STUDY REPORT W&AR-21
THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT C

1D/2D DOMAIN BOUNDARY, CROSS SECTION LOCATIONS AND DATA SOURCES

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1.0 SUMMARY

This attachment provides the data sources used to develop the bathymetric geometry of each 1D cross section (Table 1). This attachment also includes a series of maps that depict the locations of each cross section with its associated bathymetric data source as well as the 1D/2D domain boundary line. In producing the map series, the river centerline was altered to match the stream centerline at the time the LiDAR data was collected in 2012. Therefore, the rivers miles in the map series differ slightly from the USGS river miles.

Table 1. Lower Tuolumne River in-channel data sources.

Cross Section Attributes			
USGS River Mile	**HEC-RAS Model Station**	**Bathymetric Data Source**	**No. of Cross Sections**
0.88-4.40	0.8252-4.3666	CDWR (2014)	20
4.43-4.53	4.3978-4.5003	Interpolated	4
4.70-6.31	4.6664-6.3035	CDWR (2014)	8
6.71-6.94	6.7150-6.9575	FEMA (2013)	2
7.00-7.14	7.0087-7.1473	Interpolated	7
7.21-7.52	7.2192-7.5203	FEMA (2013)	2
7.64-7.79	7.6465-7.7963	Interpolated	4
7.82-10.74	7.8292-10.7413	FEMA (2013)	9
10.87-10.99	10.8658-10.9784	Interpolated	4
11.12-13.78	11.1007-13.6371	FEMA (2013)	8
13.99	13.8470	HDR Field Survey 2012	1
14.12-14.89	13.9709-14.7123	FEMA (2013)	3
15.04	14.8616	HDR Field Survey 2012	1
15.24	15.0666	FEMA (2013)	1
15.50	15.3283	HDR Field Survey 2012	1
15.66	15.4965	FEMA (2013)	1
15.72-15.74	15.5579-15.5776	Interpolated	2
15.84	15.6774	FEMA (2013)	1
15.86-15.93	15.6916-15.7665	Interpolated	4
15.98	15.8150	HDR Field Survey 2012	1
16.00-16.09	15.8351-15.9239	Interpolated	5
16.13	15.9601	USGS (2014a, 2014b)	1
16.17-16.21	15.9890-16.0263	FEMA (2013)	3
16.33-16.35	16.1409-16.1591	Interpolated	2
16.38-16.41	16.189-16.2138	USGS (2014a, 2014b)	2
16.49	16.2793	FEMA (2013)	1
16.53	16.3128	HDR Field Survey 2012	1
16.73	16.4905	FEMA (2013)	1
17.03	16.7579	HDR Field Survey 2012	1
17.16	16.8756	FEMA (2013)	1
17.52	17.1990	HDR Field Survey 2012	1
17.57-18.33	17.2472-17.9689	FEMA (2013)	3
18.46-18.49	18.0953-18.1288	HDR Field Survey 2012	2
18.70	18.3429	FEMA (2013)	1

Cross Section Attributes			
USGS River Mile	**HEC-RAS Model Station**	**Bathymetric Data Source**	**No. of Cross Sections**
18.98	18.6243	HDR Field Survey 2012	1
19.05-19.25	18.7067-18.9387	FEMA (2013)	2
19.49	19.2343	HDR Field Survey 2012	1
19.61-20.30	19.3709-20.1766	FEMA (2013)	3
20.49	20.3909	HDR Field Survey 2012	1
20.61-20.95	20.5204-20.9159	FEMA (2013)	2
21.02	21.0003	HDR Field Survey 2012	1
21.29	21.3174	FEMA (2013)	1
21.49	21.5672	HDR Field Survey 2012	1
21.63-21.82	21.7322-21.9662	FEMA (2013)	2
22.00	22.1825	HDR Field Survey 2012	1
22.26-22.44	22.4798-22.6904	FEMA (2013)	2
22.50	22.7482	HDR Field Survey 2012	1
22.55	22.8062	FEMA (2013)	1
22.59-22.62	22.8536-22.8826	TID Field Survey	2
22.78	23.0683	FEMA (2013)	1
22.83	23.1392	TID Field Survey	1
22.99	23.3244	HDR Field Survey 2012	1
23.25	23.6137	TID Field Survey	1
23.48	23.9049	HDR Field Survey 2012	1
23.50-23.85	23.9240-24.3337	TID Field Survey	3
23.98	24.4905	HDR Field Survey 2012	1
24.19	24.7347	TID Field Survey	1
24.41	24.9480	McBain and Trush (2004b)	1
24.53	25.0699	HDR Field Survey 2012	1
24.65-24.95	25.1890-25.4942	McBain and Trush (2004b)	5
25.02	25.5663	HDR Field Survey 2012	1
25.03	25.5823	Interpolated	1
25.04	25.5922	TID Field Survey	1
25.07	25.6245	McBain and Trush (2004b)	1
25.09	25.6503	TID Field Survey	1
21.12-25.36	25.6774-25.9475	McBain and Trush (2004b)	5
25.42-25.49	26.0073-26.1223	TID Field Survey	4
25.50	26.1275	HDR Field Survey 2012	1
25.54	26.1658	TID Field Survey	1
25.61	26.2474	McBain and Trush (2004b)	1
25.67	26.3109	TID Field Survey	1
25.71-25.78	26.3528-26.4306	McBain and Trush (2004b)	2
25.79-25.8	26.4409-26.4552	TID Field Survey	2
25.86	26.5125	McBain and Trush (2004b)	1
25.95-25.97	26.603-26.6222	TID Field Survey	2
26.05-27.98	26.7028-28.5435	HDR Field Survey 2012	5
28.23-28.40	28.7500-28.9000	Interpolated	3
28.60-29.47	29.1201-29.9195	HDR Field Survey 2012	3

Cross Section Attributes			
USGS River Mile	**HEC-RAS Model Station**	**Bathymetric Data Source**	**No. of Cross Sections**
29.54	29.9800	Interpolated	1
29.66-30.15	30.0853-30.5497	TID Field Survey	7
30.25	30.6561	HDR Field Survey 2012	1
30.34-30.42	30.7390-30.8268	Stillwater (2013)	3
30.52	30.9218	HDR Field Survey 2012	1
30.64-31.02	31.0461-31.4475	TID Field Survey	9
31.07	31.4911	HDR Field Survey 2012	1
31.18-31.35	31.6042-31.7817	TID Field Survey	3
31.48	31.9232	HDR Field Survey 2012	1
31.56-31.75	32.0006-32.2089	TID Field Survey	5
31.95-31.97	32.4279-32.445	Stillwater (2013)	2
32.01-36.09	32.4861-36.8374	TID Field Survey	50
36.11-36.45	36.8642-37.2503	Stillwater (2013)	11
36.49-36.67	37.2926-37.5083	TID Field Survey	5
36.70-36.74	37.5353-37.5818	Stillwater (2013)	3
36.82-37.83	37.7200-38.8828	TID Field Survey	21
37.90-41.66	38.9536-42.1508	McBain and Trush (2004a)	60
41.67	42.1600	TID Field Survey	1
41.71	42.1800	McBain and Trush (2004a)	1
41.73-41.76	42.1900-42.2400	TID Field Survey	3
41.78	42.2600	McBain and Trush (2004a)	1
41.80	42.2806	TID Field Survey	1
41.81	42.2900	McBain and Trush (2004a)	1
41.83-41.84	42.3062-42.32	TID Field Survey	2
41.86-41.88	42.3359-42.3543	McBain and Trush (2004a)	2
41.91-42.01	42.3934-42.4897	TID Field Survey	4
42.11-42.27	42.5777-42.7519	McBain and Trush (2004a)	5
42.29-42.3	42.775-42.7834	TID Field Survey	2
42.36-45.77	42.8509-46.2700	McBain and Trush (2004a)	97
45.78-46.92	46.2985-47.4044	TID/MID (2013b)	21

2.0 REFERENCES

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Federal Emergency Management Agency (FEMA). 2013. HEC-RAS modeling of the Tuolumne River and Dry Creek, Stanislaus County, CA. Prepared by HDR Engineering for FEMA in conjunction with the California Department of Water resources (CDWR) as part of the Cooperating Technical Partners Program.

McBain & Trush, Inc. 2004a. Coarse Sediment Management Plan for the Lower Tuolumne River. Revised Final. Prepared for Tuolumne River Technical Advisory Committee, Turlock and Modesto Irrigation Districts, USFWS Anadromous Fish Restoration Program and the CALFED Bay Delta Authority. Arcata, CA.

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Stillwater Sciences. 2013. Lower Tuolumne River Instream Flow Study. Final Report. Prepared by Stillwater Sciences, Davis, California for Turlock and Irrigation District and Modesto Irrigation District, California. April.

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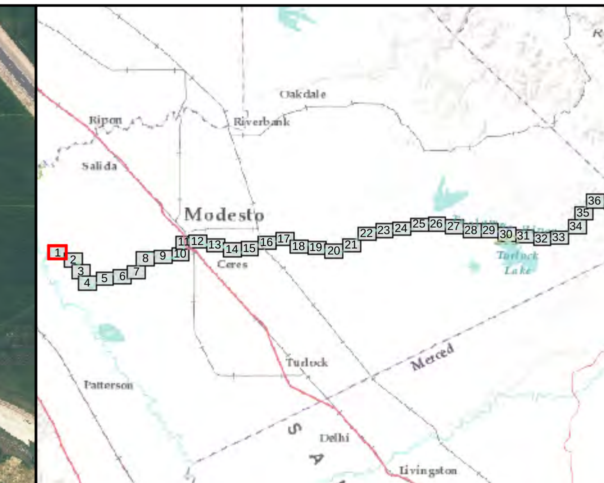

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2014 DWR-CVFED HEC-RAS Model

Interpolated

0 250 500 1,000
Feet

N

Floodplain Hydraulic Modeling

Don Pedro Project (FERC No.2299)

Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.
Data Sources: Hydrography - USGS NHD, TID/MID;
Data is NAD83, State Plane CA Zone 3 U.S. Ft.

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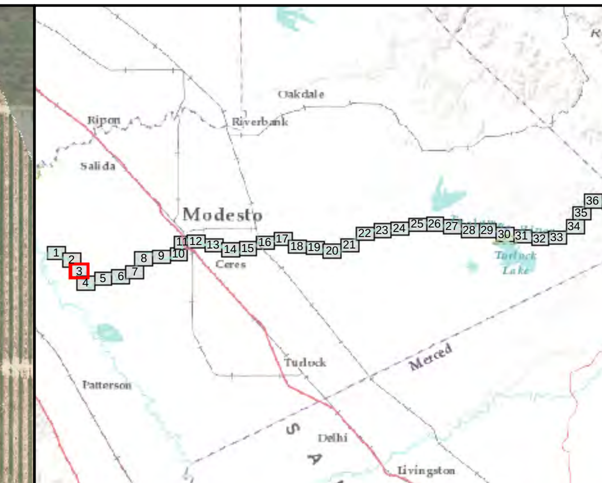

Page 3 of 37

TUFLOW 1D-2D Domain Boundary Line

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Interpolated

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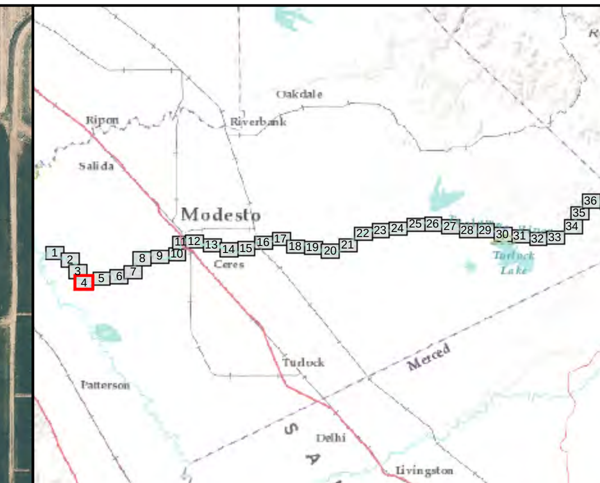

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2014 DWR-CVFED HEC-RAS Model

FEMA-CVFED HEC-RAS Model

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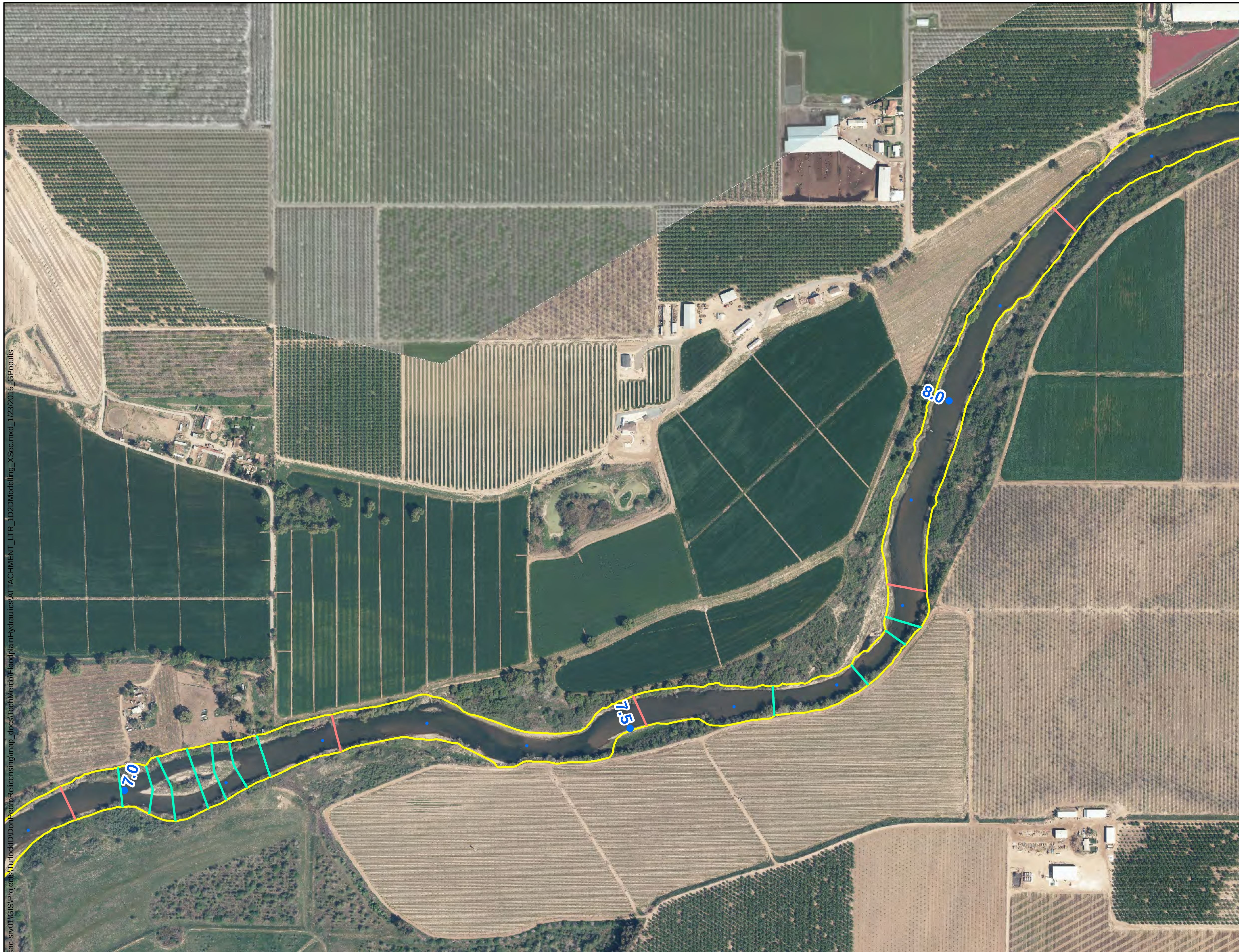

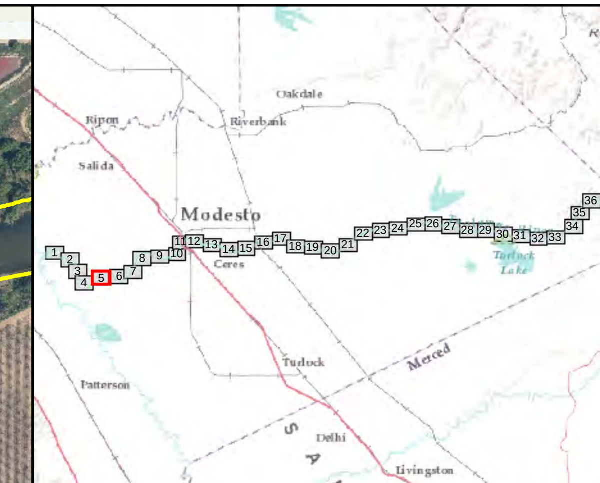

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

FEMA-CVFED HEC-RAS Model

Interpolated

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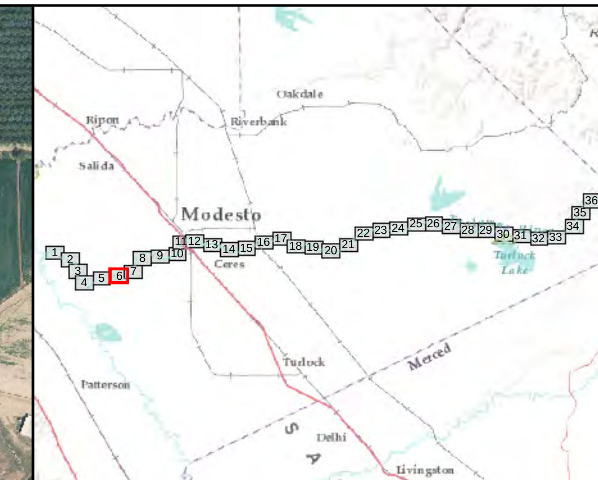

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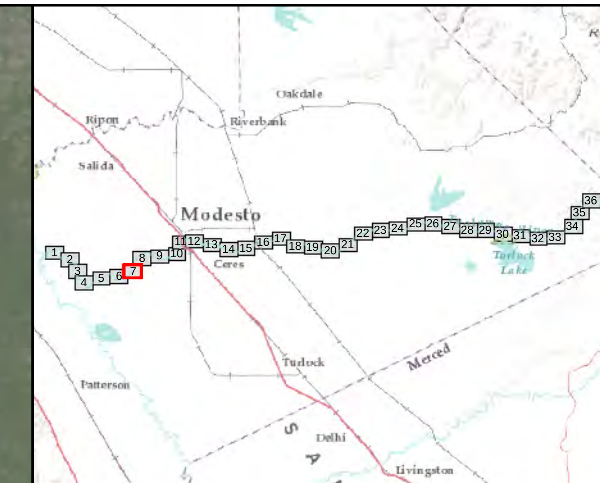

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Interpolated

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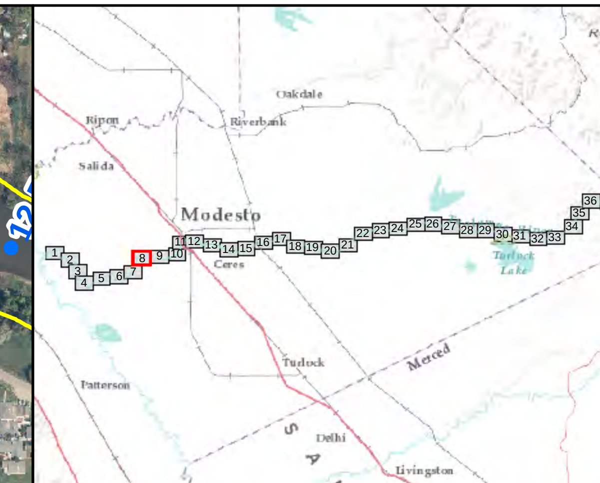

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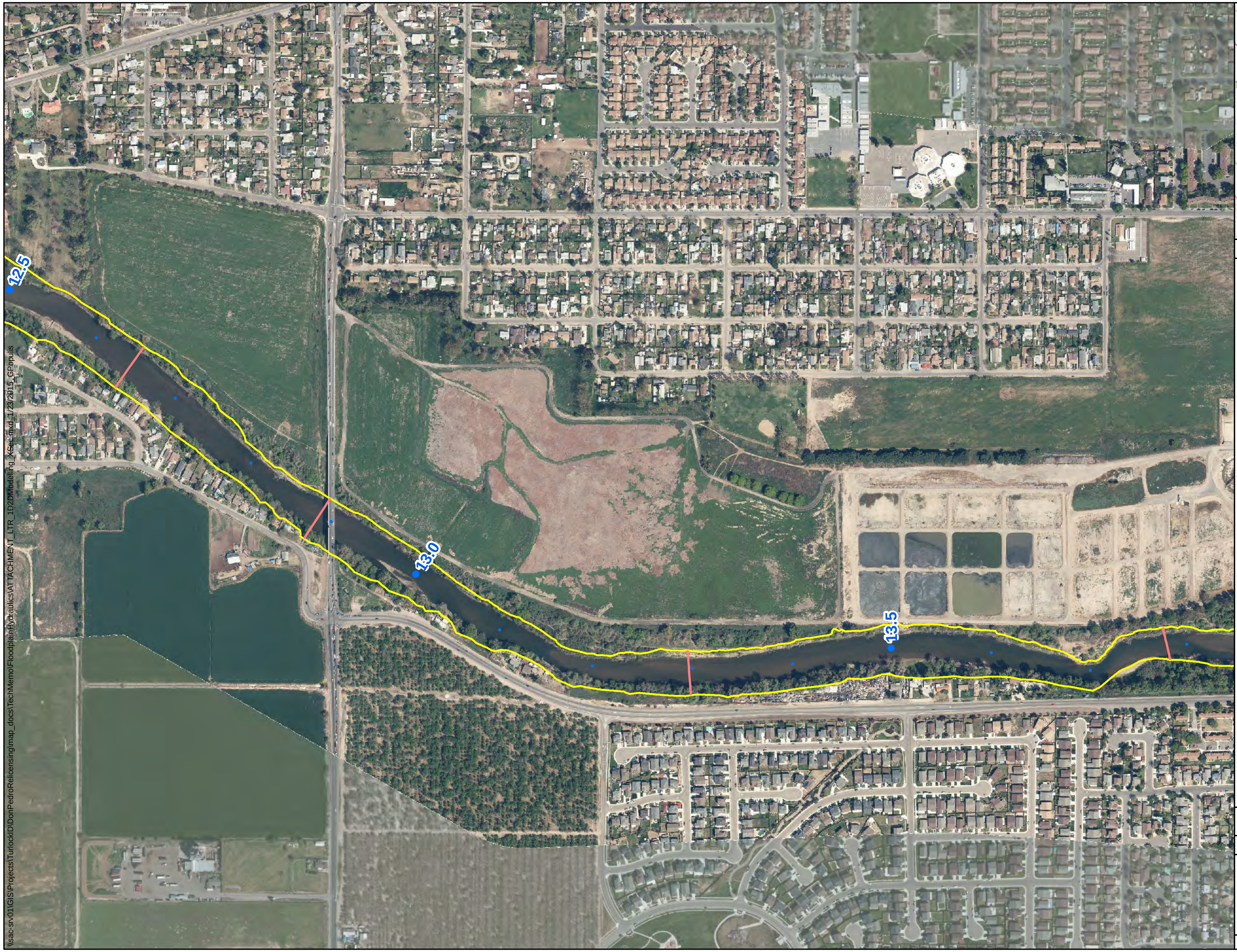

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

FEMA-CVFED HEC-RAS Model

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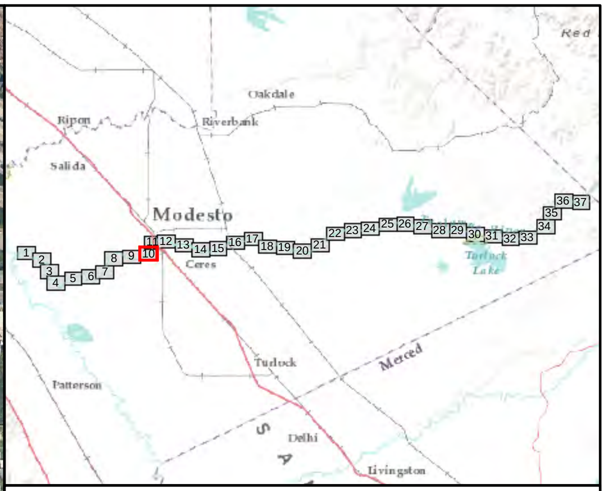

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 HDR Survey

FEMA-CVFED HEC-RAS Model

0 250 500 1,000

Feet

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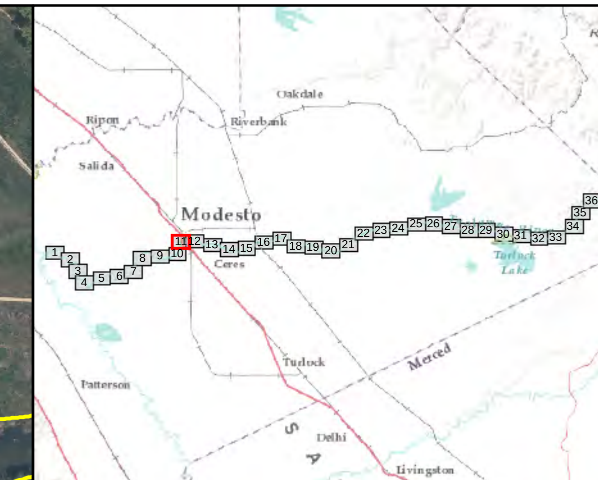

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

- 2012 HDR Survey
- FEMA-CVFED HEC-RAS Model
- Interpolated
- USGS Gage Cross Sections

0 250 500 1,000
Feet
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Floodplain Hydraulic Modeling

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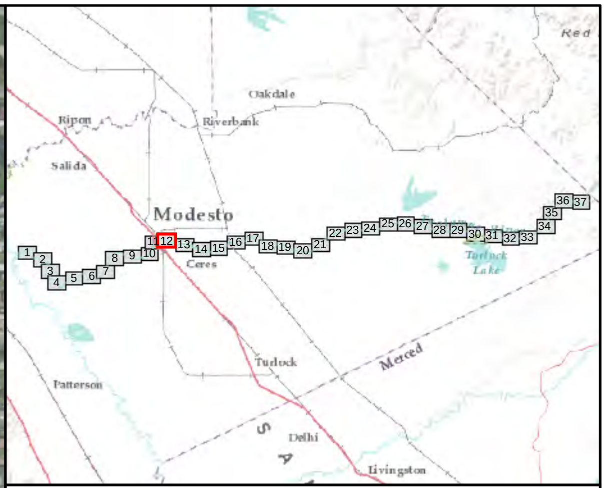

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 HDR Survey

FEMA-CVFED HEC-RAS Model

Interpolated

USGS Gage Cross Sections

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Feet

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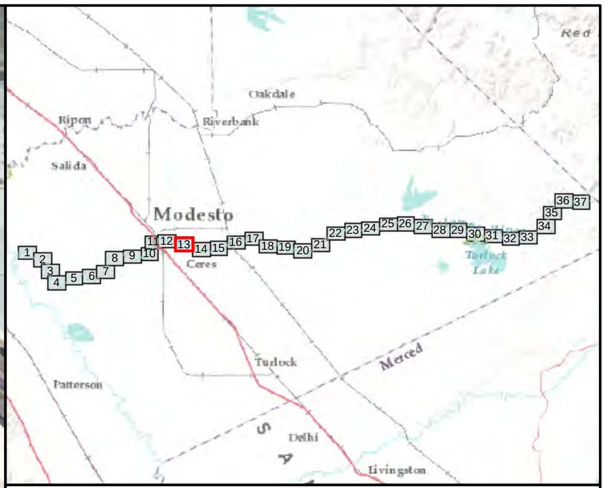

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 HDR Survey

FEMA-CVFED HEC-RAS Model

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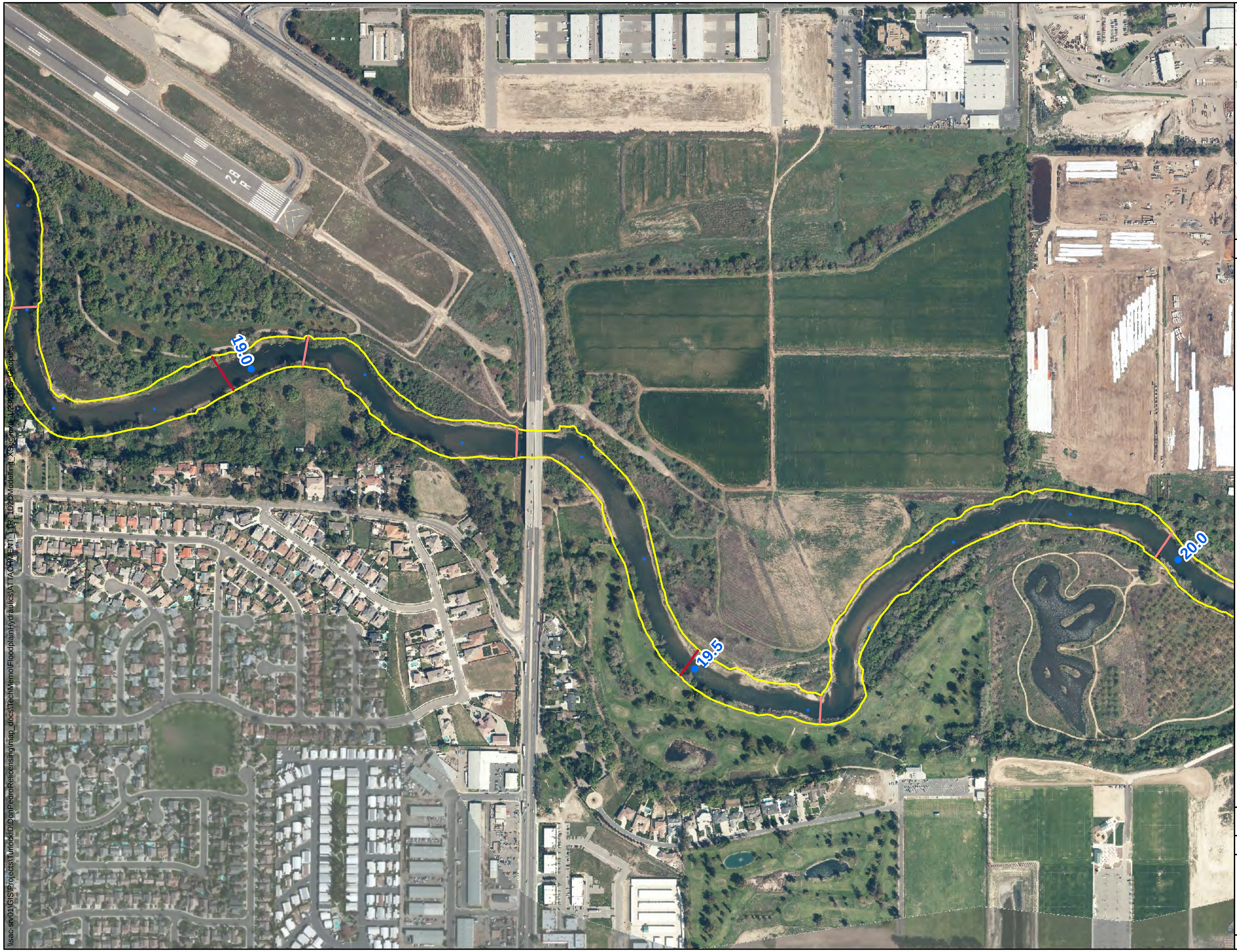

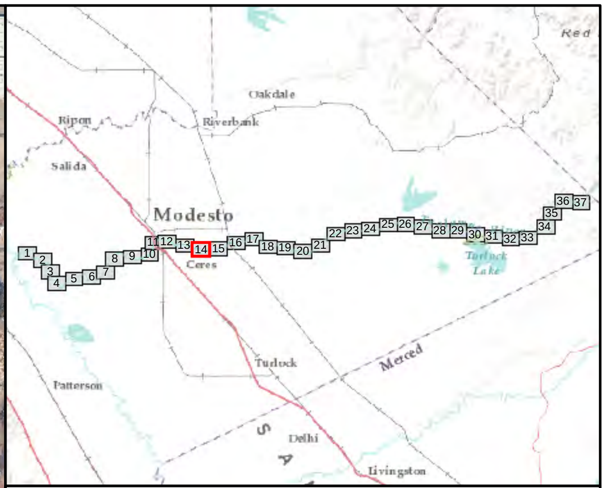

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 HDR Survey

FEMA-CVFED HEC-RAS Model

0 250 500 1,000

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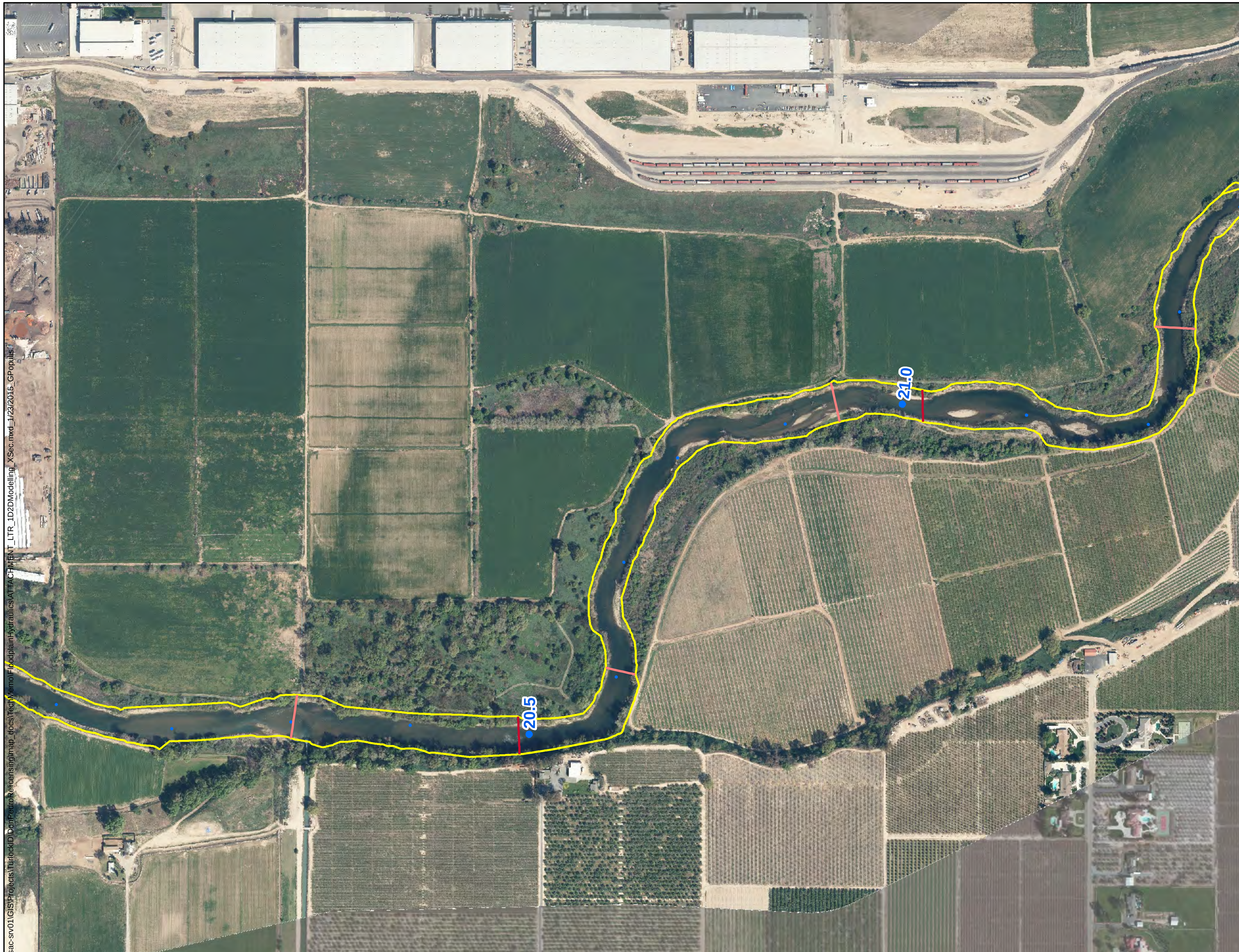

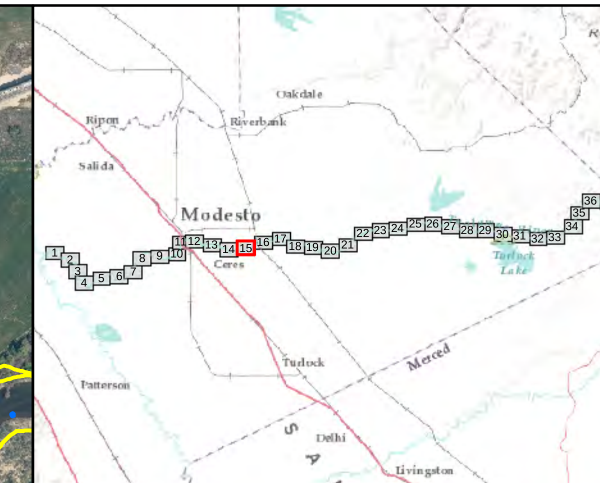

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 HDR Survey

FEMA-CVFED HEC-RAS Model

0 250 500 1,000
Feet
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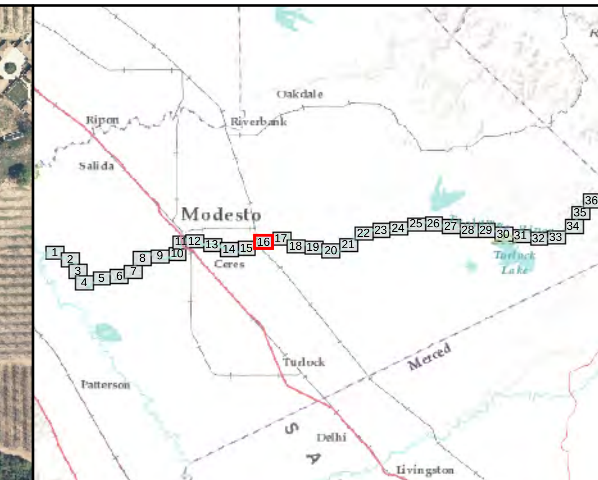

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

- 2012 HDR Survey
- 2014 FEMA HEC-RAS Model
- 2014 TID Survey
- FEMA-CVFED HEC-RAS Model

0 250 500 1,000
Feet

N

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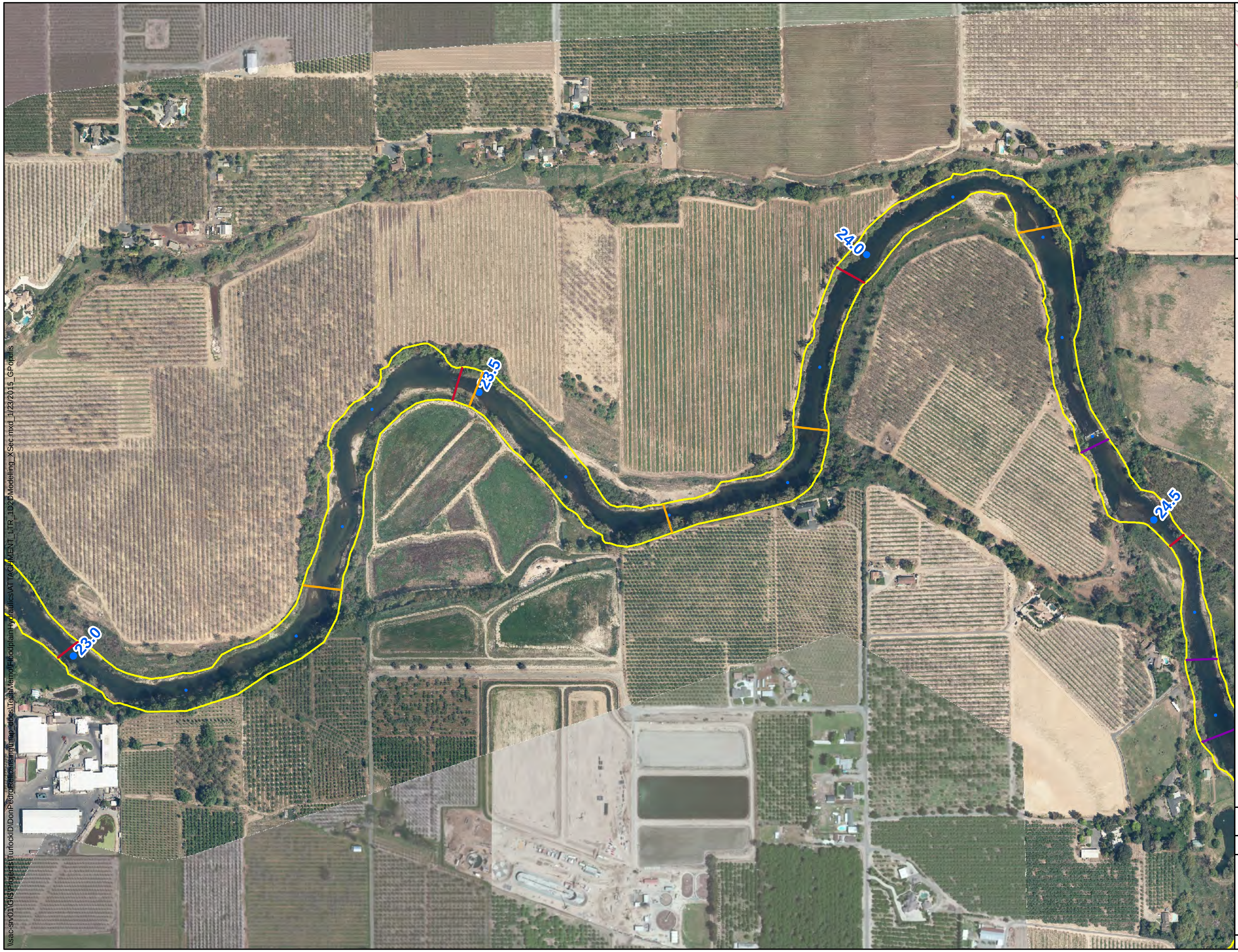

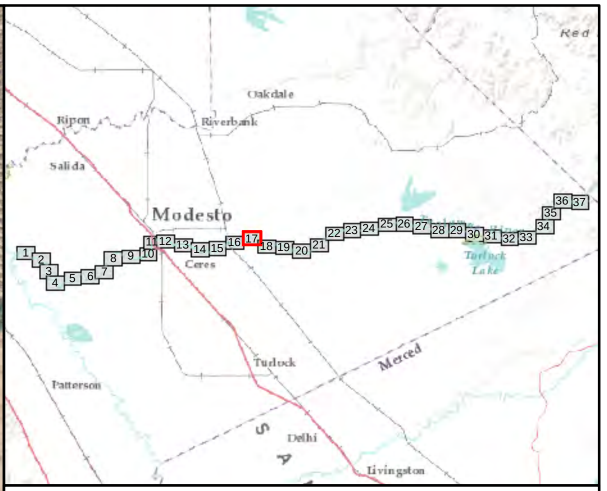

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

- 2012 HDR Survey
- 2014 TID Survey
- McBain&Trush SRP 9/10 Restoration

0 250 500 1,000
Feet

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Floodplain Hydraulic Modeling

Don Pedro Project (FERC No.2299)

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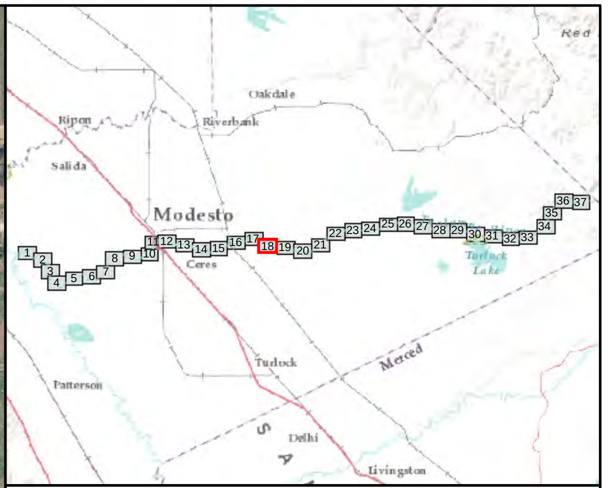

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

- 2012 HDR Survey
- 2014 TID Survey
- Interpolated
- McBain&Trush SRP 9/10 Restoration

0 250 500 1,000
Feet
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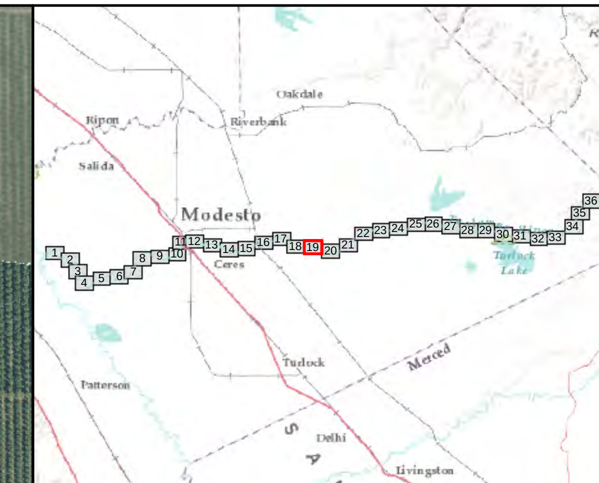

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 HDR Survey

0 250 500 1,000
Feet

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Floodplain Hydraulic Modeling

Don Pedro Project (FERC No.2299)

Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.
Data Sources: Hydrography - USGS NHD, TID/MID;
Data is NAD83, State Plane CA Zone 3 U.S. Ft.

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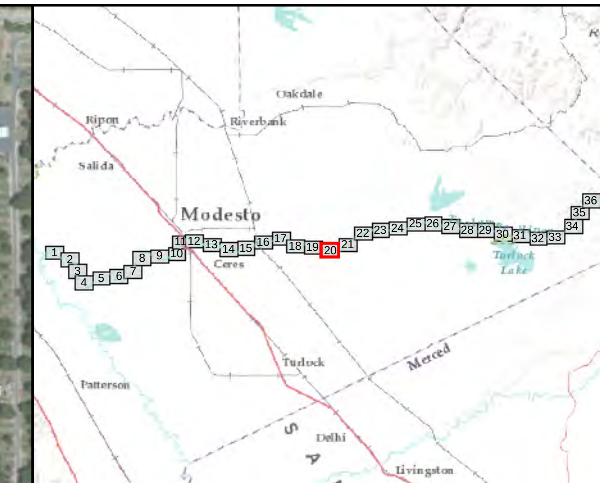

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 HDR Survey

Interpolated

0 250 500 1,000
Feet

N

Floodplain Hydraulic Modeling

Don Pedro Project (FERC No.2299)

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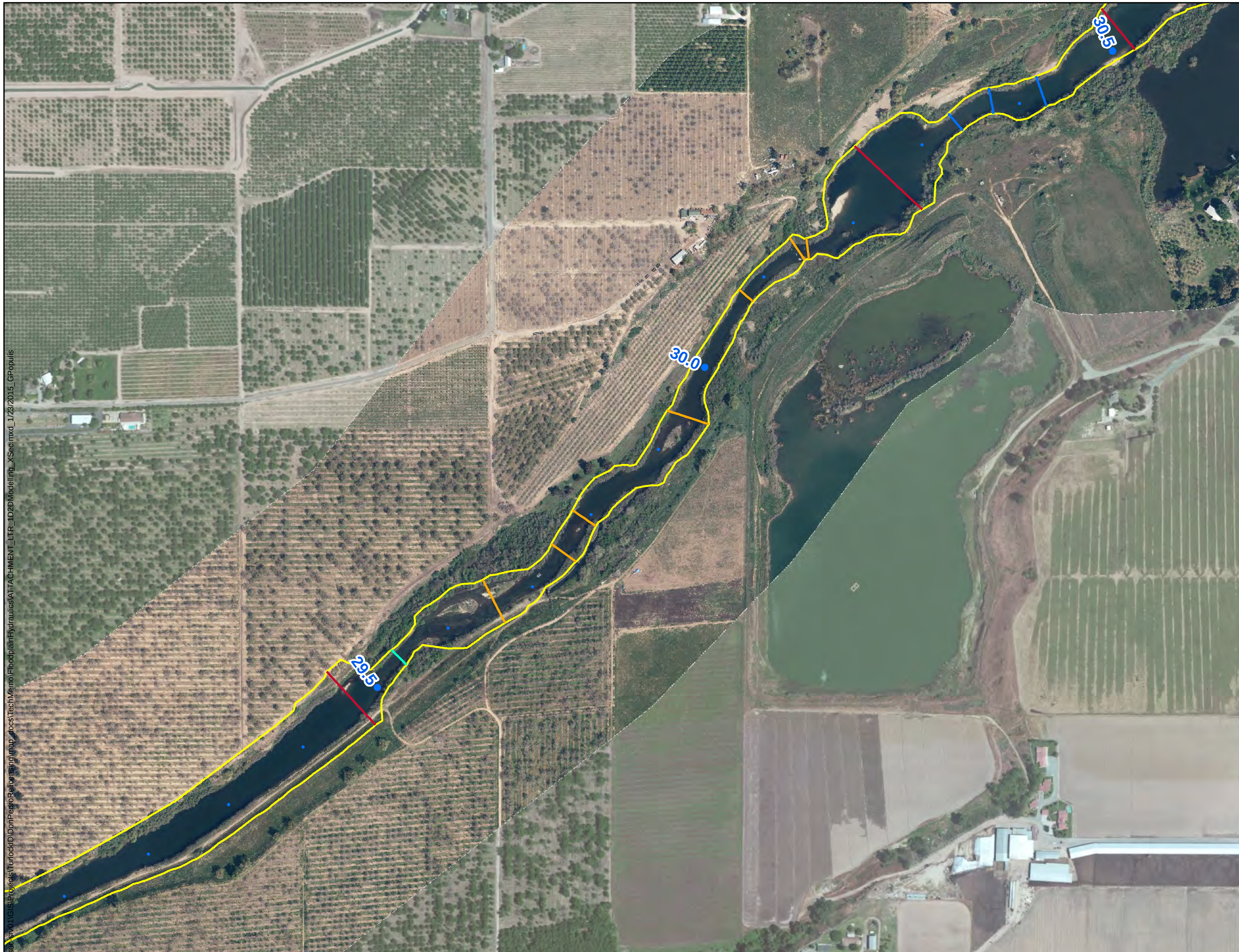

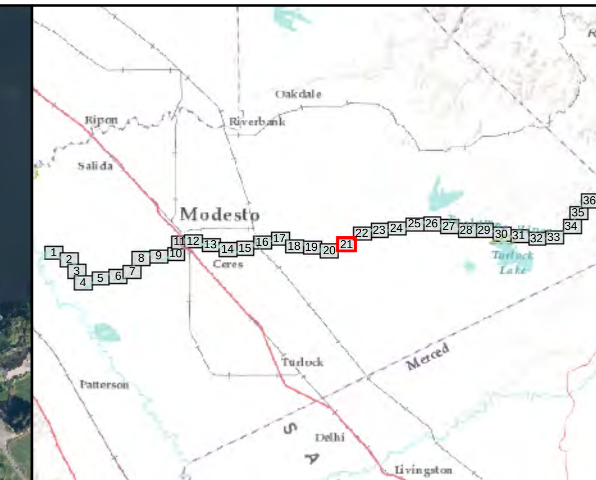

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

- 2012 HDR Survey
- 2013 Stillwater IFIM
- 2014 TID Survey
- Interpolated

0 250 500 1,000
Feet

N

Floodplain Hydraulic Modeling

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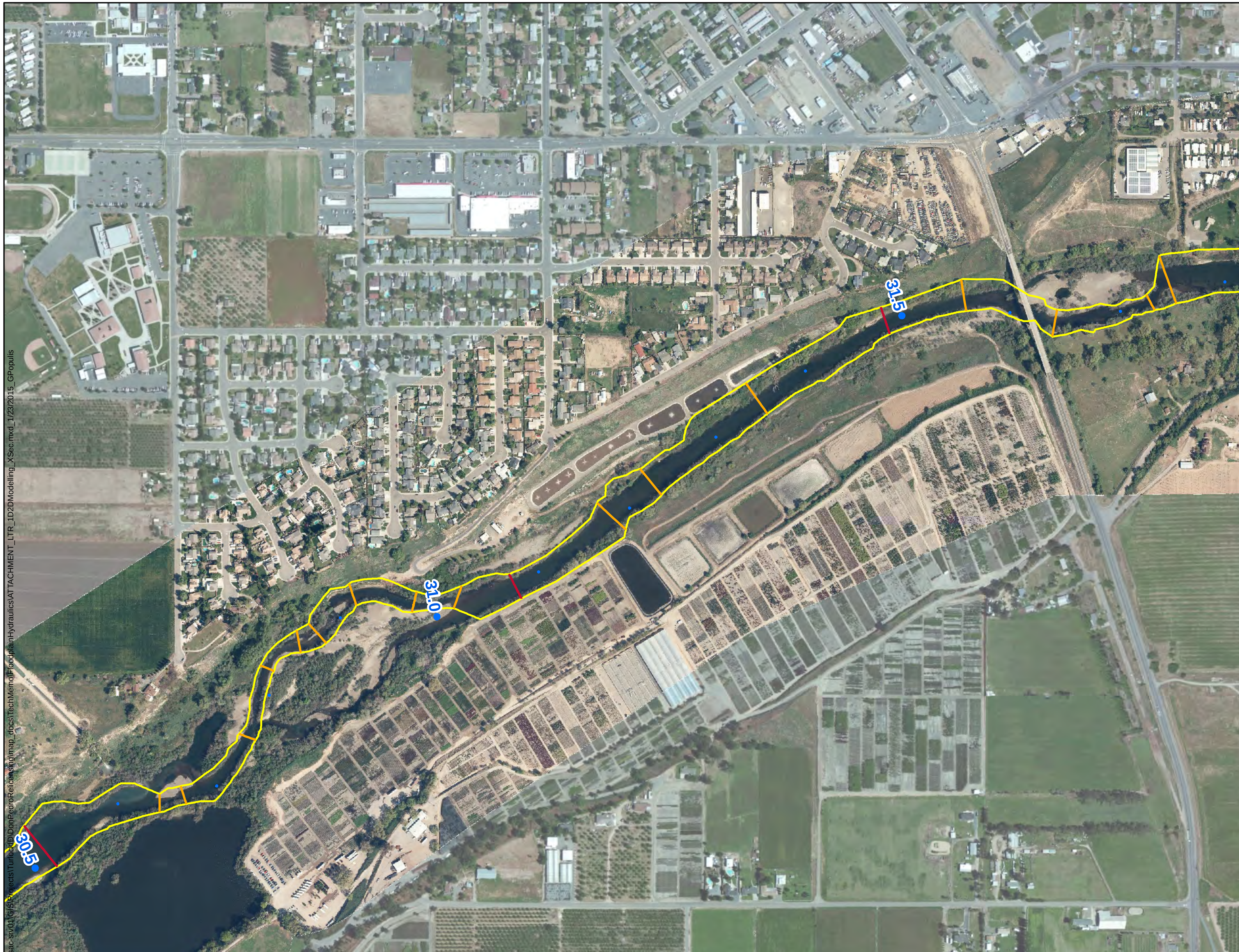

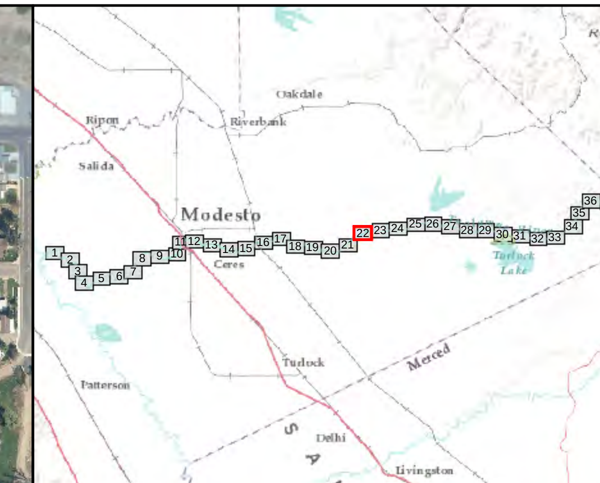

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 HDR Survey

2014 TID Survey

0 250 500 1,000

Feet

N

Floodplain Hydraulic Modeling

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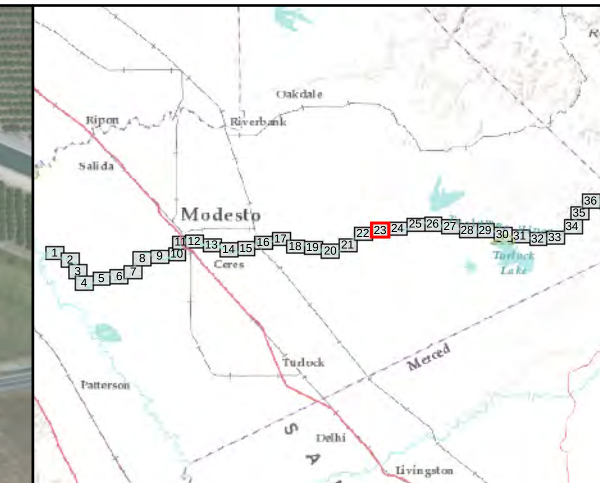

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2013 Stillwater IFIM

2014 TID Survey

0 250 500 1,000
Feet

N

Floodplain Hydraulic Modeling

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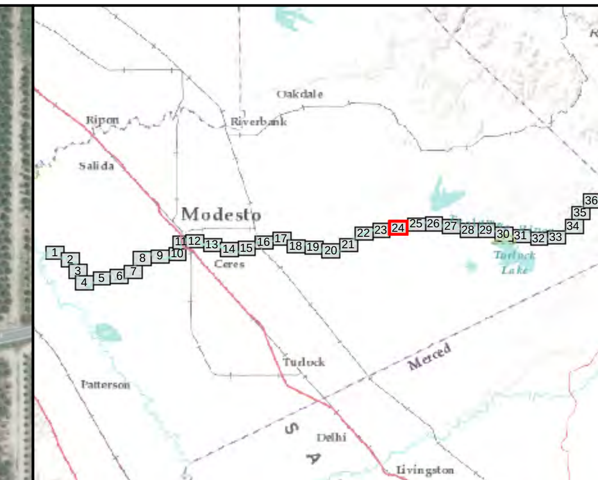

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2014 TID Survey

0 250 500 1,000
Feet

N

Floodplain Hydraulic Modeling

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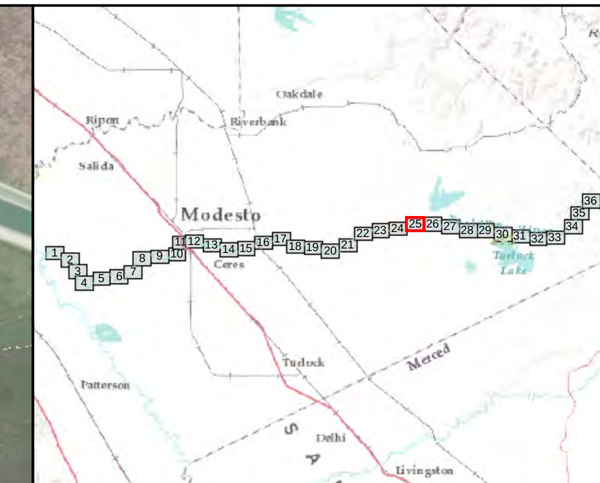

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2014 TID Survey

0 250 500 1,000
Feet

N

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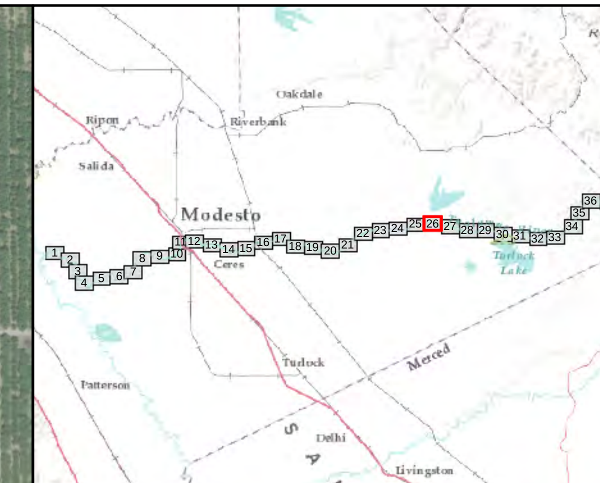

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2013 Stillwater IFIM

2014 TID Survey

0 250 500 1,000

Feet

N

Floodplain Hydraulic Modeling

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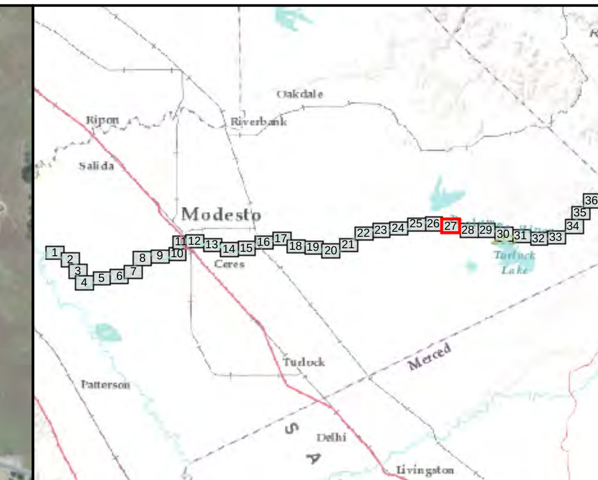

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

- 2013 Stillwater IFIM
- 2014 TID Survey
- Interpolated

0 250 500 1,000
Feet

N

Floodplain Hydraulic Modeling

Don Pedro Project (FERC No.2299)

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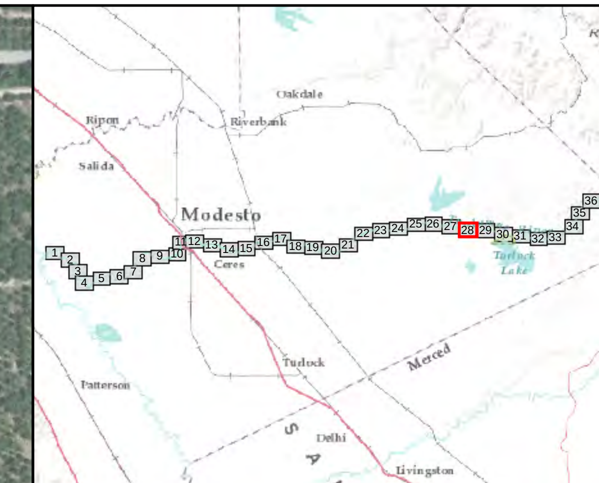

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2005 Bathymetry

2014 TID Survey

Interpolated

0 250 500 1,000

Feet

Floodplain Hydraulic Modeling

Don Pedro Project (FERC No.2299)

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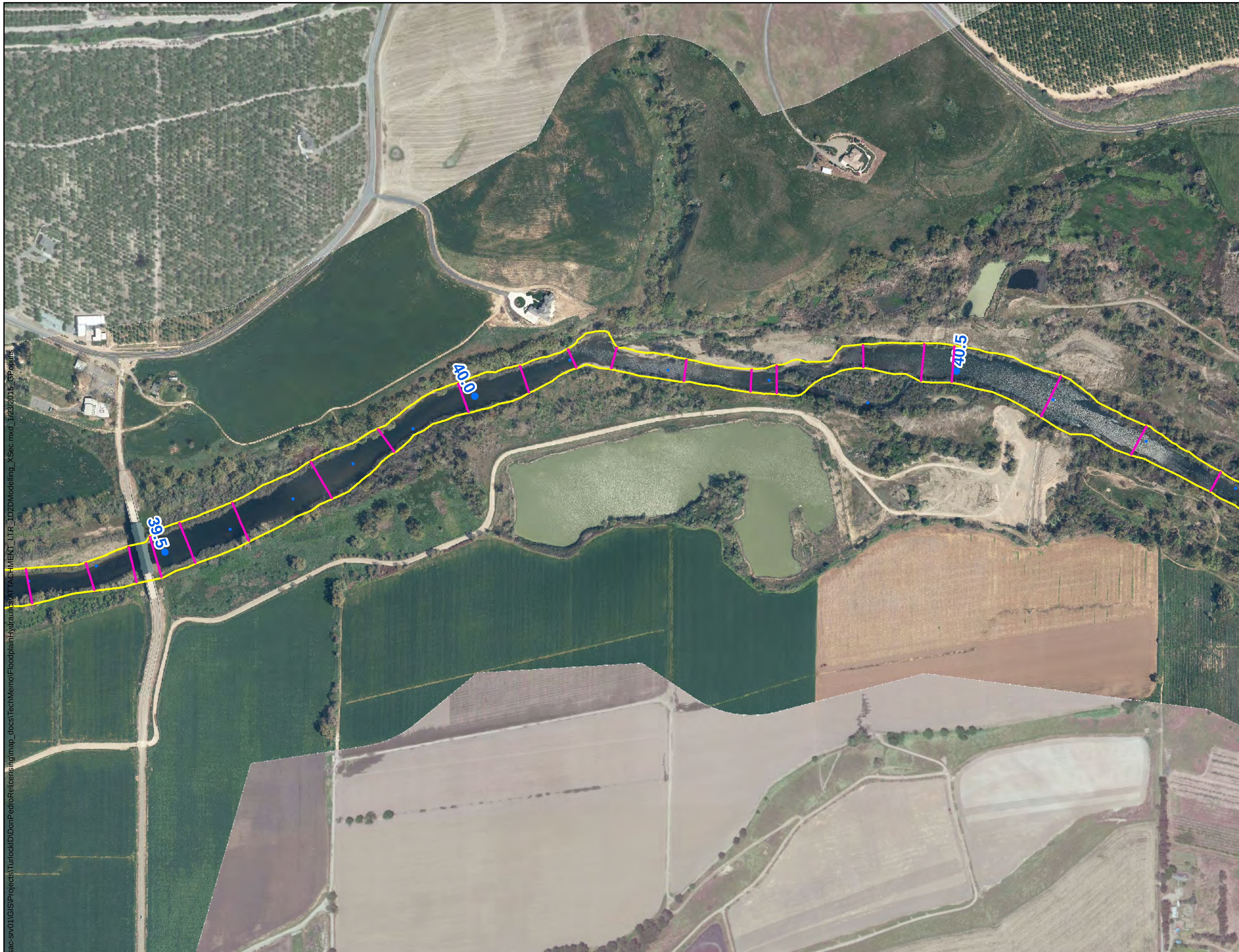

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2005 Bathymetry

0 250 500 1,000
Feet

N

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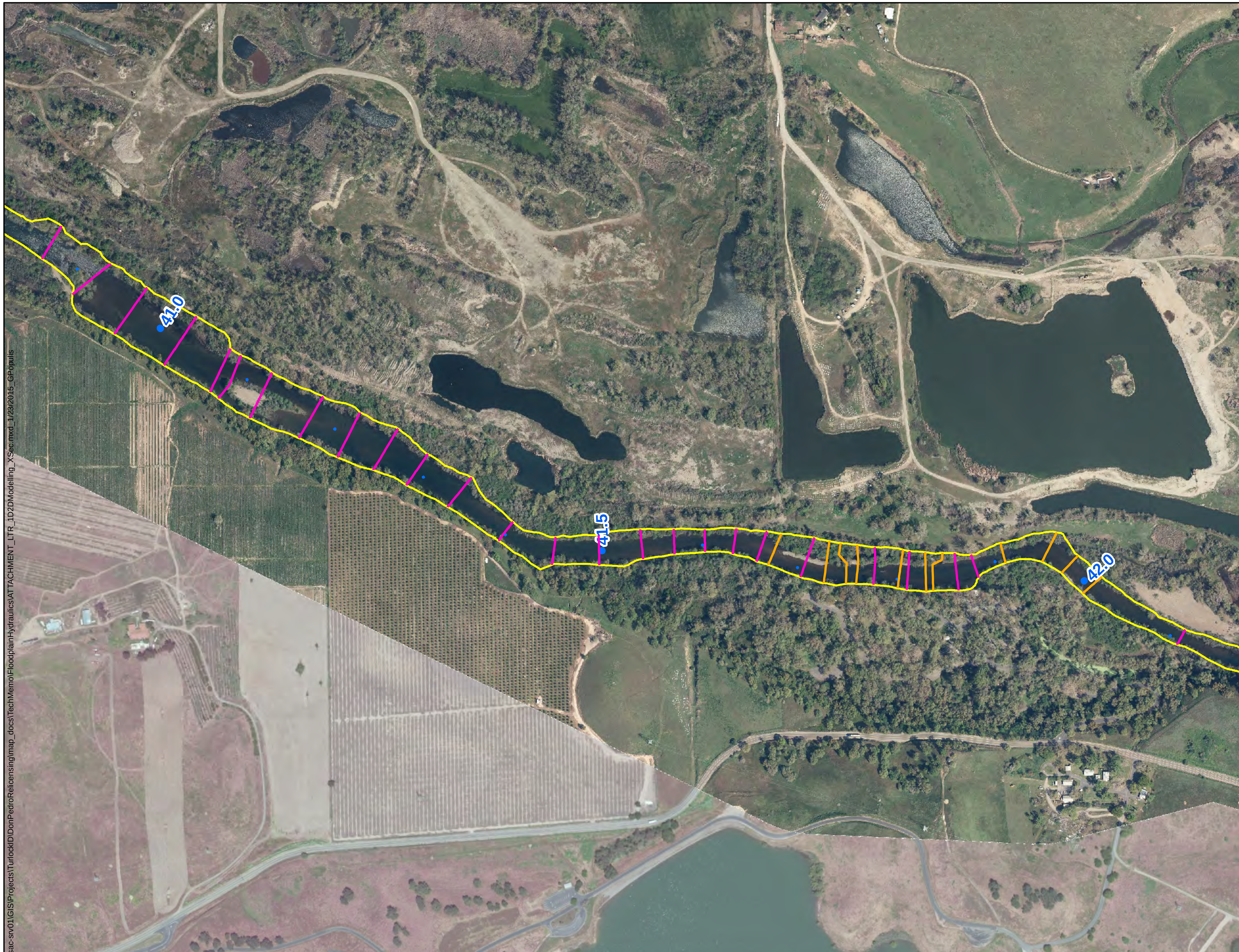

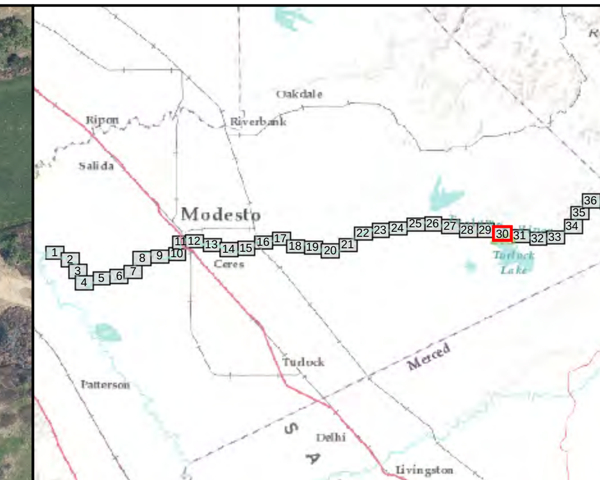

Page 30 of 37

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2005 Bathymetry

2014 TID Survey

0 250 500 1,000

Feet

N

Floodplain Hydraulic Modeling

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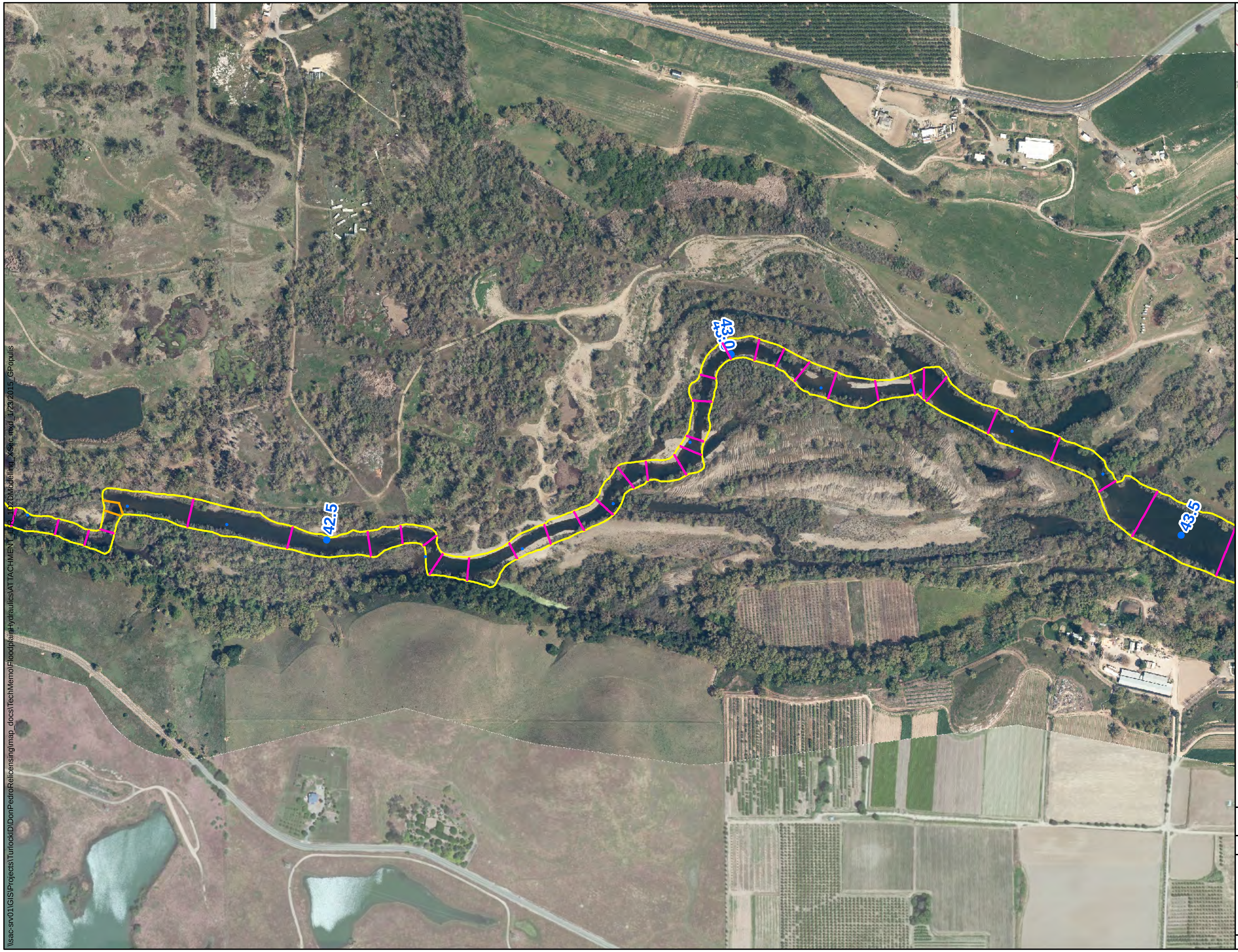

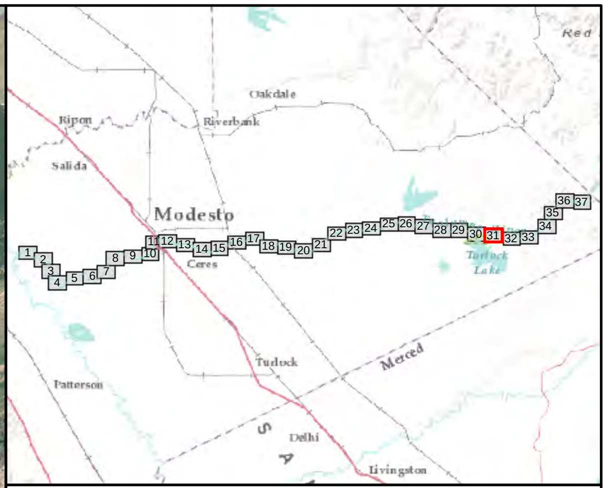

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2005 Bathymetry

2014 TID Survey

0 250 500 1,000

Feet

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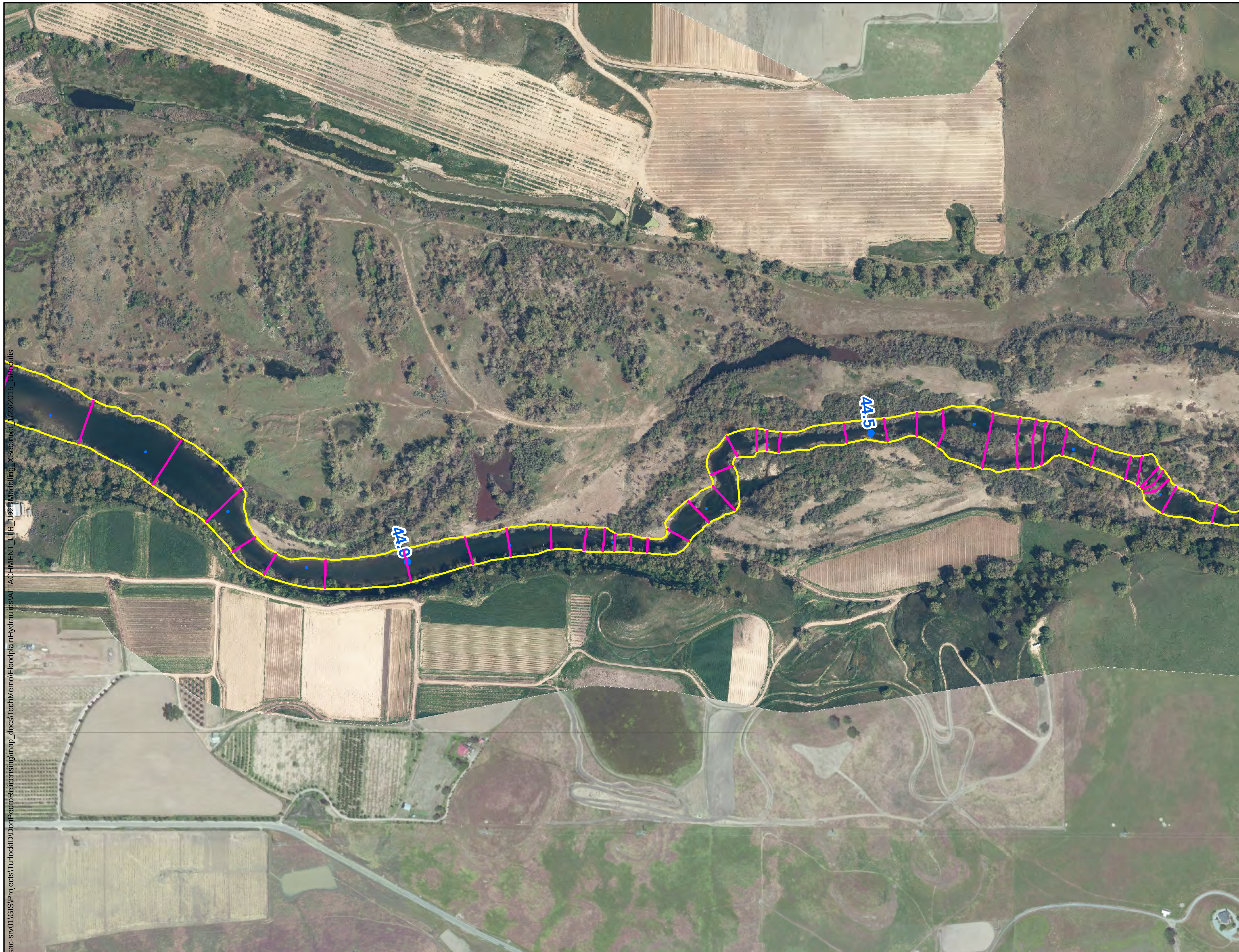

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2005 Bathymetry

0 250 500 1,000
Feet

N

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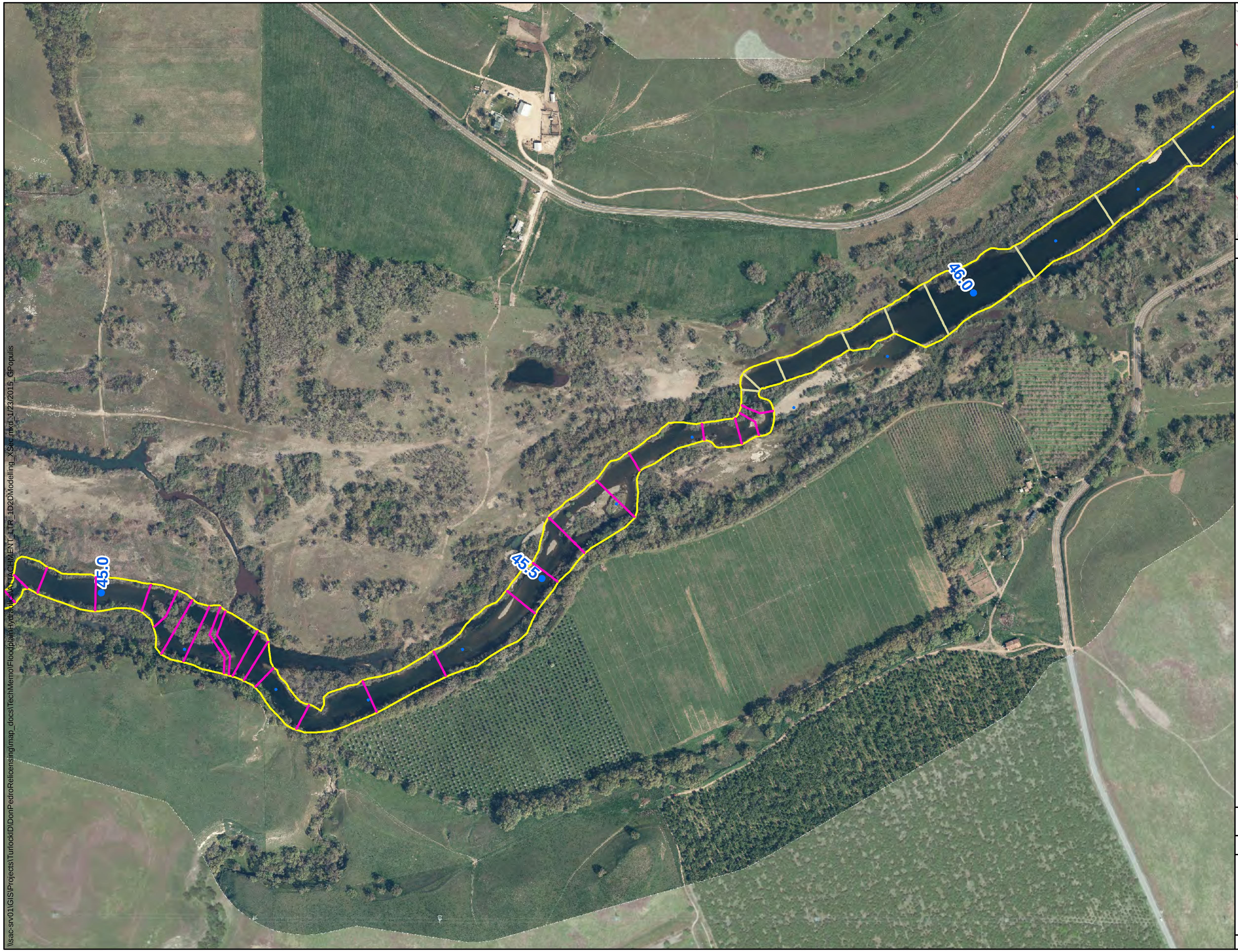

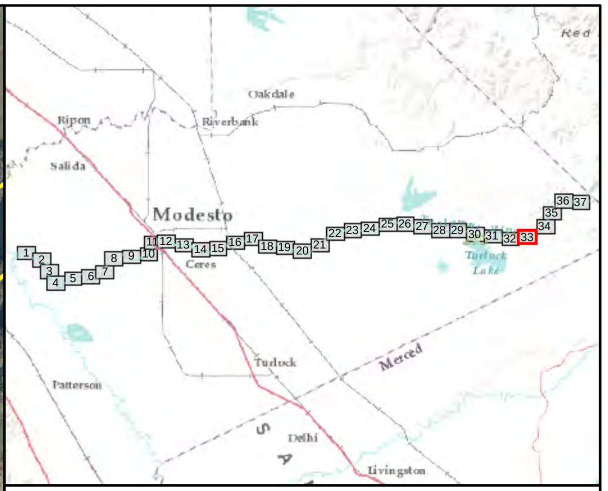

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2005 Bathymetry

2012 Bathymetry

0 250 500 1,000

Feet

N

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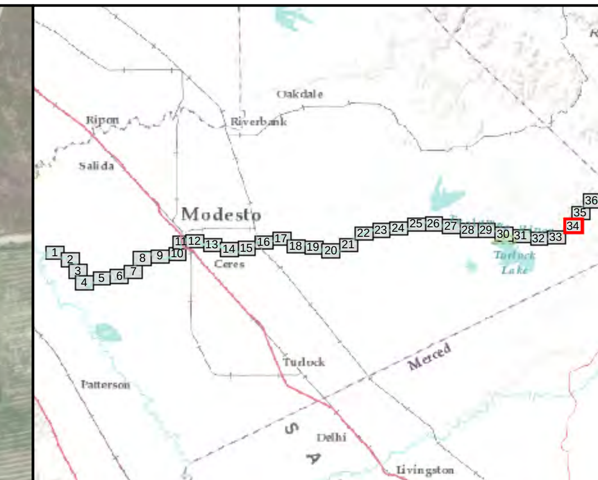

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 Bathymetry

2014 TID Survey

0 250 500 1,000

Feet

N

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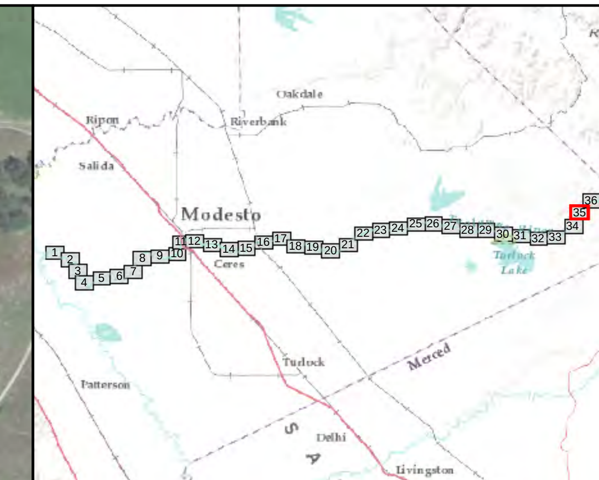

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 Bathymetry

0 250 500 1,000
Feet
N

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TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 Bathymetry

0 250 500 1,000
Feet

N

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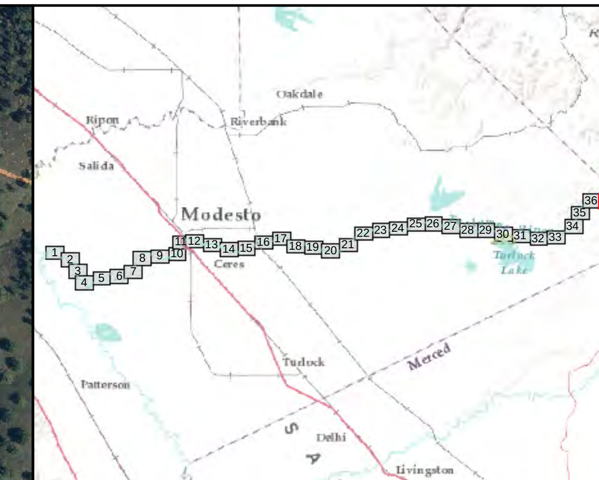

TUFLOW 1D-2D Domain Boundary Line

Cross Section Source

2012 Bathymetry

0 250 500 1,000

Feet

N

Floodplain Hydraulic Modeling

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STUDY REPORT W&AR-21
THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT D

2D OVERBANK MANNING'S N ROUGHNESS COEFFICIENTS

1.0 ROUGHNESS COEFFICENT EXAMPLES

This attachment supplements the discussion of overbank roughness coefficients in the study report. Table 1 provides roughness coefficient values for different land use and land cover categories.

Table 1. 2D domain roughness coefficient values.

Roughness Value	Description
0.03	Smooth and flat – pavement
0.04	Bare earth with gravel or finer substrate
0.05	Some herbaceous vegetation, grass, or large cobbles
0.06	Backwater areas choked with Water Hyacinth, agriculture, or irregular bedrock
0.07	Sparse permanent vegetation or low lying shrubs
0.08	Oak woodland, Cottonwood, or Aspen with some canopy spacing
0.09	Dense young riparian vegetation
0.10	Permanent dense forest (riparian or upland)
0.15	Low density residential
0.20	Industrial/Commercial
0.35	High density residential or Industrial/Commercial

Below, photos taken during fieldwork by TID in 2014 and images clipped from aerial flyover video flown May 18, 2012, exemplify the most common Manning's n designations used in the study (Figures 1 – 24).

Figure 1. Mannings n is equal to .04.

Figure 2. Mannings n is equal to .04.

Figure 3. Mannings n is equal to .04.

Figure 4. Mannings n is equal to .04.

Figure 5. Mannings n is equal to .04.

Figure 6. Mannings n is equal to .04.

Figure 7. Mannings n is equal to .05.

Figure 8. Mannings n is equal to .05.

Figure 9. Mannings n is equal to .05.

Figure 10. Mannings n is equal to .05.

Figure 11. Mannings n is equal to .06.

Figure 12. Mannings n is equal to .06.

Figure 13. Mannings n is equal to .06.

Figure 14. Mannings n is equal to .06.

Figure 15. **Mannings n is equal to .07.**

Figure 16. Mannings n is equal to .08.

Figure 17. **Mannings n is equal to .08.**

Figure 18. **Mannings n is equal to .10.**

Figure 19. **Mannings n is equal to .10.**

Figure 20. Mannings n is equal to .10.

Figure 21. Mannings n is equal to .10.

Figure 22. Mannings n is equal to .10.

Figure 23. Mannings n is equal to .10.

Figure 24. Mannings n is equal to .10.

STUDY REPORT W&AR-21
THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT E

SAN JOAQUIN RIVER BACKWATER EFFECTS IN THE TUOLUMNE RIVER

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1.0 PURPOSE

As part of the *Lower Tuolumne River Floodplain Hydraulic Assessment* (W&AR-21), 1-D/2-D modeling is being conducted in three separate sub-reaches (Models A, B, and C) to assess juvenile salmonid floodplain habitat along the Tuolumne River from river mile (RM) 52.2 to RM 0 at the confluence with the San Joaquin River (SJR). In support of modeling in Reach C (RM 21.5 to RM 0), the boundary condition assessment presented herein examines the potential range of stage-discharge relationships near the confluence. There are two goals for the boundary condition analysis: 1) to determine the upstream extent of backwater effects in the Tuolumne River due to SJR and Stanislaus River flows, and 2) to develop a representative rating curve near the Tuolumne River SJR confluence to use as the downstream boundary condition for Model C.

2.0 ANALYSIS OF TUOLUMNE RIVER BACKWATER EXTENT

The hydraulic analysis combines portions of two existing HEC-RAS flood flow models originally developed by the California Department of Water Resources (DWR) covering the SJR system. One of the DWR flood models includes approximately 6 river miles of the lower Tuolumne River and the other extends approximately 17 river miles further upstream for a total DWR-modeled reach length in the Tuolumne River of approximately 23 miles. The combination of DWR models (combined model) of the SJR extends from the Crows Landing USGS Gage, located 23 miles upstream of the confluence of the Tuolumne River and the SJR River and 11.5 miles downstream of the Merced River, to the Vernalis Gage, located 16.5 miles downstream of the SJR and Tuolumne River confluence. The Stanislaus River, 2.75 miles upstream of the Vernalis Gage, is included in the combined model, which examines the potential influences of flow magnitudes in both the SJR and Stanislaus River on backwater in the Tuolumne River. A map of the model extent and gage locations is shown in Figure 1.

Representative flows and boundary conditions were developed from analyses of the following stream gages:

- USGS 11290000 TUOLUMNE R A MODESTO CA (1895 to present)
- USGS 11303000 STANISLAUS R A RIPON CA (1940 to present)
- USGS 11274550 SAN JOAQUIN R NR CROWS LANDING CA (1995 to present)
- USGS 11274000 SAN JOAQUIN R NR NEWMAN CA (1912 to present)
- USGS 11303500 SAN JOAQUIN R NR VERNALIS CA (1923 to present)

The rating curve (downloaded from USGS) associated with the Vernalis Gage is used to define the water surface elevations at the downstream boundary of the combined model. The Crows Landing Gage is used to verify the water surface elevation of the modeled inflow at the upstream boundary of the combined model. There are no gaged inflows between the Crows Landing Gage and the Tuolumne River confluence.

The Tuolumne River floodplain model being developed as part of W&AR-21 considers flows from 1,000 cfs to 9,000 cfs. The floodplain habitat area would primarily be used by juvenile salmonids during the months of February through May, inclusive. Therefore, the analysis of backwater effects considered SJR flows occurring over this seasonal period. To develop representative sensitivity scenarios for testing the extent of backwater effects on the Tuolumne due to SJR flows, we plotted flows from the SJR Newman gage against flows recorded by the Tuolumne River Modesto gage (RM 16.2) for the months of February through May over the period WY 1971-2012, shown in Figure 2. The Crows Landing gage has a shorter period of record so was not used for the analysis to ensure consideration of the full range of possible flows in the SJR related to flows in the Tuolumne River over the study period. However, the Crows Landing gage defines the upstream boundary of the model so it is important to understand the correlation with flow at this location with flow at the Newman gage, 6.5 miles upstream. The comparison for the available period of record at Crows Landing gage is shown in Figure 3 and indicates some small variability in accretion and losses between the gages, with a linear regression slope of 1.07. This tight correlation indicates that using the range of SJR flows observed at the Newman gage as the HEC-RAS model inflow is justifiable for assessing the extent of backwater effects within the Tuolumne River.

The HEC-RAS model also includes the Stanislaus River, approximately 8 miles downstream of the Tuolumne River. A comparison of flows within the Tuolumne and Stanislaus rivers is shown in Figure 4. This figure indicates wide scatter and minimal correlation between flows.

To test sensitivity of stage within the Tuolumne River to flows within the SJR and Stanislaus River, we developed eight flow scenarios based on the minimum and maximum habitat model flows in the Tuolumne River and the approximate maximum range of observed flows in the SJR and Stanislaus River at those Tuolumne River flows based on visual interpretation of the graph in Figure 2. The minimum flow in the SJR associated with the 1,000 cfs Tuolumne River case was set to 500 cfs, slightly higher than the observed minimum, for model stability. The tested scenarios are outlined in Table 1.

Table 1. Flows selected for boundary condition model sensitivity scenarios.

Scenario Number	Tuolumne River Flow cfs	SJR Flow cfs	Stanislaus River Flow cfs
1	9,000	25,000	7,000
2			500
3		10,000	7,000
4			500
5	1,000	15,000	4,000
6			500
7		500	4,000
8			500

3.0 RESULTS OF BACKWATER ASSESSMENT

A comparison of HEC-RAS model results is shown in Figure 5, which illustrates the water surface profiles on the Tuolumne River from its confluence with the SJR. The profiles indicate that there are essentially no backwater effects occurring on the Tuolumne River upstream of the Carpenter Road Bridge near RM 13.

Table 2 show differences in Tuolumne River water surface elevations at several locations for the cases where flows in the Tuolumne River and SJR were held constant to demonstrate the impact of varying flows in the Stanislaus River. The impact is relatively insignificant, with a maximum difference of 0.27 ft at the first Tuolumne River cross section, approximately 0.5 miles upstream of its confluence, falling to less than 0.2 ft approximately 1.8 miles upstream and less than 0.1 ft about 2.7 miles upstream.

Table 2. Relative stage differences examining potential impact of flow magnitude in the Stanislaus and Tuolumne rivers.

Channel Distance	Scenario 1 Stage minus Scenario 2 Stage	Scenario 3 Stage minus Scenario 4 Stage	Scenario 5 Stage minus Scenario 6 Stage	Scenario 7 Stage minus Scenario 8 Stage
miles	ft	ft	ft	ft
0.5	0.19	0.27	0.05	0.21
1.8	0.03	0.16	0.05	-0.19
2.7	0.03	0.10	0.05	-0.08

Table 3 demonstrates the upstream influence on Tuolumne River water surface elevations due to different flows in the SJR. The results indicate that over the approximate maximum range of observed flows, water surface elevations vary at the confluence by up to 12.2 ft for the lowest study flow of 1,000 cfs in the Tuolumne. The backwater effect of SJR flows extends approximately 10 to 13 miles upstream of the confluence.

Table 3. Relative stage differences indicating potential impacts of flows in the SJR and Tuolumne River.

Channel Distance	Scenario 1 Stage minus Scenario 3 Stage	Scenario 2 Stage minus Scenario 4 Stage	Scenario 5 Stage minus Scenario 7 Stage	Scenario 6 Stage minus Scenario 8 Stage
miles	ft	ft	ft	ft
0.5	3.40	3.49	12.07	12.23
9.0	0.16	0.17	1.13	1.10
10.5	0.10	0.10	0.60	0.58
12.5	0.05	0.05	0.20	0.19
13.5	0.04	0.04	0.10	0.09

4.0 RATING CURVE DEVELOPMENT

The 2-D hydraulic model of the Tuolumne River floodplain being developed in the W&AR-21 study will require a stage-discharge rating curve to represent the downstream boundary condition at the confluence of the Tuolumne River and SJR for the range of study flows being examined. The impact analysis demonstrates that the backwater effects of the SJR on the Tuolumne River can extend up to approximately RM 13, indicating that habitat analysis within this region may be substantially influenced by the choice of rating curve. To determine a representative stage-discharge rating curve we first establish a table of flows in the SJR and Stanislaus Rivers for each of the 21 model flows in the Tuolumne River (every 250 cfs from 1,000 cfs to 3,000 cfs, and every 500 cfs from 30,000 cfs to 9,000 cfs) and then use the HEC-RAS model to simulate elevations at the confluence.

To determine a correlation of flows between the Modesto gage (Tuolumne River) and the Newman Gage (SJR), we calculated the median flow in the SJR for every 50 cfs in the Tuolumne River. For example, for a Tuolumne River flow of 100 cfs, we found the median of all SJR flows associated with Tuolumne River flows between 75 cfs and 125 cfs. Figure 6 shows the relationships for the months of February through May, the primary months of interest for habitat analysis, and for all months for water years 1971 to 2012. A fourth order polynomial relationship provides the best fit regression between the data sets and works well for both the target habitat months and consideration of all months.

We applied the same analysis for the more scattered flows in the Stanislaus River and found a power relationship to be the best fit. This relationship is less important because the influence of flow variability on water surface elevation within the Tuolumne River is small. Note that sensitivity runs indicated that the downstream boundary condition on the SJR, represented by the rating curve at the Vernalis Gage, has no impact on water surface elevation in the Tuolumne River.

Table 4 provides the regression results in the SJR and Stanislaus River for each study flow in the Tuolumne River based on the regression equations shown in Figures 6 and 7. The flows in the SJR are also prorated based on the linear correlation between flows at the Newman and Crows Landing gages shown in Figure 3 to adjust for the location of the upstream boundary of the HEC-RAS model. The water surface elevation in the Tuolumne River, shown in the final column, at approximately RM 0.9 is the downstream boundary location for the 2-D model.

Table 4. Regression flows used to develop boundary condition rating curve.

Tuolumne River Flow	SJR Flow	Stanislaus River Flow	Tuolumne River Water Surface Elevation at RM 0.9
cfs	**cfs**	**cfs**	**ft**
320	872	459	22.0
500	949	580	22.6
750	1,038	716	23.2
1,000	1,115	832	23.8
1,250	1,188	935	24.3
1,500	1,267	1,028	24.8
1,750	1,359	1,114	25.3
2,000	1,470	1,194	25.7
2,250	1,608	1,270	26.2
2,500	1,778	1,341	26.6
2,750	1,985	1,410	27.1
3,000	2,233	1,475	27.6
3,500	2,867	1,599	28.7
4,000	3,699	1,714	29.7
4,500	4,738	1,822	30.8
5,000	5,983	1,925	31.9
5,500	7,420	2,023	33.0
6,000	9,025	2,117	33.8
6,500	10,762	2,207	34.3
7,000	12,586	2,294	35.0
7,500	14,438	2,378	35.7
8,000	16,250	2,460	36.3
8,500	17,941	2,538	36.7

Tuolumne River Flow	SJR Flow	Stanislaus River Flow	Tuolumne River Water Surface Elevation at RM 0.9
cfs	cfs	cfs	ft
9,000	19,421	2,615	37.1
9,500	20,588	2,690	37.4
10,000	21,328	2,763	37.7

5.0 SENSITIVITY ANALYSIS

To investigate sensitivity of the rating curve we assumed a "high flow" and "low flow" relationship between flows in the Tuolumne River and SJR based on plus-and-minus 40 percent of the flow determined from the regression equation shown in Figure 8. An analysis of the median absolute deviation (MAD) indicates an average (and median) deviation of approximately 30 percent. We chose a broader range of plus-and-minus 40 percent to envelope most of the median flows. Sensitivity flows and water surface elevations for selected study flows in the Tuolumne River are given in Table 5. The rating curve with sensitivity results shown for several flows is displayed in Figure 8. The results indicate insignificant differences at the lowest study flow of 1,000 cfs and a range of 3.2 ft at the highest study flow of 9,000 cfs. The difference in elevation for the 9,000 cfs sensitivity flows drops to less than 0.1 ft approximately 11 miles upstream from the confluence.

Table 5. Sensitivity results for selected study flows.

Tuolumne River Flow	SJR Regression Flow/Elevation		SJR High Flow/Elevation		SJR Low Flow/Elevation	
cfs	cfs	ft	cfs	ft	cfs	ft
1,000	1,115	23.8	1,561	24.1	668	23.9
5,000	5,983	31.9	8,376	33.1	3,589	30.5
9,000	19,421	37.1	27,191	38.6	11,652	35.4

6.0 DATUM ADJUSTMENT

The DWR model and the W&AR-21 Model C were developed using different sets of surface elevation data for the overbank regions. (The channel portion of both models is based on the same set of survey data.) Both surfaces are derived from high-resolution LiDAR data flown in different years. The DWR surface was processed using ground controls based on the Geoid03 model, while the W&AR-21 study used the Geoid09 model. The geoid is a model of global mean sea level that is used to measure precise surface elevations. The elevation differences between the two geoid models vary with location. In the vicinity of the Tuolumne and San Joaquin River confluence the Geoid03 surface is 0.373 ft higher than the Geoid09 surface.

A comparison of elevations of semi-permanent features, such as roads and levees, near the confluence shows approximately 0.4 ft to 0.5 ft difference between the two models. For example, the left bank of the downstream boundary cross section from Model C is 0.40 ft higher and the levee beyond the left bank is 0.44 ft higher than the DWR model. To account for this elevation difference the rating curve was adjusted for flows above the banks (greater than 6,500 cfs) to be 0.40 feet higher. Figure 9 shows the elevation difference between the two surfaces.

7.0 CONCLUSIONS

The analysis demonstrates that the backwater effect of flows in the SJR can extend up the Tuolumne River a maximum of approximately 13 miles near the Carpenter Road Bridge for the flows being considered in the W&AR-21 study. This may affect the floodplain habitat estimated to occur by the Tuolumne River TUFLOW model. Flows in the Stanislaus River have a very small backwater effect on the Tuolumne River.

Using the flow regressions developed between stream gages in the San Joaquin, Stanislaus and Tuolumne rivers as described above, the resulting Figure 10 provides a representative stage-discharge rating curve to be used for the TUFLOW model downstream boundary condition.

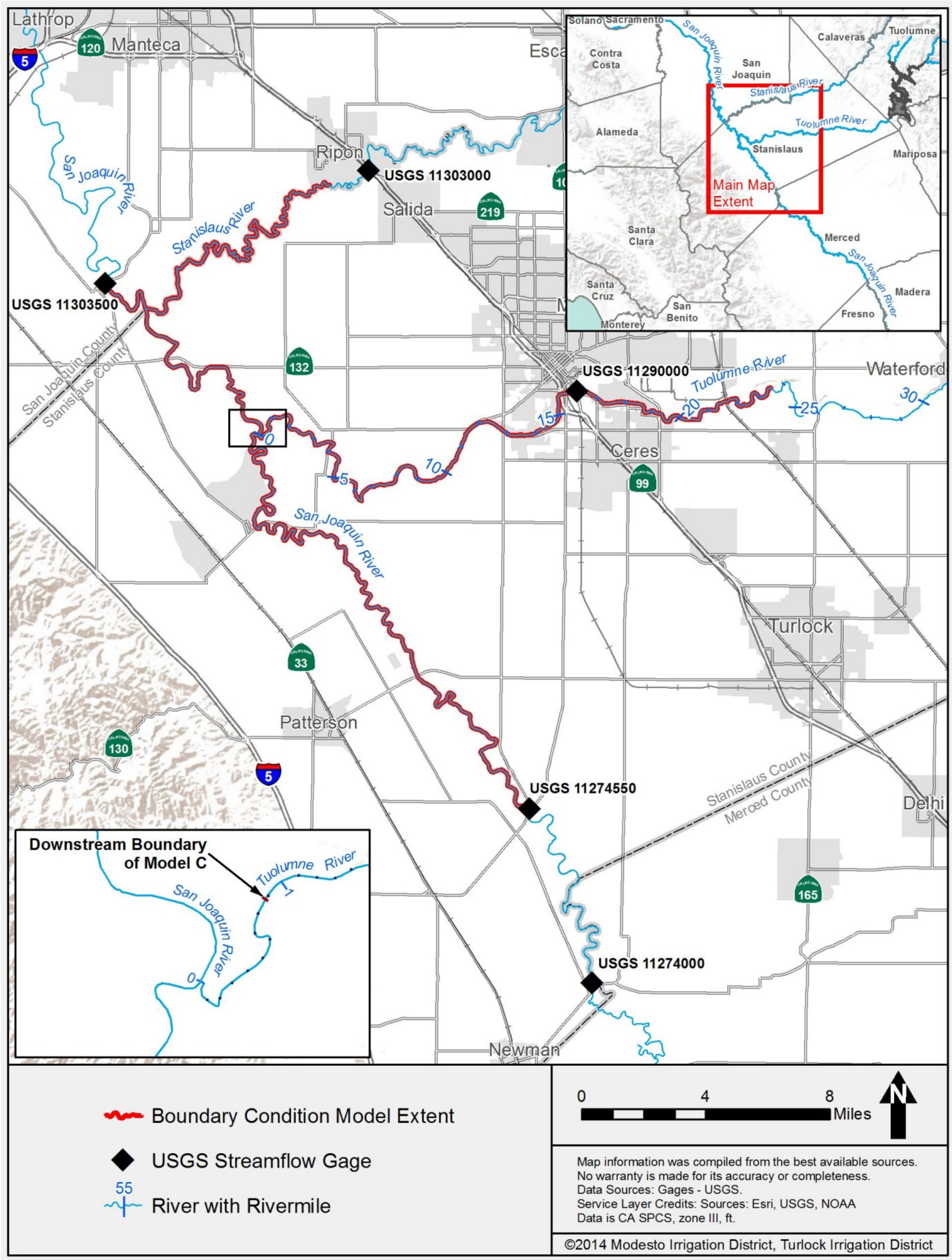

Figure 1. Location map depicting boundary condition model extents, USGS gage locations and the location for the rating curve.

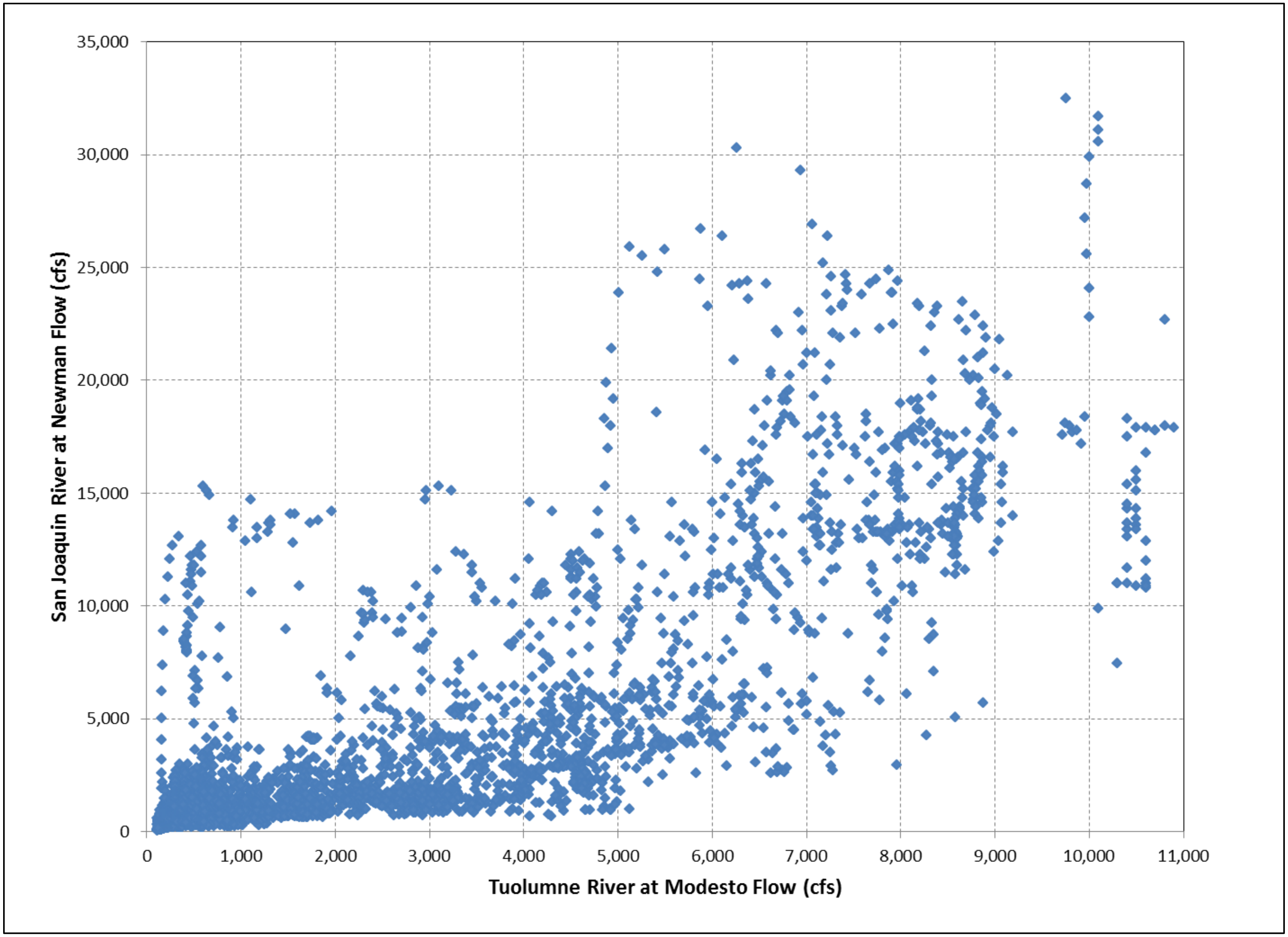

Figure 2. Comparison of flow in San Joaquin and Tuolumne Rivers, February through May, WY 1971-2012.

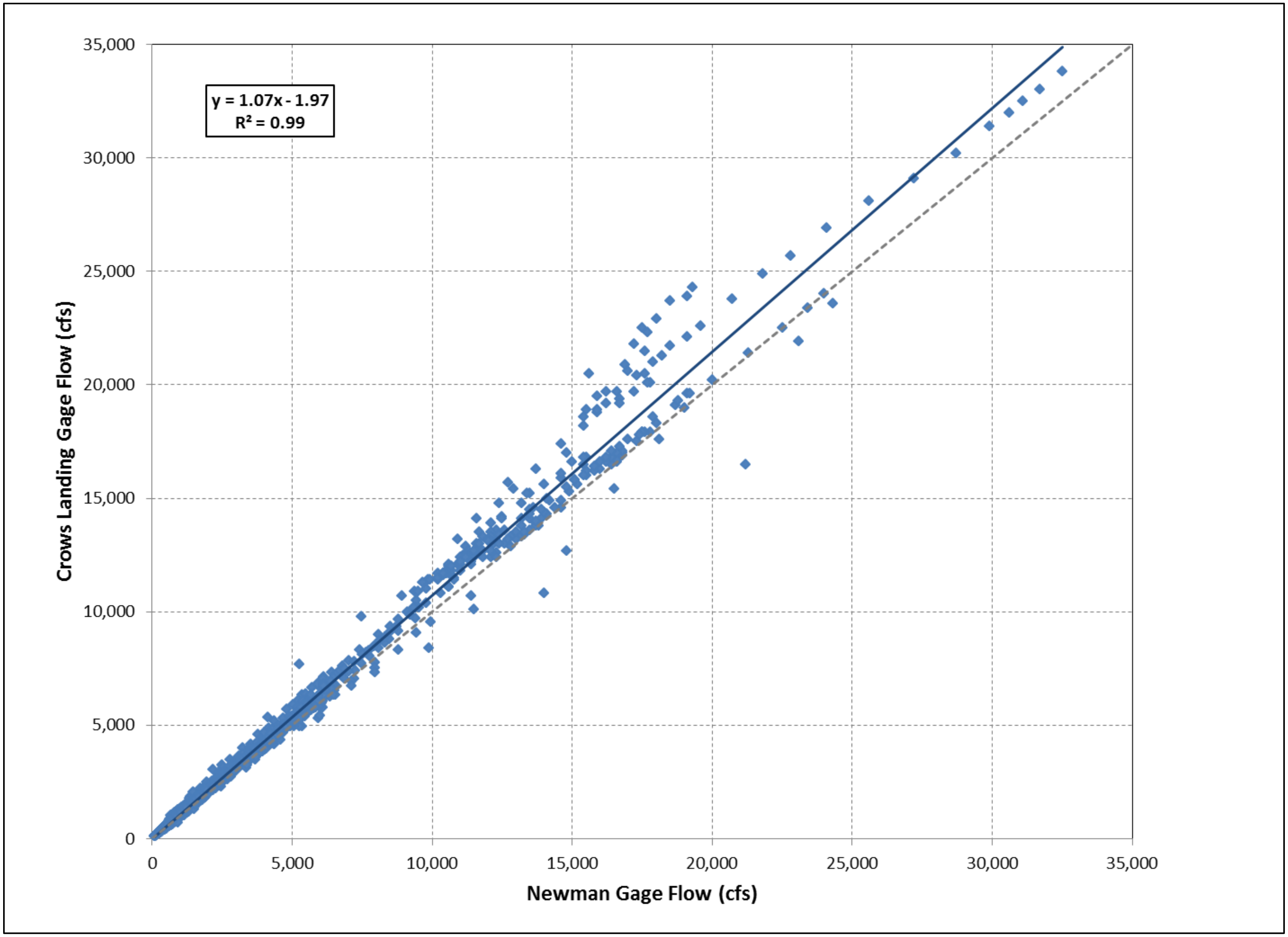

Figure 3. Comparison of Crows Landing and Newman Gage flow, February through May, 1996 to 2014.

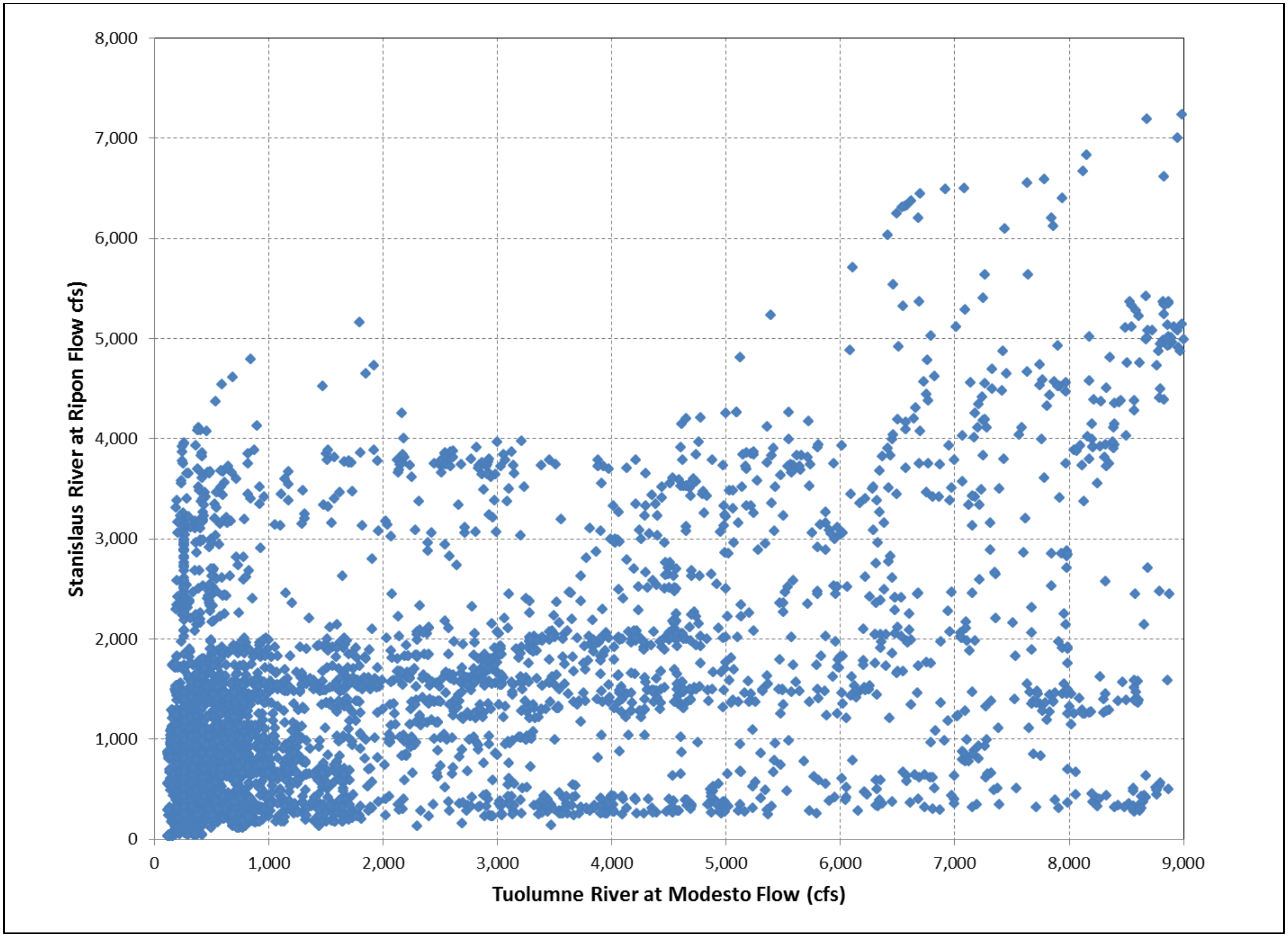

Figure 4. Comparison of flow in Tuolumne and Stanislaus Rivers, February through May, WY 1971 to 2014.

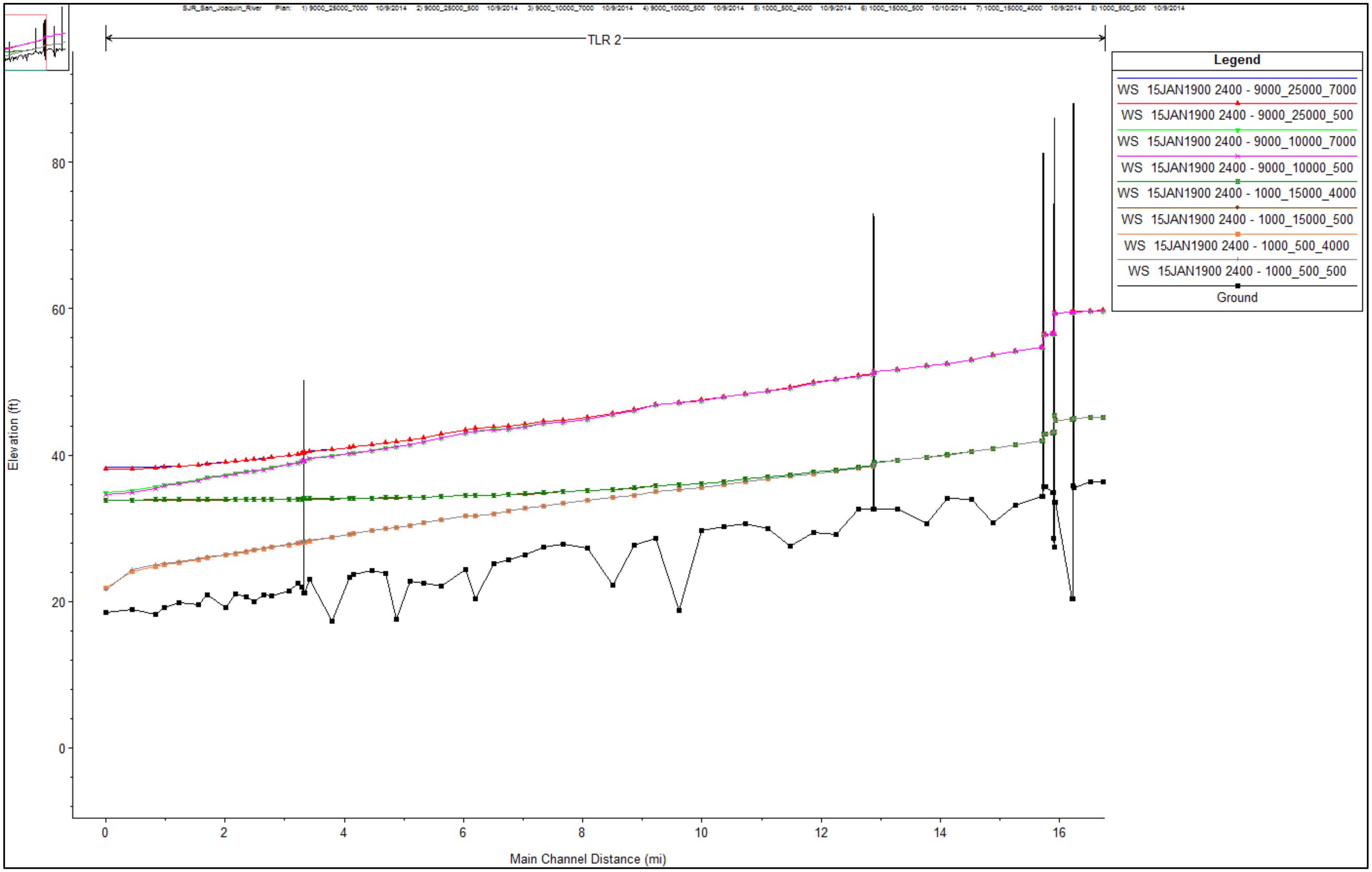

Figure 5. **HEC-RAS water surface elevation profiles for sensitivity scenarios For Tuolumne Reach from confluence with the San Joaquin River.**

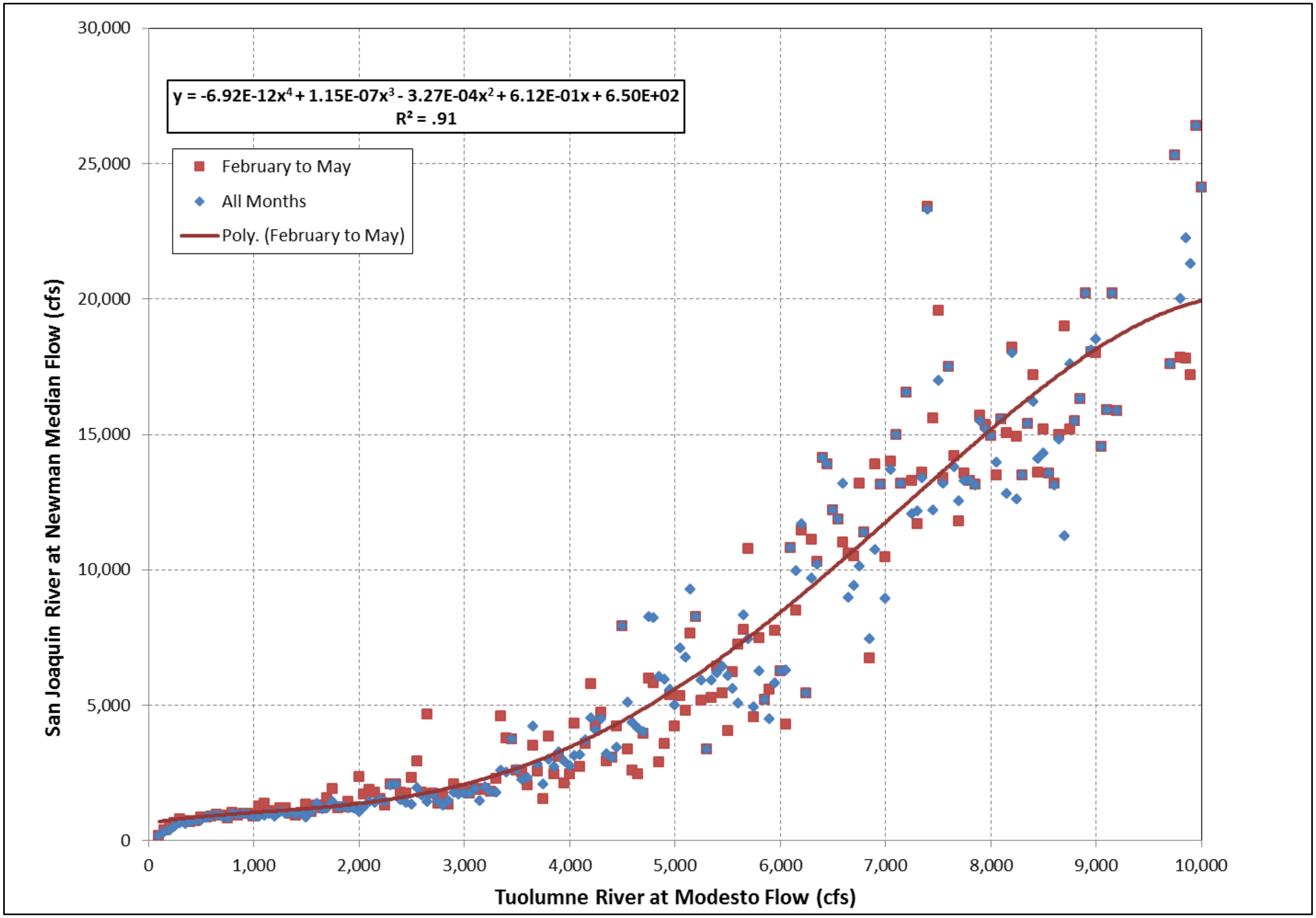

Figure 6. Correlation of median flow in San Joaquin River for 50 cfs intervals of flow in Tuolumne River, Water Years 1971 to 2012.

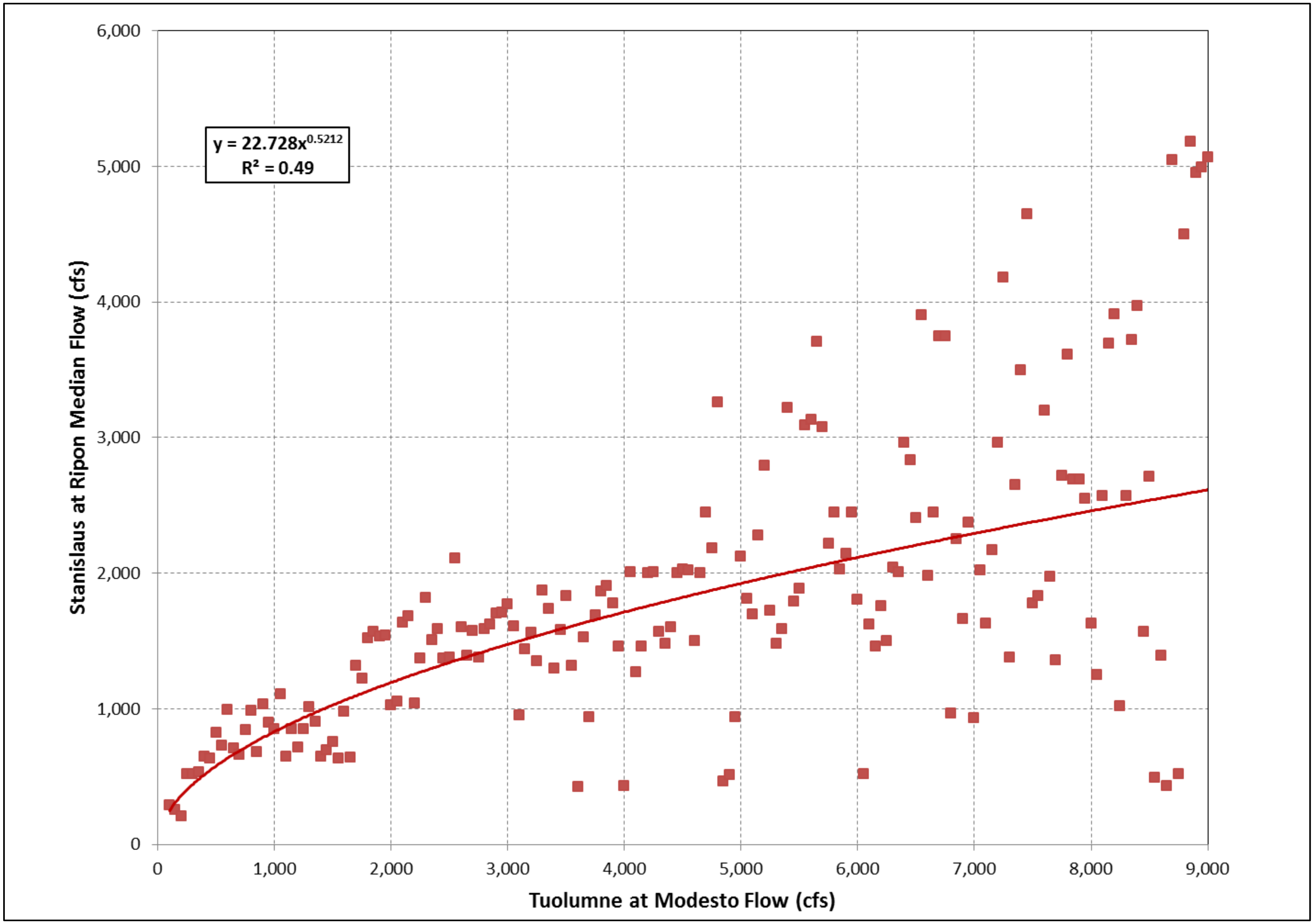

Figure 7. **Correlation of flow in Tuolumne with median flow in Stanislaus River for 50 cfs intervals, Water Years 1971 to 2012.**

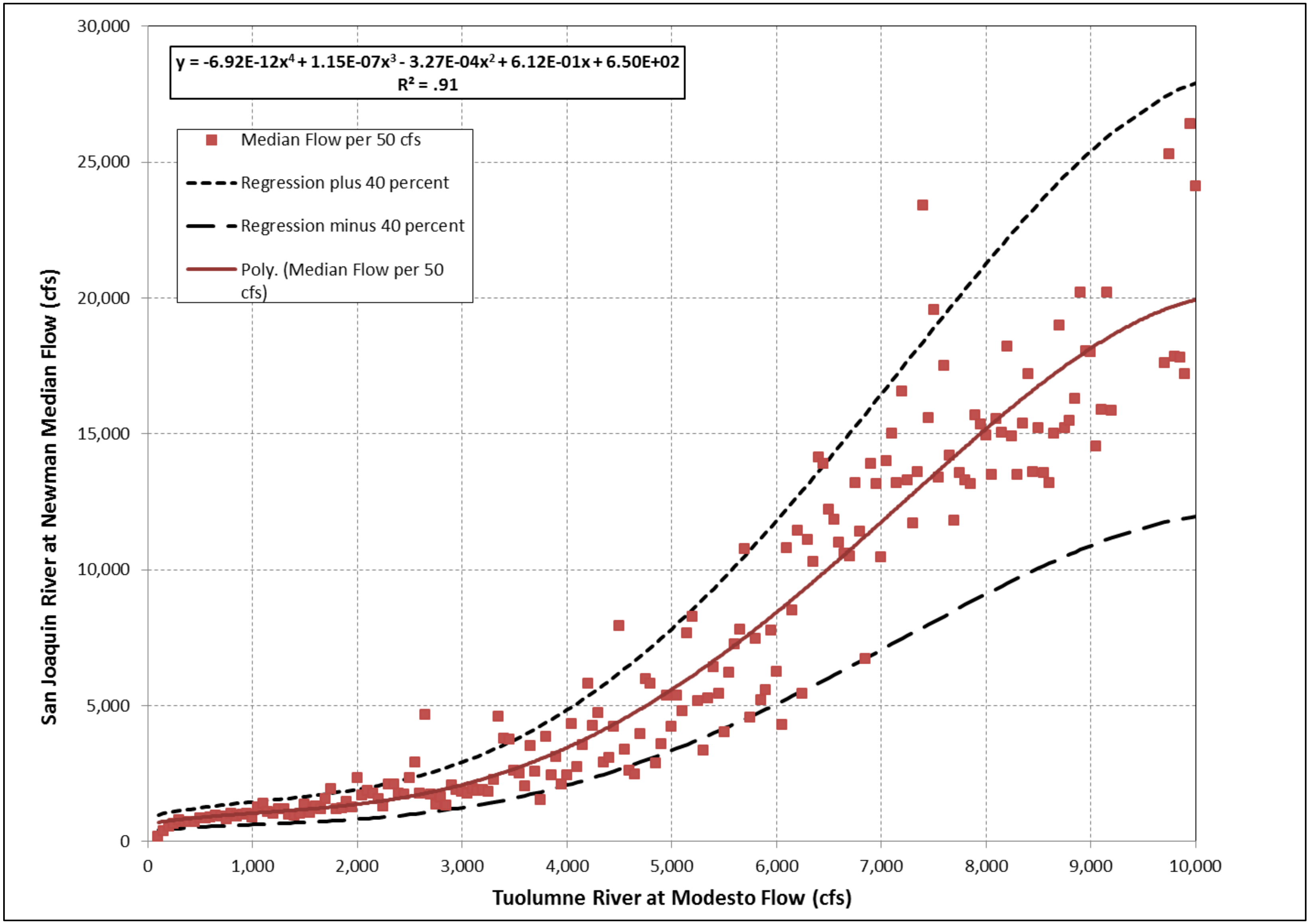

Figure 8. **Sensitivity analysis curves relating median flows in San Joaquin River for 50 cfs intervals of flows in Tuolumne River, Water Years 1971 to 2012.**

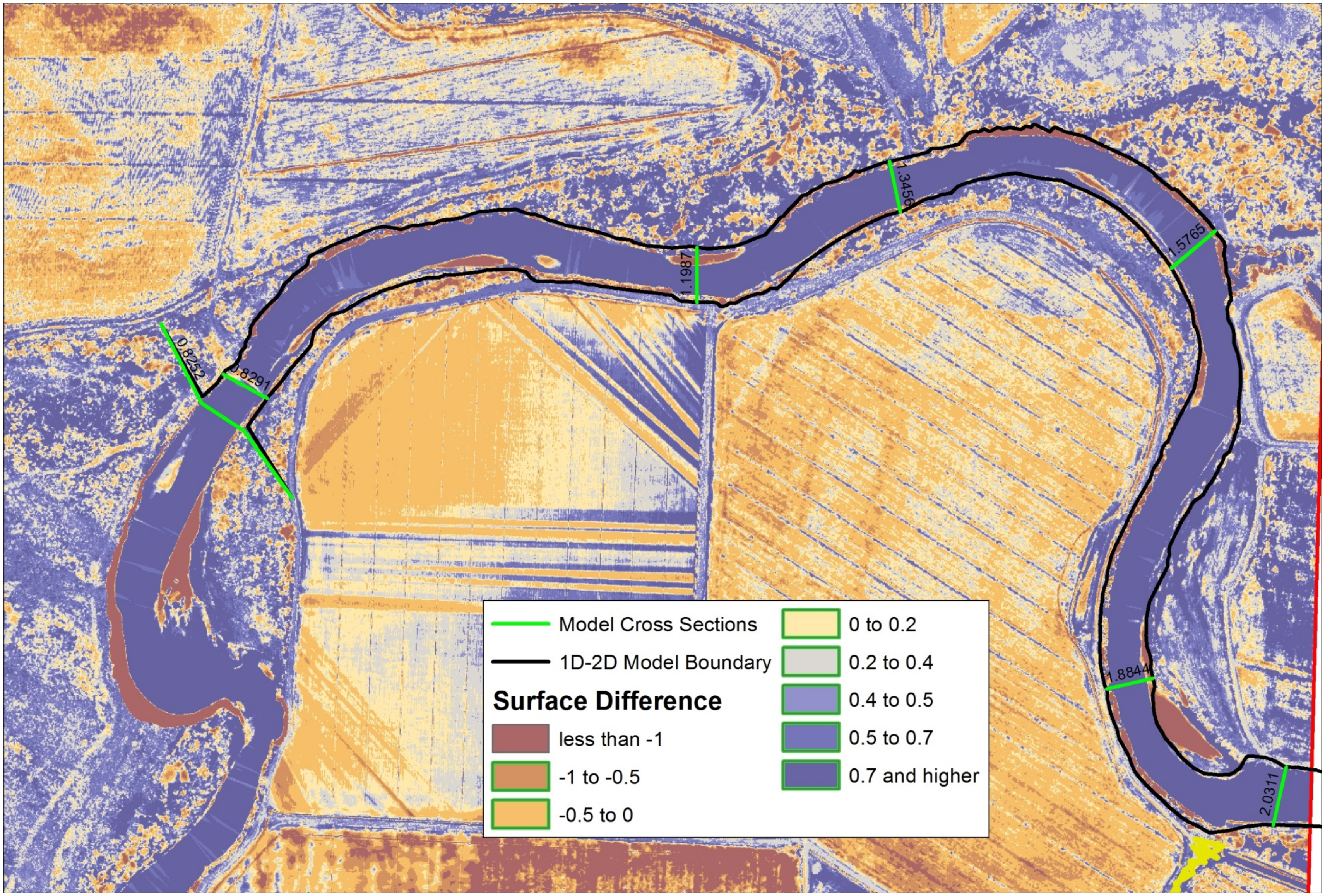

Figure 9. Difference in model terrain surfaces between DWR and W&AR-21 Model C. Levee features are consistently 0.4 to 0.5 ft higher, while some farmland areas have been eroded or compacted.

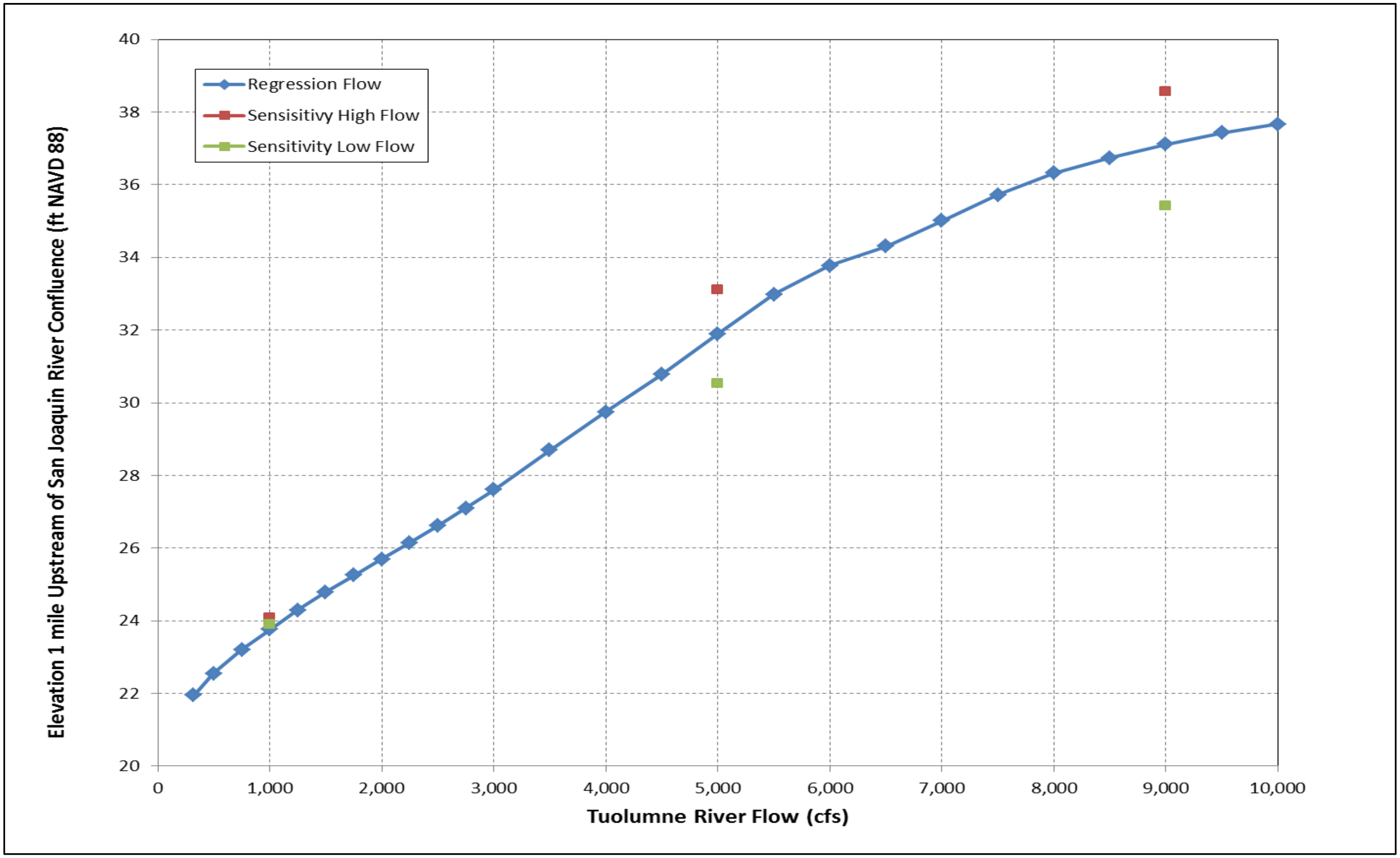

Figure 10. Model C boundary condition rating curve at RM 0.9.

STUDY REPORT W&AR-21

THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT F

LOCATIONS OF SIGNIFICANT GEOMORPHOLOGICAL CHANGES

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TABLE OF CONTENTS

Section No. **Description** **Page No.**

1.0 LOCATIONS OF SIGNIFICANT GEOMORPHOLOGICAL CHANGES 1

1.1 Model A 1

1.1.1 Artificial Dam Near RM 45.5. 1

1.1.2 Bobcat Flat Near RM 43 2

1.1.3 Inundation Areas and Construction of Ponds Near RM 42 6

1.1.4 Side Channel Near RM 50 7

1.1.5 Basso Floodplain near RM 48..12

1.1.6 Aggradation Near RM 47...13

1.1.7 Zanker Property Near RM 46 14

1.2 Model B 15

1.3 Model C 15

1.3.1 TRRP Gateway Parcel Project Near RM 16 15

1.3.2 Embankments Near RM 6.5...18

2.0 REFERENCES...20

List of Figures

Figure No. **Description** **Page No.**

Figure 1. Artificial dam RM 45.5. Dam seems to be at floodplain stage or higher (2009 imagery, flow of 490 cfs) (Google 2013). 1

Figure 2. Artificial dam at RM 45.5. Dam seems to have been overtopped during preceding high flows but still can be seen through the water (2011 imagery, flow of 1,020 cfs) (Google 2013). 2

Figure 3. Before and after restoration work at Bobcat Flat (McBain & Trush 2011).............3

Figure 4. Bobcat Flat (Domenichelli & Associates 2010). 4

Figure 5. Conditions prior to construction at Bobcat Flat (2005 imagery, flow of 4,030 cfs) (Google 2013). 4

Figure 6. The constructed floodplain at Bobcat Flat (2006 imagery, flow of 1,590 cfs) (Google 2013). 5

Figure 7. Flow in the constructed floodplain at Bobcat Flat (2010 imagery, flow between 5,400 and 6,000 cfs) (Google 2013). 5

Figure 8. Flow in the constructed floodplain at Bobcat Flat (2011 imagery, flow between 5,600 and 5,900 cfs) (Google 2013). 6

Figure 9. Inundated area near RM 42 (1995 imagery, flow of 8,400 cfs) (TID/MID 1997). 6

Figure 10. Two new constructed ponds and visible changes in floodplain flow paths near RM 42 (2011 imagery, flow of 1,020 cfs) (Google 2013). 7

Figure 11. Flow hydrograph at USGS La Grange Gage during the 1997 flood event.............8

Figure 12. No side channel exists at RM 50 prior to 1993 (1993 imagery, flow of 3,100 cfs) (TID/MID 1997). 8
Figure 13. No side channel exists at RM 50 prior to 1995 (1995 imagery, flow of 8,400 cfs) (TID/MID 1997). 9
Figure 14. 1998 imagery shows a side channel at RM 50 (flow of 1,030 cfs) (Google 2013). 9
Figure 15. 2009 imagery shows a side channel near RM 50 (flow of 490 cfs) (Google 2013). 10
Figure 16. 2011 imagery shows a side channel near RM 50 (flow of 1,020 cfs) (Google 2013). 10
Figure 17. 2006 imagery shows a side channel near RM 50 (flow of 1,590 cfs) (Google 2013). 11
Figure 18. 2005 imagery shows flow in a side channel near RM 50 (flow of 2,680 cfs) (Google 2013) 11
Figure 19. The Basso floodplain (1993 imagery, flow of 3,100 cfs) (TID/MID 1997). 12
Figure 20. The Basso floodplain (2005 imagery, flow of 4,030 cfs) (Google 2013). 12
Figure 21. Aggradation near RM 47 (1993 imagery, flow of 3,100 cfs) (TID/MID 1997). 13
Figure 22. Aggradation near RM 47 (2005 imagery, flow of 4,030 cfs) (Google 2013). 13
Figure 23. Zanker property near RM 46 (1993 imagery, flow of 3,100 cfs) (TID/MID 1997). 14
Figure 24. Zanker property near RM 46 (2005 imagery, flow of 4,030 cfs) (Google 2013). 15
Figure 25. A 2005 image of the TRRP, prior to recontouring and revegetation (Google 2013). 16
Figure 26. A 2011 image of the TRRP, following recontouring and revegetation (Google 2013). 17
Figure 27. A 2012 image of the TRRP, after recontouring and revegetation. 18
Figure 28. A 1995 image showing the embankments. There appear to be no cuts in the embankments (flow of 8,322 cfs) (TID/MID 1997). 19
Figure 29. A 2012 terrain image shows cuts in the embankments. 19

1.0 LOCATIONS OF SIGNIFICANT GEOMORPHOLOGICAL CHANGES

Between 1993 and 2012, several locations in the study area underwent significant geomorphological changes. This attachment provides a description of model revisions undertaken during the calibration process and locations requiring further investigation due to changes in reach morphology which occurred subsequent to the aerial photo dates used for comparison of inundation extents and hydraulic behavior. This section presents areas that were identified as having undergone significant morphological changes potentially affecting hydraulic properties. The changes were carefully reviewed to ensure proper hydraulic simulation through verification of model results.

1.1 Model A

1.1.1 Artificial Dam Near RM 45.5.

Figures 1 and 2 show an artificial dam on the north side of the island at RM 45.5 (Cross section 45.54416). The dam was likely created during the construction of the artificial channel upstream on the north side of the river for the purpose of raising the water surface elevation to direct more flow through the engineered channel. The dam was added to the model to improve simulation of the hydraulic behavior in the region.

Figure 1. Artificial dam RM 45.5. Dam seems to be at floodplain stage or higher (2009 imagery, flow of 490 cfs) (Google 2013).

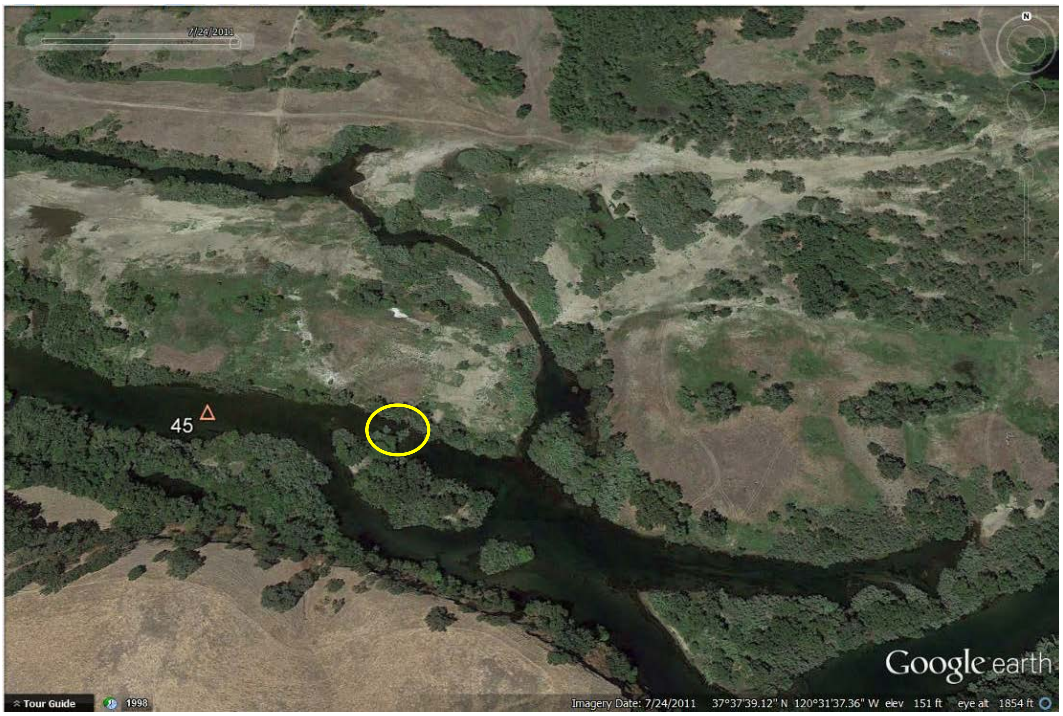

Figure 2. Artificial dam at RM 45.5. Dam seems to have been overtopped during preceding high flows but still can be seen through the water (2011 imagery, flow of 1,020 cfs) (Google 2013).

1.1.2 Bobcat Flat Near RM 43

Figures 3 – 8 show the floodplain restoration work that started in 2005 at Bobcat flat near RM 43. The purpose of the multi-phase project was to restore morphologic function and habitat for target species by lowering portions of the floodplain. Phase-I construction to restore riparian habitat, floodplain function and connectivity to the river, began in the summer of 2005 (McBain & Trush Inc. 2011). A previous hydraulic modeling study (Domenichelli & Associates 2010) showed inundation extents in the constructed floodplain at a flow of 5,000 cfs. Hydraulic behavior of the model was validated in this important region based on this documentation.

Bobcat Flat RM 43 Phase II
FINAL Technical Memorandum *McBain and Trush, Inc., 2011*

Figure 6. Pre- (November 17, 2000) and post- (September 21, 2005) construction aerial photographs for Bobcat Flat RM 43 Phase I project area.

Figure 3. Before and after restoration work at Bobcat Flat (McBain & Trush 2011).

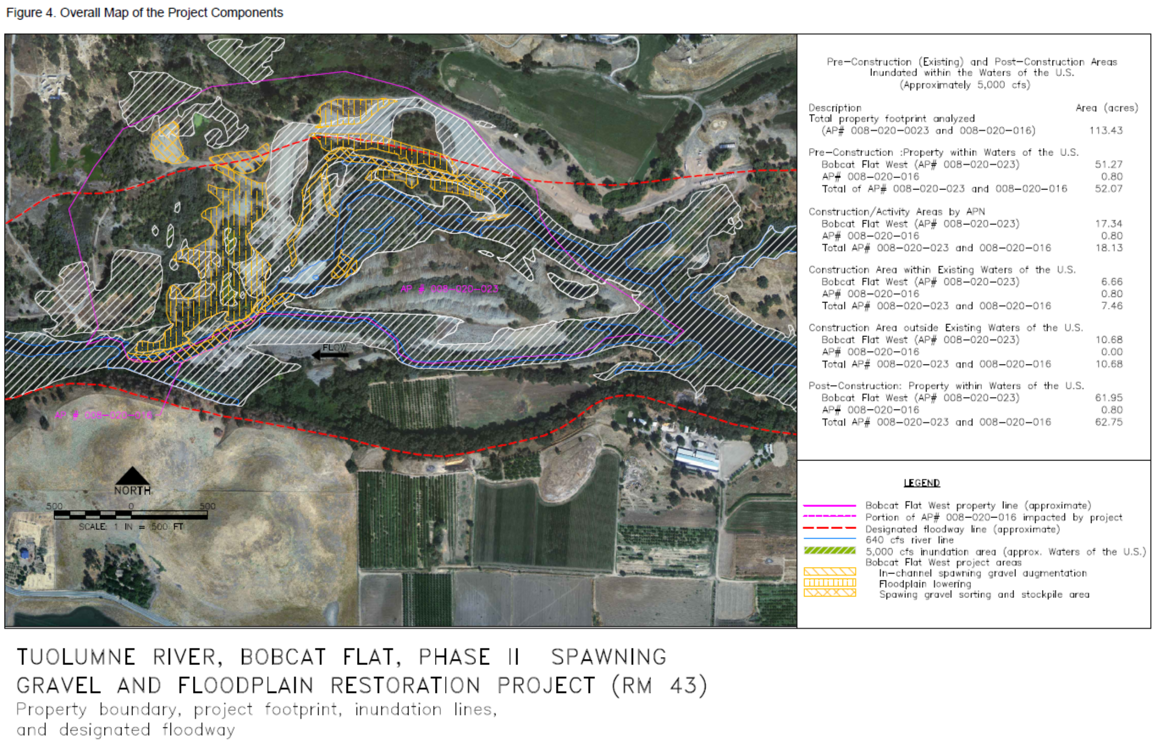

Figure 4. **Bobcat Flat (Domenichelli & Associates 2010).**

Figure 5. **Conditions prior to construction at Bobcat Flat (2005 imagery, flow of 4,030 cfs) (Google 2013).**

Figure 6. The constructed floodplain at Bobcat Flat (2006 imagery, flow of 1,590 cfs) (Google 2013).

Figure 7. Flow in the constructed floodplain at Bobcat Flat (2010 imagery, flow between 5,400 and 6,000 cfs) (Google 2013).

Figure 8. **Flow in the constructed floodplain at Bobcat Flat (2011 imagery, flow between 5,600 and 5,900 cfs) (Google 2013).**

1.1.3 Inundation Areas and Construction of Ponds Near RM 42

Figures 9 and 10 show two new constructed ponds and visible changes in floodplain flow paths over time. Model hydraulic behavior was validated in this region based on the photographs.

Figure 9. **Inundated area near RM 42 (1995 imagery, flow of 8,400 cfs) (TID/MID 1997).**

Figure 10. **Two new constructed ponds and visible changes in floodplain flow paths near RM 42 (2011 imagery, flow of 1,020 cfs) (Google 2013).**

1.1.4 Side Channel Near RM 50

The following locations experienced significant morphological changes in the river and/or floodplain since 1993, most likely due to sustained high flows during the 1997 flood event when peak flows exceeded 50,000 cfs at the USGS Gage below La Grange (Figure 11):

- Near RM 50 – Formation of side channel
- Near RM 48 – Erosion on overbank flow path leading to formation of side channel
- Near RM 48 – Aggradation on left overbank floodplain flow paths and floodplain
- Near RM 47 – Aggradation upstream of sand bar
- Near RM 46 – Aggradation on flow path connecting river to Zanker property

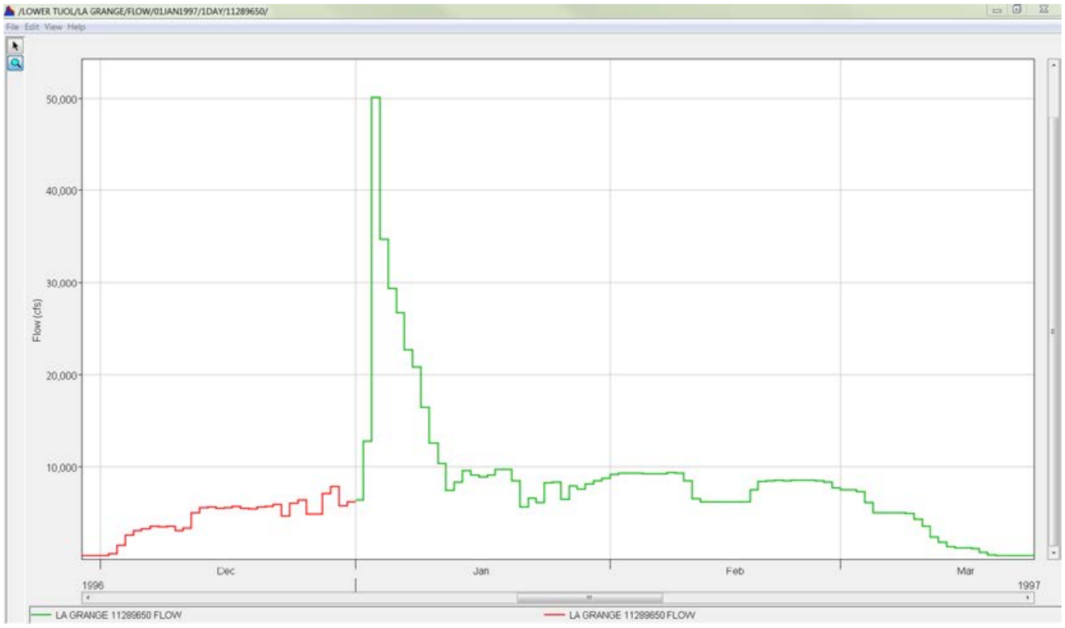

Figure 11. Flow hydrograph at USGS La Grange Gage during the 1997 flood event.

Below are images of a side channel near RM 50 on the south river bank that was created sometime between 1995 and 1998, likely due to the 1997 storm. Figures 12 – 18 show the evolution of the side channel development over time. The figures also show that once created, there is no flow in the side channel at 490 and 1,020 cfs, but flow is evident at 1,590 cfs and 2,689 cfs. Hydraulic behavior at these flows was verified during model validation.

Figure 12. No side channel exists at RM 50 prior to 1993 (1993 imagery, flow of 3,100 cfs) (TID/MID 1997).

Figure 13. **No side channel exists at RM 50 prior to 1995 (1995 imagery, flow of 8,400 cfs) (TID/MID 1997).**

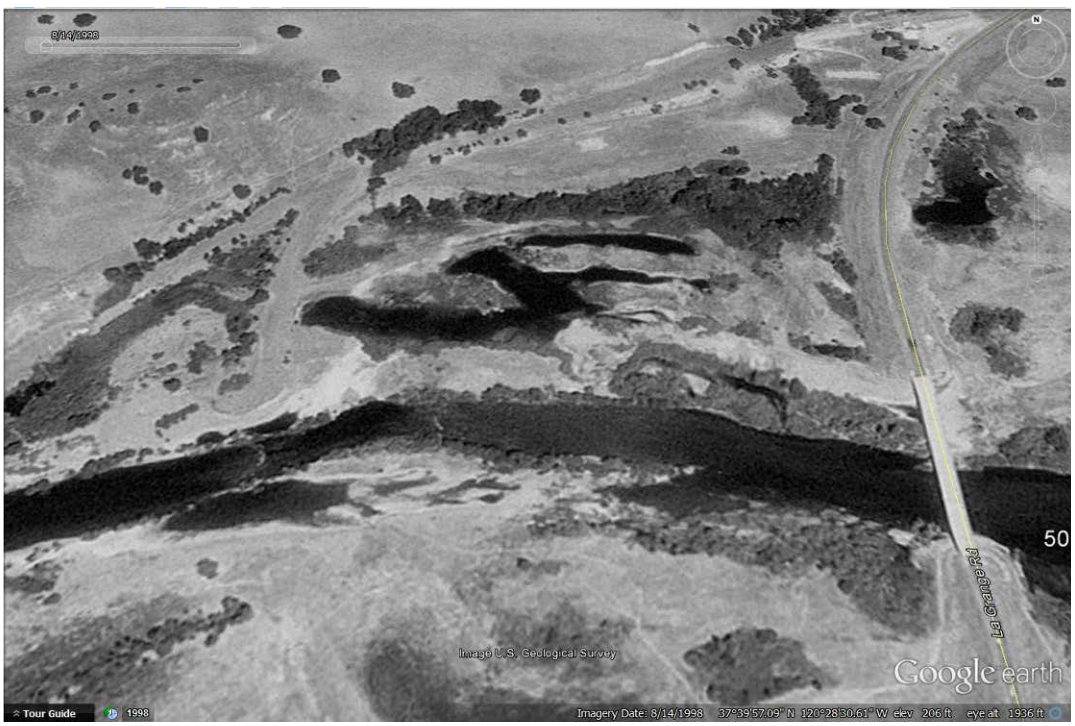

Figure 14. **1998 imagery shows a side channel at RM 50 (flow of 1,030 cfs) (Google 2013).**

Figure 15. **2009 imagery shows a side channel near RM 50 (flow of 490 cfs) (Google 2013).**

Figure 16. **2011 imagery shows a side channel near RM 50 (flow of 1,020 cfs) (Google 2013).**

Figure 17. **2006 imagery shows a side channel near RM 50 (flow of 1,590 cfs) (Google 2013).**

Figure 18. **2005 imagery shows flow in a side channel near RM 50 (flow of 2,680 cfs) (Google 2013)**

1.1.5 Basso Floodplain near RM 48

Figures 19 and 20 below show changes in the Basso Floodplain at RM 48 between 1993 and 2005. The changes suggest aggradation on the floodplain altering the extent of flow paths and inundation. Flow leaves the channel into the floodplain and returns.

Figure 19. The Basso floodplain (1993 imagery, flow of 3,100 cfs) (TID/MID 1997).

Figure 20. The Basso floodplain (2005 imagery, flow of 4,030 cfs) (Google 2013).

1.1.6 Aggradation Near RM 47.

Comparison of floodplains between 1993 and 2005 suggests aggradation upstream of the sand bar, altering flow paths and the extent of inundation(Figures 21 and 22).

Figure 21. Aggradation near RM 47 (1993 imagery, flow of 3,100 cfs) (TID/MID 1997).

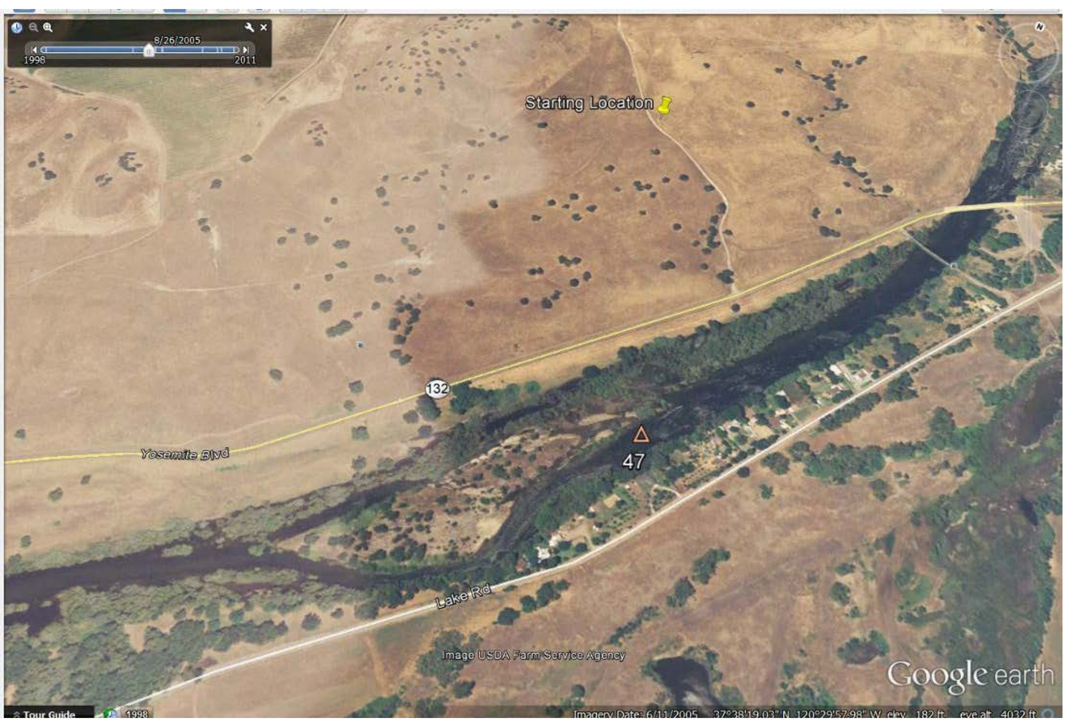

Figure 22. Aggradation near RM 47 (2005 imagery, flow of 4,030 cfs) (Google 2013).

1.1.7 Zanker Property Near RM 46

The flow path connecting the river to the Zanker property at RM 46 has changed over time. In 1993 at flows of 3,100 cfs, flow appeared to leave the river and flow into the Zanker property (Figure 23). A 2005 aerial image of flow at 4,030 cfs shows that the flow paths and inundation extent have significantly changed (Figure 24). A comparison of these two figures suggests aggradation at the location, leading to formation of a sand bar, altering flow paths and the extent of inundation.

Figure 23. Zanker property near RM 46 (1993 imagery, flow of 3,100 cfs) (TID/MID 1997).

Figure 24. Zanker property near RM 46 (2005 imagery, flow of 4,030 cfs) (Google 2013).

1.2 Model B

No location of significant morphological changes encountered during calibration.

1.3 Model C

Two significant changes in the floodplain were noted.

1.3.1 TRRP Gateway Parcel Project Near RM 16

In 2009 as part of the TRRP (Tuolumne River Regional Park) Gateway Parcel Project by the City of Modesto (Tuolumne River Trust 2012), significant floodplain storage near RM 16 was added by recontouring and revegetating the land along this stretch of the river into a series of three floodplain terraces on both sides of the 9th Street Bridge (immediately adjacent to Dennett Dam). Figures 25 through 27 show the site in 2005, 2011 and 2012 terrain.

Figure 25. A 2005 image of the TRRP, prior to recontouring and revegetation (Google 2013).

Figure 26. A 2011 image of the TRRP, following recontouring and revegetation (Google 2013).

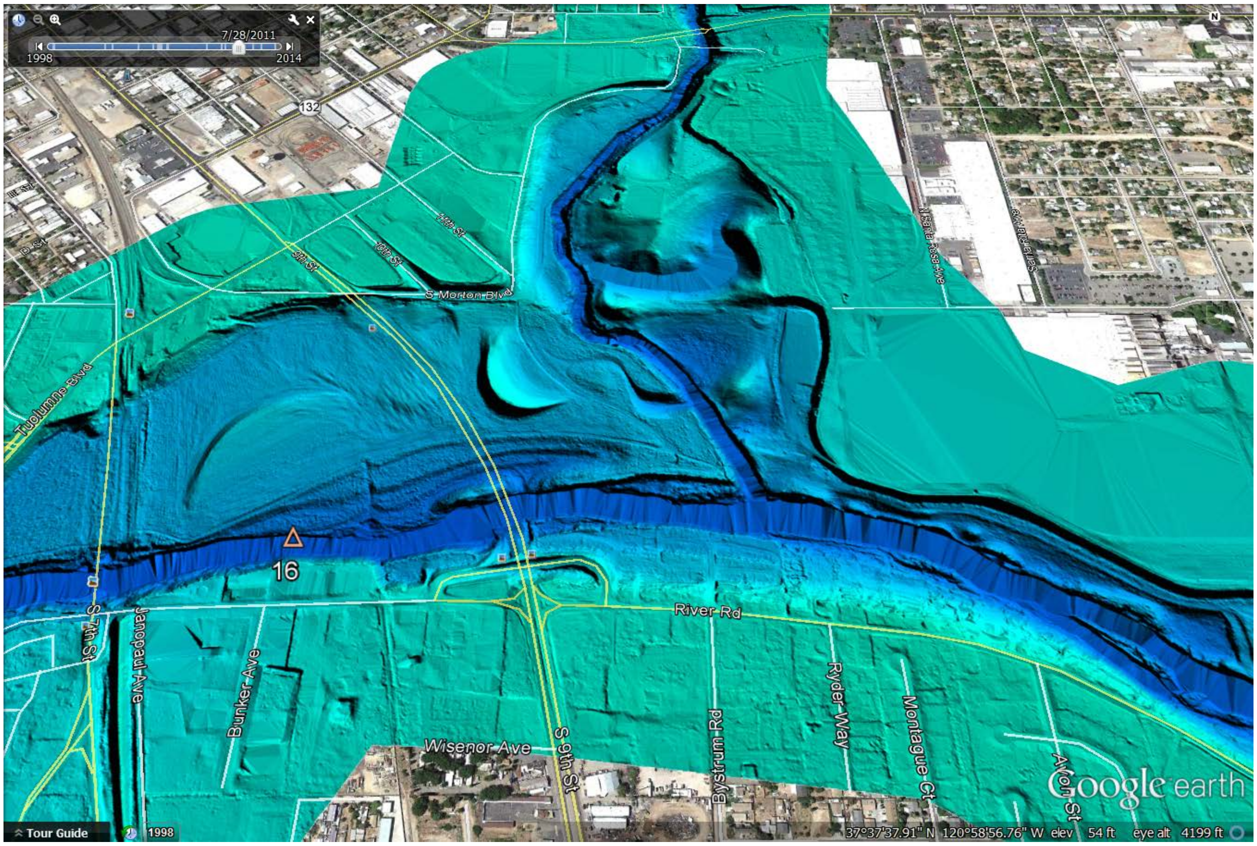

Figure 27. A 2012 image of the TRRP, after recontouring and revegetation.

1.3.2 Embankments Near RM 6.5

Near RM 6.5, some of the embankments appear to have either been breached in the 1997 flood or intentionally cut open to allow inflow. An aerial image from 1995 shows the extent of iundation at 8,322 cfs (Figure 28). In this image, there appear to be no cuts in the embankments and the adjacent fields appear dry. In contrast, the 2012 terrain shows cuts in the embankments (Figure 29). Therefore, the model was calibrated to allow water to flow into the adjacent fields connected by the embankment cuts for the calibration flow of 8,322 cfs.

Figure 28. A 1995 image showing the embankments. There appear to be no cuts in the embankments (flow of 8,322 cfs) (TID/MID 1997).

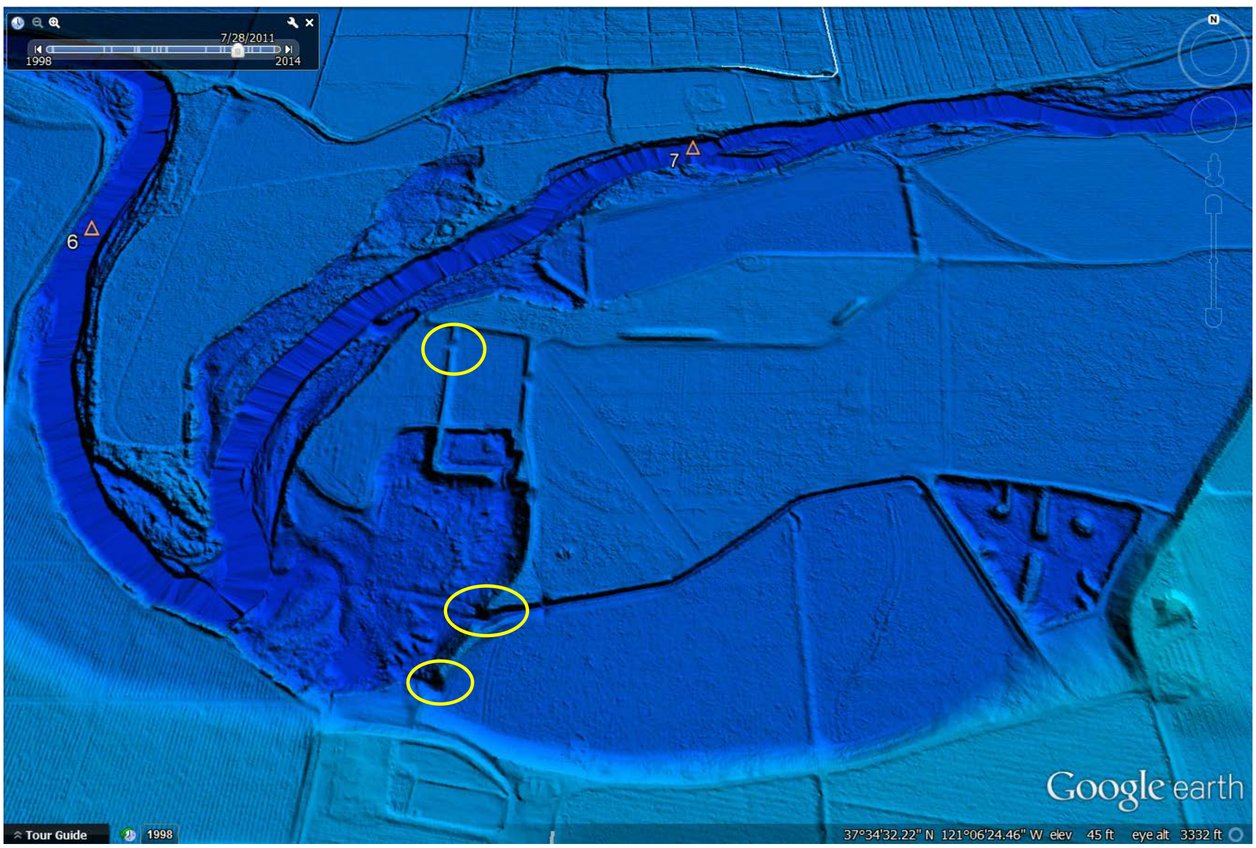

Figure 29. A 2012 terrain image shows cuts in the embankments.

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Domenichelli & Associates. 2010. Hydraulic Modeling Results – Tuolumne River, Bobcat Flat RM 43. Prepared for McBain & Trush as part of the Bobcat Flat Restoration (McBain and Trush 2011).

Google Earth Pro, Google Inc, 2013.

McBain & Trush, Inc. 2011. Bobcat Flat River Mile (RM) 43 Phase II Restoration, Final Design Document. Prepared for the Friends of the Tuolumne River, Inc. May 24, 2011.

TID/MID 1997. Imageries from Tuolumne River GIS Database Report and Map. Report 1996-14 In 1996 Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. Prepared by EA Engineering, Science, and Technology, Lafayette, California.

STUDY REPORT W&AR-21
THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT G

FLOODPLAIN INUNDATION EXTENT ANIMATIONS

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Twenty animations which show the inundation extents for steady flows from 1,000 cfs to 9,000 cfs are available electronically. A CD with animations is available upon request to Jenna Borovansky (jenna.borovansky@hdrinc.com).

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STUDY REPORT W&AR-21
THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT H

COMPARISON OF USABLE HABITAT WITHIN IN-CHANNEL AND FLOODPLAIN AREAS

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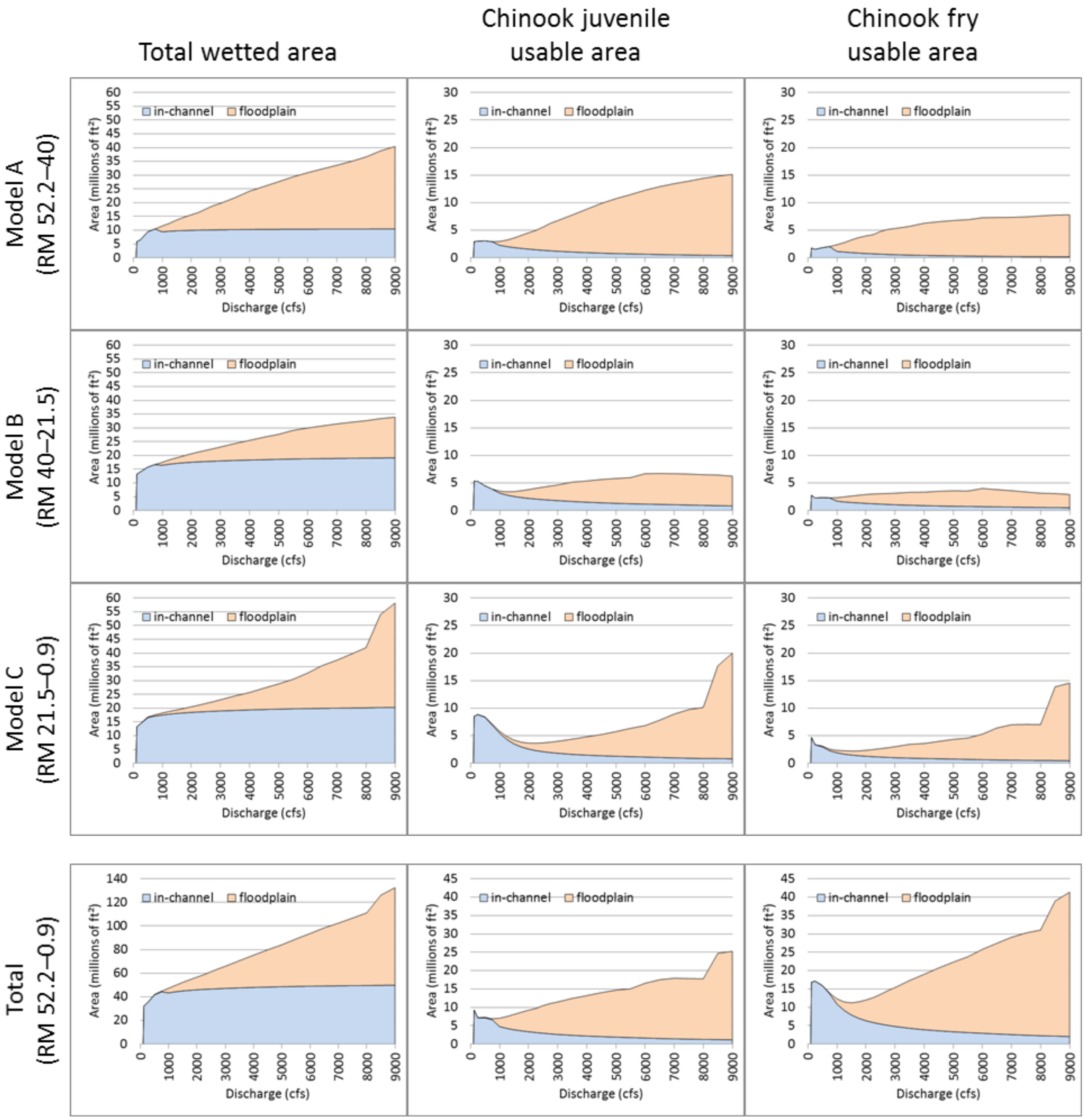

Figure 1. Variations of total wetted area and usable habitat for Chinook salmon fry and juvenile life stages within in-channel and floodplain habitats within three sub-reaches of the lower Tuolumne River as a function of discharge.

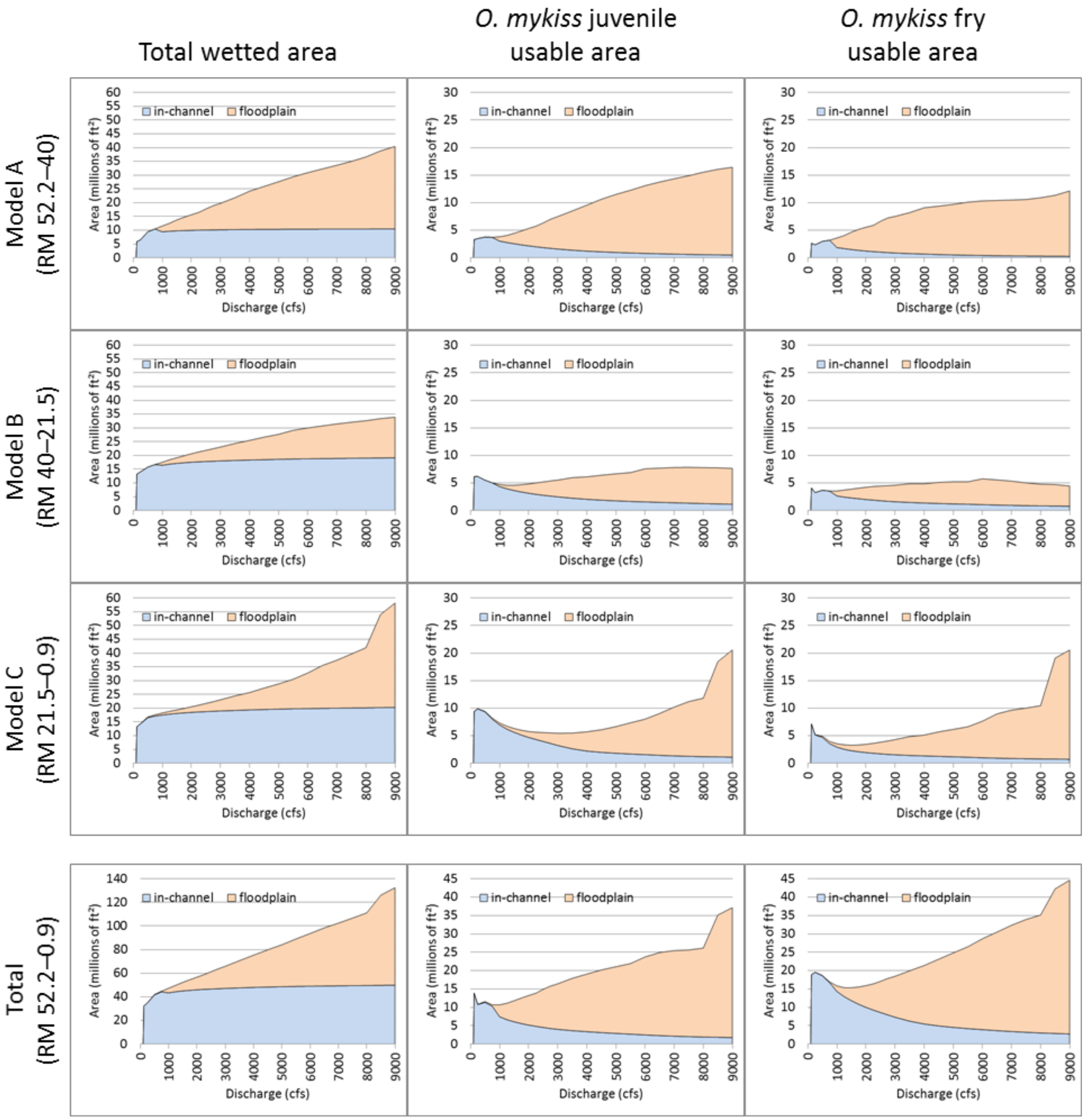

Figure 2. Variations of total wetted area and usable habitat for *O. mykiss* fry and juvenile life stages within in-channel and floodplain habitats within three sub-reaches of the lower Tuolumne River as a function of discharge.