MODELING RESERVOIR SEDIMENT EROSION BY FLOODS FOR ASSESSING THE EFFECT OF UNCERTAINTIES AND VARIABILITY OF INPUT PARAMETERS

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ABSTRACT

To cope with the uncertainty and the effect of the variability of input variables or parameters, it is necessary to use stochastic concept to assess the uncertainties and to improve the reliability of the modelling results. It could be done by integrating the stochastic concept into a deterministic model.

A one dimensional flow and sediment transport model was applied to a lock-regulated river section to study the effect of the variability of hydrograph and critical shear stress for erosion on sediment erosion. The joint effect of the peak flow charge and the hydrograph course leads to the scattering of the calculation results. The range could even amount to 10000 tons, when the variability of the critical shear stress of erosion is added. A statistical analysis of the calculation results give a reference interval, in which the uncertainties of input variable and parameter are involved.

1. INTRODUCTION

Flood protection is a major task of river management. Morphological changes, environmental impacts and economic loss due to flood events are concerned. To deal with these problems, numerous models have been developed to describe the effect of flood events on river morphology, sediment transport and water level. But most of the models are deterministic and cannot account for the uncertainties involved in the input variables and model parameters. The results often shows a wide spreading of the predicted results. Therefore, it is necessary to assess the uncertainties and to improve the reliability of the modelling results. Most stochastical approaches use probabilistic distributions of the input variables and model parameters for uncertainty assessment. In most cases, the number of data sets is often not sufficient for determining the probabilistic distribution, or the data even could not be described with a distribution function. An integration of the stochastic concept into a deterministic model provides an useful alternative to cope with most important uncertainties.

In this work, two governing parameters are regarded as stochastic. One is the hydrograph and the other is the critical shear stress of erosion ($\tau_{c,E}$). The influence of the two variables on the sediment transport will then be assessed by applying a one dimensional flow and sediment transport model (Kern and Westrich, 1996) to a 11 km lock regulated river section.

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2. METHODOLOGY

2.1 Data Set

Two field studies of the sediment erosion were made 1997 and 1998. 29 Sediment cores were taken for examining the stability of the sediment against erosion. Totally, 460 data of the critical shear stress of sediment erosion are then available.

Each value of the collected data is regarded as an independent random sample. The non-parametric bootstrapping method (Efron and Tibschirani, 1993) can yield the mean of those data which distribution is unknown or approximate the real mean of the variable on the base of the collected sample. Thus, a certain number bootstraps of the sample mean of the collected field data were produced. The bootstrapped sample means were Each bootstrapped sample mean is assumed to be the mean critical shear stress of erosion of the whole sediment in the river section, and was set the function (eq. 1) suggested by Kuijper et al. (1989) for calculating erosion rate (E),

$$E = M\left(\frac{\tau_0 - \tau_{c,E}}{\tau_{c,E}}\right)^n \tag{1}$$

where M=erosion coefficient, τ_0=shear stress, $\tau_{c,E}$=the critical shear stress for erosion, n=empirical constant. M and n were regarded as constant and set to be 7.5×10^{-4} kg/m^{2}s, 3.2 respectively.

A measured series of discharge from 1950 to 1994 are available for numerical simulations. The inflow concentrations of the suspended sediments corresponding to the discharges were calculated using an experimentally determined power law function (Kern, 1997). A field study of flood event from 28th Oct. 1998 to 4th Nov. 1998 provided another measured series of discharges and corresponding sediment concentration from experimental analysis of water samples (Haag et al., 2002).

2.2 Numerical Simulation

The effect of the variability of hydrograph and critical shear stress of erosion on the sediment transport is investigated in three cases.

Case 1. 50 long term simulations were carried out for a period of 45 years using the measured discharges from 1950 to 1994. A varied value of critical shear stress of erosion was given for each simulation. The critical shear stress of erosion was assumed to be temporal and spatial constant.

Case 2. 50 simulations were carried out for the flood event from 28th Oct. 1998 to 4th Nov. 1998 using the measured discharges during the flood event. A varied value of critical shear stress of erosion was given for each simulation. The critical shear stress of erosion was assumed to be temporal and spatial constant.

Case 3. 50 bootstrap samples of critical shear stress of erosion were generated using bootstrap sampling. Each bootstrap sample consisted of varied values drawn with replacement from the collected data. Each value is allocated to a profile. 50 simulations were carried out for the flood event from 28th Oct. 1998 to 4th Nov. 1998 using the measured discharges of this period and 50 bootstrap samples of critical shear stress of erosion.

3. RESULT AND DISCUSSION

3.1 Case Study of Long Term Simulation

Four flood events in the period from 1950 to 1994 are chosen to assess the effect of the variability of hydrograph and critical shear stress on sediment erosion. The duration of each flood event is 10 days.

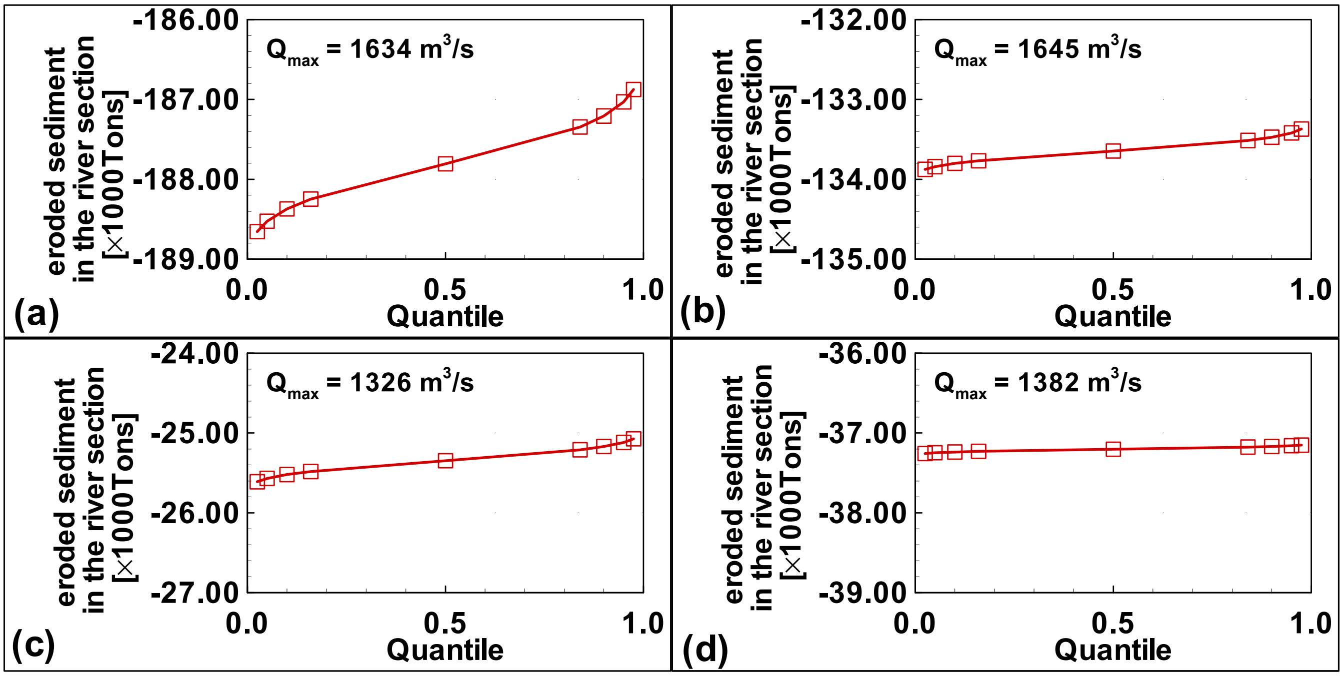

Figure 1 Calculated eroded sediment for chosen flood events with varied critical shear stress of erosion

Fig 1 shows the calculated quantiles of eroded sediment for the four chosen flood events respectively. The eroded sediment is the difference between the total amount of sediment before and after the flood event. Q_{max} means the peak flow rate of the flood event. Flood (a), (b) have higher peak flow rate than (c), (d), and have eroded much more sediment. The gradient of the line suggests an obvious effect of the variability of critical shear stress of erosion. The diagram of flood (a) has the largest gradient among the four diagrams in Fig 1. The calculated results spreads over 2000 tons. It could be inferred from Fig 1 that the peak flow rate has significant influence on the sediment transport. A comparison between flood (a) and (b) shows that the both flood events have almost the same peak flow rate, but flood (a) has eroded about 53000 tons more sediment then (b). The fact results from the course of the flood event. Fig 2 depict the courses of flood event (a) and (b). Flood event (a) has a longer phase of higher discharges. The joint effect of peak flow rate and the duration of the phase of higher flow rate is determined for the erosive impact on the sediment transport.

3.2 Case Study of Flood Event in 1998

In this section, the effect of the variability of critical shear stress of erosion on the sediment erosion will be further investigated according to case 2 and case 3 described in section 2.2. The results are illustrated in Fig 3.

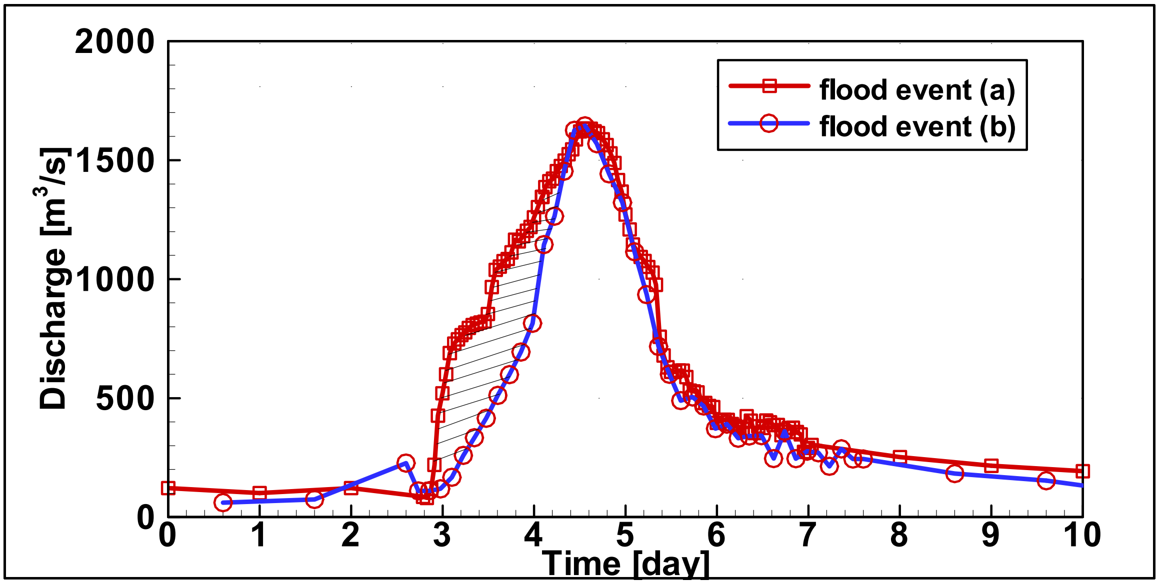

Fig 2 Courses of chosen flood events

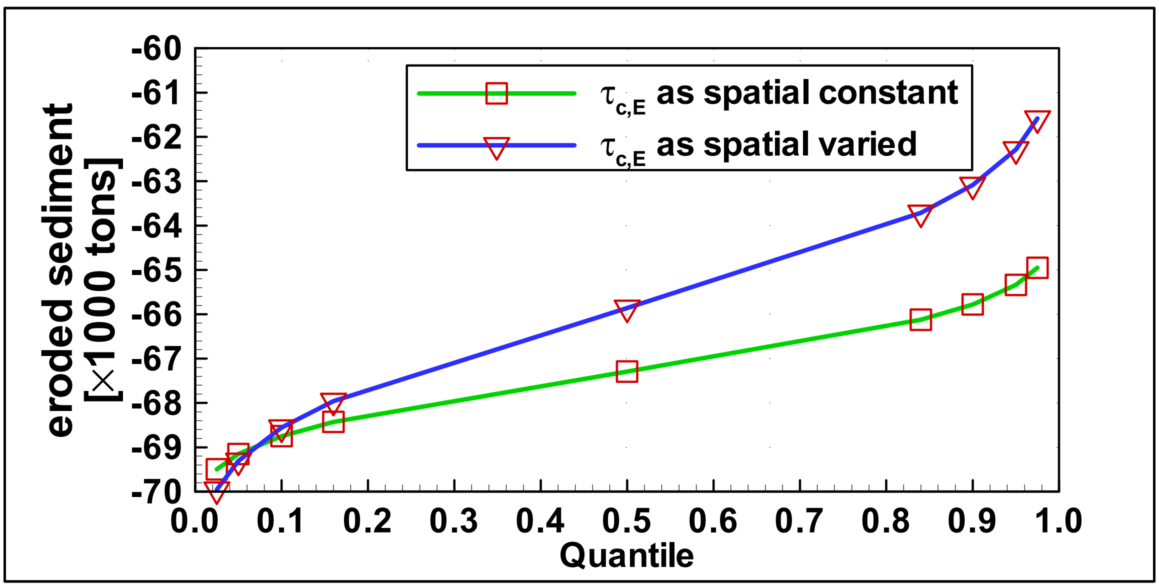

Fig 3 Quantile of calculated eroded sediment through flood event 1998 with a peak flow rate of 1055 m^3/s: (a) $\tau_{c,E}$ as spatial constant and (b) $\tau_{c,E}$ as spatial varied.

The result suggests that the flood event has eroded about 60000-70000 tons sediments. In comparison to flood events (c) and (d) in Fig 1, more sediment is eroded through flood 1998 even though it has lower peak flow charge. It is also because of the flood course. Almost all of the measure data of discharges are higher than 600 m^3/s which is defined as critical discharge of erosion for the studied river section (Kern 1997).

The calculated eroded sediment in both case spread over a wider range. In case of simulations assuming the critical shear stress of erosion to be spatial constant, the range is about 5000 tons. The range is about 10000 tons if the critical shear stress is assumed to be spatial varied. The gradient of the line for the case of spatial varied critical shear stress is apparently larger than the other case.

The discussion above points out the influence of the spatial variability of critical shear stress of erosion on sediment erosion. The difference of the results could reach about 4000 tons.

4. CONCLUSION

In the presented work, the integrated concept of deterministic and stochastic concept provides an approach to assess the influence of the variability of input variable or parameter. The bootstrap method is a effective method to treat the field data especially when there are limited number of data available or there is no information of the uncertainties of the data.

The effect of the variability of the hydrograph and critical shear stress of erosion were investigated. Generally, hydrograph is the more significant factor of sediment erosion. The amount of eroded sediment is related to the peak flow rate. Sediment erosion could be intensified through the joint effect of peak flow rate and the flood course.

The critical shear stress alone doesn't have apparent effect on sediment erosion. Its influence is apparent under certain hydrological conditions such as the joint effect of peak flow rate and the course of hydrograph in the presented work.

As what the diagram (a) of Fig 1 and Fig 3 show, the joint effect of peak flow rate and the hydrograph also lead to the spreading of calculated results. The range will be wider when the spatial variability of critical shear stress is added. In the studied case, the calculated eroded sediment spread over a range of 10000 tons.

The applied concept gives a reference interval of the eroded sediment. The reference interval involves the unknown uncertainty of the input parameter and could be useful for river management when it is combined with optimization models such as cost-benefit analysis model.

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