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TWO-DIMENSIONAL FLOODPLAIN MODELING

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and Laura Baird[3]

Abstract

A two-dimensional horizontal finite element numerical model (RMA-2) was applied to a 15 mile (24 km) river channel-floodplain reach in West Germany. Previous applications of such models have been restricted to much smaller scales. The results indicate that finite element schemes may successfully estimate river stage in large scale floodplain applications. Computed stage hydrographs compared well with observed data using loss coefficients within expected ranges.

Applications of Finite Element Modeling to River Studies

Two-dimensional flow models have been applied to certain classes of river channel problems. Applications have included detailed analyses of flow patterns near structures such as bridges (FHWA, 1989), dams (Gee & Wilcox, 1985), and floodplains (Samuels, 1985). In all these problems the scale of interest has been small, e.g. reaches of river a few river widths long. Many estuary studies have been done that were of large scale; some of these utilized a "hybrid" (numerical plus physical) modeling technique (McAnally et al., 1984). In a review of the application of finite element methods to river channels, Samuels (1985) reported that the river channel was resolved separately from the floodplain in only two studies.

Missing in previous work is attention to large scale floodplain modeling. The work reported in this paper focuses on the feasibility and accuracy of applying a two-dimensional flow model to a large floodplain. Traditional floodplain studies have used semi-empirical flow routing with steady, one-dimensional computation of water surface elevations to define inundated areas.

Model Selection

The numerical model known as RMA-2 (King and Norton, 1978) was selected for use in this study. 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 formulation of RMA-2 allows boundary roughness and geometric resolution to vary spatially to accurately reflect topography. It also provides a

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wide variety of boundary conditions. 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.

The ability of RMA-2 to allow dry areas within the solution domain during the simulation of an unsteady flow event led us to select it for testing on a floodplain problem where flow is initially within the channel, spreads into the overbank areas as the flood arrives, and returns to the channel as the flood recedes. The version of RMA-2 (ver. 4, Oct. 1988) used in this study contains a new approach to the wetting/drying problem. Previously, an element instantaneously became dry once the depth at any node in that element became zero or negative (similarly with wetting). The new approach is based upon the concept of "marsh" elements that gradually dry or wet. This is accomplished with a pseudo-porosity that operates on the flow carrying capacity of an element as the depth changes (King and Roig, 1988). The application described herein is the first application of the marsh element formulation to a floodplain.

Study Reach

The study reach selected for the RMA-2 application was that from Bad Hersfeld (upstream) to Rotenburg (downstream) of the River Fulda in West Germany. The reach is about 15 miles (24 km) long with a slope of 0.0008. The channel is about 15 ft. (4.6 m) deep and 130 ft. (40 m) wide. The floodplain is about 0.6 miles (1 km) wide, has a very shallow slope orthogonal to the river (≈ 0.0001), and is bounded by steep forested hills. The floodplain land use is mostly grazed pasture with developed areas and patches of woods and brush. Manning's n was estimated at 0.045 for the floodplain and 0.035 for the channel; woods and brush were estimated to have an n value of 0.07. Although RMA-2 allows detailed spatial variation of Manning's n, this study used only two; one for the channel and one for the overbank. An observed event of approximately 10% chance exceedance was used for testing. This flood rose from a base flow of 5000 cfs (140 cms) to a peak of 15000 cfs (425 cms) in 6 hrs. The hydrograph at Bad Hersfeld and rating curve at Rotenburg were obtained from the Fulda River Authority.

System Schematization

RMA-2 utilizes a finite element mesh composed of both triangular and quadrilateral elements. Ground elevations are defined at the corners of the elements and vary linearly between corner nodes. In this study, the channel was represented by a strip of two elements wide (Fig. 1) producing a triangular channel cross section. Overbank areas were represented by much larger elements. Ground elevations in the overbank areas were determined from 3.3 ft. (1 m) contour interval maps. The resulting finite element mesh was composed of 860 elements and 2660 nodes (Fig. 2). The ratio of maximum to minimum element areas was about 200 to 1. This variability in resolution demonstrates the flexibility of the finite element method for use in large scale floodplain modeling. Turbulent exchange coefficients used varied with element size from 500 to 1000 lb-sec/ft^2 (24000 to 48000 N-sec/m^2).

The computations were performed with a 0.5 hr. time step. No over-attenuation due to this relatively large time step was observed. One simulation was performed using an 0.25 hr. time step, yielding results the same as those with the 0.5 hr. time step.

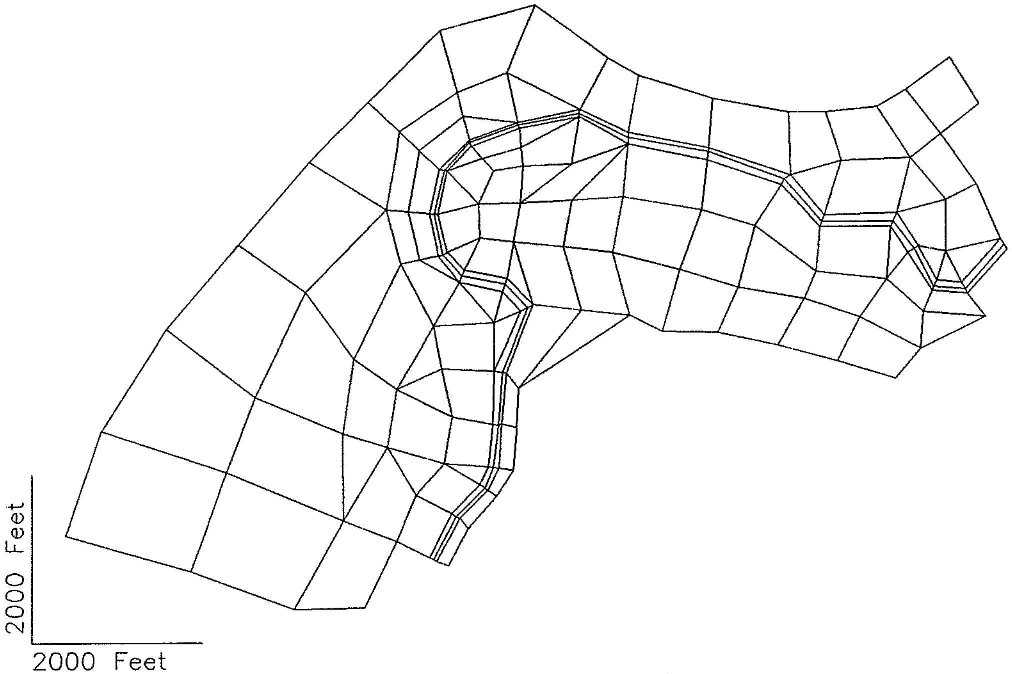

Figure 1. Fulda River Mesh (detail).

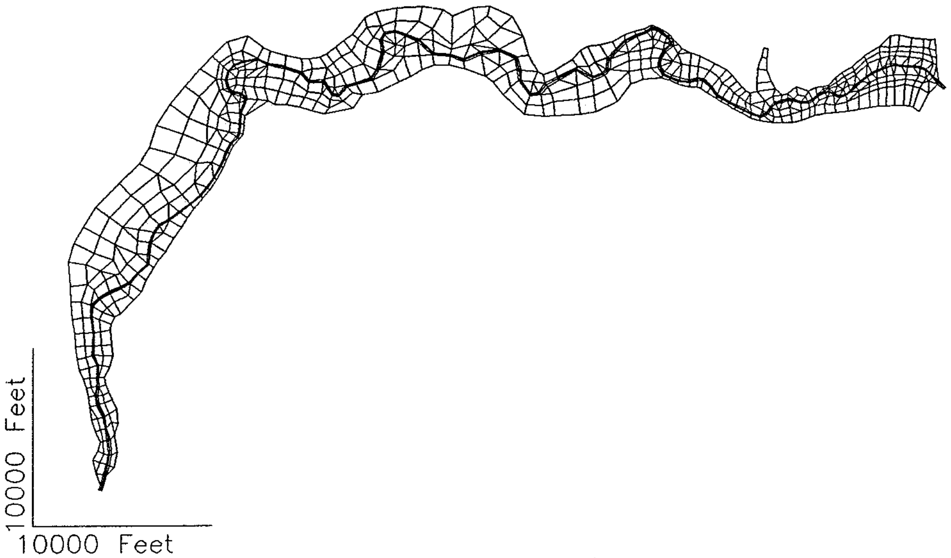

Figure 2. Fulda River Mesh (flow is right to left).

Results

Continuously recorded stage hydrographs were available at both Bad Hersfeld and Rotenburg. The observed and computed stage hydrographs at the upstream end are shown in Figure 3. These results were obtained after setting all of the overbank n values to 0.07.

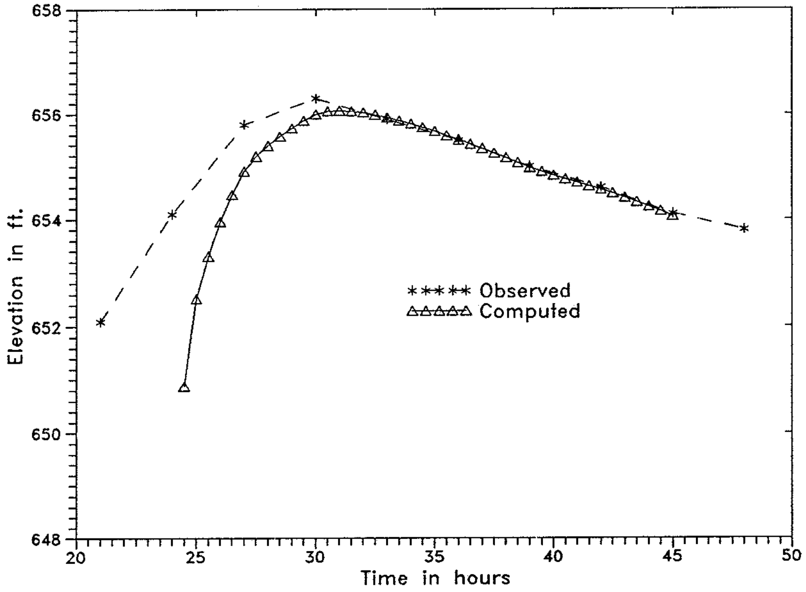

Figure 3. Upstream Stages, n_{ob} = 0.070

Figure 4 shows the computed stage at the downstream end. Note that the initial conditions do not match the observed; this is probably due to approximations made to the rating curve at the downstream end. It is possible that the anomalous behavior of the rising limb of the hydrograph is due to the rather crude description of the channel.

The two-dimensional solution obtained from RMA-2 yields velocity vectors in addition to stage at every computational node. Indeed, most applications of two-dimensional flow models have focused on velocity for purposes of constituent transport or hydraulic design. In the context of large floodplain modeling velocities are important for both definition of inundated area and determination of flood hazard. Examination of plotted velocity fields is useful for determining the extent of inundation and velocity hazard areas within the floodplain at any particular time.

Computational Aspects

Although this is not a very computationally intensive problem for the simulation of steady flow conditions, the dynamic simulations performed (consisting of 40 to 60 time steps) utilized significant computational resources. The simulations were performed on a super minicomputer rated at about 4.5 mips. Each simulation took several hours of central processing time on this machine. Although contemporary desktop computers equal or exceed the

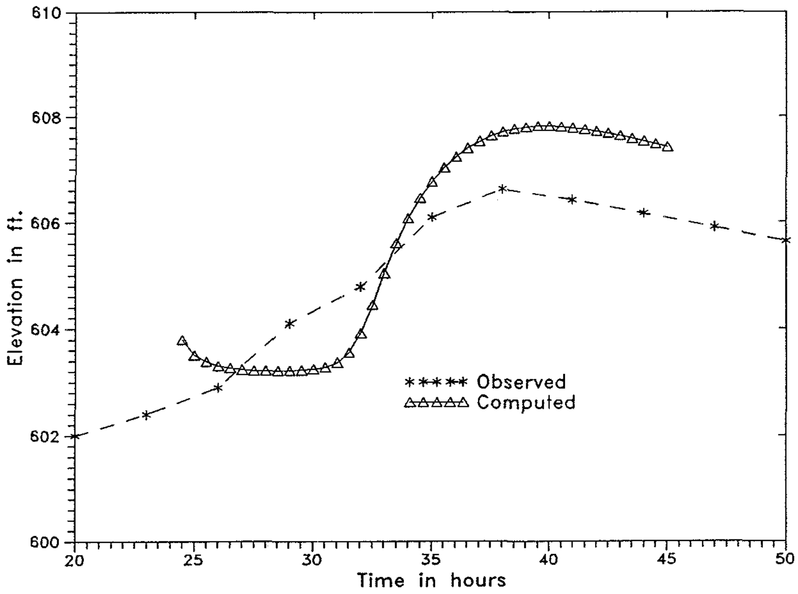

Figure 4. Downstream Stages, n_{ob} = 0.070

processing speed of this computer, the results indicate that engineers contemplating two-dimensional floodplain modeling on this scale for dynamic flow events should carefully plan their studies to minimize the number of alternatives to be modeled and utilize steady flow simulations wherever possible. Development of initial conditions (base flow) in systems with large elevation changes [>10 ft (3 m)] may also be difficult. The capability for rapid graphic representation of data and computed results is essential.

Conclusions

Application of RMA-2 to the River Fulda has demonstrated the applicability of finite element numerical models to large scale floodplain applications. The initial results indicate that RMA-2 may successfully be used for estimating the depth and lateral extent of inundation at this scale. Flow velocities and depths are directly available from the computed results, however, there were no data in this application to verify the computed velocities and flow depths. Stability of solutions for wetting and drying of large areas was greatly improved by use of the "marsh" element option in ver. 4 of RMA-2. Improvement of this capability, channel representation, initial condition development, and graphics presentation, are future research needs. Further field validation needs to be undertaken and documented to establish an experience base with these applications. Use of digital terrain and geographic information systems should blend well with this approach to floodplain analysis.

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