SEDIMENT BALANCE AND FLUSHING FLOW ANALYSIS: TRINITY RIVER CASE STUDY

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ABSTRACT

The use of sediment yield as one aspect of a flushing flow analysis is explored in a case study of the Trinity River in northwestern California. Understanding sediment balance can help in the development of a flushing flow need, but hydraulic analysis must also be done. The most important flushing flow need for the Trinity River is to increase the Trinity River flows when flows in Grass Valley Creek and other tributaries draining the Shasta Bally Batholith are high. The goal is preventing deposition of sand and fines. These flows should be followed by clear-water flushing (i.e., flushing flows when the tributaries are not high) to remove fines and sand from the stream bed.

INTRODUCTION

The use of sediment balance as part of a flushing flow study is a relatively new idea. Most flushing flow studies consider only the hydraulics of a reach of stream. This case study of the Trinity River in northwestern California shows that the analyst must consider not only the hydraulics of a reach but also the sediment balance of the stream. The work is part of a larger joint study between the U.S. Bureau of Reclamation and the National Biological Survey to develop techniques to determine flushing flows for western rivers. The Trinity River was used as a case study because much sediment load data have been collected for the river and tributaries below Lewiston Dam, and some hydraulic data were available.

TRINITY RIVER, CALIFORNIA

The Trinity River is located in northwestern California and is tributary to the Klamath River. Major facilities constructed by the U.S. Bureau of Reclamation (USBR) divert a high portion of the

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natural streamflow from the Trinity River to the Sacramento Basin. These facilities are part of the Central Valley Project. The diversions started in April 1963. Filling of the reservoirs caused an initial impact on the Trinity River stating in water year 1961. The reservoirs have had a major impact on the Trinity River and are considered to have caused a reduction in chinook salmon production because of fine sediment deposited in the gravels (Nelson et al.,1987).

The reach considered in this paper is that between Lewiston Dam and its junction with the North Fork of the Trinity, about 38 miles downstream. The reach is important for chinook salmon spawning. The mean daily flow for the period 1912 to 1960 at Lewiston was 1640 cfs. The unregulated flows of the Trinity River have a pattern of rain and rain-on-snow flows in fall and winter, with snow-melt flows in spring. The historical peak of the average daily flows occurred on 14 May (4289 cfs), and the maximum daily discharge occurred on 22 December (38,700 cfs).

The tributary watershed to the reach downstream of Lewiston but upstream of the North Fork of the Trinity has a different pattern because snow-melt is not as important. The average of the daily flows for Grass Valley Creek for the period 1976 to 1992 was 46.8 cfs. The maximum average daily discharge (215 cfs) and the maximum of the average daily discharges (2420 cfs) are on the same day (2 March).

Table 1. Annual peak daily flows (cfs) measured in the Trinity River at Lewiston, California for the unregulated period (1912-1960) and the regulated period (1965-1991).

Years	Mean	Median	Maximum	Minimum
1912-1960	14661	14400	38700	2860
1965-1991	2528	944	13800	252

The impact of the reservoirs and the diversion on the daily flows has been significant (Table 1). Except during the summer low-flow period, the reduction in the daily flows has been significant, causing the new maximum average daily flow to be 825 cfs with a maximum of the daily lows to be 13,800 cfs. The pattern, or in some ways the lack of a pattern, is completely different from the natural flows in the river.

A high percentage of the fines and sand delivered to the Trinity between Lewiston and the North Fork are

derived from the Shasta Bally Batholith and transported to the Trinity by Grass Valley Creek. The Shasta Bally Batholith is weathering rapidly to easily transported sand and finer material. Most of the Grass Valley watershed is underlain by the batholith and little of the remaining watershed is underlain by the batholith (Nelson et al., 1987). Grass Valley Creek may be transporting gravel, but the major source of gravel is probably the other tributaries and the channel and banks of the river.

EXISTING TECHNIQUES FOR DETERMINING FLUSHING FLOW NEEDS

Empirical techniques for determining a flushing flow need were reviewed by Milhous(1986). The range of the flushing flow needs is bounded by the mean annual peak flow (daily or instantaneous) and two times the average annual discharge. The unregulated mean daily peak flow is 14,660 cfs and two times the mean annual flow is 3280 cfs. If either of these flows had been used as a required flushing flow at the beginning of regulation, good conditions for salmon spawning may have resulted, but they were not used and the existing conditions are not good for spawning. The result of low peak flows between 1961 and the present is that the channel has changed. The existing bankfull width may be less than 50 percent of the pre-project bankfull width (Frederiksen, Kamine and Associates, 1980). Because of channel change, none of the empirical techniques should be used.

The state of the art is to use an analysis of the hydraulics of a reach of stream and to determine a flushing flow on the basis of a critical discharge calculated from the critical shear stress required to move the bed material. These techniques were described by Milhous (1986 and 1990).

From a habitat viewpoint there are three levels of flushing flows. The first is the level needed to keep fines and sand from being deposited in and on the stream bed ("keep sand moving"); the second is the flow level needed to remove fines and sand from the surface of the stream bed (surface flushing); and the third is the flow level needed to remove sediment from within the stream bed (depth flushing). The levels are determined using a movement parameter, beta, which is calculated the same way as the Shields coefficient, but the beta parameter is about movement and not about stability. The parameters needed for surface and depth flushing flows have been previously shown (Milhous, 1986) to

be 0.035 for depth flushing and 0.021 for surface flushing. The equation (Milhous,1990) used for the "keep sand moving" case is

$$beta = 0.066(d50bl/d50a)^{0.47}$$

where beta is the movement parameter, d50bl is the median size of the transported material, and d50a is the median size of the bed surface material. The size of the material to keep in motion (i.e. transport) was assumed to be 1.0 mm.

The data used to estimate the streamflow in the Trinity that would result in the required values of beta were adapted from Barta, Wilcock, and Shea (1993). The values used for two locations near Limekiln Gulch are given in Table 2. There is at least one problem; the report was not clear as to what the D50 represented. Was D50 for a bulk sample that included both surface and sub-surface material, or was it for the surface material? The D50 is assumed to be surface (armour) material.

Using these data the "keep sand moving" critical flow was calculated to be 1800 cfs, the critical flow for surface flushing 2820 cfs, and critical flow for depth flushing 4560 cfs.

Table 2: Data used to develop a beta versus stream flow function for the Trinity River. (Adapted from Barta, Wilcock and Shea, 1993.)

Site	Streamflow cms	Depth m	Slope %	D50 cm	Beta
Poker Bar	75.7	1.52	0.08	3.4	0.022
	164	2.17	0.11	2.3	0.065
Steel Bridge	75.7	1.05	0.16	6.5	0.016
	164	1.85	0.14	4.3	0.038

The "keep sand moving" and the surface scour concepts are similar - the objective being to keep the surface clean of fines and sand. The "keep sand moving" case is best used when there is a small amount of fines and sand introduced into the stream. The scour surface case is best used to remove sand and fines and to transport fines and sand when there is a large amount of sand introduced into the stream. Grass valley Creek introduces a lot of sand to the Trinity River. Therefore, the flushing flow for the Trinity is either the surface flushing flow (2820 cfs) or the depth flushing case (4560 cfs). Salmon spawning requires depth flushing; hence, the flushing flow need is 4560 cfs.

SEDIMENT BALANCE IN THE TRINITY RIVER

Measured data used for the analysis presented in this paper are for two U.S. Geological Survey hydrometric stations - one on Grass Valley Creek at Fawn Lodge and the other on the Trinity River below Limekiln Gulch. The yield of sediment from Grass Valley Creek is used here as an index to the sediment yield of the watershed between the Lewiston Gage and the North Fork of the Trinity. The measured annual sediment yields for the two stations are given in Table 3. The area of the watershed between the gage on the Trinity at Lewiston just downstream of the dam and the gage at Limekiln Gulch is 93 square miles. Little sediment is transported through the reservoir complex upstream; therefore, the sediment load measured at Limekiln Gulch is mostly from the watershed between the dam and the hydrometric station. The watershed area above the gage on Grass Valley Creek is 30.8 square miles - one third of the source area for sediment at the Limekiln gulch site.

Table 3: Measured Suspended Sediment Load in the Trinity River at Limekiln Gulch and in Grass Valley Creek at Fawn Lodge. (Data from the records of the U.S. Geological Survey.)

Water Year	Trinity River (tons)	Grass Valley Creek (tons)	Ratio
1976		745	
1977		126	
1978		78306	
1979		2861	
1980		13552	
1981		3877	
1982	47864	7127	6.72
1983	315916	304673	1.04
1984	26338	9714	2.71
1985	1922	977	1.97
1986	66416	59855	1.11
1987	2618	4354	0.60
1988	1476	1211	1.22
1989	4060	2560	1.59
1990	1826	1393	1.31
1991	1912	232	8.24
1992		3126	
Average (1982-89)	58327	48809	1.19

A reservoir constructed to trap some of the sediment in Grass Valley Creek upstream of the hydrometric station was completed in 1990.

The ratio of the sediment load at Limekiln Gulch to the load at Fawn Lodge is 1.19 for the period 1982 to 1989. If there was no net change in the sediment stored in the river between 1982 and 1989, a rough sediment balance can be calculated by assuming the input of sediment is 1.19 times the measured sediment load at Fawn Lodge, and the output is the measured load at Limekiln Gulch. The annual sediment balance is shown in Figure 1 for the ten years where records exist at both gages. (The ratio of 1.19 will be used for sediment balance calculations in following sections.) The data indicate there was storage of sediment in the river between Lewiston Dam and Limekiln Gulch in water years 1983, 1986, and 1987, and flushing occurred in the other years with the best flushing in 1982 and 1984. These conclusions sound at least plausible but there are some problems: (1) there is a large unmeasured load at both sites, (2) the material measured is a mixture of range of sizes of sediment that may be measured with different levels of efficiency at the two gages, and (3) the within year distribution of the sediment load can be important.

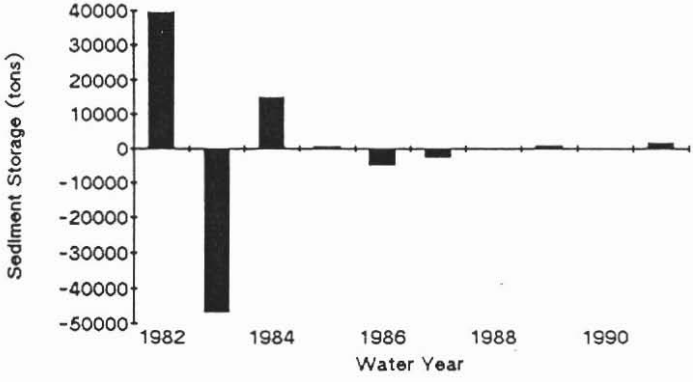

Figure 1: Sediment Balance for the Trinity River Between Lewiston Dam and the Limekiln Gage.

The application of a sediment transport capacity index in the analysis of the sedimentation aspects of an instream flow analysis was presented previously (Milhous 1992). The average annual

sediment transport capacity indices for surface flushing are given in Figure 2.

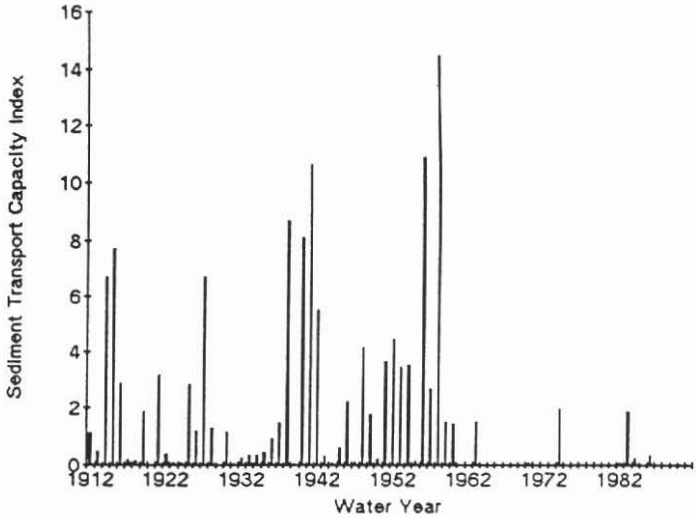

Figure 2: Annual Sediment Transport Capacity Index for surface flushing from 1912 to 1991 calculated using daily streamflows for the Lewiston Gage. (Streamflow data from records of the U.S. Geological Survey).

SEDIMENT BALANCE FOR WATER YEARS 1983 AND 1986

In this section sediment balance of the reach downstream of the dams is examined for water years 1983 and 1986. The major input of sediment is from Grass Valley Creek, and the measured sediment discharge at the hydrometric station on the Trinity River below Limekiln Gulch is the output. Water year 1983 may have provided good flushing flows and water year 1986 may have caused just the opposite - the deposition of sand in the gravels. As will become obvious in the following discussion, the case made by the data is not clear for either end result. Measured sediment loads and the sediment transport index for both surface and depth flushing for different periods of both and 1986 are given in Table 4. The sediment transport index was calculated using the daily streamflow at Lewiston.

Water year 1983 was the year with the largest sediment load from Grass Valley Creek during the period 1976 to 1992. Water year 1983 may also have been a good year for the flushing of fines and sand from the river, while at the same time depositing much material in a delta at the mouth of Grass Valley Creek that can be transported in subsequent years.

Table 4: Measured sediment load streamflow in the Trinity River below Limekiln Gulch and the measured sediment load in Grass Valley Creek at Fern Lodge. STCIM is the sediment transport index for 'keep sand moving', STCIS the index for surface flushing and STCID the index for depth flushing. SL is the sediment load in tons.

	Limekiln Gulch				Fern Lodge	Sediment
Period	STCIM	STCIS	STCID	SL	SL	Balance
WY 1983						
1 Oct-24 Jan	0	0	0	3029	1612	1111
25 Jan- 5 Feb	2	0	0	23708	73124	-63310
6 Feb-26 Feb	5	0	0	20989	8132	11312
27 Feb- 5 Mar	21	8	1	51580	181660	-164595
6 Mar-31 Mar	454	264	67	133260	2959	98043
1 Apr-30 Spt	685	404	133	83350	10551	70795
Water Year	1167	677	201	315916	304673	-46644
WY 1986						
1 Oct-12 Feb	0	0	0	3424	2937	-72
13 Feb-21 Feb	0	0	0	34597	37655	-10212
22 Feb- 6 Mar	5	0	0	14490	10771	1673
7 Mar-21 Mar	214	119	25	12152	5857	5182
22 Mar-31 Mar	0	0	0	458	969	-695
1 Apr-30 Spt	0	0	0	1295	1666	-687
Water Year	218	119	25	66416	59855	-4812

There were two stream flow events with high flows in 1983. The indicators from the information in the previous sections are mixed about water year 1983. The sediment transport capacity index was one of the two with substantial flushing in the 27 years since completion of the project, but the sediment balance data in Figure 1 indicate sediment may have been stored some where in the Trinity. The data in Table 4 indicate sediment was stored in the Trinity River during 1983, but the sediment removal from storage during the periods sediment was not being supplied in large quantities during 1983 indicates that sediment was flushed from the river as well. There is a good chance sediment was stored in a delta at the mouth of Grass Valley Creek and at the same time flushed from other parts of the river. This conclusion was based on the observation that the sediment transport index of the releases from

Lewiston were zero or small during periods of high sediment yield from Grass Valley Creek and higher when there was lower sediment yield form Grass Valley Creek. The end result may have been a cleaner substrate than usual in the river but with a delta upstream that could supply sand and fines to the substrate during certain (but unknown) flow conditions. To determine the flow conditions that would deliver sediment from the delta to the river would require hydraulic modeling of the river and the delta.

The situation in 1986 was significantly different from what happened in 1983. A high sediment load period occurred in mid February but was not followed by flow conditions needed to clean the surface or, part of the time, to keep the sediment moving. In the period following the storm the stream bed was flushed to a limited extent but not to the degree the data for 1983 indicates is possible because the 1983 data indicate the measured sediment load would be reasonably high for a while during a flushing event with a reasonable sediment transport index; there should have been flushing but there was not. It is possible there was so much sand deposited in and on the stream bed that the channel became a sand-bed channel as a result of the mid-February storm. The data for 1986 are rather confusing in comparison to 1983, but the lack of significant measured sediment loads following the mid-February storm indicate the stream was probably transporting sand without moving the gravel and cobbles. In 1986 the conditions may have been correct for deposition in and on the stream channel instead of in the delta; the reason cannot be determined without a hydraulic model of the Trinity River below Grass Valley Creek and a hydraulic study of the junction of Grass Valley Creek and the Trinity River (the delta area).

CONCLUSIONS

The major conclusion about the Trinity River is that the system is dynamic and that sediment can be removed by the available flows but the frequency of flows producing surface (2820 cfs) and depth flushing conditions (4560 cfs) must be increased. The best use of flushing flows is to keep the sediment from being deposited when the flows in Grass Valley Creek are high by increasing the flow from the dam to at least the "keep sand moving" level (1800 cfs). During water year 1983 sediment may have been deposited in a delta at the mouth of Grass Valley Creek because the sediment transport

capacity was too small (see Table 4). This indicates flushing flows should be released when the tributary flows are high but not high enough to keep the sediment in motion once in the Trinity River. The increased reservoir releases would increase the transport capacity in the river at the delta and reduce sedimentation in the delta. Clear water releases (i.e., releases when the tributary flows are low) should be considered to improve the stream bed.

Conclusions about the methodological approach are that the logic associated with the beta parameters needs to be improved and that hydraulic analysis must be done on the fate of sediment in the river. Too many assumptions were required about what was happening in the stream channel. Sediment can be routed through a stream channel and the hydraulics of the deltas modeled with two- or three-dimensional models. This was not done because the objective was to see how far sediment balance logic could be pushed to develop a flushing flow need for the Trinity. The sediment balance approach adds information to the usual results from the state of the art; however, this is still not good enough. Hydraulics of sediment movement through the Trinity River must be added.

Better than average spawning conditions may have occurred in the period 1982 to 1985 because of possible flushing of fines from the stream bed in 1982 and in 1983. The stream bed conditions may have became more like the average in 1986 because sediment may have been transported from the delta or directly from Grass Valley Creek to the stream bed.

If the spawning fish return to the Trinity 3 to 4 years after they were deposited as eggs, then there should have been good returns of spawning fish in 1986 to 1989, with more typical returns in the other years. Figure 3 is in general agreement with idea that the flow conditions in 1982 and 1983 created cleaner substrate then occurs in most years. However, one should not assume that the limiting factor on chinook salmon production is sediment in the stream. Many alternative explanations of the increase in spawners in 1986 and the subsequent reduction to previous levels are possible.

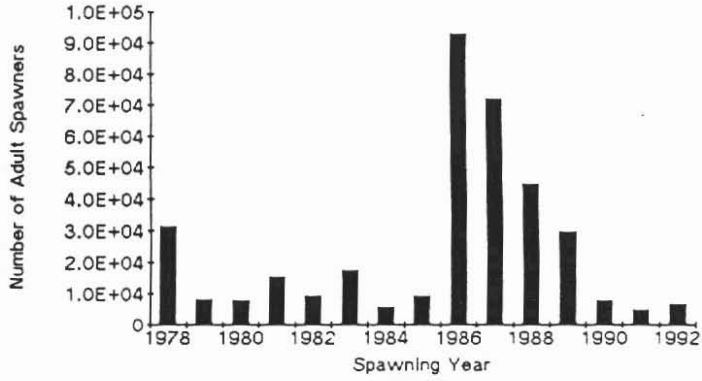

Figure 3: Number of Adult Spawners passing above Willow Creek from 1978 to 1992. Hatchery Production Excluded. (Data from California Fish and Game Department).

BIBLIOGRAPHY

California Fish and Game Department. 1992. Klamath-Trinity Program. Escapment data prepared December 20, 1992.

Barta, A.F., P.R. Wilcock, and C.C. Shea. 1993. Determination of Flushing Flows for Salmonid Spawning Gravels. Third Progress Report to Southern California Edison Company. Rosemead, CA.

Frederiksen, Kamine and Associates. 1980. Proposed Trinity River Basin Fish & Wildlife Management Program. Appendix B: Sediment & Related Analysis. U.S. Bureau of Reclamation. Sacramento, CA.

Milhous, R.T. 1986. Determining Instream Flows for Flushing of Fines and Channel Maintenance - A Review. in H.J. Morel-Seytoux and J.W. Warner, editors. Proceedings of the Sixth Annual AGU Front range Branch HYDROLOGY DAYS. HYDROLOGY DAYS Publications. Fort Collins, Colorado.

Milhous R.T. 1990. The Calculation of Flushing Flows for Gravel and Cobble Bed Rivers. in H.H. Chang and J.C. Hill editors. Hydraulic Engineering. American Society of Civil Engineers. New York, NY.

Milhous, R.T. 1992. Water and Sediment in the Middle Rio Grande Valley, New Mexico: Use of a Sediment Transport Capacity Index. in H.J. Morel-Seytoux editor. Proceedings of the Twelfth Annual American Geophysical Union HYDROLOGY DAYS. HYDROLOGY DAYS Publications. 57 Selby Lane. Atherton, CA.

Nelson, R.W., J.R. Dwyer, W.E. Greenberg. 1987. Regulated Flushing in a Gravel-Bed River for Channel Habitat Maintenance: A Trinity River Fisheries Case Study. Environmental Management. Vol.11, No.4, pp479-493. Springer-Verlag New York.

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