RESTORING RIVER SUBSTRATE USING INSTREAM FLOWS: THE GUNNISON AND TRINITY RIVERS

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ABSTRACT

The Gunnison and Trinity Rivers are two western rivers with major reservoirs were downstream aquatic habitat must be relatively free of sediment. The Gunnison River is a gravel bed river with large loads of fine material. The discharge needed to maintain the river in the condition needed by Colorado squawfish varies from 210 to 484 cubic meters per second (cms) depending on the objective. The overall objectives will be met if the discharge exceeds 484 cms one in every three years, with one in every two years having a discharge of at least 354 cms, and two in every three years having a discharge of 354 cms for at least four days. The Trinity River has a gravel bed and the river transports large quantities of sand; fines (material ≤ 0.062 mm) are relatively unimportant. The Trinity River is spawning and rearing habitat for Chinook salmon. The streamflow required to flush sediment from the substrate is 190 cms. The discharge needed to transport sediment size which should be transported and not allowed to deposit on the stream bed (1 mm or smaller) is 70 cms. This discharge is required only when Grass Valley Creek (a tributary moving large quantities of sand) is transporting sediment to the Trinity River.

INTRODUCTION

The objective of an instream flow for restoration of the substrate is to remove undesirable accumulations of sediment deposited on and in the substrate. Gravel and cobble bed rivers are considered in this paper. Sand-bed rivers may also require a restoration streamflow. Application of these concepts to a sand-bed river are presented in Milhous (1997a). Long periods of low maximum annual streamflows can result from storage reservoir operations. These flows may cause fines and sand to accumulate on and in gravels. Sediment of all sizes can also fill pools in the river and thereby reduce pool habitat. A substrate restoration instream flow is needed to remove undesirable sediments in order to restore the physical habitat to conditions

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suitable for desirable aquatic animals. A restoration flow should be followed by periodic streamflows adequate to maintain the substrate in the desirable condition.

The analysis presented herein is applied to the Gunnison and Trinity Rivers and relates the sizes of sediment important in biological processes to the size of sediment transported as wash, suspended, and bed loads (Milhous, 1997c). The technique was used to determine the instream flows needed to maintain habitat for Colorado squawfish in the Gunnison River in western Colorado (Milhous, 1997d) and to determine restoration streamflows for the substrate of the Trinity River in Northern California (Milhous, 1996). The analytical procedure uses programs of the Physical Habitat Simulation System (Milhous et al, 1989) supplemented by programs specifically designed to do the calculations required for the analysis.

The Gunnison River has a mean discharge of 73 cubic meters per second (cms); flows of both sediment and water have been modified by the construction of reservoirs and by major diversions for irrigation (Milhous,1995). A major impact of the reservoirs has been a reduction of the capacity of the river to transport sediment. Restoration flows are needed to improve the habitat of the Colorado squawfish.

The Trinity River in northern California provides habitat for Chinook salmon. The mean discharge prior to construction of a major storage reservoir and diversions from the basin was 46.5 cms; following construction, the mean discharge is 12.0 cms. A major tributary, Grass Valley Creek, discharges large quantities of sand to the river and has caused a loss of habitat for Chinook salmon (Milhous,1996). Restoration flows are needed to remove sand from the river and to keep fines from covering spawning locations (redds).

GUNNISON RIVER

Surges of fine sediment and sand are delivered to the lower Gunnison River by tributary streams. Some of the sediment is deposited on the surface of the stream bed and some within the stream bed. The major impact of storage reservoirs has been to reduce the capacity of the river to cleanse the bed material of the fines and sand resulting in more fines and sand deposited on, and within, the stream bed than would be expected under natural conditions.

Under natural conditions, the fine sediment would most likely be removed during the next spring runoff, but with existing conditions, the sediment may not be removed because the peak flows have been reduced by storage in the reservoirs. A sediment transport capacity index (STCI) has been developed to help better understand the process (Milhous, 1995). The equation for STCI is

$$STCI = \Sigma\left[\frac{Q((Q-Qcrt)^{b-1})}{Qref^{b}}\right]$$

where Q is the measured daily discharge, Qref is a reference discharge, and b is the exponent in the power relation between sediment load and discharge. The summation is over a water year on a daily computational basis.

The relation between maximum size of sediment moved as wash, suspended, or bed load is shown in Figure 1. An analysis of the sand and fine material on the surface of the stream bed showed that almost all of the material is finer than 2 mm; based on this analysis, it is assumed the streamflow required for sand and fines removal should move 2 mm sand or finer sediment as suspended load. The streamflow required for transport of 2 mm size material is the maximum of three possible values: the flow required to suspended 2 mm material, the streamflow required to transport 2 mm material as bed load, or the flow at which the maximum size of the bed load exceeds the size of the maximum size of the suspended load. This is a streamflow of 180 cms.

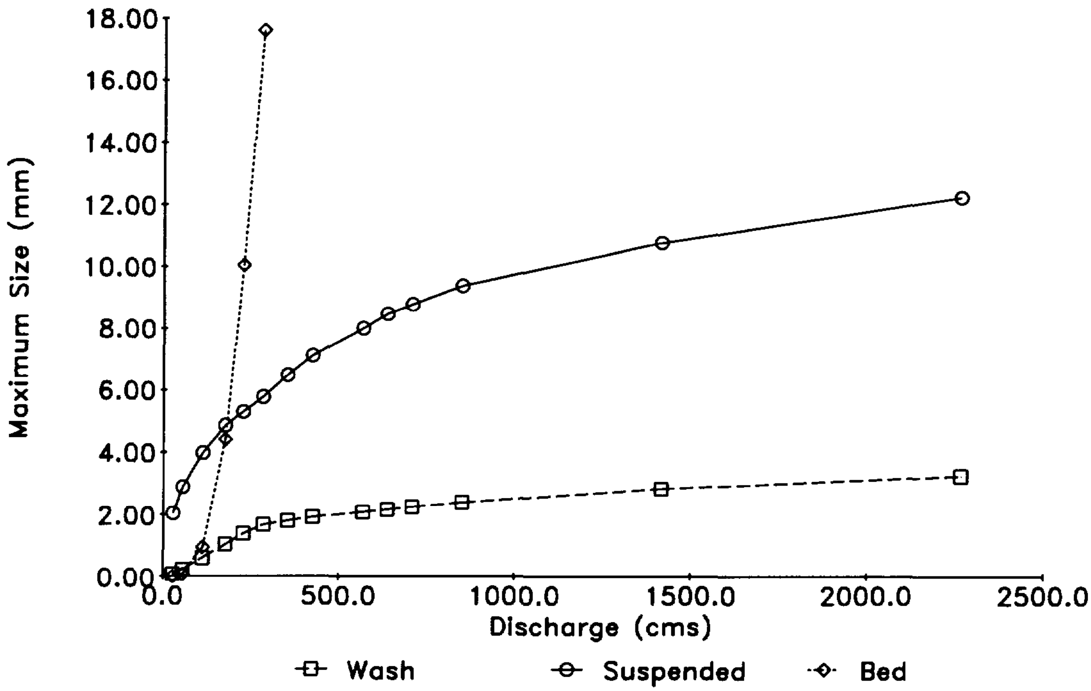

Figure 1. Maximum size of the wash load, suspended load, and bed load as a function of the discharge in the Gunnison River at the Dominguez Flats study reach.

The capacity to transport sediment was calculated using a critical discharge of 180 cms (the discharge required to move 2 mm sediment as suspended load). The computed annual STCI values are presented in Figure 2. The power term, b, is 2.0.

The reservoirs in the basin have had two impacts: 1) reduced the capacity of the river to transport 2 mm sediment, and 2) reduced the frequency of the conditions needed to move 2 mm sediment. Prior to the 1993 spring runoff the river bed was largely covered by sediment to the extent that it could not be considered habitat for any aquatic animal with a preference for gravels. The 1993 runoff did remove much of the undesirable sediment, but after that event, sediment was found at the margins of the river and on low bars. The 1993 runoff was, in effect, a restoration flow. The

1995 spring runoff completed the process of removing fines and sand from the river. There were still locations covered with sand but these existed because of local hydraulic conditions.

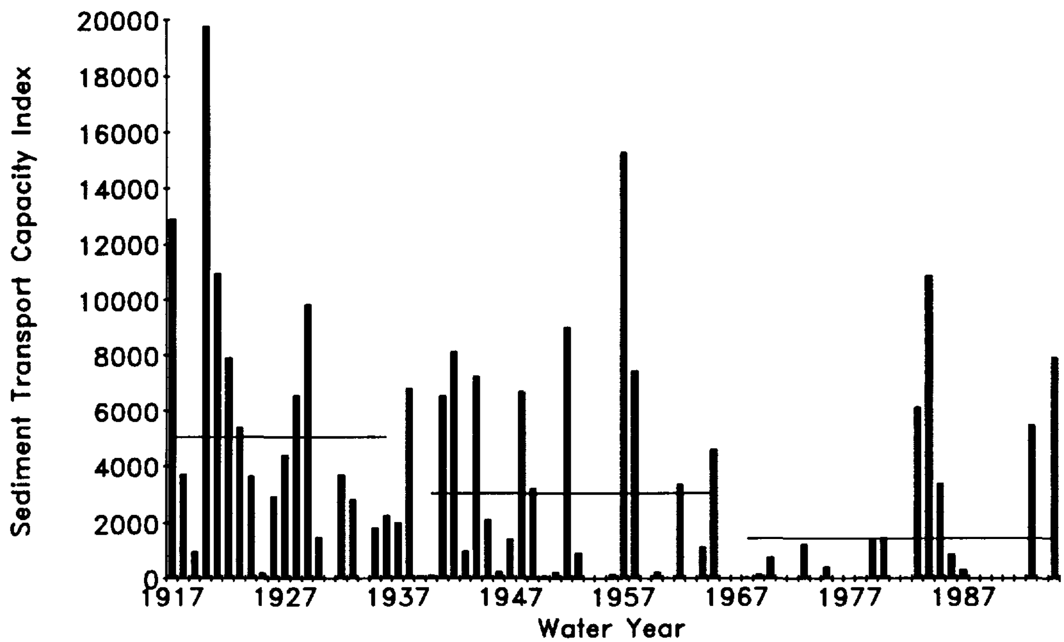

Figure 2. Sediment transport capacity index (STCI) for the removal of sand of 2 mm or smaller from the bed of the Gunnison River.

The use of 2 mm sand met only one of the possible objective of restoration flows; other objectives for maintaining Colorado squawfish habitat are presented in Milhous (1997d). These are to remove course sand and pea gravel from the riffles, remove sand from the river, remove gravel from the pools, scour side channels, and keep sand from settling in the riffles during the spawning periods (the maintenance flow). The sizes selected as target sizes for removal and deposition prevention , and a summary of the results discussed above are given in Table 1 for the magnitude of the required flushing flow. (ß is a sediment movement parameter).

Table 1. The instream flows needed to maintain habitat for Colorado squawfish Spawning in the Dominguez Flats reach of the Gunnison River, Colorado (from Milhous, 1997d).

Objective	Target Size (mm)	ß	Transport Load Mode	Required Discharge (cms)
Flush Riffles	4.74		Suspended	355
Flush River	2.0		Wash	354
Maintain Riffles	0.50		Wash	27
Clean Pools of gravel		0.021/0.016	Bed	484
Scour Side-channels	1.0		Wash	210

Frequency and duration of restoration flows are also important. A summary of the results given in Milhous (1997d) for the frequency and duration, expressed either in terms of required number of days or sediment transport capacity index for the objective, is given in Table 2.

Combining the conclusions in Tables 1 and 2, one concludes that the discharge needed to restore the river to the condition needed by Colorado squawfish varies from 210 to 484 cms depending on the objective. The overall objectives will be meet if the discharge exceeds 484 cms one in every three years with 1 in every two years having a discharge of at least 354 cms, and two in every three years having a discharge of 354 cms for at least four days. This will maintain bars in the state needed by the Colorado squawfish for spawning. A maintenance flow, required during the spawning period, should be at least 27 cms.

Table 2. The frequency and duration of the instream flows needed to maintain habitat for Colorado squawfish Spawning in the Dominguez Flats reach of the Gunnison River, Colorado (from Milhous, 1997d).

Objective	Critical Discharge (cms)	Duration (days)	Duration (STCI)	Frequency Years
Flush Riffles	355		16	1 in 3
Flush River	354	4		1 in 2
Clean Pools of gravel	484		6	1 in 3
Scour Side-channels	210		20	2 in 3

TRINITY RIVER

The Trinity River has a major tributary (Grass Valley Creek) that transports large quantities of sand to the river. The construction of reservoirs and diversions has reduced the sediment transport capacity of the Trinity River (Milhous, 1996, and 1997a). Reduced sediment transport capacity has resulted in the intrusion of sand into, and deposition over the surface of the stream bed causing a loss of Chinook salmon habitat (Williamson et al, 1993). Under natural conditions most of the sediment from Grass Valley Creek would pass downstream as suspended load; in contrast, the regulated conditions can cause the sand to pass downstream as sand waves on the bed surface (Milhous,1997b). A brief summary of the restoration flow needs of the Trinity River are presented below; see Milhous, 1996 and 1997c, for details.

The substrate must be kept free of material less than 1 mm following spawning and material less than 4 mm should be removed at intervals and must be removed from both the surface (armour) and from the substrate material below the armour (Milhous, 1996).

The maintenance streamflow required to keep sediment of 1 mm or smaller moving as suspended load through the stream is 10.2 cms and is required at all times when Chinook salmon eggs are incubating in the substrate of the Trinity River. Because of the high sediment loads in Grass Valley Creek, sediment 1 mm or smaller must be transported as wash load when the streamflows in Grass Valley Creek are large enough to transport appreciable quantities of sediment. The objective is to prevent 1 mm or smaller material from becoming part of the bed material. The discharge needed to transport 1 mm or smaller sediment as wash load is 70 cms and is required when the discharge in Grass Valley Creek exceeds 1.7 cms.

Because of the high sediment loads in the river, 4 mm or smaller sediment must be removed from the stream bed each year. The streamflow required first to remove the sediment from the stream bed and then transport it from the stream reach as suspended load is 190 cms (see Milhous ,1997c, for details).

DISCUSSION

The approach presented herein is an analytical (modeling) approach to determining the instream flows needed to restore the condition of a substrate to the state needed to support a desirable aquatic ecosystem. Two results obtained from application of the model suggest the model may give good results; these are 1) the model correctly indicates the 1993 high-water event in the Gunnison River would restore the substrate, and 2) the model correctly shows the movement of sand as bed load under existing conditions that, with natural conditions, would have been moved as suspended load (described in Milhous, 1997b).

REFERENCES

Milhous, R.T. 1995. Changes in Sediment Transport Capacity in the Lower Gunnison River, Colorado, USA. in Geoffrey Petts ed. Man's Influence on Freshwater Ecosystems and Water Use. IAHS Publication No 230. International Association of Hydrological Sciences. Wallingford, Oxfordshire, UK. pp275-280.

Milhous, R.T. 1996. Streamflows for the Management of Sediment: The Trinity River, California. in Morel-Seytoux, Hubert J., ed. Sixteenth Annual Hydrology Days. Hydrology Days Publications, Atherton, CA. pp305-316.

Milhous, R.T. 1997a. Sediment Yields from Three Western American Rivers and their Ecosystem Impacts. LOC Proceedings of Oral Presentations - FRIEND'97. Acta Hydrotechnica 15/18. University of Ljubljana. Ljubljana, Slovenia. pp137-149.

Milhous, R.T. 1997b. Reservoir Construction, River Sedimentation and Tributary Sediment Size. in D.E. Walling and J.-L. Probst, editors. Human Impact on the Erosion and Sedimentation. IAHS Publication No 245. International Association of Hydrological Sciences. Wallingford, Oxfordshire, UK. pp275-282.

Milhous, R.T. 1997c. Numerical Modeling of Flushing Flow Needs in Gravel-Bed Rivers. in P.C. Klingeman, R. Beschta, P. Komar, and J. Bradley eds. Gravel-bed Rivers in the Environment. Water Resources Publications. Littleton, CO. (in press)

Milhous, R.T. 1997d. Modeling of Instream Flow Needs: The Link Between Sediment and Aquatic Habitat. Regulated Rivers: Research and Management. (accepted).

Milhous, R.T., M.A. Updike, and D.M. Schneider. 1989. Physical Habitat Simulation System Reference Manual - Version II. Instream Flow Information Paper No. 26. U.S. Fish and Wildlife Service. Biological Report 89(16). Washington, D.C. v.p.

Williamson, S.C., J.M. Bartholow, and C.B. Stalnaker. 1993. Conceptual model for quantifying pre-smolt production from flow-dependent physical habitat and water temperature. Regulated Rivers:Research and Management 8:15-28.