

Sediment Flux Variation in Two Central Valley Rivers

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Abstract

Physical processes such as water and sediment movement exert strong influences on species and habitats in Central Valley streams and the Sacramento-San Joaquin Delta. In particular, accrual of sediment is critical to restoring ecological function to those areas that have previously been isolated from streams by levees. The present work quantifies the differences in flow and sediment flux regimes in the Cosumnes and Mokelumne Rivers, upstream of their confluence. The Cosumnes River is the last un-dammed river flowing into the Central Valley, whereas the Mokelumne River is highly regulated. Current and Sediment Flux Monitoring Stations (CSFMS) were constructed and deployed on each river. Each CSFMS recorded time-series measurements of current velocity, temperature, optical backscatter (a measure of suspended sediment concentration), water surface elevation and distance to the bed (a measure of bedload transport). The autonomous measurements were supplemented by both suspended and bottom sampling of the sediment and cross-channel depth profiling at the measurement sites. Using these data it has been possible to partition the sediment transport on each system between suspended sediment and bedload transport. Combining suspended and bedload transport provides a more realistic measure of the overall sediment flux.

Introduction

The Cosumnes River originates at an elevation of about 2,316 meters (7,600 ft) in the Sierra Nevada and flows westward to the Delta, Figure 1. The Cosumnes basin drains an area of 2,445 km² (944 mi²). It is tributary to the Mokelumne River approximately 32 kilometers (20 miles) upstream of that river's junction with the San Joaquin River. The San Joaquin then joins the Sacramento River after an additional 32 kilometers (20 miles).

There are no major storage reservoirs in the Cosumnes basin. The Cosumnes River is only slightly regulated by a small reservoir of 50-million cubic meters (40,570 acre-ft), and by small diversions for irrigation and domestic supply. The basin can be considered the best remaining representation of sediment supplies of the eastern basins of the San Joaquin Valley prior to extensive regulation.

The Mokelumne River basin is the next basin south of the Cosumnes River and is heavily regulated by Salt Springs Reservoir (1931), Pardee Reservoir (1929), and Camanche Reservoir (1963). The total drainage area is 1,927 km² (744 mi²). It also has other smaller diversion dams below Camanche Reservoir. The dams are regulated for flood control and hydropower production.

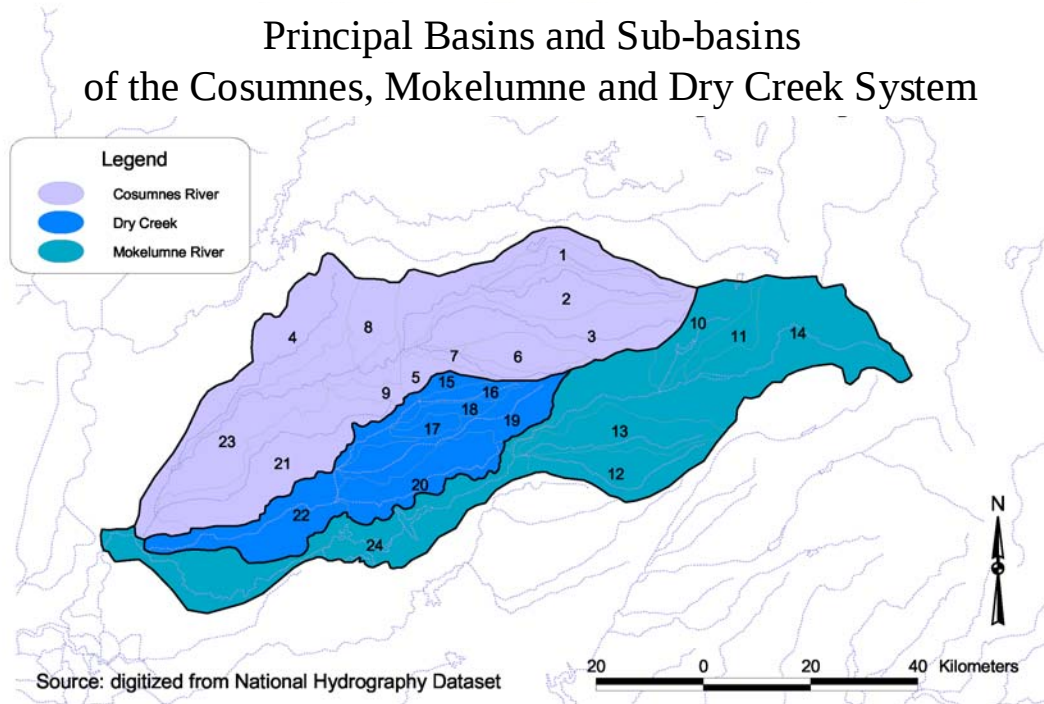


Figure 1 Relationship of the Cosumnes and Mokelumne River basins.

Historic sediment data were collected from 1957-1966 on both the Cosumnes and Mokelumne basins (Porterfield, 1980). For the Cosumnes basin the historical averaged daily stream-flow was most nearly approximated by the period of 1957-1959, so data from this period were used by Porterfield to estimate an averaged daily suspended-sediment load of 238.5 tons/day (mega-grams/day) at Michigan Bar and 442 tons/day at

McConnell. Porterfield also reported on how sensitive the sediment transport was to flow peaks. For the 1957-1966 period almost 60% of the sediment was transported by 25% of the water flows in 1% of the time period. A total of 97% of the sediment was transported over 15% of the time. No changes in sediment supply over the sampling period were apparent due to basin land-use changes, but only due to flow regime differences.



Figure 2 Important locations on the Cosumnes and Mokelumne basins.

On the Mokelumne River, Porterfield collected sediment samples 1-mile downstream of the Camanche Dam site. The sediment supply is greatly affected by the regulation and was further modified by the completion of Camanche Dam in 1963. While there were also some minor flow variations in the time period before and after the Camanche Dam completion, the sediment supply was nearly cut in half from 32 tons/day for the period of 1957-1959 to 16 tons/day for 1964-1966.

Methodology

Current and Sediment Flux Monitoring Stations (CSFMS) were installed in both the Cosumnes and Mokelumne river systems. Each CSFMS includes a Nortek EasyQ flow monitor supplemented with a D&A optical backscatter sensor. On the Cosumnes River, the CSFMS was mounted to the downstream side of the leading pier on the main channel at the Twin Cities Bridge. For the Mokelumne River, the CSFMS was mounted to the downstream side of the inside pier of a pump station approximately 150-meters below the New Hope Road bridge. Fifteen second averaged data were collected at 1-minute intervals to provide sufficient bottom sand wave information.

The CSFMS sends two acoustic beams horizontally across the channel to measure velocity in 3 cells, Figure 3. The cell sizes are user programmable so the best possible coverage of the channel can be provided. A 3rd acoustic beam points vertically to measure stage above the instrument, which is duplicated with a pressure sensor. The 4th acoustic beam points 45 degrees downward toward the streambed to measure changes in bed elevation (produced by sediment movement on the bed). An optical backscatter sensor by D & A is incorporated on an external analog port to obtain a measure of the suspended sediment concentration. The attached D&A optical backscatter sensor was calibrated against samples collected at each river location and analyzed for suspended sediment concentrations in the lab.

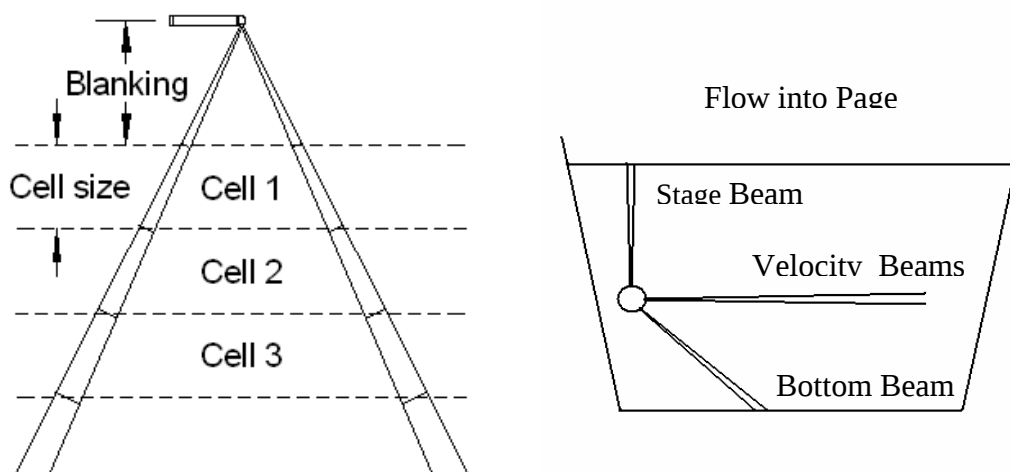


Figure 3 CSFMS schematic depicting acoustic beam to measure velocity, stage, and bottom elevation

A regression of these data was used together with flow data to determine total suspended sediment concentrations (TSS) for the year, Figure 4. Since years 2003 and 2004 provided higher flow and therefore higher TSS values, these data were incorporated into the regression for 2002. While it did not change the 2002 regression significantly, the justification for the use of the regression relationship for projections is strengthened. Suspended sediment flux was calculated from the relationship developed from the optical backscatter data, physical samples, and the calculated flow rates. The hysteresis typically found between the rising and falling limb of the hydrograph was found in the collected data and demonstrated in Figure 5.

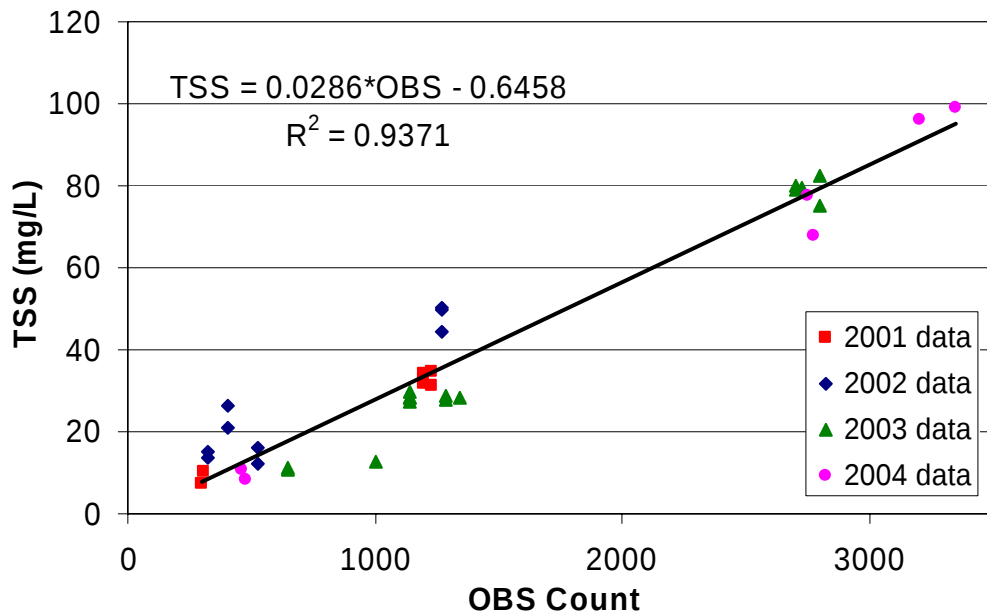


Figure 4 Regression of OBS output to measured TSS concentrations

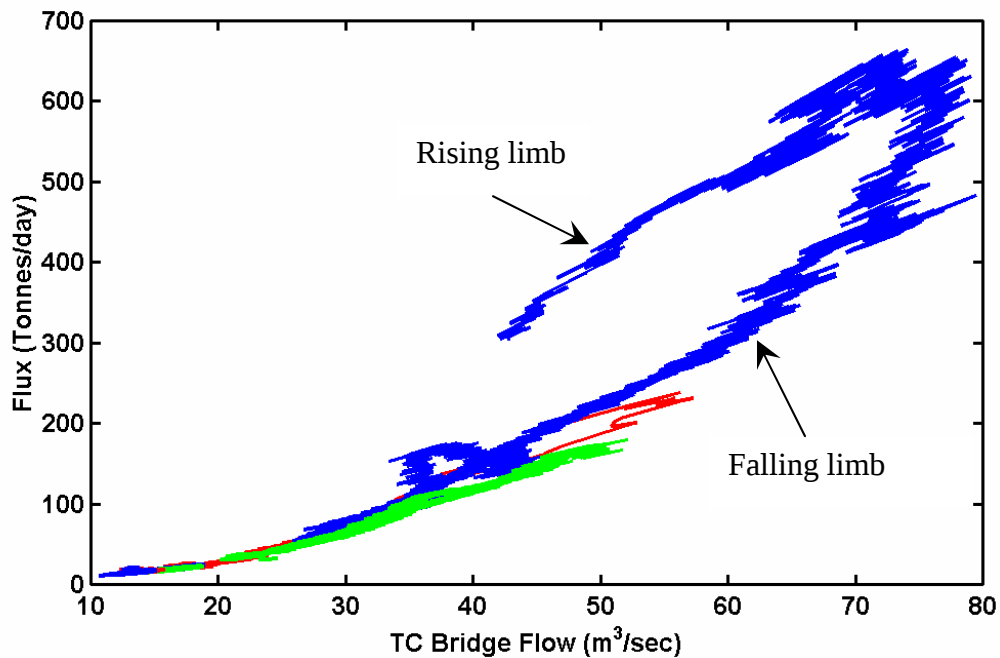


Figure 5 Hysteresis of sediment flux due to flow for 3 pulses in 2002.

Water Year 2002

The conditions under which data were collected during 2001-2002 (water year 2002) were not representative of the averaged daily flow measured since 1909 at Michigan Bar. The 2002 averaged daily flow at Michigan Bar was 7.8 m³/sec (275 cfs) versus 14.1 m³/sec (498 cfs) for the years 1909-2004. The difference is easily observed in Figure 6 depicting both maximum daily flow and total volume for each year and in Figure 7 showing the daily mean flows for 2002 along with the historical mean.

Flow rates were calculated at the CSFMS site on each river using an area-velocity relationship (see Appendix). Cosumnes River flow at Twin Cities Bridge (TCB) was calculated at magnitudes both above and below the reported gage values upstream at Michigan Bar, Figure 8. If all the flow remained in the river channel, the flow at TCB would typically be greater than that upstream at Michigan Bar due to input from additional drainage as the river flows downstream. Several conditions can exist to alter this occurrence. When flows are initiated in the fall of the year, the early flow is subject to infiltration into the ground, as the channel is re-wetted. At higher flows when channels spill, some water can be lost to over-bank spill and capture and not returned to the river

channel. On the Cosumnes, there is a bifurcation upstream of TCB and the secondary channel at the TCB location carries additional flow.

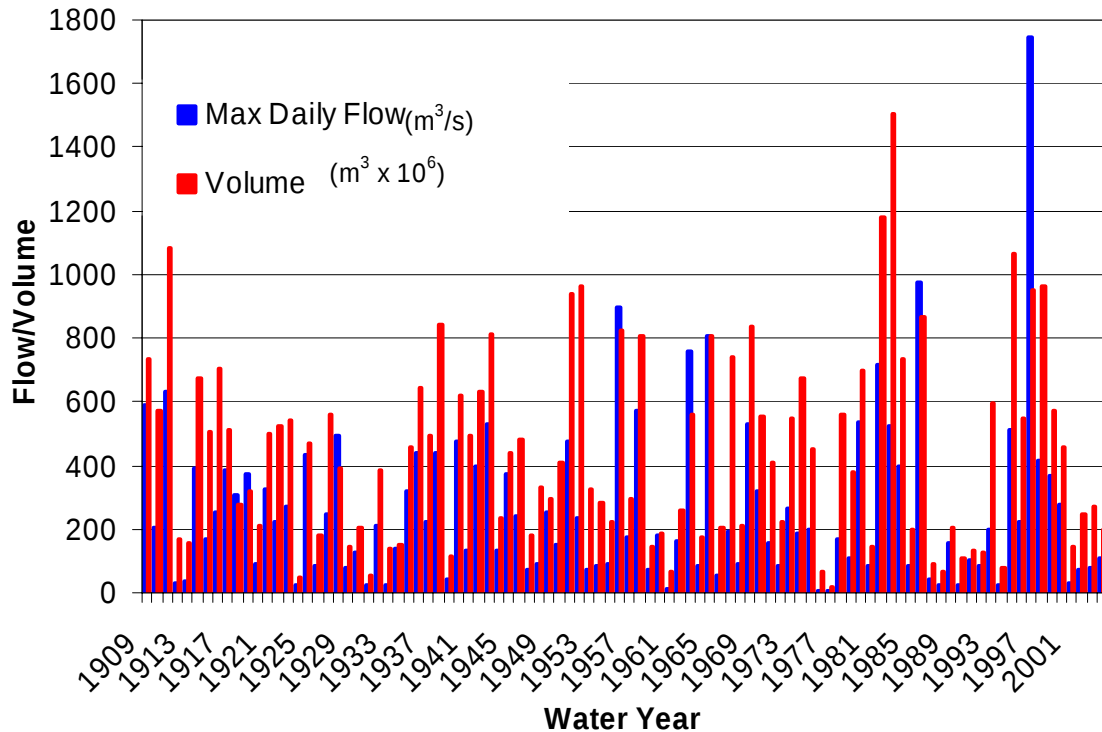


Figure 6 Historic maximum daily flows and annual flow volumes at Michigan Bar on the Cosumnes River.

Flow on the Mokelumne River demonstrated its tidal influence while holding true to the mean controlled release upstream, Figure 10. The stage on the Mokelumne demonstrated both the tidal signal from the bay and a backwater effect from the Cosumnes stage. The higher backwater periods significantly mitigate the tidal influence. Missing data is due to either water levels too low to measure, or equipment anomalies.

Water temperature for each river shows little difference except during spring snowmelt runoff periods that influence the Cosumnes River.

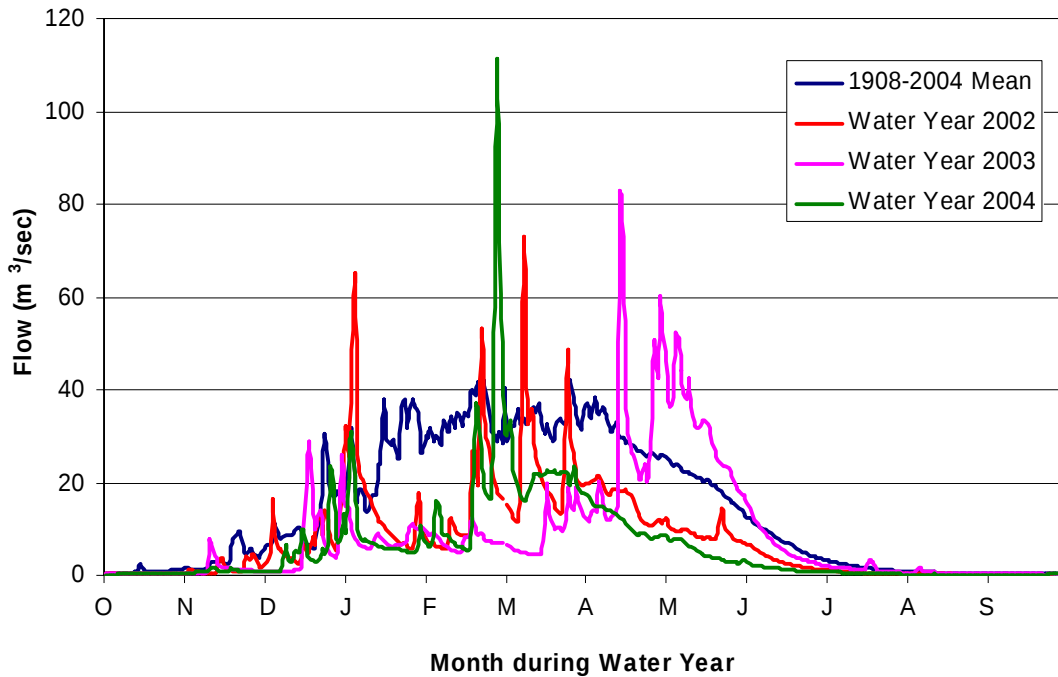


Figure 7 Averaged daily flows at Michigan Bar for water years 2002, 2003, and 2004 compared to mean for 1908-2004

The periodic signals from the bottom location measurement were used to estimate the quantity of bed-load sediment transport, Figure 9. Events were observed where a peak flow brought with it a large volume of bedload, which was deposited and then slowly eroded away. Other events have demonstrated an opposite pattern, eroding the bottom with the peak of the event and then slowly re-depositing sediment on the receding limb. Further measurements are needed to determine why events produce different effects, but the results are consistent with observations made by others (Dinehart, personal communication).

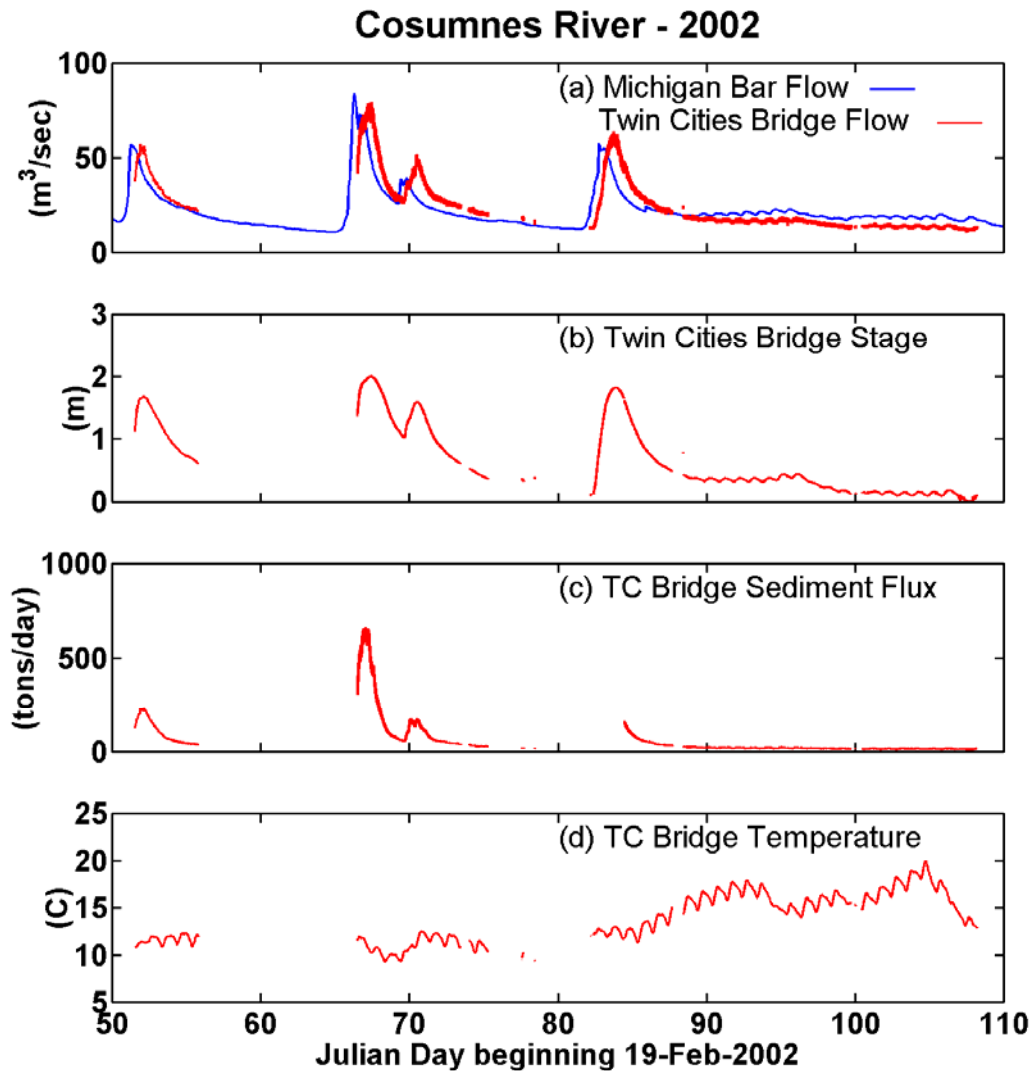


Figure 8 Cosumnes River Measurements

The 2002 water year on the Cosumnes River watershed produced a daily averaged flow at Michigan Bar of $7.8 \text{ m}^3/\text{sec}$ (277 cubic feet per second) and followed an even lower 2001 daily averaged flow of $4.6 \text{ m}^3/\text{sec}$ (161 cfs). The flow numbers compare to an average of $14.0 \text{ m}^3/\text{sec}$ (494 cfs) from 1909-59 and $14.4 \text{ m}^3/\text{sec}$ (508 cfs) from 1960-2002. Porterfield (1980) reported averaged daily suspended-sediment transport at Michigan Bar of 238 tons/day and at McConnell to be 442 tons/day. For 2002, applying the relationship calculated from the TCB data, there would be a total of 13 tons/day of suspended sediment transport. Applying the same relationship on 1959 flows at Michigan Bar would predict 184 tons/day versus the 238 tons/day reported by Porterfield

(1980). Since his reported data demonstrated that most of the mass transport was done under the largest discharges that did not occur during 2002, the shortfall is easily understood.

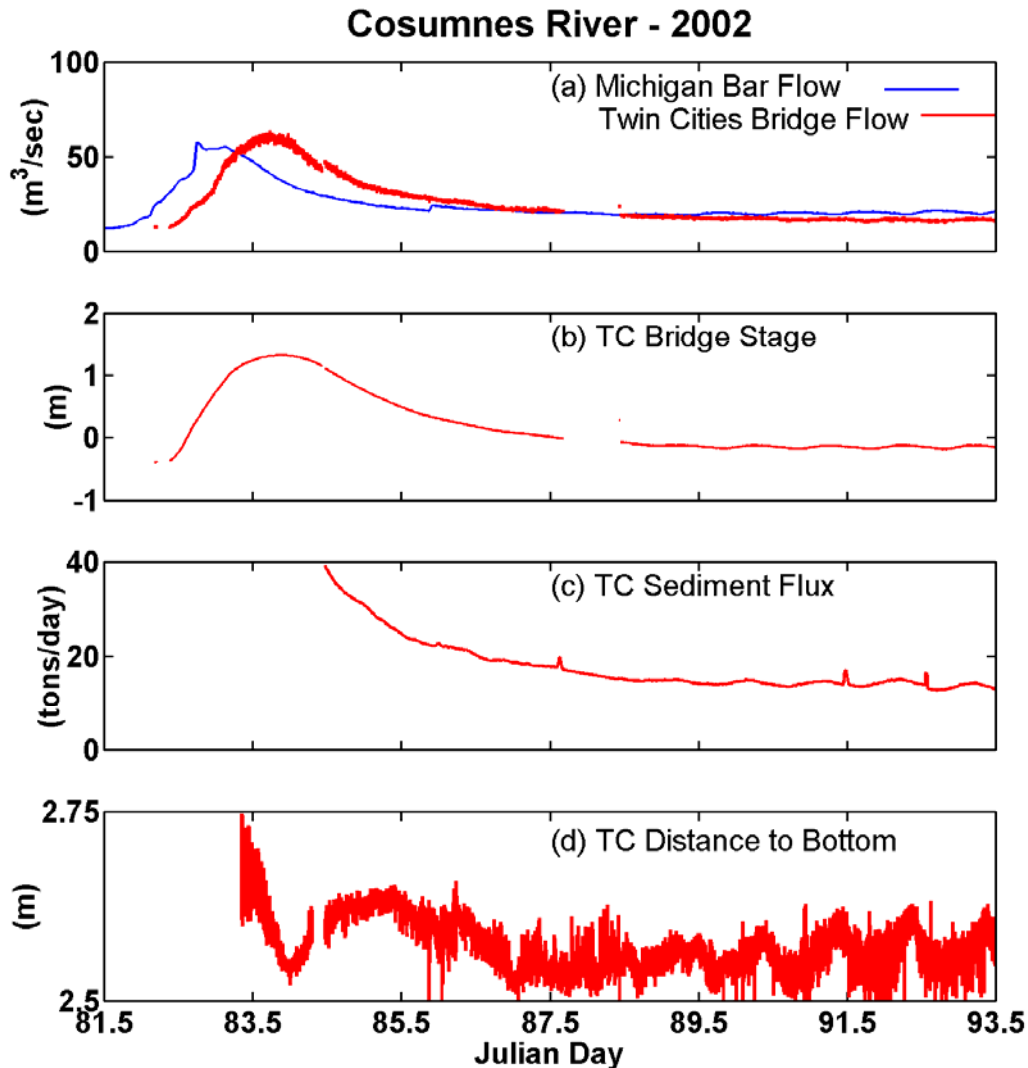


Figure 9 Bottom bedform wave movement over 12-day event

Bed-load transport for the Cosumnes River was calculated from the signals of the bottom tracking acoustic sensor during days 84-92 in Figure 9. From the 5 cm high wave passing daily bedload was estimated at 4 tons/day, during a period when the suspended-sediment flux is approximately 18 tons/day. That puts the bedload at 22% of the suspended load and nearly twice as high as the typically reported upper limit. Clearly it is too short a record to comfortably apply to extended periods. Unfortunately no estimate

of bed-load has previously been made for the Cosumnes River. Caution should be used when applying this value.

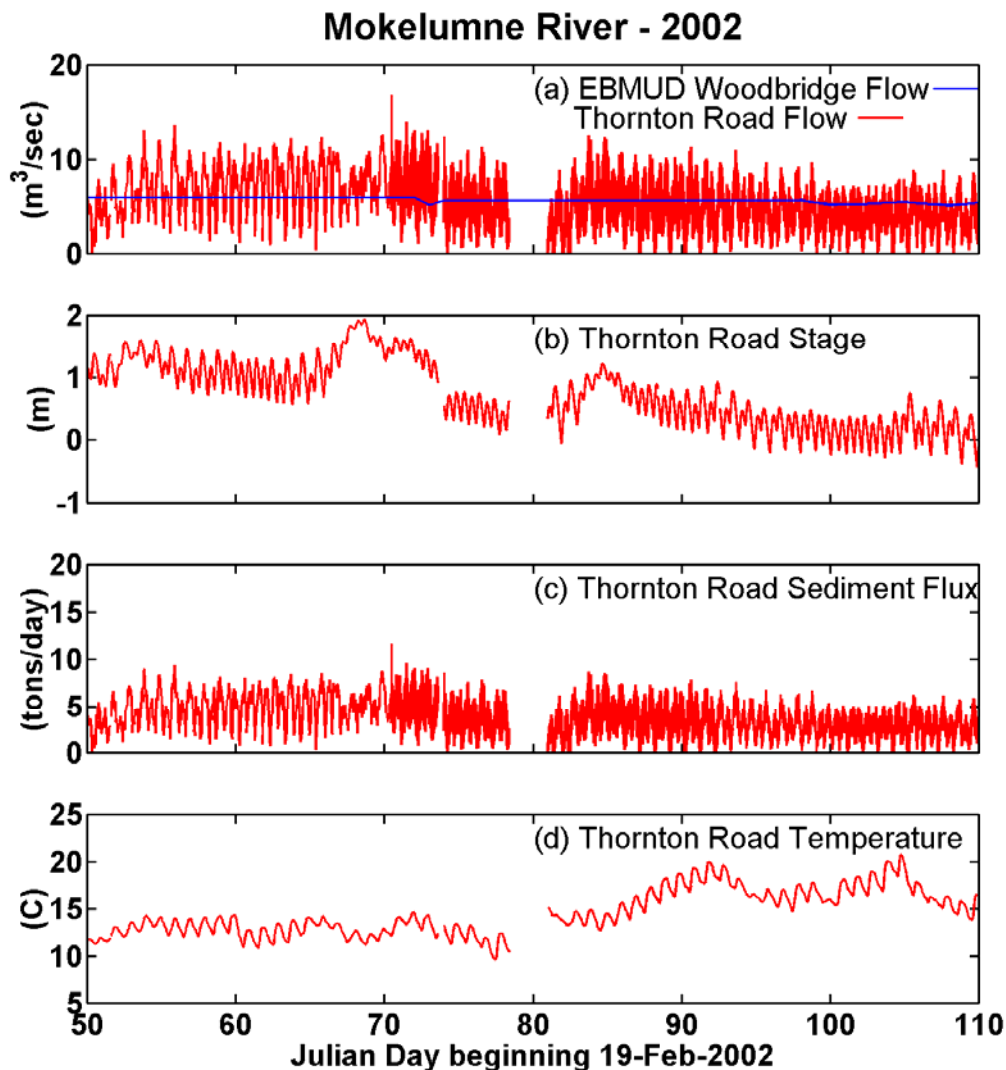


Figure 10 Mokelumne River measurements

On the Mokelumne River system the flows for the period, calculated at 5.7 m³/sec (210 cfs), were less than typical winter values. The CSFMS system tracked the flow with the tidal average, Figure 10. The suspended-sediment flux was approximately 4 tons/day, well below the 18 tons/day reported by Porterfield (1980), but not unexpected due to the significantly reduced flows, 19.3 m³/sec (681 cfs) versus 5.7 m³/sec (210 cfs), and the fact that the measurements were made downstream of additional diversion dams. The data suggest that the suspended-sediment concentration is now fairly constant and the

flux dependent solely on flow. The low, tidally influenced flows in the Mokelumne River system demonstrated no discernable bedform movement.

Water Year 2003

The conditions under which data were collected during 2002-2003 (water year 2003) were not representative of the averaged daily flow measured since 1909 at Michigan Bar. The 2003 averaged daily flow at Michigan Bar was $8.5 \text{ m}^3/\text{sec}$ (275 cfs) versus $14.1 \text{ m}^3/\text{sec}$ (498 cfs) for the years 1909-2004. The difference is easily observed in Figure 6 depicting both maximum averaged daily flows and total volume for each year and in Figure 7 showing the averaged daily flows for 2003 along with the historic average.

Since the highly regulated Mokelumne River system offered little chance of change in sediment and the flow is accurately gauged at the Wood bridge diversion dam, the second CSFMS was relocated to the secondary Cosumnes River tributary at the TCB for 2003. Relocation would permit an accurate assessment of the hydraulic significance of this stream to the flow and sediment regime. All other procedures were maintained.

As shown in Figure 11, the largest storm pulse in 2003 came late in the season with a peak at TCB on April 14, 2003 (Julian Day 104). Because of the late date, the instrument in the east bridge could not be left in place. Early data in 2003 offer little in the way of information of flow split or sediment contribution under the east bridge. The flow peak under the west bridge approached $80 \text{ m}^3/\text{sec}$ and the sediment flux exceeded 1000 tons/day on Julian Day 104. The reduced water temperature during the peak suggests that the flow was produced by rain-induced snowmelt. While the later peak in the flow under the west bridge is nearly 75% as great as the early peak, it produces only 25% of the suspended sediment flux magnitude. Again, this demonstrates the strong suspended sediment transport dependency on the flow rate.

The flow events were too short in 2003 to allow the CSFMS to be raised high enough off the bottom of the channel to collect additional data on bedform movement.

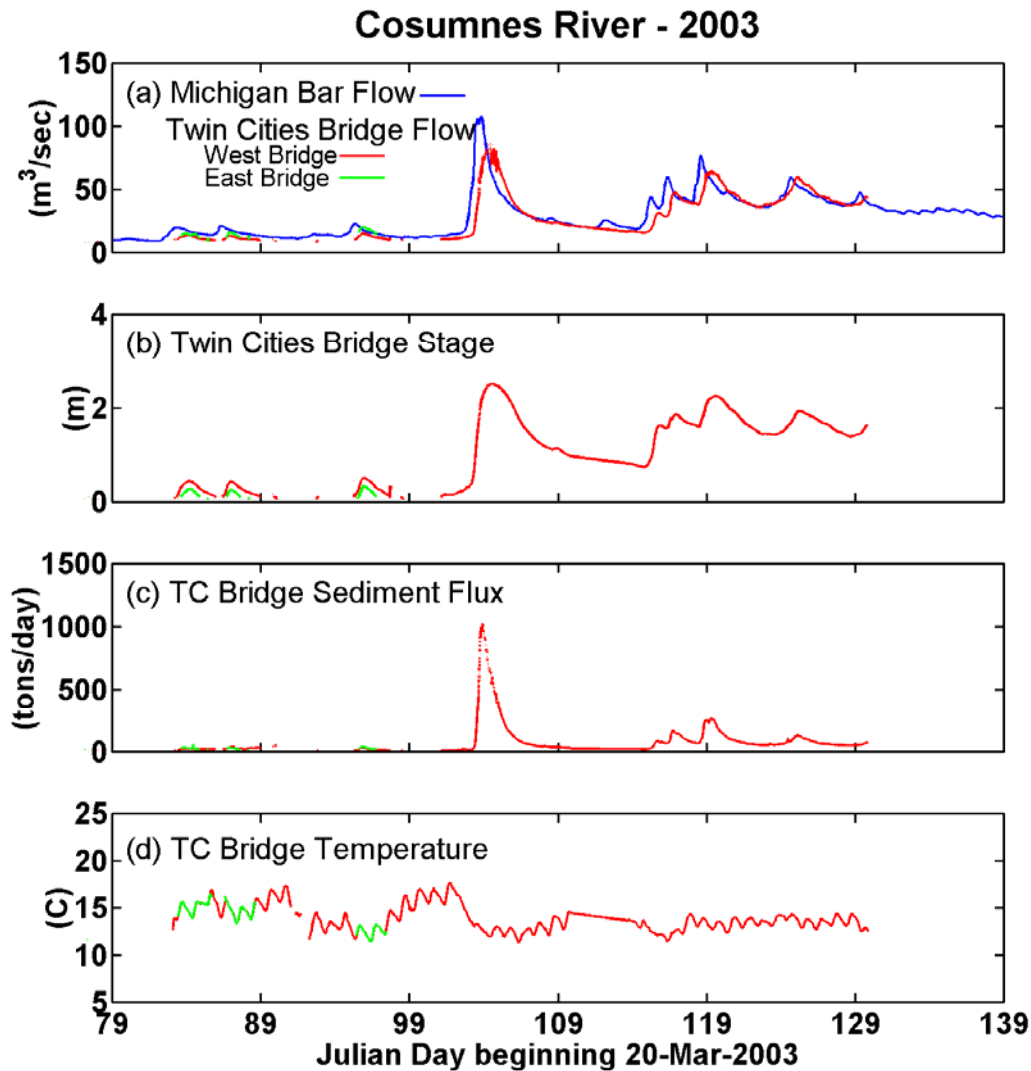


Figure 11 Both Twin City Bridges on the Cosumnes River

Water Year 2004

The conditions under which data were collected during 2003-2004 (water year 2004) continued to be unrepresentative of the averaged daily flow measured since 1909 at Michigan Bar. The 2004 averaged daily flow at Michigan Bar was $6.3 \text{ m}^3/\text{sec}$ (275 cfs) versus $14.1 \text{ m}^3/\text{sec}$ (498 cfs) for the years 1909-2004. The difference is easily observed in Figure 6 depicting both maximum averaged daily flow and total volume for each year and in Figure 7 showing the averaged daily flows for 2004 along with the historic average.

The second year of deployment under both Cosumnes River bridges at Twin City Road yielded better results even though the water year was still poor. Examination of Figure 12 demonstrates that the east bridge can carry a significant amount of water and sediment under the flow conditions of 2004. The east channel typically carries 50% of the flow of the west channel in higher flow events.

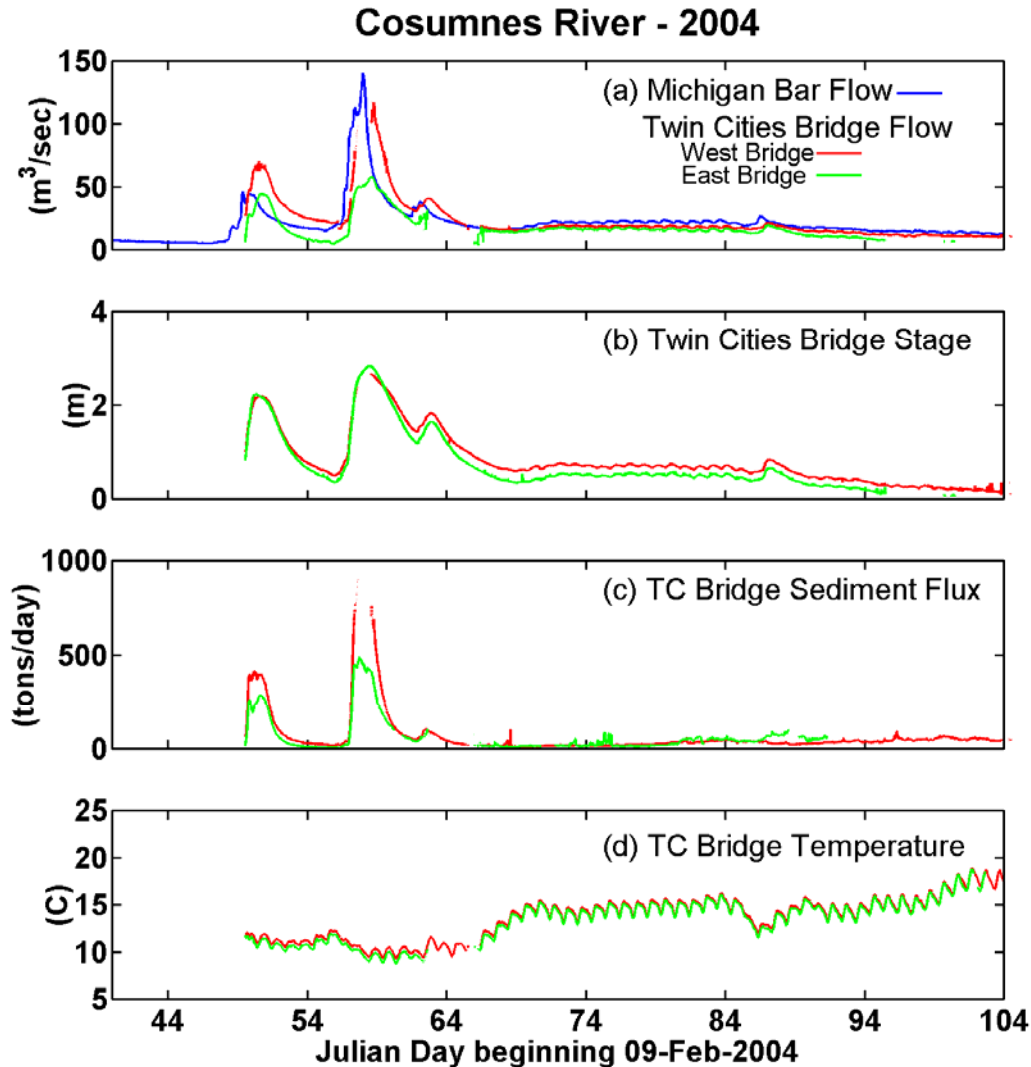


Figure 12 Both Twin City Bridges on the Cosumnes River

After the first small flow peak around Julian Day 50, the east channel carried more than 50% of the west channel but dropped considerably lower than the west channel after this event. These data suggest that the east channel received more local rainfall contribution

and less from the west channel. In the later peak event on Julian Day 57 the east channel contains less than 50% of the west channel but does not fall off much more than the west channel. These data suggest that the west channel is spilling into the east channel and the local contributions to the east channel are considerably less.

Earlier, from the 2002 data, it was projected that 184 tons/day of daily averaged sediment could be expected to pass under the TCB. Porterfield (1980) had projected 238 tons/day at Michigan Bar and 442 tons/day at McConnell based on his data. The 2004 data suggest that the east channel could carry up to 50% of the sediment as the west channel. Applying a simple 50% increase would suggest that up to 276 tons/day of averaged daily sediment could be anticipated. These data are still considerably lower than Porterfield's predictions and suggest that poor water years are preventing a reasonable estimation or that sediment loads have been significantly reduced.

Data from the USGS are presented in Figure 13. The round symbols are USGS data at Michigan Bar, while the triangles are UCD data collected at TCB. Examination of the USGS data demonstrates that the rating curve over the full flow range does not provide a single rating curve, but 3 separate curves. The data collected over the past few years does not provide direct information on the suspended sediment values expected at higher flow rates, but OBS data calibrated against suspended sediment concentrations are interpolated at higher flow rates. The interpolated data do demonstrate that the suspended sediment concentrations at TCB are lower than for the same flow rate at Michigan Bar at the upper end of measured flow rates. Although higher suspended sediment concentrations were found at TCB than at Michigan Bar for equivalent lower flow rates, a projection of the rating curve developed from the last few years' data, projects less sediment at TCB than the USGS has measured at Michigan Bar. If the Michigan Bar rating curve developed before 1974 still holds at Michigan Bar, then the predictions using the recent data are too low.

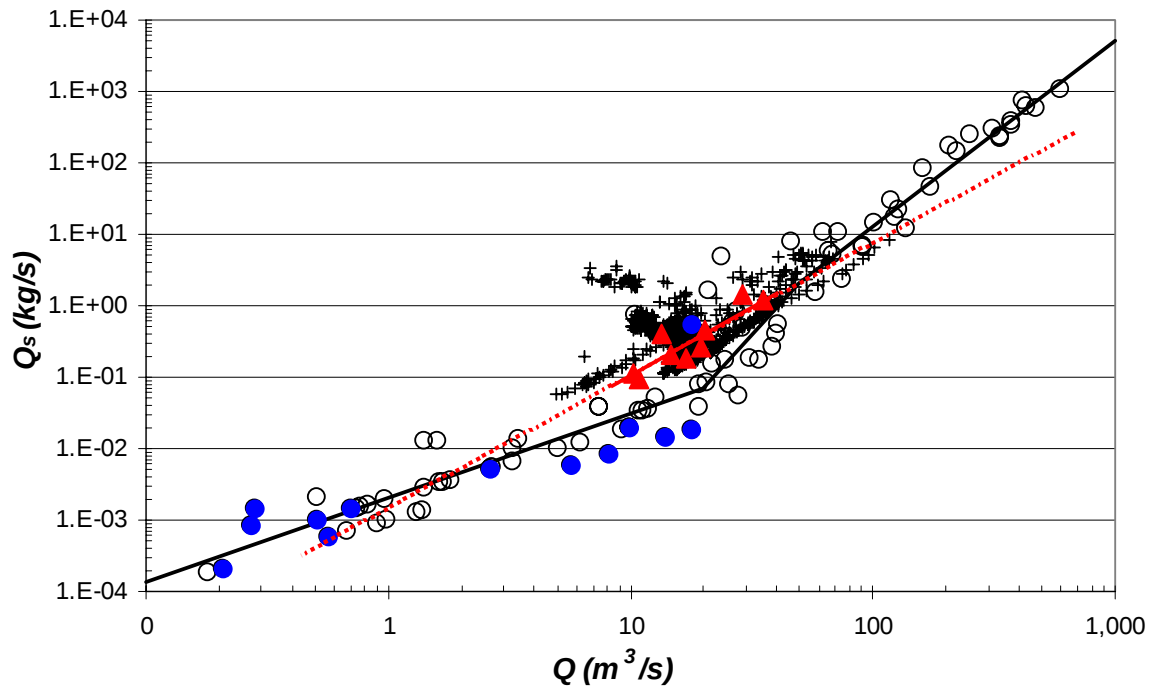


Figure 13 Sediment flux as a function of flow. Round symbols from the USGS data taken at Michigan Bar, hollow for 1965-74 and filled for 2001-2004. Filled triangles are from UCD physical sample data at TCB with projection represented by dashed line, black + symbols are suspended sediment fluxes inferred from regression of OBS signals with lab samples.

Conclusions

The data presented in this report are not representative of a ‘typical’ water year. All three water years contained substantially less volume and lower peak flow rates than average years. All the actual suspended sediment samples collected and analyzed were for flow rates below 40 m³/s. Suspended sediment values have been projected to larger flows using the continuous OBS measurements, but under predict the data collected during higher flows before 1974. Since historic evidence suggests that suspended sediment concentrations increase faster than the flow rate, it cannot be assumed that suspended sediment fluxes have decreased.

The acoustic bottom-tracking beam is oriented at a 45-degree angle. Due to the low flow of the study years, water levels were not consistently high enough for the CFMS package to be raised and the bottom-tracking beam to be focused on the center of the

channel. The one short period where the bottom was tracked produced an estimated 4 tons/day of bedload transport. Since net accretion and net erosion were both observed during falling hydrograph limbs, no overall estimates can be inferred from the single successful bedload measurement. The instrument can provide useful data when flows are higher and further study is warranted to verify useful bedload estimates.

References

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Appendix

Mokelumne River cross-section

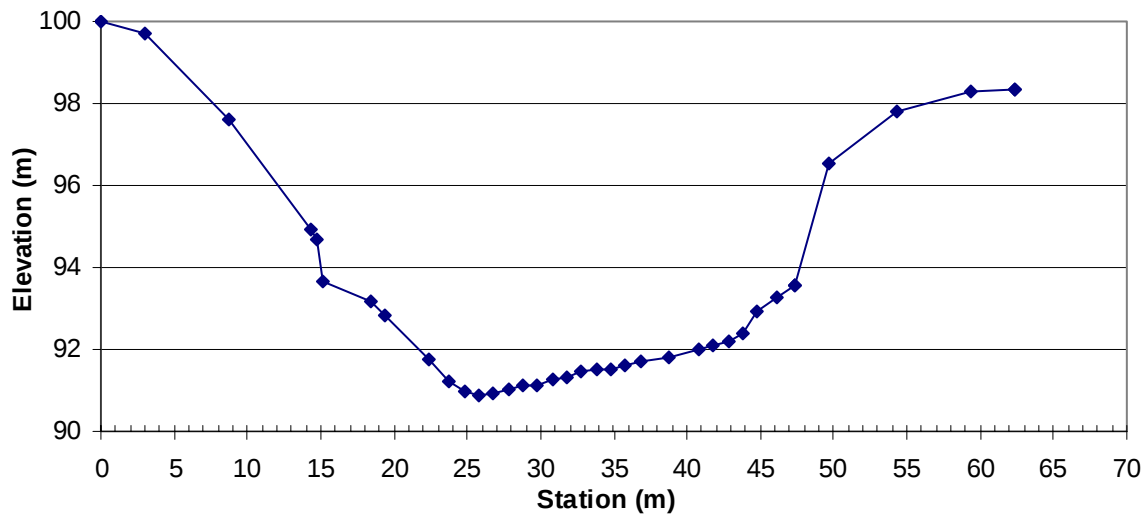


Figure 14 Mokelumne River cross-section measured from left bank.

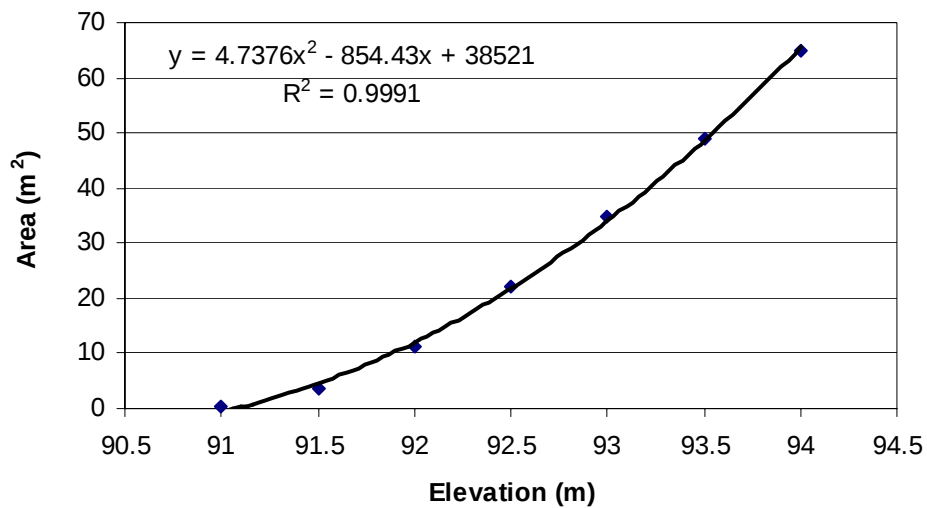


Figure 15 Mokelumne River cross-section - area as function of elevation.

Cosumnes River – West Bridge

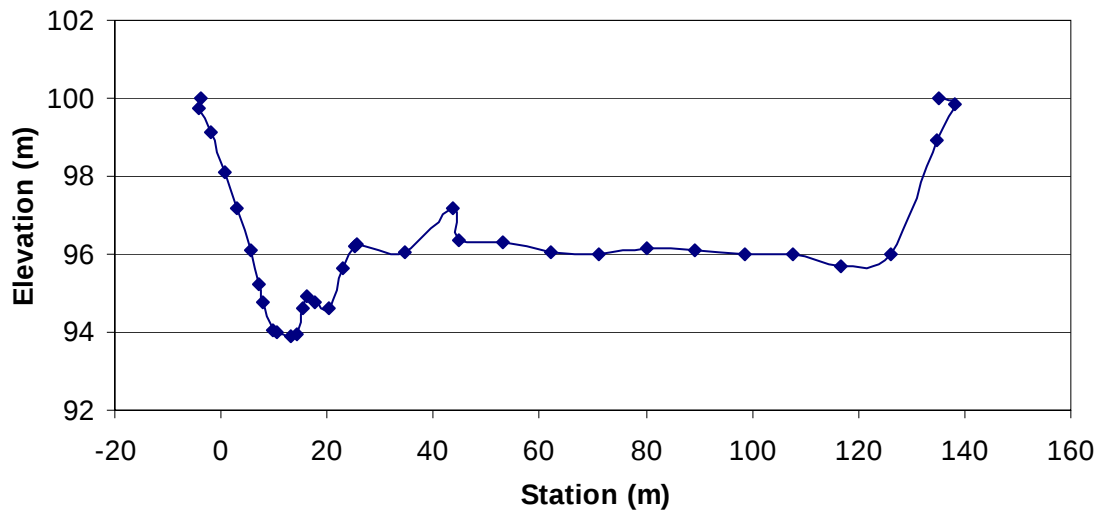


Figure 16 Cosumnes River Cross section measured from left bank – west bridge at Twin Cities Road.

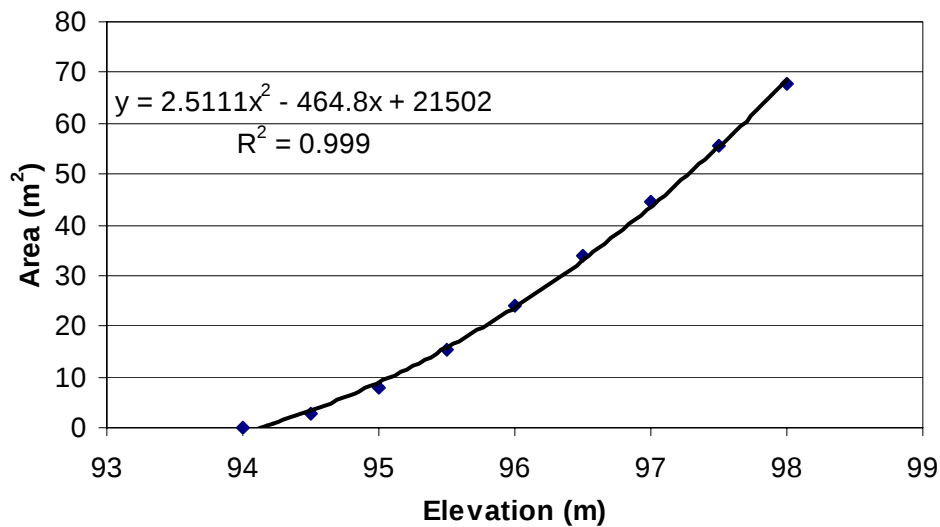


Figure 17 Cosumnes River cross-section, west bridge - area as function of elevation.

Cosumnes River – East Bridge

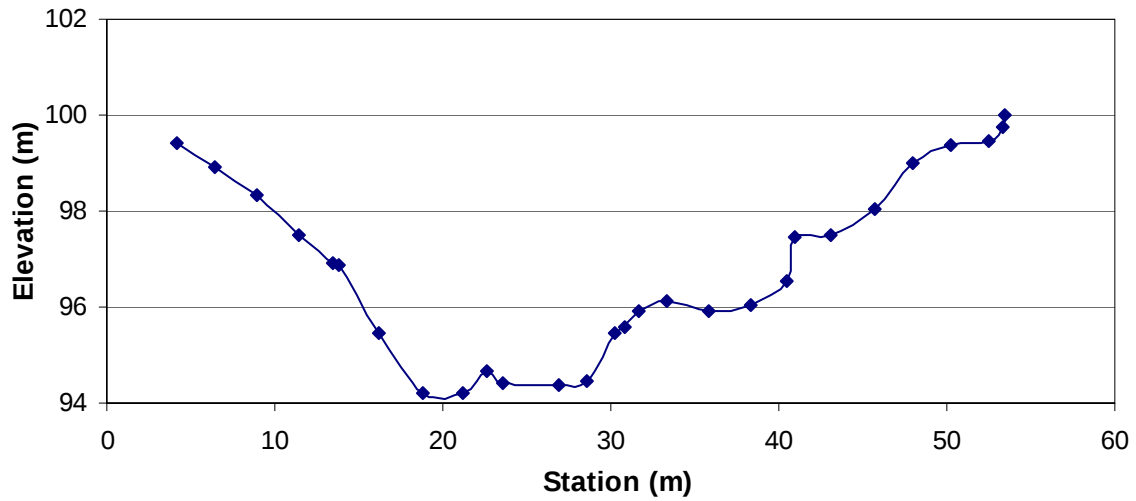


Figure 18 Cosumnes River Cross section measured from left bank – east bridge at Twin Cities Road.

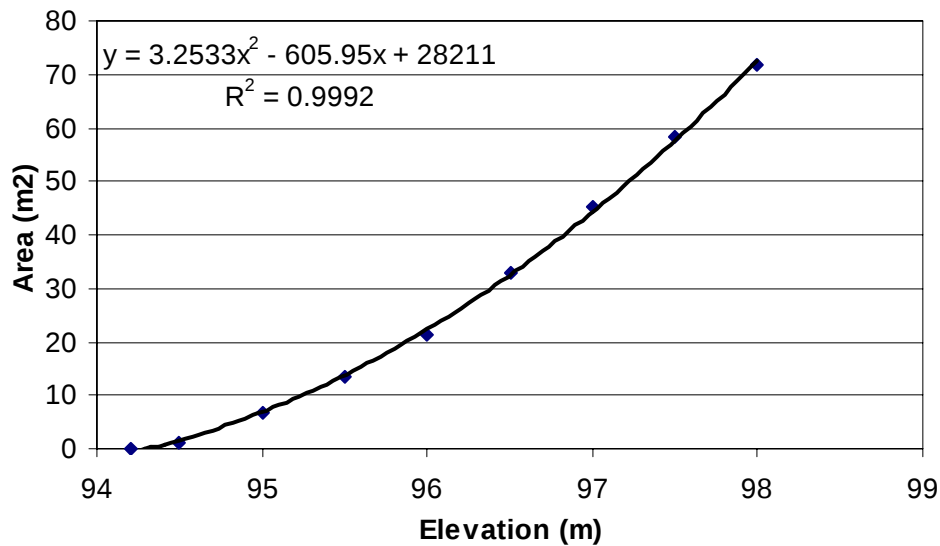


Figure 19 Cosumnes River cross-section, east bridge - area as function of elevation.