Capes Dam Removal Analysis DRAFT

PREPARED FOR: The City of San Marcos
PREPARED BY: Recreation Engineering & Planning Inc.
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Recreation Engineering and Planning
485 Arapahoe Ave.
Boulder, CO 80302

303-545-5883 (office)
gary@boaterparks.com
www.boaterparks.com

TBPE Firm Number: 13981

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Introduction

This report describes the hydraulic analysis conducted for Capes Dam located within the City of San Marcos, Texas. This analysis focuses on dam removal impacts to the San Marcos River and the existing Mill Race channel created by the dam.

Capes Dam is currently in a state of disrepair. It was built in the 1800's to create head and divert water for a mill located downstream. The dam failed during floods in 1998 and a weir structure was constructed immediately upstream to maintain water depths. Further damage was sustained during flooding in 2015 and again in 2016. Today, the dam continues to divert water into the Mill Race channel, but the condition of the dam poses a hazard to any navigation in the San Marcos River and threatens endangered species in the area.

The City of San Marcos contracted Recreation Engineering and Planning (REP) to complete a site feasibility study and propose a solution to the failing and dangerous Capes Dam that not only eliminates the hazard, but also makes for an attractive area that the community can enjoy.

Location

Figure 1 shows the location of Capes Dam. It is located on the San Marcos River just downstream of the I35 bridge, and very near the University campus. The dam diverts water from the river into the Mill Race channel. The Mill Race channel flows parallel to the San Marcos River, passes under Cape Street, and then rejoins the river at the old mill site.

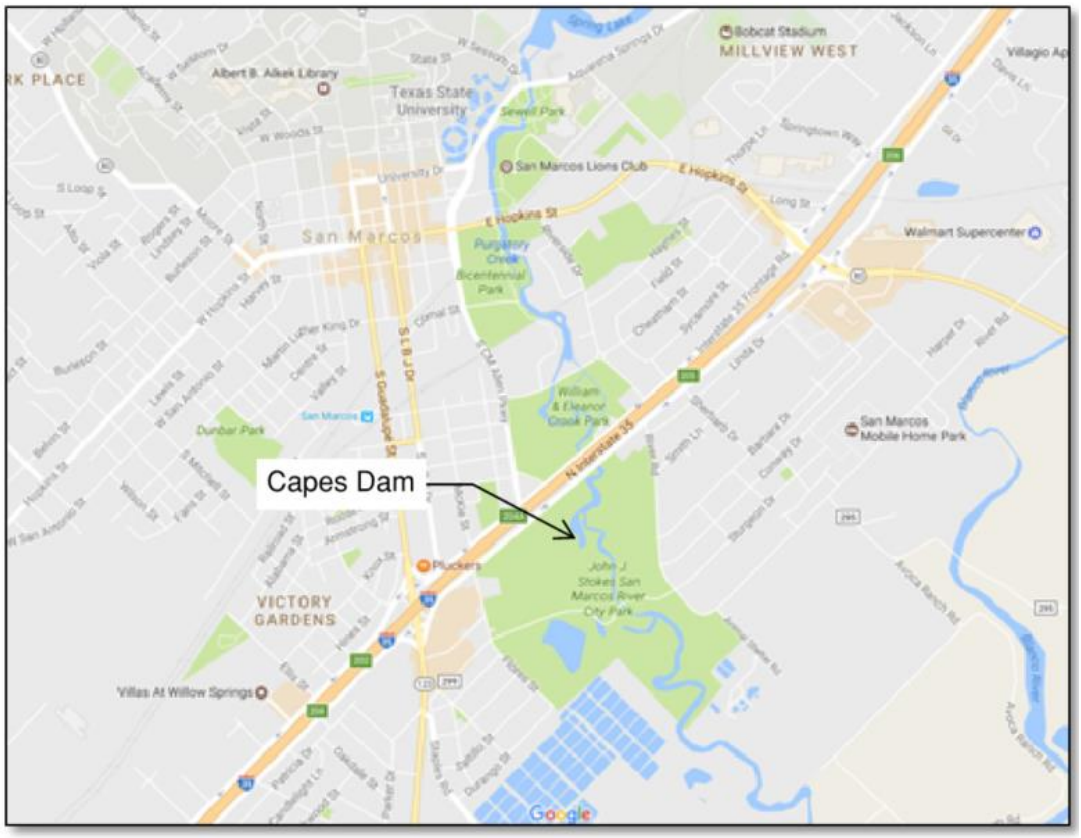

Figure 1: Project Location Map

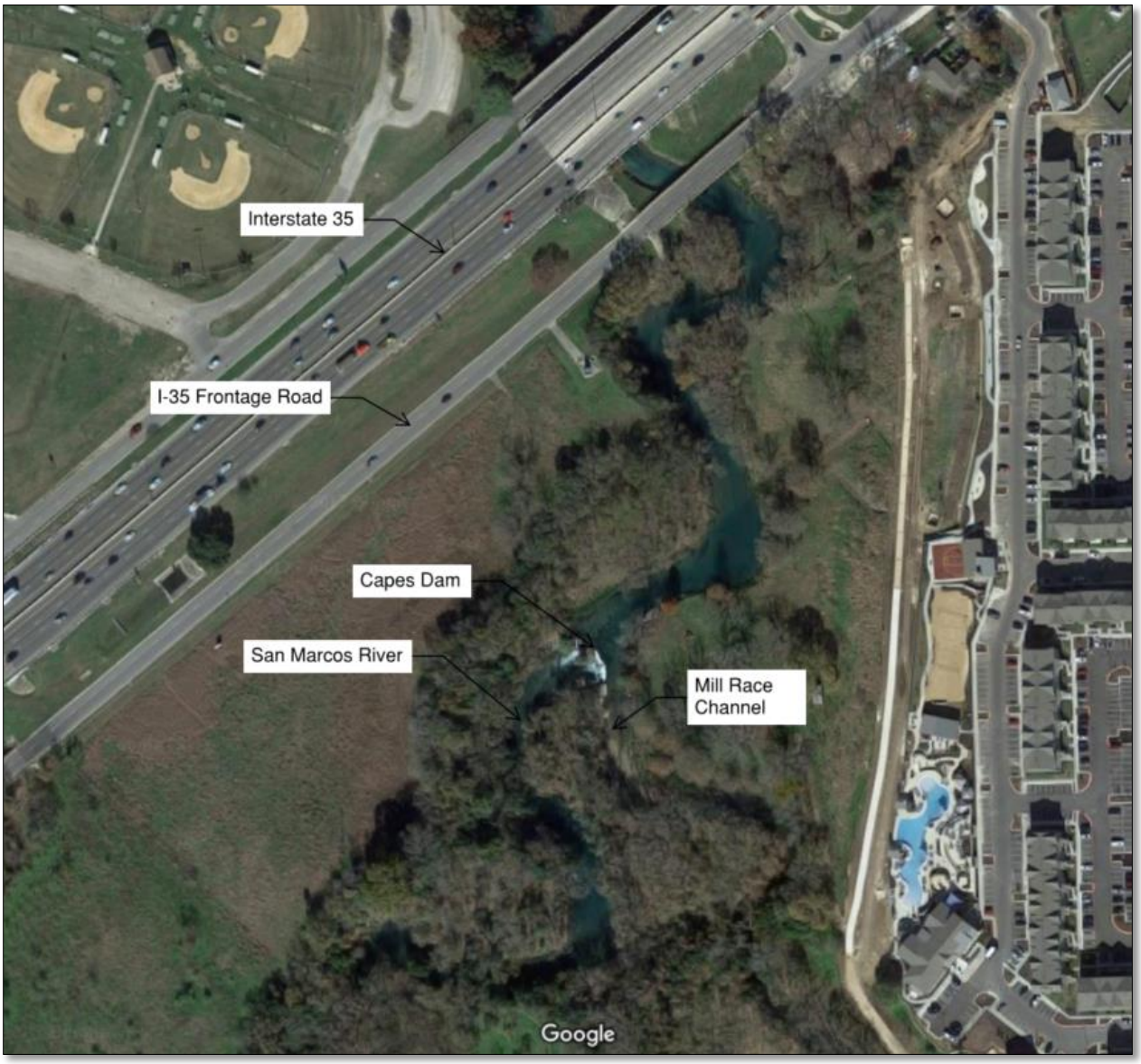

Figure 2: Capes Dam Location Map

Existing Conditions

Capes Dam continues to divert water into the Mill Race channel, however the current configuration of the dam is a hazard to navigation. There is considerable woody debris that creates entrapment hazards and the crest of the dam is uneven with protruding steel bars and broken concrete. Many users recreate in this area, yet any attempt to navigate Capes Dam is ill advised in its current condition. See the photos below.

The channel in this area is highly sinusoidal and braided. Apart from the dam, this section of the San Marcos River is very calm and flat, meandering through a heavily vegetated area. Backwater flooding from the Rio Blanco is a common occurrence during major floods.

The Mill Race channel is well established with conditions similar to the main stem of the San Marcos River in that it is very flat and vegetated. The channel drops only slightly as it meanders parallel to the San Marcos River. It passes under Cape Street with the water surface elevation reaching almost to the low chord of the bridge (Figure 4). At the end of the Mill Race channel, the water drops over a small weir creating a waterfall feature shown in Figure 5.

Figure 3: Existing Conditions, Capes Dam

Figure 4: Mill Race passing under Cape Street

Figure 5: Old Mill Site. Confluence with the San Marcos River

HYDROLOGY

Discharge information for the modeled reach containing the project location was obtained from USGS gauge 08170500 San Marcos River at San Marcos, TX. Flow rates in the San Marcos River are relatively stable, rarely varying outside the 150-200 cubic feet per second (cfs) range except during short high intensity rainfall events. The average flows are shown in the figures below.

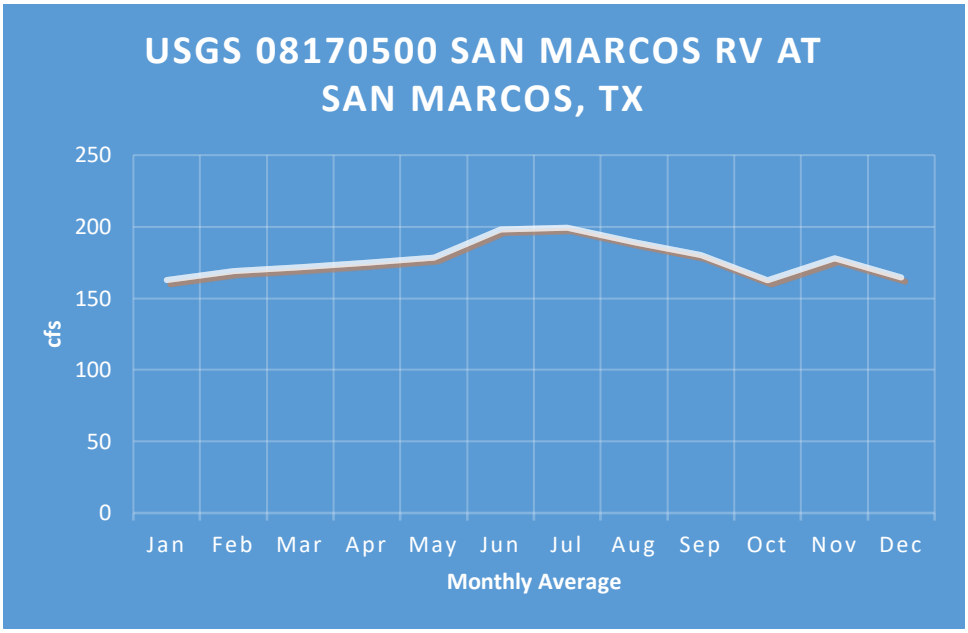

Figure 6: San Marcos River Average Flow by Month

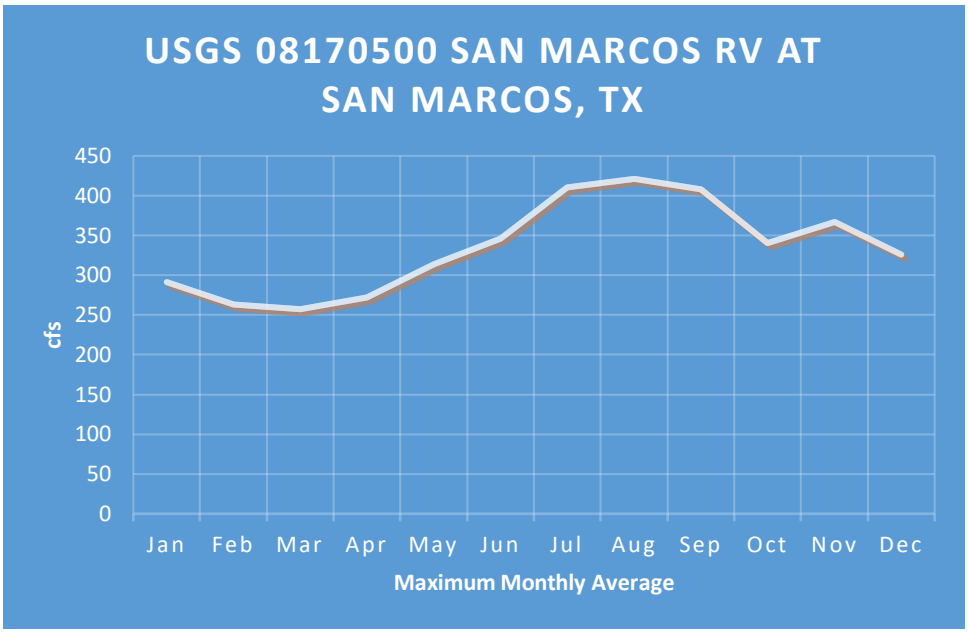

Figure 7 San Marcos River Average Maximum Flow by Month

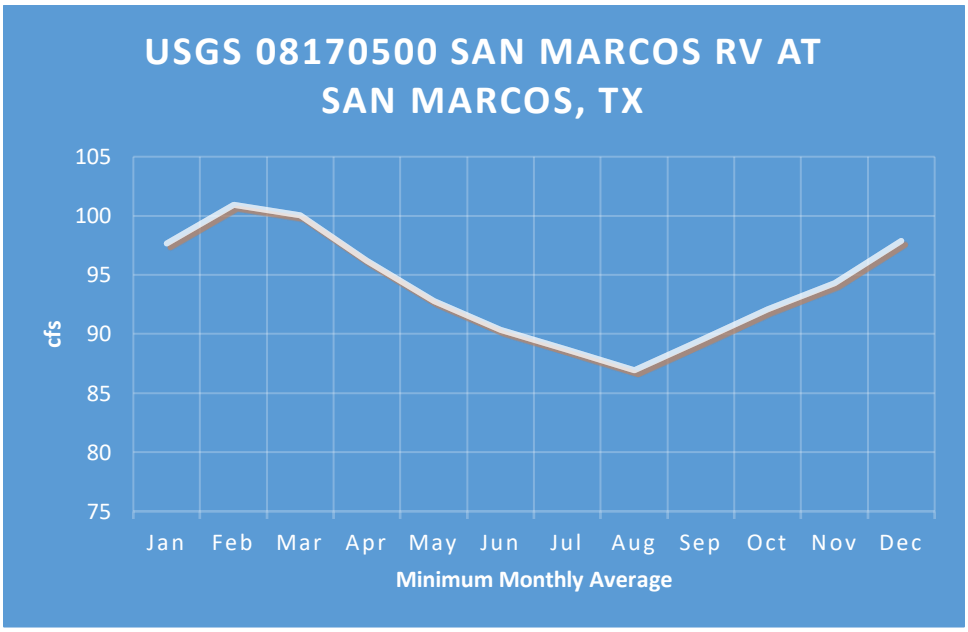

Figure 8 San Marcos River Average Minimum Flow by Month

Proposed Design

The area in which Capes Dam is located attracts all forms of recreation, is near a university campus, and home to various endangered species. This contributes to the need to make the San Marcos river safely navigable by all in this location. The primary goal of this dam removal is to eliminate a safety hazard, but simultaneously create an amenity for the community and an environmental improvement.

The proposed design will not only remove the dam, but also continue to divert water into the Mill Race channel. This is desirable because the Mill Race channel meanders through an attractive area and can be used to navigate back upstream. The proposed design removes the dam and leaves a grade control riffle with a specified crest elevation. The removal of the dam eliminates the hazard to navigation and benefits the habitats for the endangered Texas wild rice and fountain darters in the San Marcos River. In addition to the removal of the dam, the proposed design includes lowering the elevation of the Mill Race channel inlet invert and dredging the channel bed between 1 and 3 feet along the length of the Mill Race. The crest of the waterfall/weir at the exit of the Mill Race channel will be lowered by approximately 2 feet as well. Lowering the elevation of the Mill Race channel allows for continued flow through the channel after removal of the dam and also allows for safe passage under the existing Cape Street Bridge. The design is optimized for the various flows in the river. Even at low flows, just enough water enters the Mill Race channel to make it navigable and attractive while the vast majority of the water at all flows remains in the main channel of the San Marcos River. See the Results section.

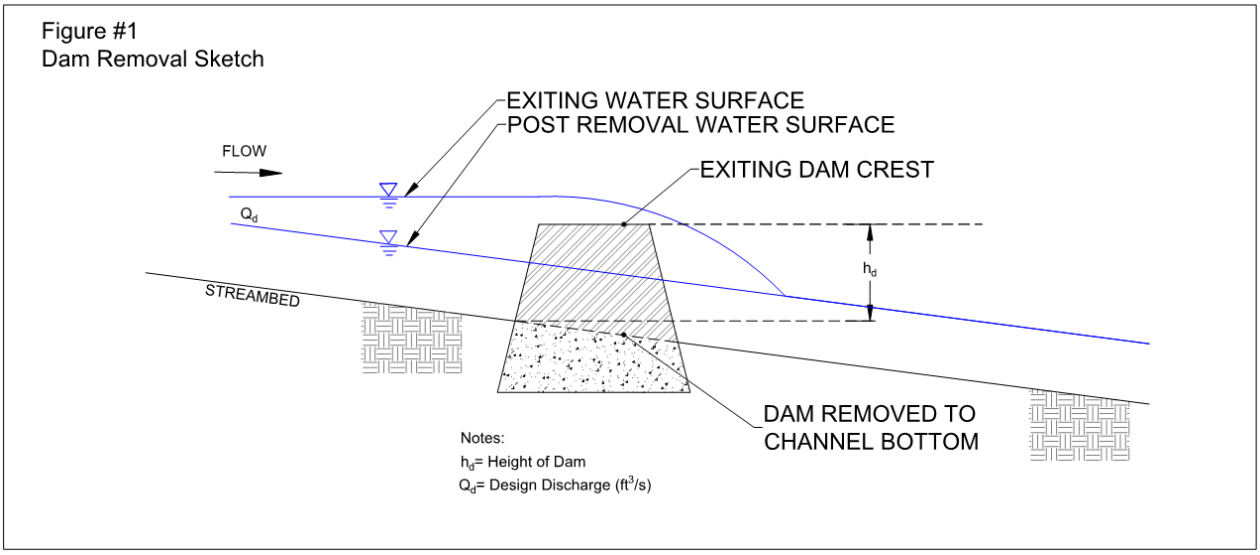

Figure 9: Conceptual Profile Sketch of the Proposed Dam Removal (not to scale)

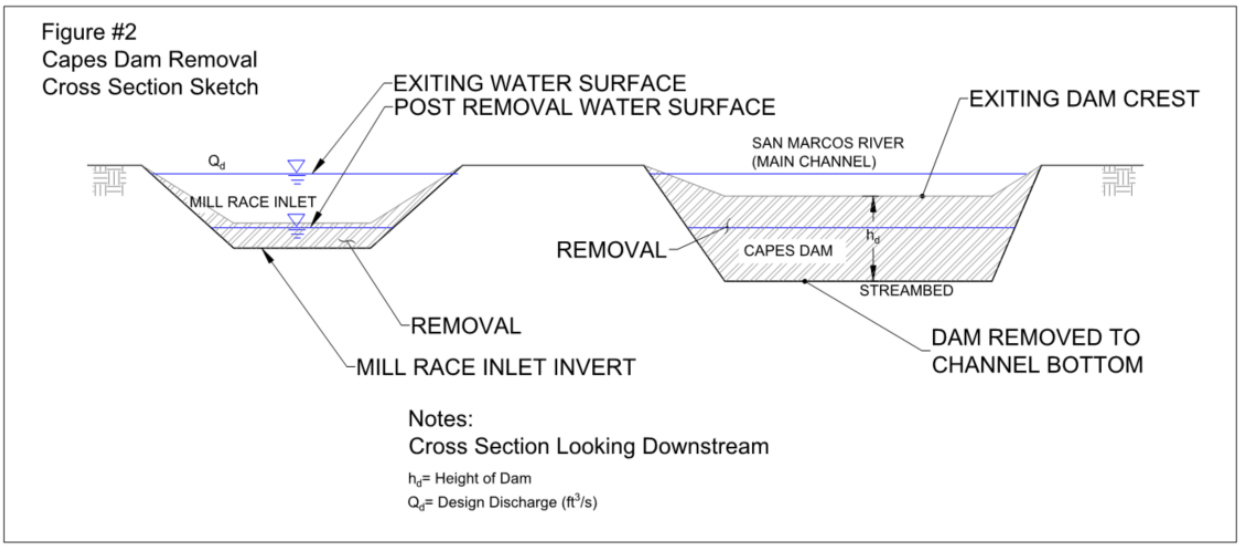

Figure 10: Conceptual Cross Section Sketch of the Proposed Dam Removal (not to scale)

Hydraulic and Sediment Transport Modeling

Modeling Methodology

Hydraulic and sediment transport modeling was performed to determine the effects of the proposed dam removal on the surrounding river system and Mill Race. Two types of models were developed, a one-dimensional hydraulic model using HEC-RAS and a two-dimensional morphodynamic using iRIC.

The one-dimensional hydraulic model was developed to determine preliminary design elevations and perform a flow split analysis between the mill race and the main channel of the San Marcos River. The one-dimensional model allows for quick run times for multiple design iterations, while producing accurate results.

A two-dimensional morphodynamic model was developed for the project reach in order to investigate the upstream channel bed evolution after removal of Capes Dam. The upstream backwater created by the dam is used by recreationalists, and there is a desire to maintain flow depth in this area.

1D HEC-RAS Hydraulic Model

HEC-RAS (Hydraulic Engineering Center – River Analysis System) is a one-dimensional step backwater program created by the U.S. Army Corps of Engineers. The program is applicable for analysis of floodplain impacts and is the standard program used by FEMA to create FISs and FIRMs. The program has the ability to perform split flow analysis on branching channels, such as the Mill Race split from the San Marcos River.

Discharges for analysis in HEC-RAS were chosen to represent a range of low to high flows expected in the San Marcos River, and for consistency with the flows analyzed by Hardy and Raphelt[1].

Table 1. Steady State San Marcos River Discharges Data Used in HEC-RAS model

Flow (cfs)	% Exceedance
45	"Drought of Record"
100	90
173	50
300	10

EXISTING CONDITIONS & CALIBRATION

Halff Associates, Inc. developed an unsteady HEC-RAS version 4.1.0 model for the USACE (United States Army Corp of Engineers) for the San Marcos and Blanco Rivers dated July 23, 2015 and provided to REP on May 12, 2016. This model presents time varied water surfaces referencing the NAVD 88 datum.

The model was developed for floodplain analysis of large flow events. To accurately model the project reach for low flow events, REP created a new reach for the Mill Race, added new cross sections to the San Marcos and the Mill Race, and updated existing cross section elevation data. Topography and river bathymetry data was provided to REP by Watershed Systems Group.

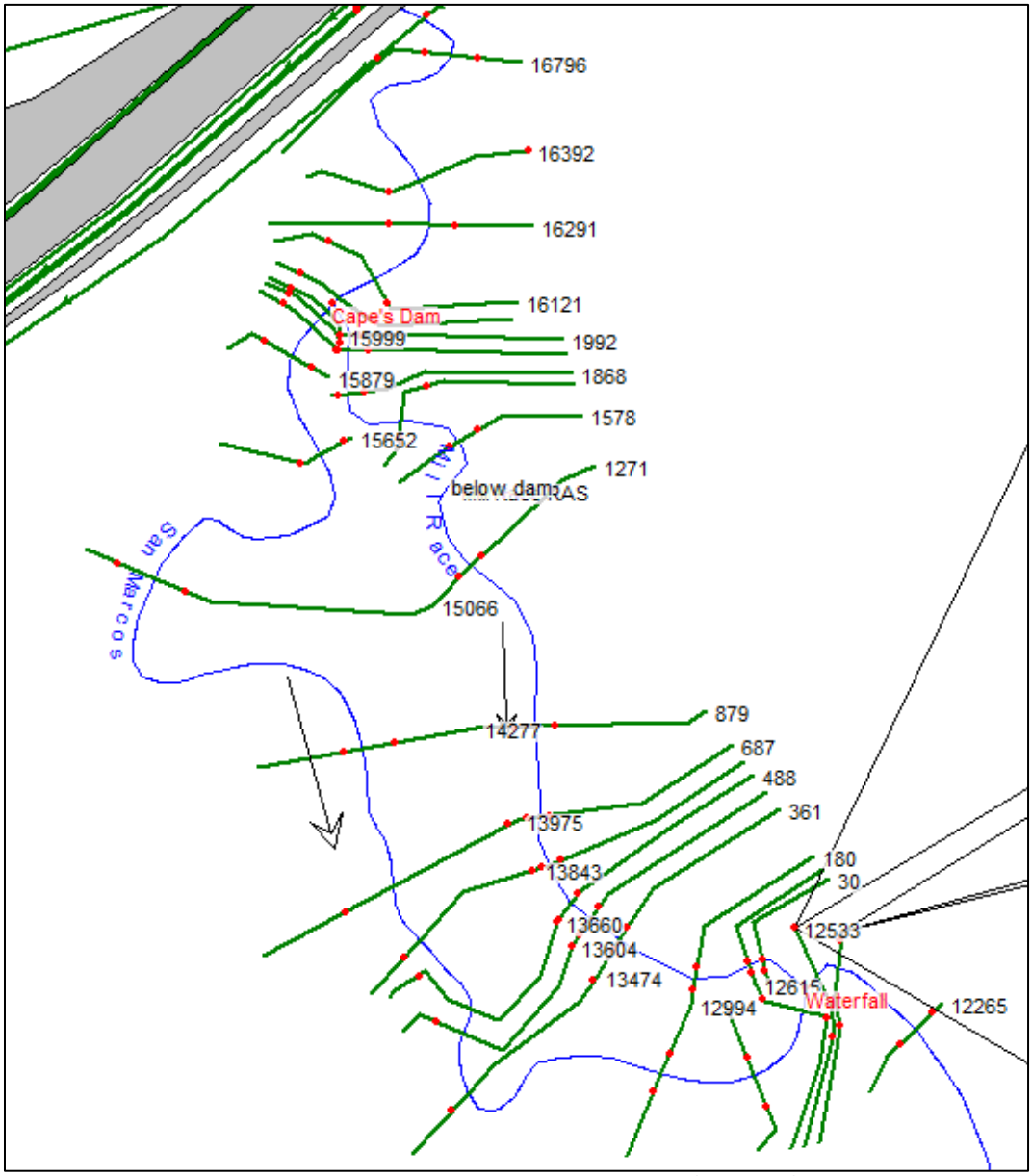

Figure 11: HEC-RAS XS and reaches in the project area. Flow is from top of image to bottom.

The Existing Conditions model was calibrated to water surface elevations in the Mill Race and the San Marcos River upstream of Capes Dam provided in the "Cape Dam and Mill Race Assessment" by Hardy[2]. The flow measurements were taken in the Mill Race on 8/19/2016 at a discharge in the San Marcos River of 283cfs, and in the San Marcos River upstream of the dam on 12/16/2016 at a discharge of 245cfs.

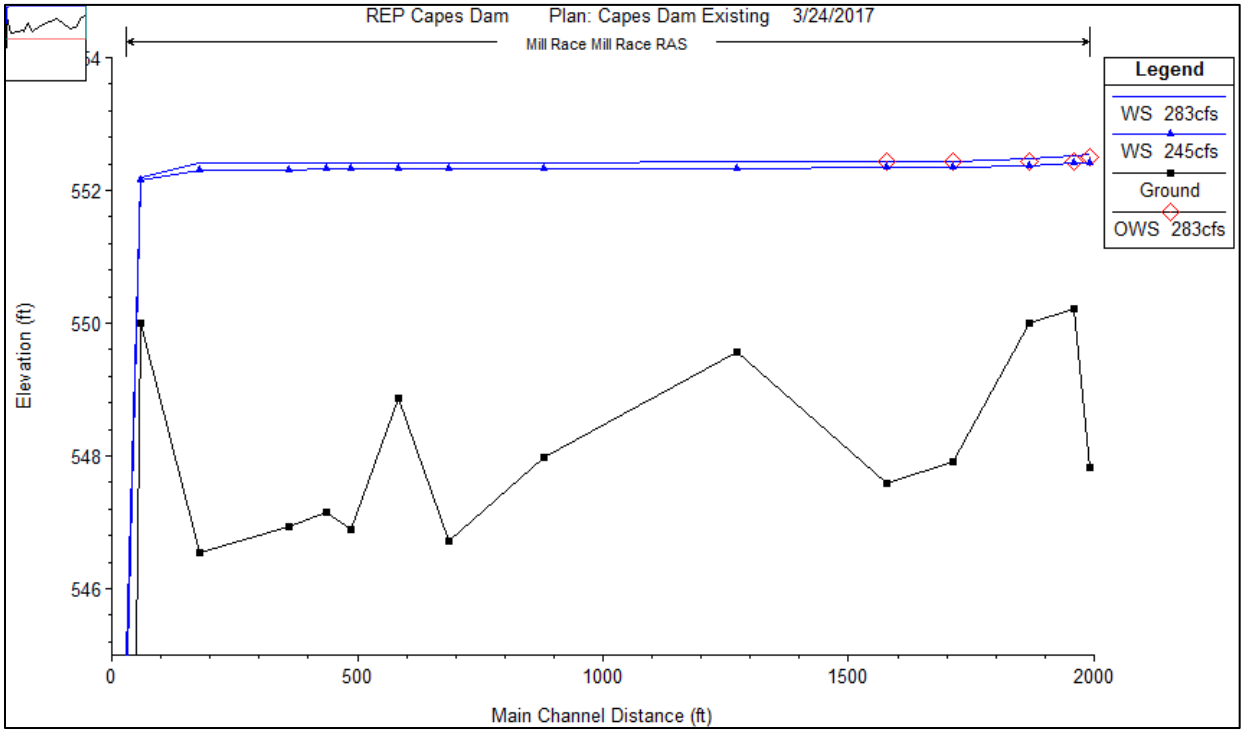

Figure 12: Existing conditions Mill Race reach profile with calibrated water surface elevations and observations.

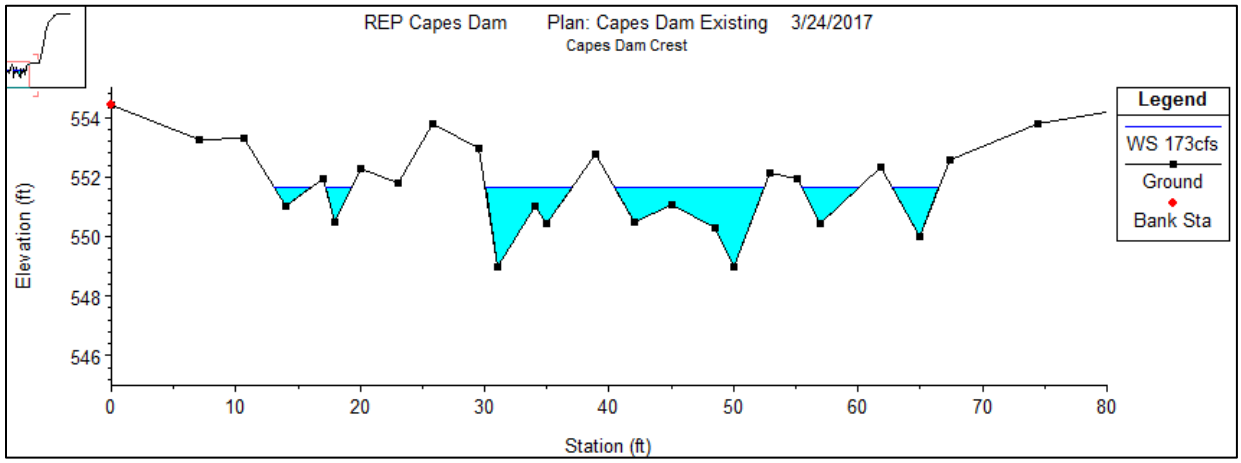

Figure 13: Existing Capes Dam crest cross section at median flow.

PROPOSED CONDITIONS MODEL

The proposed dam removal design geometry was input into the model and the flow split and water surface elevations analyzed.

The proposed geometry includes dredging of the Mill Race, lowering the "waterfall" weir crest at the downstream end of the Mill Race, and replacing the Capes Dam crest with the grade control riffle crest.

All elevations are NAVD88. The crest of the weir at the downstream end of the Mill Race was set to EL 548.2. The Mill Race cross-sections were modified to represent dredging of the Mill Race to EL 547.0. See Figure 14. The invert of the new Capes Dam crest (grade control riffle) cross section is EL 546.5 as shown in Figure 15 below.

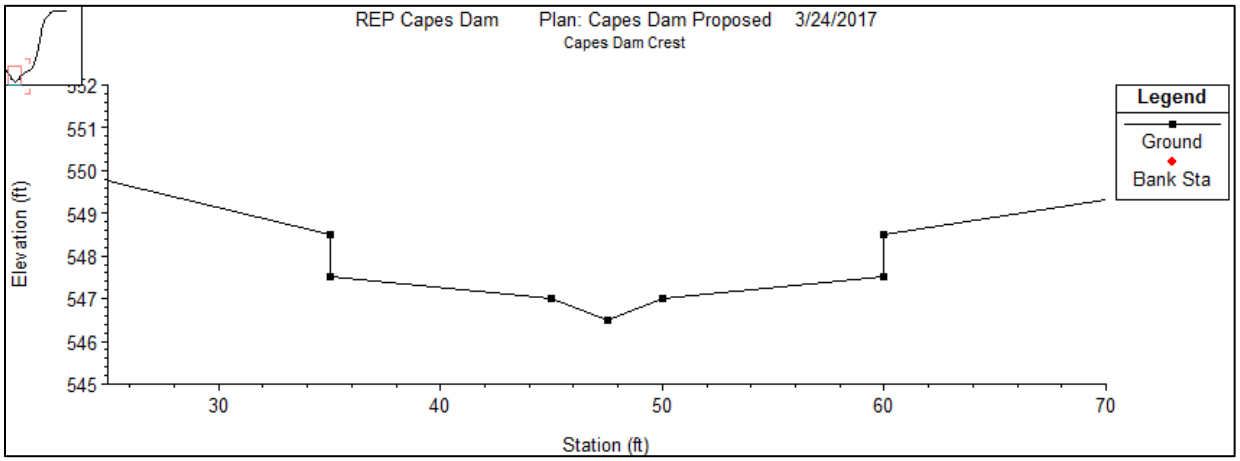

Figure 164: Proposed Capes Dam crest cross-section.

RESULTS

The model was run under mixed flow conditions with split flow optimization at the Mill Race. Water surface elevations (WSEL) and discharge outputs were compared for the flows analyzed and evaluated the project objectives. Results of the split flow analysis are shown below in Table 2. At flows of 100cfs and below, nearly all of the discharge flows into the main San Marcos River channel rather than the Mill Race. However, depths in the Mill Race are maintained due to backwater effect of the "waterfall" weir crest even at minimal discharges, allowing passage for small watercraft. WSEL along the Mill Race profile at various flows is shown in Figure 18.

Table 2. Split flow results for Proposed Geometry

Flow (cfs)	Discharge in Mill Race (cfs)	Discharge in River Channel (cfs)
45	0	45
100	1.6	98.4
173	8.4	164.6
300	22.3	277.7

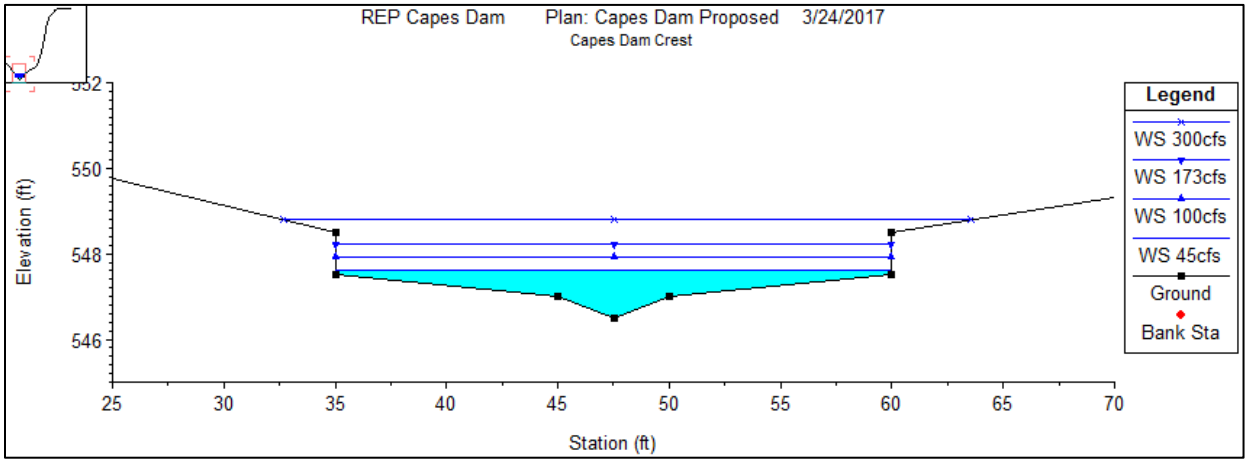

Figure 15: Proposed Capes Dam cross section at all flows.

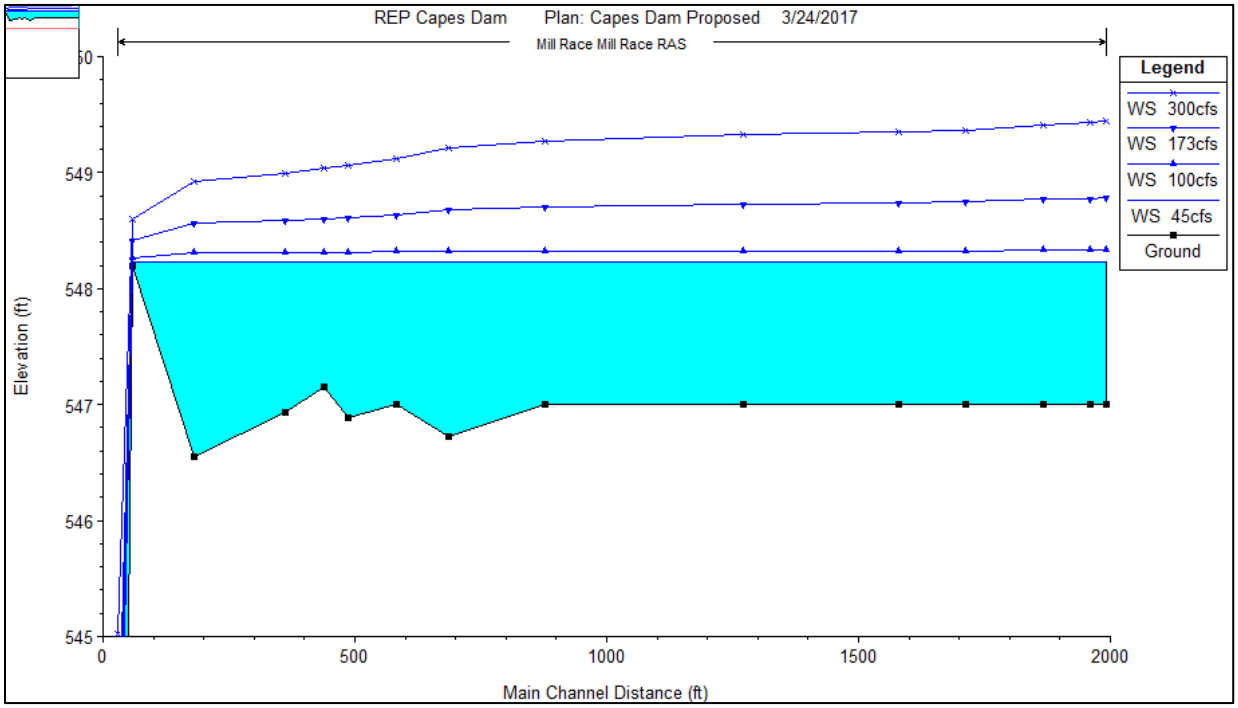

Figure 16: Proposed conditions profile of Mill Race channel

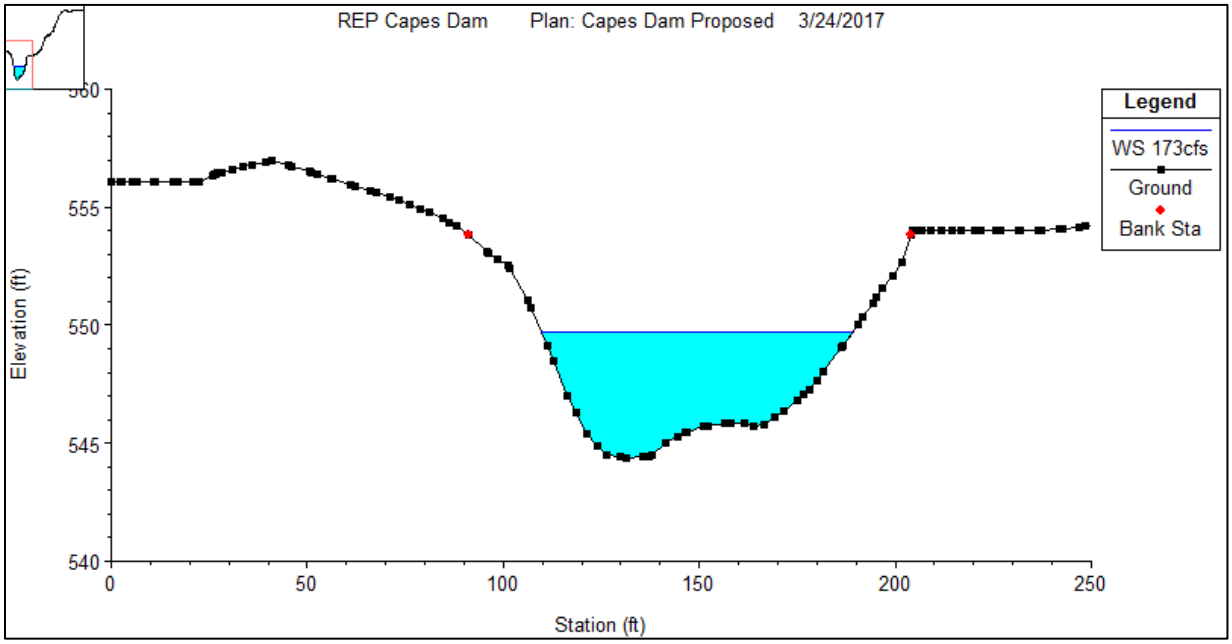

Figure 177:HEC-RAS RS 16796, Proposed Median Flow Conditions 170ft DS of I35

2D iRIC Morphodynamic Model

The purpose of the two-dimensional morphodynamic model was to investigate the upstream effects on the San Marcos River after removal of Capes Dam. The upstream backwater created by the dam is used by recreationalists, and there is a desire to maintain flow depth in this area.

The analysis was performed using the International River Interface Cooperative (iRIC) software. iRIC is a public-domain river flow and riverbed variation analysis software package which combines the functionality of hydraulic modeling software developed by the U.S. Geological Survey (USGS) and the Foundation of Hokkaido River Disaster Prevention Research Center, among others. The iRIC software includes many different solvers, capable of modeling complex 2D and quaisi-3D hydraulics, as well as riverbed morphology change.

Model Development

The Nays2DH solver within iRIC (version 2.3) was chosen for its robust two-dimensional unsteady flow solver, and capability to model sediment transport and riverbed change. Topography and river bathymetry data was provided to REP by Watershed Systems Group. From this data, a 2D mesh was created in iRIC with nodes generated on a curvilinear grid with 3 meter spacing.

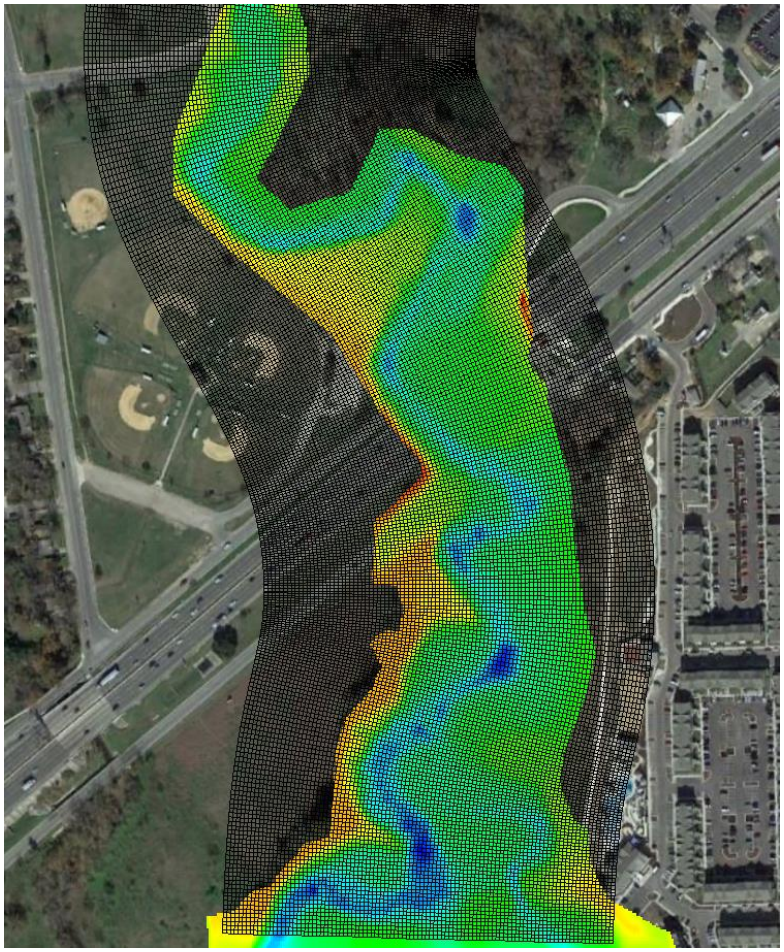

Figure 18: 2D Mesh and Base Topography Data.

Boundary conditions for the two-dimensional analysis were developed based on the one-dimensional HEC-RAS model for the reach. An existing "Dam In" model was built from the base topography data, and a proposed "Dam Out" model was built with the removed Capes Dam. Dredging of the Mill Race was not included in this model run.

RESULTS

Both the existing and proposed models were run with flows of 100cfs, representing low flow conditions, and 173cfs, the median flow for the reach. The water surface extents and depths were compared, as shown in Figure 19 and 20.

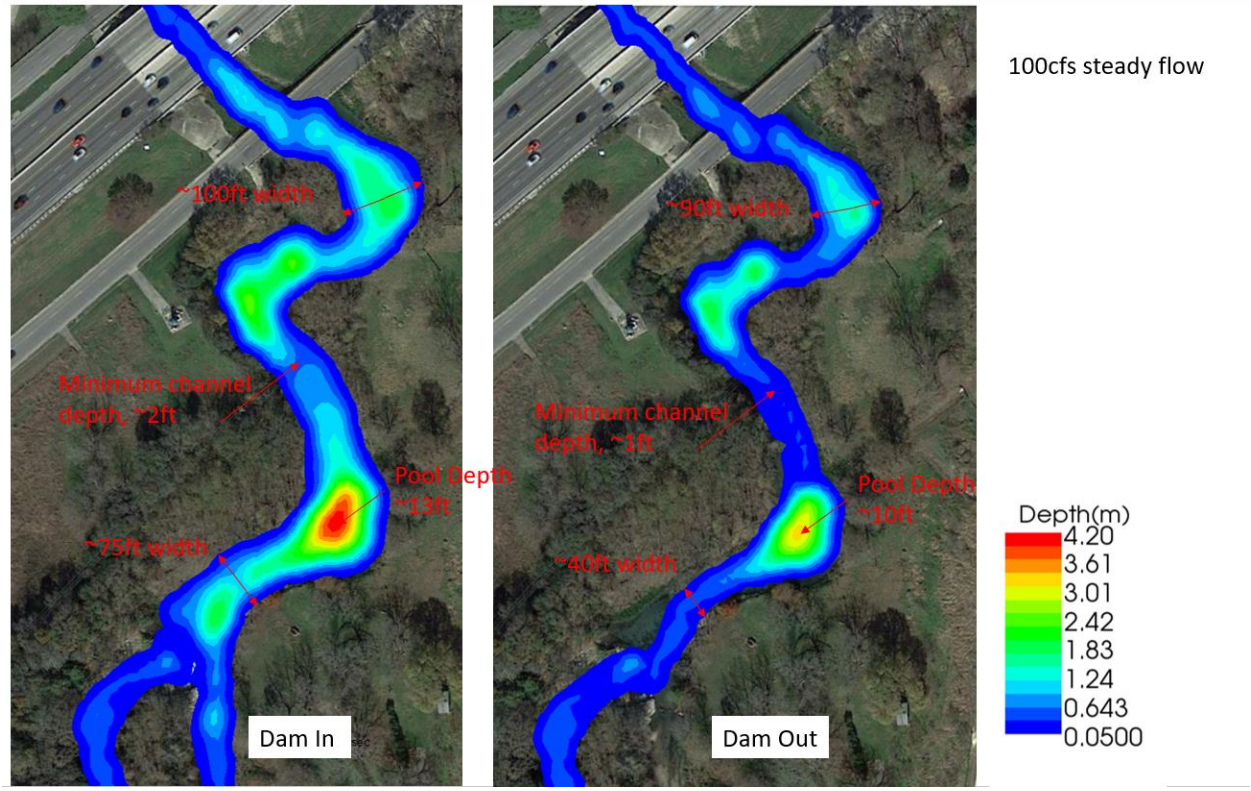

Figure 19. Existing and Proposed Conditions models with a discharge of 100cfs

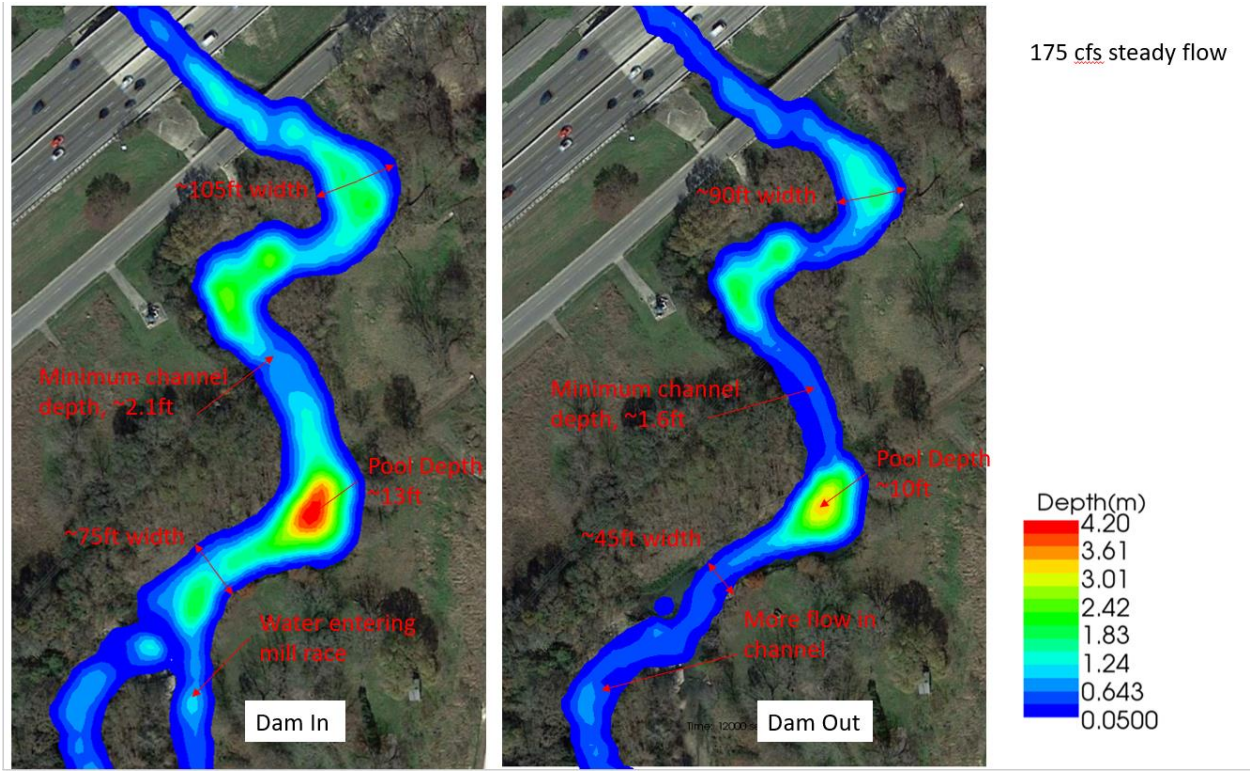

Figure 20 Existing and Proposed Conditions model with a discharge of 175cfs.

HIGH FLOW EVENT

Sediment accumulated upstream of the dam will mobilize as a result of increased channel slope from removal of Capes Dam. Channel forming flows or "bank full" discharges are generally assumed by fluvial geomorphologists to be 1.5yr to 2yr flow events. In order to investigate sediment transport and resulting river bed morphology change during such an event, the hydrograph of the high flow event that occurred on September 26, 2016 (Figure) was routed through the modeled reach with "Dam Out" topography.

For this analysis, a uniform grain diameter of 0.55mm was modeled. The bed morphology change modeled here is based on bed load sediment transport, computed using the Ashida and Michiue formula, and the vector of bedload transport uses the Watanabe formula.

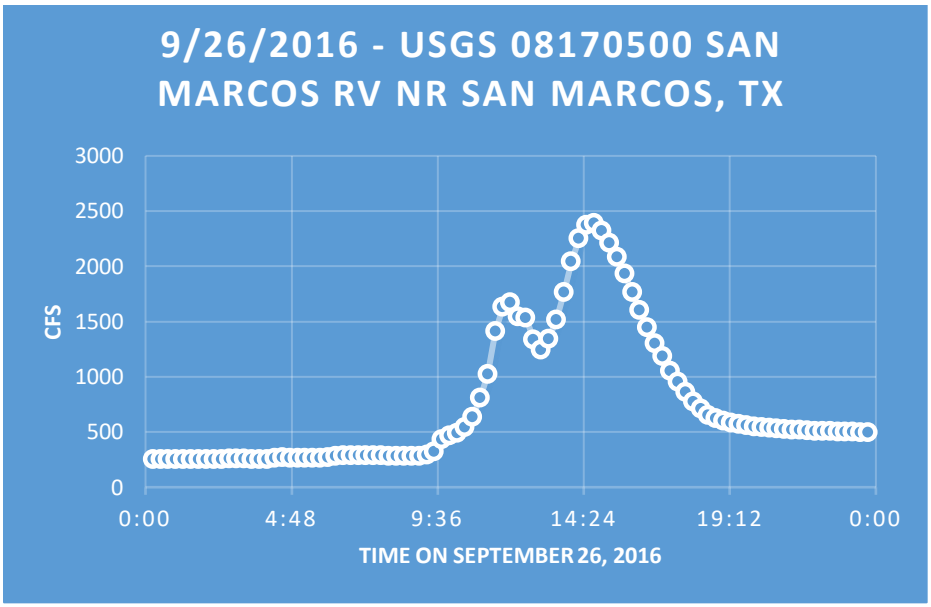

Figure 21 San Marcos River Flow Hydrograph for September 26, 2016

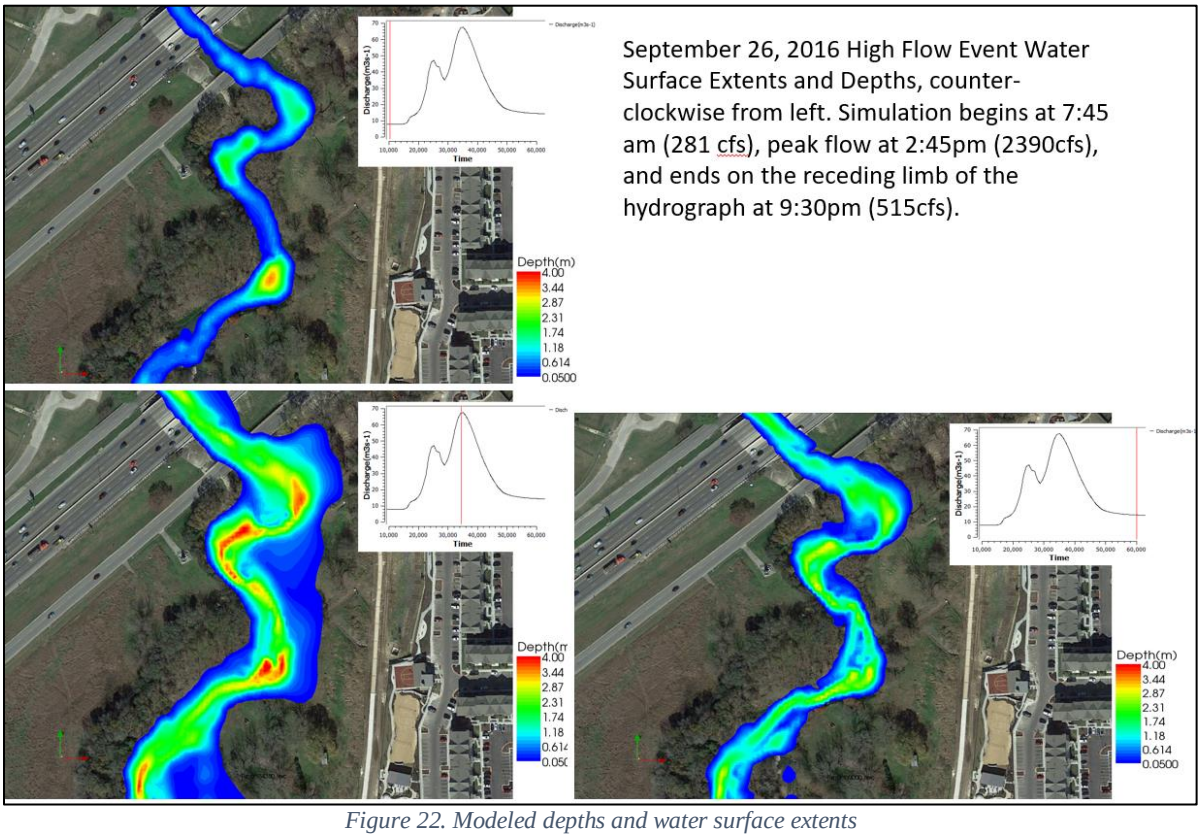

Figure 22. Modeled depths and water surface extents

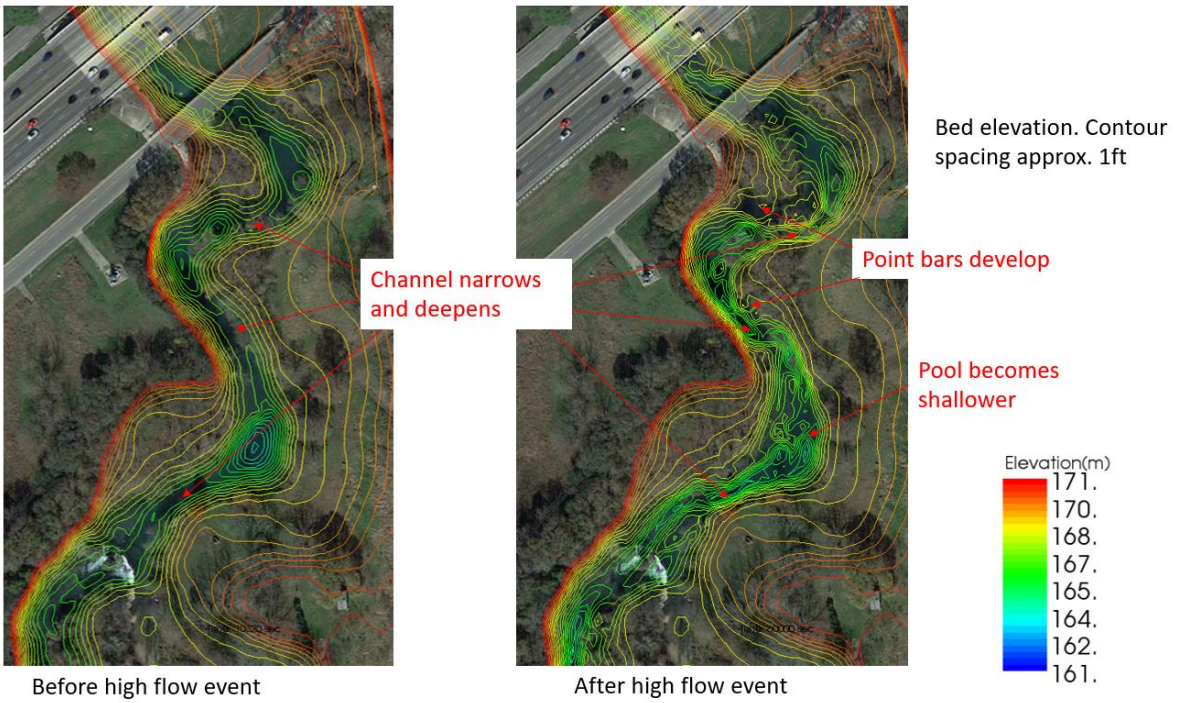

Figure 23. Riverbed morphology change.

With Capes Dam removed, it can be seen that after a channel forming event such as the flow that occurred on September 26, 2016 there will be upstream impacts to the riverbed. As the river erodes the sediment deposited in the existing reservoir, the channel will deepen. The eroded sediment is expected to deposit as point bars on the downstream end of the inside river bends, narrowing the active channel.

Conclusion

The Capes Dam removal proposed in this report accomplishes many desired objectives. The existing public safety hazard that the dam poses will be eliminated as well as many adverse impacts the dam has on natural habitats. During low flow, all discharge will flow through the main San Marcos river channel, which was a specific concern for the endangered species in the project reach. The Mill Race will be retained and enhanced as a recreational amenity even during low flow events. The existing backwater upstream of Capes Dam will become a more natural river channel with adequate flow depths for recreationalists. This dam removal addresses public safety and environmental concerns while enhancing recreation in the reach and creating an amenity for the community.

References

[1] Effects of Changing Height of Cape's Dam on Recreation, Texas Wild Rice and Fountain Darter Habitat in the San Marcos River, Textas, Dr. Thomas B. Hardy and Dr. Nolan Raphelt, October 12, 2015.
[2] Cape Dam and Mill Race Assessment, Dr. Thomas B. Hardy, City of San Marcos