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Hydrologic Engineering Center

Predicting Deposition Patterns in Small Basins

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A technique for estimating sediment depositional patterns based upon flow patterns is described. Flow patterns are computed using a finite element model for two-dimensional, vertically averaged flow. Once the velocity and depth fields are computed, the bed shear stress distribution can be found. If the annual volume and approximate particle size of the inflowing load is known, anticipated depositional locations and quantities can then be estimated. Use of this technique to forecast the temporal development of the deposits by computing the velocity fields for several steady flow conditions is described. The resulting graphical displays of velocity fields and shear stress contours are very useful to the design engineer. This procedure avoids the complexity associated with use of a two-dimensional sediment transport and dispersion model. Application of the technique to the design of a basin 180 feet (55 meters) wide by 620 feet (186 meters) long is described.

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PREDICTING DEPOSITION PATTERNS IN SMALL BASINS[1]

By D. Michael Gee, Research Hydraulic Engineer, Hydrologic Engineering Center, Davis, CA.

ABSTRACT

A technique for estimating sediment depositional patterns based upon flow patterns is described. Flow patterns are computed using a finite element model for two-dimensional, vertically averaged flow. Once the velocity and depth fields are computed, the bed shear stress distribution can be found. If the annual volume and approximate particle size of the inflowing load is known, anticipated depositional locations and quantities can then be estimated. Use of this technique to forecast the temporal development of the deposits by computing the velocity fields for several steady flow conditions is described. The resulting graphical displays of velocity fields and shear stress contours are very useful to the design engineer. This procedure avoids the complexity associated with use of a two-dimensional sediment transport and dispersion model. Application of the technique to the design of a basin 180 ft. (55 m.) wide by 610 ft. (186 m.) long is described.

INTRODUCTION

Conventional sediment basin design procedures rely on volumetric relationships to determine flow through times, estimated trap efficiency, and average annual deposition rates. Design guidance has been prepared by USACE (1989). These approaches do not necessarily reflect the interaction between changes in bed topography due to scour and/or deposition and the influence of these changes on velocity and shear stress distributions. Some designs have been approached using one-dimensional numerical modeling of flow and sediment such as HEC-6 (USACE-HEC, 1990). Some concerns with these approaches are that complex velocity patterns such as recirculation and short circuiting may not be properly described. These flow patterns may result in uneven distributions of sediment concentration and, therefore, an uneven distribution of sediment deposits (Montgomery, et al. 1983). The use of a fully two-dimensional model for both flow and sediment distribution such as TABS-2 (McAnally et al. 1984) is an attractive approach to improve the prediction of the distribution of sediment deposits. The use of such a model, however, may involve more effort and data acquisition than can be justified for small basin design. The technique described herein represents a midway approach that includes the velocity and shear stress fields in detail, from which the sediment deposition distribution and rates can be inferred. A brief description of this approach was presented by Deering and Larock (1989).

MODEL SELECTION

It is assumed that the salient flow features of small basins can be described in the two horizontal directions and that the variance of velocity in the vertical is the traditional logarithmic velocity distribution for turbulent flow in open channels (French 1985). A widely used model that is suitable for this condition is RMA-2 (King & Norton 1978). RMA-2 has been applied to a wide variety of problems including floodplain analysis (Gee et al. 1990), marsh flooding (MacArthur et al. 1990), sediment basin design (Deering & Larock 1989), has been adapted for bridge design (FHWA 1989), and serves as the hydrodynamic module of the TABS-2 system (McAnally et al. 1984). This model solves the depth integrated Reynolds equations for two-dimensional free-surface flow in the horizontal plane using the finite element method for both steady and unsteady flows. The finite element

[1]Presented at the Fifth Federal Interagency Sedimentation Conference, Las Vegas, Nevada, March 1991.

formulation of RMA-2 allows boundary roughness and geometric resolution to vary spatially to accurately depict topography. It also provides a wide variety of boundary conditions. Wetting and drying of portions of the solution domain is allowed. The two-dimensional approach relieves the engineer from having to construct cross sections that are perpendicular to the flow for all flows, as is required in a one-dimensional analysis.

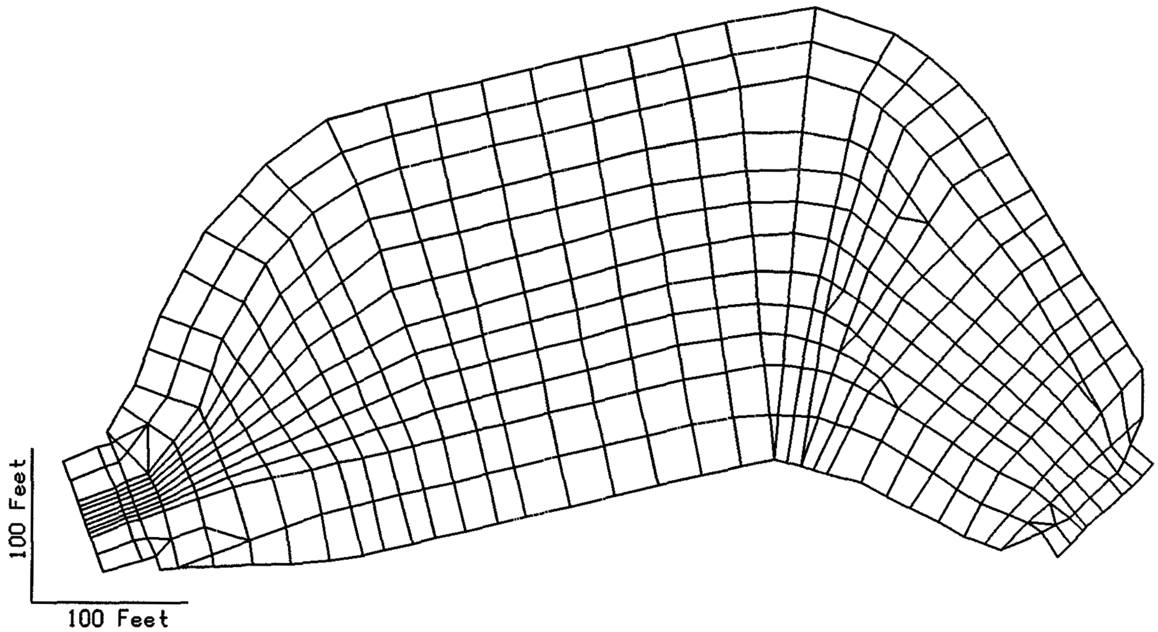


Figure 1. Example Finite Element Mesh, Wildcat Creek Basin.

APPROACH

An example finite element mesh is shown in Fig. 1. Note that the elements are both quadrilateral and triangular. Computational nodes exist at the corners and mid-sides of each element. The bottom elevation is given at each corner node and linearly interpolated for the mid-side nodes. Bed roughness and turbulent exchange coefficients are assigned to groups of elements (not necessarily neighbors) by the user. Solution of the two-dimensional flow equations provides the x- and y-components of the velocity, and the depth, at each computational node. The local shear stress can be calculated from these variables if one assumes that the relation for average shear in a cross section can be applied locally as follows.

$$\tau = \gamma RS \tag{1}$$

Where τ is the bed shear stress, γ is the unit weight of water, R is the hydraulic radius (taken here as the local nodal depth) and S is the friction slope. Now, rewriting Manning's equation in terms of S, we have:

$$S = \frac{n^2u^2}{2.22R^{4/3}} \tag{2}$$

Where u is the resultant of the calculated x and y nodal velocity components, as shown in equation (3) and n is Manning's roughness coefficient.

$$u^2 = u_x^2 + u_y^2 \tag{3}$$

Combining, we can solve for the shear stress:

$$\tau = \gamma \frac{n^2u^2}{2.22R^{1/3}} \tag{4}$$

One must now relate the n-values, which are associated with elements, with the computed values for u and R (depth) which are located at nodes. For this study, the n-value associated with a node was computed as the arithmetic average of the n-values for all elements connected to that node. We have placed these computations in the vector plotting program (VECTOR) which is a post-processor for RMA-2. VECTOR also prepares files of water surface elevation and velocity magnitude for contouring.

AN EXAMPLE

Introduction

The Wildcat Creek sediment basin was designed to trap sediment that potentially could cause excess scour or deposition in a downstream flood control channel. Right-of-way considerations and environmental concerns dictated the bent alignment shown in Fig. 1 (flow is from right to left). Based on cross section average velocity and settling lengths computed from the particle fall velocity, it was estimated that the basin would trap 100% of the sediment larger than fine sand (0.125 mm). A hydrodynamic analysis was performed to ascertain whether the bent alignment would indeed trap the size range and volume of sediment needed and whether high velocities would impinge on the banks requiring some form of bank protection.

Sediment Basin Description

The Wildcat Creek sediment basin was designed to have a maximum width of 180 ft. (55 m.) and length of 610 ft. (186 m.). The bottom slope is 0.0005 and the side slopes 1V:3H. The maximum depth is about 12 ft. (3.7 m.).

Hydraulics

As Wildcat Creek is ephemeral, continuous simulation was not necessary. Therefore, several hydraulic scenarios were studied to verify that the basin would perform as designed. It was planned that deposits would most likely have to be removed from the basin on an annual basis. This led to simplification in the number of conditions to be analyzed because the problem was reduced to evaluation of the interactions between average annual deposition and the occurrence of the design (1% exceedance) event. The results presented here are only for the design event; refer to Deering and Larock (1989) for information on other scenarios. Furthermore, as the basin volume is small relative to the hydrograph volume, the analysis could be performed assuming steady flow. The 1% chance exceedance event is 2300 cfs (65 cms). The drainage area is about 7.8 mi^2 (2000 hectares).

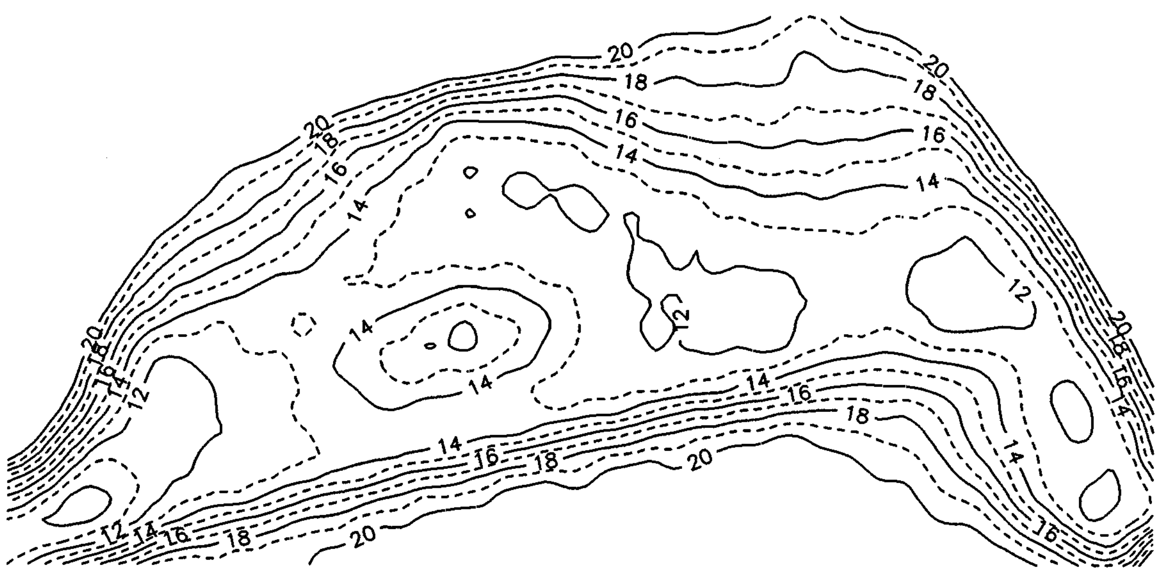
Scenario

The situation presented herein represents the condition of the basin after several years' average annual deposition (not removed). The flow evaluated is that of the design (1% chance exceedance) event. The distribution of the deposits shown in Fig. 2 was created based on simulation of the shear stress distribution in the empty basin and observation of other flood control projects having similar flow and sediment transport conditions. The bar deposits are formed from flows expanding into open areas. Initial deposits will form in the lower velocity areas causing the flow to redistribute, expanding again and reinitiating the bar formation process. This results in bar formation on the left and right banks, immediately downstream of the entrance, and a central bar further downstream. The assumed deposition pattern has a volume equivalent to that of the average annual deposits for the time period selected. The nodal elevations of the finite element mesh that was developed for the design (empty) basin were modified to reflect this hypothetical deposition pattern.

Modeling parameters

The Manning's n-values were set to 0.03 for most of the basin based on it being maintained as smooth earth. The values for one portion of the left bank were set to 0.06 based on maintaining the native heavy vegetation there. The sensitivity of the results to these values, assuming the project is

Figure 2. Bottom Elevations (ft).



not well maintained should be checked and may be significant to the design event water surface elevation. The turbulent exchange coefficients were uniformly set to 10 lb-sec/ft^2 (480 N-sec/m^2) for all elements. This was based on prior experience with finite element meshes of this scale. The sensitivity of the results to variation of these values within reasonable ranges was checked and found to be insignificant.

Boundary conditions

This is a simple 2-D problem in that it is analogous to traditional 1-D backwater computations with regard to boundary conditions. A discharge was specified at the upstream (right) end of the model. In 2-D, however, the direction of the discharge must be given which was selected to be perpendicular to the inflow boundary line (see Fig. 3). The downstream boundary condition was specified as a water surface elevation appropriate for the discharge being analyzed based on design studies of the downstream reach. A rating curve could have been used for the downstream boundary if appropriate. Along all other boundaries, the flow direction is parallel to the boundary.

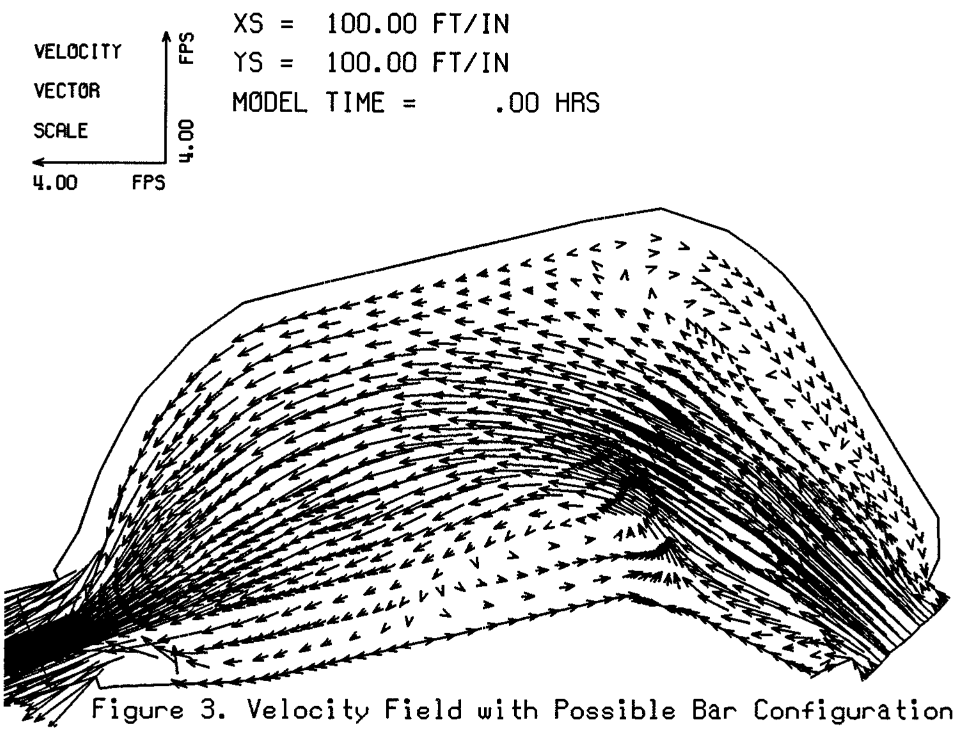


Figure 3. Velocity Field with Possible Bar Configuration. Q=2300 cfs.

Modeling results

The flow field for the design event is depicted on Figure 3. The flow enters the basin as a plume of relatively high velocity. Recirculation zones are seen on each side of the inflow plume. This is obviously not a one-dimensional situation. The hypothetical bar formations do not appear to force the higher velocity jet against either of the banks as originally suspected. The associated shear stress field for this flow and bottom condition is shown in Figure 4.

The shear stress is low enough that sediments of the size of interest will be trapped in the basin. Note particularly the zones of near zero shear that correspond to the recirculation cells near the left and right banks. The clustering of contours near the banks is an artifact of the contouring process.

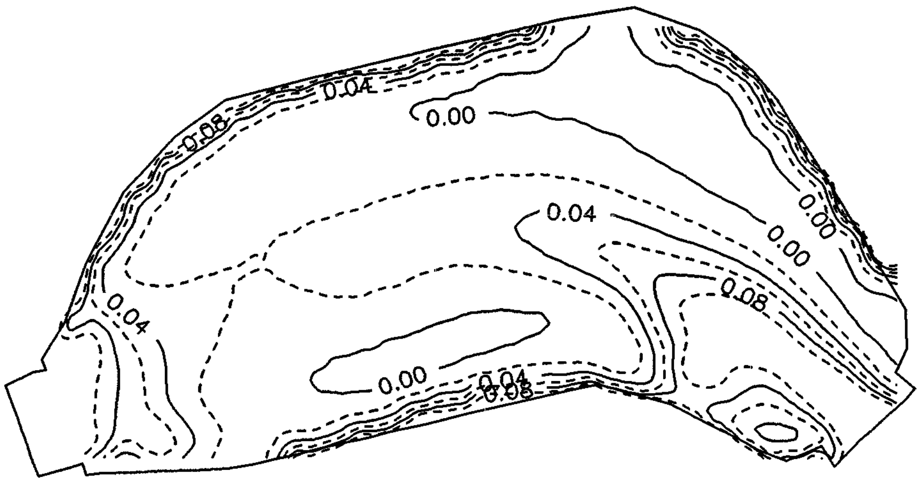


Figure 4. Shear Stress (lb/sq ft).

CONCLUSIONS

The technique presented herein represents a midway approach to the prediction of spatially complex sediment transport processes. Much can be inferred from viewing the velocity and shear stress distributions. Once the velocity field has been computed, the computation of the shear stress distribution is trivial. If, at this stage, one determines that simulation of the full two-dimensional transport and dispersion of sediment is necessary, the hydrodynamic analysis already performed can be used directly in the sediment transport simulation.

COMPUTATIONAL ASPECTS

The finite element mesh used for this study contains about 550 elements and 1370 nodes. This produces about 2300 simultaneous equations. To solve this system for steady flow using six iterations takes about 15 minutes on a 25 MHz 386 computer. The system can be run within the DOS 640K limitation.

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