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Sediment transport sampling for environmental data collection

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ABSTRACT Case histories are presented on the collection of adequate sediment samples for rivers where environmental concerns are critical. The environmental concerns are associated with improving and/or maintaining the biological properties of a river channel for fishery habitat and the desirable vegetative growth characteristics for migratory birds such as whooping cranes. The collected sediment data consist of suspended sediment samples and channel hydraulic parameters for use in computing total sediment transport by the modified Einstein procedure. Sediment data are collected for use in regulating river discharges from an upstream dam either to improve or to maintain the proper habitat characteristics. Problems associated with obtaining reliable sediment data for rivers having differing sediment transport characteristics are described.

Transport des particules sédimentaires - prises d'échantillons pour considérations relatives à l'environnement

RESUME On présente certaines cas concernant le prélèvement d'échantillons adéquats de sédiments en rivière là où les considérations relatives à l'environnement concluent à un cas critique. Il s'agit d'améliorer et/ou de maintenir les propriétés biologiques du lit fluvial en tant qu'habitat pour les poissons et de conserver également les caractéristiques de croissance végétale favorables aux oiseaux migrateurs tels que les grues. Les données obtenues sur la sédimentation comportent des échantillons de particules en suspension et des valeurs des paramètres hydrauliques du chenal fluvial servant au calcul du transport sédimentaire total, selon le procédé modifié d'Einstein. Les données sur la sédimentation sont recueillies en vue de leur utilisation pour la régularisation des débits d'une rivière à partir d'un barrage en amont, dans le but d'améliorer ou de maintenir les caractéristiques nécessaires de l'ecosystème favorable à la vie des poissons. Certains problèmes concernant l'obtention de données fiables sur la sédimentation dans des rivières à caractéristiques de transport sédimentaire différentes sont exposés.

INTRODUCTION

Changes in both the volume of water and flow patterns in river channels downstream from dams, diversion dams, and other project facilities have contributed to many environmental concerns. These concerns usually involve changes that may effect the maintenance of a desirable habitat for particular species of fish or wildlife. The habitat may be quite varied - from biological growth within the stream channel to vegetative growth on the river bank or flood plain. Sediment transport and channel morphology changes are two important factors influencing these environmentally associated channel changes. Many mathematical models are now available to compute sediment transport, and techniques have been developed to make geomorphology studies as described by Shen (1979). However, before applying any of these mathematical models or stream pattern evaluations in predicting changes, reliable field data are essential.

The type of field data needed to study existing channel processes or compute sediment transport for a channel will vary considerably depending on a stream's hydraulic and sediment transport characteristics along with the time and money available to collect and analyse the field data.

This paper describes four river channels in the USA, where sediment data were collected under the direction of the Water and Power Resources Service (formerly Bureau of Reclamation) for use in evaluating and recommending solutions to environmental problems. The four streams considered were the San Juan River below Navajo Dam in New Mexico and Utah, the Trinity River below Lewiston Dam in California, the East Fork of the Smith's Fork River in Utah and Wyoming, and the Niobrara River below the proposed Norden Dam in Nebraska.

ENVIRONMENTAL CONCERN

San Juan River

In the 293 km reach on the San Juan River below Navajo Dam, closure of the dam in 1962 produced drastic changes in the downstream channel. The river immediately below the dam was changed from a relatively warm water stream with average suspended concentration of about 3600 mg l^{-1} (suspended load of 32% sand, 43% silt, and 25% clay) to a cold and clear stream. This closure created an excellent cool water fishery.

A plan under consideration for adding a power plant to Navajo Dam may have an effect on the trout fishery. This effect may occur for some 26 km below the dam, but the first 5 km are of most concern. A data collection programme was started in 1979 to (a) obtain background data on the physical, chemical, and biological characteristics for the entire 293 km of channel, with special emphasis on the upper 26 km, (b) establish relationships between benthic invertebrates and riverine habitat, and (c) predict the effects of the proposed power plant on the physical, chemical, and biological components of potential future streamflow regimes for the entire reach.

Trinity River

Storage began above Trinity Dam on the Trinity River in 1960. Full diversions from Lewiston Dam (an afterbay structure below Trinity Dam) began in 1964, with an average of about 80-85% of flows of the Trinity River diverted from the basin. The Trinity River below Lewiston Dam has changed drastically with this decrease in releases to the channel combined with some high inflow of coarse sand-size sediments from tributary streams such as Grass Valley Creek. With this sand-gravel material (D_{50} = 2.0 mm) filling pools and covering riffles, the spawning and rearing habitat for anadramous fish on the Trinity River has been drastically altered. Since formation of a task force and work groups in 1970, many studies have been conducted and changes recommended to define and correct the Trinity River fish and wildlife resources problems.

One study initiated in 1979 was directed towards collection of sediment samples to provide a basis for determining a range of possible discharges that could be released from the dam. These discharges were to scour the sand-size materials from the channel and restore a prime fishery.

East Fork of the Smith's Fork River

The sediment problems on the East Fork of the Smith's Fork River occurred because of construction activities in the reservoir area above Stateline Dam during 1977-1978. Clearing of the reservoir area before closure of the dam in 1979 exposed sediments that were flushed through the dam and deposited in the gravel spawning reach of the river for a distance of about 9 km downstream from the dam.

The sampling programme was initiated to determine both the quantity and size distribution of deposited sediments. The samples collected were also used to verify the mathematical model used for predicting the necessary flow pattern and volume of water released from the dam that would move the deposits downstream into a reach of river where they would be less harmful to fish propagation.

Niobrara River

A 64 km reach on the Niobrara River below the proposed Norden Dam has been designated as habitat and possible feeding area for the whooping crane, an endangered species. Studies indicate that two critical features necessary for whooping crane habitat are shallow water depths and open areas free of visually obstructive high vegetative growth. The Niobrara River in this critical reach has developed extensive sand bar areas free of vegetation. These areas result from a movable bed having meandering and braided channel characteristics. Ice formations and the annual break up of numerous ice jams may also influence the lack of vegetative growth on these sand bars.

The objective of a study underway on the Niobrara River is to evaluate morphological conditions along with sediment transport so as to develop a release pattern from the proposed Norden Dam that will maintain an open channel that will provide desirable whooping crane habitat. Sediment samples are also used for a sediment transport study for predicting the potential degradation below Norden Dam.

SEDIMENT SAMPLING AND ANALYSIS

Field measurements

The sampling programme on all four rivers varied considerably, primarily because of the bed material composition. The normal sampling procedure described by Guy & Norman (1970) was only possible on the Niobrara River because the bed material (D_{50}) averaged about 0.28 mm. The sampling programme on the Niobrara River was ideally suited for a total transport computation by the modified Einstein method (Colby & Hembree, 1955) because the suspended sediment had some material <0.062 mm, but was for the most part uniformly distributed between 0.062 and 0.5 mm.

The variations in measured discharges, channel hydraulics, suspended sediment, and bed material on the four rivers are given in Tables 1 and 2.

Because of shallow depths, suspended sediment sampling at all locations on the four rivers was accomplished by use of the rod sampler DH-48 or handline DH-59, either by wading, from a small

Table 1 Measured hydraulic data

River	No. of measurements	Variation in measurements			
		Discharge ($m^3 s^{-1}$)	Width (m)	Average depth (m)	Average velocity ($m s^{-1}$)
San Juan	22	12-70	44-132	0.25-0.75	0.3-1.6
Trinity	22	8.5-62.3	21-41	0.9	0.4-1.5
East Fork of Smith's Fork	10	4.5-8.2	10-26	0.40-0.54	0.8-1.1
Niobrara	27	14.2-42.1	86-430	0.10-0.27	0.4-1.0

Table 2 Measured sediment data

River	Bed material			Suspended sediment	
	Maximum size (mm)	% of bed covered by nontransportable size	Transportable D_{50} (mm)	Conc. ($mg l^{-1}$)	Maximum size (mm)
San Juan	100	12-100	0.25	6-22 000	0.5
Trinity	8.0	0-5*	2.0	4-64	4.0
East Fork of Smith's Fork	8.0	85	0.43	27-190	1.0
Niobrara	16.0	0	0.28	170-2600	2.0

*This does not include the riffle reaches in the Trinity River where gravel and cobbles cover nearly 100% of the bed.

boat, or off a low bridge. In all cases sampling was accomplished by the equal width interval (EWI) method described in the *Journal of the American Society of Civil Engineers* (ASCE, 1975) and by the Office of Water Data Coordination (1977). The transit velocity of the sampler was uniform and depth integrated samples collected at equally spaced stream verticals across the measured cross section provided a discharge-weighted concentration. In this way a composite of all samples results in only one sample for analysis in the laboratory for concentration and particle size distribution. Suspended sediment load for the cross section sampled is computed as:

$$Q_S = \bar{C}\ Q\ k$$

where Q_S = suspended sediment discharge (t day^{-1}), Q = water discharge ($m^3\ s^{-1}$), $\bar{C}$ = discharge-weighted concentration (mg l^{-1}), and k = conversion factor of 0.0864 for sediment concentrations less than about 15 000 mg l^{-1} (this should be increased for higher concentrations).

A unique problem, not uncommon in sampling programmes associated with environmental concerns, was the bed material sampling for the San Juan, Trinity, and East Fork of the Smith's Fork Rivers. For these rivers the bed material was bimodal with gravel-cobble materials occurring in both the more quiescent reaches of the stream as well as in the riffles or rapids and sand-size sediments intermixed with the larger material. This required sampling of both types of bed material. For the sand-size bed a conventional bed material sampler is used such as the BMH-60 described by the Interagency Committee (1963) or, for wading a clam shell type sampler as shown in Fig. 1. Sampling the larger gravels and cobbles is more difficult. The more common sampling techniques are described by Kellerhals & Bray (1971).

Bed material sampling of gravel-cobble materials, as found in the three rivers cited above, was limited to either a square grid photograph, bulk sample shovelled into a bag for sieve analysis, or visual classification. The visual classification, whereby a rough estimate was made by observing the range and maximum size covering the stream bed, was possible in some studies. This approach was permitted because only low to moderate river discharges were being studied to determine either the fishery habitat or the releases from a dam for transporting the small sand-size sediments. The studies did not include any transport computations under flood conditions which would have required more refinement in sampling the coarser bed materials.

In the studies described in this report, another problem with a bimodal bed mixture is to define the per cent of area covered by the two different types of bed materials. As shown in Fig. 2, material A (sand) would require at least three to five samples across the section, while material B (gravel and cobbles) could be either sampled or visually classified. The areal extent or the *lateral and longitudinal coverage of both the sand and gravel-*cobble materials must be determined. If the example cross section shown on Fig. 2 for lateral coverage is equally representative of the longitudinal coverage, then about 40% of bed material is sand

Fig. 1 Field crew taking discharge measurement, collecting suspended samples, and collecting bed material samples on the Niobrara River in Nebraska, USA.

and 60% is gravel and cobbles.

The environmental concerns on both the Trinity River and the East Fork of the Smith's Fork River required an additional field measurement. A measure of the volume of sand material throughout the study reach required an estimate of the depth of sand overlying the gravel-cobble bed as illustrated in Fig. 2. Probings of sand depths were made to compute the volume of sand that was to be transported out of the reach.

Transport computations

The data collection programme described in this report has provided field data on the four rivers for use in verifying an appropriate mathematical model. The modified Einstein method requires a discharge measurement and a measured suspended sediment load and bed material size analysis. It was used to model the total sediment discharge. Once the total sediment discharge was determined for a specific measurement, a mathematical model with less field data requirements was selected which provided the best overall check on these computed total loads. The selected model could then be used in studies for predicting future channel changes and sediment transport under varying release discharges from an upstream dam. Although many sediment transport equations were tried, the best overall check was with the velocity-xi adjustment to Einstein described by Pemberton (1972). Some fairly good checks were made using the Ackers & White (1973) or Meyer-Peter, Müller (1948) transport equations. An example is shown in Fig. 3 of the verification necessary to support the best sediment transport model for use in the Trinity River below

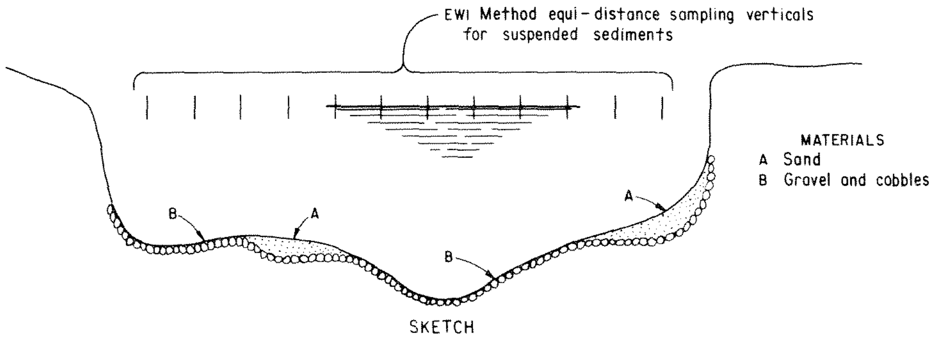

Fig. 2 Suspended and bed material sampling locations at river section for variation in bed material.

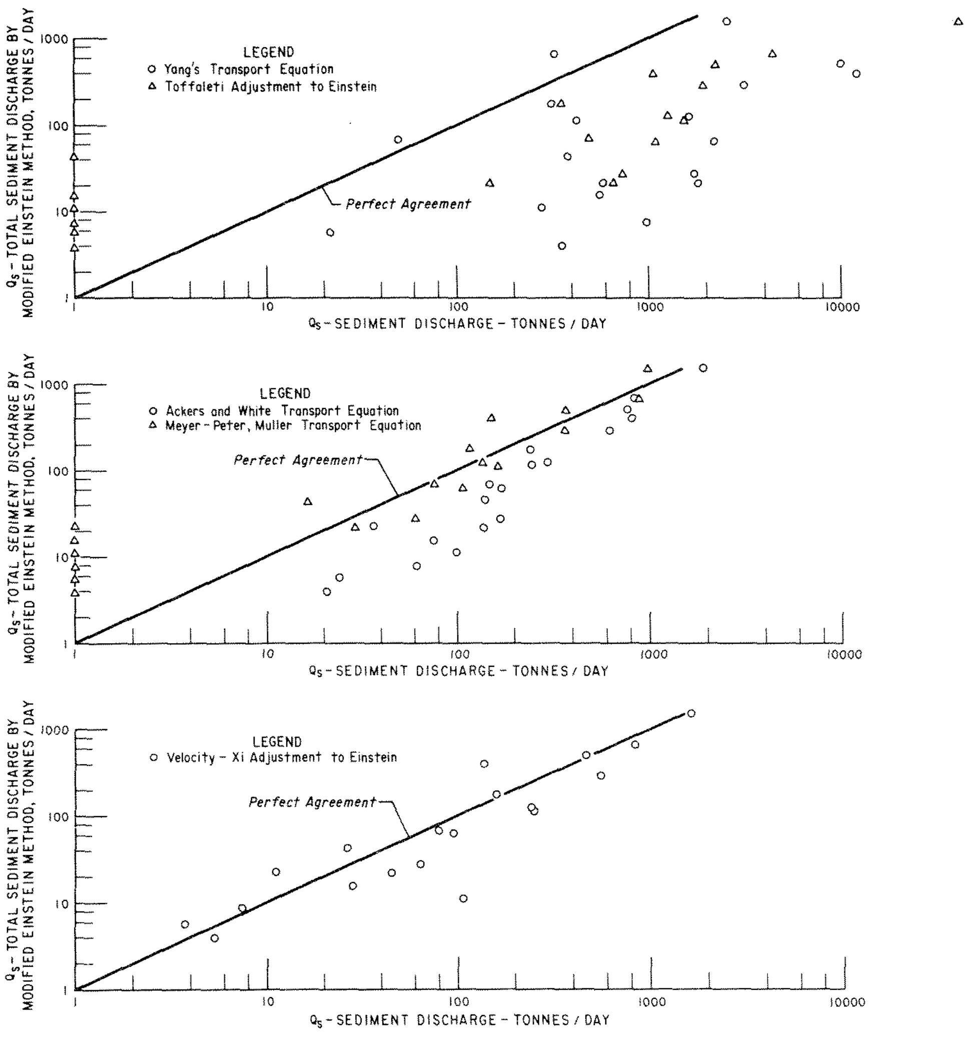

Fig. 3 Comparison of computed sediment discharge for other methods with the modified Einstein method for Trinity River, California.

Lewiston Dam in California.

One problem that may arise in using the modified Einstein method involves situations where material sampled in the stream bed is not found in suspension. In these situations, a modified Einstein computation is not possible; therefore, the total sediment discharge would be a combination of measured suspended load plus the computed bed load by an equation such as the Meyer-Peter, Müller equation.

CONCLUSIONS

A thorough understanding of the environmental concerns and their relationship to both sediment transport and channel hydraulic characteristics for a river are required before undertaking a sediment sampling programme. Once the purpose and objectives of such a programme are determined, adequate sediment and channel hydraulic data are collected to verify the mathematical model used in predicting future events or remedies to alleviate existing problems. One of the most reliable techniques is to collect data that are used in computing total sediment transport by the modified Einstein method (Colby & Hembree, 1955). This provides verification data to select the best model for predictive purposes.

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