

EFFECTS OF BANK REVETMENT ON SACRAMENTO RIVER, CALIFORNIA¹

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Abstract: Twelve low radius of curvature bends, half of which were rivetted, were studied in the Butte Basin reach of Sacramento River, California, to determine whether bank revetment deleteriously affected salmonid habitat. At low discharge (128.6 cubic meters/s) it was demonstrated that revetment does not cause channel narrowing or deepening, nor does it prevent re-entrainment of gravels on point bars. Point bar sediments in rivetted bends are not coarser than those in non-rivetted bends. Point bar morphology is stage-dependent, and therefore, point bars are both sources and sinks for spawning-size gravel which can mitigate against reduced gravel recruitment due to bank revetment.

Approximately 20 percent of the total bank length (both banks) in the Butte Basin reach of Sacramento River has been rivetted to prevent bank erosion and meander migration that have threatened flood-control levees and flood-relief structures. Revetment in this paper refers to the bank protection method of sloping back an eroding bank (2H:1V) and covering it with rock. A number of concerns have been expressed about the possible effects of bank revetment on the morphologic characteristics of the bends on the river, which in turn may have adverse effects on the salmonid fishery (CA Department of Fish and Game (DFG) 1983; CA Department of Water Resources (DWR) 1984). Approximately 57 percent of the total spawning area in the river is associated with meander bends (fig. 1), and meander bends are also important juvenile rearing areas (DWR 1984). Chinook salmon select spawning areas with a narrow range of physical conditions. Spawning conditions appear to be optimum when the gravel size in the substrate is between 25 and 152 millimeters, flow depth is greater than 0.25 meters, and flow velocity is between 0.2 and 1.5 meters/s (Diebel and Michny 1986). Rearing areas are generally shallow and have low velocity (DFG 1983). Preferred salmon spawning areas are at pool-riffle interchanges (fig. 1) in a bend (Reiser and Bjornn 1979).

Bank erosion rates and the rates of lateral migration of the channel are highest on Sacramento River when the bend radius of curvature to width ratio (R_c/W) is 2.5, and they are both lower when R_c/W is greater

or lesser than 2.5 (Nansen and Hickin 1986; Harvey 1988). Measured lateral migration rates range from 37 to 10 meters/year (Harvey 1989). Bends are generally rivetted when R_c/W is between 2.3 and 3.8 because the rates of bank erosion are high. The principal concerns on Sacramento River are that revetment will: (1) cause the river to deepen and narrow, (2) cause a coarsening of sediments on the point bars, (3) prevent re-entrainment of gravels deposited on the point bars, and (4) prevent gravel recruitment from the eroding banks. The objective of this investigation was to determine whether revetment of low radius of curvature bends in the Butte Basin reach was adversely affecting the salmonid habitat by modifying the morphologic characteristics of the bends.

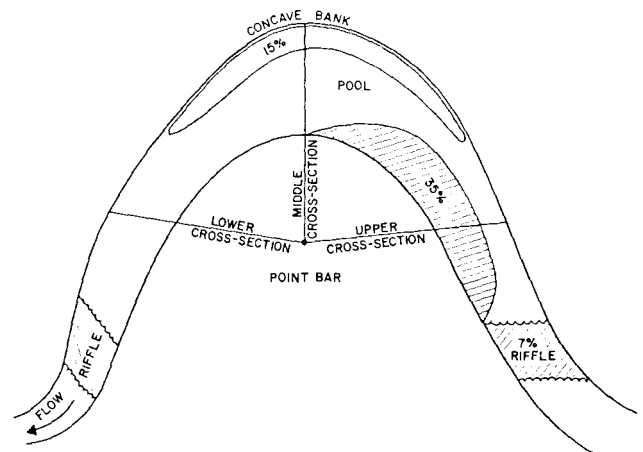


Figure 1— Schematic diagram of a meander bend that shows the locations of surveyed cross sections. The cross-hatched areas are preferred salmon spawning areas and the percentages indicate the importance of these with respect to all spawning areas along the Middle Sacramento River (DWR 1984).

Few studies have been conducted to determine the effects of bank revetment on river morphology. Friedkin (1945) in a laboratory study of a model stream with sand bed and sand banks observed that revetment caused thalweg deepening and vertical accretion of the point bars in bends with a wide range of radii of curvature, but channel narrowing occurred only in bends with a

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high radius of curvature. The concerns expressed about the effects of revetment (DFG 1983; DWR 1984) appear to be based on the results of this study. Following revetment of a low radius of curvature bend on Red River, Arkansas, water-surface width increased, flow depth decreased and cross-section area did not change. Therefore, revetment did not cause channel narrowing or deepening (Water Engineering and Technology, Inc. 1987). Fall River, Colorado, is a very sinuous, sand and gravel transporting meandering stream with banks that are root reinforced. The extreme resistance of the bank materials is analogous to the effects of bank revetment. Point bars on Fall River are dynamic, stage-dependent geomorphic features even when the concave bank does not retreat (Anthony and Harvey 1987a, 1987b; Harvey and others 1987).

Sacramento River Field Study

Data Collection

Under low-flow conditions (128.6 cubic meters/s) twelve bends in the Butte Basin reach were investigated. Half of the bends were revetted and half were not. The radii of curvature of both sets of bends ranged from 381 to 572 meters. Harvey (1989) demonstrated that the morphology and dynamics of bends on Sacramento River could be related to the radius of curvature of the bends. At each bend three cross sections were surveyed to a common datum with a boat-mounted fathometer and an EDM-theodolite (fig. 1). The cross sections were located consistently at: (1) the upstream limb of the bend (upper), (2) the bend apex (middle), and (3) the downstream limb of the bend (lower). In the non-revetted bends the toe sediments of the concave bank which were primarily composed of point bar sands and gravels (non-cohesive) or abandoned-channel fills (cohesive) were recorded at each cross section. Wolman counts (Wolman 1954) of the lower point bar sediments were made at the head of each point bar to determine the size distribution of the sediments because the sediments at this location are the coarsest on the point bar (Bluck 1971). From the cross-section surveys the following data were obtained: (1) water-surface width, (2) maximum flow depth, (3) average flow depth, and (4) cross-section area below the water surface. Average flow velocities were calculated from the continuity equation ($Q = A.V$). The survey data was also used to determine the water-surface slope through the bend. Grain-size distribution parameters were obtained from the Wolman counts.

Data Analysis

Mean and standard deviations for each of the variables for the revetted and non-revetted bends were determined and the means were tested for statistically significant differences with a t-Test (90% probability level). The results of the t-Tests of the means for all the revetted (18) and non-revetted (18) cross sections (table 1) indicate that: (1) water-surface width in revetted bends is less than that of non-revetted bends, (2) there is no difference in maximum depth, (3) average depth is less in revetted bends, and (4) cross-section area is less in revetted bends. When the non-revetted cross sections were subdivided on the basis of the cohesiveness of the concave bank toe sediments and were compared to the revetted cross sections, the statistical analyses indicate that: (1) there is no difference in water-surface width, (2) the maximum depth is associated with cohesive sediments, (3) average depth is less in revetted bends, and (4) cross-section area is less in revetted bends. These results indicate that the effect of revetment on water-surface width is equivocal, but revetment does cause a reduction in average flow depth and cross-section area. The deepest (maximum depth) flows were associated with the occurrence of cohesive sediments in the toe of the concave bank.

Table 1 — Comparison of cross section variables at revetted and non-revetted bends of Sacramento River. Discharge was 128.6 cms.

Type of Bend	Water Surface Width (m)	Max. Depth (m)	Average Depth (m)	Cross Section Area (m ²)
revetted	106.7+20.5	3.7+1.5	1.6+0.8	166.3+69.7
(No. Obs.)	18	18	18	18
Non-revetted	119.5+20.8	4.2+1.6	2.3+0.7	263.4+55.0
(No. Obs.)	¹ 18	² 18	¹ 18	¹ 18
Non-CohesiveToe	118.6+17.7	3.7+0.9	2.1+0.5	246.1+46.1
(No. Obs.)	² 13	² 13	¹ 13	¹ 13
Cohesive Toe	121.6+29.7	5.7+2.1	2.7+1.0	308.2+178.9
(No. Obs.)	² 5	¹ 5	¹ 5	¹ 5

¹ Significantly different from revetted value at 90% probability level.

² Not significantly different from revetted value at 90% probability level.

The revetted and non-revetted cross sections were compared on the basis of their locations within a bend: upper, middle, lower (table 2). The results of the statistical tests indicate that: (1) revetment has no effect on water-surface width, nor maximum flow depth, at any of the locations within a bend, (2) revetment causes a reduction in average flow depth in the upper and middle cross sections, but has no effect on the lower cross section within a bend, and (3) revetment causes a reduction in cross-section area in the upper and middle cross sections, but it has no effect on the lower cross section within a

bend. The results indicate that the effects of revetment are limited to the upper and middle parts of a bend, and the principal effect is a reduction of average flow depth.

Water-surface slopes and grain-size parameters for the revetted and non-revetted bends were compared statistically (table 3). The results indicate that revetment has no effect on water-surface slope or on the grain-size distributions of the point bar sediments.

Table 2 — Comparison of cross section variables at different locations in revetted and non-revetted bends of Sacramento River. Discharge was 128.6 cms.

Cross Section	Water Surface Width (m)	Maximum Depth (m)	Average Depth (m)	Cross Section Area (m ²)
Upper:				
revetted	110.6+27.7	3.0 + 1.3	1.3+0.6	136.3+47.5
Non-revetted	127.7+24.7	3.9 + 0.4	2.2+0.3	271.0+12.7
(No. Obs.)	² 6	² 6	¹ 6	¹ 6
Middle:				
revetted	109.1+19.0	3.4 + 0.9	1.6+0.7	164.1+69.4
Non-revetted	112.5+20.0	4.3 + 1.3	2.3+0.5	256.2+32.4
(No. Obs.)	² 6	² 6	¹ 6	¹ 6
Lower:				
revetted	99.7+19.0	4.8 + 1.6	2.1+1.1	198.4+84.5
Non-revetted	117.8+17.5	4.5 + 2.5	2.4+1.2	262.7+94.5
(No. Obs.)	² 6	² 6	² 6	² 6

¹ Significantly different at 90% probability level.

² Not significantly different at 90% probability level.

Table 3 — Comparison of water-surface slopes and grain-size variables at revetted and non-revetted bends of Sacramento River. Discharge was 128.6 cms.

Type of Bend	Water Surface Slope (m/m)	d ₅₀ (mm)	d ₉₅ (mm)	¹ d _s (mm)
revetted	0.00013+0.000083	15.1+6.9	38.6+12.7	2.1 + 0.3
(No. Obs.)	² 6	² 6	² 6	² 5
Non-revetted	0.000101 +0.000091	12.4+4.7	42.5+14.0	2.1 + 0.4
(No. Obs.)	6	6	6	5

¹d_s is geometric standard deviation

² Not significantly different at 90% probability level.

Discussion

This investigation of the effects of revetment on salmonid habitat, which was conducted under low-flow conditions, when the alleged effects of revetment are considered to be most deleterious (DFG 1983), has addressed some of the principal concerns about the effects of revetment on river morphology. Revetment does not cause an increase in channel depth, but in fact appears to cause a

reduction in average flow depth in the upper and middle parts of a bend, which may increase the area of rearing habitat in a bend (DFG 1983). The reduction in average flow depth is not sufficient to reduce flow depths below those required for spawning (0.25 meters: Diebel and Michny 1986). The effects of revetment on water-surface width are equivocal because the statistical analyses have produced conflicting results (tables 1 and 2). Revetment does not induce a coarsening of the point bar sediments (table 3), nor does it appear to affect water-surface slope (Friedkin 1945). However, because of continuity, a reduction in cross-section area at a constant discharge must result in higher average velocity in revetted bends. When all of the cross sections (36) were considered, the mean flow velocity + 1 standard deviation of the revetted and non-revetted bends were 0.97 + 0.35 and 0.57 + 0.15 meters/s, respectively. The results of a *t*-Test indicate that the means were different statistically. There was no statistically significant difference between the mean velocities in revetted and non-revetted bends at the lower cross section. However, the mean velocity (0.97 + 0.30 m/s) of the revetted middle cross sections was significantly different from that of the middle non-revetted cross sections (0.56 + 0.08 m/s). This was true also for the upper cross sections (1.16 + 0.39 m/s *vs.* 0.52 + 0.02 m/s). Therefore, revetment appears to cause an increase in the average flow velocity in the middle and upper parts of the bend. However, the increased velocities are well within the limits of 0.2 to 1.5 meters/s required for spawning (Diebel and Michny 1986).

The effects of revetment on gravel re-entrainment from point bars could not be addressed directly in this investigation. However, data from the Butte Basin reach of Sacramento River are available, (Gundlach and Murray 1983), where monumented cross sections were resurveyed at different discharges (fig. 2). The repeat surveys demonstrate that point bar morphology is stage-dependent, and that vertical accretion occurs during higher discharges. This accords with the observations of Anthony and Harvey (1987a, 1987b) and Harvey and others (1987).

There is no doubt that revetment of a bend prevents recruitment of gravel from the floodplain at that location. Vanoni (1987) concluded that 85 percent of spawning-size gravels are derived from bank and bar erosion, and therefore, revetment will reduce gravel availability. However, to some extent the reduced availability from bank erosion sources is mitigated by the fact that point bars are both sinks for and sources of gravel because they accrete vertically during higher flows and are eroded during recessional flows (Anthony and Harvey 1987a, 1987b; Harvey and others 1987) provided that there is an upstream source of gravels.

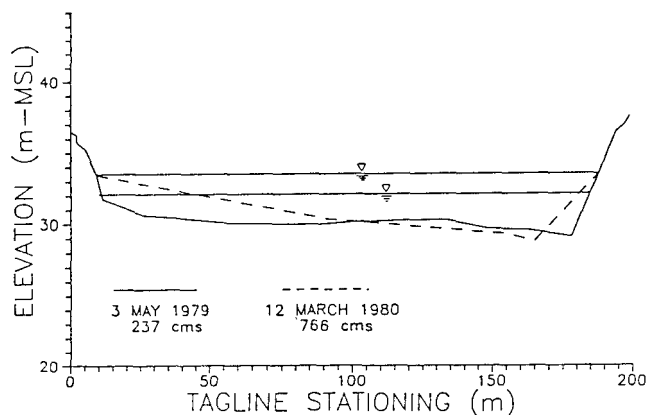


Figure 2 Cross section adjustments with change in discharge in a revetted bend. Data from Gundlach and Murray (1983).

Conclusions

Revetment of individual bends in the Butte Basin reach of Sacramento River does not effect salmonid habitat adversely. Revetment does not cause channel narrowing or deepening, nor does it prevent re-entrainment of point bar gravels or cause coarsening of the point bar sediments. Gravel recruitment from point bars mitigates to some extent the elimination of the banks as gravel sources provided that there is an upstream source of gravels.

Acknowledgments

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References

- Anthony, D.J.; Harvey, M.D. 1987a. Response of bed topography to increased bedload, Fall River, Colorado. *Int. Assoc. Hydrol. Sci. Publ. No. 165*; 387-388.
- Anthony, D.J.; Harvey, M.D. 1987b. Stage-dependent point bar adjustments, Fall River, Colorado. *Trans. Amer. Geophys. Union*, 68(4); 1297.
- Bluck, B.J. 1979. Sedimentation in the meandering River Endrick. *Scottish Journal of Geology*, 7; 93-138.
- California Department of Fish and Game. 1983. Sacramento River and tributaries bank protection and erosion control investigation: evaluation of impacts on fisheries. State of California, Department of Fish and Game Report; 92 p.
- California Department of Water Resources. 1984. Middle Sacramento spawning gravel study. State of California, Department of Water Resources Report, August, 1984; 34 p.
- Diebel, R.; Michny, F. 1986. Sacramento River, Butte Basin reach salmon spawning study. Report U.S. Fish and Wildlife Service, Division of Ecological Services, Sacramento California, December, 1986; 32 p.
- Friedkin, J.F. 1945. A laboratory study of the meandering of alluvial rivers. U.S. Army Mississippi River Division, Waterways Experiment Station, Vicksburg, Mississippi; 176 p.
- Gundlach, D.L.; Murray, L.A. 1983. Data collection program, Sacramento River bend study, California. U.S. Army Corps of Engineers, Sacramento District, March, 1983; 24 p.
- Harvey, M.D. 1989. Meanderbelt dynamics of the Sacramento River, California. (These proceedings).
- Harvey, M.D.; Pitlick, J.; Hagans, D.K. 1987. Adjustments of point bar morphology during a snowmelt runoff period. *Trans. Amer. Geophys. Union*, 68(4); 1297.
- Nanson, G.C.; Hickin, E.J. 1986. A statistical analysis of bank erosion and channel migration in Western Canada. *Bulletin Geological Society of America*, 97; 497-504.
- Reiser, D.W.; Bjornn, T.C. 1979. Habitat requirements for anadromous salmonids. USDA Forest Service, General Technical Report, PNW -96; 54 p.
- Vanoni, V.A. 1987. Sedimentation aspects of the Sacramento River between Bend Bridge and Colusa. Report to U.S. Army Corps of Engineers, Sacramento District, May, 1987; 29 p.
- Water Engineering and Technology, Inc. 1987. Geomorphic and hydraulic analysis of Red River from Shreveport, LA to Dennison Dam, TX. Report to U.S. Army Corps of Engineers, Vicksburg District, Contract No. DACW38-86-D-0062/7, August 1987; 226 p.
- Wolman, M.G. 1954. A method of sampling coarse river-bed material. *Trans. Amer. Geophys. Union*, 35; 951-956.