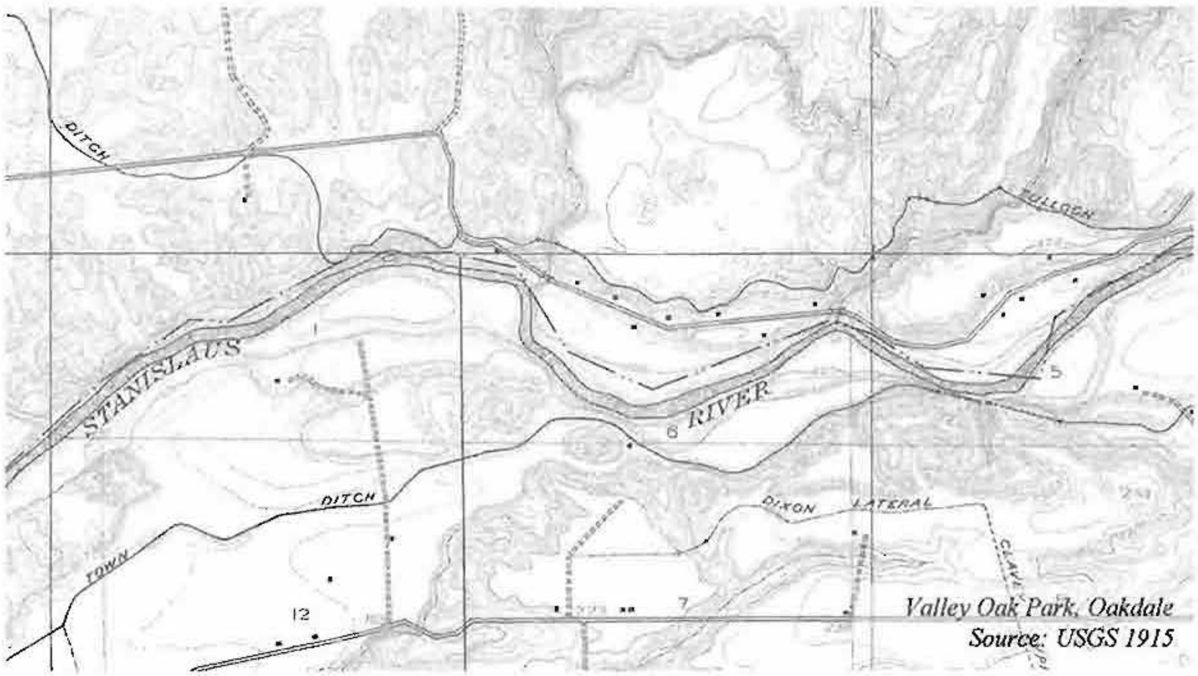
Reconnaissance-Level Assessment of Channel Change and Spawning Habitat on the Stanislaus River Below Goodwin Dam

G.M. Kondolf
A. Falzone
K.S. Schneider



Report to the
U.S. Fish and Wildlife Service
Sacramento, CA

March 22, 2001

G. Mathias Kondolf, PhD
2241 Ward Street
Berkeley CA 94705

Reconnaissance-Level Assessment of Channel Change and Spawning Habitat on the Stanislaus River Below Goodwin Dam

G. Mathias Kondolf, Anthony Falzone, Katrina S. Schneider

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER 1. INTRODUCTION AND SCOPE

The Stanislaus River is one of three principal tributaries to the San Joaquin River (**Figure 1.1**). It drains 1,100 mi^2 on the western slope of the Sierra Nevada Range, with about 40% of its basin above snowline. From the foothills-valley floor transition at Knights Ferry, the Stanislaus River flows 59 miles to its confluence with the San Joaquin River. The San Joaquin River and its tributaries (the Merced, Tuolumne, and Stanislaus) formerly had runs of 200,000 to 500,000 Chinook Salmon (*Oncorhynchus tshawytscha*) annually (Yoshiama et al. 1996), principally spring-run that took advantage of the large snowmelt component of these rivers, which drain the highest elevations in the Sierra Nevada. The spring run were extirpated by the early part of the century, as Goodwin and Melones dams cut off access to their spawning grounds, but the fall-run persisted. By 1991-2, populations of the remnant fall-run had dropped to less than 300 fish (**Figure 1.2**). Although a series of wet years has increased the run size since 1995, the continued survival of the San Joaquin chinook salmon is uncertain, and it is a candidate for the Endangered Species Act (ESA) listing (Calfed 2000). Similarly, Central Valley steelhead trout (*O. mykiss*) were listed as threatened in March 1997 by the National Marine Fisheries Service.

Factors potentially limiting chinook salmon survival in the river include: 1) low minimum flows; 2) high rates of predation on outmigrating fry and juvenile salmon by introduced species; 3) redd superimposition and egg mortality due to overutilization of upstream spawning habitat; and 4) poor quality of spawning gravels due to deposition of sand and fine sediment (Calfed 2000).

The Central Valley Project Improvement Act of 1992 called for doubling of anadromous fish populations in the Central Valley through improving in-river and delta conditions, (USDOI 1997) and the Calfed Bay-Delta program shares similar goals of restoring fish runs by restoring the ecosystem functions that supported the species (Calfed 1999). Restoration actions to improve habitat conditions for fall-run chinook salmon have already been undertaken on San Joaquin tributaries below the dams. The restoration program on the Tuolumne River is the most advanced, with an overall restoration plan in place, several projects to isolate the channel from gravel pits and restore spawning riffles already completed, and numerous riparian land purchases funded. Restoration of the Merced River is not as far along as the Tuolumne, but already a comprehensive program of geomorphic and biological data collection is underway, a restoration plan is in progress, and two projects to isolate the channel from captured gravel pits have been completed. Gravel enhancement projects on the Merced, Tuolumne, and Stanislaus rivers constructed (with funding from the Four-Pumps program) in the early 1990's had washed out by 1995 (Kondolf et al. 1996a), but the design of subsequent projects have evidently been taking geomorphic processes more into account.

There has been debate and uncertainty regarding the need for channel maintenance flows to maintain quality spawning and rearing habitat in the Stanislaus River. We address this question through the following tasks of our report:

- Analysis of historical changes in flow from USGS gauging records. (***Chapter 4***)

- Qualitative assessment of historical channel changes (especially since closure of New Melones Dam) from historical aerial photographs, field reconnaissance, and historical cross section data. Illustrative maps of channel change are prepared for three sites. (***Chapter 5***)
- Compilation, review, and evaluation of available spawning gravel size and distribution. (***Chapter 6***)
- Observation and reconnaissance level assessment of a range of potential spawning gravel sites (natural and enhanced) from Goodwin Dam downstream to Oakdale. (***Chapter 6***)
- Estimation of the flows needed to mobilize spawning gravels at five representative sites (TM1, R1, R5, R28A, R78) based on field surveys of channel conditions and application of standard tractive force formulae. (***Chapter 7***)
- Estimation of current and historical sediment budget. (***Chapter 8***)
- Estimation of the magnitude of channel maintenance (or "flushing") flows needed for spawning habitat in the lower Stanislaus River, identification at the conceptual level of other actions needed to make the flows effective, and recommendations for implementation in light of current opportunities and constraints. (***Chapter 9***)

In addition to indicating overall trends in the Lower Stanislaus River in Chapter 9, we conclude this report by highlighting directions for future research that would yield the most benefit in terms of future management of the river (***Chapter 10***).

CHAPTER 2. METHODS

This study was intended to be a preliminary assessment of channel change and spawning habitat, to highlight important changes visible from inspection of aerial photographs and field evidence, to assess spawning gravel abundance from field reconnaissance and review of historical information, and to develop recommendations for further study to resolve critical uncertainties.

2.1. Watershed Overview

To understand current ecological conditions in the Stanislaus River requires an understanding of historical changes to the channel and watershed. Large scale human alterations in the basin began in the mid 1800s, prior to documentation of environmental conditions, so we have no record of pristine conditions in the Stanislaus. The best we can hope to achieve is an inferred understanding of the natural state of the watershed based on a historical characterization of the watershed and use of current geomorphic and hydrologic relationships in alluvial river systems. As such, we assembled historical information about the Stanislaus watershed, including basin scale and study site longitudinal profiles, climatic data, flora and fauna features, history of Stanislaus basin inhabitants, and a description of engineered alterations in the basin. Reconstructions of vegetation and human history were based primarily on Nedeff (1984), and details regarding New Melones Dam and downstream flood easements were based on McAfee (2000).

2.2. Hydrology

Study Period and Flow Gauges

To assess hydrologic alteration resulting from human induced changes in the basin requires first reconstructing the natural hydrologic conditions preceding human impact. Sporadic collection of flow data over time, as well as changes in gauge locations, limits our ability to characterize a "pre-impact" hydrograph on the Stanislaus River. Flow data preceding construction of Old Melones Dam in 1926, when only 4% of average unimpaired runoff was captured by basin dams (**Figure 2.1 and Table 2.1**), allows for our best representation of "pre-impact" conditions. Although dam impacts obviously began with construction of the first dam in the basin, around the turn-of-the century, we defined "post impact" as after construction of New Melones Dam in 1979. The pre-Old Melones "pre-impact" period of record is 23 years (1903-1925). We also made calculations for longer periods, such as a flood frequency analysis for the entire period preceding construction of New Melones Dam.

Flow data are available in digital format from both the USGS data retrieval center (http://waterdata.usgs.gov/nwis-w/CA/) and Hydrosphere CD data, and in written format from USGS Surface Water Supply papers No. 251, 271, 291, 299, 311, 331, 361, 391 and, since 1971, from annual reports "Water Resources Data for California, Vol. 31". A summary of gauges used for hydrologic analyses on the Stanislaus is detailed in **Table 2.2.** **Figure 2.2** schematically describes gauge locations.

Flood Frequency Analysis and Peak Flows

A flood frequency analysis estimates the likelihood that given flows will occur (or be exceeded) in a given year. We performed a flood frequency analysis using annual maximum series discharge data from US Geological Survey gauges on the Stanislaus River for the periods 1904-1979 (pre-dam) and 1979-2000 (post-dam). As data do not exist from a single gauge for this whole period, we augmented records for the currently operating Knights Ferry gauge #11302000 data with data from gauge #11299500 "Melones Dam" (1933-1956) and from the gauge #11300000 "Stanislaus River at Knight's Ferry" (1862, 1904-1932). Although the Melones gauge is located upstream of the Knights Ferry gauges (with a 70 mi^2 less drainage area), its peak flows should be equivalent to downstream peak flows because there would be little peak flow attenuation from the minimal reservoir storage downstream (500 AF) for the period of record used (1931-1957), prior to construction of Tulloch reservoir in 1958. We also performed flood frequency analyses for the periods 1941-1978 and 1979-1999 at Ripon (#11303000, DA: 1075 mi^2), 34 miles downstream.

After separating flood frequency data for the pre- and post New Melones Dam periods, we sorted and ranked the annual peaks to calculate the recurrence interval (i.e., the average number of years between events of equal of greater magnitude than the given flow). Plotting positions were calculated using the formula recurrence interval $T= (n+1)/m$, where n is the number of years of record and m is the rank of the flow, i.e., T=1 for the largest flood in the period, T=n for the smallest (Dunne et al. 1978). The points are plotted on logarithmic probability paper to yield a flood frequency curve. We did not conduct a duration series analysis (which includes all floods greater than a threshold discharge) because the USGS does not provide such data for highly regulated rivers such as the Stanislaus (P. Schiffer, USGS, personal communication 2000).

Flow Duration Analysis

Flow duration curves show how long mean daily flows are equaled or exceeded over a long period of time. Flow duration curves for "pre-impact" and "post-impact" periods can reveal changes in the frequency and magnitude of streamflows. We compared mean daily flow data for the pre- Old Melones Dam period, 1903-1926 (gauges #11302000 at Knights Ferry and #11300000 near Knights Ferry) and the post New Melones Dam period, 1979-1998 (gauge #11302000 below Goodwin Dam). We ordered mean daily flows into 21 class ranges, ranked from lowest (1%) to highest (99%) exceedance probability, with equal number of days in each class interval. Flow duration curves mask inter-annual and seasonal variability, but are useful in highlighting changes in streamflow due to regulation (McBain et al. 2000).

Annual Hydrographs

Graphing of "pre-dam" hydrographs with hydrographs following construction of New Melones Dam allows for the characterization of seasonal alteration for different year types.

Water years during the period of record (1903 to present) are classified in the categories of extremely wet, wet, normal, dry, and critically dry. We calculated annual historical unimpaired flow data from a compilation of monthly flow data at the Stanislaus River at Goodwin (SNS) gauge, sensor #65 (http://cdec.water.ca.gov/cgi-progs/). Year type classification is designated based on a compilation by McBain and Trush (2000) in the neighboring Tuolumne River with adjustments made based on Stanislaus River flow data (**Table 2.3**). McBain and Trush (2000) classified flow years by symmetrically dividing annual runoff using annual exceedance probabilities of 0.80, 0.60, 0.40, and 0.20, in order to create a system that addresses the range of variability in annual water yield and equally distributes water year classification around the median. After classifying flow years on the Stanislaus, annual hydrographs for year types preceding construction of Old Melones Dam (1903-1928) are compared with those following construction of New Melones Dam (1979 – present). In most cases, the years compared had equivalent unimpaired runoff. Although these hydrographs do illustrate differences between two given classified water years, "pre and post impact," it is important to recognize that they are only illustrative, and that there is considerable variability in hydrographs within each class.

Characteristic patterns, or "hydrograph components," including fall storm pulses, winter and summer baseflows, winter floods, spring snowmelt floods, and snowmelt recession are identified on the "pre-impact" hydrographs due to their important influence on channel morphology and function, riparian vegetation, and chinook salmon life history (McBain et al. 2000).

Average Monthly Flows

A comparison of average unimpaired monthly flows with regulated water yields following construction of New Melones Dam helps to illustrate the seasonal changes in river flows due to water development in the basin. Unimpaired flow data is derived from monthly flow data at the Stanislaus River at Goodwin (SNS) gauge, sensor #65 (http://cdec.water.ca.gov/cgi-progs/). The period of record preceding construction of Old Melones Dam, from 1901 to 1926, is compared with regulated flows at Knights Ferry following construction of New Melones Dam, 1979 to now. The "post-impact" mean monthly data was derived by applying the Indicators of Hydrologic Alteration (IHA) model on mean daily flow data at gauge # 11302000 (Schneider 2000).

2.3. Geomorphic Investigations/Air Photo Analysis

Aerial Photographs

We analyzed aerial photographs from 1937 to 1998 to identify historical channel and floodplain features, their changes over time, and land use changes that have affected physical processes. We identified over fifteen flights of the Stanislaus River at scales ranging from 1:12,000 feet to 1: 48,000 feet (**Table 2.4**). Given the time available in this study, we focused on a comparison of the earliest photographs available (1937) with photos preceding (1957) and following (1998) construction of New Melones Dam. We cannot document "pre-alteration" geomorphic conditions from air photographs, as none exist from prior to construction of Old Melones Dam (1926), let alone prior to gold mining impacts. We digitally scaled 1937, 1957, and 1998 photo details for three reaches to illustrate changes in channel features and urban encroachment over the past sixty years.

Field Reconnaissance and Other Estimates

We also observed channel form and riparian vegetation on river reconnaissance trips in the spring and summer of 2000 from Knights Ferry (RM 55) and Oakdale (RM 41) to provide additional insight into channel conditions and change. We have included photographs of some of the features and noted their locations on assembled air photographs.

Channel and Floodplain Change

Lack of historical cross section data limited quantitative analysis of channel changes, but we used field observations of root crown exposure and current cross sections from Carl Mesick Consultants (1998) to estimate the scale of channel and floodplain changes that have occurred since New Melones Dam.

We also incorporated estimates of channel widening during 1997 and 1998 flows by Schneider (1999) based on a comparison of Feb. and Nov. 1996 surveys (CMC 1996) and Oct. 27 1999 surveys (Schneider 1999) at five cross sections (TM1, R10, R27, R58, and R78)[1].

Historical Cross Section Data

Our search for historical cross section information involved searching the library databases on the University of California, Berkeley campus; contacting experts from different agencies and consulting firms on the Stanislaus River or San Joaquin Valley region; and visiting the US Army Corps of Engineers (USACE) office in Sacramento, the Federal Emergency Management Agency (FEMA) office in San Francisco, and the California Department of Transportation (Caltrans) office in Sacramento.

Within the UC library system, we searched the Bancroft Library using Web-based databases. We reviewed all documents at the Water Resource Center Archives relating to the study reach for cross sections. After we exhausted the resources on the Berkeley campus, we contacted individuals with expertise on the Stanislaus River from governmental agencies and consulting firms by phone and inquired about the existence of historical cross sections. We asked each individual to recommend other people or agencies who might have more information. We made appointments to search the available documents at three agencies: FEMA, USACE, and Caltrans. First, we reviewed the Flood Insurance Study for Stanislaus County and the current Flood Insurance Rate Map at the San Francisco FEMA office. Typically, the Flood Insurance Rate Maps show the locations of cross sections that were taken to compute the flood stages and different flood hazard zones on the flood map tell how the 100-year floodplain was

[1] Schneider (1999) surveys were conducted on October 27, 1999 with Carl Mesick and three classmates at five field sites associated with the 25 Gravel Project riffles. The group surveyed three cross section transects with relative elevations at TM1, R27, and R58 at ten foot intervals and at all slope breaks. They collected only channel width data at R10 and R78. The group used survey pins from 1996 wherever possible, with pins present on both banks only at TM1, and on one bank only at R10, R27, and R78. No 1996 pins remained at R58.

determined. The flood profiles in the back of the Flood Insurance Studies also show the locations of cross sections used in computing the flood stage. For the Stanislaus River, no cross sections were noted on the flood profile figures or on the Flood Insurance Rate Maps. Next, we visited the Hydraulic Design Section of the USACE office in Sacramento and searched through documents in the office. The archivist performed a search of cataloged materials in storage but didn't find any historical cross sections. Lastly, we met with Suong Vu of the Caltrans Hydraulics Department in Sacramento to search for bridge survey reports in our study reach. We collected information on the Highway 120 Bridge in Oakdale, Orange Blossom Bridge, and the Knight's Ferry Bridge.

2.4. Spawning Sites Analyses

Review of Previous Studies

We compiled, reviewed, and evaluated three previous studies by California Department of Fish and Game (CDFG), Department of Water Resources (DWR), and Carl Mesick Consultants (CMC) of spawning gravel area and size distributions for the Stanislaus River between Goodwin Dam and the City of Riverbank, **Table 2.6**. From each report we identified the methods, results, and conclusions.

Field Reconnaissance, Spawning Area Estimation, and Pebble Counts

Criteria for suitable spawning habitat reported in the literature vary as a function of fish size and habitat availability in different channels. Example spawning habitat criteria from the literature include velocities of 1.2 to 3.6 ft/sec, depths greater than 0.8 ft., and gravel size 13 to 102 mm (Bjornn et al. 1991), and velocities of 2 to 4.7 ft/sec, depths of 3.2 to 6.4 ft. and gravel sizes of 25 to 150 mm, (Geist et al. 1998). We estimated the area of Chinook salmon spawning gravel (Goodwin Dam to Oakdale) using criteria similar to those measured by CDFG (1972) and DWR (1994), **Table 2.7**. In addition, to be considered suitable spawning habitat, sites had to meet the following criteria: 1) riffle must have hydraulic head and the water surface must drop across the riffle, 2) waves from the riffle must break the surface of the water, 3) the riffle should "look like" a Chinook Salmon spawning riffle. Based on our criteria, we measured the suitable spawning area.

We assessed gravel quality during the summer of 2000. We relocated riffles from the previous studies using river mile estimates listed in DWR (1994), a copy of the map included in CDFG (1972) on which Carl Mesick added his enhancement sites and other projects, geographic landmarks on USGS topographic maps, aerial photographs, and Carl Mesick's assistance. Each report used a different method to record riffle locations. CDFG (1972) included a base map showing locations of riffles. In the DWR 1994 report, study riffles were located from estimating the river mile from 7.5-minute USGS topographic maps, but a detailed map with the riffle locations was not included in the report. Re-occupying these sites based only on the estimated river mile is imprecise, because numerous riffles occur within a short distance in some reaches of the river, and the error estimating location could potentially cover numerous riffles. We attempted to contact DWR staff who conducted the field work and prepared the 1994 report, but unfortunately all personnel directly involved in field data collection and analysis have left DWR

(W. Rowe, personal communication 2000). The CMC riffle locations were clearly located on USGS 7.5 minute topographic base maps (included in the report and well marked in the field with flagging and pins in trees). We matched riffles by river mile between the CMC 2000 and DWR 1994 reports as best as possible. We excluded some DWR 1994 riffles from comparison with the CMC 2000 report and our survey because the reported locations didn't match with current riffles. We conducted uniform set of measurements at each riffle, and recorded the results on field data collection sheets. Using a 100-meter tape, we measured the average length and width to determine the area for the riffles being compared to the CDFG 1972 and DWR 1994 reports. We recorded a qualitative estimate of the gravel size distribution and took velocity measurements using the orange peel method, in which a buoyant object is timed as it travels a measured distance. We noted the location of the riffle, the quality of the banks, and the riparian and floodplain vegetation. At most DWR 1994 and CMC 2000 riffles, we took pictures facing upstream, downstream and either from one bank facing the center of the river or from the center of the river facing one bank. We qualitatively assessed the amount of fine sediment by digging the heel of a boot into the gravel and observing the resulting amount of fine sediment suspended. We assigned a freshness factor based on the degree of sand, moss, or muck that covered or filled in the riffle. We qualitatively assessed embeddedness or armoring of the gravel by gauging the degree of effort required to dig one's heal into the gravel surface and move it back and forth, as an indication of the difficulty a salmon might have building a redd. All embeddedness measurements were relative to the Knight's Ferry Gravel Replenishment Project (KFGRP) site R1 at the Knight's Ferry Bridge, which we considered optimal. Lastly, we assigned an overall rating of riffle quality by consensus of the field crew and sketched the location of the pebble counts on the back of the data sheets.

We conducted Wolman pebble counts (Wolman 1954) at the head of each relocated DWR 1994 riffle (**Figure 2.3**) and at selected CMC 2000 riffles in a homogenous area of gravel to document the change in size distribution of the surface layer of gravel. With our eyes closed, we selected pebbles randomly by vertically dropping an outstretched finger into the river and picking up the first pebble encountered. We measuring the intermediate axis of each pebble with a ruler and counted particles falling into size intervals bounded by 256, 180, 128, 90, 64, 45, 32, 22.6, 16, 11.3, 8, 5.6, 4 mm. We recorded particles smaller than 4 mm as < 4 mm. We plotted cumulative percent finer for each size class on a semi log plot and used a transform written for SigmaPlot to interpolate values of D10, D16, D25, D50, D75, D84, and D90, the sizes at which 10, 16, 25% (etc) is finer (Kondolf 1997a).

On November 17 and December 3, 2000 we surveyed the use of salmon spawning riffles by fall-run Chinook Salmon by floating down the river in a canoe and looking for signs of active spawning between Goodwin Dam and Valley Oak Park and in a 1 km reach downstream of Oakdale. Depending on whether or not we observed salmon and/or fresh redds, we categorized usage as low, medium, or high. We excluded riffles with fewer than 3 salmon or redds or riffles in which less than 10% of the crest of the riffle was used. We qualitatively assessed the spawning usage of riffles by reach, but we did not attempt to quantify the spawning usage at each site. Using a Garmin Etrex GPS unit we located the riffles in which either redds or salmon were observed. We then uploaded the locations to a USGS 7.5 minute topographic digital map using Topo! Software.

Assessment of Gravel Quality

We compared gravel size and fine sediment content of all gravel quality studies on the Stanislaus River with standards from the literature.

Comparison of Spawning Areas and Gravel Quality Reported From 1972 to 2000

To effectively compare the preferred spawning area in each study, we had to transform the data in our survey. Both the DWR 1994 and CMC 2000 reports measured the crest of the riffles that Fall-run Chinook Salmon in the Stanislaus River prefer for spawning. Our survey measured the total riffle length from a depth of 3.5 feet upstream to the crest of the riffle and then downstream until the velocity, depth, or gravel size dropped out of the preferred range. This approach overestimated the preferred spawning area. To compare our results with the previous studies, our areas were calibrated to 25 riffles measured by CMC in 1999. We calculated a conversion factor by dividing the CMC areas into our areas and then applied this calibration factor to the remainder of the suitable riffles measured in our survey.

In order to compare our study with the pebble counts in the DWR 1994 study, we had to standardize all of the data into comparable formats. Only cumulative size curves were presented in DWR (1994) (and we could not obtain tabular data from DWR), so we read the values of D10,D16, D25, etc., from the curves using a straight edge and magnifying glass. DWR (1994) conducted pebble counts to 1mm, while we measured pebbles only to 4mm size class (because of the inherent imprecision of the pebble count when applied to small grains). We truncated the DWR (1994) pebble counts at 4 mm and computed summary statistics to compare the two studies. We computed the geometric mean, dg, and the geometric sorting index, sg, (Otto 1939) as

$$dg = [(D84)(D16)]^{0.5}$$

$$sg = [(D84)/(D16)]^{0.5}$$

The D50 is the median, and is arguably the best measure of central tendency in gravel size distributions, but the geometric mean (dg) is often used because it is influenced to a greater degree by the extreme values and the size distribution (Vanoni 1975). The sorting index (sg) is a measure of dispersion and expresses the degree that fluvial processes have sorted similarly sized grains together (lower values of sg mean better sorting) (Kondolf 2000). We did not calculate skewness (sk) because Wolman pebble counts do not fully capture the tails needed to calculate the skewness. We plotted the results of the DWR 1994 study and our study using box and whisker plots (Tukey 1977), in which the box is bounded by the D25 and D75, the median is shown by a horizontal line in the middle of the box, and the whiskers are the D10 and D90. We used box and whisker plots to display the data because overlapping cumulative curves are difficult to compare (Kondolf 2000). Note that the <4 mm size category is plotted as 2 mm in the Tukey box and whisker plots.

Comparing the bulk samples between the CMC 2000 and the DWR 1994 reports required manipulation of the data to a comparable format. For both reports we interpolated the D5, D10, D16, D20, D25, D50, D75, D84, D90, and D95 using a transform written for SigmaPlot. The geometric mean, dg, and the sorting index, sg, and skewness, sk, were also calculated (Kondolf et al. 1993b).

$$sk = \log (dg/D50)/\log (sg)$$

2.5. Bed Mobility Analysis

Bed mobilization in gravel-bed rivers initiates a range of alluvial functions including the transport of fine sediments from spawning gravels, sorting of bed material, and spatial sorting of the coarse surface layer (McBain et al. 2000). Integrating our analyses of the contemporary flow regime (chapter 4) and the site-specific gravel conditions (chapter 6) allows for interpretation of the frequency of mobilization of the channelbed surface. We modeled bed mobility thresholds using basic shear stress, velocity, and flow equations. Additional approaches outside the scope of this study (i.e., tracer rock experiments) could allow for more accurate predictions of bed mobility thresholds.

To calculate flow thresholds for bed mobility we used previously collected transect survey data (CMC 1998); slopes from longitudinal water surface profiles surveyed November 2000 and estimated from USGS 7.5 minute topographic maps (1987, 1:24,000 scale); and bed surface particle size surveyed summer 2000 (Chapter 6). We estimated the slope with the topographic maps for the Knights Ferry and Oakdale quadrangles by measuring the distance between the nearest contour lines crossing the river upstream and downstream of the study site, using a string. We surveyed longitudinal water surface profiles (> ten channel widths) in December, 2000 at two sites (R1 and R28A) to obtain better estimates of slope than possible with the 20 foot contour intervals on the 1:24,000 topographic maps or with the previously surveyed transect data (CMC 1998), which were surveyed at a low flow (500 cfs) and over too short a distance (one to two channel widths) to accurately represent the water surface slope. The surveyed slopes closely agreed with the slope estimate from the topographic map at R1 (0.00121 vs. 0.00118), yet was half the topographic slope value at R28A (0.000473 vs. 0.000952). The limited scope of this study precluded surveying more longitudinal profiles, but to do so would improve the precision of the bed mobility estimates.

To estimate bed mobility, we first estimated the forces applied on the bed (bed shear stress), and the forces needed to mobilize the bed material (critical shear stress) using Shield's criterion for the D_{50} and D_{84} at five different spawning sites (TM1, R1, R5, R28A, and R78). In many alluvial gravel-bed rivers, the ratio of the bankfull boundary shear stress (T_b) to critical shear stress (T_{c50}) for the D_{50} of the bed material is about equal to one. The dimensionless shear stress (τ^*_{ci}) was assumed equal to 0.047 based on an analysis done by Kondolf et al. (1996a) of similar gravel rehabilitation projects on the Merced River. We solved for the critical shear stress to mobilize the D_{50} and D_{84} using the equation:

$$\tau_{ci}=\tau^*_{ci}(\rho_s-\rho_f)g(D_i)$$ (Vanoni 1975; Richards 1982)

where, τ_{ci} = *the critical shear stress (N/m²) to mobilize* d_i
τ^*_{ci} = *dimensionless shear stress factor (range: 0.03 to 0.06,* $\tau^*_{ci} = 0.047$ *assumed)*
ρ_s = *sediment density (assumed to be 2650 kg/m³)*
ρ_f = *water density (1000 kg/m³)*
g = *gravity (9.81 m/s²)*
D_i = *diameter of sediment particle (m) for a given size percentile (i)*

We estimated the depths required to attain the critical shear stress for the D_{50} and D_{84} using the equation:

$$\tau_d=\rho_f(g)RS$$ (Leopold et al. 1964)

where, τ_d = *bed shear stress (=*τ_{ci} *to mobilize* D_{50} *and* D_{84} *above)*
R = *hydraulic radius (m) [area (A)/ wetted perimeter (WP)] – approx. as avg depth.*
S = *energy gradeline (downstream rate of loss of potential energy due to friction) -- approximated by water surface slope (Leopold 1964).*

We used the D_{50} data assuming that the entire channel bed is mobilized at the critical shear stress needed to mobilize the D_{50} (Parker et al. 1982). Solving for "R", we approximated the water depth associated with the critical shear stress as equal to the hydraulic radius R, due to the shallow and wide nature of the channel (Kondolf et al. 1996a).

Using the hydraulic radius at critical shear stress, we calculated the corresponding average velocity using Manning's equation:

$$V = (R)^{0.67}(S)^{0.5}/n$$ (Leopold et al. 1964)

where, V = *flow velocity (m/s)*
n = *Manning roughness coefficient (estimated, range from 0.01-0.06)*

and calculated the corresponding discharge with the flow equation:

$$Q = VA$$ (Chow 1959)

where, Q = *discharge (cfs)*
A = *area of channel cross section (ft²)*

To calculate the average velocity and discharge associated with the depth at critical shear stress we first had to estimate the roughness, or Manning's n. We plotted the transect data from November 1998 (CMC 1998)[2], measured cross-sectional area and wetted perimeter, and back-calculated the roughness at 1800 cfs. Using this roughness value, n, and the plotted cross sections (counting the squares, each 1 ft²), we estimated the flows at the depths producing critical shear stress for D_{50} and D_{84} (**Appendix C**).

Unfortunately, the cross sections available (CMC 1998) were surveyed only to characterize in-channel habitat conditions and they did not extend onto the adjacent floodplains. At two (R1, R28A) out of five riffle sites studied, the D_{50} depth associated with the critical shear

[2] Water Surface elevations for 1800 cfs were marked on one bank with a surveyor stake in October 1998 and measured in November 1998 at 500 cfs flow.

stress exceeded the top of plotted cross section, so we estimated cross-sectional areas by extrapolating bank heights based on the trajectory of adjacent data points where possible. Extending cross section surveys onto the floodplains is a priority for further study on the Stanislaus, but it is difficult due to the dense growth of encroached riparian vegetation.

2.6. Sediment Budget

A sediment budget is an accounting of the fluxes and sinks of sediment from its point of erosion to its eventual exit from a drainage basin (Reid et al. 1996). For the study reach we constructed a crude sediment budget using an estimate of sedimentation yield to New Melones Reservoir (USACE 1990) and an estimate of the volume of gravel mining from 1937 to 1999 using aerial photographs. No reservoir sedimentation surveys have been made of New Melones Reservoir, so we used an estimate of sediment yield from the USACE (1990). Accurate records of gravel extraction are also not available, so we estimated minimum volumes extracted by measuring areas of extraction visible on sequential aerial photographs and estimated extraction depths. Thus, our sediment budget should be considered a rough, first order estimate of the relative magnitude of sources, transport, and supply.

Estimates of Gravel Extraction

To identify gravel extraction sites, we examined historical USGS 1:24,000 topographical maps from 1915 to the current maps and aerial photographs 1939 to 1999 (**Table 8.1 and Table 2.4**) between Goodwin Dam and Oakdale. For a base map, we enlarged the current USGS 1:24,000 topographic maps 150% on a photocopier. We divided the study reach into three subreaches bounded by Goodwin Dam, The Knight's Ferry Covered Bridge, Orange Blossom Bridge, and Oakdale. Within each subreach, we highlighted all gravel pits and dredger tailing piles labeled on both the current and historical USGS maps, gravel pits and dredged reaches mapped by Carl Mesick, and gravel pits and dredged reaches appearing on aerial photographs from 1937, 1956, 1957, 1964, 1978, 1993, 1997, 1998, and 1999 (**Table 2.4**). We transferred the gravel mining sites identified from these sources onto our base map.

To train our eyes in recognizing gravel mines on aerial photos, we looked at the location of gravel mines identified on the published topographic maps and in the field on the air photos. Using a magnifying glass, we examined all aerial photos in the study reach for gravel pits, areas of apparent gravel extraction, and channel alteration that likely resulted from gravel extraction, marking each feature on the air photos. Some of the aerial photos were taken during the flood season when mining was not active, but we searched for clues of past gravel extraction activity. Where the channel was altered from a typical riffle-pool sequence visible in the 1937 aerial photos to either a braided channel or a single wide and shallow channel with significantly reduced riparian vegetation, and when these channel alterations were close to active gravel operations, we interpreted this as evidence of instream gravel mining.

We classified gravel extraction activities in the active channel and on the floodplain into three categories: gravel pits, skimming operations, and dredged areas. Gravel pits were located either in the active channel (typically with the river diverted to the other side) or in floodplain gravels. The pits can range in depth from a few feet to more than 30 feet. Gravel skimming (or scalping) typically removed the top few feet of the gravel either in the active channel or on the floodplain. Dredging was done primarily for gold mining, but construction aggregate was also dredged out of the active channel.

After we transferred all gravel extraction features to the base map, we rejected potential mining-related features that were isolated from other gravel extraction projects and that seemed unpractical for gravel extraction due to limited access to established roads. We rejected a few other potential gravel pits because they appeared to be maintained stock ponds and irrigation storage ponds related to farming operations. We assigned a letter or number to each gravel extraction feature and calculated the area of each feature with a planimeter. We assigned an estimated depth to each method of extraction (**Table 8.3**) based on our observations of current operations and reasonable assumptions about mining operations. The estimates are probably conservative in that they likely underestimate the depths of extraction. We created a summary table (by reach) with the area and volume of each pit listed. For presentation purposes, we transferred the features delineated on the base map to a 1:24,000 scale digital USGS topographic map.

Sediment Yield Estimates

We used an estimate of sediment yield from the watershed above New Melones Reservoir from the USACE (1990) of 210 $yd^3/mi^2/yr$. Multiplying by the drainage area above New Melones Dam (904 mi^2) and assuming bedload to be 10% of the total load (Collins et al. 1990), we calculated a pre-dam bedload sediment yield over the 50-year period of active sand and gravel mining. By applying the USACE estimated sediment yield above New Melones Reservoir, we estimated the sediment yield from tributaries downstream of Goodwin Dam. Actual sediment yield below the dams is probably lower in sand and gravel but may be higher in fine sediment. We delineated the boundary of the watershed below New Melones Dam on the USGS Oakdale 1:100,000 scale map using major topographic features. We did not correct for the potential effect of irrigation canals that may trap sediment and otherwise affect runoff sediment delivery.

CHAPTER 3. RESULTS: WATERSHED OVERVIEW

3.1. The Stanislaus Watershed

The Stanislaus River flows 120 miles, from its headwaters at elevations over 11,500 feet in the western Sierra Nevada Mountains, to its confluence with the San Joaquin River in the Central Valley (**Figure 1.1**). The Stanislaus River drainage basin lies north of the Tuolumne watershed and south of the Calaveras and Mokelumne watersheds. The river drains approximately 1,100 mi^2 of mountainous and valley terrain, with 40% of the basin above the snowline (USACE Post Flood Assessment 1999), tapering from a width of about 24 miles at the Sierra crest to about 10 miles at its midpoint (**Figure 3.1**).

The upper Stanislaus watershed is underlain by glaciated granite, mid-reaches by metamorphic rock, and below New Melones Dam, mostly volcanic rocks until just a few miles upstream of Knights Ferry (**Figure 3.2**). From Knights Ferry to Ripon, terraces of late Pleistocene fill terraces border the Stanislaus River as it flows through Holocene alluvial deposits (Nedeff 1984). In the lowest reaches of the river, near Ripon, the gradient of the river substantially decreases to an average of less than 0.0004 (2 ft/RM) as the river traverses the San Joaquin Valley floor to its confluence with the San Joaquin River at an elevation of 20 feet (**Figure 3.3 and 3.4**). The terrace sequences disappear and are replaced by wide natural levees that dominate the landscape of the lowest reach (Nedeff 1984).

Before large scale human settlement and land alteration, the Lower Stanislaus River was an alluvial river flanked by extensive floodplains; river terraces and natural levees; actively meandering reaches with large gravel bars; sloughs and oxbows; and broad riparian forests and wetlands (Nedeff 1984). The dynamic nature of the river, driven by frequent floods, allowed for frequent changes in morphology, with a migrating channel and significant sediment transport and deposition. At Caswell Memorial State Park (RM 4.5 to RM 9.5), the river is not confined by human-made levees and one can find remnant evidence of active river meandering in features such as abandoned river channels, oxbow lakes, and sloughs (**Figure 3.5**).

3.2. Climate and Hydrology

The Stanislaus basin experiences a Mediterranean climate with very dry summers and nearly all (~90%) of the precipitation falling between November and April. Average annual precipitation ranges from 10 in/yr near the confluence with the San Joaquin River, 18 in/yr in the Stanislaus foothills around Knights Ferry, and over 50 in/yr in the headwaters. Precipitation is greater eastward in the basin because of orographic lift by the Sierra Nevada and the decreased effect of the rainshadow from the Coast Ranges.

Rainfall in the winter (December to March) and snowmelt in the late spring (April to June) caused frequent flooding before the completion of New Melones Dam, with the largest peak flows typically resulting from rains on snow. Average unimpaired basin runoff is approximately 1,200 thousand acre-feet (TAF) (Calfed 1999). A historical maximum unimpaired runoff occurred in 1889-90 with 3,580 TAF and a minimum in 1923-24 with 260 TAF (DWR CDEC web data). Stream flow records have been kept on the Stanislaus for various periods over the last century by 35 gauging stations, ranging in drainage area from 0.09 to 1075 mi^2, with flow data first recorded in Oakdale (#113025) in 1895. Flow data are currently recorded in the basin by over twenty gauges operated by DWR and USGS.

Historically, floodwaters typically spilled over the banks of the Stanislaus about every other year, renewing a broad riparian forest with deposits of rich sediment, debris, and seeds (Nedeff 1984). The frequency, magnitude, and duration of these high flow events are very important factors for riparian vegetation, aquatic-terrestrial habitats, and floodplain morphology. There have been significant changes to watershed hydrology, discussed later, since the beginning of mining and agricultural development in the basin in the 1850s.

3.3. Flora and Fauna

Vegetation

Early travelers described the Lower Stanislaus and nearby Central Valley as "lush jungles of oak, sycamore, ash, willow, walnut, alder, poplar, and wild grapes which comprised almost impenetrable walls of vegetation on both sides of all major valley rivers and their tributaries" (Smith 1980: 1-2, cited by Nedeff 1984). Riverbank and Modesto age river terraces Oakdale 80 feet above the river were covered with dense belts of valley oak *(Quercus lobata)* stands that stretched for miles across the Stanislaus (Branch 1881)[3]. Vegetation composition along the middle and lower reaches of the Stanislaus effectively corresponded to elevation changes and distance from the river channel -- reflecting the differences in water table elevations, soil characteristics, and frequency of flooding. Between Knights Ferry and Ripon, dense cottonwood-dominated stands occupied late Pleistocene and Holocene landforms within 20 vertical feet of the water level, while closer to the river channel, ash, willow *(Salix spp.)*, cottonwood *(Populus fremontii)*, boxelder, and other shrubs tend to grow on terraces and floodplains (Nedeff 1984) [4].

Exotic species found in the Stanislaus basin include: domesticated figs *(Ficus carica)*, tree-of-heaven *(Ailanthus altissima)*, black locust *(Robinia pseudo-acacia)*, giant reed *(Arundo donax)*, cosmopolitan cockleburr *(Xanthium spinosum)*, various annual grasses, and agricultural crops due to nearby farming practices (Nedeff 1984).

Wildlife

In addition to the rich plant communities, other species found within the Stanislaus area include Chinook salmon, steelhead trout, giant garter snake, Swainson's hawk, greater sandhill crane, western yellow-billed cuckoo, riparian brush rabbit, San Joaquin Valley woodrat, shorebirds, wading birds, waterfowl, neotropical migratory birds, native resident fishes, and

[3] Scattered rose *(Rosa californica)* and blackberry *(Rubus vitifolia)*, brushes, sedges, and grasses also covered these natural levees and terraces (Nedeff 1984:133).

[4] Predominantly alder *(Alnus rhombifolia)* and big leaf maple *(Acer macrophyllum)* grow in the foothills and black walnut *(Juglans hindsii)* and sycamore *(Platanus racemosa)* in lowlands (Nedeff 1984).

lamprey (Calfed ERPP 1999). Early accounts spoke of thousands of wild horses, elk and antelope in the region (Thompson et al.1879). Species of concern in addition to anadromous fish species discussed below, include remnant populations of riparian brush rabbits *(Sylvilagus bachmani riparius)* found in Caswell Memorial park that are close to extinction (Nedeff 1984).

Anadromous Salmonids

Multiple runs of chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*) use the rivers in the Central Valley of California for spawning, separated by their seasonal patterns of migration, spawning, incubation, emergence and outmigration. The *spring-run* chinook salmon migrates upstream during periods of heavy snowmelt in May and June, spends the summers in freshwater, and spawns in the late fall. The spring-run, once the most abundant chinook salmon in the San Joaquin basin, went extinct in the Stanislaus, Tuolumne, and Merced Rivers by 1930 because dams prevented their migration to cold, deep pools in the mountains that allowed for their survival through dry California summers. The Central Valley *fall-run* and *late-fall-run* chinook salmon migrated upstream during fall or early winter and spawned shortly thereafter at about 1,000 ft in elevation. These fish persist but the run is a candidate for ESA listing (Calfed ERPP 2000), and is a species of primary management concern under the San Joaquin River Management Program Advisory Council (SJRMPAC).

The Central Valley steelhead trout, which spawn below Goodwin Dam, were listed as threatened in March 1997 by the National Marine Fisheries Service (NMFS). Juvenile steelhead trout commonly rear in the reach from Goodwin Dam to Riverbank. Most Central Valley juvenile steelhead spend two years in freshwater before migrating to the ocean (Hallock et al. 1961). After two to three years of ocean residence and maturing, steelhead trout return to their natal stream to spawn (Calfed ERPP 2000).

As there were no reliable counts of salmon numbers before most of the large dams were put in place in the San Joaquin basin, we can only estimate the size of the populations using the Stanislaus prior to human disturbance. Yoshiama et al. (1996) estimate pre-disturbance salmon runs of 4,000 to 35,000 fish, matched by the 1953 high of 35,000 fish (S. Spaulding, USFWS, pers. comm. 2000) (**Figure 1.2**).

Chinook salmon and steelhead trout spawn in cold, freshwater streams with gravel of suitable spawning sizes, typically in tails of pools/heads of riffles. Females deposit their eggs in redds, or nests, which they excavate in the gravel surface in relatively swift moving water (USDOI 1997). The eggs hatch six to nine weeks after spawning occurs and the salmon fry remain in the gravel for another two to four weeks until the yolk of the egg is fully absorbed (USDOI 1997). The chinook salmon fry feed and grow in shallow, low velocity, nearshore habitat, moving to progressively deeper and faster water as they grow, feeding on terrestrial and aquatic insects and zooplankton (Bjornn et al. 1991). After two to three months, the juveniles typically migrate to the ocean.

Factors limiting chinook salmon production and survival in the San Joaquin River system include: (1) the reduced quantity and quality in spawning habitat (egg mortality, low egg survival to emergence); (2) inadequate streamflow during fry and juvenile emigration; (3) reduced and degraded rearing habitat for fry and juveniles; (4) increased predation by non native fish; (5) increased bay delta and ocean mortality (delta pumping, sport and commercial harvest, predation); and (6) elevated temperatures in the river and delta (CDFG 1987 testimony – cited in Kondolf et al. 1996a; McBain et al. 2000; Calfed ERPP 1999). **Figure 1.2** shows the annual Stanislaus River chinook salmon escapement recorded since 1940.

3.4. Stanislaus Inhabitants and Historical Alterations in the Watershed

The Northern Yokut people, whose range extended throughout the Central Valley, were the first inhabitants of the lower Stanislaus river region (Wallace 1978:463), with the river named after the Lakisamni Chief and war leader, Estanislao (Nedeff 1984: 81)[5]. The first permanent settlement on the banks of the Stanislaus was by Mormon pioneers near Ripon in 1846 where they settled "Stanislaus city," planted 80 acres of wheat, erected a saw mill, and established a river ferry (Nedeff 1984: 91). They were driven out though within the year by severe flooding which inundated the region in the winter of 1847 (Thompson et al. 1879:100-101). In the 1850-60s villages were established and land cultivated throughout the lower Stanislaus[6], following the discovery of gold in the Sierra foothills. Foothill river water was used for mining activities with water development primarily done on an individual basis, with tributaries damned and ditches built much like the other speculative activities associated with the Gold Rush (Jackson et al. 1979). Through the end of the 19th Century, settlement, agricultural development, and transportation construction continued with Stanislaus County noted as the "banner grain producing county of the state" (Sweet et al. 1909: 12) as wheat became the dominant crop in the region.

Since the arrival of settlers to the region, the Stanislaus River watershed has been altered by urban and agricultural development, gold and other mineral mining, instream and floodplain mining (including aggregate mining and gold dredging), logging, livestock grazing, water storage and diversion, and hydropower activities. These activities have decreased the frequency of large floods, reduced the variability of seasonal and inter-annual flows, cut off coarse sediment supplies, degraded channel morphology, decreased floodway capacity, created large in-stream and off-stream extraction pits, impaired water quality, reduced riparian vegetation diversity and regeneration, and increased non-native species numbers. These changes, facilitated by the construction of dams, reservoirs, by-passes and canals (Sands 1978:218), have cumulatively led to major impacts to native aquatic, terrestrial, and riparian species, and have heavily degraded habitats along the Stanislaus River corridor.

Dams and Reservoirs

Dams and impoundment of flows have substantially affected the Stanislaus River watershed. Over forty dams (Kondolf et al. 1993a) regulate the Stanislaus basin, with 85% of total storage contained in New Melones Reservoir. Stanislaus River dams are now able to

[5] Relatively little is known about the Lakisamni people, with the survival of few architectural items, due primarily to their rapid disappearance as a result of disease, missionization, and the influx of settlers and miners around the time of the Gold Rush (Nedeff 1984: 80-81).

[6] Settlement focused on terraces and levees due to plentiful water, game, timber, transportation route, and ferries. Ferry crossings were regularly moved as the river course changed with flooding (Annear 1950: 47).

capture almost 240% of average unimpaired runoff (**Figure 2.1**). The first dam on the Stanislaus was built in 1853 to power a sawmill for wheat near Knights Ferry and to divert water to irrigate orchards (Nedeff 1984:102). Subsequent dams consisted mainly of small diversion dams for mining and agriculture followed by private electric utility company dams. Construction for hydroelectric power generation began in late 1890s with most of the power exported outside of the region.

Goodwin Dam, built at RM 59 in 1912 by Oakdale Irrigation District (OID) and South San Joaquin Irrigation District (SSJID), diverts water into the Oakdale and South San Joaquin Irrigation Canals. It is the upstream barrier for steelhead and salmon migration on the Stanislaus. The irrigation districts built Melones Reservoir (capacity 112 TAF) at RM 74 in 1926 and the Tri-Dam Project (total capacity 203 TAF) in the 1950s, with Donnells and Beardsley Dams in the upper basin and Tulloch Dam 7.5 miles downstream of Melones Dam (**Figure 3.3 and Table 2.1**).[7]

Federal involvement in water development on the Stanislaus began with authorization for New Melones Dam (RM 60) in the 1944 Flood Control Act with a proposed capacity of 450 TAF and the ability to enlarge to 1,100 TAF. New Melones Dam was to expand storage to help alleviate flooding problems along the Stanislaus and Lower San Joaquin Rivers. Re-authorized by the Flood Control Act of 1962, the U.S. Army Corps of Engineers was charged with constructing a larger, multipurpose reservoir with authorization for flood control, hydropower generation, recreation, fishery enhancement, and implementing a water quality control plan (USBR webpage; USACE 1972) (**Table 3.1**). The project was initially met with local resistance, but after the Christmas Day flood of 1964, which saw peak flows exceeding 40,000 cfs, local residents urged the federal construction of New Melones Dam and reservoir. Five "unavoidable" environmental effects of New Melones Dam were identified by the Corps including the loss of: whitewater boating; historic, archeological, and geological sites; scenic values; wildlife and wildlife habitat; and the reduction of water quality (USACE 1972). Preliminary construction began in 1966 with the dam completed in 1979, when operation and maintenance responsibility was transferred by Public Law 87-874 to the U.S. Bureau of Reclamation (USBR) as part of the Central Valley Project (USACE 1980: 1-5).[8] Cited as having the most popular whitewater west of the Mississippi river just upstream of the New Melones Dam site (Jackson et al. 1979), Friends of the River and other groups fought to limit reservoir filling to full capacity through Proposition 17 (Nov. 1974), Proposition 13 (Nov. 1982), and other unsuccessful efforts. New Melones was approved for filling in 1981 and reached its flood control pool height by 1983 (McAfee 2000). New Melones is the largest reservoir in the San Joaquin basin with a gross pool capacity of 2,400 TAF, and impounds over 200% of annual runoff in the Stanislaus, virtually eliminating flood flows in the lower Stanislaus River (**Figure 3.6 and Figure 3.7**) The spillway capacity is 112,600 cfs at maximum water surface elevation of 1123.4 ft (USBR webpage) and the total controlled discharge capacity from the dam is 19,000 cfs (W. Moore, USBR, personal communication 2000).

[7] Pacific Gas and Electric (PG&E) partnered with the irrigation districts based on projected revenues from hydropower, which allowed for project construction (Jackson and Mikesell 1979).
[8] USACE documents provide that flood control operations occur in accordance with the rules and regulations of the Secretary of the Army (USACE 1967).

Floodplain Development, Levees, and River Easements

Urban development along the Lower Stanislaus River is primarily centered around the towns of Riverbank, Ripon, and Oakdale. Agricultural development is concentrated on the valley floor, west of the foothills. The development within the floodplain areas adjacent to the lower Stanislaus puts constraints on future restoration.

New Melones Dam is designed to control floods up to the Q_{100}, the 100-year flood, or the flood with a 1% chance of occurring in any year. Up to this flood, New Melones Dam will release no more than 8,000 cfs, the designated 100-year flood downstream of the dam (USACE 1972). Accordingly, the USACE is required to maintain an 8,000 cfs floodway from Goodwin Dam to the San Joaquin River, subject to the condition that local landowners and responsible local interests agree to maintain private levees and prevent encroachment on the channel between levees (USACE 1967: 1). The flood control provided by New Melones Dam has encouraged settlement up to the 8,000 cfs line, despite the "residual risk" (just under a 1% chance each year) of a flow exceeding 8,000 cfs in a given year (see flood frequency, chapter 4). Moreover, actual operations have kept releases much lower than 8,000 cfs in most years, which has encouraged agricultural encroachment on fertile floodplain lands within the 8,000 cfs floodway.

The 8,000 cfs floodway from Goodwin Dam to the San Joaquin River was to consist of flood easements on many parcels, and fee-title-purchase of 5,100 acres (USACE 1972: 60; McAfee 2000). The language of these easements limits the magnitude and timing of flow releases and in some cases restricts releases outside of the active channel for only flood control purposes and not fishery enhancement (J. Anderson, USACE park ranger, personal communication 2000). Not all the intended purchases have yet occurred (McAfee 2000). Their status and spatial relationship to recent encroachment by high value orchards within the 8,000 cfs floodway has not been clearly documented and is worthy of further study and documentation.

Orchards within or near the 8,000 cfs floodway are reportedly affected by seepage under the levees and high water tables at flows greater than 1,500 cfs. Although in the winter, when the crops are dormant, flows of up to 3,000 cfs can be tolerated (McAfee 2000).

Responding to a lawsuit by a downstream orchard owner, the USBR studied the potential damages to downstream crops located within the 8,000 cfs floodway so that appropriate flows in the river could be prescribed. They estimated that flows above 1,500 cfs at Ripon could cause excessive seepage and potentially damaging soil saturation (McAfee 2000). In 1982 two orders by the U.S. Court of Appeals, 9th Circuit, restricted flow releases based on potential damage to downstream properties or interests (McAfee 2000). Documentation of flood control easements and the damage that is caused by releases between 1,200 cfs and 3,500 cfs is still underway, and McAfee (2000) reported "the question of what magnitude of flow is allowed downstream from New Melones Dam and exactly where this maximum flow is to be measured remain very much in question." For now, these flow restrictions severely limit the potential to realize hydrologic, geomorphic and biological benefits from higher river flows, as discussed in more detail later in this report.

3.5. Other Activities on the Stanislaus

Water Quality, Fishery Flows, and VAMP

Water quality and fishery issues on the Stanislaus are closely linked to what occurs in the lower San Joaquin River, the Sacramento and San Joaquin Delta, and the San Francisco Bay (**Figure 1.1**). The U.S. Army Corps of Engineers' Environmental Impact Statement (EIS) (USACE 1972) established minimum releases from New Melones Dam to meet water quality requirements and fishery needs at Vernalis, which is just downstream of the confluence of the San Joaquin and Stanislaus rivers. There currently exists a minimum allocation of 70 TAF/yr from New Melones Dam released during the irrigation season for water quality purposes and for the Bureau of Reclamation (USBR) to meet water quality standards[9].

An additional aspect associated with the management of the Stanislaus flow regimes is the role of fishery flow releases in a 1987 agreement between the California Department of Fish and Game (CDFG) and the USBR. Provision for these flows began after a protest by CDFG due to USBR water right applications to divert water from New Melones Reservoir (Calfed 1999: 408). The agreement established annual flow allocation for fisheries from 98.3 TAF to 302.1 TAF, depending on carryover storage and inflow into New Melones (Calfed 1999). Fall minimum flows and spring pulse flows are prescribed to sustain fall run chinook salmon runs.

As part of the Central Valley Project (CVP), operation of New Melones is also subject to meeting the requirements of the Anadromous Fish Restoration Program (AFRP) established in the 1992 Central Valley Project Improvement Act (CVPIA). The Vernalis Adaptive Management Plan (VAMP) emerged from discussions about how to implement environmental measures in the lower San Joaquin River. VAMP flows are part of an ongoing experiment by the Department of Interior to evaluate the effects of increased flow at Vernalis for salmon smolt survival through the Delta (S. Rosecrans, Environmental Defense, personal communication 2000). Recently agencies have been coordinating fishery releases, water quality flow releases, and releases for water sales and transfers (Calfed 1999: 408).

Gravel Restoration Activities and CALFED

In an attempt to partly mitigate impacts of the large water projects, various agencies have implemented gravel replenishment projects to improve spawning habitat between Goodwin Dam and Oakdale on the Stanislaus River (**Table 3.2**). The canyon reach between Knights Ferry to Goodwin Dam has the best quality steelhead habitat and self-sustaining, wild trout populations. Steelhead recovery efforts have focused on providing access to historical habitats and/or maintaining water temperatures below the Stanislaus dams for oversummer rearing of juveniles (Calfed 1999: 411). In September of 1994 DWR implemented gravel replenishment and riffle construction projects under the Four Pumps program at the Horseshoe Bend Recreation Area (Kondolf et al. 1996a). CDFG implemented additional projects to restore salmon spawning habitat in 1997 and 1998 in Goodwin Canyon.

[9] Release of more water than what is available is often needed to actually meet these standards.

The CALFED Bay-Delta Program [10] Ecological Restoration Program Plan (ERPP) (Calfed 1999) vision statement for the Stanislaus River called for reactivating and maintaining important ecological processes to create and sustain habitats for salmon and steelhead. The program seeks to increase the chance of survival of chinook salmon, steelhead, and native resident fish and wildlife by improving and enhancing streamflow conditions, such as through spring flow events in late April or early May in normal and wet years. The program identifies these higher spring pulse flows, which mimic natural conditions, as important for assisting young salmon and steelhead in their downstream migration to the bay, delta and ocean, and to benefit river and Bay-Delta foodweb structure and ecosystem productivity (Calfed 1999). Calfed also seeks to improve gravel recruitment, stream channel and riparian habitats and recently funded the Knights Ferry Gravel Replenishment Project (KFGRP) between Two-mile Bar (RM 56.8) and Oakdale (RM 40) (**Figures 6.1 to 6.5**). This project involved artificially adding gravel to 18 sites, varying in riffle crest height and type of gravel added, and monitoring conditions at 7 control sites to assess the performance of gravel augmentation and inform future restoration planning (CMC 2000). Calfed (1999) also identified summer water temperatures for juvenile rearing and unscreened diversions as factors affecting salmon and steelhead survival in the Stanislaus River.

Army Corps of Engineers Comprehensive Study

In December of 1996 and January of 1997, one of the costliest and geographically most extensive floods hit California as a series of subtropical storms dropped 30 inches of warm rain on existing large snowpacks. The flood control infrastructure was overwhelmed and over 250 square miles of the Central Valley was inundated. Most of the flooding that occurred was due to the failure of levees, many of which had been considered to be in excellent condition. The result: damage or destruction to nearly 20,000 homes, the loss of nine lives, and an estimated $2 billion in economic damages. As the flood damages in California and elsewhere in the nation were examined, the changes set in motion by the Mississippi floods of 1993[11] provided a foundation for comprehensive coordinated approaches to floodplain management in California.

The U.S. Congress authorized the USACE to provide a comprehensive analysis of the Sacramento and San Joaquin River basin flood management systems and develop master plans for flood management in the future. Partnering with other federal and state agencies, the "Comprehensive Study" seeks to integrate and improve flood management and integrate ecosystem restoration throughout the Sacramento and San Joaquin river basins (USACE: 1999: 6). Phase I was completed in April 1999 and produced a Post Flood Assessment, and developed hydrologic and hydraulic models, topographic and bathymetric data, an ecosystem functions model, and a GIS database. Phase II, scheduled for completion in 2002, concentrates on developing basin master plans and programmatic EIS/EIR to support implementation. The

[10] The Calfed Bay Delta Program is a State-federal cooperation that was formalized in June 1994 with the signing of a Framework Agreement by the state and federal agencies with management and regulatory responsibility in the Bay-Delta Estuary. The mission of the Calfed Bay-Delta Program is to develop a long-term comprehensive plan that will restore ecological health and improve water management for beneficial uses of the Bay-Delta System.

[11] The two co-equal goals set up by the Galloway Report in 1994 --reducing flood losses *and* restoring natural resources and floodplain functions – aided the Federal Government in establishing a new direction for responding to the flood damages in California.

Comprehensive Study, and associated analyses, primarily focus on the lowest reach of Stanislaus River, downstream of Ripon.

CHAPTER 4. RESULTS: HYDROLOGIC ANALYSIS

4.1. Flood Frequency

The flood frequency analysis (based on a composite record from gauges near Knights Ferry; **Figure 4.1**) shows a substantial reduction in peak flows since dam constructions. The frequent floods, those with return intervals of one to five years, and the flows that move the most sediment over time in many natural alluvial channels (commonly considered the "channel forming" flows) (Kondolf et al. 1999; Leopold et al. 1964), are three to four times smaller since the construction of New Melones Dam. For example, the $Q_{1.5}$ (i.e., the flow equaled or exceeded once per 1.5 years), considered the bankfull flow in many rivers, has been reduced from 5,340 cfs to 1,840 cfs. The Q_{10} and Q_{20} were reduced by six to eight times after construction of New Melones Dam. (**Figure 4.2 and Table 4.1**).

Flow data following construction of New Melones Dam comprise only 20 years of record, limiting the accuracy of the resulting flood frequency analyses (Dunne et al. 1978; Wanielista et al. 1997). This mostly affects extrapolations beyond return intervals of 20 years for estimation of 50- and 100-year floods. Differences in flows of various return intervals not only reflect the different length of flow record at the two sites, (75 years at Knights Ferry area, 38 years at Ripon) but also the different gauge locations (Knights Ferry gauges near RM 60, and Ripon RM 15 near the confluence with the San Joaquin) (**Figure 2.2 and Table 2.2**). Moreover, the "pre New Melones Dam" period was not truly "pre impact," as dams had been built as early as 1902.

4.2. Flow Duration

The flow duration analysis for the pre-dam (1903-1926) and post-dam (1979-2000) periods shows essentially no change in median and smaller flows since dam construction, but large reductions in less frequent flows (**Figure 4.3**). For example, the 10% exceedance flow (the flow exceeded on average 10% of the time) decreased from 5140 cfs to 2030 cfs, reflecting storage of high flows for later release for irrigation. The apparent lack of reduction in the more common exceedance flows (50% to 99% exceedance) most likely reflects water storage that already existed in the system before construction of Old Melones Dam.

4.3. Annual Comparisons – Extremely Wet, Wet, Dry, and Critically Dry Years

Plots of daily average flows for given water year types for the pre-dam and post-dam periods are found in **Figures 4.4** to **4.7** with a summary of average unimpaired runoff, peak flows, and other aspects of the hydrograph in **Table 4.3** (note changes in scale among figures). **Figure 4.4** comparison of critically dry years 1924 and 1987 reveals similar hydrographs in terms of peak flows attained (1,700 cfs vs. 1,360 cfs), but the distinguishing components of the hydrograph including winter floods, snowmelt floods, and snowmelt recession are not identifiable in the 1987 hydrograph. Although higher in annual unimpaired runoff by 110 TAF, 1987 was used for comparison of critically dry years as there were no other post-dam years equivalent to 1924 unimpaired flows. The dry year comparison of 1919 and 1989 reveals a significant reduction after New Melones Dam in early winter floods and late spring snowmelt peak flows (**Figure 4.5**). Comparison of wet years 1922 and 1996 similarly reveals a lack of identifiable snowmelt peak flows, although sustained higher winter flows of almost 4,000 cfs occurs in late February and March (**Figure 4.6**). The rather boxy shape of these flows is quite different from the 1922 spiked peak flows. The plot of extremely wet years (1904, 1998) in **Figure 4.7** shows not only the reduction in these winter and spring floods, but a tendency for annually constant flow releases following construction of New Melones Dam. The 1904 hydrograph also reveals a tendency for rain on snow events in the winter to cause the highest peak flows in extremely wet years. The releases made in water year 1998 maintained a relatively constant flow of about 1,800 cfs (lasting almost eighteen months) leaving distinctive flow lines on bedrock walls that are still visible (see photograph in **Figure 5.2**).

4.4. Seasonal Hydrograph

The ability to store high winter and spring flows and release them during the summer irrigation season has allowed for dramatic alteration to the seasonal distribution of river flow. A graph of mean monthly flows from before Old Melones Dam and after New Melones Dam (**Figure 4.8 and Table 4.4**) reveals the highest pre-dam historical average monthly unimpaired flows occurred in April, May, and June, with a peak of almost 5,200 cfs in May. These peaks were both reduced and shifted to earlier in the year by New Melones Dam. The lowest flows of the year historically occur in September, October and November, but flows in these months were up to five times higher after New Melones Dam. Post-dam mean monthly flows vary less seasonally. This "flattening" of the hydrograph has significant implications for anadromous fish species, discussed in chapter 9.0.

In summary, since 1979 the annual hydrographs of the Stanislaus River are distinctively flatter, with New Melones and upstream reservoirs absorbing winter and snowmelt peak flows, gradually releasing water in the summer irrigation season. Peak flows decreased, flows greater than the median flow decreased, and the minimum flows have increased.

CHAPTER 5. RESULTS: GEOMORPHIC INVESTIGATIONS/AIR PHOTO ANALYSIS

5.1. Introduction

The geomorphic form of rivers is determined by the interaction of streamflow, geological controls, riparian vegetation, and human activities (McBain et al. 2000). The fundamental building block of single-thread meandering and wandering alluvial rivers is the alternate bar unit, composed of a narrow, deep scour hole ("pool") that widens to an oblique lobe front (riffle and point bar) (Dietrich 1987). Opposite the point bar is typically a pool, a zone of scour during high flows. The structural complexity provided by an alternate bar sequence provides a wide range of habitats for aquatic organisms.

McBain and Trush (2000) developed a set of "Attributes of Alluvial River Ecosystem Integrity" (**Table 5.1**) based on historical conditions in the neighboring Tuolumne River and natural fluvial processes documented in other alluvial rivers. "The fundamental attributes of river ecosystem integrity are defined by the physical processes that create and maintain the ecosystem form and physical structure.... Restoring these critical attributes, within boundaries defined by societal constraints, is essential for improving the health and productivity of the Tuolumne River" (McBain et al. 2000: 38-39). Our analysis of natural physical processes on the adjacent Stanislaus River explores how these attributes have changed over the last century with the construction of major irrigation dams and other human alterations in the watershed.

Documenting the condition of the river channel before human alteration helps determine appropriate objectives for restoration as well as assess the capacity of a river system to adjust to changes in sediment load and flow (Kondolf et al. 1995). Documentation of channel incision can indicate channel degradation due to either a change in the sediment budget or an increase in the discharge of the stream.

5.2. Air Photograph Analysis

Historical aerial photographs illustrate how the river changed from a dynamic system with its floodplain hydrologically connected with the river channel, dynamic alternate bar sequences, active scour and fill, and meander migration. Following construction of New Melones Dam in 1979, bars that were previously scoured periodically by seasonal high flows became stabilized and thickly vegetated. Dense riparian vegetation has established along the length of the low flow channel, fossilizing the former active channel and establishing a static channel corridor. With the dam-guaranteed flood protection to 8,000 cfs, urban and agricultural development has encroached into the floodplain and even the formerly active channel.

Table 5-2 summarizes the peak flows recorded during the sequence of analyzed air photographs, detailed in chapter 3. High flows preceding the 1937 air photo include 19,300 cfs in February 1936 and 46,000 cfs in 1928 (the sixth highest flow on record). From 1938 to 1957, annual peaks exceeded 8,000 cfs in 12 out of the 20 years, with the second highest flow of record (62,900 cfs) occurring in December 1955 (water year 1956). Between the 1957 and 1998 photographs, a peak flow of 40,200 cfs occurred in the Christmas Day floods of 1964. Since 1978, no flows in excess of 8,000 cfs have occurred; the largest flow (7,350 cfs) occurred during the New Years day floods of 1997.

Flows at the times of the aerial photographs studied (**Table 5.2**) ranged from 592 cfs on March 23, 1957 and 1,350 cfs on April 25, 1957 to 1780 cfs during the 1998 flight. The published USGS flows during the 1957 air photographs vary from 592 cfs to 1,350 cfs (USGS 1957).

Specific observations from sequential air photographs of three sub reaches follow: 1) Knights Ferry (RM 54.7 to RM 53.1); 2) Orange Blossom Bridge (RM 47.4 to 45.5); and 3) Oakdale (RM 42.4 to 41.2) (**Figure 5.1**).

Knight's Ferry (RM 54.7 to RM 53.1):

From the end of the Goodwin Canyon above the original Knight's Ferry Bridge (upstream of point A) at river mile 54.7, to downstream of Lava Bluffs (across from point E), river mile 53.1 (**Figure 5.2**), there is a break in slope between the confined, steep canyon and the flatter valley bottom. Bedrock outcrops are observed upstream of the covered bridge, at Russian Rapids (Photo #2), and at Lava Bluffs (Photo #1).

Unvegetated, alternating bar sequences adjacent to the river channel were visible in the 1937 photos. Along the left bank, across from the town of Knights Ferry, discontinuous woody bank vegetation, lack of vegetation on the point bar at point B on the left bank, and open gravel bars at A, C, D, and E suggests frequent scour by high flows.

The 1957 aerial photograph showed further evidence of flood scour outside of the active channel, limiting vegetation development along the banks and bars, most attributable to the 62,900 cfs flood in December of 1955. There was also evidence of deposition of sand and gravel on the bars and floodplains.

In contrast to the 1937 and 1957 photographs, the 1998 aerial photographs showed the disappearance of the alternating bars and appearance of dense, riparian vegetation armoring the banks and forming a continuous wall along the channel (Photo #3 at R78). The bar at point C was completely obscured by vegetation and the large bar at point D was cut off from the river channel by a wall of vegetation. A gravel pit (approximately 2,600 sq. yd.) lined by vegetation and full of water was visible just below and to the right of point E (1998 photograph). The pit appeared to be partially refilled from capturing bed load. The gravel bar at point A is now a U.S. Army Corps of Engineers recreation area office, picnic area, and boat launch. Note the line of vegetation along the margins of the bar. The County Bridge, crossing the channel just downstream of point A, was constructed in 1987.

Orange Blossom Bridge (RM 47.4 to 45.5):

From about 1,800 ft. upstream of Orange Blossom Bridge (OBB) to about 8,800 ft. downstream of OBB, the sub reach is characterized by a large, leftward bend starting above Orange Blossom Bridge (downstream point M) at river mile 47.4, and extending below the large island (point N) at river mile 45.5 (**Figure 5.3**).

In 1937 agricultural development extended to a dense riparian corridor within which alternating river bars were clearly visible, indicating periodic bed mobility. Indications of overbank flow and deposition of sediment were visible on the bar at point M, with light colored deposits elongated in the flow direction.

In 1957, gravel deposits and bar features were visible, as was evidence of flood scour, probably from the 1955 flood. Standing water, either the result of gravel mining or bar scour during the 1955 flood, was visible at the bar at point M.

In 1998, continuous woody vegetation lined the low flow channel, with bars no longer identifiable. The bar at point M was armored with vegetation and no evidence of overbank flow is visible. Orchards had replaced row crops in the southern end of the bend, and the island at point N has been converted to what appears to be a fish farm.

Oakdale (RM 42.4 to 41.2):

From river mile 42.4 upstream of the water tank to the Highway 120 Bridge in downtown Oakdale at river mile 41.2 (**Figure 5.4**) is a mostly straight reach with a small southward bend.

Alternating bars and islands were prominent features in the 1937 photographs. The islands were vegetated, but also had bare areas reflecting frequent scour by high flows (which prevented permanent establishment of riparian vegetation).

The 1957 photographs showed bars scoured, almost entirely in some cases, of riparian vegetation. The alternating bars evident in the 1937 photograph at point R consisted of one large, entirely bare island. Gravel deposits downstream consisted of a wide river channel, possibly a result of gravel mining. A thick, unvegetated gravel deposit upstream of the water tank, point S, was bisected by a straight channel, probably cut by heavy equipment as channel "maintenance."

By 1998 the channel was continuously flanked by woody vegetation along both banks for the entire reach. The gravel bars in the upper reach were reduced in size and colonized by vegetation, with no evidence of flood scour. The gravel deposits by point S and T were entirely covered by thick vegetation. Orchards right along the river channel in the uppermost portion of this reach had replaced what was once a riparian forest. Orchard land at point U on a Holocene terrace above the river channel had been replaced by urban development.

5.3. Field Reconnaissance and Other Estimates

River reconnaissance trips in the spring and summer of 2000 between Knights Ferry (RM 54.7) and Oakdale (RM 41.2) supplemented observations on the air photographs.

Channel and Floodplain Change

Unfortunately, documentation of pre-dam channel dimensions did not exist (section 5.4). Field observations between Knights Ferry (RM 55) and the Highway 120 Bridge at Oakdale (RM 41) in April and July 2000 showed extensive exposure of tree root crowns. These could be evidence of either channel incision of about 0.5 to 1.0 meter or lateral bank erosion or both (**Figure 5.6**). At Riffle 58 (RM 45), a historically used chinook spawning site, erosion at the base of recently-constructed steps, along with anecdotal reports that the steps were built down to the summer water level, would imply even greater incision (**Figure 5.7**). By assuming 1 to 3 feet of uniform incision since New Melones Dam at two different cross sections (R5 and R20), the estimated discharge required for overbank flows onto the floodplain is about twice that needed for the unincised historical channel (**Figures 5.8 and 5.9**).

Comparison of field measurements by Carl Mesick in February and November 1996 with those of Schneider in October 1999 suggests a degree of channel widening at all study sites (TM1, R10, R27, R58, and R78)[12] over the interim three year period (**Table 5.3**).

This apparent widening occurred during prolonged releases in 1997 and 1998, when mean daily flows of 1,500 to 2,200 cfs (a 1.2 to 1.6 year return interval post-dam flow, **Table 4.1**) occurred for approximately a third of the total days. The greatest apparent widening was observed at sites requiring the largest flows to mobilize the d_{50} and d_{84} gravels (Schneider 1999). Unfortunately, there were numerous limitations in precisely comparing cross sections at studied sites (including the loss of Mesick's 1996 survey pins) so widening could only be estimated.

Documenting changes in channel dimensions was also complicated by the addition of over 13,000 tons of spawning gravels at 18 sites between Goodwin Dam and Oakdale between 1996 and 1999 (C. Mesick, Carl Mesick Consultants, personal communication 1999).

Riparian Recruitment

An examination of riparian vegetation features also provides indications of altered geomorphic processes. Field observations from Knights Ferry to Orange Blossom Bridge by a riparian ecologist indicated a dominance of clonal reproduction (D. Peterson, The Nature

[12] Although flow varied up to 80 cfs between the different surveys, Schneider compared the 1996 and 1999 widths since 1) flows were roughly equivalent between 1996 and 1999; 2) the 1996 survey stakes were used in the 1999 surveys where possible; and 3) the steep nature of the channel banks limits the variation in width resulting from an 80 cfs difference.

Conservancy, personal communication 2000). This observation would be consistent with a lack of high flows to disperse seeds and create fresh surfaces for vegetative establishment.

5.4. Historical Cross Section Data

As a result of our research, we found only limited historical cross section data on the Stanislaus River. We contacted over 30 individuals at almost 20 agencies or firms but found little data to document historical channel conditions (**Table 5.4**). A search of the UC library system failed to locate any cross sections within the study reach. We located pre- and post-project cross sections (1998 – 2000) for recent gravel enhancement projects on the Stanislaus River from Carl Mesick Consultants and Steve Baumgartner of the California Department of Fish and Game (CDFG). According to Mark Gard of the US Fish and Wildlife Service (USFWS) in Sacramento, cross sections were surveyed for the Instream Flow Incremental Methodology (IFIM) study completed on the Stanislaus, but no permanent benchmarks were established (M. Gard, USFWS, Sacramento, personal communication 2001).

United States Army Corps of Engineers:

The biggest disappointment for us in the search for historical survey information was the lack of topography held by the USACE. Most individuals that we contacted assumed the USACE had extensive and detailed records on the Stanislaus River. However, our requests for cross section information on the Lower Stanislaus River to Sacramento and Knight's Ferry USACE offices were fruitless. According to employees at the Sacramento office, information was misplaced when the office was relocated, and most of the staff who worked on the New Melones Project had retired. The USACE archives contained numerous plans of New Melones Dam and related structures, but no cross sections within the study reach. Considering that the USACE built the New Melones Project, and acquired and maintains the Lower Stanislaus River Parkway, it is surprising that basic topographic data were not collected for planning, design, and future monitoring.

United States Geological Survey:

The US Geological Survey (USGS) prepared the original Flood Insurance Study (FIS) for FEMA in 1978. However, the USGS has since turned over all Flood Insurance Studies back to FEMA. The current FIS says, "Cross section data were taken from a study contractor survey in the fall of 1975"(FEMA 2000). We didn't find the supporting documentation for the original FIS from FEMA, USGS, or Michael Baker, the firm responsible for the majority of the engineering work for FEMA. Walt Swain, hydrologist, at the USGS commented that most likely the cross sections would have been retained by the unidentified contractor and not included in the material that was archived for the FIS (W. Swain, USGS, Sacramento, personal communication 2001).

Potentially, inspections from USGS gauging stations can be analyzed to re-create cross sections. On the Stanislaus the two operational USGS gauges are located in either a stable reach of Goodwin Canyon or within the depositional zone at Ripon and are not suitable for incision analysis.

California Department of Transportation:

Of the four bridges that cross the Stanislaus River in the study reach, Caltrans has the original construction plans and bridge surveys for three of them: the Highway 120 Bridge at Oakdale, the Orange Blossom Bridge, and the new Knight's Ferry Bridge. Caltrans resurveyed Orange Blossom Bridge (built in 1967) in 1980 and 1993 (**Figure 5.7**). The cross sections show approximately 1.5 ft of incision over 13 years. Unfortunately, no as-built plans were available from the Stanislaus County Department of Public Works. We did not re-occupy this site in 2001 for this study as it is a KFGRP gravel enhancement site.

The Oakdale Bridge was built in 1934 and widened in 1971. Caltrans generated bridge reports in 1969, 1983, 1996, and 1999, but we were unable to use these cross sections due to data discrepancies and therefore we removed the Oakdale Bridge from consideration.

The new Knight's Ferry Bridge was built in 1987 and Caltrans produced one bridge report in December 1999, but its survey was after Carl Mesick Consultants added gravel to enhance the spawning riffle under the bridge, covering any evidence of channel incision.

Bridges are poor sites to document channel change because they are commonly located to take advantage of straight reaches (often bounded by resistant bank material), bedrock outcrops for abutments, and geologic conditions that resist incision to prevent the undermining of the bridge. When constructed in erodible alluvium, bridges often constrict high flows and induce scour and degradation (especially around piers) that is not reflective of changes over the entire reach. USGS gauges are typically located in stable, straight reaches, which remain relatively constant over time. In mobile, sand-bedded channels, the USGS commonly pours a sill of concrete to stabilize the channel at the location of a gauge. For these reasons, cross sections from bridge surveys or from gauging stations are commonly not representative of channel reaches up- or downstream (Kondolf et al. 1995).

CHAPTER 6. RESULTS: SPAWNING GRAVEL ANALYSIS

6.1. Review of Previous Studies

California Department of Fish and Game 1972

This report addressed the potential impacts of the New Melones Project on the fish and wildlife in the Stanislaus River Watershed, and concluded that the New Melones Project represented an opportunity to develop and obligate a supply of water within the San Joaquin River system to meet water quality conditions in the lower San Joaquin River. The CDFG report requested that the USBR adopt conditions outlined in the report and based the majority of recommendations on spawning gravel studies from 1961 and 1972 (CDFG 1972).

The CDFG 1972 survey employed the Westgate method to determine the amount of spawning gravel available at four different flows, 100, 150, 200, and 250 cfs. This method required detailed measurements at representative test riffles to determine the percent of usable spawning area within the study area. CDFG applied the percentage of usable spawning gravel from the test riffles to the remaining riffles between Goodwin Dam and the Riverbank where CDFG had mapped and measured the length and width of each riffle. CDFG included the length of each riffle and a base map with the riffle locations in the report (CDFG 1972).

The 1972 survey reported that approximately 35% of the spawning gravel had been lost from a previous CDFG survey in 1961 due to vegetation encroachment, scouring flood flows, and gravel extraction. The CDFG report also presented minimum conditions for the operation of the New Melones Project to preserve the salmon fishery (CDFG 1972).

Department of Water Resources 1994

In 1993, DWR assessed the location, area, and quality of salmon spawning gravel on the Stanislaus, Tuolumne, and Merced Rivers. The study included surface and bulk sampling of spawning gravel, measuring spawning gravel area, and observing river conditions such as vegetation encroachment or excess fine sediment in the riffles. The recommendations from this report aimed to guide CDFG in restoring salmonid habitat (DWR 1994).

DWR completed fieldwork from June to November 1993 at flows from 200 to 375 cfs. DWR estimated the location of each riffle by river mile from USGS topographic 1:24,000 scale maps. DWR took surface, subsurface, and combined surface and subsurface bulk samples and performed Wolman pebble counts at the heads of 22 riffles. For the bulk samples DWR used a shovel to sample an area of 2 feet by 3 feet and a surface layer depth defined by the diameter of the largest pebble for the surface layer sample. DWR sieved the sample using the size classes of 152.4, 76.2, 38.1, 19.05, 9.525, 4.75, 2.36, 1.18, 0.6, 0.3, 0.15, and 0.075 mm and recorded the maximum grain size in each sample. In an appendix of the report, DWR plotted cumulative curves for the pebble counts and bulk samples. DWR measured the area and length of suitable spawning habitat at 65 riffles from Goodwin Dam to Riverbank based on the criteria listed in **Table 2.7** and included a table summarizing the area for each riffle in the report, (DWR 1994).

The DWR report presented seven findings and recommendations and concluded that the riffle gravel was suitably sized for salmon spawning. Of the three rivers DWR studied, the Stanislaus had the most sand in spawning riffles. The DWR study reported that the sand-sized particle content was greater than what is considered optimal for spawning and rearing habitat and potentially could cause higher egg or alevin mortality rates. The DWR report noted that vegetation encroached in the riffles due to the reduction of spring peak flows from regulation of the flow regime. The DWR report recommended the removal or abatement of vegetation to improve spawning habitat and continued monitoring of vegetation encroachment. To increase the permeability of the sand-laden riffles the DWR researchers recommended using ripping bars on a bulldozer. The DWR report listed gravel mining as a possible source of the increased sand in the riffles below mined reaches and recommended a study to determine the amount of sand that was contributed from active gravel mining before any further restoration activities were undertaken. Lastly, the DWR report recommended the addition of gravel along the reach immediately downstream from Goodwin Dam, (DWR 1994).

Carl Mesick Consultants 2000

The "Pre-Project Evaluation Report: Knight's Ferry Gravel Replenishment Project" (CMC 2000) documented the pre-project spawning habitat conditions between 1998 and August 1999. The Knight's Ferry Gravel Replenishment Project added over 13,000 tons of gravel from Goodwin Dam to Riverbank in late September of 1999 to 18 riffles and included pre- and post-project monitoring of the gravel addition sites and 7 control sites for three years. CMC performed pre-project monitoring to test hypotheses regarding the relationships between spawning habitat restoration and salmon use, expected egg survival to emergence, and useful life of the restored riffles (CMC 2000).

During a fall 1995 survey, CMC numbered and located spawning riffles on USGS 7.5 minute topographic maps. CMC took measurements of spawning use, streambed elevation and contour mapping, substrate permeability, intergravel dissolved oxygen concentration, intergravel flow, and substrate bulk samples at the 25 sites. CMC measured spawner use by identifying redds in the substrate and revisiting riffles numerous times during the spawning season. CMC used a total station to map each of the study riffles and established permanent benchmarks. CMC measured substrate permeability and calculated expected survival of salmon eggs based on the permeability measurements. CMC collected surface and intergravel dissolved oxygen concentrations and measured the upwelling or downwelling of surface and intergravel flow. CMC collected substrate bulk samples at each of the study riffles with an 18-gauge steel cylinder, 18 inches in diameter and 42 inches high. The cylinder was driven 12 inches into the substrate and a shovel was used to excavate the substrate, keeping the surface and subsurface samples separate. CMC took samples at each of the study riffles, except for riffles R12A, R13, R14, R16, R19A, R57 and R59 due to excessive water depth. All samples were dried and then sieved with sieve sizes of 180, 63, 31, 16, 9.5, 8, 4, 2, 1 and 0.85 mm. CMC weighed the material caught in each sieve and in the pan to the nearest gram and weighed large rocks separately. CMC included summary tables of the data and cumulative curves in the report (CMC 2000).

The CMC report summarized the progress and results from data collected and analyzed from the fall of 1998 and summer 1999 to establish baseline data. The CMC report concluded that the retention of sediment behind upstream dams contributed to the armoring of riffles in Goodwin Canyon and below the Knight's Ferry Bridge. Comparisons between CDFG surveys and previous surveys by CMC showed that un-mined riffles had shortened and become armored (while mined riffles had disappeared). The CMC study reported a negative relationship between redd density and distance from Goodwin Dam, which increased from 1994 to 1998 (CMC 2000).

6.2. Field Reconnaissance, Spawning Area Estimation, and Pebble Counts

Field Reconnaissance and Spawning Area

At each riffle we qualitatively assessed gravel size distribution, water velocity and depth, embeddednes, amount of fine sediment, and freshness and assigned a rating of bad, poor, fair, acceptable, good, excellent. Riffles that we rated acceptable or better were considered usable and are summarized in **Table 6.1**. We measured 274,400 ft^2 of suitable spawning area by these criteria and derived 100,700 ft^2 of preferred spawning area by using a conversion factor from CMC 2000 measurements. We documented all the riffles we rated fair or better and all the DWR 1994 riffles on USGS 1:24,000 scale topographic maps in **Figures 6.1** to **6.5.** We complied **Table 6.2** to show the relationship between the CMC 2000 riffles and the DWR 1994 riffles and the comparable pebble counts between this study and DWR 1994.

Spawning Usage

Our results of the spawning usage survey show that the most heavily used riffles are located between Goodwin Dam and Willms Pond. **Figures 6.6 to 6.8** show the location where we observed salmon spawning or fresh redds and we summarized our results in **Table 6.3**. At the Goodwin sites the enhanced gravel was almost completely washed away, but all three riffles experienced heavy use. We observed redds dug in the banks of the stream in dirt adjacent to the upper most site. The redd counts from the CMC 2000 report and this study show a concentration of spawning usage above Willms Pond. This trend has been increasing over the last six years (CMC 2000), which we graphed in **Figure 6.9**.

Pebble Counts

Our pebble counts show a fining of the spawning riffles since the pebble counts of DWR in 1994, indicating a degradation of gravel quality and probable reduction in embryo survival (Bjornn et al. 1991). Of the 12 DWR (1994) riffles that we measured, three had been augmented by CMC in 1999. **Figure 6.10** displays the results of the 2000 pebble counts we performed this summer on CMC enhanced riffles to establish a baseline against which to measure future change. Riffle R12B, which is located downstream of an active gravel mine, had the most fine sediment of the riffles we measured. Of the twelve riffles we re-located, R20, R29, R56, and R69 all had a large percentage of fine sediment in the bed material in 1993 (**Figure 6.11**). Our pebble counts on nine DWR (1994) riffles that were not later augmented with gravel had high percentages of fine sediment (**Figure 6.12**), seven with D10s less than 4 mm. At DWR (1994) sites that were later augmented with gravel, our pebble counts show improvements in the size distribution (as illustrated by Riffle R29 in **Figure 6.13**). The non-enhanced DWR riffles have further filled in with fine sediment over time. Eight of the riffles increased the concentration of fine sediment while one coarsened between 1993 (DWR 1994) and our study (**Figure 6.14**). In **Table 6.4** we calculated the difference between the percentile values in DWR (1994) and our report, which illustrates the fining of the riffles. Summary statistics and cumulative curves for all pebble counts in our study are included in **Appendix A**.

6.3. Assessment of Gravel Quality

D50 values reported in Kondolf & Wolman (1993b) for spawning Chinook Salmon in California rivers range from 31.0 to 66.0 mm. The D50 values from our pebble counts were smaller and ranged from 9.2 to 44.5 mm. Although spawning gravel is cleaned by the digging action of the female salmon when making the redd, (Kondolf et al. 1993b) fine sediment may subsequently deposit on or within the completed redd (Bjornn et al. 1991). There are two sizes of fine sediment that affect spawning gravel quality: sediments < 1mm reduce permeability and the water circulation through the redd (needed to provide oxygen and remove waste products) and sediments 1-10 mm, which impede emergence of fry through the gravel (Kondolf 2000 and Bjornn el at. 1991). The quality of the enhanced riffles will decay rapidly without high flows to remove the fine sediment from the gravel.

Bulk Samples

To quantify the increase in fine sediment we compared bulk samples from five riffles sampled by both DWR (1994) and CMC (2000) (**Appendix B**). The number of riffles in common was limited because CMC didn't sample all of the CMC study riffles due to high flows and uncertainty in matching the riffle locations between the two studies. Direct comparisons between the studies were further complicated by the different sampling methods utilized. The CMC method used fewer sieves, didn't include the diameter of the largest pebble in the sample and reported all pebbles passing through a 180 mm sieve, which exaggerates the upper end of the distribution, an effect visible on the cumulative curves and in the summary table in **Appendix B**. In contrast, the maximum pebble size sampled by DWR ranged from 76.2 to 152.4mm. Comparison of DWR (1994) and CMC (2000) bulk samples shows a trend of increasing fine sediment from 1994 to 2000 (**Table 6.5**). We reported only the D25, D50, and D75 in **Table 6.5** due to the poor definition of the coarse tail in CMC (2000).

6.4. Comparison of Spawning Areas and Gravel Quality Reported From 1972 to 2000

The different methods used in each of the studies made it difficult for us to draw conclusions from comparing the data. Different methods utilized to measure spawning habitat and the subjective nature of determining the preferred spawning area in the field make the errors associated with these parameters large. The differences among the studies were probably less than the error associated with the measurement methods. For example, the difference between our spawning area measurements and CMC (2000) measurements for the same set of riffles was greater than the difference between the DWR (1994) report and our study. Flows differed by

225 cfs between the DWR (1994) (flows 200 to 375 cfs) and CDFG (1972) (flows 100 to 250 cfs), which could result in different estimates of available spawning habitat.

Comparison of Spawning Area

According to the data provided in CDFG (1972) and DWR (1994) the total area of spawning gravel between Goodwin Dam and Riverbank decreased 33% from 1961 to 1972 and 40% from 1972 to 1993. Our observations suggest that the area of spawning gravel decreased further from 1993 to 2000, but the measured differences are probably well within our margin of error (**Table 6.6**). Our results indicate that the individual riffles increased in area while decreasing in length, implying that the width of the channel (or the area used by the spawners) increased.

Pebble Counts and Bulk Samples

Our comparison of 9 pebble counts between the DWR 1994 report and our study showed an increase in fine sediment in all but one of the riffles. Our comparison of 5 bulk samples between the DWR 1994 and CMC 2000 reports showed an increase in fine sediment in 3 of the 5 riffles.

CHAPTER 7. RESULTS: BED MOBILITY

7.1. Bed Mobility Flow Estimates

Results of the bed mobility analysis for five (TM1, R1, R5, R28A, and R78) of nine sites studied suggest that flows around 5,000 to 8,000 cfs are necessary to mobilize the D_{50} of the channel bed material (**Table 7.1 and Appendix C**). Higher flows would probably be needed to mobilize bars to prevent encroachment of riparian vegetation in the active channel. To remove already encroached vegetation and rejuvenate alluvial features would require much larger flows because of the resistance to disruption provided by the roots of established riparian trees (Kondolf et al. 1996b).

Our bed mobility estimates suggest that the flows necessary to mobilize the bed increase downstream, from a minimal 280 cfs at TM1 to about 5,800 cfs at R78. The mobility of the gravel at TM1 probably reflects the smaller diameter of the augmented gravel, rather than the mobility of the gravels that would naturally occur in this steeper reach. The largest flows are needed to mobilize the D_{50} at study sites R1 (~6,550 cfs) and R5 (~6,500 cfs), which both have flatter slopes than TM1. It is reasonable to expect the highest necessary flows for mobilization at the furthest downstream and flattest site, R78, yet calculations of critical shear stress are more sensitive to the relatively larger D_{50}'s at R1 (~40 mm) and R5 (~36 mm) (vs. R78: ~29mm) than the local slopes. It is important to bear in mind the crude nature of these estimates, based as they are on rough estimates of slopes, often inadequate cross sections, and application of the Manning's and Shield's equations. Moreover, the existing grain sizes have been disturbed by gravel mining and other management actions.

We could not accurately estimate the D_{50} mobilizing flow at R28A because the existing cross section did not extend far enough up to contain the depth estimated to mobilize the bed (~8.6ft). Extending surveys onto the adjacent floodplains could help address this problem.

Table 7.2 provides details regarding each of these five sites, including discussion regarding the appropriateness of representing estimated bed mobility flows with calculations from these sites. **Appendix C** includes cross section plots with mobilizing depths indicated for all five sites.

Before construction of New Melones Dam, a bed mobilizing flow of 5,000-8,000 cfs was equivalent to a 1.5 to 1.8 year return interval flow. On the unnatural, post-dam curve, 5,000 cfs is approximately a 5-year flow, and 8,000 cfs exceeds all flows within the twenty one year study period (max flow 7,350 cfs).

CHAPTER 8. RESULTS: SEDIMENT BUDGET

Based on our measurements of the area of gravel mines and estimated extraction depths, we calculated that a minimum of 5,292,500 yd^3 of gravel was extracted from the floodplain and 1,031,800 yd^3 of gravel was extracted from the active channel for a total of 6,324,300 yd^3 of gravel extracted from the study area from 1949 to 1999. We limited the gravel extraction analysis to our study reach, excluding significant gravel extraction downstream visible on aerial photographs. In **Table 8.1**, we listed the estimated area, depth, and volume of gravel extracted for each gravel extraction feature in the three sub-reaches. In **Figures 8.1** to **8.4**, we delineated the areas of gravel extraction on digital 1:24,000 scale USGS topographic base maps and labeled each extraction feature, the different shades represent the depth of extraction. In **Figure 8.5**, we graphically represented the sediment budget over the 50-year period. The amount of gravel and sand extracted, 6,324,300 yd^3, is 600% larger than the amount naturally supplied from the watershed, 1,033,900 yd^3. Nearly all the sand and gravel supplied from the watershed was captured behind Melones or New Melones Dam, Tulloch Dam, and Goodwin Dam. Even using the sediment yield for the upper watershed, the amount of sand and gravel produced in the unregulated contributing area below the dams was almost two orders of magnitude smaller than the volume extracted.

We emphasize the reconnaissance-level nature of this sediment budget, and we likely underestimated the volume extracted from the study reach. Moreover, the amount of coarse sediment supplied by the tributaries below the dams is probably overestimated considerably, as the upper watershed is more likely to produce gravel-sized sediment.

CHAPTER 9. DISCUSSION

9.1. Dam-Induced Changes to the Flow Regime:

Comparing "pre-impact" and "post-impact" flow conditions, changes in the seasonal hydrograph, annual peak flows, and mean daily flows indicate:

- Peak annual flows have decreased, with the post-New Melones Dam Q_{20} almost eight times smaller and the $Q_{1.5}$ about three times smaller than the pre-New Melones value;
- The annual hydrographs of the Stanislaus River are distinctively flatter, with New Melones and upstream reservoirs absorbing winter and snowmelt peak flows, gradually releasing water in the summer irrigation season. Summer baseflows have increased.

The changes in the flow regime have serious implications for the life cycle requirements of aquatic species, vegetation establishment and recruitment, and sediment and geomorphic processes. Juvenile chinook salmon depend on high spring snowmelt flows for their oceanward migration. There is a positive relationship between magnitude of spring flows and the number of fall-run Chinook salmon returning to spawn 2-3 years later (Calfed 1999). Increases in streamflow at particular times of the year also provide important migration cues for adult Chinook salmon, with higher flows (and associated lower water temperatures) after the first fall storms stimulating upstream migration of the fall-run Chinook salmon (USDOI 1997). Low flows and higher water temperatures can inhibit or delay migration to spawning areas, which delays egg laying and hatching, and thereby causes problems for juveniles the next spring who outmigrate later when the temperatures are higher in the Stanislaus and San Joaquin rivers.

In addition, salmonids need gravels that are flushed of fine sediment for the survival of eggs laid during spawning. A dam-reduced flow regime may not flush fine sediments. Changes in the flow regime can also negatively impact the life cycle requirements of other aquatic species. The "flattened hydrograph" since construction of New Melones Dam has severely limited the dynamic nature of the Stanislaus River and contributed to substantial geomorphic change, discussed in 8.2. We found in our comparison of the seasonal hydrograph that mean monthly flows in May, a rough surrogate for the snowmelt runoff, are less than 25% of historical unimpaired values, thereby affecting downstream migration of fall-run chinook salmon smolts (spring-run having already been extirpated from the basin).

9.2. Geomorphic Investigations:

Study of the aerial photographs and field observations along the lower Stanislaus River indicate a shift from a dynamic river system, characterized by depositional and scour features, to a relatively static and entrenched system. Changes since construction of New Melones include:

- Reductions in channel diversity through loss of alternating bar sequences;
- Large scale vegetation encroachment in the formerly active channel and armoring along channel banks, bars and islands;
- Substantial encroachment by urban and agricultural development, particularly orchards, in floodplain areas, thereby altering the natural river channel-floodplain connection;
- Absence of evidence of floodplain scouring flows; and
- An apparently incised river channel that is no longer hydrologically or geomorphologically connected to its floodplain (twice the flow needed to access the floodplain)

Changes ongoing before construction of New Melones Dam but intensified since include:

- Sediment starvation from trapping behind dams of sand and gravel sized sediment supplied from the watershed;
- Mining of sand and gravel at rates nearly ten times greater than pre-dam coarse sediment supply from the catchment.

River diversity and aquatic species health are threatened by the loss of open gravel bars and pioneer stage vegetation and disconnection of river channels and floodplains (Ward et al. 1995).

These geomorphic changes are primarily a result of two factors. The first factor is associated with overall changes in the flow regime as the hydrograph is "flattened" with higher summer flows and commonly with increased duration of bankfull flows, concentrating flow energy and sediment export within the channel. The lack of winter and snowmelt peak flows, which naturally scour vegetation and reform floodplain surfaces, compounded by higher summer flows, allows for riparian vegetation to anchor in place and limit the ability of peak flows to remove them. This essentially armors the channel banks and floodplain surfaces, thereby limiting river migration and sediment transport processes. Elimination of these higher flows also prevents inundation and scouring of floodplain surfaces.

The second factor associated with observed morphologic changes is the nature of sediment-starved water from upstream dams, or "hungry water[13]," with excess energy no longer dissipated by the transport of sediment. The water released from dams tends to compensate, at least partly, its transport capacity and sediment load by entraining sediment from the bed and banks of the river. This results in channel incision and downcutting of the river bed, coarsening

[13] The loss of gravel recruitment is further complicated by the fact that dams capture most of a river's sediment supply (up to 95%) which may lead to additional lateral erosion of banks as the river attempts to regain part of its sediment load (Kondolf, 1997b). Over-widening of the river channel can eliminate fish and other aquatic species habitat during low flow periods as well as modify bed shear stress by changing pool and riffle sequences (Knighton, 1984).

or "armoring" of bed material, and erosion of river banks downstream (Kondolf 1997b). Once begun, the process of channel incision itself has a positive feedback, as flows are increasingly confined, limiting the dispersal of flows and energy out onto the broader floodplain. Bed armoring may have a negative feedback that limits the rate of incision. These faster moving, deeper, confined flows thus have an even stronger ability to erode the bed and transport sediment, resulting in additional incision of the channel and erosion of channel banks.

As a result, peak flows, already limited due to flow capture by upstream dams, are further prevented from floodplain access and mobilization due to river channel incision resulting from "hungry water" and constriction of flows by encroached vegetation.

This isolation of floodplain lands from the river channel resulted in the loss of important terrestrial-aquatic habitat, contributing to native species decline, and impacted other sediment processes. The overtopping of the banks permits deposition of fine sediment on the floodplain. The life-cycles for many riverine species require a mosaic of habitat types created and maintained by hydrologic variability and the connection between the river channel and floodplain (Sparks 1995; Reeves et al. 1996). Given the geomorphic and biological importance of the fluvial processes that allow for the connection between floodplains and river channels, restoring and maintaining more natural river processes may be the most successful and least expensive way of restoring and maintaining the ecological integrity of flow-altered rivers (Stanford et al. 1996) like the Stanislaus.

Changes in overbank flooding can be better documented by more extensive and precise channel surveys and application of hydraulic models. Quantifying how these changes alter the frequency of connection between the river channel and the broader floodplain will provide further insight into how these hydrologic and geomorphologic changes have impacted riverine ecology.

9.3. Distribution and Abundance of Spawning Gravels Over Time

It is difficult to compare among studies due to the subjective nature of quantifying the preferred spawning area of a riffle, but the earlier studies indicate:

- There was a reduction in spawning gravel from 1972 to 1994 of 160,000 sq. ft. from Goodwin Dam to Riverbank;
- The number of suitable spawning riffles has decreased between 1972 and 2000; and
- The distribution of spawning riffles is concentrated between Willms Pond and Goodwin Dam.

Both the distribution and abundance of spawning gravel have decreased since 1961, evidently due to human impacts on the Stanislaus River system. Instream gravel mining for construction aggregate and gold dredging of the channel has reduced the amount of gravel available for spawning. Vegetation has encroached into the channel and colonized bars historically available for spawning. Flows released from the New Melones Project do not flush sand from the riffles and do not inundate floodplains to allow for overbank deposition of fine sediments. The increase in sand from 1993 to 2000 is likely a result of mobilizing sand from the beds of captured gravel pits.

9.4. Fine Sediment, Gravel Quality, and Spawning Gravel Additions

Our field work and review of previous reports indicate that the framework size of gravels are in a suitable range for chinook salmon spawning; the high concentration of sand in the riffles could limit reproductive success; and the source and transport of sand requires further study.

While the framework size of gravels was generally suitable for spawning by chinook salmon, the high levels of sand observed in the spawning riffles in our reconnaissance observations could limit salmon spawning success. This sand may have been derived from sand left in the bottom of in-channel pits excavated by gravel mining operations, and scoured during 1997 and 1998 flows.

Thus, aside from their role as habitat for exotic warmwater fish that prey upon juvenile salmonids, as documented on the Tuolumne and Merced Rivers (Kondolf et al. 1996a; EA 1992), the in-channel gravel pits thus pose at least two additional problems: as a trap for any gravel transported in the river from upstream reaches in the future (whether the source be deliberate additions, or erosion from bed and banks), and as a source of sand inherited from gravel mining operations.

Addition of gravel to the channel is likely to be a component of any program to restore salmon spawning habitat along the Stanislaus. A first step to planning this effort should be to develop an accurate map depicting historical areas of gravel extraction to identify reaches that have been stripped of their original gravel beds and to locate in-channel pits and holes that would act as sediment traps for gravels added in the future. The location of the stripped reaches and pits should influence the choice of sites for gravel injections to minimize losses of injected gravel to the pits in the short run before the pits can be isolated. In addition to the potential losses to gravel supply by trapping in the pits, the pits may contain large amounts of fine sediment left over from gravel mining operations, sediment which is suspended and scoured at high flows. This hypothesis should be tested with field observations (by sampling bottom material).

An additional problem on the Stanislaus is that flow regulation (and to a lesser extent channel incision) has virtually eliminated overbank flows, the flows at which suspended fine sediment is normally deposited on the floodplain. While the amount of overbank deposition will depend on numerous factors, a range of studies have shown that around one quarter of a flood's sediment load can be deposited on the floodplain (Walling et al. 1996). Thus, without access to the floodplain, fine sediment stays in the channel.

9.5. Sediment Routing by Size Class

The two populations of sediment present have different ecological implications: the gravels are needed by spawning salmon, while the sand, in large amounts, degrades spawning and rearing habitat. The sand and gravel can be expected to have different mobilization thresholds and transport modes. An adequate understanding of present distribution of sand and gravel deposits, potential gravel traps and sand sources, and the mobility of these deposits at various flows, will be needed to design an optimal flushing flow program that maximizes sediment maintenance whilst minimizing release of water. Moreover, as the optimal flow regime depends on the distribution and abundance of these deposits, physical modifications to the channel (such as isolation of gravel pits, lowering floodplains along incised reaches, and removal of vegetated berms encroached onto the formerly active channel bed) can change the optimal flow regime.

9.6. Bed Mobilization

The results of our preliminary estimates of bed mobilization on the Lower Stanislaus River suggest:

- Flows in excess of 5,000 to 8,000 cfs are needed to mobilize the bed and thereby maintain channel form and gravel quality; and
- These flows occurred with a pre-dam return period of about 1.5 to 1.8 years, but now occur less than once every 5 to 20 years since construction of New Melones Dam.

Estimates of bed mobility are based on sediment size and supply, channel morphology (dimensions and slope), and discharge, which have all significantly changed due to dam construction and gravel mining. The frequency of bed mobilization is not only reduced by decreased flood flows, but in many reaches it is also reduced by armoring of the bed. This bed coarsening results from sediment starvation caused by the cut-off of sediment supply from upstream dams and from in-channel gravel mining.

Our flow estimates are preliminary and need to be improved by more extensive field surveys, to improve our slope estimates and to extend our cross section surveys onto the floodplain. Moreover, our estimates are based on application of simple tractive force equations to get flow depths at mobilization and application of the manning equation to calculate flows producing those depths. These equations provide only rough approximations of actual values, in that they assume uniform, steady flow conditions rarely satisfied in natural channels, and they lump numerous sources of flow resistance into empirical coefficients. Conditions in the Lower Stanislaus will deviate from the steady uniform flow assumed by the Manning equation, but less so than in more irregular, higher-gradient channels. Estimates of flows needed to mobilize the bed could be improved through observations of actual bed movement over a range of flows (as through use of tracer gravels, repeated cross section surveys, etc.) and field observations of water surface elevations at a range of flows (to calibrate the stage-discharge relations at study sites).

In addition to the caveats for applying this approach in general we can really only predict mobilization at four sites where the depths needed to mobilize the bed are contained within the available cross section surveys. These sites span a wide range of conditions (from higher gradient, coarse-bedded canyon reach at TM1 to the low gradient R78 near Oakdale), but are not necessarily representative of many of the other sites, where flow is over bank at lower, more frequent discharges.

9.7. Sediment Budget

Trapping of sediment by upstream dams and gravel extraction from the channel have created a massive sediment deficit in the study reach. Even if mining were to cease today and the natural annual sediment supply from the watershed somehow restored, it would take 300–400 years for sediment inflows to make up for the losses from extraction over the last 50 years. Our analysis was crude; however, even improved information is unlikely to change the basic finding of a substantial sediment deficit.

Impacts of Pit Mining

Instream pits trap bedload sediment and pass sediment-starved water downstream where it typically erodes the channel bed and banks to regain its sediment load. At the upstream end of the pit, the over-steepened bed is an unstable knickpoint, which migrates upstream (Kondolf 1998). Incision resulting from the pit migrates both up and down stream, potentially undermining structures, destabilizing the channel banks, and mobilizing spawning riffles (Kondolf 1994). On the Stanislaus River incision in the channel has been limited and no bridges have been undermined; however, this is likely due to the reduction in channel forming flows from the construction of New Melones Dam in 1979. Often, as with Willms Pond (**Figure 8.2**, Pit I), gravel pits located next to the channel are captured by the active channel and transform the lotic environment into a lentic environment, creating habitat for exotic, warm water fish species that prey on salmon smolts (Kondolf 1998).

Impacts of Skimming Operations

Although the volume of gravel extracted from skimming the top layer of gravel from the active channel is smaller than pit mining, the practice has major impacts on aquatic organisms. Skimming operations alter the cross section of the channel and remove the pavement layer of the channel that regulates the entrainment of fine particles. Skimming operations create a wide, shallow cross section without confinement, resulting in a thin sheet of water in the channel at low flows. Removal of the pavement layer may result in bed mobility at low flows, entrainment of fine sediment, and deposition of fine sediment in spawning gravels and pools downstream (Kondolf 1994).

Other Impacts

Gravel extraction operations impact the aquatic environment as well as the surrounding riparian forest. Operation of heavy equipment in the channel and discharge of muddy water from floodplain mining operations can increase the amount of suspended sediment. The increased turbidity can reduce the population of benthic invertebrates and change the composition of fish populations to ones tolerant of higher concentrations of suspended sediment (Forshage et al. 1973). The deposition of fine sediment in the riffles directly below the active gravel mining operation on the Stanislaus River is attributed to mining activities in our report, the DWR 1994 report, and the CMC 2000 report. Riparian habitat is removed during gravel mining operations and processing plants and stock piles displace large areas of riparian forest. Noise and truck traffic can also scare wildlife close to active mining operations from the riparian forest (Kondolf 1994).

Impacts of Dams on Sediment Transport

Dams also have major impacts on the sediment budget of a river; they trap all spawning gravel, releasing sediment starved, "hungry" water, which tends to erode bed and banks. The modified flow regime of a regulated river can reduce the high peak flows, thereby reducing the hungry water effect but also eliminating the frequent flushing of fine sediment from spawning gravels. Reduced flood peaks also allow vegetation to encroach into the channel, and riparian vegetation can bind sediment that would have otherwise been mobilized during high flows. (Kondolf 1995)

CHAPTER 10. RECOMMENDATIONS FOR FUTURE STUDY

Given the limited scope of the present study, we have been able only to indicate overall trends and to highlight directions for future research that would yield the most benefit in terms of future management of the river. We specifically recommend:

1) ***More extensive surveying of longitudinal profiles and cross sections at gravel mobility study sites.*** Longitudinal profiles of the water surface should extend at least ten channel widths in length to yield a representative picture of variations in slope from pool-riffle sequences and other irregularities. Cross sections should extend onto the floodplain to permit modeling of higher flows. Conducting such surveys are more difficult and time-consuming than might be assumed at first, due to the densely encroached vegetation along the channel. Our analyses were severely hampered by a lack of historical survey data, so to develop a baseline against which future change can be measured, channel surveys should involve setting permanent benchmarks.

2) ***Quantitative analysis of historical aerial photography and field observations to document channel changes.*** Better information on the history of channel change in general would shed light on causative factors (e.g., how much is due to New Melones versus earlier impoundments or land-use changes on the floodplain in recent decades?). For example, the extent of vegetation encroachment onto former spawning gravels could help to explain some differences in spawning gravel abundance from earlier surveys to present. Channel changes can be mapped and areas gained/lost can be measured from sequential aerial photographs, using GIS programs to rectify the images and to calculate areas in different cover classes in various years. Field observations of vegetation established within the former active channel and development of berms or other sedimentation along the floodplain could calibrate changes observed on the air photos.

   In addition to the years presented in this report, other years' air photos should be analyzed quantitatively, including large-scale 1978 photographs, where rectification will require considerable effort, but which could help isolate the effects of New Melones Dam from the Tri-Dam project and other influences.

3) ***Collection of all available data and estimation of historical (and current) extraction amounts and locations along the channel and floodplain.*** Extraction rates are probably the most important term in the post-New Melones sediment budget, but these data are considered proprietary information by gravel miners and the state regulatory agencies. Normally, extraction rates can be obtained only in county totals, and not even in this form when counties have less than three operators (C. Downey, California Mines and Geology Board, personal communication 2000). The state did not even systematically collect extraction and production data until the early 1990's, and the data available prior to this are notoriously unreliable. In other cases in California, production data reported for establishing a vested right have been found to differ from those reported for tax purposes. Despite these caveats, some effort invested into obtaining the best available data could

significantly improve the existing sediment budget. In addition to reported figures, minimum rates of extraction can be estimated from gravel pits appearing on aerial photographs. We are interested not only in the totals for the entire study reach, but also the distribution of the extractions over space and time, especially to inform sediment routing through the channel.

4) ***Further study and quantification of fine sediment sources including the role of existing instream gravel pits***. It is important to understand the sources of fine sediment to the channel, especially during non-flood periods, as fine sediments are known to impair incubation and/or emergence of salmon embryos and fry (Everest et al. 1987). Possible point sources for fine sediment include tributary stream channels, gullies, and erosion from agricultural fields carried by irrigation return flow.

   More significantly, existing gravel pits in the river may contribute to fine sediment during flows high enough to scour fine sediments accumulated on the pit bottoms, the "fines" produced during processing of gravels. How much fine sediment is contained within these pits? How is sediment dispersed to downstream reaches during high flow events? If these pits are large contributors of fine sediment, opportunities to isolate these sources should be explored.

5) ***Role of floodplains, channel shape, and fine sediments.*** Naturally, fine sediment deposits on floodplain surfaces during overbank flows, but flow regulation and channel incision prevent most overbank flows on the Stanislaus River, so fine sediments can deposit only in the channel. Thus, restoring channel-floodplain connectivity could help improve water quality to downstream reaches.

6) ***Potential to restore a more dynamic flow regime.*** Given that many of the ecological problems of the Lower Stanislaus River stem from the elimination of high flood flows, re-operation of New Melones Reservoir to release higher flows should be investigated. The total maximum release capacity of New Melones Dam is 19,000 cfs, the sum of the two generators at 4,500 cfs capacity each, two lower level outlets totaling 2,500 cfs, and two flood control outlets totaling 7,500 cfs (G. Cawthorne, USBR New Melones Dam, personal communication 2000).

   Increasing the authorized release from New Melones Dam will require identifying urban and agricultural developments that have encroached down to the 8,000 cfs line (the current maximum allowable release), and addressing potential conflicts through flood easements, fee title purchases, moving mobile homes and similar structures from floodplains, flood-proofing of isolated buildings and infrastructure such as bridges, and ring levees to protect settlements that cannot practically be moved.

   One advantage of higher flow releases would be greater flexibility in managing the flood-control functions of the reservoir. If dam operators were permitted to release 15,000 cfs instead of the current 8,000 cfs, the flood pool could be reduced and the effective storage of the reservoir could be increased.

The costs, benefits, and environmental consequences of restoring high flows through changed flood control operations should be analyzed to provide a sound basis for assessing the pros and cons of re-operation.

7) ***Restoration of coarse sediment supply.*** The potential to add gravels to the river below Goodwin Dam (to mitigate for sediment starvation due to trapping in upstream dams) should be analyzed by calculating the sediment transport capacity of the river under its current flow regime and under a flow regime with higher releases. Costs, optimal injection sites, and rates of gravel addition should be analyzed.

   However, even restoring the pre-dam sediment supply to the reach will not overcome the large sediment deficit resulting from gravel mining. Thus, such actions should be undertaken in coordination with a program to isolate instream gravel pits and restore gravel to the beds of reaches that were dredged by instream mining.

REFERENCES

Annear, M.L. 1950. A Brief History of Stanislaus County. Stanislaus County School District, California.

Bjornn, T.C. & D.W. Reiser 1991. Habitat Requirements of Salmonids in Streams. *Influences of forest and rangeland management on salmonid fishes and their habitats*. eds. Meehan, W.R.

Branch, L.C. 1881. *History of Stanislaus County, California*. San Francisco: Elliot and Moore, Publishers.

Calfed Bay Delta Program 1999. Ecosystem Restoration Program Plan (ERPP). Vol. 2: Ecological Management Zone Visions. *Draft PEIS/EIR Technical Appendix*. Sacramento, CA.

Calfed Bay Delta Program 2000a. Ecosystem Restoration Program Plan (ERRP). Vol. 1: Ecological Attributes of the San Francisco Bay-Delta Watershed. *Final PEIS/EIR Technical Appendix*. Sacramento, CA.

Calfed Bay Delta Program August 2000b. *Calfed Stage 1 Actions Central Valley Tributary Assessments: Tuolumne River East San Joaquin Basin Ecological Management Zone*. Prepared by: Tributary Assessment Team.

Caltrans (California Department of Transportation) Various. Bridge reports for structures across the Stanislaus River from Oakdale to Knight's Ferry, Division of Structure Maintenance and Investigations, Hydraulics Office.

CDFG (California Department of Fish and Game) 1972. Report to the California State Water Resources Control Board on Effects of the New Melones Project on Fish and Wildlife Resources of the Stanislaus River and Sacramento-San Joaquin Delta, Region 4- Fresno

CMC (Carl Mesick Consultants) 1996. Spawning habitat limitations for fall-run Chinook salmon in the Stanislaus River between Goodwin dam and Riverbank. Review draft. (Survey data at 12 riffles from 1995)

CMC (Carl Mesick Consultants) 1998. Streambed Data Collected at Carl Mesick Consultants' Knights Ferry Gravel Replenishment Project Riffles in the Stanislaus River, November 1998. (Digital data provided by author).

CMC (Carl Mesick Consultants) 2000. Task 3 Pre-project evaluation report Knight's Ferry Gravel Replenishment Project for CALFED Bay Delta Program

Chow, V.T. 1959. *Open Channel Hydraulics*. McGraw-Hill Book Co., New York.

Collins, B. & T. Dunne 1990. Fluvial geomorphology and river gravel mining: A guide for planners, case studies included. California Division of Mines and Geology Special Publication 98.

Dietrich, W. 1987. Mechanics of flow and sediment transport. Institute British Geographers Special Publication #18, KS Richards, editor. Basil Blackwell Scientific Publications.

Dunne, T. & L.B. Leopold 1978. *Water in Environmental Planning*. W.H. Freeman and Company, N.Y., N.Y.

DWR (California Department of Water Resources). California Data Exchange Center. (http://cdec.water.ca.gov). Stanislaus River at Goodwin (SNS) gauge, sensor #65 (http://cdec.water.ca.gov/cgi-progs/).

DWR (California Department of Water Resources) 1993. Dams within the Jurisdiction of the State of California, Bulletin No. 17-93

DWR (California Department of Water Resources) 1994. San Joaquin River Tributary Spawning Gravel Assessment. William Rowe, Northern District

DWR (California Department of Water Resources) CDEC website. 2000. Data for USGS gauge, Stanislaus R-Goodwin (SNS), sensor#65,http://cdec.water.ca.gov/cgiprogs/selectQuery?station_id=SNS&sensor_num=65&dur_code=M&start_date=1903&end_date=now.

EA (EA Engineering, Science, and Technology Inc.) 1992. Don Pedro project fisheries studies report. FERC article 39, Project 2299. EA, Lafayette, California.

Everest, F.L., R.L. Beschta, J.C. Scrivener, K.V. Koski, J.R. Sedell, and C.J. Cederholm. 1987. Fine sediment and salmonid production – a paradox. In E.O. Salo and T.W. Cundy (eds), *Streamside Management: Forestry and Fishery Interactions.* College of Forest Resources, University of Washington, Seattle. Pp. 98-142.

FEMA (Federal Emergency Management Agency) 2000. Flood insurance study, Stanislaus County, California unincorporated areas.

Forshage, A. & N.E. Carter 1973. Effect of gravel dredging on the Brazos River. Proceedings of the 27th Annual Conference, Southeastern Association of Game and Fish Commission (24): 695-708.

Geist, D.R. & D.D. Dauble 1998. Redd site selection and spawning habitat use by Fall Chinook Salmon: the importance of geomorphic features in large rivers. *Environmental Management*, 22(5) pp 655-669

Hallock, R.J., W.F. Van Woert, and L. Shapovalov 1961. An evaluation of stocking hatchery-reared stellhead rainbow trout in the Sacramento River system. Fisheries Bulletin, No. 114. California Dept. of Fish and Game, Sacramento.

Jackson, W.T. & S.D. Mikesell 1979. The Stanislaus River drainage basin and the New Melones Dam: Historical evolution of water use priorities. California Water Resources Center, University of California Contribution No. 178.

Knighton, D.K. 1984. *Fluvial Forms and Processes*. Wiley and Sons, Inc., London.

Kondolf, G.M. and W.V. Graham Matthews 1993a. Management of coarse sediment on regulated rivers. Report No. 80 ISSN 0575-4968, Oct. 1993, CA Water Resources Center, University of California.

Kondolf, G.M. & M.G. Wolman 1993b. The size of salmonid spawning gravels, *Water Resources Research*, Vol 29, No. 7 pp 2275-2285

Kondolf, G.M. 1994. Geomorphic and environmental effects of instream gravel mining. *Landscape and Urban Planning*, 28 (1994) 225-243.

Kondolf, G.M. 1995. Managing bedload sediment in regulated rivers: examples from California, U.S.A. Natural and anthropogenic influences in fluvial geomorphology, *Geomorphology Monograph* 89, American Geophysical Union.

Kondolf, G.M. & M. Larson 1995. Historical channel analysis and its application to riparian and aquatic habitat restoration. *Aquatic conservation: marine and freshwater ecosystems*, Vol 5, 109-126.

Kondolf, G.M., J.C. Vick, & T.M. Ramirez 1996a. Salmon Spawning Habitat Rehabilitation in the Merced, Tuolumne, and Stanislaus Rivers, California: an Evaluation of Project Planning and Performance, University of California Water Resources Center, Report No. 90

Kondolf, G.M and P.R. Wilcock 1996b. The flushing flow problem: defining and evaluating objectives. *Water Resources Research.* 32(8): 2589-2599.

Kondolf, G.M. 1997a. Application of the Pebble Count: Notes on purpose, method, and variants, *Journal of the American Water Resource Association*, Vol 33, No 1

Kondolf, G.M. 1997b. Hungry water: effects of dams and gravel mining on river channels. *Environmental management*, 21(4):533-551.

Kondolf, G.M. 1998. Environmental effects of aggregate extraction from river channels and floodplains, In *Aggregate resources: a global perspective*, P.T. Bobrowsky eds. A.A. Balkema, Rotterdam, Netherlands.

Kondolf, G.M., & J.G. Williams 1999. Flushing Flows: A Review of Concepts Relevant to Clear Creek, California. A report prepared for USFWS, Red Bluff, CA. Berkeley, CA.

Kondolf, G.M. 2000. Assessing Salmonid Spawning Gravel Quality, *Transactions of the American Fisheries Society*, 129:2262-281

Leopold, L.B., M.B. Woman, & J.P. Miller 1964. *Fluvial Processes in Geomorphology*. W.H. Freeman and Sons, San Francisco.

McAfee, Kimra 2000. Post-Audit of New Melones Dam, Central Valley Project, Stanislaus River. San Francisco State University Master's Thesis, May 2000.

McBain & Trush 2000. Habitat Restoration Plan for the Lower Tuolumne River Corridor. Report to the Tuolumne River Technical Advisory Committee.

Nedeff, N.E. 1984. The historic extent of riparian forest vegetation along the lower Stanislaus River, California. Masters thesis, Dept. of Geography, UCB.

Otto, G.H. 1939. A modified logarithmic probability graph for interpretation of mechanical analysis of sediments. *Journal of Sedimentary Petrology*. Vol. 9: 62-76.

Parker, G. & P.C. Klingemman 1982. On why gravel bed streams are paved. *Water Resources Research* 18(5):1409-1423.

Reid, L. & T. Dunne 1996. *Rapid Evaluation of Sediment Budgets*. Reiskirchen: CATENA VERLAG

Richards, K. 1982. *Rivers: form and process in alluvial channels*. Methuen, London.

Reeves G.H., L.E. Benda, K.M. Burnett, P.A. Bisson, & J.R. Sedell 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. *American Fisheries Society Symposium*, 17: 334-349.

Sands, A. 1978. Public involvement in riparian habitat protection, a California case history. Proceedings of the national symposium on strategies for protection and management of floodplain wetlands and other riparian ecosystems. Callaway Gardens, Georgia. Dec. 11-13, 1978, pp. 216-226.

Schneider, K. Unpublished 1999. Channel adjustments downstream of Goodwin Dam, Stanislaus River: an examination of river morphology and hydrology from 1996-1999. Prepared for LA 227: Restoration of rivers and streams, U.C. Berkeley, December 15, 1999.

Schneider, K. 2000. Unpublished data using Indicators of Hydrologic Alteration (IHA) model with mean daily flow data at gauge # 11302000.

Smith, R.L. 1980. *Ecology and field biology*. New York: Harper and Row.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. *Bioscience* 45:168-182.

Stanford, J.A., J.V. Ward, W.J. Liss, C.A. Frissell, R.N. Williams, J.A. Lichatowich, & C.C. Coutant 1996. A general protocol for restoration of regulated rivers. *Regulated rivers, research, and management*, 12: 48-60.

Sweet, A.T., J.F. Warner, & L.C. Holmes 1909. *Soil Survey of the Modesto-Turlock area, California.* USDA Govt. Printing Office, Washington, D.C.

Thompson, T.H., & A.A. West 1879. *History of San Joaquin County, California.* Oakland, California.

Tukey, J.W. 1977. *Exploratory data analysis.* Addison-Wesley, Reading, Massachusetts.

USACE (US Army Corps of Engineers) 1967. New Melones Reservoir general design. July 1967. Dept. of the Army.

USACE (US Army Corps of Engineers) 1972. Environmental Impact Statement: New Melones Lake Stanislaus River, California. US Army Engineer District, Sacramento California.

USACE (US Army Corps of Engineers) 1980. New Melones Dam and Lake, Stanislaus River, California: report on reservoir regulation for flood control, San Joaquin River basin, California. U.S. Department of the Army, Corps of Engineers, Sacramento District. January 1980. Sacramento, California.

USACE (US Army Corps of Engineers) 1999. Sacramento and San Joaquin River Basins, California, Post-Flood Assessment. Sacramento District, March 1999.

USACE (US Army Corps of Engineers) 1990. American River and Metro Investigations, California, Hydrology Office report, unpublished. USACE, Sacramento District, January 1990.

USBR (US Bureau of Reclamation) webpage. 2000. Data Web: New Melones Dam. http://dataweb.usbr.gov/dams/ca10246.htm

USDOI (US Department of the Interior) 1997. Fisheries technical appendix. Central Valley Project Improvement Act: draft programmatic environmental impact statement. Nov. 7, 1997. U.S. DOI, Bureau of Reclamation, Sacramento, CA.

USGS (US Geologic Survey) data retrieval center. http://waterdata.usgs.gov/nwis-w/CA/

USGS (US Geologic Survey) various. Surface Water Supply of the United States: Pacific slope basins in California. Paper Nos. 251 (1908), 271 (1909), 291 (1910), 299 (1903-1912), 311 (1911), 331 (1912), 361 (1913), 391 (1914), 1315-A (1904-1933), 1515 (1957). Department of the Interior, Government Printing Office, Washington.

USGS (US Geologic Survey) 1987. 7.5 Minute Topographic Maps, Knights Ferry and Oakdale Quadrants. Washington, D.C.: Department of the Interior, USGS.

USGS (US Geologic Survey) 1999. National Water Data Storage and Retrieval System. http://waterdata.usgs.gov/

USGS (US Geologic Survey) 2000. National Water Data Storage and Retrieval System. http://waterdata.usgs.gov/

Vanoni, V.A. 1975. *Sedimentation Engineering*, the American Society of Civil Engineers, New York, New York

Wagner, D.L., E.J. Bortugno, & R.D. McJunkin 1991. Geologic Map of the San Francisco-San Jose Quadrangle, California Department of Conservation, Division of Mines and Geology, map No. 5A, scale 1:250,000.

Wallace, W.J. 1978. Northern Vallet Yokuts. In *Handbook of North American Indians, California.* R.F. Heizer, ed., Smithsonian Institution, Washington, D.C.

Walling, D.E., Q. He, & A.P. Nicholas 1996. Floodplains as suspended sediment sinks. In MG Anderson, DE Halling, and PD Bates, ed., In *Floodplain Processes.* John Wiley and Sons, Chichester, UK.

Wanielista, M., R. Kerston, & R. Eaglin 1997. *Hydrology: Water Quantity and*

Quality Control. John Wiley and Sons, Inc., New York.

Ward, J.V. & J.A. Stanford 1995. Ecological connectivity in alluvial river ecosystems and its disruption by flow regulations. *Regulated rivers, research and management*, 10: 105-119.

Wolman, G.M. 1954. A Method of Sampling Coarse Riverbed Material, *Transactions of the American Geophysical Union*, Vol 35 No 6

Yoshiyama, R.M., E.R. Gerstung, F.W. Fisher, & P.B. Moyle 1996. Historical and present distribution of Chinook Salmon in the Central Valley drainage of California. *Sierra Nevada ecosystem project, final report to congress, vol. III, assessments, commissioned reports, and background information.* Davis: University of California, Center for Water and Wildland Resources.

Figures