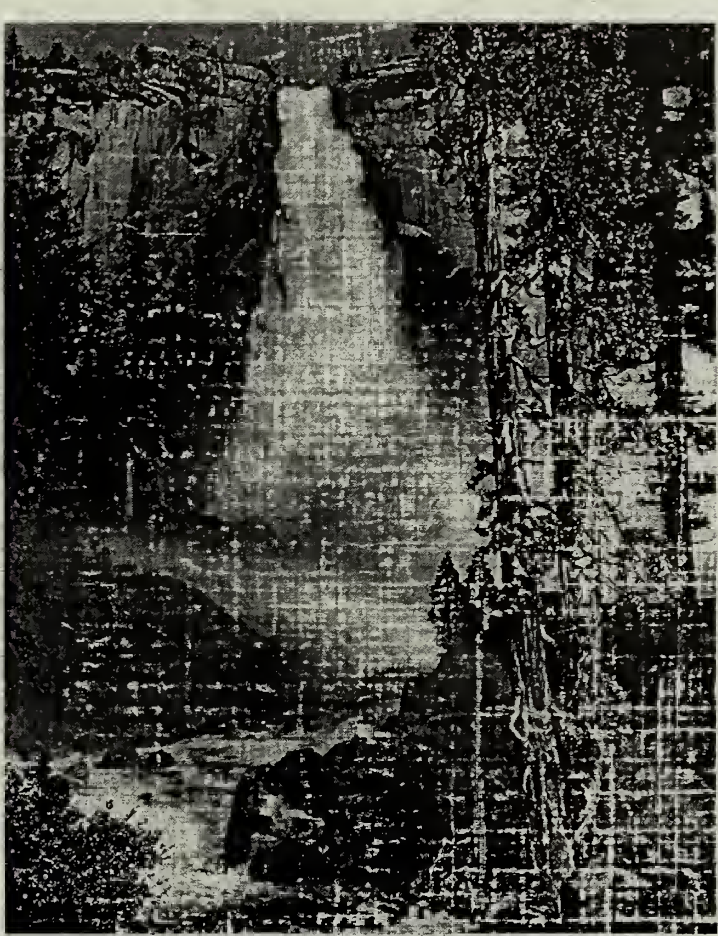
WRD Resource Room

YOSE

CHANNEL CHANGES IN THE MERCED RIVER FOLLOWING THE JANUARY, 1997 FLOOD

Mary Ann Madej (1), Vicki Ozaki (2), Carrie Jones (2), and Gregory Gibbs (1)



United States Department of the Interior
1-U.S. Geological Survey Biological Resources Division
2-Redwood National and State Parks

USGS
science for a changing world

REDWOOD NATIONAL & STATE PARKS

Cover Photo By Ansel Adams

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHANNEL CHANGES IN THE MERCED RIVER FOLLOWING THE JAUNUARY, 1997 FLOOD

Mary Ann Madej (1), Vicki Ozaki (2), Carrie Jones (2), and Gregory Gibbs (1)

1-U. S. Geological Survey Biological Resources Division
2-Redwood National and State Parks

I. INTRODUCTION

Northern California was drenched by a series of rainstorms December 29, 1996 through January 4, 1997. A "pineapple express" brought a series of storms from the central Pacific that caused heavy, prolonged and unusually warm precipitation across the northern half of the state. These conditions caused widespread flooding from central California to Oregon. Several U.S. Geological Survey stream gages recorded the largest peak flows in the history of their operation (U.S. Geological Survey, 1997). This storm provides an important opportunity to examine the watershed processes that are active under extreme events, and to learn how man-made infrastructure, riparian vegetation, valley floor configuration and stream channel morphology interact to produce the effects observed in a river corridor following the flood.

The Merced River flows through Yosemite Valley in Yosemite National Park in the Sierra Nevada, California (Figure 1). On January 1-3, 1997, the Merced River in Yosemite National Park had its largest flood since stream gage monitoring was initiated in 1916. Heavy snowstorms earlier in the season followed by snowmelt during the storm contributed to high runoff. Historically, such rain-on-snow events caused the largest flood peaks in the Merced River (Madej and others, 1991). The U.S. Geological Survey (USGS) has operated a stream gage at Happy Isles since 1916. Peak flows on the Merced River at the Happy Isles Bridge from 1916 to 1997 are shown in a graph generated by the U.S. Geological Survey (Figure 2). The USGS estimates the January, 1997 peak flow at this station (USGS Number 11264500) to be 10,100 cfs (56 cfs/mi^2), and about 24,600 cfs at the Pohono Bridge station (Number 11266500) farther downstream. These estimates are considered preliminary and may be revised as the USGS reviews its gaging station records and conducts further studies. These preliminary estimates are higher than the previously recorded extreme of 1955 (Figure 2).

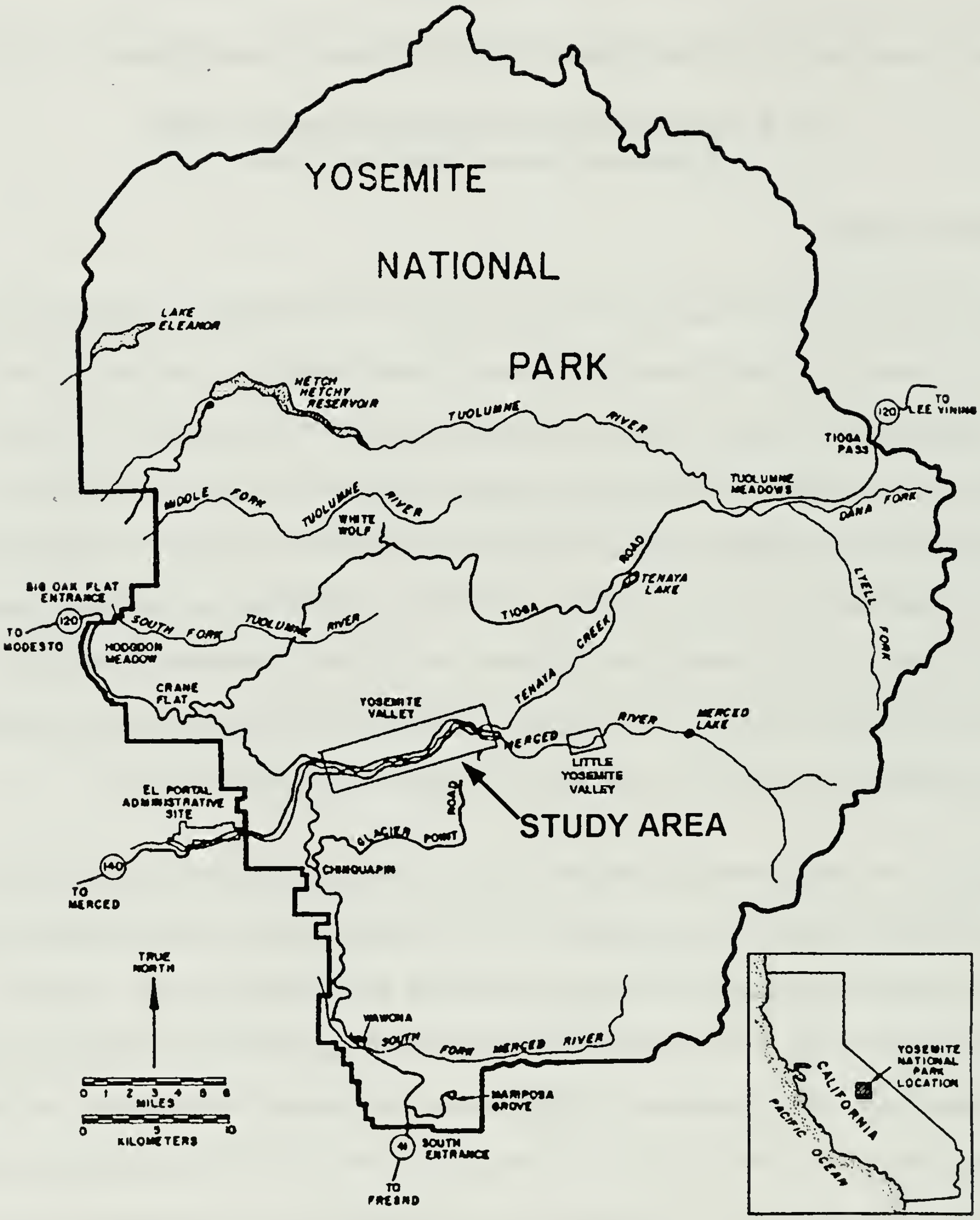
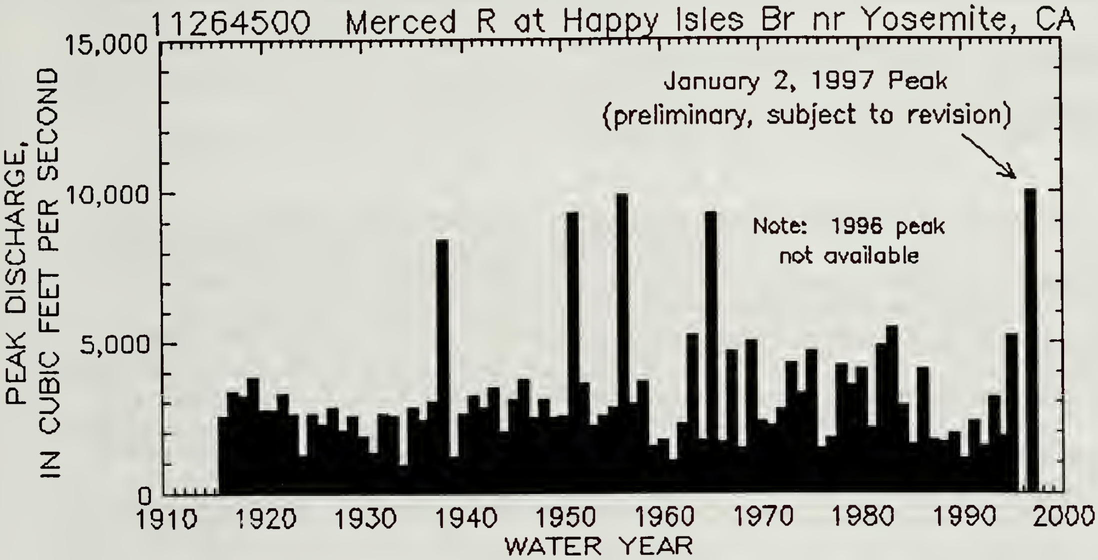


Figure 1. General location map of study area.

USGS

11264500 - Warning! Provisional Data Subject To Revision
MERCED RIVER AT HAPPY ISLES BRIDGE, NEAR YOSEMITE, CA



This USGS site is maintained by Sacramento Field Office

LOCATION.--Lat 37°43'54", long 119°33'28", unsurveyed, Mariposa County, Hydrologic Unit 18040008, Yosemite National Park, on right bank 10 ft downstream from footbridge at Happy Isles, 0.4 mi downstream from Illilouette Creek, and 2.0 mi southeast of Yosemite National Park Headquarters.

DRAINAGE AREA.--181 mi2.

PERIOD OF RECORD.--August 1915 to current year.

REVISED RECORDS.--WSP 1215: 1938(M).

GAGE.--Water-stage recorder. Datum of gage is 4,016.58 ft above sea level. Prior to Nov. 2, 1916, nonrecording gage at datum 0.55 ft lower.

REMARKS.--Records good. Up to 5 ft3/s can be diverted upstream from station for Yosemite Valley water supply.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 9,860 ft3/s, Dec. 23, 1955, gage height, 12.73 ft, from rating curve extended above 4,000 ft3/s on basis of contracted-opening measurements at gage heights 10.4 and 11.55 ft; minimum daily, 1.5 ft3/s, Sept. 26, 1977.

Figure 2: Annual peak flows for the Merced River at the Happy Isles Bridge.

Damage to Yosemite National Park's infrastructure was severe. Yosemite National Park's Detailed Assessment Report (1997) documents damage to four main routes leading into the park, major electrical and sewer systems, 224 units of employee housing, more than 500 guest lodging units and 350 campsites, 17 restoration projects and at least ten known archeological sites. The estimate of total recovery costs listed in this report was $197,153,000.

Jackson, Smillie and Martin (1997) conducted a field review of flood-damaged sites in Yosemite Valley soon after the flood. Their summary, "Analysis of the Hydrologic, Hydraulic and Geomorphic Attributes of the Yosemite Valley Flood: January 1-3, 1997," covers the reach of the Merced River from the town of El Portal to upstream of the Tenaya Creek confluence. The report includes maps of the inundated valley floor. Their analysis provides an overview of the flood effects in Yosemite Valley, the recurrence intervals and the hydraulic characteristics of the flood, and the implications of the flood on valley planning. The present report builds upon their work, and is based on field work conducted in August, 1997. This report focuses on analyzing more detailed information on flood effects on a shorter reach of the Merced River. The Merced River downstream of Devil's Elbow and tributary streams such as Tenaya Creek and Royal Arches Creek are not included in the present assessment.

The purposes of this report are to:

1. Identify watershed processes, such as overbank flows and woody debris recruitment, that affected Yosemite Valley during the flood, and which park managers should consider in planning for future flooding.

2. Describe changes in the Merced River channel in Yosemite Valley based on pre- and post-flood surveys of 37 cross-sectional transects.

3. Assess the effectiveness of river restoration projects along the banks of the Merced River in terms of withstanding a 100-year flood.

4. Design monitoring protocols and provide baseline information on several channel characteristics in order to assess future river channel and valley changes.

5. Provide park managers with both baseline information and recommendations for future planning of land use, visitor use, and infrastructure concerns in Yosemite Valley.

II. OVERVIEW OF WATERSHED PROCESSES

There are several ecological and geomorphological processes that are active in a watershed before, during and following a flood that influence channel changes. These processes should be identified and acknowledged when planning for future uses of the river corridor. The following is a brief overview of the most important processes affecting natural and cultural resources along the Merced River .

Bank Erosion

Bank erosion has been a concern of Yosemite National Park management staff for many years, especially in the campground areas of Yosemite Valley. Previous studies (Madej and others, 1991) have documented the magnitude and location of bank erosion in Yosemite Valley that occurred between 1919 and 1989. Bank erosion that occurred during the 1997 flood is addressed in Part III of this paper.

Banks erode by several mechanisms, such as surface erosion, rainsplash, windthrow, fluvial entrainment, and mass movement. Stream flow, sediment transport and bank properties determine rates of bank retreat (Richards, 1982). In a natural system like the Merced River watershed, there is little human influence on the amount and timing of flood flows and sediment transport, although severe wildfires may influence both. In terms of bank properties, however, human use can change some of them, especially the type and density of riparian vegetation.

Riparian vegetation increases the resistance of streambanks to erosion. Smith (1976) showed that uncohesive streambank sediments that were reinforced by roots were thousands of times more resistant to erosion than bare sediment. Yosemite National Park is using this concept as it attempts to revegetate bare stream banks along the Merced River. Rainsplash, rill erosion, frost action and freeze-thaw cycles all work to loosen stream bank material and induce bank erosion, whereas stream bank vegetation helps bind stream bank particles together to resist this erosion.

Besides increasing the resistance to bank erosion, riparian trees can cause erosion as well, through windthrow, treefall and subsequent scour around the fallen logs. Windthrown trees along streambanks directly deliver sediment into the channel when their rootballs detach from the bank. Stream flow is often deflected against the bank by the resultant woody debris dams or where scallops formed in the bank after the trees have fallen (Abernathy and Rutherford, 1998).

As floodwaters flow against a stream bank, they can carry away clay, silt, sand and gravel (called fluvial entrainment) and this can lead to bank retreat. Again, riparian vegetation can increase the resistance of the stream banks to the eroding force of water, and protect streambank material from erosion.

Another mechanism for bank erosion is through mass movement processes, or landslides. These include bank slumping, toppling slabs, shallow debris slides and deep-seated rotational or translational failures. In the Merced River immediately downstream of Clarks Bridge, the banks are too low for mass movement to play an important role. Farther downstream, near Lower River campground, the left bank of the Merced River is steep and nearly vertical. This bank is subject to mass failure, but the bank is composed of cohesive clay and silt and does not show signs of recent failures. Where banks are taller than the depth of tree roots, mass movement of bank material can lead to bank retreat. In the study area in Yosemite Valley described below, however, mass movement was not a dominant erosional process during the 1997 flood.

Treefall and Large Woody Debris

As described above, treefall caused by windthrow can contribute sediment and wood to stream channels. Trees can also enter the stream through natural mortality, landslides or bank erosion. In addition, the amount of treefall is influenced by ecological factors, such as forest stand characteristics. At the time of the 1997 flood, many trees had already fallen into the Merced River upstream of Happy Isles Bridge from the air blast and rockfall a few years earlier. The flood did not transport these to any significant degree, but they represent a source of woody debris in future years as they decay and break down in the channel. During the flood there was also extensive treefall along Tenaya Creek due to bank erosion.

When trees enter the river channel they can remain where they fell, if the stream power is not sufficient to move them. Alternatively, they can be rotated by the flow, or transported farther downstream. The effects of treefall on the channel depends on the size of the tree, its orientation in the river, channel width, and the strength of the river flow. Treefall contributes large woody debris to stream channels. The role of large woody debris in streams is discussed in more detail in Section III-C. Treefall can cause scour of the bank or bed, or can trap sediment if it forms a dam or obstruction in the flow. From the mid-1960's to the mid-1990's it was the policy of Yosemite National Park to remove trees that had fallen into the Merced River channel in Yosemite Valley. Because treefall is important in increasing the complexity of the river channel and increasing the variety of aquatic habitats available, we recommend that the Park retain the in-stream woody debris wherever possible.

Mass Movement

Mass movement, or landsliding, can occur along the banks of the Merced River (discussed above). It can also occur on the hillslopes throughout the watershed of the Merced River. Rockfall is an important process in Yosemite Valley, and can contribute large volumes of sand to boulder-sized material to the valley bottom and the river channel. As park managers make decisions about removing development from the floodplain, they must also consider the danger of rockfall at the base of cliffs on the valley floor. This study did not assess the contribution of sediment from mass movement processes, but an analysis of sequential aerial photographs of the Merced River watershed could quantify the locations, timing and magnitude of various mass movement features in the basin.

III. MONITORING STUDIES

Some stream monitoring efforts were initiated in 1987 (Madej and others, 1991), and Yosemite National Park staff expanded these efforts when designing and implementing restoration activities along the Merced River. The U.S. Fish and Wildlife Service has also conducted channel studies in Yosemite Valley. Channel monitoring includes cross-sectional and longitudinal transects, large woody debris surveys, and channel substrate characterization. The following sections describe the methods used to monitor channel changes in the Merced River, and the results of these monitoring efforts.

A. CROSS-SECTIONAL SURVEYS

Cross-sectional transects of the stream channel provide a useful tool to document changes in channel shape through time. Repeated surveys document bank erosion or accretion, and channel filling or scouring during a given time period. In this case, pre- and post- flood surveys of cross sections were used to evaluate channel changes in Yosemite Valley due to the January, 1997 flood. They are also useful in documenting the effectiveness of streambank restoration projects.

Since initiation of the long-term channel monitoring program in 1989, 37 permanent channel cross sections (X/S) have been established on the Merced River in Yosemite Valley. Cross sections extend from Clarks Bridge downstream to Devil's Elbow and are grouped into four reaches (Figure 3): Lower Pines Campground to Housekeeping (X/S 10-29), Sentinel Bridge (X/S 40-44), El Capitan Meadow (X/S 1 and 2, X/S 30-34), and Devil's Elbow (X/S 35-38). General cross section locations are shown in Figure 4. Yosemite National Park's Resource Management Division has more detailed information on cross section endpoint locations on file.

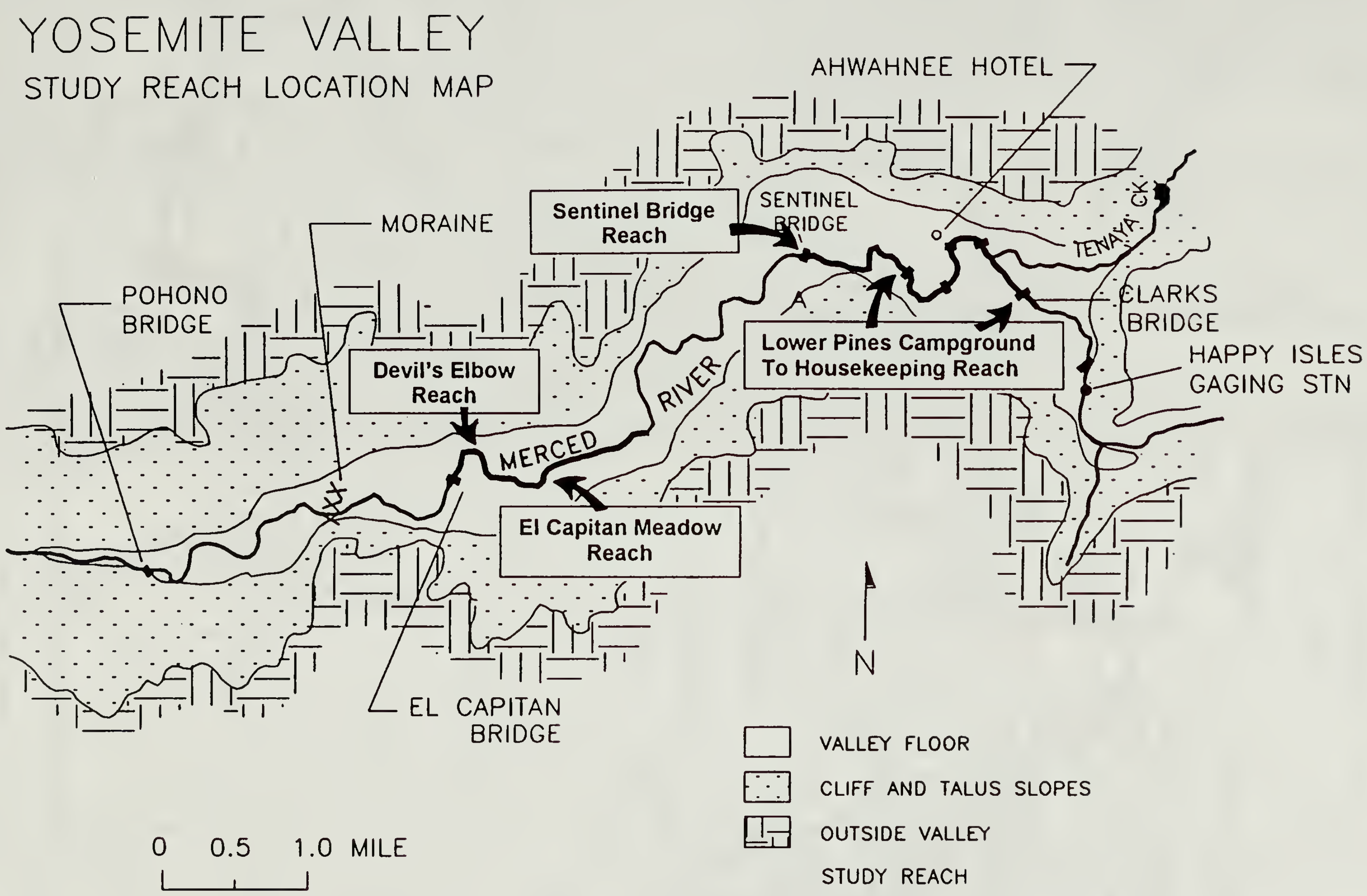


Figure 3. Location map of study reaches along the Merced River in the Yosemite Valley.

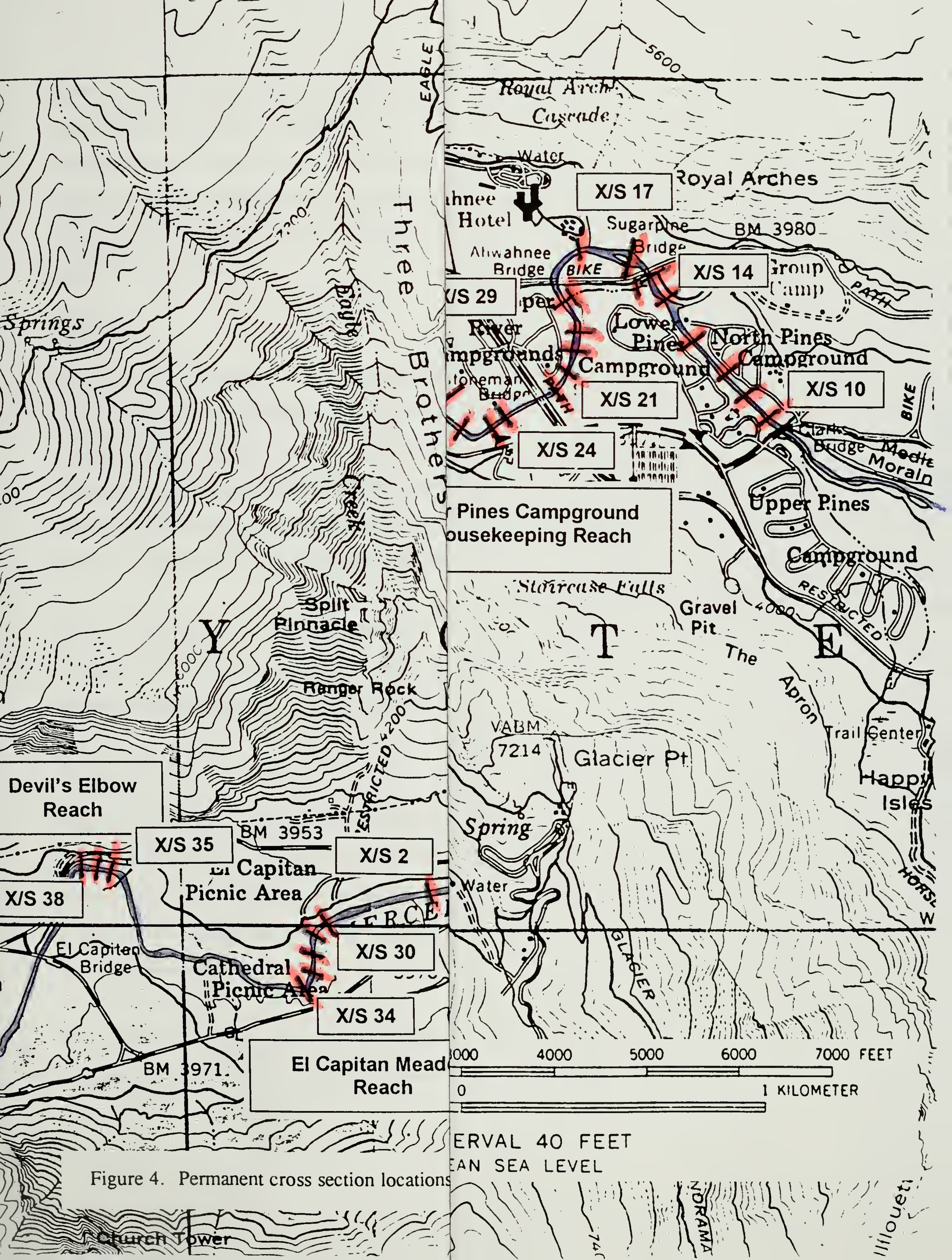


Figure 4. Permanent cross section locations

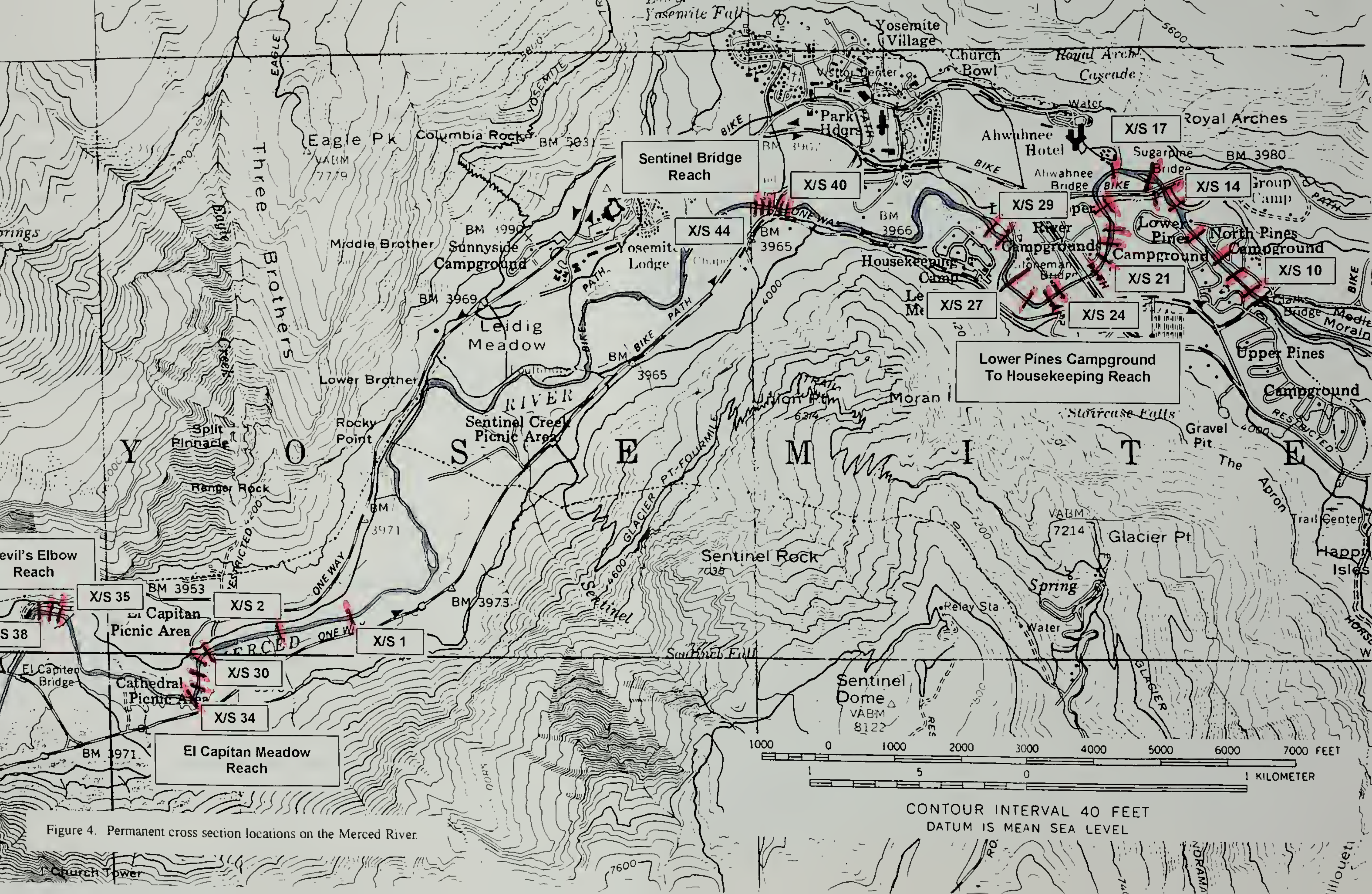


Figure 4. Permanent cross section locations on the Merced River.

In the summer of 1989, the National Park Service established 21 cross sections in the Lower Pines Campground to Housekeeping reach (X/S 10- 27) and three cross sections in the El Capitan Meadow reach (X/S 1- 3). Subsequently cross sections were established to monitor bank restoration work. Selected cross sections were surveyed from 1992-1996 (Appendix A). Some of the original cross section endpoints could not be relocated after the 1997 flood, and are not included in this report.

Methods

Cross sections were surveyed between two permanent end points of known elevation and were monumented with 2-inch diameter steel rebar with aluminum caps. Relative elevations between end points were established by leveling (Emmett, 1974). Cross sections were surveyed during the summer months with either an automatic level, tape and stadia rod or an electronic total station. High water marks, top and base of channel banks, the thalweg (deepest point in the channel), any significant breaks-in-slope, and edge of vegetation were recorded in the field.

Each cross section was photographed from four perspectives. A set of four photos with the cross section centered in them document the conditions of the right and left bank, and the channel looking in an upstream and downstream direction.

Terminology

The terminology of Varnum and Ozaki (1986) was used in this report (Figure 5). The thalweg (T) is defined as the lowest point in the streambed in a cross-sectional profile. Bankfull channel width (W) is the channel width when high flows fill the channel completely and the water surface is level with the lowest floodplain. It is identified by vegetation breaks, breaks-in-slope, and channel morphology.

Net change in streambed area (ΔA_s) is the difference between the area of fill and area of scour across the streambed. Mean change in streambed elevation (ΔE_c) is a normalized value that

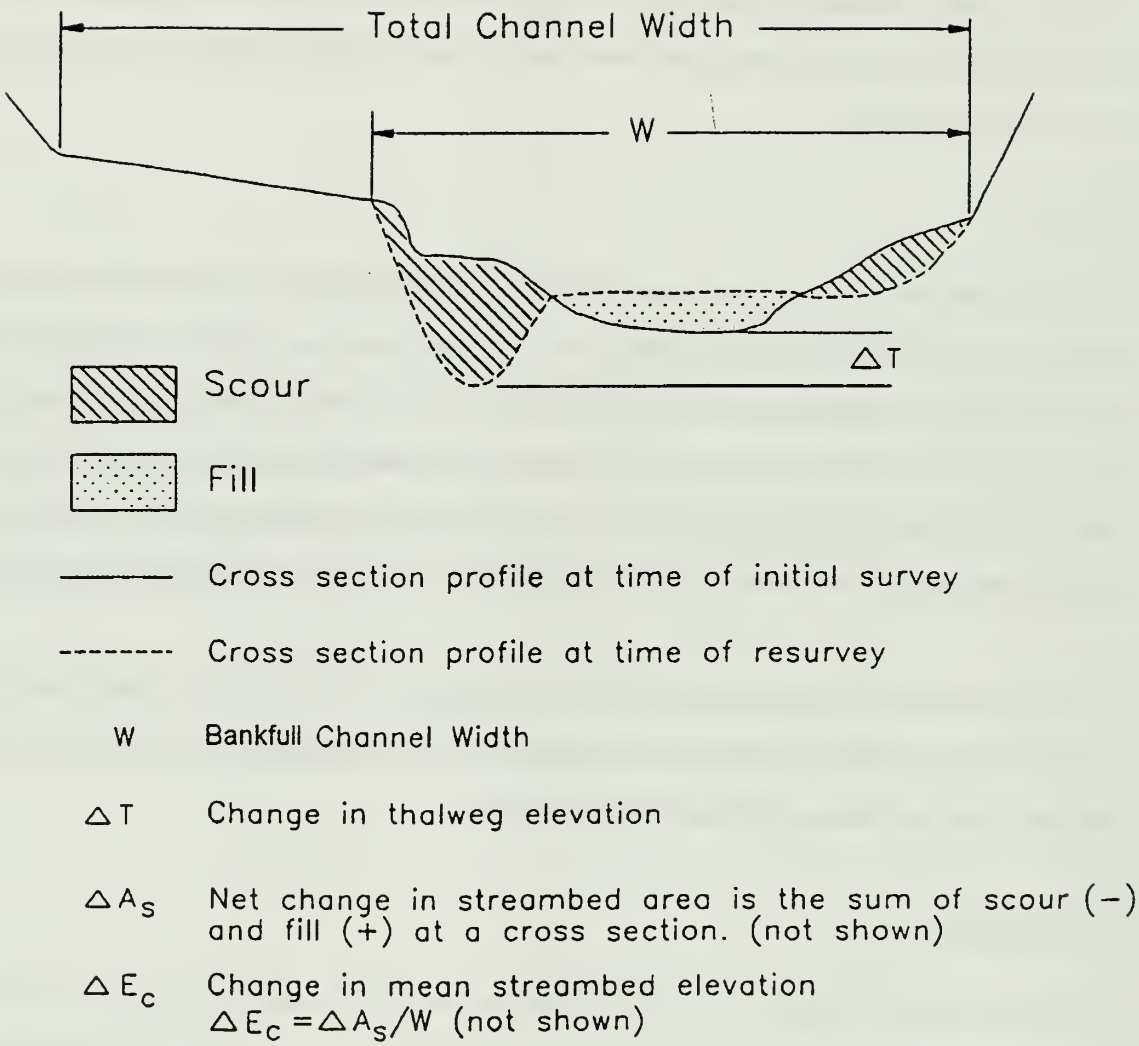


Figure 5. Terms and symbols used to describe changes at cross sections.

compares the relative importance of changes at cross sections of different widths and is derived by dividing the net change in streambed area (ΔA_s) by the bankfull width (W):

Change in Mean Streambed Elevation: $\Delta E_c = (\Delta A_s/W)$

Thus, a lowering of the mean streambed elevation by 0.15 ft ($\Delta E_c = -0.15$) produces the same percent change in a 10 ft-wide cross section as it does in a 100 ft-wide cross section, even though more material has moved through the wider cross section. A change in mean streambed elevation of 0.2 ft or less is within the survey measurement error and cross-sectional changes within this range are considered to be insignificant.

For each survey year, the cumulative change in mean streambed elevation is calculated. The cumulative change in mean streambed elevation is plotted by year to show trends at individual cross sections over time and can depict general trends in infilling, scouring, or stability at the cross section.

Results and Discussion

This report presents the results of cross-sectional changes observed on the Merced River in 1997. The permanent cross sections along the Merced River in Yosemite Valley were surveyed in August, 1997, following the 100-year flood in January of that year.

Changes at cross sections on the Merced River are quantified in Table 1. The net change in area, mean change in streambed elevation, and the change in thalweg (deepest part of the channel) elevation were calculated. Plots of cross-sectional changes and cumulative change in mean streambed elevation for all cross sections are included in Appendix A. Figure 6 is a summary plot of the change in mean streambed elevation at all the surveyed cross sections, and allows a comparison of the relative magnitude of change in different portions of the Merced River. The cross sections showing the largest changes from the 1997 flood are: XS 13, 15, 28 and 43. In

Table 1. Summary of 1997 Channel Changes at Merced River Cross Sections, Yosemite, CA

Cross Section Number	Location	Year Estab.	Change in Thalweg Elev. (ft)	Scour (-) (ft2)	Fill (+) (ft2)	Net Change in Area (ft2)	Bankfull Channel Width (ft)	EC[1] (ft)	Absolute Change (ft)	Comparison Year
LOWER PINES TO HOUSEKEEPING										
10	Lower Pines	1989	-1.01	163.42	19.53	-143.89	159.0	-0.90	1.15	1995
11	Lower Pines	1989	-1.24	103.46	6.41	-97.05	137.6	-0.71	0.80	1995
12	Lower Pines	1989	0.62	36.93	59.29	22.36	221.9	0.10	0.43	1995
13	Lower Pines	1989	1.08	12.62	301.85	289.23	225.5	1.28	1.39	1995
14	Lower Pines	1989	0.43	33.73	68.66	34.93	255.5	0.14	0.40	1995
15	Sugar Pine Bridge	1989	1.56	99.24	339.86	240.62	160.8	1.50	2.73	1995
15a	Overflow Channel	1989	-0.66	112.44	87.99	-24.45	241.6	-0.10	0.83	1995
15d	Overflow Channel	1989	-0.39	39.57	84.85	45.28	127.7	0.35	0.97	1995
16	Sugar Pine Bridge	1989	0.35	23.26	68.89	45.63	309.4	0.15	0.30	1995
17	Ahwahnee Cottage	1989	-0.17	23.73	25.69	1.96	160.0	0.01	0.31	1995
18	Upper River/Lower Pines	1989	-0.38	95.75	35.14	-60.61	232.9	-0.26	0.56	1995
19	Upper River/Lower Pines	1989	0.13	33.81	91.42	57.61	215.3	0.27	0.58	1995
20	Upper Pines	1989	0.36	25.61	92.27	66.66	188.2	0.35	0.63	1995
21	Upper Pines	1989	-0.02	32.59	27.18	-5.41	161.0	-0.03	0.37	1995
22	U/S Stoneman Bridge	1989	0.03	24.38	34.71	10.33	144.7	0.07	0.41	1995
24	Lower River	1989	-3.34	82.87	145.99	63.12	213.2	0.30	1.07	1992
25	Lower River	1989	-0.47	74.89	72.61	-2.28	242.2	-0.01	0.61	1992
26	Lower River	1989	-0.34	131.01	24.10	-106.91	288.0	-0.37	0.54	1989
27	Lower River	1989	-7.27	293.96	145.75	-148.21	345.3	-0.43	1.27	1995
28	Housekeeping	1992	1.51	36.00	286.70	250.70	166.5	1.51	1.94	1993
29	Housekeeping	1992	0.30	18.07	37.77	19.70	193.0	0.10	0.29	1993

1 Highlighted numbers indicate no significant change. Ec is within measurement error.

Table 1 (con't). Summary of 1997 Channel Changes at Merced River Cross Sections, Yosemite, CA

Cross Section Number	Location	Year Estab.	Change in Thalweg Elev. (ft)	Scour (-) (ft2)		Fill (+) (ft2)	Net Change in Area (ft2)	Bankfull Channel Width (ft)	EC[1] (ft)	Absolute Change (ft)	Comparison Year
EL CAPITAN MEADOW											
1	El Capitan Meadow	1989	-0.17	35.92		47.64	11.72	160.3	0.07	0.52	1989
2	El Capitan Meadow	1989	-1.14	104.04		57.20	-46.84	197.8	-0.24	0.82	1989
30	El Capitan Meadow	1992	-2.61	232.76		101.87	-130.89	175.0	-0.75	1.91	1994
31	El Capitan Meadow	1992	1.36	426.94		238.97	-187.97	240.1	-0.78	2.77	1994
32	El Capitan Meadow	1992	0.77	266.00		363.74	97.74	255.8	0.38	2.46	1994
33	El Capitan Meadow	1992	1.93	335.61	*	316.84	-18.77	393.4	-0.05	1.66	1994
34	El Capitan Meadow	1992	1.98	393.91	**	160.70	-233.21	474.3	-0.49	1.17	1994
DEVIL'S ELBOW											
35	Devil's Elbow	1992	0.31	66.78		37.97	-28.81	230.3	-0.13	0.45	1994
36	Devil's Elbow	1992	0.16	30.21		74.51	44.30	168.0	0.26	0.62	1994
37	Devil's Elbow	1992	-2.12	75.00		166.13	91.13	169.0	0.54	1.43	1994
38	Devil's Elbow	1992	-1.27	117.88		26.30	-91.58	172.0	-0.53	0.84	1994
SENTINEL BRIDGE											
40	Sentinel Bridge	1994	0.73	66.22		99.19	32.97	157.5	0.21	1.05	1994
41	Sentinel Bridge	1994	1.77	19.51		119.83	100.32	130.7	0.77	1.07	1994
42	Sentinel Bridge	1994	2.64	16.66		148.25	131.59	150.0	0.88	1.10	1994
43	Sentinel Bridge	1994	3.06	30.27		270.21	239.94	147.0	1.63	2.04	1994
44	Sentinel Bridge	1994	2.06	67.71		215.30	147.59	165.0	0.89	1.72	1994

* X/S 33 168.54 bank scour

** X/S 34 243.38 bank scour

1 Highlighted numbers indicate no significant change. Ec is within measurement error.

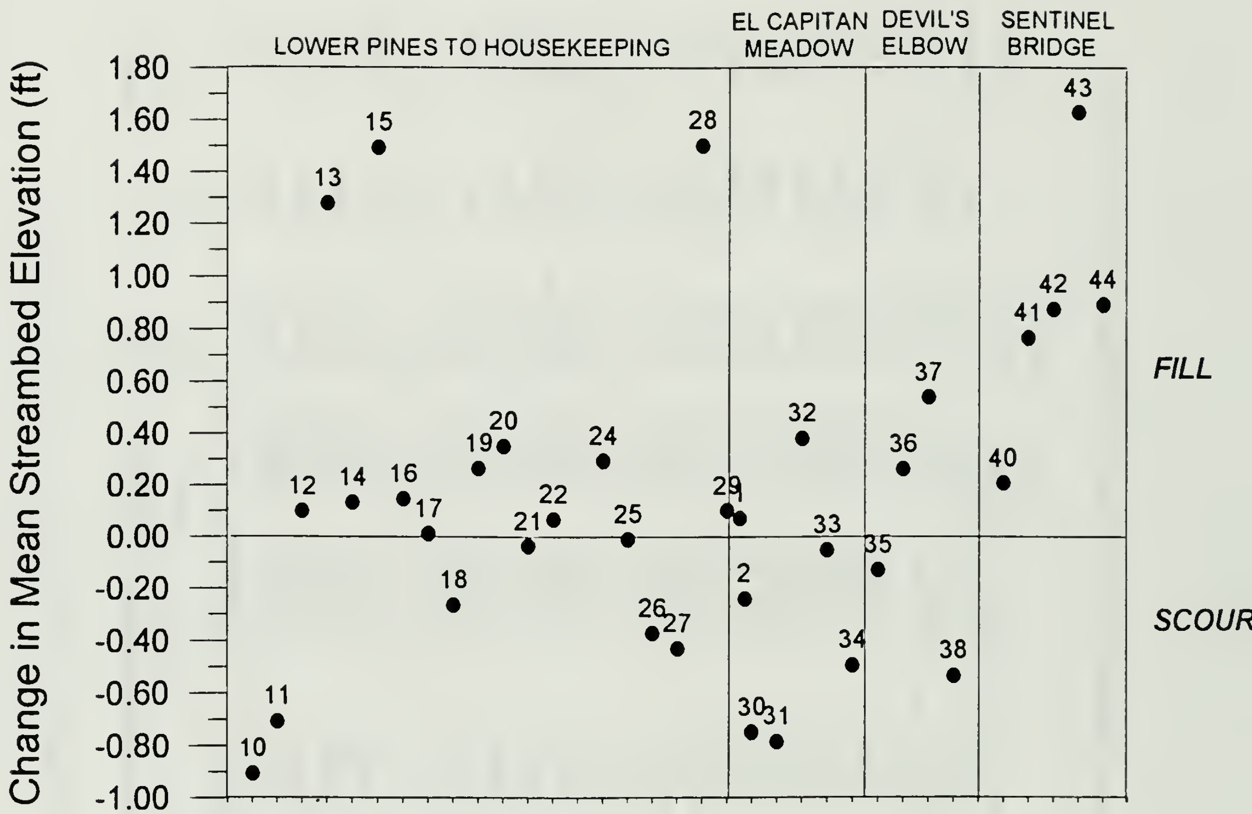


Figure 6. Change in mean streambed elevation for cross sections on the Merced River.

general, the Merced River channel filled upstream of Stoneman Bridge and near Sentinel Bridge. In the reaches of river near Sugar Pine Bridge, El Capitan Meadow, and Devil's Elbow the Merced River bed showed both scour and fill. Specific changes are discussed more fully in the following section.

Also, the stream bank was protected from erosion by riprap at several cross section locations, (XS 15, 15A, 16, 18, 22, 24, 28, 29, 32, 40, 41, 42, and 43), so the bank erosion documented by the cross-sectional surveys is less than what might be expected under natural conditions.

The cross sections are grouped into four general reaches, and study reaches are shown in Figure 3. These reaches do not necessarily correspond to the study reaches documented in other reports (Jackson and others, 1997; U. S. Fish and Wildlife Service, in progress). The following is a description of the channel changes in our study reaches. A brief description of treatments at Merced River restoration sites is included. The Merced River Restoration Report (Yosemite National Park, internal document) gives more detailed information on project sites, restoration techniques and revegetation efforts.

Lower Pines to Housekeeping Reach (X/S 10-29):

In 1989, 19 cross sections were established in this reach and extend from Clarks Bridge (X/S 10) downstream to Housekeeping Camp (X/S 29). Two additional cross sections (X/S 15a and 15d) are located in the overflow channel near the Lower Pines campground.

Figure 7 summarizes the changes in mean channel bed elevations at the 19 cross sections on the Merced River from upstream to downstream in this study reach. At six cross sections, the channel filled with sediment, at five cross sections the channel scoured, and at eight cross sections changes were within the survey error. When a channel aggrades (that is, fills in with sediment), the flood-carrying capacity of the channel may decrease because the area available to

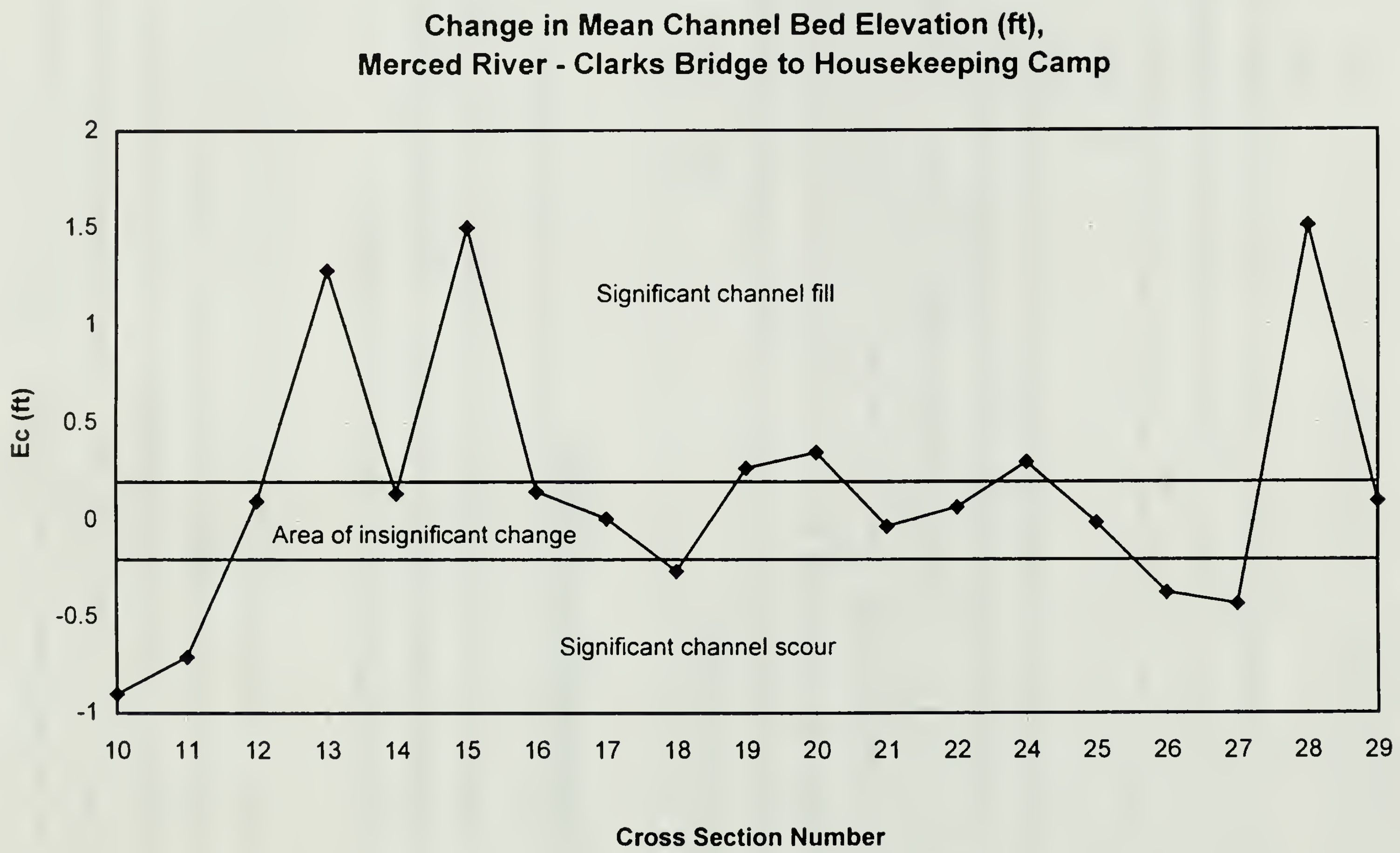


Figure 7: Change in mean streambed elevation due to the January, 1997 flood in the Merced River from Cross Sections 10 to 29.

carry flow is decreased. However, at most cross sections the channel area had already become larger due to past bank erosion (Madej and others, 1991), so the minor aggradation that occurred in the 1997 flood was not a factor in increasing the overbank flooding in Yosemite Valley. The following is a discussion of the specific channel changes that occurred in sections of this study reach .

From Clarks Bridge to Sugar Pine Bridge (X/S 10-15)

Channel response in this section was highly variable. Figure 7 is a plot of the change in mean streambed elevation, showing which cross section had net scour or fill after the flood. The lines connecting the observation points have no physical meaning, but are used to highlight the sequence of observations along the Merced River channel. The Merced River channel upstream of the Tenaya Creek confluence is wide and shallow, with low banks (Figure 8), and there is abundant evidence of past bank erosion. The cross sections upstream of the Tenaya Creek confluence show that this part of the channel scoured during the 1997 flood. Cross Section 10 and 11 scoured to a depth of almost one foot across the channel bed. At Cross Sections 12 and 14 the changes were within the survey error. At Cross Section the channel bed filled in with sediment to a depth of about three feet across much of the channel, with a mean streambed elevation increase of 1.3 ft. The channel at Cross Section 13 was influenced by the floodwaters of Tenaya Creek, and evidence for flow over the left bank was obvious at this location. This part of the channel has a more gentle gradient than the average for the study reach (discussed later). There may have been some decrease in flow velocity at this cross section, leading to deposition at this site during the flood.

At Cross Section 15, located on the upstream side of the Sugar Pine Bridge, the deepest point in the channel flipped from the right bank before the flood to the left bank after the flood, and the thalweg filled in 1.6 ft. A portion of the floodwaters at this point were diverted into an overflow channel due to the constriction of the channel by Sugar Pine Bridge. The overflow channel was partly constricted by road fill at its upstream end.

Figure 8: Looking upstream in the Merced River from Cross Section 12 towards Clarks Bridge, showing a wide, shallow channel and low streambanks. The stump at the left side of the photograph is in the active channel and provides evidence of past bank erosion.

From downstream of Sugar Pine Bridge to Stoneman Bridge (X/S 16-22)

In this section of channel, channel shape or geometry was not altered significantly by winter floods and the maximum change in thalweg was less than 0.4 feet. Immediately upstream of X/S 16, some flow was diverted out of the main channel and was flowing through the overflow channel in this area, so the main channel was not carrying all the floodwaters through this meander bend. Riprap along the right bank on the outside of the meander bend precluded bank retreat in this area. The river has a straight channel pattern between X/S 18 and X/S 22, where only minor changes occurred. There was some erosion of the right bank on X/S 18, where floodwaters from the overflow channel reentered the main channel of the Merced River. The U.S. Fish and Wildlife Service (USFWS) conducted more detailed mapping of the channel downstream of the Ahwahnee Bridge following the flood, which was used as one of their control reaches (in progress).

Overflow Channel (X/S 15a and 15b)

Topographic maps made in 1919 show several small overflow channels across the floodplain and meander bend downstream of the Tenaya Creek confluence (Figure 9-A). Since construction of the road, two bridges (Sugar Pine and Ahwahnee) and campground, the many small channels have been reduced to one overflow channel (Figure 9-B). This overflow channel has become wider and deeper during the last few decades for several reasons. Sugar Pine Bridge constricts the flow in the Merced River, and at high flows, water is diverted through the overflow channel. The 1919 maps show the topography with 2-ft. contour intervals, and so the probable 1919 stream dimensions can be reconstructed (Figures 10A and B). The roadway forms an artificial high right bank for the upstream part of the overflow channel (Figures 10A and 11). Prior to development, flood flows were distributed among several smaller channels across the meander bend. However, construction of the roadway (now a bicycle path) and the bridges focused floodwaters into a single channel. Because the smaller overflow channels that were present in 1919 are no longer functional, the floodwaters diverted into the single overflow channel have sufficient power to erode banks and scour the channel bed. Cross Section 15d (Fig 10-B)

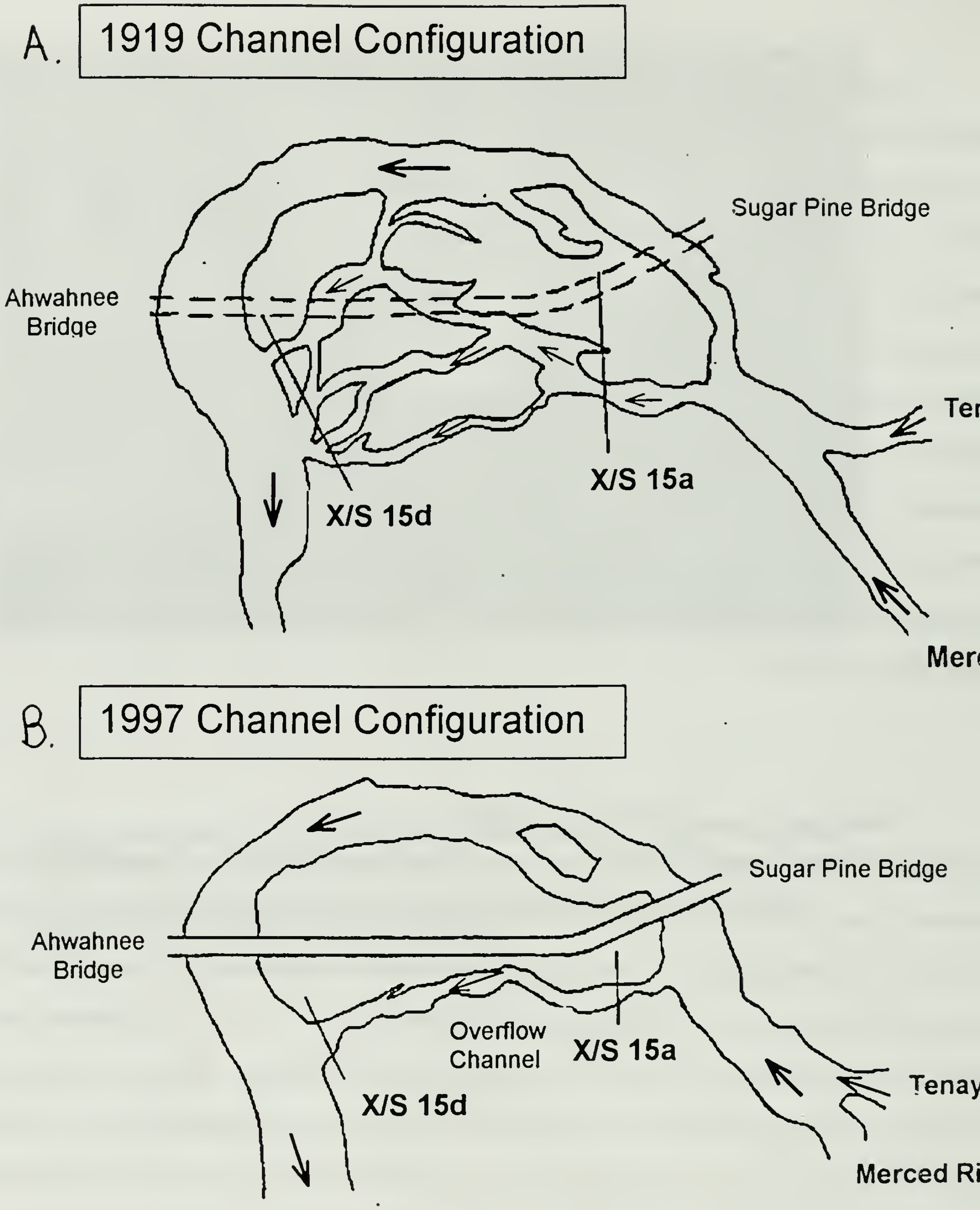
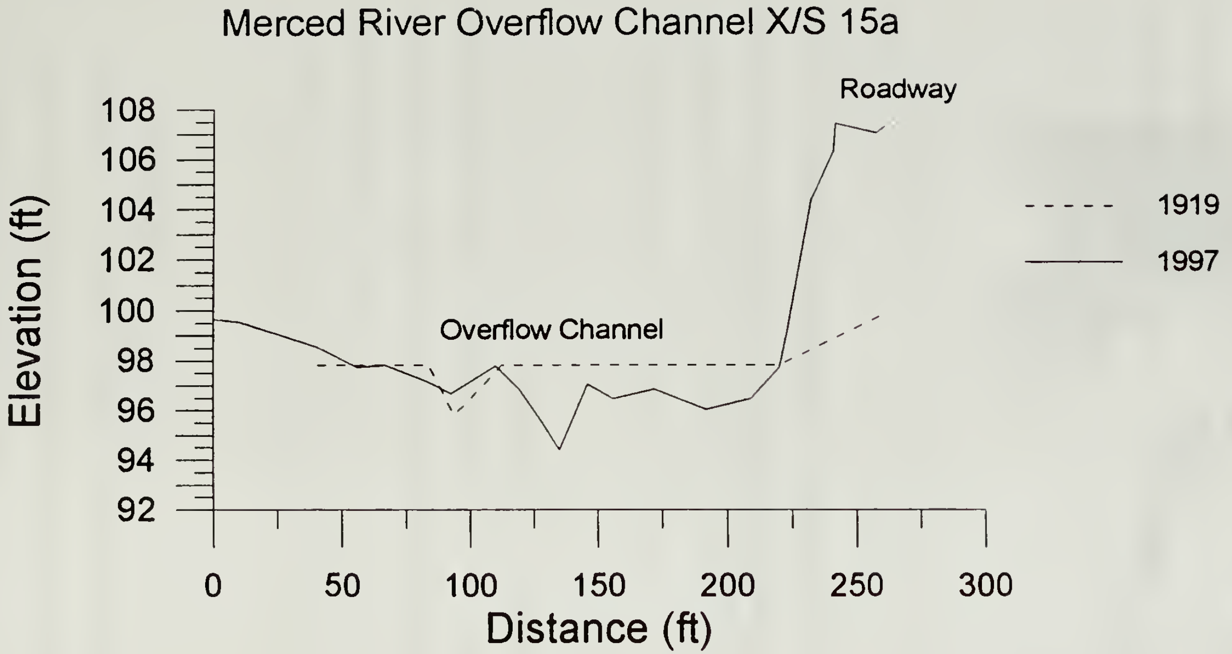


Figure 9: Plan map of the Merced River and overflow channel downstream of Tenaya Creek.
A) 1919
B) 1997



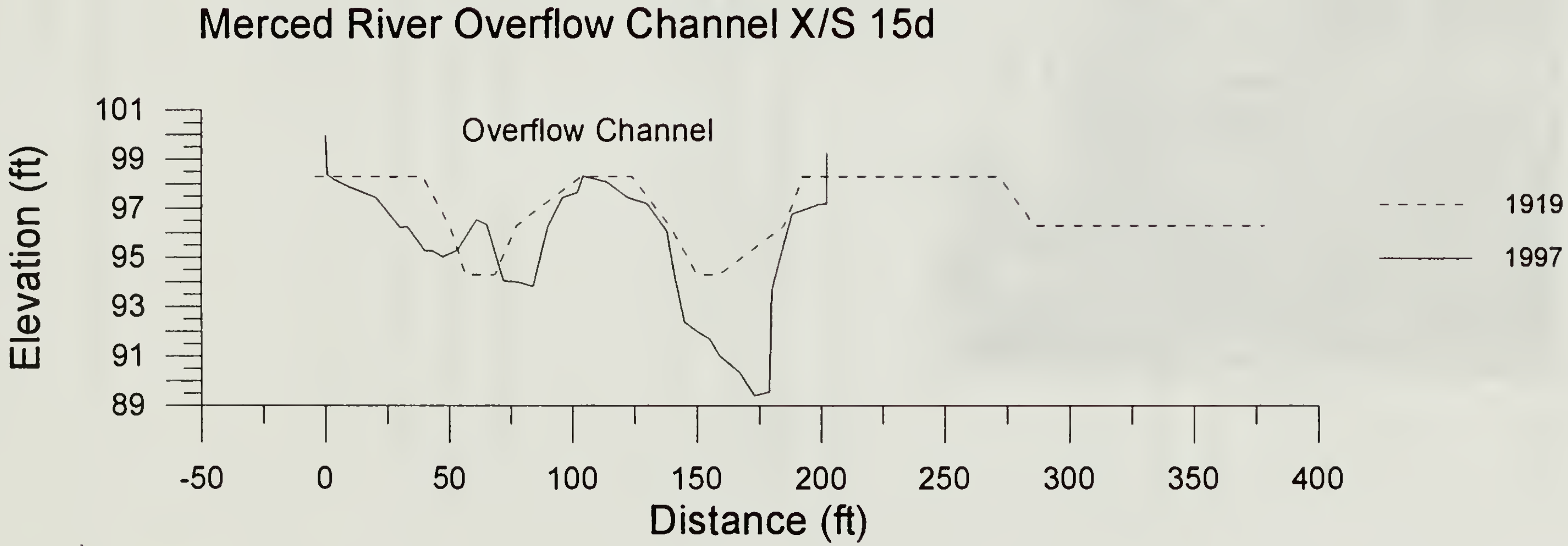


Figure 10: Plots of Cross Sections 15A and 15D in overflow channel, constructed from 1919 maps and 1997 surveys.

Figure 11: Looking downstream in the overflow channel near Sugar Pine Bridge. The road fill (right side of photograph) forms an artificially high, hardened bank. This channel has enlarged considerably since 1919.

indicates that both bank erosion and scour of the channel bed has occurred in the downstream portion of the overflow channel since 1919.

The 1997 flood caused only minor changes at Cross Sections 15a and d. Because the entire floodplain was inundated in this area, floodwaters were spread out across the valley floor, and little bank erosion occurred in the overflow channel. Large woody debris (discussed later) can cause bank erosion or channel scour, but little new debris entered the overflow channel. A large debris jam was deposited near the head of the overflow channel, but did not substantially change the flow patterns. If the woody debris had blocked Sugar Pine Bridge or had lodged directly in the overflow channel, bank and bed erosion would have been more extensive.

Restoration at Lower River Campground (X/S 24 & 25)

Two cross sections (X/S 24 and 25) are located in the Lower River Campground restoration site downstream of Stoneman Bridge. In the summer of 1991 and 1992, about 600 feet of the right bank was restored. Bank revetment (riprap) was removed and streambanks recontoured. Nine campsites were also removed from the river's edge. The terrace and streambank were revegetated and watered during the dry months in 1992.

At Cross Section 24, the mid-channel bar filled more than one foot in places and the thalweg scoured more than 3 ft. Downstream at Cross Section 25, the amount of fill at the cross section equaled the amount of scour. However, the right bank and mid-channel bar built out. Since 1992, the restored right bank has built out laterally about four feet at both cross sections. The USFWS has more detailed mapping of this reach (in progress).

XS 26 and 27

Cross Section 26 is in a straight section of river downstream of Stoneman Bridge and the restoration site (Figure 12). Only minor changes occurred at Cross Section 26 during the 1997 flood. The left bank is cohesive and relatively resistant to bank erosion. Minor deposition

Figure 12: Looking upstream from Cross Section 26 towards Stoneman Bridge.
A streambank restoration site is on left side of photograph, where scattered vegetation is growing on the banks.

occurred in the shallow right bank channel at Cross Section 27. The most prominent change in this area was the deep scour hole that developed in the main channel at Cross Section 27. The water was too deep and swift during the summer surveys to determine the cause of the scour, but surveyors commented on an obstruction (possibly a rootwad) at the bottom of the scour hole. A snorkel survey would help determine the cause of this pool, but because the scour was not threatening any infrastructure, it was not investigated further during this phase of the study.

Restoration at Lower River Housekeeping Camp (X/S 28 & 29)

Two cross sections were established in 1992 to monitor bank restoration immediately downstream of Housekeeping Footbridge. The right bank was restored and revegetated in 1992 and the left bank was treated in 1995. In 1992, a 950-foot section of the right bank was treated (Lower River Housekeeping project). This restoration included removing a paved path and relocating it farther back on the terrace. Riprap was also removed from the channel, and the streambanks replanted. Finally a fence was constructed to protect the project site. In 1995, 1300 feet of the left bank was restored (Housekeeping Camp project) and treatment included removing riprap revetment boulders, anchoring fifteen large logs (2-4 ft diameter and averaging 25 ft long) along the riverbank, and revegetating streambanks by brush layering and planting. In addition, 25 logs were placed across the terrace and a fence was constructed to protect the project site.

During the floods of 1997, no significant changes occurred on either bank. Willows growing on the right bank withstood the flood well (Figure 13). Cross Section 28 is located downstream of the scour pool at Housekeeping Bridge. Here, the section of channel bed extending from the center of the channel to the base of the left bank aggraded, and the thalweg elevation increased 1.5 feet. Cross Section 29 is located several hundred feet downstream of Cross Section 28 in a straight reach, and showed no significant change.

Figure 13: Looking downstream from Housekeeping Bridge, towards right bank of the Merced River. Willow plantings on the right bank survived the 1997 flood with little damage.

Sentinel Bridge Reach (Cross Section 40-44):

In 1994, five cross sections were established to monitor bank restoration and bank revegetation following the removal of the old Sentinel Bridge and construction of the new bridge. The streambanks at the old bridge site were recontoured and replanted, and native vegetation was replanted at all sites impacted by construction activities. Two cross sections are located upstream of the new Sentinel Bridge and three downstream.

In 1997, all cross sections in the Sentinel Bridge Reach aggraded. Figure 14 shows the Merced River upstream of the bridge at X/S 40. This site receives a high level of visitor use (as do many of the cross section locations in Yosemite Valley). In general aggradation increased in a downstream direction. Thalweg elevation increased between 0.7 to 3 ft. No significant bank changes occurred at these cross sections and aggradation was accommodated across the channel bed. The changes in mean channel bed elevation in this reach were among the highest measured in the August, 1997 survey (Figure 6). Most of the aggradation occurred downstream of the new bridge. This pattern (deposition in expansion areas downstream of bridge constrictions) is typical of past depositional patterns as well (Madej and others, 1991). The USFWS conducted more detailed channel mapping in this area (in progress).

Near this restoration site, a valuable record of previous flood inundation levels was found marked on a garage wall near the old Superintendent's House near Yosemite Creek (Figure 15). The 1997 flood level was higher than any of the previously marked floods. As buildings are modified in post-flood reconstruction, it is important to clearly document these flood levels to be used in future studies. We recommend the installation of inconspicuous crest staff gages at various locations in the floodplain to help determine the extent and depth of future flooding.

Figure 14. Looking upstream from the newly constructed Sentinel Bridge and Cross Section 40. Although most of the streambanks are well vegetated, high visitor use in localized areas results in some bare, trampled areas.

Figure 15: A record of high water marks from past floods on the garage wall of the old Superintendent's House (Residence 1) had been kept by Yosemite National Park staff. Fingers point to high water marks from (bottom up): 5-16-96, 12-23-41 (44" above floor), 11-19-50 (66"), 12-23-55 (70"), 1983 - Hole in top of doorway, and 1-2-97 - Ceiling of garage.

El Capitan Meadow Reach (Cross Section 1, 2 and 30-34):

There are seven cross sections located in this reach. Five were established in 1992 to monitor restoration along the right bank of the Merced River. Three other cross sections (X/S 1 -3) were established in 1989 but only two (X/S 1 and 2) were relocated and resurveyed. The right bank of Cross Section 33 and 34 are located in the former El Capitan dumpsite. Cross Sections 30 to 32 are located in the restored El Capitan picnic area and Cross Sections 1 and 2 are located within a few hundred feet upstream.

In 1991, restoration at the dumpsite began. This work included: 1) removal of dumpsite materials adjacent to the river's edge on the right bank, 2) restoring the terrain at the site to match the surrounding natural topography, 3) replanting the terrace and exposed streambank, and constructing a fence to protect the project site.

Restoration of the El Capitan picnic area began in the summer of 1992 and revegetation work continued through 1994. Riprap was removed from more than 330 ft of the right bank and 630 feet of bank was replanted. In addition, two parking lots were removed and the terrace surface decompacted, replanted and an irrigation system installed.

The most significant channel changes due to the 1997 floods were observed in this reach. In general, cross sections scoured in this reach and significant bank erosion occurred on the right bank at all the cross sections in the area of the El Capitan picnic and dump restoration site (X/S 30-34). The average bank erosion at five cross sections in this reach was 21 ft, and the maximum bank erosion observed in the reach was about 43 ft. Figure 16 shows the erosion and treefall that was typical along the right bank in this reach.

The type of channel changes observed in this reach following the 1997 flood were not uncommon historically. Although the river gradient in this reach is gentle, natural channel

Figure 16: Looking downstream at the El Capitan Restoration Site. During the 1997 flood, a new sand and gravel bar built out along the left bank and about 30 ft. of the right bank eroded. Woody debris accumulated along the right bank, where trees fell and logs floated in from upstream reaches. Floodwaters overtopped the right bank and flowed across the floodplain, resulting in some sand deposition and minor gullying on the floodplain surface.

meandering and lateral shifting are common (Madej and others, 1991). During flooding in the early 1960's the river channel meandered one full channel width exposing the materials in the dump along the right bank for a length of 75 ft (Yosemite National Park, 1995). In 1997, floodwaters overtopped the right bank and flowed across the floodplain on the meander bend in this reach. Fresh gullies up to 3 ft deep on this floodplain were oriented in line with this overbank flow. Floodwaters coming from the straight reach upstream directly flowed against the right bank, and the force of this water on newly planted banks, as well as water flowing over the bank and across the floodplain, probably caused the bank erosion. Flow velocities here may have been greater than at the downstream Devil's Elbow Restoration site because of ponding by a downstream moraine (Jackson and others, 1997), but more detailed floodplain mapping would be necessary to determine high water marks, floodplain gradient, and size of material moved across the floodplain. More detailed channel mapping in this reach was conducted by the USFWS (in progress).

Large woody debris plays an important role in influencing channel change. Several trees along the banks are now leaning into the channel, and several trees fell from the right bank during the flood. Although treefall is a natural process, as described in Section II, the fallen trees may have accelerated scour at the base of the right bank, leading to bank retreat. Nevertheless, large woody debris is an important component of aquatic habitat.

Devil's Elbow Reach (Cross Section 35-38):

In 1992, four cross sections were established in the Devil's Elbow Reach to monitor changes associated with restoration and revegetation work on the right bank. The restoration work was located on the outside of a large meander bend in the Merced River. In 1993, the Devil's Elbow picnic area and parking lot were removed from the right bank and soils were decompacted. Along the streambank, areas of steep slopes were revegetated using a brush layering technique, and all other areas were replanted with native vegetation. During the summer of 1994, all

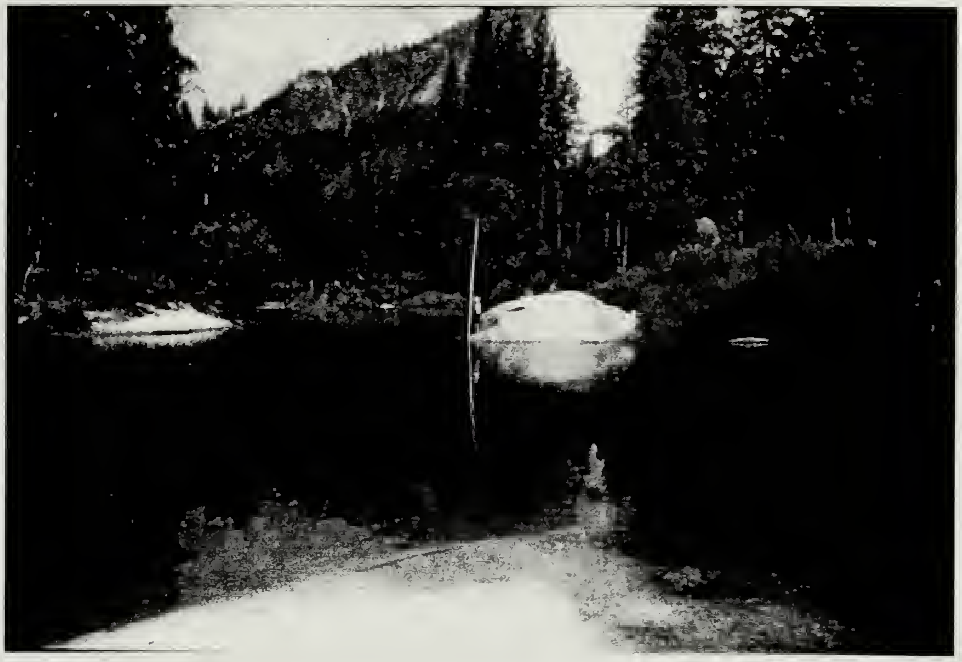


Figure 17: Looking downstream from Cross Section 36 in the Devils Elbow Reach. Person is holding a stadia rod vertically as a scale. Pool depth at the large boulder is 14 ft. during summer low flow. Willows planted along the right bank in the fall of 1993 withstood the 1997 flood with little damage.

plantings were irrigated to establish a strong root system.

In 1997, the middle two cross sections filled, the upstream-most cross section scoured, and the downstream cross section showed no significant change. No major channel changes occurred in this reach, and the plantings on the right bank survived the flood with little damage (Figure 17). In general, the total amount of fill at cross sections was about equal to the total amount of scour for the reach. More detailed mapping of this reach was conducted in 1997 by the USFWS (in progress). Less erosion occurred at this restoration site than at the El Capitan site. There are several possible reasons for the success of this site. Vegetation was better established at this site because of irrigation of the young plants (Yosemite National Park, personal communication).

Also, this area of the valley is near the El Capitan Moraine, which forms a hydraulic control for the central chamber of Yosemite Valley (Jackson and others, 1997). Although the valley was inundated here during the 1997 flood, flow velocities were not as high as in upstream reaches (Jackson and others, 1997). Floodwaters were flowing over the floodplain along the inside of the meander at the left bank, and it is probable that the outside of the bend where the restoration plantings were located (on the right bank) was not subjected to extreme forces.

B. LONGITUDINAL PROFILE SURVEYS

Surveys of the deepest part of the channel in a downstream direction (longitudinal profile, or thalweg profile, surveys) are used to document changes in pools and riffles in a reach. When such surveys are repeated over a number of years, the changes in pool form and aquatic habitat can be documented and related to floods, land use changes, input of large woody debris, etc. Thalweg profiles are used to characterize the number, depth and distribution of pools, which are important components of aquatic habitat. No previous data on longitudinal profiles showing this level of detail of the Merced River were found. A profile was surveyed in 1997 to characterize stream gradient, pool distributions and depths, pool-forming obstructions, and substrate

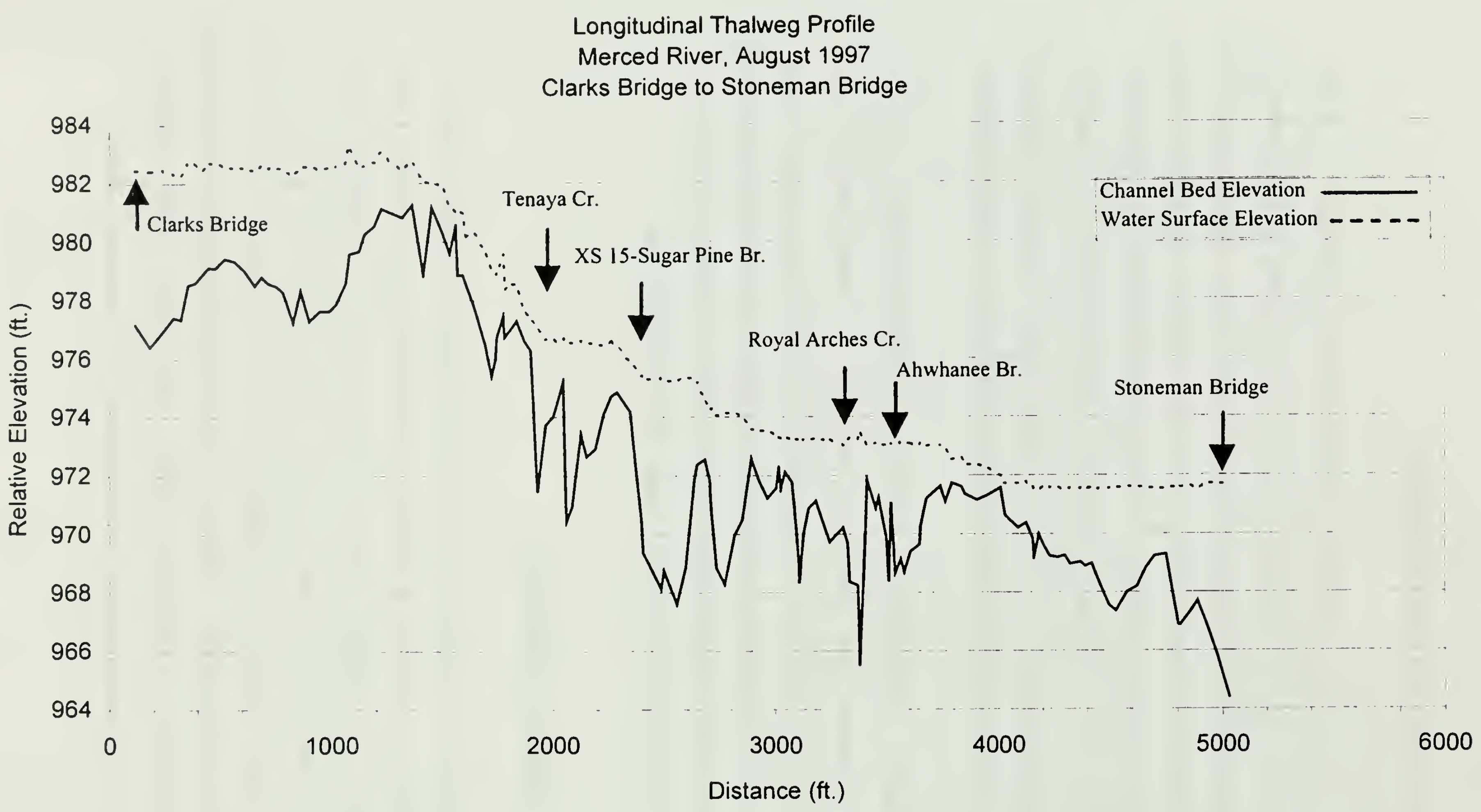


Figure 18: Longitudinal Profile of the Merced River from Clarks Bridge to Stoneman Bridge

composition. This survey can be used as a baseline against which future channel changes can be compared. A separate longitudinal profile and map were surveyed across the floodplain downstream of Clarks Bridge to determine the gradient and hydraulic characteristics of the floodwaters (discussed later).

Stream Gradient

The thalweg (deepest part) of the Merced River was surveyed on August 7, 1997, and the survey data are included as Appendix B. The survey began at the upstream side of Clarks Bridge and extended downstream to Stoneman Bridge, a channel distance of about 5000 ft. (Figure 18). This is part of Reaches 4 and 5 as described by Jackson and others (1997). A total station was used to survey the channel upstream of Sugar Pine Bridge, and an automatic self-leveling level was used to survey the channel downstream of that point. Both the channel bed and the water surface were surveyed. Points were surveyed at every break in slope in the channel bed to define all pools, riffles and other channel features. Average spacing between survey points was 30 ft. Channel distances were measured with a fiberglass tape which was placed on the ground adjacent to the left edge of water in the channel. We were not able to measure the centerline distance of the channel because the depth and velocity of the flow were too high. The left bank distance as measured by the tape underestimates the centerline distance slightly between the Sugar Pine and Ahwahnee Bridges because of a large bend in the river. Water depths were measured with a stadia rod. The dominant channel bed substrate and other channel features were also recorded at each survey point.

The average slope of the river channel in the surveyed reach is 0.30 %, which represents a fall of 15.8 ft over a one-mile reach of river. In this reach 19% of the channel is classified as riffle habitat. There is a steeper section between channel distance 1300 and 2300 ft (Figure 18), with a more gentle grade near Clarks Bridge.

Pool Depths and Frequency

Although at first glance an observer may think the bed of the Merced River is smooth, the thalweg profile (Figure 18) shows there is considerable variation in the streambed profile. Some of the deepest parts of the channel are associated with man-made structures (surveyed water depths are in parentheses): Clarks Bridge (6 ft) Sugar Pine Bridge (7.6 ft), a water intake near the confluence of Royal Arches Creek (8 ft), the Ahwahnee Bridge (4.7 ft) and Stoneman Bridge (> 8 ft). Scour at the base of riprap, groins, or pieces of cement along the left and right streambanks caused minor pools (2 - 4 ft deep). Natural features also caused a few pools. A large boulder downstream of the mouth of Tenaya Creek caused a 6.1 ft scour pool, and scattered stumps along the banks were associated with pools 3 to 5 ft deep. There were few logs within the low flow channel in this reach, although farther downstream (near the El Capitan reach) instream woody debris is an important factor in pool formation.

The residual water depths of all pools in this reach were calculated. A residual pool depth is a useful monitoring tool because it is a measurement that is independent of the amount of flow in the channel, and can be used to compare pools from season to season or year to year. It is defined as the depth of a pool below the downstream riffle crest (Lisle, 1987). Residual pool depths are always less than or equal to the surveyed water depth, because a residual depth is equivalent to the depth of water in a pool at zero flow. Figure 19 is a histogram showing the distribution of residual pool depths for this reach of the Merced River. Ten pools with residual depths of greater than 2 feet were recorded, with a mean depth of 4.2 ft. These pools are shown in Figure 20. A two-foot threshold was used as the cutoff to define a pool (that is, an area of slow, flat water at low flow) based on field observations.

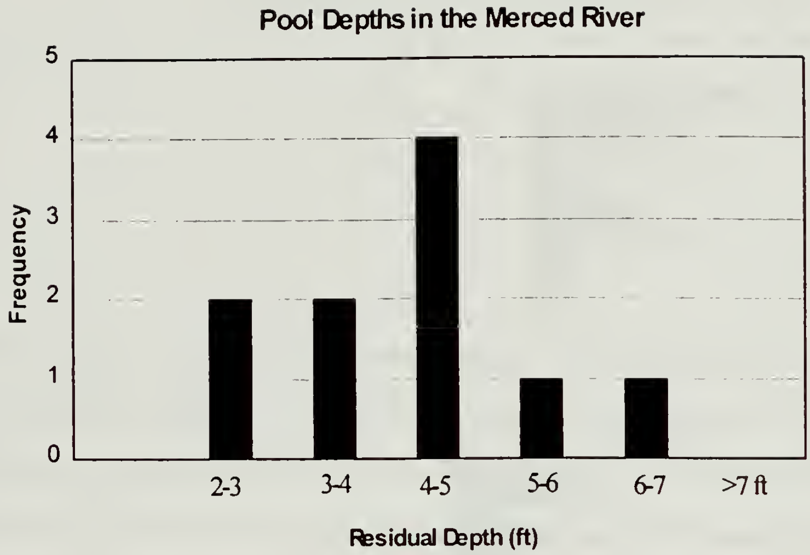


Figure 19: Frequency Distribution of Residual Pool Depths, Merced River, 1997.

Channel Bed Substrate

The type of material found in a channel bed influences what type of aquatic invertebrates live in the stream. A sandy bottom supports different fauna than a bouldery bed. Channel substrate also influences the stability of the channel bed. For example, small gravel and sand can be mobilized at relatively low flows, whereas cobbles and boulders require higher flows to transport them. Land use changes, fires, large landslides, etc. can cause changes in the size of channel bed material. The following represents a general description of channel bed substrate in the reach of river downstream of Clarks Bridge, which can be used as a baseline for future studies. The dominant particle size of the channel bed was recorded at each survey point in the longitudinal profile, based on visual observation.

The terminology used is:

Substrate Class	Diameter (mm)	Diameter (inches)
Sand	<2	< 0.1
Gravel	2 to 64	0.1 to 2.5
Cobble	64 to 256	2.5 to 10
Boulder	> 256	> 10

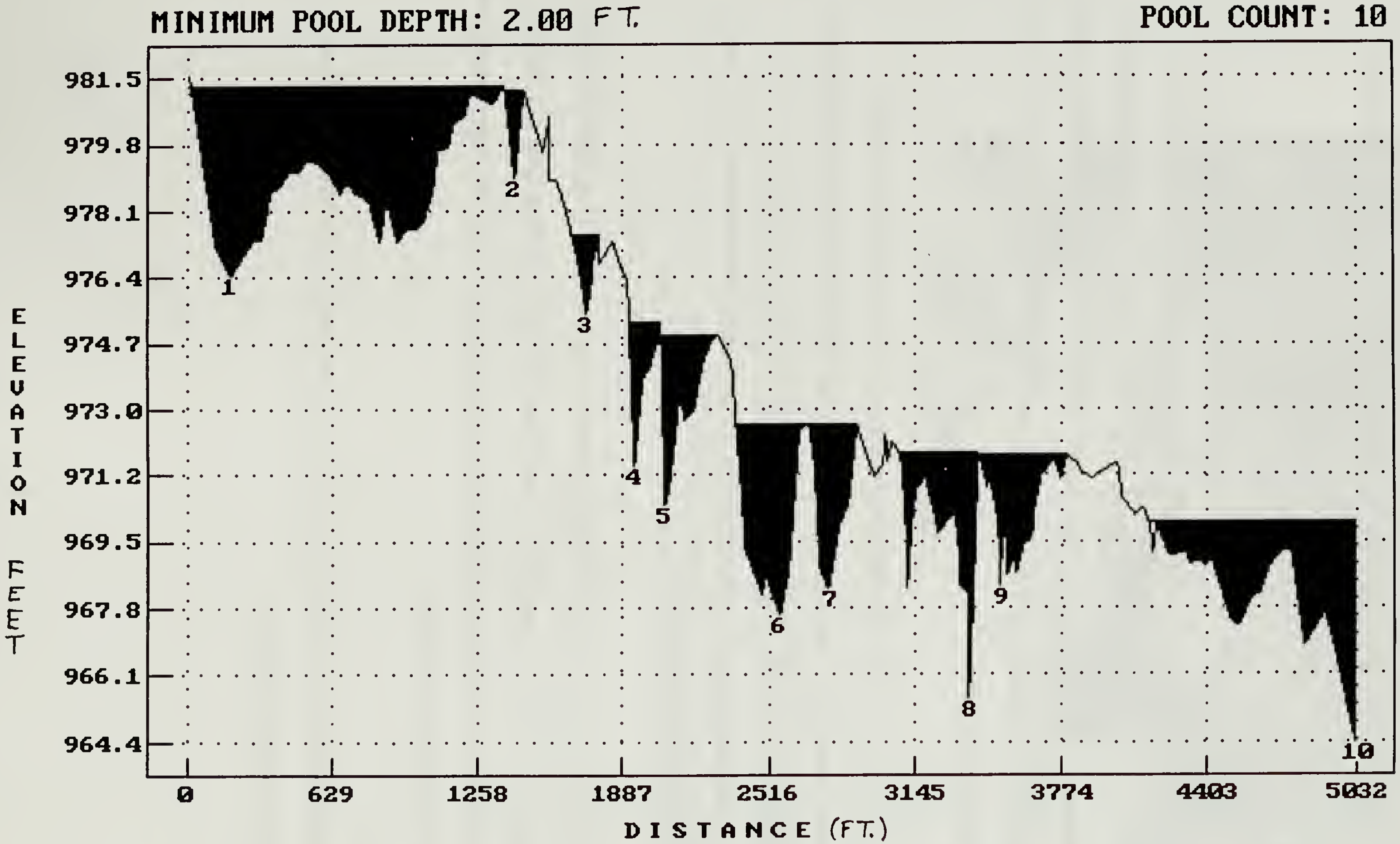
In the surveyed reach, 54% of the thalweg bed was dominated by sand, 28% by cobble, 12% by gravel and 6% by boulders. These values are meant only to provide a general description of the channel bed, but are not to be used for quantitative analysis. For example, even in areas where the "sand" category was dominant, many fine pebbles (small gravel) were commonly included as well. If the park needs accurate measurements of bed particle size for descriptions of aquatic habitat, calculating sediment transport rates, or other purposes, more intensive sampling of the bed material is required.

Hydraulic Information

Hydraulic information (flow depths and velocities, water slope) is useful to help interpret the damage to infrastructure in Yosemite Valley. Longitudinal profile surveying and floodplain mapping document hydraulic characteristics of the flood flow through Lower Pines Campground. Some of the standard hydraulic calculations require metric units, so the following discussion reports results in both metric and English units.

During the January 1997 flood, the Merced River was flowing over its floodplain at Lower Pines Campground. Abundant evidence on the floodplain indicates that the floodwaters in this area were traveling with moderately high velocity. We mapped the floodplain, noting areas of fresh sand deposits, asphalt parking areas that had been ripped up and scoured by the flood waters, bear-proof food cabinets made of heavy metal that had been knocked over, picnic tables and logs.

MERCED RIVER, AUGUST, 1997
CLARKS BRIDGE TO STONEMAN BRIDGE



Mean Pool Length: 406.14
Mean Riffle Length: 106.92
Mean Distance Between Pools: 538.80
Mean Distance Between Riffles: 407.90

Figure 20: Distribution of pools in the Merced River. The colored areas represent pools with residual water depths > 2 ft. deep.

that were carried some distance, scour around the restroom facilities, and cobble-sized particles (64 mm in diameter) which had been transported across the floodplain surface (Figure 21). These pieces of flood evidence were most prominent at and downstream of the confluence of Tenaya Creek

We surveyed high water marks and the ground surface across the floodplain. The gradient of the high water marks across the floodplain was 0.45%, which is substantially steeper than the channel gradient of 0.30%. This is to be expected, because the floodwaters were traversing a shorter distance across the floodplain than if the waters had stayed confined in the longer channel in the meander bend. The average depth of inundation on the floodplain across from the Tenaya Creek confluence was one meter (3 ft).

It would be useful to know how fast the floodwaters were traveling across the floodplain, because the faster the water, the more likely damage would occur to both natural resources and human-made structures. The following is a description of how we estimated the force and velocity of water during the floods. For readers who do not wish to know the technical details, they may skip the next four paragraphs.

Moving water constitutes a force across the channel bed. Since the force is applied in the same direction as the flow, it is called a shear force. Shear force divided by area is called a shear stress, usually denoted by τ (Dingman, 1984). The common definition of boundary shear stress (the shear stress on the channel bed) is:

$$\tau_0 = \gamma D S$$

where γ is the weight density of water, D is the depth of flow, and S is the energy gradient (approximated by the channel slope).

Figure 21: The Lower Pines Campground was severely damaged by overbank flooding. Asphalt roads and parking sites were ripped up, and picnic tables and restrooms were damaged. The person is standing next to a heavy metal food cabinet with four cement footings that was completely overturned during the flood, and filled with sand and gravel. Such evidence attests to high flow velocities in this area during the flood.

Experimental data led Yalin and Karahan (1979) to develop relationships between how large a particle can be moved and a particular shear stress. The critical sediment diameter (d_c) that can just be eroded by a given flow can be approximated as:

$$d_c = 13.7 \, D \, S,$$

where D is depth in meters, and S is the slope (Dingman, 1984).

In the case of the Merced River, water flowing over the floodplain in Lower Pines Campground should have been forceful enough to move a particle:

$$d_c = 13.7 \times (1 \text{ m deep}) \times (0.0045) = 0.06 \text{ m or } 60 \text{ mm in diameter.}$$

This prediction is in excellent agreement with the field observations of 64 mm cobbles recently transported across the floodplain. The campground and floodplain surface was quite smooth, with no low-lying ground vegetation, and many asphalt surfaces. Gravel and cobble movement was not constrained by imbrication (packing) of gravels or the opportunity to hide behind larger boulders. This means that once sand, gravel, and cobbles were carried to the surface of the floodplain, they could easily be transported by the floodwaters across the campground area. Bear-proof food cabinets in the campground that were filled with gravel are testaments to the ability of the floodwaters to transport coarse sediment across the floodplain (Figure 21).

This analysis can be extended to compute the velocity of the flow under flood conditions (Dingman, 1984, Equation 8-35 and Figure 8.8). The critical velocity to move 60 mm particles across this floodplain with a depth of flow of one meter is about 2 m/sec (about 6.5 ft/sec). The Manning equation (Dingman, 1984) can also be used to estimate the velocity across a floodplain that has a fairly smooth surface (such as a gravel or light grass surface, with a roughness value of Manning's n = 0.20). This method produces a velocity estimate of 5 ft/sec. These values of 5 to 6.5 ft/sec are higher velocities than that estimated in the reach downstream of Sentinel Bridge, where a backwater effect from the El Capitan Moraine was affecting the floodwaters (Jackson and others, 1997).

Commonly floodplains have higher roughness values (Manning's n = 0.7 to 0.9) due to thick vegetation (Barnes, 1977), and floodwaters do not have such high velocities. Nevertheless, the flood velocities estimated here are not unrealistic, considering the smooth campground surface, the lack of resistance from bushes or other understory vegetation, and the relatively steep floodplain surface (compared to large, lowland rivers). The high velocity of floodwaters through the campground was responsible for much of the damage to the infrastructure, and their is the risk of periodic flood damage to infrastructure in the future. Park management should acknowledge this risk, anticipate high velocities in future overbank flooding, and relocate critical facilities outside of these high velocity areas.

There is little previous work dealing with the hydraulic characteristics of the Merced River floodplain. The USGS made hydraulic calculations of roughness and velocity at four cross sections near its gage at Happy Isles Bridge. For example, at a moderate flow of 1950 cfs, Manning's n was 0.065, mean bed particle size was 253 mm (10 inches), channel width was 63 to 78 ft., mean depth was 4 to 4.9 ft., and mean velocity was 6 to 7.4 ft/sec (Barnes, 1977). This shows that high velocities should be expected in the Merced River during floods, and that the roughness values in an undisturbed reach of stream are high. However, these values cannot be extrapolated to the downstream study reaches because the channel is steeper, narrower and coarser at the gaging station than it is farther downstream where the National Park Service cross sections are located. Nevertheless, the roughness of the floodplain in the Lower Pines Campground area under pristine conditions was probably much higher than at present. Revegetation of the floodplain surface and streambanks wherever possible would help reduce the velocity of overbank flow during future floods.

C. TREEFALL AND LARGE WOODY DEBRIS LOADING

Treefall along streambanks and the transport of down trees during the 1997 flood greatly influenced the channel changes documented above. Treefall contributed large volumes of woody debris to the channel, especially in Tenaya Creek. Also, many trees had fallen previously from a large rockfall near Happy Isles, where about 30 trees were brought into the channel. Where fallen trees entered the river and where woody debris was transported and deposited influenced patterns of bank erosion, scour and deposition of sediment.

No previous information on large woody debris loading in the Merced River in Yosemite Valley was found. Documentation of all fallen trees along the river corridor was beyond the scope of this project, but an initial assessment of woody debris loading was conducted downstream of Clarks Bridge. The purpose of this assessment was two-fold: 1) to develop a protocol that would be useful to document the size, type, location and function of woody debris in the Merced River, and 2) to provide park management with baseline data on large woody debris loading in a short reach of the Merced River.

Large woody debris in the river channel has been identified as an important structural control in providing aquatic habitat (Bisson and others, 1987). Wood can provide cover for fish and cause scour pools in the channel bed. Wood can alternately protect a streambank from erosion or cause bank erosion, depending on its size and orientation to the flow. The USFWS also conducted surveys of woody debris in several study reaches (in progress) and their estimates of debris loading can be compared to those in our study reach.

Large Woody Debris Inventory

Redistribution and input of large woody debris by floods is common. The effect of large floods on woody debris in the Merced River is unknown because no data on large woody debris had been collected prior to this survey.

In March 1997, Yosemite National Park staff conducted a reconnaissance of large woody debris along the Merced River from Clark's Bridge downstream to below Devil's Elbow. The purpose of the inventory was to document large woody debris input following the 100 year flood experienced in January of that year. Information was plotted on a GIS base map showing the general orientation in the channel, the tree species, diameter (measured 5 ft. from roots) and location of log jams. Also noted was whether the tree was anchored or the roots were free. During the summer of 1997, staff reinventoried large woody debris from Clark's Bridge downstream to Sugar Pine Bridge.

Large woody debris was defined as a piece of wood greater than 10 feet long and more than 0.5 feet in mean diameter or root wads greater than 3 feet in diameter. For each piece of wood that met the criteria, tree species, total length, length of log in the channel, and mean diameter was recorded. Other information collected included whether a root wad was attached to the log, and orientation downstream (angle from the bank) for pieces of wood in the channel. Each piece was also evaluated for the input mechanism; that is, contribution of wood to the channel due to bank undercutting, windthrow, mass movement, if it floated in, or if undetermined. In addition, a Decay Class Rating from I to V was assigned. The decay class rating was a subjective measure of the quality of the wood. Logs with a Decay Class of I were fresh pieces of wood and a Decay Class of V indicated the log was rotten and falling apart. Also recorded was if the wood was a single piece or part of a group, and locations of wood were plotted on a GIS base map. The volume of large woody debris was calculated for each piece using the following equation:

$$\text{volume} = \text{pi} \ \times \ (\text{radius})^2 \ \times \ \text{total length}$$

Results

In the past, this reach has been managed for hazard trees and any identified hazard tree along the bank was removed. In-channel woody debris was also removed because of the perceived hazard to bridges and rafters. In the mid-1990's, the woody debris removal program was discontinued in this reach. This new policy provides an ideal opportunity to document natural woody debris loading associated with a large flood and to differentiate loading rates from floods versus annual or background rates.

A total of 94 pieces of wood were inventoried in the 2400 foot long section of channel from Clarks Bridge to Sugar Pine Bridge. Seven groups of large woody debris and 14 individual pieces of large wood were mapped.

Fifty-nine percent of the wood in this reach was included in three large woody debris piles or log jams. All debris piles were located on the left bank outside the summer low flow channel and did not influence the summer flows or contribute to summer aquatic habitat. The largest groups of wood were located at the upstream end of the overflow channel at Sugar Pine Bridge.

Figure 22 is a histogram of the mean diameter of wood pieces in four diameter class sizes: small (0.5-0.9 ft), medium (1.0-1.5 ft), large (2.0-2.9 ft), and very large (>3.0 ft). Class sizes were based on class sizes used by Ruediger and Ward (1996) for a large woody debris inventory for the Stanislaus National Forest, California. About 72% of the wood inventoried (68 pieces of large woody debris) had a mean diameter between 1 to 1.5 ft. Of the wood in the largest size class (> 3 ft), the largest four out of six pieces were root wads.

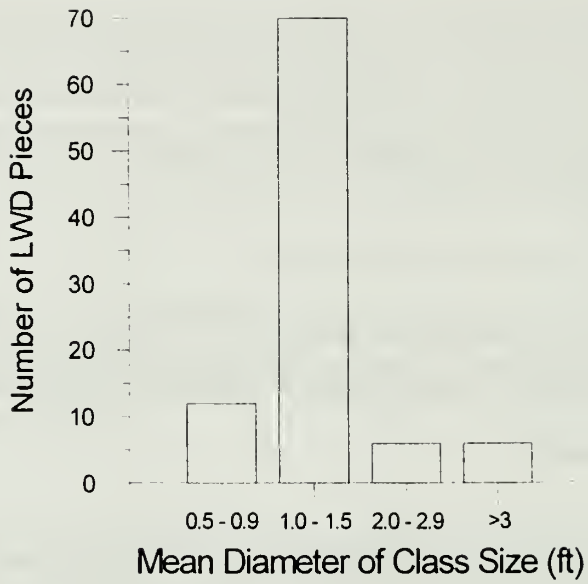


Figure 22: Distribution of large woody debris (LWD) by mean diameter, in the reach from Clarks Bridge to Sugar Pine Bridge.

Large woody debris did not influence sediment storage and provided little influence to channel structure in this section of the Merced River. Less than ten percent of the wood (8 pieces) was located within the bankfull channel in the reach and those pieces accounted for less than ten percent of the total volume of wood. In general, these logs were parallel to the bank and never angled more than 50 degrees from the bank in a downstream direction. Only three logs formed scour pools along the bank, with depths ranging from 3 to 5 feet. None of the wood significantly influenced sediment retention and no accumulations of sediment were observed upstream or adjacent to wood. Nearly all (>90%) of the large woody debris in this reach is only available during very large flood events; that is, when floodwaters occupy the overflow channel or flow across the floodplain.

The density of woody debris loading in this reach that had an effect on summer aquatic habitat or channel structure averaged about 1 piece per 100 m (density data reported in the literature is in metric units). This woody debris density was significantly less than for other reaches of the

Merced River in the Yosemite Valley (Table 2). However, the density of large woody debris averaged 9 pieces per 100 m.

Table 2: Density of large woody debris loading in the Merced River			
Site	Number of Pieces of Wood	Approximate Length of Reach (m)	Mean Density (#/100m)
Merced River			
Clarks Bridge to Sugar Pine Bridge	8	730	1
Ahwahnee Bridge Control[1]	28	300	9
Stoneman Bridge Restoration[1]	13	110	12
Stoneman Bridge Control[1]	13	190	7
Sentinel Bridge Restoration[1]	15	180	8
El Capitan Picnic Area[1]	28	260	11
Devils Elbow Restoration[1]	16	100	16

[1] USFWS preliminary data subject to revision

Average density of wood loading on the Merced River was significantly less than the density observed on unmanaged reaches (18 pieces/100 m), but was similar to the second growth riparian reaches (9 pieces/100m) in the Stanislaus National Forest (Table 3). The similarity between mean woody debris density on the Merced River and second-growth riparian reaches on the Stanislaus National Forest is probably an artifact of the past management of riparian trees along portions of the Merced River. Ruediger and Ward (1996) found that density of large woody debris on Sierra Nevada streams, on average, was lower than in streams in the Coast and Cascade Ranges of Oregon. Our preliminary results support their findings.

Table 3. Comparison of density of large woody debris on the Merced River with streams in the Stanislaus National Forest. Study reaches vary in length.

Site	# Study Reaches	Mean Density (#/100m) Mean (range)
Merced River, Yosemite Valley[1]	7	9 (1-17)
Stanislaus National Forest[2]		
Unmanaged (no stumps in riparian area)	57	18 (1-50)
Salvaged (some stumps in riparian area)	18	13 (1-60)
Second Growth (riparian area harvested)	18	9 (1-24)

[1] USFWS preliminary data subject to revision

[2] Ruediger and Ward, 1996

The longitudinal profile of this reach (see previous section) documented five pools along the deepest part of the channel. These pools were associated with man-made structures or boulders, and not woody debris.

Large woody debris did not span the channel in this reach. The bankfull channel widths (average 194 ft) in this reach were significantly wider than the average length of large woody debris (averaged 46 ft and ranged from 8 - 133 ft). Extensive bank erosion occurred here in the past, making it even more unlikely that fallen trees would span the channel.

Observations of large woody debris loading are specific to this reach. Other sections of channel had different responses to the flood and differing amounts of debris loading and corresponding function in the channel. Farther downstream woody debris plays a more important role in the channel and providing instream habitat and structure (see USFWS report in progress).

IV. SUMMARY

The results of our studies support the conclusions and recommendations made by Jackson and others (1997). Their recommendations included setback of infrastructure from the river as much as possible, locating more valuable structures higher in the floodplain, and accepting the risk of occasional inundation. The Valley Implementation Plan is consistent with restoring natural processes and effective floodplain management. In most of the areas studied, the damage to natural resources was minimal, and restoration sites withstood the high flood levels without many problems. Most of the problems associated with the flood involved buildings, roads and other infrastructure rather than damage to the Merced River channel.

The January, 1997 flood was the largest recorded by the U.S. Geological Survey, which began in monitoring water flows in the Merced River in 1916. Although this particular flood is estimated to be a 100-year flood (Jackson and others, 1997), overbank flooding in Yosemite Valley has occurred several times in the last few decades. Future flooding should be expected every 10 to 20 years, and park infrastructure and planning need to reflect the reality of occasional overbank flow and inundation of much of the Valley floor. Damage in Lower Pines Campground was especially severe in the downstream portion, where the elevation of the floodplain was lower than the upstream campground, and flow from Tenaya Creek influenced the hydraulics of the floodwaters. Similar conditions should be expected in future flooding. Moderately high velocities of 5 to 6 ft/second in floodwaters crossing this floodplain resulted in the transport of picnic tables, ripping up of asphalt, scour around restrooms, deposition of coarse sediment, etc. If the floodplain were heavily vegetated, floodwater velocities would be lower; however, if the campground is to remain open, park management must realize periodic flooding of the area will occur. The restoration of a thickly vegetated, multi-storied riparian zone at least 50 ft wide along Lower Pines Campground might decrease the amount of cobble and sand deposition on the campground surface in future floods.

The cutoff channel at Sugar Pine Bridge is problematic. Constriction by the bridge and road prism exacerbates the problem of flow being diverted into the channel and accelerating bank erosion. Removal of the bridge would alleviate some of the problem. Nevertheless, the meander bend has changed radically since 1919 when there were several small channels across the floodplain. Due to the extent of bank erosion and channel bed scour in the overflow channel since 1919, it will be difficult to restore the channel completely, but bioengineering techniques can help stabilize the channel and prevent further enlargement.

For the most part, revegetation of bare streambanks withstood the January, 1997 flood. If the river erodes the base of high banks below the rooting level or vegetation, bank erosion will occur. The riprap revetment that is still in place along the Merced River controlled bank erosion at those sites. If riprap is removed and banks revegetated, natural processes will be encouraged. Bank erosion, however, is a natural process and some banks may retreat even though they are revegetated. This is especially true for sites on the outside of meander bends where high velocity flows are forced against the bank.

Woody debris loading increased in the Merced River as a result of the 1997 flood. In addition, there is a supply of in-channel wood available for eventual transport in Tenaya Creek and upstream of Happy Isles. Although the increase in wood in the channel will probably improve aquatic habitat, it presents a problem for bridges in future flooding as debris piles up against bridge abutments and decks, and presents a hazard for rafters. The U.S. Fish and Wildlife Service's surveys of fish utilization and in-stream wood accumulations (in progress) will help determine the importance of wood in providing aquatic habitat for fish. Once their report is complete, park managers will be able to weigh the relative risks and advantages of retaining woody debris in the river channel.

V. RECOMMENDATIONS FOR FUTURE MONITORING:

All monitoring should be coordinated by one division, preferably the Resource Management

Division. Coordination between physical and biological monitoring efforts is essential. Several studies have now been conducted in the Merced River in Yosemite Valley. We recommend that Yosemite National Park construct a map and database that documents the location and type of study, objectives of study, monitoring technique, investigator, period of study, list of products, etc. Such a compilation would be extremely helpful to park administration, resource managers, and future researchers. In addition, the park should develop a baseline channel map showing pertinent features and channel distances, on which all future river work can be referenced. Aerial photographs of the channel enlarged to a scale of about 1:500 would be useful for documenting future studies.

1. Cross section monitoring:
   a. Resurvey cross section sites every five years or after moderately high (10-year) flows.
   b. Use a GPS to document cross section endpoints for expedient and reliable relocation of monuments for future surveys.
   c. Rephotograph photopoints at cross sections when transects are surveyed.

2. Longitudinal Profile monitoring:
   a. Resurvey channel thalweg on same schedule as cross section surveys.
   b. Extend the surveys to monitor the same reaches as in the USFWS survey.

3. Large Woody Debris surveys:
   a. Conduct periodic woody debris inventory of selected reaches to determine annual loading rates.
   b. Need to compare woody debris loading in other reaches of Yosemite Valley and conduct literature search for comparisons to other Sierran streams.
   c. Compile information on orientation of logs to provide general guidelines for orientation and placement of logs during channel restoration and woody debris loading projects.
   d. Determine decay resistance of wood in channel and the residence times of wood.

e. Conduct a more detailed study of the role and function of large woody debris in the Merced River. Compare and contrast the woody debris loading in different channel reaches.

4. Hydraulic characteristics:

a. Install crest stage gages at several locations in the floodplain to accurately determine the extent and depth of inundation during future flooding events.

b. Conduct analysis of long-term USGS gaging records from the Happy Isles and Pohono Bridge sites to determine hydraulic and bed level changes since 1916.

c. Expand river corridor studies to the watershed scale to incorporate effects of rockfall, debris flows, wildfires and other influences on the Merced River and its tributaries.

Acknowledgments

We would like to thank Louise Johnson and many of the staff of the Resources Management Division of Yosemite National Park for their help with setting up the project and assisting with the field work. Don Jones, Tracy Duckhart and Gordon Grant also helped us in the field. We are grateful to all our field assistants for their energy and hard work under occasionally difficult conditions.

VI. REFERENCES CITED

Abernathy, B. and I.D. Rutherford. 1998. Where along a river's length will vegetation most effectively stabilize stream banks? Geomorphology 23:55-75.

Barnes, H.H. Jr., 1977. Roughness Characteristics of Natural Channels. U.S. Geological Survey Water-Supply Paper 1849. 213 p.

Bisson, P.A., Bilby, R.E., Bryant, M.D., Dolloff, C.A., Grette, G.B., House, R.A., Murphy, M.L. Koski, K.V., and Sedell, J.R. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present and future. Pages 143-190 In: E.O. Salo and T. Cundy, editors. Proceedings of the symposium Streamside Management: Forestry and Fishery Interactions. Univ. of Washington Press, Seattle, Washington.

Department of Interior. U.S. Geological Survey. 1997. 1997 Northern California Floods. http://water.wr.usgs.gov/floods97/

Dingman, S.L. 1984. Fluvial Hydrology. W.H. Freeman and Company. New York. 383 p.

Emmett, W. W. 1974. Channel Changes. Geology 2:271-272.

Jackson, W.J., Smillie, G.M., and Martin, M.W. 1997. Analysis of the hydrologic, hydraulic and geomorphic attributes of the Yosemite Valley flood: January 1-3, 1997. Technical Report NPS / NRWRD / NRTR-97 / 129. 43p.

Lisle, T. E. 1987. Using "Residual depths" to monitor pool depths independently of discharge. Res. Note PSW-394. Berkeley, Ca.: Pacific Southwest Forest and Range Experiment Station, Forest Service. U.S. Department of Agriculture. 4 p.

Madej, M. A., Weaver, W., and Hagans, D. 1991. Analysis of bank erosion on the Merced River, Yosemite Valley, Yosemite National Park, California. Redwood National and State Parks, Arcata, Ca. 91 p. + Appendices.

Richards, K.S. 1982. Rivers, Form and Process in Alluvial Channels. Methuen, London, 358 pp.

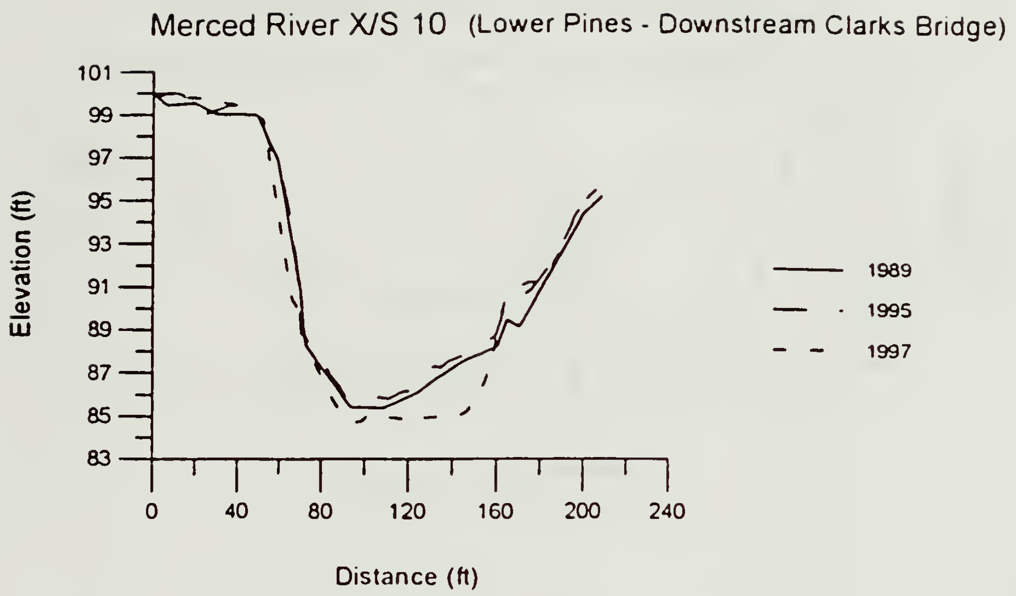
Ruediger, R. and Ward, J. 1996. Abundance and function of large woody debris in central Sierra Nevada streams. US Forest Service. Fish Habitat Relationships Technical Bulletin, No. 20.

Smith, D.G., 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. Geological Society of America Bulletin 87: 857-860.

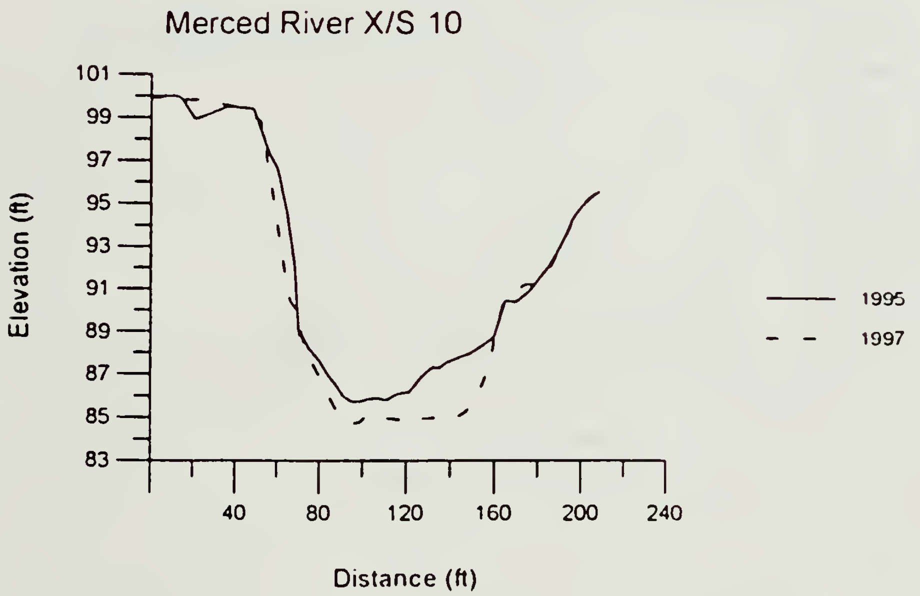
Varnum, N. and Ozaki, V. 1986. Recent channel adjustments in Redwood Creek, California. Redwood National Park Technical Report 18. Redwood National and State Parks, Arcata, Ca. 74p.

Yalin, M. S. and E. Karahan. 1979. Inception of sediment transport. American Society of Civil Engineers Proceedings, Journal of the Hydraulics Division 105 (HY-11): 1433-1443.

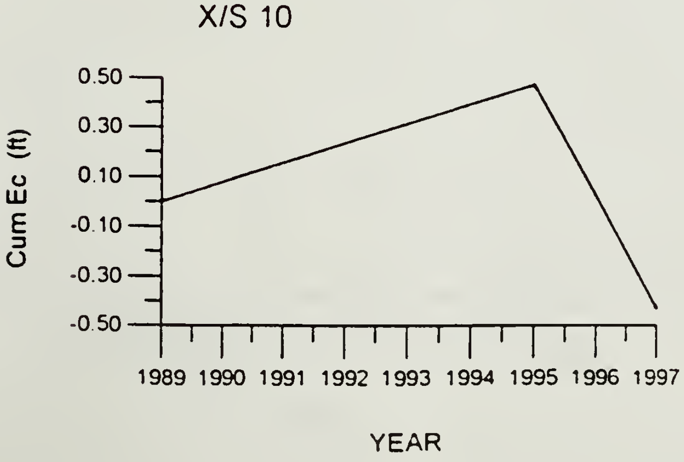
APPENDIX A: PLOTS OF CROSS-SECTIONAL CHANGE AT MERCED RIVER TRANSECTS, 1989 TO 1997, AND CUMULATIVE CHANGES IN STREAMBED ELEVATION



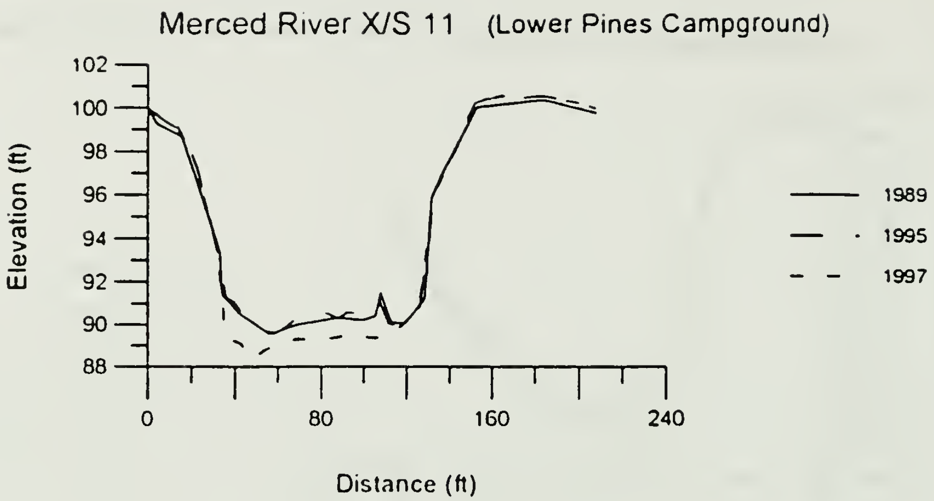
Merced River X/S 10 (Lower Pines - Downstream Clarks Bridge)
Elevation (ft)
101
99
97
95
93
91
89
87
85
83
0
40
80
120
160
200
240
Distance (ft)
1989
1995
1997

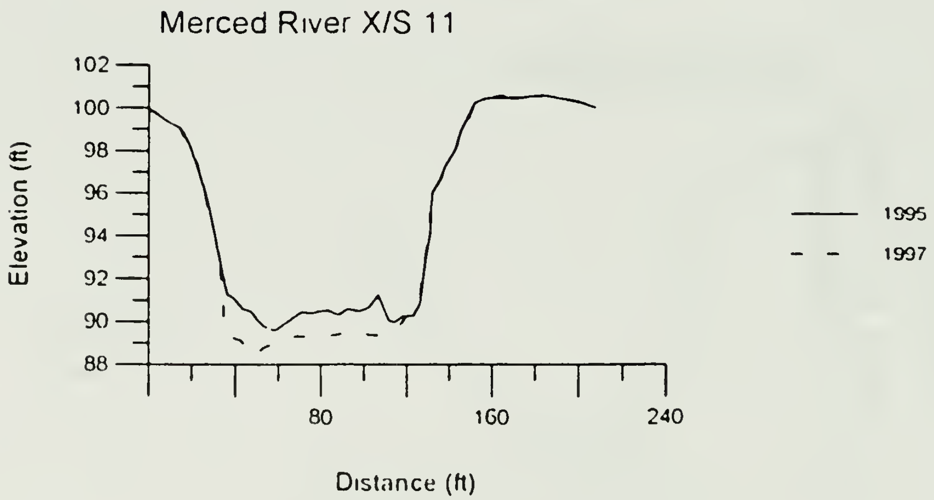


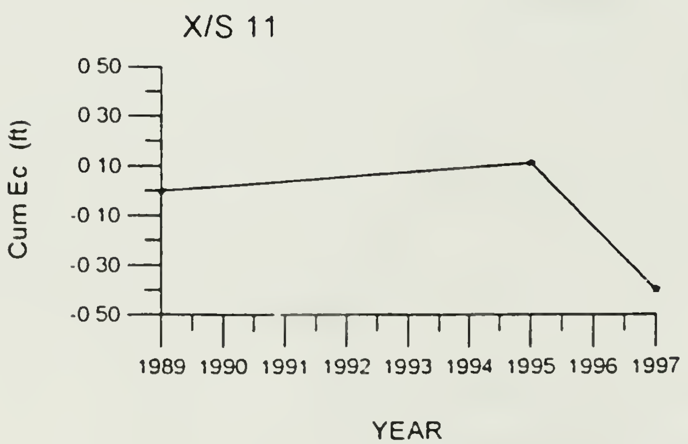
Merced River X/S 10
Elevation (ft)
101
99
97
95
93
91
89
87
85
83
40
80
120
160
200
240
Distance (ft)
1995
1997

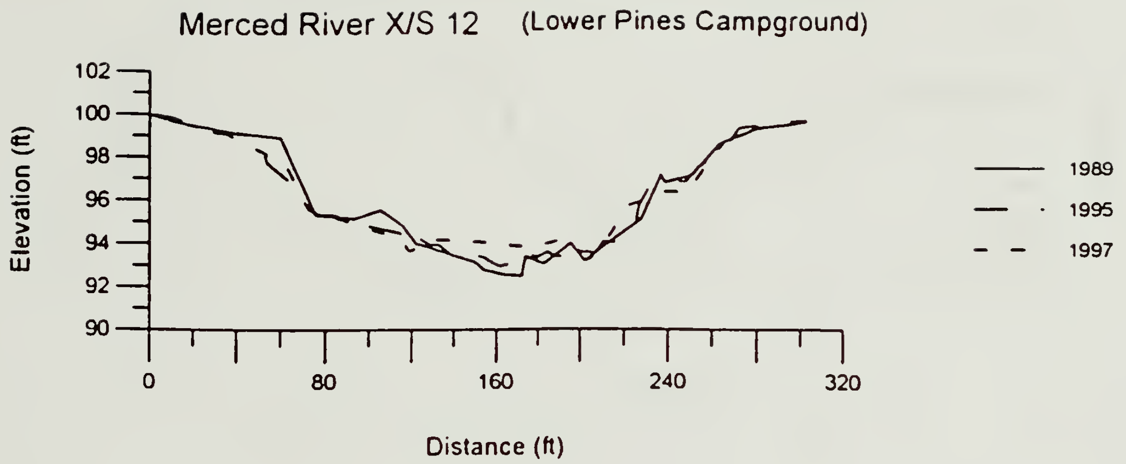


X/S 10
Cum Ec (ft)
0.50
0.30
0.10
-0.10
-0.30
-0.50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

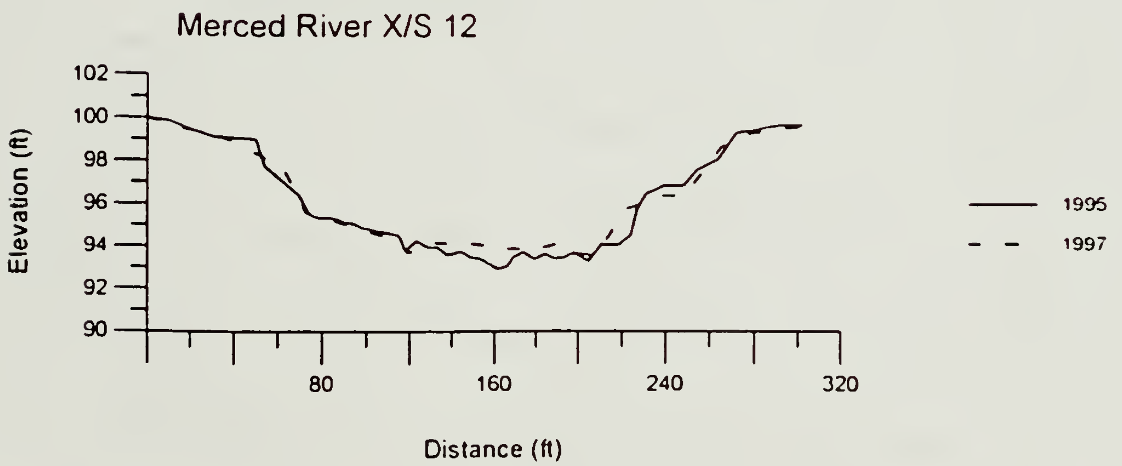

Merced River X/S 11 (Lower Pines Campground)
Elevation (ft)
102
100
98
96
94
92
90
88
0
80
160
240
Distance (ft)
1989
1995
1997


Merced River X/S 11
Elevation (ft)
102
100
98
96
94
92
90
88
80
160
240
Distance (ft)
1995
1997

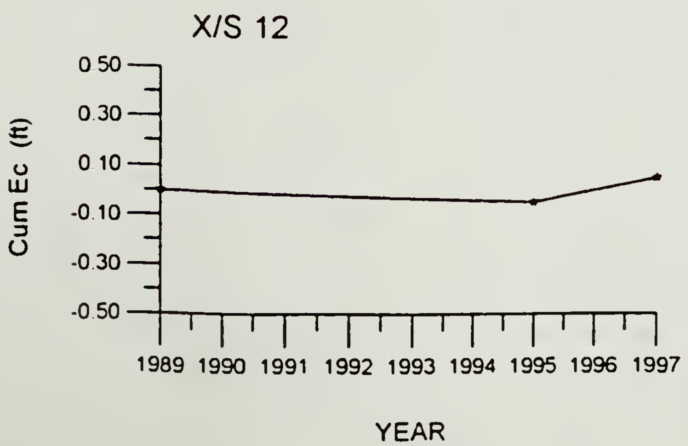

X/S 11
CumEc (ft)
0 50
0 30
0 10
-0 10
-0 30
-0 50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR



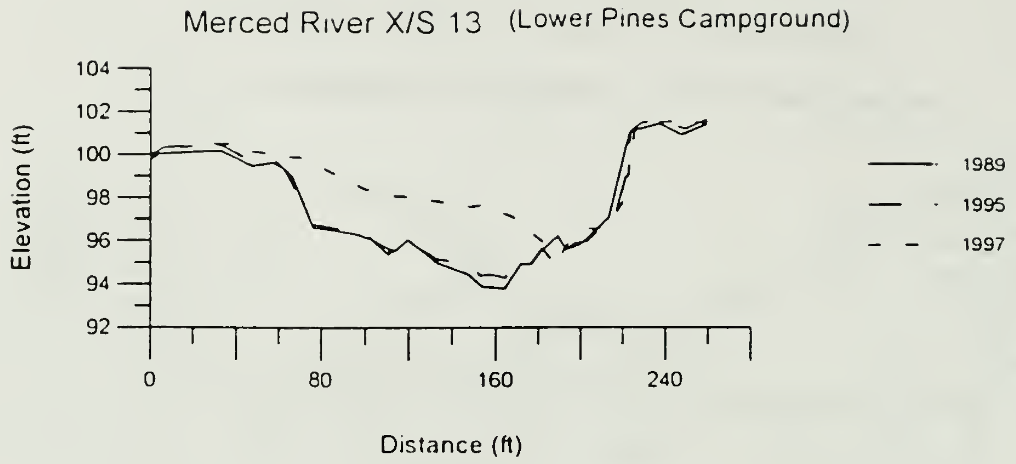
Merced River X/S 12 (Lower Pines Campground)
Elevation (ft)
102
100
98
96
94
92
90
0
80
160
240
320
Distance (ft)
1989
1995
1997

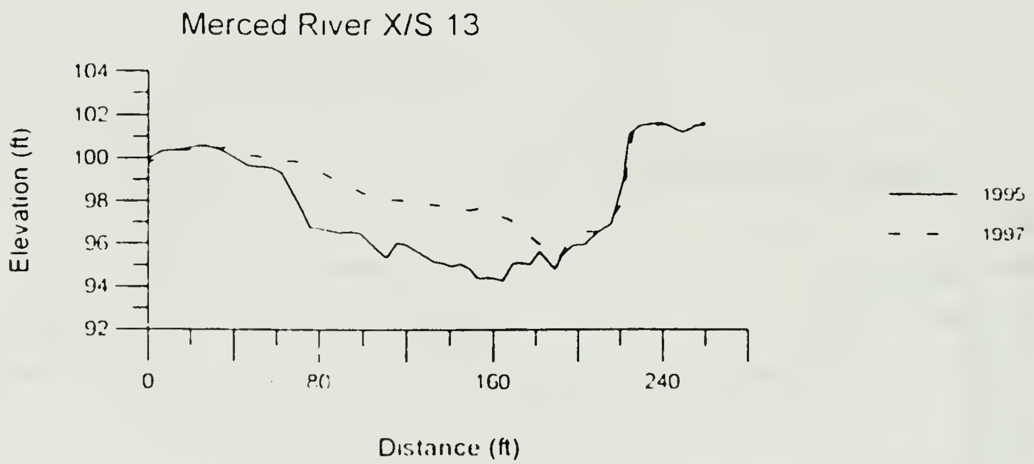


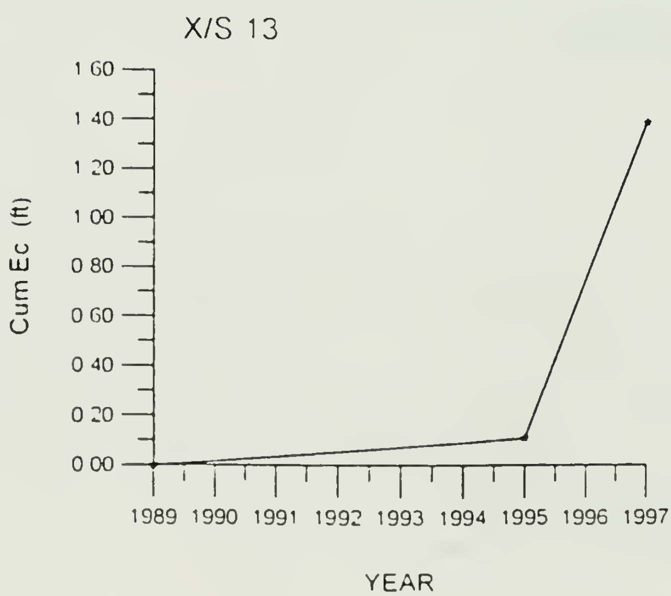
Merced River X/S 12
Elevation (ft)
102
100
98
96
94
92
90
80
160
240
320
Distance (ft)
1995
1997

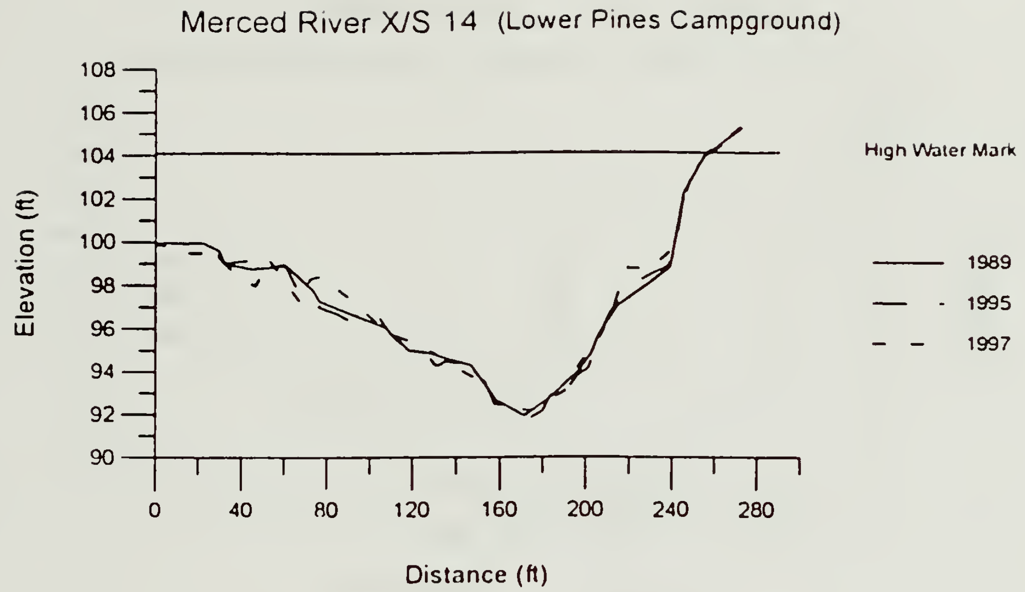


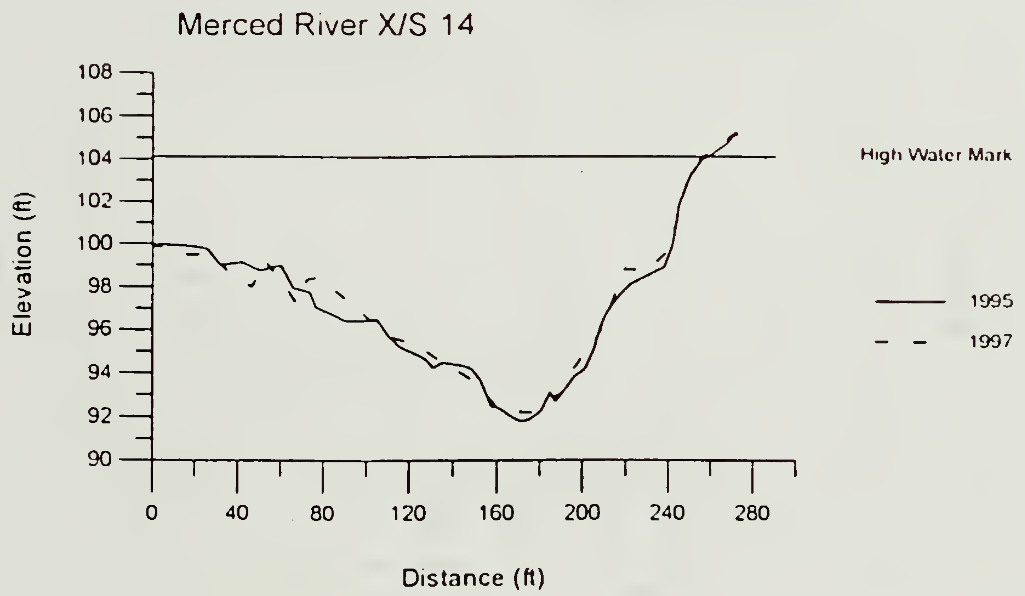
X/S 12
Cum Ec (ft)
0.50
0.30
0.10
-0.10
-0.30
-0.50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

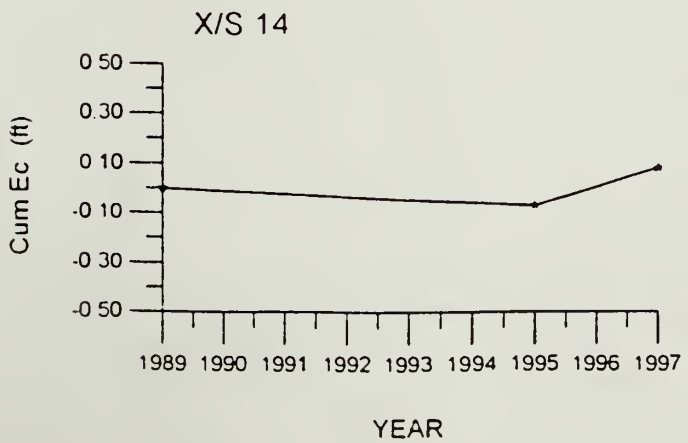

Merced River X/S 13 (Lower Pines Campground)
Elevation (ft)
104
102
100
98
96
94
92
0
80
160
240
Distance (ft)
1989
1995
1997

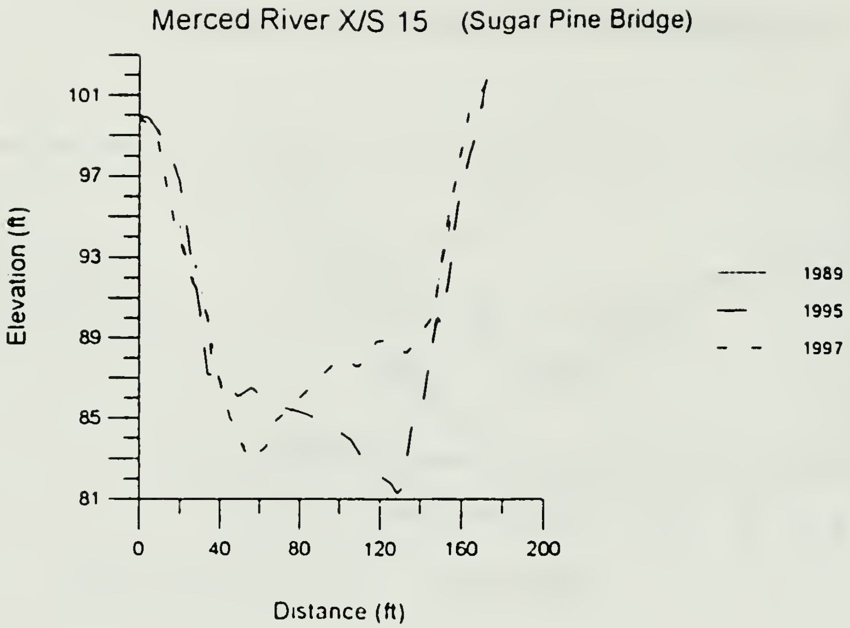

Merced River X/S 13
Elevation (ft)
104
102
100
98
96
94
92
0
80
160
240
Distance (ft)
1995
1997

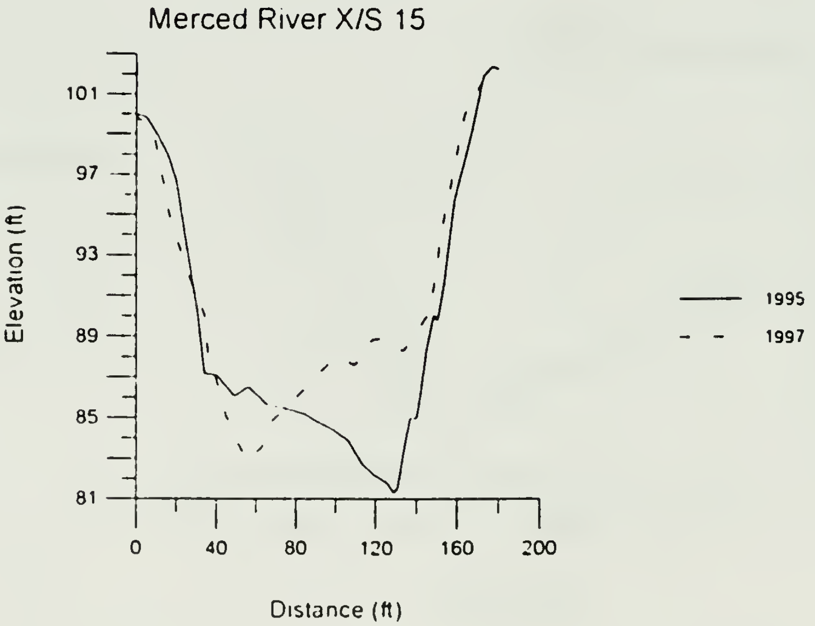

X/S 13
Cum Ec (ft)
1 60
1 40
1 20
1 00
0 80
0 60
0 40
0 20
0 00
1989 1990 1991 1992 1993 1994 1995 1996 1997
YEAR

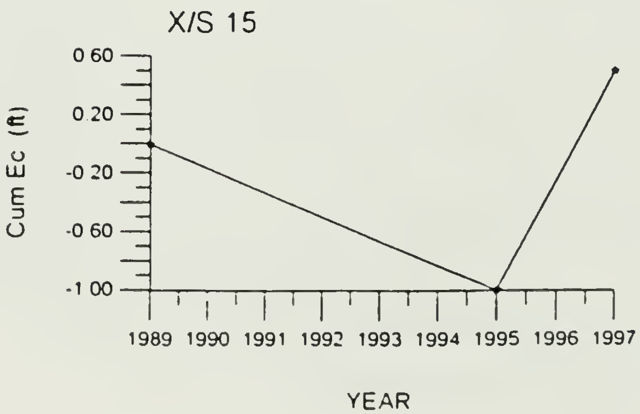

Merced River X/S 14 (Lower Pines Campground)
Elevation (ft)
108
106
104
102
100
98
96
94
92
90
0
40
80
120
160
200
240
280
Distance (ft)
High Water Mark
1989
1995
1997


Merced River X/S 14
Elevation (ft)
108
106
104
102
100
98
96
94
92
90
0
40
80
120
160
200
240
280
Distance (ft)
High Water Mark
1995
1997

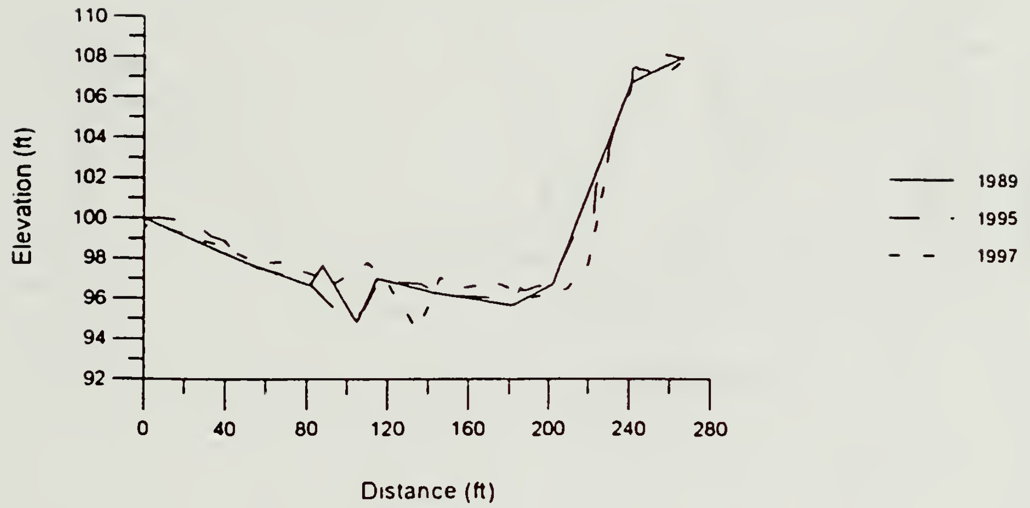

X/S 14
Cum Ec (ft)
0 50
0.30
0 10
-0 10
-0 30
-0 50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR


Merced River X/S 15 (Sugar Pine Bridge)
Elevation (ft)
101
97
93
89
85
81
0
40
80
120
160
200
Distance (ft)
1989
1995
1997

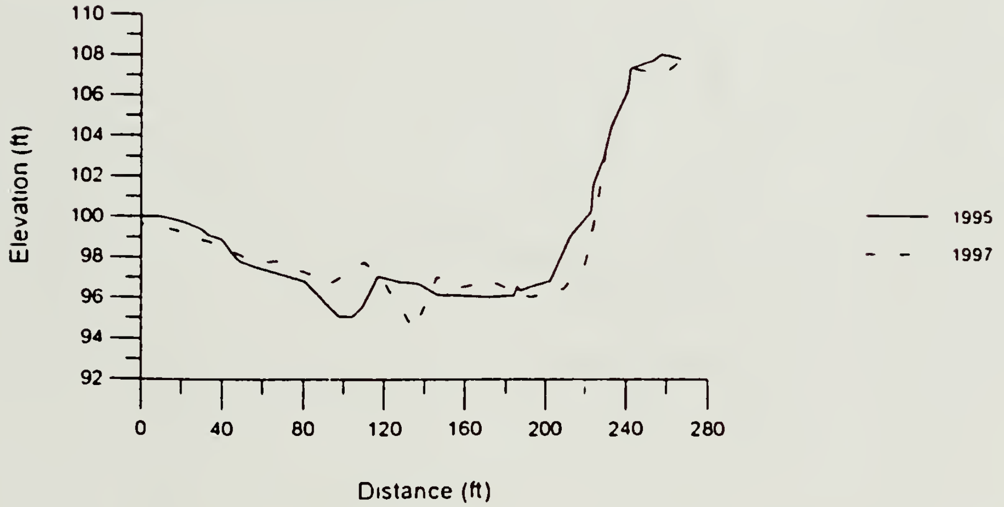

Merced River X/S 15
Elevation (ft)
101
97
93
89
85
81
0
40
80
120
160
200
Distance (ft)
1995
1997


X/S 15
Cum Ec (ft)
0 60
0.20
-0 20
-0 60
-1 00
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

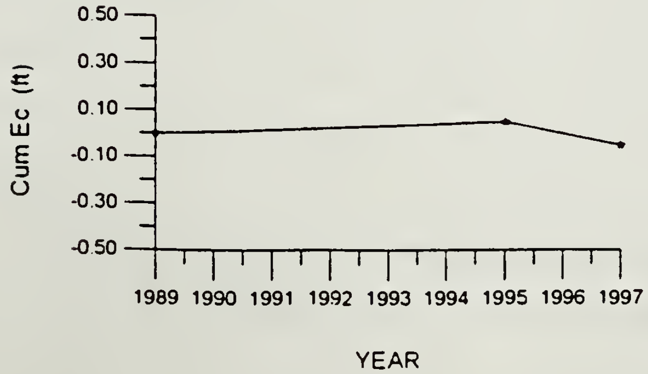
Merced River X/S 15a (Overflow Channel)

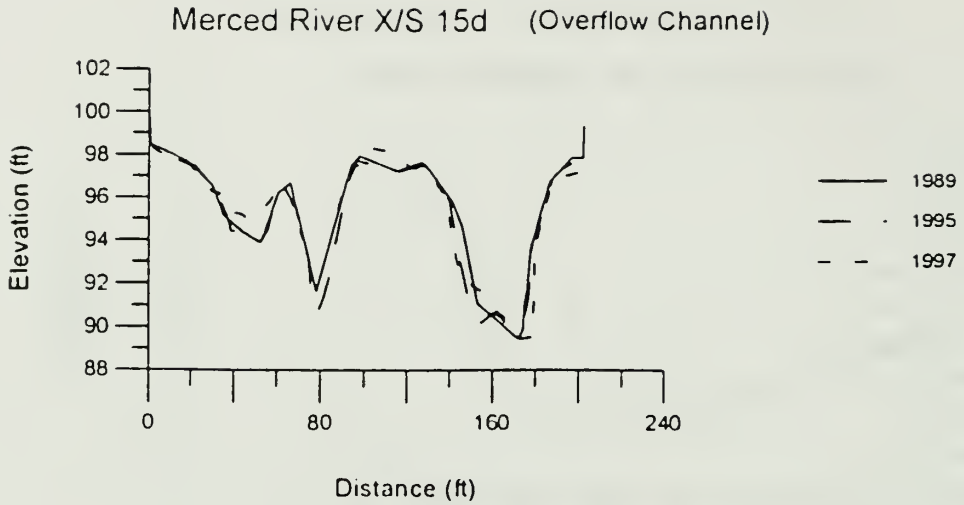


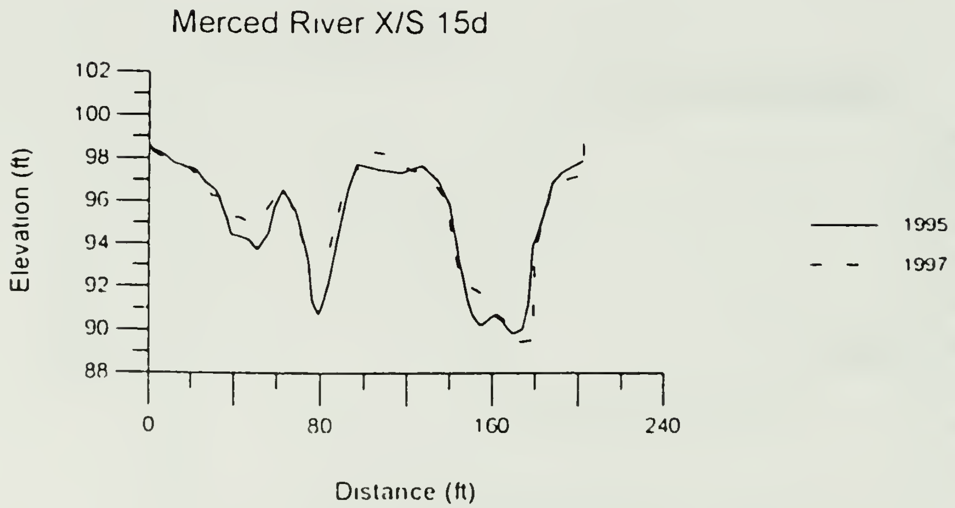
Merced River X/S 15a

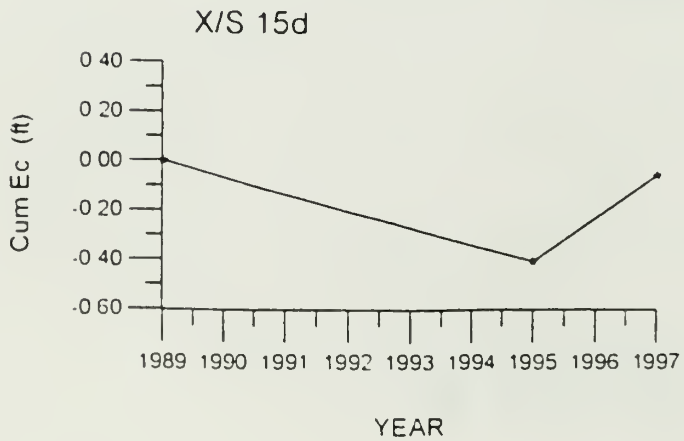


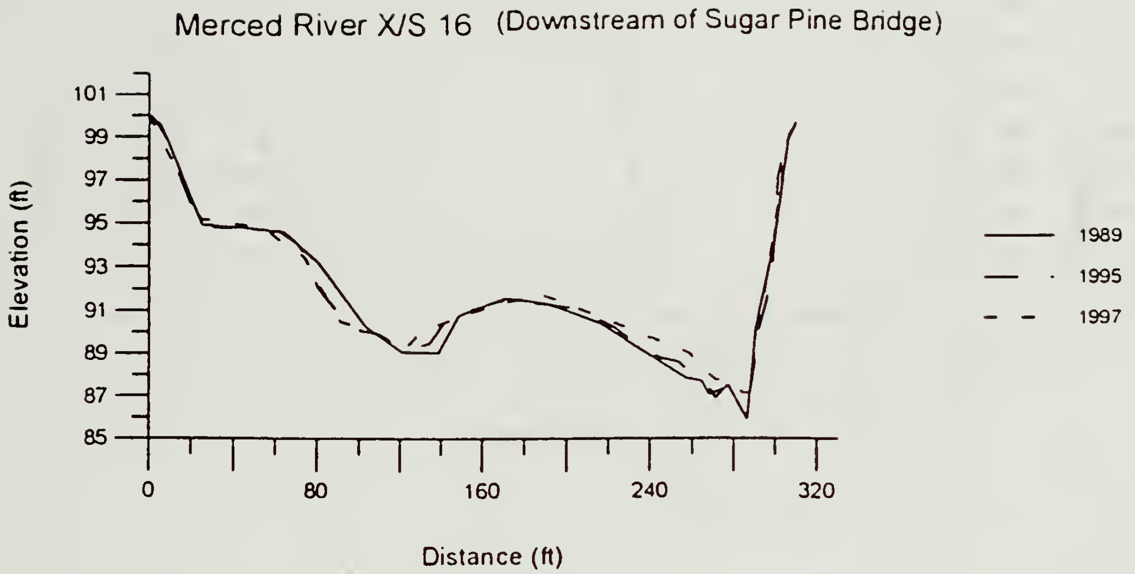
X/S 15a



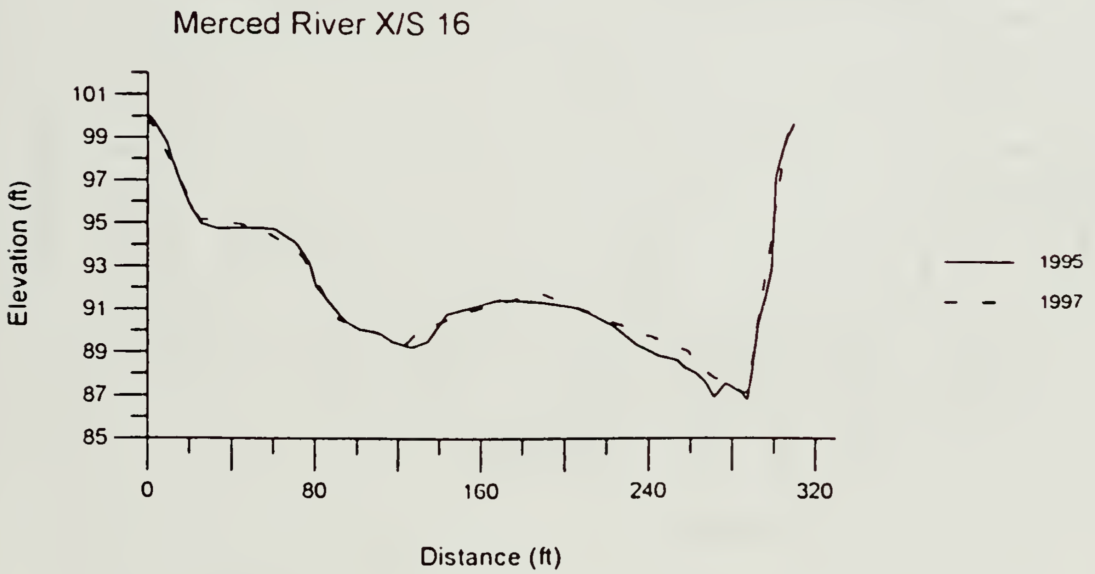

Merced River X/S 15d (Overflow Channel)
Elevation (ft)
102
100
98
96
94
92
90
88
0
80
160
240
Distance (ft)
1989
1995
1997


Merced River X/S 15d
Elevation (ft)
102
100
98
96
94
92
90
88
0
80
160
240
Distance (ft)
1995
1997

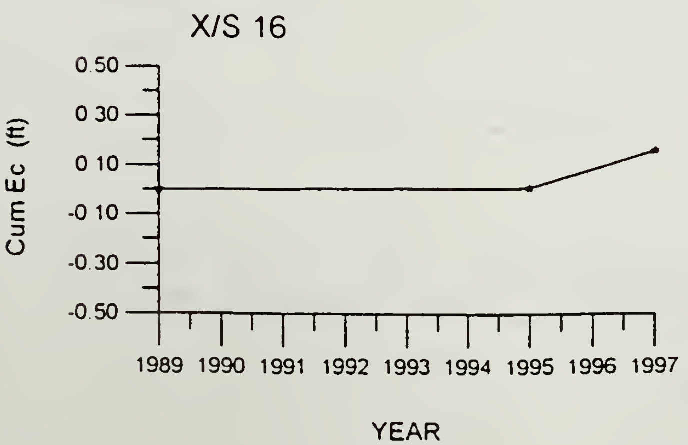

X/S 15d
Cum Ec (ft)
0 40
0 20
0 00
-0 20
-0 40
-0 60
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR



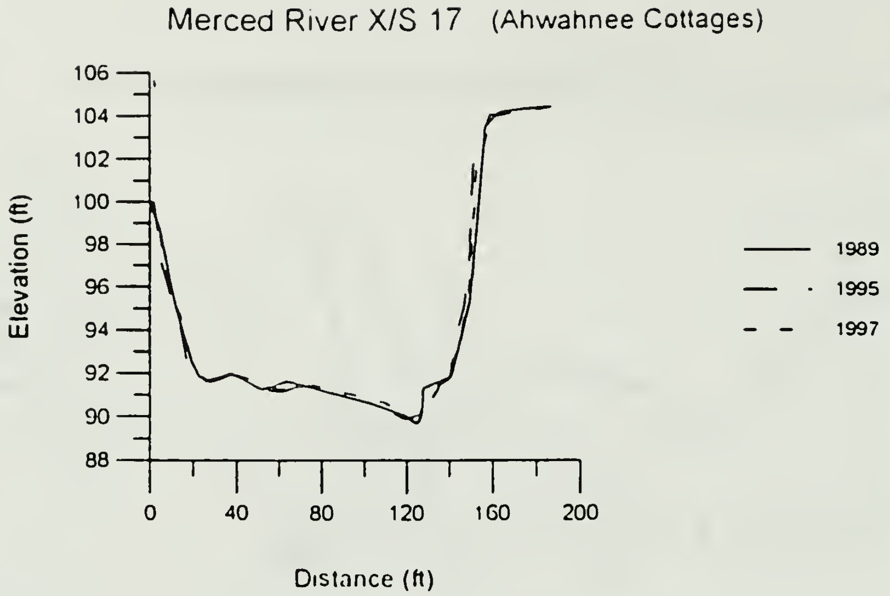
Merced River X/S 16 (Downstream of Sugar Pine Bridge)
Elevation (ft)
101
99
97
95
93
91
89
87
85
0
80
160
240
320
Distance (ft)
1989
1995
1997

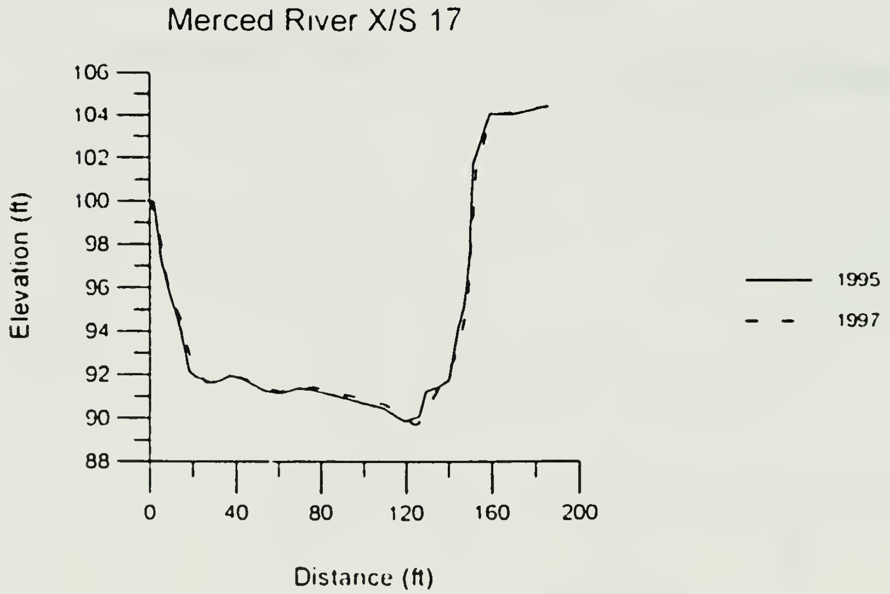


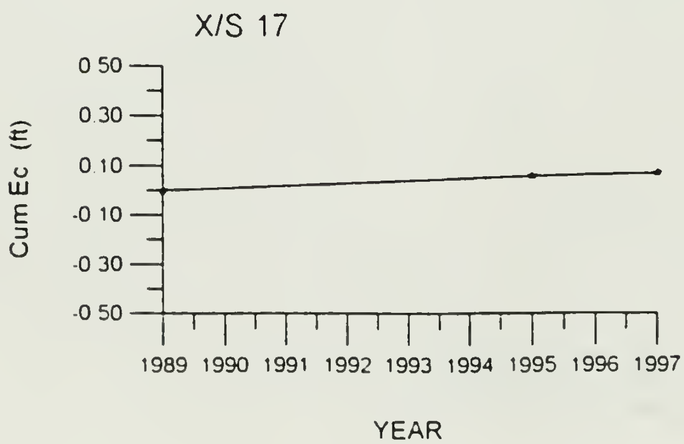
Merced River X/S 16
Elevation (ft)
101
99
97
95
93
91
89
87
85
0
80
160
240
320
Distance (ft)
1995
1997

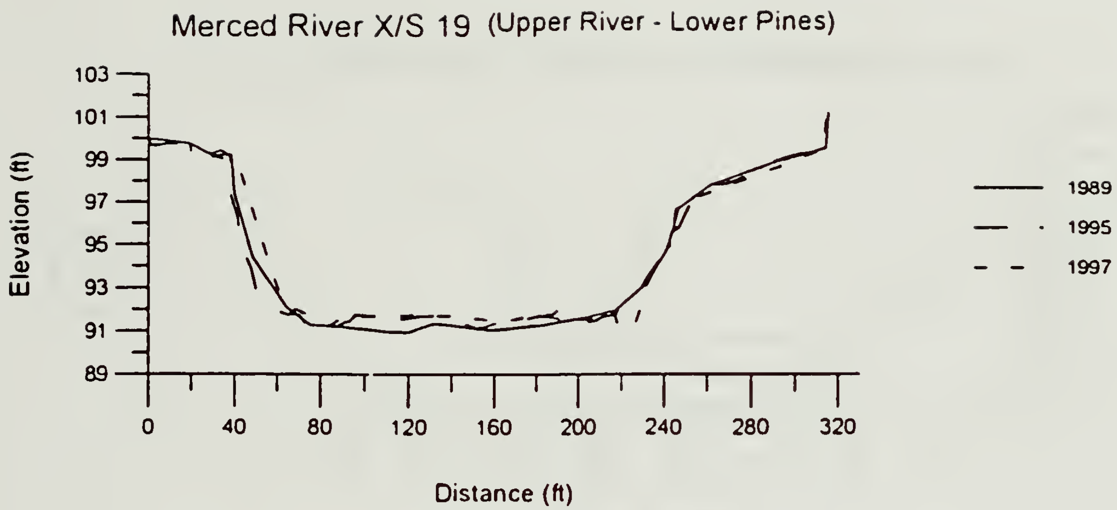


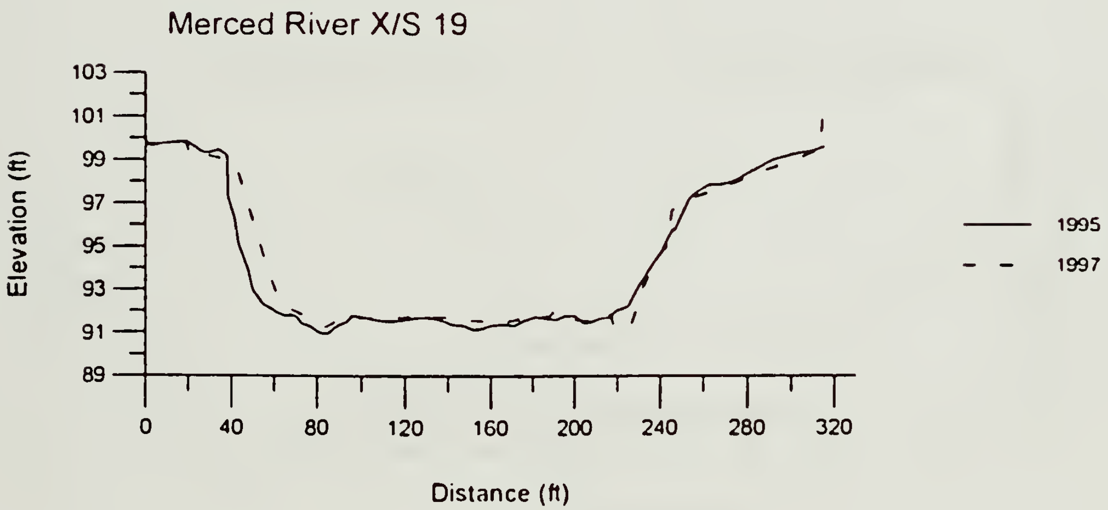
X/S 16
Cum Ec (ft)
0.50
0 30
0 10
-0 10
-0.30
-0.50
1989 1990 1991 1992 1993 1994 1995 1996 1997
YEAR

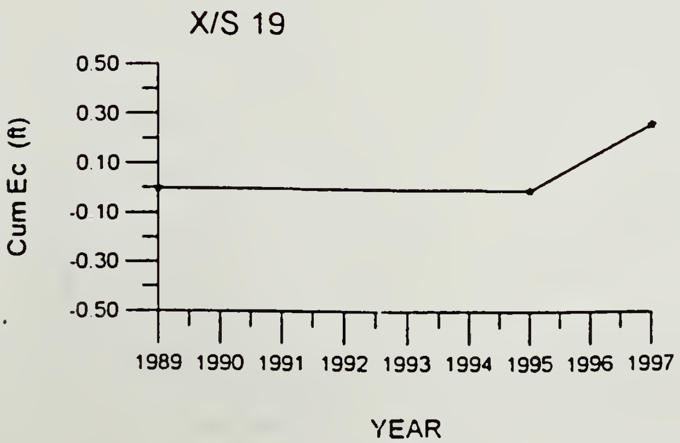

Merced River X/S 17 (Ahwahnee Cottages)
106
104
102
100
98
96
94
92
90
88
Elevation (ft)
0
40
80
120
160
200
Distance (ft)
1989
1995
1997

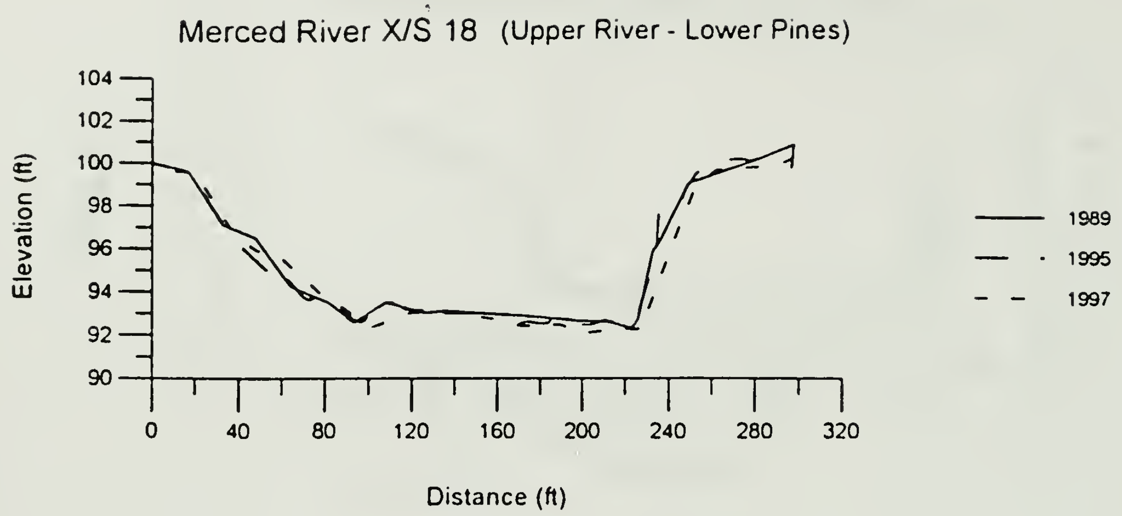

Merced River X/S 17
106
104
102
100
98
96
94
92
90
88
Elevation (ft)
0
40
80
120
160
200
Distance (ft)
1995
1997

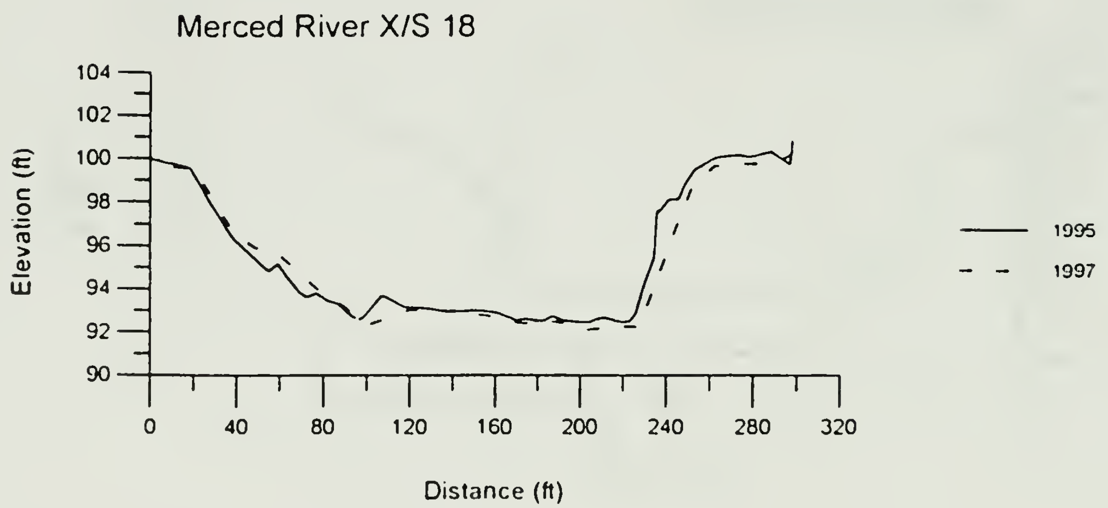

X/S 17
0 50
0.30
0.10
-0 10
-0 30
-0 50
Cum Ec (ft)
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

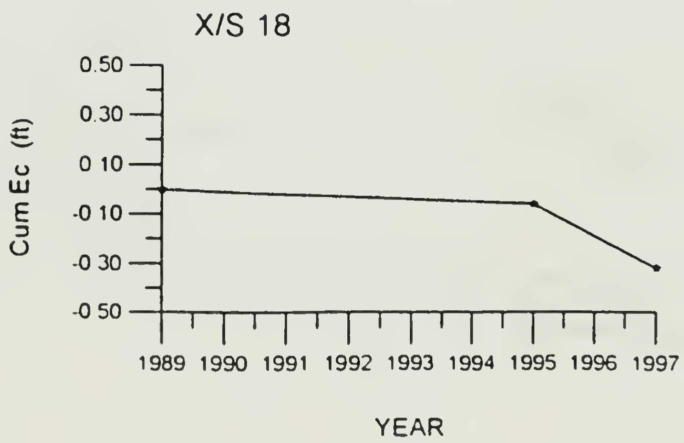

Merced River X/S 19 (Upper River - Lower Pines)
Elevation (ft)
103
101
99
97
95
93
91
89
0
40
80
120
160
200
240
280
320
Distance (ft)
1989
1995
1997

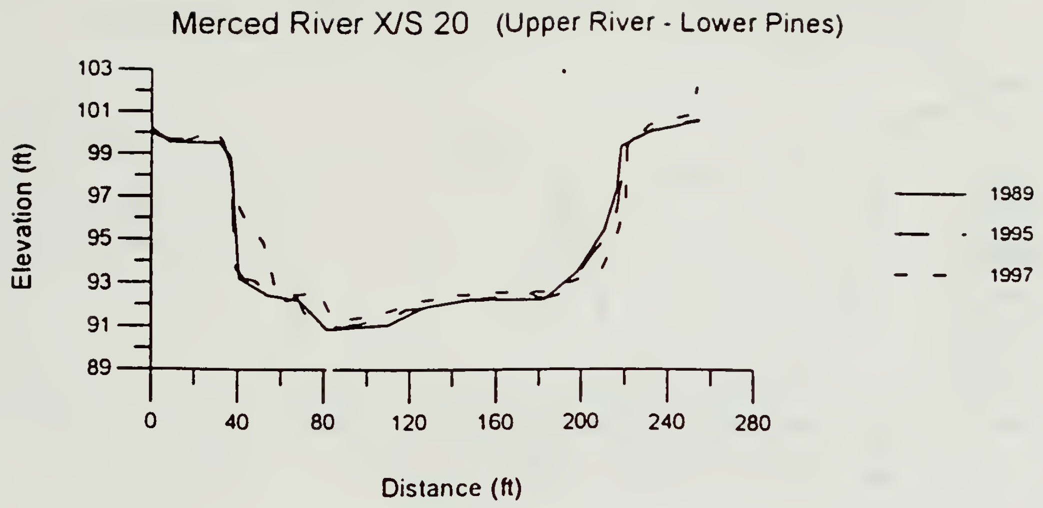

Merced River X/S 19
Elevation (ft)
103
101
99
97
95
93
91
89
0
40
80
120
160
200
240
280
320
Distance (ft)
1995
1997

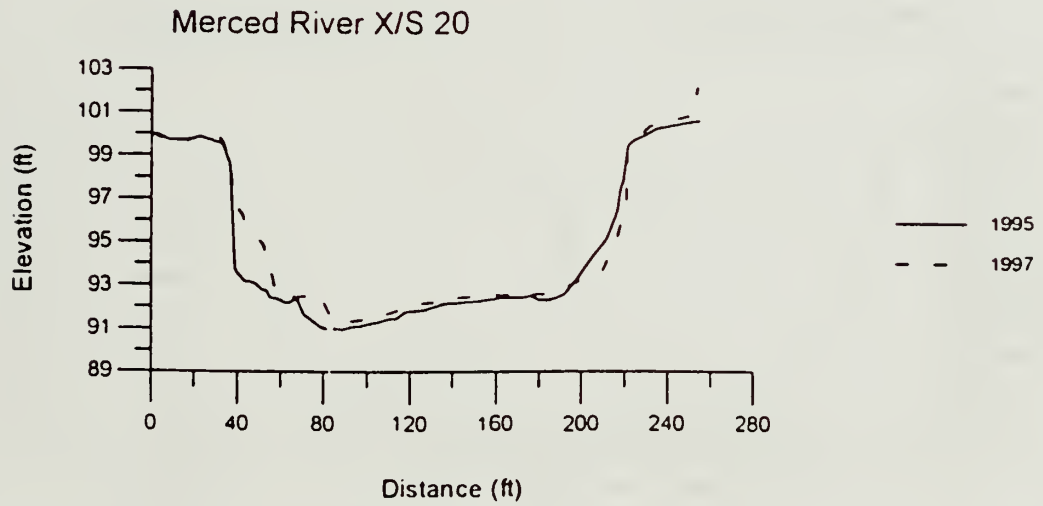

X/S 19
CumEc (ft)
0.50
0.30
0.10
-0.10
-0.30
-0.50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

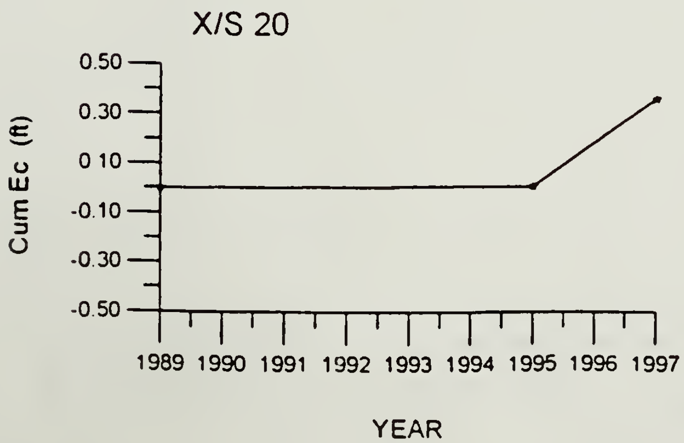

Merced River X/S 18 (Upper River - Lower Pines)
104
102
100
98
96
94
92
90
Elevation (ft)
0
40
80
120
160
200
240
280
320
Distance (ft)
1989
1995
1997


Merced River X/S 18
104
102
100
98
96
94
92
90
Elevation (ft)
0
40
80
120
160
200
240
280
320
Distance (ft)
1995
1997

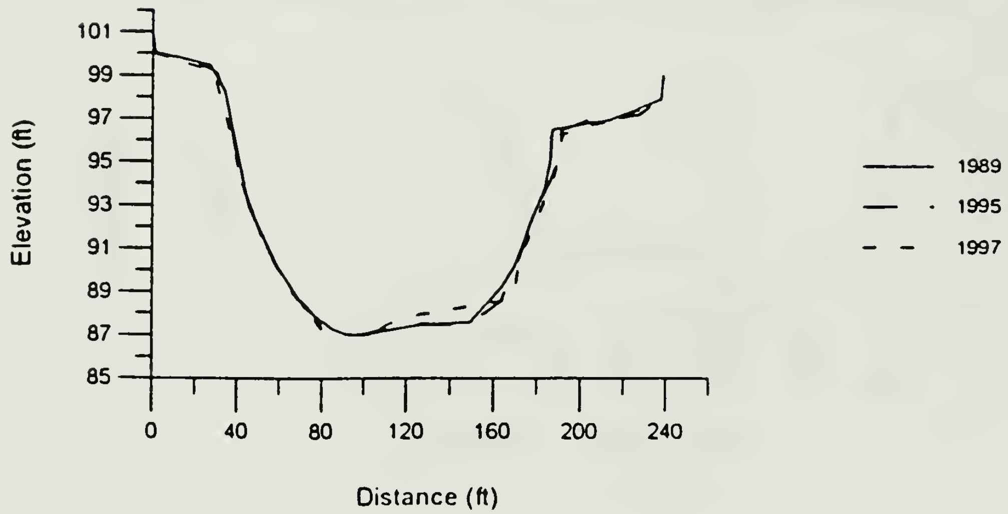

X/S 18
0.50
0.30
0 10
-0 10
-0 30
-0 50
Cum Ec (ft)
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR


Merced River X/S 20 (Upper River - Lower Pines)
Elevation (ft)
103
101
99
97
95
93
91
89
0
40
80
120
160
200
240
280
Distance (ft)
1989
1995
1997

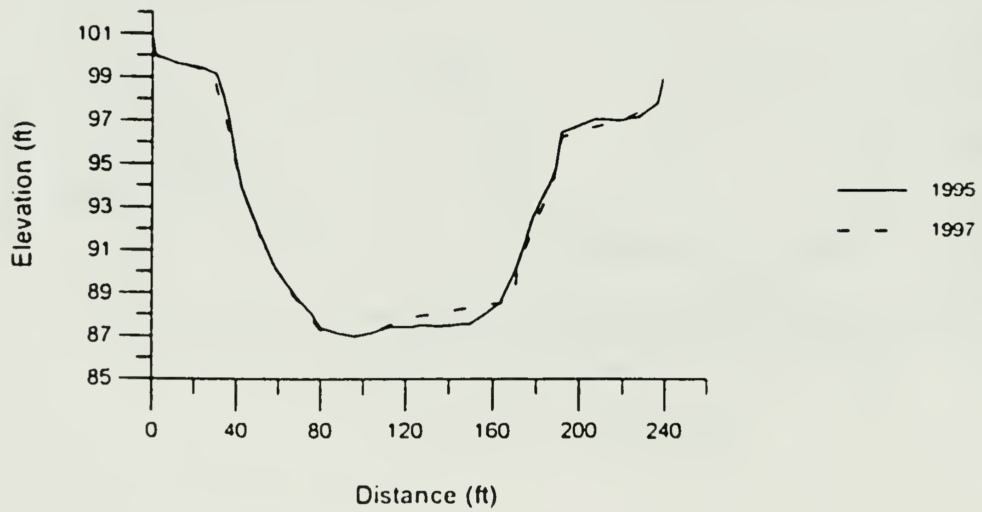

Merced River X/S 20
Elevation (ft)
103
101
99
97
95
93
91
89
0
40
80
120
160
200
240
280
Distance (ft)
1995
1997


X/S 20
Cum Ec (ft)
0.50
0.30
0.10
-0.10
-0.30
-0.50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

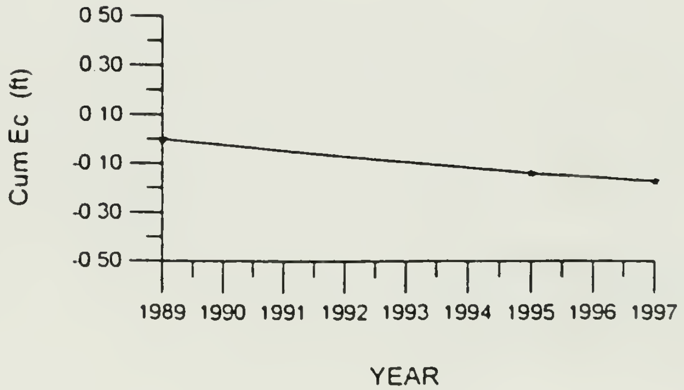
Merced River X/S 21 (Upper River - Lower Pines)

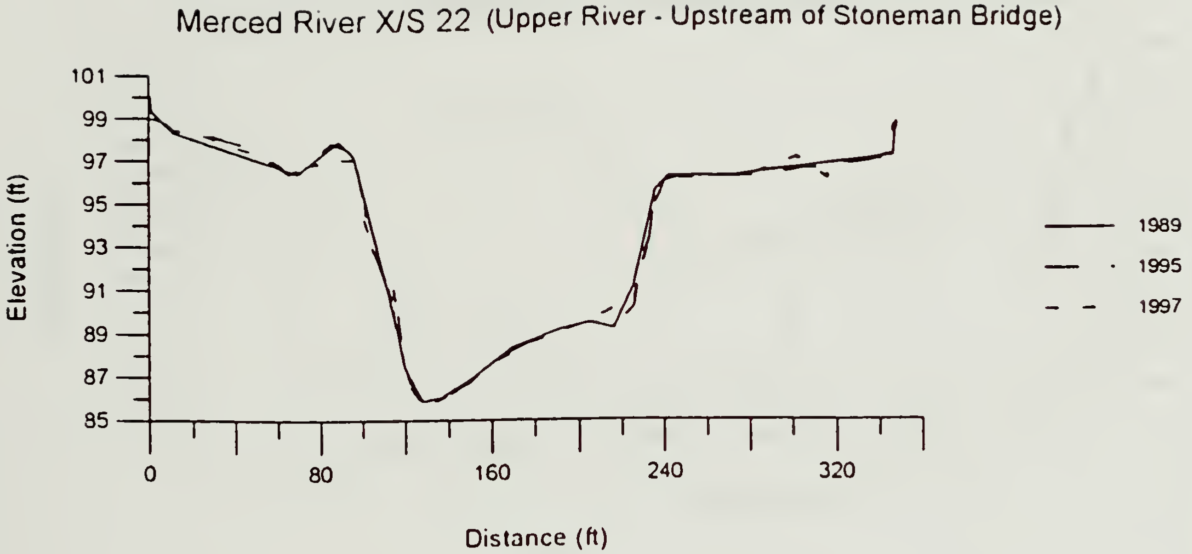


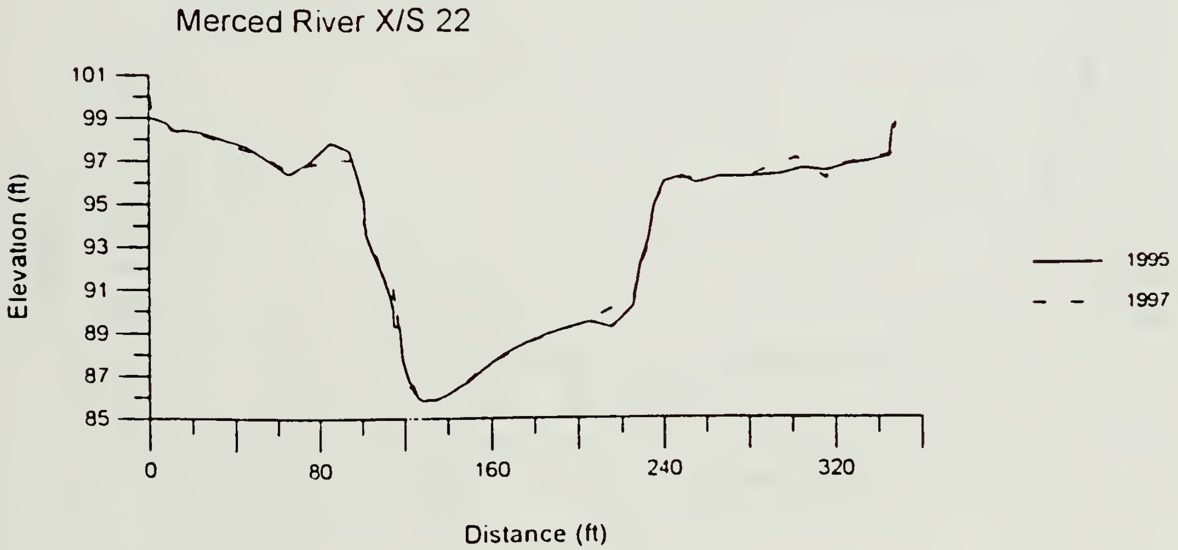
Merced River X/S 21

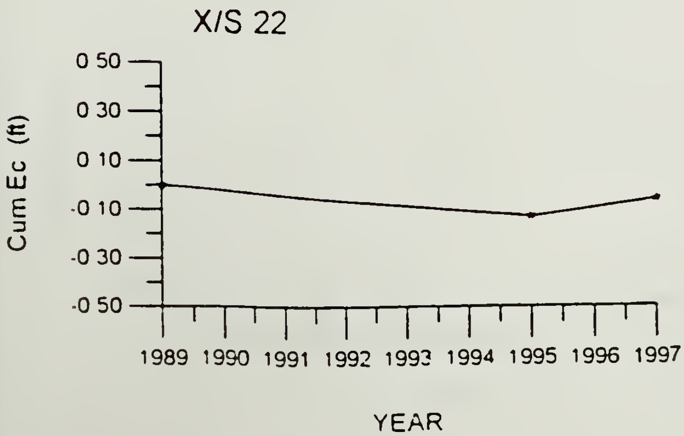


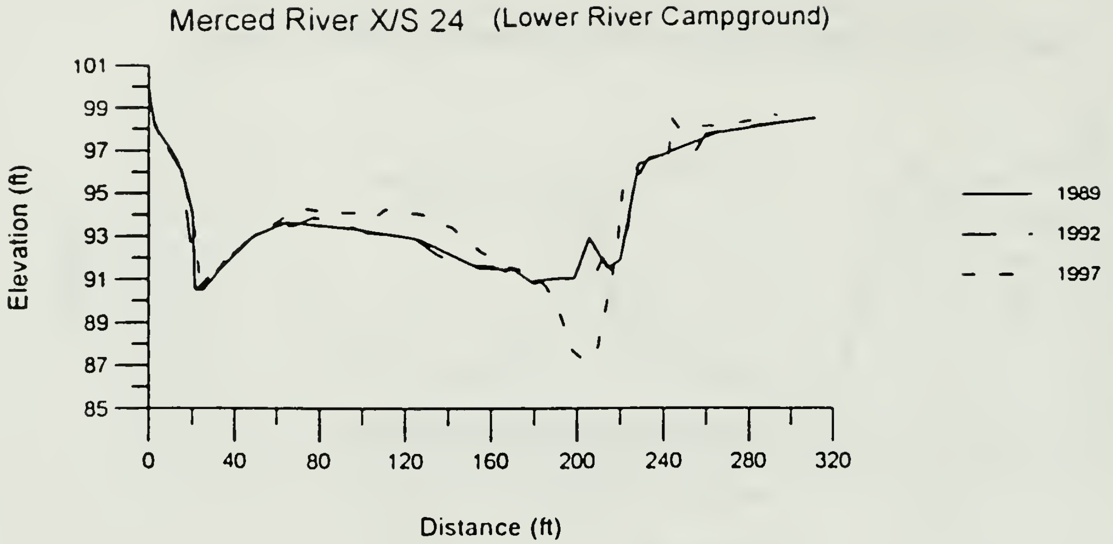
X/S 21

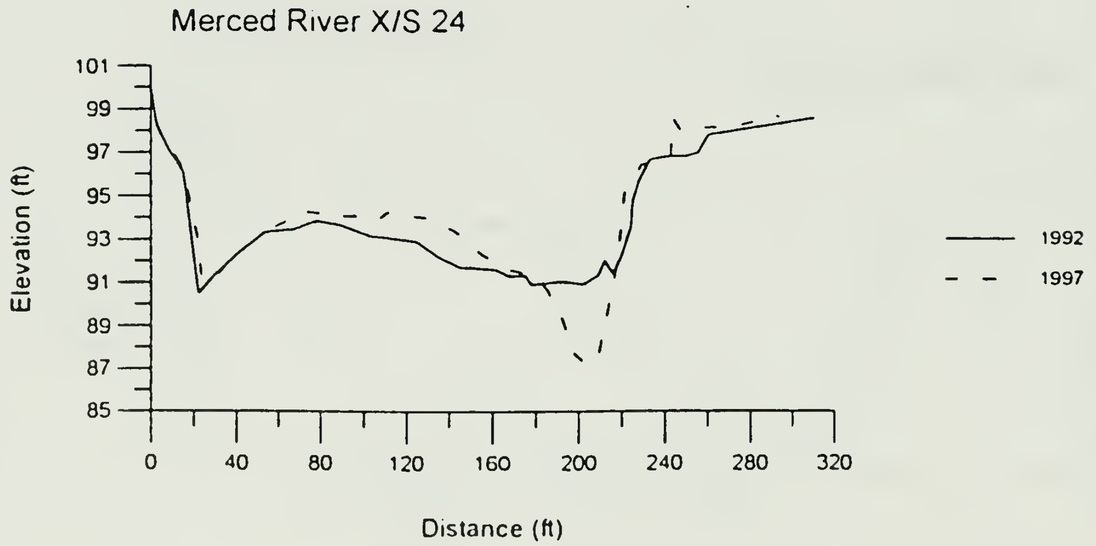


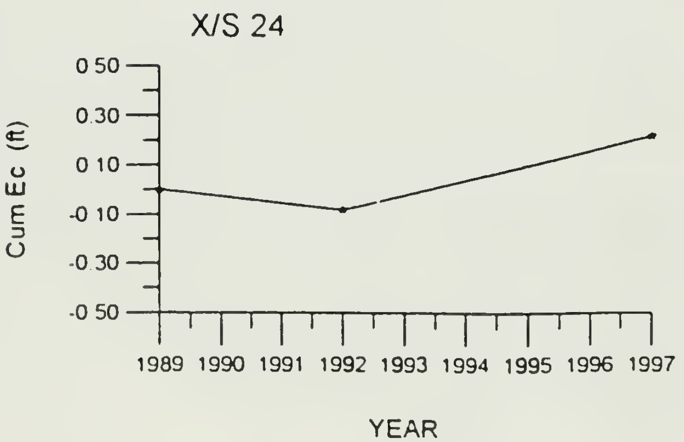

Merced River X/S 22 (Upper River - Upstream of Stoneman Bridge)
Elevation (ft)
Distance (ft)
1989
1995
1997


Merced River X/S 22
Elevation (ft)
Distance (ft)
1995
1997

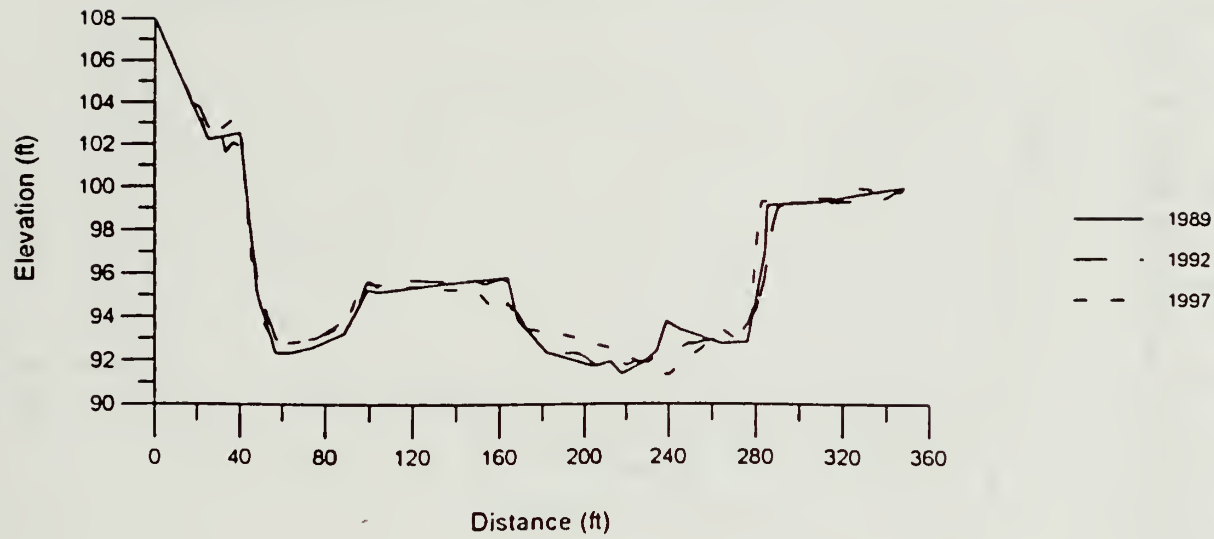

X/S 22
Cum Ec (ft)
YEAR


Merced River X/S 24 (Lower River Campground)
Elevation (ft)
101
99
97
95
93
91
89
87
85
0
40
80
120
160
200
240
280
320
Distance (ft)
1989
1992
1997

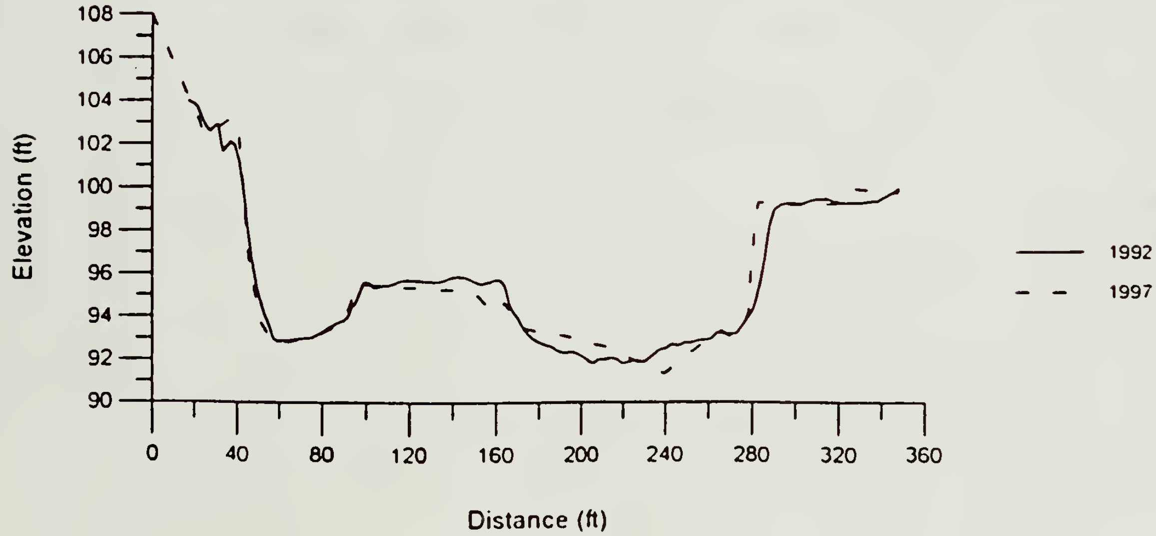

Merced River X/S 24
Elevation (ft)
101
99
97
95
93
91
89
87
85
0
40
80
120
160
200
240
280
320
Distance (ft)
1992
1997


X/S 24
Cum Ec (ft)
0.50
0.30
0.10
-0.10
-0.30
-0.50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

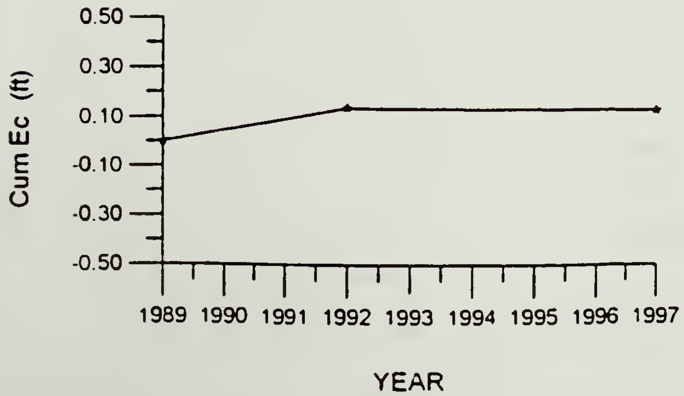
Merced River X/S 25 (Lower River Campground)

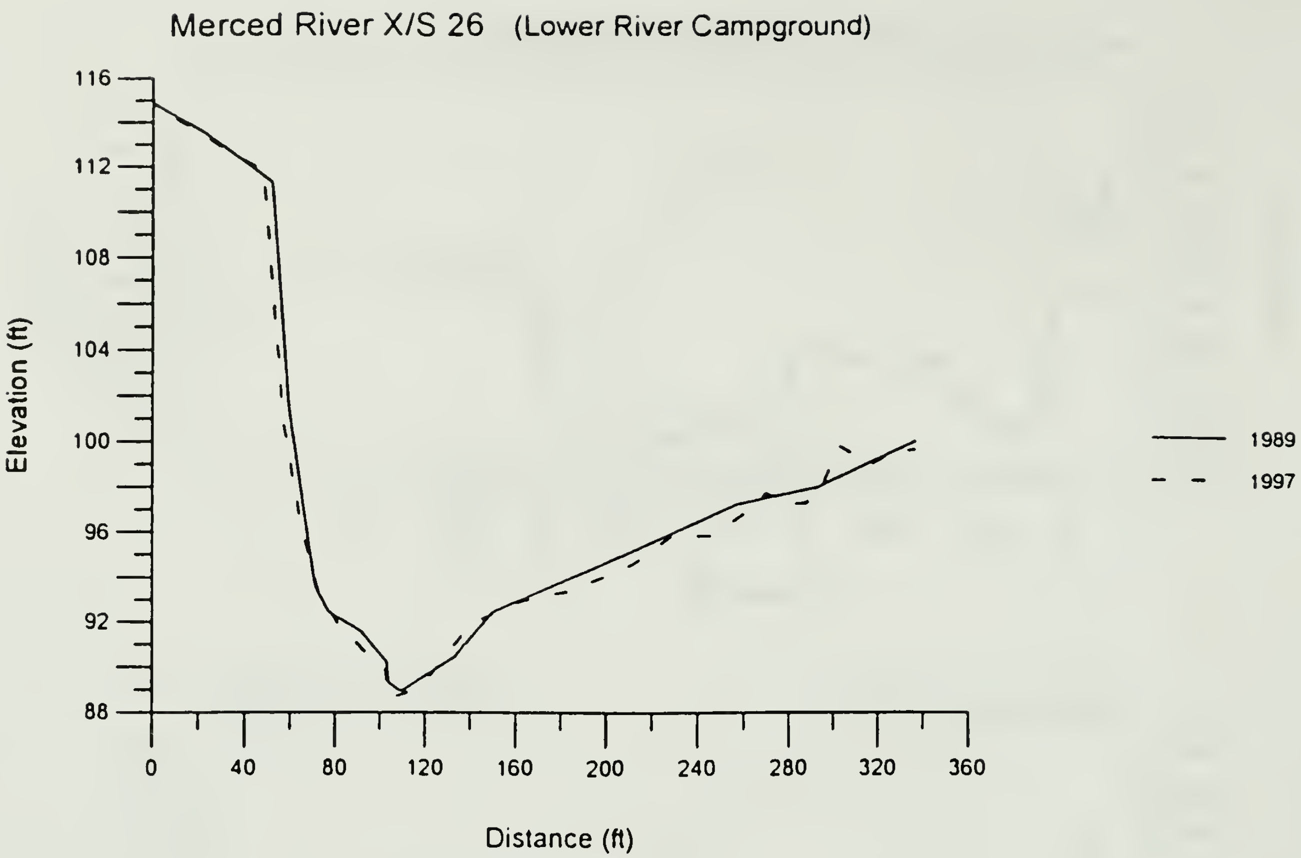


Merced River X/S 25

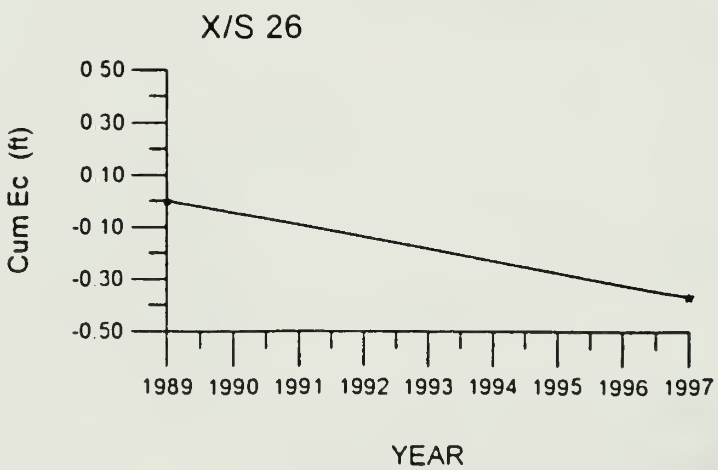


X/S 25



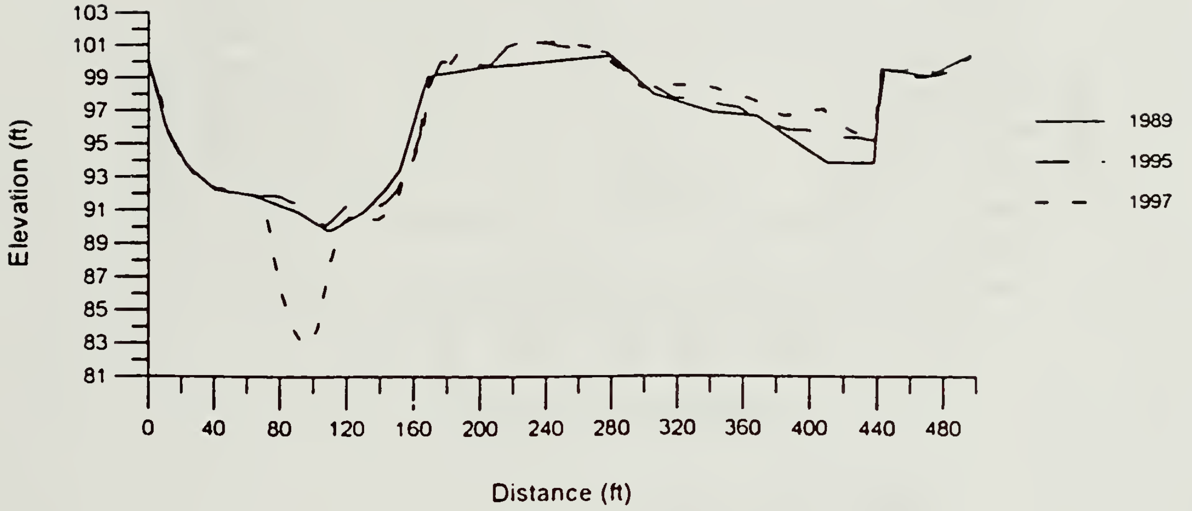


Merced River X/S 26 (Lower River Campground)
116
112
108
104
100
96
92
88
Elevation (ft)
0
40
80
120
160
200
240
280
320
360
Distance (ft)
1989
1997

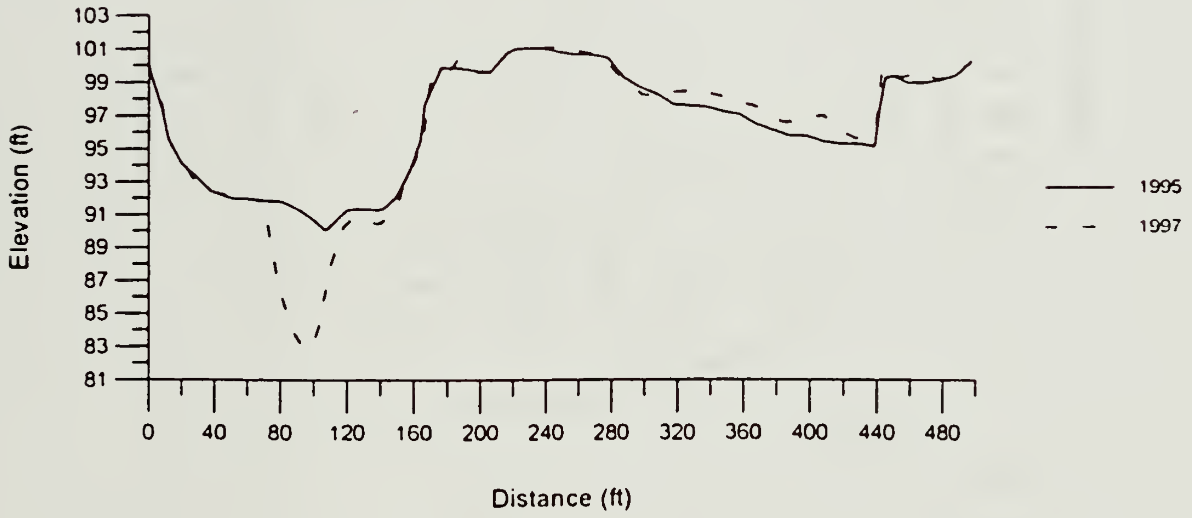


X/S 26
0.50
0.30
0.10
-0.10
-0.30
-0.50
Cum Ec (ft)
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

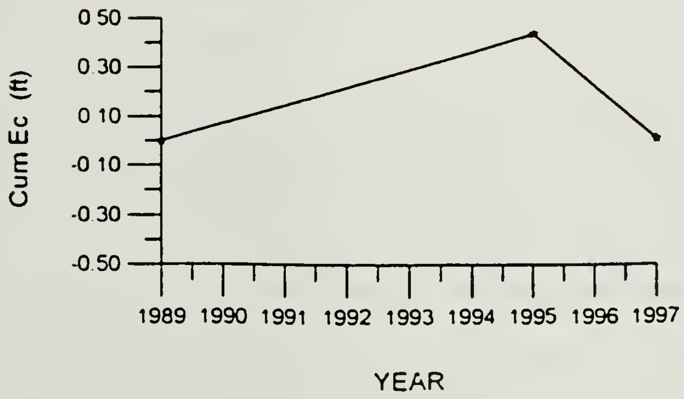
Merced River X/S 27 (Lower River Campground)

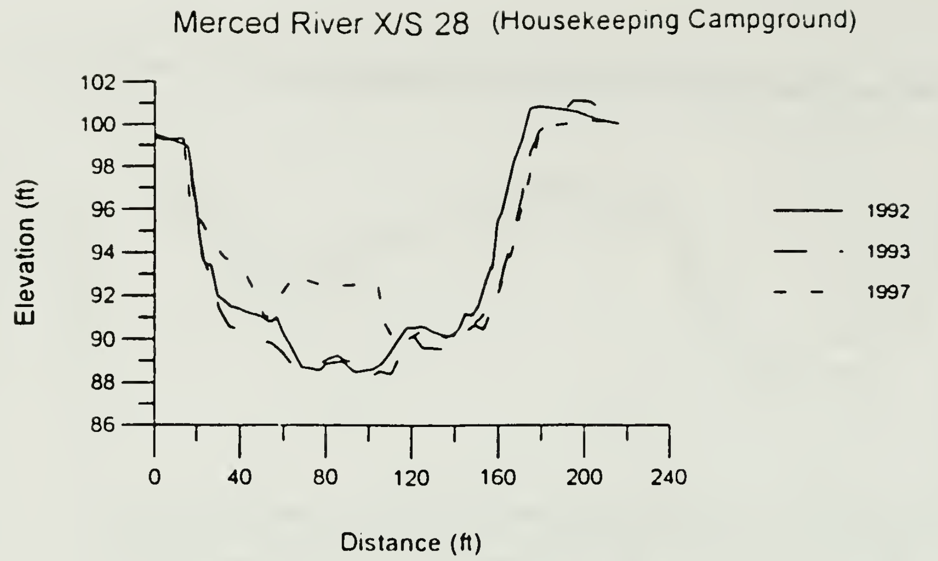


Merced River X/S 27

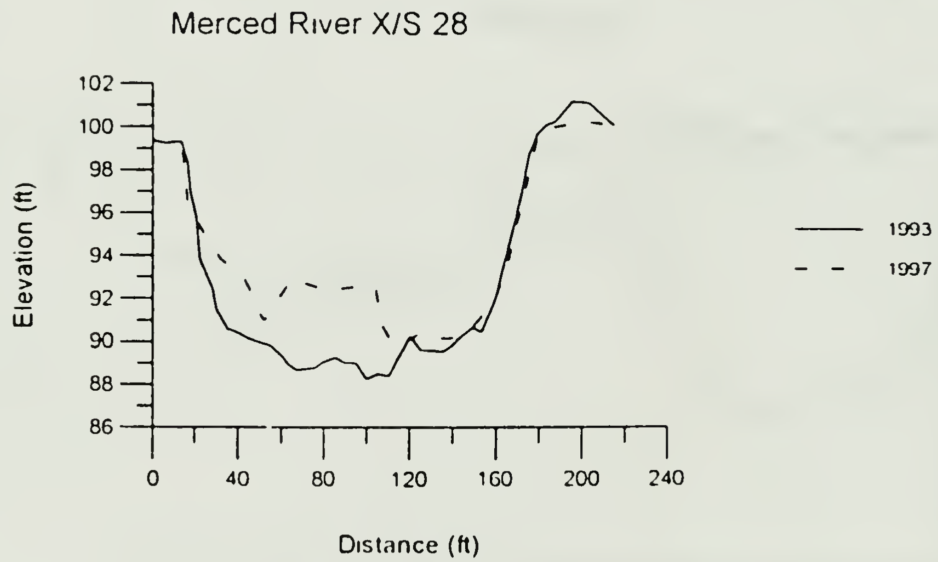


X/S 27

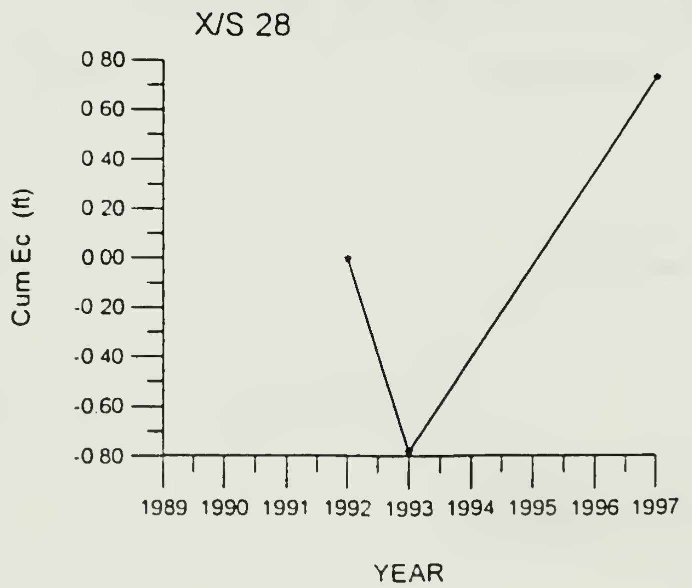




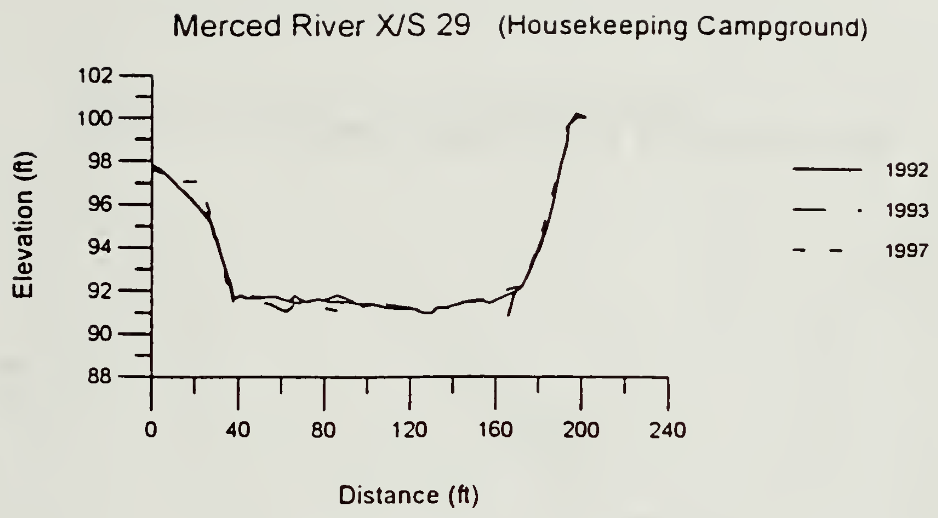
Merced River X/S 28 (Housekeeping Campground)
102
100
98
96
94
92
90
88
86
Elevation (ft)
0
40
80
120
160
200
240
Distance (ft)
1992
1993
1997



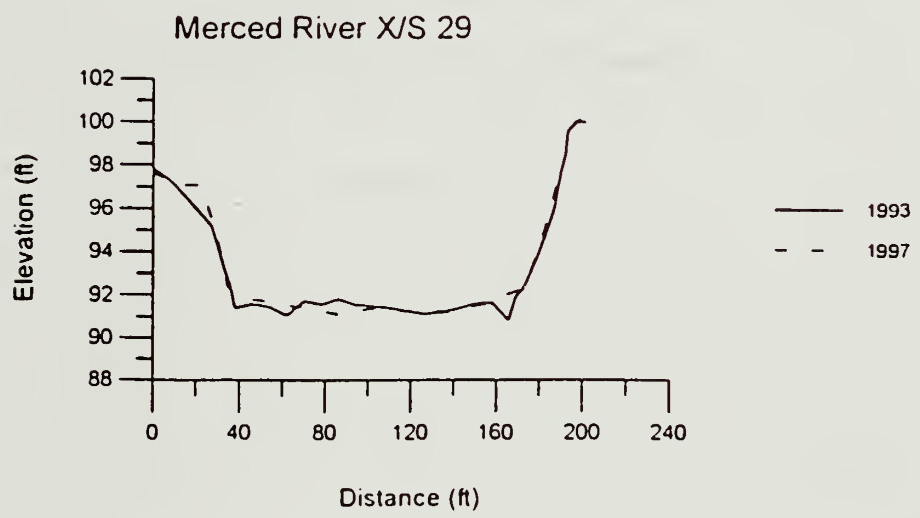
Merced River X/S 28
102
100
98
96
94
92
90
88
86
Elevation (ft)
0
40
80
120
160
200
240
Distance (ft)
1993
1997



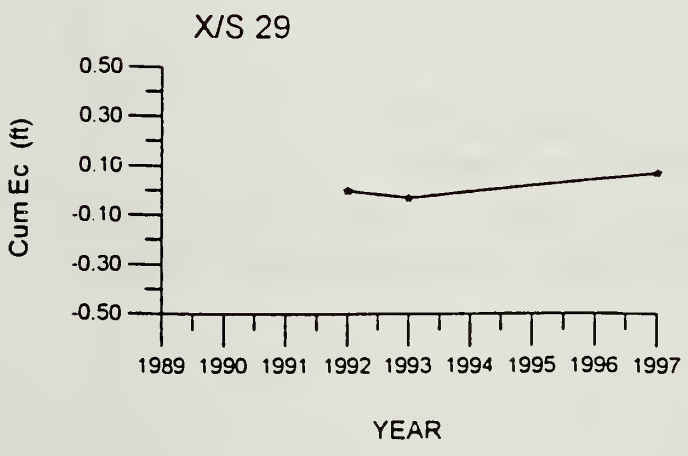
X/S 28
0 80
0 60
0 40
0 20
0 00
-0 20
-0 40
-0.60
-0 80
Cum Ec (ft)
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR



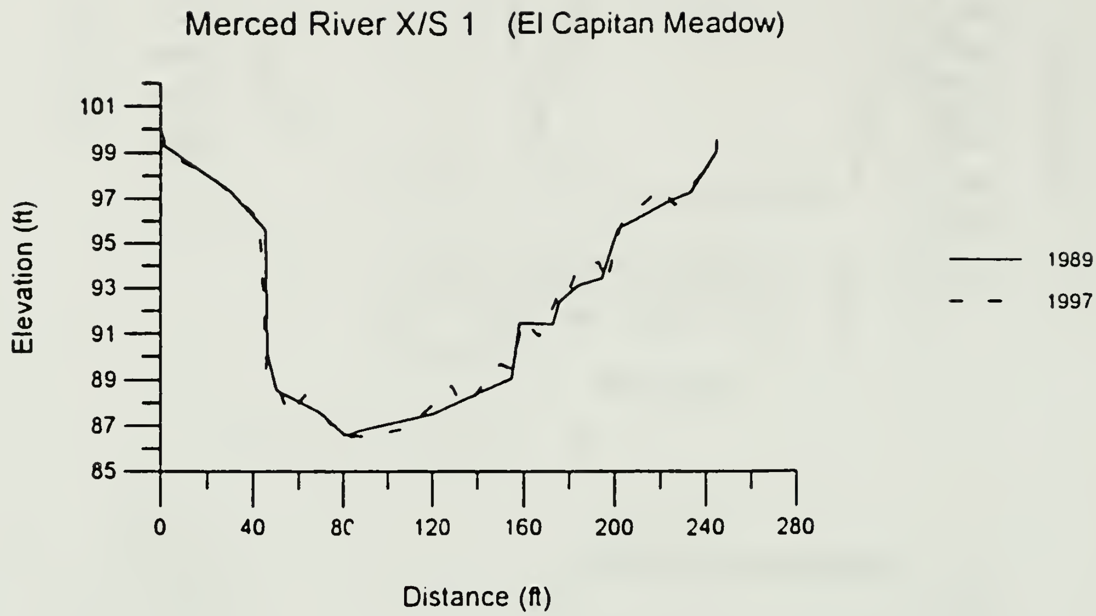
Merced River X/S 29 (Housekeeping Campground)
Elevation (ft)
102
100
98
96
94
92
90
88
0
40
80
120
160
200
240
Distance (ft)
1992
1993
1997



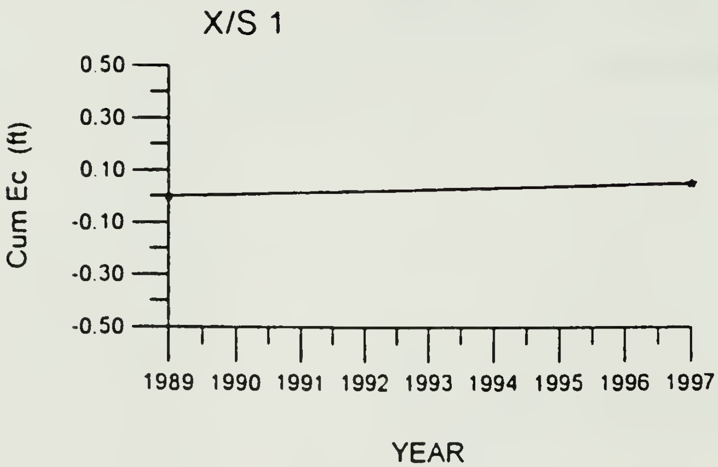
Merced River X/S 29
Elevation (ft)
102
100
98
96
94
92
90
88
0
40
80
120
160
200
240
Distance (ft)
1993
1997



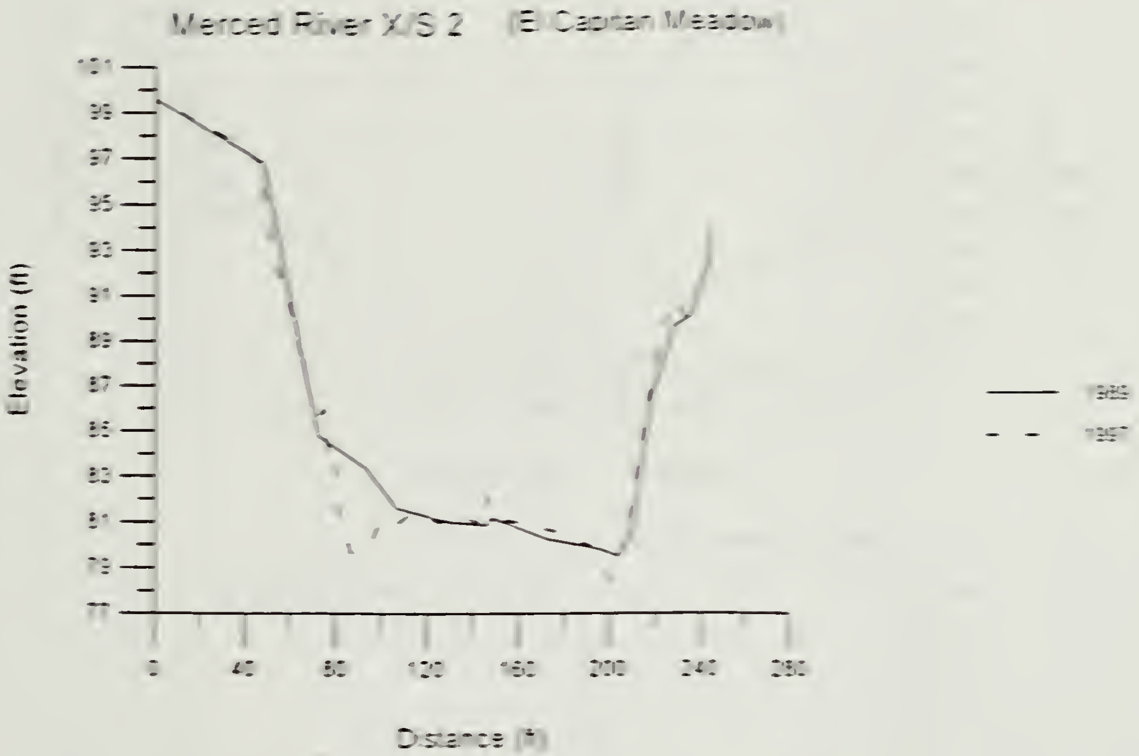
X/S 29
Cum Ec (ft)
0.50
0.30
0.10
-0.10
-0.30
-0.50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

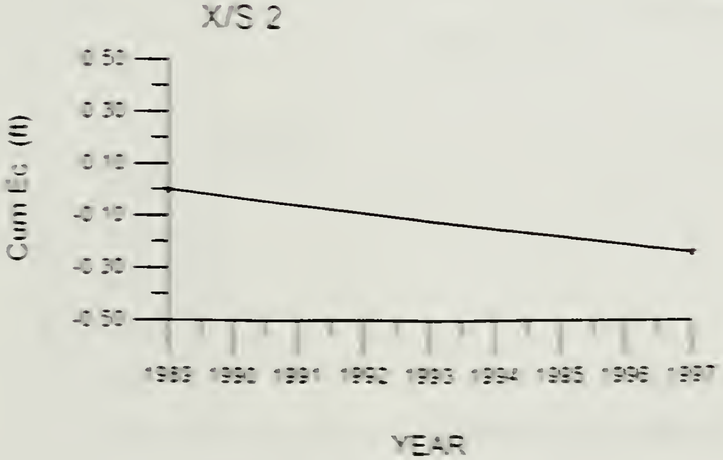


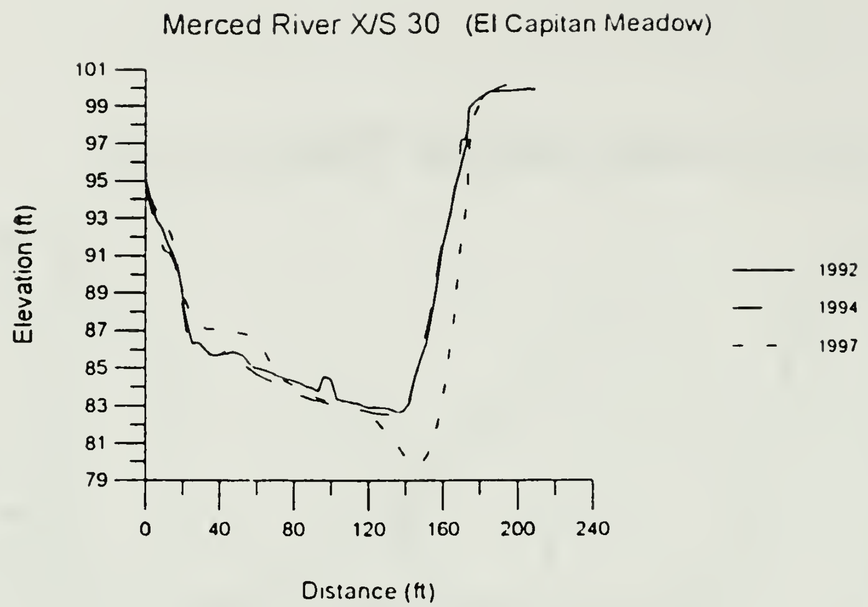
Merced River X/S 1 (El Capitan Meadow)
Elevation (ft)
101
99
97
95
93
91
89
87
85
0
40
80
120
160
200
240
280
Distance (ft)
1989
1997



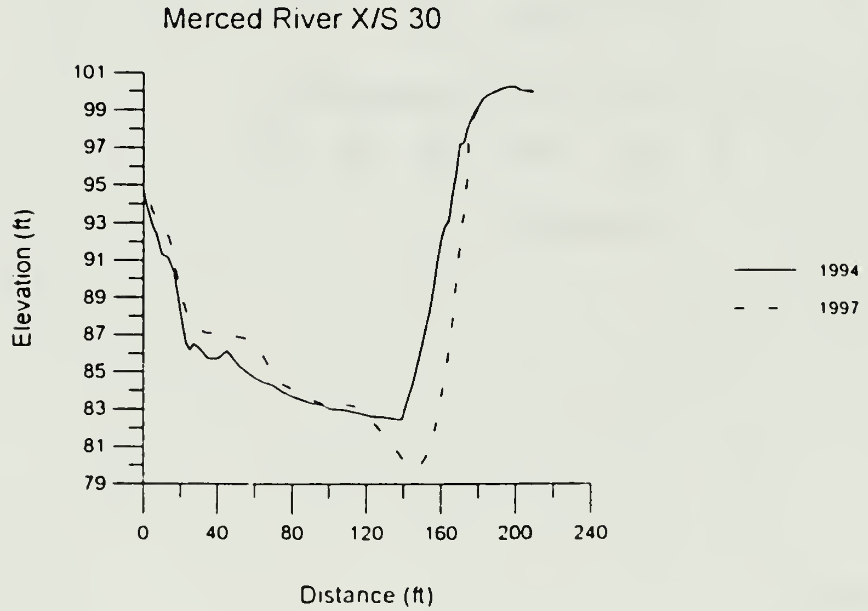
X/S 1
Cum Ec (ft)
0.50
0.30
0.10
-0.10
-0.30
-0.50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR


Merced River X/S 2 (El Capitan Meadow)
Elevation (ft)
Distance (ft)
1989
1997

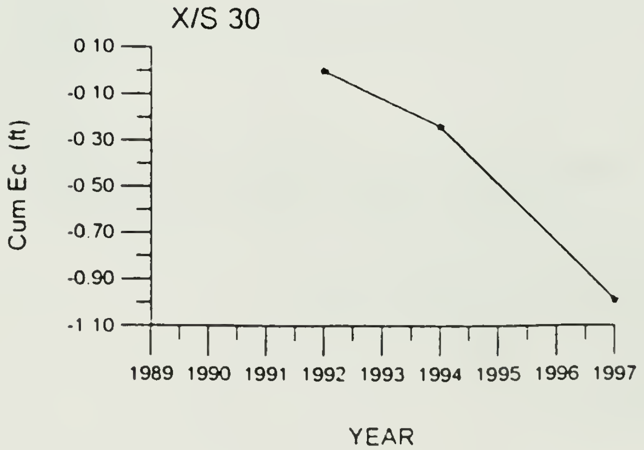

X/S 2
Cum Ec (ft)
YEAR



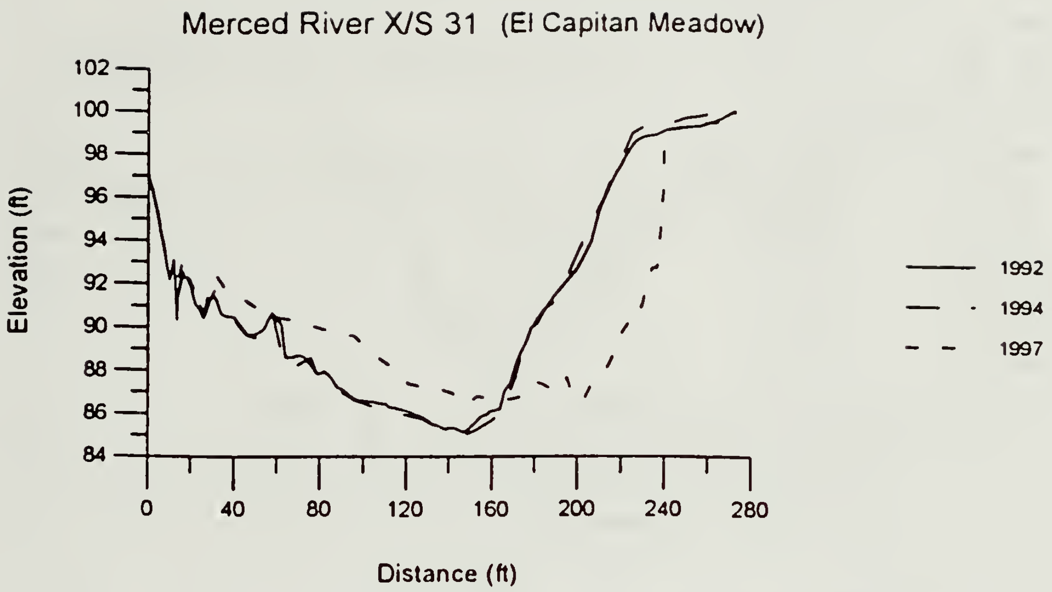
Merced River X/S 30 (El Capitan Meadow)
Elevation (ft)
Distance (ft)
1992
1994
1997

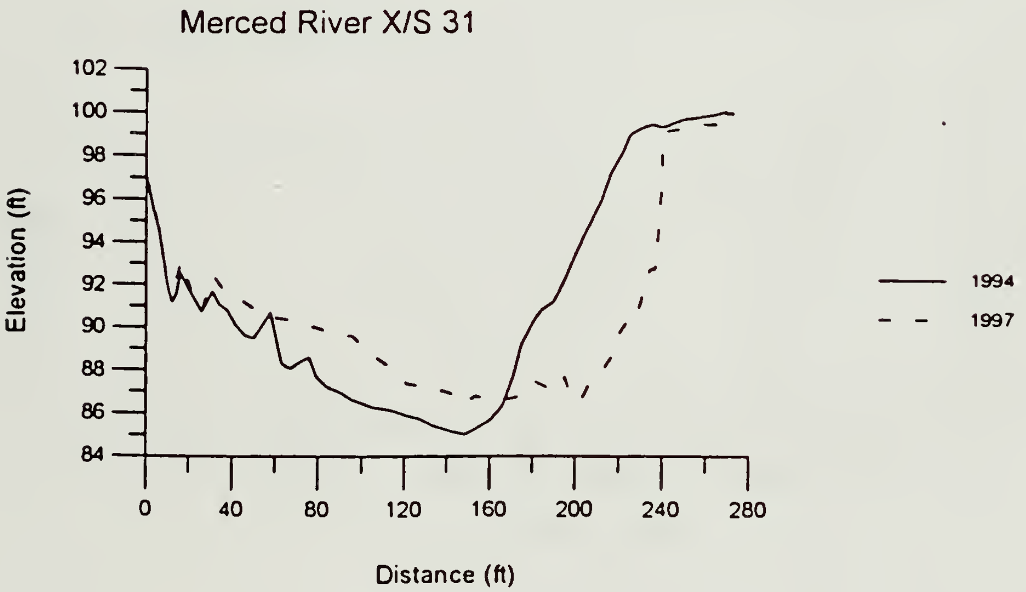


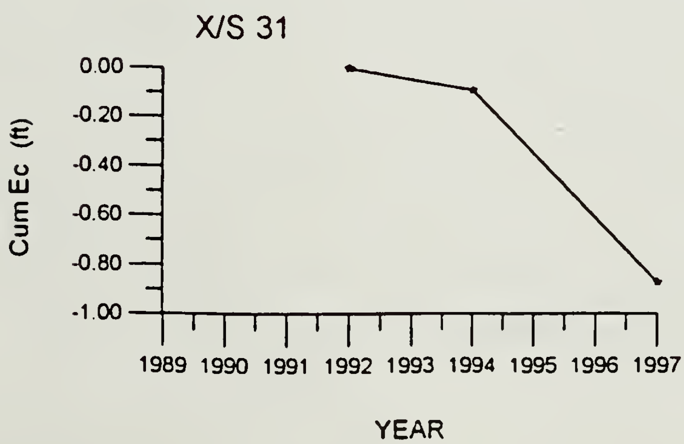
Merced River X/S 30
Elevation (ft)
Distance (ft)
1994
1997

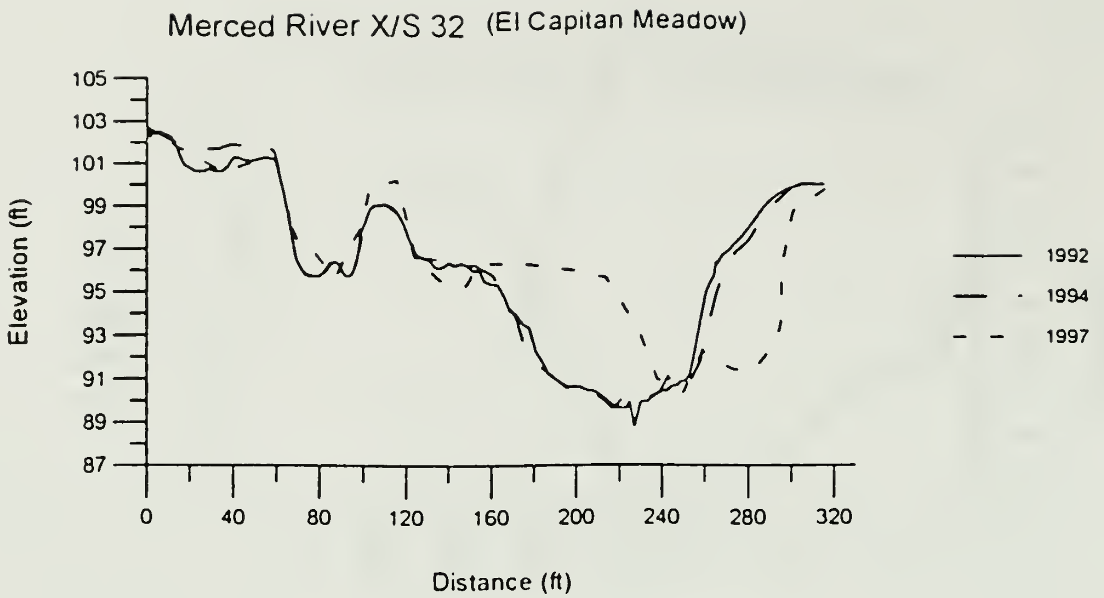


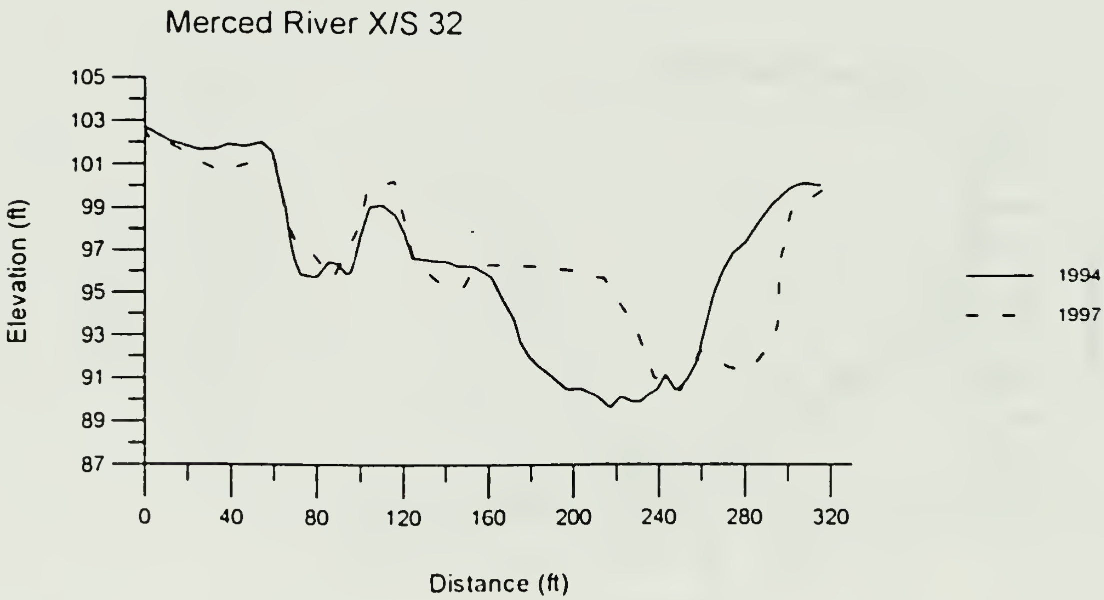
X/S 30
Cum Ec (ft)
YEAR

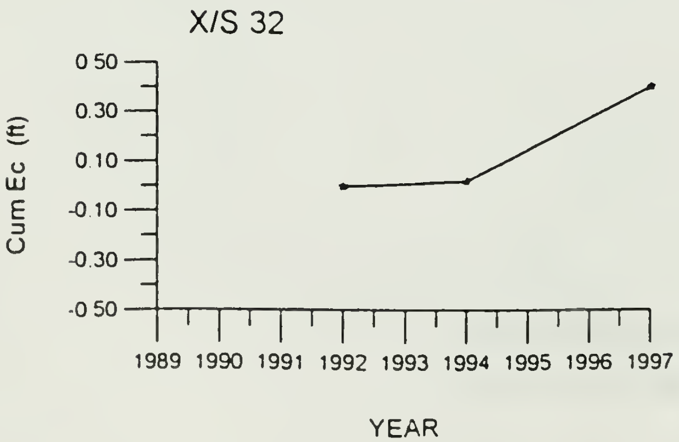

Merced River X/S 31 (El Capitan Meadow)
Elevation (ft)
102
100
98
96
94
92
90
88
86
84
0
40
80
120
160
200
240
280
Distance (ft)
1992
1994
1997


Merced River X/S 31
Elevation (ft)
102
100
98
96
94
92
90
88
86
84
0
40
80
120
160
200
240
280
Distance (ft)
1994
1997


X/S 31
Cum Ec (ft)
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

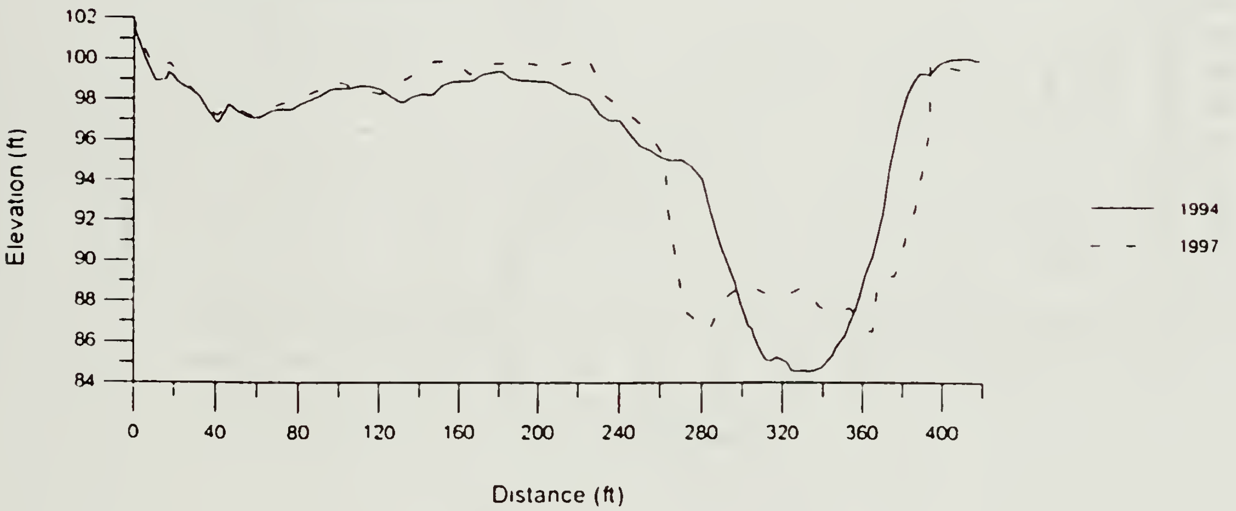

Merced River X/S 32 (El Capitan Meadow)
Elevation (ft)
Distance (ft)
1992
1994
1997


Merced River X/S 32
Elevation (ft)
Distance (ft)
1994
1997

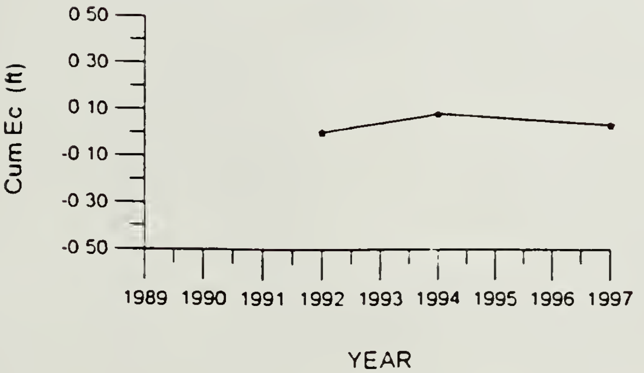

X/S 32
Cum Ec (ft)
YEAR

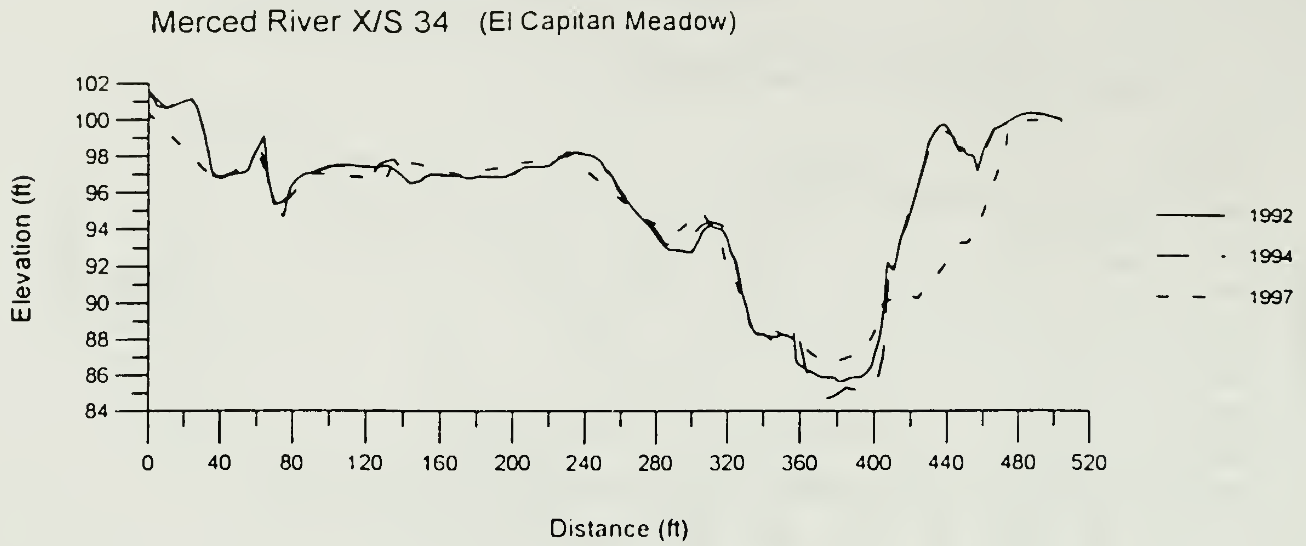
Merced River X/S 33 (El Capitan Meadow)

Merced River X/S 33

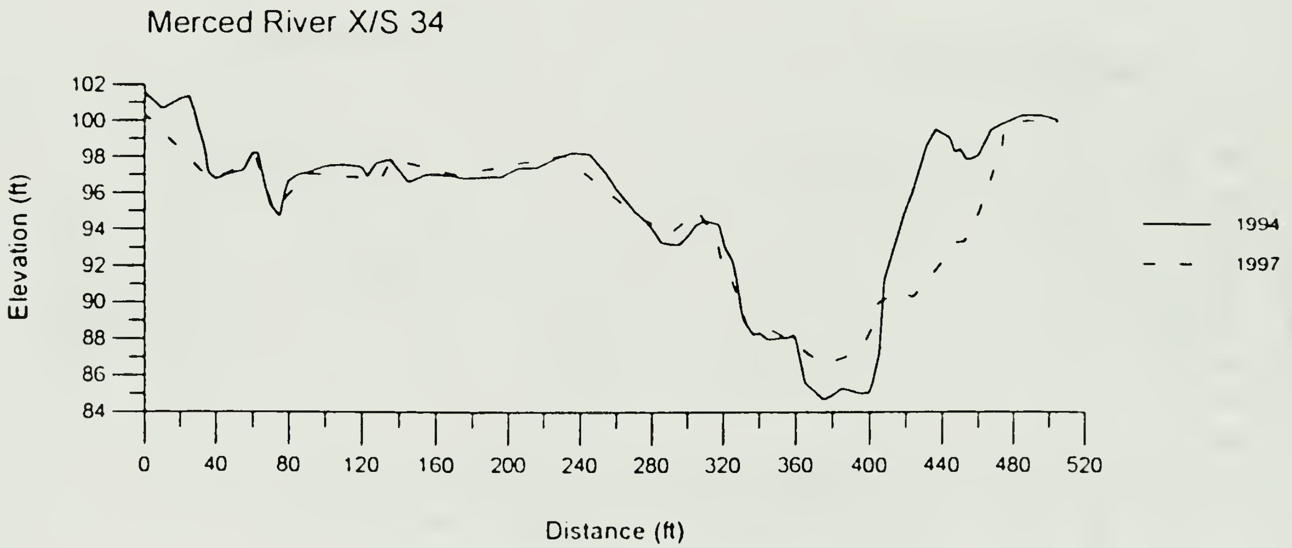


X/S 33

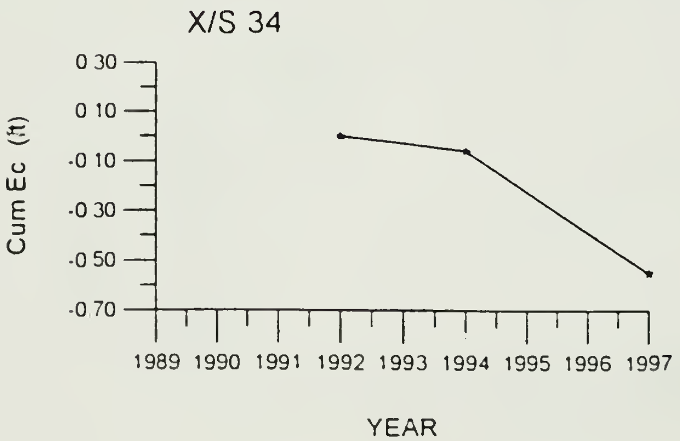




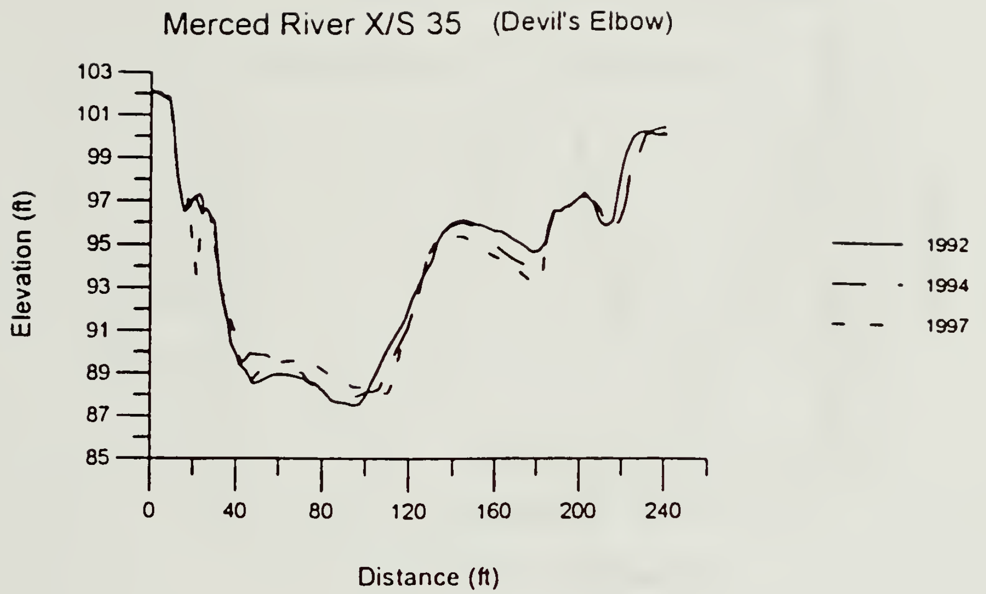
Merced River X/S 34 (El Capitan Meadow)
Elevation (ft)
Distance (ft)
102
100
98
96
94
92
90
88
86
84
0
40
80
120
160
200
240
280
320
360
400
440
480
520
1992
1994
1997

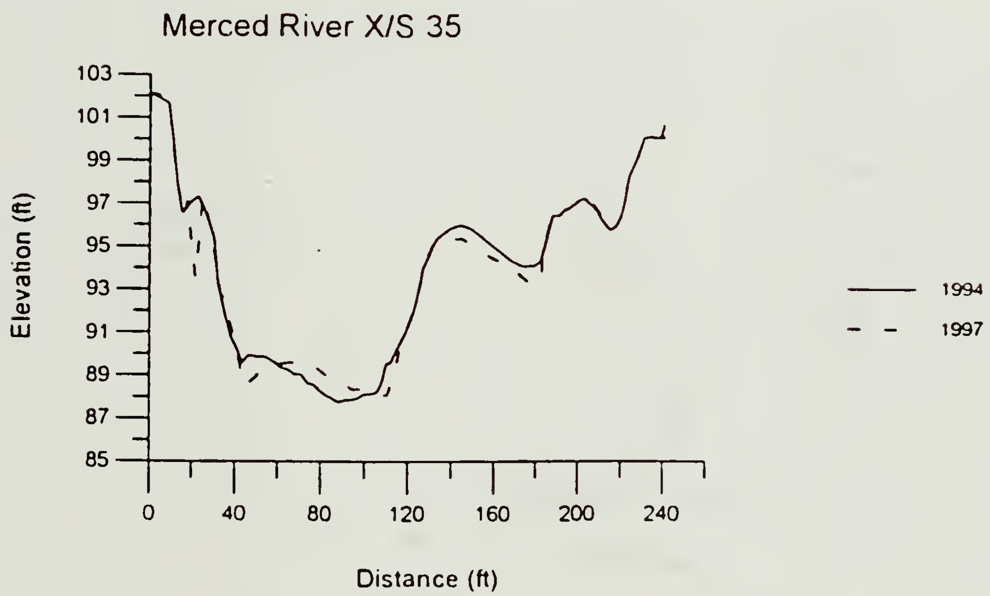


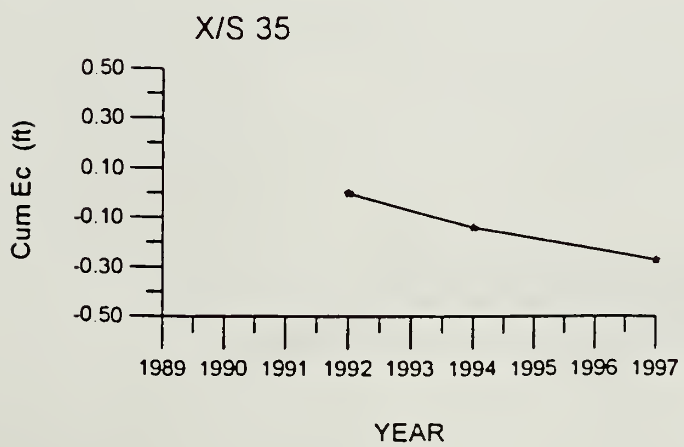
Merced River X/S 34
Elevation (ft)
Distance (ft)
102
100
98
96
94
92
90
88
86
84
0
40
80
120
160
200
240
280
320
360
400
440
480
520
1994
1997

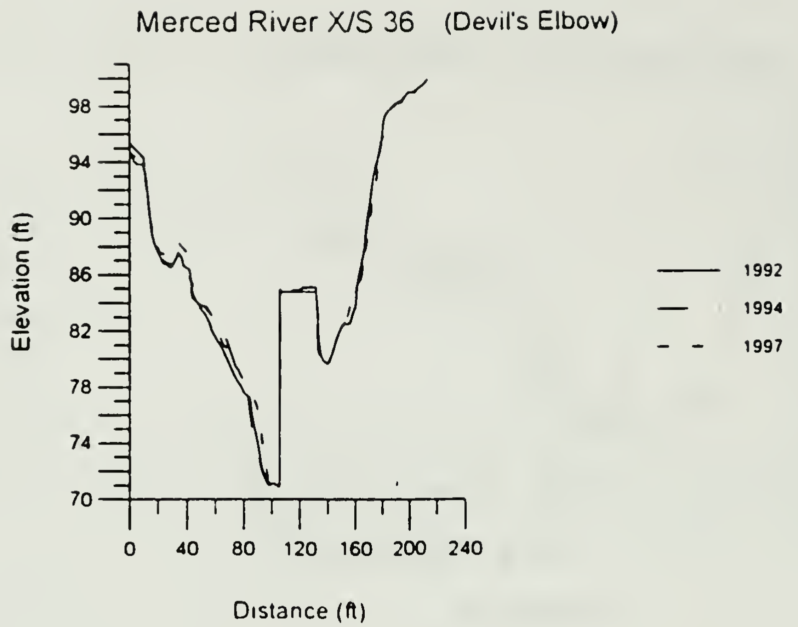


X/S 34
Cum Ec (ft)
YEAR
0 30
0 10
-0 10
-0 30
-0 50
-0 70
1989
1990
1991
1992
1993
1994
1995
1996
1997

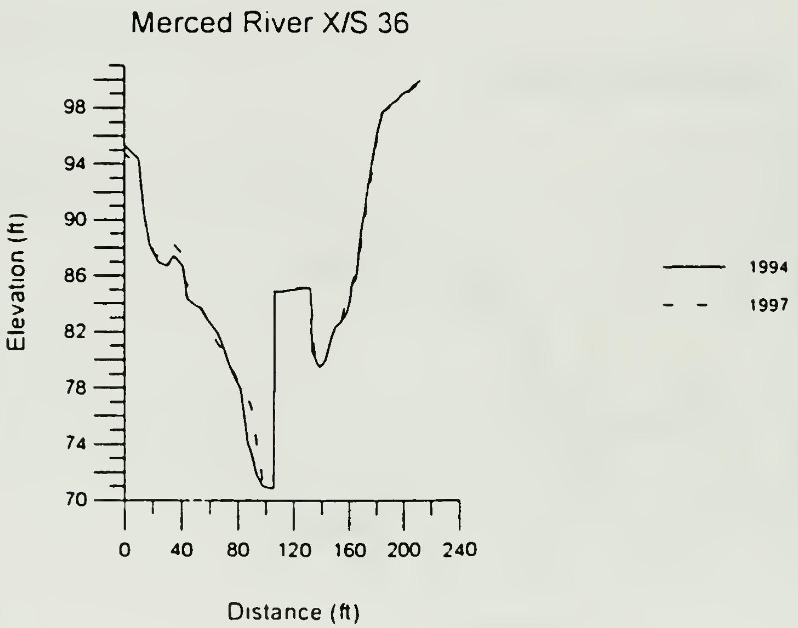

Merced River X/S 35 (Devil's Elbow)
Elevation (ft)
Distance (ft)
103
101
99
97
95
93
91
89
87
85
0
40
80
120
160
200
240
1992
1994
1997


Merced River X/S 35
Elevation (ft)
Distance (ft)
103
101
99
97
95
93
91
89
87
85
0
40
80
120
160
200
240
1994
1997

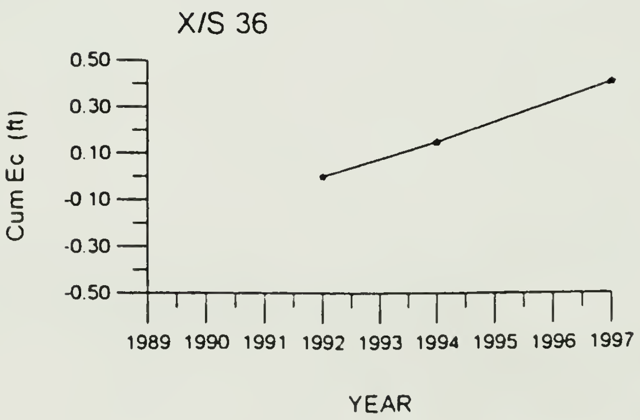

X/S 35
Cum Ec (ft)
YEAR
0.50
0.30
0.10
-0.10
-0.30
-0.50
1989
1990
1991
1992
1993
1994
1995
1996
1997



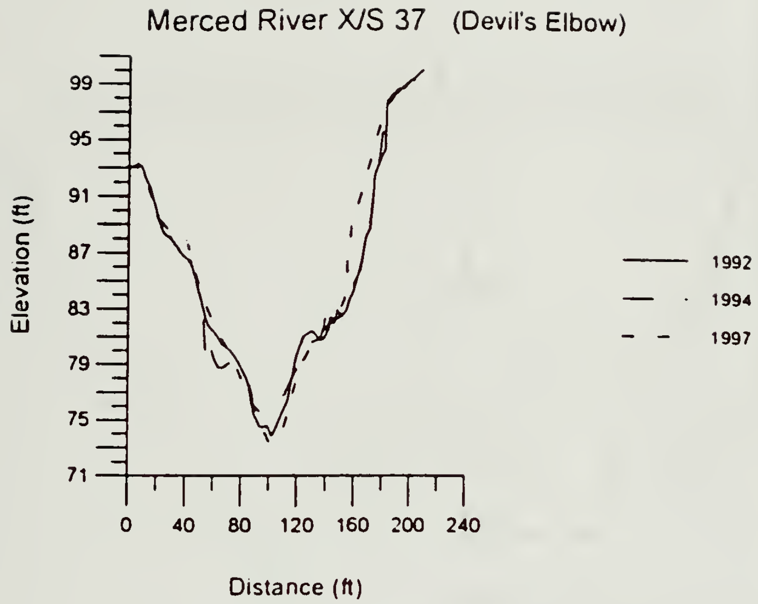
Merced River X/S 36 (Devil's Elbow)
Elevation (ft)
98
94
90
86
82
78
74
70
0
40
80
120
160
200
240
Distance (ft)
1992
1994
1997



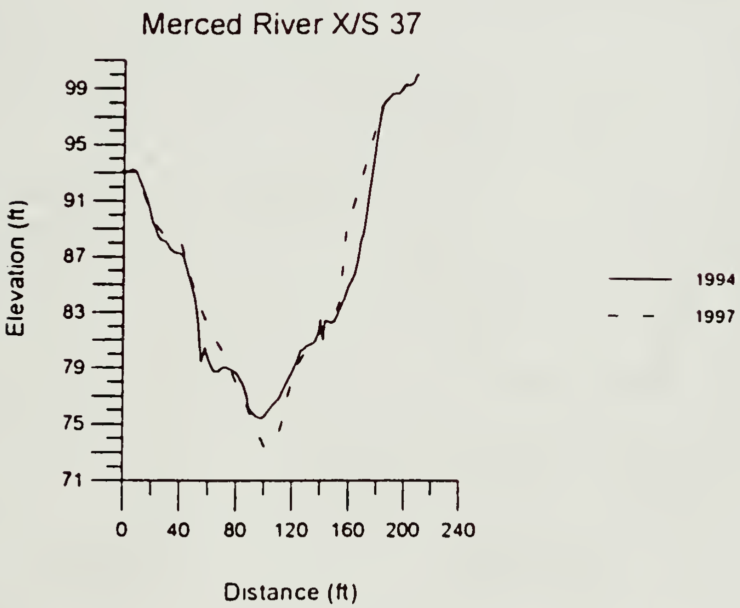
Merced River X/S 36
Elevation (ft)
98
94
90
86
82
78
74
70
0
40
80
120
160
200
240
Distance (ft)
1994
1997



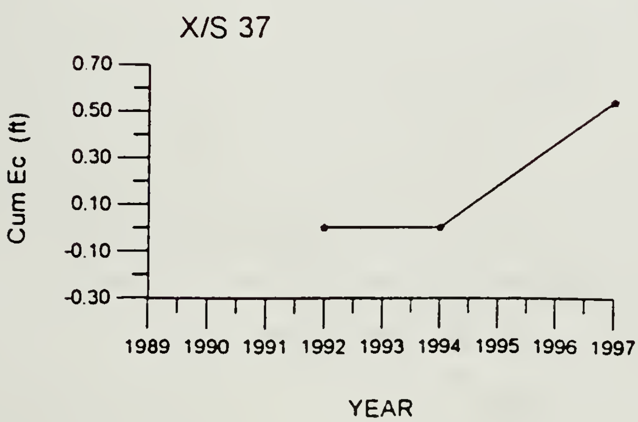
X/S 36
Cum Ec (ft)
0.50
0.30
0.10
-0.10
-0.30
-0.50
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR



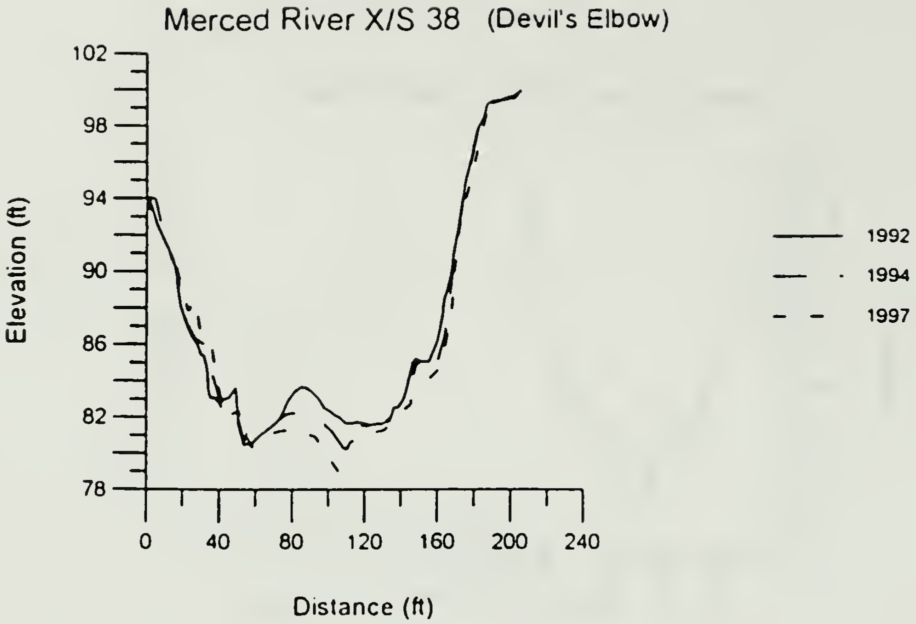
Merced River X/S 37 (Devil's Elbow)
Elevation (ft)
99
95
91
87
83
79
75
71
0
40
80
120
160
200
240
Distance (ft)
1992
1994
1997



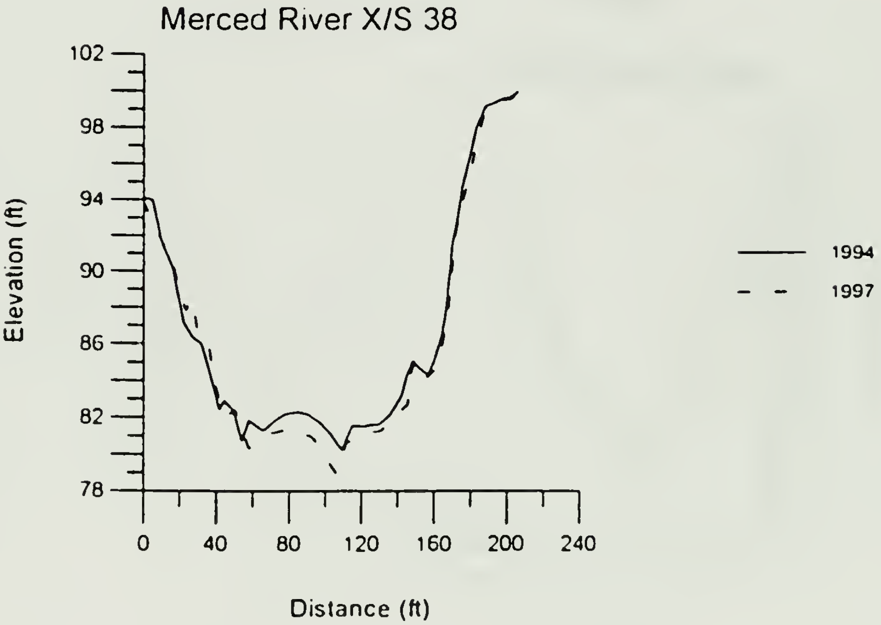
Merced River X/S 37
Elevation (ft)
99
95
91
87
83
79
75
71
0
40
80
120
160
200
240
Distance (ft)
1994
1997



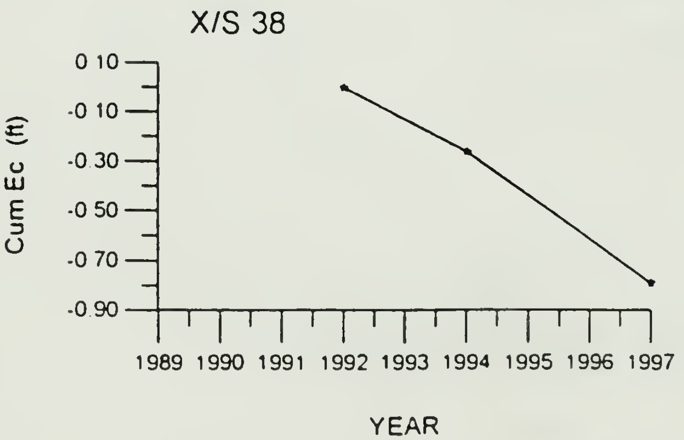
X/S 37
Cum Ec (ft)
0.70
0.50
0.30
0.10
-0.10
-0.30
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR



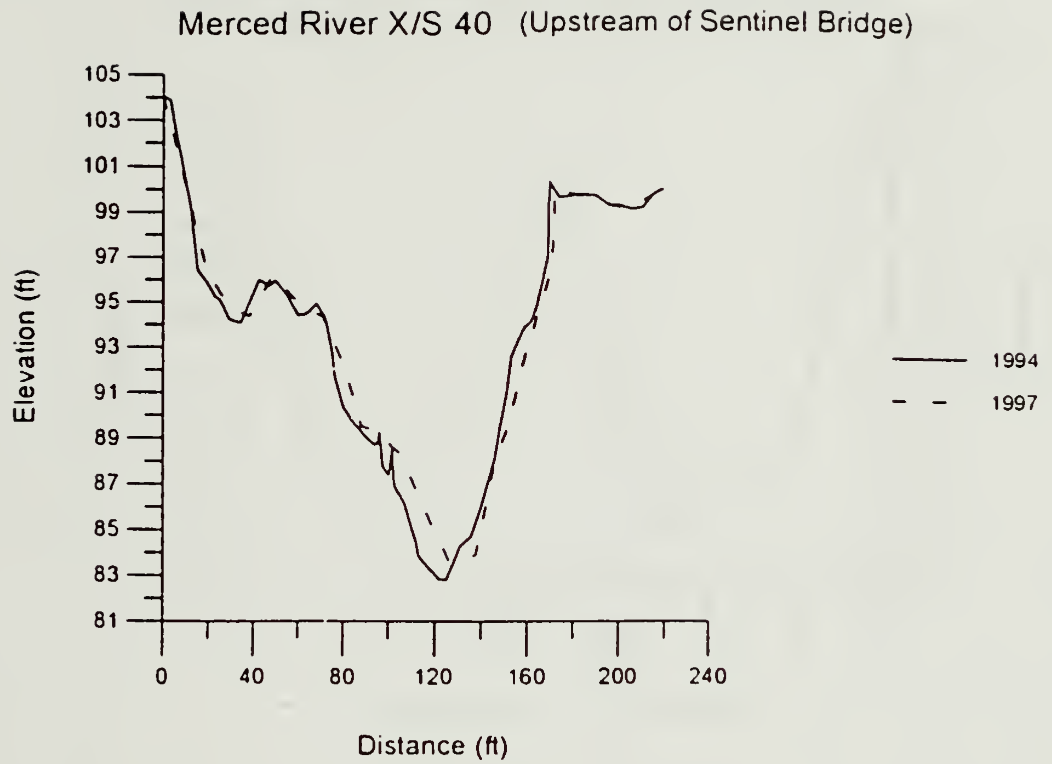
Merced River X/S 38 (Devil's Elbow)
Elevation (ft)
Distance (ft)
1992
1994
1997



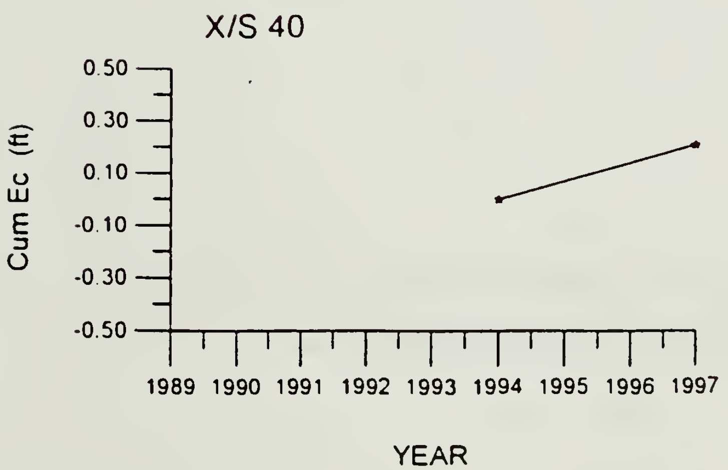
Merced River X/S 38
Elevation (ft)
Distance (ft)
1994
1997



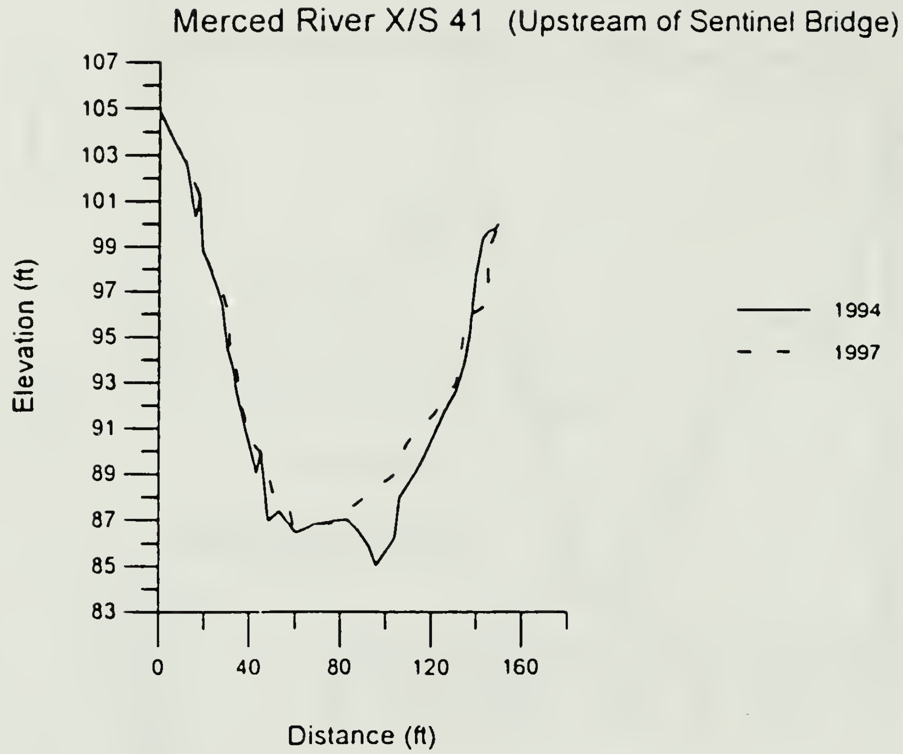
X/S 38
Cum Ec (ft)
YEAR

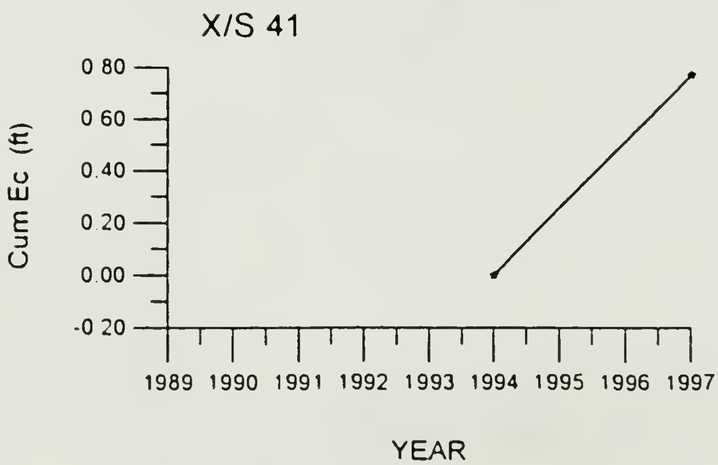


Merced River X/S 40 (Upstream of Sentinel Bridge)
105
103
101
99
97
95
93
91
89
87
85
83
81
Elevation (ft)
0
40
80
120
160
200
240
Distance (ft)
1994
1997

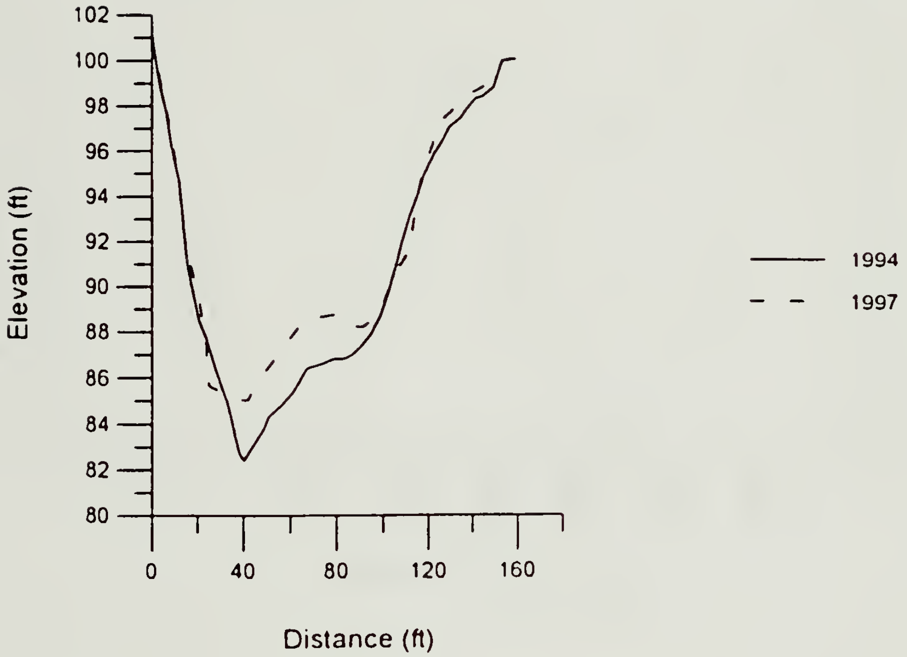


X/S 40
0.50
0.30
0.10
-0.10
-0.30
-0.50
Cum Ec (ft)
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

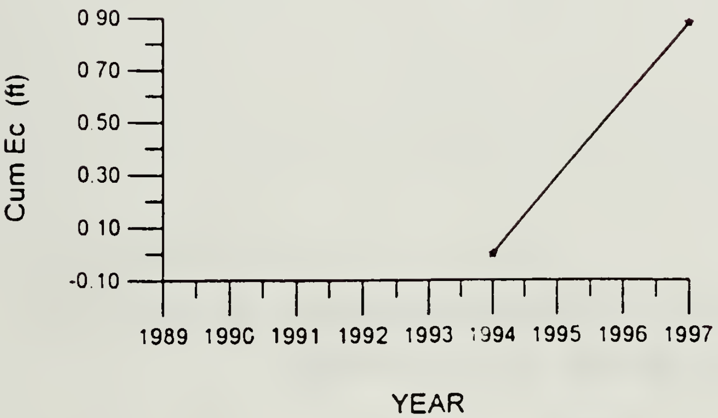

Merced River X/S 41 (Upstream of Sentinel Bridge)
107
105
103
101
99
97
95
93
91
89
87
85
83
Elevation (ft)
0
40
80
120
160
Distance (ft)
1994
1997

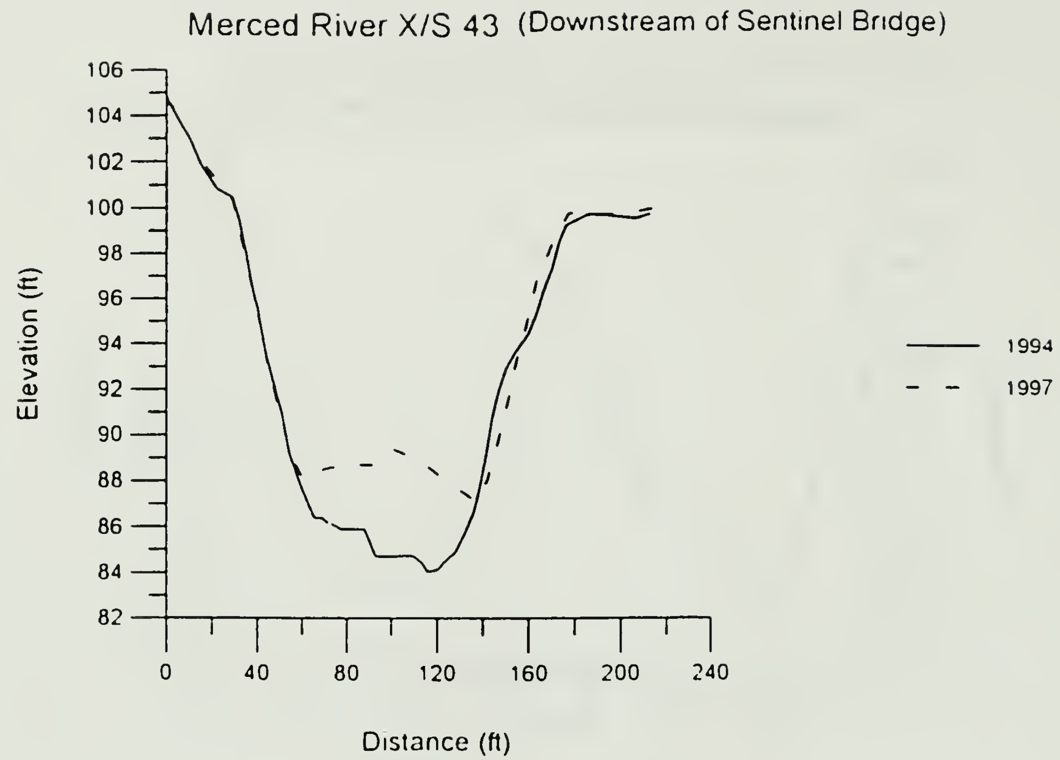

X/S 41
0 80
0 60
0.40
0.20
0.00
-0 20
Cum Ec (ft)
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

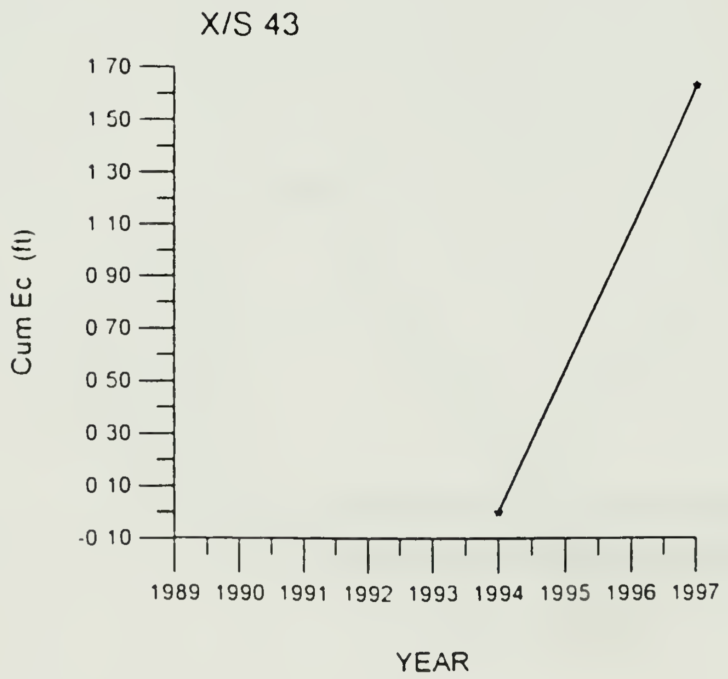
Merced River X/S 42 (Downstream of Sentinel Bridge)

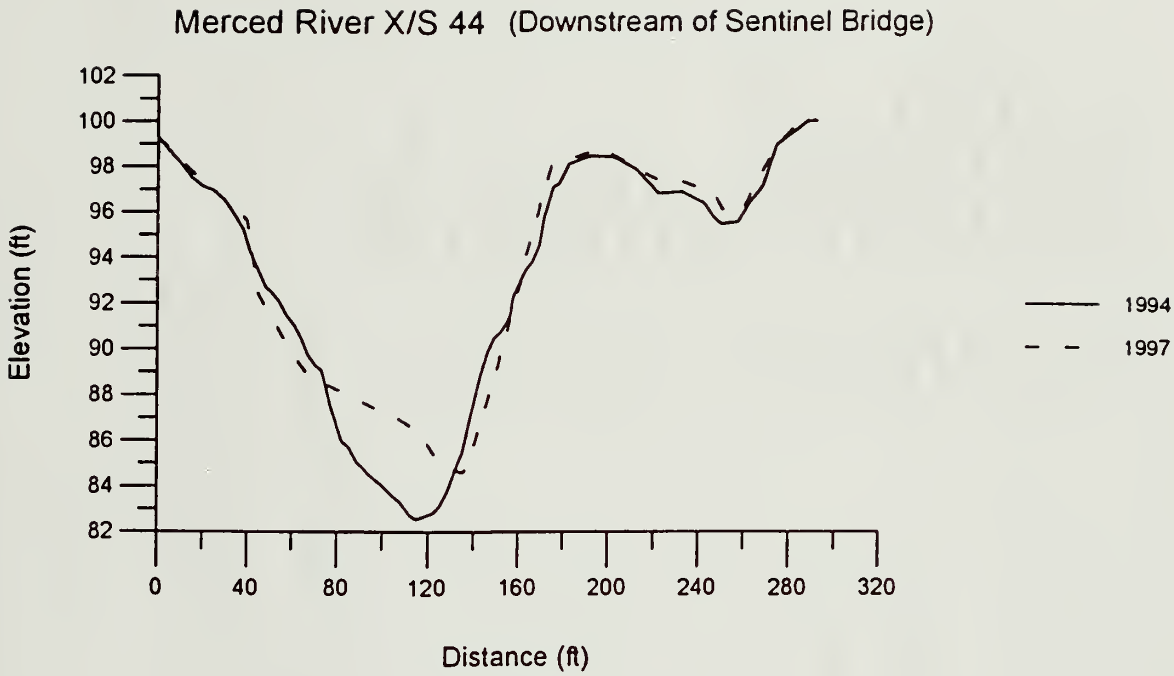


X/S 42

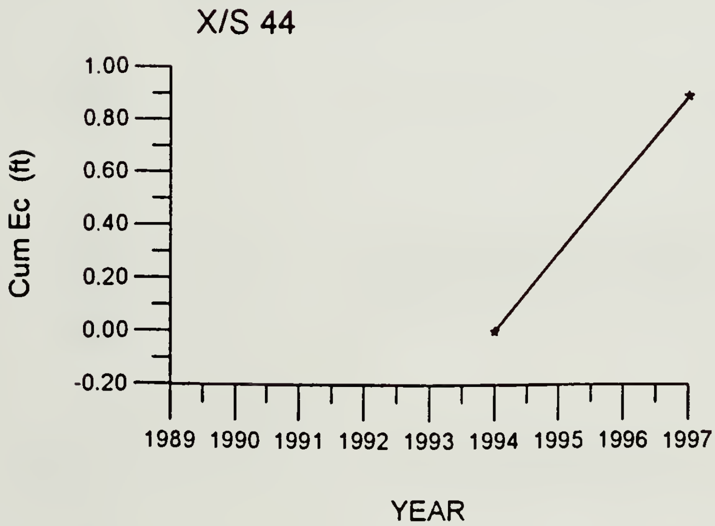



Merced River X/S 43 (Downstream of Sentinel Bridge)
Elevation (ft)
Distance (ft)
1994
1997
106
104
102
100
98
96
94
92
90
88
86
84
82
0
40
80
120
160
200
240


X/S 43
Cum Ec (ft)
YEAR
1 70
1 50
1 30
1 10
0 90
0 70
0 50
0 30
0 10
-0 10
1989
1990
1991
1992
1993
1994
1995
1996
1997



Merced River X/S 44 (Downstream of Sentinel Bridge)
Elevation (ft)
102
100
98
96
94
92
90
88
86
84
82
0
40
80
120
160
200
240
280
320
Distance (ft)
1994
1997



X/S 44
Cum Ec (ft)
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
1989
1990
1991
1992
1993
1994
1995
1996
1997
YEAR

APPENDIX B: Longitudinal Profile Survey of the Merced River

6-Aug-97

Channel Distance (ft)	Channel Bed Elevation (ft)	Water Suface Elevation (ft)	Water Depth (ft)	COMMENTS
162.2				Bench Mark elevation = 1000 ft. (arbitrary elevation), BM is located on LB upstream edge of Clarks Bridge. At sidewalk entrance to bridge is a worn sign "Clarks Bridge". Above a nail (1") in the top center of the sign is ledge. BM is on ledge directly above nail. Survey instrument was set up 162 ft. upstream of Clarks Bridge
114.13	977.18	982.46	5.3	RUN\ 1.5' dia. log leaning against US side of bridge
180.17	976.41	982.41	6.0	S (very sandy)
235.58	976.92	982.47	5.6	S,C \ STUMP @ REW
286.94	977.42	982.32	4.9	S,C
320.76	977.35	982.3	5.0	S,G,C:B
351.1	978.53	982.68	4.2	C,S
384.77	978.61	982.71	4.1	S,C:B
418.19	978.91	982.46	3.6	C,B
442.76	979.12	982.72	3.6	S,P,B
475.22	979.11	982.66	3.6	S,P:B
*374.66		0	0.0	*rew @ rx-10
517.65	979.43	982.63	3.2	S,P,C,B
562.11	979.34	982.49	3.2	S,C,B
606.9	979.02	982.56	3.5	S,P,C
654.87	978.51	982.41	3.9	S,P:B\ 3' DIA. STUMP @ REW
684.6	978.8	982.63	3.8	S,B,C
717.68	978.57	982.52	4.0	S,C,B \ Lg. PONDEROSA ON LB
750.51	978.49	982.54	4.1	S,C,B
*857.81		0		*LEW at Lx-11
782.3	978.3	982.5	4.2	S,C:B
829.76	977.26	982.26	5.0	S,P:B
861.73	978.33	982.53	4.2	S:C:B
902.13	977.3	982.6	5.3	S:P STUMP @ REW
944.98	977.64	982.49	4.9	S,P,C:B

LEGEND

BM	**Bench Mark**
S	**Sand**
P	**Pebble**
C	**Cobble**
B	**Boulder**
RB	**Right Bank**
LB	**Left Bank**
RW	**Root Wad**
:	**Some**
/	**Contact**
LFC	**Low Flow Channel**
TP	**Turning Point**
FS	**ForeSight**
BS	**Back Sight**
BIS	**Break In Slope**
LEW	**Left edge of water**
REW	**Right edge of water**
Lx	**Left monument**
Rx	**Right monument**
US	**Upstream**
DS	**Downstream**

Channel	Bed	Water Suface	Water	COMMENTS
989.5	977.64	982.54	4.9	S,P:B SOME STUMPS @ LB
1018.58	977.87	982.57	4.7	S,C:B STUMPS @ LEW
1061.63	978.59	982.69	4.1	S,G:B
1076.65	979.59	983.29	3.7	S,C,B PONDEROSA IN LOW FLOW CHAN @ LEW
1119.99	979.68	982.58	2.9	S,C,P
1144.6	980.27	982.59	2.3	S,C,B
1188	980.52	982.72	2.2	B,S,C CEDARS IN LFC at LEW
*1229.18		0		TP LOW (FS) NEGATIVE DISTANCE IS FROM TP TO INSTRUMENT
*1236.41		0		TP HIGH FS
*1229.36		0		TP LOW BS
*1236.21		0		TP HIGH BS
*1200.65		0		LEW XS-12
1220.05	981.13	983.05	1.9	B,C,S
1314.93	980.83	982.45	1.6	C:B:S
1358.92	981.26	982.76	1.5	S,C,B,P
1409.08	978.89	982.09	3.2	C:B,S LOG ON LB, SM SCOUR POOL @ ROOT WAD
1447.88	981.18	981.98	0.8	C,B,P, TOP OF RIFFLE, WILLOWS IN LFC @ RB
1496.54	980.29	981.94	1.7	C,B RIFFLE
1529.63	979.61	981.21	1.6	C,P,B RIFFLE
*1585.95		0		LEW @ XS-13
1556.45	980.52	981.02	0.5	C,P MID-CHANNEL STUMP
1565.28	978.86	981.06	2.2	S SM SCOUR POOL DS OF Mid-Channel STUMP
1589.33	978.87	980.97	2.1	P,C US OF Mid-Channel STUMP
1603.46	978.57	980.17	1.6	C,S:B DS OF Mid-Channel STUMP
1641.54	977.81	980.31	2.5	FAST WATER AGAINST RB
1692.98	976.52	979.62	3.1	C,S,B
1724.11	975.42	979.02	3.6	SCOUR POOL ON RB
1740.84	976	978.9	2.9	SM POOL BY FALLEN LOG
1746.14	976.74	978.94	2.2	SEWER PIPE XING
1775.23	977.47	979.57	2.1	US OF ROOT
1781.74	976.74	978.39	1.7	S,P,C DS OF ROOT
1809.29	977	978.6	1.6	C,P:B
1836.83	977.3	978.5	1.2	C,P:B TOP OF RIFFLE
1873.5	976.59	977.59	1.0	C,P:B

Channel	Bed	Water Suface	Water	COMMENTS
1900.66	976.28	977.38	1.1	US EDGE OF CONFL W\ TENAYA CR. US EDGE OF TREE
1931.89	971.45	977	5.6	S,P,C\B =DS SIDE OF TENAYA CR. POOL
1968.28	973.72	976.67	3.0	B,C:S
2001.57	974.01	976.71	2.7	C,S,P
2022.46	974.57	976.57	2.0	P,C US OF TREE GROWING IN RIVER
2046.82	975.23	976.68	1.5	S,C:B
2062.22	970.45	976.55	6.1	US OF LG. B IN RIVER @RB
2086.46	970.95	976.55	5.6	DS OF LG. B IN RIVER @RB
2126.85	973.41	976.61	3.2	S,P,C:B
2153.15	972.65	976.55	3.9	S,C:B
2191.51	972.91	976.51	3.6	S,C,P
2228.07	974.12	976.42	2.3	S,C:B
2261.36	974.71	976.61	1.9	C,P,S
2287.18	974.84	976.44	1.6	C,S:B
2346.25	974.18	975.88	1.7	C,P:S
2397.03	970.41	975.41	5.0	XS 15 US SIDE OF SUGAR PINE BRIDGE
2403.4	969.37	975.27	5.9	S,B US SIDE OF SUGAR PINE BRIDGE
*2404.93		0		TP HIGH ON SUGAR PINE BRIDGE (US EDGE) FS
*2403.8		0		TP LOW ON SUGAR PINE BRIDGE (US EDGE) FS
		0		**BEGIN DAY TWO 7AUG97 @ SUGAR PINE BRIDGE**
*2404.37		0		TP HIGH BS
2404.37		0		TP LOW BS
		0		LX XS-15
		0		LX XS-15A
2483.37	968.14	975.34	7.2	DS OF SUGAR PINE BRIDGE RIP RAP ALONG RB
2495.37	968.75	975.25	6.5	S,C DS OF BRIDGE @ LG. SUGAR PINE--RIP RAP
2554.37	967.62	975.22	7.6	C,B:S
2593.37	968.86	975.36	6.5	B,C,P,S--END OF NEW RIP RAP--BEGIN CCC RIP RAP
2634.37	971.89	975.29	3.4	C,P,B
2646.37	972.38	975.18	2.8	C,B:P TOP OF RIFFLE
2682.37	972.55	974.55	2.0	C,P,B MID RIFFLE
2704.37	971.83	974.23	2.4	C,B BIS
2708.37	971.06	974.26	3.2	PLUNGE POOL OVER BLDRS @RB
2733.37	968.84	974.04	5.2	CEMENT TOE @ BASE OF RIP RAP

Channel	Bed	Water Suface	Water	COMMENTS
2770.37	968.3	974.1	5.8	S,P,C,B
2814.37	969.96	974.16	4.2	C,B,P REO MC BAR
2850.37	970.5	974	3.5	C,P,B
2892.37	972.58	973.58	1.0	C,S:P TOP RIFFLE CONFLUENCE OF TWO BRANCHES
2926.37	971.84	973.54	1.7	
2965.37	971.23	973.53	2.3	
3004.37	971.57	973.37	1.8	
3016.37	972.3	973.3	1.0	TOP BLDR RIFFLE
3026.37	971.58	973.28	1.7	BASE RIFFLE
3045.37	972.12	973.32	1.2	P,C,S
		0		**TP HIGH FS**
		0		**TP LOW FS**
		0		**TP HIGH BS SWITCH FRM TOTAL STA. TO LEVEL**
		0		**TP LOW BS**
3077.37	971.77	973.22	1.5	P,C
3094.37	970.23	973.23	3.0	C,P THALWEG ALONG RB
3106.37	968.95	973.25	4.3	S,P,C CONFLUENCE W\ DRY CHAN ON RB CONCRETE IN CHAN
3109.37	968.32	973.22	4.9	S,C,P
3127.37	970.02	973.22	3.2	C,S,P
3150.37	970.88	973.23	2.4	S,P,C UNDERCUT ROOTS ON RB
3184.37	971.14	973.24	2.1	S,P
3219.37	970.32	973.22	2.9	S,P
3245.37	969.73	973.23	3.5	S,P,C
3304.37	970.23	973.03	2.8	P,C,S
3325.37	969.71	973.21	3.5	C,S MOUTH OF ROYAL ARCHES CR ON RB/LRG C BAR ON LB
3334.37	968.37	973.27	4.9	S,C INTAKE FOR AHWAHNEE PUMP STATION
3371.37	968.24	973.24	5.0	S,P,C
3378.37	966.49	974.49	8.0	P,C,B
3404.37	970.05	973.15	3.1	P,C:S TAIL OF POOL
3413.37	971.84	973.04	1.2	C,P
3450.37	970.9	973.1	2.2	S BASE OF RIFFLE
3464.37	971.25	973.05	1.8	B,C,P US EDGE OF AHWAHNEE BRIDGE
3497.37	969.94	973.04	3.1	B,C,S THALWEG THROUGH BRIDGE
		4.7	4.7	DEEPEST PART OF WATER THROUGH BRIDGE

Channel	Bed	Water Suface	Water	COMMENTS
3518.37	971.09	973.09	2.0	B,C,S DS SIDE OF AHWAHNEE BRIDGE
3536.37	968.67	973.02	4.4	S,P
3561.37	969.13	973.13	4.0	C
3576.37	968.71	973.11	4.4	S,P,C
3604.37	969.39	973.09	3.7	S,P,C RIP RAP ALONG BANK, RW FLOATED IN
		0		**TP HIGH FS**
		0		**TP LOW FS**
		0		**TP HIGH BS**
		0		**TP LOW BS**
3644.37	969.63	972.99	3.4	P,C
3648.37	970.28	973.08	2.8	P,C
3675.37	971.2	973	1.8	C,P
3738.37	971.63	973.03	1.4	C,B TOP ARTIFICIAL RIFFLE
3760.37	971.12	972.92	1.8	C,P END OF LOG
3790.37	971.74	972.54	0.8	P,C MOUTH OF OVERFLOW CHANNEL
3833.37	971.61	972.61	1.0	P,C TOP ARTIFICIAL RIFFLE
3849.37	971.36	972.36	1.0	S,P,C: B BOTT OF B RIFFLE
3904.37	971.16	972.36	1.2	P,C
3947.37	971.3	972.3	1.0	P:C
4011.37	971.57	971.97	0.4	P STUMP ON LB
4032.37	970.63	971.73	1.1	S SUBMERGED LOG
		0		RX XS - 19
4090.37	970.21	971.71	1.5	P,S,C SM SCOUR POOL AROUND STUMP IN CHANN
4126.37	970.38	971.78	1.4	S,P TOP OF RIFFLE, 2 DOWNED TREES ON LB
		0		ARTIFICIAL RIFFLE & GROIN ON LB
4156.37	969.83	971.63	1.8	S,P,C DS END OF RIFFLE
		0		LX XS 20 GRND SURFACE OF LB TERRACE
4161.37	969.21	971.56	2.4	SM SCOUR POOL BY GROIN
4183.37	969.98	971.48	1.5	S,C SCOUR BY LOGS AND GROIN
4204.37	969.62	971.62	2.0	S,P,C
		0		TP HIGH FS
		0		TP LOW FS
		0		TP HIGH BS
		0		TP LOW BS

Channel	Bed	Water Suface	Water	COMMENTS
4233.37	969.23	971.58	2.4	S:C THALWEG ADJAC TO FALLEN TREE ON LB
4271.37	969.19	971.59	2.4	S:C:P DS END OF FALLEN TREE
4301.37	969.26	971.51	2.3	S:C
4325.37	968.96	971.56	2.6	S:P
4373.37	969.03	971.55	2.5	S,P:C STUMP ON LB @ INSTRUMENT
4392.37	968.88	971.53	2.7	S,P
4422.37	968.98	971.58	2.6	S,P:C
4450.37	968.42	971.52	3.1	S:C
4499.37	967.55	971.55	4.0	S,C:B
4529.37	967.36	971.56	4.2	S, SCATTERED C
4579.37	968	971.6	3.6	S,C
4622.37	968.19	971.59	3.4	S:C
4660.37	968.82	971.57	2.8	S,P,C US END OF RIP RAP ON LB
4699.37	969.23	971.53	2.3	S,C:P
4751.37	969.29	971.54	2.3	S,C:P
		0		BAR ELEVATION\ TERRACE LEVEL ON RB
4804.37	966.89	971.59	4.7	S,C THALWEG @ XS-21
4811.37	966.87	971.57	4.7	S,C
4859.37	967.34	971.64	4.3	C,S LEANING PINE ON LB
4889.37	967.7	971.5	3.8	C,S:P
4929.37	966.91	971.71	4.8	S,C
4973.37	965.89	971.69	5.8	C
5029.37	<964.4	971	>8.0	
*5052.37				Ended survey at Stoneman Bridge. The bridge has several rows of rocks. Counting from the LEW, four rock rows up is a ledge that juts out one foot. The last survey reading was the left-most, upstream-most corner of the ledge. Elevation of this last point = 977.78 ft.

Merced River, Yosemite National Park
Date:
Reach: Clark's Bridge downstream to Sugar Pine Bridge
Surveyors: MAM, VO, LJ, G. Grant (day1); VO, CJ (day2)

GROU #	STA (feet)	SPECIES (code)	ROOT WAD (Y/N)	LENGTH (feet) Total	LENGTH (feet) In Channel	DIAMETER (feet) Mean Diam	DIAMETER (feet) Min Diam	LWD VOL (cu ft)	INPUT MECH (code)	DECAY CLASS (code)	GROUPING (G\U)	POOL TYPE (code)	ORIENTATION Downstream (deg)	COMMENTS
1		Oak	Y	67	0	1.3		82.2	Float	I	G			Group 1 on L. Bank; In winter chnl, not in summer low flow
1			Y	31	0	1.3		43.1	Float	III	G			Group 1 Just U/S of overflow channel
1		Alder	Y	43	0	0.5		8.4	Float	I	G			same as above
1		Alder	Y	47	0	0.8		25.4	Float	I	G			same as above
1				11	0	1.8		26.5	Float	IV	G			same as above
2		Oak	Y	41	0	1.0		32.2	L. BAN	I	G			Group 2 on L. Bank, In winter chnl, not in summer low flow
2		Cedar	Y	26	0	1.3		31.9	L. BAN	I	G		90	same as above
2		Cedar	Y	61	0	1.4		93.9	L. BAN	I	G			same as above
2		Cedar	Y	102	0	1.5		180.2	L. BAN	I	G			same as above
2		Cott	Y	34	0	1.7		74.5	Float	III	G			same as above
2		Cedar	Y	81	0	1.0		63.6	L. BAN	I	G			Small Debris floated in amoung large pieces
2		Cedar	Y	77	0	1.8		202.5	Float	IV	G			
2		Cott	N	32	0	1.3		39.3	Float	II	G			
2		Pine	Y	45	0	1.5		79.5	Float	III	G			
2		?		26	0	1.8		66.2	Float		G			Cut Log
2		Cedar		26	0	1.3		31.9	Float		G			
2		Cedar		62	0	1.0		48.7	L. BAN	I	G			
2		Cedar	Y	67	0	1.2		75.8	Float	I	G			
2		White Fir	Y	70	10	1.2		79.2	Float	I	G	LAT		Cut off from main low flow chnl
2		Alder	N	54	0	0.8		29.2	Float	IV	G			
2		Pine	Y	56	0	0.8		30.3	Float	III	G			
4		Oak	N	30	0	1.8		78.9	Float	IV	U		20	Piled against oak
5		White Fir	Y	64	0	1.3		84.9	Float	I	U			Piled against stump
6		Cedar	Y	98	0	1.5		173.2	L. BAN	I	U			
7		Cott	N	36	0	1.1		33.0	Float	II	G			
7		Alder	Y	47	0	1.0		36.9	Float	I	G			Has attacked 8" pine, 30' long
7		?	N	19.5	0	1.1		17.9	Float	V	G			
7		Cedar	Y	103	0	1.5		182.0	Float	I	G			Hung up on stump
7		POPI	Y	51	0	1.6		100.0	Float	I	G			
		?	N	24	0	1.4		38.0	Float	IV	G			
7		Cedar	Y	53	0	1.3		73.6	Float	I	G			
7		Cedar	Y	40	0	1.2		43.0	Float	I	G			
7		Cedar	Y	54	0	1.4		83.1	Float	I	G			
7		Pine	Y	54	0	1.3		71.7	Float	I	G			
7		Cedar	Y	54	0	1.3		71.7	Float	I	G			
7		Pine	Y	19	0	1.2		21.5	Float	V	G			

APPENDIX C
LARGE WOODY DEBRIS FIELD DATA

Merced River, Yosemite National Park
Date:
Reach: Clark's Bridge downstream to Sugar Pine Bridge
Surveyors: MAM, VO, LJ, G. Grant (day1); VO, CJ (day2)

GROU	STA	SPECIES	ROOT WAD	LENGTH (feet)		DIAMETER (feet)		LWD VOL	INPUT MECH	DECAY CLASS	GROUPING	POOL TYPE	ORIENTATION Downstream	COMMENTS	
#	(feet)	(code)	(Y/N)	Total	In Channel	Mean Diam	Min Diam	(cu ft)	(code)	(code)	(G\U)	(code)	(deg)		
7		Pine		47	0	0.9		29.9	Float	I	G				
8		?	RW		0	7.0	3	0.0	Float	V	U			RW on LB	
9			RW		0	8.0	3	0.0	Float	IV	U				
10		Alder	Y	54	0	0.8		27.1	Float		U			Caught on stump	
11		Pine	Y	133	133	1.8		338.4	L. BAN	I	U	3' LAT	10	Perp. to flow when first fell in, almost II to bank now	
12		Cedar	Y	72	38	1.1		68.4	Float	I	G			RW near azalea grove, undercut banks	
12		Cedar	Y	48	0	1.8		122.1	Float	I	G			Double trunk	
12		Cedar	Y	35	0	1.6		70.4	Float	I	G			Double trunk	
13		Cott.	N	75	20	1.0		58.9	Float	I	U		10	Campsite #62; On X/S 12; Broken RW's caught behind stump on LB	
14		Cott.	N	41	0	2.0		128.8	Float	I	U			Campsite #62; On X/S 12; Broken RW's caught behind stump on LB	
15		Cedar	Y	60	0	3.0		424.1	Float	I	G			At overflow channel	
3		Cedar	Y	54	0	1.9		156.3	Float	I	G			At overflow channel	
3		Oak	N	25	0	0.9		16.6	Float	II	G			At overflow channel	
3		Oak	N	29	0	1.1		26.6	Float	II	G			At overflow channel	
3		Alder	Y	45	0	1.0		35.3	Float	I	G			At overflow channel	
3		Pine	N	76	0	1.0		59.7	Float	I	G			LWD jam u/s end of overflow channel	
3		?	N	38	0	1.5		67.2	Float	IV	G			LWD jam u/s end of overflow channel	
3		Oak	Y	44	0	1.4		67.7	Float	I	G			LWD jam u/s end of overflow channel	
3			RW	3	0	4.0		37.7	Float	V	G			LWD jam u/s end of overflow channel	
3			RW	3	0	4.0		37.7	Float	IV	G			LWD jam u/s end of overflow channel	
3		Cedar	N	100	0	2.0		314.2	Float	I	G			LWD jam u/s end of overflow channel, in overflow channel II to flow direction	
3		Pine	N	40	0	0.9		26.6	Float	II	G			LWD jam u/s end of overflow channel, in overflow channel II to flow direction	
3		Cedar	N	57	0	1.7		124.9	Float	IV	G			Perp. to flow	
3		Cedar	N	55	*	1.1		50.4	Float	I	G			Perp. to flow	* 34' 6",20' 6"
3		?	N	18	0	1.0		14.1	Float	III	G			Perp. to flow	
3		?	N	23	0	1.0		18.1	Float	IV	G			Perp. to flow	
3		?	N	16	0	1.4		25.3	Float	IV	G			Perp. to flow	
3			N	28	0	1.7		61.3	Float	IV	G			Perp. to flow	
3		Alder	Y	25	*	0.8		13.5	Float	I	G			Perp. to flow	*16, 19
3		Oak	N	25	0	1.1		22.9	Float	II	G			Perp. to flow	
3		?	N	28	0	1.5		49.5	Float	II	G			Perp. to flow	
3		?	N	20	0	1.6		39.2	Float	V	G			Perp. to flow	
3		?	N	17	0	1.8		40.9	Float	V	G			Perp. to flow	
3		?	N	19	0	1.5		33.6	Float	V	G			Perp. to flow	
3		Cedar	Y	78	0	1.3		95.7	Float	I	G				
3		?	N	29	0	2.5		142.4	Float	V	G				

LARGE WOODY DEBRIS FIELD DATA

Merced River, Yosemite National Park
Date:
Reach: Clark's Bridge downstream to Sugar Pine Bridge
Surveyors: MAM, VO, LJ, G. Grant (day1); VO, CJ (day2)

GROU #	STA (feet)	SPECIES (code)	ROOT WAD (Y/N)	LENGTH (feet) Total	LENGTH (feet) In Channel	DIAMETER (feet) Mean Diam	DIAMETER (feet) Min Diam	LWD VOL (cu ft)	INPUT MECH (code)	DECAY CLASS (code)	GROUPING (G\U)	POOL TYPE (code)	ORIENTATION Downstream (deg)	COMMENTS
3		?	N	18	0	2.0		56.5	Float	III	G			Cut end log
3		Pine	ORT O	55	0	3.2		442.3	Float	I	G			Perp to flow
3		Pine	Y	88	0	1.3		108.0	Float	I	G			Perp to flow
3		Alder	Y	40	0	0.9		26.6	Float	I	G			
3		Alder	Y	48	0	1.0		37.7	Float	II	G			Double alder
3		Alder	Y	49	0	0.8		26.5	Float		G			Double alder
3		?	N	21	0	1.7		47.7	Float	V	G			
3		Cedar	Y	49	*	1.1		44.9	Float	I	G			II flow *20', 29'
3		Cott	N	63	*	1.0		49.5	Float	I	G			II flow *17', 46'
3		Alder	Y	21	0	1.3		29.2	Float	I	G			Perp to flow
3		Alder	N	42	0	0.9		27.9	Float	I	G			II flow
3		Cedar	N	29	0	1.4		45.9	Float	I	G			Perp to flow
3		?	N		0	1.0		0.0	Float	IV	G			Perp to flow
16		?	N	86	0	2.6		456.6	Float	V	U			Near campsite #39, log on terraceside of trees at river edge II to bank
17		?	N	16	16	1.7		35.0	Float	III	G		45	X/S 11; 5 2' scour hole, 1/2 of log out of water, II to bank
17		Alder	Y	51	51	1.3		70.9	BAN	I	G		50	X/S 11; Lat scour pool submerged log, fallen in at bank tree undermined, II to
18		?		31	0	2.0		97.4	Float	III	U			Double Tree (see below), D/S end of amphitheater
18		?		7.9	0	1.5		14.0	Float	III	U			Double Tree (see above); Log floated into lg scallop shaped eroded bank u/s
18		Cedar	Y	40	0	1.8		101.8	Float	III	U			Log II to bank on terrace side of river edge trees; in u/s side amphitheater
19		Pine	N	21	21	1.1		20.0	Float	I	U		30	Log II to bank; no pool, totally in channel, adj To campsite 19
														u/s of lg Scalloped shape eroded bank 30" across
20		?	N	34	34	1.2		36.6	Float	III	U		0	immed u/s of Tenaya ck., II to bank
21		?	Y	43	43	1.0		33.8	Float	I	U			D/S end of Tenaya Ck, mid channel, 35 degrees totally submerged, II to bank

SPECIES CODES: POPI=Ponderosa Pine, Cott.=Cottonwood, DEC=deciduous, CON=conifer, MAP=maple, Oak, Cedar, Alder, White Fir, Pine
INPUT MACHANISM CODES: MAS=mass movement; BAN=bank undercutting, W IND=indeterminate, Float
POOL TYPE CODES: LAT=lateral scour pool, PLU=plunge pool, DAM=dammed pool, BAC=backwater pool
DECAY: I=Fresh V=rotten, falling apart
OTHER CODES: RWI=rootwood attached and in channel, RWO=rootwood attached but outside of channel,
ROB=resting on channel bed, AIC=anchored in channel bed, AIB=anchored in bank, B FSL=full-spanning log.