conditions. Slight increases in TWR habitat under half-height and the no dam scenarios are primarily related to increases in available water depths less than 1.0 meter at the stream margins. Furthermore, increased velocity fields under half-height and no dam scenarios would favor reduction in the accumulation of fine sediments directly attributed to the existing backwater effects of the dam (Stanley and Doyle 2003). Although incremental reductions in fountain darter habitat are suggested by these modeling results, we point out that they do not incorporate the expected increase in aquatic vegetation species such as TWR we believe will occur under the half-height or no dam scenarios. Sunlight attenuation increases with greater depths and suspended solids, resulting in declines of submerged aquatic vegetation growth (Kemp et al. 2004). Therefore, reduced depths and increased current velocities predicted with partial or complete removal of Cape's Dam would likely increase sunlight penetration and consequently promote vegetation growth in more areas. We believe the additive benefit of increased vegetation would likely result in substantial increases in fountain darter habitat.

Even though our modeling results did not suggest substantial increases in TWR or fountain habitat upstream of Cape's dam with the partial or complete removal of the dam, we believe removal of the dam would still be demonstrably beneficial for several reasons including:

1) Allow transport of fine sediments through the Cape's Dam reach which currently inhibits preferred substrates (i.e., gravel) for native aquatic vegetation establishment;

2) Improve the potential for native aquatic vegetation growth;

3) Support the potential to meet long term biological targets for listed species identified under the Edwards Aquifer Habitat Conservation Plan; and

4) Restore stream connectivity for fish passage for species such as the fountain darter.

Removal of Cape's Dam would likely reestablish natural current velocities, remove fine sediment accumulation, and restore coarse sediment transport within this reach of the San Marcos River, thus providing improved habitat for vegetation growth and expansion. Fish species richness and diversity generally increase in reconnected areas after dam removal (Burroughs et al. 2010; Catalano et al. 2007; Bednarek 2001).

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