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

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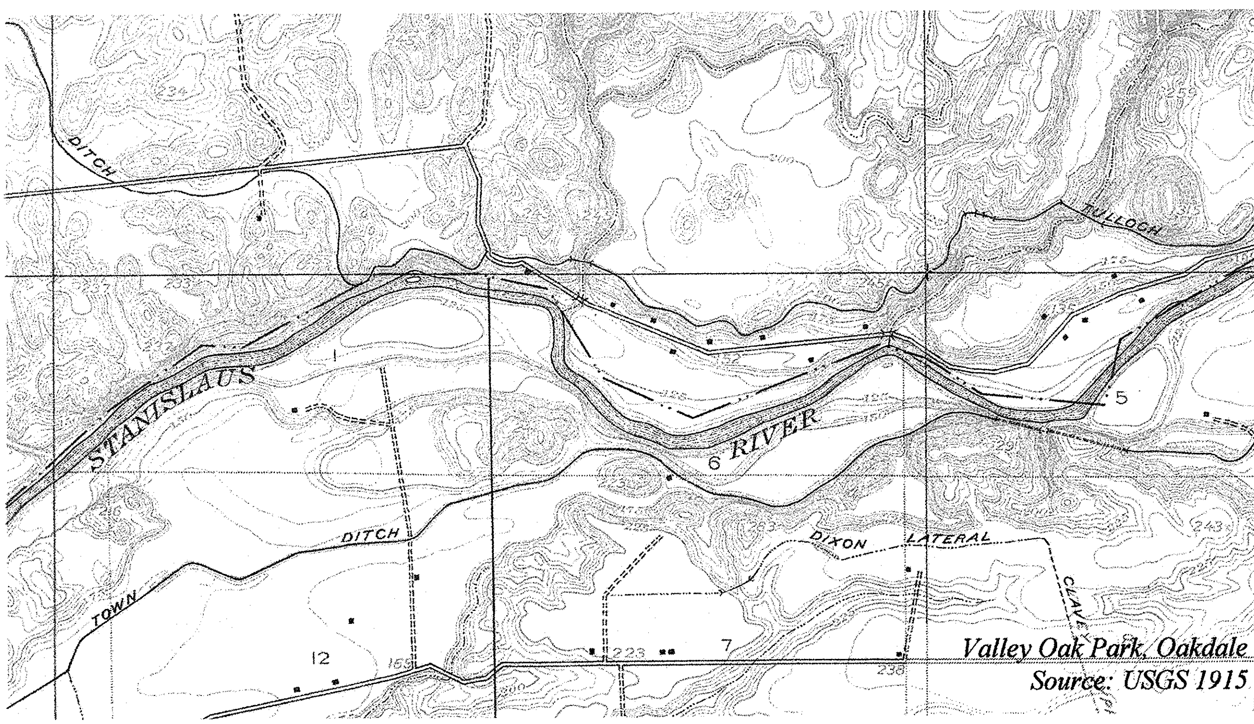

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CHAPTER 1. INTRODUCTION AND SCOPE

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

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[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/m^2) to mobilize d_i*
τ^*_{ci} = *dimensionless shear stress factor (range: 0.03 to 0.06, τ^*_{ci} = 0.047 assumed)*
ρ_s = *sediment density (assumed to be 2650 kg/m^3)*
ρ_f = *water density (1000 kg/m^3)*
g = *gravity (9.81 m/s^2)*
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 (ft^2)*

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 ft^2), 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

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[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

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[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).

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[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.

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[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

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[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

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[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.

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Figures

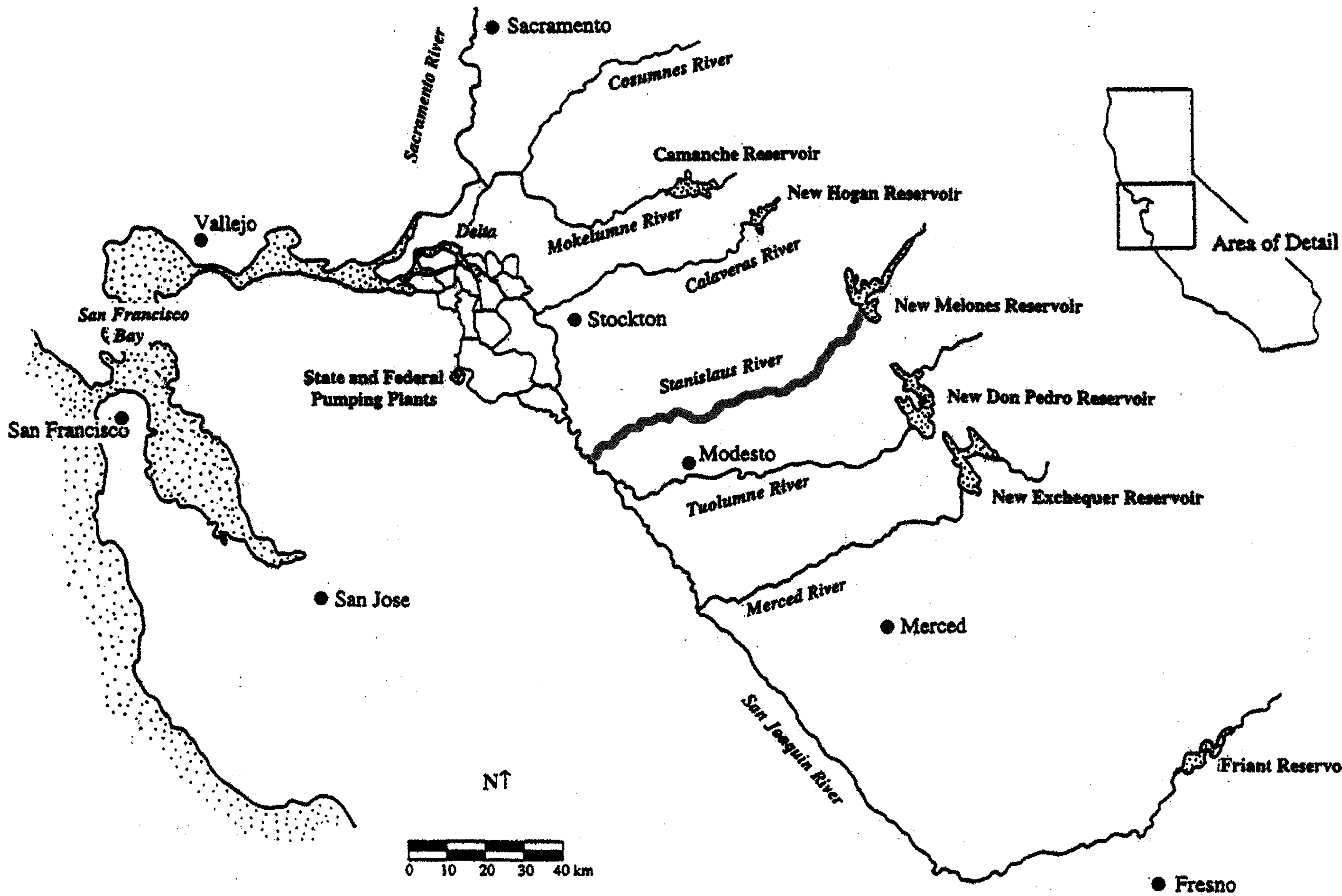
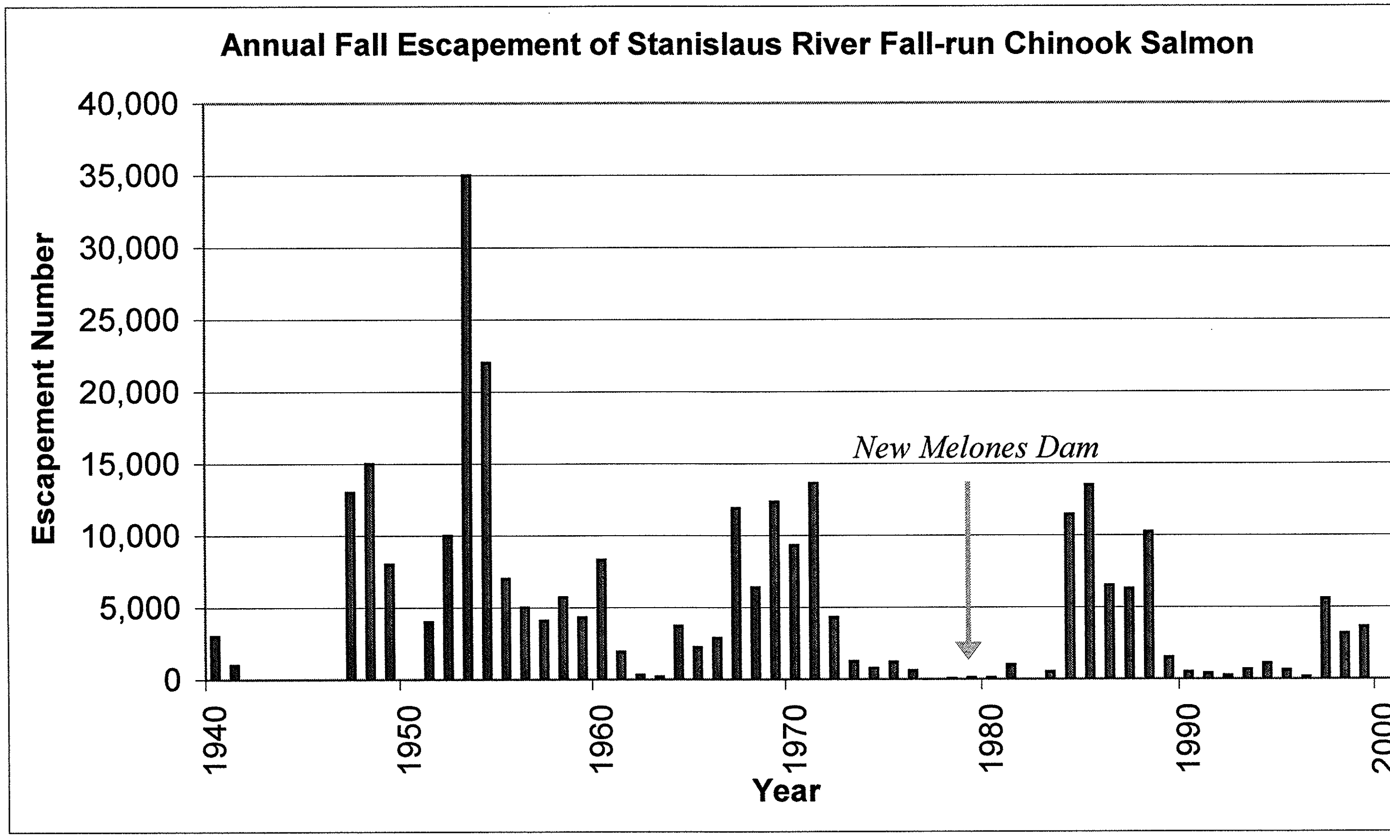
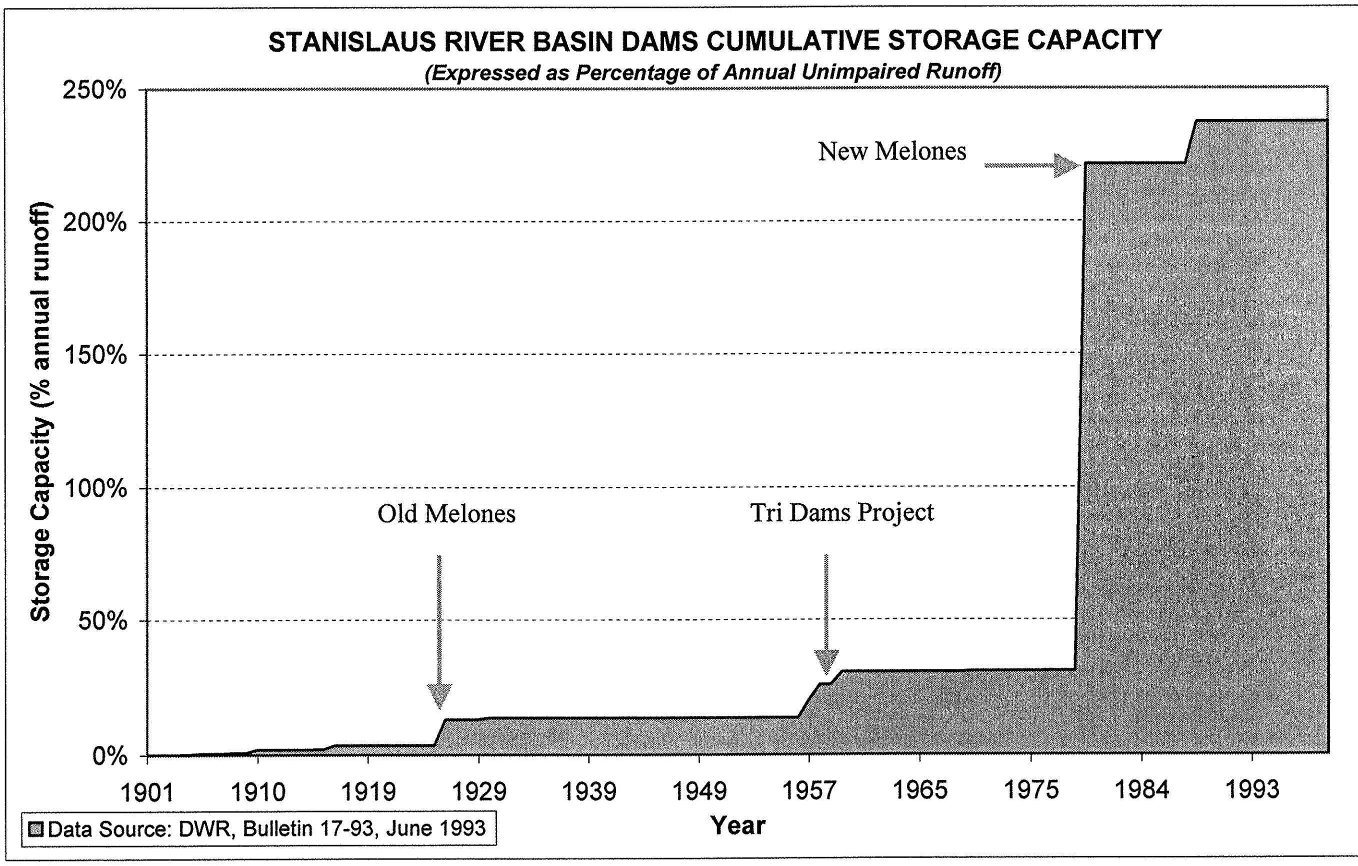


Figure 1.1: Stanislaus River Location Map, California. The Stanislaus River (highlighted) is the northernmost large tributary to the San Joaquin River basin, one of the two large river systems in California that drain Central Valley and adjacent mountain waters into the San Francisco Bay. The Stanislaus runs 120 miles in length, with headwaters at 11,000 foot elevation in the western Sierra Nevada. The river drains 1,100 square miles. The study reach is located in the lowest half of the watershed, from RM 41 at Oakdale to RM 59 at Goodwin Dam. *(Map adapted from Kondolf et al. 1996a).*



Year	Quantity	Year	Quantity
1940	3,000	1971	13,621
1941	1,000	1972	4,298
1942	nd	1973	1,234
1943	nd	1974	750
1944	nd	1975	1,200
1945	0	1976	600
1946	nd	1977	0
1947	13,000	1978	50
1948	15,000	1979	100
1949	8,000	1980	100
1950	0	1981	1,000
1951	4,000	1982	0
1952	10,000	1983	500
1953	35,000	1984	11,439
1954	22,000	1985	13,473
1955	7,000	1986	6,497
1956	5,000	1987	6,292
1957	4,090	1988	10,212
1958	5,700	1989	1,510
1959	4,300	1990	480
1960	8,300	1991	394
1961	1,900	1992	255
1962	315	1993	677
1963	200	1994	1,079
1964	3,700	1995	611
1965	2,231	1996	160
1966	2,872	1997	5,583
1967	11,885	1998	3,147
1968	6,385	1999	3,619
1969	12,327	2000	nd
1970	9,297		

Figure 1.2: Annual Stanislaus River Fall-run Chinook Salmon Escapement. Note the high of 35,000 spawners in 1953 and recent low of less than 300 fish in 1991-2. New Melones dam was built in 1978. *(Fall run escapement data source: Scott Spaulding, USFWS, Presented July 2000)*.



Photograph of New Melones Dam: Constructed 1979, Capacity: 2,400,000 acre feet, or 200% of average unimpaired runoff. (Photo source: USBR webpage).

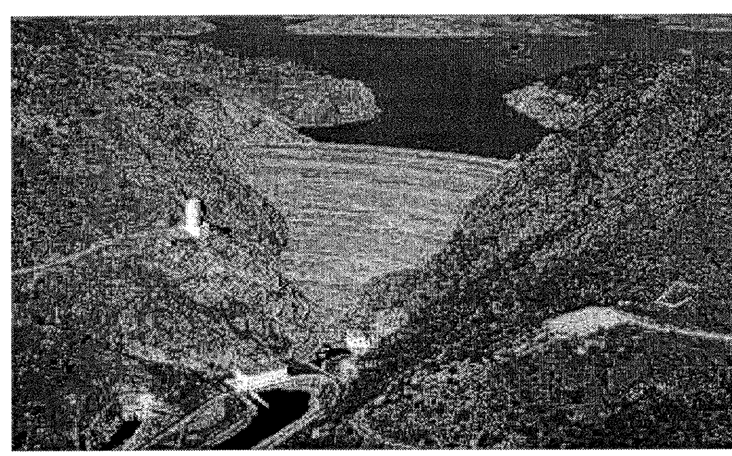


Figure 2.1: Stanislaus River Dams Capacity. Incremental increase in storage capacity expressed as a percentage of mean annual runoff. Note the most noticeable jumps occur in 1926 with the construction of Old Melones dam, 1957-8 with the Tri-dams project, 1979 with New Melones dam (see photo below), and 1988 with New Spicer Meadows. See Table 2.1 for details regarding calculations.

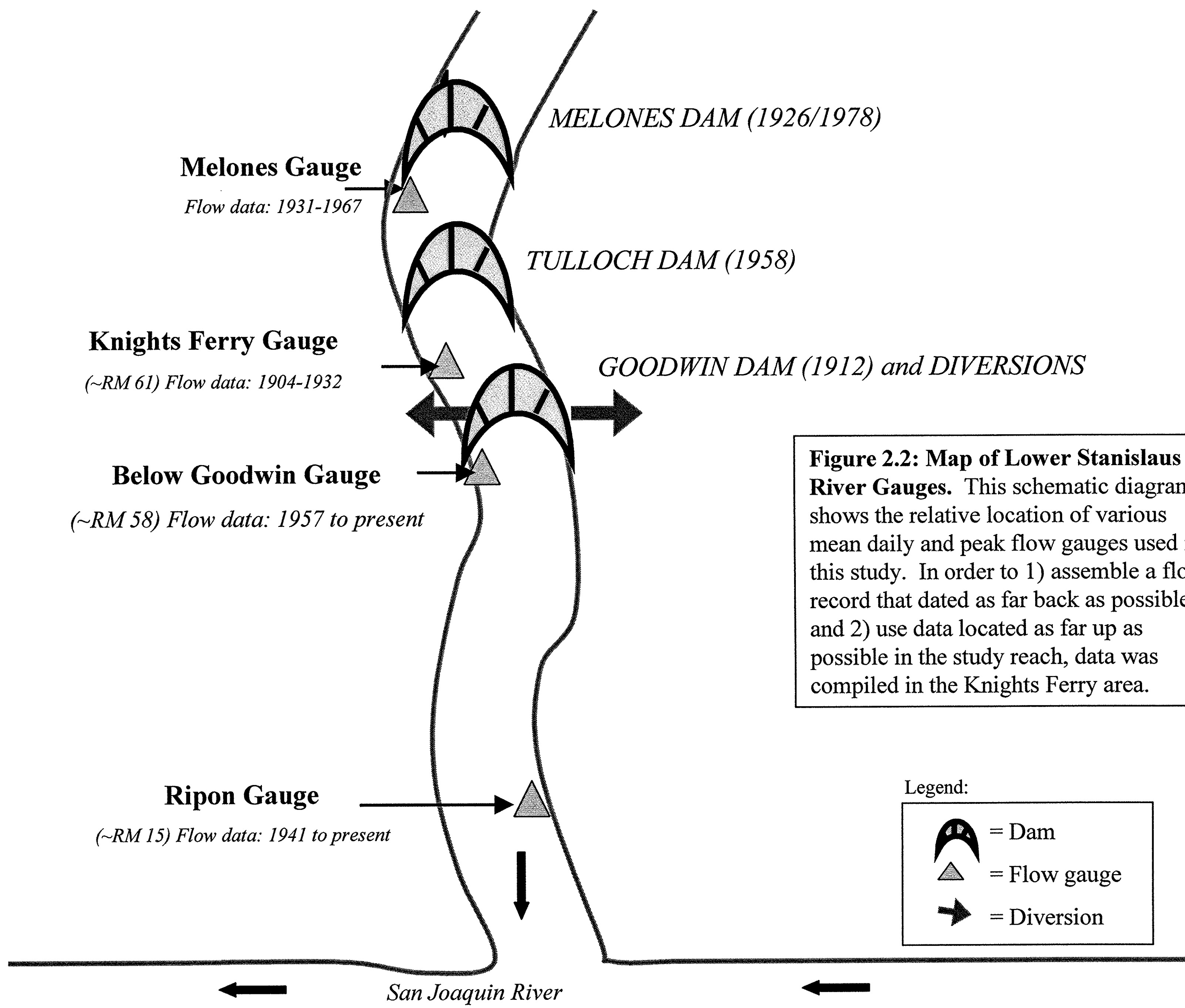


Figure 2.2: Map of Lower Stanislaus River Gauges. This schematic diagram shows the relative location of various mean daily and peak flow gauges used in this study. In order to 1) assemble a flow record that dated as far back as possible and 2) use data located as far up as possible in the study reach, data was compiled in the Knights Ferry area.

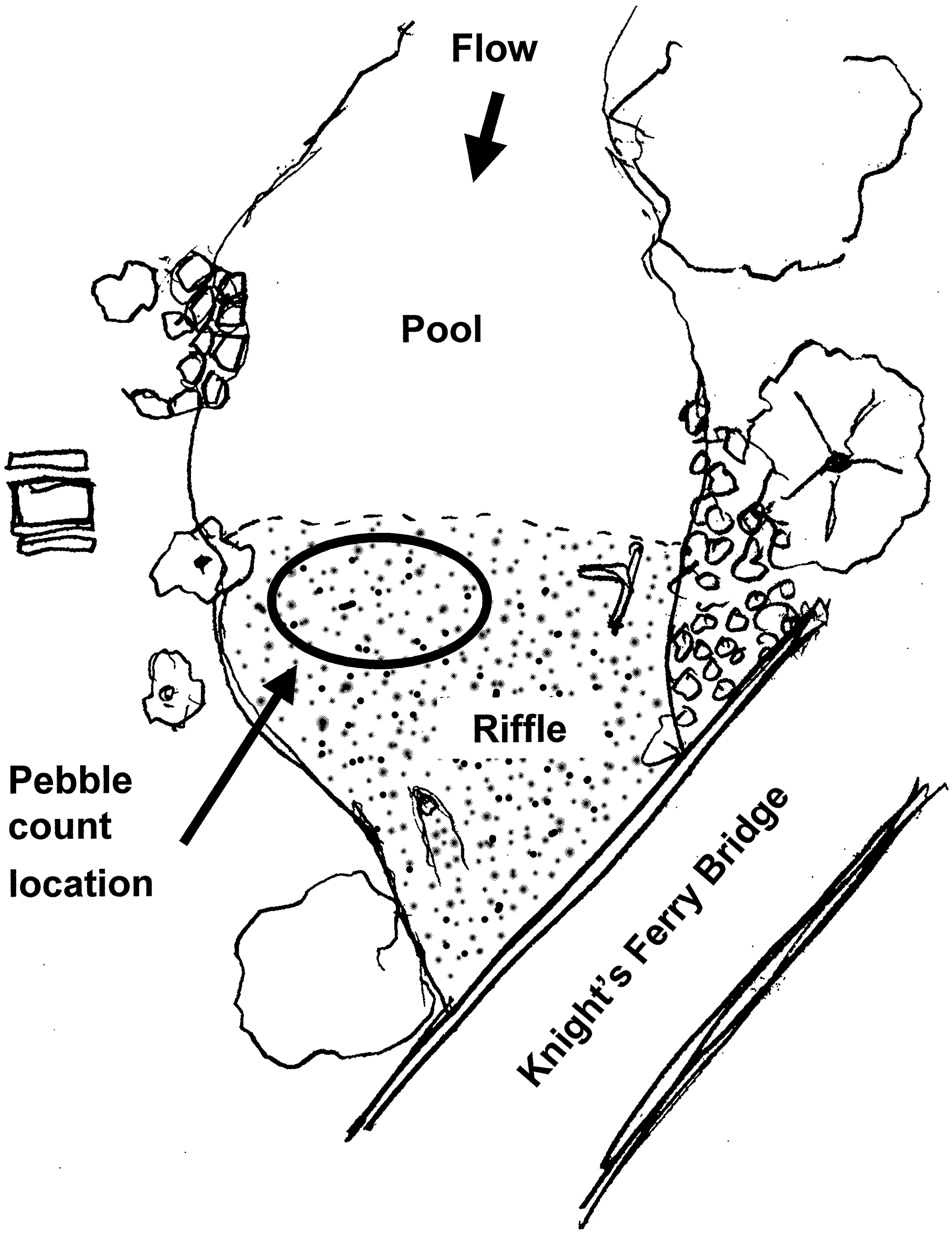
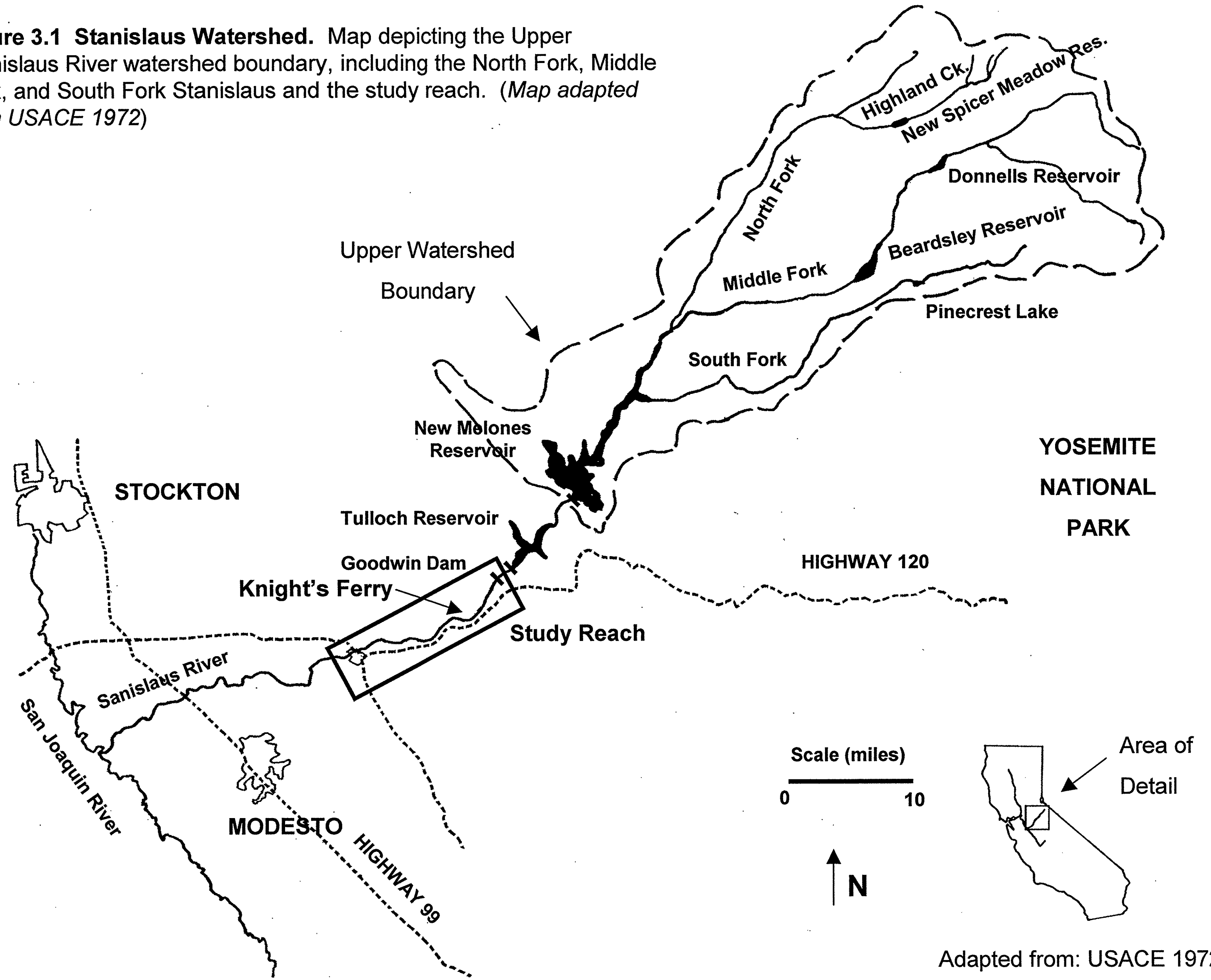


Figure 2.3: Representative Location of Pebble Count at Riffles. We conducted Wolman Pebble Counts at the head of the riffle, as this figure illustrates. Adapted from field sketch made at Riffle R1, immediately upstream of the new Knight's Ferry Bridge.

Figure 3.1 Stanislaus Watershed. Map depicting the Upper Stanislaus River watershed boundary, including the North Fork, Middle Fork, and South Fork Stanislaus and the study reach. (*Map adapted from USACE 1972*)



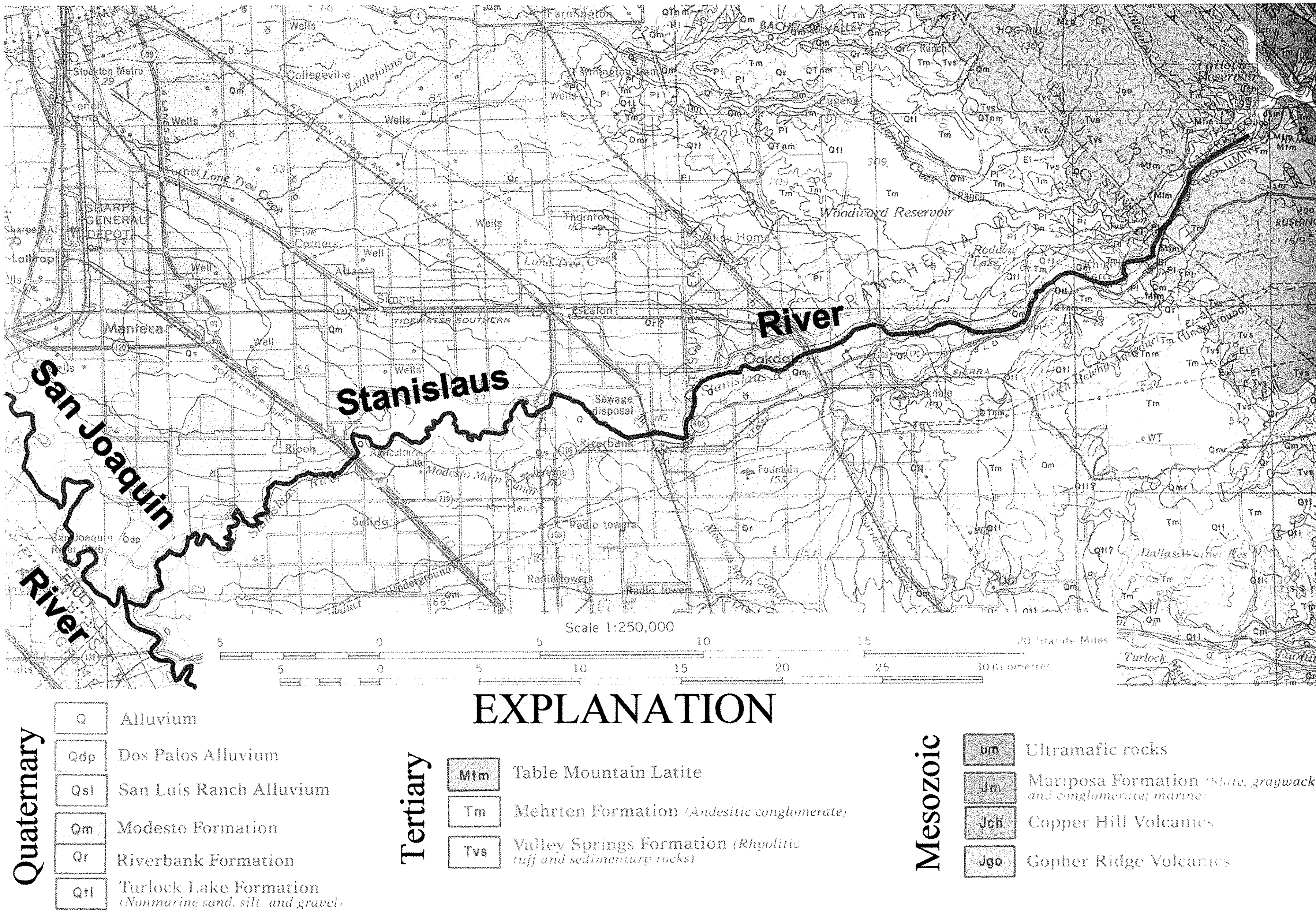


Figure 3.2: Geologic Map of the Stanislaus River Basin. Figure showing the geology of the lower Stanislaus River (highlighted in blue) from Tulloch Reservoir to the confluence with the San Joaquin River (highlighted in blue). Below Goodwin Canyon the channel cuts through alluvial deposits. Adapted from Wagner et al. 1991.

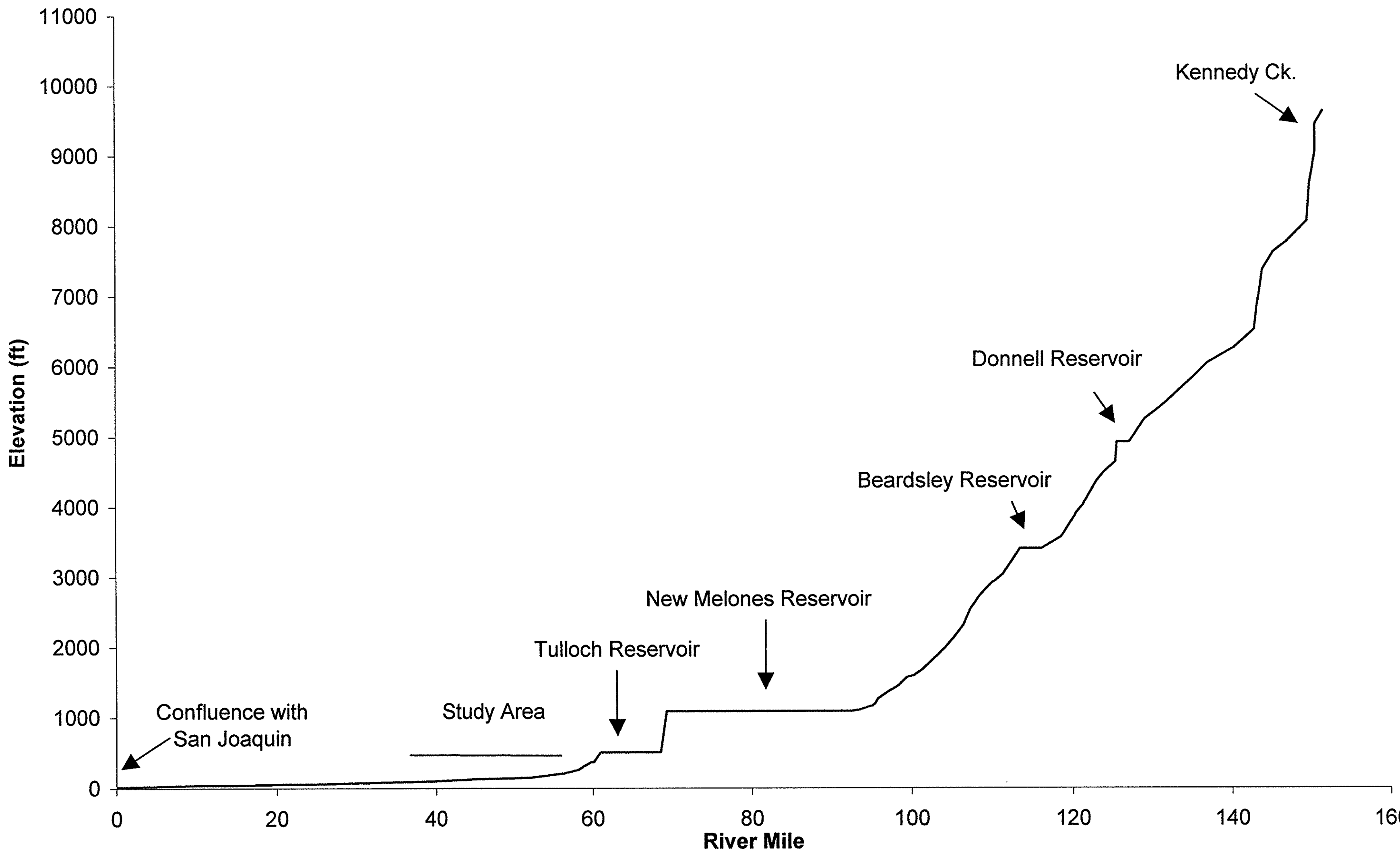


Figure 3.3: Longitudinal Profile of the Stanislaus River. This elevation profile was created by tracing the Stanislaus River from the Confluence with the San Joaquin to the headwaters. The spot elevation points were generated from USGS 30 meter DEM data. The average slope of the watershed from the headwaters to New Melones Reservoir is 2.1%, and the average slope from New Melones Reservoir to Goodwin Dam is 0.5%. Figure 3-4 provides more detail of the reach from Goodwin Dam to the Confluence with the San Joaquin River. *(Data source: Nation Geographic Maps CA Series digital USGS 1:24,000 topographic maps and Topo! Software).*

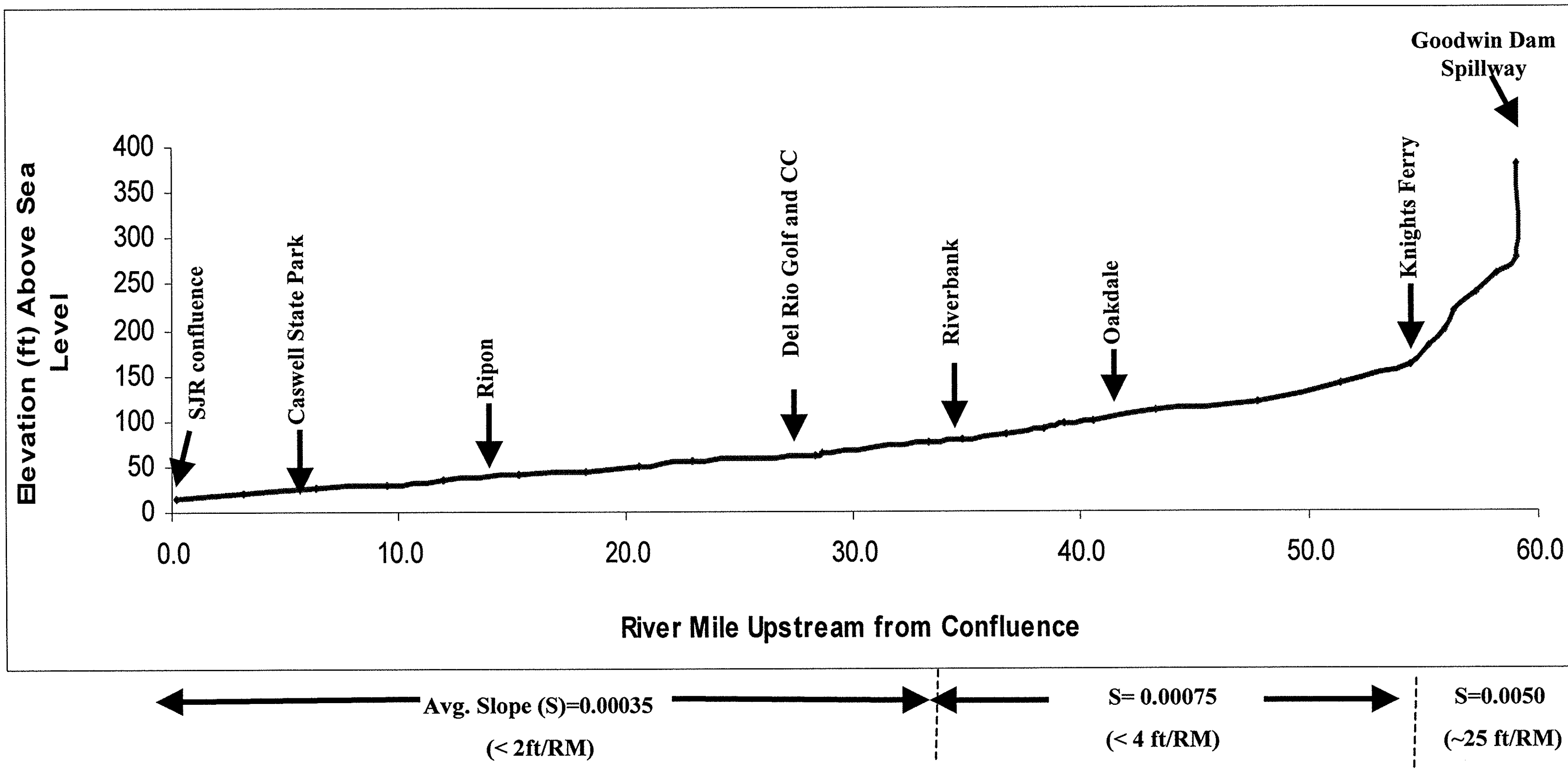


Figure 3.4: Lower Stanislaus River Longitudinal Profile (vertically exaggerated). *Using the elevations and river mileage from USGS 1: 24,000 (7.5 min) topographic maps, we estimate average slopes from Goodwin Dam to the confluence with the San Joaquin River. The lowest reach, from the confluence to Riverbank, is composed of Holocene alluvium deposits and has an average gradient less than 2 ft/river mile. The reach between Riverbank and Knights Ferry descends an average of 4 ft/RM with Riverbank formation materials also present. From Knights Ferry to Goodwin Dam, slopes average 25 ft/RM with Gopher Ridge volcanics present in the uppermost reach. (Geology summarized from Wagner et al. Geologic Map of SF-San Jose Quadrangle).*

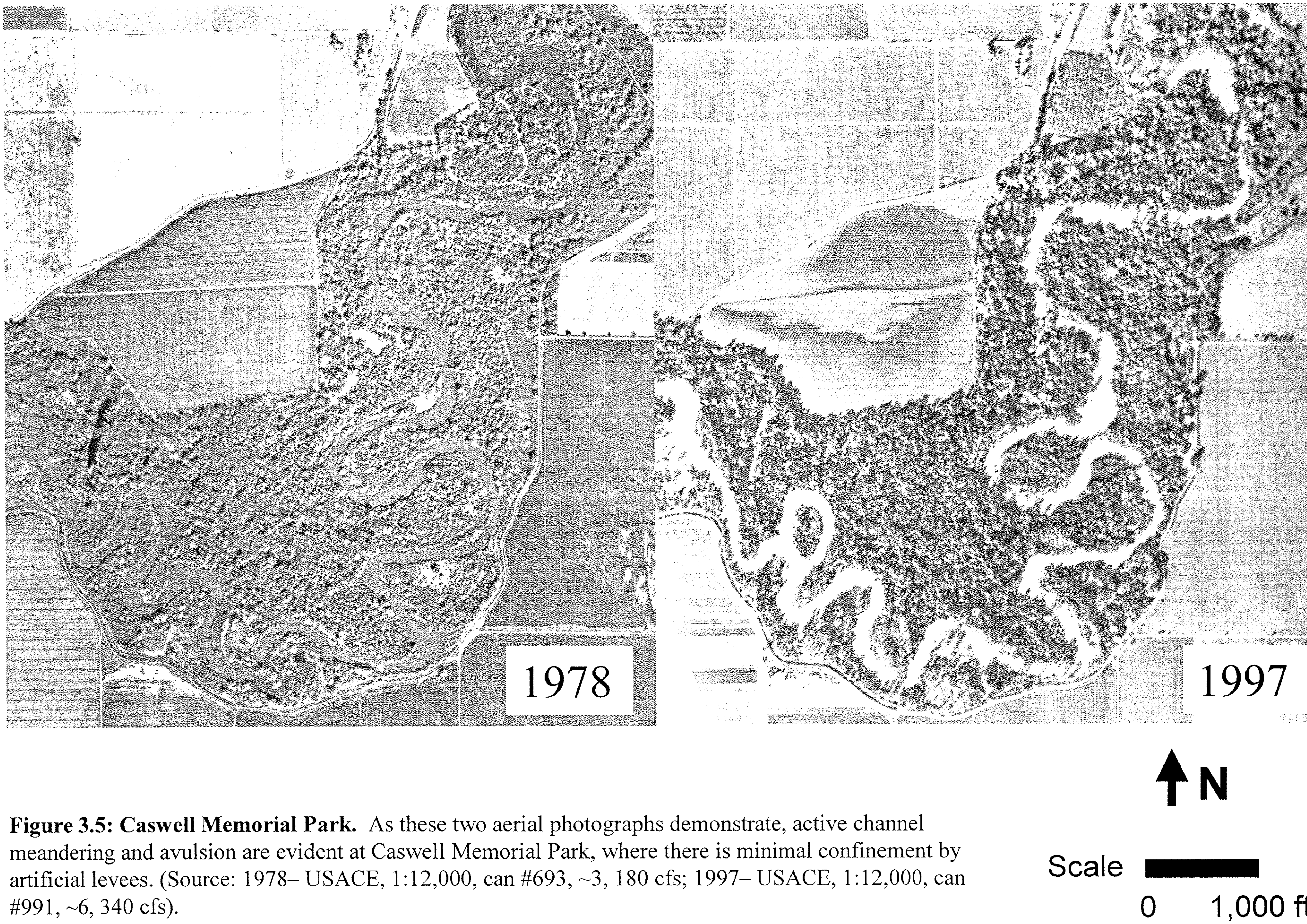


Figure 3.5: Caswell Memorial Park. As these two aerial photographs demonstrate, active channel meandering and avulsion are evident at Caswell Memorial Park, where there is minimal confinement by artificial levees. (Source: 1978– USACE, 1:12,000, can #693, ~3, 180 cfs; 1997– USACE, 1:12,000, can #991, ~6, 340 cfs).

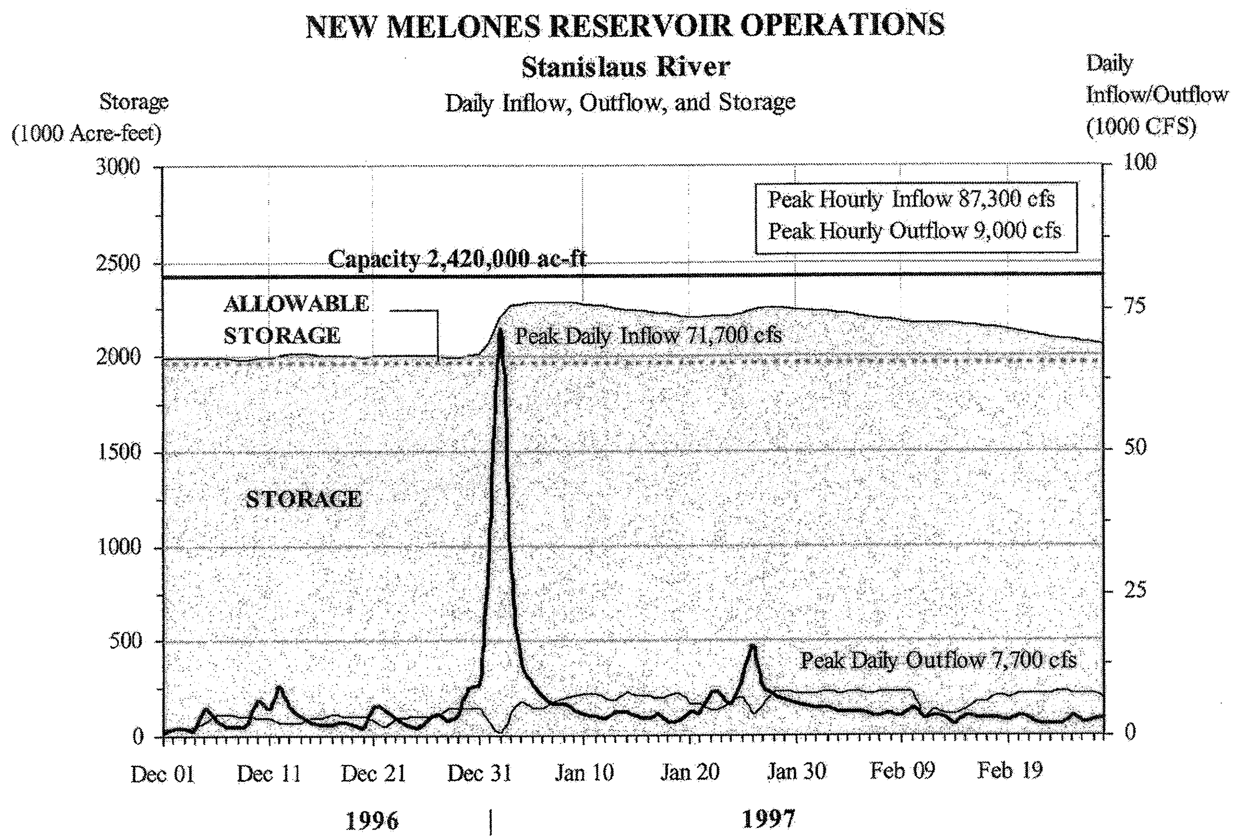
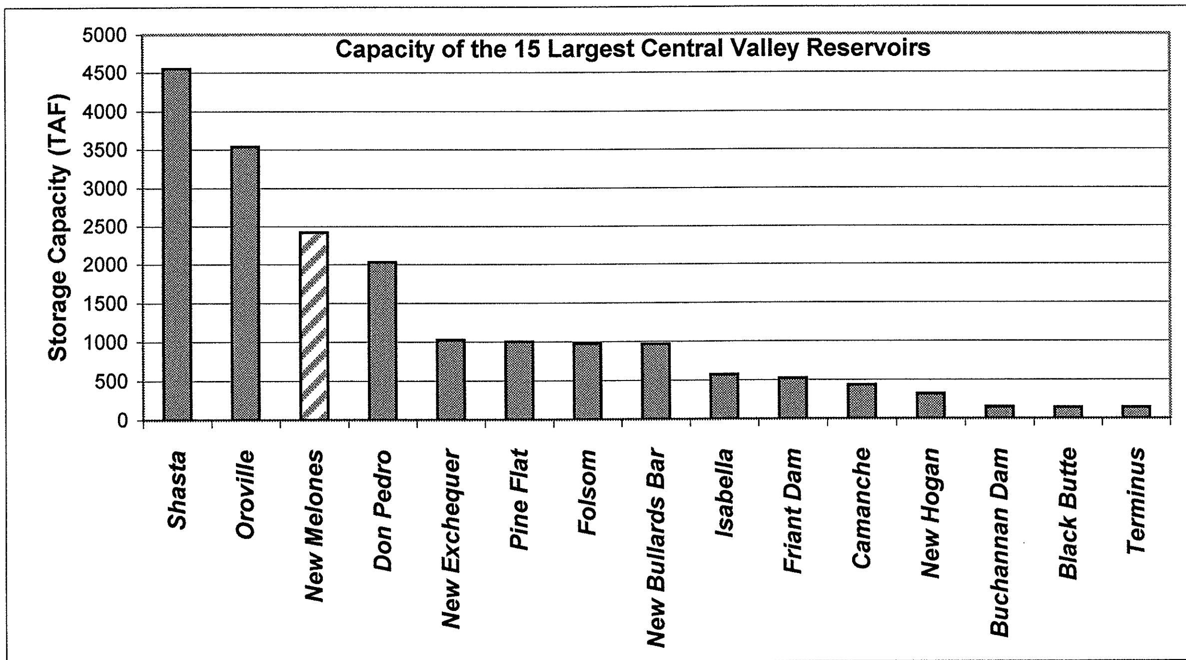
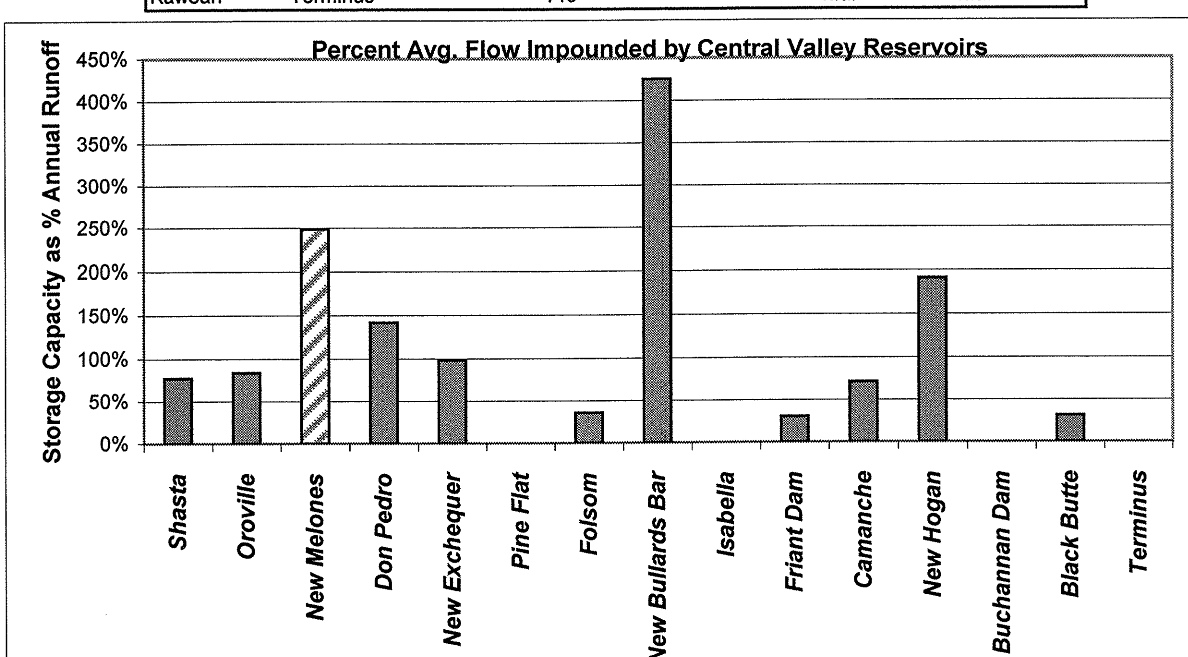


Figure 3.6: Performance of New Melones Dam in the January 1997 Floods. This 1997 flood hydrograph from the USACE Post Flood Assessment presents daily time series data for hydrologic conditions and reservoir operations during the 1997 rain flood event (USACE 1999). Inflow (cfs) and outflow (cfs) from New Melones dam is plotted for a three month period around the 1996-1997 flood event. Note that even though 71,700 cfs was flowing into New Melones, its capacity of 2.4 maf (over 200% of average annual unimpaired runoff) allowed for a maximum release of 7,700 cfs. Flow releases are limited to less than 8,000 cfs in the Lower Stanislaus River. *(Source: USACE Post-Flood Assessment, March 1999, Appendix E).*

Figure 3.7: Central Valley Reservoirs Capacity and Percent Impoundment of Average River Flow



River	Dam Name	Capacity (TAF)[1]	Avg. Runoff (TAF)	% Runoff Impounded
Sacramento	Shasta	4,552	5,898	77%
Feather	Oroville	3,538	4,226	84%
Stanislaus	***New Melones***	***2,420***	***974***	***248%***
Tuolumne	Don Pedro	2,030	1,436	141%
Merced	New Exchequer	1,025	1,045	98%
Kings	Pine Flat	1,000	n.a.	n.a.
American	Folsom	977	2,718	36%
Yuba	New Bullards Bar	966	227	426%
Kern	Isabella	568	n.a.	n.a.
San Joaquin	Friant Dam	521	1,698	31%
Mokelumne	Camanche	431	603	71%
Calaveras	New Hogan	317	166	191%
Chowchilla	Buchannan Dam	150	n.a.	n.a.
Stony Creek	Black Butte	144	460	31%
Kaweah	Terminus	143	n.a.	n.a.



Data Source: [1]*: USACE Post Flood Assessment, page 3-4 and A25-10. Storage rounded to nearest 1000 AF.*

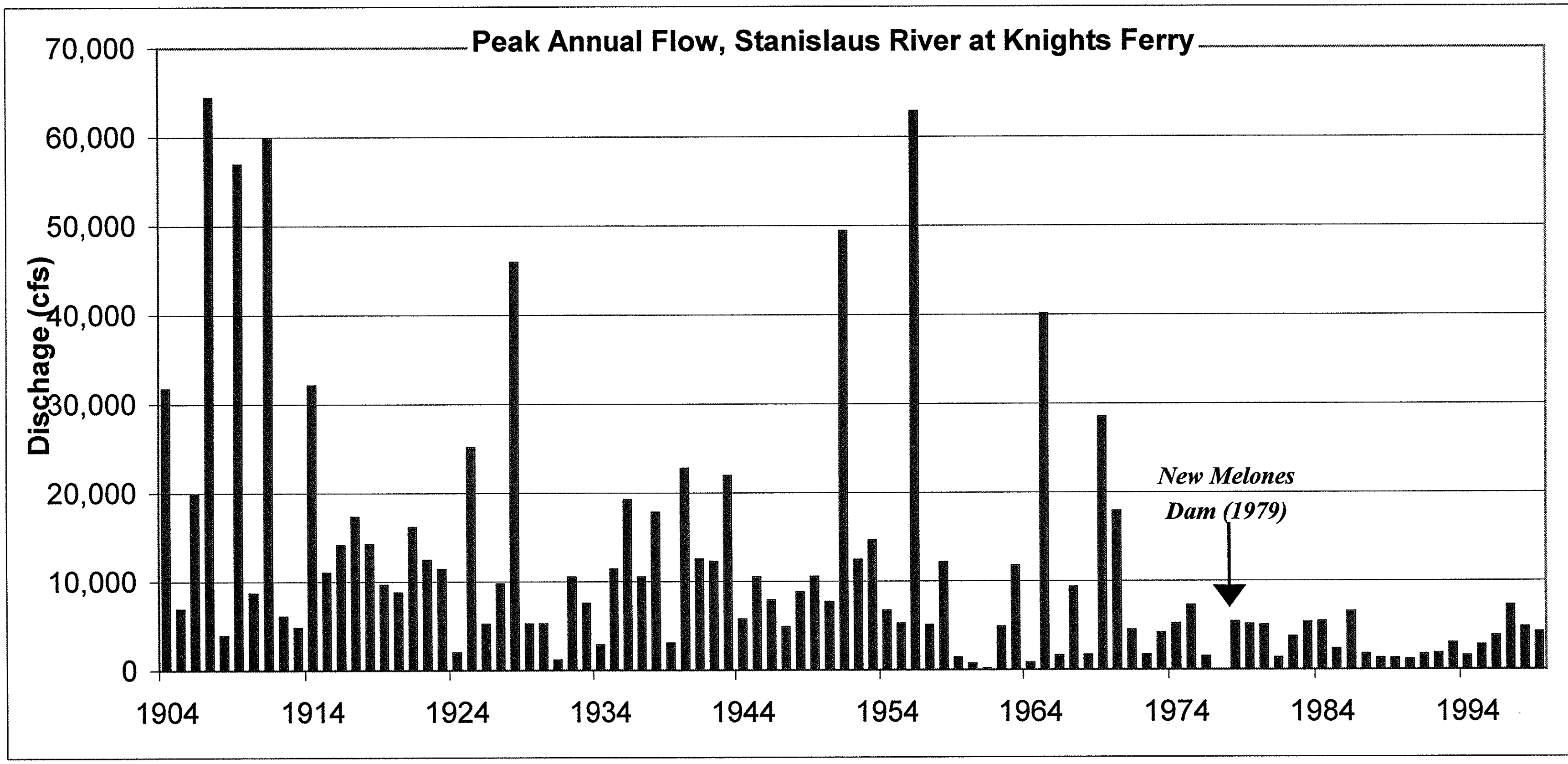


Figure 4.1: Annual Peak Flow, Stanislaus River at Knights Ferry, 1904-1999. Graph of all peak flows since 1904. Compiled with peak flow data from the gauges: Stan River near Knights Ferry (#11300000) 1904-1932; Melones Powerhouse (#11299500) 1933-1955; and Goodwin Dam near Knights Ferry (#1102000) 1956-1999. Note the pre-New Melones dam high of 64,500 cfs on March 19, 1907 and post-New Melones dam peak of 7,350 cfs on January 3, 1997. New Melones dam was authorized for construction, in part, based on the flood management benefits it would provide.

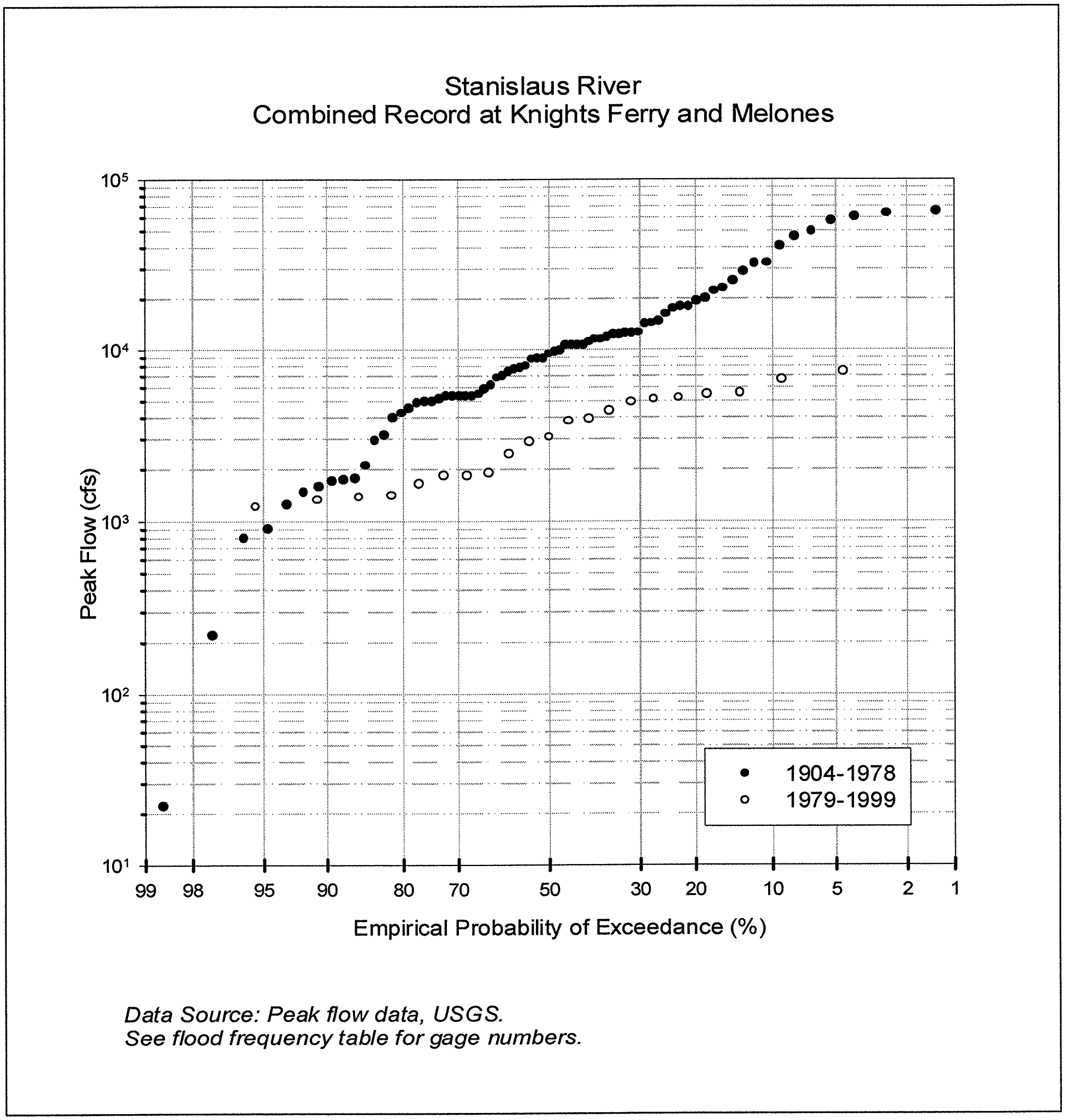


Table 4-2

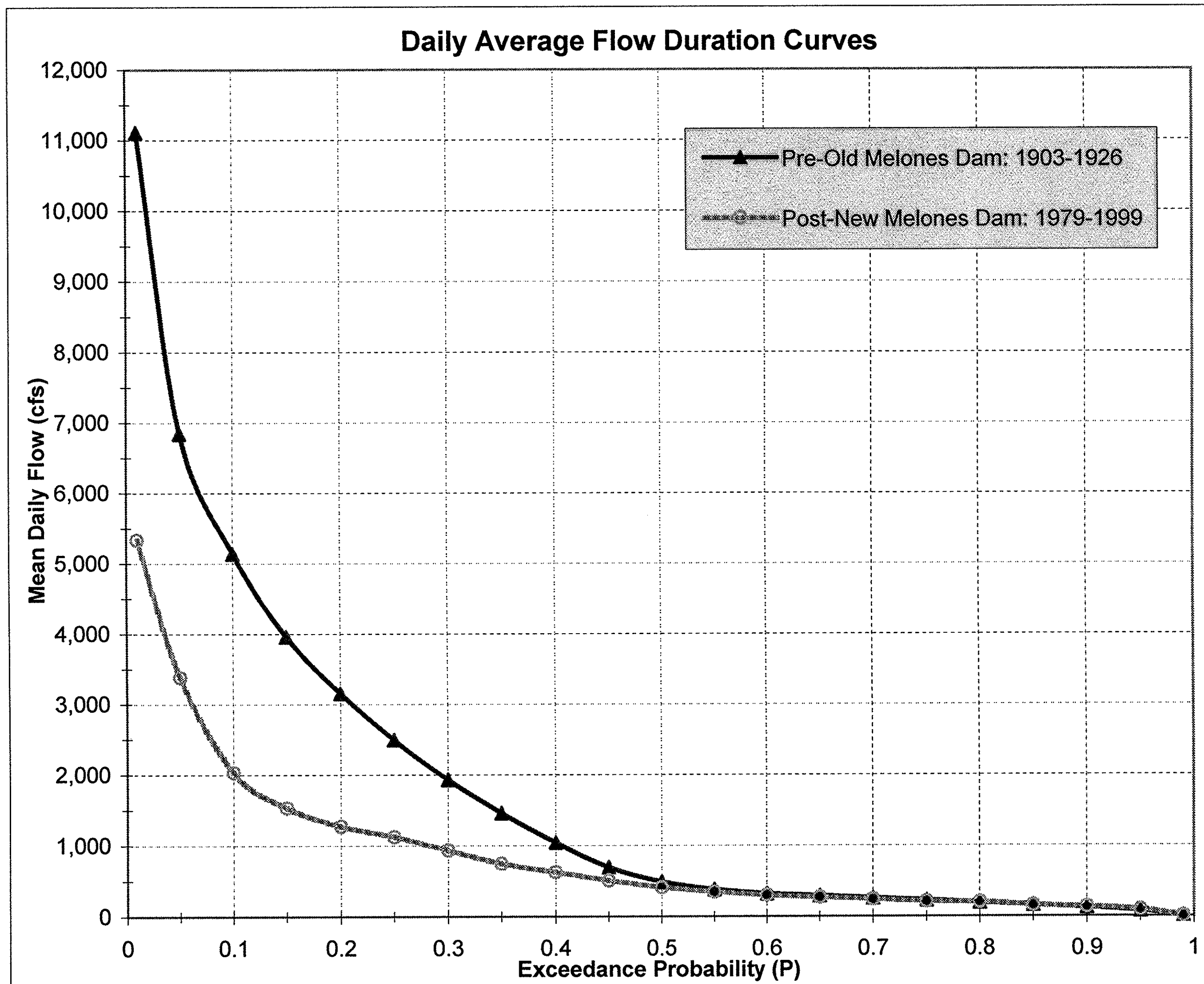
$Q_{\text{Return Period}}$ (cfs)	*Approx.* Pre NM	*Approx.* Post NM
$Q_{1.5}$	5,380	1,840
Q_2	9,430	3,070
Q_5	19,100	5,300
Q_{10}	35,000	6,600
Q_{25}	60,000	7,350+ **

***: insufficient data to estimate the Q_{25} due to only 21 years of post NM dam data.*

Figure 4-2: Flood Frequency Plots, Stanislaus River. Annual maximum flood frequency plots for Pre-New Melones dam (1904 -1978) and Post- New Melones dam (1979 -1999) flows near Knights Ferry (drainage area 905 to 986 mi^2). Gage numbers for each period are detailed in Table 4-1. The approximate flows associated with the $Q_{1.5}$, Q_2, Q_5, Q_{10}, and Q_{25} are summarized in **Table 4-2**.

Figure 4.3: Flow Duration Analysis for Pre-Old Melones Dam and Post-New Melones Dam Study Periods.

Exceedance Probability	Pre- OM Mean Daily Flow (cfs)	Post- NM Mean Daily Flow (cfs)
0.01	11,110	5,330
0.05	6,840	3,380
0.1	5,140	2,030
0.15	3,960	1,530
0.2	3,150	1,270
0.25	2,490	1,120
0.3	1,930	933
0.35	1,460	742
0.4	1,040	622
0.45	694	505
0.5	**488**	**407**
0.55	380	345
0.6	320	299
0.65	288	270
0.7	258	241
0.75	226	212
0.8	195	202
0.85	160	156
0.9	120	136
0.95	76	93
0.99	7	6
mean flow =	1767	868



Data Source:

<u>Pre- Old Melones dam: May 19, 1903 to Jan. 31, 1926:</u> 1903-1914 data from USGS WS Papers #299, 361, 391. 1903-1908 data, only gage height and rating tables available, requiring data conversion to cfs. Data from "Stan River at Knights Ferry" gage, #11302000. Begins May 19, 1903 and Ends Sept. 30, 1914.

1915-1926 data from USGS webpage http://waterdata.usgs.gov/nwis-w/CA/data.components/hist.cgi?statnum=11300000. Gauge name: "Stan. River near Knights Ferry."

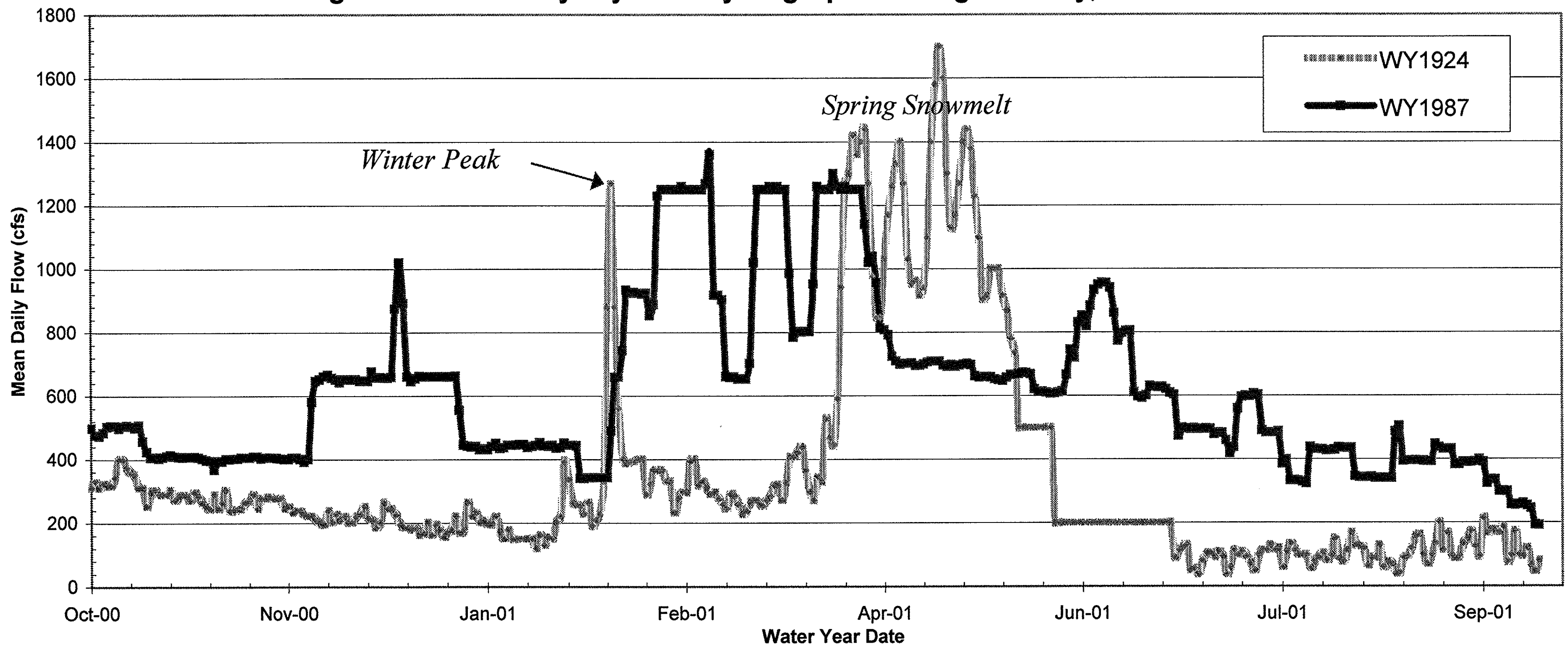
Period begins Dec. 18, 1915 and ends Jan. 31, 1926, with stopping point chosen based on construction of Old Melones dam in 1926.

Data concerns: No data available from Oct. 1, 1914 to Dec. 17, 1915; 1903-1914 gauge below Goodwin dam, 1915-1926 data from 2 miles upstream of Goodwin dam.

<u>Post New Melones dam: Jan 1, 1979 to Sept. 30, 1999:</u> USGS webpage http://waterdata.usgs.gov/nwis-w/CA/data.components/hist.cgi?statnum=11302000.

Gauge name: "Stan River below Goodwin near Knights Ferry."

Figure 4.4: Critically Dry Year Hydrographs -- Knights Ferry, Stanislaus River



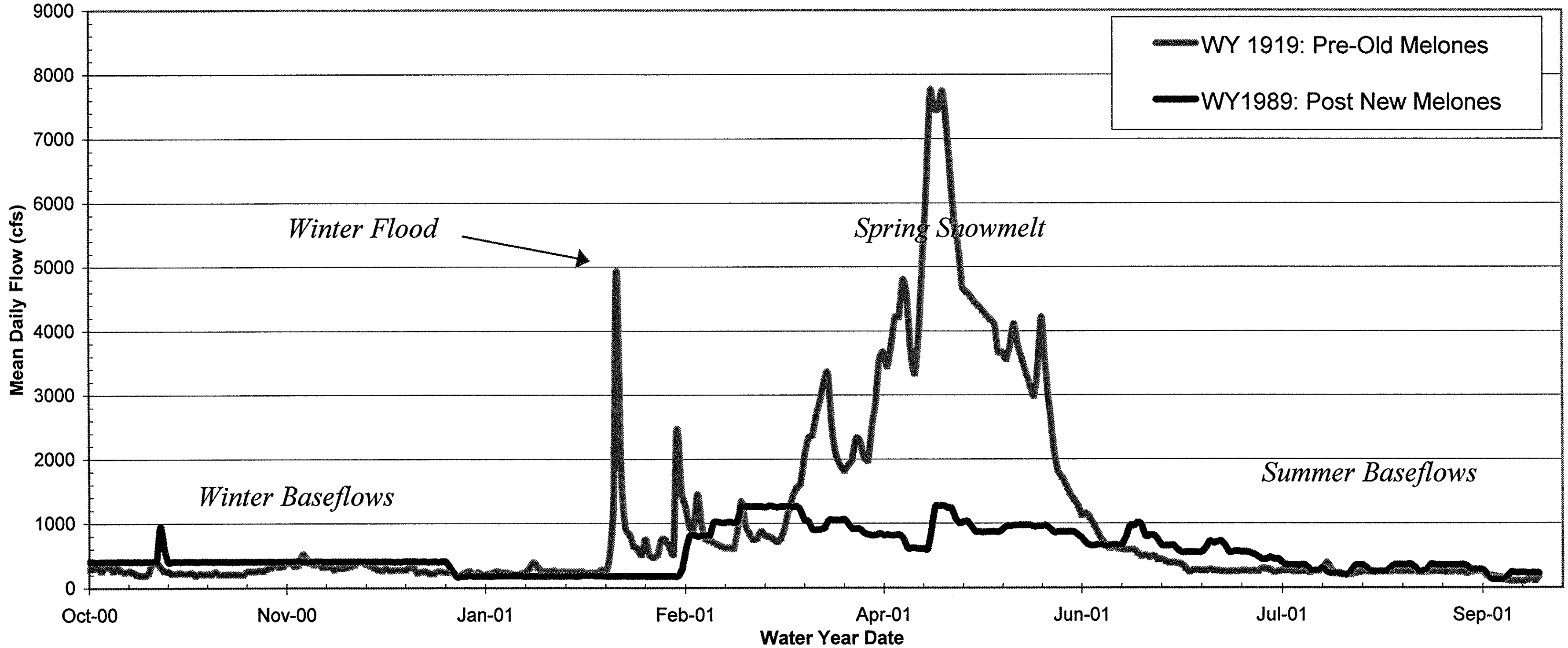
Notes: ***1924 Unimpaired Flow is over 100 TAF less than 1987 flows, but is the only "critically dry" year designated pre- Old Melones dam***

"Critically Dry" Year designation comes from McBain and Trush (2000) ranking in Tuolumne River with adjustments based on Stanislaus (SNS, sensor #65) data at http://cdec.water.ca.gov/cgi-progs/selectQuery

WY 1924 data, gage #11300000, near Knights Ferry, from USGS webpage (Unimpaired flow .26 maf)

WY1987 data, gage #11302000, below Goodwin dam, from USGS webpage (Unimpaired flow ..37 maf)

Figure 4.5: Dry Year Hydrographs -- Knights Ferry, Stanislaus River

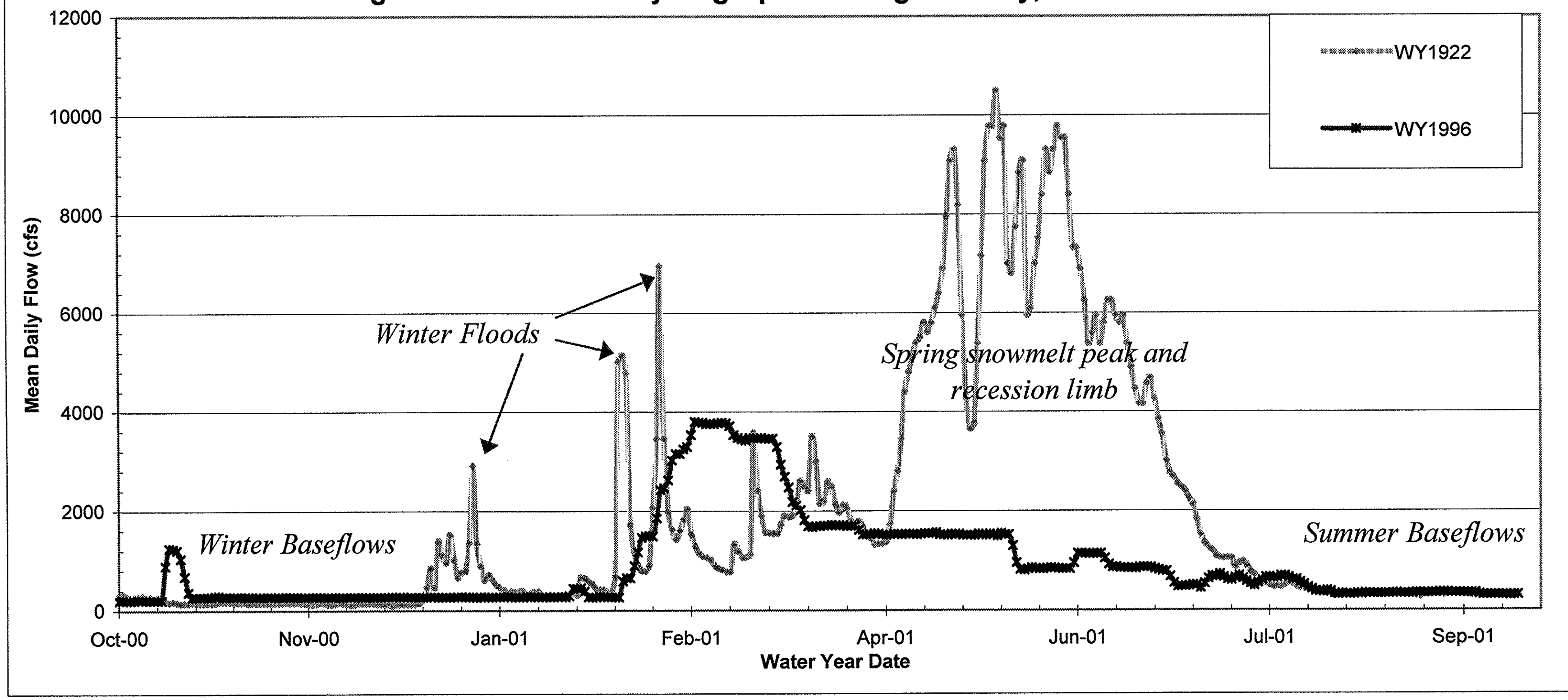


Notes: "Dry" Year designation comes from McBain and Trush (2000) ranking in Tuolumne River with adjustments based on Stanislaus (SNS, sensor #65) data at http://cdec.water.ca.gov/cgi-progs/selectQuery

WY 1919 data, gage #11300000, near Knights Ferry, from USGS webpage (Unimpaired flow .77 maf)

WY1989 data, gage #11302000, below Goodwin dam, from USGS webpage (Unimpaired flow .78 maf)

Figure 4.6: Wet Year Hydrographs -- Knights Ferry, Stanislaus River

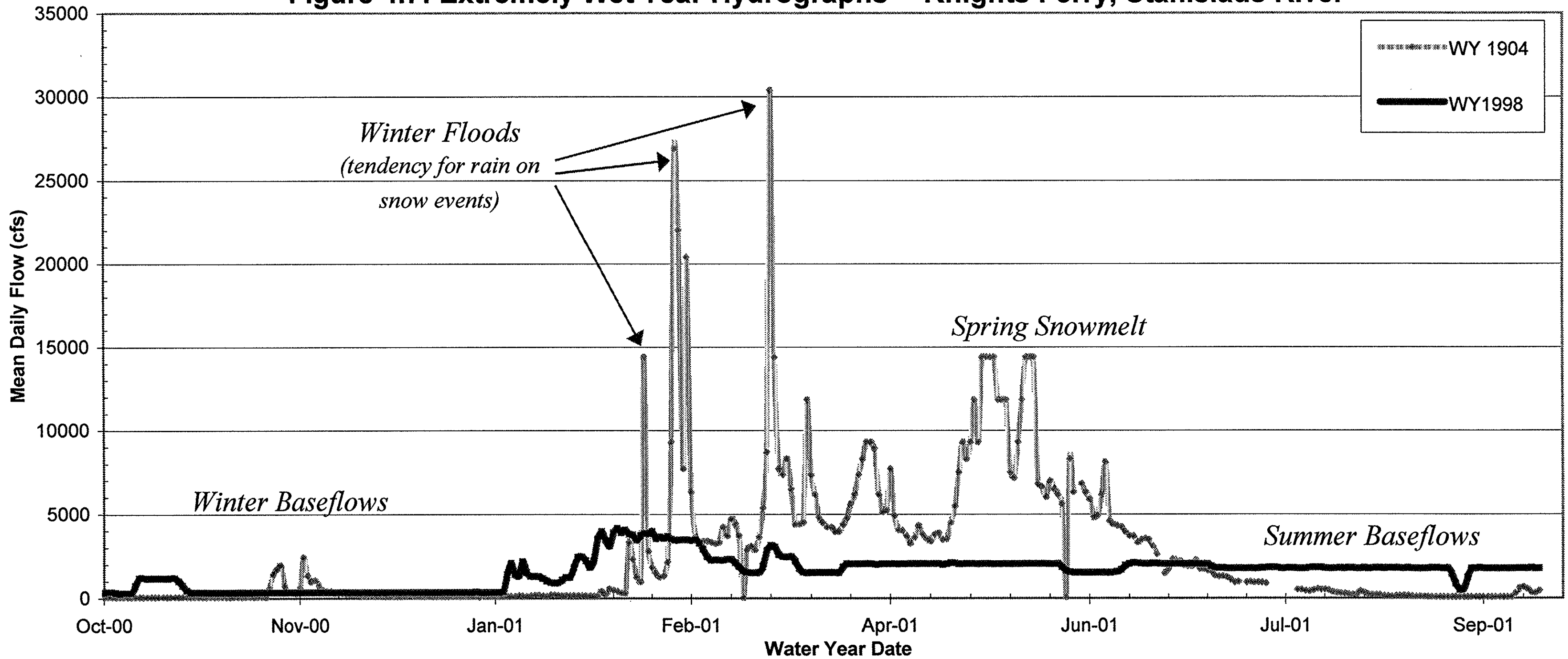


Notes: "Wet" Year designation comes from McBain and Trush (2000) ranking in Tuolumne River with adjustments based on Stanislaus (SNS, sensor #65) data at http://cdec.water.ca.gov/cgi-progs/selectQuery

WY 1922 data, gage #11300000, near Knights Ferry, from USGS webpage (Unimpaired flow 1.43 maf)

WY1996 data, gage #11302000, below Goodwin dam, from USGS webpage (Unimpaired flow 1.49 maf)

Figure 4.7: Extremely Wet Year Hydrographs -- Knights Ferry, Stanislaus River



Notes: "Extremely Wet" Year designation comes from McBain and Trush (2000) ranking in Tuolumne River with adjustments based on Stanislaus (SNS, sensor #65) data at http://cdec.water.ca.gov/cgi-progs/selectQuery

WY 1904 data, gage #11302000, near Knights Ferry, from WSpaper299 (Unimpaired flow =2.05 maf)

WY1998 data, gage #11302000, below G+B4oodwin dam, from USGS webpage (Unimpaired flow= 2.09 maf)

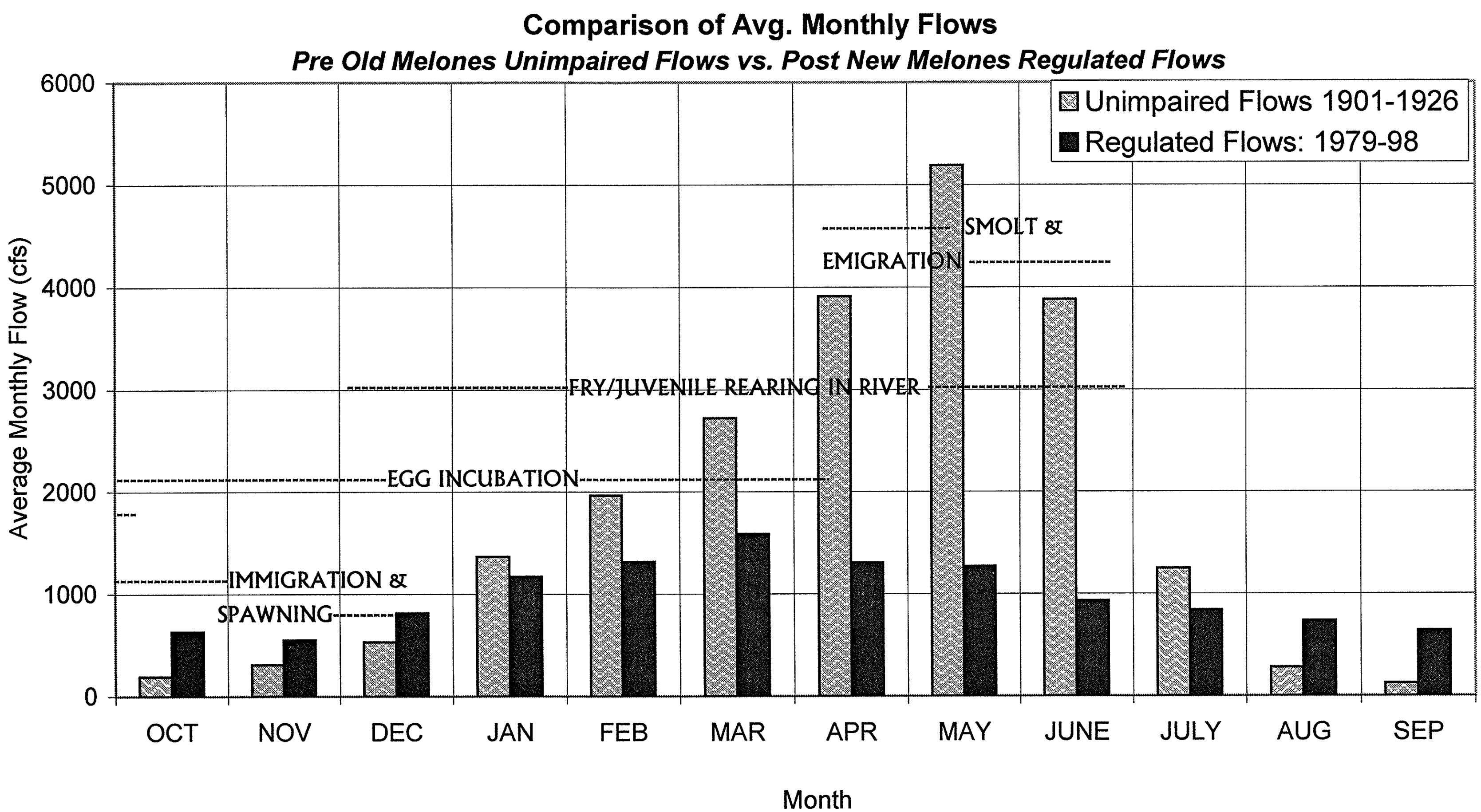


Figure 4.8: Comparison of Average Monthly Flows, Stanislaus River. The following graph compares average unimpaired monthly flows from before Old Melones dam (1901-1926) with regulated monthly flows following construction of New Melones dam (1979-1999). Basin dams impounded less than 4% of the average annual unimpaired runoff during the 1901-1926 period (see ***figure 2-1***). Note the significant reduction in winter and late spring average flows and the increase in summer monthly flows. Life cycle of the Stanislaus River fall-run chinook salmon is related to the average annual runoff patterns.

Data Source: Unimpaired flows from "Full Natural Flow" data, USGS gauge at Stanislaus R-Goodwin (SNS), Sensor #65, Elev. 252'.
http://cdec.water.ca.gov/cgi-progs/selectQuery?station_id=SNS&sensor_num=65&dur_code=M&start_date=1903&end_date=now
Post New Melones dam regulated flows from analysis of mean daily flow data using the Indicators of Hydrologic Alteration Model (IHA) (Schneider, May 2000).

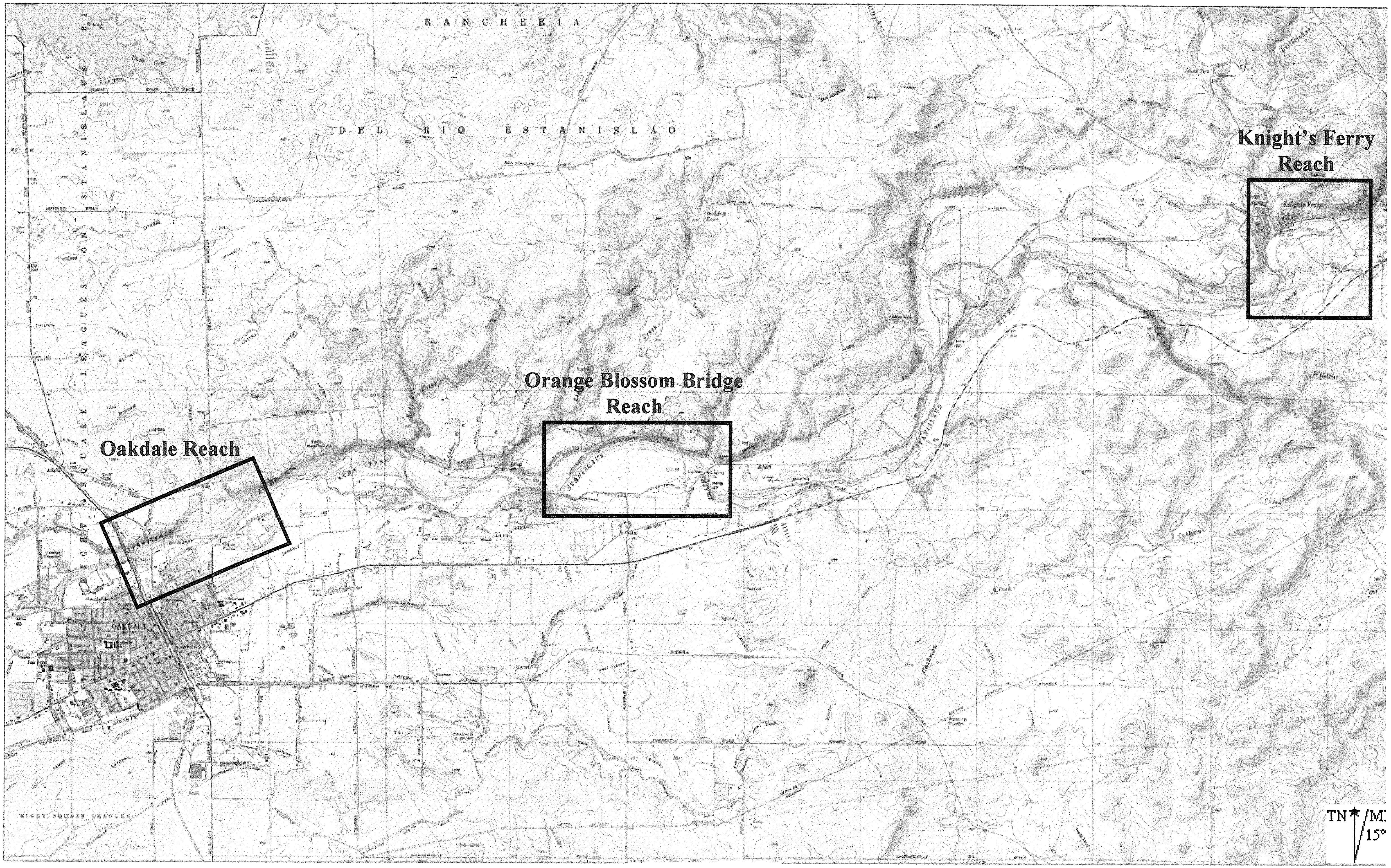
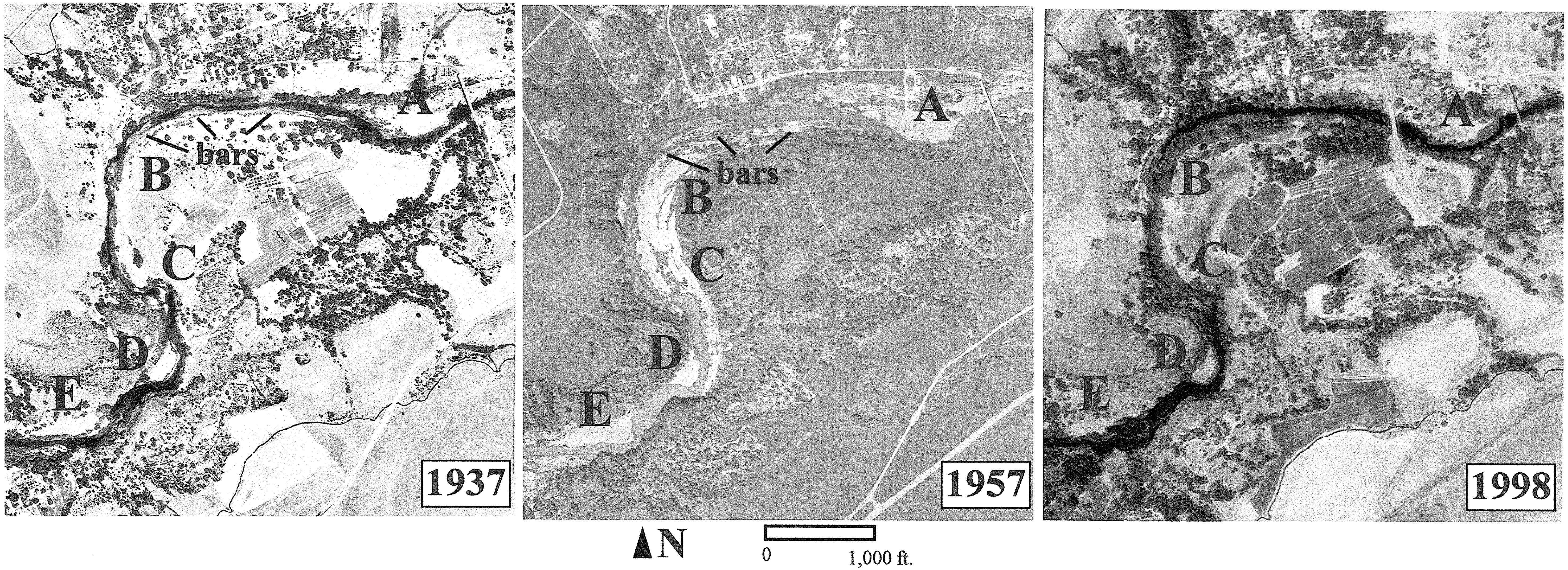


Figure 5.1: Location Map of the Three Selected Sites. The boxes show the location of the three areas of detailed analysis with historical aerial photographs from 1937, 1957, and 1998. The Knight's Ferry Reach is illustrated in Figure 5.2 and the Orange Blossom Bridge Reach is illustrated in Figure 5.3, and the Oakdale Reach is illustrated in Figure 5.4. Source: USGS 1:24,000 topographic map from Topo! Software.

Figure 5.2

Knight's Ferry (RM 54.7 to 53.1)



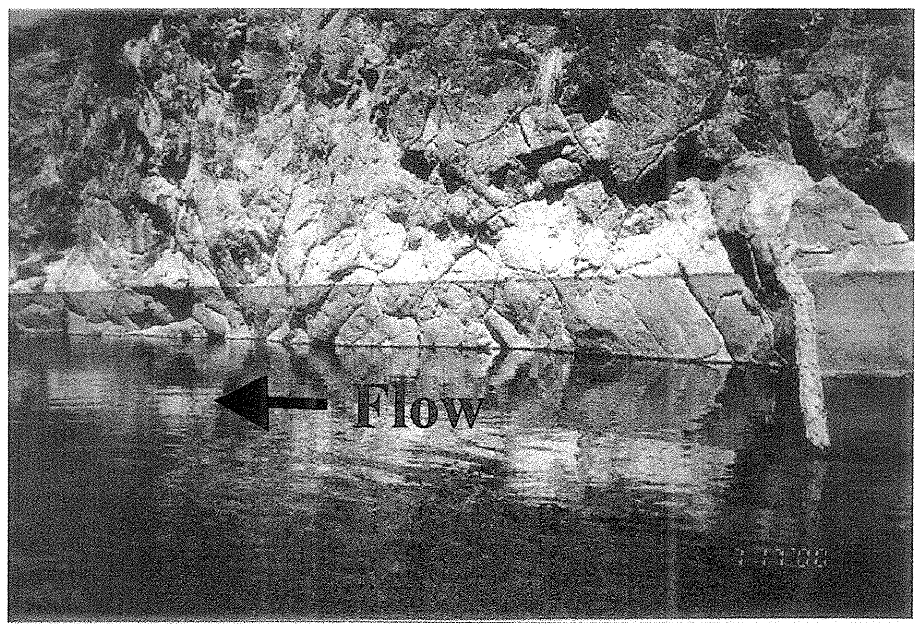


Photo #1 Bedrock control at Point E, Lava Bluffs

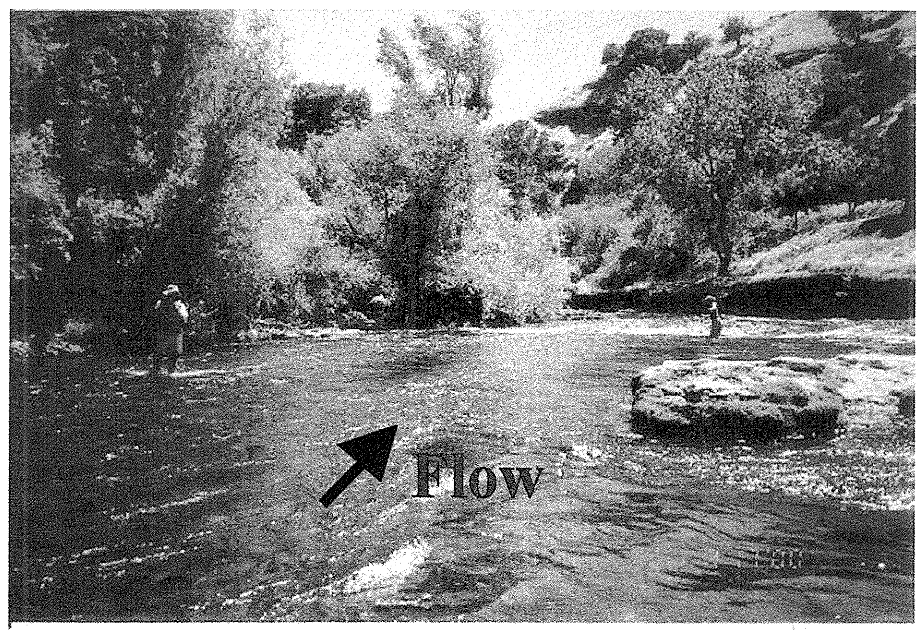


Photo #2 Bedrock Control at Russian Rapids (Point B) also note dense riparian vegetation. Riffle R6.

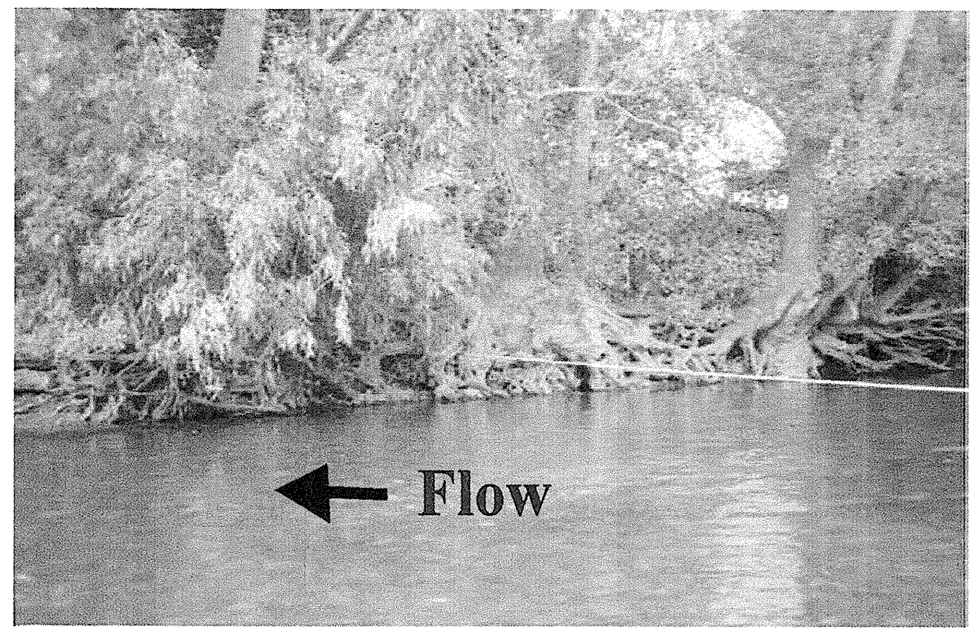


Photo #3 Dense Riparian vegetation and evidence of incision at Riffle R78.

Figure 5.3

Orange Blossom Bridge (RM 47.4 to 45.5)

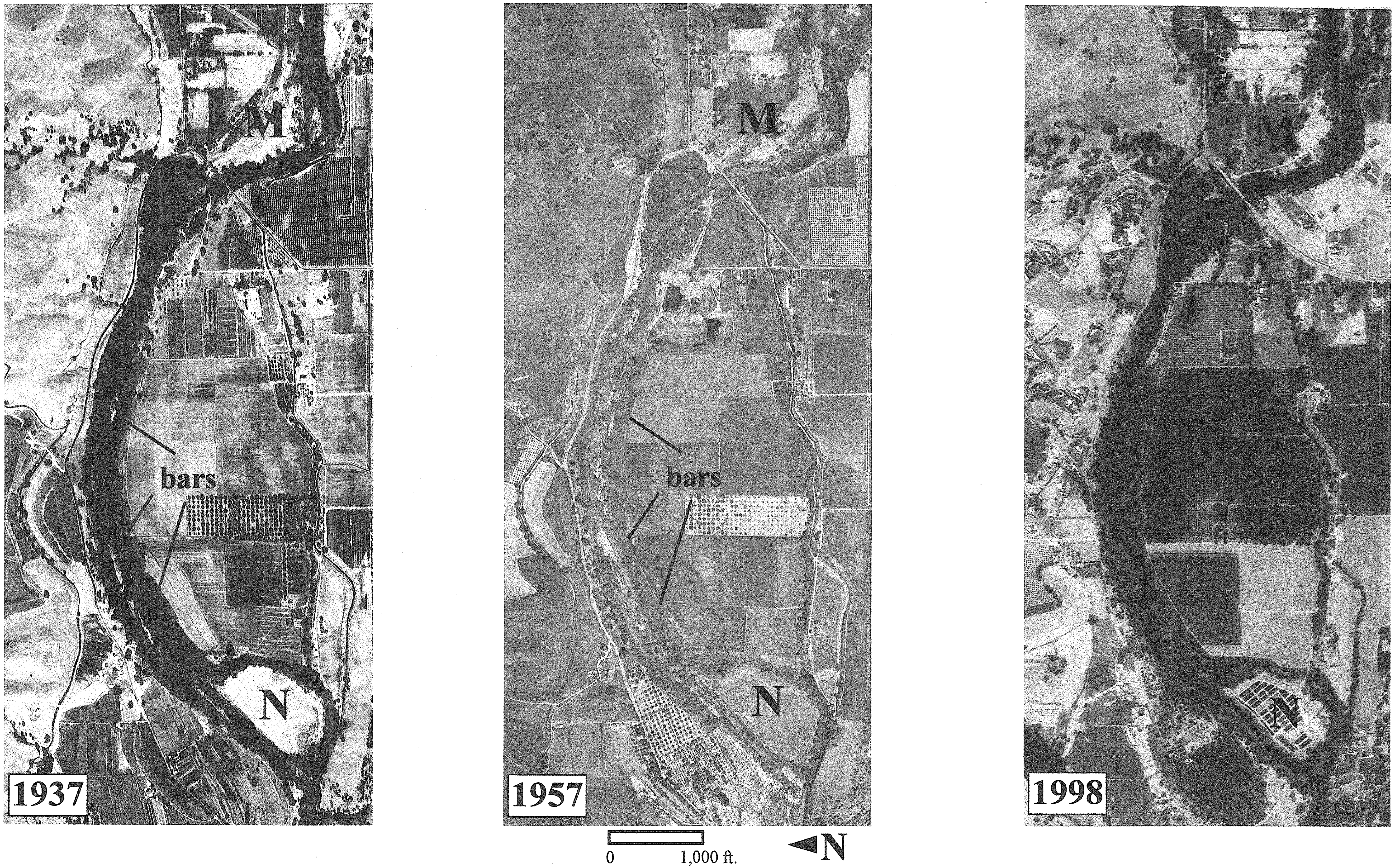


Figure 5.4

Oakdale (RM 42.4 to 41.2)

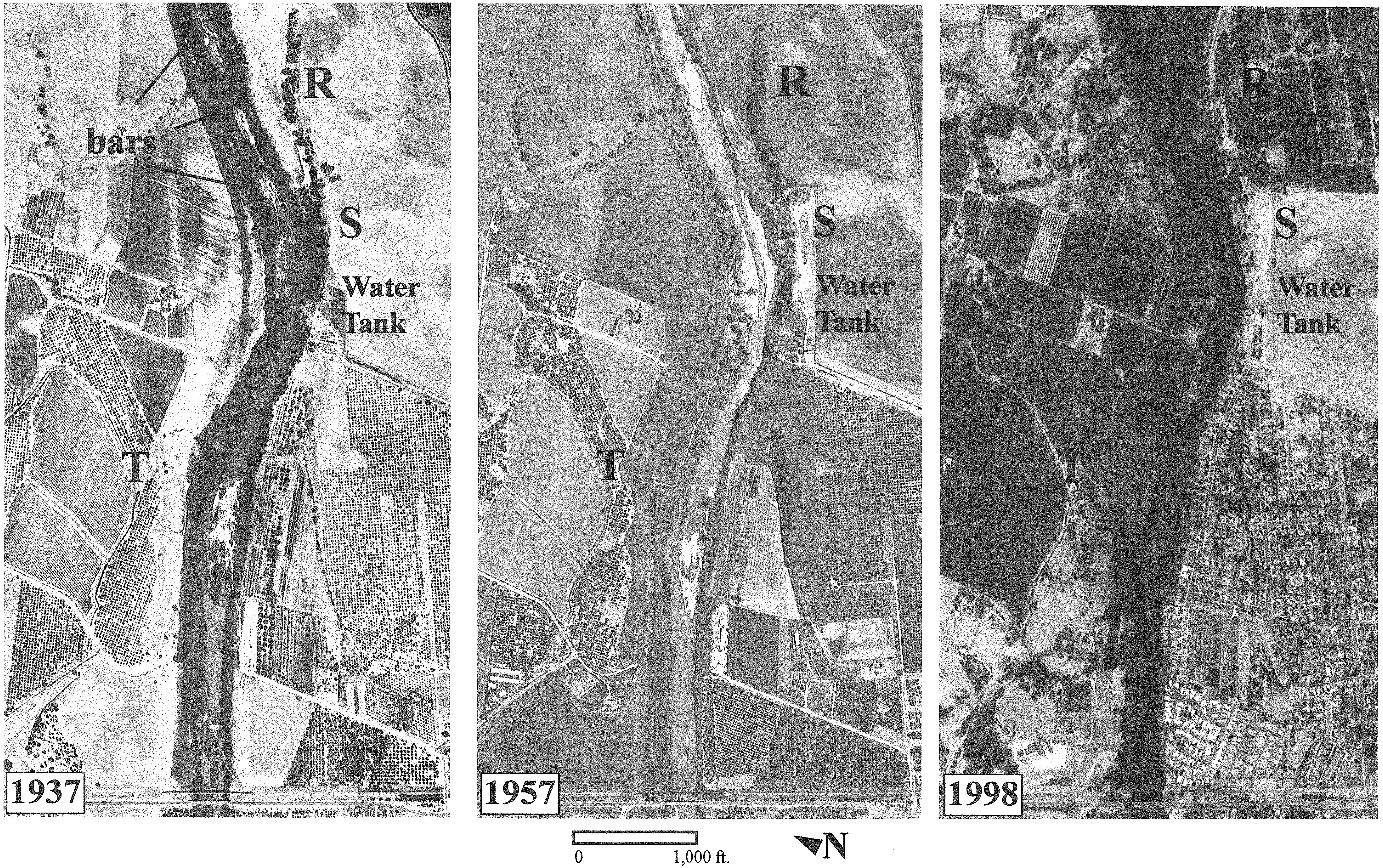


Figure 5.5: Root Crown Exposure at R78, Stanislaus River. (RM 40: 375cfs). Note the vegetation encroachment and extent of root wad exposure at this site, indicating channel incision and erosional processes (Photo, K. Schneider, 10/27/99).

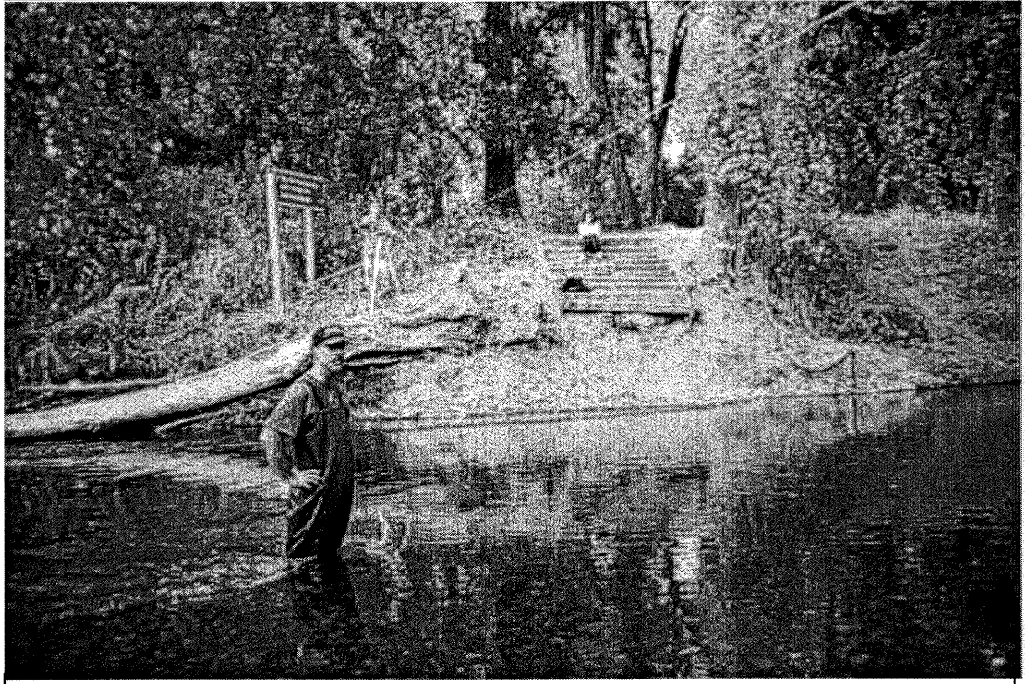


Figure 5.6: Erosion at R58, Stanislaus River. (RM 45, 375cfs). Significant erosion below the stairway in the background has been observed in the last couple of years at Riffle 58. Gravel additions as part of the Knights Ferry Gravel Replenishment Project limit the ability to quantify the channel incision at this site due to the addition of spawning gravels for Chinook Salmon. (Photo, K. Schneider, 10/27/99).

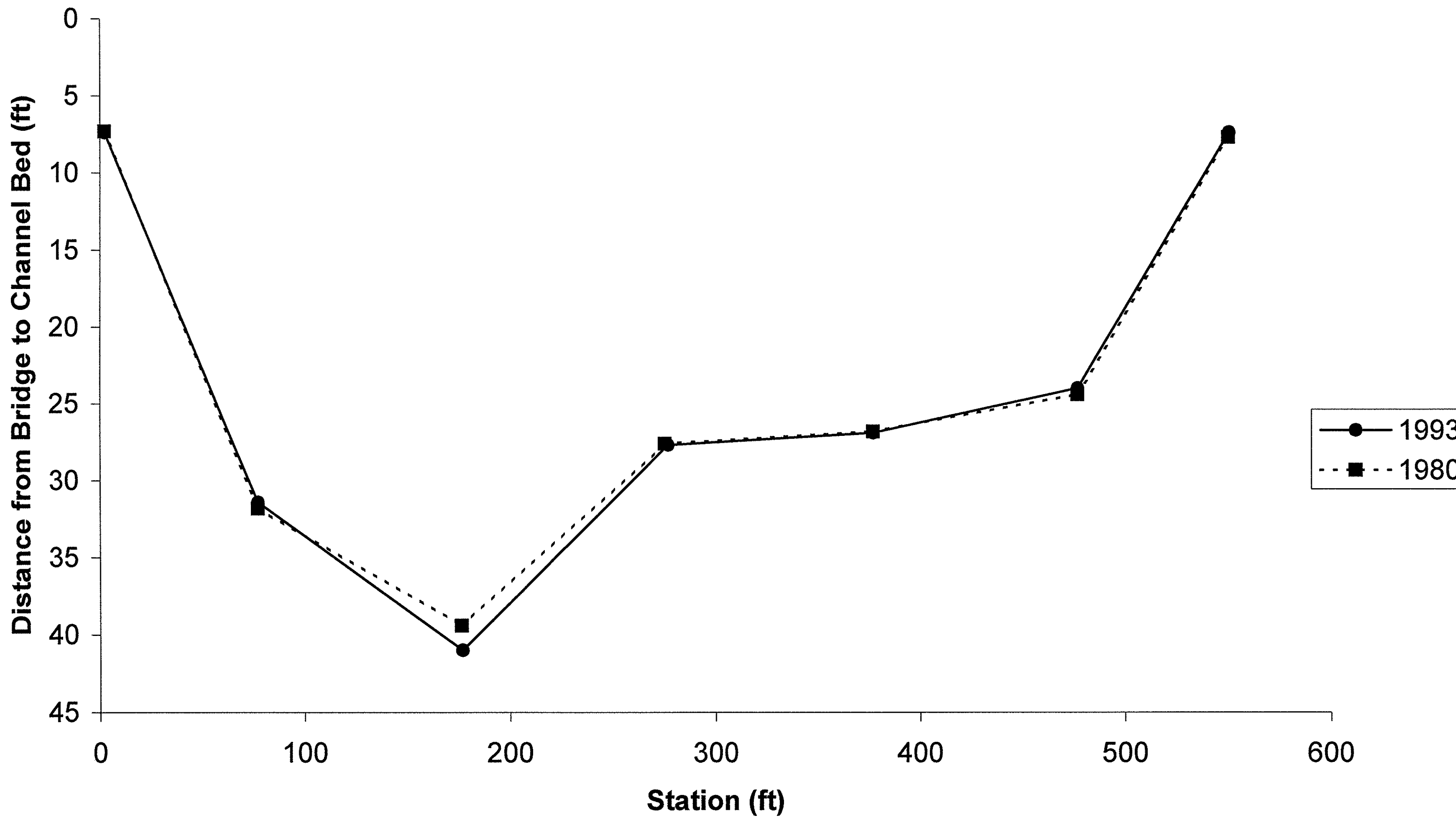


Figure 5.7: Orange Blossom Bridge Historical Cross Section. This figure shows two cross sections taken from Caltrans bridge survey reports from 1980 (dashed line) and 1990 (solid line). The difference between the cross sections shows 1.6 ft of incision.

Figure 5.8: Cross Section Russian Rapids

(R5: Mesick, Nov. '98 survey; all units in ft)

Cross Section	$Area_{BF}$ (ft^2)	$Depth_{BF}$ (ft)	Slope n	Slope S	Vel. [3] (ft/s)	Q_{BF}=V*A (cfs)	FF Return Interval (yrs)[4] Post NM	FF Return Interval (yrs)[4] Pre NM
R5: Post Dam Actual[1]	512	7.2	0.028	0.0012	6.87	**3,519**	~2.1	~1.22
R5: Pre Dam Estim.[2] - 2' incision	446.7	5.2	0.028	0.0012	5.53	**2,472**	~1.7	~1.18
R5: Pre Dam Estim.[2] - 3' incision	380.1	4.2	0.028	0.0012	4.80	**1,824**	~1.4	~1.15

[1]: *Bankfull estimated by assuming the slope break occurs at the end of Mesick (1998) cross section.*

[2]: *Incision is assumed to be uniform across the cross section for calculations. Root crowns indicate ~0.5-1 meter of incision, so various estimates are used in calculations.*

[3]: *Velocity estimated with the Manning's equation,* $V=(1.49/n)(R_{\cdot})^{.66}(S)^{.5}$. *Hydraulic radius R is approximated as =D*

[4]: ***Annual duration** flood frequency data used to estimate return interval for bankfull flows since partial duration series data is not available for the Stanislaus River.*

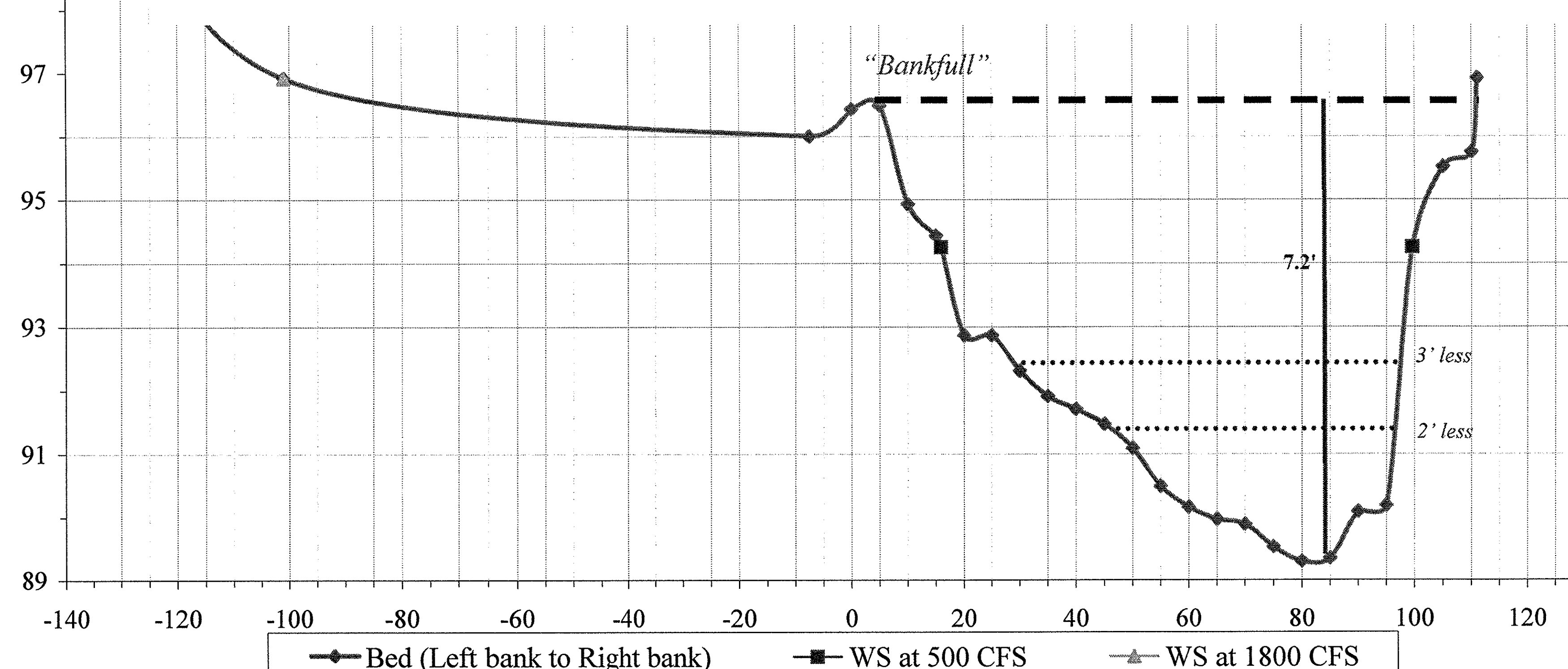


Figure 5.9: Cross Section near Lover's Leap

(R20: Mesick, Nov. '98 survey, all units in ft)

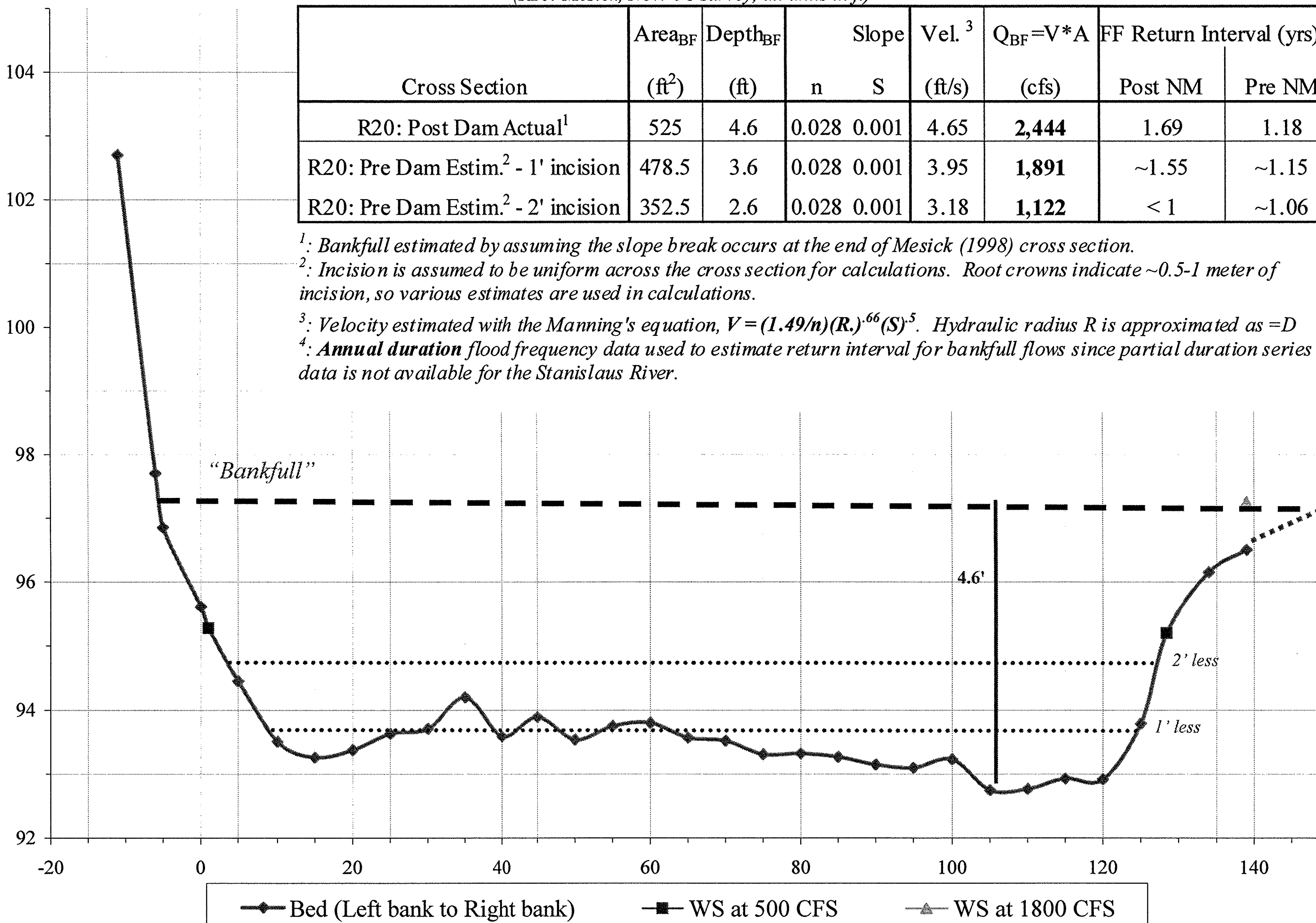
Cross Section	$Area_{BF}$ (ft^2)	$Depth_{BF}$ (ft)	Slope n	Slope S	Vel.[3] (ft/s)	Q_{BF}=V*A (cfs)	FF Return Interval (yrs)[4] Post NM	FF Return Interval (yrs)[4] Pre NM
R20: Post Dam Actual[1]	525	4.6	0.028	0.001	4.65	**2,444**	1.69	1.18
R20: Pre Dam Estim.[2] - 1' incision	478.5	3.6	0.028	0.001	3.95	**1,891**	~1.55	~1.15
R20: Pre Dam Estim.[2] - 2' incision	352.5	2.6	0.028	0.001	3.18	**1,122**	< 1	~1.06

[1]: *Bankfull estimated by assuming the slope break occurs at the end of Mesick (1998) cross section.*

[2]: *Incision is assumed to be uniform across the cross section for calculations. Root crowns indicate ~0.5-1 meter of incision, so various estimates are used in calculations.*

[3]: *Velocity estimated with the Manning's equation,* $V = (1.49/n)(R.)^{.66}(S)^{.5}$. *Hydraulic radius R is approximated as =D*

[4]: ***Annual duration** flood frequency data used to estimate return interval for bankfull flows since partial duration series data is not available for the Stanislaus River.*



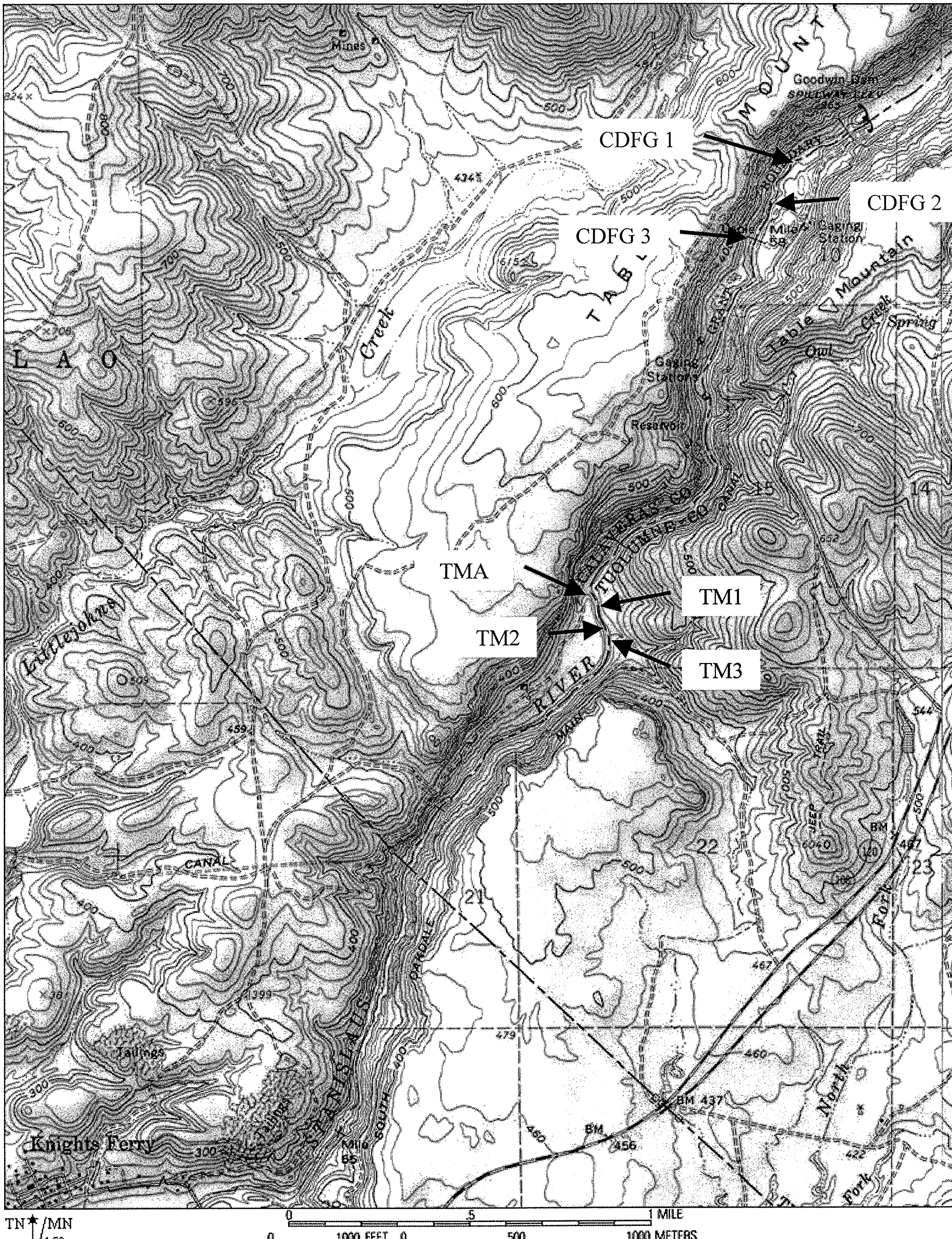


Figure 6.1: Riffle Location Map: Goodwin Dam to Two Mile Bar. This figure shows the location of historical spawning rifles from DWR 1994, CDFG 1972, CMC 2000, and our study that we re-visited.

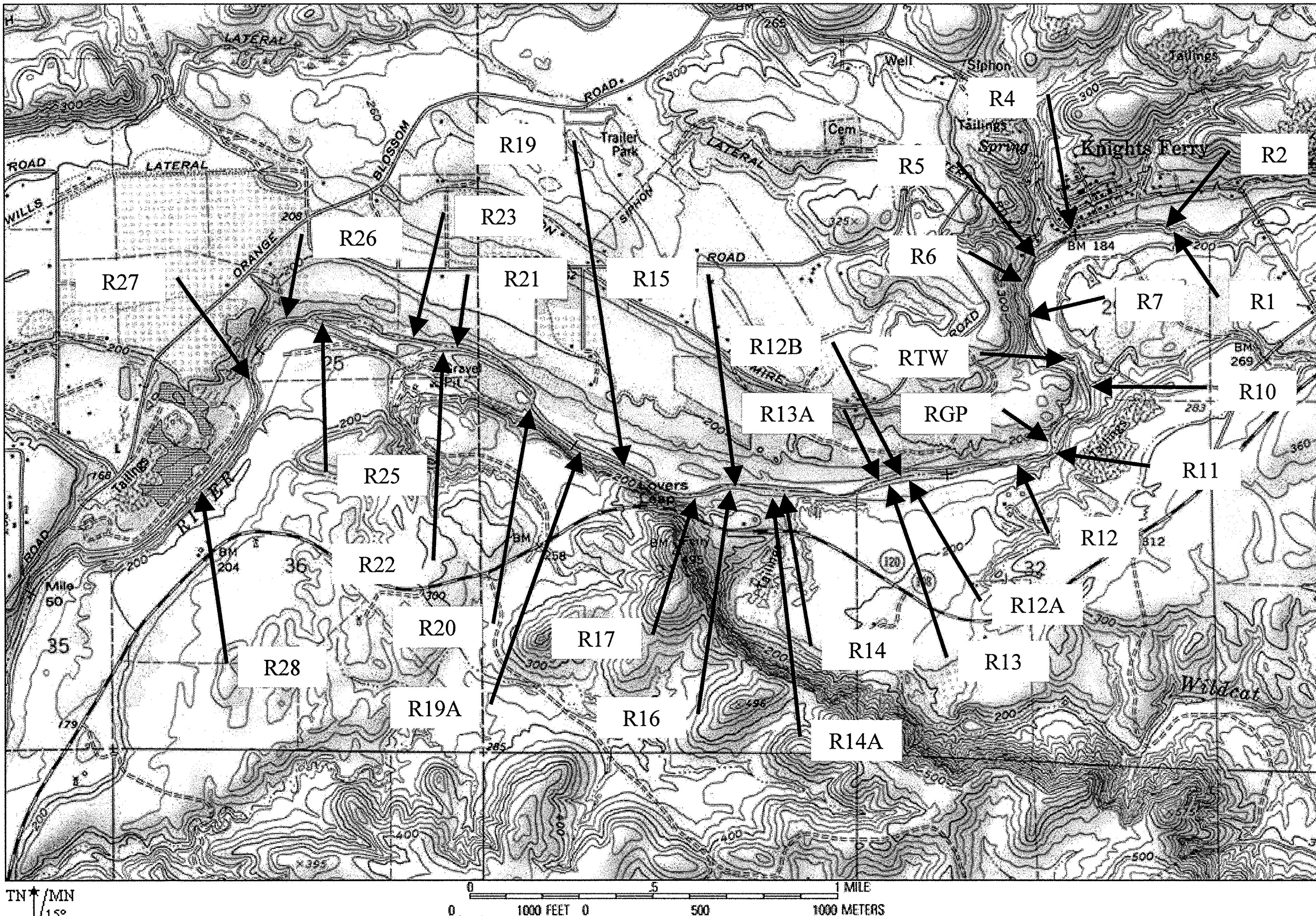


Figure 6.2: Riffle Location Map: Knight's Ferry to R28. This figure shows spawning riffles from DWR 1994, CDFG 1972, CMC 2000, and our study that we re-visited.

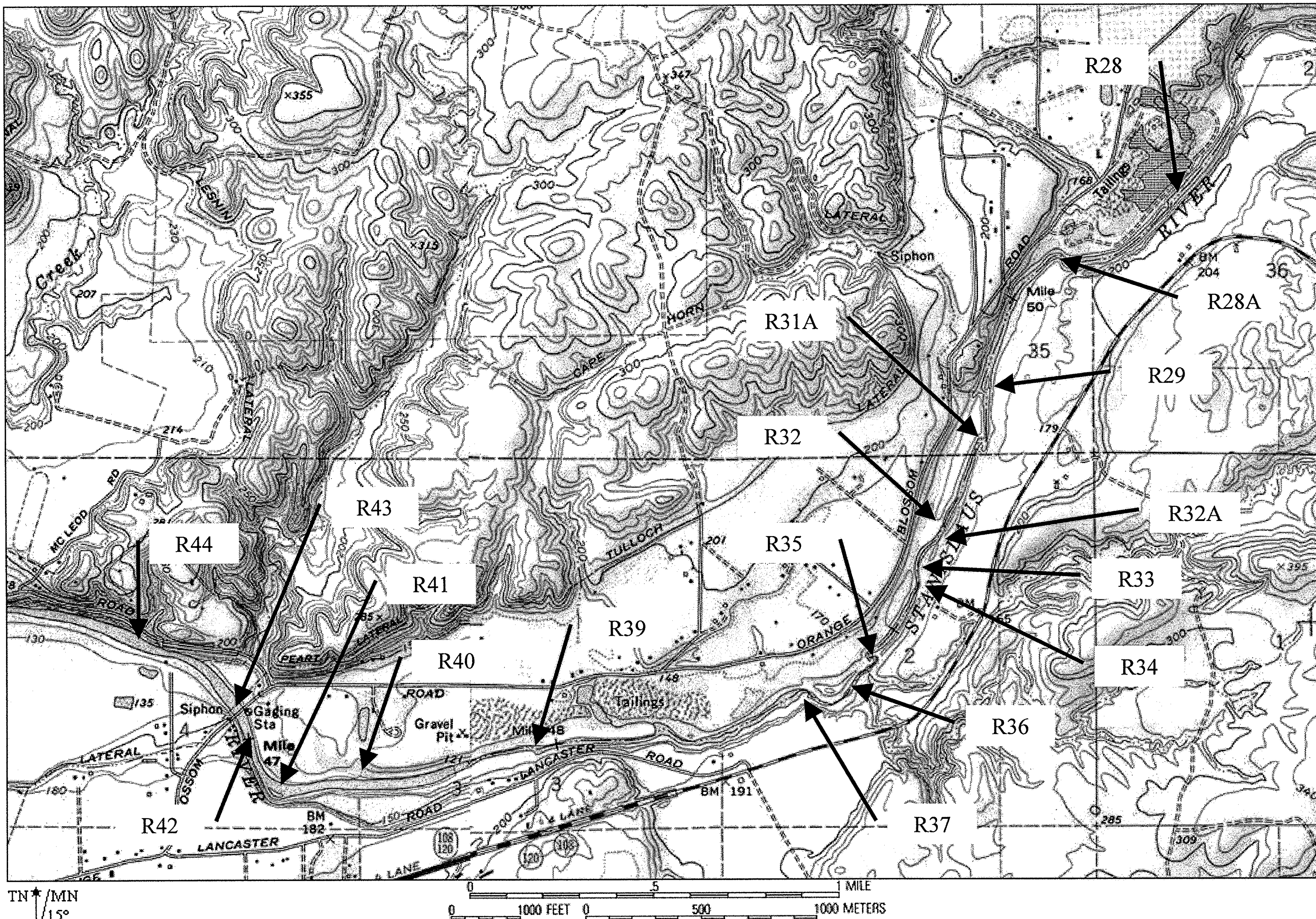


Figure 6.3: Riffle Location Map: R28 to Orange Blossom Bridge. This figure shows spawning riffles from DWR 1994, CDFG 1972, CMC 2000, and our study that we re-visited.

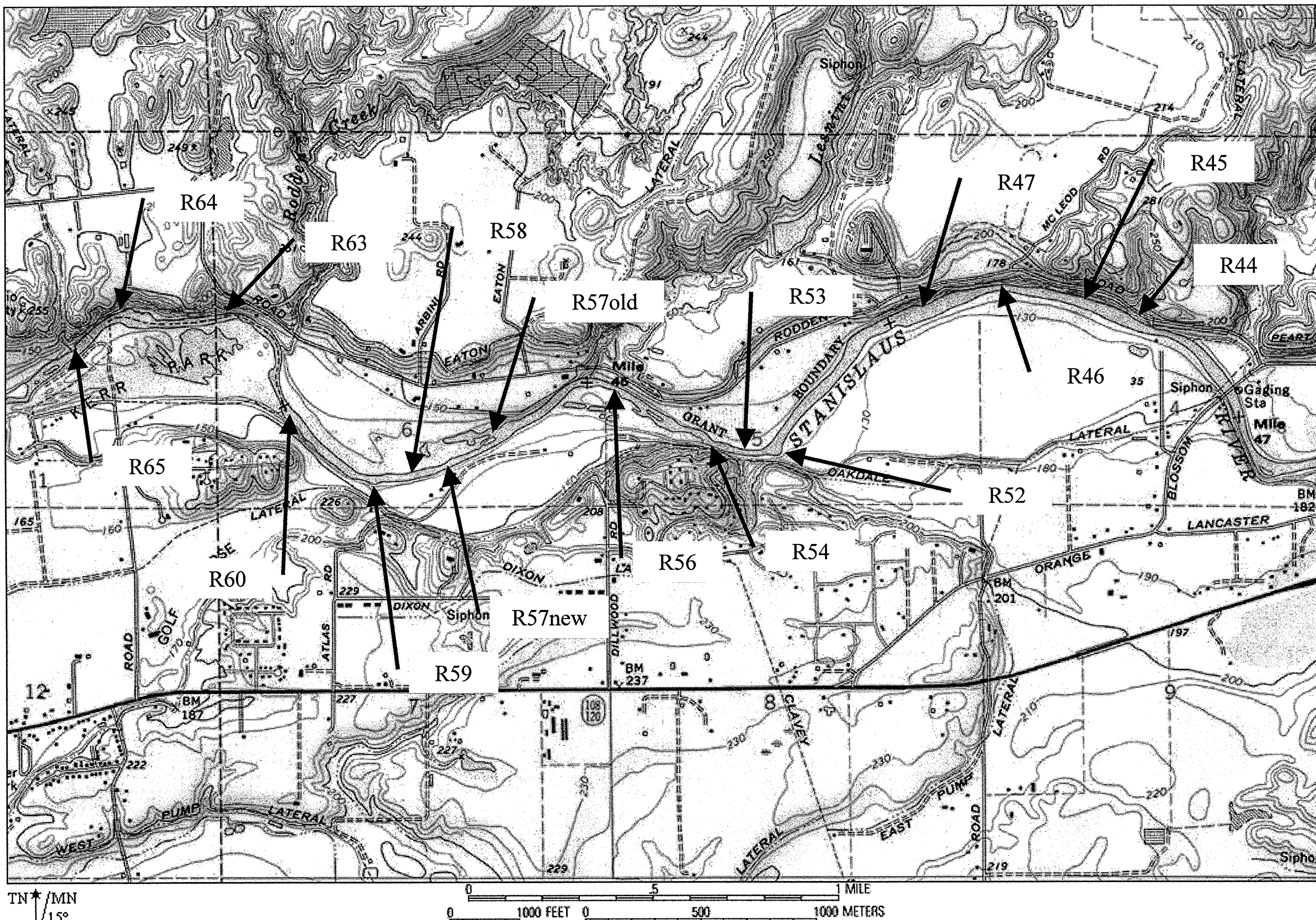


Figure 6.4: Riffle Location Map: Orange Blossom Bridge to Kerr Park. This figure shows spawning riffles from DWR 1994, CDFG 1972, CMC 2000, and our study that we re-visited.

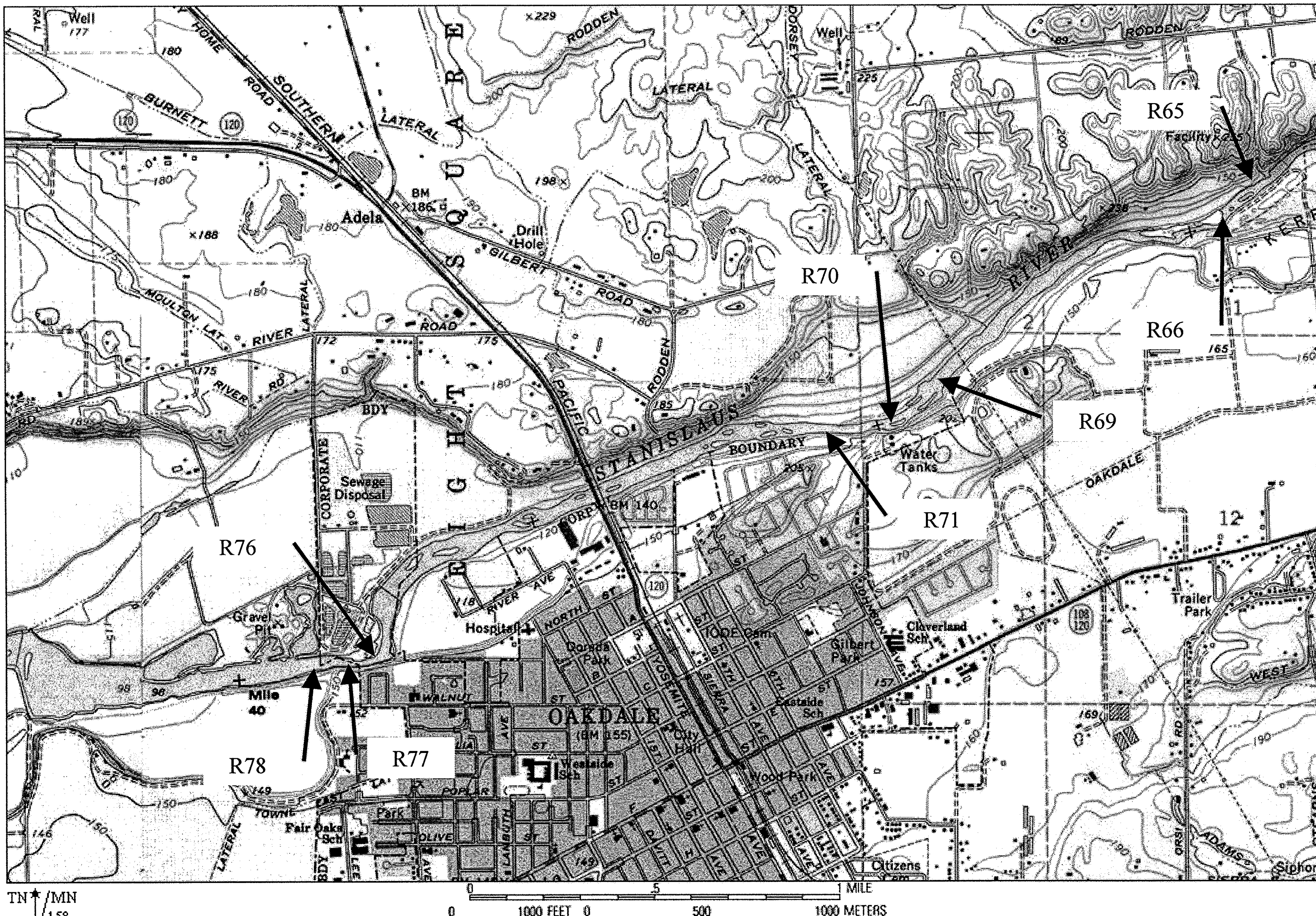


Figure 6.5: Riffle Location Map: Kerr Park to Oakdale. This figure shows spawning riffles from DWR 1994, CDFG 1972, CMC 2000, and our study that we re-visited.

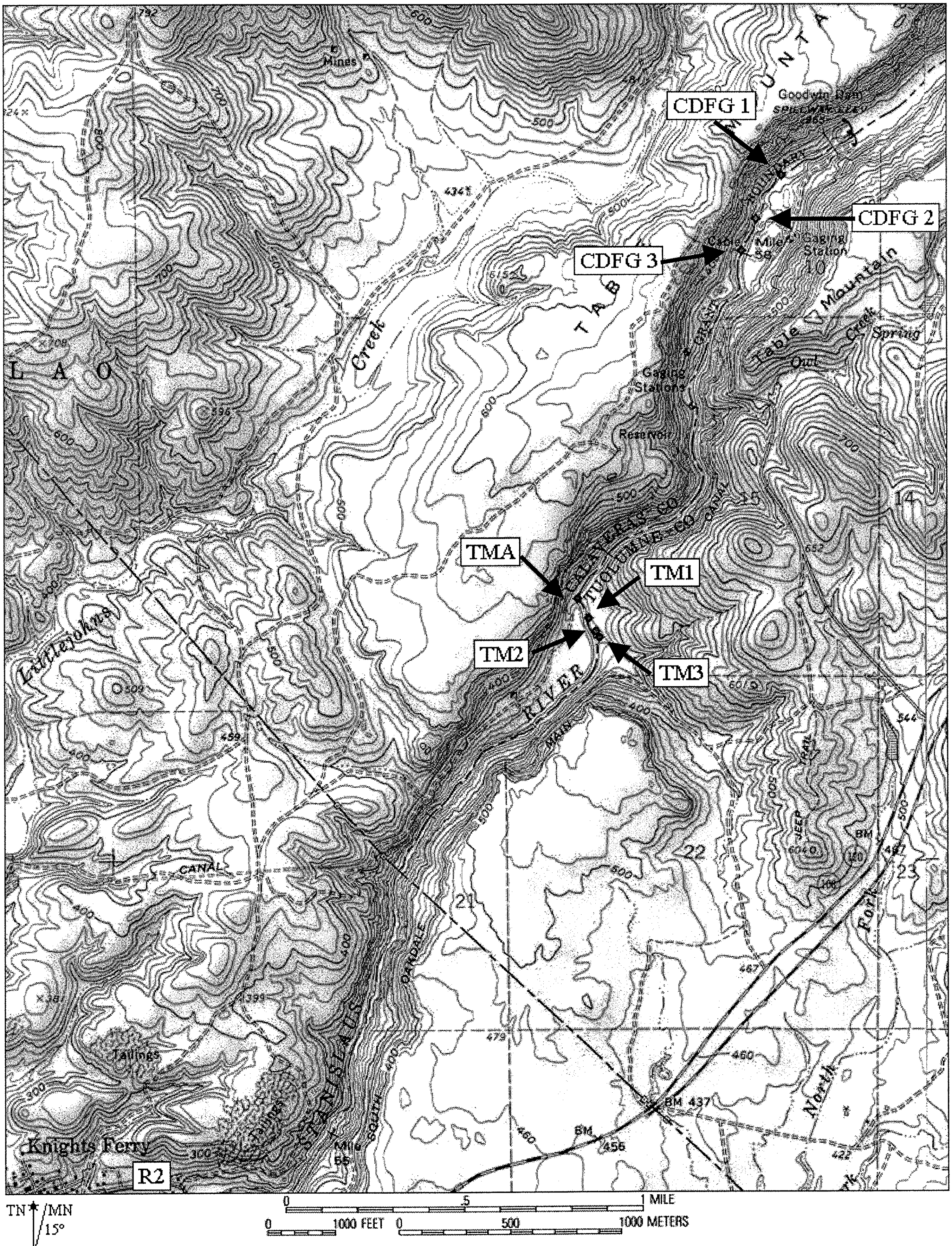


Figure 6.6: Observed Spawning Locations: Goodwin Dam to Two Mile Bar. This figure shows the location of observed spawning salmon or fresh redds during our study.

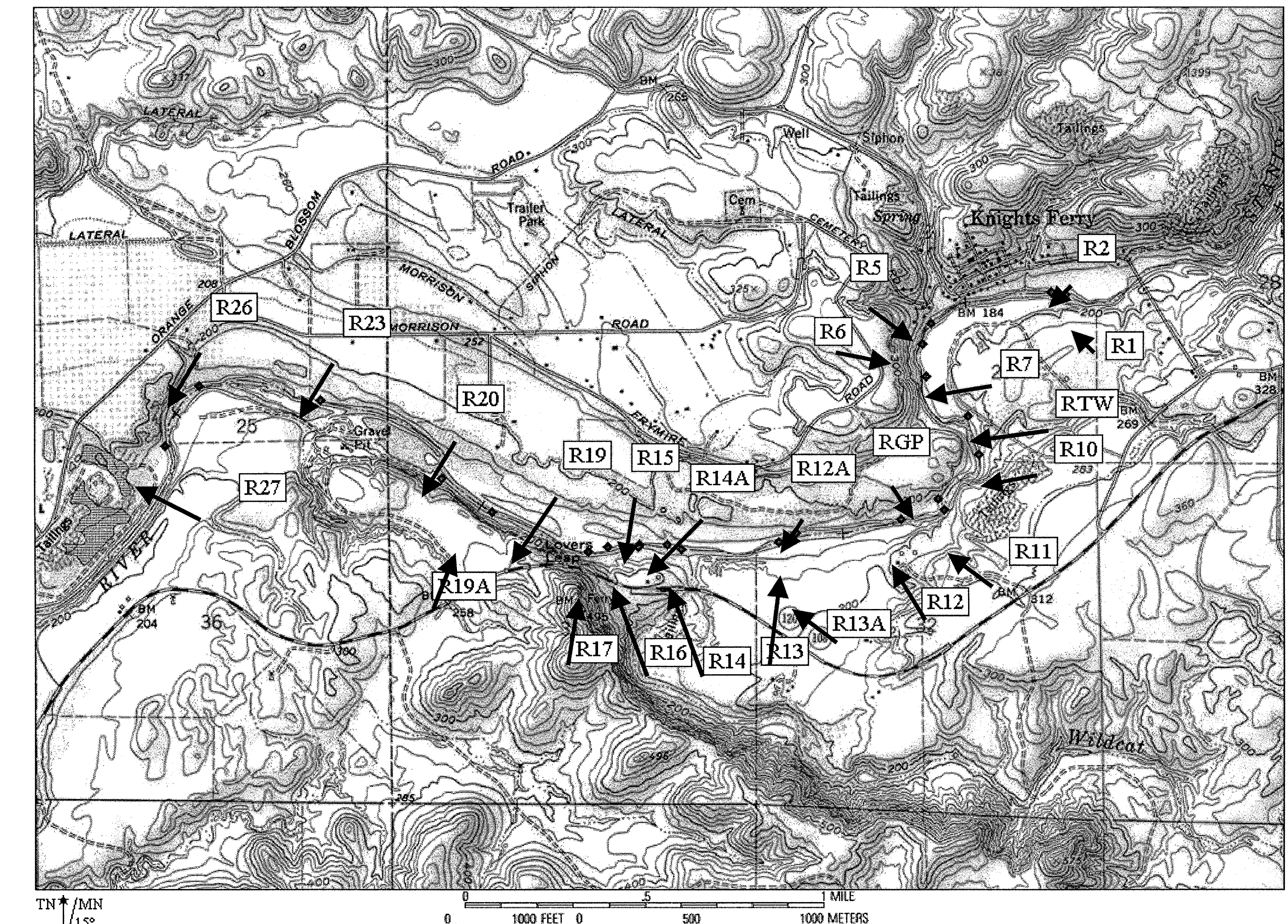


Figure 6.7: Observed Spawning Locations: Knight's Ferry to R27. This figure shows the location of observed spawning salmon or fresh redds during our study.

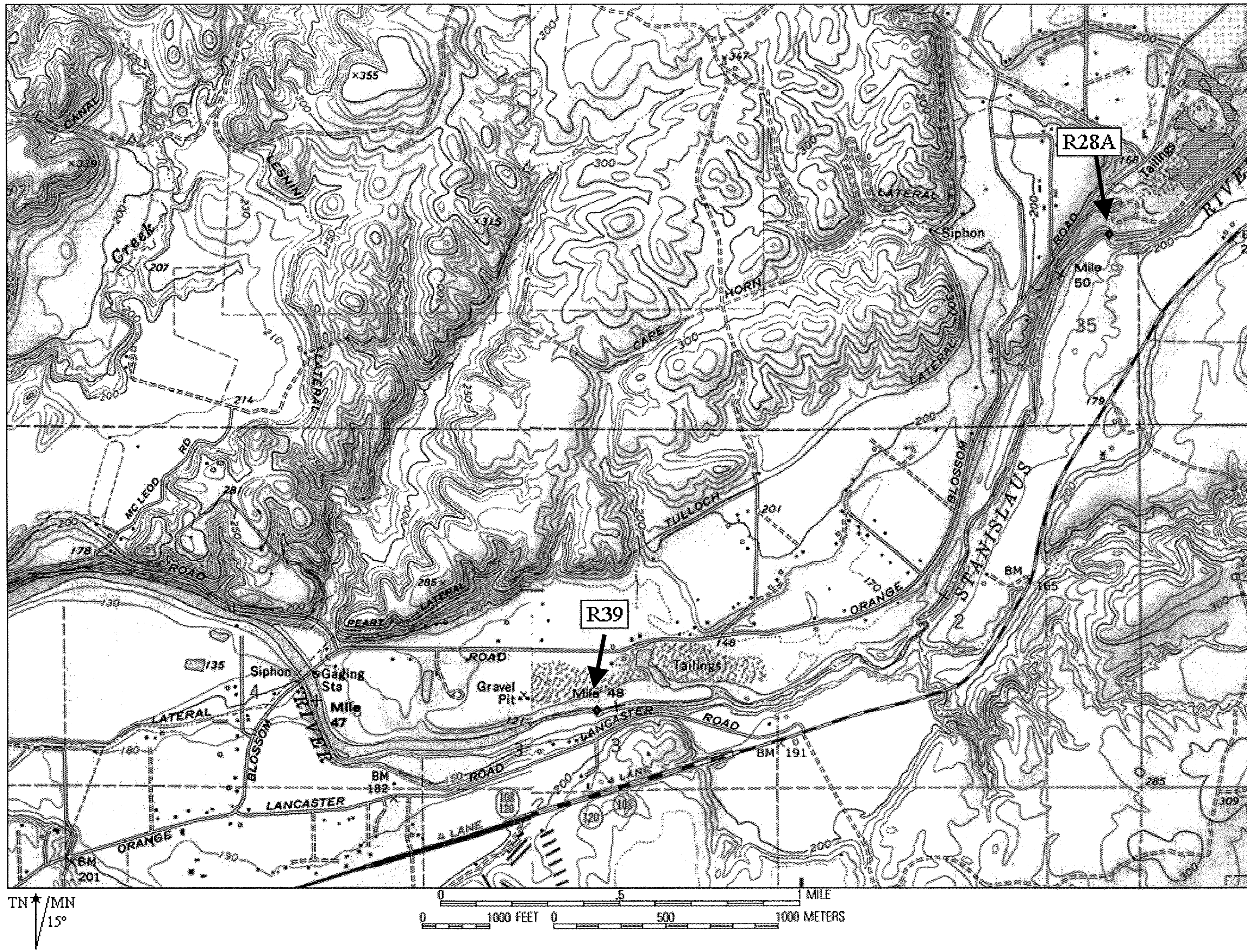


Figure 6.8: Observed Spawning Locations: R28 to R39. This figure shows the location of observed spawning salmon or fresh redds during our study.

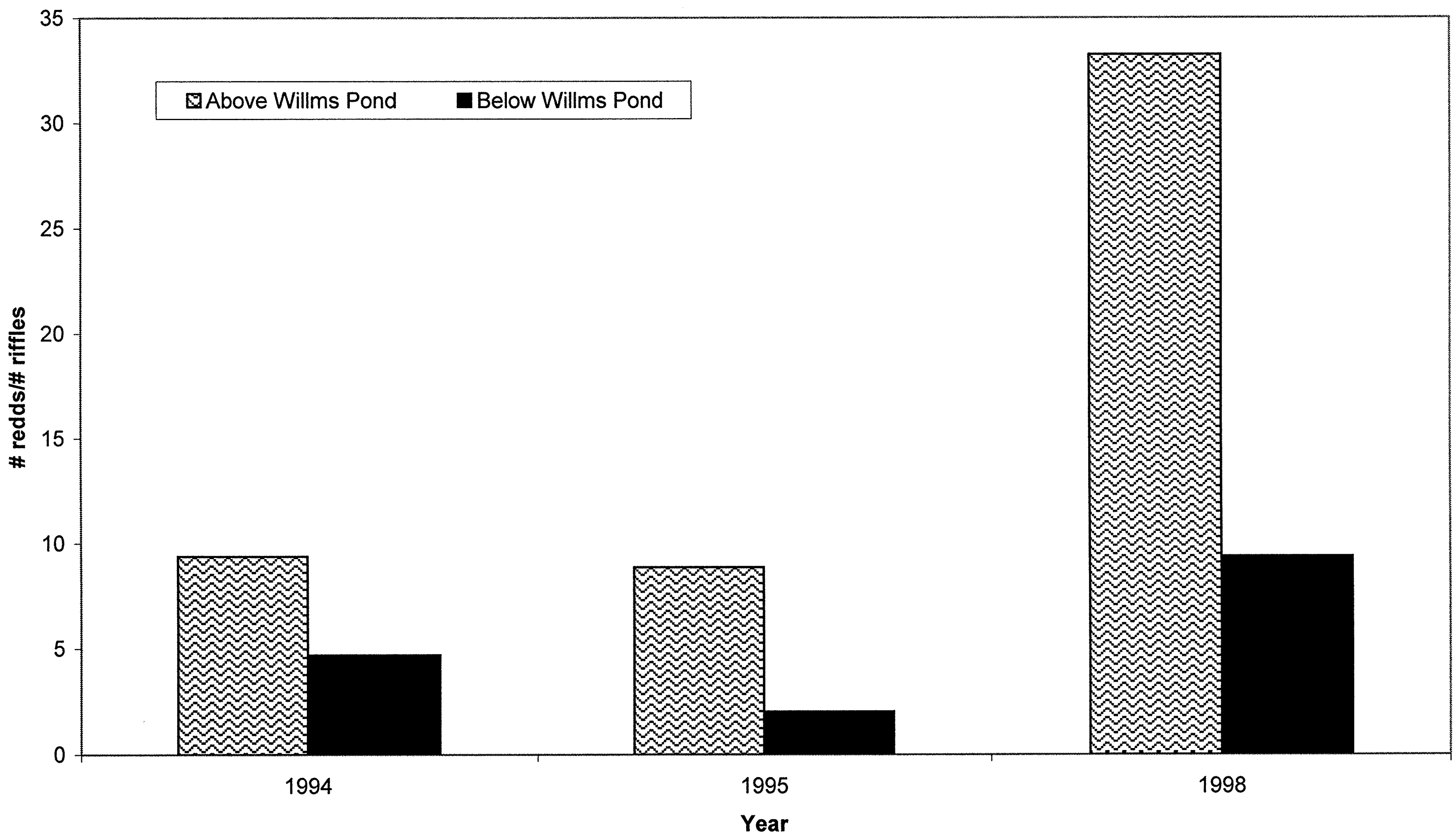


Figure 6.9: Redds per Riffle Above and Below Willms Pond. This figure shows the change concentration of spawning above and below Willms Pond. From 1994 to 1998 more salmon spawned in the reach between Goodwin Dam and Willms Pond. *Data source: CMC 2000*.

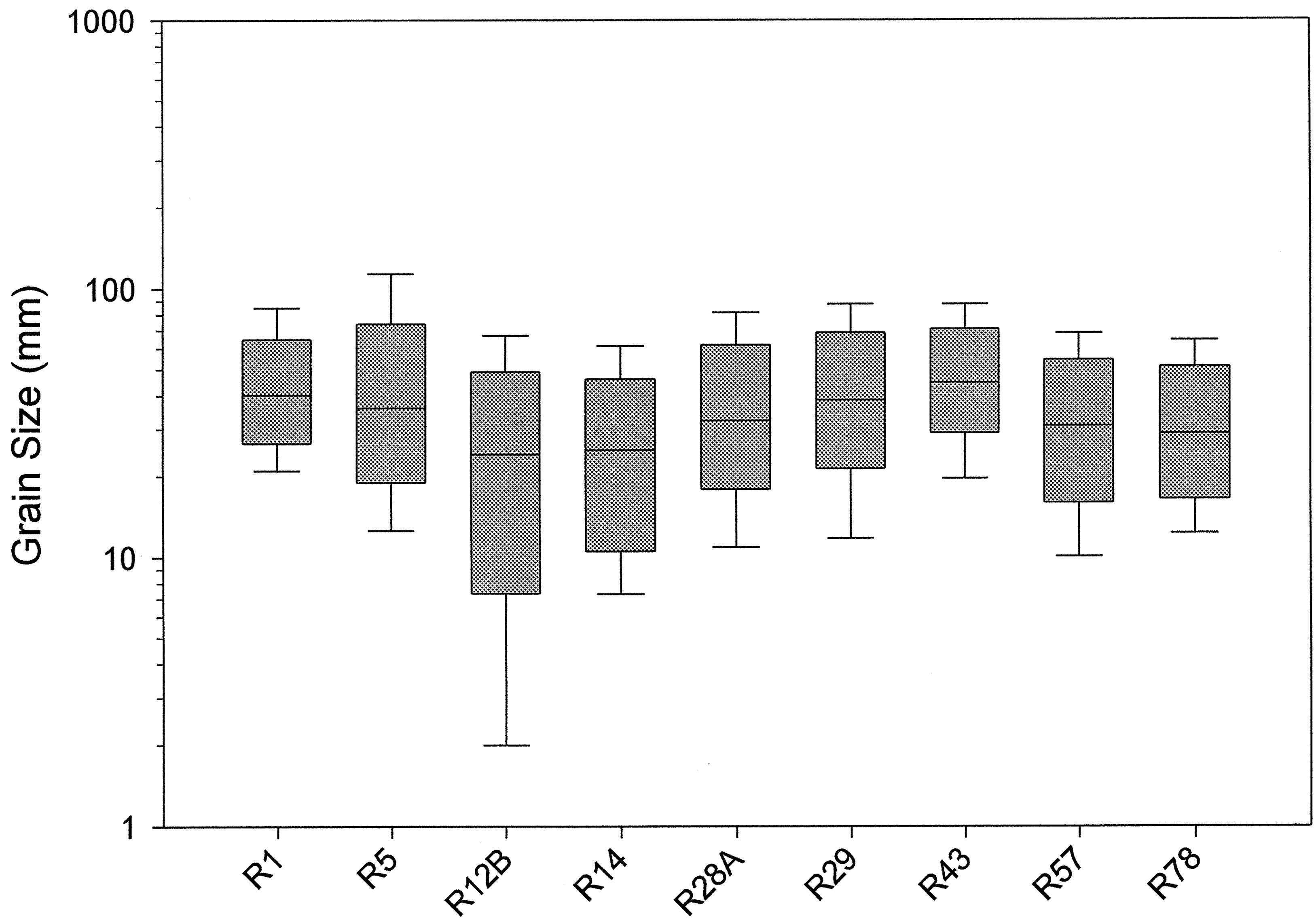


Figure 6.10: Year 2000 Pebble Counts on Riffles Enhanced in 1999. We performed pebble counts on riffles enhanced in 1999 by CMC (2000) riffles to establish a baseline to document future change in the size distribution of the surface layer of gravel. Riffle R12B (**Figure 6.2**) is adjacent to an active gravel mine and has the highest concentration of fine sediment of the CMC (2000) riffles we measured. Note: All grains in the size class <4 mm are plotted at 2 mm.

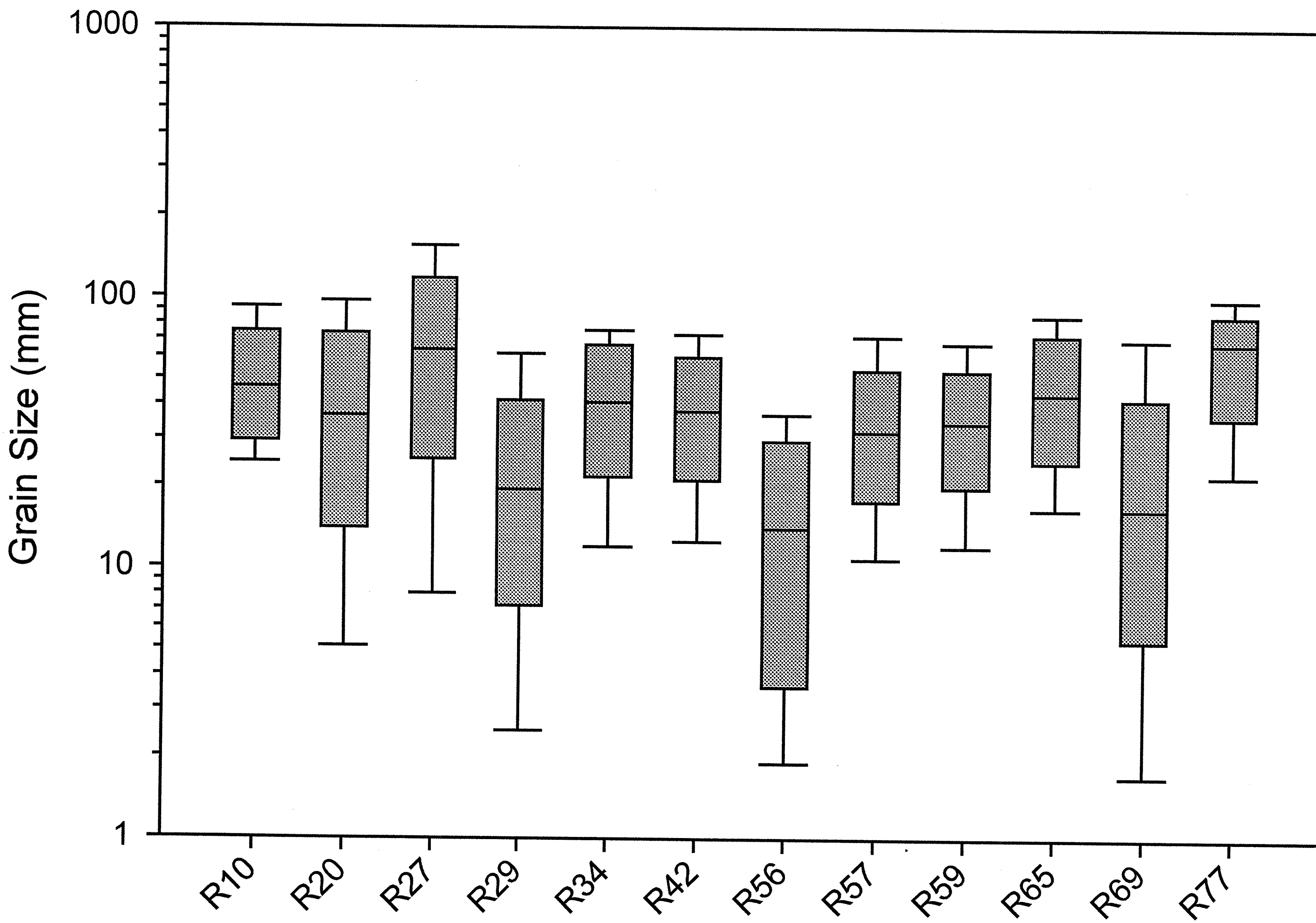


Figure 6.11: DWR 1994 Pebble Counts. We plotted pebble count data from DWR 1994 for all the riffles we relocated. Of the twelve relocated riffles two were enhanced by CMC in 1999 (R29 and R58) and one by CDFG in 1994 (R27), after the DWR 1994 study. Note: All grains in the size class <4 mm are plotted at 2 mm.

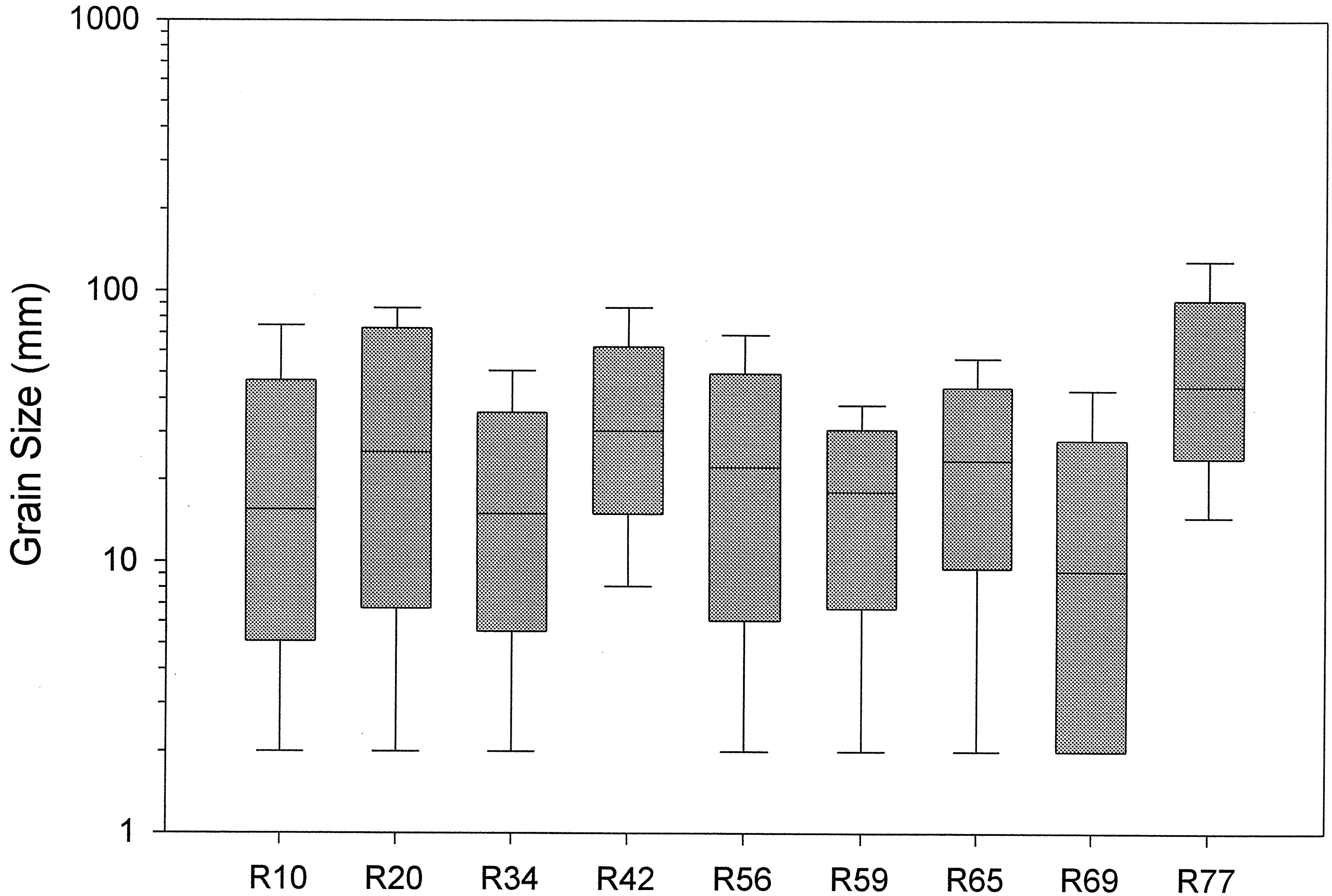


Figure 6.12: Re-visted DWR Riffles Pebble Counts, Non-enhanced. We plotted pebble counts we performed during the summer of 2000 on the re-located DWR 1994 riffles that had not been enhanced by CMC in 1999. Note: All grains in size class < 4 mm are plotted as 2.0 mm.

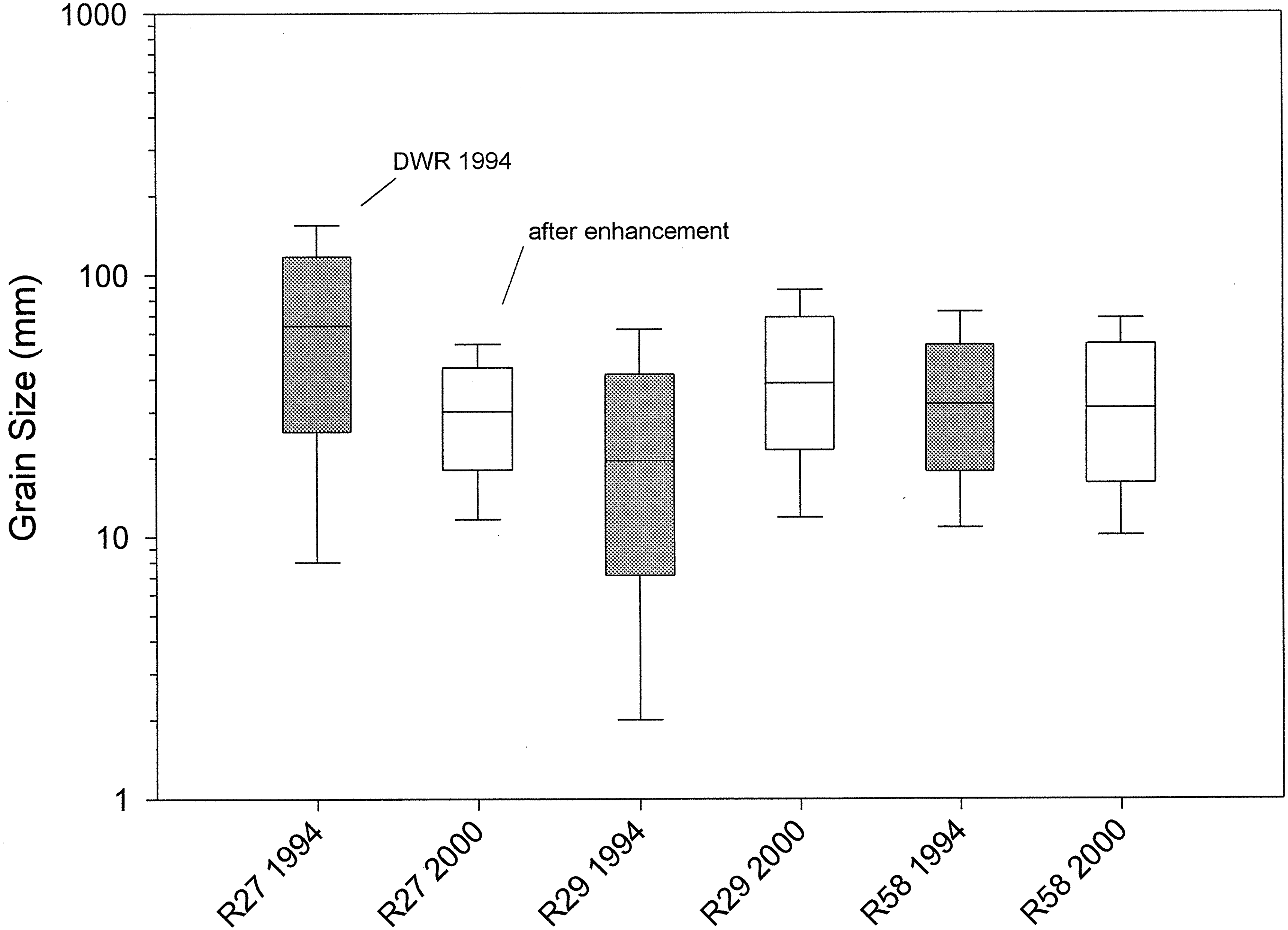


Figure 6.13: Pebble Counts DWR 1994 Riffles Vs. Enhanced Riffles. This figure compares the relocated DWR 1994 riffles with two riffles enhanced by CMC in 1999 (R29 and R58) and one CDFG enhanced riffle at Horseshoe Bend Recreation Area in 1994 (R-27) (**Table 3.2**). Two of the riffles show that the amount of fine sediment decreased after enhancement (R27 and R29). Note: All grains in the < 4 mm size class are plotted at 2 mm.

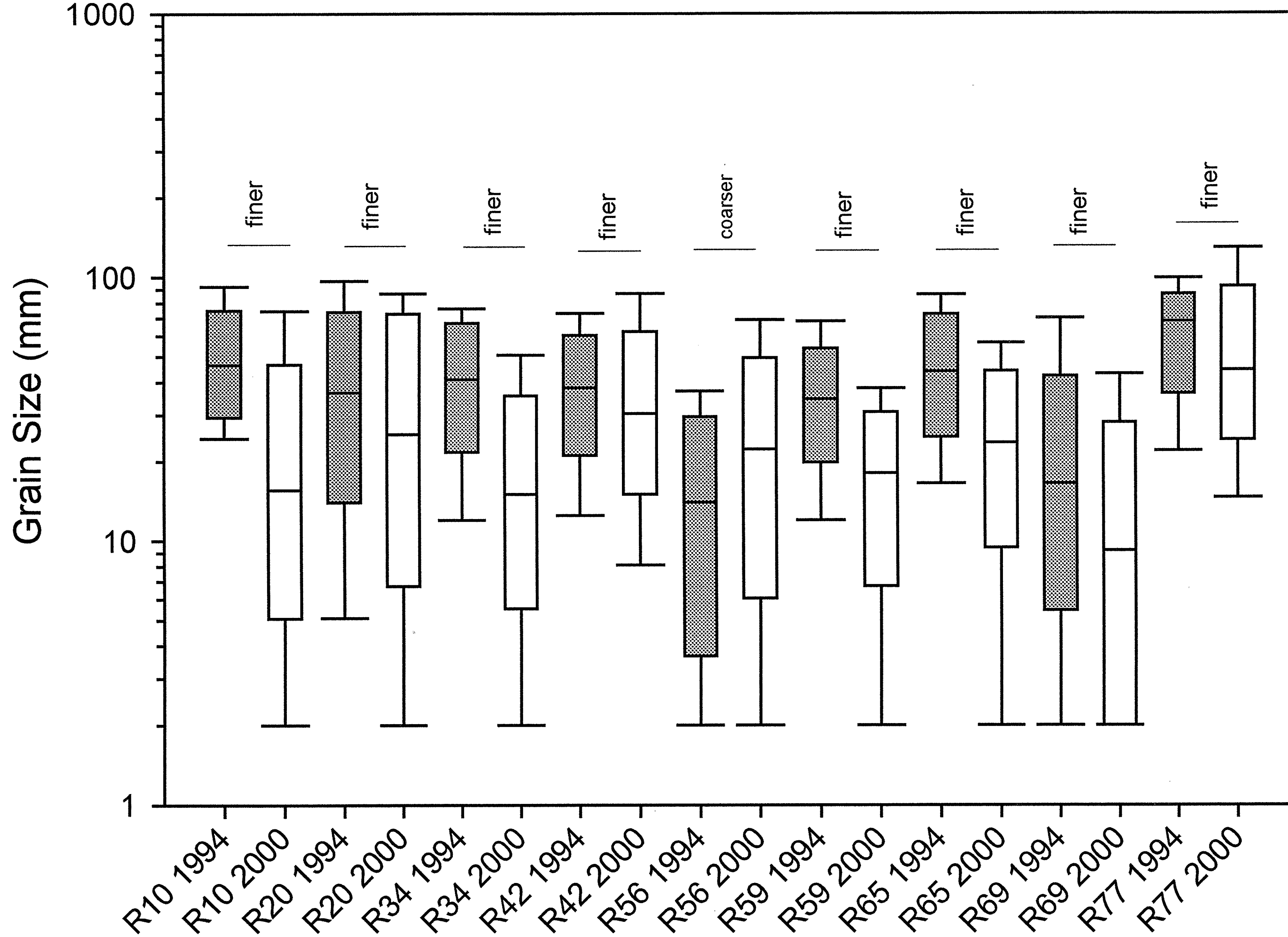
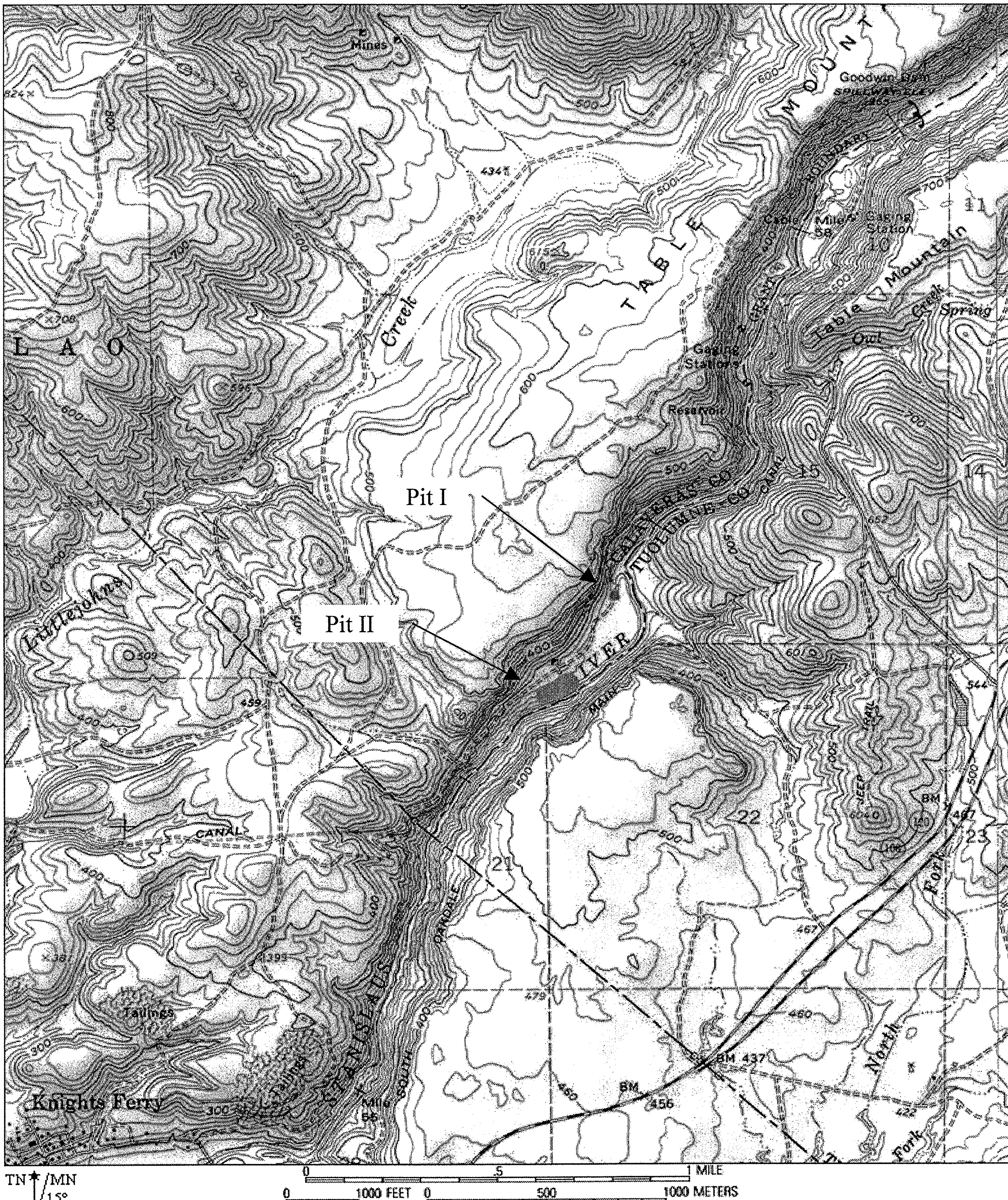


Figure 6.14: Pebble Counts Non-enhanced Riffles 1993 Vs. 2000. This figure compares the DWR 1994 data we plotted from DWR pebble counts in 1993 with the pebble counts we preformed in 2000 for this study. Eight of the nine re-located riffles show an increase in the amount of fine sediment from 1993 to 2000. Note: All grains in the < 4 mm size class are plotted at 2 mm.



Depth of extraction 3.3 m

Figure 8.1: Gravel Extraction Location Map: Goodwin Dam to Two Mile Bar. This figure shows the location of gravel extraction we identified from historical aerial photographs and USGS topographic maps from 1949 to 1999.

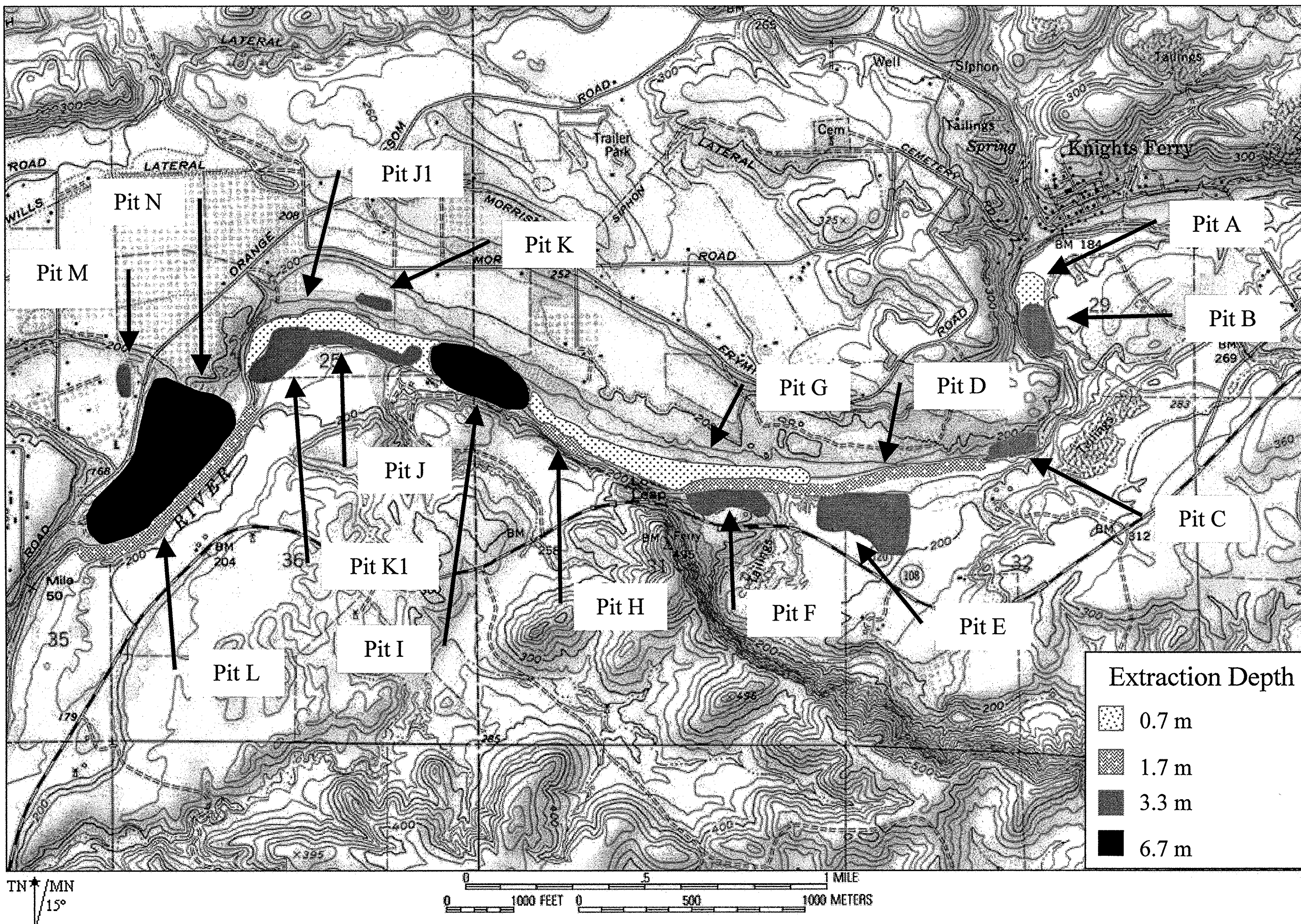


Figure 8.2: Gravel Extraction Location Map: Knight's Ferry to Horseshoe Bend Recreation Area. This figure shows the location of gravel extraction we identified from historical aerial photographs and USGS topographic maps from 1949 to 1999.

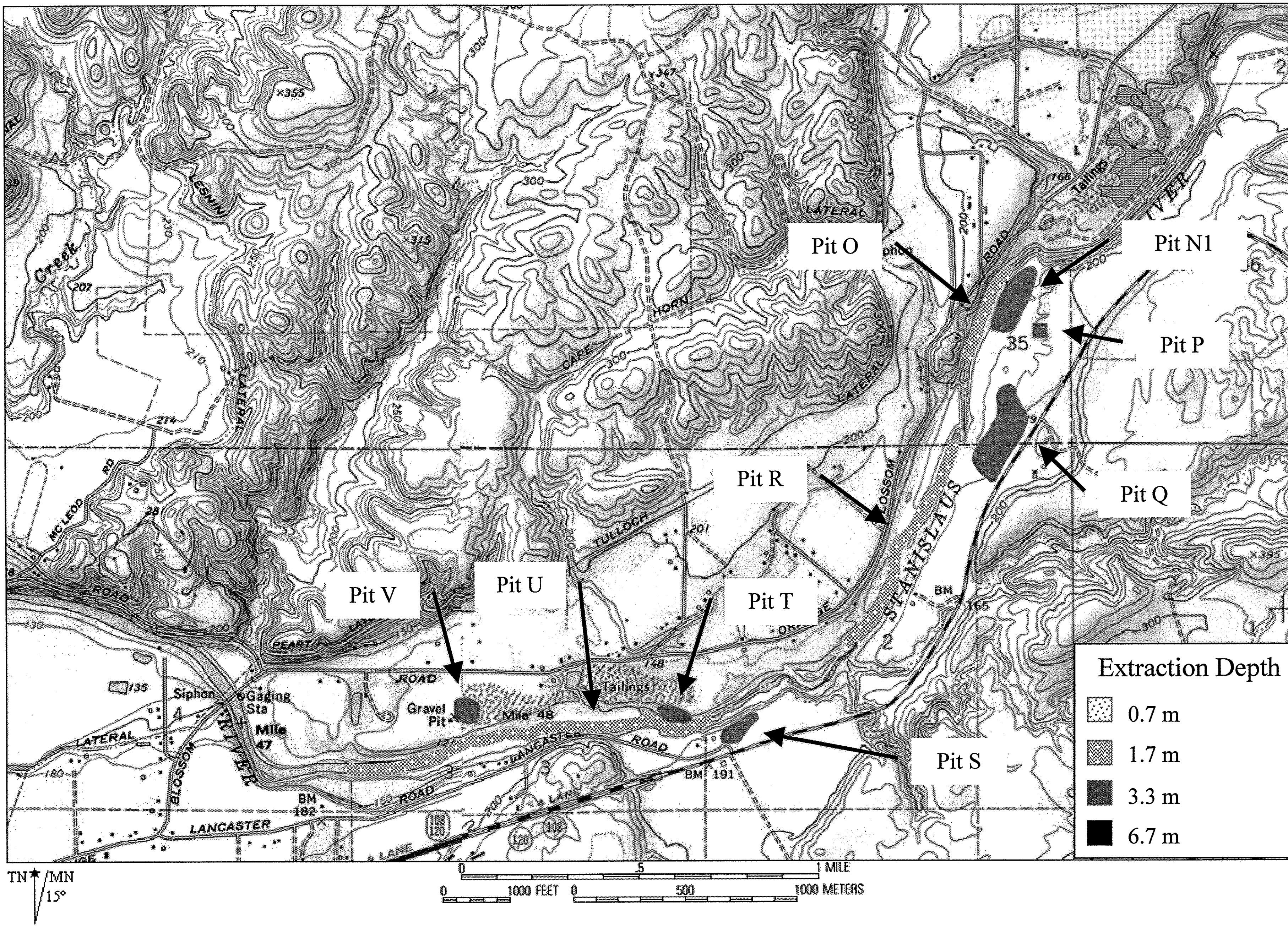


Figure 8.3: Gravel Extraction Location Map: Horseshoe Bend Recreation Area to Orange Blossom Bridge. This figure shows the location of gravel extraction we identified from historical aerial photographs and USGS topographic maps from 1949 to 1999.

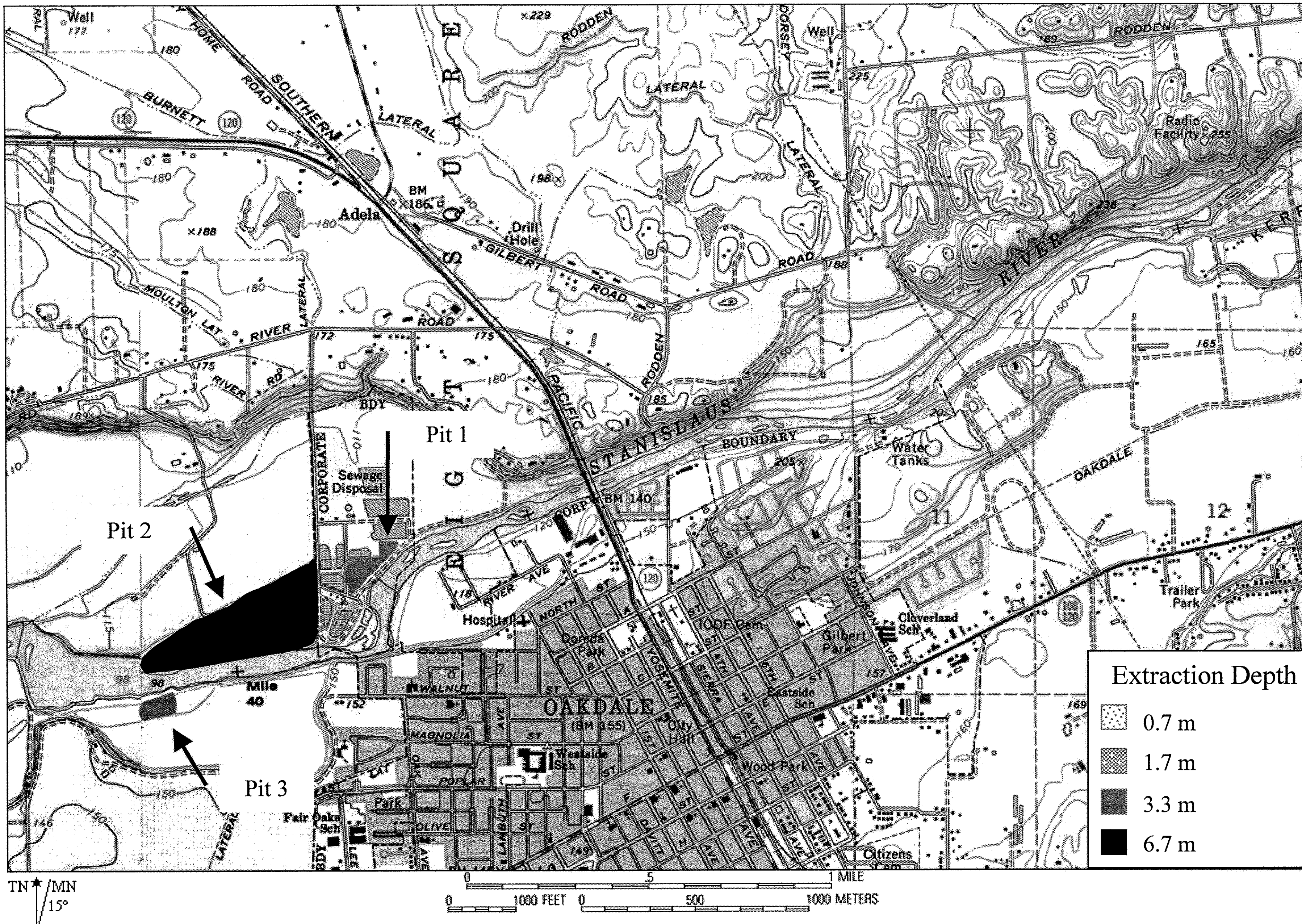


Figure 8.4: Gravel Extraction Location Map: Kerr Park to Oakdale. This figure shows the location of gravel extraction we identified from historical aerial photographs and USGS topographic maps from 1949 to 1999.

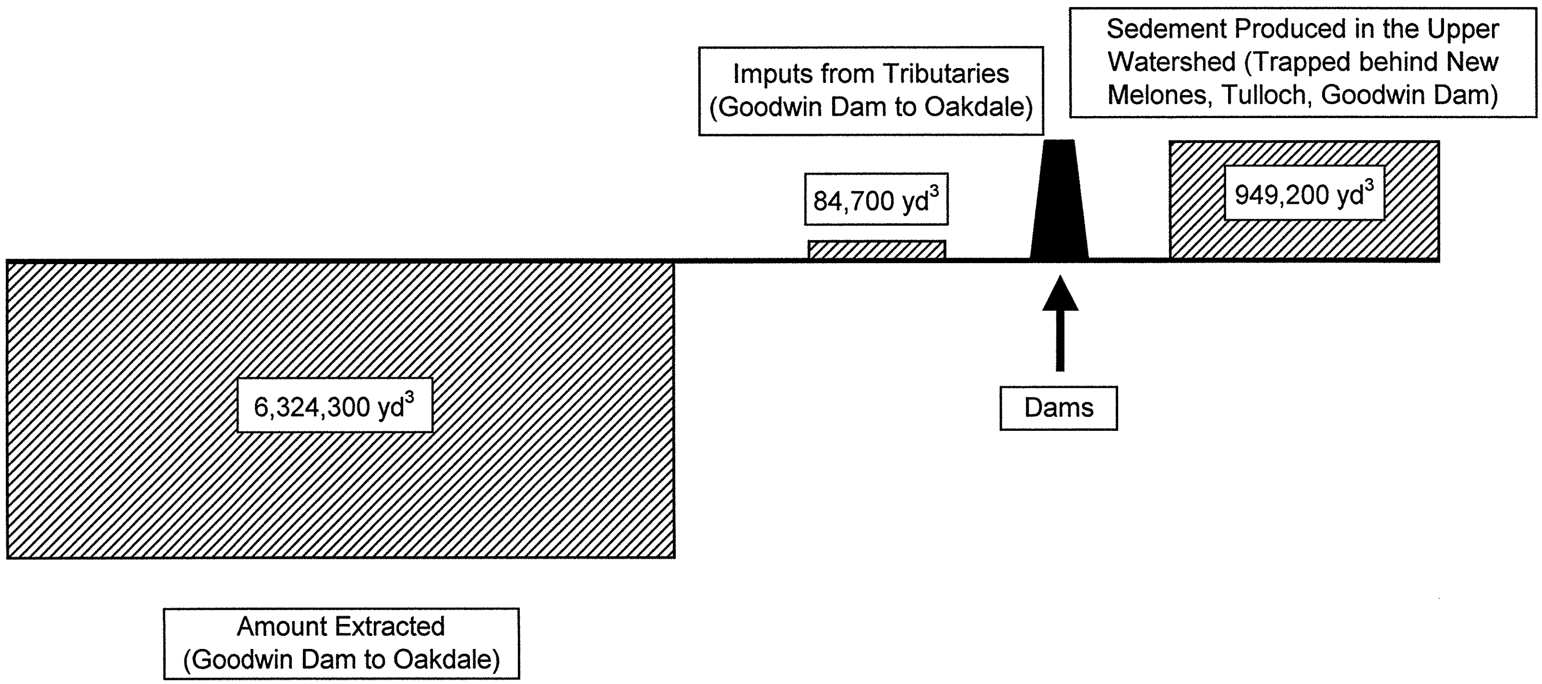


Figure 8.5: Sediment Budget: 1949 to 1999. This figure illustrates the imbalance in the sediment budget for the Stanislaus River over a fifty year period. Extraction for aggregate was 600% greater than the amount of sand and gravel produced in the watershed. When the amount of sand and gravel trapped behind Melones, New Melones, Tulloch, and Goodwin dams is accounted for, the amount of sand and gravel extracted is almost two orders of magnitude greater than the amount produced

STANISLAUS RIVER BASIN DAMS
CUMULATIVE STORAGE CAPACITY

(Expressed as a percentage of average unimpaired runoff) [1]

A Year	B Dam Name		C Stream	Capacity (m3)	D Storage Capacity (AF)	E Cumulative Storage (AF)	F Cum. Storage as % annual unimpaired runoff
1902	Union	NF	N Fork	2,470,000	2,000	2,000	0.2%
1905	Copperopolis	M	Penney Creek	278,000	225	2,225	0.2%
1906	Alpine	NF	Silver Creek	5,670,000	4,596	6,821	0.6%
1908	Stan FB	M	Trib Stan. River	395,000	320	7,141	0.6%
1908	Utica	NF	N Fork	2,960,000	2,399	9,541	0.8%
1910	Relief	MF	Relief Creek	18,700,000	15,158	24,699	2.1%
1912	Goodwin	M	Mainstem	617,000	500	25,199	2.1%
1916	Rodden Lake	M	Lesnini Creek	469,000	380	25,579	2.1%
1916	Main Strawberry	SF	South Fork	22,900,000	18,312	43,891	3.7%
1926	Old Melones [3]	M	Mainstem	139,000,000	112,674	156,566	13.0%
1928	Hunters	NF	Mill Creek	246,000	199	156,765	13.1%
1930	Lyons - PGE	SF	South Fork	7,680,000	6,228	162,993	13.6%
1938	McCarty	M	Trib Johnny Creek	115,000	93	163,086	13.6%
1953	Murphys Afterbay	M	Trib Angels Creek	49,300	40	163,126	13.6%
1953	Murphys Forebay	M	Trib Angels Creek	66,600	54	163,180	13.6%
1953	Fly in Acres	NF	Moran Creek	123,000	100	163,280	13.6%
1957	Beardsley	MF	Middle Fork	120,000,000	77,600	240,880	20.1%
1958	Tulloch	M	Mainstem	84,400,000	68,400	309,280	25.8%
1958	Beardsley Afterbay	MF	Middle Fork	395,000	320	309,600	25.8%
1958	Donnells	MF	Middle Fork	79,600,000	56,893	366,493	30.5%
1965	Reba	NF	Trib Bloods Creek	296,000	240	366,733	30.6%
1970	Utica	NF	No. Fork Stan	2,960,748	2,400	369,133	30.8%
1975	Forest Meadows	M	Angels Creek	133,000	108	369,241	30.8%
1975	Bear Vly Sewage Hldg	NF	Trib Bloods Creek	427,000	346	369,587	30.8%
1976	Holman	M	Trib Angels Creek	308,000	250	369,836	30.8%
1978	Leland Meadows	MF	Leland Creek	97,000	79	369,915	30.8%
1979	New Melones	M	Mainstem	2,960,000,000	2,400,000	2,657,241	221.4%
1980	Murphy's Wastewater	M	Trib Six-Mile Creek	173,000	140	2,657,381	221.4%
1983	Andrew Cademartori	M	Trib Angels Creek	175,000	142	2,657,523	221.5%
1988	North Fork Diversion	NF	No. Fork Stan	148,037	120	2,657,643	221.5%
1988	New Spicer Meadows	NF	Highland Creek	233,000,000	188,871	2,846,514	237.2%
1989	McKays Pt Div	NF	No. Fork Stan	2,590,654	2,100	2,848,614	**237.4%**
	TOTAL LISTED DAMS:	32			TOTAL CAPACITY:	**2,846,514**	AF
	(including Old Melones)					TOTAL:	**237%**
					avg unimpaired runoff Stan basin:	1,200,000	AF [2]
					1 m3 =	*0.000810606*	AF

Data source:

[1] *Department of Water Resources, Bulletin17-93, Dams Within the Jurisdiction of the State of California, June 1993.*

[2] *CALFED Bay-Delta Program, ERPP Draft PEIS/EIR Tech. App., Vol. 2 - Ecological Management Zone Visions, 6/99.*

[3] *Kondolf et al, 1996a, Water Resources Center Rept. 90 (for data on Old Melones Reservoir)*

Note -- storage from Old Melones (built in 1926) was subtracted when New Melones was filled (1979).

Table 2.1: Stanislaus River Basin Dams and Cumulative Storage Capacity. Data on the dams within the Stanislaus basin large enought to be regulated by the Division of Safety of Dams (DOSD), including the year the dam was built (col. A), watershed location (C.), and its storage capacity (D). Col. E details the cumulative storage capacity within the basin after the construction of each additional dam. Col. F expresses this cumulative storage as a percentage of total average unimpaired runoff in the basin (1.2 maf, Calfed, 1999). The total dam storage capacity in the Stanislaus basin exceeds 2.8 maf, or almost 240% of average annual unimpaired runoff.

Gauge No. (Name)	*Water Year*	*Drainage Area*	*Data Source*[1]	*Remarks*
# 11302000 ("Stan. River at Knights Ferry")	1903-1914	982 mi^2 *(revised; Meyer, USGS, 4/3/00)*	USGS Water Supply Paper 299 (1903-1912); #361 (1913); #391 (1914).	Established May 19, 1903 until Sept. 14, 1914. Location: downstream of Goodwin Dam, Elev. 157.53 ft. Flows not "unimpaired" due to diversions from S. Fork to Tuolumne Basin, from N. Fork near Murphy and Angels, and numerous mining ditches. Diversions from S.San Joaq. Canal and Oakdale Canal begin 1914. 1903-1908: only gage height data with rating tables available for mean daily flow. Data converted to cfs using rating tables and linear interpolation. 1909-1914: mean daily in cfs. No water flowed over Goodwin Aug. or Sept. 1914. Peak flow data (cfs) 1903-1912 available from USGS website.
#11300000 ("Stan. River near Knights Ferry")	1915-1932	972 mi^2 *(Meyer, USGS, 4/3/00. web says 980 mi^2)*	Hydrosphere CD USGS website	Established Dec. 18, 1915 with full operation 2/1/16. Location: 2 miles upstream of Goodwin dam (300 ft. upstream of current day Tullock dam, filled in 1957). Lat: 37deg53'30"; Long: 120deg36'20" , Elev. 370 ft. (Meyer, USGS, 4/3/00) Mean daily flow and annual peak flow data in cfs
#11299500 ("Stan River below Melones Powerhouse")	1931-1967	905 mi^2 *(web)*	Hydrosphere CD USGS website	Established Feb. 1, 1931. Location: Lat: 37deg56'50", Long: 120deg31'45" Records "good" except during periods of no gage-height record or backwater from Tullock Reservoir, which are "fair." Backwater from Tullock affects record since 11/25/57 (since storage began). Mean daily flow and annual peak flow data in cfs
#11302000 ("Stan River below Goodwin near Knights Ferry")	1957 – present	986 mi^2	Hydrosphere CD USGS website	Established: Feb. 1957. Location: Lat: 37deg51'06", Long: 120deg38'13"; .9 mi downstream Goodwin and 2.9 mi NE Knights Ferry. Elev. 252.83 ft above sea level. Records equivalent to Stan R at KF, 1903-14, and Stan River nr. Knights Ferry, 1915-32, if adjusted for diversions: Stan and SJ Water Co's Canal, and Oakdale (#11301000) and S San Joaquin Canals (#11300500) which divert 1 mile upstream at Goodwin Dam. Records "good."

Table 2.2: Stream Gauges on the Stanislaus River. Flow data from 1903-1929 (pre Old Melones dam) are used to characterize "pre-impact" period, and data following construction of New Melones dam in 1979 characterizes "post-impact." Flood frequency analysis required longer periods of record, so peak flow data preceding construction of New Melones dam (1903-1978) are compared with peak flows following construction of the dam (1979-2000).

[1] Data Sources: 1) USGS website: http://waterdata.usgs.gov/nwis-w/CA/; 2) Hydrosphere CD; 3) USGS Water Supply Papers (Note: WS Paper #299 (1903-1912) updates WS Papers 251, 271, 291, 311, 331); 4) Personal communication with Robert W. Meyer, Surface Water Specialist, USGS, 4/3/00. Meyer provided revised drainage area values and other information from USGS materials including "Compilation of Records of Surface Waters of the United States through Sept. 1950."

Table 2.2: Continued:

Other Data used:				
Gauge No. (Name)	*Water Year*	*Drainage Area*	*Data Source*	*Remarks*
Oct. 1940-current #11303000 ("Ripon")	1940 - present	1075 mi^2	Hydrosphere CD USGS website	Established Oct. 1940. Location: Lat: 37deg43'50", Long: 121deg06'35"; left bank, 1mi SE Ripon, 15 mi upstream mouth. SSJ Canal (#11300500) and Oakdale Canals (#11301000) divert at Goodwin Dam 34 mi upstream. Records "good" Peak flow data from Ripon used in flood frequency to compare data from a single gauge.
#11301000 (Diversion data at Oakdale Canal near Knights Ferry)	1914 - present	n.a.	Hydrosphere CD	Established May 3, 1914. (Operated: 5/3/14-10/31/33; 3/21/34-10/28/34; 7/31/35-10/31/35; 3/1/36-9/30/99). Location: Lat: 37deg51'32", Long: 120deg37'56"; on left bank .3 mi downstream of Goodwin Dam headgate and 3.4 mi NE Knights Ferry (for OID irrigation). Records "good" except for estimated daily discharges, which are poor. Records for Water years 1933-36 incomplete. Monthly and yearly estimates published in WSP 1315-A.
#11300500 (Diversion data at SSJ Canal nr. Knights Ferry)	1914 – present	n.a.	Hydrosphere CD	Established March 1, 1914. Location: Lat: 37deg51'10", Long: 120deg38'15"; left bank .8 mi downstream Goodwin Dam headgate and 3.0 mi NE Knights Ferry. Monthly and yearly discharge only for some periods (in WSP 1315-A) Records "fair." Canal diverts from right bank (?) of Stan at Goodwin Dam (for irrigation in Oakdale and SSJ Irrigation Districts).

	----- Pre - Old Melones Dam -------				*----- Post - New Melones Dam -------*		
Category	Year	Unimpaired Flow (maf)	Year Type		Year	Unimpaired Flow (maf)	Year Type
CRIT DRY	**1924**	**0.26**	**crit dry**		**1987**	**0.37**	**crit dry**
					1988	0.38	crit dry
					1994	0.46	crit dry
					1990	0.47	crit dry
					1992	0.49	crit dry
DRY	1913	0.59	dry		1991	0.51	dry
	1912	0.60	dry		1981	0.59	dry
	1926	0.61	dry		1985	0.68	dry
	1908	0.62	dry		**1989**	**0.78**	**dry**
	1920	0.74	dry				
	1919	**0.77**	**dry**				
	1918	0.83	norm/dry				
NORM	1905	0.98	norm				
	1903	1.12	norm		2000	1.16	norm
	1923	1.13	norm		1979	1.16	norm
	1925	1.22	norm				
	1921	1.26	norm				
	1915	1.30	norm				
WET	1917	1.38	wet		1999	1.35	wet
	1910	1.41	wet		1984	1.43	wet
	1922	**1.43**	**wet**		**1996**	**1.49**	**wet**
	1916	1.67	wet		1993	1.56	wet
EXT. WET	1914	1.77	ext. wet		1997	1.76	ext wet
	1909	1.93	ext. wet		1980	1.80	ext wet
	1904	**2.05**	**ext. wet**		1986	1.94	ext wet
	1911	2.36	ext. wet		**1998**	**2.09**	**ext wet**
	1906	2.41	ext. wet		1995	2.34	ext wet
	1907	2.83	ext. wet		1982	2.35	ext wet
					1983	2.95	ext wet

Data source: Unimpaired flow data derived from SNS station, sensor #65 at http://cdec.water.ca.gov/cgi-progs/selectQuery?station_id=SNS&sensor_num=65&dur_code=M&start_date=1903&end_date=now

Table 2.3: Stanislaus River Unimpaired Flow for Categorized Year Types. Sorted list of unimpaired flows (maf) for the Pre- Old Melones Dam period (1903-1926) and Post - New Melones Dam period (1979-2000). Unimpaired flow data derived from DWR CDEC website for the SNS station (sensor #65). Water year type determined using McBain and Trush (2000) classification at the adjacent Tuolumne River, with adjustments made based on actual Stanislaus unimpaired flow data. Designated water year type also compared to DWR 60-20-20 classification for the Stanislaus and other nearby rivers. Water years indicated in bold were used for annual hydrograph comparisons discussed in chapter four and graphed in Figures 4.4 to 4.7.

Table 2.4: Aerial Photographs of the Lower Stanislaus River Identified in This Study

Time Period		Year	Date	Scale	Avg. Daily Flow (cfs)	Gauge for Flow #	Gauge for Flow Name	Photo Location	Notes
I. Historical Photographs 1937-1939	X	1937	8/7	1:20,000	1190	11299500	Old Melones	National Archives	
		1939	1/18	alt. 7,500'	854	11299500		USACE	Can #412*
II. Historical Photographs Pre-New Melones 1957-1978	X	1957	3/23; 4/25	*(adjusted)*	592; 1350	11299500	Old Melones	UCD	
		1961	6/8	1:12,000	67	11303000		USACE	Can #439
		1972	4/20	1:48,000	142	11303000	Ripon	USACE	Can #595
		1978	3/24; 3/25	1:12,000	3180; 3170	11303000		USACE	Can #693
III. Post New Melones 1979-2000		1982	6/17	1:9,600	1270	11303000	Ripon		
		1987	8/5	1:3,000	497	11303000			
		1993	5/9	1:40,000		11302000	Goodwin Dam		
	X	1998	8/15	1:40,000	1780	11302000			
Flood/High Water Events		1956	1/17	alt 12,000	11800	1130300	Ripon	USACE	Can #379
		1964	12/31	1:6,000	6580	"	"	USACE	Can #483-4
		1967	3/19	1:6,000	7000	"	"	USACE	Can #513
		1980	1/18	1:6,000	4780	"	"	USACE	Can #726
		1997	1/13	1:12,000	6340	"	"	USACE	Can #991

**: Can #412 could not be located by the COE and is still missing.*

X: photographs used in this analysis

Table 2.5: List of Previous Spawning Studies Reviewed

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), 2000. Task 3 Pre-project evaluation report Knight's Ferry Gravel Replenishment Project for CALFED Bay Delta Program

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

Table 2.6: Criteria Compared Between the Three Studies

Study	**Criteria (range of preferred Values)** Size class (mm)	**Depth (ft)**	**Velocity (cfs)**	**Embeddedness**	**Flows during study (cfs)**
CDFG 1972	26 to 153	0.8 to 2.0	1.5 to 2.5	NA	100 to 250
DWR 1994	14 to 113*	0.75 to 3.5*	1 to 3	Not compacted	200 to 375
This Study	25 to 150	0.5 to 3.5	1 to 5	Movable with foot	350 to 425

* not explicitly stated, inferred from report summary

Table 2.7: Categories of Salmon usage of Redds.

Category	# of Salmon or # of redds	% of crest of rifle used
Not counted	<3	<10
Low	3-5	10-30
Medium	5-8	30-60
High	>8	>60

Table 3.1: Principal Objectives of the New Melones Project
(*Source: USACE 1967 General Design*).

Objective	*Description*
Flood Protection	Provide a high degree of flood protection to cities and agriculture areas along the Stanislaus river (estimated 35,000 acres in Ripon, Riverbank, and Oakdale areas) and lower San Joaquin River.
Irrigation Water	Provide water for irrigation by storage of surplus water during periods of high runoff for release during periods when irrigation demand are high.
Hydropower	Provide for maximum development of electric hydropower within the limits of flood control and irrigation operations.
Recreation	Provide the opportunity for water oriented recreational activities.
Fisheries	Provide enhancement of reservoir and downstream fisheries.
Water Quality	Provide water quality control in the Stanislaus river below the dam to prevent damage to downstream fishery and to maintain good quality irrigation water in the lower San Joaquin river.

Table 3.2: Gravel Enhancement Projects on the Stanislaus River

Year	Agency/Organization (funding source)	Volume Added (yd^3)	Cost	Reach	Notes:
1994	CDFG, DWR (4-Pumps)	3,070	$194,000	Horseshoe Bend Recreation Area	Excavated the channel bed to removed silt, rock, and cobble at 3 sites (RM 47.4, 50.4, and 50.9); replaced with 0.5 inch to 4 inch washed gravel to 1-1.5 ft depth; 5,680 sq. yds gravel area enhanced. Project washed out by November 1995. [1]
1997	CDFG (salmon stamps)	2,222	$46,620	Goodwin Canyon	Stanislaus Fly Fishermen Inc., contractors for the project, abandoned placement of gravel using a hydraulic delivery system and completed the project using a skip loader. Placed gravel where none existed previously; salmon used site three weeks after completion; received heavy spawning use; half of gravel moved downstream during winter flows. [2]
1997	CDFG (CVPIA)	741	$110,000	Goodwin Canyon	Placed gravel by helicopter; used by salmon almost immediately; gravel washed downstream by 1998. [3]
1998	CDFG (salmon stamp)	4,444	$66,620	Goodwin Canyon	Stanislaus Fly Fisherman Inc., as the contractor, added gravel using a skip loader to the 1997 riffles. Salmon appeared immediately upon completion of addition of gravel; 30 redds; 67% of gravel still in place one year post project completion. [4]
1999	Carl Mesick Consultants (CALFED prop 204)	9,630	$633,000	Goodwin Canyon to the City of Oakdale	Used a skip loader to place gravel at 18 riffles from Goodwin Dam to Oakdale; includes $180,000 monitoring budget for 3 yrs. (17 river miles; Two Mile Bar to City of Oakdale) This project is a field experiment designed to evaluate different riffle construction configuration and gravel types. [5]

Sources:
[1] Kondolf et al. (1996a); S. Spaar, DWR, pers. comm., 10/20/99
[2] Dave Boucher, pers. comm., 1999
[3] Larry Pucket, USFWS, pers. comm., 10/8/99
[4] Dave Boucher, pers. comm., 1999
[5] Carl Mesick, pers. comm., 12/27/99, S. Spaulding USFWS-AFRP pers. comm. 1/10/00

Table 4.1: FLOOD FREQUENCY ANALYSIS
Knights Ferry Combined Gages

Flood Frequency Stanislaus River near Knights Ferry Ca, *Tuolumne Co, Upper Stanislaus Basin*

Water Years Retrieved: 1904-1914 (KF1), 1915-1932 (KF2), 1933-1955 (M), 1956-1999 (KF3). Data Source (Peak Flow Data):

1904-1914: ***Stan. River at Knights Ferry ("KF1")*** *, US Geological Survey, Station # undesignated, Drainage Area: 982 sq. mi.*

1915-1932: ***Stan. River Near Knights Ferry ("KF2")*** *, US Geological Survey, Station # 11300000, Drainage Area: 972 sq. mi.*

1933-1955: ***Melones Dam ("M")*** *, US Geological Survey, Station # 11299500, Drainage Area: 905 sq. mi. **

1956-1999: ***Goodwin Dam Near Knights Ferry ("KF3")*** *, US Geological Survey, Station # 11302000, Drainage Area: 986 sq. mi.*

Pre-New Melones Dam (1904-1978)				No. data points (N)=		75
Water Year	Date	Data Source (gage)	Annual Peak Discharge (cfs)	Rank Order by discharge M	Probability of Occurrence (%) P=(1/T)*100	Return Period (yrs) (Recurrence Interval) T = (N + 1)/M
1907	1907.03.19	KF1	64500	1	1.32	76.00
1956	1955.12.23	KF3	62900	2	2.63	38.00
1911	1911.03.31	KF1	60000	3	3.95	25.33
1909	1909.01.21	KF1	57000	4	5.26	19.00
1951	1950.11.21	M	49500	5	6.58	15.20
1928	1928.03.25	KF2	46000	6	7.89	12.67
1965	1964.12.24	KF3	40200	7	9.21	10.86
1914	1914.01.25	KF1	32200	8	10.53	9.50
1904	1904.02.24	KF1	31800	9	11.84	8.44
1969	1969.01.21	KF3	28600	10	13.16	7.60
1925	1925.02.06	KF1	25200	11	14.47	6.91
1940	1940.03.31	M	22800	12	15.79	6.33
1943	1943.03.10	M	22000	13	17.11	5.85
1906	1906.01.19	KF1	19900	14	18.42	5.43
1936	1936.02.22	M	19300	15	19.74	5.07
1970	1970.01.22	KF3	18000	16	21.05	4.75
1938	1938.02.11	M	17900	17	22.37	4.47
1917	1917.03.21	KF2	17400	18	23.68	4.22
1921	1921.01.18	KF2	16200	19	25.00	4.00
1953	1953.04.27	M	14700	20	26.32	3.80
1918	1918.03.12	KF2	14300	21	27.63	3.62
1916	1916.03.20	KF2	14200	22	28.95	3.45
1941	1941.05.12	M	12600	23	30.26	3.30
1922	1922.05.18	KF2	12500	24	31.58	3.17
1952	1952.05.28	M	12500	25	32.89	3.04
1942	1942.05.23	M	12300	26	34.21	2.92
1958	1958.04.04	KF3	12200	27	35.53	2.81
1963	1963.02.02	KF3	11800	28	36.84	2.71
1923	1923.04.06	KF2	11500	29	38.16	2.62
1935	1935.04.08	M	11500	30	39.47	2.53
1915	1915.05.13	KF2	11100	31	40.79	2.45
1932	1932.05.18	KF2	10600	32	42.11	2.38
1937	1937.05.15	M	10600	33	43.42	2.30
1945	1945.04.30	M	10600	34	44.74	2.24
1949	1949.05.14	M	10600	35	46.05	2.17
1927	1927.05.17	KF2	9840	36	47.37	2.11
1919	1919.05.01	KF2	9700	37	48.68	2.05
1967	1967.05.24	KF3	9430	38	50.00	2.00
1920	1920.05.20	KF2	8860	39	51.32	1.95
1948	1948.05.27	M	8850	40	52.63	1.90
1910	1910.03.20	KF1	8750	41	53.95	1.85
1946	1946.05.06	M	7980	42	55.26	1.81
1950	1950.05.22	M	7780	43	56.58	1.77
1933	1933.05.31	M	7660	44	57.89	1.73
1975	1975.06.02	KF3	7360	45	59.21	1.69
1905	1905.03.19	KF1	7000	46	60.53	1.65
1954	1954.05.09	M	6800	47	61.84	1.62
1912	1912.05.30	KF1	6160	48	63.16	1.58
1944	1944.05.22	M	5840	49	64.47	1.55
1978	1978.05.25	KF3	5470	50	65.79	1.52
1926	1926.04.05	KF2	5330	51	67.11	1.49

Table 4.1: FLOOD FREQUENCY ANALYSIS
Knights Ferry Combined Gages

Water Year	Date	Data Source (gage)	Annual Peak Discharge (cfs)	Rank Order by discharge M	Probability of Occurrence (%) P=(1/T)*100	Return Period (yrs) (Recurrence Interval) T = (N + 1)/M
1929	1929.06.06	KF2	5330	52	68.42	1.46
1930	1930.05.19	KF2	5330	53	69.74	1.43
1955	1955.05.29	M	5310	54	71.05	1.41
1974	1974.04.02	KF3	5300	55	72.37	1.38
1957	1957.05.20	KF3	5140	56	73.68	1.36
1962	1962.06.01	KF3	4970	57	75.00	1.33
1947	1947.05.04	M	4940	58	76.32	1.31
1913	1913.05.19	KF1	4880	59	77.63	1.29
1971	1971.06.27	KF3	4550	60	78.95	1.27
1973	1973.05.16	KF3	4240	61	80.26	1.25
1908	1908.04.21	KF1	3990	62	81.58	1.23
1939	1939.04.08	M	3160	63	82.89	1.21
1934	1934.03.26	M	2940	64	84.21	1.19
1924	1924.05.03	KF2	2100	65	85.53	1.17
1972	1971.12.25	KF3	1770	66	86.84	1.15
1968	1968.04.01	KF3	1730	67	88.16	1.13
1966	1965.12.03	KF3	1710	68	89.47	1.12
1976	1975.10.20	KF3	1590	69	90.79	1.10
1959	1959.02.25	KF3	1480	70	92.11	1.09
1931	1931.05.14	KF2	1250	71	93.42	1.07
1964	1964.01.22	KF3	900	72	94.74	1.06
1960	1960.04.23	KF3	798	73	96.05	1.04
1961	1961.01.08	KF3	219	74	97.37	1.03
1977	1976.12.21	KF3	22	75	98.68	1.01

Post New Melones Dam (1979-1999)					No. data points (N)=	21
Year	Date	Gage	Peak Q (cfs)	M	P=(1/T)*100	T = (N + 1)/M
1997	1/3/97	KF3	7350	1	4.55	22.00
1986	3/15/86	KF3	6620	2	9.09	11.00
1984	1/14/84	KF3	5550	3	13.64	7.33
1983	4/23/83	KF3	5400	4	18.18	5.50
1979	2/21/79	KF3	5170	5	22.73	4.40
1980	1/16/80	KF3	5080	6	27.27	3.67
1998	2/4/98	KF3	4900	7	31.82	3.14
1999	2/12/99	KF3	4340	8	36.36	2.75
1996	3/2/96	KF3	3890	9	40.91	2.44
1982	1/5/82	KF3	3810	10	45.45	2.20
1993	1/17/93	KF3	3070	11	50.00	2.00
1995	3/12/95	KF3	2870	12	54.55	1.83
1985	1/31/85	KF3	2440	13	59.09	1.69
1992	4/23/92	KF3	1900	14	63.64	1.57
1987	3/6/87	KF3	1830	15	68.18	1.47
1991	4/27/91	KF3	1820	16	72.73	1.38
1994	4/26/94	KF3	1640	17	77.27	1.29
1981	4/14/81	KF3	1410	18	81.82	1.22
1988	3/31/88	KF3	1380	19	86.36	1.16
1989	5/3/89	KF3	1330	20	90.91	1.10
1990	5/5/90	KF3	1220	21	95.45	1.05

Methodology: Annual flood peak magnitudes entered and sorted with the largest intensity Q given a rank of M=1.
Probability of Occurrence (P): probability (in percent) that a specified discharge will be equalled or exceeded in a given year. (P=10 means that in any year there is a 10% chance that the value will be exceeded.)
Recurrence Interval/Return Period (T): avg interval (yrs) between events equaling or exceeding a given flow Q.
**: Data From Melones Gage used as stand in for Knights Ferry, recognizing peak flows will likely be somewhat higher at Melones than Knights Ferry due to reservoir storage capacity at Tulloch and Goodwin Dams.*

Table 4-3: Summary of Annual Hydrograph Comparisons. Summary of total runoff (millions of acre feet, maf), annual peak flows (cubic feet per second, cfs), and average summer flows (cfs) for the water year types used to compare pre- Old Melones Dam and post- New Melones Dam annual hydrographs.
(*Data source: http://cdec.water.ca.gov/cgi*).

Year Type	**Water Year**	**Total Runoff (maf)**	**Annual Peak Flow (cfs)**	**(date)**	**July 1- Sept.30 Average (cfs)**	**Plotted Hydrograph**
Critically Dry	1924 1987	0.26 0.37	1,700 1,360	May 3 March 6	106 409	Figure 4-4
Dry	1919 1989	0.77 0.78	7,740 1,270	May 1 March 21; May 4	365 325	Figure 4-5
Wet	1922 1996	1.43 1.49	10,500 3,780	May 18 March 2	668 441	Figure 4-6
Extremely Wet	1904 1996	2.05 2.09	30,400 4,150	March 20 Feb. 9	533 1,764	Figure 4-7

FLOWS (AF)													
Water Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	TOTAL
*Pre-dam Flows **:*													
AVG 1901-1926 *:	11,777	18,377	32,542	83,746	108,923	166,938	232,181	318,454	230,462	76,638	16,988	7,296	1,304,323
AVG 1901-1957:	9,711	23,199	46,870	70,297	93,698	140,970	216,955	304,186	203,184	62,223	13,850	5,851	1,190,995
AVG 1901-2000:	10,372	26,041	48,973	85,392	101,490	141,154	203,571	292,266	193,353	61,051	14,032	6,962	1,184,657
Post-dam Flows:													
AVG 1979-1998:	38,737	32,670	49,969	71,851	72,881	97,478	77,369	77,732	55,313	51,479	45,059	38,034	708,573
*Δ post NM/preOM *:*	*329%*	*178%*	*154%*	*86%*	*67%*	*58%*	*33%*	*24%*	*24%*	*67%*	*265%*	*521%*	*54%*

FLOWS (cfs)													
Water Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	TOTAL
*Pre-dam Flows **:*													
AVG 1901-1926 *:	192	309	530	1,364	1,965	2,720	3,909	5,188	3,880	1,249	277	123	21,705
Post-dam Flows:													
AVG 1979-1998:	631	550	814	1,171	1,315	1,588	1,303	1,266	931	839	734	640	11,782
*Δ post NM/preOM *:*	*329%*	*178%*	*154%*	*86%*	*67%*	*58%*	*33%*	*24%*	*24%*	*67%*	*265%*	*521%*	*54%*

**: 1901-1926 represents the "Pre - Old Melones" dam flow records and is graphed in Figure 4-9.*

***: Unimpaired flow data from "Full Natural Flow" data, USGS gauge at Stanislaus R-Goodwin (SNS), Sensor #65, Elev. 252'.*

Table 4.4: Average Monthly Flows, Stanislaus River. Comparison of unimpaired flows for various time frames with post New Melones dam regulated flows. The most significant changes have occurred with a shift to lower winter and spring flows and higher late summer and fall flows.

No.	Attribute	*Description*
1.	**Spatially complex channel morphology**	*No single segment of channelbed provides habitat for all species, but he sum of channel segments provides high-quality habitat for native species. A wide range of structurally complex physical environments supports diverse and productive biological communities.*
2.	**Streamflows and water quality are predictably variable**	*Inter-annual and seasonal flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to runoff patterns produced by storms and droughts. Seasonal water quality characteristics, especially water temperature, turbidity, and suspended sediment concentration, are similar to regional unregulated rivers and fluctuate seasonally. This temporal "predictable unpredictability" is a foundation of river ecosystem integrity.*
3.	**Frequently mobilized channelbed surface**	*In gravel-bedded reaches, channelbed framework particles of coarse alluvial surfaces are mobilized by the bankfull discharge, which on average occurs every 1-2 years. In sand-bedded reaches, bed particles are in transport much of the year, creating migrating channelbed "dunes" and shifting sand bars.*
4.	**Periodic channelbed scour and fill**	*Alternate bars are scoured deeper than their coarse surface layers by floods exceeding 3- to 5-year annual maximum flood recurrences. This scour is typically accompanied by re-deposition, such that net change in channelbed topography following a scouring flood usually is minimal. In gravel-bedded reaches, scour was most likely common in reaches where high flows were confined by valley walls.*
5.	**Balanced fine and coarse sediment budgets**	*River reaches export fine and coarse sediment at rates approximately equal to sediment inputs. The amount and mode of sediment storage within a given river reach fluctuates, but sustains channel morphology in dynamic quasi-equilibrium when averaged over many years. A balanced coarse sediment budget implies bedload continuity: most particle sizes of the channelbed must be transported through the river reach.*
6.	**Periodic channel migration and/or avulsion**	*The channel migrates at variable rates and establishes meander wavelengths consistent with regional rivers with similar flow regimes, valley slopes, confinement, sediment supply, and sediment caliber. In gravel-bedded reaches, channel relocation can also occur by avulsion, where the channel moves from one location to another, leaving much of the abandoned channel morphology intact. In sand-bedded reaches, meanders decrease their radius of curvature over time, and are eventually bisected, leaving oxbows.*
7.	**A functional floodplain**	*On average, floodplains are inundated once annually by high flows equaling or exceeding bankfull stage. Lower terraces are inundated by less frequent floods, with their expected inundation frequencies dependent on norms exhibited by similar, but unregulated river channels. These floods also deposit finer sediment onto the floodplain and low terraces.*
8.	**Infrequent channel resetting floods**	*Single large floods (i.e., >10-yr to 20-yr recurrences) cause channel avulsions, rejuvenate mature riparian stands to early-successional states, form and maintain side channels, and create off channel wetlands (e.g., oxbows). Resetting floods are as essential for creating and maintaining channel complexity as lesser magnitude floods, but occur less frequently.*
9.	**Self-sustaining diverse riparian plant communities**	*Based on species life history strategies and inundation patterns, initiation, maturation, and mortality of native woody riparian plants culminate in early- and late-successional stand structures and species diversities (canopy and understory) characteristic of self-sustaining riparian communities common to regional unregulated river corridors.*
10.	**Naturally-fluctuating groundwater table**	*Groundwater tables within the floodway are hydrologically connected to the river, and fluctuate on an inter-annual and seasonal basis with river flows. Groundwater and soil moisture on floodplain, terraces, sloughs, and adjacent wetlands are supported by this hydrologic connectivity.*

Table 5.1: Attributes of Alluvial River Ecosystem Integrity, from McBain and Trush (2000). McBain and Trush (2000) developed a list of attributes based on historical conditions in the Tuolumne River and literature documentation of natural fluvial processes in other alluvial rivers.

Period	Years	Total Years	% Years Peak over 8,000 cfs	% Years Peak over 16,000 cfs	Max Flow (cfs)	Max Flow (date)
I.	1904-1937	34	68%	32%	64,500	3/19/1907
II.	1938-1957	20	60%	25%	62,900	12/23/1955
III.	1958-1978	21	29%	14%	40,200	12/24/1964
III.	1979-1998	20	0%	0%	7,350	1/03/1997

Table 5.2: Summary of Flows During Sequence of Air Photographs. Table 5.2 summarizes the flow conditions that occurred between the 1937 (period I), 1957 (II), and 1997 (III) air photographs used in our air photo analysis of historical channel and floodplain conditions. Although the photographs from 1937 do not represent "pre-impact" conditions on the Stanislaus (Old Melones dam built in 1926, first dam in basin 1853), they are the earliest photographs available. (*Data source: USGS* National Water Data Storage and Retrieval System: http://waterdata.usgs.gov/).

XS Site	1999 Measured Width LEW-REW (ft)	1999 *Adjusted Width LEW – REW (ft)*	*10/27/99 Hourly Flow (cfs)*	1996 Measured Width LEW–REW (Mesick)	*1996 Hourly Flow (cfs)*	**Estimated Change in Width Low to High (ft)**
TM1	101.3	--	344	99 (2/96)	300	**+ 2.3**
R10	85.90	--	344	80.25 (2/96)	397	**+ 5.65**
R27	89.3	*104.30*	340	91 (2/96)	319	**-1.7 to +13.30**
R58	95.2	*96.60*	344	93.50 (11/96)	421	**+1.7 to +3.10**
R78	95.40	--	347	82.00 (11/96)	421	**+13.4**

Table 5.3: Comparison Channel Width Surveys (Mesick, 1996 vs. Schneider, 1999). Estimated change (low to high) in channel width at TM1, R10, R27, R58, and R78 from Schneider (1999). "1999 Measured Width" data obtained from surveyed distance, left edge to right edge of water. "1999 Adjusted Width" accounts for unusual features, such as overhanging root wads or gravel piles, at the cross sections (see Schneider, 1999). Hourly flow data during the 1996 and 1999 surveys (from OBB gauge, DWR CDEC website) verify similar channel conditions at the time of surveys.

Table 5.4: Contacted Sources for Historical Cross Sections

Agency/ Company	Office	Person Contacted	Historical X Sections	Notes
USACE	Sacramento	Dale Hatch Wilbur Huang Raymond Dennis	No	Very little information exists on the Stanislaus at the Sacramento office. Most information relates to the dam or the area between Old Melones and New Melones. They have HEC-2 runs but no locations for the cross sections. Information on the Stanislaus was lost when the office moved to its new location.
	Oakdale	Jason Anderson	No	Knew of no USACE surveys on the Stanislaus
		Phil Holcomb	No	No survey information on the covered bridge at the Oakdale office.
FEMA	San Francisco	Cynthia McKenzie	No	Have flood photos, Flood Insurance Studies, and Flood Insurance Rate Maps, but they do not have supporting documentation or data.
Michael Baker (FEMA)	Alexandria, VA	Tom Robinson	Yes	Recovered surveyors notes from archives but they are outside of the study reach and the benchmarks aren't re-locatable. Also included HEC-2 runs but no locations for the cross sections were included.
DWR	Sacramento		No	
	Fresno	Kevin Faulkenberry Iris Yamagata	No No	Have information for other rivers, but not the Stanislaus. Could re-create from gauging records at Orange Blossom Bridge.
USBR	Sacramento	Peggy Manza	No	
Carl Mesick Consultants	El Dorado	Carl Mesick	Yes	Pre and Post gravel enhancement cross sections at enhancement and control sites 1998 to current.
USGS	Sacramento	Pat Shiffer Carole Marlow	No	Could recreate cross sections from gauging records, but most gauges are located at bedrock controls in Goodwin Canyon or outside of the study reach.
		Robert Meyer	Possible	Sending data to plot gauge height vs mean depth. If this shows a relationship measurement notes can be pulled for select years with cross sections.
	Menlo Park			No cross sectional information in the library database nor card catalog

Agency/ Company	Office	Person Contacted	Historical X Sections	Notes
Cal Trans	Sacramento	Nick Burmas Steve Ng Suong Vu	Yes	Bridge cross sections.
Stan. Co. Public Works		Ron Cherry	No	
State Reclamation Board		Sam Brandon	No	
San Joaquin Co. Public Works		Mike Callahan	No	
		John Sanchez	No	Reported that the county gave all information regarding the covered bridge at Knight's Ferry to the USACE.
State Lands Commission		Frank Berry	No	
NRCS	Stockton		No	
Oakdale Irrigation District		Ron Rinitz	No	
SP Cramer		Doug Demko	No	Suggested looking at IFIM reports.
CDFG	Oakdale	Steve Baumgartner	Yes	Only has cross sections for before and after gravel enhancement projects in Goodwin Canyon.
	Sacramento	Rob Titus	No	
EIP Associates		Roy Liety	No	
USFWS	Sacramento	Mark Gard	No	IFIM report on the Stanislaus has cross section but no permanent benchmarks used making re-visiting the cross sections impossible.
NMFS	Sacramento	Dennis Smith	No	Recommended looking at IFIM reports.

Table 6.1: Spawning Gravel Area

Riffles #	RM	Length (ft)	Width (ft)	Area (ft^2)	CMC converted (ft^2)	Quality	Size Dist.	Fine Sed.	Looseness	Notes
1	54.6	89	100	8,900	3,266	beautiful	med	none	very loose	CMC added 395 yd3 in 1999 Above Knight's Ferry Bridge
2	54.4	175	81	14,175	5,202	beautiful	med	none	loose	below Knight's Ferry Bridge
15	52.5	41	127	5,207	1,911	beautiful	small/med	med	loose	CMC added 610 yd3 in 1999
16	52.48	41	129	5,289	1,941	beautiful	small/med	med	loose	CMC added 240 yd3 in 1999
27	50.8	96	85	8,160	2,995	beautiful	large	low	loose	CMC Control Upper 4-Pumps
29	49.75	96	78	7,488	2,748	beautiful	med	low	loose	CMC added 210 yd3 in 1999 Honolulu Bar Rec Area
58	44.5	173	94	16,262	5,968	beautiful	med	med	med/high	CMC added 465 yd3 in 1999
19A	52.06	75	87	6,525	2,395	beautiful	med	low	loose	CMC added 680 yd3 in 1999
28A	50.2	42	82	3,444	1,264	beautiful	med	low	med	CMC added 250 yd3 in 1999
		828	**863**	**75,450**	**27,690**					
TMA		35	106	3,710	1,966	good	med	low	loose	CMC added 470 yd3 in 1999
TMA		45	50	2,250	1,193	"	"	"	"	
5	53.9	5	49	245	90	good	med	low	loose	CMC added 315 yd3 in 1999
12A	52.82	53	113	5,989	2,198	good	med	low	loose	CMC added 380 yd3 in 1999
12B	52.77	50	92	4,600	1,688	good	med	low	loose	CMC added 470 yd3 in 1999
13	52.8	78	84	6,552	2,405	good	small/med	med	loose	CMC added 860 yd3 in 1999
14	52.6	310	81	25,110	9,215	good	med-large	low	loose	CMC added 1055 yd3 in 1999
19	52.13	248	87	21,576	7,918	good	med	med	loose	CMC added 465 yd3 in 1999
26A	51.1	60	125	7,500	2,753	good	med/large	low	loose	
32	49.4	40	33	1,320	484	good	med	med	loose	
32A	49.3	90	60	5,400	1,982	good	med			
35	48.9	300	120	36,000	13,212	good	med	low	loose	
43	46.9	130	94	12,220	4,485	good	med	med/low	loose	CMC added 315 yd3 in 1999
57new	44.6	80	52	4,160	1,527	good	med	med	med/high	CMC added 645 yd3 in 1999
78	40.2	236	80	18,880	6,929	good	med	med	med-high	CMC added 405 yd3 in 1999
78	40.2	60	40	2,400	881	"	"	"	"	
		1,820	**1,266**	**157,912**	**57,954**					

		(ft)		(ft^2)	(ft^2)					
					CMC					
Riffles #	RM	Length	Width	Area	converted	Quality	Size Dist.	Fine Sed.	Looseness	Notes
TM1		75	95	7,125	3,776	acceptable	large	med	med	
21.5	51.6	100	75	7,500	2,753	acceptable	large	low	med/high	merges into R22
25	51.2	80	50	4,000	1,468	acceptable	med/large	med		
27A	50.7	40	30	1,200	440	acceptable	med			
36A	48.8	40	25	1,000	367	acceptable	med			
60	44	60	40	2,400	881	acceptable	med/large	low/med	loose	
63	43.7	160	75	12,000	4,404	acceptable	med	med	med	
71	41.9	200	29	5,800	2,129	acceptable	med	med	med	
		755	**419**	**41,025**	**15,056**					
		3,403	**2,548**	**274,387**	**100,700**	total of beautiful, good, acceptable				
		NA	**NA**	**95,448**	**37,098**	- CMC ehance riffles (CMC 2000)				
				178,939	**63,602**	total less CMC				

Table 6.2: Relationship between CMC 2000 Riffles and DWR 1994 Riffles

CMC riffle #	CMC RM	CMC enhanced/ control	DWR RM	Comparable pebble counts this study & DWR 1994	Notes
TMA	56.8	enhanced		no	
TM1	56.6	control		no	
			2MI	no	DWR no RM can't tell which of the 3 riffles it is
R1	54.55	enhanced			
R5	53.9	enhanced			
R10	53.5	control	53.4	yes	
			53.4	no	Couldn't locate, too many riffles close together
R12	53.3	control			
R12A	52.82	enhanced			
R12B	52.77	enhanced			
R13	52.73	enhanced			
R14	52.6	enhanced	52.5	no	
R14A	52.57	enhanced			
R15	52.51	enhanced			
R16	52.48	enhanced			
R19	52.13	enhanced			
R19A	52.06	enhanced			
R20	51.8	control	51.9	yes	
R24	51.3		51.4		Couldn't re-locate, this entire reach has become a run
R27	50.8	control	50.9	yes	Site of 4 pumps riffle project 1994
R28A	50.2	enhanced			
R29	49.75	enhanced	49.7	no	
R32	49.4		49.4	no	Has become a run
R34	49.2		49.2	yes	
R35	48.9		48.8	no	R36 (fadded red tag on tree) has become a run, R35 is suitable, too close to tell
R40	47.3		47.3	no	Not measured because washed out in center
R42	47		47.0	no	
R43	46.9	enhanced			
R56	45.1		45.2	yes	
R57	44.6	enhanced	44.7	no	
R58	44.5	enhanced		no	
R59	44.4	control	44.2	yes	
R65	43.2		43.2	yes	
R69	42.3		42.2	yes	
R76	40.35	control			
R78	40.2	enhanced	40.2	no	
			38	no	Outside study reach
			36	no	Outside study reach
			34.15	no	Outside study reach

Table 6.3: Riffle Usage by Spawning Salmon

Degree of Spawning Usage	# of riffles within each reach (# of enhanced riffles)	
	Goodwin Dam to Willms Pond	Willms Pond to Valley Oak Park
High	14 (10)	0
Medium	7 (4)	0
Low	9 (0)	5 (2)
Total	30 (14)	5 (2)

Table 6.4: Summary Statistics Comparing Pebble Counts From 1993 (DWR 1994) to 2000 (this study)

Riffle #	River Mile	Year of Study	D10	D16	D25	D50	D75	D84	D90	dg [1]	sg [2]
			Size (mm)								
R10	53.4	1993	24.5	28.0	31.0	46.5	69.0	80.0	92.0	47.33	1.69
		2000	<4	4.4	6.1	15.6	37.4	56.5	74.4	15.82	3.57
Difference			--	-23.6	-24.9	-30.9	-31.6	-23.5	-17.6	-31.5	1.9
R20	51.9	1993	5.1	8.9	17.0	36.5	66.0	79.0	97.0	26.52	2.98
		2000	<4	5.5	8.3	25.4	68.0	79.1	86.6	20.85	3.80
Difference			--	-3.4	-8.7	-11.1	2.0	0.1	-10.4	-5.7	0.8
R34	49.2	1993	12.0	18.5	25.0	41.0	64.0	59.0	76.0	30.04	1.79
		2000	<4	4.7	6.7	15.0	30.5	41.4	50.7	13.95	2.97
Difference			--	-13.8	-18.3	-26.0	-33.5	-17.6	-25.3	-16.1	1.2
R42	47	1993	12.5	18.0	24.0	38.0	56.0	66.0	73.0	34.47	1.91
		2000	8.1	12.2	17.3	30.4	54.2	67.6	86.8	28.74	2.35
Difference			-4.4	-5.8	-6.7	-7.6	-1.8	1.6	13.8	-5.7	0.4
R56	45.2	1993	<4	<4	4.2	14.0	27.0	33.5	37.0	--	--
		2000	<4	<4	7.4	22.3	43.1	56.4	68.9	--	--
Difference			--	--	3.2	8.3	16.1	22.9	31.9	--	--
R59	44.2	1993	12.0	17.5	22.5	34.5	49.0	59.0	68.0	32.13	1.84
		2000	<4	<4	8.3	18.1	28.4	32.0	37.9	--	--
Difference			--	--	-14.2	-16.4	-20.6	-27.0	-30.1	--	--
R65	43.2	1993	16.5	21.5	27.5	44.0	68.0	76.0	86.0	40.42	1.88
		2000	<4	4.3	11.9	23.6	39.9	47.6	56.4	--	--
Difference			--	-17.2	-15.6	-20.4	-28.1	-28.4	-29.6	--	--

Riffle #	River Mile	Year of Study	Size (mm) D10	D16	D25	D50	D75	D84	D90	dg [1]	sg [2]
R69	42.2	1993	<4	4.0	6.6	16.5	33.0	50.0	70.0	14.05	3.56
		2000	<4	<4	<4	9.2	23.1	33.1	43.0	--	--
Difference			--	--	--	-7.3	-9.9	-16.9	-27.0	--	--
R77	40.2	1993	22.0	30.0	41.0	68.0	82.0	88.0	99.0	51.38	1.71
		2000	14.6	19.9	27.3	44.5	80.1	104.2	129.2	45.54	2.29
Difference			-7.4	-10.1	-13.7	-23.5	-1.9	16.2	30.2	-5.8	0.6

Footnotes

[1] Geometric mean, $dg = (D16 * D84)^{0.5}$ (mm)

[2] Sorting index, $sg = (D84/D16)^{0.5}$, dimensionless

Note: sg, skewness, was not included because the pebble count method doesn't fully capture the smaller size categories that may significantly affect the skewness of the distribution.

Table 6.5: Comparison of Bulk Samples from DWR (1994) and CMC (2000)

Surface, Subsurface and Combined Samples

CMC Riffle #	DWR RM	Sample Type	Year Report	Sampled	D25	D50	D75
R10	53.4	Surface	DWR	1993	29.83	60.27	82.31
			CMC	1999	14.16	40.16	78.60
		Subsurface	DWR	1993	13.64	31.33	58.06
			CMC	1999	4.73	17.78	53.84
		Combined	DWR	1993	16.26	33.48	61.08
			CMC	1999	7.65	28.11	62.99
R20	51.9	Surface	DWR	1993	19.15	48.18	87.91
			CMC	1999	28.11	50.31	96.59
		Subsurface	DWR	1993	13.15	36.51	77.01
			CMC	1999	25.84	49.29	96.57
		Combined	DWR	1993	14.72	39.90	80.65
			CMC	1999	27.38	50.03	96.59
R27	50.9	Surface	DWR	1993	17.15	37.92	84.44
			CMC	1999	22.82	41.10	58.89
		Subsurface	DWR	1993	5.81	27.38	61.20
			CMC	1999	6.37	20.97	37.97
		Combined	DWR	1993	8.33	31.31	68.01
			CMC	1999	16.15	31.43	51.70
R58	44.7	Surface	DWR	1993	3.95	15.11	31.43
			CMC	1999	2.31	12.45	24.04
		Subsurface	DWR	1993	0.71	4.28	21.23
			CMC	1999	<0.85	6.50	19.63
		Combined	DWR	1993	0.78	6.91	23.43
			CMC	1999	0.99	9.41	22.25
R59	44.2	Surface	DWR	1993	15.14	36.55	60.84
			CMC	1999	0.88	9.22	27.55
		Subsurface	DWR	1993	4.07	18.69	37.52
			CMC	1999	<0.85	7.65	24.25
		Combined	DWR	1993	6.42	22.93	45.84
			CMC	1999	0.86	8.53	26.00

DWR = Department of Water Resources Report 1994
CMC = Carl Mesick Consultants Report 2000
RM = River Mile

Table 6.6: Comparison Among Studies in Spawning Gravel Area and Length

Comparison Among Studies in Spawning Gravel Area

Study	Reach of study (# of riffles)	Area (ft^2)	Reach of study (# of riffles)	Area (ft^2)	Reach of study (# of riffles)	Area (ft^2)
CDFG 1972	Goodwin to Knight's Ferry (3)	15,900			Knight's Ferry to Riverbank (86)	376,700
DWR 1994	Goodwin to Knight's Ferry (1)	5,500	Knight's Ferry to Oakdale (48)	92,885	Knight's Ferry to Riverbank (64)	226,620
This Study 2000	Goodwin to Knight's Ferry including enhancements, adjusted based on CMC criteria (2)	6,935	Knight's Ferry to Oakdale including enhancements, adjusted based on CMC criteria (29)	93,765		
	Goodwin to Knight's Ferry excluding enhancements, adjusted based on CMC criteria (2)	4,694	Knight's Ferry to Oakdale excluding enhancements, adjusted based on CMC criteria (29)	58,908		

Comparisons Among Studies in Length of Spawning Riffles

Study	Reach of study (# of riffles)	Length (ft)	Reach of study (# of riffles)	Length (ft)	Reach of study (# of riffles)	Length (ft)
CDFG 1972	Goodwin to Knight's Ferry (3)	505	Knight's Ferry to Orange Blossom Bridge (29)	5,097	Orange Blossom Bridge to Oakdale Bridge (27)	3,775
DWR 1994	Goodwin to Knight's Ferry (1)	NA	Knight's Ferry to Orange Blossom Bridge (25)	NA	Orange Blossom Bridge to Oakdale Bridge (23)	NA
This Study 2000	Goodwin to Knight's Ferry (2)	155	Knight's Ferry to Orange Blossom Bridge including enhancements (24)	2,621	Orange Blossom Bridge to Oakdale Bridge including enhancements (5)	603
			Knight's Ferry to Orange Blossom Bridge excluding enhancements (11)	1,493	Orange Blossom Bridge to Oakdale Bridge excluding enhancements (2)	220

I. A&B. SHIELD'S EQN for Critical Shear Stress (T_c) to mobilize gravel

Solve for depth to attain T_c (*Using slope from 1:24,000 topo map*)

ρ_w = 1000 kg/m^3

ρ_s = 2650 kg/m^3

g = 9.81 m/s^2

T^*_{ci} = 0.047

$T_{ci} = T^*_{ci}(\rho_s - \rho_w)g(d_i)$ *[I. A.]*

$R = T_d/(\rho_f g S_2)$ *[I. B.]*

II. B, C, D: Calc. area inundated at D_T, using XS plots

Avg V with Manning's Eqn

$V=1.49(R^{.67}S^{.5})/n$

Discharge Q w/ Flow Eqn

Q=VA

XS Site	Ptx size %ile	Ptx Size FIELD (mm)	Critic Shear St T_c (N/m^2)	Shear Stress T_d (N/m^2)	S_1 (1:24K topo map slope)	Hydr. Rad $R=T_d/(\rho_f g S_2)$ (m)	*assume R=D* D_T (ft)	*Note*	Area A_T @D_T (ft^2)	n *back calcul'd*	V *back-calc* (ft/s)	Q *Q=VA (w/ map n)* (cfs)	Estim. Return Period Pre NM Dam (FFA)	Estim. Return Period Post NM Dam (FFA)
TM1	50	*35.00*	26.63	26.63	0.004444	0.61	2.00		145	0.077	2.05	**297**	**~1**	**<1**
	84	*100.00*	76.08	76.08	0.004444	1.74	5.72		580	0.077	4.12	**2,389**	**~1.2**	**~1.65**
R1	50	40.20	30.58	30.58	0.001176	2.65	8.69		1060	0.035	6.17	**6,544**	**~1.6**	**10+**
	84	70.00	53.25	53.25	0.001176	4.61	*15.13*	*	--	*0.035*	*8.94*	--	--	--
R5	50	36.10	27.46	27.46	0.001176	2.38	7.81		898	0.028	7.24	**6,502**	**~1.6**	**10+**
	84	85.40	64.97	64.97	0.001176	5.63	*18.46*	*	--	*0.028*	*12.86*	--	--	--
R28A	50	32.30	24.57	24.57	0.000952	2.63	8.63	*	--	0.034	5.62	--	--	--
	84	68.50	52.11	52.11	0.000952	5.58	*18.30*	*	--	*0.034*	*9.28*	--	--	--
R78	50	28.90	21.99	21.99	0.000714	3.14	10.29		1065	0.035	5.40	**5,749**	**~1.5**	**8+**
	84	57.30	43.59	43.59	0.000714	6.22	*20.41*	*	--	*0.035*	*8.52*	--	--	--

II. A. FLOW AND MANNINGS EQNS (to back-calculate n) **Q= VA, $V=1.49(R^{.67}S^{.5})/n$**

XS Site	*[1]* Q (cfs)	*[2]* A (ft2)	*[3]* WP (ft)	*[1] / [2]* V (ft/s) V=Q/A	*[2] / [3]* R (ft) R=A/WP	Slope S_1 (topo)	n (map)
		Nov 98 survey data					
TM1	1800	557	140	3.23	3.98	0.00444	**0.077**
R1	1800	486	120	3.70	4.04	0.00118	**0.035**
R5	1800	533	214	3.38	2.49	0.00118	**0.028**
R28A	1800	536	135	3.36	3.98	0.00095	**0.034**
R78	1800	543	110	3.31	4.95	0.00071	**0.035**

calculated value

Notes: ** Indicates XS's where estimated mobilizing depths exceed bankfull conditions, so no discharge could be calculated*

D_{50} and D_{84} particle size from pebble counts (Falzone, summer 2000) except at TM1, where restoration gravel size (Mesick, 1998) is used (in italic).

Areas in IIA computed by counting squares of plotted cross sections (Mesick, Nov. 1998), using 1800 cfs as "bankfull."

Areas in IIB computed by graphing the estimated mobilizing depth and counting squares in Mesick (Nov. 1998) surveys (attached).

Wetted perimeter determined via trigonometric calculations for each plotted cross section (Mesick, Nov. 1998).

The topographic map slope is used for slope estimates, with surveys (Nov. 2000) resulting in a slope at R1 or 0.0021 and R28A or 0.000473.

Table 7.1: Bed Mobility Calculations -- 5 Sites. The following table summarizes the flows needed to mobilize gravels at five different study sites (all nine sites studied in Appendix C) on the Lower Stanislaus River. Bed mobility thresholds are modeled using basic basic shear stress, velocity and flow equations. D_{84} mobilizing depths exceeded the cross sectional survey data for all sites except for TM1, and the D_{50} mobilizing depths exceeded survey data at R28A, thereby limiting an estimate of mobilizing flows. We recommend more extensive surveys to address this problem *(Data Source: Mesick, Nov. 1998 surveys)*.

Riffle	RM	Advantages	Disadvantages
TM1	56.6	✓ Bed mobility analysis results in flow estimates for mobilizing both the D_{50} (280cfs) and the D_{84} (2,400 cfs).	✓ A general value for the D_{50} and D_{84} based on the size of restoration gravels had to be used due to a lack of pre-project pebble count data at TM1. Thus, the imported gravels are unusually mobile and would probably wash out in high flow releases. ✓ Site conditions at TM1, with a slope four times as steep as other sites, do not necessarily best reflect the conditions at most of the spawning sites in the study reach. Bed mobility equations are highly sensitive to the steep slope, resulting in potential underestimated mobilizing flows.
R1	54.55	✓ Existing cross section data allows for an estimate of D_{50} mobilizing flow (6,450cfs). ✓ R1 is covered in our aerial photograph analysis. ✓ Field slope data collected Nov. 2000 are equivalent to topographic slopes.	✓ Existing cross section data does not allow for an estimate of D_{84} mobilizing flow due to the very deep mobilizing depth (over 15 ft) and limited cross section data.
R5	53.9	✓ Existing cross section data allows for an estimate of D_{50} mobilizing flow (6,500cfs). ✓ R5 is covered in our aerial photograph analysis. ✓ Estimate of changes in floodplain inundation (chapter 5) are performed at R5.	✓ Existing cross section data does not allow for an estimate of D_{84} mobilizing flow due to the very deep mobilizing depth (over 18 ft) and limited cross section data.
R28A	50.2	✓ Estimate of changes in floodplain inundation (chapter 5) are performed at R28A. ✓ R28A is representative of four of nine total sites in which estimates of D_{50} and D_{84} bed mobility flows could not be estimated due either to limited cross section data and/or an indication that flows in far excess of 5,000-8,000 cfs are needed for bed mobilization.	✓ Existing cross section data does not allow for an estimate of either D_{50} or D_{84} mobilizing flows as even just 8.6 feet depth exceeds the cross section data. ✓ Field slope data collected Nov. 2000 (not used in calculations) indicates a slope that is half as steep as the topographic slope, indicating even larger flows are necessary to mobilize gravels.
R78	40.2	✓ Existing cross section data allows for an estimate of D_{50} mobilizing flow (5,750cfs).	✓ This site, which is downstream of Oakdale, is at the very bottom of our study reach and is not covered in air photo analysis.

Table 7.2: Selected Bed Mobility Riffle Sites. A summary of the sites selected in the bed mobility analysis summarized in table 7-1, as well as notes regarding advantages and disadvantages in using these sites to characterize bed mobility flows for the Lower Stanislaus River. Plotted cross sections with mobilizing depths indicated for each of these five sites is found in Appendix C. Bed Mobilization calculations from all nine riffle sites studies is found in Appendix C. See figures 6.1 to 6.5 for map identifying the location of each site.

Table 8.1: Maps Used in Sediment Budget Analysis

Map Title	Publisher	Year	Scale	Notes
Oakdale	USGS	1994	1:100,000	
Oakdale	USGS	1987	1:24,000	Photo revised from 1968 USGS map
Oakdale	USGS	1968	1:24,000	
Oakdale	USGS	1953	1:24,000	
Oakdale	USGS	1915	1:31,680	
Knight's Ferry	USGS	1987	1:24,000	Photo revised 1962 USGS map
Knight's Ferry	USGS	1962	1:24,000	
Copperopolis	USGS	1916	1:62,500	Original Knight's Ferry map at smaller scale

Table 8.2: Estimated Gravel Mining Area and Volume

Reach	Pit #	Method of Extraction	Floodplain/ In Channel	Measured Area (yd^2)	Estimated Depth (yd)	Volume (yd^3)	Source/Notes
Goodwin Canyon							
	I	Pit	Floodplain	11,852	3.3	39,506	1978 air photos
	II	Pit	Floodplain	19,753	3.3	65,843	1999 air photos
		Total extracted	**Floodplain**	**31,605**		**105,349**	
			In Channel	**0**		**0**	
			Total	**31,605**		**105,349**	
Goodwin to Orange Blossom Bridge							
	A	Skim	Floodplain	27,654	0.7	18,436	1978 air photos
	B	Pit	Floodplain	45,432	3.3	151,440	1978 airphotos
	C	Pit	Floodplain	25,679	3.3	85,596	CMC map
	D	Dredge	In Channel	69,136	1.7	115,226	CMC map
	E	Pit	Floodplain	124,444	3.3	414,813	1999 air photos
	F	Pit	Floodplain	49,383	3.3	164,608	1978 air photos
	G	Skim	Floodplain	138,271	0.7	92,181	1978 air photos/CMC map
	H	Dredge	In Channel	27,654	1.7	46,090	CMC map
	I	Pit	In Channel	94,814	6.7	632,096	all air photos and maps
	J	Pit	Floodplain	25,679	3.3	85,596	1956 air photo
	J1	Skim	In Channel	63,210	0.7	42,140	1956, 1957 air photo
	K	Pit	Floodplain	19,753	3.3	65,843	1964 air photo
	K1	Pit	Floodplain	43,457	3.3	144,855	1957 & 1999 air photo
	L	Skim	In Channel	69,136	0.7	46,090	1964 air photo
	M	Pit	Floodplain	7,901	3.3	26,337	1956 air photo
	N	Pit	Floodplain	266,666	6.7	1,777,770	all air photos and maps
	N1	Pit	Floodplain	33,580	3.3	111,934	1937 air photo
	O	Dredge	In Channel	19,753	1.7	32,922	CMC map
	P	Pit	Floodplain	7,901	3.3	26,337	1937 air photo
	Q	Pit	Floodplain	67,160	3.3	223,867	1997 air photo
	R	Skim	In Channel	65,185	0.7	43,457	1956 air photo

Reach	Pit #	Method of Extraction	Floodplain/ In Channel	Area (yd^2)	Depth (yd)	Volumne (yd^3)	Source/Notes
	S	Pit	Floodplain	19,753	3.3	65,843	1957 air photo
	T	Pit	Floodplain	17,778	3.3	59,259	1956 air photo
	U	Skim	In Channel	110,617	0.7	73,745	1956 air photo
	W	Pit	Floodplain	9,877	3.3	32,922	1953 USGS map
		Total extracted	**Floodplain**	**930,366**		**3,547,639**	
			In Channel	**519,504**		**1,031,765**	
			Total	**1,449,870**		**4,579,404**	
Orange Blossom Bridge to Oakdale							
	1	Pit	Floodplain	21,728	3.3	72,428	1964 air photo
	2	Pit	Floodplain	229,135	6.7	1,527,565	all photos, 1953 USGS map,
	3	Pit	Floodplain	11,852	3.3	39,506	1964 air photo
		Total extracted	**Floodplain**	**262,715**		**1,639,499**	
			In Channel	**0**		**0**	
			Total	**262,715**		**1,639,499**	
	Total for all reaches		**Floodplain**	**1,224,686**		**5,292,487**	
			In Channel	**519,504**		**1,031,765**	
			Total	**1,744,190**		**6,324,252**	

Table 8.3 Estimated Depths of Different Methods of Gravel Extraction.

Method of Extraction	Estimated Depth of Extraction (ft)
Pit: Shallow	10
Pit: Deep	20
Skim	2
Dredging	5

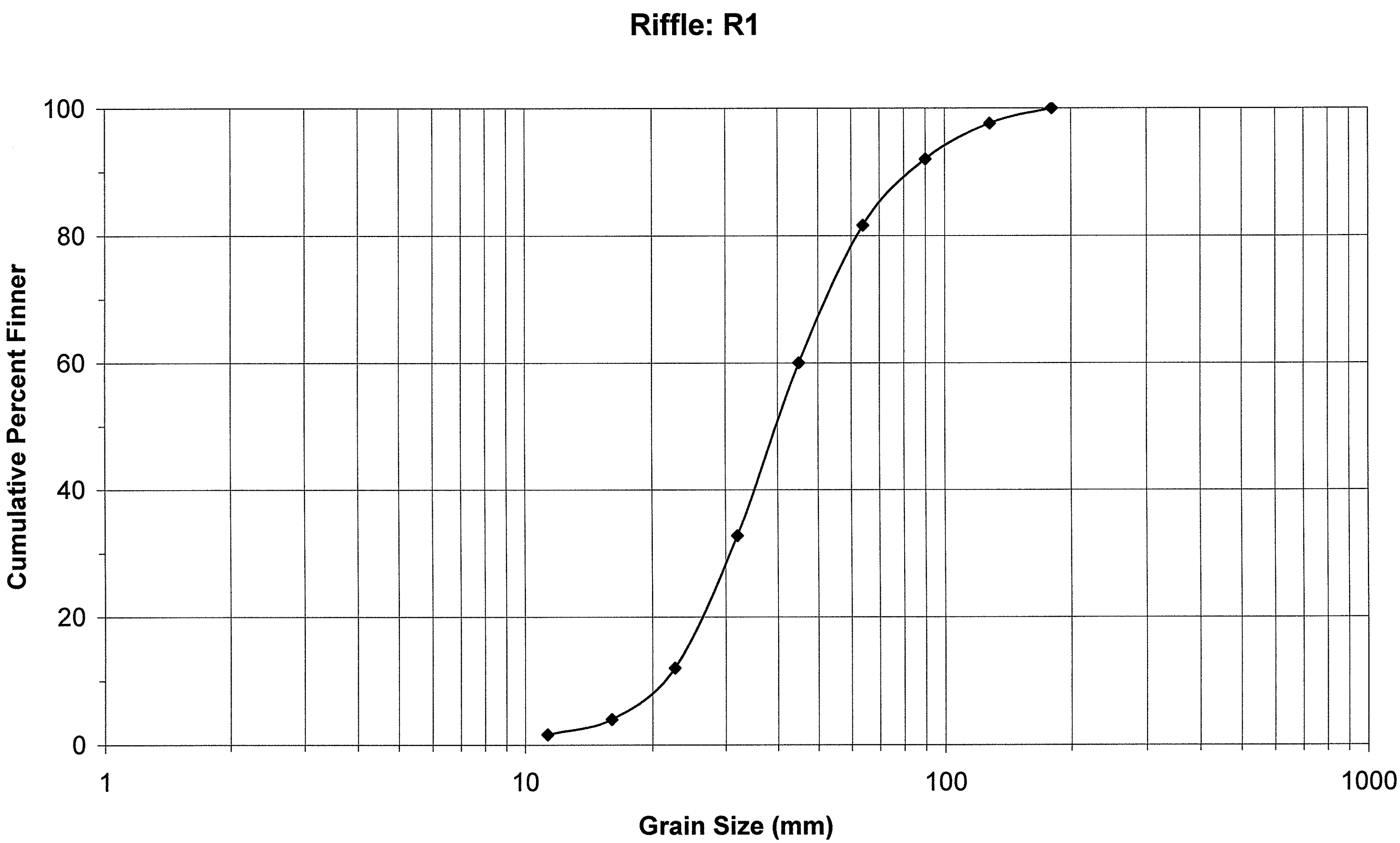
Appendix A, Table 1

Summary Statistics of Pebble Counts Completed in 2000 and Interpreted from 1994 DWR Report

		Size (mm)								
Riffle #	RM	D10	D16	D25	D50	D75	D84	D90	dg	sg
Field data collected Summer 2000										
R1	54.55	21.0	24.4	28.5	40.2	58.2	70.0	85.0	41.33	1.69
R5	53.9	12.6	15.4	21.1	36.1	60.8	85.4	113.8	36.27	2.35
RTB		8.2	11.4	15.4	34.7	58.5	73.5	87.2	28.94	2.54
R10	53.5	<4	4.4	6.1	15.6	37.4	56.5	74.4	15.82	3.57
R12	53.3	<4	5.8	7.9	20.4	46.6	57.4	66.2	18.32	3.13
R12B	52.77	<4	<4	9.1	24.2	43.1	55.9	66.9	--	--
R14	52.6	7.3	9.0	11.6	25.1	41.2	50.3	61.2	21.27	2.36
R20	51.8	<4	5.5	8.3	25.4	68.0	79.1	86.6	20.85	3.80
R20II		4.8	6.6	9.8	27.0	46.1	59.4	72.4	19.79	3.00
R27	50.8	11.6	14.9	20.1	30.1	40.8	44.8	54.4	25.79	1.74
R28A	50.2	10.9	14.7	20.3	32.3	55.3	68.5	81.8	31.71	2.16
R29	49.75	11.8	17.7	24.6	38.5	62.6	77.3	87.6	36.99	2.09
R34		<4	4.7	6.7	15.0	30.5	41.4	50.7	13.95	2.97
R42		8.1	12.2	17.3	30.4	54.2	67.6	86.8	28.74	2.35
R43	46.9	19.7	24.8	32.1	44.8	65.1	78.7	87.8	44.18	1.78
R56		<4	<4	7.4	22.3	43.1	56.4	68.9	--	--
R58(newR57)	44.6	10.1	13.4	18.0	30.9	49.7	59.2	68.3	28.11	2.11
R59	44.4	<4	<4	8.3	18.1	28.4	32.0	37.9	--	--
R65		<4	4.3	11.9	23.6	39.9	47.6	56.4	--	--
R69		<4	<4	<4	9.2	23.1	33.1	43.0	--	--
R77		14.6	19.9	27.3	44.5	80.1	104.2	129.2	45.54	2.29
R78	40.2	12.3	14.7	17.9	28.9	47.1	57.3	64.4	29.02	1.97

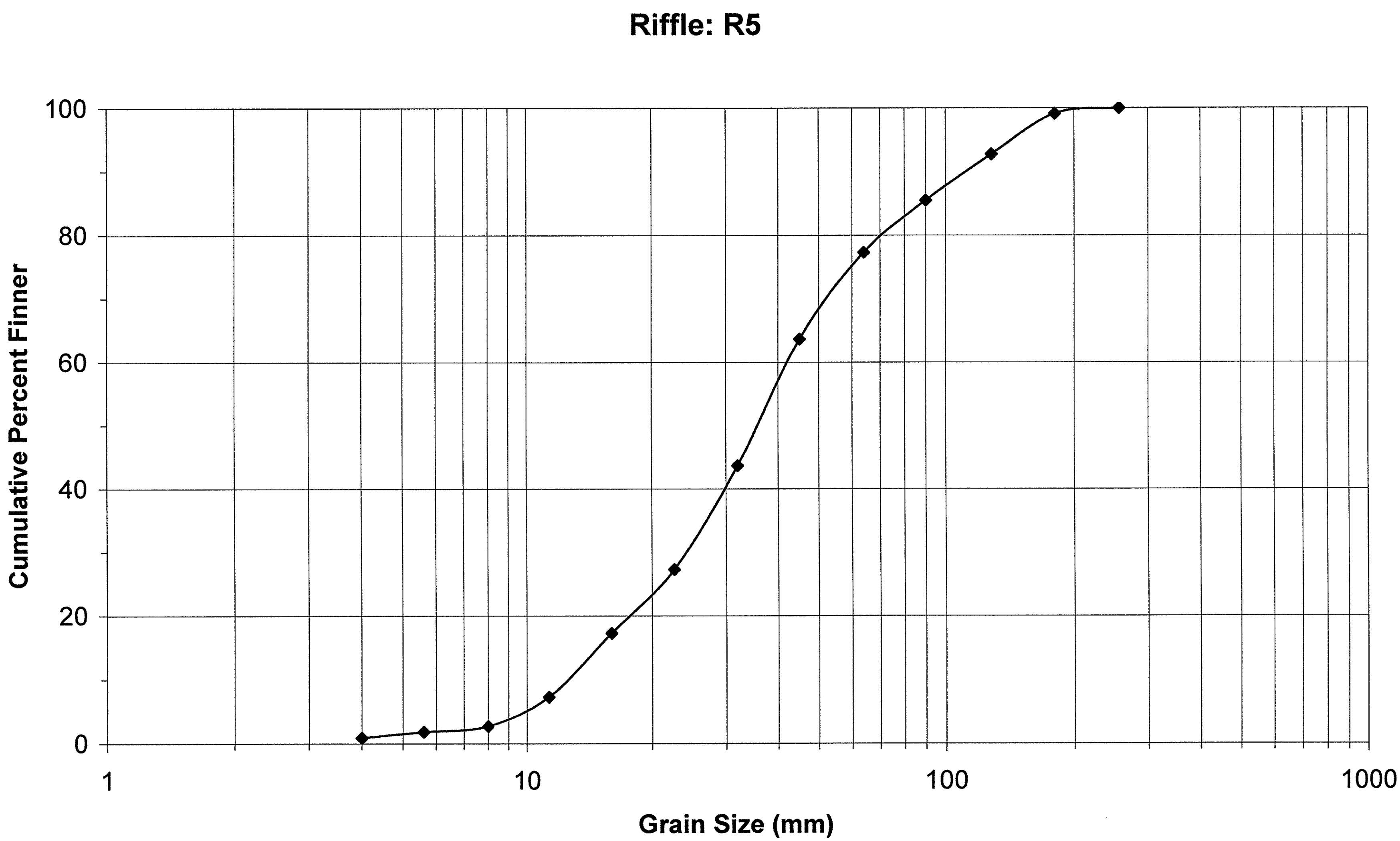
		Size (mm)								
Riffle #	RM	D10	D16	D25	D50	D75	D84	D90	dg	sg
DWR Riffles 1994 (data interpolated from Wolman plots)										
R10	53.4	24.5	28.0	31.0	46.5	69.0	80.0	92.0	47.33	1.69
R20	51.9	5.1	8.9	17.0	36.5	66.0	79.0	97.0	26.52	2.98
R27	50.9	8.0	20.0	31.0	64.0	105.0	135.0	155.0	51.96	2.60
R29	49.7	<4	4.0	8.8	19.5	35.0	47.0	62.0	13.71	3.43
R34	49.2	12.0	18.5	25.0	41.0	64.0	59.0	76.0	33.04	1.79
R42	47	12.5	18.0	24.0	38.0	56.0	66.0	73.0	34.47	1.91
R56	45.2	<4	<4	4.2	14.0	27.0	33.5	37.0	--	--
R58(newR57)	44.7	10.8	16.5	20.0	32.0	48.0	58.0	72.0	30.94	1.87
R59	44.2	12.0	17.5	22.5	34.5	49.0	59.0	68.0	32.13	1.84
R65	43.2	16.5	21.5	27.5	44.0	68.0	76.0	86.0	40.42	1.88
R69	42.2	<4	4.0	6.6	16.5	33.0	5.0	70.0	4.44	1.13
R77	40.2	22.0	30.0	41.0	68.0	82.0	88.0	99.0	51.38	1.71

RM = river mile
dg = (D16*D84$)^{0.5}$ (mm)
sg = $(D84/D16)^{0.5}$, dimesionless
note: sg, skewness, was not included because the pebble count method doesn't fully capture the smaller size categories that may significantly affect the skewness of the distribution.



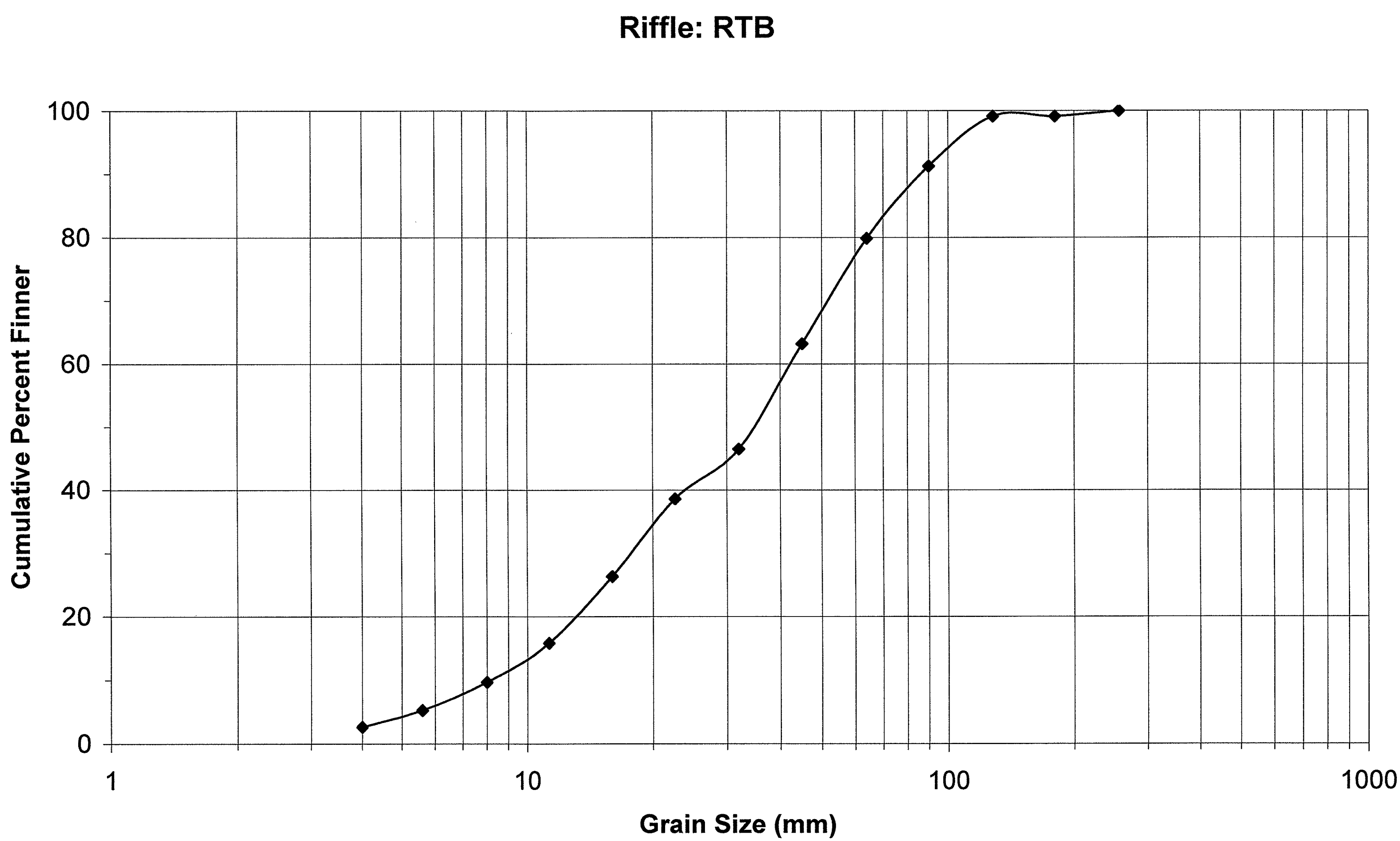
D16=21.0 D50=40.2 D84=70.0

Appendix A, Figure 1



D16=15.4 D50=36.1 D84=85.4

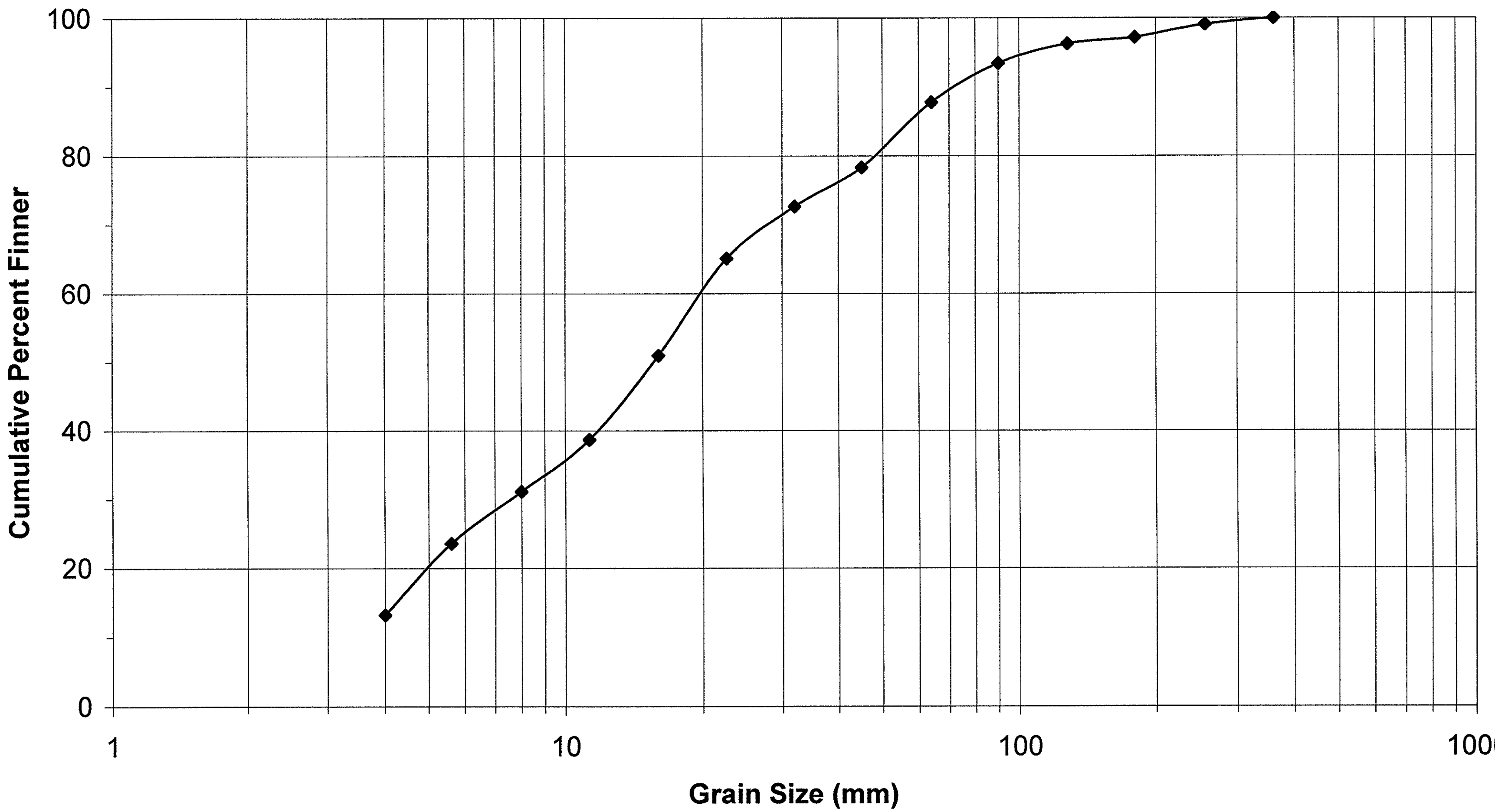
Appendix A, Figure 2



D16=11.4 D50=34.7 D84=73.5

Appendix A, Figure 3

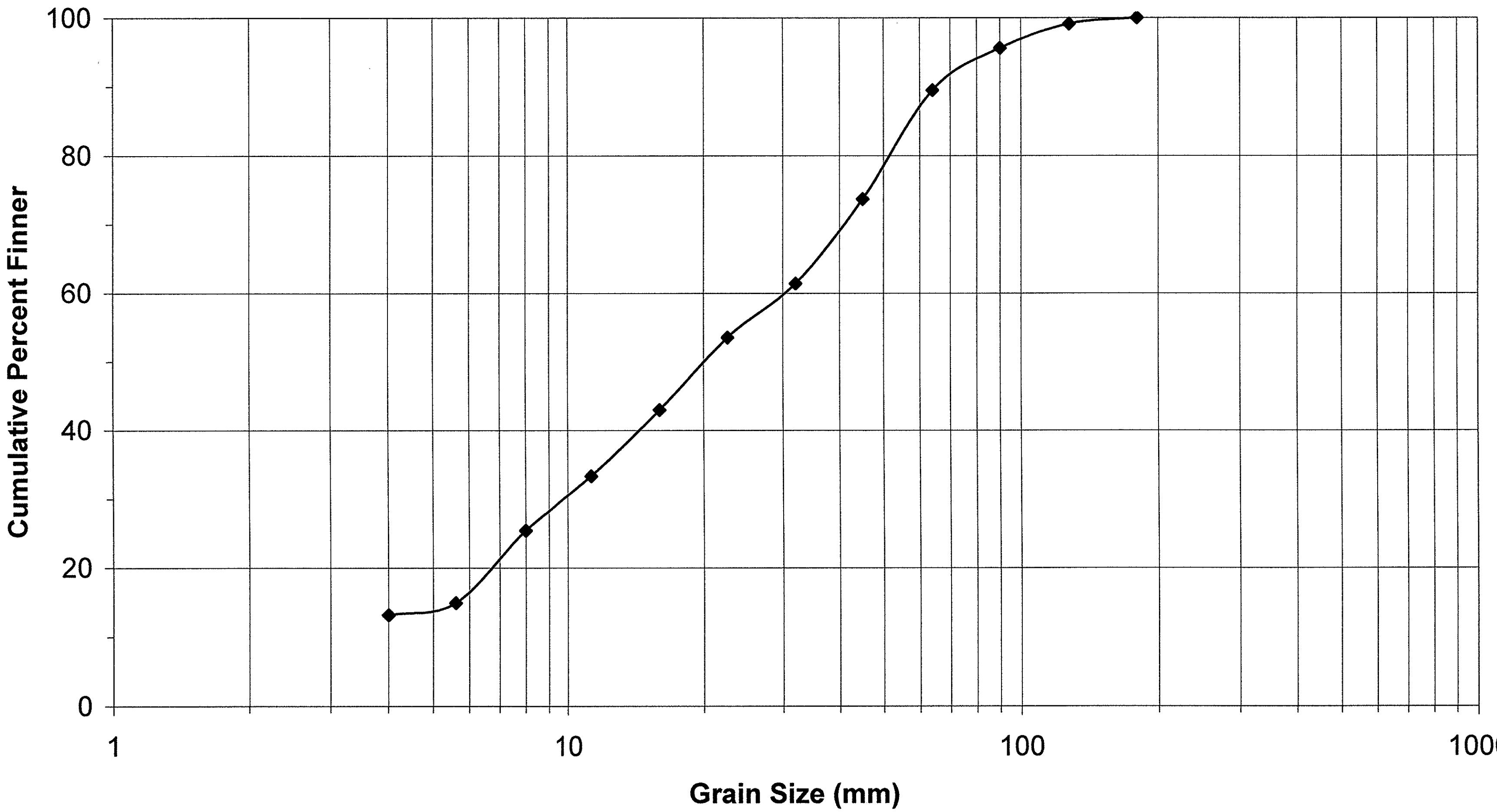
Riffle: R10



D16=4.4 D50=15.6 D84=56.5

Appendix A, Figure 4

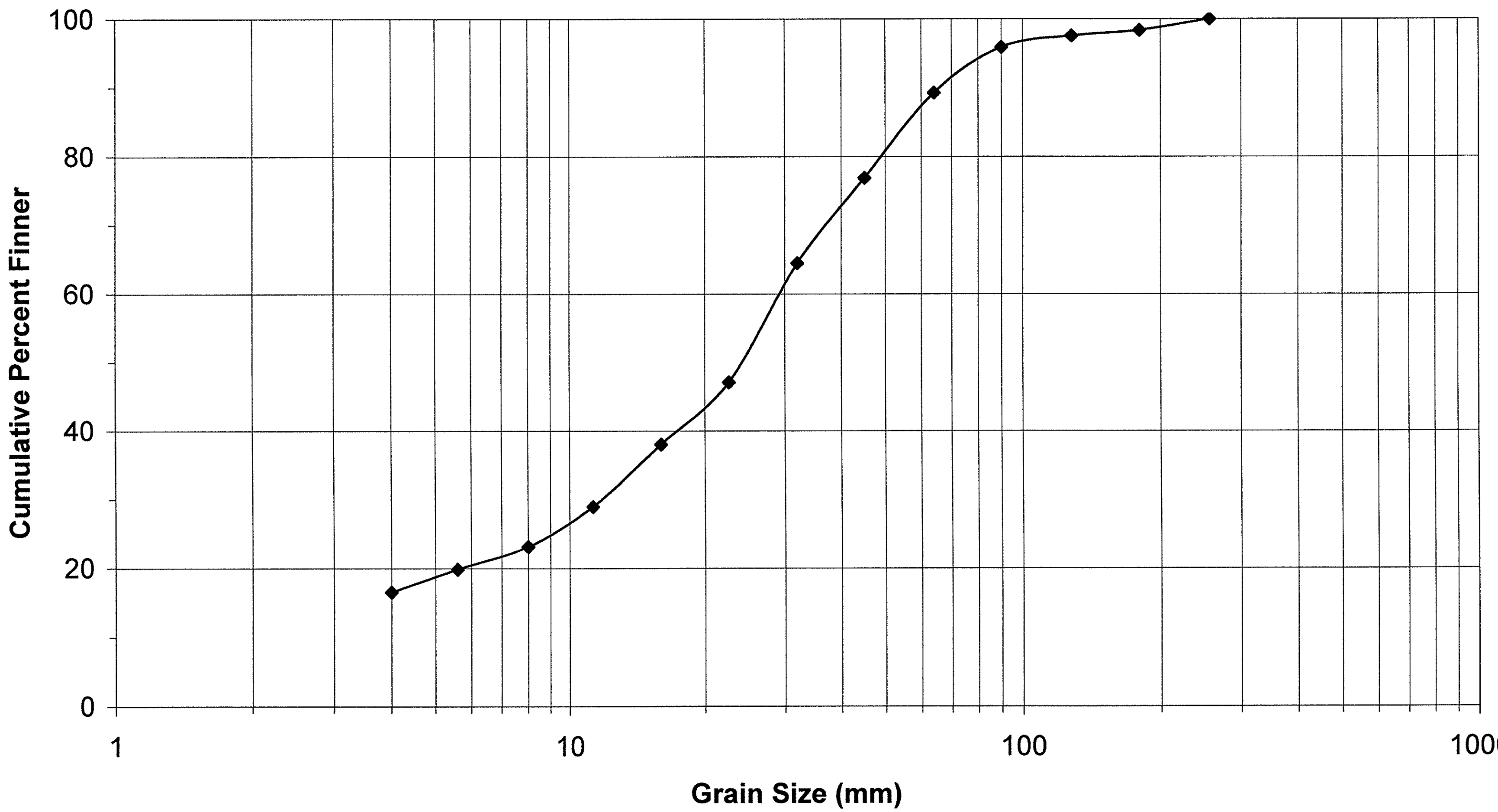
Riffle: R12



D16=5.8 D50=20.4 D84=57.4

Appendix A, Figure 5

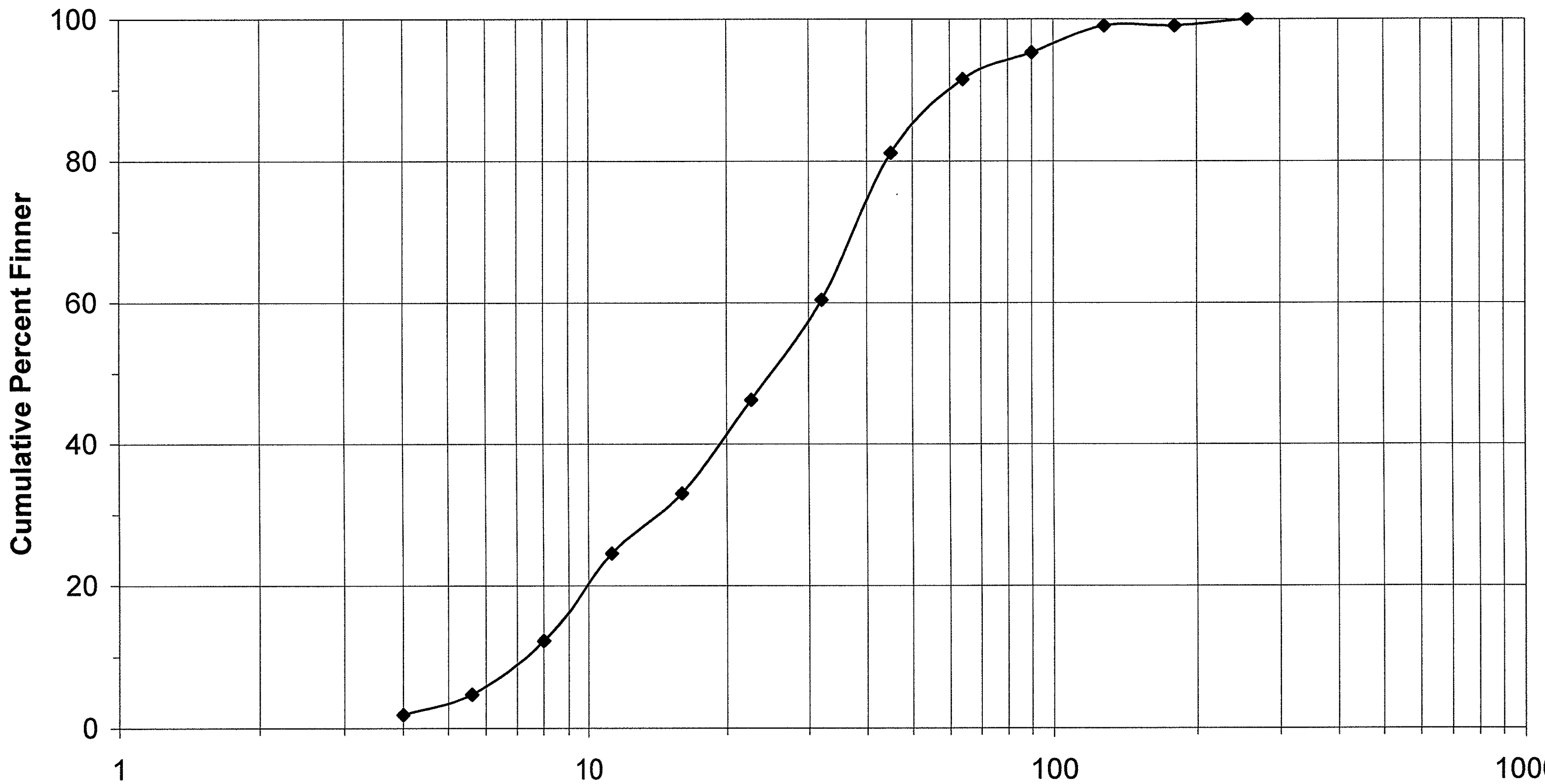
Riffle: R12B



D16=<4 D50=24.2 D84=55.9

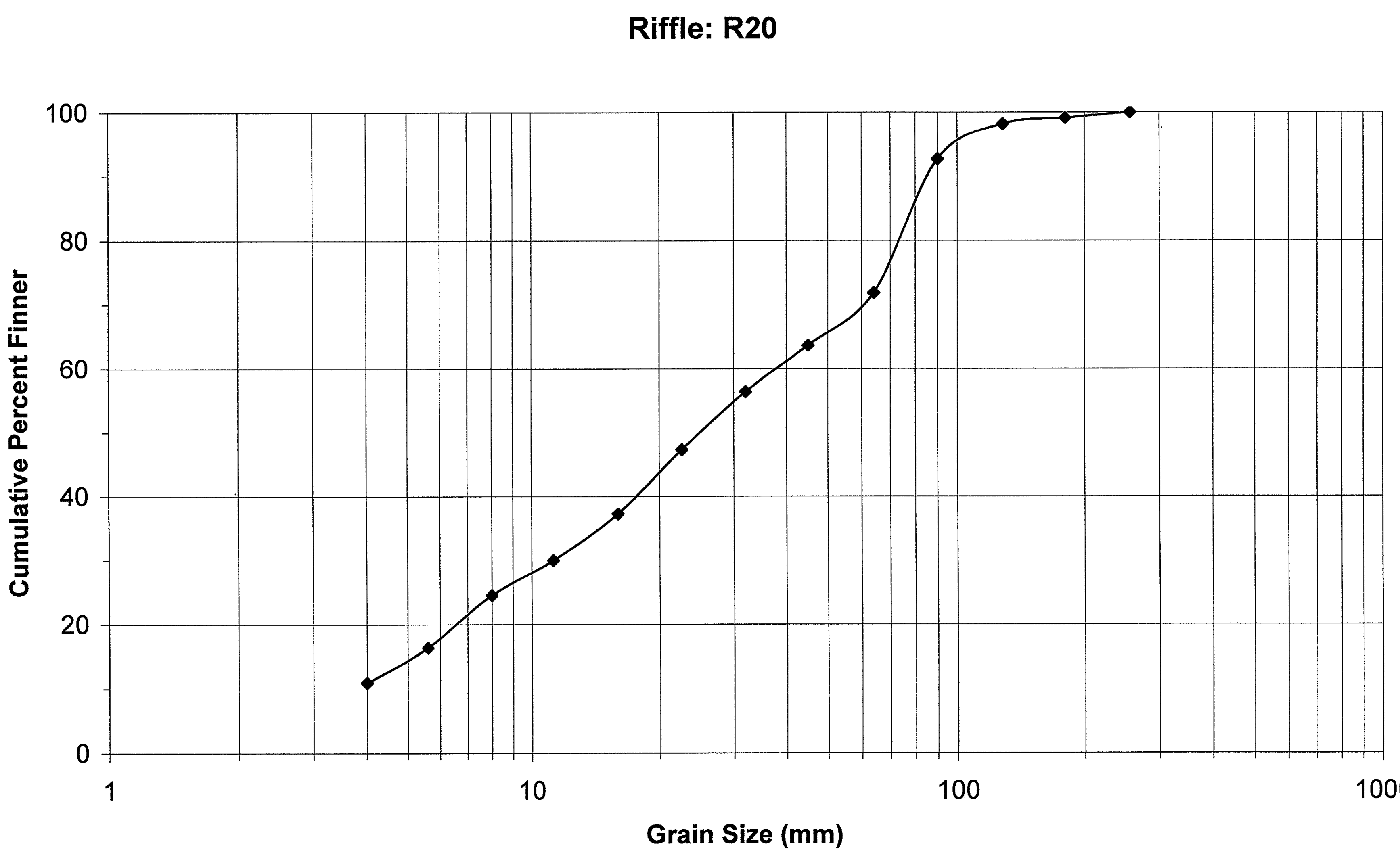
Appendix A, Figure 6

Riffle: R14



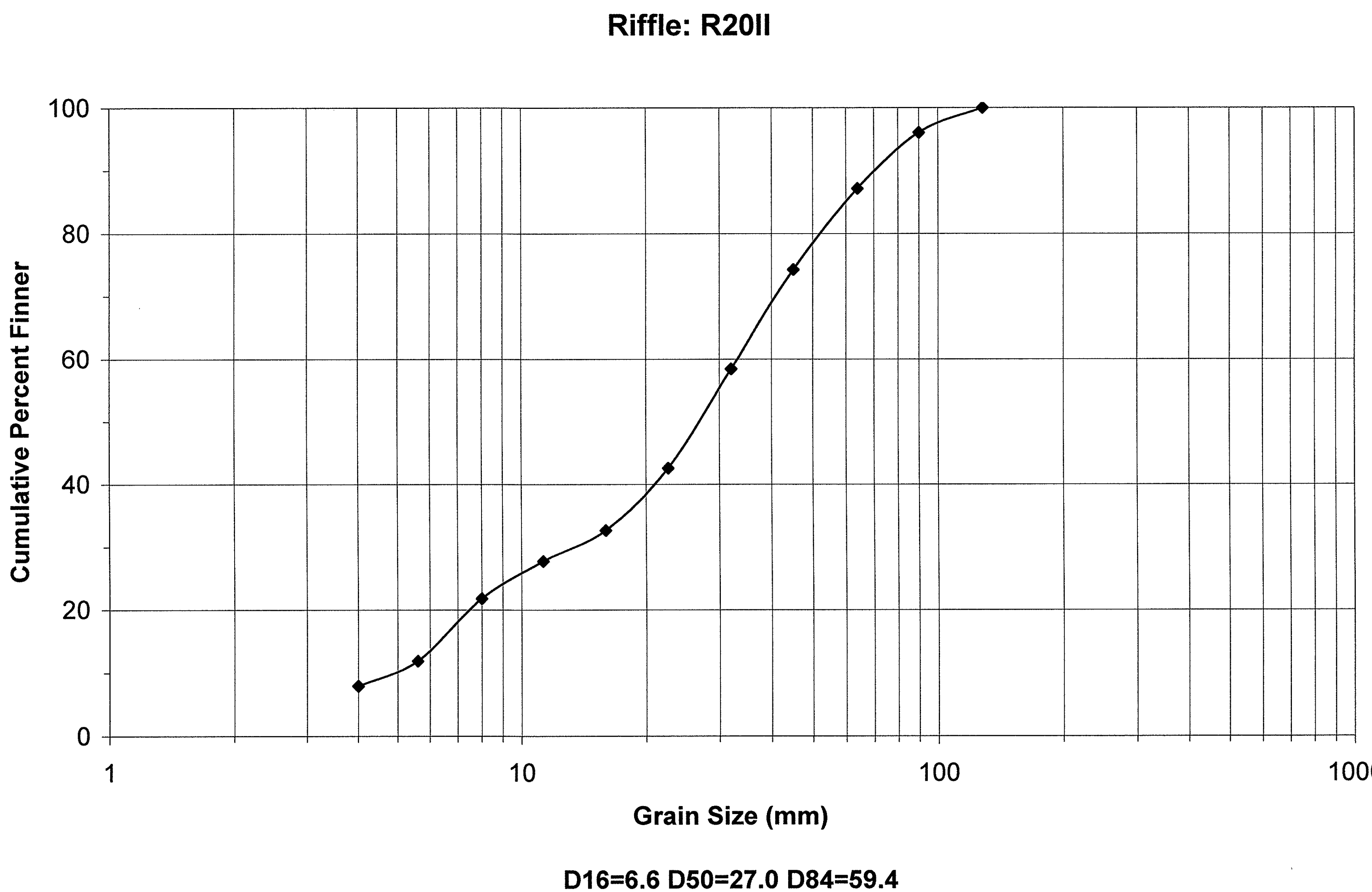
D16=9.0 D50=25.1 D84=50.3

Appendix A, Figure 7

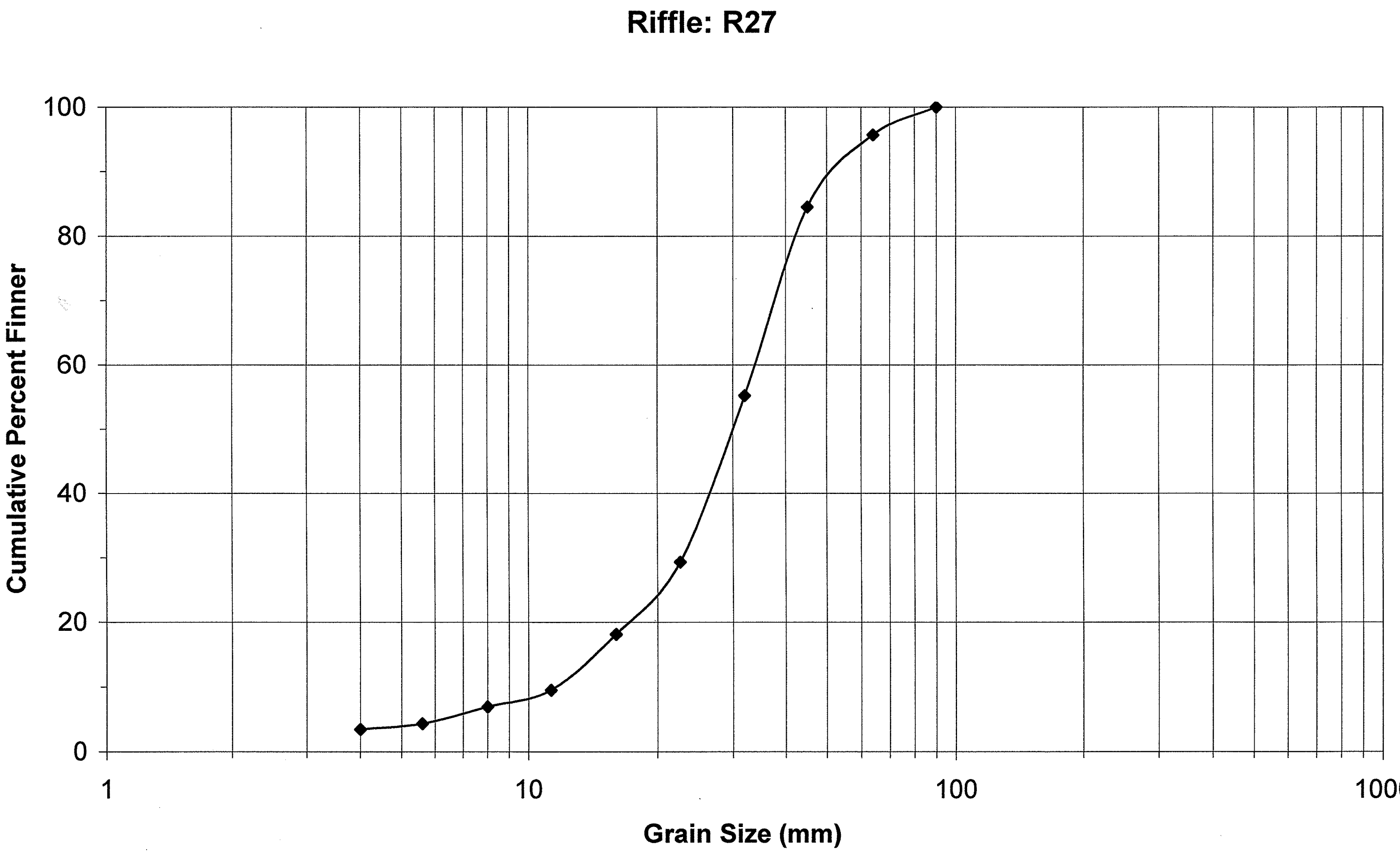


D16=5.5 D50=25.4 D84=79.1

Appendix A, Figure 8



Appendix A, Figure 9

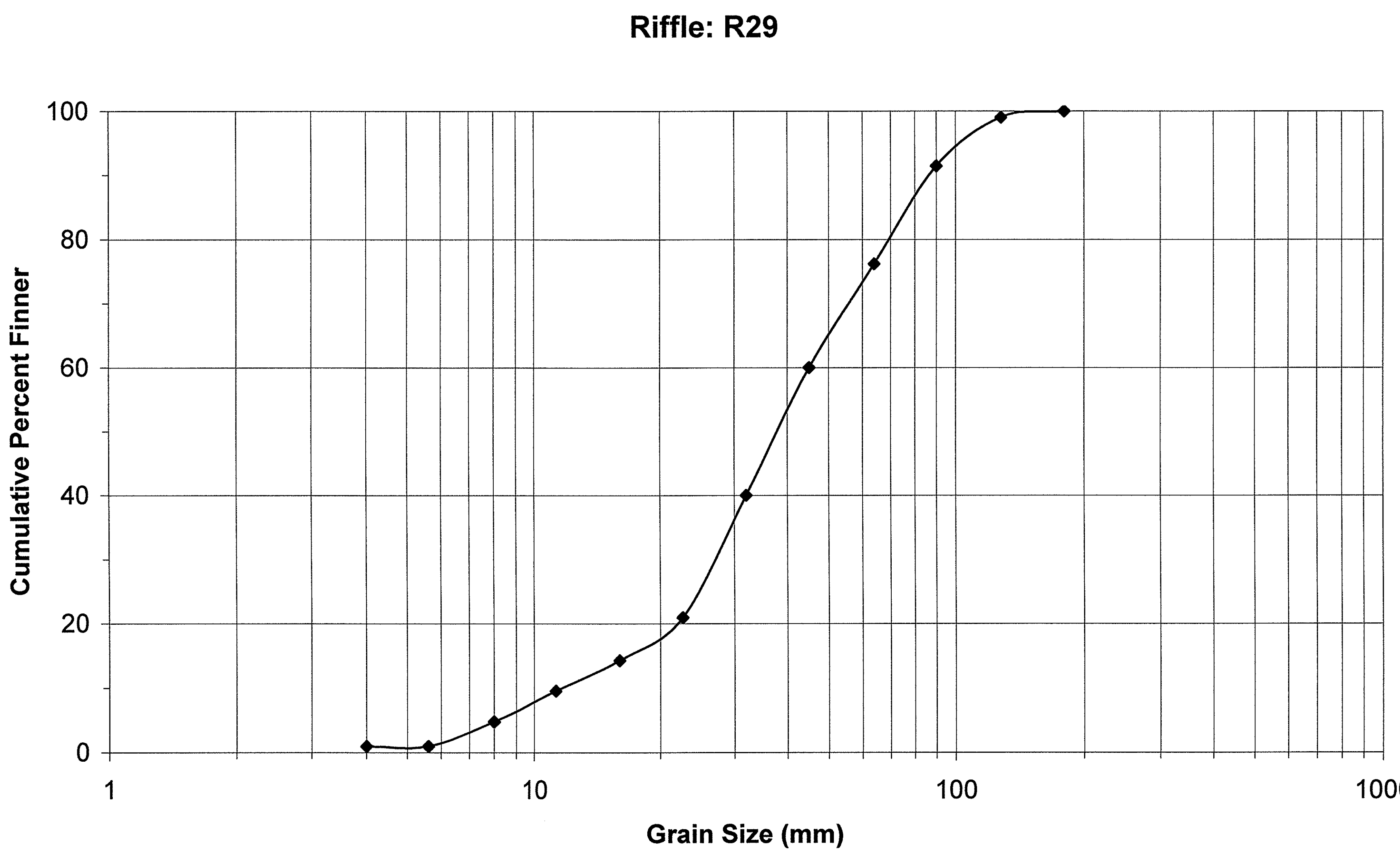


D16=14.9 D50=30.1 D84=44.8

Appendix A, Figure 10

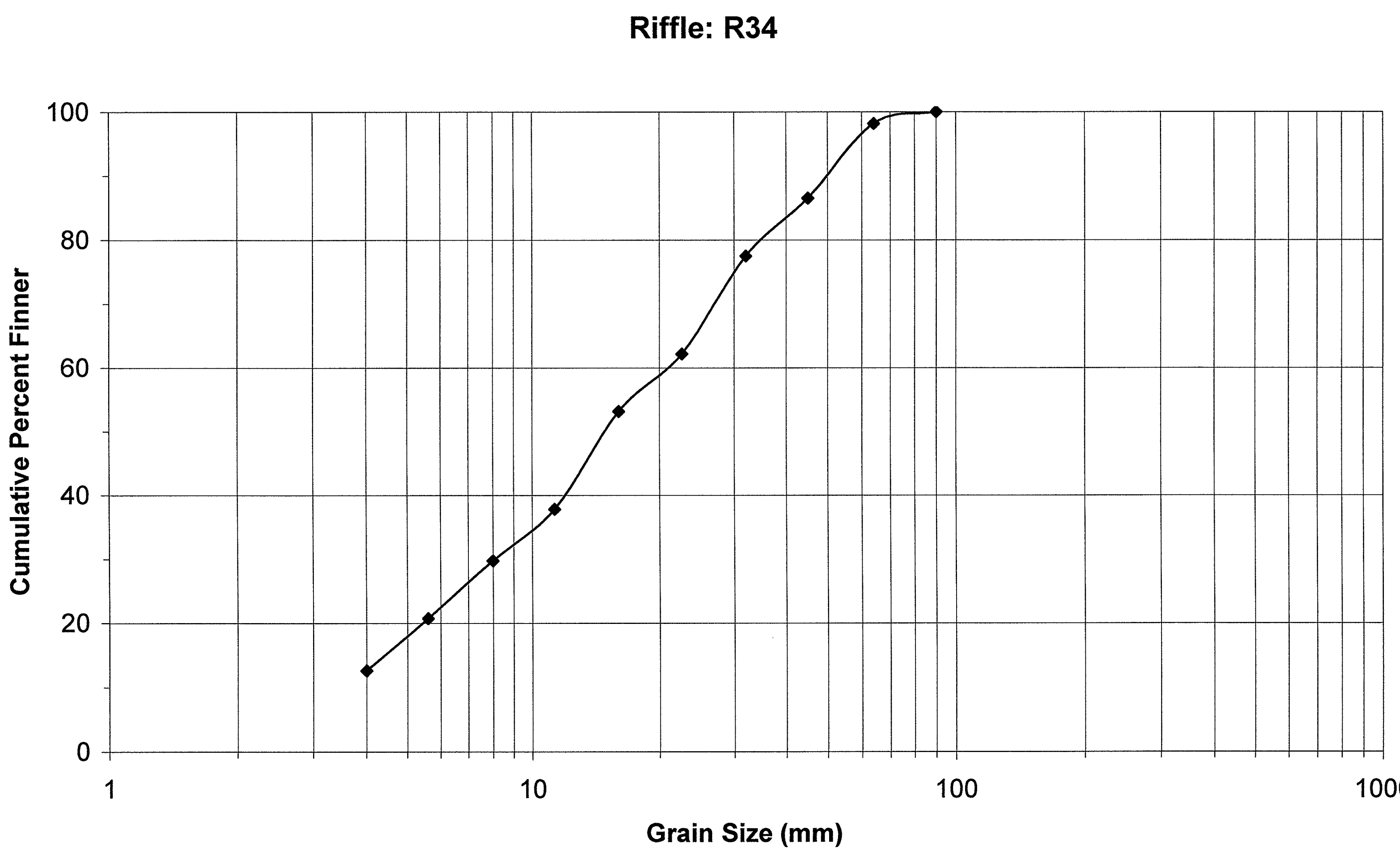
D16=14.7 D50=32.3 D84=68.5

Appendix A, Figure 11



D16=17.7 D50=38.5 D84=77.3

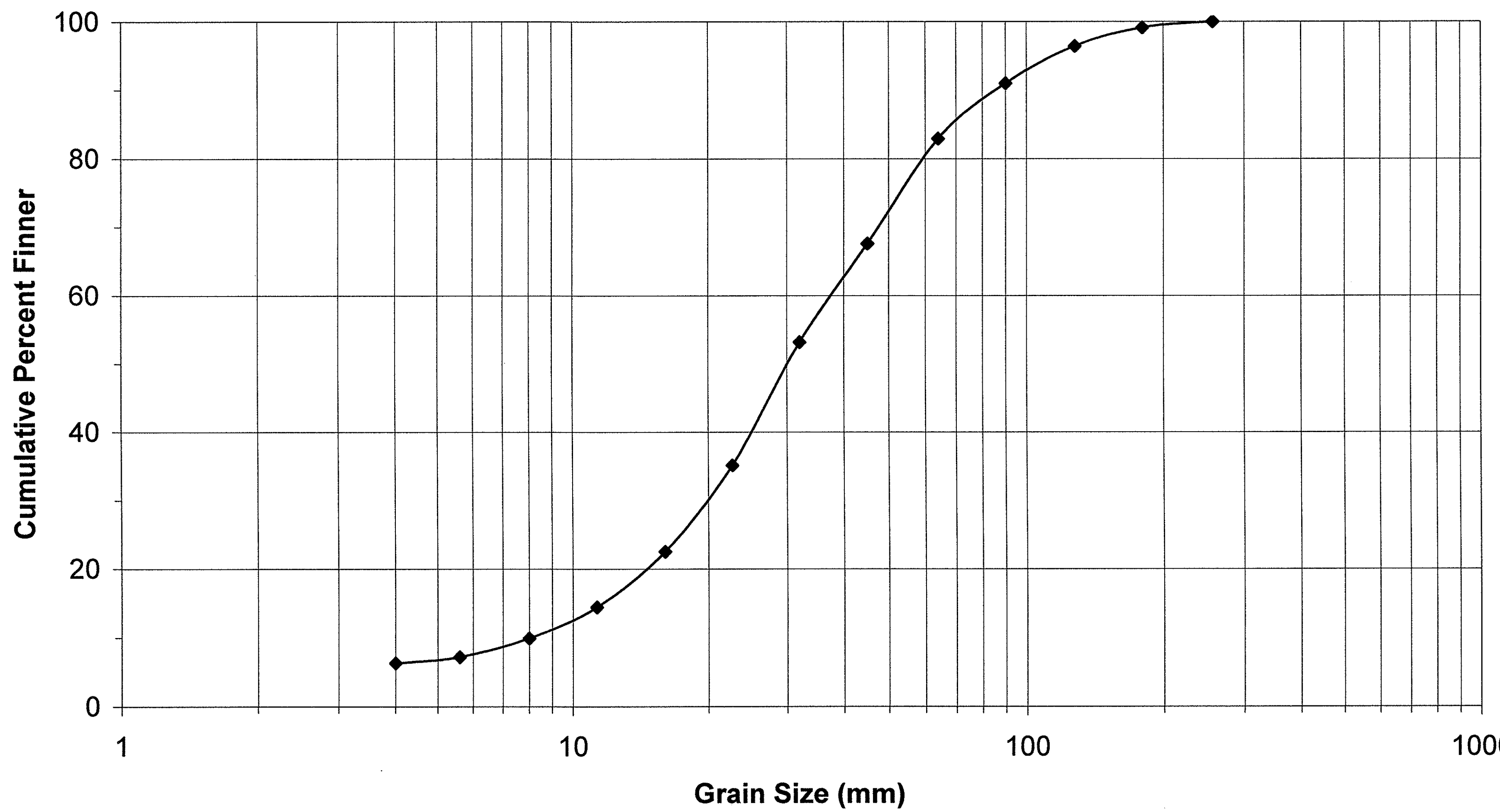
Appendix A, Figure 12



D16= D50= D84=

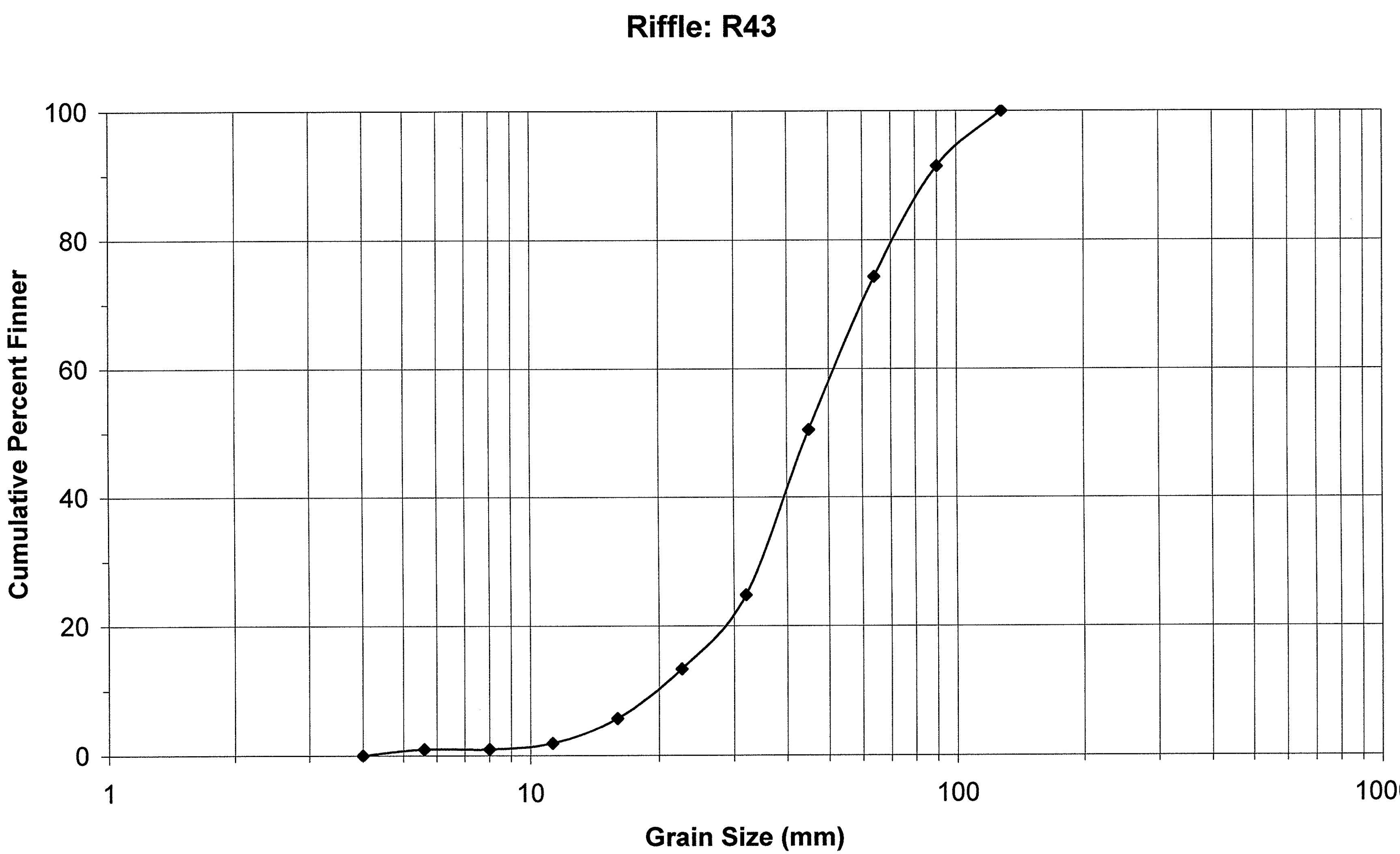
Appendix A, Figure 13

Riffle: R42



D16=12.2 D50=30.4 D84=67.6

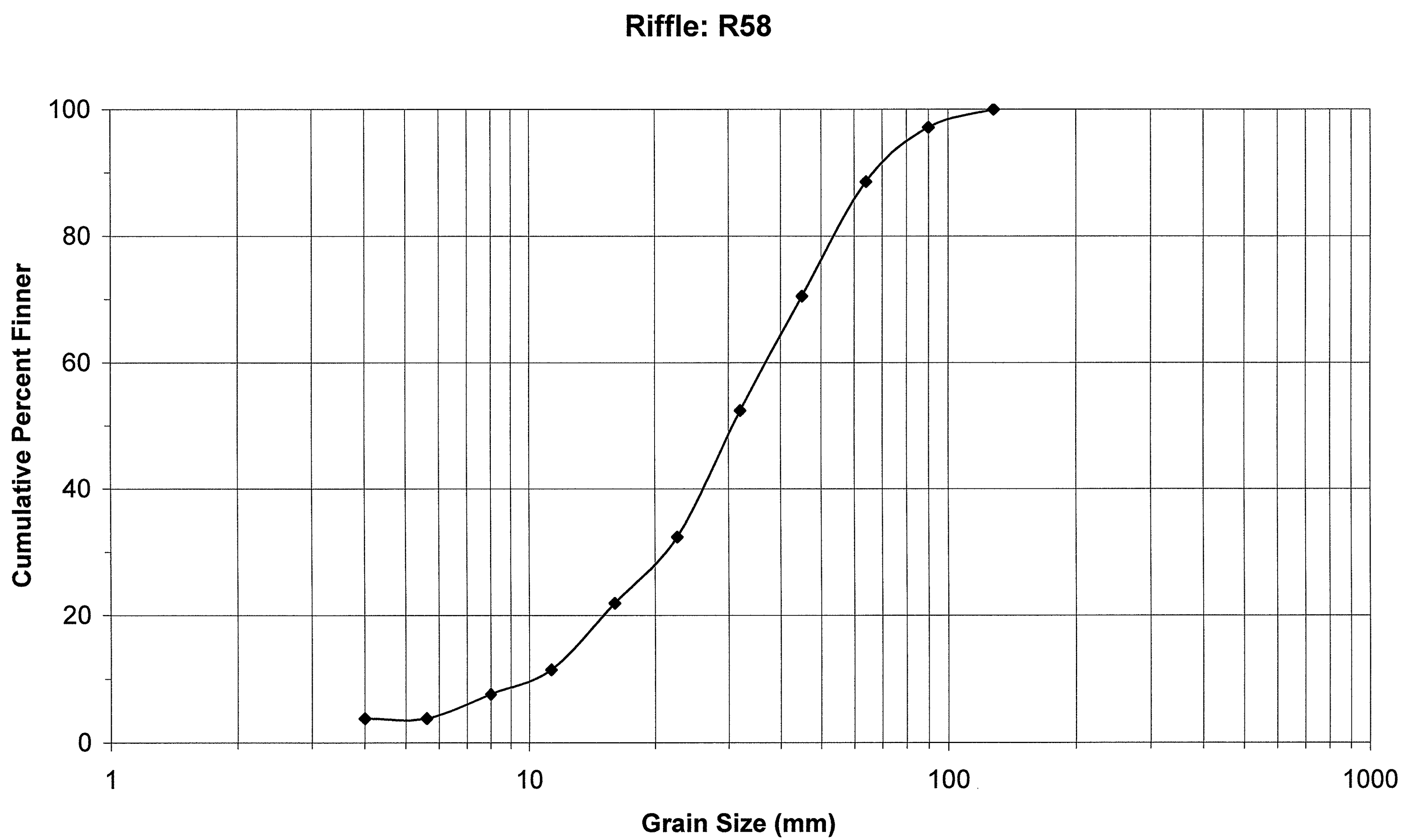
Appendix A, Figure 14



D16=24.8 D50=44.8 D84=78.7

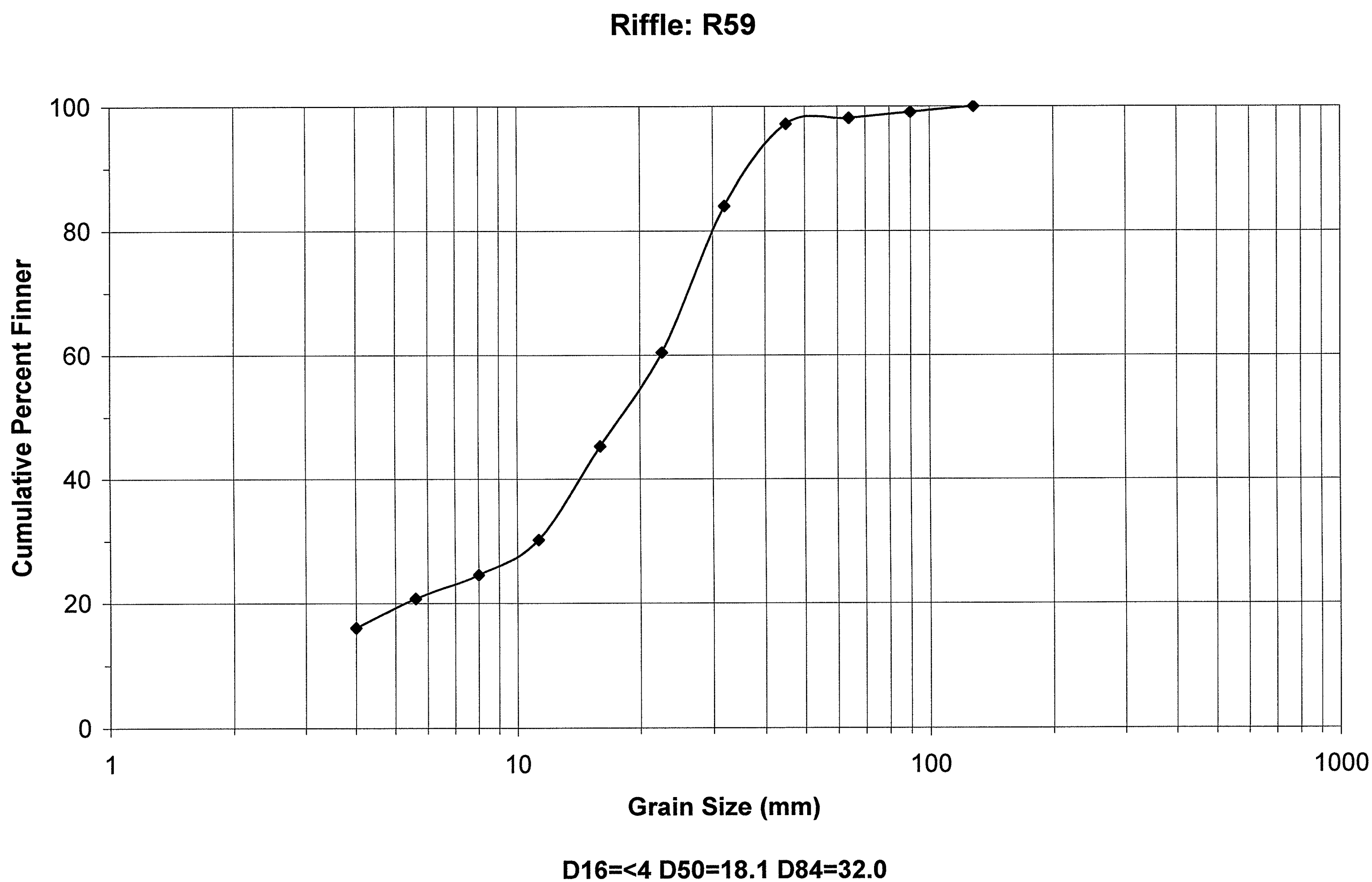
Appendix A, Figure 15

Appendix A, Figure 16

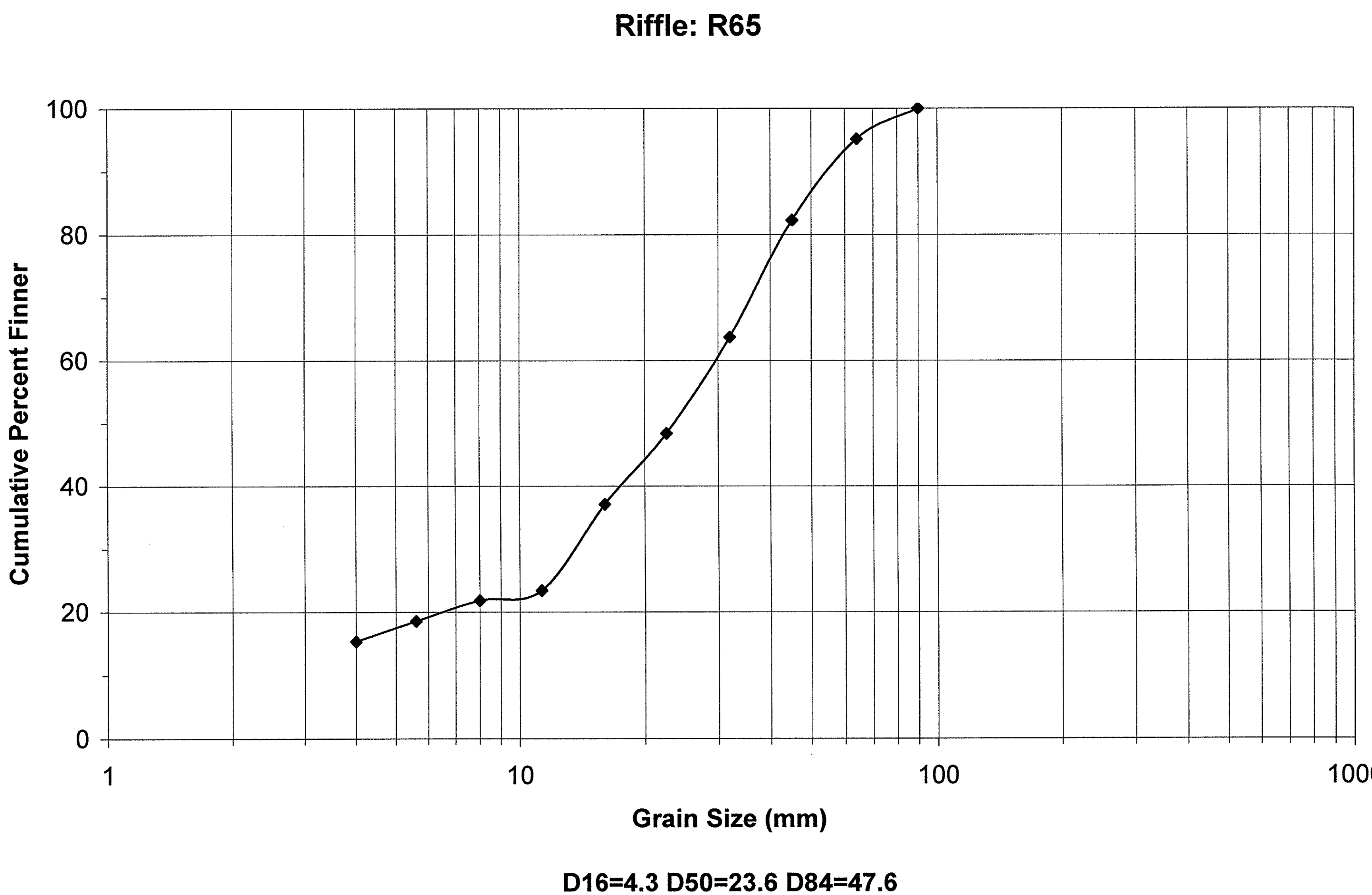


D16=13.4 D50=30.9 D84=59.2

Appendix A, Figure 17

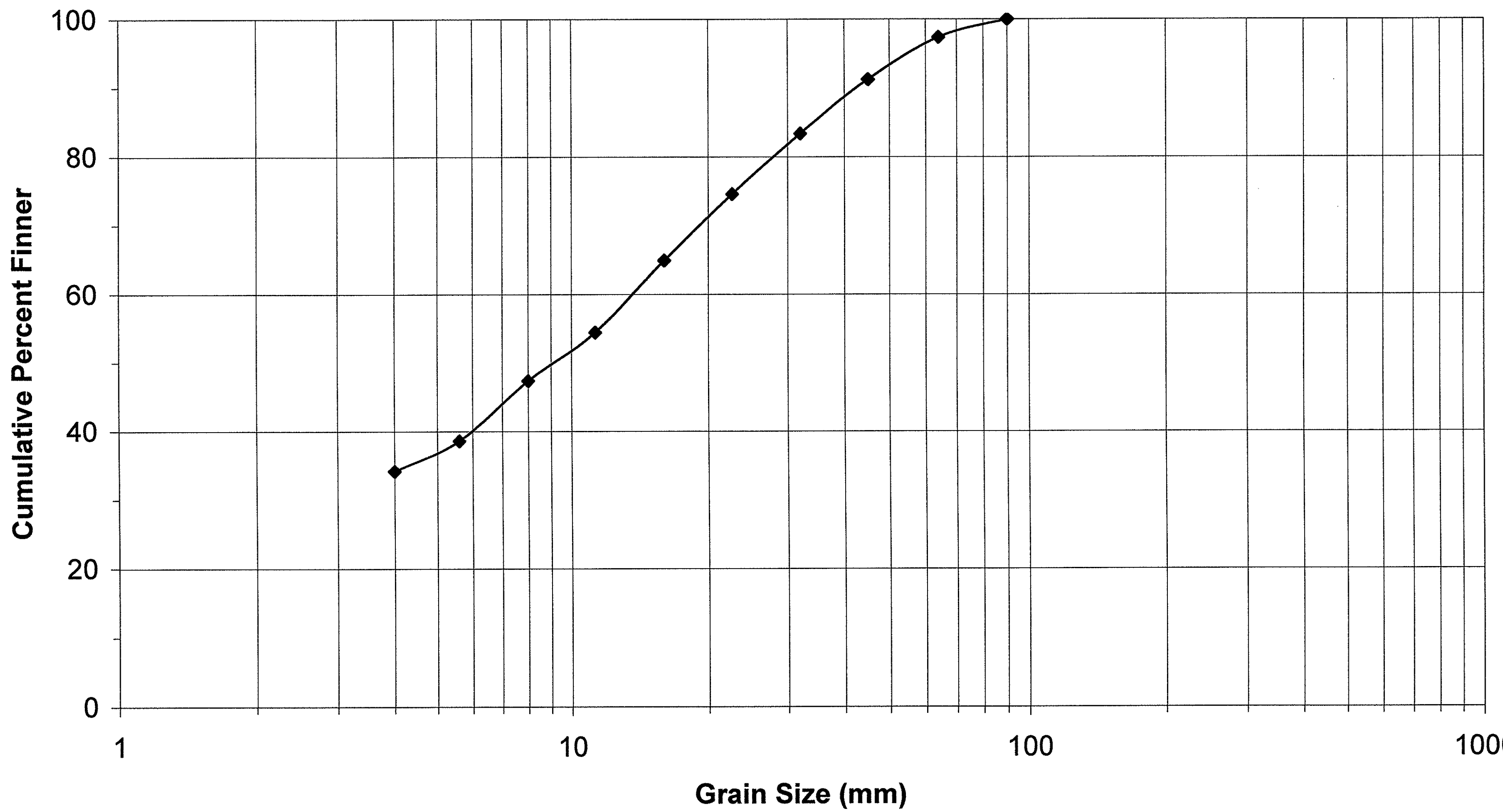


Appendix A, Figure 18



Appendix A, Figure 19

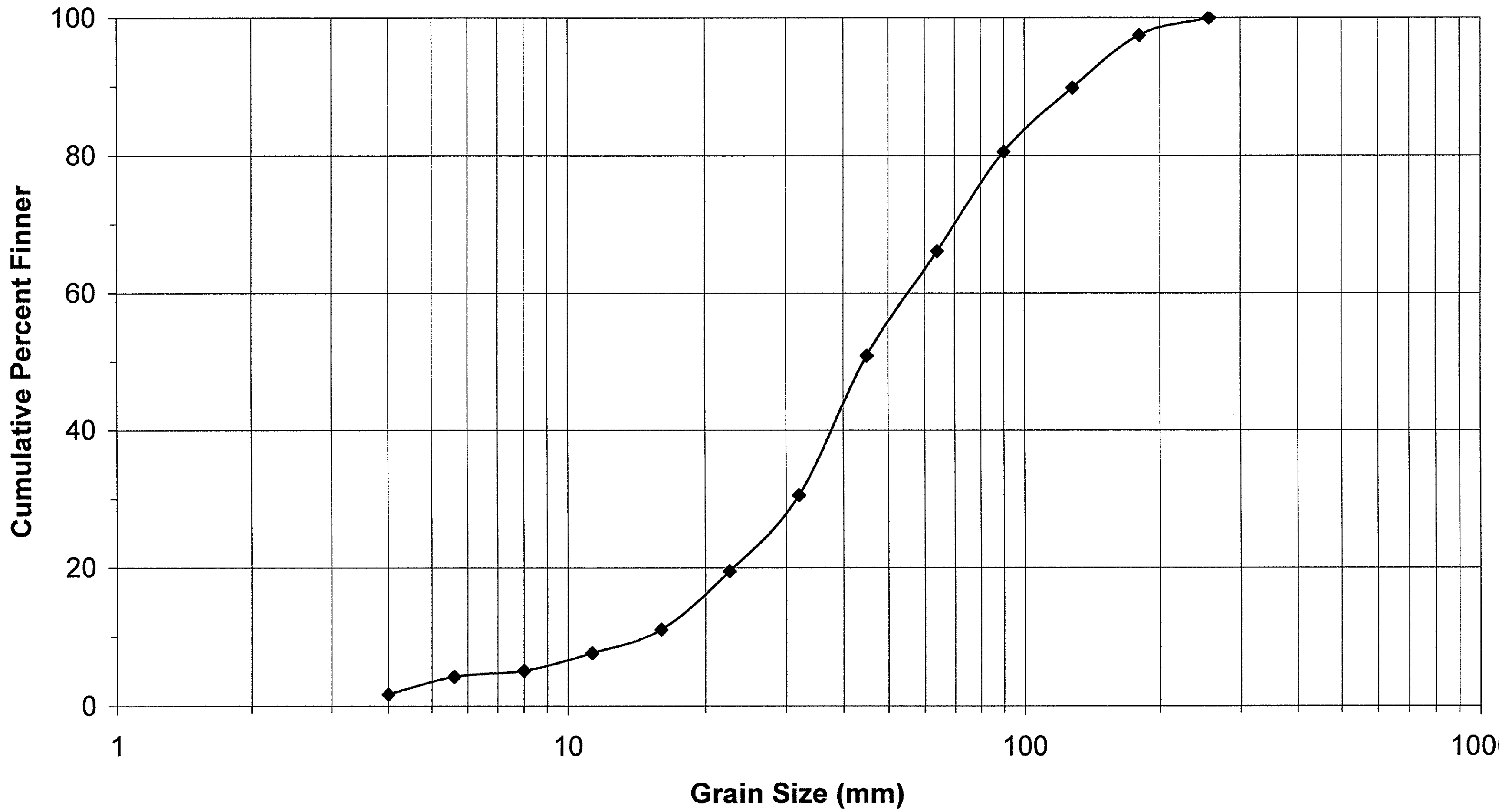
Riffle: R69



D16=<4 D50=9.2 D84=33.1

Appendix A, Figure 20

Riffle: R77



D16=19.9 D50=44.5 D84=104.2

Appendix A, Figure 21

Appendix A, Figure 22

Appendix B, Table 1

Summary Statistics of Bulk Samples from 1994 DWR Report and CMC Report Combined, Surface and Subsurface

CMC Riffle #	DWR RM	Location in bed	D5	D10	D16	D20	D25	D50	D75	D84	D90	D95	dg	sg	sk
			Size (mm)												
DWR Bulk Samples															
R10	53.4	Surface	7.74	12.07	17.84	22.22	29.83	60.27	82.31	87.46	90.60	93.22	39.50	2.21	-0.5317
		Subsurface	0.74	1.92	5.78	9.42	13.64	31.33	58.06	70.24	80.58	94.26	20.15	3.49	-0.3535
		Combined	0.94	2.69	8.08	11.78	16.26	33.48	61.08	72.57	83.82	95.89	24.22	3.00	-0.2953
R20	51.9	Surface	2.43	6.64	11.63	14.96	19.15	48.18	87.91	111.13	126.60	139.50	35.94	3.09	-0.2596
		Subsurface	1.44	4.11	7.45	9.67	13.15	36.51	77.01	104.15	122.25	137.32	27.86	3.74	-0.2052
		Combined	1.70	4.70	8.37	11.06	14.72	39.90	80.65	106.48	123.70	138.05	29.85	3.57	-0.2282
R27	50.9	Surface	0.84	2.03	6.54	10.84	17.15	37.92	84.44	108.90	125.21	138.81	26.69	4.08	-0.2496
		Subsurface	0.47	0.90	1.78	2.97	5.81	27.38	61.20	77.46	105.57	128.98	11.74	6.60	-0.4487
		Combined	0.54	1.07	2.31	4.57	8.33	31.31	68.01	92.22	114.79	133.59	14.60	6.32	-0.4139
R58	44.7	Surface	0.33	0.49	0.85	1.56	3.95	15.11	31.43	38.87	52.87	64.53	5.74	6.77	-0.5063
		Subsurface	0.25	0.36	0.49	0.57	0.71	4.28	21.23	28.67	33.62	37.75	3.75	7.65	-0.0652
		Combined	0.26	0.38	0.52	0.61	0.78	6.91	23.43	30.76	35.64	48.91	3.99	7.71	-0.2693
R59	44.2	Surface	1.19	3.82	8.27	11.35	15.14	36.55	60.84	69.64	75.52	93.82	24.01	2.90	-0.3947
		Subsurface	0.56	0.83	1.13	1.87	4.07	18.69	37.52	51.04	60.48	68.34	7.59	6.72	-0.4725
		Combined	0.62	0.94	1.77	3.43	6.42	22.93	45.84	57.99	66.10	72.85	10.14	5.72	-0.4678
CMC Bulk Samples															
R10	53.4	Surface	<0.85	2.39	6.24	9.47	14.16	40.16	78.60	115.10	139.44	159.72	26.81	4.29	-0.2774
		Subsurface	<0.85	0.94	2.00	3.14	4.73	17.78	53.84	89.91	123.69	151.85	13.41	6.70	-0.1481
		Combined	<0.85	1.40	3.32	5.11	7.65	28.11	62.99	105.11	133.19	156.60	18.68	5.63	-0.2365
R20	51.9	Surface	8.09	13.96	19.66	23.08	28.11	50.31	96.59	126.62	146.64	163.32	49.90	2.54	-0.0088
		Subsurface	9.60	14.38	19.14	22.07	25.84	49.29	96.57	126.60	146.63	163.31	49.23	2.57	-0.0012
		Combined	8.54	14.10	19.49	22.76	27.38	50.03	96.59	126.61	146.63	163.32	49.68	2.55	-0.0074
R27	50.9	Surface	1.31	10.28	17.34	19.78	22.82	41.10	58.89	82.59	119.12	149.56	37.84	2.18	-0.1058
		Subsurface	<0.85	<0.85	1.70	3.20	6.37	20.97	37.97	46.98	52.99	57.99	8.94	5.26	-0.5139
		Combined	<0.85	1.70	7.24	11.56	16.15	31.43	51.70	59.00	74.30	127.15	20.67	2.85	-0.3997

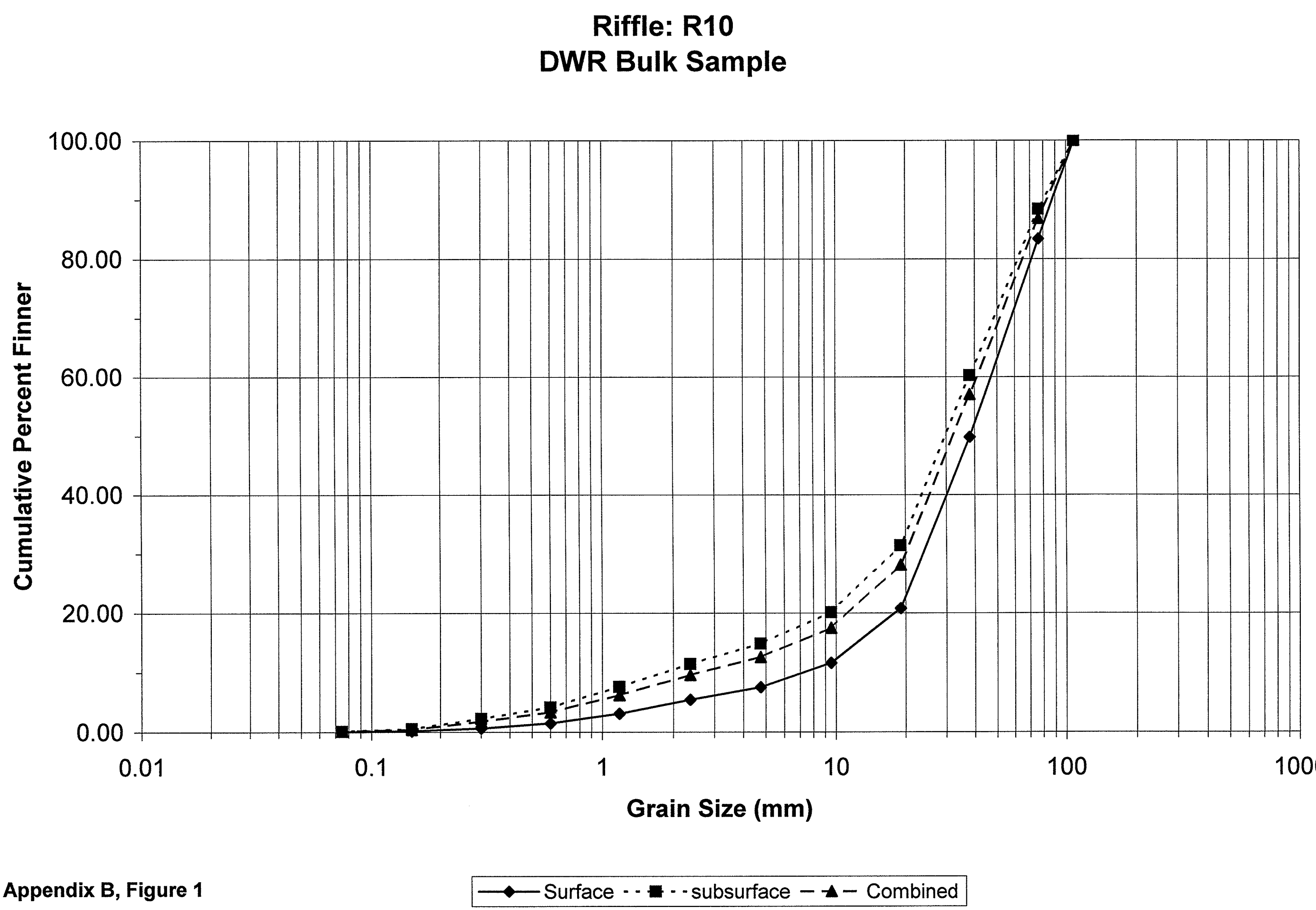
CMC Riffle #	DWR RM	Location in bed	Size (mm)										dg	sg	sk
			D5	D10	D16	D20	D25	D50	D75	D84	D90	D95			
R58	44.7	Surface	<0.85	<0.85	<0.85	1.17	2.31	12.45	24.04	29.47	38.64	50.82	--	--	--
		Subsurface	<0.85	<0.85	<0.85	<0.85	<0.85	6.50	19.63	26.10	32.67	47.83	--	--	--
		Combined	<0.85	<0.85	<0.85	<0.85	0.99	9.41	22.25	28.10	35.99	49.50	--	--	--
R59	44.2	Surface	<0.85	<0.85	<0.85	<0.85	0.88	9.22	27.55	43.93	57.28	101.28	--	--	--
		Subsurface	<0.85	<0.85	<0.85	<0.85	<0.85	7.65	24.25	35.18	45.61	54.31	--	--	--
		Combined	<0.85	<0.85	<0.85	<0.85	0.86	8.53	26.00	39.84	51.82	61.81	--	--	--

RM = river mile

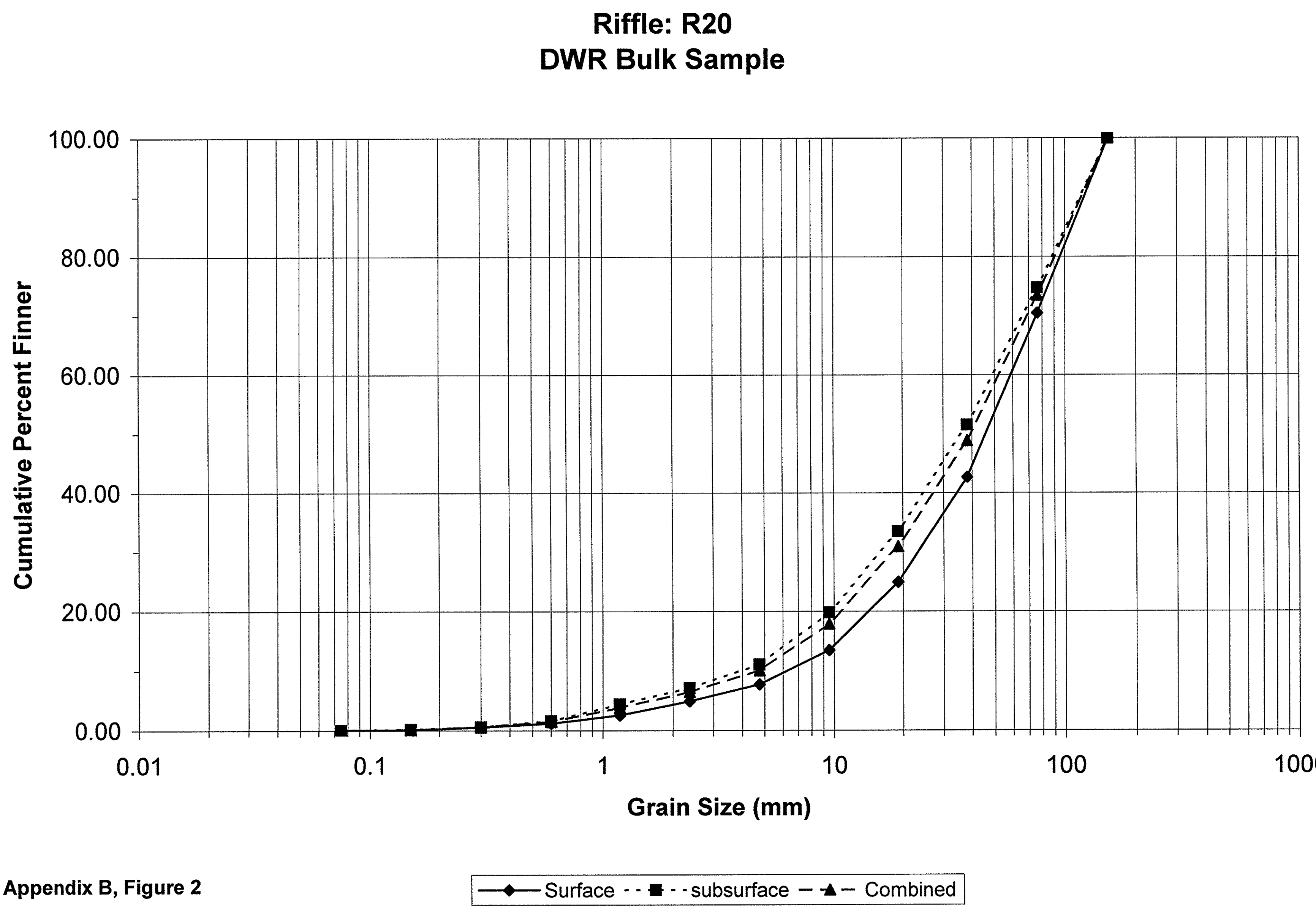
dg = $(D16*D84)^{0.5}$ (mm)

sg = $(D84/D16)^{0.5}$, dimensionless

sk = log(dg/D50)/log(sg) , dimensionless

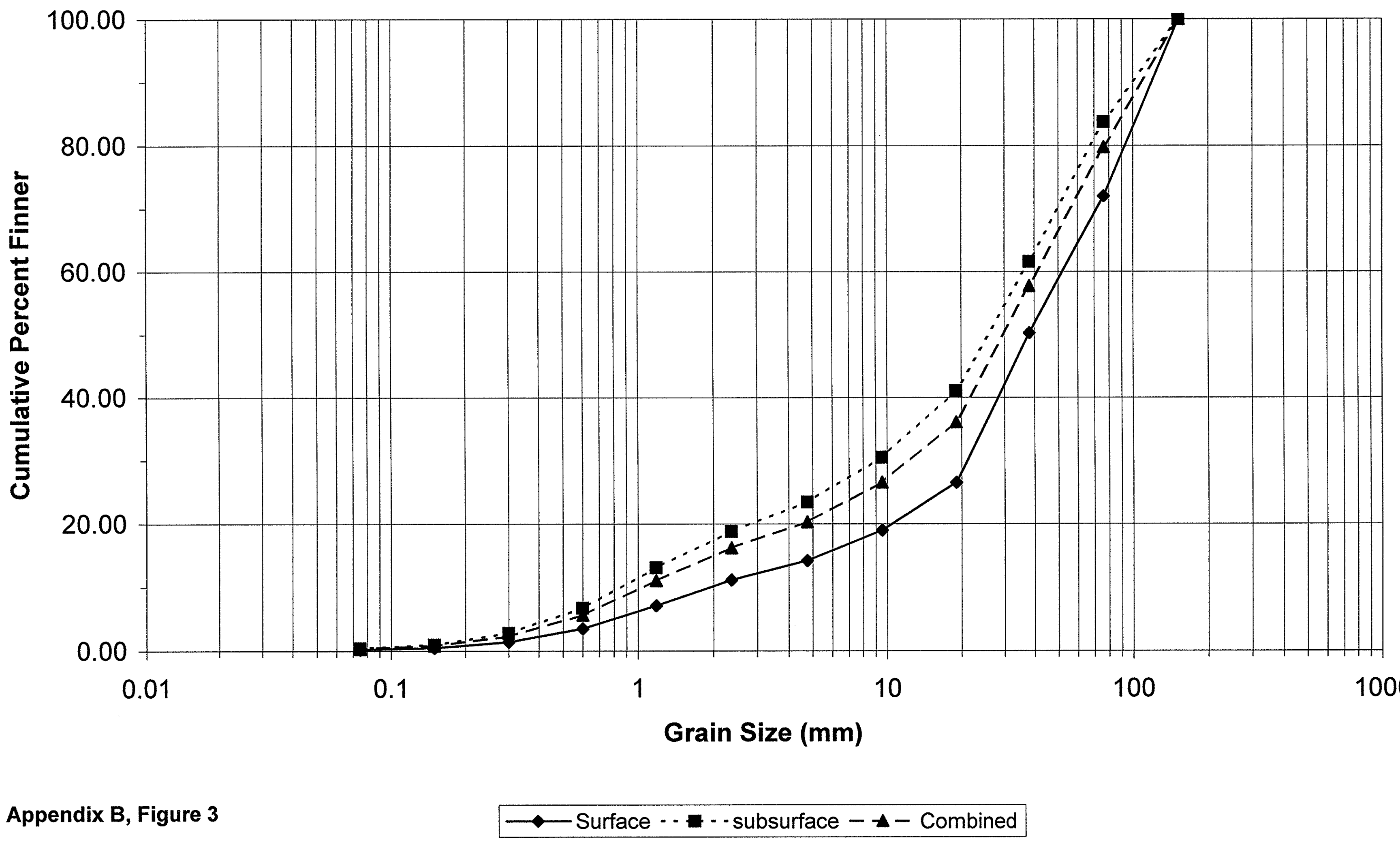


Appendix B, Figure 1

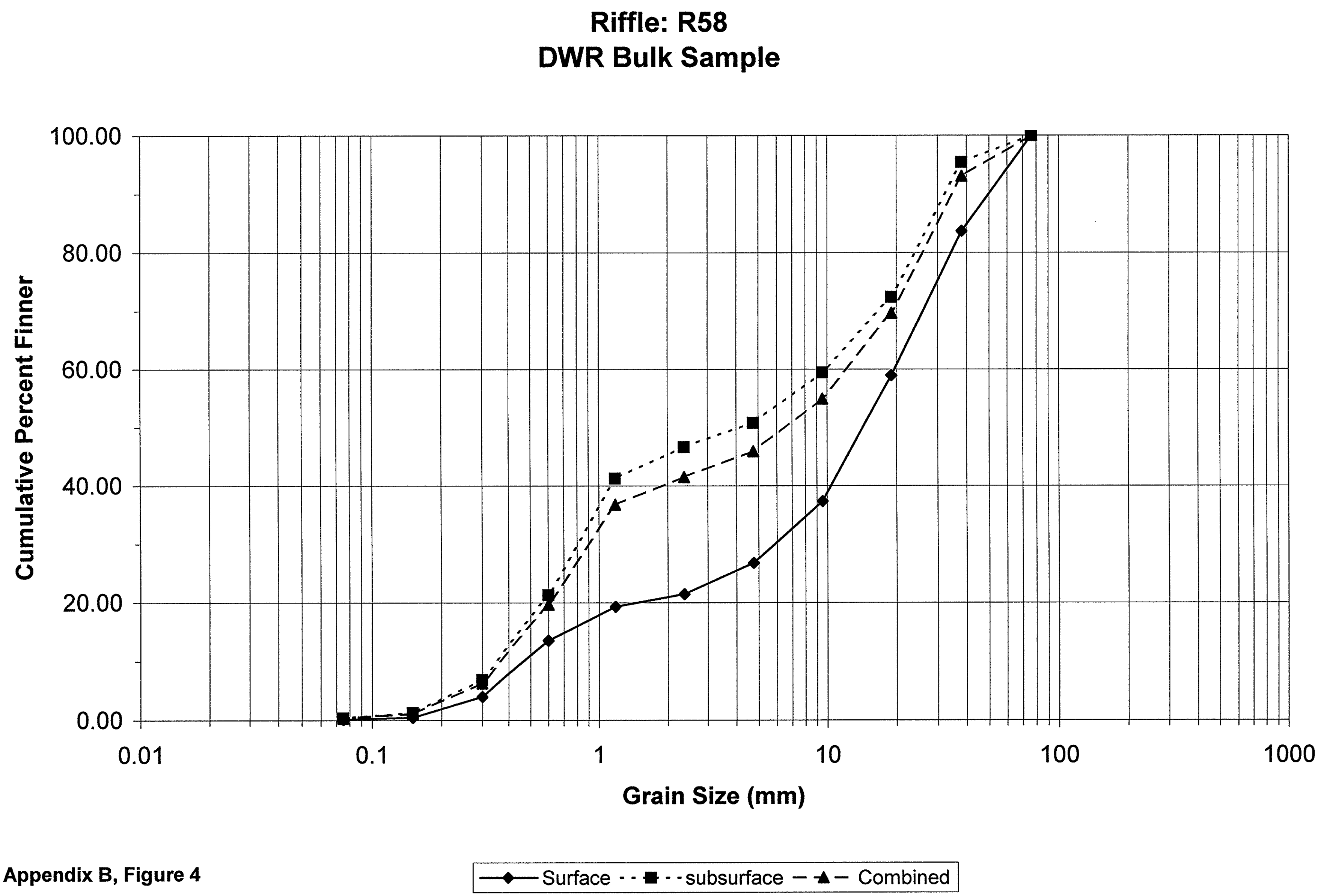


Appendix B, Figure 2

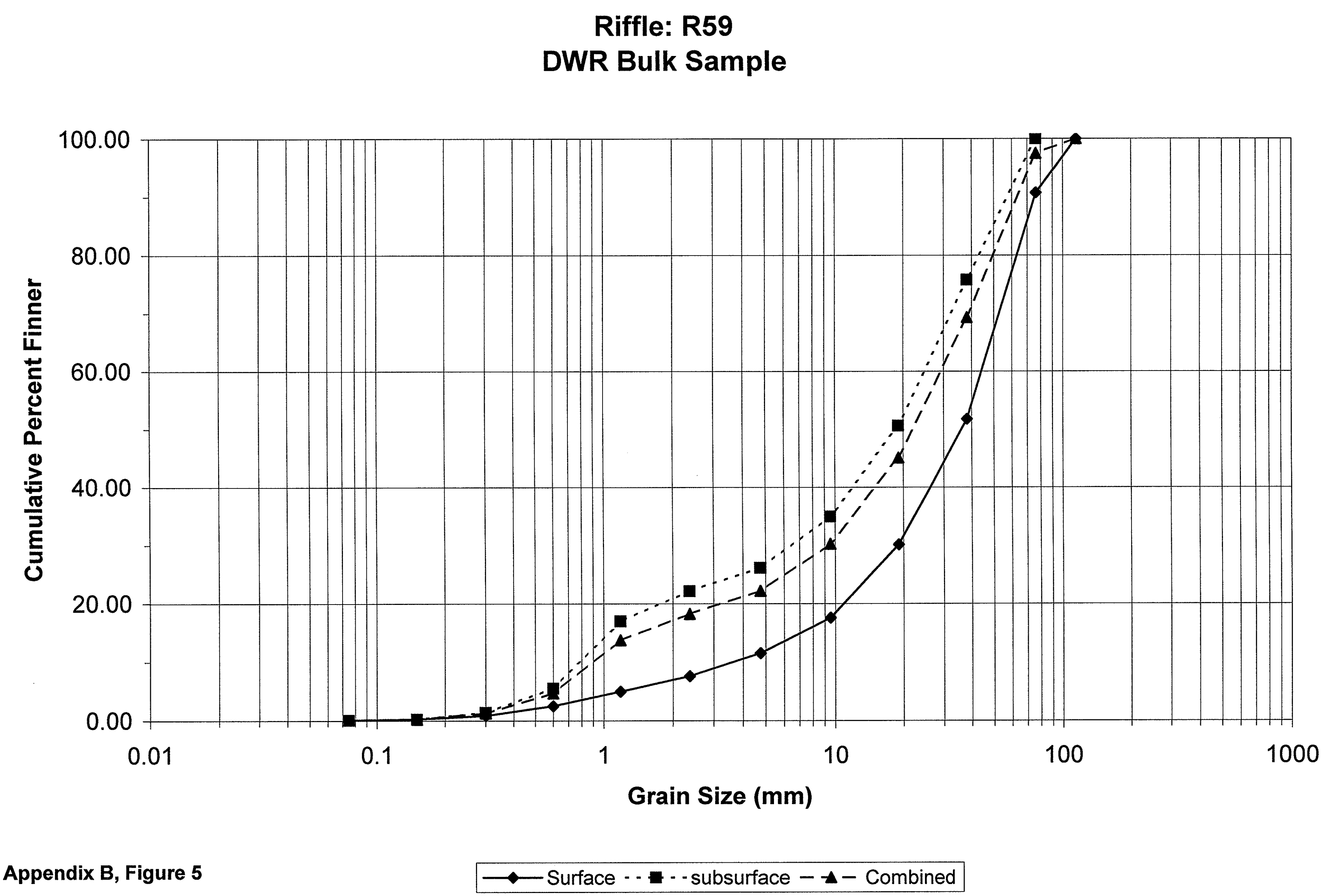
Riffle: R27
DWR Bulk Sample



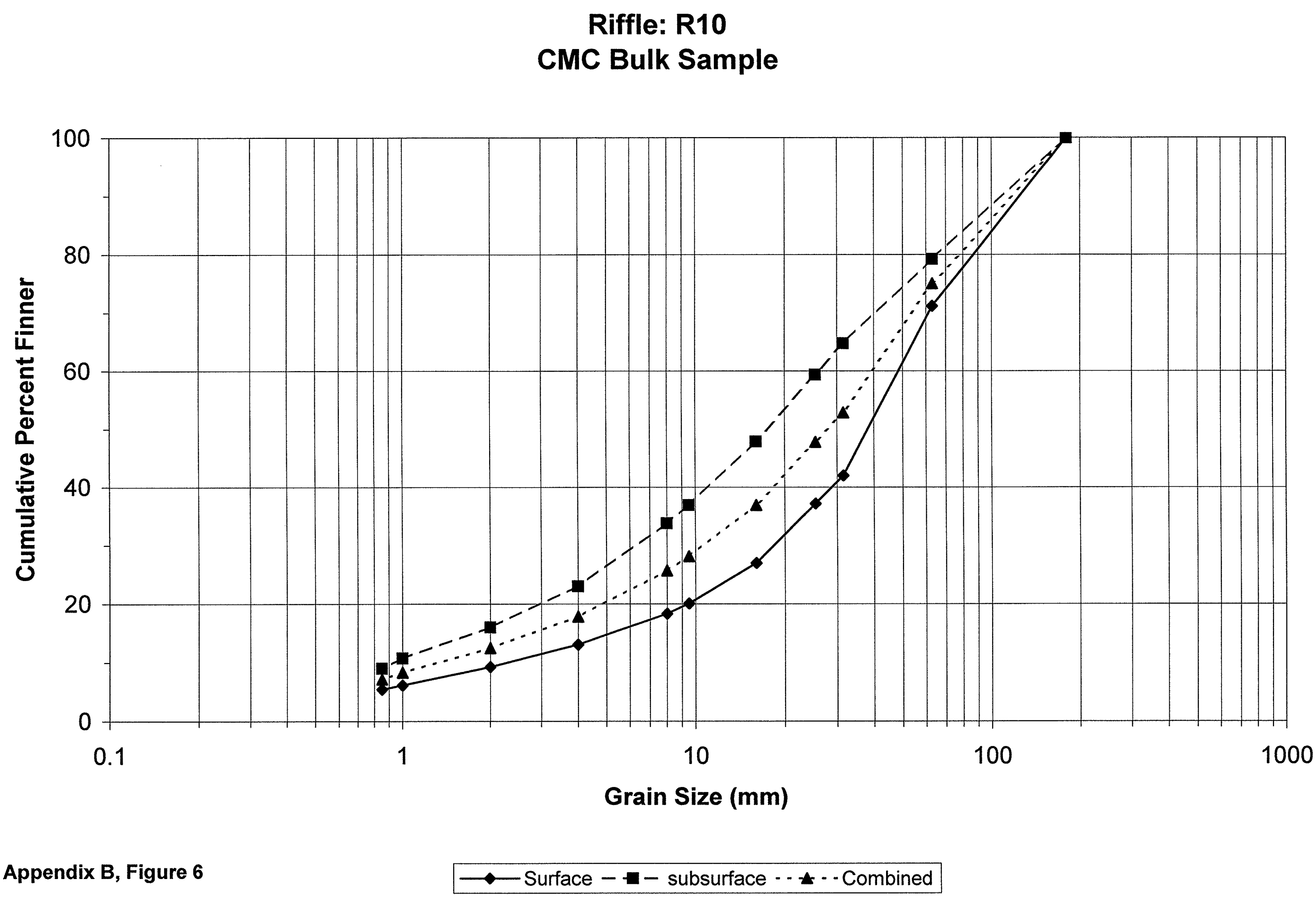
Appendix B, Figure 3



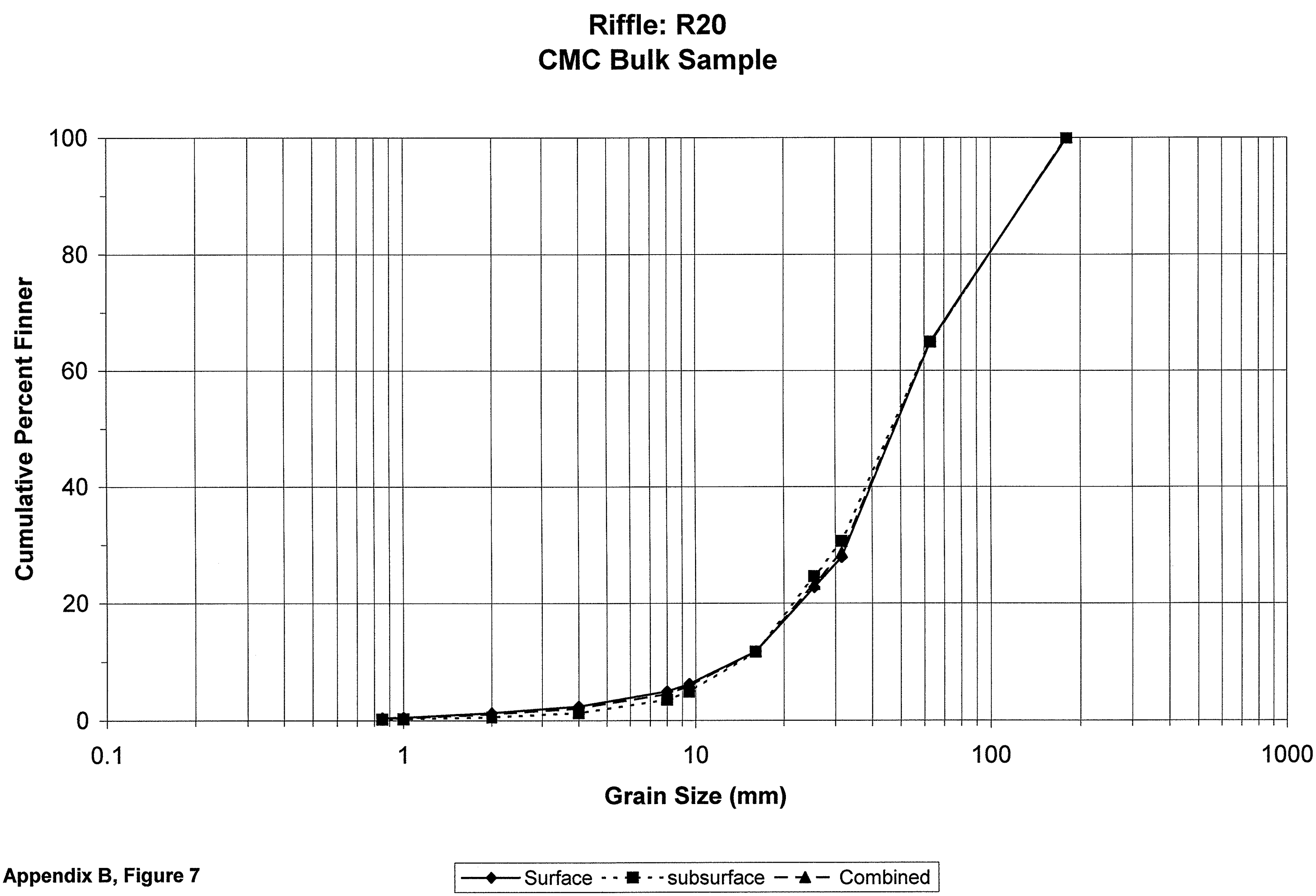
Appendix B, Figure 4



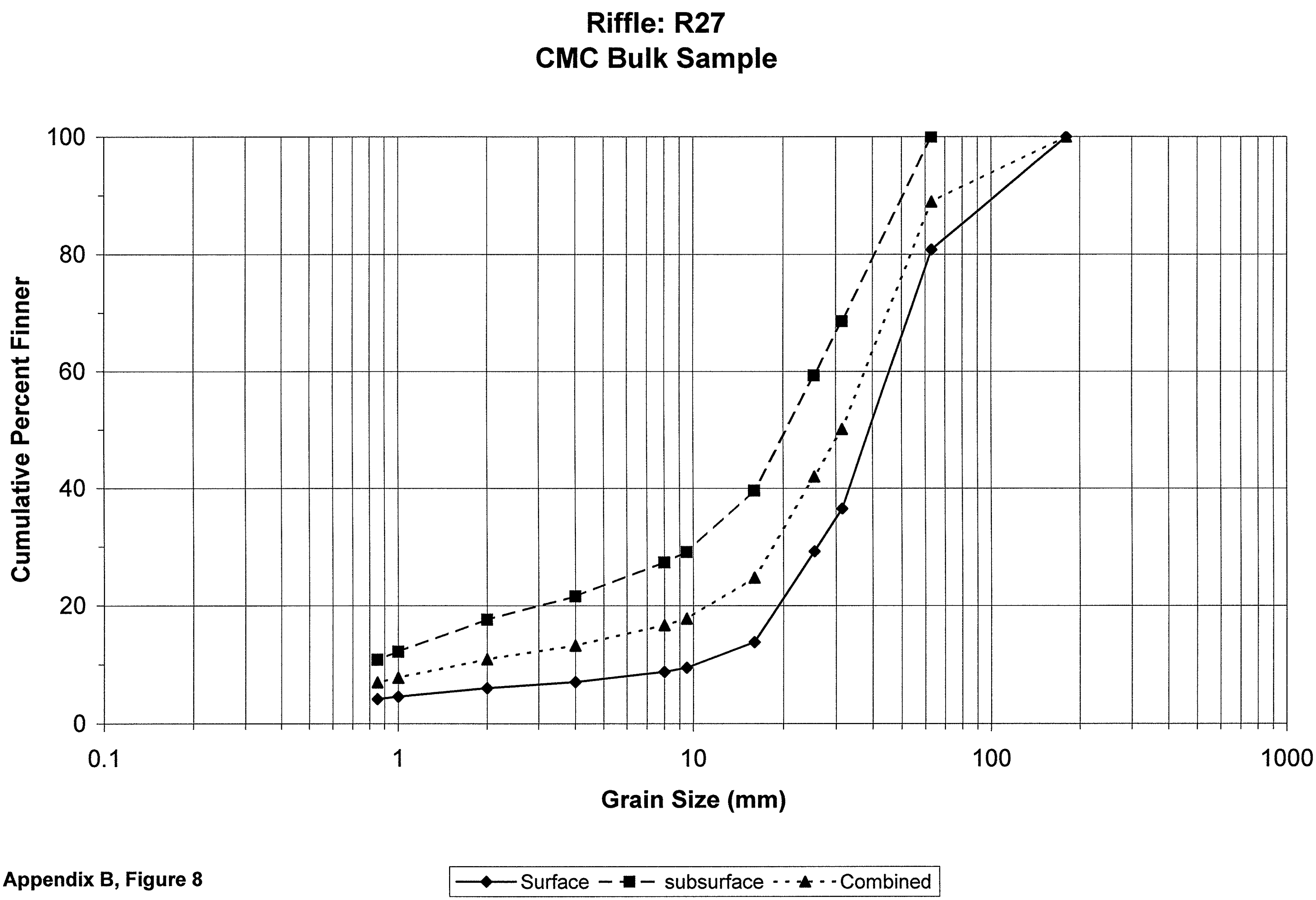
Appendix B, Figure 5



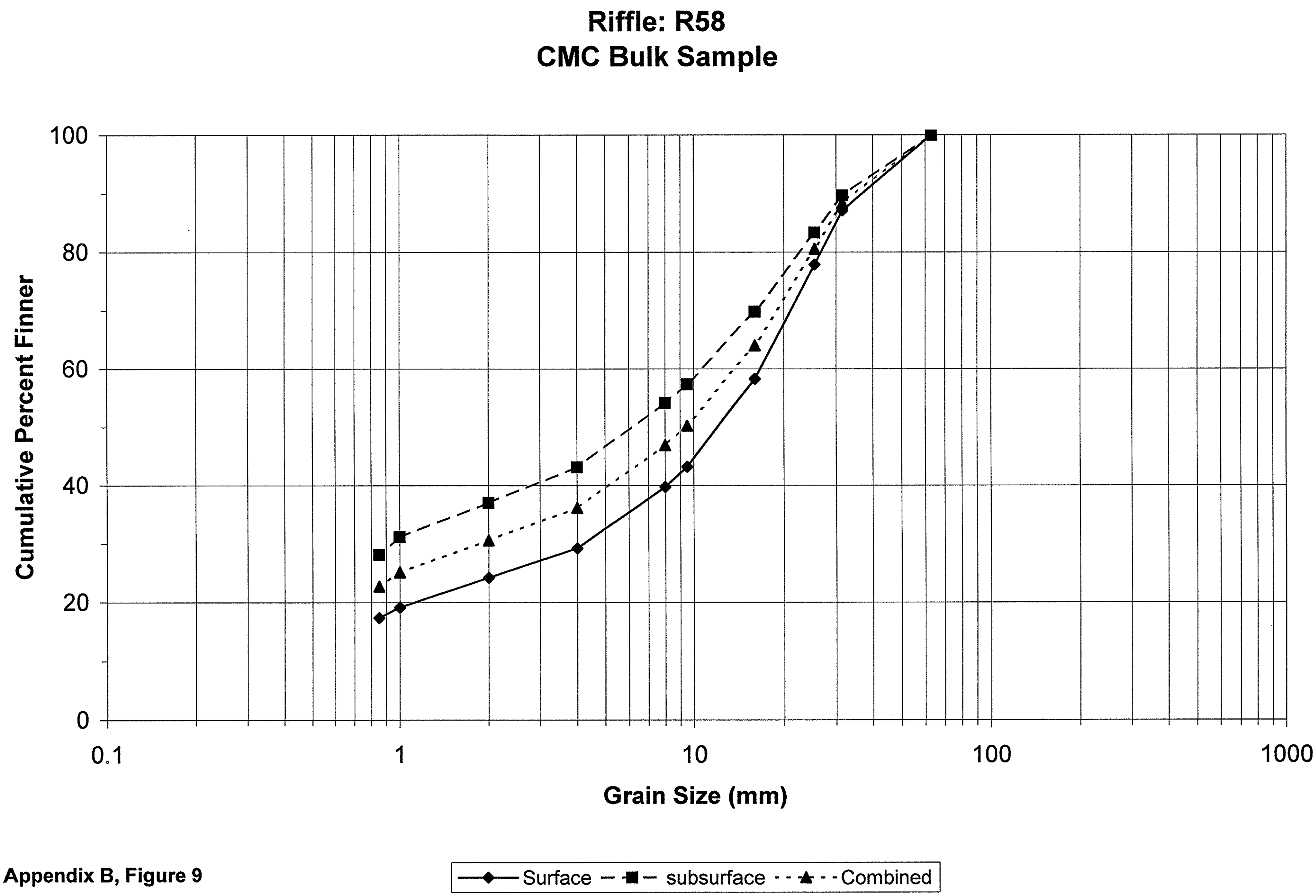
Appendix B, Figure 6



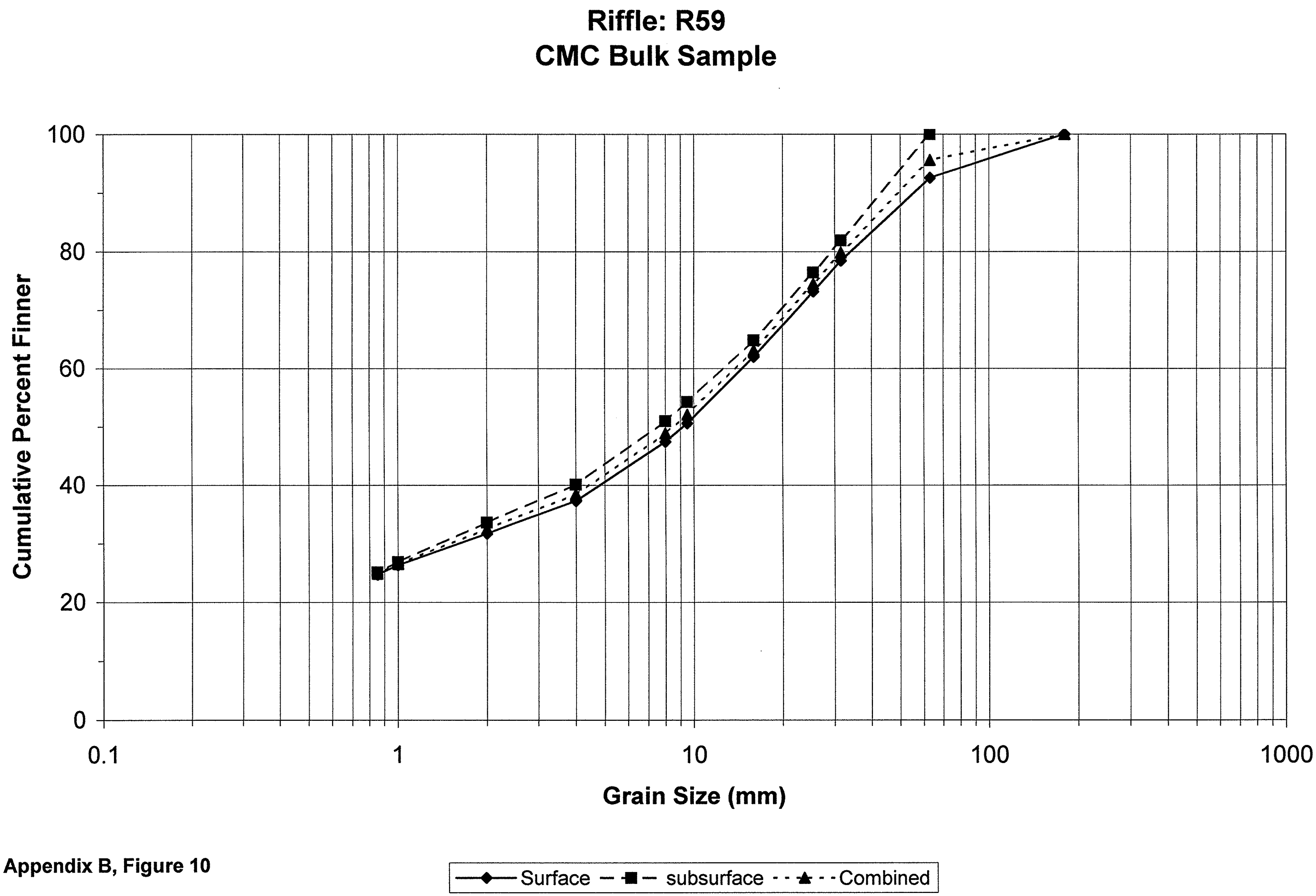
Appendix B, Figure 7



Appendix B, Figure 8



Appendix B, Figure 9



Appendix B, Figure 10

Table 7.1: Bed Mobility Calculations -- 5 Sites. The following table summarizes the flows needed to mobilize gravels at five different study sites (all nine sites studied in Appendix C) on the Lower Stanislaus River. Bed mobility thresholds are modeled using basic basic shear stress, velocity and flow equations. D_{84} mobilizing depths exceeded the cross sectional survey data for all sites except for TM1, and the D_{50} mobilizing depths exceeded survey data at R28A, thereby limiting an estimate of mobilizing flows. We recommend more extensive surveys to address this problem *(Data Source: Mesick, Nov. 1998 surveys)*.

I. A&B. SHIELD'S EQN for Critical Shear Stress (T_c) to mobilize gravel
Solve for depth to attain T_c (*Using slope from 1:24,000 topo map*)

ρ_w = 1000 kg/m^3
ρ_s = 2650 kg/m^3
g = 9.81 m/s^2
T^*_{ci} = 0.047

$T_{ci} = T^*_{ci}(\rho_s - \rho_w)g(d_i)$ *[I. A.]*
$R = T_d/(\rho_f g S_2)$ *[I. B.]*

II. B, C, D: Calc. area inundated at D_T, using XS plots
Avg V with Manning's Eqn
$V=1.49(R^{.67}S^{.5})/n$
Discharge Q w/ Flow Eqn
Q=VA

XS Site	Ptx size %ile	Ptx Size FIELD (mm)	Critic Shear St T_c (N/m^2)	Shear Stress T_d (N/m^2)	S_1 (1:24K topo map slope)	Hydr. Rad $R=T_d/(\rho g S_2)$ (m)	*assume R=D* D_T (ft)	*Note*	Area A_T @D_T (ft^2)	n *back calcul'd*	V *back-calc* (ft/s)	Q *Q=VA (w/ map n)* (cfs)	Estim. Return Period Pre NM Dam (FFA)	Estim. Return Period Post NM Dam (FFA)
TM1	50	*35.00*	26.63	26.63	0.004444	0.61	2.00		145	0.077	2.05	**297**	~1	**<1**
	84	*100.00*	76.08	76.08	0.004444	1.74	5.72		580	0.077	4.12	**2,389**	~1.2	**~1.65**
R1	50	40.20	30.58	30.58	0.001176	2.65	8.69		1060	0.035	6.17	**6,544**	~1.6	**10+**
	84	70.00	53.25	53.25	0.001176	4.61	*15.13*	*	--	*0.035*	*8.94*	--	--	--
R5	50	36.10	27.46	27.46	0.001176	2.38	7.81		898	0.028	7.24	**6,502**	~1.6	**10+**
	84	85.40	64.97	64.97	0.001176	5.63	*18.46*	*	--	*0.028*	*12.86*	--	--	--
R28A	50	32.30	24.57	24.57	0.000952	2.63	8.63	*	--	0.034	5.62	--	--	--
	84	68.50	52.11	52.11	0.000952	5.58	*18.30*	*	--	*0.034*	*9.28*	--	--	--
R78	50	28.90	21.99	21.99	0.000714	3.14	10.29		1065	0.035	5.40	**5,749**	~1.5	**8+**
	84	57.30	43.59	43.59	0.000714	6.22	*20.41*	*	--	*0.035*	*8.52*	--	--	--

II. A. FLOW AND MANNINGS EQNS (to back-calculate n) **Q= VA, $V=1.49(R^{.67}S^{.5})/n$**

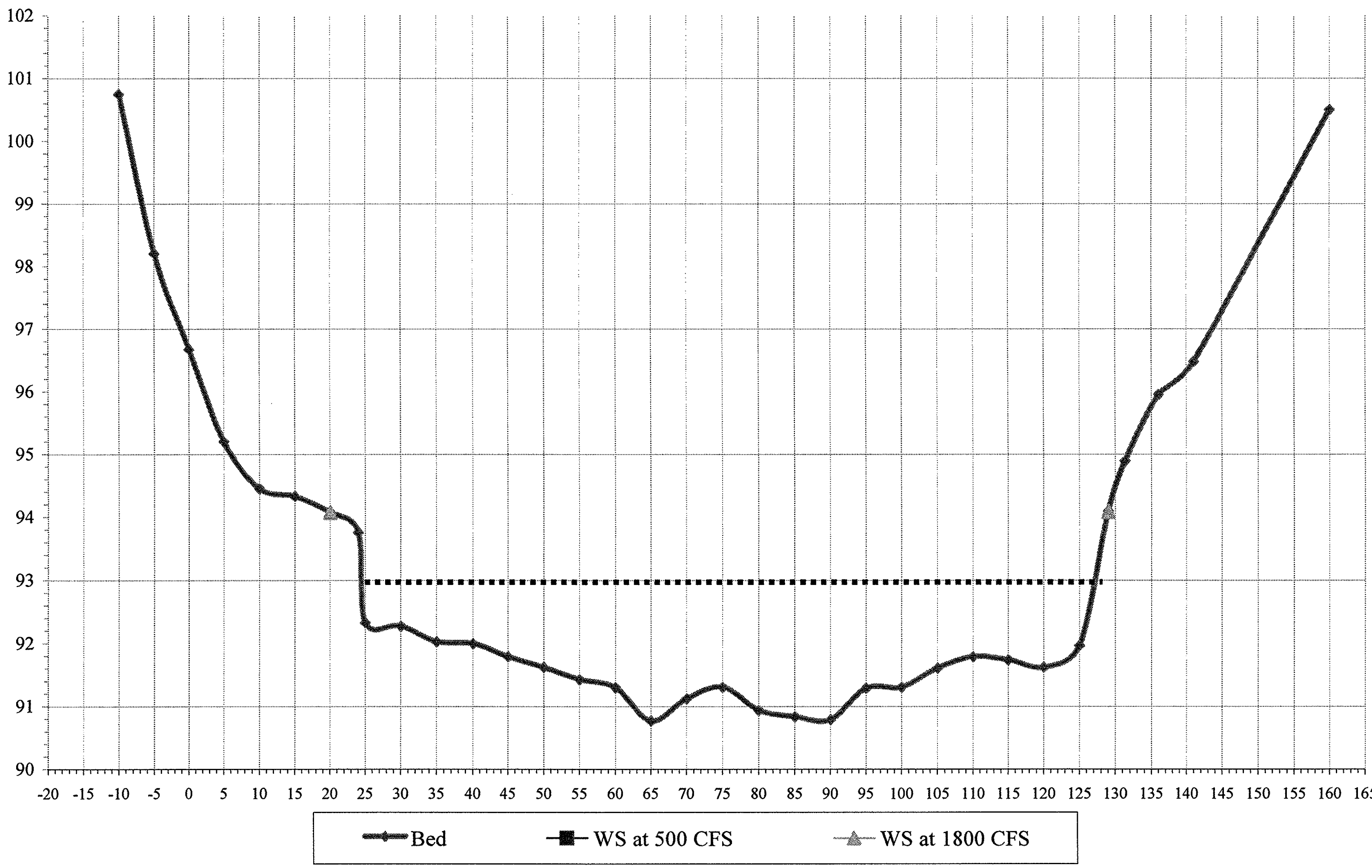
XS Site	*[1]* Q (cfs)	*[2]* A (ft2)	*[3]* WP (ft)	*[1] / [2]* V (ft/s) V=Q/A	*[2] / [3]* R (ft) R=A/WP	Slope S_1 (topo)	n (map)
		Nov.98 survey data					
TM1	1800	557	140	3.23	3.98	0.00444	**0.077**
R1	1800	486	120	3.70	4.04	0.00118	**0.035**
R5	1800	533	214	3.38	2.49	0.00118	**0.028**
R28A	1800	536	135	3.36	3.98	0.00095	**0.034**
R78	1800	543	110	3.31	4.95	0.00071	**0.035**

(shaded) calculated value

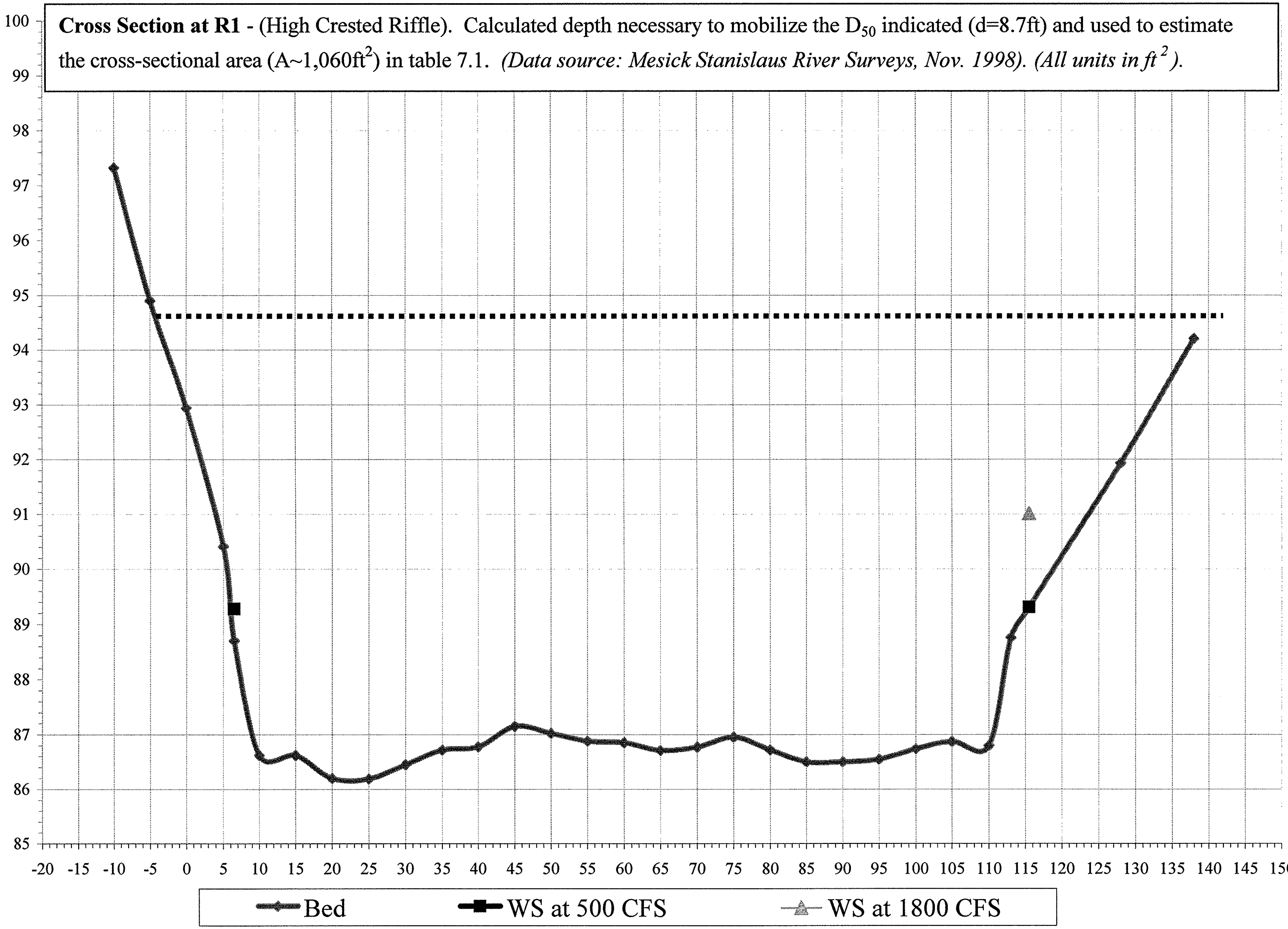
Notes:
** Indicates XS's where estimated mobilizing depths exceed bankfull conditions, so no discharge could be calculated*
D_{50} and D_{84} particle size from pebble counts (Falzone, summer 2000) except at TM1, where restoration gravel size (Mesick, 1998) is used (in italic).
Areas in IIA computed by counting squares of plotted cross sections (Mesick, Nov. 1998), using 1800 cfs as "bankfull."
Areas in IIB computed by graphing the estimated mobilizing depth and counting squares in Mesick (Nov. 1998) surveys (attached).
Wetted perimeter determined via trigonometric calculations for each plotted cross section (Mesick, Nov. 1998).
The topographic map slope is used for slope estimates, with surveys (Nov. 2000) resulting in a slope at R1 or 0.0021 and R28A or 0.000473.

Appendix 3, figure 1

Cross Section at TM1. (High Crested Riffle). Calculated depth necessary to mobilize the D_{50} indicated (d =2 ft) and used to estimate the cross-sectional area (A~145ft2) in table 7.1. *(Data source: Mesick Stanislaus River Surveys, Nov. 1998). (All units in ft^2).*



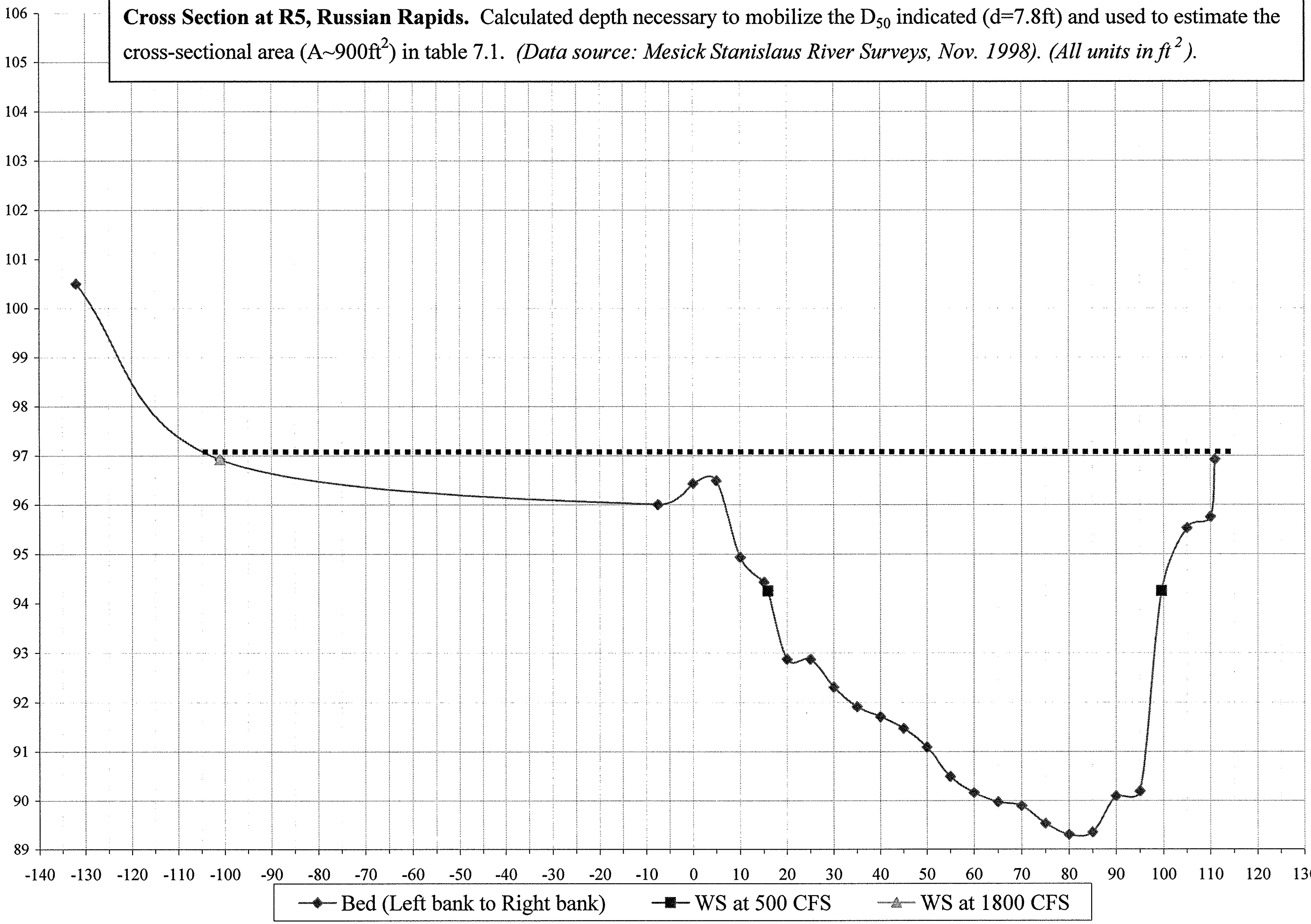
Appendix 3, figure 2



Cross Section at R1 - (High Crested Riffle). Calculated depth necessary to mobilize the D_{50} indicated (d=8.7ft) and used to estimate the cross-sectional area (A~1,060ft^2) in table 7.1. *(Data source: Mesick Stanislaus River Surveys, Nov. 1998). (All units in ft^2).*

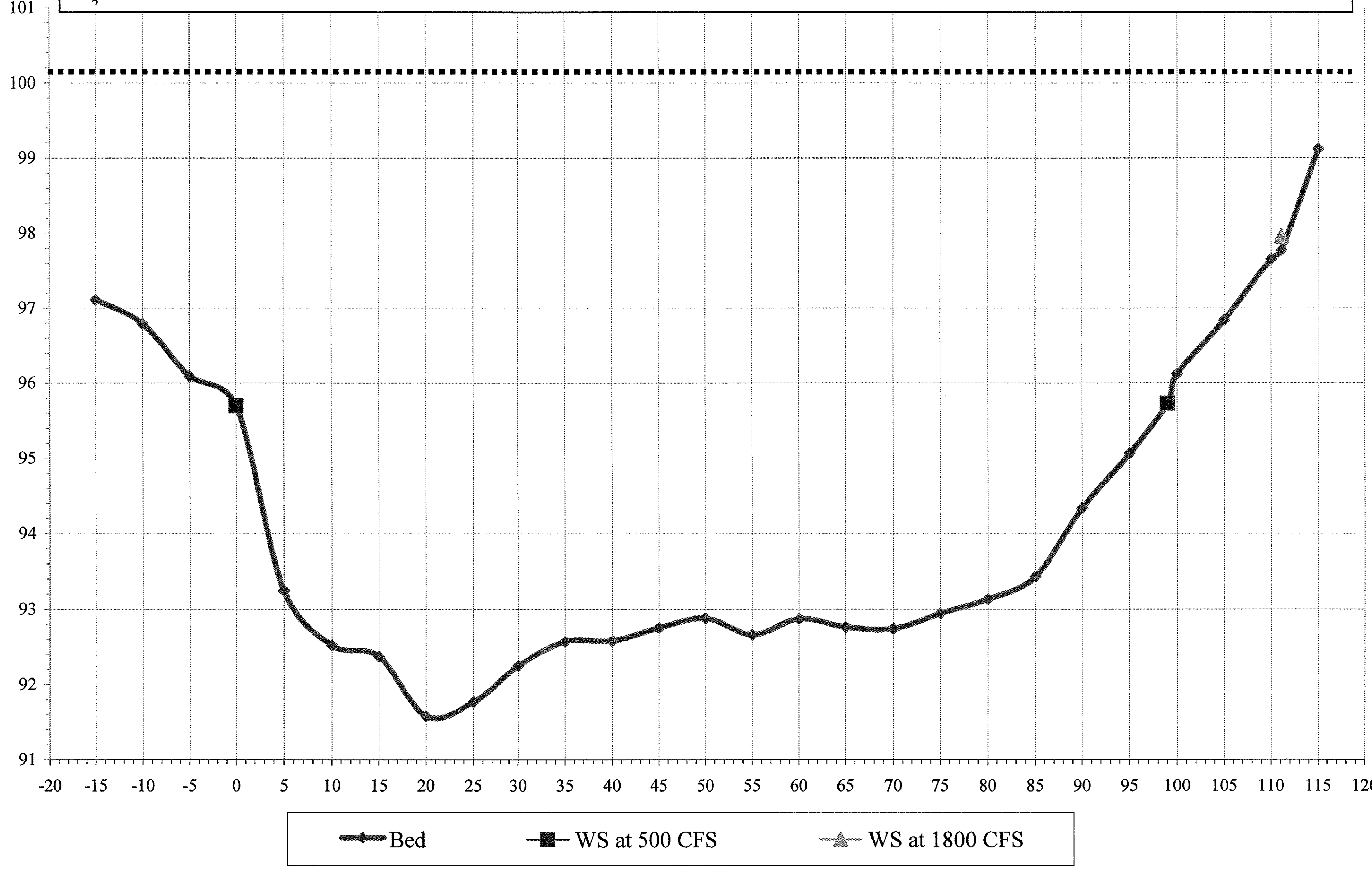
Appendix 3, figure 3

Cross Section at R5, Russian Rapids. Calculated depth necessary to mobilize the D_{50} indicated (d=7.8ft) and used to estimate the cross-sectional area (A~900ft^2) in table 7.1. *(Data source: Mesick Stanislaus River Surveys, Nov. 1998). (All units in ft^2).*



Appendix 3, figure 4

Cross Section at R28A. (High Crested Riffle). Calculated depth necessary to mobilize the D_{50} indicated (d~8.6ft) could not be used to estimate the cross-sectional area as it exceeded the survey. *(Data source: Mesick Stanislaus River Surveys, Nov. 1998). (All units in*



Appendix 3, figure 5

Cross Section at R78 - (Moderate Crested Riffle). Calculated depth necessary to mobilize the D_{50} indicated (d=10.3ft) and used to estimate the cross-sectional area (A~1,065ft^2) in table 7.1. *(Data source: Mesick Stanislaus River Surveys, Nov. 1998). (All units in ft^2).*