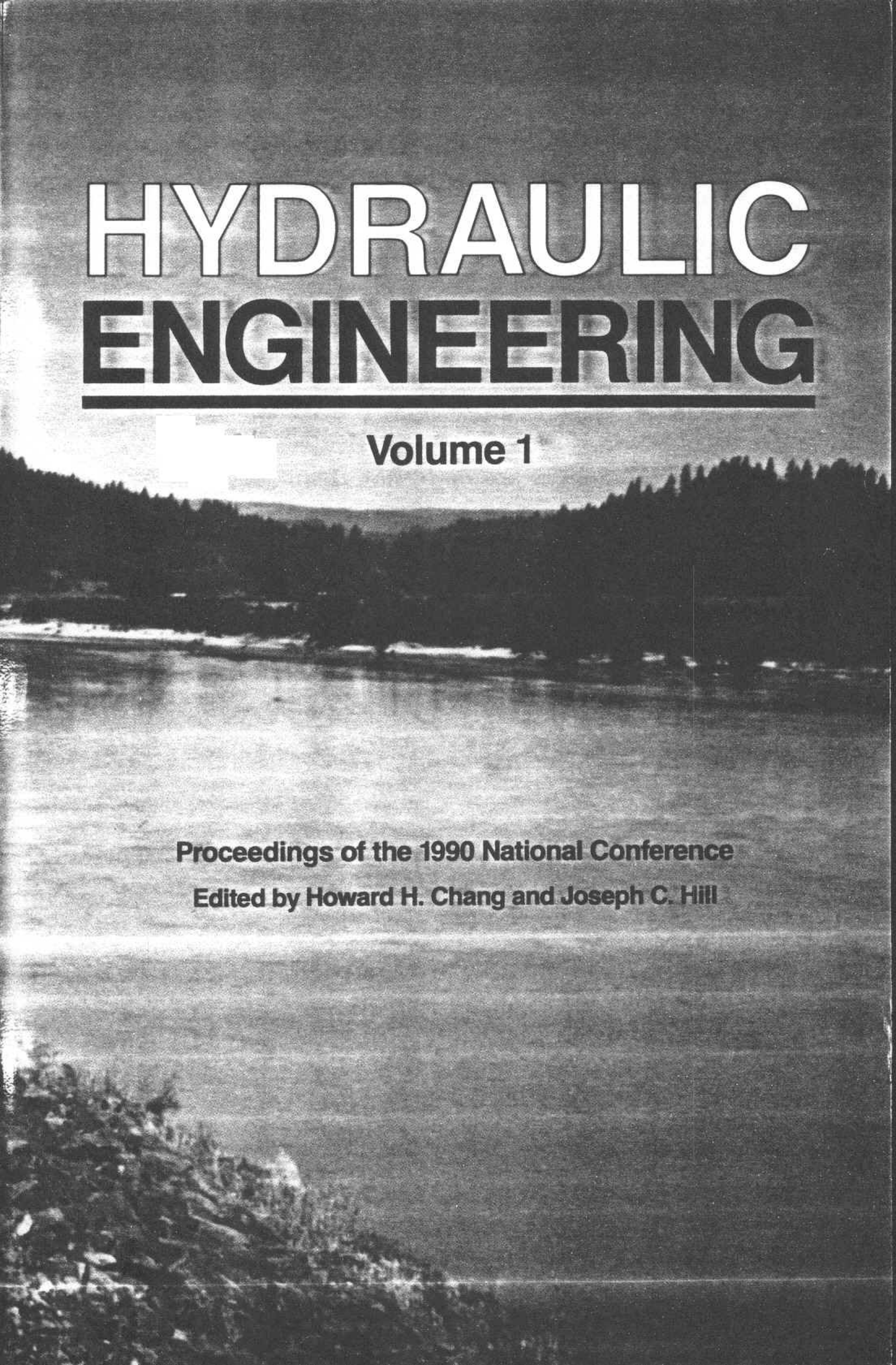

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APPLICATION OF THE U.S.G.S. DHM FOR FLOODPLAIN ANALYSIS

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Abstract

The two-dimensional Diffusion Hydrodynamic Model, DHM, is applied to the evaluation of floodplain depths resulting from an overflow of a leveed river. The environmental concerns of flood protection and flow velocities can be studied with the two-dimensional DHM flow model. Although the DHM generates considerable information, it is easy to use and does not require expertise beyond that required for use of the one-dimensional approaches.

Introduction

The main objective of this paper is to review the findings of a detailed study of the Santa Ana River 100-year event floodplain in the City of Garden Grove, California, using the two-dimensional Diffusion Hydrodynamic Model (DHM) (Hromadka, 1985, Hromadka et al, 1985, Guyman and Hromadka, 1986, Hromadka and Durbin, 1986, Hromadka and Nestlinger, 1985, Hromadka and Yen, 1986, Hromadka and Yen, 1987).

The local terrain slopes southwesterly at a mild gradient (i.e., 0.4%) and is fully developed with mixed residential and commercial developments. Freeways form barriers through the study site so that all flows are laterally constrained with outlets at railroads and major streets crossing under the freeways. Because of the flood flow conveyed through the floodplain and the mild cross-sectional terrian, the floodplain analysis needs to include two-dimensional unsteady flow effects.

Description of the DHM

The DHM provides the capability to model two-dimensional unsteady flow where storage effects and diverging flow paths are important, and hence, the steady state one-dimensional flow approach may be inappropriate.

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The two-dimensional unsteady flow equations consist of the equation of continuity

$$\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial z}{\partial t} = 0 \qquad (1)$$

and two equations of motion

$$\frac{\partial Q_x}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q_x^2}{Ax}\right) + \frac{\partial}{\partial y}\left(\frac{Q_x Q_y}{Ax}\right) + gAx\left[S_{fx} + \frac{\partial h}{\partial x}\right] = 0 \qquad (2a)$$

$$\frac{\partial Q_y}{\partial t} + \frac{\partial}{\partial y}\left(\frac{Q_y^2}{Ay}\right) + \frac{\partial}{\partial x}\left(\frac{Q_x Q_y}{Ay}\right) + gAy\left[S_{fy} + \frac{\partial h}{\partial y}\right] = 0 \qquad (2b)$$

in which t is time, x and y (and the subscripts) are the orthogonal directions in the horizontal plane; q_x and q_y are the flow rates per unit width in the x and y-directions; z is the depth of water; Q_x and Q_y are the flow rates in the x and y-directions, respectively; h is the water surface elevation measured vertically from a horizontal datum; g is the acceleration of gravity; Ax and Ay are the cross-sectional areas; and S_{fx} and S_{fy} are the friction slopes in the x,y-directions. The DHM utilizes the uniform grid element to model the two-dimensional unsteady flow, therefore, Ax and Ay are defined as the length of uniform grid element times the depth of water.

The friction slopes S_{fx} and S_{fy} can be estimated by using Manning's formula

$$S_{fx} = \frac{n^2 Q_x^2}{C^2 Ax^2 R_x^{4/3}} \qquad (3a)$$

and

$$S_{fy} = \frac{n^2 Q_y^2}{C^2 Ay^2 R_y^{4/3}} \qquad (3b)$$

in which n is the Manning's roughness factor; R_x, R_y are the hydraulic radiuses in x,y-directions; and the constant C=1 for SI units and 1.486 for U.S. Customary units.

In the DHM, the local and convective acceleration terms in the momentum equation (i.e., the first three terms of Eq. 2) are neglected (Akan and Yen, 1981). Thus, Eq. (2) is simplified as

$$S_{fx} = -\frac{\partial h}{\partial x} \qquad (4a)$$

and

$$S_{fy} = -\frac{\partial h}{\partial y} \qquad (4b)$$

Combining Eqs. (3) and (4) yields

$$Q_x = \frac{C}{n} A_x R_x^{2/3} \frac{\left\{-\frac{\partial h}{\partial x}\right\}}{\left|\frac{\partial h}{\partial x}\right|^{1/2}} \tag{5a}$$

$$Q_y = \frac{C}{n} A_y R_y^{2/3} \frac{\left\{-\frac{\partial h}{\partial y}\right\}}{\left|\frac{\partial h}{\partial y}\right|^{1/2}} \tag{5b}$$

which may account for flows in both positive and negative x and y-directions. The flow rates per unit width in the x and y-directions can be obtained from Eq. (5) as

$$q_x = \frac{C}{n} Z R_x^{2/3} \frac{\left\{-\frac{\partial h}{\partial x}\right\}}{\left|\frac{\partial h}{\partial x}\right|^{1/2}} \tag{6a}$$

$$q_y = \frac{C}{n} Z R_y^{2/3} \frac{\left\{-\frac{\partial h}{\partial x}\right\}}{\left|\frac{\partial h}{\partial x}\right|^{1/2}} \tag{6b}$$

Substituting Eq. (6) into Eq. (1), gives

$$\frac{\partial}{\partial x}\left[\frac{C}{n} Z R_x^{2/3} \frac{\left\{-\frac{\partial h}{\partial x}\right\}}{\left|\frac{\partial h}{\partial x}\right|^{1/2}}\right]$$

$$+\frac{\partial}{\partial y}\left[\frac{C}{n} Z R_x^{2/3} \frac{\left\{-\frac{\partial h}{\partial y}\right\}}{\left|\frac{\partial h}{\partial y}\right|^{1/2}}\right] + \frac{\partial h}{\partial t} = 0$$

or

$$\frac{\partial}{\partial x}\left[K_x \frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_y \frac{\partial h}{\partial y}\right] = \frac{\partial h}{\partial t} \tag{7}$$

where

$$K_x = \frac{C}{n} Z R_x^{2/3} \Big/ \left|\frac{\partial h}{\partial x}\right|^{1/2}$$

and

$$K_y = \frac{C}{n} Z R_y^{2/3} \Big/ \left|\frac{\partial h}{\partial y}\right|^{1/2}$$

The numerical algorithms used for solving Eq. (7) are fully discussed by Guymon and Hromadka (1986) and in the U.S.G.S. Water Resources Investigation Report, 87-4137 (Hromadka and Yen, 1987). The data preparation needs for a floodplain analysis is also discussed in the U.S.G.S. Water Resources Investigation Report (Hromadka and Yen, 1987).

Application of the DHM to the Study Area

A global Manning's roughness coefficient of n = 0.045 was initially used in this study, except at major obstructions, such as freeways. Roughness coefficients for freeway undercrossings were assumed to be n = 0.020. Effective grid areas (Fig. 1) were also assigned to the elements that are adjacent to the freeways. This decreased the available storage of the particular grid. The net effects of using the flow path reduction factor and the decreased available storage is to achieve more realistic results for the floodplain analysis.

Based upon an aerial photograph and a field investigation of the study area, it was assumed that the flood flows will mostly be contained within flow-paths in which streets exist. On the average, widths of these flow-paths comprise one-fifth of a typical cross-section, i.e, the flow-path reduction factor is 0.8. An average effective grid area was also found from the aerial photograph. Buildings occupied thirty-five percent of the photographed area. In this study all buildings were assumed to be excluded from available storage; therefore a global effective area factor of 0.65 was applied.

A 100-year frequency runoff hydrograph of the Santa Ana River at Imperial Highway (see Figure 1) was generated by the U.S. Army Corps of Engineers, Los Angeles District (1987). This hydrograph was used in the subject DHM model, by dividing the runoff hydrograph into segments (see Figure 2) according to the peak breakout flowrates estimated in the referenced Corps of Engineers' study. The peak 5000 cfs was applied at Katella Avenue; the next 19,000 cfs breaks out just north of the Garden Grove Freeway. Immediately south of the Garden Grove Freeway, 1000 cfs breaks out on the west and east banks. Only the west bank overflow was applied to the model. An underlying assumption in the Corps' breakout analysis was that the eastern overflows return to the river downstream from the study site, so the overflow is ignored in this model. Finally, 3000 cfs overflows the west bank at Fairview Street.

The maximum flood depths calculated using the DHM are shown in Figure 3. These depths occur at various times throughout the total simulation time of 24 hours, although depths close to the maximum depths will remain for hours before and after the peaks. The floodplain boundary (see Figure 2) is derived from the maximum flood depths and the ground elevations.

In general, the DHM is used for floodplain analysis because this approach is capable of handling unsteady backwater effects in overland flow, unsteady overland flow due to constrictions, such as culverts, bridges, freeway underpasses, and so forth, unsteady flow overland flow across watershed boundaries due to backwater and ponding flow effects. In general, several important types of information can be generated from the DHM analysis. These include (1) the time versus flood depth relationship; (2) the flood wave arrival time; (3) the maximum flood depth arrival time; (4) the *direction and magnitude of the flood wave; (5) the stage versus discharge* relationship; and (6) the outflow hydrograph at any specified grid element within the study area.

Conclusions

The DHM (1987), which provides another tool for floodplain management, was published by the U.S. Geological Survey as a Water Resources Investigations Report (87-4137). The flow-path reduction factor and the effective grid area were added to the DHM (1987) for a more realistic representation of the field conditions.

Because the DHM provides a two-dimensional hydrodynamic response, use of the model eliminates the uncertainty in predicted flood depths due to the variability in the choice of cross-sections used in the one-dimensional models. That is, model users might select a cross-section perpendicular to *the direction of flow, but on urban area* the selection becomes somewhat arbitrary. Additionally, the DHM accommodates both backwater effects and unsteady flow, which are typically neglected in HEC-2 (1973) floodplain analysis.

NOTICE

The computational results shown in this paper are to be used for research purposes only. No governmental approval of the results shown are to be construed nor implied.

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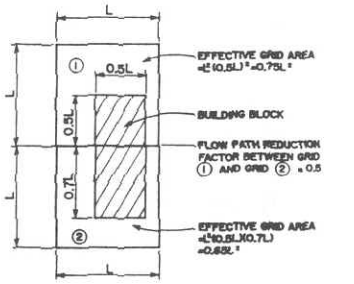

Figure 1. Flow Path Reduction Factor and Effective Grid Area Features.

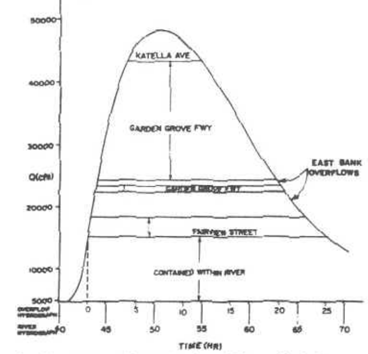

Figure 2. Segmented Santa Ana River 100-Year Runoff Hydrograph at Imperial Highway.

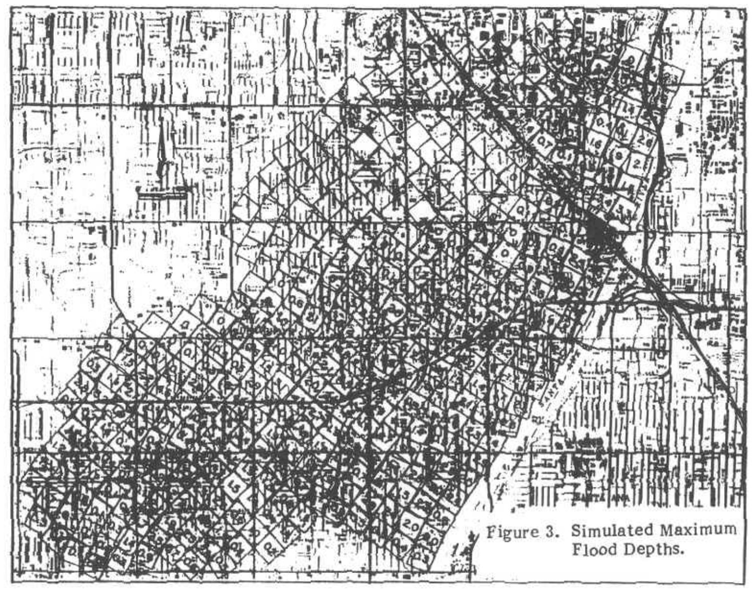

Figure 3. Simulated Maximum Flood Depths.