THE MIDDLE SACRAMENTO RIVER: HUMAN IMPACTS ON PHYSICAL AND ECOLOGICAL PROCESSES ALONG A MEANDERING RIVER[1]

Koll Buer, Dave Forwalter, Mike Kissel, and Bill Stohler[2]

Abstract: Native plant and wildlife communities along Northern California's middle Sacramento River (Red Bluff to Colusa) originally adapted to a changing pattern of erosion and deposition across a broad meander belt. The erosion-deposition process was in balance, with the river alternately building and eroding terraces. Human-induced changes to the Sacramento River, including bank protection, gravel mining, pollution, riparian vegetation removal, flow regulation, and flood control, have resulted in a number of physical and ecological effects. This study focuses on changes in bank erosion, bank composition, river length, depth, width, and sinuosity, and floodplain deposition (ongoing study, Sacramento River Bank Erosion Investigation, Department of Water Resources, Red Bluff, California.) *The Department of Water Resources, Northern District, is monitoring these changes using old survey maps, aerial photographs, and field surveys. Completed studies indicate that bank protection has significantly reduced a source of salmon spawning gravel from freshly eroded banks and will over time decrease the number of preferred spawning areas such as point bar riffles, chute cutoffs, multiple channel areas, and areas near islands. Bank protection also increases the tendency of the confined river to deepen and narrow, further reducing spawning habitat. Because of flood protection from dams and extensive bank protection along eroding banks, most of the rich high terrace soils and all but a few percent of the original riparian forest has been converted to agriculture and other uses. In addition, only 45 percent of the original streambank vegetation remains. Wildlife populations have declined markedly due to loss of riparian habitat and suppression of the natural successional processes that maintain the density and diversity of habitat within the riverine environment. Some species that are adapted to the dynamics of the erosional-depositional cycle are threatened with extinction or extirpation as key habitat elements are lost from the newly stabilized river system. Flood control has interrupted the natural equilibrium between erosion and deposition, resulting in reduction in bank erosion rates and in overbank sediment deposition. Solutions to these problems will require a comprehensive river management program that incorporates the natural processes of meandering and bank erosion.*

The Sacramento River is the largest and most important river system in California. The basin represents about 17 percent of California's land area, yet yields 35 percent of the water supply. It drains the north half of the Great Central Valley of California. The river is the State's most important salmon resource. Biologically, the riparian corridor between Red Bluff and Colusa is also one of the richest and most diverse that remains in California.

The Department of Water Resources (DWR), Northern District, has an ongoing study of geomorphic changes in this vital reach of the river (fig. 1). The Department began its bank erosion studies in 1977. For two years, four bank erosion sites were monitored. A report was published in 1979 outlining the results (DWR 1979b). Several of these sites were monitored until 1983.

A new monitoring program began in 1986. Nine new bank sites were surveyed in the 58-mile study reach. An additional six sites were surveyed in 1988. The scope was also expanded to include overbank deposition and bank composition. Ten floodplain cross-sections were surveyed to monitor sediment deposition and long-term changes. The study also considers long-range geomorphic changes caused by such human activities as dams, bank protection, and gravel mining. Geomorphic changes include channel narrowing and deepening; changes in riparian vegetation, channel length, width, sinuosity, and bank erosion, and sediment transport rates.

Historical Aspects

Before settlement of the Sacramento Valley, the Sacramento River was free flowing. Late summer flows were low, averaging 3,000 cubic feet per second (cfs), and in dry years dropping as low as 1,000 cfs. The river, however, would fluctuate widely in response to winter rains and spring snowmelt. Periodically, it would overflow its banks and flood large areas of the valley floor. These areas were covered by dense forests of riparian vegetation adapted to the periodic flooding.

[1]Presented at the California Riparian Systems Conference; September 22-24, 1988; Davis, California.

[2]Senior Engineering Geologist, Graduate Student Assistant, and Student Assistants, respectively, Department of Water Resources, Red Bluff, California.

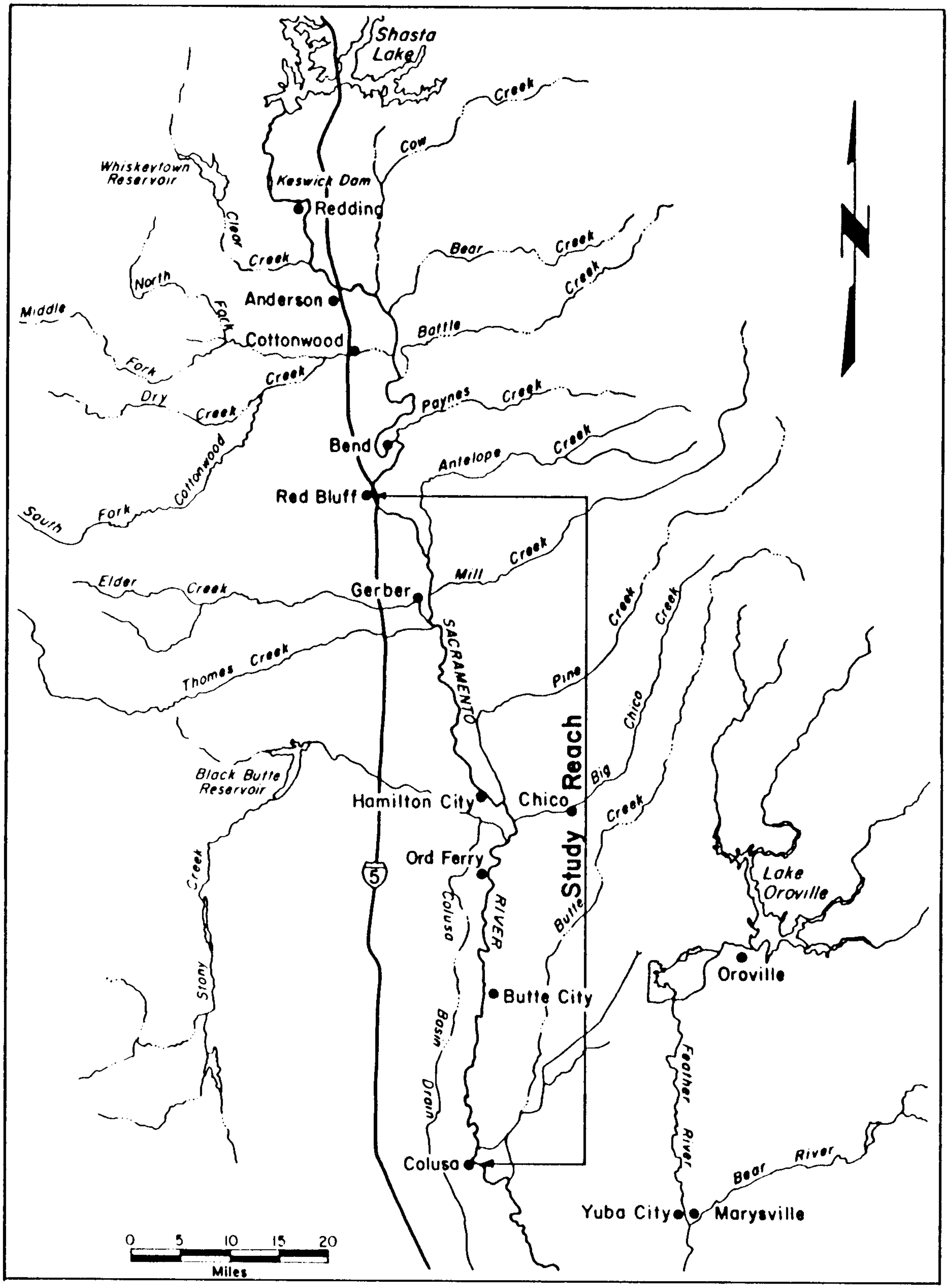

Figure 1— Sacramento River from Keswick Dam to Colusa

Below Red Bluff, bank erosion and lateral migration across the floodplain were natural processes. Large floods uprooted streamside vegetation, caused banks to recede and the river to meander. Sediment derived from tributaries and from bank erosion deposited in overbank areas where vegetation reduced water velocities.

Over a period of years, erosion and deposition were roughly in balance, so that the valley floor neither aggraded nor degraded. The riparian forests played a doubly important role here, first by reducing bank erosion and, second, by inducing deposition on the floodplain.

A large number of chinook salmon *(Oncorhynchus tshawytscha)* migrated up the Sacramento River each year to spawn. Although there were probably four runs then, as there are today, the two largest runs were thought to have occurred in the fall and spring. The other two runs, winter and late fall, are not as well documented historically, especially their numbers. Most of the spring- and winter-run salmon, as well as part of the fall and late-fall salmon, were thought to have spawned upstream from the present location of Shasta Dam. However, large numbers of spring- and fall-run salmon also spawned in many Sacramento tributaries.

Since about 1850, the study reach has undergone a number of hydrologic, geomorphic, and environmental changes, most of which have been detrimental to locally adapted species. These changes are caused by dams and diversions, bank protection, urbanization, stream gravel removal, hydraulic mining, agriculture, and logging. Many of these changes have had long-reaching effects, including alteration of river characteristics, such as depth, width, gradient, sinuosity, and bank erosion. This in turn has reduced riparian vegetation, water quality, hydrologic diversity, and fish and wildlife resources.

Urbanization, primarily in Redding, Anderson, Cottonwood, and Red Bluff, has caused additional problems in the study reach. Gravel extraction for highways, housing, and other projects averages more than 1.3 million cubic yards per year in Shasta County and 0.5 million in Tehama County, mostly from tributary streams. This, in conjunction with Shasta, Keswick, Whiskeytown, and other dams that prevent gravel recruitment from upstream reaches, has eliminated the spawning gravel available in downstream reaches.

Along with the rapid expansion of the mining industry, California agriculture also grew. First to be converted to agriculture were the fertile rimlands. Rimlands are next to the river, higher than the surrounding tule lands, and are less often flooded. Flood control had its inception in the low levees constructed on the rimlands by farmers protecting their crops.

Next to be developed were the tule, or swamp and overflow, lands. Through a series of legislative acts passed between 1855 and 1868, the State sold these lands to farmers who were obliged to reclaim them individually or through the formation of reclamation districts. Within a period of 3 years following the last act, practically all of such lands had passed into private ownership (Jones 1967). To date, as a consequence of just these two kinds of agricultural development, about 98 percent of the original riparian forest has been removed (DWR 1988).

Dams and unscreened or poorly screened diversions have severely depleted the river's fishery. Early dams and diversions built by miners and farmers obstructed miles of habitat without allowance for fish passage or mitigation measures. By the 1920s, at least 80 percent of the Central Valley spawning grounds had been cut off by obstructions, according to the U. S. Bureau of Reclamation (USBR 1972). Dams affect riparian areas mostly by the reduced incidence of flooding, bank erosion, and silt deposition required for the regeneration of riparian habitat. Flood control also encourages the development of riparian lands along the river.

More recently, major water development projects, such as Shasta and Keswick Dams and the Trinity River Diversion, have affected Sacramento River hydraulics. Shasta Dam stores 4.5 million acre-feet and, to a large extent, regulates flows from the Pit, McCloud, and upper Sacramento Rivers. Keswick Dam, 9 miles downstream from Shasta provides water regulation, stops salmon migration and acts as a fish-trapping facility.

The effect of Shasta Dam on the natural flow (DWR 1984) has been to:

1. Decrease the minimum discharge and increase the number of very low discharges. This occurs when the powerhouse is closed for repairs.

2. Increase the number of moderate discharges, particularly during the summer and fall irrigation season.

3. Reduce the number and the volume of high and very high flows.

Since December 1963, water has been diverted from the Trinity River Basin through the Clear Creek Tunnel and Judge Francis Carr Powerhouse to Whiskeytown Lake. The Spring Creek Tunnel then diverts Trinity water and most of Clear Creek water through another power plant into Keswick Lake. An average of about 1 million acre-feet of Trinity River water is now diverted into the Sacramento River Basin each year.

The effect of the Trinity River diversion on post-Shasta flows has been to increase average Sacramento River discharge by about 1,000 to 1,500 cubic feet per second throughout most of the year.

River Geomorphology and Ecology

Using such channel characteristics as gradient, geometry, underlying rock types, and gravel distribution, it is possible to divide the Sacramento River between Redding and Colusa into seven distinct reaches. These reaches were described in detail by the Department of Water Resources (1984; 1985) and are only briefly described here.

Typically, the river between Redding and Red Bluff (reaches 1 to 5) is a bedrock reach. The river is entrenched, in places, with some vertical banks 100 feet or more high.

Below Red Bluff, the Sacramento River is mostly an alluvial stream. Reach 6 is between Red Bluff and Chico Landing. It is sinuous and anabranching. Reach 6 has been divided into eight subreaches (6A to 6H) based on bank erosion, sinuosity, and meander belt width. Reaches 6A, 6C, 6E, and 6G are short, narrow, straight reaches with low sinuosity, low gradient, and only minor bank erosion. Between the short, stable reaches are longer, more sinuous, unstable reaches 6B, 6D, 6F, and 611.

Reach 7 is between Chico Landing and Colusa. Here the gradient is less; the river tends to be more sinuous with fewer islands. The most distinctive feature of this reach is the gradual downstream development of natural levees. This reach has been divided into five subreaches (7A to 7E), based on the criteria used for reach 6.

Bank Erosion

A river erodes both its banks and bed. Bed erosion leads to degradation and grading of the stream profile. In a bedrock stream, this process is generally slow, except during periods of geologically rapid rejuvenation and uplift. Bed erosion also occurs in alluvial streams, but the erosion is generally balanced by deposition over a period of years.

Bank erosion is generally of much more interest and concern to people. Bank erosion is dependent on channel shape, bed and bank material, and river hydraulic characteristics. Because of the generally stable banks of the Sacramento River between Keswick and Red Bluff, bank erosion is insignificant in most places. Between Red Bluff and Colusa, significant bank erosion occurs. Downstream of Colusa, flows and associated velocities are greatly reduced by overflow occurring upstream during flooding (both overbank flow and flow at the Moulton and Colusa overflow weirs). In addition, the flatter slopes of the channel bed downstream minimize the erosion potential.

In alluvial river systems, banks erode and sediments are deposited. Floodplains, islands, and side channels will undergo modification with time.

Bank erosion generally occurs on the outside of meander bends. Here, banks are susceptible to erosion because high-flow velocities impinge directly onto banks and turbulent motion along the channel thalweg undercuts the banks. Eroding banks may be either high-terrace or low terrace. High terrace banks normally have a deep soil profile containing mostly loamy sand and silt. Below the soil is a deposit of sand and gravel which usually originates as the point bars on the wide edges of river beds. A low-terrace bank consists mostly of a sand and gravel which was deposited as point bars with a thin soil profile on top.

The fish, wildlife, and riparian vegetation are adjusted to the cycle of erosion, deposition, and changing channel pattern in which the river swings slowly back and forth across a broad meander belt. The health and productivity of the system at any one point is dependent on the periodic rejuvenation associated with these changes.

Salmon prefer to spawn in fresh, uncompacted gravels that have recently moved. These spawning beds tend to occur in wide areas with multiple channels or chute cutoffs because of increased spawning flow velocity, reduced flood-flow velocity, shallower depths, and greater hydraulic diversity there. Gravel in the subsoil horizons of an eroding bank provides fresh gravel to spawning beds. Much of the sand and silt from the bank is redeposited in the riparian forests downstream. Abandoned channel oxbows and sloughs are ideal habitat for warmwater fish, such as largemouth bass and catfish.

Bank erosion is important for the recruitment of spawning gravel. It allows for the re-entrainment of gravel deposited on point bars. Between Red Bluff and Colusa, bank erosion is estimated to contribute about 85 percent of the total available spawning gravel (DWR 1984; 1985).

Bank erosion is also the driving force for riparian plant succession. On the outside of bends, high-terrace banks with a mature forest typically consisting of valley oak, box elder, and black walnut are eroded. On the opposite side is a point bar consisting of sand and gravel. Willows and cottonwoods become established here. The rapid invasion of riparian vegetation slows floodflow velocities and allows sand and silt to deposit. With time, riparian stages with a succession of different plant species occurs as the point bar becomes higher and farther away from the river.

Various birds and other wildlife use different riparian stages for feeding, nesting, and reproduction. The climax valley oak forests are relatively sterile compared to the younger riparian stages. Therefore, bank erosion and riparian rejuvenation are necessary to maintain a healthy and productive ecosystem.

Sediment deposition is inextricably linked to bank erosion. Without deposition, the channel would simply widen until it was so large that erosion would terminate. However, the coarser material eroded from the bank is deposited on point bars downstream. The point bars constrict the bend and enable erosion to continue.

DWR (1979) observed bank erosion over a 2-1/2-year period at six sites in the Red Bluff-to-Colusa Reach. This investigation has been expanded and is presently continuing. Bank erosion was divided into summer (low-flow) erosion and winter (high-flow) erosion. Only two of the six sites showed any erosion during the summer. Average bank recession between April and October 1977 was 11.4 and 2.2 feet, respectively.

In contrast, high flows were far more conducive to erosion. A major storm occurred in January 1978. Erosion was greatest during the period that included this storm, with erosion ranging from 30 to 50 feet of bank recession. During the storm itself, Woodson Bridge State Recreation Area below Thomes Creek lost over 40 feet in a single 24-hour period.

Beginning in 1986, nine new erosion sites were surveyed. Six more were added in 1988, for a total of fifteen sites. Figure 2 shows one of these. Each site is surveyed three to four times yearly. Successive bank lines are plotted and eroded bank area calculated.

Figure 3 shows the Sacramento River discharge and bank erosion between 1986 and 1988 at ten erosion sites. Note that no floodflows occurred during the 2 years and that the highest peak flow was about 65,000 cfs. At Ord Ferry, the flood stage, or bankfull discharge, is about 110,000 cfs and floodflow in March 1983 was about 160,000 cfs.

Six of the nine sites had essentially no erosion during the low-flow period. The Princeton site has eroded several thousand feet since 1978 and is the most erodible site on the river. It eroded an average of 4 feet during the low-flow period and an additional 30 feet during the two higher flow periods.

Another goal of the bank erosion study was to determine total bank erosion, gravel and silt produced from bank erosion, and bank recession rates. A total of 67 bank erosion sites were identified and evaluated by comparing 1976 and 1987 aerial photographs. Eroded areas were measured using a planimeter. Thirty of the sites were field surveyed. Longitudinal profiles were measured showing bank height, thickness of gravel, and thickness of silt. Gravel samples were sieved and analyzed. The additional 37 sites were identified as showing significant erosion, but were not sampled or measured in detail. Data from the surveyed sites were averaged by geomorphic reach and applied to the unsurveyed sites. Aerial photographs from 1976 and 1987 were compared and bank erosion areas measured using a planimeter. Table 1 is a summary of bank erosion data for the reach.

There are a number of interesting observations that can be made from this table. The average bank height from the bottom of thalweg to the top of the bank is about 25 feet, with 16 feet of gravel and 9 feet of silt. The average bank recession of an actively eroding bank is about 20 feet per year, ranging from a few feet to nearly 80 feet. The average length of an eroding bank is about 3,000 feet, for a total of about 197,000 linear feet. This represents 34 percent of the bank in the reach. Another 18 percent was eroding but has been protected with rock riprap.

Between 1976 and 1987, about 1,230 acres have been eroded. This has produced about 29 million cubic yards of sand and gravel and 20 million cubic yards of silt. Most of the gravel is redeposited on point bars immediately below the eroding bank. Some of the silts are deposited on the floodplain and some are washed downstream.

DWR (1979a,b), U. S. Corps of Engineers (USCE 1981), and the U. S. Geological Survey (USGS 1977) have compared pre- and post-Shasta erosion rates. All three investigations concluded that there has been a significant reduction of about 25 percent in bank erosion between the period 1896-1946 and 1946-1980. The differences in rates can be attributed in part to a reduction in the frequency and magnitude of peak flows resulting from regulation by Shasta Dam. Secondly, since bank erosion increases exponentially with discharge, any reduction in the occurrence of high flows will reduce the amount of bank erosion (DWR 1984; 1985).

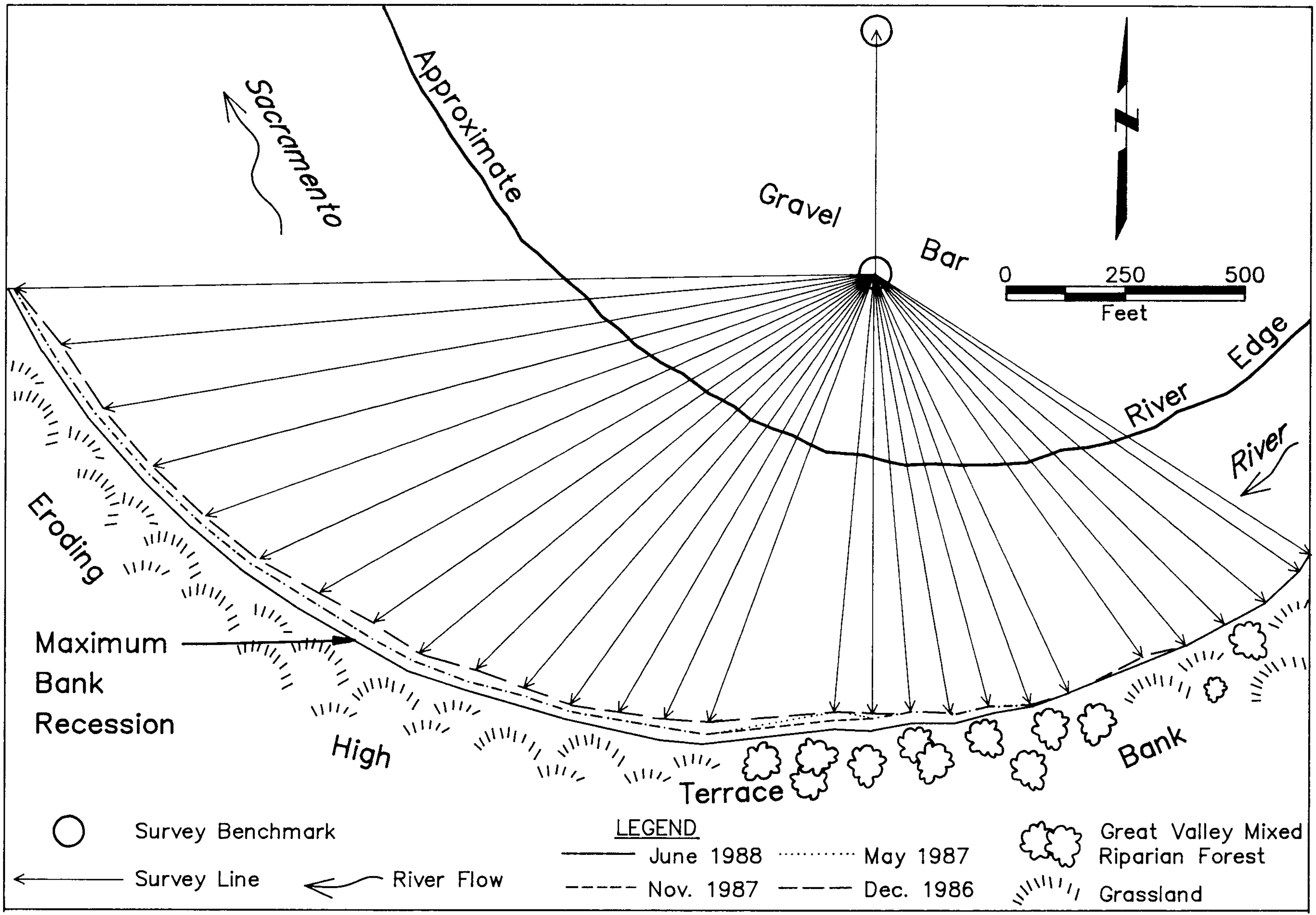

Figure 2— Golden State Island Surveyed Erosion Site December 9, 1986 through June 7, 1988

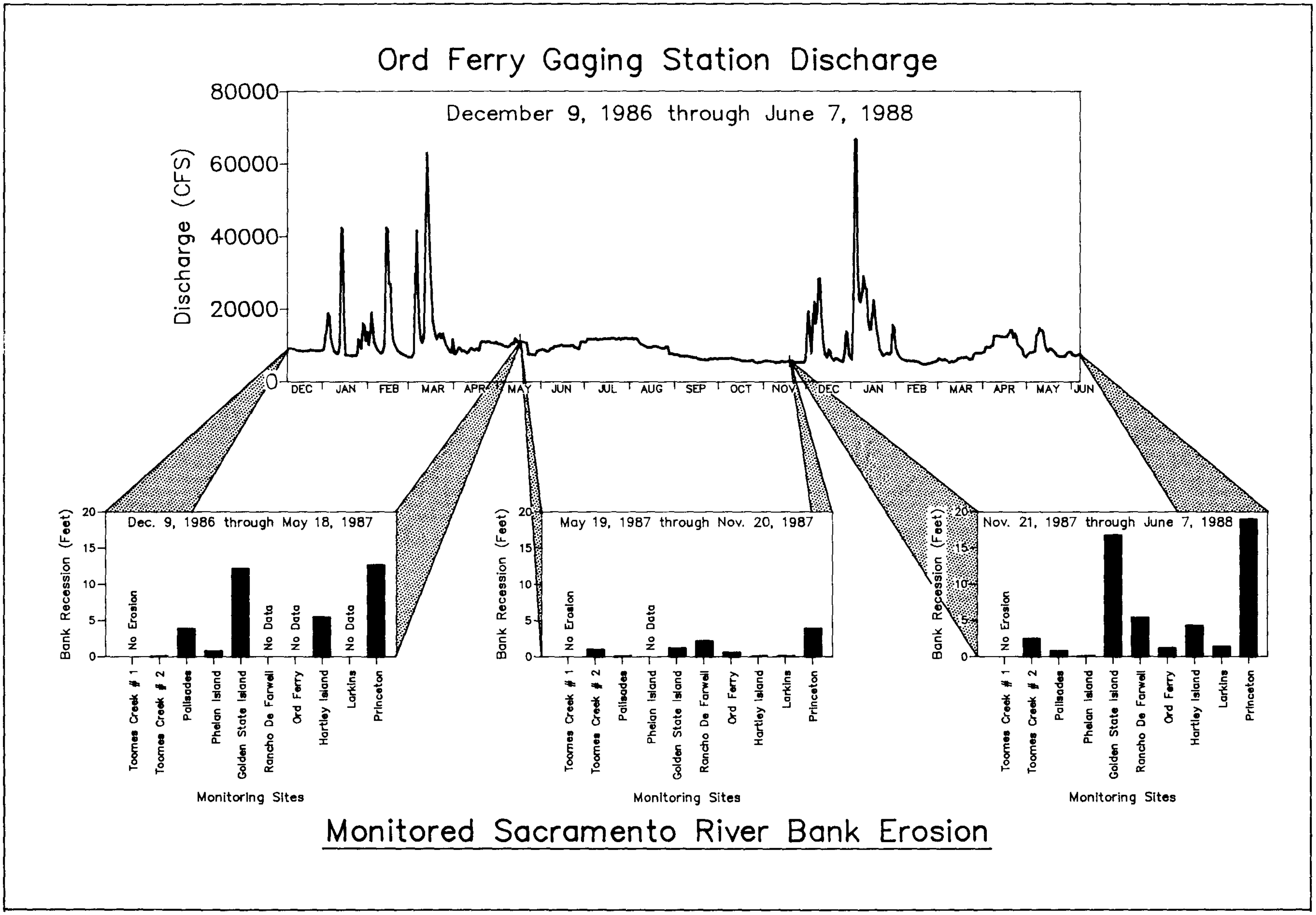

Figure 3– Sacramento River Discharge and Bank Erosion for Three Hydrologic Periods - December 9, 1986 through June 7, 1988

REACH	EROSION SITE	RIVER MILE	AVERAGE BANK HEIGHT (FEET)	AVERAGE GRAVEL THICKNESS (FEET)	ERODED BANK AREA (SQUARE FEET X 1,000)	TOTAL GRAVEL VOLUME ERODED (CUBIC YARDS X 1,000)	TOTAL FINE VOLUME ERODED (CUBIC YARDS X 1,000)	TOTAL BANK VOLUME ERODED (CUBIC YARDS X 1,000)	LENGTH OF ERODED BANK (FEET)	MAXIMUM BANK RECESSION FOR 11 YEARS (TOTAL FEET)	AVERAGE BANK RECESSION FOR 11 YEARS (TOTAL FEET)	AVERAGE BANK RECESSION PER YEAR (FEET)
6A	ERODING BANK	240.5	20.7*	14.2*	336	176.7**	80.9**	257.6**	3680	160	91.3	8.3
	SACT 1	239.9	21.1	13.7	236	119.7	64.7	184.4	1770	240	133.3	12.1
	ERODING BANK	239.5	20.7*	14.2*	141	74.2**	33.9**	108.1**	1960	160	71.9	6.5
	ERODING BANK	239.0	20.7*	14.2*	63	33.1**	15.2**	48.3**	1280	80	49.2	4.5
	ERODING BANK	239.0	20.7*	14.2*	32	16.8**	7.7**	24.5**	800	100	40.0	3.6
	SACT 2	238.5	20.3	14.7	742	404.0	153.9	557.9	3360	520	220.8	20.1
6B	ERODING BANK	237.0	19.9*	13.1*	3140	1519.6**	798.6**	2318.2**	5640	800	556.7	50.6
	SACT 3	236.5	15.4	12.0	485	215.6	61.1	276.6	3200	228	151.6	13.8
	ERODING BANK	236.0	19.9*	13.1*	96	46.5**	24.4**	70.9**	1090	135	88.1	8.0
	ERODING BANK	235.5	19.9*	13.1*	85	41.1**	21.6**	62.8**	1100	100	77.3	7.0
	SACT 4	235.0	23.3	13.2	1614	789.1	603.8	1392.8	4800	700	336.3	30.6
	ERODING BANK	234.0	19.9*	13.1*	665	321.8**	169.1**	491.0**	4520	240	147.1	13.4
	ERODING BANK	233.0	19.9*	13.1*	253	122.4**	64.3**	186.8**	1860	190	136.0	12.4
	SACT 5	232.9	21.1	14.0	468	242.7	123.1	365.7	3530	400	132.6	12.1
	ERODING BANK	232.0	19.9*	13.1*	96	46.5**	24.4**	70.9**	970	200	99.0	9.0
	ERODING BANK	231.5	19.9*	13.1*	371	179.5**	94.4**	273.9**	2220	320	167.1	15.2
	ERODING BANK	231.0	19.9*	13.1*	193	93.4**	49.1**	142.5**	1514	250	127.5	11.6
6C	SACT 6	228.9	33.9	16.9	144	90.1	90.7	180.8	2480	88	58.1	5.3
6D	ERODING BANK	227.5	27.2*	15.4*	786	447.3**	345.5**	792.8**	3840	460	204.7	18.6
	ERODING BANK	226.0	27.2*	15.4*	645	367.1**	283.5**	650.6**	3960	360	162.9	14.8
	SACT 7	225.5	30.7	14.8	44	24.1	25.9	50.0	1480	40	29.7	2.7
	SACT 8	224.4	20.8	19.9	131	96.6	4.4	100.9	2220	136	59.0	5.4
	SACT 9	223.3	26.8	14.2	264	138.8	123.2	262.0	3400	144	77.6	7.1
	ERODING BANK	223.0	27.2*	15.4*	605	344.3**	265.9**	610.2**	1980	560	305.6	27.8
	TOOMES 1 & 2	222.5	27.0	7.7	3118	889.2	2228.8	3118.0	5100	1080	611.4	55.6
	ERODING BANK	222.0	27.2*	15.4*	228	129.8**	100.2**	230.0**	1950	210	116.9	10.6
	SACT 28	221.3	24.4	20.5	407	309.0	58.8	367.8	2260	480	180.1	16.4
	ERODING BANK	221.0	27.2*	15.4*	257	146.3**	113.0**	259.2**	1900	260	135.3	12.3
	PALISADES	219.0	33.7	15.1	633	354.0	436.1	790.1	2880	440	219.8	20.0
6E	ERODING BANK	217.5	27.2*	16.2*	155	93.0**	63.1**	156.1**	1740	110	89.1	8.1
	ERODING BANK	216.0	27.2*	16.2*	1893	1135.8**	771.2**	1907.0**	8860	870	213.7	19.4
6F	SACT 12	213.1	19.0	6.4	1968	466.5	918.4	1384.9	2380	1280	826.9	75.2
	SACT 13	212.5	28.4	13.9	624	321.2	335.1	656.4	920	1280	678.3	61.7
	SACT 10	211.9	21.0	16.8	430	267.6	66.9	334.4	2350	312	183.0	16.6
	SACT 14	211.2	20.9	11.0	1469	599.5	538.6	1137.1	5100	620	288.0	26.2
	SACT 15	210.6	30.4	23.7	1161	1019.1	288.1	1307.2	3000	760	387.0	35.2
	SACT 16	210.4	23.9	13.6	1476	743.5	563.1	1306.5	4750	568	310.7	28.2
	ERODING BANK	209.0	27.1*	17.0*	547	343.8**	205.8**	549.6**	4620	240	118.4	10.8
	ERODING BANK	208.0	27.1*	17.0*	251	157.8**	94.5**	252.2**	1710	225	146.8	13.3
	SACT 17	207.2	40.2	35.0	41	53.1	7.9	61.0	620	120	66.1	6.0
	ERODING BANK	207.0	27.1*	17.0*	511	321.2**	192.3**	513.5**	2500	300	204.4	18.6
	ERODING BANK	206.0	27.1*	17.0*	401	252.0**	150.9**	402.9**	1850	330	216.8	19.7
	SACT 18	204.2	23.3	20.2	330	246.9	37.9	284.8	2660	220	124.1	11.3
	SACT 19	203.2	31.5	7.3	144	38.9	129.1	168.0	1700	140	84.7	7.7
	ERODING BANK	203.0	27.1*	17.0*	2333	1466.3**	877.9**	2344.2**	5220	1225	446.9	40.6
	ERODING BANK	202.0	27.1*	17.0*	610	383.4**	229.5**	612.9**	2500	375	244.0	22.2
	SACT 20	201.5	32.7	21.8	1235	997.1	498.6	1495.7	3230	600	382.4	34.8
	ERODING BANK	201.0	27.1*	17.0*	169	106.2**	63.6**	169.8**	1360	220	124.3	11.3
6G	ERODING BANK	199.0	26.5*	19.1*	245	173.3**	67.1**	240.5**	1900	215	128.9	11.7
6H	ERODING BANK	198.0	25.8*	21.2*	188	147.3**	32.4**	179.6**	2000	170	94.0	8.5
	ERODING BANK	196.0	25.8*	21.2*	1074	841.3**	185.0**	1026.3**	2580	695	416.3	37.8
	ERODING BANK	195.5	25.8*	21.2*	1110	869.5**	191.2**	1060.7**	2970	840	373.7	34.0
	ERODING BANK	195.5	25.8*	21.2*	1220	955.7**	210.1**	1165.8**	2560	680	476.6	43.3
	ERODING BANK	194.5	25.8*	21.2*	682	534.2**	117.5**	651.7**	2820	475	241.8	22.0
	SACT 21	194.0	23.3	21.9	294	238.5	15.2	253.7	2220	220	132.4	12.0
	ERODING BANK	193.5	25.8*	21.2*	285	223.3**	49.1**	272.3**	1800	220	158.3	14.4
	SACT 24	193.0	28.3	20.4	576	435.2	168.5	603.7	2820	320	204.3	18.6
7A	ERODING BANK	192.0	22.8*	12.1*	2321	1040.2**	918.1**	1958.2**	5810	520	399.5	36.3
	PHELAN	191.5	27.0	6.5	1955	470.6	1484.4	1955.0	4620	920	423.2	38.5
	GOLDEN STATE	190.0	26.0	6.0	1598	355.1	1183.7	1538.8	4080	652	391.7	35.6
	ERODING BANK	190.0	22.8*	12.1*	439	196.7**	173.6**	370.4**	3195	250	137.4	12.5
	SACT 23	189.0	47.9	43.7	102	165.1	15.9	181.0	1200	300	85.0	7.7
	SACT 25	187.7	21.9	13.6	1440	725.3	442.7	1168.0	3980	576	361.8	32.9
	ERODING BANK	187.0	22.8*	12.1*	1707	765.0**	675.2**	1440.2**	3400	1000	502.1	45.6
	ERODING BANK	187.0	22.8*	12.1*	2616	1172.4**	1034.8**	2207.1**	4200	1070	622.9	56.6
	SACT 26	186.5	21.4	21.0	2608	2028.4	38.6	2067.1	5800	1200	449.7	40.9
	R.D. FARWELL	185.5	17.6	13.4	1264	627.3	196.6	823.9	5140	500	245.9	22.4
	TOTAL		1678.4	1076.7	53750	28755.7	19698.0	48453.8	196909	29699	15768.0	1433.6
	AVERAGE		25.1	16.1	802	429.2	294.0	723.2	2939	443	235.3	21.4

* MEAN VALUES OF SURVEYED DATA BY GEOMORPHIC REACH
** GENERATED FROM MEAN VALUES OF SURVEYED DATA

Table 1. Sacramento River Erosion Site Parameters

Between Red Bluff and Chico Landing, 94,000 feet of riverbank has been riprapped and an additional 81,000 feet of riprap have been proposed. If this is developed, the total riprap in this reach would comprise 34 percent of the riverbank. In the Butte Basin reach (River Mile 176 to 194), 15 percent of the banks are protected and an additional 10 percent are planned (USCE 1988).

Bank protection, when effective, stops bank erosion and lateral migration. It prevents loss of valuable agricultural lands, transportation facilities, and structures.

Bank protection, particularly if it is along all the eroding banks of the river, will cause some long-range geomorphic changes. First, it will have a stabilizing effect on length and sinuosity. Second, it will prevent the re-entrainment through bank erosion of gravel deposited on point bars. This will have some long-range effects on the amount of available spawning gravel. Third, over a period of time, it will tend to narrow the channel, increase the depth of flow, and reduce the hydrologic diversity. Sloughs, tributary channels, and oxbow lakes will fill with sediment and no new ones will be created.

Changes in Length and Sinuosity

Analyses of channel length and sinuosity were done on eleven sets of maps and photographs dated between 1896 and 1987. These were tabulated and published in DWR (1985). No trends were apparent, however, in that some reaches are increasing in length and sinuosity and others are decreasing.

Changes in Depth and Width

The Department of Water Resources (1984) theorized that bank protection would cause the channel to narrow and deepen. When a channel is stabilized, it will no longer erode its banks but will erode its bed. Deposition will continue on the inside of the bend, causing the channel to narrow and deepen. Such a channel will have less hydraulic diversity and salmon spawning area.

As part of the bank erosion studies, sonar surveys were used to measure depths along eroding and riprapped banks. The surveys were done during the summer of 1987. River widths were measured from June 1987 aerial photographs.

Figure 4 shows the thalweg depths plotted with river mile. There were 37 riprapped banks and 28 eroding banks measured and plotted. The lines are 4-point running averages showing that the mean thalweg along riprapped banks average 6 feet deeper than comparable eroding banks.

A similar analysis was completed for river widths. Figure 5 shows that the average width at riprapped sites is about 90 feet less than at eroding sites. The difference in widths appears to remain fairly constant from Ord Ferry (River Mile 184.3) to River Mile 223; then the difference decreases until from River Mile 235 to Red Bluff, it is essentially nonexistent. This is a consequence of the more stable banks near Red Bluff.

The effects of Shasta Dam on river geomorphology are complex. In principle, Shasta Dam would tend to reduce width because of less frequent floodflows. However, this effect may be offset by factors that tend to increase channel width, such as riparian loss. Further study is necessary to adequately assess this complex issue.

Conclusions

Some of the conclusions of the study are that:

- Human activities causing adverse impacts include hydraulic gold mining, gravel mining, bank protection, flood control, and removal of riparian vegetation by agriculture.
- Changes in the hydrologic regime, primarily due to Shasta Dam, have reduced bank erosion rates and overbank deposition.
- Eroding banks consist predominantly of gravel, and the gravel is vital in replenishing salmon spawning areas.
- Floodplain deposition replaces silt lost by bank erosion. Our ongoing study will help to determine if the system is in balance.
- Bank erosion is necessary to maintain riparian succession, anadromous fish and wildlife habitat in the reach.
- Most of the bank erosion occurs during the winter. Summer erosion is significant in a few places along the river. Eroding sites differ considerably in bank erosion rates. The average rate is about 20 feet per year for the last 11 years. Between Red Bluff and Ords Ferry, this is about 110 acres per year or about 2 acres per year per mile. The high rate is most likely due to two large floods that occurred during this period.
- Bank protection will have several negative, long-range effects. Since over 85 percent of the gravel provided to the river comes from bank erosion, it will prevent the recruitment of gravel to salmon-spawning areas. It will cause the river to narrow and deepen. A survey of riprapped and eroded banks shows that riprapped banks are an average of 6 feet deeper at the thalweg. A similar survey of river width shows that the river at riprapped banks is an average of 90 feet narrower. Finally, it will affect the natural rejuvenation of riparian vegetation, reducing or eliminating the habitat for many species of birds and animals.

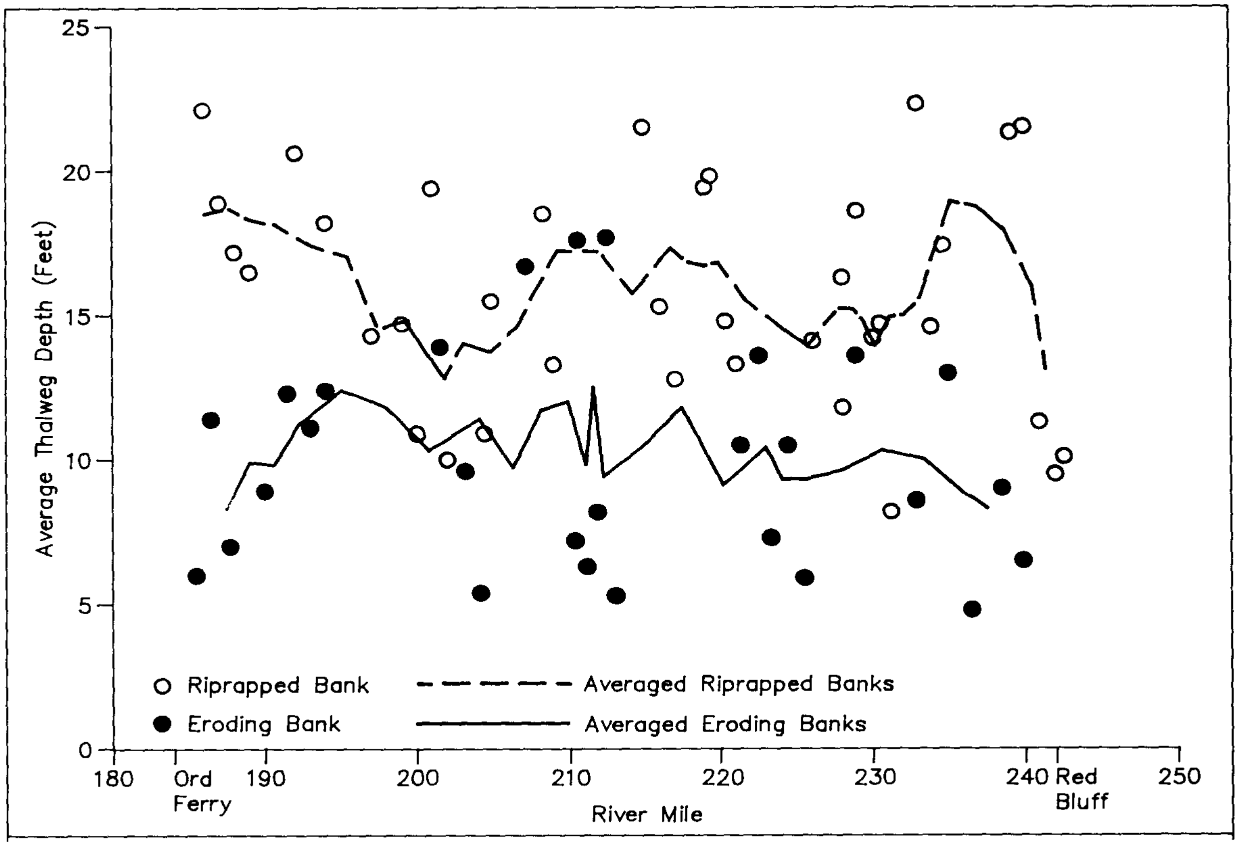

Figure 4– Thalweg Depths Next to Eroding and Riprapped Banks Sacramento River, Summer 1987

Recommendations

Recommendations of the study include development of a comprehensive management plan that will:

- Protect, enhance, and maintain the natural fish, wildlife, and riparian habitat along the Sacramento River. This includes regulation to protect erosion-dependent features such as salmon spawning areas, bank swallow nesting sites, oxbow lakes and offstream wet areas, riparian vegetation, and the attendant wildlife habitats.

- Continue monitoring programs of the Sacramento River geomorphology, including bank erosion, meandering, river depth and width, spawning gravel supply, and floodplain deposition.

References

California Department of Fish and Game. 1965. "California Fish and Wildlife Plan". Volume III, Part B. Sacramento, Calif. CDFG. 370 p.

California Department of Water Resources, Northern District. 1979a. "Land use change in the Sacramento River riparian zone, Redding to Colusa, An update - 1972 to 1977". Red Bluff, Calif. 34 p.

California Department of Water Resources, Northern District. 1979b. "Observations of Sacramento River bank erosion, 1977-1979". Red Bluff, Calif. 58 p.

California Department of Water Resources, Northern District. 1980. "Upper Sacramento River spawning gravel study". Red Bluff, Calif. 200 p.

California Department of Water Resources, Northern District. 1983. "Land use changes in the Sacramento River riparian zone, Redding to Colusa, A second update - 1977 to 1982". Red Bluff, Calif. 28 p.

California Department of Water Resources, Northern District. 1984. "Middle Sacramento River spawning gravel study." With River Atlas. Red Bluff, Calif. 194 p.

California Department of Water Resources, Northern District. 1985. "Sacramento River spawning gravel studies - Executive Summary." Red Bluff, Calif. 38 p.

California Department of Water Resources, Northern District. 1987. "Land use changes in the Sacramento River riparian zone, Redding to Colusa, A third update - 1982 to 1987". Red Bluff, Calif. 20 p.

Jones, Gerald II. 1967. Alteration of the regimen of the Sacramento River attributable to engineering activities during the past 116 years. Sacramento Section, U. S. Corps of Engineers.

United States Bureau of Reclamation (USBR). 1972. "Salmon in California".

United States Corps of Engineers. 1978. "Reconnaissance report Sacramento River and tributaries, bank protection and erosion control investigation, California". Sacramento, Calif. 94 p.

United States Corps of Engineers. 1981. "Sacramento River and tributaries bank protection and erosion control investigation, California". 252 p.

United States Corps of Engineers. 1988. "Butte Basin Reach - Sacramento river bank protection project". Sacramento, Calif. 211 p.

United States Department of the Interior, Bureau of Fisheries (now U. S. Fish and Wildlife Service). 1940. "An investigation of fish salvage problems in relation to Shasta Dam". Special Scientific Report No. 10. Washington, D. D.C.

United States Geological Survey. 1977. "Lateral migration of the Middle Sacramento River, California". U. S. Geological Survey Water Resources Investigations 77-43. 51 p.

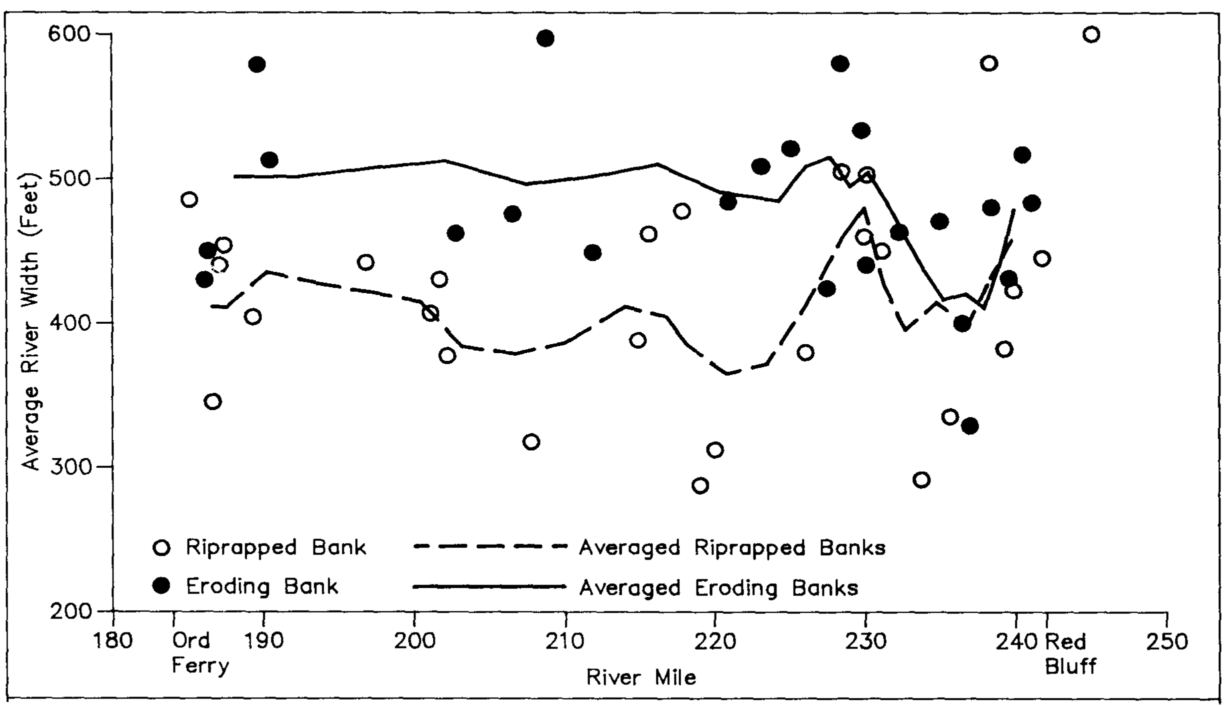

Figure 5-- River Widths Next to Eroding and Riprapped Banks Sacramento River, Summer 1987