Attachment

Bed Sediment Sampling

Draft
Geomorphology, Sediment Transport, and Vegetation Assessment
Appendix

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

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Abbreviations and Acronyms

DWR	California Department of Water Resources
lb	pound
mm	millimeter
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
SH	State Highway
SSCS	Sand Slough Control Structure
TSC	Technical Service Center

1.0 Overview

Sediment data were collected on the San Joaquin River during the week of February 4, 2008. Sediment data collection was a joint effort between California Department of Water Resources (DWR) and U.S. Department of the Interior, Bureau of Reclamation (Reclamation); both the local field office as well as the Technical Service Center (TSC). Data were collected on both the main stem of the San Joaquin River and the bypasses between Friant Dam and the confluence of the Merced River. Data collection efforts will result in sediment data that will be used in the modeling efforts being performed by Reclamation TSC.

The following pages describe the methodology, data collection site locations, and resulting information. An electronic database will be available on the project ftp site. An accompanying report describes the field photos taken during the February 2008 sediment sampling trip.

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2.0 Methods

Sediment sampling used two methods: bulk sampling and pebble counts. Bulk sampling typically identifies (by weight) the size characterization of a surface and a subsurface sample for a narrow aerial extent. Pebble counts identify (by areal frequency) the size characterization of a surface material for a larger aerial extent than the bulk samples.

2.1 Bulk Sampling and Sieving

Sieving is a robust method that accounts for all sediment sizes present in a given sample site. Sediment data collection for sieving involved two samples per site: a surface sample and a subsurface sample, unless there was no discernable difference between the two layers. When the two layers could be distinguished, often the surface layer was coarser because as the flood hydrograph recedes the ability to mobilize the coarser sediment reduces and only the finer sized sediments are winnowed away. One site location, however, involved sampling separately a sandy dune traversing a gravely substrate. Where two layers were indistinguishable, one bulk sample was collected.

Different sampling procedures were used to collect the bulk samples, depending on whether the sample area is above or below the water. If the sample area is dry, a square area is staked. For larger sized sediment (gravel and cobble), one 3- by 3-foot grid was used. For smaller sized sediment (sand and gravel), a 2- by 2-foot grid may have been used. A tarp was placed adjacent to the sample site. The surface layer was collected and placed on the tarp for analysis. For coarse gravel and cobble-sized sediment, typically one layer of sediment was removed by hand to constitute the surface sample. In areas of more uniform sediment sizes, a shovel was used to remove the surface layer to a depth approximately equal to the largest grain size of the surface sample. After the surface sample was collected, a subsurface sample was collected from within the same area as the surface sample. The depth of the subsurface was approximately equal to the largest grain size diameter from the surface sample.

To limit the volume of sediment transported to the laboratory, the sample was typically passed through a 32-millimeter (mm) sieve in the field. Particles larger than 32 mm were classified by size using a Wolman board and each size class was weighed on a scale supported by a survey tripod (typically a 70-pound (lb) scale with 0.1-lb increments). The material passing the 32-mm field sieve was put in a sample bag and labeled to be sent to a laboratory for further sieve analysis. A picture of the field sieving setup is given in Figure 2-1.

Figure 2-1.
Photograph of Field Sieving Setup

If the sample area was under water, two possible methods were used. One method is with a clamshell sampler, which can collect a sample and lose a minimum of material as the sample is lifted through the water column. A second method is with a shovel and sample bag. The sample was collected by placing the bag against the bed with the opening perpendicular to the direction of flow. The shovel was used to scoop the bed material into the bag. The surface layer was shoveled first and a subsurface sample was collected in a second bag if a discernable difference in material was identified.

Subsurface material samples are likely biased for three reasons. First, surface material from upstream may have rolled atop the newly exposed subsurface material before the subsurface sample may be collected. Second, exposed subsurface material may have winnowed away after the coarser surface layer was removed and before a subsurface sample was taken. Lastly, because the sample is collected underwater, more sands, silts, and clays may be lost as the material goes under, around, and through the permeable sample bag. An underwater surface sample is shown being collected in Figure 2-2.

Figure 2-2.
Under Water Sediment Sample Collection

Combined samples are collected when there are no discernable surface and subsurface layers. This is typically indicative of the sandy reaches of the San Joaquin River downstream from Gravely Ford; in this case, the bulk sample was collected with a shovel and sample bag.

A discernable difference between the bed material and the bank material was made in certain reaches. In these cases, a bulk sample of the sandy bed material was collected as well as a bulk sample of the finer bank material. No field sieving was necessary based on size, and both samples were sent to the laboratory in their entirety.

The total weight of the bulk sample should be related to the maximum particle size in the sample (Bunte and Abt 2001, Haschenburger 2005). Figure 2-3 contains recommended sample weights given the maximum diameter of the sample. This guideline may not have been met for the coarser reaches of the river due to time and budget limitations.

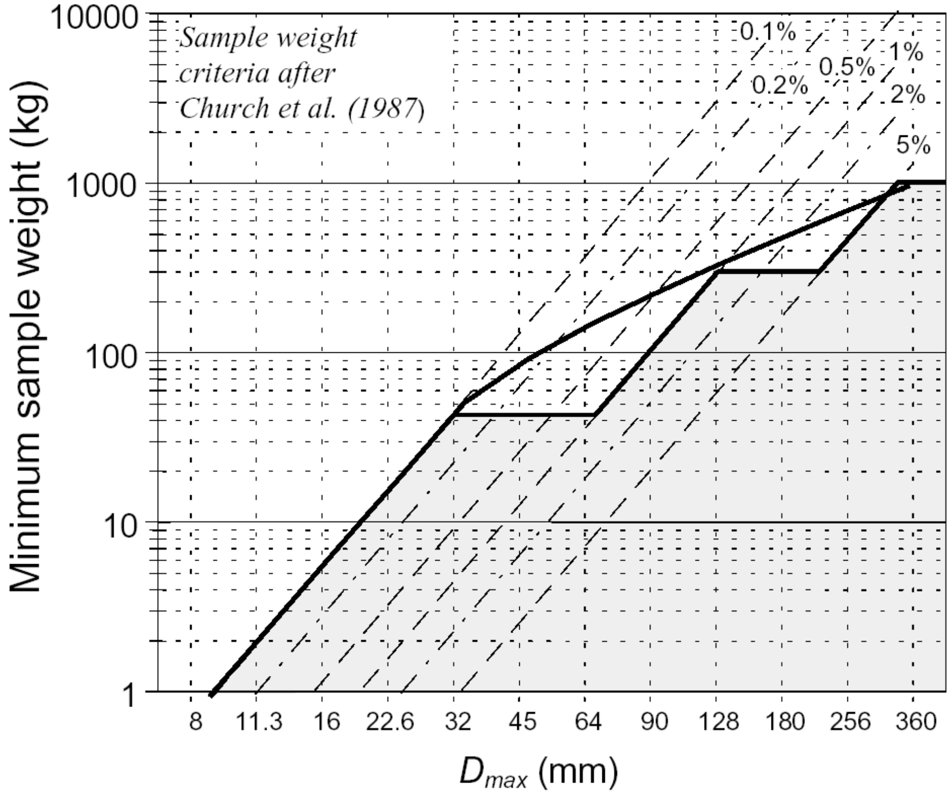

Fig. 4.20: Minimum sample weight for sediment with different D_{max} sizes (D_{max} = 0.1% m for a D_{max} <32 mm, D_{max} = 1% m for a D_{max} <128 mm, and D_{max} = 5% m for D_{max} > 128 mm) (after Church et al. 1987). The thick line represents a linear regression function fitted through the "corner points" of the stair-case function derived from the three sample-mass criteria by Church et al. (1987).

Figure 2-3.
Figure Taken from Bunte and Abt, 2001, Summarizing Recommendations from Church et al., 1987

2.2 Pebble Count

Pebble counts are used to develop a validation data set for the sieve samples, or to supplement the sieve data set with additional locations when there are budget and/or time constraints. Also, pebble count data characterize a larger aerial extent than a bulk sample. For bars or channels at least 100 feet wide, the first step of the pebble count data collection method was to lay a 100-foot tape across the section to be measured. For bars, the starting point (zero mark) of the tape began at the water edge, and extended away from the wet channel perpendicular to the direction of flow. For channels, the line extended from wet edge to wet edge. At approximately 1-foot intervals, a piece of sediment was selected by the data collector; the intermediate (or "B") axis was measured using a Wolman board and recorded. The intermediate axis can be thought of as the limiting width that prevents the particle from fitting through a square grid opening. The pebble was chosen by averting one's eyes from the ground, then leaning down with an extended index finger. The first rock hit by the finger was then measured. The measurement was recorded by another person and the process repeated. At least 100 data points were collected along each pebble count line.

If the bar or channel being sampled was narrower than 100 feet wide or edge effects (vegetation) began to occur along the outer edges, the pebble count was collected in adjacent lines or in a grid. For the adjacent lines, two 50- or four 25-foot lines were placed and the same method as described above is used. At least 100 total data points were collected. Figure 2-4 is a photo of two adjacent in-channel pebble counts in a wet channel less 100 feet wide.

For the grid method, a rectangular area was staked that was usually between 30 and 50 feet on a side. Two tape measures were used to form a cross in the middle. Each side of the rectangular grid was divided into 10 equal segments forming 100 grid cells within the rectangular area. One pebble was counted within each grid cell totaling 100 measurements.

Once the 100 measurements were collected, the data was tabulated into bins of sediment sizes and a particle size gradation curve was computed.

Figure 2-4.
Photograph of Adjacent In-Channel Wolman Pebble Counts

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3.0 Reach Observations

3.1 Reach 1

Reach 1 begins at Friant Dam and continues down to Gravelly Ford. The reach has been subdivided at State Highway 99 into Reaches 1a and 1b. The bed material in Reach 1 is primarily gravel and cobble with a sandy substrate, and transitions to a sand-bed in the downstream section of the reach. There are multiple gravel mining operations in Reach 1. The river is narrow due to the levees that are in place to protect agricultural lands and golf courses, as well as preventing gravel pits from capturing the river in the reach. The lower portion of Reach 1a runs along the north side of the Fresno Metropolitan Area as a further need for levees in this reach. Water was present throughout Reach 1 during the sediment sampling trip. The source of flow for Reach 1 is primarily the releases from Friant Dam. Grassy vegetation along with cottonwoods are found in the riparian corridor of Reach 1. Figure 3-1 is a photograph from a cobble bar on the Defehr Property (Reach 1a), and Figure 3-2 is a photograph of the gravel bed with interstitial sands in Reach 1b.

Figure 3-1.
Cobble and Gravel Bar in Reach 1a

Figure 3-2.
Gravel and Sand in Reach 1b

3.2 Reach 2

Reach 2 begins at Gravelly Ford and continues downstream to Mendota Dam. The reach has been subdivided at the Chowchilla Bifurcation Structure into Reaches 2a and 2b. The bed material of Reach 2 is primarily sand but in the upper reaches is transitioning from gravel to sand. Approximately 2 miles downstream from Gravelly Ford, there is sparse riparian vegetation, a sand-dominated bed (although lenses of gravel can still be found), and water ceases to be present in the channel. At the Chowchilla Bifurcation Structure (start of Reach 2b), the San Joaquin River flows can be diverted into the Chowchilla Bypass.

The bypass is a flood control channel that eases the stresses on and the potential for flooding of the San Joaquin River. The river has levees on both sides for most of this reach to protect agricultural lands adjacent to the river corridor. Figure 3-3 is a photograph of the upper transition zone of Reach 2a, and Figure 3-4 is a photograph from the middle of Reach 2a (after the transition zone from gravel to sand).

Figure 3-3.
Transition Zone in Upper Portion of Reach 2a

Figure 3-4.
Sand-Bed Channel in Reach 2a

3.3 Reach 3

Reach 3 begins at Mendota Dam and extends downstream to Sack Dam. Access was not provided for the San Joaquin River in any portion of this reach during the sediment sampling trip. This reach was characterized during a previous site visit (August 2007), by a narrow, sand-bed channel with ample bank vegetation. In-channel flow was present during the previous August 2007 site visit. Flow in Reach 3 can be a combination from three potential sources: Reach 2 of the San Joaquin River, the Fresno Slough, and the Delta-Mendota Canal. Figure 3-5 is a photograph of the San Joaquin River in the middle of Reach 3 from the August 2007 site visit.

Figure 3-5.
San Joaquin River in Middle of Reach 3

3.4 Reach 4

Reach 4a begins at Sack Dam and continues downstream to Bear Creek. The Sand Slough Control Structure (SSCS) divides the reach into Reaches 4a and 4b, and the Mariposa Bypass further divides Reach 4b into Reaches 4b1 and 4b2. The SSCS can divert flow from the San Joaquin River into the Eastside Bypass. Access was not provided to the San Joaquin River between Sack Dam and State Highway (SH) 152. The river downstream from SH 152 consisted of a sand-bed channel. Some ponded water in the San Joaquin River was present for 1 or 2 miles upstream from Washington Road. Active groundwater pumping was occurring during the sampling trip to irrigate the fields adjacent to the river in Reach 4a. Irrigation return flows are thought to be the source of the ponded water in the river (Figure 3-6). The bed material is dominated by sand.

Access was not provided to Reach 4b1 during the sediment sampling trip although the reach was accessed during the August 2007 site visit (Figure 3-7). Water was present in the San Joaquin River in Reach 4b2. The river runs through the San Luis National Wildlife Refuge in this reach. Vegetation is more prevalent in the river for this reach, and the sandy bed material appears to have a higher percent of fines in it. Figure 3-8 is a photograph of the San Joaquin River in the San Luis National Wildlife Refuge in Reach 4b2.

Figure 3-6.
Ponded Water in Sand-Bed Reach 4a

Figure 3-7.
San Joaquin River in Reach 4b1 During August 2007 Field Visit

Figure 3-8.
San Joaquin River in San Luis Wildlife Refuge, Reach 4b2

3.5 Reach 5

The flows from the Eastside Bypass join with Bear Creek in Reach 4b2, and Reach 5 begins at the confluence of Bear Creek and the San Joaquin River. Reach 5 ends at the confluence of the Merced River and the San Joaquin River. The bed material in Reach 5 is characterized as sandy with a more prevalent concentration of fines and organic material. Levees are found in Reach 5 but the river is typically wider with more floodplain connectivity than is found in the more upstream reaches. The reach is similar to Reach 4b2 in that there are number of slough inputs, remnant channels, and in general the river is not intrinsically well defined and discernable. More grassy and woody vegetation is found in the riparian corridor, and flow was present during the sediment sampling trip. Figure 3-9 is a photograph of the San Joaquin River in the upstream portion of Reach 5. Figure 3-10 is a photograph of the confluence of the San Joaquin River (background) and the Merced River (foreground).

Figure 3-9.
San Joaquin River in Upstream Portion of Reach 5

Figure 3-10.
Confluence of the San Joaquin and the Merced Rivers

3.6 Bypass Channels

At the Chowchilla Bifurcation Structure (start of Reach 2b) the San Joaquin River flows can be diverted into the Chowchilla Bypass. The Bypass is a flood control channel that eases the stresses on and the potential for flooding of the San Joaquin River. The bypass is leveed for most of its length to protect the agricultural lands adjacent to the river corridor, and runs essentially parallel to the San Joaquin River until it empties into Bear Creek, which subsequently empties into the San Joaquin River (start of Reach 5). The bypass channel consists of a sand-bed for most of its length. Figure 3-11 is a photograph just downstream from the Chowchilla Bifurcation Structure. Erosion of the native silty-sand material near SH 152 is evident in the bypass channel (Figure 3-12), and there is a layer of sand on the bed of the channel. The erosion of the native material likely happens during rising limbs of storm hydrographs and the deposition of the relatively coarser sand occurs during the falling limb. Figure 3-13 is a photograph of the sandy bed material and the native silt material in the Chowchilla Bypass in Reach 4a. There was no water present in the Chowchilla Bypass channel during the sampling trip. Some vegetation was present on the banks of the Chowchilla Bypass and the bed was mostly unvegetated.

Figure 3-11.
Sand-Bed Channel in Chowchilla Bypass Just Downstream from Bifurcation Structure

Figure 3-12.
Erosion in Bypass Channel at SH 152

Figure 3-13.
Sand-Bed and Silt Bank in Reach 4a Chowchilla Bypass

The Chowchilla Bypass becomes the Eastside Bypass at the SSCS. The SSCS, which delineates San Joaquin River Reaches 4a and 4b1, is a second location where flow from the river can be diverted into a bypass for flood reduction purposes. The presence of ponded water began approximately 2 miles downstream from the SSCS in the Eastside Bypass. The Eastside Bypass bed consists of sand, and much more grassy vegetation was present compared to the Chowchilla Bypass upstream from the SSCS.

The Mariposa Bypass intersects the Eastside Bypass approximately 9 miles downstream from the SSCS on the bypass side. The Mariposa Bypass is an equilibration structure that allows water to pass either to or from the San Joaquin River and the Eastside Bypass, depending on the need. The bed material of the Mariposa Bypass is sandy and overlain with grassy vegetation (Figure 3-14) and water was not present during the sampling trip. More in-channel water was present in the Eastside Bypass downstream from the Mariposa Bypass, with the bed material apparently having a higher percentage of fine material mixed in with the sand. Figure 3-15 presents a photograph of the Eastside Bypass near the confluence with Bear Creek. The flows from the Eastside Bypass join with Bear Creek, and Reach 5 of the San Joaquin River begins at the confluence of Bear Creek and the San Joaquin River.

Figure 3-14.
Grassy Sand-Bed Channel of the Mariposa Bypass

Figure 3-15.
Eastside Bypass near Confluence with Bear Creek

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4.0 Results

Figure 4-1 provides an overview schematic map with the restoration reach breaks and the sampling locations. This attachment provides sampling locations with select site photos over aerial photographs.

Figures 4-2 through 4-9 present sediment sample representative diameters (D16, D50, and D84) for all samples collected on the San Joaquin River. Figures 4-10 and 4-11 present the same information for samples in the bypasses. A river mile system was created for the bypass with “0” occurring at the confluence of Bear Creek with the San Joaquin, and the Chowchilla Bifurcation Structure occurring at River Mile 52.1.

Access was not provided to most of Reach 4a and the entirety of Reaches 2b and 3 during the sediment sampling trip. These are locations where more sampling will be required.

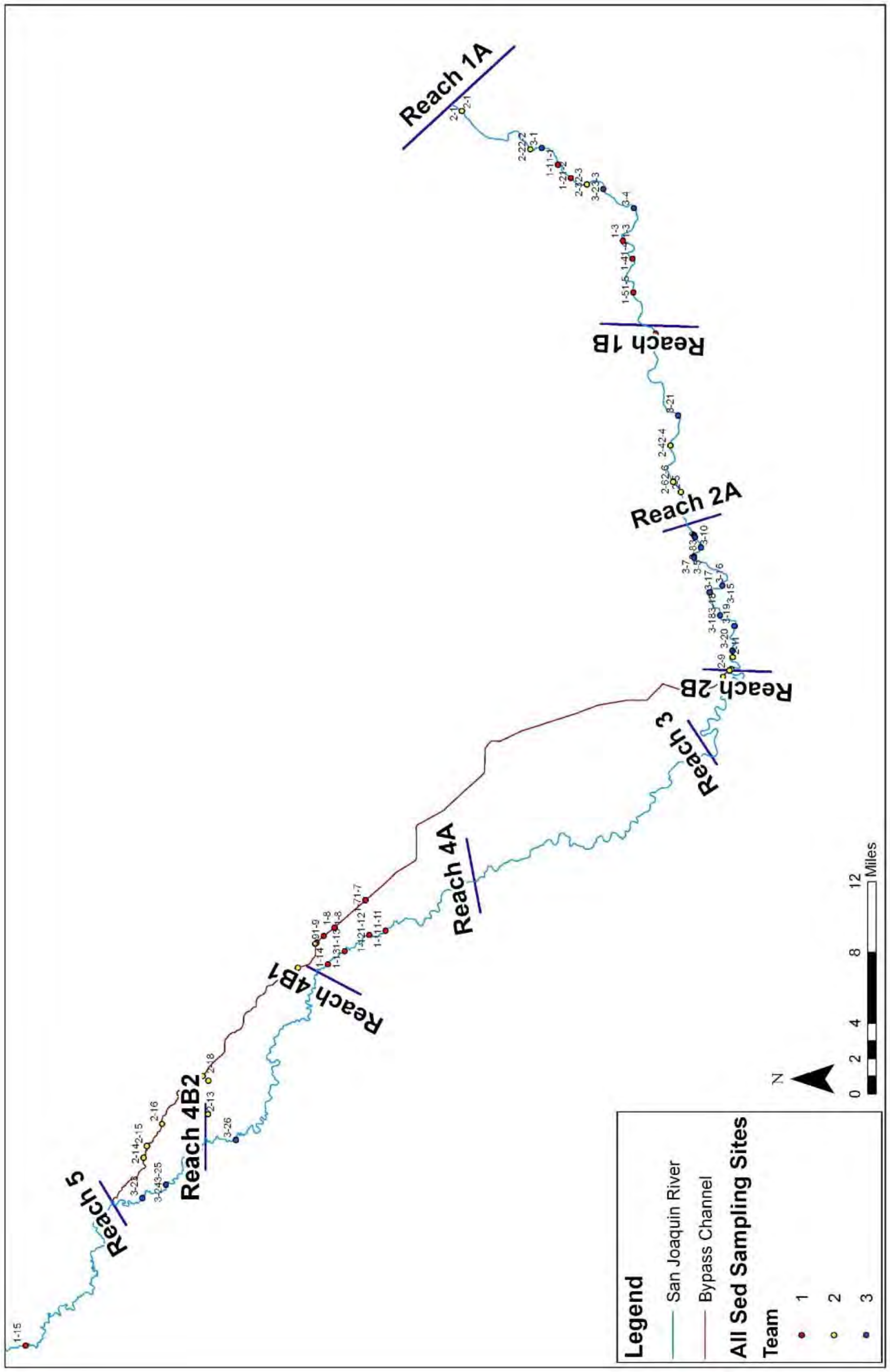

Figure 4-1.
Overview Schematic Map with Sample Locations and Reach Breaks

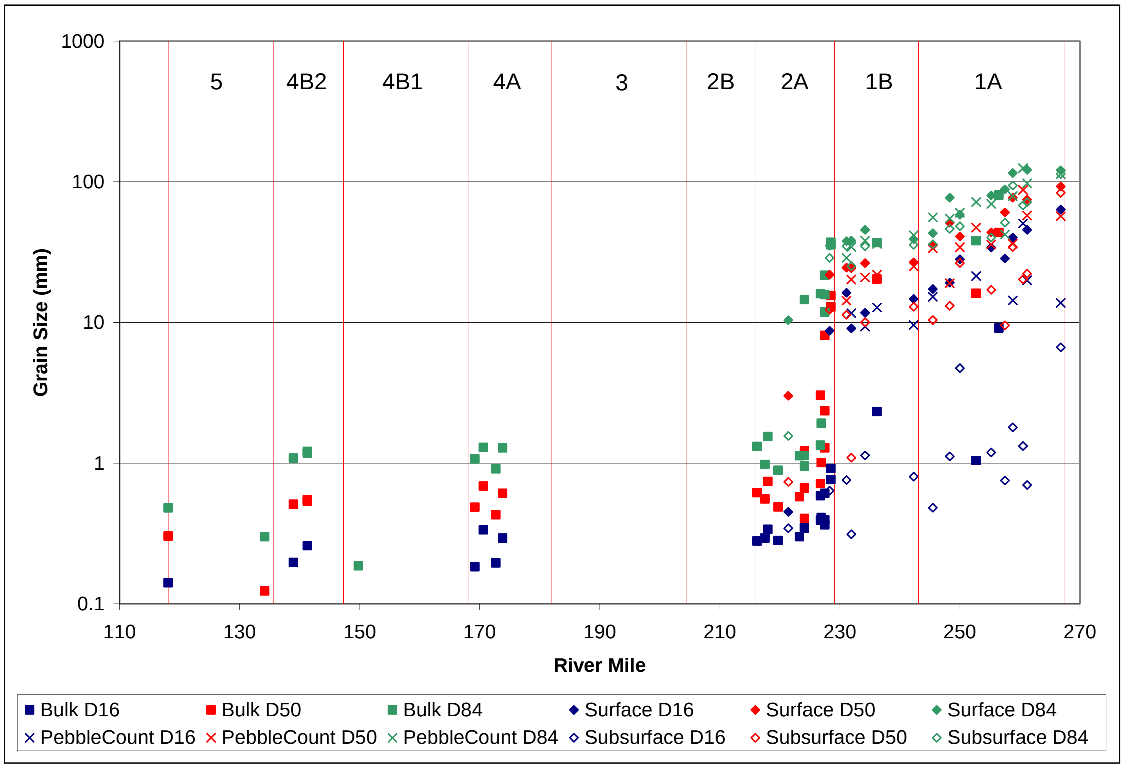

Figure 4-2.
Data Sample Representative Diameters from Friant Dam to Merced River

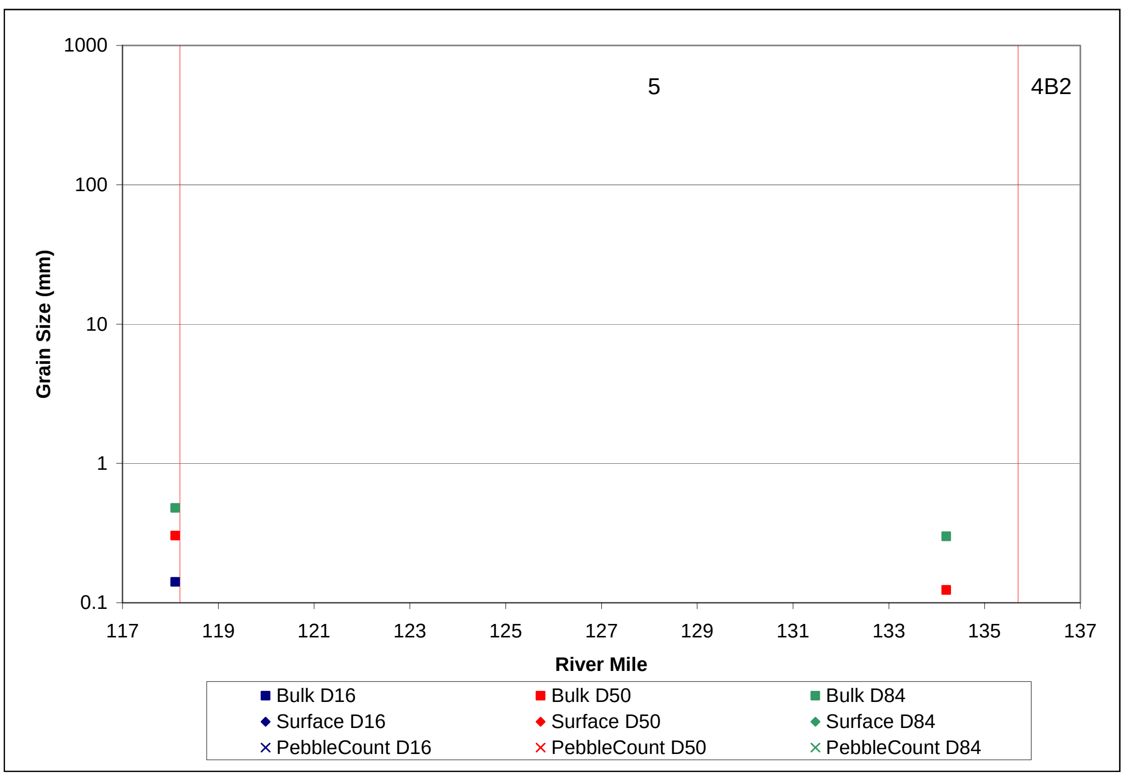

Figure 4-3.
Surface, Bulk, and Pebble Count Representative Diameters for Reach 5

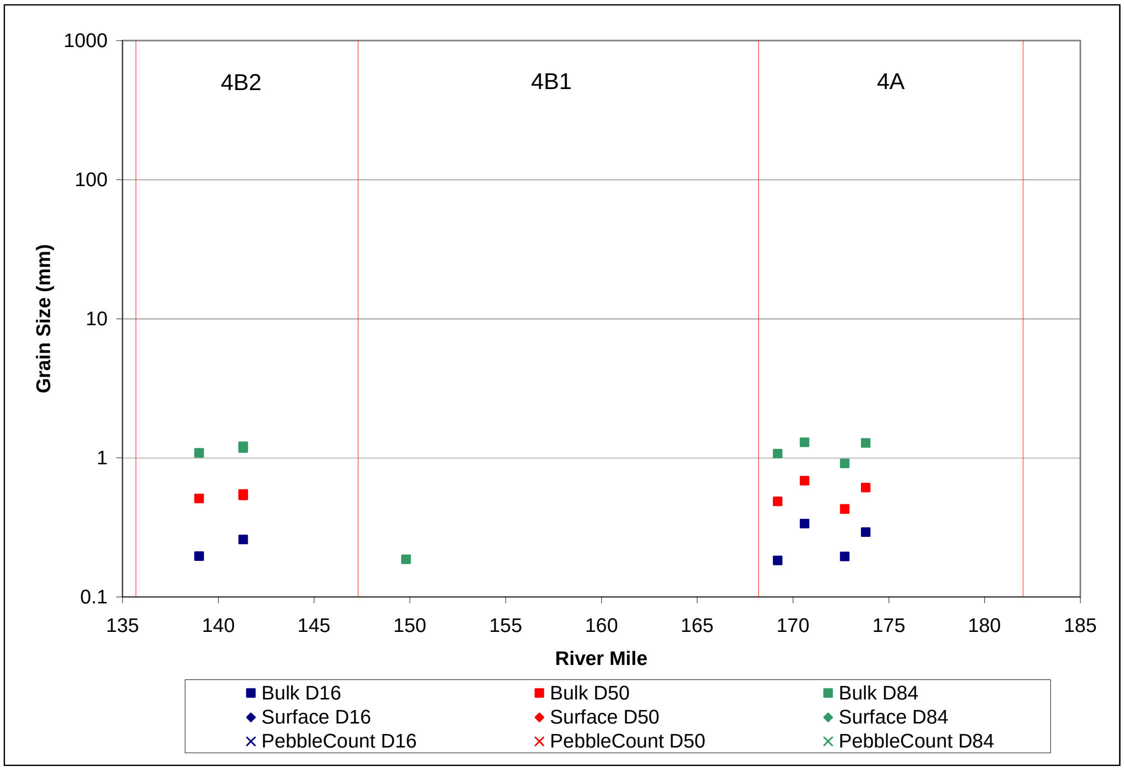

Figure 4-4.
Surface, Bulk, and Pebble Count Representative Diameters for Reach 4

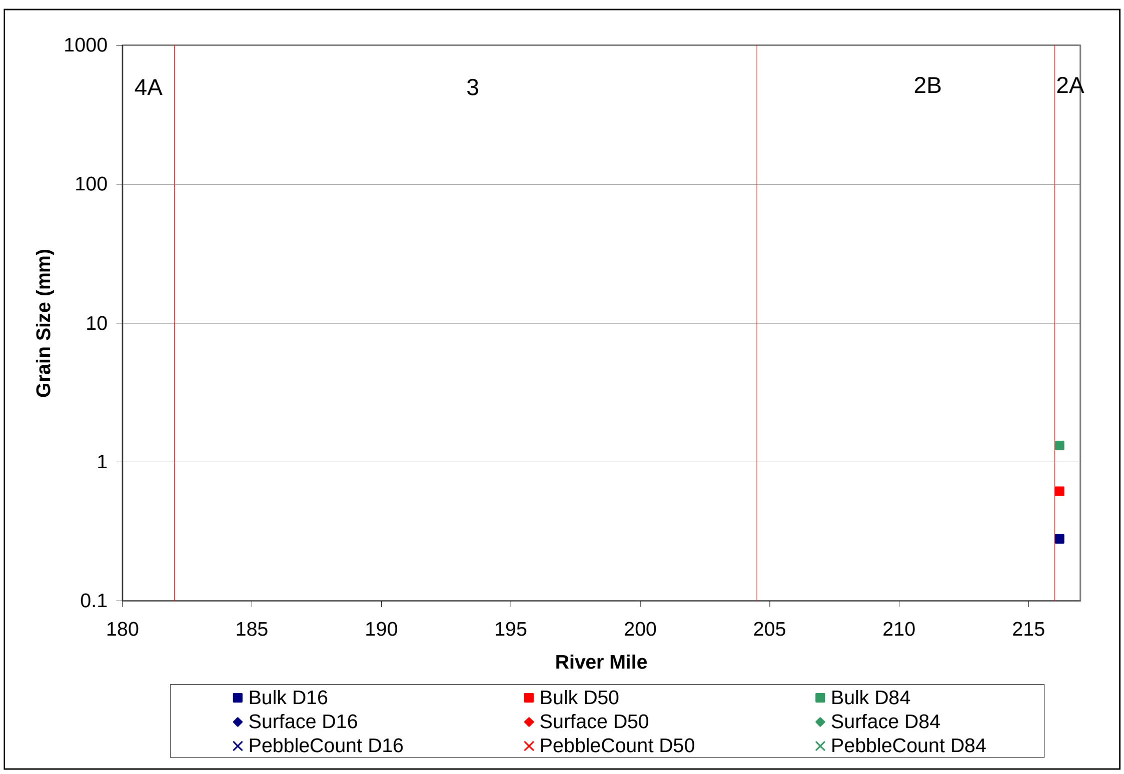

Figure 4-5.
No Sampling in Reaches 2b or 3

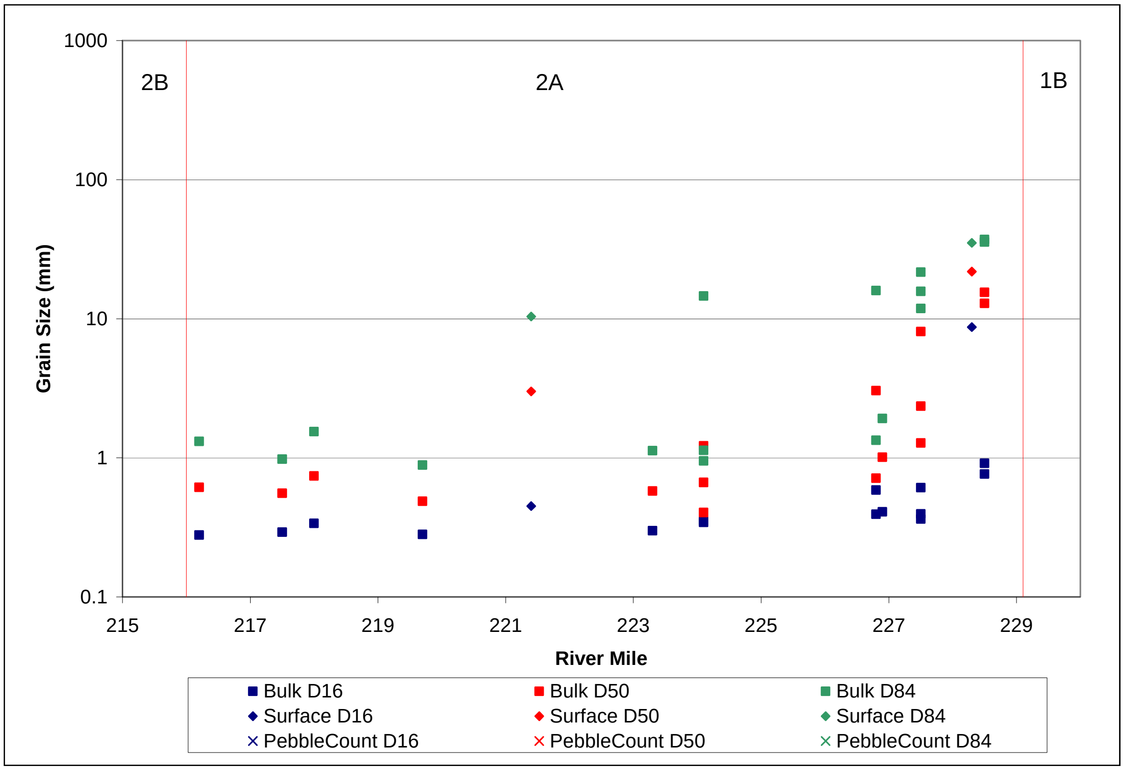

Figure 4-6.
Surface, Bulk, and Pebble Count Representative Diameters for Reach 2a

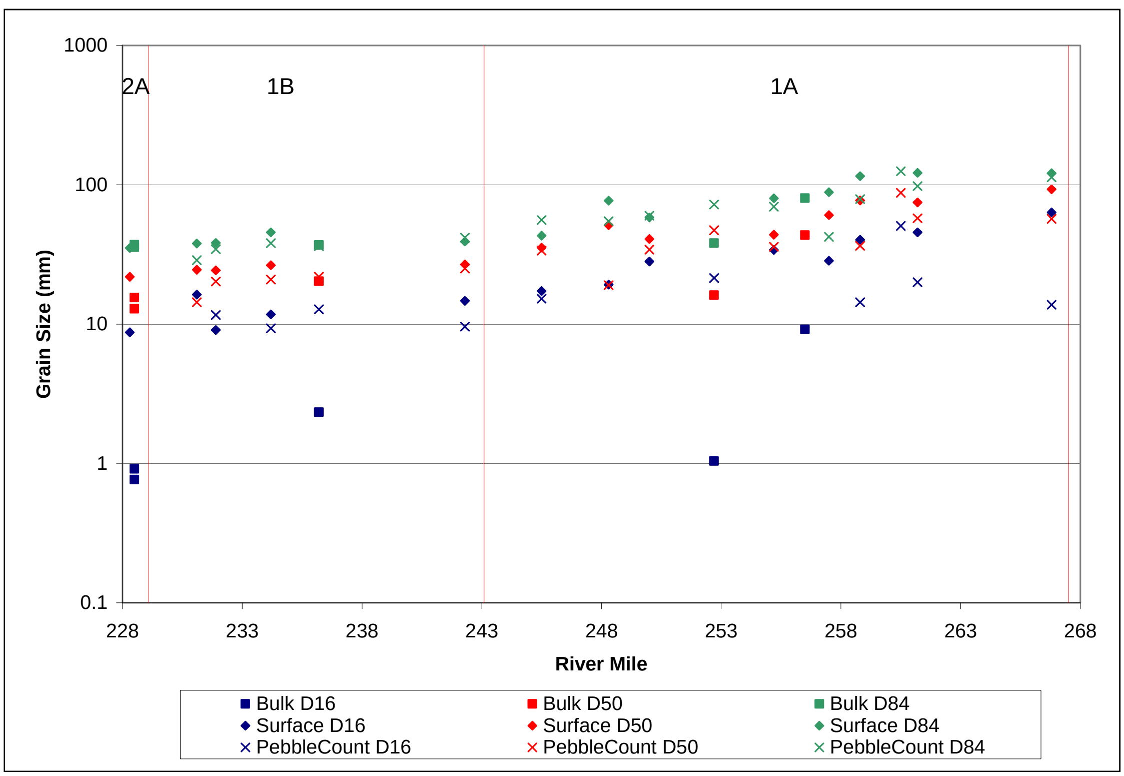

Figure 4-7.
Surface, Bulk, and Pebble Count Representative Diameters for Reach 1

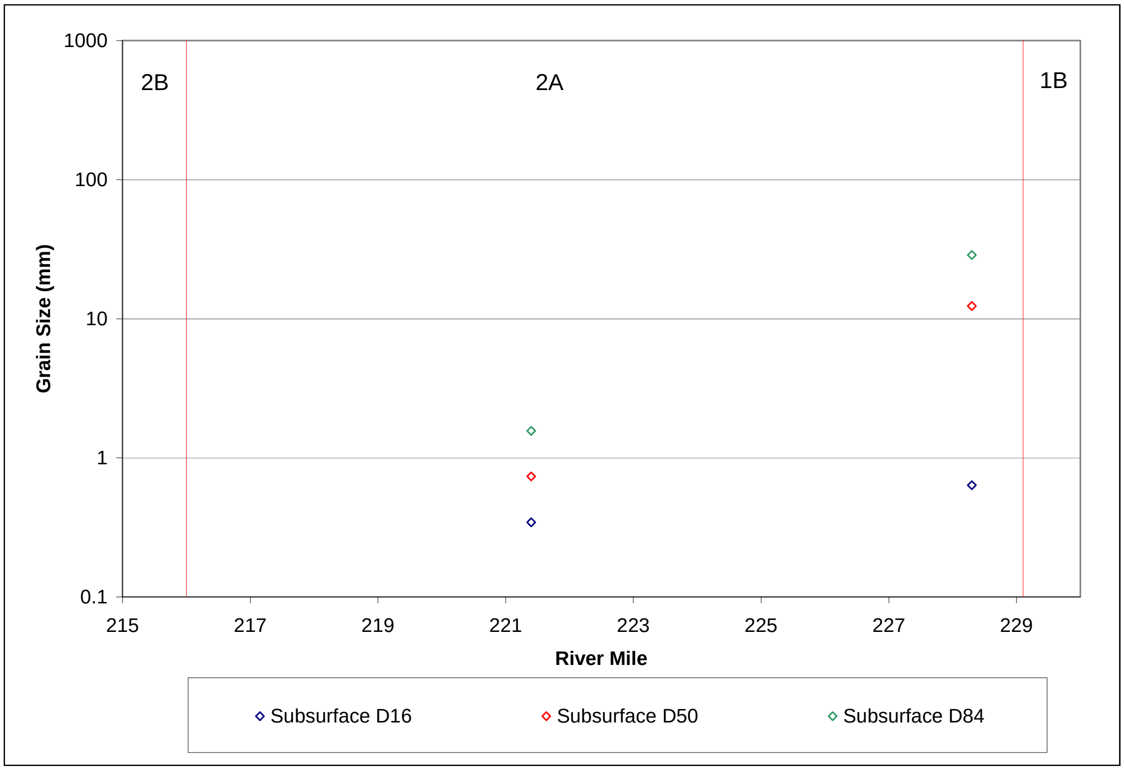

Figure 4-8.
Subsurface Representative Diameters for Reach 2a

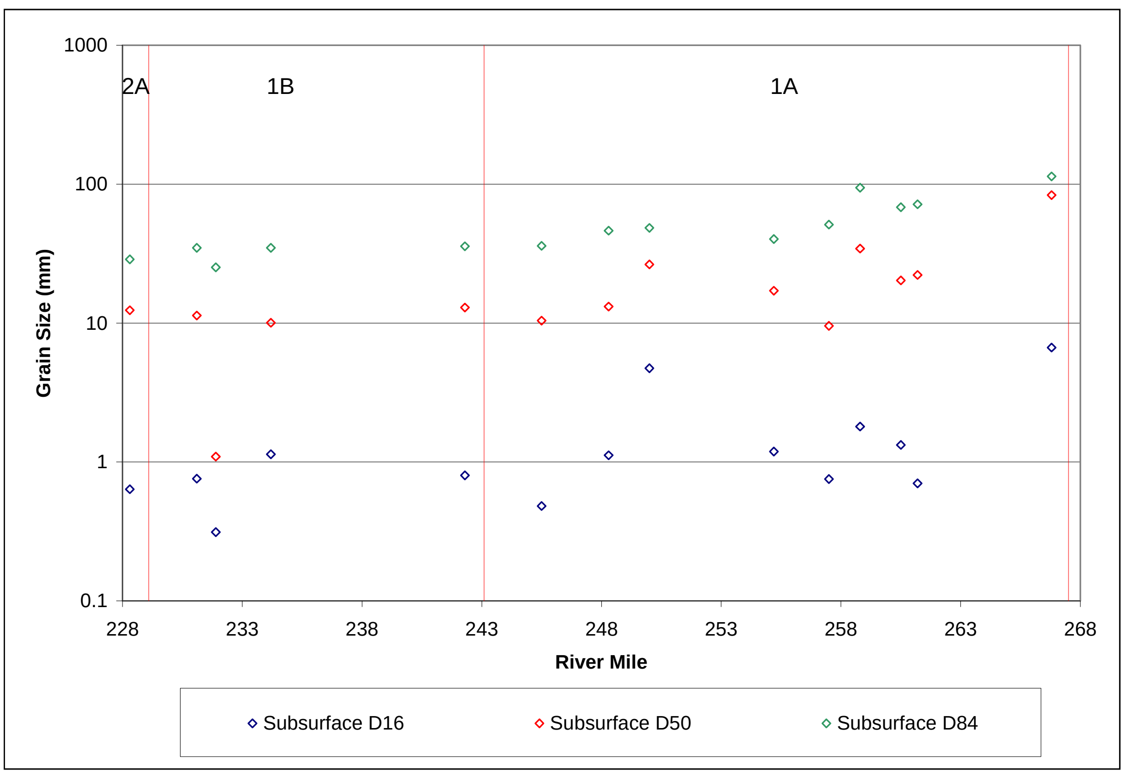

Figure 4-9.
Subsurface Representative Diameters for Reach 2a

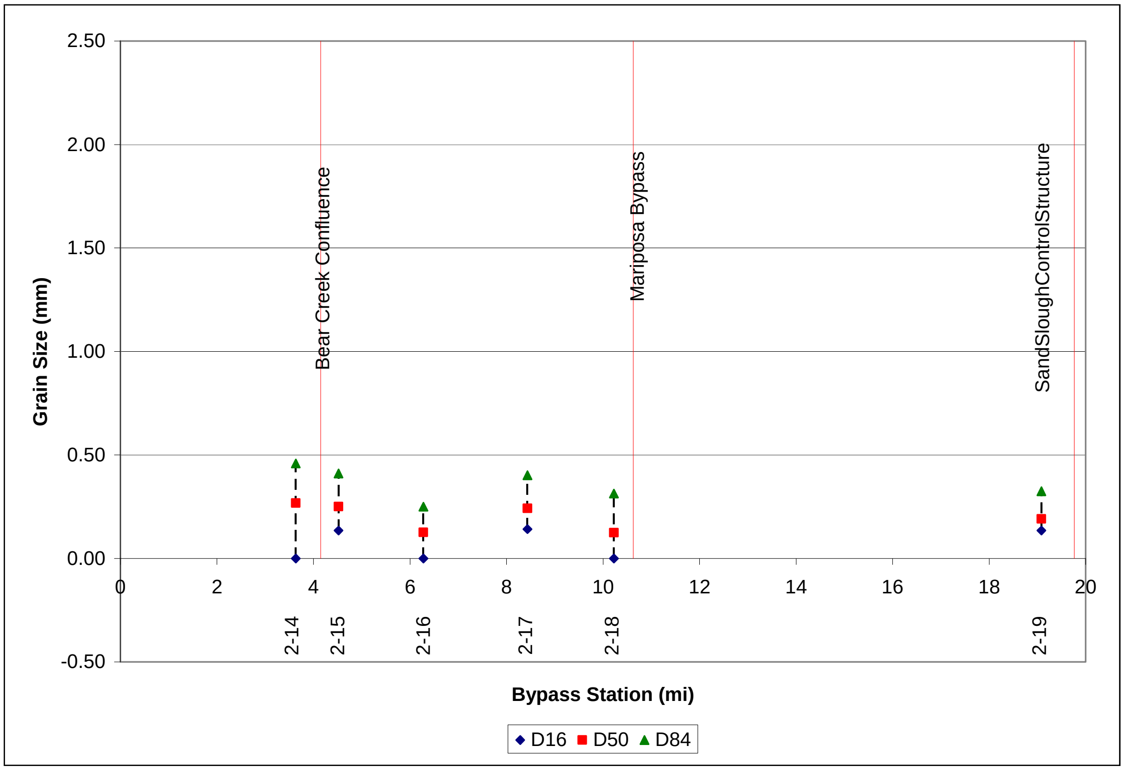

Figure 4-10.
Bulk Sample Representative Diameters for Samples in Eastside Bypass

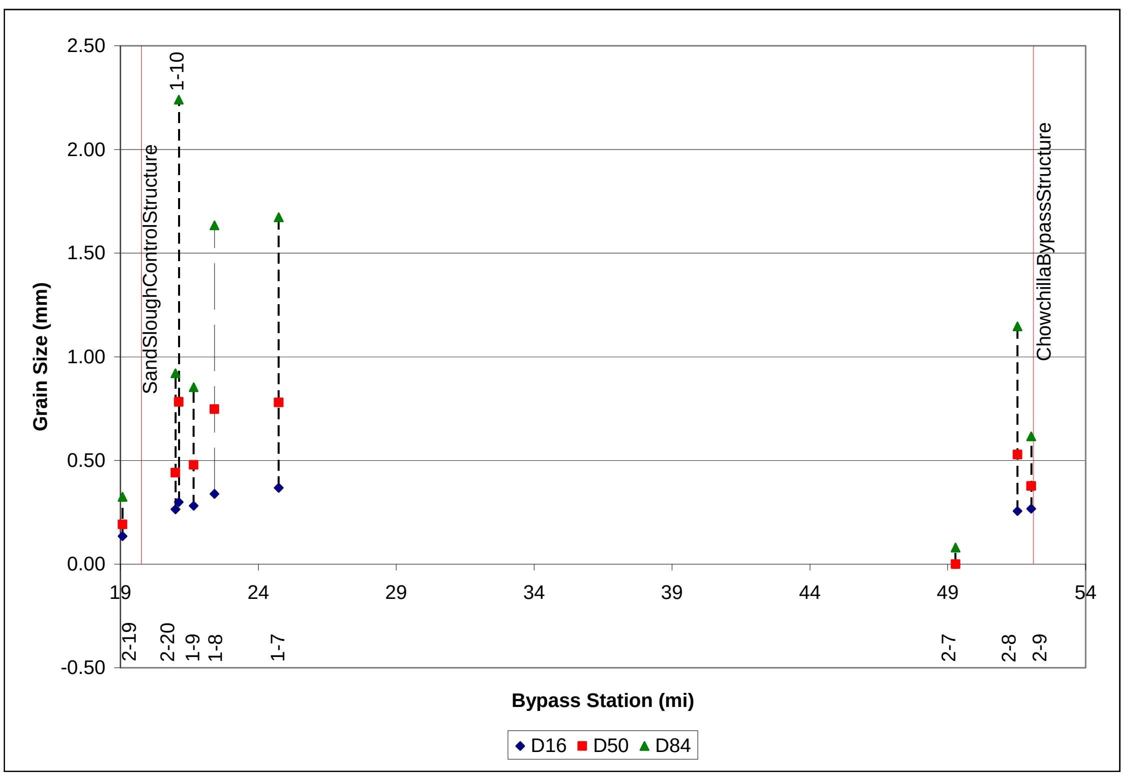

Figure 4-11.
Bulk Sample Representative Diameters for Samples in Chowchilla Bypass

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5.0 Future Data Needs

Access restriction led to missing data in Reaches 2b and 3. Access to the Chowchilla Bypass was not provided between the Fresno River and SH 152. Only one sample was collected in Reach 4b1. A return sampling trip may be needed to get more data for Reach 4b1, and to get data for Reaches 2b and 3. Additional sampling in Reach 5 will also be required. A boat and a clamshell sampler with a long neck would allow more intensive sampling.

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6.0 References

Bunte, K., and S.R. Abt. 2001. "Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel and Cobble-Bed Streams for Analyses in sediment Transport, Hydraulics and Streambed Monitoring." U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-74.

Haschenburger, J., E. Voyde, and S. Rice. 2005. "An Experimental Assessment of Bulk Sediment Sampling Criteria for Gravel-Bed Rivers," in proceedings of 6th Gravel Bed Rivers Conferences. September 5-9. Austria.

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Attachment

San Joaquin River Geomorphic Assessment Using Historical Aerial Photographs, California
Friant Dam to Route 99 Bridge

Draft
Geomorphology, Sediment Transport, and Vegetation Assessment Appendix

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

San Joaquin River Geomorphic Assessment Using Historical Aerial Photographs, California

Friant Dam to Route 99 Bridge

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San Joaquin Geomorphic Assessment using Historical Aerial Photographs

FRIANT DAM TO ROUTE 99 BRIDGE

Technical Approval

The results, findings, and recommendations provided in this decision document are technically sound and consistent with current Reclamation practice, and are consistent with the source document(s).

Jeanne E. Godaire — 4/9/2009

Prepared by
Jeanne E. Godaire, M.S.
Geomorphologist

Date

Peer Review Certification

This section has been reviewed and is believed to be in accordance with the service agreement and standards of the profession.

Ralph E. Klinger — 4/9/2009

Peer reviewed by
Ralph E. Klinger, Ph.D.
Geomorphologist

Date

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Table of Contents

Exhibits

Tables

Figures

List of Abbreviations and Acronyms

cfs	cubic feet per second
ft3	cubic feet
km	kilometer
m	meter
m3 x 103	thousands of cubic meters
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RM	river mile
Rt.	Route

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1.0 Introduction

This geomorphic assessment is in support of the San Joaquin River Restoration Program and is part of a larger analysis that focuses on the sediment transport and geomorphic characteristics of the San Joaquin River. Geomorphic data in this study provide information about the characteristics of the river channel, and the dominant fluvial processes operating before dam construction and extensive in-channel gravel mining. This study also provides documentation of the changes in river planform during the last 70 years and can be used to evaluate various restoration options given future flow and sediment supply scenarios.

The study reach extends for approximately 24 miles from Friant Dam to the Route (Rt.) 99 Bridge and is located within Reach 1A, as defined by the San Joaquin River Restoration Study (McBain and Trush, Inc. 2002). The river in this reach flows across a gravel/cobble bed, which is bounded by bedrock between Friant Dam and Ledger Island and transitions to a predominantly alluvial system downstream from Ledger Island. While a more complex channel network existed historically, multiple channels are still present in sections of this reach. Riparian vegetation exists along sections of the river, although much of the reach is heavily mined and therefore has removed much of the vegetation that existed before large-scale gravel operations. Channel morphology spans a variety of types, depending on location in the reach and includes straight, single-channel, island-braided, and low-amplitude, irregular meanders. In 1938, the reach contained numerous split-flow channels around vegetated islands, long side channels and relatively unvegetated flood channels formed during high-flow events. Sediment mobilization of smaller material than present today is evident from visible sediment splays along the margins of the main channel and unvegetated mid-channel and point bars that had been recently modified by flows equal to or less than bankfull. Channel gradient is low, ranging from 0.001 to 0.0004 with an average of 0.0007 (Cain 1997). Stillwater Sciences (2003) measures a slope of 0.00056 from Friant Dam to Gravelly Ford and compares it to other rivers in the Central Valley, greater California, and Pacific Northwest to emphasize the unusually low gradient for a gravel-bed river.

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2.0 Study Objective

The goal of this geomorphic assessment is to analyze changes in channel planform between 1938 and 2007. This assessment can be used to help identify pre-dam river conditions and post-dam river adjustments. Upon the release of larger flows, this assessment should help to identify likely geomorphic characteristics that would most likely develop under an altered flow and sediment regime.

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3.0 Previous Work

While there are many studies and data available for the San Joaquin River, two references provide data and information that are most relevant to this assessment. The San Joaquin River Restoration Study Background Report (McBain and Trush, Inc. 2002) provides a compilation of existing data for the San Joaquin River from Friant Dam to its confluence with the Merced River, a total of 265 river miles. Chapter 3, Fluvial Forms and Processes is of particular interest to this study. Five main reaches are defined from Friant Dam to the confluence with the Merced River on the basis of channel morphology (Table 3-1). Reach 1, from Friant Dam to Gravelly Ford, differs from downstream reaches in that it is the only reach with a gravel bed. Channel morphology in this reach is described as poorly defined meanders and differs from Reach 2 in which meanders become more sinusoidal with numerous split channels, side channels, and high-flow scour channels. In Reach 3, this morphology transitions into a meandering system with a highly sinuous single channel and a floodplain with abandoned channels and high-flow scour channels. Reaches 4 and 5 exhibit anabranching channel morphology with extensive tule marshes and sloughs. Average depths at bankfull stage are relatively constant; however, the width-to-depth ratio shows a general decrease with distance downstream from Reach 1B to 4A and an increase in Reaches 4B and 5. This trend is reflective of bank resistance to erosion and the effects of rising base level at the confluence with the Merced River.

Cain (1997) focuses on channel changes in Reach 1, as defined by the San Joaquin River Restoration Study. The author maps changes in planform morphology from Friant Dam to Lanes Bridge, a total distance of 18 kilometer (km) (11.25 miles) and investigates changes in bed elevation between Friant Dam and Gravelly Ford, a total distance of 37.7 km (36.1 miles). He splits Reach 1 into five reaches (Table 3-2), some with subreaches, and uses maps from 1914 and 1989 and aerial photographs from 1939, 1980, and 1993 for the analysis. The active channel is mapped in 1939 photography. The low-flow channel is mapped using the 1939, 1989, and 1993 photos while the high-flow channel is mapped in 1980. Cain defines the active channel as the area occupied by the bankfull or dominant discharge, following Leopold et al. (1964). The low-flow channel is mapped as the area inundated by flow during the fall months. Channel widths of the main, secondary, or high-flow channel were measured every 200 feet within the study reach. From his analysis, Cain found that there was a marked decrease in channel width between 1939 and 1980 but little change in the low-flow channel except a slight narrowing by vegetation encroachment since 1939. Cain also observed that there was a marked decrease in channel network complexity, involving a decrease in the number of bars, backwaters, and side channels. This observation is qualitative but is somewhat reinforced by the decrease in channel length measurements through time. Cain also compared cross-section measurements from Friant Dam to Gravelly Ford (approximately 58 km, 36 miles) using data from 1878, 1914, 1939, 1970, 1989, 1996, and 1997. The results show channel incision at most cross sections. The greatest incision of 18.7 feet (5.7 meter (m)) was measured 22.5 miles (36 km) downstream from Friant Dam, which suggests that incision here is mostly related to gravel mining rather than dam construction. Cain notes that at some locations, bedrock in the channel has limited the magnitude of the incision.

Table 3-1.
Compilation of Changes in Channel Elevation and Slope

Reach No.	Mile (km)	Description	Slope of Water Surface Elevation		Cross-Section Measurements	
			1939 slope	1989 slope	Elevation change (1939-1996) feet (meters)	Distance d/s from Friant Dam miles (km)
1A-1	0-4.0 (0-6.4)	Friant Dam to Ledger Island	0.0007	0.0006	-6.95 (-2.12) -6.99 (-2.13) 2.92 (0.89) 3.18 (0.97)	0.81 (1.30) 0.96 (1.54) 1.58 (2.53) 2.01 (3.21)
1A-2A	4.0-7.2 (6.4-11.5)	Ledger Island to Rank Island	0.0008	0.0006	0.79 (0.24)	6.58 (10.53)
1A-2B	7.2-8.9 (11.5-14.2)	Rank Island to Friant Pumice Outcrop	0.0008	0.0008	-4.46 (-1.36)	7.78 (12.44)
1A-3A	8.9-11.4 (14.2-18.2)	Friant Pumice Outcrop to Lanes Bridge (Rt. 41)	0.0005	0.001	--	--
1A-3B	11.4-20.9 (18.3-33.4)	Lanes Bridge (Rt. 41) to Santa Fe Railroad Bridge	0.0005	0.0008	-5.25 (-1.6)	11.56 (18.5)
1A-4	20.0-31.7 (33.4-50.68)	Santa Fe Railroad Bridge to Skaggs Bridge (Rt. 99)	0.0005	0.0004	-18.70 (-5.7) -2.98 (-0.91)	22.5 (36) 31.31 (50.1)
1B	31.7-36.1 (50.68-57.7)	Skaggs Bridge (Rt. 99) to Gravelly Ford	0.0004	0.0005	--	--

Source: Compiled from Cain 1997
Key:
km = kilometer
No. = Number
Rt. - Route

Table 3-2.
Reach Locations Defined by the San Joaquin River Restoration Study Background Report

Reach	Subreach	Reach Boundary (River Post)	General Description
1	1A	267.5 – 243.2	Friant Dam to State Route 99
	1B	243.2 – 229.0	State Route 99 to Gravelly Ford
2	2A	229.0 – 216.1	Gravelly Ford to the Chowchilla Bypass Bifurcation Structure
	2B	216.1 – 204.8	Chowchilla Bypass Bifurcation Structure to Mendota Dam
3	3	204.8 – 182.0	Mendota Dam to Sack Dam
4	4A	182.0 – 168.5	Sack Dam to the Sand Slough Control Structure
	4B	168.5 – 135.8	Sand Slough Control Structure to the confluence with Bear Creek and Eastside Bypass
5	5	135.8 – 118.0	Confluence with Bear Creek and the Eastside Bypass to the Merced River confluence

Source: From McBain and Trush, Inc. 2002

Longitudinal profiles and slope measurements between 1939 and 1989 show mixed results that do not reveal a consistent pattern between changes in bed elevation and slope adjustments (Table 3-2). Reaches with decreased slope extend from Friant Dam to Rank Island and from Santa Fe Railroad Bridge to Skaggs (Rt. 99) Bridge. Cross sections within these reaches show both increases and decreases in bed elevations. Reaches with increased slope extend from Lanes (Rt. 41) Bridge to the Santa Fe Railroad Bridge and from Skaggs (Rt. 99) Bridge to Gravelly Ford. Few cross sections are available in these reaches to make a valid comparison between slope and bed elevation changes. The cross sections that do exist show decreased bed elevations between 1939 and 1989.

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4.0 Methodology

For this geomorphic assessment, georeferenced aerial photography from 1938 and 2007 were used to measure changes in channel planform. For each year of photography, active channels, side channels, unvegetated bars, vegetated bars, and flood channels were mapped (Exhibit B). The 1938 photography primarily showed evidence for a wider channel that was able to convey infrequent high-magnitude flows and flood channels that served as overflow routes for the largest floods.

The active channel is defined and mapped as “the portion of a channel that contains flow at the time of measurement…” (p. 7, Neuendorf et al. 2005). Based on this definition, the active channel includes both the main channel and wetted side channels. A side channel is defined in this study as a channel that is less than 30 percent of the main (or widest) channel width (in keeping with Cain’s methodology) in at least one section, that flows around a channel bar or island with at least sparse vegetation, indicating some stability. Unvegetated bars are characterized by absent or sparse vegetation and show evidence for surface modification by recent flows. Bars can be of various types including alternating bars, point bars, or mid-channel bars. Vegetated bars have the majority of their surfaces covered by vegetation. They show marginal to no evidence for surface modification by recent flows and are typically located in areas where split flow occurs. They can also be present where high flows have isolated vegetated patches on an otherwise unvegetated bar and are occasionally mapped as point bars or alternating bars where it is obvious that they are a bar feature rather than a floodplain feature. In many cases, these features could also be called islands where they exist as mid-channel features. While much can be learned by understanding the evolution of bars following the construction of Friant Dam, the limited nature of this study dictated that bar types be mapped as one unit rather than separate units.

Active channel width was measured every 400 feet, which is twice the distance of Cain’s channel width measurements, but is as detailed as was possible for this study. Approximately 300 transects were measured across the channel in the 1938 photography; all measurements were made along the transects and perpendicular to flow. A concerted effort was made to measure the channel width in the same location for both sets of photography whenever possible; however, changing orientations of the channel between the photo sets made this difficult in some areas. In the 2007 photography, width was not measured in areas where a through-flowing channel could not be identified. This occurred where the channel flowed through gravel pits. Measurements for both active channels and side channels along each transect were combined to derive a total width at each transect.

Channel sinuosity is defined as the “ratio of the length of the channel to the down-valley distance” (p. 602, Neuendorf et al. 2005). The length of the channel centerline in both the 1938 and 2007 photography was measured by mapping along the center of the active channel; where split flow occurred and both channels were of similar width, the channel that appeared to be more sinuous was mapped. Otherwise, the largest active channel was used to map the channel centerline. Flow paths through gravel pits in the 2007 photography had to be inferred since the channel is undefined in these areas. The valley length was mapped along the center of the river corridor in the 1938 photography and used for both the 1938 and 2007 sinuosity measurements. One sinuosity measurement for the entire reach was made for each year.

5.0 Results and Discussion

Results from this assessment illustrate that the San Joaquin River has experienced substantial decreases in channel width, and area of the active channel, side channels, vegetated bars, and unvegetated bars (Table 5-1).

Table 5-1.
Summary of Measured Parameters

Parameter	1938	2007	Magnitude of Change	Percent Change
Average width	310 feet	145 feet	-2.1	-53
Sinuosity	1.19	1.23	0.96	4
Active channel area	901 acres	432 acres	-2.1	-52
Side channel area	337 acres	31 acres	-9.8	-91
Unvegetated bar area	183 acres	82 acres	-2.2	-55
Vegetated bar area	628 acres	428 acres	-1.5	-32

Note: Negative values indicate a decrease while positive values indicate an increase in the parameter from 1938 to 2007.

Average channel width decreased by a factor of two between 1938 and 2007. The change is largely a result of the altered flow regime in which annual peak flows were dramatically reduced by a factor of four following the construction of Friant Dam (Figure 5-1).

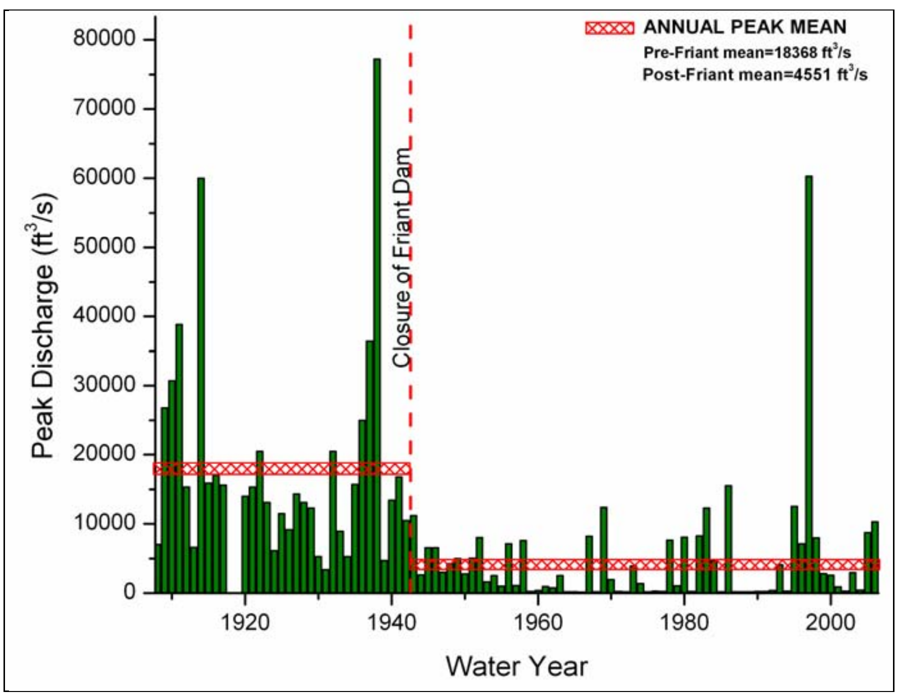


Figure 5-1.
Annual Peak Discharges, San Joaquin River Below Friant, California
(USGS Gaging Station No. 11251000)

Comparing width measurements over time, active channel widths are, for the most part, narrower in 2007 when compared to 1938 at each location along the length of the study reach (Figure 5-2). A few exceptions do occur, most of which are in areas where gravel mining may have taken place in the channel, but is not obvious. Between 11 and 15 miles downstream from Friant Dam, several locations have greater channel width in 2007 when compared to 1938. This particular area has been heavily mined and the channel currently flows between two large gravel pits. The width of the channel in this area is predominantly a function of the constructed channel through the pits and does not reflect channel response to fluvial processes or geologic controls. In 1939, channel width measurements were wider at about 11 miles downstream from Friant Dam, or between River Posts 254 and 257, when compared to other channel widths in 1939. Aerial photography shows this reach as predominantly single channel with a few side channels. Thus, the greater width in this reach does not appear to be caused by a greater number of side channels included in the width measurements, but rather by a single main channel that was wider and most probably shallower than comparative reaches.

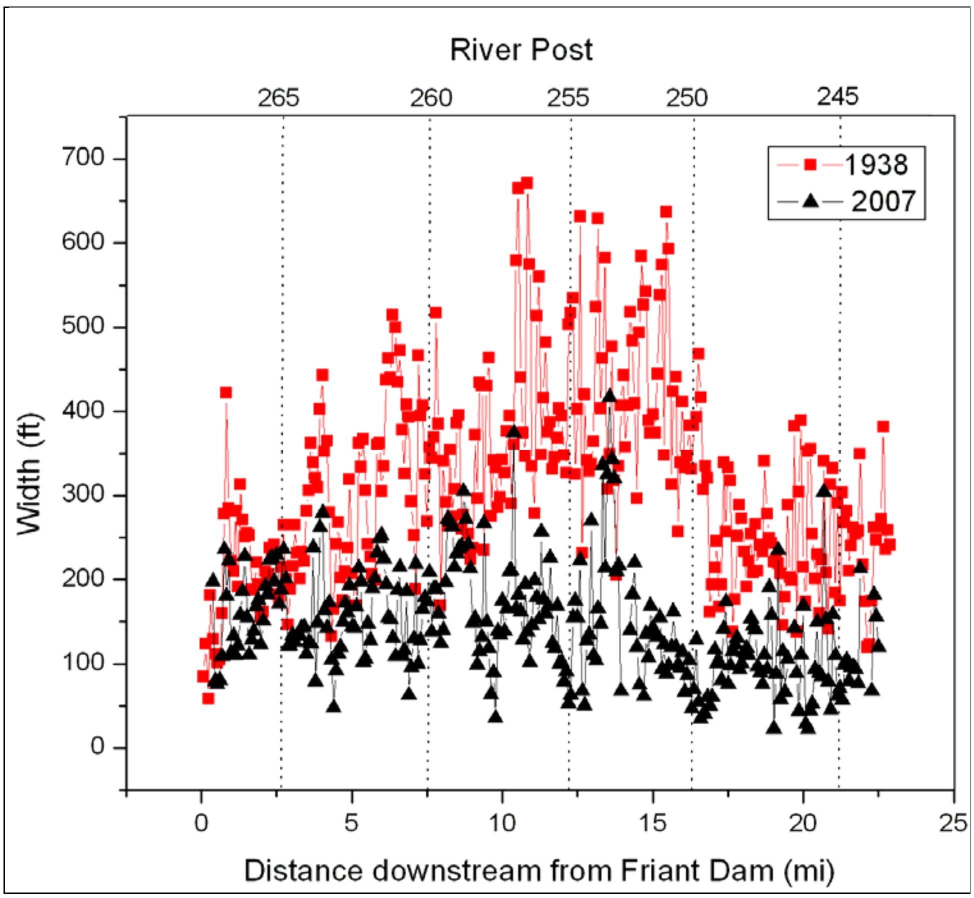


Figure 5-2.
Active Channel Width Comparison by Location

Cain's (1997) study found that channel width decreased by 20 percent, 50 percent, and 60 percent for Reaches 1A-1, 1A-2, and 1A-3A defined in his study, respectively. Changes in channel width for comparative reaches between this study and Cain's study are similar despite the addition of 27 years between the final photo sets and differences in measurement techniques including the addition of side channel measurements in this study's analysis and measurement of the bankfull channel width in Cain's study (Table 5-2). The greatest difference in results occurs in Reach 1, where the channel narrowed by 34 percent between 1938 and 2007 and by 20 percent between 1939 and 1980. This would suggest that this reach has undergone further channel narrowing between 1980 and 2007. The smaller change overall in Reach 1, when compared to Reaches 2 and 3A, is caused by bedrock confinement on both sides of the river, which provides a geologic control on maximum channel width that can be obtained.

Table 5-2.
Comparison of Width Measurements to Cain (1997) Width Measurements

Reach No.	Reach Description	Distance (km)	% Change this study (1938-2007)	% Change Cain (1997) (1939-1980)
Reach 1	Friant Dam to Ledger Island	0-6.4	34%	20%
Reach 2	Ledger Island to Friant Pumice Outcrop	6.4-14.2	46%	50%
Reach 3A	Friant Pumice Outcrop to Lanes Bridge (Rt. 41)	14.2-18.2	61%	60%

Key:
% = percent
km = kilometer

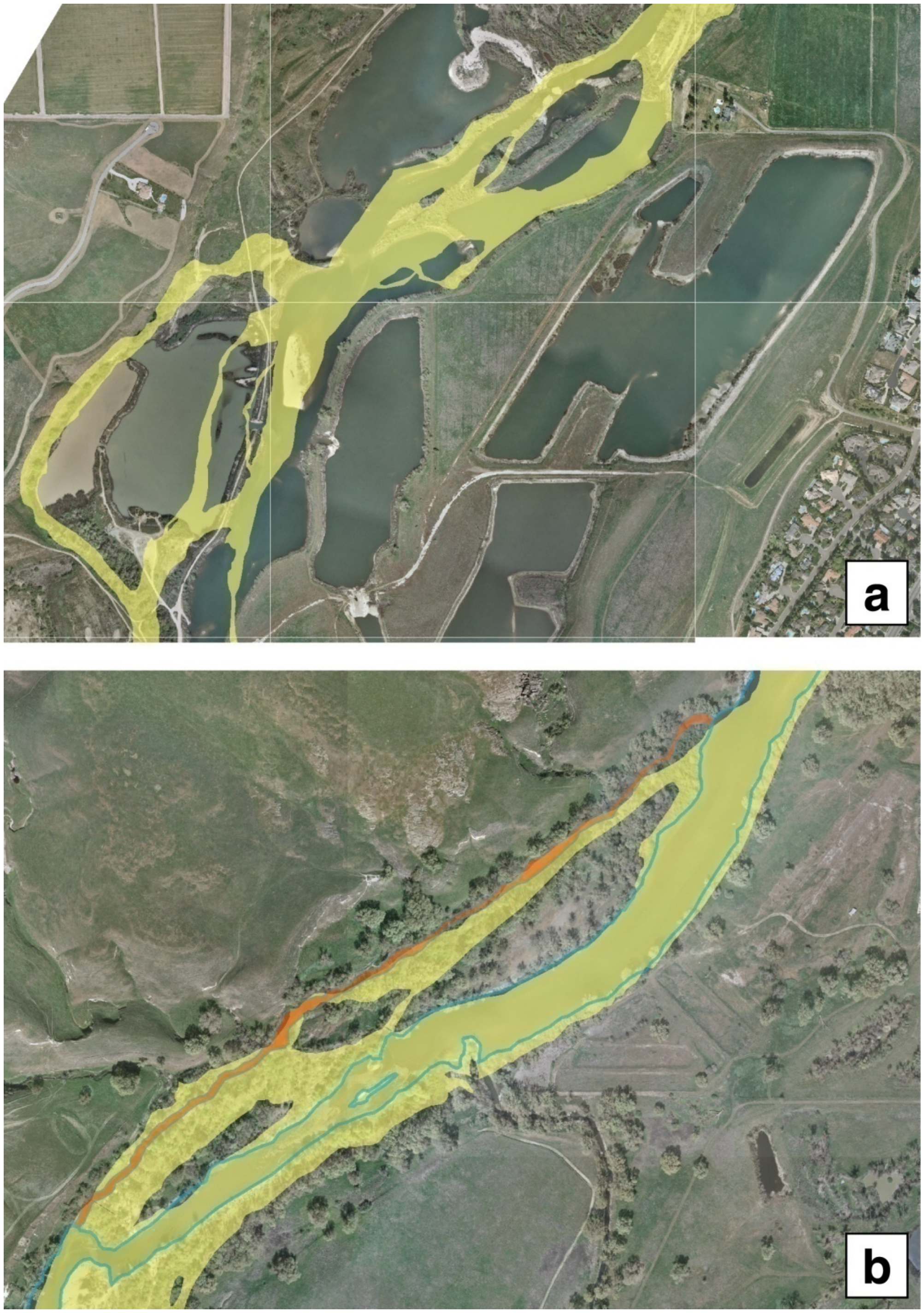
Stillwater Sciences (2003) reports bankfull channel widths that range from 300 feet to 1,000 feet, as measured from 1998 aerial photos in this reach. Stillwater's measurements are similar to Cain's (1997) 1939 bankfull channel width measurements (termed "active channel" in his study), which range from about 630 feet to 1,590 feet. Stillwater's measurements and Cain's measurements are larger than the active channel measured in the current study because they include unvegetated gravel bars in their width measurements to arrive at a bankfull channel width. A comparative study does not exist for the river reach that extends from Lanes Bridge to the Rt. 99 Bridge.

Main channel sinuosity remained relatively unchanged and increased slightly between 1938 and 2007. This increase is very small and could be considered negligible. Sinuosity measurements were made over the entire reach and may not capture local changes within the study reach. While many of the side channels and active channel area have been lost over the 70-year period due to the reduction in flows, Cain (1997) states that the actual channel position has remained very similar, which helps to explain why the sinuosity has remained essentially the same despite many other drastic changes in the channel. Sinuosity values suggest that the channel morphology is intermediate between meandering and straight channel types. Meandering rivers can have sinuosity values as low as 1.5, while a straight channel would theoretically have a sinuosity value of 1.0 (Schumm 1963). Schumm has theorized that sinuosity has little to do with discharge but rather is dependent on the dominant grain size in the system (Schumm 1963). Thus, it is possible for a channel to maintain a similar sinuosity despite changes in the flow regime.

Active channel area decreased by about half between 1938 and 2007, while side-channel area decreased by 91 percent between 1938 and 2007. It is readily apparent that side-channel habitat is the single feature that has been most drastically impacted by current river management practices on the San Joaquin River. While a few of the larger side channels from 1938 remain, they are much narrower in 2007 than in the past. Other side channels have been lost to gravel mining and exist as ponds, while others were simply abandoned as channel flow was reduced following dam construction (Figure 5-3).

Unvegetated and vegetated bar areas decreased by 55 percent and 32 percent, respectively. The decrease in unvegetated bar area is related to the reduction in large flows that previously scoured these surfaces in a time frame that was frequent enough to prevent a large amount of vegetation from establishing on the surfaces. The loss of vegetated bars is related to the loss of side channels; as side channels were abandoned, these bars reattached to the bank through sediment filling and vegetation encroachment and became part of the floodplain. Cain's (1997) study found a 45 percent to 54 percent increase in the area of riparian vegetation in Reaches 1 and 2, and an 18 percent decrease in the area of riparian vegetation in Reach 3 between 1939 and 1989. The area of sparsely vegetated or exposed gravel and sand decreased by 85 percent for Cain's entire study reach between 1939 and 1989. Differences in the actual percentages reported between this study and Cain's study could be due to a number of factors, including the difference in the defined study reach, flow at the time of aerial photography, and mapping interpretation on the 1989 topographic map. Cain also examined changes in the vegetation assemblage and found that much of the areas that were historically composed of cottonwood and willow had become populated with alder and button willow. This is predominantly due to the absence of scouring flows, which are required for the establishment of cottonwood seedlings.

Flows in the active channel during the aerial flight for the 1938 and 2007 photography were most likely different and should be discussed as a factor in channel measurements. Although there are not discharge data for September 1938, monthly mean data for the gaging station, San Joaquin River below Kerchoff Powerhouse, can be used to provide an estimate of what the flow in the river might have been. Using data from 1910 to 1914 and 1937, the monthly mean in September was 584 cubic feet per second (cfs). The 2007 daily mean for the date of photography, March 23, 2007, was 219 cfs. Based on these limited data, it is possible that flow in the 1938 aerial photography may have been about twice the flow in the 2007 aerial photography. Despite lower flows in 2007, the number of unvegetated bars still decreased; therefore, flow in the channel may not be a significant factor in the measurement values. Also, much of the active channel was mapped from vegetated bank to vegetated bank, so change in flow would not be an issue here either. In addition, Cain's channel width measurements include unvegetated bars and show similar decreases in width when compared to this study.



Notes: (a) 1938 active channel (shown in yellow on 2007 photo base) demonstrates the loss of channel complexity in areas where extensive gravel extraction exists (scale 1:8,000); (b) side channel narrowing showing the 2007 active channel in blue, 2007 side channel in orange, and 1938 channel in yellow (scale 1:5,000).

Figure 5-3.
Examples of Channel Changes Between 1938 and 2007

Cain’s cross-section measurements between 1938 and 1996 indicate that the channel is in a state of degradation resulting from scour of the channel bed during the intervening approximately 70 years. The rate of this process is uncertain, but appears to be due to the construction of Friant Dam and the reduction in sediment supply from upstream reaches as well as the excavation of gravel within the active channel (Cain 1997). Photos during the intervening years would assist in developing a timeline for this rate of channel degradation. Historical cross sections from 1878 to 1997 and slope measurements between 1939 and 1989 by Cain (1997) show that the channel is in a state of degradation in this reach and provide additional confirmation for the qualitative observations.

In addition to quantitative measurements, several qualitative observations can be made regarding changes in the river between 1938 and 2007. While fieldwork has not been performed to verify observations made from aerial photography, it is readily apparent that flood channels that convey water during high-magnitude flows have become all but nonexistent due to the regulation of high flows that historically removed vegetation from adjacent floodplain surfaces and maintained flood channels. These channels have now filled in with sediment and vegetation and become part of the floodplain environment. The side channels that still exist are predominantly formed within the active channel of 1938 or have formed along one branch of split-flow channels mapped in 1938. Gravel pits dug between 1938 and 2007 exert a dramatic visual and physical impact on current channel morphology, especially where they have been dug within the active channel. Pits documented by Cain (1997) cover an area of 857 hectares (2,118 acres) (Friant Dam to the Rt. 145 Bridge), and a volume of 3,703,086 thousands of cubic meters (m^3 X 10^3) (130,756 X 10^6 cubic feet (ft^3)). These features create extensive pools with slow velocities, and contribute to the loss of channel complexity and channel degradation in this reach.

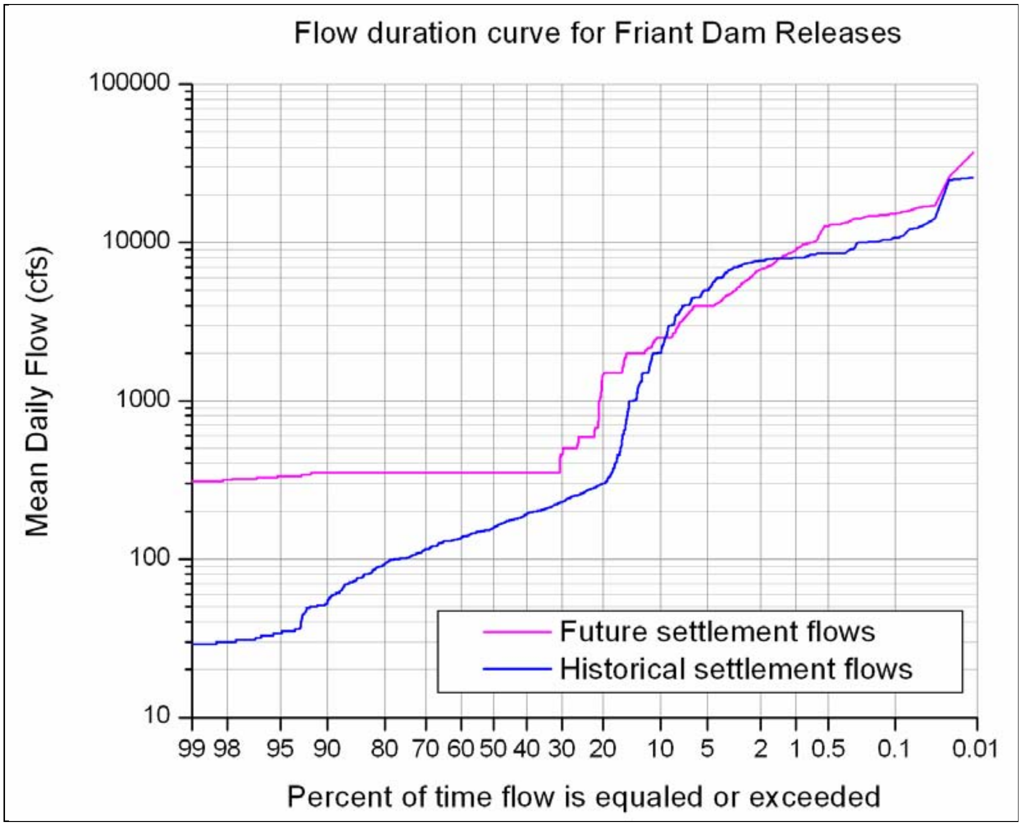
5.1 Changes in Bed Material

Presently, the transition between a gravel-dominated channel bed and sand-dominated channel bed occurs near Gravelly Ford at the downstream end of Reach 1. However, in the past, the channel bed in Reach 1 was characterized by a mixed load of sand and gravel. Cain’s research into William Hammond Hall’s transit books from 1878 reveal several observations by Hall’s assistant, Lieutenant Grunsky, that describe a river bed composed of sand and gravel between Friant Bridge and the old rock dam in Lost Lake County Park. For example, referring to the area near Friant Bridge, Grunsky writes, “’River fordable – water flows over sand and fine gravel, and very flat – low sandbars sub divided into a number of streams. Bedrock forms the side and bed of the stream above Hamptonville” (Hall 1878; as quoted in Cain 1997). Other descriptions include “December 21(1878), Monday. San Joaquin River at Hamptonville 2.5 miles below Millerton is about 500 feet wide – sand bottom level across. Sand all filled in by floods of 1862 and 1868.” (Hall 1878; as quoted in Cain 1997). At the river near Herndon, Grunsky wrote, “December 23, Saturday. Gauged San Joaquin River today above RR bridge at Sycamore. The water is clear. Bottom above bridge all sandy but sand evidently lie on cobbles and gravel.”(Hall 1878; as quoted in Cain 1997). Cross sections surveyed by the U.S. Department of the Interior, Bureau of Reclamation (Reclamation), in 1939

(Reclamation 1939) contain notes about sand bars in the study reach as well, indicating that at the time of dam construction, this reach was still a mixed-load reach. For example, at the Riverview gaging station, 16.66 miles downstream from Friant Dam, a “uniform sand bar for several hundred feet” (p.24, Transit book SJR X-1(Hall 1878)) is noted and appears to be a lateral bar along the right bank that was about 5 feet to 7 feet above the water surface on August 4, 1939. Mid-channel sand bars are also noted, some which are a similar elevation as the water surface (August 18-19, 1939), such as those noted near the Cobb Pump Station, 11.55 river miles (RM) downstream from Friant Dam and near the E.C. White Pump Station, RM 20.91. Other mid-channel bars range that are noted in the cross sections range from about 0.1 foot to 0.7 foot above the water surface elevation and include those noted at the CA West States Life Pump at RM 7.35, Howes Middle Pump at RM 10.6, Cobbs Pump at RM 10.24 and Lanes Pump at RM 11.24. It is likely that more sand bars existed in 1939 than are noted in the cross sections. The 1938 aerial photography show many bars that could potentially be composed of sand or mixed sand and gravel. Based on these cross sections, it is likely that the sand component of the bed material was eroded following the construction of Friant Dam.

5.2 Changes in Channel Morphology with Future Settlement Flows

The proposed target flows for the river restoration alternatives range from 475 cfs to 4,500 cfs for the entire reach of the San Joaquin River from Friant Dam to its confluence with the Merced River (Initial Program Alternatives Report Draft (SJRRP 2008)). Future settlement flows are proposed to reach 8,000 cfs in the various restoration alternatives for Reach 1A (Friant Dam to Rt. 99). Results from this analysis are preliminary; actual settlement conditions may contain slightly lower peak discharges. Based on flow-duration curves, flow in Reach 1A will not drop below 300 cfs, versus 30 cfs under the historic settlement flows, or gage flows adjusted to the settlement conditions (Sutley 2008) (Figure 5-4). Major increases in mean daily flow between the historic and future settlement flow-duration curves occur between the 30- and 10-percent exceedence, mean daily flow with the greatest increase occurring at the 20 percent exceedence where the flow increases from 300 cfs to 1,050 cfs. After the 10-percent exceedence, the differences between the historic and future settlement flow-duration curves are minor, amounting to about 100 to 200 cfs.



Source: From Sutley, 2008

Figure 5-4.
Flow-Duration Curves for Future and Historical Settlement Flows

Changes in the flow-duration curves at less than the 30-percent exceedence will produce minimal channel change in the study reach. The channel already experiences these flows and they will not be large enough to exert substantial modifications. For flows of 8,000 cfs, a greater area of the channel will be inundated and vegetated areas adjacent to the active channel may be minimally scoured, which will result in a gradual decrease in vegetated bars and an increase in unvegetated bars. Vegetated bars may also decrease by more prolonged inundation of near-channel vegetation, causing a gradual increase in channel width and a decrease in vegetated bars. Depending on the local cross-section geometry and channel conveyance, there could be greater flow in existing side channels and intermittent reconnection of currently abandoned side channel, depending on their height above the active channel. Huang and Greimann (2008) find that for flows of 8,000 cfs or less, only a minimal amount of sediment is mobilized in this reach. Based on their results, there is no reach-averaged sediment mobilization for flows less than 20,000 cfs. Regarding local sediment mobilization, 20 percent of gravel sample sites in Reach 1A will be slightly mobilized while 43 percent of gravel sample sites in Reach 1B will be slightly mobilized at 8,000 cfs. Flows would have to be greater than 20,000 cfs to mobilize half the sites in Reach 1A.

While larger flows are possible, the 1997 peak discharge of 60,300 cfs downstream from Friant Dam illustrates that infrequent large floods may not exert enough shear stress to produce significant channel change. The 1998 aerial photography of Reach 1A shows moderately scoured overflow channels and floodplain surfaces, removing some vegetation for the first several miles downstream from Friant Dam. While vegetation was eroded on floodplain surfaces, the vegetation that lined the stream banks persisted. Downstream from about Lanes Bridge, where the majority of in-channel gravel pits are located, changes in vegetated areas are less obvious and the channel shows minor flood modified morphology. The dissipation of energy in the gravel pits and attenuation of flood peaks likely reduces the shear stress available to erode vegetation in these downstream sections. Thus, based on observations from the 1997 flood, larger releases will likely result in scoured floodplain surfaces, the persistence of vegetation-lined stream banks, and minimal change in channel width. Because the system will not be restored to pre-dam flows, many of the side channels, flood channels, and extensive unvegetated gravel bars that existed in 1939 are not recoverable because they are most likely more elevated above the current active channel and would require much larger releases than those in the proposed flow regime. Channel width will also not reach the extent of 1939. Other features have been obliterated by gravel pits or other development in the floodplain and are not recoverable. The following discussion focuses on changes within each reach as defined by Cain (1997) (Figure 5-5).

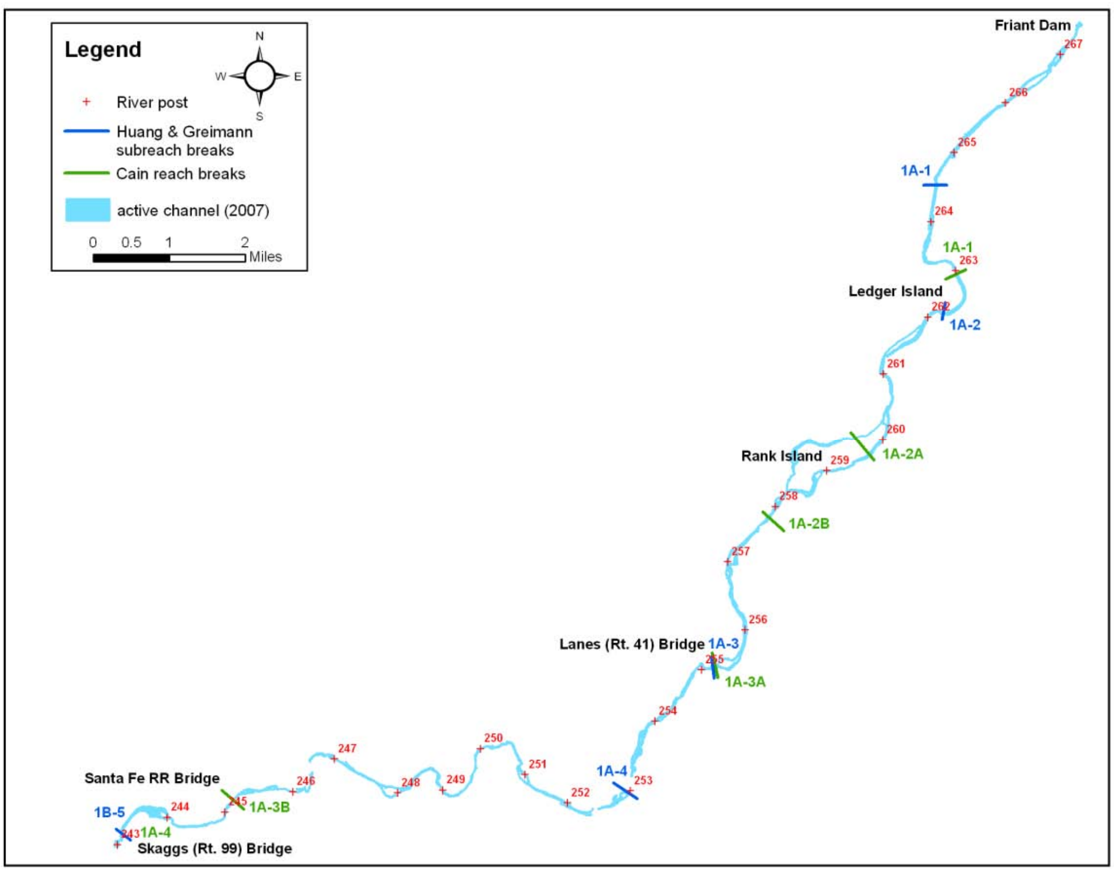


Figure 5-5.
Comparison Map of Reach Breaks Between Cain (1998) and Huang and Greimann (2008)

5.2.1 Reach 1A-1A: Friant Dam to Ledger Island

This reach is bounded by bedrock along much of its length and also has bedrock exposed intermittently in the channel bed. With an increase in flows, this reach could experience slight widening and localized incision; however, the changes would be limited given the bedrock constraints on the channel.

5.2.2 Reach 1A-2A: Ledger Island to Rank Island

This reach has experienced major reductions in channel width and loss of multiple side channels. Increase in flows will serve to widen the active channel and existing side channels slightly. It may be possible to reconnect some of the 1939 side channels during 3- to 10-year events. Those that appear most promising are located at the downstream end of Ledger Island near River Posts 262 and 261.

5.2.3 Reach 1A-2B: Rank Island to Friant Pumice Outcrop

Reach 2B encompasses most of Rank Island and is a relatively short reach that has maintained a similar form to the 1939 channel form with a moderate loss of side channels and reduction in active channel width. An increase in flows will allow for an increase in active channel width and unvegetated gravel bars. There are several side channels in this reach that have been abandoned but only one that could potentially be reactivated if it is not highly elevated above the 2007 active channel. This side channel occurs at the upstream end of the reach along the north side of Rank Island between RM 260 and 259.

5.2.4 Reach 1A-3A: Friant Pumice Outcrop to Lanes Bridge

Reach 3A has experienced loss of one major side channel complex and major reductions in channel width. The number of side channels in the 2007 aerial photography, when compared to 1939, still exist in this reach, although in different configurations and widths. If flows are large enough and the gravel pits are isolated from flow, it may be possible to reactivate the 1939 side channels between River Posts 257 and 256. The construction of the Rt. 41 Bridge at the downstream end of Reach 3A limits the potential of reconnecting the side channel at the downstream end of the reach. Future increases in flow should also allow for slight increases in active channel width and unvegetated bar area.

5.2.5 Reach 1A-3B: Lanes Bridge to RR Bridge

Reach 3B has probably experienced the most channel change between 1939 and 2007 with losses of multiple side channels of considerable length and major reductions in channel width. Gravel pits are prevalent in this reach and there are several areas where the active channel is discontinuous as it flows through ponded areas. Due to the attenuation of flow through these pits, it is unlikely that increased flows will result in noticeable change in this reach. It would be very difficult to recover any of the side channels in this reach without first blocking flow into the gravel pits. While many of the side channels have been obliterated by gravel mining, there are several that could be reactivated if the gravel pits were isolated from the active channel.

5.2.6 Reach 1A-4: Railroad Bridge to Skaggs Bridge (Rt. 99)

Reach 4 is a short reach that has experienced loss of one major side channel at the upstream end of the reach and considerable reductions in channel width. Although the area of the side channel is not heavily modified, it is unclear whether the future settlement flows would be large enough to reactivate it.

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6.0 Conclusions

This geomorphic assessment provides data concerning channel conditions before the construction of Friant Dam and documents the changes in channel morphology during the last 70 years including changes in channel width, sinuosity, character, and position of active channels, side channels, and bars. Observations of changes in bed material are also made to provide additional information concerning the condition of the river under pre-1940's flow conditions.

Data developed during this assessment indicate that between 1938 and 2007, channel width narrowed by about 50 percent on average while sinuosity remained similar. The active channel and side channels decreased in areal coverage by approximately 50 percent and 90 percent, respectively. The number and areal coverage of both unvegetated and vegetated bars also decreased in the study reach by about 55 percent and 30 percent, respectively. These data indicate that overall channel complexity has been dramatically reduced over the 70-year historical period. Reduced flows from dam construction, modifications to the channel by gravel mining operations, as well as reductions in sediment load, are likely causes for these changes. This information should be helpful in understanding the morphologic features that have been lost and help guide possible restoration alternatives under a future altered flow regime.

With future settlement flows, changes in the flow-duration curves at less than the 30-percent exceedence will produce minimal channel change in the study reach. The channel already experiences these flows and they will not be large enough to exert substantial modifications. For flows of 8,000 cfs, a greater area of the channel will be inundated and vegetated areas adjacent to the active channel may be inundated, which will result in a decrease in vegetated bars and an increase in unvegetated bars. This change could be gradual in the absence of larger, more erosive flows. Evidence from the 1997 flood, however, indicate that even larger, infrequent floods may not change channel width or position to a great extent. Depending on the magnitude of flows, there could be greater flow in existing side channels and intermittent reconnection of currently abandoned side channels, depending on their height above the active channel. Slight increases in channel width may also occur in association with the removal of vegetation along channel margins.

The results of this analysis are based solely on the interpretation of historical aerial photography and a review of readily available literature. Field verification of mapping was not performed; therefore, uncertainty in the mapping exists because the characteristics of the river were not directly observed in the field. Sources of uncertainty in this analysis may include, but are not limited to, channel width measurements, contacts between mapped units, classification of various features and hence the interpretation of results.

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Exhibit

Historical Channel Measurements

Draft
San Joaquin River Geomorphic Assessment Using Historical Aerial Photographs, California
Friant Dam to Route 99 Bridge Attachment

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Draft
April 2011

1938 Channel Measurements

1938 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
1	400	0.08	85	0	85
2	800	0.15	124	0	124
3	1,200	0.23	59	0	59
4	1,600	0.30	182	0	182
5	2,000	0.38	129	0	129
6	2,400	0.45	112	0	112
7	2,800	0.53	101	0	101
8	3,200	0.61	105	0	105
9	3,600	0.68	160	0	160
10	4,000	0.76	278	0	278
11	4,400	0.83	422	0	422
12	4,800	0.91	285	0	285
13	5,200	0.98	222	0	222
14	5,600	1.06	210	0	210
15	6,000	1.14	281	0	281
16	6,400	1.21	191	0	191
17	6,800	1.29	313	0	313
18	7,200	1.36	271	0	271
19	7,600	1.44	251	0	251
20	8,000	1.52	255	0	255
21	8,400	1.59	253	0	253
22	8,800	1.67	188	0	188
23	9,200	1.74	188	0	188
24	9,600	1.82	220	0	220
25	10,000	1.89	194	0	194
26	10,400	1.97	156	0	156
27	10,800	2.05	162	0	162
28	11,200	2.12	210	0	210
29	11,600	2.20	206	0	206
30	12,000	2.27	238	0	238
31	12,400	2.35	232	0	232
32	12,800	2.42	241	0	241
33	13,200	2.50	183	0	183
34	13,600	2.58	176	0	176
35	14,000	2.65	215	0	215
36	14,400	2.73	265	0	265
37	14,800	2.80	200	0	200
38	15,200	2.88	147	0	147
39	15,600	2.95	189	0	189
40	16,000	3.03	216	0	216
41	16,400	3.11	220	44	265

1938 Channel Measurements (contd.)

1938 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
42	16,800	3.18	232	0	232
43	17,200	3.26	201	0	201
44	17,600	3.33	233	0	233
45	18,000	3.41	222	0	222
46	18,400	3.48	281	0	281
47	18,800	3.56	306	0	306
48	19,200	3.64	363	0	363
49	19,600	3.71	339	0	339
50	20,000	3.79	321	0	321
51	20,400	3.86	309	0	309
52	20,800	3.94	403	0	403
53	21,200	4.02	443	0	443
54	21,600	4.09	311	41	352
55	22,000	4.17	365	0	365
56	22,400	4.24	280	0	280
57	22,800	4.32	133	0	133
58	23,200	4.39	165	0	165
59	23,600	4.47	242	0	242
60	24,000	4.55	268	0	268
61	24,400	4.62	202	0	202
62	24,800	4.70	176	0	176
63	25,200	4.77	210	0	210
64	25,600	4.85	238	0	238
65	26,000	4.92	319	0	319
66	26,400	5.00	207	0	207
67	26,800	5.08	169	0	169
68	27,200	5.15	170	0	170
69	27,600	5.23	363	0	363
70	28,000	5.30	334	0	334
71	28,400	5.38	367	0	367
72	28,800	5.45	306	0	306
73	29,200	5.53	215	27	242
74	29,600	5.61	153	74	227
75	30,000	5.68	206	0	206
76	30,400	5.76	199	0	199
77	30,800	5.83	361	0	361
78	31,200	5.91	294	69	363
79	31,600	5.98	219	87	305
80	32,000	6.06	238	97	335
81	32,400	6.14	318	119	438
82	32,800	6.21	395	69	463
83	33,200	6.29	440	0	440
84	33,600	6.36	515	0	515
85	34,000	6.44	500	0	500

1938 Channel Measurements (contd.)

1938 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
86	34,400	6.52	435	0	435
87	34,800	6.59	473	0	473
88	35,200	6.67	267	112	378
89	35,600	6.74	123	204	326
90	36,000	6.82	224	185	408
91	36,400	6.89	298	95	393
92	36,800	6.97	234	59	293
93	37,200	7.05	173	79	253
94	37,600	7.12	189	0	189
95	38,000	7.20	467	0	467
96	38,400	7.27	335	60	395
97	38,800	7.35	407	0	407
98	39,200	7.42	325	0	325
99	39,600	7.50	269	0	269
100	40,000	7.58	357	0	357
101	40,400	7.65	344	0	344
102	40,800	7.73	370	0	370
103	41,200	7.80	517	0	517
104	41,600	7.88	385	0	385
105	42,000	7.95	170	0	170
106	42,400	8.03	341	0	341
107	42,800	8.11	292	0	292
108	43,200	8.18	264	0	264
109	43,600	8.26	355	0	355
110	44,000	8.33	274	0	274
111	44,400	8.41	308	0	308
112	44,800	8.48	386	0	386
113	45,200	8.56	396	0	396
114	45,600	8.64	260	0	260
115	46,000	8.71	262	15	277
116	46,400	8.79	236	0	236
117	46,800	8.86	254	0	254
118	47,200	8.94	225	0	225
119	47,600	9.02	211	27	238
120	48,000	9.09	322	50	372
121	48,400	9.17	239	57	296
122	48,800	9.24	376	58	434
123	49,200	9.32	431	0	431
124	49,600	9.39	235	0	235
125	50,000	9.47	431	0	431
126	50,400	9.55	464	0	464
127	50,800	9.62	275	0	275

1938 Channel Measurements (contd.)

1938 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
128	51,200	9.70	342	0	342
129	51,600	9.77	333	0	333
130	52,000	9.85	286	0	286
131	52,400	9.92	298	0	298
132	52,800	10.00	343	0	343
133	53,200	10.08	327	0	327
134	53,600	10.15	377	0	377
135	54,000	10.23	298	97	395
136	54,400	10.30	197	93	290
137	54,800	10.38	269	93	361
138	55,200	10.45	452	126	579
139	55,600	10.53	665	0	665
140	56,000	10.61	440	0	440
141	56,400	10.68	375	0	375
142	56,800	10.76	346	0	346
143	57,200	10.83	671	0	671
144	57,600	10.91	575	0	575
145	58,000	10.98	335	0	335
146	58,400	11.06	279	0	279
147	58,800	11.14	514	0	514
148	59,200	11.21	560	0	560
149	59,600	11.29	323	26	349
150	60,000	11.36	400	16	416
151	60,400	11.44	482	0	482
152	60,800	11.52	376	0	376
153	61,200	11.59	387	0	387
154	61,600	11.67	331	0	331
155	62,000	11.74	345	0	345
156	62,400	11.82	369	0	369
157	62,800	11.89	363	41	404
158	63,200	11.97	353	42	395
159	63,600	12.05	268	80	348
160	64,000	12.12	246	81	327
161	64,400	12.20	403	101	503
162	64,800	12.27	408	109	517
163	65,200	12.35	394	141	535
164	65,600	12.42	239	86	325
165	66,000	12.50	403	0	403
166	66,400	12.58	632	0	632
167	66,800	12.65	232	0	232
168	67,200	12.73	420	0	420

1938 Channel Measurements (contd.)

1938 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
169	67,600	12.80	342	0	342
170	68,000	12.88	329	0	329
171	68,400	12.95	337	0	337
172	68,800	13.03	364	0	364
173	69,200	13.11	481	44	524
174	69,600	13.18	567	62	629
175	70,000	13.26	378	26	404
176	70,400	13.33	463	0	463
177	70,800	13.41	583	0	583
178	71,200	13.48	254	54	308
179	71,600	13.56	266	84	350
180	72,000	13.64	333	144	477
181	72,400	13.71	236	81	317
182	72,800	13.79	161	43	205
183	73,200	13.86	308	27	335
184	73,600	13.94	374	33	407
185	74,000	14.02	408	34	443
186	74,400	14.09	245	111	357
187	74,800	14.17	266	140	407
188	75,200	14.24	271	247	518
189	75,600	14.32	211	273	484
190	76,000	14.39	282	128	410
191	76,400	14.47	177	119	296
192	76,800	14.55	372	122	494
193	77,200	14.62	446	140	585
194	77,600	14.70	423	104	527
195	78,000	14.77	435	109	543
196	78,400	14.85	263	126	390
197	78,800	14.92	280	95	375
198	79,200	15.00	286	111	397
199	79,600	15.08	226	149	375
200	80,000	15.15	344	101	445
201	80,400	15.23	419	119	538
202	80,800	15.30	410	164	574
203	81,200	15.38	192	156	348
204	81,600	15.45	471	167	637
205	82,000	15.53	490	103	593
206	82,400	15.61	313	0	313
207	82,800	15.68	424	0	424
208	83,200	15.76	441	0	441
209	83,600	15.83	257	0	257
210	84,000	15.91	318	21	339

1938 Channel Measurements (contd.)

1938 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
211	84,400	15.98	373	40	412
212	84,800	16.06	274	59	333
213	85,200	16.14	245	102	347
214	85,600	16.21	384	0	384
215	86,000	16.29	331	0	331
216	86,400	16.36	384	0	384
217	86,800	16.44	393	0	393
218	87,200	16.52	468	0	468
219	87,600	16.59	417	0	417
220	88,000	16.67	307	0	307
221	88,400	16.74	335	0	335
222	88,800	16.82	303	18	321
223	89,200	16.89	141	21	162
224	89,600	16.97	194	0	194
225	90,000	17.05	214	0	214
226	90,400	17.12	246	0	246
227	90,800	17.20	168	0	168
228	91,200	17.27	194	0	194
229	91,600	17.35	339	0	339
230	92,000	17.42	257	0	257
231	92,400	17.50	333	0	333
232	92,800	17.58	317	0	317
233	93,200	17.65	138	0	138
234	93,600	17.73	177	0	177
235	94,000	17.80	252	0	252
236	94,400	17.88	288	0	288
237	94,800	17.95	273	0	273
238	95,200	18.03	233	0	233
239	95,600	18.11	191	0	191
240	96,000	18.18	222	0	222
241	96,400	18.26	254	0	254
242	96,800	18.33	208	0	208
243	97,200	18.41	195	72	266
244	97,600	18.48	156	55	211
245	98,000	18.56	154	86	241
246	98,400	18.64	233	0	233
247	98,800	18.71	341	0	341
248	99,200	18.79	278	0	278
249	99,600	18.86	249	0	249
250	100,000	18.94	243	0	243
251	100,400	19.02	221	0	221
252	100,800	19.09	150	72	222

1938 Channel Measurements (contd.)

1938 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
253	101,200	19.17	128	91	219
254	101,600	19.24	207	0	207
255	102,000	19.32	146	0	146
256	102,400	19.39	179	0	179
257	102,800	19.47	288	0	288
258	103,200	19.55	203	0	203
259	103,600	19.62	199	0	199
260	104,000	19.70	383	0	383
261	104,400	19.77	138	0	138
262	104,800	19.85	304	0	304
263	105,200	19.92	390	0	390
264	105,600	20.00	215	0	215
265	106,000	20.08	174	0	174
266	106,400	20.15	352	0	352
267	106,800	20.23	356	0	356
268	107,200	20.30	254	0	254
269	107,600	20.38	201	0	201
270	108,000	20.45	199	32	230
271	108,400	20.53	160	0	160
272	108,800	20.61	224	0	224
273	109,200	20.68	341	0	341
274	109,600	20.76	208	0	208
275	110,000	20.83	142	0	142
276	110,400	20.91	313	0	313
277	110,800	20.98	305	28	332
278	111,200	21.06	126	58	184
279	111,600	21.14	196	95	291
280	112,000	21.21	93	82	175
281	112,400	21.29	133	170	303
282	112,800	21.36	166	101	267
283	113,200	21.44	154	128	281
284	113,600	21.52	211	0	211
285	114,000	21.59	240	0	240
286	114,400	21.67	262	0	262
287	114,800	21.74	254	0	254
288	115,200	21.82	258	0	258
289	115,600	21.89	350	0	350
290	116,000	21.97	218	0	218
291	116,400	22.05	174	0	174
292	116,800	22.12	120	0	120
293	117,200	22.20	123	0	123
294	117,600	22.27	175	0	175

1938 Channel Measurements (contd.)

1938 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
295	118,000	22.35	262	0	262
296	118,400	22.42	247	0	247
297	118,800	22.50	262	0	262
298	119,200	22.58	272	0	272
299	119,600	22.65	382	0	382
300	120,000	22.73	236	0	236
301	120,400	22.80	259	0	259
302	120,800	22.88	241	0	241
Average					312

2007 Channel Measurements

2007 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
	400	0.08			
	800	0.15			
	1,200	0.23			
	1,600	0.30			
5	2,000	0.38	198	0	198
6	2,400	0.45	80	0	80
7	2,800	0.53	76	0	76
8	3,200	0.61	81	0	81
9	3,600	0.68	109	0	109
10	4,000	0.76	207	29	236
11	4,400	0.83	128	53	181
12	4,800	0.91	223	0	223
13	5,200	0.98	113	0	113
14	5,600	1.06	133	0	133
15	6,000	1.14	77	33	110
16	6,400	1.21	79	42	122
17	6,800	1.29	111	47	158
18	7,200	1.36	104	82	186
19	7,600	1.44	120	108	228
20	8,000	1.52	114	41	155
21	8,400	1.59	111	0	111
22	8,800	1.67	129	0	129
23	9,200	1.74	139	0	139
24	9,600	1.82	168	0	168

2007 Channel Measurements

2007 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
25	10,000	1.89	176	0	176
26	10,400	1.97	123	0	123
27	10,800	2.05	151	0	151
28	11,200	2.12	192	0	192
29	11,600	2.20	183	0	183
30	12,000	2.27	224	0	224
31	12,400	2.35	226	0	226
32	12,800	2.42	198	0	198
33	13,200	2.50	229	0	229
34	13,600	2.58	171	0	171
35	14,000	2.65	188	0	188
36	14,400	2.73	236	0	236
37	14,800	2.80	201	0	201
38	15,200	2.88	121	0	121
39	15,600	2.95	122	0	122
40	16,000	3.03	134	0	134
41	16,400	3.11	126	0	126
42	16,800	3.18	133	0	133
43	17,200	3.26	134	0	134
44	17,600	3.33	143	0	143
45	18,000	3.41	144	0	144
46	18,400	3.48	112	0	112
47	18,800	3.56	126	0	126
48	19,200	3.64	124	0	124
49	19,600	3.71	238	0	238
50	20,000	3.79	79	0	79
51	20,400	3.86	149	0	149
52	20,800	3.94	262	0	262
53	21,200	4.02	279	0	279
54	21,600	4.09	164	0	164
55	22,000	4.17	143	0	143
56	22,400	4.24	173	0	173
57	22,800	4.32	105	0	105
58	23,200	4.39	48	0	48
59	23,600	4.47	92	0	92
60	24,000	4.55	112	0	112
61	24,400	4.62	120	0	120
62	24,800	4.70	150	0	150
63	25,200	4.77	172	0	172
64	25,600	4.85	161	0	161
65	26,000	4.92	193	0	193
66	26,400	5.00	144	0	144
67	26,800	5.08	143	0	143

2007 Channel Measurements (contd.)

2007 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
68	27,200	5.15	168	0	168
69	27,600	5.23	214	0	214
70	28,000	5.30	198	0	198
71	28,400	5.38	102	0	102
72	28,800	5.45	106	0	106
73	29,200	5.53	148	0	148
74	29,600	5.61	128	0	128
75	30,000	5.68	190	0	190
76	30,400	5.76	202	0	202
77	30,800	5.83	212	20	232
78	31,200	5.91	230	18	249
79	31,600	5.98	201	53	253
80	32,000	6.06	204	21	225
81	32,400	6.14	167	28	195
82	32,800	6.21	110	45	155
83	33,200	6.29	137	16	153
84	33,600	6.36	102	29	131
85	34,000	6.44	109	0	109
86	34,400	6.52	188	0	188
87	34,800	6.59	215	0	215
88	35,200	6.67	109	0	109
89	35,600	6.74	116	0	116
90	36,000	6.82	186	0	186
91	36,400	6.89	63	0	63
92	36,800	6.97	96	0	96
93	37,200	7.05	130	0	130
94	37,600	7.12	219	0	219
95	38,000	7.20	78	22	100
96	38,400	7.27	128	0	128
97	38,800	7.35	146	19	165
98	39,200	7.42	158	20	179
99	39,600	7.50	155	20	174
100	40,000	7.58	183	26	209
101	40,400	7.65	120	18	138
102	40,800	7.73	189	0	189
103	41,200	7.80	169	20	189
104	41,600	7.88	125	35	160
105	42,000	7.95	93	32	125
106	42,400	8.03	88	52	140
107	42,800	8.11	78	119	197
108	43,200	8.18	123	149	272
109	43,600	8.26	110	159	269

2007 Channel Measurements (contd.)

2007 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
110	44,000	8.33	114	148	263
111	44,400	8.41	95	120	215
112	44,800	8.48	82	150	231
113	45,200	8.56	70	166	237
114	45,600	8.64	54	186	240
115	46,000	8.71	51	254	305
116	46,400	8.79	107	165	272
117	46,800	8.86	196	46	242
118	47,200	8.94	165	47	213
119	47,600	9.02	57	92	149
120	48,000	9.09	110	44	154
121	48,400	9.17	99	0	99
122	48,800	9.24	115	0	115
123	49,200	9.32	92	40	132
124	49,600	9.39	267	0	267
125	50,000	9.47	150	0	150
126	50,400	9.55	119	0	119
127	50,800	9.62	64	0	64
128	51,200	9.70	90	0	90
129	51,600	9.77	36	0	36
130	52,000	9.85	139	0	139
131	52,400	9.92	135	0	135
132	52,800	10.00	175	0	175
133	53,200	10.08	139	0	139
134	53,600	10.15	166	0	166
135	54,000	10.23	210	0	210
136	54,400	10.30	192	19	211
137	54,800	10.38	375	0	375
138	55,200	10.45	145	21	166
139	55,600	10.53	128	54	182
140	56,000	10.61	162	0	162
141	56,400	10.68	129	0	129
142	56,800	10.76	195	0	195
143	57,200	10.83	138	0	138
144	57,600	10.91	79	23	102
145	58,000	10.98	146	0	146
146	58,400	11.06	199	0	199
147	58,800	11.14	179	0	179
148	59,200	11.21	153	0	153
149	59,600	11.29	257	0	257
150	60,000	11.36	177	0	177
151	60,400	11.44	160	0	160

2007 Channel Measurements (contd.)

2007 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
152	60,800	11.52	169	0	169
153	61,200	11.59	226	0	226
154	61,600	11.67	125	0	125
155	62,000	11.74	119	0	119
156	62,400	11.82	169	0	169
157	62,800	11.89	100	0	100
158	63,200	11.97	102	0	102
159	63,600	12.05	79	0	79
160	64,000	12.12	91	0	91
161	64,400	12.20	53	0	53
162	64,800	12.27	63	0	63
163	65,200	12.35	155	0	155
164	65,600	12.42	175	0	175
165	66,000	12.50	155	0	155
166	66,400	12.58	223	0	223
167	66,800	12.65	68	0	68
168	67,200	12.73	51	0	51
169	67,600	12.80	128	0	128
170	68,000	12.88	135	0	135
171	68,400	12.95	270	0	270
172	68,800	13.03	110	0	110
173	69,200	13.11	104	0	104
174	69,600	13.18	166	0	166
175	70,000	13.26	148	0	148
176	70,400	13.33	336	0	336
177	70,800	13.41	214	0	214
178	71,200	13.48	325	0	325
179	71,600	13.56	417	0	417
180	72,000	13.64	343	0	343
181	72,400	13.71	320	0	320
182	72,800	13.79	210	0	210
183	73,200	13.86	217	0	217
184	73,600	13.94	68	0	68
185	74,000	14.02			
186	74,400	14.09			
187	74,800	14.17			
188	75,200	14.24	140	0	140
189	75,600	14.32	183	0	183
190	76,000	14.39	220	0	220
191	76,400	14.47	120	0	120
192	76,800	14.55	75	0	75
193	77,200	14.62			

2007 Channel Measurements (contd.)

2007 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
194	77,600	14.70	62	0	62
195	78,000	14.77	136	0	136
196	78,400	14.85	108	0	108
197	78,800	14.92	128	41	169
198	79,200	15.00	143	0	143
199	79,600	15.08	137	0	137
200	80,000	15.15	132	0	132
201	80,400	15.23	155	0	155
202	80,800	15.30	94	0	94
203	81,200	15.38	123	0	123
204	81,600	15.45	88	0	88
205	82,000	15.53	98	0	98
206	82,400	15.61	103	17	120
207	82,800	15.68	162	0	162
208	83,200	15.76	120	0	120
209	83,600	15.83	99	0	99
210	84,000	15.91	95	0	95
211	84,400	15.98	114	0	114
212	84,800	16.06	67	0	67
213	85,200	16.14	87	0	87
214	85,600	16.21	104	0	104
215	86,000	16.29	31	15	47
216	86,400	16.36	70	0	70
217	86,800	16.44	129	0	129
218	87,200	16.52	55	0	55
219	87,600	16.59	35	0	35
220	88,000	16.67	40	0	40
221	88,400	16.74	40	0	40
222	88,800	16.82	61	0	61
223	89,200	16.89	50	0	50
224	89,600	16.97	61	0	61
225	90,000	17.05	117	0	117
226	90,400	17.12	101	0	101
227	90,800	17.20	102	0	102
228	91,200	17.27	81	0	81
229	91,600	17.35	142	0	142
230	92,000	17.42	174	0	174
231	92,400	17.50	76	0	76
232	92,800	17.58	98	0	98
233	93,200	17.65	115	0	115
234	93,600	17.73	123	0	123
235	94,000	17.80	131	0	131

2007 Channel Measurements (contd.)

2007 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
236	94,400	17.88	63	31	94
237	94,800	17.95	101	0	101
238	95,200	18.03	90	24	114
239	95,600	18.11	55	64	119
240	96,000	18.18	58	52	110
241	96,400	18.26	100	54	154
242	96,800	18.33	63	82	145
243	97,200	18.41	74	67	141
244	97,600	18.48	97	0	97
245	98,000	18.56	90	0	90
246	98,400	18.64	76	0	76
247	98,800	18.71	111	0	111
248	99,200	18.79	94	0	94
249	99,600	18.86	191	0	191
250	100,000	18.94	84	74	158
251	100,400	19.02	23	0	23
252	100,800	19.09	88	0	88
253	101,200	19.17	235	0	235
254	101,600	19.24	58	0	58
255	102,000	19.32	115	0	115
256	102,400	19.39	67	0	67
257	102,800	19.47	106	0	106
258	103,200	19.55			
259	103,600	19.62			
260	104,000	19.70	143	0	143
261	104,400	19.77	89	0	89
262	104,800	19.85	44	0	44
263	105,200	19.92	111	0	111
264	105,600	20.00	169	0	169
265	106,000	20.08	29	0	29
266	106,400	20.15	23	0	23
267	106,800	20.23	45	0	45
268	107,200	20.30	53	0	53
269	107,600	20.38	94	0	94
270	108,000	20.45	150	0	150
271	108,400	20.53	89	0	89
272	108,800	20.61	85	0	85
273	109,200	20.68	304	0	304
274	109,600	20.76	153	0	153
275	110,000	20.83	79	0	79
276	110,400	20.91	46	0	46
277	110,800	20.98	159	0	159

2007 Channel Measurements (contd.)

2007 Meas. No.	Down-Valley Distance (feet)	Down-Valley Distance (miles)	Active Channel Width (feet)	Side Channel Width (feet)	Total Width (feet)
278	111,200	21.06	110	0	110
279	111,600	21.14	62	0	62
280	112,000	21.21	71	0	71
281	112,400	21.29	57	0	57
282	112,800	21.36	99	0	99
283	113,200	21.44	105	0	105
284	113,600	21.52	80	0	80
285	114,000	21.59	96	0	96
286	114,400	21.67	97	0	97
287	114,800	21.74	94	0	94
288	115,200	21.82	77	0	77
289	115,600	21.89	213	0	213
290	116,000	21.97			
291	116,400	22.05			
292	116,800	22.12			
293	117,200	22.20			
294	117,600	22.27	68	0	68
295	118,000	22.35	182	0	182
296	118,400	22.42	156	0	156
297	118,800	22.50	120	0	120
298	119,200	22.58	138	0	138
299	119,600	22.65	136	0	136
300	120,000	22.73	61	0	61
301	120,400	22.80		119	0
302	120,800	22.88			
Average					145

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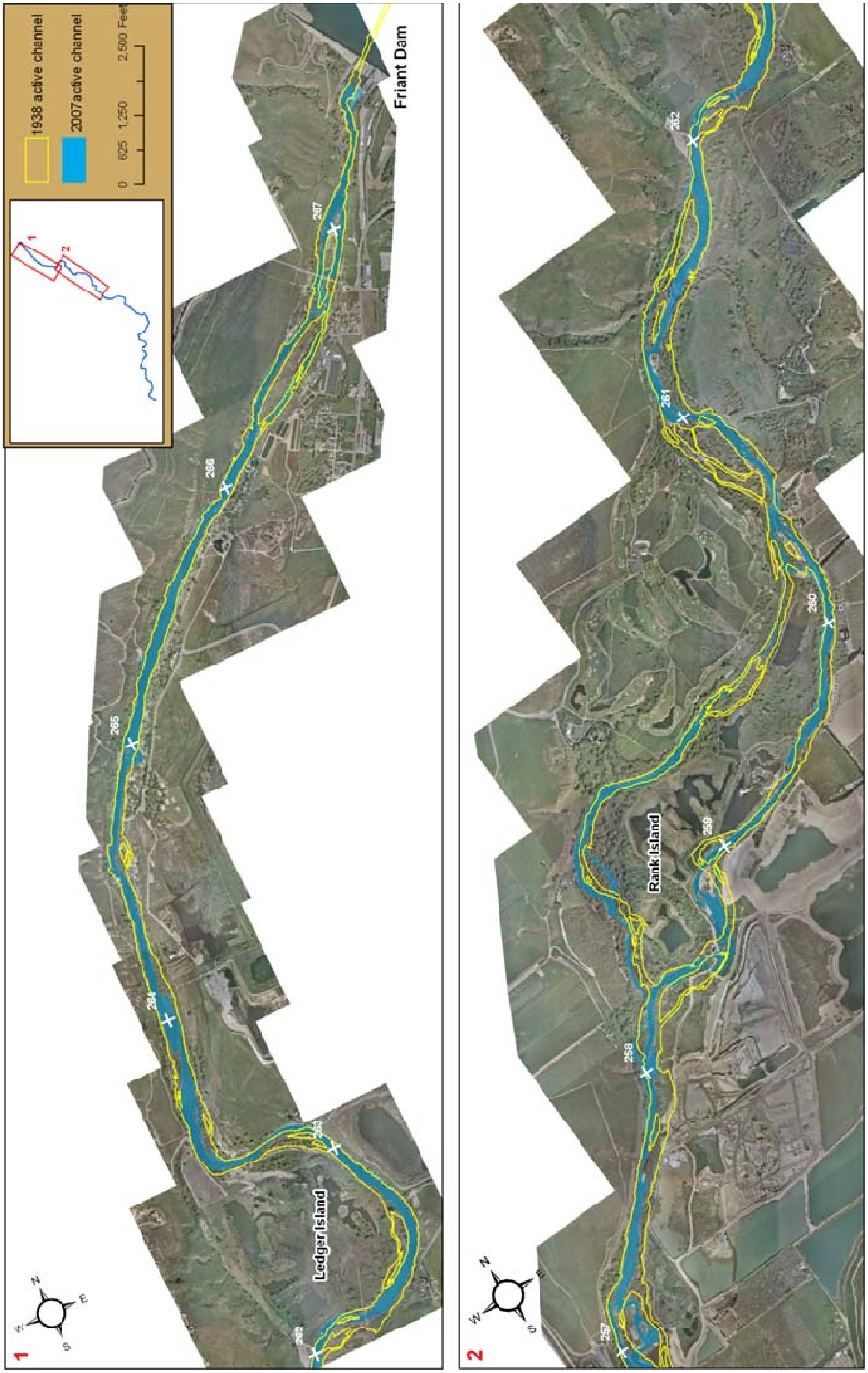
Exhibit

Channel Mapping

Draft
San Joaquin River Geomorphic Assessment Using Historical Aerial Photographs, California
Friant Dam to Route 99 Bridge Attachment

SAN JOAQUIN RIVER RESTORATION PROGRAM

Draft
April 2011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2007active channel
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Friant Dam
Ledger Island
Rank Island
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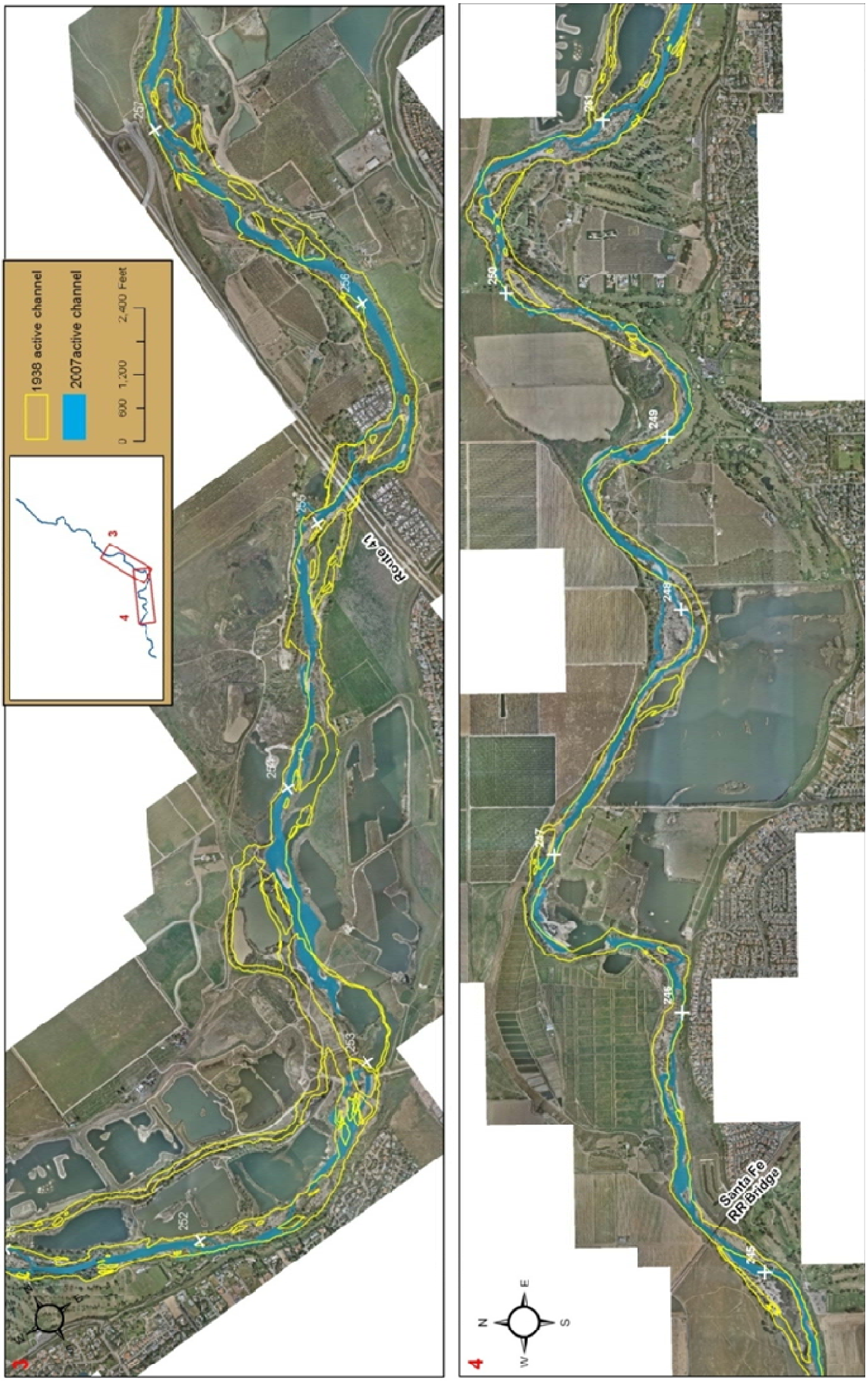
2
N
E
S
W


1938 active channel
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0 600 1,200 2,400 Feet
3
4
257
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Route 41
254
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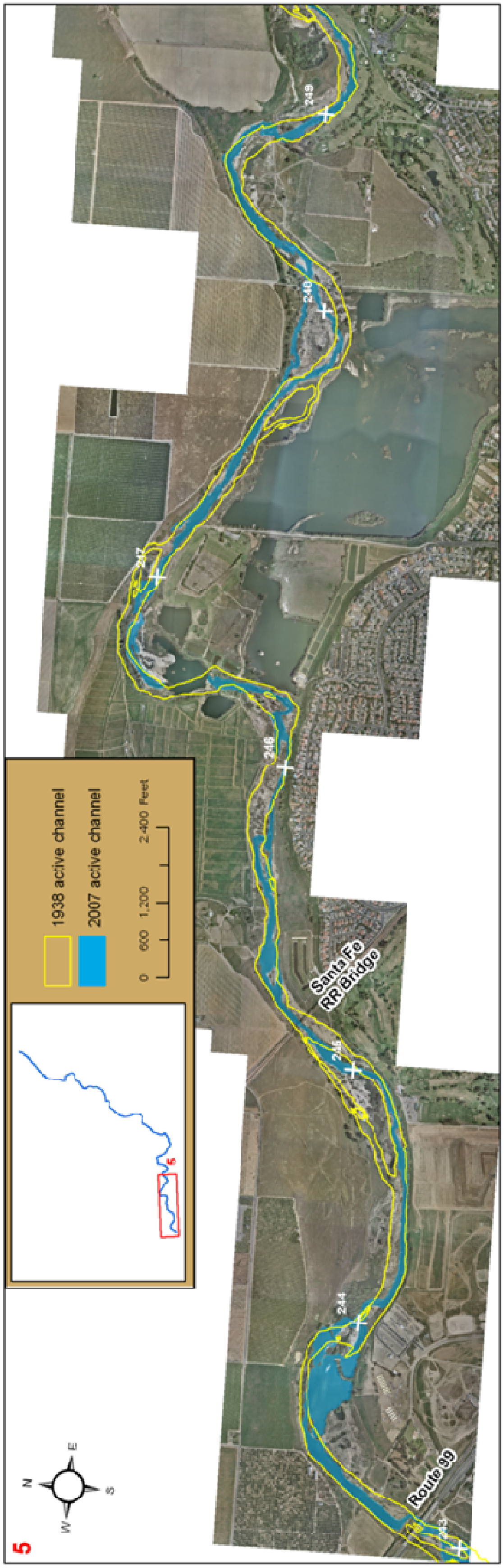
246
Santa Fe RR Bridge
245
N
E
S
W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249
248
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243
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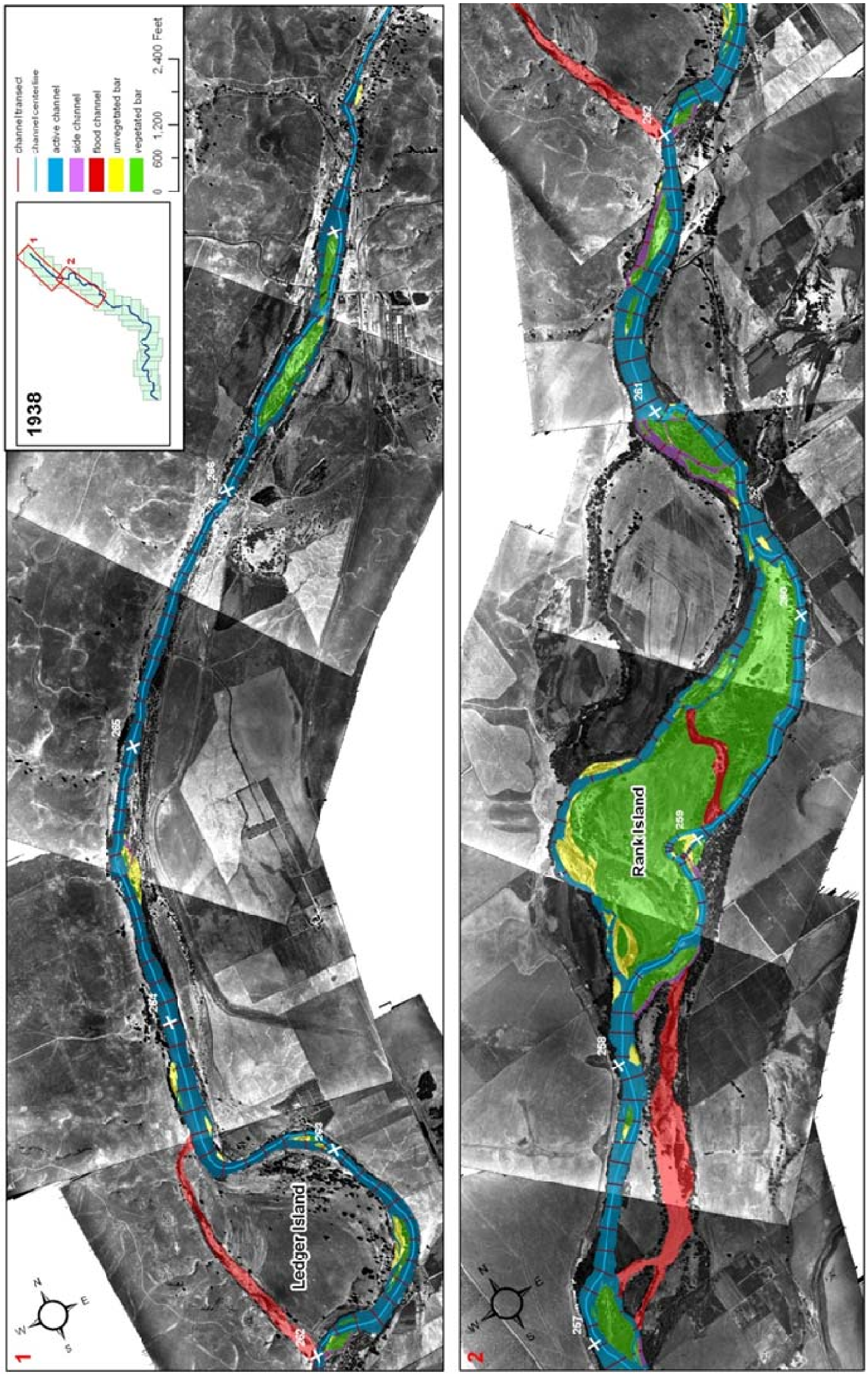
Route 99
N
E
S
W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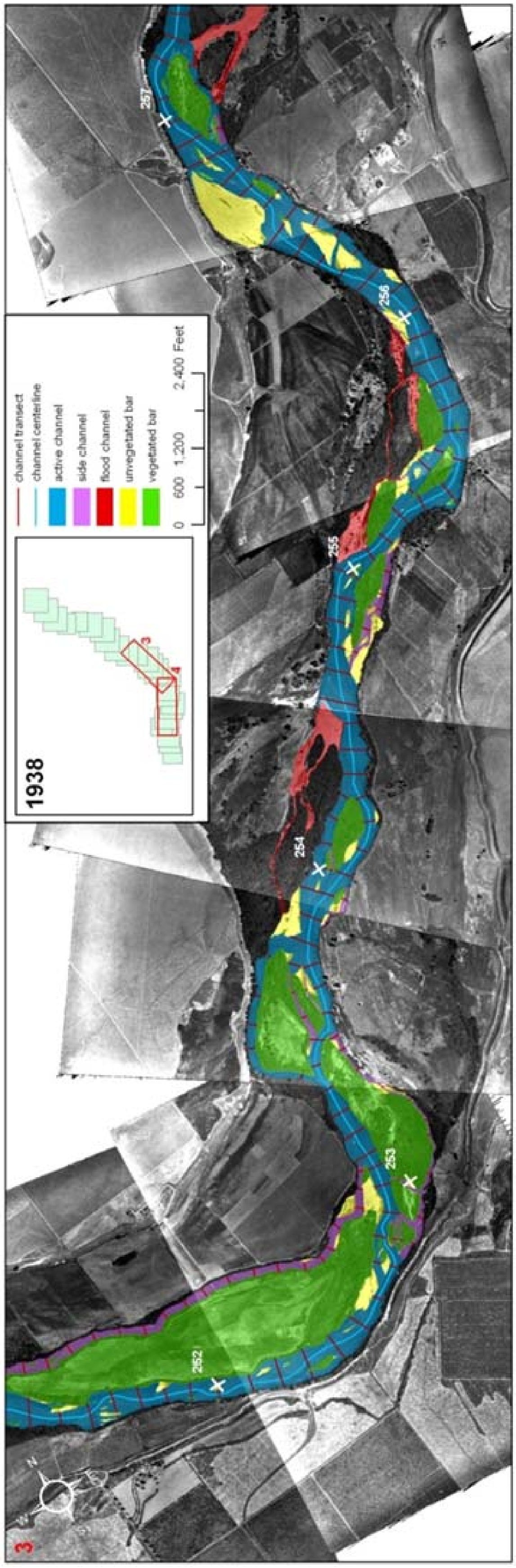
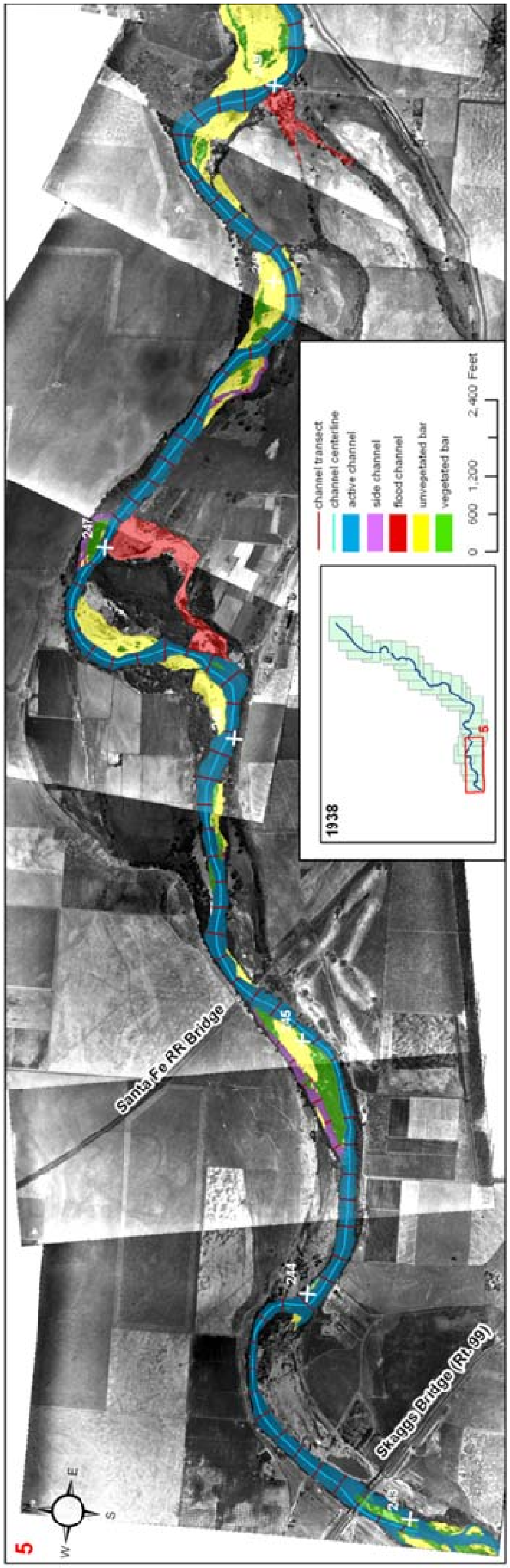
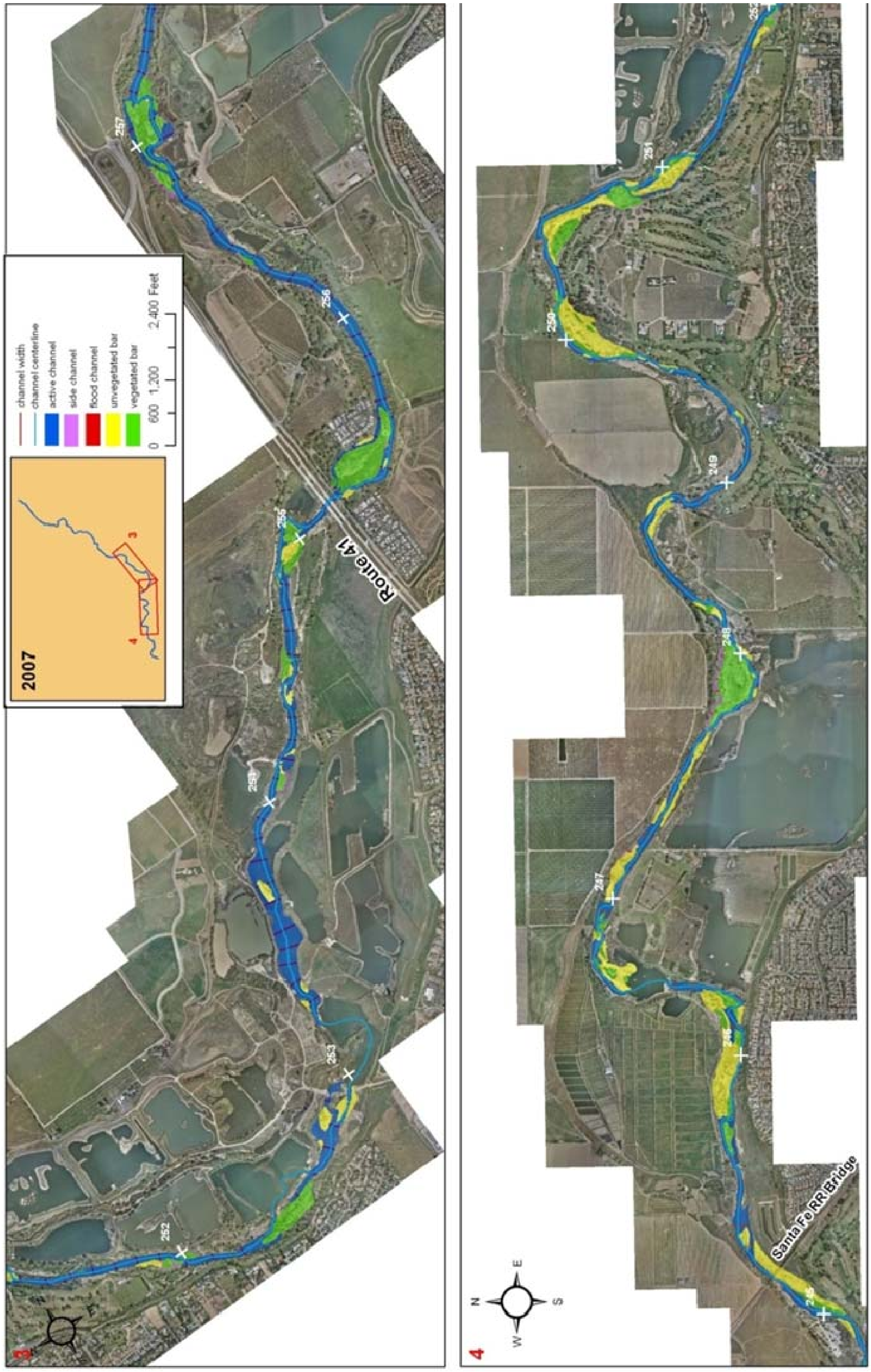
channel centerline
active channel
side channel
flood channel
unvegetated bar
vegetated bar
0 600 1,200 2,400 Feet
Ledger Island
Rank Island
1
2

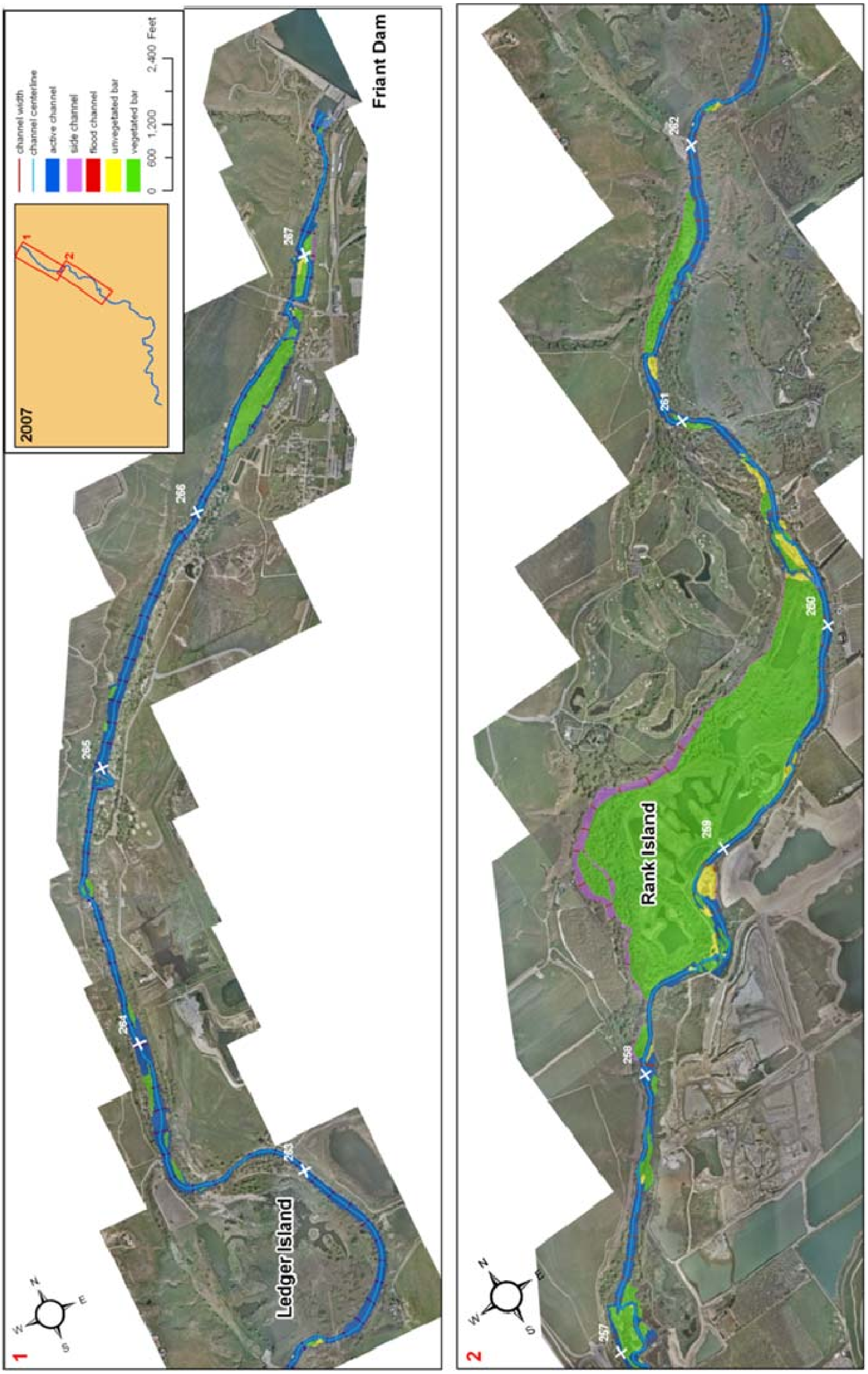

3
1938
channel transect
channel centerline
active channel
side channel
flood channel
unvegetated bar
vegetated bar
0 600 1,200 2,400 Feet
252
253
254
255
256
257

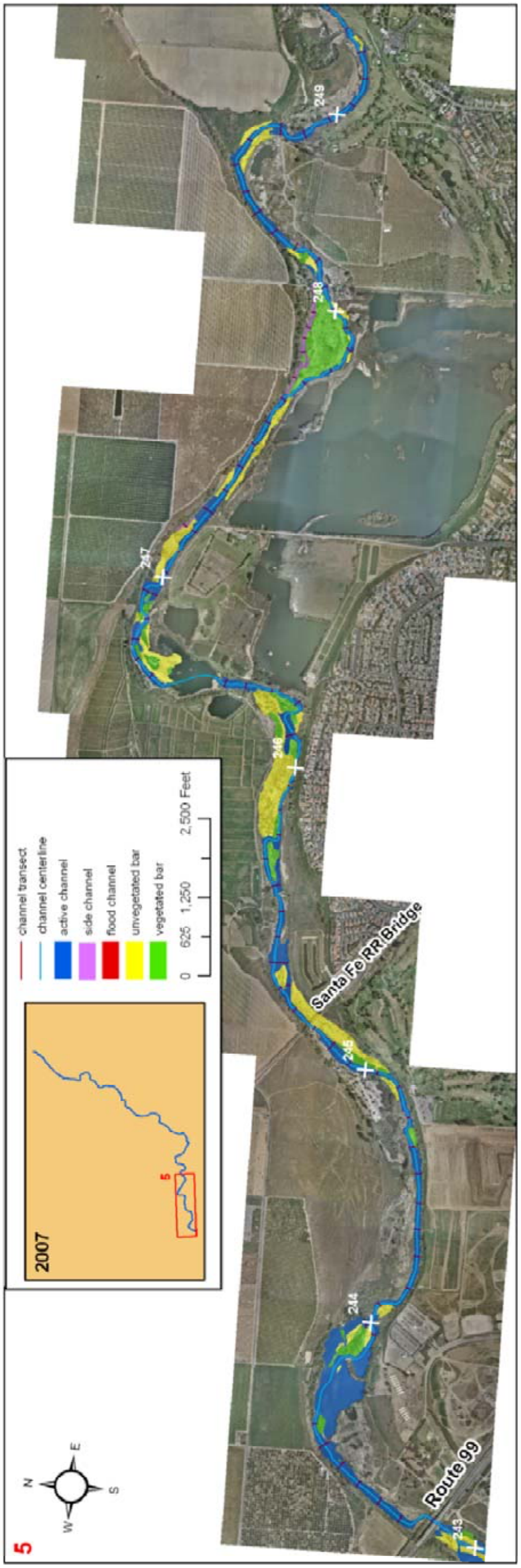

4
N
E
S
W
Santa Fe RR Bridge
246
247
248
249
250
251



channel transect
channel centerline
active channel
side channel
flood channel
unvegetated bar
vegetated bar
0 600 1,200 2,400 Feet
1938
5
247
245
244
243
Santa Fe RR Bridge
Skaggs Bridge (Rt.99)
E
S
W


2007
channel width
channel centerline
active channel
side channel
flood channel
unvegetated bar
vegetated bar
0 600 1,200 2,400 Feet
3
4
Route 41
Santa Fe RR Bridge
257
256
255
253
252
251
250
249
248
247
246
245
N
E
S
W


Friant Dam
2007
channel width
channel centerline
active channel
side channel
flood channel
unvegetated bar
vegetated bar
0 600 1,200 2,400 Feet
267
266
265
264
263
Ledger Island
1
N
E
S
W
262
261
260
259
Rank Island
258
257
2


5
N
E
S
W
2007
5
channel transect
channel centerline
active channel
side channel
flood channel
unvegetated bar
vegetated bar
0 625 1,250 2,500 Feet
249
248
247
246
245
244
243
Santa Fe RR Bridge
Route 99

n

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