STREAM SEDIMENT TRANSPORT AND ASSOCIATED WATER QUALITY MODELING

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Abstract. Stream sediments act as sources and sinks for some nutrients and thus may affect stream water quality. In addition, sediment transport processes also affect the fate of the nutrients. A mathematical model is developed to quantify the effect of sediment transport on nutrient concentration changes. The model is being developed in 3 stages: hydraulics, sediment transport, and nutrients recycling. Data collected on the Oconee River have been used to calibrate the first two stages (hydraulics and sediment transport) of the model. Encouraging results were obtained.

INTRODUCTION

Sediment transport is an important and interesting feature of a river and has been studied for more than a century (Simons 1992). Many of the past investigations conducted in the field of civil engineering focused on sediment transport rate under steady state hydraulic conditions (Yang 1996, Simons et al. 1992, Rijn 1984a, b, Graf 1971, Einstein 1950). Modeling approaches were adopted in the simulation of river channel morphological changes caused by sediment transport. However, few of these engineering-oriented models incorporate water quality constituents in them (Chang 1988, US Army Corps of Engineers et al. 1996).

On the other hand, although many of the existing water quality models consider sediment nutrient a phase of nutrient and incorporate components that deal with nutrient exchange between sediment and the water body, almost none of them has the capacity for simulating sediment transport (Bowie et al. 1985).

Van der Perk (1996) studied the role of sediments during flood events by analyzing the observed behavior of dissolved nutrients and suspended sediments. He considered that phosphorus and nitrogen were removed from solution by biomass uptake and adsorption to bed and suspended sediments, and released from interstitial water between bed sediments by entrainment.

In the present study, a mathematical model incorporating open channel hydraulics, sediment transport, and sediment-nutrient interaction has been developed. The first two stages of the model were tested against available field data. Upon successful calibration and verification, the model may be used in engineering practice and policy- making regarding river management.

FIELD METHOD

1. The Oconee River

The reach between Barnett Shoals dam and USGS gauging station (02218300) near Penfield was selected as the case study reach. Barnett Shoals dam is a hydropower facility operated by Georgia Power Co. It is located south of Athens and down-stream of the confluence of the North Oconee River and the Middle Oconee River. The USGS station at Penfield is approximately 17 km down-stream of Barnett Shoals dam.

Immediately above the Barnett Shoals dam, equipment was set up to measure the hydraulic head over the spillway. The hydraulic head was converted to discharge later using a rating curve obtained from historical flood records. An attached data logger recorded readings at 15 minute intervals. An ISCO sampler was set up to collect surface water samples for laboratory analysis of suspended sediment and nutrient contents. The samples were taken every 4 hours on week days and every 8 hours on weekends.

Gauge levels were measured at the USGS Penfield gauging station and posted on the Internet by USGS. Another ISCO sampler was set up at Penfield. Samples were taken with the same frequency as at Barnett

Shoals dam and were also retrieved to the lab-oratory for analysis.

On a daily basis, the samples were taken back to the School of Forest Resources for suspended sediment content analysis. A gravimetric method was used to determine the content of suspended sediment. The samples were then analyzed in the Environmental Process Control Laboratory (EPCL) for nutrient content analysis (Beck and Liu 1998). In the EPCL, total organic carbon, ortho-phosphate, ammonium, nitrite, and nitrate etc. were measured. The data were logged into a laptop computer.

The morphological information was provided by USGS Georgia district and previous work done by U.S. Army Corps of Engineers (US Army Corps of Engineers 1977). Some assumptions were made with regard to the cross-section morphology, because such data are not available.

2. The Weihe River

A second high quality and comprehensive data set was used to calibrate the model's hydraulics and sediment transport stages. The studied reach is a 77.4 km long reach along a major tributary of the Chinese Yellow River, which is known for its extremely high sediment content. Hydrologic data sets (discharge, gauge level, suspended sediment concentration, sediment particle-size distribution, and river morphological changes etc.) were collected on a regular basis, at the upper end (Lintong gauging station), the middle (Weinan gauging station), and the lower end (Huaxian gauging station) of the reach, by the Water Resource Committee of the Yellow River. Data were collected every 4 or 5 days during regular flow conditions, and were collected several times a day during high flow (or high sediment content) conditions. Data of a 20-day period, taken from the 1973 Chinese Hydrologic Yearbook, were chosen because of the extreme hydrologic conditions presented.

MODELING APPROACH

The model has a 3-stage structure. In the first stage, one-dimensional open-channel hydraulics is investigated. Hydrodynamics are solved using information of geomorphology and upstream hydraulic conditions. The second stage calculates sediment transport under non-equilibrium hydraulic conditions. Phosphate and nitrogen recycling in the water body and suspended and bed sediment will be simulated in the third stage.

In the first stage of the model, a St. Venant equation system, which is the combination of the equation of mass conservation and the equation of momentum conservation, is solved numerically using a Preissmann Scheme.

In the second stage, sediment transport potential is computed using van Rijn's (1984a,b) approach. Based on the resulting potential and the upper boundary condition for sediment transport, the actual suspended sediment concentration is computed using a revised version of a simplified solution for the suspended sediment convection-diffusion equation (Zhang, 1983). The resulting equation has several parameters to be determined. In order to assess the quality of a simulation, an objective function (sum of squared differences between the simulation and the observation) is formed and evaluated for different parameter values. The parameter set that gives the minimum objective function value is considered the best. In the present study, a con-trolled random search procedure has been used to minimize J (Price 1979).

In the third stage, the suspended sediment is considered a sink for dissolved nutrients. Erosion releases nutrients from interstitial water, which is considered a source of the nutrients. Biomass uptake is considered a sink. This stage of the model is still being tested and associated results were not presented in this paper.

RESULTS AND DISCUSSION

The Yellow River data were used in testing the hydraulics and sediment-transport stages of the model. Observed and simulated discharges at Weinan gauging station (in the middle of the reach) were compared (Figure 1). Observation and simulation of gauge levels at the same station were also presented (Figure 2).

Suspended sediment concentrations under the non-equilibrium hydraulic condition were computed. Observed and simulated suspended sediment concentrations were compared (Figure 3). It is reasonable to say that the model performed well in simulating open channel hydraulics and suspended sediment transport.

The first two stages of the model were then applied to the Oconee River. Observed and simulated suspended sediment concentrations at Penfield station were presented (Figure 4). Some discrepancies were shown in the plot, although the simulation followed the observed trend reasonably well.

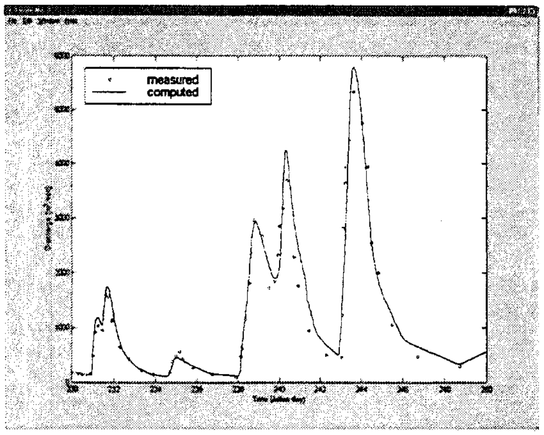

Fig.1 Discharge at Weinan gauging station.

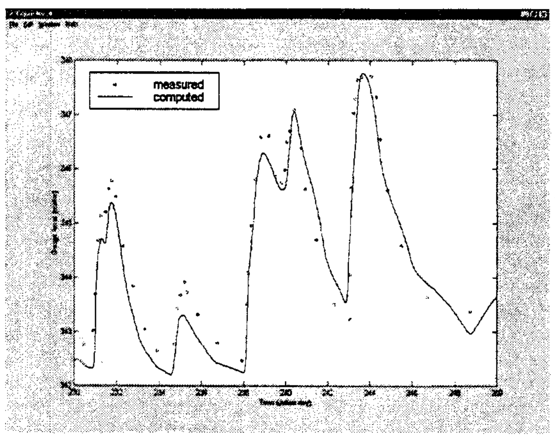

Fig.2 Gauge levels at Weinan gauging station.

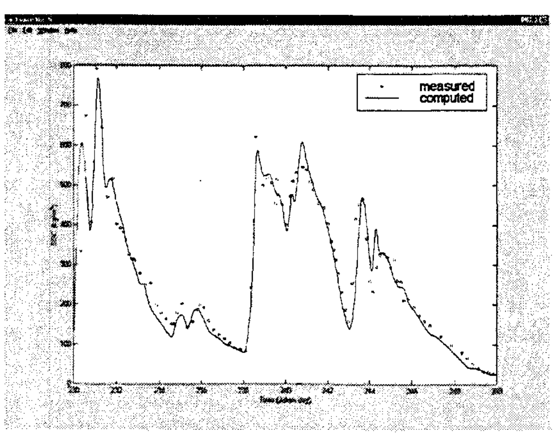

Fig.3 SSC at the Weinan gauging station.

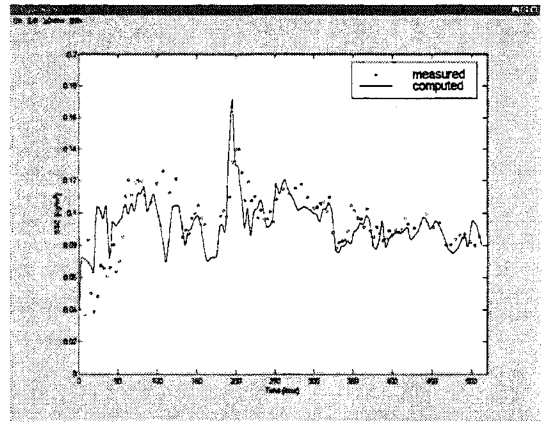

Fig.4 SSC at Penfield USGS gauging station.

Further application of the model's first two stages may reveal interesting features of the studied reaches, like the deposition and entrainment characteristics under different hydraulic conditions and upstream sediment load.

The first two stages of the model provide the basis for the building of a nutrient recycling stage of the model, which is now under development.

CONCLUSION

The first two stages of the model has been tested against field data and performed well. It is reasonably to say that these stages of the model are successfully developed and that they provide a solid basis for the further development of the nutrient-recycling stage.

Upon successful calibration and verification of all three stages, the model is expected to be able to simulate nutrient transport changes caused by different hydraulic conditions, sediment transport, and the allocation and operation of wastewater treatment plants along the rivers.

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