SEDIMENT SORTING AND BED CHANGES IN LARGE RIVERS

Dr. G. Akbari, Asst. Prof. Civil Engineering, Dept., USB, Zahedan, Iran

< gakbari@hamoon.usb.ac.ir > Tel: 05412446251, 09155192754

Abstract

In natural streams the flow varies from time to time, cross-sectional geometry changes and bed material is not uniform. Therefore, in a realistic flow-sediment transport prediction model, it is necessary to incorporate unsteady, non-uniform flow computation components, a sediment transport equation and a grain sorting and armouring algorithm in order to model water -sediment movement satisfactorily.

The non-linear coupled model incorporated with and without a grain sorting and armouring algorithm for uniform and graded sediments (NCM and NCMG models) were applied to real river data and some sediment routing examples were studied. The relative merits of the models were also discussed. ***The Missouri river downstream of Garrison dam*** is selected as a case study to deal with the most serious problems involved within a natural river. Descriptions of this river, the data sets used, and the results of application of the NCM and NCMG models to flow and sediment routing are discussed in the following sections.

Keywords:
Missouri river, NCM/NCMG models, Grain sorting, Armoring

Introduction

The prediction of changes in channel characteristics due to the construction of hydraulic structures is an important problem in the hydraulic engineering field. In particular degradation downstream of hydraulic structures is a well- known problem. The numerical models developed by author can be used to study such long- term channel development problems.

Description of River and Data Sets

The example, degradation in the Missouri river between the tail water of Garrison dam and Station Gauge, is chosen for applying the NCM and NCMG models. The location and plan of this river is shown in figure 1.
As reported by Chen [1973], data for the 14.5 km. long reach of the Missouri river downstream of Garrison dam, was prepared by the US Geological Survey during three years flooding seasons measurement (1954 to 1956). The data include rating curves at the tail water and at Station Gauge, the geometry and hydraulics of cross-sections, the sediment data consisting the bed material sizes d_{10}, d_{50}, and d_{90} as well as the monthly suspended load at Station Gauge.
As can be seen from the Chen report, for this river reach the measured bed level was available only for 8 months after operation of the Garrison dam. The bed material in this river reach consists of mixed grain sediment though not well graded [Table 1]. Two models NCMG and NCM incorporated with and without a grain sorting and armoring algorithm were applied to this river and their performances were compared. It was thought interesting, even with the comparative lack of grading, to compare these models and assess the importance of the grading algorithm in the degradation process. Details of the data taken from Chen are as follows:

Channel characteristics

As reported by Chen, the experimental 14.5 km long reach downstream of Garrison dam to Station gauge (Fig.1) was divided into seven sub-reaches. The hydraulic properties of the seven sections along the channel are given in table (1). The data include bed roughness (Manning's n), width of channel, depth of water, and bed slope at different sections downstream of the dam. The upstream flow hydrograph (Fig.2) as well as the rating curves at the tail water and Station Gauge were provided. These data, although limited, have been the subject of many researches.

The results of numerical calculations obtained by the NCM and NCMG models are also compared with the Chen model. The Chen model, is one-dimensional the three basic equations of sediment continuity, flow continuity and momentum for sediment-laden water are solved in a coupled way using a linear implicit finite difference scheme. The model was developed for uniform sediments without incorporation of an armoring algorithm. Details of the model can be seen from ref. [4].

Table 1 Channel characteristics and the initial values for depths and bed slopes, Station Gauge below Garrison dam, Missouri river {after Chen [1973]}

Nodes	1-Tail-Water	2	3	4	5	6	7 Station Gauge
Dist. D/S (km)	0.0	2.0	4.2	6.8	9.2	11.6	14.5
Manning's n	0.018				0.02	0.028	
Width (m)	460	460	290	290	300	480	480
Bed slopes	0.00006					0.0003	0.00035
Depth (m)	1.00	1.00	1.4	1.4	1.52	1.1	1.1

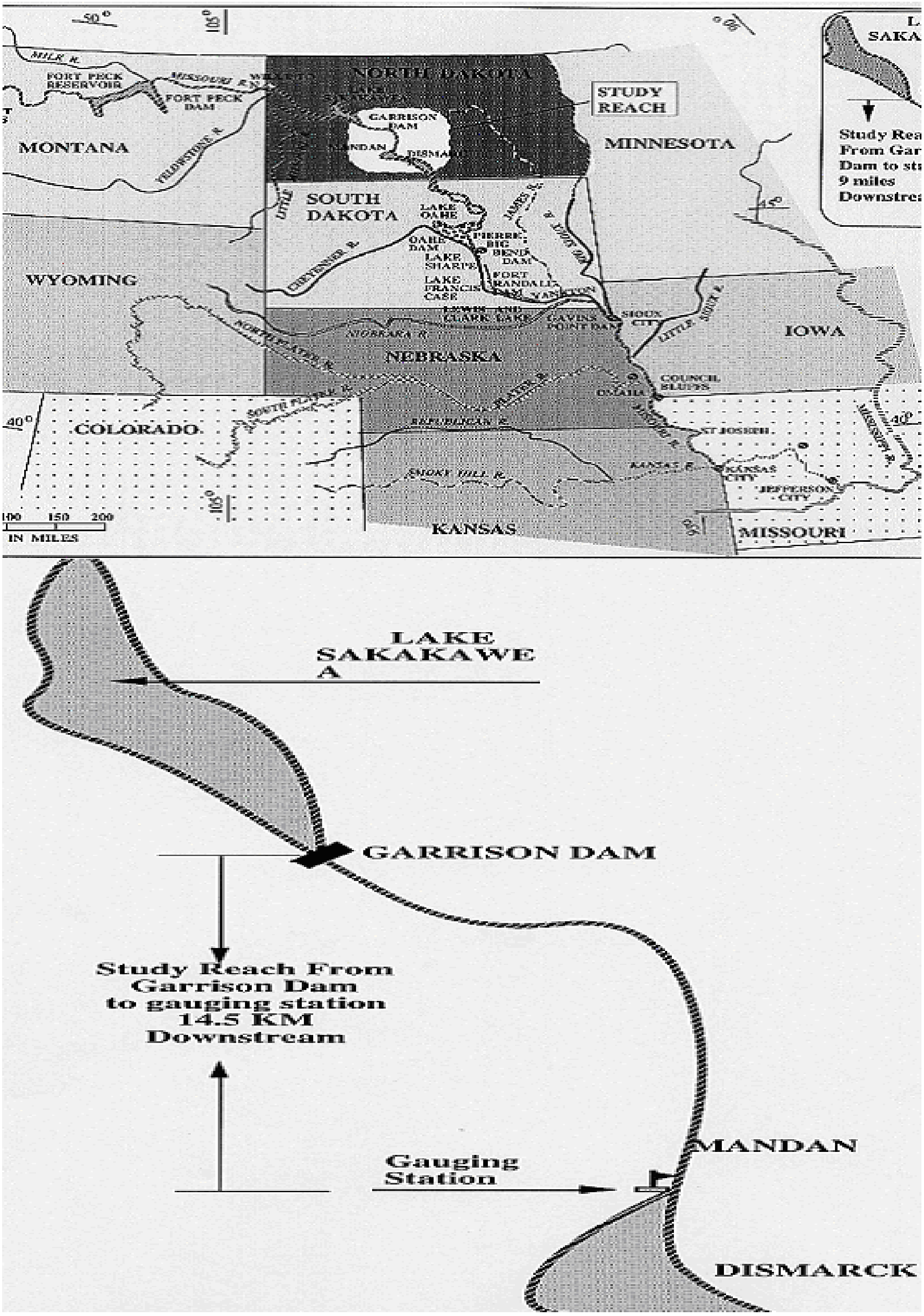

Figure 1 Map and location, Missouri river below Garrison dam flow–sediment studies

Initial and boundary conditions

The initial discharge for every section was taken as $426m^3$ (base flow in December 1953). The initial depths of flow and bed slopes are presented in table (1). One upstream boundary condition was defined by the 1954 discharge hydrograph (fig. 2), and another boundary condition, for bed level at the upstream was defined by Eq. 1, where input sediment was assumed as zero.

$$\Delta A_{d\,(1)} = (Q_{su} - Q_{se})\,\Delta t\,/[c\,P_w\;\; p\,\Delta x] \qquad (1)$$

Where, Q_{su} is the upstream sediment input [this is taken from the upstream inflow sediment hydrograph] and Q_{se}, the equilibrium sediment load as calculated by the sediment load formula. P_w, is the upstream wetted perimeter. The value of c was assumed to be 1.0 [this is assumed in such away that cΔx represents a physically reasonable distance to avoid computational problems at the first computational point.
The downstream boundary condition was defined by the Manning's equation.

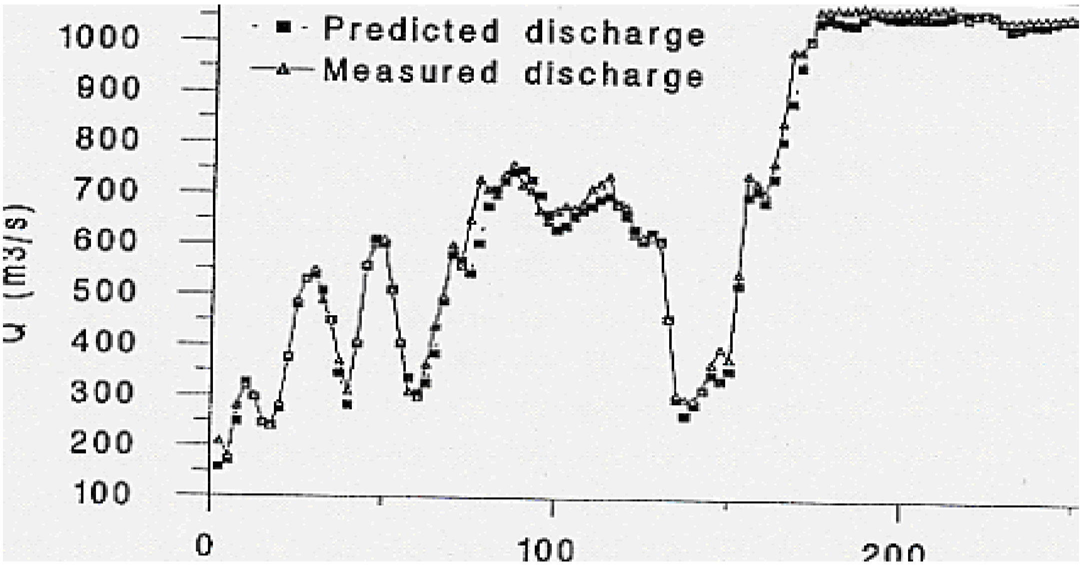

Figure 2 predicted flow discharge compared with measured after 200 days operation.

Sediment characteristics

The sediment data adopted herein, taken from Chen, are limited to the original and final bed size distribution at the downstream, 8 months after the operation of the dam. These are used for comparing the performance of the numerical prediction. 6 different size classes with different fractions, as used by Chen, were used in this study. These are shown in table 2. From the report prepared by Chen, the available sediment data are sand size material with particle sizes of d_{10}, d_{35}, d_{50}, and d_{90} as 0.15, 0.2, 0.3, 0.5 mm respectively. The sediment uniformity index is about 2.1, and the value of sediment porosity, p, was taken to be 0.56.

Table 2 Missouri river bed size distribution

Sed.dia. (mm)	0.1	0.2	0.5	1.0	2.0	2.5
% Finer (original bed)	8.0	36.	93.	98.	99.5	100.
% Finer Measured (after 8 months)	4.0	26.	91.	96.	98.	99.5

Lateral flow

The lateral discharge was estimated from q_l = -0.03 Q/L, as given by Chen, where L is the length of the reach.

Frictional slope:

For conditions in a river or natural stream, estimation of roughness values at different sections along the reach is not an easy task. For instance, in the Missouri river, cross-section changes, flow and sediment conditions vary from one section to another so the resistance of the river bed, calculated from an equation varies along the channel.

Manning's formula was used to estimate the frictional slope. Different roughness values for the upstream and downstream portion of the reach were taken from Table 1 for friction calculations. These roughness values, α=0.018, α=0.02, 0.028 were used in numerical calculations for the specified reach lengths as given in Table1.

Sediment Loads:

Any standard sediment transport formulae can be applied for calculating sediment discharge in the NCMG model. Accurate prediction of the sediment load in a mathematical model is very important. The accuracy of evaluating the degradation in this study can therefore depend on application of a reliable sediment transport formulae for calculating sediment discharge. In this study the modified Ackers-White formula [1973], and a simplified sediment transport equation [Eq. 2], were employed for comparison. Eq. 2 was used with the parameters, $\alpha_1=2.7 \times 10^{-8}$, β_1=3., γ1= 2., initially estimated by comparison with the Ackers-White formula for a given effective size of d_{35}=0.2 mm.

$$\mathbf{Q_S = \alpha_1\, Q(Q/A)^{\beta 1}\, y\, /d_m^{\gamma 1}} \qquad \textbf{(2)}$$

In this equation, Q is in m^3/s, A is in m^2, y is in m, and d_m is in m.

Routing of Graded Bed Material

In this example, for a river downstream of a dam it was assumed that;

i) The sediment was completely arrested by the dam,

ii) The river- banks were not erodible, [this is the case for the steady flow in the U/S released from the dam without putting sludge into the reach],

iii) The bed material characteristics are affected by the degradation [predicted by NCMG model].

Figure 2 shows the predicted and measured discharge hydrographs over a period of 8 months, at Station Gauge. The predicted results agree well with the measured one.

In figure 3 the calculated bed level changes for this river reach after the 1954 flood are compared with the measured bed and Chen (1973) results. The predicted and measured results show good agreement. However, the result of simulation by the NCM and NCMG models, can be further improved, if the initially selected sediment parameters used here are further adjusted by optimisation using real measured data.

In fig. (3), models with and without incorporating armoring algorithm are compared. In this figure, comparing measured bed change results with those predicted by the NCM, NCMG and Chen models, the NCMG generally performs better than the NCM and Chen models. When free-sediment water is released from reservoir downstream of a dam, bed erosion is generally expected. This is captured by the NCM model before incorporating it with a grain sorting and armoring algorithm. When the NCMG model is applied, it confirms that the NCM model needs to be incorporated with a grain sorting and armoring algorithm, clearly, even with this poorly graded material, the effect of grain sorting is significant in reducing the erosion downstream of the dam.

Comparing the NCM and Chen result in Fig. (3), Chen has not determined the large erosion expected probably because of the following reasons;

- **The Chen model is a uniform sediment transport model,**
- **The sediment transport formula used in the Chen model is different from the NCM and NCMG,**
- **Chen used the Toffaleti [1958] sediment transport formula, which seems to be more suitable for uniform sediments, in his sediment transport predictor a mean diameter of d_{50}, was used, which did not predicted suspended and finer particles accurately for this particular case.**
- **Moreover, the Chen results differ from the NCM and NCMG because the Chen model is linear i.e. it uses a linear implicit finite difference solution.**
- **In linear models the high order and nonlinear partial differential terms of the governing equations are approximated linearly which can lead to errors for real river problems with relatively widely varying flow and sediment conditions.**

- **Also in the Chen model, a fixed value of the space weighting factor ϕ = 0.5 is considered. This is a centered implicit scheme model, which is suitable for fixed bed channels but may not be suitable for moving bed channels.**
- **Furthermore, Chen generally underestimated bed erosion, because in this particular case study, the bed is poorly graded. A major part of the bed is fine sand which is likely to be washed and moved within the water, fine particles washed away or transported in suspension is not counted for bed load erosion, thus the bed load formula used underestimated bed erosion.**

Over all, it is expected that a model applied to the case of erosion downstream of a dam would handle variable flow, non-uniform bed material, and simulate bed degradation and armoring. The results of the comparison (Fig.3) confirm that a nonlinear method of solution (NCMG model) incorporated with grain sorting is advantageous.

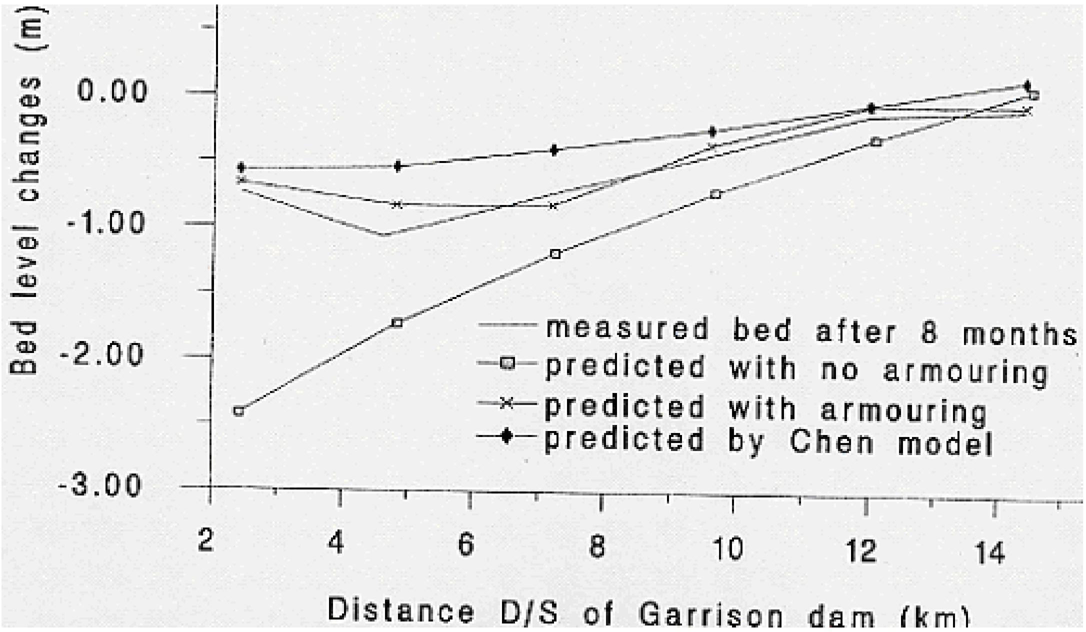

Figure 3 predicted bed level changes compared with measured along Missouri river.

Discussion

In this paper the following conclusions are reached concerning application of different models as discussed as above to real river situations.

Flow and graded sediment routing, sorting and armoring algorithms were applied satisfactorily to two different natural rivers. As can be seen the flow and sediment characteristics in the Missouri river is broadly variable, for instance the flow discharge in the Missouri varies from 100 to 1100 m^3/s [Fig. 2]. Also a wide difference can be seen in the size and grading of the bed materials. The Missouri river bed consists of sand size (0.1-2.5 mm) with d_{50} equal to 0.25 mm, and uniformity index equal to 2.1, models thus worked for different bed materials.

The measured size distributions show that the bed sediment for this river is graded and hydraulic sorting of the bed material can occur due to preferential transport of finer sediments.

The proposed grain sorting and armoring algorithm, and the assumed active layer thickness for determining the natural river bed degradation and bed gradation were shown to give encouraging results in terms of bed level changes and sediment sorting.

The Ackers-White formula has been shown to be one of the best available to predict sediment transport in both laboratory and real river situations. For Missouri, however, a simpler relationship (Eq. 2) is also worked. It has been shown that, with the parameters in Eq. (2), chosen by comparison with Ackers-White, the performance of the two equations is similar. Thus equation can be used with correctly optimized parameters, in particular for real river situations.

Overall, selection of an appropriate numerical sediment routing model incorporating the grain sorting and armoring algorithm for a particular application, depends upon the variability of flow, depth and sediment material characteristics as well as the influence of the boundary conditions. The NCMG model, applied to Missouri river predicted reasonably good results.

Comparing the performance of the NCMG, with the Chen model, applied to a real river data, a good improvement is achieved in the sediment transport modeling, though, generally, the reliability of the data sets used in a numerical model is not certain. Chen (1973) reported that his model results compared with the measured one, showed a deviation of more than 50% in sediment transport and bed level prediction. Deviation for NCMG results as compared with the measured values for Missouri river studied here is less than 30%.

References:

1. Ackers, P., and White, W.R., “Sediment Transport-New Approach and Analysis,” Journal of the Hydraulics Division, ASCE, Vol. 99, No. HY11, November, 1973, 2041-2060.

2. **Akbari, G.H**., Wormleaton, P.R., Ghumman, A.R., “A Simple Bed Armoring Algorithm for Graded Sediment Routing in Rivers”, Water for a Changing Global Community, 27th IAHR Congress, 10-15 August 1997 San-Francisco, USA.

3. **Akbari, G.H**., “Optimizing resistance parameter for using real river data bed level calculations”, Journal Science and Engineering, USB, Vol 6, Summer 2004"

4. **Akbari, G.H**., "Sensitivity analysis of the most important sediment transport parameters in a sediment transport model", Journal Science and Engineering, USB, Vol 6 Summer, 2004".

5. **Akbari, G.H**., “Fully coupled non-linear mathematical model for flow-sediment routing through rivers”, PhD Thesis, Q.M. University of London, 2003

6. Chen Y. H., "Mathematical Modeling of Water and Sediment Routing in Natural Channels" PhD degree, University of Colorado, 1973.

7. Ghumman A. R, Wormleaton P.R, Hashmi H.N, **Akbari G.H**, "Parameter identification for Sediment Routing in Rivers" IAHR, Journal of Hyd. Research, Vol. 34-1996.

8. Lyn, D. A. and Goodwin, P., “Stability of General Preissman Scheme”, J. Hyd. Eng.., ASCE, Vol. 113, No. 1, pp 16-28, 1987.

9. Fisher, K.R. “Manual of Sediment Transport in Rivers” HR, Wallingford Report, 1995.

10. “NAG Fortran Library Manual”, QMW, Univ. of London, 1985.

11. Van Rijin, L.C., “Sediment transport”, Part 1,2, and 3, J. Hyd. Engg., ASCE, Vol. 110, pp. 1431-56, 1613, 41, and 1733-54, 1984.

12. White W.R., and Day, T.J., “Transport of Graded Gravel Bed Material”, Gravel Bed Rivers, Hey, R.D., Bathurst J.C, and Thorne, C.R., ed., John Wiley & Sons, pp. 181-223., 1982.

13. Wormleaton, P.R., Ghumman, A., R., and **Akbari G., H**., "A Comparison of the Performance of Coupled/Uncoupled Non-linear Models for Sediment Routing in Rivers, Proceedings of the Regional Conf. on Water Resources Management (WRM 95), Isfahan, Iran, 1995.