APPENDIX F

Lower Feather River Corridor Management Plan Hydraulic Analysis—Baseline Model Documentation

Lower Feather River
Corridor Management Plan
Hydraulic Analysis-Baseline
Model Documentation

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1 Introduction

The California Department of Water Resources (DWR) has initiated development of a Corridor Management Plan (CMP) project of the Lower Feather River (LFR) from the Sutter Bypass to the Yuba River. The CMP project will develop a vision and strategy for future management of flood protection facilities, conveyance channels, floodplains, and associated uplands; and will include recommended policies for compatible land uses, such as agriculture and recreation. It will address existing and future habitat restoration and conservation, river ecosystem functions, flood maintenance activities, and regulatory permitting strategies.

2 Purpose

As part of the CMP project, a hydraulic analysis for the study area is needed to determine the hydraulic effects associated with various scenarios of future conditions and features within the river corridor. Determination of hydraulic effects requires the development of 1) baseline hydraulic conditions and 2) future hydraulic conditions. This report documents the model development and hydraulic analysis of the baseline condition for the CMP. Included in this document are:

- Background on the hydraulic model used for the analysis;
- A description of the hydrology in the study area;
- A description of the model calibration;
- A description of the modeled baseline condition;
- Water surface elevation profiles derived from the hydraulic analysis;
- Top-of-levee elevation profiles in relation to water surface elevation profiles;
- Velocity contours derived from the hydraulic analysis.

Future reports will be prepared to document the hydraulic effects associated with various scenarios of future conditions and features.

3 Methodology

The methodology to determine hydraulic effects is to conduct hydraulic model simulations of both baseline conditions and potential future conditions. The model results from simulating scenarios of future conditions and features will be compared to the baseline conditions. Differences in water surface elevation and velocities are the key aspect in comparison. Simulations will focus on larger flood events, such as the 100-, 200- year events, and 1957 Sacramento River Flood Control Project (SRFCP) Design Flow.

Development of the baseline condition simulations consists of formulating two model geometries. One model geometry is for use in calibrating roughness coefficients from the last major flood event (January 1997) and the other model geometry is for use in representing conditions as of 2011. Two model geometries are necessary since there have been significant levee realignments along the LFR since the January 1997. A model geometry consisting of vegetation conditions and levee alignments as of January 1997 was developed and calibrated (Calibration Model). Model development and calibration is discussed in Section 6.

Once reasonable calibration was achieved for conditions in January 1997, the calibration model was modified to reflect levee alignments and vegetation conditions as of 2011. This modified model represents the baseline condition (Baseline Model). Future project conditions will be simulated in new model runs derived from the Baseline Model and their model results will be compared to the Baseline Model in order to determine the hydraulic effects of the projects. Model development and simulations for the baseline condition are discussed in Section 7.

4 Model Software

The hydraulic model software used for this analysis is RMA-2 Version 4.5 (Corps, 2008). RMA-2 is a two dimensional finite element hydrodynamic numeric model (2-D model). It computes water surface elevation and horizontal velocity components for subcritical, free surface two-dimensional flow fields. RMA-2 solves the depth integrated equations of fluid mass and momentum conservation in two horizontal directions.

The RMA-2 hydraulic model is assembled with Surface Water Modeling System (SMS) Version 10.1 and 11.0. SMS is a pre- and post-processor for surface water modeling and analysis. SMS provides a graphical user interface to develop the two dimensional model and to visualize and analyze results.

5 Topography and Sources of Data

The model's topographic and hydrographic data were compiled from numerous sources. The majority of the topography and hydrographic data used for development of the model were derived from topographic and bathymetric surveys in 1999 performed by the Corps of Engineers, Sacramento District, and used in hydraulic analyses for the Sacramento-San Joaquin Rivers Comprehensive Study (Ayres, 2003).

Areas of improvements within the study area that would render the 1999 Comprehensive Study (Comp Study) topography obsolete were patched into the composite surface of the model to better represent conditions in the year 2011. These areas include: Shanghai Bend setback area, Shanghai Bend old levee degrade, Feather River setback area, old Feather River levee degrade, Star Bend (LD1) setback area, Star Bend (LD1) old levee degrade, the Bear River setback area, and the old Bear River levee degrade. In addition, MBK Engineers did not possess highresolution topography for the Sutter Bypass within the study area. CVFED (DWR, 2011) LIDAR and bathymetric data was used to generate a digital terrain surface in the lower Sutter Bypass.

The horizontal datum for the topography in the model is in North American Datum 1983, California State Plane Coordinate System, Zone 2. The vertical datum is National Geodetic Vertical Datum (NGVD) of 1929. Elevation data originally referenced in North America Vertical Datum (NAVD) 1988 was converted to NGVD 1929 by applying a conversion of 2.3 feet (HJW, 2010). The data and the original source's vertical datum are listed as follows (See Figure 1 for plan-view):

- Sacramento-San Joaquin Rivers Comprehensive Study (Corps, 2011) – NGVD 1929
- Shanghai Bend (DWR, 2010) - NAVD 1988
- Feather River Setback Design Drawings (GEI, 2007) - NGVD 1929
- Bear River Setback Design Drawings (GEI, 2007) - NGVD 1929
- Star Bend Setback Area and Borrow Pit As-Builts (Wood Rodgers, 2010) - NGVD 1929
- Feather River Setback Top-of-Levee Elevation (PSOMAS, 2010) - NGVD 1929
- Bear River Setback Top-of-Levee Elevation (PSOMAS, 2010) - NGVD 1929
- Sutter Bypass (DWR, 2010) - NAVD 1988

6 Hydraulic Model - Calibration

6.1 Mesh Development

A finite element mesh of the Sutter Bypass, Feather, Bear, and Yuba Rivers was developed using the SMS software. The finite element mesh consists of triangular and quadrilateral elements, which represent the topography and the roughness distribution in the study area.

The model's study area is referenced in river miles (RM) established by the Corps' Comprehensive Study. The study area begins at RM 28.7 on the Feather River and extends down the Feather River in the Sutter Bypass at RM 2.9. The Bear River was simulated from RM 4.75 to the Feather River confluence at RM 12.1. A short portion of the Yuba River was simulated up to RM 1.2.

The 2-D model was calibrated to the January 1997 flood event, as this flood event is the most recent event with significant amount of available hydrologic and hydraulic data. The extent of the finite element mesh used for calibration purposes is presented in Figure 2.

6.2 Calibration Boundary Conditions

The January 1997 flood event was simulated in the 2-D model under steady-state conditions. The 2-D model's boundary conditions were obtained from a HEC-RAS model developed by Peterson Brustad Inc. (PBI model) prepared for the Sutter-Butte Flood Control Agency as part of the "Feather River West Levee Rehabilitation Project." The PBI model is a recently improved version of the Corps' Sacramento River Comprehensive Study. The PBI model and the improvements made are documented in a technical memorandum entitled "Revised Design Water Surface Profiles for the Feather River West Levee Rehabilitation Project," June 2011 (PBI, 2011). The PBI model was reviewed by MBK Engineers and the findings and recommendations, with respect to the PBI model, are documented in a technical memorandum in Appendix A.

The input hydrology in the PBI model is synthetic inflow hydrographs developed by the Corps of Engineers for the Sacramento River Basins Comprehensive Study. Details on the development of the hydrology are documented by the Corps (2002). In summary, the synthetic inflow hydrographs in the PBI model is generated by the Shanghai Bend (SHY) storm centering. This centering focuses on the Feather River at Shanghai Bend with Yuba River emphasis.

Flow values and stage-elevation data were extracted from the HEC-RAS model at a single time-step that corresponded to the January 1997 flood event's maximum water surface profile. The upstream boundary conditions require a flow at the following locations:

- Feather River below Jack Slough at RM 28.75
- Yuba River at Western Pacific Railroad (WPRR) RM 1.23
- Bear River above Western Pacific Interceptor Canal (WPIC) RM 4.75
- Yankee Slough at Bear River RM 0.54
- WPIC at Bear River RM 0.06
- Sutter Bypass above Feather River RM 68.13

The model's most downstream boundary condition is on the Sutter Bypass above (upstream of) the Sacramento River at RM 61.83, and requires a peak stage boundary condition. Table 1 presents the boundary conditions used for the calibration.

Table 1. January 1997 Calibration Boundary Conditions

Boundary Condition[1]	Stage (feet-NGVD)	Peak flow (cfs)
Feather River Below Jack Slough RM 28.75	N/A	144,000
Yuba River at WPRR RM 1.23	N/A	167,400
Bear River Above WPIC RM 4.75	N/A	37,800
Yankee Slough at Bear River RM 0.54	N/A	400
WPIC at Bear River RM 0.06	N/A	-2,200
Sutter Bypass above Feather River RM 68.13	N/A	95,300
Sutter Bypass above Sacramento River RM 61.83	41.2	N/A

[1]Naming convention is in reference to the cross section location in the PBI Model and is named as 'River Reach Station.'

6.3 Calibration Process

Calibration of the model consists of adjusting the Manning's roughness coefficients, or Manning's 'n,' until the computed water surface elevation closely matched river stage gages and surveyed high-water marks. The available gages within the model domain are the Feather River at Yuba City Gage (YUB) and the Feather River near Nicolaus Gage (NIC). The surveyed high water mark elevations were collected by the Corps of Engineers on the Feather and Bear River following the January 1997 flood. Most of the high-water marks in the study reach were taken along the right bank of the Feather River and along the left bank of the Bear River.

Manning's roughness coefficients were first assigned to the finite elements based on 2011 aerial photography and detailed vegetation mapping performed by AECOM. The AECOM maps delineate the vegetation types within the study area as of 2011. Aerial photography captured in 1997 was then used to revise roughness coefficient assignments on mesh elements where significant vegetation changes have occurred between the 2011 AECOM mapping and the 1997 conditions.

The roughness coefficients for vegetation types were selected based on guidelines established by Chow (1959) and field survey verification of mapped vegetation. Calibration simulations were then performed to adjust the roughness coefficients within the ranges established by Chow (1959). Engineering judgment was applied in selecting the appropriate roughness coefficients to calibrate and their reasonable range of variance. Calibration was achieved when computed water surface elevations reasonably matched that of observed values.

To simulate head-loss across bridges, higher roughness coefficients were assigned at selected bridge crossings to model the losses that occur through the bridges. The head-losses across each bridge were reviewed in the PBI model for the 1997 flood event, 100-year event, and the 200-year event to determine their average head-losses. Calibration simulations were then performed in the Calibration Model and the bridge crossing's roughness values were adjusted until the 2-D model's computed head-loss across each bridge was within the ranges of loss as calculated in the PBI model.

Figures 3 through 5 show the calibrated roughness values for the Calibration Model and Table 2, below, tabulates the range of roughness values used. The roughness values range from 0.02 to 0.08.

Table 2. January 1997 Calibration Roughness Values

Description	Habitat Code	Range of Manning's 'n' Roughness
Channel Bed	--[1]	0.02 - 0.038
Annual Grassland and Savannah, also includes Tilled Fields and Pasture	ANG	0.03
Barren	BARREN	0.03

Table 2. January 1997 Calibration Roughness Values

Description	Habitat Code	Range of Manning's 'n' Roughness
Developed	DEV	0.03
Low Herbaceous Marsh	LHM	0.03
Open Urban Park	PARK	0.03
Open Water	OW	0.03
Open Water/Floating Aquatic	OWF	0.03
Perennial Grassland	PGR	0.03
Ruderal	RUD	0.03
Sutter Bypass - Agricultural Use	--[1]	0.03
Railroad Bridge and Embankment at Lower Yuba River	--[1]	0.03
Highway 70 on the Lower Bear River	--[1]	0.03
Highway 99 at Nicolaus on the Feather River	--[1]	0.03
Gravel Bar/Sand Bar	GBSB	0.035
High Herbaceous Marsh	HHM	0.035
Himalayan Blackberry Scrub	HBS	0.045
All Other Bridge Crossings	--[1]	0.045
Open Riparian Forest, Valley Oak Woodland	ORF	0.05
Orchard – Fallow	OFA	0.05
Short Tree Orchard	STO	0.05
Upland Scrub, Open Willow Scrub, Elderberry Scrub, Bramble	UPS	0.055
Dense Willow Scrub	DWS	0.065
Walnut Orchard	WOR	0.075
Dense Riparian Forest	DRF	0.08

[1]Unvegetated or agricultural areas with assigned roughness values do not reflect AECOM Vegetation Mapping. Roughness values assigned are for modeling design roughness values, bridge crossings, or assigned for model stability.

6.4 Calibration Results

The results of the calibration are presented in tabular format in Table 3. The calibration results of simulated water surface elevations were also plotted in profile along with the surveyed high-water marks. The alignments and stationing referenced in these plots are presented in plan-view on Figures 6 through 8. The corresponding profile plots are presented in Figures 9 through 13.

Computed values compare closely with the surveyed high-water marks and the majority of the computed water-surface elevation values fall within plus or minus one foot of the observed high-water marks. The computed water surface profile along the right bank of the Feather River from RM 7.8 to 28.7 is plotted with surveyed high-water marks on Figure 9. Similarly, other figures of water surface profiles plotted with surveyed high-water marks are shown on Figure 10 along the right-bank of the Yuba River (RM 0.3 to RM 1.2), Figure 11 along the left-bank of the Bear River (RM 0.3 to RM 4.75), Figure 12 along the left-bank of the Feather River (RM 2.9 to RM 12.2), and Figure 13 along the right-bank of the Sutter Bypass (RM 61.8 to RM 68.1). Calibration results corresponding to the high-water mark locations are presented in plan-view on Figures 14 through 16.

Table 3. January 1997 Calibration Results -- (feet-NGVD)

HWM	Observed	Computed	Difference (ft)	HWM	Observed	Computed	Difference (ft)
Right Bank Feather River							
Point 122	74.8	74.7	-0.1	RF23	62.3	62.1	-0.2
Point 123	75.1	74.6	-0.5	RF22	60.7	60.7	0.0
Point 124	74.8	74.6	-0.2	RF21	60.4	60.2	-0.2
Yuba City Gage	75.2	74.5	-0.7	RF20	59.1	59.6	0.5
Point 125	70.9	74.2	3.3	RF19	59.7	58.1	-1.6
Point 126	73.2	73.0	-0.2	RF18	48.9	56.9	8.0
Point 127	72.5	72.3	-0.2	RF17	52.8	56.0	3.2
Point 128	72.5	72.0	-0.5	RF16	54.5	54.6	0.1
Point 129	72.5	71.8	-0.7	RF15	53.1	54.0	0.9
Point 130	71.2	71.6	0.4	RF14	53.1	53.4	0.3
Point 131	70.5	69.8	-0.7	RF13	52.5	53.2	0.7
RF35	69.9	69.7	-0.2	RF12	52.2	52.9	0.7
RF34	69.6	69.4	-0.2	RF11	50.9	52.7	1.8
RF33	68.9	68.6	-0.3	RF10	49.2	52.6	3.4
RF32	67.6	67.4	-0.2	RF9	51.8	52.0	0.2
RF31	67.3	67.2	-0.1	RF8	49.9	50.9	1.0
RF30	66.3	66.0	-0.3	FR7	47.9	49.8	1.9

Table 3. January 1997 Calibration Results -- (feet-NGVD)

HWM	Observed	Computed	Difference (ft)	HWM	Observed	Computed	Difference (ft)
RF29	65.6	64.7	-0.9	RF6	47.2	49.1	1.9
RF28	64.3	63.9	-0.4	RF5	48.2	49.1	0.9
RF27	64.6	63.5	-1.2	RF4	48.6	48.8	0.2
RF26	62.0	62.7	0.7	RF3	47.2	47.5	0.3
RF25	63.3	62.6	-0.7	RF2	46.9	47.4	0.5
RF24	63.0	62.4	-0.6	RF1	46.6	47.1	0.5
Right Bank Sutter Bypass				**Left Bank Feather River (Upstream of Yuba River)**			
Point 207	44.6	44.8	0.2	Point 119	75.1	74.8	-0.3
Point 208	44.3	44.6	0.3	Point 118	74.8	74.6	-0.2
Point 209	44.0	44.6	0.6	Point 117	74.8	74.3	-0.5
Point 210	43.3	43.7	0.4	**Left Bank Bear River**			
Point 211	43.3	43.5	0.2	Point 90	56.8	58.6	1.8
Point 212	42.7	43.0	0.3	Point 89	57.4	57.8	0.4
Point 213	42.3	42.3	0.0	Point 88	55.1	57.6	2.5
Point 214	42.0	42.1	0.1	F34	55.8	56.9	1.1
Point 215	42.0	41.5	-0.5	F33	56.1	56.4	0.3
Left Bank Feather River				F32	55.1	55.2	0.1
F27	53.1	52.6	-0.6	F31	54.5	54.8	0.3
F26	51.2	52.2	1.0	F30	53.5	54.4	1.0
F25	51.2	51.9	0.7	F29	52.5	53.4	0.9
F24	43.0	51.1	8.1	F28	49.9	52.9	3.0
F23	48.6	50.6	2.0	**Right Bank Yuba River**			
F22	48.6	49.5	0.9	Point 115	77.8	74.6	-3.2
F21	45.3	49.4	4.1	Point 116	74.5	74.4	-0.1
F20	45.6	49.4	3.8				
F19	47.2	49.2	2.0				
F18	47.2	47.9	0.6				
Nicolaus Gage (F17)	47.2	46.8	-0.4				

Table 3. January 1997 Calibration Results -- (feet-NGVD)

HWM	Observed	Computed	Difference (ft)	HWM	Observed	Computed	Difference (ft)
F16	44.9	44.8	-0.1				
F15	44.0	44.6	0.6				
F14	42.7	43.8	1.1				
F13	43.3	47.3	4.0				
F12	41.3	43.6	2.3				
F11	39.0	42.4	3.4				
F9	42.0	42.9	0.9				
F-10	40.7	42.0	1.3				
F-8	41.7	41.7	0.0				
F7	41.0	41.5	0.5				
F-6	40.0	41.3	1.3				

Some of the larger differences between the observed water-surface elevation and the computed water-surface elevation in Table 3 (i.e. RF18) are likely due to the quality of the high water mark. High water mark staking is typically done after the flood event by visual observation and the quality of high water mark is dependent of the experience of the personnel collecting the data. An indicator of a high water mark is a debris line consisting of vegetation, mud, or actual water stain on the side of a bridge abutment or pier. Misinterpretation of the high water mark in the field can lead to high water marks that are much lower or higher than the actual peak water surface elevation. All of the high water marks that have been provided are shown in the tables, maps, and charts such that interpretation of which high water marks could be made by others.

7 Hydraulic Model - Baseline Condition

7.1 Mesh Development

A 2011 baseline condition model of the study area was developed to represent the vegetation condition, levee configurations and setback area topography as of 2011. Since 1997, various levees within the study area have been realigned and set back to improve floodway conveyance and levee stability. Following levee realignments, habitat improvements were constructed in setback areas with defined roughness coefficients based on approved vegetation plans. These design vegetation plans were approved by the Central Valley Flood Protection Board (CVFPB) as a component of the overall setback project design. Therefore, the roughness coefficients in setback areas do not necessarily reflect the 2011 vegetation types as mapped by AECOM. This deviation is intended to represent the effects of the approved design vegetation habitat. These areas are described as follows:

- Feather River Levee Setback Project
  The Feather River east levee from approximately RM 17.1 to 24.3 was set back. The survey performed for the Corp's Comp Study was initially used in the setback area. Design features were then appended to the Comp Study topography with As-Built elevations and design grade elevations. As-built elevations surveyed for the borrow pits, fish swales, and levee degrades were incorporated into the baseline condition model. Design grade elevations for the top-of-setback levee, toe-of setback levee, and stability berms were incorporated into the baseline model. The design roughness value in the setback area approved by the CVFPB is n = 0.1.

- Shanghai Bend Levee Setback Project
  The Shanghai Bend west levee from approximately RM 24.6 to RM 25.0 was setback following the January 1997 flood by the Corps of Engineers. CVFED LIDAR elevations were used in the baseline model for the setback area. Design roughness values for the setback area were not available, thus roughness coefficients were assigned according to the AECOM vegetation mapping with the exception to a small area behind the remnant levee. The area behind the remnant levees were causing instability during model simulation and a higher roughness value of n = 0.1 were assigned to remedy the issue. This area is relatively small when compared to the entire model and it is our opinion that the roughness value would not affect the overall calculated hydraulics of the study area.

- Star Bend Levee Setback Project
  The Star Bend west levee from approximately RM 17.0 to RM 18.1 was setback. The survey performed for the Corp's Comp Study was initially used in the setback area. Design features were then appended to the Comp Study topography with As-Built elevations. As-built elevations surveyed for the top-of-setback levee, toe-of setback levee, levee degrade, and borrow pits were incorporated into the baseline model. The design roughness value in the setback area approved by the CVFPB is n = 0.07 and was assigned in the baseline condition model.

- Bear River Setback Project
  The Bear River north levee from approximately RM 0.3 to RM 3.2 was setback. The survey performed for the Corp's Comp Study was used in the setback area floodplains. Design features were then appended to the Comp Study topography with As-Builts and design grades. As-built elevations surveyed for the top-of-setback levee were used in the baseline model. Design grade elevations for the toe-of-setback, stability berms, and drainage swale were incorporated into the baseline model. Two design roughness values were assigned in the setback area, n = 0.1 and n = 0.06 for the southerly and northerly reaches respectively of the Bear River.

For areas not in the levee setbacks, vegetation types assigned to those elements in the 1997 calibration model mesh were reverted to 2011 vegetation types according to the AECOM vegetation maps. Roughness values determined from the calibration process were assigned to the baseline mesh's vegetation types.

These processes discussed in this Section compose the single baseline condition model. The extents of the finite element mesh for baseline conditions are presented in Figure 17. Figures 18 through 20 show the roughness values for the finite element mesh in the baseline model.

Table 4. 2011 Baseline Roughness Values

Description	Habitat Code	Range of Manning's 'n' Roughness
Channel Bed	--[1]	0.02 - 0.038
Annual Grassland and Savannah, also includes Tilled Fields and Pasture	ANG	0.03
Barren	BARREN	0.03
Developed	DEV	0.03
Low Herbaceous Marsh	LHM	0.03
Open Urban Park	PARK	0.03
Open Water	OW	0.03
Open Water/Floating Aquatic	OWF	0.03
Perennial Grassland	PGR	0.03
Ruderal	RUD	0.03
Sutter Bypass - Agricultural Use (field crops)	--[1]	0.03
Railroad Bridge and Embankment at Lower Yuba River	--[1]	0.03
Highway 70 on the Lower Bear River	--[1]	0.03
Highway 99 at Nicolaus on the Feather River	--[1]	0.03
Gravel Bar/Sand Bar	GBSB	0.035
High Herbaceous Marsh	HHM	0.035
Himalayan Blackberry Scrub	HBS	0.045
All Other Bridge Crossings	--[1]	0.045
Open Riparian Forest, Valley Oak Woodland	ORF	0.05
Orchard – Fallow	OFA	0.05
Short Tree Orchard	STO	0.05
Upland Scrub, Open Willow Scrub, Elderberry Scrub, Bramble	UPS	0.055
Bear River Setback Area - Upper Setback Area Design Conditions	--[1]	0.06
Dense Willow Scrub	DWS	0.065

Table 4. 2011 Baseline Roughness Values

Description	Habitat Code	Range of Manning's 'n' Roughness
Bear River Setback Area - Lower Setback Area Design Conditions	--[1]	0.07
LD1 Setback Area - Design Conditions	--[1]	0.07
Walnut Orchard	WOR	0.075
Dense Riparian Forest	DRF	0.08
Feather River Setback Area - Design Conditions	--[1]	0.10
Bear River Setback Area - Lower Setback Area Design Conditions	--[1]	0.10
Shanghai Bend - Areas behind Remnant Levee	--[1]	0.10

[1]Unvegetated or agricultural areas with assigned roughness values does not reflect AECOM Vegetation Mapping. Roughness values assigned are for modeling design roughness values, bridge crossings, or assigned for model stability.

7.2 Boundary Conditions

The baseline condition is simulated with two Annual Exceedance Probability (AEP) hydrologies and the 1957 Corps' SRFCP Design Flow. The two AEP hydrologies are the 1-in-100 AEP and the 1-in-200 AEP. The AEP hydrologies and the SRFCP Design Flows were then further subdivided into two hypothetical flow centerings to emphasize the models on the upper reaches of the Feather River (Upper Feather Centering) and the lower reaches of the Feather River (Lower Feather Centering). They are identified as follows:

- 1-in-100 AEP – Upper Feather Centering
- 1-in-100 AEP – Lower Feather Centering
- 1-in-200 AEP – Upper Feather Centering
- 1-in-200 AEP – Lower Feather Centering
- 1957 SRFCP Design Flow – Upper Feather Centering
- 1957 SRFCP Design Flow – Lower Feather Centering

The boundary conditions associated with the AEP hydrologies were obtained from the PBI model as discussed in Section 6.2. Flow values and stage-elevation data were extracted from the PBI model at time-steps that corresponded to the event's maximum water-surface profile at the Upper Feather Centering and the Lower Feather Centering.

The boundary conditions used in the 2-D model for the 1-in-100 AEP and 1-in-200 AEP are tabulated in Tables 5 through 8. The flow boundary conditions for the Upper Feather Centerings were extracted from the PBI model at a single time-step that yielded the maximum water surface elevations along the lower reaches of the Yuba River and the upper reaches of the Feather River. Similarly, flow and stage boundary conditions were extracted from the PBI model at a single time-step that yielded the maximum water-surface elevations at the lower reaches of the Bear River, lower reaches of the Feather River, and the lower reaches of the Sutter Bypass. In general, the maximum water-surface elevations in their reaches corresponded with their maximum flows.

Positive flow boundary conditions indicate flow direction into the model boundary. Negative flow boundary conditions indicate flow direction away from the model boundary. In other words, the negative flow boundary conditions represent flow reversal from the model boundary back into the tributary. Negative flow conditions exist in the WPIC at the Bear River during the Upper Centerings of the 1-in-100 AEP and the 1-in-200 AEP. Negative flow conditions also exist in Yankee Slough at the Bear River during the 1-in-200 AEP Upper Feather Centering.

Table 5. 1-in-100 AEP Flood Upper Feather Centering Boundary Conditions

Boundary Condition[1]	Stage (feet-NGVD)	Peak flow (cfs)
Feather River Below Jack Slough RM 28.75	N/A	130,100
Yuba River at WPRR RM 1.23	N/A	154,600
Bear River Above WPIC RM 4.75	N/A	37,000
Yankee Slough at Bear River RM 0.54	N/A	0
WPIC at Bear River RM 0.06	N/A	-6,100
Sutter Bypass above Feather River RM 68.13	N/A	94,000
Sutter Bypass above Sacramento River RM 61.83	41.5	N/A

Table 6. 1-in-100 AEP Flood Lower Feather Centering Boundary Conditions

Boundary Condition[1]	Stage (feet-NGVD)	Peak flow (cfs)
Feather River Below Jack Slough RM 28.75	N/A	162,900
Yuba River at WPRR RM 1.23	N/A	91,500
Bear River Above WPIC RM 4.75	N/A	28,100
Yankee Slough at Bear River RM 0.54	N/A	0
WPIC at Bear River RM 0.06	N/A	6,200
Sutter Bypass above Feather River RM 68.13	N/A	164,000
Sutter Bypass above Sacramento River RM 61.83	43	N/A

Table 7. 1-in-200 AEP Flood Upper Feather Centering Boundary Conditions

Boundary Condition[1]	Stage (feet-NGVD)	Peak flow (cfs)
Feather River Below Jack Slough RM 28.75	N/A	160,100
Yuba River at WPRR RM 1.23	N/A	199,800
Bear River Above WPIC RM 4.75	N/A	46,500
Yankee Slough at Bear River RM 0.54	N/A	0
WPIC at Bear River RM 0.06	N/A	-8,400
Sutter Bypass above Feather River RM 68.13	N/A	141,000
Sutter Bypass above Sacramento River RM 61.83	43.8	N/A

Table 8. 1-in-200 AEP Flood Lower Feather Centering Boundary Conditions

Boundary Condition[1]	Stage (feet-NGVD)	Peak flow (cfs)
Feather River Below Jack Slough RM 28.75	N/A	190,000
Yuba River at WPRR RM 1.23	N/A	109,300
Bear River Above WPIC RM 4.75	N/A	39,500
Yankee Slough at Bear River RM 0.54	N/A	600
WPIC at Bear River RM 0.06	N/A	3,400
Sutter Bypass above Feather River RM 68.13	N/A	217,600
Sutter Bypass above Sacramento River RM 61.83	45	N/A

[1]Naming convention is in reference to the cross-section location in the PBI Model and is named as 'River Reach Station'

The flow boundary conditions associated with the SRFCP Design Flows were developed using a flow balance approach at each centering. The upper Feather River centering's flow boundary conditions are determined by balancing the system's flows with respect to the Yuba River. The lower Feather River centering's flow boundary conditions are determined by balancing the system's flows with respect to the Bear River. The most downstream stage boundary condition is determined by extracting the design water-surface elevation from the 1957 project design flood plane. The 1957 project design flood plane required a conversion factor of -3 feet. This was necessary to convert the US Corps Engineers Datum (USED) to NGVD 1929. The boundary conditions used in the 2-D model for the 1957 SRFCP Design Flows are tabulated in Tables 9 and 10.

Table 9. 1957 SRFCP Design Flow Upper Feather Centering Boundary Conditions

Boundary Condition[1]	Stage (feet-NGVD)	Peak flow (cfs)
Feather River Below Jack Slough RM 28.75	N/A	210,000
Yuba River at WPRR RM 1.23	N/A	90,000
Bear River Above WPIC RM 4.75	N/A	20,000
Yankee Slough at Bear River RM 0.54	N/A	0
WPIC at Bear River RM 0.06	N/A	0
Sutter Bypass above Feather River RM 68.13	N/A	60,000
Sutter Bypass above Sacramento River RM 61.83	40.5	N/A

Table 10. 1957 SRFCP Design Flow Lower Feather Centering Boundary Conditions

Boundary Condition[1]	Stage (feet-NGVD)	Peak flow (cfs)
Feather River Below Jack Slough RM 28.75	N/A	210,000
Yuba River at WPRR RM 1.23	N/A	70,000
Bear River Above WPIC RM 4.75	N/A	40,000
Yankee Slough at Bear River RM 0.54	N/A	0
WPIC at Bear River RM 0.06	N/A	0
Sutter Bypass above Feather River RM 68.13	N/A	60,000
Sutter Bypass above Sacramento River RM 61.83	40.5	N/A

1Naming convention is in reference to the cross-section location in the PBI model and is named as 'River Reach Station'

7.3 Baseline Condition Results

Water- surface elevation profiles from the 2-D model were plotted with their corresponding top-of-levee elevations. These plots display the water surface elevations at baseline conditions for the 1-in-100 AEP, 1-in-200 AEP, and the 1957 SRFCP Design Flow. The alignments and stationing for these plots are presented in plan-view on Figures 21 through 23. The profile plots are presented on Figures 24 through 47. The 2-D model's calculated water surface elevations were converted from NGVD 29 to NAVD 88 by applying a +2.3 feet conversion. The profile plots are referenced to NAVD 88. Velocity contours calculated for the baseline condition during the 1-in-100 AEP, 1-in-200 AEP, and 1957 SRFCP Design Flows are plotted in Figures 48 through 65.

In general, velocity magnitudes range from 0 to 15 feet per second (fps) with relatively higher velocities occurring in and around areas of transitioning flow regimes. These areas are typically at: the interfaces between the floodplain and the main channel, around remnant levees, around maintenance and boat launching ramps, and major grade transitions in the channel (jumps and drops) and within the floodplain.

During the 1-in-100 AEP, the Feather River levees (RM 2.9 to 28.7) has freeboard ranging from 5 feet to 8 feet and the Bear River levees (RM 0.3 to 4.75) has freeboard ranging from 5 feet to 7 feet. During the 1-in-200 AEP, the Feather River levees (RM 2.0 to 28.7) has freeboards ranging from 3 feet to 6 feet, with less than 3 feet of freeboard occurring between approximately RM 17 and Wilkie Avenue on the right (west) levees of the Feather River. During the 1-in-200 AEP, the Bear River levees (RM 0.3 to 4.75) has freeboard ranging from 3 feet to 6, feet with less than 3 feet freeboards occurring upstream of the WPIC to approximately RM 4.

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Appendix A

Feather River 2-D Model
Boundary Condition Source Determination

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TECHNICAL MEMORANDUM

DATE: December 7, 2011

SUBJECT: Determination of Sources of Feather River 2-D Model Boundary Condition Data

Prepared by: Michael Archer, P.E.

Reviewed by:

The purpose of this Technical Memorandum is to document the source of the boundary condition data for a proposed 2-dimensional (2-d) hydraulic simulation model of the Feather River from the Yuba River to the Sutter Bypass.

The 2-d model will be a steady state model. The elevation data in the 2-d model will be referenced to the National Geodetic Vertical Datum of 1929 (NGVD29). The locations of the 2-d model boundaries and corresponding hydraulic parameters are summarized in Table 1.

Table 1. 2-d Model Boundary Conditions

Location	Parameter
Feather River below Jack Slough (RM 28.75)	Flow
Yuba River at WPRR (RM 1.23)	Flow
Bear River above UP Interceptor (RM 4.75)	Flow
Yankee Slough at Bear River (RM 0.54)	Flow
UP Interceptor at Bear River (RM 0.06)	Flow
Sutter Bypass above Feather River (RM 68.13)	Flow
Sutter Bypass above Sacramento River (RM 61.83)	Stage
RM = Comp Study[1] river mile	

Boundary conditions are needed for the following simulations:

- Calibration (January 1997 flood event),
- Verification (January 2006 flood event),
- 100-year flood event,
- 200-year flood event,

None of the flow boundaries are located at or near gages that report flows, and the downstream stage boundary is not located at or near a gage. Therefore, another source of boundary condition data is needed for the calibration and verification simulations. There are a number of 1-dimensional (1-d) hydraulic simulation models that cover the 2-d model study area that have

[1] Sacramento and San Joaquin River Basins Comprehensive Study

been used to simulate the 1997 and 2006 flood events. Computed data from a 1-d model could be used to define the boundary conditions of the 2-d model. The following 1-d models were reviewed to determine which would be the best source of boundary condition data for the calibration, verification, 100-year and 200-year simulations.

1. MBK Feather River HEC-RAS model, version 10 (MBK Model)
2. USACE Sacramento River HEC-RAS model, release 3 (USACE Model)
3. PBI Feather River-Sutter Bypass HEC-RAS model (PBI Model)

Model Descriptions

MBK Model

The MBK Model is a modified version of USACE Feather River HEC-RAS model that was originally developed in 2003 for the Lower Feather River Floodplain Mapping Study. Elevations in the MBK Model are referenced to the NGVD29 vertical datum. The MBK Model was calibrated with January 1997 flood event. The January 2006 flood event has not yet been simulated with the MBK Model.

The MBK model has been used for design and hydraulic impact analyses for levee improvement projects by the Three Rivers Levee Improvement Authority. 100-year and 200-year flood simulations have been made for both the Feather River at Shanghai Bend storm centering (Shanghai Centering) and the Bear River storm centering.

USACE Model

The USACE Model is a HEC-RAS version of Comp Study Sacramento River UNET model (without Butte Basin). Elevations have been converted to North American Vertical Datum of 1988 (NAVD88) using values determined for USACE by HJW GeoSpatial, Inc. The USACE Model was calibrated with January 1997 flood event and verified with the January 2006 flood event.

The hypothetical N-year simulations provided with the USACE Model do not include the Feather River at Shanghai Bend hydrologic centering (Shanghai Centering), only the Sacramento River at latitude of Sacramento centering (Sacramento Centering), and assume that levees overtop without failing.

PBI Model

The PBI Model is a modified version of the USACE Model. Elevations are referenced to the NAVD88 vertical datum. The PBI Model was calibrated with January 1997 flood event and verified with the January 2006 flood event.

The following hypothetical N-year simulations were provided with the PBI Model:

- 100-year; Shanghai Centering; levees overtop without failing.
- 200-year; Shanghai Centering; levees overtop without failing.
- 500-year; Shanghai Centering; levees overtop without failing.

Review of Calibration of Selected Models

The USACE and PBI models simulated both the 1997 and 2006 flood events for their calibration and verification. The MBK model has currently only simulated the 1997 event for calibration.

Since the 1-d model is only going to be used to define the steady state boundary conditions for the 2-d model, the key comparisons are the computed flows near the upstream boundaries and the computed stage near the downstream boundary. Computed peak flows from 1997 and 2006 flood simulations from each of the 1-d models are compared to available observed peak flows in Table 2. Computed peak stages from 1997 and 2006 flood simulations in the vicinity of the 2-d model downstream boundary from each of the 1-d models are compared to available observed peak stage data in Table 3. Profile plots of the vicinity of the 2-d model downstream boundary showing the computed and observed peak stages from the 1997 and 2006 flood simulations are provided in Figures 1 and 2. All of the models do a reasonable job of reproducing the observed value.

Table 2. Computed Peak Flows From 1-d Models At or Near 2-d Model Upstream Boundaries

			USACE Model		PBI Model		MBK Model	
Location	Flood Event	Observed Peak Flow (cfs)	Computed Peak Flow (cfs)	% Diff from Observed	Computed Peak Flow (cfs)	% Diff from Observed	Computed Peak Flow (cfs)	% Diff from Observed
Feather River near Gridley (RM 50.6)	1997	163,000	158,000	-3.1%	157,900	-3.1%	158,100	-3.0%
	2006	87,500	80,600	-7.9%	80,600	-7.9%	n/a	n/a
Yuba River at Marysville (RM 6.0)	1997	161,000	168,400	4.6%	166,800	3.6%	162,400	0.9%
	2006	114,000	123,100	8.0%	121,100	6.2%	n/a	n/a
Bear River at Wheatland (RM 11.5)	1997	34,900	32,700	-6.3%	32,700	-6.3%	34,200	-2.0%
	2006	36,400	35,800	-1.6%	35,800	-1.6%	n/a	n/a

Table 3. Computed Peak Stages From 1-d Models in Vicinity of 2-d Model Downstream Boundary

				USACE Model		PBI Model		MBK Model	
Flood Event	Type	Location (Comp Study River Mile)	Observed Peak Elevation (ft NGVD29)	Computed Peak Elevation (ft NGVD29)	Diff from Observed (ft.)	Computed Peak Elevation (ft NGVD29)	Diff from Observed (ft.)	Computed Peak Elevation (ft NGVD29)	Diff from Observed (ft.)
1997	Gage[1]	68.1	44.8	46.2	1.4	46.2	1.4	44.9	0.1
	HWM	62.57	41.9	42.4	0.5	42.7	0.8	41.6	-0.3
	HWM	61.63	41.4	41.9	0.5	42.3	0.9	41.2	-0.2
	HWM	61.43	41.1	41.8	0.7	42.2	1.1	41.1	0
	Gage[2]	58.9	40.2	40.4	0.2	40.6	0.4	39.7	-0.5
	Gage[3]	58.5	40.1	40.4	0.3	40.6	0.5	39.7	-0.4
2006	Gage[1]	68.1	41.4	41.5	0.1	41.5	0.1	n/a	n/a
	Gage[2]	58.9	36.7	36.3	-0.4	36.5	-0.2	n/a	n/a
	Gage[3]	58.5	36.5	36.3	-0.2	36.5	0	n/a	n/a

1 Willow Slough near Nicolaus (DWR A02943)
2 Sutter Bypass at RD1500 Pump Plant near Karnak (DWR A02927)
3 Sacramento Sl nr Karnak (DWR A02925)

Other Factors

The USACE model release only included simulations of the Sacramento Centering hydrology. The peak stages and flows on the Feather River occur with the Shanghai Centering.

In the PBI and USACE models, the elevations for Yuba River lateral structure 8.0, which represents the right levee upstream of Marysville, were not converted from NGVD29 vertical datum to NAVD88 along with the rest of the model geometry. The elevations for this lateral structure in the PBI and USACE models are the same as those in the MBK model which is in NGVD29 vertical datum. As a result the elevations are approximately 2.3 feet too low, which allows for excess water to escape the Yuba River on the right bank upstream of Marysville that may otherwise stay in the river.

Recommendation

All of the models would be a satisfactory source of boundary condition data for the Feather River 2-d model. However, due to the additional refinement in the Feather River and Sutter Bypass and the availability of Shanghai Centering simulations, the recommendation is to use the PBI model with Yuba River lateral structure 8.0 corrected to vertical datum NAVD88.

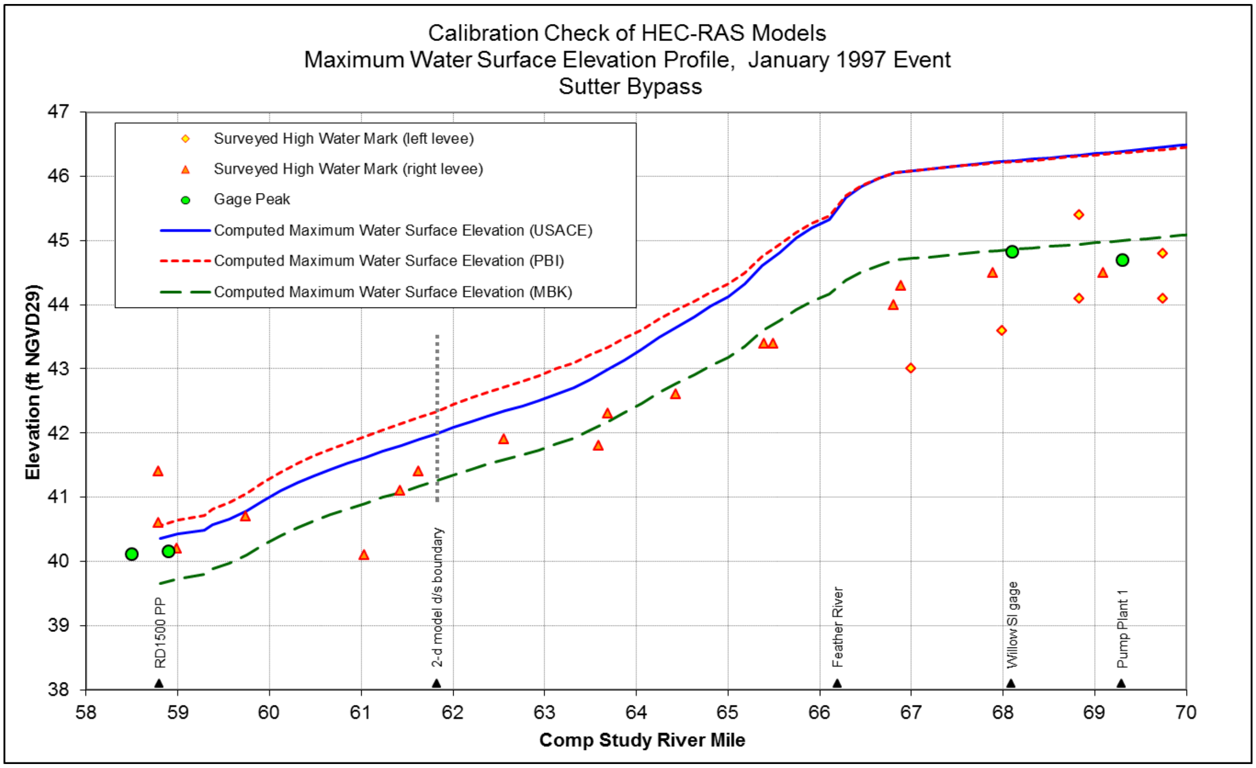


Figure 1. January 1997 Calibration Simulation Maximum Water Surface Elevation – Sutter Bypass

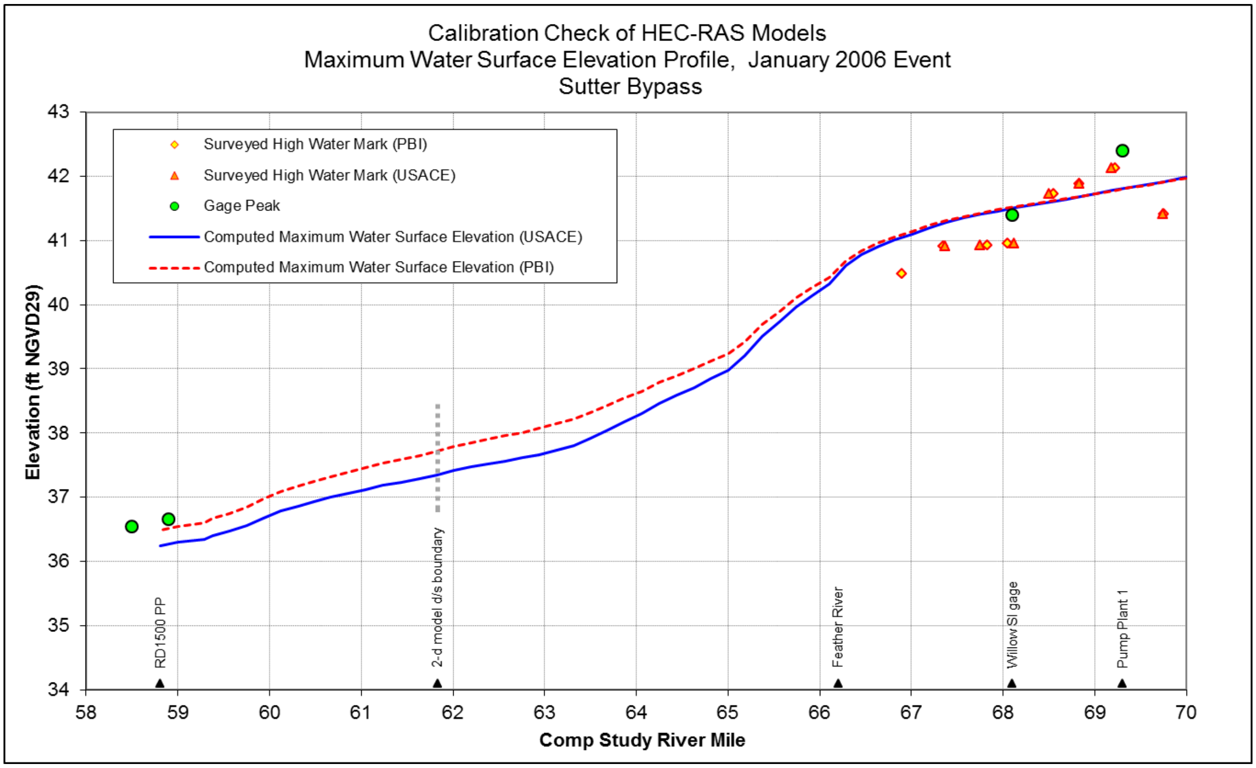
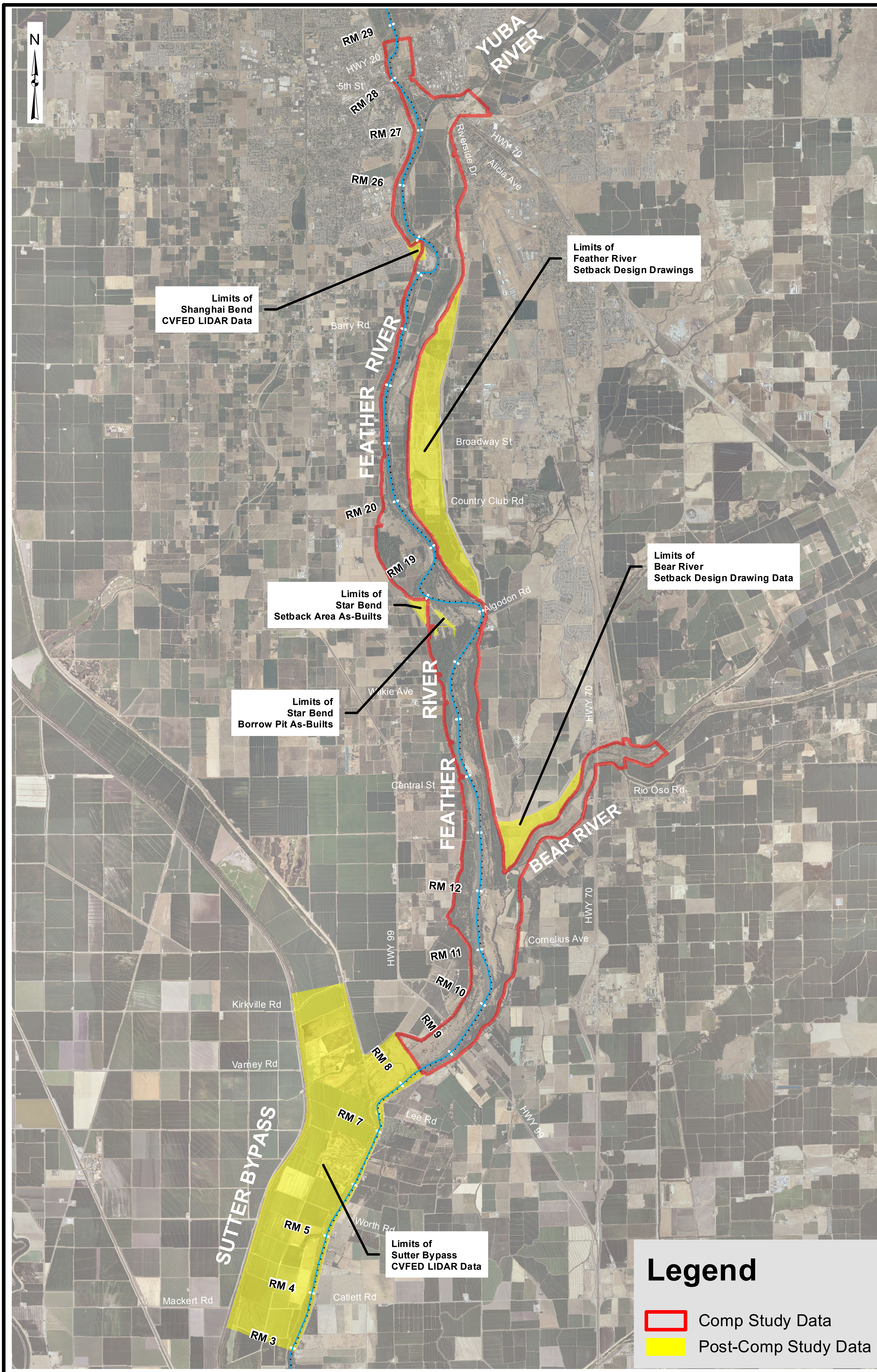


Figure 2. January 2006 Calibration Simulation Maximum Water Surface Elevation – Sutter Bypass

Figures



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Topographic Data Limits

0 8,000
Scale in Feet

Figure 1

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RMA2 Model - 1997 Calibration
Finite Element Mesh

0 8,000
Scale in Feet

Figure 2

Friday, January 06, 2012
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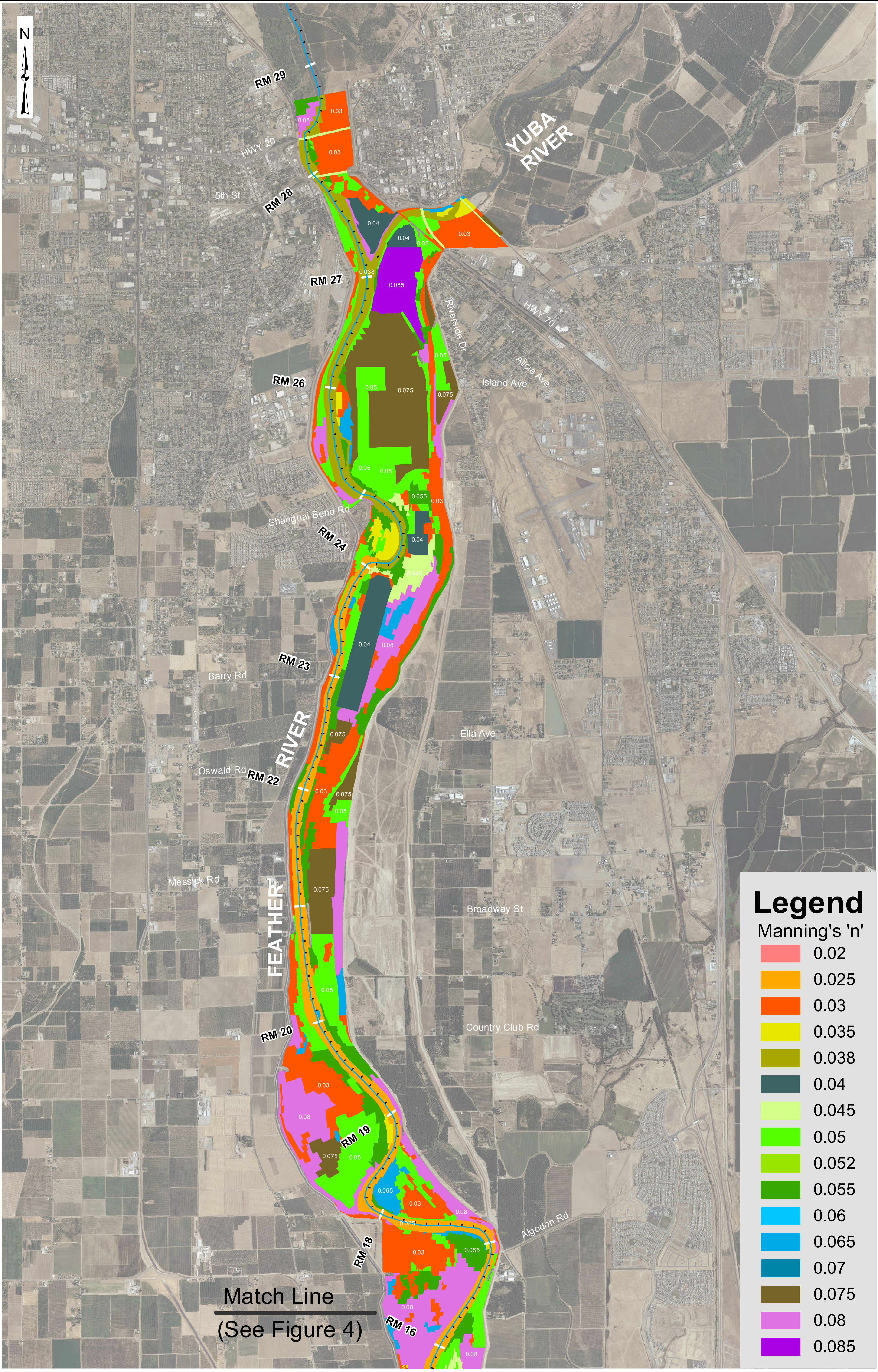

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RMA2 Model - 1997 Calibration Roughness Values

0 4,000
Scale in Feet

Figure 3

Thursday, January 05, 2012
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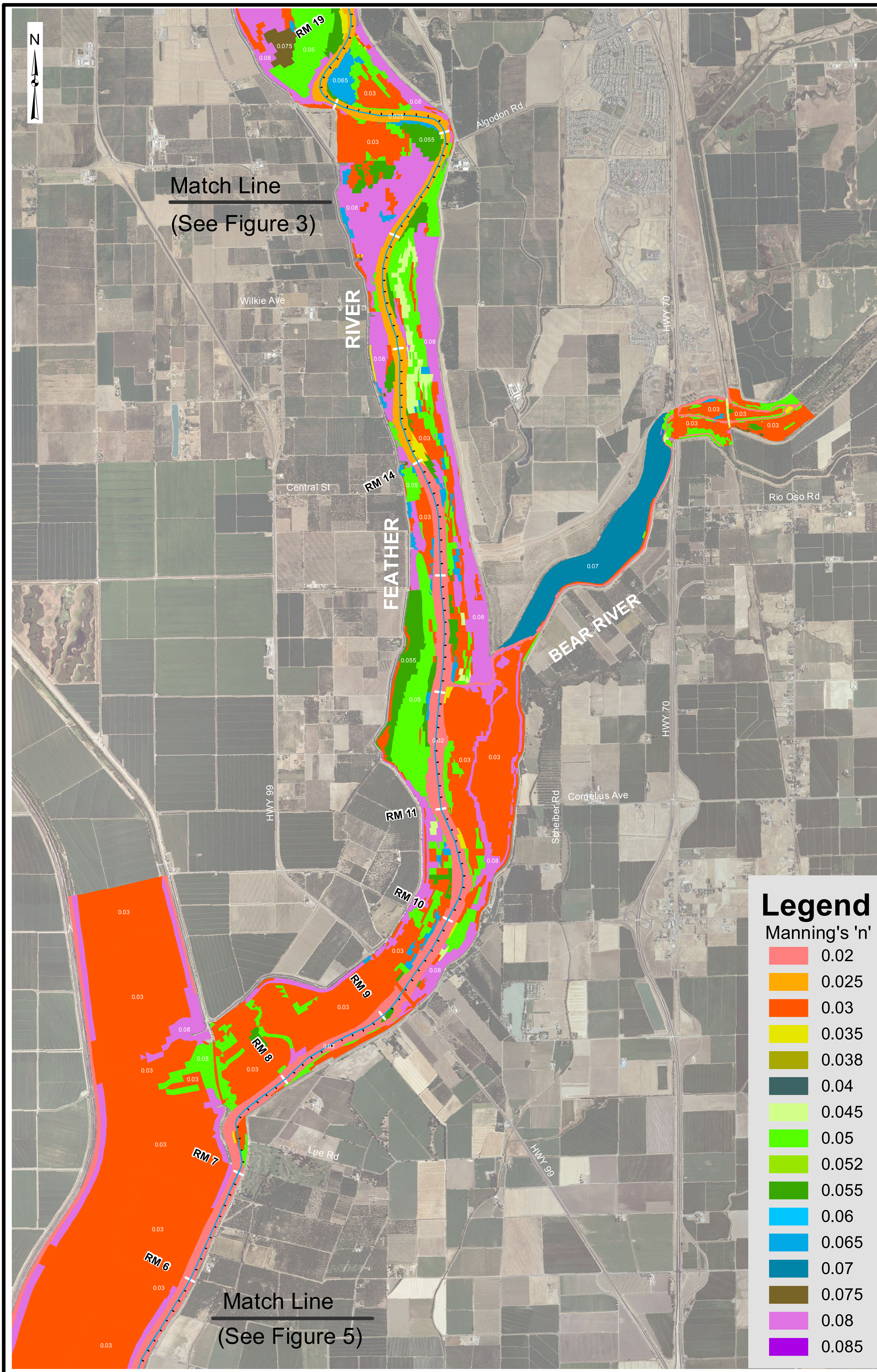

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RMA2 Model - 1997 Calibration
Roughness Values

Figure 4

Thursday, January 05, 2012
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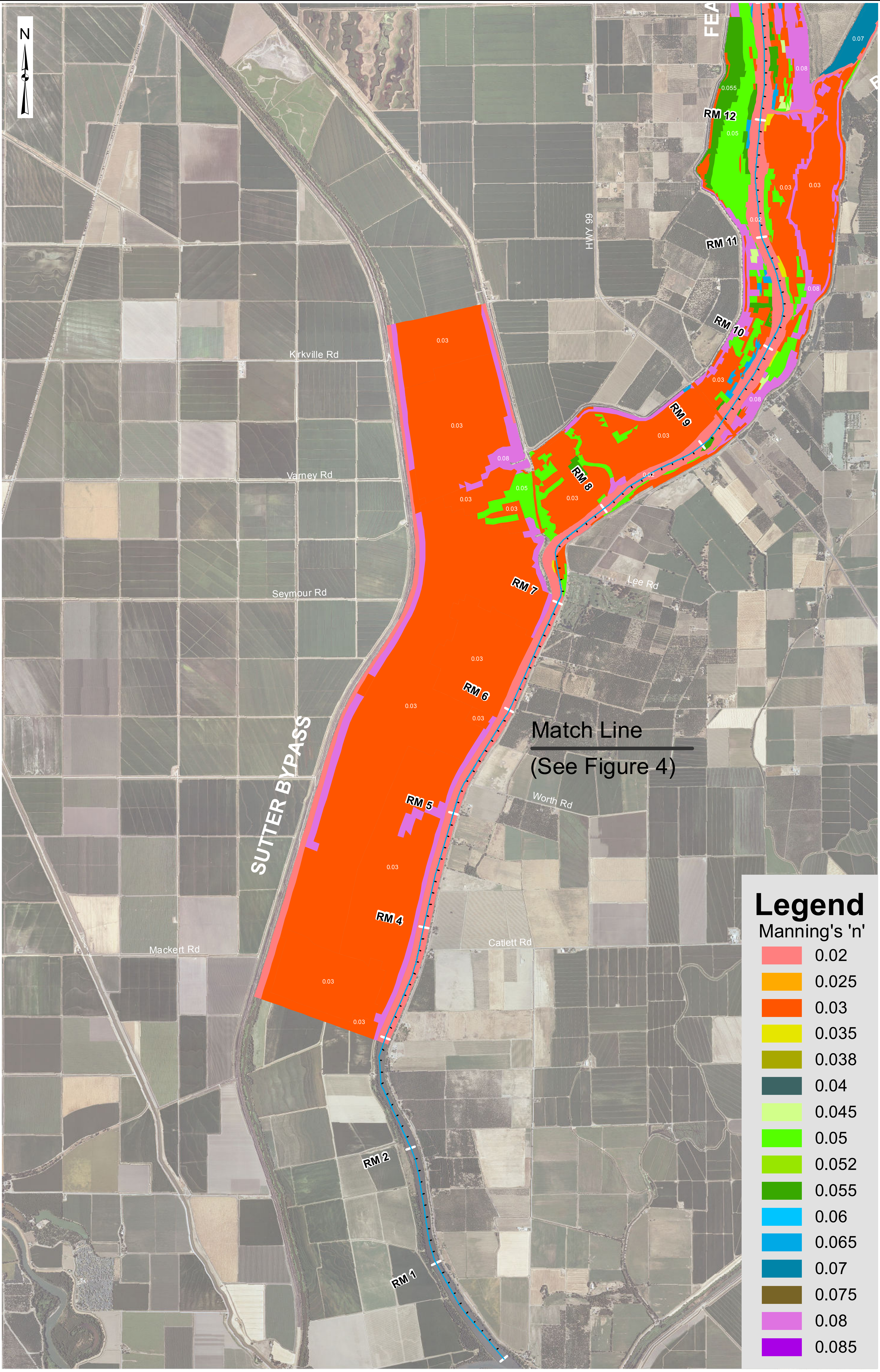

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RMA2 Model - 1997 Calibration Roughness Values

0 4,000
Scale in Feet

Figure 5

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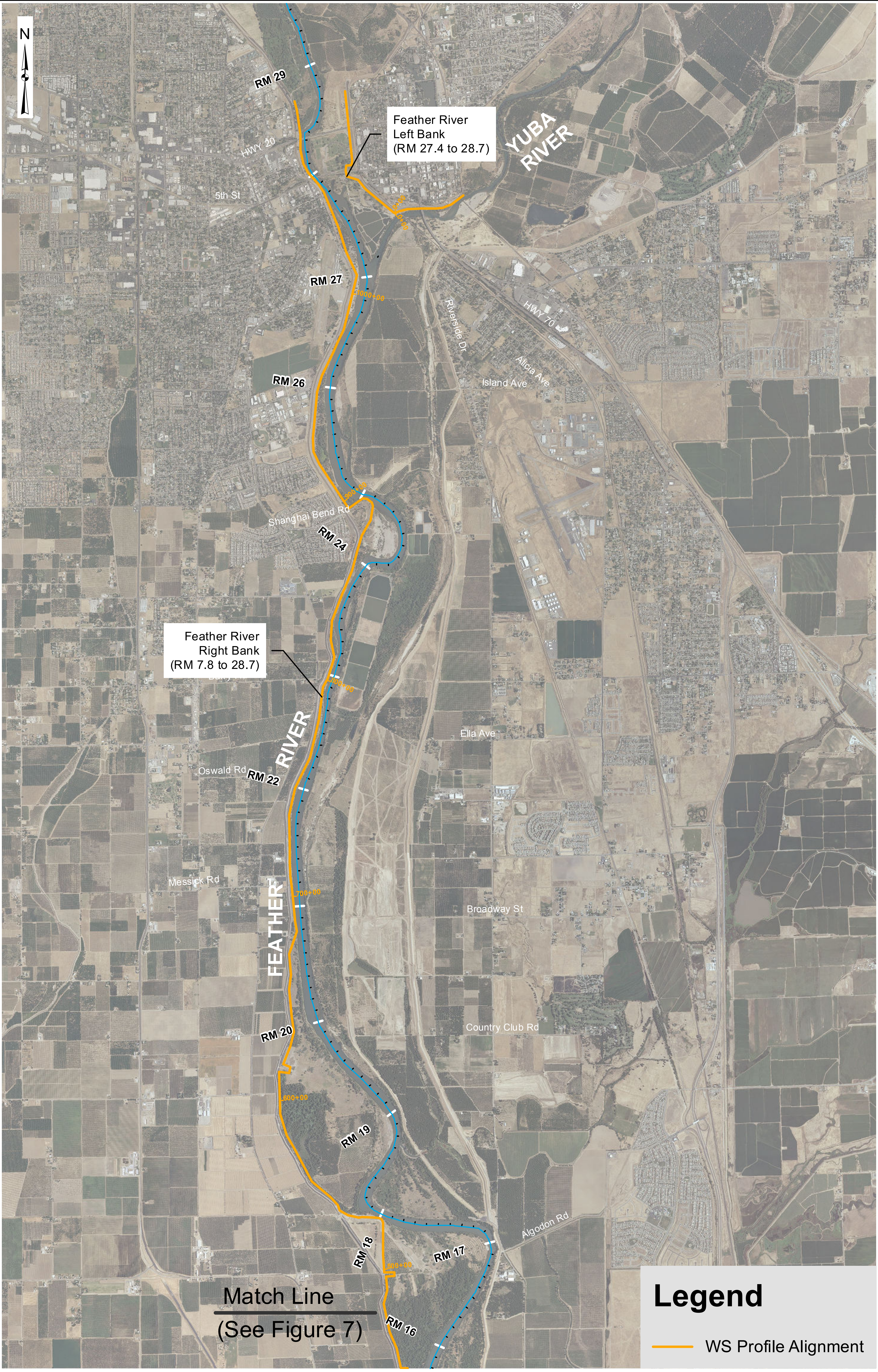

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RMA2 Model - 1997 Calibration
Water Surface Profile Alignments

0 4,000
Scale in Feet

Figure 6

Thursday, January 05, 2012
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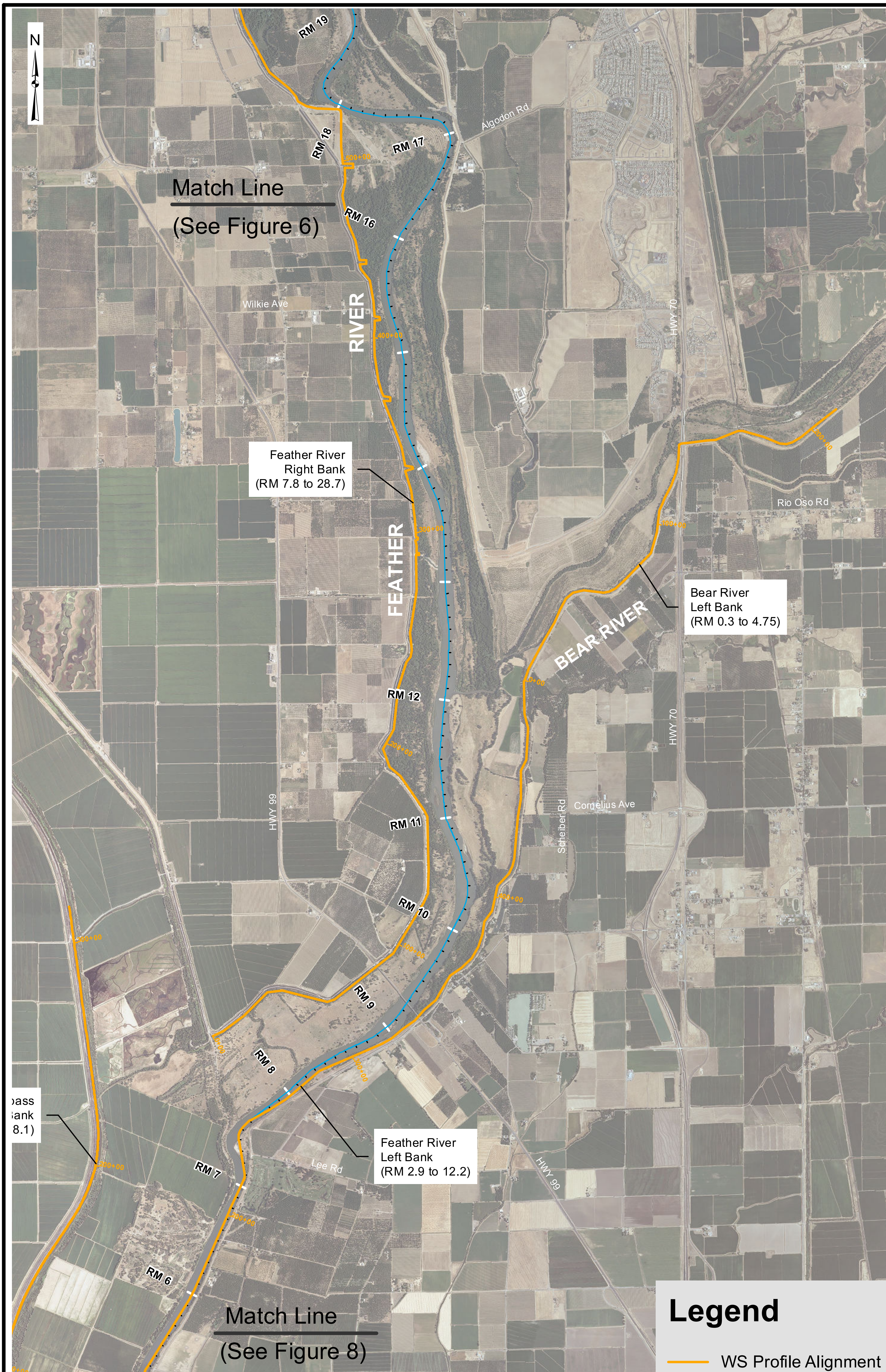

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RMA2 Model - 1997 Calibration
Water Surface Profile Alignments

0 4,000
Scale in Feet

Figure 7

Thursday, January 05, 2012
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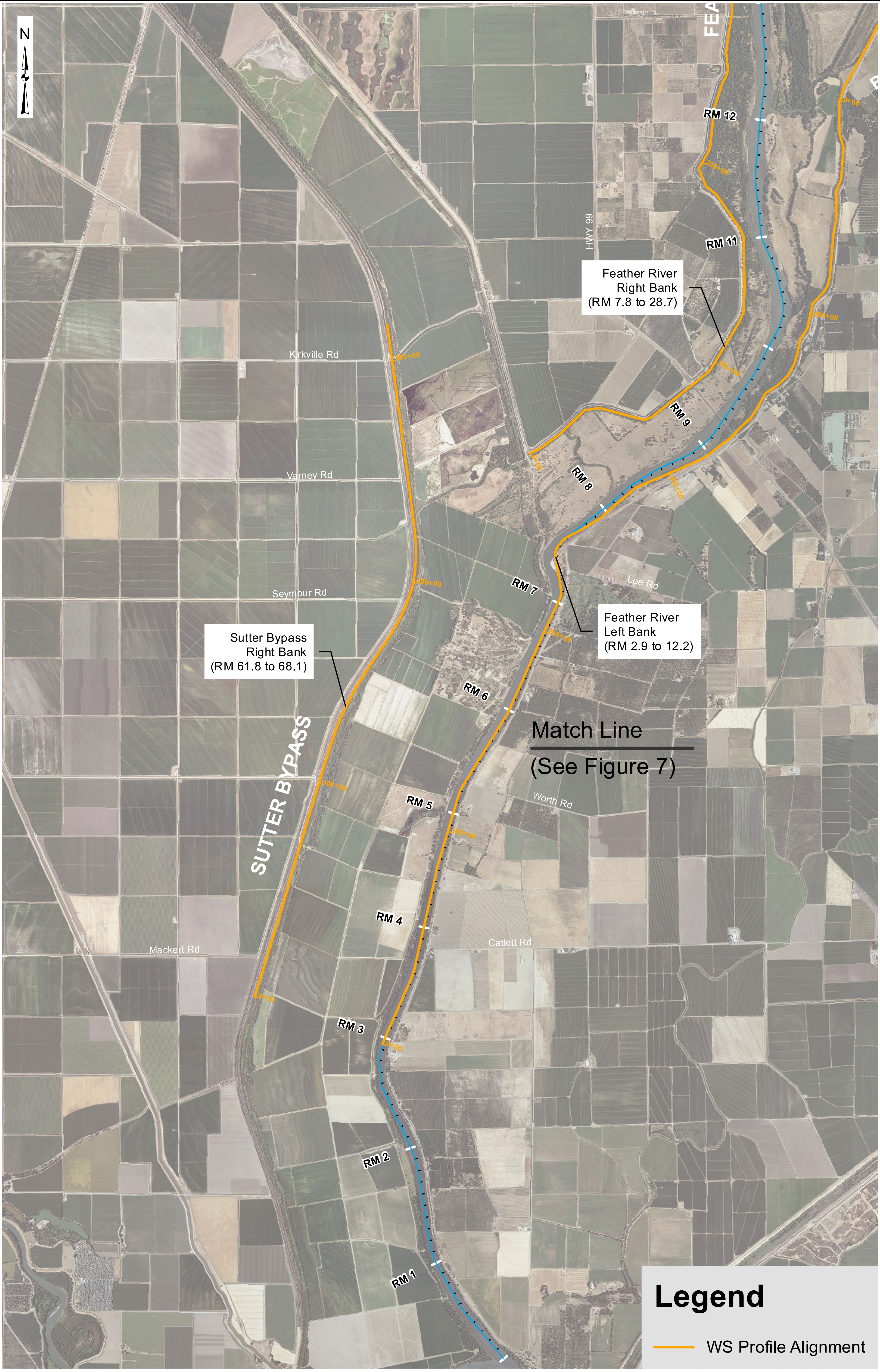

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RMA2 Model - 1997 Calibration
Water Surface Profile Alignments

0 4,000
Scale in Feet

Figure 8

Thursday, January 05, 2012
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Figure 9
Feather River - Right Bank (RM 7.8 to 28.7)
Maximum Water Surface Profile (2-D Model) - January 1997 Calibration

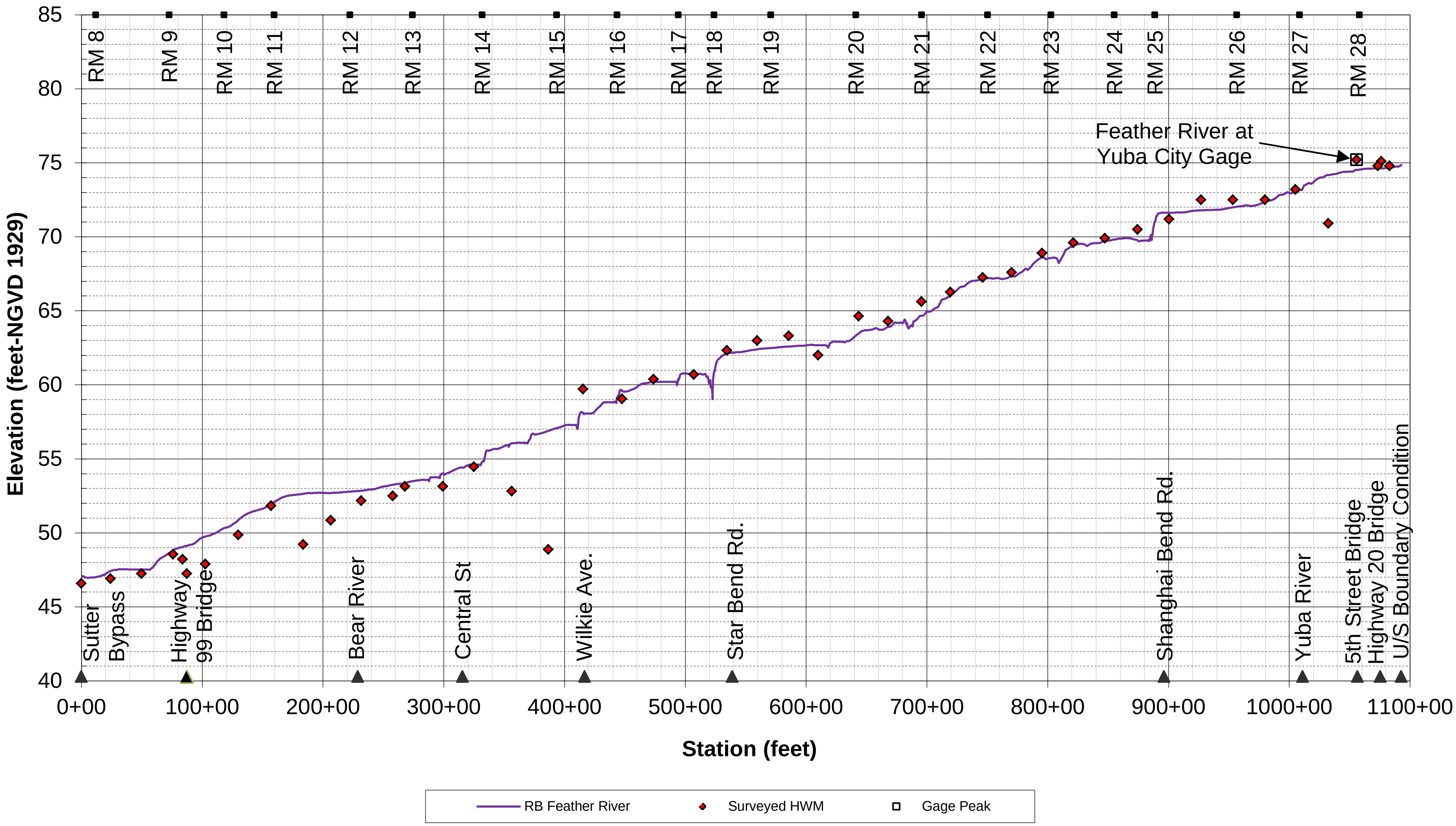

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Figure 10
Yuba River - Right Bank (RM 0.3 to 1.2)
Maximum Water Surface Profile (2-D Model) - January 1997 Calibration

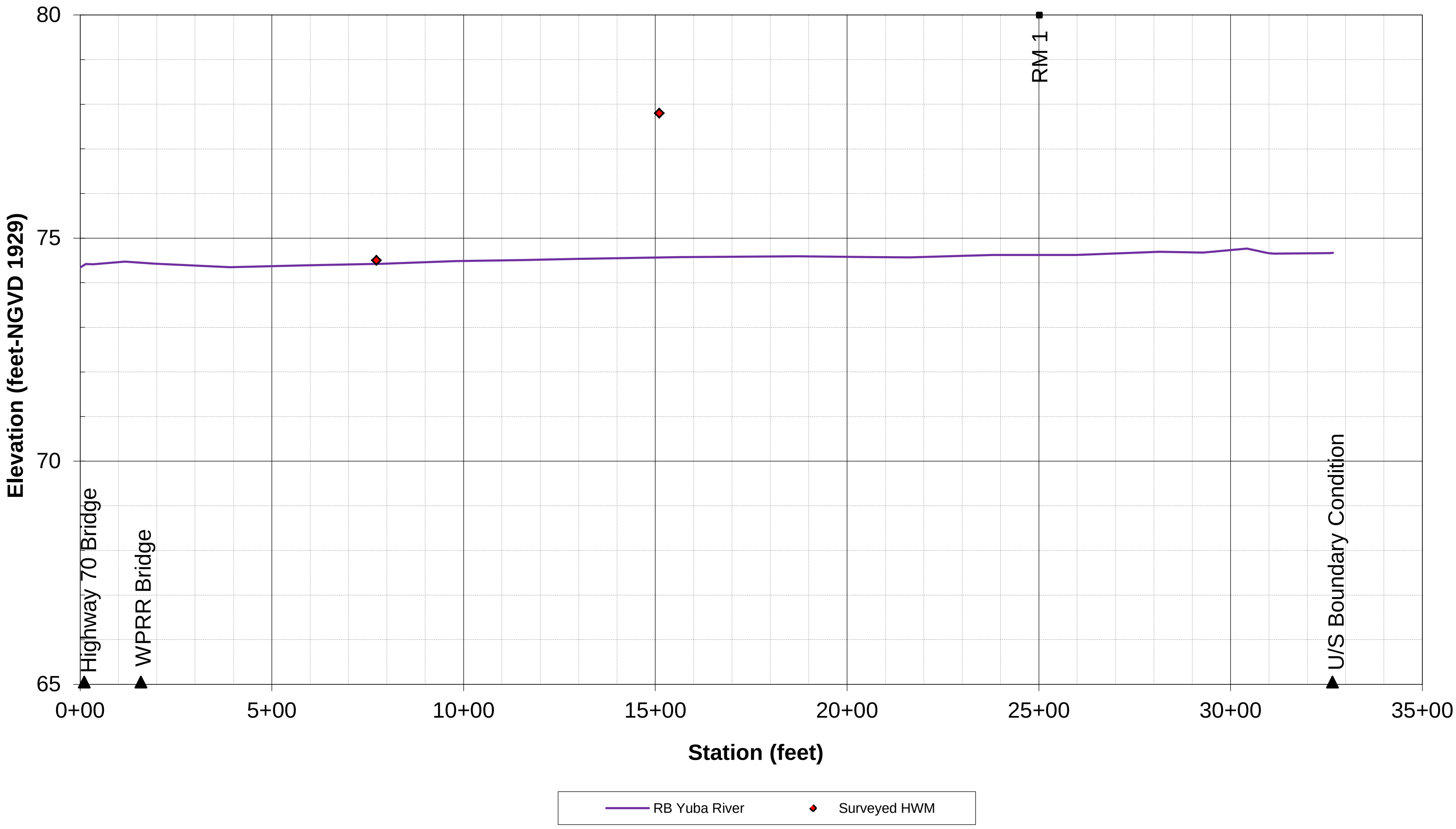

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Figure 11
Bear River - Left Bank (RM 0.3 to 4.75)
Maximum Water Surface Profile (2-D Model) - January 1997 Calibration

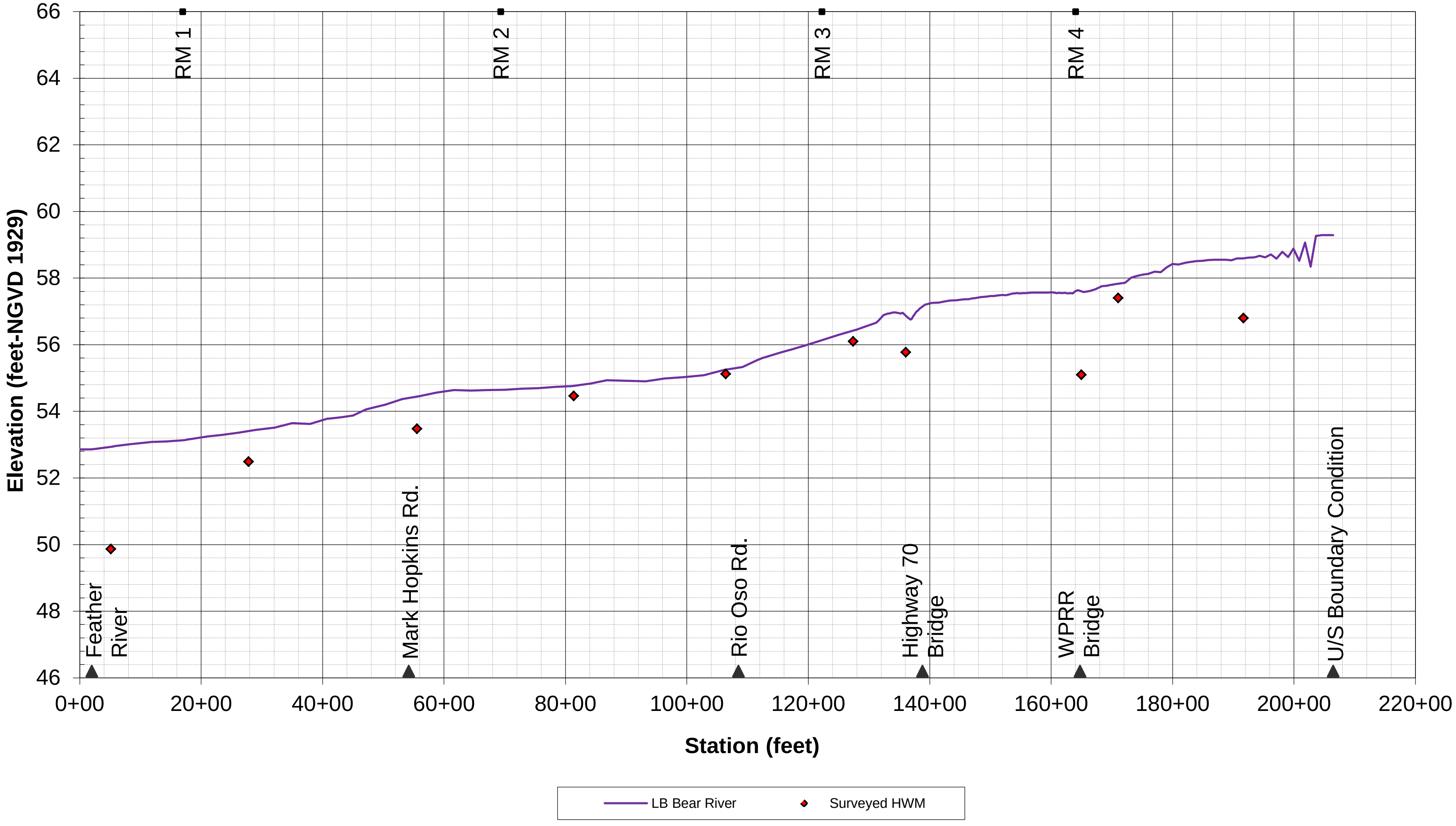

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Figure 12
Feather River - Left Bank (RM 2.9 to 12.2)
Maximum Water Surface Profile (2-D Model) - January 1997 Calibration

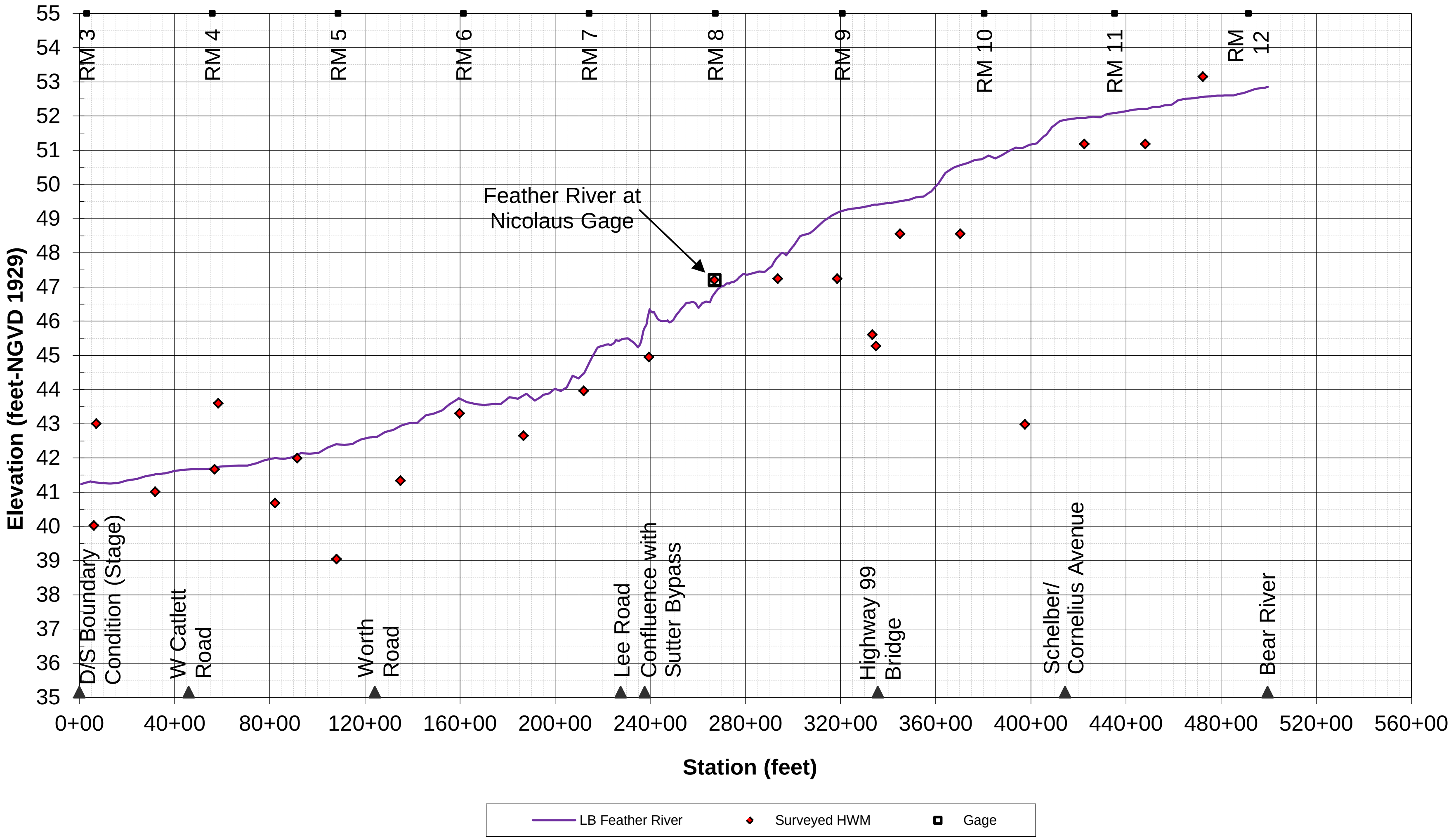

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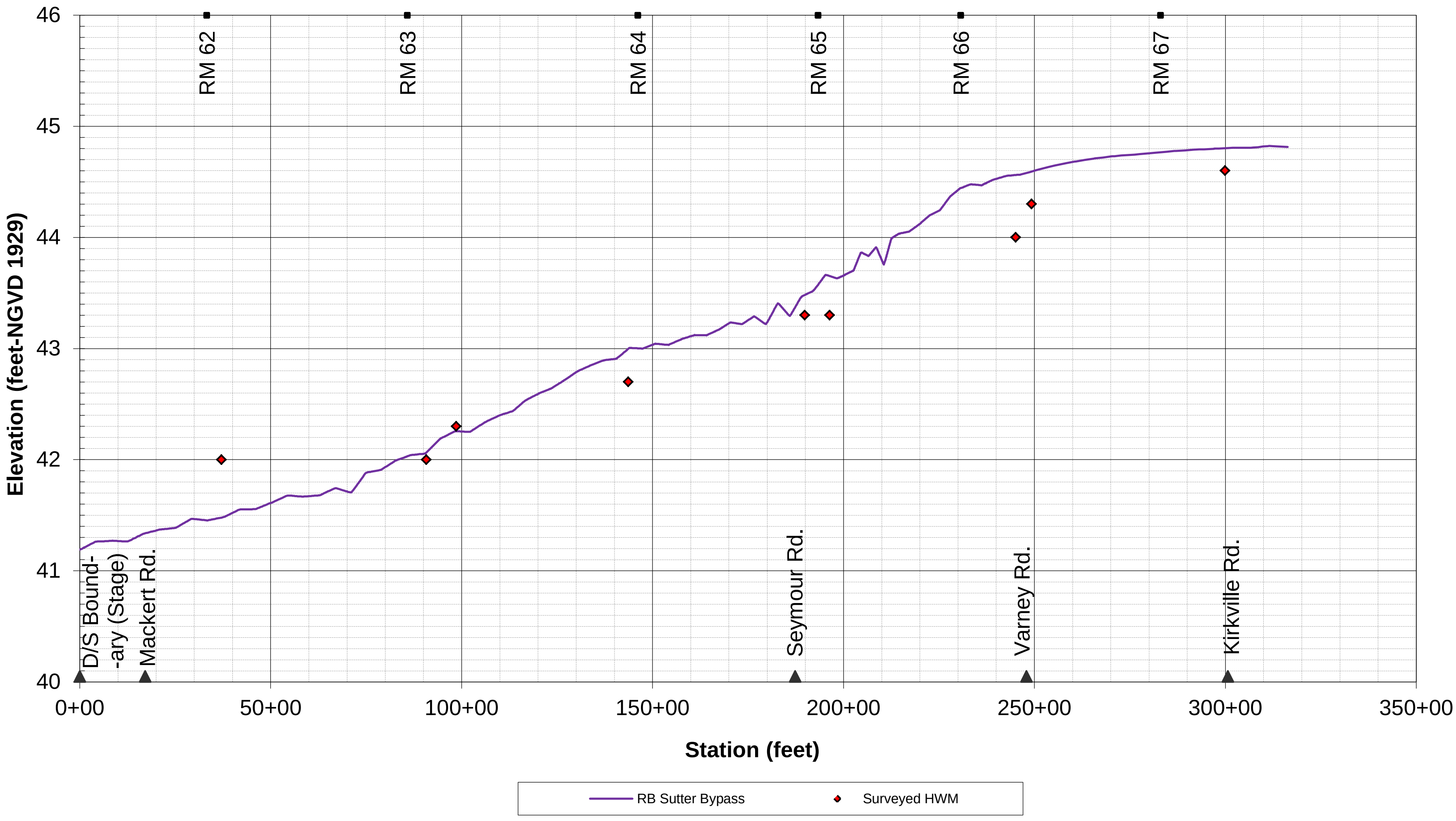
Figure 13
Sutter Bypass - Right Bank (RM 61.8 to 68.1)
Maximum Water Surface Profile (2-D Model) - January 1997 Calibration



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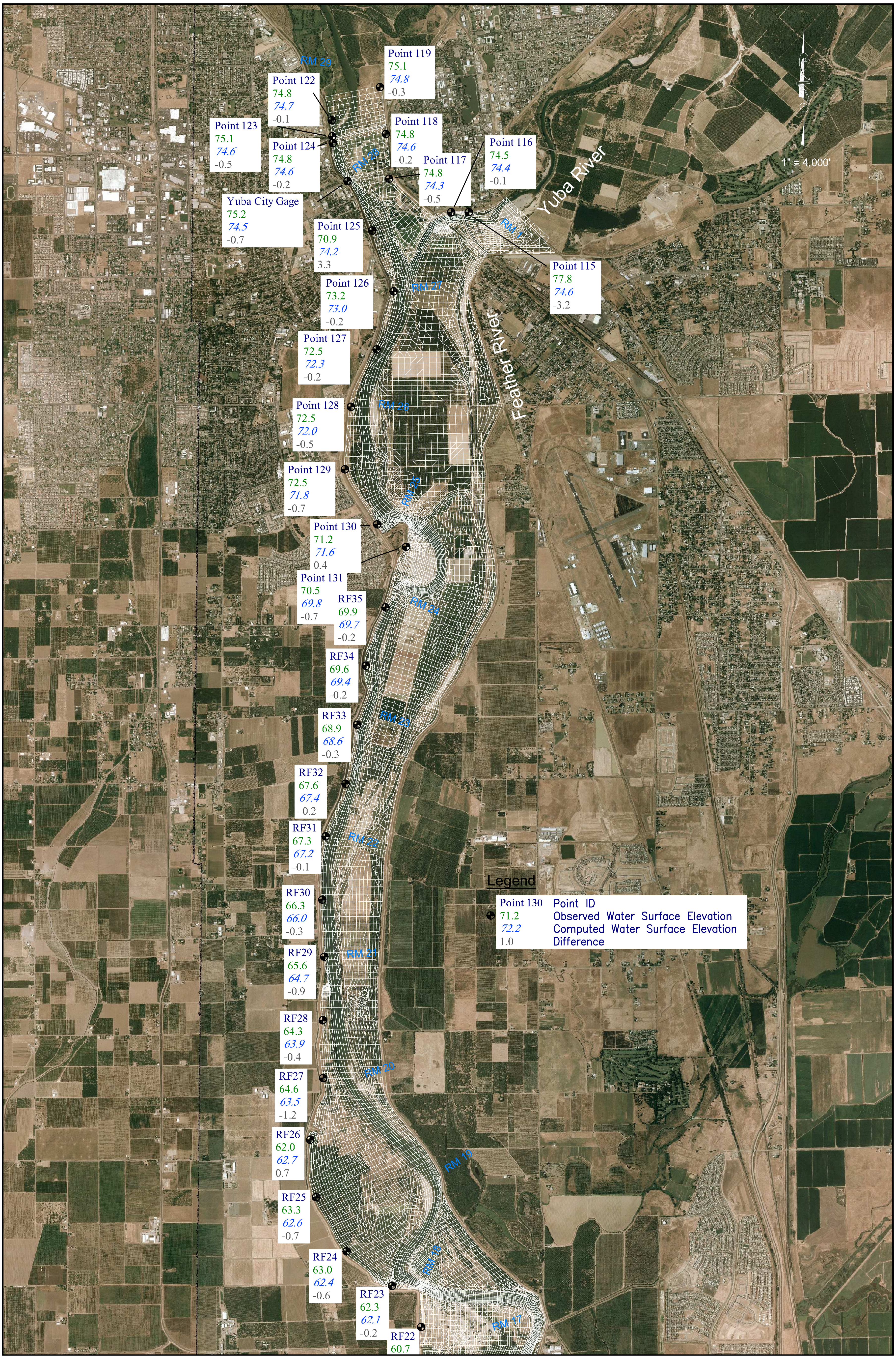

No.	DATE	APPROVED	REVISION

SCALE: 1"=4,000'
JOB NUMBER: 1403
REQUESTED BY: DT
DRAWN BY: PH
DATE: December 2011

Bar Length On Original Drawing Equals One Inch. Adjust Scale Accordingly.

Figure 14

Lower Feather River Corridor Management Plan

January 1997 Calibration Results

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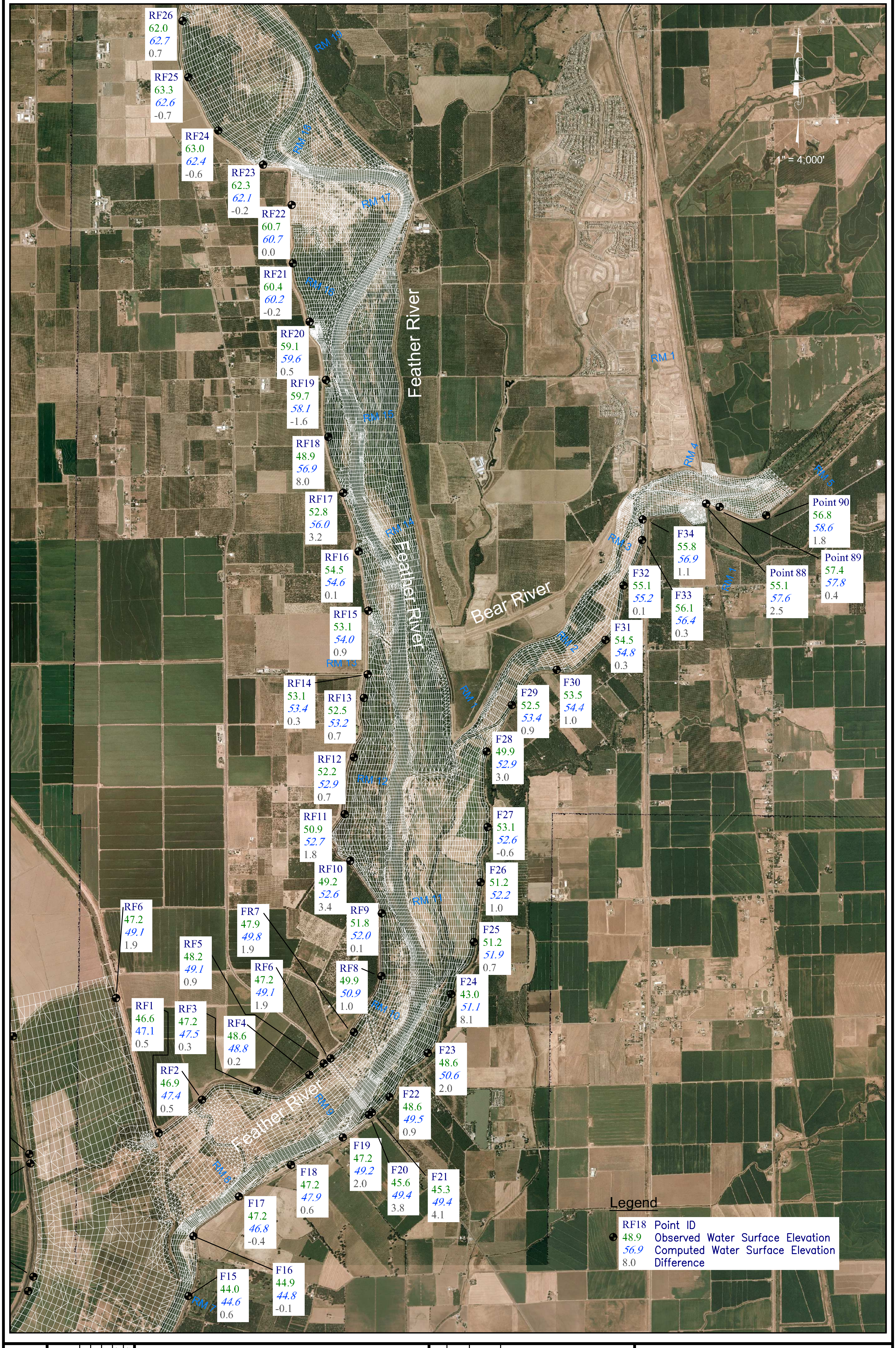

Figure 15	Lower Feather River Corridor Management Plan
	January 1997 Calibration Results

SCALE: 1"=4,000'
JOB NUMBER: 1403
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DRAWN BY: PH
DATE: December 2011

Bar Length On Original Drawing Equals One Inch. Adjust Scale Accordingly.

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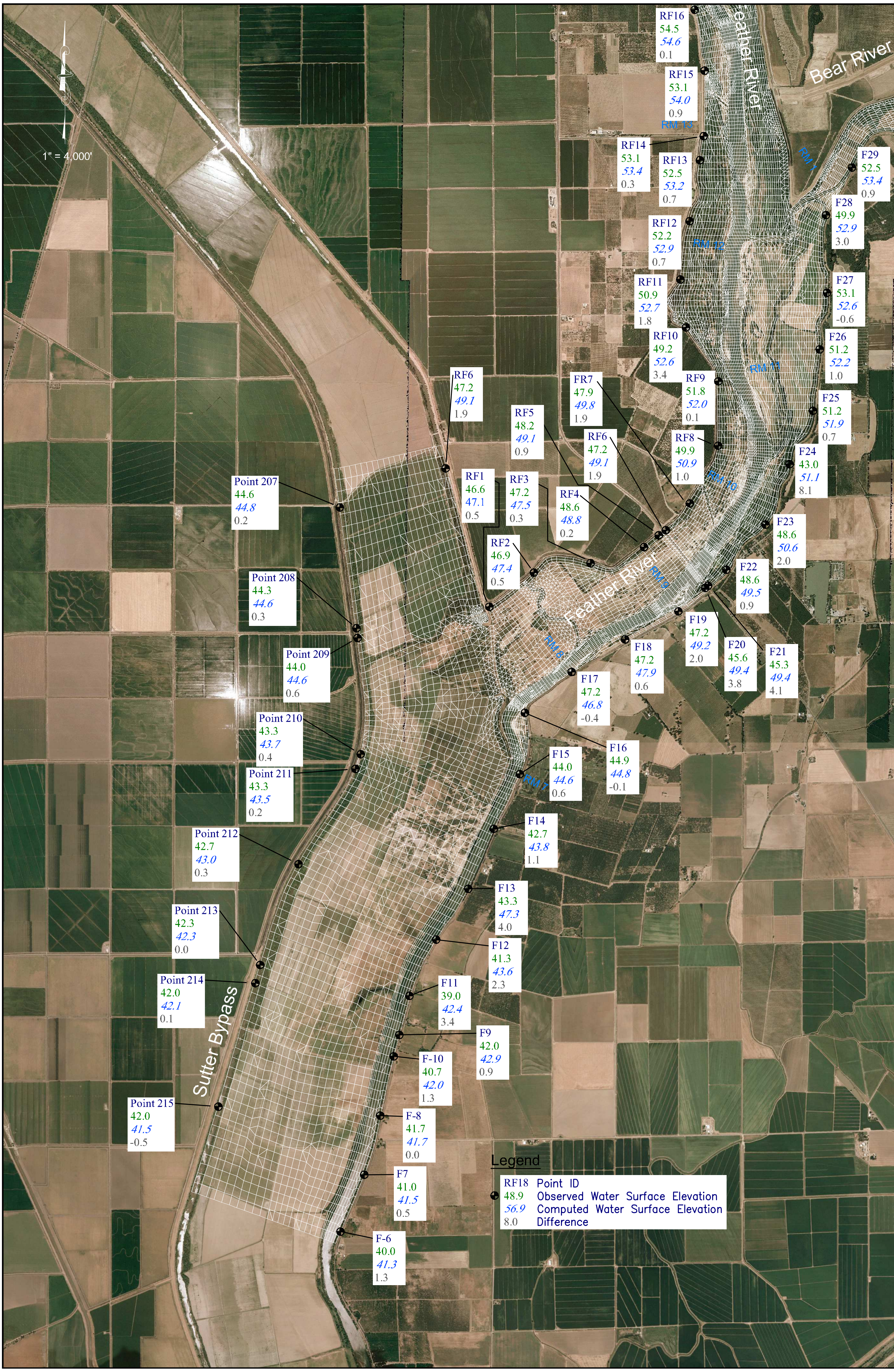

Figure 16

SCALE: 1"=4,000'
JOB NUMBER: 1403
REQUESTED BY: DT
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DATE: December 2011

Bar Length On Original Drawing Equals One Inch. Adjust Scale Accordingly

Lower Feather River Corridor Management Plan

January 1997 Calibration Results

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RMA2 Model - Baseline Condition
Finite Element Mesh

0 8,000
Scale in Feet

Figure 17

Friday, January 06, 2012
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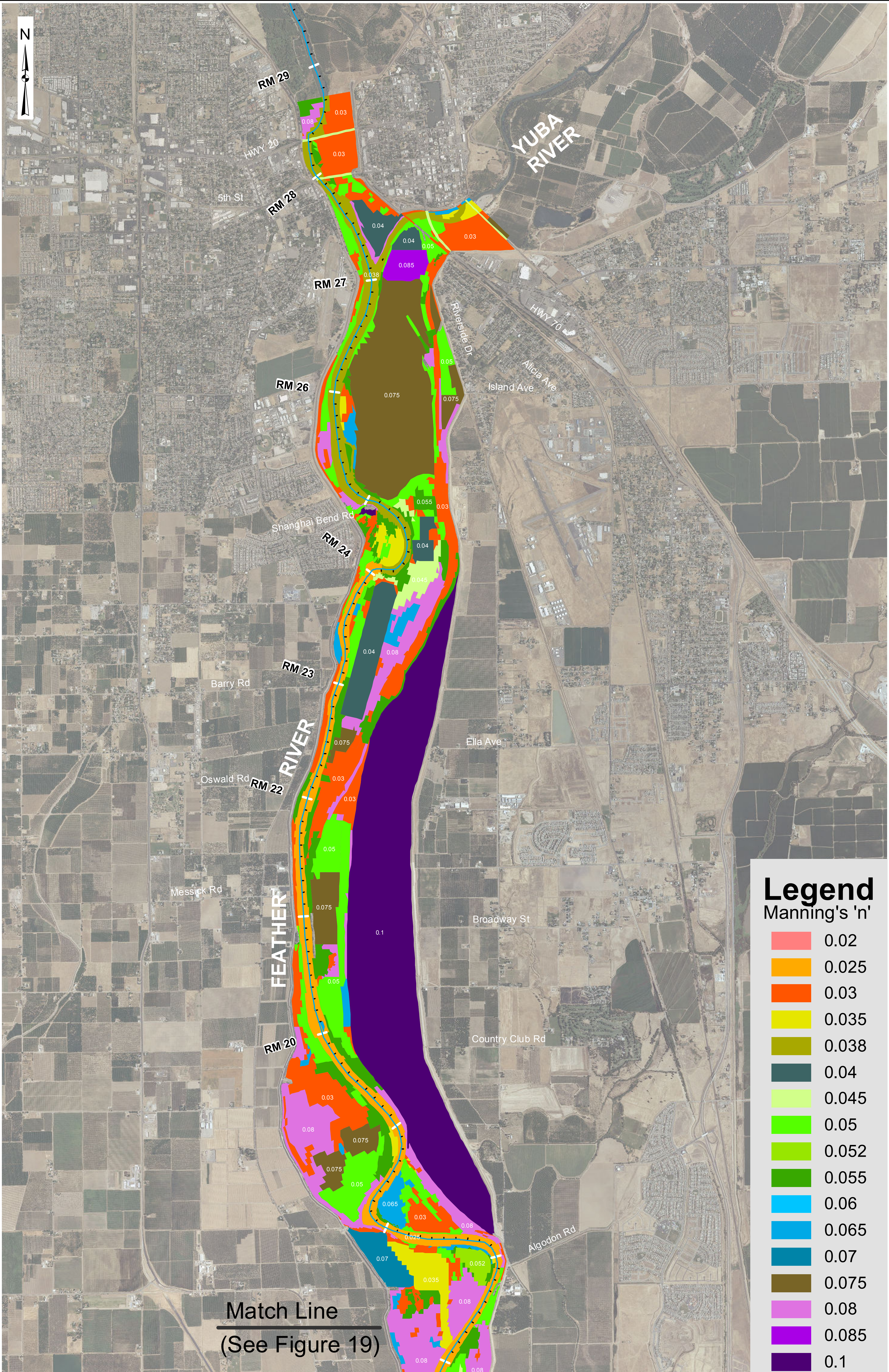

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RMA2 Model - Baseline Condition
Roughness Values

0 4,000
Scale in Feet

Figure 18

Thursday, January 05, 2012
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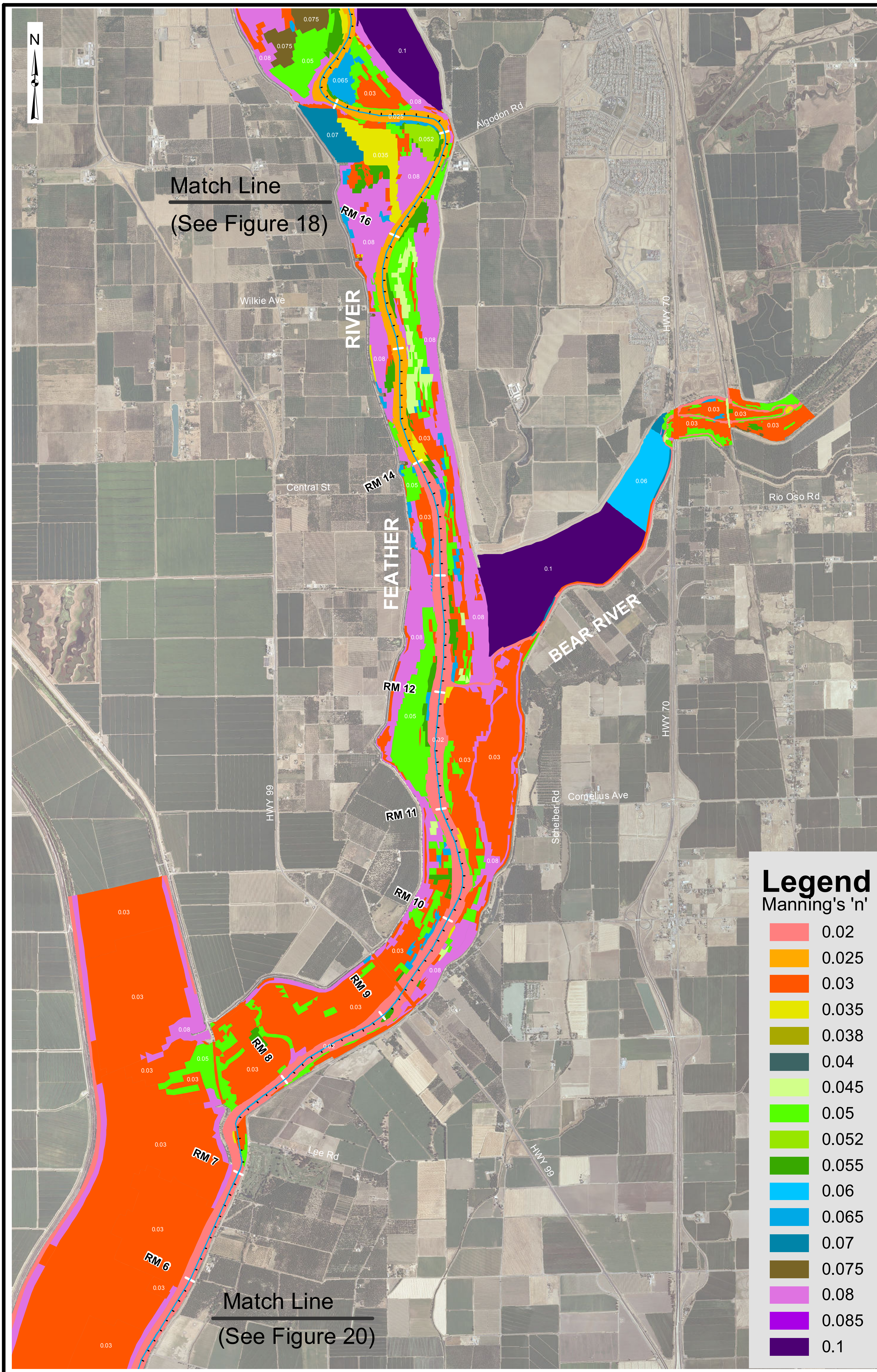
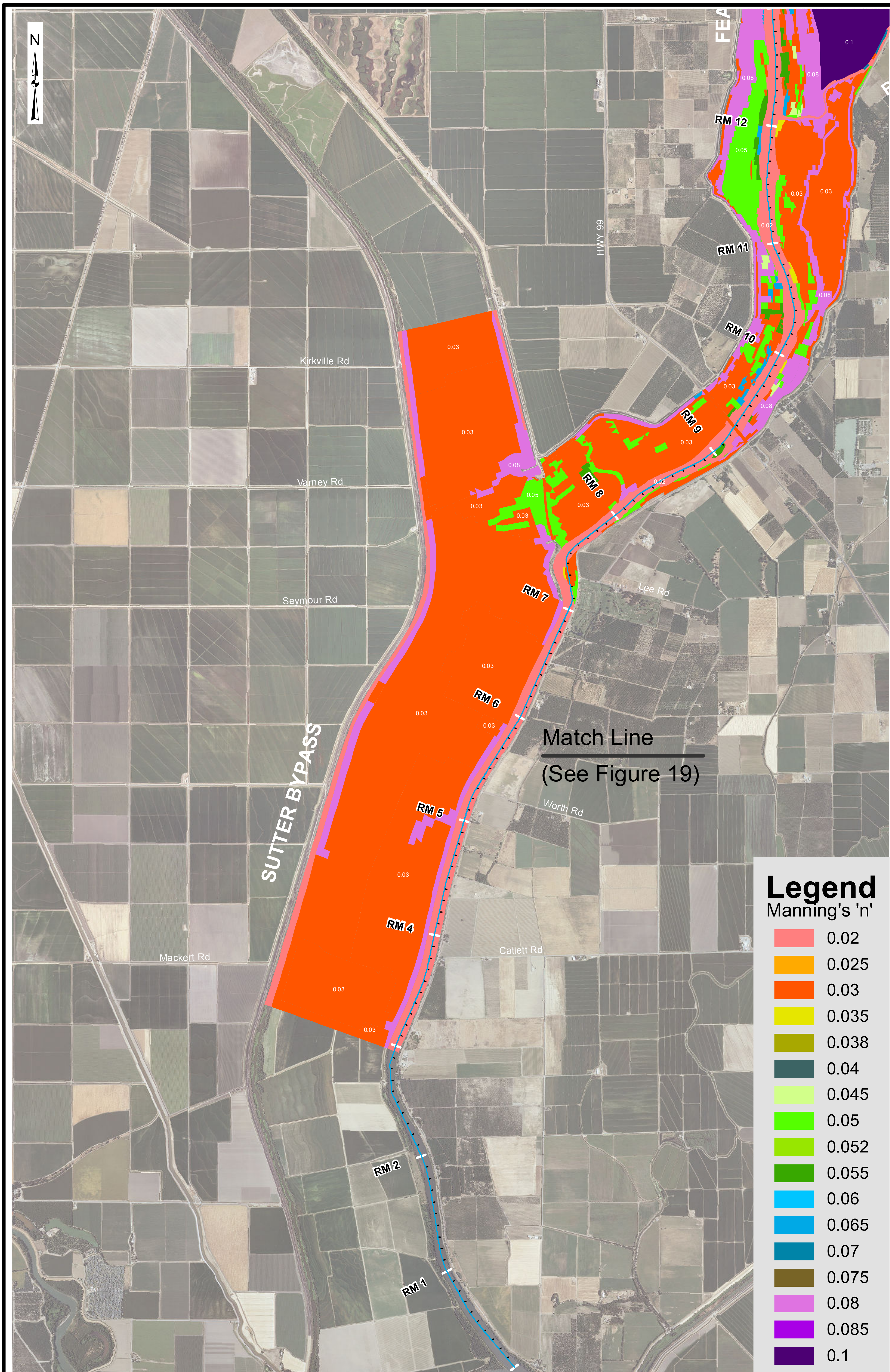


MBK ENGINEERS 1771 Tribute Road, Suite A Sacramento, California 95815-4401 (916) 456-4400	RMA2 Model - Baseline Condition Roughness Values	0 — 4,000 Scale in Feet	Figure 19

Thursday, January 05, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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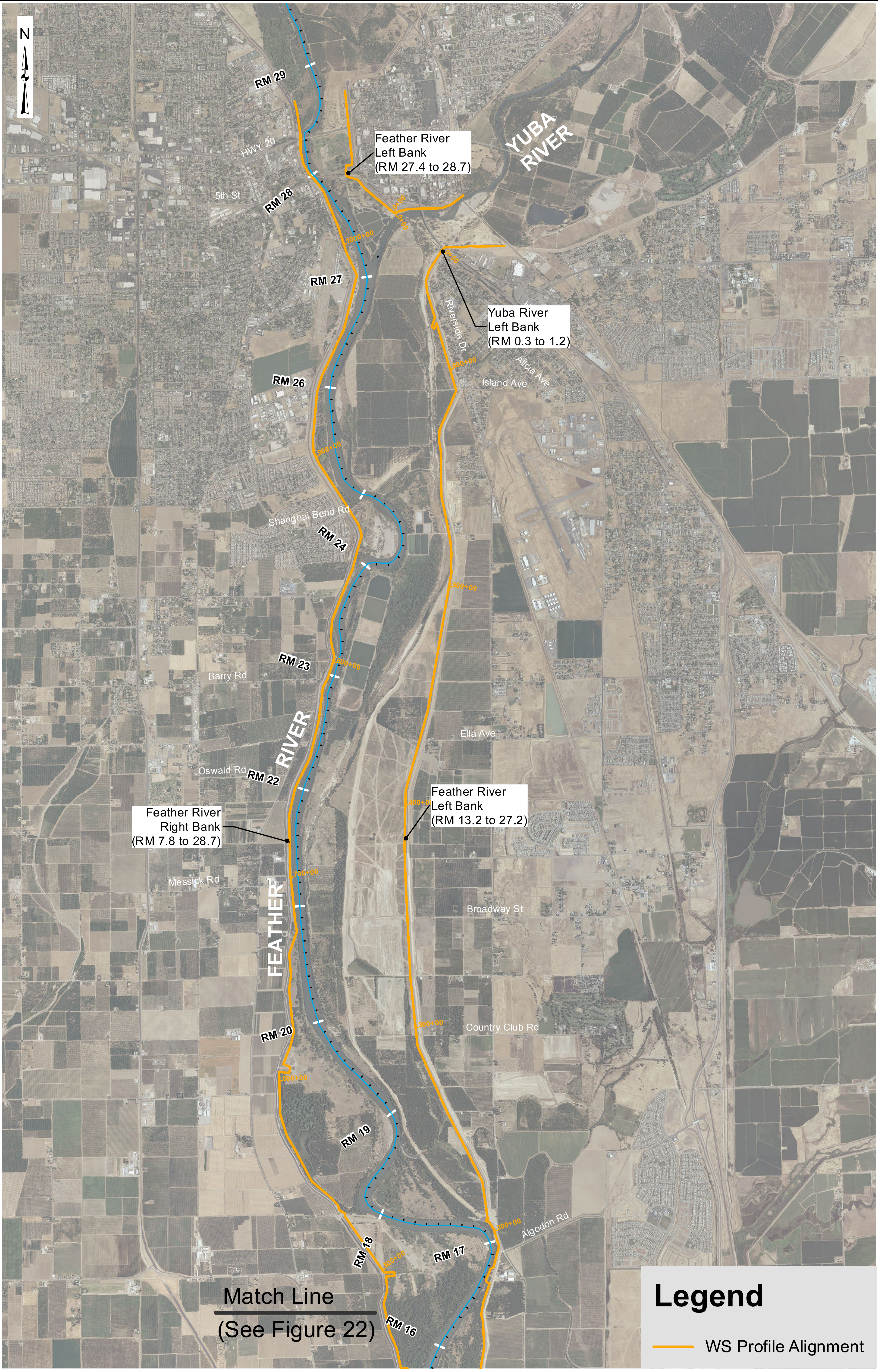
RMA2 Model - Baseline Condition
Roughness Values

0 4,000
Scale in Feet

Figure 20

Thursday, January 05, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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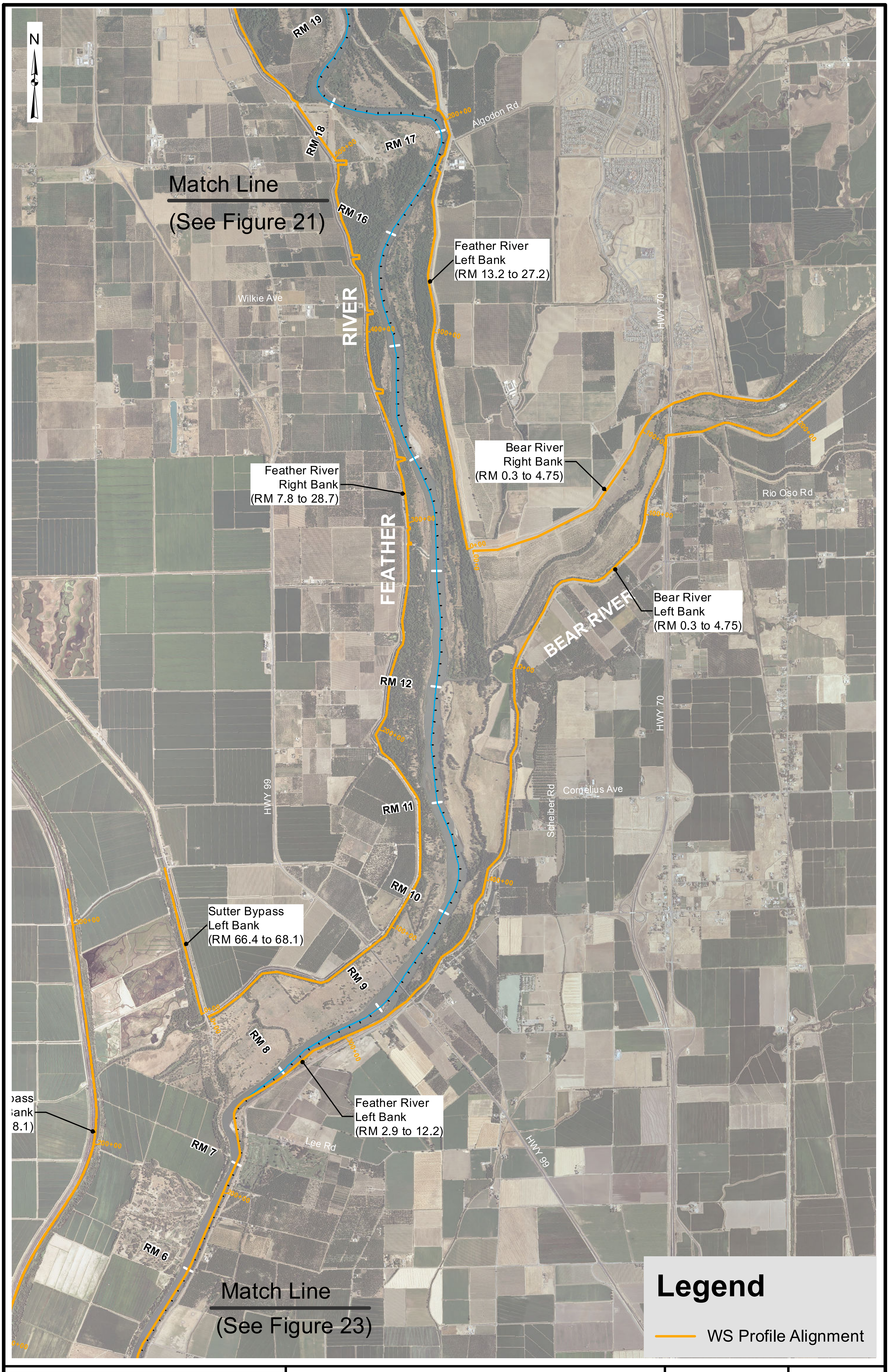
RMA2 Model - Baseline Condition
Water Surface Profile Alignments

0 4,000
Scale in Feet

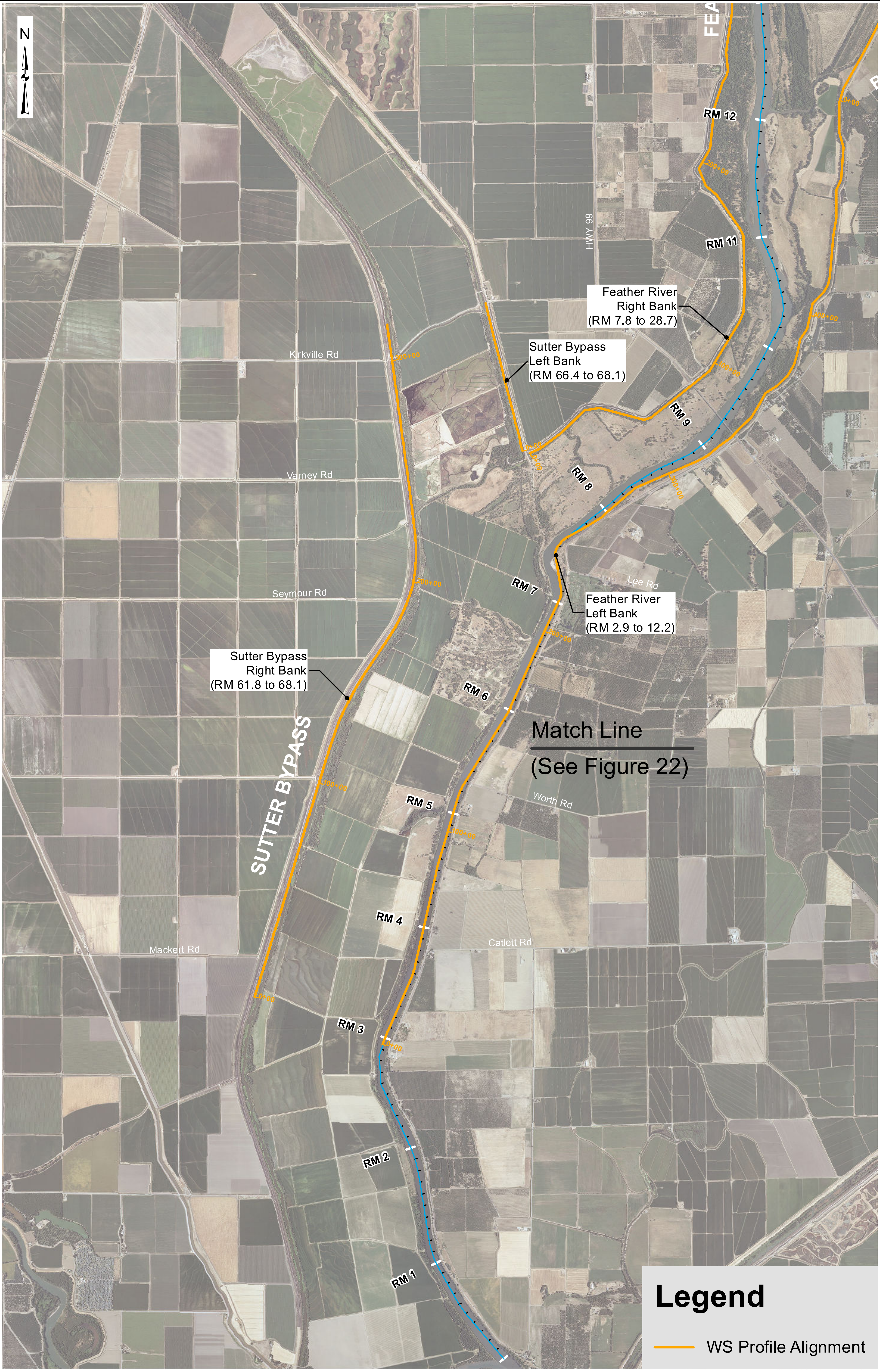
Figure 21

Thursday, January 05, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



MBK ENGINEERS 1771 Tribute Road, Suite A Sacramento, California 95815-4401 (916) 456-4400	**RMA2 Model - Baseline Condition Water Surface Profile Alignments**	0 4,000 Scale in Feet	**Figure 22**

Thursday, January 05, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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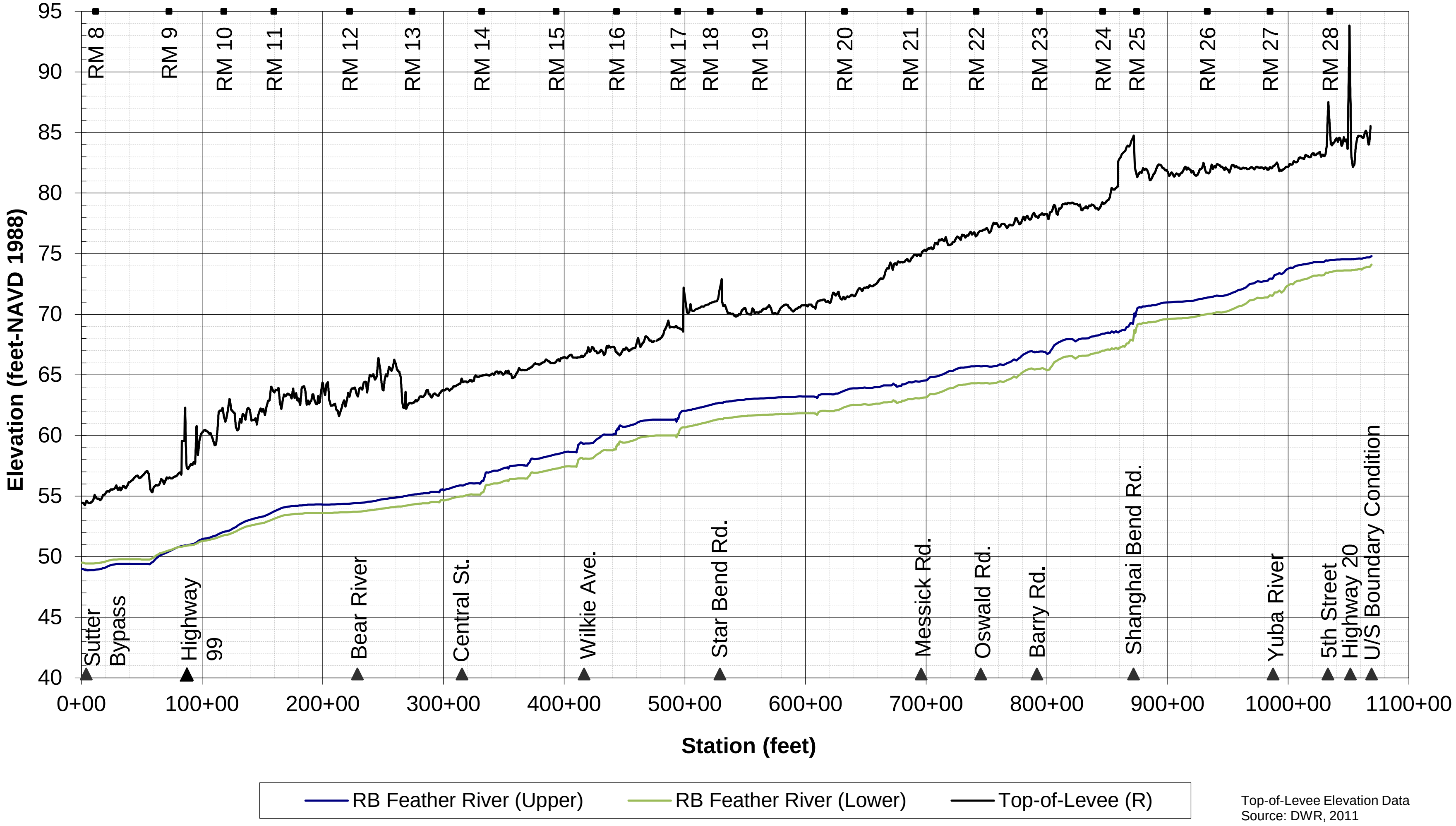
RMA2 Model - Baseline Condition
Water Surface Profile Alignments

0 4,000
Scale in Feet

Figure 23

Thursday, January 05, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd

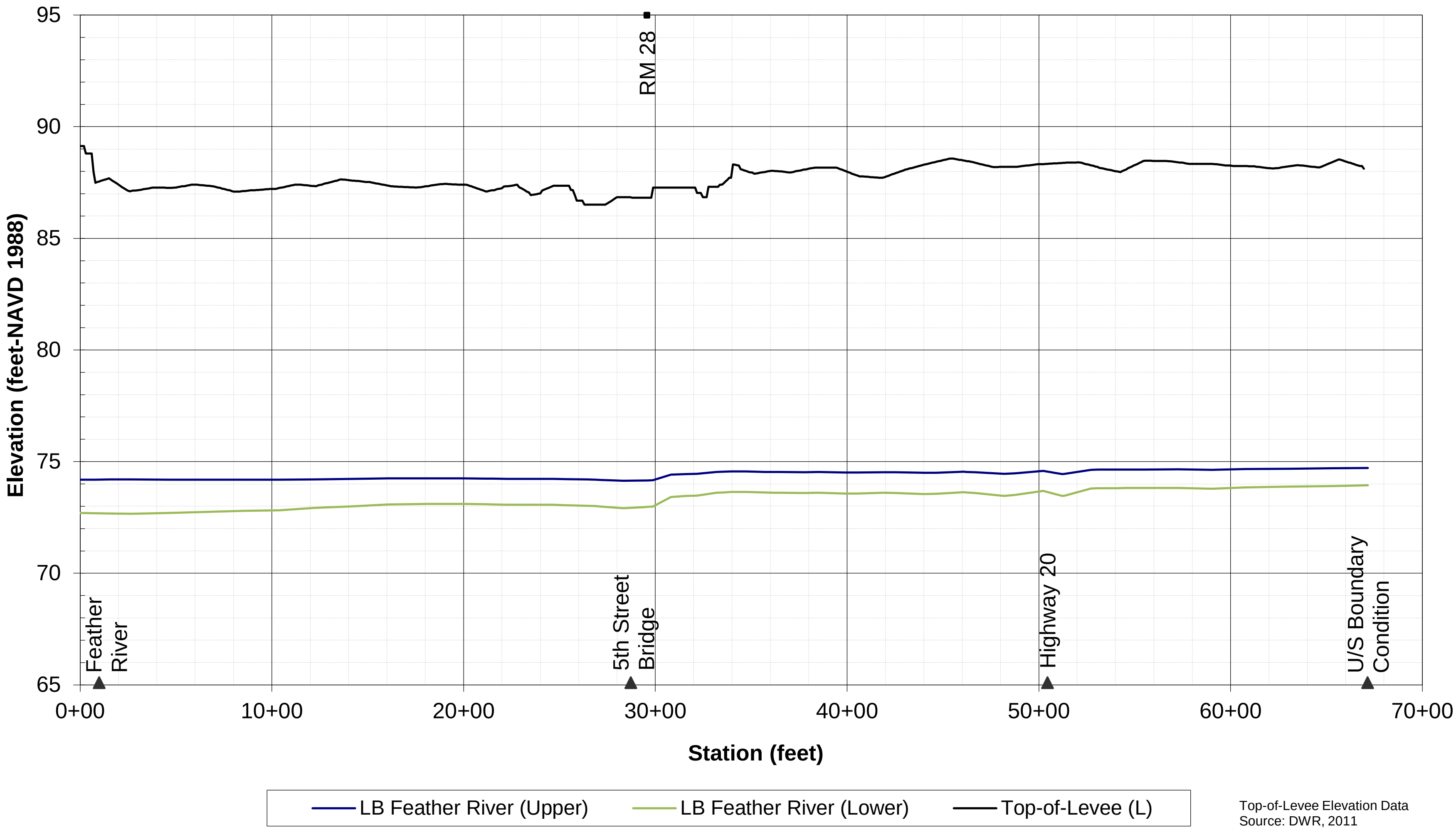
Figure 24
Feather River - Right Bank (RM 7.8 to 28.7)
Maximum Water Surface Profile (2-D Model)-1-in 100 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\100yr_Max_WS_Profile_NAVD

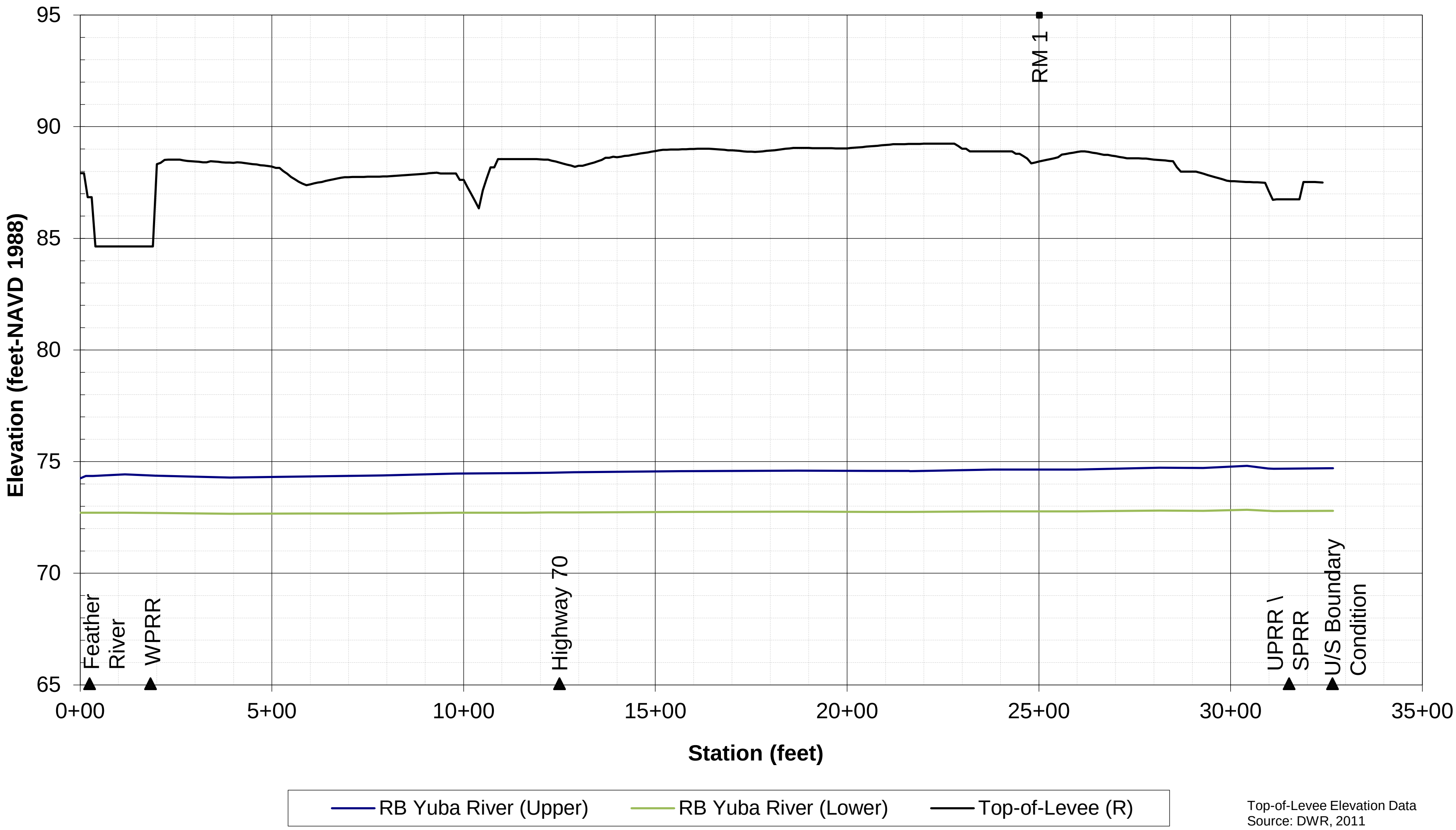
Figure 25
Feather River - Left Bank (RM 27.4 to 28.7)
Maximum Water Surface Profile (2-D Model)-1-in 100 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\100yr_Max_WS_Profile_NAVD

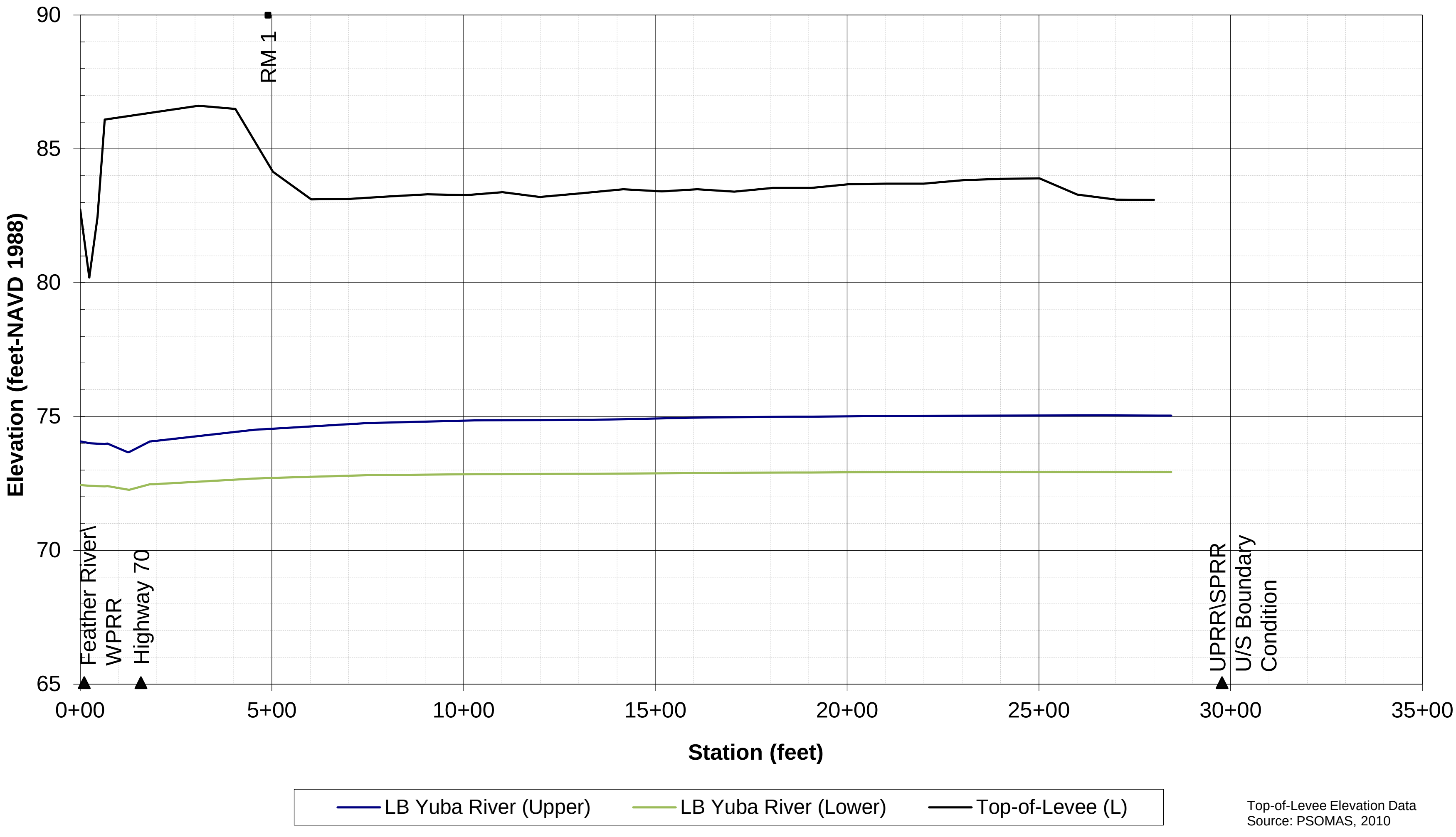
Figure 26
Yuba River - Right Bank (RM 0.3 to 1.2)
Maximum Water Surface Profile (2-D Model)-1-in 100 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\100yr_Max_WS_Profile_NAVD

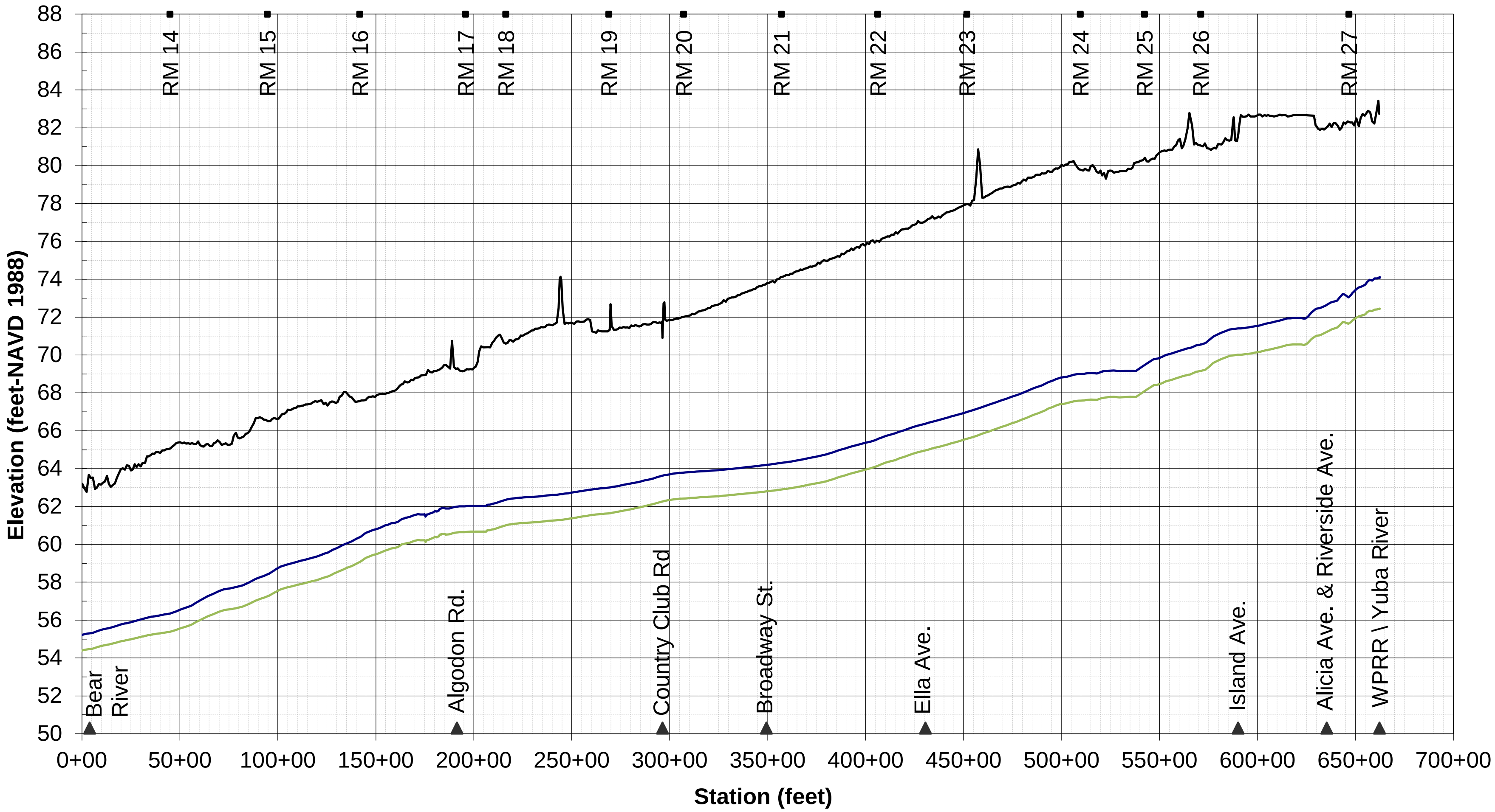
Figure 27
Yuba River - Left Bank (RM 0.3 to 1.2)
Maximum Water Surface Profile (2-D Model)-1-in 100 AEP



Top-of-Levee Elevation Data
Source: PSOMAS, 2010

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\100yr_Max_WS_Profile_NAVD

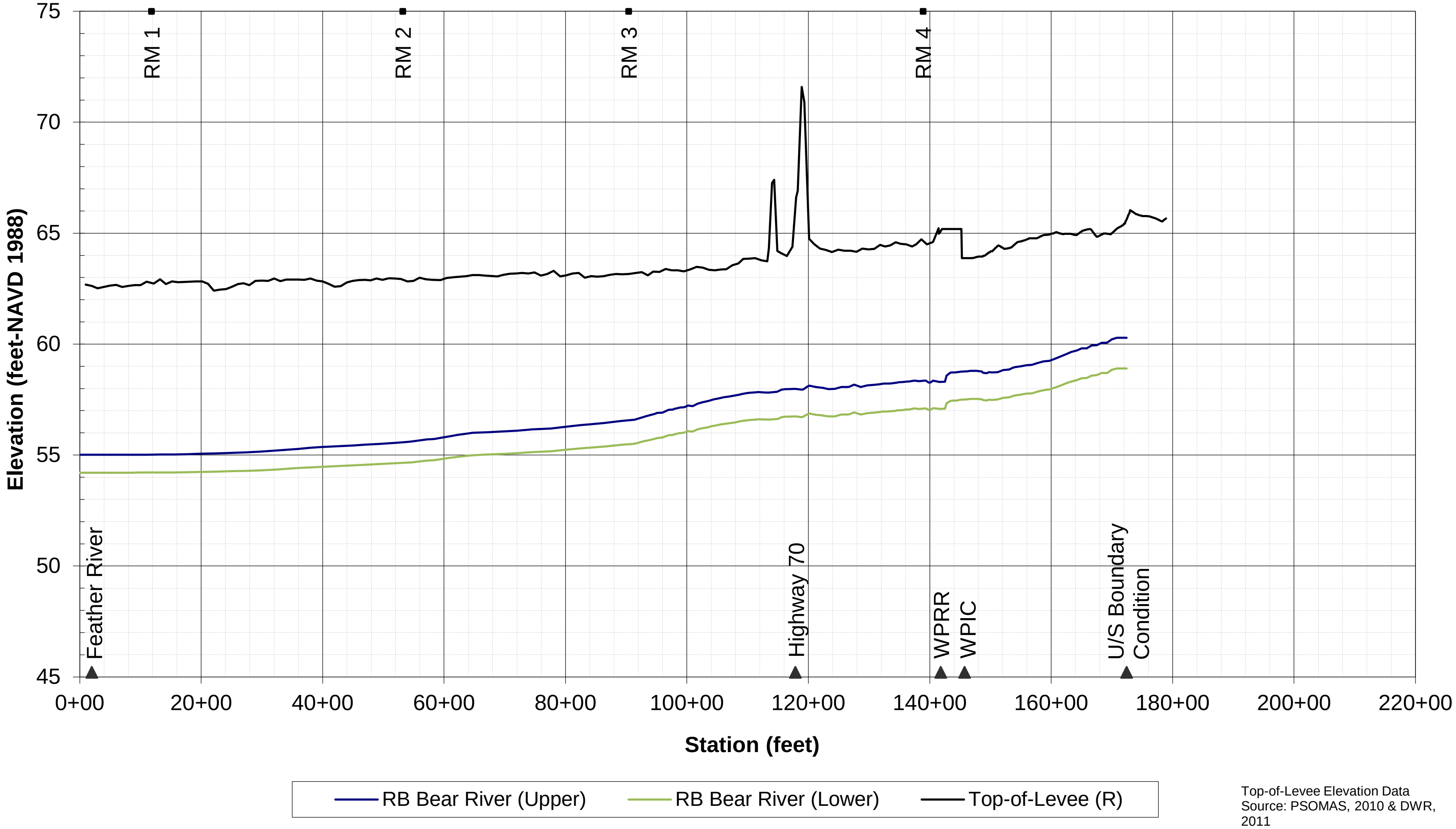
Figure 28
Feather River - Left Bank (RM 13.2 to 27.2)
Maximum Water Surface Profile (2-D Model)-1-in 100 AEP



Top-of-Levee Elevation Data
Source: PSOMAS, 2010

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\100yr_Max_WS_Profile_NAVD

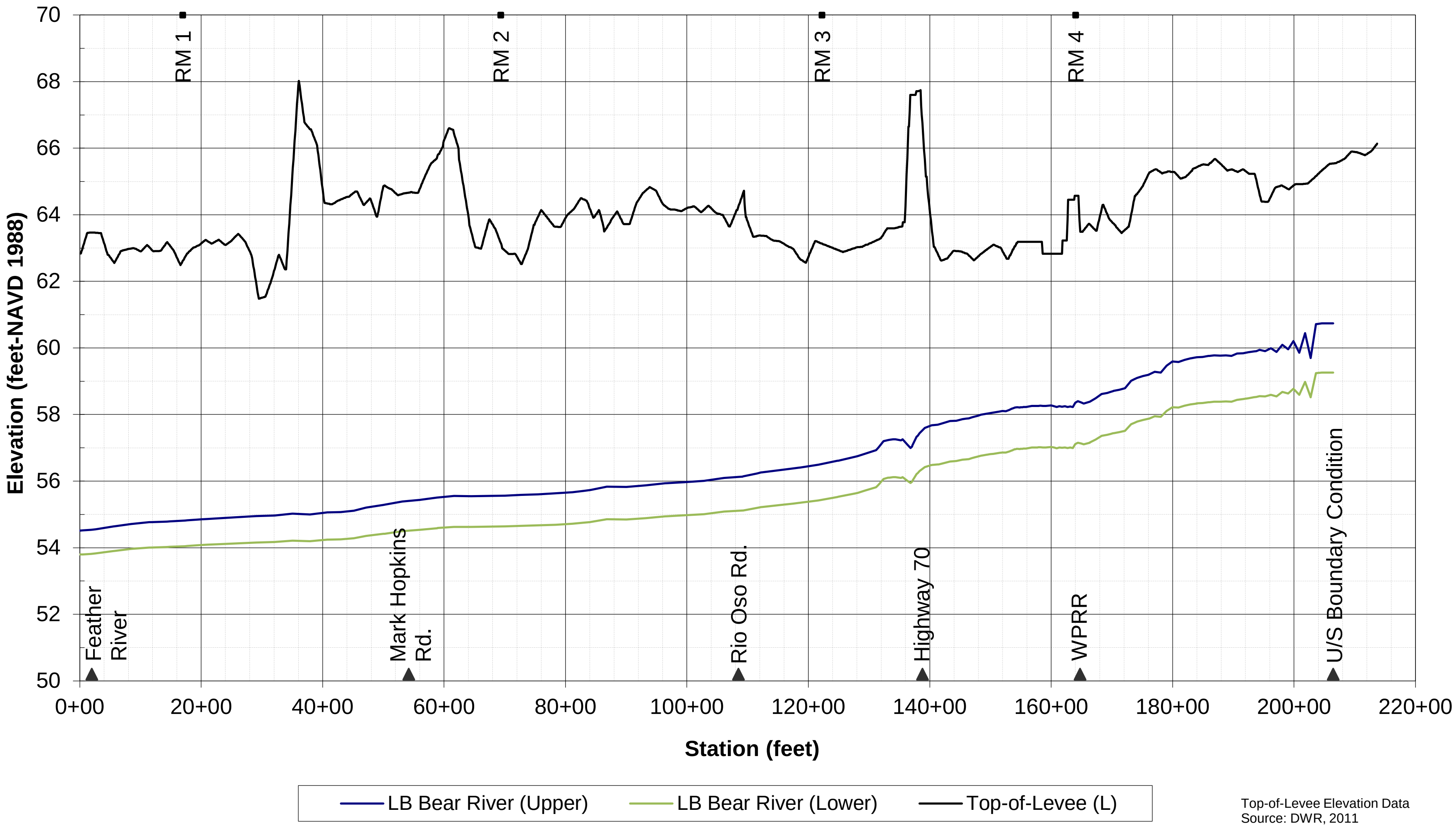
Figure 29
Bear River - Right Bank (RM 0.3 to 4.75)
Maximum Water Surface Profile (2-D Model)-1-in 100 AEP



Top-of-Levee Elevation Data Source: PSOMAS, 2010 & DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\100yr_Max_WS_Profile_NAVD

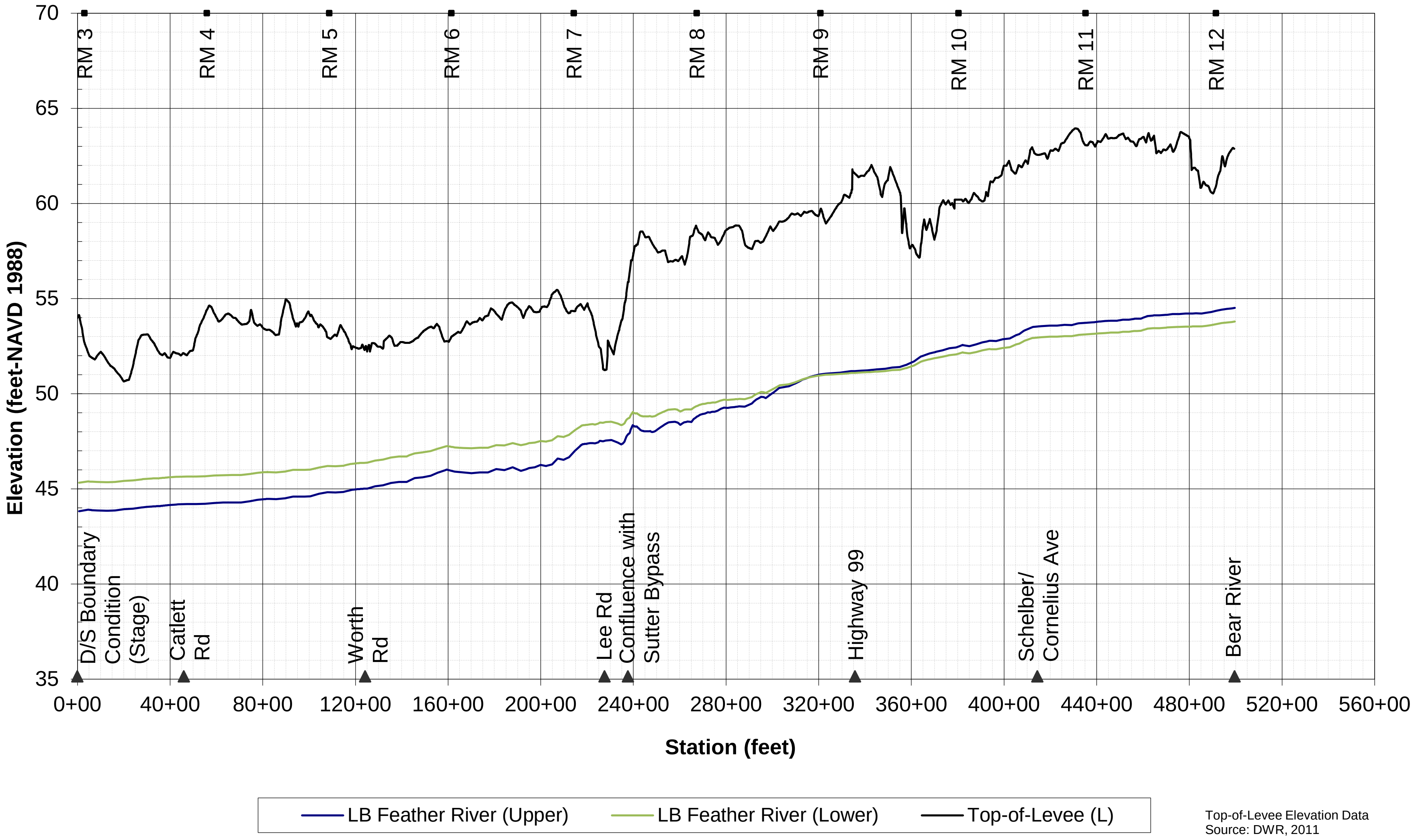
Figure 30
Bear River - Left Bank (RM 0.3 to 4.75)
Maximum Water Surface Profile (2-D Model)-1-in 100 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\100yr_Max_WS_Profile_NAVD

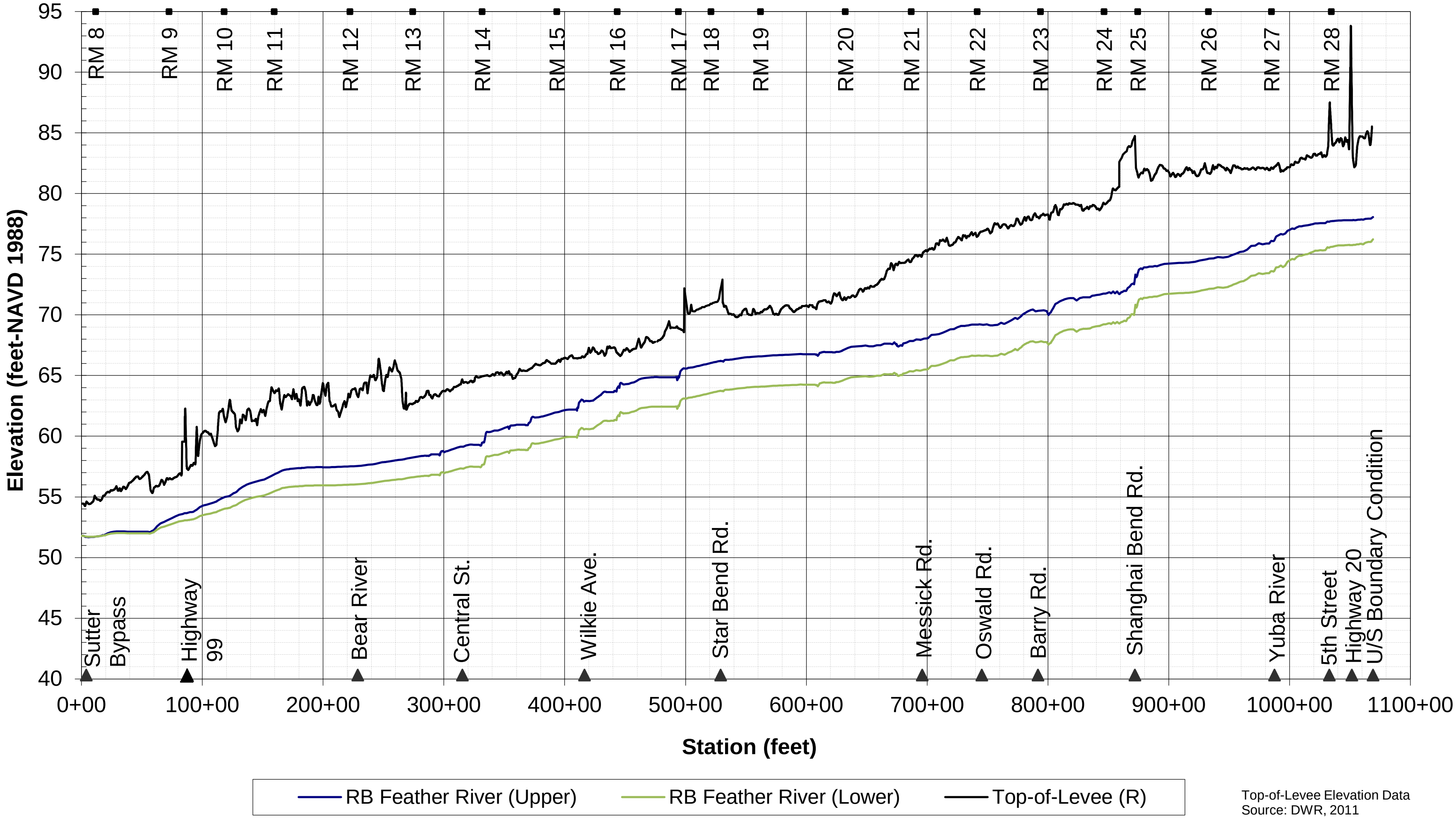
Figure 31
Feather River - Left Bank (RM 2.9 to 12.2)
Maximum Water Surface Profile (2-D Model)-1-in 100 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\100yr_Max_WS_Profile_NAVD

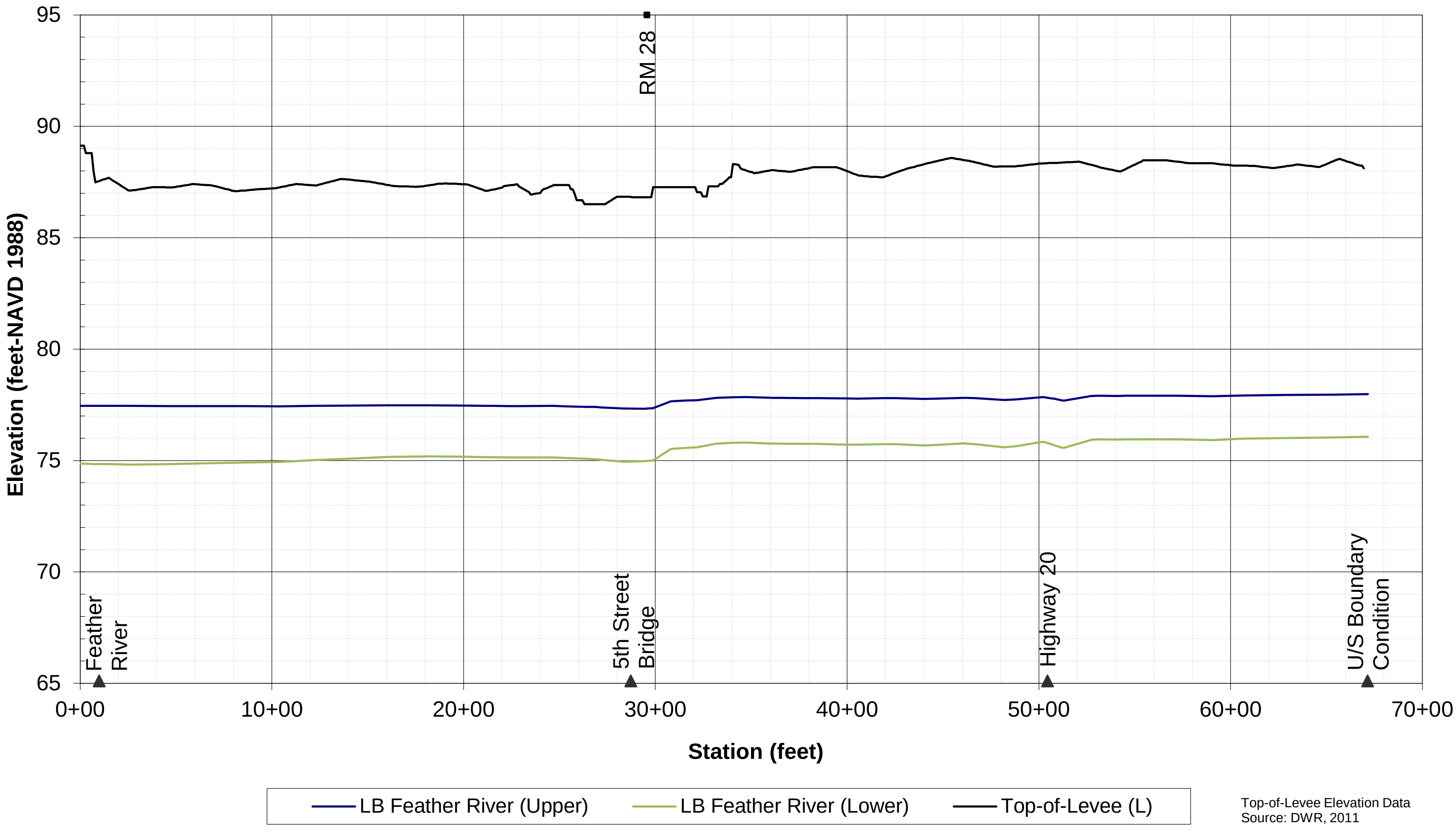
Figure 32
Feather River - Right Bank (RM 7.8 to 28.7)
Maximum Water Surface Profile (2-D Model)-1-in-200 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\200yr_Max_WS_Profile_NAVD

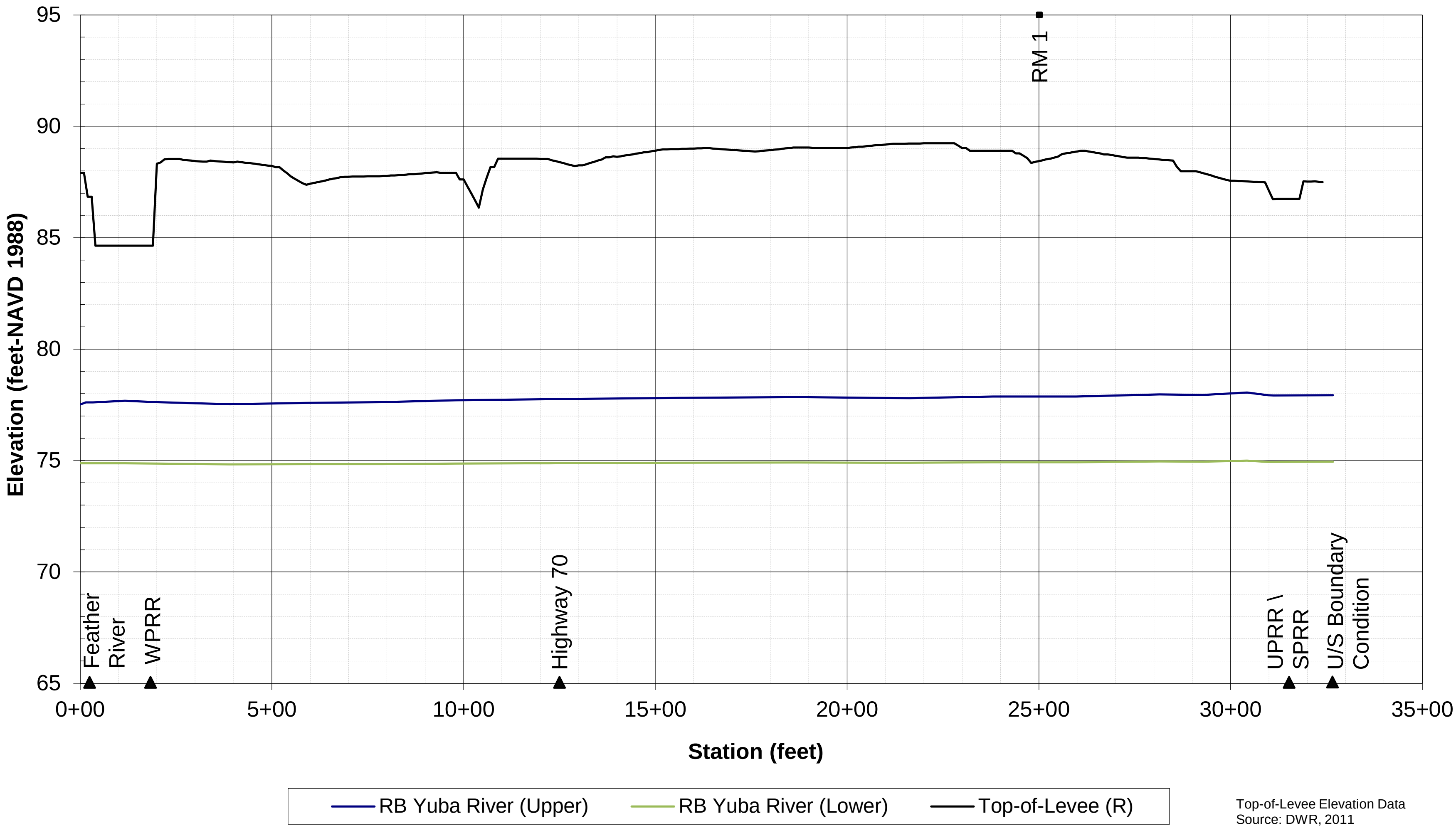
Figure 33
Feather River - Left Bank (RM 27.4 to 28.7)
Maximum Water Surface Profile (2-D Model)-1-in-200 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\200yr_Max_WS_Profile_NAVD

Figure 34
Yuba River - Right Bank (RM 0.3 to 1.2)
Maximum Water Surface Profile (2-D Model)-1-in-200 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\200yr_Max_WS_Profile_NAVD

Figure 35
Yuba River - Left Bank (RM 0.3 to 1.2)
Maximum Water Surface Profile (2-D Model)-1-in-200 AEP

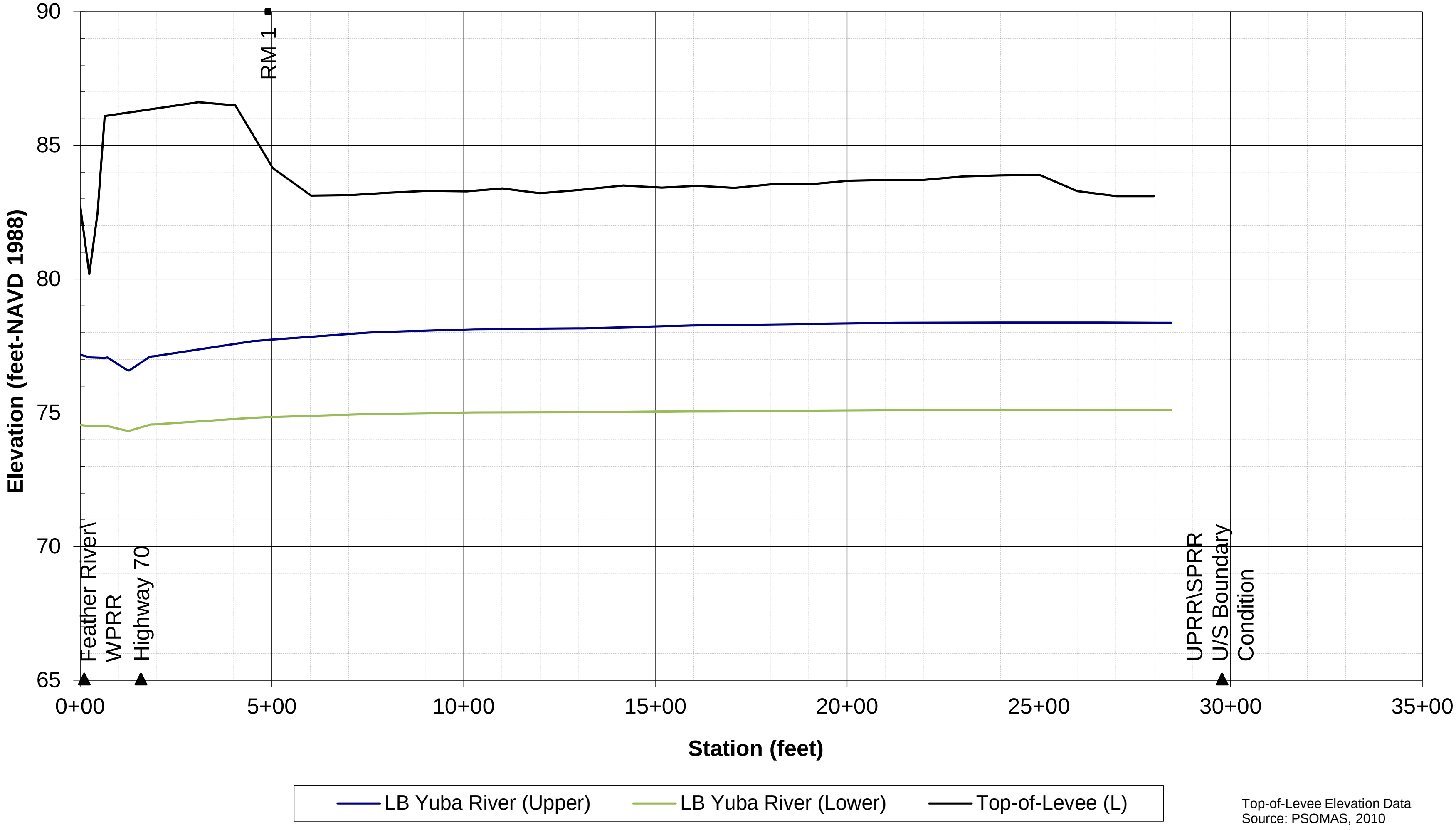


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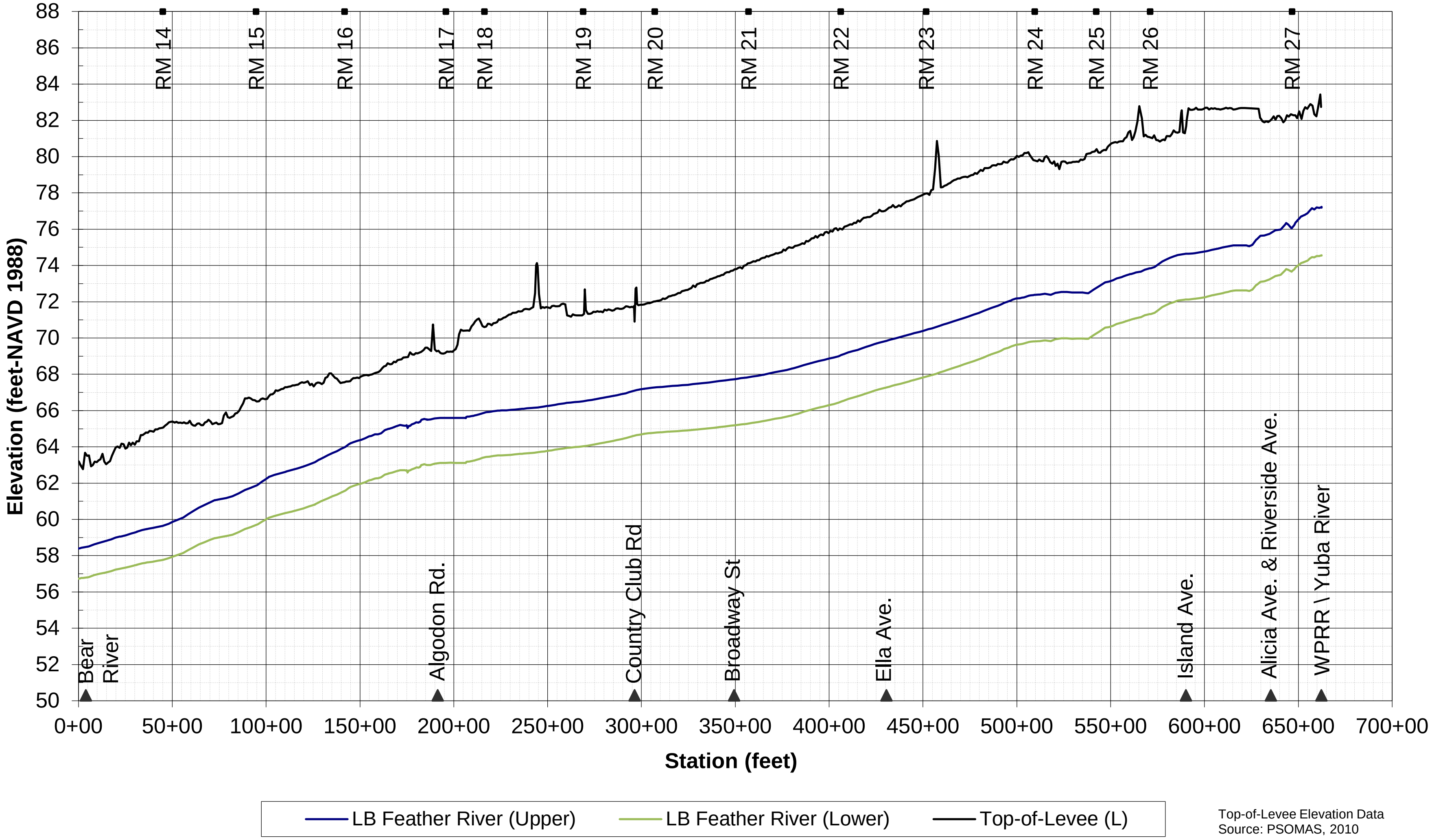
Figure 36
Feather River - Left Bank (RM 13.2 to 27.2)
Maximum Water Surface Profile (2-D Model)-1-in-200 AEP



Top-of-Levee Elevation Data
Source: PSOMAS, 2010

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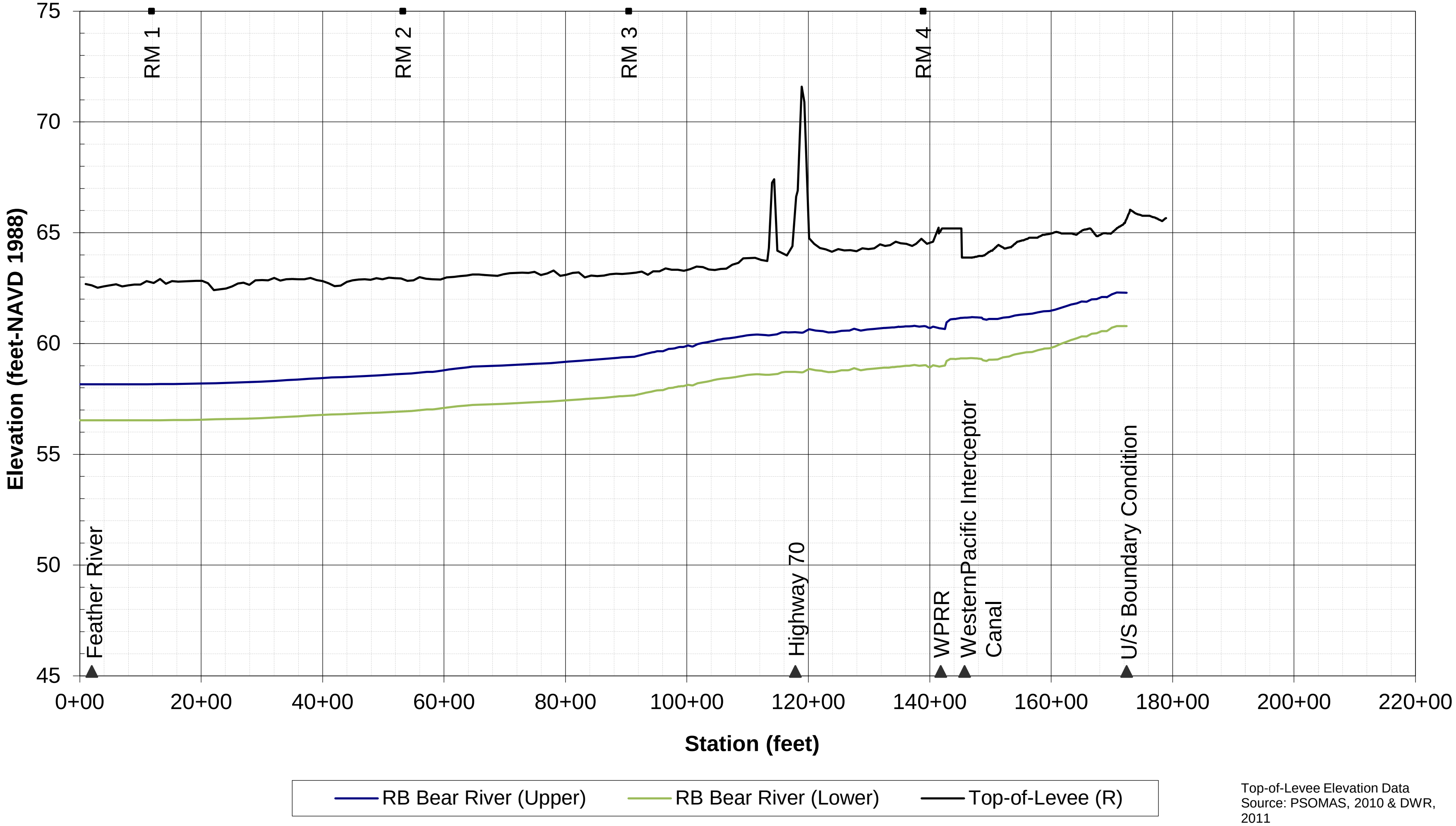
Figure 37
Bear River - Right Bank (RM 0.3 to 4.75)
Maximum Water Surface Profile (2-D Model)-1-in-200 AEP



Top-of-Levee Elevation Data Source: PSOMAS, 2010 & DWR, 2011

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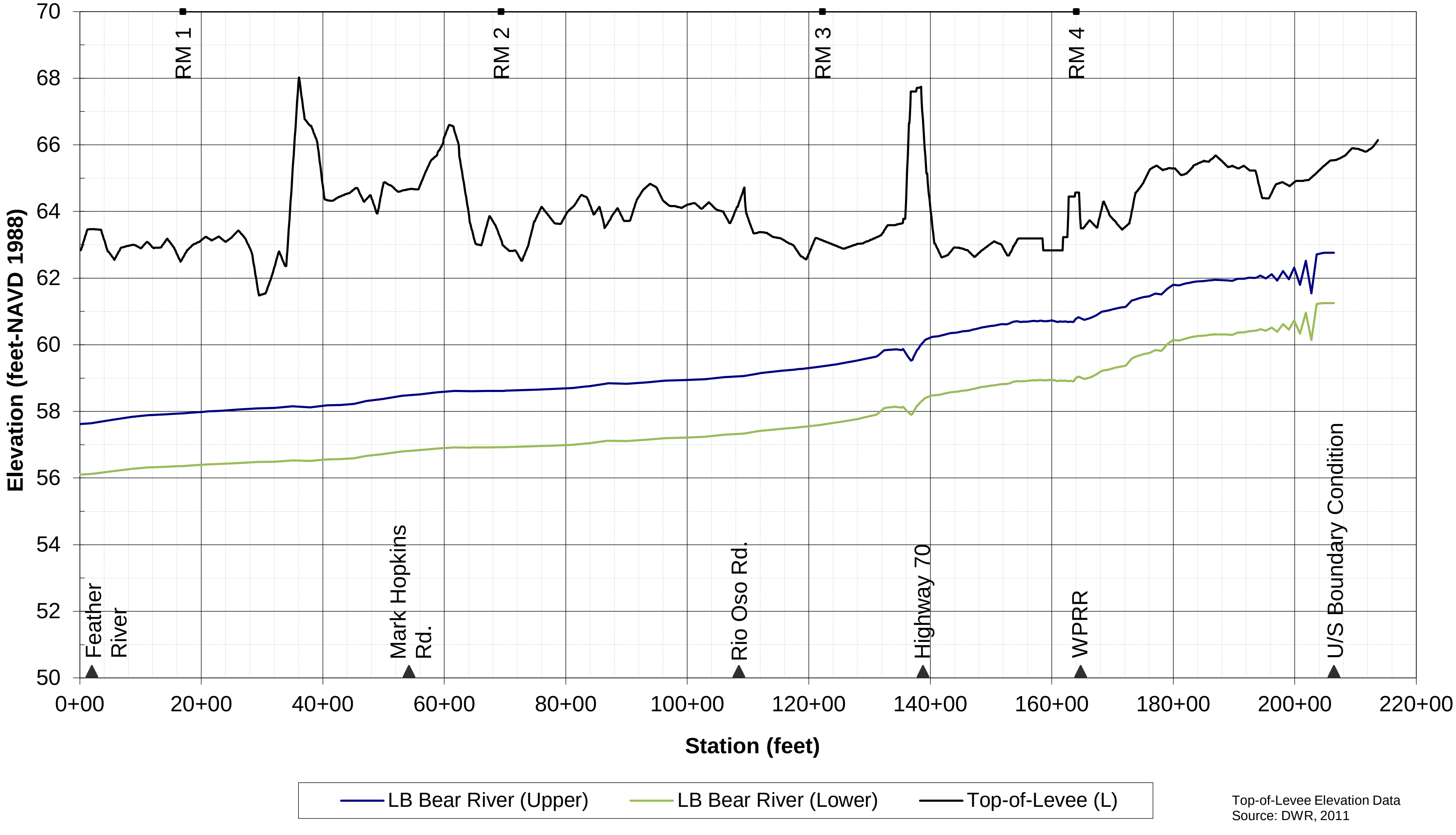
Figure 38
Bear River - Left Bank (RM 0.3 to 4.75)
Maximum Water Surface Profile (2-D Model)-1-in-200 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

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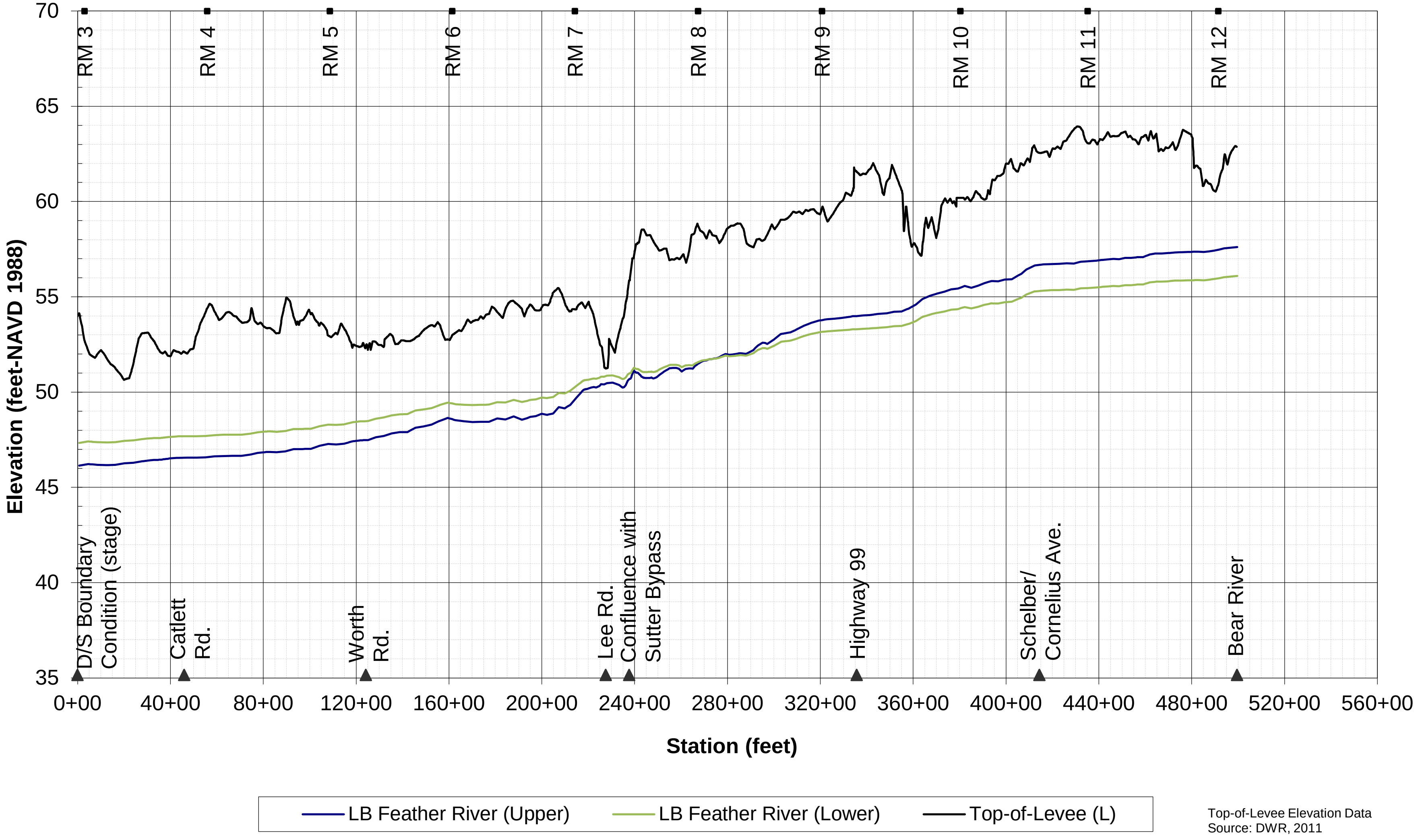
Figure 39
Feather River - Left Bank (RM 2.9 to 12.2)
Maximum Water Surface Profile (2-D Model)-1-in-200 AEP



Top-of-Levee Elevation Data
Source: DWR, 2011

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Figure 40
Feather River - Right Bank (RM 7.8 to 28.7)
Maximum Water Surface Profile (2-D Model)-1957 SRFCP Design Flow

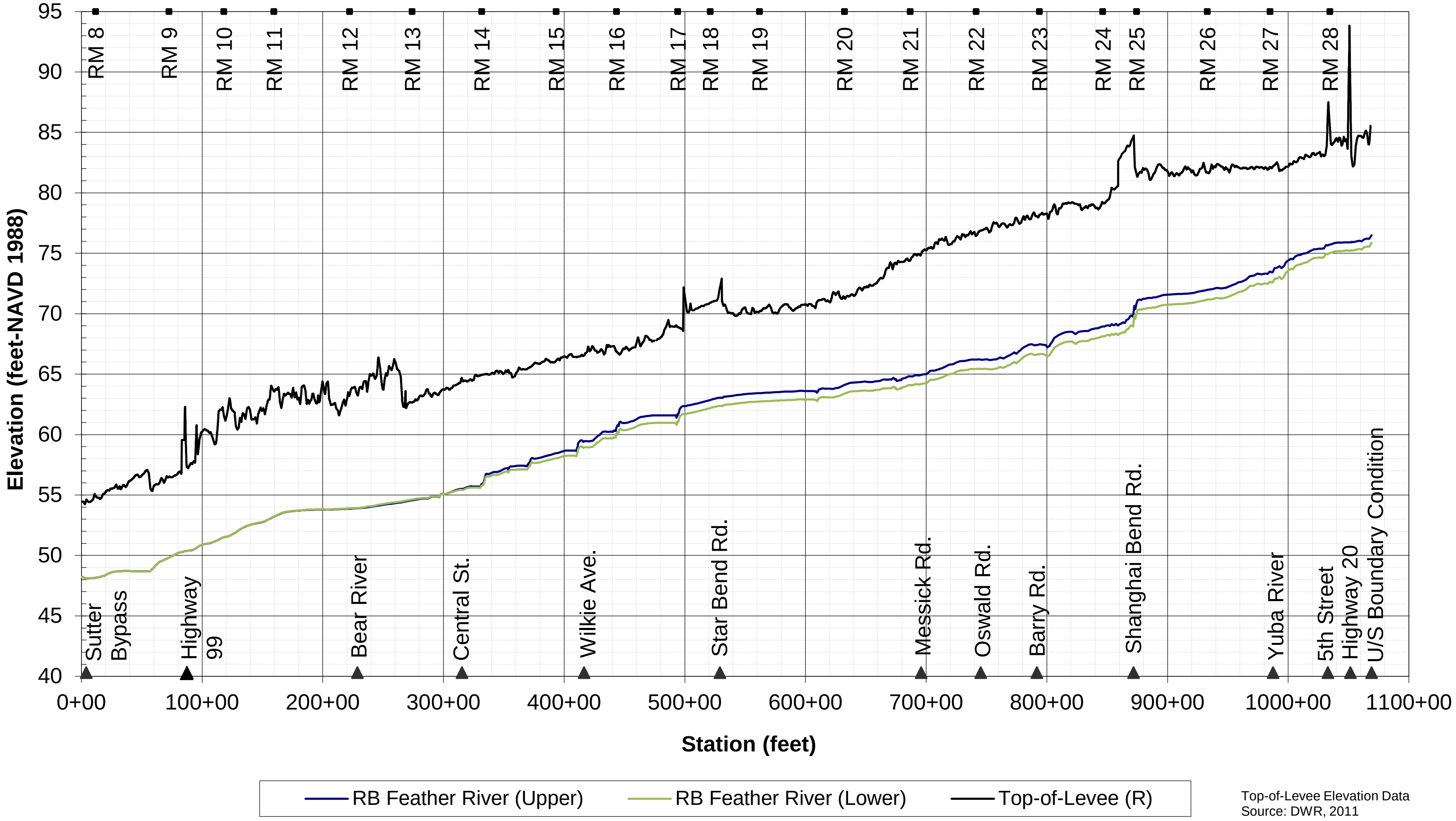

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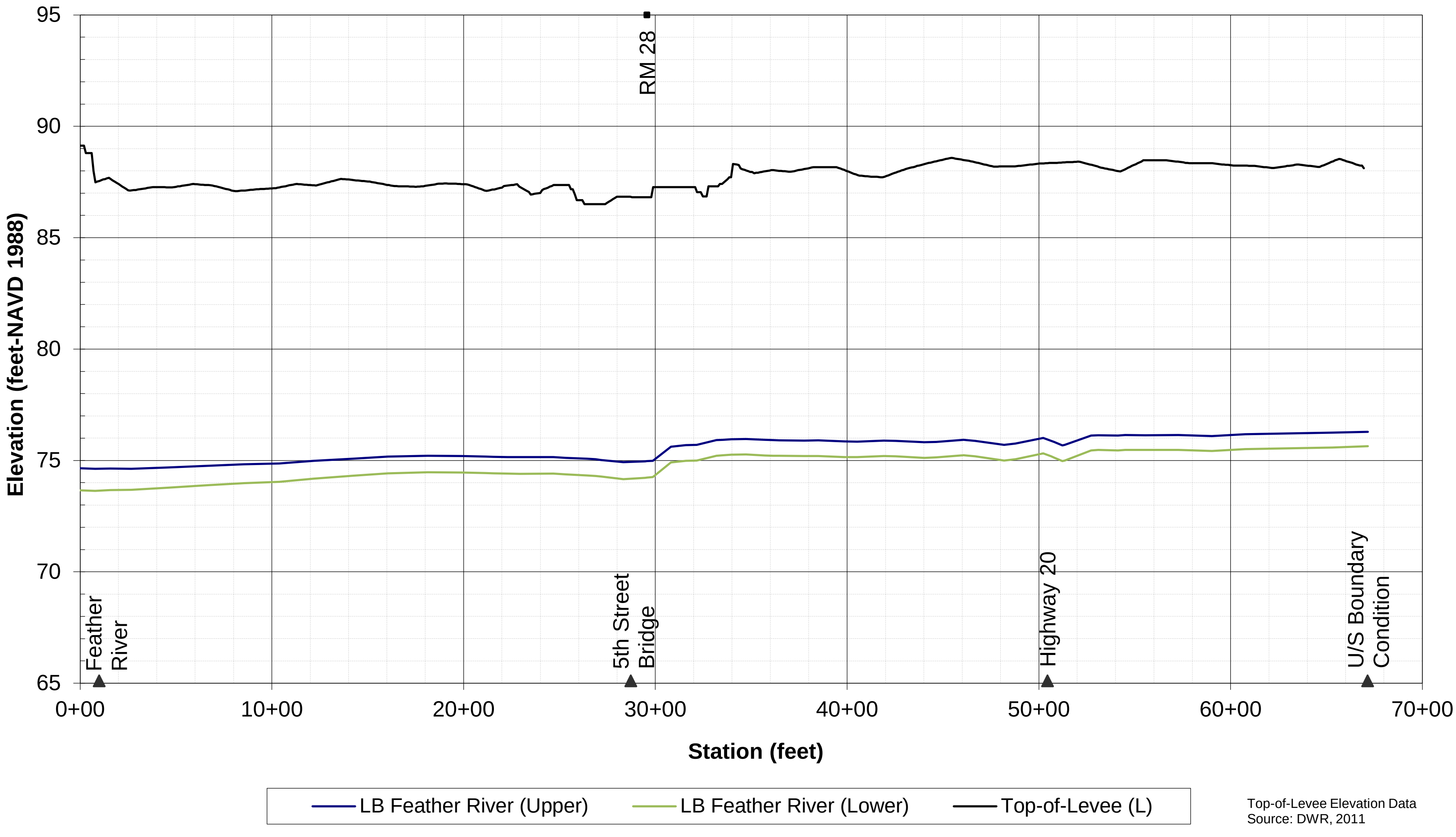
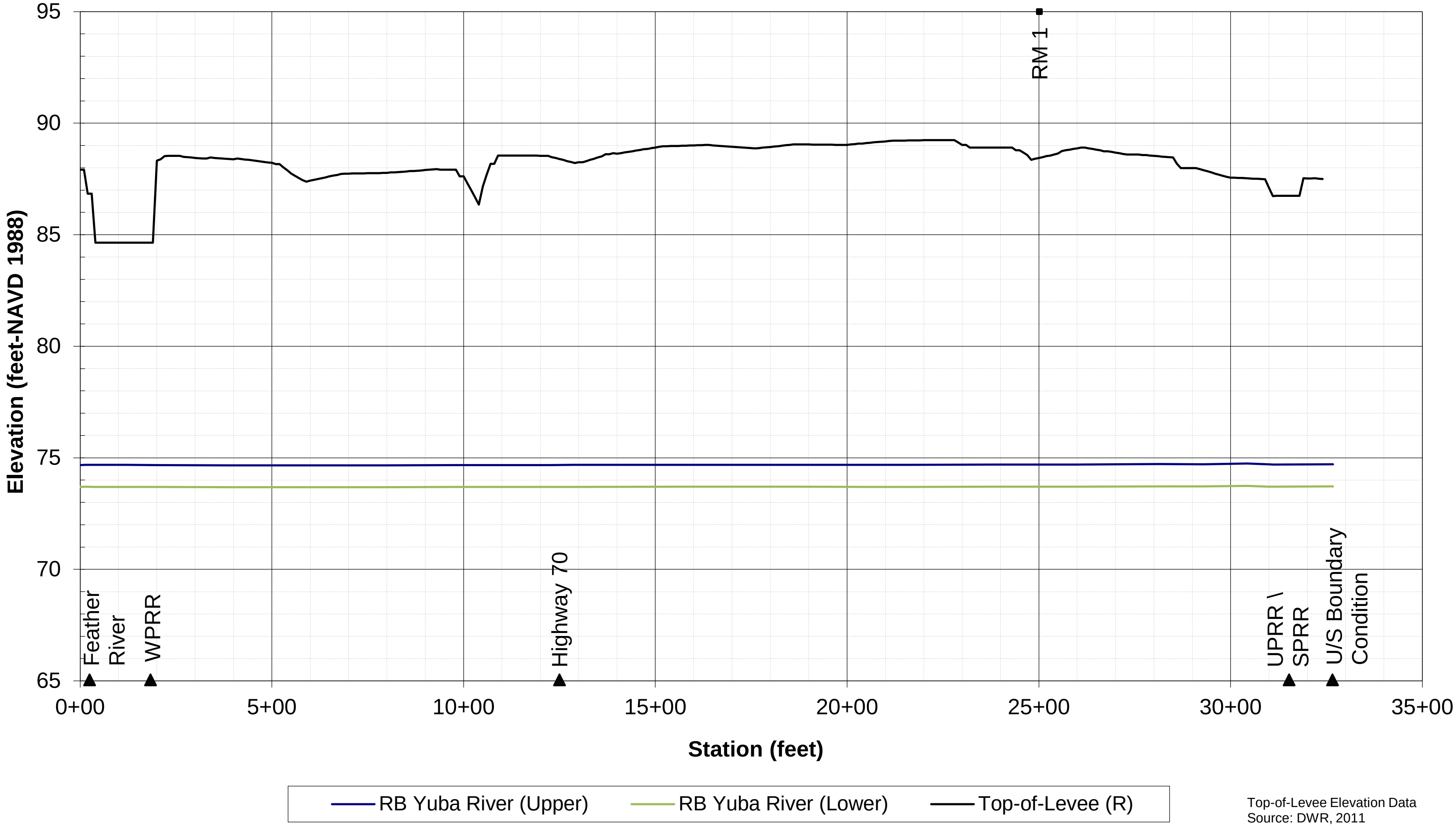
Figure 41
Feather River - Left Bank (RM 27.4 to 28.7)
Maximum Water Surface Profile (2-D Model)-1957 SRFCP Design Flow



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\1957SRFCP_Max_WS_Profile_NAVD

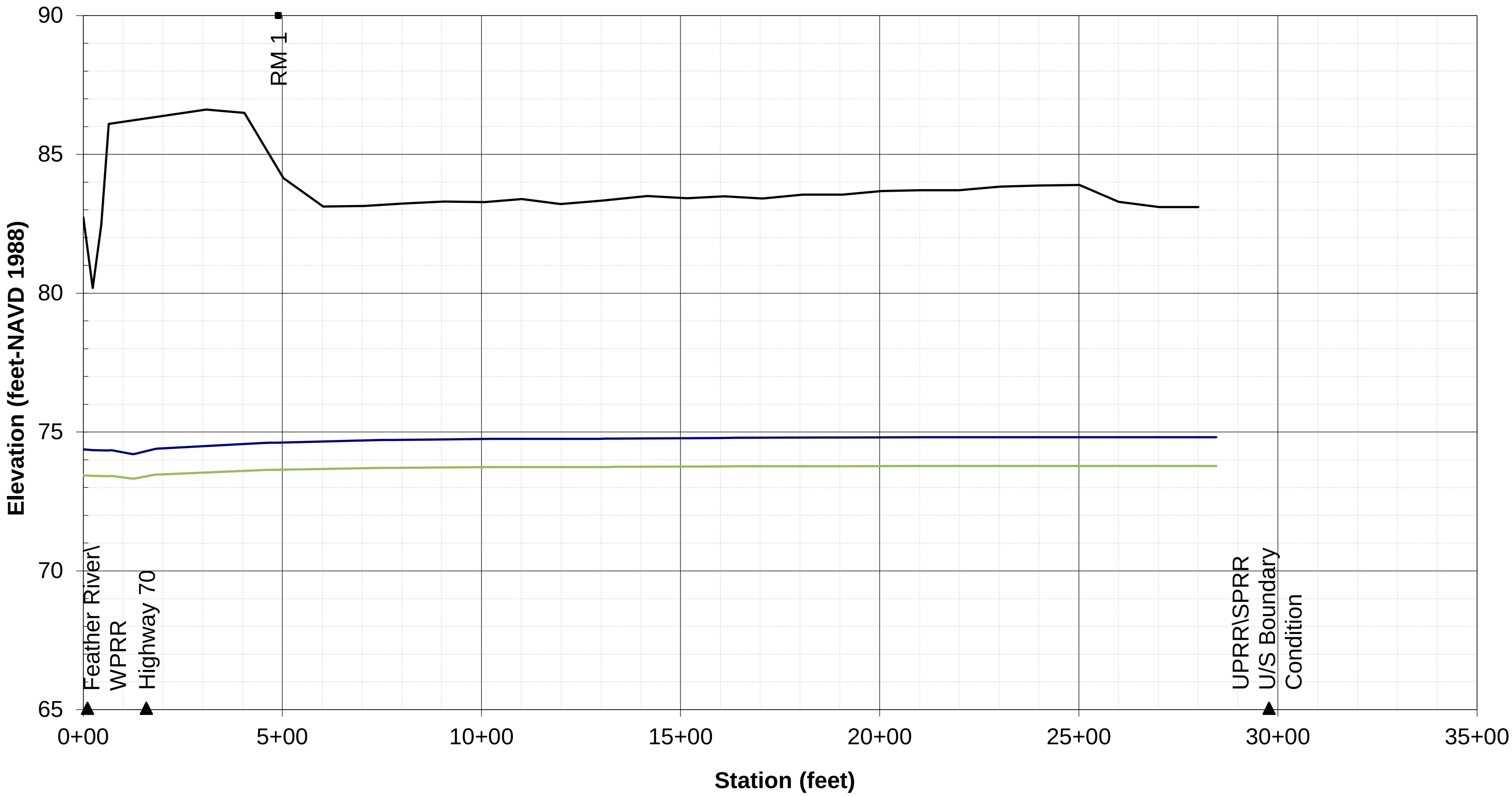
Figure 42
Yuba River - Right Bank (RM 0.3 to 1.2)
Maximum Water Surface Profile (2-D Model)-1957 SRFCP Design Flow



Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\1957SRFCP_Max_WS_Profile_NAVD

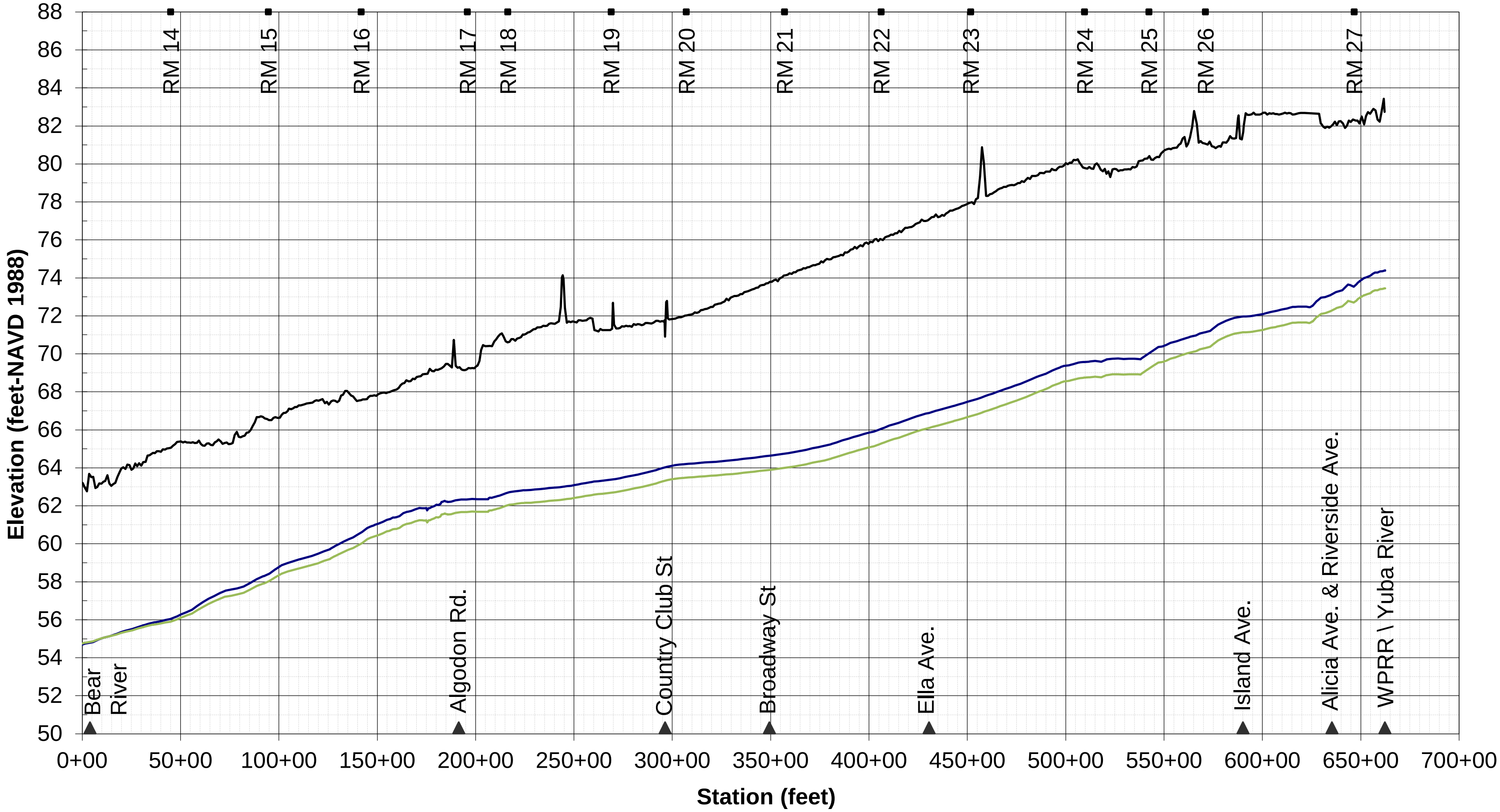
Figure 43
Yuba River - Left Bank (RM 0.3 to 1.2)
Maximum Water Surface Profile (2-D Model)-1957 SRFCP Design Flow



Top-of-Levee Elevation Data
Source: PSOMAS, 2010

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\1957SRFCP_Max_WS_Profile_NAVD

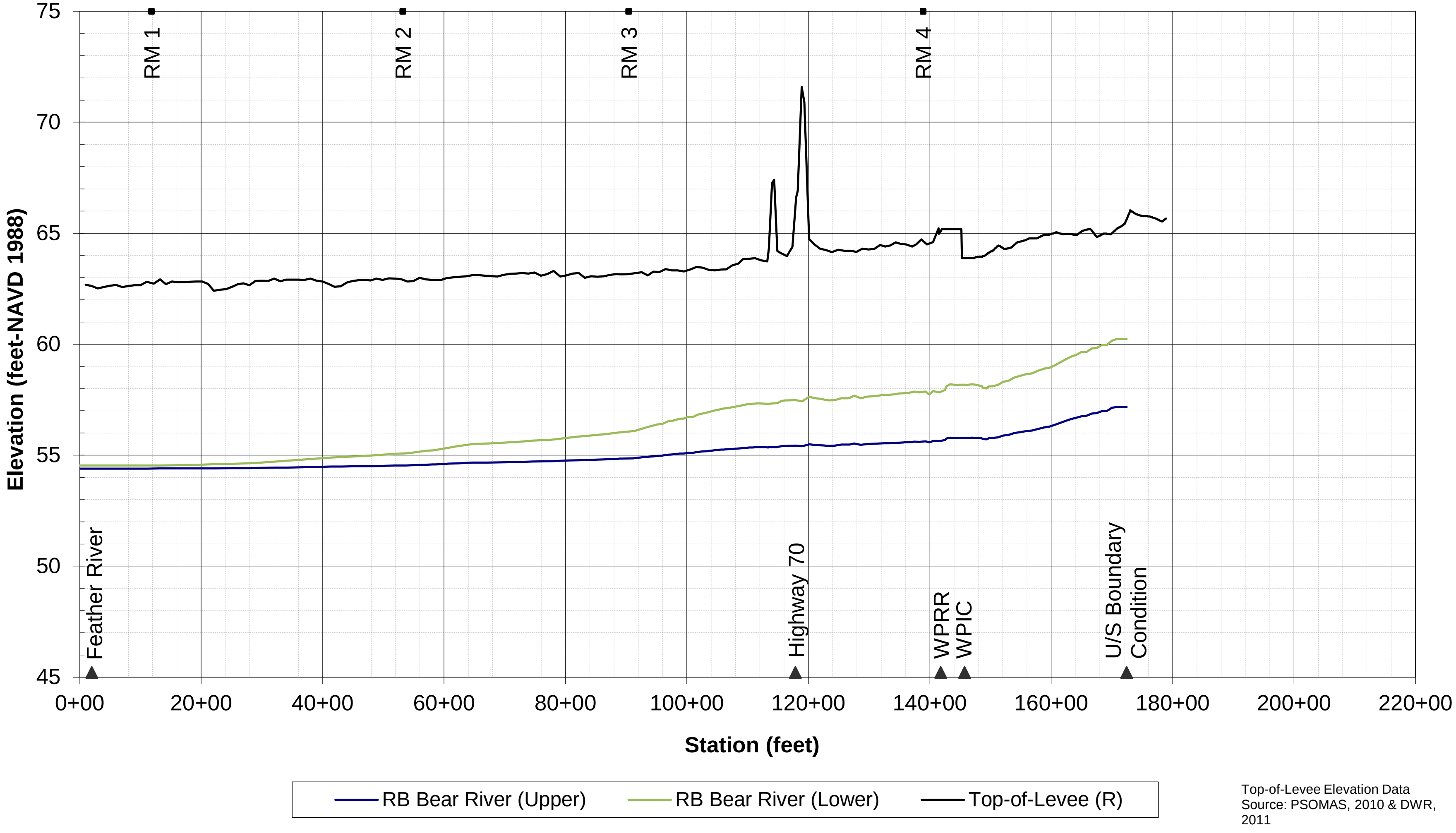
Figure 44
Feather River - Left Bank (RM 13.2 to 27.2)
Maximum Water Surface Profile (2-D Model)-1957 SRFCP Design Flow



Top-of-Levee Elevation Data
Source: PSOMAS, 2010

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\1957SRFCP_Max_WS_Profile_NAVD

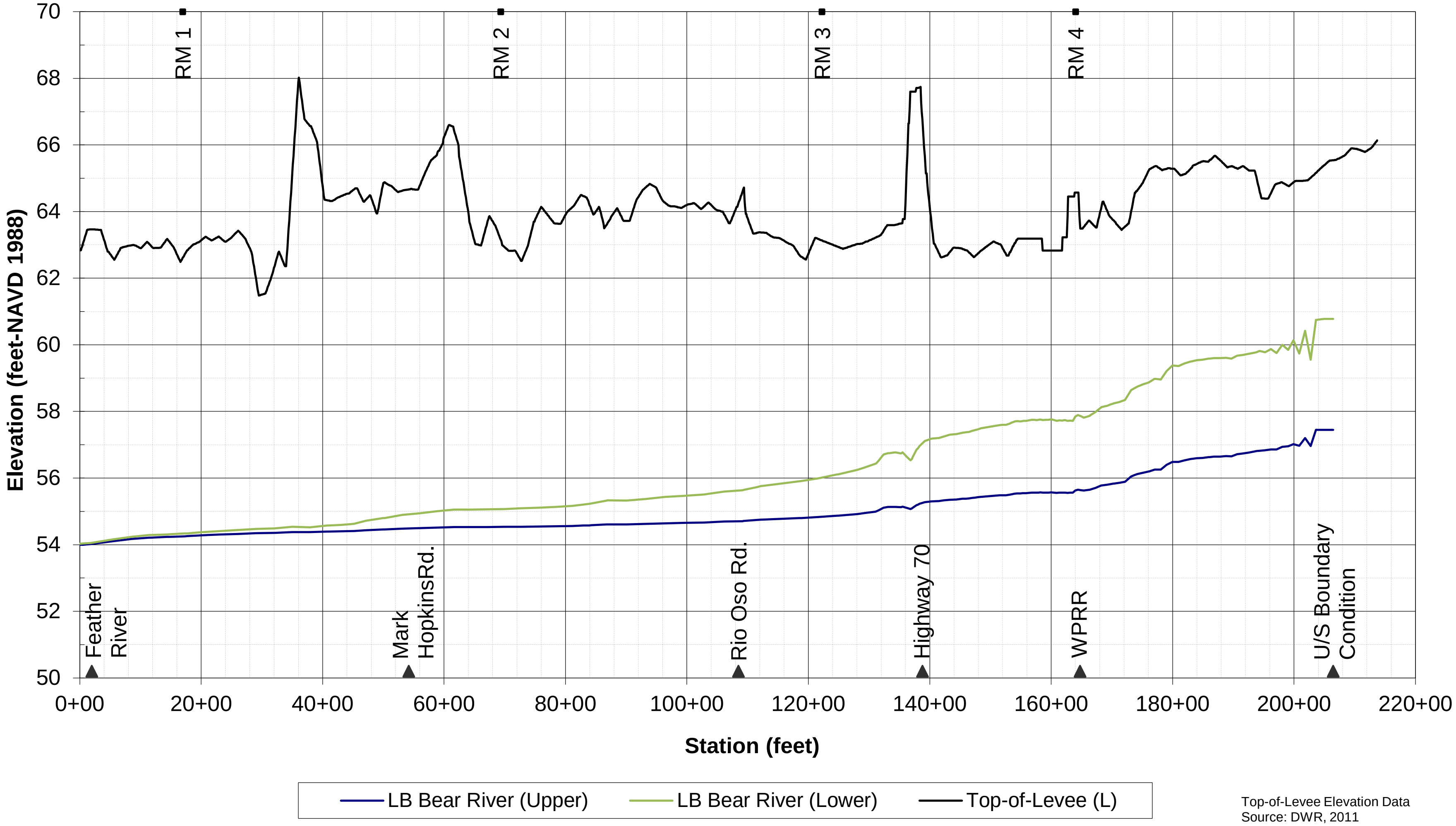
Figure 45
Bear River - Right Bank (RM 0.3 to 4.75)
Maximum Water Surface Profile (2-D Model)-1957 SRFCP Design Flow



Top-of-Levee Elevation Data Source: PSOMAS, 2010 & DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\1957SRFCP_Max_WS_Profile_NAVD

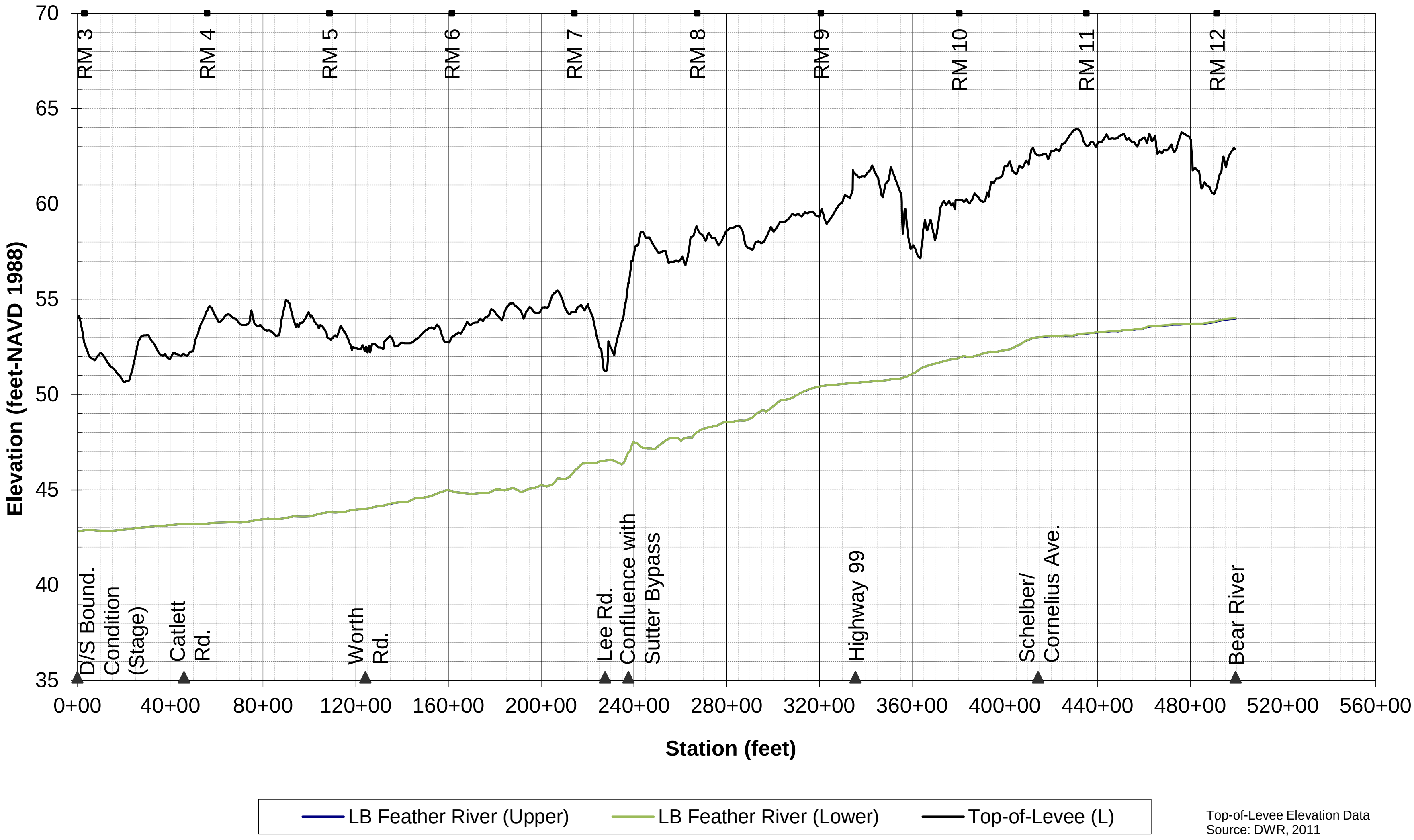
Figure 46
Bear River - Left Bank (RM 0.3 to 4.75)
Maximum Water Surface Profile (2-D Model)-1957 SRFCP Design Flow



Top-of-Levee Elevation Data
Source: DWR, 2011

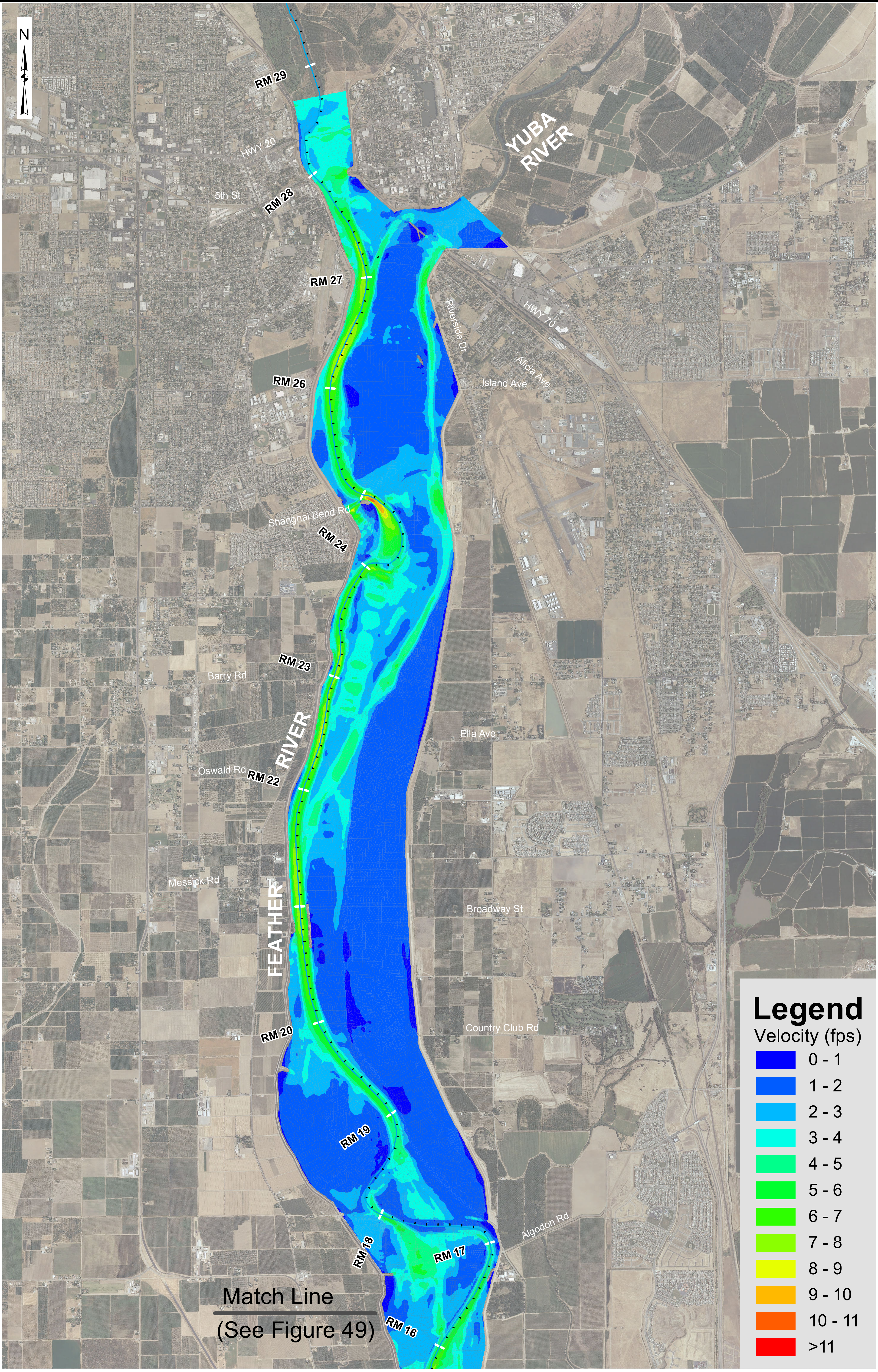
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\1957SRFCP_Max_WS_Profile_NAVD

Figure 47
Feather River - Left Bank (RM 2.9 to 12.2)
Maximum Water Surface Profile (2-D Model)-1957 SRFCP Design Flow



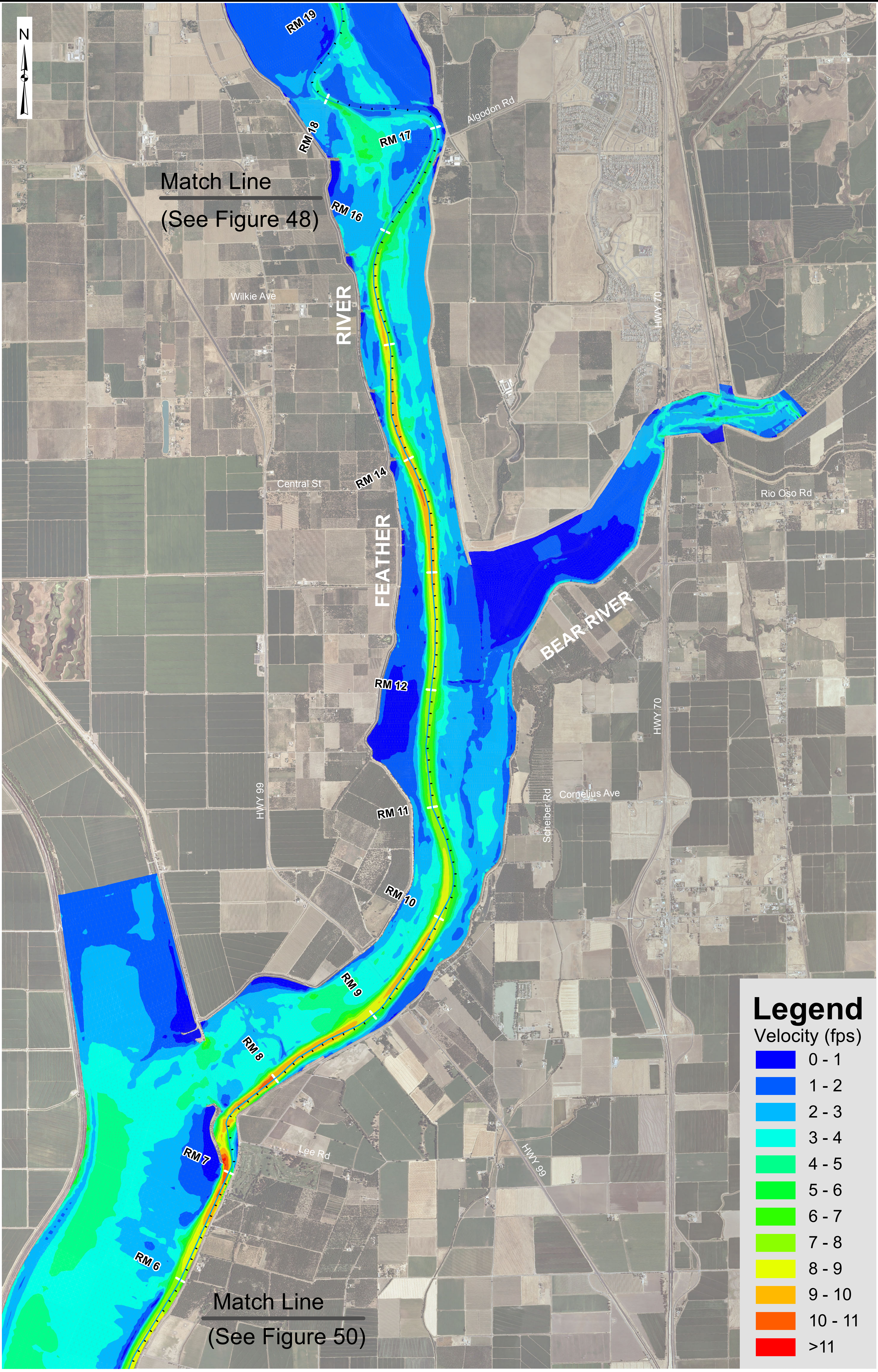
Top-of-Levee Elevation Data
Source: DWR, 2011

R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\1957SRFCP_Max_WS_Profile_NAVD



MBK ENGINEERS 1771 Tribute Road, Suite A Sacramento, California 95815-4401 (916) 456-4400	Baseline Condition 1-in-100 AEP Velocity Contours (Lower Feather Centering)	0 4,000 Scale in Feet	Figure 48

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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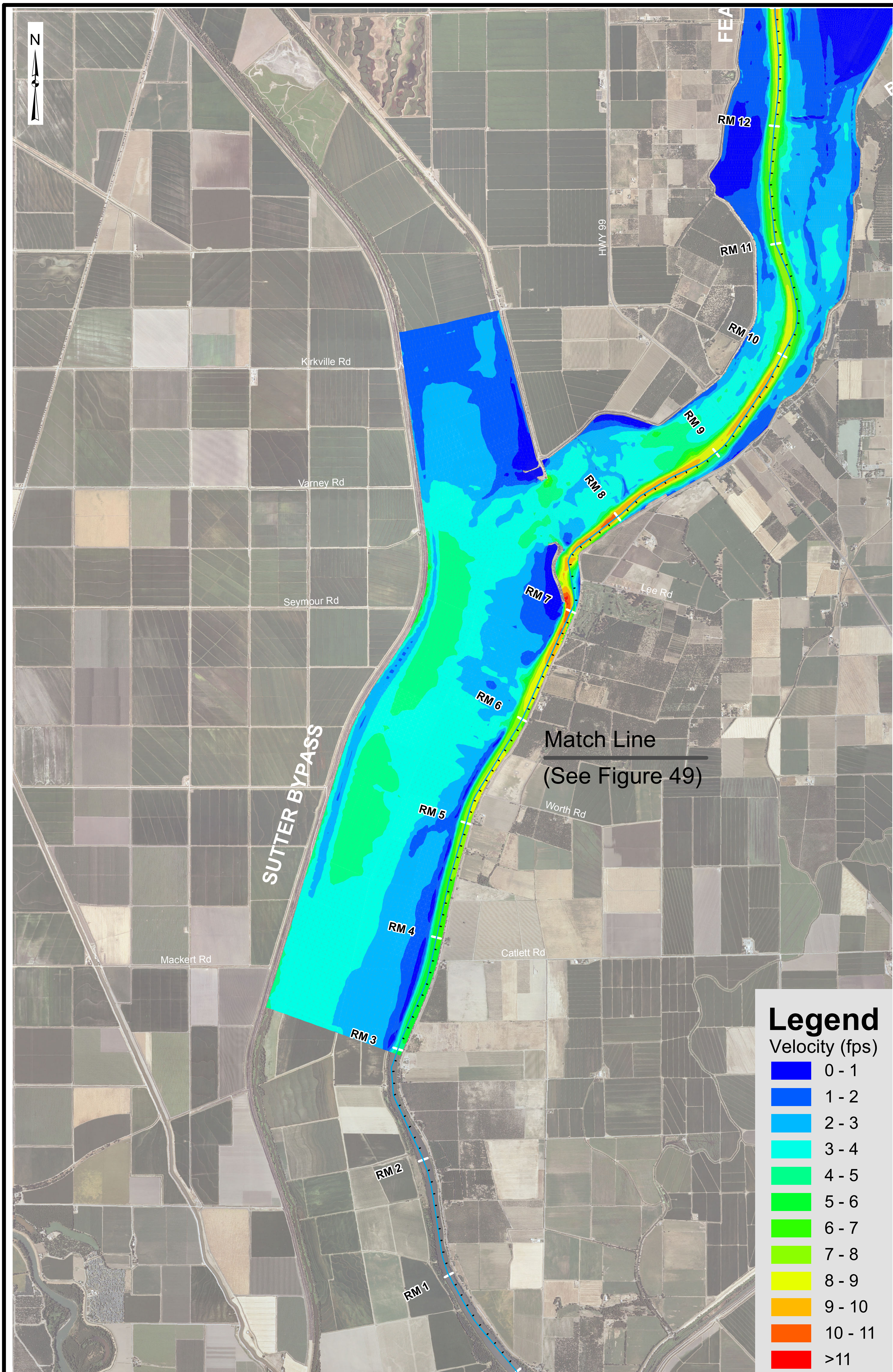
Baseline Condition 1-in-100 AEP
Velocity Contours (Lower Feather Centering)

0 4,000
Scale in Feet

Figure 49



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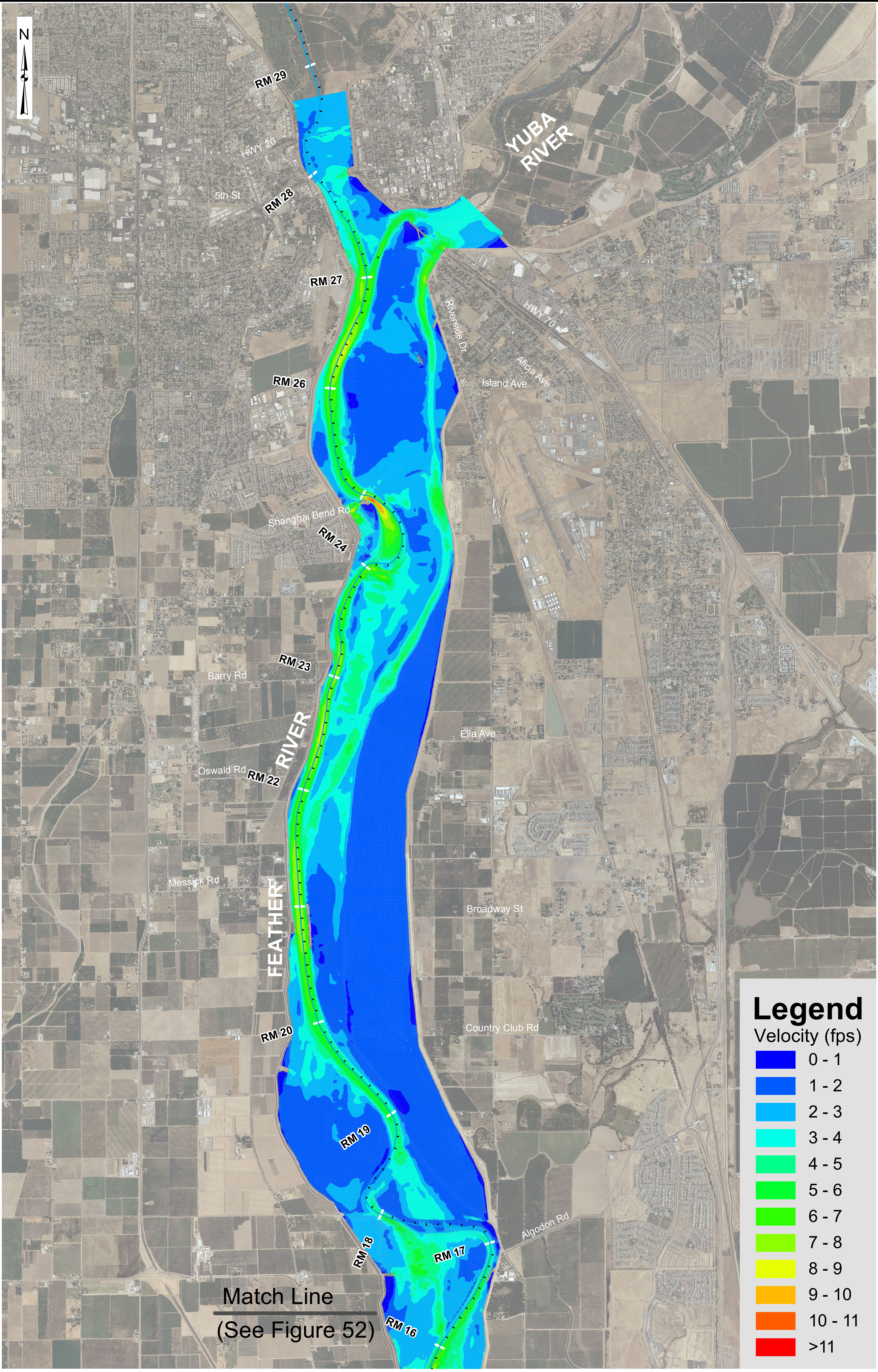
Baseline Condition 1-in-100 AEP
Velocity Contours (Lower Feather Centering)

0 4,000
Scale in Feet

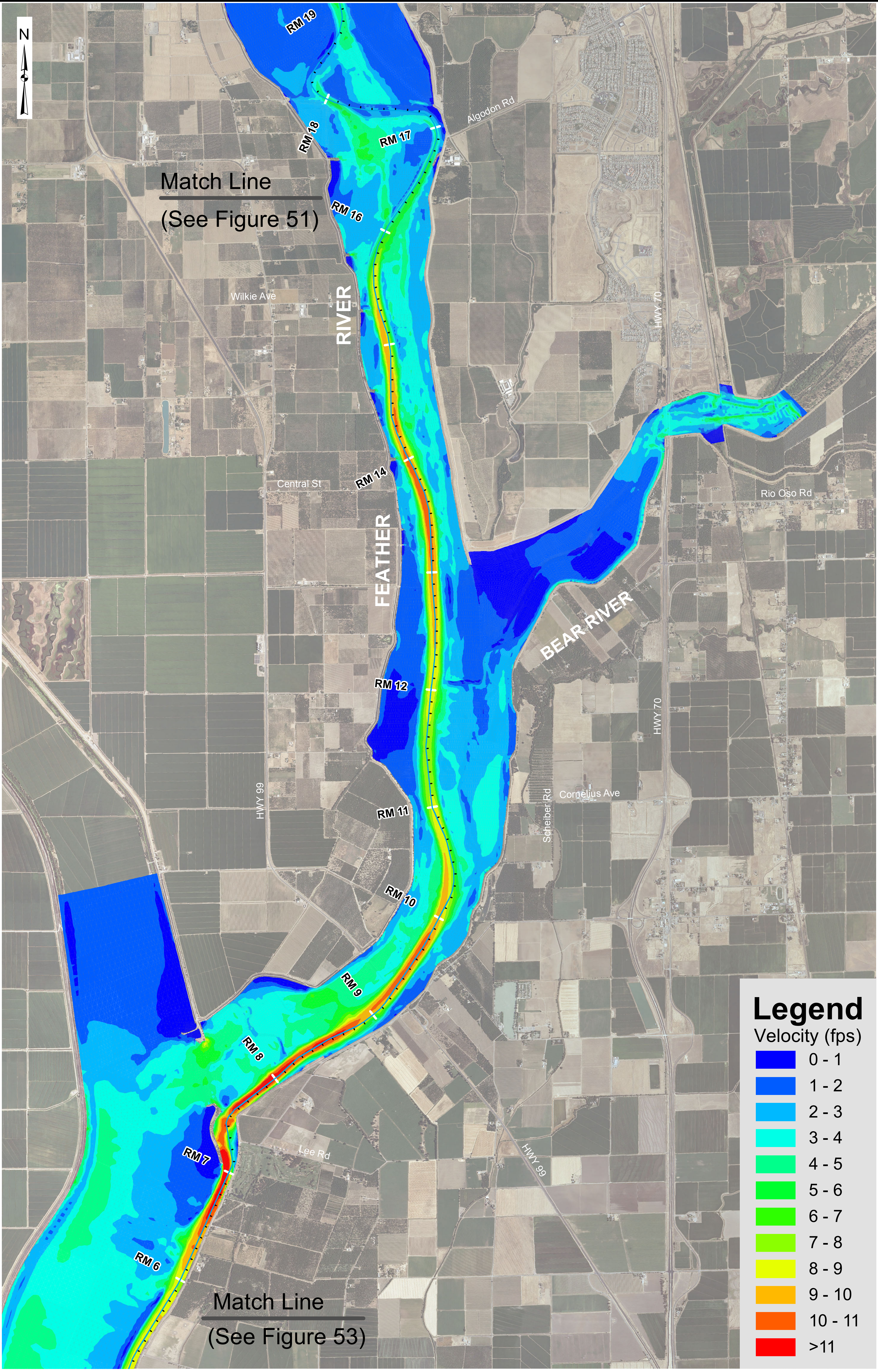
Figure 50

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



MBK ENGINEERS 1771 Tribute Road, Suite A Sacramento, California 95815-4401 (916) 456-4400	Baseline Condition 1-in-100 AEP Velocity Contours (Upper Feather Centering)	0 — 4,000 Scale in Feet	Figure 51

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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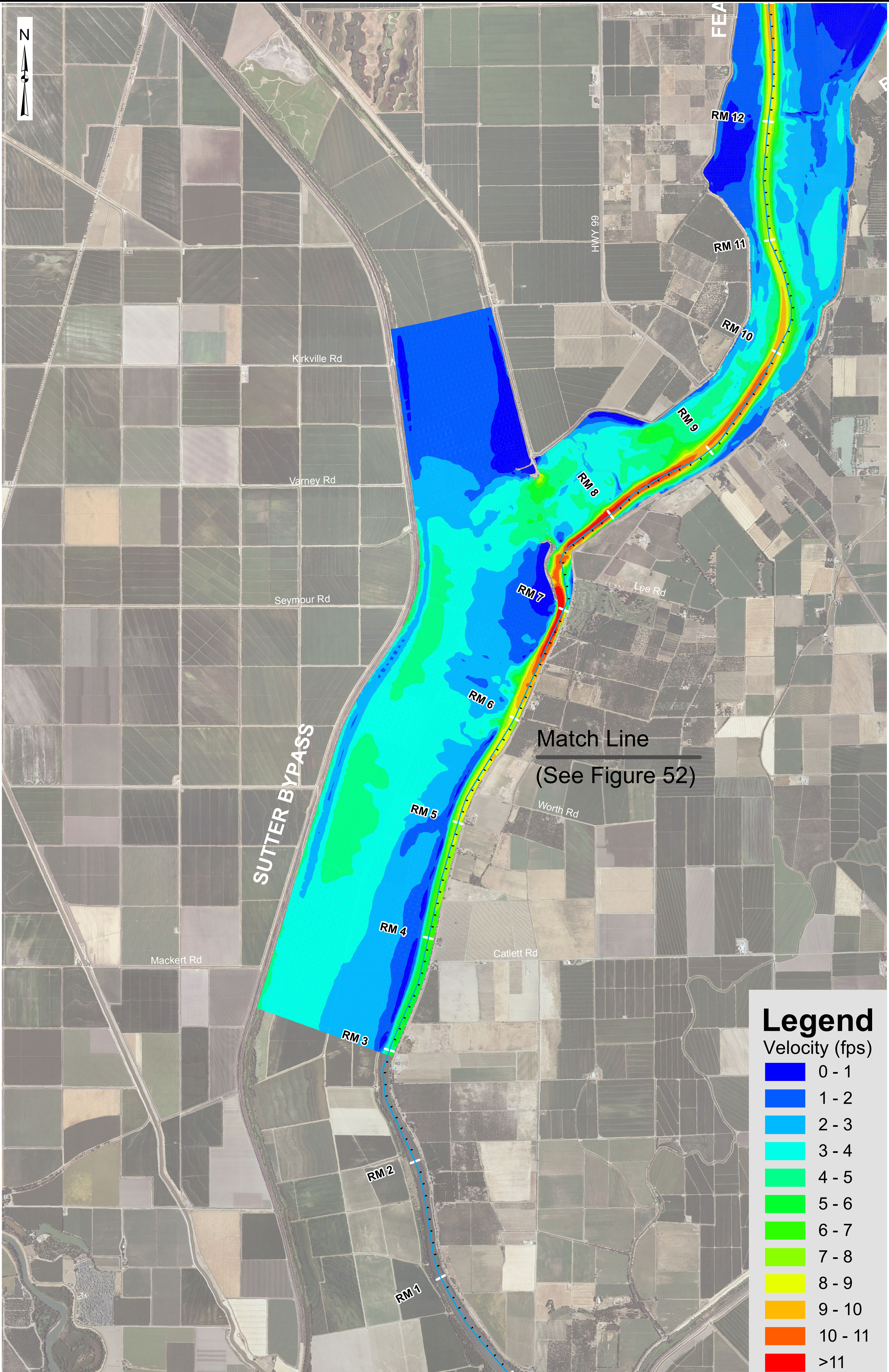
Baseline Condition 1-in-100 AEP
Velocity Contours (Upper Feather Centering)

0 4,000
Scale in Feet

Figure 52

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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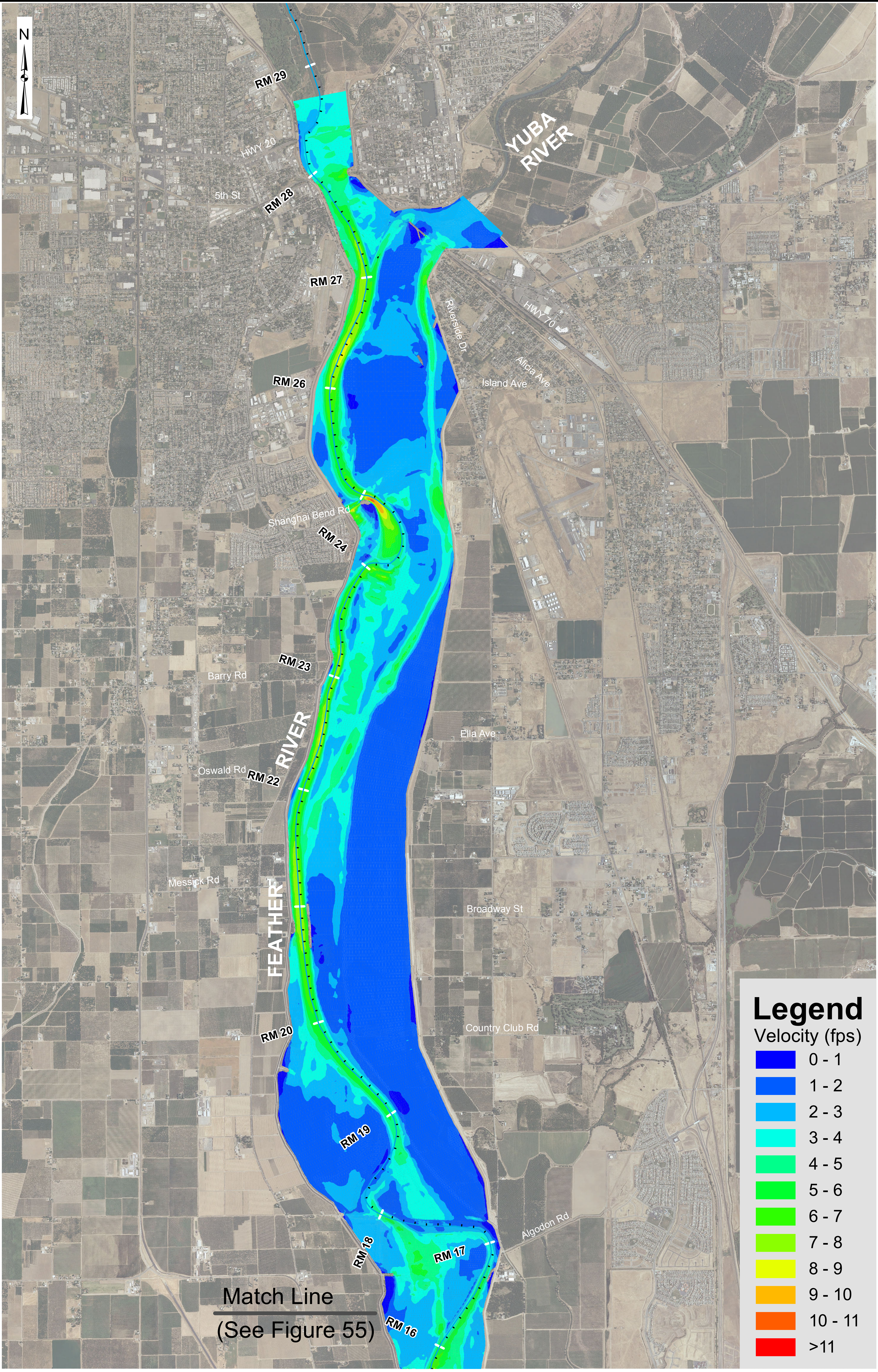
Baseline Condition 1-in-100 AEP
Velocity Contours (Upper Feather Centering)

0 4,000
Scale in Feet

Figure 53

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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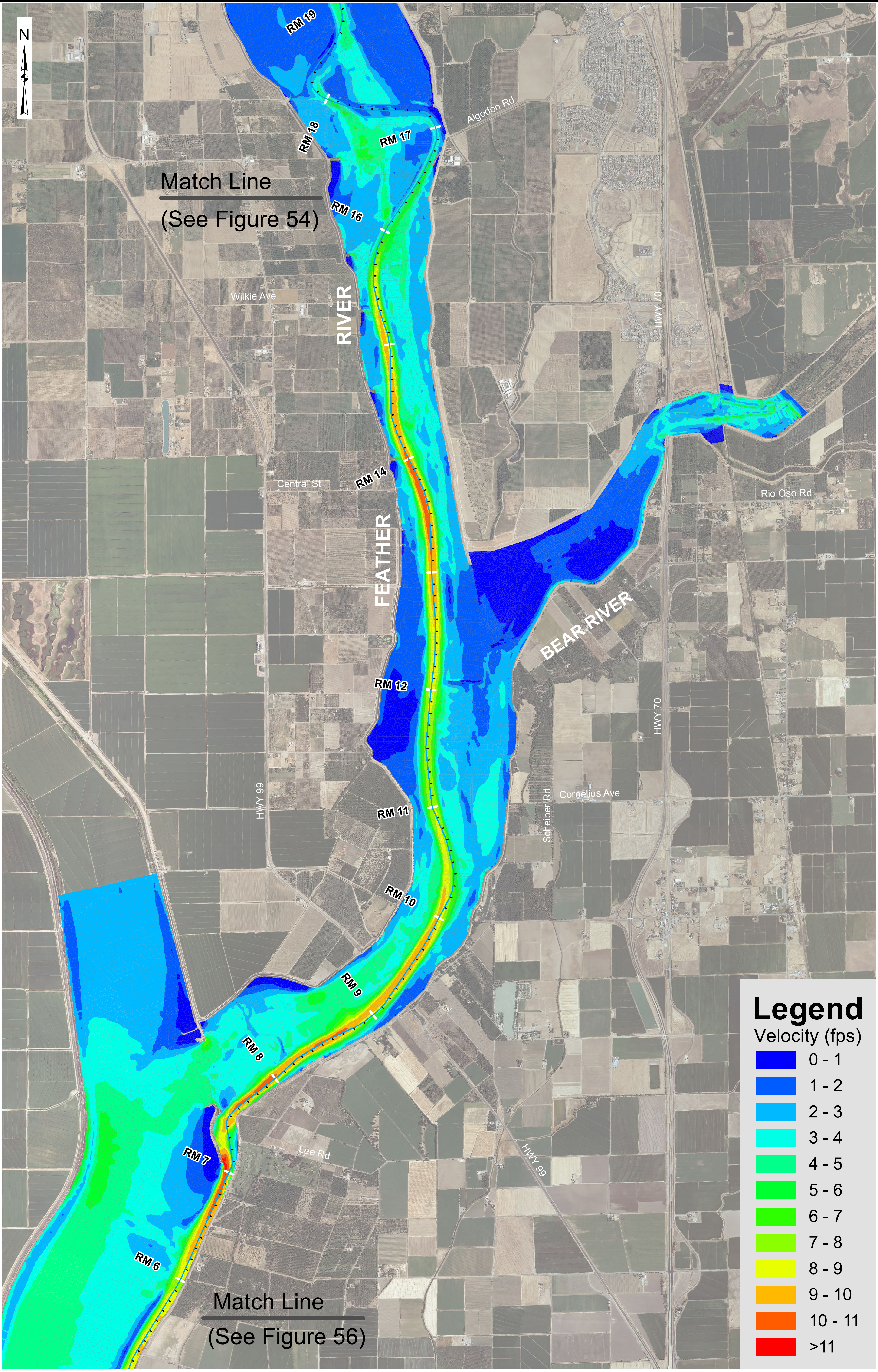
Baseline Condition 1-in-200 AEP
Velocity Contours (Lower Feather Centering)

0 4,000
Scale in Feet

Figure 54

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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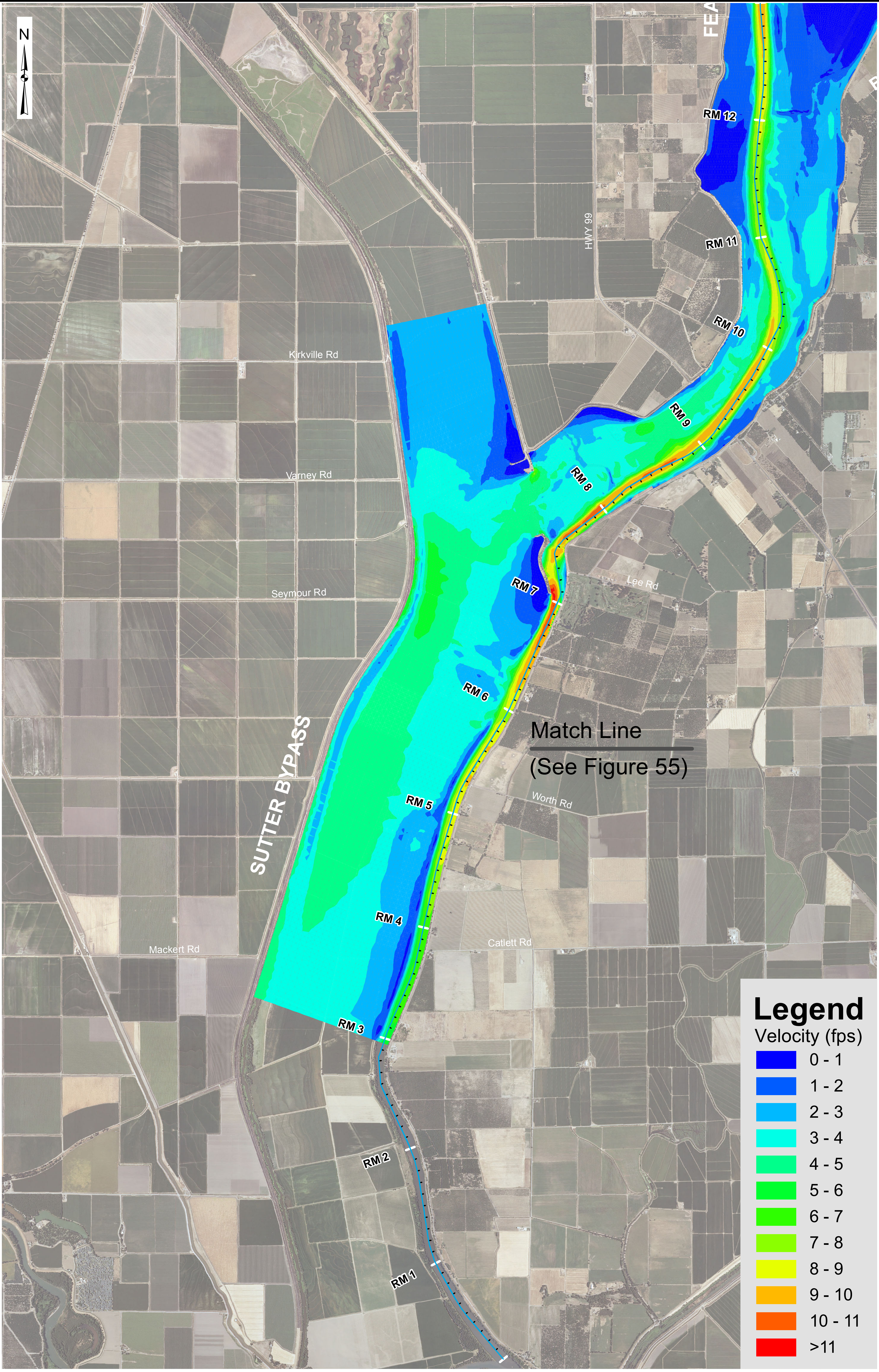
Baseline Condition 1-in-200 AEP
Velocity Contours (Lower Feather Centering)

0 4,000
Scale in Feet

Figure 55

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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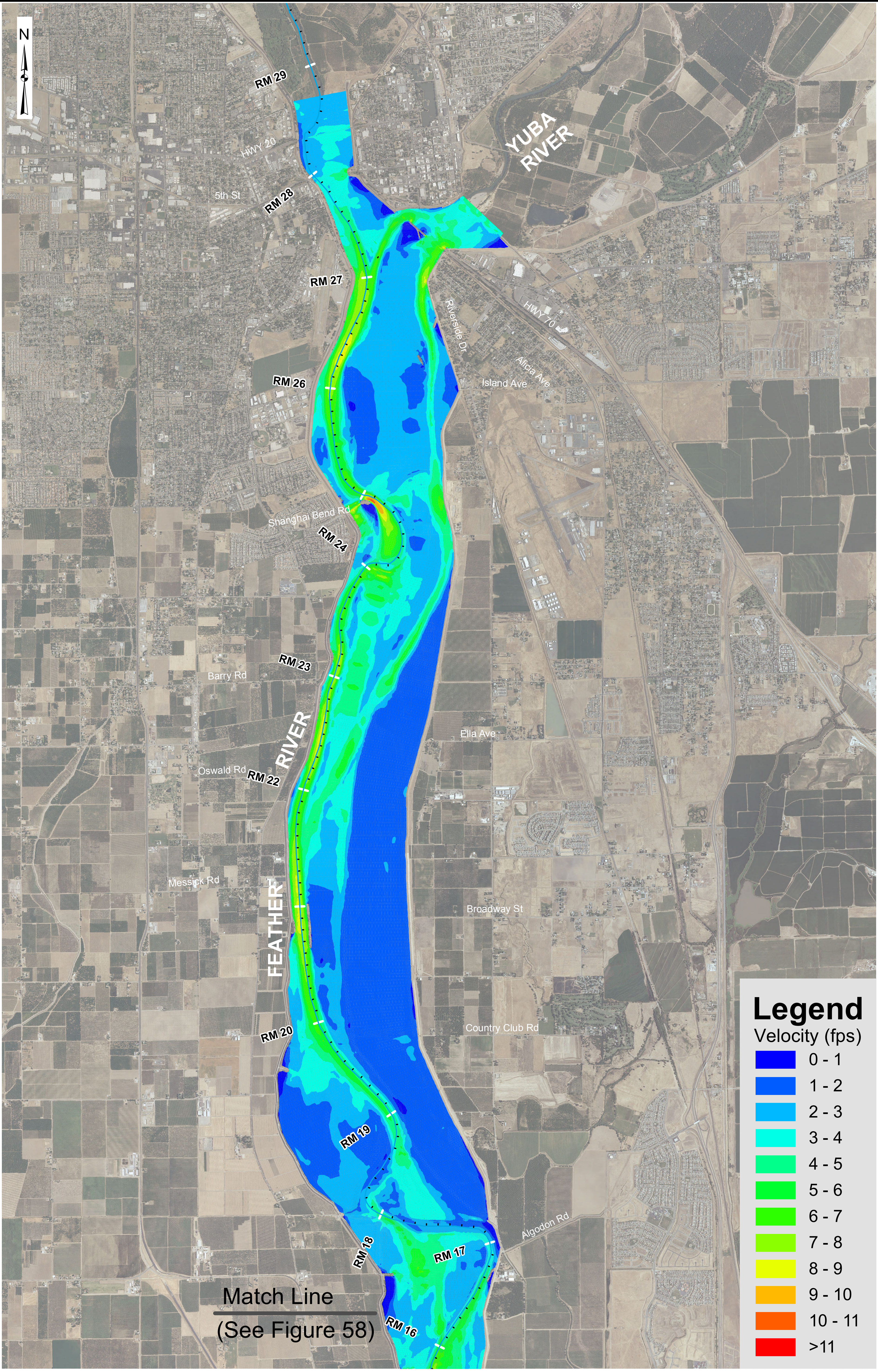
Baseline Condition 1-in-200 AEP
Velocity Contours (Lower Feather Centering)

0 4,000
Scale in Feet

Figure 56

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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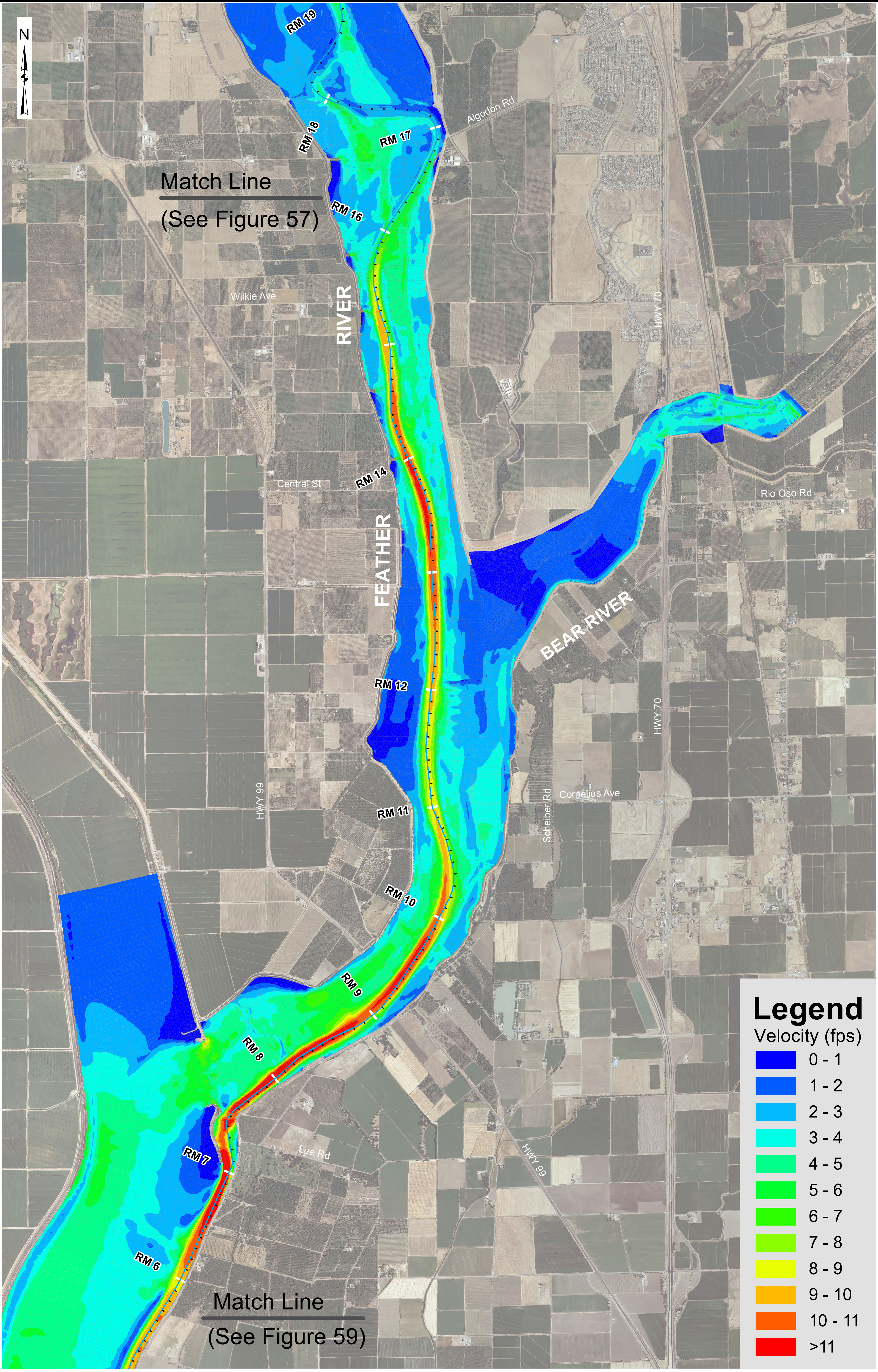
Baseline Condition 1-in-200 AEP
Velocity Contours (Upper Feather Centering)

Figure 57

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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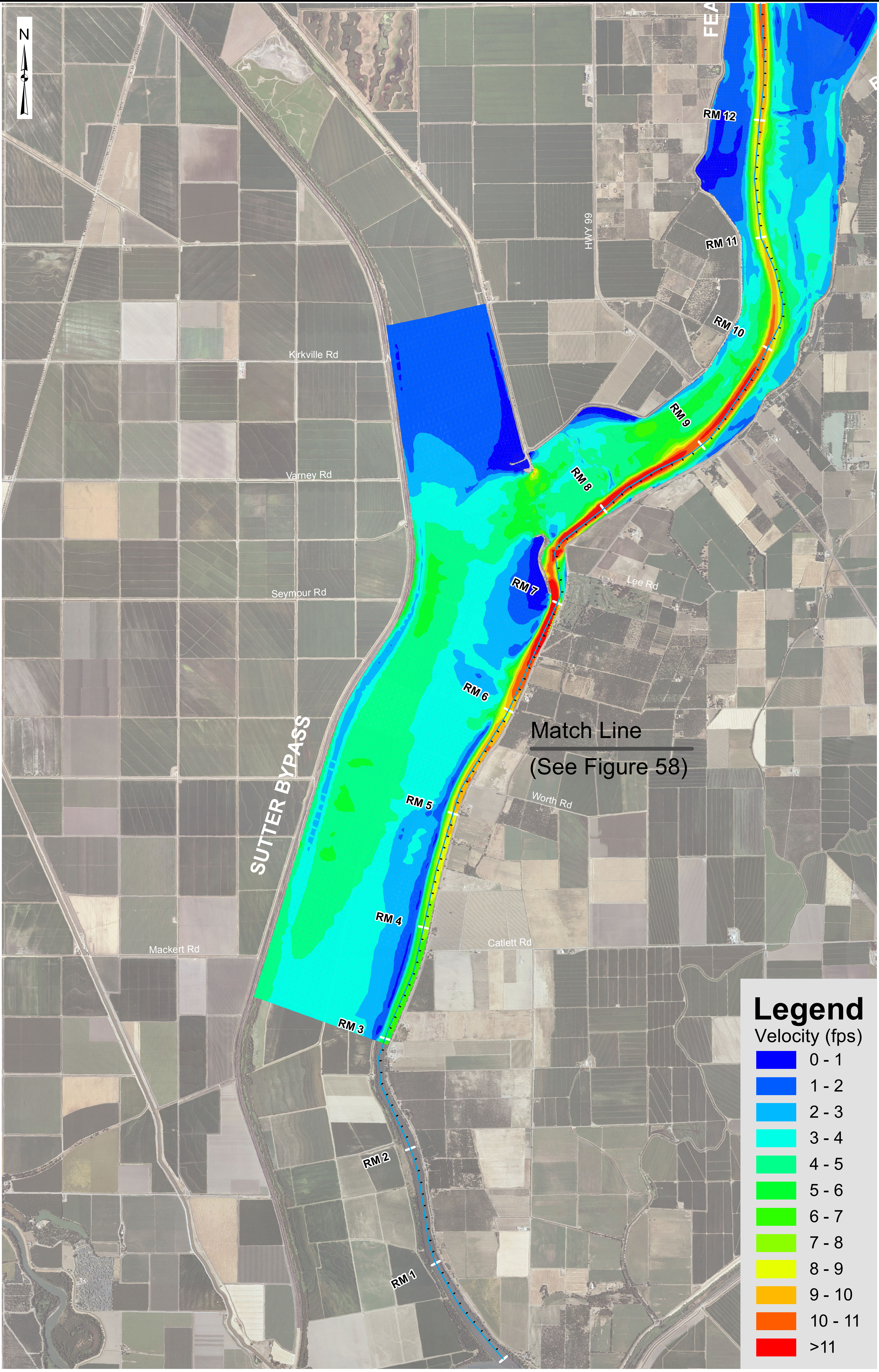
Baseline Condition 1-in-200 AEP
Velocity Contours (Upper Feather Centering)

0 4,000
Scale in Feet

Figure 58

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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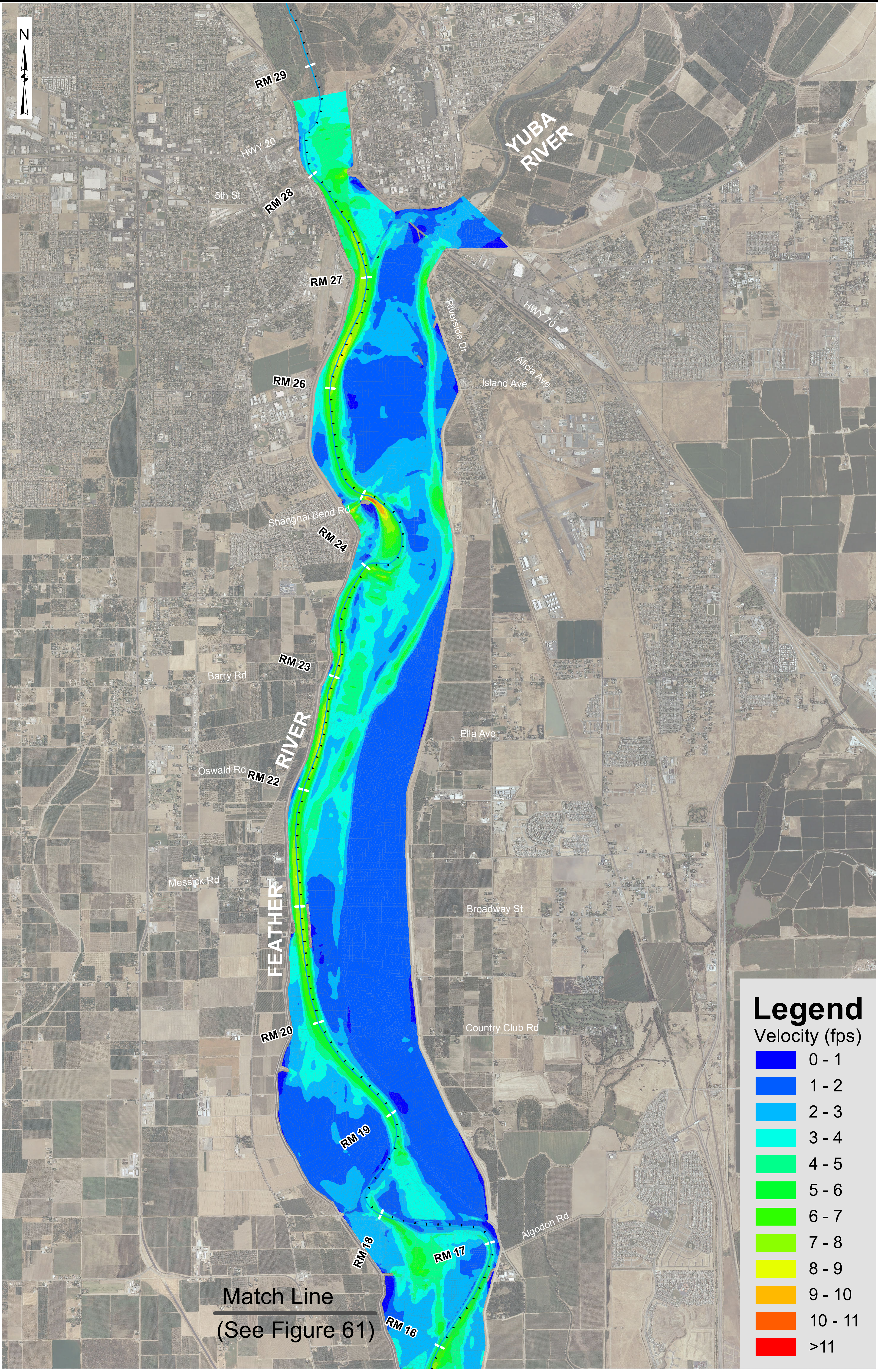
Baseline Condition 1-in-200 AEP
Velocity Contours (Upper Feather Centering)

0 4,000
Scale in Feet

Figure 59

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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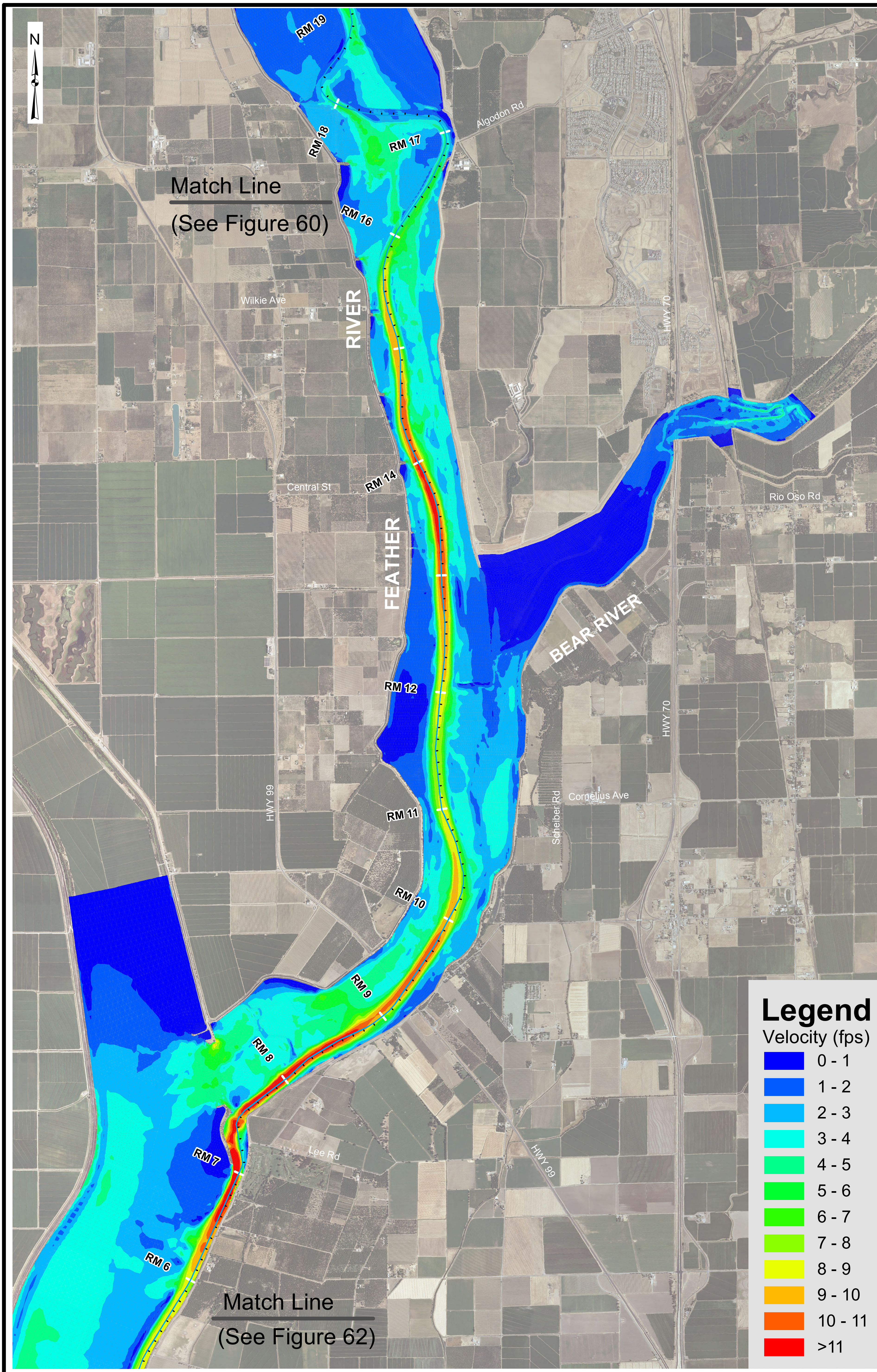
Baseline Condition 1957 SRFCP Design Flow Velocity Contours (Upper Feather Centering)

0 4,000
Scale in Feet

Figure 60

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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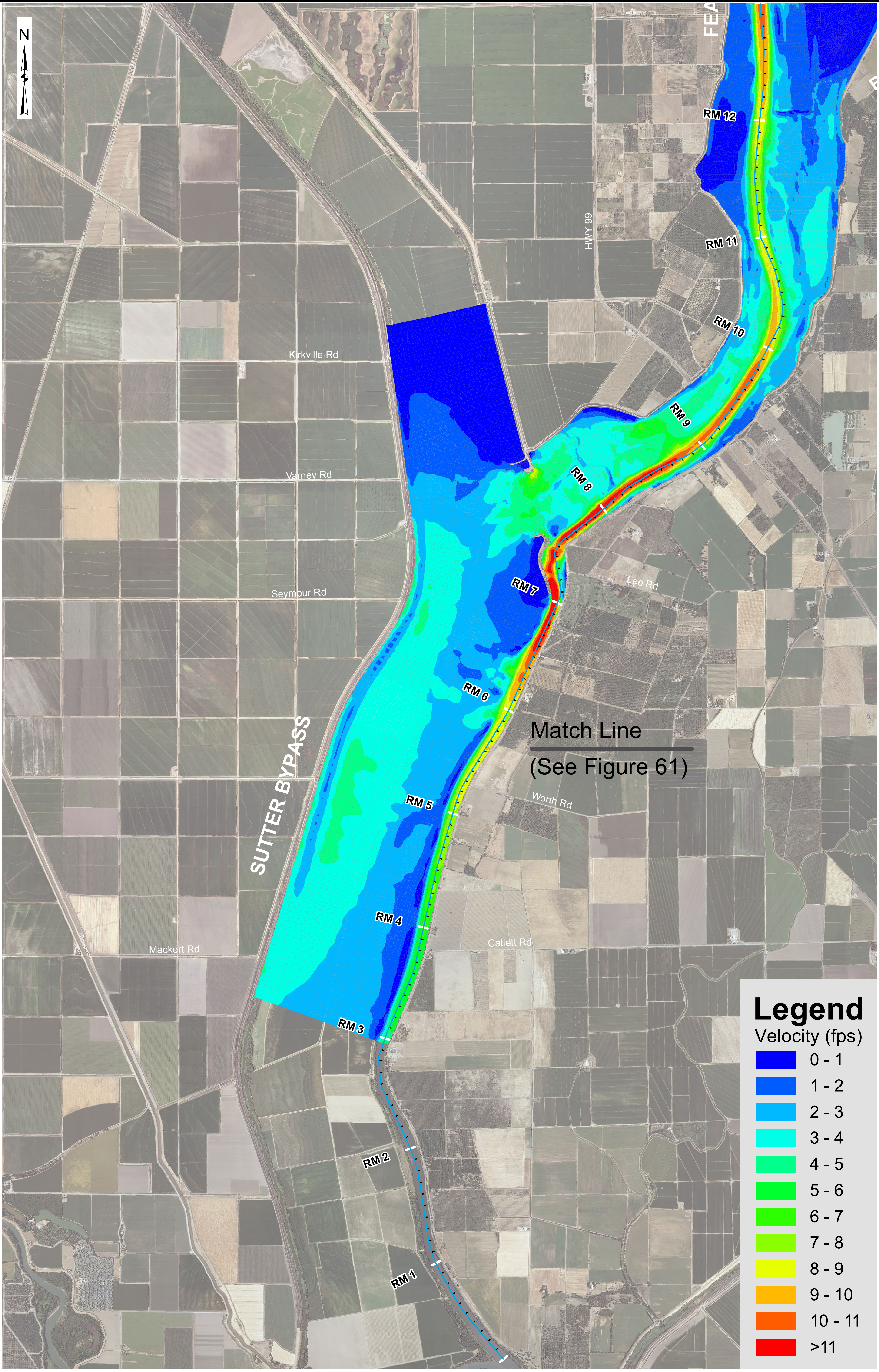
Baseline Condition 1957 SRFCP Design Flow Velocity Contours (Upper Feather Centering)

Figure 61

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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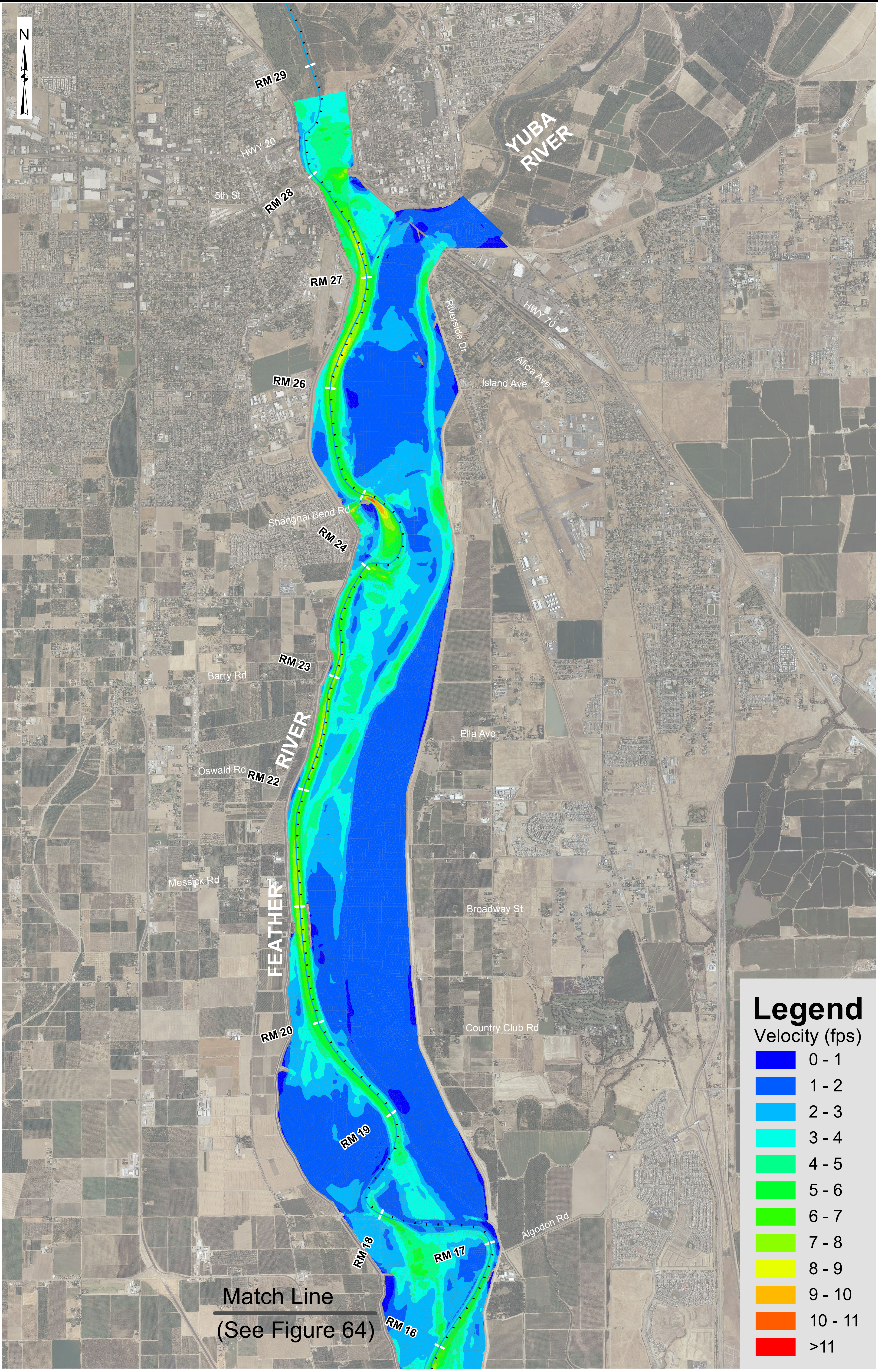
Baseline Condition 1957 SRFCP Design Flow
Velocity Contours (Upper Feather Centering)

0 4,000
Scale in Feet

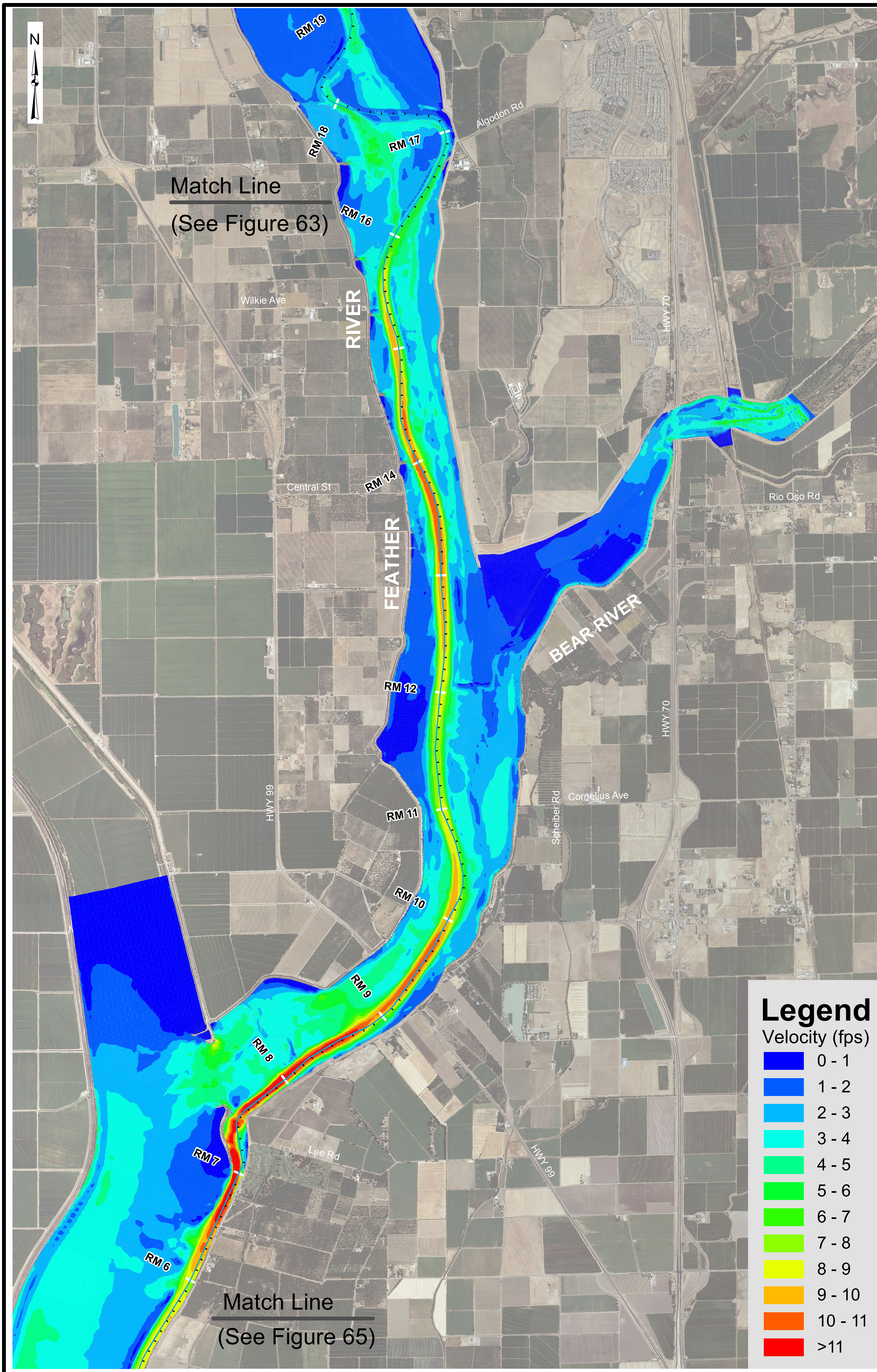
Figure 62

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



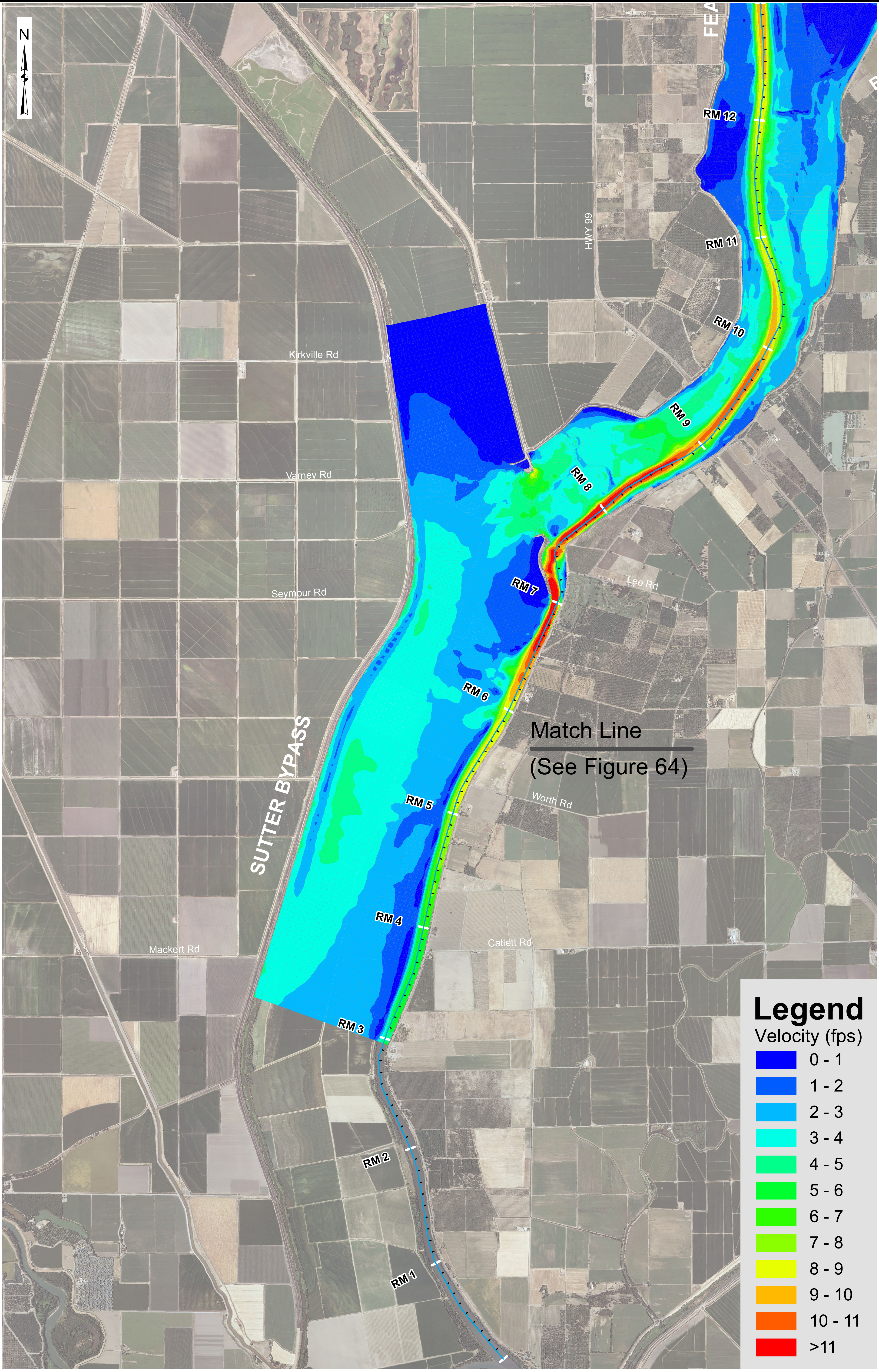
MBK ENGINEERS — 1771 Tribute Road, Suite A, Sacramento, California 95815-4401, (916) 456-4400	**Baseline Condition 1957 SRFCP Design Flow Velocity Contours (Lower Feather Centering)**	0 — 4,000 Scale in Feet	**Figure 63**

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



MBK ENGINEERS 1771 Tribute Road, Suite A Sacramento, California 95815-4401 (916) 456-4400	**Baseline Condition 1957 SRFCP Design Flow** **Velocity Contours (Lower Feather Centering)**	0 4,000 Scale in Feet	**Figure 64**

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd



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Baseline Condition 1957 SRFCP Design Flow Velocity Contours (Lower Feather Centering)

0 4,000
Scale in Feet

Figure 65

Tuesday, January 10, 2012
R:\1403 AECOM-LFRCMP\SMS\Baseline Condition\RMA2_LFRCMP_Baseline_Arc10.mxd