Appendix B:

Dry-Weather Discharge and Depth Analysis of the Santa Ana River from RIX to MWD Crossing

(WEI, May 2014)

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Wildermuth Environmental, Inc.

May 13, 2014

Somach Simmons and Dunn Attorneys at Law
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500 Capitol Mall, Suite 1000
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Subject: ***Dry-Weather Discharge and Depth Analysis of the Santa Ana River from the Rialto Channel to MWD Crossing***

Dear Mr. Hitchings:

The City of San Bernardino Municipal Water Department (SBMWD) is assessing the potential impacts of the proposed Clean Water Factory[1] project on the Santa Ana River environment, Santa Ana River hydrology, and Santa Ana Sucker habitat. Per the direction of the SBMWD, Wildermuth Environmental, Inc. (WEI) completed a hydraulic analysis of the Santa Ana River from the SBMWD's Rapid Infiltration and Extraction facility (RIX) in the City of Colton to the Metropolitan District of Southern California's Upper Feeder Crossing at the Santa Ana River (MWD Crossing) in the City of Riverside (Figure 1). The objective of this investigation was to analyze the current dry-weather discharge and depth relationship along the Santa Ana River between RIX and the MWD Crossing. The results of this investigation are to be used by RBF Consultants and their project biologist to help characterize Santa Ana Sucker habitat for a range of RIX discharge reductions in dry-weather conditions.

To estimate flow depth in the Santa Ana River for a range of RIX discharges in dry-weather conditions, WEI developed a gradually-varied, steady-flow hydraulic model between the Rialto Channel and MWD Crossing. This required the acquisition of high-resolution river channel geometry and discharge data collected during a temporary discharge shutdown at RIX and during normal-RIX discharge operations. Specifically, the data collected for the model included: 1) LiDAR data acquired in October 2012, 2) stream gage data measured at three sites along the Santa Ana River between RIX and the MWD Crossing, 3) Santa Ana River discharge time history data at the MWD Crossing, and 4) RIX and City of Rialto wastewater treatment plant discharge time history data. Using this model, WEI estimated the flow depth ranges and discharge rates associated with various RIX discharges between

[1] The proposed Clean Water Factory will treat effluent from the San Bernardino Water Reclamation Plant to a quality approved for recharge—as set by the California Department of Public Health and the Santa Ana Regional Water Quality Control Board—and convey the recycled water to the Waterman Basins, the East Twin Creek Spreading Grounds, and the Devil Canyon and Sweetwater Basins for surface spreading.

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0 and 50 cubic feet per second (cfs) in dry-weather conditions. The following provides an overview of the data collection, analyses, and results of the Santa Ana River hydraulic model.

Data Collection

LiDAR

Evaluation of the Santa Ana River discharge-depth relationship in dry-weather conditions required the acquisition of high-resolution channel geometry as well as hydraulic parameters, such as discharge and Manning's n. Manning's n is the channel bottom roughness coefficient used in Manning's equation to calculate energy losses and is a key parameter in determining changes in river depth and discharge for various RIX discharge rates.

High-resolution channel geometry was obtained from airborne LiDAR mapping of the Santa Ana River between RIX and the MWD Crossing on October 19, 2012 and October 25, 2012 by GeoDigital International (Figure 1). Two days of LiDAR mapping was required for this investigation to capture and compare the river under very low and normal discharge conditions. In an effort to map the river channel at its lowest stage, LiDAR acquisition coincided with RIX treatment plant scheduled maintenance and a temporary discharge shutdown by the SBMWD: the SBMWD ceased discharge at RIX for approximately twelve hours. The only known contributors of river discharge during this time interval were the City of Rialto's wastewater discharge treatment plant (discharged through the Rialto Channel) and rising groundwater (Figure 1). Analysis by WEI, using discharge data collected during the temporary shutdown of RIX (routine maintenance) and data for USGS gage 11066460 (Santa Ana River at MWD Crossing), demonstrated that a minimum of 10 to 12 hours was needed to assure maximum channel dewatering and stabilization of river flow. In addition, zero to very low discharge in the river was critical for LiDAR acquisition. The LiDAR signal may scatter when striking water, resulting in a signal with an erroneous elevation. Data from the second LiDAR flight, flown on October 25, 2012, were used to compare the flow patterns and area inundated by the river under normal-RIX discharge conditions to the zero-RIX discharge conditions (October 19, 2012).

Stream Gaging Between RIX and MWD Crossing

The objective of the stream gaging effort was to measure discharge in the Santa Ana River under normal-RIX discharge conditions, prior to the temporary RIX discharge shutdown, and during the temporary RIX discharge shutdown. These discharge data were used to supplement the LiDAR and imagery data in developing the channel geometry and hydraulic parameters, such as Manning's "n" for the hydraulic model.

Scheduled and periodic river discharge measurements were taken before and during the temporary RIX discharge shutdown as well as after RIX resumed discharge to the river. Discharge measurements were made approximately every 3 to 4 hours at the three sites shown in Figure 1, using techniques outlined by the USGS (Carter and Davidan)[2] and methods adopted by WEI.

Selection of the stream gage sites was based on the spatial distribution between RIX and the MWD Crossing, access to the river, and operational safety during day and night hours. Table 1 shows the approximate timeline of actual events, including RIX shutdown, LiDAR acquisition, and stream gage measurements. The concurrent discharge data, depth measurements, and the LiDAR/imagery data provided a robust dataset for use in developing the Santa Ana River hydraulic model between RIX and the MWD Crossing.

USGS Stream Gage Data at MWD Crossing

Similar to the stream gaging effort between RIX and MWD Crossing, the objective of collecting and reviewing the stream gage data at MWD Crossing (USGS Gage 11066460 Santa Ana River at MWD Crossing) was to also monitor and measure discharge in the Santa Ana River under normal-RIX discharge conditions, prior to the temporary RIX discharge shutdown, and during the temporary RIX discharge shutdown. Collection of this data was important because it provided nearly continuous discharge information on the river's response to the temporary RIX shutdown.

In an effort to coincide with the temporary RIX shutdown, LiDAR, and stream gaging effort, the USGS scheduled their stream gaging measurement of the Santa Ana River at MWD Crossing on October 18th, 2012 (one day prior to temporary RIX shutdown). Measuring the river discharge as close as possible to the scheduled temporary RIX shutdown ensured the discharge measurements at the MWD Crossing reflected the most current stage and discharge conditions.

RIX and Rialto Effluent Discharge Data

Collection of effluent discharge from both RIX and the City of Rialto was needed to accurately ascertain a baseline condition of discharge to the river prior to and during the temporary RIX shutdown. Likewise, this data was critical in developing the Santa Ana River hydraulic model.

Data Collection Results

LiDAR

The LiDAR and imagery acquired on October 19th and 25th were collected at a horizontal and vertical accuracy of approximately 18.3 cm (7.2 in) or better in open, non-vegetated terrain with a point density of 20 to 30 points per square meter. Imagery was collected simultaneously with the LiDAR at an approximate resolution of 1.5 cm (0.6 in). The area covered by the LiDAR is shown in Figure 1. Data were collected between 12:30 pm and 3:00 pm on October 19th and between 4:30 pm and 6:00 pm on October 25th. GeoDigital processed all raw files and delivered .las (LiDAR) point format data, classified as water,

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[2] Carter, R. W., and Davidan, J. (1968). *General Procedure for Gaging Stations.* Denver: U.S. Geologic Survey.

bare-earth, vegetation, and non-ground features; 1-ft topographic contours; and GeoTiFF orthoimagery. Appendices A and B contain the .las (LiDAR) files, orthoimagery, and contours for both flight dates. WEI processed the .las files creating a terrain dataset for the bare-earth point classification in ArcMap 10.1 (3D Analyst extension). Figure 2 shows an example of the bare-earth model for the zero-RIX discharge period at Site 002 (SAR at Mission Inn Ave). Imagery for the zero- and normal-RIX discharge period at Site 002 (SAR at Mission Inn Ave) is shown in Figures 3a and 3b, respectively. Figure 3a shows that the channel bottom is exposed and the river top width is narrower under zero-RIX discharge conditions compared to normal-RIX discharge conditions in Figure 3b.

Stream Gaging

Figure 4 shows the time history of the stream gage measurements and discharge at RIX, the City of Rialto wastewater treatment plant, and the MWD Crossing. RIX discharged an average of approximately 53 cfs prior to shutdown beginning at 5:00 am (October 19, 2012). RIX completed discharge shutdown at 6:00 am the same day. City of Rialto wastewater treatment plant discharge was constant during shutdown at about 9 cfs.

At Site 001 (Santa Ana River at Riverside Ave), discharge declined from about 46 cfs at 5:00 am to about 4 cfs by 2:30 pm. Maximum depth varied from approximately 1.50 ft at 5:00 am to a depth of 0.75 ft at 2:30 pm. Figures 5a and 5b show river discharge and river top width variation during zero- and normal-RIX discharge conditions at Site 001. The river top width reduced from approximately 19 ft under normal-RIX discharge conditions to approximately 13 ft under zero-RIX discharge conditions. Cobbles and gravels were exposed during the river's lowest stage. Photographs under normal-RIX discharge conditions were not taken on October 19th, as discharge measurements were taken during night and early morning hours; photographs were taken on October 17, 2012 during a site reconnaissance (Figure 5b).

At Site 002 (Santa Ana River at Mission Inn Ave), discharge declined from about 39 cfs at 6:15 am to 4 cfs by 4:00 pm. Maximum depth varied from approximately 1.30 ft at 6:00 am to a depth of 0.70 ft at 4:00 pm. Figures 6a and 6b show river discharge and river top width variation during zero- and normal-RIX discharge conditions. The river top width reduced from approximately 47 ft under normal-RIX discharge conditions to approximately 7 ft under zero-RIX discharge conditions. During the river's lowest stage at this site, discharge was constrained along the right bank (Figure 6a). Photographs under normal-RIX discharge conditions were not taken on October 19th, as discharge measurements were taken during night and early morning hours; photographs were taken on October 17, 2012 during a site reconnaissance (Figure 6b).

At Site 003 (Santa Ana River at Railroad Crossing), discharge reduced from about 63 cfs at 7:30 am to 21 cfs by 10:15 pm. Maximum depth varied from approximately 1.10 ft at 8:00 am to a depth of 0.70 ft at 6:15 pm. Figures 7a and 7b show river discharge and river top width variation during zero- and normal-RIX discharge conditions. The river top width was approximately 63 ft under both zero- and normal-RIX discharge conditions. An 8-foot wide section of the channel bottom was exposed near the right bank under zero-RIX discharge conditions (Figure 7a). Photographs under normal-RIX discharge conditions were not taken on October 19th, as discharge measurements were taken during night and early morning hours; photographs were taken on October 17, 2012 during a site reconnaissance (Figure 7b).

Review of Figure 4 indicates that the decline in discharge observed at Site 003 and the MWD Crossing lags RIX shutdown by approximately 4 hours. Additionally, the river reach between Sites 002 and 003 shows a stream discharge gain of approximately 30 cfs. This discharge gain may be explained by groundwater seepage to the river as well as from unknown dry-weather discharge through tributary drainages within this river reach. Based on the low-flow orthoimagery, we identified rising groundwater to begin approximately 0.63 miles downstream from Site 002. The imagery shows discharge in the channel widening, increased vegetation coverage, and exposed bedrock along the river banks.

Discharge-Depth Characterization for Various RIX Discharges

Hydraulic Model

WEI applied a gradually-varied, steady-flow hydraulic model to characterize flow depths in the Santa Ana River reach from the Rialto Channel to the MWD Crossing under various RIX discharges, using HEC-RAS v4.1 (U.S. Army Corps of Engineers Hydrologic Engineering Center). The model boundary, shown in Figure 1, extends from the Rialto Channel to 0.22 miles downstream of the MWD Crossing. The HEC-RAS model required two major components: geometric data and steady flow data. Geometric data included channel geometry (cross-sections perpendicular to flow), river centerlines, flow paths, bank locations, and Manning's "n." Steady flow data included RIX and City of Rialto treatment plant discharge data, discharge measured at the three stream gage sites on October 19, 2012, and updated rating curve data for USGS gage 11066460 (Santa Ana River at MWD Crossing).

Channel Geometry

A bare-earth, digital terrain model developed from the LiDAR data acquired on October 19, 2012 was used to represent the ground surface within the investigation area. The channel geometry for the Santa Ana River was developed using 93 cross-sections between the Rialto Channel and MWD Crossing. The orthoimagery and LiDAR information was used to lay out the cross-section transects. The average distance between cross-sections was approximately 500 ft with less distance between cross-sections near bridges and at abrupt changes in channel geometry. Each cross-section was identified with a river station (the river station is the cumulative distance from the model end in feet) and is shown in Figures 8a, b, c. Elevation data for each cross-section transect were extracted using HEC-geoRAS in conjunction with ArcMap 10.0 and imported into HEC-RAS. HEC-geoRAS was also used to define the river centerline, flow paths, and banks; the river centerline, flow paths, and banks were manually digitized in HEC-geoRAS using the October 2012 imagery and imported into HEC-RAS.

Accurate LiDAR data acquisition was limited to above the water surface. As discussed earlier, LiDAR typically cannot penetrate the water surface in the wetted area of a channel.

To approximate the channel bottom, the existing channel geometry below the water line was modified to a trapezoidal geometry. The trapezoidal geometry was defined with Manning's equation using side slopes, wetted river top width, discharge, river bottom width, and flow depth. All cross-sections were modified to a trapezoidal geometry below the water line, except for the three cross-sections where discharge and flow depths were measured by WEI (Sites 001, 002, and 003 [Stn. 39769, 21972, and 4879]). A limitation to using a trapezoidal channel shape is that the channel bottom no longer preserves bed bottom undulations, channel bars, riffles, bank incisions, or maximum flow depth. The trapezoidal geometry, however, at each cross-section does preserve conveyance and average maximum flow depth in the channel.

Based on their field observations conducted on October 19, 2012 during the zero-RIX discharge period, RBF Consultants and GEI Consulting identified the river reach between RIX and 0.6 miles downstream of Riverside Ave as an "area of interest" for their analysis of Santa Ana Sucker habitat. Moreover, RBF Consultants stated that better-defined channel geometry in this reach of the river was necessary for their analysis.

On February 18 and February 21, 2013, WEI surveyed a total of 18 river channel cross-sections along a 2.1-mile stretch of the Santa Ana River from the RIX outfall to approximately 0.6 miles downstream of Riverside Ave (Figure 8a; Stn. 46895 to 35457). Figure 8a shows the boundary of the reach of interest identified by RBF Consultants within the model boundary. Cross-sections were located as close as possible to the original cross-sections delineated in HEC-geoRAS. Aerial photos and a handheld GPS were used to mark the starting point of each survey cross-section. Each cross-section extended approximately 15 ft to each side of the wetted channel. After completion of the survey, the data were processed to obtain elevations. The bare-earth terrain model served as a benchmark to establish the survey instrument height and subsequently the cross-section elevations. The new channel bottom survey data were combined with the existing LiDAR data above the wetted channel and imported into HEC-RAS.

Manning's "n" Values

For each discharge measurement site, Manning's equation was used to calculate and refine Manning's roughness coefficient, "n." For the remaining sections of the river, where no measured discharge data were recorded to estimate Manning's roughness coefficient, "n" values were estimated and/or interpolated between the calculated values at stream gage Sites 001, 002, and 003. The "n" values were checked against the imagery, field photographs, and field notes. The table below (Manning's Roughness Coefficient "n" Used in the HEC-RAS Model) summarizes the range of values used in the model. The Manning's "n" values were consistent with published data and our professional experience.

Manning's Roughness Coefficient "n" Used in the HEC-RAS Model

Model Station	River Section	Range of "n" Values		
		Left Overbank	Channel	Right Overbank
46895 to 39769	Rialto Channel to Site 001	0.0626-0.12	0.0347	0.07-0.12
39769 to 21972	Site 001 to 002	0.033-0.12	0.0277-0.047	0.0355-0.12
21972 to 4879	Site 002 to 003	0.283-0.12	0.0277-0.0314	0.07-0.12
4879 to 42	Site 003 to MWD Crossing	0.07-0.12	0.0314	0.07-0.1

Discharge Data

Discharge data within the Santa Ana River model boundary were collected from the three stream gage sites (Sites 001, 002, and 003), USGS site 11066460 (Santa Ana River at MWD Crossing), RIX, and the City of Rialto wastewater treatment plant. Based on the discharge results (shown in Figure 4), discharge is not constant along the river's length. Within the investigation area, the Santa Ana River is a losing stream from RIX to about 0.63 miles downstream of Mission Inn Ave, becomes a gaining stream from this point to Site 003, and loses water from approximately Site 003 to MWD Crossing. The location of where rising groundwater begins is based on increased vegetation coverage, wetted channel width observed from imagery, as well as published groundwater elevation data (WEI, 2011).[3] The table below (Santa Ana River Discharge at Measured Sites for the Normal- and Zero-RIX Discharge Scenarios) shows the HEC-RAS model input discharge rates for the "normal discharge" (pre-RIX shutdown) scenario and the "zero discharge" (RIX shutdown) scenario for each of the measured sites, the Rialto Channel, and the Santa Ana River at MWD Crossing. An additional ten RIX discharge scenarios (3, 5, 10, 15, 20, 25, 30, 35, 40, and 45 cfs) were also modeled.

Santa Ana River Discharge at Measured Sites for the Normal- and Zero-RIX Discharge Scenarios

River Station	River Site Name	Normal-RIX Discharge (cfs)†	Zero-RIX Discharge (cfs)†
46895	Rialto Channel	62.5	9.5
39769	Site 001	45.5	5.2
21972	Site 002	36.7	7.7
4879	Site 003	62.5	37.3
978	MWD Crossing	52.4	32.6

†Includes Rialto Channel discharge to the Santa Ana River.

Hydraulic Model Projected Flow Depth Results

The HEC-RAS model was calibrated for the normal- and zero-RIX discharge scenarios by adjusting Manning's roughness coefficient to better match the measured site flow depth measurements. The table below (HEC-RAS Model Flow Depth Verification) shows the maximum depth measured in the field at Sites 001, 002, and 003 compared to the modeled maximum flow depth results.

[3] Wildermuth Environmental, Inc. (2011). *Recomputation of Ambient Water Quality in the Santa Ana Watershed for the Period 1990 to 2009.* Lake Forest: Author.

HEC-RAS Model Flow Depth Verification

River Station	River Site Name	Normal-RIX Discharge		Zero-RIX Discharge	
		Measured Depth (ft)	Modeled Depth (ft)	Measured Depth (ft)	Modeled Depth (ft)
39769	Site 001	1.45	1.5	0.72	0.80
21972	Site 002	1.33	1.21	0.6	0.70
4879	Site 003	1.07	0.96	0.82	0.75

Gradually-varied, steady-flow simulations were run for a total of twelve RIX discharge scenarios (0, 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 cfs) between the Rialto Channel and the MWD Crossing. All HEC-RAS model inputs are included in Appendix C.

As discussed above, RBF Consultants identified a reach within the modeled boundary as an "area of interest" for their characterization of the Santa Ana Sucker habitat. This reach, shown in Figure 8a, extends from RIX to approximately 0.6 miles downstream of Riverside Ave (Stn. 46895 to 35457). Figures 8b and 8c show the remaining extent of the model boundary as well as the locations of the model cross-sections downstream of the river reach of interest to MWD Crossing. For the purpose of this report, only the model flow depths generated from HEC-RAS for the river reach of interest were plotted against various RIX discharges. Figures 9a through 9f show six rating curves within the river reach of interest identified by RBF Consultants. Rating curves for the entire river reach of interest are included in Appendix D. The rating curves provide a useful tool in estimating flow depth for various RIX discharges. Figures 10a through 10f show the channel geometry and water surface elevations for the rating curves shown in Figures 9a through 9f. Cross-section plots for the entire river reach of interest are included in Appendix D. The cross-section plots illustrate the variability of the channel bottom at each site and flow depth for various RIX discharges. Table 2 provides a summary of the average maximum flow depth under zero- and normal-RIX discharge conditions for the river reach identified by RBF Consultants (Stn. 46895 to Stn. 35457).

We appreciate the opportunity to assist in this hydraulic analysis of the Santa Ana River. Please contact me or Mark Wildermuth if you have any questions, comments, or concerns.

Wildermuth Environmental, Inc.

Mike Blazevic, PG
Senior Scientist I

Mark J. Wildermuth, PE
President and Principal Engineer

Jeff Hwang, PhD
Principal Engineer

Enclosures:

Tables 1 and 2

Figures 1 through 10

Appendix A – LiDAR, orthoimagery, and contours of the Santa Ana River on 10/19/2012 (Disk)

Appendix B – LiDAR, orthoimagery, and contours of the Santa Ana River on 10/25/2012 (Disk)

Appendix C – HEC-RAS input data (Disk)

Appendix D – Rating curves and cross-sections from Rialto Channel to 0.6 mi downstream of Riverside Ave (Disk)

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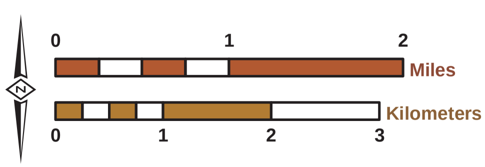
Table 1
Timeline for the RIX Shutdown, Santa Ana River LiDAR Survey Flight, and Santa Ana River Stream Gaging Between RIX and MWD Crossing on October 19, 2012

Time	RIX Operation	LiDAR Flight	Sequence of Santa Ana River Discharge Measurements for Manning's "n" Calibration		
			Measure Q Site 001†	Measure Q Site 002	Measure Q Site 003
10/19 12:00 AM	Steady Discharge		Measurement 1		
1:00 AM				Measurement 2	
2:00 AM					
3:00 AM					Measurement 3
4:00 AM					
5:00 AM			Measurement 4		
6:00 AM				Measurement 5	
7:00 AM	No Discharge (6am to 5pm)				Measurement 6
8:00 AM					
9:00 AM			Measurement 7		
10:00 AM				Measurement 8	
11:00 AM					
12:00 PM					Measurement 9
1:00 PM		LiDAR Survey (12pm - 3pm)			
2:00 PM			Measurement 10		
3:00 PM					
4:00 PM				Measurement 11	
5:00 PM					Measurement 12
6:00 PM	Resume Discharge				
7:00 PM					
8:00 PM					
9:00 PM					
10:00 PM					Measurement 13
11:00 PM				Measurement 14	
10/20 12:00 AM					
1:00 AM					Measurement 15
2:00 AM					

†Discharge was not measured after RIX resumed discharge due to unsafe conditions (deep flow and rapids).

Table 2
HEC-RAS Model Flow Depth Results

River Station	Normal-RIX Discharge Average Max Depth (ft)	Zero-RIX Discharge Average Max Depth (ft)
46895	1.10	0.36
46475	1.40	0.42
46132	1.56	0.72
45475	1.25	0.43
44975	1.34	0.45
44475	1.13	0.40
43975	1.45	0.51
43504	1.41	0.58
42975	1.09	0.32
42510	1.10	0.42
41975	1.54	0.53
41476	1.88	0.61
40976	1.31	0.60
40476	2.16	0.70
39769	1.51	0.61
39476	1.10	0.31
38988	1.04	0.35
38463	1.02	0.42
37884	1.45	0.75
37475	0.91	0.41
36982	1.02	0.43
36462	1.34	0.56
35838	1.32	0.60
35457	0.95	0.35
Minimum	**0.91**	**0.31**
Maximum	**2.16**	**0.75**
Average	**1.31**	**0.49**



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Author: MAB
Date: 4/4/2013
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Location Map

Santa Ana River from RIX to MWD Crossing

Figure 1

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Figure 2
A Bare-Earth, Terrain Model at Site 002 (SAR at Mission Inn Ave) Generated from LIDAR Acquired During Zero-RIX Discharge

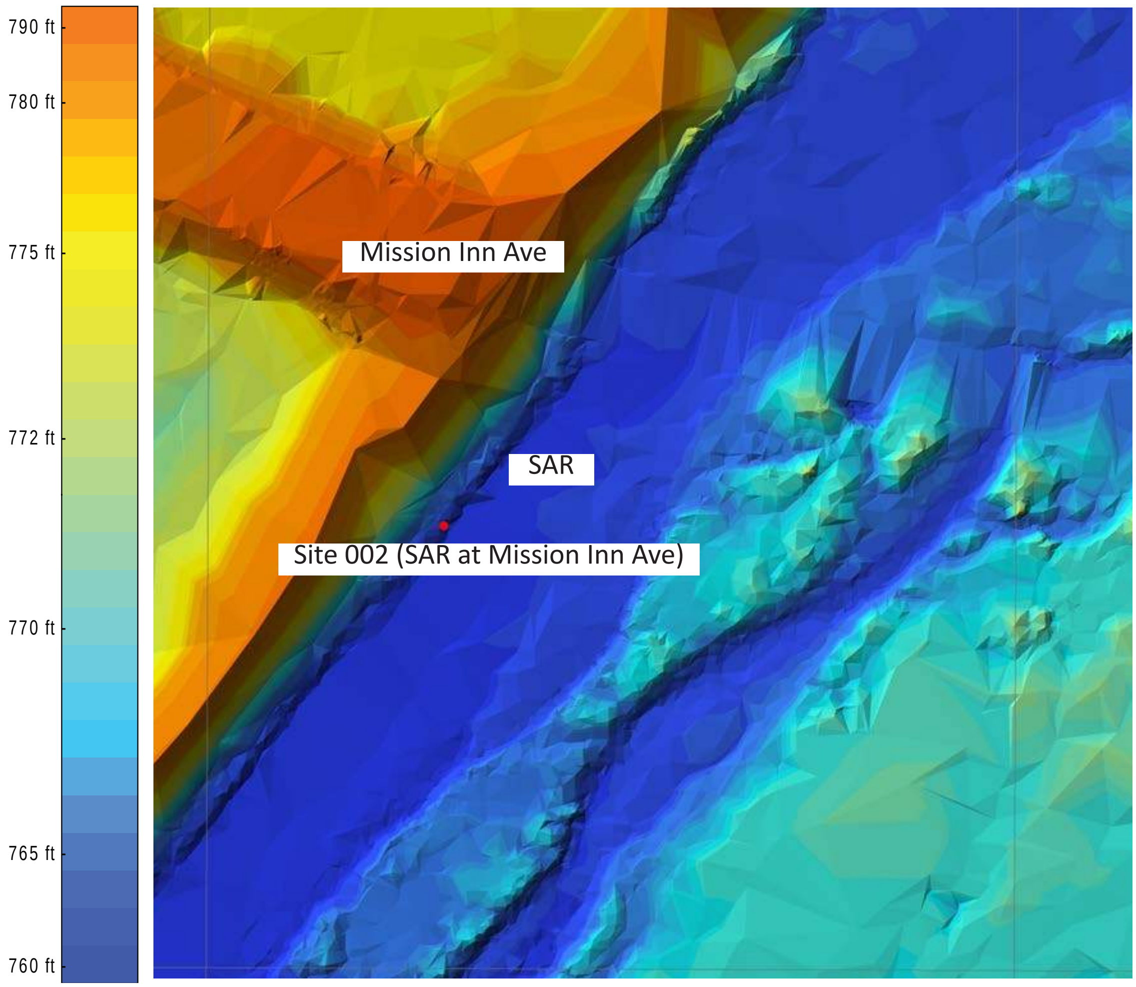

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Figure 3a
GeoTiff Orthoimagery at Site 002 Acquired During Zero-RIX Discharge

Figure 3b
GeoTiff Orthoimagery at Site 002 Acquired During Normal-RIX Discharge

Figure 4
Santa Ana River Discharge at Selected Stations Before, During, and After RIX Shutdown October 19 - 20, 2012

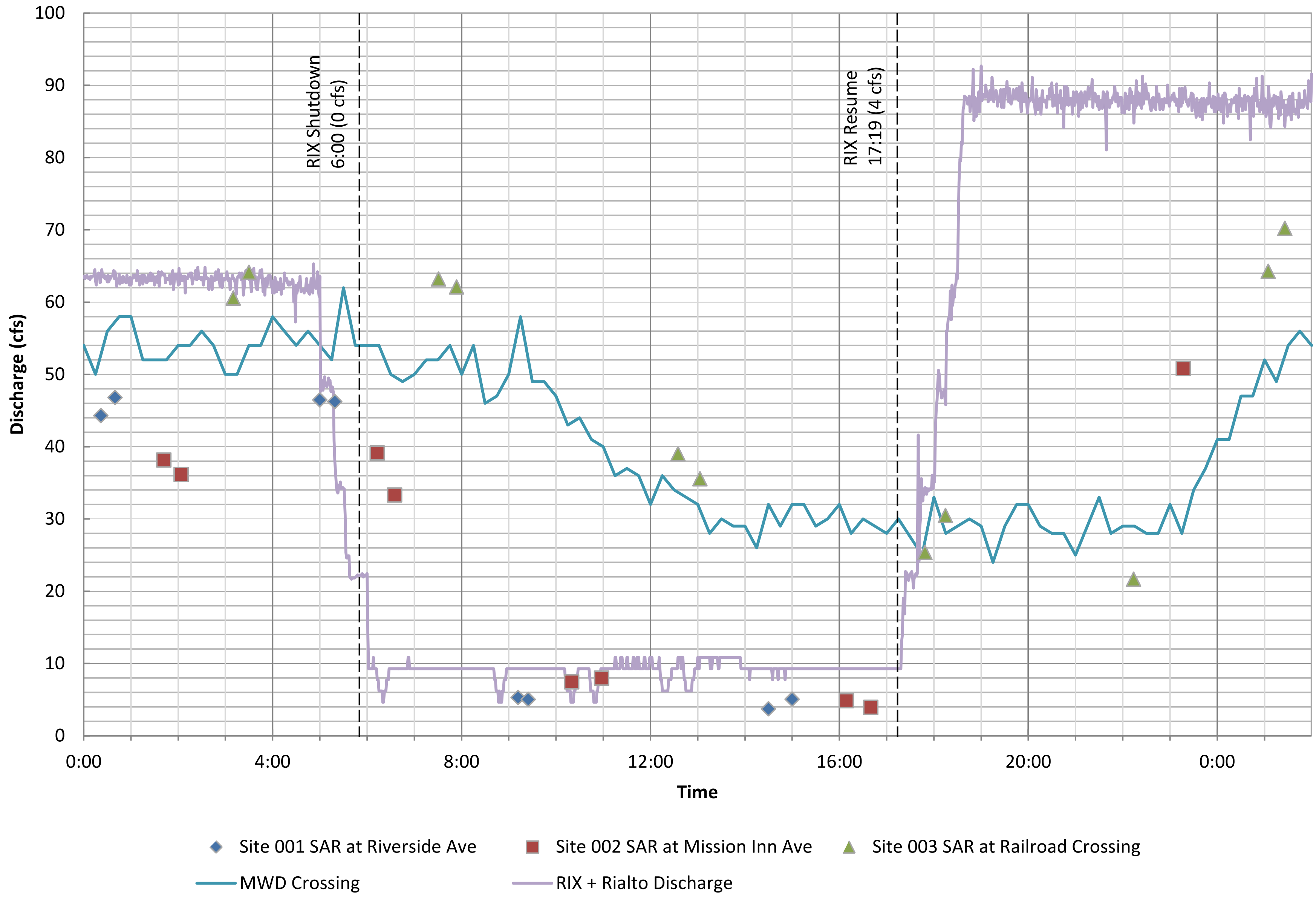

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Figure 5a
Site 001 (SAR at Riverside Ave) at 2:50 pm Viewed Upstream on 10/19/12
During Zero-RIX Discharge

Figure 5b
Site 001 (SAR at Riverside Ave) at 8:50 am Viewed Upstream on 10/17/12
During Normal-RIX Discharge

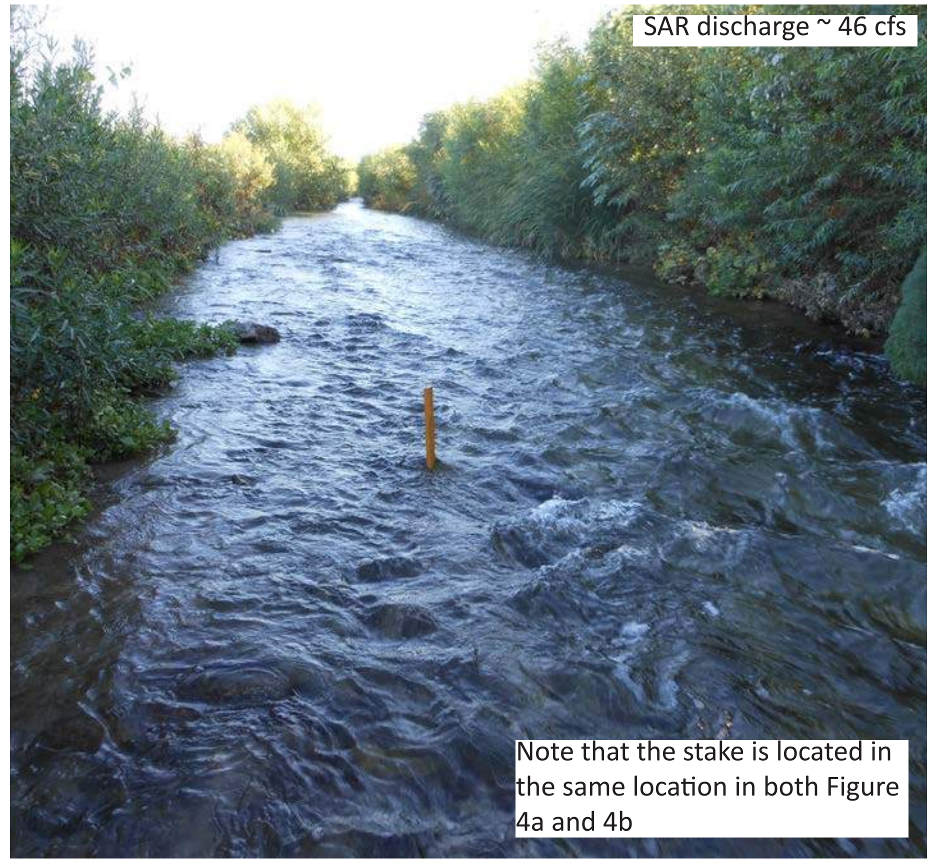

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Figure 6a
Site 002 (SAR at Mission Inn Ave) at 4:30 pm Viewed Upstream on 10/19/12
During Zero-RIX Discharge

Figure 6b
Site 002 (SAR at Mission Inn Ave) at 9:22 am Viewed Upstream on 10/17/12
During Normal-RIX Discharge

Figure 7a
Site 003 (SAR at Railroad Crossing) at 6:45 pm Viewed Downstream on 10/19/12 During Zero-RIX Discharge

Figure 7b
Site 003 (SAR at Railroad Crossing) at 8:00 am Viewed Downstream on 10/19/12 During Normal-RIX Discharge

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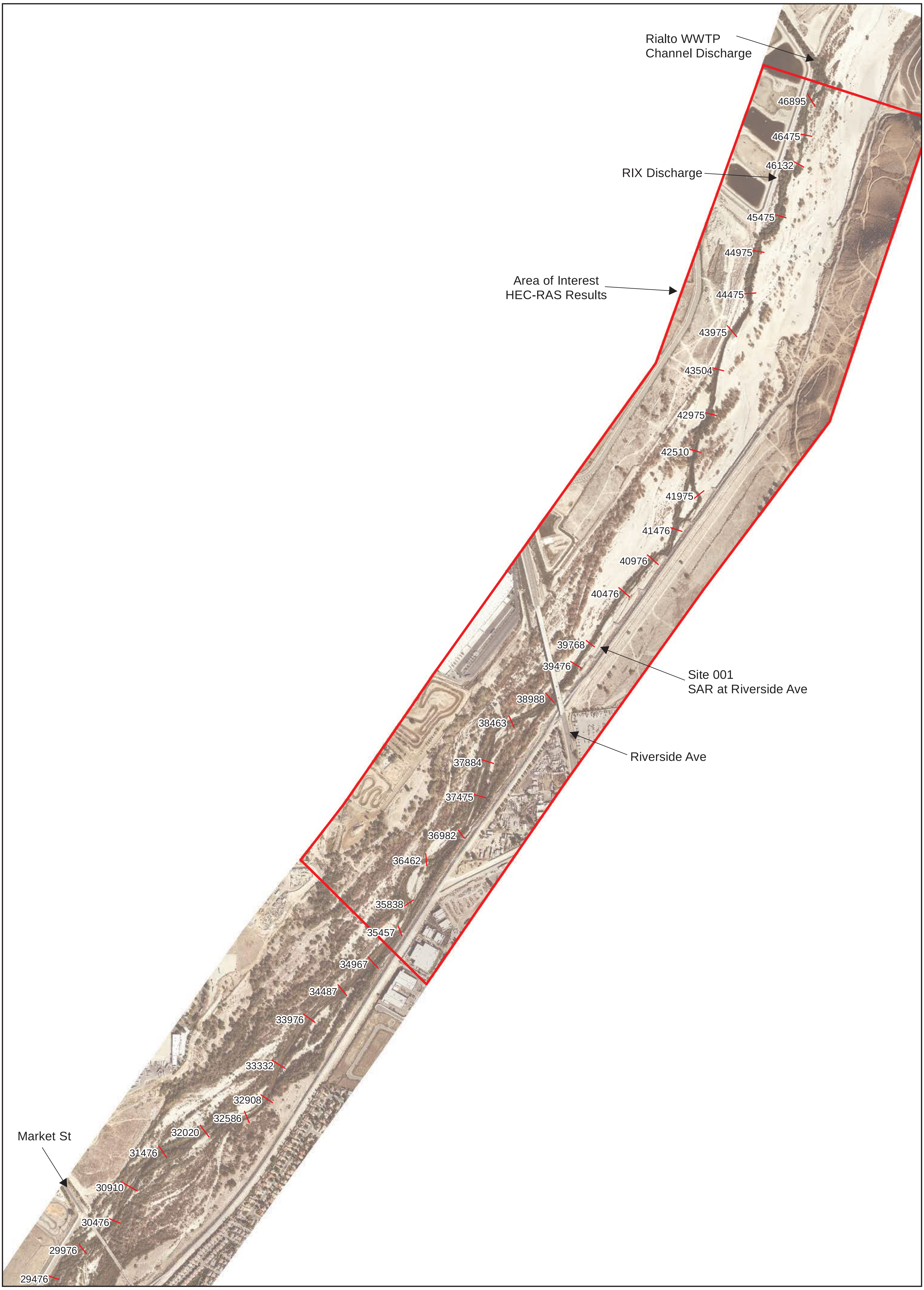

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Author: MAB
Date: 4/4/2013
File: Figure8a.mxd

0 1,000 2,000 Feet
0 200 400 600 Meters

Santa Ana River
HEC-RAS Cross-Sections
Stn. 46895 to Stn. 29476

Figure 8a

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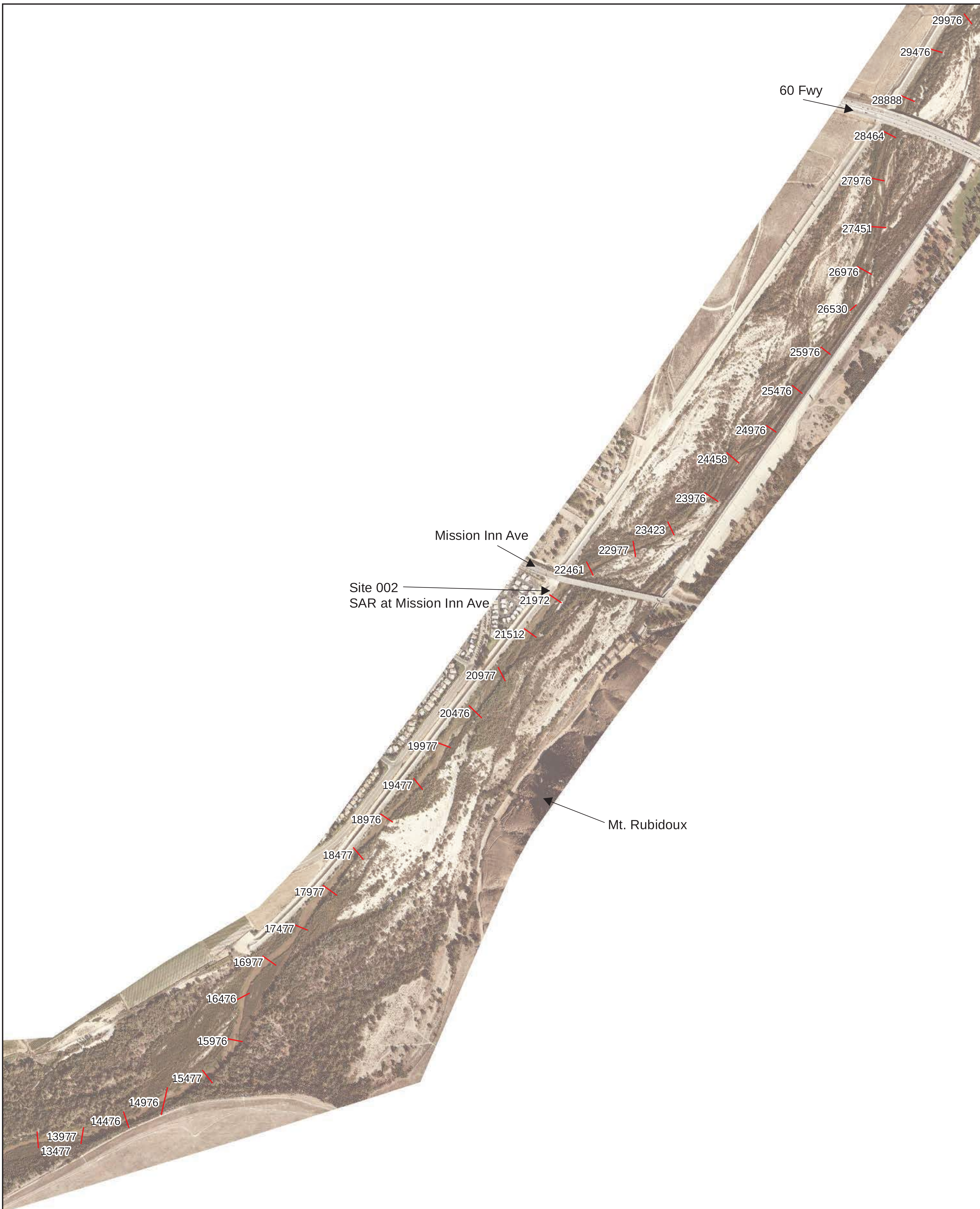

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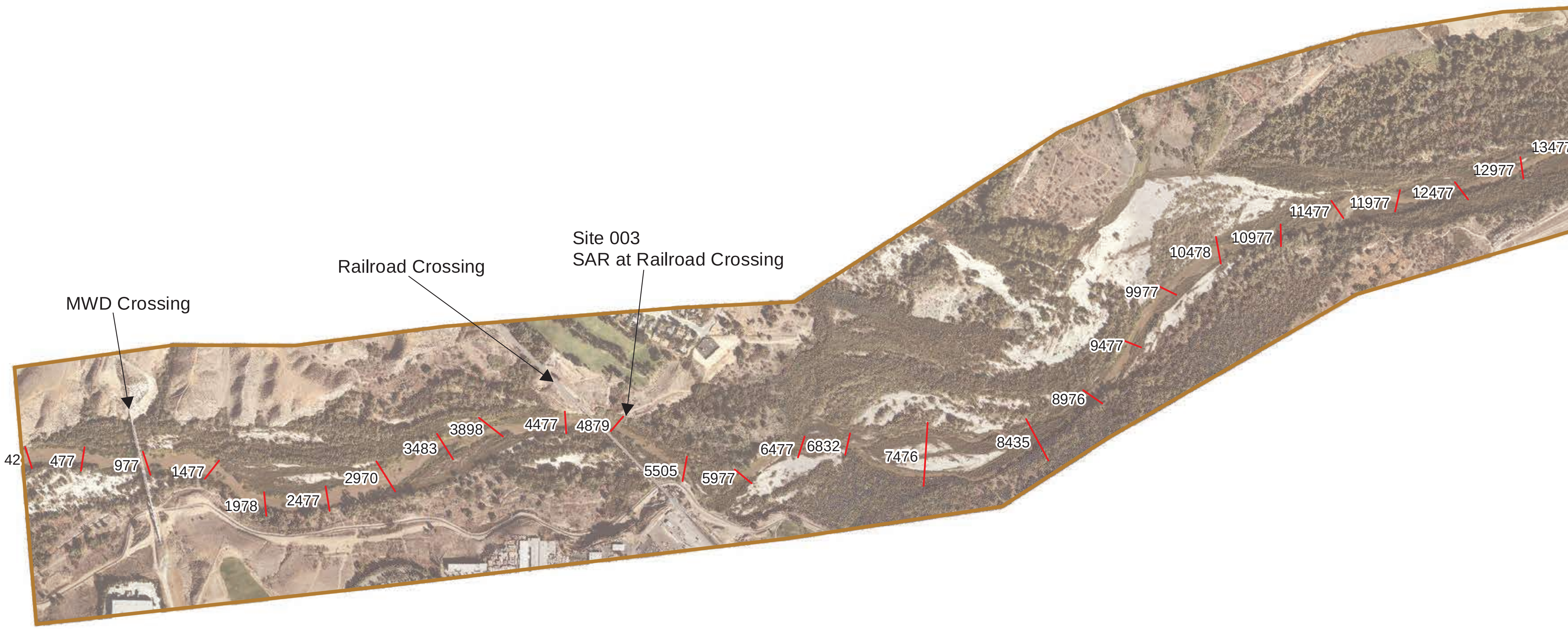
Author: MAB
Date: 4/4/2013
File: Figure8b.mxd

0 | 1,000 | 2,000 Feet
0 | 200 | 400 | 600 Meters

Santa Ana River
HEC-RAS Cross-Sections
Stn. 29976 to Stn. 13477

Figure 8b



Prepared by:

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Lake Forest, CA 92630
949.420.3030
www.wildermuthenvironmental.com

Author: MAB
Date: 5/7/2013
File: Figure8c.mxd

0 1,000 2,000 Feet

0 200 400 600 Meters

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ATTORNEY WORK PRODUCT

Santa Ana River
HEC-RAS Cross-Sections
Stn. 13477 to Stn. 42

Figure 8c

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Figure 9a
Flow Depth Versus RIX Discharge at River Station 45475

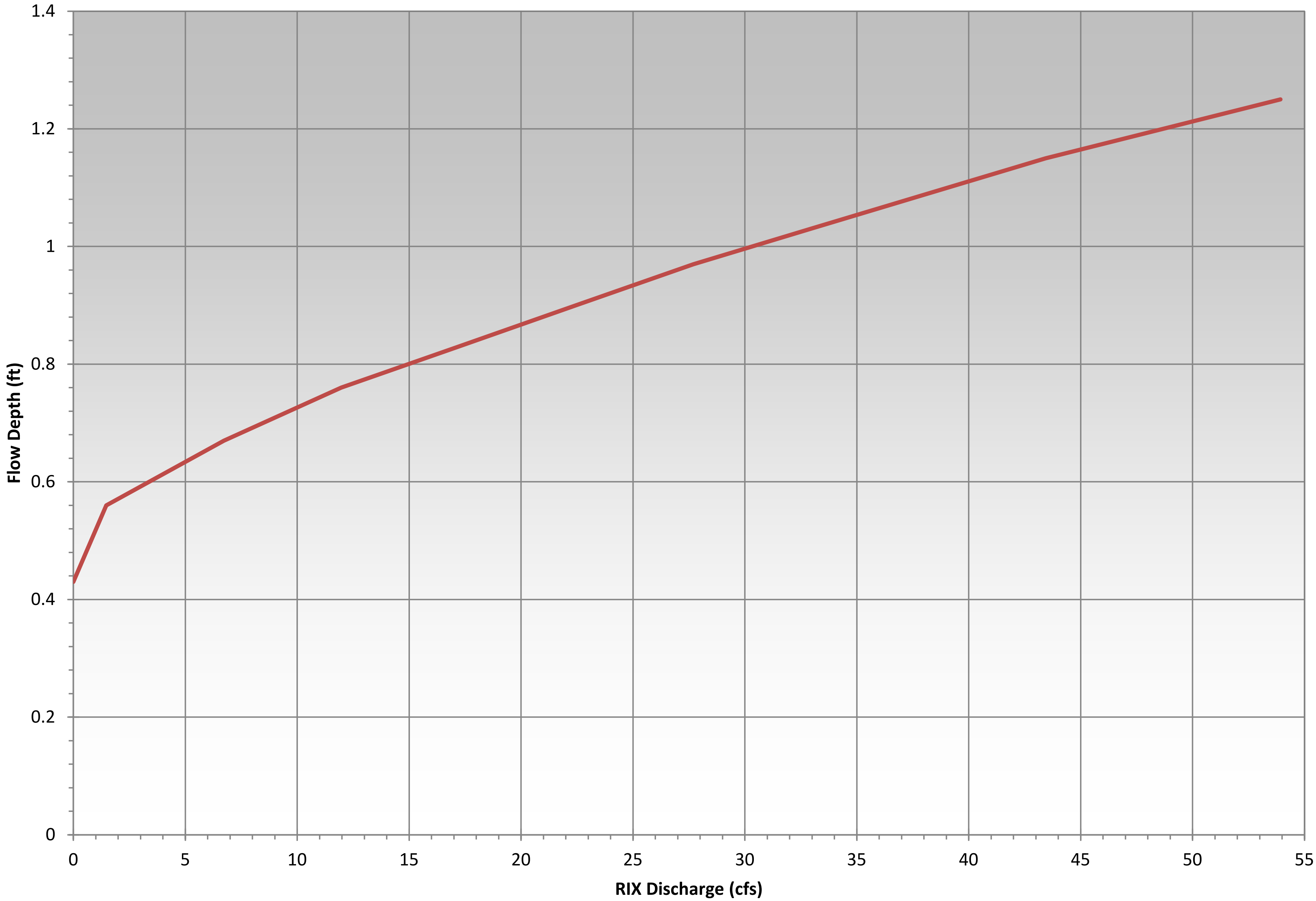

Figure 9b
Flow Depth Versus RIX Discharge at River Mile Station 43504

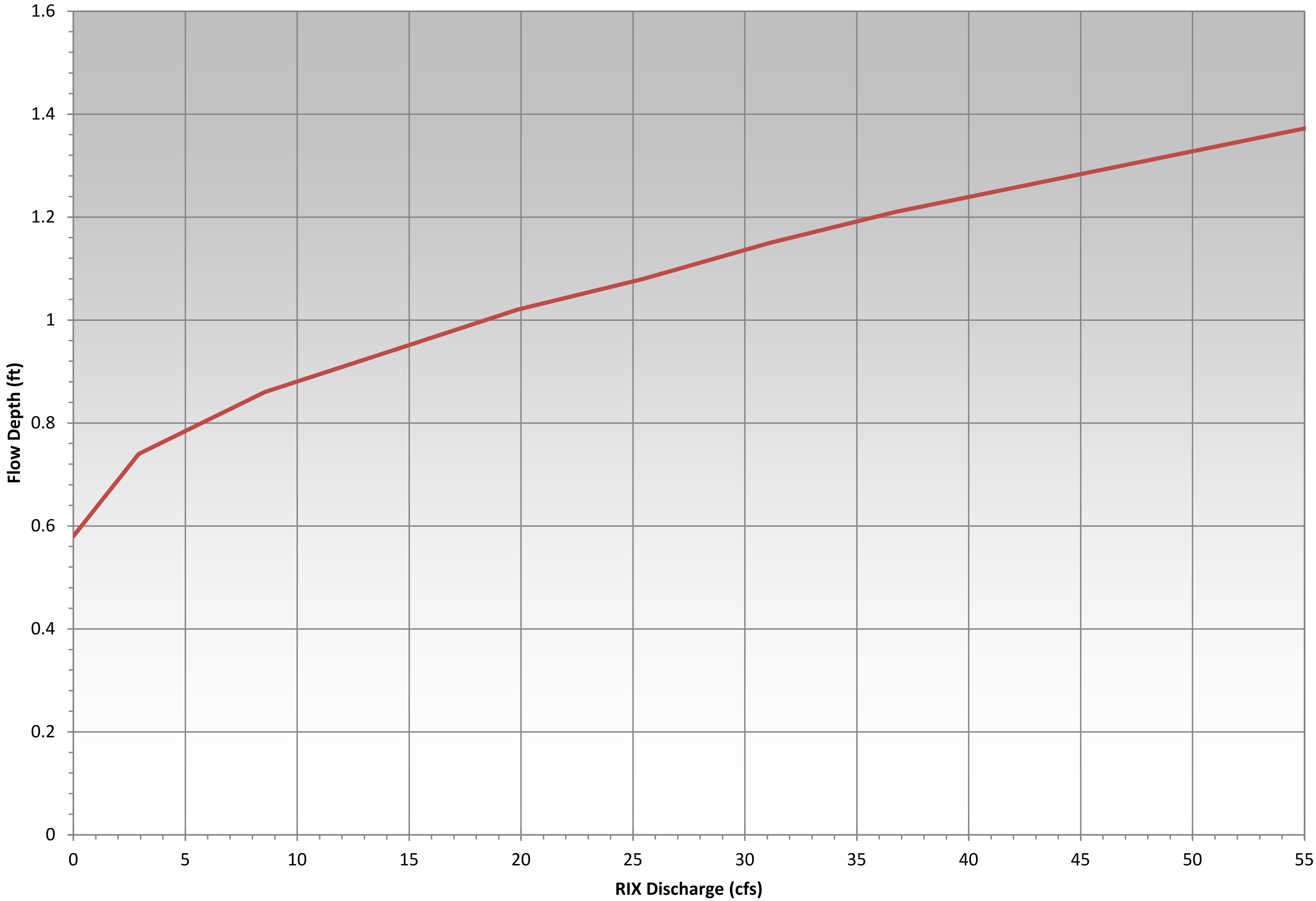

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Figure 9c
Flow Depth Versus RIX Discharge at River Station 41476

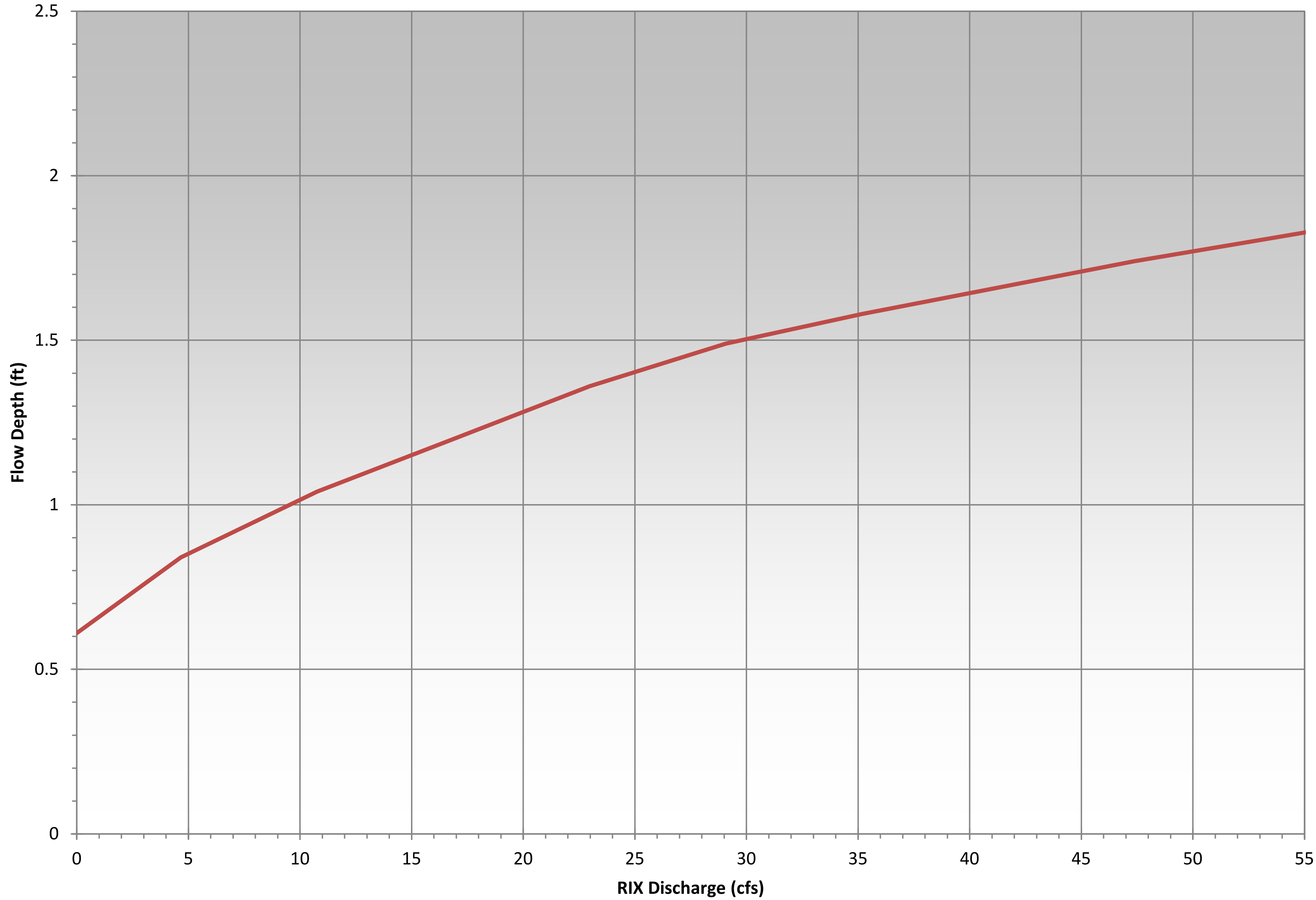
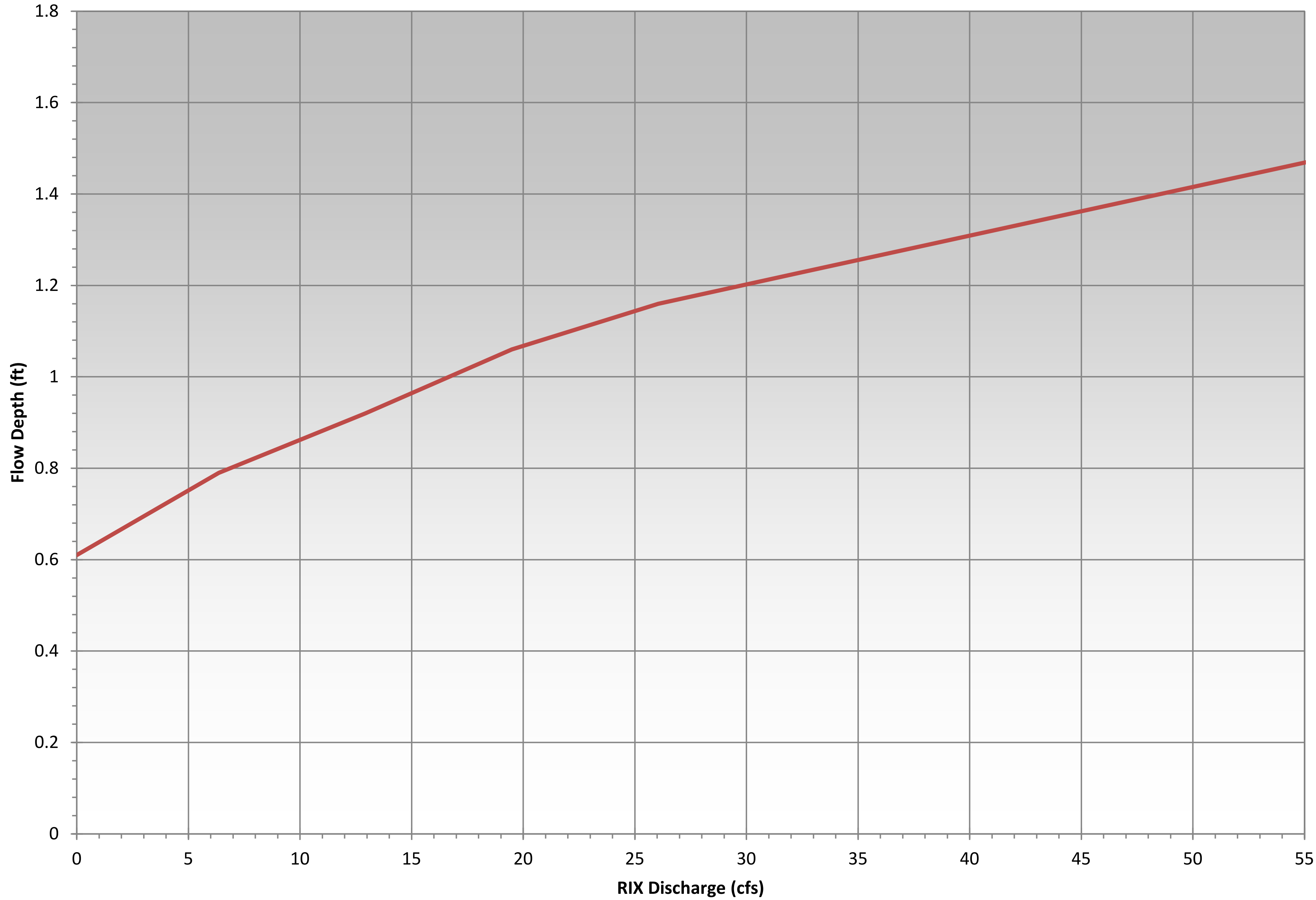


Figure 9d

Flow Depth Versus RIX Discharge at River Station 39769



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ATTORNEY WORK-PRODUCT

Figure 9e

Flow Depth Versus RIX Discharge at River Station 37884

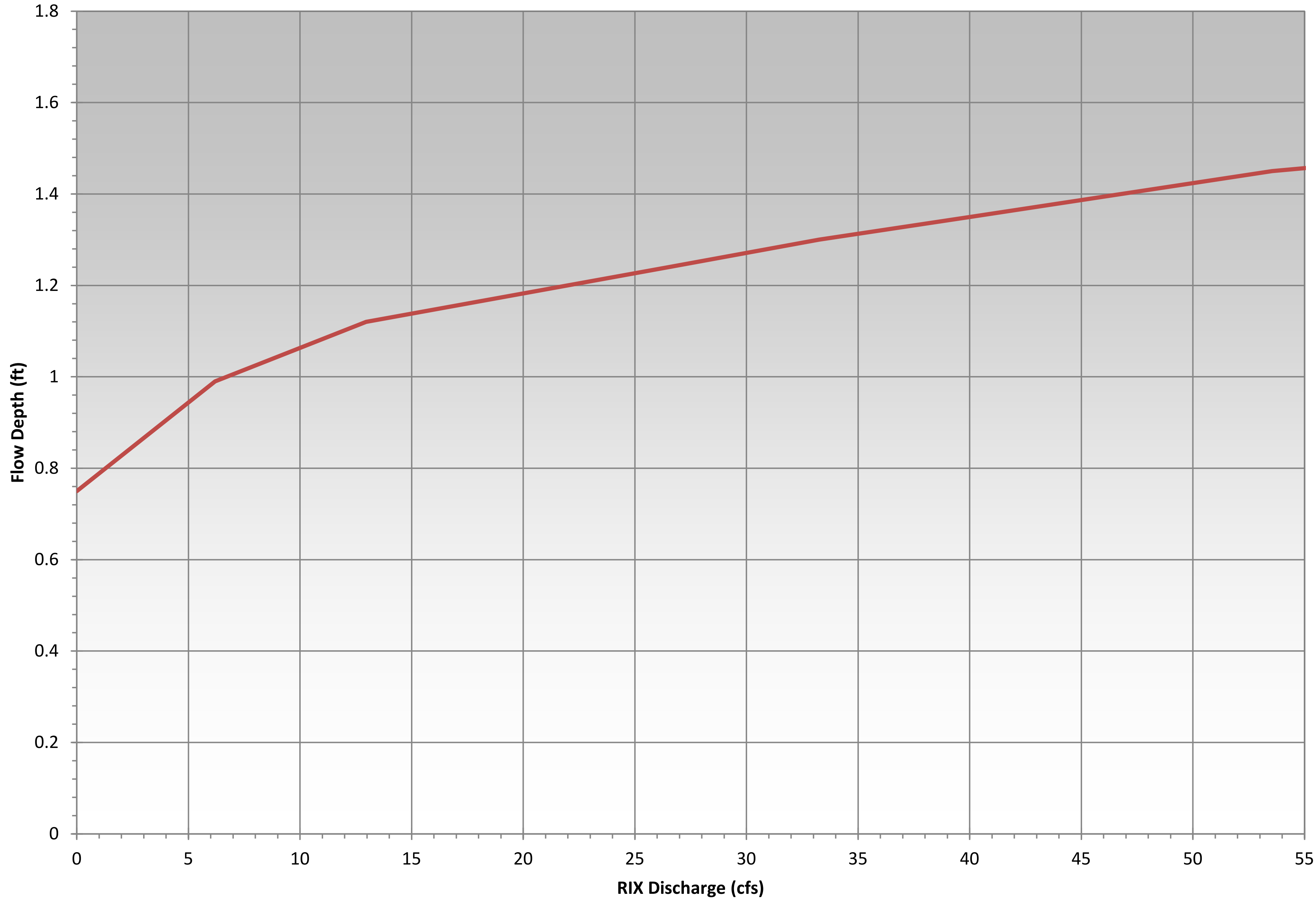

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Figure 9f
Flow Depth Versus RIX Discharge at River Station 35457

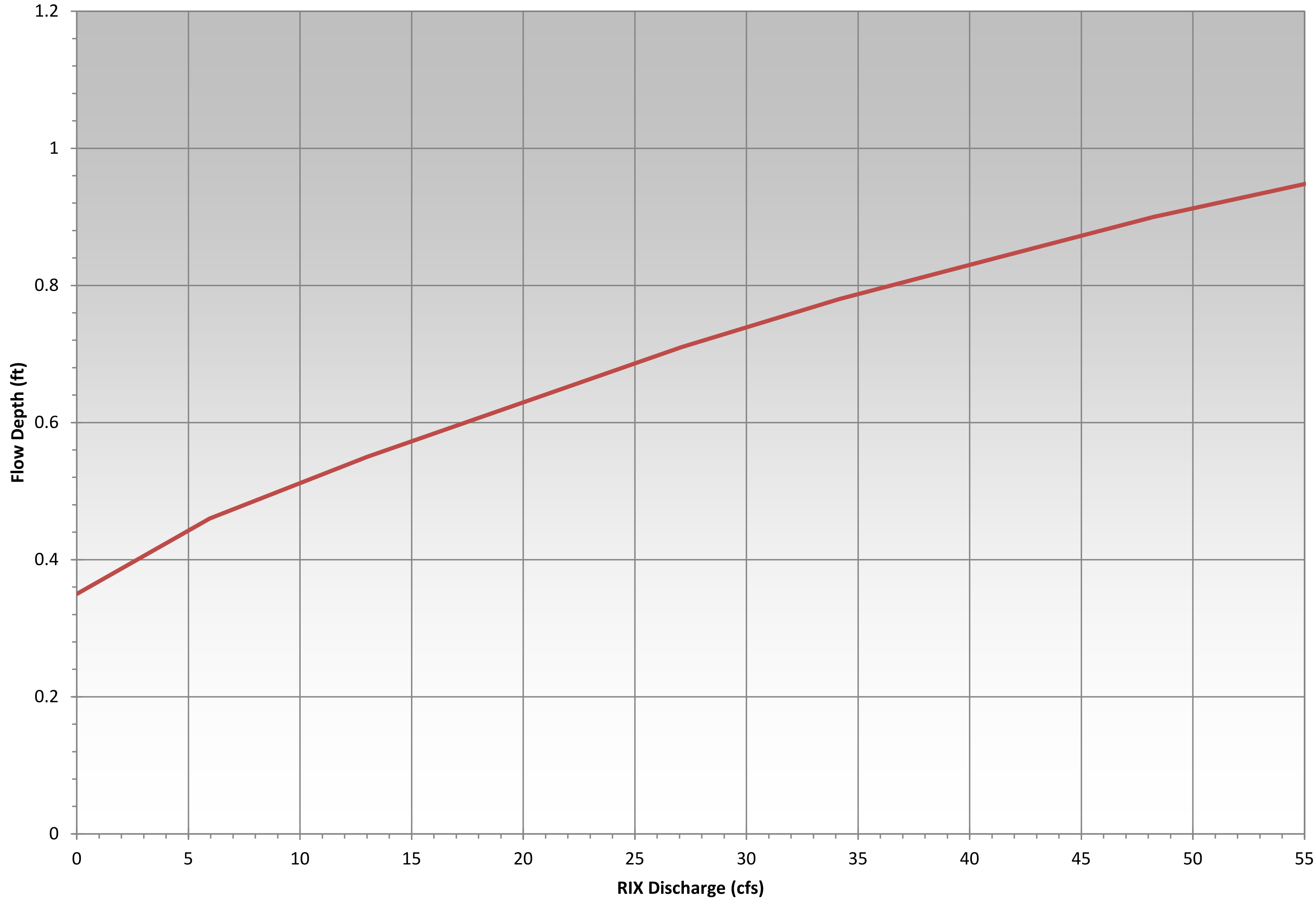
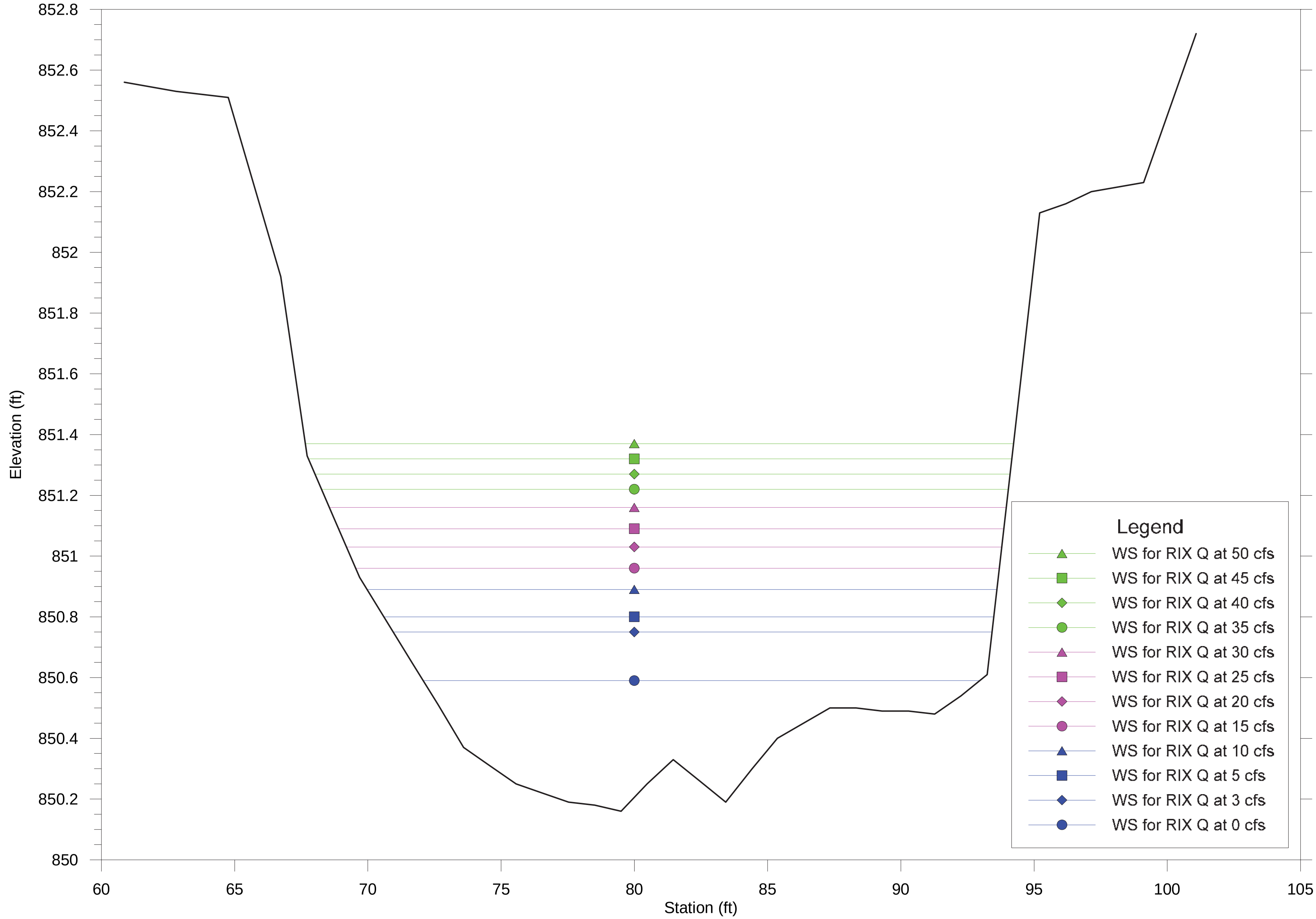


Figure 10a
River Station 45475 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY WORK-PRODUCT

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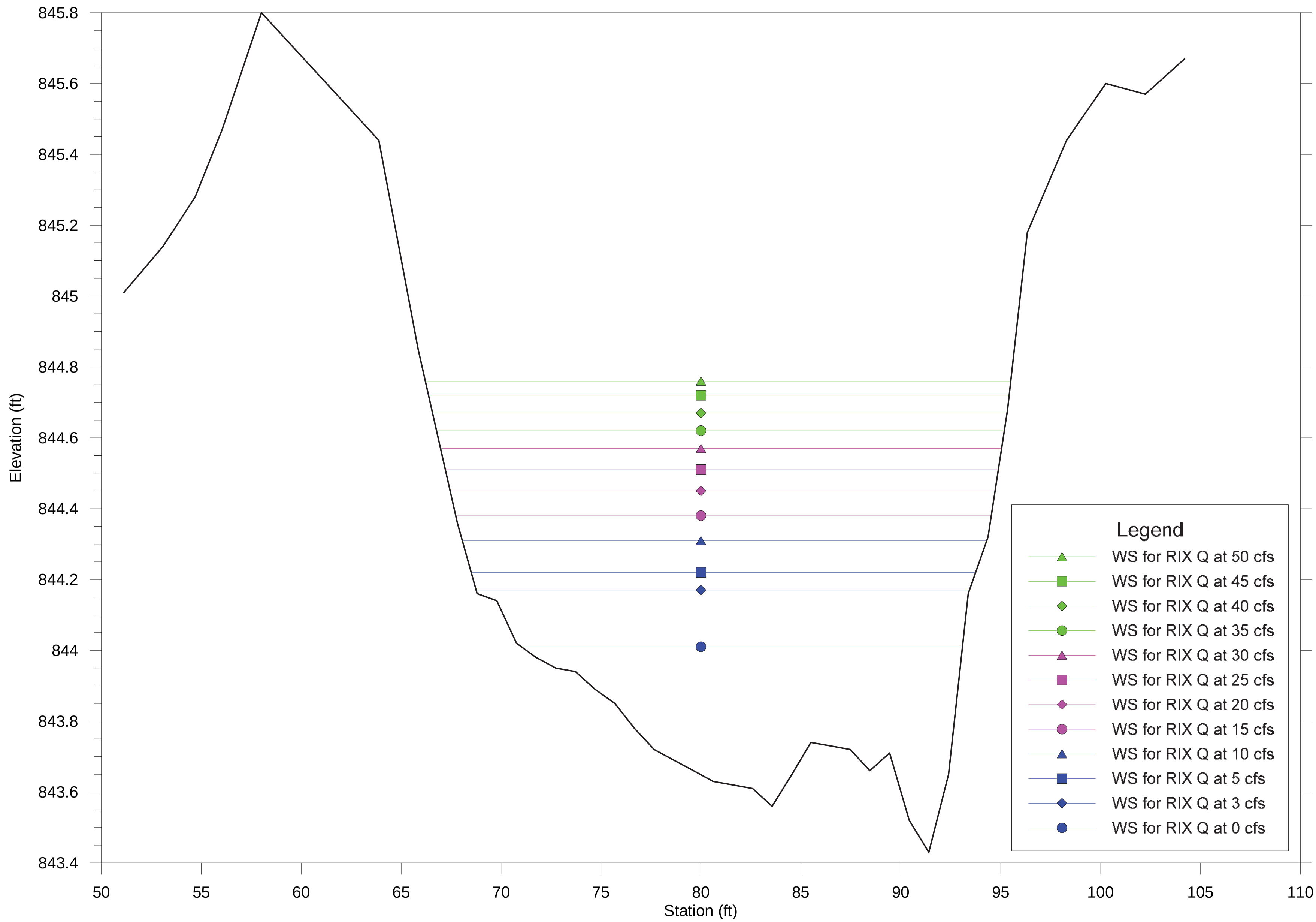
Figure 10b
River Station 43504 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY WORK-PRODUCT

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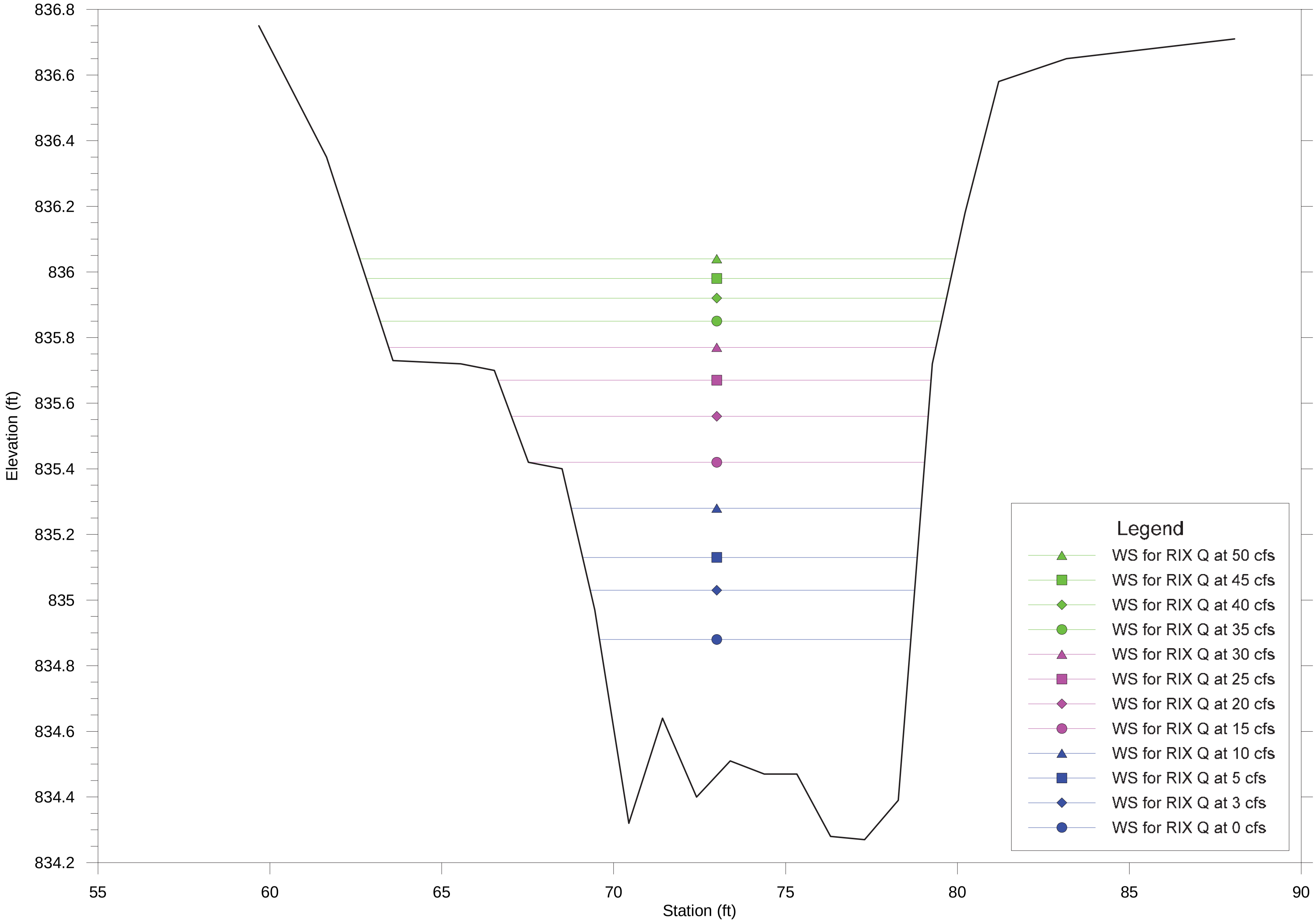
Figure 10c
River Station 41476 Channel Geometry and Water Surface Elevations for Various RIX Discharges



PRIVILEGED AND CONFIDENTIAL
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ATTORNEY WORK-PRODUCT

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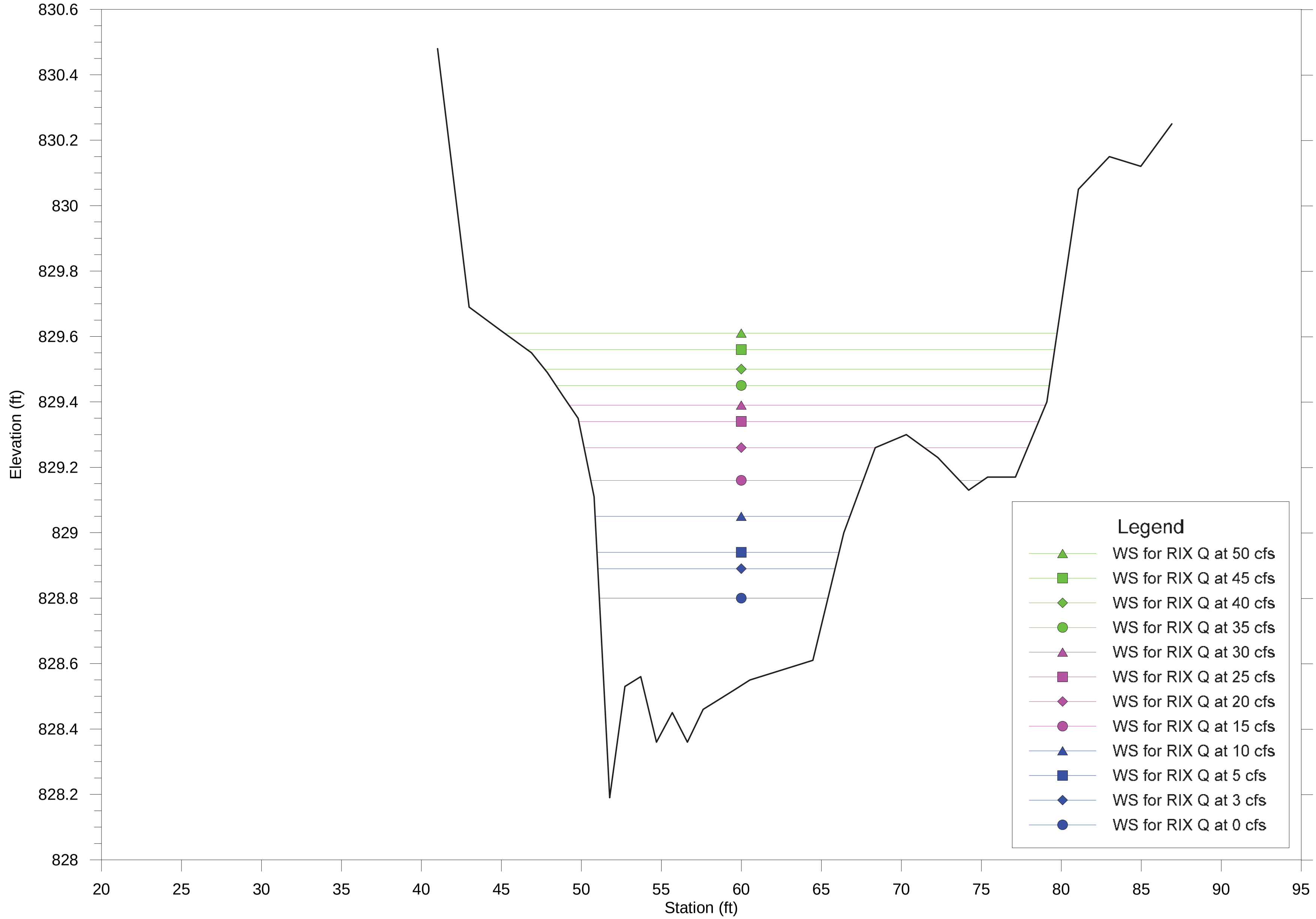
Figure 10d
River Station 39769 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY WORK-PRODUCT

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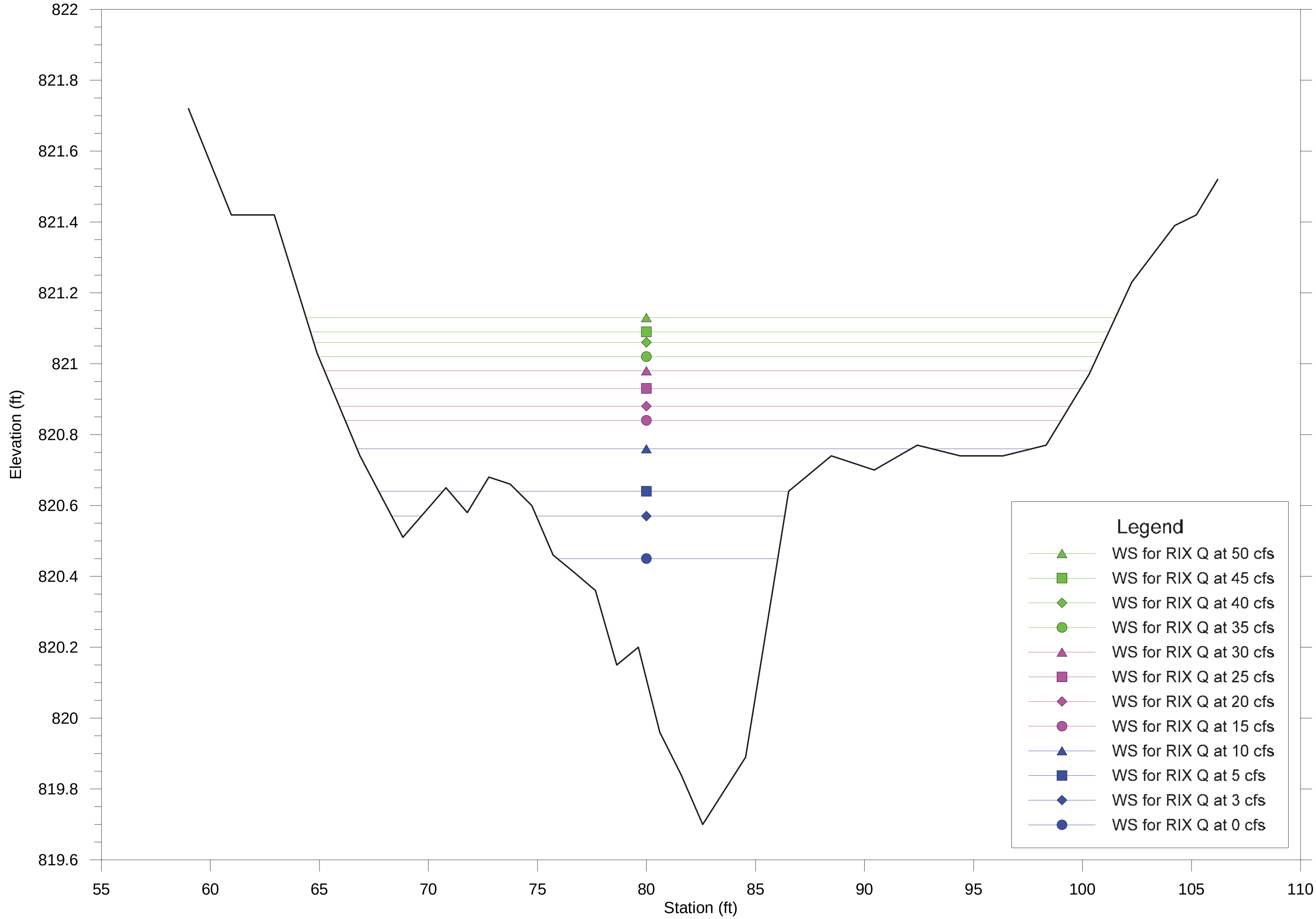
Figure 10e
River Station 37884 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY WORK-PRODUCT

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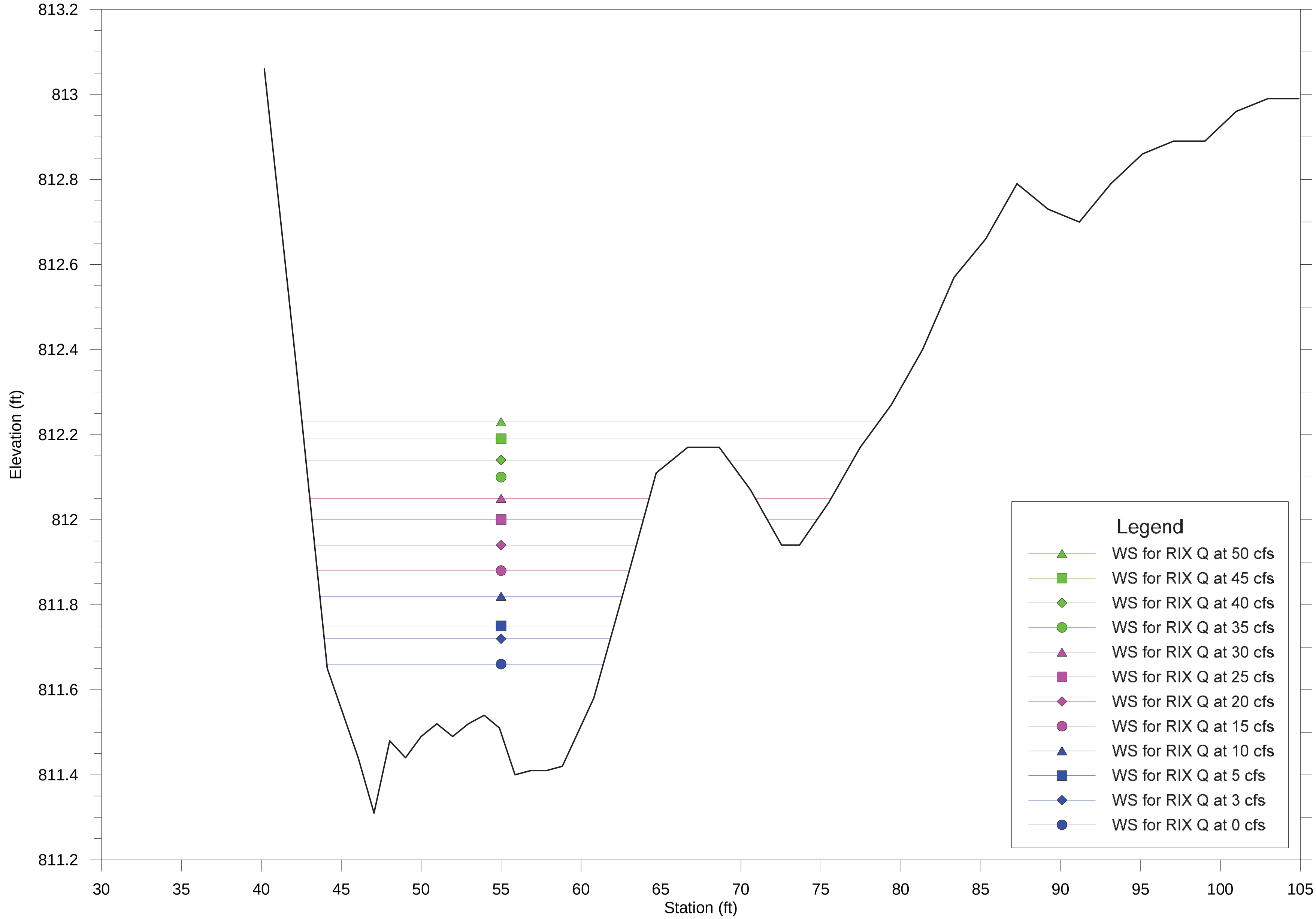
Figure 10f
River Station 35457 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY WORK-PRODUCT

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WEI Appendix D, Rating Curves

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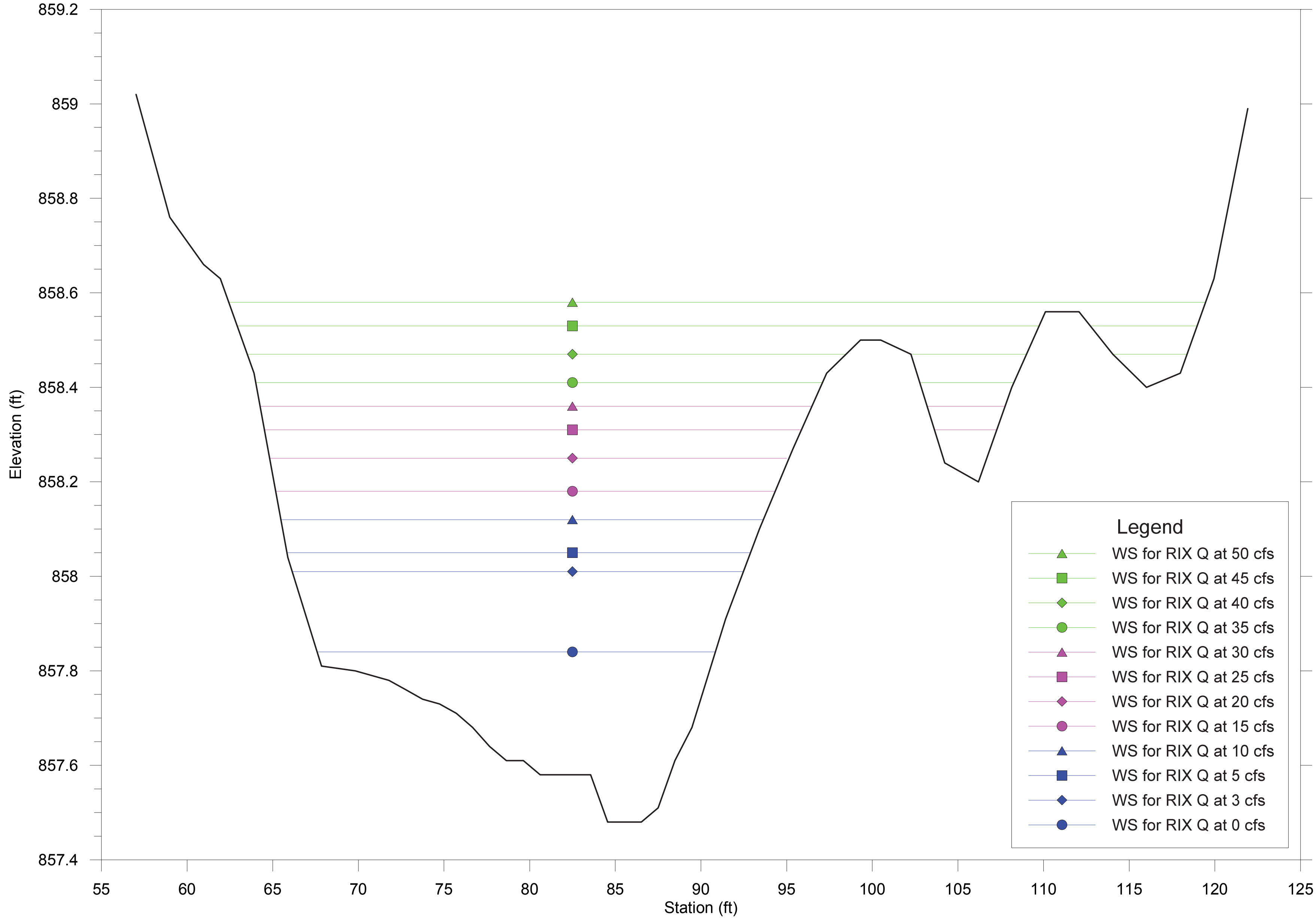
River Station 46895 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

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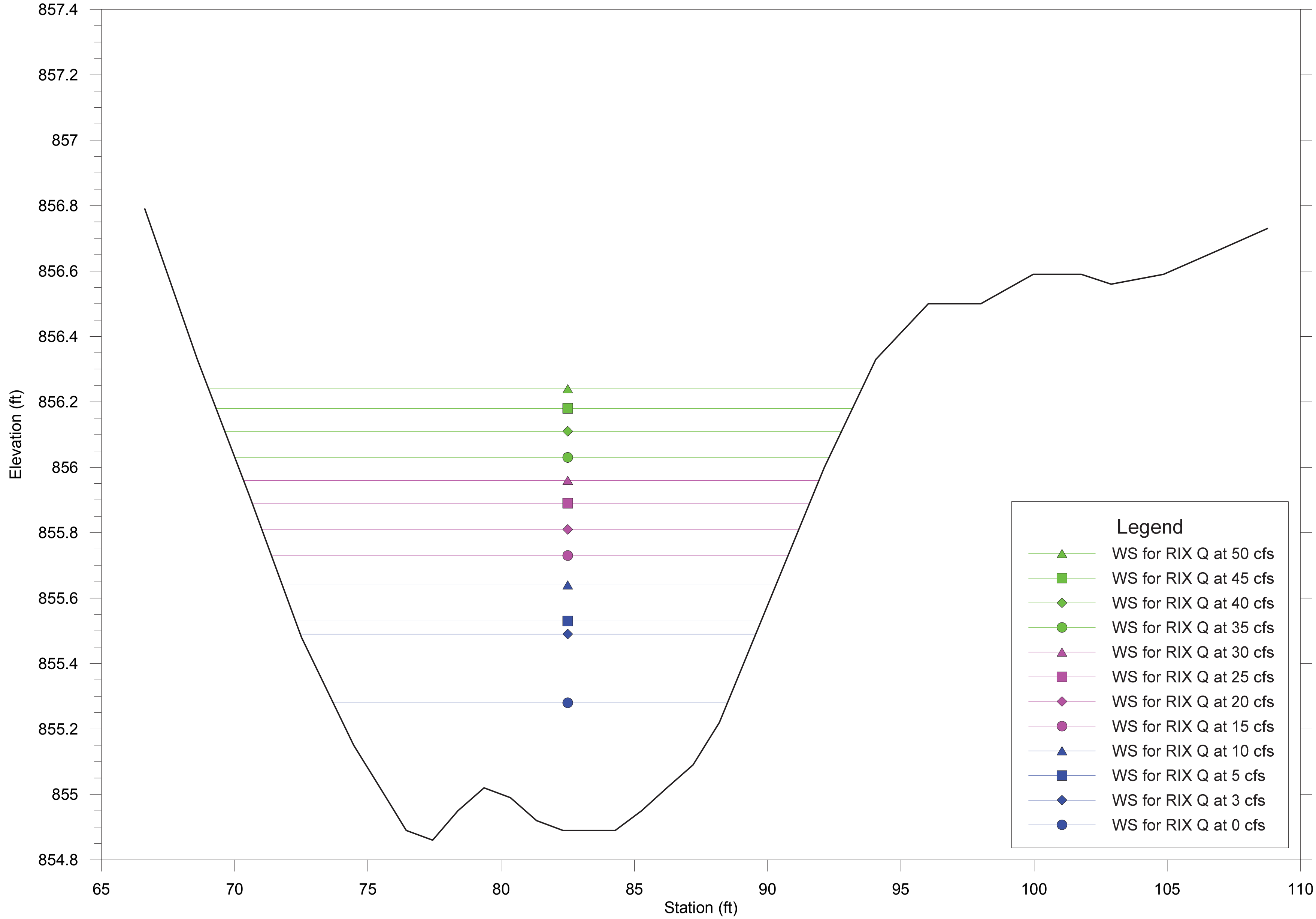
River Station 46475 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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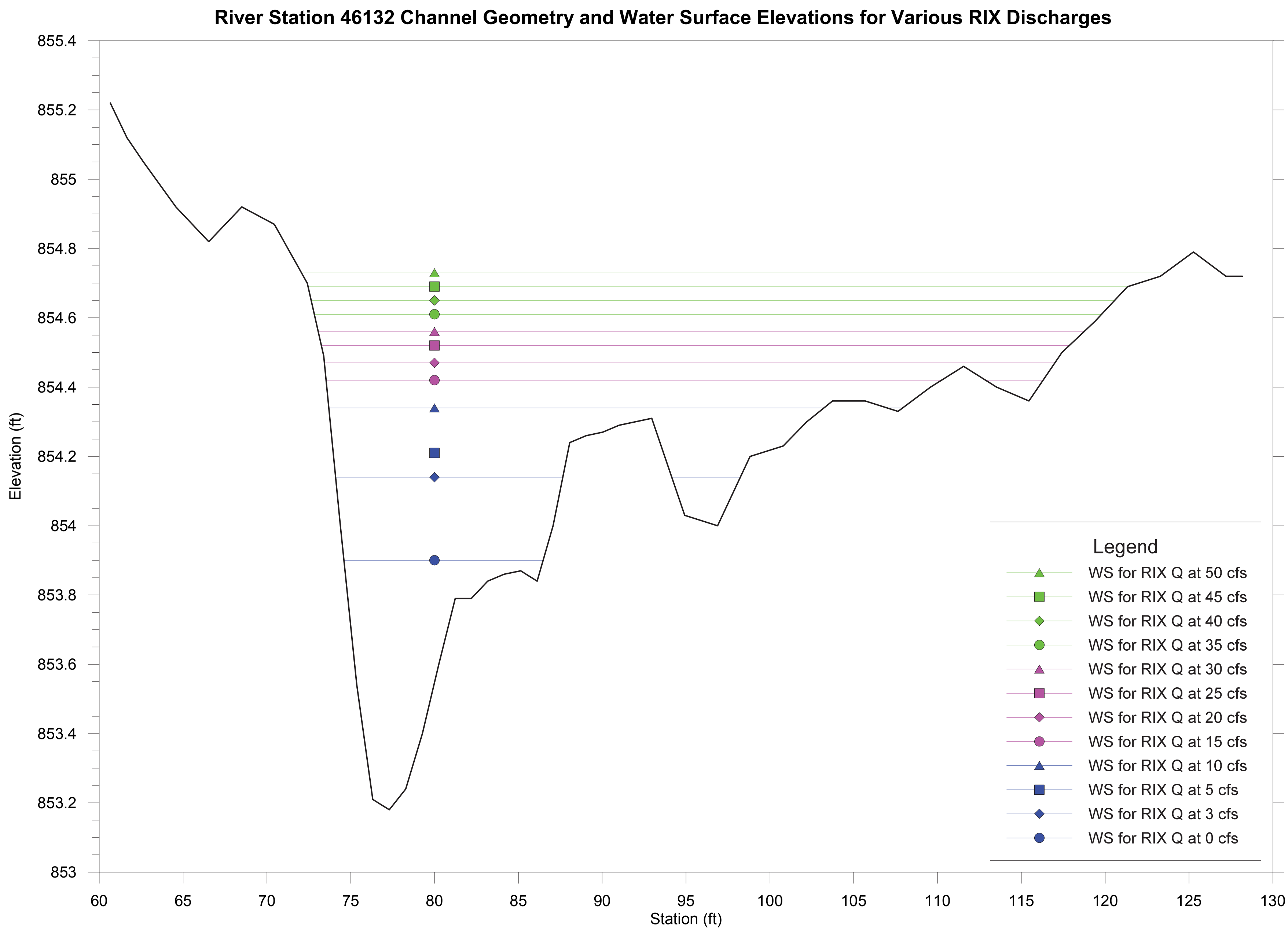
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.



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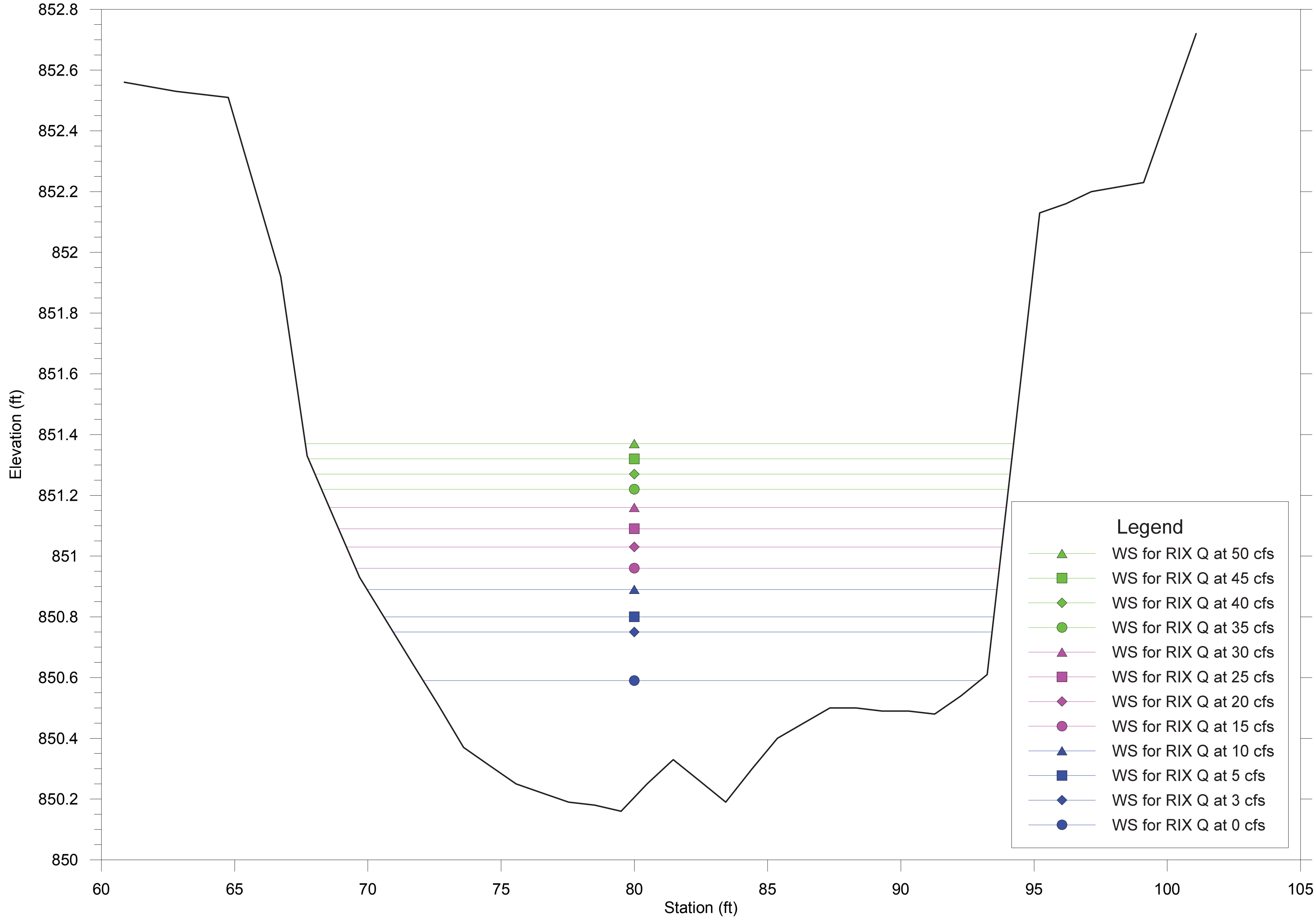
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 45475 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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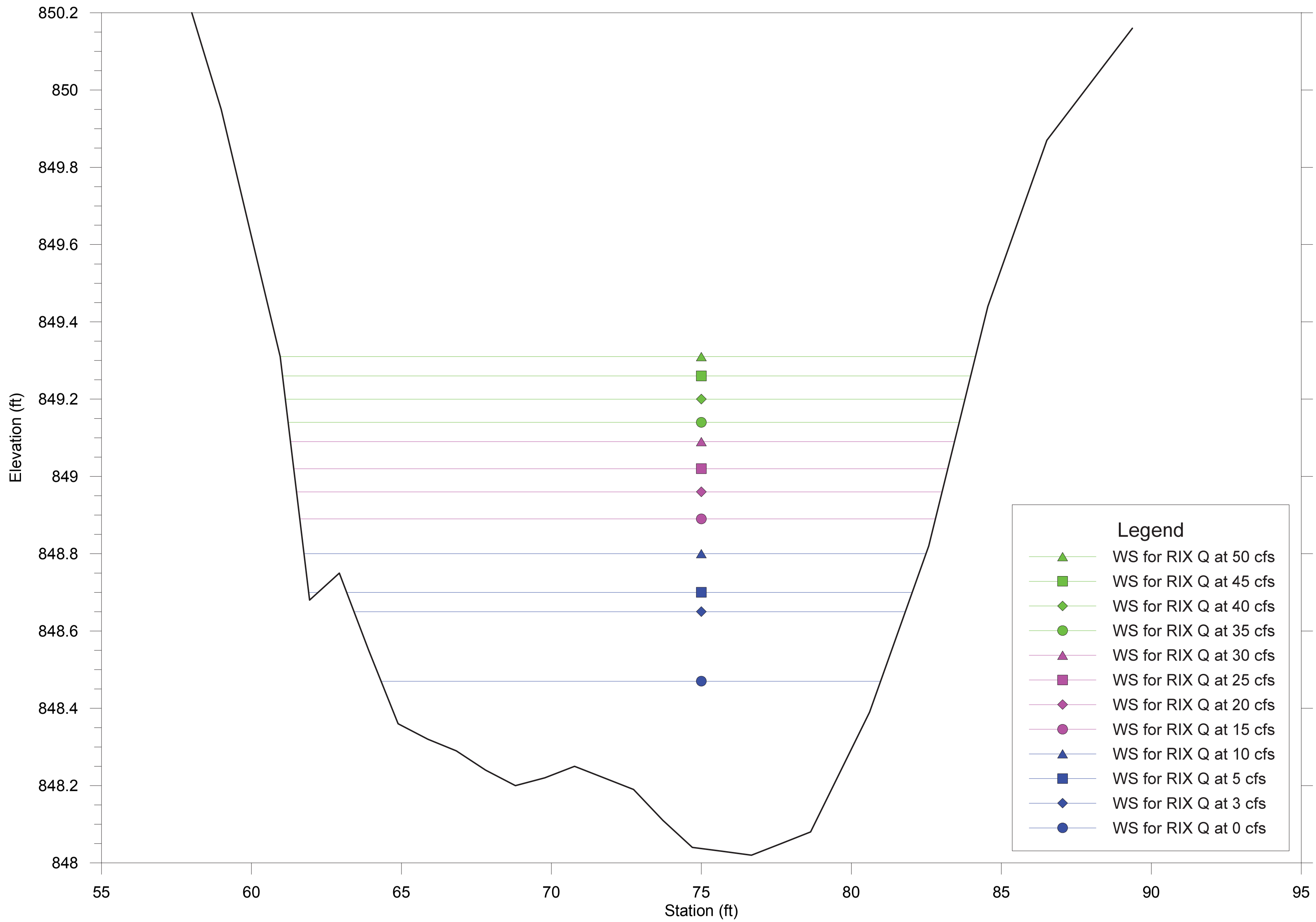
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 44975 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

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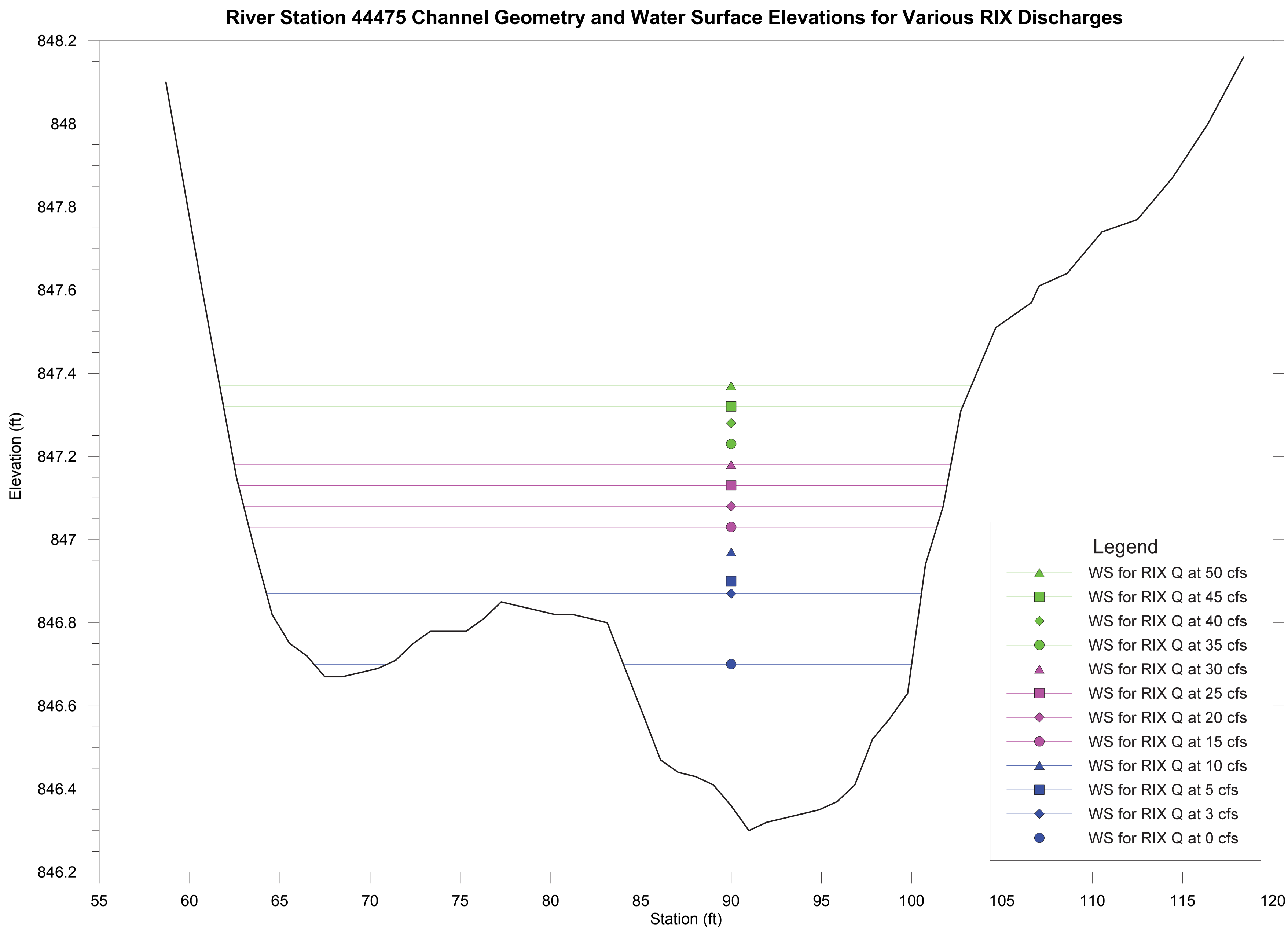

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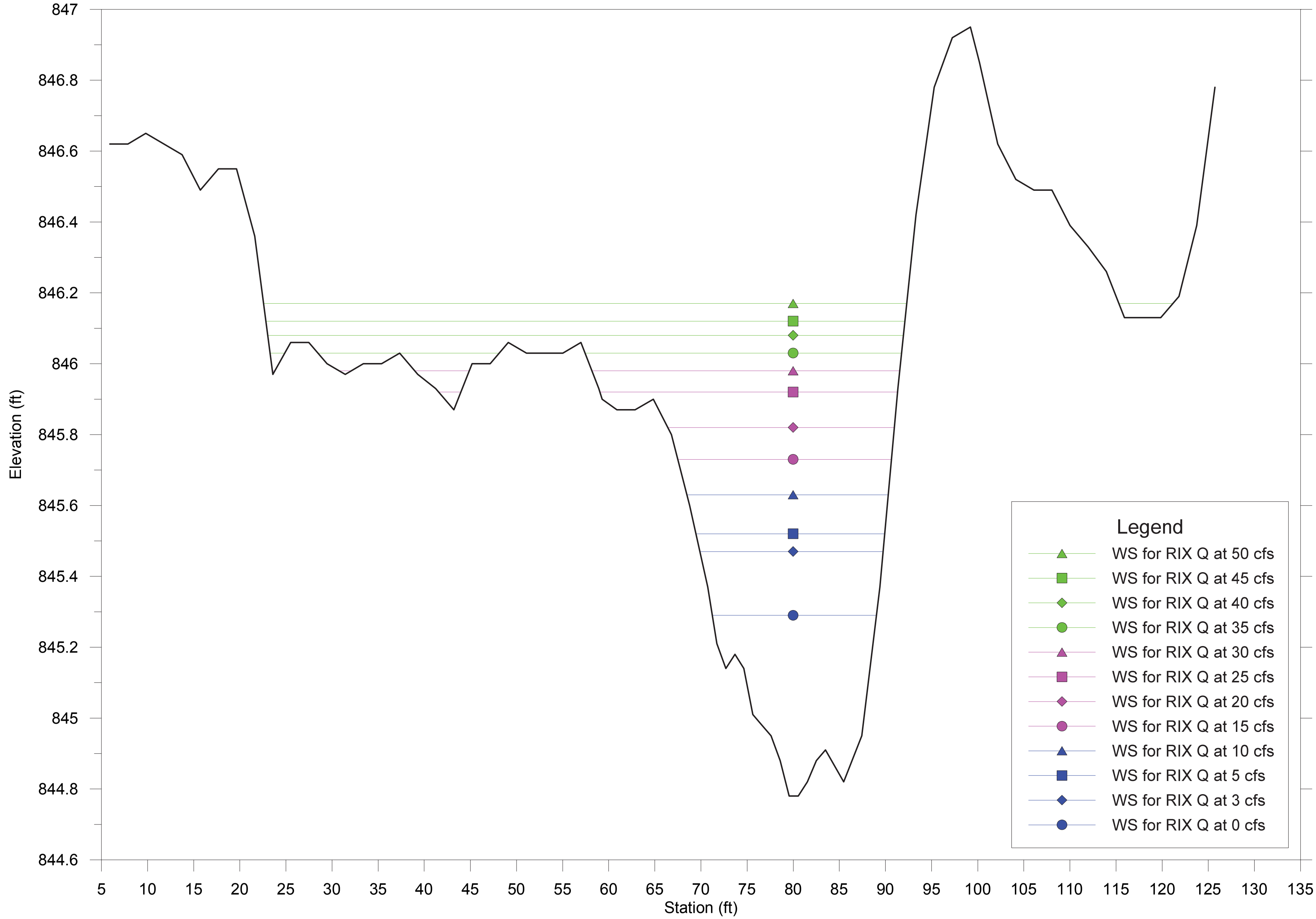
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 43975 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY WORK-PRODUCT

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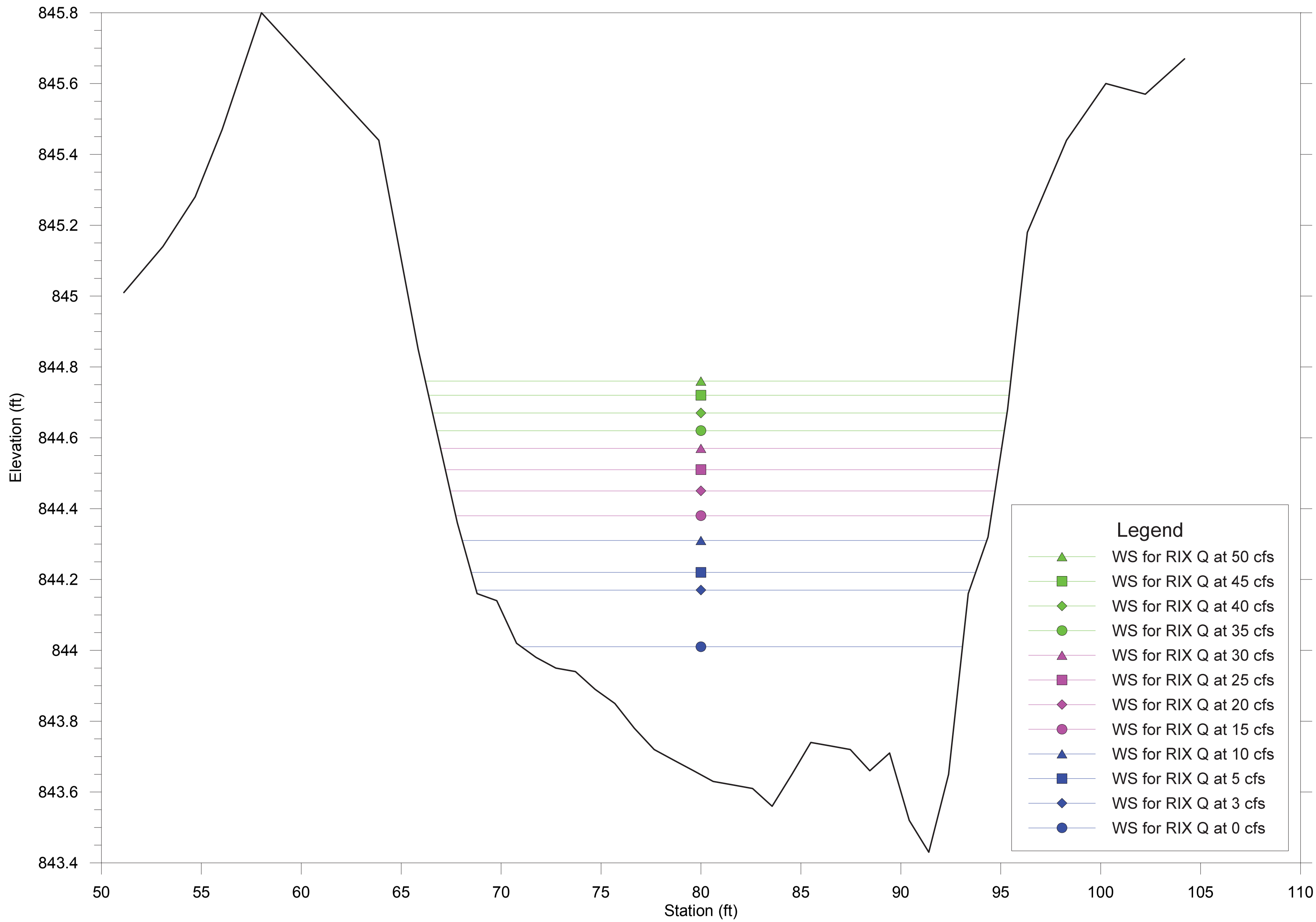
River Station 43504 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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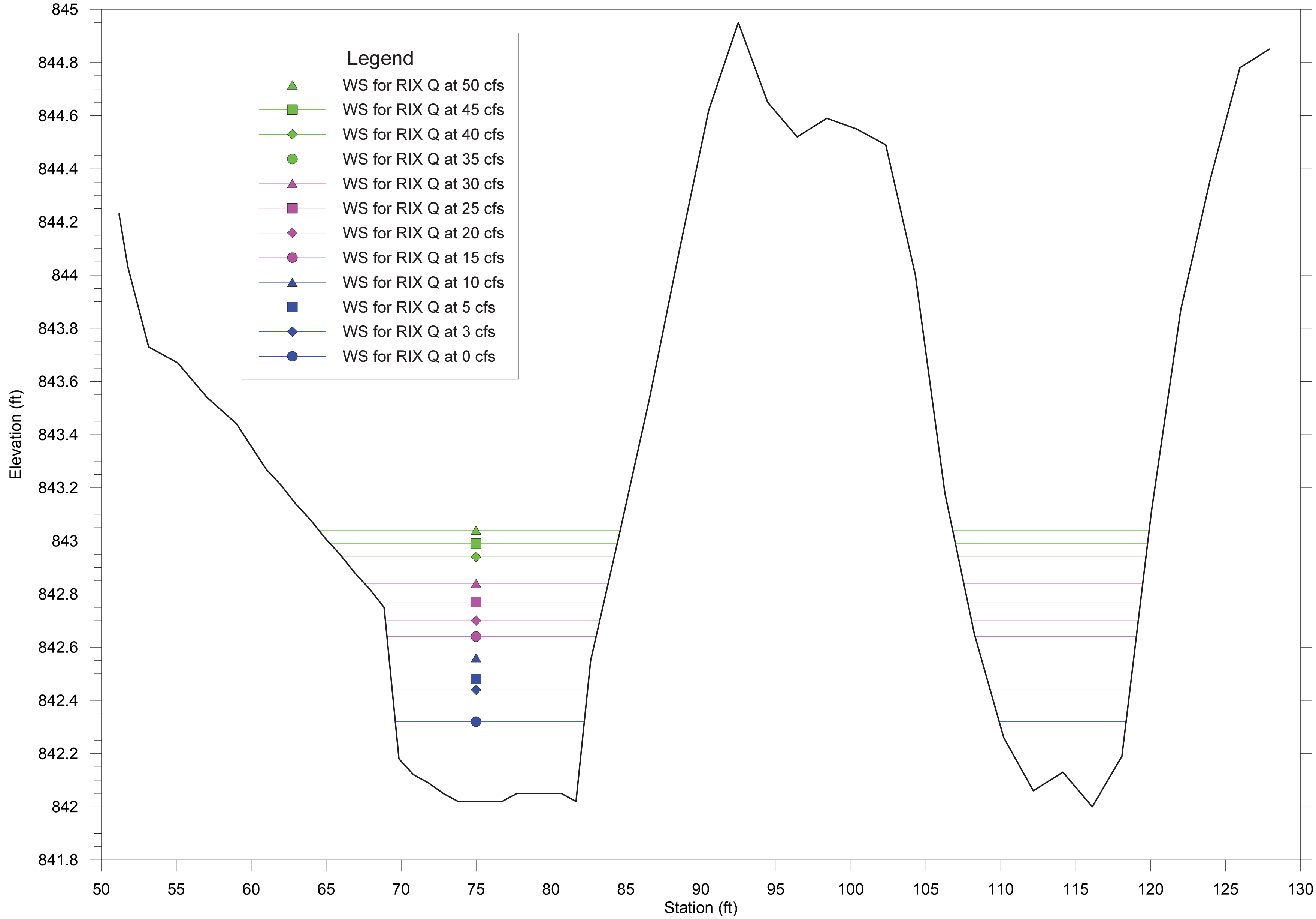
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 42975 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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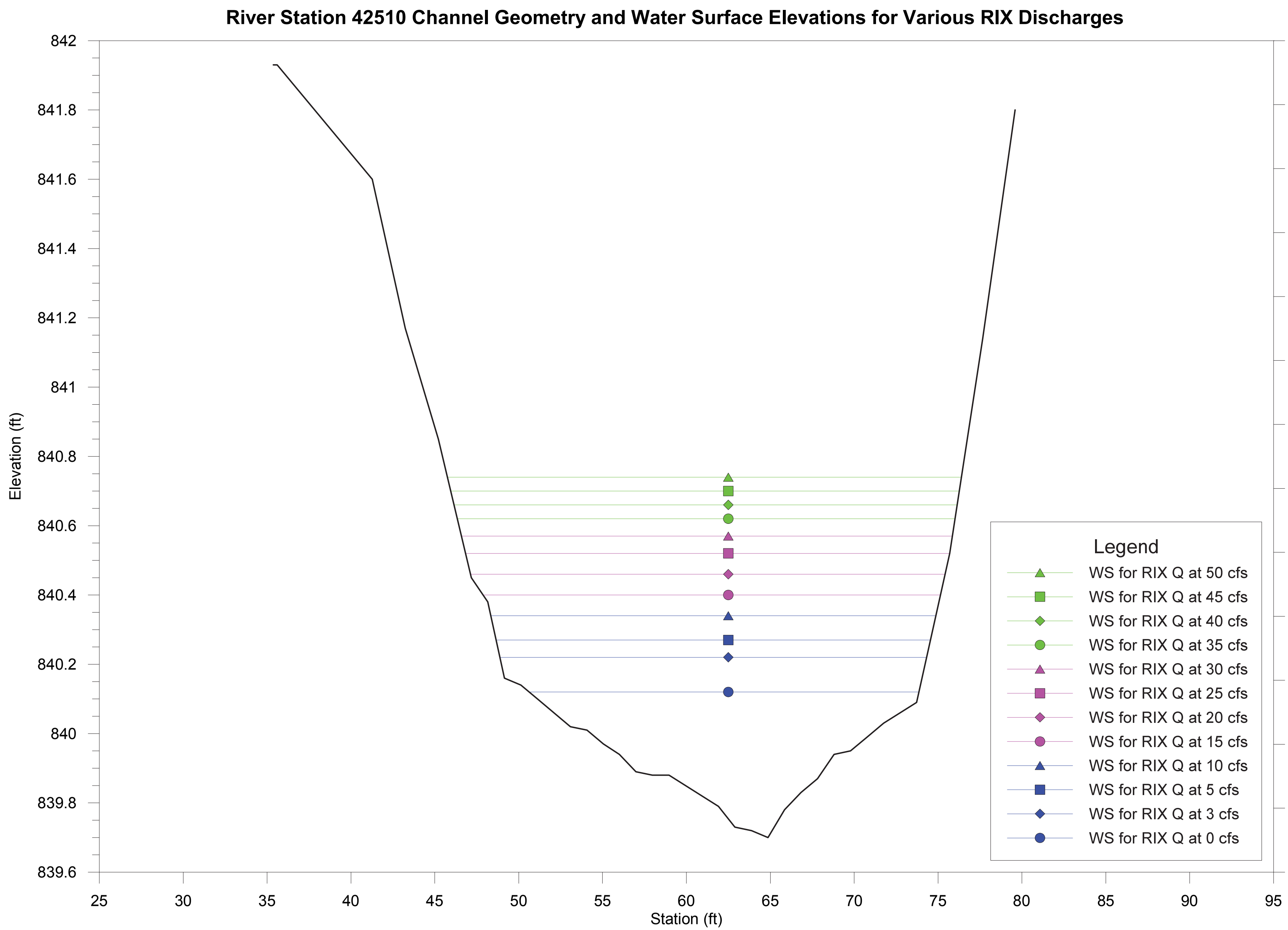

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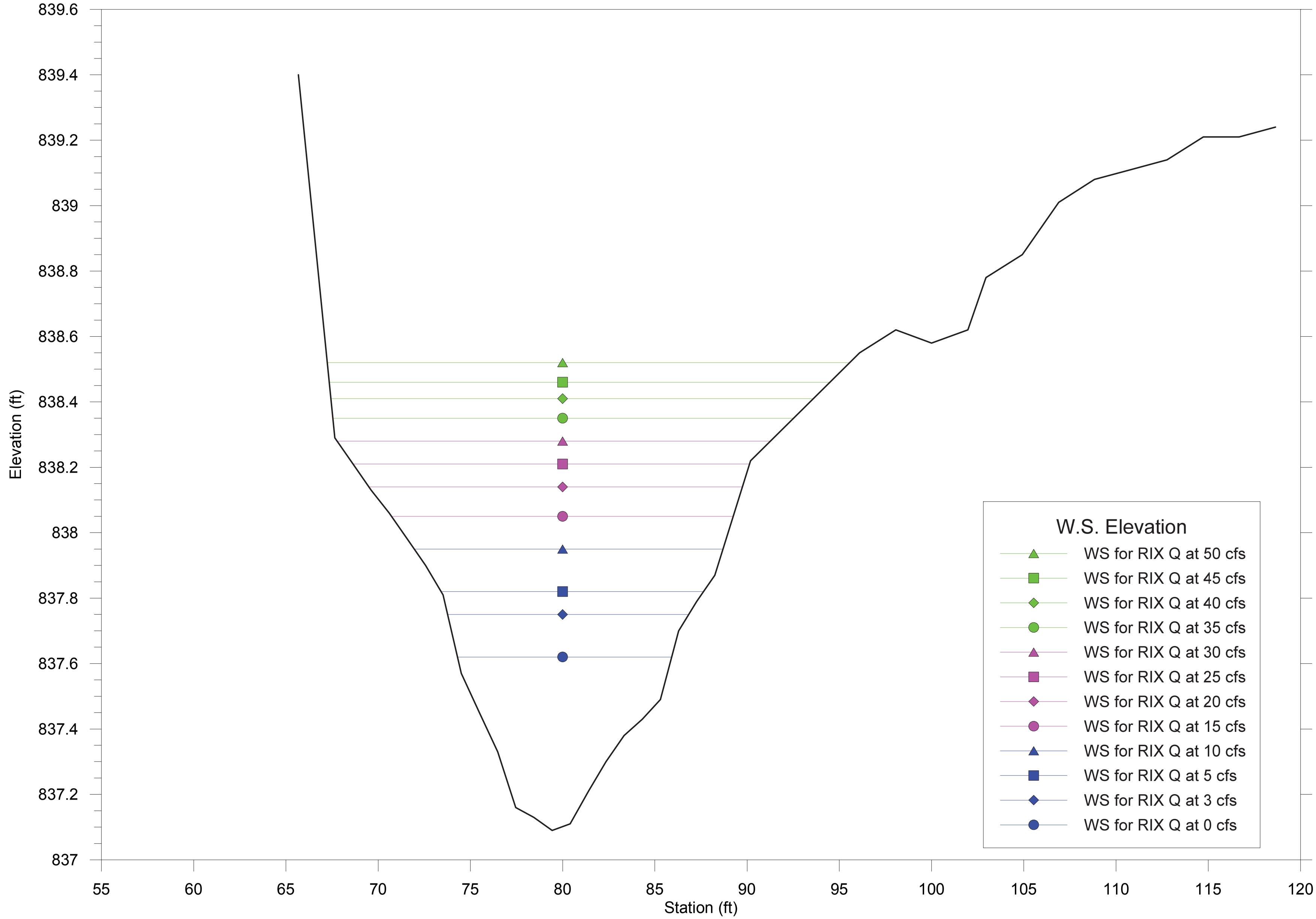
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 41975 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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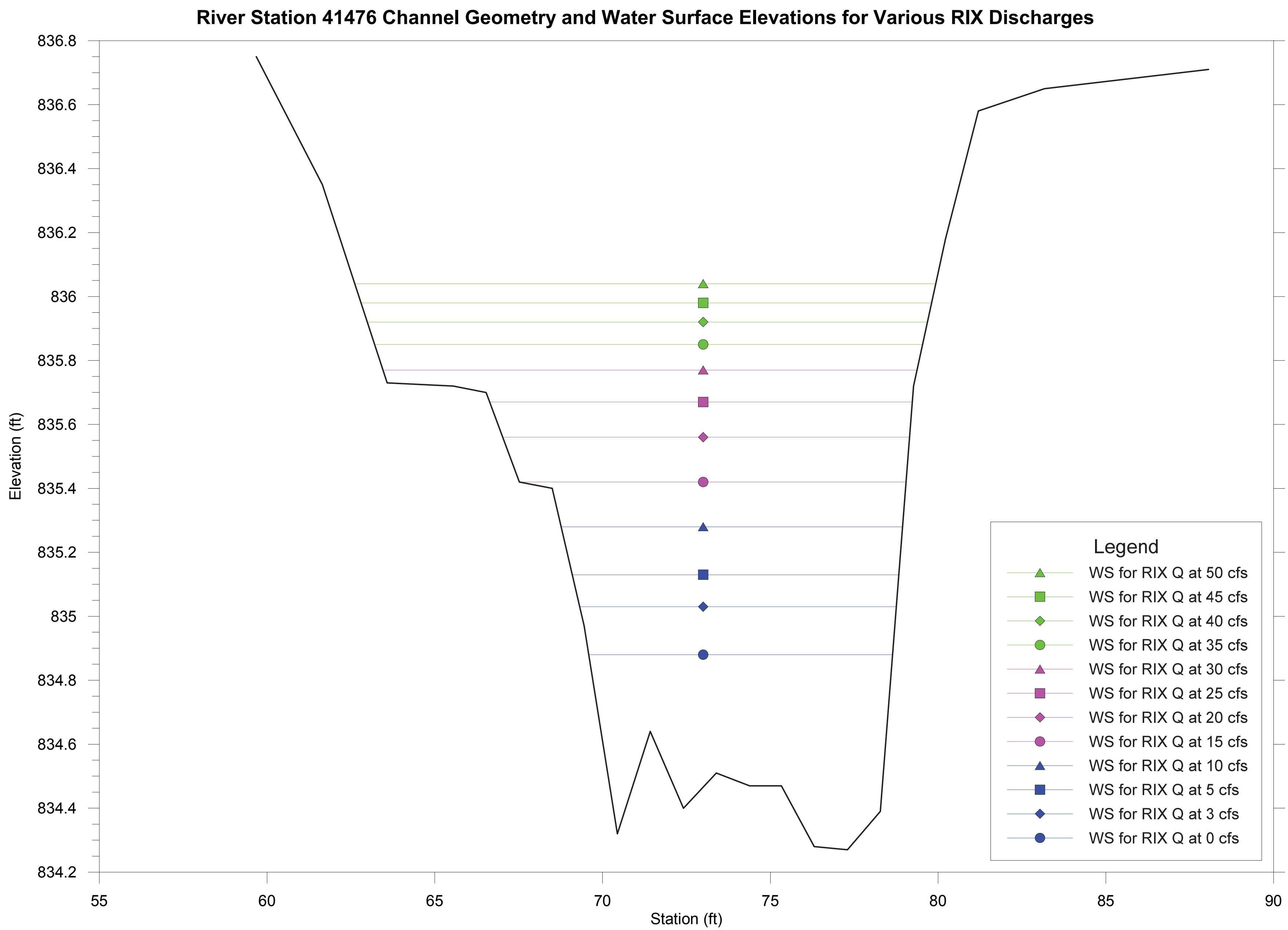
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.



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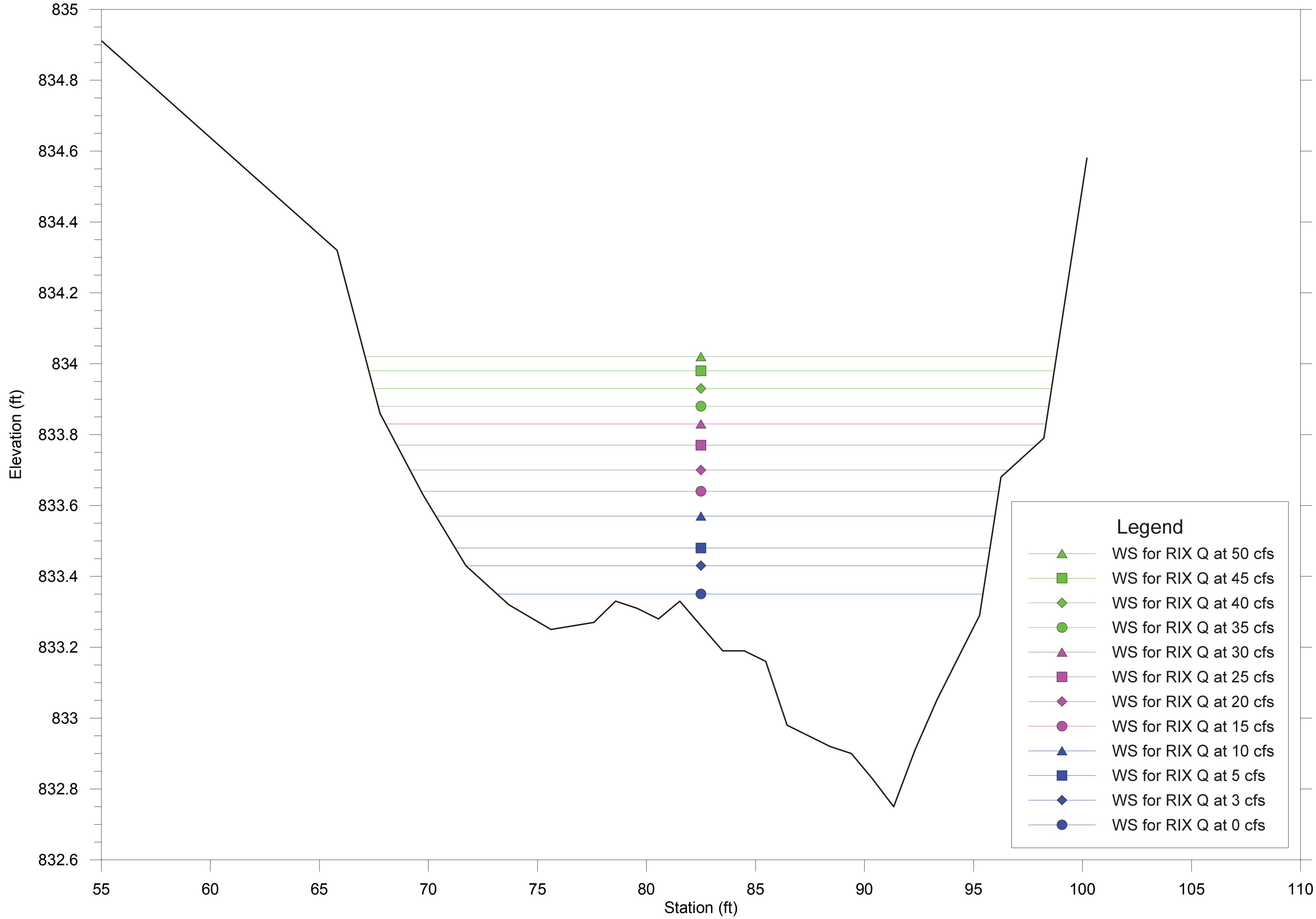
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 40976 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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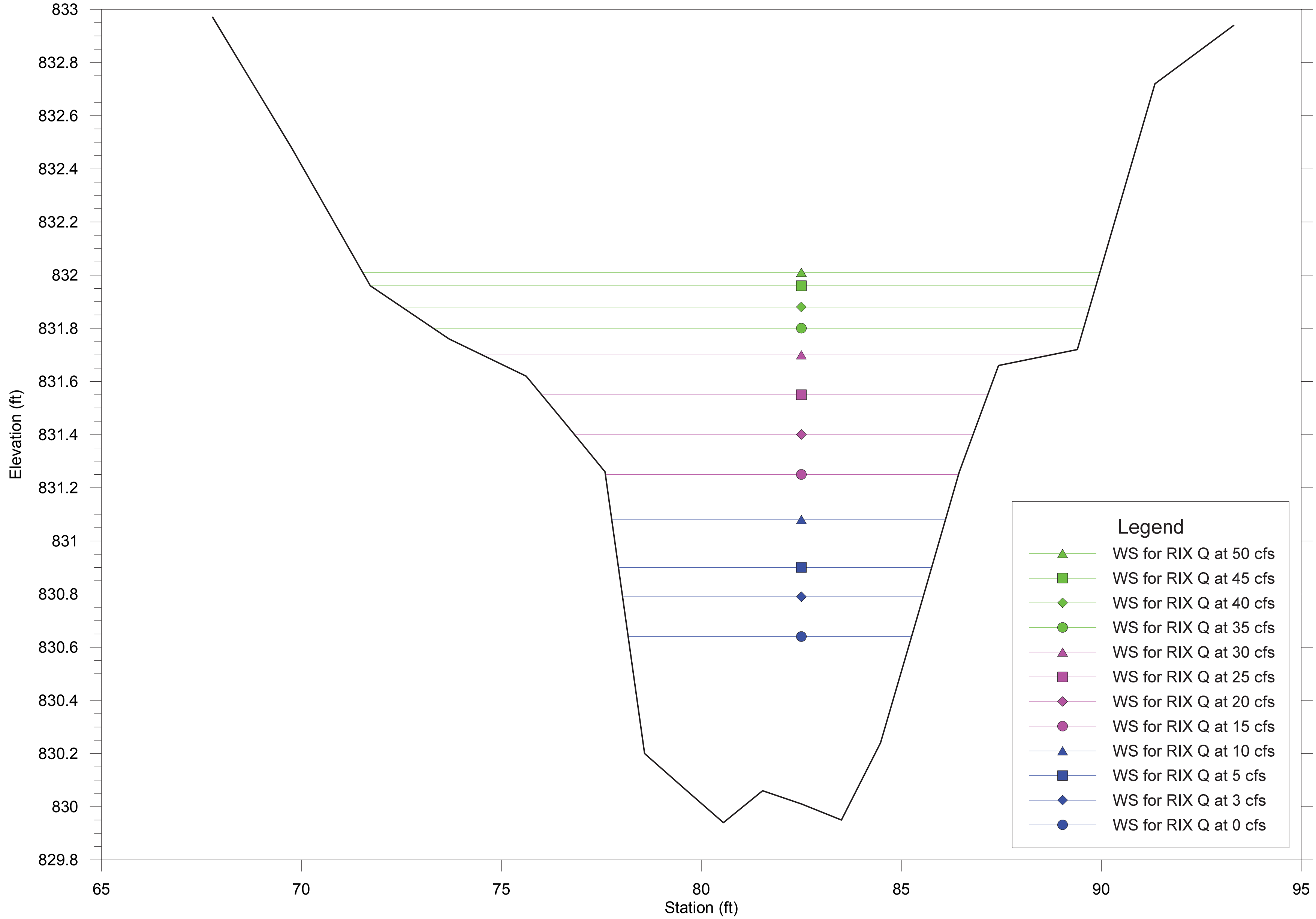
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 40476 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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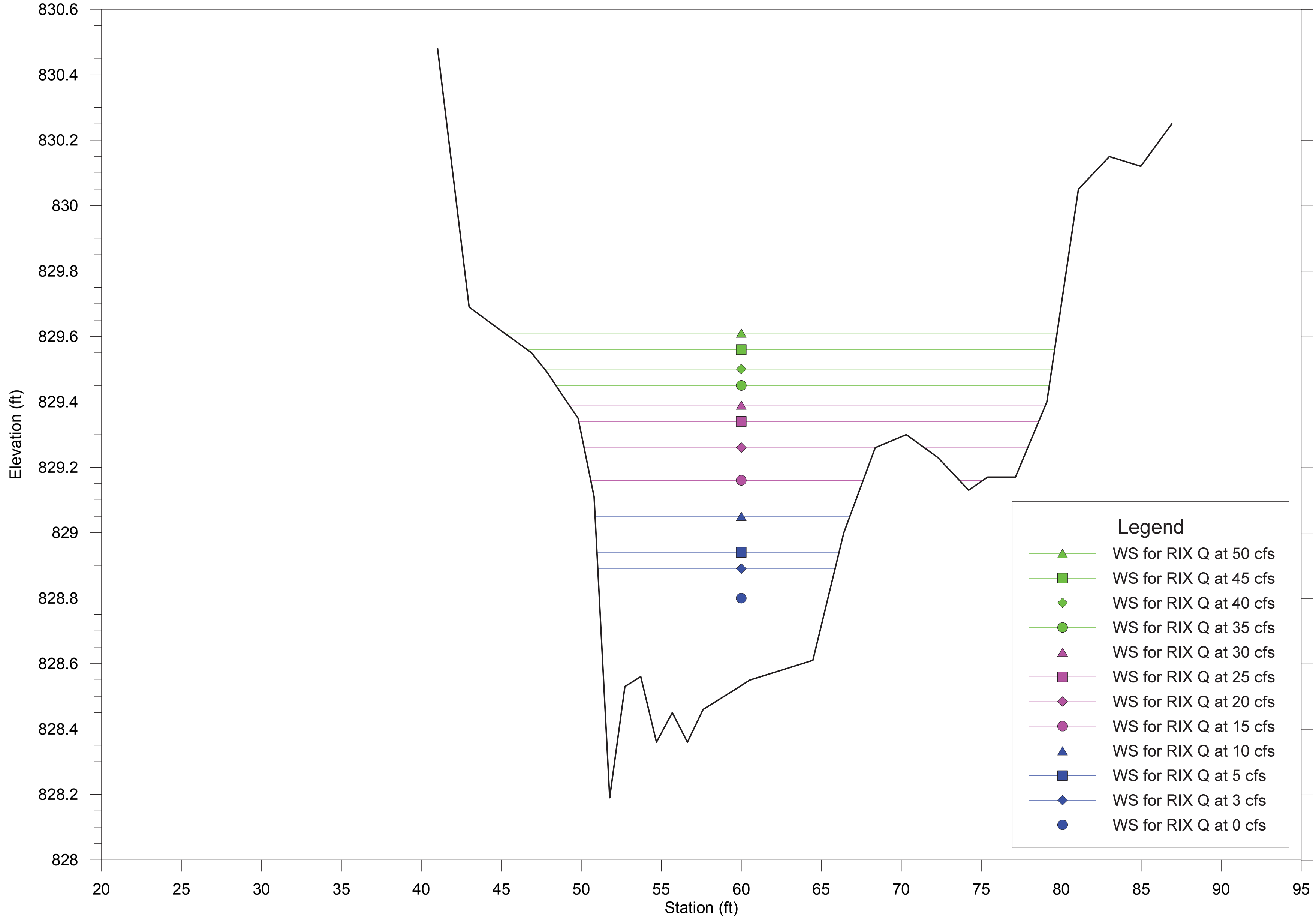
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 39769 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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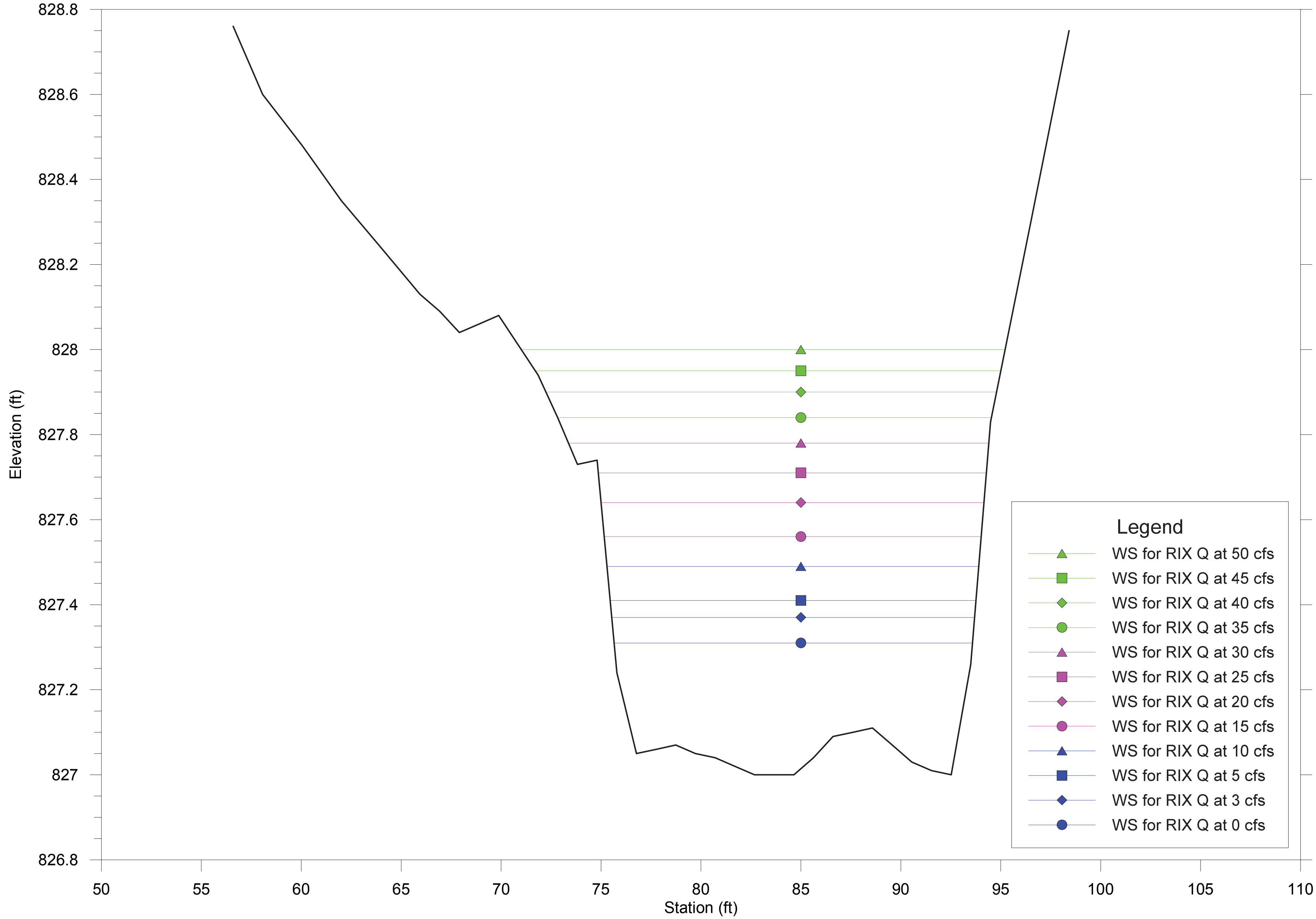
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 39476 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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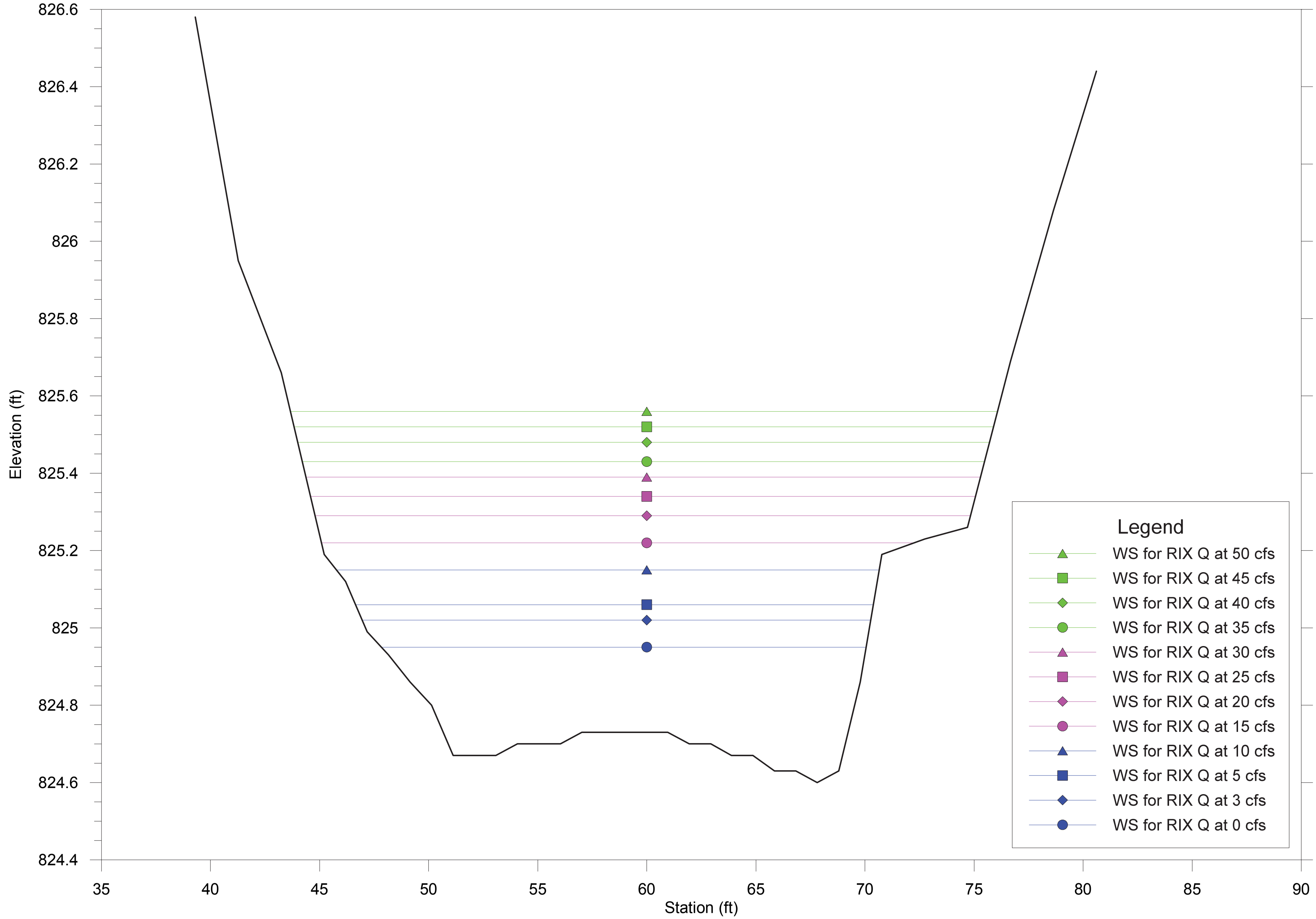
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

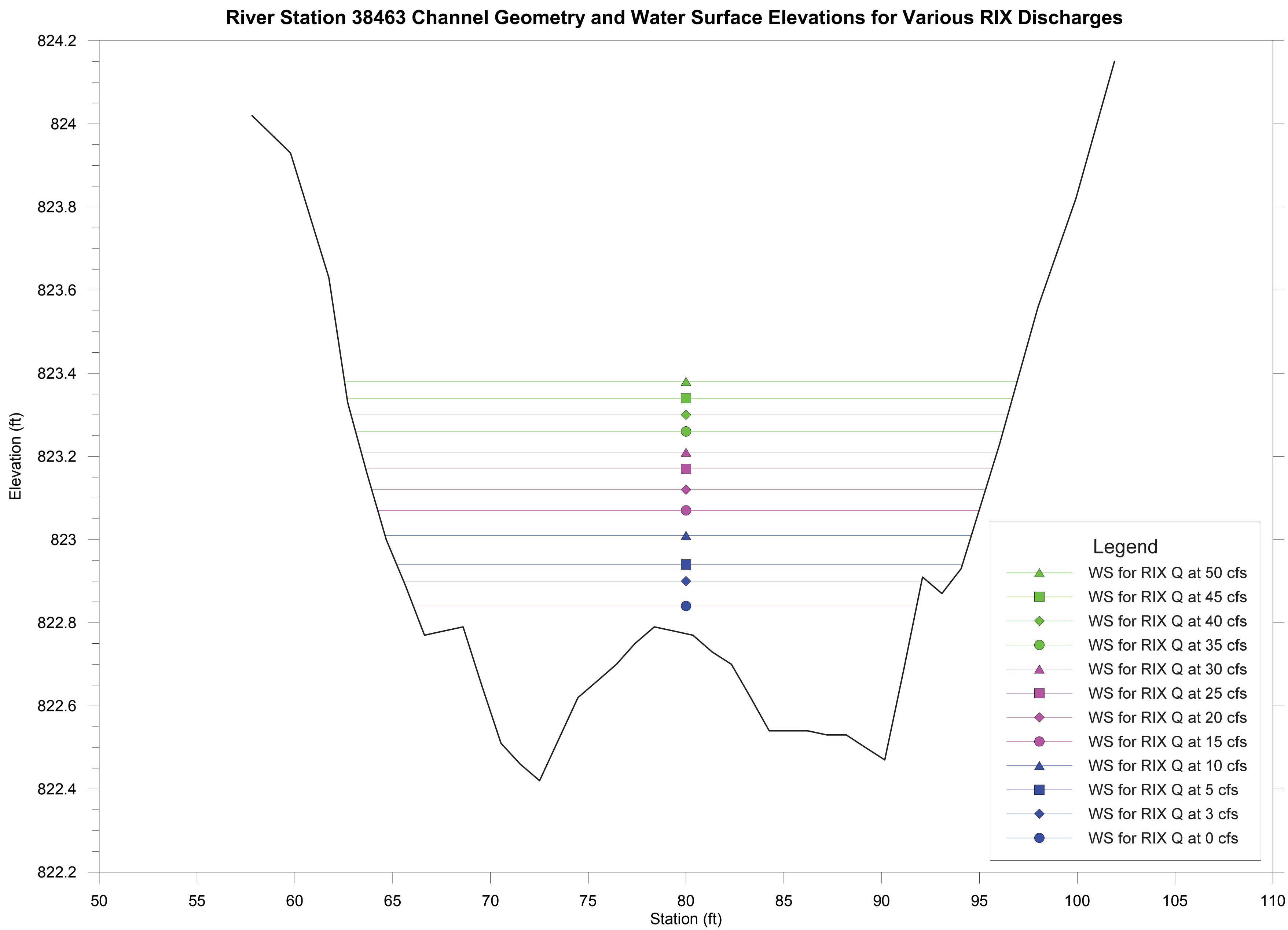
WILDERMUTH™ ENVIRONMENTAL INC.

River Station 38989 Channel Geometry and Water Surface Elevations for Various RIX Discharges



PRIVILEGED AND CONFIDENTIAL
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.



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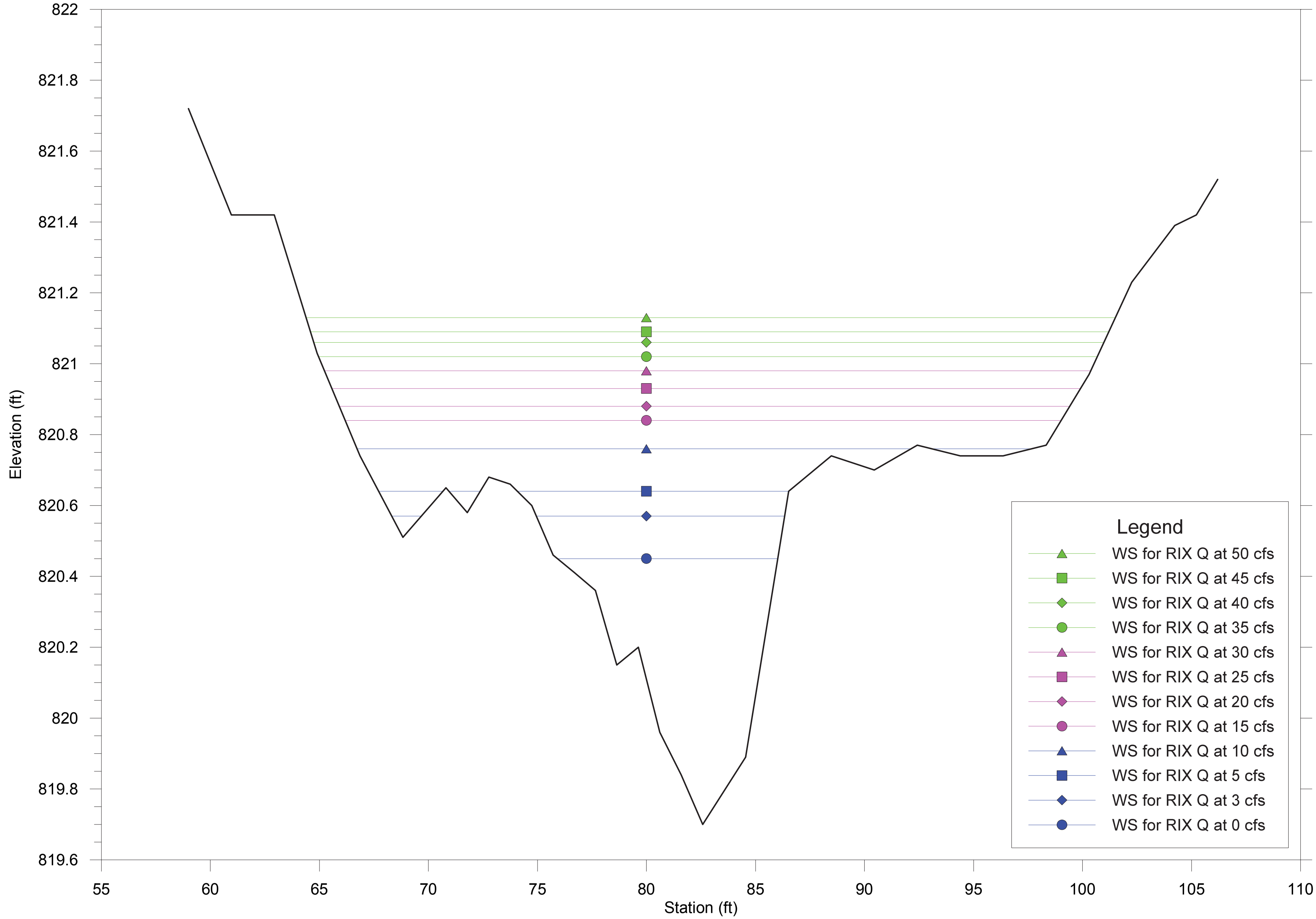
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 37884 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

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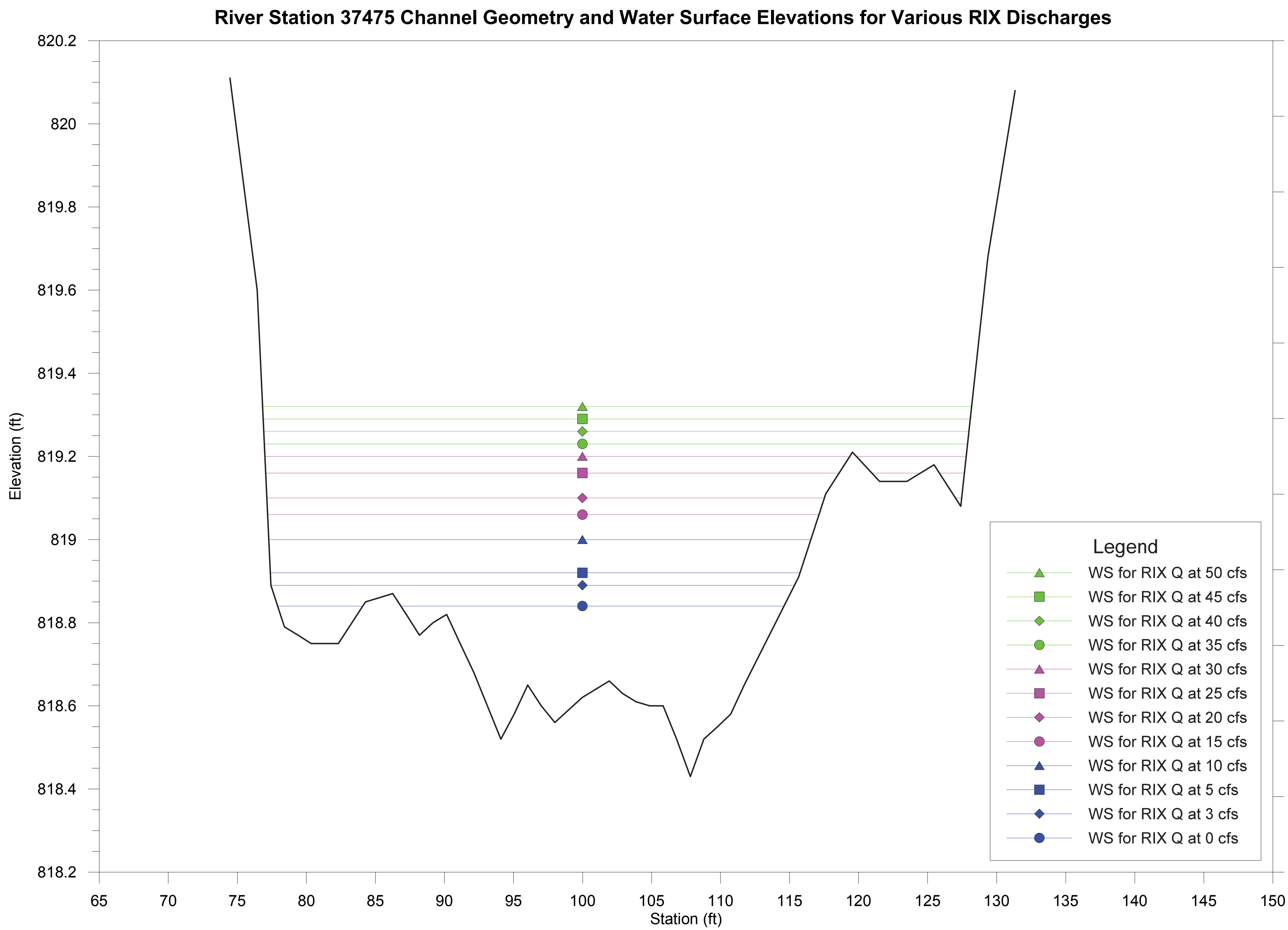

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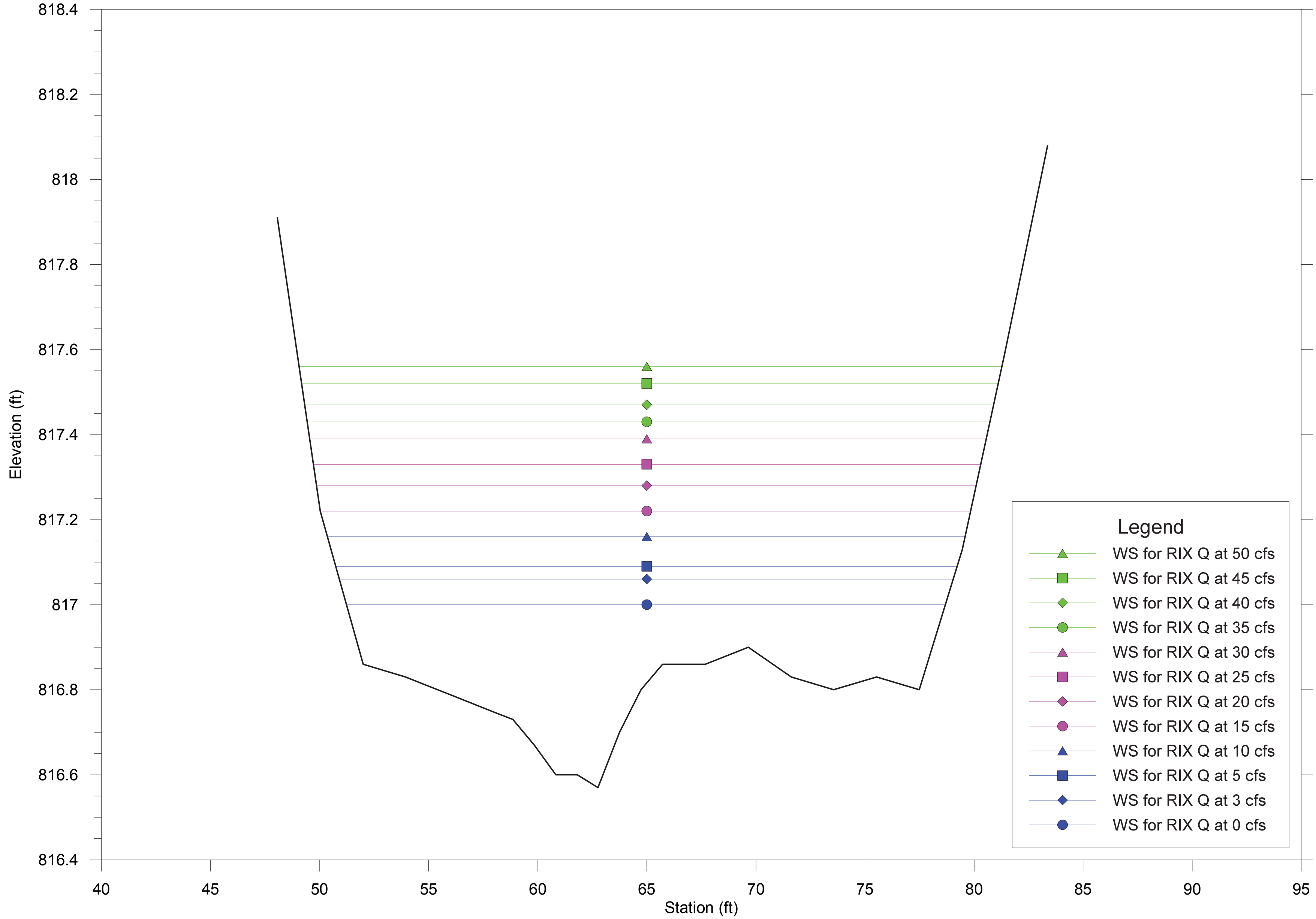
ATTORNEY-CLIENT PRIVILEGE
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 36982 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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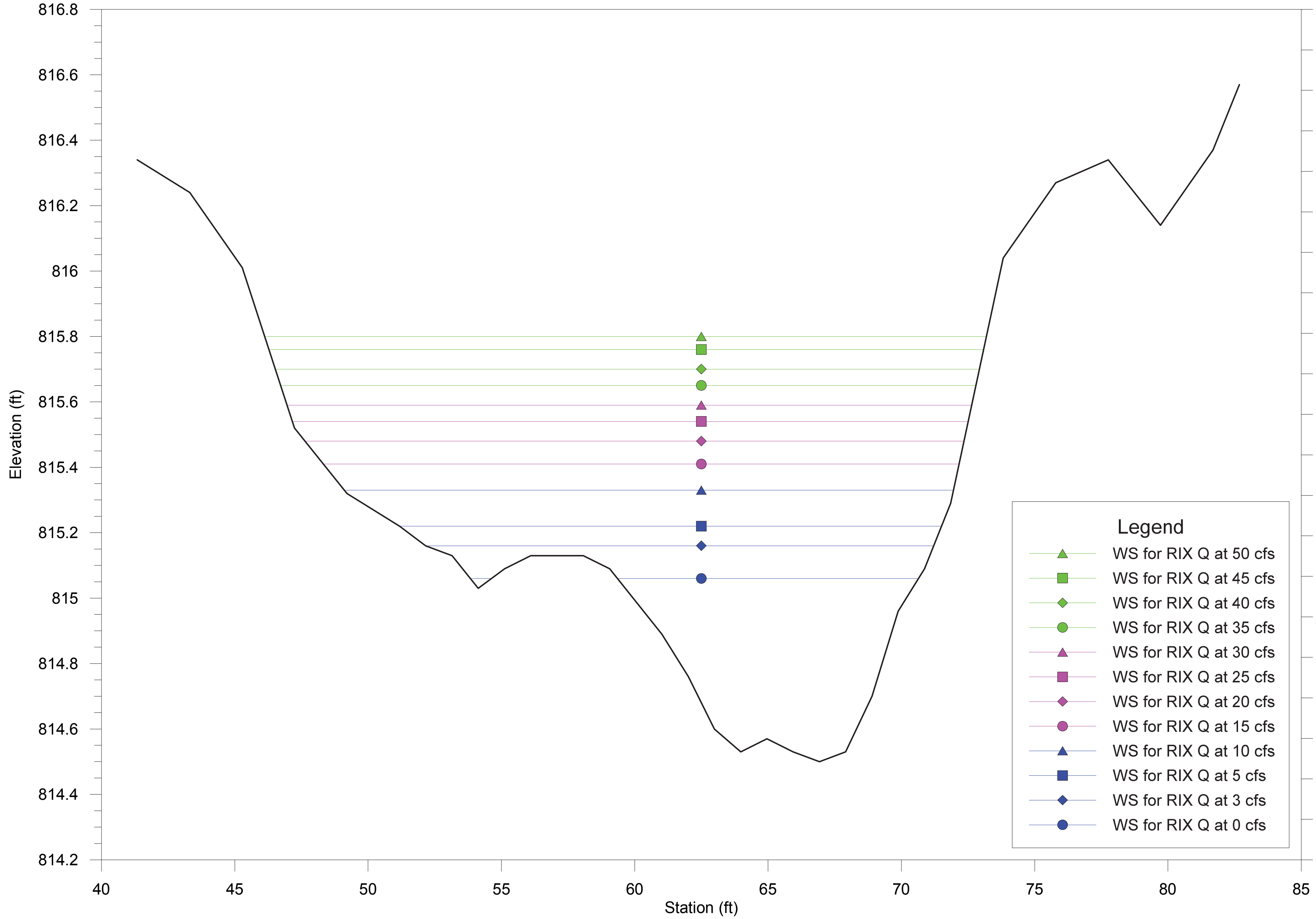
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 36462 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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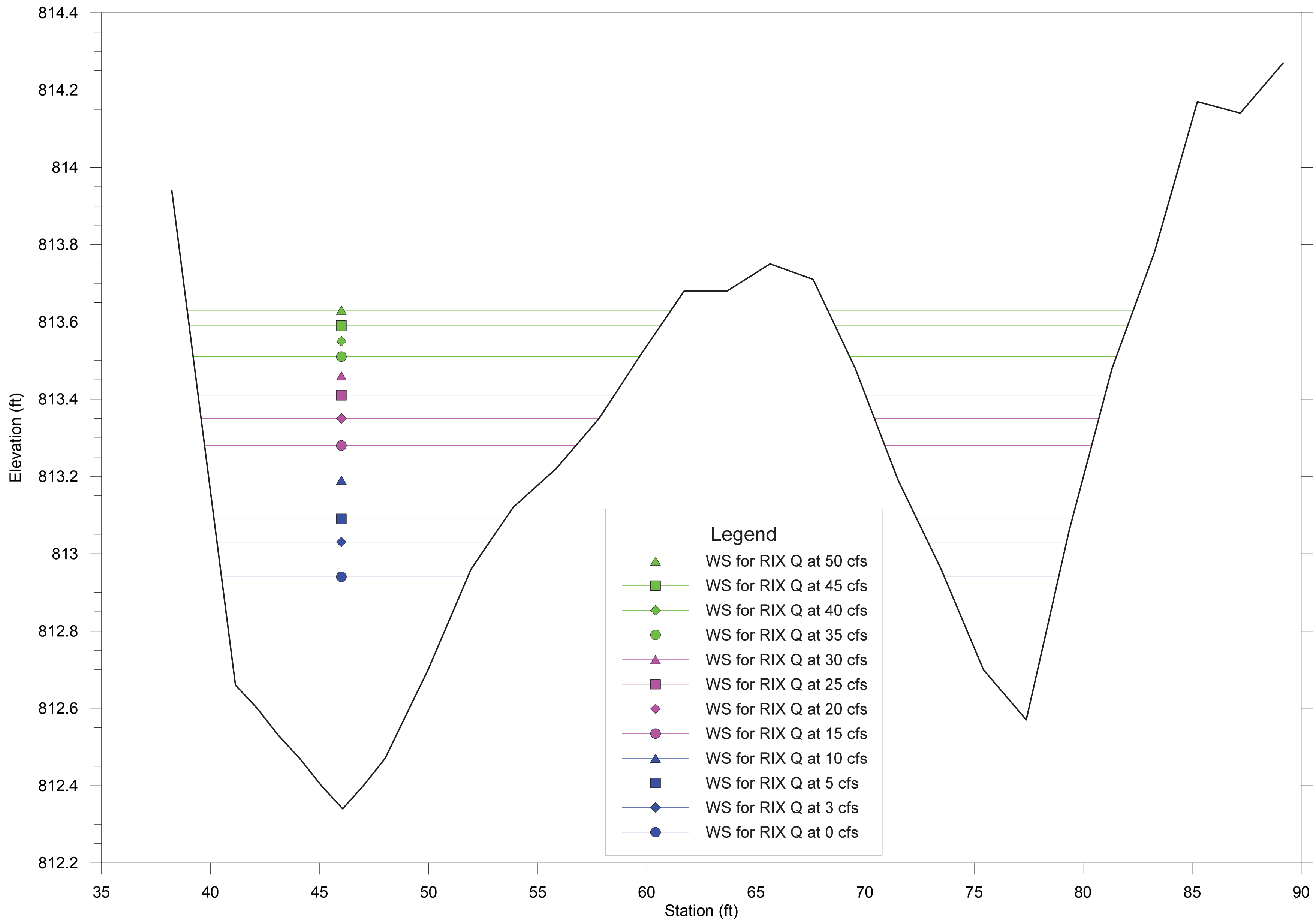
ATTORNEY WORK-PRODUCT

WILDERMUTH™ ENVIRONMENTAL INC.

River Station 35838 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY WORK-PRODUCT

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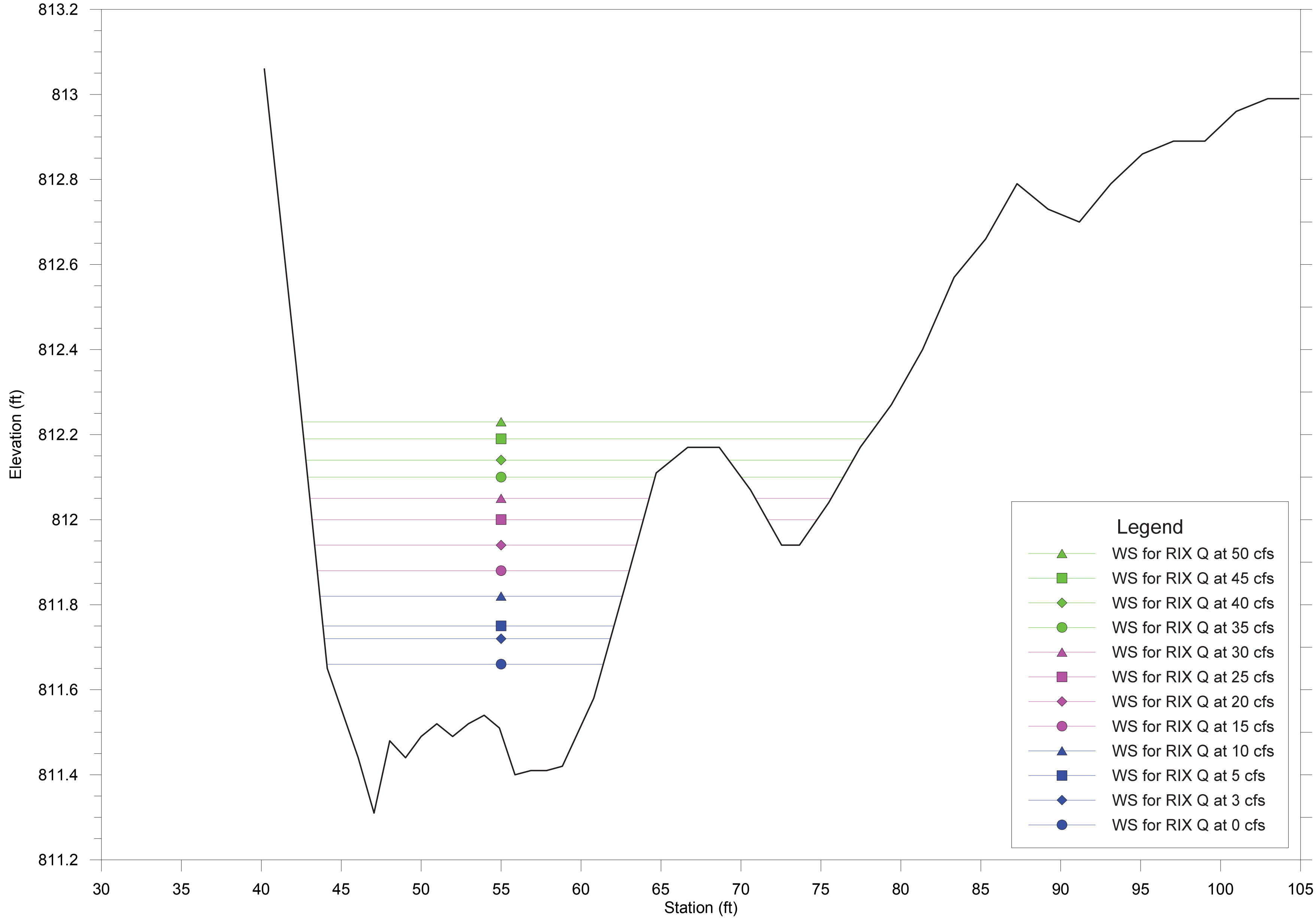
River Station 35457 Channel Geometry and Water Surface Elevations for Various RIX Discharges



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ATTORNEY WORK-PRODUCT

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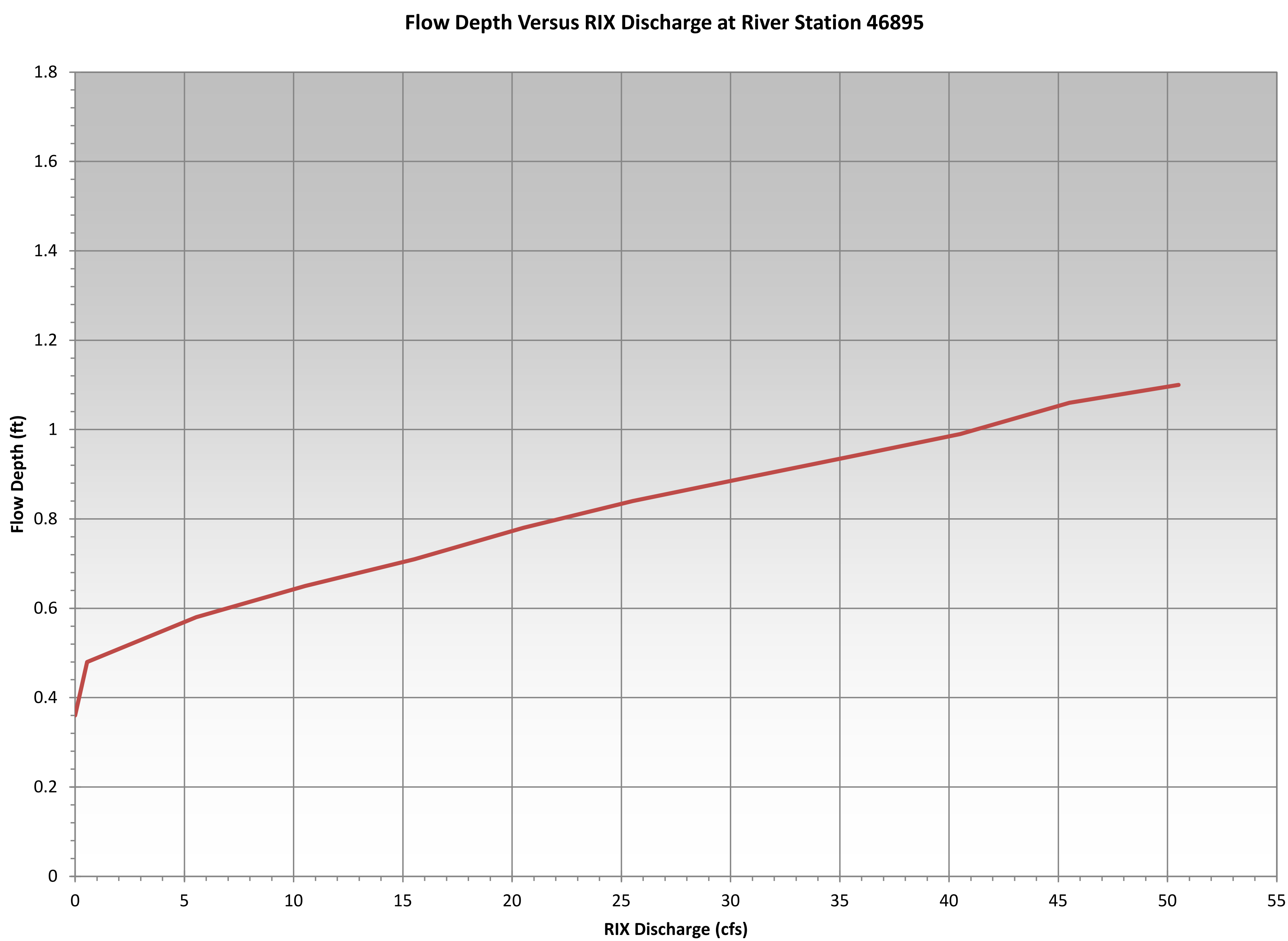

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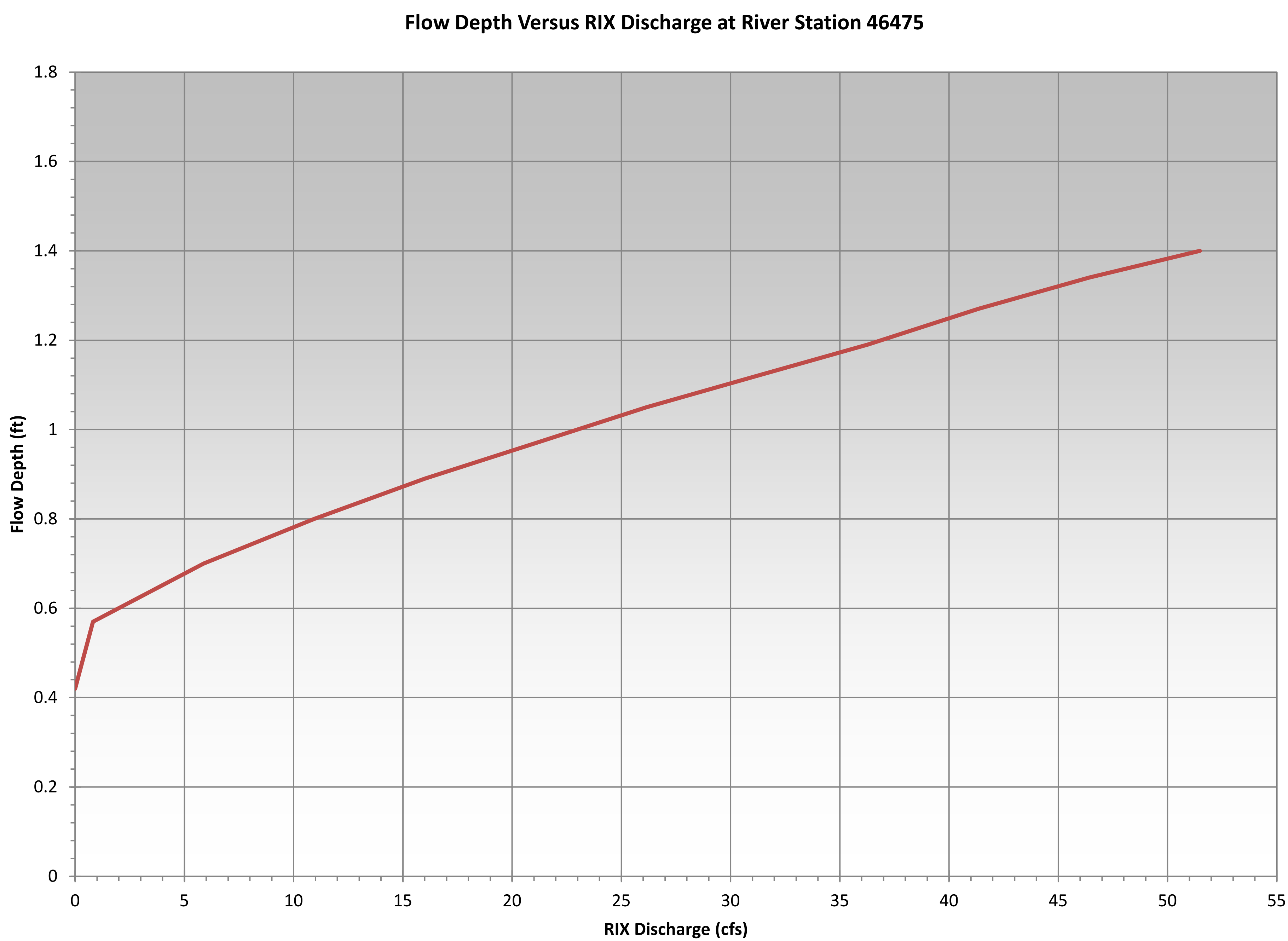
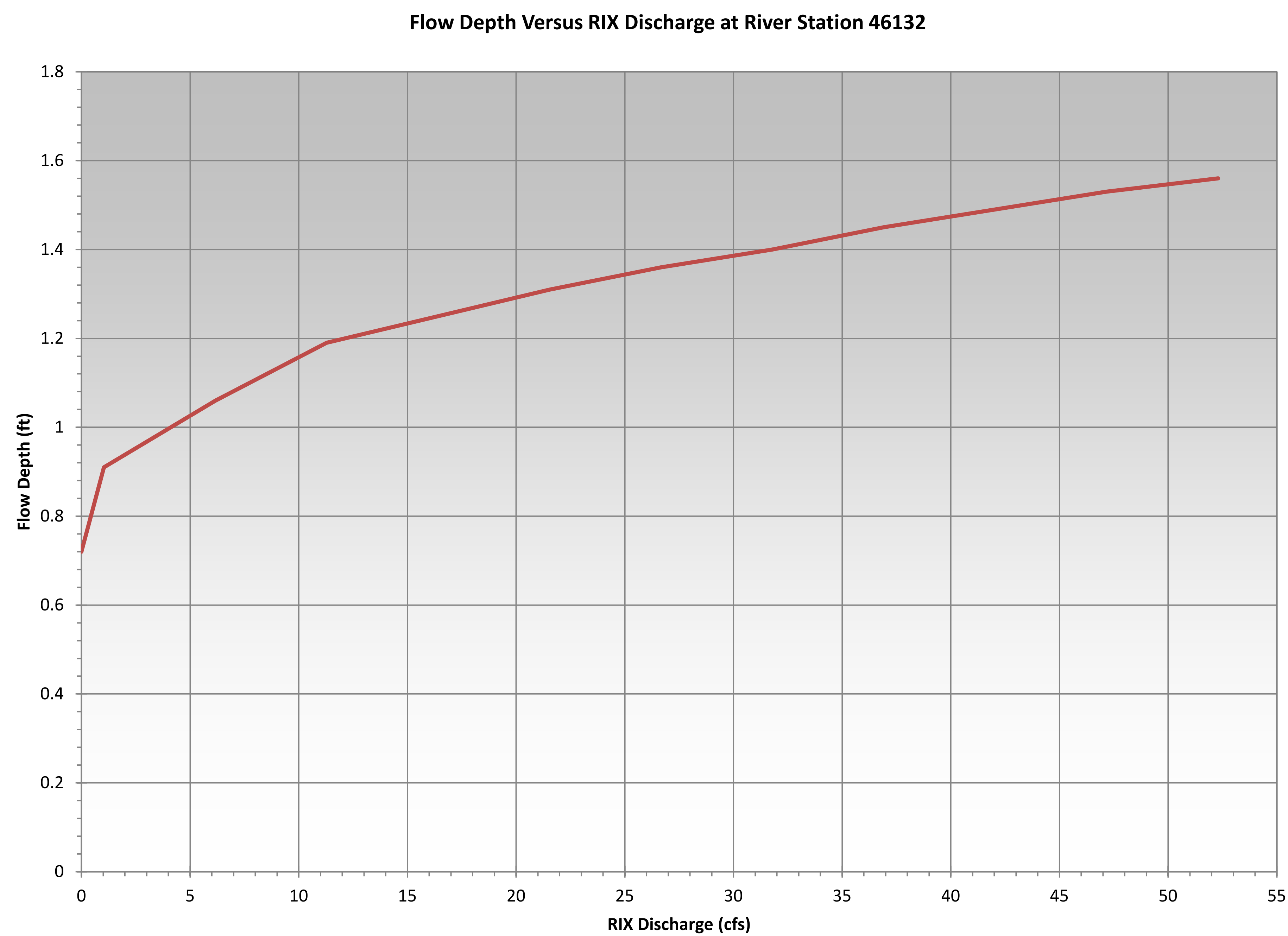
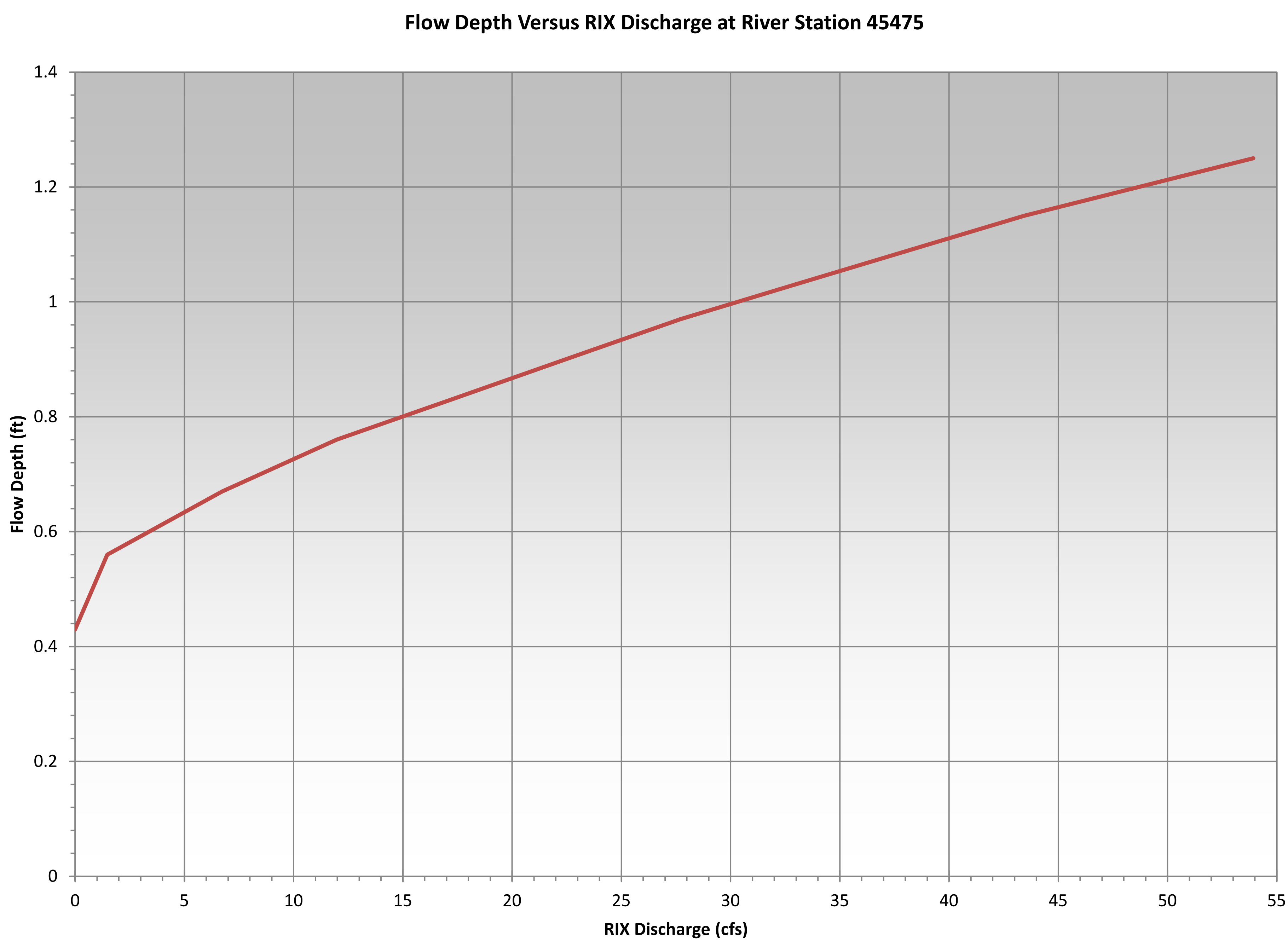
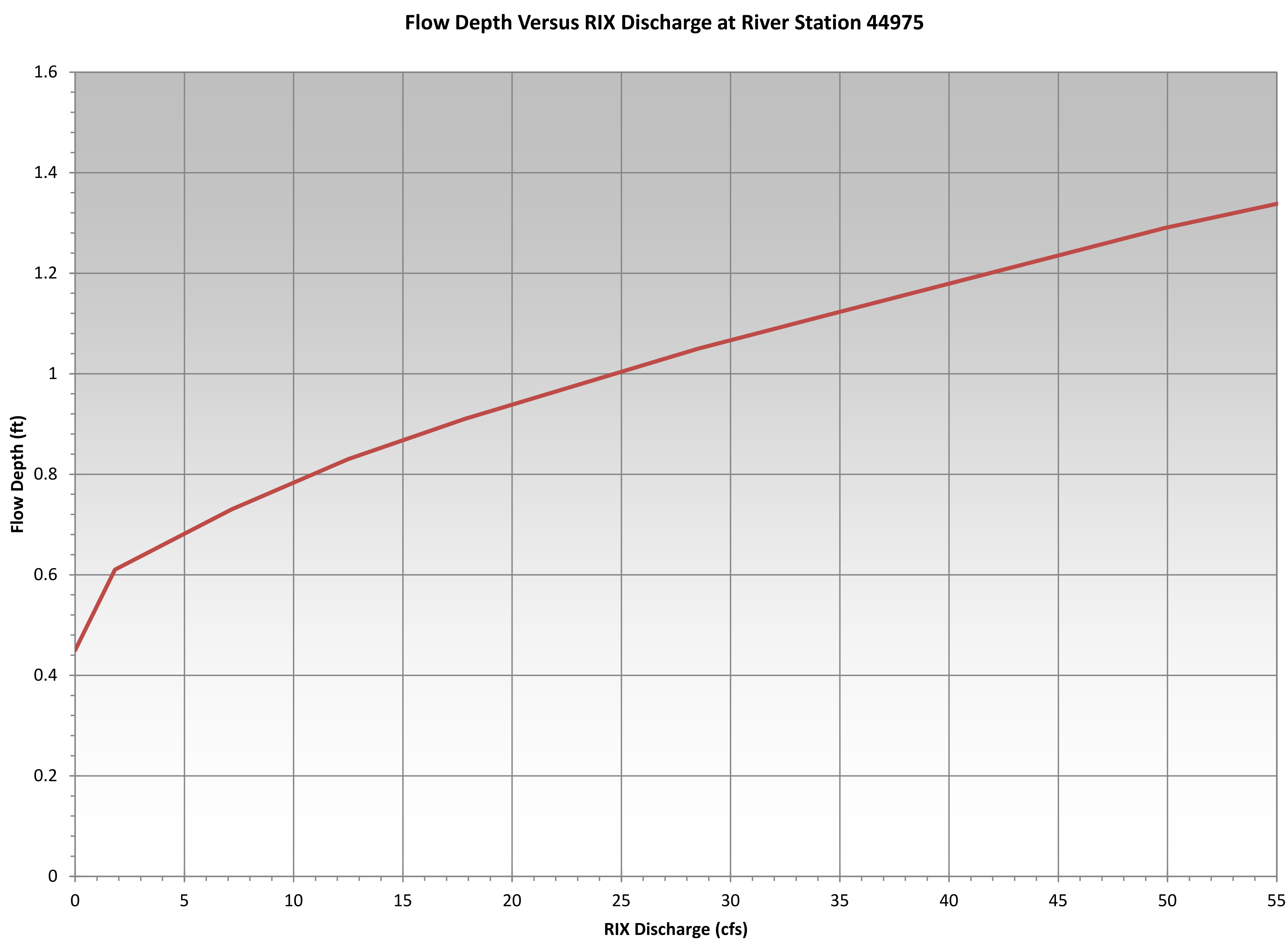
Plan9_RatingCurve_MAB4 46894.7

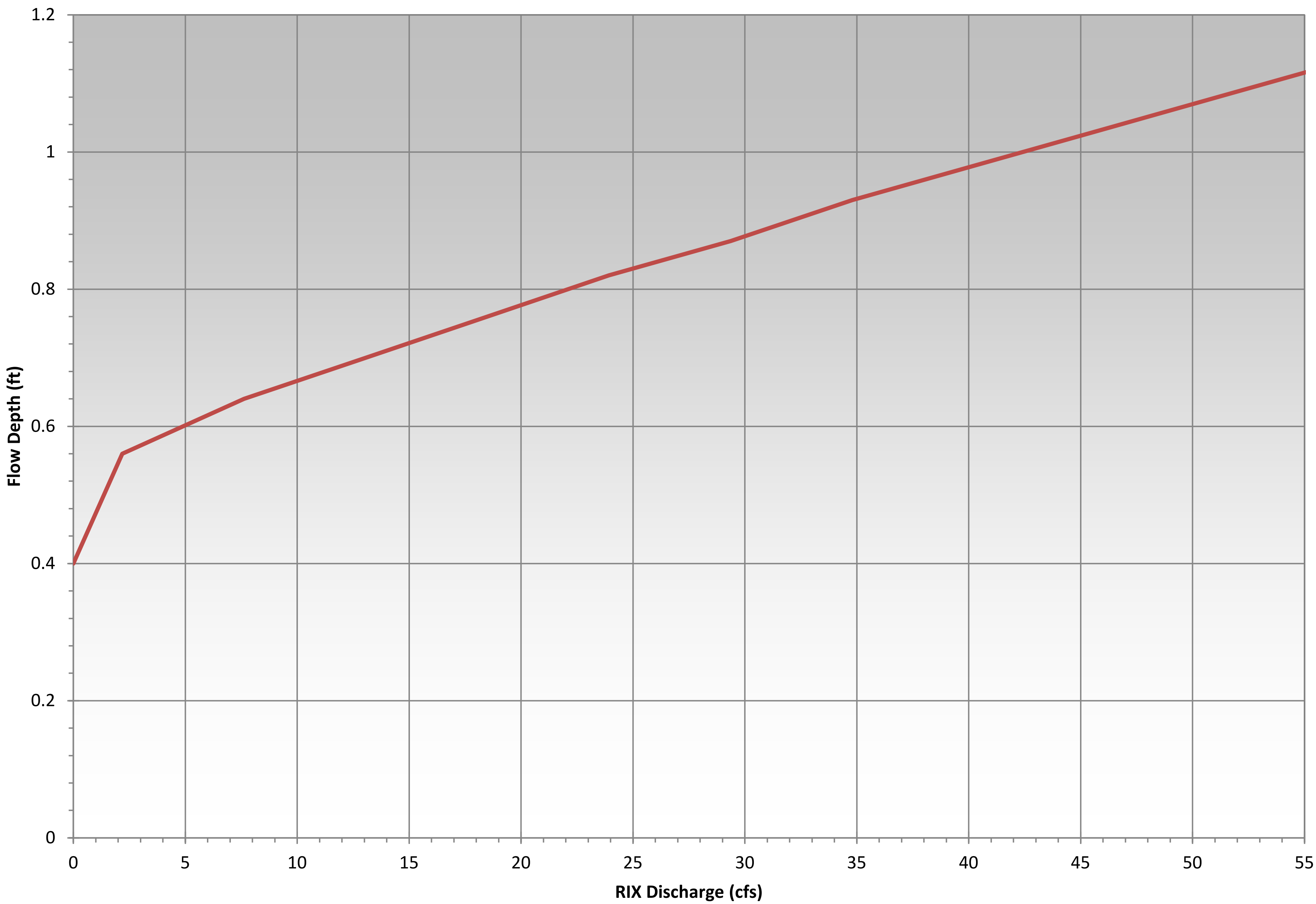

Flow Depth Versus RIX Discharge at River Station 46475
Flow Depth (ft)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
50
55
RIX Discharge (cfs)


Flow Depth Versus RIX Discharge at River Station 46132
Flow Depth (ft)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
50
55
RIX Discharge (cfs)

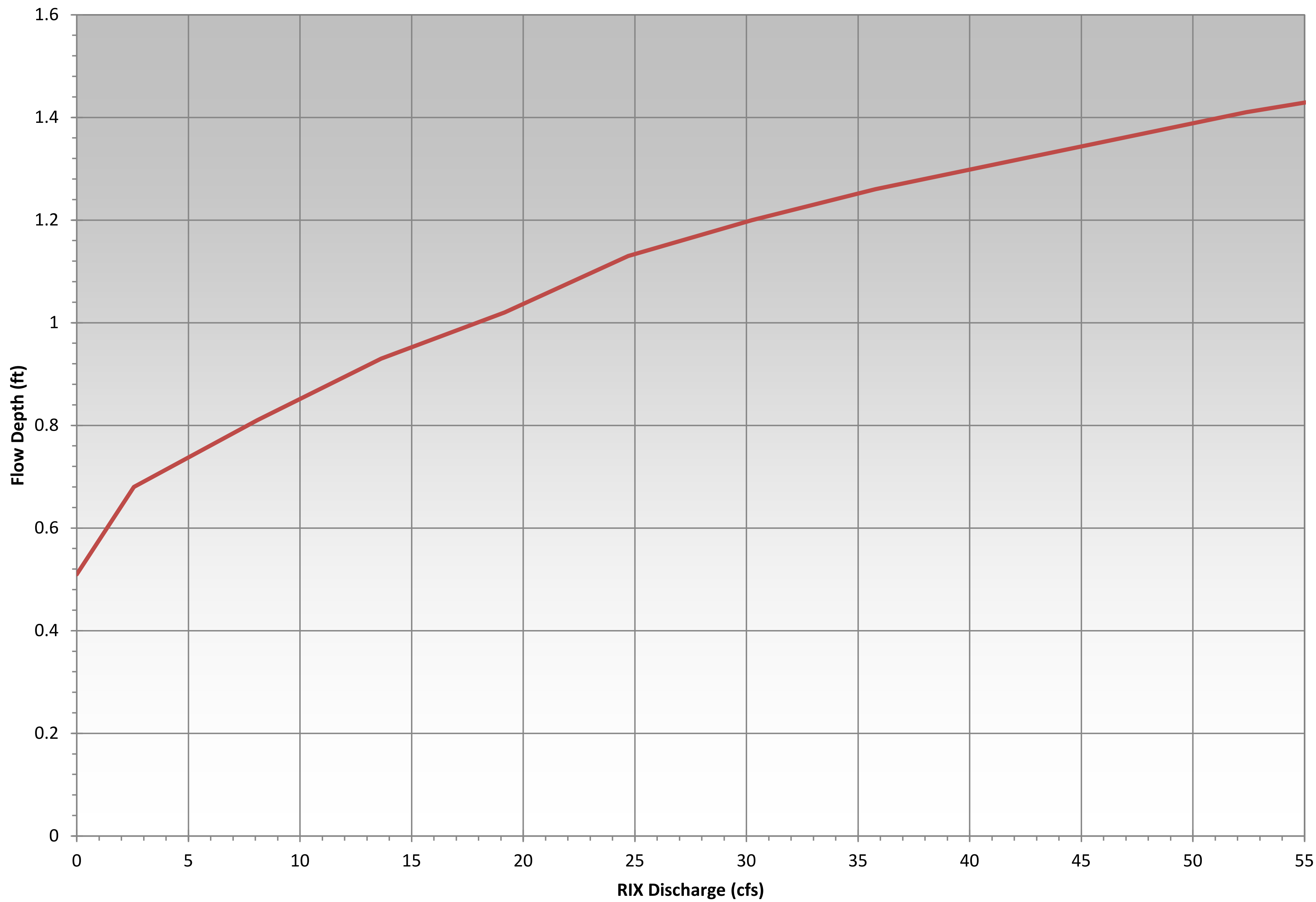

Flow Depth Versus RIX Discharge at River Station 45475
Flow Depth (ft)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
5
10
15
20
25
30
35
40
45
50
55
RIX Discharge (cfs)


Flow Depth Versus RIX Discharge at River Station 44975
Flow Depth (ft)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
5
10
15
20
25
30
35
40
45
50
55
RIX Discharge (cfs)

Flow Depth Versus RIX Discharge at River Station 44475



Flow Depth Versus RIX Discharge at River Station 43975



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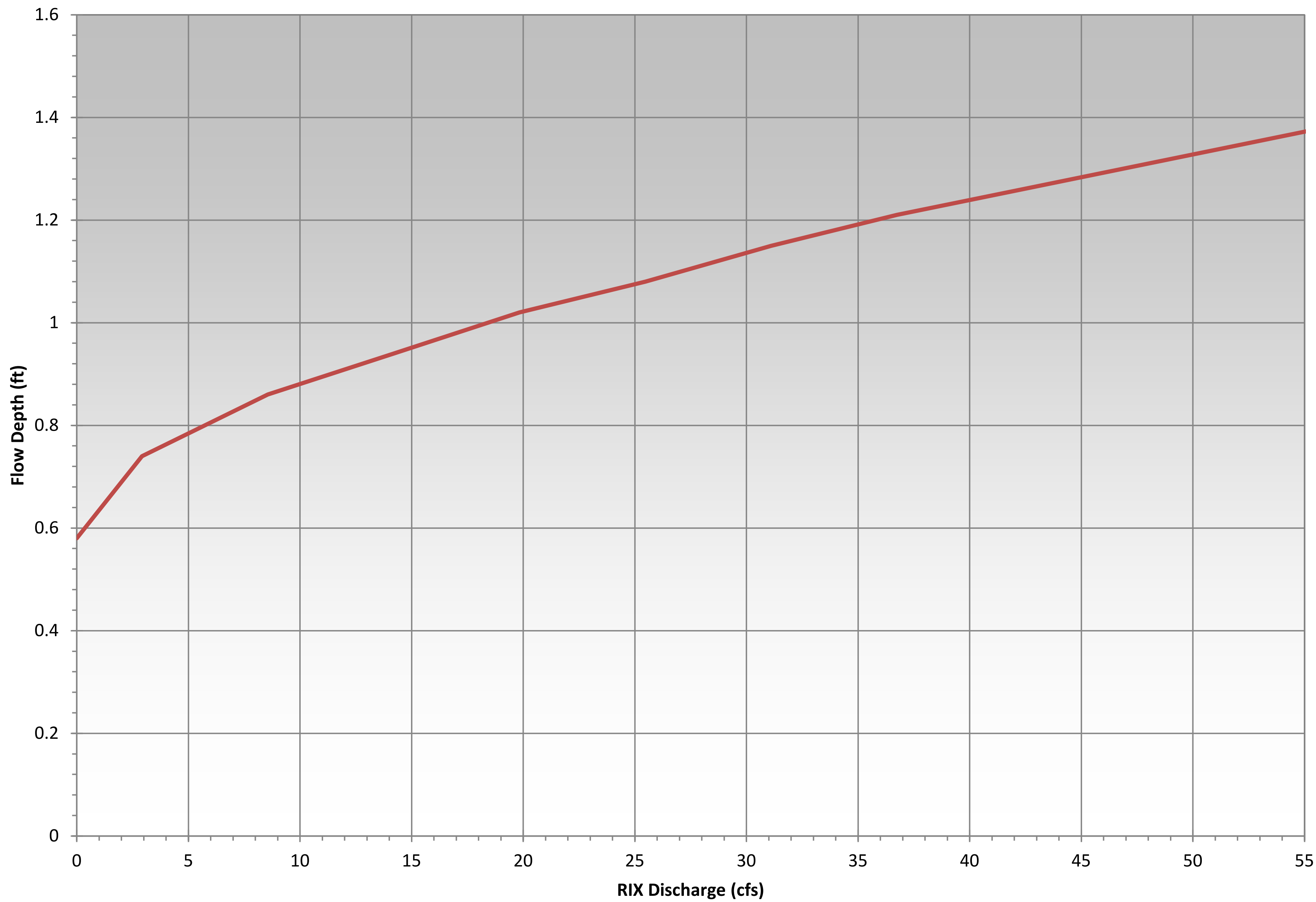
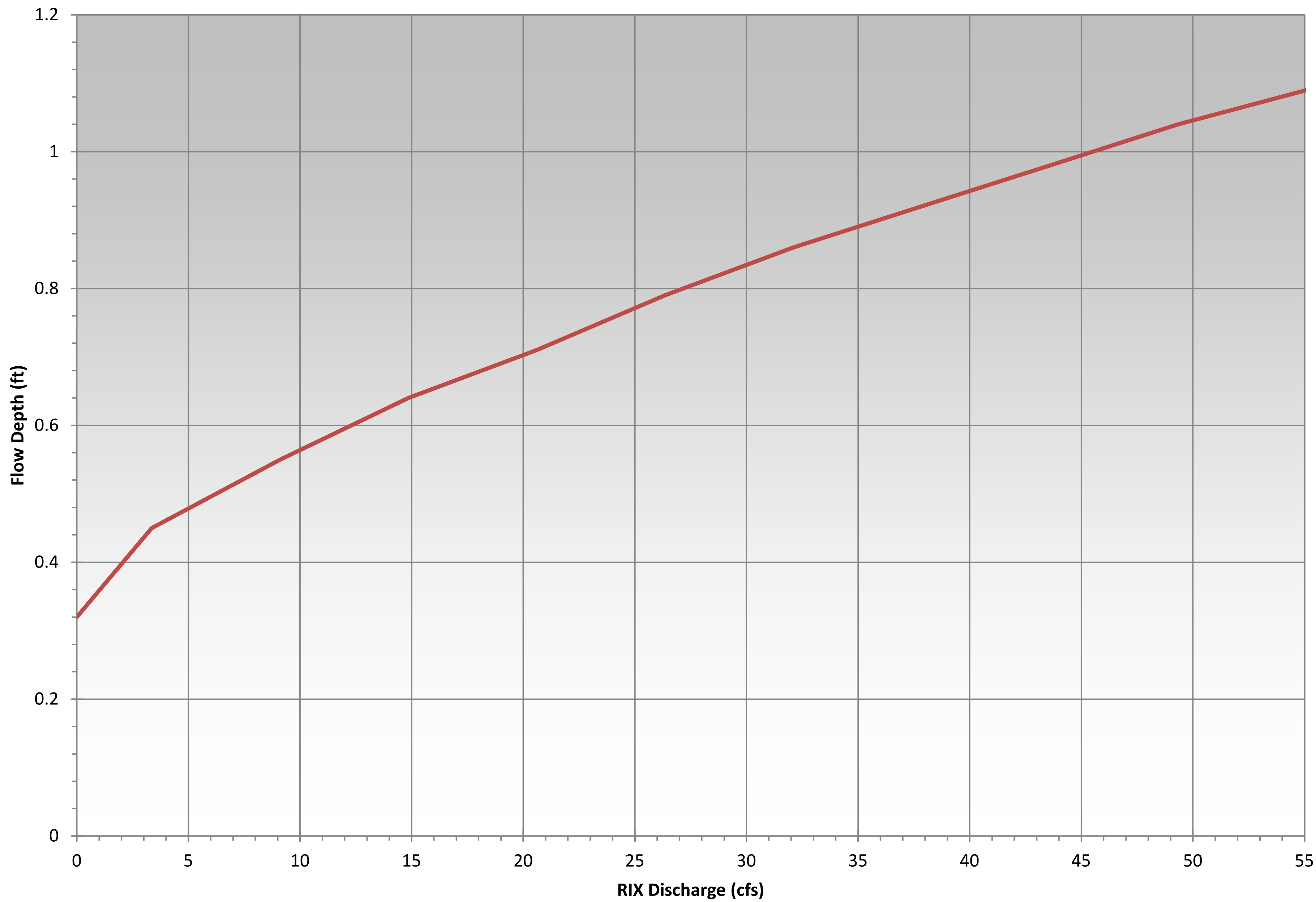
Flow Depth Versus RIX Discharge at River Mile Station 43504



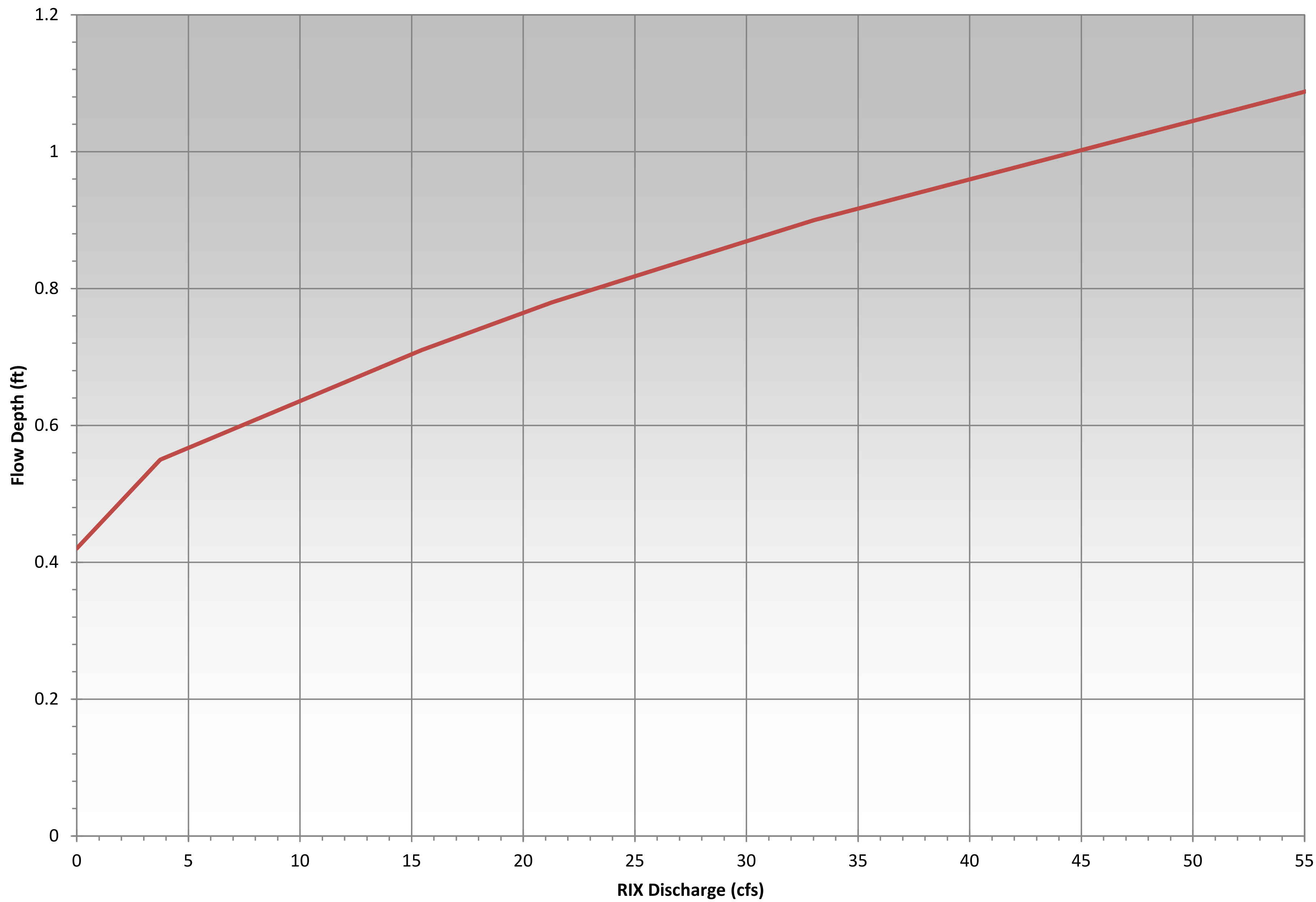
WILDERMUTH™ ENVIRONMENTAL INC.

Flow Depth Versus RIX Discharge at River Station 42975



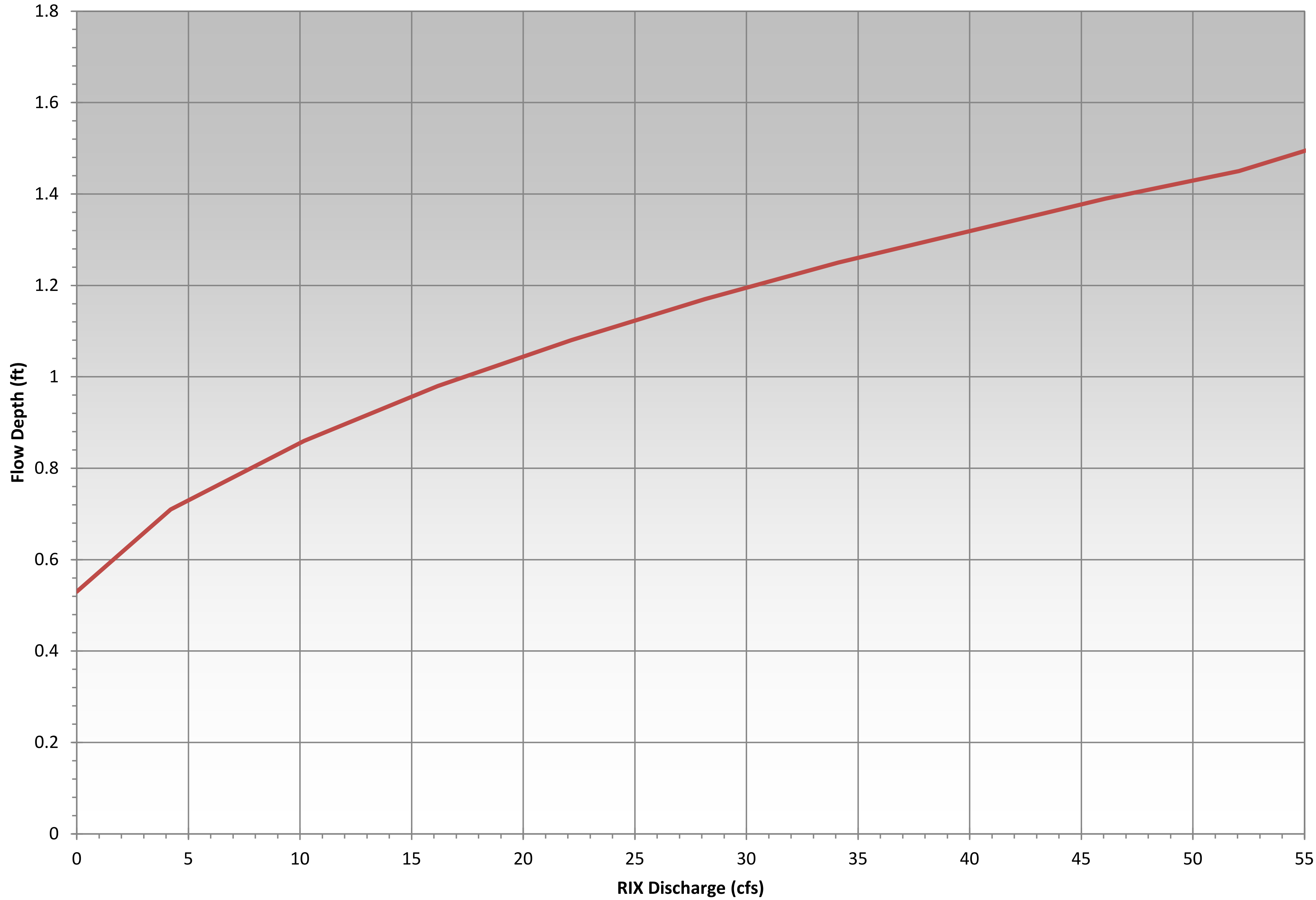
WILDERMUTH™ ENVIRONMENTAL INC.

Flow Depth Versus RIX Discharge at River Station 42510

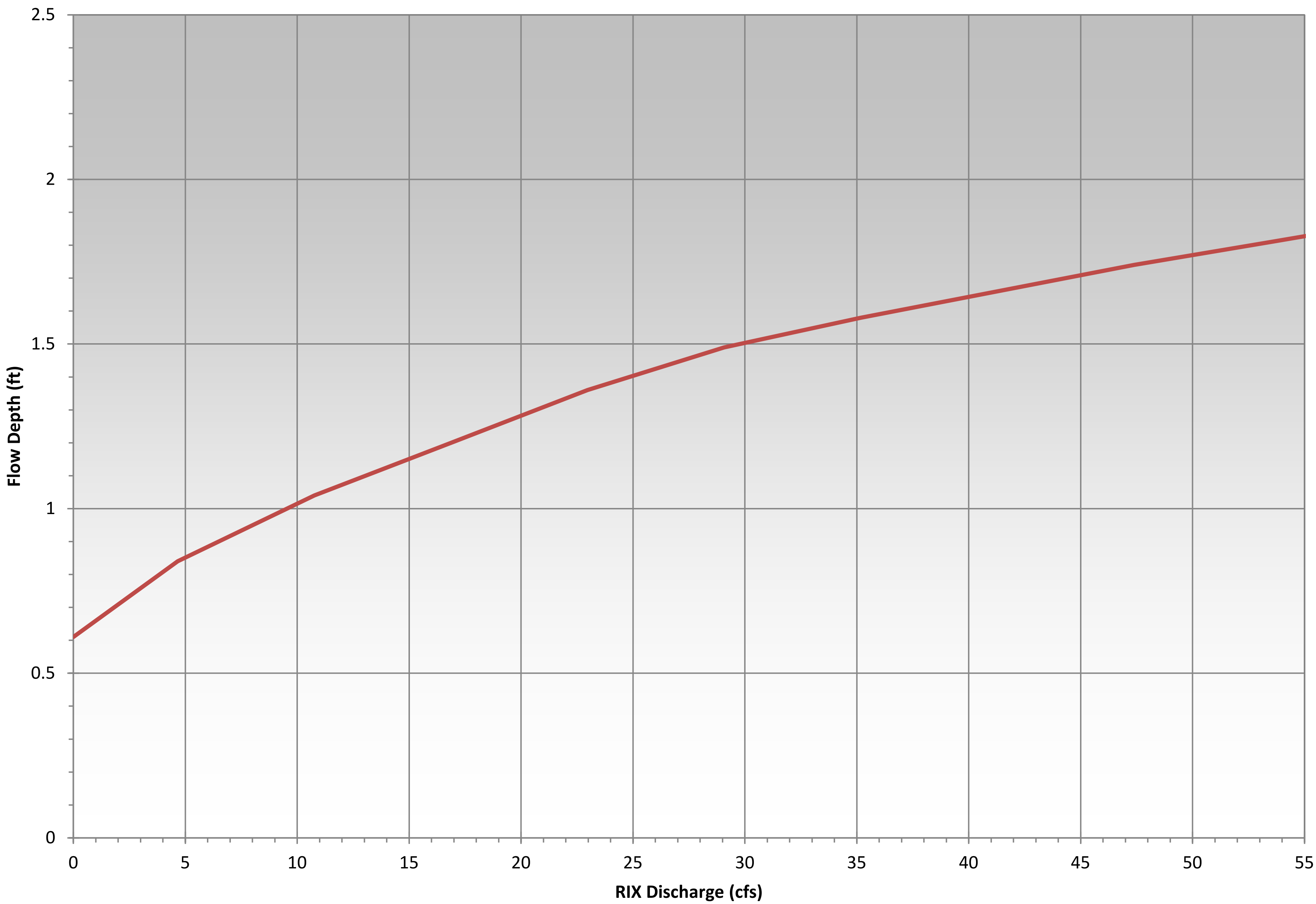


WILDERMUTH™ ENVIRONMENTAL INC.

Flow Depth Versus RIX Discharge at River Station 41975



Flow Depth Versus RIX Discharge at River Station 41476



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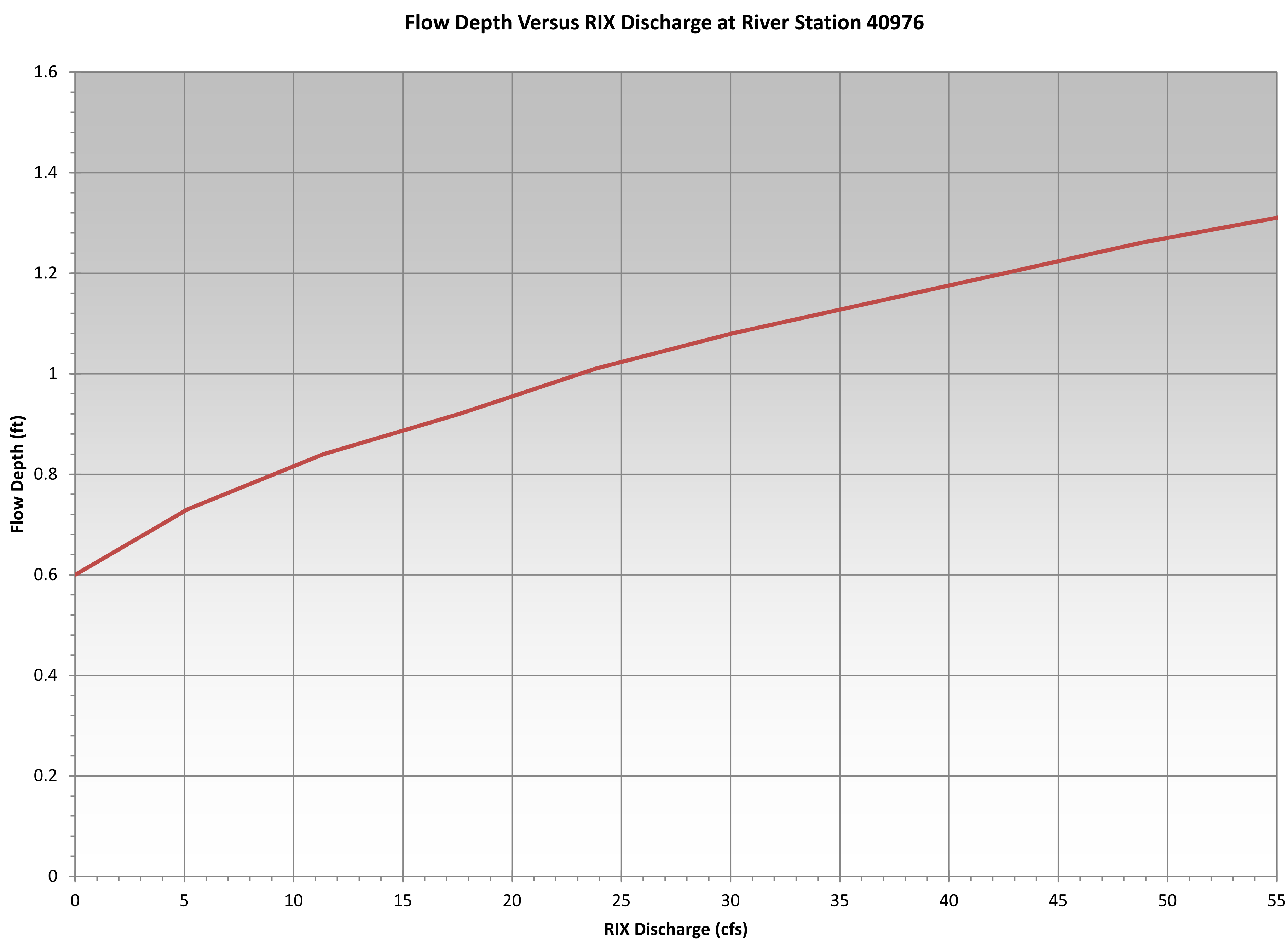

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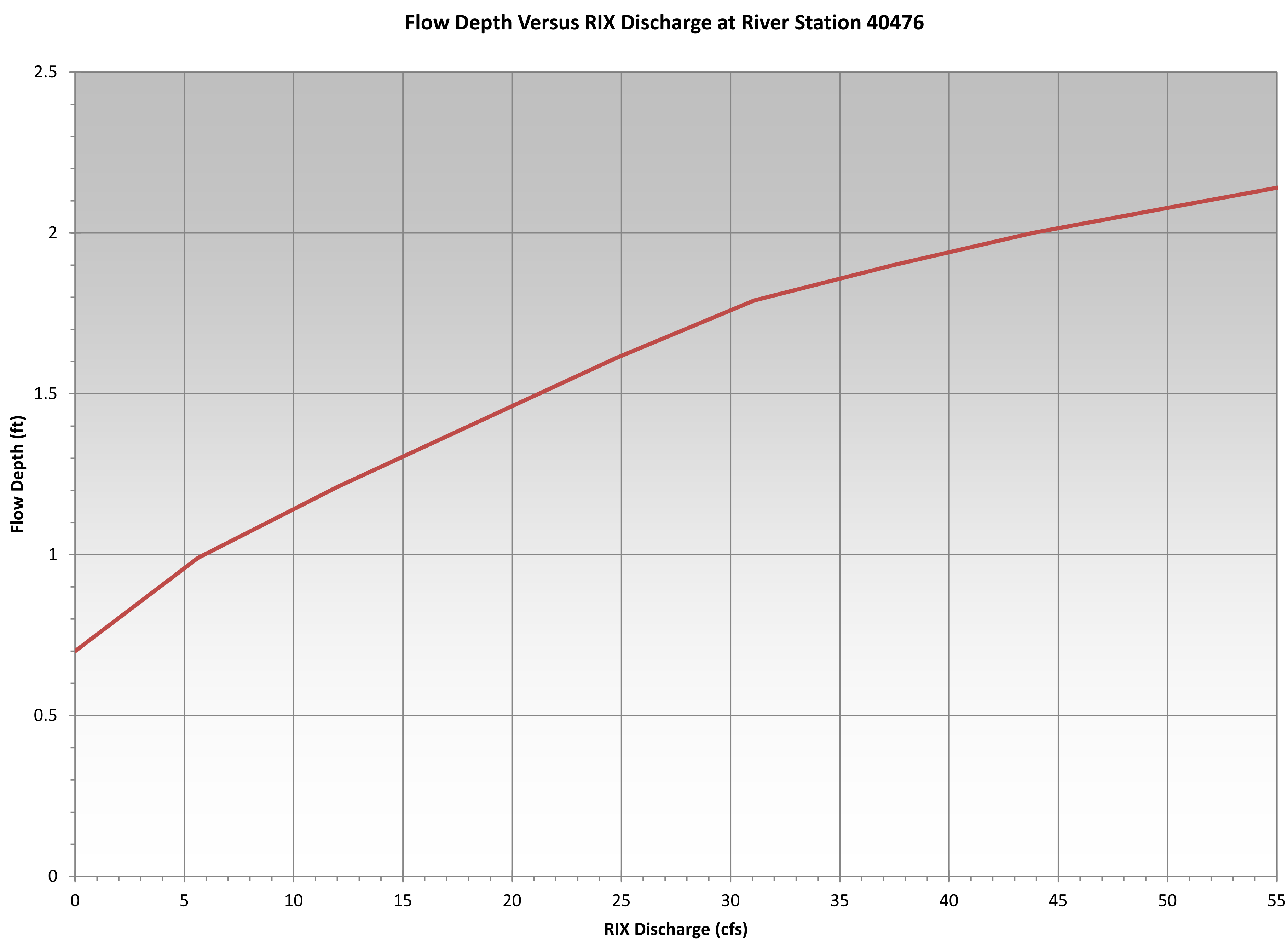
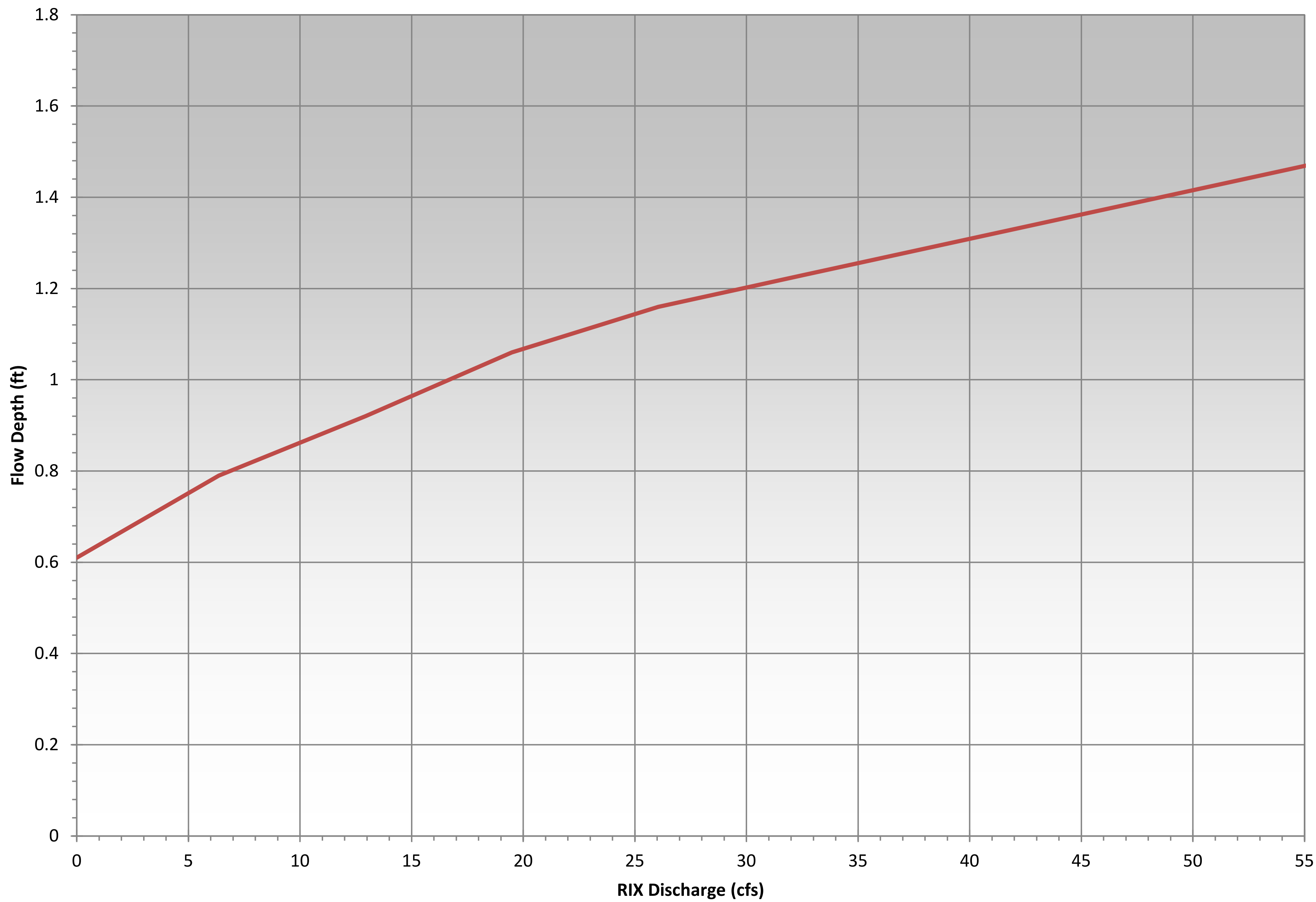
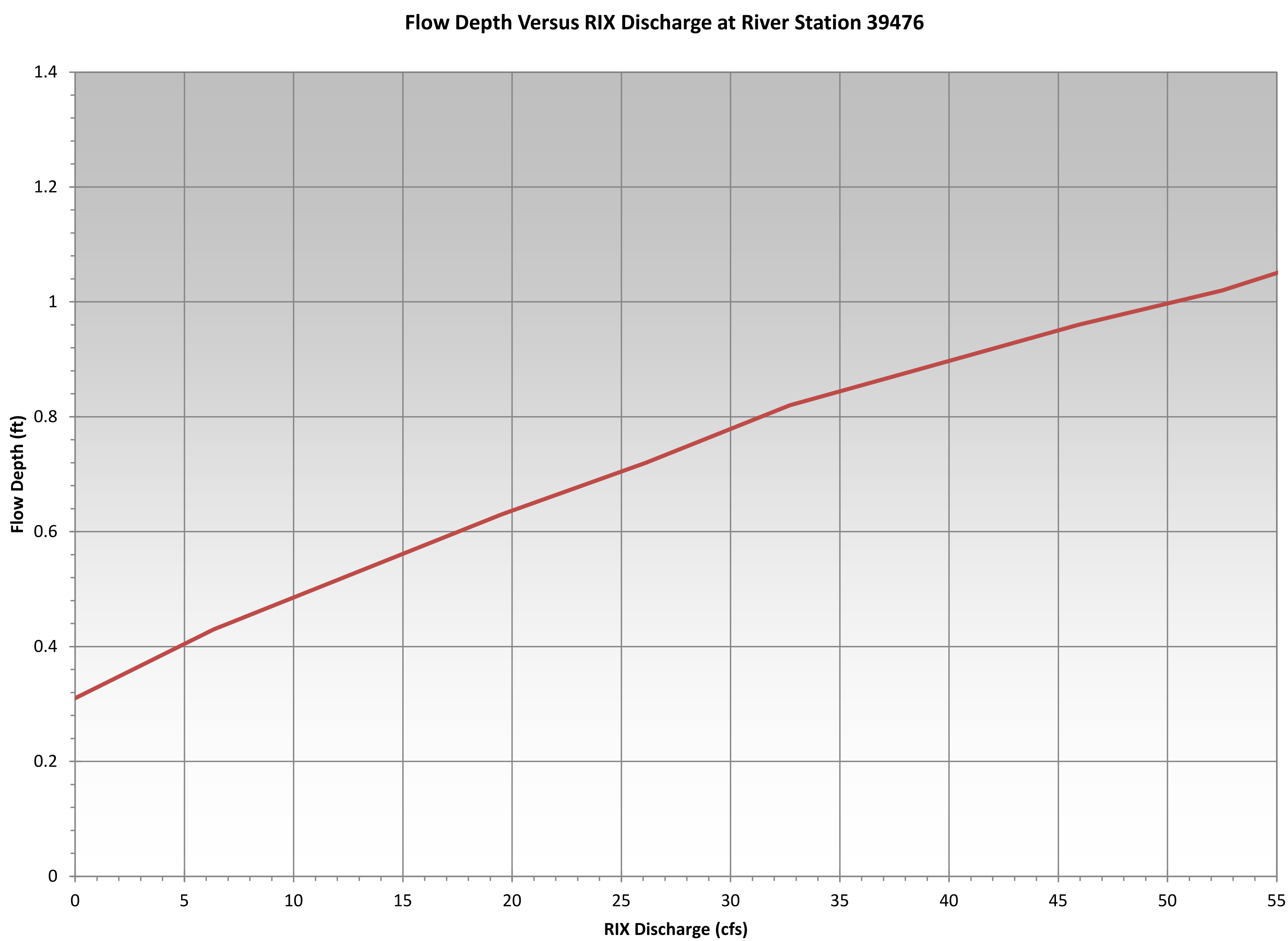


Flow Depth Versus RIX Discharge at River Station 40476
Flow Depth (ft)
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
55
RIX Discharge (cfs)

Flow Depth Versus RIX Discharge at River Station 39769





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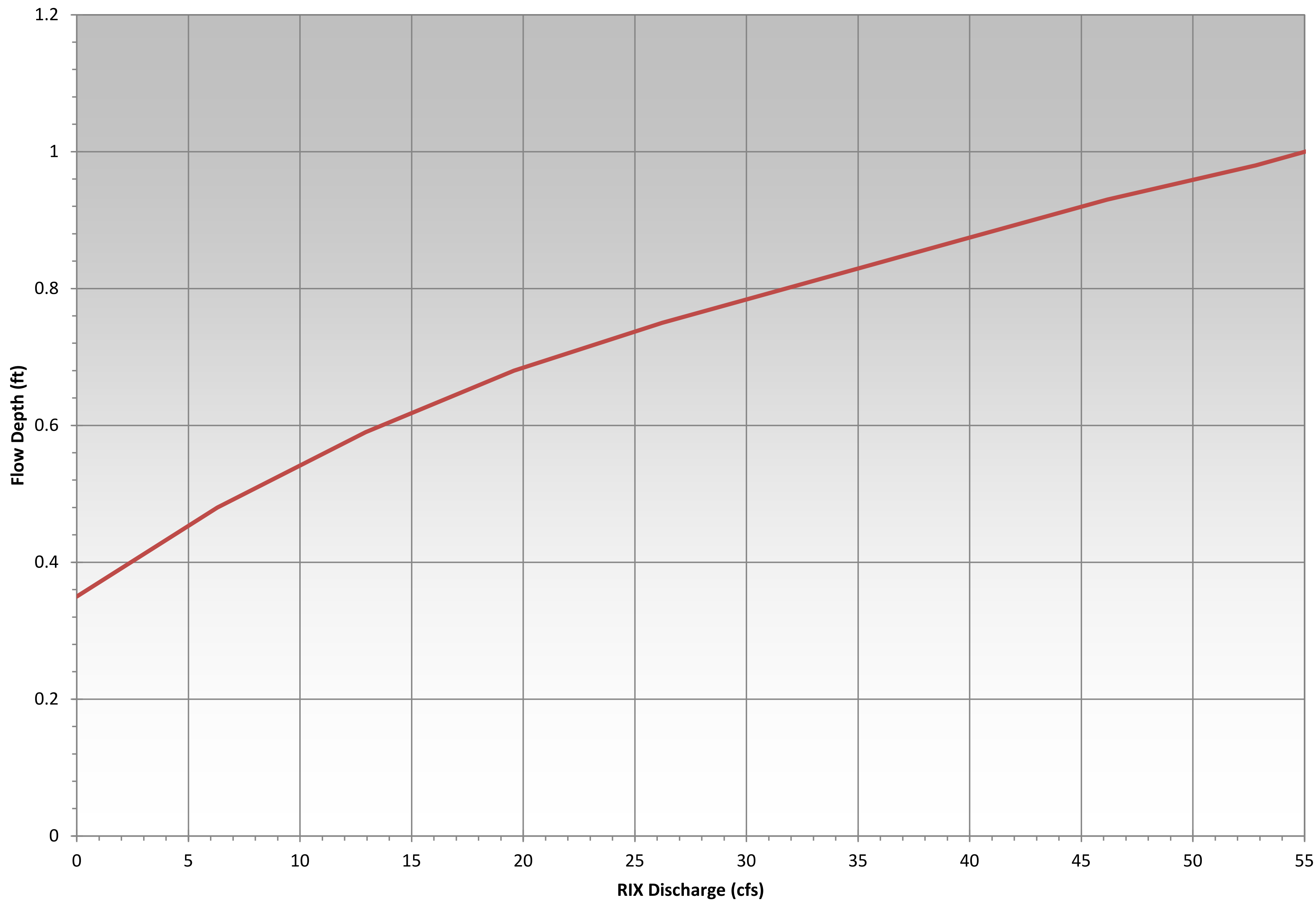
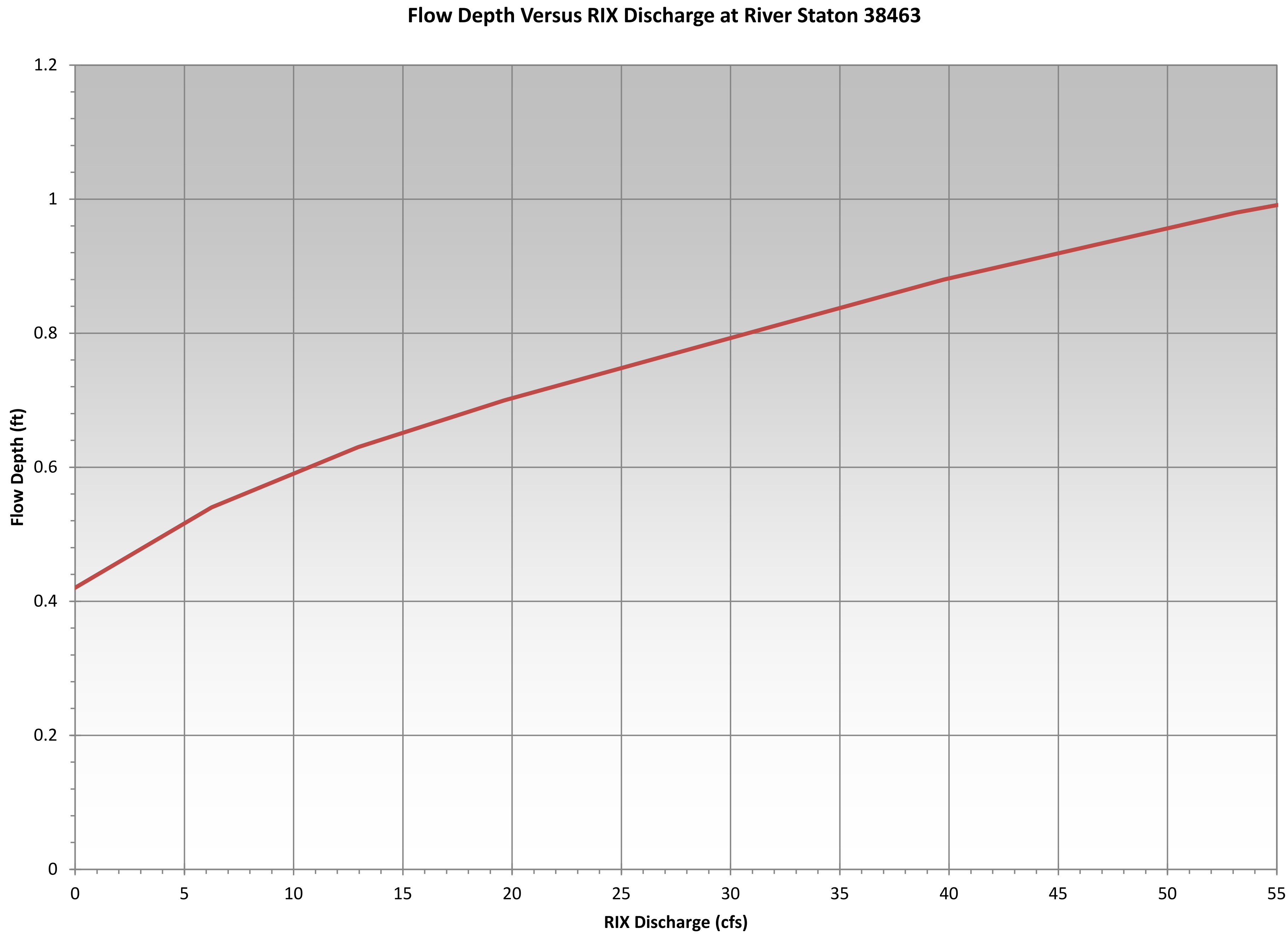
Flow Depth Versus RIX Discharge at River Station 38989





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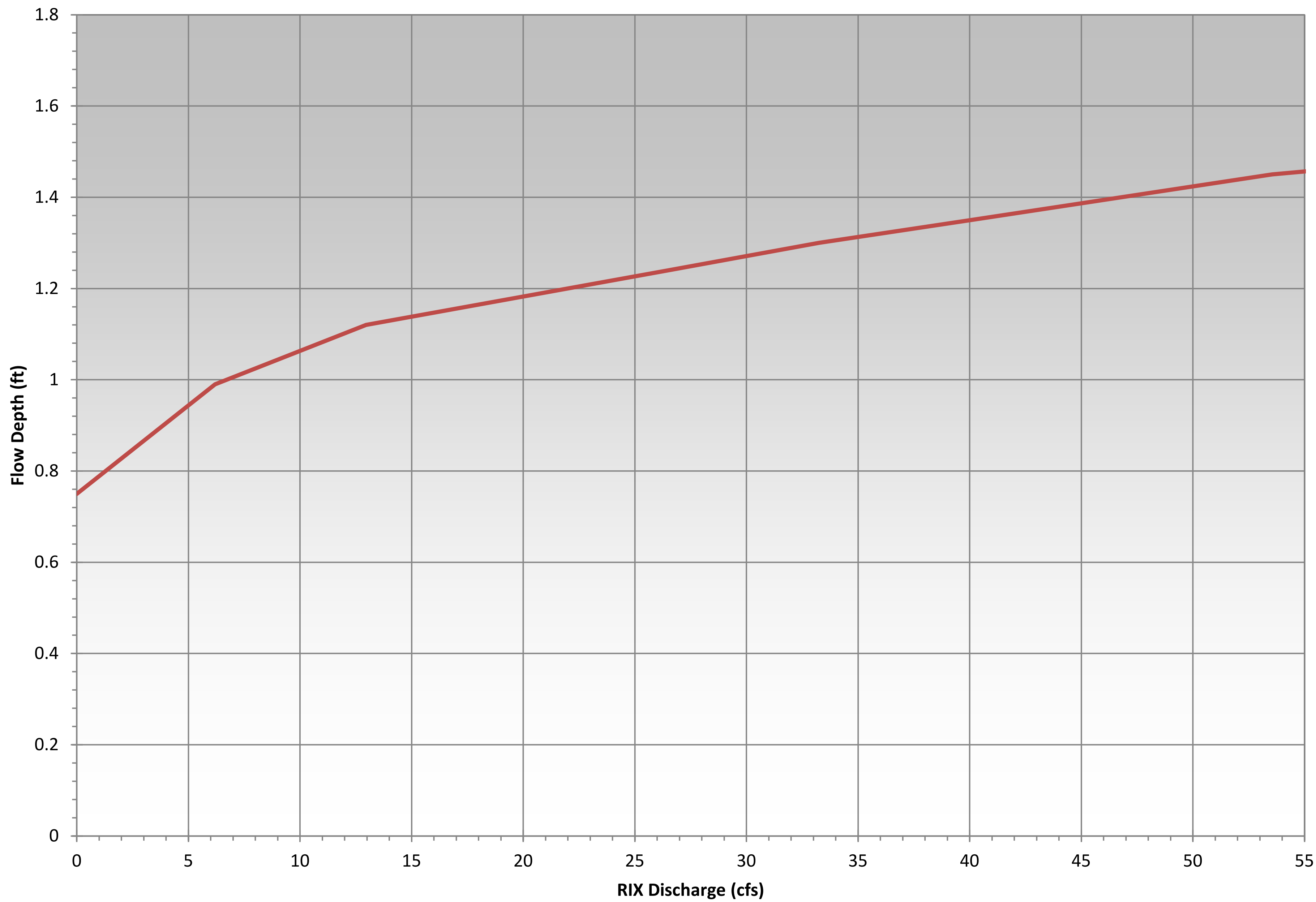
Flow Depth Versus RIX Discharge at River Station 37884



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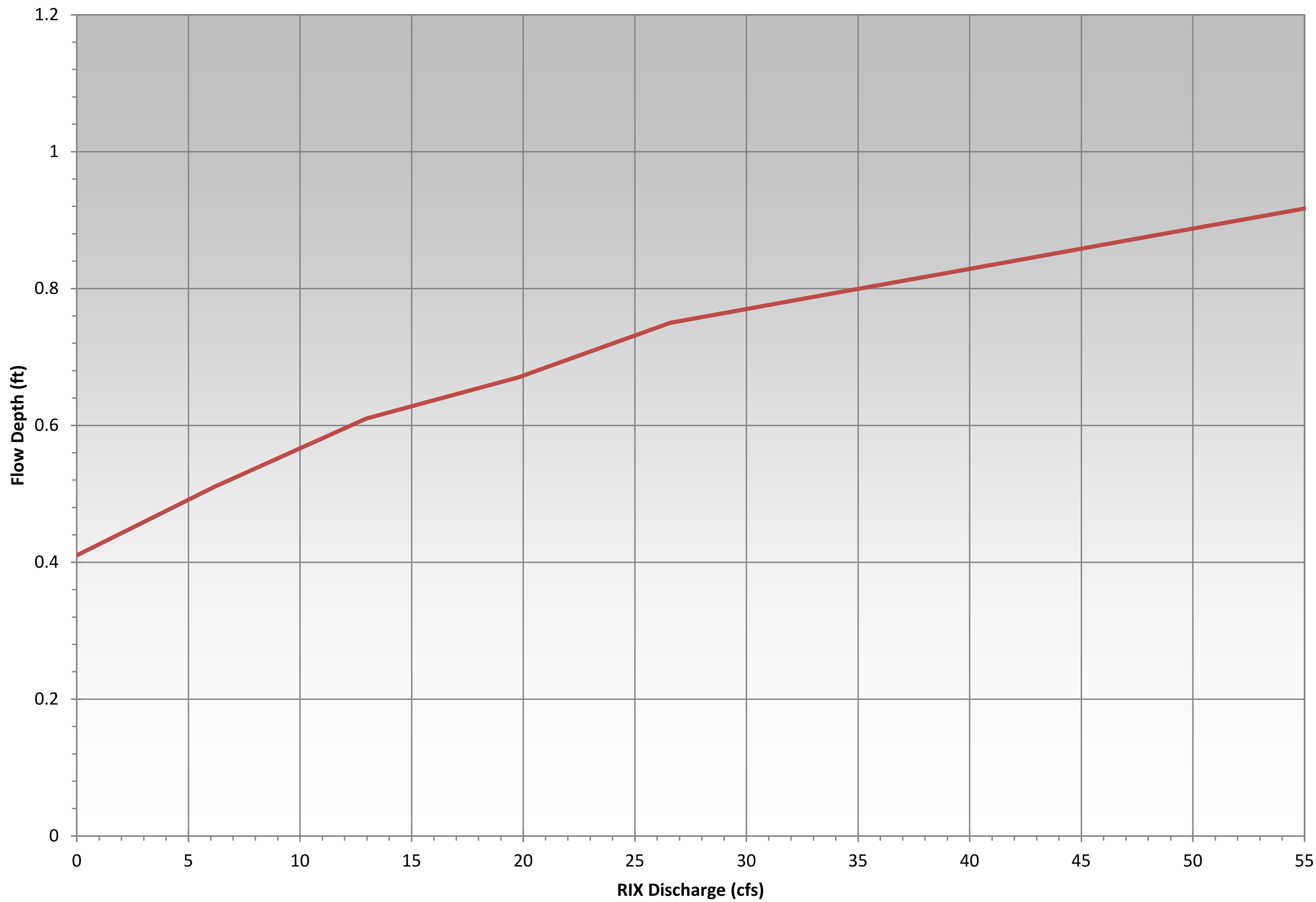
Flow Depth Versus RIX Discharge at River Station 37475



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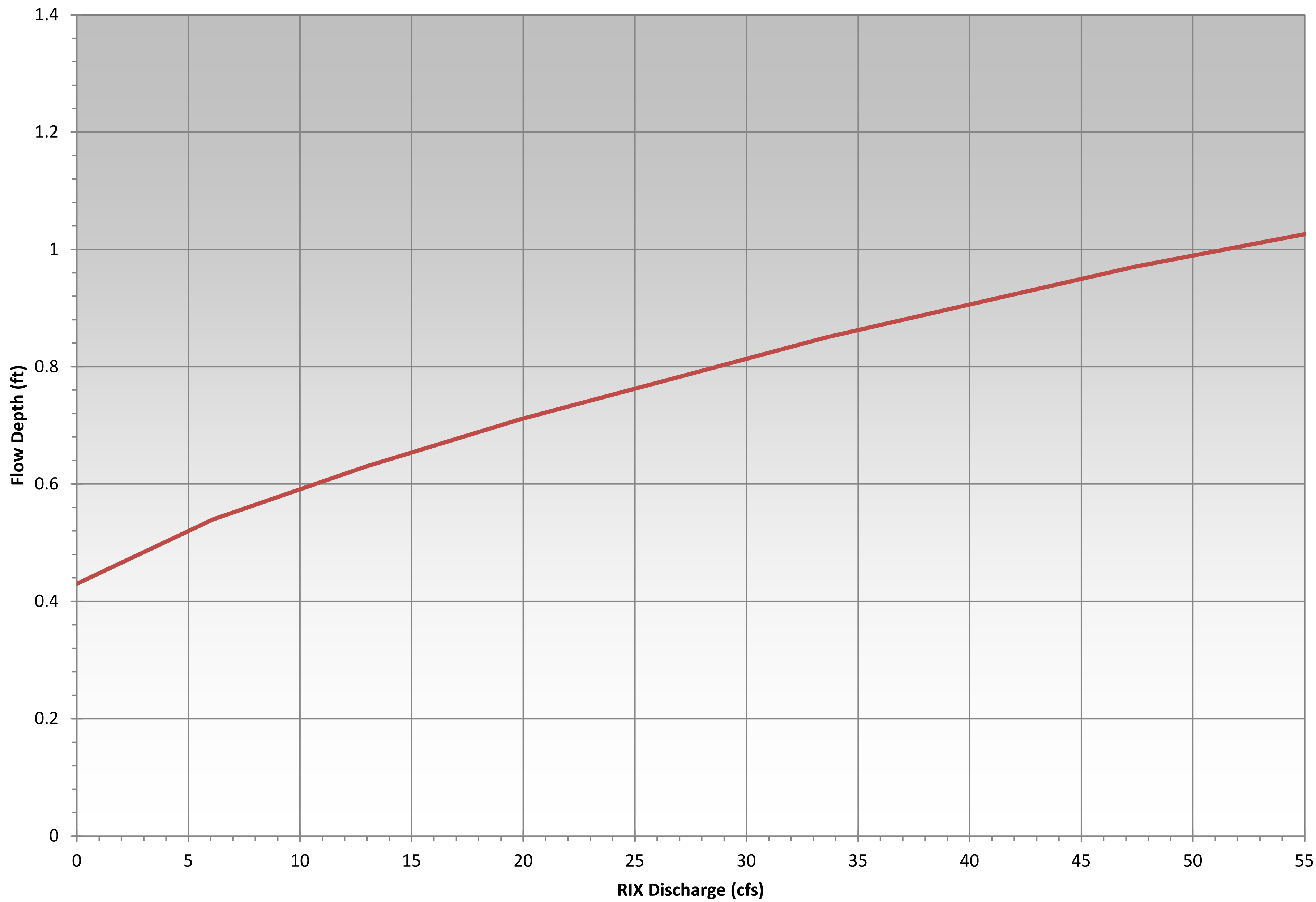
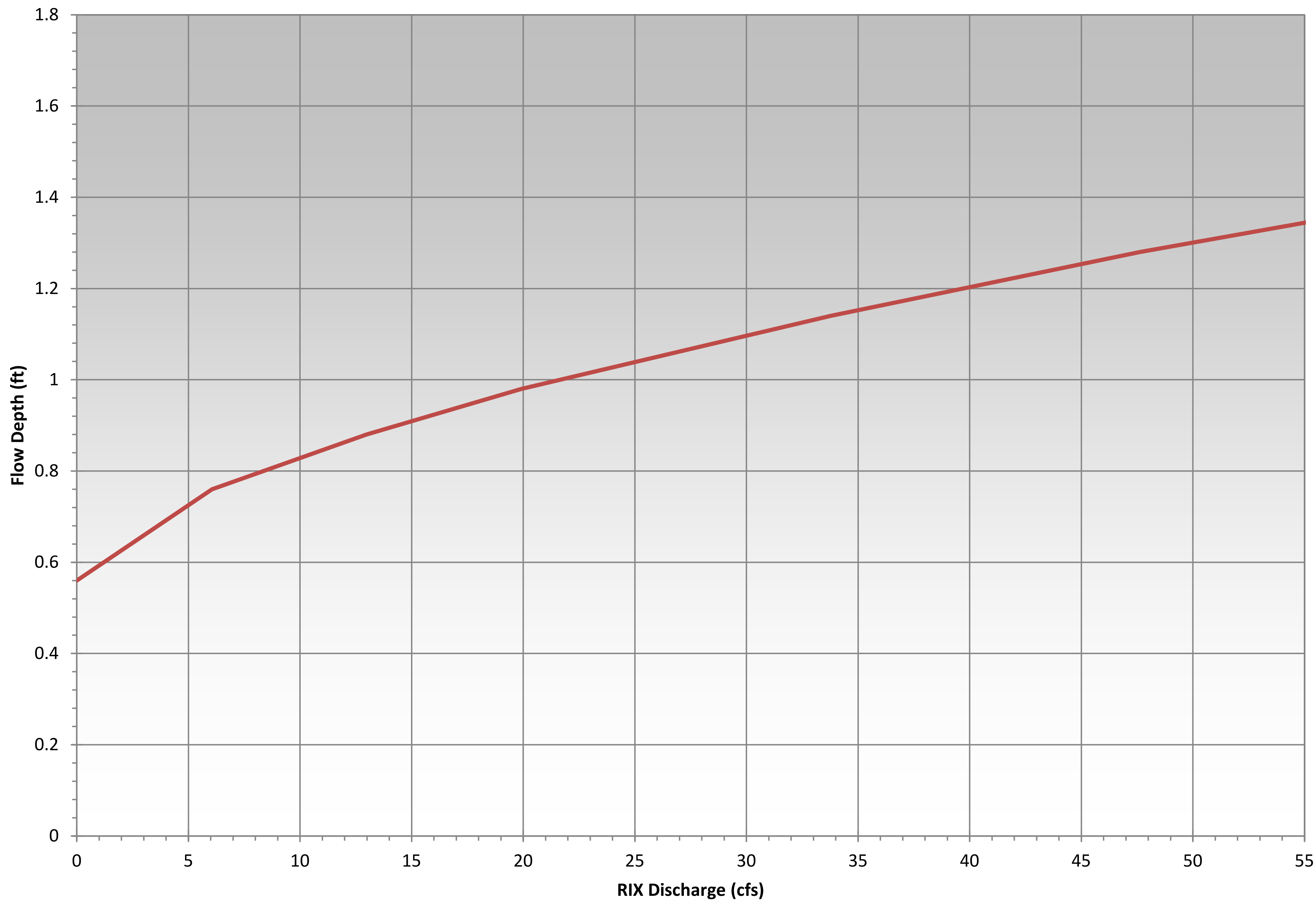
Flow Depth Versus RIX Discharge at River Station 36982



Flow Depth Versus RIX Discharge at River Station 36462



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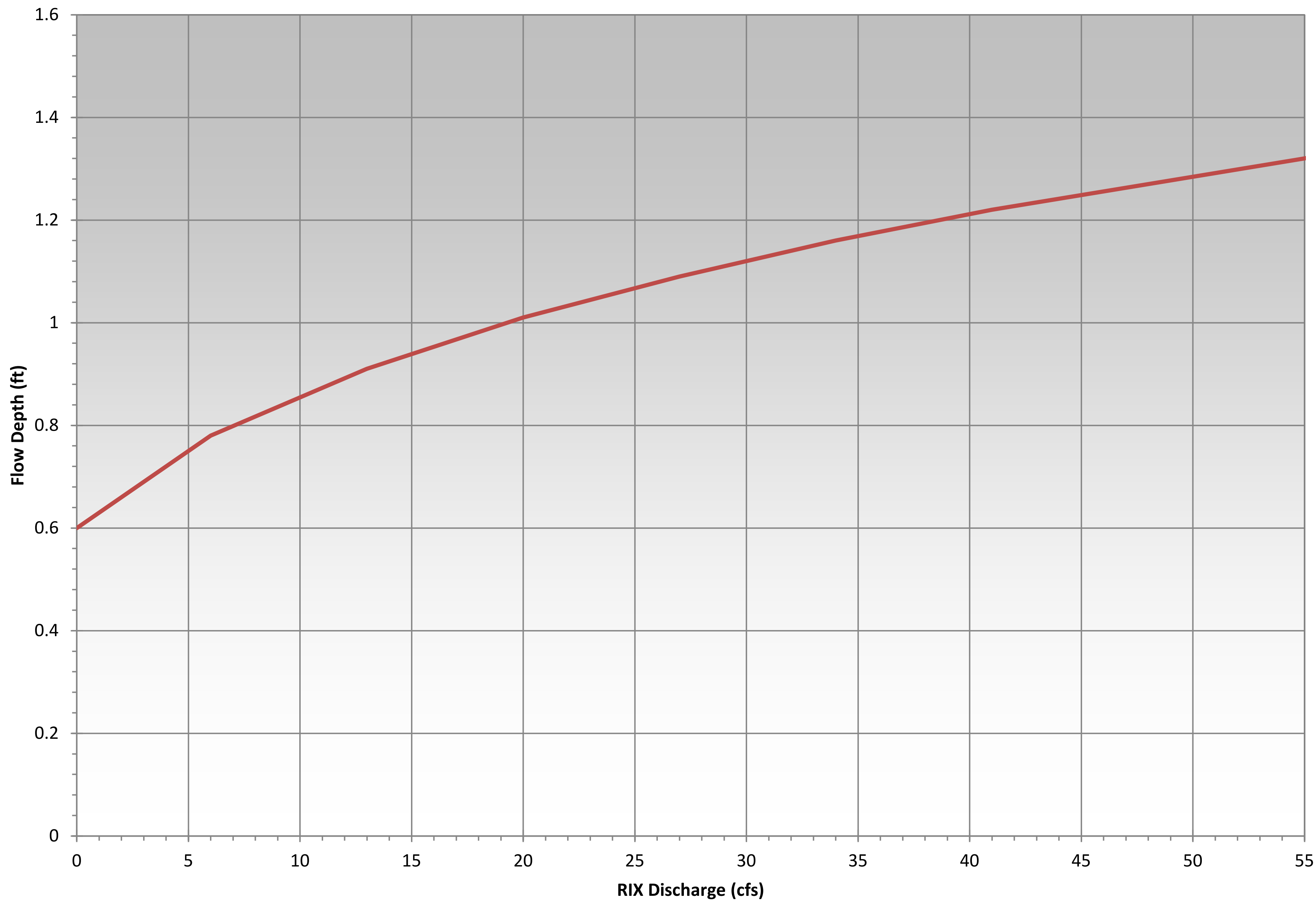
Flow Depth Versus RIX Discharge at River Station 35838



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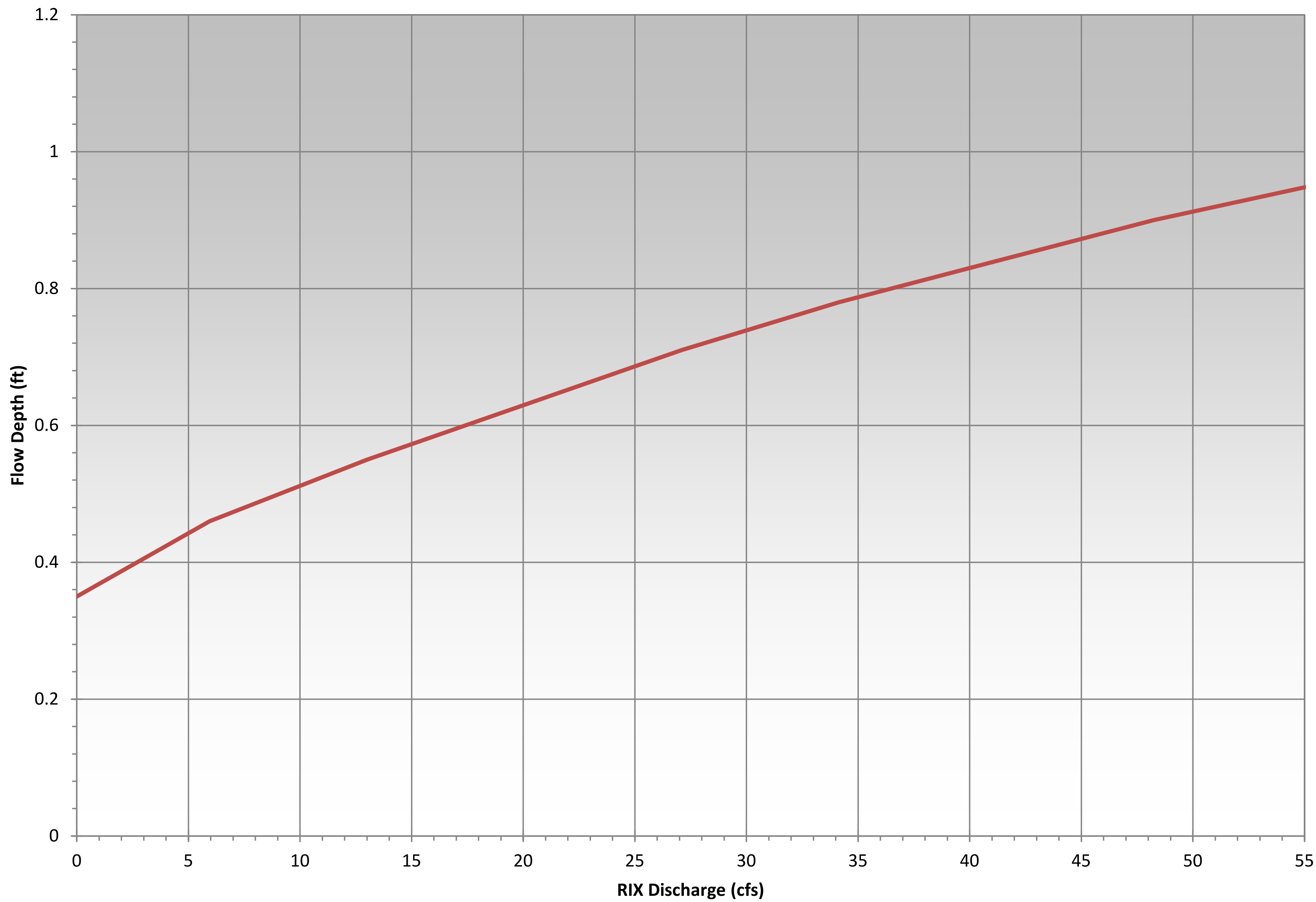

Appendix C:

In-Depth Analysis of the Santa Ana River HEC-RAS Hydraulic Modeling Results for the River Reach between RIX and the MWD Crossing

(WEI, March 2014)

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WILDERMUTH™ ENVIRONMENTAL INC.

March 24, 2014

Somach Simmons and Dunn Attorneys at Law
Attn: Andrew M. Hitchings
500 Capitol Mall #1000
Sacramento, CA 95814

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ATTORNEY WORK-PRODUCT

Subject: ***In-depth Analysis of the Santa Ana River HEC-RAS Hydraulic Modeling Results for the River Reach Between RIX and the MWD Crossing***

Dear Mr. Hitchings,

Pursuant to the Clean Water Factory Low Flow Workshop discussions conducted on October 9-10, 2013 between Wildermuth Environmental, Inc. (WEI), GEI, RBF, Ruth Villalobos, and the City San Bernardino (City), we are pleased to submit this letter report on the *In-depth Analysis of the Santa Ana River HEC-RAS Hydraulic Modeling Results for the River Reach Between RIX and the MWD Crossing.* This analysis builds on the *Dry-Weather Discharge and Depth Analysis of the Santa Ana River from the Rialto Channel to MWD Crossing* report conducted by WEI (2013)[1]. In the WEI (2013) report, WEI developed a gradually-varied, steady-flow hydraulic model between the Rialto Channel and the MWD Crossing. This required the acquisition of high-resolution river channel geometry and discharge data collected during normal-Rapid Infiltration and Extraction facility (RIX) discharge operations as well as during a temporary shutdown of RIX discharge to the Santa Ana River. For the subject analysis, we modified the existing HEC-RAS model to: 1) update the existing model with the City's new discharge reduction plan scenario for RIX, and 2) generate width, depth, and velocity distribution plots for each of the existing model's channel cross-sections between RIX and the MWD Crossing. This data was provided to GEI biologists to assist in their habitat utilization analysis of the Santa Ana Sucker.

Methods

The existing hydraulic model of the Santa Ana River was developed using HEC-RAS v4.1[2] as a gradually-varied, steady-flow hydraulic model for the river reach between the Rialto Channel and the MWD Crossing (Figure 1). The HEC-RAS model required two major components: geometric data and discharge data. Geometric data included channel

[1] Wildermuth Environmental, Inc. (2013). *Dry-Weather Discharge and Depth Analysis of the Santa Ana River from the Rialto Channel to MWD Crossing.* Memorandum. Lake Forest: Author.
[2] U.S. Army Corps of Engineers Hydrologic Engineering Center.

geometry (cross-sections perpendicular to discharge), river centerlines, flow paths, bank locations, and Manning's "n." Discharge data were obtained from RIX and the City of Rialto treatment plant discharge data, discharge measured at the three stream gage sites on October 19, 2012, and rating curve data at USGS gage 11066460 (Santa Ana River at MWD Crossing). For a complete description of the model components see WEI (2013).

For this updated version of the model, five new discharge scenarios were run based on the City's phased reduction plan for the RIX facility. In addition to these scenarios, baseline and zero-RIX discharge operation was also run. Table 1 shows the RIX discharge phased reduction scenarios. As discussed in WEI (2013), discharge data entered into the model was collected from three stream gaging sites, the USGS gage at MWD Crossing (11066460), the City of Rialto wastewater treatment plant (discharged through the Rialto Channel), and RIX (see Figure 1 for locations). Discharge data was collected during both normal- and zero-RIX discharge operations. Discharge data for all other river cross-sections, was calculated based on interpolating between the stream gaged sites and RIX. Likewise, discharge data for each RIX discharge scenario (Phases 1 to 5) was interpolated between the normal- and zero-RIX discharge scenarios.

Table 1. RIX Discharge to the Santa Ana River Phased Reduction Scenarios

Discharge Scenarios	Year	MGD	CFS
Baseline[1]	2012	34.3	53.0
Phase 1	2015	29.0	44.9
Phase 2	2020	24.8	38.4
Phase 3	2025	20.8	32.2
Phase 4	2030	17.0	26.3
Phase 5	2035	13.4	20.8
Zero[2]	2012	6.1	9.5

For the model, baseline discharge was based on average RIX discharge measured on October 18-19, 2012. Average discharge was approximately 53 cfs.
MGD=million gallon per day; CFS= cubic feet per second.
[2]Zero discharge is based on zero discharge from RIX, but it is assumed the City of Rialto wastewater treatment plant will continue to discharge approximately 10 cfs to the Santa Ana River.

Results

For verification purposes, the updated model discharge results were compared against the previous discharge results in WEI (2013). This was done to ensure consistency and accuracy between model versions. The results are shown in the Table 2 (see Figure 1 for site locations).

Table 2. Discharge Comparison and Verification Between WEI's Santa Ana River HEC-RAS Models

Site Location	October 2012 HEC-RAS Modeled Discharge (Normal-RIX Discharge)	December 2013 HEC-RAS Modeled Discharge (Normal-RIX Discharge)
Site 001	45.93	45.52
Site 002	36.67	36.67
Site 003	62.48	62.47
MWD Xing	52.40	52.46

The objectives of this analysis were to: 1) update the existing model with the new discharge reduction plan for RIX, 2) extract width, depth, and velocity data at each cross-section for each of RIX's discharge reduction scenarios, and 3) generate a profile view of the depth and velocity distribution for each cross-section. Figures 2A to 2G show the HEC-RAS modeled Santa Ana River velocity, width, and depth between the Rialto Channel and the MWD Crossing for the five plus normal and zero-discharge RIX discharge scenarios. A complete set of the velocity distribution plots for each of RIX's discharge reduction scenarios is included in Appendix A. Velocity distribution tables are also included in Appendix B. The results of this in-depth analysis of the Santa Ana River HEC-RAS model will be utilized by GEI biologists to assist in their habitat utilization analysis of the Santa Ana Sucker.

We appreciate the opportunity to assist in the hydraulic analysis of the Santa Ana River. Please contact me or Mark Wildermuth if you have any questions, comments, or concerns.

Wildermuth Environmental, Inc.

Mark J. Wildermuth, PE
President

Michael A. Blazevic, PG
Senior Scientist II

Enclosures:

Figure 1
Figures 2A to 2G
Appendix A
Appendix B

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Appendix D:

Evaluation of the Phased RIX Flow Reduction Plan on Santa Ana Suckers, Based on Predicted Changes in Physical Habitat in the Santa Ana River from the Rialto Drain to the MWD Crossing

(GEI, July 2014)

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Geotechnical
Environmental
Water Resources
Ecological

Evaluation of the Phased RIX Flow Reduction Plan on Santa Ana Suckers, Based on Predicted Changes in Physical Habitat in the Santa Ana River, from the Rialto Drain to the MWD Crossing

Submitted to:
City of San Bernardino Municipal Water Department
300 North D Street
San Bernardino, CA 92418

Submitted by:
GEI Consultants, Inc.
Ecological Division
4601 DTC Boulevard, Suite 900
Denver, CO 80237

July 2014

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List of Acronyms and Abbreviations

C&A	Chadwick & Associates, Inc.
CEC	Chadwick Ecological Consultants, Inc.
CEQA	California Environmental Quality Act
cfs	cubic feet per second
EIR	Environmental Impacts Report
ERO	ERO Resources Corporation
ft/s	feet per second
GEI	GEI Consultants, Inc.
IFIM	Instream Flow Incremental Methodology
LIDAR	Light Detection and Ranging
MBC	MBC Applied Environmental Sciences
MGD	million gallons per day
MWD	Metropolitan Water District
OCWD	Orange County Water District
PCA	principal components analysis
PCEs	Primary Constituent Elements
PHABSIM	Physical Habitat Simulation System
RIX	Rapid Infiltration and Extraction
SAR	Santa Ana River
SAS	Santa Ana sucker
SAWPA	Santa Ana Watershed Project Authority
SBMWD	San Bernardino Municipal Water Department
SMEA	San Marino Environmental Associates
sq ft	square feet
UAA	Use-Attainability Analysis
USFWS	U.S. Fish & Wildlife Service
USGS	U.S. Geological Survey
WEI	Wildermuth Environmental, Inc.
WUA	weighted usable area
WWTP	Wastewater treatment plant

1.0 Introduction

The City of San Bernardino Municipal Water Department (SBMWD) and the City of Colton are members of a Joint Powers Agency that own and operate the Rapid Infiltration and Extraction (RIX) Facility, which currently provides tertiary municipal wastewater treatment at the RIX facility in the City of Colton. The RIX facility discharges the treated wastewater into the Santa Ana River just downstream of the Rialto Drain (which carries treated wastewater from the City of Rialto's facility) (Figure 1).

Reclaimed water from the RIX facility and the treated wastewater discharged by the City of Rialto into the Rialto Drain are the primary sources of flow in the middle reach of the Santa Ana River during dry-weather conditions. Prior to 1976, flows into this reach of the Santa Ana River typically percolated to the underlying groundwater, leaving much of the reach from E Street in San Bernardino to Mission Boulevard in Riverside dry (Wildermuth Environmental, Inc. [WEI] 2013a). Downstream of Mission Boulevard, flows in the river were usually continuous due to a combination of rising groundwater and discharge from the City of Riverside wastewater treatment plant (WWTP). River discharge became continuous from E Street to Prado dam between 1978 and 1983, due to higher groundwater levels, an increase in wastewater discharge to the river from the earlier San Bernardino and Colton facilities at E Street and La Cadena Avenue locations, respectively, and a wet period during this time. In 1996, the RIX facility began discharging to the Santa Ana River just downstream of the Rialto Drain discharge. Since that time and the accompanying cessation of flows from the older San Bernardino and Colton facilities, the Santa Ana River has generally been dry from E Street downstream to Rialto Drain except during storm events (WEI 2013a).

The City of San Bernardino is evaluating the potential for reuse of a portion of the water currently discharged from the RIX facility to the Santa Ana River (aka: Clean Water Factory Project). Implementation of the proposed Clean Water Factory project would result in phased reductions in discharges to the Santa Ana River from the RIX facility over time through five phases. To evaluate the impacts from the proposed reduced RIX flow on the Santa Ana River and its biota, an Environmental Impacts Report (EIR) is being produced.

This report serves as technical appendix to the EIR, and evaluates the potential impacts to the Santa Ana sucker (*Catostomus santaanae*) from the phased reduction in RIX flow, based on the changes in physical habitat in the Santa Ana River from the Rialto Drain to the Metropolitan Water District of Southern California Upper Feeder Crossing (MWD Crossing) (Figure 1).

For the purposes of the analyses presented in this report, the portion of the Santa Ana River of interest has been evaluated focusing on three reaches (Figure 1), as described in greater detail in Section 2.2.1. The upstream Reach 1 is approximately 2.2 miles long and is from

Rialto Drain downstream to 0.6 miles downstream of Riverside Avenue. The middle Reach 2 is approximately 3.0 miles long and begins 0.6 miles downstream of Riverside Avenue and continues downstream to 0.63 miles past Mission Boulevard, where rising groundwater was. The downstream Reach 3 is approximately 3.5 miles long and begins 0.63 miles downstream of Mission Boulevard and continues downstream to just below the MWD Crossing.

Delineation of these reaches allows for better characterization of changes in habitat for relatively distinct reaches of the Santa Ana River in terms of biological, physical, and hydrologic characteristics.

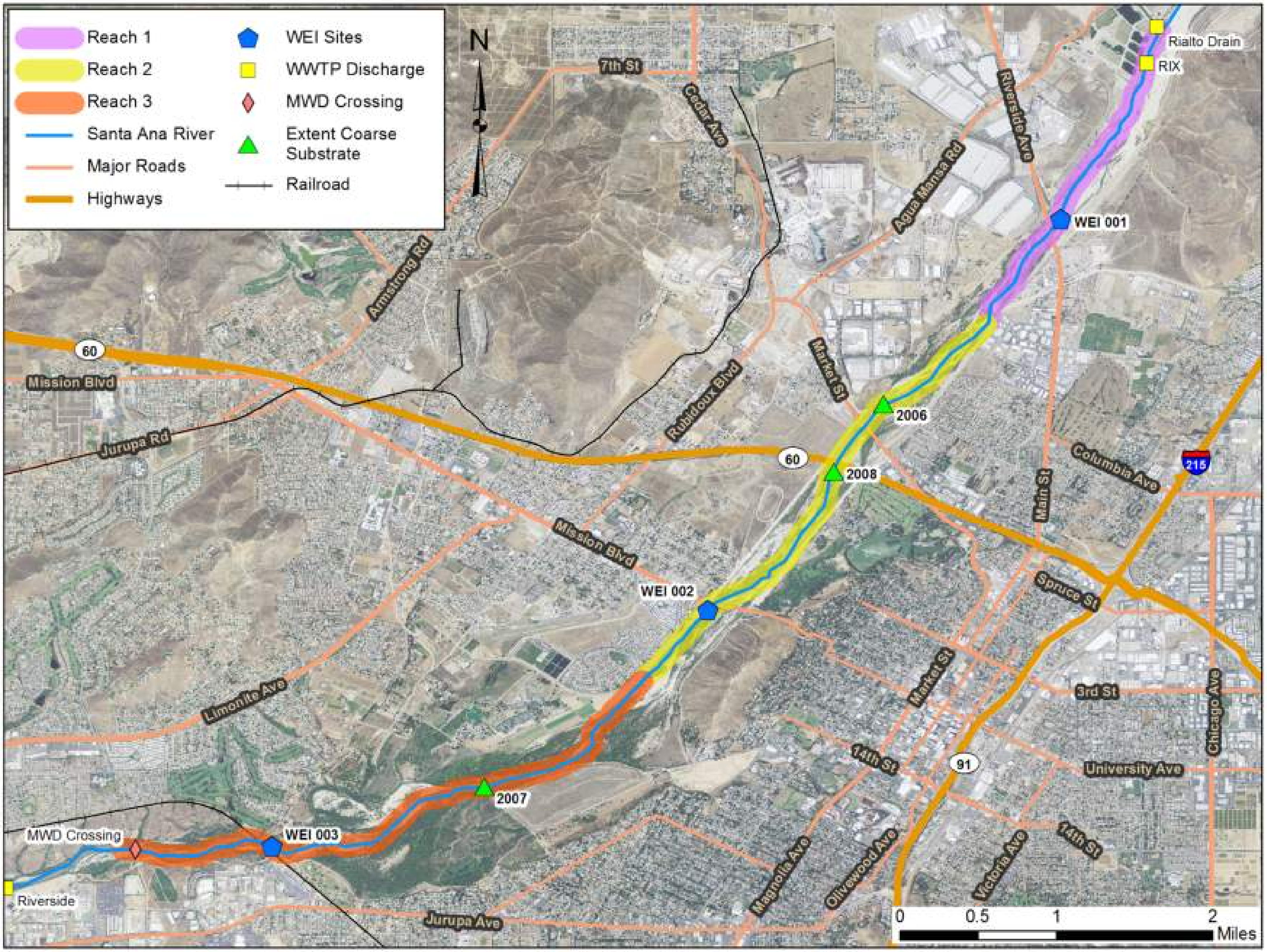

Figure 1: Map depicting study reaches, WEI sites, and points of interest along the Santa Ana River.

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2.0 Affected Environment

2.1 Historic Analyses

2.1.1 Historic Hydrological Analysis of Dry-Weather Discharge Conditions

A historic hydrologic analysis of dry-weather discharge conditions in the Santa Ana River from E Street (City of San Bernardino) to River Road (City of Chino) for the time period between 1938 and 1977 was also completed (WEI 2013a). This study area is larger than the current analysis area discussed above, with E Street approximately 4.5 miles upstream of the current RIX facility and River Road approximately 11.5 miles downstream of the MWD Crossing (Figure 2). The objective of the historic study was to characterize the Santa Ana River's historical hydrology in terms of wet and dry reaches, dry-weather discharge variability, discharge top width and flow depth variability, and surface water and groundwater interaction (WEI 2013a). A number of resources were used to characterize the historical hydrology of the Santa Ana River, including historical aerial photographs, topographic maps, surface water, wastewater, imported water, and groundwater discharge data (WEI 2013a).

The overall climate of the Santa Ana River watershed during the 1938 to 1977 study period was predominantly dry, with a few short wet periods (WEI 2013a). During a dry period from 1945 to 1976, the Santa Ana River was typically dry from E Street downstream to Mission Boulevard. Downstream of Mission Boulevard, river discharge was usually continuous due to rising groundwater and discharge from the City of Riverside WWTP (WEI 2013a). Santa Ana River discharge became continuous from E Street to Prado Dam sometime between 1978 and 1983 due to high groundwater levels, groundwater discharge to the river, an increase in wastewater discharge, and a wet period during these years (WEI 2013a).

Flow, width, and depth for 11 years (1938, 1948, 1952, 1953, 1954, 1959, 1962, 1966, 1967, 1974, and 1977) were estimated during the 1938 to 1977 study period for six segments within the study area – E Street to RIX, RIX to Riverside Avenue, Riverside Avenue to Mission Boulevard, Mission Boulevard to Van Buren Boulevard, Van Buren Boulevard to Hamner Avenue, and Hamner Avenue to River Road (WEI 2013a). Three of these segments approximately correspond with reaches delineated in the current hydrological modeling section: RIX to Riverside Avenue corresponds approximately with Reach 1, Riverside Avenue to Mission Boulevard corresponds with Reach 2, and Mission Boulevard to Van Buren Boulevard corresponds to Reach 3 (Figure 2).

Results of the WEI historical analysis (WEI 2013a) are summarized by individual years in Table A-1 of Appendix A. The average flow, average width, and average maximum depth values of all years with data for each segment are presented below in Table 1. Maximum depths were evaluated for the historical data to be consistent with the current hydrology modeling that produces maximum depths.

Historical flow estimates for the Santa Ana River were largely limited to above and below Riverside Narrows and demonstrated substantially greater flows below Riverside Narrows (Table 1), defined as at the MWD Crossing by WEI for this analysis (WEI 2013a).

Table 1: Minimum, maximum, and average flow, width, and maximum depth for six stream segments of the Santa River for 11 years from 1938 to 1977.

	Average Flow (cfs)				Average Width (ft)				Maximum Depth (ft)			
Segment	**Min**	**Max**	**Ave**	**N**	**Min**	**Max**	**Ave**	**N**	**Min**	**Max**	**Ave**	**N**
Above Riverside Narrows												
E St to RIX	1	42	19	11	0	90	46	6	0	0	0	2
RIX to Riverside (Reach 1)					0	66	25	9	0	1.6	0.7	9
Riverside to Mission (Reach 2)					0	28	10	9	0	1.8	0.6	8
Mission to Van Buren (Reach 3)					17	50	37	8	0.94	2.9	1.9	8
Below Riverside Narrows[1]												
Van Buren to Hamner	33	126	60	11	19	100	60	10	0.33	2.6	1.2	10
Hamner to River Rd					52	121	79	9	0.37	0.8	0.5	9

[1] Riverside Narrows was defined as at MWD Crossing, which is located within Reach 3.

The historical analysis of the Santa Ana River identified several differences in hydrological characteristics between the reaches upstream and downstream of Mission Boulevard. Dry river segments were identified upstream of Mission Boulevard in 1948, 1952, 1953, 1959, 1962, 1974, and 1977 (WEI 2013a). In contrast, continuous discharge was identified downstream of Mission Boulevard and the river was typically wider and a single channel that shifted, compared to the narrower, shifting, and often braided channel upstream of Mission Boulevard (WEI 2013a). River top width ranged from 0 to 180 feet (ft) upstream of Mission Boulevard and 0 to 240 ft downstream of Mission Boulevard (WEI 2013a). Depth also differed between these reaches, with depth ranging between 0 and 2 ft with most depths less than 0.5 ft upstream of Mission Boulevard, and depth ranging from 0 to 3 ft with most depths less than 1 ft downstream of Mission Boulevard (WEI 2013a). Overall, the Santa Ana River was dry more often, narrower, and shallower upstream of Mission Boulevard than downstream of Mission Boulevard, during the historical time period of 1938 to 1977.

Figure 2: Historical map depicting study reaches, historical fish sampling sites, and points of interest along the Santa Ana River.

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2.1.2 Historic Pre-RIX Santa Ana Sucker Sampling

Prior to the RIX discharge, little quantitative data on the distribution and abundance of Santa Ana sucker in the Santa Ana River were available until surveys were conducted in 1991 as part of a use-attainability analysis (UAA) (C&A 1992; CEC 1996). During these surveys, Santa Ana suckers were found to be absent just upstream of Reach 1, rare in Reach 2 near Mission Boulevard, and abundant in and just downstream of Reach 3 near the MWD Crossing (C&A 1992). Several sites were sampled throughout the Santa Ana River in March, June, August, and November of 1991 (C&A 1992) (Figure 2). Two sites upstream of the current RIX discharge location were frequently dry, consistent with the historic hydrology report (WEI 2013a), and contained no fish when water was present (Table 2). Several sites were sampled in the just upstream of the current RIX facility and near Mission Boulevard, and suckers were absent except at the site just upstream of Mission Boulevard, which had a low density of suckers present in March, but none present in June, August, or November.

Table 2: Santa Ana sucker density (fish/mile) for sites sampled on the Santa Ana River in 1991 (C&A 1992). Sites are arranged from upstream to downstream. CWTF and RWTF stand for Colton and Rialto Water Treatment Facilities, respectively. NS = Not Sampled.

Site	March	June	August	November
SAR 1	0	Dry	Dry	Dry
SAR 2	0	0	Dry	Dry
Highway 215 Crossing				
SAR 3 (upstream of CWTF) (upstream of Reach 1)	0	0	0	0
SAR 4 (upstream of RWTF) (immediately upstream of Reach 1)	0	0	0	0
SAR5 (upstream of Mission Blvd) (current Reach 2)	19	0	0	0
SAR 6 (at MWD Crossing) (current Reach 3)	0	1,519	522	284
SAR 7 (downstream of Van Buren Blvd)	0	0	5,087	674
SAR 8 (upstream of Hamner)	NS	0	29	15
SAR 9	NS	0	0	NS
SAR 9A	NS	NS	NS	0

Species richness increased during the 1991 surveys at the next two sites downstream (C&A 1992), near the MWD Crossing and downstream of Van Buren Boulevard, and Santa Ana sucker abundance, although highly variable among months, was similar at these sites to the Santa Ana sucker abundance post-RIX discharge, at the Riverside Avenue site from 2005 through 2011 (see discussion below, Section 2.3.3). These sites with increased Santa Ana sucker abundance during the 1991 surveys correspond with Reach 3 (Figure 2), where rising groundwater is present, as it has been historically (WEI 2013a). Santa Ana suckers were rare at the next site sampled downstream, just upstream of Hamner Avenue, and were absent at two sites further downstream, upstream of Prado Dam. Surveys were also conducted in 1991 that showed Santa Ana suckers utilized the tributaries located near the Riverside Narrows in Reach 3 as spawning/nursery streams (C&A 1992).

Additional sampling was conducted in 1995 and 1996, and the majority of Santa Ana suckers collected in the main stem were again collected from sites located immediately downstream of tributaries in the Riverside Narrows reach as was the case in 1991, suggesting these tributaries were providing important habitat for the Santa Ana sucker in this main stem reach at that time (CEC 1996). Habitat characteristics commonly associated with Santa Ana sucker habitat requirements (as described in Section 2.3.3), including coarse substrates and algae growth, were more commonly observed in 1991 and 1996 in tributaries than in the main stem river (CEC 1996).

Habitat characteristics were evaluated during the 1991 surveys from E Street (above the current RIX discharge) to just above Prado Dam, and were generally described as poor, with shifting sand substrate throughout the study area (C&A 1992). Somewhat higher habitat ratings of fair were given for sites in the vicinity of the current RIX discharge, due to the relative lack of channelization, improved riparian vegetation, and improved substrate characteristics near the Rialto Drain inflow. During that study, water quality was poor in the reach from E Street downstream to Mission Boulevard, and it was suggested that chlorine and un-ionized ammonia could have been a limiting factor for fish populations in this reach (C&A 1992). This reach was also largely channelized and flood control operations resulted in the lack of woody riparian vegetation (Appendix B, Photo B-2, Photo B-4, and Photo B-6) (C&A 1992). Coarser substrates, which are now prevalent in this reach post-RIX discharge, were not common in 1991.

Santa Ana suckers were most abundant in 1991 near the MWD Crossing where shifting sand substrate was dominant, as it is currently (Photo B-7 and Photo B-8), and especially in areas around vegetated islands, where scour on the edges of these islands provided some small areas of deeper habitat with vegetative cover and small amounts of gravel mixed with sand (S. Canton, personal observation).

The historic hydrologic analysis conducted by WEI (2013a) suggests that Reach 3, encompassing the Riverside Narrows and portions downstream, has consistently provided enough water to support fish populations. And while not specifically matching the date-range of the historical hydrologic analysis, the pre-RIX fish sampling in the 1991 UAA indicates this same reach supported abundant populations of Santa Ana suckers.

2.2 Hydrology

2.2.1 Hydrologic Analysis of Dry-Weather Discharge Conditions for the Santa Ana River

WEI conducted a hydraulic analysis of the Santa Ana River from SBMWD's RIX facility in the City of Colton to the MWD Crossing in the City of Riverside (WEI 2013b) (Figure 1). The objective of the hydraulic analysis was to determine the relationship between the current dry-weather discharge and river depth along the Santa Ana River between the RIX facility and

MWD Crossing. This portion of the river is of specific interest due to the presence of the Santa Ana sucker.

Given the variability in the biological, physical, and hydrological characteristics of the Santa Ana River, the results in this report were analyzed for three separate reaches of river as modeled by WEI (Figure 1). The upstream reach (Reach 1) is approximately 2.2 miles long and is from Rialto Drain downstream to 0.6 miles downstream of Riverside Avenue. The middle reach (Reach 2) is approximately 3.0 miles long and begins 0.6 miles downstream of Riverside Avenue and continues downstream to 0.63 miles past Mission Boulevard, where rising groundwater was identified. The downstream reach (Reach 3) is approximately 3.5 miles long and begins 0.63 miles downstream of Mission Boulevard and continues downstream to just below the MWD Crossing. Establishment of these reaches allows for characterizing changes in habitat for relatively distinct reaches of the Santa Ana River in terms of biological, physical, and hydrologic characteristics.

To estimate depths in the Santa Ana River for a range of RIX discharges in dry-weather conditions, a gradually-varied, steady-flow, Hydrologic Engineering Centers River Analysis System (HEC-RAS) hydraulic model was developed by WEI (2013b). River channel geometry data were used in the model and collected for the study area, using Light Detection and Ranging (LIDAR) remote sensing, acquired in October 2012 during both normal RIX operation and during a scheduled RIX maintenance shutdown. Discharge data were collected at three sites in the study reach at intervals prior to, during, and after RIX shutdown to aid in calibrating the model. Discharge data for the Santa Ana River and for the RIX and City of Rialto WWTPs were also used to develop the model. Details of the hydraulic model development are presented in WEI (2013b). Simulations from the resulting hydraulic model provided estimates of depth, wetted width, and average water column velocity at transects from the Rialto Drain to just downstream of the MWD Crossing for RIX discharge scenarios between 0 and 60 cubic feet per second (cfs) in dry-weather conditions.

Reach 1 in the study area near Riverside Avenue currently supports a greater number of suckers than farther downstream. Accordingly, RBF Consulting identified this reach as a specific “reach of interest” and requested more detailed data be collected to characterize the stream channel. As a result, a total of 24 additional river channel cross-sections were surveyed by WEI on February 18 and February 21, 2013, along this 2.1-mile stretch of the Santa Ana River (WEI 2013b). These cross sections were used to better characterize the stream channel during hydraulic modeling for Reach 1, supplementing the trapezoidal geometry used below the water line for the remaining transects downstream. The WEI (2013b) report focuses on results from this upstream reach of interest. However, the model also produced results for the entire study area, and these results are used in characterizing changes to stream habitat with reductions in RIX discharge for the entire study area from RIX downstream to the MWD Crossing. The locations of all transects in the study area are depicted in Figures 8a, 8b, and 8c of the WEI hydraulic modeling report (WEI 2013b).

Depth, width, and discharge measurements collected before, during, and after RIX shutdown by WEI (2013b), provide a range of values for "Normal" RIX discharge to "Zero" RIX discharge at several sites throughout the study area (Table 3). Depth, width, and discharge measurements were collected at three sites on the Santa Ana River; Site 001 (at Riverside Avenue), Site 002 (at Mission Boulevard), and Site 003 (at Railroad Crossing [approximately 1 km upstream of the MWD Crossing]) (Figure 1). Discharge measurements were also available for RIX, City of Rialto WWTP, and the U.S. Geological Survey (USGS) gage at MWD Crossing.

2.2.2 General Findings of the Hydraulic Modeling

The Santa Ana River was characterized to be a losing stream from Rialto Drain downstream to approximately 0.63 miles downstream from Site 002 (at Mission Boulevard), a gaining stream from this point downstream to approximately Site 003 (at Railroad Crossing), and a losing stream downstream to the MWD Crossing (WEI 2013b). Reductions in depth from "Normal" to "Zero" RIX discharge were similar at sites 001 and 002, but wetted width was reduced more substantially at Site 002 than at Site 001 (Table 3). Reductions in depth, width, and discharge were least at Site 003 (WEI 2013b). Flow increased approximately 30 cfs between sites 002 and 003 under both "Normal" and "Zero" RIX discharges, which can be explained by rising groundwater input and tributaries (e.g., Sunnyslope Channel, Lake Evans Outlet) in this reach (WEI 2013b).

Table 3: Measured maximum depth, wetted width, and discharge for sites on the Santa Ana River and the Rialto Drain for "Normal" and "Zero" RIX discharge scenarios (WEI 2013b). Sites 001, 002, and 003 are located in reaches 1, 2, and 3, respectively.

Site Name	Maximum Depth (ft)			Wetted Width (ft)			Discharge (cfs)		
	Normal RIX	Zero RIX	% Change	Normal RIX	Zero RIX	% Change	Normal RIX	Zero RIX	% Change
RIX/Rialto Drain	--	--	--	--	--	--	62.5[a]	9.5[b]	-85
Santa Ana River									
Site 001	1.45	0.72	-50	19	13	-32	45.5	5.2	-89
Site 002	1.33	0.60	-55	47	7	-85	36.7	7.7	-79
Site 003	1.07	0.82	-23	63	63	0	62.5	37.3	-40
MWD Crossing	--	--	--	--	--	--	52.4	32.6	-38

[a] Represents the combined flow from RIX and Rialto Drain.
[b] Represents zero RIX flow and 9.5 cfs from Rialto Drain.

2.2.3 Additional Hydraulic Modeling

To better assist GEI Consultants, Inc. (GEI) with assessing the potential impacts of flow modifications to the physical habitat and Santa Ana suckers found along this reach of the Santa Ana River, WEI used the original hydraulic model (WEI 2013b) to develop a supplemental model that produced more detailed depth and velocity data in the context of the Clean Water Factory project's phased RIX reduction plan (WEI 2014). The same transects and basic calibration data (e.g., flow measurements before and during RIX shutdown) were used, except instead of producing one maximum velocity and average water column velocity per transect, a series of depths and velocities across each transect were produced. This allowed integration of Santa Ana sucker habitat utilization data on depth and velocity to be compared more directly to instream hydrology (current and projected), as detailed below. Modeling was conducted for flows corresponding to the baseline flow and the five phases of the proposed RIX reduction (Table 4). A more detailed discussion of the additional hydraulic modeling is available in WEI (2014).

Table 4: RIX, Rialto, and Santa Ana River flow at the upstream end of the study area (Model SAR Input) for baseline flow and the five phases of RIX reduction.

RIX Scenario	Baseline	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
RIX (cfs)	53.0	44.9	38.4	32.2	26.3	20.8
Rialto (cfs)	9.5	9.5	9.5	9.5	9.5	9.5
Model SAR Input (cfs)	62.5	54.4	47.9	41.7	35.8	30.3

2.3 Biological Environment

A literature review was conducted to summarize available data on the general riparian habitat conditions in these reaches of the Santa Ana River, as well as the ecology and population dynamics of Santa Ana suckers. Much of the information available on the ecology and life history characteristics of Santa Ana suckers in the Santa Ana River since the initiation of RIX discharge are available from studies conducted by San Marino Environmental Associates (SMEA) as part of the Santa Ana sucker Conservation Program (SMEA 2003, 2004, 2006, 2009, 2010a, 2010b, 2011). Limited information is available regarding the population characteristics of Santa Ana suckers prior to the initiation of RIX discharge, with the majority of that information available from a Use Attainability Analysis (UAA) in 1991 (Chadwick & Associates, Inc. [C&A] 1992) and a report that described the status of Santa Ana suckers in 1996 (Chadwick Ecological Consultants, Inc. [CEC] 1996).

2.3.1 Riparian Habitats

MBC Applied Environmental Sciences ([MBC] 2000) conducted an assessment of riparian vegetation from the RIX facility downstream to Highway 60, which includes Reach 1 and approximately half of Reach 2, and found riparian vegetation in the river is composed primarily of mixed willow woodland, with a significant invasion of *Arundo donax* in various segments of the river. This is consistent with an earlier study, where *Arundo donax* also dominated the reach from the railroad bridge (approximately 0.7 mile upstream of the MWD Crossing) downstream to about 1 mile downstream of Hamner Road (ERO Resources Corporation [ERO] 1991). *Arundo donax* is a non-native aquatic plant and is considered a primary threat due to its ease of establishment, ability to alter the hydrology of the system through bank stabilization, and excessive use of water (Bell 1997; U.S. Fish & Wildlife Service [USFWS] 2012). There are no management plans that address the threat of *Arundo donax*; however, some removal efforts have been conducted in the Santa Ana River (USFWS 2011).

Riparian vegetation surveys were conducted in 1991 on the Santa Ana River throughout the study area of the current project, from San Bernardino to the Prado Flood Control basin, and indicate changes compared to the current riparian condition. Streambank vegetation in 1991 was dominated by low herbaceous vegetation with an average maximum height of overstory from 5 to 8 ft from just upstream of Interstate 15 downstream to approximately 5,000 ft downstream of Mission Boulevard, where taller mixed woody vegetation, became more common (ERO 1991). The current riparian condition in this reach is relatively well developed with conditions in this segment more typical of the mixed woody vegetation (Photo 1 and Photo 3) than of the less developed and shorter herbaceous vegetation present during the early 1990s (Photo 2 and Photo 4).

Photo 1: Santa Ana River (just upstream of Riverside Ave) – October 2012

Photo 2: Santa Ana River (just downstream of Riverside Ave) – March 1992

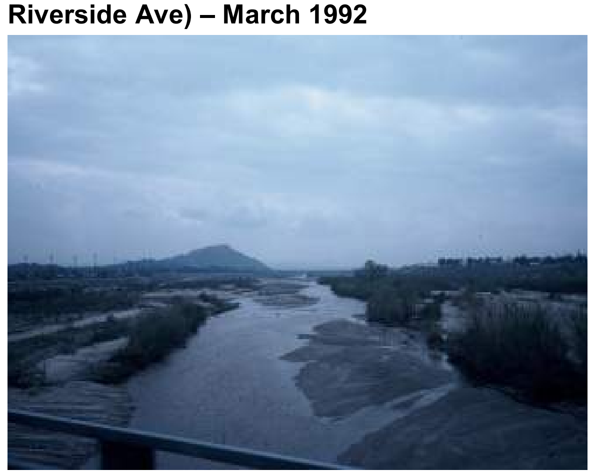

Photo 3: Santa Ana River (downstream of Mission Blvd) – October 2013

Photo 4: Santa Ana River (upstream of Mission Blvd) – Nov. 1991

Precipitation is extremely variable from year to year, subjecting the riparian vegetation to drought, flooding, scouring and deposition. Flooding, although infrequent, can be severe. Storms in 1938, 1962 and 1969 tore out vast stands of woodland vegetation. The native riparian species comprising the vegetation along this reach of the Santa Ana River are adapted to a regime of variable precipitation and disturbance.

MBC (2000) classified the riparian vegetation as a transitional plant community, forming an ecotone or zone of overlap between the instream habitat and adjacent coastal sage scrub upland area bordering the river, with three separate zones: 1) an active zone closest to the stream that is most subject to disturbance from flooding, which is characterized by willow and cottonwood; 2) a border zone that is less subject to disruption but has a reliable source of water, which is characterized by larger trees of willow and cottonwood, and a well-developed understory with considerable plant diversity; and 3) an outer zone on higher terraces that are only occasionally subjected to flooding but where trees such as sycamore take advantage of the higher water tables and grow to very large size. The three zones do not occur in all reaches, but are most representative in the half mile stretch of river bracketing the RIX facility (MBC 2000). In areas where the river is constrained by levees, the third zone lacks native vegetation. MBC (2000) concluded that the reduction of discharge from the RIX facility would likely result in a small decline in willow woodland vegetation. However, they also concluded that any anticipated decline in riparian habitat as the result of water diversion from RIX will likely be minor compared to the impacts due to flooding and scouring during flows following large storm events.

2.3.2 River Dynamics

Although this report focuses on the changes in flow from RIX during dry-weather periods, the Santa Ana River is highly dynamic and is in part structured by periodic flood events (Figure 3). Most of the flood events from 1970 through 2012 occurred during the typical "rainy season" from November through March, with only five events outside this time frame. Nearly 80% of the annual maximums of the mean daily flows were less than 5,000 cfs;

however, from 1970 through 2012, the maximum mean daily flow exceeded 5,000 cfs in 9 of the 43 years (Figure 3). In December 2010, the mean daily flow was 17,400 cfs, which was the second highest value since 1970. This high flow resulted in a significant restructuring of the channel in all three reaches of the current study. In Reach 1, the active channel was moved to the opposite (south) bank, resulting in a relatively wide channel with little bank vegetation as shown through Google Earth imagery (Figure 4). Images of this same reach in 2012 and 2013 (Figure 4), as well as photo documentation (Appendix B, Photo B-1 and Photo B-3), illustrate the rapid regrowth of bank vegetation.

Google Earth imagery also illustrates the movement of the channel, and the removal and regrowth of bank and island vegetation in reaches 2 and 3, following storm events (Appendix C). Smaller flood events likely also result in restructuring of the channel, although to a lesser degree.

Thus, although this report focuses on the changes in flow from RIX during dry-weather periods, these low-flow changes must be viewed in context of the dynamic nature of the river, and variability associated with the restructuring of the channel following storm events.

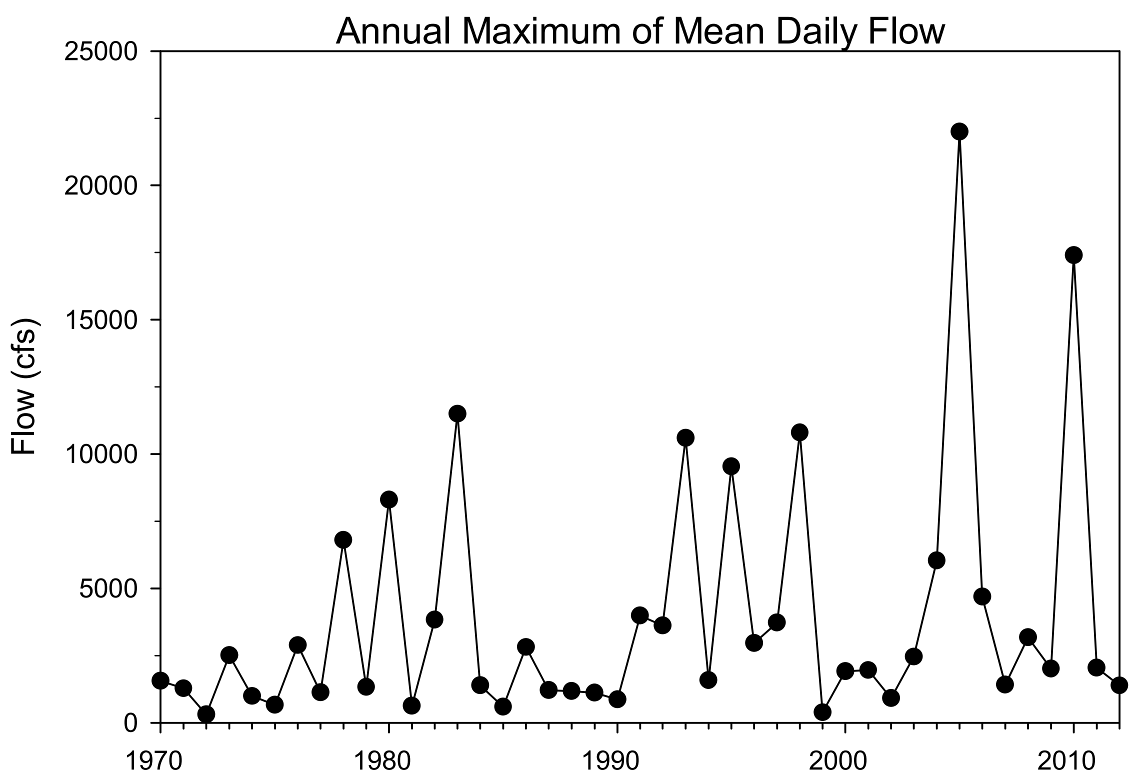

Figure 3: Annual maximum of the mean daily flow for the Santa Ana River at MWD Crossing (USGS Gage 11066460).

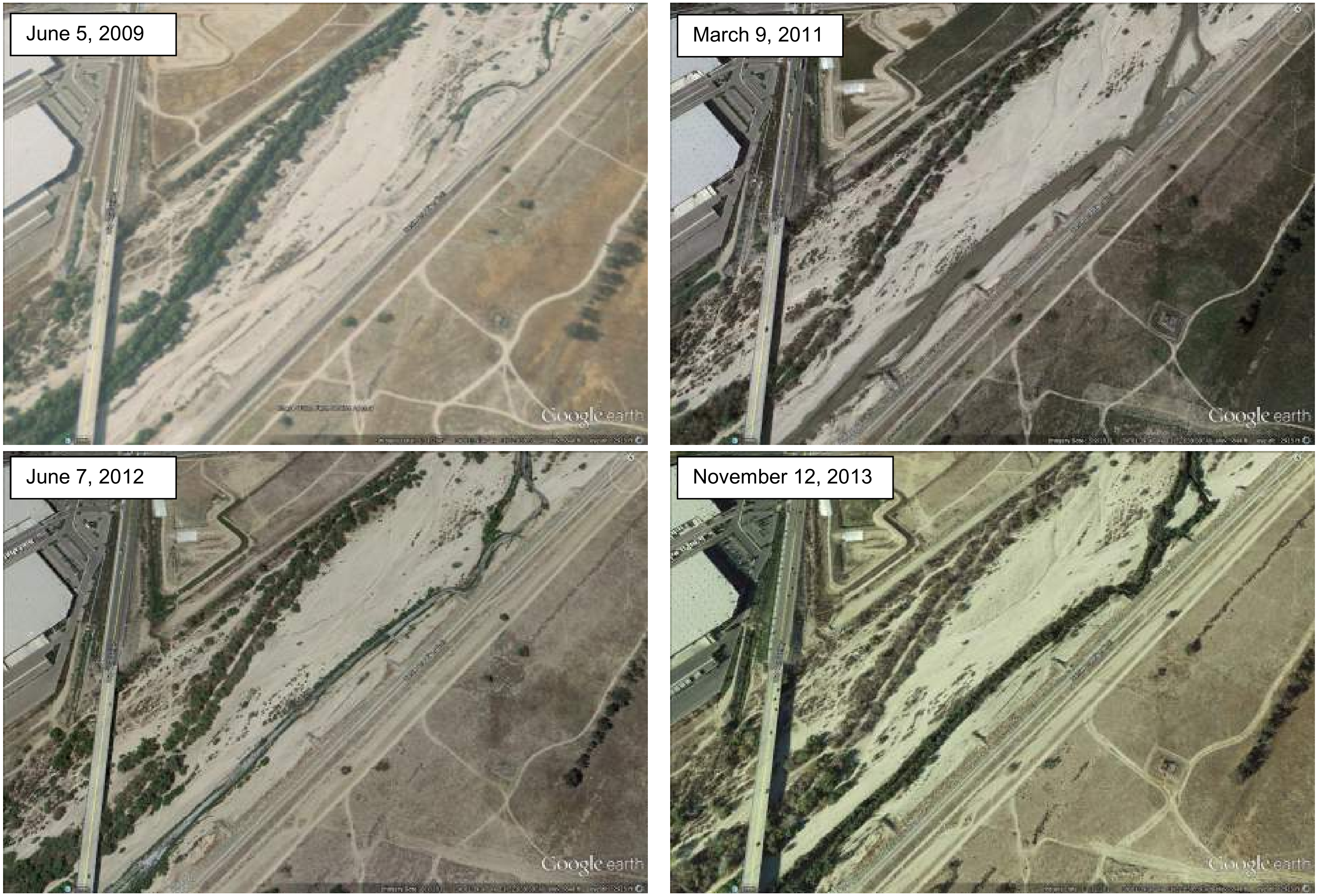

Figure 4: Santa Ana River at Riverside Avenue, before and after December 2010 flood event.

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2.3.3 Santa Ana Sucker Ecology and Habitat

The Santa Ana sucker is listed as a federally and State of California threatened fish species. The Santa Ana sucker is a small (generally less than six inches in length), short-lived member of the sucker family. Santa Ana suckers are associated with the main stem Santa Ana River and several tributaries, and have been found from the Rialto Drain downstream to Imperial Highway in Orange County. Currently, the largest population has been identified in the area from Rialto Drain downstream to Mission Boulevard, particularly in the area near Riverside Avenue, although similar sized populations were found further downstream in the Riverside Narrows reach historically (C&A 1992; CEC 1996). Santa Ana suckers are sporadically found near Imperial Highway, including a specimen collected as recently as 2011 (GEI 2011).

Santa Ana suckers can tolerate a wide variety of stream conditions, inhabiting flowing streams with varying water depths, velocities, and streambed substrates (Moyle and Yoshiyama 1992). Specific tolerance to water quality parameters have not been determined for the Santa Ana sucker; however, they are typically most abundant in unpolluted, clear water, at temperatures less than 72ºF (Moyle 2002; USFWS 2012). The continued presence of the Santa Ana sucker in the Santa Ana River suggests they can also tolerate seasonally elevated temperatures and turbidity. Optimal stream conditions include gravel and cobble substrates, which may also be mixed with sand, as well as a combination of shallow (riffles) and deep (pools and runs) habitats (SMEA 2003; USFWS 2011). In-stream or overhanging bank-side riparian vegetation, provide shade and cover for Santa Ana suckers, but becomes less important for adults when deeper habitat is present (Moyle 2002; USFWS 2011).

Much of the acquired knowledge of the Santa Ana sucker must be put in the context of the limited geographical extent of their populations. Smith (1966) characterized the Santa Ana sucker as typically found in small to medium sized streams, usually less than 7 meters wide, with depths ranging from a few centimeters to over a meter. Spawning occurs between mid-March and early-July, with peak activity in April (Moyle 2002). Eggs hatch within 360 hours. Fry utilize shallow, slow water along the downstream edge of flow obstructions, such as vegetation or sand bars, with silt deposits from the reduced rate of flow, and move into deeper water as they mature (SMEA 2003).

Several authors indicate that the preferred substrate for Santa Ana suckers are coarse substrates (i.e., gravel and cobble) with occasional suckers found on sand or mud substrates (Moyle 2002; SMEA 2003; Thompson et al. 2010). SMEA (2003) demonstrated that both juveniles and adults select coarse substrates and may avoid sand substrate in both the Santa Ana River and the upper San Gabriel River drainage. Santa Ana suckers feed primarily on algae and detritus, with small aquatic insects occasionally consumed (Moyle 2002). The preference of gravel and cobble substrate is likely related to it being the primary substrate where algae grow (USFWS 2011). Accordingly, open areas of shifting sand substrate lack suitable habitat for algae production and therefore, sucker feeding (USFW 2011).

Spawning also requires coarse substrates and takes place over gravelly-riffles where eggs adhere to the substrate (Moyle 2002; SMEA 2003; Thompson et al. 2010). The seasonal abundance patterns of Santa Ana suckers in tributaries (i.e., Sunnyslope Channel, Tequesquite Arroyo, and Anza Park Drain) near Riverside Narrows during sampling in 1991, suggested that they may have historically used tributaries in this reach for spawning (C&A 1992). However, eight tributaries, including Rialto Drain, RIX outlet, Evans Lake Drain, Mount Rubidoux Creek, Tequesquite Arroyo, Sunnyslope Channel, Anza Park Drain, and Hidden Valley Drain, were evaluated as possible reproduction sites by Swift (2001a) and larvae were only collected in Rialto Drain and Sunnyslope Channel (Swift 2001a; SMEA 2003). The seasonal presence of suckers in tributary streams may also be related to the cooler temperatures they provide than in the main stem (Swift 2001a), or the refugia they provide during flood events or possibly from large predators in the main stem (C&A 1992). Spawning was observed on two occasions in Rialto Drain and Sunnyslope Channel in 2001 over medium gravel, approximately 1.6 ft deep, and velocity between 0.66 and 0.79 feet per second (ft/s) (SMEA 2003). Santa Ana sucker fry were observed on several occasions in 2006 in Sunnyslope Channel and Rialto Drain, demonstrating the continued use of these tributaries for spawning (SMEA 2006). Restoration activities were conducted in 2011 and 2012 to enhance habitat and continue to provide access to Sunnyslope Channel, and several Santa Ana suckers have been collected during surveys in these years (Orange County Water District [OCWD] 2012). Main stem Santa Ana River sites were also surveyed for Santa Ana sucker fry a total of 7 times in 2006, and fry were collected only once. No spawning substrate was available where they were collected suggesting they may have drifted from upstream or off-channel tributary locations (SMEA 2006). However, Swift (2001a) collected fry in the main stem and concluded there was significant spawning in the main stem (SMEA 2003).

USFWS (2010) states that historically the upper Santa Ana River, City Creek, Plunge Creek, and Mill Creek were significant contributors of coarse sediment to the downstream, occupied reaches of the river, based on a sediment transport study of the Santa Ana River conducted by Humphrey et. al. (2004). However, currently with Seven Oaks Dam and a settling basin present in Plunge Creek for mining, only City Creek and Mill Creek continue to contribute coarse sediment into the occupied reaches of the Santa Ana River (USFWS 2010). A study is currently being prepared for review by the USGS that evaluates the gravel transport capacity of the main stem Santa Ana River, the effects of Seven Oaks Dam, the importance of tributaries as a source of gravel, and the fate of the gravel in the reach occupied by Santa Ana suckers.

Thompson et al. (2010) characterized the longitudinal changes in substrate over a 30 km reach from the RIX facility downstream to Interstate 15, which encompasses the study area of this low flow study and additional stream length downstream of the MWD Crossing. The proportion of coarse versus fine substrate was characterized every 300 meters of the 30 km reach in 2006, 2007, and 2008. An abrupt transition between coarse substrates upstream and fine substrates downstream was documented in each year; however, the location where the transition occurred was variable among years (Thompson et al. 2010). Continuous coarse substrate extended downstream of the RIX outfall for 4.2 km in 2006, 9.6 km in 2007, and 5.1 km in 2008 (Thompson et al. 2010) (Figure 1). These distances downstream correspond to downstream of Riverside Avenue and upstream of Highway 60 in 2006, approximately halfway between Mission Boulevard and the MWD Crossing in 2007, and at Highway 60 in 2008. These results illustrate the highly dynamic nature of substrate characteristics in reaches 2 and 3 of the study area and also demonstrate that the upstream reach (Reach 1) of the study area near Riverside Avenue has consistently had coarser substrates in recent years. The presence of abundant coarse substrates in the upstream portion of the study area is a relatively new phenomenon, as substrate characteristics were generally described as shifting sand substrates throughout this reach during surveys in 1991 (C&A 1992).

The temporal variability of the substrate characteristics and stream morphology in Reach 2 was evident during site visits in October 2012 and October 2013. From October 2012 to October 2013, vegetation had encroached on the channel from the right bank (looking upstream) into the middle of where the channel was in 2012, restricting flow to one side of the stream, resulting in the wetted width being approximately 50% reduced (Photo 5 and Photo 6). Substrate characteristics changed from mostly sand with some small gravel in 2012 to mostly gravel in 2013 (Photo 7 and Photo 8). Changes in substrate could be related to the restricted width, resulting in more stream power to flush fine sediments and/or the transport of coarse gravels into this reach between October 2012 and October 2013.

Photo 5: Santa Ana River (looking at Mission Blvd) – Oct. 2012 (partial RIX flow reduction)

Photo 6: Santa Ana River (looking at Mission Blvd) – October 2013 (Normal RIX flow)

Photo 7: Santa Ana River (at Mission Blvd) – Oct. 2012 (typical substrate)

Photo 8: Santa Ana River (at Mission Blvd) – October 2013 (typical substrate)

Thompson et al. (2010) also evaluated the statistical relationships between environmental variables and the variability in Santa Ana sucker abundance among sites and years. The best model found a significant, positive relationship with the amount of coarse substrate and discharge explaining 65% of the variability in the abundance of Santa Ana suckers (Thompson et al. 2010). Flow represents the combination of stream depth, width, and velocity, thus any of these variables could drive the relationship between discharge and Santa Ana sucker abundance. Saiki et al. (2007) and Brown et al. (2005) also evaluated the relationship between environmental variables and Santa Ana sucker abundance, but the range of habitat characteristics varied among the three studies. Thompson et al. (2010) concluded based on the three studies together that the relationship between environmental variables and Santa Ana sucker abundance is parabolic, with optimal habitat conditions characterized by a mix of coarse and fine substrate, rates of discharge between approximately 18 and 106 cfs, and mean depth between 0.3 and 1.3 feet.

The Santa Ana River, like other streams in which Santa Ana suckers are found, is subject to periodic and major flooding events, which result in drastic reductions in all fish populations and other aquatic organisms. The sucker is adapted to withstand these events, with high reproductive rates (females can produce up to 16,000 eggs at a time), short generation times (begin spawning at age-1+ years old), and a prolonged spawning period (Greenfield et al. 1970), provided the populations are of sufficient size and survivors are in close enough proximity for recolonization following these events. Greenfield et al. (1970) found that the Santa Ana sucker was able to recolonize the Santa Clara River following a severe flood in 1969 in a single breeding season from a small residual population that survived the flood event. Sampling conducted in the Santa Ana River in 1991, 1995, and 1996 found a lower abundance of Santa Ana suckers in 1995 and 1996 than in 1991, which may have been related to the high peak flows in 1993 and 1995, compared to during the years prior to the 1991 sampling (CEC 1996).

The current distribution of the Santa Ana sucker is limited by dams, extended reaches of no flow, and other impassable structures (Prado Dam, La Cadena drop structure, and Seven Oaks Dam) that preclude further upstream dispersal or migration of fish. The low flow study area addresses the Santa Ana sucker distribution in the middle reach of the river from the Rialto Drain, which is downstream of the La Cadena drop structure, downstream to the MWD Crossing, which is upstream of Prado Dam. The Santa Ana sucker population considered in the study area is an isolated population, due to these impassable structures at the upstream and downstream ends of the study area. The modification, fragmentation, and loss of habitat due to these structures and other factors associated with urbanization and human population growth are considered a significant threat to the recovery of the species (USFWS 2012).

The U.S. Fish and Wildlife Service (USFWS) listed the Santa Ana sucker as threatened on April 12, 2000. On February 25, 2004, USFWS designated 21,129 acres of stream in Los Angeles and San Bernardino counties as Critical Habitat for the sucker. Currently, there are two conservation programs meant to afford the sucker protection, including the Conservation Program for the Santa Ana sucker within the Santa Ana River Watershed (Santa Ana Sucker Conservation Program) and the Western Riverside County Multiple Species Habitat Conservation Program. Both programs are described in detail in the EIR. There is no management program in place in the upper reaches of the Santa Ana River, above RIX, where flood flows and coarse sediments originate.

The Santa Ana Sucker Conservation Program was issued by USFWS on May 17, 2005. On December 2, 2010, the USFWS issued a revision to the Critical Habitat that added an additional 9,331 acres of streams and rivers in Los Angeles, Riverside, and San Bernardino counties that included upstream, unoccupied habitat that is an important source of coarse sediments. This final designation of Critical Habitat also listed several Primary Constituent Elements (PCEs) USFWS states are essential to the conservation of the Santa Ana sucker and, more specifically, allow evaluation of stream reaches for critical habitat designation. The PCEs are listed below with some notes (bulleted items) related to the literature review above.

Primary Constituent Elements

1. A functioning hydrologic system that experiences peaks and ebbs in the water volume that contain sources of water and sediment necessary for all life stages of the species,
    - There is no specific study cited by USFWS addressing this element, other than the fact that the sucker inhabits flowing streams.
2. Stream channel substrate consisting of a mosaic of loose sand, gravel, cobble, and boulder substrates in a series of riffles, runs, pools and sand stream margins,
    - This is consistent with the summary of substrate characteristics cited by USFWS and the literature review above.

3. Water depths greater than 3 cm and bottom velocities greater than 0.01 ft/s,
   - The ranges for depth and velocities utilized by the sucker, as cited by USFWS and in the literature above, are generally well above these values. As such, the values for depth and velocity presented in this element do not appear to be (nor does USFWS state) the "minimum habitat requirements for persistence of the sucker," per se, but rather provide the bare minimum values needed to include wetted areas as having the potential to be designated "critical habitat."
4. Clear or occasionally turbid water,
   - This is consistent with the summary cited by USFWS and the literature review above.
5. Water temperatures less than 86 degrees Fahrenheit,
   - This is consistent with the summary cited by USFWS and the literature review above.
6. Instream habitat that includes a source of food (such as plankton and aquatic invertebrates), and associated aquatic emergent vegetation and adjacent riparian vegetation to provide shading, shelter during high water flows, and protective cover from predators, and
   - This is consistent with the summary cited by USFWS and the literature review above.
7. Areas within perennial stream courses that may be periodically dewatered but that serve as connective corridors between occupied or seasonally occupied habitat through which the species can move when wetted.
   - This is consistent with the characteristics cited by USFWS and the literature review above.

The Santa Ana sucker Conservation Program has been billed as the first step in the overall recovery of the species. The main goal of the conservation program is to be able to enhance and restore sucker habitat by determining what habitat characteristics are important to restore and maintain in order to support a healthy sucker population.

Santa Ana Sucker Population Trends

As part of the conservation program, SMEA conducted annual monitoring of Santa Ana suckers in the Santa Ana River from 2001 through 2011. Monitoring focused on Santa Ana suckers from Riverside Avenue downstream to the MWD Crossing (Table 5). Suckers occur downstream of the MWD Crossing, but abundance is lower and fish are scattered (SMEA 2011). Data were collected at Riverside Avenue (Reach 1), Highway 60 (Reach 2), and Mission Boulevard (Reach 2) during each year of the monitoring period and at the MWD Crossing (Reach 3) in 2010 and 2011 (Figure 1).

Table 5: Santa Ana sucker density (fish/mile) at three monitoring sites from 2001-2011 and two years of monitoring at the MWD Crossing. Data from SMEA (2011).

Site	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Riverside Ave	209	756	805	644	1,579	1,689	1,561	3,445	880	2,108	3,718
Highway 60	2,639	2,736	1,545	3,235	16	0	1,625	322	528	0	772
Mission Blvd	1,432	2,350	1,014	32	16	0	0	580	16	64	595
MWD Crossing	--	--	--	--	--	--	--	--	--	853	70
Average (w/ MWD)	1,427	1,947	1,121	1,304	537	563	1,062	1,449	475	724 (756)	1,695 (1,364)

The USFWS 5-Year review of the Santa Ana sucker (USFWS 2011) and the Recovery Outline for the Santa Ana sucker (USFWS 2012) reference SMEA (2009, 2010a), and state that over the 10-year period surveyed (2001 – 2010), there was a decline in density and abundance of Santa Ana sucker at all locations surveyed. However, with the addition of the more recent data collected in 2011, it appears that while the total average density of Santa Ana sucker varied substantially through 2010, average density recovered in 2011 to a density similar to what was observed during the first year of monitoring in 2001 (SMEA 2011) (Table 5).

Figure 1 in SMEA (2011) depicts a decreasing trend in the overall average density of Santa Ana sucker, incorporating the MWD Crossing data in the average ("average line" of Table 5). However, this trend is not statistically significant regardless of whether the new MWD Crossing monitoring site data for 2010 and 2011 are included (as done in SMEA 2011) (R^2 = 0.08, p = 0.409) or not (R^2 = 0.08, p = 0.399) (Figure 5). Considering the sampling locations individually, a significant increasing trend in Santa Ana sucker density over time was present at Riverside Avenue (R^2 = 0.58, p = 0.006), a significant decreasing trend was present at Highway 60 (R^2 = 0.47, p = 0.019), and an overall decrease in Santa Ana sucker density but not a significant trend was observed at Mission Boulevard (R^2 = 0.36, p = 0.052) (Figure 5).

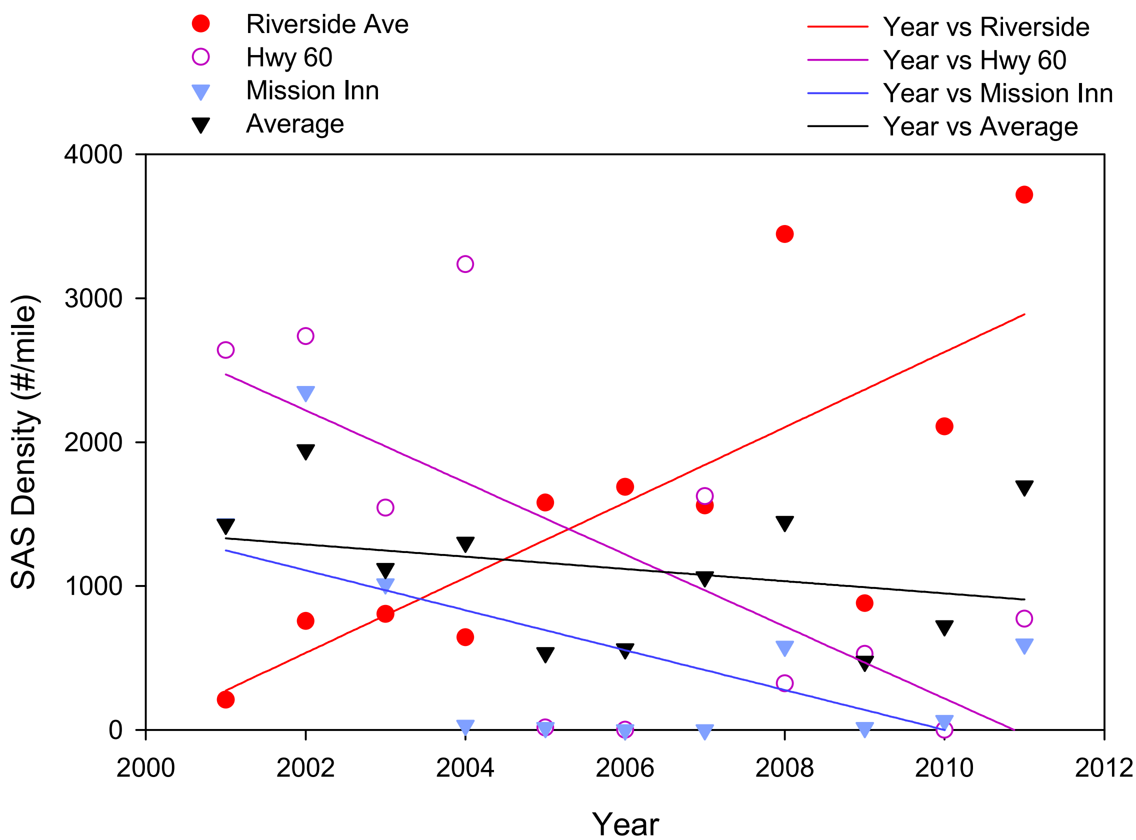

Figure 5: Santa Ana sucker density (fish/mile) for three sites and the overall average density on the Santa Ana River. Lines represent linear regression relationships for each site and for average density. Data from SMEA (2011).

The SMEA monitoring results illustrate that Santa Ana sucker density has been highly variable over the monitoring period, with overall density similar between 2011 and 2001 when monitoring began. Thus, population declines suggested by USFWS for the 10-year time period (2001-2010) have not actually occurred when evaluating all data, especially when the 1991 UAA data noted earlier are considered. Frequent fluctuations in numbers of suckers between periods of low and high abundance are characteristic of Santa Ana sucker populations due to the unpredictable fluvial system they inhabit (CEC 1996). Both winter flood events and summer drought may cause catastrophic decreases (Greenfield et. al. 1970).

It is important to note that this variability has been observed in the absence of any substantial changes in RIX flows, as proposed for the five phases being evaluated herein. When combined with the pre-RIX population data noted earlier, this indicates the Santa Ana suckers represent a highly resilient population.

The Santa Ana sucker population has shifted from being most abundant at the downstream sites (i.e., Highway 60 and Mission Boulevard) from 2001 through 2004 to being most abundant at the upstream Riverside Avenue site in the remaining years from 2005 through 2011 (Table 5 and Figure 5). This trend of a shift in the population upstream becomes even more apparent when considering the data collected in the early 1990s pre-RIX, when suckers were virtually absent upstream of the MWD Crossing site (C&A 1992). The shift in Santa Ana sucker density from the MWD Crossing to near Riverside Avenue is likely a result of improved water quality and habitat over time in the Riverside Avenue reach compared to during the pre-RIX time period, which is at least, in part, a result of the RIX discharge.

Substrate Composition Trends

USFWS (2012) also cite work by Thompson et al. (2010) and state that surveys of gravel and cobble throughout the Santa Ana River indicate that the available suitable habitat for successful breeding and feeding are in decline. However, there is no evidence of reduced coarse substrate availability during recent times. Thompson et al. (2010) illustrate the dynamic nature of substrate in the Santa Ana River, including its relationship to Santa Ana sucker abundance; however, they do not claim a decline in coarse substrate abundance or habitat availability. As noted earlier, coarse substrate extended downstream of the RIX outfall for 4.2, 9.6, and 5.1 km in 2006, 2007, and 2008, respectively (Thompson et al. 2010). These data do not indicate a declining trend in coarse substrate availability, nor are declining trends in coarse substrate apparent for the three sites sampled annually by Thompson et al. (2010) from 2003 through 2008 (Figure 6).

In fact, the abundance of coarser substrates in the upper reaches is a relatively new phenomenon, as shifting sand substrates were dominant throughout the study area during surveys in 1991 (C&A 1992). The presence of water near Riverside Avenue, along with coarse substrates and well-developed riparian vegetation (Photo 9) compared to the frequently dry channel, with sand substrate and little to no riparian vegetation in this reach prior to RIX discharge (Photo 10) suggests that suitable Santa Ana sucker habitat has actually increased since the early 1990s. Additional photos comparing pre- and post-RIX instream habitat conditions can be found in Appendix B.

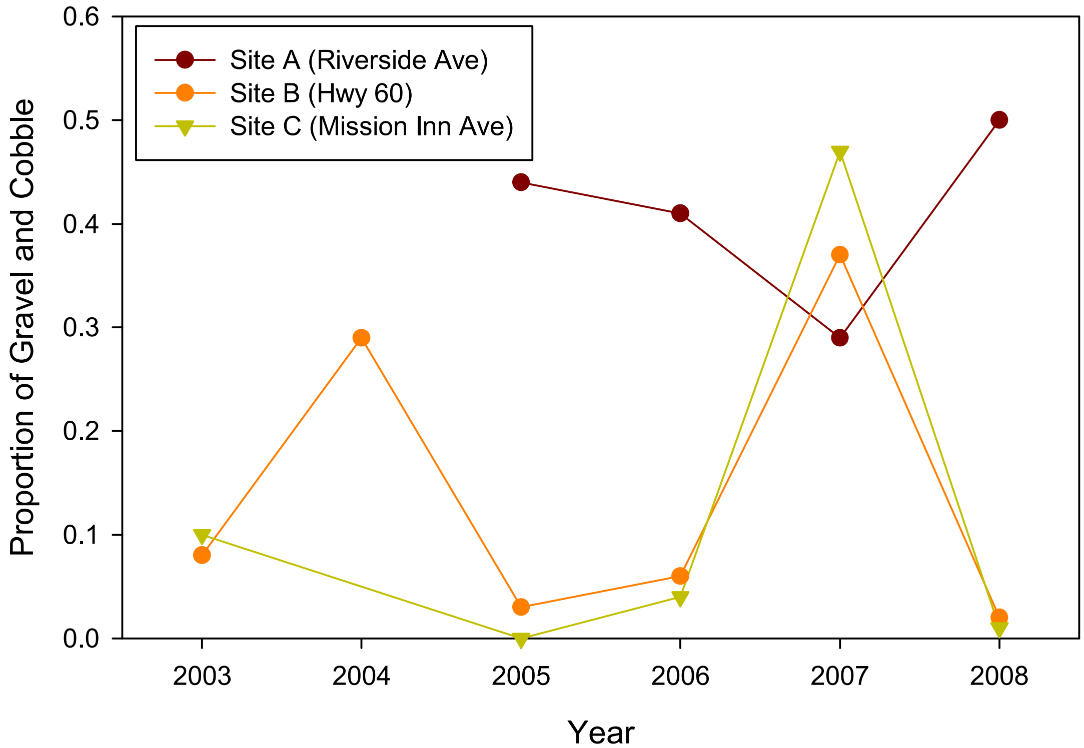

Figure 6: Proportion of gravel and cobble substrates at three sites on the Santa Ana River from 2003 through 2008 (data from Table 2 of Thompson et al. 2010).

Photo 9: Santa Ana River (looking upstream from Riverside Ave) – Oct. 2013 (Normal RIX discharge)

Photo 10: Santa Ana River (looking upstream from Riverside Ave) – March 1992 (Pre-RIX)

3.0 Methods for Evaluation of Proposed Flow Changes

The evaluation of the proposed changes in RIX flow presented in this report were assessed in terms of changes to hydraulic and channel conditions and concurrent changes in habitat availability. These analyses were conducted separately, but are discussed together in terms of the potential impacts to Santa Ana suckers. All model results were analyzed for three separate reaches of river (Figure 1):

- Reach 1, from Rialto Drain downstream to 0.6 miles downstream of Riverside Avenue;
- Reach 2, from 0.6 miles downstream of Riverside Avenue to 0.63 miles past Mission Boulevard; and
- Reach 3, from 0.63 miles downstream of Mission Boulevard to just downstream of the MWD Crossing.

3.1 Hydraulic Analysis

Results from the hydraulic model were first used to describe the predicted changes in the depth, velocity, and wetted width for the three reaches of the Santa Ana River as flows are reduced from baseline through the five phases of RIX reduction, using model results from WEI (2014). The maximum depth, wetted width, and average water column velocity were calculated for each transect, and the minimum, maximum, and average values of all transects in each reach are presented for the various flow scenarios. For each metric, the percent change from baseline was then calculated for the five phases of RIX reduction.

3.2 Habitat Availability Analysis

In an attempt to quantify the potential impacts to the Santa Ana sucker from the phased reductions in flows, a method was needed to synthesize the flow-related changes in habitat characteristics with biological requirements of the Santa Ana sucker. As described in the affected environment section, several studies have attempted to characterize habitat conditions used by the Santa Ana sucker, including Brown et al. (2005), Saiki et al. (2007), Thompson et al. (2010), and the habitat utilization studies of SMEA (2003, 2004).

These studies have made some efforts to describe habitat associations for depth, velocity, and substrate with locations where suckers have been found. However, they have primarily provided the range of values for which these habitat variables have been associated with suckers, and broad comparisons of these habitat variables among sites with varying abundance of suckers within the Santa Ana River and other streams (Brown et al. 2005; Saiki et al. 2007; Thompson et al. 2010). No efforts have been made in those prior studies to specifically quantify if "preferred" values are within the range of conditions noted, or to quantify how the amount of "useable" habitat varies with changes in flow in the Santa Ana River. This is the focus of this Low Flow Study.

As such, an approach consistent with the Physical Habitat Simulation System (PHABSIM) was used to more quantitatively evaluate Santa Ana sucker useable habitat for the different phases of flow reduction. This was accomplished using Santa Ana sucker habitat utilization data (SMEA 2003, 2004) as well as mountain sucker habitat utilization data (Rempel et al. 2012) as a surrogate to represent Santa Ana sucker utilization in shallower habitats, such as in Reach 3, and the expanded WEI modeling data (WEI 2014), as described below.

3.2.1 Hydraulic Component

PHABSIM is a component of the Instream Flow Incremental Methodology (IFIM) (Bovee 1982) and is used for evaluating the effects of changes in flow on fish habitat availability in streams. In this case, the hydraulic component was modeled by WEI using HEC-RAS to produce depth and average water column velocity values, for multiple sub-sections located along a transect, for multiple transects in the study area (WEI 2014). The area between transects was also estimated for each sub-section, by multiplying the width for each sub-section along the transect, by the length. Lengths were estimated by dividing the total reach length by the number of transects, giving the same length for each transect, and resulting in each transect weighted equally within the three reaches. Thus, each sub-section along each transect had a modeled depth, average velocity, and surface area for the baseline flow and the five phased RIX reduction flows.

3.2.2 Habitat Utilization Component

Habitat availability and habitat utilization relationships for depth, bottom velocity, and substrate were developed for use in PHABSIM modeling for juvenile and adult Santa Ana suckers using data collected by SMEA (2003, 2004). Habitat availability was described based on 1,068 point measurements, while habitat utilization data were based on 252 juvenile sucker and 161 adult sucker observations for the two years combined (SMEA 2003, 2004). Fish were observed by crawling upstream using a viewing tube without disturbing them, markers were placed where fish were observed, and habitat type, substrate, depth, and bottom velocity were measured at each fish location. The number of suckers reported by SMEA may represent more than one sucker at an observation, not individual observations (Dr. Baskin, personal communication). When combined, these observations were used to determine utilization curves, as described below (SMEA 2003, 2004).

PHABSIM is often utilized to evaluate hydraulic output against data that represents what fish "prefer" (i.e., habitat suitability curves based on "preference"). These preference curves are generally based on measures of habitat utilization versus habitat availability, using co-located data. While availability data were collected (Appendix A, Table A-2 through Table A-4), these data were collected using different methodology than the utilization data, resulting in the inability to calculate preference curves for the Santa Ana sucker (e.g., some depths were "utilized" that had zero "availability"). Thus, for this analysis, habitat suitability curves were based on "utilization", which simply represent the depths, bottom velocities, and substrates suckers were observed using.

Five sites from Riverside Avenue to Mission Boulevard were sampled over two years by SMEA (2003, 2004), and the percentage of juvenile and adult suckers within defined depth, bottom velocity, and substrate categories were reported for each site (Appendix A, Table A-5 through Table A-10). Because the data were reported as the total number of suckers observed, which would likely be more than the individual number of observations where suckers were found (because of schooling), all five sites were averaged together to increase sample size, resulting in average depth, bottom velocity, and substrate utilization relationships for the entire reach for juveniles and adults. Utilization relationships were standardized to 1.0 by dividing each percentage value by the largest value of the categories. The resulting depth, bottom velocity, and substrate relationships were then smoothed to account for irregularities based on small sample sizes and the expected biology of the Santa Ana sucker (Figure 7 through Figure 12).

To ensure that the depth, velocity, and substrate utilization relationships used to model habitat were appropriate, the relationships were compared to published curves for other sucker species, including a previously developed general, combined juvenile and adult white sucker curves (Twomey et al. 1984) and curves for several life stages of mountain sucker, developed from the Fraser River, British Columbia (Rempel et al. 2012) (Figure 7 through Figure 12). Given the differences in the size and ecology between white suckers and Santa Ana suckers, these relationships would be expected to be only relatively similar. Mountain suckers are more similar to Santa Ana suckers in size, ecology, and ancestry; however, the mountain sucker curves were developed in a different river system; thus, they too may be expected to be only relatively similar. No other attempts at developing utilization or preference curves for Santa Ana suckers or other mountain sucker populations have been developed to our knowledge.

3.2.2.1 Depth Utilization Curves

The adult mountain sucker curve (i.e., 3+ years old) (Rempel et al. 2012) and the general juvenile/adult white sucker curve (Twomey et al. 1984) had utilization at depths shallower than where utilization began for adult Santa Ana suckers (Figure 7). For example, based on the SMEA (2003, 2004) data, most adult Santa Ana sucker utilization data did not occur until a depth of 0.94 ft and with maximum utilization at 2.3 ft and greater. Whereas, adult mountain sucker had utilization beginning at approximately 0.27 ft and maximum utilization from 0.98 to 2.62 feet. White suckers had utilization starting at depths greater than 0.5 ft, with maximum utilization between 2.3 and 3.3 ft (Figure 7).

Given that utilization began for other sucker species at depths of 0.5 ft or less, the SMEA Santa Ana sucker data was smoothed, such that utilization began at a depth of 0.6 ft, which was the first indication of some utilization based on the observed data (Figure 7). However, the resulting smoothed Santa Ana sucker curve was developed using data only from reaches 1 and 2 of the study area, which are substantially deeper than in Reach 3 (see Section 4.1.1). Given that Santa Ana suckers still currently reside in Reach 3, and were abundant in this reach pre-RIX discharge, the smoothed Santa Ana sucker curve was averaged with the adult mountain sucker curve, which allows for some utilization at shallower depths, to produce an average relationship for Santa Ana suckers (Figure 7). This average curve incorporates the utilization of deeper habitats in the upper reaches based on the SMEA studies and the ability of Santa Ana suckers to utilize some shallower habitats as has been observed in Reach 3, through the use of the mountain sucker curve as a surrogate.

This decision is further justified given that Saiki et al. (2007) found Santa Ana suckers at an average depth of 0.7 feet. The average depth from Saiki et al. (2007) was based on the depths of where 157 Santa Ana suckers were collected, at the MWD Crossing on the Santa Ana River, over five sampling events from December 1998 to December 1999 (Saiki et al. 2007). While this includes both juveniles and adults, the majority (approximately 62%) of fish measured, based on the histograms presented, were adults. Thus, adults were likely using depths in Reach 3 less than that found by SMEA in reaches 1 and 2. After averaging the smoothed Santa Ana sucker curve with the adult mountain sucker curve, the final depth curve used in the analysis still only results in a utilization of approximately 0.35 for a depth of 0.7 ft (Figure 7), which appears reasonable given the combination of the SMEA (2003, 2004) studies, Saiki et al. (2002) and that Thompson et al. (2010) also concluded optimal mean depth was between 0.3 and 1.3 feet.

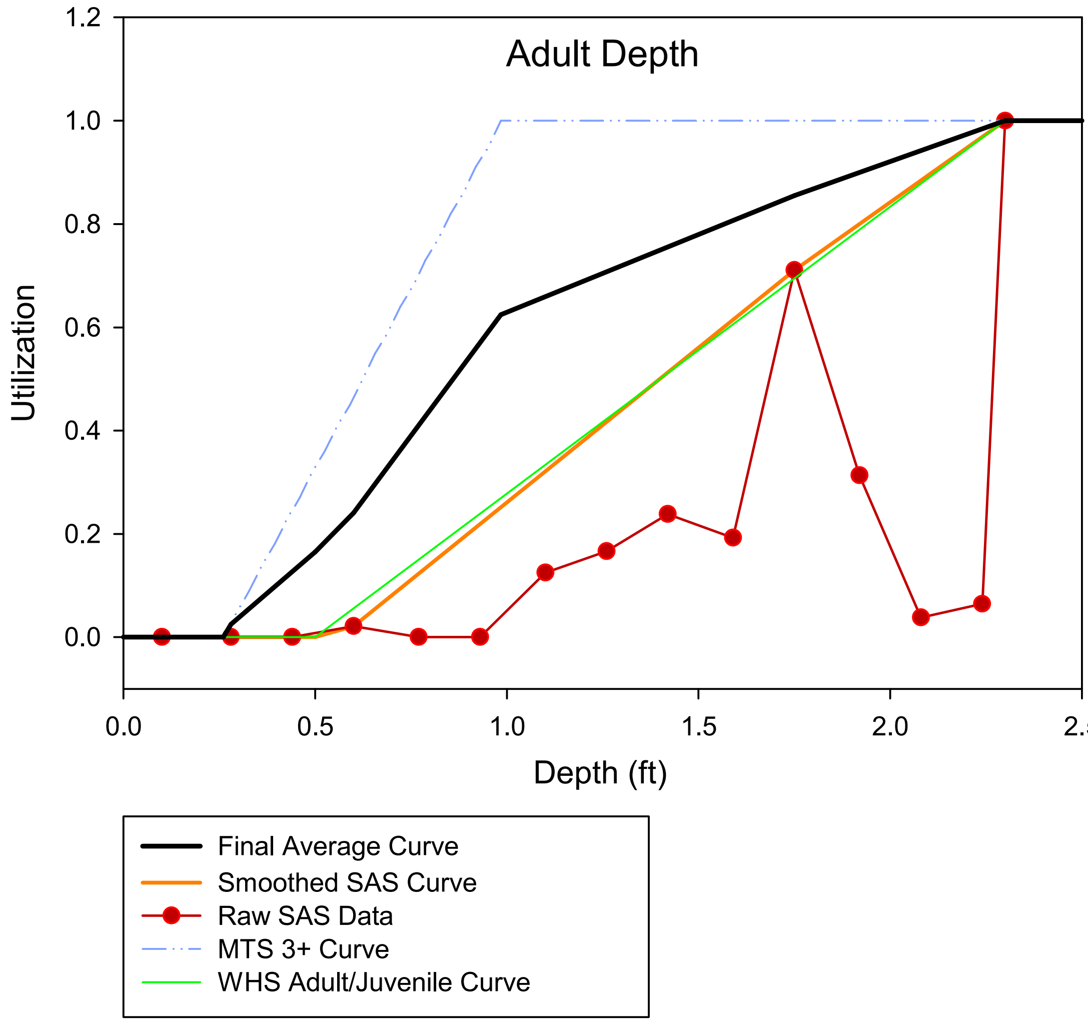

Figure 7: Adult depth Santa Ana sucker (SAS) utilization curves. Raw SAS data represents the average of five sites sampled by SMEA (2003, 2004) and the smoothed SAS curve represents the smoothing of these data. White sucker (Twomey et al. 1984) and mountain sucker (Rempel et al. 2012) curves are provided for comparison. The final average curve represents the average of the mountain sucker 3+ curve and the smoothed SAS curve, and are used for modeling.

Juvenile Santa Ana suckers, based on the smoothed SMEA data (2003, 2004) begin utilizing depth at 0.29 ft, with a maximum utilization at 1.1 ft, and reduced utilization at deeper depths (Figure 8). Juvenile mountain suckers (i.e., ages 0+ and 1/2+) utilized shallower depths than juvenile Santa Ana suckers, based on the smoothed SMEA data (2003, 2004); however, relationships were relatively similar and no other studies were available to indicate that utilization of juvenile Santa Ana suckers should occur at shallower depths than shown in the SMEA (2003, 2004) data. Thus, the smoothed SMEA (2003, 2004) data were used for the analysis and no averaging to mountain sucker relationships was conducted.

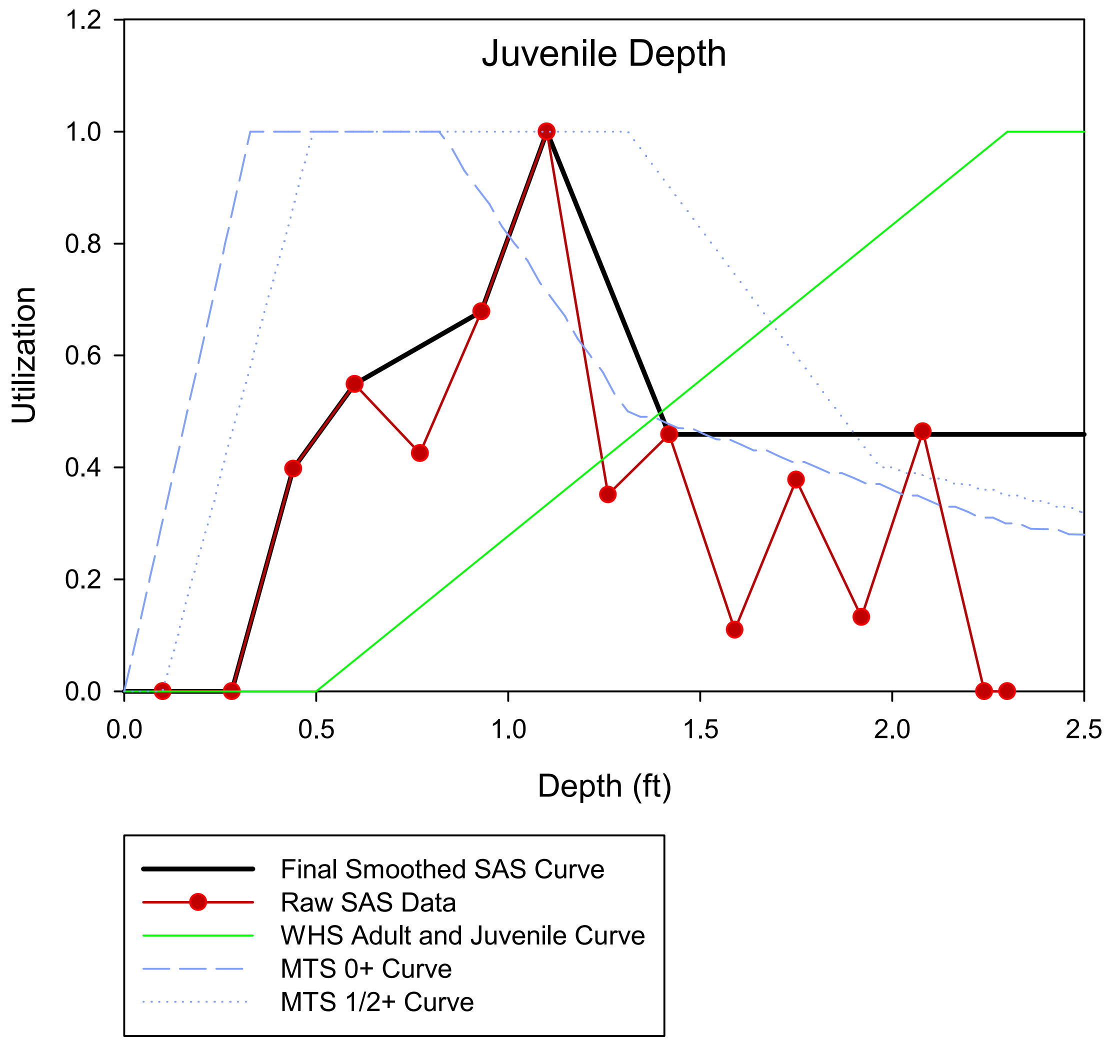

Figure 8: Juvenile depth Santa Ana sucker (SAS) utilization curves. Raw SAS data represents the average of five sites sampled by SMEA (2003, 2004) and the final smoothed SAS curve represents the data used for modeling. White sucker (Twomey et al. 1984) and mountain sucker (Rempel et al. 2012) curves are provided for comparison.

3.2.2.2 Velocity Utilization Curves

In order to incorporate velocity as a modeling parameter, a conversion was needed to make the bottom velocity utilization data (SMEA 2003, 2004) compatible with the modeled average water column velocity (WEI 2014). Thus, the bottom velocity utilization data was converted to average water column velocity data using the Prandtl-von Karman 1/7th power law equation, provided in the PHABSIM user manual as a formula used by the software for calculating nose velocity (i.e., velocity at the depth the fish resides) for a given depth (USGS 2001). In this case the formula was rearranged to calculate the average water column velocity given the known bottom velocity (i.e., the nose velocity for the Santa Ana sucker, which resides on the bottom). Average water column velocity was calculated for each bottom velocity as:

$$\bar{V} = \frac{V_b}{(1 + \frac{1}{7})(\frac{D_b}{D})^{\wedge}(\frac{1}{7})}$$

Where: $\bar{V}$ = average water column velocity, V_b = bottom velocity, D_b = bottom depth, estimated at 0.1 ft, and D = total depth, estimated as 2.3 ft for adults and 1.1 ft for juveniles, which correspond to the depths where maximum utilization begins for adults and juveniles, respectively. The conversion to average water column velocity from bottom velocity shifts the utilization curve to the right, increasing the velocity, which is appropriate; given that velocity increases moving from the bottom substrate to the water surface (Allan 1995).

The final smoothed, average water column velocity utilization curves were then compared to the mountain sucker (Rempel et al. 2012) and white sucker (Twomey et al. 1984) velocity utilization curves for adults and juveniles (Figure 9 and Figure 10). The adult and juvenile Santa Ana sucker curves demonstrated high utilization at low velocities and decreasing utilization as velocity increased, which was similar to the white sucker utilization curve (Figure 9) and the 0+ mountain sucker curve (Figure 10). The adult (3+) and 1/2+ mountain sucker velocity utilization relationships, showed greater utilization at faster velocities than for Santa Ana suckers and white suckers (Figure 9 and Figure 10). However, given that the general life history of most sucker species is a preference for low velocities, and the Santa Ana sucker relationships were similar to the white sucker and 0+ mountain sucker relationships, the Santa Ana sucker average water column velocity utilization relationships used in this study appear appropriate.

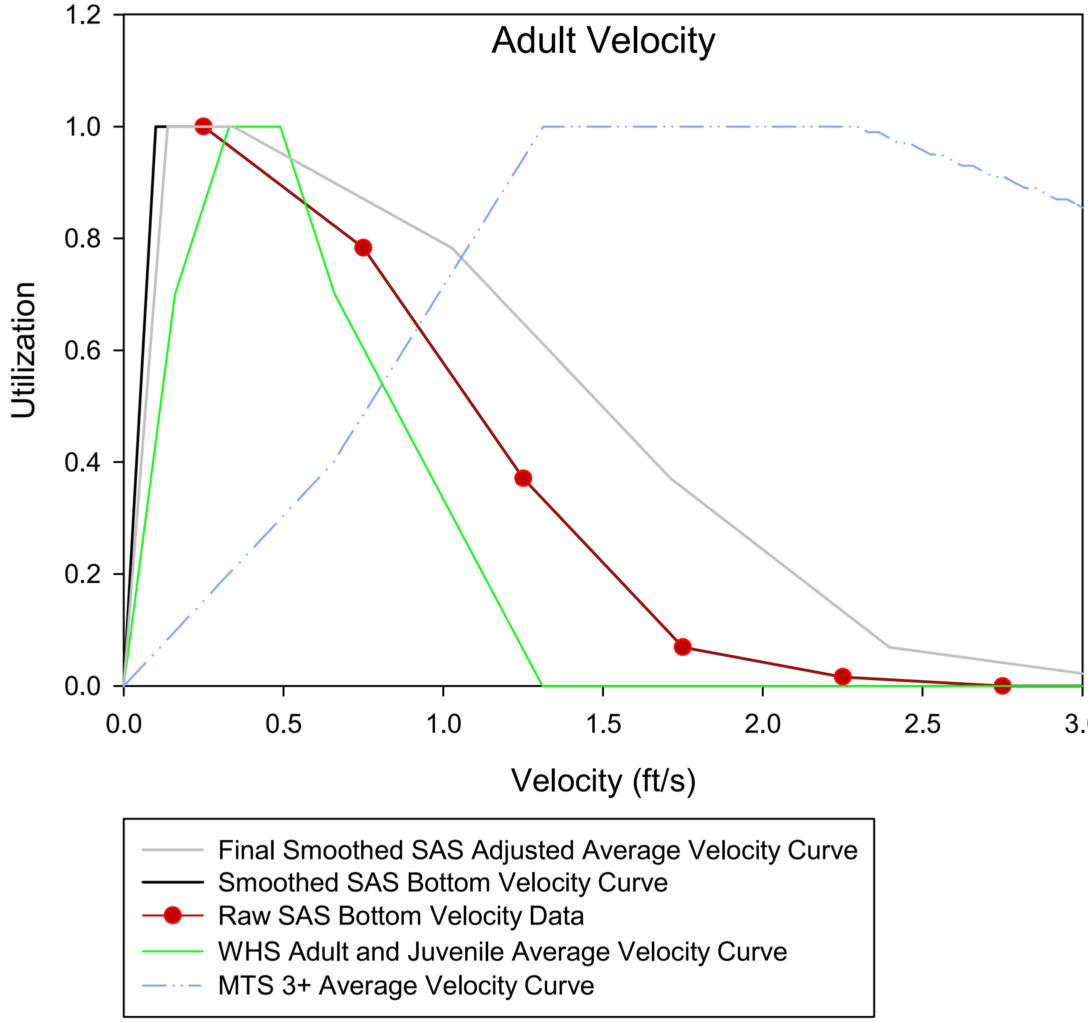

Figure 9: Adult average water column and bottom velocity Santa Ana sucker (SAS) utilization curves. Raw SAS bottom velocity data represents the average of five sites sampled by SMEA (2003, 2004) and the final smoothed adjusted average water column velocity SAS curve represents the data used for modeling. White sucker (Twomey et al. 1984) and mountain sucker (Rempel et al. 2012) curves are provided for comparison.

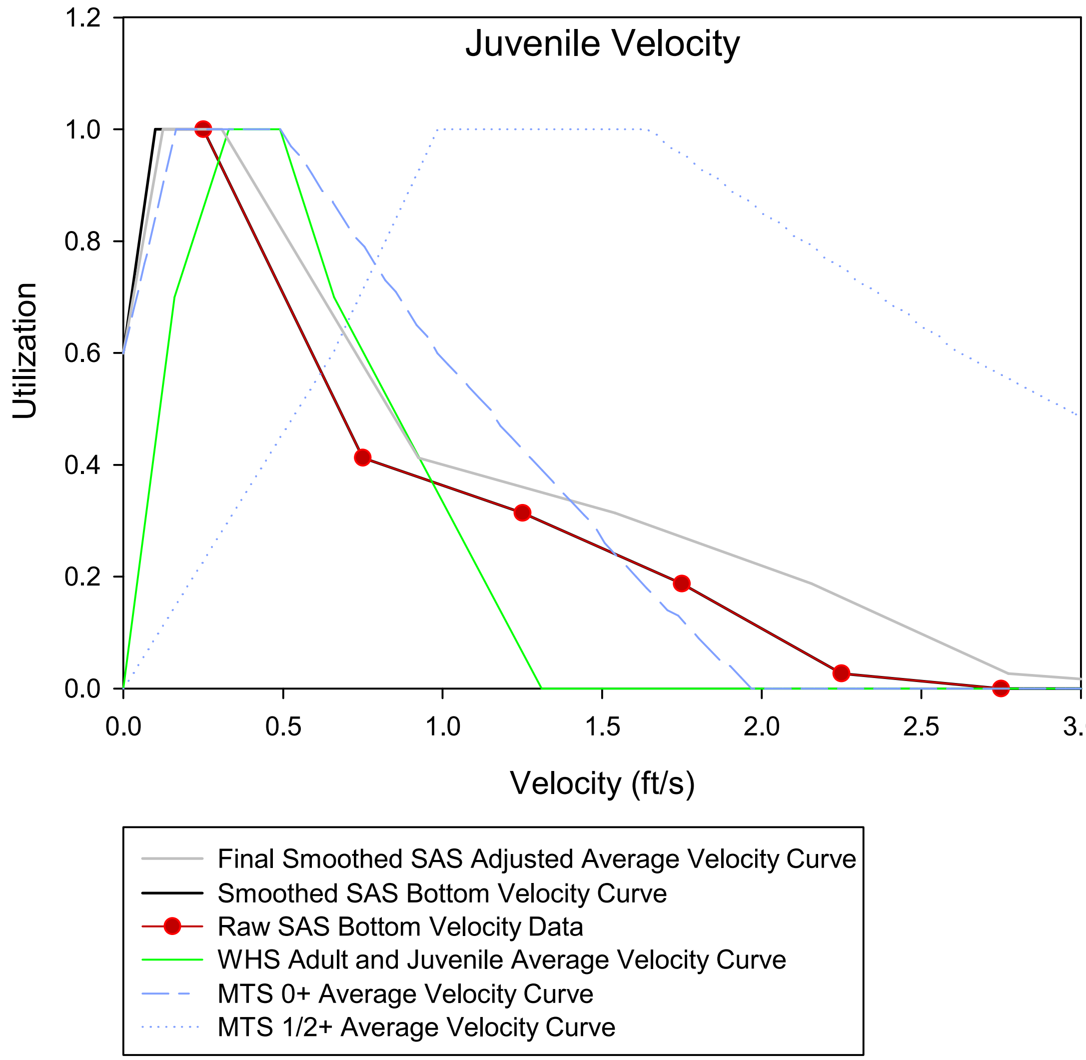

Figure 10: Juvenile average water column and bottom velocity Santa Ana sucker (SAS) utilization curves. Raw SAS bottom velocity data represents the average of five sites sampled by SMEA (2003, 2004) and the final smoothed adjusted average water column velocity SAS curve represents the data used for modeling. White sucker (Twomey et al. 1984) and mountain sucker (Rempel et al. 2012) curves are provided for comparison.

3.2.2.3 Substrate Utilization Curves

Substrate data were also collected by SMEA (2003, 2004) and illustrate the type of substrate being utilized by Santa Ana suckers (Figure 11 and Figure 12). However, the availability of some substrate types were rare compared to others, such that utilization would not be expected for all substrate categories. For example, silt and boulders are rare in the Santa Ana River compared to sand and gravel, and thus would be expected to have low utilization. Similarly, cobble substrate as a category by itself, would be rare in the Santa Ana River, compared to substrate categories that incorporate cobble and sand or cobble and gravel. Thus, some substrate categories would be expected to have low utilization based on the low availability in the river and/or sampling design (i.e., inability to calculate preference and category groupings).

The substrate utilization data for Santa Ana sucker adults and juveniles were compared to the substrate utilization data for mountain suckers (Rempel et al. 2012). Substrate utilization was similar between the two species, with the exception of cobble being utilized by mountain suckers and not Santa Ana suckers, which is a product of the sampling design and differences in the study locations, explained above. In general, adult and juvenile Santa Ana suckers, and mountain suckers, utilized sand/gravel or gravel substrates to a much greater extent than sand substrates (Figure 11 and Figure 12).

Point-specific substrate data were not available for the sub-sections along the transects used in hydraulic modeling. Thus, for the purposes of this analysis, a single value for each reach was applied as the substrate utilization value for all sub-sections along the transect. And since various substrate types would have some use, all substrate utilization values are a fraction of 1. Therefore, the overall effect of incorporating substrate into the analysis is that it scales the reaches according to substrate habitat quality, but has no effect on the changes in habitat availability among the various flows within a reach.

To determine the applicable substrate utilization value for each reach, the findings of Thompson et al. (2010) were examined. Thompson et al. (2010) published the proportion of coarse substrates (i.e., gravel and larger) along the Santa Ana River in 2006, 2007, and 2008, illustrating that the longitudinal location of the transition from coarse to fine substrates was highly variable among years. However, given these data and observations throughout the study reach in 2012 and 2013, the transition from coarse to fine substrates generally appears to occur within Reach 2 and as far downstream as the upper portion of Reach 3.

Thus, for Reach 1, with coarser substrates always present, the utilization values from the sand/gravel and gravel categories were averaged to get the value of 0.92 for adults and 0.70 for juveniles, given that these substrate characteristics are predominant and represent the most utilized substrate types for Santa Ana suckers (Figure 11 and Figure 12). In Reach 2, the average of the values from a blend of coarse and fine substrate utilization data (Figure 11 and Figure 12) were used to represent the transition in substrate size observed in this reach, with a value of 0.67 for adults and 0.48 for juveniles, representing the intermediate substrate conditions that exist in this reach. In Reach 3, since sand substrate is predominant, the utilization values of 0.42 and 0.26 for sand substrate were applied for adults and juveniles, respectively (Figure 11 and Figure 12).

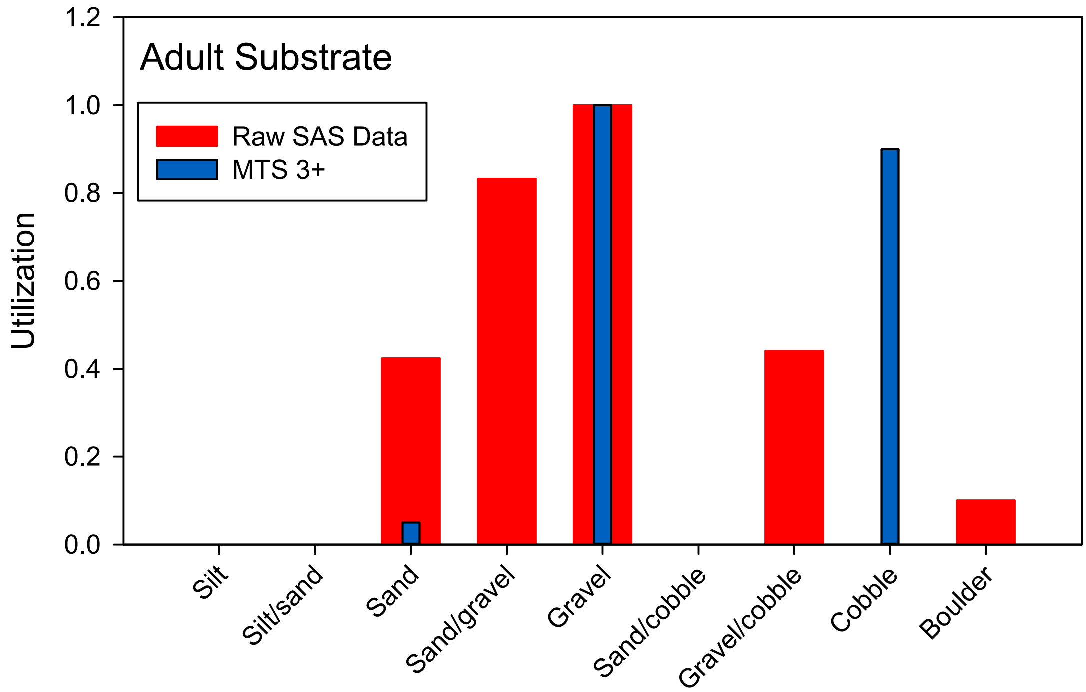

Figure 11: Adult substrate Santa Ana sucker (SAS) utilization data. Raw SAS data represents the average of five sites sampled by SMEA (2003, 2004). White sucker (Twomey et al. 1984) and mountain sucker (Rempel et al. 2012) curves are provided for comparison.

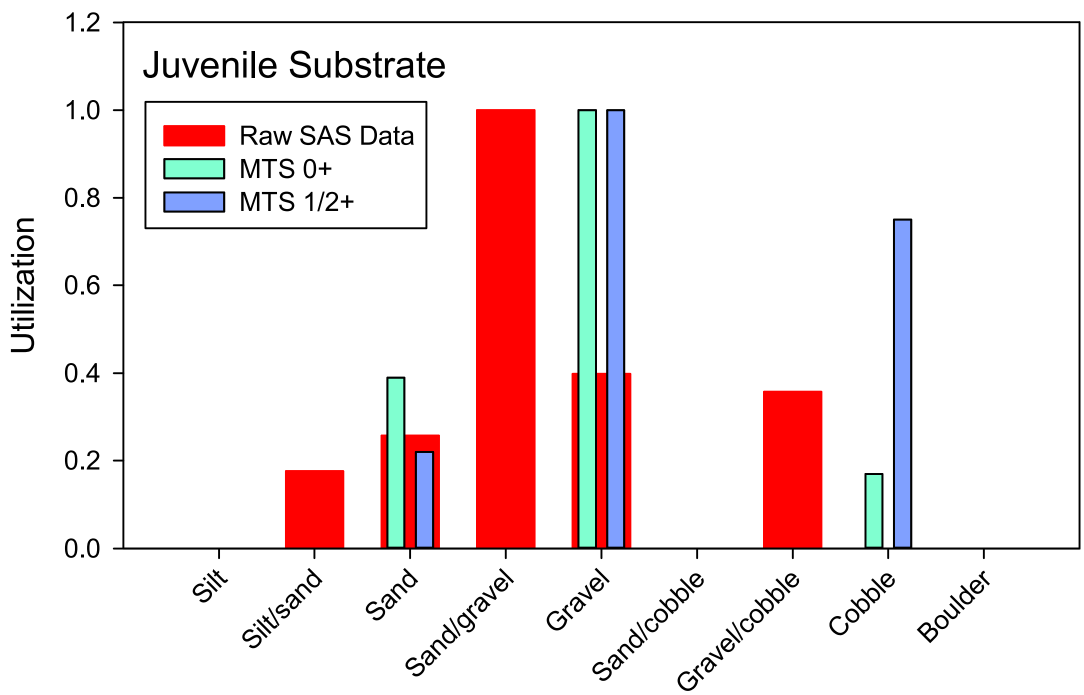

Figure 12: Juvenile substrate Santa Ana sucker (SAS) utilization data. Raw SAS data represents the average of five sites sampled by SMEA (2003, 2004). White sucker (Twomey et al. 1984) and mountain sucker (Rempel et al. 2012) curves are provided for comparison.

3.2.2.4 PHABSIM Model Development

The final step in the modeling process is to combine the smoothed Santa Ana sucker utilization relationships for depth, velocity, and substrate with the modeled hydraulic data to produce the quantity of useable habitat (or weighted usable area [WUA]) (square feet [sq ft]) for juveniles and adults, for the baseline flow and the five phases of RIX reduction. WUA results were interpreted as the total value for the three distinct reaches previously discussed and the effects of flow changes for each phase were determined as a percent change in WUA from baseline conditions. The WUA values were also compared to the total “available” habitat for a reach, which was calculated as the surface area and an assumed utilization value of 1.0 for each component (i.e., a hypothetical total amount of area that could be used).

A step-wise approach was used to evaluate the relative influence of the depth, velocity, and substrate variables on the useable habitat. As such, four separate models were developed; including 1) depth only, 2) depth and substrate, 3) depth and velocity, and 4) depth, velocity, and substrate. Evaluations of each model were conducted separately and results were compared among models, when appropriate. Analysis of the four independent models serves as a “sensitivity” analysis to evaluate the relative influence of the depth, velocity, and substrate variables. Furthermore, given the potential limitations in the velocity modeling noted below, this approach allows for interpretation of the less complex models, while still providing the framework for a full analysis based on depth, velocity, and substrate.

3.3 Impacts Analysis

Once all analyses were conducted, potential impacts to Santa Ana suckers were evaluated for Clean Water Factory’s five phases of reduced RIX flow, based on the modeled changes in hydrologic conditions and as a result changes in the amount of useable habitat (i.e., WUA). Impacts were evaluated based on the 2014 California Environmental Quality Act (CEQA) Statute and Guidelines. As described in Appendix G (CEQA 2014), effects could be described as “No Impact,” “Less than Significant Impact”, or “Potentially Significant Impact”. The category “Less than Significant with Mitigation Incorporated” is not considered herein, as mitigation measures have not yet been determined.

The intensity of effects on Santa Ana suckers (i.e., “No Impact”, “Less than Significant Impact”, and “Potentially Significant Impact”) were evaluated on a case-by-case basis for each stream reach using the PHABSIM output. Specifically, the percent change in WUA from baseline for each phase was considered. Percent change in WUA was available for adult and juvenile life stages. The adult WUA was the most limiting (i.e., greatest decrease in WUA) life stage, and thus was used for determining impacts to be conservative in nature. A “significant effect on the environment”, as described in CEQA (2014), is a “substantial, or potentially substantial, adverse change in any of the physical conditions within the area affected by the project . . . .” [See CEQA Guidelines sec. 15382]. Differences in adult WUA of less than 10 percent would be unlikely to result in any effects to Santa Ana suckers, because a change of less than 10 percent would be undetectable from background natural variability. Thus, changes in adult WUA less than 10 percent were described as “No Impact” (Table 6). Changes in adult WUA between 10 and 25 percent were deemed unlikely to result in “substantial or potentially substantial” changes to Santa Ana suckers, as these changes to the populations would likely be within the range of natural variability, and thus were described as a “Less than Significant Impact”. Changes in adult WUA greater than 25 percent, could have a significant effect on the Santa Ana sucker population, and thus were described as a “Potentially Significant Impact”.

Parameters not included in the PHABSIM modeling, or not included with a high level of detail in the modeling, but are believed to be important habitat characteristics for Santa Ana suckers, are discussed qualitatively, when appropriate. The effects of potential changes to other resources areas (e.g., river geomorphology, water quality, sediment transport, etc.) on the Santa Ana sucker have not been considered herein and will be evaluated in the EIR. Potential effects to other aquatic resources and terrestrial resources will be evaluated in the EIR. Guidelines for determining “No Impact”, “Less than Significant Impact”, and “Potentially Significant Impact” to Santa Ana suckers based on the modeled changes in adult WUA are described in detail in Table 6.

Table 6: Impact designations and intensity descriptions for Santa Ana suckers in the Santa Ana River based on changes in habitat.

Impacts	Intensity Description
No Impact	Changes in adult Santa Ana sucker WUA are predicted to be less than 10%. The proposed action could result in a slight change to the Santa Ana sucker population, but the change would not be of measurable or of perceptible consequence, and would be within natural variability.
Less than Significant Impact	Changes in adult Santa Ana sucker WUA are predicted to be from 10 to 25%. The proposed action may result in a change to the Santa Ana sucker population. The change would potentially be measurable, but not substantial, and likely not outside the range of natural variability.
Potentially Significant Impact	Changes in adult Santa Ana sucker WUA are predicted to be greater than 25%. The changes are predicted to be substantial or potentially substantial, and potentially outside of the historic range of natural variability.

4.0 Evaluation of Proposed Flow Changes – Results and Discussion

Petition to decrease discharge from 36 MGD (55.7 cfs) to 11.9 MGD (18.4 cfs) was submitted by SBMWD in 2010 (WEI 2010 cited in USFWS 2011). USFWS (2011) protested, stating specifically that the Santa Ana sucker is dependent on discharges from the RIX facility to maintain suitable habitat for spawning and foraging.

A previous study attempted to address the potential effects on the Santa Ana sucker from reducing wastewater discharge into the Santa Ana River. Swift (2001b) analyzed possible effects on the sucker and its habitat from changes in flow in the Santa Ana River, specific to expected changes in wetted area and depth. Swift (2001b) noted several observations of 30 to 60% reduction in the wetted surface with 50% reduction in RIX flow. However, no attempt was made to compare changes in channel conditions (e.g., depth, velocity, and substrate) with data on how suckers use those channel characteristics.

As part of this low flow study, we have attempted to better synthesize the flow-related changes in habitat characteristics with biological requirements of the Santa Ana sucker. WEI modeled the hydrology conditions in the Santa Ana River for the current baseline flow and the five proposed phases of RIX reduction. GEI evaluated these changes based on utilization curves derived from site-specific studies (SMEA 2003, 2004) and utilization of adult mountain suckers as a surrogate for Santa Ana suckers, using a PHABSIM-type analysis. The following sections evaluate the modeled changes in the hydrologic and habitat conditions, while considering the habitat requirements of the Santa Ana sucker.

4.1 Changes to Channel Characteristics

4.1.1 Depth

Based on the modeling results, the 52% reduction in RIX discharge from the baseline Santa Ana River flow of 63 cfs to the Phase 5 flow of 30 cfs would result in a 13% reduction in the maximum depth in Reach 1 from 2.08 to 1.82 ft (Table 7). The average of all maximum depths in Reach 1 would be reduced 14%, from 1.26 to 1.08 ft, for the baseline to Phase 5 flow (Table 7). Reach 1 coincides with the greatest density of Santa Ana suckers currently, which is likely related to the consistent coarse substrate present within this reach and also to the deeper habitats available in this reach compared to downstream reaches (Table 7, Figure 13 and Figure 14).

Table 7: **Minimum, maximum, and average of maximum transect depths (ft) for each reach for baseline flow and the five phases of RIX reduction. Data summarized from data provided by WEI (2014). Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, values in brackets indicate percent change in Santa Ana River flow, and n values represent the number of transects evaluated per reach.**

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave
Baseline (63)	0.82	2.08	1.26	0.48	1.68	0.99	0.33	1.56	0.61
Phase 1 (54)	0.80	2.06	1.24	0.45	1.58	0.94	0.31	1.52	0.58
Phase 2 (48)	0.79	2.02	1.21	0.42	1.50	0.89	0.30	1.49	0.56
Phase 3 (42)	0.76	1.97	1.18	0.39	1.42	0.84	0.28	1.45	0.54
Phase 4 (36)	0.74	1.90	1.13	0.37	1.34	0.79	0.26	1.41	0.52
Phase 5 (30)	0.70	1.82	1.08	0.33	1.26	0.73	0.23	1.35	0.49
Percent Change from Baseline									
Phase 1 [-14]	-2	-1	-2	-6	-6	-5	-6	-3	-5
Phase 2 [-24]	-4	-3	-4	-13	-11	-10	-9	-4	-8
Phase 3 [-33]	-7	-5	-6	-19	-15	-15	-15	-7	-11
Phase 4 [-43]	-10	-9	-10	-23	-20	-20	-21	-10	-15
Phase 5 [-52]	-15	-13	-14	-31	-25	-26	-30	-13	-20

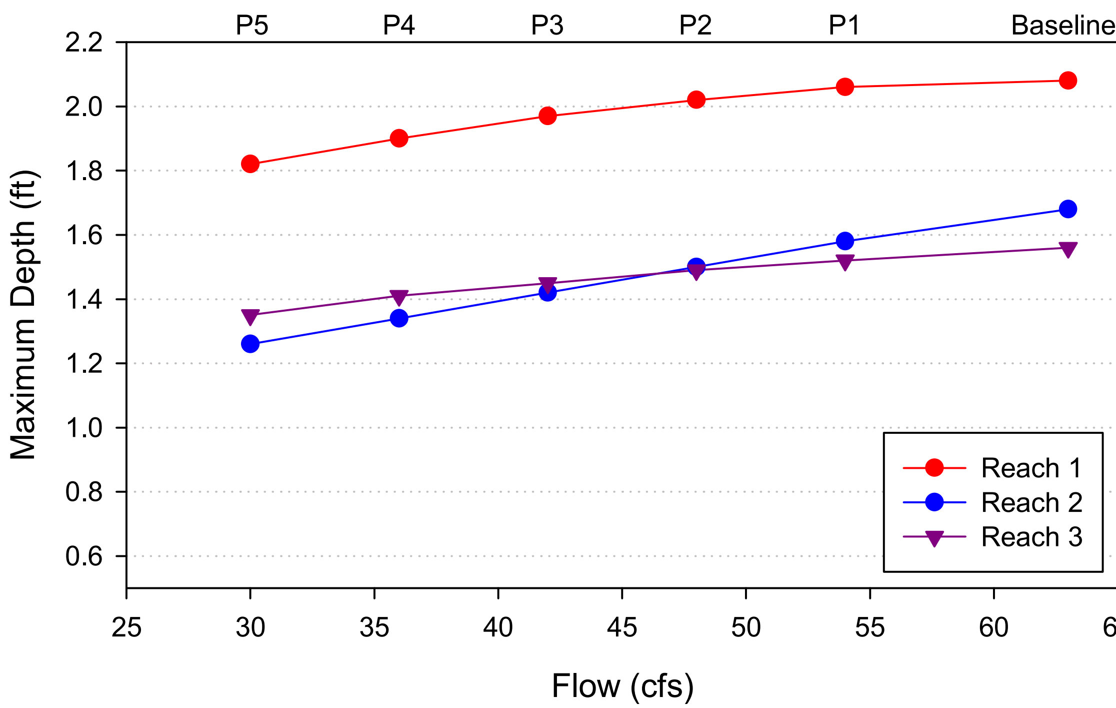

Figure 13: **Maximum depth for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.**

The percent reductions in maximum depth with decreasing flow were greater in reaches 2 and 3 than in Reach 1 (Table 7). The greatest percent reduction in maximum depths for each flow occurred in Reach 2, with maximum and average of the maximum depths for Phase 5 being reduced up to 25% and 26% from baseline, respectively. In Reach 3, the maximum and average of the maximum depths for Phase 5 were reduced up to 13% and 20%, respectively.

The rate of decrease in maximum depth with decreasing flow was similar between reaches 1 and 3. However, the rate of decrease was greater in Reach 2, such that maximum depth was greater in Reach 2 than in Reach 3 for the baseline, Phase 1, and Phase 2 scenarios and less than in Reach 3 for the lower flows (Figure 13).

Although the maximum depths were similar between reaches 2 and 3 and switched in magnitude with reductions in flow, the average maximum depth of all transects was substantially lower in Reach 3 than in Reach 2 for all flow scenarios, and both were substantially lower than the average maximum depths in Reach 1 (Figure 14).

The amount of variability in the maximum depth values was similar for all three reaches for the baseline flow and all five phases of RIX reduction (Figure 14), with the difference between the maximum and minimum values generally between 1.0 and 1.3 feet.

In general, overall depths showed minor decreases as a result of the first three phases in reaches 1 and 3, with somewhat greater changes in Reach 2. Reductions in depth in Reach 3 were intermediate between the reductions in reaches in 1 and 2. The pattern of Reach 1 having deeper water remained consistent compared to the other two reaches, regardless of flow.

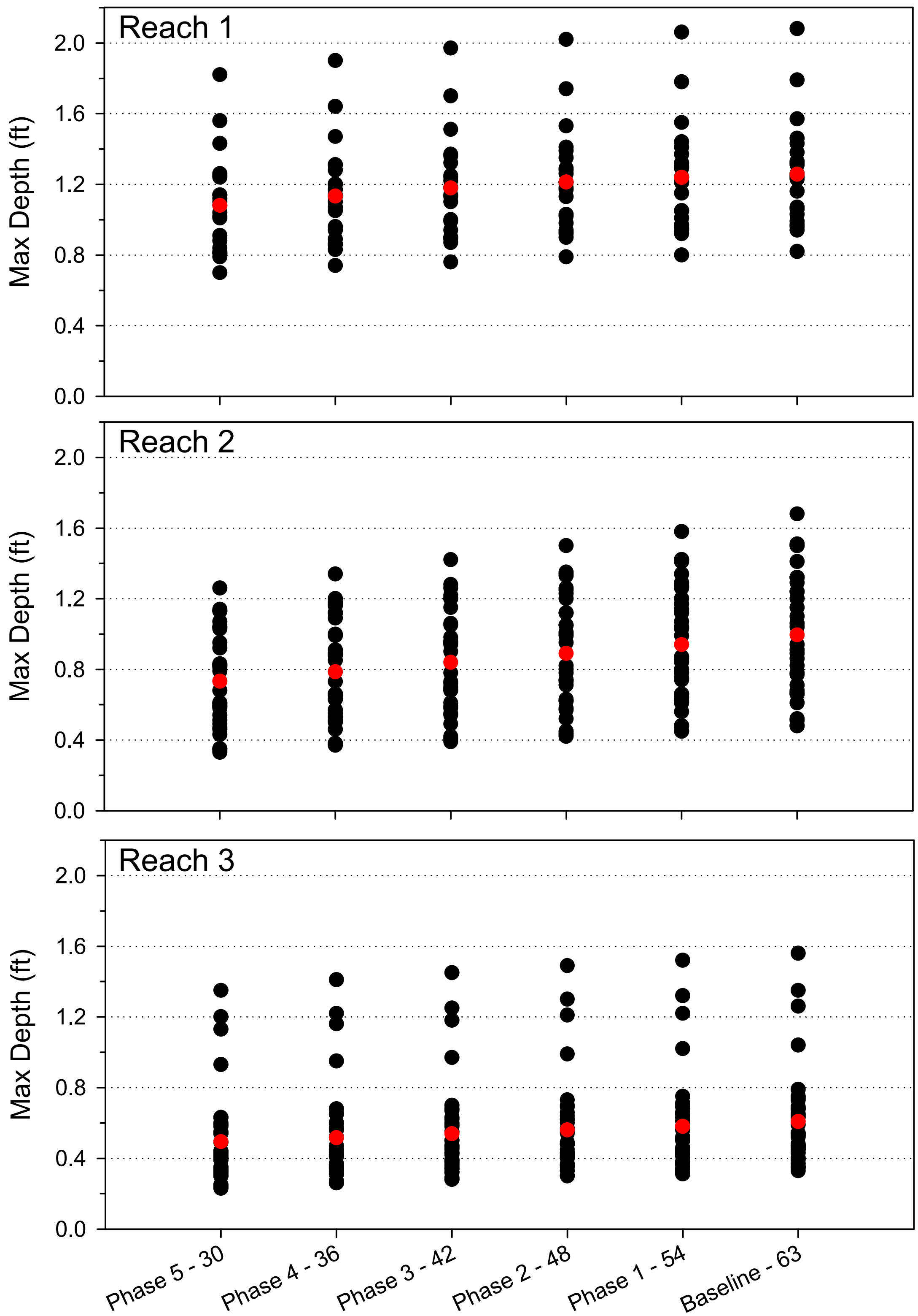

Figure 14: Maximum depth values for each transect in each reach, for baseline flow and the five phases of RIX reduction. Red circles represent the average of all maximum depth values.

4.1.2 Stream Width

The 52% reduction in RIX discharge from the baseline Santa Ana River flow of 63 cfs to the Phase 5 flow of 30 cfs would result in a reduction in average wetted width of 5%, from 33.5 to 31.8 ft in Reach 1 (Table 8, Figure 15). Wetted widths were similar in Reach 2 and a 13% reduction from 35.9 to 31.2 ft would occur, from baseline to Phase 5 flow. Wetted widths were greater in Reach 3 than in reaches 1 and 2, and a 7% reduction from 73.6 to 68.3 ft occurred for baseline to Phase 5 flow. These reductions in wetted width are much less than the corresponding percent reduction in flow, illustrating that the reduction in the amount of wetted habitat is not a one-to-one relationship with reduction in flow.

Overall, average stream width exhibited little change through all five phases of the project in reaches 1 and 3, and through the first four phases in Reach 2. As with the depth data above, it appears that general stream channel characteristics change only gradually as flows decrease.

Table 8: Minimum, maximum, and average transect wetted widths (ft) for each reach for baseline flow and the five phases of RIX reduction. Data summarized from data provided by WEI (2014). Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, values in brackets indicate percent change in Santa Ana River flow, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave
Baseline (63)	18.8	55.1	33.5	20.67	69.5	35.9	37.7	157.4	73.6
Phase 1 (54)	18.8	52.7	33.2	20.67	64.4	35.2	35.8	157.4	73.1
Phase 2 (48)	18.8	52.7	33.0	18.87	63.2	33.5	33.9	157.4	72.1
Phase 3 (42)	18.8	52.7	32.6	16.21	63.2	33.0	33.9	157.4	70.8
Phase 4 (36)	17.9	52.7	32.1	16.21	63.2	32.3	32.0	157.4	69.6
Phase 5 (30)	17.9	52.7	31.8	15.06	53.1	31.2	28.2	157.4	68.3
Percent Change from Baseline									
Phase 1 [-14]	0	-4	-1	0	-7	-2	-5	0	-1
Phase 2 [-24]	0	-4	-1	-9	-9	-7	-10	0	-2
Phase 3 [-33]	0	-4	-3	-22	-9	-8	-10	0	-4
Phase 4 [-43]	-5	-4	-4	-22	-9	-10	-15	0	-5
Phase 5 [-52]	-5	-4	-5	-27	-24	-13	-25	0	-7

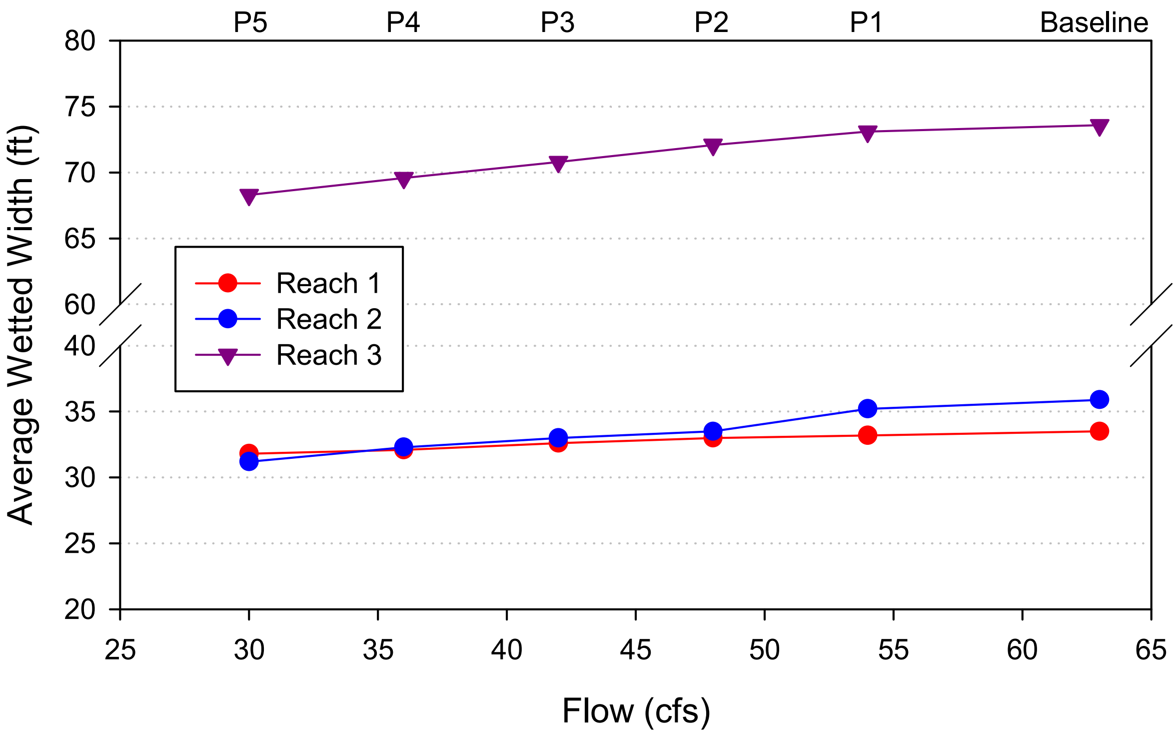

Figure 15: Average transect wetted width for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

4.1.3 Stream Velocity

Reach 1 had the greatest reduction in velocity from baseline for each flow reduction scenario (Table 9, Figure 16). Average velocity in Reach 1 was reduced by 41%, from 1.77 to 1.04 ft/s for baseline to Phase 5 flows. In Reach 2, this reduction from baseline to Phase 5 flow, resulted in only a 22% reduction in velocity from 1.62 to 1.27 ft/s, while in Reach 3 velocity was reduced 10% from 1.51 to 1.36 ft/s.

When reviewing the model output, the mean-column velocities produced by the HEC-RAS model increased uniformly with depth. While interpretation of these velocity results is appropriate for evaluating relative changes in velocity among phases and reaches, the results do not reflect the fine-scale variability in velocity that would occur in the river and is needed for PHABSIM modeling, as is discussed in greater detail below (Section 4.2.3).

Overall, reductions in flow from baseline through Phase 5, resulted in more moderate reductions in depth, as shown by the smaller percent changes from baseline for the average maximum depth in Reach 1 than in reaches 2 and 3. Accordingly, the reductions in velocity with decreasing flow were greater in Reach 1 than in reaches 2 and 3 (Figure 16). Santa Ana suckers appear to prefer deeper and slower velocity habitat given utilization studies conducted in the Santa Ana River. Santa Ana suckers have also been shown to prefer habitats with coarse substrates. How substrate composition will change with reductions in RIX flow is unknown.

Table 9: Minimum, maximum, and average of average transect velocities (ft/s) for each reach for baseline flow and the five phases of RIX reduction. Data summarized from data provided by WEI (2014). Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, values in brackets indicate percent change in Santa Ana River flow, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave
Baseline (63)	1.36	2.26	1.77	0.96	2.22	1.62	0.95	2.01	1.51
Phase 1 (54)	1.20	1.99	1.57	0.87	2.00	1.53	0.94	1.96	1.46
Phase 2 (48)	1.13	1.79	1.42	1.04	1.92	1.48	0.93	1.91	1.43
Phase 3 (42)	1.01	1.61	1.28	0.95	1.80	1.41	0.96	1.90	1.40
Phase 4 (36)	0.90	1.44	1.16	0.90	1.70	1.33	1.00	1.87	1.37
Phase 5 (30)	0.79	1.37	1.04	0.79	1.67	1.27	0.98	1.80	1.36
Percent Change from Baseline									
Phase 1 [-14]	-12	-12	-11	-9	-10	-6	-1	-2	-3
Phase 2 [-24]	-17	-21	-20	8	-14	-9	-2	-5	-5
Phase 3 [-33]	-26	-29	-28	-1	-19	-13	1	-5	-7
Phase 4 [-43]	-34	-36	-34	-6	-23	-18	5	-7	-9
Phase 5 [-52]	-42	-39	-41	-18	-25	-22	3	-10	-10

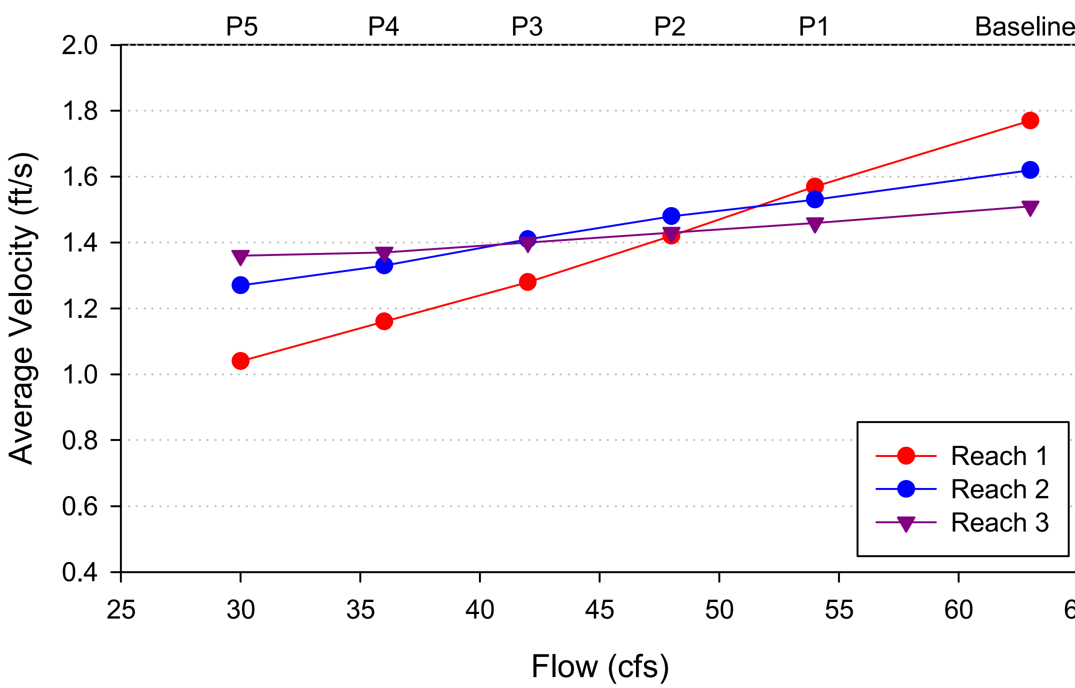

Figure 16: Average of the average transect velocities for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

4.2 Weighted Useable Area (WUA) Changes

4.2.1 Depth Model

4.2.1.1 Adult

Adult Santa Ana sucker WUA was greatest in Reach 3 for the baseline flow and for each of the five phases of RIX reduction (Table 10, Figure 17). WUA was greater in Reach 2 than in Reach 1, for the baseline flow and Phase 1, similar between the two reaches for Phase 2, and lower in Reach 2 than in Reach 1 for the remaining phases. This has the appearance of being contrary to the deeper water that is available in Reach 1 than in reaches 2 and 3 (Figure 13), and the preference of adult Santa Ana suckers for deeper water, as reflected in the depth utilization curve used in this modeling (Figure 7). However, the utilization curve also allows for intermediate depths to be utilized, which are readily available in Reach 3, and given that the total area of Reach 3 is more than four times as large as Reach 1 and more than two times as large as Reach 2, this results in greater total WUA in Reach 3, even though it is shallower. In other words, even though greater depths are available in Reach 1, more area of marginal depth is available in reach 3. As such, for the baseline and Phase 1 flows the relative order of the amount of WUA corresponds with the total amount of area in the reaches.

For all three reaches, adult WUA decreased with decreasing flow (Figure 17), due to associated decreases in depth. The amount of adult WUA as a percentage of the total area available was greatest in Reach 1 followed by reaches 2 and 3 (Table 10, Figure 18). These results illustrate that suitable adult habitat decreases as a percentage of the total area in downstream reaches. The decrease downstream is a function of the utilization curve used in the modeling, which has greater utilization at increasing depth, and this deeper habitat as a percentage of the total area becomes less common downstream.

For Reach 1, relatively small reductions from baseline in adult WUA of 2.7% and 6.8% occurred for phases 1 and 2, respectively (Table 10, Figure 19). Subsequent decreases in flow resulted in approximately 6 to 8% reductions in WUA between each phase. In Reach 2, adult WUA was reduced by approximately 10% for each phase (Table 10, Figure 19). The reduction in adult WUA from baseline in Reach 3 was similar to in Reach 2, but with slightly smaller percent reductions for each phase (Table 10, Figure 19).

Table 10: Depth Model Results - Adult Santa Ana sucker weighted usable area (WUA) (sq ft), percent change in WUA from baseline, and WUA as a percent of total area at baseline flow for each reach for baseline and the five phases of RIX reduction. Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline
Baseline (63)	128,749	--	35.0	152,515	--	22.5	171,265	--	11.0
Phase 1 (54)	125,212	-2.7	34.1	135,712	-11.0	20.0	153,112	-10.6	9.8
Phase 2 (48)	119,966	-6.8	32.6	121,493	-20.3	17.9	139,606	-18.5	8.9
Phase 3 (42)	112,698	-12.5	30.7	107,749	-29.4	15.9	126,074	-26.4	8.1
Phase 4 (36)	103,438	-19.7	28.1	93,062	-39.0	13.7	111,154	-35.1	7.1
Phase 5 (30)	93,167	-27.6	25.4	78,638	-48.4	11.6	99,279	-42.0	6.4

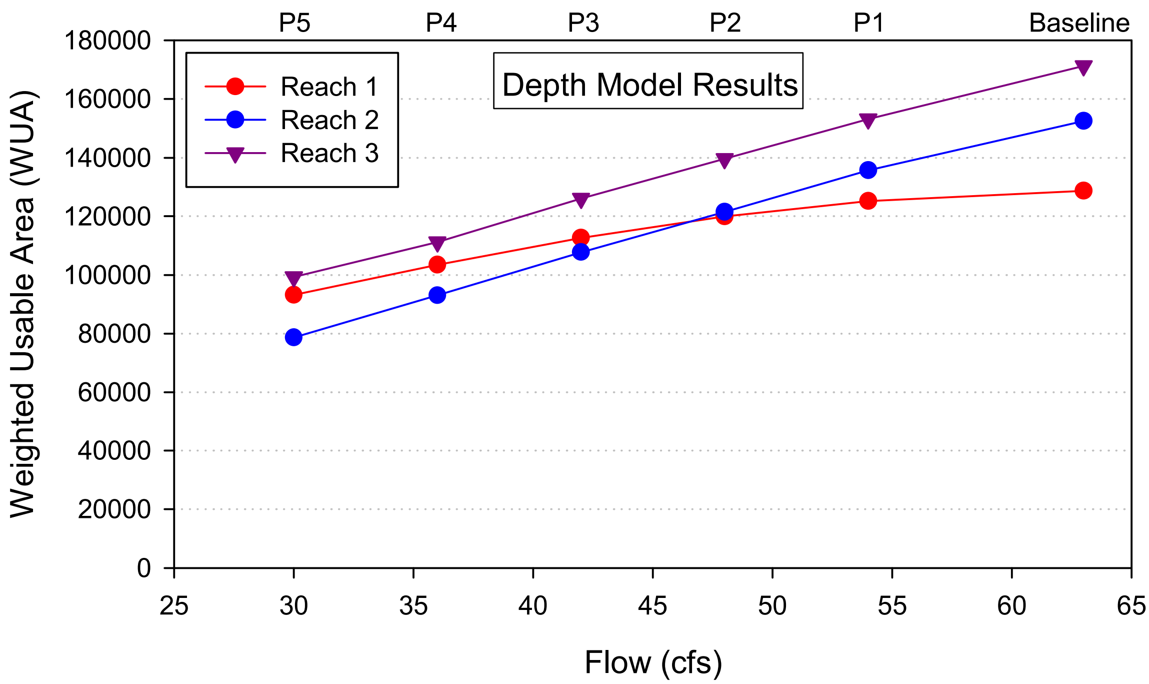

Figure 17: Total adult Santa Ana sucker weighted usable area (WUA) (sq ft) for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

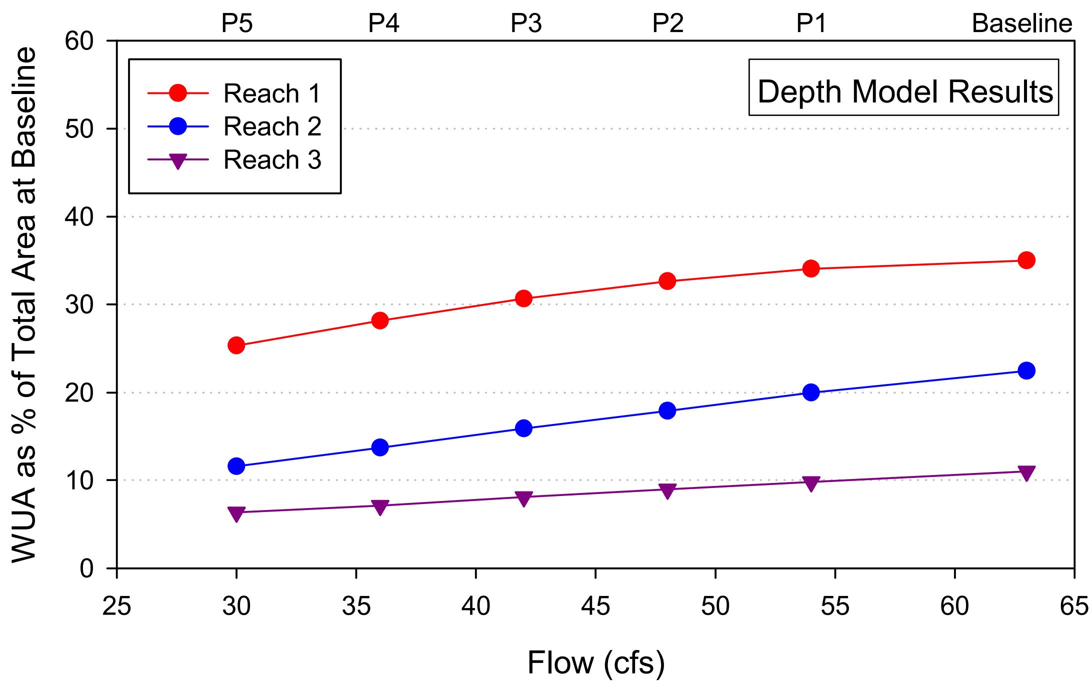

Figure 18: Adult Santa Ana sucker weighted usable area (WUA) as percent of total area at baseline flow for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

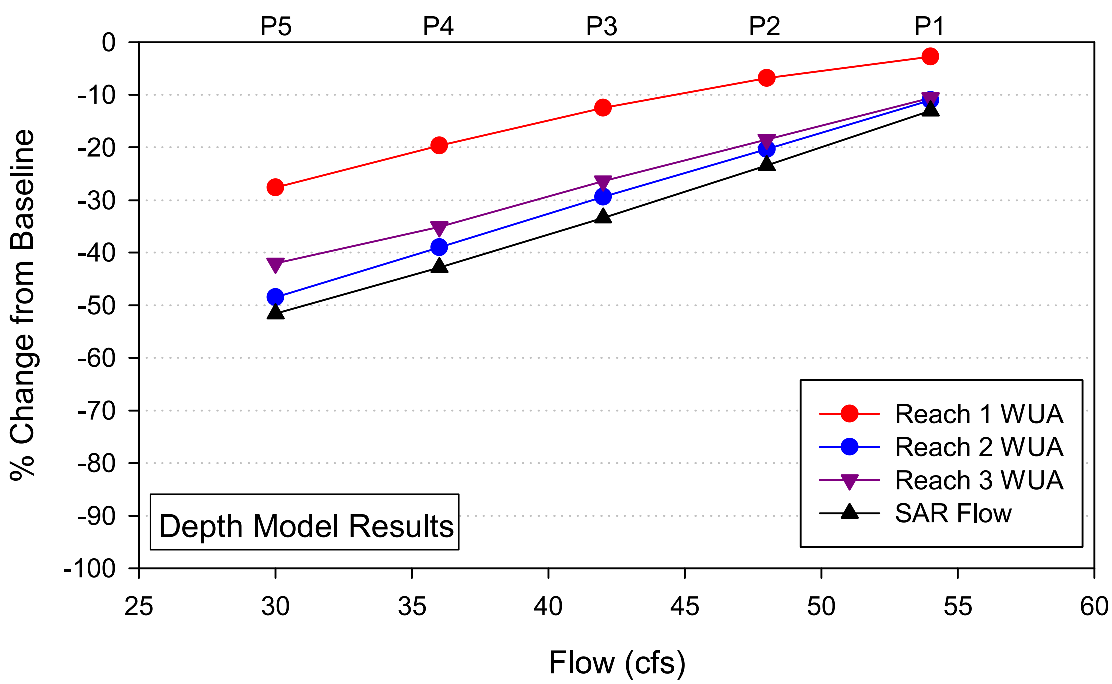

Figure 19: Cumulative percent change in adult Santa Ana sucker weighted usable area (WUA) and Santa Ana River (SAR) flow from baseline for each reach for the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the Santa Ana River flow at the upstream end of the study area.

4.2.1.2 Juvenile

Juvenile Santa Ana sucker WUA was greatest in Reach 3, followed by reaches 2 and 1 for the baseline flow and all five flows of the phased RIX reduction plan (Table 11, Figure 20). For all three reaches, juvenile WUA decreased with decreasing flow (Figure 20), due to associated decreases in depth.

The amount of juvenile WUA as a function of the total area was high for all flows and reaches compared to adult WUA (Figure 21). Juvenile WUA as a percentage of the total area was greatest in Reach 1 and decreased in a downstream direction. The percent changes from baseline in juvenile Santa Ana sucker WUA were smallest in Reach 1, and increased moving downstream in reaches 2 and 3 (Table 11, Figure 22). In Reach 1, the percent change in WUA from baseline did not exceed 10% until Phase 4, and the total percent change for Phase 5 was less than 20%. In reaches 2 and 3, the percent reduction in WUA exceeded 10% by Phase 2. The reduction in juvenile WUA was near 40% for Phase 5 for reaches 2 and 3.

The results of greater WUA for juveniles than adults, demonstrate the importance of the depth utilization curve in determining the amount of WUA. The juvenile Santa Ana sucker utilization curve increases faster at lower depths and has a maximum utilization at a lower depth than the adult Santa Ana sucker curve. Thus, the WUA is greater for juveniles than adults, and the changes among phases of flow from the baseline flow are smaller.

Table 11: Depth Model Results - Juvenile Santa Ana sucker weighted usable area (WUA) (sq ft), percent change in WUA from baseline, and WUA as a percent of total area at baseline flow for each reach for baseline and the five phases of RIX reduction. Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline
Baseline (63)	179,737	--	48.9	241,682	--	35.6	386,232	--	24.8
Phase 1 (54)	176,353	-1.9	48.0	225,364	-6.8	33.2	349,675	-9.5	22.4
Phase 2 (48)	171,471	-4.6	46.7	209,258	-13.4	30.8	319,457	-17.3	20.5
Phase 3 (42)	164,338	-8.6	44.7	190,346	-21.2	28.0	287,761	-25.5	18.4
Phase 4 (36)	154,946	-13.8	42.2	172,033	-28.8	25.3	256,730	-33.5	16.5
Phase 5 (30)	144,522	-19.6	39.3	152,248	-37.0	22.4	227,779	-41.0	14.6

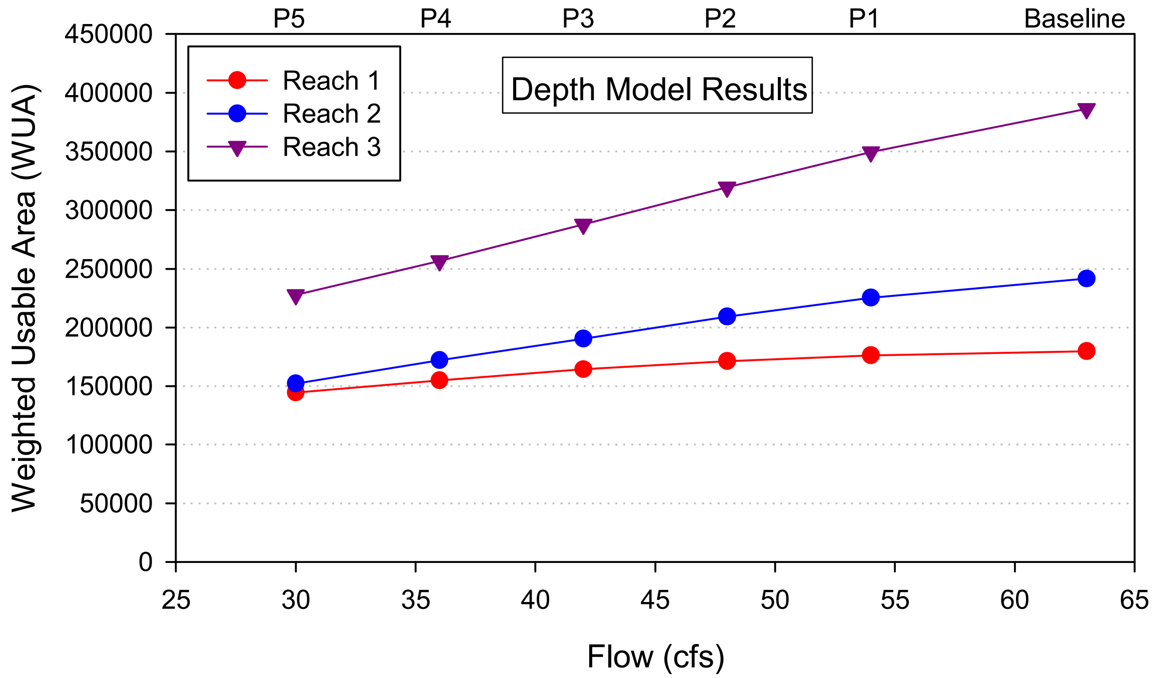

Figure 20: Total juvenile Santa Ana sucker weighted usable area (WUA) (sq ft) for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

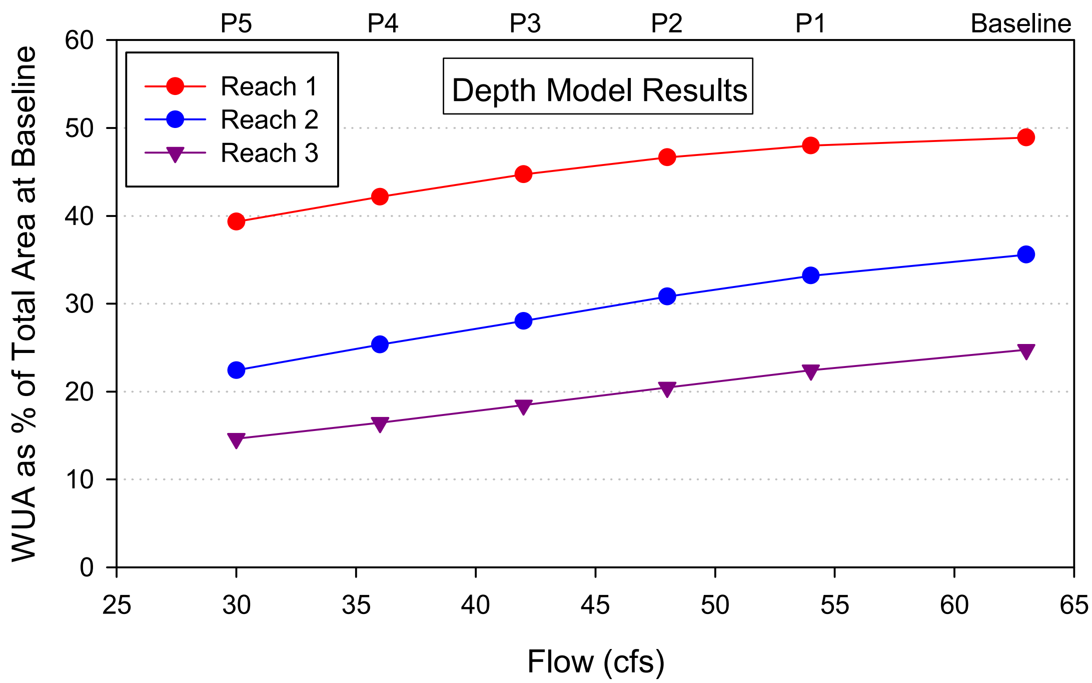

Figure 21: Juvenile Santa Ana sucker weighted usable area (WUA) as percent of total area at baseline flow for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

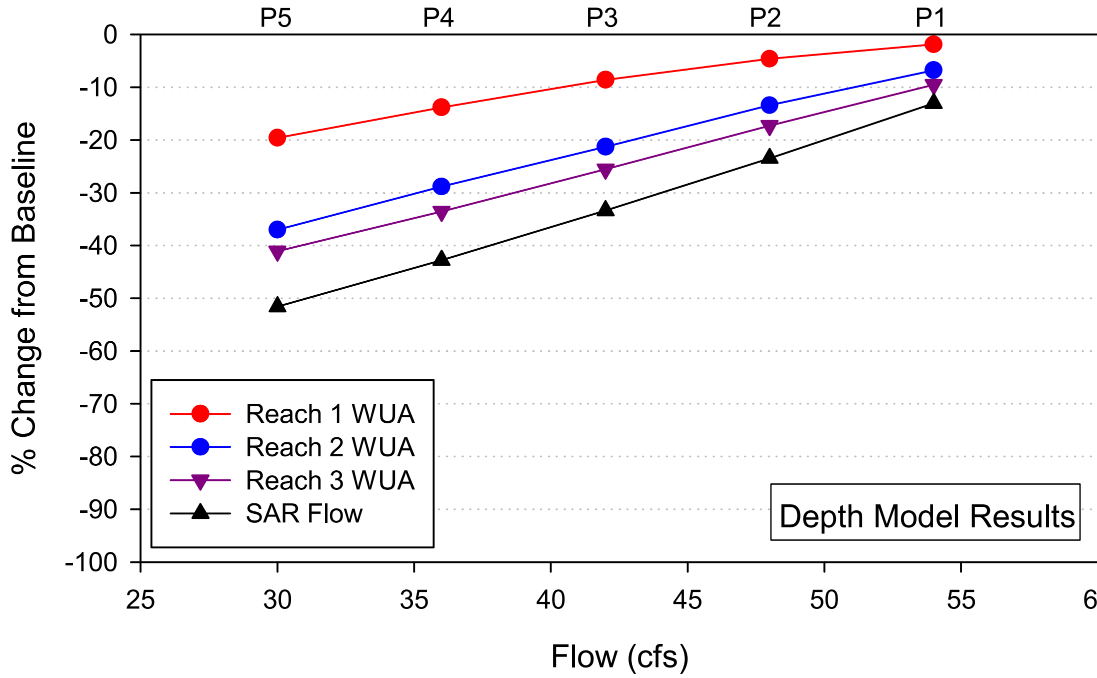

Figure 22: Percent change in juvenile Santa Ana sucker weighted usable area (WUA) and Santa Ana River (SAR) flow from baseline for each reach for the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

4.2.2 Depth and Substrate Model

Substrate characteristics were not modeled by WEI (2014), but by estimating the substrate suitability as a separate constant for each reach, substrate was incorporated into the model. The addition of substrate into the model as a constant with values less than 1.0 (as detailed earlier), result in decreases in total WUA for all three reaches compared to with modeling depth alone. The reductions in WUA with depth and substrate compared to with depth alone were smallest in Reach 1, greatest in Reach 3, and intermediate in Reach 2 for both adult and juvenile suckers. These relative reductions in WUA by reach, represent the longitudinal change in substrate conditions from predominantly gravel and cobble in Reach 1,which is preferred by the Santa Ana sucker, to a mix of gravel and sand substrate in Reach 2, and predominantly sand substrate in Reach 3. Tables and figures in the following adult and juvenile sections present the percent change from baseline results, but the discussion is not repeated, as the percent change from baseline results do not change (see Depth Results, Section 4.2.1).

4.2.2.1 Adult

Adult Santa Ana sucker WUA, incorporating depth and substrate variables, was greatest in Reach 1 and lowest in Reach 3 for the baseline flow and for each of the five phases of RIX reduction (Table 12, Figure 23). These results are largely the opposite as that seen with depth alone. The change in results to a greater amount of WUA in Reach 1, followed by reaches 2 and 3, is because of the incorporation of substrate suitability, which is greater upstream and decreases downstream. The reductions in adult WUA for modeling with depth and substrate, compared to with depth alone, were an 8% reduction in Reach 1, a 33% reduction in Reach 2, and a 58% reduction in Reach 3, which correspond to the substrate suitability constants applied to each reach. For all three reaches, adult WUA decreased with decreasing flow (Figure 23), due to associated decreases in depth.

The amount of adult WUA for the combined depth-substrate analysis was relatively low compared to the total area available for all flow scenarios in reaches 2 and 3 compared to in Reach 1 (Table 12, Figure 24). These results illustrate that the suitable adult habitat as a percentage of the total habitat is limited in reaches 2 and 3. The decrease downstream in WUA as a percentage of the total area is a function of deeper habitat becoming less common downstream and substrate characteristics becoming less suitable (see Figure 25).

Table 12: Depth and Substrate Model Results - Adult Santa Ana sucker weighted usable area (WUA) (sq ft), percent change in WUA from baseline, and WUA as a percent of total area at baseline flow for each reach for baseline and the five phases of RIX reduction. Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline
Baseline (63)	118,449	--	32.2	102,445	--	13.6	71,931	--	4.5
Phase 1 (54)	115,195	-2.7	31.3	90,927	-11.2	12.1	64,307	-10.6	4.0
Phase 2 (48)	110,369	-6.8	30.0	81,400	-20.5	10.8	58,634	-18.5	3.6
Phase 3 (42)	103,682	-12.5	28.2	72,192	-29.5	9.6	52,951	-26.4	3.3
Phase 4 (36)	95,163	-19.7	25.9	62,352	-39.1	8.3	46,685	-35.1	2.9
Phase 5 (30)	85,714	-27.6	23.3	52,687	-48.6	7.0	41,697	-42.0	2.6

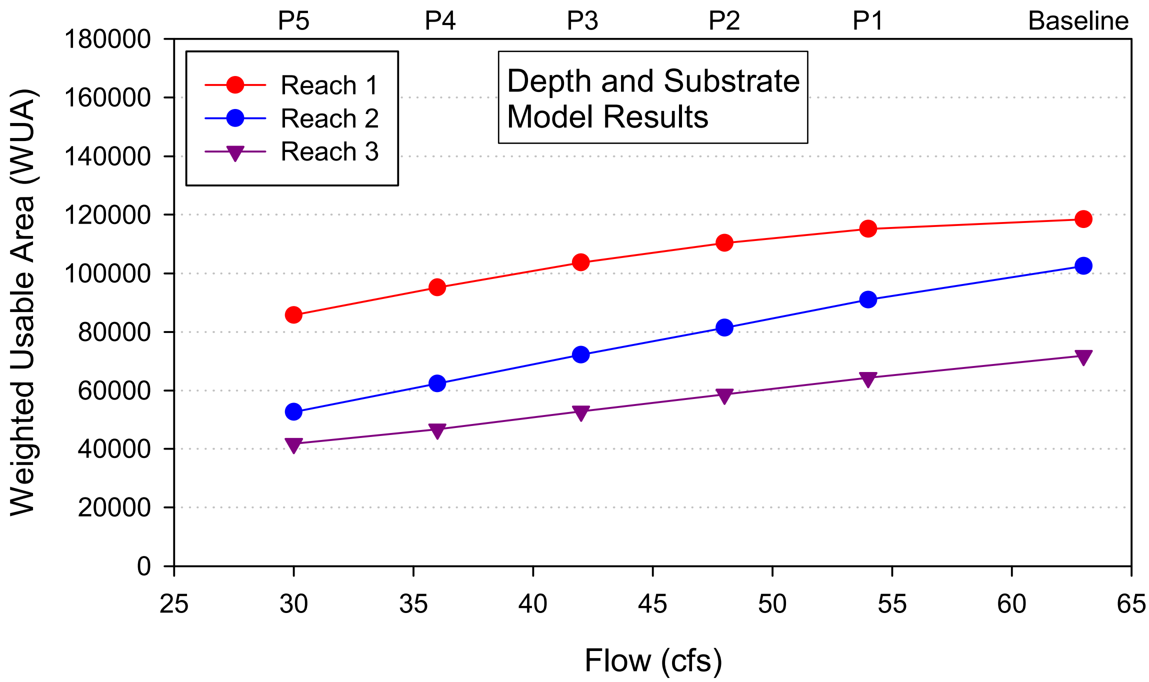

Figure 23: Total adult Santa Ana sucker weighted usable area (WUA) (sq ft) for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

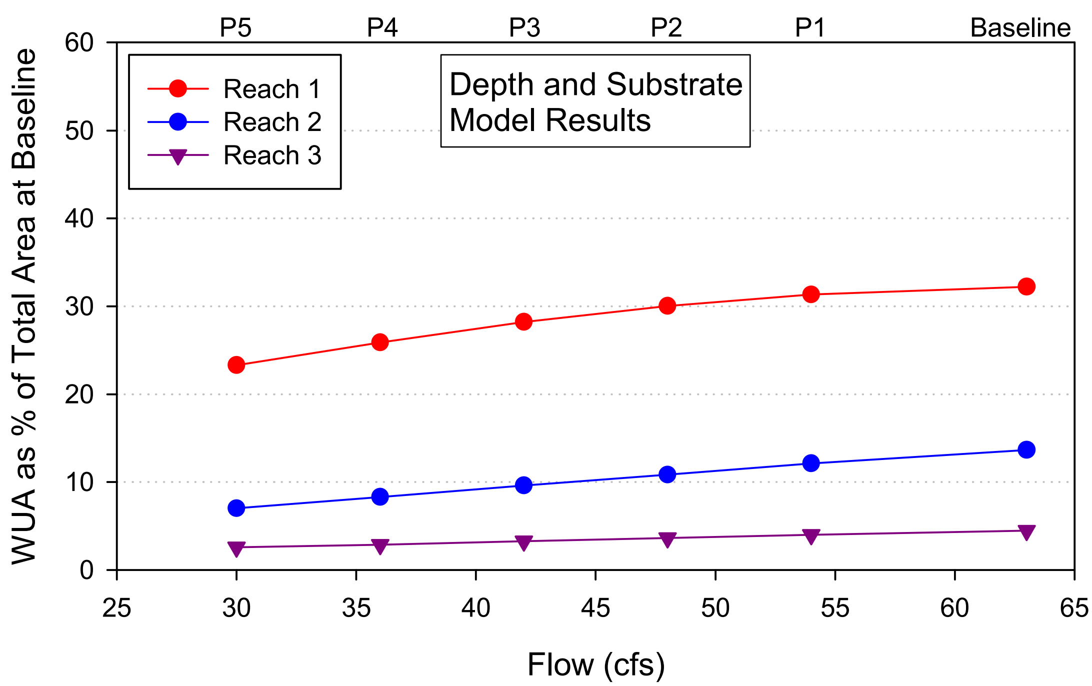

Figure 24: Adult Santa Ana sucker weighted usable area (WUA) as percent of total area at baseline flow for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

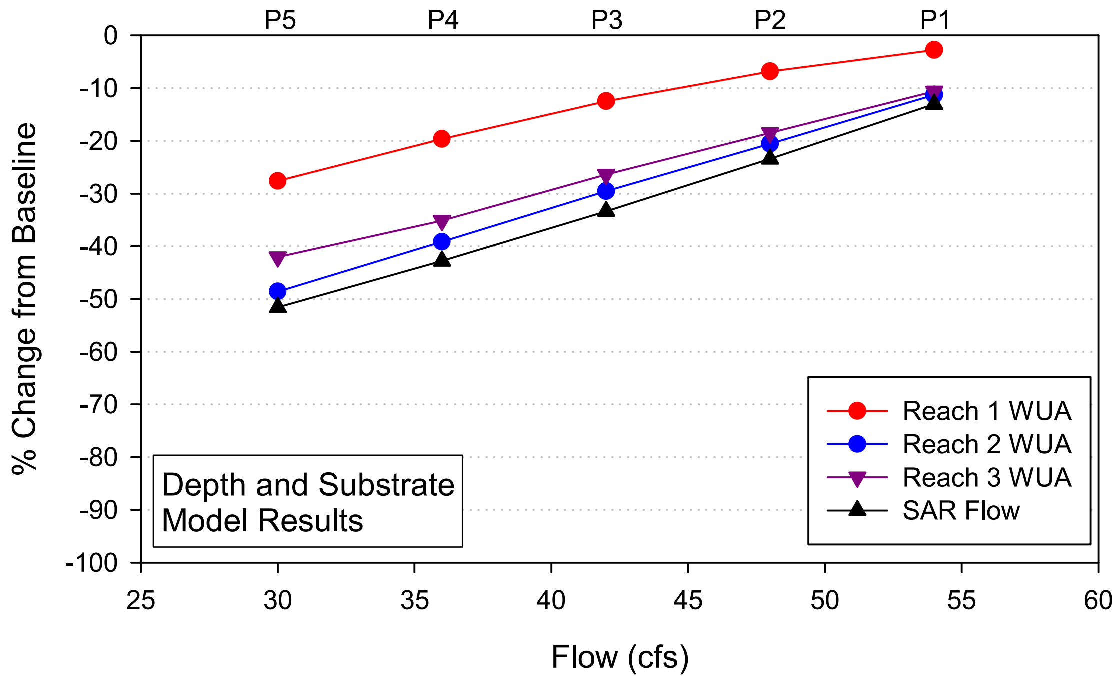

Figure 25: Percent change in adult Santa Ana sucker weighted usable area (WUA) and Santa Ana River (SAR) flow from baseline for each reach for the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the Santa Ana River flow at the upstream end of the study area.

4.2.2.2 Juvenile

The reductions in juvenile WUA for modeling with depth and substrate, compared to with depth alone, resulted in a 30% reduction in Reach 1, a 52% reduction in Reach 2, and a 74% reduction in Reach 3, which correspond to the substrate suitability constants applied to each reach.

In contrast to the results for modeling with depth alone, where juvenile WUA was greatest in Reach 3, followed by reaches 2 and 1 (Figure 20), juvenile WUA was greatest in Reach 1, followed by reaches 2 and 3 when substrate was incorporated (Table 13, Figure 26). This change is the result of the relatively high substrate utilization value of 0.70 for juvenile suckers used in Reach 1, and the relatively low substrate utilization value of 0.26 for juvenile suckers used in Reach 3. For all three reaches, juvenile WUA decreased with decreasing flow (Figure 26), due to associated decreases in depth.

The amount of juvenile WUA as a function of the total area was greater for all flows and reaches compared to adult WUA (Figure 24 and Figure 27). Percent changes in juvenile WUA compared to baseline (Figure 28) were the same as with depth alone (Figure 18).

Table 13: Depth and Substrate Model Results - Juvenile Santa Ana sucker weighted usable area (WUA) (sq ft), percent change in WUA from baseline, and WUA as a percent of total area at baseline flow for each reach for baseline and the five phases of RIX reduction. Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline
Baseline (63)	125,816	--	34.2	116,448	--	15.5	100,420	--	6.2
Phase 1 (54)	123,447	-1.9	33.6	108,175	-7.1	14.4	90,916	-9.5	5.6
Phase 2 (48)	120,030	-4.6	32.7	100,444	-13.7	13.4	83,059	-17.3	5.2
Phase 3 (42)	115,037	-8.6	31.3	91,366	-21.5	12.2	74,818	-25.5	4.6
Phase 4 (36)	108,462	-13.8	29.5	82,576	-29.1	11.0	66,750	-33.5	4.1
Phase 5 (30)	101,165	-19.6	27.5	73,079	-37.2	9.7	59,223	-41.0	3.7

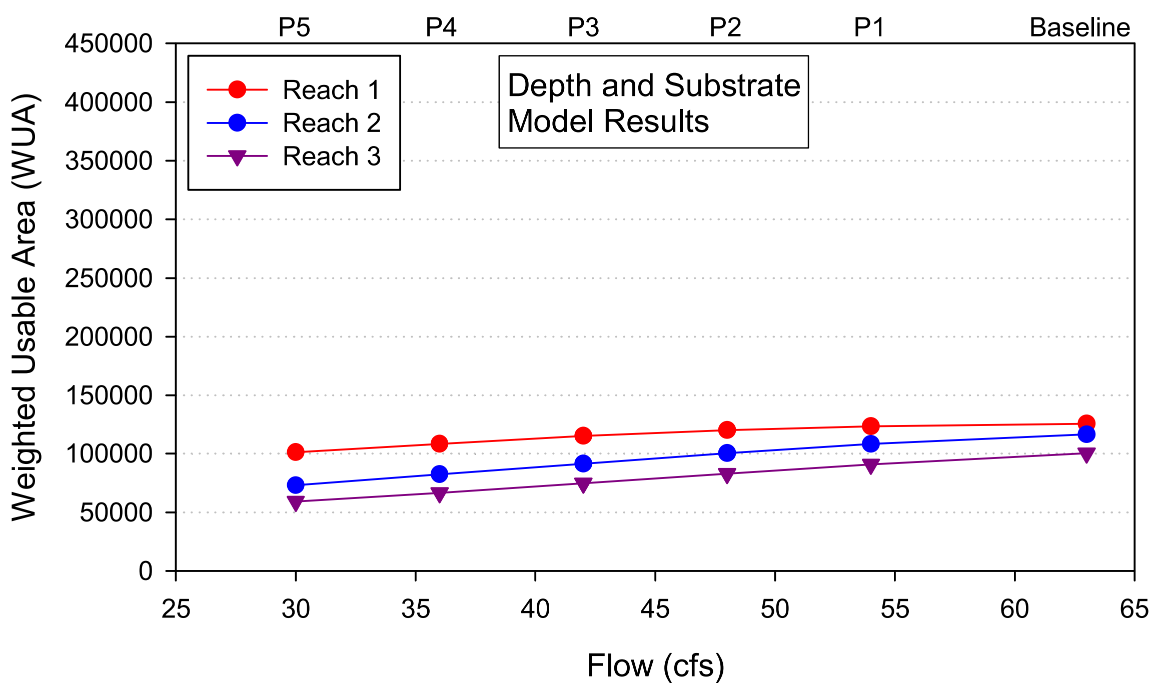

Figure 26: Total juvenile Santa Ana sucker weighted usable area (WUA) (sq ft) for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

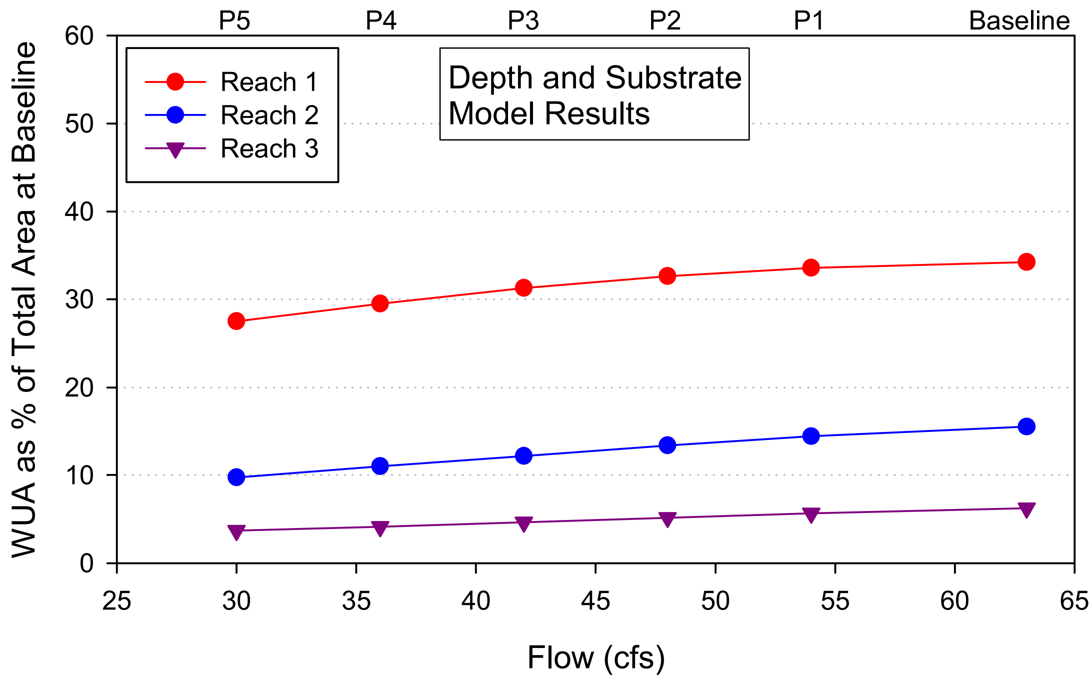

Figure 27: **Juvenile Santa Ana sucker weighted usable area (WUA) as percent of total area at baseline flow for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.**

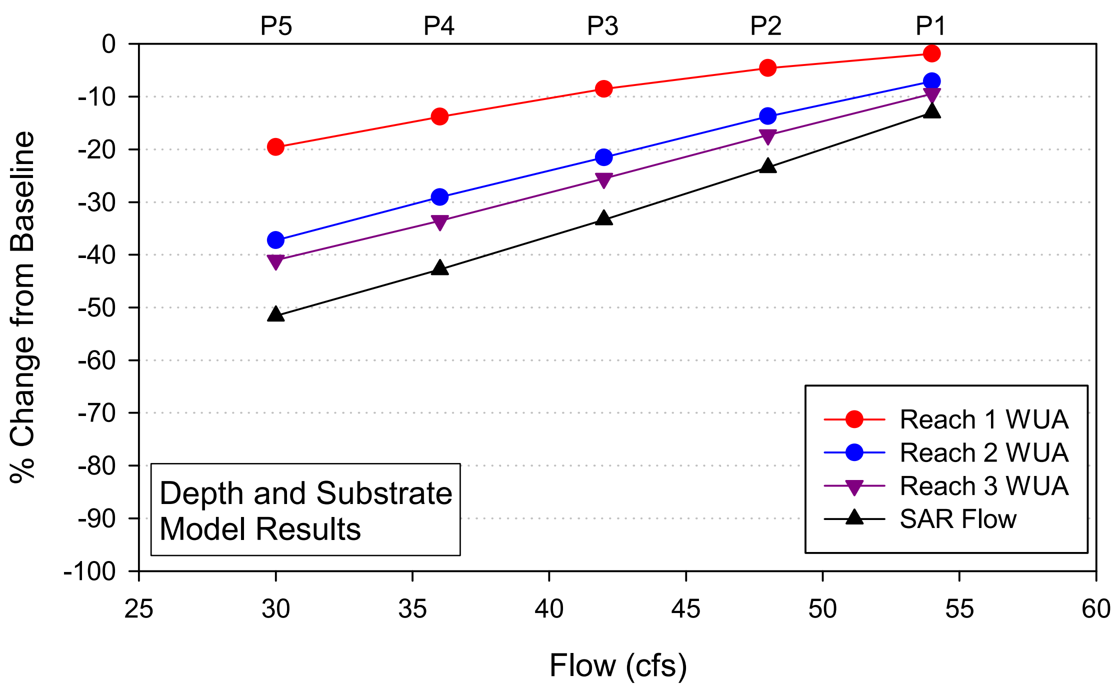

Figure 28: **Percent change in juvenile Santa Ana sucker weighted usable area (WUA) and Santa Ana River (SAR) flow from baseline for each reach for the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the Santa Ana River flow at the upstream end of the study area.**

4.2.3 Depth and Velocity Model

The addition of velocity as a modeling parameter to the depth only model, changes the relationship between WUA and flow that were observed with the depth alone model in Reach 1. In Reach 1, adding velocity as a parameter, results in increases in WUA through Phase 5 for adults and juveniles, as opposed to the decreases in WUA with decreases in flow with depth alone. In reaches 2 and 3, modeling based on depth and velocity resulted in decreases in WUA with decreases in flow, as was observed with depth alone. The increases in WUA in Reach 1 compared to the continued decreases in reaches 2 and 3, when incorporating velocity, are related to the deeper and faster velocity habitats that were modeled in Reach 1, and the greater rate of decrease in velocity with decreasing flows (Figure 16) in this reach, compared to in reaches 2 and 3.

These increases in WUA with decreases in flow in Reach 1 are related to limitations of the modeled velocity data, where the results do not reflect the fine-scale variability in velocity that would occur in the river and is needed for PHABSIM modeling. For example, reductions in velocity behind a large rock or island, that may produce high quality habitat for Santa Ana suckers, were not modeled in HEC-RAS, as opposed to other hydrologic models used in PHABSIM that are calibrated to measured velocities. Without such fine-scale velocity modeling, the habitat availability results below that incorporate velocity as a modeling parameter should not be considered in the effects analyses until velocity modeling can be refined.

4.2.3.1 Adult

Adult Santa Ana sucker WUA, incorporating depth and velocity, was greatest during baseline flow and phases 1 through 3 in Reach 3. However, increases in WUA in Reach 1 compared to decreases in WUA in reaches 2 and 3 with decreasing flow, resulted in greater WUA in Reach 1 for phases 4 and 5 (Table 14, Figure 29).

The amount of adult WUA was low compared to the total area available, for all flow scenarios and reaches (Table 14, Figure 30). The greatest amount of WUA as a function of total area occurred in Reach 1, with the WUA making up 6.9% of the total area for the baseline flow and 14.7% of the total area for the Phase 5 flow. In Reach 2, WUA comprised 5.2% and 4.5% of the total area for the baseline and Phase 5 flows, respectively. In Reach 3, WUA comprised 3.8% and 2.6% of the total area for the baseline and Phase 5 flows, respectively. These results illustrate that the suitable adult habitat is limited in each reach and decreases as a percentage of the total area in downstream reaches. The limited adult WUA is a function of the depth and velocity utilization curves used in the modeling, which have maximum utilization in deep and slow velocity habitats and progressively lower utilization in shallower and faster habitats. Based on the available hydraulic modeling data, deep and slow velocity habitat do not occur together, thus only marginal habitat is being utilized in this modeling scenario.

For Reach 1, large increases in WUA from baseline occurred through Phase 5 (Table 14, Figure 31). An opposite trend occurred for Reach 2, with reductions in WUA from baseline ranging from 0.9% to 12.9% for phases 1 and 5, respectively (Table 14, Figure 31). Reductions in WUA from baseline also occurred for all phases in Reach 3, with reductions ranging from 5.4% to 30.5% for phases 1 and 5, respectively (Table 14, Figure 31).

Table 14: Depth and Velocity Model Results - Adult Santa Ana sucker weighted usable area (WUA) (sq ft), percent change in WUA from baseline, and WUA as a percent of total area at baseline flow for each reach for baseline and the five phases of RIX reduction. WUA calculations based on depth and velocity modeling data (WEI 2014), and adult depth and velocity utilization relationships. Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline
Baseline (63)	25,265	--	6.9	38,996	--	5.2	60,462	--	3.8
Phase 1 (54)	35,675	+41.2	9.7	38,652	-0.9	5.1	57,196	-5.4	3.6
Phase 2 (48)	43,289	+71.3	11.8	38,486	-1.3	5.1	54,583	-9.7	3.4
Phase 3 (42)	49,198	+94.7	13.4	38,177	-2.1	5.1	51,176	-15.4	3.2
Phase 4 (36)	52,537	+107.9	14.3	36,598	-6.2	4.9	46,010	-23.9	2.9
Phase 5 (30)	53,944	+113.5	14.7	33,969	-12.9	4.5	42,028	-30.5	2.6

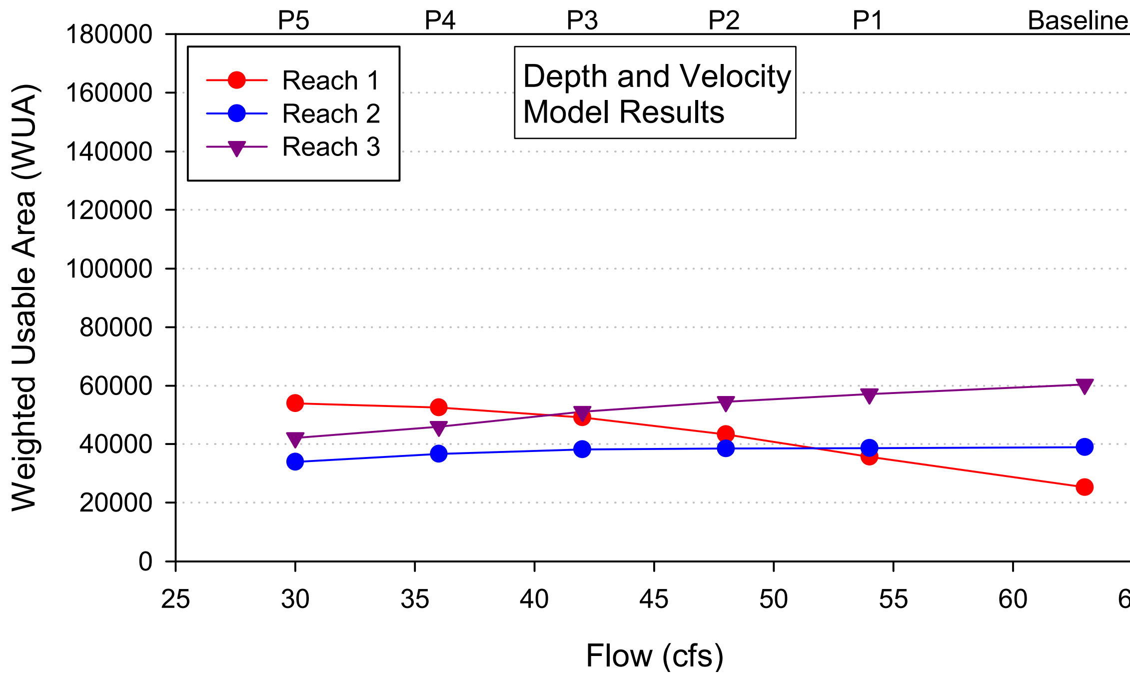

Figure 29: Total adult Santa Ana sucker weighted usable area (WUA) (sq ft) for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

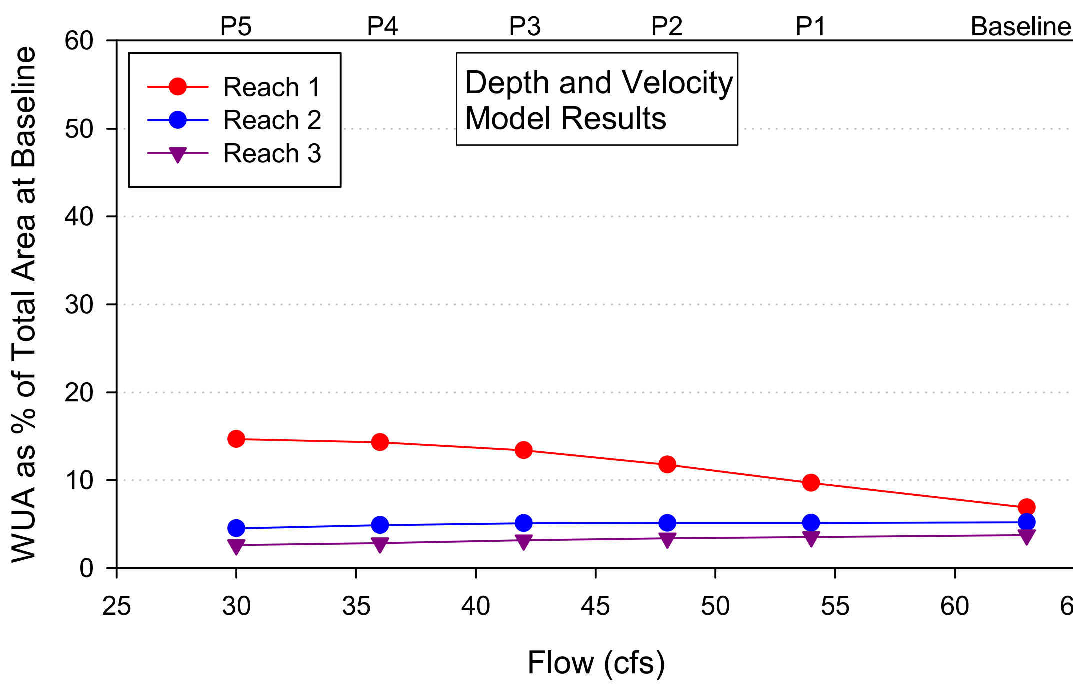

Figure 30: Adult Santa Ana sucker weighted usable area (WUA) as percent of total area at baseline flow for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

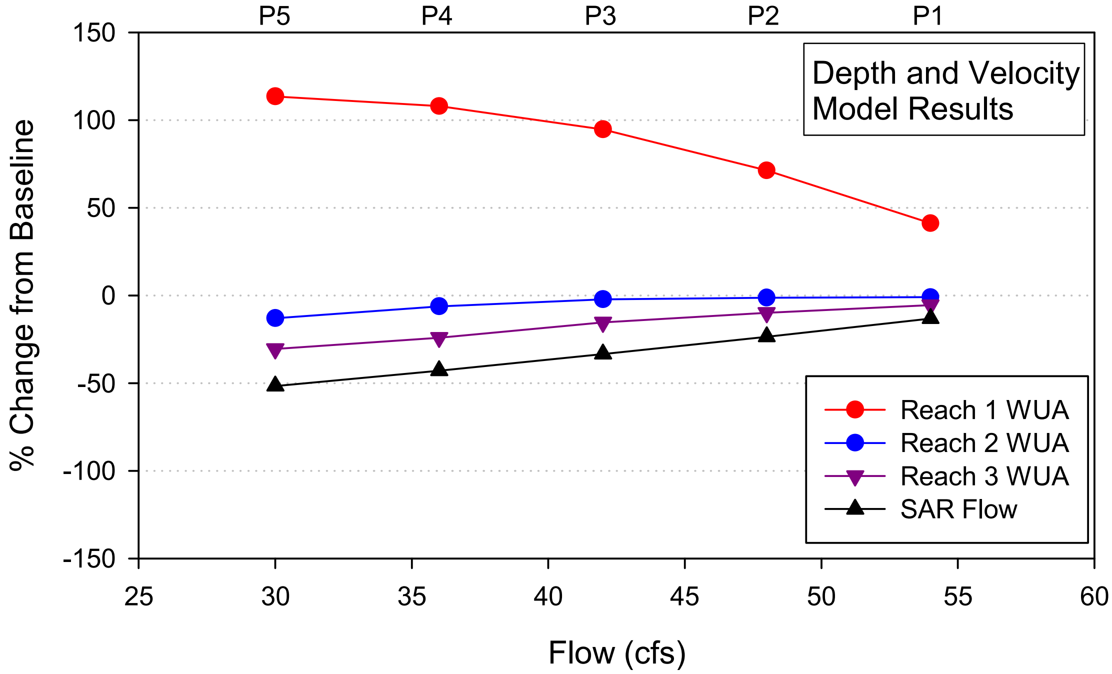

Figure 31: Percent change in adult Santa Ana sucker weighted usable area (WUA) and Santa Ana River (SAR) flow from baseline for each reach for the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the Santa Ana River flow at the upstream end of the study area.

4.2.3.2 Juvenile

Juvenile Santa Ana sucker WUA, incorporating depth and velocity, was greatest in Reach 3 for the baseline flow and for all phases of RIX reduction. For the baseline flow, WUA was lowest in Reach 1; however, increases in WUA in Reach 1 compared to decreases in WUA in Reach 2 with decreasing flow, resulted in greater WUA in Reach 1 by Phase 4 (Table 15, Figure 32).

The amount of juvenile WUA as a function of the total area for all flows and reaches was similar to adult WUA as a function of the total area (Figure 30 and Figure 33). The WUA as a function of total area for depth and velocity (Figure 33) was substantially less than with depth only (Figure 21) or depth and substrate modeling (Figure 27).

For Reach 1, large increases in WUA from baseline occurred through Phase 4, with little change between phases 4 and 5 (Table 15, Figure 34). An opposite trend occurred for Reach 2, with reductions in WUA from baseline ranging from 1.2% to 17.5% for phases 1 and 5, respectively (Table 15, Figure 34). Reductions in WUA from baseline also occurred for all phases in Reach 3, with reductions ranging from 7.5% to 37.2% for phases 1 and 5, respectively (Table 15, Figure 34).

Table 15: Depth and Velocity Model Results - Juvenile Santa Ana sucker weighted usable area (WUA) (sq ft), percent change in WUA from baseline, and WUA as a percent of total area at baseline flow for each reach for baseline and the five phases of RIX reduction. WUA calculations based on depth and velocity modeling data (WEI 2014), and juvenile depth and velocity utilization relationships. Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline
Baseline (63)	35,435	--	9.6	55,938	--	7.5	105,471	--	6.5
Phase 1 (54)	43,558	+22.9	11.9	55,240	-1.2	7.4	97,532	-7.5	6.1
Phase 2 (48)	48,149	+35.9	13.1	54,361	-2.8	7.2	90,681	-14.0	5.6
Phase 3 (42)	50,821	+43.4	13.8	52,181	-6.7	7.0	82,685	-21.6	5.1
Phase 4 (36)	51,841	+46.3	14.1	49,637	-11.3	6.6	74,289	-29.6	4.6
Phase 5 (30)	52,007	+46.8	14.2	46,152	-17.5	6.1	66,258	-37.2	4.1

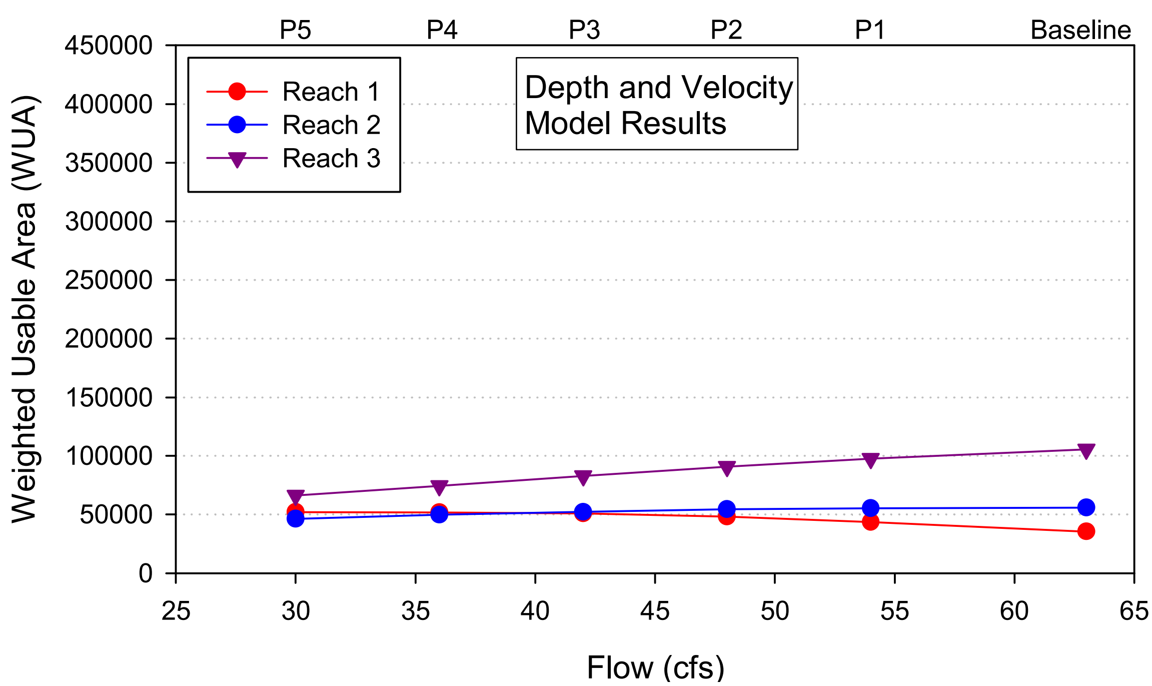

Figure 32: Total juvenile Santa Ana sucker weighted usable area (WUA) (sq ft) for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

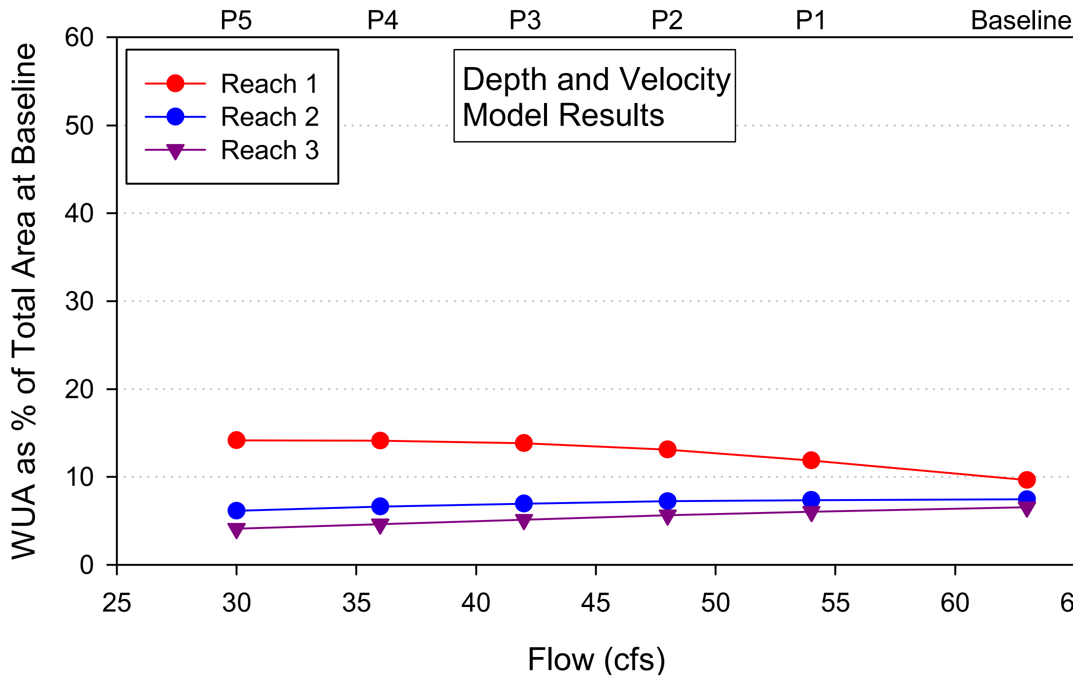

Figure 33: Juvenile Santa Ana sucker weighted usable area (WUA) as percent of total area at baseline flow for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

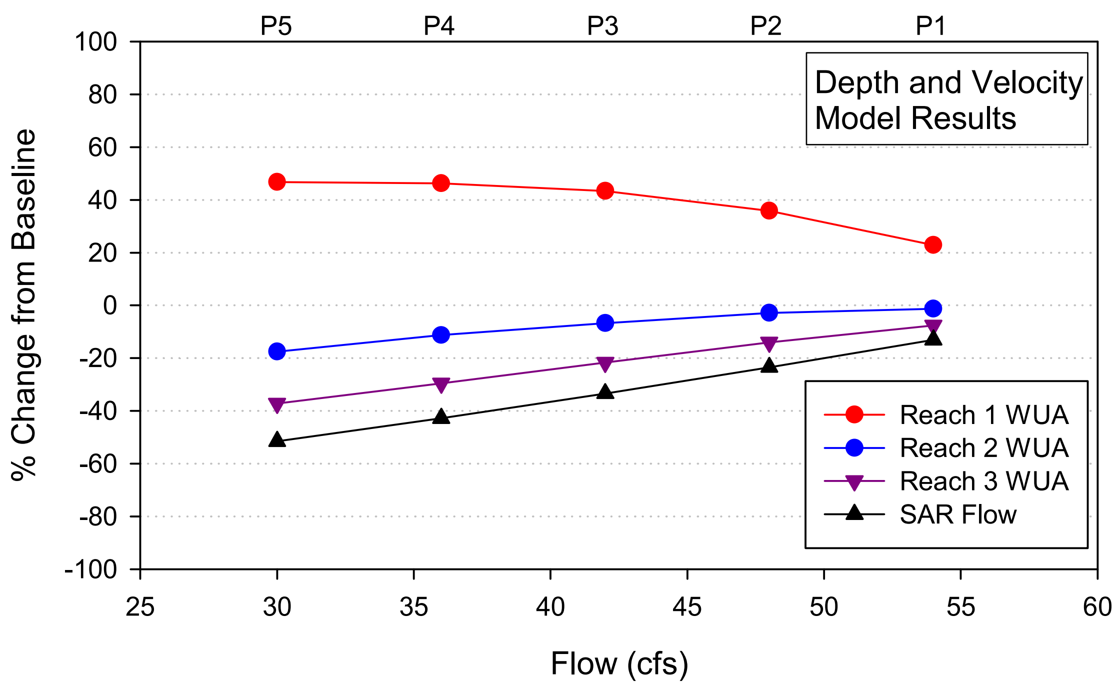

Figure 34: Percent change in juvenile Santa Ana sucker weighted usable area (WUA) and Santa Ana River (SAR) flow from baseline for each reach for the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the Santa Ana River flow at the upstream end of the study area.

4.2.3.2.1 Velocity Modeling Caveats

It should be noted that velocity values produced by the HEC-RAS model increased with depth, and, as such, do not reflect the fine-scale variability in velocity that would likely occur in the river. This is because the modeled velocities were produced to allow a specific "volume" of water to move through a channel with known width and depth. There is no calibration to an observed velocity data set. Calibration to an observed velocity data set can result in variable velocities across a transect (Figure 35) that would more closely resemble what might be observed along a transect than the HEC-RAS modeled velocities, which simply reflect the width-depth relationship (Figure 36). While PHABSIM modeling can be conducted without calibrating to a velocity data set, is recommended that this be limited to where field conditions, equipment failures, time limits, or resources, prevent the collection of at least one velocity calibration data set (USGS 2001). If velocity modeling is to be conducted without calibrating to a velocity data set, the user must check the model output for realism (USGS 2001).

The increases in WUA with decreases in flow based on the combined depth and velocity model are a result of this limitation in the modeled velocity data. Since utilization curves are based on Santa Ana suckers utilizing deep and slow habitats, WUA increases with decreasing flow when both parameters are included, because based on the velocity modeling, slow velocities only occur at shallow depths, and this scenario becomes more prevalent with reduced flow. Given that modeled velocities do not reflect the fine-scale variability in velocity in the river (Figure 36), and the absence of any modeled data that reflect the deep and slow velocities that is the preferred habitat for Santa Ana suckers based on observational data collected by SMEA (2003, 2004) in the river, the HEC-RAS velocity data is not suitable for use in this PHABSIM modeling. As such, WUA results that incorporate velocity as a modeling parameter should be used with caution when interpreting impacts. Acquiring velocity data consistent with PHABSIM modeling would be a good focus for future efforts and allow refinement of the PHABSIM models that incorporate velocity.

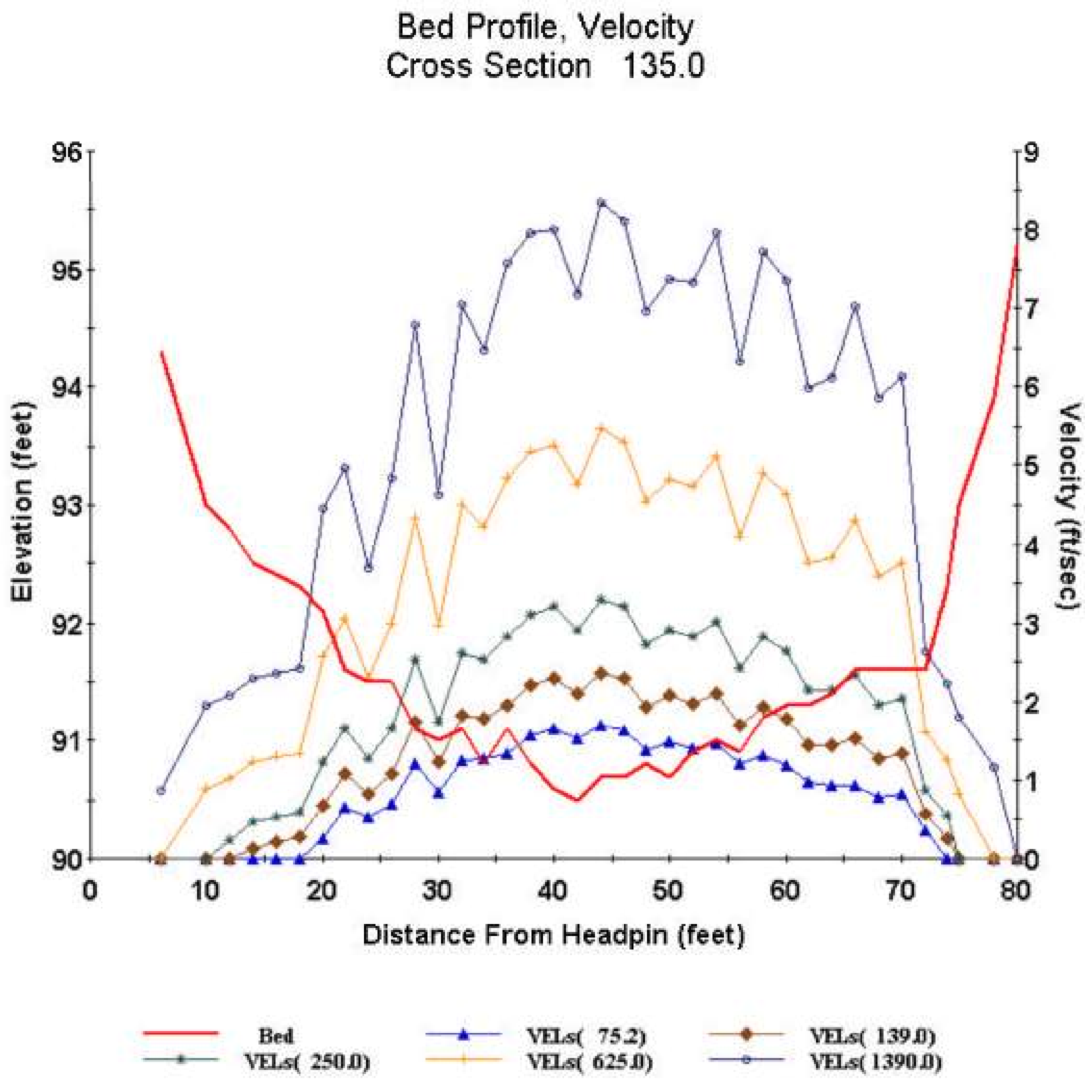

Figure 35: Example of velocity profile with fine-scale variability in the modeled velocities across a transect, based on calibration to observed velocities. Figure 2-19 from USGS (2001).

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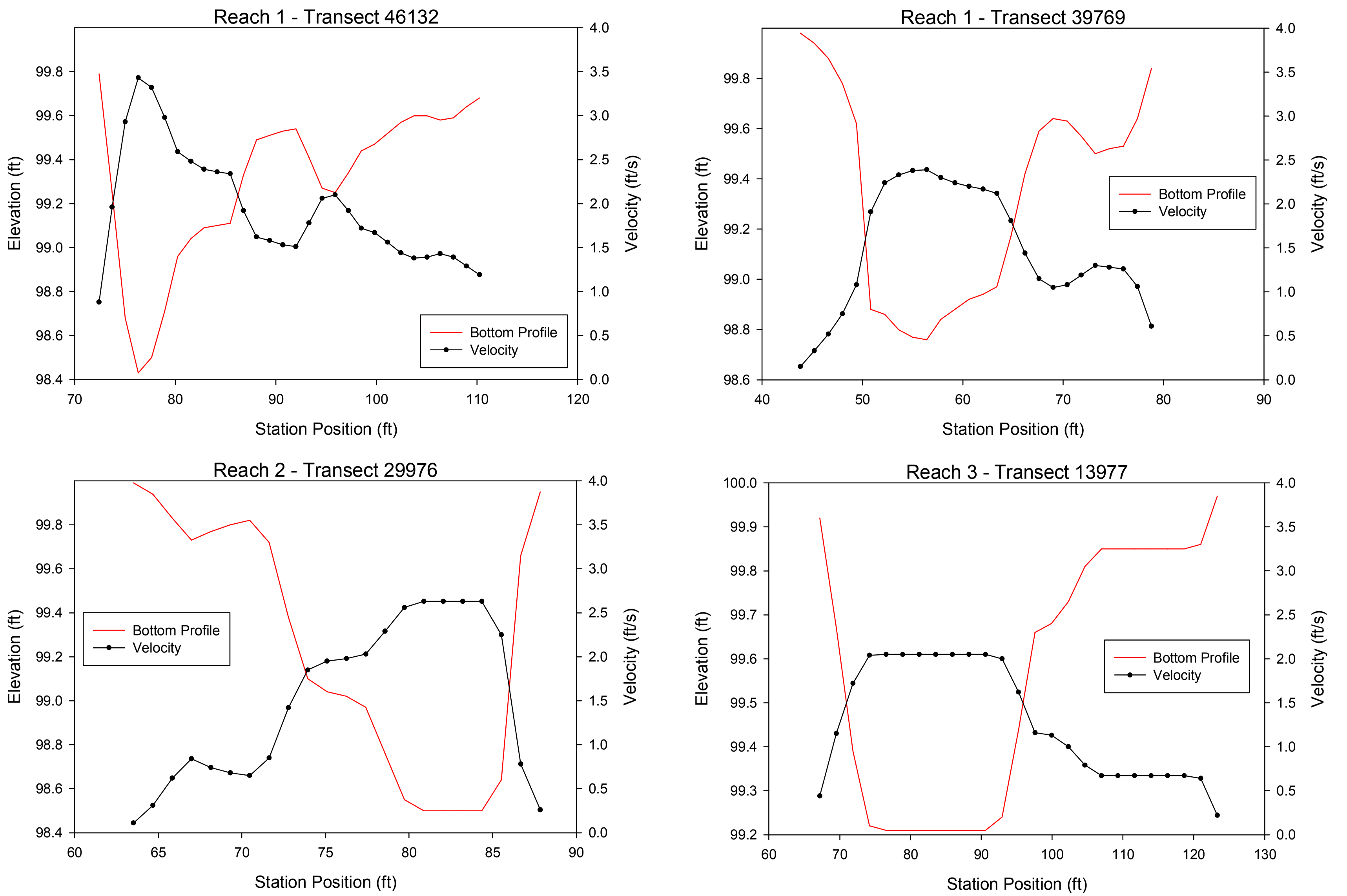

Figure 36: Examples of modeled velocity (ft/s) profiles for four representative transects at baseline flow (63 cfs), demonstrating the absence of fine-scale variability across transects and the mirroring of the bottom profiles.

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4.2.4 Depth, Velocity, and Substrate Model

The addition of velocity and substrate as modeling parameters, along with depth, gives the same relationships between WUA and flow as was observed with depth and velocity as modeling parameters, for each reach. Incorporating substrate to the depth and velocity model, as a separate constant for each reach, results in decreases in WUA for all three reaches compared to with depth and velocity (Table 16 and Table 17, Figure 37 through Figure 42). The reductions in WUA with depth, velocity, and substrate compared to with depth and velocity were smallest in Reach 1, greatest in Reach 3, and intermediate in Reach 2 for both adult and juvenile suckers. These relative reductions in WUA by reach, represent the longitudinal change in substrate conditions from predominantly gravel and cobble in Reach 1, a mix of gravel and sand substrate in Reach 2, and predominantly sand substrate in Reach 3. The reductions occurred for all phases, thus the percent changes from baseline for each phase are the same as the results presented for depth and velocity for both adult and juveniles.

Table 16: Depth, Substrate, and Velocity Model Results - Adult Santa Ana sucker weighted usable area (WUA) (sq ft), percent change in WUA from baseline, and WUA as a percent of total area at baseline flow for each reach for baseline and the five phases of RIX reduction. Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline
Baseline (63)	23,244	--	6.3	26,127	--	3.5	25,394	--	1.6
Phase 1 (54)	32,821	+41.2	8.9	25,897	-0.9	3.4	24,022	-5.4	1.5
Phase 2 (48)	39,826	+71.3	10.8	25,786	-1.3	3.4	22,925	-9.7	1.4
Phase 3 (42)	45,262	+94.7	12.3	25,578	-2.1	3.4	21,494	-15.4	1.3
Phase 4 (36)	48,334	+107.9	13.2	24,520	-6.2	3.3	19,324	-23.9	1.2
Phase 5 (30)	49,629	+113.5	13.5	22,759	-12.9	3.0	17,652	-30.5	1.1

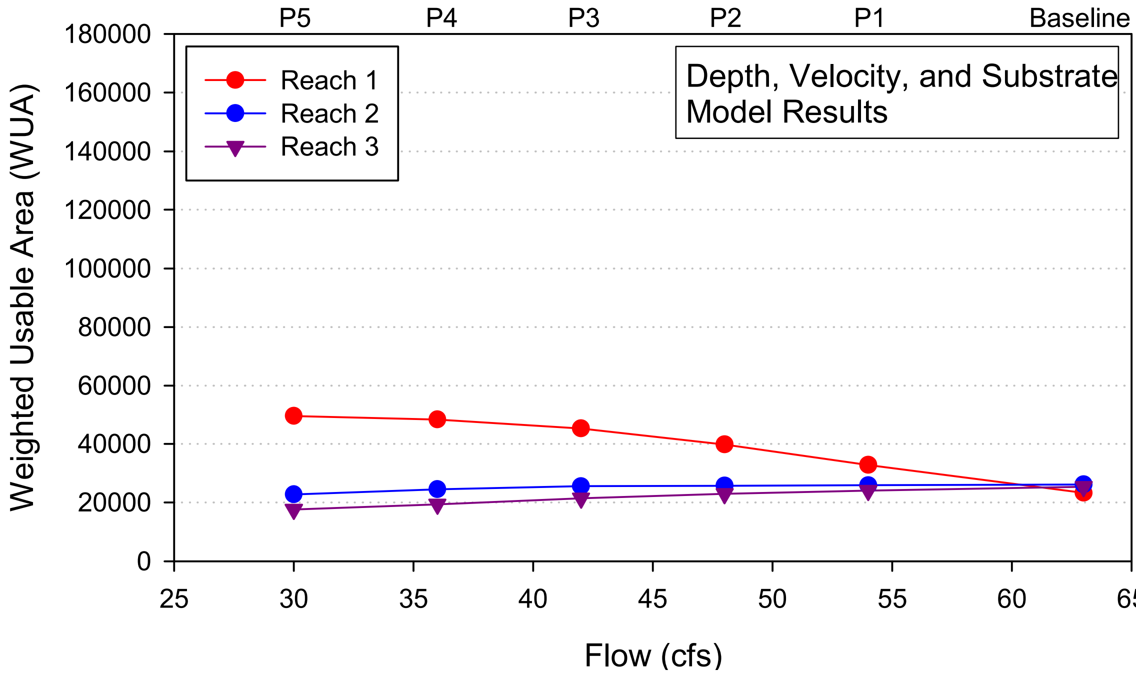

Figure 37: Total adult Santa Ana sucker weighted usable area (WUA) (sq ft) for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

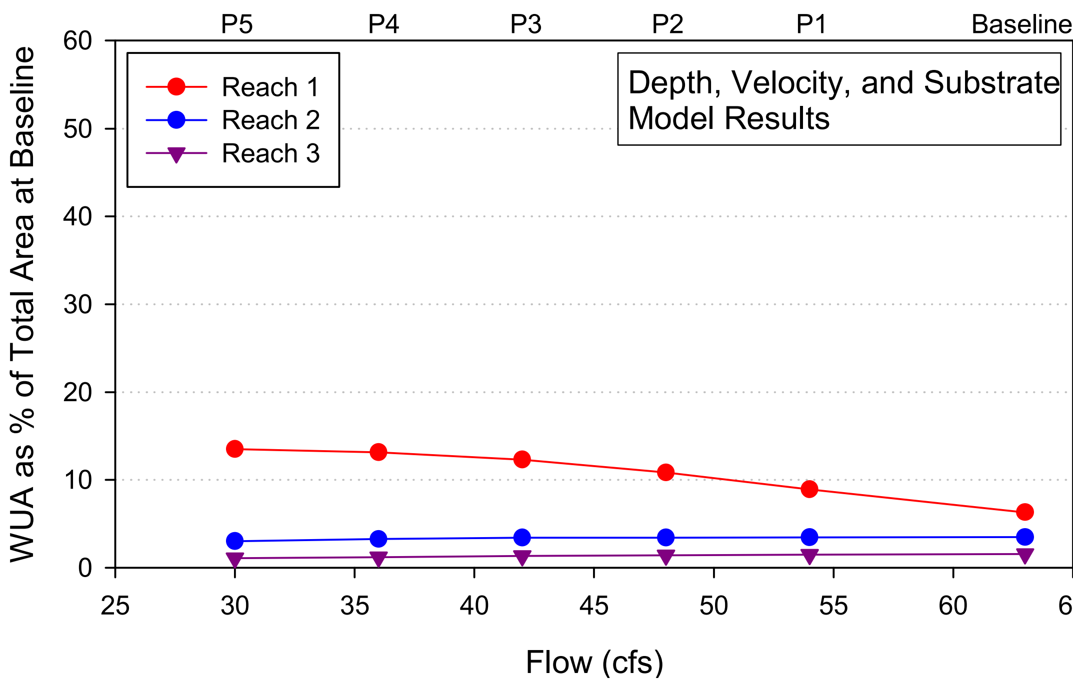

Figure 38: Adult Santa Ana sucker weighted usable area (WUA) as percent of total area at baseline flow for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

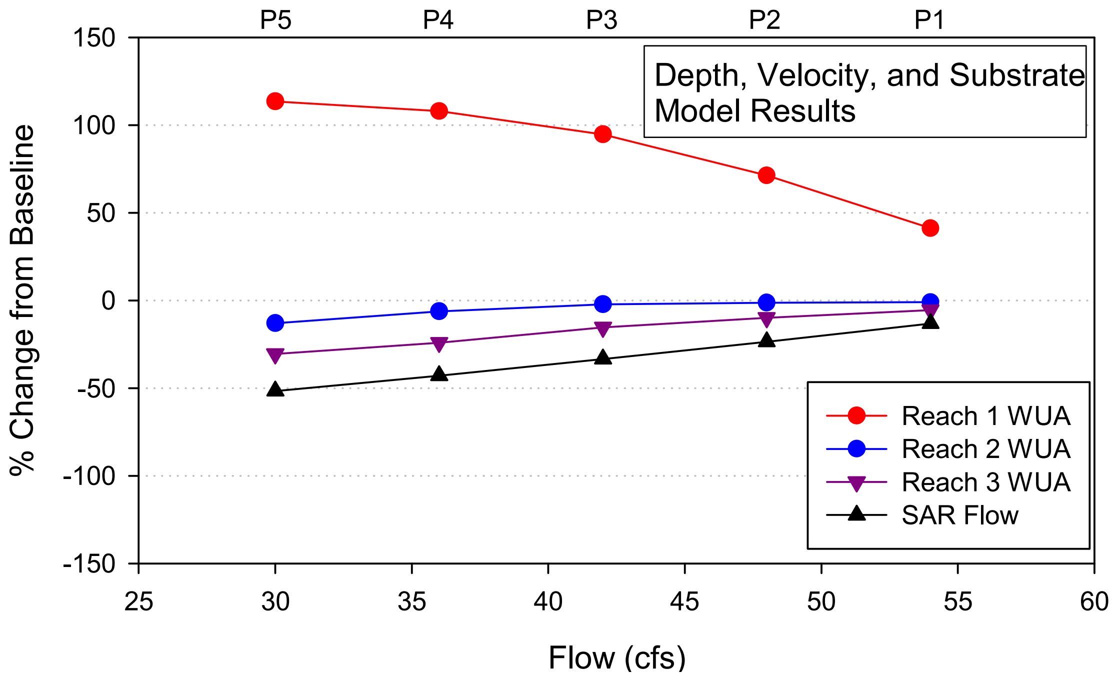

Figure 39: Percent change in adult Santa Ana sucker weighted usable area (WUA) and Santa Ana River (SAR) flow from baseline for each reach for the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the Santa Ana River flow at the upstream end of the study area.

Table 17: Depth, Substrate, and Velocity Model Results - Juvenile Santa Ana sucker weighted usable area (WUA) (sq ft), percent change in WUA from baseline, and WUA as a percent of total area at baseline flow for each reach for baseline and the five phases of RIX reduction. Values in parentheses indicate total Santa Ana River flow at the upstream end of the study reach, and n values represent the number of transects evaluated per reach.

Phase (SAR cfs)	Reach 1 (n = 22)			Reach 2 (n = 33)			Reach 3 (n = 36)		
	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline	WUA (sq ft)	% change from baseline	WUA as % of total area at baseline
Baseline (63)	24,805	--	6.7	26,850	--	3.6	27,422	--	1.7
Phase 1 (54)	30,491	+22.9	8.3	26,515	-1.2	3.5	25,358	-7.5	1.6
Phase 2 (48)	33,704	+35.9	9.2	26,093	-2.8	3.5	23,577	-14.0	1.5
Phase 3 (42)	35,575	+43.4	9.7	25,047	-6.7	3.3	21,498	-21.6	1.3
Phase 4 (36)	36,289	+46.3	9.9	23,826	-11.3	3.2	19,315	-29.6	1.2
Phase 5 (30)	36,405	+46.8	9.9	22,153	-17.5	3.0	17,227	-37.2	1.1

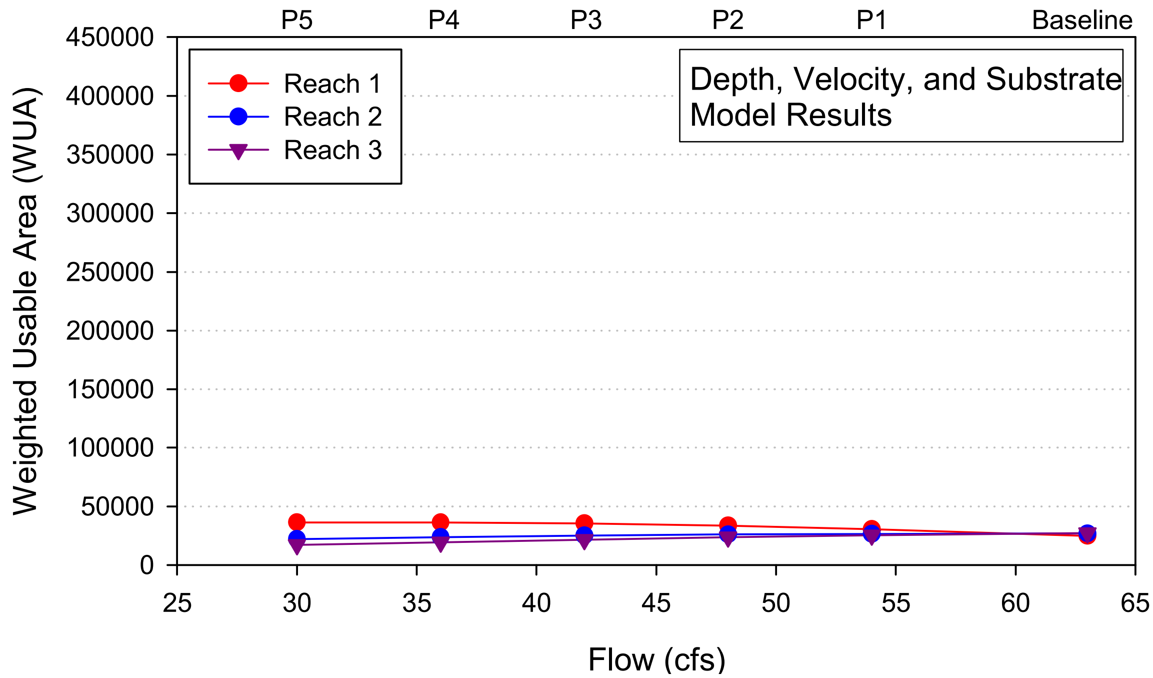

Figure 40: Total juvenile Santa Ana sucker weighted usable area (WUA) (sq ft) for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

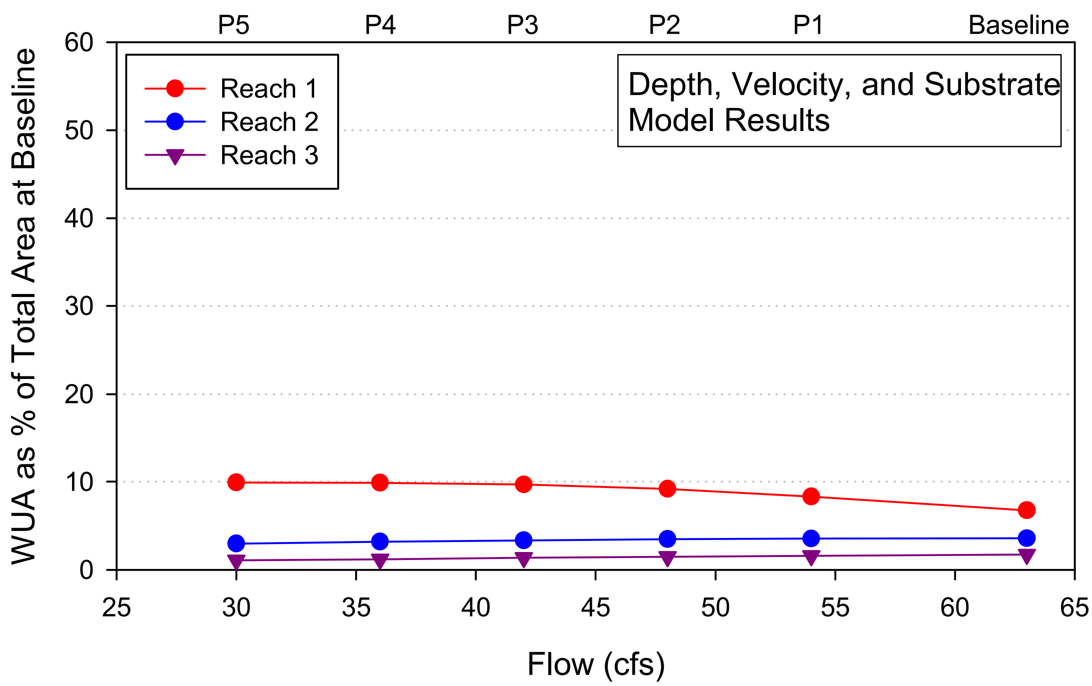

Figure 41: Juvenile Santa Ana sucker weighted usable area (WUA) as percent of total area at baseline flow for each reach for baseline flow and the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the flow in the Santa Ana River at the upstream end of the study area.

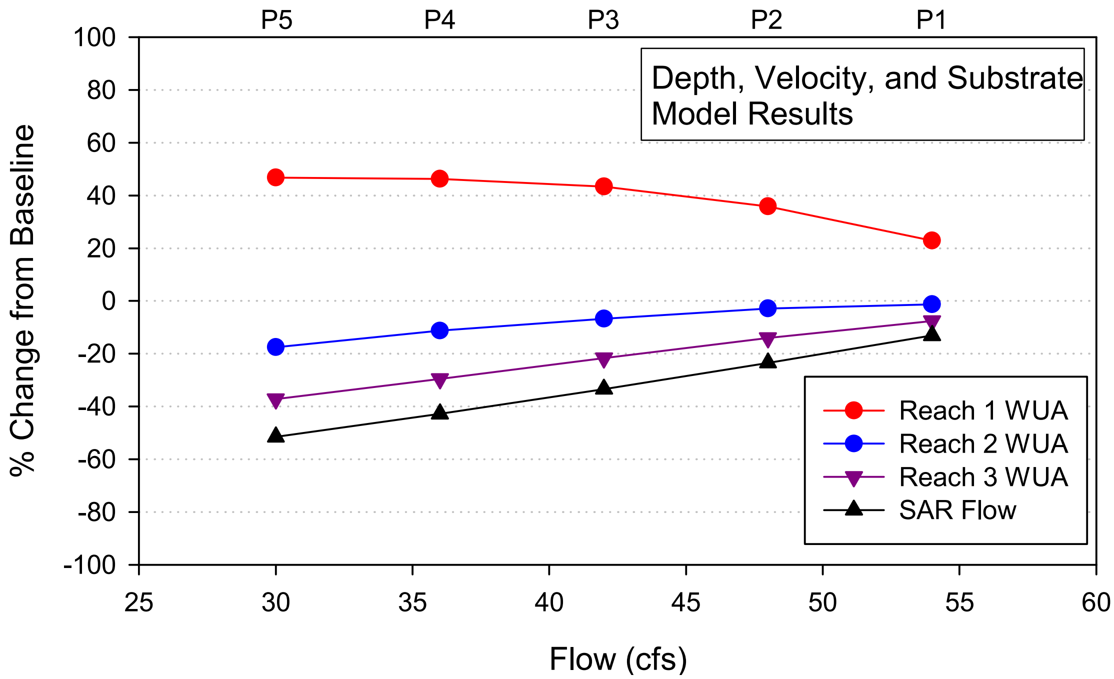

Figure 42: Percent change in juvenile Santa Ana sucker weighted usable area (WUA) and Santa Ana River (SAR) flow from baseline for each reach for the five phases of RIX reduction (P1 through P5) (top x-axis). The bottom x-axis represents the Santa Ana River flow at the upstream end of the study area.

As described previously, velocity values produced by the HEC-RAS model increased with depth, and did not reflect the fine-scale variability in velocity that would likely occur in the river. The increases in WUA with decreases in flow, observed for the depth, velocity, and substrate model, are a result of this limitation in the modeled velocity data. As such, the WUA results presented for the depth, velocity, and substrate model, along with the results for the depth and velocity model, should not be used for the effects analysis until additional velocity data consistent with PHABSIM can be collected for model calibration.

4.2.5 Model Selection for Impacts Analysis

Given the unreliable WUA results for the models that incorporate velocity, based on the velocity data not being calibrated to observed velocities, modeling results that incorporate velocity, including the depth and velocity model and the depth, velocity, and substrate model are not used. Two models remain, including the depth only model and the depth and substrate model. While the addition of substrate to the depth model does not change the relative changes in WUA among flow levels, the addition of substrate scales the results by reach to incorporate the longitudinal change in substrate conditions from predominantly gravel and cobble in Reach 1, a mix of gravel and sand substrate in Reach 2, and predominantly sand substrate in Reach 3. As such, the model that incorporates both depth and substrate was chosen as the most appropriate model for assessing potential impacts to the Santa Ana sucker, and is the model discussed in the remainder of this report.

5.0 Impacts Analysis

Impacts were evaluated separately for the three reaches due to the differences in the abundance of Santa Ana suckers, habitat characteristics, and available modeling results for each reach, using the approach outlined in Section 3.3. Impacts were rated based on the percent change in the adult WUA, as the adult life stage was the most limiting.

5.1 Reach 1

The reduction in adult WUA from baseline in Reach 1 was 2.7, 6.8, 12.5, 19.7, and 27.6% for phases 1 through 5, respectively (Table 12). Juvenile WUA did not exceed a 10% reduction from baseline until Phase 4 (Table 13). As such, "No Impacts" would be expected for phases 1 and 2, "Less than Significant Impacts" would be expected for phase 3 and 4, and "Potentially Significant Impacts" would be expected for Phase 5 for Reach 1. Greater negative impact designations in later phases are largely associated with reductions in depth, which are reflected in the WUA results based on depth and substrate data.

Santa Ana suckers have also been shown to prefer slow velocities. While velocity was not included into the final PHABSIM model used for effects designations, reductions in velocity in Reach 1 with reductions in flow may be beneficial for Santa Ana suckers given their preference for slow velocities.

The inclusion of substrate as a constant scales the results by reach to incorporate the longitudinal change in substrate conditions. Principal components analyses (PCA) evaluating the relationship between Santa Ana sucker abundance and habitat characteristics (SMEA 2010b) also suggests that substrate is an important variable in explaining the variation in Santa Ana sucker abundance. Although deeper habitats will be reduced with reductions in flow, the substrate in Reach 1 is largely made up of cobble and gravel, which is the preferred substrate by Santa Ana sucker. Provided coarse substrates remain in this reach with reduction in flow, which is expected to at least some degree given the availability of coarse substrates from within the reach and upstream, the coarse substrates in this reach should help the Santa Ana sucker population persist in Reach 1 by providing a forage base and substrate for spawning.

Predation risk from wading or diving animals can be higher in shallower water than deeper water; however, it can be mediated by increased cover (Harvey and Stewart 1991). With shallower depths in the Santa Ana River, predation by birds or other shore animals could increase, but, predation may be mediated to some extent in Reach 1 by the continued presence of overhanging vegetation and structure compared to Reach 2, where the river largely meanders through a wider sand bottom channel.

5.2 Reach 2

In Reach 2, reductions in adult and juvenile WUA from baseline were greater than in Reach 1 for all phases, reflecting the different channel characteristics in this reach. Slightly less useable habitat was available to begin with during the baseline flow in Reach 2 than in Reach 1 despite a greater total area; however, this would be expected given the shallower and more marginal substrate conditions. The reductions for juvenile WUA were smaller than for adult WUA and the total amount of juvenile WUA was greater than adult WUA for each flow. The greater reductions in WUA in Reach 2 than in Reach 1 resulted in some greater negative impact designations than in Reach 1. As a result of the reductions in adult WUA in Reach 2, "Less than Significant Impacts" would be expected for phases 1 and 2, and "Potentially Significant Impacts" would be expected for phases 3, 4, and 5.

Reductions in flow in Reach 2 would also potentially have a negative impact on the Santa Ana sucker through increased predation by birds or shore animals. This reach is often unconfined by the streambanks resulting in a meandering stream between at least one sand bank, which provides little overhead cover from predation.

Although reducing depth in this reach would likely have a negative impact on Santa Ana suckers as reflected in the impacts designations, reductions in flow would also reduce velocity, which may result in more velocities in the preferred range for Santa Ana suckers. It is also possible the limiting factor in this reach is the lack of consistent coarse substrate. The transition point from a mix of cobble and gravel to nearly all fine substrate occurred approximately 25% of the way downstream into Reach 2 in 2006, extended through Reach 2 in 2007, and approximately 40% of the way into Reach 2 in 2008 (based on Thompson et al. 2010). The lack of suitable substrate in some years and the limited deeper habitats under current conditions, indicate that Reach 2 currently provides marginal habitat for Santa Ana suckers in some years, compared to the deeper habitats and continuous coarse substrate in Reach 1. The variable abundance of Santa Ana suckers at Highway 60 and Mission Boulevard since 2001 and the general low abundance of Santa Ana sucker since 2005 at these sites are likely related to this fluctuation in the amount of suitable habitat during some years.

Reductions in depths could have less of an effect than the predicted reductions in adult and juvenile WUA in this reach as modeled stream depths represent more of an "average" value in reaches 2 and 3, based on the trapezoidal stream bottom geometry used in modeling, which is different from maximum values based on the actual stream bottom channel shape as in Reach 1. Maximum depths could be greater than the values presented, due to areas of scour typically located along the streambanks and island edges in reaches 2 and 3. In other words, if stream bottom data were available for reaches 2 and 3 with the same detail as Reach 1, maximum depths could be greater, which would likely result in greater amounts of WUA than what has been presented and the associated negative effects may be less than predicted.

5.3 Reach 3

Adult and juvenile WUA was lower in Reach 3 than in reaches 1 and 2 for all flows, due to the lack of deeper habitats and the relatively poor substrate conditions. The reductions in WUA from baseline were similar to in Reach 2, resulting in the same impact designations.

Reductions in WUA for each phase are related to the reductions in depth in Reach 3. The deeper preferred habitat of Santa Ana suckers in this reach is rare compared to in reaches 1 and 2, which likely contributes to the low abundance of suckers in this reach. The actual maximum depths would likely be greater for each flow, given that modeling was conducted with a uniform trapezoidal channel; however, this habitat is still rare compared to upstream reaches.

Coarse substrates, which are preferred by Santa Ana suckers, are also rare in this reach, which may be another limiting factor in the use of this reach. The low abundance of Santa Ana suckers in Reach 3 under the current conditions is likely related to the small amount of deeper habitats available and the rarity of coarse substrates compared to upstream where deeper habitats and coarse substrates are more readily available. While the reductions in flow would result in reductions in WUA based on reduced depth, the reduced WUA may not be as large as expected based on modeling alone in Reach 3, as the current suitable habitat for Santa Ana suckers in this reach is already largely limited to discrete areas of scour located along streambanks and islands that provide additional depth and some coarse substrates, which is not accounted for in the modelling.

5.4 Impacts Analysis Summary

In Reach 1, “No Impacts” would be expected from the reduction in Santa Ana River flow for phases 1 and 2 on Santa Ana suckers, based on changes in habitat. “Less than Significant Impacts” would be expected for phases 3 and 4, and “Potentially Significant Impacts” would be expected for Phase 5 (Table 18). In reaches 2 and 3, the reductions in flow would result in “Less than Significant Impacts” to Santa Ana suckers for phases 1 and 2, and “Potentially Significant Impacts” for phases 3, 4, and 5 (Table 18).

It is important to consider that impacts designations are based on modeling a static channel, where the changes in hydraulic characteristics and habitat availability are based only on reductions in flow from RIX. In reality, the Santa Ana River is a dynamic river with winter floods capable of scouring away riparian vegetation and islands, relocating the active channel, and redistributing substrate. MBC (2000) concluded that changes in riparian conditions from reductions in RIX flows would likely be minor compared to the impacts due to flooding and scouring following large storm events. Evaluation of imagery from Google Earth, before and after the flood event in December 2010, strengthens this finding, and illustrates significant movement of the active channel throughout the floodplain, and the fast regrowth of riparian and island vegetation. Thus, it is likely that the channel should adapt along with the reduction in flows from RIX and will be periodically "reset" from flooding events.

Santa Ana suckers have been shown to tolerate a wide variety of stream conditions, inhabiting flowing streams with varying water depths, velocities, and streambed substrates (Moyle and Yoshiyama 1992). As such, we believe the effects designations for Santa Ana suckers (Table 18), which are based on the modeling results, are in general, conservative in nature. Incorporating the general tolerance and resiliency of Santa Ana suckers, as well as the predicted changes in habitat from reduced RIX flow in the context of the overall changes to the channel that occur following storm events, all of which highlight the adaptability of the channel and the Santa Ana suckers, could result in lower levels of impacts than what is shown in Table 18. However, given the uncertainties in modeling and the threatened status of the Santa Ana sucker, we believe a conservative approach, with the impact analysis based on the modeling results and defined criteria, as presented in Table 18, is appropriate.

Table 18: Impact designations based on changes in habitat for Santa Ana suckers in the Santa Ana River. All "Less than Significant" and "Potentially Significant" impacts are considered negative.

Phase (SAR cfs)	Reach 1	Reach 2	Reach 3
Phase 1 (54)	No Impact	Less than Significant	Less than Significant
Phase 2 (48)	No Impact	Less than Significant	Less than Significant
Phase 3 (42)	Less than Significant	Potentially Significant	Potentially Significant
Phase 4 (36)	Less than Significant	Potentially Significant	Potentially Significant
Phase 5 (30)	Potentially Significant	Potentially Significant	Potentially Significant

5.4.1 Sucker Distribution and Habitat Conditions

The modeling results represent the expected changes in the current habitat conditions and effects associated with the current distribution of the Santa Ana sucker in the Santa Ana River. However, as noted earlier, since the UAA data collected in the early 1990s, the distribution of Santa Ana suckers has shifted from the MWD Crossing upstream to the Riverside Avenue reach as a result of changes in water quality, flow, riparian vegetation, and general channel characteristics since RIX began discharging. Even recently, since 2001 when SMEA began annual monitoring, Santa Ana sucker populations were most abundant near Highway 60 and Mission Boulevard (Reach 2) from 2001 through 2004, yet are now most abundant at the upstream Riverside Avenue site (Reach 1) in the remaining years from 2005 through 2011. The shift in Santa Ana sucker density to near Riverside Avenue, suggests that the habitat in this reach is preferable to further downstream where abundance has decreased.

This period of monitoring by SMEA coincides with two high flow events in 2005 and 2010 (Figure 3), the both of which shifted the channel in some locations, and removed bank and island vegetation (Figure 4; Appendix C). This shift in the Santa Ana sucker population upstream, as well as its continued presence, is illustrative of the resiliency and adaptive nature of the Santa Ana sucker.

As described above in Section 2.1.2, prior to SMEA monitoring and prior to RIX discharge, Santa Ana suckers were found to be absent at several sites just upstream of Reach 1, rare in Reach 2 near Mission Boulevard, and abundant at two sites in and just downstream of Reach 3 during the 1991 UAA surveys (C&A 1992). Santa Ana sucker abundance during these surveys, although highly variable among months, was comparable at the MWD Crossing and downstream of Van Buren Boulevard sites as is currently found at the Riverside Avenue site from 2005 through 2011. These sites correspond with where rising groundwater is present (WEI 2013a). Surveys were also conducted in 1991 and additional sampling in 1995 and 1996, found the majority of Santa Ana suckers in the main stem at sites located immediately downstream of tributaries in the Riverside Narrows reach, indicating these tributaries were providing important habitat for the Santa Ana sucker in this main stem reach at that time (CEC 1996). Habitat characteristics commonly associated with Santa Ana sucker habitat requirements, including coarse substrates and algae growth, were more commonly observed in 1991 and 1996 in those tributaries than in the main stem river (CEC 1996) in Reach 3 of the current study.

Habitat characteristics during the 1991 surveys from E Street (above the current RIX discharge) to just above Prado Dam, and were generally described as poor, with shifting sand substrate throughout the study area (C&A 1992). Somewhat higher habitat ratings of fair were given for sites in the vicinity of the current RIX discharge, due to the relative lack of channelization, improved riparian vegetation, and improved substrate characteristics near the Rialto Drain inflow. During that study, water quality was poor in the reach from E Street downstream to Mission Boulevard, and it was suggested that chlorine and un-ionized ammonia could have been a limiting factor for fish populations in this reach (C&A 1992). This reach was also largely channelized and flood control operations resulted in the lack of woody riparian vegetation (Appendix B, Photo B-2, Photo B-4, and Photo B-6) (C&A 1992). Coarse substrates, which are now prevalent in this reach compared to downstream, and appear to be providing preferred habitat and as a result an abundant Santa Ana sucker population, were not common in 1991. Santa Ana suckers were most abundant in 1991 near the MWD Crossing where depths were relatively more shallow than currently observed in Reach 1 and shifting sand substrate was dominant as it is currently (Photo B-7and Photo B-8), suggesting the sucker is adaptable and able to populate reaches without the greater depths and desired substrate conditions now present in Reach 1.

Areas of scour associated with the margins of vegetated islands, which is where Santa Ana suckers were most abundant during the 1990s surveys in the MWD Crossing area, are still present currently in this reach. However, Santa Ana suckers have shifted their population upstream to near Riverside Avenue, due to the readily available deeper habitats and coarse substrates in this reach. Even though some reductions in average depth will occur with reducing flow, the localized deeper areas of scour along stream banks and island edges should remain, as they do now and did prior to RIX discharge. These localized areas of scour are likely in part related to high flow events, which create scour in some areas, but also remove bank and island vegetation, which is followed by establishment of new islands and bank vegetation.

In Reach 1, even under the Phase 5 RIX flow reduction scenario, the maximum and average maximum depths for all transects would be 1.82 and 1.08 ft, respectively – both greater than the average depth of 0.7 ft that supported Santa Ana suckers in Reach 3 in the Saiki et al. (2007) study. Furthermore, coarse substrates should remain in Reach 1, to at least some degree with reductions in RIX flow, given the availability and supply of coarse substrates from within the channel and upstream tributaries. Thus, conditions in Reach 1 with reductions in RIX flow would appear to remain more favorable than recent past and current conditions in Reach 3, which supported suckers in the UAA (C&A 1992) and Saiki et al. (2007) study, given the availability of greater depths and the presence of coarse substrates.

It must be noted that the changes in habitat with reductions in RIX flow presented in this report represent the predicted habitat characteristics resulting solely from the reduction in RIX flow. Potential long-term changes in stream morphology or substrate conditions that would be associated with changes in RIX flow would also affect useable habitat and should be monitored over time as part of an adaptive management program. For example, a reduction in flow may result in initial decreases in average depth, but if wetted width decreases due to encroaching riparian vegetation, this may allow for deeper habitats and coarser substrates to remain available through restructuring of the channel over the long-term. Thus, while the overall area of wetted channel may be reduced, as the channel regains its form, the reductions in WUA as predicted by the modeling may become lessened. This scenario appears reasonable given the natural response to the channel following large flow events. Winter flow events are capable of relocating the active channel, and scouring away bank and island vegetation, effectively "resetting" the stream channel. Reestablishment of bank vegetation and islands can occur rather quickly as seen in 2011 through 2013, following the 2010 storm event (Appendix C).

By implementing the RIX flow reduction plan as a phased plan, the river may reestablish a new dynamic equilibrium state providing habitat similar to that currently observed. The phased approach would allow time for additional monitoring of sucker populations and collection of additional data on habitat utilization and channel hydraulics to allow more quantitative PHABSIM modeling to better predict changes for later phases.

5.4.2 Potential Mitigation and Adaptive Management

Given that the Santa Ana sucker is a federally listed species due to loss of habitat from flood control activities, including two major dams and channelization of the river that has restricted the Santa Ana sucker to a fixed portion of the river, any reduction in discharge from RIX should be carefully structured and managed to include conservation measures for the long-term management and maintenance of the Santa Ana sucker and its habitat. Avoidance, minimization, and mitigation measures will need to be considered and approved for any reduction in discharge from RIX. It is assumed that this would occur as part of acquiring an Incidental Take Permit for the Clean Water Factory project and could effectively be proposed as part of an adaptive management plan for managing the Santa Ana sucker, river management, and water discharge for this reach of the Santa Ana River. Such an adaptive management approach, if implemented, should recognize that managing the reach of the Santa Ana River between the Rialto Drain and the MWD Crossing is part of a large conservation program for managing the Santa Ana sucker in the Santa Ana River. Separate management components will need to address the following areas of the Santa Ana River:

- Upstream of the Rialto Drain (Sediment transport)
- Rialto Drain to MWD Crossing (Clean Water Factory)
- MWD Crossing to Prado Dam (Transition Zone)
- Below Prado Dam (Historic habitat)

An adaptive management plan should consist of the continued monitoring of Santa Ana suckers at the locations recently monitored by SMEA including, Riverside Avenue, Highway 60, Mission Boulevard, and the MWD Crossing. Monitoring should be structured to be able to detect potential shifts in population structure as related to habitat availability and other factors, allowing evaluation of long-term trends in the populations.

Habitat characteristics, including wetted width, depth, velocity, substrate, and riparian conditions should also be monitored to determine if changes occur after RIX reductions and if changes in habitat are associated with changes in fish populations. The phased implementation also allows the adaptive management plan to incorporate additional studies to better model the hydraulic characteristics of the river, the habitat utilization and development of preference-based habitat suitability curves, and improve upon the PHABSIM analysis herein.

By implementing the RIX flow reduction plan as a phased plan, this naturally lends itself to an adaptive management approach with monitoring of Santa Ana sucker populations and habitat, and with future management actions outlined that are dependent on the monitoring results.

An effective adaptive management plan will need to have mechanisms in place to detect changes or shifts in Santa Ana sucker populations and habitat characteristics, and strategies to implement changes in management if an overall decline in the Santa Ana sucker population associated with the RIX reduction is detected. Active habitat restoration may also be an important tool to help maintain Santa Ana sucker habitat, if the stream channel does not respond naturally to changes in flow.

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Appendix A

Additional Tables

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Table A-1: Estimates of historic flow, width, and depth for the Santa Ana River. Data summarized from WEI (2013a).

	1938			1948			1952			1953			1954			1959		
	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)
Above Riverside Narrows																		
E Street to RIX	42	NA	NA	1	0	0	1	0	0	1	27	NA	5	NA	NA	22	NA	NA
RIX to Riverside Ave		NA	NA		0	0		0	0		10	0.55		NA	NA		11	1.13
Riverside Ave to Mission Blvd		NA	NA		12	NA		0	0		0	0		NA	NA		0	0
Mission Blvd to Van Buren Blvd		NA	NA		40	2.56		NA	NA		44	2.86		NA	NA		17	1.9
Below Riverside Narrows																		
Van Buren Blvd to Hamner Ave	74	NA	NA	35	100	1.9	109	84	0.65	126	77	0.65	51	61	2.64	33	19	0.56
Hamner Ave to River Rd		NA	NA		121	0.59		97	0.45		87	0.45		NA	NA		69	0.46

Table A-1: (Continued)

	1962			1966			1967			1974			1977		
	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)	Ave Flow (cfs)[1]	Ave Width (ft)	Max Depth (ft)
Above Riverside Narrows															
E Street to RIX	22	NA	NA	40	90	NA	15	68	NA	33	NA	NA	30	89	NA
RIX to Riverside Ave		0	0		64	0.77		66	1.6		65	1.31		12	0.64
Riverside Ave to Mission Blvd		8	0.8		26	0.93		8	0.92		28	1.77		7	0.27
Mission Blvd to Van Buren Blvd		29	1.46		33	1.86		45	1.99		50	1.46		39	0.94
Below Riverside Narrows															
Van Buren Blvd to Hamner Ave	42	38	1.46	42	46	1.31	45	54	0.33	52	68	1.45	55	49	0.85
Hamner Ave to River Rd		74	0.37		80	0.54		66	0.75		62	0.45		52	0.5

[1] Values represent estimates of flow above and below Riverside Narrows. Average values are presented when estimates were available for multiple dates.

Table A-2: Depth availability of all sites sampled (SMEA 2003, 2004). Depth ranges have been converted from cm to ft.

Depth (ft)	Individual Sites Surveyed Utilization as Percent of Total					Average Availability All Sites Combined
	SMEA (2003)			SMEA (2004)		
	Mission Blvd	Hwy 60	Riverside Ave	Downstream Hwy 60	Between Hwy 60 and Mission	
0-0.16	1.8	5.6	7.1	6.9	8.8	6.0
0.20-0.33	4.2	18.0	6.3	10.3	10.5	9.9
0.36-0.49	10.2	25.9	10.3	0	14.4	12.2
0.52-0.66	16.2	16.4	14.3	10.3	23.9	16.2
0.69-0.82	15.0	14.8	11.1	17.2	22.9	16.2
0.85-0.98	19.8	8.2	9.5	24.1	13.7	15.1
1.02-1.15	12.0	6.9	10.3	20.7	3.9	10.8
1.18-1.31	15.0	1.3	11.1	10.3	1.5	7.8
1.34-1.48	1.8	1.0	10.3	0	0.2	2.7
1.51-1.64	1.2	0.7	1.6	0	0	0.7
1.67-1.80	1.8	0.7	2.4	0	0	1.0
1.84-1.97	0.6	0.0	2.4	0	0	0.6
2.00-2.13	0.6	0.3	1.6	0	0	0.5
2.16-2.30	0.0	0.3	1.6	0	0	0.4
2.30+	n/a	n/a	n/a	0	0	0

Table A-3: Bottom velocity availability of all sites sampled (SMEA 2003, 2004).

Bottom Velocity (ft/s)	Individual Sites Surveyed Utilization as Percent of Total					Average Availability All Sites Combined
	SMEA (2003)			SMEA (2004)		
	Mission Blvd	Hwy 60	Riverside Ave	Downstream Hwy 60	Between Hwy 60 and Mission	
0.00-0.50	15.1	17.2	26.6	48.3	64.1	34.3
0.51-1.00	16.9	20.8	16.9	51.7	35.9	28.4
1.01-1.50	18.7	27.9	27.4	0	0	14.8
1.5-2.00	24.1	19.2	20.2	0	0	12.7
2.01-2.50	18.7	14.0	6.5	0	0	7.8
2.51-3.00	6.6	1.0	2.4	0	0	2

Table A-4: Substrate type availability of all sites sampled (SMEA 2003, 2004).

Substrate Type	Individual Sites Surveyed Utilization as Percent of Total					Average Availability All Sites Combined
	SMEA (2003)			SMEA (2004)		
	Mission Blvd	Hwy 60	Riverside Ave	Downstream Hwy 60	Between Hwy 60 and Mission	
Silt	2.4	1.9	2.4	0	2.0	1.7
Silt/sand	7.2	4.5	15.9	0	0.2	5.6
Sand	68.3	76.0	22.2	53.6	49.4	53.9
Sand/gravel	19.2	13.6	48.4	39.3	39.3	32.0
Gravel	1.2	0.3	4.8	3.6	6.7	3.3
Sand/cobble	0.0	2.9	5.6	3.6	1.5	2.7
Gravel/cobble	0.0	0.6	0.8	0	0	0.3
Cobble	0.6	0.0	0.0	0	0	0.1
Boulder	1.2	0.0	0.0	0	1.0	0.4

Table A-5: Juvenile sucker depth utilization of all sites sampled (SMEA 2003, 2004). Depth ranges have been converted from cm to ft.

Depth (ft)	Individual Sites Surveyed Utilization as Percent of Total					Average Utilization All Sites Combined N=252	Utilization (Standardized to 1.0)
	SMEA (2003)			SMEA (2004)			
	Mission Blvd N=54	Hwy 60 N=65	Riverside Ave N=18	Downstream Hwy 60 N=34	Between Hwy 60 and Mission N=81		
0-0.16	0	0	0	0	0	0	0
0.20-0.33	0	0	0	0	0	0	0
0.36-0.49	0	0	22.2	11.8	6.2	8.0	0.40
0.52-0.66	9.3	9.2	33.3	0	3.7	11.1	0.55
0.69-0.82	5.6	10.8	16.7	0	9.9	8.6	0.43
0.85-0.98	11.1	16.9	27.8	2.9	9.9	13.7	0.68
1.02-1.15	66.7	12.3	0	14.7	7.4	20.2	1.00
1.18-1.31	0	4.6	0	23.5	7.4	7.1	0.35
1.34-1.48	0	41.5	0	0	4.9	9.3	0.46
1.51-1.64	7.4	0	0	0	3.7	2.2	0.11
1.67-1.80	0	0	0	38.2	0	7.6	0.38
1.84-1.97	0	4.6	0	8.8	0	2.7	0.13
2.00-2.13	0	0	0	0	46.9	9.4	0.46
2.16-2.30	0	0	0	0	0	0	0
2.30+	0	0	0	0	0	0	0

Table A-6: Adult sucker depth utilization of all sites sampled (SMEA 2003, 2004). Depth ranges have been converted from cm to ft.

Depth (ft)	Individual Sites Surveyed Utilization as Percent of Total					Average Utilization All Sites Combined N=161	Utilization (Standardized to 1.0)
	SMEA (2003)			SMEA (2004)			
	Mission Blvd N=28	Hwy 60 N=20	Riverside Ave N=37	Downstream Hwy 60 N=29	Between Hwy 60 and Mission N=47		
0-0.16	0	0	0	0	0	0	0
0.20-0.33	0	0	0	0	0	0	0
0.36-0.49	0	0	0	0	0	0	0
0.52-0.66	3.6	0	0	0	0	0.7	0.02
0.69-0.82	0	0	0	0	0	0	0
0.85-0.98	0	0	0	0	0	0	0
1.02-1.15	0	5.0	5.4	0	10.6	4.2	0.13
1.18-1.31	7.1	0	2.7	13.8	4.3	5.6	0.17
1.34-1.48	10.7	10.0	10.8	0	8.5	8	0.24
1.51-1.64	0	10.0	18.9	3.4	0	6.5	0.19
1.67-1.80	28.6	30.0	0	58.6	2.1	23.9	0.71
1.84-1.97	0	10.0	21.6	6.1	14.9	10.5	0.31
2.00-2.13	0	0	0	0	6.4	1.3	0.04
2.16-2.30	0	0	10.8	0	0	2.2	0.06
2.30+	50.0	35.0	29.7	0	53.2	33.6	1.00

Table A-7: Juvenile sucker bottom velocity utilization of all sites sampled (SMEA 2003, 2004).

Bottom Velocity (ft/s)	Individual Sites Surveyed Utilization as Percent of Total					Average Utilization All Sites Combined N=252	Utilization (Standardized to 1.0)
	SMEA (2003)			SMEA (2004)			
	Mission Blvd N=54	Hwy 60 N=65	Riverside Ave N=18	Downstream Hwy 60 N=34	Between Hwy 60 and Mission N=81		
0.00-0.50	66.7	38.7	0	55.9	96.3	51.5	1.00
0.51-1.00	13.0	17.7	27.8	44.1	3.7	21.3	0.41
1.01-1.50	1.9	29.0	50.0	0	0	16.2	0.31
1.51-2.00	14.8	11.3	22.2	0	0	9.7	0.19
2.01-2.50	3.7	3.2	0	0	0	1.4	0.03
2.51-3.00	0	0	0	0	0	0	0

Table A-8: Adult sucker bottom velocity utilization of all sites sampled (SMEA 2003, 2004).

Bottom Velocity (ft/s)	Individual Sites Surveyed Utilization as Percent of Total					Average Utilization All Sites Combined N=161	Utilization (Standardized to 1.0)
	SMEA (2003)			SMEA (2004)			
	Mission Blvd N=28	Hwy 60 N=20	Riverside Ave N=37	Downstream Hwy 60 N=29	Between Hwy 60 and Mission N=47		
0.00-0.50	25.0	0.0	40.5	62.1	95.7	44.7	1.00
0.51-1.00	21.4	61.5	54.1	37.9	0	35.0	0.78
1.01-1.50	50.0	23.1	5.4	0	4.3	16.6	0.37
1.51-2.00	0.0	15.4	0.0	0	0	3.1	0.07
2.01-2.50	3.6	0.0	0.0	0	0	0.7	0.02
2.51-3.00	0.0	0.0	0.0	0	0	0	0

Table A-9: Juvenile sucker substrate type utilization of all sites sampled (SMEA 2003, 2004).

Substrate Type	Individual Sites Surveyed Utilization as Percent of Total					Average Utilization All Sites Combined N=252	Utilization (Standardized to 1.0)
	SMEA (2003)			SMEA (2004)			
	Mission Blvd N=54	Hwy 60 N=65	Riverside Ave N=18	Downstream Hwy 60 N=34	Between Hwy 60 and Mission N=81		
Silt	0	0	0	0	0	0	0
Silt/sand	38.9	0	0	0	0	7.8	0.18
Sand	38.9	10.8	0	5.9	1.2	11.4	0.26
Sand/gravel	5.6	78.5	83.3	32.4	21.0	44.2	1.00
Gravel	0	0	16.7	5.9	65.4	17.6	0.40
Sand/cobble	0	0	0	0	0	0	0
Gravel/cobble	0	10.8	0	55.9	12.3	15.8	0.36
Cobble	0	0	0	0	0	0	0
Boulder	0	0	0	0	0	0	0

Table A-10: Adult sucker substrate type utilization of all sites sampled (SMEA 2003, 2004).

Substrate Type	Individual Sites Surveyed Utilization as Percent of Total					Average Utilization All Sites Combined N=161	Utilization (Standardized to 1.0)
	SMEA (2003)			SMEA (2004)			
	Mission Blvd N=28	Hwy 60 N=20	Riverside Ave N=37	Downstream Hwy 60 N=29	Between Hwy 60 and Mission N=47		
Silt	0	0	0	0	0	0	0
Silt/sand	0	0	0	0	0	0	0
Sand	35.7	40.0	0	0	0	15.1	0.42
Sand/gravel	35.7	25.0	54.1	27.6	6.4	29.8	0.83
Gravel	10.7	35.0	45.9	0	87.2	35.8	1.00
Sand/cobble	0	0	0	0	0	0	0
Gravel/cobble	0	0	0	72.4	6.4	15.8	0.44
Cobble	0	0	0	0	0	0	0
Boulder	17.9	0	0	0	0	3.6	0.10

Appendix B

Current Versus Historical Photo Log

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Photo B-1: Santa Ana River (looking upstream from Riverside Ave) – Oct. 2013 (Normal RIX discharge)

Photo B-2: Santa Ana River (looking upstream from Riverside Ave) – March 1992 (Pre-RIX)

Photo B-3: Santa Ana River (just upstream of Riverside Ave) – October 2012 (partial RIX discharge)

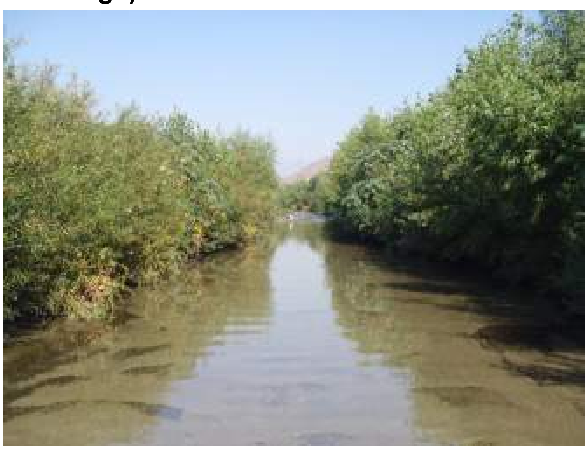

Photo B-4: Santa Ana River (just downstream of Riverside Ave) – March 1992 (Pre-RIX)

Photo B-5: Santa Ana River (downstream of Mission Blvd) – Oct. 2013 (Normal RIX discharge)

Photo B-6: Santa Ana River (upstream of Mission Blvd) – Nov. 1991 (Pre-RIX)

Photo B-7: Santa Ana River (downstream of Railroad crossing) – Oct. 2012 (Normal RIX discharge)

Photo B-8: Santa Ana River (downstream of Railroad crossing) – Nov. 1991 (Pre-RIX)

Appendix C

Google Earth Imagery

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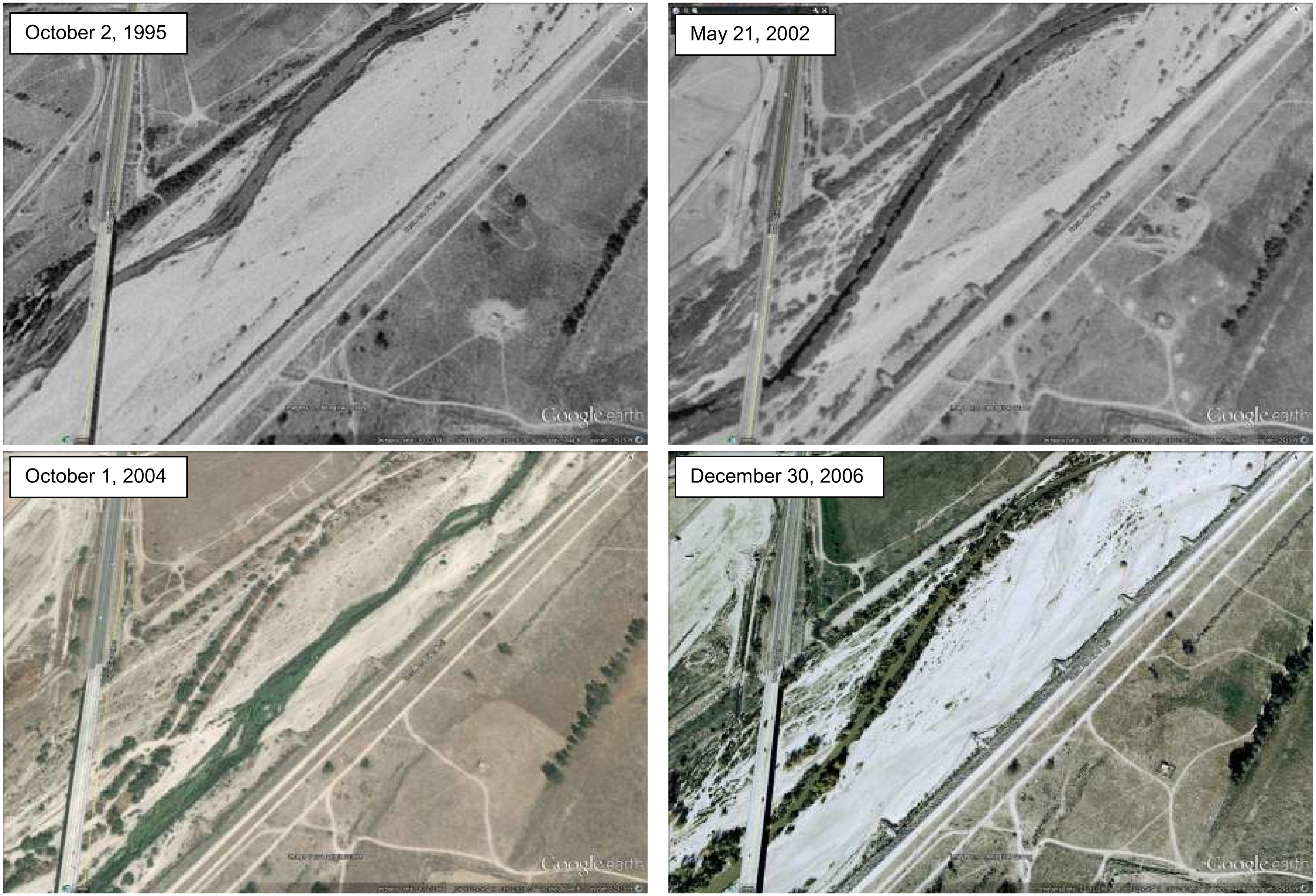

Figure C-1: Santa Ana River at Riverside Avenue imagery through time.

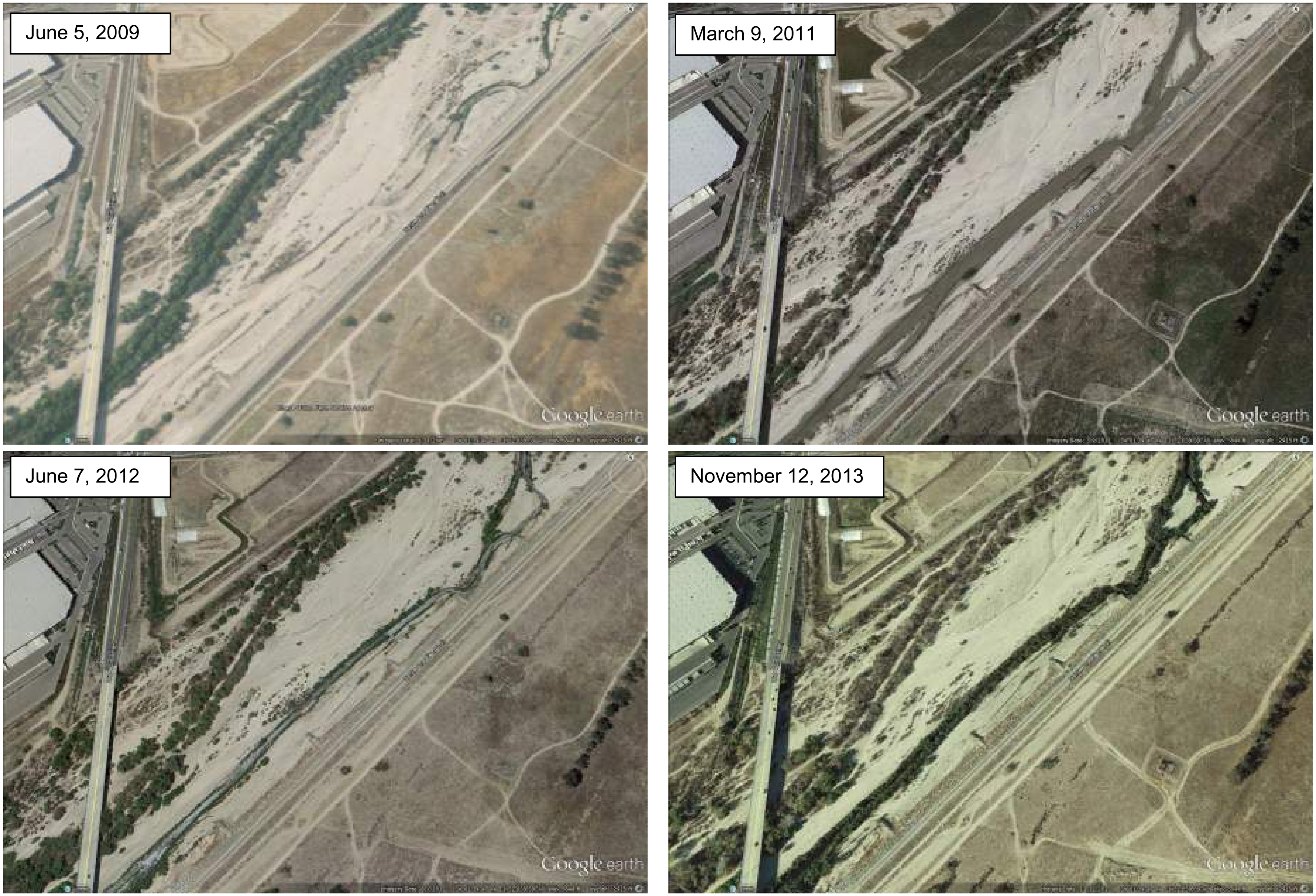

Figure C-1 (Continued): Santa Ana River at Riverside Avenue imagery through time.

Figure C-2: Santa Ana River at Mission Boulevard imagery through time.

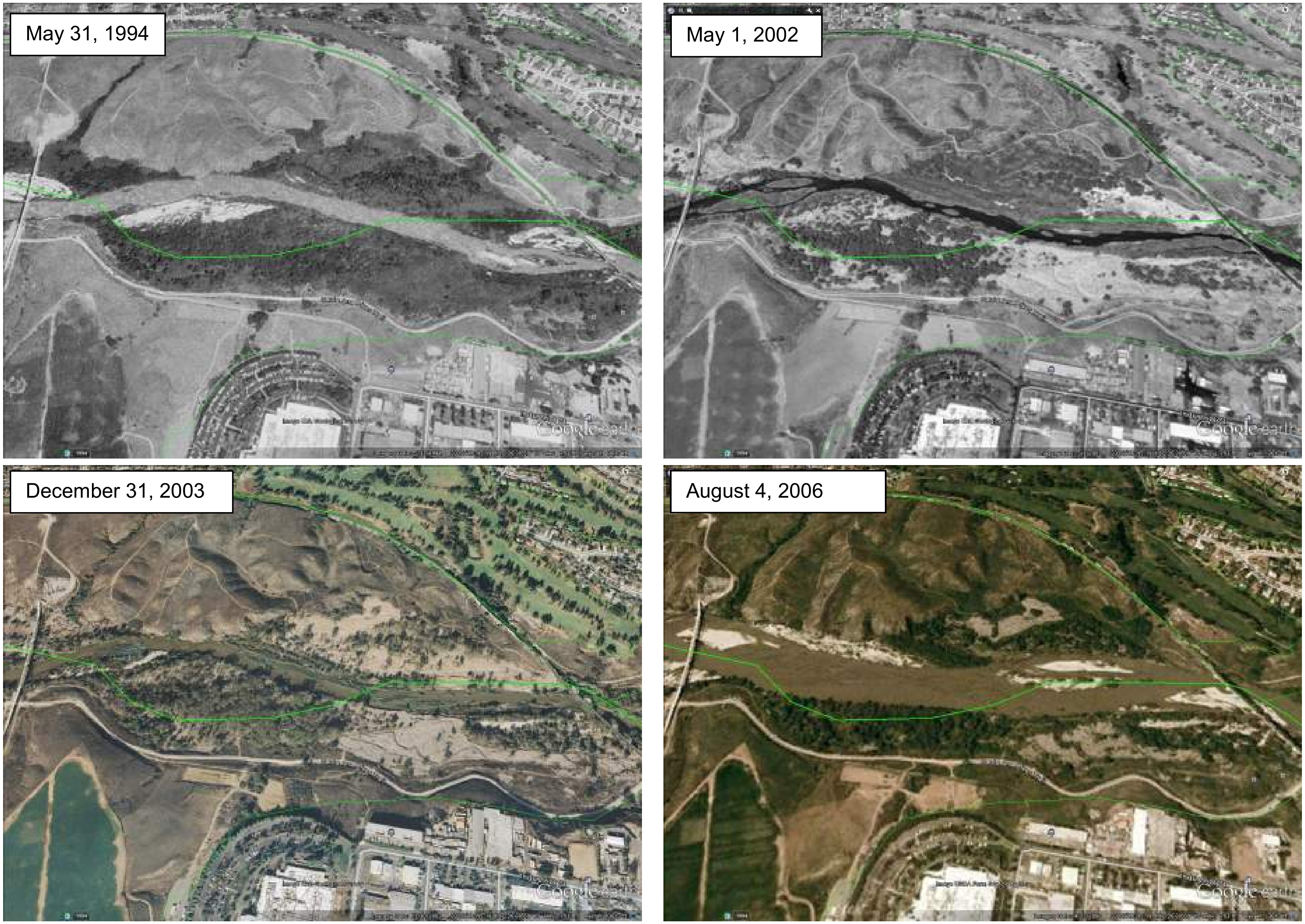

Figure C-3: Santa Ana River at MWD Crossing imagery through time.

Figure C-3 (Continued): Santa Ana River at MWD Crossing imagery through time.

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Appendix E:

Clean Water Factory Rapid Infiltration/Extraction (RIX) Low-Flow Sediment Scour and Transport Modeling in the Santa Ana River

(Michael Baker, August 2015)

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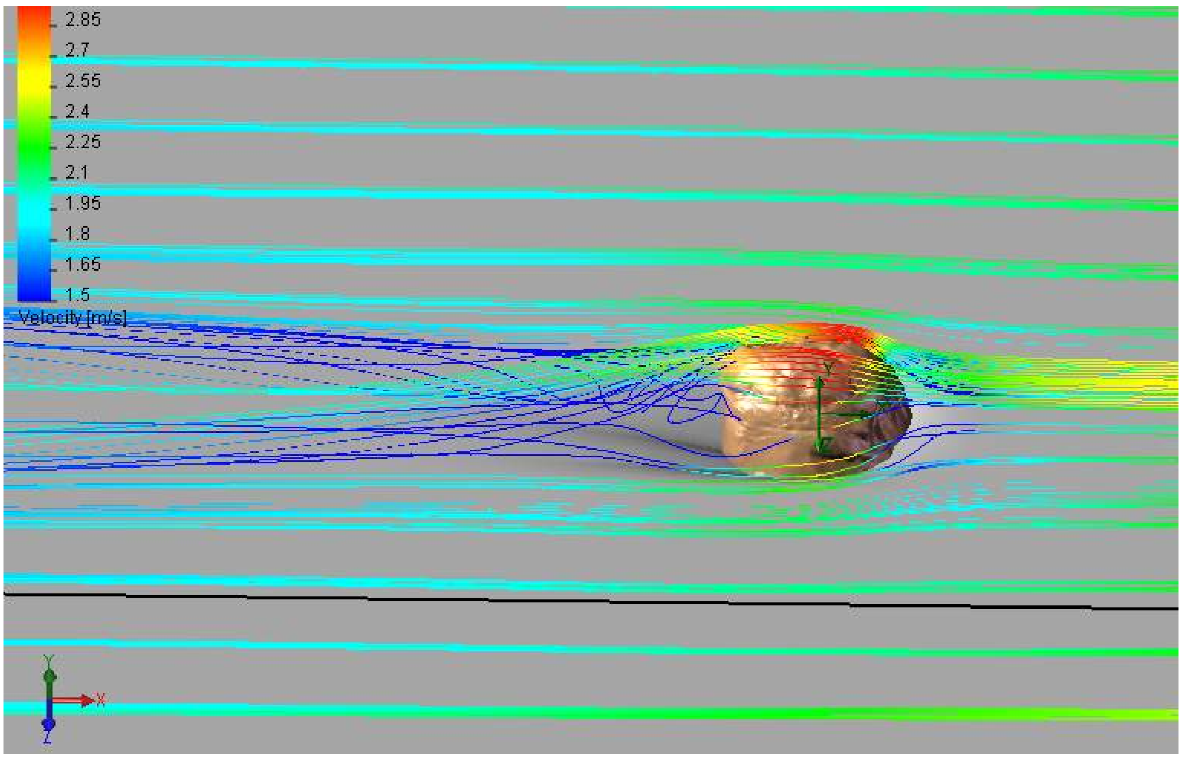
Michael Baker INTERNATIONAL

Innovation Done Right...We Make a Difference

Clean Water Factory Rapid Infiltration/Extraction (RIX) Low-Flow Sediment Scour and Transport Modeling in the Santa Ana River



Submitted to:
John A. Claus
Director of Water Reclamation
City of San Bernardino Municipal Water Department

Submitted by:
Scott Jenkins, Ph.D. and Tom McGill, Ph.D.
Michael Baker International

Draft: 23 August 2015; Revised Draft: 26 October 2015; Final: 10 December 2015

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ABSTRACT:

A coupled fluvial hydraulics/sediment scour and transport modeling approach was invoked to determine whether or not discharges under dry weather conditions from the Rapid Infiltration/Extraction (RIX) facility and flow reductions due to the Clean Water Factory can scour and clear sand blankets that could potentially bury cobble substrate in the inset channel of the Santa Ana River after a significant flood event. The study area is in the biologically sensitive upper reaches of the Santa Ana River immediately downstream of RIX that are inhabited by the Santa Ana sucker. The modeling effort was directed towards achieving scour goals that would re-establish biological field study baseline conditions for cobble exposure following an initial post-flood scenario of complete burial of the cobble beds and riffles by a blanket of newly deposited river sands. The estimated return period of this depositional event is 5 years based on published sediment rating curves and cumulative residual analysis of the Santa Ana River.

The fluvial model used in this study is the U.S. Army Corps of Engineers HEC-RAS model while the scour model used is the US Navy Vortex Lattice Scour-Burial Model. Both models were initialized for Santa Ana River bathymetry between the RIX facility and the MWD crossing based on river channel cross sections derived from a 2012 LIDAR survey. Current forcing and water surface elevations were input to the Vortex Lattice Model at each channel cross section based on the HEC-RAS model results for ten separate RIX low-flow and maximum-flow discharge scenarios. These HEC-RAS inputs to the Vortex Lattice Model account for percolation and groundwater upwelling along each reach of Santa Ana River that was evaluated for sediment scour and transport.

The general lesson learned from the model simulations is that scour by RIX discharges and exposure of the cobble/gravel riffles in the inset channel will not be uniform following burial by a post-storm sand blanket. There are regions identified as *scour hot spots* where the cobble and gravel substrate will be scoured and exposed very rapidly, even at average RIX discharge rates; and these areas will provide immediate post-storm micro-environments for the Santa Ana sucker. Generally these scour hot-spots are caused by six types of kinematic or dynamical conditions: 1) contractions of the inset channel width, 2) turns or bends in the inset channel that create centrifugal acceleration of the flow towards the outside of the turn, 3) bifurcation of the inset channel, 4) increase in bed gradient of the inset channel, 5) increase in hydraulic gradient due to ground water upwelling, and 6) hydraulic jumps from super-critical flow velocities at higher RIX discharge rates. However, wherever there are scour hot-spots, depositional areas are nearby. These depositional areas are very common near inset channel bifurcations, especially when those bifurcations occur in proximity to a bend in the inset channel. When a channel bifurcation occurs at a bend in the river, the flow does not divide evenly; and instead, concentrates under the effects of centrifugal acceleration in the channel on the outside of the turn, leaving the inside channel with flow speeds below threshold scour speed, and causing those inside channels to become depositional over time. These depositional bifurcated channels will remain unsuitable for Santa Ana sucker habitat until a significant flood event can augment channel flow by RIX to sufficient degree that general scour occurs across the entire river bed.

The scour model results for restoration of biological baseline conditions (as defined by river walk substrate data), in the most sensitive upper reach of the river (Reach-1), can achieved in 5.8 days when inset channel flow rates are equivalent to the 2014 RIX discharge average of *Q*

= 29 mgd; and can be achieved in less than a day at flow rates approaching the maximum permitted RIX discharge rate of Q = 64 mgd. It was also determined that the minimum threshold for achieving sand scour in the inset channel occurs at a discharge rate of Q = 4.8 mgd, comparable to recent daily discharges from the Rialto WWTP, (Rialto Channel).

Because none of the inset channel flow rates that induce sand scour exceed the discharge capacity of RIX, it appears that restoration of the biological baseline conditions of the river following a rare, high-deposition, flood event are within the operating capabilities of RIX. This expectation is further enhanced by the fact that coverage of the cobble bed by a thick blanket of sand is a wet-weather occurrence, when percolation losses of stream flow are minimal along the biologically sensitive section of inset channel in Reach-1.

1) Introduction:

The US Fish and Wildlife Service (USFWS) review of the Low Flow Study for the City of San Bernardino Clean Water Factory, concluded that sediment transport modeling is needed to satisfactorily evaluate potential effects of the Phased RIX Flow Reduction Plan on the availability of Santa Ana sucker habitat. The previous Low Flow Study was based on results from HEC-RAS hydraulic modeling for the river reach between RIX and the MWD Crossing (WEI, 2013; 2014), as well as the Physical Habitat Simulation modeling (GEI, 2013). During a presentation of this model to USFWS, two concerns were raised: 1) habitat modeling relied on hydrologic data that provided flow rates and river depth and width but did not include any sediment analysis which is an integral component of suitable sucker habitat; and 2) would the phased reduction in flows from RIX hinder the removal of the episodic sandy deposition that occurs during storm events such that the exposed cobble substrate needed for foraging and breeding by sucker would be quickly re-established following a storm event. The question to be answered by the present study addresses the second concern of whether or not the reduced flows from the RIX facility can scour the sandy patches off the cobble substrate and flush the scoured sands downstream from the biologically sensitive upper reaches of the river.

2) Coupled Modeling Approach:

The Vortex Lattice Scour-Burial Model (Jenkins et al. 2007), was initialized for Santa Ana River bathymetry between the RIX Facility and the MWD crossing based on river channel cross sections derived from a 2012 LIDAR survey and provided by Wildermuth Environmental, Inc. Current forcing and water surface elevations were input to the Vortex Lattice Model at each channel cross section based on the HEC-RAS model results for each RIX low-flow increment reported in WEI, (2013; 2014). These HEC-RAS inputs to the Vortex Lattice Model account for percolation and groundwater upwelling along the length of Santa Ana River that was evaluated for sediment scour and transport. The WEI, (2013; 2014) HEC-RAS model simulations were calibrated with stream gage data measured at three sites along the Santa Ana River between RIX and MWD Crossing. These gage stations were identified as Site 001 (Santa Ana River at Riverside Ave), Site 002 (Santa Ana River at Mission Inn Ave), and Site 003 (Santa Ana River at Railroad Crossing). These 2013 gage station calibration data enabled the HEC-RAS model to properly account for the dry weather flow rates at which the Santa Ana River is losing stream flow between RIX and a point about 0.63 miles downstream of Mission Inn Ave (Figure 1); gaining stream flow from this point to Site 003; and then losing stream flow between Site 003 and MWD Crossing. Because the Vortex Lattice Model uses these calibrated HEC-RAS stream flows for current forcing, the sediment scour and transport results account for the variations in discharge along the river's length due to percolation and ground water upwelling.

2.1) Scour Modeling Approach: While the HEC-RAS model provides the current forcing function with the embedded dynamics of river bed percolation and upwelling, the scour induced by this current forcing is modeled using the *The Vortex Lattice Scour-Burial Model* (Jenkins et al. 2007). This model was developed at Scripps Institution of Oceanography under

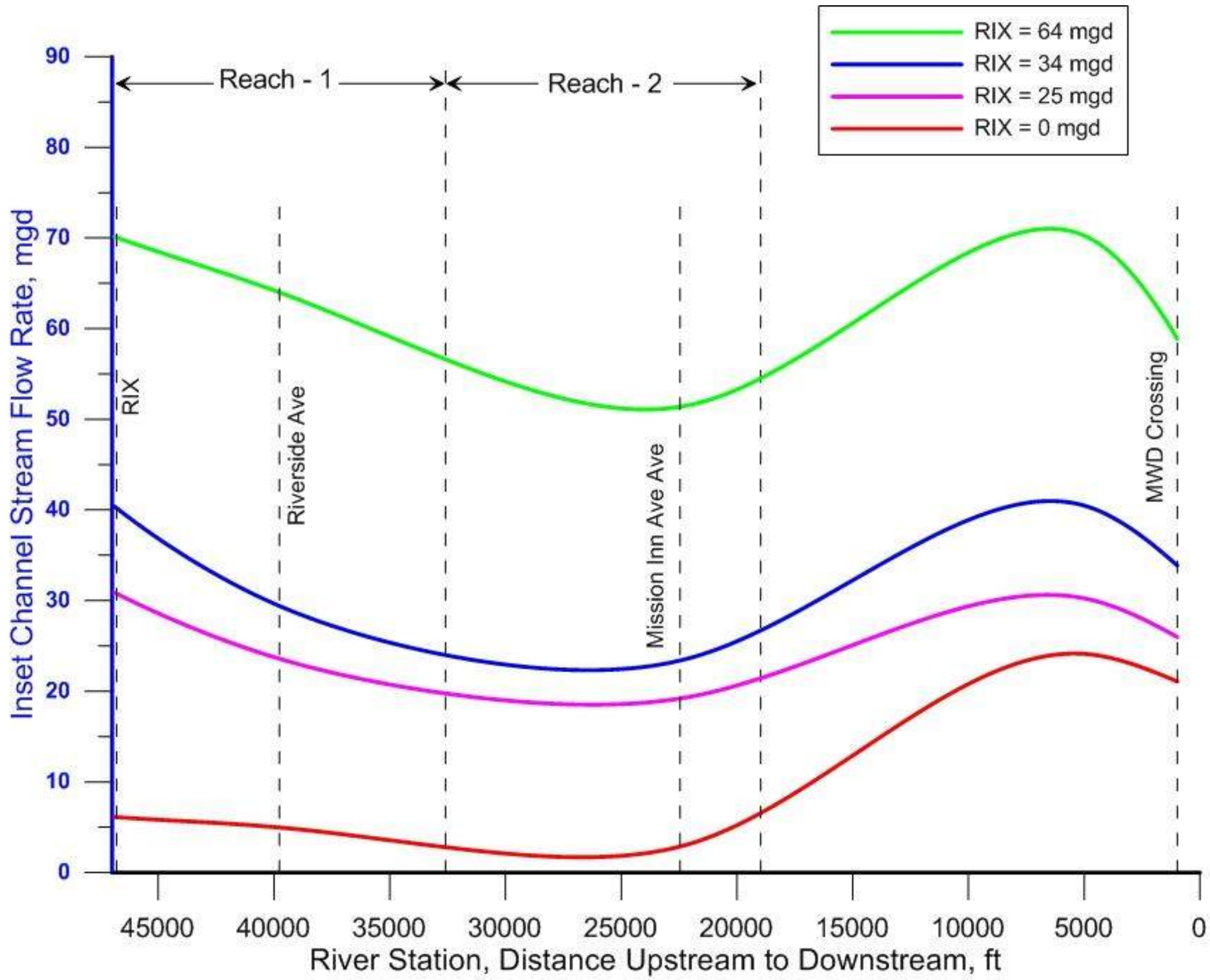


Figure 1: Variation in flow rates in the inset channel of the Santa Ana River due to percolation losses and ground water upwelling at various RIX discharge rates. Data from calibrated HEC-RAS simulations after WEI (2013a & b; 2014).

funding from the Office of Naval Research, (ONR), and has been validated in field experiments in both river and coastal environments conducted under ONR's Mine Burial Program. The field validation experiment having the most in common with the Santa Ana River was conducted on the Missouri River at Omaha, NE. These experiments involved the prediction of scour, burial and movement of mines disguised to resemble cobbles (Figure 2). In addition to geophysical similitude, a USGS gage station #06610000 has been maintained on the Missouri at Omaha, NE, since 1928, providing daily flow rate records and significant monitoring of daily suspended sediment flux. An important feature which the Missouri River at Omaha shares with the Santa Ana River environment is a series of upstream dams, (five total), beginning with the Fort Randall Dam completed in 1953, the Garrison Dam in 1954, the Gavins Point Dam in 1957, the Oahe Dam in 1962, and the most recent dam, The Big Bend Dam whose construction was completed in 1964. These dams had the effect of reducing the peak discharges after 1964.

To model sediment transport around cobbles using the vortex lattice technique, the cobble and adjacent riverbed is subdivided into a set of panels (*lattice*) as shown in Figure 2a. The vortex field induced by the cobble is constructed from an assemblage of horseshoe vortices, with a horseshoe vortex prescribed for each panel. This computational technique is known as the *vortex lattice method* and has been widely used in aerodynamics and naval architecture, and more recently in problems of bridge scour by river hydrologists. For any given i^{th} panel in the lattice, the horseshoe vortex consists of a bound vortex, Γ_o, that contains all of the vorticity generated on the surface of a panel, and a pair of trailing vortex filaments, $+\Gamma_i$ and $-\Gamma_i$, that discharge vorticity from the panel into the flow, causing a vertical wake. The trailing vortex filaments scrub the bed of surrounding sediments and induce scour and suspension of bottom sediment as shown schematically in Figures 3a and 3b.

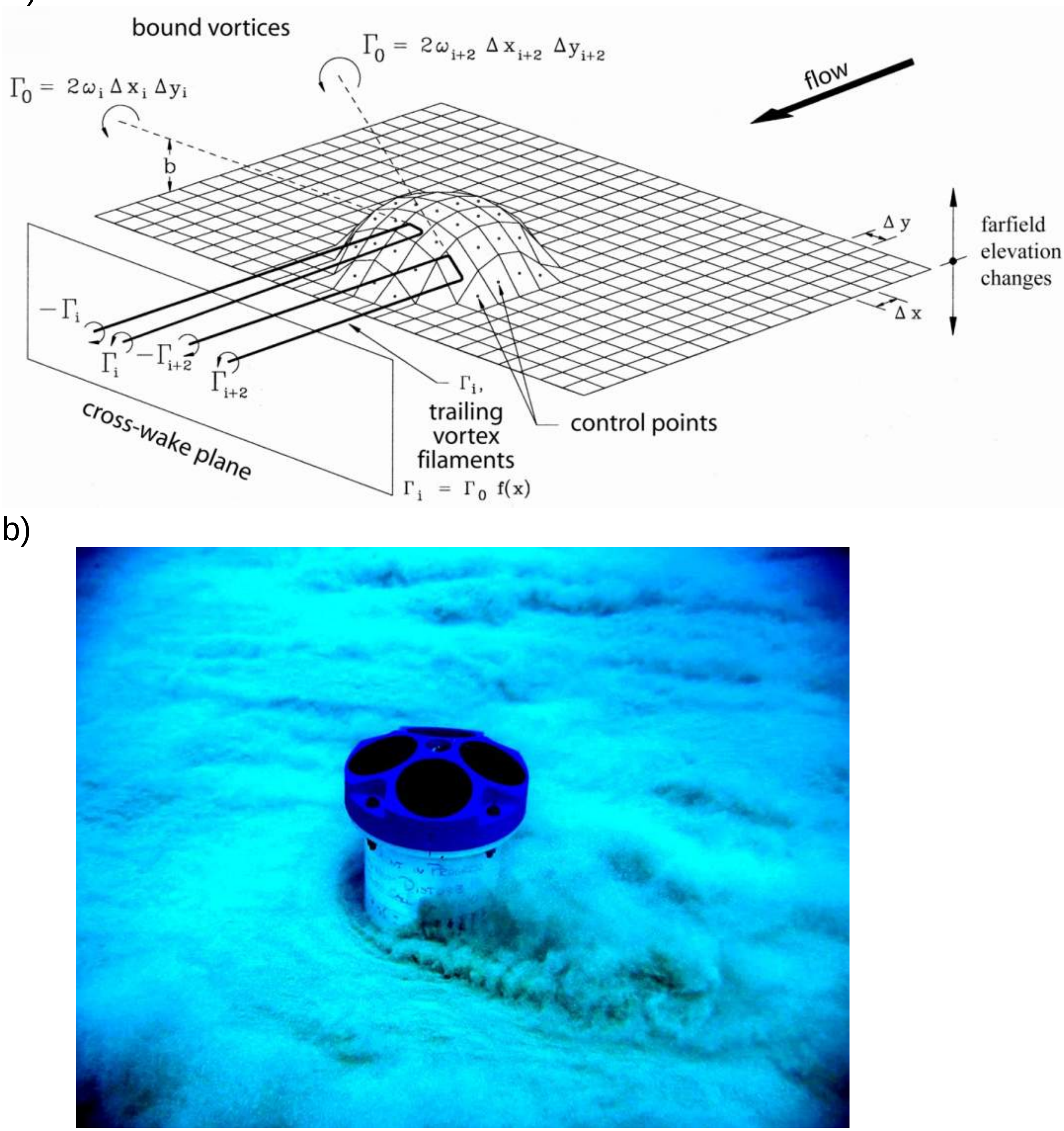
The circulation of the vortex, Γ_o, bound to the panel is calculated from the boundary layer velocity shear [after Peace and Riley, 1983]:

$$\Gamma_o = \int_0^{\delta}\int_{-S}^{S} \left\{ \Re\left(\frac{\partial \tilde{u}}{\partial z}\right)^2 \right\}^{1/2} dxdz \qquad (1)$$

where $\tilde{u}$ is the local near-bed velocity at the top of the bottom boundary layer, δ is the boundary layer thickness; S is the half-width of the lattice panel; $\Re$ is the real part operator, and the shear of the near-bottom flow, $\partial\tilde{u}/\partial z$, is prescribed from perturbation solutions for the boundary layer profile after Van Dyke (1975). The boundary layer thickness used to evaluate (1) is derived from G. I. Taylor, 1946 by finding for each panel the local solutions to the transcendental equation:

$$\frac{30\delta}{Z_i}\log\left(\frac{30\delta}{Z_i}\right) = 1.2\left(\frac{d_0}{2Z_i}\right) \qquad (2)$$

a)



b)

Figure 2. Vortex lattice method: upper) lattice and horseshoe vortex system; lower) horseshoe vortices inducing sediment transport in nature. [Photo courtesy Kimball Millikan].

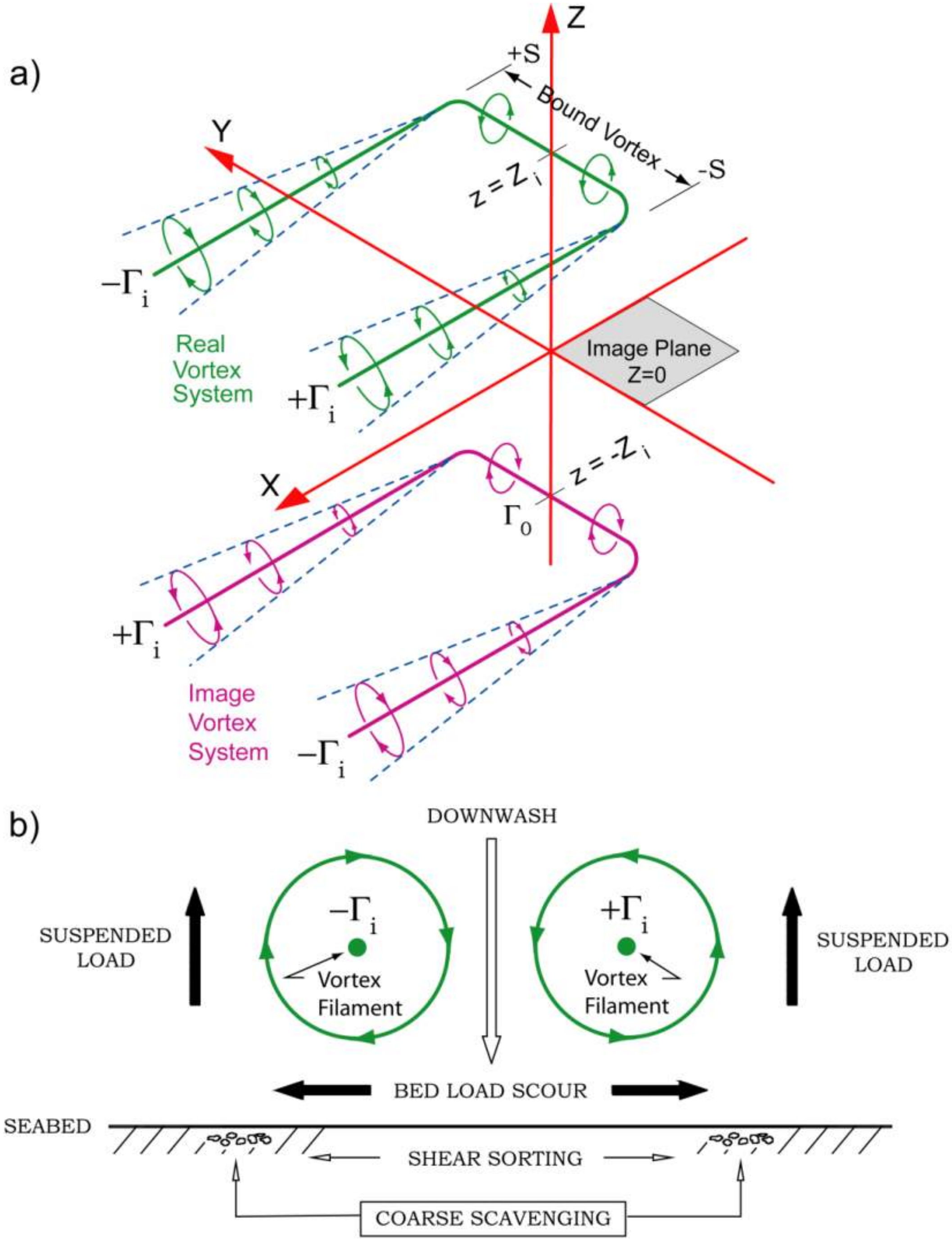


Figure 3: a) Image method for vortex-induced velocity at any point near the bed (image plane) due to the horseshoe vortex sytem of an arbitrary lattice panel (Figure 2a). The real vortex of the lattice panel is diagrammed in magenta, the image vortex is in green. b) Schematic in the cross-wake plane of a pair of vortex filaments trailing out of the page.

where Z_i is the elevation of the i[th] panel above the river bed and d_0 is the median cobble diameter in the inset channel as approximated by the USGS cobble size distribution curves.

The trailing vortices consist of right/left pairs whose circulation have equal but opposite rotation, $+\Gamma_{\text{i}}\ vs - \Gamma_{\text{i}}$ (Figures 2a and 3a). To prevent these vortices from inducing normal flow through the bottom plane, there is a set of image vortices beneath the bottom plane (Figure 3a). The mathematical representation of the trailing vortex filaments from a panel is derived from lifting line theory in ground effect according to Van Dyke (1964; 1975). Taking *x* as the stream-wise coordinate along the axis of the riverbed, *y* as the cross-stream component, and *z* measured vertically upward from the riverbed plane, the horseshoe vortex for the i[th] panel in the lattice is represented by,

$$\Gamma_{\text{i}} = -\frac{\Gamma_{\text{o}}}{4\pi}\left\{\tan^{-1}\left[\frac{(z-Z_i-b')(y+S)}{x\sqrt{x^2+(y+S)^2+(z-Z_i-b')^2}}\right]-\tan^{-1}\left[\frac{(z+Z_i+b')(y+S)}{x\sqrt{x^2+(y+S)^2+(z+Z_i+b')^2}}\right]\right\}$$

$$-\frac{\Gamma_{\text{o}}}{4\pi}\left\{\tan^{-1}\left[\frac{(z+Z_i+b')(y-S)}{x\sqrt{x^2+(y-S)^2+(z+Z_i+b')^2}}\right]\right\}-\frac{\Gamma_{\text{o}}}{4\pi}\left\{\tan^{-1}\left[\frac{(z-Z_i-b')(y-S)}{x\sqrt{x^2+(y-S)^2+(z-Z_i-b')^2}}\right]\right\}$$

$$-\frac{\Gamma_{\text{n}}}{4\pi}\left\{\tan^{-1}\left[\frac{(z+Z_i+b')}{(y-S)}\right]-\tan^{-1}\left[\frac{(z-Z_i-b')}{y-S)}\right]\right\}$$

$$-\frac{\Gamma_{\text{n}}}{4\pi}\left\{\tan^{-1}\left[\frac{x(z+Z_i+b')}{(y-S)\sqrt{x^2+(y-S)^2+(z+Z_i+b')^2}}\right]-\tan^{-1}\left[\frac{x(z-Z_i-b')}{(y-S)\sqrt{x^2+(y-S)^2+(z-Z_i-b')^2}}\right.\right.$$

$$-\frac{\Gamma_{\text{n}}}{4\pi}\left\{\tan^{-1}\left[\frac{(z-Z_i-b')}{(y+S)}\right]-\tan^{-1}\left[\frac{(z+Z_i+b')}{(y+S)}\right]\right\}$$

$$-\frac{\Gamma_{\text{n}}}{4\pi}\left\{\tan^{-1}\left[\frac{x(z-Z_i-b')}{(y+S)\sqrt{x^2+(y+S)^2+(z-Z_i-b')^2}}\right]-\tan^{-1}\left[\frac{x(z+Z_i+b')}{(y+S)\sqrt{x^2+(y+S)^2+(z+Z_i+b')^2}}\right]\right.$$

(3)

where b' is the displacement thickness. The first two lines of Equation 3 above represent the bound vortex and its image, the next two lines are the $+\Gamma_{\text{i}}$ trailing vortex filament (right side of Figure 3(b)] and its image, while the last two lines are the $-\Gamma_{\text{i}}$ trailing vortex filament (left side of Figure 3(b) and its image. As the pair of trailing vortex filaments extends downstream, the circulation Γ_n decreases due to diffusion of vorticity. This is represented schematically in Figure 3a by the increasing diameters of the rotational paths. Mathematically the decay of trailing vortex filaments in ground effect due to vorticity diffusion is prescribed by Peace and Riley, (1983) as,

$$\Gamma_{\mathrm{n}} = \Gamma_{\mathrm{o}} f(x) \tag{4}$$

where the perturbation series of the decay function can be written:

$$f(x) = 1 - \frac{1}{u_m} \int_0^{N\Delta x} \left\{ u^{(1)} + u^{(2)} \left(\frac{x\sigma}{u_m S^2} \right)^{1/2} + \left(\frac{x\sigma}{u_m S} \right) \left(u^{(1)} + S^2 \frac{\partial^2 u^{(2)}}{\partial x^2} \right) \right\} dx \tag{5}$$

Here *N* is the number of lattice panels. From Peace and Riley, (1983), the displacement thickness, b', in Equation 3 can be approximated by:

$$b' = \int_0^{\infty} \left(1 - \frac{\Gamma_{\mathrm{o}}}{u\delta} \right) dz \cong 1.344\delta \tag{6}$$

The release of trailing vortex filaments from each panel in Figure 2a causes scour of the neighboring river bed. When viewed in any cross-wake plane [Figure 3(b)] each pair of filaments induces a downwash flow that converges on the riverbed and results in lateral bedload scour. Assuming ideal granular sediment transport physics, the bedload scour transport rate is proportional to the cube of the vortex strength Γ_{i}, and inversely proportional to the cube of the grain size, *D*. Beyond the lateral extent of the bedload scour, the vortex filaments induce an upwashing flow of suspended load, which for ideal granular sediments is proportional to $\Gamma_{\mathrm{i}}^4 / D^4$. Adopting the ideal granular transport relations, the bedload scour rate for any given vortex filament (i-vortex) is given by:

$$i_{\mathrm{bi}} = \frac{\varepsilon_{\mathrm{b}} C_D \rho \Gamma_{\mathrm{i}}^3}{D^3 (\tan\varphi - \tilde{u}\beta / |\tilde{u}|)} \tag{7}$$

while the suspended load scour is:

$$i_{\mathrm{si}} = \frac{\varepsilon_{\mathrm{s}} C_D \rho \Gamma_{\mathrm{i}}^3 |\Gamma_{\mathrm{i}}|}{D^4 (W_{\mathrm{o}} - \tilde{u}\beta)} \tag{8}$$

where ε_{b} is the bedload transport efficiency; ε_{s} is the suspended load transport efficiency; C_D is the riverbed drag coefficient which is a function of Mannings roughness, W_o is the settling velocity for any given sediment grain size bin represented by a characteristic grain diameter, *D*, and β is the local slope of the riverbed. The transport efficiency factors are derived during model calibration using the USGS sediment transport data, while the grain sizes were obtained from the USGS grain size distribution of the sandy sediment deposits observed over the cobble bed of the inset channel of the Santa Ana River.

The bed and suspended load transport rates from Eq. 12 and 13 are calculated every model time step in the duration sensitivity analysis and summed over *N(t)* number of lattice panels that make up the cobble beds. The vortex induced disturbance acting on the cobble bed is:

$$\Gamma = \sum_{i}^{N(t)} \Gamma_i \qquad (9)$$

This disturbance generates increments of erosion and deposition flux, depending on the sign of Eq. 7 and 8, that are accumulated each time step of simulation and mapped back into a revised lattice following the time-stepped loop. The number of exposed lattice panels on the cobble bed *N* (t) varies with each time step depending on the distribution of erosion and deposition fluxes over the lattice, and also with changes in the elevation of the sediment layer based on mass conservation.

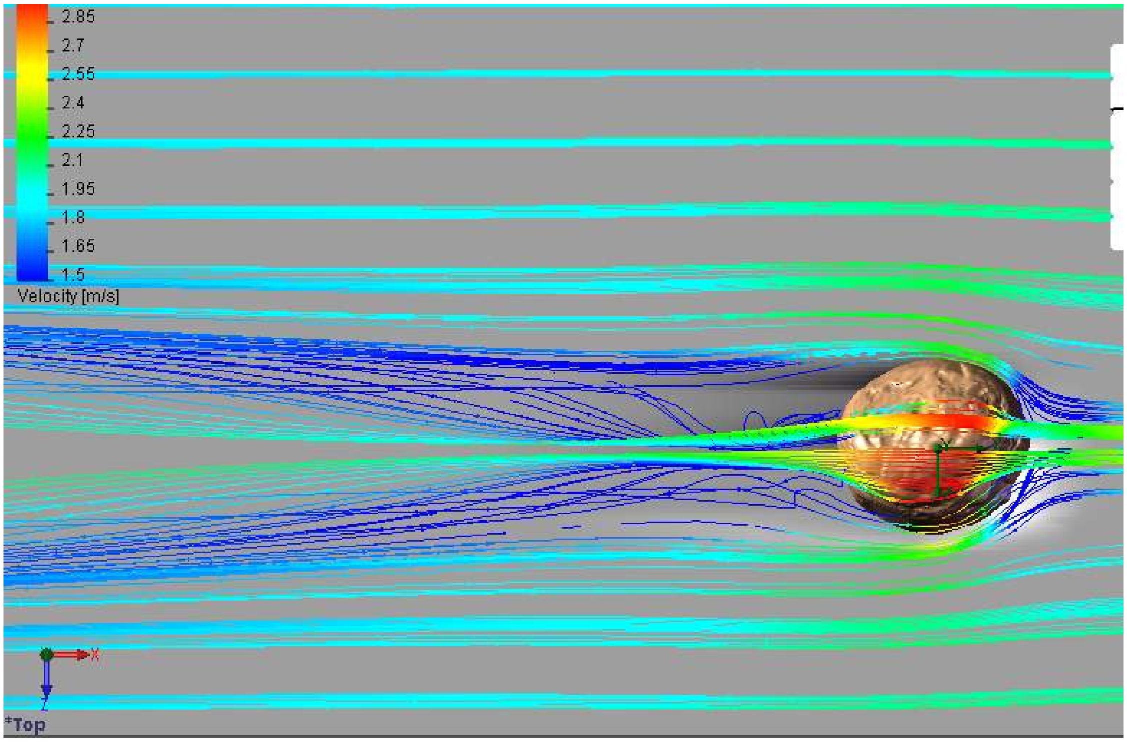
Simulations of scour produced by the vortex lattice method around a large partially buried cobble projecting from a bed of sand are shown in Figure 4. From the Figure 4 examples, it appears that the vortex lattice method can make realistic 3-dimensional simulations of scour when applied over a bed of cobble partially buried by patches of ideal granular sediment in unidirectional flow. In application to the cobble bed of the inset channel of the Santa Ana River, many such cobles are replicated in COSMOS SolidWorks using cobble size distribution measurements provided by USGS.

3) Model Initialization:

The Vortex Lattice Scour-Burial Model was initialized using Santa Ana River bathymetry, water elevations, mean channel velocities and inset channel flow rate data provided by Wildermuth Environmental, Inc for a range of RIX discharge rates between Q = 0 mgd and and the maximum permitted discharge of Q = 64 mgd (99.1 cfs). Cobble size and sediment grain size inputs to the model that were specific to the study reaches of the Santa Ana River were provided by the USGS California Water Science Center, Sacramento, CA.

3.1 River Bathymetric Inputs: High-resolution channel geometry was obtained from airborne LiDAR mapping of the Santa Ana River between RIX and MWD Crossing on October 19, 2012, and October 25, 2012, by GeoDigital International. Two days of LiDAR mapping was required for this investigation to capture and compare the river under very low and normal discharge conditions. In an effort to map the river channel at its lowest stage, LiDAR

a)



b)

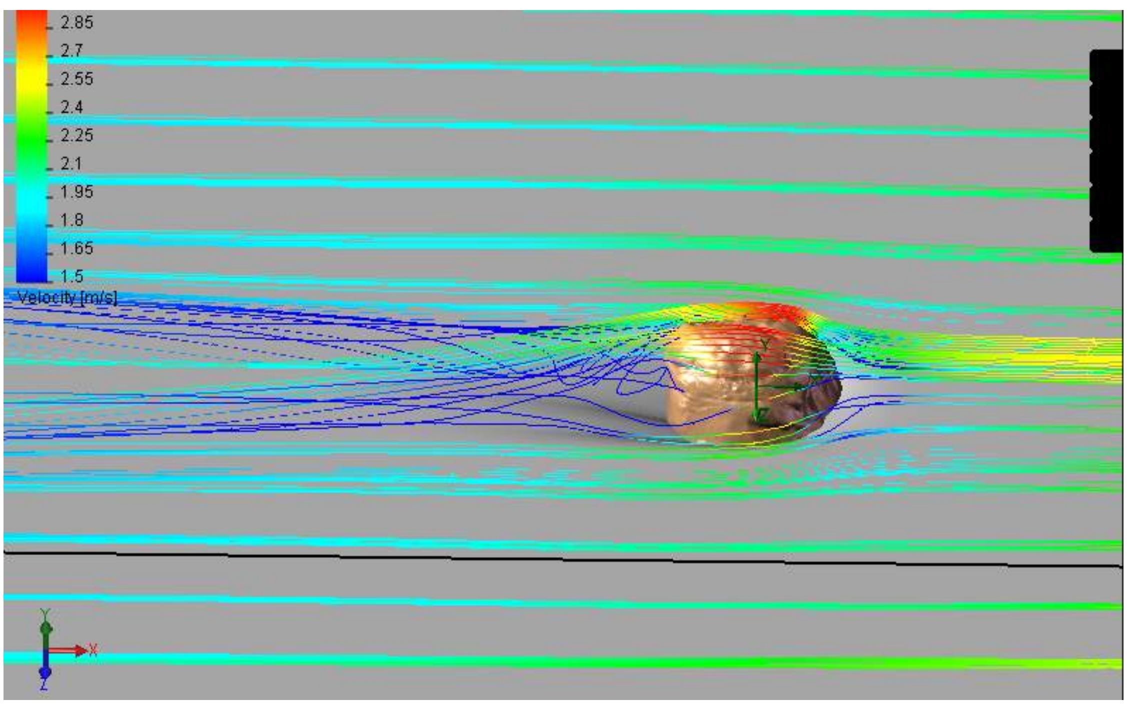


Figure 4: Vortex Lattice Model simulation of a partially buried and scoured cobble on a river bed of fine sand at Omaha, NB. Burial depth = 8 cm, ambient velocity = 21 cm/sec (0.41 kts); dry bulk mass = 2.8 kg.

acquisition coincided with the RIX treatment plant scheduled maintenance and temporary discharge shutdown. The LiDAR data was processed by Wildermuth Environmental, Inc and provided in an electronic file: <20150311_XS_Elev.xlsx>. This file provided cross sections of the Santa Ana River and its inset channel at approximately 500 ft. station intervals from the Rialto Channel down to the MWD Crossing . River Station horizontal datum for these cross sections were expressed NAD83 UTM Zone 11N coordinates. Channel elevation vertical datum for the cross sections were given in NAVD88. These cross sections were input to the 3-d CAD software SolidWorks and lofted as a 3-d model of the Santa Ana River bed with vertical exaggeration by a factor of 3.28 between the Rialto Channel down to the MWD Crossing.

3.2 River Hydraulics Inputs: Current forcing and water surface elevations were input to the Vortex Lattice Model at each channel cross section based on the HEC-RAS model results for each RIX low-flow increment listed in an electronic file: <20150225_SAR_HECRAS_Exportv3.xlsx>, provided by Wildermuth Environmental, Inc. The historic variation of RIX discharges into the inset channel of the Santa Ana River are plotted in Figure 5. The average annual discharge for 2014 was 29 mgd and the maximum permitted discharge is 64 mgd. For each of ten potential RIX discharge rate, (Q = 0 mgd, 4.8 mgd, 6.1 mgd, 19.5 mgd, 23.6 mgd, 26.9 mgd, 29 mgd, 35.1 mgd, 40.4 mgd and 64 mgd), the <20150225_SAR_HECRAS_Exportv3.xlsx>, file provided the following HEC-RAS output at each channel cross section:

Total Discharge Rate (cfs) ,
Minimum Channel Elevation (ft.),
Water Surface Elevation (ft),
Critical Water Surface Elevation (ft.),
E.G. Elevation (ft.),
E.G. Slope (ft./ft.),
Mean Channel Velocity (ft./s),
Flow Area (ft^2),
Top Width (ft.),
Froude Number, and
Mean Channel Depth (ft.).

These HEC-RAS outputs were formatted into a structured text input file to the Vortex Lattice Model that was re-initialized at each channel cross section. The total flow rate inputs are plotted in Figure 1, showing how the WEI stream gage calibrations eneabled the HEC-RAS model to predict the variation in flow rate in the inset channel between the Rialto Channel down to the MWD Crossing over the full range of potential RIX discharge rates.

3.3 Gravel and Cobble Size Inputs to Bed Roughness: The USGS California Water Science Center, Sacrament CA conducted sediment (bedload) transport measurements at Site 001 on the Santa Ana River at Riverside Ave, on June 26, 2014 and again on January 14, 2015. This site is also designated as USGS gage station #340151117212901. The site is approximately 0.8 km upstream from Riverside Bridge in the inset channel, at lat/long coordinates: 34° 1'50.86"N, 117°21'28.78"W. Here, "pebble counts" were performed on a "riffle", (a short, relatively shallow gravel- and cobble-bedded length of stream), with counts performed on both the upstream side and downstream sides. Figure 6 presents the gravel and cobble size distribution curves produced

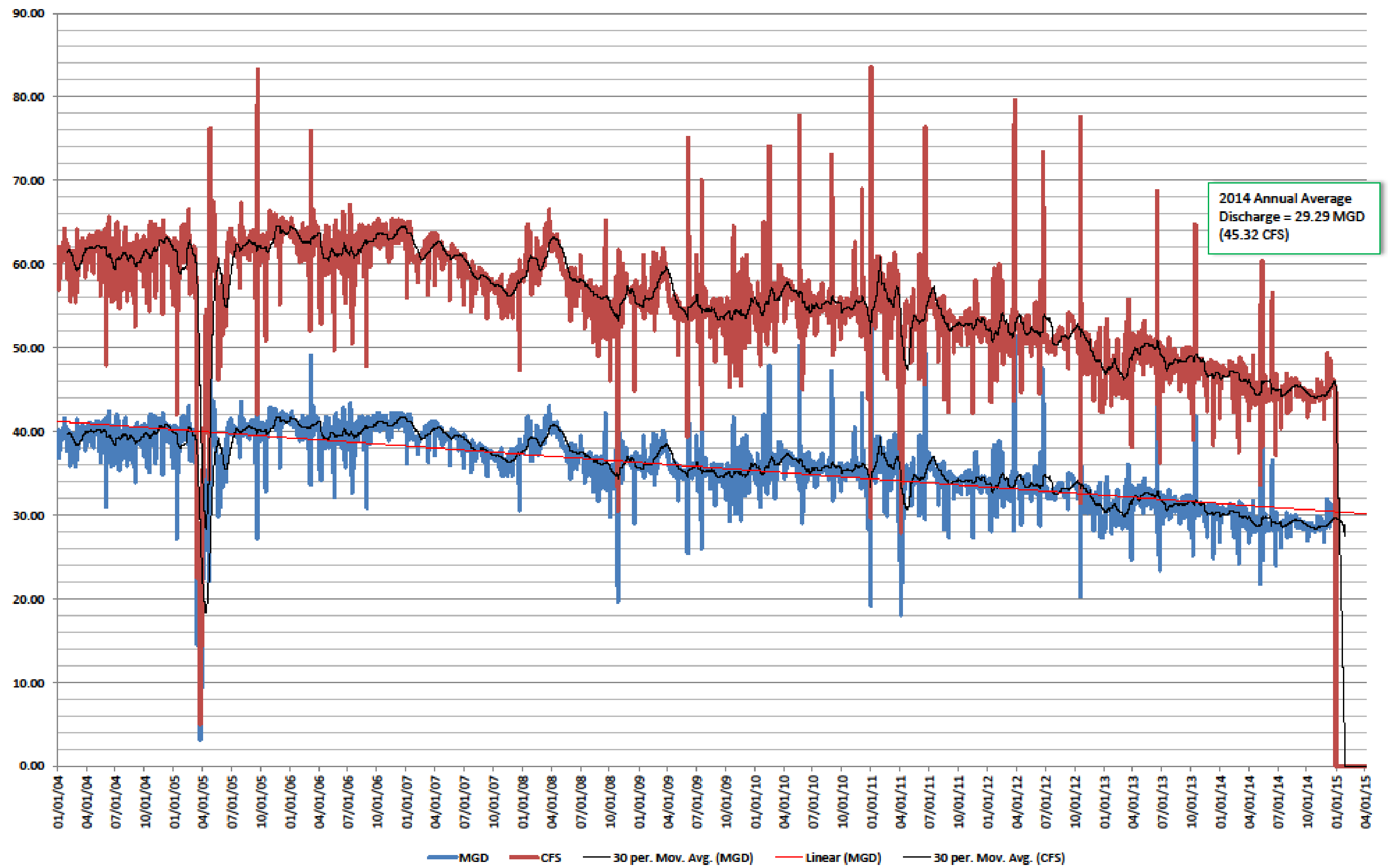


Figure 5: RIX discharge flow rate history in cubic feet per second (red), and in millions of gallons per day (blue). Data provided by Water Reclamation Division of the City of San Bernardino, Municipal Water Department.

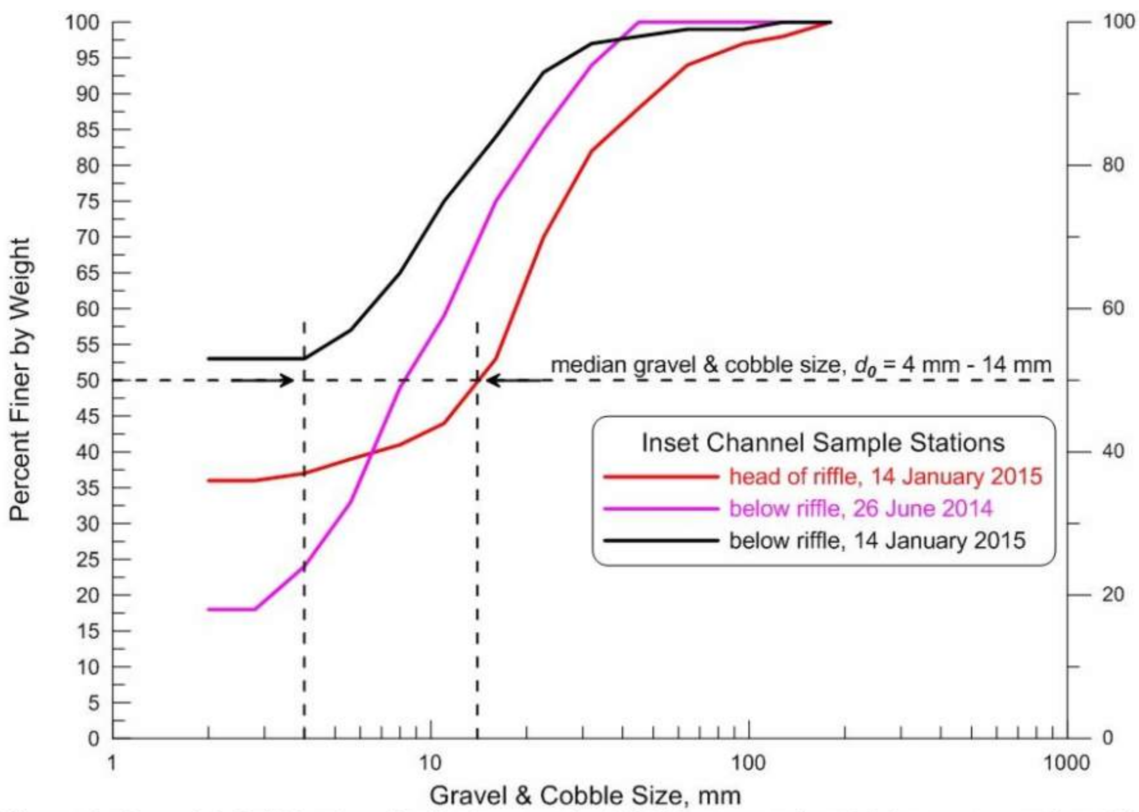


Figure 6. Gravel & Cobble size distributions, at the USGS gage station 0.8 km upstream from Riverside Ave. Bridge, during the 14 January 2015 bedload sediment transport field measurement program. Data provided by Scott Wright, USGS California Water Science Center Sacramento, CA.

by these pebble counts as expressed in percent abundance by weight. The maximize size of coble observed was 180 mm, but these largest size fractions accounted for less than 2% of the cobble population by weight, and less than 0.02% by number. Depending on the day and location, the median gravel and cobble size of the hard surface bed ranges from 4 mm to 14 mm, or an ensemble average of 9 mm. This value is used to initialize the median cobble size, d_0, in Eq. (2) of the Vortex Lattice Scour Model, (see Section 2).

3.4 Sand Blanket Grain Size Inputs: The USGS California Water Science Center, Sacramento, CA, also took sediment grab samples from sand patches immediately downstream of the gravel-cobble riffle at its bedload transport monitoring site on 14 January 2015, located approximately 0.8 km upstream from Riverside Bridge in the inset channel, at lat/long coordinates: 34° 1'50.86"N, 117°21'28.78"W. Sediment grab samples were taken along both the left and right hand banks of the inset channel (as viewed facing the downstream direction) and in the center of the inset channel. The samples were dried and sieved at the USGS California Water Science Center, and the results are plotted in Figure 7. The sediments from the sand patches range from medium to coarse sand mixed with very-fine to medium pebbles with the finest fractions of medium sand being 0.25 mm and the coarsest fractions of medium pebbles being 16 mm. The sediments in the sand blanket are much more well sorted along the right hand bank as a consequence of the inset channel making a gradual left hand bend at the sampling location. Here the median sand size is D_{50} = 0.9 mm and increases to D_{50} = 1.1 mm. The least well sorted sediments in the sand patch are found in the center of the inset channel where the median grain size is D_{50} = 3 mm, corresponding to very fine granules. Altogether, the USGS grain size data in Figure 7 allowed nine separate grain size bins to be populated in the Vortex Lattice Scour Model to perform the sediment transport calculations in Eq. 8 & 9.

3.5) Calibration: The scour and sediment transport results of the Vortex Lattice Model were calibrated using the USGS grain and cobble size distributions and sediment (bedload) transport measurements at Site 001 (Santa Ana River at Riverside Ave), conducted on 14 January 2015. Site 001 is also designated as USGS gage station #340151117212901, which recorded flow rates of 36.2 cfs to 36.8 cfs (23.4 mgd to 23.8 mgd) concurrent with sediment transport measurements, and bedload transport rates of 1,634 kg/day to 2,268 kg/day. After initializing the Vortex Lattice Model for the sand and coble size distributions observed by USGS and plotted in Figures 6 & 7, free parameters model were iteratively adjusted, (namely, ε_b the bedload transport efficiency, ε_s the suspended load transport efficiency; and C_D the riverbed drag coefficient which is a function of Mannings roughness), until the model was able to reproduce the aggregate bedload transport rates of 1,634 kg/day to 2,268 kg/day for flow rates of Q = 23.4 mgd to Q = 23.8 mgd at the Riverside Ave Bridge. This calibrated reproduction of the measured bedload transport rates was achieved for each mobile grain size fraction as well as for the aggregate total transport rates as shown in Figure 8. The coefficient of determination for the calibrated model was r^2 = 0.96 at a flow rate of Q = 23.4 mgd; and r^2 = 0.94 at a flow rate of Q = 23.8 mgd.

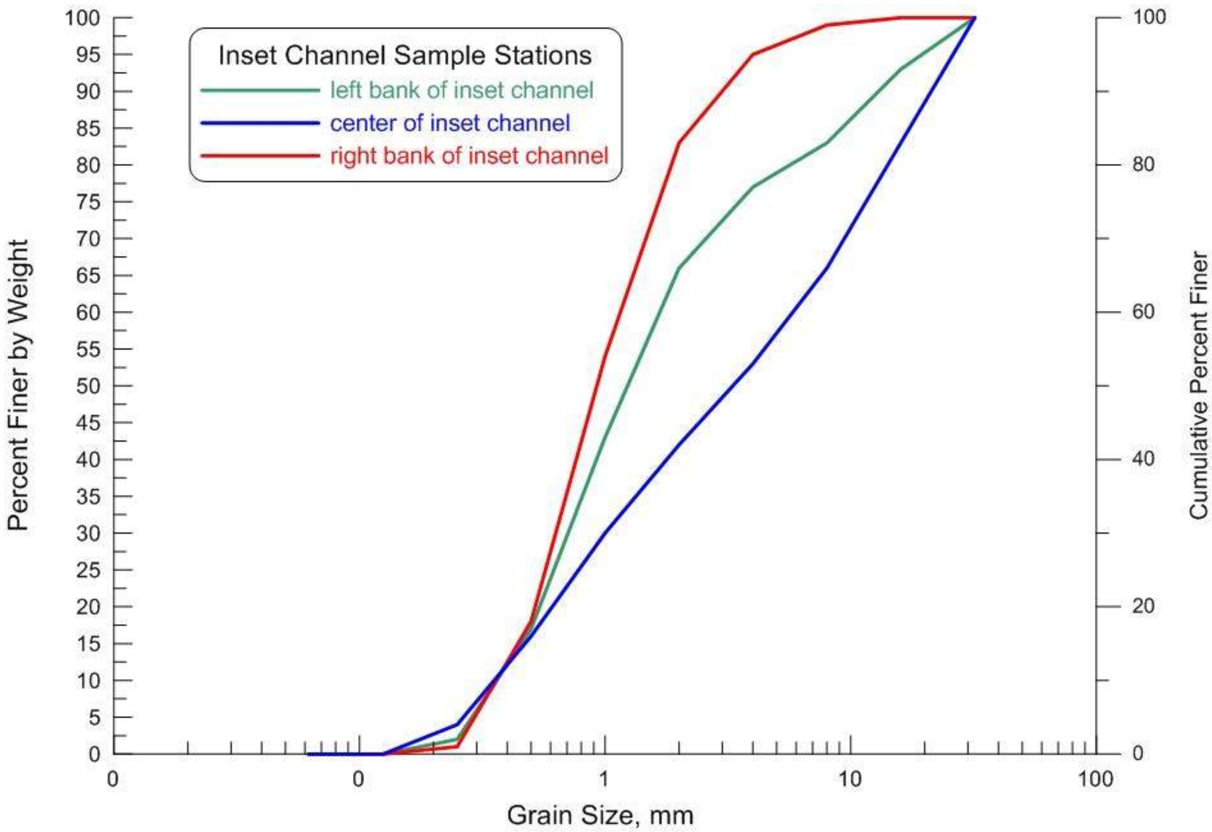


Figure 7. Sediment grain size distributions, at the USGS gage station 0.8 km upstream from Riverside Ave. Bridge, during the 14 January 2015 bedload sediment transport field measurement program. Data provided by Scott Wright, USGS California Water Science Center Sacramento, CA.

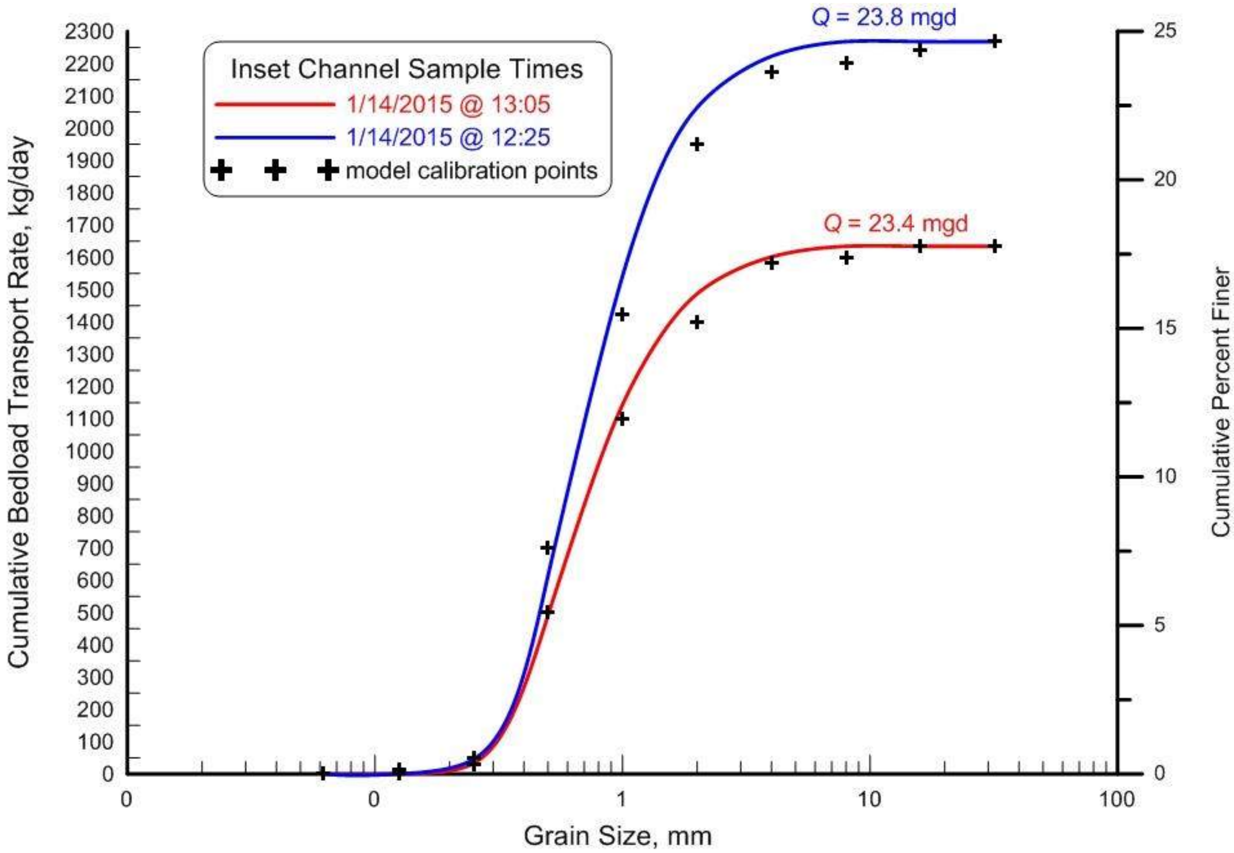


Figure 8. Bedload transport rates as a function of grain size, at the USGS gage station 0.8 km upstream from Riverside Ave. Bridge, during the 14 January 2015 bedload sediment transport field measurement program. Data provided by Scott Wright, USGS California Water Science Center Sacramento, CA.

4) Sediment Scour and Transport Simulations Induced by RIX Discharges:

The scour and transport scenario to be studied by hydrodynamic simulation is based on the fact that the majority of the gravel/cobble bed below Riverside Avenue support significant (greater than 25%) sand cover year round; and that the percentage of cover rapidly increases with increasing distance downstream past Riverside Avenue and exceeds 50% below Reach-1 of the study area, (GEI, 2013), where Reach-1 extends from RIX to 0.6 miles downstream of Riverside Ave.

4.1 Formulating Model Scenarios: The baseline conditions in the model were posed to reflect the cobble exposure conditions reported in GEI, (2013). In 2015, a survey of substrate was made for each of the 27 channel cross section stations in Reach 1. Each station is nominally 500 feet apart. The results of this survey can be roughly grouped into baseline conditions that establish the following generalized modeling goals:

Reach-1: RIX to 0.6 miles downstream of Riverside Ave.

- Stations 46132 to 42975: 100% cobble/gravel exposure
- Stations 42975 to 40475: 95% cobble/gravel exposure and 5% sand coverage
- Stations 40475 to 36462: 75% cobble/gravel exposure and 25 % sand coverage
- Stations 36462 to 32586: 50% cobble/gravel exposure and 50% sand coverage

Reach-2: 0.6 miles downstream of Riverside Ave to 0.6 miles downstream of Mission Inn Ave.

- Stations 32587 to 18976: 50% cobble/gravel exposure and 50% sand coverage

In terms of present habitat value for the Santa Ana sucker, Reach-1 is generally considered the more sensitive of the two reaches of river bed, (GEI, 2013). These 2015 conditions were used to establish the desired modeling goals; that is, the end states of the model simulations in Reach-1, and/or in the combined section of Reach-1 and Reach-2, beginning from an initial condition of total sediment cover of the cobble bed in the inset channel of the Santa Ana River.

The initial condition for total sediment cover requires a sand blanket of sufficient thickness to cover every riffle in Reaches 1 & 2. On a percent basis of sediment coverage, the required coverage of this sand blanket is equivalent to the percentages of cobble/gravel exposure for the baseline conditions listed above for Reaches 1 & 2. This computation is a complex 3-dimensional geometric problem as the riffles often extend from bank-to-bank across the inset channel, while the inset channel varies in width between 5.8 m and 17.4 m. The sand blanket is not a flat surface either as the depth of the inset channel varies from 0 cm at the banks to between 22 cm and 55 cm in the center of the channel, and the channel often bifurcates. The thickness of the sand blanket must be sufficient to cover not only the majority of gravel and cobble in the 4mm to 14 mm size regime, but also the occasional largest cobbles in the 96 mm to 180 mm size regime. To resolve this problem, the volumetric tools and the intersecting solids features of the SolidWorks 3-dimensional CAD program were invoked. The physical volume of this blanket of variable width and thickness was calculated to be 122.6 cubic meters in Reach-1 and 79.7 cubic meters in Reach-2, where a cubic meter of medium to coarse sand weighs 1.6 metric tons. However, not all of this blanket is sand; much of it is occupied by the buried cobbles. Assuming the gravels and cobbles are arranged in cubic packing in the riffles, then 61% of the physical blanket is occupied by cobbles and gravels and only 39% of it is sand. Consequently the amount of sand which the RIX discharges must scour from the buried riffles are 0.39 x 122.6 = 47.8 cubic meters or 76.5 metric tons in Reach-1 and 0.39 x 79.7 = 31.1 cubic meters = 49.7 metric tons in Reach-2, or a total of 126.2 metric tons of sand in the combined sections of Reaches 1 & 2.

4.2 Results of Modified Scenarios: Beginning with an initial condition of total sediment cover (126.2 metric tons of sand) over the gravel/cobble riffles in the inset channel, the model was run for 10 different stream flow rates normalized to the Riverside Ave Bridge site (*Q* = 0 mgd, 4.8 mgd, 6.1 mgd,19.5 mgd, 23.6 mgd, 26.9 mgd, 29 mgd, 35.1 mgd, 40.4 mgd and 64 mgd). For each of these flow rates, the model was run for the duration required to achieve the modeling goals of cobble/gravel exposure in Reach-1 and Reach-2 as described in Section 4.1 above. Beginning with the example of inset channel flow Q = 29 mgd equivalent to the 2014 RIX average discharge, we show the scour and transport rates in Figure 9 on day-3 of the simulation for Reach-1 between RIX at Station 46132 downstream to Station 42510. Several very intense areas of local scour are evidenced by the red *scour hot-spots* in Figure 9 where scour and transport rates approach 8 metric tons per day. In a close up view of the intense scour area closest to RIX, we show the corresponding velocity distribution in the inset channel in Figure 10 for the first two sections of this reach between Station 46132 and Station 44975. This is some of the most sensitive reach of Santa Ana sucker habitat, and these two figures indicate very vigorous scour and rapid bearing of the cobble/gravel substrate and riffle fields are likely in this area even under average RIX operating conditions. In fact Figure 10 indicates flow velocities in the inset channel of between 0.75 m/s (2.5 ft./s) and 1.5 m/s (5.0 ft/s) over most of this reach. Comparing these flow velocities against the Hjulstrom curve for critical scour speeds in Figure 11, we find that the inset channel currents immediately below RIX are more than sufficient to scour even the largest grain size fractions of the sand blanket, as represented by the USGS grain size distributions in Figure 7. Inspection of the sediment scour and transport rates for the remaining sections of Reach-1 in Figures 12-14, we find significant scour and transport rates persist on the order of 4 to 5 metric tons per day throughout most of Reach-1 with a number of additional scour hot-spots, especially in the lower section of Reach-1 between Station 36462 and Station 32586, (Figure 14). In Reach-2 (Figures 15-17), scour and transport rates are less uniform, with a long section of scour hot-spots in the middle of Reach-2 between Station 25976 and Station 22461 (Figure 16), bookended by long sections of only moderate scour rates in the range of 3 to 4 metric tons per day between Station 32586 and Station 26976 (Figure 15), and between Station 22461 and Station 18976.

The general lesson to be learned from the scour simulations in Figures 9-17 is that scour and exposure of the cobble/gravel riffles in the inset channel will not be uniform following burial by a post-storm sand blanket. There are regions identified by the scour hot spots where the cobble and gravel substrate will be scoured and exposed very rapidly, even at average RIX

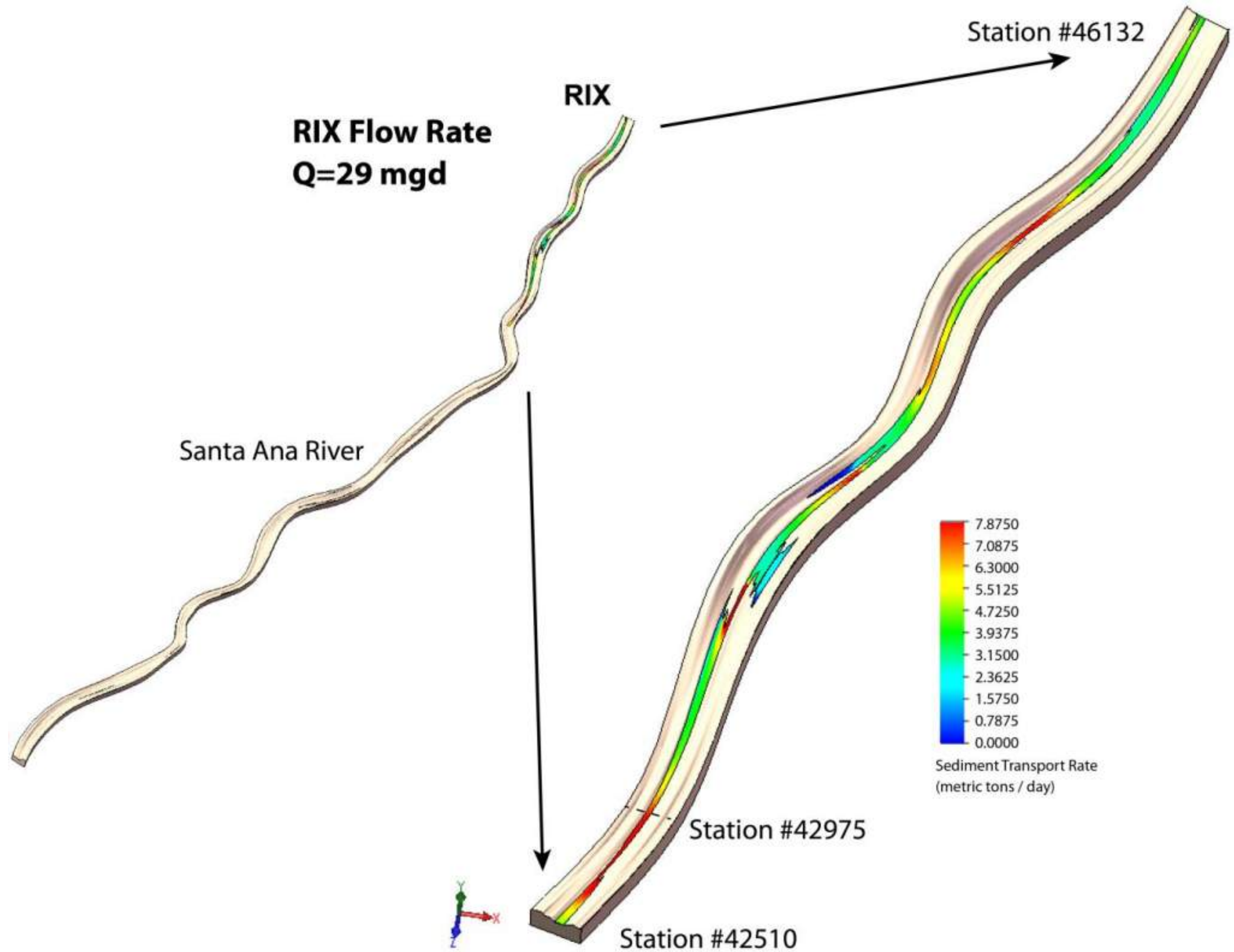


Figure 9: Vortex Lattice Scour Model simulation of sediment transport at t = 3 days in Reach-1 of Santa Ana River between RIX at Station 46132 to Station 42510. The model was run with an inset channel flow rate = 29 mgd using an initial state of total sediment cover over the cobble bed of the inset channel. The figure shows the spatial variation in bedload sand transport rate according to the color bar scale with vertical exaggeration by a factor of 3.28. The model was run until an end-state of 100% exposure of cobble/gravel was achieved. Note Station 42975 is 465 ft. upstream from Station 42510.

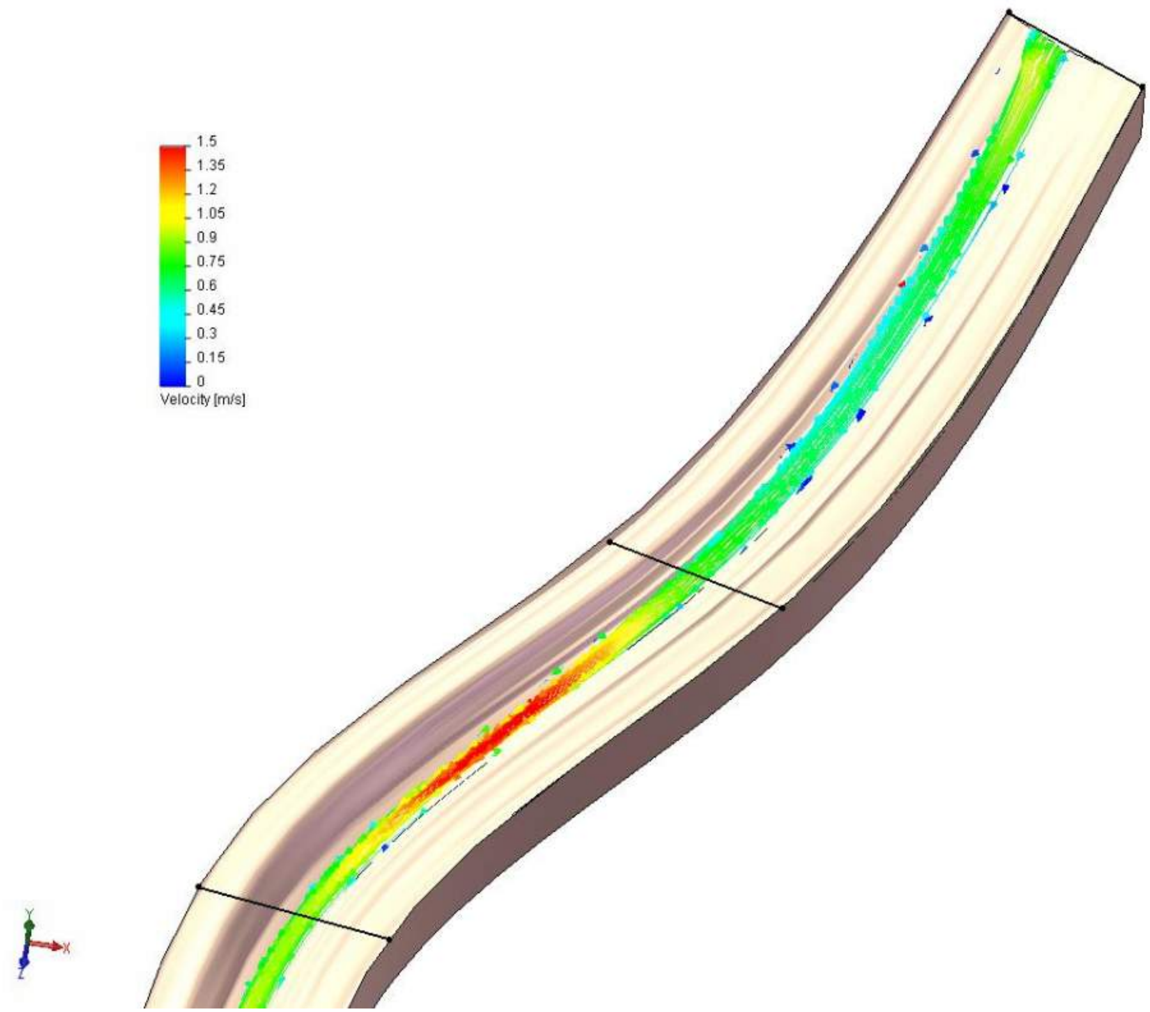


Figure 10: Vortex Lattice Scour Model simulation of scour velocities in the inset channel at t = 3 days in Reach-1 of Santa Ana River between RIX at Station 46132 and Station 44975. The model was run with an inset channel flow rate = 29 mgd using an initial state of total sediment cover over the cobble bed of the inset channel. The figure shows the spatial variation in channel velocity according to the color bar scale with vertical exaggeration by a factor of 3.28.

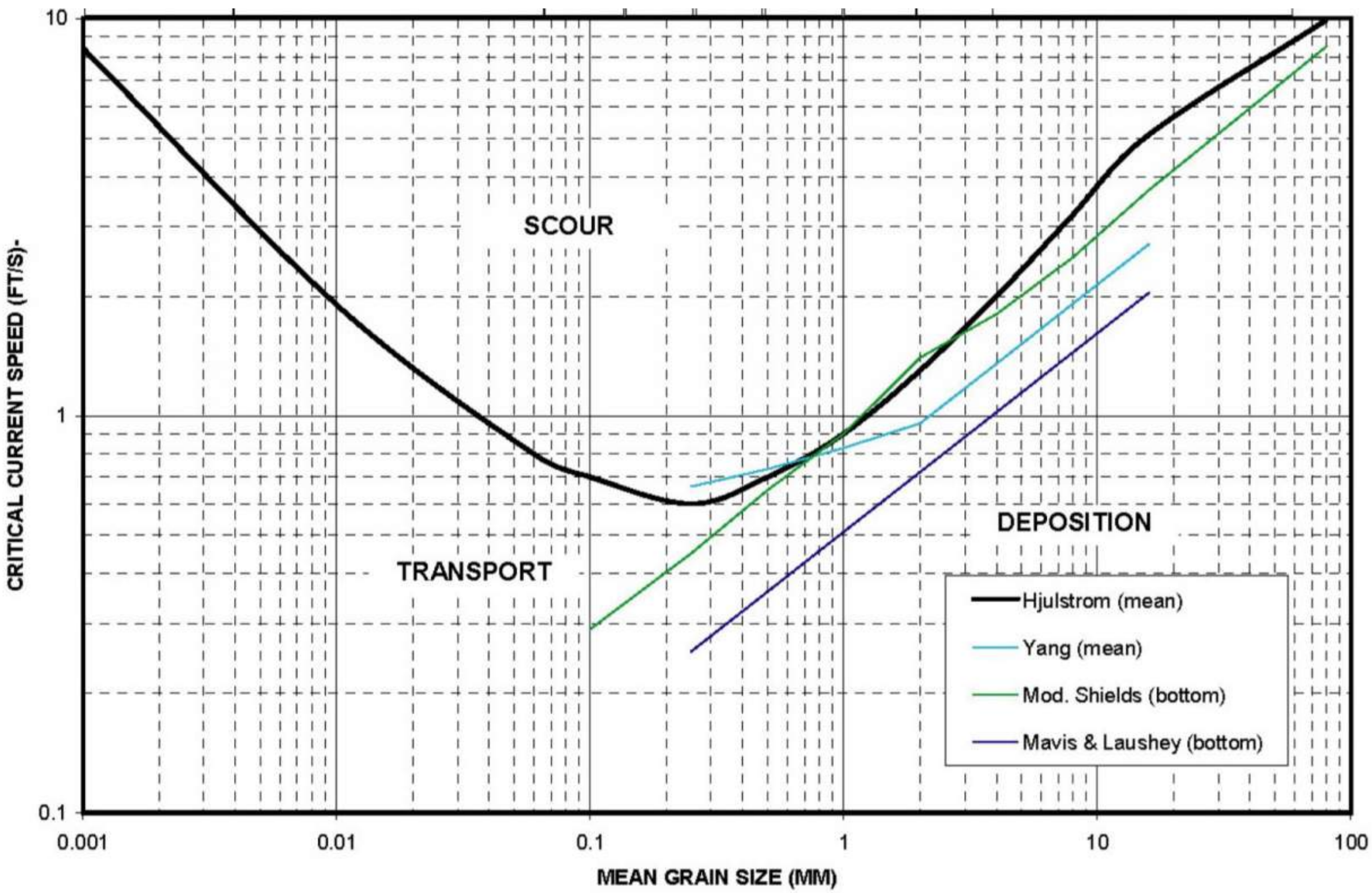


Figure 11: Hjulstrom curve for critical current speeds of quartz sediment as a function of mean grain size, from Everest, (2007).

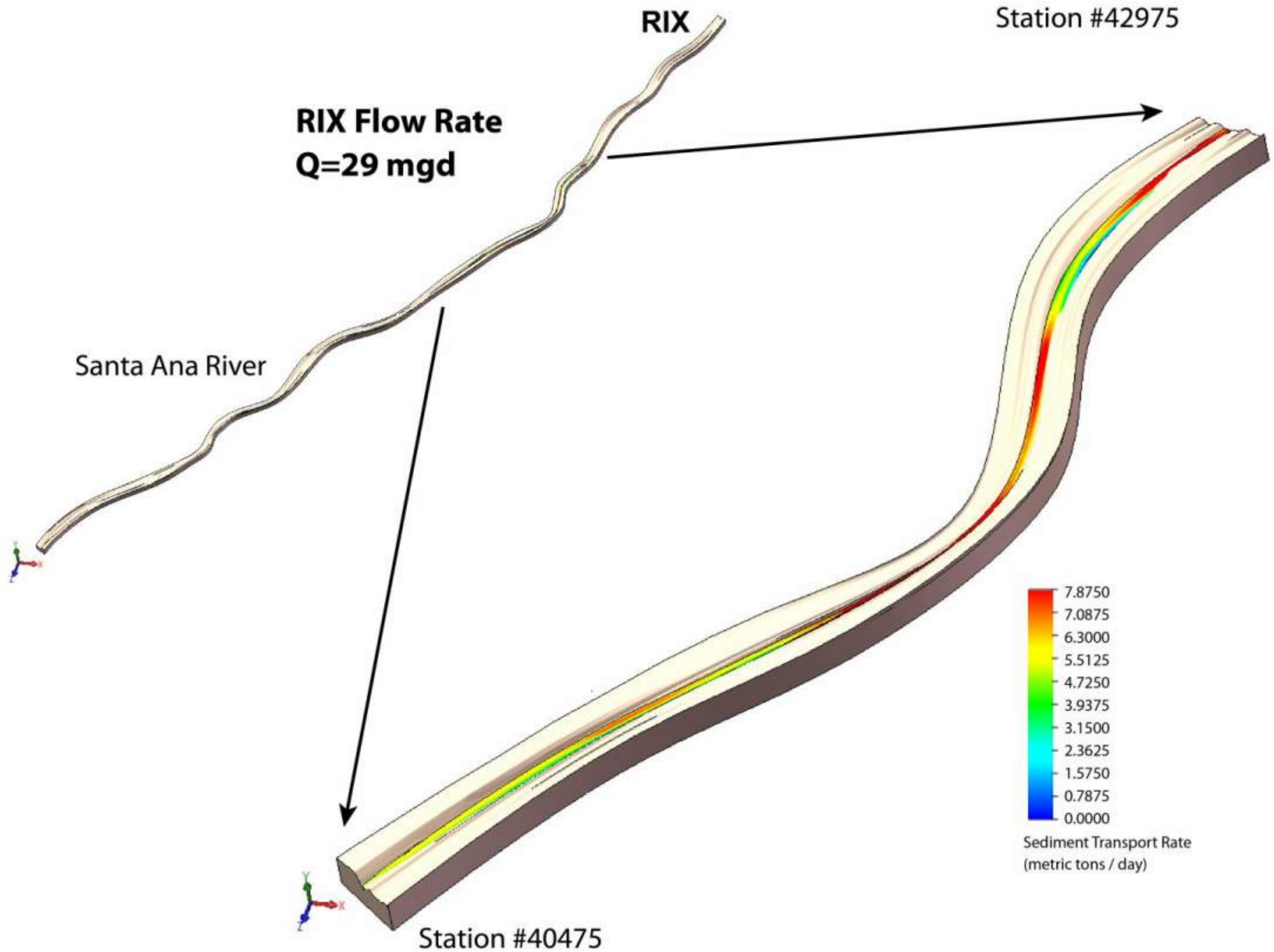


Figure 12: Vortex Lattice Scour Model simulation of sediment transport at $t = 3$ days in Reach-1 of Santa Ana River downstream of RIX at Station 42975 to Station 40475. The model was run with an inset channel flow rate = 29 mgd using an initial state of total sediment cover over the cobble bed of the inset channel. The figure shows the spatial variation in bedload sand transport rate according to the color bar scale with vertical exaggeration by a factor of 3.28. The model was run until an end-state of 95% exposure of cobble/gravel was achieved with 5% residual sand.

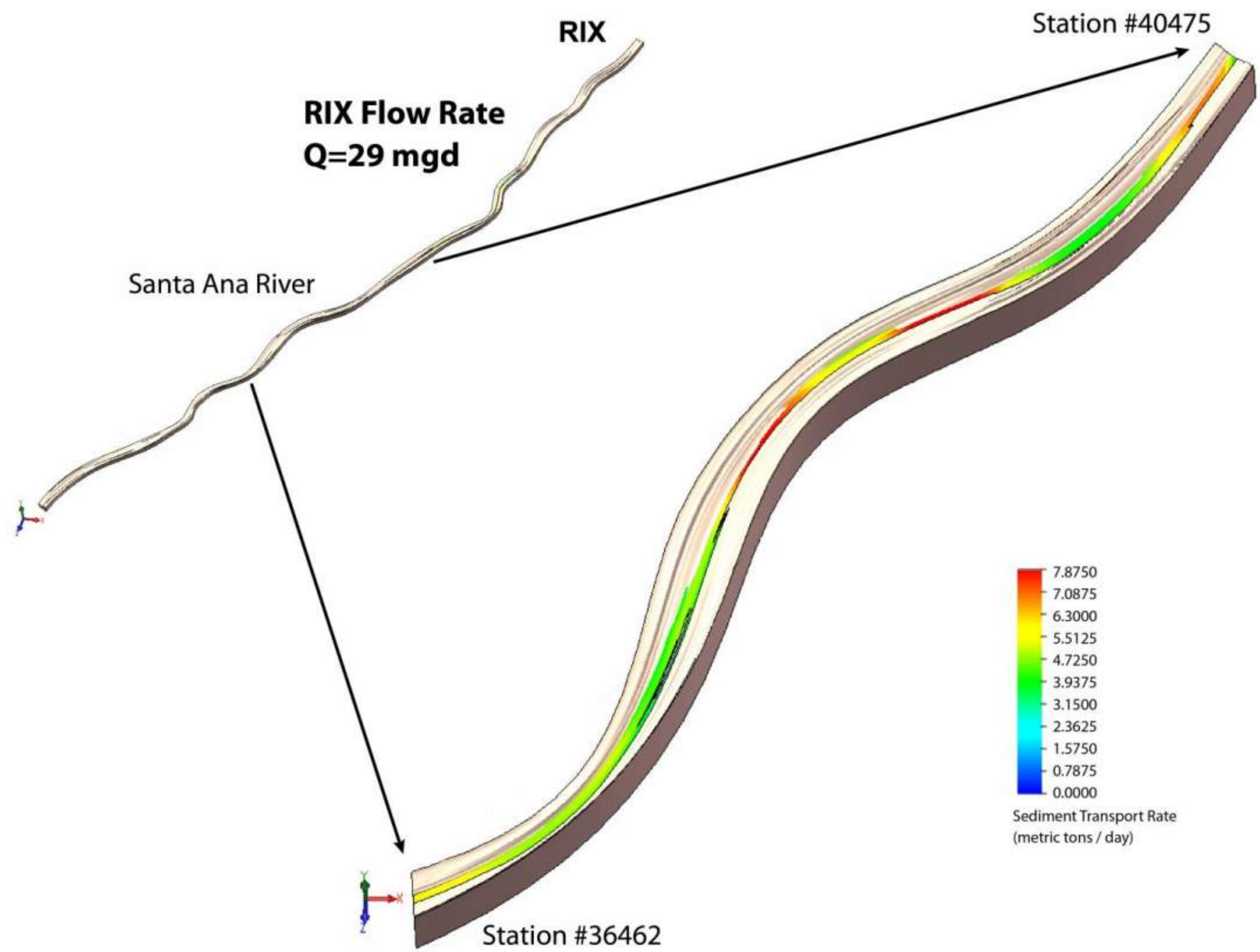


Figure 13: Vortex Lattice Scour Model simulation of sediment transport at $t = 3$ days in Reach-1 of Santa Ana River downstream of RIX at Station 40475 to Station 36462. The model was run with an inset channel flow rate = 29 mgd using an initial state of total sediment cover over the cobble bed of the inset channel. The figure shows the spatial variation in bedload sand transport rate according to the color bar scale with vertical exaggeration by a factor of 3.28. The model was run until an end-state of 75% exposure of cobble/gravel was achieved with 25% residual sand.

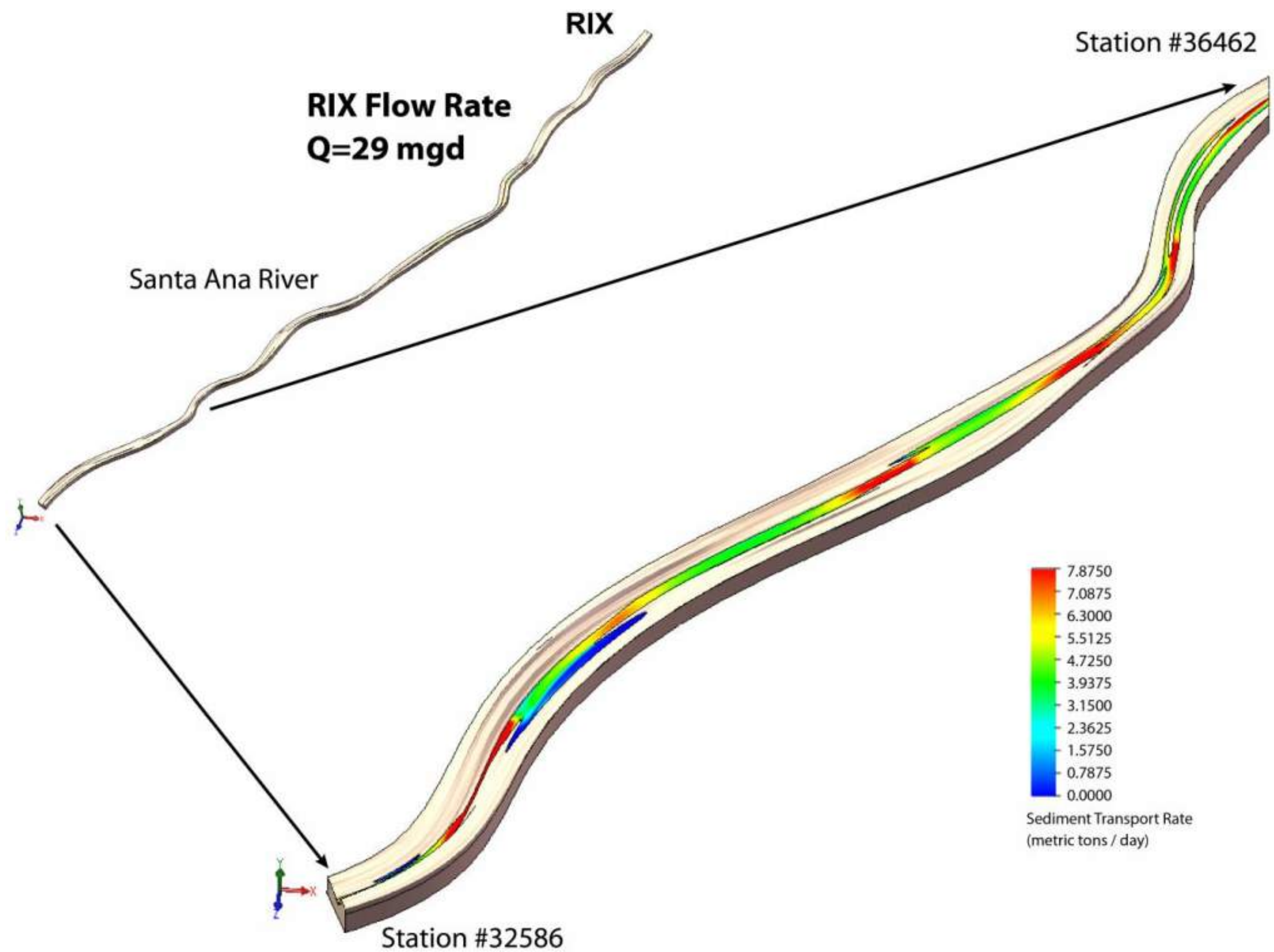


Figure 14: Vortex Lattice Scour Model simulation of sediment transport at t = 3 days in Reach-1 of Santa Ana River downstream of RIX at Station 36462 to Station 32586. The model was run with an inset channel flow rate = 29 mgd using an initial state of total sediment cover over the cobble bed of the inset channel. The figure shows the spatial variation in bedload sand transport rate according to the color bar scale with vertical exaggeration by a factor of 3.28. The model was run until an end-state of 50% exposure of cobble/gravel was achieved with 50% residual sand.

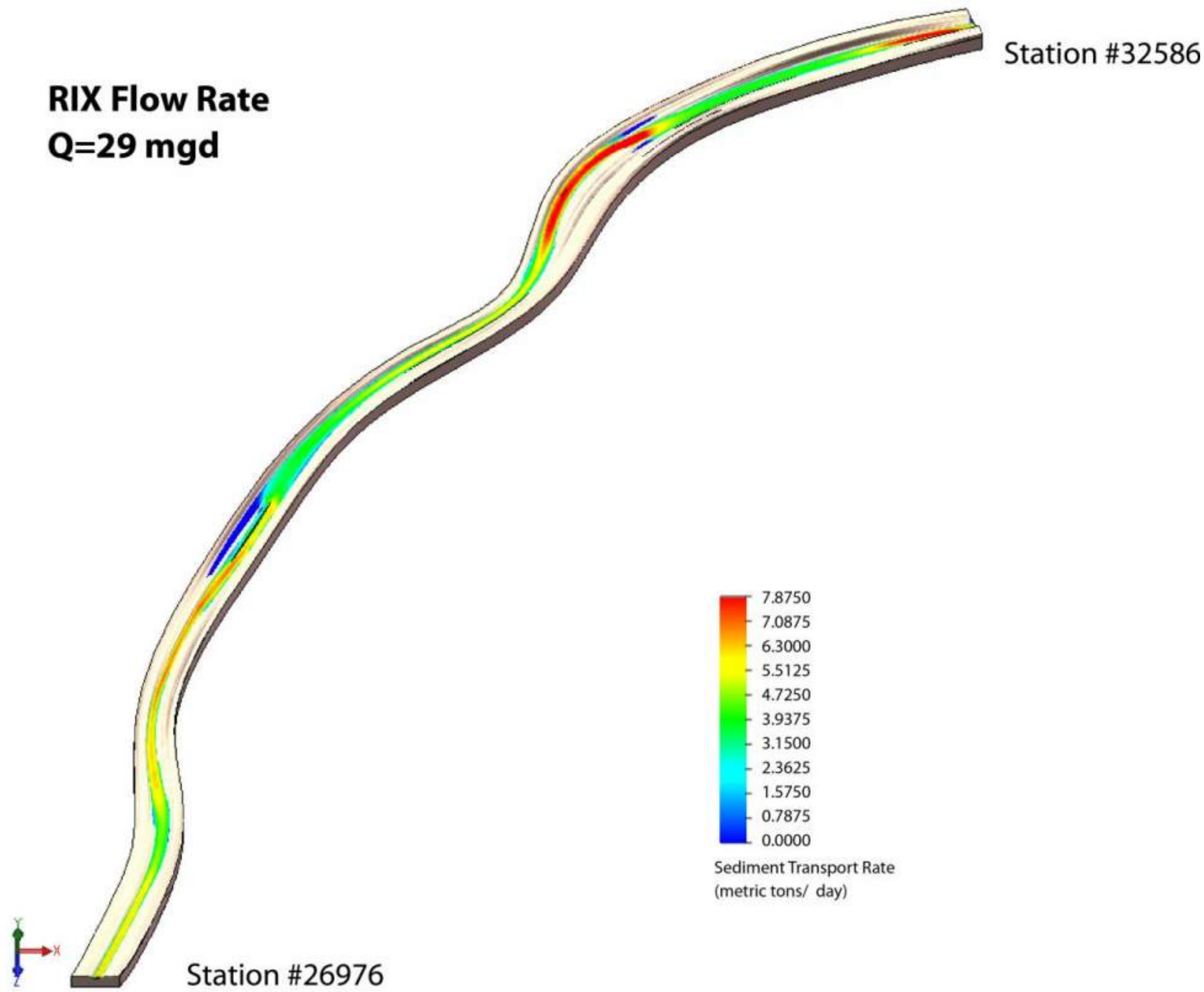


Figure 15: Vortex Lattice Scour Model simulation of sediment transport at t = 3 days in Reach-2 of Santa Ana River downstream of RIX at Station 32586 to Station 26976. The model was run with an inset channel flow rate = 29 mgd using an initial state of total sediment cover over the cobble bed of the inset channel. The figure shows the spatial variation in bedload sand transport rate according to the color bar scale with vertical exaggeration by a factor of 3.28. The model was run until an end-state of 50% exposure of cobble/gravel was achieved with 50% residual sand.

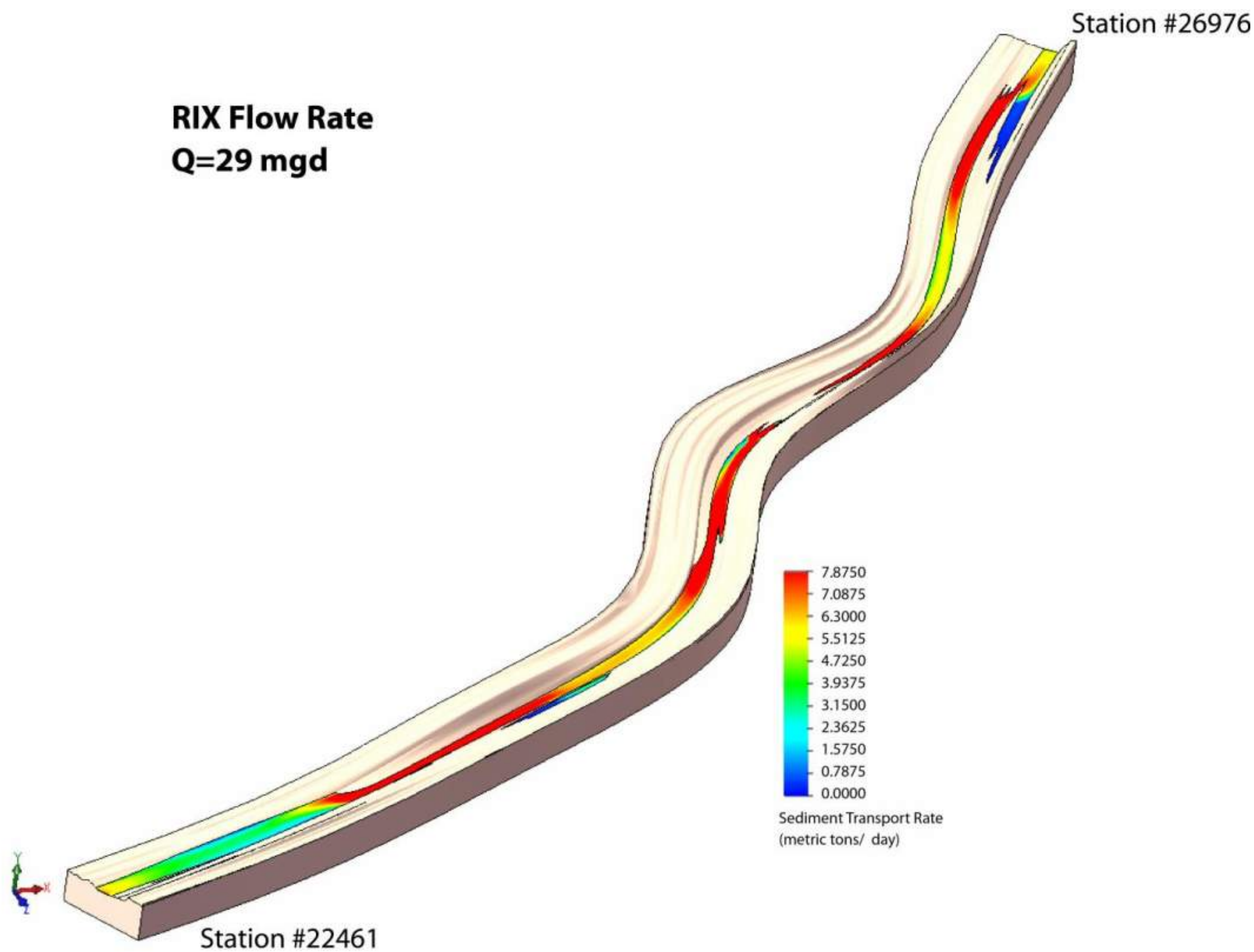


Figure 16: Vortex Lattice Scour Model simulation of sediment transport at t = 3 days in Reach-2 of Santa Ana River downstream of RIX at Station 26976 to Station 22461. The model was run with an inset channel flow rate = 29 mgd using an initial state of total sediment cover over the cobble bed of the inset channel. The figure shows the spatial variation in bedload sand transport rate according to the color bar scale with vertical exaggeration by a factor of 3.28. The model was run until an end-state of 50% exposure of cobble/gravel was achieved with 50% residual sand.

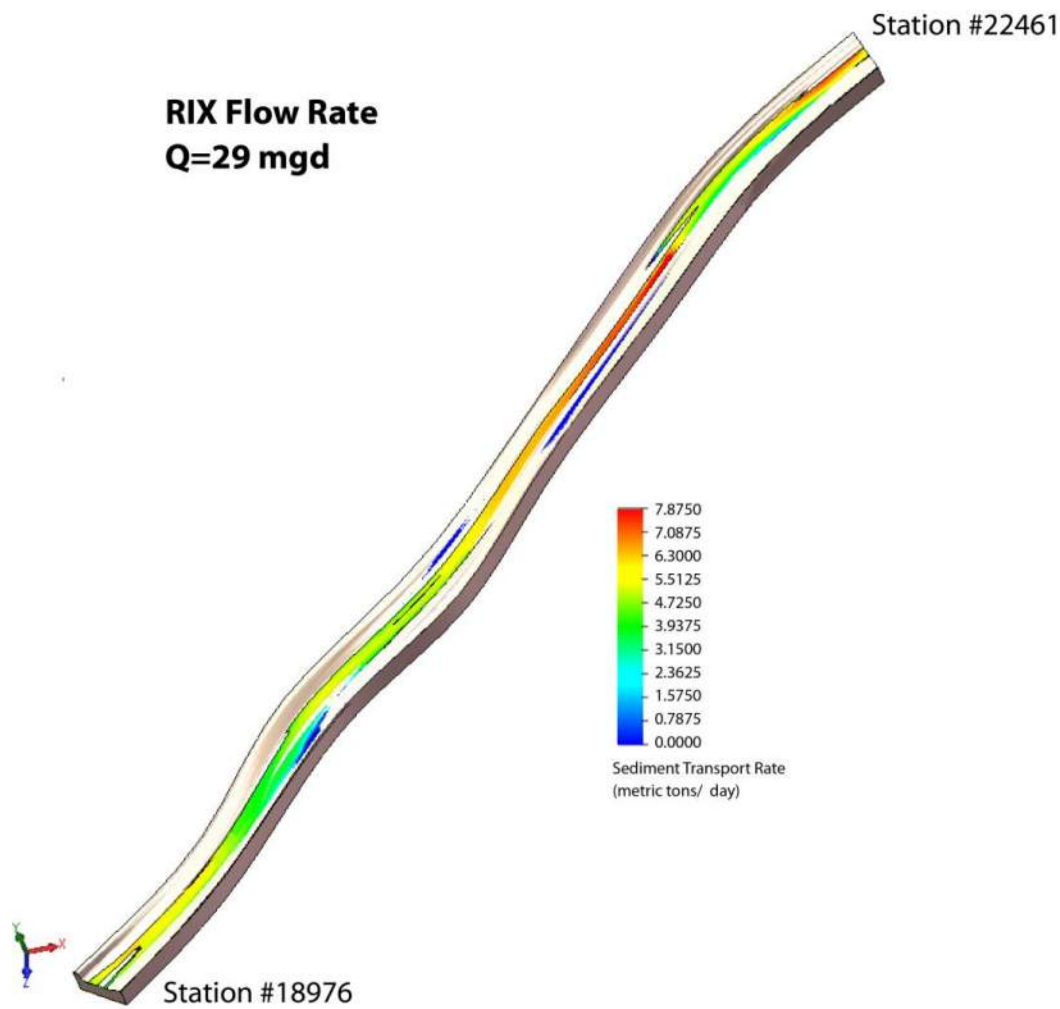


Figure 17: Vortex Lattice Scour Model simulation of sediment transport at t = 3 days in Reach-2 of Santa Ana River downstream of RIX at Station 22461 to Station 18976. The model was run with an inset channel flow rate = 29 mgd using an initial state of total sediment cover over the cobble bed of the inset channel. The figure shows the spatial variation in bedload sand transport rate according to the color bar scale with vertical exaggeration by a factor of 3.28. The model was run until an end-state of 50% exposure of cobble/gravel was achieved with 50% residual sand.

discharge rates, and these areas will provide immediate post-storm micro-environments for the Santa Ana sucker. Generally these scour hot-spots are caused by six types of kinematic or dynamical conditions: 1) contractions of the inset channel width, 2) turns or bends in the inset channel that create centrifugal acceleration of the flow towards the outside of the turn, 3) bifurcation of the inset channel, 4) increase in bed gradient of the inset channel, 5) increase in hydraulic gradient due to ground water upwelling, and 6) hydraulic jumps from super-critical flow velocities at higher RIX discharge rates. However, wherever there are scour hot-spots, depositional areas are nearby, as denoted by the blue areas in the sediment scour and transport patterns in Figures 9 – 17. These depositional areas are very common near inset channel bifurcations, especially when those bifurcations occur in proximity to a bend in the inset channel as shown by the inserted cross-sectional view in Figure 18. When a channel bifurcation occurs at a bend in the river, the flow does not divide evenly and concentrates under the effects of centrifugal acceleration in the channel on the outside of the turn, leaving the inside channel with flow speeds below threshold scour speed, and causing those inside channels to become depositional over time. These depositional bifurcated channels will remain unsuitable for Santa Ana sucker habitat until a significant flood event can augment channel flow by RIX to sufficient degree that general scour occurs across the entire river bed.

We focus summary discussion on three of the ten flow rates evaluated to bracket the envelope of variability in the inset channel. These were Q = 23.6 mgd (the value during the USGS field measurements); Q = 29 mgd, same as the operational mean discharge from RIX during 2014; and Q = 64 mgd, same as the maximum permitted discharge capacity of RIX. Figure 19 shows the simulated scour history of sand blanket over gravel/cobble riffles in the combined Reach-1 and Reach-2 sections of the of the Santa Ana river as a function of sustained discharge rates in the inset channel. The flow in the inset channel is a combination of three sources, namely, base-flow of the Santa Ana River, (which is typically nil during dry weather conditions), discharges from the Rialto WWTP, or Rialto Channel (which may become di minimis under future operating conditions), and discharges from RIX. The results in Figure 19 are derived from time-integration of scour and transport rates, and consequently the point-wise variation in scour rates evidenced in Figures 9-17 are averaged out along the whole of Reach-1 and Reach-2. The horizontal dashed green lines in Figure 19 represent the generalized aggregate scour goals to re-establish the baseline conditions outlined in Section 4.1, achieved by removing 76.5 metric tons of sand blanket from Reach-1 and a total of 126.2 metric tons of sand from the combined sections of Reaches 1 & 2. Figure 20 shows how well these generalized scour goals are achieved over distance downstream from RIX by each of these three RIX discharge rates. The dashed green lines in Figure 20 represent the generalized scour goals, while the black crosses show the observed percentages of exposed substrate that define the biological baseline conditions as determined during the river walk surveys, GEI, (2013). The coefficients of determination of the modeled scour end-states in Figure 20 for matching the river walk substrate data is r^2 = 0.84 at Q = 23.6 mgd (red); r^2 = 0.87 at Q = 29 mgd (blue); and r^2 = 0.88 at Q = 64 mgd (magenta). These statistics represent moderately high predictive skill.

From Figure 19, it is apparent that scour and transport of the sand blanket does not occur uniformly over time; but rather begins at a rather slow rate over the initially featureless surfaces of the post-flood sand blanket. However, as scour begins to expose the larger cobble sizes, creating vortex shedding and vortex scour in the wakes of these exposed cobbles, the scour and transport rates begin to increase. That increase exposes additional smaller cobbles that have greater abundance, creating more and more flow disturbances, vortex shedding and subsequent

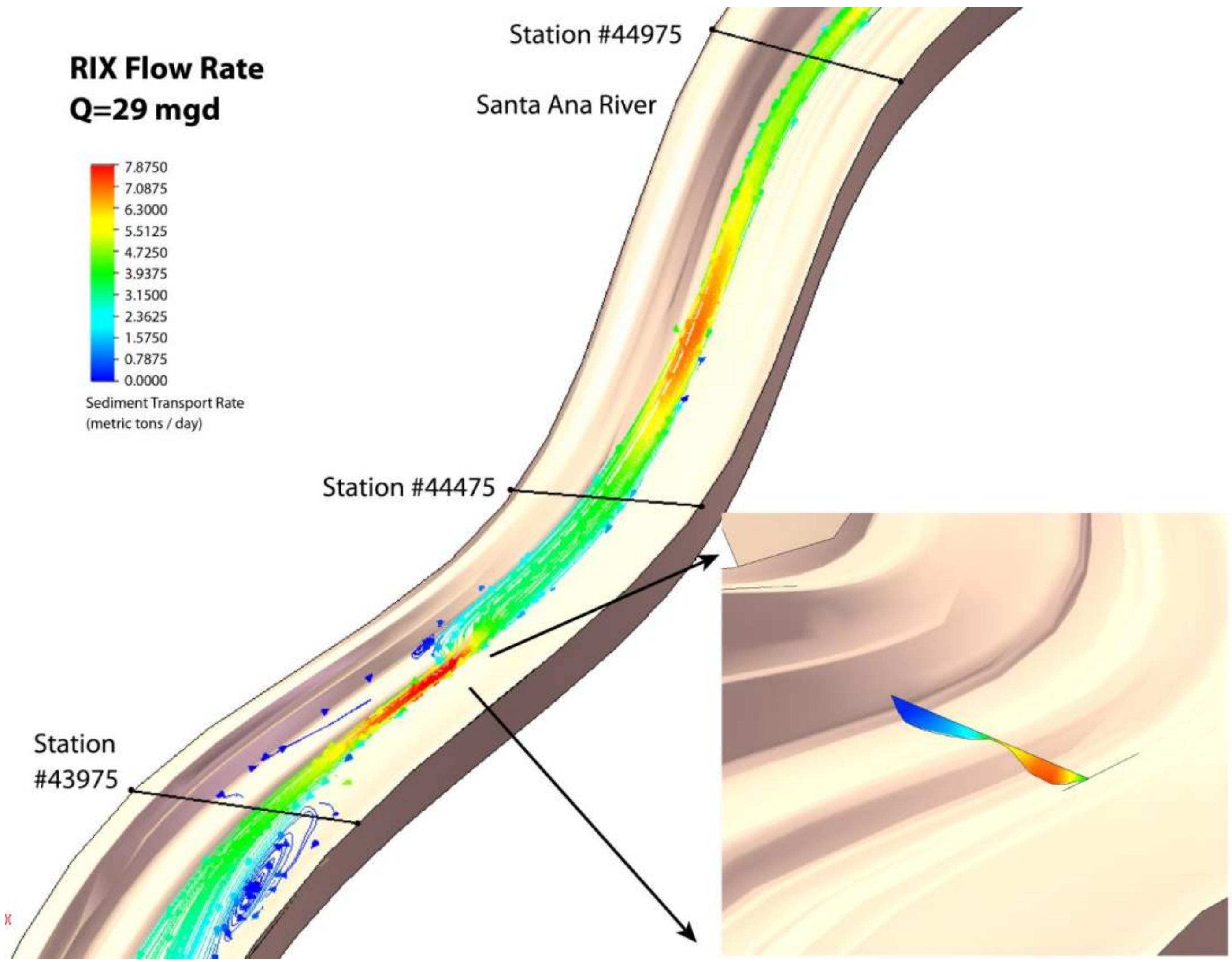


Figure 18: Vortex Lattice Scour Model simulation of sediment transport at $t = 3$ days in Reach-1 of Santa Ana River showing intense scour area (red) adjacent to depositional area (blue) with back-water eddies in the bifurcated section of inset channel below RIX between Station 44975 and Station 43975.

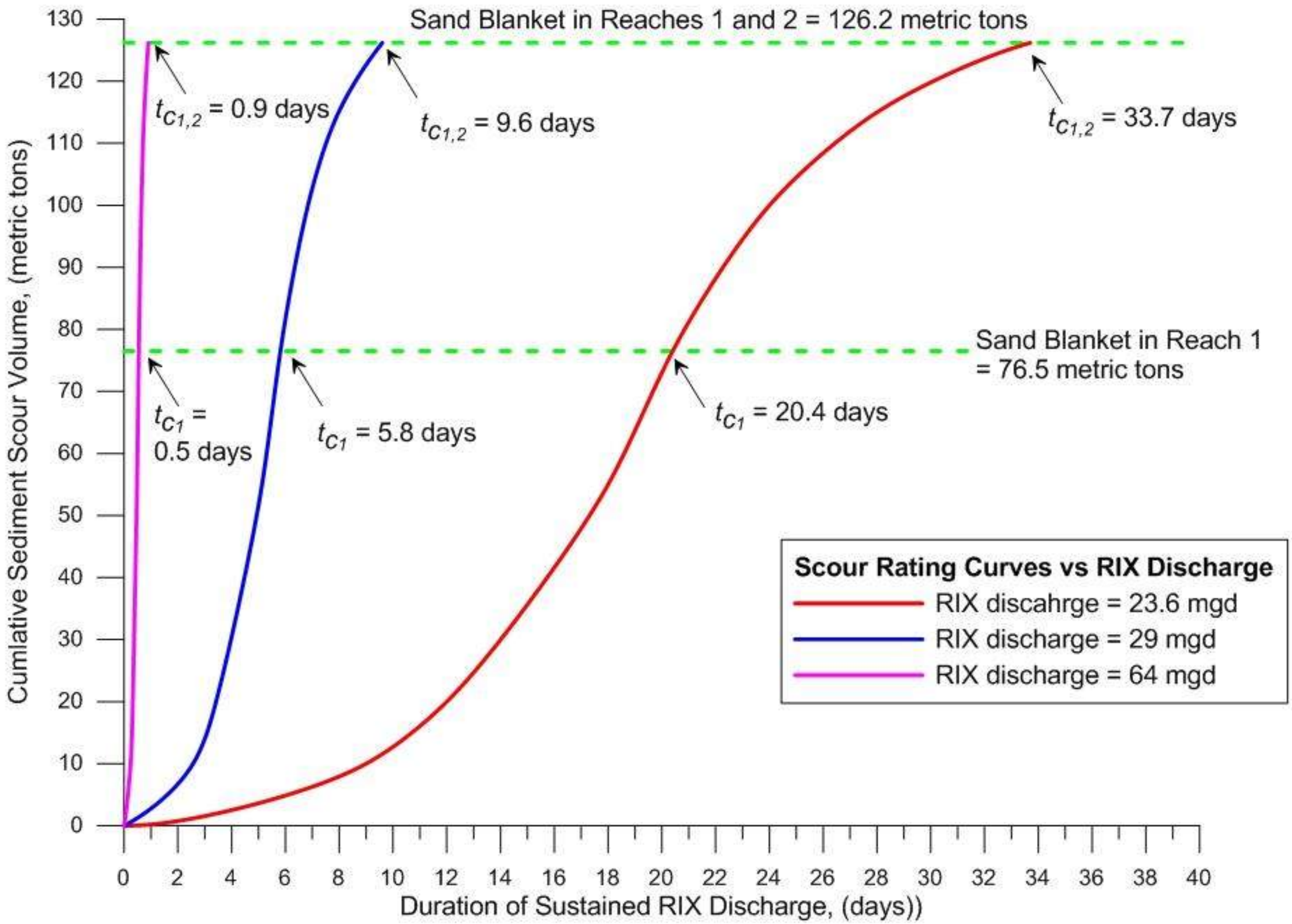


Figure 19: Simulated scour history of sand blanket over gravel/cobble riffles in the combined Reach-1 and Reach-2 sections of the Santa Ana River as a function of flow rates in the inset channel.

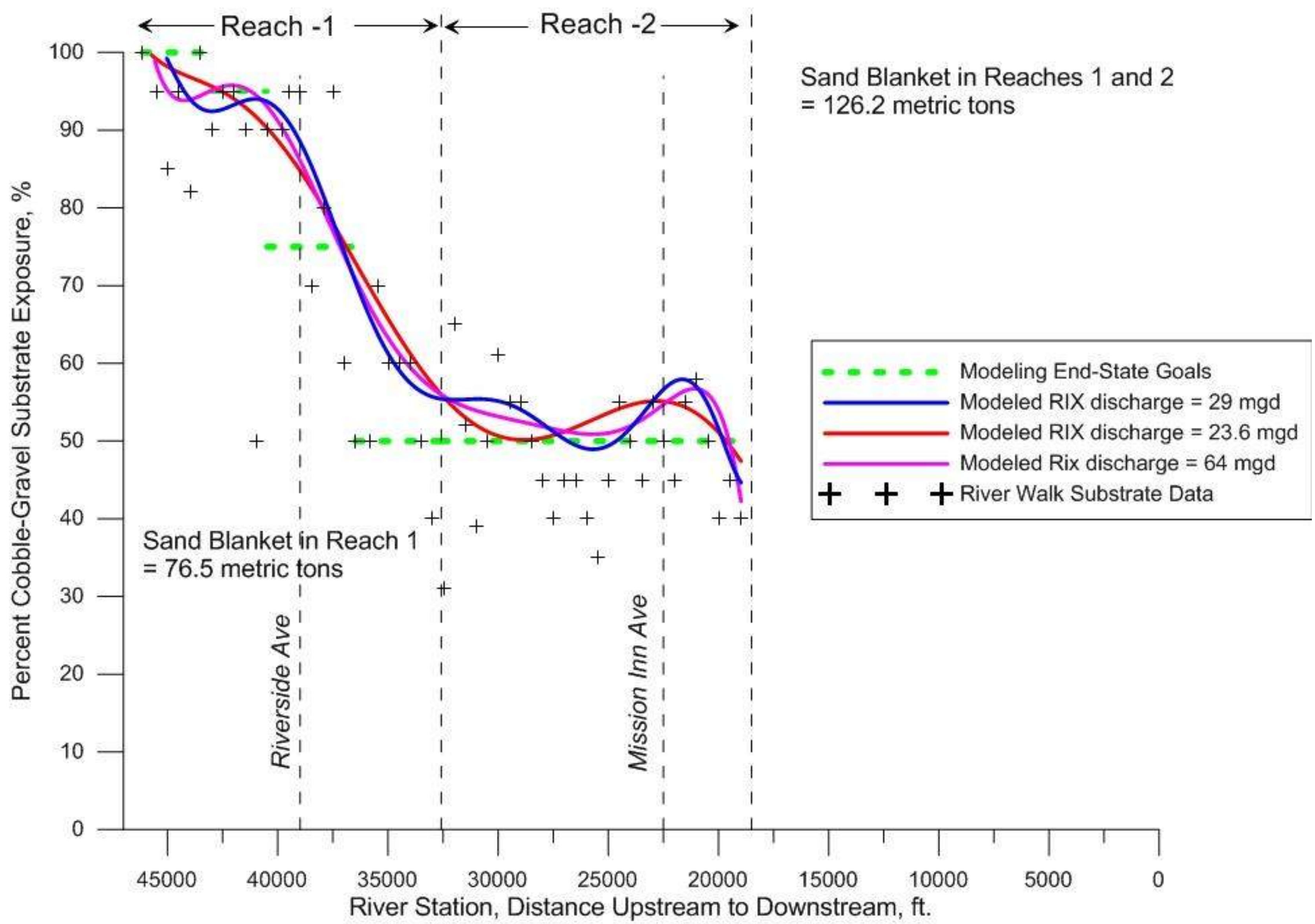


Figure 20: Simulated scour and exposure of cobble/gravel substrate in the combined Reach-1 and Reach-2 sections of the Santa Ana River as a function of flow rates and distance in the inset channel.

vortex scour. This process accelerates over time until most of the cobbles in a given riffle are exposed, whence additional scour of the sand blanket becomes limited by the local sand supply, whence the scour and transport rates begin to decline over time. Inspection of Figure 19 reveals that the scour goals for removing 76.5 metric tons of sand blanket from Reach-1 are achieved in 5.8 days when inset channel flow rates are equivalent to the 2014 RIX discharge average of Q = 29 mgd , and that the combined goals of removing 126.2 metric tons from the combined sections of Reach- 1 & 2 can be achieved in 9.6 days. But these scour and transport rates are a highly non-linear function of the inset channel flow rate, and the scour goals for Reaches 1 & 2 can be achieved in less than a day at flow rates approaching the maximum permitted RIX discharge rate of Q = 64 mgd. At reduced flow rates such as Q = 23.6 mgd, as occurred during the 14 January 2015 USGS field measurements, the scour goals of restoring baseline conditions in Reaches 1 & 2 can take as long as 33.7 days. These results are summarized below in Table-1 below. Extrapolating from the results of the scour simulations from all ten of the discharge scenarios evaluated (Q = 0 mgd, 4.8 mgd, 6.1 mgd, 19.5 mgd, 23.6 mgd, 26.9 mgd, 29 mgd, 35.1 mgd, 40.4 mgd and 64 mgd), we are able to make continuous projections in Figure 21 of the discharge duration required to clear post-flood sand coverage of the coble bed that RIX must maintain for any arbitrary discharge rate within the operating capacity of RIX. From these results we conclude that the minimum threshold for achieving sand scour in the inset channel occurs at a discharge rate of Q = 4.8 mgd, comparable to recent daily discharges from the Rialto WWTP, (Rialto Channel).

Because none of the inset channel flow rates in Table-1 or Figure 21 exceed the discharge capacity of RIX, (see Figure 5) it appears that restoration of biological baseline conditions of the river following a relatively rare, high-deposition, flood event, are within the operating capabilities of RIX. The estimated return period of this depositional event is 5 years based on sediment rating curves and cumulative residual analysis of the Santa Ana River published in Inman and Jenkins (1998, 1999). This expectation is further enhanced by the fact that coverage of the cobble bed by a thick blanket of sand is a wet-weather occurrence, when percolation losses of stream flow are minimal along the biologically sensitive section of inset channel in Reach-1.

Table-1 Summary of Results of Modified Scenarios

Inset Channel Stream Flow Rates at Riverside Ave Bridge	Initial Sediment Transport Rate	Average Sediment Transport Rate	Flow Duration to Achieve Scour Goals Reach-1 (removal of 76.5 tons of sand)	Flow Duration to Achieve Scour Goals Reaches-1&2 (removal of 126.2 tons of sand)
23.6 mgd	0.46 metric tons/day	3.75 metric tons/day	20.4 days	33.7 days
29 mgd	4.96 metric tons/day	13.2 metric tons/day	5.8 days	9.6 days
64 mgd	86.5 metric tons/day	142 metric tons/day	0.5 days	0.9 days

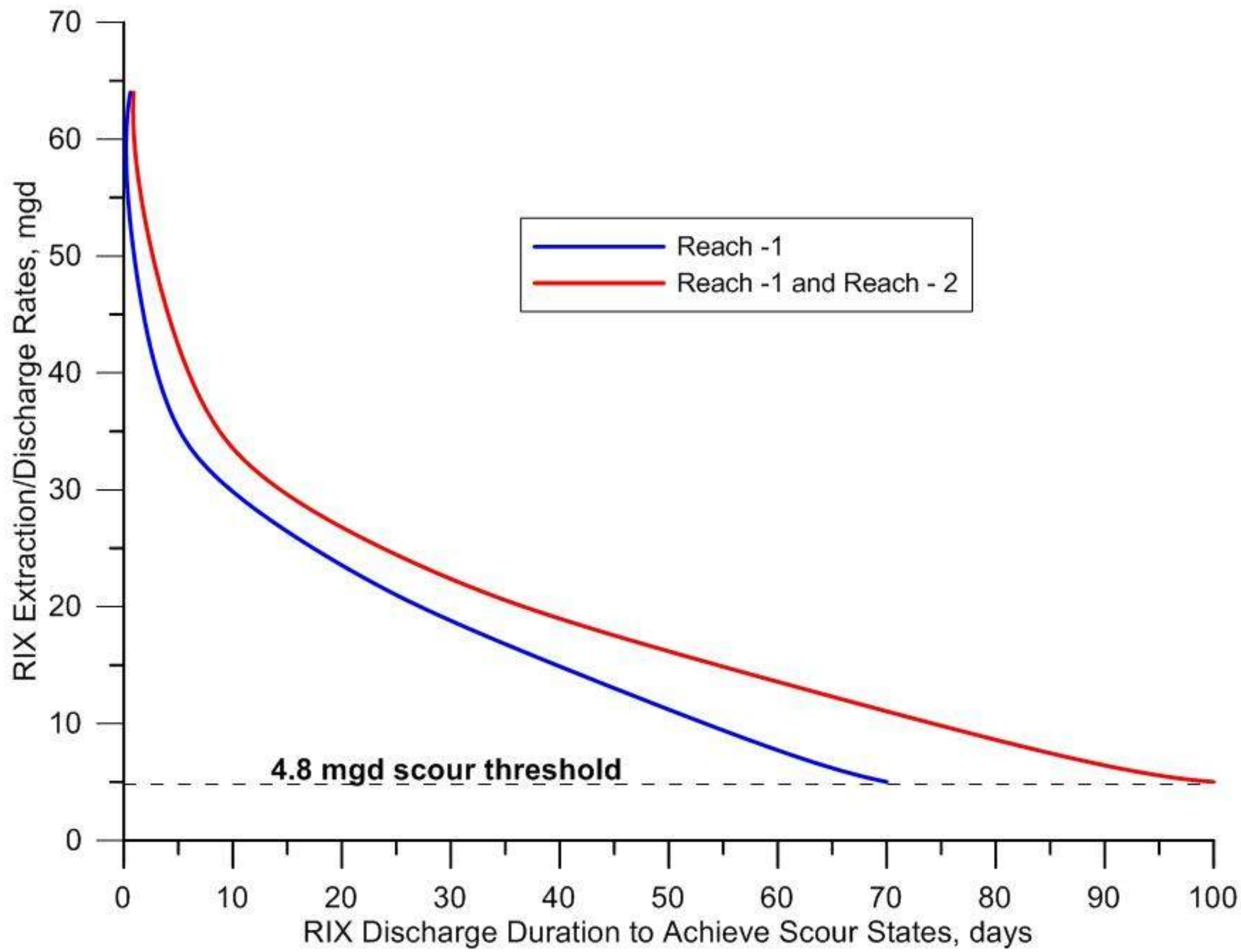


Figure 21: RIX discharge duration curves to achieve scour goals that restore baseline cobble exposure states in Reach-1 (blue) and in the combined sections of Reach-1 and Reach-2 (red). Scour goals based on removal of 76.5 metric tons of sand blanket from Reach-1 and a total of 126.2 metric tons of sand from the combined sections of Reaches 1 & 2.

5) Conclusions:

A coupled fluvial hydraulics/sediment scour and transport modeling approach was invoked to determine whether or not discharges under dry weather conditions from the Rapid Infiltration/Extraction (RIX) facility and flow reductions due to the Clean Water Factory can scour and clear sand blankets that could potentially bury cobble substrate in the inset channel of the Santa Ana River after a significant flood event. The study area is in the biologically sensitive upper reaches of the Santa Ana River immediately downstream of RIX that are inhabited by the Santa Ana sucker. The modeling effort was directed towards achieving scour goals that would re-establish biological field study baseline conditions for cobble exposure following an initial post-flood scenario of complete burial of the cobble beds and riffles by a blanket of newly deposited river sands. The estimated return period of this depositional event is 5 years based on published sediment rating curves and cumulative residual analysis of the Santa Ana River.

The fluvial model used in this study is the U.S. Army Corps of Engineers HEC-RAS model while the scour model used is the US Navy Vortex Lattice Scour-Burial Model. Both models were initialized for Santa Ana River bathymetry between the RIX facility and the MWD crossing based on river channel cross sections derived from a 2012 LIDAR survey. Current forcing and water surface elevations were input to the Vortex Lattice Model at each channel cross section based on the HEC-RAS model results for ten separate RIX low-flow and maximum-flow discharge scenarios. These HEC-RAS inputs to the Vortex Lattice Model account for percolation and groundwater upwelling along each reach of Santa Ana River that was evaluated for sediment scour and transport.

The general lesson learned from the model simulations is that scour by RIX discharges and exposure of the cobble/gravel riffles in the inset channel will not be uniform following burial by a post-storm sand blanket. There are regions identified as *scour hot spots* where the cobble and gravel substrate will be scoured and exposed very rapidly, even at average RIX discharge rates; and these areas will provide immediate post-storm micro-environments for the Santa Ana sucker. Generally these scour hot-spots are caused by six types of kinematic or dynamical conditions: 1) contractions of the inset channel width, 2) turns or bends in the inset channel that create centrifugal acceleration of the flow towards the outside of the turn, 3) bifurcation of the inset channel, 4) increase in bed gradient of the inset channel, 5) increase in hydraulic gradient due to ground water upwelling, and 6) hydraulic jumps from super-critical flow velocities at higher RIX discharge rates. However, wherever there are scour hot-spots, depositional areas are nearby. These depositional areas are very common near inset channel bifurcations, especially when those bifurcations occur in proximity to a bend in the inset channel. When a channel bifurcation occurs at a bend in the river, the flow does not divide evenly; and instead, concentrates under the effects of centrifugal acceleration in the channel on the outside of the turn, leaving the inside channel with flow speeds below threshold scour speed, and causing those inside channels to become depositional over time. These depositional bifurcated channels will remain unsuitable for Santa Ana sucker habitat until a significant flood event can augment channel flow by RIX to sufficient degree that general scour occurs across the entire river bed.

The scour model results for restoration of biological baseline conditions (as defined by river walk substrate data), in the most sensitive upper reach of the river (Reach-1), can achieved in 5.8 days when inset channel flow rates are equivalent to the 2014 RIX discharge average of Q

= 29 mgd; and can be achieved in less than a day at flow rates approaching the maximum permitted RIX discharge rate of Q = 64 mgd. It was also determined that the minimum threshold for achieving sand scour in the inset channel occurs at a discharge rate of Q = 4.8 mgd, comparable to recent daily discharges from the Rialto WWTP, (Rialto Channel).

Because none of the inset channel flow rates that induce sand scour exceed the discharge capacity of RIX, it appears that restoration of the biological baseline conditions of the river following a rare, high-deposition, flood event are within the operating capabilities of RIX. This expectation is further enhanced by the fact that coverage of the cobble bed by a thick blanket of sand is a wet-weather occurrence, when percolation losses of stream flow are minimal along the biologically sensitive section of inset channel in Reach-1.

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