Channel Migration
Analysis of NODOS

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Managing Water in the West

Technical Report No. SRH-2011-21

Sacramento River Migration Analysis of NODOS Alternatives

Mid Pacific Region
NODOS Investigation Report

U.S. Department of the Interior
Bureau of Reclamation

July 2011

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

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Mid Pacific Region
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Prepared by:

7-26-2011

Jianchun Victor Huang, Ph.D., P.E. Date
Visiting Hydraulic Engineer, Sedimentation and River Hydraulics Group, 86-68240
Research Scientist, Department of Civil Engineering, Colorado State University

7-26-11

Blair Greimann, Ph.D., P.E. Date
Hydraulic Engineer
Sedimentation and River Hydraulics Group, 86-68240

Report Reviewed by:

7/26/2011

David Varyu, M.S., P.E. Date
Hydraulic Engineer
Sedimentation and River Hydraulics Group, 86-68240

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1 Introduction

The Sedimentation and River Hydraulics Group at the Technical Service Center (TSC) of the Bureau of Reclamation has been tasked, at the request of the Mid Pacific Regional Office, to provide analysis to support the North of Delta Off-Stream Storage (NODOS) Administrative Draft Environmental Impact Report/Study (ADEIR/S) and Feasibility Study (FS). This report provides results of channel migration in two spatial scales: a short reach near the New Delevan Pipeline and a long reach from Red Bluff to Colusa (Figure 1-1). The downstream end (bottom in the figure) of the stream is Colusa, which is not shown in the Figure.

CH2MILL (2011) developed model simulations for the NODOS ADEIR/S and FS. The modeling simulations that were completed were labeled as:

- Existing Conditions
- No Action Alternative
- NODOS Alternative A
- NODOS Alternative B
- NODOS Alternative C

These flows were used as input to the analyses presented in this report.

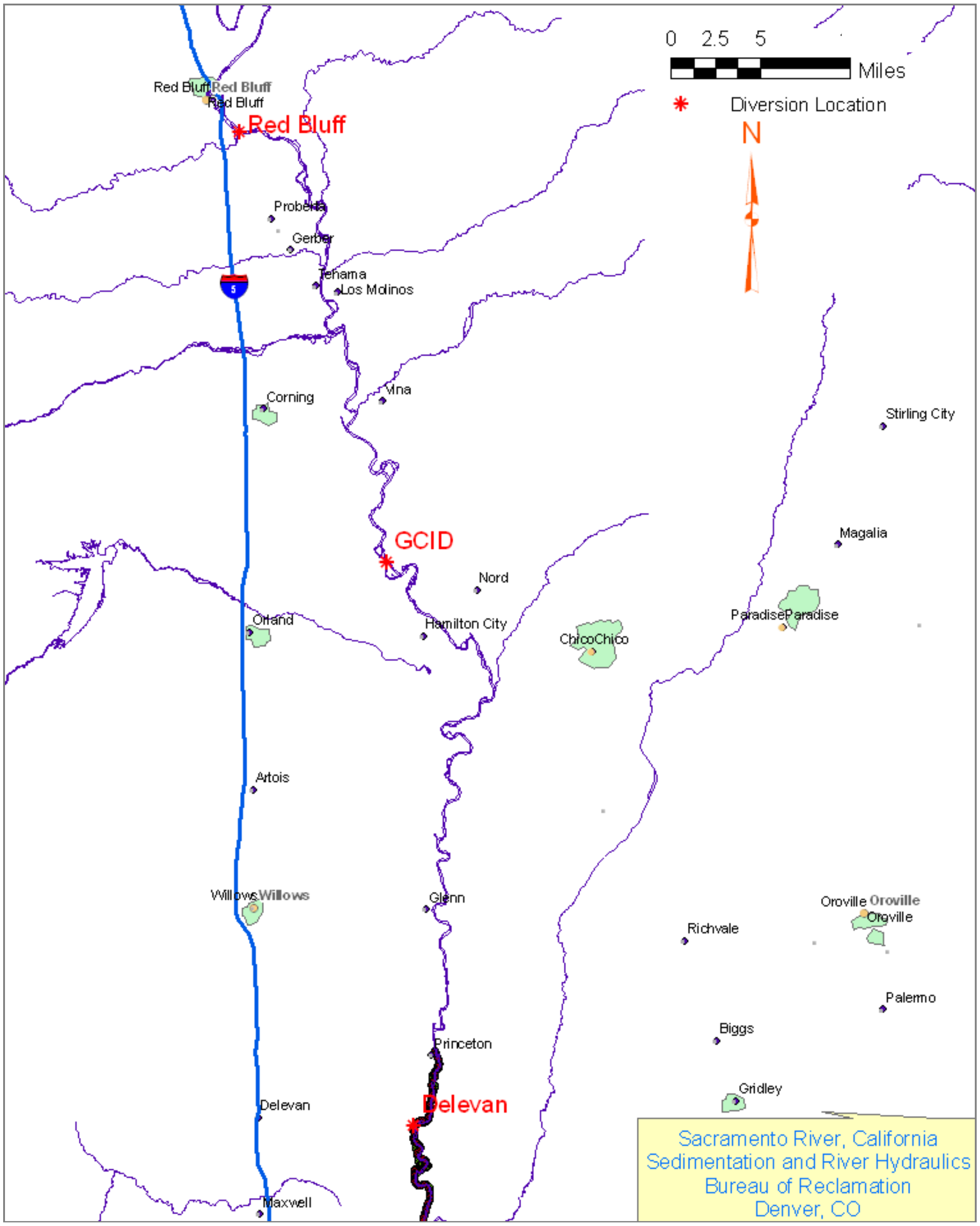


Figure 1-1. Site map of the Sacramento River between Red Bluff and Colusa

2 Model Description

SRH-Meander (Sedimentation and River Hydraulics – Meander, Greimann and Huang, 2007) is a computer model that simulates the bed topography, flow field, and bank erosion rate in curved channel with an erodible bed. In each time step, SRH-Meander first calculates the flow field based on the standard step method, normal depth method, or a user input rating curve. It then computes the channel bank erosion rate. Finally the channel alignment is updated with the erosion rate, followed by a channel cutoff if needed. The model can be used to predict the channel migration in meandering rivers.

SRH-Meander uses the meander method first proposed by Johannesson and Parker (1989). It is a re-derivation of the analysis by Engelund (1974). The basic idea behind these analyses is to write the flow variables as a sum of two parts. The first part is the solution to the case of flow in a straight channel. The second part is equal to the deviation from the straight channel solution for the case of a slightly curved channel. The deviation is assumed to be linearly related to the maximum curvature of the channel. These perturbed flow variables are substituted into the 3D flow equations. The equations are then simplified and grouped into the terms responsible for the straight channel solution and those due to the channel curvature. The equations become ordinary differential equations and can be solve analytically or through relatively simple numerical methods. The sediment transport is assumed to be a function of the local velocity and shear stress.

Sun at al. (2001a, b) improved Johannesson and Parker‟s (1989) linearization theory to calculate bank erosion in river meanders by incorporating multiple-size sediment transport equation. Johannesson and Parker (1989) assume the bank erosion rates are related to the near-bank depth-averaged flow velocity, which is calculated by a small perturbation approach. The near bank depth-averaged flow velocity is decomposed into two parts: the component characterized by local curvature forcing (e.g. point bars) and the component characterized by the free system (e.g. alternate bars).

SRH-Meander adopted the Sun at al. (2001a, b) method which incorporates multiple-size sediment transport equation. More information on SRH-Meander can be found in Greimann and Huang (2007).

3 Channel Migration Near New Delevan Pipeline

SRH-Meander will be used to predict the channel migration during the alternatives evaluation process. As such, a calibration to historic meander rates was completed because “it is not possible to determine the erodibility coefficients a priori, based on bank properties, presence of vegetation, etc.” for real rivers without “calibrating the erodibility coefficients on field observations” (Crosato, 2007). The meander channel model extends 12.5 miles from RM 164 to RM 151.5 as presented in Figure 3-1

The historical gage record at USGS Gage 11389000 (Sacramento River at Butte City, California) was used for model calibration and verification. This gage (RM 168.5) is located about 10 miles upstream of the Delevan new pipeline; however, the available data were for a period prior to June 30, 1995. A bias correction method was used to create the missing data from 7/1/ 1995 to 10/1/2009 via USGS Gage 11377100 (Sacramento River above Bend Bridge near Red Bluff, California) by using a common period from 10/1/1976 to 6/30/1995. The period used for model calibration was from 10/1/1976 to 9/30/1999. The period from 9/30/1999 to 10/1/2009 was used for model verification.

USRDOM was used to simulate flows under the existing operations (Existing) and the proposed NODOS program alternatives: No Action, Alternative A, Alternative B, and Alternative C (CH2MHILL, 2011). The simulated flows were used in SRH-M to predict future channel meandering. The simulated flows

The daily flows from 10/1/1980 to 9/30/2000 were used to predict twenty years of channel meander from 10/1/2010 to 9/30/2030.

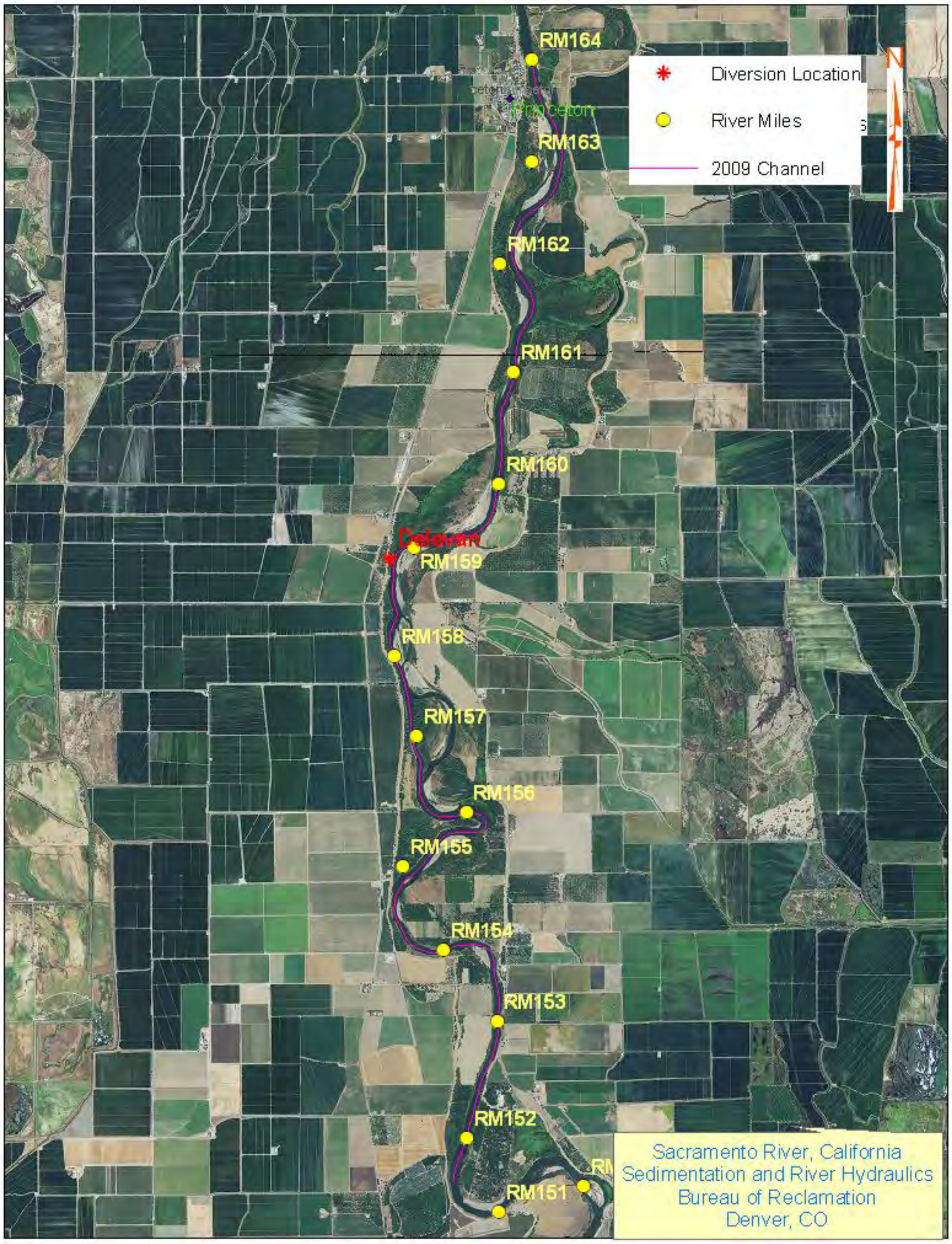


Figure 3-1. Meander channel model study area with 2009 aerial photo

3.1 Data Pre-Processing

No modifications were made to the flow data as described in the previous section. However, a filter is present in SRH-Meander so that flow data that may not affect river meandering can be excluded. For instance, it is generally accepted that base flows do not cause changes in channel morphology. However, due to the linear nature of the computer model, these base flows yield a calculated meander length, however minor. Conversely, when flows of a river exceed the carrying capacity of a channel, the excess flow spills out on to the floodplain, and the flood waters have little effect on channel-forming processes. Without an imposed upper bound on the flow rates, the rate of bank erosion would increase linearly as the flow rate increases. Thus, an upper and lower limit was applied to the input flow data set. Based on the flow hydrograph and the results of the RAS model, lower and upper limits of 35,000 and 90,000 cfs, respectively, were used for the Sacramento River. When the flow is less than the lower limit, the channel migration is neglected. When the flow is larger than the upper limit, the channel migration is considered not increasing.

The HEC-RAS model associated with the 2002 US Army Corps of Engineers (USACE) study was used to derive cross-sectional and profile geometry parameter values. Rather than assume a cross-sectional shape and associated descriptive parameters (e.g., side slope and bottom width for a trapezoidal cross-section) to represent the river, a more generic approach was taken. The HEC-RAS model was run multiple times using a series of steady flow rates. Average hydraulic parameters were calculated for the study reach. The geometry parameters were tabulated into a format which the SRH-Meander model can interpret. Thus, a table was created with flow rates from 35,000 to 90,000 cfs along with associated average values for velocity, friction slope, hydraulic depth, top width, and hydraulic radius. The friction slope parameter was used for profile geometry considerations in lieu of assuming that the bed slope approximates the energy slope. SRH-Meander model linearly interpolates hydraulic parameters for flow rates between the tabulated values.

Planform geometry data were extracted from available California Department of Water Resources (CDWR) GIS maps. The SRH-Meander model uses a GIS point file representing the centerline of the river to compute radii of curvature and other parameters which are necessary to estimate the rate of river meander. The CDWR GIS maps contained polygons which depicted the „active‟channel alignments for years 1976 and 1999. Polylines were digitized in ArcGIS to represent the centerline of the 1976 channel and the 1999 channel as shown in Figure 3-2, which are the „starting‟ and „ending‟ conditions to which the model was to be calibrated. The 2009 channel center line was digitized using 2009 aerial photography as a base image. In addition, a valley axis for the 1976 channel was digitized (Figure 3-2) which is used to allow for channel cutoffs. The cutoff ratio is a calibration parameter. When the length of the channel bend divided by the length of the valley for the same bend exceeds the cutoff ratio, the model allows a cutoff to occur.

Model inputs related to channel roughness and bed material size for the calibration were estimated from the USACE study (2002). The USACE study reported Manning roughness coefficients and bed material size information at discrete cross-sections along the Sacramento River. Cross-sections that fell within the model reach were selected, and the reported values were averaged to produce a single roughness and single representative bed material size for each sub-reach. The Manning roughness coefficient used in this study is 0.028. There was very little variation in bed material size according to the USACE study, so these values were not adjusted and not considered calibration parameters. A median bed material size of 14 mm was used.

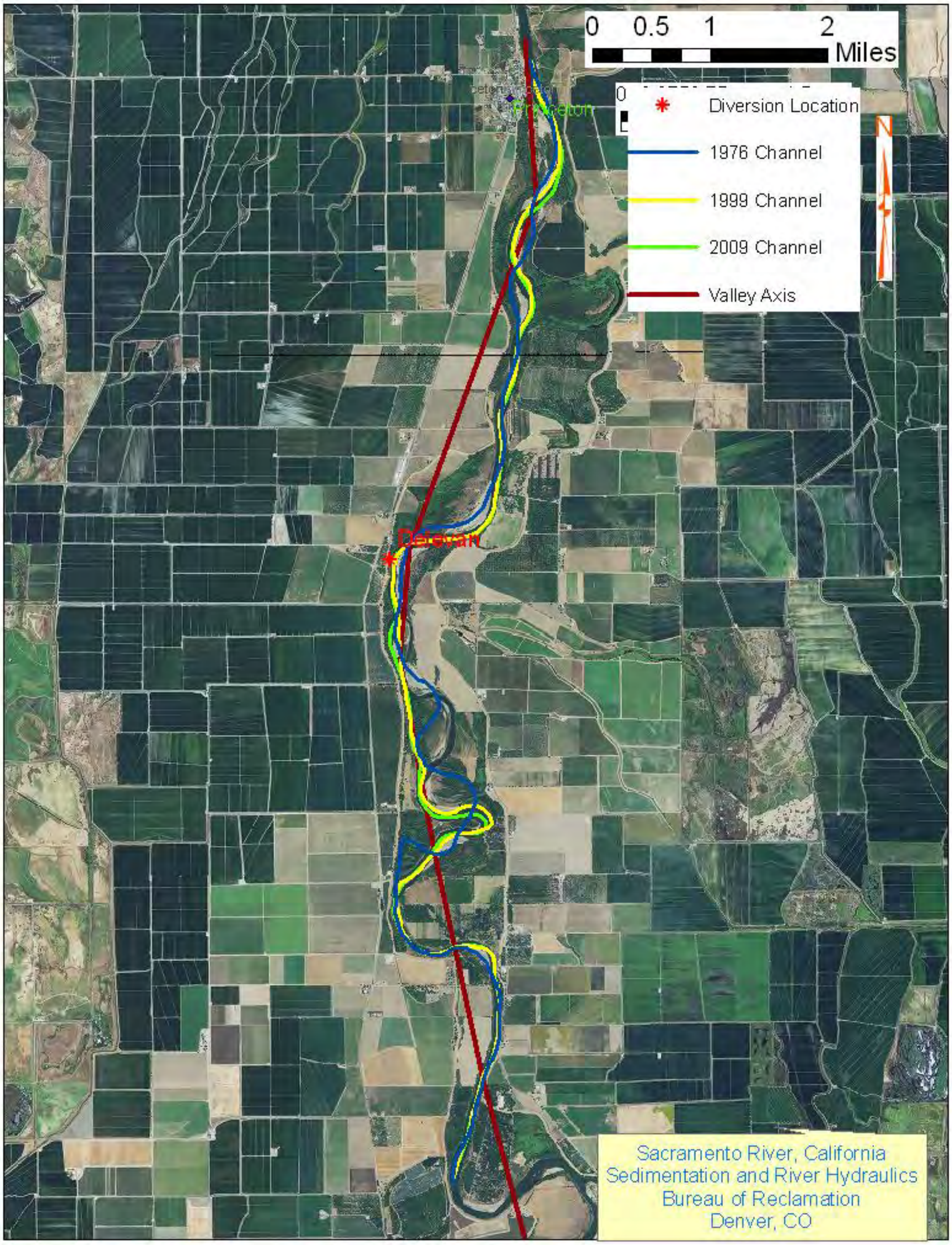


Figure 3-2. Channel center lines in 1976, 1999, and 2009 for model calibration, verification, and prediction

In order to spatially assign erosion coefficients, a series of calibration polygons were created in ArcMap. The polygons mirror the bank segments as identified by the CDWR. In 2005, CDWR conducted an expedition in order to describe the channel banks of the Middle Sacramento River. The erosion polygons were digitized to represent bank properties for bank slope, height, material, geomorphology, and riprap presence, as described by CDWR, and the polygons are small enough for calibration. A total of 87 polygons as displayed in Figure 3-3 was used to represent the bank properties.

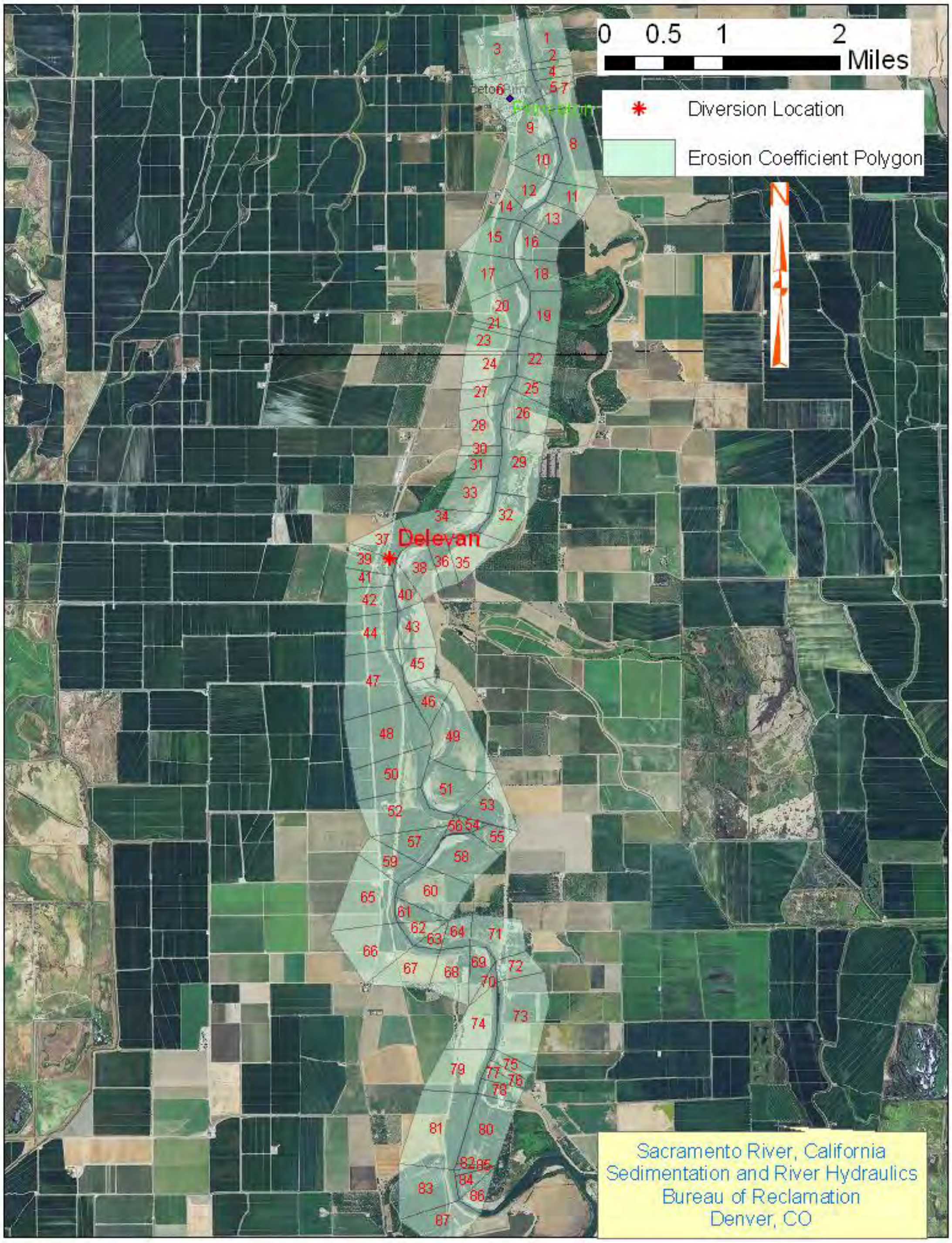


Figure 3-3. Polygons used to represent bank properties

3.2 Model Calibration

Completing the data pre-processing described above resulted in properly formatted data inputs for the SRH-Meander model. The parameters that were changed during calibration (i.e., the calibration parameters) were the cutoff ratio and the erosion coefficients.

Calibration compares the output channel alignment to the actual channel alignment at the end of the time interval being modeled. An iterative approach was taken in calibrating the model. Erosion coefficients were adjusted after an observed model run as necessary until the model output alignment represented the actual channel alignment to a sufficient degree of accuracy.

Table 3-1 presents a summary of the parameters – showing both the calibration parameters as well as those determined before calibration – used during calibration of the SRH-Meander model to the Sacramento River. All of the erosion coefficients are not listed, but rather the minimum, average, and maximum values for each sub-reach are presented.

Figure 3-4 displays the centerlines for the 1976 and 1999 channels, and the SRH-Meander output nodes representing the model output channel centerlines in 1999. The model calculated the 1999 channel fairly well. The channel splits at location marked as “A” in Figure 3-4, and the model does not have the functionality to represent this phenomenon.

Table 3-1. Summary of parameters used during SRH-Meander model calibration

		Model Reach
Pre-determined parameters	**Ave. Channel Width (ft)**	773
	Manning n (-)	0.028
	Ave. Energy Slope (ft/ft)	0.00036
	Bed Material Size (mm)	14
	Number of Polygons	87
Calibration parameters	**Grid Spacing (-)**	0.6
	Cutoff Ratio (-)	3.5
	Min. Erosion Coefficient (-)	1.00E-08
	Ave. Erosion Coefficient (-)	1.72E-05
	Max. Erosion Coefficient (-)	1.00E-04

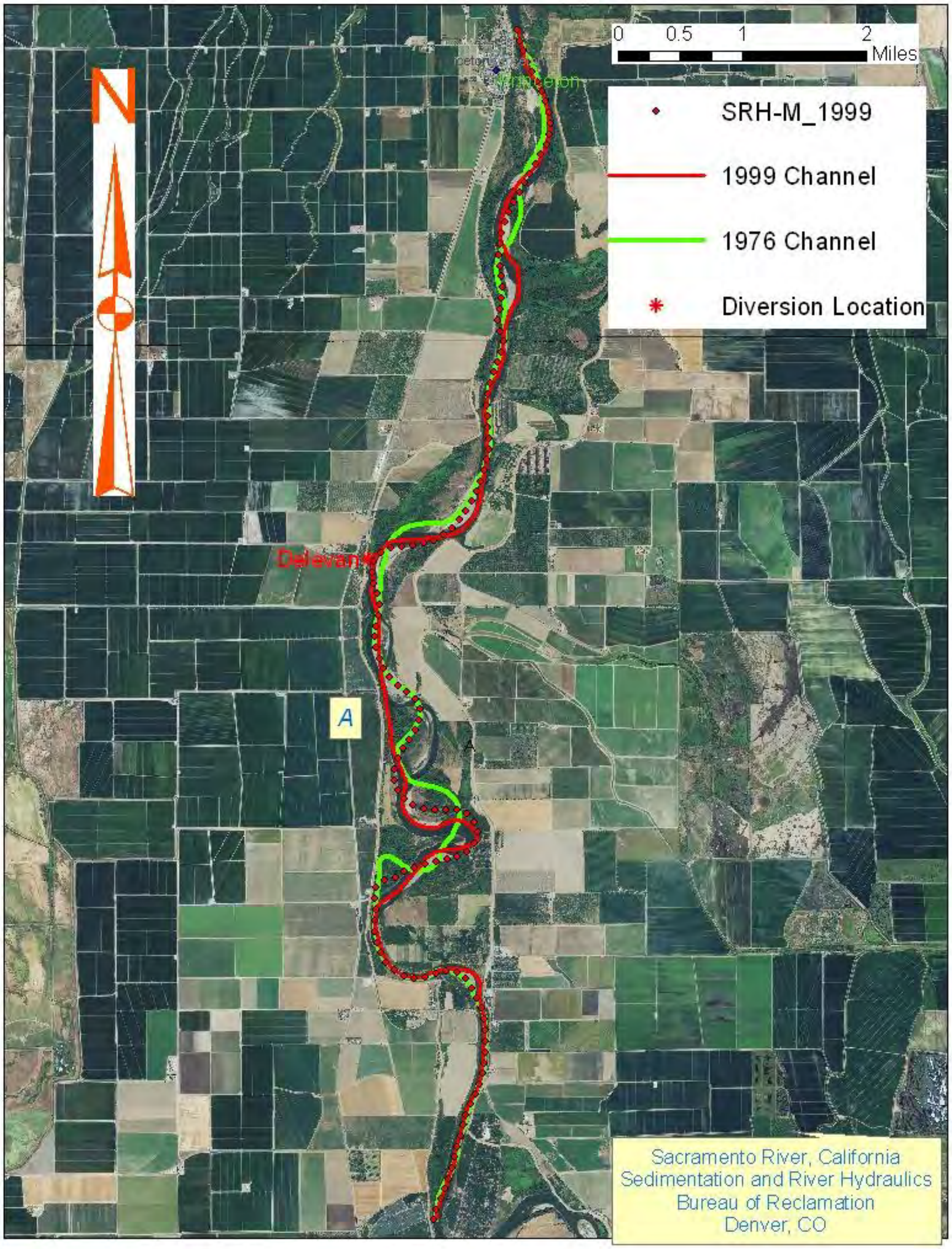


Figure 3-4. Calibration results

3.3 Model Validation and Prediction

The model was verified by using the calibrated model to predict the channel profile in 2009 with initial channel alignment from 1999 photography and flow rate from 1999 to 2009 at the same gage (USGS Gage 11389000, Sacramento River at Butte City, California). The erosion coefficients, the channel roughness, the grid spacing, and all other parameters are kept unchanged. The simulated 2009 channel alignment was compared with field data in 2009. The agreement between the simulated 2009 channel alignment and 2009 field data is fairly good (Figure 3-5), considering the uncertainties associated with the simplification of the model, the bank properties, and the accuracy of the map used to digitize the channel.

The model captured the amplification and downstream migration of the bends upstream of the new Delevan Pipeline. However, the model did not predict the reduction of the big bend marked as “B”. Theoretically it is difficult to explain why this bend is reduced and it is not clear if this bank was ripraped there, but it is possible since the bend is located close to the levee.

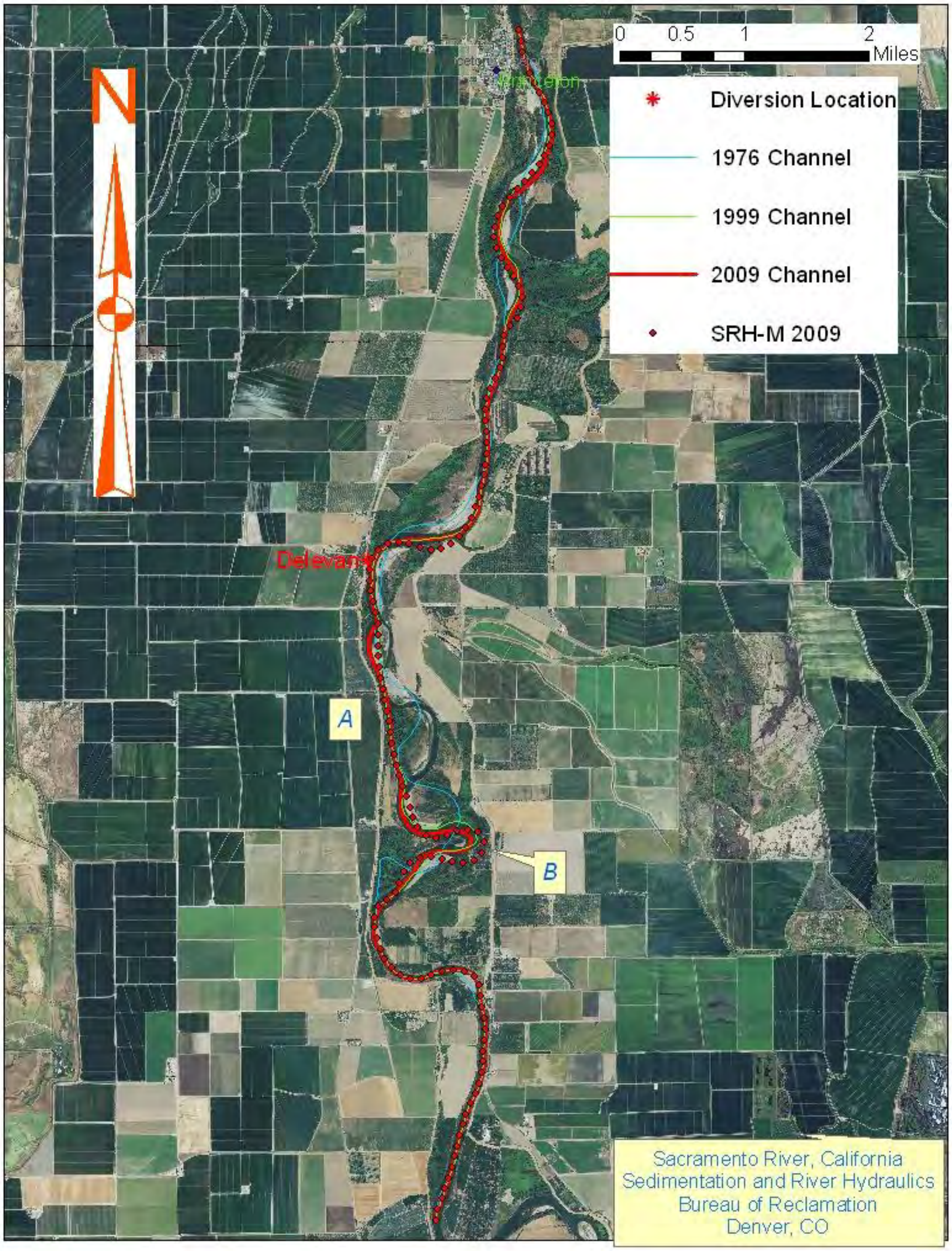


Figure 3-5. Model verification in 2009

Figure 3-6 illustrates the predicted channel alignment in 2030 with flow conditions of Existing, No Action, AltA, AltB, and AltC. There is no noticeable difference in channel alignments between the five flow conditions. Model results show the bend located upstream of the new intake, marked as “C” in Figure 3-6, will continue to migrate downstream unless bank protection is provided. The bend at the new intake, marked as “D”, will continue to migrate to river right. These results indicate that protecting the right river bank near the new intake would be beneficial. A cutoff will occur at the bend located downstream of the diversion, marked as “B”, and the channel will shift to river right. The model indicates bank protection should also be provided downstream of the diversion near location “A” since the river continued to migrate to the right side and the channel is close to the levee.

Figure 3-7 displays the predicted channel alignment in 2030 with bank ripraped at the locations marked as “C” and “D” in Figure 3-6. The bank riprap locations are also illustrated in Figure 3-7. The simulation shows that bank protection at the displayed locations could prevent the bank from migrating in the vicnity of the new intake.

Figure 3-8 compares the 2030 channel alignments near the new intake calculated as the current bank condition versus a ripraped bank. In the 20-year simulation, results show the left bank upstream of the intake will migrate about 650ft to channel left if the bank is not ripraped, and the right bank near the intake will migrate about 300ft to the right if the bank is not ripraped. The bank lines show no difference in channel migration beyond the ripraped bends near the intake.

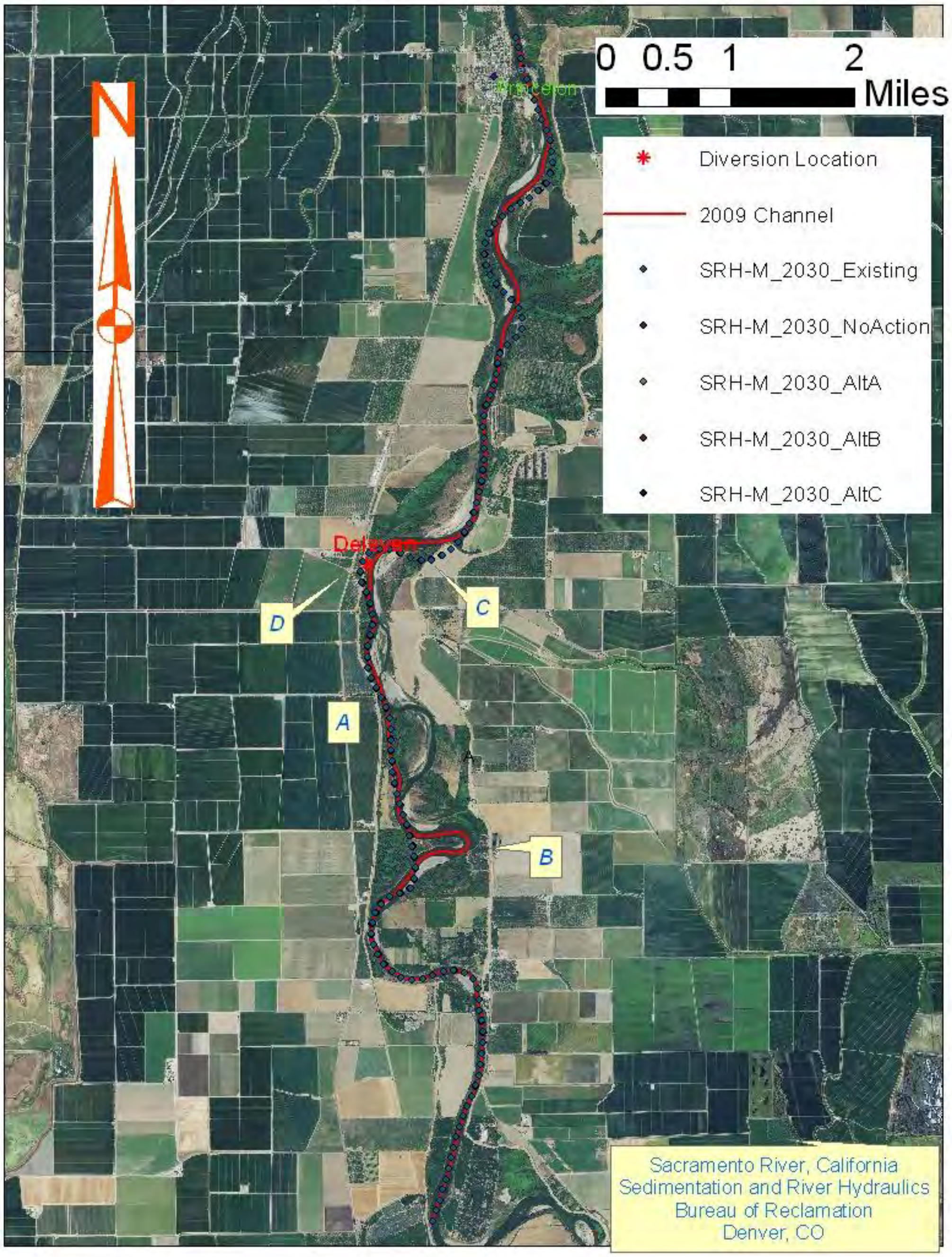


Figure 3-6. Channel alignments predicted in 2030 with hydrological conditions of Existing, NoAction, AltA, AltB, and AltC without riprap along the bank. Results show that there is no noticeable difference in channel alignments between different hydrological conditions.

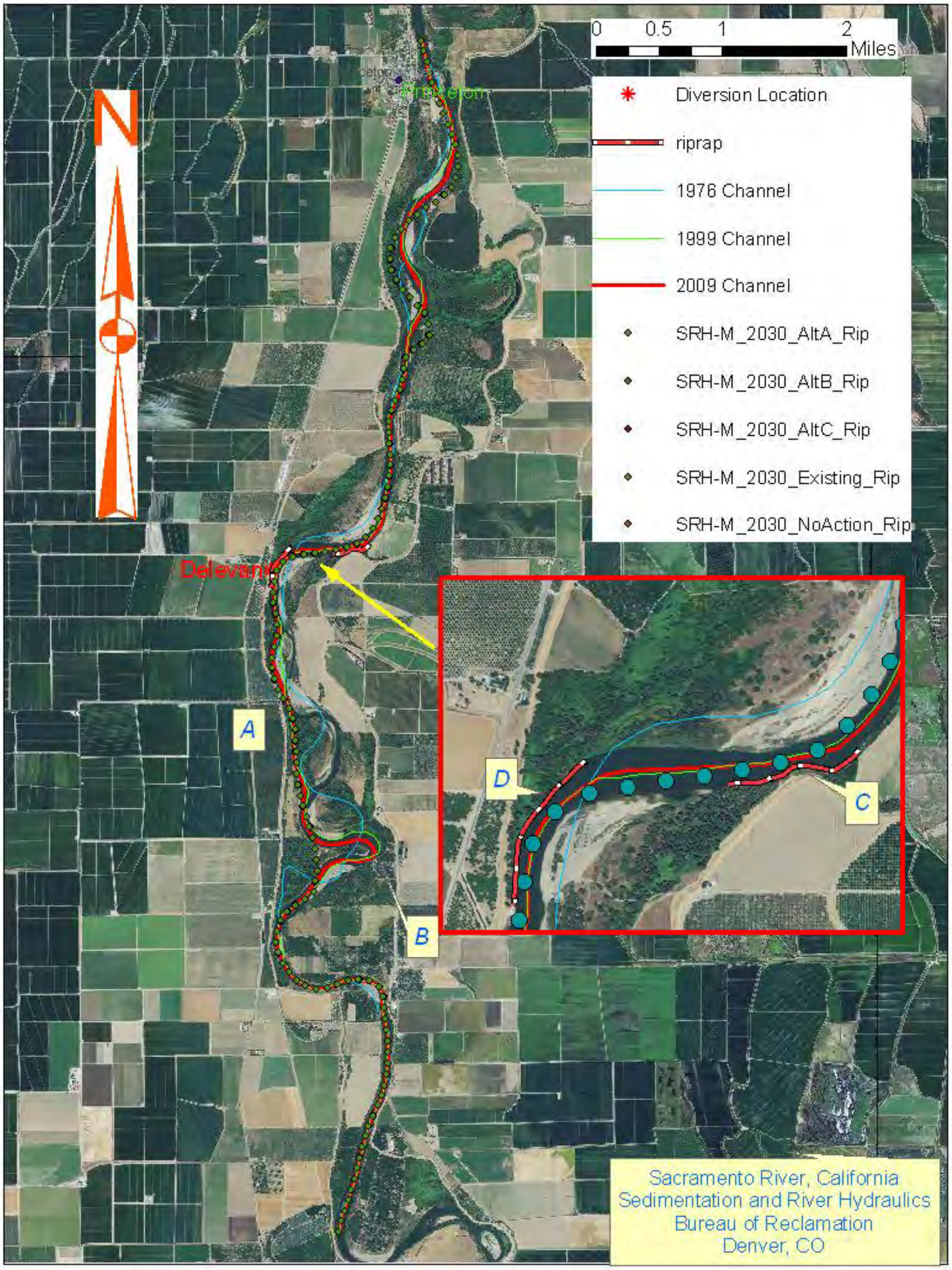


Figure 3-7. Channel alignments predicted in 2030 with hydrological conditions of Existing, NoAction, AltA, AltB, and AltC with bank ripraped near the new intake. Results show that there is no noticeable difference in channel alignments between different flow conditions.

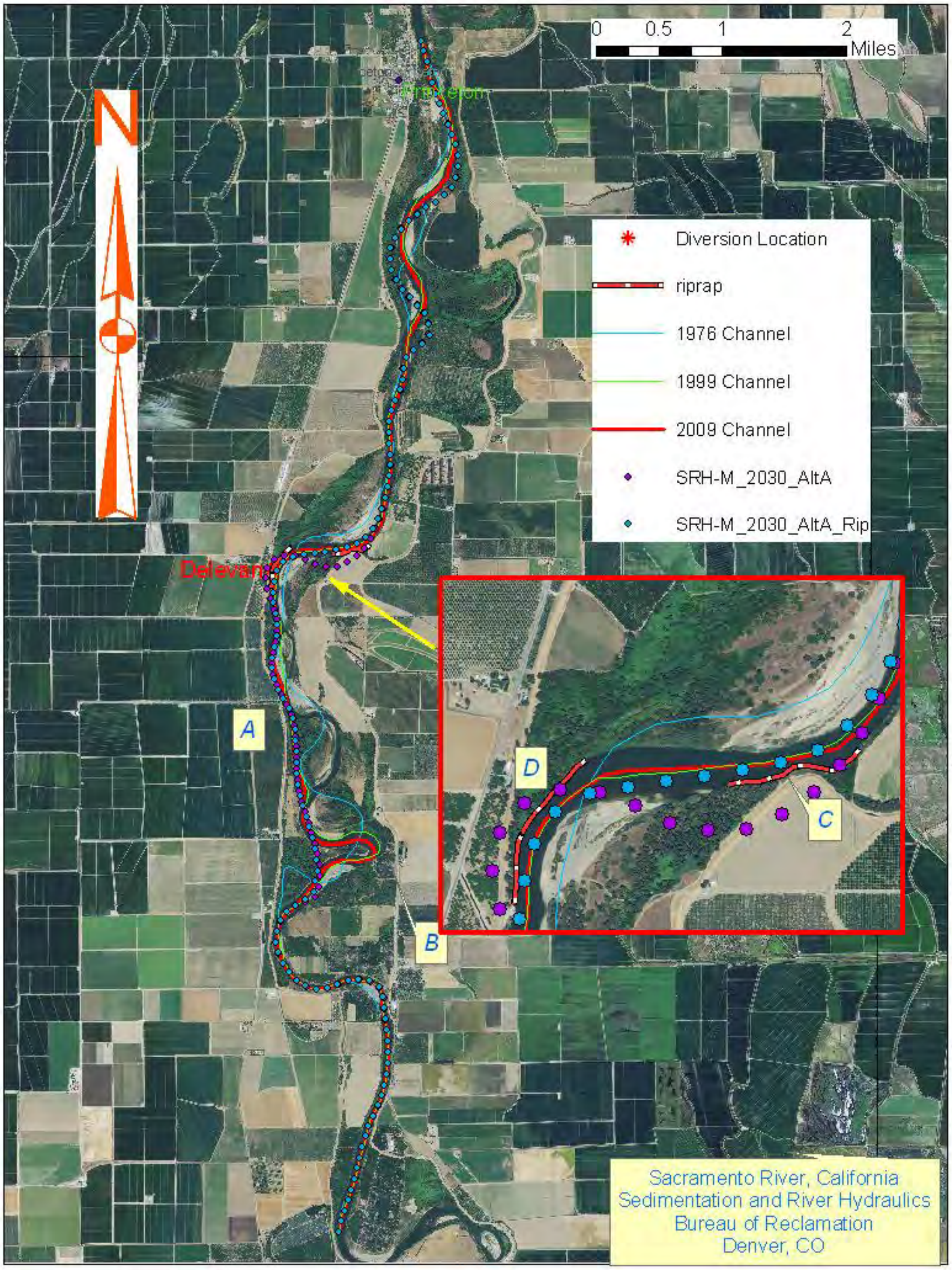


Figure 3-8. Comparison of channel alignments predicted in 2030 under conditions of current bank versus the addition of riprap along the bank (Alternative A only presented for simplicity).

4 Channel Migration from Red Bluff to Colusa

The model extends 101 miles from Red Bluff (RM 243) to Colusa (RM 142) as presented in Figure 1-1. The period of record used for model calibration was from 10/1/1976 to 9/30/1999 and the model is used to predict the channel alignment at 2030.

Flow data from gages operated by the State of California Department of Water Resources (CDWR) were utilized for model calibration. Mean daily flows for the period of record from 10/01/76 to 09/30/99 for CDWR datasets were used. Three CDWR gages are used, including gage „VIN‟ atVina Woodson Bridge (RM 219), gage „NMC‟ at Hamilton City (RM 199.2), and gage „ORD‟ at Ord Ferry (RM 184.2). Some gage flow data are missing in a period of time due to various reasons, and a correlation was built between each gage to calculate the flow data at one gage from the same date at another gage.

Profile and cross-sectional geometry information was taken from a United States Corps of Engineers publication, "Sacramento and San Joaquin River Basins, Comprehensive Study" (U.S. Army Corps of Engineers, 2002). This study produced a HEC-RAS geometry model of the river that was used in this study. River planform geometry was made available by CDWR in the form of aerial photographs and GIS maps consisting of traces of the active channels.

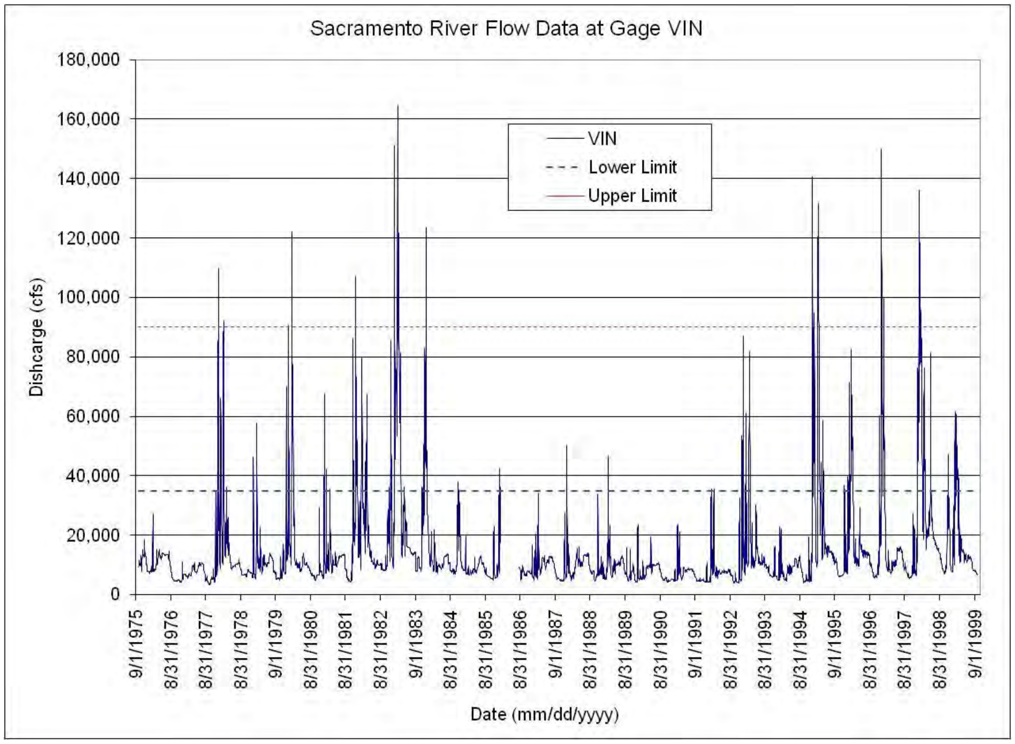
From the 2002 USACOE publication, information on channel roughness, namely Manning‟s roughness coefficient values, was obtained. Also from the study, information on bed material size was gathered and used as input to the model.

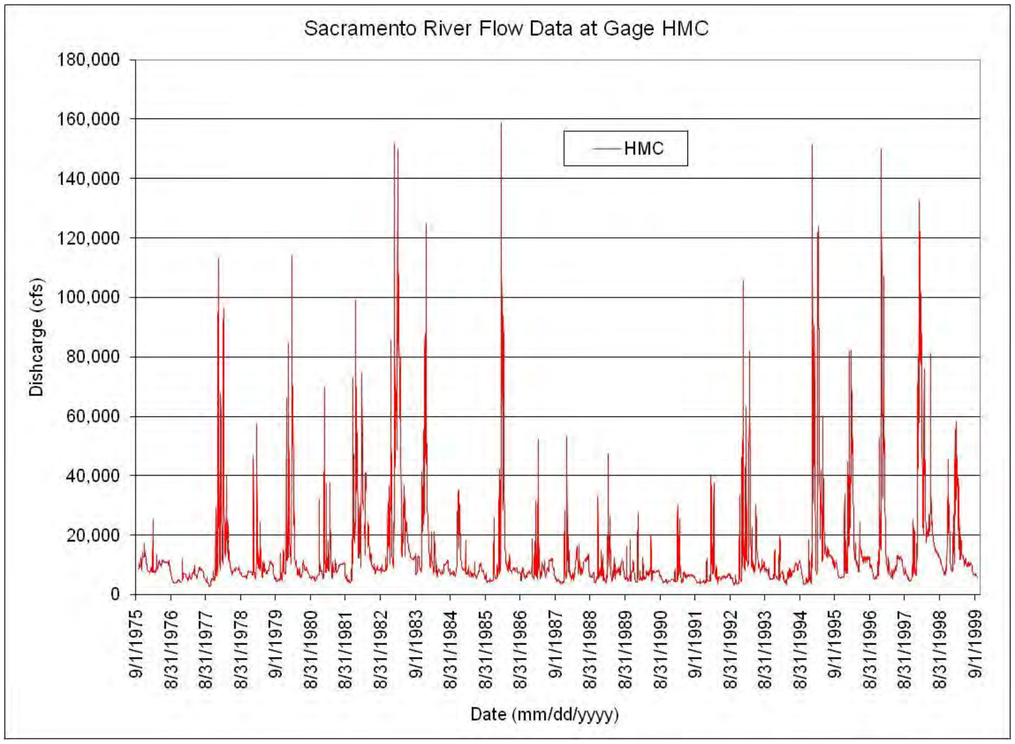
The bank erosion rates were not based on available data, but rather were adjusted during the calibration process. During this study a correlation between the calibrated erosion coefficient and existing field data, such as surface geology, vegetation, land use, channel bank information, levee location, riprap linings, etc. were explored.

4.1 Model Calibration

No modifications were made to the existing flow data acquired from CDWR. Missing data are calculated by the correlation between neighbor gages. A filter is present in SRH-Meander so that flow data that may not effect river meandering can be excluded. For instance, it is generally accepted that base flows do not cause changes in channel morphology. However, due to the linear nature of the computer model, these base flows yield a calculated meander length, however minor. Conversely, when flows of a river exceed the carrying capacity of a channel, the excess flow spills out onto the floodplain, and the flood waters have little effect on channel-forming processes. Without an imposed upper bound on the flow rates, the rate of bank erosion would increase linearly as the flow rate increases. Thus, an upper and lower limit was applied to the input flow data set. Based on the flow hydrograph and the results of the RAS model, lower and upper limits of 35,000 and 90,000 cfs, respectively, were used for the Sacramento River.

Flow data from CDWR gage „VIN‟ was used for the reach upstream of Hamilton City, gage data „HMC‟ was used between Hamilton City and Ord Ferry, and gage data „ORD was used downstream of Ord Ferry. SRH-Meandering accepts upstream incoming flow rate and lateral flows. To simulate the different flow rates along the Sacramento River, flow data from gage „VIN‟ was used as incoming flow at Red Bluff. Flow difference between gage „HMC‟ and „VIN‟ was used as lateral flow located at gage station „HMC‟. The flow difference between gage „ORD‟ and „HMC‟ was used as lateral flow located at gage station „ORD‟. Figure 4-1 presents the hydrographs for the gages used, along with the upper and lower limits specified for the model. The limits are only applied to the upstream incoming flow.





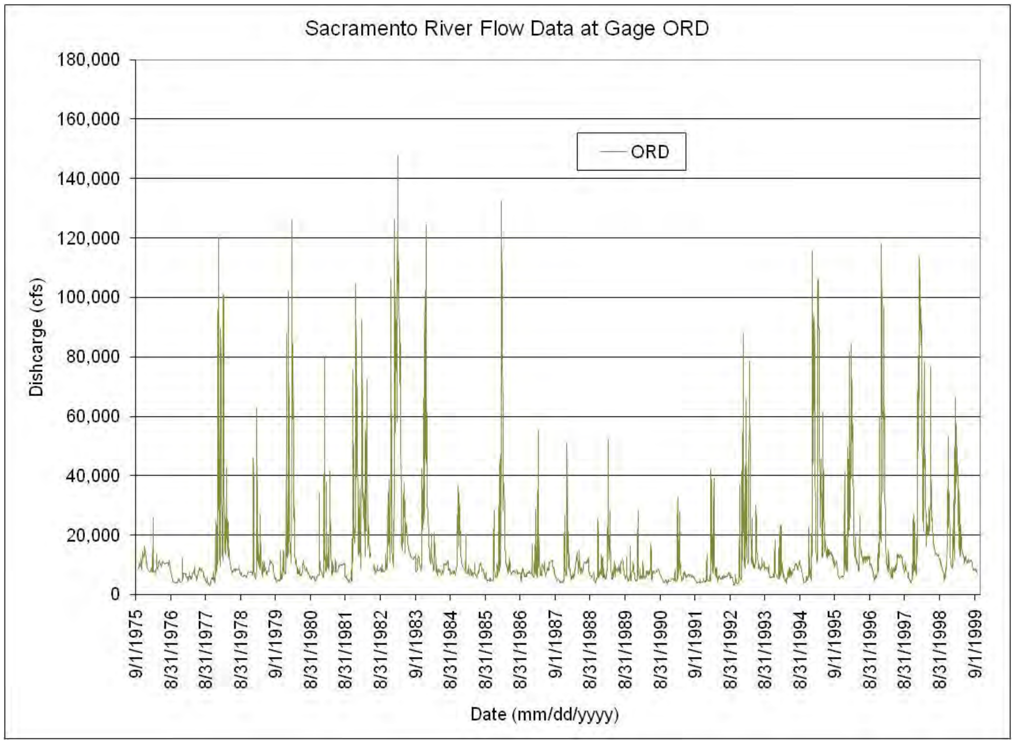


Figure 4-1. Flow hydrograph used for the field calibration (CDWR gages VIN, HMC, and ORD).

Completing the data pre-processing described above resulted in properly formatted data inputs for the SRH-Meander model. The parameters that were changed during calibration (i.e., the calibration parameters) were: the cutoff ratio, the model grid spacing, and the erosion coefficients. The grid spacing is not a parameter reflecting a physical process, but rather a necessary parameter for numerical modeling purposes. It determines the distance between nodes of the modeled centerline, and scales with the reach-averaged channel width.

No channel geometry were input, instead the rating curve table was used to calculate the average flow velocity, channel top width, hydraulic radius, and energy slope at specific flow rate. The rating curve table was obtained by a separate HEC-RAS model with 1976 channel geometry. The rating curve is presented in Table 4-1.

Calibration compares the output channel alignment to the actual channel alignment at the end of the time interval being modeled. An iterative approach was taken in calibrating the model to match the field data. Erosion coefficients were adjusted after an observed model run as necessary until the model output alignment represented the actual channel alignment sufficiently well. The cutoff ratio is also adjusted in each polygon defining the erosion coefficient to reproduce the channel cutoff at specific location.

Table 4-1. Rating Curve

Q	Velocity	Friction Slope	depth	Tw	Rh
m^3/s	m/s	m/m	m	m	m
849.51	1.179	5.786E-04	2.774	271.482	2.758
991.09	1.234	5.626E-04	2.927	284.233	2.910
1132.67	1.285	5.479E-04	3.072	291.911	3.054
1274.26	1.332	5.399E-04	3.216	297.914	3.196
1415.84	1.376	5.360E-04	3.350	303.491	3.330
1557.43	1.401	5.430E-04	3.415	315.194	3.395
1699.01	1.426	5.484E-04	3.507	323.956	3.486
1840.60	1.456	5.529E-04	3.610	331.497	3.588
1982.18	1.485	5.621E-04	3.697	337.876	3.675
2123.76	1.511	5.680E-04	3.795	341.866	3.773
2265.35	1.535	5.659E-04	3.894	350.249	3.870
2406.93	1.561	5.681E-04	3.995	353.004	3.972
2548.52	1.582	5.699E-04	4.085	355.679	4.061
2690.10	1.603	5.709E-04	4.172	358.245	4.147

Table 4-2 presents a summary of the parameters – both calibration parameters as well as those determined before calibration – used during calibration of the SRH-Meander model to the Sacramento River. All of the erosion coefficients are not listed, but rather the minimum, average, and maximum values are presented.

Table 4-2. Summary of parameters used during SRH-Meander model calibration

Pre-determined parameters	**Manning n (-)**	0.032
	Ave. Energy Slope (ft/ft)	0.00056
	Bed Material Size (mm)	14
	Number of Polygons	542
Calibration parameters	**Grid Spacing (-)**	0.6
	Cutoff Ratio (-)	2.3-4.5
	Min. Erosion Coefficient (-)	8.90E-09
	Ave. Erosion Coefficient (-)	2.23E-05
	Max. Erosion Coefficient (-)	1.40E-04

Figure 4-2 through Figure 4-4 display three examples of calibration results – the centerlines for the 1976 and 1999 channels and the simulated SRH-Meander channel centerlines in 1999. The model was calibrated moderately well. The average absolute distance of the model output coordinates to the actual channel centerline was 88.1 feet for the whole reach. These values are small relative to the average channel top widths about 1000 ft. The value of 0.60 for the grid spacing was used and it agrees with the finding of Crosato (2007) for numerical meander models that the "optimal distance between successive grid points had the order of half the channel width".

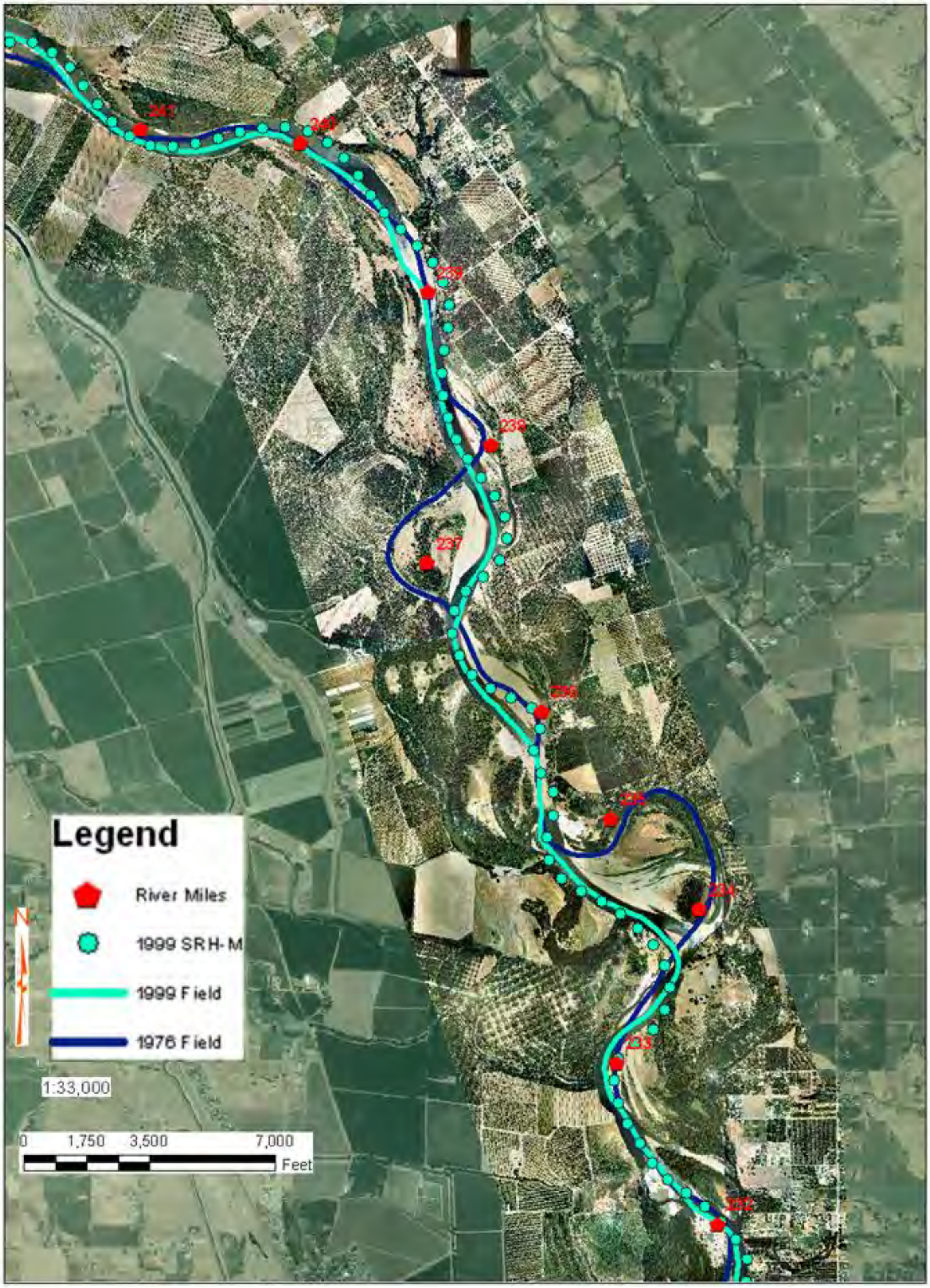


Figure 4-2. Calibration result in location 1.

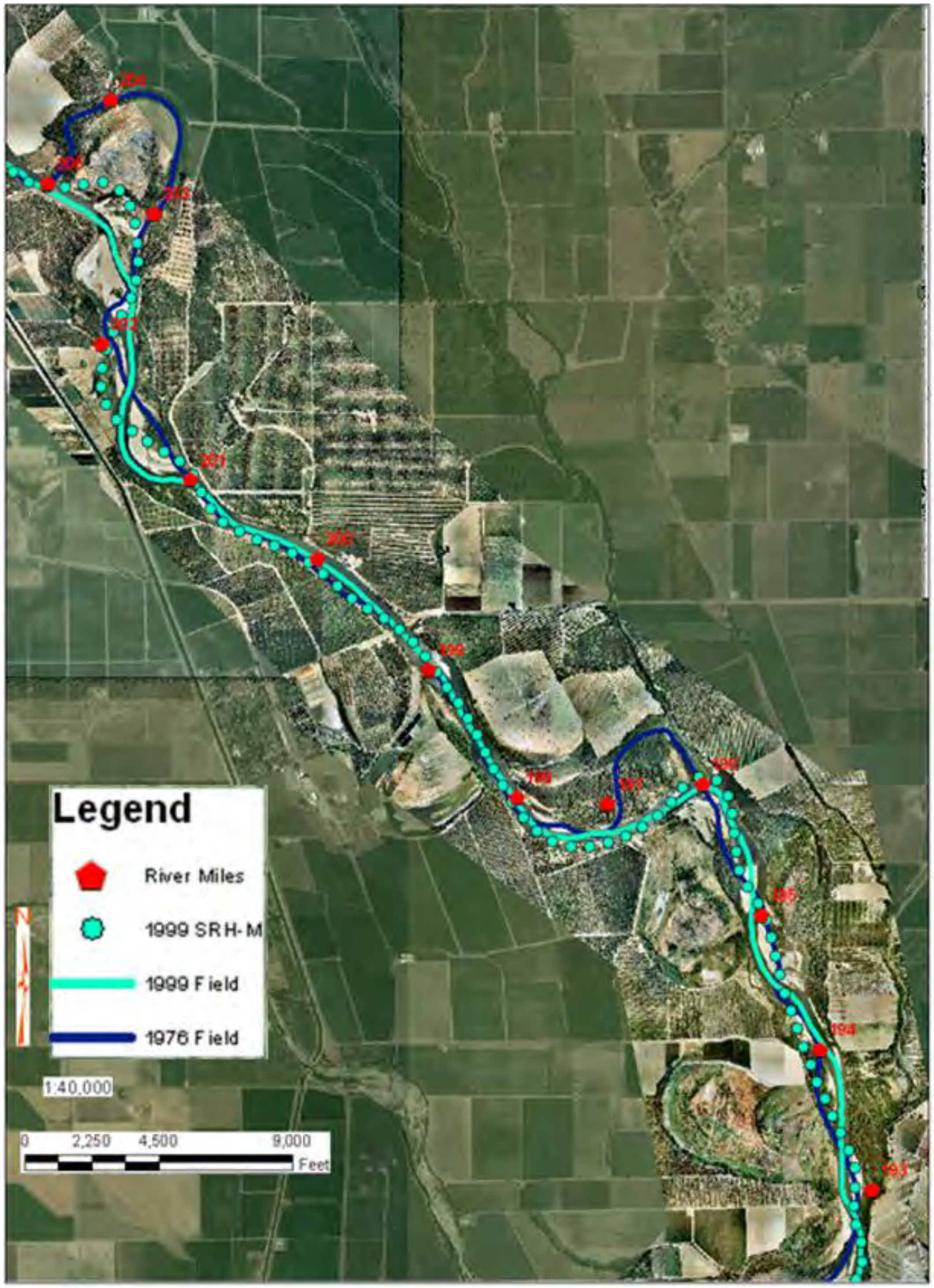


Figure 4-3. Calibration result in Location 2.

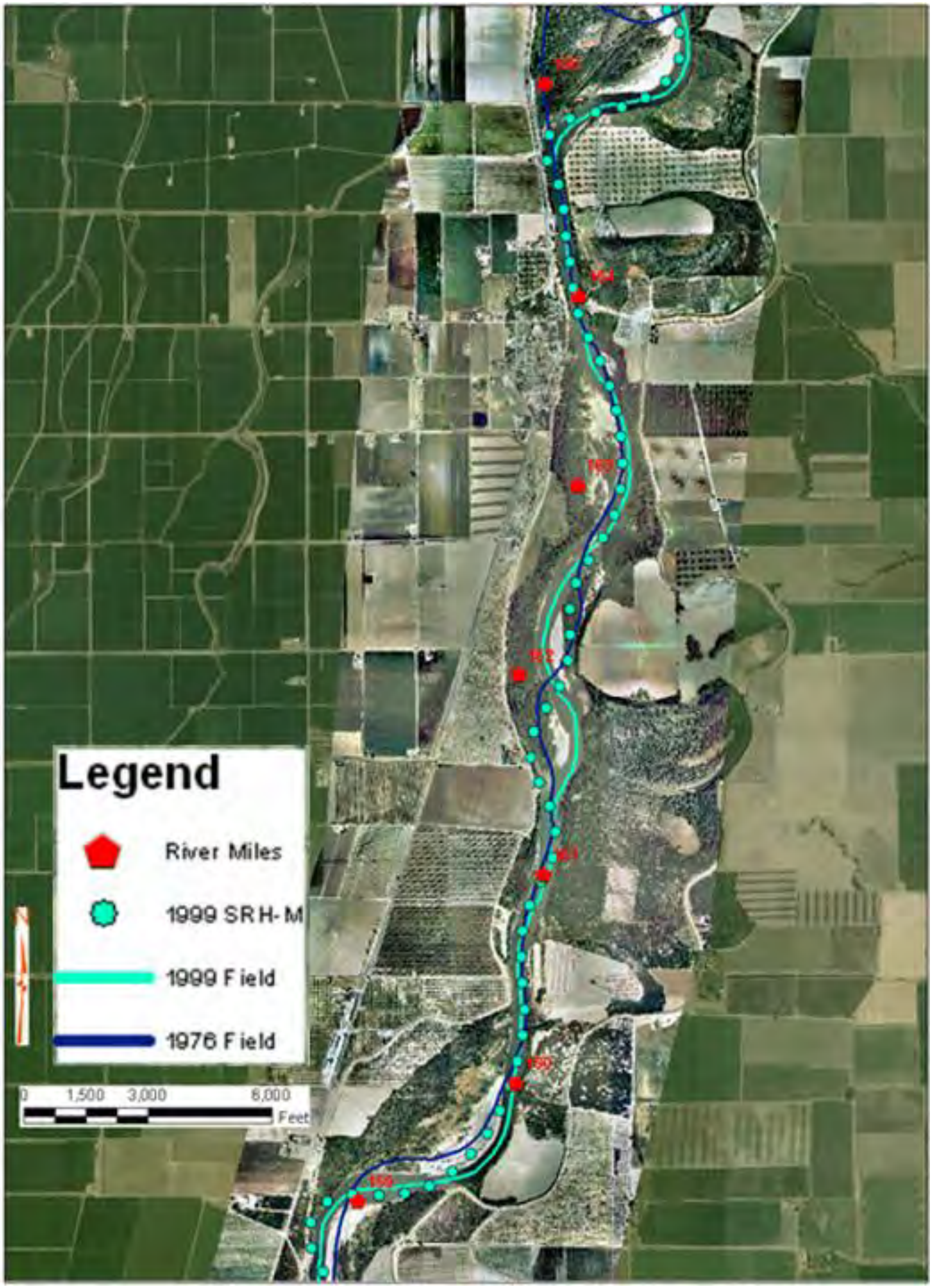


Figure 4-4. Calibration result in location 3.

In general, the SRH-Meander was better at modeling changes in bend amplitude than at modeling bend translation (Figure 4-2). Whether the model predicts translation versus amplification is primarily a function of the channel roughness input parameter combined with the calculated curvature of the centerline. The roughness parameter can only have a single value for the entire model and for the full range of flows used, which may not reflect the actual channel. Calibrating one bend with a given curvature to amplify properly may cause a subsequent bend of similar curvature to not translate as was observed.

Channel cutoff was predicted in the study reach. SRH-Meander simulates the channel cutoffs when the ratio of the length of channel to the length of the valley exceeds a threshold value input by the user. When the channel sinuosity exceeds a limit, the channel has not enough energy to carry the incoming flow and sediment, and the river abandons an existing portion of its length to find a new shorter and steeper path. A straight line is used to link the two points of the channel during the cutoff. After the cutoff, points are redistributed along the channel at equal distances. The model calibration tried to match the simulated channel profile with 1999 field data.

4.2 Model Prediction

The calibrated model was used to predict the channel profile in 2030 with initial channel alignment from 2009 photography, the USRDOM simulated hydrology at difference locations of the Sacramento River. The erosion coefficients, the channel roughness, the grid spacing, the cutoff ratios, and all other parameters are kept unchanged from the calibration model.

USRDOM simulated the flow hydrology at the Sacrament River from 1921 to 2003 with different water managements for river restorations options (named Existing, NoAction, AltA, AltB, and AltC). The simulation provided flow hydrology upstream from Shasta Reservoir to downstream at Colusa, and flow hydrology from tributaries including Antelope Creek, Elder Creek, Miller Creek, Thomas Creek Creek, Deer Creek, Big Chico Creek, and Stony Creek. The hydrology from 10/1/1980 to 9/30/2000 was used to predict channel meander from 2010 to 2030. Flow data from the gage at Red Bluff Diversion Dam (RM 243.0, Control Point 160) was used as upstream incoming flow. Flow rate varies along the over 100 mile reach due to incoming flows from tributaries, distribution of flows into irrigation cannels, and water infiltrations. The Control Points located in this study reaches are CP 175 at Red Bluff Diversion Dam (RM 242.8), CP 170 at Antelope Creek (RM 235.0), CP 165 at Elder Creek and Mill Creek (RM 229.6), CP 162 at Thomas Creek (RM 225.3), CP 160 at Deer Creek(RM 219.5), CP 150 at Glenn-Colusa Canal (GCC) Diversion (RM 206.2),CP 142 at Stone Creek (RM 189.8), CP 140 at Ord Ferry (RM 189.0), CP 135 at Butte City (RM 169.0), and CP 128 at Delevan Pipeline (RM 158.3). Flow rate differences from Control Points are input as lateral inflows/outflows to adjust the varying flow along the river.

Figure 4-5 to Figure 4-7 present the hydrographs at Red Bluff Diversion Dam, GCC Diversion, and the New Delevan Pipeline. The upper and lower limits (section 4.1) are only specified at upstream (Red Bluff) for the model. Only minor differences are displayed along different hydrographs.

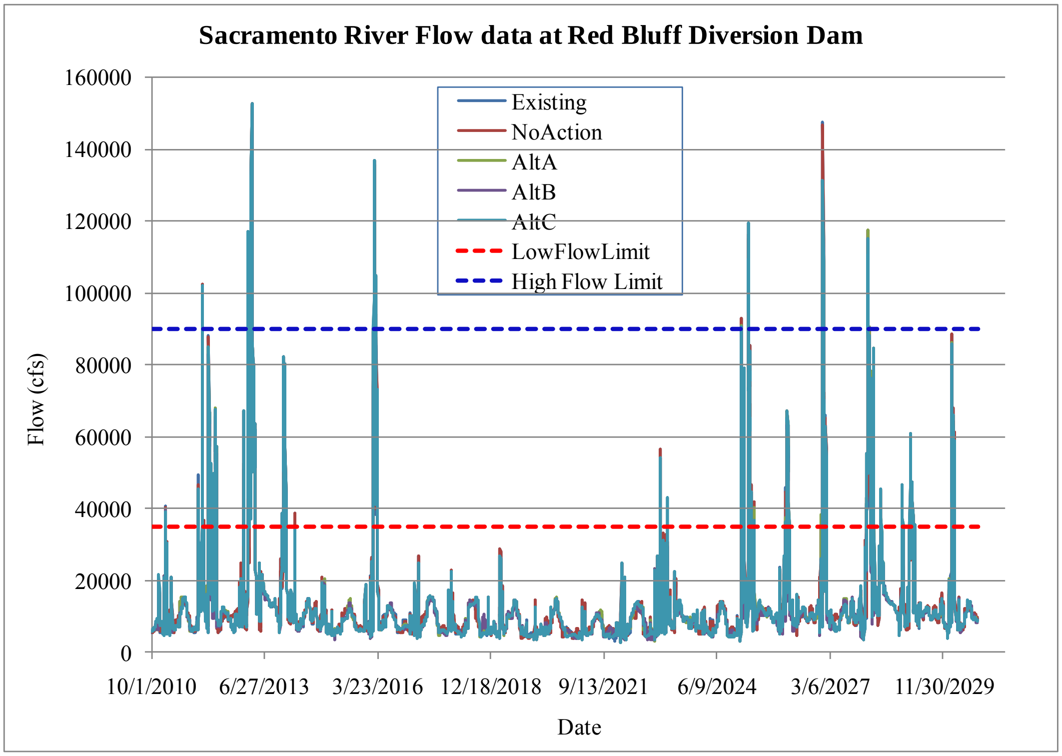


Figure 4-5. Flow hydrograph of Sacramento River at Red Bluff used for future prediction

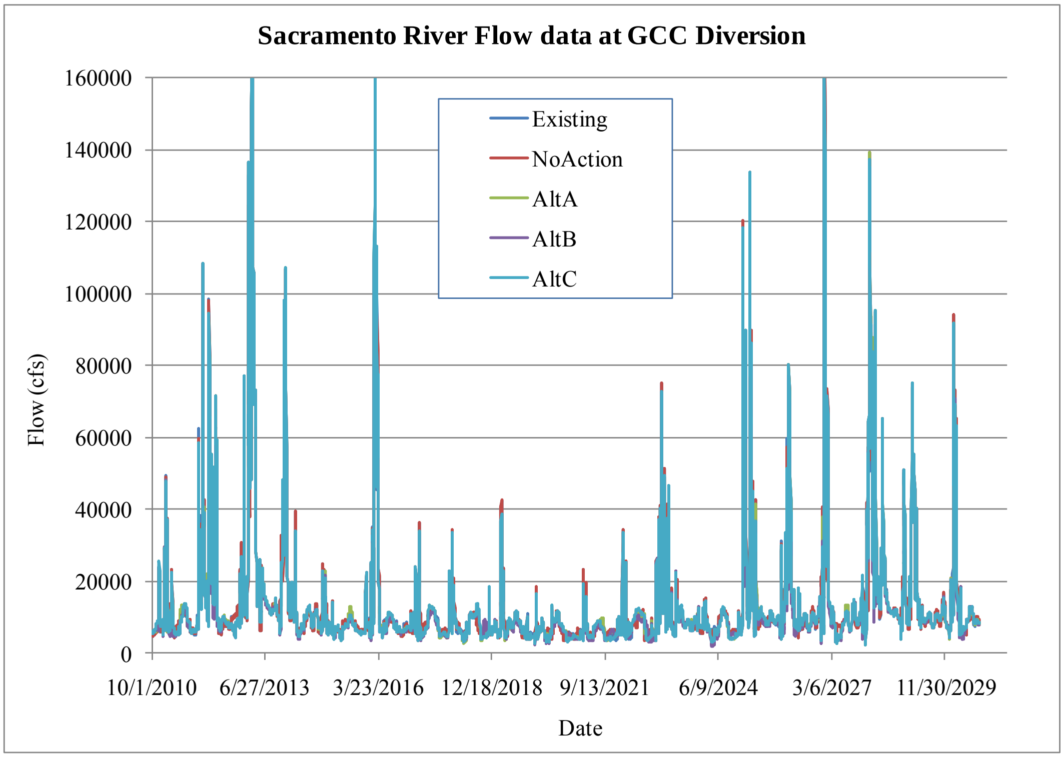


Figure 4-6. Flow hydrograph of Sacramento River at GCC Diversion used for future prediction at GCC Diversion

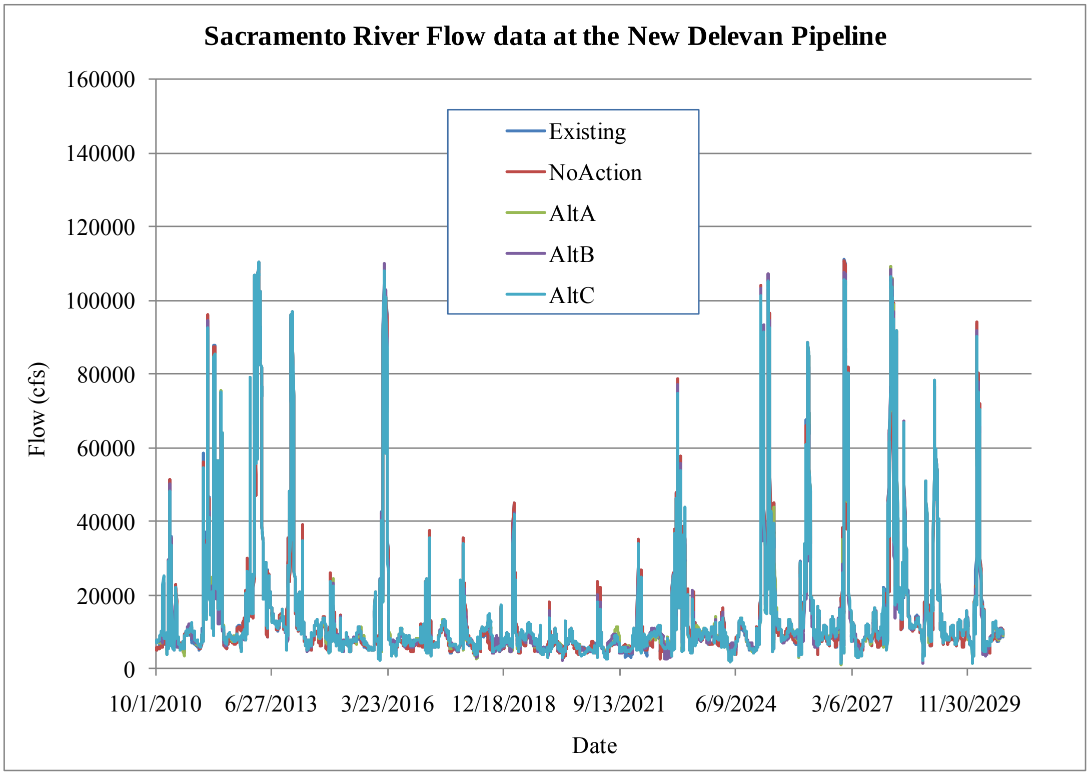


Figure 4-7. Flow hydrograph of Sacramento River at the New Delevan Pipeline used for future prediction .

Flow duration curves under difference alternatives are given in Figure 4-8 to Figure 4-10. Only minor differences exist along difference alternatives. At Red Bluff, AltA, AltB, and AltC conditions have less flows under 10,000 cfs comparing with Existing and NoAction conditions. At GCC diversion, AltA, AltB, and AltC conditions have less flows under 7,000 cfs and between 10,000 and 20,000 cfs comparing with Existing and NoAction conditions. At New Delevan Pipeline, AltA, AltB, and AltC conditions have less flows under 5,000 cfs and between 10,000 and 20,000 cfs, and have more flows between 6,000 to 10,000 cfs comparing with Existing and NoAction conditions.

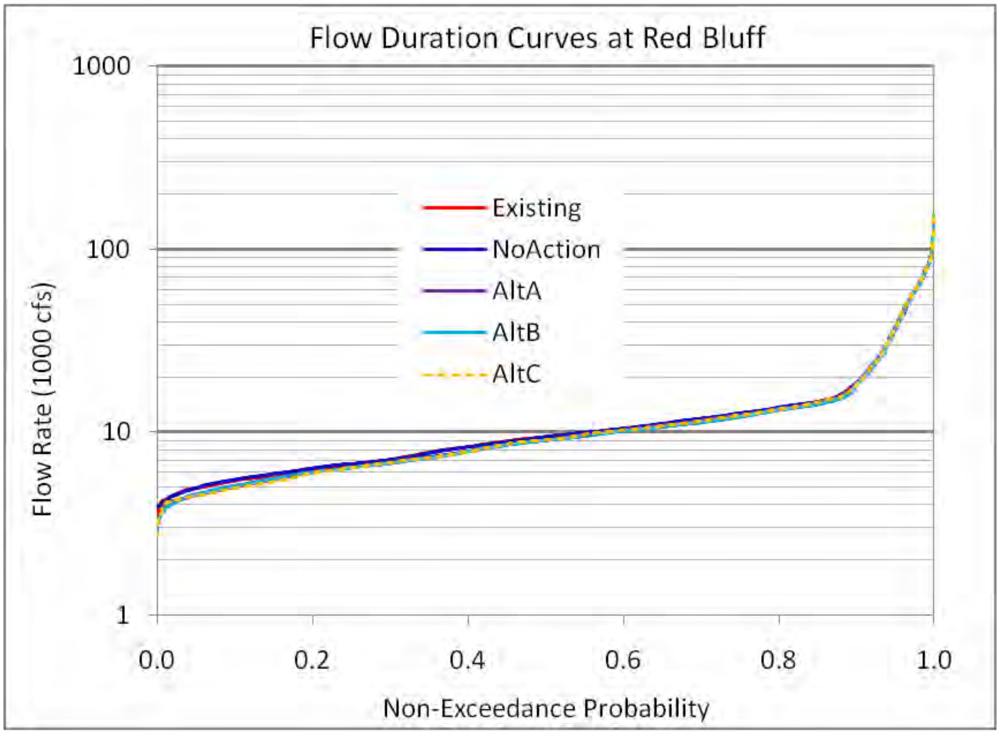


Figure 4-8. Flow Duration Curves at Red Bluff. The flow duration curve is derived from USRDOM results from Oct. 1, 1980 to Sept. 30, 2000.

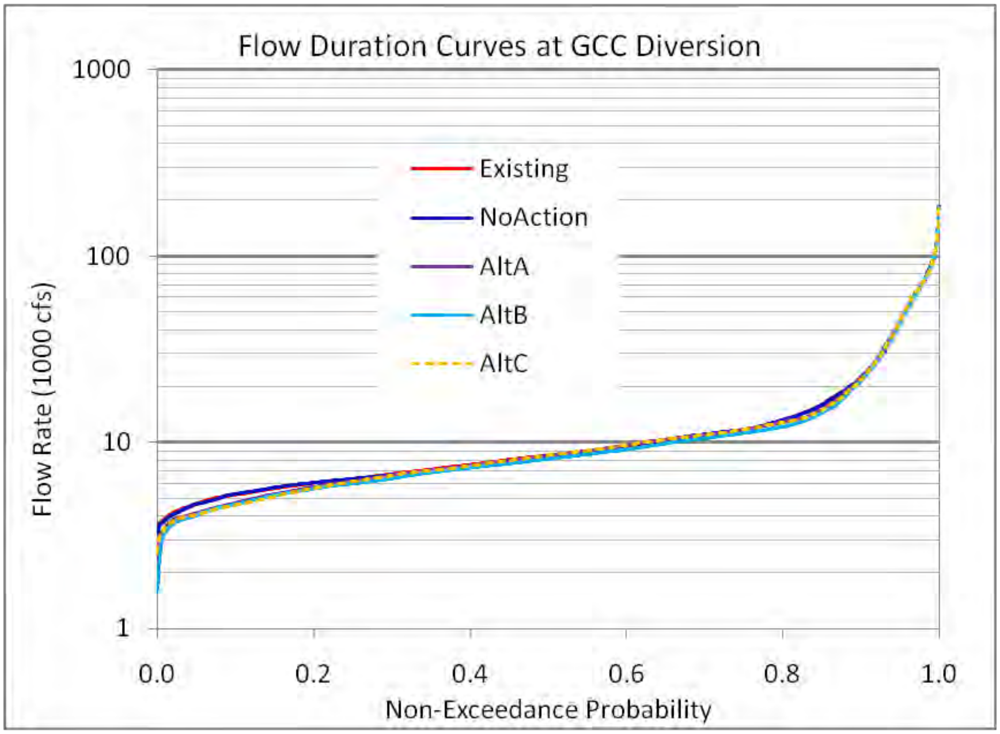


Figure 4-9. Flow Duration Curves at GCC Diversion. The flow duration curve is derived from USRDOM results from Oct. 1, 1980 to Sept. 30, 2000.

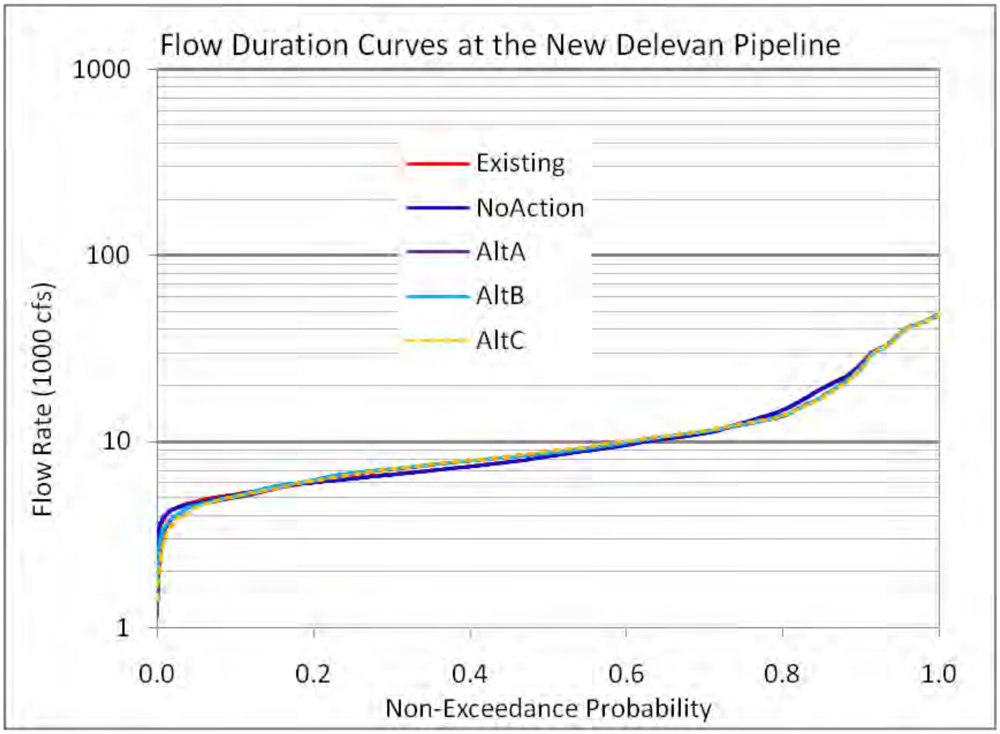


Figure 4-10. Flow Duration Curves at the New Delevan Pipeline. The flow duration curve is derived from USRDOM results from Oct. 1, 1980 to Sept. 30, 2000.

Future channel migration is predicted in two conditions: the current conditions and ripraped conditions. In the current conditions, no modification is made to the calibrated erosion coefficients and the channel will continue to migrate at the same rate as in calibration period from 1976 to 1999. In the ripraped condition, the channel alignment is fixed where the existing bank is ripraped. A DWR 2008 GIS map was provided with updated ripraped banks. In some locations, the channel has encountered geological control (for example at the right bank of Delevan RM 158.5)and is identified as Tehama or Modesto bank. In these cases, the erosion coefficients are set at one order of magnitude lower than the value determined during calibration.

Review comments from Koll Buer (Koll, 2011, personal communication) were incorporated to update channel conditions regarding bank riprap locations and geological controls. At the right bank of RM222, Modesto Formation is exposed along this bank from the mouth of Thomas Creek in the upstream part of the bend, and extending downstream to RM222. From this point on downstream, geologic control continues southward along the boundary between the riparian vegetation and the tan grassy field, continuing to Deer Creek. At the left bank of RM 208, the riprap at the lower end of the bend may have washed out. The 2030 simulation assumes that the riprap will be maintained and it will prevent future channel migrations there. At the right bank of RM201, the bend is mostly geologic control except a floodplain deposit which may be eroded in the future.

Geologic control is exposed upstream, in the center of, and at the downstream end of this bend. At the upstream of the left bank of RM 172, the geologic control follows the levee and road that goes along the bank. This area is still eroding floodplain deposits and will continue to do so until it hits geologic control. At RM191, a cut off will be allowed in the model to show the potential of channel alignment, even though the entire bend is heavily ripraped to keep it from cutting off.

The predicted channel alignment in 2030 is shown in Appendix A. The Sacramento River continues to meander at the same rate. Results show that channel cutoff might happen at the big bend from RM 190 to RM 187 unless the channel bank is enforced at this location.

Accumulated channel migration distances with current conditions are shown in Figure 4-11 to Figure 4-14. Channel migration distance represents the distance that the channel works through in the floodplain. After the channel central alignment is calculated, it is shifted normally to the left and to the right by a distance half of the channel width to obtain the left and right bank, respectively. If any bank point is located outside of a channel envelop, the bank point is inserted into the channel envelop to obtain the new channel envelop. The channel envelope represents the area where the channel has worked through during the simulated duration. After the area of the channel envelop is calculated, it is then divided by the initial channel length to obtain the envelop width. The envelop width subtracted by the initial channel width, which is the same as the initial envelop width, represents the accumulated channel migration distance. Results shows that channel is most active meandering from Stony Creek (RM 190) to Moulton Weir (RM 158.5) and least active from Moulton Weir (RM 158.5) to Colusa Weir (RM 143) for all water management options.

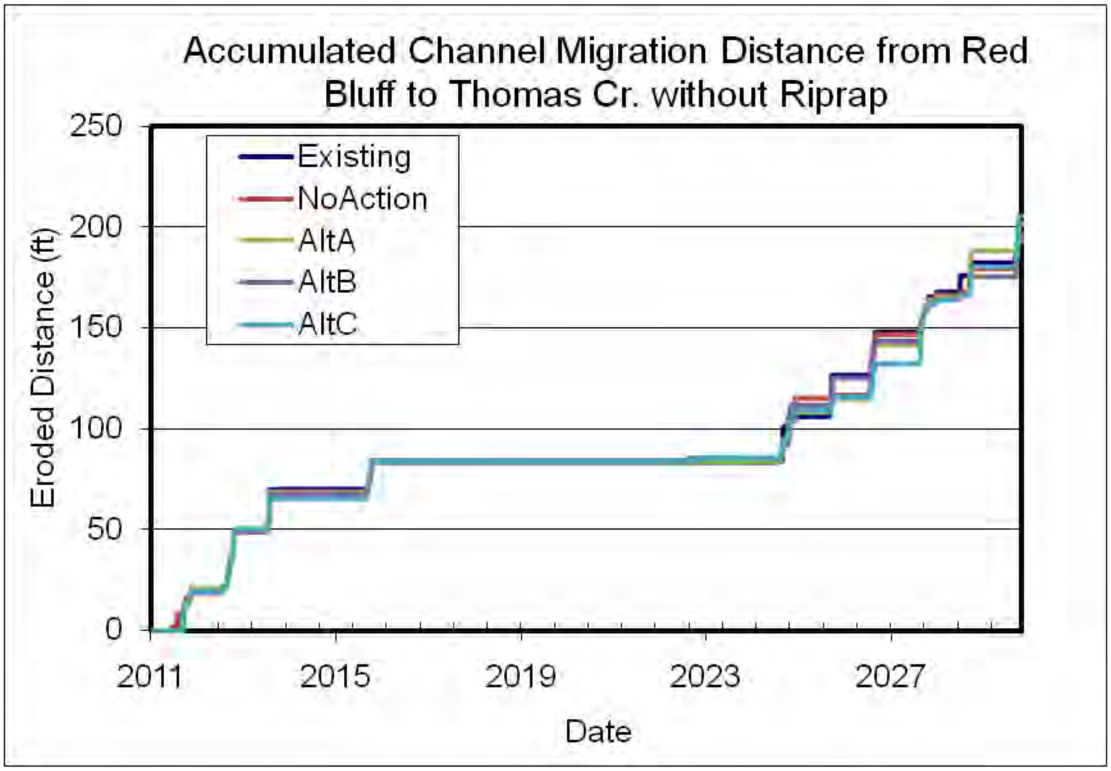


Figure 4-11. Accumulated channel migration distance in reach from Red Bluff Diversion Dam to Thomas Creek with current erosion coefficients

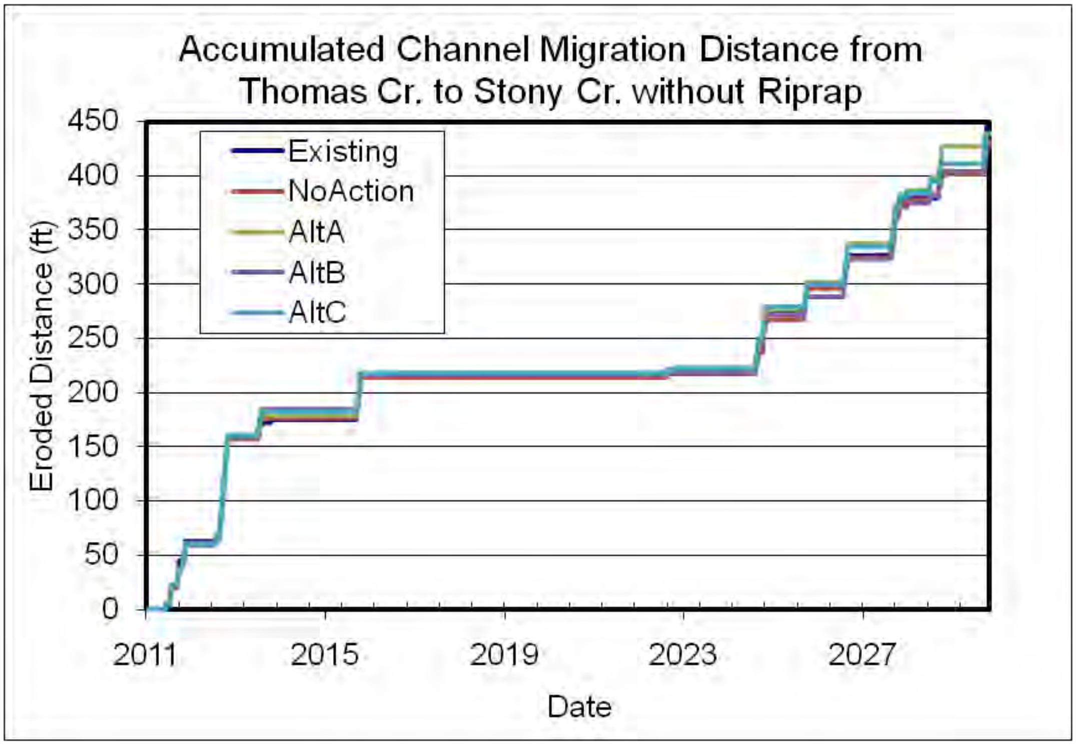


Figure 4-12. Accumulated channel migration distance in reach from Thomas Creek to Stony Creek with current erosion coefficients

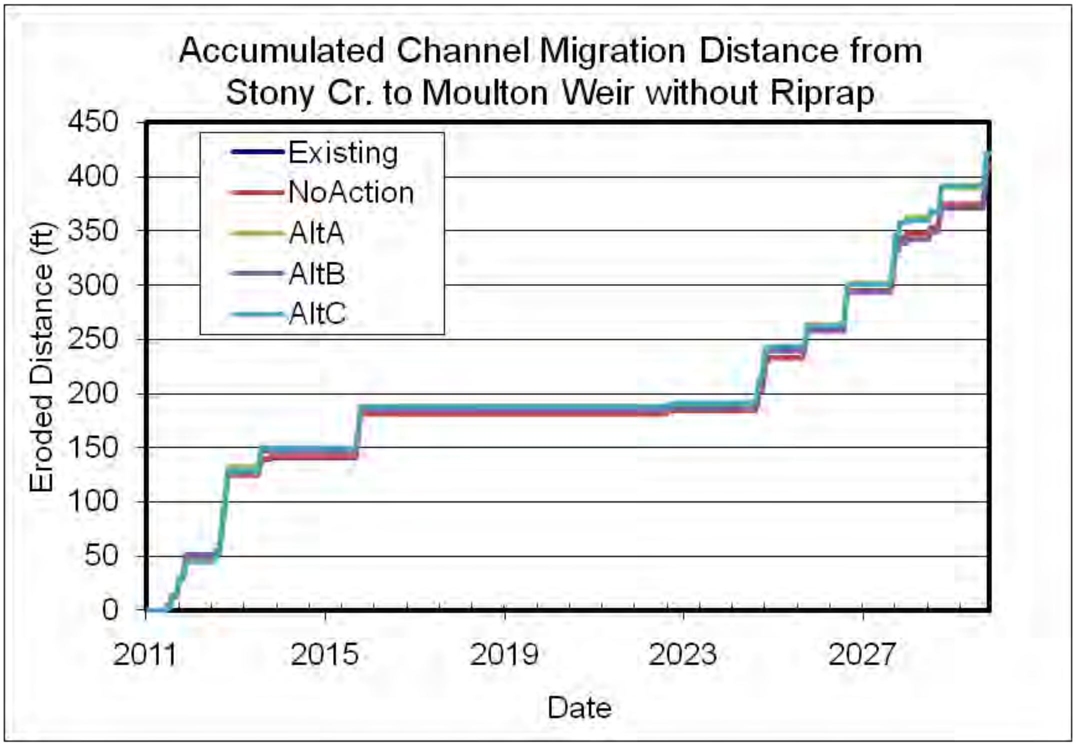


Figure 4-13. Accumulated channel migration distance in reach from Stony Creek to Moulton Weir with current erosion coefficients

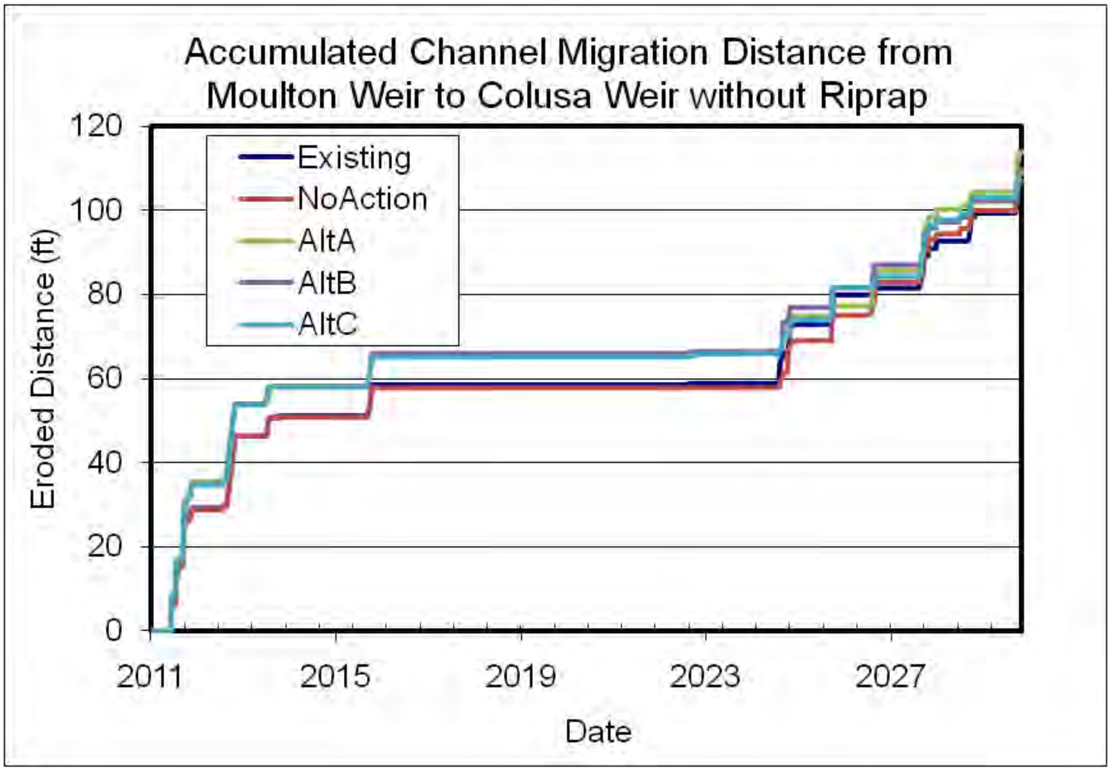


Figure 4-14. Accumulated channel migration distance in reach from Moulton Weir to Colusa Weir with current erosion coefficients

Figure 4-20 and Figure 4-15 shows averaged accumulated channel migration distance for the whole study reach from Red Bluff Diversion Dam (RM 243) to Colusa Weir (142) under the current erosion coefficient condition. AltA and AltC conditions have slightly more meander tendency than other alternatives, but difference is not considered significant considering inherent variability in system.

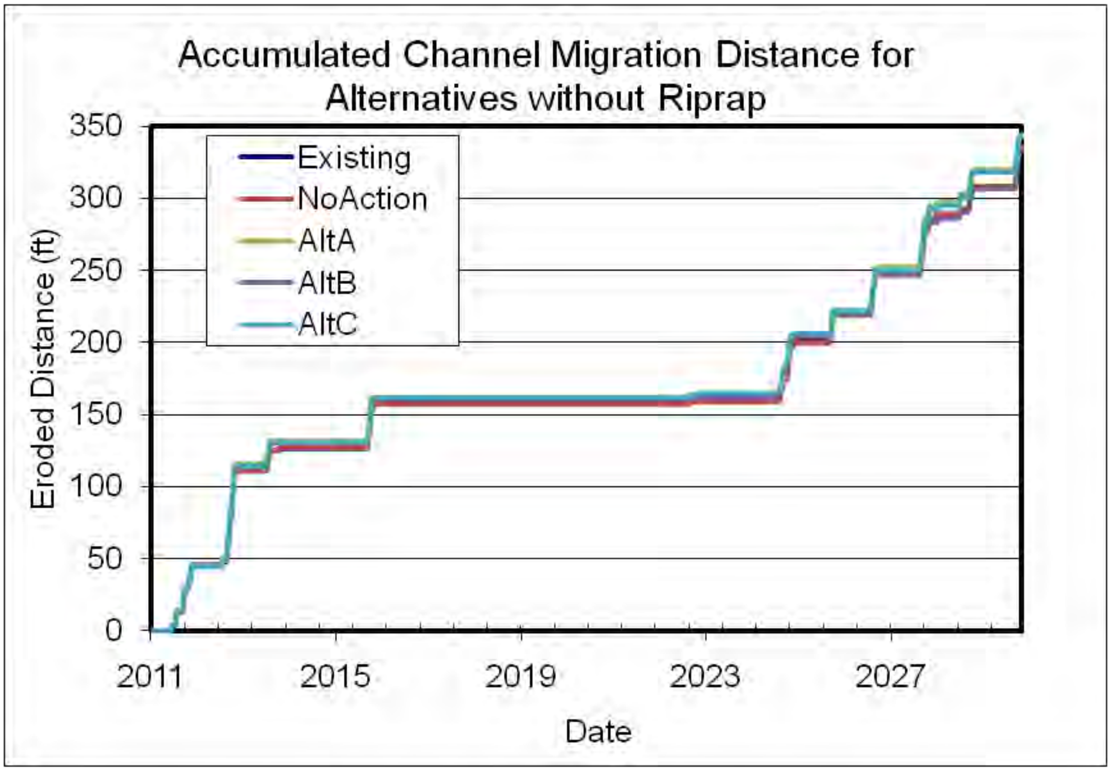


Figure 4-15. Averaged accumulated channel migration distance in the whole reach from Red Bluff Diversion Dam to Colusa Weir with current erosion coefficients

Accumulated channel migration distances with ripraped banks and geological controls are shown in Figure 4-16 to Figure 4-19. The results under this ripraped condition are based on the assumption that the current ripraped banks will be maintained to restrict the channel from any migration and the geological controls will continue to confine the channel at a low migration rate. Compared with results predicted with current erosion coefficients, the averaged channel migration distance reduces with ripraped banks and geological controls. For example, under AltA hydrology, the averaged channel migration distance reduced from 202 ft under the current condition to 139 ft (31% less) under the ripraped bank and geological control condition from Red Bluff Diversion Dam to Thomas Creek. The averaged channel migration distance with ripraped bank and geological control reduces to 218ft (50% less from 439ft) in the reach from Thomas Creek to Stony Creek, 205 ft (51% less from 422ft) in the reach from Stony Creek to Moulton Weir, and 126 ft (11% more from 114ft) in the reach from Moulton Weir to Colusa Weir. Figure 4-20 shows averaged accumulated channel migration distance for the whole study reach from Red Bluff Diversion Dam (RM 243) to Colusa Weir (142) under the riprapped and geologic control condition. AltA and AltC conditions have slightly more meander tendency than other alternatives, but difference is not considered significant considering inherent variability in system.

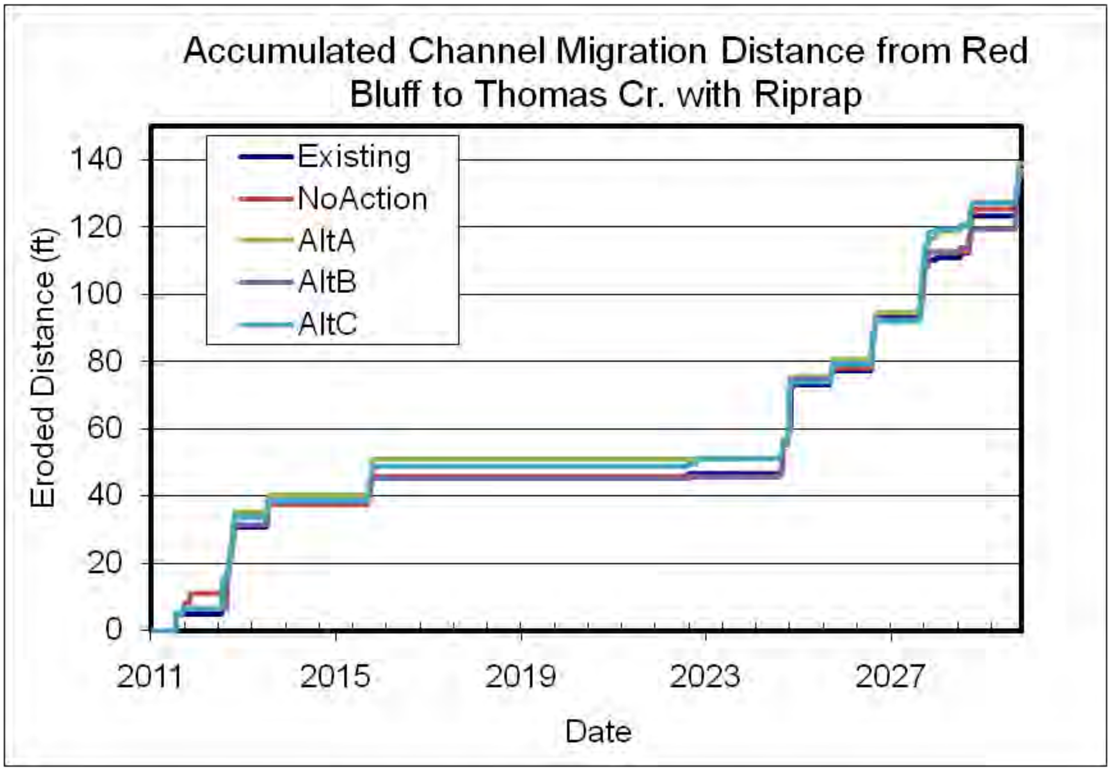


Figure 4-16. Accumulated channel migration distance in reach from Red Bluff Diversion Dam to Thomas Creek with riprap and geologic control

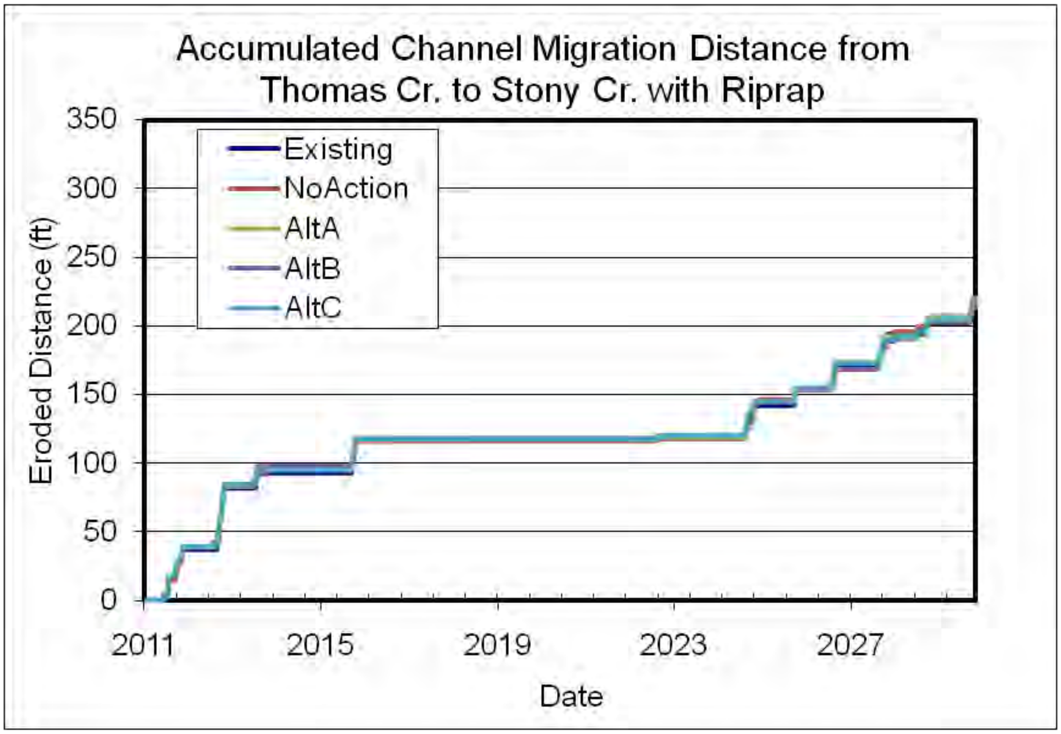


Figure 4-17. Accumulated channel migration distance in reach from Thomas Creek to Stony Creek with riprap and geologic control

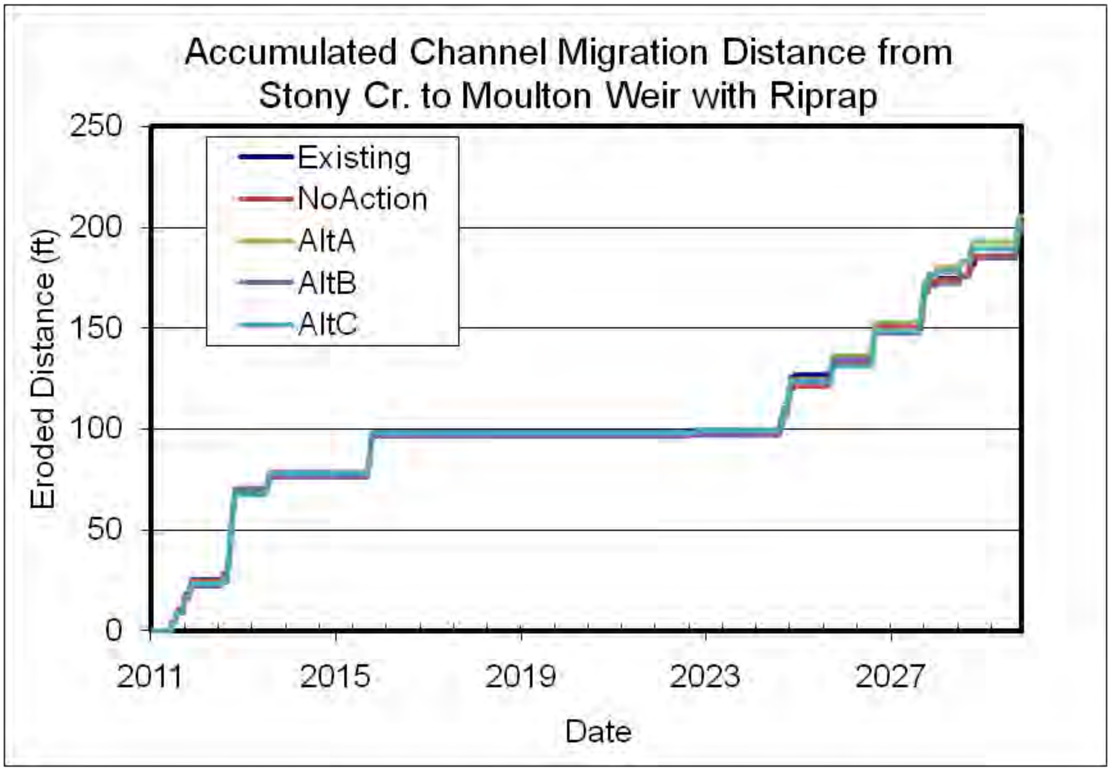


Figure 4-18. Accumulated channel migration distance in reach from Stony Creek to Moulton Weir with riprap and geologic control

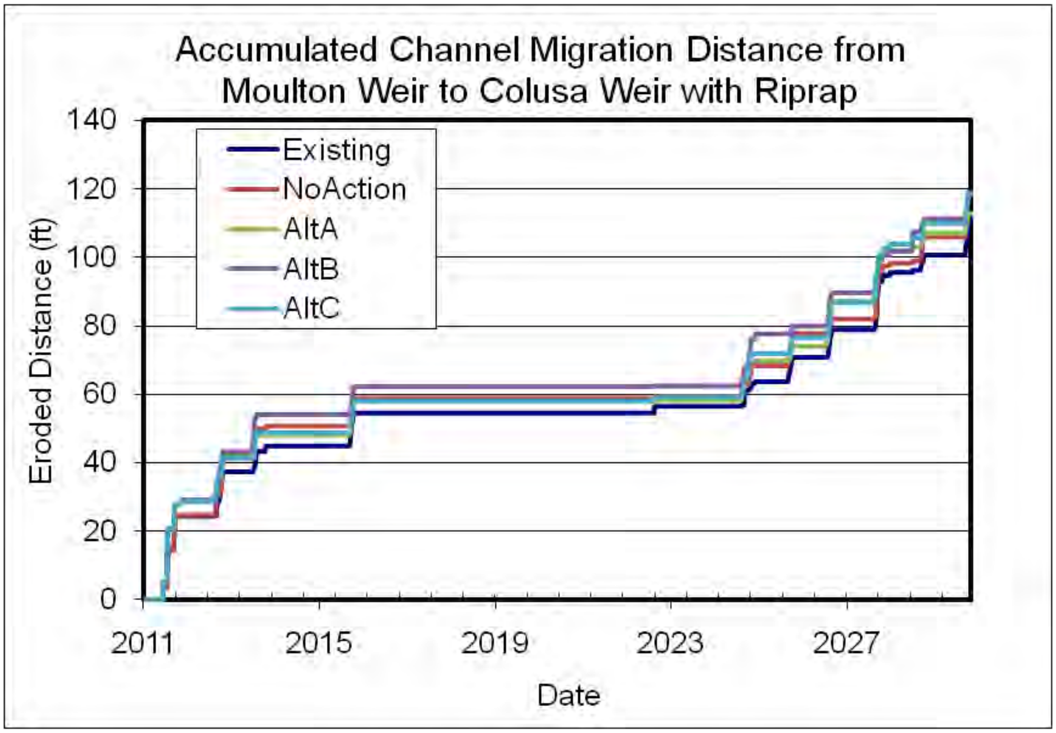


Figure 4-19. Accumulated channel migration distance in reach from Moulton Weir to Colusa Weir with riprap and geologic control.

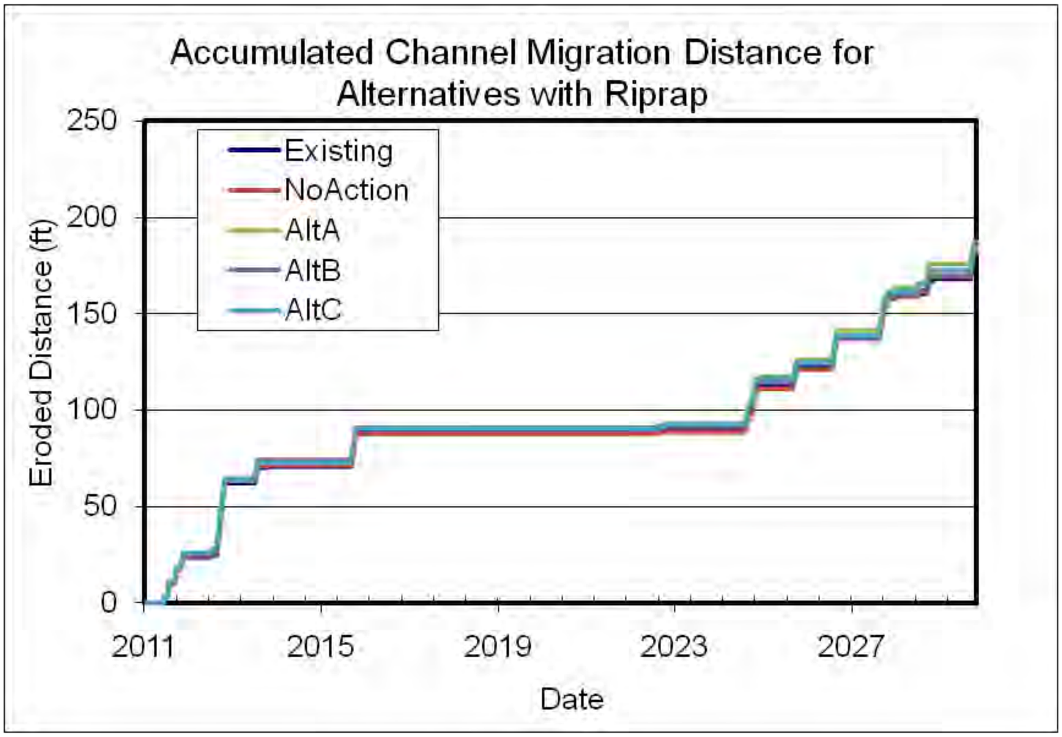


Figure 4-20. Average accumulated channel migration distance in the whole reach from Red Bluff Diversion Dam to Colusa Weir with riprap and geologic control

5 Conclusions

SRH-Meander was used to predict the channel alignments in 2030 based on 2009 channel alignment and modeling twenty years of hydrology from 10/1/2010 to 9/30/2030 using USRDOM flows under the Existing, NoAction, AltA, AltB, and AltC conditions. The channel migration study results are summarized below:

Near the New Delevan Pipeline,

- No major difference exists between channel alignments along Existing, NoAction, AltA, AltB, and AltC conditions .
- The bend upstream of the diversion will continue to migrate downstream unless the bank is protected. Given 20 years, the channel will migrate 650 ft downstream and to the left.
- The channel near the intake will migrate to the right (looking downstream) where levee is close to the main channel. In 20 years, the channel will migrate about 300 ft to the right.
- A cutoff may occur in the bend downstream of the New Delevan Pipeline.
- Bank protection in the vicinity of the intake will prevent the channel from migrating at that location and will not affect the channel migration upstream and downstream of the two ripraped bends.

For the whole reach from Red Bluff to Colusa,

- No major differences exist between the channel alignments for Existing, NoAction, AltA, AltB, and AltC conditions . AltA and AltC conditions yield slightly more meander tendency than other conditions.
- The reach between Stony Creek to Moulton Weir will experience most active channel migration. In twenty years, the channel will migrate more than 400 ft on average. The reach between Moulton Weir to Colusa Weir will experience less channel migration. In twenty years, the channel will migrate 110 ft on average.

6 References

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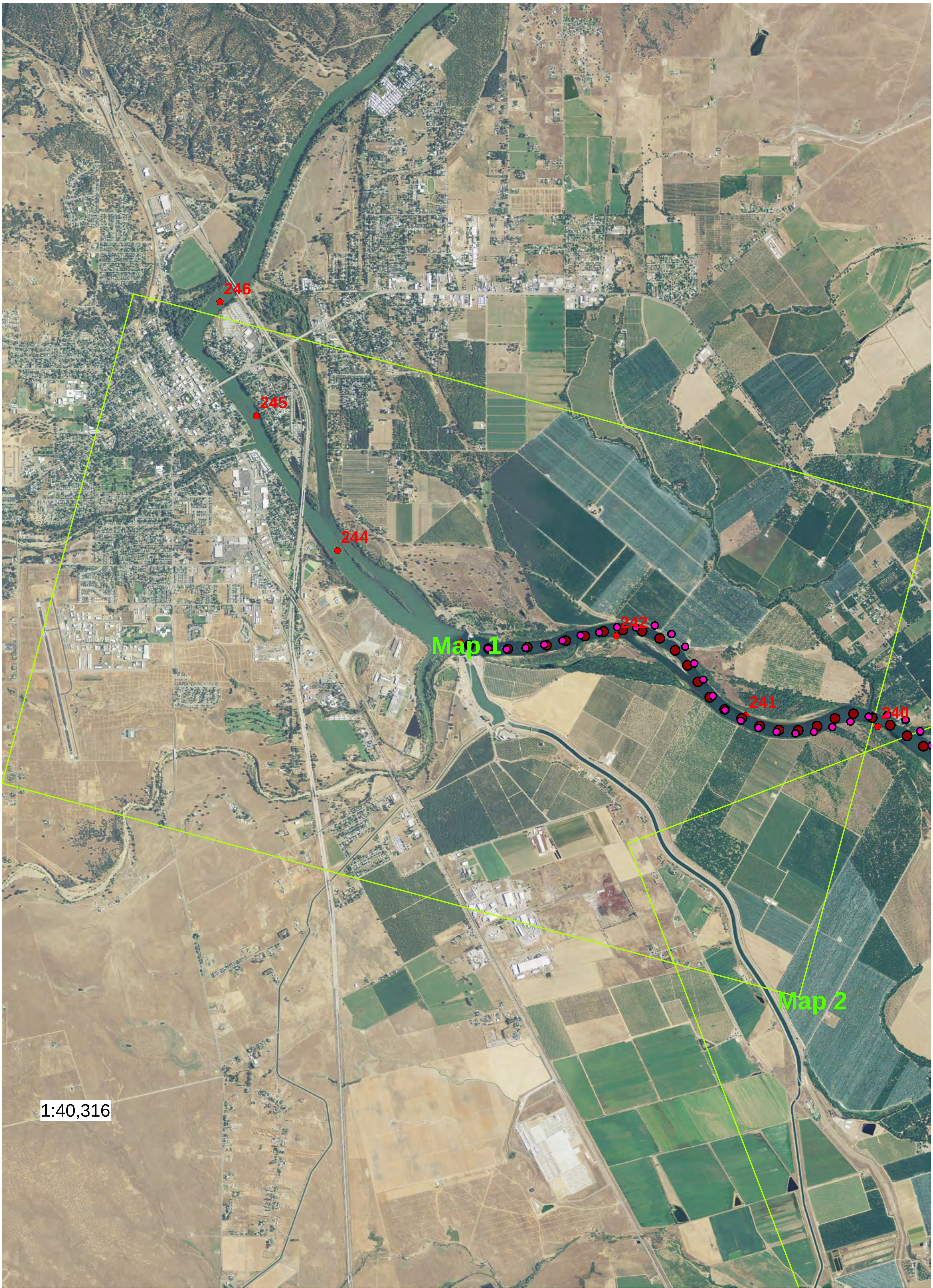
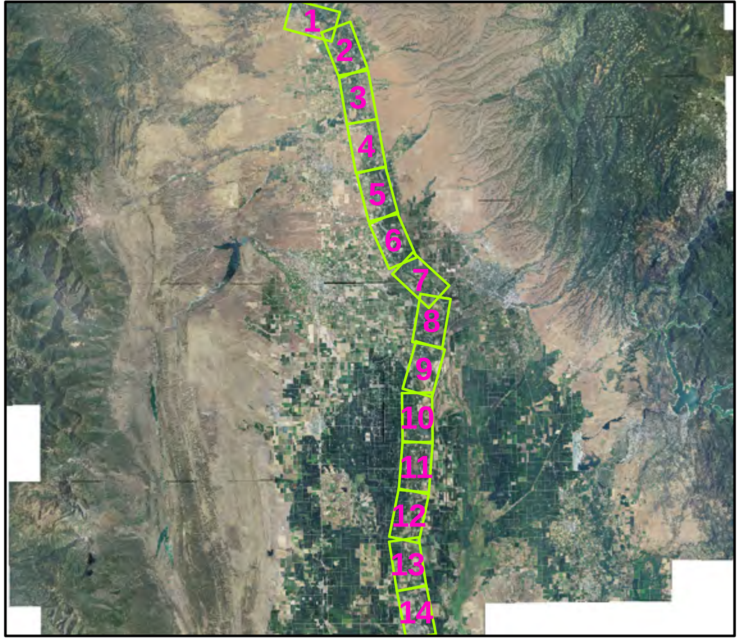
Appendix A





Legend

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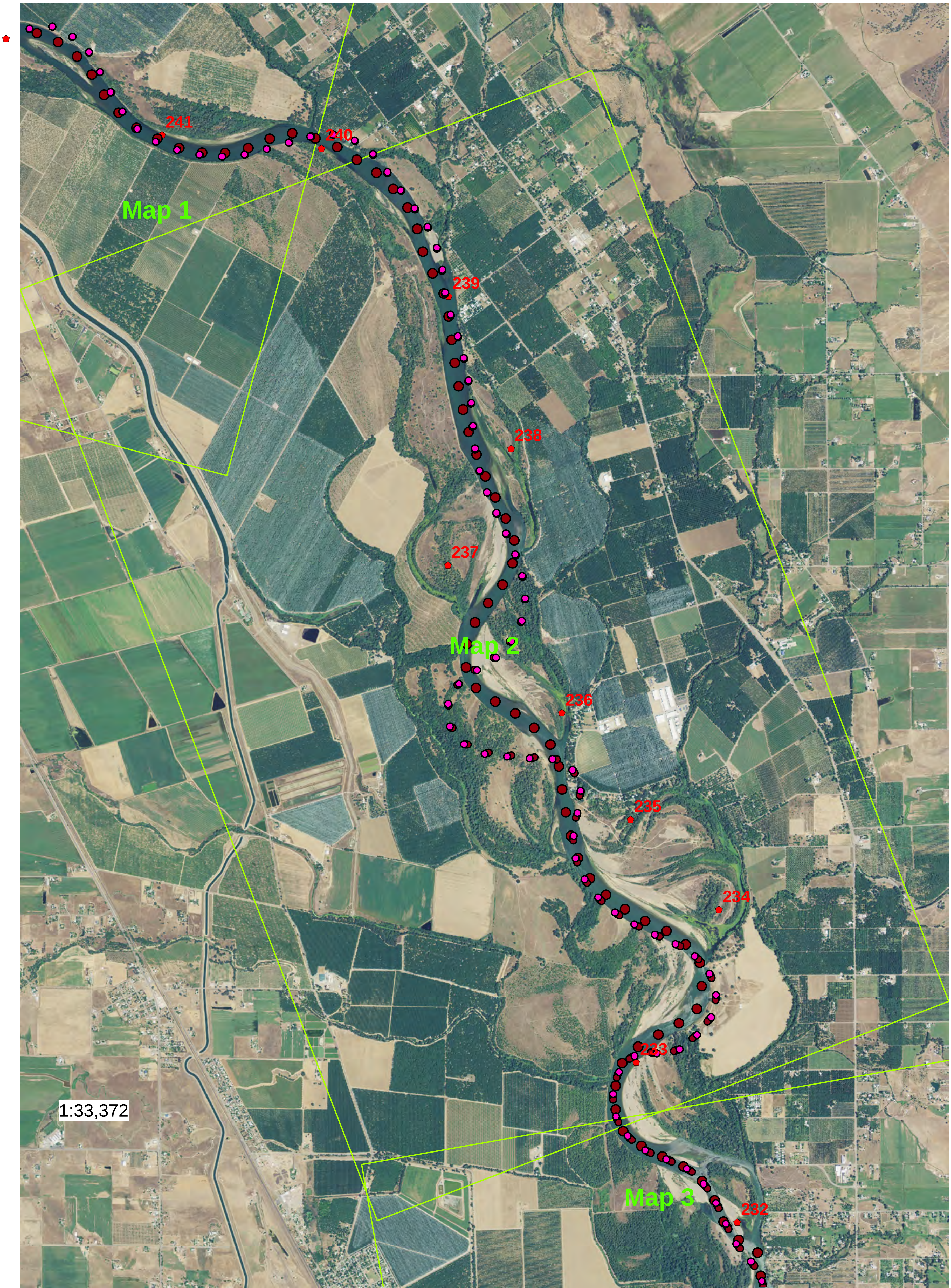
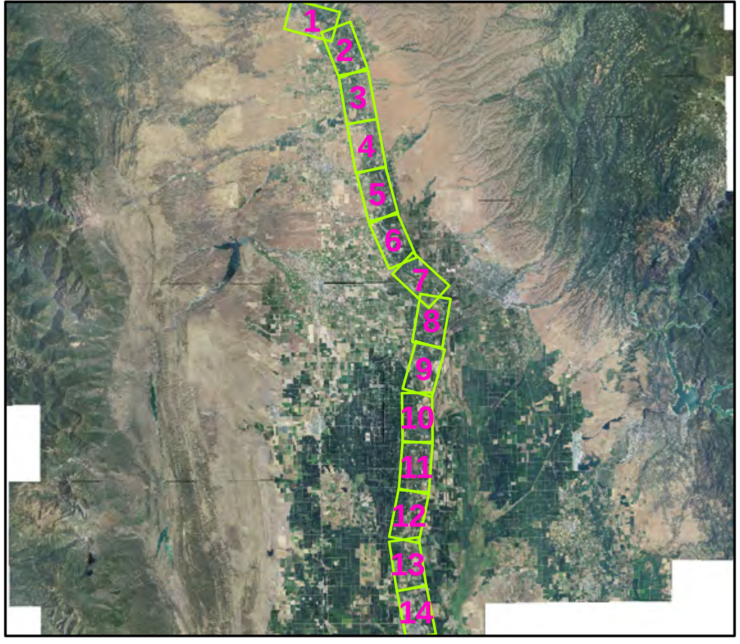
- ● SRH_M-2030_AltB
- ● SRH_M-2030_AltC
- ● SRH_M-2030_Existing
- ● SRH_M-2030_NoAction
- ● SRall_2009_Central_Points MZ
- ⬟ River Miles

N

0 2,200 4,400 8,800 Feet

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO





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- ● SRH_M-2030_AltC
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- ● SRH_M-2030_NoAction
- ● SRall_2009_Central_Points MZ
- ⬟ River Miles

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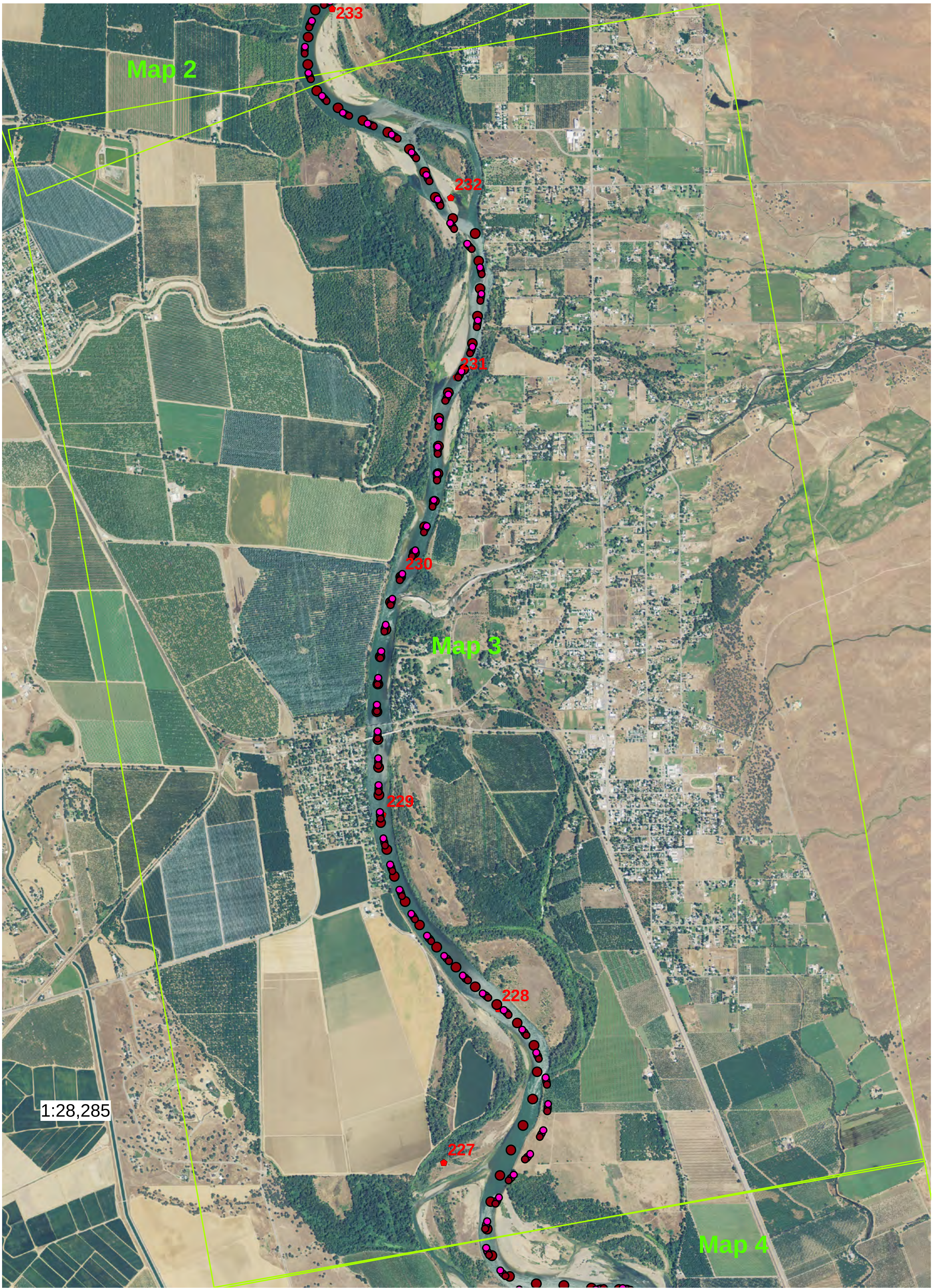
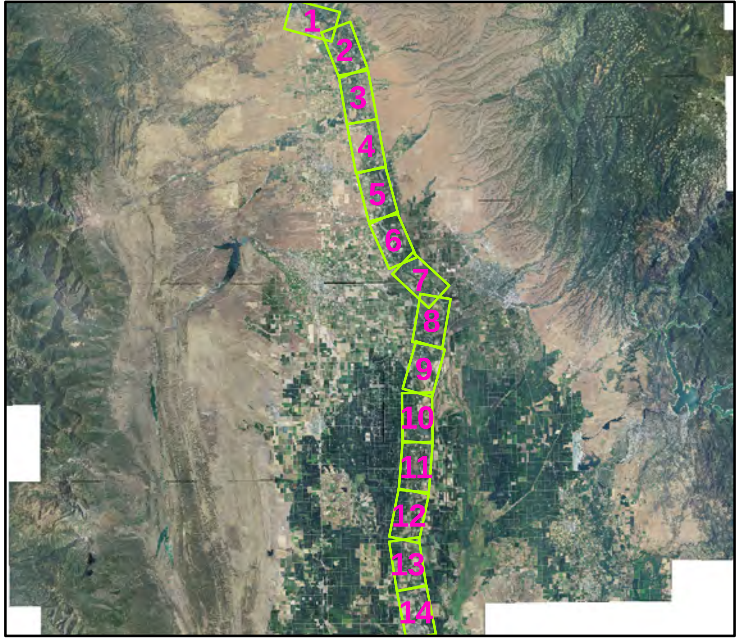
Feet

N

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO





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●	SRH_M-2030_AltC
●	SRH_M-2030_Existing
●	SRH_M-2030_NoAction
●	SRall_2009_Central_Points MZ
⬟	River Miles

N

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Feet

Sacramento River, California
Channel Migration Predictions
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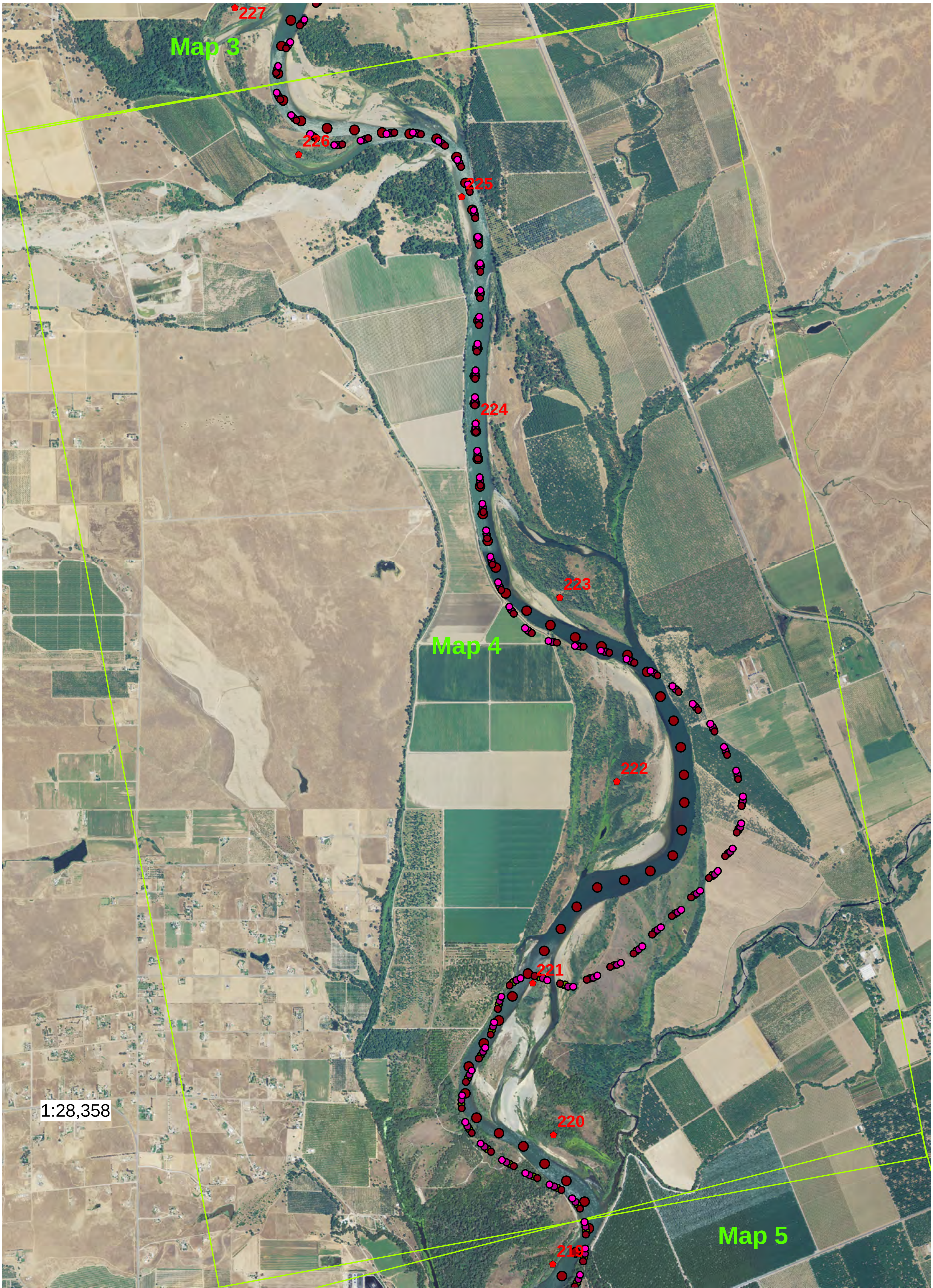
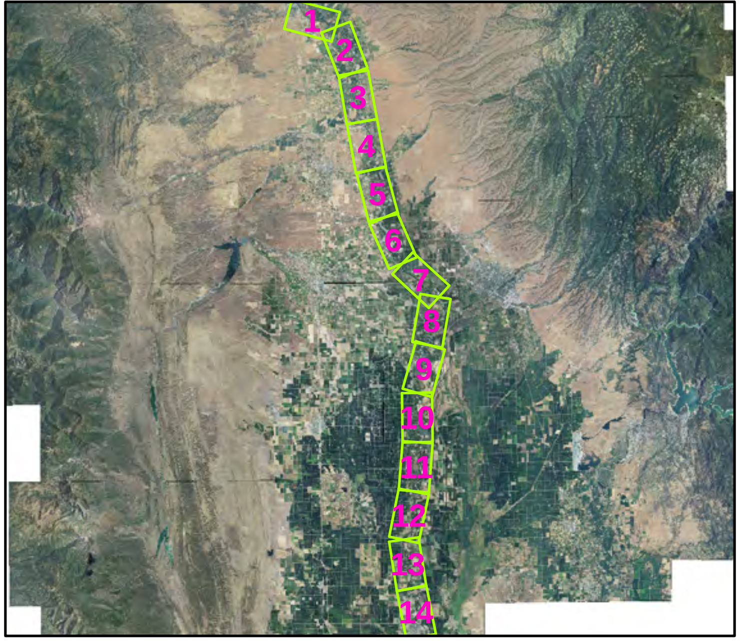
Bureau of Reclamation
Denver, CO





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- ● SRall_2009_Central_Points MZ
- ⬟ River Miles

N

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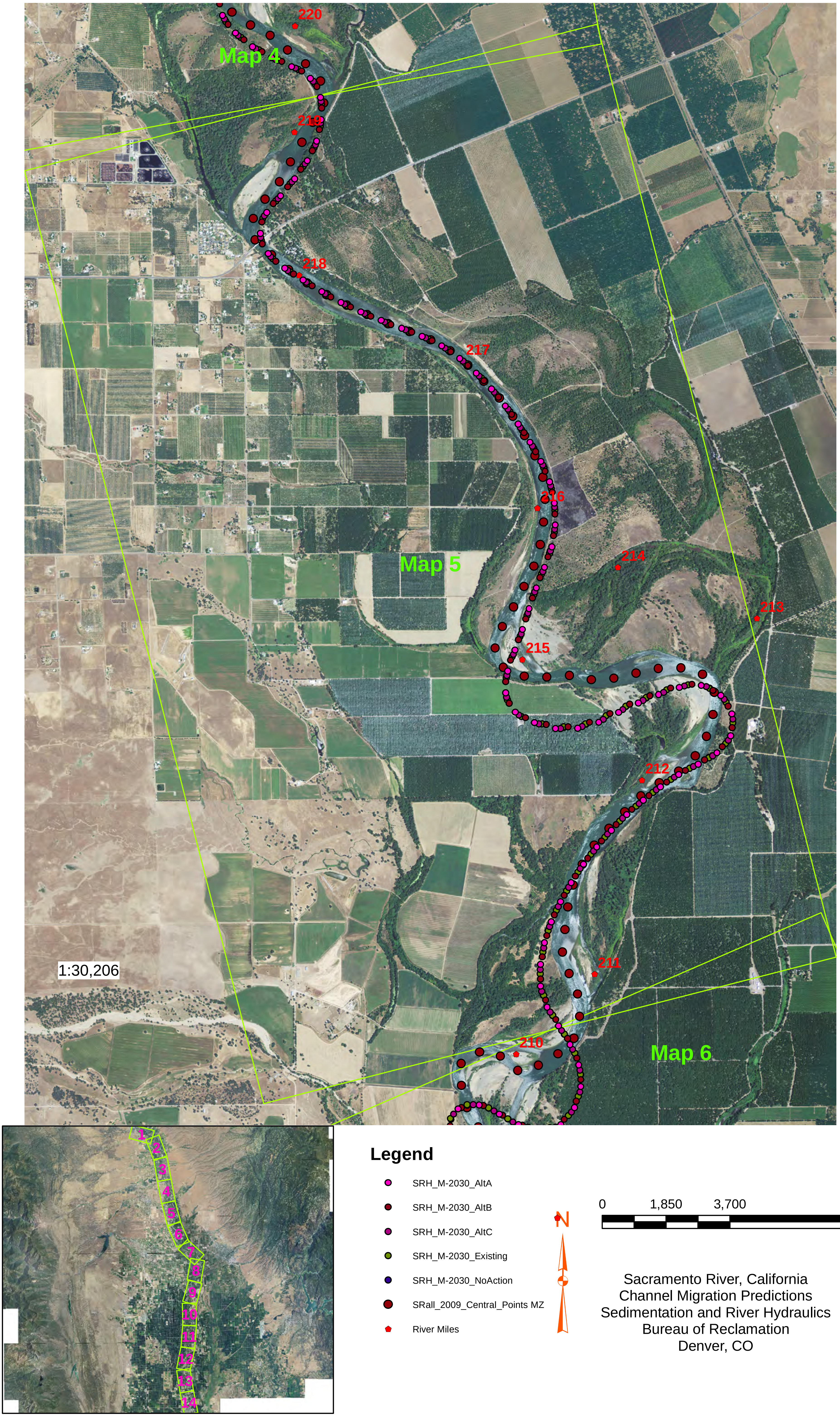
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO



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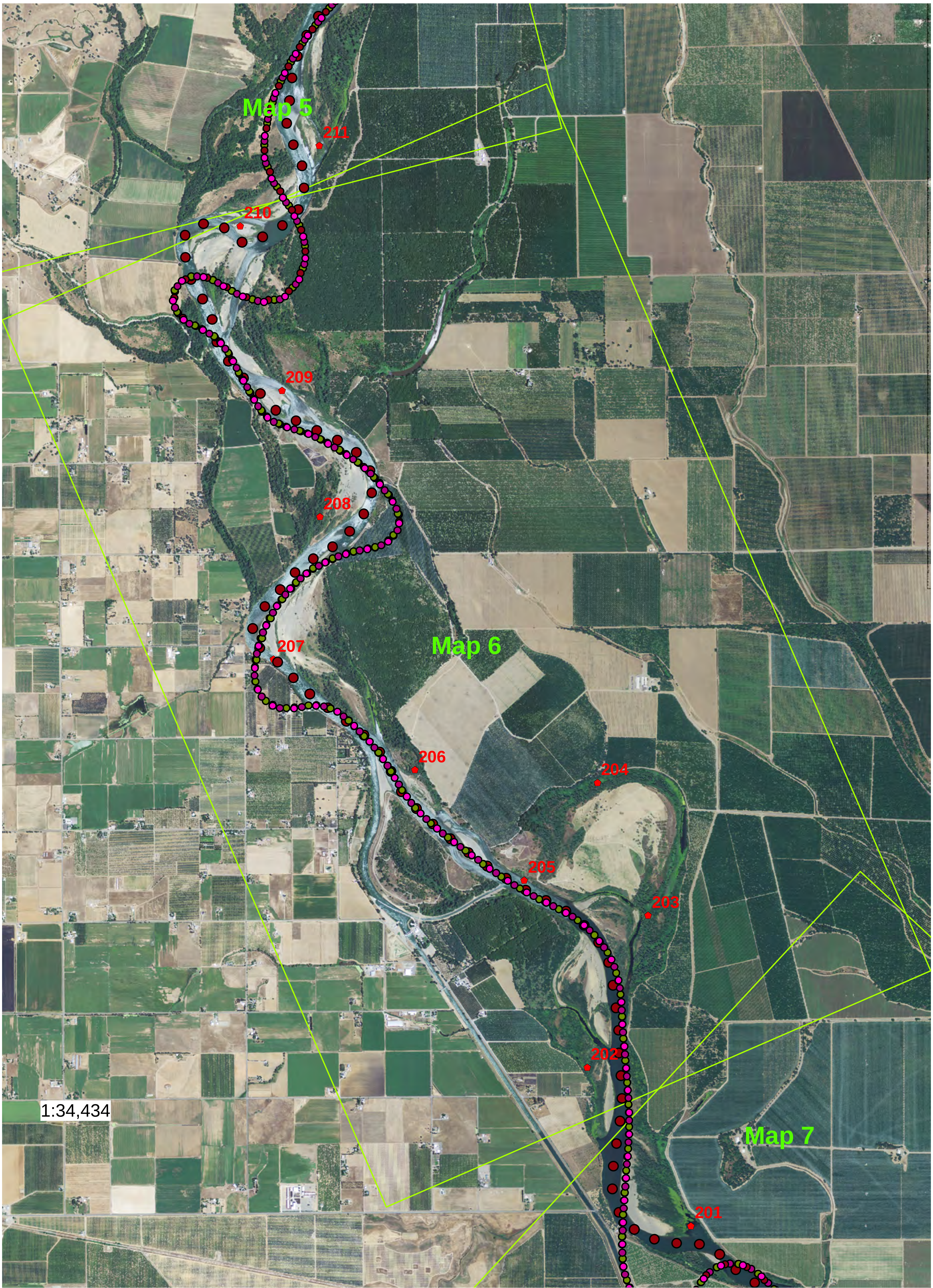

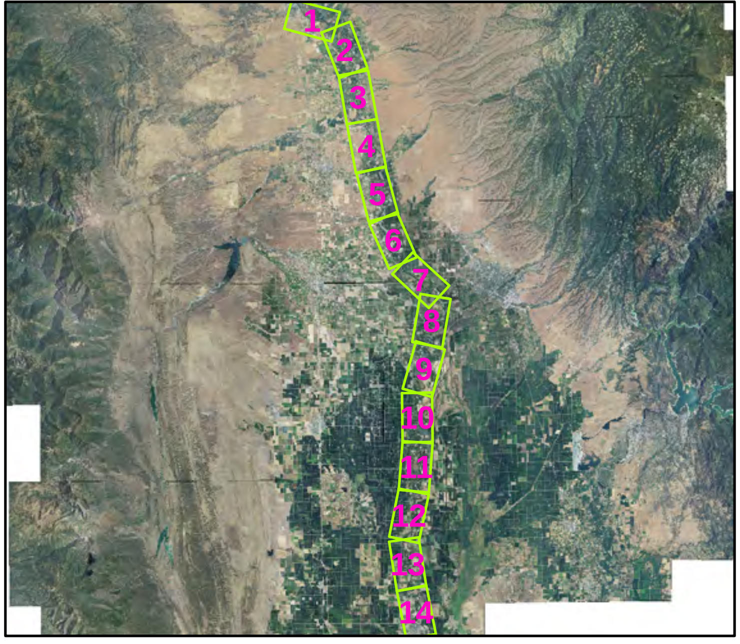

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- ● SRH_M-2030_NoAction
- ● SRall_2009_Central_Points MZ
- ⬟ River Miles

N

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Sacramento River, California
Channel Migration Predictions
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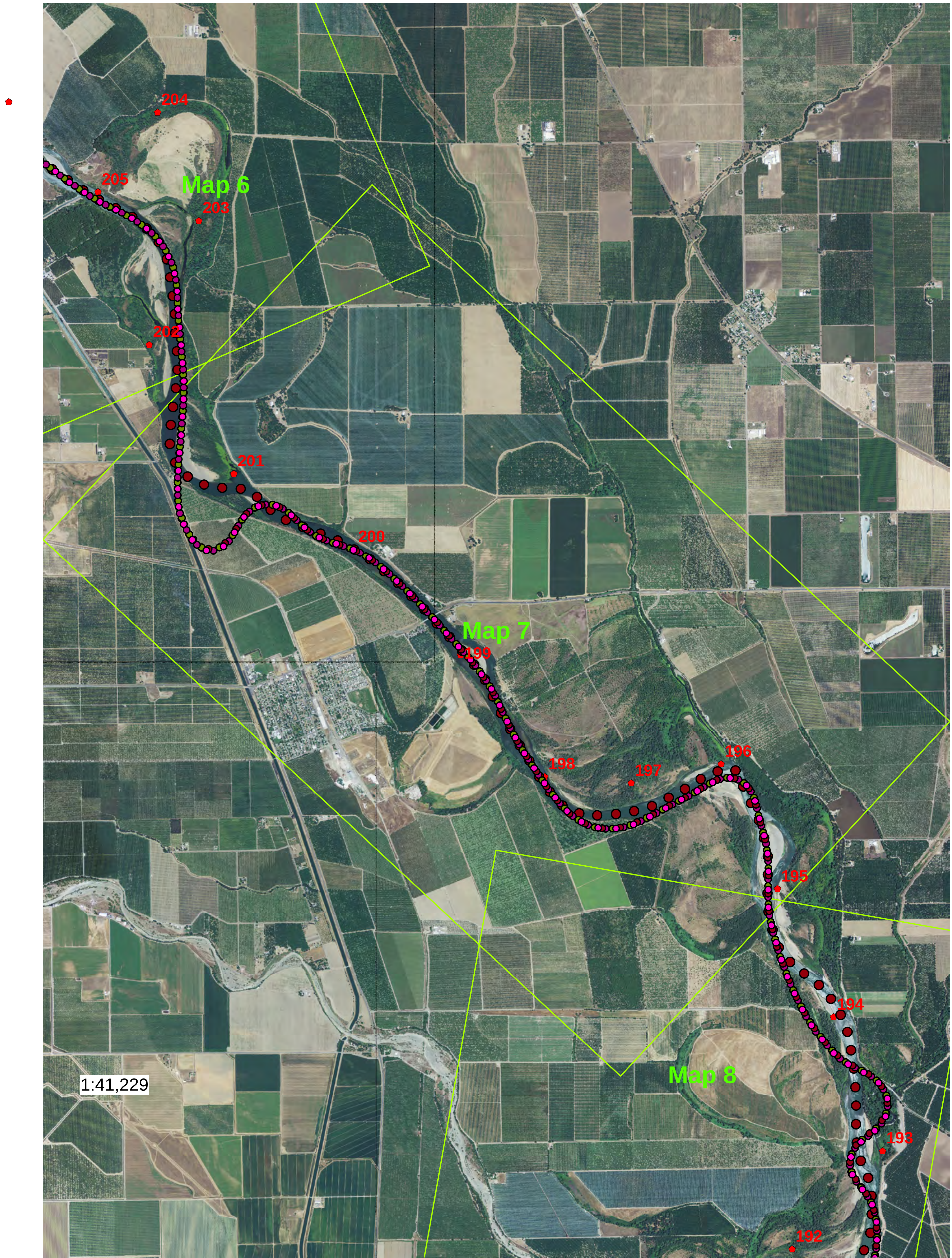
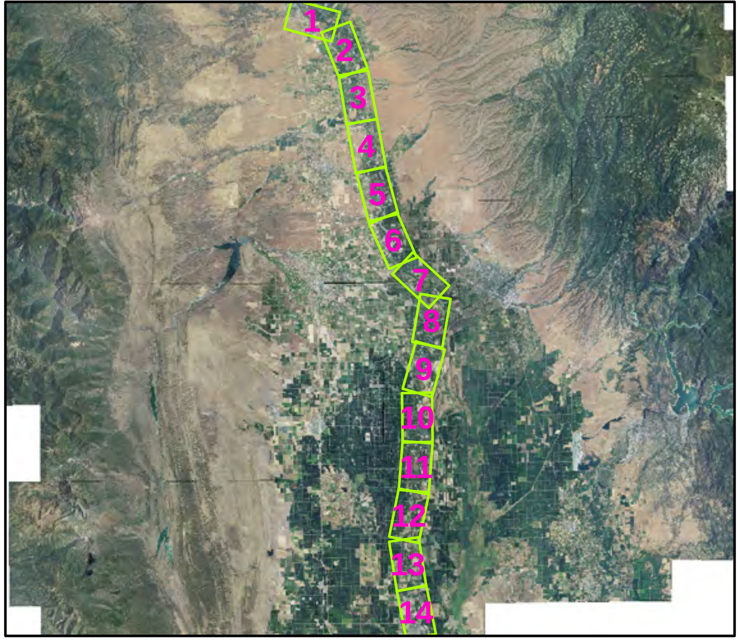
Denver, CO





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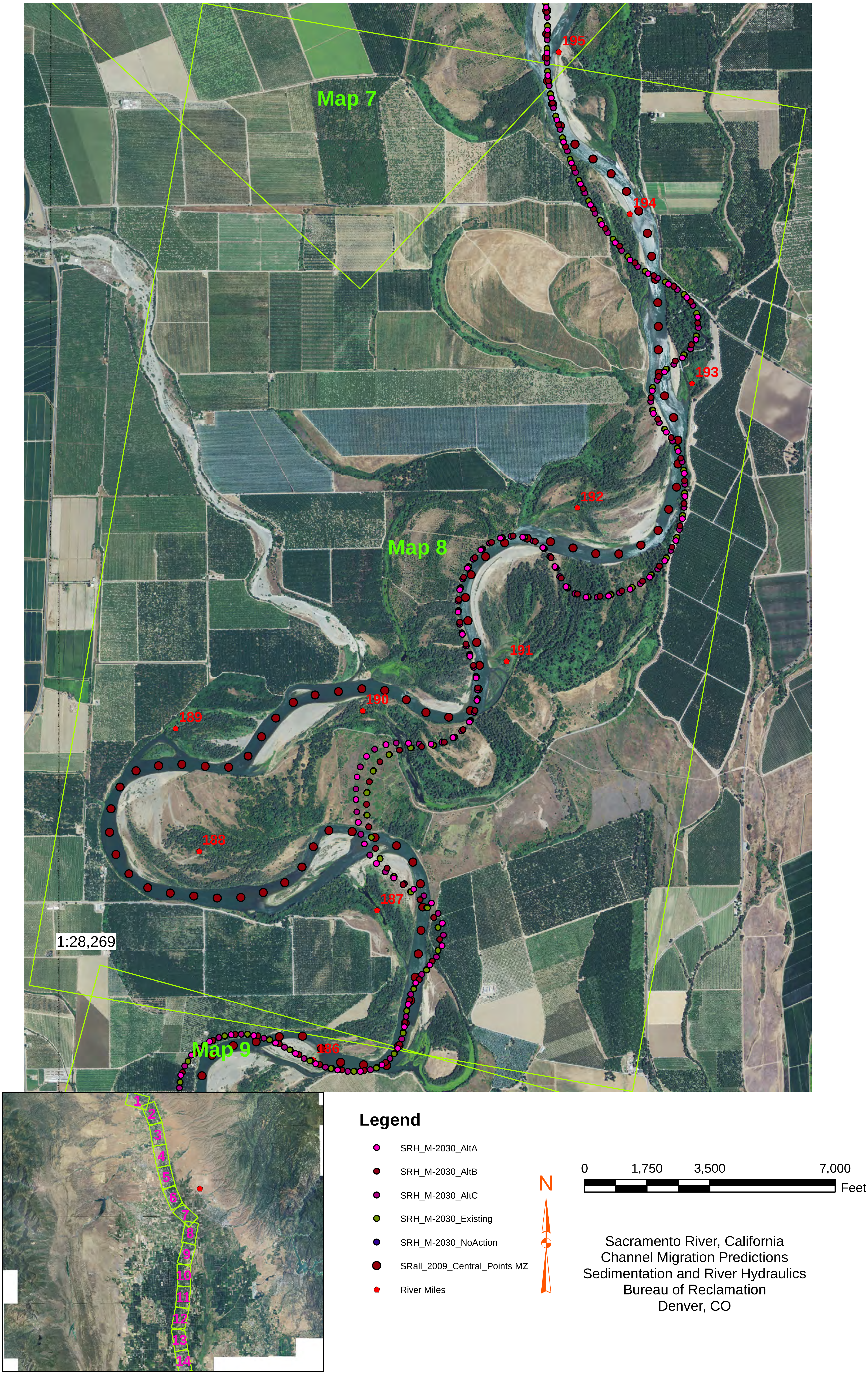
- ● SRall_2009_Central_Points MZ
- ⬟ River Miles

N

0 2,550 5,100 10,200
Feet

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO



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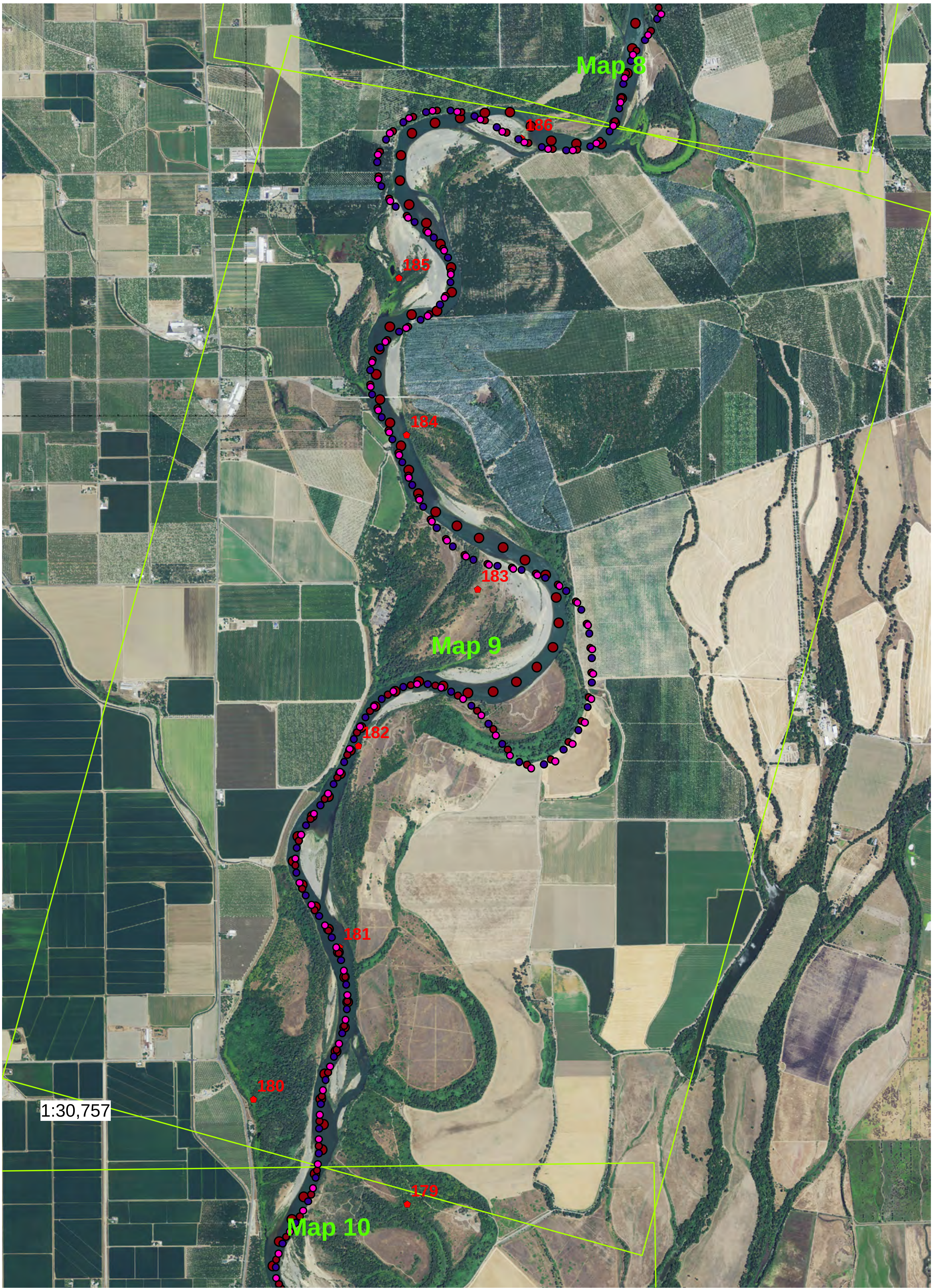

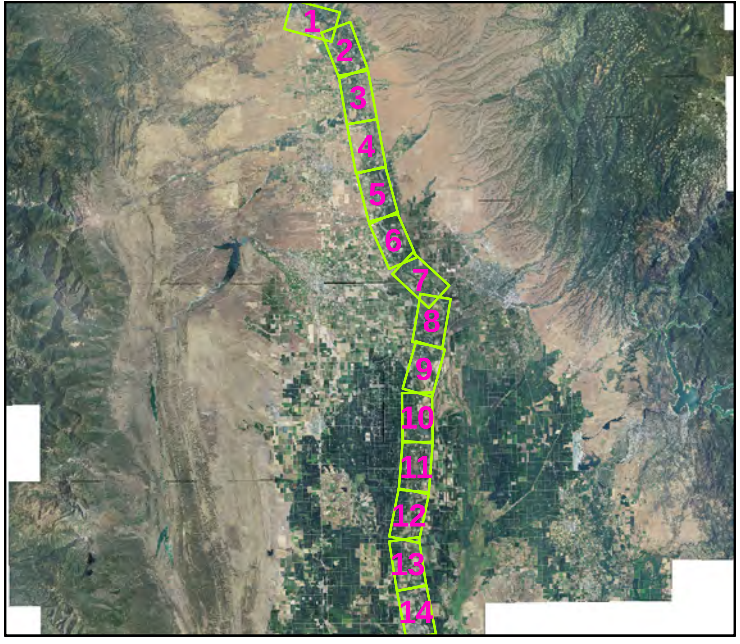

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Channel Migration Predictions
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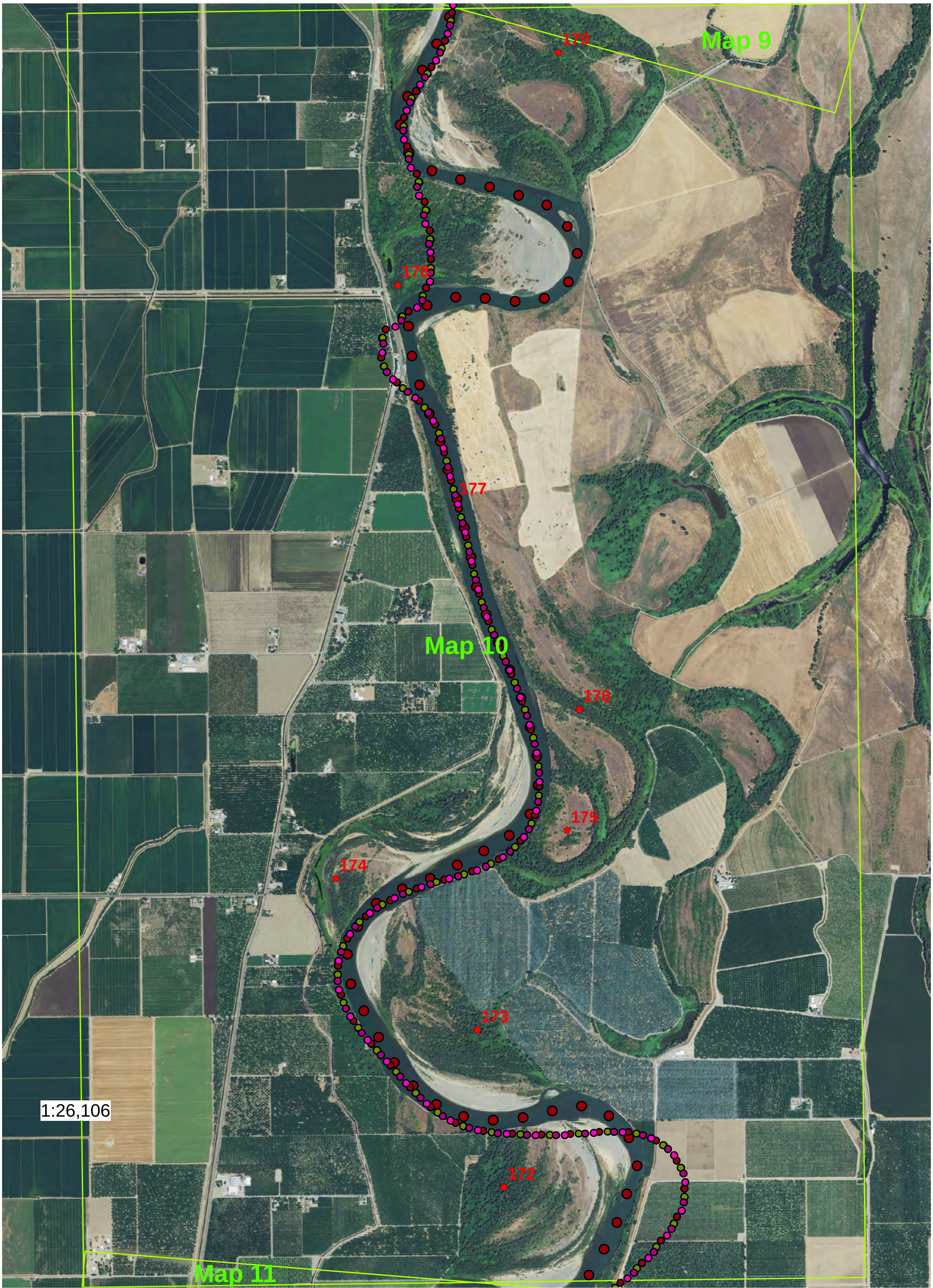

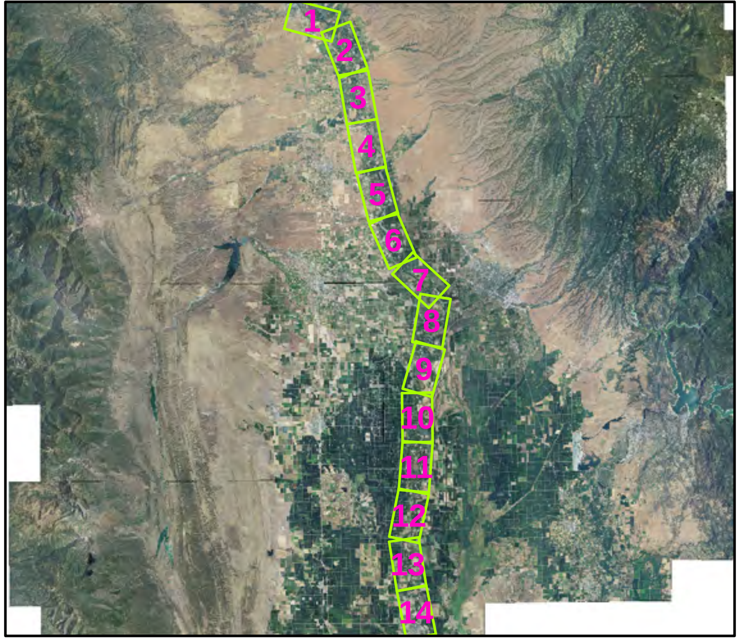

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- ● SRall_2009_Central_Points MZ
- ⬟ River Miles

N

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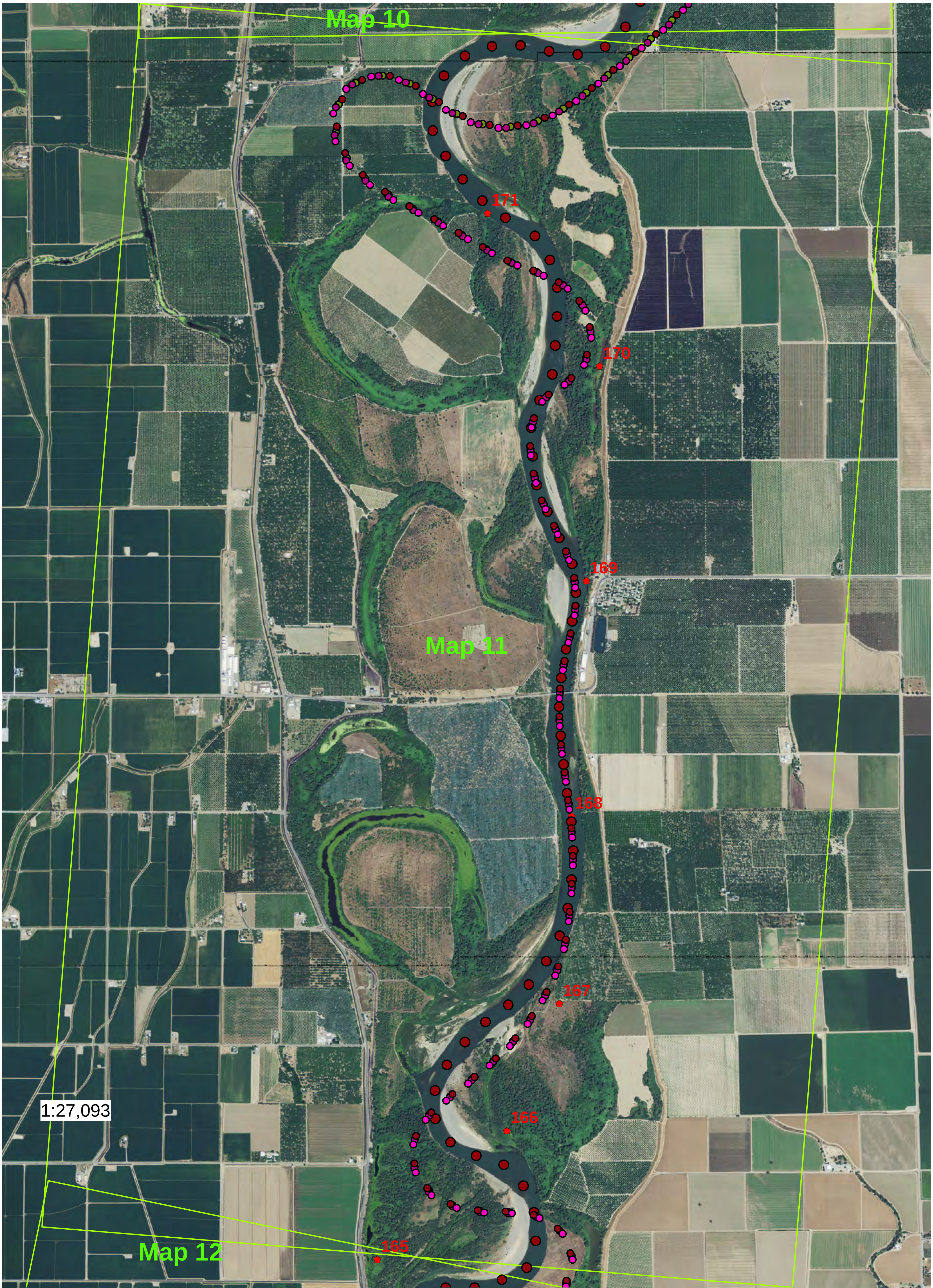
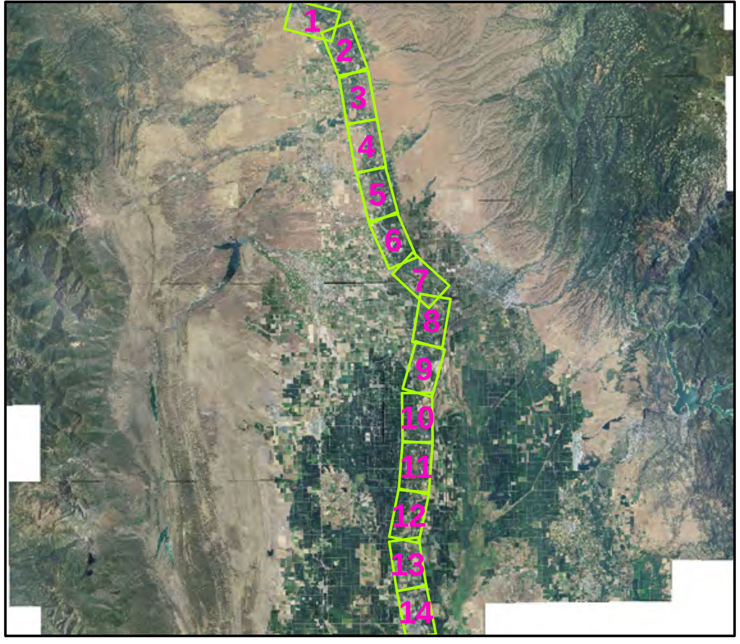
Feet

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO





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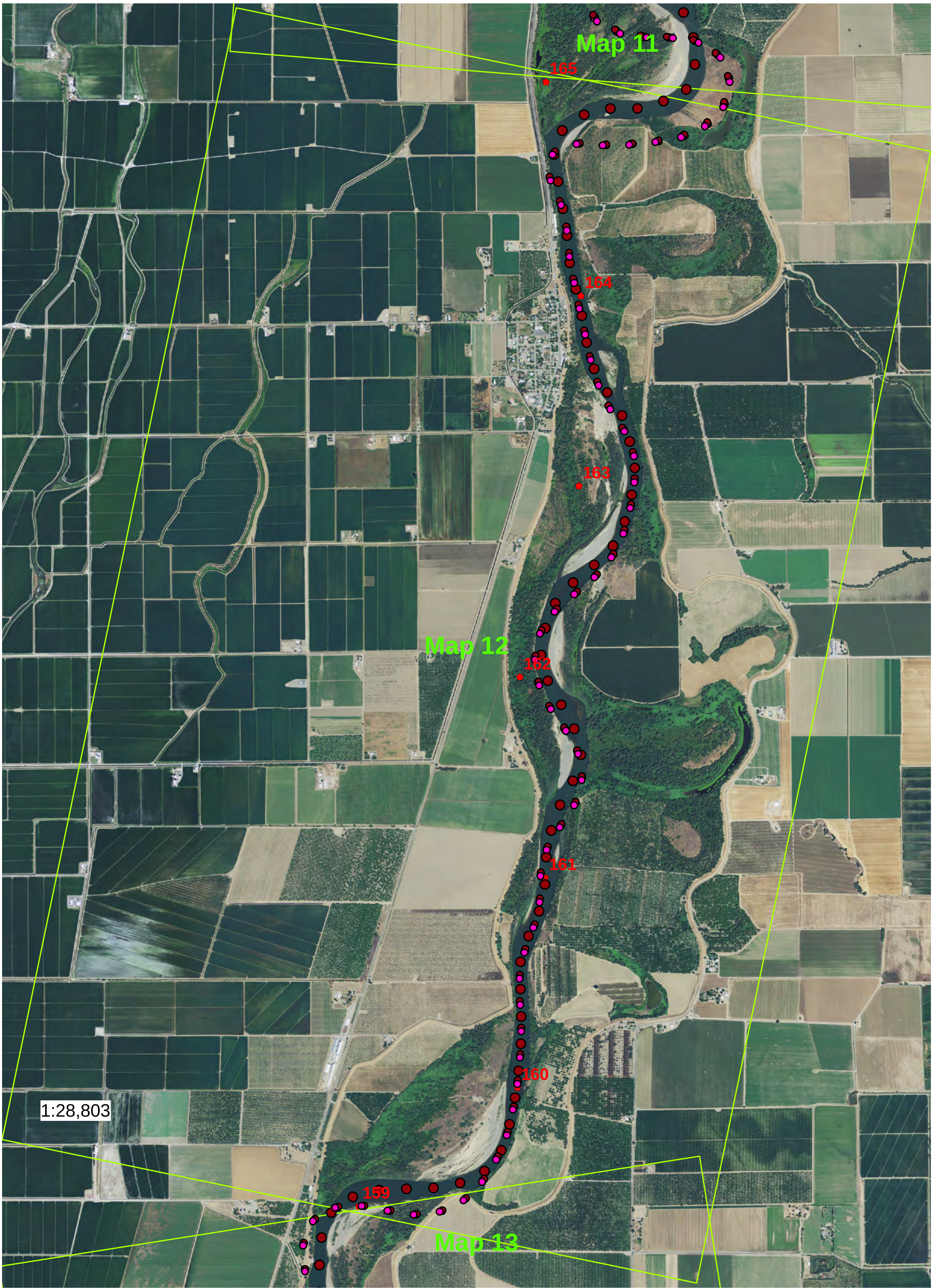
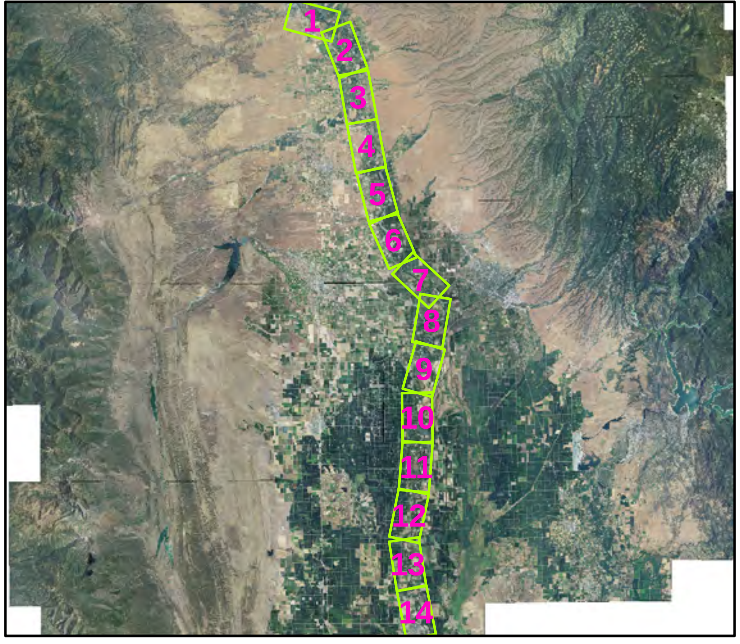
- ● SRH_M-2030_AltB
- ● SRH_M-2030_AltC
- ● SRH_M-2030_Existing
- ● SRH_M-2030_NoAction
- ● SRall_2009_Central_Points MZ
- ⬟ River Miles

N

0 1,500 3,000 6,000
Feet

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO





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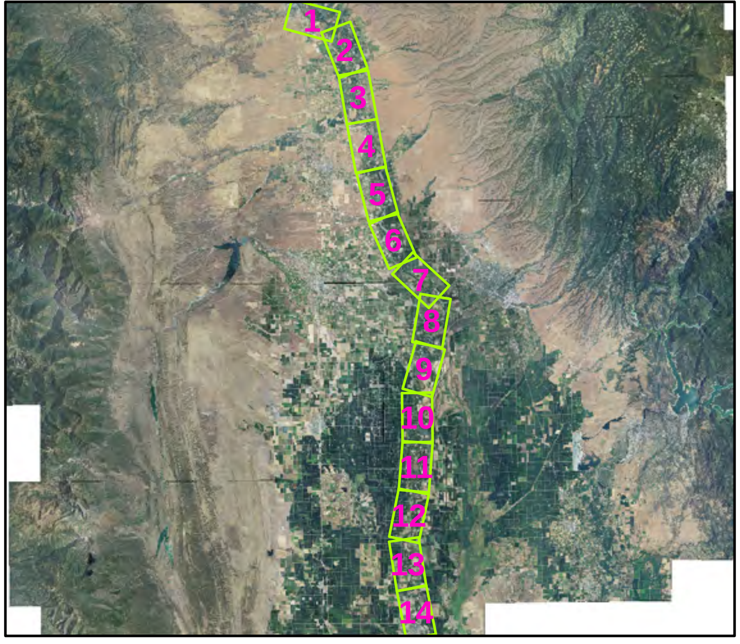
- ● SRH_M-2030_NoAction
- ● SRall_2009_Central_Points MZ
- ⬟ River Miles

N

0 1,625 3,250 6,500 Feet

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO



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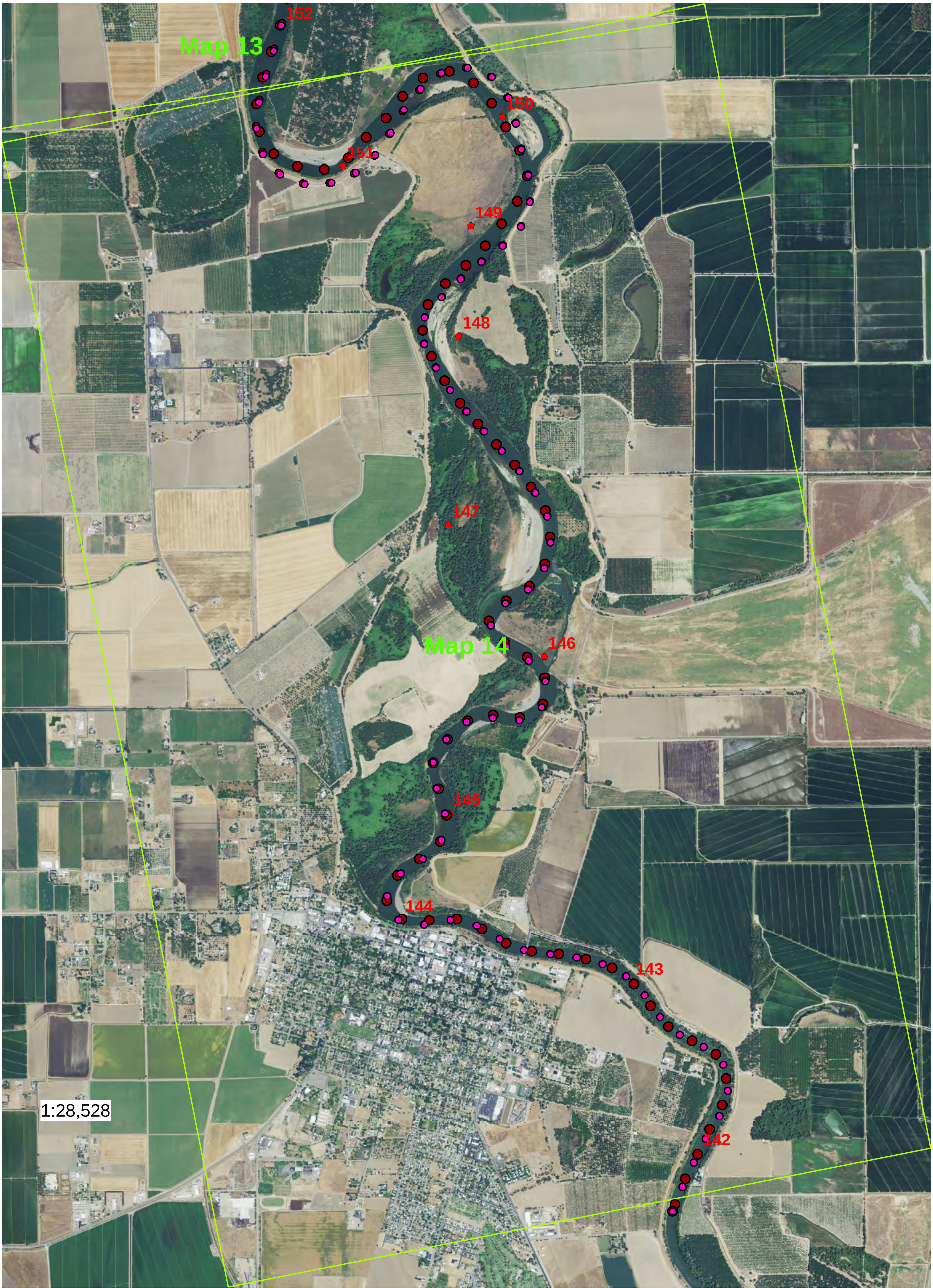
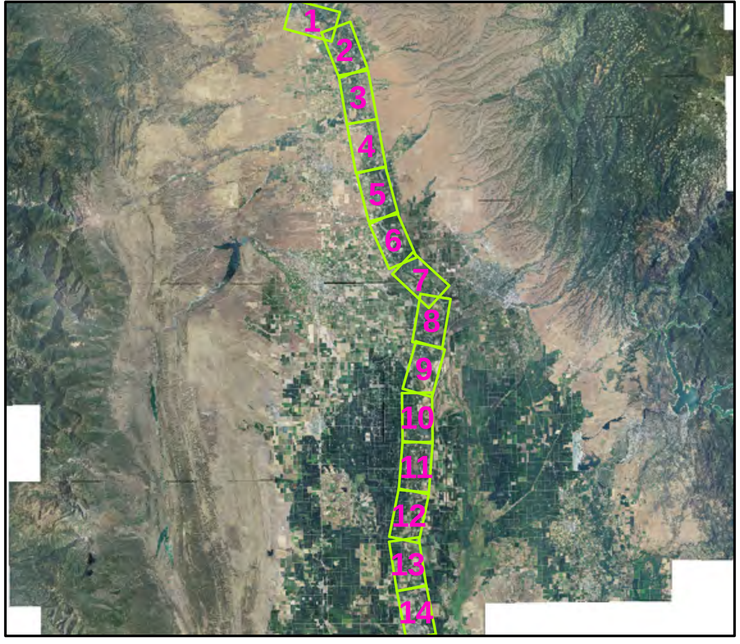
●	SRH_M-2030_AltB
●	SRH_M-2030_AltC
●	SRH_M-2030_Existing
●	SRH_M-2030_NoAction
●	SRall_2009_Central_Points MZ
⬟	River Miles

N

0 1,600 3,200 6,400
Feet

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO





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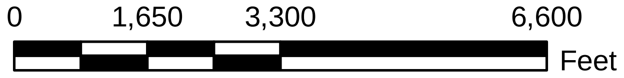
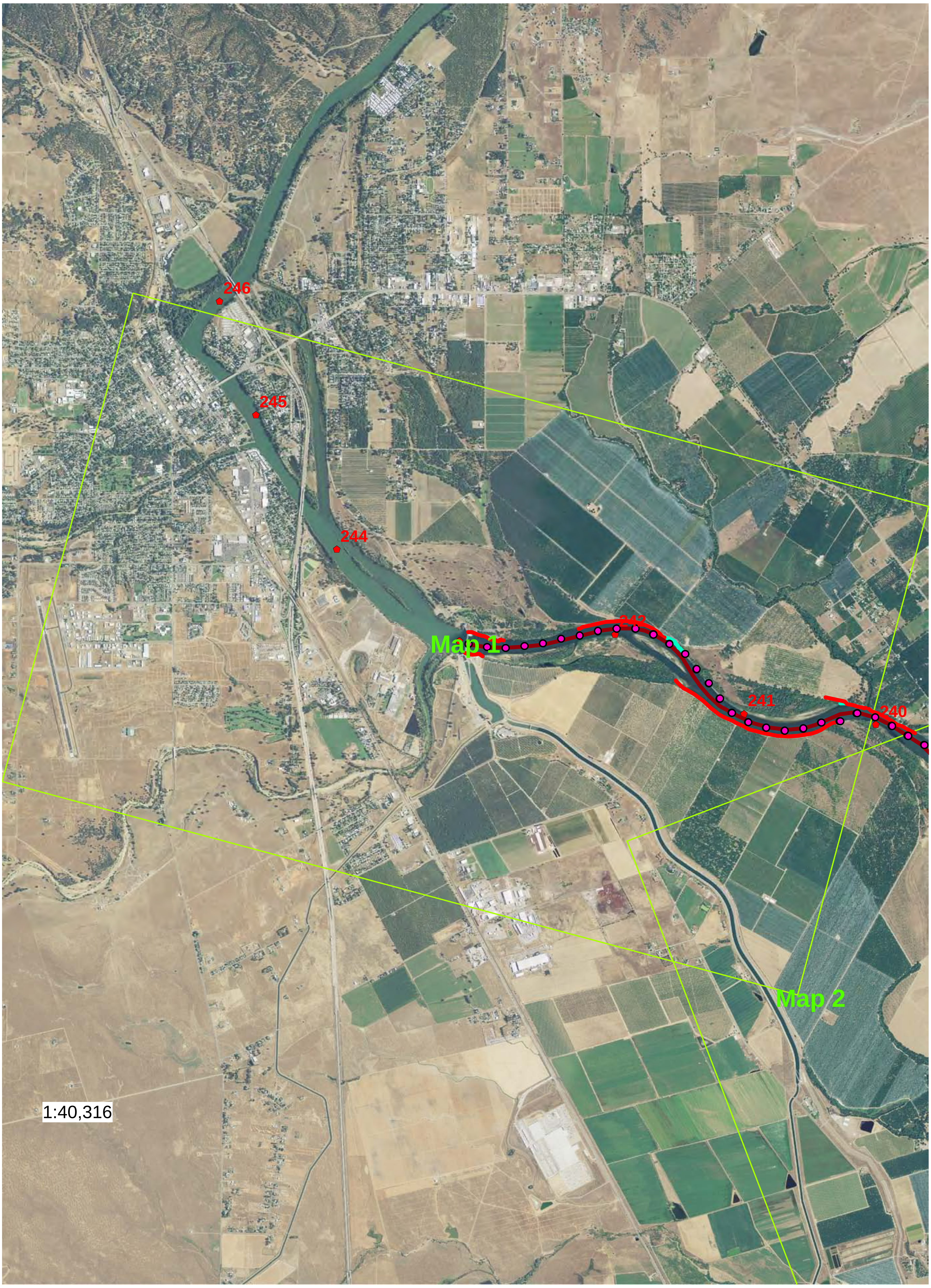
- ● SRall_2009_Central_Points MZ
- ⬟ River Miles

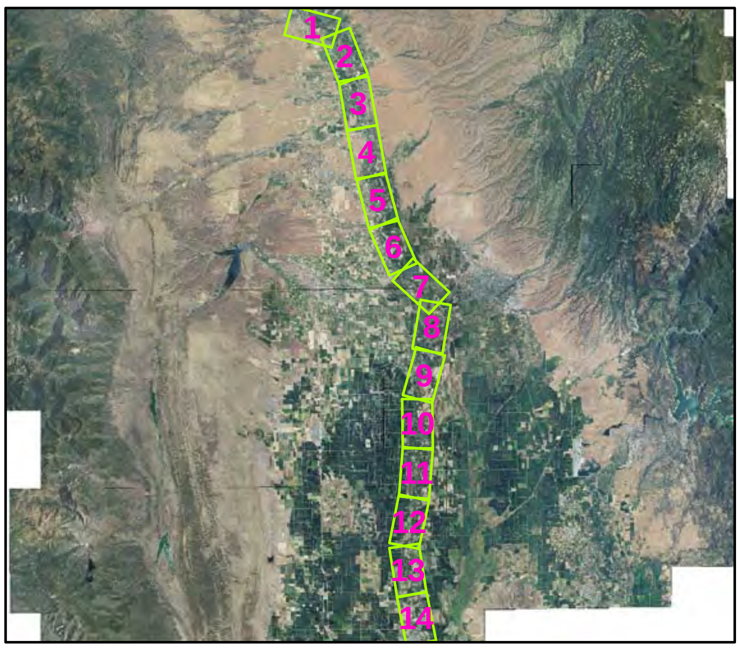
N



Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO

Appendix B





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- ● SRH_M-2030_Existing
- ● SRH_M-2030_NoAction
- ⬟ River Miles
- — Riprap
- — Geo Control

N

0 2,950 5,900 11,8

Sacramento River, California
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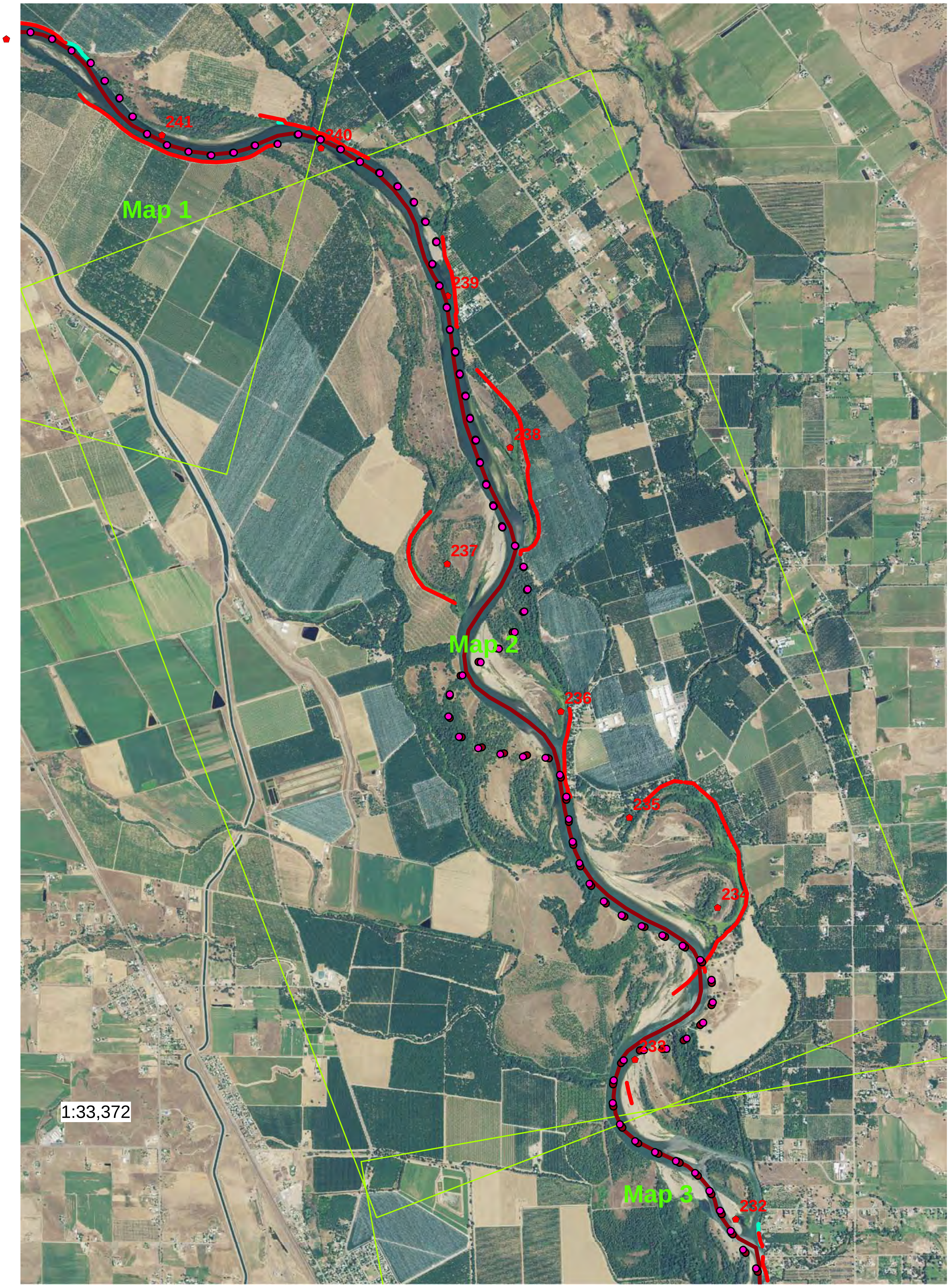

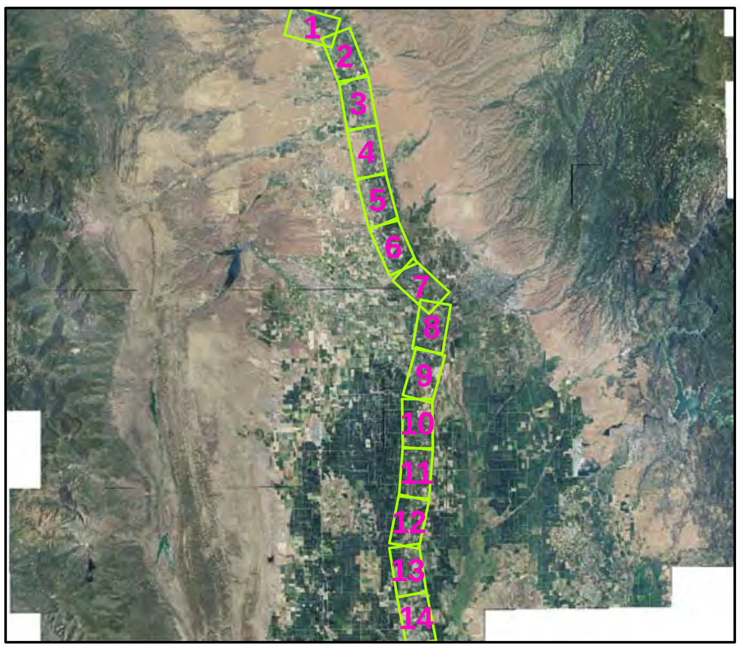

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- ● SRH_M-2030_AltC
- ● SRH_M-2030_Existing
- ● SRH_M-2030_NoAction
- ⬟ River Miles
- — Riprap
- — Geo Control

N

0 2,350 4,700 9,400 Fe

Sacramento River, California
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Sedimentation and River Hydraulics
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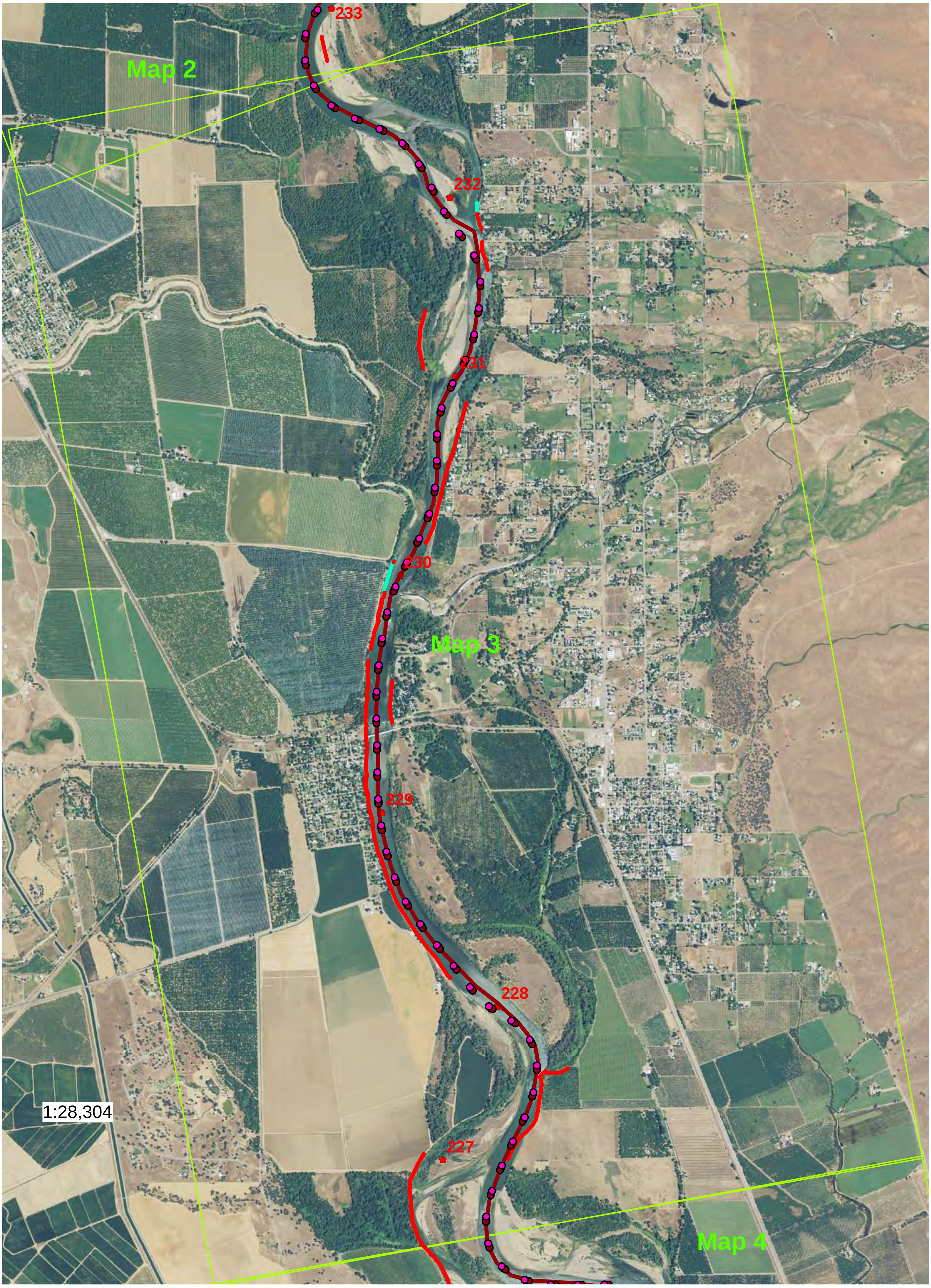

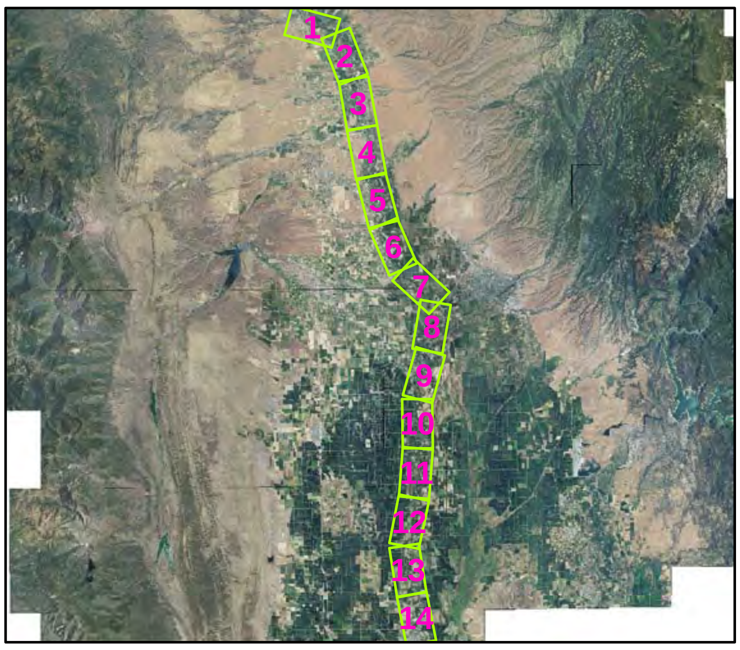

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- ● SRH_M-2030_AltC
- ● SRH_M-2030_Existing
- ● SRH_M-2030_NoAction
- ⬟ River Miles
- — Riprap
- — Geo Control

N

0 2,000 4,000 8,000 Fe

Sacramento River, California
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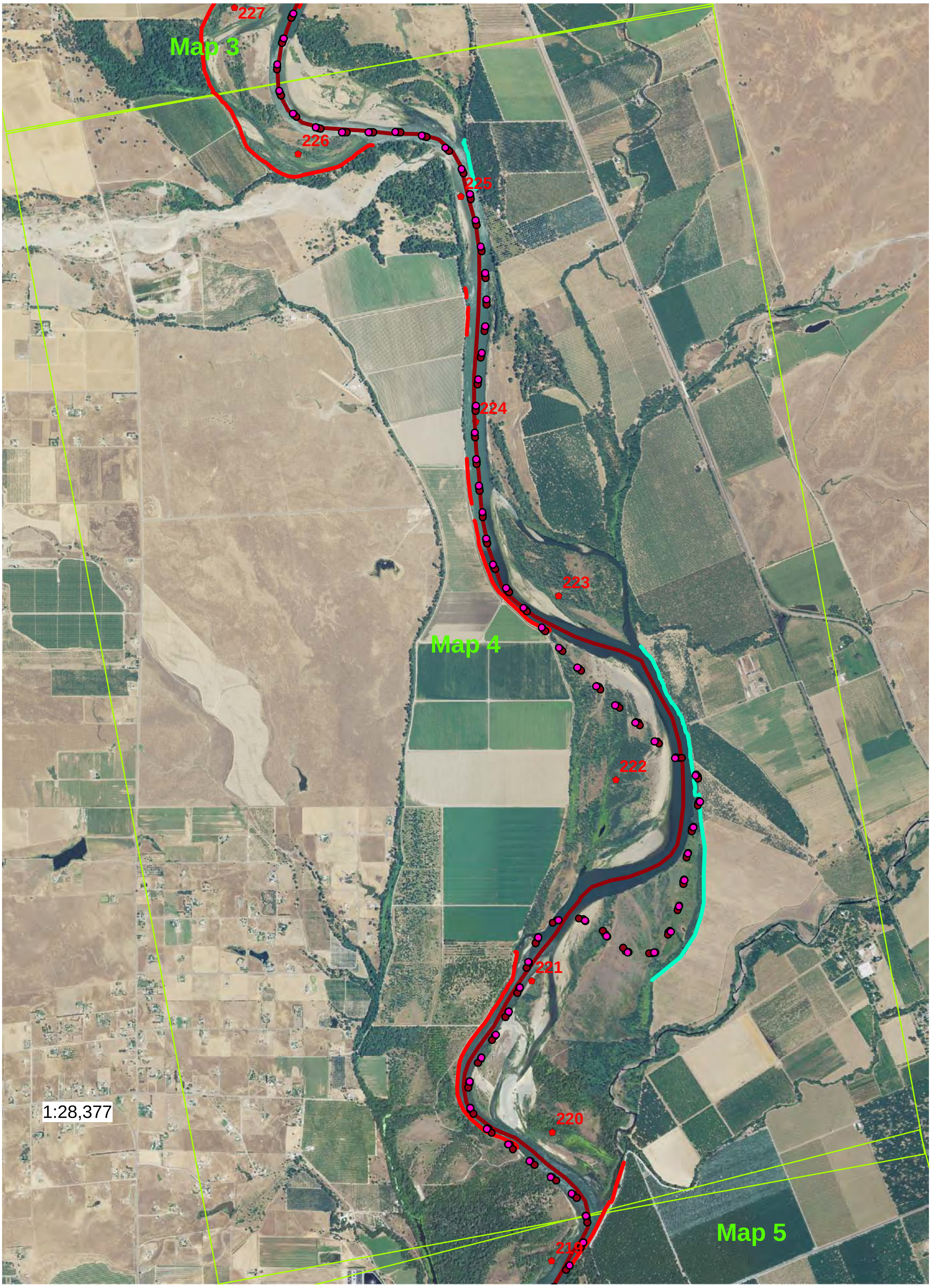

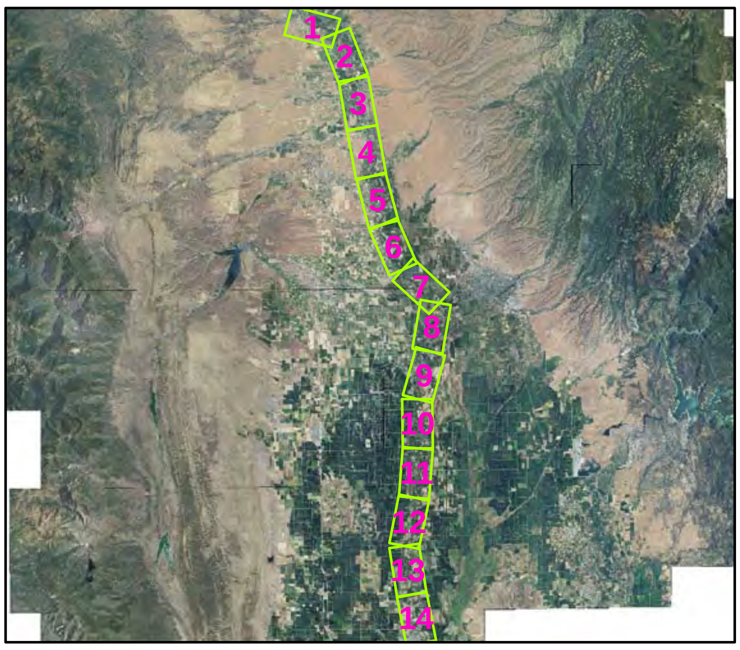

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- ● SRH_M-2030_AltC
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- ● SRH_M-2030_NoAction
- ⬟ River Miles
- — Riprap
- — Geo Control

N

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
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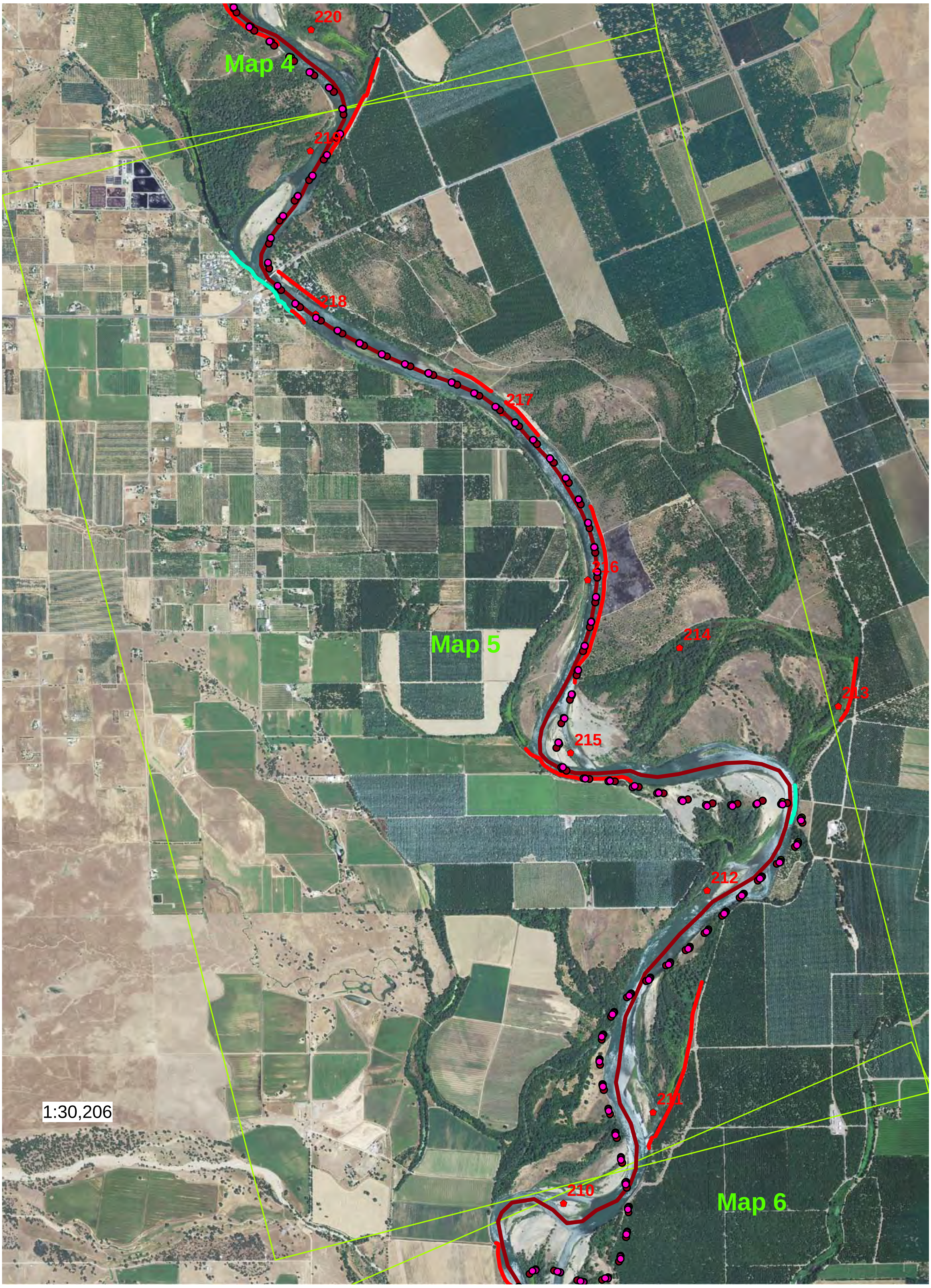

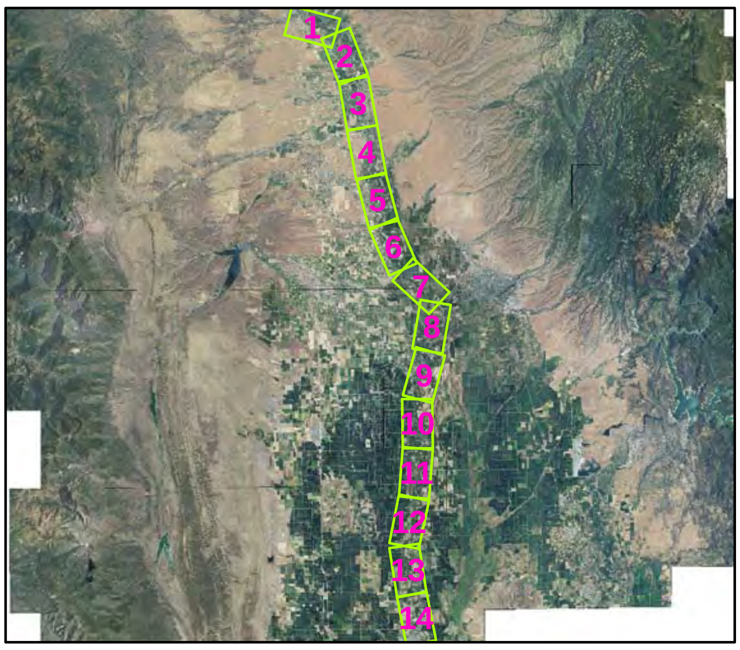

Legend

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- ● SRH_M-2030_AltC
- ● SRH_M-2030_Existing
- ● SRH_M-2030_NoAction
- ⬟ River Miles
- — Riprap
- — Geo Control

N

0 2,150 4,300 8,600 Fe

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
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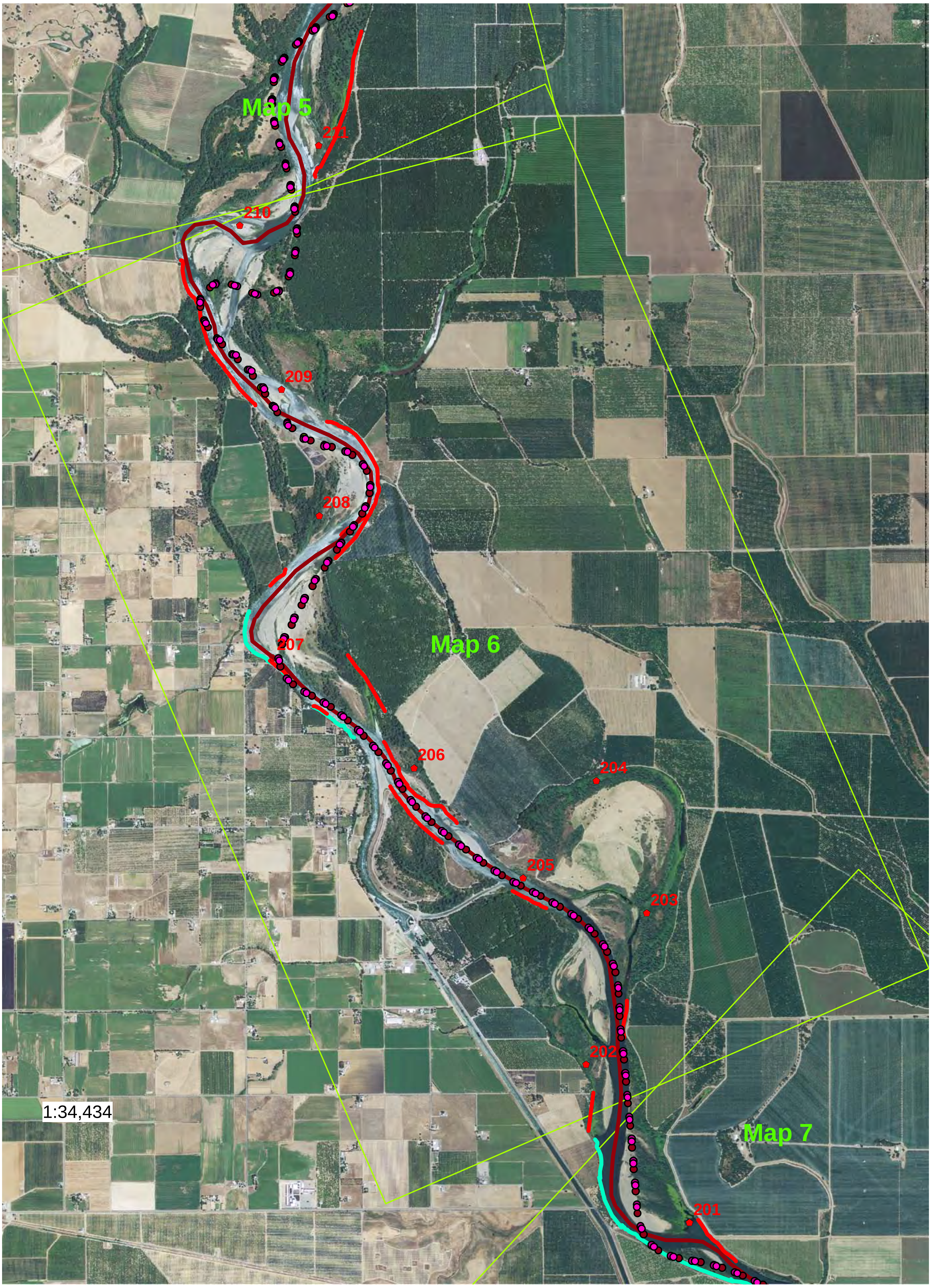

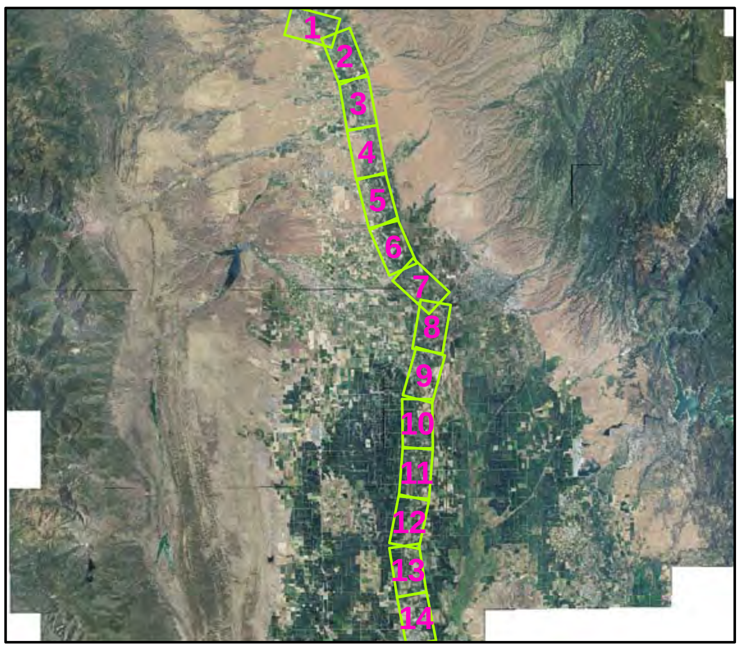

Legend

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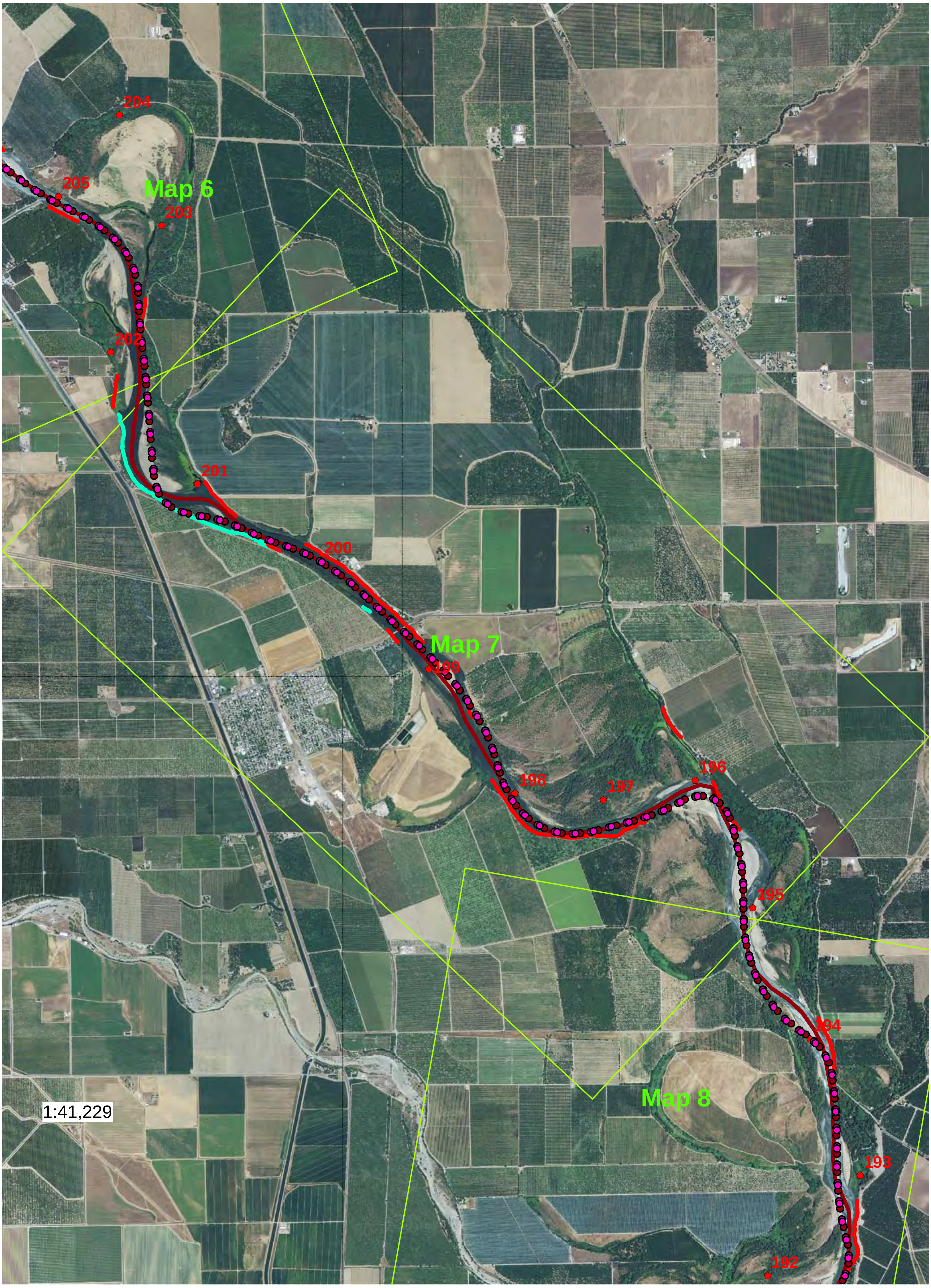
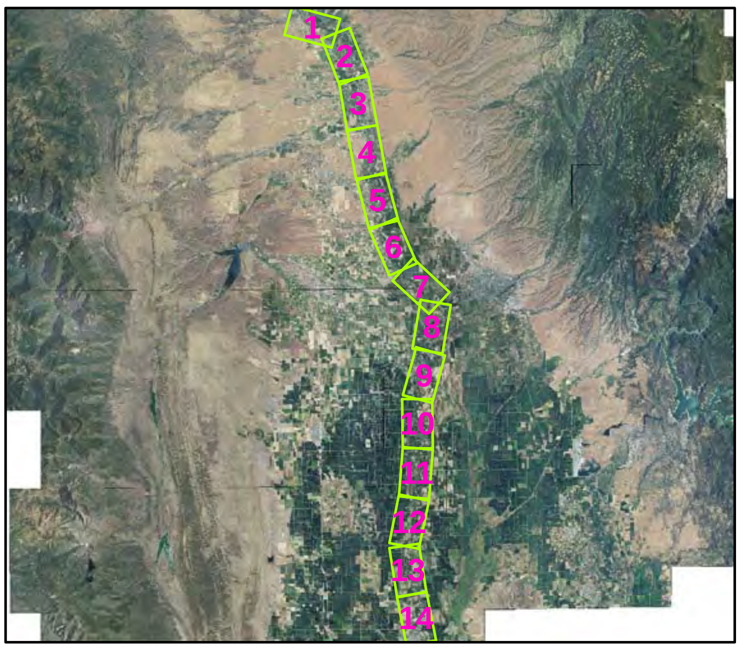
- ● SRH_M-2030_AltB
- ● SRH_M-2030_AltC
- ● SRH_M-2030_Existing
- ● SRH_M-2030_NoAction
- ⬟ River Miles
- ━ Riprap
- ━ Geo Control

N

0 2,450 4,900 9,800 Fe

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO





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●	SRH_M-2030_AltB
●	SRH_M-2030_AltC
●	SRH_M-2030_Existing
●	SRH_M-2030_NoAction
⬟	River Miles
—	Riprap
—	Geo Control

N

0 2,950 5,900 11,80

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
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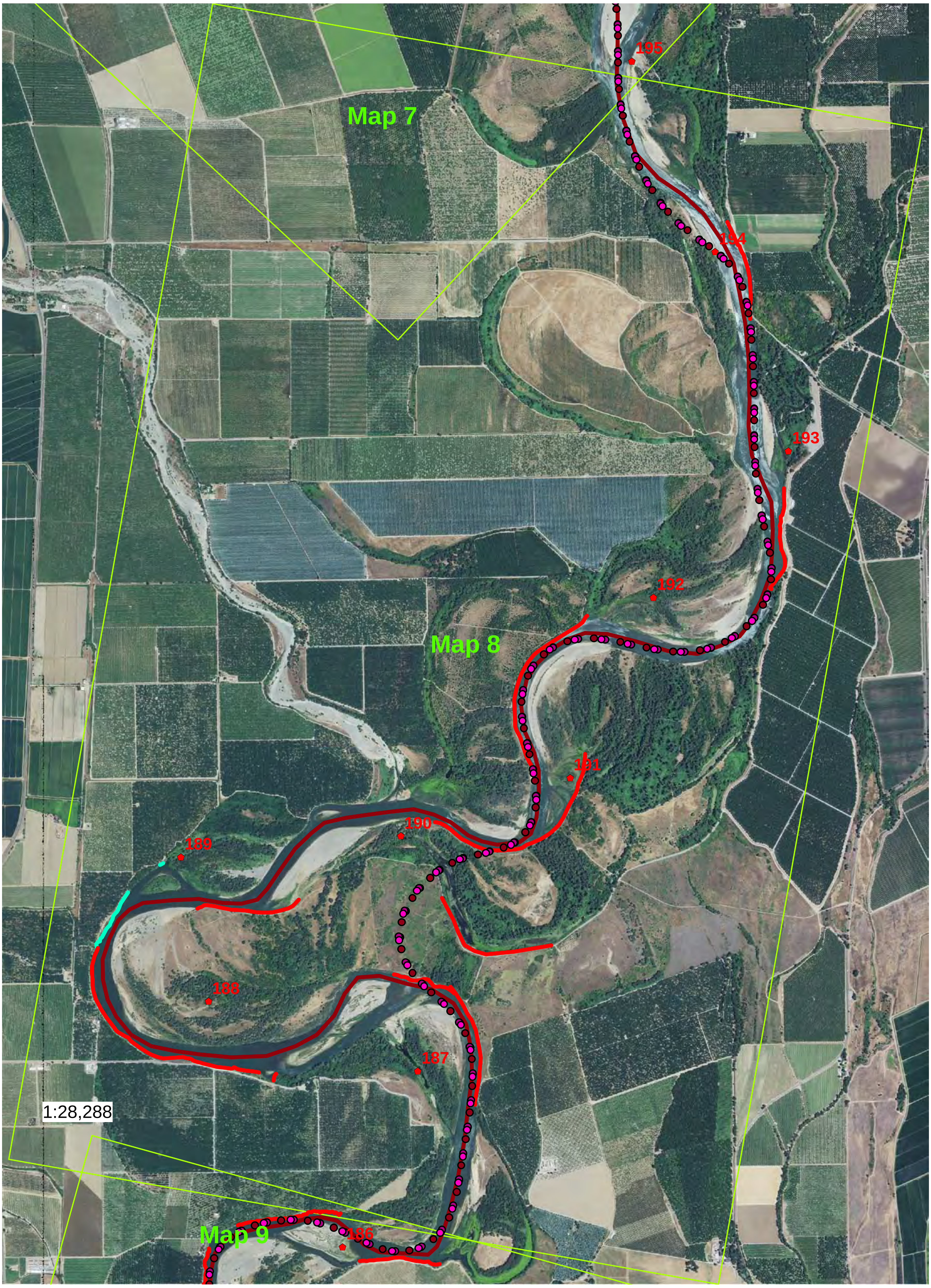

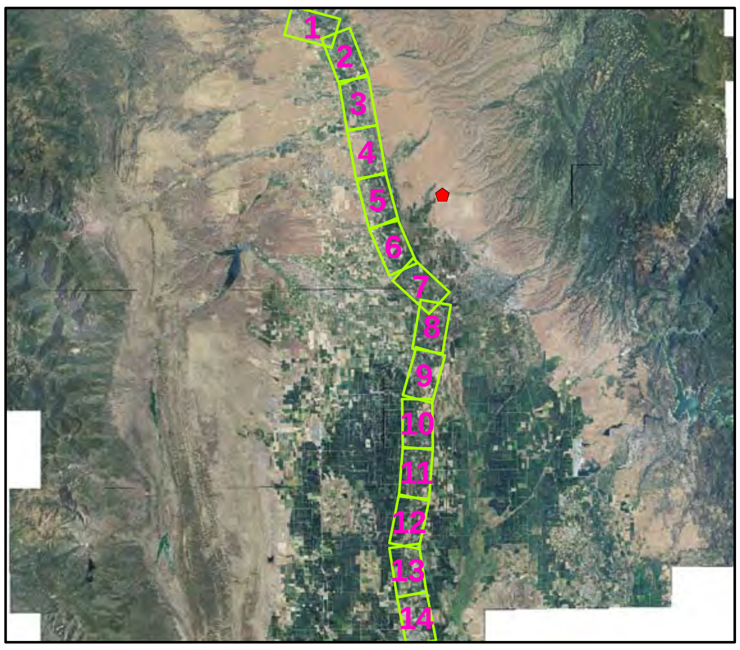

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- ⬟ River Miles
- ▬ Riprap
- ▬ Geo Control

N

Sacramento River, California
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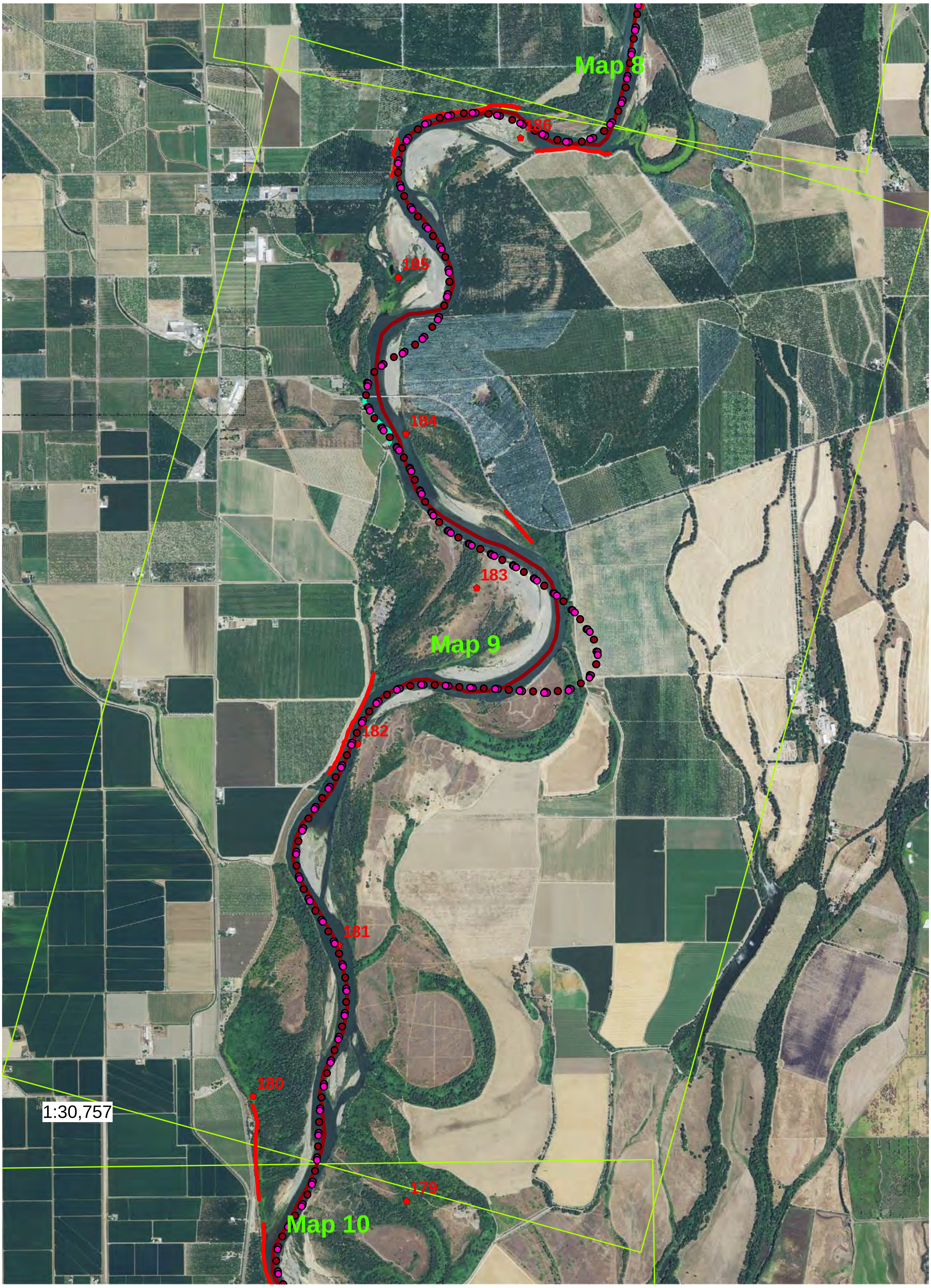

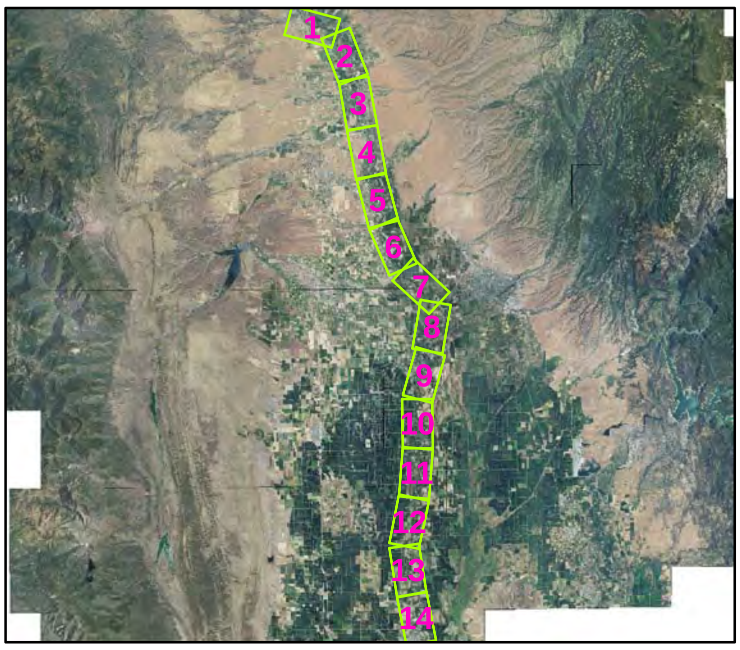

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- ● SRH_M-2030_Existing
- ● SRH_M-2030_NoAction
- ⬟ River Miles
- ━ Riprap
- ━ Geo Control

N

0 2,250 4,500 9,0

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
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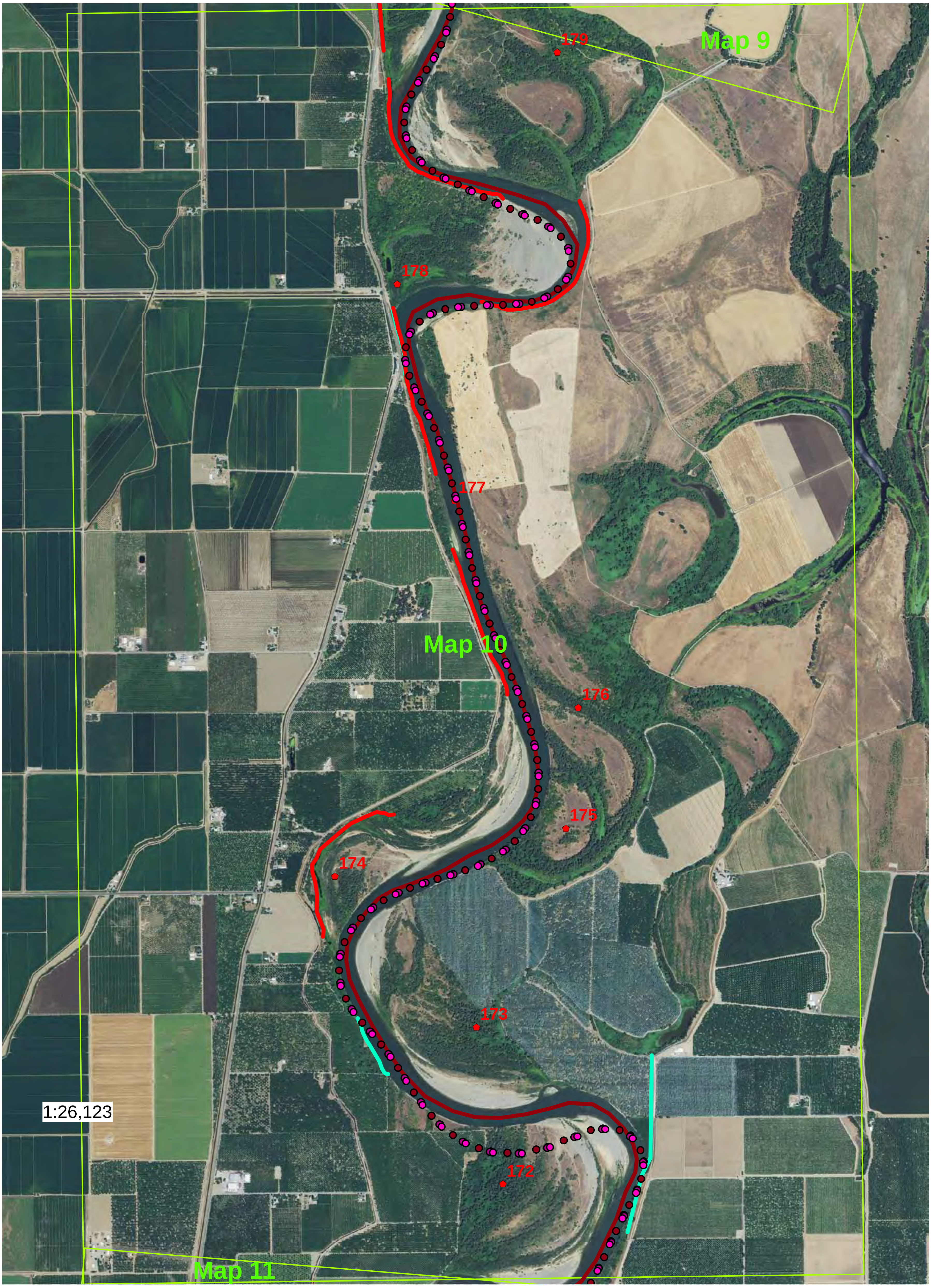

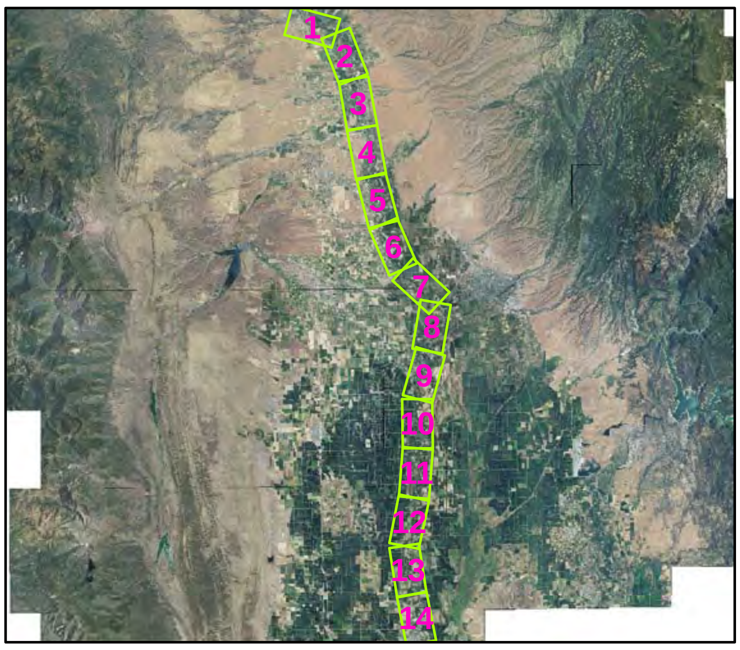

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- ● SRH_M-2030_NoAction
- ⬟ River Miles
- ━ Riprap
- ━ Geo Control

N

0 1,750 3,500 7,000 Feet

Sacramento River, California
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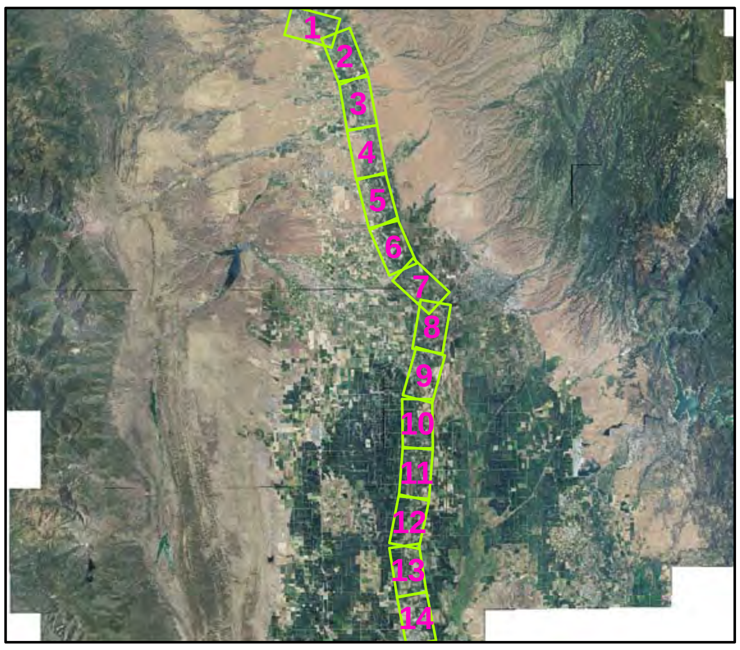

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- ● SRH_M-2030_NoAction
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- ━ Riprap
- ━ Geo Control

N

0 1,850 3,700 7,400 Feet

Sacramento River, California
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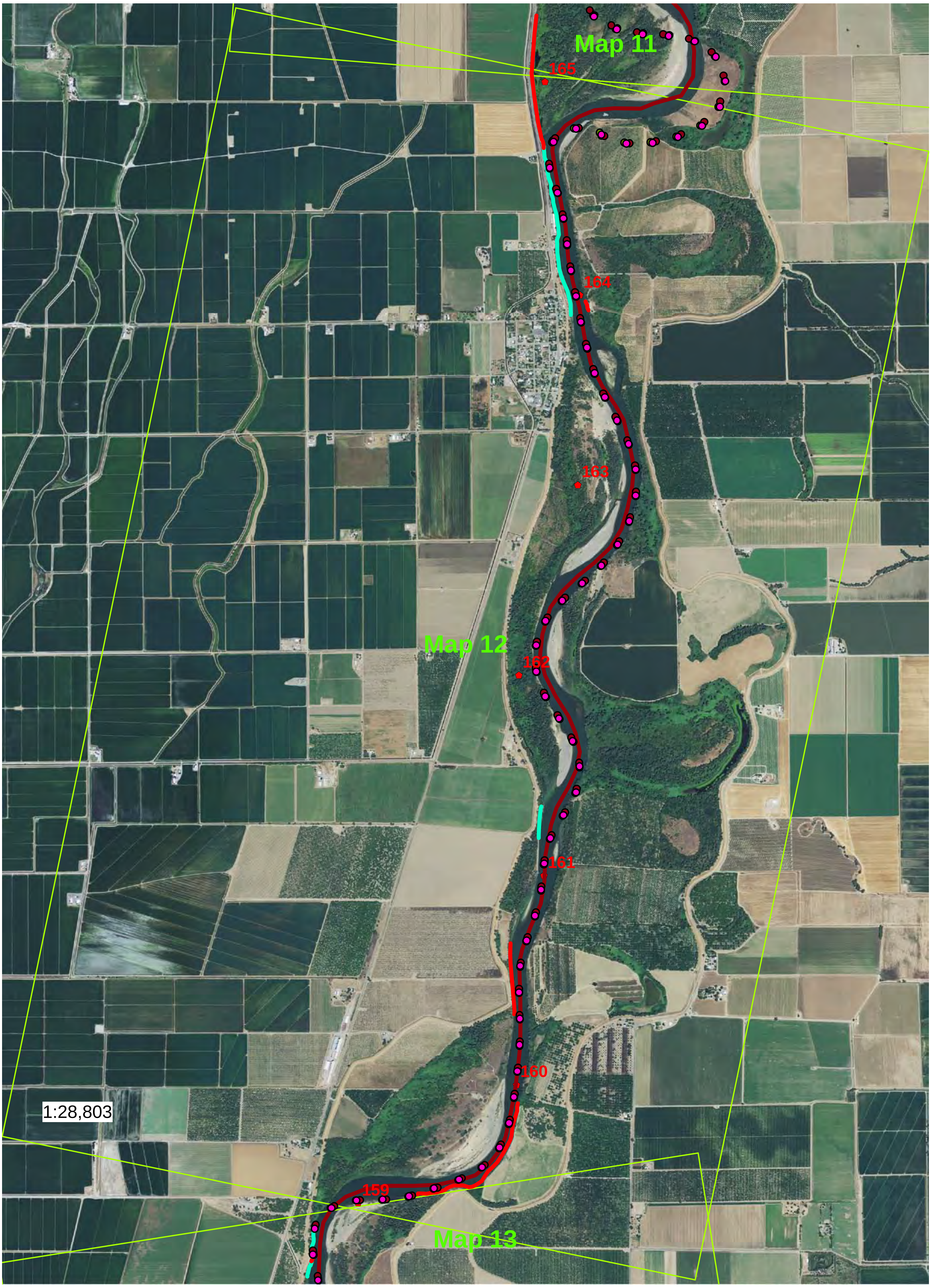

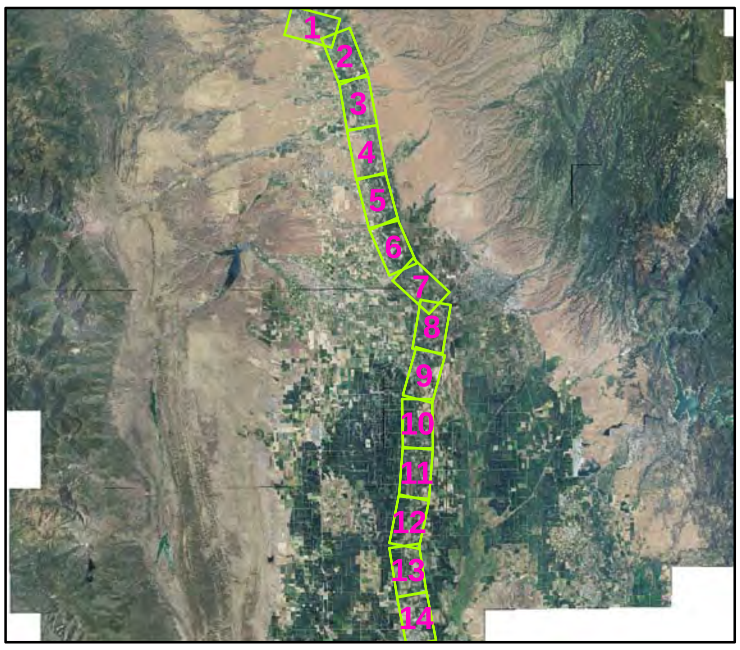

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- ● SRH_M-2030_NoAction
- ● River Miles
- — Riprap
- — Geo Control

Sacramento River, California
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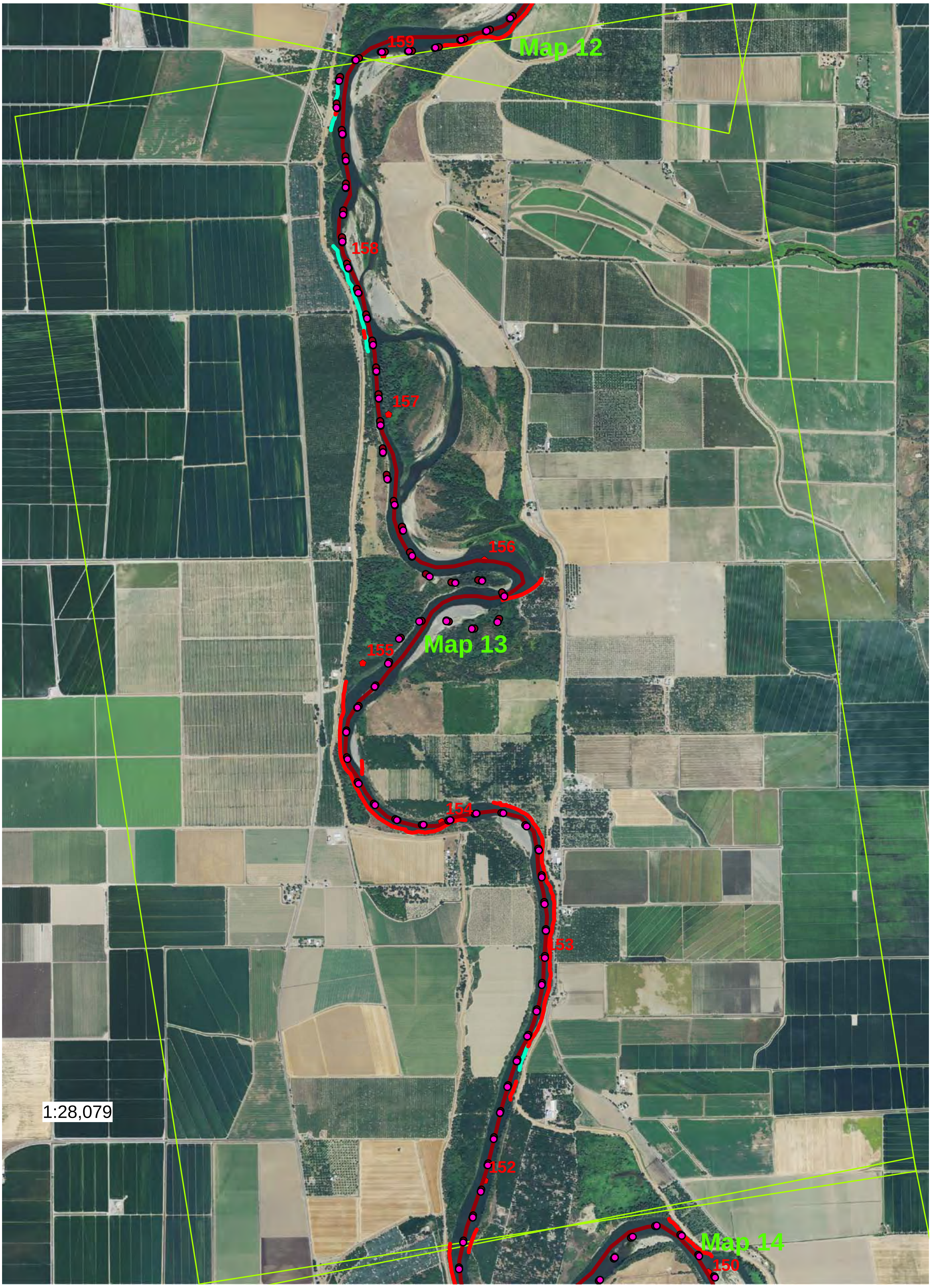

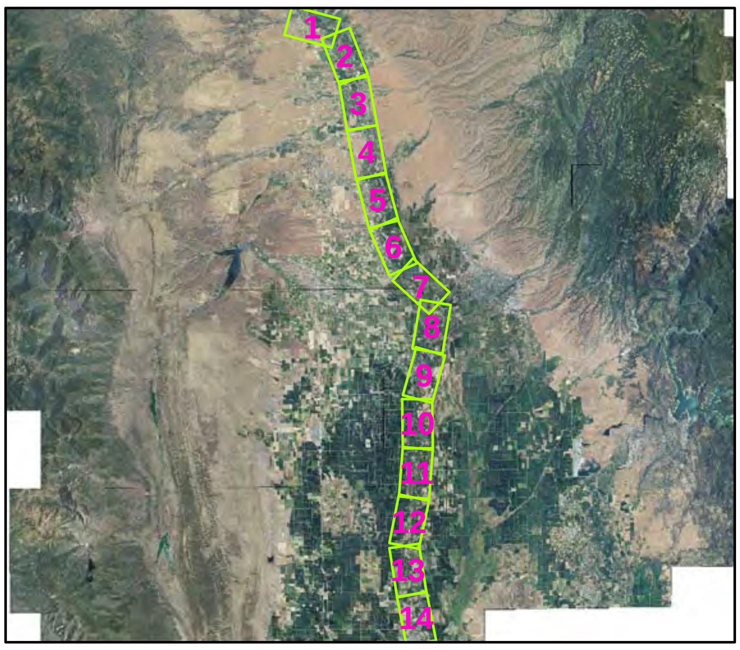

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- ● SRH_M-2030_NoAction
- ⬟ River Miles
- ▬ Riprap
- ▬ Geo Control

N

0 1,950 3,900 7,800
Fee

Sacramento River, California
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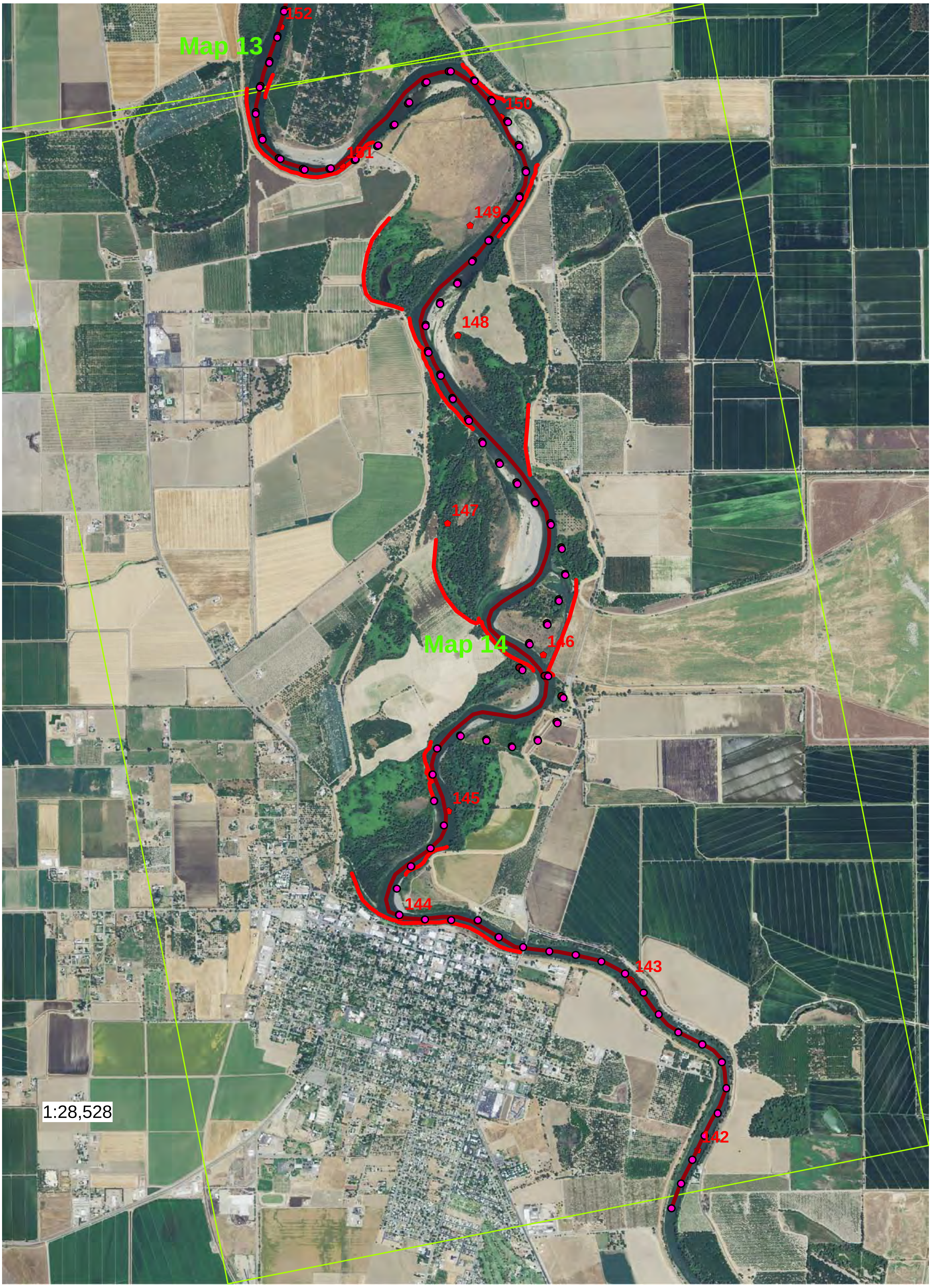

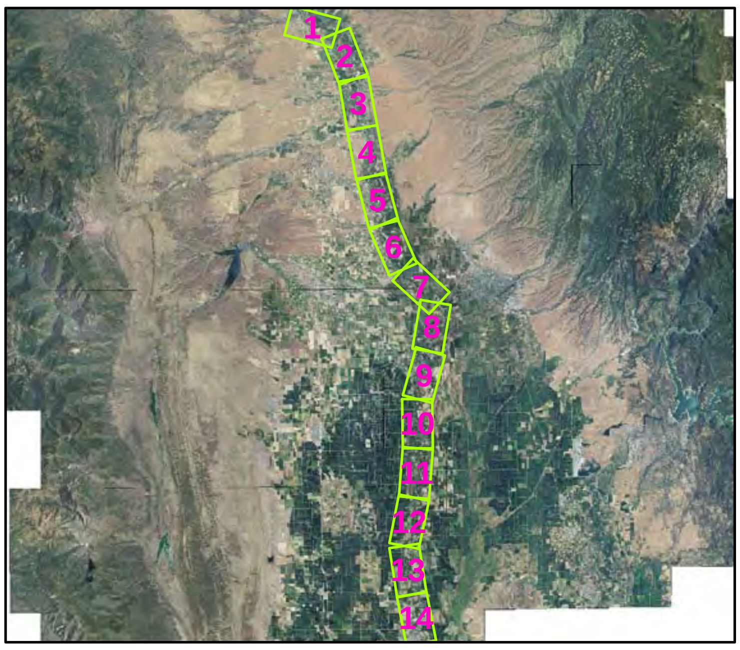

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- ● SRH_M-2030_Existing
- ● SRH_M-2030_NoAction
- ⬟ River Miles
- — Riprap
- — Geo Control

N

0 2,000 4,000 8,000
Fe

Sacramento River, California
Channel Migration Predictions
Sedimentation and River Hydraulics
Bureau of Reclamation
Denver, CO

Sacramento Sediment Loads at NODOS Diversions

RECLAMATION
Managing Water in the West

Technical Report No. SRH-2011-22

Sediment Loads at Tehama-Colusa, Glen-Colusa, and Delevan Diversions

Mid Pacific Region
NODOS Investigation Report

U.S. Department of the Interior
Bureau of Reclamation
June 2011

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation’s natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

Technical Report No. SRH-2011-22

Sediment Loads at Tehama-Colusa, Glen-Colusa, and Delevan Diversions

Mid Pacific Region
NODOS Investigation Report

Prepared by:

Jianchun Huang 7-11-11
Jianchun Victor Huang, Ph.D., P.E. Date
Visiting Hydraulic Engineer, Sedimentation and River Hydraulics Group, 86-68240
Research Scientist, Department of Civil Engineering, Colorado State University

7-11-11
Blair Greimann, Ph.D., P.E. Date
Hydraulic Engineer
Sedimentation and River Hydraulics Group, 86-68240

Report Reviewed by:

Mike Sixta 7/11/11
Mike Sixta, M.S., P.E. Date
Hydraulic Engineer
Sedimentation and River Hydraulics Group, 86-68240

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The current Tehama-Colusa (TC) Canal, Glenn-Colusa (GC) Canal, and the proposed New Delevan Pipeline will be used to convey water to the proposed Sites Reservoir. The TC Canal accepts water from the Red Bluff Pumping Plant at RM 243.0. The GC accepts water from the Glen-Colusa Irrigation District Diversion at RM 206.2. The New Delevan Pipeline will be a new diversion point for the proposed Sites Reservoir and will be located near Colusa at RM 158.5. This report estimates the sedimentation loads diverted into these three canals under the alternatives defined in the North-of-the-Delta Off-stream Storage (NODOS) Administrative Draft Environmental Impact Report/Study (ADEIR/S) and Feasibility Study (FS). Daily stream flows and diversions under the alternatives were developed by CH2MILL (2011) and these were defined as:

- Existing Conditions (Existing)
- No Action Alternative (NoAction)
- NODOS Alternative A (AltA)
- NODOS Alternative B (AltB)
- NODOS Alternative C (AltC)

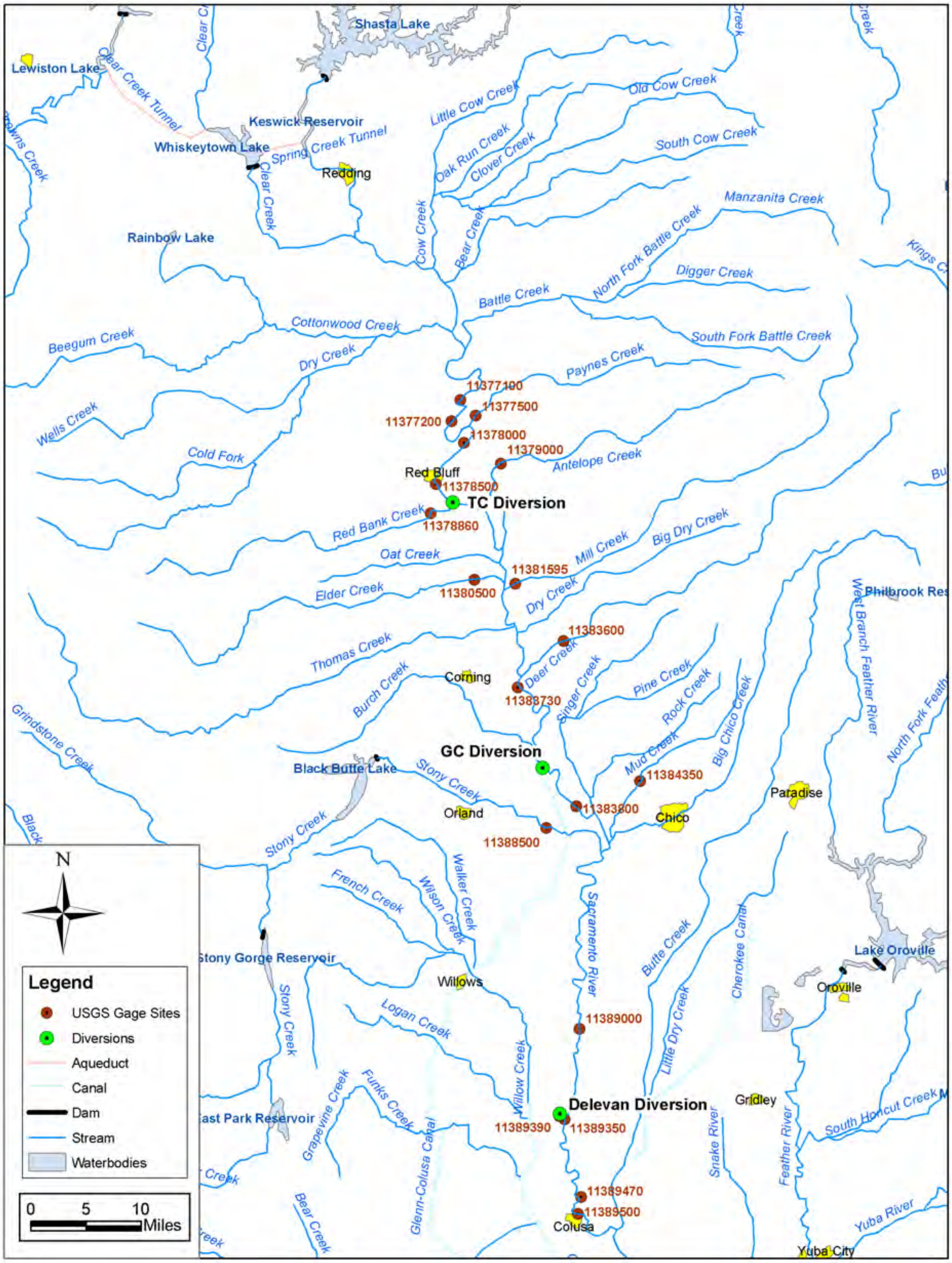

Figure 1-1. Site map of the Sacramento River between Red Bluff and Colusa.

2 Sediment Loads

2.1 Suspended Sediment Data

A total of eight US Geological Survey (USGS) gages are located in the study area, of which, seven provided sediment data for the study. The locations along with the USGS gage numbers are shown in Table 2-1. The periods of suspended sediment collection are listed in Table 2-2.

Table 2-1. USGS gage descriptions and locations in the study area.

Gage #	Description	Latitude	Longitude
11377100	SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA	-122.186664	40.288488
11377200	SACRAMENTO R AT BEND BRIDGE NR RED BLUFF CA	-122.223054	40.264043
11378500	SACRAMENTO R A RED BLUFF CA	-122.181663	40.231822
11383730	SACRAMENTO R A VINA BRIDGE NR VINA CA	-122.093041	39.909324
11383800	SACRAMENTO R NR HAMILTON CITY CA	-121.995535	39.751548
11389000	SACRAMENTO R A BUTTE CITY CA	-121.994141	39.457662
11389390	SACRAMENTO R OPPOSITE MOULTON WEIR CA	-122.031086	39.343220
11389500	SACRAMENTO R A COLUSA CA	-122.000250	39.214056

Table 2-2. Location of USGS Suspended Sediment Gages and sample collection periods.

Gage #	River Mile	Sample collection period	Used for diversion
11377100	RM 260.2	1977-1983, 1996-2000	TC Canal at Red Bluff (RM 243.0)
11377200	RM 257.7	1967-1970	
11378500	RM 250.2	1956-1966	
11383730	RM 218.3	2000 (only 6 samples)	Not enough data for GC Canal at Hamilton City
11383800	RM 199.3	1977-1979	
11389000	RM 168.5	1977-1980	New Delevan Pipeline (RM 158.5)
11389390	RM 158.0	1956-1980,1995-2002	
11389500	RM 143.5	No data	

2.2 Sediment Rating Curves

The sediment rating curves were developed in two steps. First, the average concentrations were calculated in different flow bins. Then, the following function was fit to the average concentration:

$$C = aQ^b$$

C is the concentration in mg/l,
Q is the Sacramento River flow in cfs.

In most cases, a single power function did not fit the data and different values of a and b were used to fit different ranges of flow. If not enough data was available at a given site, then the information was interpolated from surrounding stream gage information.

2.2.1 Rating Curve at Red Bluff

Gages 11377100, 11377200, and 11378500 were used to develop the rating curves for TC Canal at Red Bluff. To develop regression equations that represent the average concentration in the Sacramento River, the average concentration in various flow bins was first computed. The average concentration for various flow bins is shown in Figure 2-2. There is a break in the slope of the relationship between concentration and discharge at between 10,000 to 20,000 cfs. Therefore, because of the break in slope, a single power fit was not able to fit this data because it would under-predict concentrations at low flows and over-predict the concentrations at high flows. Therefore, three different sets of coefficients were used: a_1 and b_1 for flows less than 10,000 cfs, a_2 and b_2 for flows between 10,000 cfs and 20,000 cfs, and a_3 and b_3 for flows greater than 20,000 cfs. The coefficients a_3 and b_3 for the flow bin greater than 20,000 cfs were derived by minimizing the sum of the squares between the observed and computed concentrations. The coefficients a_2 and b_2 for the 10,000 cfs to 20,000 cfs flow bin were derived by best fitting b_2 and calculating a_2 so that C is a continuous function at a flow of 20,000 cfs. The same procedure was used for the flow bin below 10,000 cfs. All regression coefficients are summarized in Table 2-3.

Separate regressions were performed on the data from 1956 to 1970, 1977 to 1983, and 1996 to 2000. Results indicate there has been a significant decline in suspended sediment loads since the 1950s, but this is partly an artifact of the gage being moved. The sample location was moved upstream from Red Bluff to Bend Bridge in 1967, and moved again to above Bend Bridge in 1977. The Bend Bridge site is upstream of a few tributaries such as Dibble and Payne Creeks and therefore the sediment supplied from these tributaries would affect the Red Bluff site and not the Bend Bridge site. However, it is likely that there is also a decline in suspended loads in time because the gage has been at the same location since 1977 and there is still a significant decrease in suspended loads at this one gage location since 1977 based upon the regression lines drawn in Figure 2-2. The concentrations based upon the 1996 to 2000 data are approximately 2.8 times less than concentrations for the same flow based upon the 1977 to 1983 data. However, there is much more data from 1977 to 1983 than from 1996 to 2000. A USGS study by Wright and Schoellhamer (2004) calculated that the suspended sediment loads delivered to the San Francisco Bay by the Sacramento River decreased by about one-half from 1950 to 2001. Because there is not enough overlapping data between the two sites it is difficult to determine how much of the decline in sediment loads is due to the site move versus the temporal trend in sediment loads. At this stage of analysis, we recommend using the regression coefficients derived from all the data and perform more detailed analyses of sediment load trends at the next phase of analysis.

To determine if there is a seasonal influence on sediment concentrations, additional regressions were performed on the data grouped by months of November to January, February to May, and June to October from 1996-2000 (see Figure 2-3) and using the date from 1956 to 2000 (see Figure 2-4). The highest concentrations occur from November to January during most of the flow rates, and the summer concentrations are significantly less. The concentration in the late winter and spring (February to May) are also less than the winter (October to January) concentrations. It is probable that the winter flows act as flushing flows and are typically dominated by the tributary flows, which inject more sediment into this reach than do releases from Shasta Dam. As with the regression for 1996 to 2000 data not grouped by month,the sediment concentrations were lower than that derived from all the data from 1956 to 2000.

Table 2-3. Regression coefficients used to fit suspended sediment data.

Flow Bin (cfs)	**< 10,000**		**10,000 to 20,000**		**> 20,000**	
Coefficient	**Coefficient Values for various data groups**					
	a_1	b_1	a_2	b_2	a_3	b_3
All Data	3.68E-05	1.50	2.32E-10	2.80	0.34	0.67
1956-1970	6.06E-05	1.50	3.82E-10	2.80	0.55	0.67
1977-1983	2.84E-05	1.50	1.79E-10	2.80	0.26	0.67
1996-2000	1.07E-03	1.00	6.76E-11	2.80	9.81E-02	0.67
1996-2000 Nov to Jan	2.09E-10	2.80	5.25E-08	2.20	2.00E-01	0.67
1996-2000 Feb to May	9.70E-02	0.60	0.56	0.41	4.30E-02	0.67
1996-2000 June to Oct	0.58	0.30	9.24E-08	2.00	5.00E-02	0.67
1956-2000 Nov to Jan	3.69E-10	2.80	3.69E-10	2.80	0.54	0.67
1956-2000 Feb to May	2.21E-05	1.50	1.39E-10	2.80	2.02E-01	0.67
1956-2000 June to Oct	2.58E-02	0.67	2.58E-02	0.67	2.58E-02	0.67

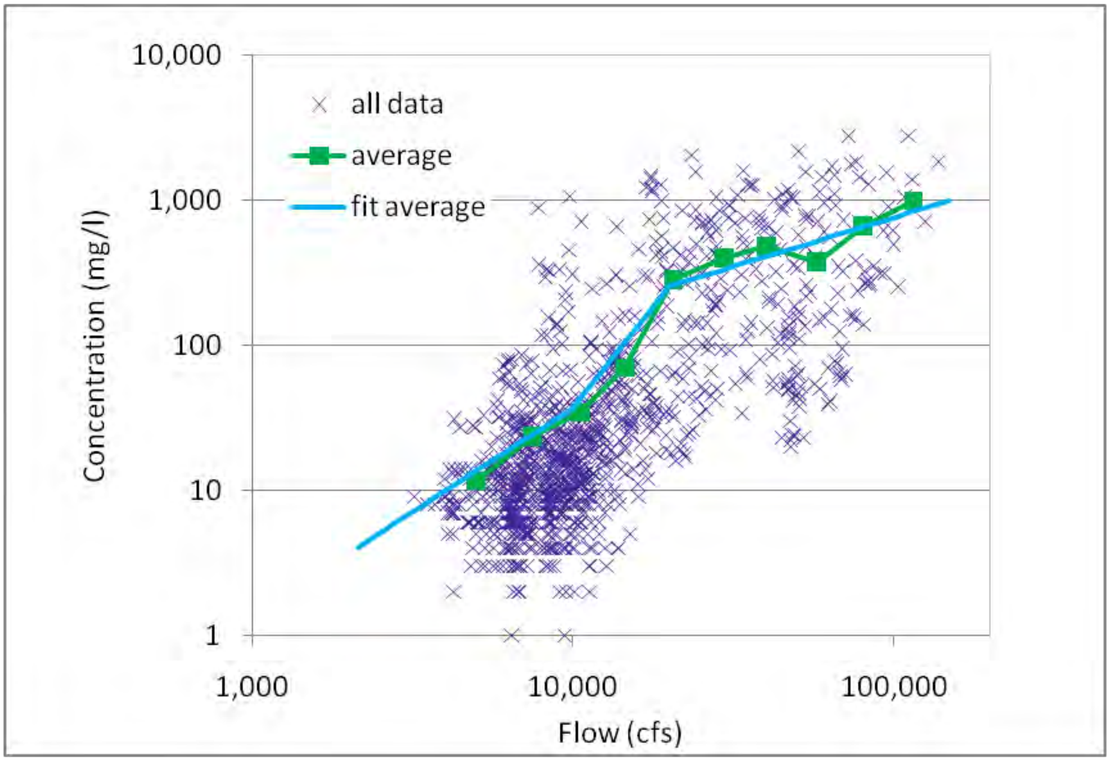

Figure 2-1. All suspended sediment data collected by USGS gages near Red Bluff Diversion. Regression fits are shown as solid lines and data is given as points.

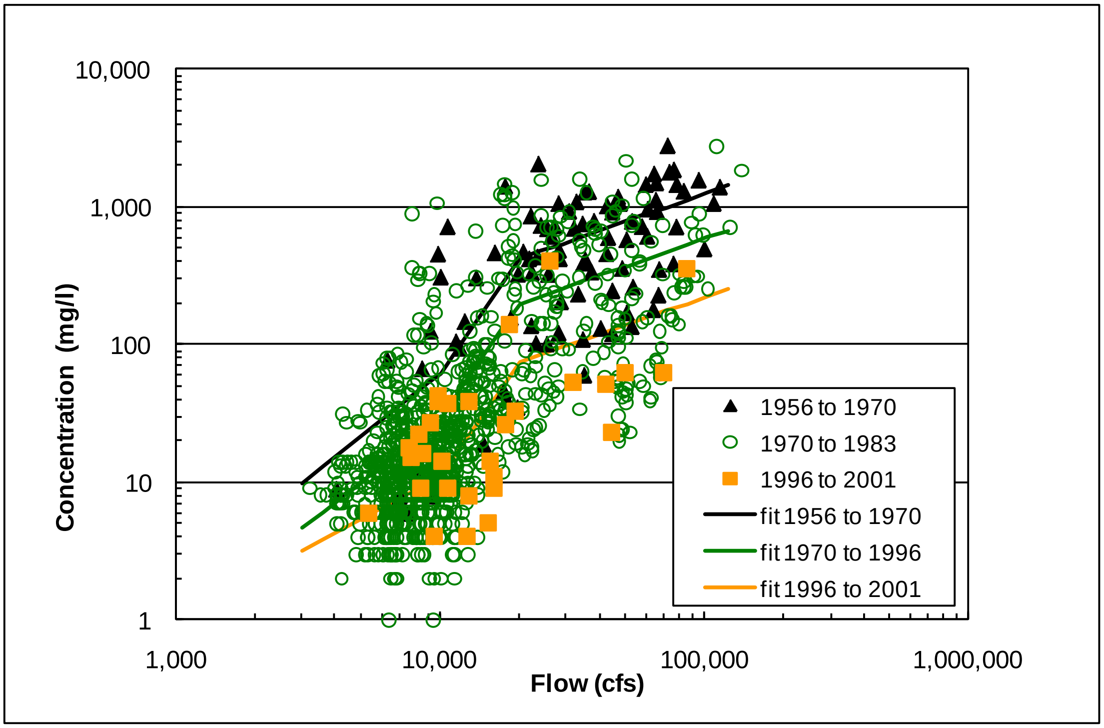

Figure 2-2. USGS suspended sediment data by various time periods. Regression fits are shown as solid lines and data is given as points.

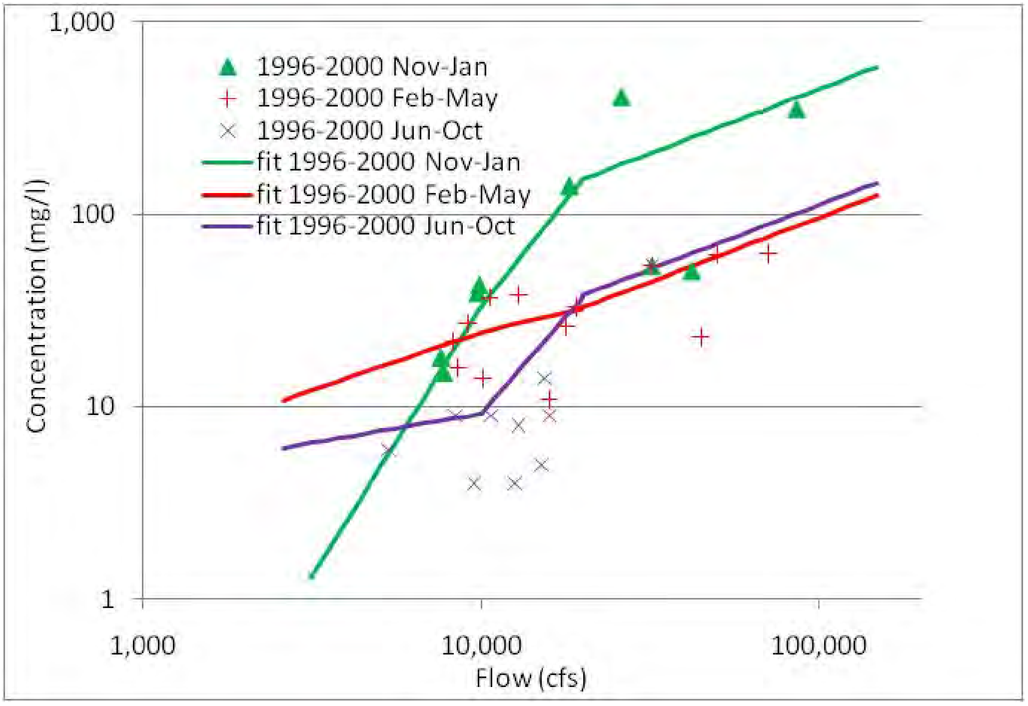

Figure 2-3. 1996 to 2000 suspended sediment data given by time of year collected. Regression fits are shown as solid lines and data is given as points.

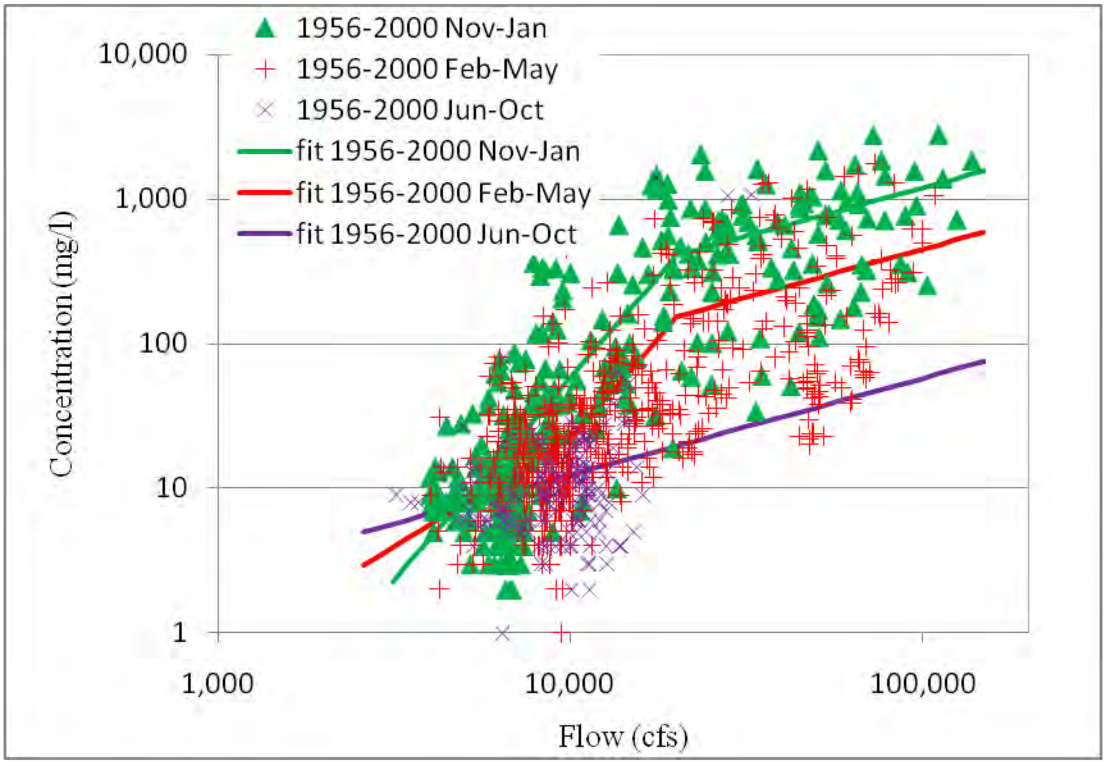

Figure 2-4. 1956 to 2000 suspended sediment data given by time of year collected. Regression fits are shown as solid lines and data is given as points.

2.2.2 Rating Curve near the New Delevan Pipeline

Gages 11389000 (SACRAMENTO R A BUTTE CITY CA , RM 158) and 11389390 (SACRAMENTO R OPPOSITE MOULTON WEIR CA, RM 168.5) were used to develop the rating curves for the new Delevan Pipeline (RM 158.5). The Butte City gage operated from 1977-1980, while the Moulton Weir gage operated from 1956 to 1980 and from 1995 to 2002. The difference in sediment loads at these two gages are not considered significant because there are no major tributaries between these gages.

Similar to the situation at Red Bluff, a single value for both a and b could not completely describe the data. Therefore, two different sets of coefficients were used; a_1 and b_1 for flows less than 14,500 cfs, coefficient a_2 and b_2 for flows greater than 14,500 cfs. The coefficients a_2 and b_2 for the flow bin greater than 14,500 cfs were derived by minimizing the sum of the squares between the observed and computed concentrations. Then the coefficients a_1 and b_1 for flow less than 14,500 cfs were derived by best fitting b_1 and calculating a_1 so that C is a continuous function at a flow of 14,500 cfs. All regression coefficients are summarized in Table 2-4..

Regressions were performed on the data from 1972 to 1980, and 1996 to 2000 (see Figure 2-6). There has been a significant decline in suspended sediment loads from 1996. Based on the fit of the regression equations, the average sediment loads have decreased by more than a factor of 2 at a flow rate of 10,000 cfs. However, there is limited data at flows greater than about 50,000 cfs and therefore it is difficult to determine trends in the concentrations for high flows. This trend of decrasing sediment concentration is consistent with the previously described data at Red Bluff and the Wright and Schoellhamer (2004) study.

Regressions were also performed on the data grouped by months of November to January, February to May, and June to October from 1996-2000 (see Figure 2-7). For flows higher than 15,000 cfs, the highest concentrations occur from November to January. For flow less than 15,000 cfs, the highest concentrations occur in the summer from June to October and high flow seldom occur during this period. Regressions were also performed on the data grouped by months of November to January, February to May, and June to October using all data from 1972-2000 (see Figure 2-7). For most of the flows from 8,000 to 80,000 cfs, the highest concentrations occur from November to January.

Table 2-4. Regression coefficients used to fit the suspended sediment data near the New Delevan Pipeline.

Flow Bin (cfs)	**< 14,500**		**14,500 to 57,500**		**> 57,500**	
Coefficient	**Coefficient Values for various data groups**					
	a_1	b_1	a_2	b_2	a_3	b_3
All Data	9.84E-05	1.50	4.52E-02	0.86	4.52E-02	0.86
1972-1980	6.80E-06	1.80	0.16	0.75	0.16	0.75
1996-2000	2.04E-03	1.10	3.00E-04	1.30	3.00E-04	1.30
1996-2000 Nov to Jan	1.83E-04	1.37	2.66E-05	1.57	0.49	0.67
1996-2000 Feb to May	1.17E-04	1.41	5.00	0.30	0.09	0.67
1996-2000 Jun to Oct	7.75E-02	0.68	7.75E-02	0.68	-	-
1972-2000 Nov to Jan	1.02E-07	2.25	0.41	0.66	0.41	0.66
1972-2000 Feb to May	1.71E-04	1.374	1.71E-04	1.374	1.71E-04	1.374
1972-2000 Jun to Oct	7.75E-02	0.68	7.75E-02	0.68	-	-

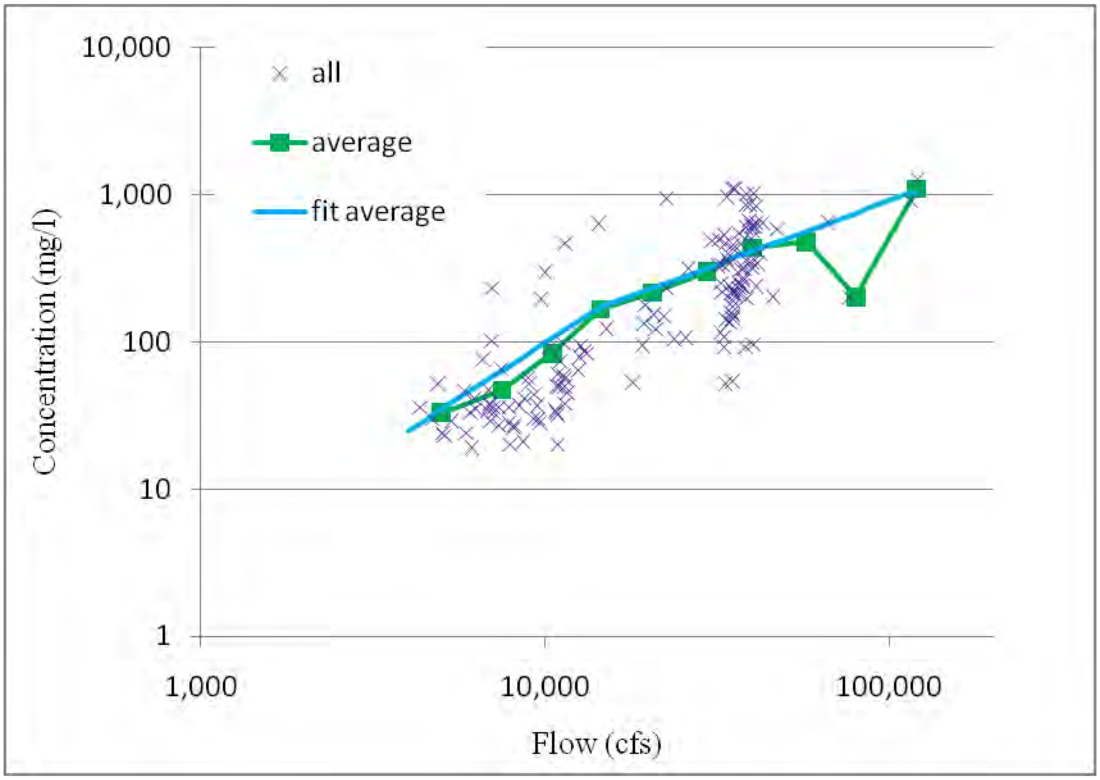

Figure 2-5. All suspended sediment data collected by USGS gages near the New Delevan Pipeline. Fits are shown as solid lines and data is given as points.

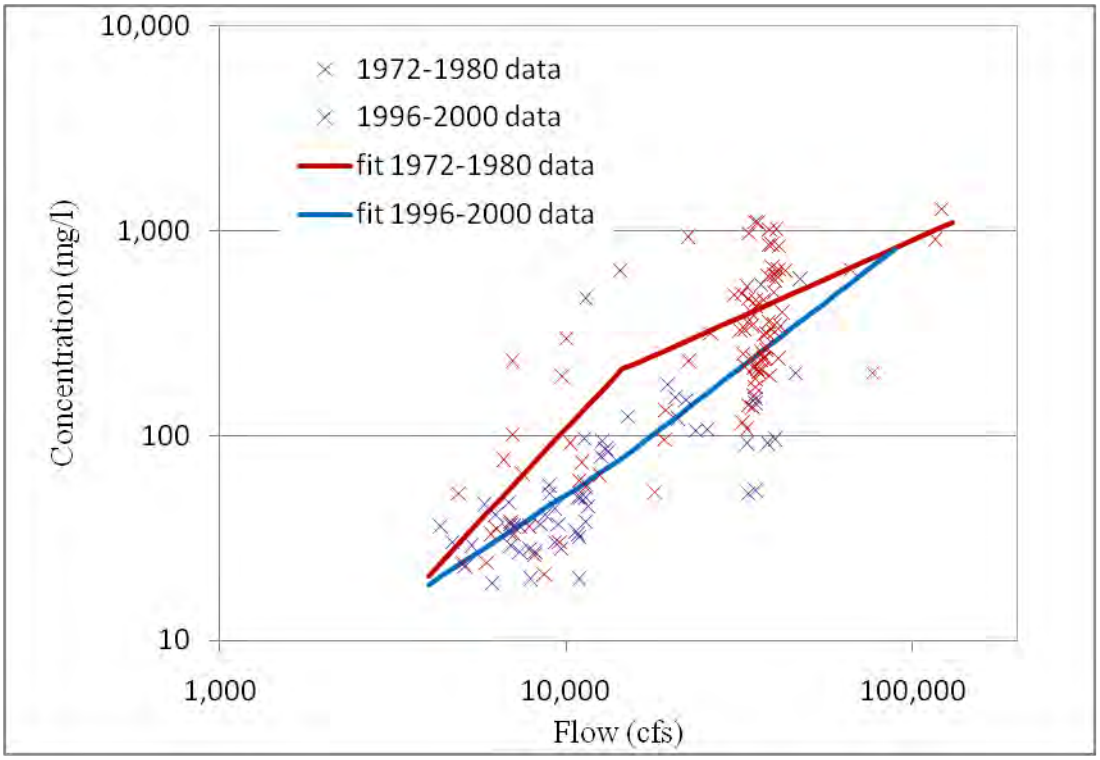

Figure 2-6. USGS suspended sediment data near the New Delevan Pipeline by various time periods. Fits are shown as solid lines and data is given as points.

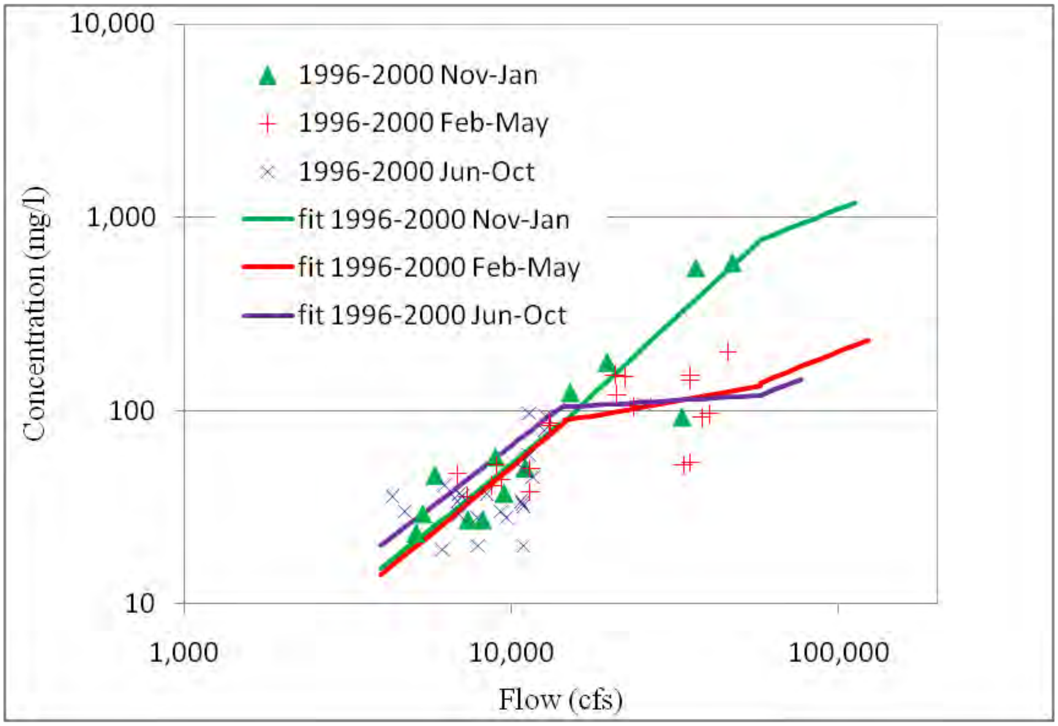

Figure 2-7. 1996 to 2000 suspended sediment data near the New Delevan Pipeline given by time of year collected. Fits are shown as solid lines and data is given as points.

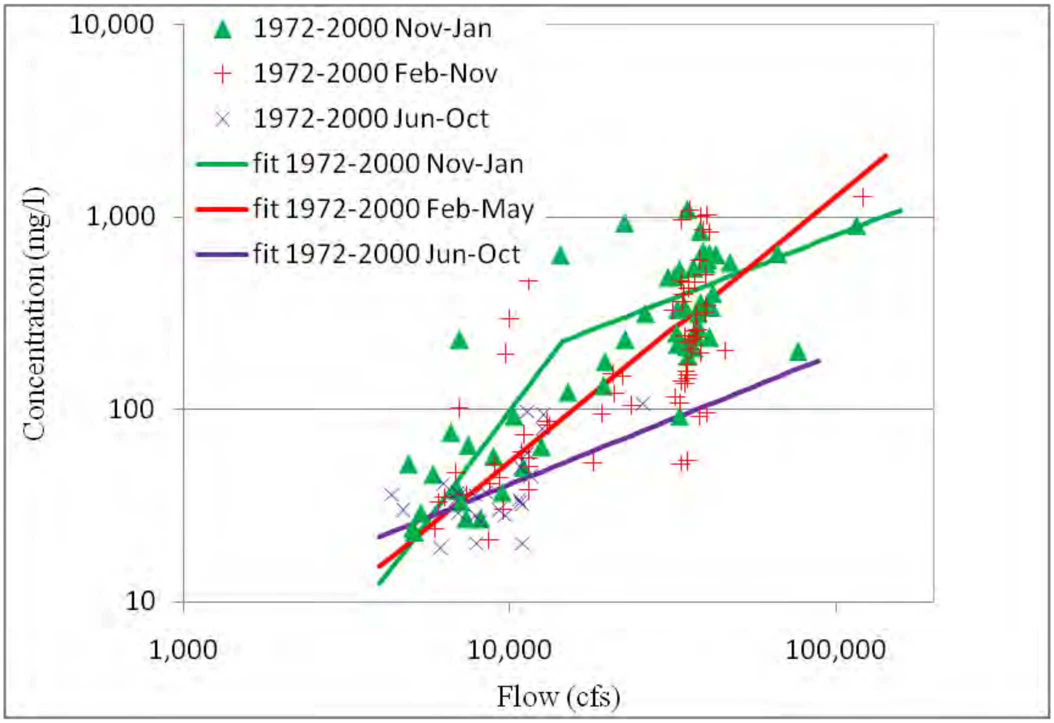

Figure 2-8. 1972 to 2000 suspended sediment data near the New Delevan Pipeline given by time of year collected. Fits are shown as solid lines and data is given as points.

2.2.3 Rating Curve near GC Canal

Gages 11383730 and 11383800 were used to develop the rating curves for the GC Canal. Two different sets of coefficients were used; coefficients a_1 and b_1 for flows less than 10,000 cfs, and coefficients a_2 and b_2 for flows greater than 10,000 cfs. The coefficients a_2 and b_2 for the flow bin greater than 10,000 cfs were derived by minimizing the sum of the squares between the observed and computed concentrations. Then the coefficients a_1 and b_1 for flow less than 10,000 cfs were derived by best fitting b_1 and calculating a_1 so that C is a continuous function at a flow of 10,000 cfs. All regression coefficients are summarized in Table 2-5.

Separate regressions were performed on the data from 1977 to 1979, and 2000 (see Figure 2-10). The amount of available data was insufficient to develop a reasonable rating curving for 2000 data. However, the limited data did indicate a potential decline in suspended sediment loads since 1979.

Because the data is limited at these gages, the suspended sediment concentrations at Hamilton City were assumed to be the average of the concentrations near Red Bluff upstream and near Delevan downstream to compute the annual sediment loads delivered to the canal.

Table 2-5. Regression coefficients used to fit the suspended sediment data near the GC Canal.

Flow Bin (cfs)	< 10,000		>= 10,000	
Coefficient	Coefficient Values for various data groups			
	a_1	b_1	a_2	b_2
All Data	8.00E-11	3	2.00E-04	1.4
1977-1979	8.00E-11	3	2.00E-04	1.4
2000	No data	No data	1.3E+02	0

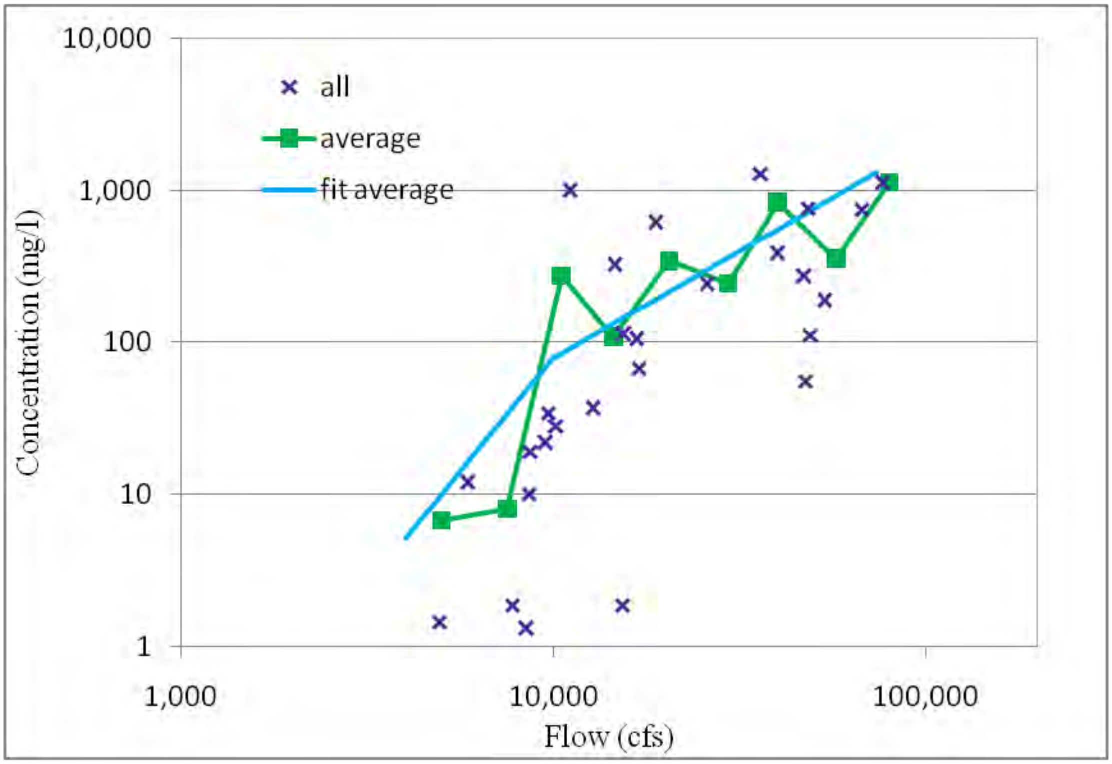

Figure 2-9. All suspended sediment data collected by USGS gages near the GC Canal. Fits are shown as solid lines and data is given as points.

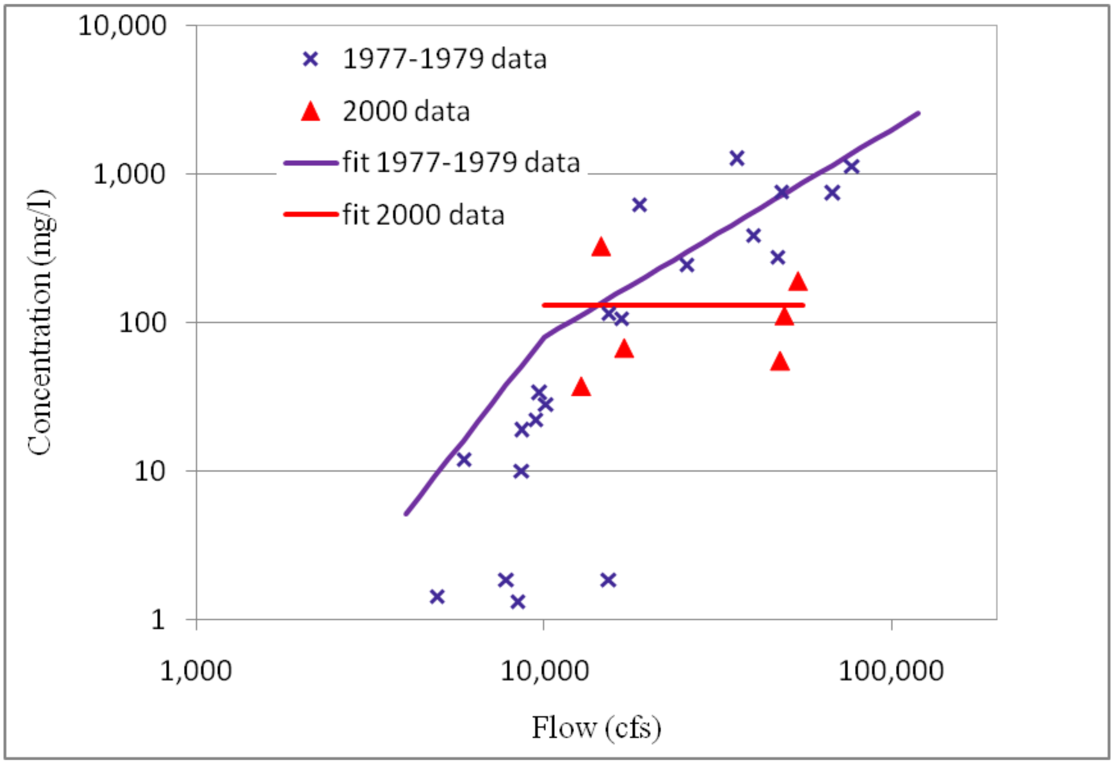

Figure 2-10. USGS suspended sediment data near the GC Canal by various time periods. Fits are shown as solid lines and data is given as points.

2.3 Sediment Loads

Daily flows from 10/1/1921 to 9/30/2003 were provided in a HEC-DSS format as described in CH2MHILL (2011). These flows were simulated using the Sacramento River daily operations model (USRDOM) under the existing conditions (Existing), future No Action Alternative (NoAction), and the proposed NODOS program alternative operations, identified as Alternative A (AltA), Alternative B (AltB), and Alternative C (AltC). Cumulative flows in the Sacramento River at Red Bluff, Hamilton City, and Colusa from the simulation are displayed in Figure 2-11 to Figure 2-13, respectively. Diversion flows to TC Canal, GC, and the New Pipeline are displayed in Figure 2-14 to Figure 2-16, respectively.

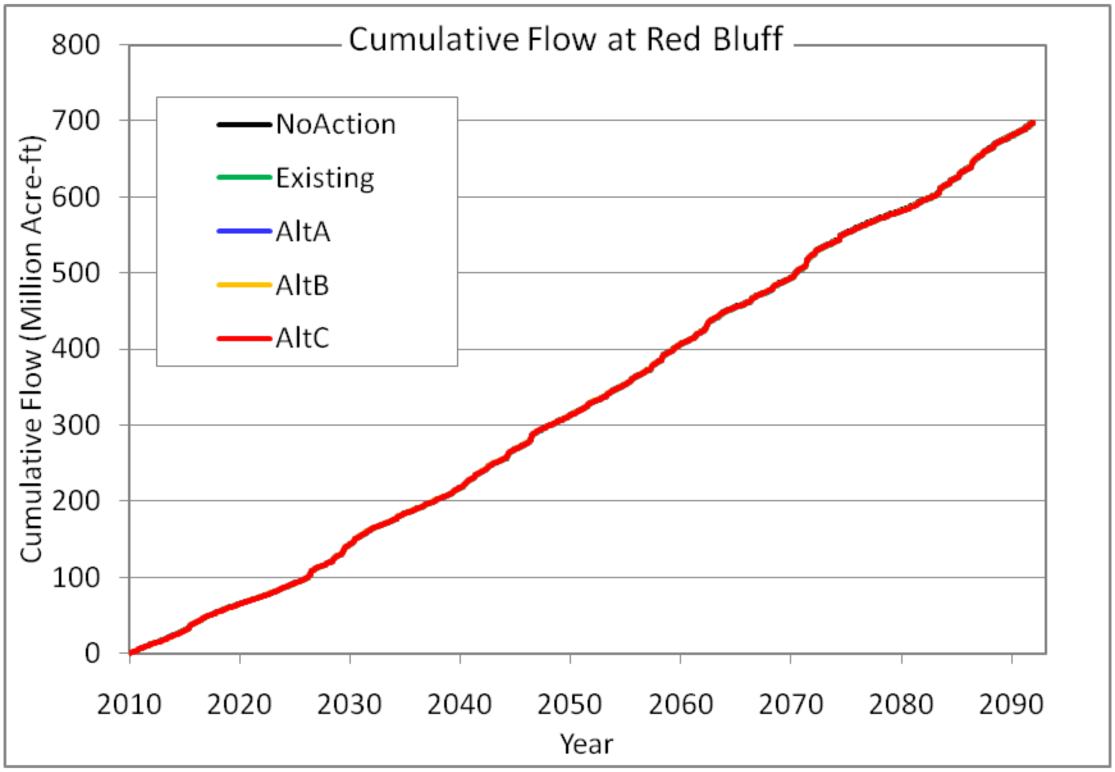

Figure 2-11. Cumulative flow in Sacramento River at Red Bluff.

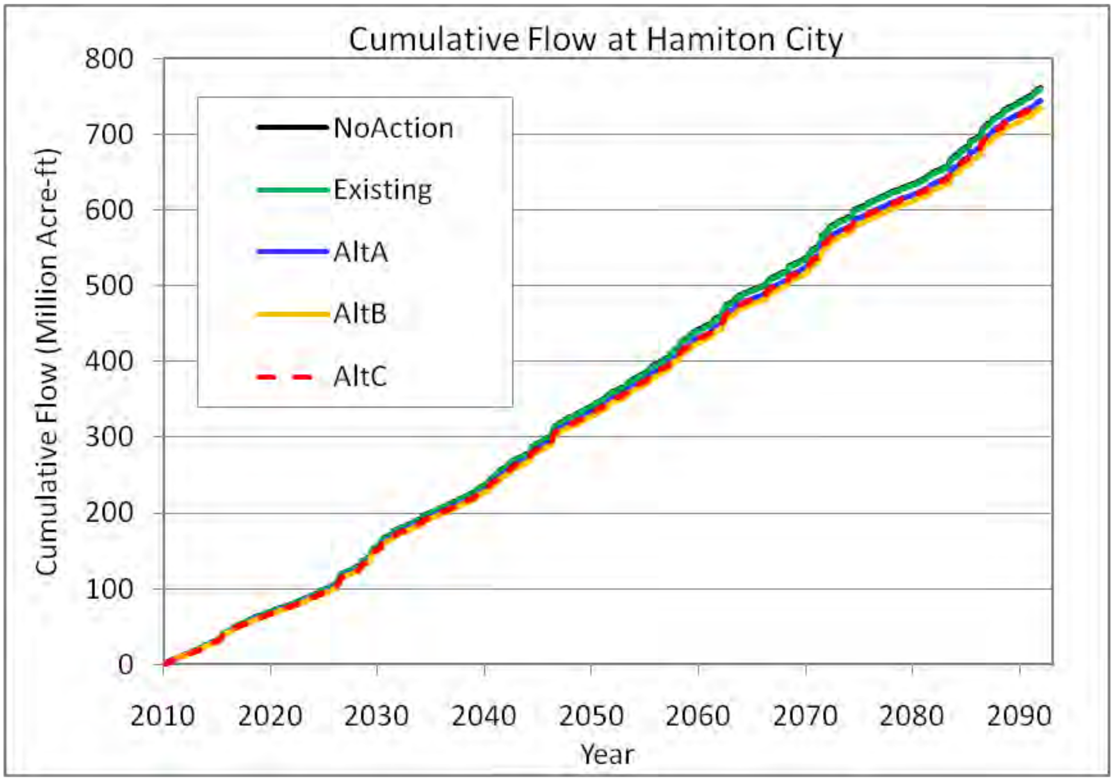

Figure 2-12. Cumulative flow in Sacramento River at Hamilton City.

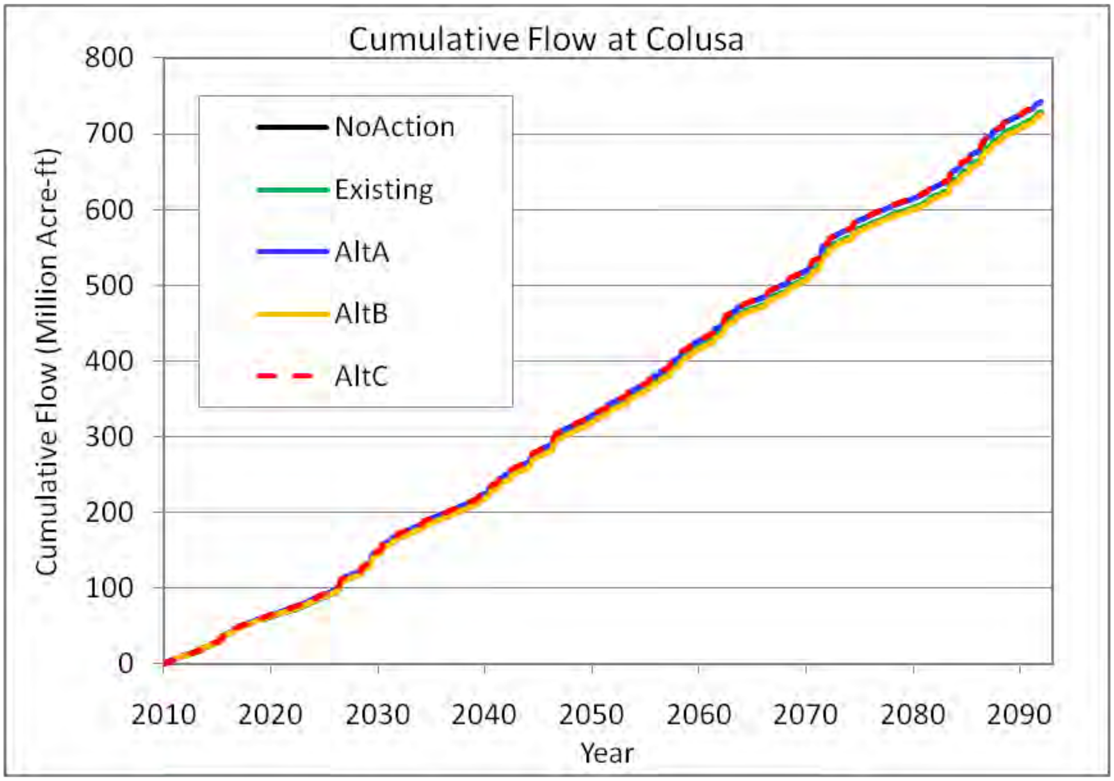

Figure 2-13. Cumulative flow in Sacramento River at Colusa.

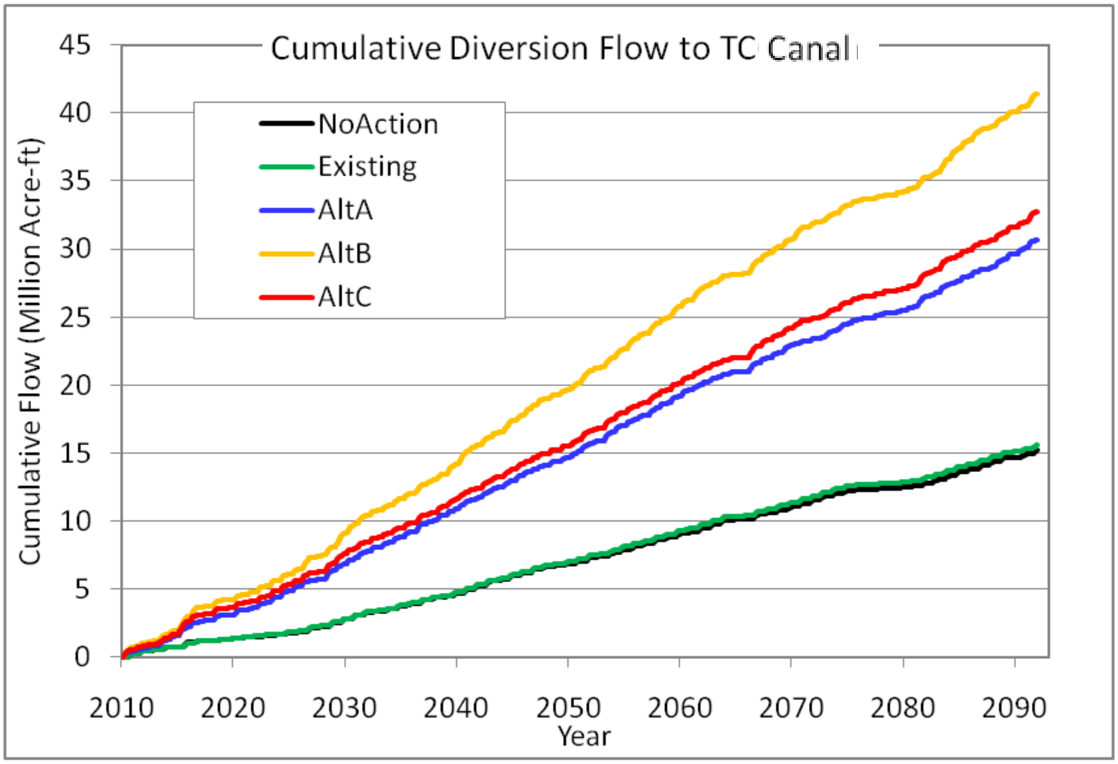

Figure 2-14. Cumulative diversion flow to TC canal.

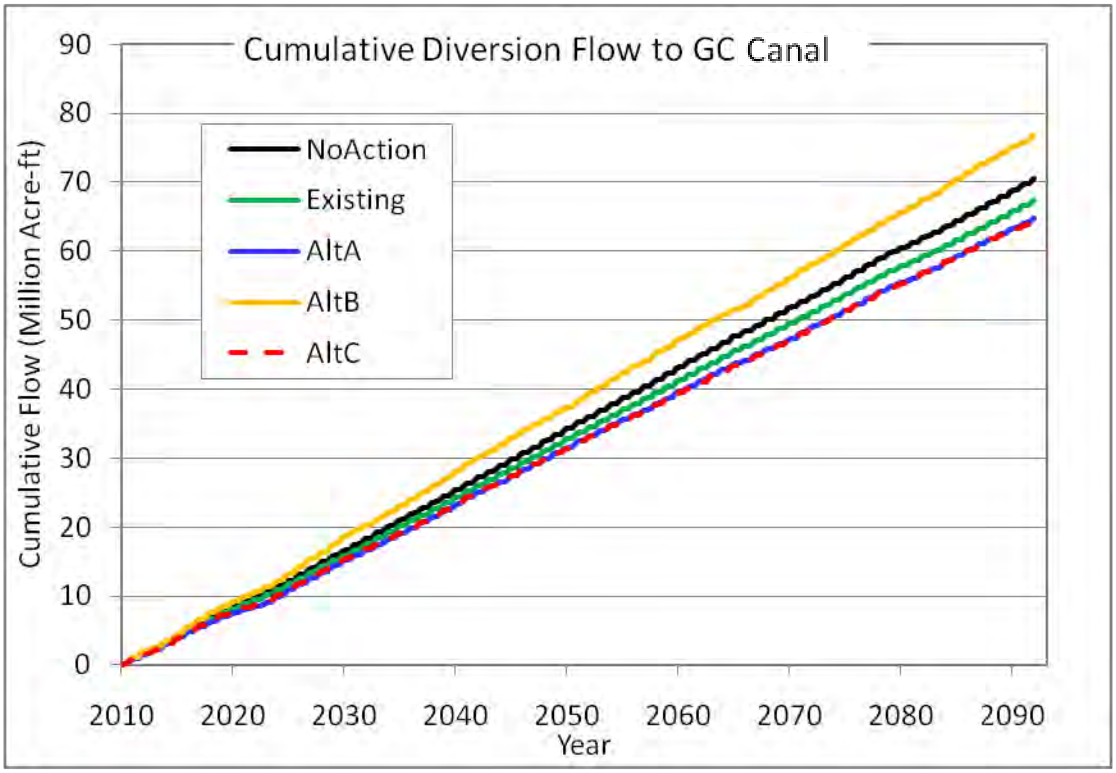

Figure 2-15. Cumulative diversion flow to GC canal.

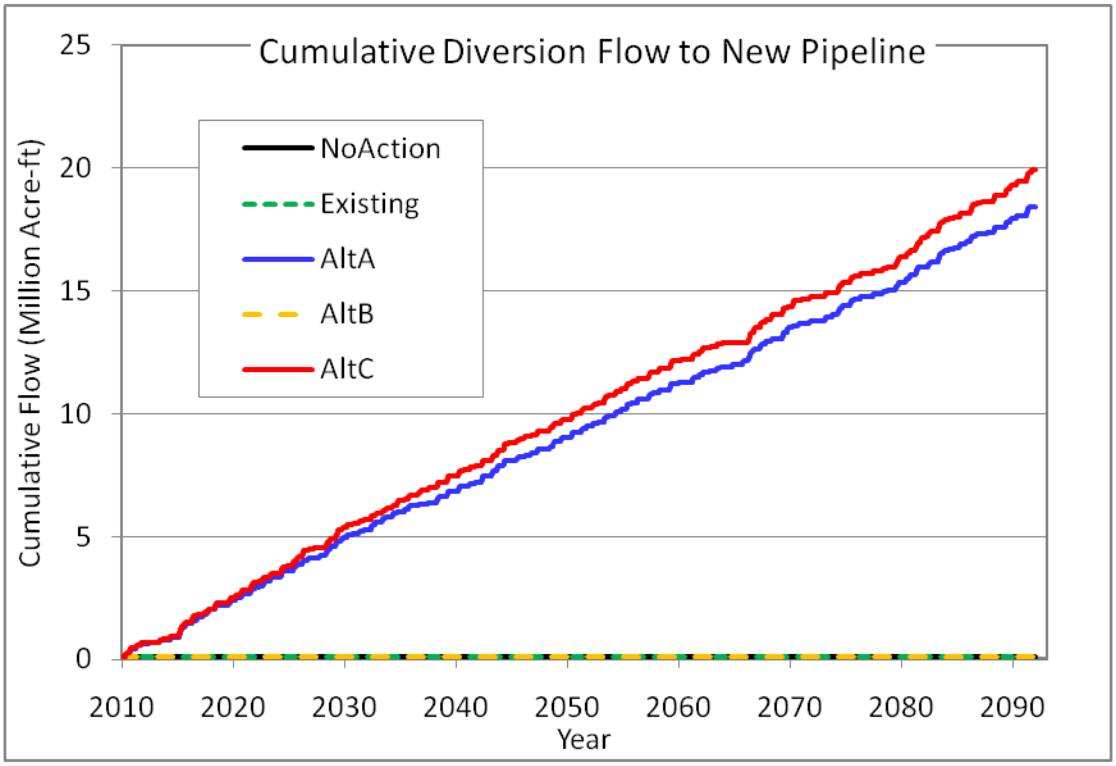

Figure 2-16. Cumulative diversion flow to the New Pipeline.

The total sediment volume delivered into the canal was calculated using the following function:

$$W_s = A\Delta t\sum_{t=1}^{n} C_s Q_d$$

Where W_s = sediment load in tons (1 ton=2000 pound dry sediment),
Δt = seconds in a day $= 3600 \times 24$,
C_s = suspended sediment concentration (mg/l) calculated with the total flow rate at that location,
Q_d = flow diversion (m^3),
n = total days simulated,
A = conversion constant from (gram to English tons) = 1/1.0E6*1000/0.4536/2000

The total sediment loads were predicted using two sets of rating curves. Figure 2-17 to Figure 2-19 show the predicted total sediment loads using sediment data from 1996 to 2000. Figure 2-20 to Figure 2-22 display the predicted total sediment loads using sediment data from 1956 to 2000. The daily flows from 10/1/1921 to 9/30/2003 were used to predict the sediment loads from 10/1/2010 to 9/29/2092.

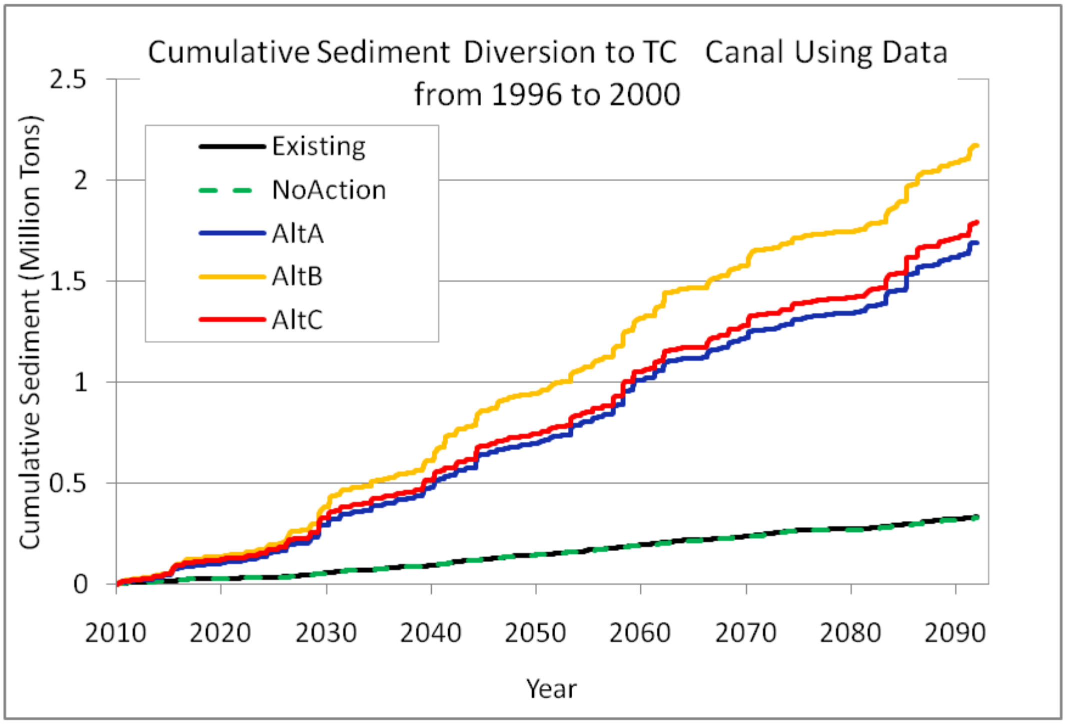

Figure 2-17. Sediment load delivered into TC Canal at Red Bluff using data from 1996 to 2000. 1 ton = 2000 pound dry sediment.

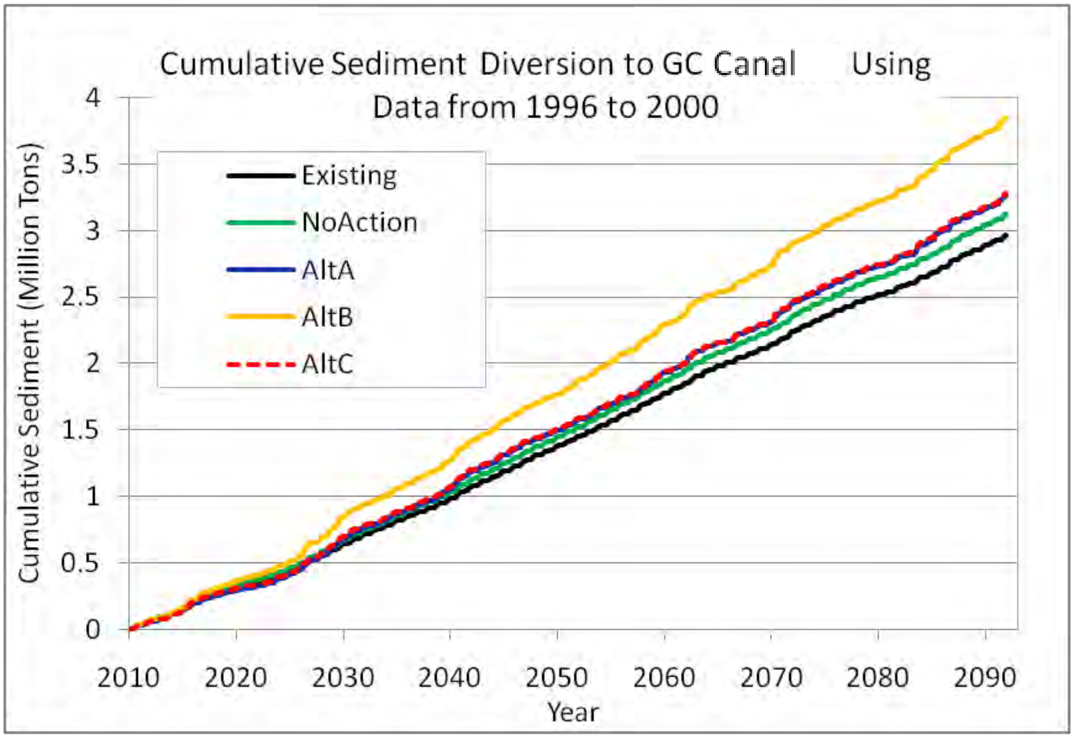

Figure 2-18. Sediment load delivered into GC Canal at Hamilton City using data from 1996 to 2000. 1 ton = 2000 pound dry sediment.

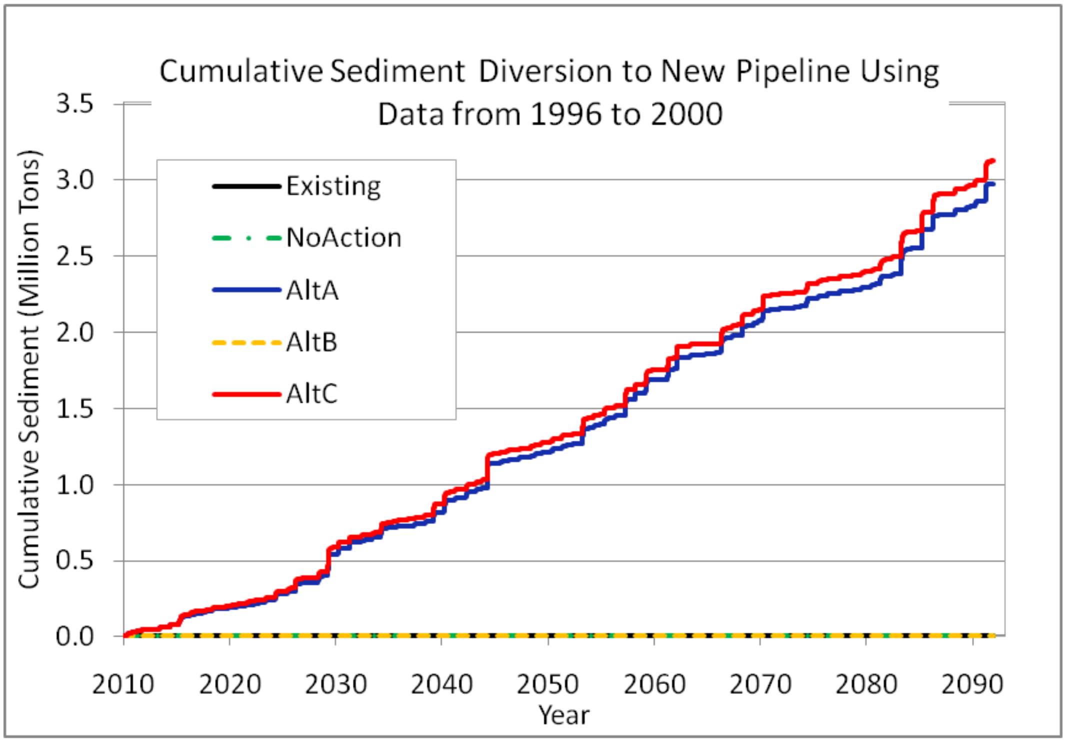

Figure 2-19. Sediment load delivered into the New Delevan Pipeline at Colusa using data from 1996 to 2000. 1 ton = 2000 pound dry sediment.

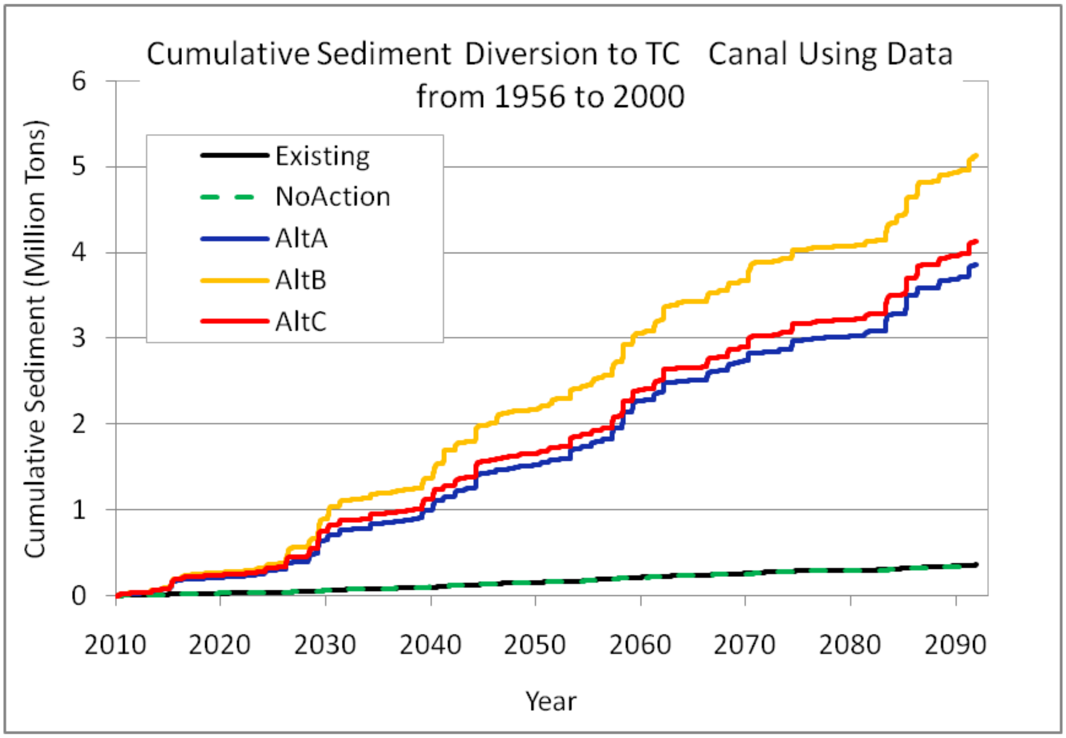

Figure 2-20. Sediment load delivered into TC Canal at Red Bluff using data from 1956 to 2000. 1 ton = 2000 pound dry sediment.

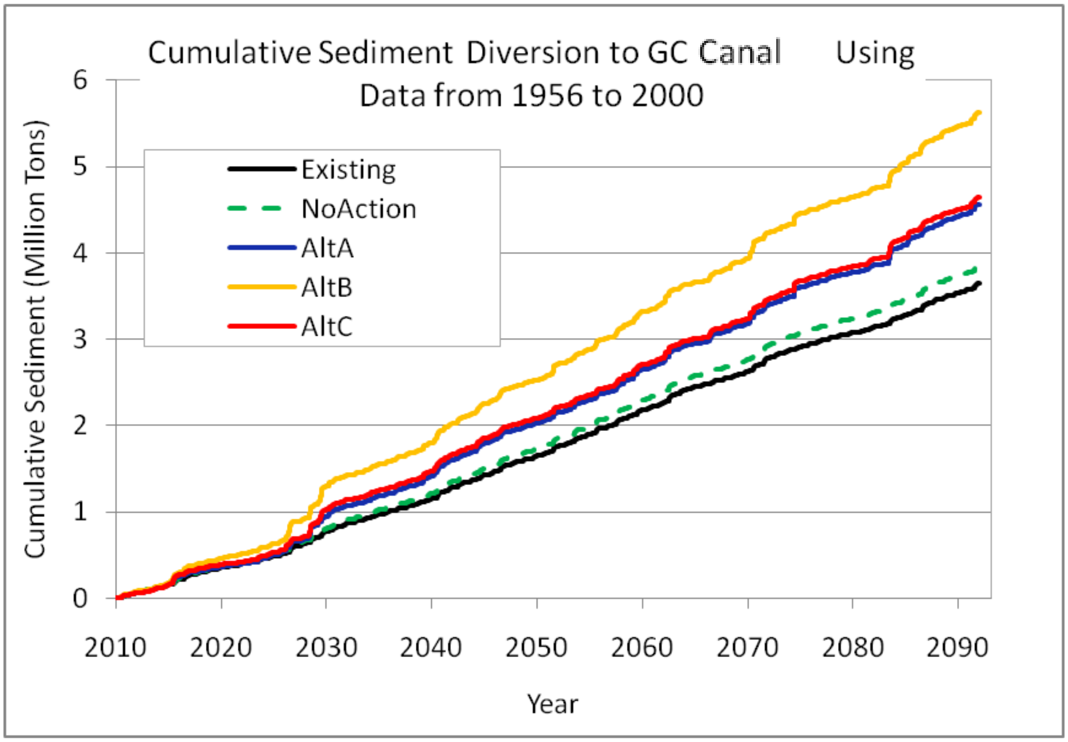

Figure 2-21. Sediment load delivered into GC Canal at Hamilton City using data from 1956 to 2000. 1 ton = 2000 pound dry sediment.

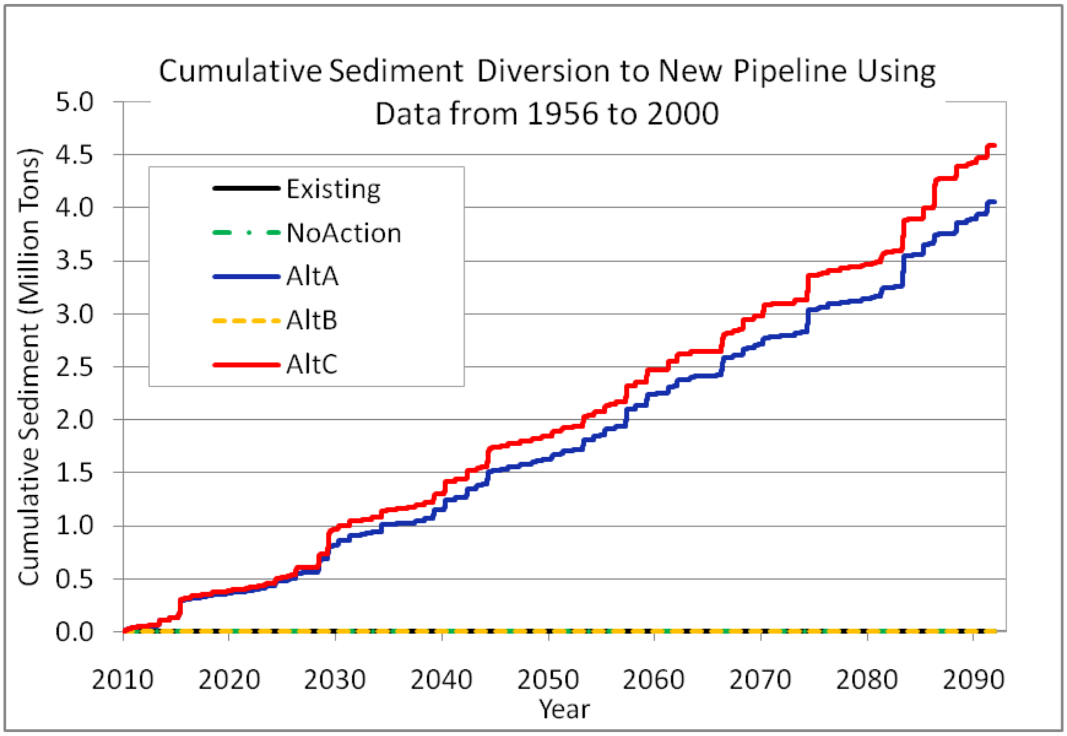

Figure 2-22. Sediment load delivered into the New Delevan Pipeline at Colusa using data from 1956 to 2000. 1 ton = 2000 pound dry sediment.

Results show the predicted sediment loads are lower using the sediment rating curves derived from the 1996 to 2000 data. At this stage of analysis, we suggest using the estimated sediment loads using all the sediment data because it is a more conservative estimate and further analysis of the decreasing sediment load trends should be performed. However, the projections using the more recent data are also presented to give a lower estimate of sediment loads that may occur in the future.

All three proposed NODOS program alternative operations deliver more water to the TC Canal than Existing Conditions and No Action Alternative, and Alt B delivers the most. The sediment load delivered to the TC Canal is approximately 10 times greater under the NODOS program alternatives than under the No Action Alternative. The large increase in the TC canal sediment loads is due to the fact that the NODOS Alternatives divert more water and during the winter season when sediment concentrations are much higher.

AltB also delivers more water to GC Canal than Existing and NoAction conditions, and AltA and AltC deliver less water to GC Canal than Existing and NoAction conditions. However, all NODOS alternatives deliver more sediment to the GC canal because more of the diversion occurs during winter flow periods when the sediment concentrations are higher.

The New Delevan Pipeline at Colusa only delivers water under the proposed alternative AltA and AltC conditions, and AltC delivers more water than AltA.

A summary of the predicted annual sediment loads for each alternative are presented in Table 2-6.

Table 2-6. Estimated Annual Sediment Loads at Three Diversions.

	Using all data			**Using 1996-2000 data**		
	Annual Sediment Loads (tons)			**Annual Sediment Loads (tons)**		
Condition	TC Canal	GC Canal	New Pipeline	TC Canal	GC Canal	New Pipeline
Existing	4,000	44,000	0	4,000	36,000	0
NoAction	4,000	47,000	0	4,000	38,000	0
AltA	47,000	56,000	49,000	21,000	40,000	36,000
AltB	62,000	69,000	0	27,000	47,000	0
AltC	50,000	57,000	56,000	22,000	40,000	38,000

Note: 1 ton of sediment = 2000 pound dry sediment

3 Conclusions

Suspended sediment rating curves were estimated based on suspended sediment concentrations at seven USGS gages. Average annual sediment loads for the TC Canal, GC Canal, and New Delevan Pipeline were estimated based on the sediment rating curves and diversion and flow rates under Existing, NoAction, AltA, AltB, and AltC conditions as simulated in the USRDOM model (CH2MHILL, 2011). The sediment load analysis results are summarized as follows:

- Annual sediment loads delivered into the TC Canal is estimated to be 4,000, 4,000, 47,000, 62,000, and 50,000 tons under Existing, NoAction, AltA, AltB, and AltC conditions, respectively.
- The Annual sediment loads delivered into the GC Canal is estimated to be 44,000, 47,000, 56,000, 69,000 and 57,000 tons under Existing, NoAction, AltA, AltB, and AltC conditions, respectively.
- The Annual sediment loads delivered into the New Delevan Pipeline is estimated to be 0, 0, 49,000, 0, and 56,000 tons under Existing, NoAction, AltA, AltB, and AltC conditions, respectively.

References

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Wright SA, Schoellhamer DH. 2004. Trends in the sediment yield of the Sacramento River, California, 1957-2001. San Francisco Estuary and Watershed Science [online serial]. Vol. 2, Issue 2 (May 2004), Article 2. http://repositories.cdlib.org/jmie/sfews/vol2/iss2/art2.

Attachment A. USGS suspended sediment data

Table A-1. USGS suspended sediment data at sites near Red Bluff.

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/3/1977	5550	14	210
11377100	3/3/1977	5550	14	210
11377100	3/7/1977	6820	10	184
11377100	3/11/1977	6910	12	224
11377100	3/15/1977	6970	12	226
11377100	3/19/1977	6200	18	301
11377100	3/23/1977	6040	16	261
11377100	3/27/1977	6090	14	230
11377100	3/30/1977	5930	12	192
11377100	4/1/1977	6310	10	170
11377100	4/4/1977	6240	9	152
11377100	4/7/1977	6260	11	186
11377100	4/7/1977	6400	8	138
11377100	4/7/1977	6560	7	124
11377100	4/8/1977	6790	9	165
11377100	4/11/1977	7520	12	244
11377100	4/14/1977	8810	14	333
11377100	4/19/1977	9580	11	285
11377100	4/21/1977	9470	10	256
11377100	4/26/1977	10000	14	378
11377100	4/29/1977	10000	12	324
11377100	5/2/1977	10300	11	306
11377100	5/4/1977	10200	11	303
11377100	5/4/1977	10200	6	165
11377100	5/5/1977	9760	5	132
11377100	5/6/1977	8430	6	137
11377100	5/6/1977	8430	6	137
11377100	5/6/1977	8430	6	137
11377100	5/7/1977	8380	7	158
11377100	5/10/1977	9160	11	272
11377100	5/14/1977	7750	24	502
11377100	5/18/1977	7400	14	280
11377100	5/22/1977	7400	14	280
11377100	5/27/1977	7630	16	330

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	5/31/1977	7350	12	238
11377100	6/1/1977	7050	8	152
11377100	6/1/1977	6980	6	113
11377100	6/1/1977	6790	6	110
11377100	6/5/1977	8190	12	265
11377100	6/9/1977	8750	10	236
11377100	6/14/1977	9420	12	305
11377100	6/19/1977	10400	12	337
11377100	6/22/1977	10500	11	312
11377100	7/5/1977	10800	14	408
11377100	7/5/1977	10700	9	260
11377100	7/8/1977	10700	20	578
11377100	7/16/1977	10700	24	693
11377100	7/22/1977	11200	22	665
11377100	7/27/1977	10600	16	458
11377100	7/30/1977	10800	23	671
11377100	8/1/1977	10800	12	350
11377100	8/1/1977	10800	13	379
11377100	8/1/1977	10700	24	693
11377100	8/5/1977	10300	26	723
11377100	8/13/1977	8260	20	446
11377100	8/27/1977	7110	12	230
11377100	9/3/1977	6400	6	104
11377100	9/6/1977	6020	8	130
11377100	9/6/1977	5950	13	209
11377100	9/10/1977	5250	13	184
11377100	9/17/1977	6460	21	366
11377100	9/21/1977	4970	27	362
11377100	9/24/1977	4770	6	77
11377100	9/30/1977	4460	14	169
11377100	10/8/1977	3530	8	76
11377100	10/15/1977	3200	9	78
11377100	10/22/1977	3710	8	80
11377100	10/29/1977	5360	14	203
11377100	11/1/1977	5530	14	209
11377100	11/1/1977	5770	15	234
11377100	11/1/1977	5770	12	187
11377100	11/1/1977	5810	16	251
11377100	11/2/1977	5890	15	239

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	11/3/1977	5960	13	209
11377100	11/4/1977	5930	12	192
11377100	11/5/1977	6000	12	194
11377100	11/7/1977	5960	11	177
11377100	11/8/1977	5850	10	158
11377100	11/9/1977	5870	10	158
11377100	11/12/1977	5510	9	134
11377100	11/12/1977	5510	9	134
11377100	11/13/1977	5490	10	148
11377100	11/15/1977	5450	8	118
11377100	11/23/1977	7850	361	7650
11377100	11/25/1977	5580	20	301
11377100	11/28/1977	4860	11	144
11377100	11/28/1977	4790	12	155
11377100	11/29/1977	4630	9	113
11377100	11/29/1977	4300	8	93
11377100	11/30/1977	4200	8	91
11377100	11/30/1977	4200	8	91
11377100	11/30/1977	4270	7	81
11377100	12/1/1977	4220	13	148
11377100	12/1/1977	4220	8	91
11377100	12/1/1977	4220	7	80
11377100	12/1/1977	4220	9	103
11377100	12/1/1977	4220	8	91
11377100	12/1/1977	4220	9	103
11377100	12/2/1977	4170	7	79
11377100	12/3/1977	4070	5	55
11377100	12/4/1977	4040	8	87
11377100	12/5/1977	4070	7	77
11377100	12/6/1977	4040	8	87
11377100	12/7/1977	4100	10	111
11377100	12/8/1977	3980	9	97
11377100	12/9/1977	3980	12	129
11377100	12/10/1977	4070	7	77
11377100	12/11/1977	4120	14	156
11377100	12/11/1977	4150	7	78
11377100	12/12/1977	4610	14	174
11377100	12/13/1977	4440	27	324
11377100	12/14/1977	18100	517	25300

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	12/14/1977	18900	985	50300
11377100	12/14/1977	18900	561	28600
11377100	12/15/1977	24100	1560	102000
11377100	12/15/1977	18800	1270	64500
11377100	12/15/1977	17600	1200	57000
11377100	12/15/1977	17600	1160	55100
11377100	12/15/1977	16900	1230	56100
11377100	12/15/1977	16600	302	13500
11377100	12/16/1977	8420	326	7410
11377100	12/16/1977	7810	885	18700
11377100	12/17/1977	30700	766	63500
11377100	12/17/1977	19200	748	38800
11377100	12/18/1977	9780	1060	28000
11377100	12/19/1977	6220	54	907
11377100	12/20/1977	5270	33	470
11377100	12/21/1977	4880	28	369
11377100	12/22/1977	6990	32	604
11377100	12/22/1977	9310	66	1660
11377100	12/23/1977	33900	1600	146000
11377100	12/24/1977	9500	232	5950
11377100	12/25/1977	6930	48	898
11377100	12/26/1977	5850	42	663
11377100	12/27/1977	6440	32	556
11377100	12/28/1977	7450	78	1570
11377100	12/30/1977	7140	74	1430
11377100	12/31/1977	5790	37	578
11377100	1/1/1978	5400	14	204
11377100	1/2/1978	5380	17	247
11377100	1/3/1978	9070	331	8110
11377100	1/3/1978	8300	334	7490
11377100	1/3/1978	8200	293	6490
11377100	1/3/1978	7980	118	2540
11377100	1/4/1978	6920	86	1610
11377100	1/4/1978	7860	46	976
11377100	1/5/1978	17500	1460	69000
11377100	1/6/1978	13700	660	24400
11377100	1/7/1978	9470	206	5270
11377100	1/7/1978	8900	141	3390
11377100	1/8/1978	8280	118	2640

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	1/9/1978	50500	2160	295000
11377100	1/10/1978	38800	278	29100
11377100	1/10/1978	35900	1260	122000
11377100	1/10/1978	27600	685	51000
11377100	1/10/1978	28000	616	46600
11377100	1/10/1978	26300	705	50100
11377100	1/10/1978	24200	500	32700
11377100	1/11/1978	15000	256	10400
11377100	1/11/1978	14700	100	3970
11377100	1/12/1978	14500	161	6300
11377100	1/12/1978	13600	306	11200
11377100	1/13/1978	19600	334	17700
11377100	1/13/1978	24100	854	55600
11377100	1/14/1978	30800	916	76200
11377100	1/15/1978	69600	730	137000
11377100	1/15/1978	46000	934	116000
11377100	1/16/1978	53000	1570	225000
11377100	1/16/1978	89300	765	184000
11377100	1/17/1978	58700	1140	181000
11377100	1/18/1978	26700	566	40800
11377100	1/19/1978	44900	1100	133000
11377100	1/20/1978	25300	314	21400
11377100	1/20/1978	22000	59	3510
11377100	1/21/1978	19100	230	11900
11377100	1/24/1978	15400	80	3330
11377100	1/25/1978	12500	69	2330
11377100	1/25/1978	11800	26	828
11377100	1/26/1978	10400	56	1570
11377100	1/26/1978	9100	24	590
11377100	1/27/1978	8580	45	1040
11377100	1/28/1978	7990	36	777
11377100	1/29/1978	7710	38	791
11377100	1/30/1978	7470	25	504
11377100	1/31/1978	6730	26	472
11377100	2/1/1978	5800	23	360
11377100	2/2/1978	6610	26	464
11377100	2/2/1978	6610	32	571
11377100	2/2/1978	6660	30	539
11377100	2/2/1978	7210	32	623

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	2/3/1978	7000	42	794
11377100	2/3/1978	6680	28	505
11377100	2/4/1978	6230	29	488
11377100	2/5/1978	6380	53	913
11377100	2/5/1978	12100	28	915
11377100	2/6/1978	18700	446	22500
11377100	2/6/1978	23700	285	18200
11377100	2/7/1978	28900	288	22500
11377100	2/7/1978	37800	722	73700
11377100	2/7/1978	53400	738	106000
11377100	2/8/1978	39800	527	56600
11377100	2/8/1978	34800	480	45100
11377100	2/9/1978	38800	636	66600
11377100	2/9/1978	33500	305	27600
11377100	2/10/1978	27900	189	14200
11377100	2/10/1978	27000	66	4810
11377100	2/11/1978	24600	142	9430
11377100	2/11/1978	24200	43	2810
11377100	2/12/1978	21200	44	2520
11377100	2/12/1978	22900	69	4270
11377100	2/13/1978	27500	200	14900
11377100	2/13/1978	26900	45	3270
11377100	2/14/1978	27200	172	12600
11377100	2/14/1978	26300	94	6680
11377100	2/15/1978	26200	142	10000
11377100	2/15/1978	26000	36	2530
11377100	2/16/1978	21100	90	5130
11377100	2/16/1978	20500	32	1770
11377100	2/17/1978	18700	66	3330
11377100	2/17/1978	17900	34	1640
11377100	2/18/1978	15100	34	1390
11377100	2/18/1978	13600	52	1910
11377100	2/19/1978	13100	62	2190
11377100	2/20/1978	12900	76	2650
11377100	2/21/1978	12700	46	1580
11377100	2/22/1978	11700	42	1330
11377100	2/23/1978	10100	36	982
11377100	2/24/1978	9930	38	1020
11377100	2/25/1978	8900	33	793

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	2/25/1978	8090	17	371
11377100	2/26/1978	8170	32	706
11377100	2/27/1978	9160	34	841
11377100	2/28/1978	7530	26	529
11377100	3/1/1978	7230	30	586
11377100	3/1/1978	7170	26	503
11377100	3/1/1978	7160	22	425
11377100	3/1/1978	7160	20	387
11377100	3/1/1978	7140	24	463
11377100	3/2/1978	8400	154	3490
11377100	3/2/1978	13800	155	5780
11377100	3/3/1978	17300	732	34200
11377100	3/3/1978	28600	844	65200
11377100	3/4/1978	44300	455	54400
11377100	3/4/1978	56700	388	59400
11377100	3/5/1978	50200	343	46500
11377100	3/5/1978	41000	200	22100
11377100	3/6/1978	43600	192	22600
11377100	3/6/1978	40700	212	23300
11377100	3/7/1978	35800	143	13800
11377100	3/7/1978	35100	126	11900
11377100	3/8/1978	60900	155	25500
11377100	3/8/1978	81000	323	70600
11377100	3/9/1978	63100	556	94700
11377100	3/9/1978	53300	479	68900
11377100	3/10/1978	54800	233	34500
11377100	3/10/1978	53300	216	31100
11377100	3/11/1978	68700	58	10800
11377100	3/11/1978	56800	404	62000
11377100	3/12/1978	50300	64	8690
11377100	3/12/1978	49300	72	9580
11377100	3/13/1978	47200	96	12200
11377100	3/13/1978	47100	125	15900
11377100	3/13/1978	47100	112	14200
11377100	3/13/1978	47000	137	17400
11377100	3/13/1978	47000	156	19800
11377100	3/13/1978	47000	120	15200
11377100	3/14/1978	43400	104	12200
11377100	3/14/1978	41700	87	9800

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/15/1978	38200	80	8250
11377100	3/15/1978	34600	64	5980
11377100	3/16/1978	30800	92	7650
11377100	3/17/1978	23000	81	5030
11377100	3/17/1978	20400	62	3420
11377100	3/17/1978	20300	35	1920
11377100	3/18/1978	16900	64	2920
11377100	3/18/1978	16500	16	713
11377100	3/19/1978	15200	30	1230
11377100	3/19/1978	14800	42	1680
11377100	3/20/1978	13300	48	1720
11377100	3/20/1978	12700	20	686
11377100	3/21/1978	11700	28	885
11377100	3/21/1978	11300	22	671
11377100	3/22/1978	12400	50	1670
11377100	3/22/1978	11900	24	771
11377100	3/23/1978	11400	18	554
11377100	3/23/1978	11500	31	963
11377100	3/24/1978	12000	17	551
11377100	3/24/1978	11600	64	2000
11377100	3/25/1978	10900	36	1060
11377100	3/25/1978	10800	36	1050
11377100	3/26/1978	10500	14	397
11377100	3/27/1978	10200	24	661
11377100	3/27/1978	10200	16	441
11377100	3/28/1978	10100	27	736
11377100	3/29/1978	9940	12	322
11377100	3/29/1978	9950	12	322
11377100	3/29/1978	9910	22	589
11377100	3/30/1978	9880	24	640
11377100	3/30/1978	9950	9	242
11377100	3/31/1978	9840	10	266
11377100	3/31/1978	10000	8	216
11377100	4/1/1978	17200	298	13800
11377100	4/2/1978	15600	159	6700
11377100	4/3/1978	12500	60	2030
11377100	4/3/1978	12400	54	1810
11377100	4/3/1978	12400	42	1410
11377100	4/3/1978	12300	47	1560

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	4/4/1978	13900	55	2060
11377100	4/5/1978	11500	244	7580
11377100	4/5/1978	10200	28	771
11377100	4/6/1978	23900	142	9160
11377100	4/6/1978	23000	44	2730
11377100	4/7/1978	19500	24	1260
11377100	4/7/1978	19200	253	13100
11377100	4/8/1978	18000	40	1940
11377100	4/9/1978	18200	38	1870
11377100	4/10/1978	17500	46	2170
11377100	4/11/1978	17000	34	1560
11377100	4/12/1978	16000	35	1510
11377100	4/13/1978	15200	28	1150
11377100	4/14/1978	16800	14	635
11377100	4/15/1978	15400	31	1290
11377100	4/16/1978	18200	28	1380
11377100	4/17/1978	18000	32	1560
11377100	4/18/1978	16700	36	1620
11377100	4/19/1978	15200	24	985
11377100	4/20/1978	18200	18	885
11377100	4/21/1978	14200	31	1190
11377100	4/22/1978	12900	16	557
11377100	4/23/1978	12400	24	804
11377100	4/24/1978	9970	16	431
11377100	4/25/1978	18100	420	20500
11377100	4/26/1978	21600	324	18900
11377100	4/27/1978	12400	32	1070
11377100	4/28/1978	12600	27	919
11377100	4/29/1978	15900	61	2620
11377100	4/30/1978	15300	67	2770
11377100	5/1/1978	15300	50	2070
11377100	5/1/1978	15300	29	1200
11377100	5/1/1978	15200	30	1230
11377100	5/1/1978	15200	27	1110
11377100	5/1/1978	15100	34	1390
11377100	5/2/1978	14700	24	953
11377100	5/3/1978	14500	20	783
11377100	5/4/1978	14000	22	832
11377100	5/5/1978	14100	14	533

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	5/6/1978	14000	8	302
11377100	5/7/1978	13800	9	335
11377100	5/8/1978	12800	20	691
11377100	5/9/1978	12700	13	446
11377100	5/10/1978	12500	16	540
11377100	5/11/1978	11600	13	407
11377100	5/12/1978	11500	13	404
11377100	5/13/1978	11500	12	373
11377100	5/14/1978	11500	33	1030
11377100	5/15/1978	11500	4	124
11377100	5/16/1978	10600	11	315
11377100	5/17/1978	10200	8	220
11377100	5/18/1978	10100	6	164
11377100	5/19/1978	9910	9	241
11377100	5/20/1978	9860	11	293
11377100	5/21/1978	9710	11	288
11377100	5/22/1978	9480	10	256
11377100	5/23/1978	8830	10	238
11377100	5/24/1978	8690	10	235
11377100	5/25/1978	8690	13	305
11377100	5/26/1978	8650	18	420
11377100	5/27/1978	8310	5	112
11377100	5/28/1978	8400	8	181
11377100	5/29/1978	8500	6	138
11377100	5/30/1978	8430	5	114
11377100	5/31/1978	8330	18	405
11377100	6/2/1978	8310	10	224
11377100	6/2/1978	8270	9	201
11377100	6/2/1978	8260	12	268
11377100	6/5/1978	8200	22	487
11377100	6/7/1978	8920	9	217
11377100	6/9/1978	9410	10	254
11377100	6/11/1978	9370	9	228
11377100	6/13/1978	9500	16	410
11377100	6/15/1978	9950	12	322
11377100	6/17/1978	10100	2	55
11377100	6/19/1978	9990	29	782
11377100	6/21/1978	9940	4	107
11377100	6/23/1978	9910	18	482

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	6/25/1978	10400	8	225
11377100	6/27/1978	10400	8	225
11377100	6/29/1978	10500	13	369
11377100	7/1/1978	10400	5	140
11377100	7/3/1978	10500	6	170
11377100	7/5/1978	10800	17	496
11377100	7/5/1978	10700	11	318
11377100	7/5/1978	10600	7	200
11377100	7/5/1978	10500	14	397
11377100	7/7/1978	10100	15	409
11377100	7/9/1978	10300	19	528
11377100	7/11/1978	10100	4	109
11377100	7/13/1978	10200	6	165
11377100	7/15/1978	11300	14	427
11377100	7/17/1978	11300	10	305
11377100	7/19/1978	11300	4	122
11377100	7/21/1978	11200	8	242
11377100	7/23/1978	11400	6	185
11377100	7/25/1978	11300	3	92
11377100	7/27/1978	11300	9	275
11377100	7/29/1978	11300	2	61
11377100	7/31/1978	11200	3	91
11377100	7/31/1978	11200	12	363
11377100	7/31/1978	11200	9	272
11377100	8/1/1978	11300	9	275
11377100	8/10/1978	11100	5	150
11377100	8/15/1978	12700	3	103
11377100	8/23/1978	9910	5	134
11377100	8/31/1978	8630	4	93
11377100	9/5/1978	8490	3	69
11377100	9/12/1978	7410	9	180
11377100	9/19/1978	6420	1	17
11377100	9/26/1978	6500	6	105
11377100	10/3/1978	6340	7	120
11377100	10/9/1978	6480	7	122
11377100	10/16/1978	6450	6	104
11377100	10/23/1978	6520	5	88
11377100	11/1/1978	5930	5	80
11377100	11/3/1978	5710	5	77

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	11/4/1978	6500	4	70
11377100	11/6/1978	6610	6	107
11377100	11/7/1978	6580	3	53
11377100	11/7/1978	6540	3	53
11377100	11/7/1978	6540	3	53
11377100	11/8/1978	6540	6	106
11377100	11/10/1978	6530	5	88
11377100	11/12/1978	6540	3	53
11377100	11/12/1978	6540	2	35
11377100	11/12/1978	6570	3	53
11377100	11/13/1978	6610	7	125
11377100	11/13/1978	6630	8	143
11377100	11/14/1978	6710	3	54
11377100	11/15/1978	6690	4	72
11377100	11/17/1978	6750	2	36
11377100	11/18/1978	6800	3	55
11377100	11/19/1978	6800	15	275
11377100	11/20/1978	7050	18	343
11377100	11/20/1978	7210	12	234
11377100	11/21/1978	7340	5	99
11377100	11/21/1978	7350	4	79
11377100	11/21/1978	7360	5	99
11377100	11/22/1978	7220	3	58
11377100	11/22/1978	7150	6	116
11377100	11/24/1978	6930	6	112
11377100	11/26/1978	6810	2	37
11377100	11/28/1978	6860	3	56
11377100	11/30/1978	6830	3	55
11377100	12/1/1978	6840	4	74
11377100	12/1/1978	6860	5	93
11377100	12/1/1978	6870	5	93
11377100	12/2/1978	6870	6	111
11377100	12/5/1978	6780	5	92
11377100	12/7/1978	6790	6	110
11377100	12/9/1978	6750	6	109
11377100	12/11/1978	6780	10	183
11377100	12/13/1978	6830	19	350
11377100	12/15/1978	6750	6	109
11377100	12/18/1978	7000	6	113

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	12/20/1978	6730	7	127
11377100	12/22/1978	6740	6	109
11377100	12/27/1978	6700	8	145
11377100	12/29/1978	6720	11	200
11377100	1/2/1979	6990	8	151
11377100	1/2/1979	6970	9	169
11377100	1/4/1979	6870	9	167
11377100	1/6/1979	5940	9	144
11377100	1/8/1979	6140	4	66
11377100	1/9/1979	8670	27	632
11377100	1/9/1979	8610	23	535
11377100	1/9/1979	8490	27	619
11377100	1/10/1979	6790	19	348
11377100	1/10/1979	6730	20	363
11377100	1/10/1979	6700	26	470
11377100	1/11/1979	23000	376	23400
11377100	1/11/1979	27600	429	32000
11377100	1/12/1979	13400	95	3440
11377100	1/12/1979	12800	52	1800
11377100	1/12/1979	25100	52	3520
11377100	1/14/1979	14000	68	2570
11377100	1/14/1979	20700	65	3630
11377100	1/15/1979	40600	660	72300
11377100	1/15/1979	38600	688	71700
11377100	1/15/1979	33600	34	3080
11377100	1/16/1979	14700	38	1510
11377100	1/16/1979	14300	53	2050
11377100	1/16/1979	13500	10	364
11377100	1/17/1979	10600	7	200
11377100	1/18/1979	8020	20	433
11377100	1/20/1979	7570	7	143
11377100	1/21/1979	7440	22	442
11377100	1/22/1979	7390	6	120
11377100	1/23/1979	7080	10	191
11377100	1/24/1979	6310	6	102
11377100	1/25/1979	6400	6	104
11377100	1/26/1979	6260	8	135
11377100	1/27/1979	6160	8	133
11377100	1/29/1979	6140	16	265

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	1/30/1979	6100	62	1020
11377100	1/31/1979	5980	11	178
11377100	1/31/1979	5840	3	47
11377100	1/31/1979	5640	4	61
11377100	2/1/1979	5580	6	90
11377100	2/2/1979	5210	16	225
11377100	2/2/1979	5210	11	155
11377100	2/2/1979	5360	5	72
11377100	2/2/1979	5320	4	57
11377100	2/3/1979	4880	4	53
11377100	2/4/1979	4800	3	39
11377100	2/5/1979	4800	14	181
11377100	2/7/1979	4380	13	154
11377100	2/9/1979	4290	14	162
11377100	2/10/1979	4220	5	57
11377100	2/11/1979	4250	2	23
11377100	2/11/1979	4270	31	357
11377100	2/13/1979	19000	409	21000
11377100	2/13/1979	22300	149	8970
11377100	2/13/1979	25400	703	48200
11377100	2/15/1979	9670	170	4440
11377100	2/15/1979	8920	138	3320
11377100	2/15/1979	8670	95	2220
11377100	2/16/1979	16700	50	2250
11377100	2/17/1979	8450	36	821
11377100	2/18/1979	8840	38	907
11377100	2/18/1979	17000	54	2480
11377100	2/19/1979	13000	92	3230
11377100	2/20/1979	9270	102	2550
11377100	2/20/1979	12100	65	2120
11377100	2/21/1979	22500	264	16000
11377100	2/21/1979	26900	241	17500
11377100	2/21/1979	29000	94	7360
11377100	2/21/1979	30200	241	19700
11377100	2/22/1979	13000	124	4350
11377100	2/22/1979	12700	265	9090
11377100	2/23/1979	17600	106	5040
11377100	2/23/1979	15200	82	3370
11377100	2/23/1979	13600	82	3010

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	2/24/1979	11200	84	2540
11377100	2/25/1979	7940	51	1090
11377100	2/28/1979	7210	22	428
11377100	2/28/1979	7400	15	300
11377100	3/1/1979	19600	185	9790
11377100	3/1/1979	16200	127	5560
11377100	3/1/1979	15100	100	4080
11377100	3/2/1979	9500	14	359
11377100	3/2/1979	9100	16	393
11377100	3/3/1979	7990	19	410
11377100	3/3/1979	7870	22	467
11377100	3/3/1979	7870	14	297
11377100	3/4/1979	7800	10	211
11377100	3/5/1979	7410	31	620
11377100	3/6/1979	6970	30	565
11377100	3/7/1979	6930	35	655
11377100	3/8/1979	7100	5	96
11377100	3/8/1979	7220	13	253
11377100	3/9/1979	7210	20	389
11377100	3/10/1979	6910	16	299
11377100	3/11/1979	6600	19	339
11377100	3/12/1979	6270	35	593
11377100	3/15/1979	5970	7	113
11377100	3/15/1979	5920	11	176
11377100	3/16/1979	6410	8	138
11377100	3/16/1979	7120	16	308
11377100	3/16/1979	7420	19	381
11377100	3/17/1979	7770	14	294
11377100	3/17/1979	7510	21	426
11377100	3/17/1979	7510	22	446
11377100	3/18/1979	8140	20	440
11377100	3/18/1979	7790	8	168
11377100	3/18/1979	7600	44	903
11377100	3/19/1979	10700	37	1070
11377100	3/19/1979	10400	44	1240
11377100	3/19/1979	9820	68	1800
11377100	3/21/1979	6870	50	927
11377100	3/23/1979	6830	54	996
11377100	3/24/1979	6230	21	353

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/26/1979	5890	59	938
11377100	3/26/1979	5890	32	509
11377100	3/26/1979	5870	32	507
11377100	3/27/1979	6080	73	1200
11377100	3/27/1979	6290	80	1360
11377100	3/27/1979	7430	64	1280
11377100	3/28/1979	14900	73	2940
11377100	3/28/1979	15000	71	2880
11377100	3/28/1979	15500	71	2970
11377100	3/29/1979	13600	79	2900
11377100	3/29/1979	13500	90	3280
11377100	3/29/1979	13400	34	1230
11377100	3/30/1979	13400	74	2680
11377100	4/2/1979	11100	36	1080
11377100	4/2/1979	11000	24	713
11377100	4/2/1979	11000	22	653
11377100	4/3/1979	9950	8	215
11377100	4/4/1979	7470	6	121
11377100	4/5/1979	7420	8	160
11377100	4/6/1979	7360	15	298
11377100	4/6/1979	7400	18	360
11377100	4/6/1979	7440	30	603
11377100	4/7/1979	7470	4	81
11377100	4/8/1979	7340	15	297
11377100	4/9/1979	7310	17	336
11377100	4/10/1979	6250	25	422
11377100	4/11/1979	5470	6	89
11377100	4/12/1979	5310	3	43
11377100	4/13/1979	5250	9	128
11377100	4/14/1979	5640	3	46
11377100	4/15/1979	7290	5	98
11377100	4/16/1979	7320	4	79
11377100	4/16/1979	7420	11	220
11377100	4/17/1979	7690	6	125
11377100	4/17/1979	7600	13	267
11377100	4/17/1979	7540	8	163
11377100	4/18/1979	7470	6	121
11377100	4/19/1979	7290	5	98
11377100	4/21/1979	7890	4	85

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	4/22/1979	8240	7	156
11377100	4/22/1979	8610	6	139
11377100	4/22/1979	8760	3	71
11377100	4/23/1979	10200	25	688
11377100	4/23/1979	10400	14	393
11377100	4/24/1979	13700	17	629
11377100	4/25/1979	11100	18	539
11377100	4/25/1979	11100	9	270
11377100	4/25/1979	11000	13	386
11377100	4/26/1979	9800	14	370
11377100	4/26/1979	9560	24	619
11377100	4/26/1979	9300	11	276
11377100	4/27/1979	10100	36	982
11377100	4/28/1979	9310	10	251
11377100	4/29/1979	8960	9	218
11377100	4/30/1979	8870	28	671
11377100	5/1/1979	9600	17	441
11377100	5/2/1979	9280	19	476
11377100	5/2/1979	9240	15	374
11377100	5/2/1979	9190	17	422
11377100	5/2/1979	9140	16	395
11377100	5/3/1979	8740	11	260
11377100	5/4/1979	8650	32	747
11377100	5/5/1979	9260	51	1280
11377100	5/6/1979	11900	25	803
11377100	5/6/1979	11400	37	1140
11377100	5/6/1979	10900	25	736
11377100	5/7/1979	12800	10	346
11377100	5/7/1979	12300	16	531
11377100	5/7/1979	11800	19	605
11377100	5/8/1979	9880	13	347
11377100	5/9/1979	8220	8	178
11377100	5/10/1979	8090	11	240
11377100	5/11/1979	9970	10	269
11377100	5/12/1979	9970	4	108
11377100	5/13/1979	9950	18	484
11377100	5/14/1979	9790	16	423
11377100	5/15/1979	9630	10	260
11377100	5/16/1979	9560	8	206

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	5/17/1979	9460	8	204
11377100	5/18/1979	9420	1	25
11377100	5/19/1979	9390	4	101
11377100	5/20/1979	9520	2	51
11377100	5/21/1979	9390	6	152
11377100	5/22/1979	9350	7	177
11377100	5/23/1979	9300	9	226
11377100	5/24/1979	9140	13	321
11377100	5/25/1979	9090	26	638
11377100	5/26/1979	9100	8	197
11377100	5/27/1979	9080	2	49
11377100	5/28/1979	8780	4	95
11377100	5/29/1979	8740	5	118
11377100	5/30/1979	8610	4	93
11377100	5/31/1979	9330	4	101
11377100	6/1/1979	9180	12	297
11377100	6/1/1979	9100	7	172
11377100	6/8/1979	10800	21	612
11377100	6/13/1979	10900	23	677
11377100	6/21/1979	10900	15	441
11377100	6/27/1979	12700	13	446
11377100	7/2/1979	14800	29	1160
11377100	7/3/1979	14700	53	2100
11377100	7/11/1979	14200	30	1150
11377100	7/20/1979	14200	28	1070
11377100	7/27/1979	13600	64	2350
11377100	7/31/1979	13200	39	1390
11377100	8/2/1979	13200	16	570
11377100	8/3/1979	13200	19	677
11377100	8/7/1979	12600	7	238
11377100	8/16/1979	8310	6	135
11377100	8/24/1979	8150	4	88
11377100	8/31/1979	7660	6	124
11377100	9/1/1979	7610	5	103
11377100	9/4/1979	7230	5	98
11377100	9/4/1979	7130	5	96
11377100	9/14/1979	5600	6	91
11377100	9/17/1979	5190	7	98
11377100	9/29/1979	5310	4	57

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	10/1/1979	5760	6	93
11377100	10/4/1979	5680	5	77
11377100	10/12/1979	5820	6	94
11377100	10/17/1979	5030	6	81
11377100	10/23/1979	5350	11	159
11377100	10/29/1979	4970	10	134
11377100	11/2/1979	4640	9	113
11377100	11/2/1979	4700	6	76
11377100	11/2/1979	4780	6	77
11377100	11/3/1979	4740	6	77
11377100	11/3/1979	4840	9	118
11377100	11/3/1979	5090	6	82
11377100	11/4/1979	6640	22	394
11377100	11/4/1979	6210	16	268
11377100	11/4/1979	5810	16	251
11377100	11/5/1979	6230	14	235
11377100	11/5/1979	6570	13	231
11377100	11/5/1979	6280	13	220
11377100	11/6/1979	5790	14	219
11377100	11/6/1979	5720	14	216
11377100	11/6/1979	5710	13	200
11377100	11/7/1979	5710	14	216
11377100	11/8/1979	5580	11	166
11377100	11/9/1979	5130	6	83
11377100	11/10/1979	4990	5	67
11377100	11/11/1979	4900	8	106
11377100	11/18/1979	8210	9	200
11377100	11/19/1979	7370	10	199
11377100	11/20/1979	6910	14	261
11377100	11/22/1979	6620	9	161
11377100	11/22/1979	6690	11	199
11377100	11/22/1979	6760	11	201
11377100	11/23/1979	9350	38	959
11377100	11/23/1979	8970	26	630
11377100	11/23/1979	8470	36	823
11377100	11/25/1979	8990	48	1170
11377100	11/25/1979	8820	37	881
11377100	11/25/1979	8480	42	962
11377100	11/26/1979	7680	23	477

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	11/27/1979	7270	29	569
11377100	11/28/1979	7130	29	558
11377100	11/29/1979	6970	11	207
11377100	11/30/1979	6910	9	168
11377100	12/1/1979	6860	13	241
11377100	12/2/1979	6840	14	259
11377100	12/3/1979	6780	12	220
11377100	12/3/1979	6810	10	184
11377100	12/3/1979	6810	7	129
11377100	12/4/1979	6660	10	180
11377100	12/5/1979	6610	12	214
11377100	12/6/1979	6620	5	89
11377100	12/7/1979	6620	11	197
11377100	12/8/1979	6520	11	194
11377100	12/9/1979	6470	8	140
11377100	12/10/1979	6420	4	69
11377100	12/11/1979	6330	5	85
11377100	12/12/1979	6330	4	68
11377100	12/13/1979	6350	5	86
11377100	12/14/1979	6280	7	119
11377100	12/15/1979	6280	7	119
11377100	12/16/1979	6310	8	136
11377100	12/17/1979	6260	6	101
11377100	12/18/1979	6350	8	137
11377100	12/19/1979	6350	12	206
11377100	12/19/1979	6370	9	155
11377100	12/19/1979	6370	6	103
11377100	12/20/1979	6400	18	311
11377100	12/20/1979	6420	6	104
11377100	12/20/1979	6520	10	176
11377100	12/21/1979	7320	7	138
11377100	12/22/1979	7110	11	211
11377100	12/22/1979	7020	14	265
11377100	12/24/1979	48700	1030	135000
11377100	12/24/1979	44900	858	104000
11377100	12/24/1979	54200	773	113000
11377100	12/26/1979	14000	81	3060
11377100	12/26/1979	13800	75	2790
11377100	12/26/1979	13400	74	2680

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	12/26/1979	12900	63	2190
11377100	12/27/1979	10800	33	962
11377100	12/28/1979	9820	23	610
11377100	12/30/1979	13300	76	2730
11377100	1/2/1980	12300	47	1560
11377100	1/2/1980	12000	38	1230
11377100	1/2/1980	11900	36	1160
11377100	1/13/1980	33700	563	51200
11377100	1/13/1980	34000	509	46700
11377100	1/17/1980	50200	154	20900
11377100	1/17/1980	50700	111	15200
11377100	1/30/1980	14400	42	1630
11377100	1/31/1980	14200	42	1610
11377100	2/1/1980	13000	41	1440
11377100	2/1/1980	12800	22	760
11377100	2/2/1980	11800	21	669
11377100	2/3/1980	16200	21	919
11377100	2/4/1980	12300	16	531
11377100	2/5/1980	11500	26	807
11377100	2/6/1980	11300	27	824
11377100	2/7/1980	11000	42	1250
11377100	2/7/1980	10900	26	765
11377100	2/8/1980	11000	21	624
11377100	2/9/1980	10900	24	706
11377100	2/10/1980	10300	19	528
11377100	2/11/1980	9190	23	571
11377100	2/12/1980	9100	20	491
11377100	2/13/1980	8820	16	381
11377100	2/14/1980	8920	17	409
11377100	2/14/1980	8870	17	407
11377100	2/14/1980	8820	18	429
11377100	2/15/1980	8950	18	435
11377100	2/15/1980	9000	17	413
11377100	2/15/1980	9050	17	415
11377100	2/20/1980	93700	312	78900
11377100	2/20/1980	84700	264	60400
11377100	2/21/1980	92800	620	155000
11377100	2/21/1980	83400	282	63500
11377100	2/21/1980	83300	261	58700

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	2/21/1980	83300	261	58700
11377100	2/21/1980	81600	264	58200
11377100	2/21/1980	77000	237	49300
11377100	2/22/1980	68000	61	11200
11377100	2/22/1980	67900	65	11900
11377100	2/22/1980	75600	152	31000
11377100	2/23/1980	67700	125	22800
11377100	2/23/1980	66400	75	13400
11377100	2/23/1980	65700	78	13800
11377100	2/24/1980	63100	41	6990
11377100	2/24/1980	62500	39	6580
11377100	2/24/1980	62400	70	11800
11377100	2/28/1980	73000	160	31500
11377100	2/28/1980	74900	162	32800
11377100	2/28/1980	68900	95	17700
11377100	2/29/1980	52400	23	3250
11377100	2/29/1980	51000	43	5920
11377100	2/29/1980	50700	38	5200
11377100	3/1/1980	49100	24	3180
11377100	3/1/1980	48700	42	5520
11377100	3/1/1980	48400	24	3140
11377100	3/2/1980	47700	22	2830
11377100	3/2/1980	47700	20	2580
11377100	3/2/1980	47500	30	3850
11377100	3/3/1980	47000	55	6980
11377100	3/3/1980	46900	49	6210
11377100	3/3/1980	46900	50	6330
11377100	3/3/1980	46900	58	7350
11377100	3/4/1980	49300	45	5990
11377100	3/5/1980	51200	52	7190
11377100	3/5/1980	58700	50	7920
11377100	3/5/1980	56600	54	8250
11377100	3/6/1980	50400	47	6400
11377100	3/6/1980	45900	54	6690
11377100	3/6/1980	41900	57	6450
11377100	3/7/1980	28100	50	3790
11377100	3/8/1980	25700	48	3330
11377100	3/9/1980	24700	33	2200
11377100	3/10/1980	23700	26	1660

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/11/1980	23100	25	1560
11377100	3/12/1980	22400	17	1030
11377100	3/13/1980	22200	18	1080
11377100	3/14/1980	21700	21	1230
11377100	3/16/1980	22600	24	1460
11377100	3/17/1980	21500	19	1100
11377100	3/18/1980	20300	18	987
11377100	3/19/1980	17200	12	557
11377100	3/21/1980	14600	13	512
11377100	3/22/1980	12600	12	408
11377100	3/23/1980	10500	14	397
11377100	3/24/1980	9770	9	237
11377100	3/25/1980	9560	8	206
11377100	3/26/1980	9540	8	206
11377100	3/27/1980	9280	7	175
11377100	3/28/1980	9140	7	173
11377100	3/29/1980	9020	6	146
11377100	3/30/1980	8870	12	287
11377100	3/31/1980	8990	22	534
11377100	4/1/1980	9880	25	667
11377100	4/1/1980	9930	20	536
11377100	4/1/1980	9930	20	536
11377100	4/1/1980	9980	22	593
11377100	4/2/1980	9960	19	511
11377100	4/3/1980	9750	15	395
11377100	4/4/1980	9780	15	396
11377100	4/4/1980	9780	15	396
11377100	4/4/1980	9860	15	399
11377100	4/5/1980	11100	11	330
11377100	4/6/1980	10000	14	378
11377100	4/7/1980	9190	22	546
11377100	4/8/1980	8930	17	410
11377100	4/9/1980	8840	10	239
11377100	4/10/1980	8750	8	189
11377100	4/11/1980	8660	10	234
11377100	4/12/1980	8590	7	162
11377100	4/13/1980	8420	14	318
11377100	4/14/1980	8110	10	219
11377100	4/15/1980	8290	12	269

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	4/16/1980	8100	14	306
11377100	4/17/1980	8110	20	438
11377100	4/19/1980	8870	17	407
11377100	4/19/1980	8820	19	452
11377100	4/20/1980	8950	26	628
11377100	4/21/1980	9680	19	497
11377100	4/22/1980	9280	16	401
11377100	4/23/1980	8840	15	358
11377100	4/24/1980	8320	10	225
11377100	4/25/1980	8280	8	179
11377100	4/26/1980	8500	7	161
11377100	4/27/1980	8160	4	88
11377100	4/28/1980	8110	13	285
11377100	4/29/1980	8400	7	159
11377100	4/30/1980	8560	11	254
11377100	5/1/1980	8560	12	277
11377100	5/1/1980	8560	9	208
11377100	5/1/1980	8510	8	184
11377100	5/2/1980	8610	8	186
11377100	5/3/1980	9280	9	226
11377100	5/4/1980	9290	10	251
11377100	5/5/1980	9400	9	228
11377100	5/7/1980	9330	10	252
11377100	5/9/1980	9430	15	382
11377100	5/9/1980	9590	16	414
11377100	5/12/1980	8970	14	339
11377100	5/14/1980	8740	9	212
11377100	5/16/1980	7830	10	211
11377100	5/19/1980	7640	9	186
11377100	5/21/1980	8420	9	205
11377100	5/23/1980	8350	9	203
11377100	5/26/1980	8390	4	91
11377100	5/28/1980	8280	3	67
11377100	5/30/1980	8130	4	88
11377100	6/2/1980	8470	4	91
11377100	6/3/1980	8480	9	206
11377100	6/3/1980	8480	7	160
11377100	6/4/1980	8560	14	324
11377100	6/4/1980	8560	8	185

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	6/4/1980	8560	6	139
11377100	6/5/1980	8790	16	380
11377100	6/5/1980	8790	14	332
11377100	6/5/1980	8790	13	309
11377100	6/9/1980	10600	6	172
11377100	6/11/1980	10800	21	612
11377100	6/13/1980	11600	22	689
11377100	6/16/1980	12500	28	945
11377100	6/18/1980	13900	4	150
11377100	6/20/1980	13800	4	149
11377100	6/23/1980	12100	8	261
11377100	6/25/1980	12100	5	163
11377100	6/27/1980	12000	10	324
11377100	7/3/1980	11300	20	610
11377100	7/9/1980	11200	10	302
11377100	7/18/1980	12200	9	296
11377100	7/23/1980	12100	6	196
11377100	7/30/1980	11300	4	122
11377100	8/2/1980	11000	12	356
11377100	8/2/1980	11000	8	238
11377100	8/6/1980	10400	8	225
11377100	8/7/1980	10500	6	170
11377100	8/21/1980	9070	4	98
11377100	8/29/1980	8250	3	67
11377100	9/4/1980	7880	25	532
11377100	9/10/1980	6910	9	168
11377100	9/10/1980	6910	23	429
11377100	9/18/1980	6470	80	1400
11377100	9/23/1980	6590	10	178
11377100	9/28/1980	6400	7	121
11377100	11/1/1980	5190	3	42
11377100	11/3/1980	6330	65	1110
11377100	11/7/1980	6350	3	51
11377100	11/13/1980	6230	4	67
11377100	12/2/1980	6640	6	108
11377100	1/6/1981	6070	3	49
11377100	1/29/1981	25200	228	15500
11377100	1/29/1981	25200	228	15500
11377100	2/3/1981	7180	12	233

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	3/2/1981	6900	9	168
11377100	4/1/1981	17100	27	1250
11377100	4/1/1981	17100	27	1250
11377100	5/4/1981	10900	7	206
11377100	11/3/1981	4430	8	96
11377100	11/19/1981	8190	55	1220
11377100	11/30/1981	17400	32	1500
11377100	12/22/1981	49100	186	24700
11377100	2/4/1982	12600	15	510
11377100	4/5/1982	27800	42	3150
11377100	5/4/1982	20900	16	903
11377100	11/3/1982	8900	5	120
11377100	12/1/1982	19500	19	100
11377100	12/22/1982	49100	186	24700
11377100	12/23/1982	58300	148	23300
11377100	1/3/1983	10800	8	233
11377100	3/4/1983	99300	619	166000
11377100	5/2/1983	26400	105	
11377100	3/8/1996	32100	54	
11377100	4/24/1996	8560	16	
11377100	5/30/1996	15900	11	
11377100	6/27/1996	12600	4	
11377100	7/11/1996	15100	5	
11377100	8/29/1996	12900	8	
11377100	9/20/1996	9500	4	
11377100	11/22/1996	7780	15	
11377100	12/12/1996	42200	51	
11377100	1/3/1997	86400	355	
11377100	2/20/1997	10600	37	
11377100	3/20/1997	8300	22	
11377100	4/22/1997	9140	27	
11377100	5/30/1997	10100	14	
11377100	6/25/1997	15400	14	
11377100	7/23/1997	16000	9	
11377100	8/21/1997	10700	9	
11377100	9/17/1997	8390	9	
11377100	10/22/1997	5330	6	
11377100	11/19/1997	9900	43	
11377100	12/10/1997	7620	18	

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11377100	1/14/1998	18300	141	
11377100	2/18/1998	70700	63	
11377100	3/18/1998	12900	38	
11377100	4/9/1998	19200	33	
11377100	5/14/1998	17800	26	
11377100	1/19/2000	9790	39	
11377100	1/20/2000	26100	410	
11377100	2/20/2000	44700	23	
11377100	2/21/2000	50000	62	
11377200	2/2/1967	52800	135	19200
11377200	4/27/1967	33100	232	20700
11377200	1/15/1968	44600	910	110000
11377200	2/21/1968	35200	412	39200
11377200	12/10/1968	28200	418	31800
11377200	1/3/1969	9130	125	3080
11377200	1/12/1969	53000	780	112000
11377200	1/12/1969	60500	608	99300
11377200	1/13/1969	78000	710	150000
11377200	1/23/1969	66700	228	41100
11377200	1/31/1969	34900	60	5650
11377200	2/6/1969	43000	595	69100
11377200	3/1/1969	44600	245	29500
11377200	12/19/1969	50500	575	78400
11377200	12/20/1969	48600	356	46700
11377200	12/21/1969	65200	1110	195000
11377200	1/10/1970	43000	322	37400
11377200	1/16/1970	95900	898	233000
11377200	1/17/1970	69200	322	60200
11377200	1/21/1970	90600	311	76100
11377200	1/24/1970	111000	2770	830000
11377200	1/26/1970	103000	253	70400
11377200	1/27/1970	138000	1830	682000
11377200	1/27/1970	125000	715	241000
11377200	2/2/1970	80200	139	30100
11377200	2/17/1970	27700	190	14200
11378500	11/2/1956	8590	17	394
11378500	12/11/1956	6980	8	151
11378500	1/21/1957	6270	77	1300
11378500	2/18/1957	4010	9	97

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11378500	2/28/1957	22000	137	8140
11378500	3/26/1957	7640	13	268
11378500	4/18/1957	9750	452	11900
11378500	5/14/1957	11800	94	3000
11378500	6/10/1957	9400	10	254
11378500	7/29/1957	9350	8	202
11378500	9/17/1957	7430	6	120
11378500	10/13/1957	27900	1050	79100
11378500	11/14/1957	26900	725	52700
11378500	12/29/1957	18400	156	7750
11378500	1/10/1958	22100	331	19800
11378500	1/26/1958	64200	1720	298000
11378500	1/31/1958	53400	261	37600
11378500	2/4/1958	76000	384	78800
11378500	2/12/1958	108000	1050	306000
11378500	2/22/1958	99600	493	133000
11378500	3/22/1958	42600	1010	116000
11378500	3/30/1958	34600	389	36300
11378500	4/10/1958	40300	131	14300
11378500	1/9/1959	30600	920	76000
11378500	2/16/1959	83200	1290	290000
11378500	9/19/1959	17500	1400	66200
11378500	2/8/1960	73400	1770	351000
11378500	2/9/1960	34400	748	69500
11378500	3/6/1960	23900	729	47000
11378500	12/1/1960	65900	918	163000
11378500	1/30/1961	21900	853	50400
11378500	1/31/1961	47700	1050	135000
11378500	2/1/1961	23200	431	27000
11378500	2/2/1961	35000	1270	120000
11378500	2/11/1961	38000	782	80200
11378500	12/1/1961	31900	694	59800
11378500	12/21/1961	13600	304	11200
11378500	2/15/1962	65400	1480	261000
11378500	2/16/1962	28500	204	15700
11378500	3/6/1962	59800	1440	233000
11378500	3/9/1962	17300	46	2150
11378500	10/12/1962	32600	1080	95100
11378500	11/27/1962	12300	147	4880

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11378500	12/3/1962	21600	418	24400
11378500	12/17/1962	42400	455	52100
11378500	2/1/1963	46900	1170	148000
11378500	2/10/1963	25300	690	47100
11378500	2/13/1963	25500	322	22200
11378500	5/22/1963	14500	19	744
11378500	11/12/1963	8240	10	222
11378500	1/21/1964	60800	957	157000
11378500	1/21/1964	26200	607	42900
11378500	11/11/1964	8480	67	1530
11378500	12/20/1964	9980	308	8300
11378500	12/21/1964	10600	713	20400
11378500	12/21/1964	16000	462	20000
11378500	12/21/1964	20500	469	26000
11378500	12/22/1964	72300	2750	537000
11378500	12/23/1964	114000	1380	425000
11378500	12/23/1964	94800	1550	397000
11378500	12/23/1964	78200	1440	304000
11378500	12/25/1964	57800	715	112000
11378500	12/27/1964	67100	350	63400
11378500	12/29/1964	50600	170	23200
11378500	12/30/1964	44600	120	14500
11378500	1/1/1965	27900	121	9120
11378500	1/2/1965	25200	101	6870
11378500	1/3/1965	37200	335	33600
11378500	1/8/1965	63700	179	30800
11378500	1/10/1965	34500	109	10200
11378500	1/21/1965	22900	102	6310
11378500	2/9/1965	19500	35	1840
11378500	4/2/1965	11400	103	3170
11378500	4/9/1965	36400	1280	126000
11378500	11/15/1965	23400	2030	128000
11378500	11/16/1965	11400	105	3230
11378500	11/18/1965	19600	323	17100
11378500	1/5/1966	76300	1840	379000
11378500	2/1/1966	17700	40	1910
11378500	2/6/1966	28000	481	36400
11378500	3/2/1966	8050	12	261

Table A-2. USGS suspended sediment data at sites near Hamilton City.

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load, (tons/d)
11383730	1/19/2000	12800	37	
11383730	1/19/2000	17000	67	
11383730	1/20/2000	14600	326	
11383730	2/20/2000	47500	55	
11383730	2/21/2000	48900	111	
11383730	2/21/2000	53500	190	
11383800	5/11/1977	8600	10	232
11383800	5/12/1977	9700	34	890
11383800	6/8/1977	5890	12	191
11383800	11/30/1977	4930		19
11383800	12/15/1977	35900	1280	124000
11383800	1/10/1978	11100	1010	30300
11383800	1/18/1978	48300	758	98900
11383800	2/8/1978	76500	1130	233000
11383800	2/10/1978	40000	388	41900
11383800	3/8/1978	47000	275	34900
11383800	3/22/1978	15300		76
11383800	3/22/1978	15400	115	4780
11383800	4/27/1978	16700	106	4780
11383800	6/27/1978	7770		61
11383800	8/1/1978	8440		30
11383800	1/16/1979	25800	244	17000
11383800	2/14/1979	67500	749	137000
11383800	2/15/1979	18800	620	31500
11383800	3/7/1979	10100	28	764
11383800	4/4/1979	9500	22	564
11383800	5/15/1979	8640	19	443

Table A-3. USGS suspended sediment data at sites near Colusa.

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11389000	11/3/1977	5120	24	332
11389000	12/16/1977	21000	933	52900
11389000	1/4/1978	10400	92	2580
11389000	1/11/1978	69700	648	122000
11389000	1/12/1978	31700	532	45500
11389000	1/17/1978	119000	906	291000
11389000	4/20/1978	16900	53	2420
11389000	6/1/1978	7870	36	765
11389000	7/5/1978	8090	26	568
11389000	12/27/1978	19800	231	12300
11389000	1/16/1979	37500	611	61900
11389000	2/15/1979	45900	498	61700
11389000	3/8/1979	11400	56	1720
11389000	4/5/1979	9360	30	758
11389000	5/16/1979	8650	21	490
11389000	12/27/1979	19800	231	12300
11389000	1/24/1980	43000	201	23300
11389000	2/20/1980	122000	1270	418000
11389000	4/1/1980	11000	60	1780
11389500	12/19/1972	30600	486	40200
11389500	12/20/1972	32100	492	42600
11389500	1/11/1973	32500	249	21900
11389500	1/12/1973	35100	1100	104000
11389500	1/13/1973	39200	667	70600
11389500	1/15/1973	34300	342	31700
11389500	1/16/1973	32700	331	29200
11389500	1/17/1973	38400	846	87700
11389500	1/19/1973	41000	645	71400
11389500	1/20/1973	42000	400	45400
11389500	1/22/1973	37900	315	32200
11389500	1/23/1973	37400	239	24100
11389500	1/24/1973	36700	209	20700
11389500	1/26/1973	34800	213	20000
11389500	1/27/1973	32700	218	19200
11389500	2/6/1973	33500	466	42200
11389500	2/8/1973	38300	598	61800

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11389500	2/9/1973	37200	310	31100
11389500	2/10/1973	35300	223	21300
11389500	2/12/1973	36600	232	22900
11389500	2/13/1973	36600	256	25300
11389500	2/15/1973	38600	196	20400
11389500	2/16/1973	37200	238	23900
11389500	2/17/1973	35100	172	16300
11389500	2/28/1973	35300	428	40800
11389500	3/1/1973	37700	260	26500
11389500	3/2/1973	35900	206	20000
11389500	3/3/1973	34800	157	14800
11389500	3/5/1973	34500	136	12700
11389500	3/6/1973	33200	108	9680
11389500	3/7/1973	34400	240	22300
11389500	3/8/1973	33600	141	12800
11389500	3/9/1973	32300	116	10100
11389500	11/14/1973	38500	357	37100
11389500	11/15/1973	35600	212	20400
11389500	11/16/1973	35200	189	18000
11389500	11/17/1973	37800	270	27600
11389500	11/20/1973	41000	237	26200
11389500	2/11/1975	31700	327	28000
11389500	2/13/1975	33700	969	88200
11389500	2/13/1975	35700	1090	105000
11389500	2/14/1975	40400	1020	111000
11389500	2/14/1975	41100	836	92800
11389500	3/11/1975	35300	457	43600
11389500	3/12/1975	34100	398	36600
11389500	3/12/1975	33800	365	33300
11389500	3/20/1975	39300	855	90700
11389500	3/21/1975	40000	346	37400
11389500	1/20/1977	6920	38	710
11389500	1/26/1977	7080	33	631
11389500	2/23/1977	5890	24	382
11389500	3/20/1977	7000	101	1910
11389500	3/22/1977	6060	33	540
11389500	4/26/1977	6300	35	595
11389500	11/4/1977	4890	52	687
11389500	12/17/1977	14300	636	24600

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11389500	1/3/1978	7460	65	1310
11389500	1/11/1978	40500	601	65700
11389500	1/19/1978	40100	572	61900
11389500	2/8/1978	38600	1010	105000
11389500	3/7/1978	39900	319	34400
11389500	4/19/1978	19200	95	4930
11389500	5/17/1978	9730	194	5100
11389500	1/9/1979	12500	64	2160
11389500	1/17/1979	26100	315	22200
11389500	2/15/1979	11400	467	14400
11389500	2/15/1979	37100	459	46000
11389500	3/6/1979	11100	74	2220
11389500	4/6/1979	10000	297	8020
11389500	11/6/1979	6600	76	1350
11389500	12/26/1979	41500	340	38100
11389500	1/3/1980	19400	133	6970
11389500	1/16/1980	42900	638	73900
11389500	2/28/1996	35200	151	
11389500	3/20/1996	20700	153	
11389500	4/2/1996	13000	86	
11389500	5/16/1996	8980	52	
11389500	6/17/1996	11300	59	
11389500	7/16/1996	10900	32	
11389500	8/14/1996	11600	45	
11389500	9/25/1996	9270	30	
11389500	10/9/1996	7080	36	
11389500	11/14/1996	5820	46	
11389500	12/4/1996	7340	27	
11389500	12/16/1996	33200	92	
11389500	1/4/1997	47400	579	
11389500	2/12/1997	23700	105	
11389500	3/13/1997	8700	41	
11389500	4/16/1997	6840	47	
11389500	5/20/1997	7350	36	
11389500	6/3/1997	8420	37	
11389500	7/31/1997	10800	33	
11389500	8/18/1997	7870	28	
11389500	9/25/1997	6930	29	
11389500	10/21/1997	4340	36	

Gage	Date	Discharge (cfs)	Suspended Sediment Concentration (mg/l)	Suspended Sediment Load (tons/d)
11389500	11/13/1997	5100	23	
11389500	12/9/1997	19600	177	
11389500	1/13/1998	36600	545	
11389500	2/11/1998	45900	202	
11389500	3/17/1998	22200	149	
11389500	4/8/1998	35100	144	
11389500	5/13/1998	21000	121	
11389500	6/10/1998	25600	107	
11389500	7/29/1998	12700	94	
11389500	8/12/1998	12600	79	
11389500	9/16/1998	11300	97	
11389500	10/21/1998	6250	41	
11389500	11/12/1998	8920	57	
11389500	12/29/1998	11000	50	
11389500	1/20/1999	15100	123	
11389500	2/17/1999	33500	52	
11389500	3/11/1999	35100	54	
11389500	4/8/1999	13200	83	
11389500	5/6/1999	11400	50	
11389500	6/3/1999	10800	50	
11389500	7/20/1999	9670	28	
11389500	8/17/1999	6820	34	
11389500	9/9/1999	6920	37	
11389500	10/21/1999	4710	30	
11389500	11/4/1999	5340	29	
11389500	12/10/1999	9470	37	
11389500	1/13/2000	8140	27	
11389500	2/23/2000	38200	92	
11389500	3/10/2000	40200	96	
11389500	4/12/2000	11400	38	
11389500	5/19/2000	9290	44	
11389500	6/15/2000	10700	34	
11389500	7/19/2000	10900	20	
11389500	8/18/2000	7890	20	
11389500	9/14/2000	6130	19	

Bedload Analysis of NODOS

RECLAMATION

Managing Water in the West

Technical Report No. SRH-2011-23

Sacramento River Bedload Analysis of NODOS Alternatives

Mid Pacific Region
NODOS Investigation Report

U.S. Department of the Interior
Bureau of Reclamation

June 2011

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

Technical Report No. SRH-2011-23

Sacramento River Bedload Analysis of NODOS Alternatives

Mid Pacific Region
NODOS Investigation Report

Prepared by:

06/09/2011

David Varyu, M.S., P.E. — Date
Hydraulic Engineer
Sedimentation and River Hydraulics Group, 86-68240

6-9-2011

Blair Greimann, Ph.D., P.E. — Date
Hydraulic Engineer
Sedimentation and River Hydraulics Group, 86-68240

Report Reviewed by:

Elaina Gordon — 6/9/11

Elaina Gordon, M.S., P.E. — Date
Hydraulic Engineer
Sedimentation and River Hydraulics Group, 86-68240

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1 Introduction

The Sedimentation and River Hydraulics Group at the Technical Service Center (TSC) of the Bureau of Reclamation has been tasked, at the request of the Mid Pacific Regional Office, to provide analysis to support the North of Delta Off-Stream Storage (NODOS) Administrative Draft Environmental Impact Report/Study (ADEIR/S) and Feasibility Study (FS).

CH2MILL (2011) developed model simulations for the NODOS ADEIR/S and FS. The modeling simulations that were completed were labeled as:

- Existing Conditions
- No Action Alternative
- NODOS Alternative A
- NODOS Alternative B
- NODOS Alternative C

The purpose of the analysis was to investigate sediment transport capacity rates and a sediment budget for the existing conditions and alternative scenarios. This report provides results of sediment bedload analysis in the mainstem of the Sacramento River from Keswick Dam to Colusa. The Sacramento River from Shasta Reservoir to Colusa Weir is divided into 15 reaches, identified numerically from 23 (upstream) to 9 (downstream). Reaches 1 through 8 cover from Colusa Weir to RM80 and are not included in this analysis. Figure 1-1 through Figure 1-3 locates the reaches.

This report does not analyze suspended load in the Sacramento River, only the bed load, which consists primarily of gravel sized sediment (2 mm to 64 mm).

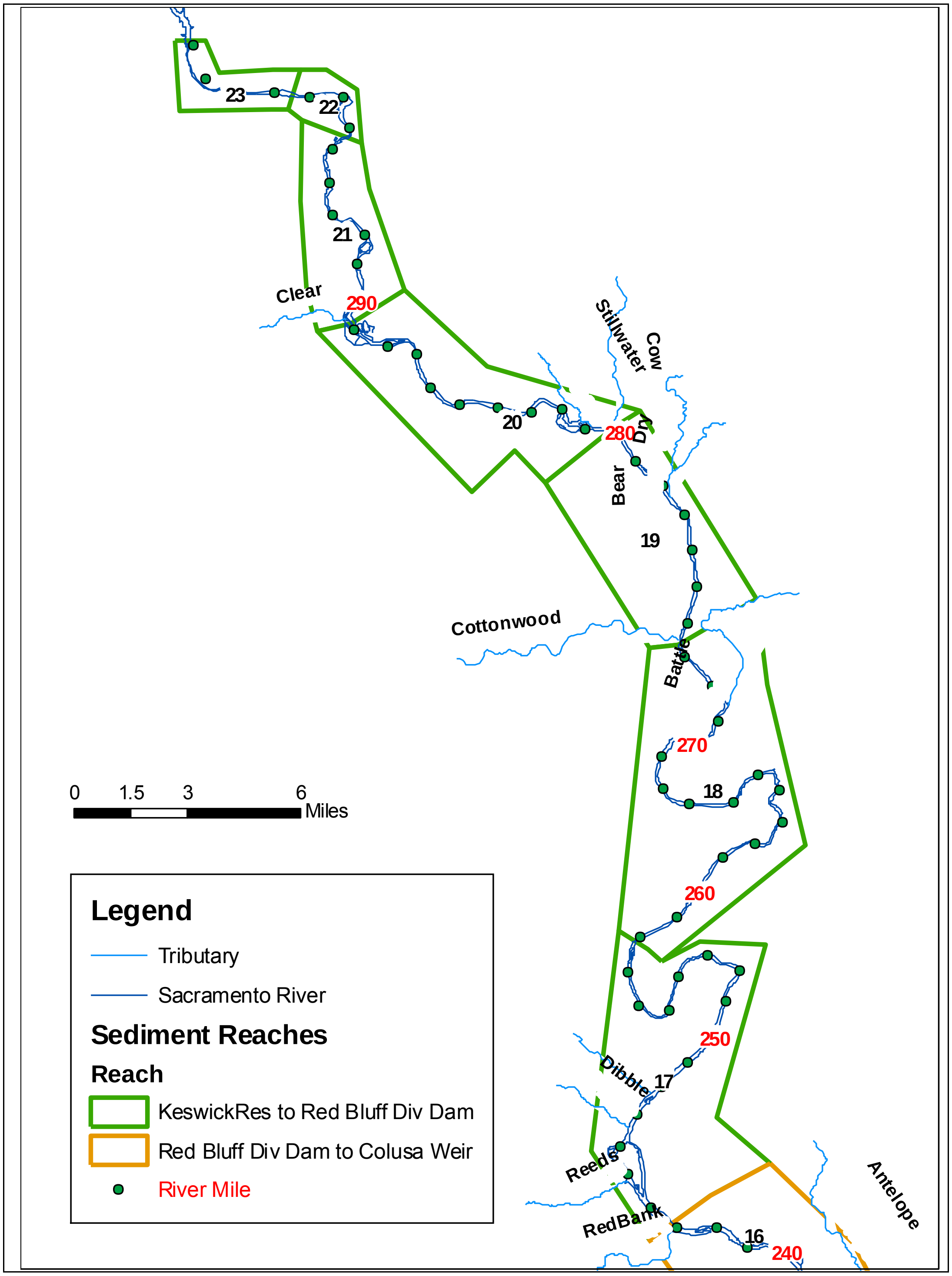

Figure 1-1. Reaches 23 - 17 with tributaries.

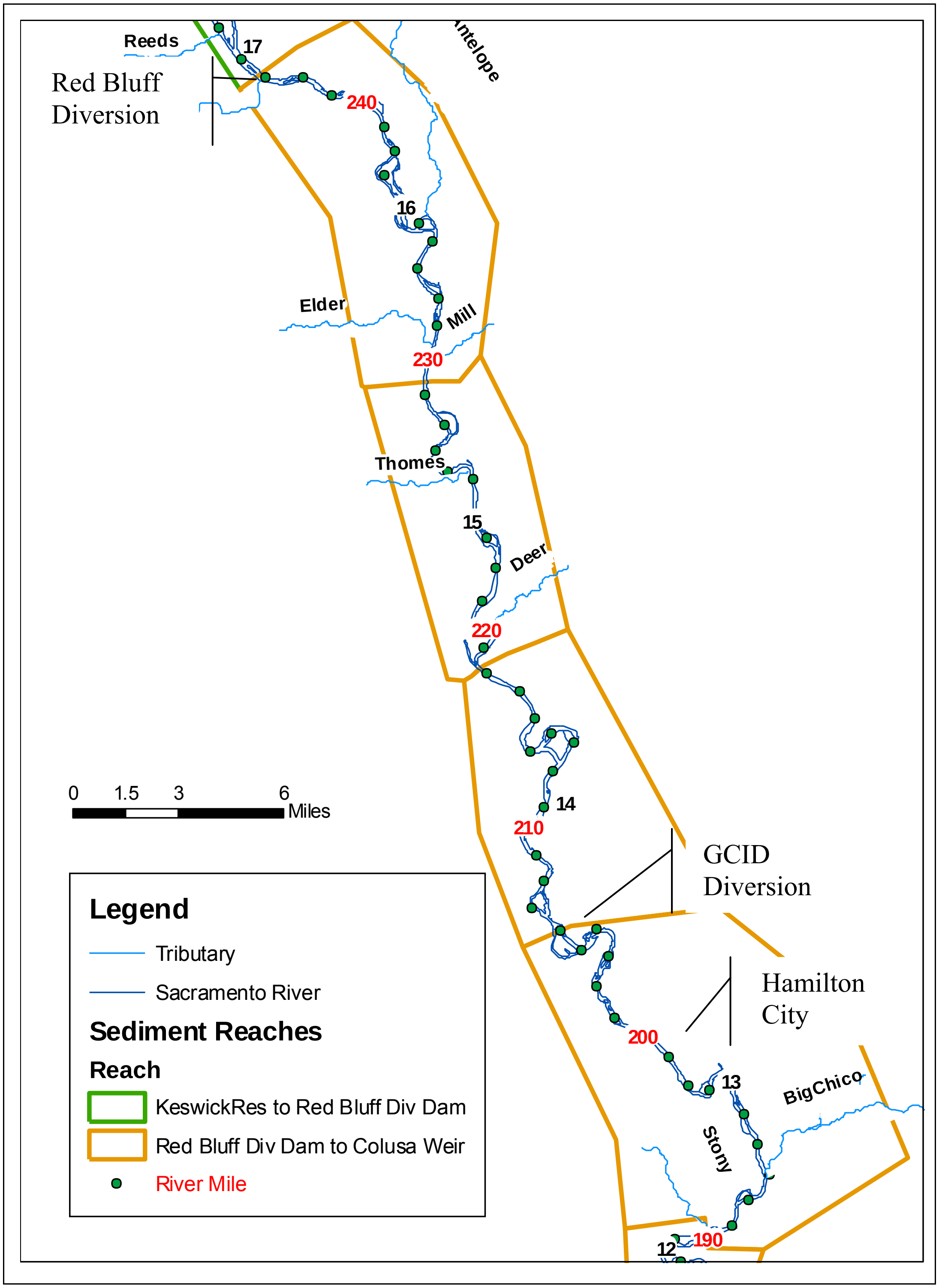

Figure 1-2. Reaches 16 - 13 with tributaries.

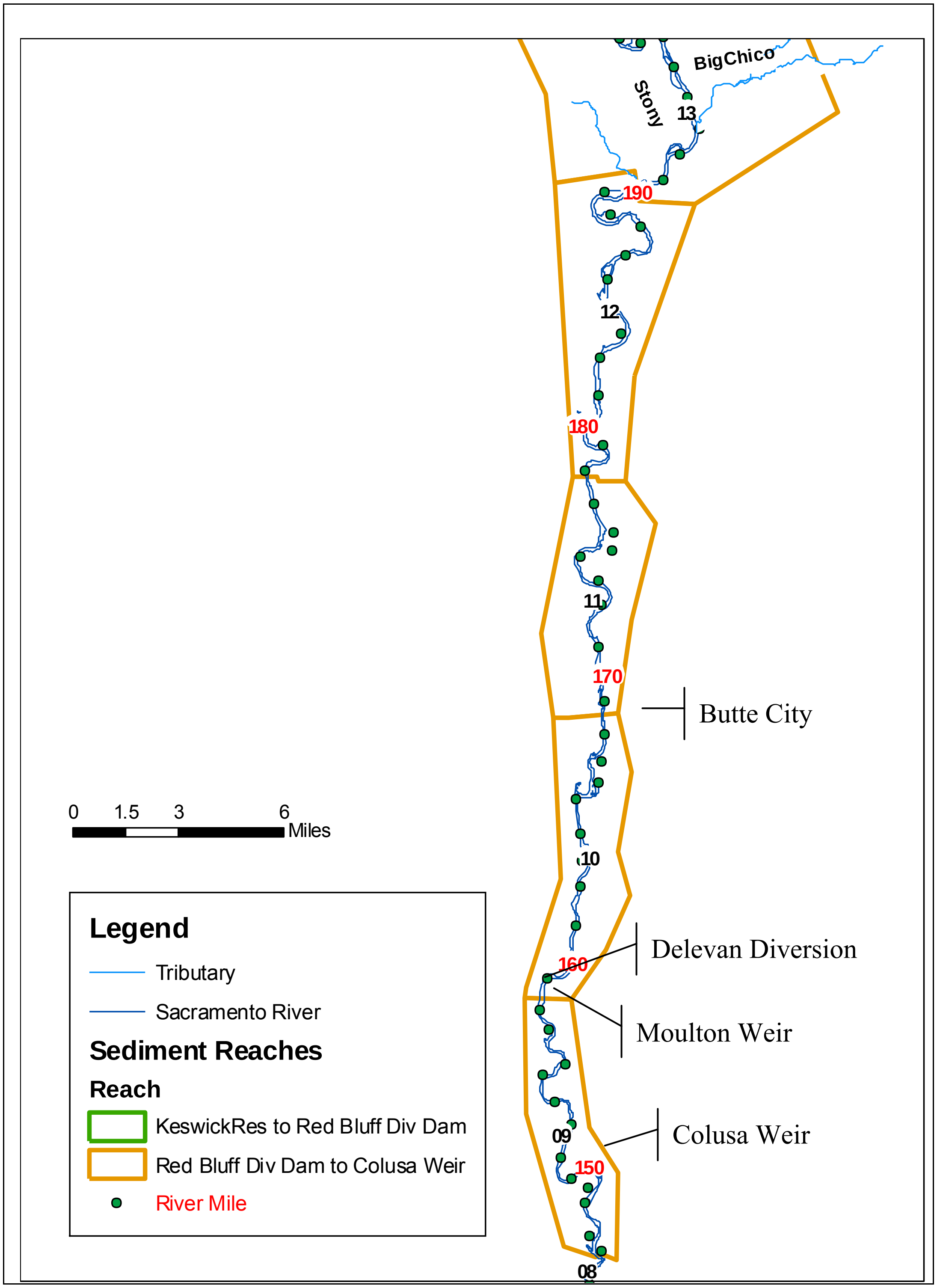

Figure 1-3. Reaches 12 - 9 with tributaries.

2 Alternative Analysis

The bedload sediment transport of five NODOS alternatives are compared to each other using sediment transport functions. The supporting data and methodology of the sediment computations are described in Reclamation (2011).

The analysis first compares the annual flow volumes and flow duration curves by reach. Then the transport capacity in tons/year for material greater than 2 mm is estimated, followed by the calculation of a sediment budget.

2.1 Annual Flow Volume

A hydrologic model (USRDOM) was developed for the Sacramento River where flow calculations were conducted at nodes (CH2MHILL, 2011). The nodes most appropriate to the 15 reaches defined above were assigned as is shown in Table 2-1. Reach 23 is the upstream-most reach and 09 is the most downstream reach.

Table 2-1. Hydrologic model nodes applied by reach.

Reach	River Miles	USRDOM ID
23	302 - 298.5	200-KESWICKDAM
22	298.5 - 295.6	197-ACID-DIV
21	295.6 - 289.3	197-ACID-DIV
20	289.3 - 280.1	195-CLEARCKINF
19	280.1 - 273.4	188-BEAR-ASHIN
18	273.4 - 257.8	185-BATTLECKIN
17	257.8 - 243	182-BENDBR-GAG
16	243 - 229.4	175-RDBLFDIVDA
15	229.4 - 218.3	162-THOMESCKIN
14	218.3 - 206	160-DEERCKINF
13	206 - 190	150-GCC-DIV
12	190 - 177.9	140-ORDFERRY
11	177.9 - 168.6	140-ORDFERRY
10	168.6 - 158.5	135-BUTTE-CITY
09	158.5 - 145.9	128-NODOS-DIV

As can be seen in Table 2-1, reaches 22 and 21 share a common hydrology, as do reaches 12 and 11; all other reaches have a unique hydrology. The hydrologic model covers a simulation period of approximately 82 years. An average annual volume of water was calculated for each reach and compared across the different alternatives. Figure 2-1 presents the difference in annual flow volume, measured in million acre feet (MAF). Figure 2-1 indicates little difference in annual flow volume between the alternatives upstream of Red Bluff Diversion Dam (Reaches 23 – 17) as well as for the river between Moulton and Colusa Weirs (Reach 9). For the river between Red Bluff Diversion Dam and Moulton Weir (Reaches 16 – 10), the following conditions in the annual flow volume are noted:

- Existing and No Action alternatives are comparable;
- Alternative A and Alternative C are comparable to each other and are less than the annual flow volume for Existing/No Action, and;
- Alternative B is lower than that of Alternative A and Alternative C.

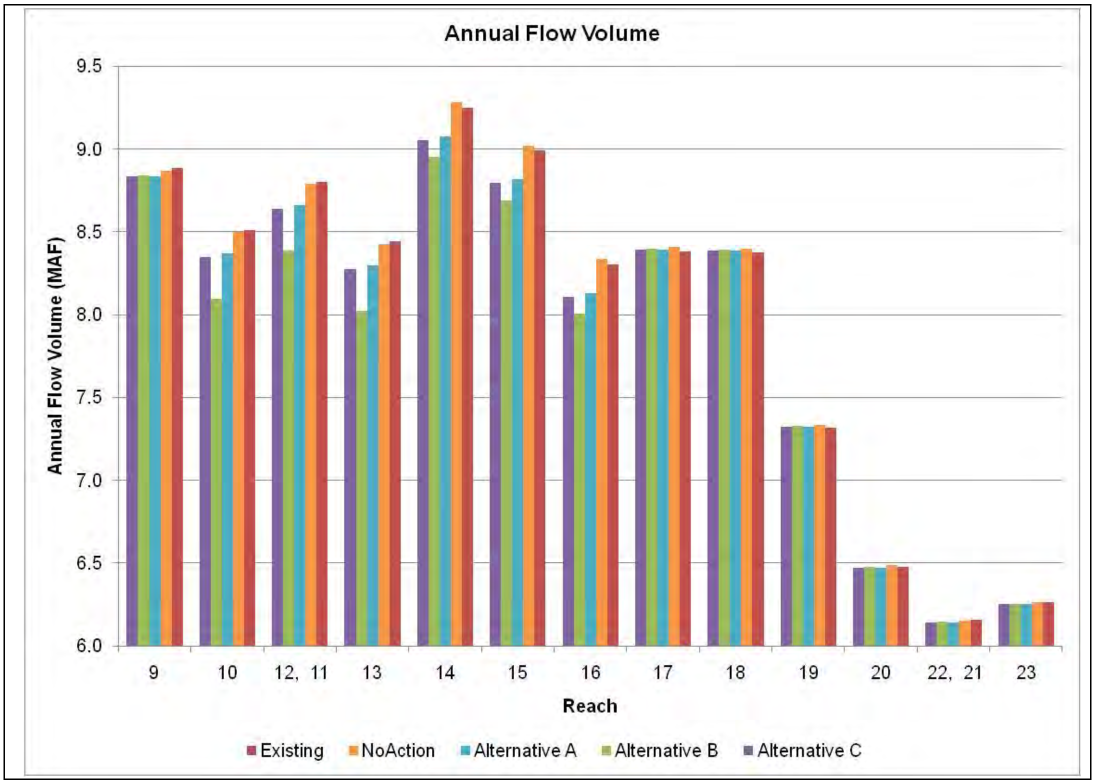

Figure 2-1. Comparison of annual flow volume for alternatives in analysis.

2.2 Flow Duration Curves

Along with total flow volume, flow rate frequency will affect sediment transport capacity; low flow transports much less sediment than high flow for the same flow volume. Existing flow duration curves (FDC) for Reaches 20, 17, 16, 13, and 10 are presented (Figure 2-2 through Figure 2-11). Because the FDCs are very similar between the alternatives, the differences in the FDCs are also presented. The reaches selected here are qualitatively representative of the reaches not presented. For instance, the existing FDC (and the discharge for the alternatives relative to existing) for reaches 23 through 19 are described by the FDC for Reach 20. Reach 17 is representative of reach 18. Reach 16 is representative for reaches 15 and 14. Reach 10 represents the characteristics for reaches 12, 11, and 9. Entire FDCs along with just the portion for flow non-exceedances greater than .99 are displayed due to the large variation in flows as the non-exceedance approaches 1.

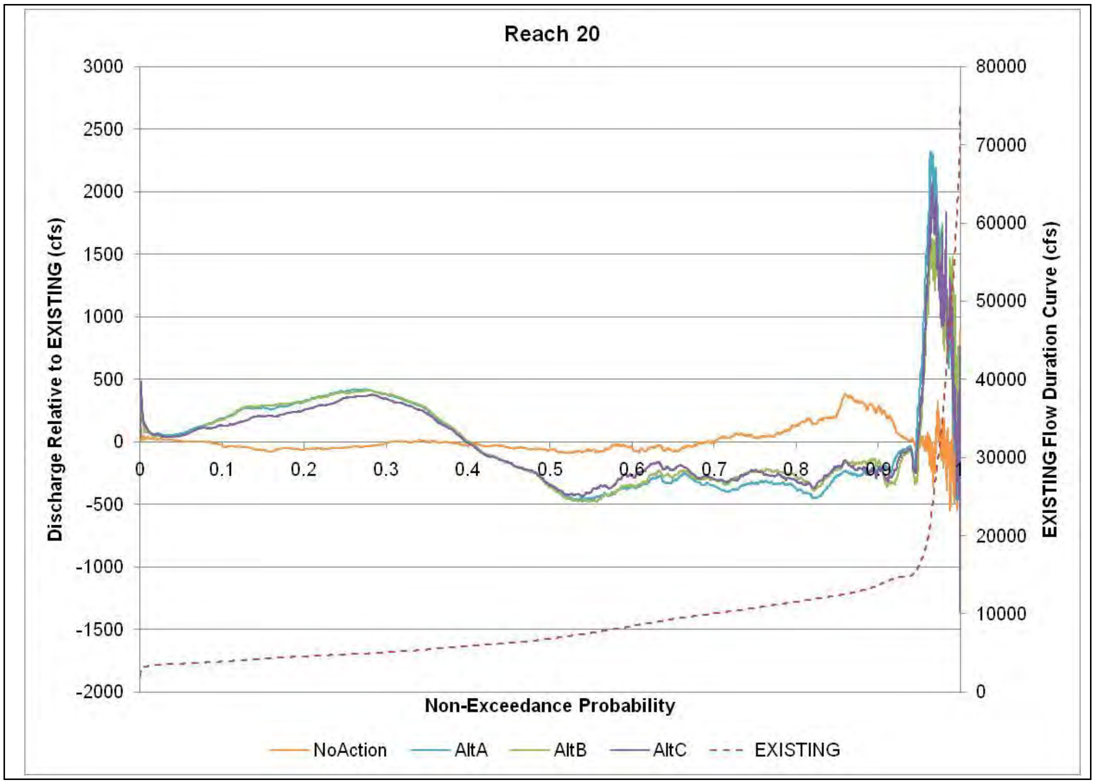

Figure 2-2. Average FDC for Reach 20, along with deviation of the alternatives from existing.

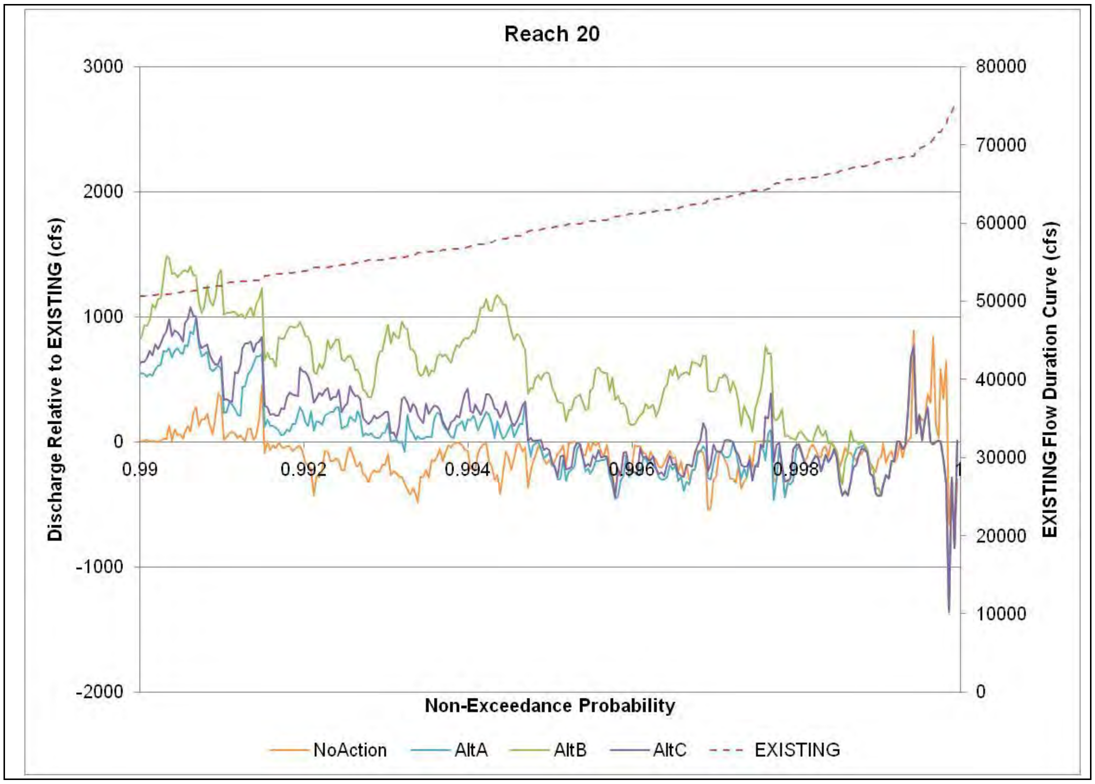

Figure 2-3. Average FDC (non exceedance > 0.99) for Reach 20, along with deviation of the alternatives from existing.

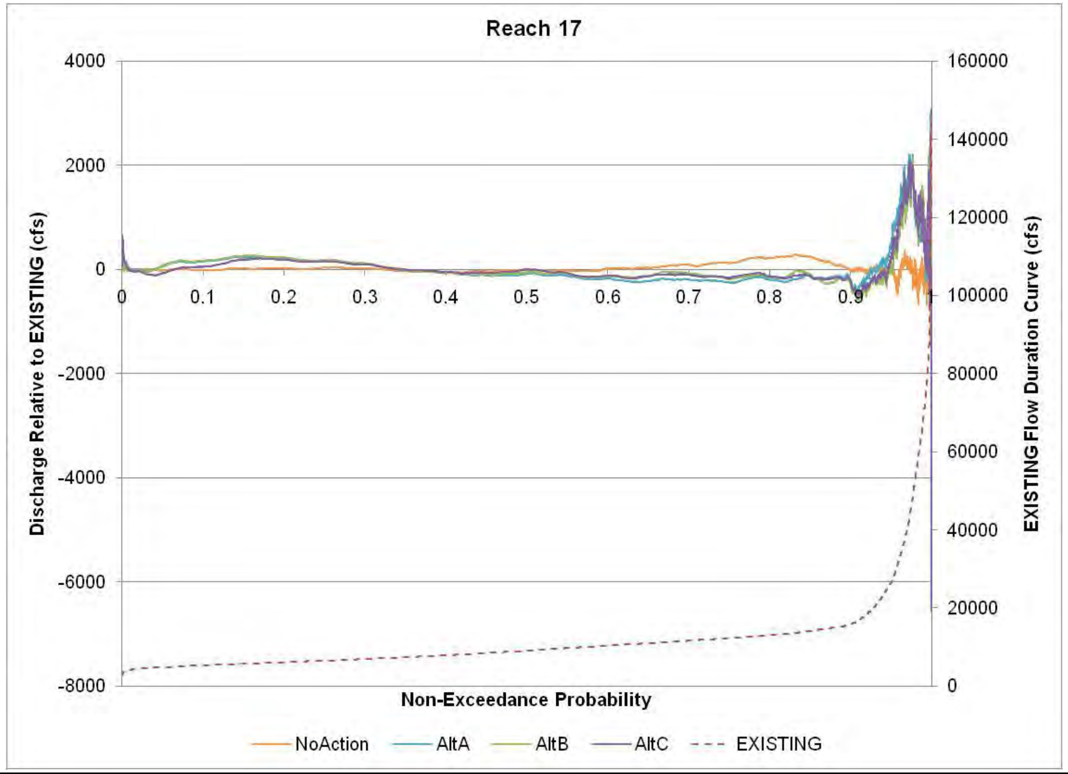

Figure 2-4. Average FDC for Reach 17, along with deviation of the alternatives from existing.

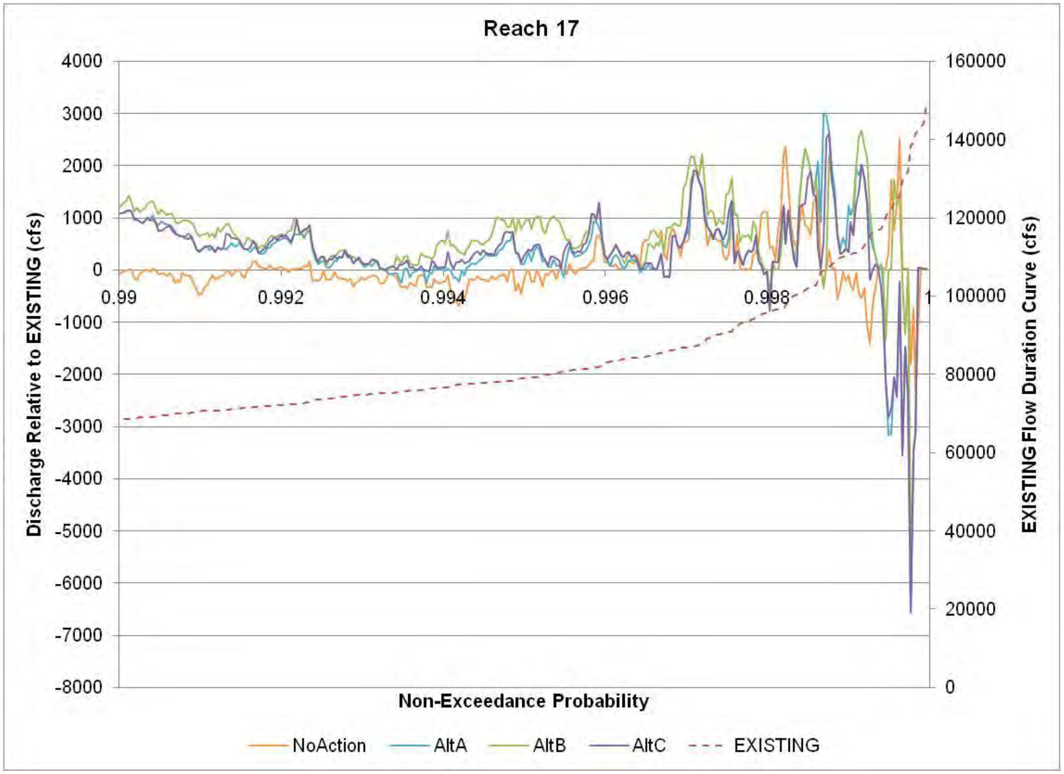

Figure 2-5. Average FDC (non exceedance > 0.99) for Reach 17, along with deviation of the alternatives from existing.

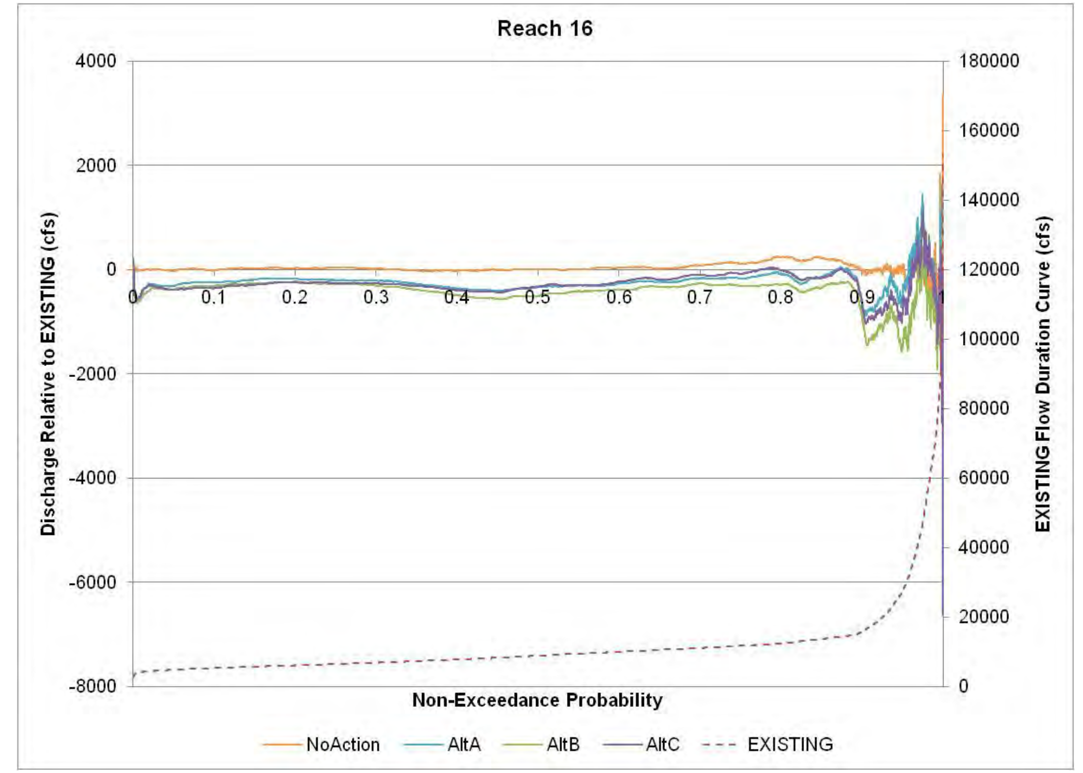

Figure 2-6. Average FDC for Reach 16, along with deviation of the alternatives from existing.

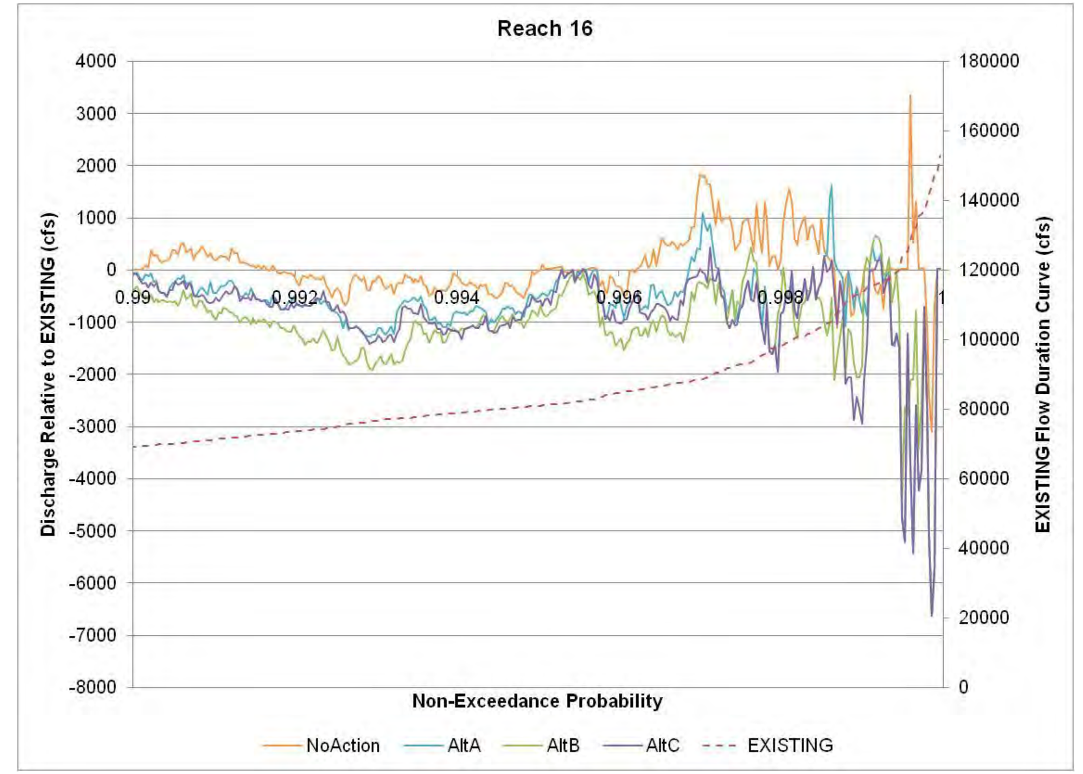

Figure 2-7. Average FDC (non exceedance > 0.99) for Reach 16, along with deviation of the alternatives from existing.

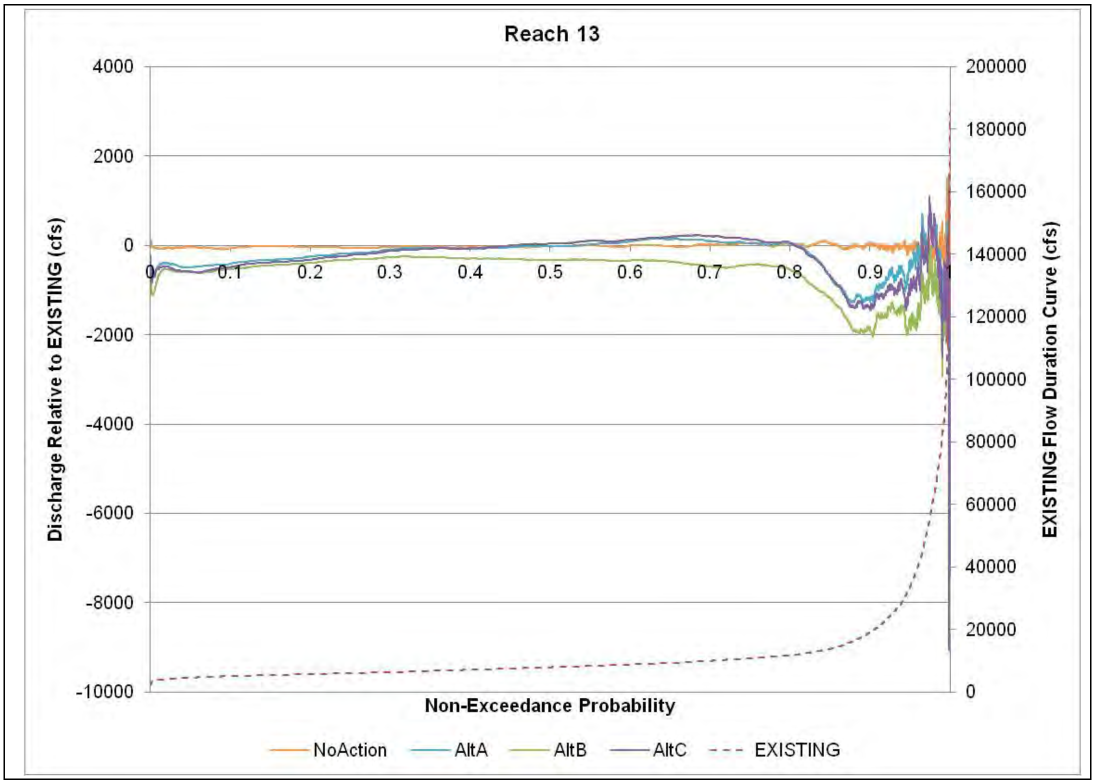

Figure 2-8. Average FDC for Reach 13, along with deviation of the alternatives from existing.

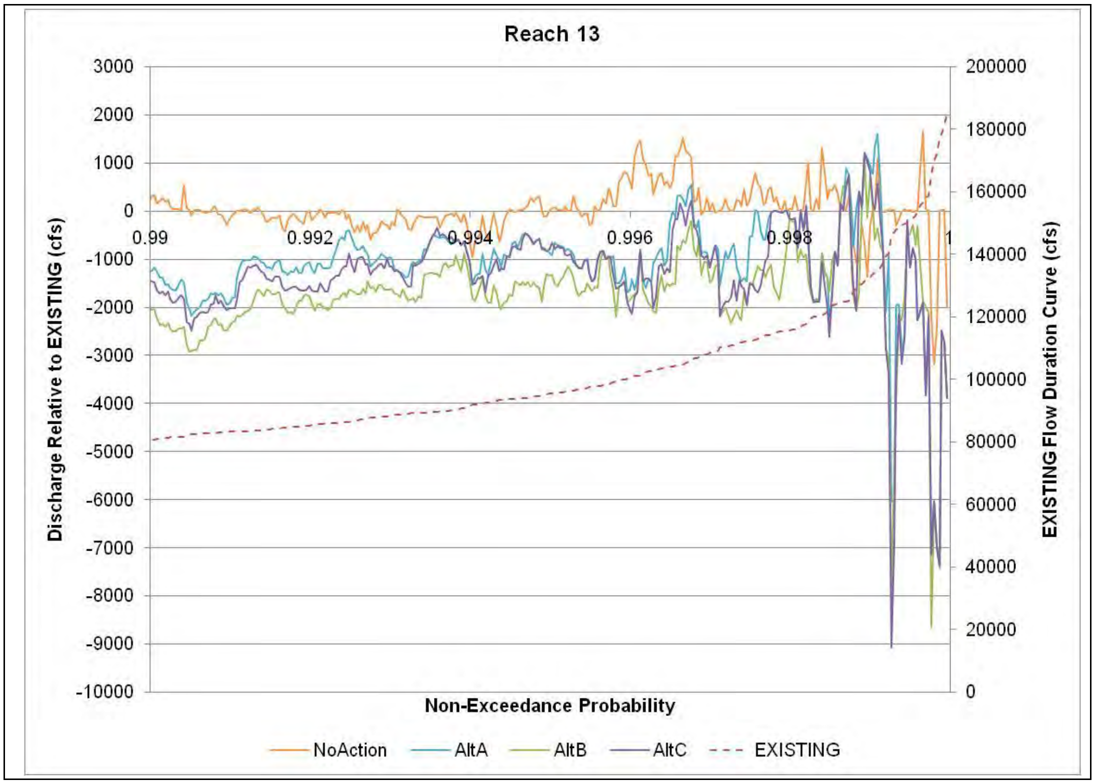

Figure 2-9. Average FDC (non exceedance > 0.99) for Reach 13, along with deviation of the alternatives from existing.

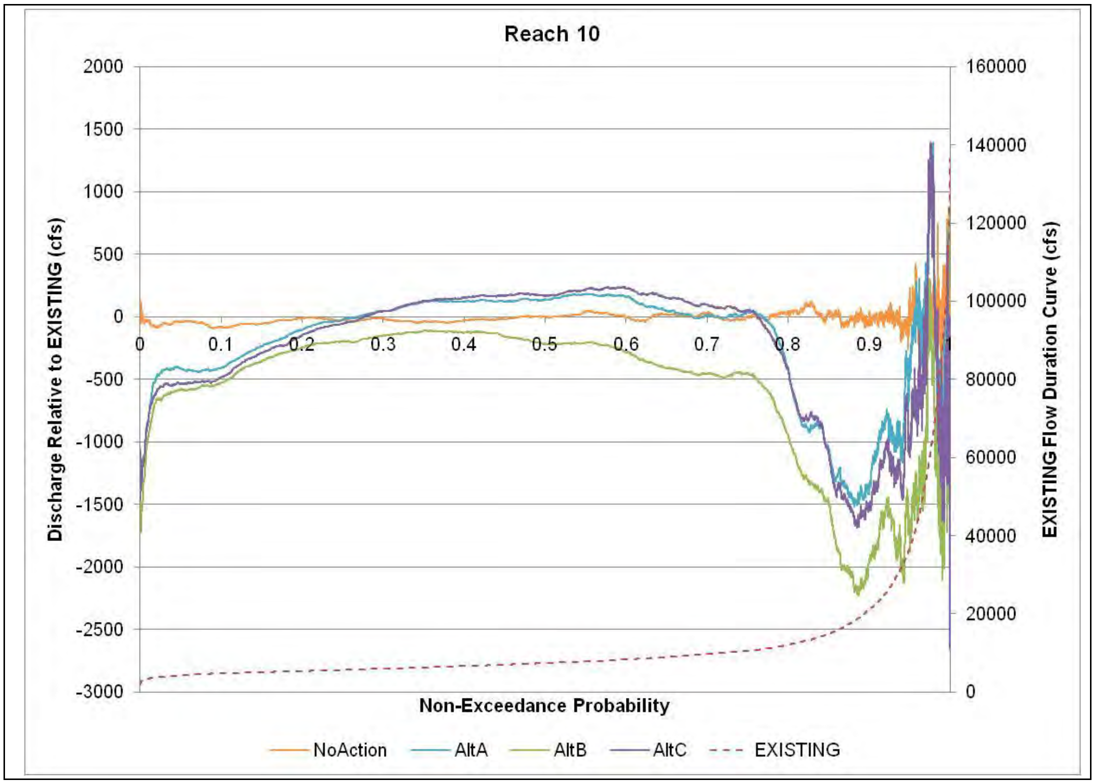

Figure 2-10. Average FDC for Reach 10, along with deviation of the alternatives from existing.

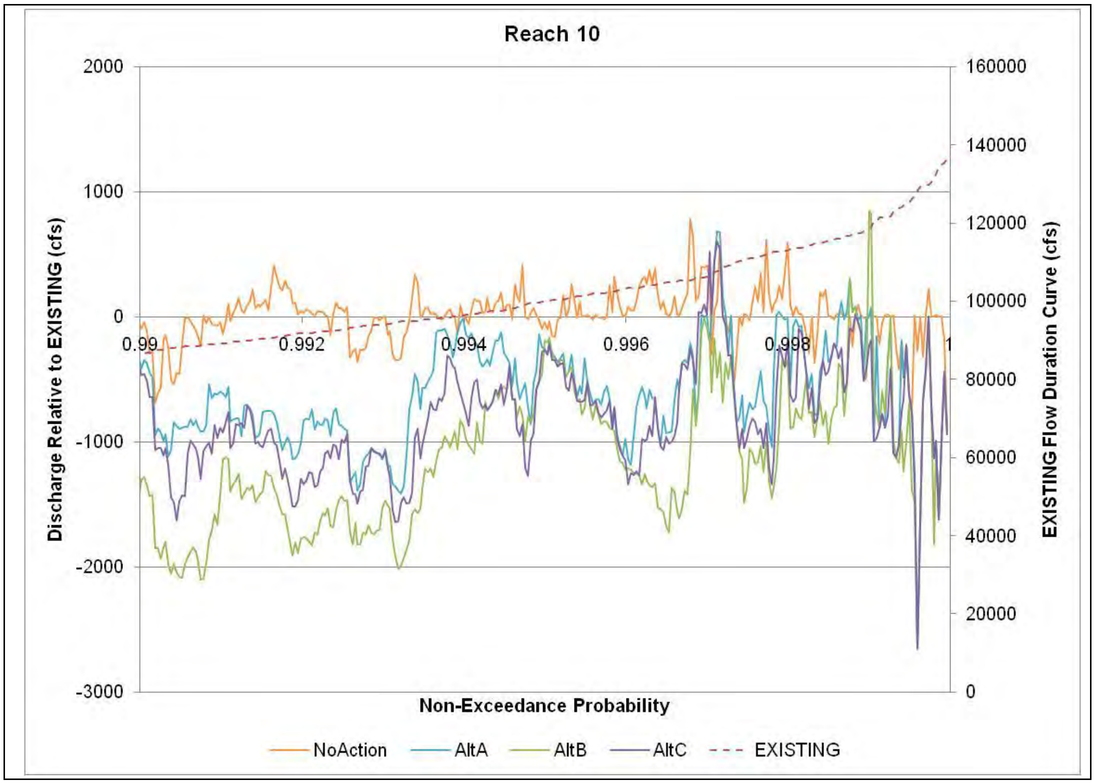

Figure 2-11. Average FDC (non exceedance > 0.99) for Reach 10, along with deviation of the alternatives from existing.

2.3 Hydraulics and Bed Material

Reach-averaged channel hydraulic properties were developed in HEC-RAS as discussed in Reclamation (2011). The bed material used to estimate sediment transport capacity is also the same as presented in Reclamation (2011).

2.4 Sediment Transport

Three sediment transport equations are used to estimate the transport capacity by reach; Parker (1990), Wilcock and Crowe (2003) and Meyer-Peter-Müller (1948). Parker and Wilcock and Crowe are utilized by applying the respective default reference shear stress and hiding factor. In addition, the reference shear stress is increased and decreased by 25% for both equations, and no sensitivity is performed on hiding factor. The Meyer-Peter-Müller (MPM) equation does not have adjustable reference shear stresses or hiding factors. An entire grain size distribution is used for both Parker and for Wilcock and Crowe, as this information is necessary in terms of particle hiding. For MPM, the median grain size is used to represent the grain size distribution as the phenomenon of hiding is not represented in this equation. Table 2-2 presents the transport scenarios (combination of equation, reference shear stress, and hiding factor) that were performed on the Sacramento River.

Table 2-2. Transport scenarios (equation and coefficients) used in this analysis.

Transport Scenario	Reference Shear Stress	Hiding Factor
Parker0.75DefaultDefault	0.0290	0.905
Parker1.00DefaultDefault	0.0386	0.905
Parker1.25DefaultDefault	0.0483	0.905
WilcockCrowe0.75DefaultDefault	0.0158	0.330
WilcockCrowe1.00DefaultDefault	0.0210	0.330
WilcockCrowe1.25DefaultDefault	0.0263	0.330
Meyer-Peter-Müller	N/A	N/A

Figure 2-12 presents the annual transport capacity (tons/year) by reach for Wilcock and Crowe, which is considered a realistic estimate of transport rates in the Sacramento based on knowledge of the system and professional judgment. Plots for all of the other scenarios presented in Table 2-2 can be found in Appendix A. The most important inference from the sensitivity analysis and the plots in Appendix A is that sediment transport results for the Sacramento River are much more sensitive to transport equation and reference shear stress than to the alternative being considered. The Parker equation estimates practically no bedload transport for Reaches 23 to 15, and then again for Reaches 10 and 9 (Figure A-1, Figure A-2, Figure A-3). The Wilcock and Crowe equations estimate much more transport for all reaches (Figure 2-12, Figure A-4, Figure A-6). The MPM equation is relatively similar to the Parker equation in that is predicts almost no transport in Reaches 23 to 15, and then again in Reaches 10 and 9 (Figure A-7). For the purpose of comparing alternatives, the Wilcock and Crowe equation is deemed the most appropriate based on knowledge of the system and professional judgement. The bedload transport capacity upstream of Red Bluff diversion are increased from existing conditions by 2 to 6% for Alternative A, B, and C (Reaches 23 to 17). This is because the high flows in this reach are increased slightly under these alternatives (see Figure 2-3).

From Red Bluff to the GCID diversion (Reaches 16 to 14), the bedload transport capacity is decreased from existing conditions for Alternatives A, B, and C. Alternative B is decreased by approximately 4%, while Alternatives A and C are decreased by 2%. The slight decrease is due to the increased diversion rates at the Red Bluff Diversion during the high flow periods. Alternative B has higher rates of diversion and therefore the impact of Alternative B is greater.

From GCID to Delevan diversion (Reaches 13 to 10), the bedload transport capacity is decreased from existing conditions by 2 to 4% for Alternatives A and C, and 6 to 10% for Alternative B.

Downstream of the Delevan diversion, the bedload transport capacities are decreased from existing conditions by 4 to 6 % for Alternative A and C and 10 to 12 % for Alternative B.

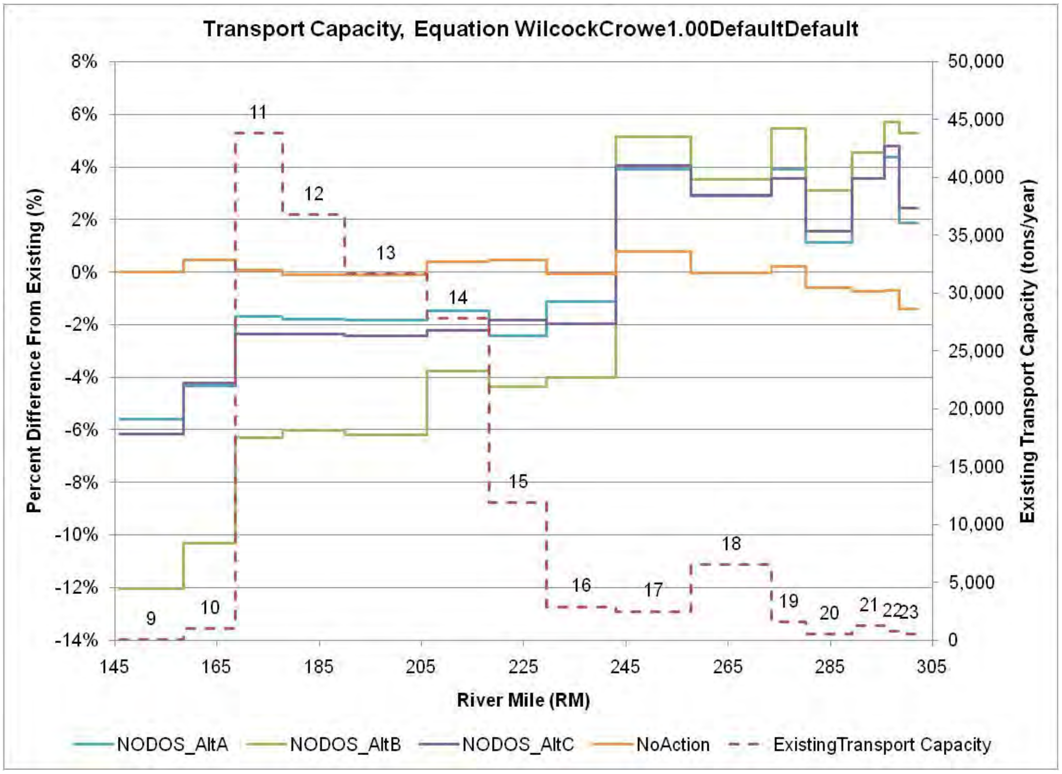

Figure 2-12. Transport capacity for Wilcock and Crowe (100% reference shear), and percent difference from existing for alternatives.

2.5 Sediment Budget

A sediment budget for the river reaches was developed with inputs to a reach being comprised of the sediment from the upstream reach and the sediment being supplied by the tributaries. See Reclamation (2011) for more information on the tributaries to the Sacramento that were identified and modeled for sediment purposes. Figure 2-13 and Figure 2-14 present the annual tributary loads for the same transport scenarios as presented in Table 2-2. There is significant uncertainty in the estimates for the tributary sediment loads, and the estimates given in Figure 2-13 and Figure 2-14 are considered to be preliminary estimates not verified by field data. Bed load data on each individual stream would be required to improve the estimates. However, because the NODOS alternatives do not impact the tributary inputs of sediment, the relative differences between the alternatives can be compared with greater confidence. The inclusion of the tributary loads is done to compute an “order of magnitude” sediment budget for the mainstem of the Sacramento River. These estimates of tributary loads could be further refined if additional analysis of the sediment budget is warranted.

Table 2-3 presents the tributaries in upstream to downstream order by reach assignment for the sediment budget.

Figure 2-15 presents a plot of the reach-averaged sediment budget for existing hydrology for Wilcock and Crowe (default parameters), with select location identifiers presented for reference. Values in the sediment transport budget of less than 10,000 ton/yr are not considered significant to the overall budget. Over a 10 mile reach, this annual load would equate to less than 0.1 inches/yr.

Three sediment budgets were developed using a consistent equation (Wilcock and Crowe, Parker, Meyer-Peter-Müller) for all reaches of and for all tributaries to the Sacramento River. The specific characteristics of a given tributary may suggest that a different equation be more appropriate than the one used for the mainstem Sacramento. However, the different alternatives being considered have no bearing on sediment hydrology or sediment delivery to the mainstem; so the comparison between alternatives is more pertinent than the absolute loads delivered by the tributaries. For simplicity, the results from a consistent transport equation – in this case Wilcock and Crowe – are used to derive the following general observations. The sediment budgets developed using Parker and Meyer-Peter-Müller can be found in Appendix B.

Reaches 23 – 17 are in relative equilibrium based on the sediment budget estimates. Reaches 23 to 20 are armored because of the lack of sediment supply, and the bed material in these reaches is relatively immobile. Reach 19 is downstream of several tributaries, but the annual sediment transport capacity of the bedload is likely less than 10,000 tons/yr based upon the sediment transport results presented in Figure 2-12. This is considered a low value relative to the size of the Sacramento River. Reaches 18 and 17 are slightly degradational and aggradational respectively. However, the annual rates of degradation and aggradation are less than 7,000 tons/yr and not considered significant.

Cottonwood Creek enters the Sacramento River in the upstream portion of Reach 18 and introduces a substantial amount of gravel sized sediment so that this reach is somewhat more mobile than upstream reaches. The predicted bedload transport capacity rates through the reach increase up to 7,000 tons/yr (Figure 2-12) The estimated sediment input to the reach is less than 7,000 tons/yr leading to a prediction of erosion (Figure 2-15). The predicted degradation caused by this deficit is less than 5,000 tons/yr and not substantial.

Reach 17 is just upstream of Red Bluff Diversion Dam and may be affected by the presence of this structure.

Reach 16 is just downstream of Red Bluff Diversion Dam and is slightly aggradational, but the rates are not considered significant.

Reach 15 is slightly degradational. Again, however, the rates are small and not significant.

Reaches 14 experiences the most degradation of all the reaches. This is a function of the total volume of annual water flowing through this reach (Figure 2-1).

Reaches 13, 12, and 11 show varying degrees of degradation but the rates are small and generally not considered significant.

Reach 10 is highly depositional. This reach is downstream of the bypass system, which typically removes flow from the top of the water column and leaves the bedload in the river. This reach may be the only reach of the Sacramento River that will demonstrate measurable amounts of deposition. The high flows transported through the main stem of the Sacramento are significantly decreased by the bypass system, thereby directly decreasing the sediment transport capacity rates in the main stem.

Reach 9 shows relative equilibrium. Most of the deposition is expected to occur in Reach 10 so that the reaches below are closer to equilibrium.

Figure 2-16 compares the resulting sediment budget by alternative for material greater than 2 mm using the Wilcock and Crowe transport equation. Within most reaches, the alternatives change the sediment budget by less than 5% from existing conditions, which is not considered significant to the sediment budget. Reach 22 shows high percent differences for the alternatives; however the calculated transport is so low that these percent differences still reflect an equilibrium conditions. The greatest differences from existing conditions are noted for Alternative B in Reaches 9 to 13, where there is a more substantial decrease in transport rates. Of these reaches, only Reach 10 exhibited a significant lack of equilibrium as discussed above. Even though the transport rates are decreased for alternatives A, B, and C in Reaches 9 to 13, the bedload sediment balance is not considerably altered because less sediment is entering these reaches from the upstream.

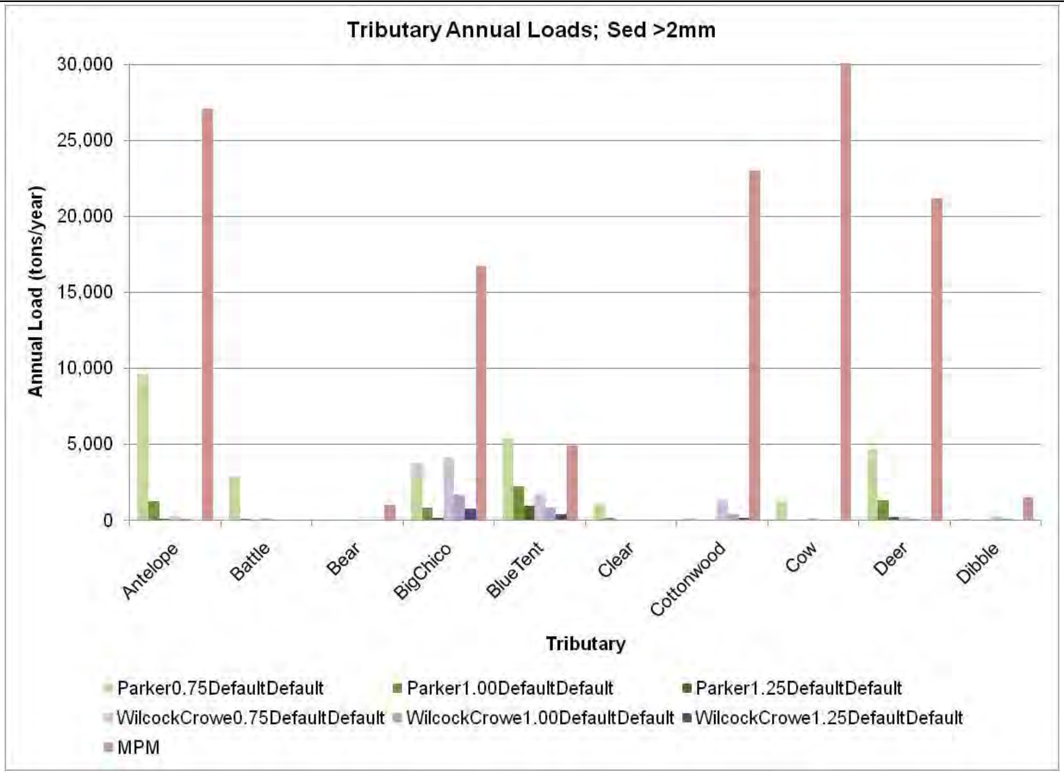

Figure 2-13. Tributary transport capacity sensitivity for first 10 alphabetically.

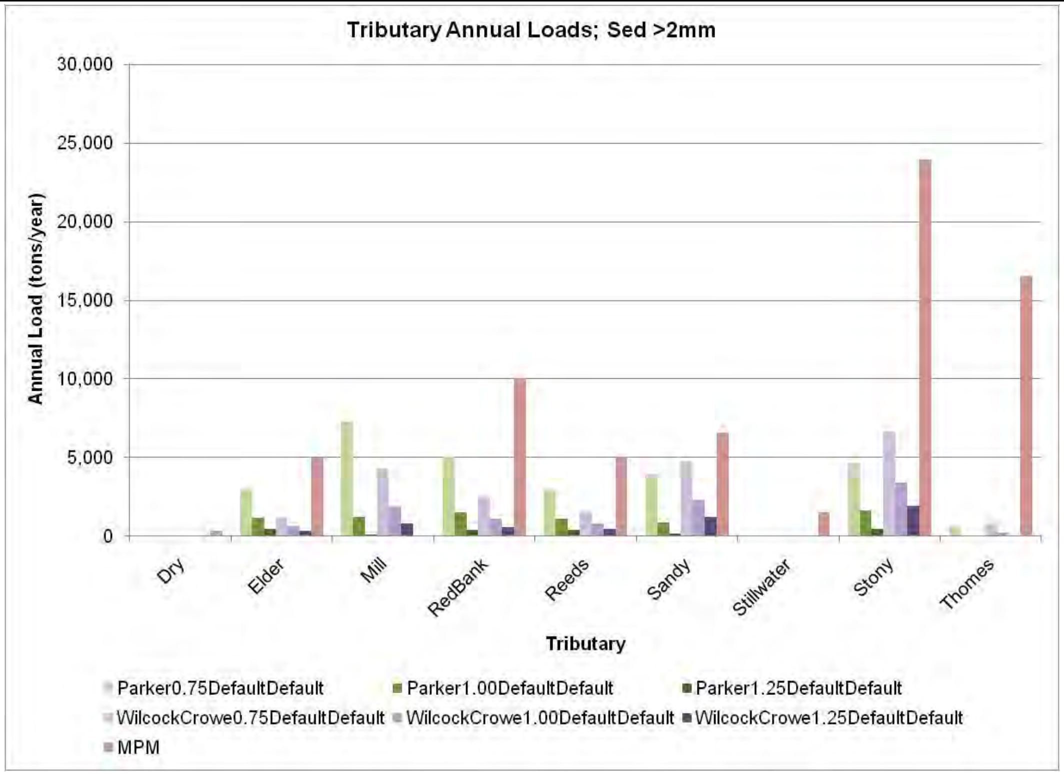

Figure 2-14. Tributary transport capacity sensitivity for last 9 alphabetically.

Table 2-3. Tributary reach assignments for sediment budget.

Reach	Upstream Tributary	Tributary	Tributary	Downstream Tributary
23	--	--	--	--
22	--	--	--	--
21	--	--	--	--
20	--	--	Clear	--
19	Stillwater	Cow	Dry	Bear
18	--	--	Cottonwood	Battle
17	--	--	Blue Tent	Dibble
16	--	Reeds	Red Bank	Antelope
15	--	Elder	Mill	Thomes
14	--	--	--	Deer
13	--	--	--	--
12	--	Sandy	Big Chico	Stony
11	--	--	--	--
10	--	--	--	--
9	--	--	--	--

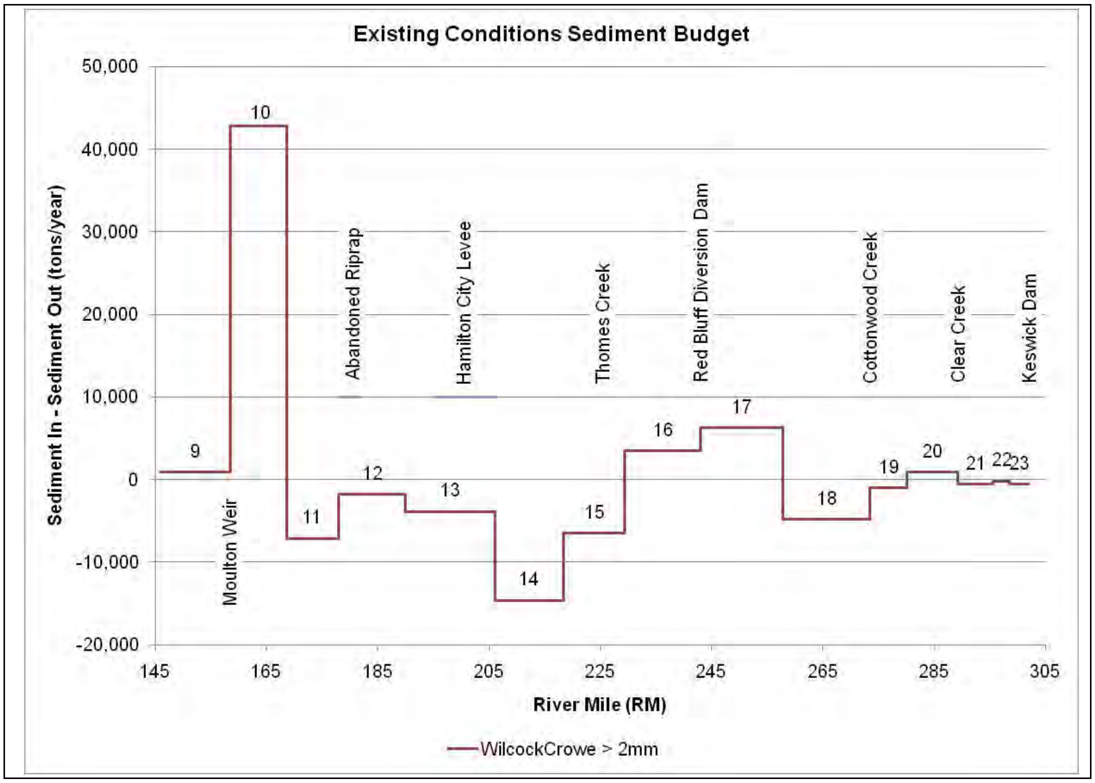

Figure 2-15. Sediment budget (existing hydrology) for material greater than 2mm using Wilcock and Crowe with default parameters.

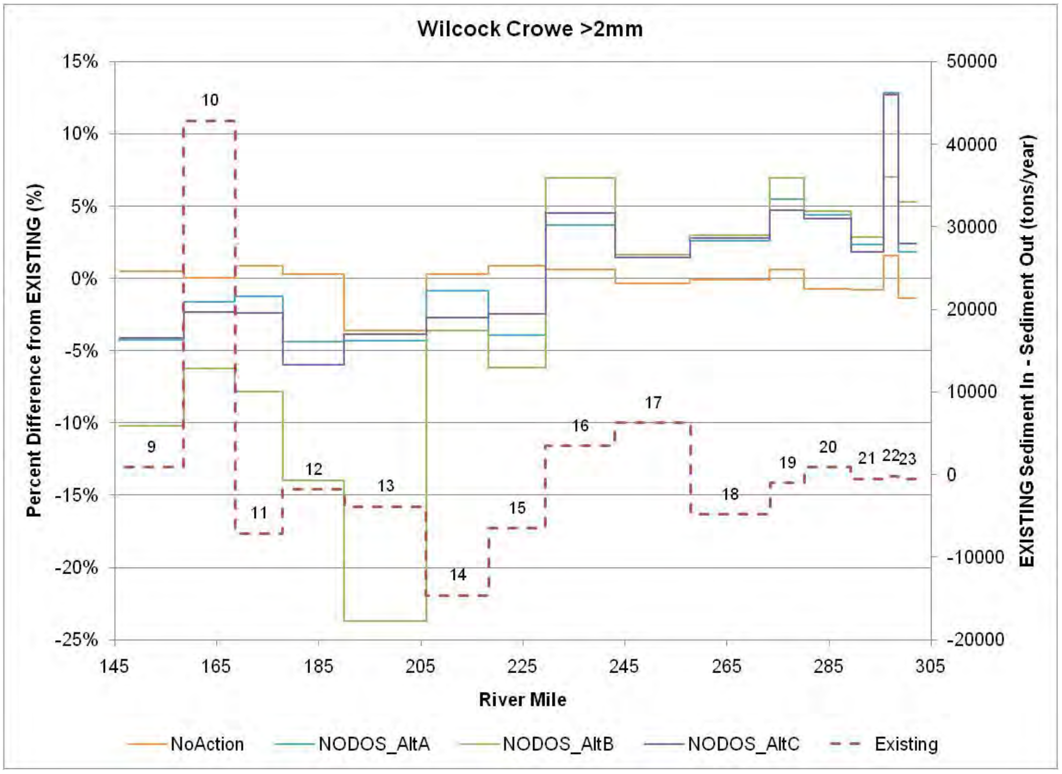

Figure 2-16. Percent difference in sediment budget for No Action and Alternatives A, B, C, relative to Existing.

3 Conclusions

The bed load in the Sacramento River and its tributaries was computed under the NODOS alternatives analysis.

The NODOS alternatives generally do not significantly affect the annual flow duration curves by more than a few percent and therefore do not significantly affect the bed load sediment balance in the Sacramento River. However, because of the increase in diversion rates from the Sacramento River, there are small effects of the alternatives on the bedload sediment transport that can be quantified. The quantitative predictions presented in this section are based upon the results of the sediment analysis using the Wilcock and Crowe equation. Results using other equations, presented in the appendices, do no influence the conclusions of this investigation.

The bedload transport capacity upstream of Red Bluff diversion are increased from existing conditions by 2 to 6% for Alternative A, B, and C (Reaches 23 to 17) using the Wilcock and Crowe equation. This is because the high flows through these reaches are increased slightly under these alternatives (see Figure 2-3; the flow duration curves for Reaches 23-17 are all fairly represented by flow duration curve for Reach 20).

From Red Bluff to the GCID diversion (Reaches 16 to 14), the bedload transport capacity is decreased from existing conditions for Alternatives A, B, and C.

Alternative B is decreased by approximately 4%, while Alternatives A and C are decreased by 2%. The slight decrease is due to the increased diversion rates at the Red Bluff Diversion during high flow periods. Alternative B has higher rates of diversion, and therefore the impact of Alternative B is greater.

From GCID to Delevan diversion (Reaches 13 to 10), the bedload transport capacity is decreased from existing conditions by 2% for Alternatives A and C, and 6% for Alternative B.

Downstream of the Delevan diversion, the bedload transport capacities are decreased by 4 to 6 % by Alternative A and C and 10 to 12 % by Alternative B.

Most reaches in the Sacramento are not experiencing measurable erosion or deposition, except for Reach 10 in the vicinity of Moulton Weir, which is experiencing aggradation. The NODOS alternatives do not significantly affect the aggradation that will continue into the future in Reach 10. However, this aggradation may impact the NODOS project because the Delevan Diversion is located in this reach. Alternative methods for reducing deposition, such as dredging of river sediment, may be necessary to maintain a sufficient flow depth for diversion.

4 References

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A Sensitivity Analysis of Sediment Transport Equations and Reference Shear Stresses

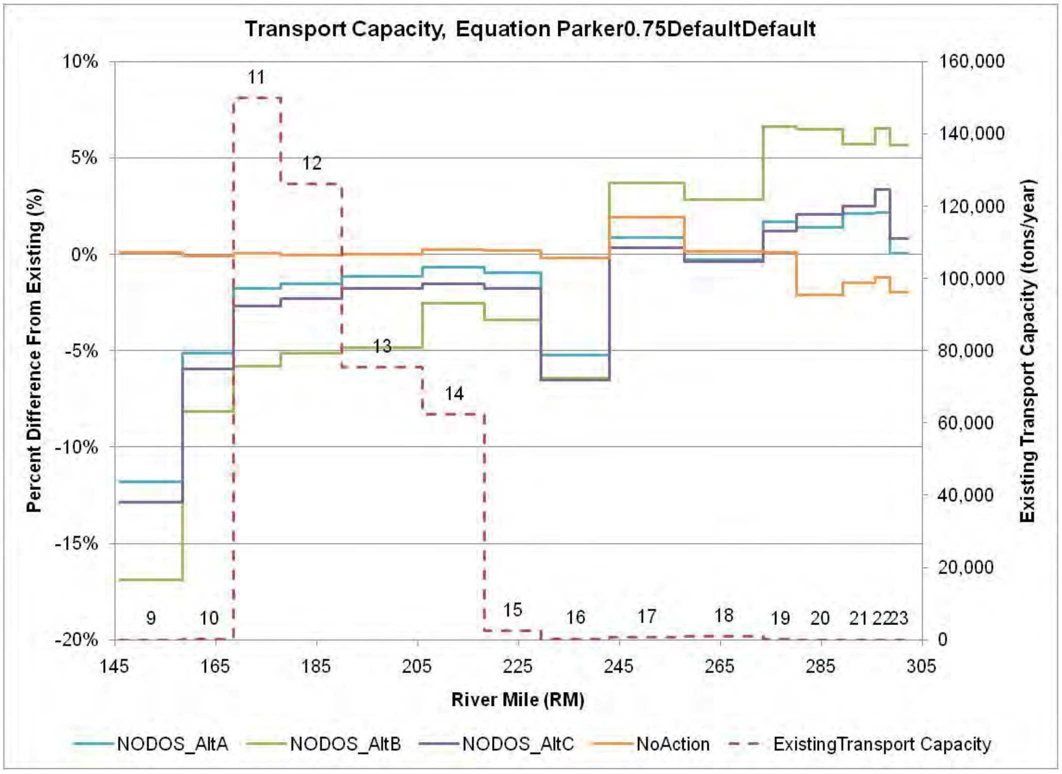

Figure A-1. Transport capacity for Parker (75% reference shear), and percent difference from existing for alternatives.

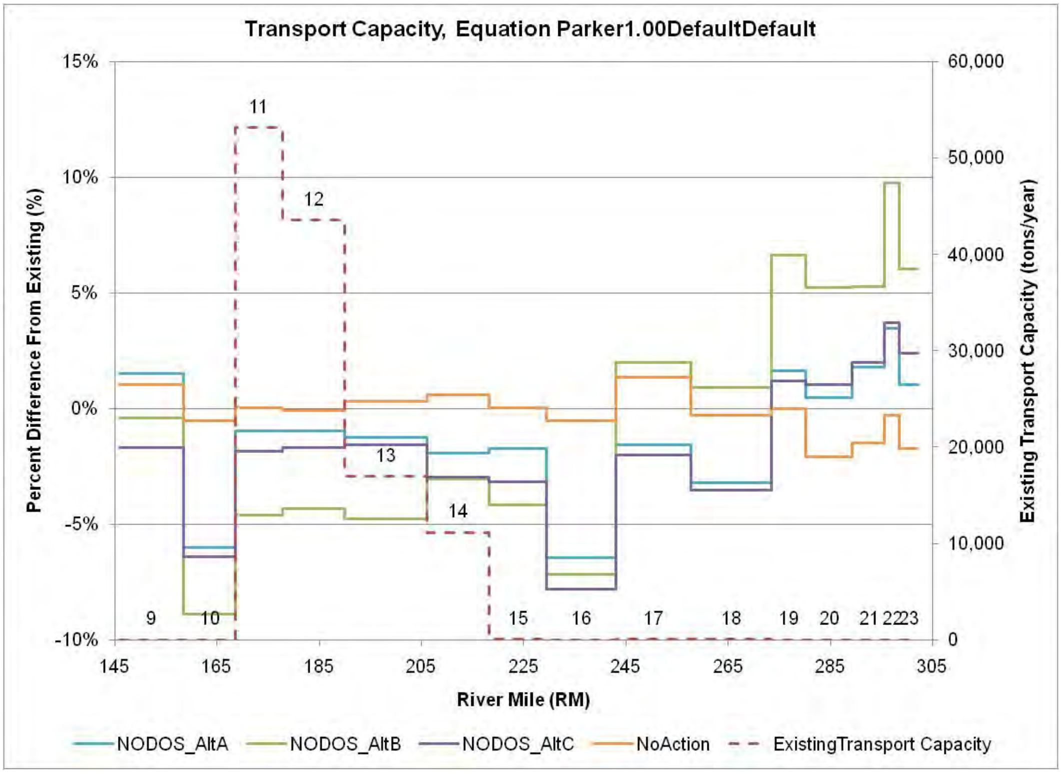

Figure A-2. Transport capacity for Parker (100% reference shear), and percent difference from existing for alternatives.

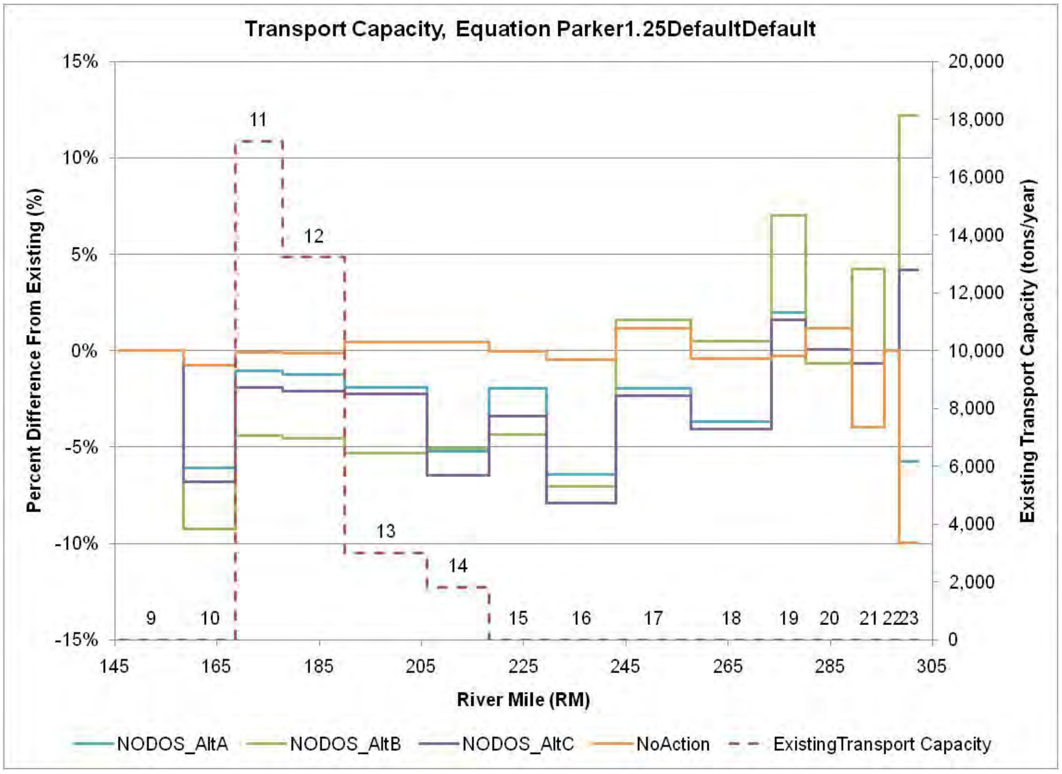

Figure A-3. Transport capacity for Parker (125% reference shear), and percent difference from existing for alternatives.

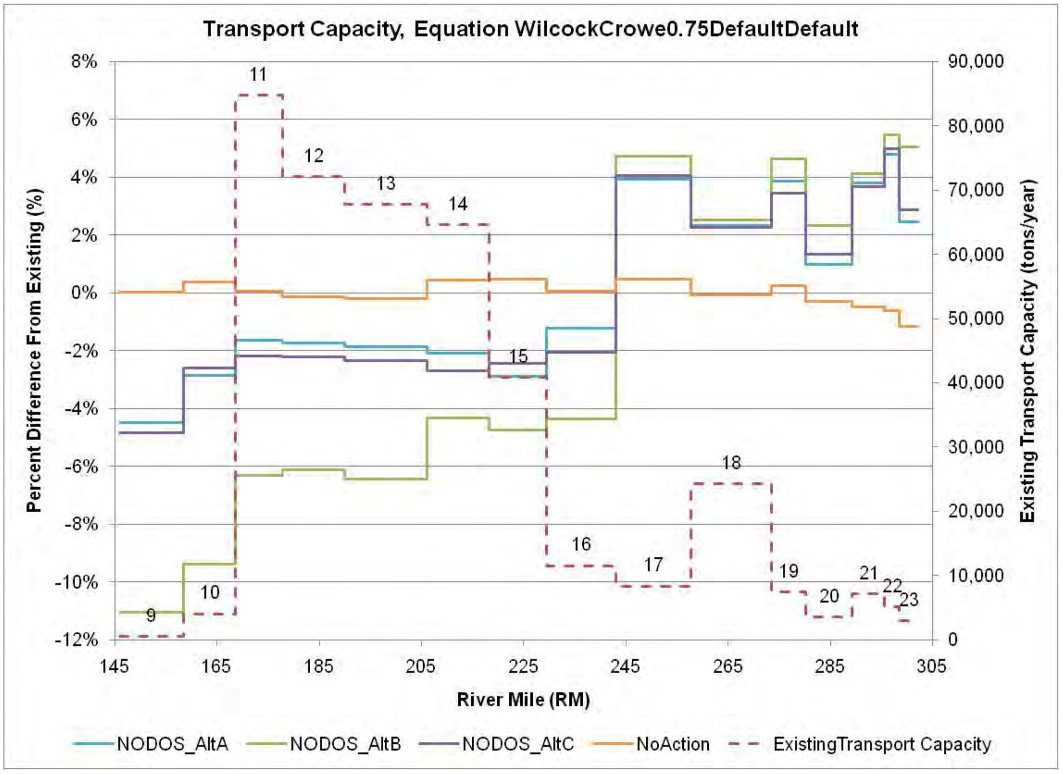

Figure A-4. Transport capacity for Wilcock and Crowe (75% reference shear), and percent difference from existing for alternatives.

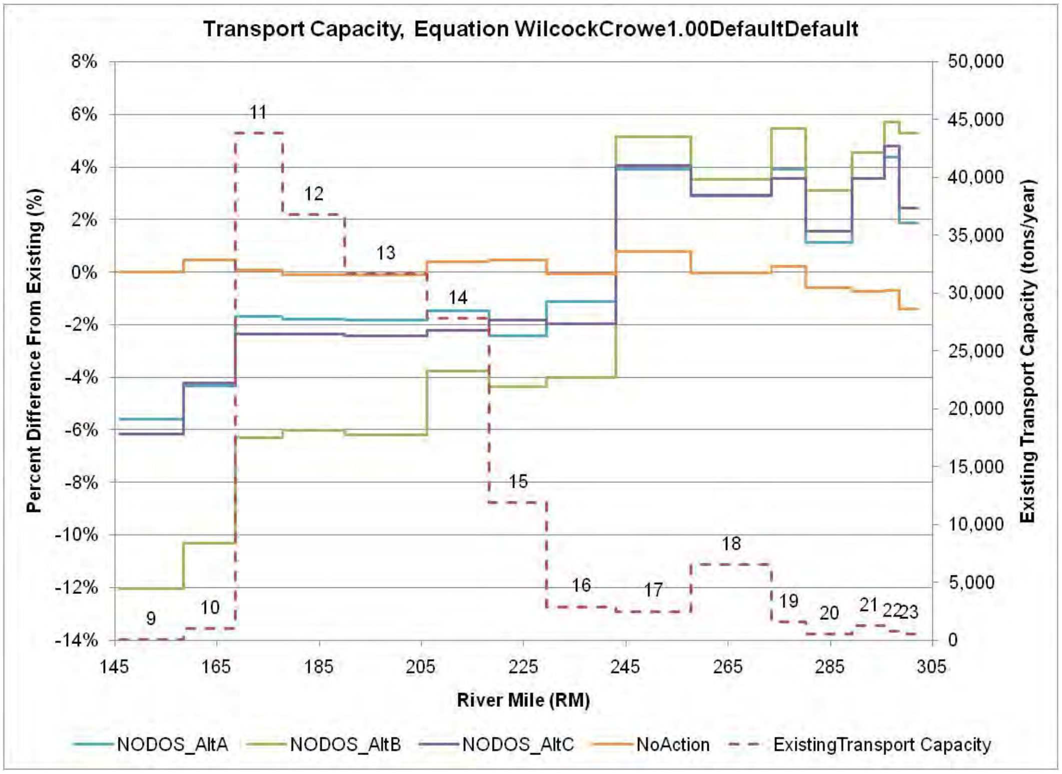

Figure A-5. Transport capacity for Wilcock and Crowe (100% reference shear), and percent difference from existing for alternatives.

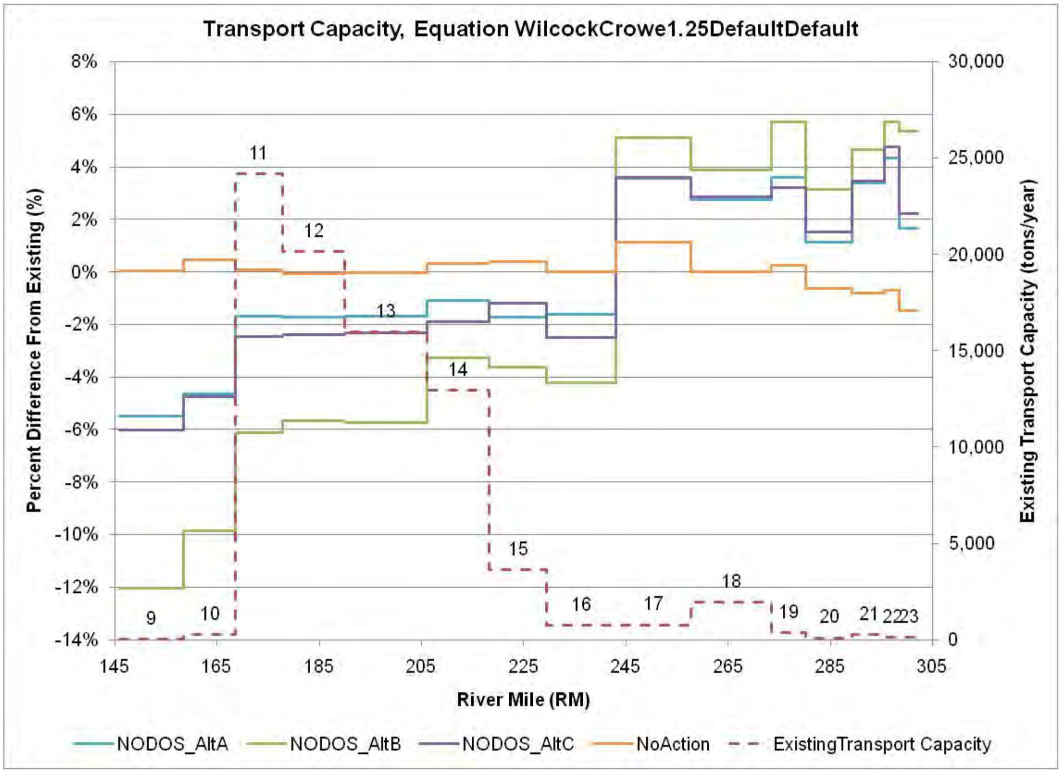

Figure A-6. Transport capacity for Wilcock and Crowe (125% reference shear), and percent difference from existing for alternatives.

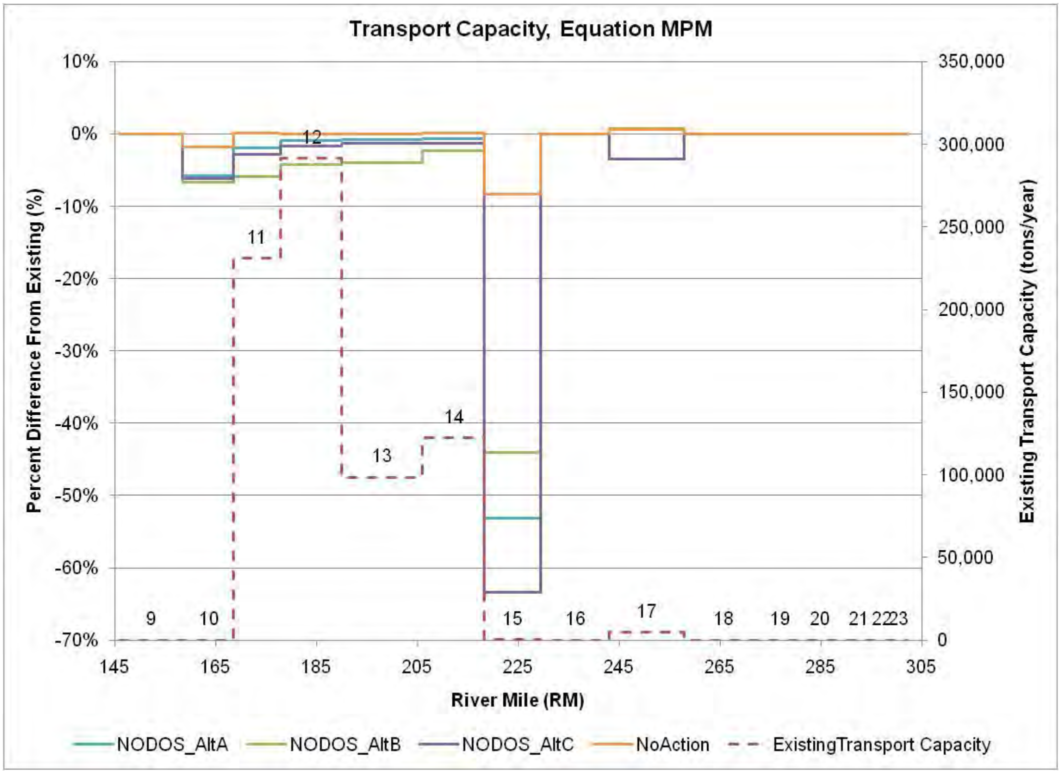

Figure A-7. Transport capacity for Meyer-Peter-Müller, and percent difference from existing for alternatives.

B Sediment Budget for Existing Conditions Comparing Three Transport Equations

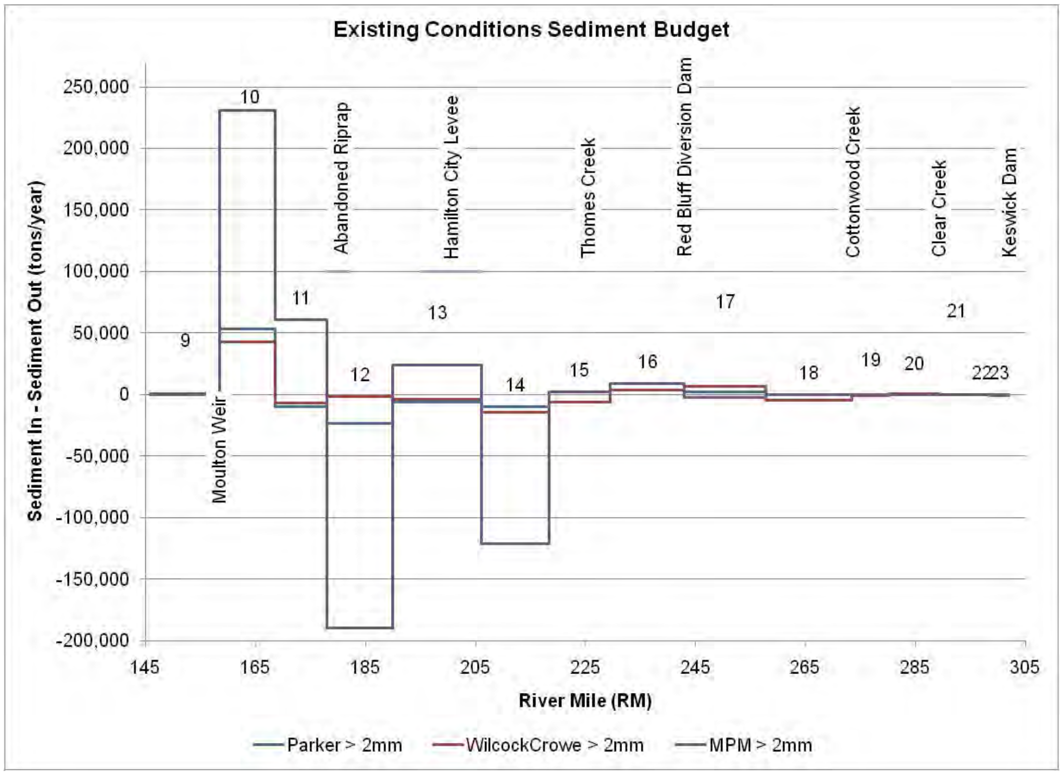

Figure B-1Sediment budget (existing hydrology) for material greater than 2mm using Parker and Wilcock and Crowe (both with default parameters) and Meyer-Peter-Müller.