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RECLAMATION

Managing Water in the West

Hydrology, Hydraulics, and Sediment Studies for the Meiners Oaks and Live Oak Levees - DRAFT Report

Matilija Dam Ecosystem Restoration Project, Ventura, CA



**U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado**

July 2007

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Hydrology, Hydraulics, and Sediment Studies for the Meiners Oaks and Live Oak Levees - DRAFT Report

Matilija Dam Ecosystem Restoration Project, Ventura, CA

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**U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado**

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Executive Summary

The Sedimentation and River Hydraulics Group of the Denver Technical Service Center US Bureau of Reclamation was requested by the Los Angeles District of the Army Corp of Engineers to complete a hydrology, hydraulics, and sedimentation study to support the design and/or improvement of two levees located along the Ventura River, Ventura, CA. The levee improvements are being constructed as part of the Matilija Dam Ecosystem Restoration Project to mitigate flood impacts from the project.

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1. Introduction

The Sedimentation and River Hydraulics Group of the Denver Technical Service Center US Bureau of Reclamation was requested by the Los Angeles District of the Army Corp of Engineers to complete a hydrology, hydraulics, and sedimentation study to support the design and/or improvement of two levees located along the Ventura River, Ventura, CA. The levee improvements are being constructed as part of the Matilija Dam Ecosystem Restoration Project to mitigate flood impacts from the project.

Throughout this document, the “Project” refers to the removal of Matilija Dam. Therefore, “Without-Project” refers to the conditions if Matilija Dam remains in place and “With-Project” refers to the conditions if Matilija Dam is removed.

All elevations in this report are given in NAVD 88 unless otherwise noted.

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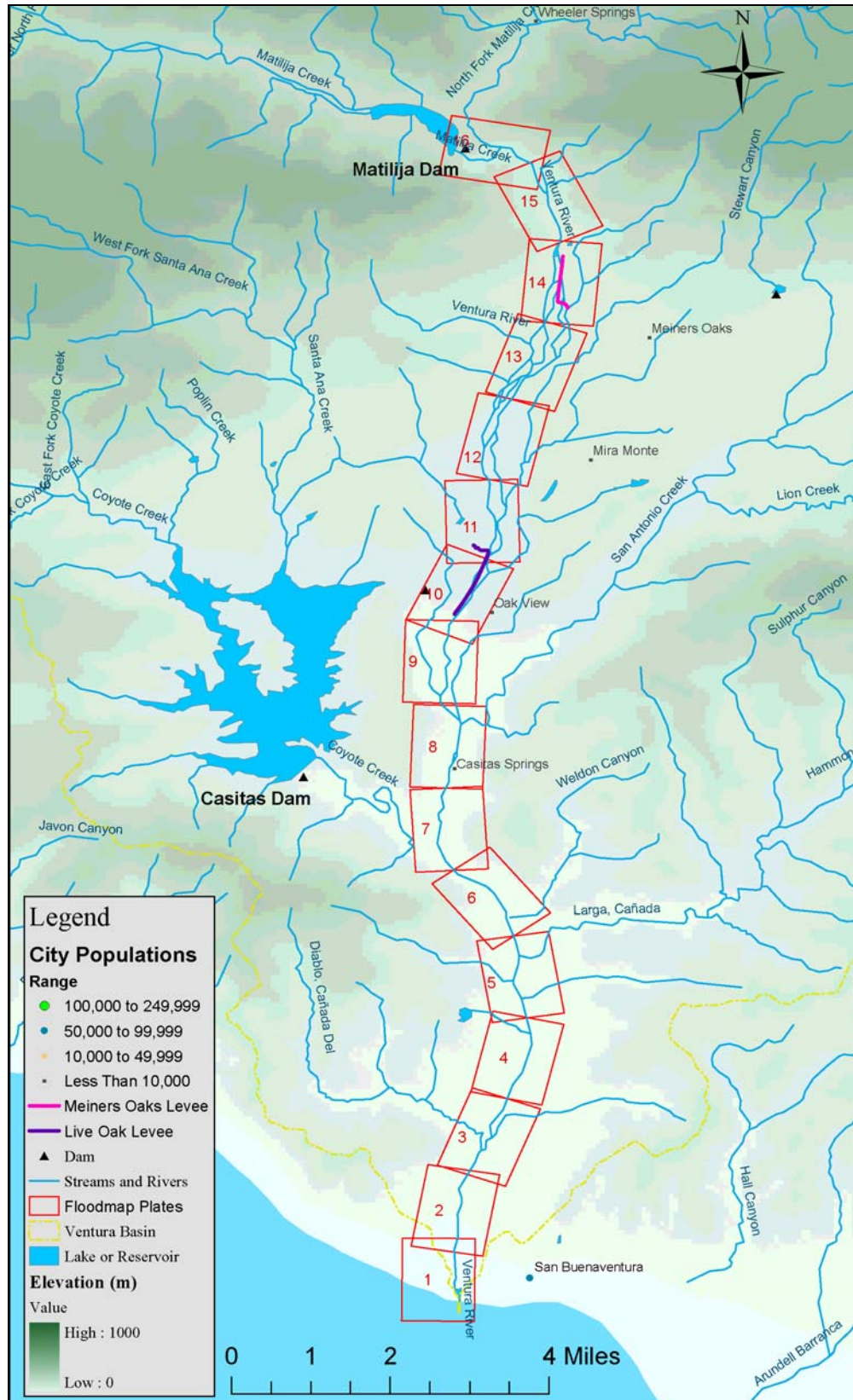


Figure 1. Project Location.

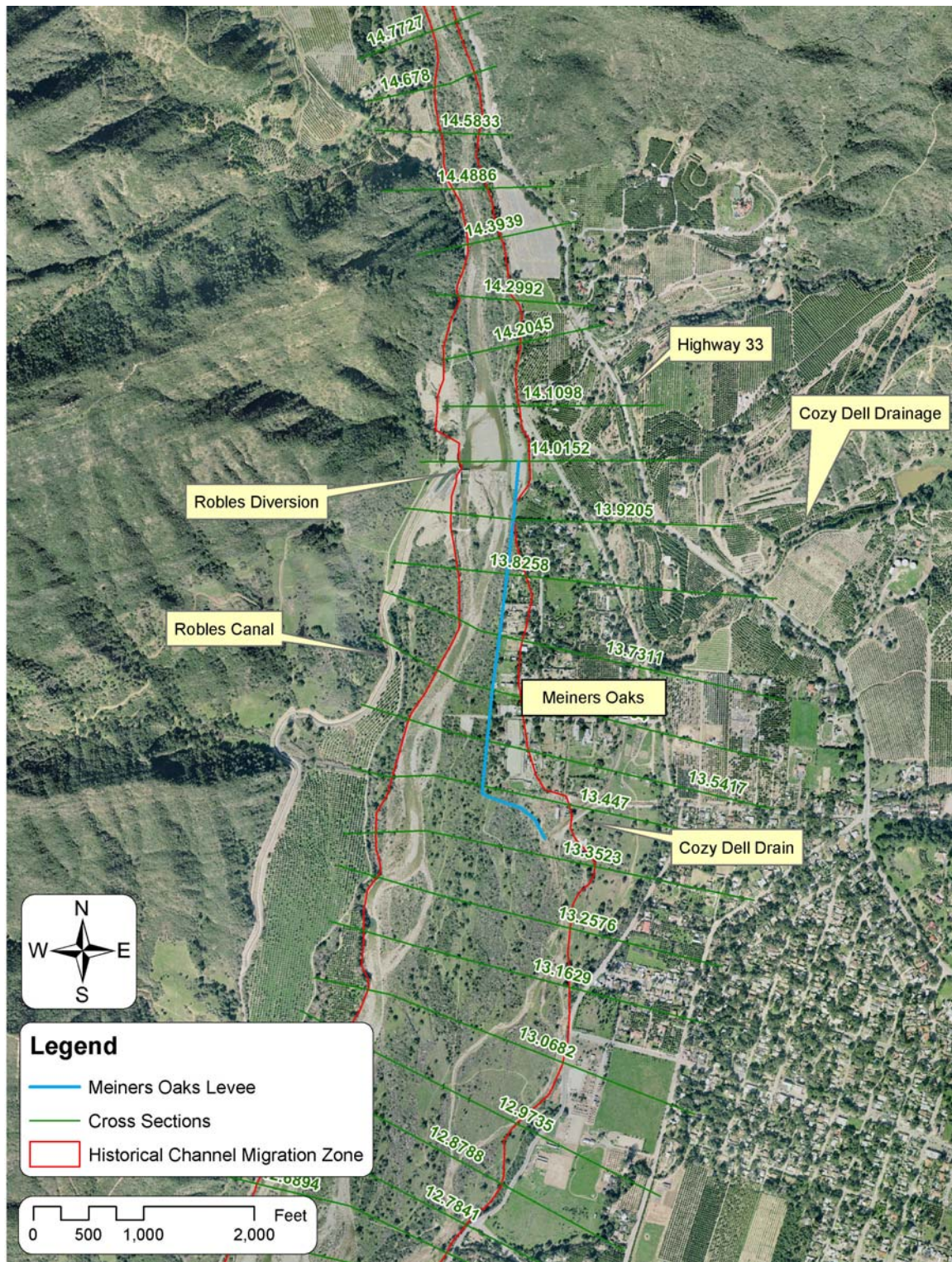


Figure 2. Map of Features near Meiners Oaks levee. River flow is top to bottom.

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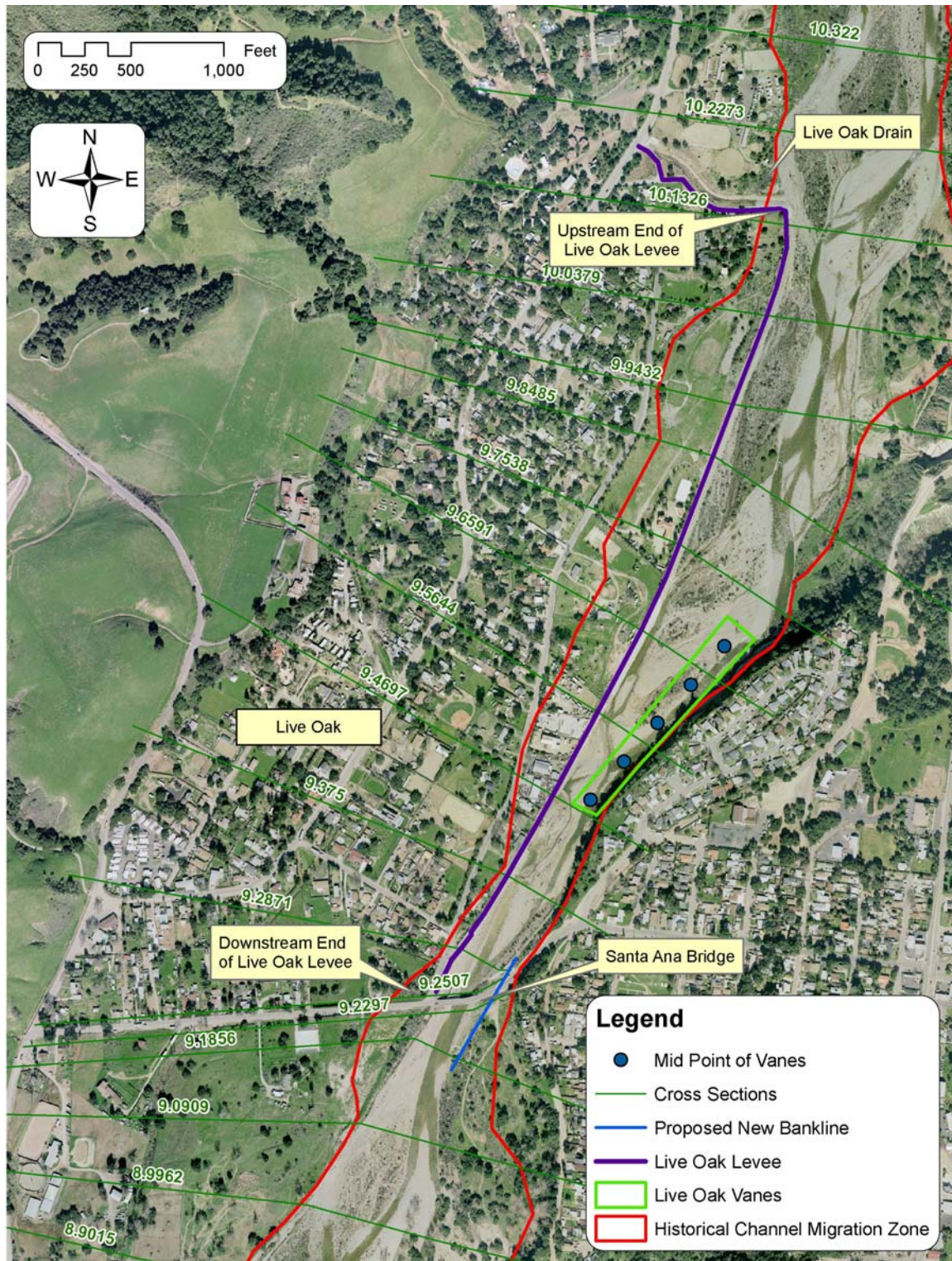


Figure 3. Map of Features near Live Oak levee.

2. Hydrology

In general, the higher elevations within the Ventura Basin receive more rain. The average annual rainfall near the mouth of the Ventura River is approximately 16.9 inches per year. The average annual rainfall of the drainage basin upstream of Matilija Dam is 23.9 inches per year. The average for the entire watershed is approximately 20 inches per year.

There is extreme seasonal variation in the rainfall and over 90 % of the rainfall occurs during the six months between November and April (Figure 4). The source of the rainfall data is the National Climatic Data Center (NCDC, <http://lwf.ncdc.noaa.gov/oa/ncdc.html>) rain gages in the cities of Ventura and Ojai. The period of record was from as early as 1874 until as late as 1995. The flows in the river show the same trend, but lag in time. This lag is due to the storage capacity of the soil in the watershed.

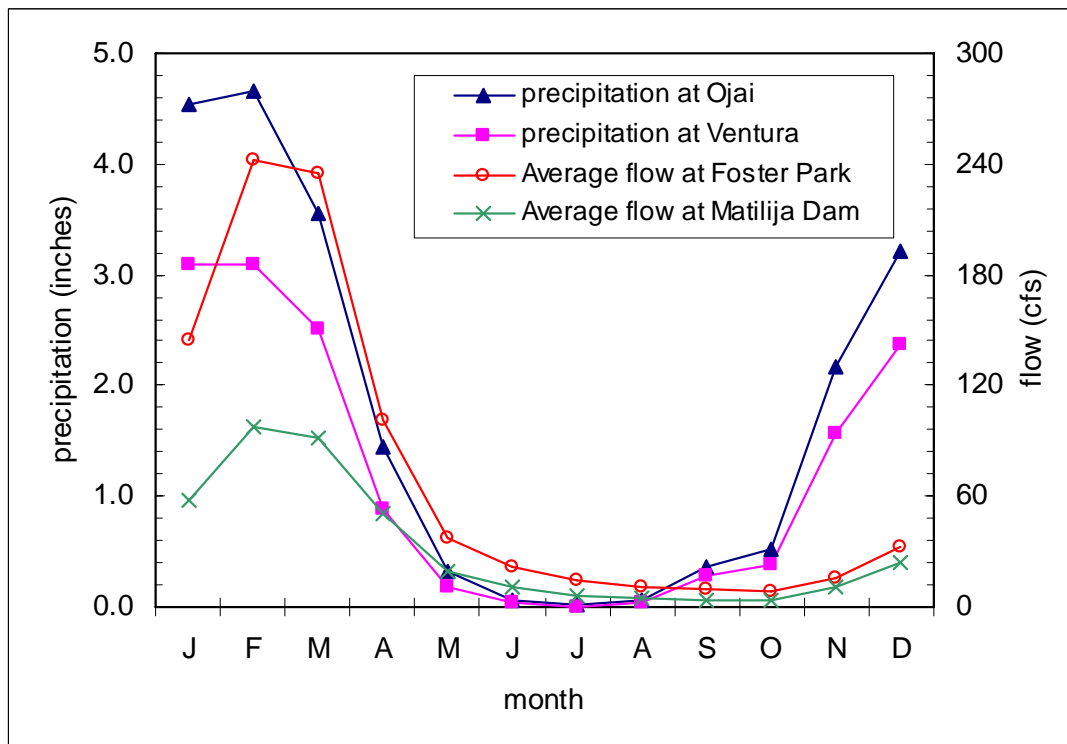


Figure 4. Seasonal variation of average rainfall and flow in Ventura River Watershed.

A flood-frequency analysis was performed for the entire length of the Ventura River. Frequency discharges for the 2-, 5-, 10-, 20-, 50-, 100-, and 500-year events were developed. The analysis is detailed in a separate report (Bullard, 2002b). Three stream gage records were used in the initial analysis: Matilija Creek above the Matilija Reservoir (USGS gage 11114500), Matilija Creek at Matilija Hot Springs (USGS gage 11115500), and Ventura River near Ventura (USGS gage 11118500). To determine the selected return period flows, various methodologies were investigated and it was determined that a top-fitting method was most appropriate for the Ventura River. The standard method recommended in Bulletin 17B (United States Water Resources Council, 1981) that uses the Log-Pierson Type III Probability distribution did not fit the data. It is expected that

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the distribution does not work well in this region of the county because of the peculiarities of the weather patterns. The top fitting method used the 7 largest floods and the frequency of those floods were fit with a regression equation and that regression equation was used to determine the flood magnitudes with a 10-, 20-, 50-, 100- and 500-year return period. To obtain the flood magnitudes with 2- and 5-year return periods, a separate analysis of partial duration series was performed (Bullard, 2002b). The results of the flood frequency analysis for the location near each levee are given in Table 1.

Table 1. Design Flood Flows near Foster Park.

Return Period (yr)	Flood Flows at Meiners Oaks Levee	Flood Flows at Live Oak Levee
2	3,250	3,380
5	7,580	7,910
10	15,000	16,000
20	18,800	19,800
50	24,000	24,800
100	27,100	28,300
500	35,200	36,700

Several structures affect the flow in the Ventura Watershed. Matilija Dam, impounding Matilija Creek, was built in 1947 with an initial reservoir capacity of 7,018 ac-ft. Matilija Reservoir currently has less than 500 ac-ft of capacity remaining and its ability to trap sediment and attenuate floods has been significantly decreased. Its present sediment trap efficiency is estimated to be 45 % (Reclamation 2004). There are no written operating criteria for Matilija Reservoir, other than CMWD's (Casitas Municipal Water District) criteria for the operation of Robles stated below. The general operating criteria for the reservoir is to maintain outflow equal to inflow when diversions are not taking place at Robles Diversion Dam, located 2 miles downstream of Matilija Dam. When diversions are being performed at Robles Diversion Dam, the reservoir level is cycled to produce larger flows in the Ventura River, optimizing the amount of the diversion. There is a 36-inch, a 12-inch, and a 6-inch release valve at Matilija Reservoir with the potential to release a combined maximum of 250 cfs.

Casitas Dam, which dams Santa Ana and Coyote Creeks, was built in 1958 with an initial reservoir capacity of 250,000 ac-ft. Casitas Dam was built as part of the Ventura River Project by Reclamation. Prior to Casitas Dam, Coyote Creek contributed 18 % of the flow in the Ventura River at Foster Park. After construction, significant flow downstream of the Casitas Dam in Coyote Creek only occurred during wet years in which water is spilled from the reservoir. As a result, Coyote Creek contributed only 5 % of the flow in the Ventura River during the period 1971-1980. Casitas Dam effectively traps all the sediment that enters into the reservoir.

3. Hydraulics

A detailed hydraulic study was performed by Reclamation (2006). The study used a LiDAR aerial survey performed by Airborne1 in March of 2005 as the base survey. A HEC-RAS 3.1.1 hydraulic model was generated using HEC-GeoRAS Ver 4.1. The hydraulic model was calibrated using high water marks from the 2005 flood. A hydraulic roughness of 0.04 was determined to be the best estimate for the hydraulic roughness using this data. The hydraulic information used here is identical to that reported in Reclamation (2006).

Flood inundation maps were also generated in Reclamation (2006). The flood boundaries in the project area are given in Appendix A for the 10-, 50-, 100-, and 500-yr flows. Three conditions are shown:

- 1) Current Conditions: The flood boundaries using the 2005 Aerial survey
- 2) Without-Project Future Conditions: The estimated flood boundaries 50-years in the future assuming that Matilija Dam remains in place for the next 50 years.
- 3) With-Project Future Conditions: The estimated flood boundaries 50-years in the future assuming that Matilija Dam is removed and the associated project features are in place.

4. Channel Morphology

The Ventura River morphology is described in more detail in Reclamation (2006). Section 12 “Appendix C: Historical Aerial Photographs” contains the aerial photographs of the reaches in 1947, 1970, 1978, 2001, and 2005.

4.1. Meiners Oaks Levee

In 1947, the Ventura River had multiple channels through the Meiners Oaks Levee reach. The main channel was actually located to the east of the proposed levee location. Parts of the community being protected by the proposed levee are essentially in the active river bed of the Ventura River. The 1947 channel was relatively narrow, which was reflective of the dry conditions of the preceding years. Robles Diversion was constructed in 1958, so it does not appear in this photo

The photo in 1970 was after one of the largest floods of record, the 1969 flood, and the channel following this storm was much wider than in 1947. There were two distinct channels, one on the left and one on the right of the proposed location of the Meiners Oaks Levee. The 1969 flood probably destroyed the timber crib dam of Robles Diversion.

The photo in 1978 was also after a large flood, but the river at this point was a single channel on the west side of the proposed levee location. By 2001, the channel had narrowed once again. The 1990s were relatively wet, but the peak flows were not as large as in 1969 and 1978. In addition, the channel has incised at this location since 1970 which can contribute to narrowing.

4.2. Live Oak Levee

In 1947, the Ventura River was relatively narrow and primarily a single thread channel through the Live Oak reach. The main channel very nearly followed the current alignment of the Live Oak levee from RM 10.1 to 9.5. The river was located on the east side from RM 9.5 to 9.2.

The river channel in 1970 was relatively wide and covered most of the Channel Migration Zone since 1947. A large portion of the main channel was located in the current town of Live Oak.

In 1978, the channel was slightly narrower, but there were parts of the main channel that extended west of the current Live Oak Levee. The Live Oak levee was constructed shortly after 1978 and this constricted the channel to the east side of the river channel. Therefore, the 2001 channel was somewhat narrower than in 1978. The 2005 channel migrated against the east bluff along the river. Some erosion at the toe of the bluff was observed and vanes were installed to prevent further erosion.

5. Sediment Transport

Reclamation (2006) performed a detailed sedimentation analysis. Most information given here is a summary of the information contained in that report.

A total of 18 surface bed material samples were collected in the Ventura River and Matilija Creek. The samples were spaced approximately every mile starting at the mouth and ending 1 mile upstream of Matilija Dam. The pebble counts near the levee locations are given in Table 2 and Table 3.

Table 2. Pebble Count Gradation near Meiners Oaks Levee, RM 13.6 (N 34° 27.5400', W 119° 17.4933').

Dia (mm)	% finer			Dia (mm)
8	0		D ₁₆	78
11	0.8		D ₅₀	201
16	1.7		D ₈₄	420
22	3.4		d _g	2.3
32	6.8			
45	10.2			
64	13.6			
90	19.5			
128	28.8			
180	40.7			
256	54.2			
360	78.8			
512	88.1			
720	95.8			
1024	98.3			
1440	99.2			
2048	99.2			
2880	99.2			
4096	100			

Table 3. Pebble Count Gradation near Live Oak Levee, RM 9.7 (N 34° 24.3383', W 119° 18.1820').

Dia (mm)	% finer			Dia (mm)
16	0		D ₁₆	64
22	0.8		D ₅₀	105
32	9.1		D ₈₄	353
45	15.7		d _g	2.4
64	28.1			
90	41.3			
128	57			

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180	71.1			
256	83.5			
360	91.7			
512	99.2			
720	99.2			
1024	100			

The concentration of suspended sediment during periods of relatively high flow has been sampled since 1968 at the USGS stream gage 11118500 at Casitas Vista Road Bridge, located at approximately RM 5.9. The data is reported in Reclamation (2006). Regression curves were fit to the clay and silt concentration and the sand concentration of the form:

$$C = aQ^b$$

where: C = Sediment concentration in mg/l

a, b = constants

Q = Flow rate (ft³/s)

The results from the regression are given in Table 4. The total sediment concentration during flood flows is often above 10 g/l and sometimes as high as 20 g/l (1 to 2 % by mass), which is considered relatively high for natural rivers.

Table 4. Regression coefficients Fit to Suspended Sediment data

River	Silt and Clay		Sand	
	a	b	a	b
Ventura River	25	.608	0.009	1.37

Figure 5 shows the change to the thalweg elevations from 1970 to 2001. From RM 7 to 6 there has been less than 2.5 feet of change. A difference of less than 2.5 feet is not considered significant because the accuracy of the 1970 survey is estimated to be +/- 2 feet and it was not possible to exactly locate the 1970 cross sections.

The elevations in the Live Oak reach have remained relatively stable since 1970. There may be some slight erosion in the upper part of the levee reach from RM 10 to 9.5, and some slight deposition in the reach from 9.5 to the Santa Bridge. However, the changes in elevation between 1970 and 2001 survey are not considered large.

The riverbed elevations have significantly lowered in the Meiners Oaks Reach from RM 14.0 to 13.0. Immediately below Robles Dam there has been up to 10 feet of erosion. From RM 13.0 to RM 12.0 there has likely been some deposition.

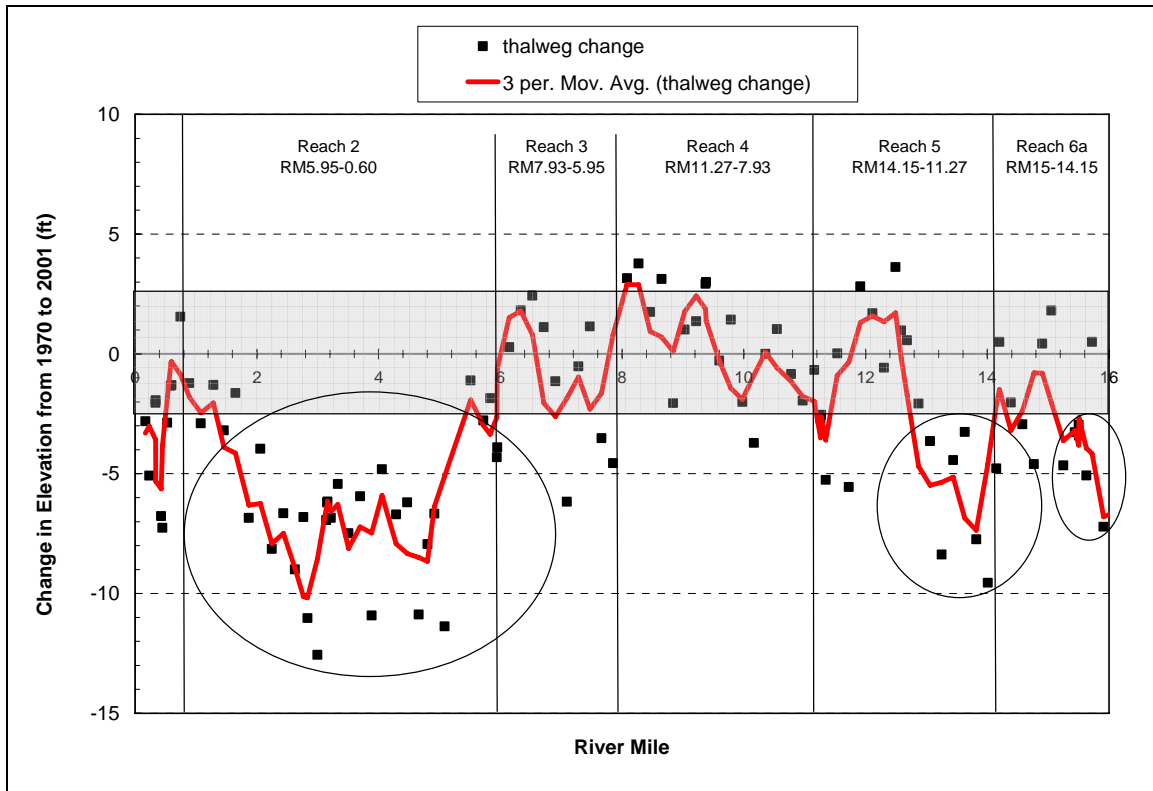


Figure 5. Comparison of change in thalweg elevation between 2001 and 1970. Negative changes indicate areas of degradation in the channel bed. Positive changes indicate areas that have aggraded. Areas within 2.5 feet of change are considered to be within the error range of the 1970 data.

6. Flood Risks

This section describes the current conditions and future conditions flood risks in the area of Live Oak Levee and the proposed Meiners Oaks Levee.

6.1. Current Conditions

6.1.1. Meiners Oaks Levee

This reach has experienced degradation after the construction of Matilija Dam and Robles Diversion because of the reduction in sediment supply. As shown in the main report (Reclamation 2006b), the 100-yr water surface elevation dropped 5 to 7 feet from 1970 to 2005.

There are several residences located to the east of the river between RM 14 and 13.4. All of these structures are constructed at grade, with no significant first floor elevation above the floodplain and there is no engineered levee. If the 100-yr does not cause any lateral migration to the east, these residences would be protected by a berm made of river deposits that extends from Robles Dam to approximately RM 13.2. Downstream of RM 13.8, however, the channel has shown evidence of large migration rates and this natural berm could be eroded by large flows. Therefore, below RM 13.8, the berm was not considered to function as a levee for the floods equal to or greater than the 50-yr flood. The channel migration zone was digitized from the 1970 and 1978 aerial ortho-rectified photos to estimate the amount of bank erosion during large floods. If the current 50-yr floodplain did not cover the maximum extent of the channel migration zone, the floodplain was extended to the extent of the zone. The berm was assumed to act as a functional levee for the 10-yr and 20-yr floods.

It should also be noted that the Cozy Dell drainage passes through the Meiners Oaks community (Figure 2) and this drainage can cause substantial flooding. The flows from Cozy Dell were not considered in this study but the project will have no effect on the flood impacts associated with the flows from Cozy Dell. However, a complete flood risk analysis should consider the flows from Cozy Dell.

6.1.2. Live Oak Levee

Live Oak Drain: Live Oak Drain enters the Ventura River from the west side just upstream of Live Oak Acres at approximately RM 10.15 (Figure 3). Live Oak Drain has a bottom elevation of approximately 457.5 feet where it crosses under Burnham Road. It was designed to carry the 100-yr flood of approximately 890 cfs at a flow depth of approximately 5 feet and a slope of 0.0009. However, the design assumed an elevation of 456.5 feet at the drain exit into the Ventura River. Since that time, the drain exit has aggraded to 458 feet. Therefore, there is a slight adverse slope in the drain from Burnham Road to the Ventura River, a distance of approximately 860 feet. It is likely that it will continue to experience aggradation. Furthermore, the 100-yr flood elevation of the Ventura River at this location is approximately 462 feet and therefore water and sediment

from the Ventura River can enter the drain directly causing backwater effects and increasing the rate of deposition within the drain. The County should continue excavation of the drain after every flood. However, deposition in the drain may still limit the conveyance during the flood. No analysis of the conveyance system above Burnham Road was performed and, therefore, Reclamation recommends that the County analyze the effect of the current deposition in the Live Oak drain on the conveyance system upstream of Burnham Road. The conveyance of the system upstream of Burnham Road may be reduced because of the increased backwater. Excavation of sediment at the drain may improve the condition, but it may be the conveyance of the system is compromised during large storm events.

The levee elevation along the drain is approximately 469.5 feet and therefore, the drain does not create a flood concern for Live Oak Acres east of Burnham Road.

Live Oak Levee: The Live Oak Levee is on the west bank of the Ventura River and extends from RM 9.25 to RM 10.15 (Figure 3). It protects the populated area of Live Oak Acres. The levee itself joins the fill of Burnham Road at the upstream side preventing it from being overtopped from the upstream end. This levee contains the 100-yr flood, but the 500-yr flood overtops the levee at approximately RM 9.47 because of the backwater caused by Santa Ana Bridge.

The Live Oak levee may be subject to erosion as evidenced by the damage caused by the Jan 2005 flood at approximately RM 9.4. The riprap placed along the Live Oak Levee is approximately ½ ton based upon the County records. From the Santa Ana Bridge to RM 9.5, it is estimated that larger rock would be required to prevent erosion for flood flows with a return period of 20-yr and greater.

East Side Vanes: Along the East Bank of the Ventura River, from RM 9.7 to 9.4, there are properties that are located at the top of a high terrace. This terrace is very steep and appears to be primarily composed of old alluvial deposits. The base of this terrace may be subject to erosion during high flows and the top of the terrace may erode from surface runoff. Most residences appear to be built 25 feet or more away from the edge of the terrace, but fences, utility poles, gazeboes, etc... are within a few feet of the edge. There was evidence of recent bank failure at RM 9.6 along this terrace. The County installed protective vanes along this bank in the summer of 2005 to prevent any further erosion at the base of the terrace (Figure 3). There are five vanes beginning approximately 1200 feet upstream of Santa Ana Bridge and extending approximately 1300 feet further upstream. The gradation for the stone used to construct the vanes is given in Table 5. Based upon these gradations, the d_{50} of the rock is 5 feet, which should be immovable based upon the hydraulic conditions in the river at that location. The depth of each vane was designed to be approximately 10 feet, which is below the depth of scour expected at this location. The top at the middle of the vane was constructed so that it was essentially at the grade of the existing river bed.

The protective vanes are intended to decrease erosion of the east bank from RM 9.7 to 9.5. The vanes will also decrease the erosion of the east bank downstream of the vanes

because they deflect flow away from the east bank. However, the presence of the vanes may increase the probability of erosion of the levee on the west bank of the river.

Table 5. Gradation used to construct the vanes (from Ventura County Watershed Protection District, 2005).

6-TON CLASS ROCK RIPRAP		
Approximate Rock Diameter	Rock Weight	Percentage Larger Than by Weight
96 inches	32.5 Tons	0
72 inches	13.5 Tons	0-50
54 inches	6 Tons	50-70
36 inches	1.75 Tons	70-85
24 inches	0.5 Tons	90-100

Santa Ana Bridge: The Santa Ana Bridge is on the downstream end of the levee (Figure 3) and it passes the 100-yr flood, but the flood elevation is only about 1 foot below the bridge soffit. There is currently deposition on the upstream side of this bridge and the County has a program to excavate the riverbed at the Santa Ana Bridge to maintain flow capacity. The bridge is a constriction on the river, increasing river velocities and increasing the scour around the bridge abutment, as evidenced in a photo taken after the 1998 flood. Following this flood, there was a large berm constructed on the downstream side of the east bank to prevent future erosion. While the rock protecting the berm is too small to stop all erosion, the berm is over 50 feet wide and will significantly delay erosion.

There is also a berm on the west of the river that extends for approximately 250 feet downstream of the bridge. This berm protects the buildings on the wet side of the river downstream of Santa Ana Blvd from flooding but it is constructed of river bed material and may be easily eroded during high flow events.

6.2. Future With-Project Conditions

The GSTAR-1D (Generalized Sediment Transport model for Alluvial Rivers – One Dimension) model was used to model the sediment transport in the Ventura River (Huang and Greimann, 2007). It is a model that was developed by the Bureau of Reclamation with support from the USEPA. The model requires multiple inputs that can be divided into three main types: Hydrologic, Hydraulic, and Sediment input.

Reclamation (2006) reports the results using several hydrological inputs. In this report, the results are derived from two representative hydrological scenarios: The 50-yr 1969 historical hydrograph and the 100-yr flood hydrograph. The 50-yr 1969 hydrograph was

derived by using the historical record from 1969 to 2001 then appending the record from 1950 to 1968, for a total of 50 years of hydrologic record. The hydrologic record consisted of daily average flows that had to be modified during the peak flow events. A storm pattern was assumed and imposed on the daily average flow record while enforcing volume conservation.

The hydraulic input was taken from the HEC-RAS model described in Section 3. The hydraulic input includes the geometry data obtained from a 2005 LiDAR study. The same hydraulic roughness values were used in the GSTAR-1D model as in the HEC-RAS model. The sediment input consisted of bed material values throughout the entire river, and sediment loads from all major tributaries. All this data is described in Reclamation (2006).

The results from the modeling will be described only for the reaches near the Live Oak Levee and Meiners Oaks Levee.

6.2.1. Meiners Oaks Levee

The natural re-supply and sediment eroded from the reservoir deposits will cause deposition in this reach under With-Project Conditions. The 100-yr water surface elevations will increase up to 9 feet immediately below Robles Diversion Dam. It should be recalled that there has been 5 to 7 feet of degradation in this area since 1970, and there was probably additional erosion in this area from the time of the construction of Robles Diversion Dam (1958) to 1970. Therefore, the riverbed in this reach will return to approximately its pre-dam elevations.

6.2.2. Live Oak Levee

Live Oak Drain: Deposition at the entrance of Live Oak Drain into the Ventura River will continue to occur under With- or Without-Project Conditions. Currently, there is an adverse slope to the drain from Burnham Road to the Ventura River based upon the 2005 LIDAR survey. This indicates that there is not a sufficient slope in the drain to transmit sediment to the Ventura River. The drain will require excavation after every significant flow in the Ventura River or Live Oak Creek.

The difference in the 100-yr WSE of the Ventura River at the Live Oak Drain between with- and without-project conditions is approximately 1 foot. This indicates that there may be slightly more deposition under With-Project conditions than under Without-Project conditions. However, maintenance of the drain will be required regardless of the Project. A difference of 1 foot is not considered significant based upon the uncertainty of sediment modeling results.

Live Oak Levee: The thalweg elevation (the elevation of the lowest point on the cross section) will increase throughout most of the Live Oak reach (Figure 8). Figure 9 shows the change to the 100-yr water surface elevations relative to current conditions. From RM 10.15 to 9.5, deposition will increase the 100-yr flood water surface elevations approximately 1 to 2 feet. Nearer the bridge, from RM 9.5 to Santa Ana Bridge, the flood water surface elevations will decrease 1 to 2 feet. The drop in water surface near the

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bridge is primarily because the bridge will be widened by approximately 60 feet under With-Project Conditions.

East Side Vanes: The rock used to construct the East Side Vanes has a d_{50} of approximately 4.5 feet. Each vane is approximately 150 feet long, 10 feet deep, and 30 feet wide. The river will be unable to transport this large rock any appreciable distance but may fail if the surrounding riverbed is scoured. Based upon the general scour predicted at the west side levee, the rock has been placed deep enough to prevent scour of the entire structure (Figure 11). The base of the vane in the river channel is below the elevation of scour expected against the West Levee. The local scour around the vane may be higher and some material off the nose of the vane may be lost at the highest flows. The County should monitor this location to determine the stability of the project. The vanes contain a large volume of large rock (over 15,000 yd³ of 4.5-foot diameter rock) that is unlikely to erode significantly in any one event. Therefore, the County will have adequate time to react to failure of a portion of the vanes before complete failure occurs. Further protection of the east side vanes could then be recommended.

The water surface elevations for floods less than the 100-yr are expected to change less than 2 feet under with-project conditions. Therefore, hydraulic conditions and resulting bank erosion potential will remain similar to the current condition. The project should have no significant impact on the erosion of the east bank along the east side vanes.

Santa Ana Bridge: The Santa Ana Bridge will be widened by approximately 60 feet on its east side. A proposed new alignment is given in Figure 3. Neither property acquisition nor traffic impacts were considered in this alignment. The widened bridge is expected to maintain 500-yr capacity. However, it is recommended that the sediment excavation program continue. The widened bridge should decrease velocities in the immediate vicinity of the bridge. Therefore, scour depths at the abutments and piers should not increase as a result of the bridge widening.

The protection of the new bridge abutment on the east side will be determined during the Santa Ana Bridge design phase. Currently, rock is protecting the east bank of the river from the bridge to 700 feet upstream. A similar length of rock protection will be required for the new bridge abutment. Downstream of the bridge, the large berm located on the east side will have to be set back to the new bank line as indicated in Figure 3. The downstream abutment and bank line will need to be protected with stable rock. The current east side berm extends approximately 275 feet downstream and the new bank protection should extend the same distance.

The west abutment of Santa Ana Bridge should also be protected downstream of the bridge. It is recommended that riprap be continued down the west bank for 200 feet downstream of the bridge. This is a similar distance to the bank protection on the opposite side of the river. The riprap should be of similar size and have similar placement characteristics to the riprap used in the downstream portion of Live Oak Levee as specified in the Section 7 titled "Rip Rap Design".

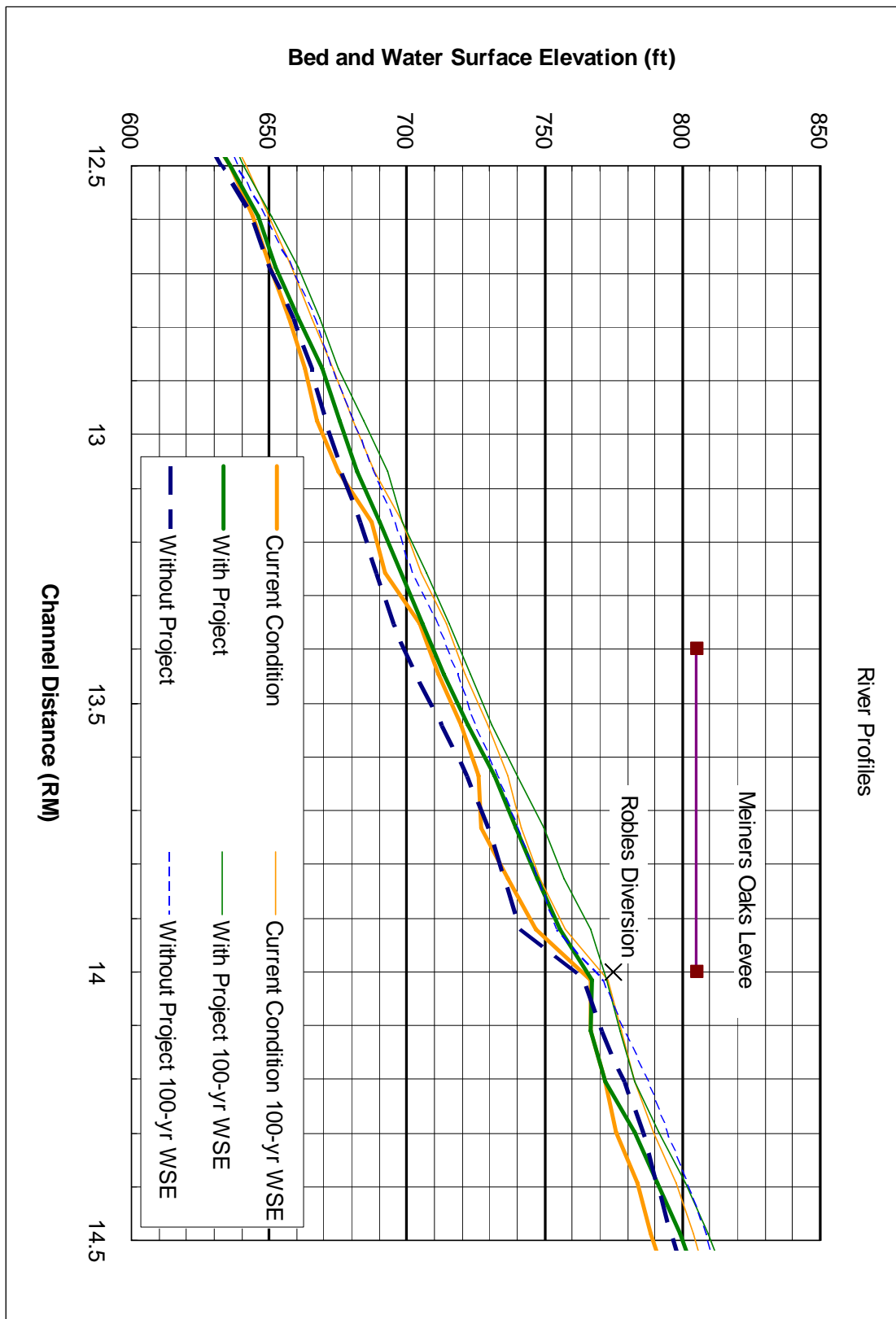


Figure 6. Bed and Flood Elevations near Meiners Oaks Levee.

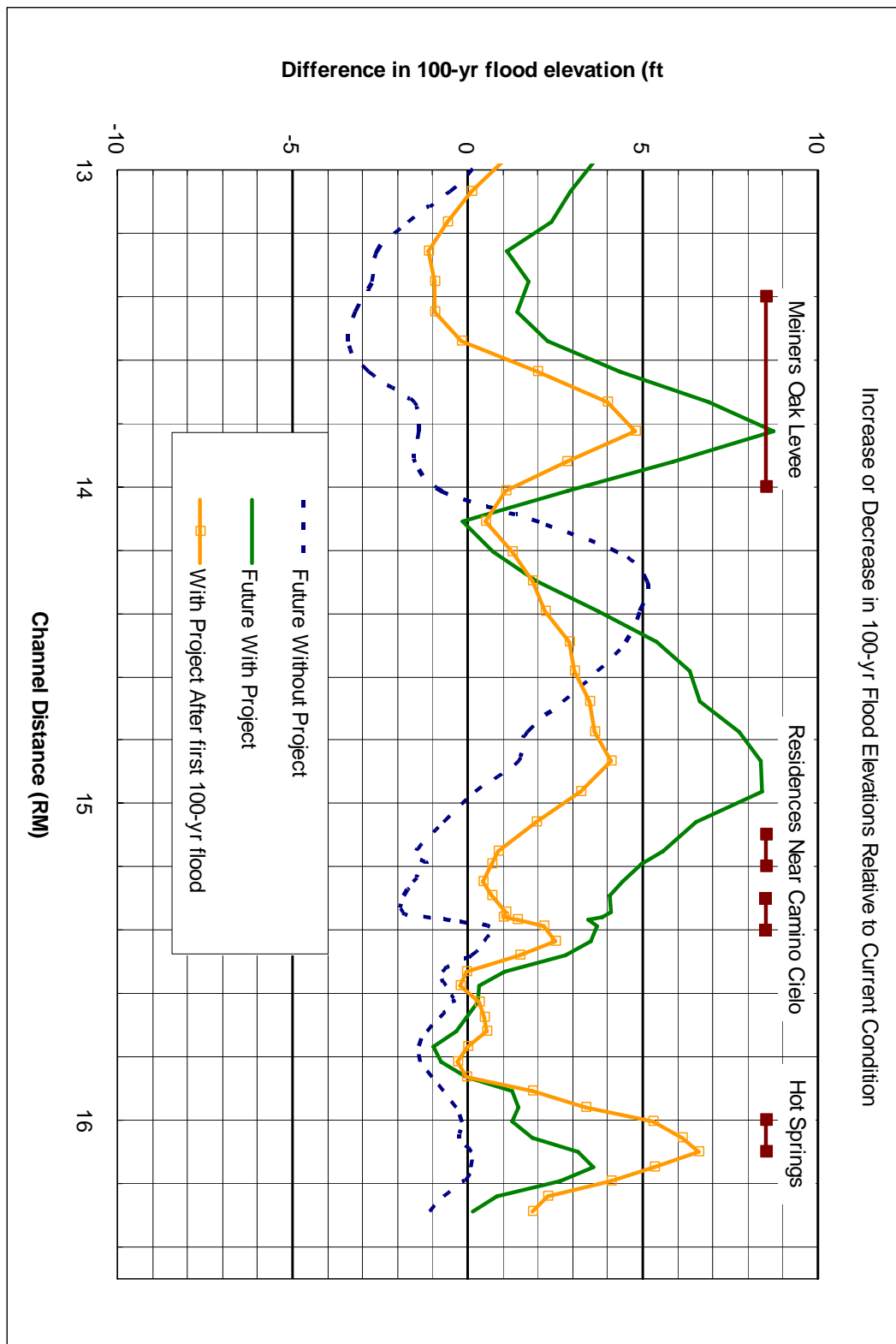


Figure 7. Change in Water Surface Elevations Relative to Current Condition near Meiners Oaks Levee.

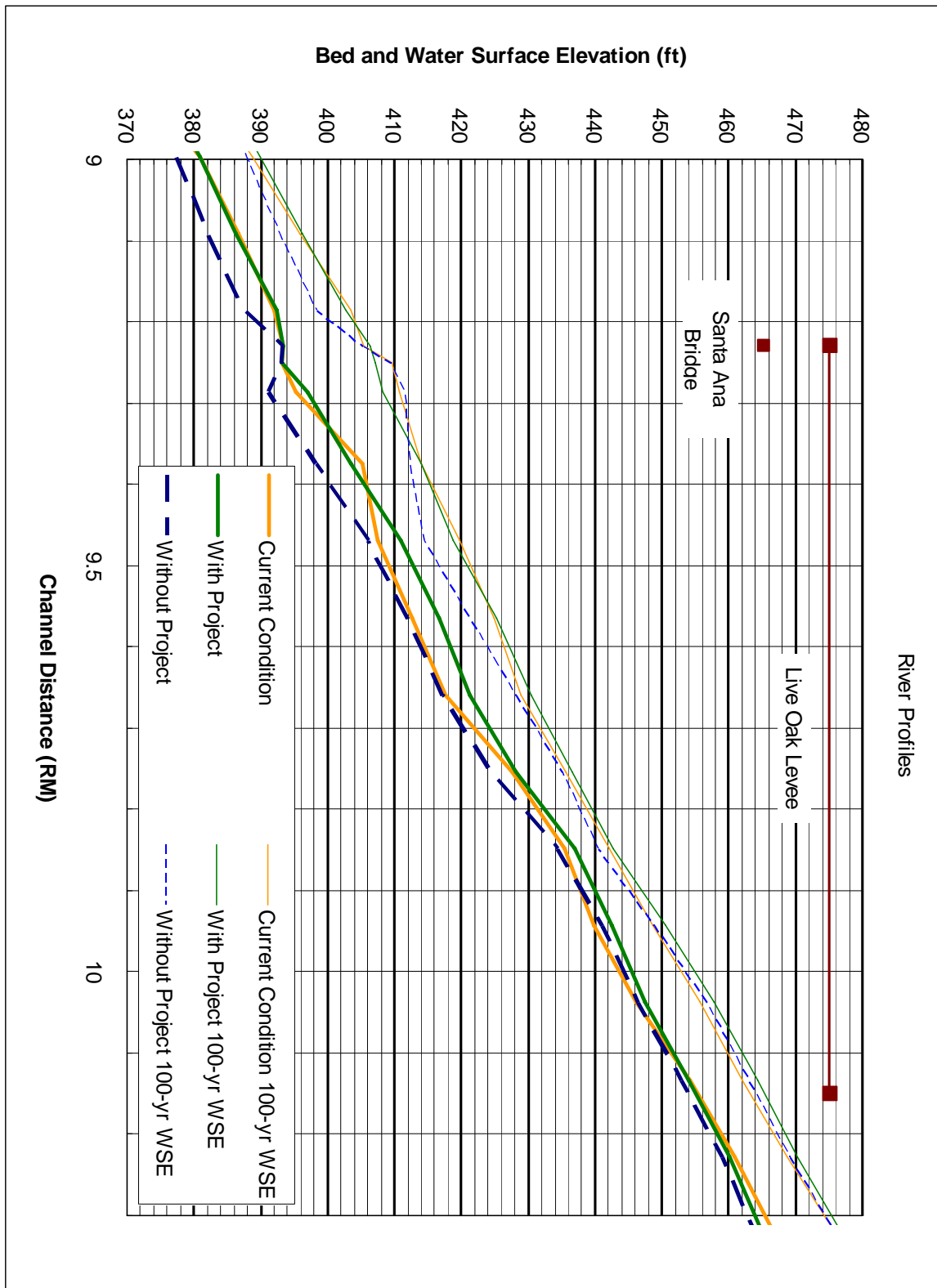


Figure 8. Bed and Flood Elevations near Live Oak Levee.

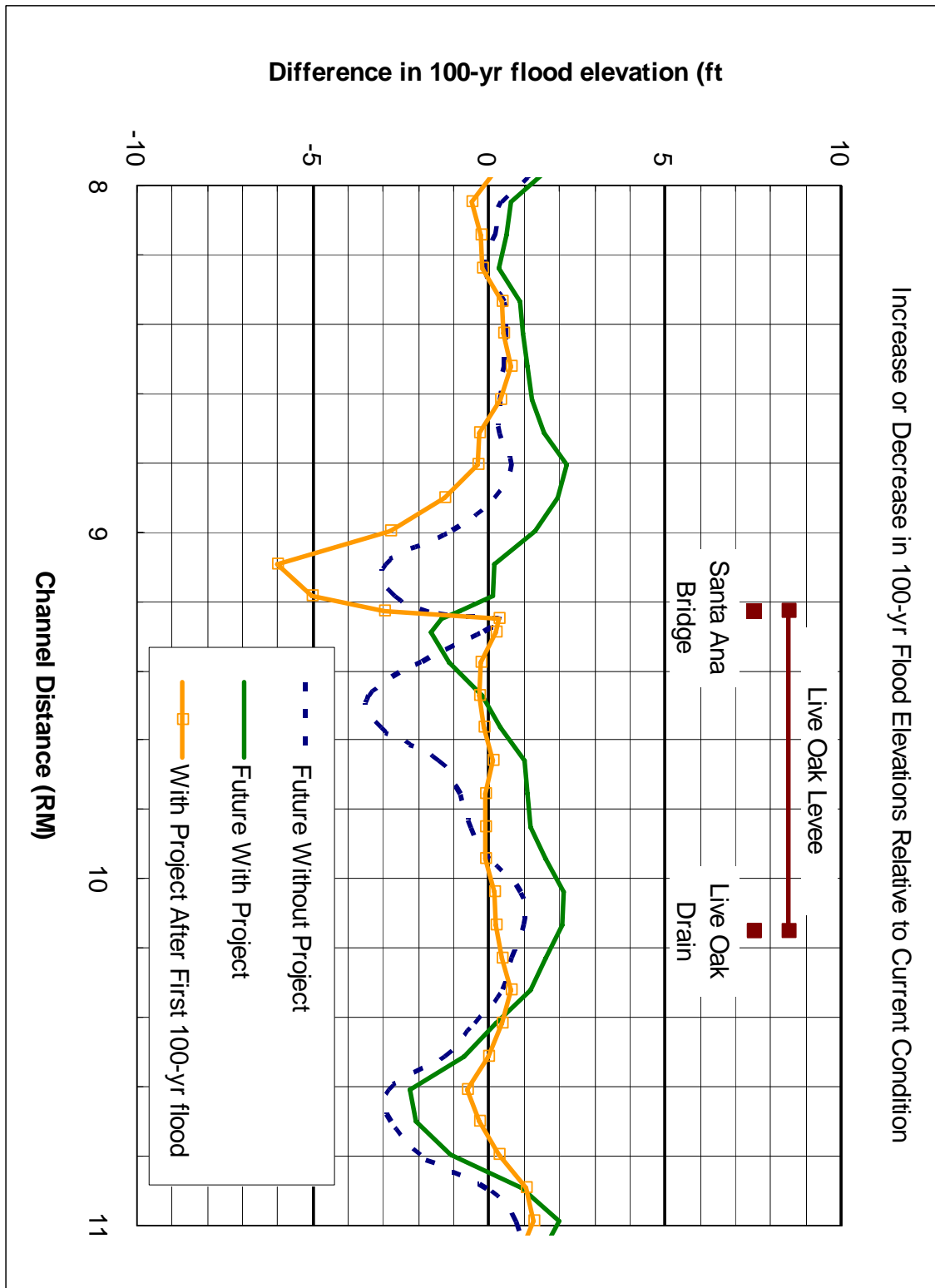


Figure 9. Change in Water Surface Elevations Relative to Current Condition Near Live Oak Levee.

7. Rip Rap Design

The levees will be lined with rock riprap to protect against erosion. The methods recommended in EM-1110-2-1601 “Hydraulic Design of Flood Control Channels” (USCOE, 1994) were used to design the size of the riprap. CHANLPRO V2.0 implements these methods to compute the stable ETL gradations that result from this method and this program was used to compute the gradations for design.

$$D_{30} = S_f C_s C_v C_T d^{-0.25} \left(\frac{V_{ss}}{\sqrt{K_1 g (s-1)}} \right)^{2.5} \quad \text{Eq 1}$$

where,

- S_f = safety factor
= 1.1, assumed in this study
- C_s = stability coefficient for incipient failure
= 0.3 for angular rock
- C_v = vertical velocity distribution coefficient
= $1.283 - 0.2 \log_{10}(\min(26, \max(2, R/W)))$
- C_T = thickness coefficient
= 0.5 to 1.0, depending upon d_{15}/d_{85} and relative layer thickness
- d = local depth of flow, at same location as V , from HEC-RAS output
- s = specific gravity of the riprap
= 2.65 (165 lb/ft³)
- V_{ss} = local side slope corrected velocity
= $V_{ave} [1.74 - 0.52 \log_{10}(\min(26, \max(2, R/W)))]$
- V_{ave} = cross section average velocity
- K_1 = side slope correction
= $\text{ERF}(.41Z^{1.443})$, where Z = run/rise of side slope
- g = acceleration of gravity
= 32.2 ft/s²

EM 1601 suggests that the most severe attack in braided streams may occur when the water surface is at or slightly above the top of the mid channel bars. On the Ventura River, the 10-yr flood is approximately the flood that begins to inundate mid-channel bars. The riprap required under the 100-yr flow was also computed, but was found to be smaller than that required for the 10-yr flood. The radius of curvature for the 100-yr flood is much larger than that under the 10-yr flood and therefore the local side slope velocity, V_{ss} , is smaller for the 100-yr flood than for the 10-yr flood.

When the riprap gradation is specified in the design of the protection, the weight of rock should take priority over the size of the rock. Also, the specific gravity should be equal to or greater than 2.6 times that of water. Larger rock will be required if the specific gravity is significantly different from this.

7.1. Meiners Oaks Levee

The hydraulic conditions for the 10-yr and 100-yr floods were computed for the Meiners Oaks reach. The hydraulic properties for the design by each condition are given in Table 6. The radius of curvature for the two flows was computed by approximately laying out a circle that matched the observed bends in the Ventura River near the Meiners Oaks Levee.

Table 6. Hydraulic Properties used for Riprap Design at Meiners Oaks Levee.

Location	Return Period (yr)	Channel Discharge (ft ³ /s)	Thalweg Depth (ft)	Channel Velocity (ft/s)	Top Width (ft)	Radius of Curvature	Side Slope
Meiners Oaks	10 yr	15000	8.8	13.0	220	1200	2
Meiners Oaks	100 yr	27100	11.5	15.2	235	6000	2

The results from the CHANLPRO analysis is given in Appendix D: CHANLPRO V2.0 Output. For all cases, the 10-yr flood with a smaller radius of curvature resulted in larger riprap than the 100-yr flood with a larger radius of curvature. The resulting recommended gradations computed from CHANLPRO are given Table 7.

Table 7. Meiners Oaks Levee Minimum Stable ETL gradations from CHANLPRO V2.0.

Name	13					
Layer Thickness (in)	70					
d_{30} (min) in	26.3					
d_{90} (min) in	38					
	d_{100} (max)	d_{100} (min)	d_{50} (max)	d_{50} (min)	d_{15} (max)	d_{15} (min)
Weight (lb)	7870	3150	2300	1580	1170	490
Diameter (in)	54	40	36	31.6	28.6	21.4

As a check on the recommended gradation, the stable diameter was computed based upon the Shields shear stress criteria:

$$\theta_{cr} = \frac{\tau_b}{(\gamma_s - \gamma)d_{cr}} \quad \text{Eq 2}$$

where θ_{cr} is the non-dimensional critical shear stress, τ_b is the average bed shear stress, g is the acceleration of gravity, γ_s is the specific weight of sediment, γ is the specific weight of water, and d_{cr} is the critical sediment diameter. The critical diameter based upon a non-dimensional Shield number of 0.02 is 25 in, which is just slightly smaller than the recommended d_{30} from CHANLPRO. A non-dimensional critical shields stress of 0.02 was used because it is a typical value used for no motion of sediment. A commonly used value of 0.04 is not for incipient motion, but for some reference transport rate, usually considered the lowest measurable rate.

7.2. Live Oak Levee

The Live Oak Levee significantly constricts the Ventura River downstream of RM 9.56. Consequently, the hydraulic conditions in the river vary significantly from the upstream part of the levee to the downstream part of the levee. The velocities are higher along the downstream portion of the levee, and the stable riprap size is also larger. Two recommended gradations are given for the levee, one for the upstream portion of the levee and one for the downstream portion.

Two hydraulic conditions for each the Upper and Lower sections of the Live Oak Levee were used to compute the required riprap gradations. The hydraulic properties for each condition are given in Table 8. The radius of curvature for the two flows was computed by approximately laying out a circle that matched the observed bends in the Ventura River near the Live Oak Levee.

Table 8. Hydraulic Properties used for Riprap Design.

Location	Return Period (yr)	Channel Discharge (ft ³ /s)	Thalweg Depth (ft)	Channel Velocity (ft/s)	Top Width (ft)	Radius of Curvature	Side Slope
Upper Live Oak	10 yr	16000	8.7	9.6	500	400	2
Lower Live Oak	10 yr	16000	11.9	12.0	220	400	2
Upper Live Oak	100 yr	28300	10.4	11.4	500	2000	2
Lower Live Oak	100 yr	28300	15.5	13.4	235	2000	2

The results from the CHANLPRO analysis is given in Appendix D: CHANLPRO V2.0 Output. For all cases, the 10-yr flood with a smaller radius of curvature resulted in larger riprap than the 100-yr flood with a larger radius of curvature. CHANLPRO was unable to find a stable gradation for the lower portion of the Live Oak Levee. The program only computes up to an ETL gradation #13, which has a d_{50} max of 36 in. However, it is possible to use Eq 1 to predict the stable d_{30} . This gives a d_{30} of 2.8 ft. To compute the required gradation, the same gradation scaling used in CHANLPRO was used.

The final recommended levee gradations are given in Table 9 for the Lower Live Oak Levee and Table 10 for the Upper Live Oak Levee. The Lower Live Oak Levee should extend at least 1,800 feet upstream from the Santa Ana Bridge, which is approximately from RM 9.25 to 9.59.

Table 9. Lower Live Oak Minimum Stable ETL gradations from Eq 1 (RM 9.25 to 9.59).

Name	--						
Layer Thickness (in)	100						
d_{30} (min, in)	34						
d_{90} (min, in)	49						
	d_{100} (max)	d_{100} (min)	d_{50} (max)	d_{50} (min)	d_{15} (max)	d_{15} (min)	
Weight (lb)	17200	6800	5100	3500	2500	1080	

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Diameter (in)	70	52	47	41	37	27.8
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Table 10. Upper Live Oak Minimum Stable ETL gradations from CHANLPRO V2.0 (RM 9.59 to 10.13).

Name	11					
Layer Thickness (in)	47					
d_{30} (min, in)	20.4					
d_{90} (min, in)	29.6					
	d_{100} (max)	d_{100} (min)	d_{50} (max)	d_{50} (min)	d_{15} (max)	d_{15} (min)
Weight (lb)	3700	1480	1100	740	550	230
Diameter (in)	42	30.9	28	24.6	22.2	16.7

Assuming a θ_c of 0.02, gives a critical sediment diameter of 24 and 18 in for the 100-yr flood for the lower and upper reaches, respectively. This is smaller than mean d_{30} recommended by CHANLPRO.

8. Scour Estimates

The riprap needs to be buried below the elevation of maximum scour. Both the 10-yr scour estimates assuming a 1,000 ft radius of curvature and the 100-yr estimates assuming a larger radius of curvature were used to estimate the scour. The 100-yr flood estimates had larger scour estimates.

8.1. Scour Estimation Methods

The scour elevations were estimated using several methods. It was assumed that the riprap is placed on a moderate bend for the methods where a bend type is needed.

8.1.1. Neill

The depth of scour below thalweg elevation, d_s , is predicted by Neill (1973) as reported in Reclamation (1984):

$$d_s = Zd_i \left(\frac{q_f}{q_i} \right)^m$$

where:

- m = exponent varying from 0.67 for sand to 0.85 coarse gravel
- d_i = bankfull depth
- q_i = Bankfull discharge
- q_f = design discharge per unit width
- Z = 0.5 for straight reach, 0.6 for moderate bend, 0.7 severe bend

8.1.2. Lacey

The scour equation of Lacey (1930) as reported in Reclamation (1984) is:

$$d_s = Z0.47 \left(\frac{Q}{f} \right)^{1/3}$$

where:

- Q = Flow rate in channel at design discharge (ft³/s or m³/s)
- f = $1.76\sqrt{d_{50}}$
- Z = 0.25 for straight reach, 0.5 for moderate bend, 1.25 for vertical rock bank
- d_{50} = mean grain size in mm

8.1.3. Blench

The scour equation of Blench (1969) as reported in Reclamation (1984) is:

$$d_s = Z \frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

where:

- q_f = design discharge per unit width
- $F_{bo} = 1.75d_{50}^{0.25}$
- d_{50} = mean grain size in mm
- Z = 0.6 for straight, 1.0 for moderate bend, 1.25 for vertical rock bank or wall.

8.1.4. Limiting Velocity

The limiting velocity method as reported in Reclamation (1984) is:

$$d_s = d_m \left(\frac{V_m}{V_c} - 1 \right)$$

where:

- d_m = mean depth
- V_m = mean channel velocity
- V_c = minimum competent velocity

The competent velocity can be estimated using a shear stress based incipient motion criteria:

$$u_\tau = \theta_c \sqrt{g(s-1)D_c}$$

where:

- u_τ = friction velocity = $nV_c \sqrt{g} / (C_m R^{\frac{1}{6}})$
- V_c = minimum competent average channel velocity
- n = Manning's roughness coefficient
- g = acceleration of gravity
- R = hydraulic radius
- C_m = Manning's constant (1.0 for SI, 1.486 for English units)
- θ_c = critical non-dimensional shear stress (often between 0.03 to 0.05)
- s = specific weight of bed material
- D_c = d_{50} of surface bed material

Alternatively, one could use the competent bottom velocity method as recommended in Reclamation (1984) Eq (3). That equation can be rewritten to be dimensionally consistent as:

$$V_c = 0.57 \sqrt{g(s-1)D_c}$$

and this equation is used in the analysis in this report.

8.1.5. EM1601

The COE manual EM1601 (COE, 1994) recommends using the following equation:

$$d_s = S_f Z d_m - d_f$$

where:

- d_m = average depth in the crossing upstream of the bend.
- d_f = depth of thalweg at bend
- S_f = Safety Factor = 1.14
- Z = factor based upon radius of curvature to width ratio
 - = $3.37 - 0.66 \ln(R/W)$ for sand bed
 - = $3.37 - 0.7 \ln(R/W)$ for gravel bed

The correlation between Z and R/W for gravel bed rivers is very weak based upon Plate B-42 in Appendix B of EM1601. We recommend using the upper value of 2.5 for this design.

8.1.6. Thorne and Abt (1993)

For gravel beds, Thorne and Abt (1993) use the following equation:

$$d_s = S_f Z d_m - d_f$$

where:

- d_m = average depth in the crossing upstream of the bend.
- d_f = depth of thalweg at bend
- S_f = Safety Factor
- Z = factor based upon radius of curvature to width ratio
 - = $2.15 - 0.27 \ln(R/W - 2)$, $2.1 \leq R/W < 22$

where the safety factor has been added for design purposes. Thorne suggests that R/W only needs to be greater than 2, but practically R/W should be greater than 2.1. The relationship is only slightly different from the one proposed in EM1601. Because the value of R/W is uncertain in braided rivers, and this relation gives approximately the same values as EM1601, this method is considered identical to EM1601 for this case.

8.1.7. HEC 11

The scour method proposed by HEC-11 (Federal Highway Administration, 1989) is only a function of bed particle size:

$$d_s = \min(12, 6.5 d_{50}^{-1.1})$$

8.2. Results

The results for each method are given in Table 11. The final design scour elevation at the well sites was computed from the average scour estimates from all the methods. A profile plot of the scour estimates giving the scour elevation for each well location is in Figure 10 and Figure 11, for the Meiners Oaks and Live Oak reach respectively.

For design purposes, the scour elevations were fit to a series of lines and the results are given in Table 12 and Table 13.

Table 11. Scour Estimates from Each Method.

	Design Scour Estimates (ft)						
RM	Neill (1973)	Lacey (1930)	Blench (1969)	Limiting Velocity	EM1601	HEC11	Averaged
Meiners Oak	7.4	3.5	7.4	2.8	3.5	6.6	5
Live Oak Upper	5.2	4.0	5.0	4.1	3.1	7.2	5
Live Oak Lower	9.5	4.0	8.3	7.0	5.5	7.2	7

Table 12. Design Scour Elevations for Meiners Oaks Levee. Easting and Northing are in State Plane California Zone V NAD 1983. Elevations are in NAVD 88.

RM	Easting	Northing	Elevation	Downstream Slope
13.9205	6173143	1993644	741	0.020
13.7311	6173019	1992591	721	0.002
13.6364	6172954	1992093	720	0.015

Table 13. Design Scour Elevations for Live Oak Levee. Easting and Northing are in State Plane California Zone V NAD 1983. Elevations are in NAVD 88.

RM	Easting	Northing	Elevation	Downstream Slope
10.1326	6168826	1974576	447	0.012
9.7538	6168248	1972849	423	0.022
9.6591	6168045	1972387	413	0.012

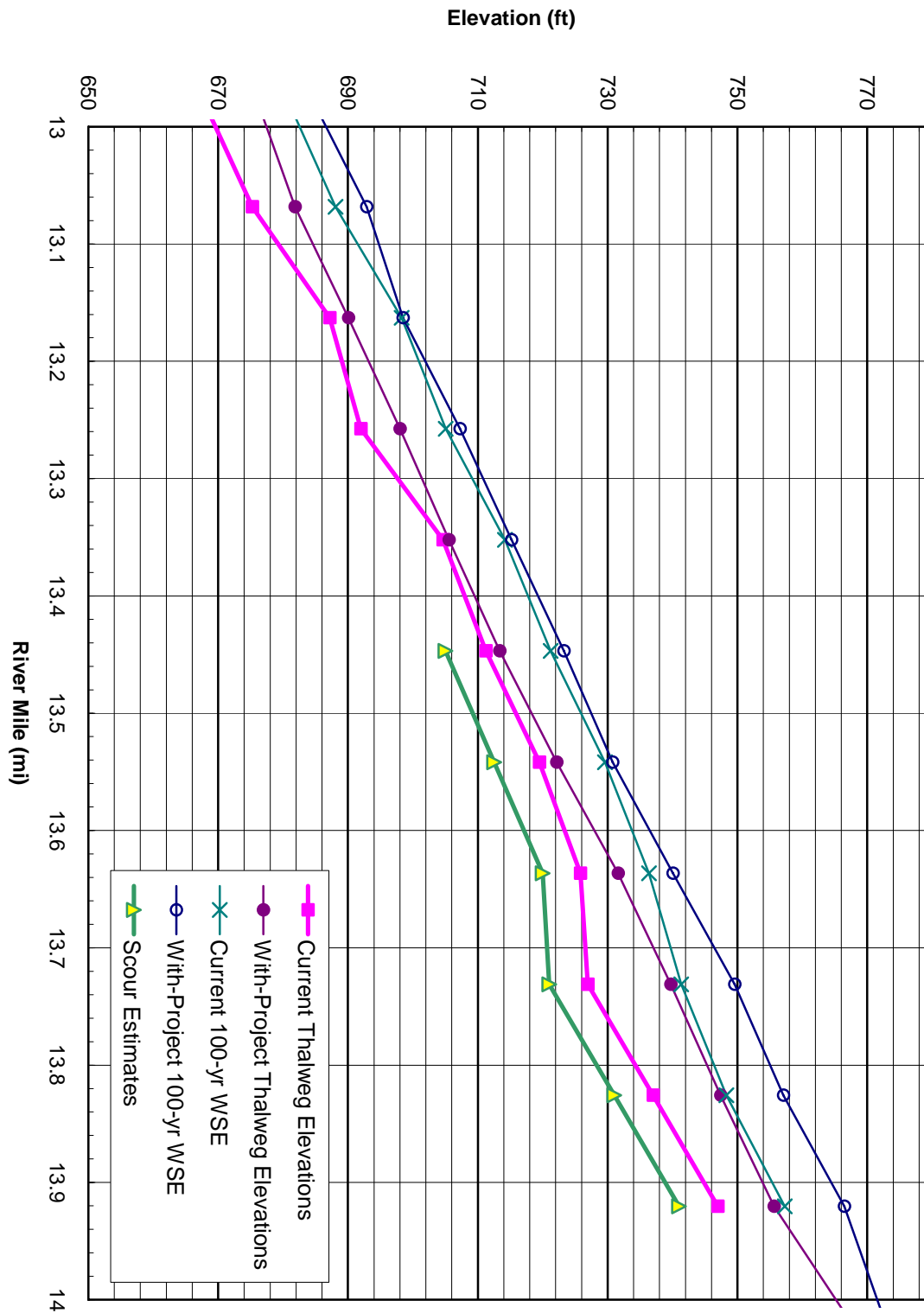


Figure 10. Scour Estimates for Riprap Design at Meiners Oaks Levee.

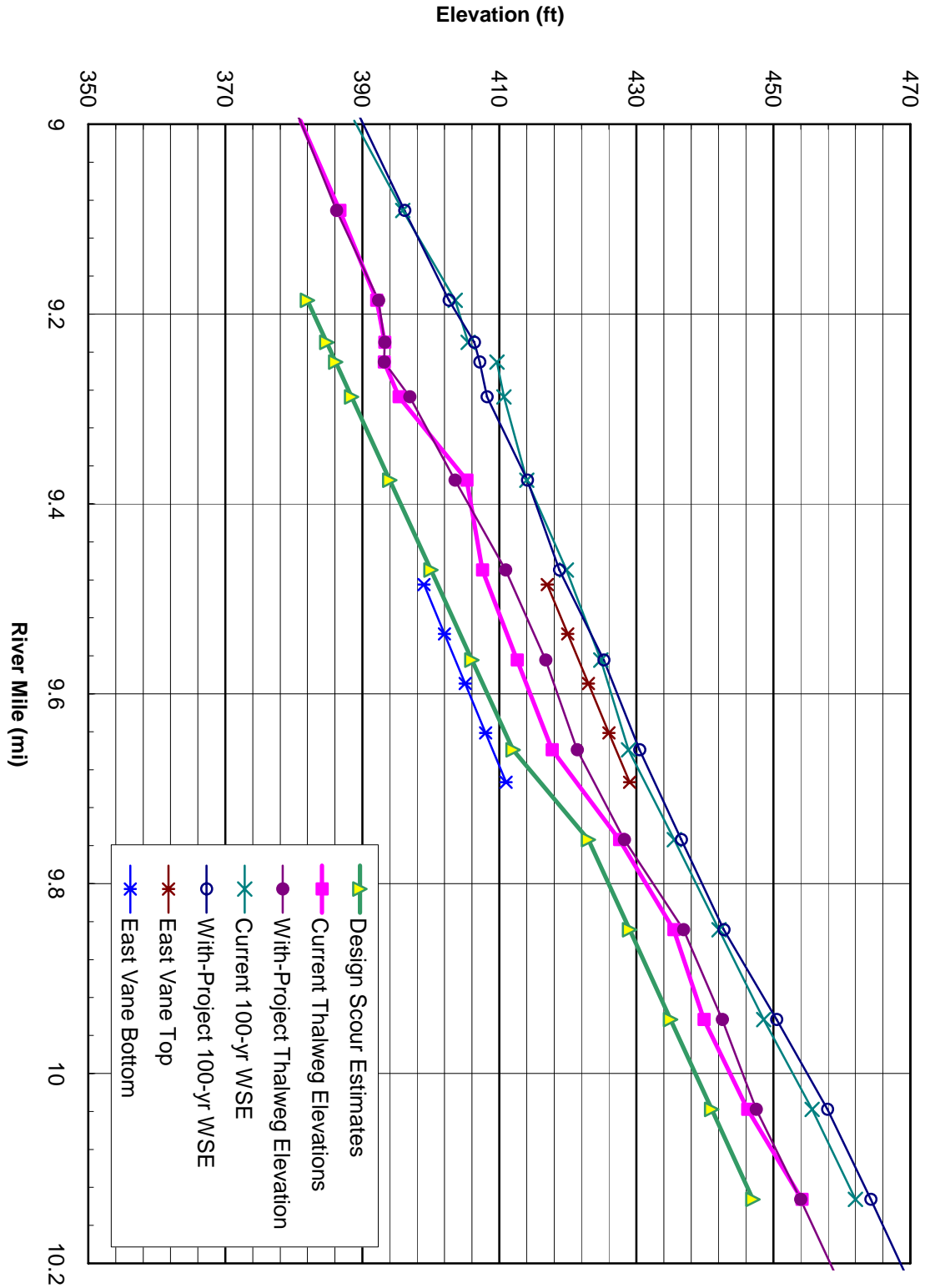


Figure 11. Scour Estimates for Riprap Design at Live Oak Levee.

9. References

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10. Appendix A: Current Hydraulic Conditions

Table 14. Hydraulic Data for Current Conditions 10-yr Flood.

RM	Return Period (yr)	Channel Discharge (ft ³ /s)	Thalweg elev (ft)	Thalweg Depth (ft)	Channel Velocity (ft/s)	Hydraulic Depth (ft)	Hydraulic Radius (ft)	Friction Slope (-)	Top Width (ft)
13.9205	10 yr	15000	747.0	7.8	12.7	5.1	5.0	0.0139	233
13.8258	10 yr	15000	736.7	8.9	12.9	5.2	5.1	0.0100	225
13.7311	10 yr	14967	726.9	12.2	11.5	6.9	6.2	0.0097	191
13.6364	10 yr	14983	725.8	9.7	13.3	5.6	5.2	0.0134	203
13.5417	10 yr	14915	719.5	10.7	11.4	4.4	3.5	0.0136	300
13.447	10 yr	14976	711.3	8.2	10.8	4.0	3.8	0.0143	349
13.3523	10 yr	14651	704.6	7.7	10.8	3.7	3.3	0.0126	365
13.2576	10 yr	14454	692.0	10.8	11.4	5.1	5.1	0.0128	247
13.1629	10 yr	14716	687.2	9.4	10.6	3.5	3.4	0.0140	401
13.0682	10 yr	14943	675.3	9.7	13.8	6.1	5.5	0.0119	178
12.9735	10 yr	15000	667.3	9.5	13.3	6.3	6.2	0.0129	178
12.8788	10 yr	14952	663.1	9.0	10.9	3.8	3.5	0.0130	364
12.7841	10 yr	14960	657.1	7.2	9.4	3.7	3.4	0.0136	424
12.6894	10 yr	14468	650.2	7.0	8.5	2.4	2.1	0.0159	719
12.5947	10 yr	15000	644.1	4.7	7.8	2.2	2.2	0.0165	858
12.5000	10 yr	14456	635.8	6.8	8.9	2.4	2.3	0.0169	668
12.4053	10 yr	14713	624.0	7.0	9.9	3.1	2.9	0.0147	479
12.3106	10 yr	14869	618.3	5.5	7.8	2.4	2.4	0.0146	783
12.2159	10 yr	14313	607.0	9.2	9.1	2.7	2.7	0.0142	586
12.1212	10 yr	13023	604.1	5.3	8.0	2.7	2.5	0.0145	616
12.0265	10 yr	14834	593.5	7.9	9.7	2.9	2.8	0.0126	527
11.9318	10 yr	14878	587.4	7.6	9.6	4.3	3.7	0.0126	363
11.8371	10 yr	11602	583.0	7.4	10.8	3.4	2.8	0.0146	314
11.7424	10 yr	11223	574.9	8.0	7.7	2.5	2.4	0.0141	591
11.6477	10 yr	11301	568.5	7.0	8.2	2.4	2.1	0.0153	587
11.5530	10 yr	12942	560.3	6.5	7.5	2.2	2.1	0.0156	804
11.4583	10 yr	15856	552.1	6.7	7.9	2.2	2.1	0.0173	908
11.3636	10 yr	16000	544.2	5.8	8.5	2.2	2.2	0.0132	858
11.2689	10 yr	15805	535.4	6.8	7.6	3.0	2.9	0.0125	701
11.1895	10 yr	15996	527.9	8.4	9.6	2.9	2.8	0.0060	568
11.1181	10 yr	15671	525.4	7.2	5.2	4.0	3.3		762
11.1098		Bridge							
11.0926	10 yr	16000	521.1	7.0	9.1	3.1	3.1	0.0139	563
10.9848	10 yr	16000	514.2	6.0	9.3	3.0	3.0	0.0131	574
10.8902	10 yr	14761	506.1	7.7	8.5	3.1	3.0	0.0115	557
10.7955	10 yr	15369	501.6	6.2	9.3	3.6	3.0	0.0124	452
10.7008	10 yr	14551	494.9	6.7	9.5	3.3	2.5	0.0124	461
10.6061	10 yr	12448	489.1	6.4	9.1	3.5	2.7	0.0131	390
10.5114	10 yr	14354	481.1	7.5	10.0	3.2	2.4	0.0123	444
10.4167	10 yr	15291	472.9	7.7	8.2	3.3	2.9	0.0111	574

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10.3220	10 yr	15152	466.7	7.8	10.0	3.8	2.8	0.0145	397
10.2273	10 yr	15974	460.8	8.8	8.9	2.5	2.4	0.0118	722
10.1326	10 yr	16000	454.2	7.6	7.3	3.1	3.1	0.0115	698
10.0379	10 yr	16000	446.2	10.3	9.9	3.0	3.0	0.0122	532
9.9432	10 yr	16000	439.9	7.4	7.8	3.2	3.2	0.0119	644
9.8485	10 yr	15998	435.5	5.2	9.7	3.1	3.0	0.0133	540
9.7538	10 yr	16000	427.5	6.8	8.1	2.9	2.9	0.0128	680
9.6591	10 yr	16000	417.7	9.7	9.6	3.2	3.2	0.0106	520
9.5644	10 yr	16000	412.6	9.6	9.4	4.7	4.7	0.0083	361
9.4697	10 yr	16000	407.5	10.0	10.9	5.9	5.7	0.0103	249
9.3750	10 yr	15981	405.3	7.7	12.0	4.8	4.7	0.0114	275
9.2871	10 yr	16000	395.3	11.1	12.4	6.2	6.1	0.0079	207
9.2507	10 yr	16000	393.2	17.0	11.4	7.9	7.6	0.0090	178
9.2468		Bridge							
9.2297	10 yr	16000	393.3	16.9	12.5	7.2	7.0	0.0091	179
9.1856	10 yr	15467	392.1	17.0	11.6	5.7	2.6	0.0108	235
9.0909	10 yr	11801	386.7	15.1	9.3	3.5	2.8	0.0141	368
8.9962	10 yr	11026	381.0	11.4	7.8	2.1	2.1	0.0160	677
8.9015	10 yr	14965	371.4	8.0	8.8	2.7	2.7	0.0123	634
8.8068	10 yr	15998	367.3	11.2	7.3	2.8	2.7	0.0127	796
8.7121	10 yr	15769	358.5	8.0	9.6	2.8	2.8	0.0148	581

Table 15. Hydraulic Data for Current Conditions 50-yr Flood.

RM	Return Period (yr)	Channel Discharge (ft ³ /s)	Thalweg elev (ft)	Thalweg Depth (ft)	Channel Velocity (ft/s)	Hydraulic Depth (ft)	Hydraulic Radius (ft)	Friction Slope (-)	Top Width (ft)
13.9205	50 yr	23989	747.0	9.7	14.7	6.7	6.4	0.0127	244
13.8258	50 yr	23995	736.7	10.9	14.6	6.7	6.2	0.0107	244
13.7311	50 yr	23834	726.9	13.9	14.6	8.5	7.2	0.0100	191
13.6364	50 yr	23593	725.8	11.9	15.0	7.6	5.9	0.0108	206
13.5417	50 yr	22924	719.5	12.5	12.4	5.9	3.7	0.0120	312
13.447	50 yr	23897	711.3	9.5	12.8	5.1	4.8	0.0131	365
13.3523	50 yr	23147	704.6	9.1	12.4	5.1	3.8	0.0131	365
13.2576	50 yr	23177	692.0	12.2	14.2	6.0	5.9	0.0138	272
13.1629	50 yr	23459	687.2	10.7	11.8	4.4	3.9	0.0126	447
13.0682	50 yr	23640	675.3	12.2	15.0	7.5	6.2	0.0121	210
12.9735	50 yr	23997	667.3	12.2	14.1	6.2	5.9	0.0131	276
12.8788	50 yr	23721	663.1	10.5	12.1	4.8	4.0	0.0133	408
12.7841	50 yr	23782	657.1	8.3	11.6	4.5	4.0	0.0146	456
12.6894	50 yr	22782	650.2	7.9	9.6	2.9	2.5	0.0162	812
12.5947	50 yr	23999	644.1	5.5	9.3	2.8	2.7	0.0162	925
12.5000	50 yr	23077	635.8	7.8	10.1	3.2	3.0	0.0154	728
12.4053	50 yr	23352	624.0	8.2	11.4	4.0	3.8	0.0144	509
12.3106	50 yr	23745	618.3	6.3	9.4	3.1	3.1	0.0144	812
12.2159	50 yr	22779	607.0	10.4	9.6	3.1	3.1	0.0146	761
12.1212	50 yr	20800	604.1	6.0	9.9	3.3	3.0	0.0140	635

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12.0265	50 yr	23673	593.5	9.3	10.2	3.7	3.5	0.0121	633
11.9318	50 yr	23521	587.4	8.9	11.5	5.2	4.2	0.0134	395
11.8371	50 yr	17242	583.0	8.8	10.8	3.4	3.1	0.0147	468
11.7424	50 yr	18401	574.9	8.9	8.9	3.1	2.9	0.0144	676
11.6477	50 yr	17635	568.5	7.8	9.3	2.8	2.4	0.0152	676
11.5530	50 yr	20889	560.3	7.4	8.1	2.5	2.3	0.0157	1034
11.4583	50 yr	24487	552.1	7.4	8.9	2.5	2.3	0.0170	1095
11.3636	50 yr	24779	544.2	6.6	9.2	2.7	2.5	0.0128	1017
11.2689	50 yr	24373	535.4	7.8	8.6	3.6	3.4	0.0122	798
11.1895	50 yr	24719	527.9	9.5	10.6	3.6	3.4	0.0057	650
11.1181	50 yr	23841	525.4	8.4	6.1	5.2	4.1		762
11.1098		Bridge							
11.0926	50 yr	24699	521.1	8.1	10.4	4.0	3.1	0.0139	602
10.9848	50 yr	24795	514.2	7.0	10.8	3.6	3.4	0.0120	635
10.8902	50 yr	22885	506.1	8.9	9.6	4.3	3.7	0.0114	562
10.7955	50 yr	23448	501.6	7.1	11.5	4.4	3.6		464
10.7008	50 yr	21590	494.9	7.8	10.5	4.3	3.1	0.0126	484
10.6061	50 yr	18813	489.1	7.2	11.4	4.3	3.1	0.0130	390
10.5114	50 yr	21334	481.1	8.7	10.8	4.3	2.6	0.0109	464
10.4167	50 yr	23347	472.9	8.8	9.3	4.1	3.6	0.0111	603
10.3220	50 yr	22339	466.7	9.0	10.8	4.1	3.0	0.0142	508
10.2273	50 yr	24676	460.8	9.7	9.9	3.2	2.8	0.0113	784
10.1326	50 yr	24800	454.2	8.6	8.7	4.1	4.0	0.0111	701
10.0379	50 yr	24798	446.2	11.4	11.2	3.9	3.9	0.0117	566
9.9432	50 yr	24800	439.9	8.4	8.9	3.9	3.9	0.0116	703
9.8485	50 yr	24761	435.5	6.2	11.2	4.0	3.8	0.0127	555
9.7538	50 yr	24800	427.5	7.7	9.5	3.8	3.8	0.0123	683
9.6591	50 yr	24800	417.7	10.8	11.2	4.2	4.1	0.0092	534
9.5644	50 yr	24800	412.6	11.5	10.3	6.5	6.4	0.0076	366
9.4697	50 yr	24800	407.5	11.7	13.1	7.4	7.2	0.0106	258
9.3750	50 yr	24739	405.3	9.2	14.1	6.3	6.1	0.0094	279
9.2871	50 yr	24800	395.3	14.0	13.0	8.6	8.4	0.0062	221
9.2507	50 yr	24800	393.2	20.1	12.7	10.5	10.0	0.0093	186
9.2468		Bridge							
9.2297	50 yr	24800	393.3	18.2	16.3	8.3	8.1	0.0099	183
9.1856	50 yr	21751	392.1	18.6	12.7	7.3	3.9	0.0104	235
9.0909	50 yr	17238	386.7	16.1	10.4	3.9	3.4	0.0144	430
8.9962	50 yr	17571	381.0	12.2	9.2	2.8	2.8	0.0156	690
8.9015	50 yr	23390	371.4	9.1	9.4	2.9	2.8	0.0123	856
8.8068	50 yr	24772	367.3	12.4	7.3	2.8	2.8	0.0128	1215
8.7121	50 yr	24318	358.5	9.2	9.4	2.7	2.7	0.0148	954

Table 16. Hydraulic Data for Current Conditions 100-yr Flood.

RM	Return Period	Channel Discharge	Thalweg elev (ft)	Thalweg Depth	Channel Velocity	Hydraulic Depth	Hydraulic Radius	Friction Slope (-)	Top Width
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	(yr)	(ft ³ /s)		(ft)	(ft/s)	(ft)	(ft)		(ft)
13.9205	100 yr	27080	747.0	10.3	15.2	7.2	6.9	0.0123	247
13.8258	100 yr	27070	736.7	11.6	15.0	7.2	6.1	0.0108	251
13.7311	100 yr	26877	726.9	14.4	15.6	9.0	6.6	0.0101	191
13.6364	100 yr	26473	725.8	12.5	15.4	8.3	5.9	0.0104	208
13.5417	100 yr	25491	719.5	13.0	12.8	6.4	4.1	0.0115	312
13.447	100 yr	26957	711.3	10.0	13.3	5.6	5.1	0.0125	365
13.3523	100 yr	25957	704.6	9.6	12.7	5.6	3.9	0.0128	365
13.2576	100 yr	26122	692.0	13.1	13.9	5.7	5.7	0.0137	329
13.1629	100 yr	26429	687.2	11.1	12.3	4.8	4.2	0.0122	447
13.0682	100 yr	26558	675.3	12.8	15.5	8.0	6.4	0.0120	214
12.9735	100 yr	27074	667.3	13.1	13.8	6.0	5.6	0.0129	330
12.8788	100 yr	26693	663.1	10.9	12.5	5.2	4.2	0.0131	409
12.7841	100 yr	26784	657.1	8.7	11.9	4.7	3.9	0.0144	482
12.6894	100 yr	25645	650.2	8.1	9.9	3.2	2.7	0.0159	815
12.5947	100 yr	27096	644.1	5.7	9.8	3.0	2.9	0.0161	935
12.5000	100 yr	26002	635.8	8.1	10.4	3.4	3.2	0.0152	741
12.4053	100 yr	26300	624.0	8.6	11.7	4.3	4.0	0.0144	528
12.3106	100 yr	26802	618.3	6.5	9.9	3.3	3.3	0.0144	816
12.2159	100 yr	25717	607.0	10.7	9.8	3.3	3.3	0.0146	795
12.1212	100 yr	23405	604.1	6.3	10.4	3.5	3.2	0.0138	639
12.0265	100 yr	26712	593.5	9.6	10.5	4.0	3.7	0.0119	641
11.9318	100 yr	26327	587.4	9.5	11.6	5.2	4.0	0.0139	438
11.8371	100 yr	19264	583.0	9.1	11.2	3.4	3.1	0.0152	503
11.7424	100 yr	20772	574.9	9.2	9.1	3.2	3.0	0.0145	718
11.6477	100 yr	20041	568.5	8.0	9.7	3.0	2.5	0.0152	689
11.5530	100 yr	23569	560.3	7.6	8.4	2.6	2.4	0.0156	1082
11.4583	100 yr	27868	552.1	7.7	9.0	2.6	2.4	0.0167	1190
11.3636	100 yr	28255	544.2	6.9	9.5	2.8	2.7	0.0126	1059
11.2689	100 yr	27780	535.4	8.2	9.0	3.8	3.7	0.0121	815
11.1895	100 yr	28172	527.9	9.9	10.9	3.7	3.6	0.0057	692
11.1181	100 yr	27080	525.4	8.8	6.4	5.6	4.4		762
11.1098		Bridge							
11.0926	100 yr	28035	521.1	8.4	10.8	4.1	3.1	0.0139	636
10.9848	100 yr	28268	514.2	7.3	11.1	3.9	3.5	0.0117	645
10.8902	100 yr	26040	506.1	9.2	10.0	4.6	3.9	0.0113	564
10.7955	100 yr	26573	501.6	7.4	12.0	4.7	3.8	0.0123	470
10.7008	100 yr	24354	494.9	8.2	10.8	4.6	3.3	0.0126	487
10.6061	100 yr	21230	489.1	7.4	12.1	4.5	3.3	0.0130	390
10.5114	100 yr	23849	481.1	9.1	11.1	4.6	2.9	0.0107	464
10.4167	100 yr	26521	472.9	9.1	9.8	4.5	3.8	0.0111	604
10.3220	100 yr	25157	466.7	9.3	11.2	4.4	3.1	0.0139	515
10.2273	100 yr	28088	460.8	10.0	10.3	3.4	2.9	0.0111	798
10.1326	100 yr	28299	454.2	8.9	9.2	4.4	4.3	0.0109	702
10.0379	100 yr	28293	446.2	11.8	11.7	4.3	4.1	0.0116	571
9.9432	100 yr	28297	439.9	8.8	9.4	4.2	4.1	0.0114	711

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9.8485	100 yr	28223	435.5	6.6	11.7	4.3	4.0	0.0125	560
9.7538	100 yr	28300	427.5	8.0	10.0	4.1	4.1	0.0122	684
9.6591	100 yr	28300	417.7	11.2	11.6	4.5	4.5	0.0086	535
9.5644	100 yr	28300	412.6	12.2	10.6	7.2	7.1	0.0074	369
9.4697	100 yr	28300	407.5	12.3	13.9	7.8	7.6	0.0107	261
9.3750	100 yr	28217	405.3	9.8	14.8	6.8	6.6	0.0083	280
9.2871	100 yr	28300	395.3	15.3	12.8	9.7	9.4	0.0054	228
9.2507	100 yr	28283	393.2	21.5	12.7	11.2	9.2	0.0094	199
9.2468		Bridge							
9.2297	100 yr	28300	393.3	19.0	17.0	9.0	8.7	0.0098	185
9.1856	100 yr	24152	392.1	19.0	13.2	7.8	4.4	0.0107	235
9.0909	100 yr	19762	386.7	16.3	11.1	4.1	3.5	0.0146	439
8.9962	100 yr	20033	381.0	12.5	9.5	3.0	3.0	0.0155	703
8.9015	100 yr	26659	371.4	9.5	9.3	2.8	2.8	0.0124	1012
8.8068	100 yr	28262	367.3	12.6	7.6	3.0	2.9	0.0128	1253
8.7121	100 yr	27721	358.5	9.6	9.4	2.7	2.6	0.0149	1095

Table 17. Hydraulic Data for Current Conditions 500-yr Flood.

RM	Return Period (yr)	Channel Discharge (ft ³ /s)	Thalweg elev (ft)	Thalweg Depth (ft)	Channel Velocity (ft/s)	Hydraulic Depth (ft)	Hydraulic Radius (ft)	Friction Slope (-)	Top Width (ft)
13.9205	500 yr	35134	747.0	11.8	16.4	8.4	7.9	0.0114	254
13.8258	500 yr	34912	736.7	13.1	16.0	8.6	6.9	0.0100	255
13.7311	500 yr	34363	726.9	16.0	17.0	10.6	7.0	0.0092	191
13.6364	500 yr	33570	725.8	14.2	16.2	9.9	6.0	0.0095	210
13.5417	500 yr	32047	719.5	14.0	13.9	7.4	4.9	0.0108	312
13.447	500 yr	34865	711.3	11.1	14.3	6.7	5.4	0.0111	365
13.3523	500 yr	32830	704.6	10.7	13.4	6.7	4.3	0.0117	365
13.2576	500 yr	33908	692.0	14.6	14.0	6.0	5.6	0.0129	407
13.1629	500 yr	34091	687.2	12.0	13.3	5.7	4.6	0.0110	447
13.0682	500 yr	34053	675.3	14.5	16.4	9.6	5.5	0.0109	216
12.9735	500 yr	35004	667.3	14.5	14.2	6.5	5.7	0.0118	380
12.8788	500 yr	34255	663.1	11.9	13.4	6.3	4.7	0.0131	409
12.7841	500 yr	34478	657.1	9.4	13.2	5.0	3.9	0.0151	528
12.6894	500 yr	32917	650.2	8.7	10.8	3.7	3.0	0.0152	831
12.5947	500 yr	35163	644.1	6.3	10.4	3.4	3.3	0.0152	989
12.5000	500 yr	33646	635.8	8.7	11.3	4.0	3.7	0.0143	749
12.4053	500 yr	34040	624.0	9.3	12.8	5.1	4.8	0.0143	528
12.3106	500 yr	34779	618.3	7.1	11.0	3.8	3.7	0.0143	828
12.2159	500 yr	33423	607.0	11.4	10.4	3.7	3.7	0.0147	869
12.1212	500 yr	29974	604.1	6.9	11.3	3.8	3.6	0.0133	694
12.0265	500 yr	34587	593.5	10.6	11.0	4.6	4.2	0.0117	683
11.9318	500 yr	33587	587.4	10.4	12.3	5.4	4.2	0.0144	505
11.8371	500 yr	24846	583.0	9.8	11.6	3.6	3.2	0.0153	587
11.7424	500 yr	27031	574.9	9.8	9.9	3.5	3.1	0.0147	770

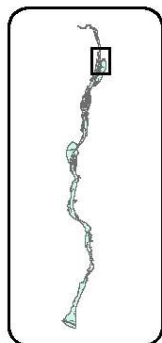
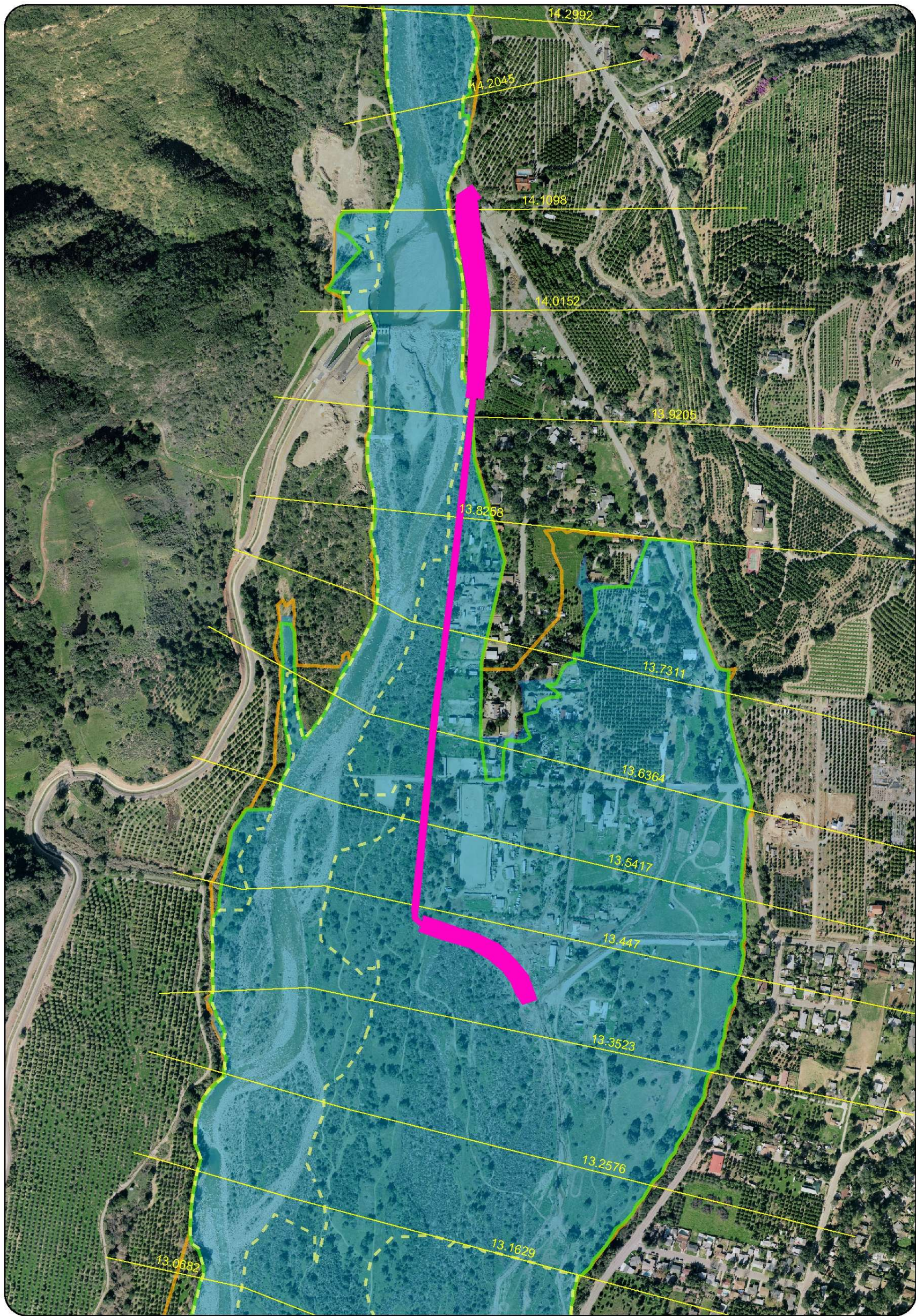
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11.6477	500 yr	25469	568.5	8.6	10.5	3.3	2.9	0.0153	728
11.5530	500 yr	30512	560.3	8.1	9.1	2.9	2.7	0.0155	1154
11.4583	500 yr	35997	552.1	8.2	9.7	2.9	2.7	0.0163	1276
11.3636	500 yr	36566	544.2	7.5	10.1	3.2	3.0	0.0124	1144
11.2689	500 yr	35947	535.4	8.8	9.8	4.4	4.1	0.0119	836
11.1895	500 yr	36451	527.9	10.7	11.6	4.3	4.1	0.0058	736
11.1181	500 yr	34585	525.4	9.6	7.1	6.4	5.0		762
11.1098		Bridge							
11.0926	500 yr	35733	521.1	9.3	11.4	4.7	3.2	0.0127	674
10.9848	500 yr	36381	514.2	8.3	11.4	4.4	3.2	0.0115	723
10.8902	500 yr	33549	506.1	9.9	11.2	5.3	4.2	0.0111	568
10.7955	500 yr	33889	501.6	8.4	12.7	5.5	4.3	0.0121	486
10.7008	500 yr	30983	494.9	8.8	12.1	5.2	3.7	0.0126	490
10.6061	500 yr	26853	489.1	8.2	12.9	5.3	3.6	0.0123	390
10.5114	500 yr	29854	481.1	9.8	12.1	5.3	3.4	0.0108	464
10.4167	500 yr	34133	472.9	9.8	11.0	5.1	4.3	0.0114	605
10.3220	500 yr	31434	466.7	10.1	11.7	4.6	3.4	0.0134	580
10.2273	500 yr	36094	460.8	10.7	10.8	3.9	3.2	0.0107	851
10.1326	500 yr	36685	454.2	9.6	10.2	5.1	5.0	0.0106	705
10.0379	500 yr	36629	446.2	12.7	12.5	4.9	4.6	0.0112	596
9.9432	500 yr	36677	439.9	9.5	10.4	4.9	4.8	0.0111	714
9.8485	500 yr	36468	435.5	7.5	12.6	5.1	4.6	0.0126	568
9.7538	500 yr	36700	427.5	8.6	11.3	4.7	4.7	0.0117	686
9.6591	500 yr	36700	417.7	12.2	12.3	5.5	5.4	0.0072	538
9.5644	500 yr	36700	412.6	14.0	11.0	8.9	8.6	0.0072	375
9.4697	500 yr	36695	407.5	13.1	16.3	8.6	7.8	0.0103	264
9.3750	500 yr	36595	405.3	11.7	14.9	8.6	7.7	0.0056	284
9.2871	500 yr	36635	395.3	18.8	12.2	12.8	11.7	0.0034	235
9.2507	500 yr	36161	393.2	25.3	12.1	15.1	10.2	0.0074	199
9.2468		Bridge							
9.2297	500 yr	36685	393.3	20.8	18.4	10.6	10.0	0.0097	188
9.1856	500 yr	29737	392.1	20.0	14.5	8.7	5.3	0.0110	235
9.0909	500 yr	25284	386.7	17.0	12.3	4.6	4.0	0.0149	447
8.9962	500 yr	26045	381.0	13.0	10.5	3.5	3.5	0.0155	713
8.9015	500 yr	34698	371.4	10.1	9.9	3.1	3.0	0.0125	1119
8.8068	500 yr	36639	367.3	13.1	8.5	3.4	3.4	0.0128	1262
8.7121	500 yr	35888	358.5	10.2	9.7	2.9	2.8	0.0146	1274

11. Appendix B: Floodmaps

These maps are reproduced from Reclamations main report (Reclamation, 2006).

Page numbers disappear after this page. Is that on purpose?



-  Project Disposal Site
-  Project Levee
-  Current 10-yr
-  Current 50-yr
-  Current 100-yr
-  Current 500-yr

Current Conditions Flood Boundaries

Matilija Dam Ecosystem Restoration Project
Ventura County, CA

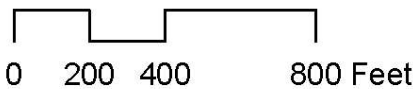
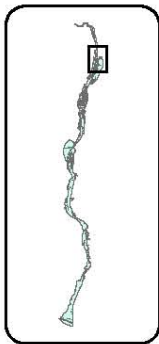
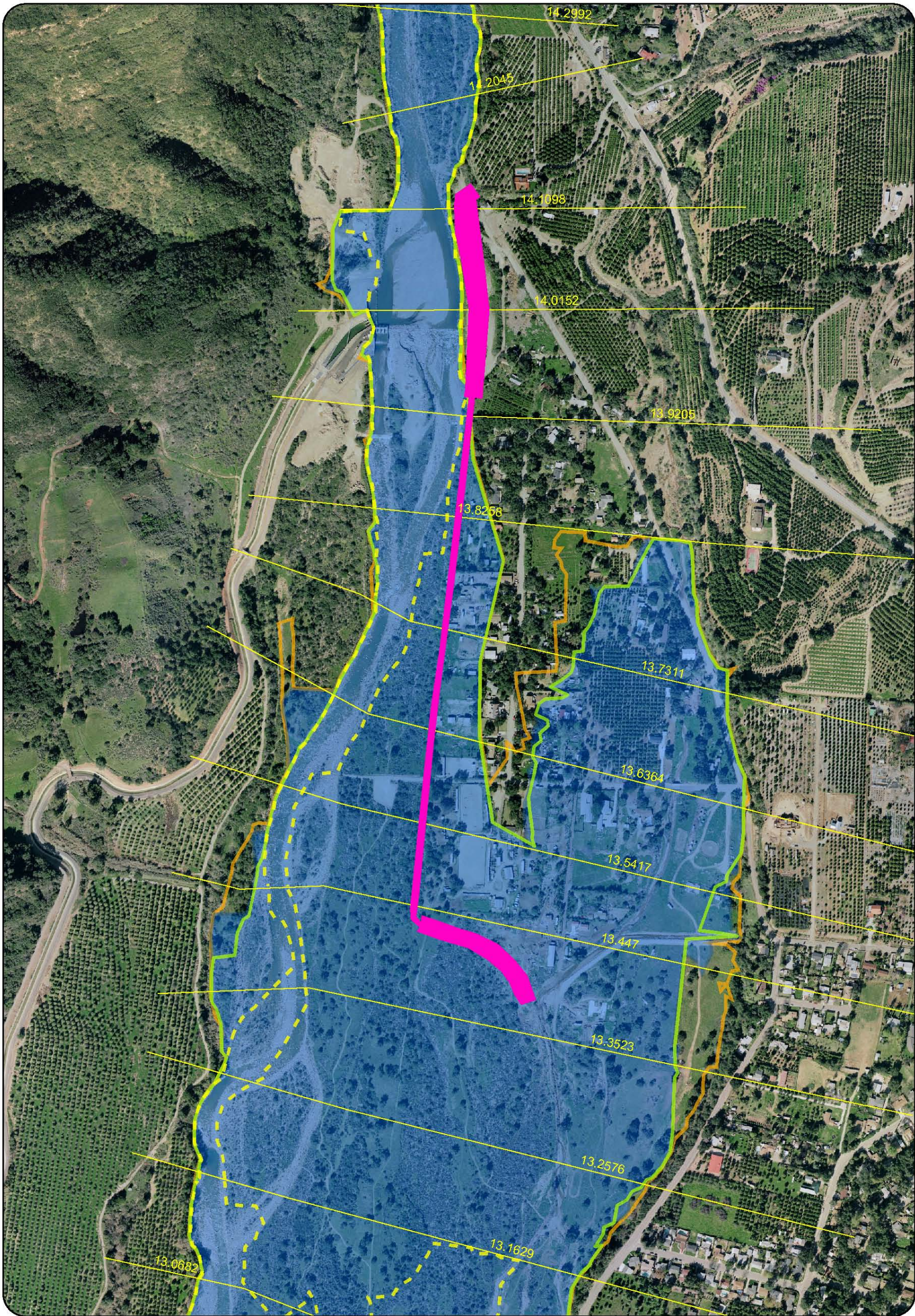


Figure 20-1 Plate 14
Principal Investigators:
Blair Greimann, David Mooney
US Bureau of Reclamation
Technical Service Center
September 14, 2006

See Page 15



- Project Disposal Site
- Project Levee
- Without-Project Future 10yr
- Without-Project Future 50yr
- Without-Project Future 100yr
- Without-Project Future 500yr

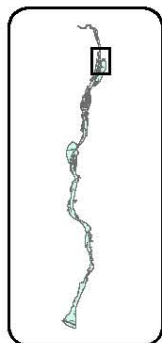
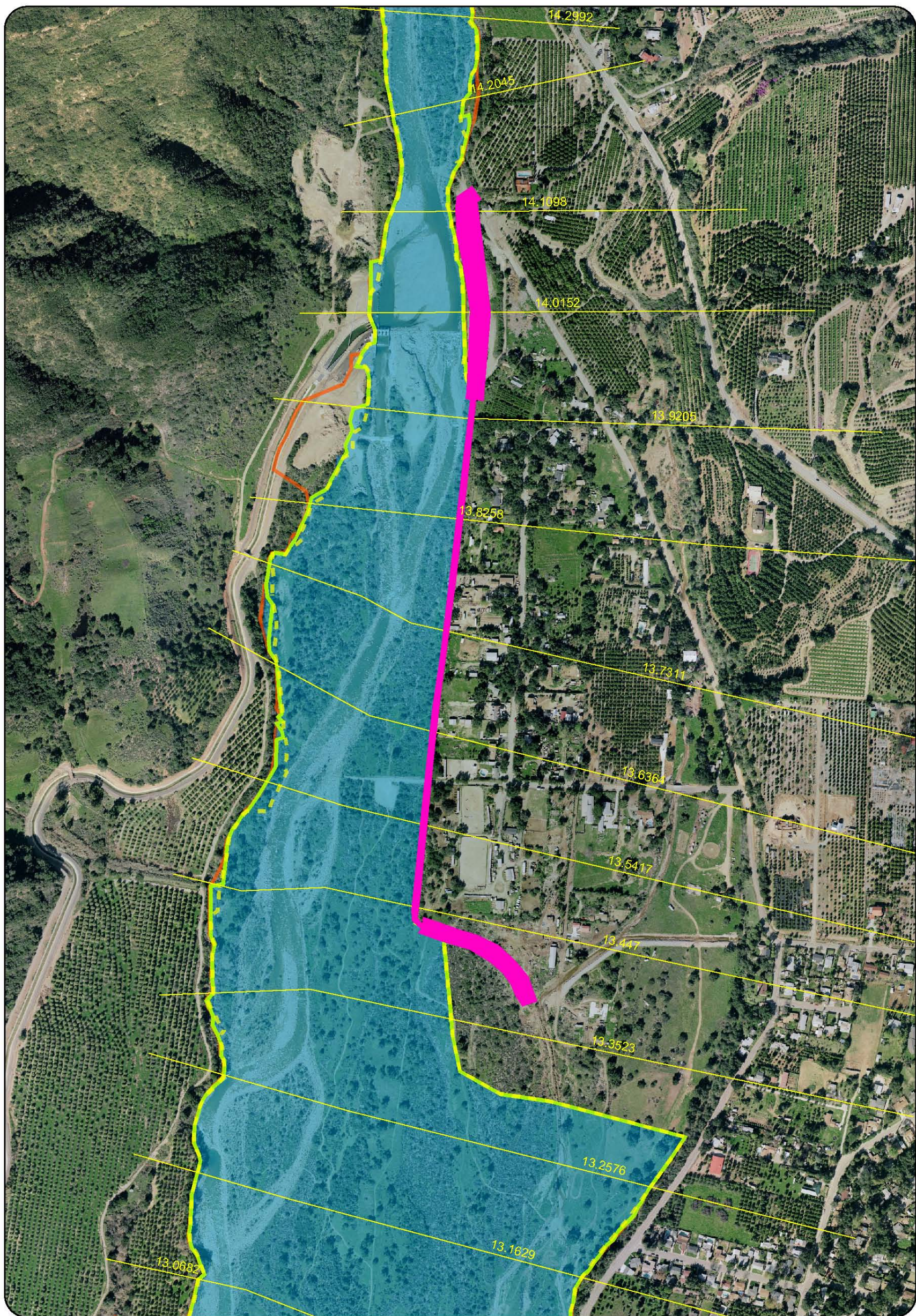
Future Without-Project Conditions Flood Boundaries

Matilija Dam Ecosystem
Restoration Project
Ventura County, CA

0 200 400 800 Feet

Figure 20-2 Plate 14

Principal Investigators:
Blair Greimann, David Mooney
US Bureau of Reclamation
Technical Service Center
September 14, 2006



-  Project Disposal Site
-  Project Levee
-  Future With-Project 10yr
-  Future With-Project 50yr
-  Future With-Project 100yr
-  Future With-Project 500yr

Future With-Project Conditions Flood Boundaries

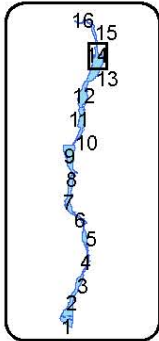
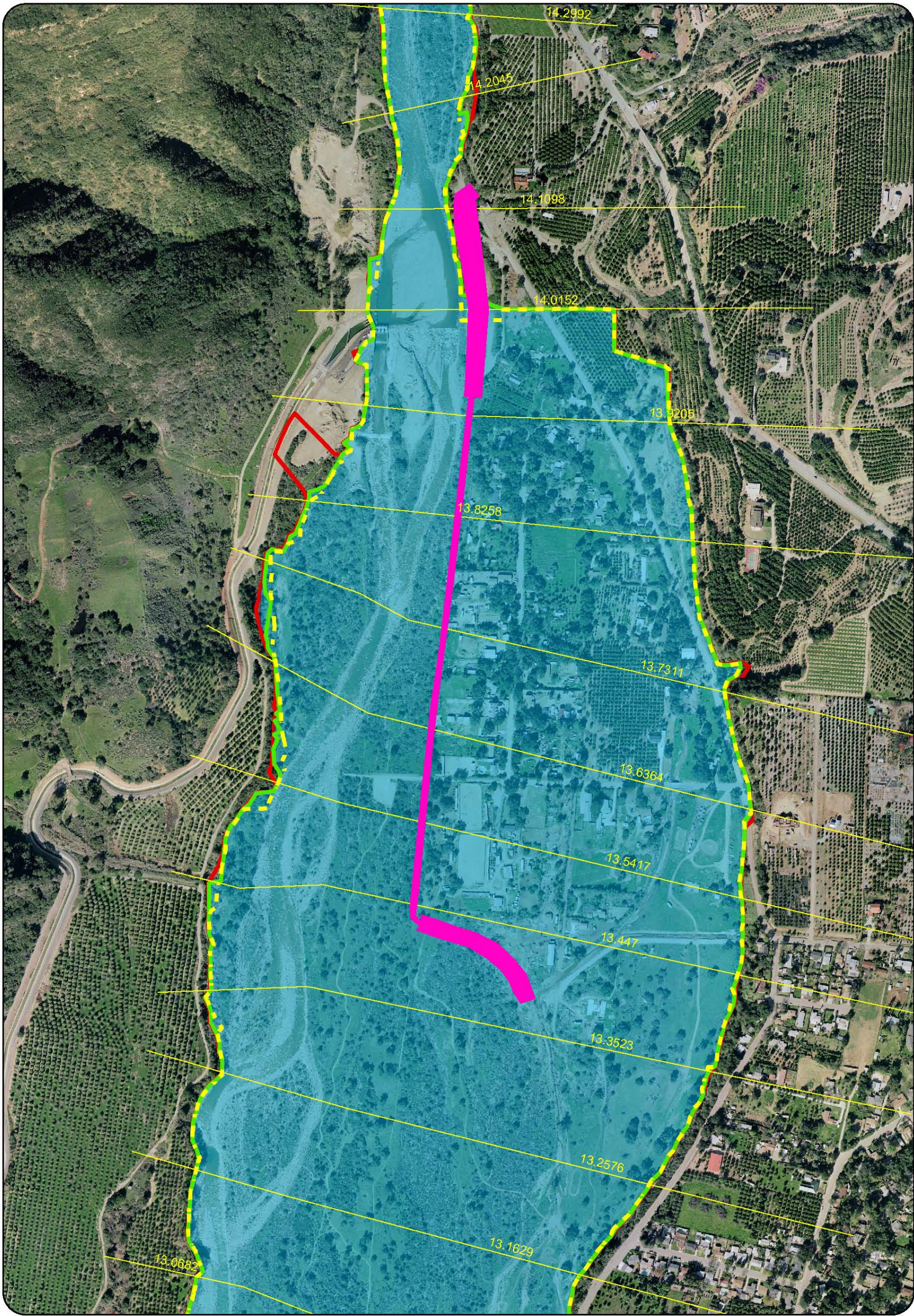
Matilija Dam Ecosystem
Restoration Project
Ventura County, CA

0 200 400 800 Feet

Figure 20-3 Plate 14

Principal Investigators:
Blair Greimann, David Mooney
US Bureau of Reclamation
Technical Service Center
September 14, 2006

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- Project Levee
- Project Disposal Site
- 10-yr No Improvements
- 50-yr No Improvements
- 100-yr No Improvements
- 500-yr No Improvements

**Future With-Project Conditions
No Improvements Flood Boundaries**

Matilija Dam Ecosystem Restoration Project
Ventura County, CA

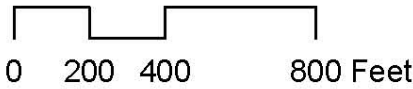
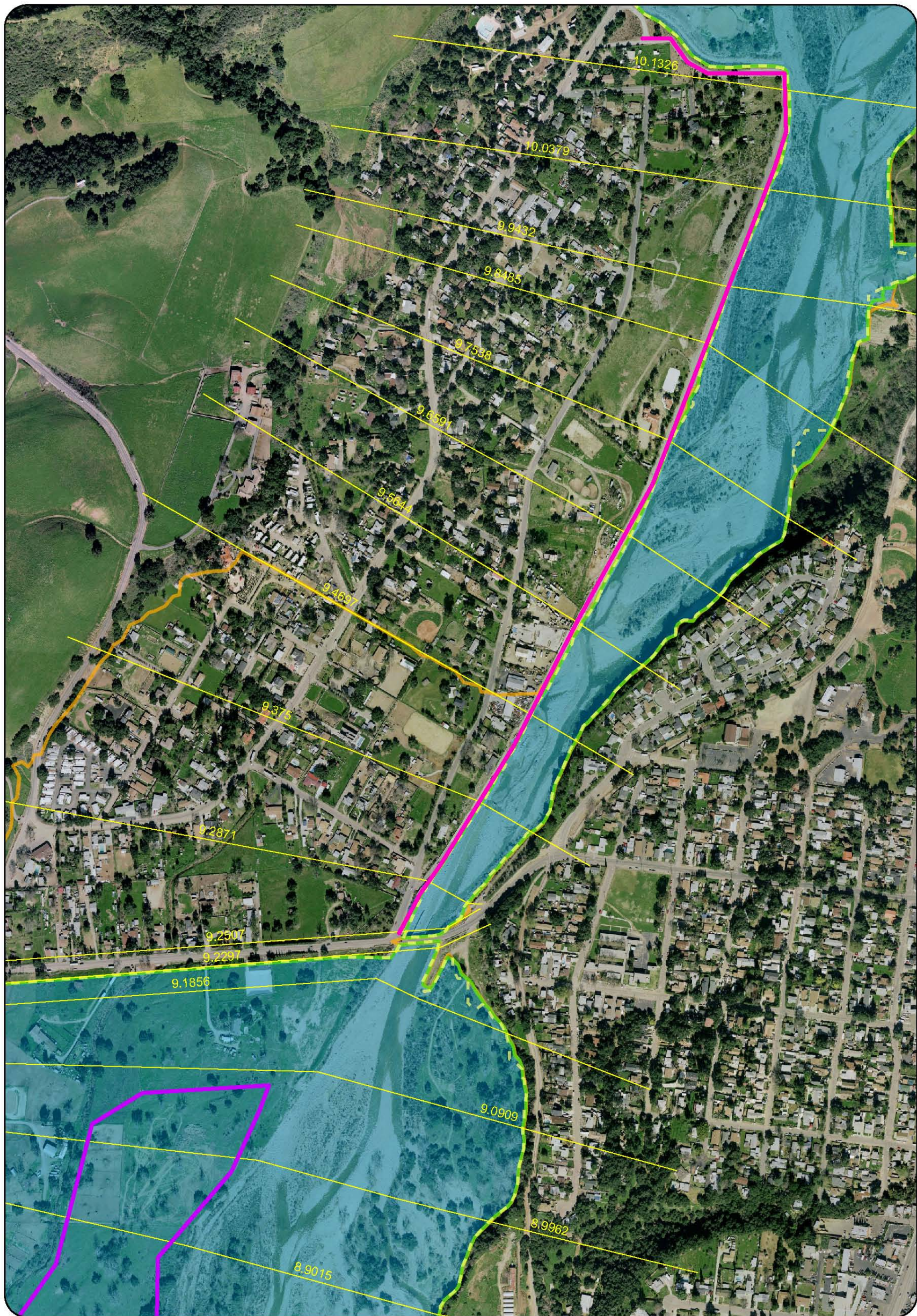
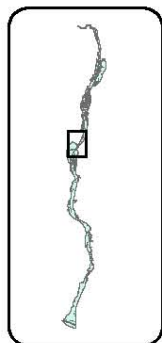


Figure 20-9 Plate 14
Principal Investigators:
Blair Greimann, David Mooney
US Bureau of Reclamation
Technical Service Center
March 1, 2007



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- Project Disposal Site
- Project Levee
- Current 10-yr
- Current 50-yr
- Current 100-yr
- Current 500-yr

Current Conditions Flood Boundaries

Matilija Dam Ecosystem
Restoration Project
Ventura County, CA

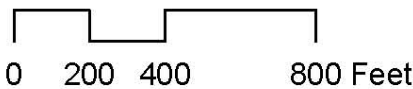
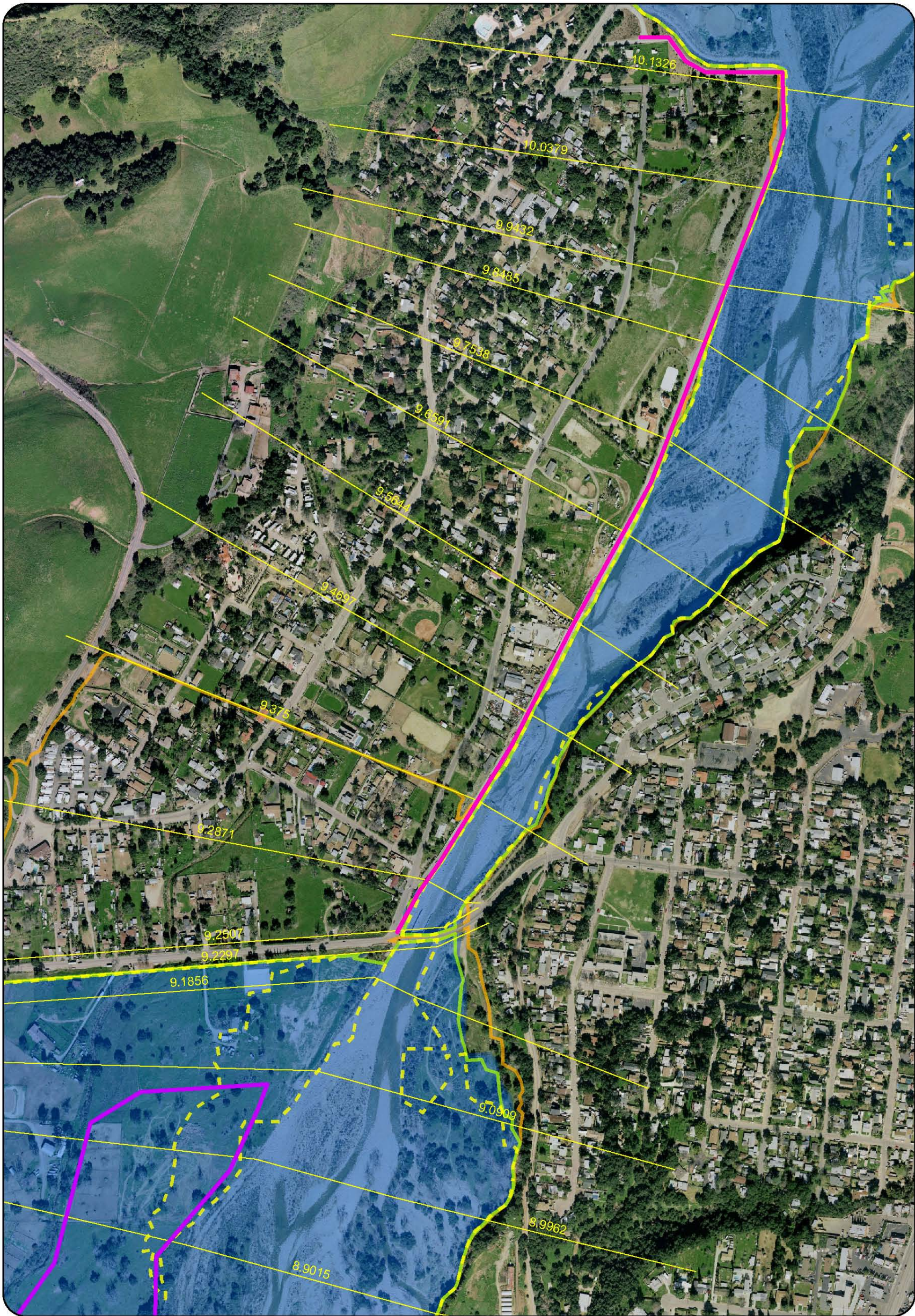


Figure 20-1 Plate 10

Principal Investigators:
Blair Greimann, David Mooney
US Bureau of Reclamation
Technical Service Center
September 14, 2006

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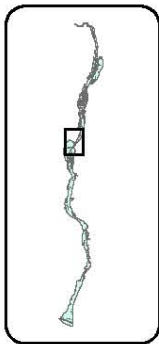
See Page 9






Future Without-Project Conditions Flood Boundaries

Matilija Dam Ecosystem
Restoration Project
Ventura County, CA

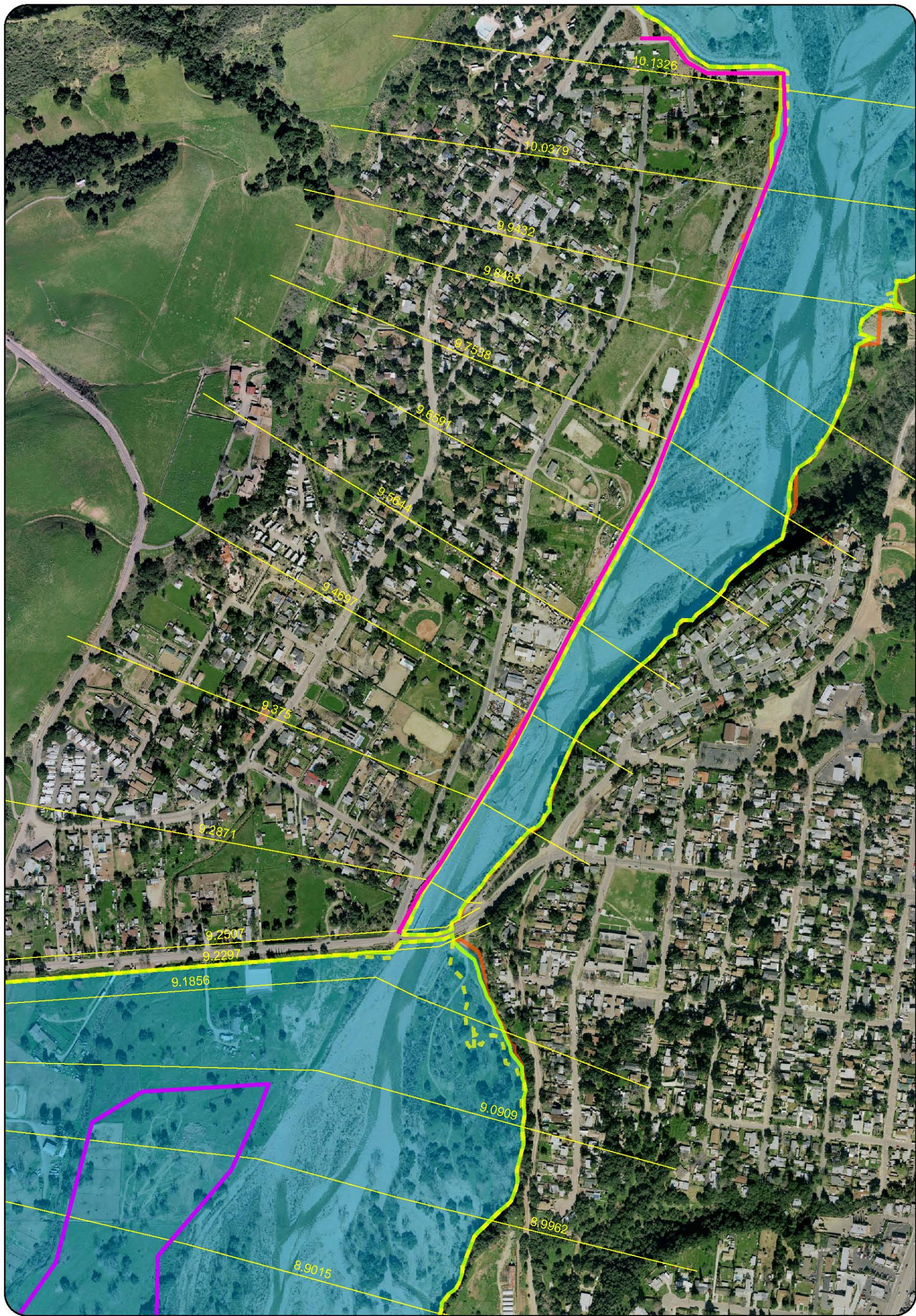
Figure 20-2 Plate 10

Principal Investigators:
Blair Greimann, David Mooney
US Bureau of Reclamation
Technical Service Center
September 14, 2006

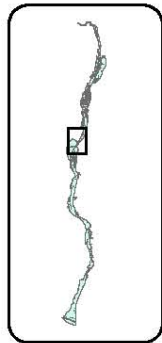


-  Project Disposal Site
-  Project Levee
-  Without-Project Future 10yr
-  Without-Project Future 50yr
-  Without-Project Future 100yr
-  Without-Project Future 500yr

0 200 400 800 Feet



See Page 9



- Project Disposal Site
- Project Levee
- Future With-Project 10yr
- Future With-Project 50yr
- Future With-Project 100yr
- Future With-Project 500yr

Future With-Project Conditions Flood Boundaries

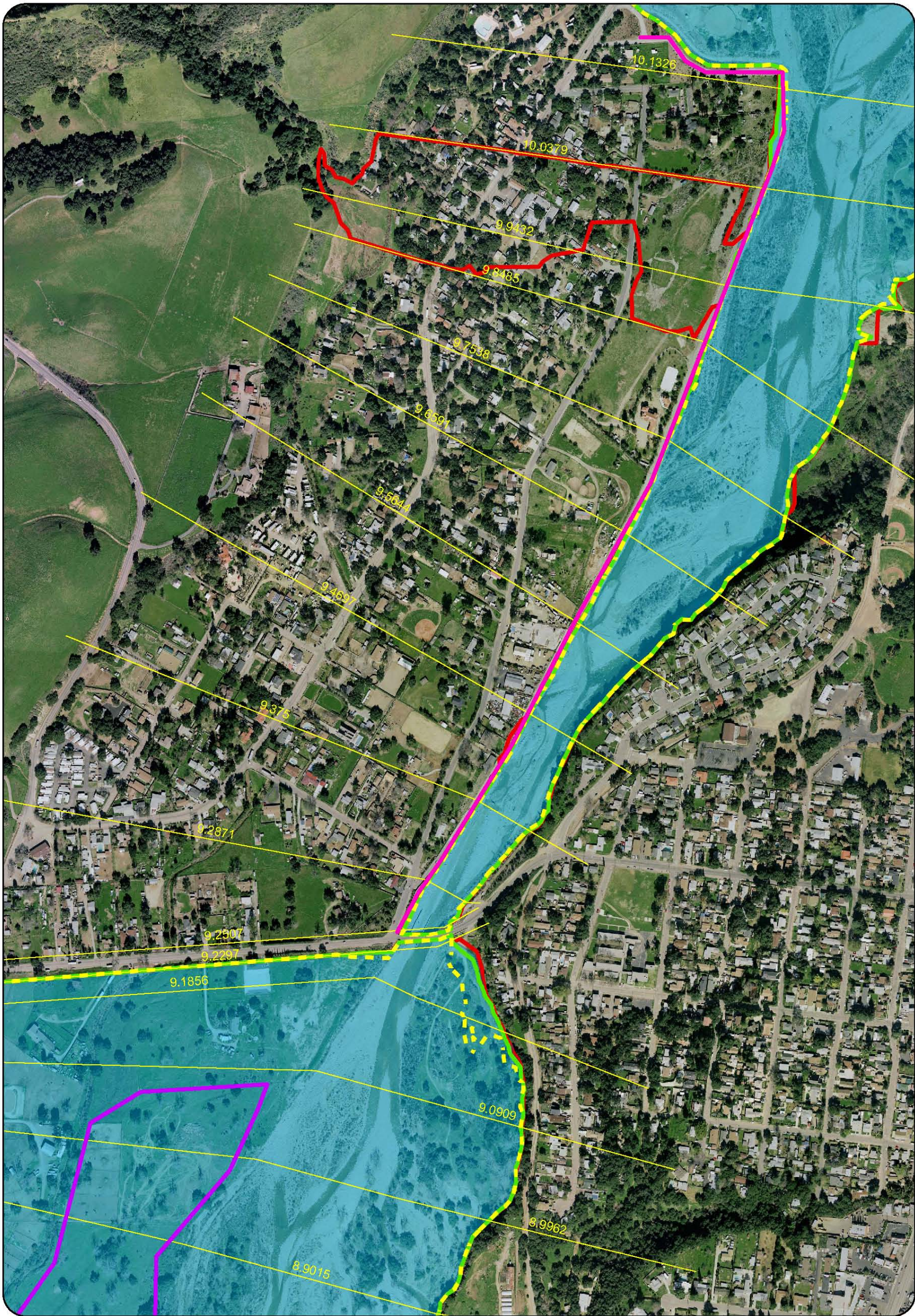
Matilija Dam Ecosystem
Restoration Project
Ventura County, CA

0 200 400 800 Feet

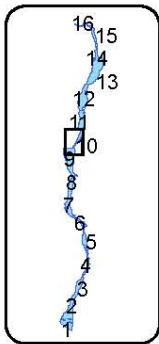
Figure 20-3 Plate 10

Principal Investigators:
Blair Greimann, David Mooney
US Bureau of Reclamation
Technical Service Center
September 14, 2006

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- Project Levee
- Project Disposal Site
- 10-yr No Improvements
- 50-yr No Improvements
- 100-yr No Improvements
- 500-yr No Improvements

**Future With-Project Conditions
No Improvements Flood Boundaries**

Matilija Dam Ecosystem Restoration Project
Ventura County, CA

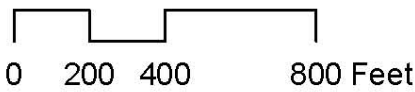


Figure 20-9 Plate 10
Principal Investigators:
Blair Greimann, David Mooney
US Bureau of Reclamation
Technical Service Center
March 1, 2007

12. Appendix C: Historical Aerial Photographs

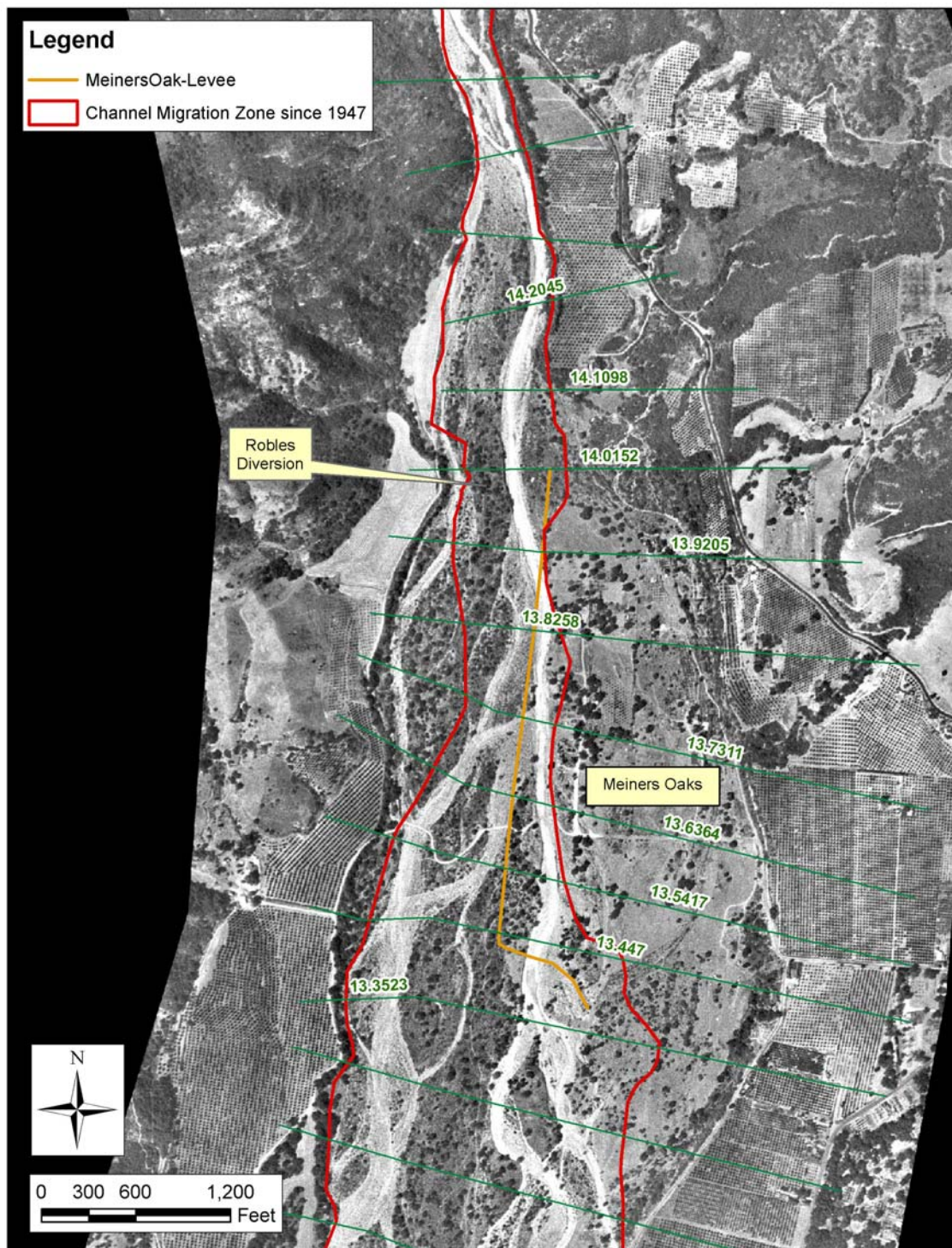


Figure 12. Meiners Oaks Aerial Dated 1947.

MATILIJIA DAM RESTORATION PROJECT
DRAFT DATED 7/2/2007

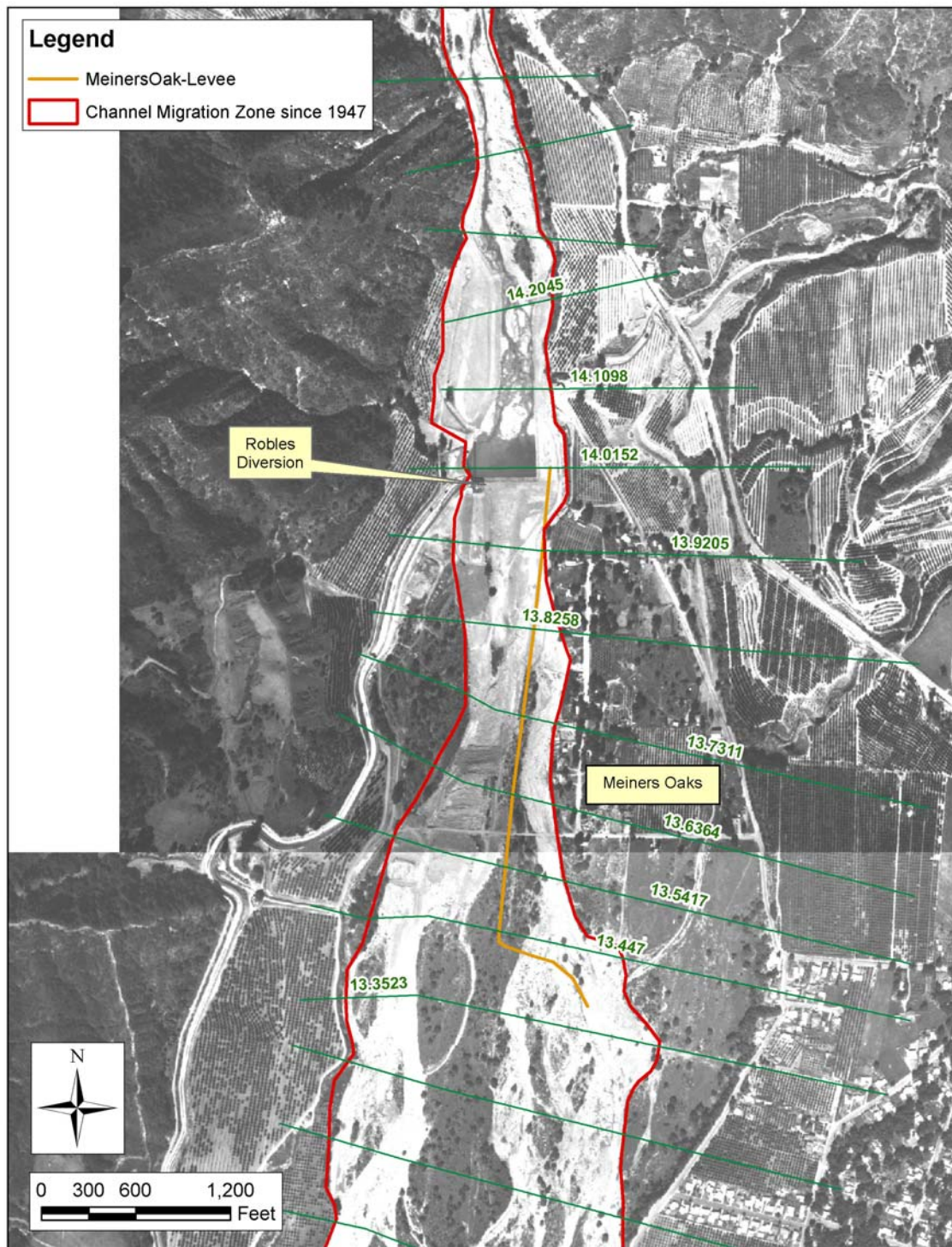


Figure 13. Meiners Oaks Aerial Dated 1970.

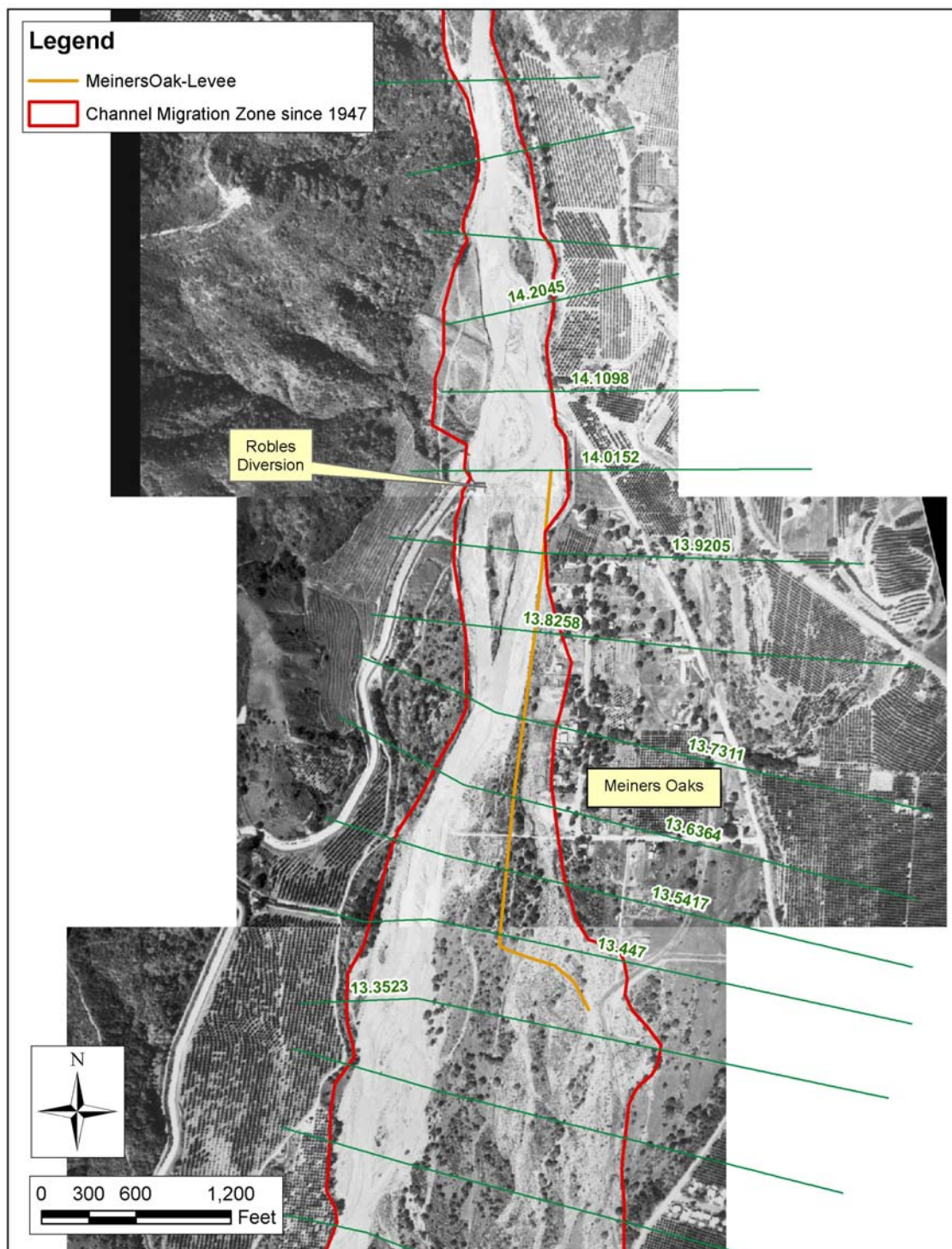


Figure 14. Meiners Oaks Aerial Dated 1978.

MATILIJA DAM RESTORATION PROJECT
DRAFT DATED 7/2/2007

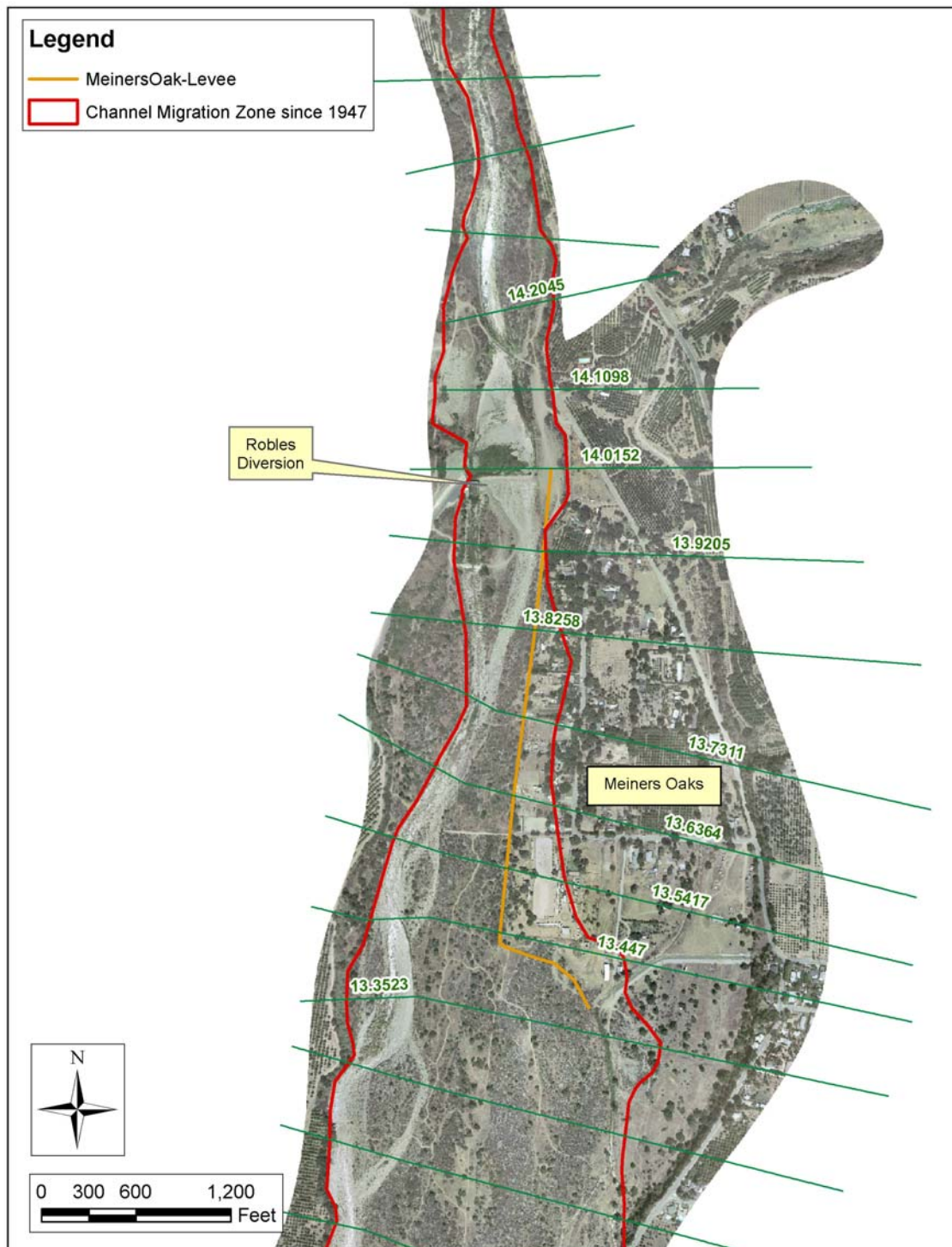


Figure 15. Meiners Oaks Aerial Dated 2001.

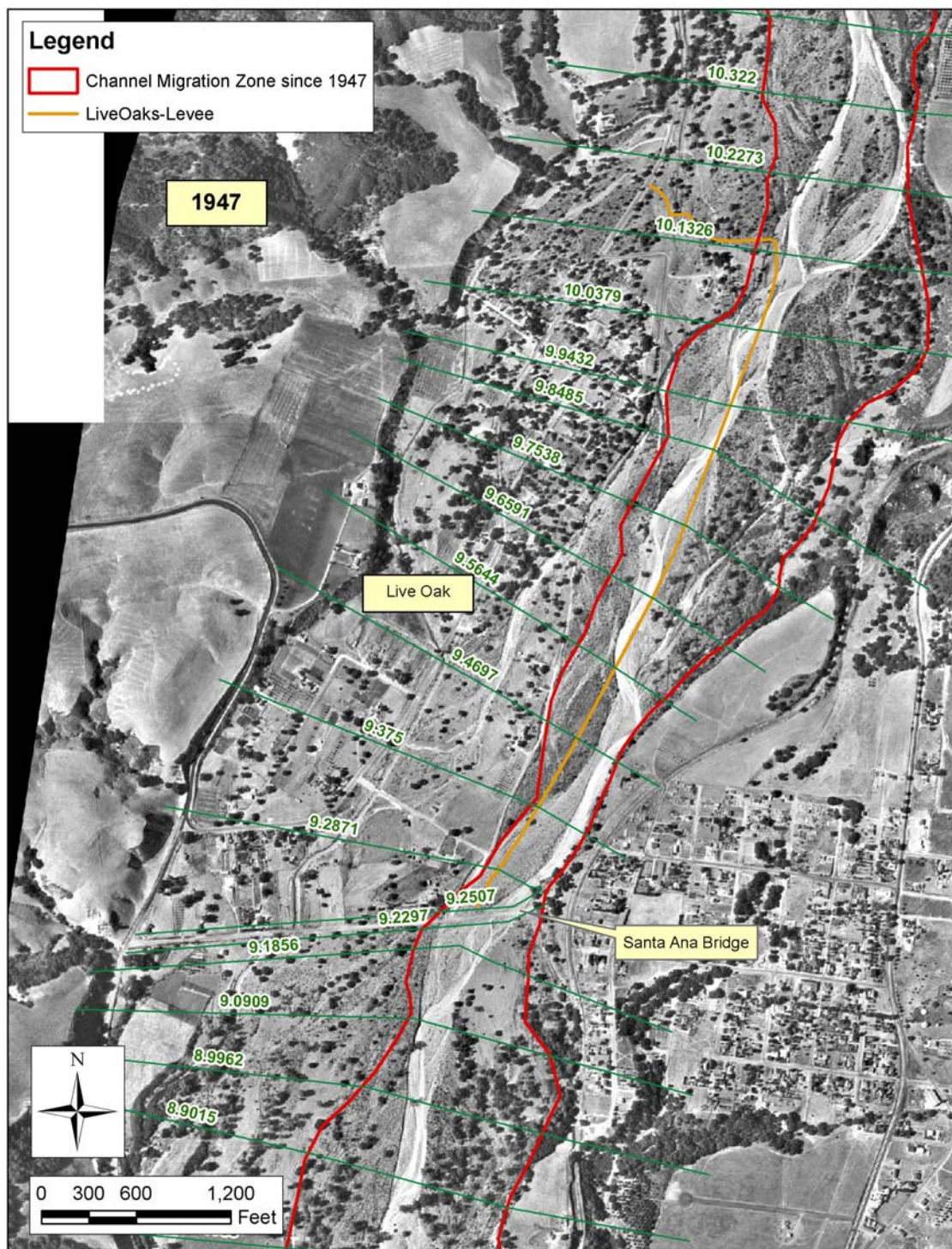


Figure 16. Live Oak Reach Aerial dated 1947.

MATILIJIA DAM RESTORATION PROJECT
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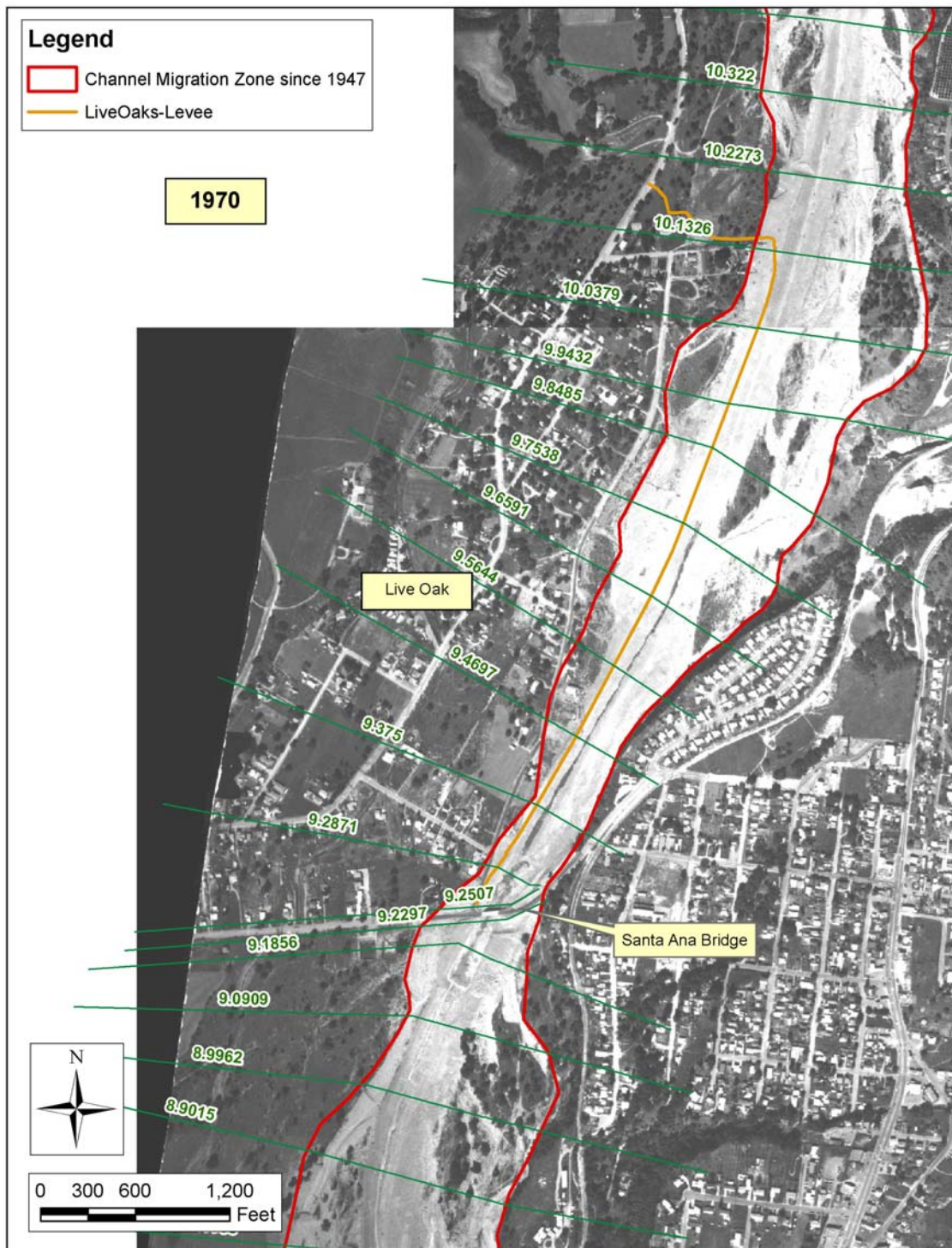


Figure 17. Live Oak Reach Aerial dated 1970.

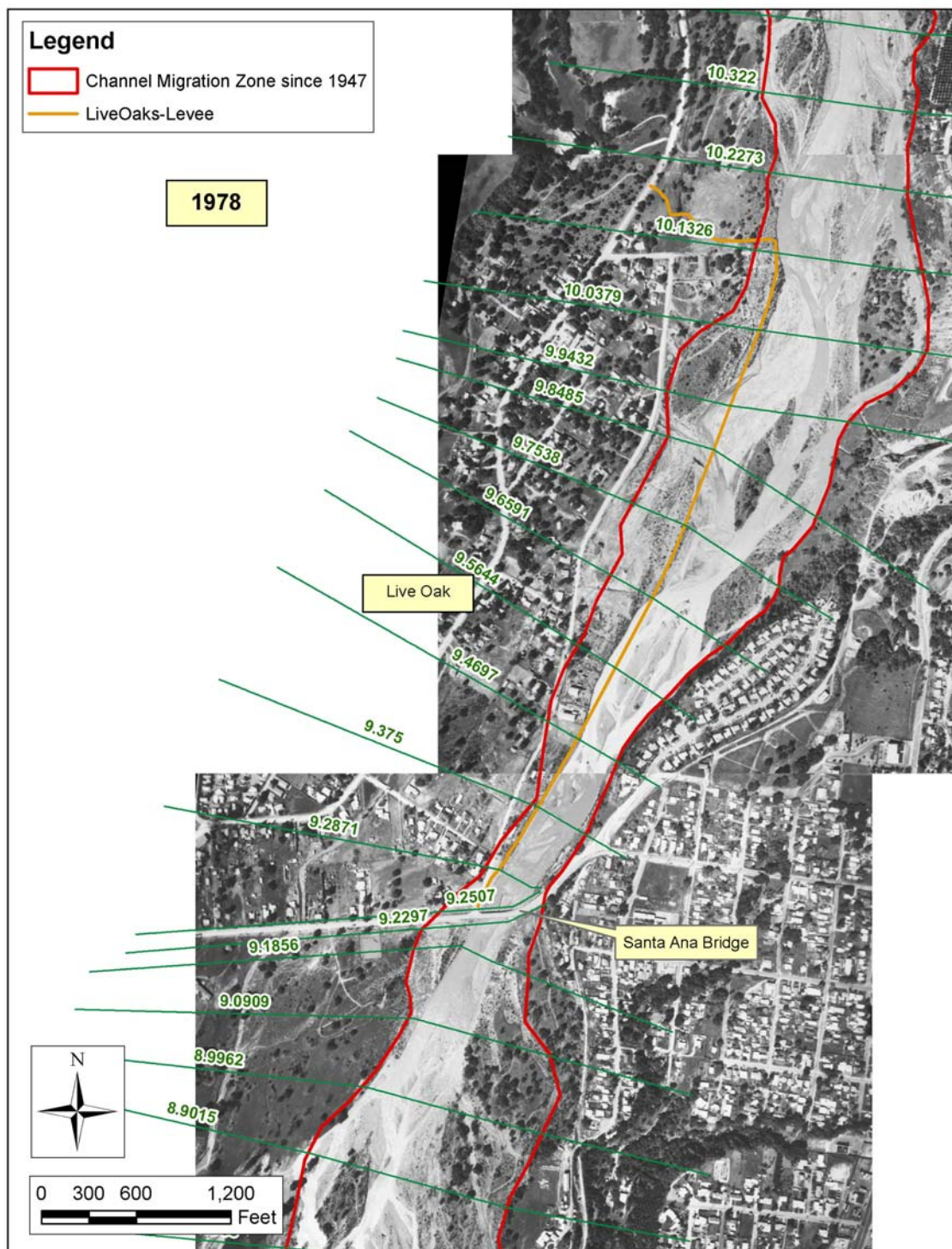


Figure 18. Live Oak Reach Aerial dated 1978.

MATILIJIA DAM RESTORATION PROJECT
DRAFT DATED 7/2/2007

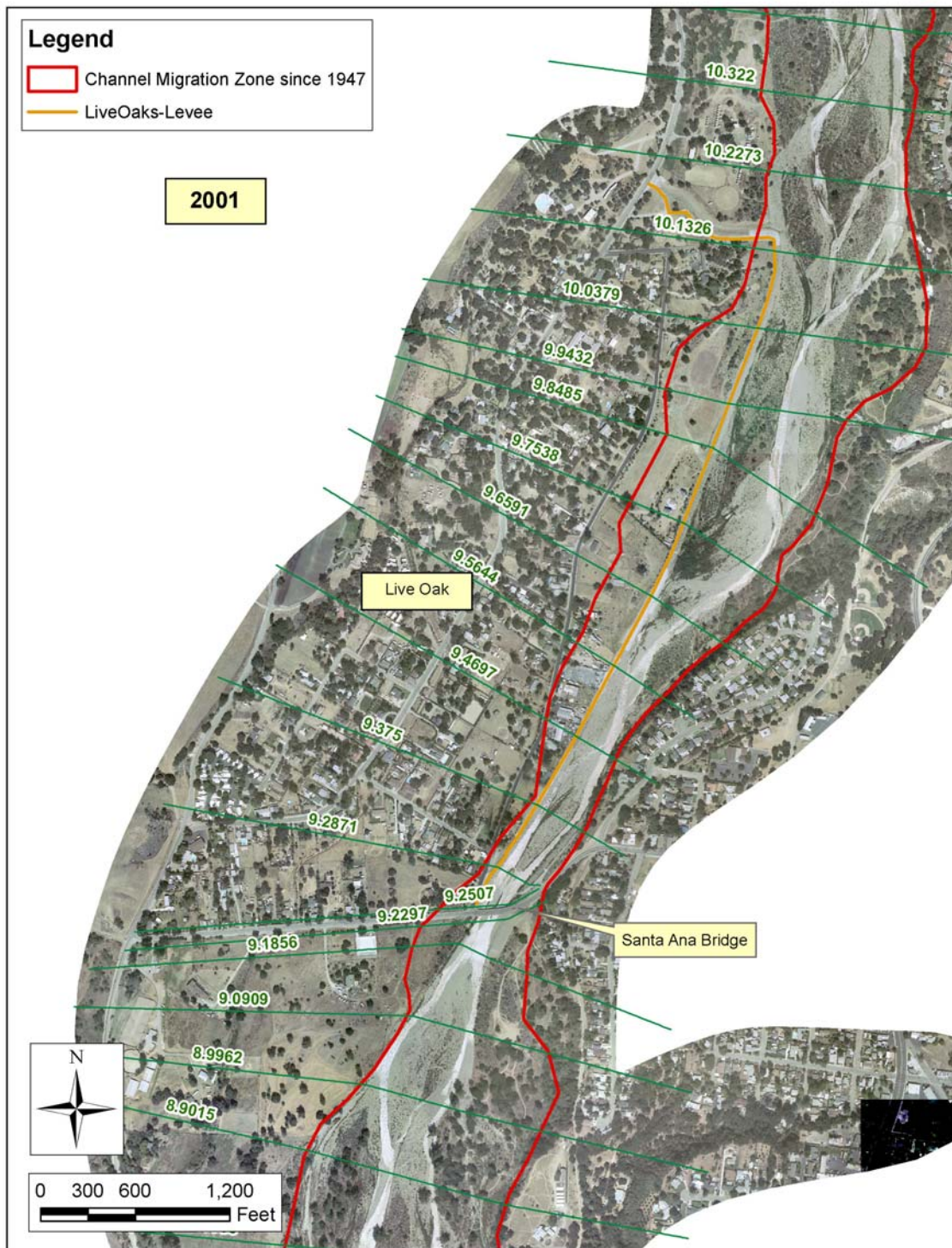


Figure 19. Live Oak Reach Aerial dated 2001.

13. Appendix D: CHANLPRO V2.0 Output

Lower Live Oak Riprap Recommended Design Output

```

PROGRAM OUTPUT FOR A NATURAL CHANNEL SIDE SLOPE RIPRAP, BENDWAY
      INPUT PARAMETERS
SPECIFIC WEIGHT OF STONE,PCF                165.0
MINIMUM CENTER LINE BEND RADIUS,FT          400.0
WATER SURFACE WIDTH,FT                      220.0
LOCAL FLOW DEPTH,FT                         11.9
CHANNEL SIDE SLOPE,1 VER: 2.00 HORZ
AVERAGE CHANNEL VELOCITY,FPS               12.00
COMPUTED LOCAL DEPTH AVG VEL,FPS            19.00
(LOCAL VELOCITY)/(AVG CHANNEL VEL)          1.58
SIDE SLOPE CORRECTION FACTOR K1             .88
CORRECTION FOR VELOCITY PROFILE IN BEND     1.22
RIPRAP DESIGN SAFETY FACTOR                 1.10

```

NO STABLE GRADATIONS FOUND

Upper Live Oak Riprap Recommended Design Output

```

PROGRAM OUTPUT FOR A NATURAL CHANNEL SIDE SLOPE RIPRAP, BENDWAY
      INPUT PARAMETERS
SPECIFIC WEIGHT OF STONE,PCF                165.0
MINIMUM CENTER LINE BEND RADIUS,FT          400.0
WATER SURFACE WIDTH,FT                      500.0
LOCAL FLOW DEPTH,FT                         8.7
CHANNEL SIDE SLOPE,1 VER: 2.00 HORZ
AVERAGE CHANNEL VELOCITY,FPS               9.60
COMPUTED LOCAL DEPTH AVG VEL,FPS            15.20
(LOCAL VELOCITY)/(AVG CHANNEL VEL)          1.58
SIDE SLOPE CORRECTION FACTOR K1             .88
CORRECTION FOR VELOCITY PROFILE IN BEND     1.22
RIPRAP DESIGN SAFETY FACTOR                 1.10

```

SELECTED STABLE GRADATIONS ETL GRADATION

NAME	COMPUTED D30(MIN) D30 FT	FT	D100(MAX) IN	D85/D15	N=THICKNESS/ D100(MAX)	CT	THICKNESS IN
10		1.46	36.00	1.70	NOT STABLE		
11	1.70	1.70	42.00	1.70	1.12	.97	47.0
12	1.75	1.95	48.00	1.70	1.00	1.00	48.0

D100(MAX) IN	LIMITS OF STONE WEIGHT,LB FOR PERCENT LIGHTER BY WEIGHT						D30(MIN) FT	D90(MIN) FT
	100	100	50	50	15	15		
42.00	3704	1482	1096	741	548	232	1.70	2.47
48.00	5529	2212	1637	1106	818	346	1.95	2.82

EQUIVALENT SPHERICAL DIAMETERS IN INCHES					
D100(MAX)	D100(MIN)	D50(MAX)	D50(MIN)	D15(MAX)	D15(MIN)
42.0	30.9	28.0	24.6	22.2	16.7
48.0	35.4	32.0	28.1	25.4	19.0

MATILIJA DAM RESTORATION PROJECT
DRAFT DATED 7/2/2007

Meiners Oaks Levee Riprap Recommended Design Output

PROGRAM OUTPUT FOR A NATURAL CHANNEL SIDE SLOPE RIPRAP, BENDWAY

INPUT PARAMETERS

SPECIFIC WEIGHT OF STONE, PCF	165.0
MINIMUM CENTER LINE BEND RADIUS, FT	1200.0
WATER SURFACE WIDTH, FT	220.0
LOCAL FLOW DEPTH, FT	8.8
CHANNEL SIDE SLOPE, 1 VER: 2.00 HORZ	
AVERAGE CHANNEL VELOCITY, FPS	13.00
COMPUTED LOCAL DEPTH AVG VEL, FPS	17.64
(LOCAL VELOCITY)/(AVG CHANNEL VEL)	1.36
SIDE SLOPE CORRECTION FACTOR K1	.88
CORRECTION FOR VELOCITY PROFILE IN BEND	1.14
RIPRAP DESIGN SAFETY FACTOR	1.10

SELECTED STABLE GRADATIONS

ETL GRADATION

NAME	COMPUTED D30 (MIN)	D100 (MAX)	D85/D15	N=THICKNESS/ D100 (MAX)	CT	THICKNESS
	D30 FT	FT	IN			IN
12		1.95	48.00	1.70	NOT STABLE	
13	2.19	2.19	54.00	1.70	1.30	.93 70.1

D100 (MAX)	LIMITS OF STONE WEIGHT, LB					D30 (MIN)	D90 (MIN)
IN	FOR PERCENT LIGHTER BY WEIGHT					FT	FT
	100	50	15				
54.00	7873	3149	2330	1575	1165	492	2.19 3.17

EQUIVALENT SPHERICAL DIAMETERS IN INCHES

D100 (MAX)	D100 (MIN)	D50 (MAX)	D50 (MIN)	D15 (MAX)	D15 (MIN)
54.0	39.8	36.0	31.6	28.6	21.4

14. Appendix E: Plate B-42 from EM1601

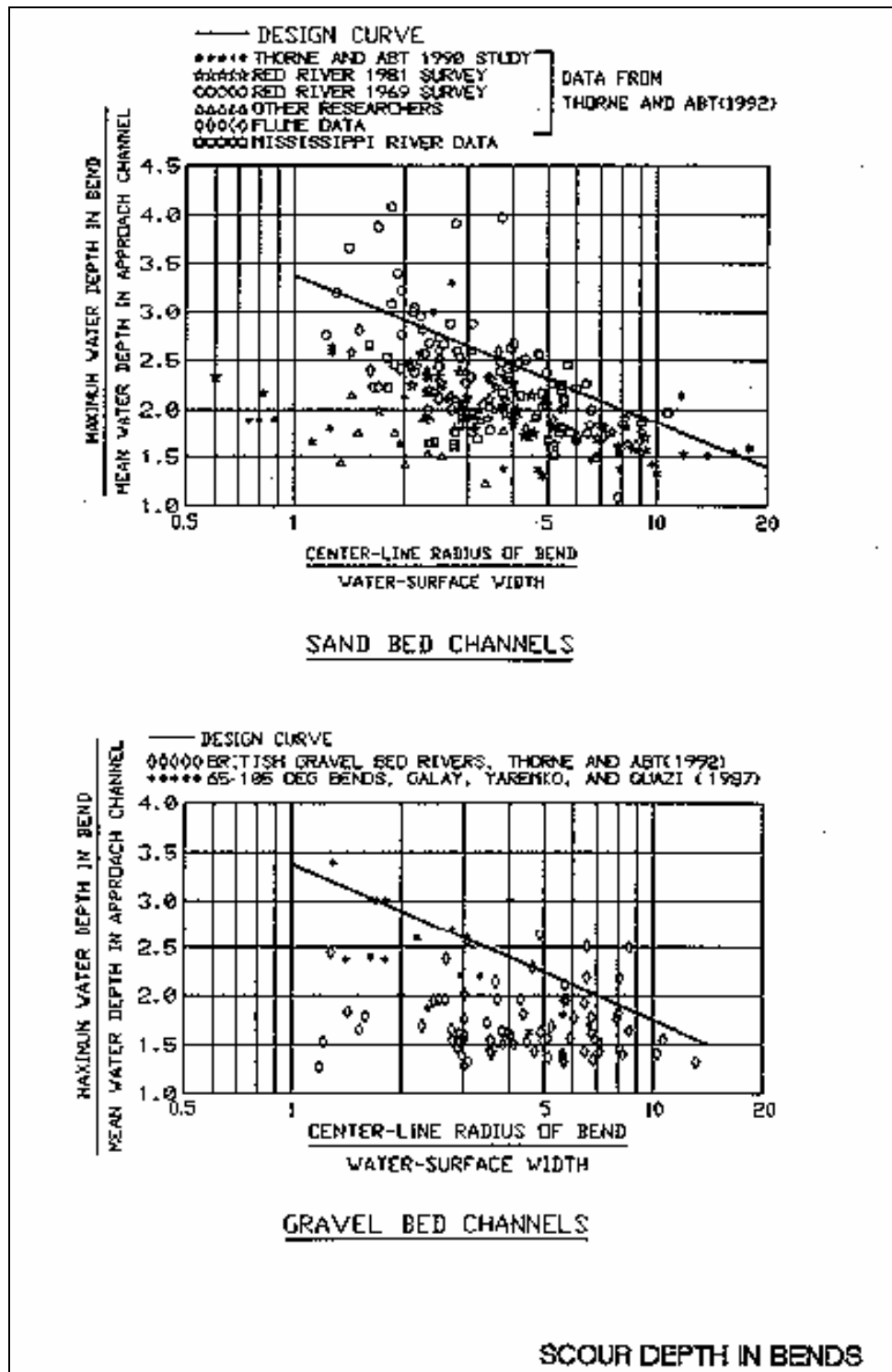


Figure 20. Plate B-42 from EM1601.

MATILJA DAM RESTORATION PROJECT
DRAFT DATED 7/2/2007