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Measurement of suspended sediment and bed load in sand bed channels and the associated problems

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ABSTRACT Techniques used in the measurement and analyses of suspended sediment load and bed load in sand bed channels are described in this brief article. A depth integrated suspended sediment sampler and a bed load sampler can be used to collect data related to sediment transport in natural sand bed channels. Simple land surveying techniques can be used to monitor the bank erosion rates of large rivers. Some preliminary measurement of lateral movement of sediments due to river traffic are also described. Four case studies are described to illustrate the various methodologies that can be employed to measure and analyse sediment transport data in natural rivers. Some of the limitations of these methods are also discussed.

La mesure de la charge en suspension et du charriage de fond dans les lits de sables, et les problèmes qui y sont associés

RESUME Ce bref article décrit des techniques untilisées pour la mesure et l'analyse des matériaux en suspension et le charriage de fond dans les lits de sable. Un appareil à prélèvement pour les matériaux en suspension et un autre appareil pour le charriage de fond peuvent être utilisées pour recueillir les données relatives au transport de sédiments dans les lits des fleuves naturels. Des techniques topographiques peuvent être utilisées pour surveiller l'érosion des rives dans les grands fleuves. Des mesures préliminaires des mouvements latéraux des sédiments pour le trafic fluvial sont également décrits. Quatre études de cas étaient utilisées pour illustrer les méthodologies qu'on peut utiliser pour mesurer et pour analyser les données du transport des sédiments dans les fleuves naturels. Les limitations de ces méthodes sont également discutées.

INTRODUCTION

The erosional nature of the basin, the hydraulics of flow, and the sediment transport characteristics of the stream are some of the basic phenomena that determine the geometric, plan form, and shape of the watershed and the conveying channel. Any change in any one of these main components will alter the other components of the whole basin including the stream itself. Basic understanding of these various components requires not only a clear knowledge of the laws of nature but also the availability of some precise field data. These help researchers to test and verify the theoretical models.

This paper will be confined to some specific case studies where the erosion rates of the basin and the stream, sediment transported by the stream, and the movement of the sediment in the lateral direction due to river traffic were measured and analysed. The theoretical background as to the erosion and sediment transport characteristics by natural and artificial streams was discussed by the American Society of Civil Engineers (1975), Simons & Sentürk (1977), and many others.

In each of the case studies, actual field data were collected or are being collected. Attempts were made to utilize standard field techniques. However, in some cases, innovative ideas had to be applied to gather data that will be useful in the long run. Some of the problems faced in the measurement of erosion and sediment transport are also discussed under each specific case study. The case studies that will be discussed are: sediment transport in the Kankakee River, bank erosion of the Illinois River, lateral movement of sediment due to river traffic, and suspended sediment measurement at gauging stations.

CASE STUDIES

Sediment transport in the Kankakee River

The Kankakee River is one of the major rivers of Illinois and Indiana in the midwestern part of the USA. The drainage basin of the Kankakee River and locations of gauging stations are shown in Fig. 1. The river drains a 1.33×10^4 km^2 area of which about 58% is in Indiana and the remaining 42% in Illinois. Sediment transport rates and water discharges were measured at Illinoi, State Line Bridge on the Kankakee River, Momence, Iroquois River at Iroquois and Chebanse, and the Wilmington gauging stations.

The suspended sediment samples were measured with a DH-59 depth integrated suspended sediment sampler. The operation and description of this sampler is given by Guy & Norman (1970). This sampler collects a mixture of water and sediment which enters the sampler at the same flow velocity as that of the surrounding water. The operator must be trained to be aware of the constraints on this sampler. The sampler is lowered and retrieved at a constant rate where samples are to be collected, and this rate of motion should not be more than 60% of the flow velocity in the stream.

For all stations except the ones at Illinoi and State Line Bridge, daily suspended sediment samples and water discharge data were measured. For the other two stations, biweekly samples were collected. The other data that were collected are bed load samples from the Chebanse, Iroquois and State Line Bridge stations. A Helley-Smith sampler, as described by Helley & Smith (1971), was used to collect these samples. This bed load sampler was designed to collect coarse bed load where the median diameter (D_{50}) varies from 2 to 10 mm in size. Since the bed materials of the main stem of the Kankakee River are basically

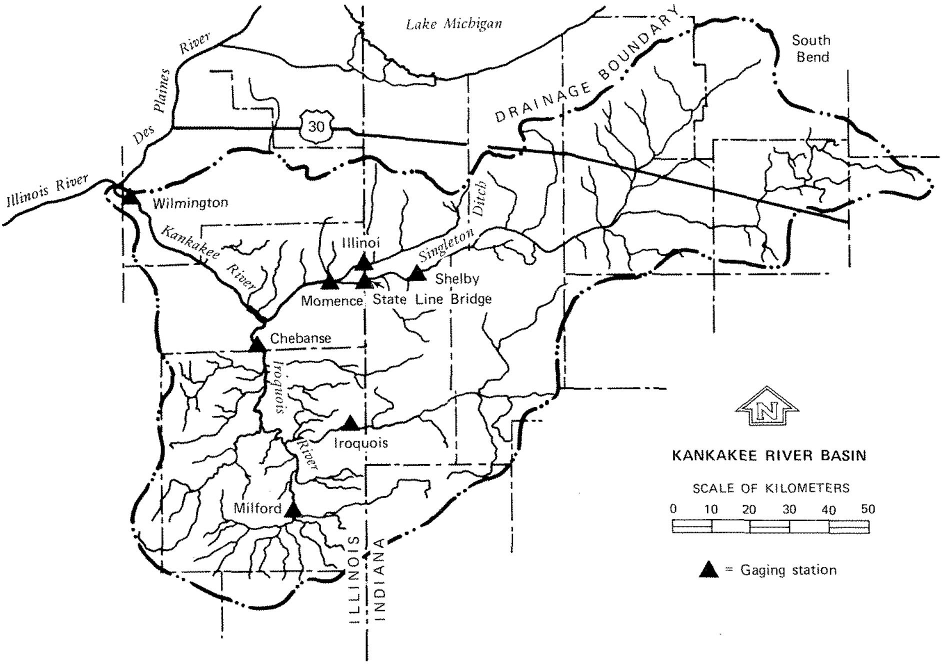

Fig. 1 Drainage basin of the Kankakee River and associated gauging stations.

sand, this sampler was used with considerable caution. Bed load data collected from a sand bed channel with this sampler may not be very satisfactory, since the sampler weighs about 29.5 kg and it may sink on the soft sand and thereby collect a biassed sample.

Another way of measuring the bed load is to monitor sand bar movement. One such sand bar was monitored continuously at the State Line Bridge and it was found to be moving about 450-600 mm a day.

The antecedent conditions in the basin, the meteorological constraints, the flow volume and many other factors determine the sediment transport in a natural stream. Many times, the river may be carrying the maximum water discharge, but not necessarily the maximum sediment load. To illustrate this point, Fig. 2 shows that the maximum water discharge for the Wilmington station occurred in early March of 1979, whereas the maximum sediment load carried by the river occurred in April 1979. Thus it is often hard to develop a direct correlation between sediment load and water discharge.

In some instances, sediment load and water discharge do correlate well. On the same river basin, at the upstream gauging station of Momence (Fig. 1) the water discharge and the sediment load correlated extremely well as is seen in Fig. 3. Here as the water discharge peaked, so did the sediment load. Thus a direct correlation between water discharge and sediment load can possibly be developed for this station.

The two different results shown in Figs 2 and 3 illustrate amply that sediment transport data must be collected over a

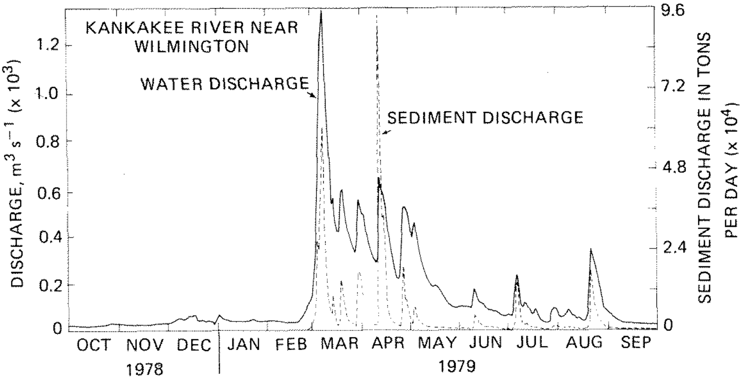

Fig. 2 Suspended sediment load and water discharge *vs.* time in days for the Kankakee River at Wilmington.

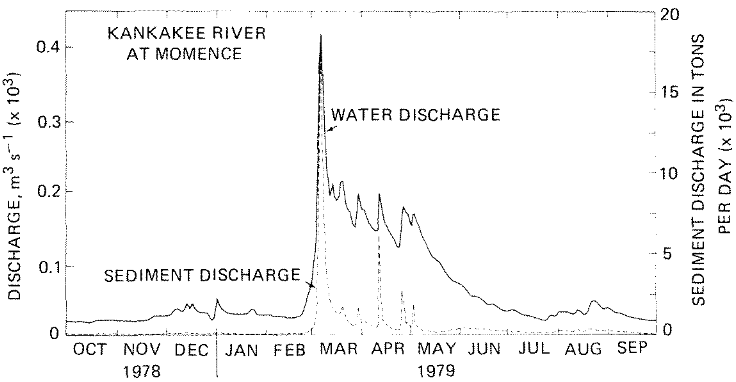

Fig. 3 Suspended sediment load and water discharge *vs.* time in days for the Kankakee River at Momence.

period of time, ranging from 10 to 20 years. This should cover most of the variabilities in the basin, in the stream regime and the climatic conditions. Interpretations and conclusions based on data collected for a short duration can be not only misleading but also wrong.

For the data collected at all the gauging stations, attempts were made to develop exponential relationships between the water discharge Q_W and the sediment load Q_S. In some instances these relationships were very good and in other instances correlations were poor. Sand bed channels carry sediment load based on the availability of the sediment. A comparison of the mean monthly suspended sediment yield in tonnes per square kilometre with mean monthly water yield in tonnes per square kilometre indicated a wide range of variability between the sediment yield and the water yield from one month to the next. During spring when most of the midwestern streams are in flood, the sediment yield per unit basin area for the same water yield was much higher than that present during the fall or winter. Thus another variability in the sediment transport measurement that should be considered is the season of the year and the relative magnitude of the precipitation.

Another characteristic of the sand bed channel is the type of sediment carried by the river at various times of the year. An analysis of the particle size distribution of the suspended sediments indicated that at most gauging stations during the spring flood the composition of the suspended sediment was mostly sand. Whereas during late summer and fall, the river basically carried silt, clay and small quantities of fine sand for the same relative flow in the river.

The bed load data measured by the Helley-Smith sampler indicated that occasionally, on a single day during the flooding season, the bed load can be as much as 40% of the total sediment load. But on an annual basis, the bed load was less than 5% of the total sediment load.

For this particular sand bed river, the bulk of the bed load moved as a sand bar. The movement of this sand bar appears to be an annual phenomenon. This may be true for other sand bed channels.

Research conducted on this project was published by the Illinois State Water Survey as *Report of Investigation 98*. For further information readers are referred to the work by Bhowmik *et al.* (1980).

Bank erosion of the Illinois River

The second case study described here relates to the measurement of bank erosion rates of the Illinois River. The detailed results of this investigation have already been reported by Bhowmik & Schicht (1980). The Illinois River, one of the major waterways of the USA, drains about 7.5×10^5 km^2 and carries tremendous amounts of river traffic.

The banks of the river have been eroding at many places. Data related to bank materials, eroded bank slopes, and present plan view of the eroded banks were collected from the field. These basic data were incorporated with hydraulic data, such as flow velocity, water depth, and bed and bank slope, to test the stability of the banks for variable discharges. As a result of this analysis, it was observed that the banks of the Illinois River should be stable as far as the ordinary flow conditions are concerned; however, the same bank with its present bank materials will be unstable against wind-generated wave action.

In the measurement of the bank erosion process, it was observed that one method that can be used successfully is to measure the eroded bank slopes at a few cross sections and then to survey the eroded bank along the selected reach. This information can subsequently be used to check the rate of erosion of the banks. For the Illinois River investigation, 20 reaches of the river ranging in length from 1 to 2 km were surveyed, bank slopes were measured at three to six locations for each reach, and this information was stored. Plots showing the bank slopes at two reaches of the river are given in Fig. 4. As can be seen, the banks can have either a single slope or two different distinct slopes at various locations. In the next few years, the same reaches of the river will be resurveyed to measure the rates of erosion of the banks at those selected 20 reaches of the river.

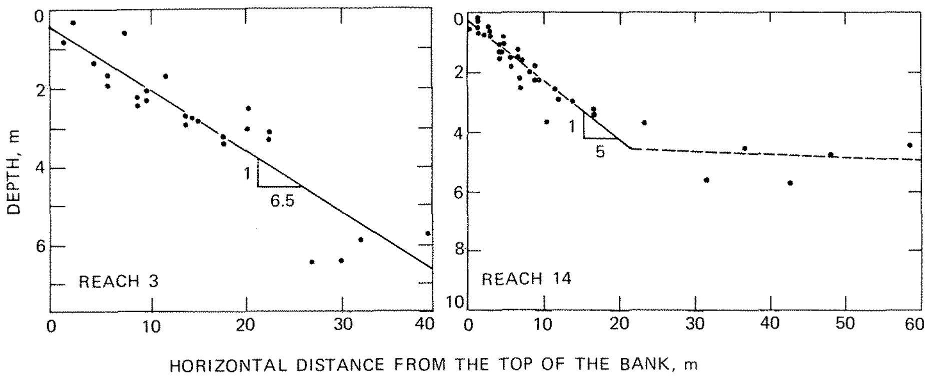

Fig. 4 Typical plots showing bank slopes.

Lateral movement of sediment due to river traffic

The sediment load carried by a river normally moves in the downstream direction. This is generally true unless some external constraints are imposed on the system which can change this normal mode of movement of the sediment particles. One such condition that is imposed on a waterway which carries commerical traffic is the movement of tows with barges. On the Illinois and Mississippi Rivers, barges with 2.7 m drafts, 32 m width, and 366 m length move at a speed of about 12 to 13 km h^{-1} Such river traffic can displace a tremendous amount of water and will disturb the bed and banks of the sand bed rivers. It is suspected that the bed materials are resuspended, moved in a lateral direction and may even be deposited in the backwater areas along these rivers.

The Illinois State Water Survey is currently investigating several aspects of this phenomenon. Some data related to the lateral movement of sediments have already been collected. A brief description of the techniques followed is given here. Depth integrated suspended sediment samples were collected from boats at two or three different locations along a cross section of the river right after the passage of a tow with barges. A DH-59 sampler (Guy & Norman, 1970) was used to collect these samples. One of the sampling boats was aligned to the track of the barge and two other boats were aligned between the shore and the barge track with one boat staying close to the shore. Data were collected continuously for the whole day with frequent sampling right after the passage of the tow with barges.

Most of the sediment samples measured in the field have been analysed and some of the results are shown in Fig. 5. On that particular day, four barges passed the measuring section. Three of the barges moved in the downstream direction and one moved in the upstream direction. The background suspended sediment concentration was about 60 mg l^{-1}. With the passage of the first barge, this concentration increased to about 500 mg l^{-1}. After the passage of four barges, the background sediment concentration had increased to about 90 mg l^{-1}.

The results shown in Fig. 5 are preliminary. More data are being collected and will be analysed before any definitive

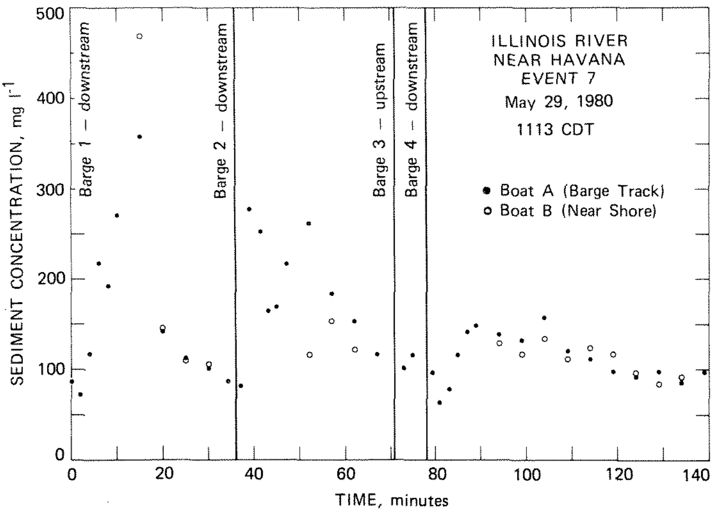

Fig. 5 Increased suspended sediment concentration due to river traffic.

statement can be made. However, this analysis indicates that the measurement of sediment load in large rivers carrying commercial traffic can be biassed if the time, frequency and duration of the river traffic are not taken into consideration before, during and after the measurement of the suspended sediment load.

Thus it appears that it is quite feasible to measure the lateral movement of suspended sediments due to river traffic using standard sediment sampling equipment. However, in large rivers where the depth of water is more than 6 m, the DH-59 sampler cannot be used to collect suspended sediment samples below a water depth of about 5.5 m. A point integrated sampler similar to the P-61 (Guy & Norman, 1970) must be used to measure the suspended sediment concentration below 5.5 m. Data at these depths will be collected by the Illinois State Water Survey for the present project.

Suspended sediment measurement at gauging stations

The last case study to be described relates to the measurement of suspended sediment at regular intervals in streams and rivers. Such data are essential to monitor the sediment movement, to identify the areas of the basin where excessive basin erosion is present, to check the effectiveness of management practices on the basin and to formulate the future courses that must be taken to better utilize this natural resource.

Data collected and analysed for the Kankakee River research project by Bhowmik *et al.* (1980) indicated that in order to best quantify the sediment transport rates in midwestern rivers of the USA, sediment samples should be collected from a gauging station at least weekly and more frequently during the flooding season. For the Kankakee River basin it was observed at various gauging stations that about 70-90% of the total yearly suspended sediment load passed the stations during the flood season within a period of about 60-90 days. Thus, considerable saving in data collection can be attained if the frequency of sampling is varied on the basis of the flow conditions in the river.

At present, the Illinois State Water Survey is monitoring the suspended sediment transport rate at 50 gauging stations around the State of Illinois where depth integrated suspended sediment samples are being collected. The DH-59 depth integrating samplers are being used. In collecting suspended sediment samples, on a regular basis, only one depth integrated suspended sediment sample is collected near the centre of the stream. Then, generally once a month about 10-12 samples are collected across the width of the stream to calibrate the single sample that is collected regularly. This technique was found to work very well in the Kankakee River project.

Collection of sediment transport data is expensive and time consuming. It requires some capital investments, and the field personnel must be trained, must be knowledgeable about the sediment sampler and the gauging equipment, and should have some background on fluid mechanics. The field technique must be mastered before the field technician is allowed to go to the river to collect samples. Sediment transport data without flow data are almost useless. Therefore, both the sediment transport data and the flow record data should be collected simultaneously for any field data collection programme. In the case of sand bed channels, extra precautions must be taken to keep the sampler from resting completely on the bed of the stream, or a biassed sample may be collected which will not be representative of the sediment transport rate of the stream.

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