THE EFFECTS OF SUBSTRATE VARIABILITY AND INCISION ON THE DOWNSTREAM-FINING PATTERN IN THE COSUMNES RIVER, CENTRAL VALLEY, CALIFORNIA

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Abstract

Downstream fining of gravel in alluvial rivers is attributed to the processes of selective sorting and abrasion and is typically modeled as an exponential decrease in median grain size over the length of the profile. Exponential downstream fining produced through selective sorting has been linked to profile concavity and declining bed shear stress. Downstream-fining patterns are sensitive to changes in sediment supply and flow regime and can be expected to change in response to human activities that alter these variables.

Over the last 70 years, flood-management practices in the Cosumnes River, California have influenced flow regime and induced incision in low-gradient reaches downstream of Highway 16. It is probable that changes in flow and the thalweg profile have been accompanied by adjustments in the downstream-fining trend, and ongoing geomorphic evolution will continue to impact the size distribution of bed material. A geomorphic survey was conducted in order to define the existing downstream-fining pattern in the study area and document the current controls on geomorphic evolution. The survey consisted of 39 bed material samples, a 42.8 km thalweg profile, and 30 cross-sections located between Highway 16 and Twin Cities Road. Data was also used to determine the processes responsible for formation of the downstream-fining trend.

Although reach-scale variations in slope exist, the overall slope of the upstream 30 km of profile is nearly constant, and bed shear stress does not decline exponentially with distance downstream. Despite the lack of profile concavity, the downstream-fining pattern in the study area is best described by an exponential function. Results demonstrate that downstream fining is the aggregate effect of selective sorting that operates discontinuously over the length of the profile rather than the product of abrasion. Sorting and fining occur in reaches where bed shear

stress is low relative to the critical shear stress required for entrainment of the surface median. Where bed shear stress is high, the channel bed experiences frequent scouring and all grain sizes are transported downstream. Median grain size does not decline exponentially with distance through these reaches as it does elsewhere. Bed shear stress and the potential for sorting are determined by local slope and depth which are largely controlled by geology in many reaches. Local-scale sorting processes may contribute to downstream fining in the study area and in other systems where slope is longitundinally constant.

The overall slope of the profile declines significantly after about 30 km and generally remains low for the final 10 km of the profile. Decreased slope and lowered maximum channel depth are achieved where the river exits a long segment bounded by levees and enters one where levees are set back from the channel and overbank flooding occurs annually. Diminished bed shear stress beginning at this transition accounts for the change in bed material from gravel to sand which requires approximately 8 km for completion. With the existence of the baseline information provided by this study, future surveys can be used to assess the effects of contemporary geomorphic response and future restoration efforts on downstream fining.

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Introduction

Reduction in the size of bed material with distance downstream is commonly observed in gravel-bed rivers. Termed *downstream fining*, researchers have attributed this feature to the processes of selective sorting (Ashworth and Ferguson, 1989; Ferguson and Ashworth, 1991; Paola et al., 1992; Ferguson et al., 1996; Seal et al., 1997) and abrasion (Bradley, 1970; Schumm and Stevens, 1973; Werrity, 1992; Kodama 1994a, 1994b). Studies in rivers with concave profiles have emphasized the role of declining slope in producing downstream fining, especially where lithologies are relatively resistant to abrasion (Parker, 1991; Paola et al., 1992; Hoey and Ferguson, 1994; Ferguson et al., 1996; Hoey and Ferguson, 1997; Seal et al., 1997). Decreasing slope implies diminishing flow competence, or ability to transport a given particle size, which leads to selective deposition of coarse grains upstream and preferential transport of fine grains downstream.

Downstream-fining patterns which reflect sediment-transport conditions are necessarily sensitive to spatial and temporal changes in flow regime and sediment supply (Wolcott, 1988; Hoey and Ferguson, 1994; Pizzuto, 1995; Hoey and Ferguson, 1997; Hoey and Bluck, 1999). Therefore, changes in flow and sediment supply induced by anthropogenic activities such as flow regulation, levee construction, channelization, and land-use practices can be accommodated through adjustments in fining patterns. These adjustments or modifications in the nature of bed material have important consequences for aquatic life. Salmonid species, for example, require specific substrate conditions for spawning (Bjornn and Reiser, 1991).

Native salmonids return annually to spawn in the Cosumnes River, California; however, populations have declined over recent years. Knowledge of the processes that alter grain-size patterns and thereby affect the quality and distribution of riparian habitat is necessary for successful restoration of native fish species in the Cosumnes and other California rivers. Unlike most western Sierran rivers, the Cosumnes has no major dam on it to regulate flow; thus, it presents a unique opportunity to examine the effects of anthropogenic change on fluvial geomorphology and related habitat suitability in the region. This field study focuses on the influences of substrate variability and profile shape, products of recent incision, on the downstream-fining pattern exhibited by the Cosumnes River. The study area is a low-gradient segment of the Cosumnes River from approximately Highway 16 downstream to Twin Cities Road.

Where downstream fining is dominated by selective sorting, the degree of fining should correlate with the degree of profile concavity (Parker, 1991). In other words, a sharp decline in median grain size over a short distance should be accompanied by significant decreases in slope and bed shear stress. In contrast, median grain size should not show substantial downstream reduction where the channel profile is linear. Bed material in the Cosumnes is relatively resistant; therefore, it is expected that selective sorting caused by declining bed shear stress dominates the production of downstream fining in the study area.

In order to document the downstream-fining pattern in the lower reaches of the Cosumnes River, 39 surface and subsurface bed-material samples were collected over 42.8 km. A thalweg profile was surveyed over the same distance to record downstream changes in slope which influence selective sorting. Despite a lack of strong profile concavity in the study area, bed material exhibits an exponential downstream-fining trend and undergoes a transition from gravel to sand. Thirty cross-sections completed in the upstream 32 km of the study area provide information about bankfull depth and channel form, characteristics which also affect sorting processes. Results suggest that exponential downstream-fining patterns can develop through selective sorting in river segments where longitudinal concavity is weak and sorting is not continuous over the length of the profile.

Background

Downstream fining

Downstream fining is defined as the decrease in bed-material grain size with distance downstream and is attributed to the processes of sorting and abrasion. A simple exponential function developed by H. Sternberg in 1875 is commonly used to describe downstream fining over a longitudinal profile with no lateral sources of coarse sediment (e.g., Shaw and Kellerhals, 1982; Paola et al., 1992; Paola and Seal, 1995; Hoey and Bluck, 1999):

$$D = D_O e^{-aL} \qquad (1)$$

where D is a characteristic grain size in mm (usually the median), D_O is grain size at the upstream end of the study reach (L=0), a is an empirical diminution coefficient (km^{-1}) that reflects the combined effects of sorting and abrasion, and L is the distance downstream in km. Diminution coefficients on the order of 10^{-3} to 10^{0} km^{-1} have been reported for alluvial rivers (Shaw and Kellerhals, 1982; Hoey and Bluck, 1999).

Fluctuations about the decline predicted by Eq. (1) signify reach-scale variations in sediment sorting related to channel geometry as well as any inconsistencies in sampling procedure from site to site (Hoey and Bluck, 1999). Sudden increases in grain size may indicate significant coarse sediment contributions by tributaries or banks (Rice, 1998). Rice and Church (1997) used lateral sediment sources to define the boundaries of sedimentary “links” or channel segments where sorting and abrasion operate relatively uninterrupted to develop unique downstream-fining trends. They found that by applying Eq. (1) to individual links, a more accurate reproduction of downstream fining in rivers with distinct lateral sources of coarse sediment was achieved.

The relative importance of sediment sorting and abrasion in determining the diminution coefficient depends on the system in question. In particular, it depends on the lithologies of the material in transport (e.g., Werrity, 1992) and whether sediment discharge is limited by transport capacity or sediment supply (e.g., Shaw and Kellerhals, 1982). Transport capacity is determined by the quantity of material that can be carried past a given point in a unit of time.

Recent flume experiments and field studies in transport-limited alluvial streams have emphasized the ability of sorting to produce downstream fining without a contribution by abrasion. In general, aggradation facilitates downstream fining through sorting by removing relatively less mobile material from the active layer and increasing the availability of smaller, relatively more mobile particles (Shaw and Kellerhals, 1982). Ferguson and Ashworth (1991) and Ferguson et al. (1996) provided field evidence for fining through sorting as a result of exponential decline in slope with distance downstream. Diminishing bed shear stress caused by decreasing slope suggests a downstream reduction in competence or ability of a certain flow to transport a given grain size. Hence, larger grains experience lesser frequencies and velocities of movement causing a segregation of sizes: larger grains are concentrated in upper reaches, and smaller ones are transported downstream. In numerous flume studies, downstream fining has been attributed exclusively to sorting because fining patterns were produced over too short of time scales for abrasion to be significant (Paola et al., 1992; Seal et al., 1997).

Despite strong evidence for sorting-dominated fining in some systems, other studies have demonstrated that abrasion may make a considerable contribution to downstream fining under certain flow and sediment-supply conditions (e.g., Bradley, 1970; Parker, 1991; Werrity, 1992;

Kodama, 1994a). Abrasion is the primary cause of downstream fining in rivers where the lithologies of material in transport are not resistant to corrasion (Parker, 1991; Werrity, 1992; Kodama, 1994a) or have markedly different abrasion properties (Kodama, 1994b). Abrasion may also contribute to fining where bed material is weathered (Bradley, 1970) or fractured.

The importance of abrasion is greater in high-energy streams that transport mixed-sized bedload (Kodama, 1994b) than in low-gradient streams. Breakdown in the former is promoted by higher impact velocities and crushing of smaller particles by larger ones during transport. Schumm and Stevens (1973) proposed that physical breakdown of grains occurs in place as well as during transport. Lift and drag forces acting on the bed surface during flows less than those required to initiate movement cause rapid oscillations and abrasion in place.

The relative influence of abrasion may also depend on the spatial scale of the investigation. Observations of downstream fining over short distances such as bar surfaces provide evidence for the effects of sorting due to local variations in bed shear stress rather than abrasion (Ashworth and Ferguson, 1989; Whiting and Dietrich, 1991). While abrasion may augment downstream fining over intermediate distances, its effect is negligible beyond the channel length required to completely grind up less resistant lithologies (Parker, 1991).

Downstream fining through sorting

Sediment sorting by fluvial processes is subdivided into three categories: sorting during entrainment, transport, and deposition. Entrainment of a particle at rest on a streambed occurs when driving lift and drag forces exceed particle weight and resisting factors associated with grain shape and packing arrangement. Threshold shear stress for incipient motion of a particle in a bed of mixed sizes shows strong dependence on relative as well as absolute grain size (Andrews, 1983; Ashworth and Ferguson, 1989; Wilcock, 1992). Relative-size effects that include hiding and protrusion tend to reduce the mobility differences between small and large particles. Small grains that settle between larger particles on the bed surface are "hidden" from the overhead flow. The mobility of fine grains is thus reduced relative to what it would be in a bed composed entirely of like sizes (Parker and Klingman, 1982). Conversely, the mobility of large grains is enhanced by the presence of sand on the bed surface (Parker and Klingman, 1982; Ferguson et al., 1989). Coarse grains protrude farther into overhead flow than surrounding sand grains, thereby increasing the likelihood of their entrainment compared to that in a bed of strictly coarse material.

Observations of relative-size effects led Parker and Klingman (1982) to formulate what is now called the equal mobility hypothesis. It states that under equilibrium transport conditions (the rate of each size fraction entering the system is equal to that leaving), surface coarsening through vertical winnowing serves to eliminate the mobility differences between coarse and fine particles. In the process of vertical winnowing, small grains fall into holes left by entrained large grains and work their way beneath the armoured surface. The presence of the surface armour reduces the otherwise high mobility of fine grains and serves to regulate transport of underlying bed material.

Subsequent studies have shown that although entrainment depends strongly on relative size, threshold shear stress for motion varies with absolute size under certain conditions (Ashworth and Ferguson, 1989; Wilcock and Southard, 1989; Wilcock, 1992). Entrainment deviates from equal mobility in beds of bimodal sediment (Wilcock, 1992) and where bed shear stress is lower than that required to break up the surface layer (Ashworth and Ferguson, 1989; Wilcock and Southard, 1989). Hence, natural gravel-bed rivers probably exhibit a range of initial-motion criteria from somewhat size-dependent to nearly size-independent (equal mobility).

Although the size distribution of sediment entrained from the bed depends on initial size distribution and flow conditions, subsequent changes in size distribution occur during transport. Sorting during transport is controlled by forces that result from longitudinal and cross-stream changes in channel curvature and bed topography as well as other elements that offer resistance to flow such as large woody debris. Local variations in bed shear stress due to bed topography cause differentiation of poorly sorted bed material into unimodal patches with different mean sizes (Paola and Seal, 1995). "Patchiness" promotes downstream fining by eliminating the effects of relative-size differences. Sand-sized material is more easily eroded from a sand patch than from a surface containing gravel, and gravel is less easily eroded from a gravel patch than from a sand bed. Therefore, the development of patches in a mixed bed encourages downstream transport of fine material and discourages transport of coarse material. The contribution of patchiness to the evolution of downstream-fining trends exemplifies the strong effect that local-scale sorting processes may have on reach-scale patterns of grain-size distribution.

Relative-size effects that influence entrainment also regulate deposition such that a particle is preferentially deposited on a bed of similarly sized material. For example, selective deposition of coarse material occurs at bar heads where increased turbulence around large clasts discourages deposition of fine grains (Powell, 1998). In flume experiments, Paola et al. (1992) and Seal et al. (1997) recorded downstream fining in bimodal sediment through selective deposition of the coarsest clasts. The rapid rates of aggradation observed in the studies rule out particle abrasion as a source for fining.

The gravel-sand transition

Changes in bed material from gravel upstream to sand downstream have been documented in numerous downstream-fining studies (e.g., Paola et al., 1992; Sambrook Smith and Ferguson, 1995; Knighton, 1999). Over the length of the gravel-sand transition, the grain-size distribution typically changes from unimodal gravel to bimodal gravel and sand and finally, to unimodal sand (Sambrook Smith and Ferguson, 1995; Sambrook Smith, 1996). Paola et al. (1992) suggested that the upstream boundary of the gravel-sand transition may be marked by an increase in the size of gravel on the bed surface. In addition, the gravel-sand transition is commonly associated with a break in slope as the sand content of the bed surface increases, and a lower slope is required for transport of surface material (Sambrook Smith and Ferguson, 1995).

Study area

The Cosumnes River, Central Valley, California

The Cosumnes River watershed occupies an area of approximately 1700 km^2 in Sacramento, Amador, and El Dorado counties of California (Fig. 1). The headwaters of the river begin at an elevation of around 2,000 m in the El Dorado National Forest on the western slope of the Sierra Nevada. Unlike most rivers draining the mountains to the Central Valley, the Cosumnes has no major dam on it to regulate flow. Its three forks meet near Highway 49 to form the main channel that flows 79 km southwest toward the Cosumnes River Preserve and the confluence with the Mokelumne River. The study area is a 42.8 km, low-gradient, alluvial length of the Cosumnes located between the Sierran foothills and the confluence with the Mokelumne. The thalweg profile, cross-sections, and grain-size measurements cover the distance from 1 km downstream of Highway 16 (0.22 km upstream of mile marker 32) to Twin Cities Road (0.25 km upstream of mile marker 5) (Fig. 2). Three tributaries join the channel in the study area, Arkansas Creek at 1.1 km, Deer Creek at 33.7 km, and Badger Creek at 38.5 km downstream of the start of the surveyed profile.

Hydrology

The Cosumnes River watershed receives an average of 97 cm of precipitation annually according to records held by the Information Center for the Environment at the University of California, Davis. The majority falls as rain between October and May. Little is contributed by snowfall since only a small percentage of the basin is located above 1500 m elevation. As a result, flow in the Cosumnes is derived mainly from winter rainfall with a very small contribution from spring snowmelt. A flood-frequency analysis of data from the USGS Michigan Bar gauge (#11335000), located approximately 20 km upstream of the study area, shows that bankfull flow corresponding to a recurrence interval of 1.5 to 2 years (Leopold et al., 1964) ranges from 178 to 295 m^3s^{-1} (6290 to 10400 f^3s^{-1}) (Fig. 3). In the winter of 1997, the Cosumnes experienced record flows exceeding 2000 m^3s^{-1} (70,000 f^3s^{-1}) (Fig.3). Winter storms in the Cosumnes basin give way to dry summers when seepage from the channel commonly causes the river to run dry. Downstream of Twin Cities Road, water level is subject to tidal influence.

Geology

Sediment supply in the Cosumnes River is derived predominantly from granitic, andesitic, and metamorphic sources in the Sierra Nevada mountains (Fig. 1). The landscape of the study area west of the Sierra was shaped during Tertiary and Pleistocene uplift and glaciation (Harden, 1998). There are three major Tertiary and Quaternary geomorphic provinces: ridges composed of Tertiary volcanics, dissected Tertiary and Quaternary alluvial fan surfaces, and Holocene floodplain deposits (Fig. 1).

Climatic fluctuations in the Tertiary and Pleistocene induced cycles of glacial advance and retreat corresponding to global sea-level fall and rise. These are recorded in the stratigraphy of the Cosumnes basin as sequences of incision, valley filling, and alluvial fan development followed by soil formation during periods of stability (Shlemon, 1972). Recession of Late Tertiary glaciers resulted in the deposition of alluvial fans collectively called the Laguna Formation which were later tilted during uplift of the Sierra Nevada (Piper et al., 1939). Below the hills composed of Laguna alluvium are terraces of Riverbank channel and fan deposits. Within the Riverbank Formation, interglacial periods are marked by well-developed soil horizons (Piper et al., 1939) which separate glacial outwash of different ages (Piper et al., 1939; Shlemon, 1972).

During the final glacial cycles of the Pleistocene, the Cosumnes incised into pre-existing fans and deposited the Modesto alluvium in valleys. Interglacial periods are also marked in the Modesto Formation by well-developed soil layers (Vick et al., 1997; Birkeland, 1999). In the western part of the study area, Modesto gravel and sand are covered by unconsolidated Holocene channel and levee deposits.

Channel management and geomorphology

Examination of historical maps has suggested that prior to European settlement of the Central Valley, the Cosumnes River downstream of Highway 16 was an anastomosing system characterized by multiple, shallow channels which experienced episodic avulsion (Florsheim and Mount, 1999). The system was described as a network of sinuous channels 1.5 to 2.5 m deep connected by a floodplain which was inundated during even moderate flows (Piper et al., 1939).

Watershed-scale land-use changes occurring since the 1850s and channel modifications that began in the early 1900s greatly influenced flow regime and sediment supply in the study area. In particular, restriction of flow to a single channel and construction of agricultural levees increased in-channel flow depth and caused riverbed lowering (Vick et al., 1997) similar to that documented in other rivers (Galay, 1983). Substantial incision resulted in excavation and erosion of duripan layers, the hardened interglacial soils preserved in Riverbank- and Modesto-aged deposits.

Available records indicate that the earliest levee construction in the study area began around 1930 just upstream of Highway 99 (U.S. Army Corps of Engineers, 1936). By 1937, levees were present along the entire length of the right bank between Dillard and Wilton Roads (Vick et al., 1997). No surveys were conducted at the time of installation; however, surveys from the 1950s through the 1990s record net incision ranging from 0.5 to 3.0 m throughout the study area (Vick et al., 1997). Contemporaneous removal of riparian vegetation for levee construction and streamside agriculture possibly weakened the shear strength of banks as it has in other systems (Simon and Darby, 1999) and lessened the availability of habitat-forming, large woody debris.

Structures currently in place that continue to influence channel evolution in the study area are levees, bank protection, and agricultural diversion dams. Various patches of rip-rap and concrete line the banks from Highway 16 to Dillard Road; however, levee construction was minimal in this segment and only occurred along 1 km of the left bank (Vick et al., 1997). Bank material ranges from mixed cobbles and sand near Highway 16 to sand and silt at Dillard Road.

The irregular meanders of the river are confined by levees between Dillard Road and Highway 99. Levees between the two major roads extend along nearly the entire right bank and a small portion of the left (Vick et al., 1997). Erosion and flooding of the left bank are restricted by high bluffs of relatively resistant Riverbank and Laguna alluvium where levees are absent. The banks are frequently lined with bank protection, and numerous diversion dams are built across the river.

From Highway 99 to Twin Cities Road, levees run the entire length of the right bank but are set back from the stream and do not prevent overbank flooding. The exception is a one-half mile stretch immediately downstream of Highway 99 that closely lines the left bank. In addition to levees, frequent outcrops of duripan in reaches downstream of Meiss Road exert considerable influence on local channel form and evolution of the thalweg profile in the study area.

Methods

Definition of the downstream-fining pattern in the study area and discussion of the processes that contribute to fining require grain-size measurements as well as profile and cross-section surveys. In addition, possible lateral sources of coarse material must be identified. Survey data provide information about slope and depth which reveals downstream changes in bed shear stress. Changes in bed shear stress imply differences in the capacity for selective sorting. It is anticipated that downstream fining in the study area is accompanied by reductions in slope and the average bankfull depth-slope product.

Grain-size sampling

Surface and subsurface bed-material samples were collected on bars in order to define the downstream-fining pattern. Samples were collected along a 42.8 km length of the river at 39 sites spaced approximately 1 km apart where bedforms existed. Where bedforms occurred less frequently, samples were spaced as near to 1 km apart as possible (Fig. 2). Samples were taken in homogeneous deposits at approximately the centers of alternate or point bars that were assumed to have formed at bankfull flow. Centers of bars were sampled in order to minimize the noise introduced to the downstream-fining data by surface fining from bar heads to tails. Actively forming bars were selected for sampling while sites exhibiting the following characteristics were avoided: an over-abundance of quartz indicating possible mine tailings, the presence of tire or boot tracks, and the presence of large woody debris. Clast imbrication and a well-defined coarse surface layer were used as indicators of alteration by recent flow conditions.

Bulk surface samples were collected over one square meter to the depth of the largest exposed grain, a method described by Church et al. (1987). Where grains with diameters less than 2 mm comprised more than 50 percent of the bar surface area, the surface was not differentiable from the subsurface, and bulk samples were collected by shoveling material from a hole no more than 10 cm deep into a bag. Bulk samples were collected at sites 25, 27, 32, 33, 35, 36, 39, and 40 and were listed as “surface” samples in all tables and appendices. The size of each sample was sufficiently large so that the mass of the largest grain constituted no more than 5 percent and usually less than 3 percent of the total sample mass according to requirements outlined by Church et al. (1987).

The samples were sieved manually in rocker sieves at half-phi intervals and weighed in the field. The sediment passing through the finest rocker sieve, material sized less than 4 mm in diameter for dry samples and less than 8 mm for wet samples, was split in the field according to the method of quartering (ASTM, 1985), and a portion was brought to the lab for drying and further sieving. This procedure assumed that the mass of the water adhered to material greater than or equal to 8 mm in diameter was insignificant relative to the mass of the grains. In some locations, surface and/or subsurface samples were not sieved in the field but were collected in bags and brought to the lab to be split and sieved.

The portion of each sample brought to the lab was placed in a metal pan and dried overnight in an oven set at 50 degrees Celsius. The dry sample was weighed and sieved through screens by hand at half-phi intervals until the remaining material was less than 2 mm in diameter. The material was split into 100 g subsamples and lightly ground using a mortar and pestle to break up any consolidated clay. The subsamples were sieved at half-phi intervals using a Ro-Tap sieve shaker with a running time of 15 minutes.

Eroding bank material was sampled in order to compare the size distribution of coarse inputs with that of the bed material. Samples were taken at site 2 (0.75 km) and at 14.9 km using the size criteria for sampling described above. At site 2, sediment was collected from the left bank using a shovel and a bucket, and all material shoveled into the bucket was sieved. The material collected at 14.9 km was removed from beneath a duripan layer on the left bank also using a shovel and bucket. All sediment was brought to the lab and sieved at half-phi intervals as previously described. Grain-size data were compiled in Appendix I.

Grain-size analysis

The mass of each size class weighed in the lab was divided by the fraction of the field sample brought to the lab in order to find the mass of the class. The percent of the total sample in each class was calculated by dividing the mass of the material in the class by the total sample mass. Based on plots of cumulative weight percent versus size class, D_5, D_{10}, D_{16}, D_{50}, D_{84}, D_{90}, and D_{95} were determined. The error involved in determining D_i was estimated and included in

Appendix II. The percent of material sand-sized and finer in each sample was found by dividing the mass of material less than 2 mm in diameter by the total sample mass.

Several sites were omitted from subsequent analyses based on anomalous grain- size measurements and evidence of site disturbance. Site 5 was previously the location of an in-stream gravel mining operation and later, airport construction. The median grain size exceeded the size of material entering from upstream or eroding from the banks. At site 6, vegetation upstream influenced depositional patterns causing the subsurface size distribution to have three modes. The fraction with the greatest mass was less than 1 mm in diameter. At site 17, many size classes present on the bed surface were not represented in the finer subsurface material, and the paving ratio (surface D_{50} to subsurface D_{50}) was anomalously high.

In order to determine downstream trends in sorting that may signify the influence of lateral inputs, the inclusive graphic standard deviation (σ_I) was calculated for surface samples and used as an index to describe sorting (Folk, 1974):

$$\sigma_I = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6} \qquad (2)$$

In the formula, grain size is given in phi (ϕ) equal to $-\log_2 D$. Folk (1974) provided the following classification scale: $\sigma_I < 0.5\phi$, well-sorted; 0.5ϕ-1.0ϕ, moderately sorted; 1.0ϕ-2.0ϕ, poorly sorted; 2.0ϕ-4.0ϕ, very poorly sorted. The index was also used to indicate the location of the gravel-sand transition. Bimodal gravel and sand deposits and associated elevated indexes have been documented at the upstream boundaries of gravel-sand transitions (Sambrook Smith and Ferguson, 1995).

Thalweg and cross-section surveys

In order to determine downstream changes in channel slope, a 42.8 km thalweg profile was surveyed during low-flow months using an auto level and stadia rod. The upstream 36.6 km were completed over 3 months during the summer of 2000, while the remaining 6.2 km were finished during the summer of 2001. Bed-surface and water-surface elevations were measured in the thalweg of the main channel approximately every 40 m. Additional measurements were recorded at the heads and tails of riffles, the location of greatest depth in pools, and the tops and bottoms of small, vertical steps in reaches with exposed duripan in the bed.

Thirty cross-sections were surveyed at sample sites along the upstream 32 km of profile in order to estimate average channel depth at bankfull. Downstream of 32 km, the majority of bedforms were composed of sand indicating that the channel had entered a transition from gravel-dominated to sand-dominated reaches. Cross-sections were restricted to sites upstream of this transition in order that D_{50} of the coarse surface layer on bars in gravel reaches could be compared with the local depth-slope product. Descriptions of the benchmarks used in this study were made in Appendix III. Profile survey data, cross-section survey data, and cross-section locations and descriptions were given in Appendices IV, V and VI, respectively.

One to three estimates of bankfull water-surface elevation were measured at each cross-section. Bankfull discharge refers to the discharge or range of discharges with a magnitude and frequency of occurrence that render it most effective in shaping the channel (Wolman and Miller, 1960). It was assumed that the bars where samples were collected formed at bankfull flow. Bankfull stage in alluvial rivers often corresponds to the elevation of the valley flat. As a consequence of incision and levee construction, much of the Cosumnes River in the study area is detached from its former floodplain; hence, bankfull stage does not correspond with the elevation of the valley floor.

Other indicators were used to determine bankfull in the field: change in bank slope, undercutting of the bank, the highest elevation on point bars, and the highest elevation of sand deposits on the bank (Williams, 1978; Harrelson et al., 1994). In reaches where exposed duripan influences channel geometry or where levees closely confine the channel, the elevation of the highest exposed and undercut tree roots helped to define bankfull. Bankfull water-surface elevation estimates made at each cross-section were included in Appendix VII.

Detailed descriptions of bed and bank materials were made at each cross-section, and general notes were compiled for the entire length of the profile. These data helped define the approximate upstream and downstream extents of duripan reaches. The term *duripan reaches* used in this study refers to those characterized by frequent or continuous duripan outcrops in the bed and banks of the stream. The locations of cobble and gravel deposits preserved in or below the duripan layers and currently eroding were also included in the field notes in Appendix IV in order to document possible lateral sediment sources.

Change in thalweg elevation

Thalweg elevations at bridges were compared to pre-existing data compiled by Vick et al. (1997) and reported by Guay et al. (1998). Maps provided by Vick et al. (1997) and Guay et al. (1998) were used to find the locations of bridge surveys. Restriction of data dated earlier than 1998 to elevations at bridges required that bridge data be used for identification of spatial and temporal trends in vertical adjustment. It was recognized that apparent elevation changes at bridges are perhaps the results of local hydraulics associated with the structures or reflect yearly elevation highs or lows instead of averages. However, the data span a sufficiently long period of time so that long-term trends in the direction of elevation change can be seen.

Depth-slope product

Use of absolute grain size to estimate critical shear stress fails to account for important factors that influence entrainment. These include the effects of relative size, packing arrangement, and grain shape. Likewise, use of the depth-slope product to generate estimates of bed shear stress neglects important depth-velocity interactions that produce spatial and temporal variations in bed shear stress and particle entrainment (Batalla and Martín-Vide, 2001). In this study, cross-sections were completed over bars where convective acceleration patterns lead to additional spatial variations in bed shear stress (Whiting and Dietrich, 1991). It was assumed that despite the influences of relative-size effects and depth-velocity interactions, median grain size and the depth-slope product are good indicators of the magnitudes of critical shear stress and average bankfull bed shear stress, respectively.

Median grain size as reported in this study provides an indicator of the critical shear stress required for entrainment of material at the centers of bars and not across the entire cross-section. Therefore, comparison of median grain size and the sectionally averaged depth-slope product required an assumption. It was assumed that a relationship exists between the surface median at the center of a bar and the median that represents the size distribution of material across the entire cross-section. Because sampling methods were consistent from site to site, the degree to which the samples represent the bed material moving through the cross-section is longitudinally constant.

The average bankfull depth-slope product was calculated for bankfull flow at each cross-section site in order to identify downstream trends in the magnitude of bed shear stress. The bed slope over a distance of 5 to 10 channel widths upstream and downstream of each cross-section was measured directly off of the profile plot and used to estimate energy slope at each site.

Bankfull cross-section area was calculated for each estimate of bankfull stage using Kaleidagraph (Synergy Software, Reading, PA) and the Integrate-Area macro. Use of the macro assumed that the cross-stream bankfull water surface at each section was horizontal. Two lines, a horizontal line representing bankfull stage and the surveyed cross-section line, were plotted. Identical x-axis boundaries and y-axis reference lines were specified for the two curves in order that the difference between the values would be equal to the bankfull cross-section area. Average bankfull depth was found by dividing the area by the measured top width of the channel at bankfull. Bankfull width, area, average depth, and width:depth ratio for each estimate of bankfull stage at each cross-section were listed in Appendix VII.

To address the uncertainty in estimating bankfull stage based on field indicators, a range of average bankfull depth values that best represents bankfull conditions was determined using a method introduced by Johnson and Heil (1996). At sites where two estimates of average bankfull depth were calculated, the numbers are a minimum and maximum that define the possible range of bankfull depths. The minimum and maximum were each assigned a significance of 0, and the mean of the two was assigned a significance of 1. At sites where three depth calculations describe the range of bankfull depths, the minimum and maximum were assigned a significance of 0, and the intermediate value was assigned a significance of 1. The significance values were plotted on the y-axis against average bankfull depth as simple line graphs, one for each cross-section.

It was decided that a range describing average bankfull depth values with a significance equal to 70 percent was sufficient to depict the uncertainty in estimating bankfull at a given cross-section. A line was drawn in each plot parallel to the x-axis at 0.7 significance. The depth values at the two intersections between this line and the plotted line were used to define a range of depths that most likely represents average bankfull depth. Using this method, the size of the range is proportional to the uncertainty in estimating bankfull at a given site. The range of average bankfull depths at each cross-section was used to calculate the range of average bankfull depth-slope products.

Results

Downstream-fining pattern

Downstream fining of the median surface and subsurface grain sizes in the study area follow exponential trends (Fig. 4). The diminution coefficient for the surface median determined by least-squares linear regression is 0.0744 km^{-1}. The exponential curve provides a good fit to surface median data upstream of 19 km; however, between 19.37 and 31.83 km, the majority of data points plot above the trendline. In other words, the size of the surface material does not decrease exponentially with distance as it does elsewhere. The plot of subsurface median grain size shows the opposite relationship: the trendline is a poorer fit to data upstream of Meiss Road (10.1 km) than to data downstream. This difference reflects higher paving ratios measured in reaches between 10.1 and 32 km than in reaches upstream (Table 1).

Downstream of 32 km, the majority of surface median sizes are around 2 mm or less. This change from primarily gravel deposition to mainly sand deposition marks the beginning of the gravel-sand transition. Gravel was found in the channel as far downstream as 39.2 km. Given these constraints, the transition from gravel to sand in the Cosumnes River occurs over about 8 km.

None of the three tributaries causes a significant discontinuity or positive step in the downstream-fining pattern of the surface median (Fig. 4). However, slight increases in the surface and subsurface median sizes occur immediately following the Deer Creek confluence. Deer Creek, the largest tributary in terms of flow and length, begins at a low elevation in the Sierran foothills and flows parallel to the Cosumnes in the study area. Deer Creek has been intensively mined for gravel, and it is unknown how mining has influenced the size of material available for bedload transport. The increases in median sizes could be part of the regular scatter seen in the downstream-fining pattern rather than reflections of inputs of coarse material to the main channel. Therefore, additional sampling at the mouth of the stream is necessary in order to determine whether Deer Creek inputs a significant amount of coarse material.

Other possible lateral sources include Modesto-aged cobble and gravel banks that line the first kilometer of the profile and discontinuous coarse deposits capped by duripan layers farther downstream. The grain-size distribution of bank material collected at site 2 (0.83 km) shows that it is finer and composed of more sand than the bed material at that location (Table 1). Therefore, additions to the bed are not followed by positive steps in the downstream-fining pattern. It is unknown how the size distribution of the coarse bank material varies with distance because no samples were collected upstream. The distribution of lithologies present in the banks is similar to that in the bed.

Cobble and gravel layers preserved in or below duripan and exposed in the banks downstream of Meiss Road (10.1 km) constitute potential sources of coarse sediment. However, only two of the nine layers mapped, those at 22.90 and 24.35 km, are followed by positive steps in surface and subsurface median grain sizes (Fig. 5). A sample collected from the left bank at 14.9 km contains a high percentage of volcanic clasts and feldspar grains which were not seen in the bed material in the channel downstream. Like most coarse layers outcropping along the channel, the layer from which the sample was collected was partially cemented by iron oxides and clays. Cementation as well as the protection of overlying duripan apparently reduce the rate of gravel erosion enough that additions to the channel do not significantly alter the lithologic composition of the bed material. Grain-size and lithologic distributions of the sediment in the lenses vary downstream since not all deposits represent the same period of valley filling and were not formed under identical flow and supply conditions.

Holocene deposits identified downstream of 20.8 km, the previously mapped boundary between Modesto alluvium upstream and Holocene alluvium downstream (California Division of Mines and Geology, 1981), are composed entirely of sand and silt. Beneath the Holocene alluvium, older Modesto and Riverbank deposits that have been exposed by incision contain cobble- and gravel-sized material as far downstream as 28.8 km. In 2001, gravel was transported as far downstream as 39.2 km. These observations suggest that transport conditions have changed through time. In particular, they suggest that recent channel-bed incision strengthened the ability of the channel to transport coarse sediment.

Thalweg elevation

Thalweg elevation survey measurements from 2000 were compared to historical survey data in order to identify spatial and temporal trends in bed-level adjustment since the 1950s. Whether the system is aggrading or degrading depends on the relationship between sediment transport and supply. The direction of channel-bed adjustment may in part determine the relative importance of sorting and abrasion in producing downstream-fining patterns (Shaw and Kellerhals, 1982).

Thalweg measurements taken at bridges in the study area since 1952 show a general trend of channel-bed lowering that has continued through 2000 in some locations (Table 2). The data show a net decrease in elevation on the order of meters at every bridge in the upstream 34 km of the profile. The least amount of incision was recorded at Highway 99 (34.0 km); however, surveys do not reflect the magnitude of incision that occurred there prior to 1957. Since construction of levees began first at Highway 99 in the early 1930s, the channel bed may have undergone considerable degradation between 1930 and 1957 that was not detected by later surveys.

Surveys completed over the last decade indicate a change in the direction of thalweg adjustment from degradation to aggradation at Dillard Road (7.2 km) and Highway 16. In alluvial rivers, incision is often followed by bank failure and subsequent aggradation resulting in wider, shallower channels (Schumm, 1999). This process is apparently underway in some upstream reaches of the study area between Dillard Road and Highway 16 where banks are unconsolidated alluvium and are not covered by bank protection.

Aerial photos taken near Highway 16 show dramatic increases in channel width over the last 60 years. This supports the hypothesis that the river is adjusting to incision through bank failure, widening, and aggradation. Stream width at sites 1 (0 km) and 2 (0.83 km) increased 316 and 217 percent, respectively, between 1937 and 2000. Factors that contribute to low bank strength and rapid adjustment of channel form at these sites are coarse, unconsolidated bank material and the absence of large woody vegetation.

Widening and aggradation near Highway 16 may have been aggravated by the flood of 1997. Large floods are capable of delivering large volumes of sediment from upstream (Madej, 1999) and causing substantial bank erosion. Since 1996, bed elevation at Highway 99 (34.0 km) has continued to fall despite any deposition that may have occurred during the 1997 flood. Elevation at Wilton Road (23.6 km) has remained relatively stable.

Thalweg profile and bed slope

The surveyed thalweg profile was used to determine downstream changes in slope and identify profile features that influence sediment transport. Downstream change in the slope of a river is a strong indicator of the importance of sorting in causing downstream fining. In particular, strong profile concavity suggests decreasing flow competence with distance which leads to downstream fining of material through selective sorting (e.g., Parker, 1991; Ferguson et al., 1996).

The Cosumnes channel in the study area lacks strong overall concavity (Fig. 6). The thalweg profile was smoothed by fitting linear and second-degree polynomial equations to hand-drawn best-fit lines in order to identify reach-scale changes in slope (Fig. 7). The boundaries of duripan and alluvial reaches were added to the smoothed profile. The influence of substrate on bed slope can be seen at Meiss Road (10.1 km) where the channel bed changes from alluvium upstream to volcaniclastic rock and duripan downstream, and slope changes abruptly from mild to more steep. Similar relationships between slope and substrate changes have been documented in heterogeneous bedrock channels where knickpoints or short, steep sections of channel called knickzones have developed at lithologic boundaries (Wohl, 1998). Vertical steps in the smoothed curve occur at the Meiss Road knickzone, diversion dams, and a smaller knickzone at 40.6 km. Diversion dams control local elevation and affect local slope by causing deposition upstream and development of plunge pools downstream.

In addition to vertical steps and distinct slope changes, other distinguishable profile features are the deep pools throughout the study area. Figures 6 and 7 as well as field notes in

Appendix IV show that the deepest pools, excluding plunge pools downstream of diversion dams, are pools scoured in duripan reaches. Potholes and grooves formed on duripan bed surfaces provide field evidence for frequent scouring. In many duripan reaches, the only gravel deposits exist as shallow veneers which are certainly mobilized at high flows.

The study area can be separated into three river segments based on substrate, bed material, and locations of levees (Fig. 7). Segment 1 is an alluvial segment from 0 km to Meiss Road (10.1 km) where the majority of the banks are not lined by levees, and bed slope decreases rapidly downstream in proximity to the scour pool and knickzone at Meiss Road. Bed material in segment 1 is mixed cobbles, gravel, and sand; and bedforms occupy the channel at regular intervals. Flow in segment 2, from Meiss Road to Highway 99 (34.0 km), is confined laterally by closely spaced levees, and substrate alternates between alluvium and duripan. Bed material in segment 2 ranges from mixed cobbles, gravel, and sand to primarily sand in some reaches. In segment 3, from Highway 99 to the end of the profile, bed material is mostly sand with some gravel deposits that are limited to reaches upstream of 39.2 km. Levees in segment 3 are set away from the channel allowing for overbank flooding.

Variations in local bed slope occur with proximity to riffles, pools, and diversion structures and due to changes in substrate (Fig. 8). In river segment 1, local bed slope decreases rapidly around 8 km as the channel enters a low-gradient reach upstream of the knickzone at Meiss Road (10.1 km). From 10.1 to 18 km in segment 2, bed slope is generally low due to deposition upstream and scour downstream of diversion dams and the knickzone. Downstream of 20 km, bed slope decreases slightly with distance. Local variations in slope result from diversion dams and substrate variability, especially between 18.3 and 29.1 km where the channel alternates between short alluvial and duripan reaches. Bed slope drops suddenly between 32 and

34 km and remains low through about 40 km with one exception. At site 38 (39.17 km), local slope is steeper than in surrounding reaches as the channel cuts down through a layer of duripan. Downstream of the knickzone at 40.6 km, bed slope increases significantly perhaps as a result of in-stream mining at Twin Cities Road (42.8 km). The volume of sand removed annually from the site and the effect of extraction on bed elevation are unknown.

Bankfull width:depth ratio

Channel width and depth at bankfull were measured in order to document downstream changes in bankfull depth and channel form which influence sediment transport (Table 3). Downstream trends in the relationship between width and depth at bankfull show correlation with the nature of bank material (Fig. 9). In general, the width:depth ratio of the channel in alluvial reaches is greater than that in duripan reaches. The width:depth ratio is highest at sites 1, 2, and 9 where bank material is unconsolidated sand or gravel, levees and bank protection are not present, and woody vegetation is minimal.

In segment 2, fine-grained alluvium, levees, bank protection, and woody vegetation cause the width:depth ratios in alluvial reaches to be lower than those upstream. The lowest ratio in an alluvial reach was recorded at site 31 (31.83 km) where the bank material is fine-grained and relatively cohesive and woody vegetation lines the banks. Fine-grained alluvium, bank protection, and woody vegetation increase bank stability and influence channel response to incision. For example, widening that was recorded at sites 1 (0 km) and 2 (0.83 km) between 1937 and 2000 did not occur downstream at site 3 (1.46 km) where bank material is finer-grained and large trees line the river.

Resistant duripan layers exert control on the evolution of channel form in some reaches. The average width:depth ratio for cross-sections in duripan reaches is 11.7 with a standard deviation of 2.5. The channel is typically narrow and deep and is stable at ratios lower than those in alluvial reaches. In general, the ratio 13.7 defines the boundary between stable channel forms in alluvial and duripan reaches (Fig. 9).

Grain-size distribution

Downstream trends in the surface paving ratio were evaluated as indicators of longitudinal changes in the relationship between sediment transport and supply. The average paving ratio in segment 1 is 2.4 (Fig. 10). Paving ratios are typically higher in segment 2 where they average 4.1. Although greater subsurface sand content (Table 1) may also contribute to higher paving ratios in segment 2, the difference suggests that sediment transport conditions are longitudinally variable. Paving ratios in segment 3 average 1.6, and values are similar to those in segment 1. Reduction in the degree of paving is expected in this segment since grain size is relatively small and surface sand content is high (Table 1).

Sorting indices calculated for surface samples were plotted in order to identify abrupt changes that may signify the start of the gravel-sand transition. The parameter generally decreases, or sediment becomes better sorted, in the downstream direction up to site 29 (29.78 km) (Fig. 11). This trend may be due to increased paving ratios or downstream fining which reduces the range of sizes available for deposition with distance. At site 29, the degree of sorting decreases abruptly where surface bed material changes from unimodal gravel to bimodal gravel and sand.

Depth-slope product

The average bankfull depth-slope product was compared to surface median grain size at each site in order to identify downstream trends in the relative magnitudes of average bankfull bed shear stress and critical bed shear stress. Average bankfull depth increases in the downstream direction by approximately a factor of 2 (Fig. 12). In contrast, changes in slope are greater from site to site and slope varies by a factor of 10 within the study area (Fig. 8). Downstream fluctuations in the depth-slope product mimic the pattern of slope change shown in Figure 8 (Fig. 13); therefore, it appears that slope has a greater influence on the depth-slope product than depth. The average bankfull depth-slope product in segment 1 oscillates between lower and higher values until the channel nears the Meiss Road (10.1 km) knickzone where it drops to the lowest estimates recorded anywhere along the profile upstream of 32 km. In river segment 2, the product increases downstream of Meiss Road and peaks around 22 km. Values show large variation from site to site between 22 and 32 km and do not show a significant net reduction with distance.

The average bankfull depth-slope product shows no direct correlation with surface median grain size (Fig. 14). However, the data points separate into two populations. This indicates that the relationship between average bankfull bed shear stress and critical shear stress is longitudinally variable. At sites above the line drawn in Figure 14, the depth-slope product is higher relative to grain size than at sites below. This suggests that bed shear stress at those locations is high relative to critical shear stress for entrainment of the median. Sites that plot in this area are located in segment 2 from 19.37 to 31.83 km. As noted earlier, paving ratios are also high at these sites (Fig. 10), and median grain size does not decrease exponentially (Fig. 4).

At two sites between 19.37 and 31.83 km, sites 21 (20.89 km) and 29 (29.78 km), the depth-slope product is low relative to median grain size. This reflects reduced local bed slope at both sites. Sites 1 – 19 (0 to 17.70 km) also plot where the depth-slope product is low relative to the size of the surface median. Over the same river length, median grain size declines exponentially. No cross-sections were measured downstream of 32 km; however, it is likely that average bankfull shear stress is relatively low. Reduced bed slope combined with decreased maximum channel depths where levees are set back from the channel support the hypothesis that bed shear stress decreases downstream of 32 km.

Discussion

Downstream fining in the Cosumnes River study area follows an exponential pattern with a diminution coefficient of 0.0744 km^{-1} for the surface median. Reported diminution coefficients for alluvial rivers range from 0.001 to 0.75 km^{-1} (Hoey and Bluck, 1999). Of these, the highest have been documented in systems where rapid declines in slope produce sorting over short distances. Diminution coefficients are inversely related to drainage basin area and stream length (Hoey and Bluck, 1999). In rivers analogous to the study area in terms of bed-material size and stream length, coefficients vary from 0.04 to 0.12 km^{-1} (Knighton, 1980; Kodama, 1994a). Therefore, the downstream-fining pattern in the study area is typical for an alluvial river of comparable length carrying similarly sized bed material.

Downstream fining in the study area is not accompanied by strong profile concavity that is thought to cause selective sorting and produce declining grain size in other rivers (e.g., Ferguson et al., 1996). There are two possible explanations for downstream fining in the absence of profile concavity: fining is produced through abrasion alone, or it is the aggregate effect of sorting that operates discontinuously over the length of the profile. In the latter case, sorting is restricted to reaches where local bed shear stress is reduced relative to grain size or varies laterally to produce patches.

The effects of abrasion can be estimated by examining data that describes downstream grain-size changes according to lithology. Lacking this information, a discussion of the factors that may contribute to the importance of abrasion in the study area is valuable. The study area is a low-gradient segment of the Cosumnes River that transports mainly dark, fine-grained volcanic and metamorphic rocks which are relatively resistant and have similar abrasion properties. Granite, which breaks apart rapidly when weathered (Sneed and Folk, 1956; Bradley, 1970), composes a very small percentage of surface gravels. The fact that subsurface sand is more quartz-rich than overlying gravel suggests that the majority of granite in the system is broken down before reaching the study area.

Coarse, weathered material added to the channel through bank erosion near Highway 16 may be initially susceptible to attrition. However, weathered rinds are typically removed over short distances (Bradley, 1970); therefore, the contribution by abrasion due to weathered supply is limited to the first 1 to 2 km of the profile. Downstream changes in the relative abundance of lithologies on the bed surface may indicate differences in abrasion properties and signify the influence of abrasion; however, no substantial changes in lithology were visible in the field. Collectively, the preceding observations suggest that abrasion plays a minor role relative to sorting in producing downstream fining in the study area.

A better explanation for exponential downstream fining in the absence of overall profile concavity is one that considers the effects of longitudinal variations in sorting processes. Longitudinal variations in the degree of fining through selective sorting may be linked to downstream changes in the relationship between transport capacity and sediment supply (Shaw and Kellerhals, 1982). Thalweg elevation surveys completed at bridges throughout the study area show net reduction in channel-bed elevation since the 1950s. Incision was likely induced in the 1930s by levee construction and associated increased flow depth (Vick et al., 1997). While evidence suggests that degradation continues in some locations, it appears that bed-level adjustment has changed direction upstream of Meiss Road (10.1 km).

Surveys completed over the last decade record a change from degradation to aggradation at Dillard Road (7.2 km) and Highway 16. Aggradation upstream of Meiss Road increases the ability of sorting processes to produce downstream fining there. Between the start of the profile and Meiss Road, surface median grain size declines exponentially. Sorting is continuous in this segment as influxes of mixed-sized material bury less mobile, coarse sediment and provide fine sediment for transport downstream. Furthermore, abundant bedforms assist downstream fining by encouraging selective deposition of coarse clasts and producing topographic complexity which results in lateral sorting of material into patches. Patches aid fining by eliminating relative-size effects on the bed surface and facilitating entrainment of fine grains (Paola and Seal, 1995). Fining through selective sorting is also enhanced by the reduction in slope and bed shear stress that occurs as the channel nears the knickzone at Meiss Road.

Multiple lines of evidence suggest that many reaches downstream of Meiss Road are currently degrading. First, bridge surveys record recent channel-bed lowering at Highway 99 (34.0 km). Second, the channel bed in duripan reaches downstream of Meiss Road is often devoid of bedforms and sometimes scoured bare. Development of potholes and grooves on bare duripan beds suggests that during bankfull flow, and perhaps during flows less than bankfull, coarse sediment is flushed through certain reaches rather than deposited. Maintenance of elevated bed shear stress relative to bed-material grain size in reaches between Meiss Road and Highway 99 is made possible by levees, bank protection, and resistant duripan banks that prohibit the channel from adjusting its width in response to incision.

High paving ratios present evidence for persistence of elevated bed shear stress in some reaches. Paving ratios upstream of Meiss Road where recent surveys detect aggradation and ratios downstream of Highway 99 where bed slope is relatively low closely match values found by Parker and Klingeman (1982) and Church et al. (1987) in alluvial streams. However, paving ratios are generally higher between Meiss Road and Highway 99. Dietrich et al. (1989) found that paving ratios in alluvial rivers are high where sediment supply is low relative to the ability of flow to transport it. This suggests that between Meiss Road and Highway 99, sediment supply is lower relative to transport capacity than in reaches upstream or downstream. Wilcock (1992) determined that paving ratios generally become more developed as bed shear stress increases relative to the critical shear stress required for entrainment of the surface median. Once a certain threshold bed shear stress is achieved, the coarse surface layer breaks up leading to full mobilization of bed material and entrainment conditions that approximate equal mobility (Wilcock, 1992). Complete mobilization of the bed minimizes opportunity for preferential downstream transport of fine material because the size distribution of the entrained bedload is similar to that of the remaining bed material.

At all but two sites between 19.37 and 31.83 km, the depth-slope product is high relative to median surface grain size indicating that bed shear stress is high relative to critical shear stress and the coarse surface layer is destroyed at bankfull. Mobilization of the bed at bankfull results in downstream transport of all sizes and reduces the potential for fining through selective sorting. The potential for sorting between 19.37 and 31.83 km is also reduced by the presence of many duripan reaches. In numerous duripan reaches, the bed is scoured bare and few bedforms exist. Coarse material entering these reaches is transported rapidly downstream instead of deposited preferentially in riffles and the heads of bars. Over this distance where data and observations suggest reduced fining, median grain size does not decrease exponentially.

At two sites between 19.37 and 31.83 km, the depth-slope product is lower relative to median grain size than at all other sites in this distance. This indicates that bed shear stress is low relative to critical shear stress in a limited number of reaches from 19.37 to 31.83 km. In these reaches, movement of the largest particles is likely less frequent than in surrounding reaches and is restricted to the highest flows. The presence of reaches where local bed shear stress is reduced relative to critical shear stress suggests that limited sorting may occur between 19.37 and 31.83 km. Sorting that does occur is apparently not sufficient to result in significant downstream fining over this distance.

Another explanation for the lack of decline in grain size between 19.37 and 31.83 km exists if the rate of erosion of coarse sediment from lateral sources is sufficiently high to alter the size distribution of bed material and negate the effects of sorting. Layers of coarse sediment exposed in the banks at 22.90 and 24.35 km are followed immediately by increases in median surface grain size downstream. However, nothing distinguishes the increases from other fluctuations recorded in the study area that are not associated with coarse inputs. Although the layers correlate with increases in median size, larger increases occur between sites where there are no sources of coarse material. For example, between 19.37 and 20.89 km where there are no coarse lenses, median size increases by 5.7 mm. This is a larger increase than detected between samples collected upstream and downstream of 22.9 km and upstream and downstream of 24.35 km. Furthermore, no changes in the lithologic distribution of surficial deposits were noted downstream of locations where coarse layers were exposed in the banks. It is reasonable to assume that cementation and the presence of overlying resistant duripan horizons limit the rate of erosion of sediment from coarse layers. Erosion is likely infrequent, and eroded cobbles and gravel do not constitute a constant source of material.

Given that little fining occurs between 19.37 and 31.83 km, grain-size reduction downstream of Meiss Road is produced mainly through sorting in reaches between Meiss Road and 19.37 km and in reaches downstream of 31.83 km. Compared to fining upstream of Meiss Road where the bed is aggradational, fining downstream of Meiss Road occurs over a longer distance and is not consistently exponential. This result corresponds with the findings of Shaw and Kellerhals (1982) for Alberta Rivers that have aggradational and degradational reaches. They found that the ability of sorting to produce exponential fining was reduced in degradational reaches relative to that in aggradational reaches.

A transition to lower bed slope downstream of 32 km allows for deposition and sorting of bed material. Reduced grain size downstream of 32 km may be linked to lower bankfull depth and bed shear stress, but no cross-section data is available for confirmation. The transition to lower slope apparently causes the change from mainly gravel deposits upstream of 32 km to predominately sand-sized material downstream.

A change from lower to higher sorting indices at site 29 (29.78 km) also indicates that the gravel-sand transition begins in the vicinity of 30 km. Increases in sorting indices accompanied by changes from unimodal gravel to bimodal gravel and sand were noted by Sambrook Smith and Ferguson (1995) and used to define the upstream boundaries of gravel-sand transitions. Gravel in the Cosumnes River is carried as far downstream as 39.2 km. It is improbable that coarse material is present in the bed downstream of Twin Cities Road (42.8 km) because flow is retarded by tidal effects and slope is low. Bed elevation at the Cosumnes River Preserve located 3 to 4 km downstream of Twin Cities Road is around 0 m (Florsheim, pers. comm.); therefore, slope must decline below Twin Cities Road and remain low. Under these constraints, the gravel-sand transition stretches for approximately 8 km beginning around 32 km. Comparison of contemporary and pre-incision Holocene channel deposits shows that the location of the gravel-sand transition has shifted at least 21 km downstream since the onset of incision.

Currently, the rate and distribution of incision in the study area are greatly influenced by geology. Increased slope downstream of a knickzone developed in duripan at 40 km indicates that the presence of the duripan is preventing degradation downstream from migrating upstream. Degradation in the vicinity of Twin Cities Road may be associated with in-stream mining. Upstream progression of degradation is likewise hindered at Meiss Road where a bedrock knickzone acts as a local base-level control allowing aggradation in upstream reaches. The rate and distribution of incision in the study area are also influenced by agricultural diversion dams that control local elevation. With continued incision, downstream fining between locations of fixed elevation may develop individual exponential patterns with unique diminution coefficients. More intensive reach-scale sampling of bed material is required in order to detect this characteristic.

Conclusions

Although the Cosumnes River profile lacks strong concavity in the study area, the downstream-fining pattern of bed material follows an exponential trend. Results from this study document downstream fining produced through sorting processes which operate discontinuously over the length of the profile. Sorting causes a rapid decline in grain size upstream of Meiss Road where the bed is aggrading, bedforms are common, and bed slope decreases with distance as the channel nears a bedrock knickzone. Between Meiss Road and Highway 99, survey data and field observations suggest that the system is generally degradational. Exhumed duripan and bedrock exert considerable influence on the distribution of sorting processes by controlling channel form and the rate and distribution of degradation in some reaches. Selective sorting occurs in a limited number of reaches where the depth-slope product is reduced relative to the median surface grain size. Local-scale sorting that promotes downstream fining occurs where lateral variations in bed shear stress cause the formation of unimodal patches and bedforms encourage deposition of coarse clasts.

The discontinuous nature of sorting between Meiss Road and Highway 99 leads to reduced fining; hence, median grain-size change through a number of reaches is less than exponential. Frequent scouring of the bed between 19.37 and 31.83 km allows for downstream transport of coarse as well as fine material and results in reduced fining. Reaches with duripan beds and few bedforms to encourage deposition facilitate downstream transport of gravel and reduce downstream fining wherever they are located. Due in particular to the degradational nature of the channel between Meiss Road and Highway 99, a contribution to fining by abrasion cannot be entirely ruled out. Further bed-material sampling that records grain size as well as lithology is required in order to determine the magnitude of fining that is produced through abrasion.

Downstream of 31.83 km, bed slope generally decreases, and the channel bed goes through a transition from gravel to sand. The transition requires a distance of approximately 8 km and ends near Twin Cities Road. Below Twin Cities Road, the channel enters a reach where slope is low and flow can no longer transport gravel downstream.

Table 1. Grain-size distribution and sorting

Surface							Subsurface			Surface D50/ Subsurface D50
Site	Distance (km)	D_{50}	D_{84}	D_{90}	Percent <2mm	sorting index	D_{50}	D_{90}	Percent <2mm	
1	0.00	36	85	100	12	2.2	16	62	22	2.3
2	0.83	40	100	110	11	2.3	11	56	26	3.6
3	1.46	34	64	73	16	2.3	17	68	24	2.0
4	2.23	17	43	54	11	2.0	14	42	19	1.2
7	3.73	24	56	66	13	2.2	12	42	25	2.0
8	4.63	26	49	56	5.5	1.4	13	56	23	2.0
9	5.39	32	56	63	4.7	1.4	12	54	24	2.7
10	5.96	37	66	77	12	2.1	14	54	23	2.6
11	7.36	26	42	45	7.6	1.5	12	48	25	2.2
12	8.50	7.2	22	26	30	2.3	8.8	27	16	0.8
13	9.16	16	34	40	12	1.8	2.9	30	44	5.5
14	10.75	11	19	22	4.8	1.0	2.1	13	49	5.2
15	11.53	22	46	51	17	2.2	8.4	42	31	2.6
16	14.33	20	37	41	11	1.7	6.2	22	24	3.2
18	16.69	11	20	21	16	1.8	1.8	12	52	6.1
19	17.70	12	26	29	14	1.8	3.3	23	42	3.6
20	19.37	9.3	15	18	14	1.5	3.3	15	42	2.8
21	20.89	15	25	29	6.6	1.2	3.6	12	30	4.2
22	21.77	12	20	22	8.5	1.4	2.0	13	49	6.0
23	22.51	7.5	14	15	8.0	1.1	1.2	3	79	6.3
24	23.44	11	19	20	10	1.4	3.2	14	41	3.4
25	24.19	0.7	1.1	1.3	96	0.8	bulk sample			
26	25.38	14	22	25	7.4	1.2	8.8	26	22	1.6
27	26.84	1.8	5.4	7.4	54	1.5	bulk sample			
28	27.88	11	17	19	9.3	1.2	2.7	17	45	4.1
29	29.78	11	24	29	23	2.1	4.8	19	33	2.3
31	31.83	8.4	18	23	22	2.1	1.3	5.7	68	6.3
32	32.97	1.0	1.9	2.8	85	0.9	bulk samples			
33	33.80	2.4	7.7	9.7	44	1.7				
34	34.32	6.0	11	13	23	1.9	2.3	10	48	2.6
35	35.29	1.2	2.9	3.8	71	1.4	bulk samples			
36	36.48	1.2	3.4	4.8	68	1.4				
37	37.48	7.2	14	16	19	1.8	3.6	12	34	2.0
38	39.17	3.1	11	14	42	2.2	1.9	14	51	1.6
39	40.26	1.2	2.6	3.5	75	1.1	bulk samples			
40	41.88	0.8	1.2	1.4	98	0.6				
Bank materials										
2	0.83	8.1	28	33	34	2.4	bulk samples			
	14.9	5.3	20	25	37	2.2				

Table 2. Change in thalweg elevation at bridges

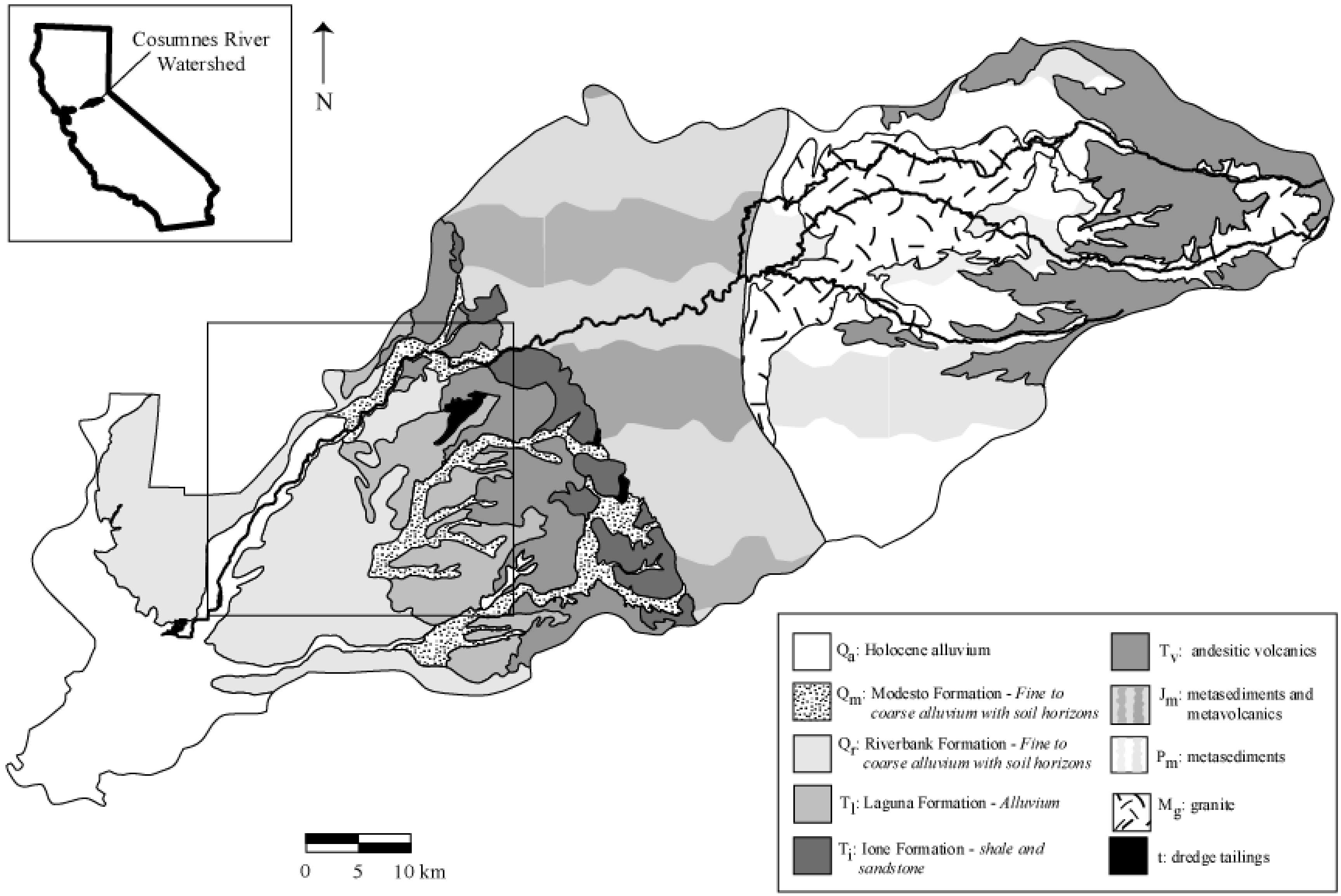
Year	Highway 99	Wilton Road	Dillard Road	Highway 16
	Elevation (m NGVD29)			
1952				35.0
1957	8.1			
1972		15.3	27.9	
1987	8.8			31.2
1992				32.9
1993			25.0	
1996	7.5	14.2		
1998*		13.9 - 14.1	26.0 - 26.7	
2000**	6.4 - 7.0	13.6 - 14.2	26.0 - 26.7	

Table 7.1. Elevations from surveys conducted by Caltrans, the Corps of Engineers, and Philip Williams and Associates, Ltd. as reported in Vick et al. (1997). *Elevations from Guay et al. (1998). **Elevations from this study. 1998 and 2000 entries are representative of the range in elevation in the vicinity of bridge sites.

Table 3. Depth-slope products and average width:depth ratios

Site	Distance (km)	Slope	Range in average bankfull depth (m)		Average bankfull width:depth ratio	Range in average bankfull depth-slope product (m x 10^{-3})	
			Low	High		Low	High
1	0.00001	0.000714	1.10	1.10	130.7	0.79	0.79
2	0.83	0.00125	2.07	2.07	51.1	2.58	2.58
3	1.46	0.000289	2.86	3.20	22.5	0.83	0.92
4	2.23	0.000519	2.56	2.81	25.6	1.33	1.46
7	3.73	0.000585	2.07	2.27	33.2	1.21	1.33
8	4.63	0.00127	1.59	1.97	39.9	2.02	2.50
9	5.39	0.000305	1.37	1.37	74.1	0.42	0.42
10	5.96	0.000889	2.59	3.34	27.0	2.30	2.97
11	7.36	0.00106	2.04	2.08	37.8	2.16	2.20
12	8.5	0.00008	2.98	3.10	19.3	0.24	0.25
13	9.16	0.000149	2.05	2.11	32.8	0.31	0.31
14	10.75	0.000105	2.58	2.58	18.4	0.27	0.27
15	11.53	0.000442	2.02	2.22	30.5	0.89	0.98
16	14.33	0.000313	3.71	4.12	13.5	1.16	1.29
18	16.69	0.000333	2.24	2.40	31.2	0.75	0.80
19	17.7	0.000474	2.88	3.28	20.1	1.37	1.55
20	19.37	0.000866	2.01	2.53	16.7	1.74	2.19
21	20.89	0.000315	2.68	3.19	13.4	0.84	1.00
22	21.77	0.00116	3.15	3.33	11.2	3.65	3.86
23	22.51	0.000493	3.99	4.15	10.1	1.97	2.05
24	23.44	0.000862	2.54	2.66	17.2	2.19	2.29
25	24.19	0.0000925	3.07	3.47	12.0	0.28	0.32
26	25.38	0.000699	3.74	3.98	9.7	2.61	2.78
27	26.84	0.000175	4.00	4.47	9.1	0.70	0.78
28	27.88	0.000685	3.64	3.88	9.3	2.49	2.66
29	29.78	0.000183	2.84	3.00	16.8	0.52	0.55
31	31.83	0.000532	3.32	3.78	10.0	1.77	2.01
32	32.97	0.000352	No cross-section surveys completed				
33	33.8	0.000121					
34	34.32	0.000227					
35	35.29	0.00009					
36	36.48	0.000143					
37	37.48	0.0001					
38	39.17	0.00088					
39	40.26	0.0001					
40	41.88	0.00108					

Figure 1. Generalized geologic map of the Cosumnes River watershed. The inset shows its location in California. The square indicates the boundaries of the study area and corresponds to Figure 2. [Modified from California Division of Mines and Geology (1981). Digital data provided by The Nature Conservancy and Teale Data Center and compiled by the Information Center for the Environment, University of California, Davis.]



Cosumnes River
Watershed
N
0 5 10 km
Q_a: Holocene alluvium
Q_m: Modesto Formation - *Fine to coarse alluvium with soil horizons*
Q_r: Riverbank Formation - *Fine to coarse alluvium with soil horizons*
T_l: Laguna Formation - *Alluvium*
T_i: Ione Formation - *shale and sandstone*
T_v: andesitic volcanics
J_m: metasediments and metavolcanics
P_m: metasediments
M_g: granite
t: dredge tailings

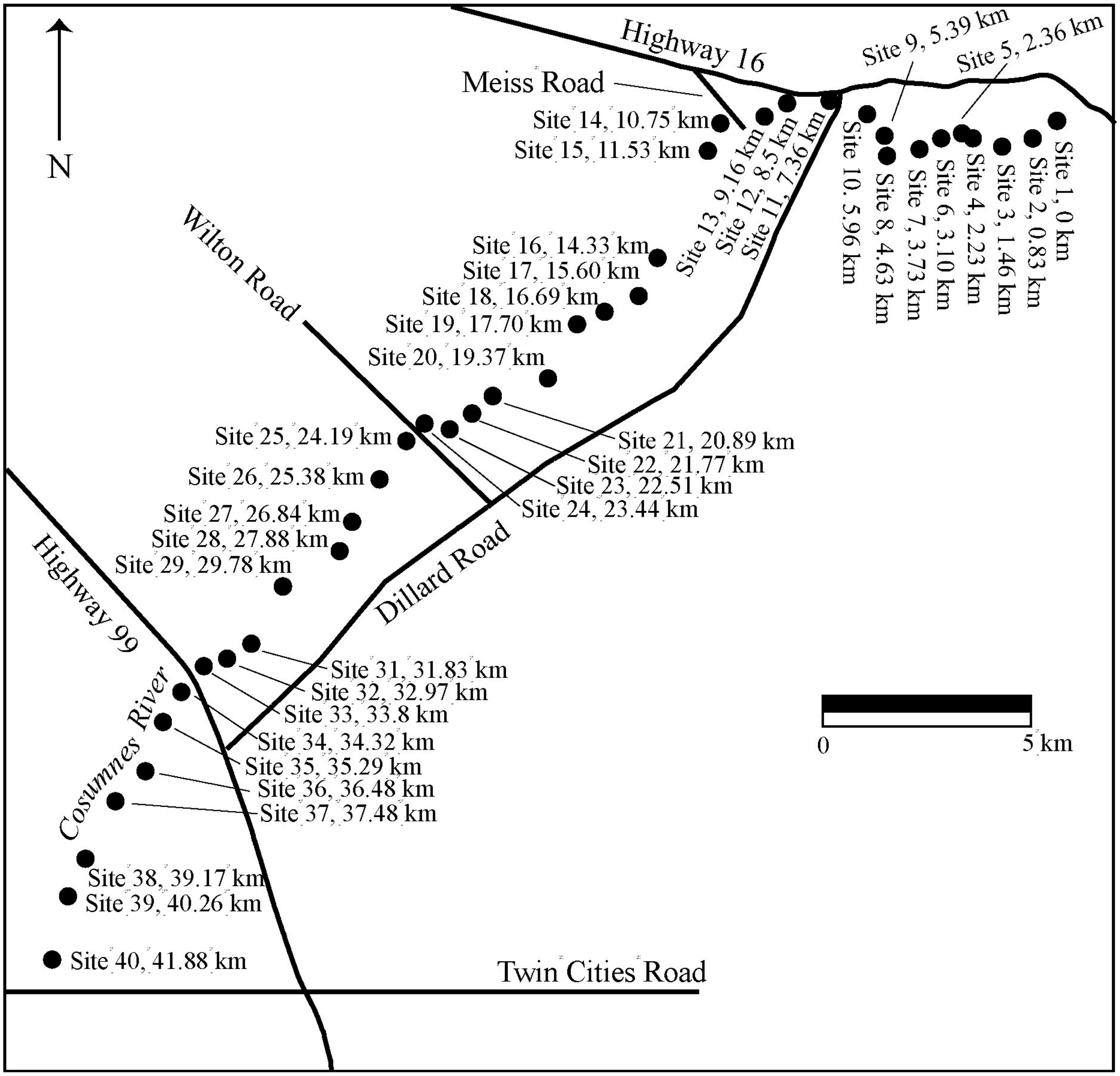
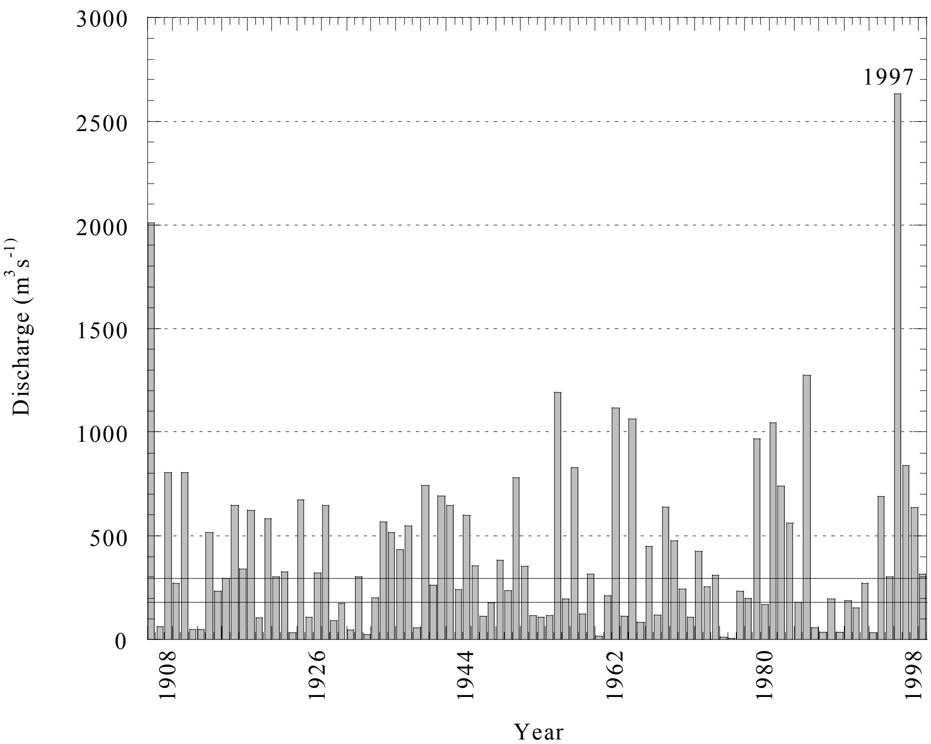


Figure 2. Study area and site map. The study area corresponds to the square in Figure 1. Major roads and site locations, numbers, and distances from the start of the profile are shown. (Digital data provided by the Information Center for the Environment, University of California, Davis.)

Figure 3. Annual peak discharge since 1907. The two solid horizontal lines indicate the range in bankfull flow or flows with recurrence intervals between 1.5 and 2.0 years. The peak flow during the flood of 1997 is labeled.



3000
2500
2000
1500
1000
500
0
1997
Discharge (m3 s-1)
1908
1926
1944
1962
1980
1998
Year

Figure 4. Downstream fining of surface and subsurface median grain sizes. Bulk samples collected on sand bars with no coarse surface layer are plotted as both surface and subsurface samples. The unfilled circles are samples collected in alluvial reaches; the filled circles are those collected in duripan reaches. The locations of the three tributaries are shown. The gravel-sand transition begins around 32 km.

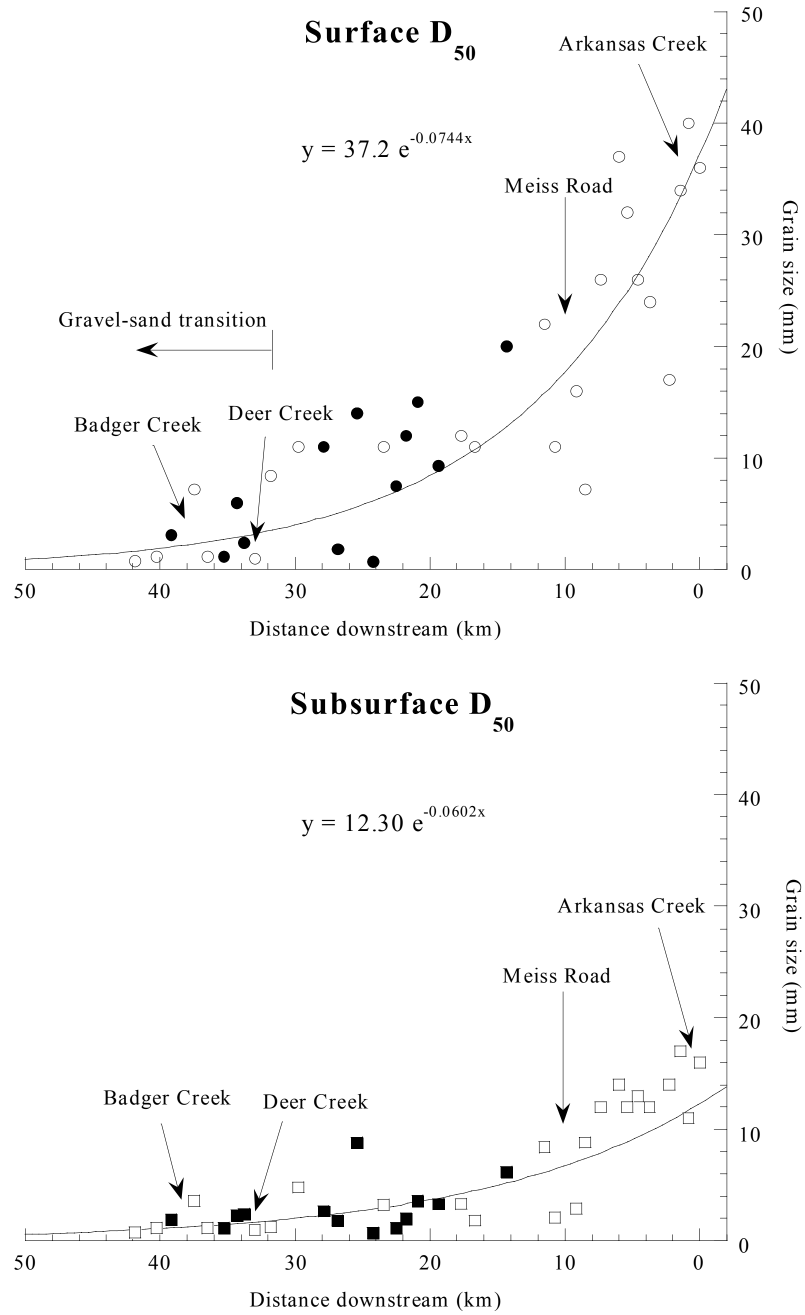

Surface D50
Arkansas Creek
y = 37.2 e-0.0744x
Meiss Road
Gravel-sand transition
Badger Creek
Deer Creek
Grain size (mm)
Distance downstream (km)
Subsurface D50
y = 12.30 e-0.0602x
Arkansas Creek
Meiss Road
Badger Creek
Deer Creek
Grain size (mm)
Distance downstream (km)

Figure 5. Locations of coarse gravel layers. Arrows indicate the locations of two layers (22.9 and 24.35 km) that are followed by increases in surface and subsurface median grain sizes. The unfilled shapes are surface samples; the filled shapes are subsurface samples. The boxes are samples collected in duripan reaches; the circles are samples collected in alluviual reaches.

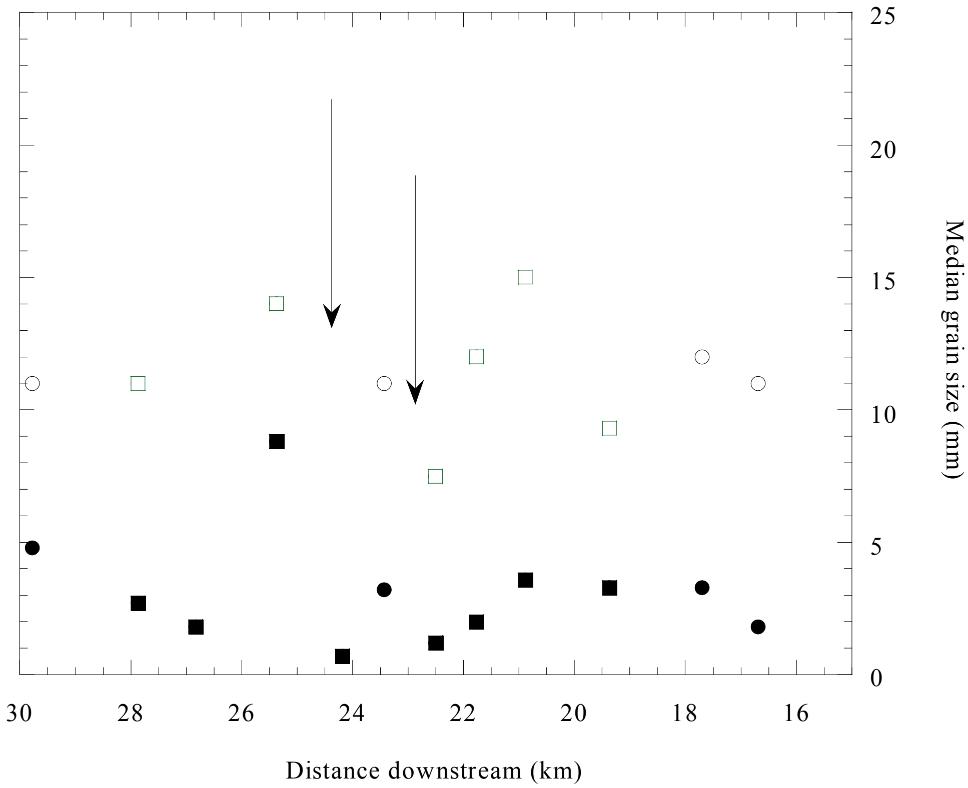


Figure 6. Cosumnes River thalweg profile. The locations of major roads, the three tributaries, and diversion dams are shown.

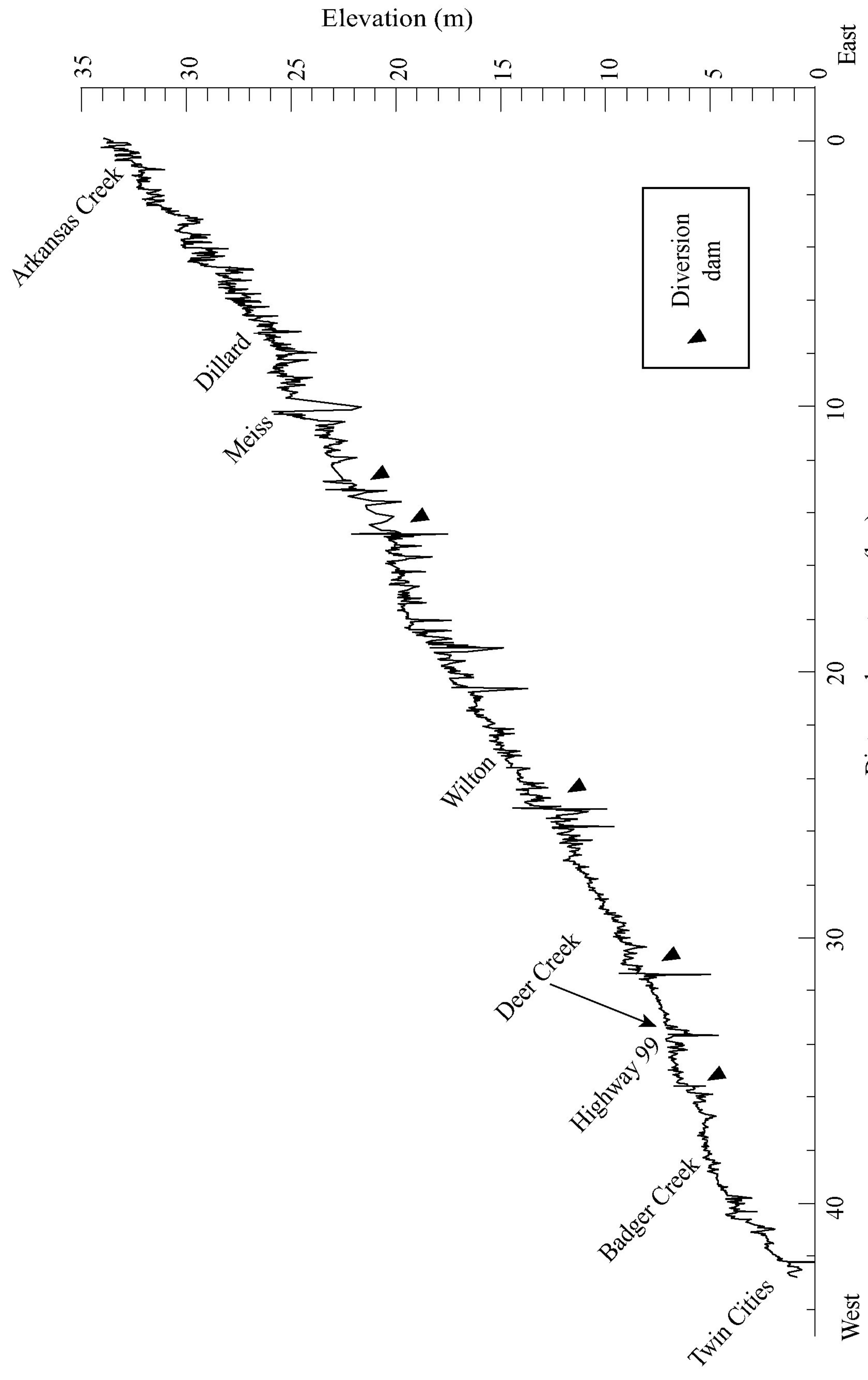
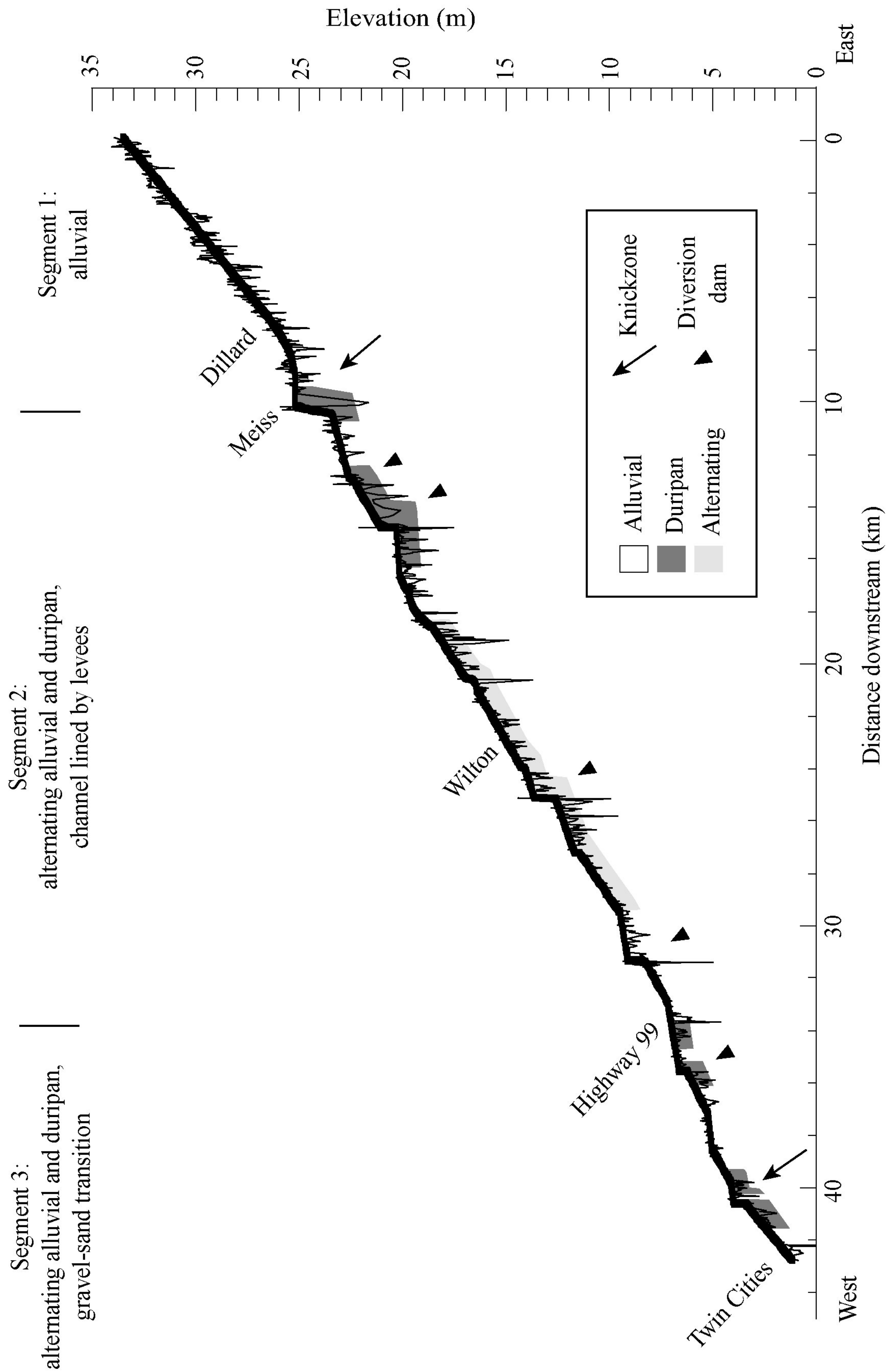

Elevation (m)
35
30
25
20
15
10
5
0
East
West
Distance downstream (km)
0
10
20
30
40
Arkansas Creek
Dillard
Meiss
Wilton
Deer Creek
Highway 99
Badger Creek
Twin Cities
Diversion dam

Figure 7. Cosumnes River smoothed profile and substrate distribution. The locations of major roads, diversion dams, and knickzones are shown. The profile is separated into 3 river segments based on substrate, bed material, and locations of levees (see text for descriptions).



Elevation (m)
Distance downstream (km)
East
West
Segment 1:
alluvial
Segment 2:
alternating alluvial and duripan,
channel lined by levees
Segment 3:
alternating alluvial and duripan,
gravel-sand transition
Dillard
Meiss
Wilton
Highway 99
Twin Cities
Knickzone
Diversion dam
Alluvial
Duripan
Alternating

Figure 8. Local bed slopes measured at sampling sites (sites 1 – 40). The plot is separated into the 3 river segments. Slope values are listed in Table 3.

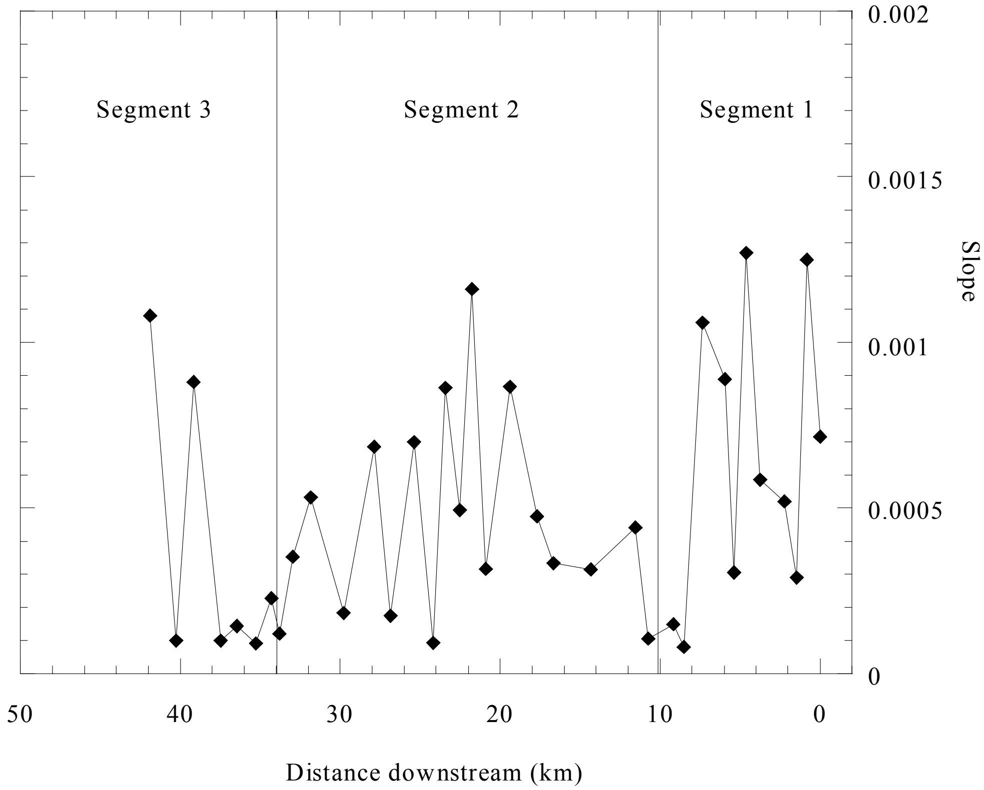


Figure 9. Width:depth ratios measured at cross-section sites (sites 1 – 31). The plotted width:depth ratios are mean values at sites where more than one estimate of bankfull was made. Sites referred to in the text are numbered. The unfilled circles are measurements taken in alluvial reaches; the filled circles are measurements taken in duripan reaches. In general, the ratio 13.7 describes the boundary between ratios measured in alluvial reaches and those measured where duripan controls channel form. Mean width:depth ratio values are given in Table 3.

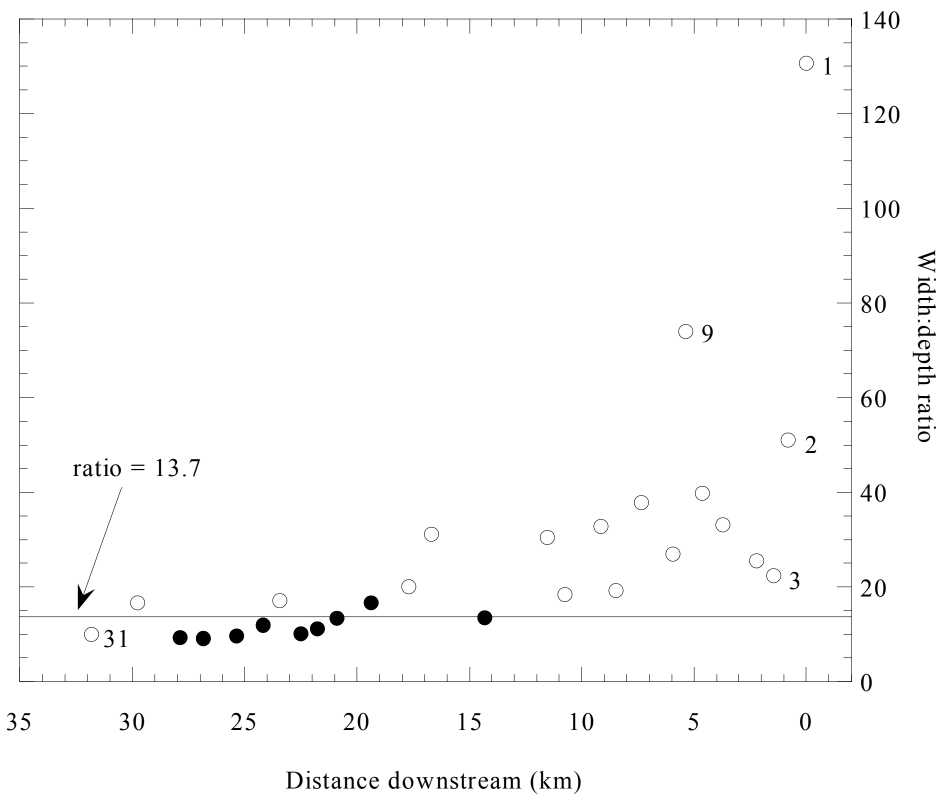


Figure 10. Surface:subsurface paving ratios. The unfilled circles are samples collected in alluvial reaches; the filled circles are those collected in duripan reaches. The plot is separated into the 3 river segments.

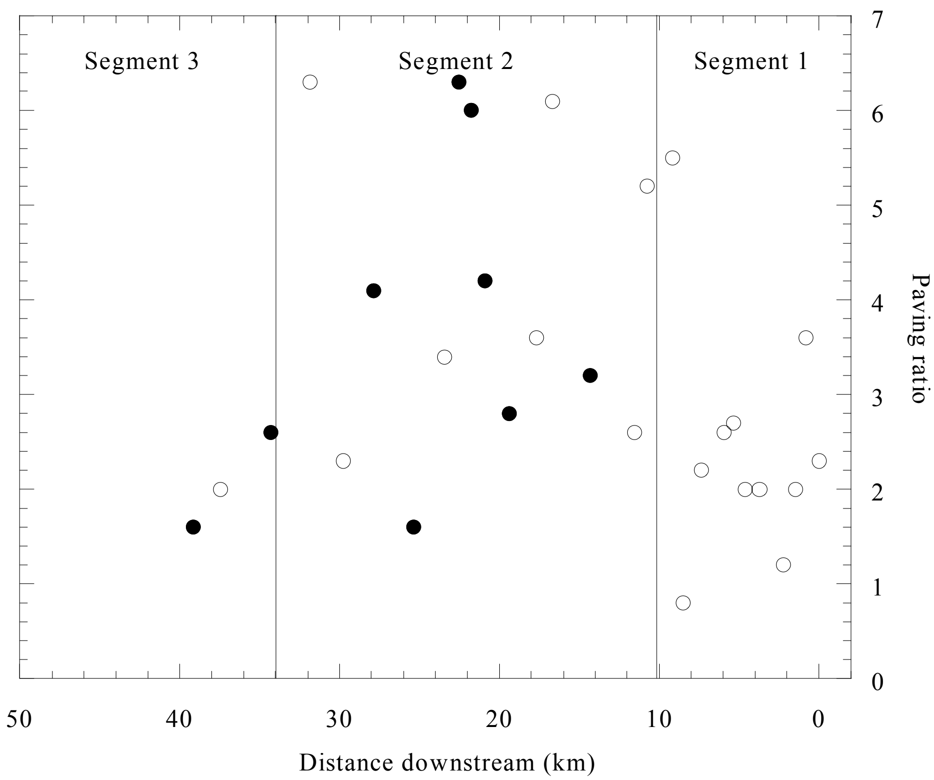


Figure 11. Surface sorting indices. The unfilled circles are samples collected in alluvial reaches; the filled circles are those collected in duripan reaches. Site 29 where the sorting index increases is numbered on the plot. Sorting indices are listed in Table 1.

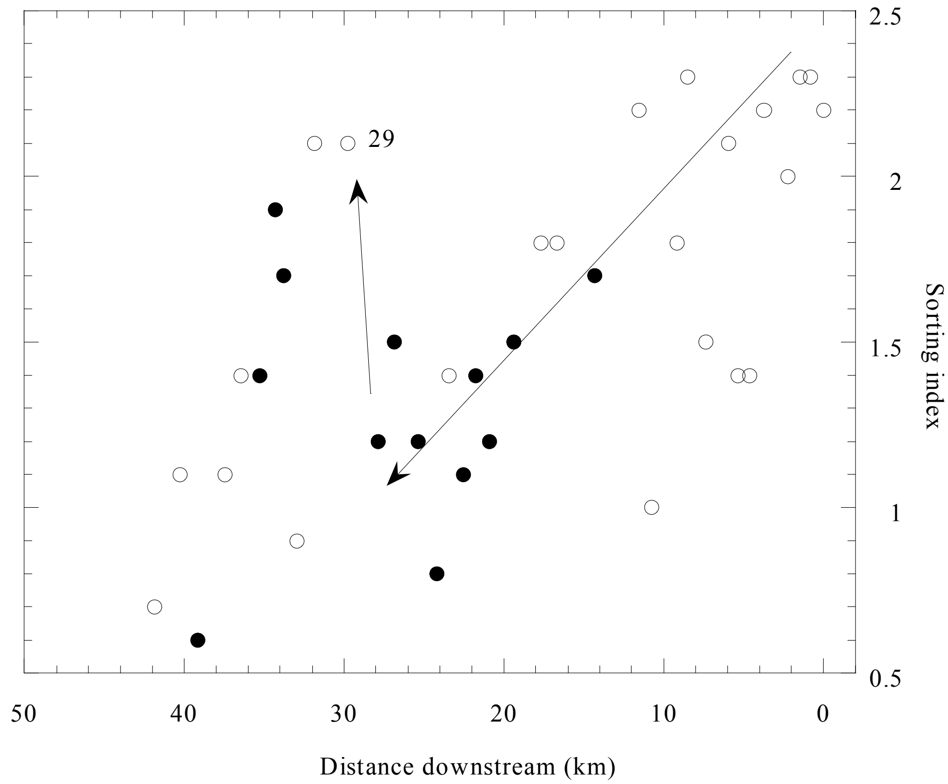


Figure 12. Ranges of average bankfull depths measured at cross-section sites. The plot is separated into the 2 river segments that are upstream of 31.83 km.

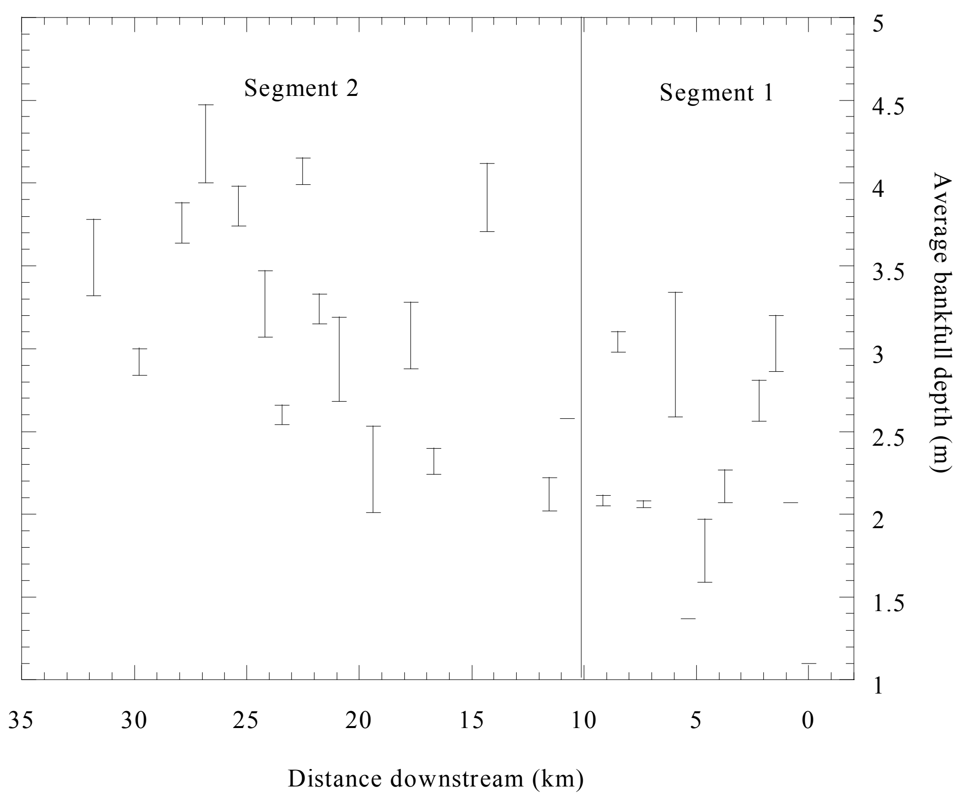


Figure 13. Ranges of average bankfull depth-slope products at cross-section sites. The plot is separated in the 2 river segments that are upstream of 31.83 km.

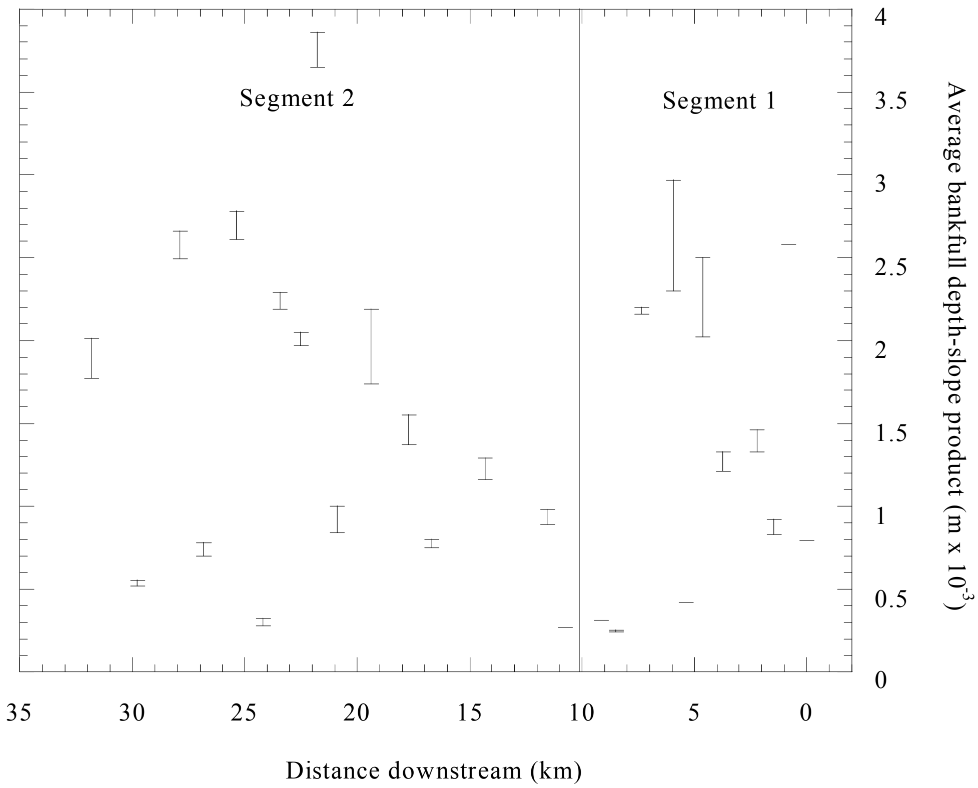
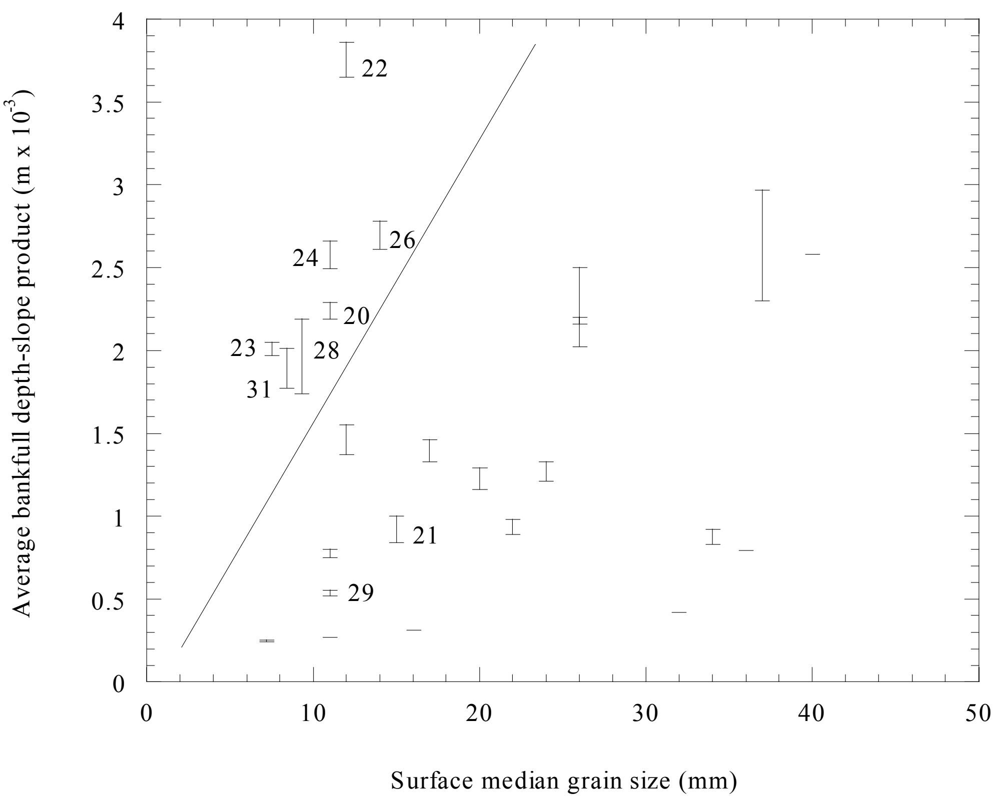


Figure 14. Comparison of depth-slope products and median surface grain sizes. The line that separates the two groups was drawn by hand. The plot does not include two sites (24.19 and 26.84 km) where surface median grain size was less than 2 mm. Data for sites between 19.37 and 31.83 km are labeled with site numbers.



References cited

American Society for Testing and Materials (ASTM) Committee E-29. 1985. *Manual on Test Sieving Methods: Guidelines for Establishing Sieve Analysis Procedures.* Philadelphia, PA: ASTM. 46 p.

Andrews, E.D. 1983. Entrainment of gravel from naturally sorted riverbed material. *Geological Society of America Bulletin* 94(10): 1225-1231.

Ashworth, P.J. and Ferguson, R.I. 1989. Size-selective entrainment of bed load in gravel bed streams. *Water Resources Research* 25(4): 627-634.

Batalla, R.J. and Martín-Vide, J.P. 2001. Thresholds of particle entrainment in a poorly sorted sandy gravel-bed river. *Catena* 44(3): 223-243.

Birkeland, P.W. 1999. *Soils and Geomorphology.* New York, NY: Oxford University Press, Inc. 430 p.

Bjornn, T.C. and Reiser, D.W. 1991. Habitat requirements of salmonids in streams. In: *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. Meehan, W. (ed). American Fisheries Society Special Publication 19. Bethesda, MD: American Fisheries Society. pp. 83-138.

Bradley, W.C. 1970. Effect of weathering on abrasion of granitic gravel, Colorado River (Texas). *Geologic Society of America Bulletin* 81(1): 61-80.

Brierley, G.J. and Hickin, E.J. 1985. The downstream gradation of particle sizes in the Squamish River, British Columbia. *Earth Surface Processes and Landforms* 10(6): 597-606.

California Division of Mines and Geology. 1981. *Geologic Map of the Sacramento Quadrangle* [map]. 1:250,000. Sacramento, CA: Division of Mines and Geology.

Church, M.A., McLean, D.G., and Wolcott, J.F. 1987. River bed gravels: Sampling and analysis. In: *Sediment Transport in Gravel-bed Rivers*. Thorne, C.R., Bathurst, J.C., and Hey, R.D. (eds). Chichester, U.K.: Wiley & Sons. pp. 43-88.

Dietrich, W.E., Kirchner, J.W., Ikeda, H., and Iseya, F. 1989. Sediment supply and the development of the coarse surface layer in gravel-bedded rivers. *Nature* 340(6230): 215-217.

Ferguson, R. and Ashworth, P. 1991. Slope-induced changes in channel character along a gravel-bed stream: The Allt Dubhaig, Scotland. *Earth Surface Processes and Landforms* 16(1): 65-82.

Ferguson, R., Hoey, T., Wathen, S., and Werrity, A. 1996. Field evidence for rapid downstream fining of river gravels through selective transport. *Geology* 24(2): 179-182.

Ferguson, R.I., Prestegaard, K.L., and Ashworth, P.J. 1989. Influence of sand on hydraulics and gravel transport in a braided gravel bed river. *Water Resources Research* 25(4): 635-643.

Florsheim, J.L. and Mount, J.F. 1999. Geomorphic and ecological response of the anastomosing lower Cosumnes River, California to anthropogenic disturbances: Implications for restoration. *GSA Abstracts with Programs* 31(7): A-202.

Folk, R.L. 1974. *Petrology of Sedimentary Rocks.* Austin, TX: Hemphill Publishing Co. pp. 1-64.

Galay, V.J. 1983. Causes of river bed degradation. *Water Resources Research* 19(5): 1057-1090.

Guay, J.R., Harmon, J.G., and McPherson, K.R. 1998. Flood Inundation Map and Water-surface Profiles for Floods of Selected Recurrence Intervals, Cosumnes River and Deer Creek, Sacramento County, California. *U.S. Geological Survey Open File Report 98-283.* Washington, D.C.: U.S. Government Printing Office.

Harden, D.R. 1998. *California Geology*. Upper Saddle River, NJ: Prentice Hall, Inc. 479 p.

Harrelson, C.C., Rawlins, C.L., and Potyondy, J.P. 1994. Stream channel reference sites: an illustrated guide to field techniques. *USDA Forest Service general technical report RM-245*. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 61 p.

Hoey, T.B. and Bluck, B.J. 1999. Identifying the controls over downstream fining of river gravels. *Journal of Sedimentary Research* 69(1): 40-50.

Hoey, T.B. and Ferguson, R.I. 1994. Numerical simulation of downstream fining by selective transport in gravel bed rivers: Model development and illustration. *Water Resources Research* 30(7): 2251-2260.

Hoey, T.B. and Ferguson, R.I. 1997. Controls of strength and rate of downstream fining above a river base level. *Water Resources Research* 33(11): 2601-2608.

Johnson, P.A. and Heil, T.M. 1996. Uncertainty in estimating bankfull conditions. *Water Resources Bulletin* 32(6): 1283-1291.

Kissam, P. 1956. *Surveying for Civil Engineers.* New York, NY: McGraw Hill. 716 p.

Knighton, A.D. 1980. Longitudinal changes in size and sorting of stream-bed material in four English rivers. *Bulletin of the Geological Society of America*. 91(1): 55-62.

Knighton, A.D. 1999. The gravel-sand transition in a disturbed catchment. *Geomorphology* 27(4):325-341.

Kodama, Y. 1994a. Downstream changes in the lithology and grain size of fluvial gravels, the Watarase River, Japan: Evidence of the role of abrasion in downstream fining. *Journal of Sedimentary Research* A64(1): 68-75.

Kodama, Y. 1994b. Experimental study of abrasion and its role in producing downstream fining in gravel-bed rivers. *Journal of Sedimentary Research* A64(1): 76-85.

Leopold, L.B., Wolman, M.G., and Miller, J.P. 1964. *Fluvial Processes in Geomorphology.* San Francisco, CA: W.H. Freeman. 522 p.

Madej, M.A. 1999. Temporal and spatial variability in thalweg profiles of a gravel-bed river. *Earth Surface Processes and Landforms* 24(12):1153-1169.

Paola, C., Parker, G., Seal, R., Sinha, S.K., Southard, J.P., and Wilcock, P.R. 1992. Downstream fining by selective deposition in a laboratory flume. *Science* 258(5089): 1757-1760.

Paola, C. and Seal, R. 1995. Grain size patchiness as a cause of selective deposition and downstream fining. *Water Resources Research* 31(5): 1395-1407.

Parker, G. 1991. Selective sorting and abrasion of river gravel. II: Applications. *Journal of Hydraulic Engineering* 117(2): 150-171.

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

Piper, A.M., Gale, H.S., Thomas, H.E., and Robinson, T.W. 1939. Geology and Ground-water Hydrology of the Mokelumne Area, California. *U.S. Geological Survey Water-Supply Paper 780.* Washington, D.C.: U.S. Government Printing Office. 230 p.

Pizzuto, J.E. 1995. Downstream fining in a network of gravel-bedded rivers. *Water Resources Research* 31(3): 753-759.

Powell, D.M. 1998. Patterns and processes of sediment sorting in gravel-bed rivers. *Progress in Physical Geography* 22(1): 1-32.

Rice, S.P. 1998. Which tributaries disrupt downstream fining along gravel-bed rivers? *Geomorphology* 22(1): 39-56.

Rice, S.P. and Church, M. 1997. Grain size along two gravel-bed rivers: statistical variation, spatial pattern and sedimentary links. *Earth Surface Processes and Landforms* 23(4): 345-363.

Sambrook Smith, G.H. 1996. Bimodal fluvial bed sediments: origin, spatial extent, and processes. *Progress in Physical Geography* 20(4): 402-417.

Sambrook Smith, G.H. and Ferguson, R.I. 1995. The gravel-sand transition along river channels. *Journal of Sedimentary Research* 65(2): 423-430.

Schumm, S.A. 1999. Causes and controls of channel incision. In: *Incised River Channels*. Darby, S.E. and Simon, A. (eds). Chichester, U.K.: Wiley & Sons. pp. 19-33.

Schumm, S.A. and Stevens, M.A. 1973. Abrasion in place: a mechanism for rounding and size reduction of coarse sediments in rivers. *Geology* 1(1): 37-40.

Seal, R., Paola, C., Parker, G., Southard, J.B., and Wilcock, P.R. 1997. Experiments on downstream fining of gravel: I. Narrow-channel runs. *Journal of Hydraulic Engineering* 123(10): 874-884.

Shaw, J. and Kellerhals, R. 1982. The composition of recent alluvial gravels in Alberta River beds. *Alberta Research Council Bulletin* 41: 151 p.

Shlemon, R.J. 1972. The lower American River area, California: a model of Pleistocene landscape evolution. *Association of Pacific Coast Geographers Yearbook* 34: 61-86.

Simon, A. and Darby, S. 1999. The nature and significance of incised river channels. In: *Incised River Channels*. Darby, S.E. and Simon, A. (eds). Chichester, U.K.: Wiley & Sons. pp 3-18.

Sneed, E.D. and Folk, R.L. 1958. Pebbles in the Lower Colorado River, Texas: A study in particle morphogenesis. *Journal of Geology* 66(2): 114-150.

U.S. Army Corps of Engineers. 1936. Preliminary examination flood control: Sacramento and San Joaquin Valleys, California. Appendix H: Mokelumne River Group. Sacramento, CA: U.S. Army Corps of Engineers. 13 p.

Vick, J., Andrews, E., and Williams, P.B. 1997. *Analysis of Opportunities for Restoring a Natural Flood Regime on the Cosumnes River Floodplain*. San Francisco, CA: Philip Williams & Associates, Ltd. 88 p.

Werrity, A. 1992. Downstream fining in a gravel-bed river in southern Poland: Lithologic controls and the role of abrasion. In: *Dynamics of Gravel-bed Rivers*. P. Billi, R.D. Hey, C.R. Thorn, and P. Tacconi (eds). New York, NY: Wiley & Sons. pp. 333-350.

Whiting, P.S. and Dietrich, W.E. 1991. Convective accelerations and boundary shear stress over a channel bar. *Water Resources Research* 27(5): 783-796.

Wilcock, P.R. 1992. Experimental investigation of the effect of mixture properties on transport dynamics. In: *Dynamics of Gravel-bed Rivers*. P. Billi, R.D. Hey, C.R. Thorn, and P. Tacconi (eds). New York, NY: Wiley & Sons. pp. 109-139.

Wilcock, P.R. and Southard, J.B. 1989. Bed load transport of mixed size sediment: Fractional transport rates, bed forms, and the development of a coarse bed surface layer. *Water Resources Research* 25(7): 1629-1641.

Williams, G.P. 1978. Bank-full discharge of rivers. *Water Resources Research* 14(6): 1141-1154.

Wohl, E.E. 1998. Bedrock channel morphology in relation to erosional processes. In: *Rivers Over Rock: Fluvial Processes in Bedrock Channels*. Tinkler, K.J. and Wohl, E.E. (eds). Washington, D.C.: American Geophysical Union. pp. 133-151.

Wolcott, J. 1988. Nonfluvial control of bimodal grain-size distributions in river-bed gravels. *Journal of Sedimentary Petrology* 58(6): 979-984.

Wolman, M.G. and Miller, J.C. 1960. Magnitude and frequency of forces in geomorphic processes. *Journal of Geology* 68(1): 54-74.

Appendix I. Grain-size data

surface

Sample no.	1	2	3	4	7	8
Distance (km)	0	0.83	1.46	2.23	3.73	4.63
Weight (kg)	46.227	33.870	45.930	24.437	53.939	21.717
Percent retained						
Sieve size (mm)						
256						
180						
128						
90	12.98	22.76	0.98		2.15	
64	16.25	12.31	14.87	5.24	8.45	5.07
45	13.17	11.40	21.84	9.17	15.26	13.12
32	12.94	9.00	14.37	12.28	15.00	21.23
22	6.40	7.26	8.53	11.42	11.25	18.79
16	6.08	6.26	7.53	14.61	7.66	12.94
11.2						
8	9.73	9.83	10.37	21.58	13.28	15.49
5.6			2.05	4.52	3.61	
4	6.25	6.72	1.81	4.44	4.02	5.41
2.8	2.00	1.49	1.09	3.36	3.42	1.32
2	2.17	1.64	0.81	2.02	2.88	1.10
1.4	2.32	1.37	1.29	1.21	0.79	1.06
1	2.56	1.44	2.11	0.92	3.20	1.14
0.71	2.76	2.03	4.07	1.20	1.46	1.37
0.5	2.04	2.18	4.11	2.33	1.36	1.08
0.35	1.36	1.85	2.38	3.26	1.77	0.52
0.25	0.62	1.21	0.93	1.28	1.91	0.21
0.18	0.22	0.73	0.42	0.40	1.33	0.08
0.13	0.08	0.33	0.22	0.30	0.67	0.03
0.088	0.03	0.10	0.08	0.15	0.23	0.01
0.063	0.02	0.05	0.05	0.11	0.14	0.01
< 0.063	0.01	0.03	0.08	0.21	0.16	0.01

surface

Sample no.	9	10	11	12	13	14
Distance (km)	5.39	5.96	7.36	8.5	9.16	10.75
Weight (kg)	23.095	58.000	18.634	18.750	15.720	9.175
Percent retained						
Sieve size (mm)						
256						
180						
128						
90		4.02				
64	9.09	13.02				
45	15.54	24.17	9.07		5.53	
32	27.32	16.03	27.85	3.25	13.49	2.83
22	14.33	5.00	26.03	12.64	17.37	6.65
16	8.57	4.50	11.75	11.84	13.87	17.00
11.2						
8	10.91	10.64	12.02	20.27	24.49	48.83
5.6						
4	6.40	7.48	4.73	14.48	9.49	16.03
2.8	1.61	1.61	0.58	4.04	1.92	2.04
2	1.55	1.69	0.37	3.17	1.58	1.78
1.4	1.19	1.34	0.22	2.96	1.19	1.10
1	1.10	1.57	0.34	3.93	1.25	0.96
0.71	0.89	2.25	0.89	5.86	1.81	1.04
0.5	0.48	2.53	1.81	5.83	2.31	0.90
0.35	0.30	2.16	2.10	5.37	2.01	0.47
0.25	0.26	1.20	1.37	2.31	1.24	0.13
0.18	0.20	0.51	0.56	1.52	0.85	0.08
0.13	0.13	0.17	0.16	1.29	0.70	0.07
0.088	0.05	0.05	0.05	0.58	0.39	0.04
0.063	0.04	0.03	0.04	0.35	0.25	0.03
< 0.063	0.03	0.03	0.06	0.32	0.26	0.04

surface

Sample no.	15	16	18	19	20	21
Distance (km)	11.53	14.3	16.69	17.7	19.37	20.89
Weight (kg)	31.463	21.849	8.573	12.787	14.350	15.960
Percent retained						
Sieve size (mm)						
256						
180						
128						
90						
64	1.27					
45	14.65	4.35		0.78		
32	19.52	20.28		5.47	0.70	4.14
22	15.22	20.78	7.47	16.58	2.09	18.92
16	11.41	14.05	24.26	16.97	10.03	26.25
11.2				14.16	23.83	19.11
8	12.43	15.88	35.70	12.88	25.31	10.18
5.6				8.59	10.68	6.41
4	6.29	9.87	12.26	5.59	6.94	3.59
2.8	1.35	2.08	2.48	3.18	3.58	2.84
2	1.11	1.76	1.56	1.98	2.40	1.98
1.4	1.74	1.20	0.90	1.07	1.92	1.44
1	1.68	1.49	1.07	0.92	1.85	1.15
0.71	3.32	2.24	2.26	1.54	2.03	0.76
0.5	5.22	1.96	3.13	2.31	1.72	0.35
0.35	3.11	1.56	3.04	3.16	1.94	0.34
0.25	1.05	0.84	1.58	2.60	1.63	0.75
0.18	0.38	0.61	0.97	1.38	1.31	0.77
0.13	0.15	0.54	1.22	0.54	0.84	0.47
0.088	0.05	0.25	0.80	0.15	0.34	0.19
0.063	0.04	0.11	0.64	0.09	0.26	0.14
< 0.063	0.03	0.15	0.68	0.06	0.58	0.23

surface

Sample no.	22	23	24	25	26	27
Distance (km)	21.77	22.51	23.44	24.19	25.38	26.84
Weight (kg)	7.184	2.702	7.960	5.492	27.501	8.328
Percent retained						
Sieve size (mm)						
256						
180						
128						
90						
64						
45						
32	0.70		0.63		2.62	
22	8.35		3.14		10.76	
16	27.56	5.55	25.63		29.89	
11.2					25.09	2.40
8	38.28	42.57	41.46		12.70	6.74
5.6				0.36	5.84	6.28
4	13.32	33.77	14.42	0.67	2.45	9.98
2.8	1.98	6.05	2.55	1.04	1.83	10.59
2	1.32	4.03	1.76	1.78	1.44	10.51
1.4	0.55	2.73	1.04	4.36	1.22	9.82
1	0.29	2.27	0.73	10.53	1.24	10.91
0.71	0.30	1.49	0.81	24.76	1.37	11.11
0.5	0.74	0.63	1.29	30.05	1.37	8.46
0.35	2.83	0.44	2.37	18.33	0.88	6.85
0.25	2.55	0.18	2.36	6.53	0.59	4.32
0.18	0.78	0.08	1.27	1.17	0.41	1.40
0.13	0.25	0.05	0.38	0.25	0.17	0.41
0.088	0.08	0.03	0.08	0.07	0.05	0.12
0.063	0.05	0.05	0.04	0.04	0.04	0.06
< 0.063	0.05	0.09	0.04	0.04	0.04	0.04

surface

Sample no.	28	29	31	32	33	34
Distance (km)	27.88	29.78	31.83	32.97	33.8	34.32
Weight (kg)	6.353	18.323	12.873	2.502	5.456	2.386
Percent retained						
Sieve size (mm)						
256						
180						
128						
90						
64						
45						
32		6.66	5.90			
22	2.05	12.66	4.97			
16	18.57	16.92	8.08		0.96	1.58
11.2		13.45	15.85	0.29	5.64	14.12
8	54.78	9.93	17.33	0.81	9.02	21.52
5.6		6.24	9.09	1.83	11.67	16.59
4	11.06	4.95	6.77	2.02	10.39	10.46
2.8	2.59	3.60	5.74	3.35	9.85	8.36
2	1.67	2.87	4.19	6.63	8.27	4.85
1.4	1.47	2.83	2.89	14.33	7.18	2.75
1	1.65	3.67	2.60	23.44	7.68	1.80
0.71	1.68	4.98	2.73	23.58	9.02	1.55
0.5	1.70	5.29	3.16	12.60	8.42	1.76
0.35	1.45	3.24	4.38	6.45	5.42	3.08
0.25	0.89	1.16	3.69	2.86	2.38	4.86
0.18	0.31	0.62	1.56	0.98	1.82	3.84
0.13	0.08	0.44	0.60	0.34	1.18	1.38
0.088	0.02	0.20	0.21	0.19	0.44	0.42
0.063	0.02	0.14	0.15	0.18	0.27	0.34
< 0.063	0.01	0.16	0.13	0.13	0.39	0.73

surface

Sample no.	35	36	37	38	39	40
Distance (km)	35.29	36.48	37.48	39.17	40.26	41.88
Weight (kg)	1.506	1.747	2.436	2.694	1.493	1.513
Percent retained						
Sieve size (mm)						
256						
180						
128						
90						
64						
45						
32						
22			0.93	2.10		
16			9.10	4.36		
11.2	0.29	0.79	18.73	10.39	0.36	
8	1.45	1.81	17.27	9.59	1.95	
5.6	2.22	4.77	13.60	10.77	2.64	
4	4.86	6.23	10.25	8.17	3.40	0.17
2.8	7.90	8.95	7.11	6.63	6.08	0.49
2	12.22	9.18	3.95	6.02	10.39	1.66
1.4	14.95	11.27	2.27	5.49	16.09	7.26
1	15.08	14.88	1.58	6.77	20.18	16.17
0.71	10.77	16.89	1.83	6.68	18.35	29.92
0.5	7.30	11.02	3.07	5.09	11.01	30.50
0.35	8.74	6.41	3.91	4.48	5.61	12.19
0.25	9.16	4.76	2.84	4.75	2.38	1.33
0.18	4.03	2.08	1.48	4.52	0.72	0.12
0.13	0.73	0.59	0.98	2.25	0.47	0.07
0.088	0.12	0.18	0.40	0.68	0.17	0.06
0.063	0.08	0.11	0.27	0.44	0.09	0.04
< 0.063	0.09	0.09	0.46	0.81	0.13	0.02

subsurface

Sample no.	1	2	3	4	7	8
Distance (km)	0	0.83	1.46	2.23	3.73	4.63
Weight (kg)	37.010	40.792	38.599	34.849	56.924	37.300
Percent retained						
Sieve size (mm)						
256						
180						
128						
90			2.38		2.46	
64	8.94	4.93	8.63	1.21	2.16	6.57
45	9.40	12.13	7.00	6.40	3.57	9.65
32	12.75	9.19	14.28	11.91	9.75	11.15
22	11.83	6.82	9.12	13.89	11.66	10.05
16	7.92	8.41	10.08	13.29	11.01	9.22
11.2						
8	12.92	15.64	13.89	19.36	19.43	14.16
5.6			4.62	8.24	4.87	
4	9.05	10.92	3.31	3.03	4.17	9.08
2.8	2.71	3.08	0.77	1.81	3.41	3.78
2	2.62	3.12	1.70	2.31	2.97	3.26
1.4	3.41	3.53	2.30	3.04	3.28	3.41
1	4.45	5.50	4.27	3.89	4.41	4.53
0.71	5.21	6.49	7.28	5.35	4.87	5.25
0.5	4.53	4.67	6.34	3.84	4.07	4.16
0.35	2.56	2.51	2.63	1.55	3.88	2.95
0.25	1.15	1.72	0.97	0.54	2.50	1.75
0.18	0.37	0.85	0.29	0.18	0.95	0.69
0.13	0.12	0.37	0.11	0.10	0.32	0.24
0.088	0.02	0.09	0.03	0.04	0.10	0.06
0.063	0.01	0.04	0.02	0.02	0.07	0.03
< 0.063	0.02	0.01	0.01	0.01	0.09	0.02

subsurface

Sample no.	9	10	11	12	13	14
Distance (km)	5.39	5.96	7.36	8.5	9.16	10.75
Weight (kg)	51.485	21.548	45.774	26.108	18.543	6.811
Percent retained						
Sieve size (mm)						
256						
180						
128						
90	2.76					
64	3.90	5.57	2.13			
45	7.65	9.47	8.85	1.69	1.67	
32	11.69	14.90	13.79	5.09	3.99	
22	9.11	8.63	8.94	8.04	5.29	1.17
16	8.95	8.35	9.42	12.87	5.72	3.52
11.2					5.39	8.52
8	15.05	15.89	17.02	27.00	5.68	8.28
5.6		4.43	4.66		5.75	7.32
4	10.93	4.02	4.43	18.20	6.08	6.77
2.8	3.10	3.11	3.64	5.99	5.90	7.66
2	2.77	2.20	2.24	5.45	5.48	7.91
1.4	2.35	2.62	3.13	4.69	5.79	9.44
1	2.96	3.85	4.08	3.88	8.53	11.62
0.71	4.41	6.21	6.24	2.22	14.21	12.80
0.5	5.36	5.62	5.58	1.47	11.75	8.71
0.35	4.15	2.85	3.18	1.44	5.40	3.76
0.25	2.64	1.34	1.56	0.91	2.28	1.33
0.18	1.31	0.55	0.65	0.54	0.73	0.55
0.13	0.57	0.23	0.27	0.31	0.26	0.32
0.088	0.16	0.07	0.09	0.11	0.07	0.16
0.063	0.09	0.04	0.06	0.06	0.04	0.11
< 0.063	0.07	0.05	0.05	0.04	0.01	0.06

subsurface

Sample no.	15	16	18	19	20	21
Distance (km)	11.53	14.3	16.69	17.7	19.37	20.89
Weight (kg)	21.498	30.479	10.507	20.502	7.383	10.621
Percent retained						
Sieve size (mm)						
256						
180						
128						
90						
64						
45	7.21	1.48				
32	10.28	2.23		3.22		
22	11.12	5.94		7.90		
16	8.70	8.96	3.05	7.90	7.31	3.58
11.2			8.95	7.61	12.19	7.53
8	13.72	23.62	9.90	7.69	10.00	11.08
5.6			6.77	6.45	10.01	11.05
4	11.22	20.48	6.69	6.66	7.54	12.73
2.8	2.88	6.40	6.61	5.67	6.23	12.36
2	3.39	7.36	5.90	4.82	5.10	11.47
1.4	3.24	6.65	6.45	4.34	4.45	9.86
1	4.07	6.55	8.39	5.42	5.37	8.54
0.71	6.91	5.30	12.90	7.81	7.56	5.34
0.5	9.41	2.80	11.70	7.60	6.59	1.75
0.35	5.80	1.24	8.93	8.86	6.20	0.93
0.25	1.50	0.59	2.51	5.38	5.93	1.44
0.18	0.39	0.22	0.61	1.94	3.45	1.22
0.13	0.11	0.11	0.35	0.59	1.40	0.64
0.088	0.03	0.04	0.14	0.11	0.36	0.22
0.063	0.01	0.02	0.08	0.04	0.16	0.14
< 0.063	0.01	0.01	0.06	0.01	0.13	0.11

subsurface

Sample no.	22	23	24	26	28	29
Distance (km)	21.77	22.51	23.44	25.38	27.88	29.78
Weight (kg)	10.562	5.140	16.894	15.749	12.488	15.723
Percent retained						
Sieve size (mm)						
256						
180						
128						
90						
64						
45						
32				4.13	1.76	2.54
22				10.54	1.92	2.54
16	4.36	0.16	4.97	15.37	8.33	9.67
11.2	11.36	0.52	11.96	12.06	11.37	10.30
8	9.74	1.17	11.84	11.88	9.27	11.37
5.6	7.20	1.56	8.32	9.52	6.02	9.45
4	6.54	2.77	8.22	6.68	5.44	7.83
2.8	6.21	4.77	7.68	3.38	5.64	6.93
2	5.15	9.59	6.38	4.16	5.67	6.75
1.4	4.48	18.42	5.02	4.05	6.75	7.07
1	5.82	27.38	5.26	4.36	8.59	9.35
0.71	7.18	20.90	6.60	4.55	9.37	9.25
0.5	7.28	9.25	7.55	3.61	8.03	3.88
0.35	9.78	2.44	7.49	2.35	5.95	1.68
0.25	9.30	0.65	5.01	1.68	3.69	0.71
0.18	3.97	0.25	2.22	1.12	1.59	0.32
0.13	1.22	0.08	0.86	0.42	0.45	0.19
0.088	0.28	0.04	0.29	0.09	0.10	0.07
0.063	0.10	0.03	0.19	0.04	0.05	0.05
< 0.063	0.04	0.02	0.16	0.03	0.03	0.03

subsurface

Sample no.	31	34	37	38
Distance (km)	31.83	34.32	37.48	39.17
Weight (kg)	7.273	2.860	2.922	1.855
Percent retained				
Sieve size (mm)				
256				
180				
128				
90				
64				
45				
32				
22	3.58			
16	1.65	1.45	1.54	6.98
11.2	2.20	6.69	9.70	11.23
8	2.75	10.47	11.27	10.17
5.6	2.80	10.57	12.31	5.52
4	3.73	9.12	11.86	4.83
2.8	5.74	7.75	11.26	5.23
2	9.15	6.21	8.35	5.23
1.4	14.23	4.65	6.06	6.75
1	19.82	4.26	4.56	10.49
0.71	18.83	5.29	3.46	11.95
0.5	9.43	7.35	3.80	9.46
0.35	3.80	10.41	4.73	6.03
0.25	1.47	9.63	4.83	2.73
0.18	0.49	4.50	3.05	2.01
0.13	0.14	1.22	1.69	0.85
0.088	0.09	0.23	0.61	0.22
0.063	0.08	0.10	0.36	0.13
< 0.063	0.02	0.10	0.56	0.21

Appendix II. Error analysis

Error in characteristic grain-size values

Error was derived from two sources: the limited accuracy in reading median grain size from cumulative percent curves and the absence of 5.6 and 11.2 mm field sieves for some of the sampling (resulting in two one-phi intervals from 4 to 8 mm and 8 to 16 mm in some cases). Reading error in determining D_{50} averaged about 3 percent. This translated to an error of approximately 1.2 mm for the coarsest grain sizes and less than 0.05 mm for the finest. For this reason, D_i estimates for all size fractions *i* were rounded to 2 significant figures.

In 7 of the 35 surface samples (sites 12, 14, 18, 22, 23, 24, 28), D_{50} fell between 4 and 16 mm when fractionation of sizes in this range was limited to 2 one-phi rather than 4 half-phi intervals. Error was estimated by distributing the mass in a one-phi interval fraction between the included half-phi intervals at various ratios. Maximum error when comparing a 50/50 distribution to a 70/30 or 30/70 distribution was about 1 mm (3 to 8 percent). This estimate included the average 3 percent reading error. Therefore, it was assumed that rounding D_{50} to 2 significant figures accounted for any error attained through lack of resolution in the grain-size distribution.

Error distribution over the longitudinal profile

Total error accrued between benchmarks listed in Appendix III was calculated and distributed among the turning point stations contained within the profile segment. The magnitude of error at each turning point was considered proportional to the distance between it and the previous station (Kissam, 1956).

Appendix III. Benchmarks used in Cosumnes River level surveys

Designation	Source	Elevation (m) NGVD29	Description
1D - 60	Sacramento Co. Public Works	46.09	Bronze tablet located in top of southeast corner of concrete gate valve outlet box at northeasterly corner of spillway outlet at lake at Rancho Murieta 350 feet north of Highway 16 and 100 feet north of Lago Drive.
1D - 39	Sacramento Co. Public	39.09	Bronze tablet located along the base of the guardrail at the southeast corner of Dillard Road Bridge.
T - 859	USGS	42.89	Bronze tablet on 20-cm high concrete block located 32 feet southwest of center of Meiss Road and 239 feet northwest of Dillard Road.
D - 953	USGS	30.26	Bronze tablet located in concrete headwall of culvert at intersection of Sloughhouse Road and Cresthill Drive.
R - 953	USGS	78.89	Bronze tablet located in concrete foundation of public scales at the former Wilton feed store 100 feet southwest of Wilton Road.
P - 953	USGS	15.79	Bronze tablet located in concrete foundation of southeast leg of steel power transmission line tower 54-230 45 feet northwest of Grant Line Road.
L - 834	USGS	15.076	Bronze tablet located in southeast corner of north abutment of Pacific Co. railroad bridge over Highway 99 12 feet east of east rail of main track.
35 B	USGS	10.753	Cap on 3.5-inch iron pipe projecting 1 foot above ground located near crossing of railroad and dirt road through TNC Valensin property 44 feet west of west rail of tracks and 19 feet south of centerline of road.
H19	USGS	5.749	Bronze tablet in 20-cm high concrete block located on north side of fenceline under solitary oak tree 0.5 km east on Twin Cities Road from east corner of bridge over main channel.

Appendix IV. Cosumnes River profile data (NGVD29)

Distance (km)	Elevation (m)	Depth (m)	Water surface (m)	Notes
-0.081	33.942	0.3	34.242	middle of riffle
-0.067	33.892	0.29	34.182	
-0.04	33.672	0.43	34.102	
-0.0175	33.677	0.425	34.102	
0	33.547	0.56	34.107	thalweg at cross-section 1, 0.22 km upstream of mile marker 32
0.02	33.702	0.435	34.137	
0.04	33.742	0.385	34.127	
0.06	33.772	0.355	34.127	
0.08	32.872	1.265	34.137	
0.1	32.737	1.4	34.137	deep pool
0.12	32.807	1.33	34.137	
0.14	32.692	1.45	34.142	
0.16	33.482	0.655	34.137	
0.18	33.652	0.495	34.147	
0.2	33.599	0.535	34.134	
0.22	33.724	0.4	34.124	tail of deep pool
0.2353	34.054	0.06	34.114	head of riffle
0.2463	33.774	0.21	33.984	middle of riffle
0.2505	33.504	0.24	33.744	tail of riffle
0.27	33.434	0.25	33.684	run
0.29	33.009	0.62	33.629	head of pool
0.31	33.169	0.44	33.609	
0.33	32.834	0.79	33.624	
0.35	32.919	0.69	33.609	
0.3645	33.384	0.21	33.594	head of riffle
0.3725	33.269	0.31	33.579	tail of riffle
0.3925	32.639	0.91	33.549	
0.4125	32.419	1.12	33.539	
0.4325	32.344	1.12	33.464	
0.4525	32.697	0.81	33.507	
0.4725	32.287	1.235	33.522	
0.4925	32.762	0.76	33.522	
0.5125	33.132	0.4	33.532	tail of pool
0.5325	33.402	0.12	33.522	head of riffle
0.5443	33.357	0.14	33.497	middle of riffle
0.5543	33.322	0.11	33.432	tail of riffle
0.575	32.592	0.845	33.437	
0.595	32.517	0.91	33.427	right bank is cutbank with veg overhanging pool
0.615	32.242	1.2	33.442	
0.635	32.202	1.235	33.437	
0.655	32.627	0.8	33.427	
0.675	32.772	0.655	33.427	

0.695	33.282	0.15	33.432	
0.715	33.297	0.155	33.452	
0.735	33.387	0.055	33.442	
0.7499	33.387	0.035	33.422	head of riffle
0.7598	33.127	0.07	33.197	middle of riffle
0.769	32.627	0.34	32.967	tail of riffle
0.789	32.537	0.41	32.947	pool
0.809	32.547	0.4	32.947	
0.829	32.432	0.5	32.932	at cross-section 2
0.849	32.472	0.47	32.942	
0.869	32.242	0.69	32.932	
0.889	32.137	0.8	32.937	
0.909	32.582	0.35	32.932	
0.929	32.607	0.29	32.897	head of riffle
0.9417	32.572	0.21	32.782	middle of riffle
0.9582	32.282	0.4	32.682	tail of riffle
0.97818	32.132	0.53	32.662	
0.99818	31.992	0.67	32.662	
1.01818	31.972	0.69	32.662	
1.03818	31.777	0.89	32.667	
1.05818	31.547	1.1	32.647	
1.076	31.042	1.6	32.642	deep scour downstream of log in duripan on outside of left meander bend
1.096	31.872	0.785	32.657	
1.116	32.262	0.39	32.652	
1.136	32.142	0.51	32.652	
1.156	32.217	0.425	32.642	
1.176	32.017	0.63	32.647	
1.196	32.062	0.585	32.647	
1.216	32.107	0.54	32.647	
1.236	32.147	0.5	32.647	
1.256	32.107	0.545	32.652	
1.276	32.367	0.28	32.647	
1.296	32.522	0.135	32.657	
1.316	32.412	0.15	32.562	
1.336	32.217	0.31	32.527	
1.356	32.252	0.275	32.527	
1.376	32.212	0.31	32.522	near pipe
1.396	31.722	0.8	32.522	scour downstream of pipe and duripan outcrop
1.416	31.872	0.655	32.527	
1.436	32.152	0.37	32.522	
1.456	32.272	0.255	32.527	at cross-section 3
1.476	32.342	0.17	32.512	
1.496	31.962	0.545	32.507	
1.516	31.907	0.6	32.507	
1.536	31.767	0.745	32.512	scour downstream of stump, rip rap on left bank
1.556	32.292	0.215	32.507	rip rap on left bank
1.576	32.282	0.235	32.517	rip rap on left bank

1.596	32.277	0.245	32.522	
1.616	32.172	0.345	32.517	
1.636	32.182	0.325	32.507	
1.656	32.212	0.315	32.527	
1.676	32.219	0.275	32.494	
1.696	32.264	0.235	32.499	
1.713	32.349	0.03	32.379	head of riffle
1.718	32.254	0.125	32.379	tail of riffle
1.738	32.349	0.04	32.389	
1.758	32.039	0.345	32.384	
1.778	32.164	0.165	32.329	
1.795	32.274	0.065	32.339	
1.803	32.109	0.215	32.324	
1.823	31.659	0.63	32.289	
1.843	31.269	1.02	32.289	
1.863	31.344	0.9	32.244	
1.883	31.454	0.785	32.239	
1.903	31.454	0.785	32.239	
1.923	31.534	0.705	32.239	
1.943	31.719	0.525	32.244	
1.963	31.874	0.375	32.249	bed surface is sand with cobbles on banks
1.983	31.819	0.435	32.254	
2.003	31.691	0.485	32.176	
2.023	31.391	0.785	32.176	
2.043	31.221	0.94	32.161	
2.063	31.111	1.05	32.161	
2.083	31.211	0.96	32.171	
2.103	31.416	0.755	32.171	
2.123	31.611	0.555	32.166	
2.143	31.641	0.525	32.166	
2.163	31.711	0.445	32.156	
2.183	31.951	0.205	32.156	
2.1975	32.041	0.1	32.141	head of riffle
2.2035	31.931	0.175	32.106	tail of riffle
2.2235	31.471	0.645	32.116	
2.2255	31.481	0.635	32.116	at cross-section 4
2.2455	31.1			
2.2655	31.055	1.02	32.075	
2.2855	31.385	0.695	32.08	
2.3055	31.495	0.575	32.07	bed surface changes from gravel and sand to cobbles
2.3255	31.7	0.375	32.075	
2.3455	31.83	0.235	32.065	
2.358	31.83	0.235	32.065	at cross-section 5
2.378	31.736	0.305	32.041	
2.398	31.856	0.16	32.016	
2.418	31.361	0.655	32.016	
2.429	31.861	0.145	32.006	head of riffle
2.436	31.761	0.25	32.011	middle

2.446	31.326	0.165	31.491	tail of riffle
2.462	31.271	0.21	31.481	head of riffle
2.4765	31.131	0.205	31.336	tail of riffle
2.4965	31.146	0.18	31.326	bed surface is large cobbles
2.5165	30.916	0.375	31.291	
2.5365	30.756	0.54	31.296	bed is duripan with few cobbles
2.5565	31.161	0.14	31.301	
2.5765	30.896	0.37	31.266	
2.5965	30.811	0.385	31.196	downstream edge of duripan
2.6165	30.806	0.385	31.191	
2.6365	30.421	0.765	31.186	in pool
2.652	30.971	0.185	31.156	head of riffle
2.6655	30.801	0.25	31.051	middle
2.6815	30.721	0.22	30.941	tail of riffle
2.7015	30.781	0.155	30.936	
2.713	30.821	0.09	30.911	head of riffle
2.726	30.681	0.16	30.841	tail of riffle, sand in channel
2.746	30.641	0.2	30.841	
2.766	30.556	0.275	30.831	
2.786	30.336	0.5	30.836	
2.806	30.358	0.44	30.798	
2.826	29.988	0.81	30.798	
2.842	29.868	0.93	30.798	
2.862	29.845	0.94	30.785	
2.882	29.565	1.22	30.785	
2.902	30.045	0.73	30.775	
2.922	29.6	1.17	30.77	channel becomes wider, banks less steep; bed is cobbles with sand
2.942	29.57	1.2	30.77	
2.962	29.28	1.495	30.775	
2.982	29.56	1.21	30.77	
3.002	29.93	0.835	30.765	
3.022	29.72	1.045	30.765	
3.042	29.63	1.13	30.76	
3.062	29.38	1.385	30.765	
3.082	29.555	1.205	30.76	
3.102	29.48	1.285	30.765	at cross-section 6
3.122	29.657	1.065	30.722	longitudinal patches of sand and gravel on bed surface
3.142	30.167	0.555	30.722	channel begins to narrow, bed surface is cobbles
3.162	30.362	0.375	30.737	
3.182	29.967	0.76	30.727	
3.202	29.947	0.8	30.747	
3.222	30.037	0.71	30.747	
3.242	30.177	0.555	30.732	
3.262	30.112	0.625	30.737	
3.282	30.232	0.495	30.727	scour downstream of large tire in channel
3.302	30.297	0.42	30.717	
3.322	30.252	0.485	30.737	

3.342	30.397	0.325	30.722	
3.362	30.487	0.23	30.717	
3.37	30.502	0.2	30.702	head of riffle
3.3777	30.437	0.17	30.607	middle
3.3872	30.317	0.285	30.602	tail of riffle
3.4072	30.302	0.25	30.552	
3.4272	30.292	0.25	30.542	
3.4472	29.857	0.665	30.522	
3.4672	29.892	0.63	30.522	left bank is steep cutbank
3.4872	29.738	0.73	30.468	channel widens
3.5072	29.688	0.78	30.468	
3.5272	28.883	1.585	30.468	
3.5472	29.283	1.18	30.463	
3.5672	29.748	0.71	30.458	bed surface changes from cobbles to sand
3.5872	29.803	0.66	30.463	
3.6072	29.118	1.335	30.453	thalweg is gravel
3.6272	29.018	1.43	30.448	
3.6472	29.498	0.95	30.448	thalweg is cobbles
3.6672	29.858	0.6	30.458	
3.6872	29.963	0.495	30.458	
3.7072	30.263	0.2	30.463	
3.726	30.263	0.185	30.448	at cross-section 7
3.746	30.12	0.285	30.405	
3.766	30.17	0.215	30.385	
3.786	29.49	0.905	30.395	bed surface is gravel with cobbles
3.806	28.82	1.58	30.4	
3.826	29.635	0.76	30.395	
3.846	30.13	0.265	30.395	
3.866	29.895	0.495	30.39	
3.886	29.695	0.695	30.39	
3.906	30.03	0.36	30.39	right bank is cutbank
3.926	30.13	0.25	30.38	
3.9378	30.2	0.16	30.36	head of riffle
3.9425	30.145	0.205	30.35	middle
3.9475	30.09	0.265	30.355	tail of riffle
3.9675	30.075	0.25	30.325	small channel along right bank has been dredged to pump water out of river between gravel alternate bar and right bank
3.9875	30.16	0.165	30.325	
4.0075	30.09	0.235	30.325	
4.014	30.145	0.105	30.25	head of riffle
4.0158	30.065	0.12	30.185	middle
4.0222	29.91	0.205	30.115	tail of riffle
4.0422	29.42	0.685	30.105	
4.0622	28.005	2.1	30.105	
4.0822	28.845	1.255	30.1	
4.1022	28.82	1.29	30.11	
4.1222	29.035	1.07	30.105	

4.1422	28.945	1.165	30.11	left bank is cutbank, bank materials are sand and gravel
4.1622	28.54	1.565	30.105	
4.1822	29.335	0.78	30.115	
4.2022	29.705	0.405	30.11	
4.2222	28.701	1.385	30.086	
4.2422	28.691	1.395	30.086	
4.2622	28.956	1.125	30.081	
4.2822	29.136	0.95	30.086	
4.3022	29.451	0.64	30.091	
4.3222	28.326	1.765	30.091	bed surface is deep sand
4.3422	28.206	1.885	30.091	
4.3622	28.681	1.41	30.091	
4.3822	29.481	0.605	30.086	
4.4022	29.73	0.365	30.095	
4.4222	29.715	0.375	30.09	
4.4422	29.77	0.32	30.09	
4.4622	29.725	0.365	30.09	
4.4822	28.685	1.415	30.1	
4.5022	29.265	0.825	30.09	
4.5222	29.82	0.255	30.075	
4.5422	29.915	0.15	30.065	head of riffle
4.5532	29.766	0.15	29.916	middle
4.5732	29.431	0.2	29.631	tail of riffle
4.5932	29.361	0.25	29.611	in pool
4.6132	29.281	0.285	29.566	
4.6332	29.316	0.23	29.546	at cross-section 8
4.6532	28.998	0.505	29.503	
4.6732	29.313	0.2	29.513	head of riffle
4.6932	29.128	0.21	29.338	middle
4.7132	29.128	0.11	29.238	
4.7198	28.933	0.115	29.048	tail of riffle
4.7398	28.518	0.35	28.868	
4.7598	27.923	0.92	28.843	
4.7798	27.958	0.905	28.863	left bank is rip rapped and cemented
4.7998	27.593	1.275	28.868	
4.8198	26.993	1.88	28.873	
4.8398	26.903	2.02	28.923	
4.8598	26.793	2.12	28.913	cement protecting left bank is undercut and collapsing
4.8798	28.123	0.78	28.903	
4.8998	28.113	0.805	28.918	
4.9198	28.113	0.8	28.913	cement ends
4.9398	27.506	1.395	28.901	
4.9598	27.361	1.54	28.901	
4.9798	27.476	1.4	28.876	
4.9998	28.136	0.715	28.851	
5.0198	28.456	0.39	28.846	
5.0238	28.576	0.26	28.836	head of riffle
5.0352	28.436	0.24	28.676	middle of riffle

5.0552	28.131	0.45	28.581	
5.0752	28.021	0.57	28.591	
5.0952	28.191	0.4	28.591	
5.1152	28.151	0.445	28.596	rip rap ends, channel becomes wider
5.1352	28.226	0.375	28.601	
5.1552	27.926	0.675	28.601	
5.1752	27.806	0.8	28.606	
5.1952	27.493	1.11	28.603	
5.2152	27.408			
5.2352	26.923	1.68	28.603	
5.2552	27.403	1.2	28.603	
5.2752	28.083	0.525	28.608	
5.2912	28.448	0.1	28.548	head of riffle
5.3003	28.118	0.375	28.493	tail of riffle
5.3203	28.093	0.44	28.533	two pipes flow into river on right bank, lots of algal growth results
5.3403	28.028	0.51	28.538	
5.3603	27.663	0.875	28.538	
5.3803	28.183	0.33	28.513	
5.3883	28.313	0.19	28.503	at cross-section 9
5.3963	28.443	0.04	28.483	head of riffle
5.401	28.403	0.125	28.528	tail of riffle
5.421	28.108	0.425	28.533	duripan exposed in bed
5.441	27.953	0.58	28.533	still along right bank of point bar of section 9
5.461	27.888	0.645	28.533	right bank has exposed duripan
5.481	27.723	0.79	28.513	
5.501	28.008	0.52	28.528	
5.521	28.423	0.085	28.508	head of riffle
5.5279	28.253	0.22	28.473	middle
5.5376	28.158	0.295	28.453	tail of riffle
5.5576	28.148	0.285	28.433	
5.5776	27.213	1.205	28.418	
5.5976	27.103	1.315	28.418	
5.6176	27.507	0.9	28.407	
5.6376	27.897	0.505	28.402	mid-channel bar is eroding
5.6576	28.002	0.385	28.387	
5.6776	27.737	0.645	28.382	left bank bar is artificial, created by tires in channel trapping sediment
5.6976	27.707	0.675	28.382	right bank is cutbank, material is silty, may be levee not floodplain deposit
5.7176	27.972	0.4	28.372	
5.7376	27.792	0.54	28.332	scour downstream of tree in channel
5.7456	28.022	0.305	28.327	head of riffle
5.746	28.117	0.195	28.312	tail of riffle
5.766	26.477	1.85	28.327	pool at left bank
5.786	26.712	1.59	28.302	bed is sand
5.806	27.347	0.97	28.317	
5.826	27.326	0.965	28.291	
5.846	27.196	1.11	28.306	

5.866	26.941	1.36	28.301	
5.886	27.011	1.295	28.306	
5.906	27.676	0.615	28.291	
5.926	28.116	0.165	28.281	head of riffle
5.9315	27.826	0.21	28.036	tail of riffle
5.9515	27.516	0.45	27.966	
5.9607	27.276	0.69	27.966	at cross-section 10
5.9737	27.798	0.165	27.963	head of riffle just downstream of 10
5.9791	27.768	0.175	27.943	middle of riffle
5.9844	27.458	0.395	27.853	tail of riffle
6.0044	27.218	0.635	27.853	
6.0244	26.528	1.325	27.853	in pool
6.0444	26.458	1.4	27.858	
6.0644	27.408	0.45	27.858	
6.0693	27.678	0.18	27.858	head of riffle
6.0779	27.257	0.52	27.777	
6.091	27.612	0.14	27.752	
6.0916	27.292	0.445	27.737	tail of riffle
6.1116	27.427	0.26	27.687	rip rap on left bank dumped 8/16/00
6.1316	27.352	0.32	27.672	scour downstream of log
6.1516	27.267	0.405	27.672	
6.1716	27.497	0.165	27.662	head of riffle
6.1809	27.417	0.135	27.552	middle of riffle
6.1909	27.127	0.385	27.512	tail of riffle
6.2109	26.927	0.55	27.477	reach becomes straighter with alternate cobble and gravel bars
6.2309	27.067	0.41	27.477	
6.2509	26.107	1.37	27.477	scour downstream of log
6.2709	26.902	0.58	27.482	
6.2909	27.247	0.245	27.492	
6.3109	27.307	0.165	27.472	
6.3309	27.047	0.415	27.462	
6.3509	26.987	0.485	27.472	
6.3709	26.832	0.625	27.457	
6.3909	27.138	0.295	27.433	
6.4109	27.093	0.34	27.433	
6.4309	27.113	0.315	27.428	
6.4509	26.928	0.49	27.418	
6.4709	27.118	0.29	27.408	
6.4909	27.128	0.285	27.413	
6.5109	27.198	0.22	27.418	
6.5309	27.148	0.265	27.413	
6.5509	27.028	0.375	27.403	
6.5709	26.803	0.605	27.408	
6.5869	27.293	0.09	27.383	head of riffle
6.5915	27.121	0.09	27.211	middle of riffle
6.5958	26.866	0.3	27.166	tail of riffle
6.6013	25.671	1.48	27.151	deepest spot in pool

6.6213	26.506	0.645	27.151	
6.6413	26.601	0.555	27.156	
6.6613	26.486	0.66	27.146	
6.6813	26.591	0.55	27.141	
6.7013	26.746	0.395	27.141	
6.7193	26.996	0.115	27.111	head of riffle
6.7307	26.886	0.17	27.056	middle
6.7379	26.761	0.28	27.041	tail of riffle
6.7579	26.606	0.38	26.986	
6.7779	26.321	0.61	26.931	
6.7979	26.101	0.83	26.931	
6.8179	26.016	0.92	26.936	
6.8379	25.682	1.23	26.912	
6.8579	25.817	1.1	26.917	
6.8779	25.987	0.915	26.902	
6.8979	26.507	0.4	26.907	
6.9179	26.357	0.55	26.907	
6.9379	25.952	0.955	26.907	
6.9523	26.612	0.28	26.892	head of riffle
6.9573	26.482	0.39	26.872	tail of riffle
6.9773	26.072	0.755	26.827	pool
6.9973	26.227	0.605	26.832	
7.0173	25.977	0.85	26.827	
7.0379	26.008	0.805	26.813	
7.0573	25.788	1.02	26.808	
7.0773	26.033	0.77	26.803	
7.0973	26.383	0.425	26.808	
7.1173	25.798	1.01	26.808	
7.1373	25.723	1.08	26.803	
7.1573	25.898	0.905	26.803	
7.1773	24.553	2.25	26.803	pool just upstream of Dillard Rd bridge
7.1973	25.393	1.395	26.788	
7.2173	26.553	0.245	26.798	under left side of bridge at downstream edge
7.2373	26.475	0.345	26.82	
7.2573	26.52	0.285	26.805	
7.2665	26.74	0.05	26.79	head of riffle
7.2681	26.565	0.175	26.74	on riffle
7.2765	26.55	0.11	26.66	middle of riffle
7.2965	26.385	0.105	26.49	riffle
7.3039	26.225	0.185	26.41	tail of riffle
7.3239	25.795	0.605	26.4	longitudinal patches of sand and gravel on bed surface
7.3439	26.195	0.19	26.385	
7.3586	26.17	0.215	26.385	at cross-section 11
7.3786	25.535	0.845	26.38	
7.3986	25.825	0.565	26.39	
7.4186	25.825	0.555	26.38	
7.4386	26.12	0.265	26.385	downstream edge of bar with section 11
7.4586	25.86	0.525	26.385	

7.4786	25.91	0.48	26.39	
7.4986	26.315	0.06	26.375	head of riffle
7.5126	26.07	0.25	26.32	middle of riffle
7.528	26.045	0.256	26.301	tail of riffle
7.548	25.825	0.445	26.27	
7.568	25.925	0.345	26.27	
7.588	25.925	0.35	26.275	bed surfaces changes from sand to gravel
7.608	25.375	0.89	26.265	
7.628	25.825	0.455	26.28	
7.648	25.075	1.19	26.265	
7.668	25.775	0.495	26.27	
7.688	25.975	0.285	26.26	
7.708	25.815	0.45	26.265	
7.728	25.53	0.73	26.26	
7.748	25.67	0.605	26.275	
7.768	25.225	1.04	26.265	
7.788	25.265	1.01	26.275	
7.808	25.095	1.1	26.195	
7.828	24.84	1.265	26.105	
7.848	25.71	0.4	26.11	
7.868	25.555	0.55	26.105	
7.888	25.285	0.82	26.105	
7.908	24.875	1.22	26.095	left bank rip rapped
7.928	24.55	1.545	26.095	
7.948	24.495	1.6	26.095	
7.968	23.83	2.265	26.095	scour up against left bank rip rap
7.988	24.08	2.035	26.115	
8.008	25.115	1.005	26.12	rip rap ends
8.028	25.135	0.985	26.12	sand bed with sand waves
8.048	25	1.125	26.125	very deep sand on bed surface
8.068	25.71	0.415	26.125	
8.088	25.68	0.45	26.13	
8.108	25.37	0.755	26.125	
8.128	25.24	0.875	26.115	
8.148	25.605	0.515	26.12	
8.168	25.41	0.71	26.12	
8.188	25.57	0.545	26.115	
8.208	25.655	0.47	26.125	
8.228	25.565	0.56	26.125	right bank rip rapped
8.248	25.145	0.98	26.125	
8.274	24.255	1.885	26.14	
8.294	24.845	1.3	26.145	
8.314	24.605	1.54	26.145	rip rap ends
8.334	24.875	1.3	26.175	
8.354	25.12	1.05	26.17	
8.374	25.43	0.765	26.195	
8.394	25.72	0.485	26.205	
8.414	25.295	0.905	26.2	

8.434	25.185	1.025	26.21	
8.454	25.665	0.55	26.215	
8.474	25.815	0.41	26.225	
8.494	25.83	0.395	26.225	
8.5035	25.745	0.475	26.22	at cross-section 12
8.5235	25.435	0.79	26.225	
8.5435	25.65	0.58	26.23	
8.5635	25.825	0.4	26.225	
8.5836	25.73	0.505	26.235	bed surface is cobbles
8.6035	25.59	0.645	26.235	
8.6235	25.545	0.69	26.235	
8.6435	25.325	0.915	26.24	
8.6635	25.705	0.54	26.245	
8.6835	26.005	0.245	26.25	
8.7035	25.95	0.3	26.25	
8.7197	26.125	0.105	26.23	head of artificial riffle, material is larger than anything presently in channel
8.7252	26.07	0.06	26.13	tail of artificial riffle
8.7452	25.61	0.49	26.1	
8.7652	25.25	0.84	26.09	
8.7852	25.46	0.62	26.08	
8.8052	25.34	0.745	26.085	
8.8252	25.385	0.69	26.075	
8.8452	25.605	0.48	26.085	
8.8652	25.415	0.66	26.075	
8.8852	24.95	1.13	26.08	
8.9029	24.84	1.24	26.08	
8.9229	24.025	2.055	26.08	
8.9429	24.48	1.595	26.075	
8.9629	24.26	1.815	26.075	
8.9829	24.97	1.105	26.075	
9.0029	25.245	0.835	26.08	
9.0229	24.61	1.48	26.09	
9.0429	24.95	1.14	26.09	
9.0629	24.83	1.25	26.08	
9.0829	24.59	1.5	26.09	
9.1029	25.19	0.895	26.085	
9.1229	25.46	0.625	26.085	
9.1429	25.2	0.885	26.085	
9.1581	25.18	0.9	26.08	at cross-section 13
9.1981	24.36	1.73	26.09	
9.2381	24.8	1.28	26.08	
9.2781	25.645	0.44	26.085	
9.3181	25.17	0.92	26.09	
9.3581	25.435	0.66	26.095	
9.3981	25.03	1.075	26.105	
9.438	24.69	1.43	26.12	left bank is steep against bluff of Mehrten
9.478	24.83	1.285	26.115	

9.518	25.03	1.085	26.115	
9.618	24.965	1.15	26.115	
9.668	25.245	0.905	26.15	duripan begins between here and next point
10.0502	21.69	4.345	26.035	upstream of Meiss Rd bridge, left bank rip rapped, water is pooling due to knickpoint downstream below bridge.
10.1125	22.11	3.91	26.02	directly beneath Meiss Rd bridge, boundary between duripan (upstream) and volcanics (downstream) is 20-30 m downstream of bridge
10.177	25.41	0.59	26	first knickpoint in volcanics just downstream of bridge
10.1819	25.88	0.125	26.005	
10.183	25.795	0.18	25.975	
10.1965	25.46	0.475	25.935	
10.2165	25.39	0.52	25.91	
10.2365	25.595	0.315	25.91	
10.2522	25.495	0.405	25.9	
10.253	25.44	0.475	25.915	
10.273	25.43	0.47	25.9	
10.2779	25.75	0.105	25.855	top of major knickpoint
10.2782	25.32	0.515	25.835	
10.2901	25.755	0.1	25.855	
10.2923	25.735	0.03	25.765	
10.2972	24.56	0.665	25.225	
10.3054	25.195	0.035	25.23	
10.3134	24.74	0.33	25.07	
10.3154	24.655	0.395	25.05	
10.3319	24.4	0.62	25.02	boundary between volcanics (upstream) and duripan (downstream)
10.3519	24.92	0.015	24.935	
10.3719	24.715	0.13	24.845	
10.3919	24.575	0.24	24.815	
10.412	24.375	0.355	24.73	
10.432	24.54	0.11	24.65	
10.452	24.36	0.115	24.475	
10.472	24.13	0.24	24.37	
10.492	23.87	0.235	24.105	
10.512	23.795	0.305	24.1	
10.532	23.715	0.385	24.1	
10.539	23.545	0.505	24.05	
10.579	22.48	1.56	24.04	
10.619	22.65	1.385	24.035	
10.659	23.015	1.015	24.03	duripan ends
10.699	23.815	0.21	24.025	
10.739	23.5	0.53	24.03	
10.7465	23.63	0.395	24.025	at cross-section 14
10.7865	22.995	1.04	24.035	
10.8265	23.01	1.04	24.05	
10.8665	23.56	0.49	24.05	
10.9065	23.855	0.205	24.06	

10.9465	23.035	1.01	24.045	transition from gravel to cobble bed surface and bars
10.9865	23.305	0.735	24.04	
11.0265	23.19	0.845	24.035	
11.0665	23.865	0.135	24	head of riffle
11.0728	23.745	0.155	23.9	middle of riffle
11.0808	23.665	0.19	23.855	tail of riffle
11.1208	23.27	0.575	23.845	
11.1608	23.615	0.235	23.85	
11.2008	23.19	0.5	23.69	
11.2408	22.59	1.1	23.69	
11.2808	22.345	1.335	23.68	
11.3208	22.85	0.83	23.68	
11.3608	22.585	1.085	23.67	
11.4008	22.705	0.97	23.675	
11.4408	23.185	0.495	23.68	
11.4808	23.15	0.535	23.685	
11.5208	23.38	0.3	23.68	
11.5318	23.42	0.265	23.685	at cross-section 15
11.5718	23.085	0.6	23.685	
11.6118	23.055	0.64	23.695	
11.6518	22.64	1.055	23.695	
11.6918	23.255	0.47	23.725	
11.7318	23.125	0.615	23.74	bed surface changes from cobbles to gravel and sand
11.7718	23.365	0.365	23.73	
11.8118	23.255	0.46	23.715	
11.8518	23.185	0.53	23.715	
11.8918	23.105	0.605	23.71	right bank rip rapped, cobble/gravel point bar on left bank
11.9318	21.87	1.825	23.695	
11.9718	22.39	1.32	23.71	
12.0118	22.51	1.2	23.71	
12.0518	22.715	1	23.715	
12.0918	22.665	1.05	23.715	
12.1318	23.065	0.655	23.72	
12.1718	22.995	0.725	23.72	
12.2118	23.095	0.64	23.735	banks are sand and silt
12.2518	23.04	0.69	23.73	
12.6633	22.575	1.11	23.685	upstream extent of duripan
12.7033	22.545	1.14	23.685	
12.7433	22.54	1.13	23.67	
12.7833	22.18	1.485	23.665	
12.8233	23.455	0.21	23.665	head of artificial riffle
12.8333	22.99	0.36	23.35	tail of artificial riffle
12.8733	22.455	0.9	23.355	
12.8933	22.105	1.26	23.365	
12.9533	21.9	1.46	23.36	scour downstream of woody debris
12.9933	22.01	1.365	23.375	
13.0333	22.23	1.14	23.37	

13.0733	22.096	1.28	23.376	
13.1133	21.891	1.46	23.351	
13.1463	23.316	0.02	23.336	upstream edge, top of small concrete diversion dam
13.1493	21.566	0.98	22.546	just below dam
13.154	22.531	0	22.531	head of rip rap just below dam
13.158	21.651	0.765	22.416	tail of rip rap
13.181	20.461	1.94	22.401	deep pool just downstream of dam
13.258	21.466	0.93	22.396	duripan has cobbles and gravel weathering out of it
13.358	21.93	0.49	22.42	
13.399	22.305	0.08	22.385	
13.4107	22.065	0.14	22.205	
13.5307	21.135	1.05	22.185	
13.5536	19.776	2.34	22.116	deep pool in duripan
13.7136	21.451	0.66	22.111	entire reach is duripan with low-flow sand and gravel deposits
13.8736	21.371	0.755	22.126	
14.0336	20.939	1.2	22.139	
14.1645	20.129	2	22.129	
14.325	20.439	1.7	22.139	at cross-section 16
14.365	20.699	1.42	22.119	
14.425	21.249	0.88	22.129	duripan below sand in channel
14.645	20.716	1.4	22.116	reach is wide, shallow and straight
14.662	20.451	1.66	22.111	
14.702	20.036	2.09	22.126	right bank rip rapped
14.762	19.787	2.315	22.102	pool upstream of concrete dam, rip rapped on both sides of channel and on channel bed
14.797	22.117	0.01	22.127	on top of concrete diversion dam
14.797	20.252	0.5	20.752	directly below top edge of dam
14.8125	17.577	3.16	20.737	pool downstream of concrete dam
14.8525	20.227	0.52	20.747	
14.8925	19.194	1.555	20.749	left bank steep and composed of duripan, a lot of gravel and cobbles weathering out of duripan
14.9051	20.529	0.18	20.709	head of riffle
14.9163	20.474	0.145	20.619	middle of riffle
14.9273	20.379	0.22	20.599	tail of riffle
14.9673	19.699	0.885	20.584	channel becomes sinuous with alternate gravel, cobble bars
15.0073	20.329	0.25	20.579	
15.0473	20.329	0.235	20.564	
15.0873	20.114	0.475	20.589	
15.1273	20.082	0.49	20.572	
15.1673	19.957	0.62	20.577	
15.2073	20.067	0.5	20.567	
15.2473	18.822	1.73	20.552	
15.2873	20.207	0.355	20.562	
15.3273	20.147	0.425	20.572	
15.3673	19.847	0.73	20.577	large woody debris in channel
15.4093	20.468	0.05	20.518	head of riffle
15.4259	20.358	0.17	20.528	tail of riffle

15.4659	20.273	0.23	20.503	
15.5059	20.333	0.16	20.493	
15.5459	19.728	0.77	20.498	
15.5859	19.893	0.6	20.493	river bumps into wall of duripan at left bank and bends sharply to the right
15.5969	20.108	0.375	20.483	at cross-section 17
15.6369	19.613	0.875	20.488	
15.6769	18.278	2.21	20.488	channel widens and bed is scoured
15.7169	19.533	0.95	20.483	
15.7569	19.558	1	20.558	left bank extremely incised and oversteepened
15.7969	19.834	0.735	20.569	
15.8369	20.399	0.165	20.564	
15.8769	20.134	0.43	20.564	
15.9169	20.044	0.515	20.559	
15.935	20.439	0.1	20.539	head of riffle
15.9454	20.279	0.21	20.489	tail of riffle
16.0854	19.859	0.63	20.489	
16.1254	20.014	0.48	20.494	
16.1654	20.014	0.46	20.474	
16.2054	18.614	1.86	20.474	
16.2504	20.182	0.225	20.407	
16.2904	19.622	0.775	20.397	
16.3304	19.782	0.61	20.392	
16.3704	19.652	0.745	20.397	
16.4104	19.892	0.515	20.407	downstream extent of duripan
16.4504	19.752	0.65	20.402	
16.4904	19.925	0.475	20.4	
16.5304	20.205	0.18	20.385	
16.5704	19.545	0.84	20.385	
16.6104	19.385	1	20.385	
16.6504	19.405	0.98	20.385	
16.6904	20.26	0.125	20.385	at cross-section 18
16.7012	20.308	0.06	20.368	head of riffle
16.7071	20.223	0.08	20.303	middle of riffle
16.7168	20.013	0.06	20.073	tail of riffle
16.7568	19.618	0.455	20.073	
16.7968	18.903	1.17	20.073	channel is wide with well-developed gravel and sand bars
16.8368	19.138	0.95	20.088	
16.8768	19.451	0.63	20.081	
16.9168	19.671	0.395	20.066	
16.9568	19.836	0.22	20.056	
16.9968	19.396	0.675	20.071	
17.0368	19.451	0.63	20.081	
17.0768	19.871	0.205	20.076	
17.1168	19.351	0.73	20.081	
17.1568	19.582	0.505	20.087	
17.1876	19.927	0.135	20.062	head of riffle

17.1904	19.872	0.18	20.052	middle of riffle
17.1963	19.832	0.2	20.032	tail of riffle
17.2038	18.812	1.23	20.042	
17.2438	19.602	0.415	20.017	
17.2838	19.537	0.475	20.012	
17.3238	19.722	0.29	20.012	
17.3638	18.932	1.095	20.027	
17.4038	18.567	1.46	20.027	
17.4438	19.872	0.15	20.022	
17.4838	19.635	0.39	20.025	
17.5238	19.615	0.395	20.01	
17.5638	19.735	0.285	20.02	
17.6038	19.65	0.355	20.005	
17.6438	19.61	0.4	20.01	
17.6775	19.92	0.07	19.99	head of riffle
17.685	19.855	0.075	19.93	middle of riffle, at cross-section 19
17.6975	19.695	0.135	19.83	tail of riffle
17.7375	19.425	0.33	19.755	
17.7775	19.485	0.275	19.76	
17.8175	19.42	0.325	19.745	
17.8575	19.46	0.285	19.745	
17.8975	19.505	0.24	19.745	
17.9375	19.44	0.3	19.74	
17.9775	19.515	0.16	19.675	
18.0175	19.12	0.565	19.685	
18.051	17.39	2.29	19.68	pool on outside of right meander, right bank is silt
18.091	18.99	0.7	19.69	
18.131	19.31	0.375	19.685	
18.171	19.17	0.515	19.685	
18.211	19.24	0.455	19.695	
18.251	19.355	0.35	19.705	channel enters alternating duripan and alluvial reaches
18.291	19.334	0.35	19.684	
18.331	19.384	0.27	19.654	duripan with gravel and cobbles weathering out of it
18.341	19.539	0.05	19.589	top of small knickpoint
18.356	19.379	0.06	19.439	bottom of knickpoint
18.396	19.319	0.11	19.429	
18.441	17.394	2.02	19.414	deep pool in duripan on outside of meander bend
18.481	18.094	1.295	19.389	
18.521	19.169	0.16	19.329	
18.561	18.535	0.69	19.225	
18.592	18.99	0.15	19.14	top of small knickpoint in duripan
18.5925	18.58	0.375	18.955	bottom of knickpoint
18.5979	18.83	0.15	18.98	head of riffle
18.6037	18.66	0.1	18.76	tail of riffle
18.6437	18.06	0.675	18.735	
18.6837	17.57	1.185	18.755	
18.7237	17.35	1.395	18.745	
18.8037	18.28	0.45	18.73	

18.8667	18.55	0.17	18.72	
18.8877	17.32	1.25	18.57	
18.9277	18.365	0.205	18.57	
18.9592	18.41	0.14	18.55	
18.9768	16.595	1.95	18.545	
19.0168	17.54	0.99	18.53	
19.0508	16.04	2.495	18.535	
19.0908	18.07	0.48	18.55	
19.0993	18.332	0.17	18.502	
19.1143	14.922	3.32	18.242	
19.2458	16.592	1.65	18.242	
19.2748	18.184	0.045	18.229	
19.3148	18.014	0.18	18.194	
19.3548	17.584	0.51	18.094	
19.3748	17.394	0.69	18.084	at cross-section 20
19.4148	17.447	0.65	18.097	
19.4548	17.487	0.615	18.102	
19.4942	18.002	0.1	18.102	head of riffle
19.5382	17.877	0.2	18.077	end of riffle
19.5782	16.704	1.18	17.884	
19.6182	17.249	0.635	17.884	
19.6582	17.464	0.4	17.864	
19.6982	17.519	0.35	17.869	
19.7338	17.794	0.07	17.864	
19.7668	17.769	0.04	17.809	
19.8068	17.269	0.465	17.734	
19.8418	17.659	0.08	17.739	
19.8818	17.164	0.515	17.679	
19.9218	17.427	0.25	17.677	
19.9618	16.967	0.705	17.672	abundant algal growth
20.0018	17.497	0.18	17.677	
20.0418	17.407	0.26	17.667	
20.0818	17.007	0.665	17.672	
20.1218	16.342	1.33	17.672	
20.1618	16.75	0.91	17.66	
20.2018	16.33	1.34	17.67	
20.2418	17.445	0.2	17.645	
20.2818	17.38	0.28	17.66	
20.3218	17.295	0.355	17.65	
20.3618	17.275	0.375	17.65	duripan with sandy bed surface, no bedforms here
20.4018	17.13	0.54	17.67	
20.4418	17.27	0.4	17.67	
20.5528	16.624	1.01	17.634	pool upstream of knickpoint
20.5811	17.309	0.13	17.439	top of knickpoint in duripan
20.5928	16.639	0.185	16.824	bottom of knickpoint
20.6043	13.734	3.045	16.779	pool downstream of knickpoint
20.7643	16.536	0.255	16.791	
20.8043	16.276	0.52	16.796	

20.8443	16.376	0.41	16.786	
20.8843	16.446	0.36	16.806	2m upstream of section 21
20.9268	15.886	0.945	16.831	
20.9668	16.291	0.535	16.826	
21.0068	15.991	0.845	16.836	
21.0468	16.211	0.625	16.836	
21.0868	16.034	0.81	16.844	
21.1268	16.264	0.58	16.844	
21.1668	16.174	0.66	16.834	
21.168	16.164	0.67	16.834	
21.2468	16.129	0.725	16.854	
21.2868	16.214	0.62	16.834	
21.3268	16.509	0.34	16.849	bed surface is gravel and sand
21.3668	16.395	0.445	16.84	
21.4068	15.84	0.91	16.75	
21.4518	16.615	0.115	16.73	
21.4918	16.075	0.41	16.485	left bank is rip rapped with concrete slabs
21.5318	16.21	0.29	16.5	
21.5718	16.185	0.315	16.5	sand in channel
21.6118	15.875	0.62	16.495	
21.6518	16.146	0.205	16.351	
21.6918	16.071	0.05	16.121	in middle of riffle
21.7318	15.671	0.345	16.016	
21.7748	15.701	0.32	16.021	at cross-section 22
21.8148	15.501	0.485	15.986	
21.8548	15.641	0.325	15.966	
21.8948	15.501	0.47	15.971	
21.9348	15.316	0.65	15.966	
21.9748	15.586	0.38	15.966	
22.0148	15.581	0.4	15.981	
22.0347	15.816	0.16	15.976	head of riffle
22.0437	15.686	0.24	15.926	middle of riffle
22.0481	15.561	0.275	15.836	tail of riffle
22.0881	15.546	0.255	15.801	
22.1152	14.407	1.365	15.772	pool at outside of meander
22.1552	15.027	0.71	15.737	
22.1952	15.282	0.47	15.752	
22.2352	14.932	0.8	15.732	channel is narrow
22.2762	15.112	0.635	15.747	
22.2982	14.742	1.015	15.757	channel is deep and narrow, constricted by duripan
22.3086	14.407	1.36	15.767	
22.3486	14.912	0.805	15.717	
22.3746	15.537	0.1	15.637	
22.3806	14.892	0.76	15.652	
22.4206	15.307	0.35	15.657	channel widens, sandy material eroding from left bank
22.4606	15.337	0.33	15.667	
22.5006	15.127	0.54	15.667	
22.5091	15.147	0.51	15.657	at cross-section 23, cobbles weathering out of duripan

22.5491	15.207	0.44	15.647	
22.5891	15.212	0.435	15.647	
22.6181	15.507	0.135	15.642	head of riffle
22.6281	15.272	0.24	15.512	tail of riffle
22.6681	14.917	0.59	15.507	
22.7081	15.082	0.43	15.512	
22.7265	15.202	0.3	15.502	
22.7665	14.856	0.63	15.486	
22.8065	14.961	0.52	15.481	
22.8465	15.001	0.49	15.491	
22.8865	14.876	0.615	15.491	
22.9035	15.311	0.185	15.496	head of riffle, cobbles weathering out of duripan
22.9115	14.976	0.3	15.276	middle of riffle
22.9249	15.051	0.23	15.281	tail of riffle
22.9479	14.096	1.19	15.286	
22.9879	14.396	0.905	15.301	sand eroding from right bank
23.0279	14.821	0.475	15.296	downstream view of straight reach in duripan with gravel, cobble bars
23.0381	15.101	0.19	15.291	head of riffle
23.0467	14.901	0.32	15.221	middle of riffle
23.0566	14.601	0.55	15.151	tail of riffle
23.0966	14.666	0.48	15.146	
23.1366	13.991	1.11	15.101	
23.1467	14.909	0.18	15.089	head of riffle
23.1706	14.644	0.335	14.979	tail of riffle
23.1986	14.389	0.59	14.979	
23.2386	14.704	0.265	14.969	
23.2786	14.749	0.23	14.979	
23.3186	14.744	0.21	14.954	
23.3586	14.675	0.16	14.835	
23.3986	14.65	0.19	14.84	
23.4406	14.62	0.19	14.81	at cross-section 24
23.4806	14.46	0.33	14.79	
23.5166	14.53	0.26	14.79	
23.5566	14.505	0.25	14.755	
23.5966	14.55	0.21	14.76	
23.6278	14.07	0.66	14.73	pool below Wilton Rd. RR bridge
23.6296	14.68	0.05	14.73	
23.6298	14.18	0.46	14.64	
23.6414	13.63	0.87	14.5	pool just downstream of Wilton Rd bridge
23.6814	14.17	0.3	14.47	downstream of Wilton Rd. bridge, channel is narrow, bed is sand, surfaces of bars are fine gravel and sand.
23.7214	14.185	0.285	14.47	
23.7614	14.175	0.295	14.47	
23.8014	14.205	0.26	14.465	
23.8414	14.07	0.4	14.47	
23.8814	14.155	0.315	14.47	
23.9214	14.028	0.415	14.443	

23.9614	13.98	0.45	14.43	
24.0014	14.18	0.255	14.435	
24.0414	14.14	0.295	14.435	
24.0814	14.08	0.35	14.43	
24.1214	14.055	0.38	14.435	
24.1614	13.85	0.59	14.44	
24.1714	13.27	1.16	14.43	
24.1891	12.99	1.435	14.425	at section 25
24.2291	13.92	0.52	14.44	
24.2691	13.4	1.035	14.435	
24.3091	13.52	0.92	14.44	
24.3491	13.192	1.24	14.432	gravel and cobbles weathering out of duripan
24.3751	12.742	1.69	14.432	
24.4151	13.842	0.59	14.432	
24.4551	14.232	0.195	14.427	no bedforms in reach
24.4951	13.692	0.735	14.427	bed surface is cobbles
24.5351	13.712	0.71	14.422	
24.5751	14.042	0.39	14.432	
24.6151	13.326	1.08	14.406	
24.6551	13.066	1.345	14.411	
24.6951	13.286	1.12	14.406	
24.7211	12.619	1.8	14.419	
24.7611	13.259	1.155	14.414	
24.8011	13.499	0.915	14.414	
24.8411	12.969	1.45	14.419	right bank is rip rapped, left bank is duripan
24.8811	13.849	0.57	14.419	
24.9211	13.849	0.57	14.419	
24.9611	13.55	0.875	14.425	
25.0011	13.595	0.82	14.415	both banks duripan
25.0411	13.15	1.265	14.415	
25.0641	12.18	2.24	14.42	pool upstream of dam at Becker property
25.1041	12.865	1.55	14.415	
25.1331	14.38	0.03	14.41	top of dam at Becker property
25.1457	12.542	0.39	12.932	bottom of dam at Becker property
25.1567	9.982	2.95	12.932	pool downstream of dam
25.1967	12.362	0.57	12.932	
25.2367	11.492	1.435	12.927	
25.2787	10.857	2.065	12.922	
25.3187	11.157	1.755	12.912	
25.3587	11.347	1.57	12.917	
25.3817	12.322	0.615	12.937	at cross-section 26
25.4217	12.347	0.555	12.902	
25.4617	12.167	0.75	12.917	
25.4854	12.637	0.275	12.912	
25.5064	12.651	0.23	12.881	
25.5074	12.791	0.05	12.841	
25.5217	11.361	1.4	12.761	
25.5617	11.916	0.83	12.746	right bank is rip rapped

25.6017	11.721	1.01	12.731	
25.6417	12.561	0.17	12.731	head of riffle
25.6527	12.281	0.445	12.726	tail of riffle
25.6927	12.356	0.36	12.716	rip rap ends
25.7327	12.009	0.65	12.659	
25.7727	12.199	0.455	12.654	
25.8127	10.029	2.63	12.659	pool where channel narrows and splits into two channels; left channel is currently active, right channel is active at higher flows; cobbles weathering out of duripan in the right channel from its beginning until it rejoins the left channel downstream.
25.8242	9.634	3.02	12.654	
25.8642	12.529	0.13	12.659	head of riffle
25.8762	12.484	0.06	12.544	middle of riffle
25.8952	12.349	0.13	12.479	tail of riffle
25.9352	11.524	0.95	12.474	
25.9752	11.684	0.8	12.484	
26.0152	11.819	0.67	12.489	
26.0552	12.079	0.4	12.479	
26.0952	12.303	0.16	12.463	
26.1352	12.073	0.355	12.428	
26.1752	11.238	1.175	12.413	
26.2152	11.743	0.69	12.433	
26.2552	11.503	0.93	12.433	
26.2842	12.028	0.405	12.433	
26.3187	10.664	1.75	12.414	
26.3587	11.809	0.555	12.364	
26.4096	12.174	0.12	12.294	
26.4166	12.034	0.11	12.144	
26.4566	11.149	0.98	12.129	two channels rejoin (river split at 25.8 km)
26.4966	11.369	0.76	12.129	
26.5366	11.734	0.4	12.134	
26.5766	11.799	0.325	12.124	
26.6166	11.614	0.51	12.124	
26.6566	11.229	0.9	12.129	
26.6966	11.299	0.82	12.119	
26.7366	11.704	0.435	12.139	
26.7766	11.437	0.685	12.122	
26.8376	11.497	0.63	12.127	at cross-section 27
26.8776	11.171	0.95	12.121	
26.9176	11.586	0.535	12.121	
26.9576	11.761	0.36	12.121	
26.9976	11.744	0.38	12.124	
27.0376	11.719	0.365	12.084	
27.066	11.989	0.075	12.064	top of small knickpoint in duripan
27.118	11.489	0.265	11.754	bottom of knickpoint
27.158	11.474	0.28	11.754	
27.193	11.444	0.3	11.744	cobbles/gravel weathering out of duripan
27.231	11.53	0.12	11.65	

27.2315	11.285	0.365	11.65	
27.2715	11.295	0.275	11.57	lots of woody debris in channel from here to 500m downstream
27.3115	10.835	0.72	11.555	
27.3515	11.4	0.15	11.55	
27.3915	11.195	0.315	11.51	
27.4315	11.308	0.12	11.428	
27.4715	11.163	0.205	11.368	
27.5115	11.203	0.145	11.348	
27.5515	11.033	0.255	11.288	
27.5915	11.078	0.21	11.288	
27.6315	10.821	0.45	11.271	
27.6715	10.961	0.31	11.271	
27.7115	10.971	0.275	11.246	cobble deposits on duripan banks
27.7515	10.706	0.485	11.191	gravel midchannel bars
27.761	10.906	0.25	11.156	head of riffle
27.787	10.406	0.63	11.036	
27.827	10.786	0.25	11.036	
27.867	10.787	0.23	11.017	
27.877	10.752	0.255	11.007	at cross-section 28
27.917	10.637	0.365	11.002	
27.957	10.872	0.115	10.987	
27.997	10.759	0.235	10.994	
28.037	10.804	0.195	10.999	
28.077	10.794	0.185	10.979	
28.117	10.529	0.42	10.949	
28.157	10.629	0.325	10.954	
28.197	10.584	0.37	10.954	
28.205	10.749	0.2	10.949	head of riffle
28.2463	10.479	0.21	10.689	tail of riffle
28.2863	10.449	0.24	10.689	
28.3263	10.359	0.255	10.614	
28.3663	10.134	0.48	10.614	
28.4063	10.374	0.23	10.604	
28.4463	10.344	0.245	10.589	
28.4863	10.244	0.3	10.544	
28.5263	10.284	0.245	10.529	
28.5513	10.464	0.03	10.494	cobbles weathering out of duripan
28.5515	10.394	0.1	10.494	head of riffle
28.5583	9.914	0.515	10.429	tail of riffle
28.5983	10.279	0.15	10.429	
28.6383	10.129	0.295	10.424	
28.6783	10.034	0.385	10.419	
28.7183	10.134	0.26	10.394	
28.7583	10.104	0.3	10.404	
28.7983	10.254	0.145	10.399	gravel weathering out of duripan
28.8383	10.119	0.255	10.374	
28.8788	10.304	0.035	10.339	head of riffle

28.898	10.084	0.16	10.244	tail of riffle
28.9258	10.034	0.19	10.224	
28.9658	9.839	0.3	10.139	
29.0058	9.969	0.155	10.124	
29.0458	9.779	0.335	10.114	
29.0588	9.574	0.535	10.109	
29.0988	9.963	0.115	10.078	downstream extent of alternating duripan and alluvial reaches
29.1078	10.028	0.035	10.063	head of gravel riffle
29.1313	9.708	0.18	9.888	tail of riffle
29.1713	9.398	0.47	9.868	
29.2113	9.238	0.64	9.878	
29.2513	9.703	0.17	9.873	
29.2913	9.671	0.2	9.871	
29.3313	9.626	0.24	9.866	
29.3668	9.431	0.395	9.826	
29.4068	9.646	0.12	9.766	
29.4468	9.091	0.65	9.741	
29.4748	9.069	0.65	9.719	
29.5148	9.159	0.57	9.729	
29.5548	9.099	0.63	9.729	
29.5868	9.444	0.285	9.729	
29.6268	9.431	0.285	9.716	
29.6668	9.256	0.44	9.696	
29.7068	8.901	0.8	9.701	
29.7468	9.431	0.255	9.686	
29.7758	9.401	0.285	9.686	at cross-section 29
29.8158	9.095	0		downstream edge of water, river is dry downstream of this point 9/30/00, water has dropped significantly since last survey (9/19/00)
29.8368	9.545			
29.8768	9.475			
29.9168	9.3			
29.9568	9.615			
29.9968	8.855			
30.0368	9.382			
30.0768	9.222			
30.1168	9.292			
30.1568	9.257			
30.1968	9.127			
30.2168	8.787			
30.2568	9.034			
30.2968	8.714			
30.3368	8.469			
30.3768	8.054			
30.4168	8.554			
30.4568	9.089			
30.4968	8.98			
30.5368	8.89			

30.5768	8.51			
30.6168	9.085			
30.6568	9.1			
30.6968	9.02			
30.7368	8.691			
30.7768	8.831			
30.8168	9.081			
30.8568	9.166			
30.8968	9.048			
30.9368	9.018			
30.9768	9.228			
31.0168	9.137			
31.0568	8.717			duripan outcrops
31.0968	8.272			undercut hardpan falling into channel
31.1368	8.522			
31.1768	8.327			
31.2078	8.862			
31.2478	8.565			sandy bed
31.2878	8.385			pipe/pump on right bank
31.3278	8.545			right bank rip rapped
31.3388	9.035			base of upstream edge of small diversion dam made of wood and rip rap
31.3388	9.29			top of upstream edge of dam
31.3418	9.32			top of downstream edge of dam
31.3428	8.965			upstream edge of rip rap lining channel immediately below dam
31.3508	8.18			on rip rap
31.3548	6.965			base of rip rap
31.3618	5.024			pool just downstream of dam, lateral bank erosion occurring
31.4018	8.064			duripan outcrops
31.4418	8.134			
31.4818	7.599			
31.5218	7.849			
31.5618	8.364			
31.6018	7.974			left bank rip rapped, rip rap installed 9/30/00
31.6418	7.95			rip rap ends
31.6818	8			
31.7178	7.8			
31.7661	7.75			downstream base of road built across channel at Mahon access
31.8061	8.055			
31.8331	7.785			at cross-section 31
31.8731	7.875	0.18	8.055	
31.9131	7.52	0.5	8.02	
31.9251	7.8	0.22	8.02	reach widens
31.9652	7.703	0.32	8.023	
32.0052	7.803	0.21	8.013	
32.0452	7.793	0.205	7.998	

32.0852	7.733	0.17	7.903	
32.1252	7.738	0.11	7.848	
32.1652	7.558	0.23	7.788	
32.1885	7.558	0.22	7.778	
32.2285	7.515	0.24	7.755	
32.2685	7.585	0.15	7.735	
32.3085	7.535	0.16	7.695	
32.3485	7.41	0.255	7.665	
32.3885	7.525	0.12	7.645	
32.4285	7.48	0.14	7.62	
32.4685	7.405	0.2	7.605	
32.4912	7.445	0.15	7.595	
32.5312	7.365	0.2	7.565	
32.5712	7.37	0.18	7.55	
32.6112	7.32	0.215	7.535	
32.6512	7.32	0.21	7.53	
32.6912	7.455	0.1	7.555	pipe entering on river right
32.7312	7.345	0.19	7.535	
32.7712	7.248	0.275	7.523	
32.8112	7.198	0.31	7.508	
32.8512	7.103	0.405	7.508	pool upstream of small, plywood dam
32.8912	6.978	0.38	7.358	20m downstream of plywood dam
32.9312	7.213	0.14	7.353	
32.9712	7.138	0.205	7.343	sample #32 collected on right bank sand bar in narrow, steep-walled reach
33.0112	7.198			
33.0512	6.969	0.36	7.329	
33.0912	7.094	0.245	7.339	
33.1312	7.089	0.255	7.344	
33.1712	7.189	0.155	7.344	
33.2112	7.141	0.2	7.341	
33.2512	7.106	0.21	7.316	
33.2912	7.131	0.18	7.311	
33.3312	6.836	0.47	7.306	channel walls are steep, bed material is sand
33.3712	6.581	0.74	7.321	
33.4112	7.066	0.26	7.326	upstream edge of duripan
33.4512	7.024	0.29	7.314	
33.4912	6.044	1.25	7.294	
33.5312	6.21	1.09	7.3	
33.5712	6.12	1.17	7.29	
33.6112	6.235	1.05	7.285	
33.6299	5.88	1.4	7.28	deepest part of pool upstream of duripan knickpoint
33.6646	6.945	0.31	7.255	top of duripan knickpoint, at Deer Creek confluence
33.6837	4.625	2.63	7.255	pool downstream of knickpoint
33.7237	6.79	0.47	7.26	
33.7637	6.88	0.385	7.265	
33.8037	6.96	0.27	7.23	Sample #33 collected at right bank gravel bar in duripan reach.

33.8437	7.1	0.14	7.24	
33.8837	7.065	0.12	7.185	
33.9237	6.615	0.58	7.195	
33.9637	6.315	0.88	7.195	
33.9967	6.66			
34.0367	6.263	0.93	7.193	at McConnell gage
34.0767	6.386	0.78	7.166	
34.1167	7.026	0.1	7.126	
34.1567	6.766	0.35	7.116	
34.1967	6.281	0.84	7.121	pool just downstream of RR bridge
34.2367	6.126	0.99	7.116	
34.2767	6.736	0.38	7.116	
34.3157	6.956	0.09	7.046	sample #34 taken at mid-channel gravel (fine) bar, duripan outcropping through bar.
34.3557	6.596	0.42	7.016	downstream extent of duripan outcrops
34.3957	6.641	0.385	7.026	
34.4357	6.836	0.18	7.016	channel is wide with gravel bars
34.4757	6.831	0.19	7.021	
34.5157	6.956	0.06	7.016	
34.5557	6.801	0.23	7.031	
34.5957	6.656	0.39	7.046	
34.6357	6.861	0.18	7.041	channel is straight, wide and shallow
34.6757	6.791	0.25	7.041	
34.7157	6.646	0.39	7.036	
34.7557	6.561	0.47	7.031	
34.7957	6.646	0.39	7.036	
34.8357	6.676	0.35	7.026	
34.8757	6.826	0.22	7.046	
34.9157	6.571	0.47	7.041	upstream edge of duripan
34.9557	6.596	0.45	7.046	
34.9797	6.986	0.02	7.006	
34.9857	6.601	0.23	6.831	
35.0197	6.751	0.08	6.831	
35.0597	6.306	0.53	6.836	
35.0997	6.471	0.38	6.851	
35.1397	6.536	0.31	6.846	
35.1717	6.771	0.07	6.841	channel is straight and in duripan
35.2117	6.511	0.245	6.756	
35.2517	6.586	0.165	6.751	
35.2917	6.476	0.26	6.736	sample 35 taken from right bank gravel bar in duripan reach
35.3317	6.301	0.45	6.751	
35.3717	6.521	0.235	6.756	
35.4117	6.546	0.21	6.756	
35.4517	6.601	0.145	6.746	duripan is present in patches through reach
35.4917	6.506	0.24	6.746	downstream edge of duripan
35.5317	6.126	0.615	6.741	pool upstream of small diversion dam
35.5557	6.086	0.65	6.736	

35.5612	6.711	0.03	6.741	top of dam made of cobbles and concrete slabs
35.5712	5.761	0.42	6.181	bottom of dam
35.5742	5.286	0.895	6.181	pool just downstream of dam
35.6142	5.821	0.365	6.186	
35.6542	5.741	0.45	6.191	
35.6942	5.841	0.355	6.196	
35.7342	6.136	0.045	6.181	
35.7742	6.096	0.035	6.131	
35.8142	6.071	0.025	6.096	
35.8222	6.086	0		downstream edge of water, channel splits around island here
35.8622	5.661			duripan outcrops
35.9022	5.051			
35.904	4.926			deepest part of pool
35.944	5.656			channels rejoin
35.984	5.236			downstream extent of duripan, duripan here is black/brown with preserved root masses
36.024	5.621			
36.064	5.481			
36.104	5.396			
36.144	5.266			
36.184	5.256			
36.224	5.776			
36.264	5.806			
36.304	5.606			
36.344	5.666			
36.384	5.561			
36.424	5.586			
36.464	5.496			
36.479	5.431			sample 36 taken from right bank gravel, sand point bar
36.519	5.511			
36.559	5.471			
36.599	5.338			channel is dry and full of sand
36.639	5.223			
36.679	4.903			duripan outcrops for 40 m along left bank, secondary channel runs same distance along left side of channel
36.719	4.768			
36.759	5.008			bed is all sand with many truck tracks, center of channel is surveyed where thalweg is not distinguishable
36.799	4.903			
36.839	5.203			
36.879	5.118			
36.919	5.258			
36.959	5.238			
36.999	5.368			
37.039	5.313			
37.079	5.268			
37.119	5.213			
37.159	5.113			

37.199	5.333			
37.239	5.293			
37.279	5.268			
37.319	5.488			
37.359	5.318			
37.399	5.373			channel becomes very wide 80-100 m across
37.439	5.583			
37.479	5.288			sample 37 collected on right bank point bar in only undisturbed spot, duripan outcrops below soil on left bank and on bed
37.519	5.138			
37.559	5.353			
37.599	5.383			
37.639	5.158			
37.679	5.163			
37.719	5.293			
37.759	5.193			
37.799	5.313			
37.839	5.163			
37.879	5.103			
37.819	5.183			
37.859	5.403			
37.899	5.218			
37.939	5.198			
37.979	5.283			large oaks line channel
38.019	5.313			
38.059	5.023			
38.099	5.078			
38.139	4.938			
38.179	5.083			
38.219	5.128			
38.259	5.343			
38.299	5.063			
38.339	5.178			
38.379	4.783			
38.459	4.878			in small channel along left bank of large gravel and sand bar
38.499	4.543			
38.539	4.988			Badger Creek confluence
38.579	5.028			
38.619	4.973			
38.659	5.058			
38.699	4.933			
38.739	4.653			
38.779	4.873			
38.819	5.128			gravel patches in channel
38.859	4.923			
38.899	4.803			upstream extent of continuous duripan bed

38.939	4.678			duripan bed has large potholes and grooves, some of duripan is capped by very hard white layer about 4 cm thick
38.979	4.698			
39.019	4.738			
39.059	4.703			
39.099	4.698			
39.139	4.638			
39.179	4.638			sample 38 taken at 39.169 km from left bank gravel/sand point bar
39.219	4.643			exposed duripan bed in wide, shallow channel with small and scattered gravel deposits
39.259	4.678			
39.299	4.468			
39.339	4.593			
39.379	4.198			
39.419	4.483			large woody debris up on top of bank probably deposited during floods
39.459	4.393			duripan bed is scoured with potholes and grooves
39.499	4.483			right bank is alluvium, left is duripan
39.539	4.258			
39.579	4.313			
39.619	4.208			
39.659	4.253			
39.699	4.193			
39.739	3.838			channel narrows
39.7693	3.758			top of knickpoint in duripan
39.7785	3.028			plunge pool below that is now sand-filled
39.7885	3.798			top of downstream edge of pool
39.818	4.228			
39.858	3.503			black clay layers are exposed on the lower left bank and on the bed; channel drops down through duripan
39.898	3.513			downstream extent of duripan bed, in deep thalweg along right bank
39.938	4.143			
39.978	3.928			
40.018	3.353			
40.058	3.788			
40.098	3.658			bed is duripan
40.138	3.888			bed is duripan
40.178	4.063			
40.218	3.628			
40.258	3.888			sample 39 taken on left bank sand point bar, area is disturbed, but even deep material seems homogeneous with what has been disturbed on the surface
40.298	3.848			large duripan outcrops in bed, upstream extent of duripan bed
40.312	2.788			bottom of pool in duripan
40.338	3.693			

40.378	3.793			
40.418	4.253			
40.458	4.198			
40.498	3.843			bed has potholes and grooves, small gravel patches in channel
40.538	3.998			ended just upstream of road across channel
40.578	3.968			duripan bed
40.618	3.613			
40.6268	3.088			upstream of concrete and rip rap road built across channel
40.6326	3.118			downstream of road
40.658	3.243			
40.698	3.283			
40.738	3.133			
40.778	3.013			
40.818	2.908			
40.858	2.433			sand no longer covers bed and duripan is bare with spotty, thin veneer of gravel and sand; channel is narrow
40.898	2.708			cobbles in channel from road where used as rip rap
40.938	2.073			
40.978	1.908			
41.018	2.363			
41.058	2.613			
41.098	3.083			
41.138	2.393			
41.178	2.593			downstream extent of duripan bed, deep sand deposits start again here
41.218	2.363			
41.258	2.323			
41.298	2.348			large trees line the banks; roots are exposed and undercut; trees are preventing channel widening in long, narrow, straight reach
41.338	2.273			
41.378	2.228			
41.418	2.278			
41.458	2.298			
41.498	1.983			
41.538	2.403			
41.578	2.218			
41.618	2.268			
41.658	2.423			
41.698	2.303			
41.738	2.218			
41.778	2.163			
41.818	2.103			
41.858	2.053			
41.898	2.013			sample 40 taken at 41.881 km on left-bank sand bar
41.938	1.903			

41.978	1.898			
42.018	1.713			
42.058	1.813			
42.098	1.563			
42.138	1.838			
42.178	1.703			
42.218	1.313			
42.234	0.018			channel drops into sandy pool
42.258	1.248			channel is incised and narrow
42.298	1.188			
42.338	1.313			
42.378	0.808			sand deposits end and the channel bed is bare mud
42.418	0.823			some sand, but mostly bare
42.481	0.639			
42.601	1.289			near fork in Cosumnes main channel, channel to right is lower so survey taken through that channel
42.709	1.239			
42.796	0.854			under Twin Cities bridge in right-hand channel

Appendix V. Cosumnes River cross-section data (NGVD29)

site no.: 1	distance: 0 km	2	0.83 km	3	1.46 km
Distance from left bank (m)	**Elevation (m)**	**Distance from left bank (m)**	**Elevation (m)**	**Distance from left bank (m)**	**Elevation (m)**
0	38.177	0	36.267	0	40.477
2.9	37.887	1.65	36.052	0.77	40.527
2.6	37.517	3.74	35.047	4.5	36.302
3.1	36.012	6.1	33.697	4.8	35.342
4.85	34.737	8.7	33.177	5.2	32.792
6.7	34.072	9.95	32.922	6.25	32.637
9.45	33.757	11.88	32.727	8	32.932
12.12	33.612	13.25	32.652	11.66	32.522
16	33.487	14.84	32.597	15.78	32.337
19.5	33.557	16.88	32.512	18.56	32.312
23.2	33.697	18.62	32.542	23	32.267
27.4	34.072	20	32.662	27.52	32.297
31	34.347	21.31	32.787	31.75	32.412
34	34.517	22.9	32.877	36	32.547
39.5	34.797	29.22	33.247	40	32.627
44	35.002	37.74	33.142	44	32.757
47.5	35.107	45.32	33.852	49	32.852
52.5	35.267	51.06	34.097	53.7	32.857
56.8	35.267	56.16	34.482	57.83	32.982
62.7	35.327	64.57	34.452	60.05	33.462
67.6	35.367	70.41	34.247	61.1	33.547
73	35.542	72.78	34.337	64.75	34.487
78.5	35.692	74.94	34.377	66.85	34.982
84	35.912	75.55	34.572	71	36.632
87.5	36.152	77.1	34.682	71.39	36.952
89.3	36.342	78.53	34.637	72.95	38.387
93	36.467	79.01	34.482	74.5	40.367
97.5	36.417	84.32	34.512		
100	36.497	90.57	34.442		
105.6	36.437	96.39	34.372		
110.6	36.432	97.7	33.812		
116.1	36.417	98.49	33.672		
123.9	35.912	98.67	33.277		
129.9	35.687	99.1	34.477		
133.6	35.517	100.14	34.842		
138	35.562	101.35	35.327		
143.6	36.567	104.27	35.627		
148.6	36.072	106.31	35.937		
149.6	35.962	114.86	38.017		
150.1	35.892	116.46	38.342		
152.4	35.647	118.57	38.137		
157.9	36.447				
163.1	38.292				

4	**2.23 km**
Distance from left bank (m)	**Elevation (m)**
0	37.45
1.4	37.17
4	36.235
5	35.945
6.5	35.375
7.5	34.495
8	33.52
9	32.905
10	32.41
10.9	32.2
14.2	32.165
19	32.45
23.7	32.2
29.5	32.16
33	32.13
39	32.155
41.05	32.1
44.4	31.935
47	31.78
49.7	31.67
53.3	31.495
59.5	31.21
63.45	31.45
65	31.575
67.65	32.04
68.2	32.44
69.05	33.07
70	33.715
72.05	34.38
74.2	34.685
76.1	35.58
77.8	36.37
79	36.46

5	**2.36 km**
Distance from left bank (m)	**Elevation (m)**
0	36.486
1.3	36.006
3.2	35.291
8.53	35.371
9.4	34.576
10.2	34.261
11.64	34.536
12.5	34.181
13.74	33.726
15.26	33.151
19.4	32.711
20.45	32.191
21.9	31.741
23.2	31.721
25.16	31.851
27.33	31.831
29.1	31.811
31.4	31.811
34.25	31.811
37.45	31.781
39.5	31.801
41.9	31.881
45.35	32.076
48.75	32.141
52.65	32.186
56.1	32.221
59.75	32.291
62.65	32.231
66.1	32.046
68.1	32.456
70.05	32.866
71.85	33.471
73.35	34.076
74.35	34.776
76.85	35.896
78.85	36.326

6	**3.10 km**
Distance from left bank (m)	**Elevation (m)**
0	36.082
3	35.947
6.7	35.532
9.4	35.282
10.5	34.817
12	34.242
15.5	33.707
21	33.562
24.1	33.317
28.8	32.417
30.6	32.282
35.35	31.737
36.8	31.837
39.5	31.547
42.3	31.582
46.55	31.057
49.9	30.877
52	30.737
55.33	30.462
59.5	30.167
64.45	30.002
69	29.737
72.65	29.532
75.5	29.527
78.55	29.887
80.05	30.637
81.25	31.497
82.75	32.432
84.17	33.282
85.9	34.082
87.75	34.347
89.29	34.477
90.93	35.002
93.47	35.257
94.1	35.387

7 3.73 km

Distance from left bank (m)	Elevation (m)
0	36.88
0.65	36.65
1.9	36.08
4.15	35.36
7	34.335
9	33.34
10.4	32.56
13.6	32.045
17.8	31.64
19.2	31.355
21.85	31.11
23.9	30.54
26.6	30.44
29.3	30.395
31.8	30.375
34.55	30.385
37.15	30.355
39.5	30.38
42.15	30.34
44.9	30.3
47.85	30.345
49.25	30.31
50.7	30.405
52.85	30.26
55.5	30.23
57.9	30.21
60.7	30.185
62.9	30.11
65.25	30.07
67.45	30.05
69.95	30.42
72.15	31.015
74.55	31.565
77.6	32.24
79.49	32.83
82.75	33.855
84.9	34.77
86.45	35.79
86.85	36.3
87.8	36.1

8 4.63 km

Distance from left bank (m)	Elevation (m)
0	35.033
0.65	35.198
1.44	35.028
4.5	34.068
6.2	33.748
7.15	33.238
9.8	32.413
12.75	31.418
15.3	31.028
16.85	30.848
20.1	29.873
26.45	29.593
28.7	29.508
31.5	29.493
32.8	29.553
40	29.793
48.25	29.863
56	29.783
59.53	29.583
62.55	29.503
64.95	29.363
68.25	29.283
72	29.333
74.75	31.103
79.8	33.763
83.5	35.218

9 5.39 km

Distance from left bank (m)	Elevation (m)
0	37.418
1	37.218
1.75	36.138
3.65	34.938
4.85	34.188
5.45	33.933
6.35	33.443
7.25	32.878
8.45	32.113
10.3	31.178
13.4	30.623
15.55	30.738
18.5	31.208
24.65	31.428
34.7	31.218
44	30.938
52.8	30.598
59	29.498
67	28.973
73.6	28.573
80.7	28.313
83.8	28.233
88	28.288
91.8	28.518
93.4	29.058
93.55	29.293
95.7	29.753
98.1	30.348
100	31.018
102.5	31.328
106.4	31.533
109.3	31.268
112.2	32.018
114	32.753
115.3	33.373
117	33.518

10	5.96 km
Distance from left bank (m)	Elevation (m)
84.5	36.468
83.8	36.278
81.65	35.283
81.05	35.098
79.31	34.708
78.5	34.268
77.8	33.608
76.88	33.088
75.98	32.568
74.85	32.003
74.05	31.673
70.7	30.318
69.1	30.073
67.05	30.033
64.8	29.638
63.3	29.818
61.45	29.538
59.6	29.313
57.25	29.078
53.5	28.938
50.5	28.848
46.68	28.738
45.1	28.523
42.95	28.288
40.1	28.188
37.25	28.098
36.2	27.708
34.87	27.928
33.95	27.998
33.2	28.073
30.7	28.108
28.2	28.193
25.8	28.263
23.5	28.353
22	28.358
16.9	28.303
13.7	28.173
12.65	27.913
11.5	27.558
10.65	27.378
9.5	27.403
8.5	27.473
7.6	27.443
6.75	27.718

10 continued	
Distance from left bank (m)	Elevation (m)
5.65	27.923
5.2	28.013
4.1	28.803
2.1	33.918
0	34.603

11	7.36 km
Distance from left bank (m)	Elevation (m)
0	32.385
1.83	32.095
2.56	31.105
3.85	30.47
5.1	29.235
8.35	29.275
11.1	30.06
12.65	30.215
14.55	30.32
16.9	30.45
18.75	30.575
20.87	30.62
22.6	30.825
23.6	30.72
24.8	30.385
26.85	30.405
28.45	30.335
32.54	30.24
36	30.15
41	29.615
44	29.67
47.3	29.41
49.4	29.48
51.1	29.6
53.9	29.455
57.75	29.11
62.4	27.155
64.85	26.865
67.9	26.8
70.3	26.63
71.4	26.615
75.75	26.7
79.15	26.54
84	26.395
86.7	26.24
88.5	26.18
91.65	26.15
93.95	26.395
94.75	26.67
96.2	27.27
97.1	27.73
97.6	30.03
100.6	31.33
100.6	34.33

11 continued		12	8.50 km	13	9.16 km
Distance from left bank (m)	**Elevation (m)**	**Distance from left bank (m)**	**Elevation (m)**	**Distance from left bank (m)**	**Elevation (m)**
101.6	34.33	70.8	36.01	-1	33.605
		58.42	26.01	0	33.605
		57.85	25.995	2	29.605
		56.6	26.215	3.51	28.525
		53.8	26.35	4.59	28.265
		52	26.415	5.4	27.71
		48.6	26.525	7.25	27.1
		46	26.585	10.4	27.03
		43.38	26.43	12.6	26.69
		42.2	26.415	15.6	26.595
		39	26.22	19.45	26.62
		33	26.11	25.92	26.305
		32.8	25.975	30.5	26.13
		31.4	25.905	33.6	26.125
		29.1	25.78	36.2	26.18
		27.7	25.705	39	26.315
		24.45	25.725	42	26.335
		22.15	25.835	43.89	26.35
		19.75	25.895	45.9	26.29
		17.6	25.865	47.79	26.21
		16.5	25.875	49.8	26.07
		15.2	26.205	51.9	25.91
		14.5	26.505	53.75	25.805
		13.75	26.605	55.15	25.47
		12.9	26.83	56.55	25.625
		11.9	27.175	60.9	25.385
		11.1	27.655	62.1	25.305
		9.53	27.815	63.8	25.23
		8.8	28.04	65.45	25.4
		8.1	28.445	66.8	25.635
		7.2	28.78	67.9	26.085
		6.1	29.4	69	26.88
		5.7	29.89	69.85	27.5
		4.75	30.505	70.9	28.125
		4	30.935	71.84	28.55
		3.4	31.285	75	28.915
		2.6	31.775	76.51	29.225
		2.1	32.175	77.71	29.49
		1.5	32.53	78.91	29.99
		0	32.675	80.51	30.725
				82.03	31.705
				83.16	32.165
				84.11	32.63
				84.86	32.79

14	10.75 km
Distance from left bank (m)	**Elevation (m)**
0	33.04
1.25	32.77
2.63	32.07
3.68	31.41
4.9	30.455
6.25	29.815
7.8	29.125
9.1	28.585
12.5	27.445
14.45	26.69
15.55	26.34
17.2	25.44
17.8	24.705
18.45	24.095
20.1	23.705
23.5	23.755
27.65	23.71
32.4	23.71
35.15	23.87
38.25	23.875
40.6	24.02
42.8	24.1
45.3	24.145
48.07	24.065
52	24.165
57.1	24.12
59.5	24.03
60.7	24.015
67	33.015

15	11.53 km
Distance from left bank (m)	**Elevation (m)**
0	29.275
8.9	26.745
10	26.28
11.15	25.94
12.8	24.87
15.35	23.9
16.55	23.76
18.2	23.69
19.9	23.58
21.1	23.475
22.9	23.47
24.65	23.44
26.65	23.45
28.95	23.685
32.6	23.9
37	23.99
40	24.06
44.4	24.15
48.8	24.115
53	24.255
56.15	24.225
59	24.55
62.15	24.415
63.5	24.955
64.5	25.01
67.5	25.065
69	25.36
69.55	25.62
70.8	25.56
71.7	25.98
72.05	26.435
73.5	26.825
75.35	27.47
76.55	28.105
77.4	28.67
78.8	29.425
79.4	29.975
80.3	30.165

16	14.33 km
Distance from left bank (m)	**Elevation (m)**
0	30.209
1	30.209
6.25	22.709
7.15	22.104
9.15	20.584
10.15	20.439
14.5	21.244
17	21.169
19.25	21.344
26.25	21.674
33.45	22.049
35.3	22.114
39.95	22.459
44	22.714
46.75	22.879
48.5	23.069
50.25	23.014
51.9	23.519
53.3	24.309
57.5	29.014
58.5	29.014

17 15.60 km

Distance from left bank (m)	Elevation (m)
0	28.918
2.22	28.273
2.95	27.493
4.2	26.858
4.7	26.083
6.1	25.583
7.3	25.628
9.35	24.543
10.85	23.313
13.2	22.578
14.75	22.078
15.9	21.443
18.4	20.808
21.05	20.743
22.8	21.073
23.35	20.933
24.1	20.903
24.85	20.493
26.1	20.298
27.25	19.883
29	19.948
30.5	20.208
32.05	20.378
33.25	20.488
36.25	20.658
41.1	21.178
44	21.718
47.95	22.273
51.1	22.678
52.9	22.568
56.3	22.703
58	22.578
60.9	22.768
62.9	23.628
64.55	24.648
66.3	25.368
68.35	25.283
71	24.998
74.5	25.148
77.7	25.838
79.5	26.458
81.45	26.868
83.95	27.353
85.6	27.743

17 continued

Distance from left bank (m)	Elevation (m)
86.4	28.368
87.2	28.843
87.9	28.838

18 16.69 km

Distance from left bank (m)	Elevation (m)
0	27.928
2	27.508
2.95	26.988
6	26.288
9.1	26.133
14.5	25.333
17.55	25.063
22.25	24.358
26.35	24.123
26.9	23.653
34.35	23.198
40.05	23.388
42.7	23.403
43.75	23.013
46.05	22.648
48.1	21.883
50.7	21.303
56.1	21.153
61.4	20.993
66.55	20.703
71.4	20.413
75	20.273
77.85	20.273
82.55	20.408
88.6	20.448
91.69	20.303
93.45	20.828
96.25	21.053
99.05	21.378
103.44	28.678
104.44	28.678

19	17.70 km
Distance from left bank (m)	Elevation (m)
0	24.855
1.8	24.325
4.7	20.535
5.6	20.01
6.55	19.885
8.3	19.79
9.8	19.825
11.3	19.86
14.25	19.88
16.15	19.91
18.6	20.06
20.9	20.14
23	20.13
26	20.06
29	20.14
33	20.18
35.6	20.235
38	20.285
41	20.375
44.4	20.36
47.8	20.12
51.6	20.025
52.5	19.985
53	19.935
53.9	20.04
56.3	20.585
58	21.08
58.7	21.185
60.1	21.755
61.7	22.67
63.1	24.11
64.25	24.76
65.05	25.25
65.35	25.69
65.85	25.79

20	19.37 km
Distance from left bank (m)	Elevation (m)
0	25.417
0.2	25.417
1.2	24.422
2.6	23.537
3	23.107
5	21.927
8	20.362
10	19.537
11.4	18.602
12.9	18.047
16	17.412
20.9	17.547
24.3	17.752
27.5	17.902
29.7	18.092
33.5	18.282
36.95	18.287
38	18.332
39	18.547
39.8	18.792
40.1	19.412
41.4	19.682
42	19.967
42.7	20.412
43.2	21.332
43.4	21.637
44	21.782
44.7	21.947
45.55	22.237

21	20.89 km
Distance from left bank (m)	Elevation (m)
0	24.386
1.05	24.136
2.5	23.291
4.3	21.731
5	21.486
5.65	20.926
10.9	18.326
14.6	17.146
15.8	16.676
17.1	16.446
18.5	16.226
20	16.326
21.8	16.356
23.6	16.286
24.7	16.401
26.1	16.376
27.4	16.476
28.8	16.456
30	16.471
31.5	16.596
32.6	16.781
34.4	17.086
35.8	17.026
36.3	17.336
37.8	17.766
39.3	17.916
40.3	18.106
41.2	18.756
42.3	19.166
43.4	19.706
44.6	20.691
45.5	21.396
46.8	22.241
47.3	22.471
47.85	22.676
48.55	22.946

22 21.77 km

Distance from left bank (m)	Elevation (m)
0	23.141
2.6	22.066
3.7	21.221
5.7	20.111
6.5	19.391
7	18.491
9.7	17.536
10.5	16.771
11.4	16.461
13.05	16.161
15.5	16.226
19.1	16.236
21.6	16.001
23.3	15.876
24.85	15.746
25.7	15.686
27.8	15.646
29.5	15.696
31.35	15.686
33.5	15.786
35.1	15.801
36.3	15.976
37.05	16.426
39.05	17.466
42.1	19.886
44.4	21.546
45	21.656

23 22.51 km

Distance from left bank (m)	Elevation (m)
0	23.457
2	22.382
3.3	21.697
5.35	20.827
6.65	20.442
8.25	20.222
9.85	19.832
11	17.932
12.5	16.832
14.4	16.382
17.4	16.192
19	15.927
20.2	15.832
22.1	15.942
23.7	16.012
25.9	15.987
28.2	15.862
30.35	15.657
32.3	15.542
34.2	15.457
36	15.397
37.7	15.312
39.3	15.202
41.9	15.157
42.9	15.122
44.5	15.102
45.2	15.262
45.4	15.662
46.6	16.942
46.95	17.222
47.25	17.892
47.7	18.327
48	18.677
48.3	18.777
49	21.777

24 23.44 km

Distance from left bank (m)	Elevation (m)
0	21.63
0.6	21.535
0.9	20.35
1.75	19.525
2.2	19.015
3.5	17.905
6.6	16.765
8.6	15.48
10	15.385
11.5	15.43
13.65	15.56
16.6	15.78
20.05	15.665
23	15.345
26	15.045
29.3	14.86
31.8	14.785
33.3	14.66
34.1	14.575
35.5	14.625
37.45	14.635
39.3	14.66
40.95	14.705
41.7	14.825
42.25	15.12
42.95	15.635
44.5	16.205
47.3	17.31
47.8	18.35
49.45	19.27
51	20.375
52.4	21.025
53.3	21.515

25 24.19 km

Distance from left bank (m)	Elevation (m)
0	20.23
0.8	20.11
1.9	18.99
3.1	18.075
4.6	17.285
5.7	16.375
7	15.775
8	15.155
11.5	14.86
14.85	14.64
18.45	14.565
23	14.565
26.6	14.55
27.95	14.405
29	14.08
30.55	13.59
31.85	13.305
33.25	12.865
35	13.785
36.4	13.9
37	14.44
37.85	15.35
38.7	15.95
40	16.78
41.7	18.34
42	18.815
42.5	19.15
43.15	19.845
43.7	20.165
44	20.455
44.7	20.705
45.1	20.805

26 25.38 km

Distance from left bank (m)	Elevation (m)
0	19.787
1.3	18.792
1.9	18.602
2	17.982
2.75	17.612
3.8	17.417
4.4	17.487
5	17.167
5.8	16.842
6.5	16.567
7.6	16.387
8.1	16.067
8.8	15.912
9.1	15.647
10.3	14.977
10.6	14.887
11.5	14.272
12.7	14.027
13.6	13.842
14	13.247
16.2	13.077
18	13.097
18.7	13.007
21.3	12.742
23.2	12.457
24.95	12.207
26.3	12.012
27	12.217
27.8	12.317
28.95	12.502
30.4	12.627
31.8	12.737
32.4	12.872
32.85	13.422
34.3	14.067
34.6	14.477
36.2	15.182
36.75	15.727
37.65	16.457
38.5	17.562
39.5	17.927
40.15	18.622
40.8	19.067
41.05	19.647

26 continued

Distance from left bank (m)	Elevation (m)
41.5	19.802

27	**26.84 km**
Distance from left bank (m)	**Elevation (m)**
0	19.147
0.7	19.097
0.7	18.427
1	18.112
2	16.152
3.1	15.597
4.25	15.082
5.2	14.427
5.5	14.407
5.9	14.007
6.3	13.832
7.1	12.907
8.5	12.597
10.15	12.217
10.4	12.102
11.55	12.097
12.85	12.182
14.4	12.202
16.6	12.127
18.1	12.137
18.9	12.127
20.45	12.052
22.05	12.067
24.1	11.887
24.65	11.707
26.1	11.537
27.1	11.677
28	11.667
29.1	11.652
30.1	11.757
30.8	11.772
31.8	11.962
33	12.112
42.9	20.112

28	**27.88 km**
Distance from left bank (m)	**Elevation (m)**
0	17.507
1	17.507
1.3	16.612
1.6	16.417
1.6	16.147
2.4	15.532
2.6	15.267
3.2	15.107
3.4	14.302
5.5	14.032
6.2	13.532
6.4	12.797
6.8	12.282
7.55	11.767
8.5	11.457
9.15	11.417
10.2	11.452
10.7	11.467
11.3	11.392
12.6	11.337
14	11.372
15	11.392
17.75	11.297
18.87	11.182
20.1	11.017
21.3	10.902
22	10.857
23.1	10.837
24.4	10.797
25.4	10.737
26.45	10.727
27.3	10.802
28	10.857
28.5	10.957
29.1	11.022
29.7	11.142
30.25	11.372
31	11.677
32.5	12.117
33.6	13.142
35.5	15.087
38.9	16.582
39.7	17.407
40.1	17.692

28 continued	
Distance from left bank (m)	**Elevation (m)**
40.5	17.717

29	29.78 km
Distance from left bank (m)	**Elevation (m)**
0	16.345
2	15.325
3	14.785
4.5	13.78
5.65	13.125
7	12.505
8.4	11.625
9.05	11.275
9.5	10.555
10.45	9.99
12.2	9.82
13.5	9.71
14.5	9.825
15.65	9.62
16.1	9.495
17.3	9.43
18	9.34
19.1	9.32
20.7	9.33
21.75	9.4
22.65	9.5
23.8	9.71
24.8	9.92
25.85	10.16
27.3	10.5
29.1	10.61
31.4	10.67
34.25	10.7
37.3	10.67
40.3	10.62
42.3	10.52
43.6	10.44
44.8	10.33
45.7	10.1
46.9	9.95
47.95	9.985
48.6	10.34
49.1	10.76
49.5	11.17
50.45	11.02
51.2	11.16
51.6	11.63
52.3	13.045
53	13.24

29 continued	
Distance from left bank (m)	**Elevation (m)**
53.7	13.42
54.3	13.71
54.7	13.83
55.15	14.57
55.55	15.315
56.15	15.42

31	31.83 km
Distance from left bank (m)	**Elevation (m)**
0	13.655
0.5	13.575
0.9	13.34
1.6	12.335
2.2	11.715
3	11.38
3.8	10.84
3.85	10.15
5.75	9.495
6.9	8.9
7.7	8.54
8.2	8.26
9.65	8.16
11.6	8.145
13.6	8.19
14.6	8.2
15.6	8.19
16.6	8.255
18.4	8.3
19.5	8.31
20.5	8.225
21.75	8.11
22.5	8.02
23.65	7.83
24.5	7.75
25.9	7.71
26.95	7.74
27.5	7.81
28.3	7.805
29.4	7.795
30.2	7.97
30.6	8.315
31.3	8.765
31.9	9.29
32.1	9.55
32.7	9.99
34.1	10.4
34.55	10.77
35.45	12.03
36.6	13.38
37.35	13.94
37.8	14.19
38.4	14.33
38.6	14.51

31 continued

Distance from left bank (m)	Elevation (m)
39.15	14.565

Appendix VI. Cross-section descriptions

Site	Distance downstream* (km)	Orientation (degrees from North)	Description	Leveed banks**
1	0	324	Cross-section is located 0.9 km downstream of Hwy 16 bridge across the center of a right-bank cobble point bar. The cobbles are imbricated. The left bank is oversteepened at the boundary between developed soil above and sand and gravel paleochannel deposits below. The left bank is actively eroding. Willows line the right bank. The cross-section is located approximately 0.4 km upstream of access at grassy drive to Schneider pump 0.7 mile from start of drive at Highway 16 (marked by driving auto).	none
2	0.75	350	Cross-section is located across the center of a right-bank cobble alternate bar. The cobbles are imbricated. The left bank is composed of sand to cobbles and is currently eroding. The right bank is lined by willows. The cross-section is located approximately 0.4 km downstream of access at Schneider pump.	none
3	1.5	015	Cross-section is located across small left-bank cobble/gravel mid-channel bar and larger right-bank alternate bar. Drive past house turning left before second cattle guard and follow drive around pond. After coming through the aluminum gate on the top of the left bank, procede about 10 m upstream along the channel-side of the fence to find the left-bank pin. The banks are high, steep, and actively widening. The bank materials are clay, silt, and fine sand with a 0.5 m layer of gravel at the top. Large trees are growing at the tops of both banks. Evidence of recent bank failure exists on both banks approximately 10 m downstream of section.	none
4	2.23	022	Cross-section is located across a left-bank sandy gravel bar. The reach is generally deeper than upstream with a sandy channel floor. Cobbles and gravel line the banks. The bank materials are silty sands with minor gravels. Gravel is eroding out of silty deposits on the left bank. Both banks are lined with trees. To access site, drive through aluminum gate and along right edge of field for a total of 1 mile past the Schneider home. Cross barbed-wire fence to river.	none

5	2.35	005	Cross-section is located across right-bank cobble alternate bar just downstream of cross-section 4. The sections are closely spaced to document the abrupt change in grain size between the two adjacent bars. The right bank pin is located in an opening in the trees that line the channel. The banks here are lower than upstream and are composed of silty sand.	none
6	3.1	315	Cross-section is located across a left-bank cobble alternate bar about 0.9 km downstream of last access on Schneider property. Areas of higher elevation on the bar are vegetated with sand deposits developing around the vegetation. The reach is generally wide. The right bank is currently eroding sand and gravel materials.	none
7	3.73	none taken	Cross-section is located across depression on left-bank alternate gravel/cobble bar about 1.5 km downstream of last access on Schneider property. The left bank is rip rapped with some recent sand deposits on top of the basal rip rap. The right bank is eroding, and the bank materials are sand and gravel. The reach is wide.	left
8	4.63	030	Cross-section is located across left-bank alternate cobble bar. The bar is approximately 2.6 km upstream of Dillard Road bridge. The bar has some vegetation and very little sand deposited on its surface. The left bank is has rip rap at the base and partway up the slope. The right bank is leveed and covered with dense willow trees.	left
9	5.39	090	Cross-section is located across a left-bank cobble point bar just downstream of two flow pipes dumping water from a right-bank local source. Nutrients from the waste are causing algal growth. The cross-section is approximately 1.8 km upstream of Dillard Road bridge. The left bank is a scarp with sandy bank material. The right bank is heavily vegetated and the bank slope is more gradual. The right bank pin is located through a clearing in the trees that line the channel.	left
10	5.96	040	Cross-section is located across mid-channel cobble bar and right-bank lobe of gravel point bar. The mid-channel bar is imbricated, and the sample was taken here. The cross-section is approximately 1.3 km upstream of Dillard Road bridge. The right-bank pin is located in a brushy clearing between trees at the top of the levee. The left-bank pin is above a steep section of bank composed mainly of sand. The bank materials are mostly sand with some gravel.	none

11	7.36	005	Cross-section is located across a left-bank gravel lobe of a sandy point bar approximately 200 m downstream of Dillard Road bridge. The section reoccupies USGS section 106 in OFR 98-283. The right bank is a steep cutbank into silty floodplain deposits. The section is located across a bare area of the right-bank slope. The reach is wide, and the channel is wide and shallow.	left, right
12	8.5	316	Cross-section is located across a mid-channel gravel and cobble bar. The right bank is rip rapped, leveed, and steep. The left bank is eroding, and the material is sand. The left-bank pin is located just upstream of a gulley forming on the slope. The cross-section is located at USGS section 104 in OFR 98-283.	right
13	9.16	335	Cross-section is located across a left-bank gravel alternate bar and mid-channel bar. The sample was taken on the alternate bar. The left bank is steep and mass wasting, and its materials are silt and sand. The right bank is leveed and densely vegetated by willows. Cattle from a nearby ranch enter the channel here on the left bank.	right
14	10.75	315	Cross-section is located across a left-bank gravel alternate bar and mid-channel bar. The left bank is steep and mass wasting, and its materials are silt and sand. The right bank is a densely vegetated and leveed. Access from right-bank levee.	right
15	11.53	300	Cross-section is located across the middle of a right-bank gravel alternate bar. The left bank is clear cut and the slope has been damaged by tractors. Sand from the bank has been dumped into the river here. The right bank is also sandy. The right-bank levee is set back from the channel. The lower left bank is rip rapped. The cross-section nearly reoccupies USGS section 98 in OFR 98-283.	right
16	14.33	295	Cross-section is located across a right-bank gravel alternate bar. The reach is narrow and the channel very deep at the left bank where duripan outcrops. The banks are extremely steep (55 degrees), and the right bank is heavily vegetated . The cross-section is located 0.18 mile (marked by auto driven on the levee road) upstream of the aquaduct. There is a tree on the west side of the levee at this location.	right

17	15.6	355	Cross-section is located across a right-bank gravel point bar. The river makes a sharp right-hand turn here where the left edge is forced against cohesive duripan. The right-bank material is sand. The cross-section is located approximately 20 m downstream of a large dead tree at the top of the left bank and next to the upstream end of a fence line. Access from cement diversion dam 0.2 mile south of aquaduct on levee.	right
18	16.69	320	Cross-section is located across a left-bank gravel bar. The right bank is steep, and the material is sand. A small cobble bar is building at the base of the right bank. The left bank is more gradually sloping. The reach is generally wide with cobbles and gravel on the bed surface. The section is located about 1.1 miles downstream of the aquaduct (as marked by auto driving on the levee).	right
19	17.7	005	Cross-section is located across a mid-channel gravel bar. Much of the bar is vegetated with willow trees. The left bank is steep and lower than the right bank. The right-bank material is sand, while the left-bank material is silt. The reach is wide with many bars. The cross-section crosses the downstream end of a riffle. The section is located approximately 1.5 miles downstream of the aquaduct (as marked by auto driving on the levee).	right
20	19.37	315	Cross-section is located across a mid-channel gravel bar closer to the right bank. The reach is deep and narrow and incised into duripan. The left-bank material above the duripan is sand. The elevation of the top of the bar is low. The section is located approximately 2.7 miles downstream of the aquaduct (marked by auto driving on the levee).	left, right
21	20.89	320	Cross-section is located across a right-bank gravel alternate bar in a duripan reach. The channel is wide with a sand and gravel surface. The left bank is steep, and the material above the duripan is sand. Large woody debris is caught at its base. The right bank is duripan with silt above that. The section is located approximately 3.6 miles downstream of the aquaduct (marked by auto driving on the levee).	right
22	21.77	325	Cross-section is located across a left-bank gravel alternate bar in a duripan reach. The left bank is sandy above the duripan. The right bank is very steep with a duripan bench at its base.	left, right

23	22.5	005	Cross-section is located across a left-bank sand and gravel alternate bar. The left bank material is sand. The right bank is duripan, extremely steep and densely vegetated. There is a lot of large woody debris on the downstream end of the bar. The section closely reoccupies USGS section 75 from OFR 98-283.	left, right
24	23.44	015	Cross-section is located across a left-bank gravel bar in a wide reach just upstream of Wilton Road bridge. The left-bank material is sand beneath well-developed soil horizons. The right-bank material is silt. There is a large log in the center of the channel here.	none
25	24.19	240	Cross-section is located across a left-bank sandy bar. The left-bank material is sand, and the right-bank material duripan. There is a significant bench developed at the base of the right bank. The channel is narrow and deep. The section is located at USGS section 70 from OFR #98-283 but is at different orientation across bar.	left, right
26	25.38	020	Cross-section is located across a left-bank gravel alternate bar in a duripan reach. The left-bank material is duripan with overlying sand deposits. The top meter of the bank is rip rapped. The right-bank material is duripan at the base and sand above. Access from the Becker property. Last right-hand drive on Gay Road (off of Cosumnes Road south) before sharp left-hand turn.	right
27	26.84	265	Cross-section is located across a left-bank sandy gravel bar. The left-bank material is duripan. The right bank is rip rapped and covered with grape vines. Rip rap in the channel downstream may be influencing formation of the bar.	right
28	27.88	300	Cross-section is located across a left-bank gravel alternate bar in a duripan reach. Both banks are duripan and extremely steep. The right bank is bare while the top of the left bank is covered in vines and small trees. Access from Mosher Ranch. 10161 Grantline Road (east off of Hwy 99 south).	right
29	29.78	315	Cross-section is located across a right-bank gravel point bar. The right bank is silt and is bare and steep. The left bank is composed of sand and silt and is protected by rip rap on the top 1-2 m. There is a lot of large, woody debris in the channel. A long, straight duripan and silt reach ends here where the channel widens.	none

31	31.83	280	Cross-section is located across a left-bank gravel alternate bar just downstream of the Mahon access. The right bank is steep, and its material is silt. The left bank is composed of silt and sand. The channel is narrow. Mahon Ranch is 1.0 mile east on Grantline Road off of Hwy 99.	left
* As measured from the beginning of the profile				
** According to maps created by Vick et al. (1997) based on USGS quad sheets with revisions from The Nature Conservancy and Sacramento County				

Appendix VII. Bankfull estimates, width, depth, and thalweg and sample elevations

Site	Distance (km)	Reach type*	Bankfull elevation (m)	Bankfull width (m)	Area (m^2)	Average depth (m)	Width-depth ratio	Thalweg elevation (m)	Sample elevation (m)
1	0.00001	A	36.45	143.7	158.02	1.10	130.7	33.487	34.797
2	0.83	A	36.05	105.6	218.21	2.07	51.1	32.512	33.852
3	1.46	A	35.34	64.4	158.81	2.47	26.1	32.297	32.852
			36.63	67.6	242.41	3.59	18.9		
4	2.23	A	34.38	65.4	148.43	2.27	28.8	31.210	32.160
			35.38	69.3	215.35	3.11	22.3		
5	2.36	A	34.58	65.4	142.14	2.17	30.1	31.811	32.221
			35.37	73.6	194.74	2.65	27.8		
6	3.1	A	33.32	60.0	141.68	2.36	25.4	29.527	31.057
			34.24	75.2	205.07	2.73	27.6		
			35.28	84.3	287.81	3.41	24.7		
7	3.73	A	32.56	68.7	125.82	1.83	37.5	30.070	30.380
			33.34	72.2	180.52	2.50	28.9		
8	4.63	A	30.85	58.4	65.92	1.13	51.7	29.283	29.863
			32.41	68.0	164.76	2.42	28.1		
9	5.39	A	31.53	101.7	139.51	1.37	74.1	28.233	29.498
10	5.96	A	30.32	68.0	117.62	1.73	39.3	27.378	28.358
			31.67	71.4	211.13	2.96	24.1		
			33.09	74.4	314.46	4.23	17.6		
11	7.36	A	30.03	67.6	143.08	2.12	31.9	26.150	26.700
			30.47	87.8	176.24	2.01	43.7		
12	8.5	A	39.40	57.9	164.36	2.84	20.4	25.725	26.585
			39.89	59.3	192.18	3.24	18.3		
13	9.16	A	28.27	67.1	132.11	1.97	34.1	25.230	26.350
			28.53	68.6	149.65	2.18	31.4		
14	10.75	A	26.69	47.5	122.50	2.58	18.4	23.710	24.165
15	11.53	A	25.94	60.5	104.45	1.73	35.0	23.440	24.060
			26.44	62.9	134.96	2.15	29.3		
			26.75	64.8	154.57	2.39	27.2		
16	14.33	D	25.37	50.3	162.27	3.23	15.6	20.439	22.459
			26.97	52.8	243.46	4.61	11.5		
17	15.6	D	25.37	67.0	206.08	3.08	21.8	19.883	21.718
			25.63	71.3	223.83	3.14	22.7		
18	16.69	A	23.40	68.7	141.36	2.06	33.4	20.273	20.703
			24.12	74.9	193.94	2.59	28.9		
19	17.7	A	22.67	58.1	140.36	2.42	24.0	19.790	20.180
			24.11	60.6	226.58	3.74	16.2		
20	19.37	D	19.41	30.0	42.42	1.41	21.2	17.412	18.282
			21.64	38.0	119.40	3.14	12.1		
21	20.89	D	19.17	33.3	69.28	2.08	16.0	16.226	17.086
			21.49	41.0	155.56	3.79	10.8		
22	21.77	D	19.39	35.2	103.70	2.95	11.9	15.646	16.236
			20.11	36.7	129.48	3.53	10.4		

23	22.51	D	19.83	38.7	147.46	3.81	10.2	15.122	16.012
			20.83	43.5	188.47	4.33	10.0		
24	23.44	A	17.91	44.2	106.37	2.41	18.4	14.575	15.345
			18.35	45.0	126.15	2.80	16.1		
25	24.19	D	17.29	36.0	93.77	2.61	13.8	12.865	14.565
			18.99	40.5	159.09	3.93	10.3		
26	25.38	D	17.49	35.7	123.12	3.45	10.4	12.012	13.007
			18.60	38.6	164.59	4.26	9.1		
27	26.84	D	16.15	35.7	123.68	3.46	10.3	11.537	12.202
			18.11	39.5	197.31	5.00	7.9		
28	27.88	D	15.11	32.4	108.77	3.36	9.7	10.737	11.297
			16.42	37.1	154.50	4.16	8.9		
29	29.78	A	13.05	46.7	123.49	2.64	17.7	9.320	10.700
			13.83	50.6	161.53	3.19	15.9		
31	31.83	A	11.38	32.5	90.53	2.79	11.7	7.710	8.300
			13.34	36.4	157.30	4.32	8.4		
32	32.97	A	No cross-section surveys completed					7.138	no data
33	33.8	D						6.960	no data
34	34.32	D						6.956	7.351
35	35.29	D						6.476	6.951
36	36.48	A						5.431	5.961
37	37.48	A						5.188	5.818
38	39.17	D						4.538	5.163
39	40.26	A						2.438	3.463
40	41.88	A						0.583	0.803
*A and D represent alluvial and duripan reaches, respectively.									