Using the Diffusion Hydrodynamic Model (DHM) to Evaluate Flood Plain Environmental Impacts

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Abstract

The two-dimensional Diffusion Hydrodynamic Model or DHM is applied to the evaluation of flood plain depths developed from an overflow of a leveed river. The environmental concerns as to flood protection and high flow velocities can be better studied with the help of the two-dimensional DHM flow model than by use of the standard one-dimensional modeling techniques. In the considered test case, the predicted flood depth differences between the DHM and the standard one-dimensional approach are found to be significant. The approach to using the new DHM to an actual field problem is presented, along with comparative results developed by a sensitivity analysis. Although the DHM develops considerable information, it is straightforward to use and does not require expertise beyond that required for use of the more standard one-dimensional models.

1. INTRODUCTION

The main objective of this report is to summarize the findings of a detailed study of the Santa Ana River 100-year event flood plain in the City of Garden Grove, near Garden Grove Boulevard and Haster Street, using the new two-dimensional Diffusion Hydrodynamic Model (DHM) developed in [1]-[9], recently approved for publication in the US Geological Survey Water Resources Division [11] (and is available to the public as a non-proprietary computer program). With the DHM, two-dimensional unsteady flow characteristics can be evaluated at the study site rather than using the traditional one-dimensional methods (e.g. HEC-2) such as typically utilized in engineering studies of flood plains.

Because the DHM provides a two-dimensional hydrodynamic response, use of the model eliminates the sensitivity in predicted flood depths due to the variability in the choice of cross-sections used in the standard one-dimenionalmodels. That is, model users might select a cross-section perpendicular to the direction of flow, but on alluvial fans the selection becomes somewhat arbitrary even though ti affects the results. Additionally, the DHM accommodates both backwater effects and unsteady flow, which are typically neglected in flood plain studies (see [10]).

It is stressed that the objectives of this paper are not developmental, but rather to provide a demonstration in the application of the DHM to an actual flood plain study. Because the DHM is a new computer model recently developed for the public use, applications of the mdoel are few and there is an important need to demonstrate the modeling technique in typical environmental flood plain studies.

The subject application study site is located in the City of Garden Grove, California, at the northwest corner of the street intersection of Garden Grove Boulevard and Haster Street (see Fig. 1). The local terrain slopes southwesterly as a mild gradient and is fully developed with mixed residential and commerical developments. The Garden Grove Freeway forms a barrier on the southerly side of the study boundary in that all flows are blocked with an outlet at the Garden Grove Boulevard crossing under the freeway. Consequently, flood flows from the Santa Ana River would flow in this region southwesterly from the Santa Ana River, bounded by the Garden Grove Freeway. Because of the large quantity of flood flows and the mild cross-sectional terrain, the flood plain hydraulics needs to include the effects of both unsteady flow and the two-dimensional flow characteristics.

2. DHM MODELING APPROACH

The DHM provides the capability to model two-dimensional unsteady flows where storage effects and divergin flow paths are important and hence, traditional models of steady-state one-dimensional flows (such as HEC-2) may be inappropriate. Details on the theory, use, and verification of the DHM are contained in the cited references and, in full development, the U.S.G.S.DHM report. Because of the available references, and the length of detail needed to develop the DHM, any discussion of the DHM is not presented herein. Rather, only the application of the DHM to develop flood plain environmental impacts is considered.

The modeling approach to the subject study is to utilize two models of the considered anta Ana River over-

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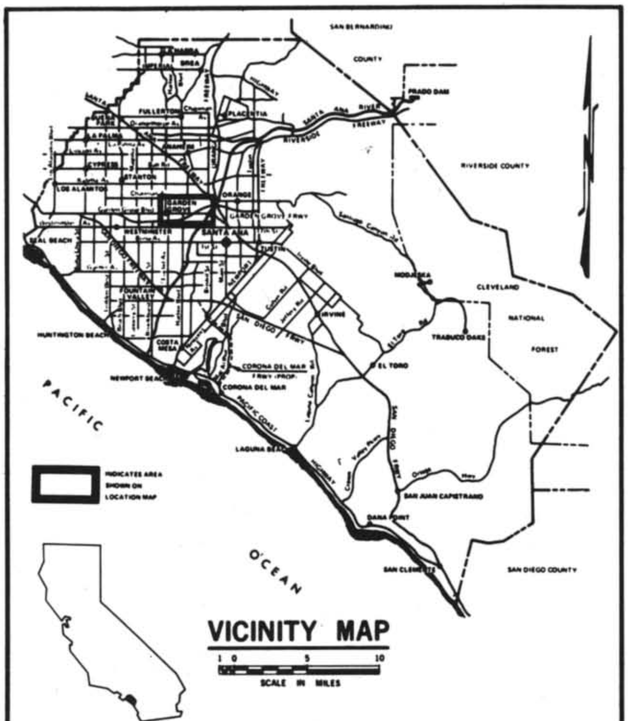

FIGURE 1
VICINITY MAP OF PROJECT SITE

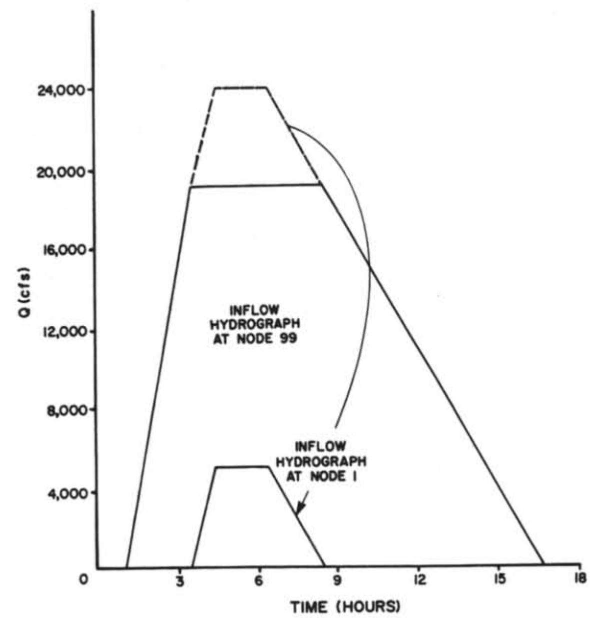

FIGURE 2
INFLOW HYDROGRAPHS AT NODES 1 AND 99 OF GLOBAL DHM MODEL

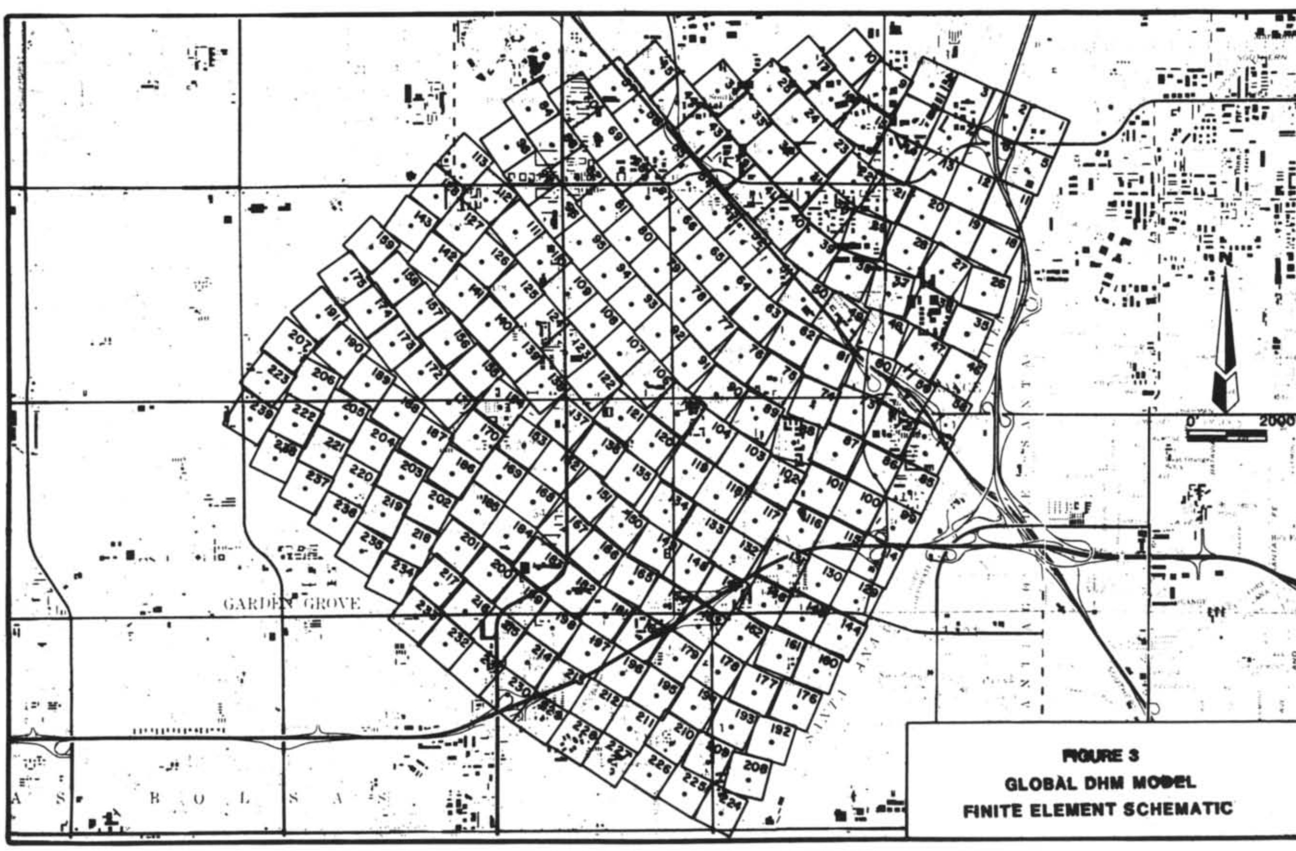

FIGURE 3
GLOBAL DHM MODEL
FINITE ELEMENT SCHEMATIC

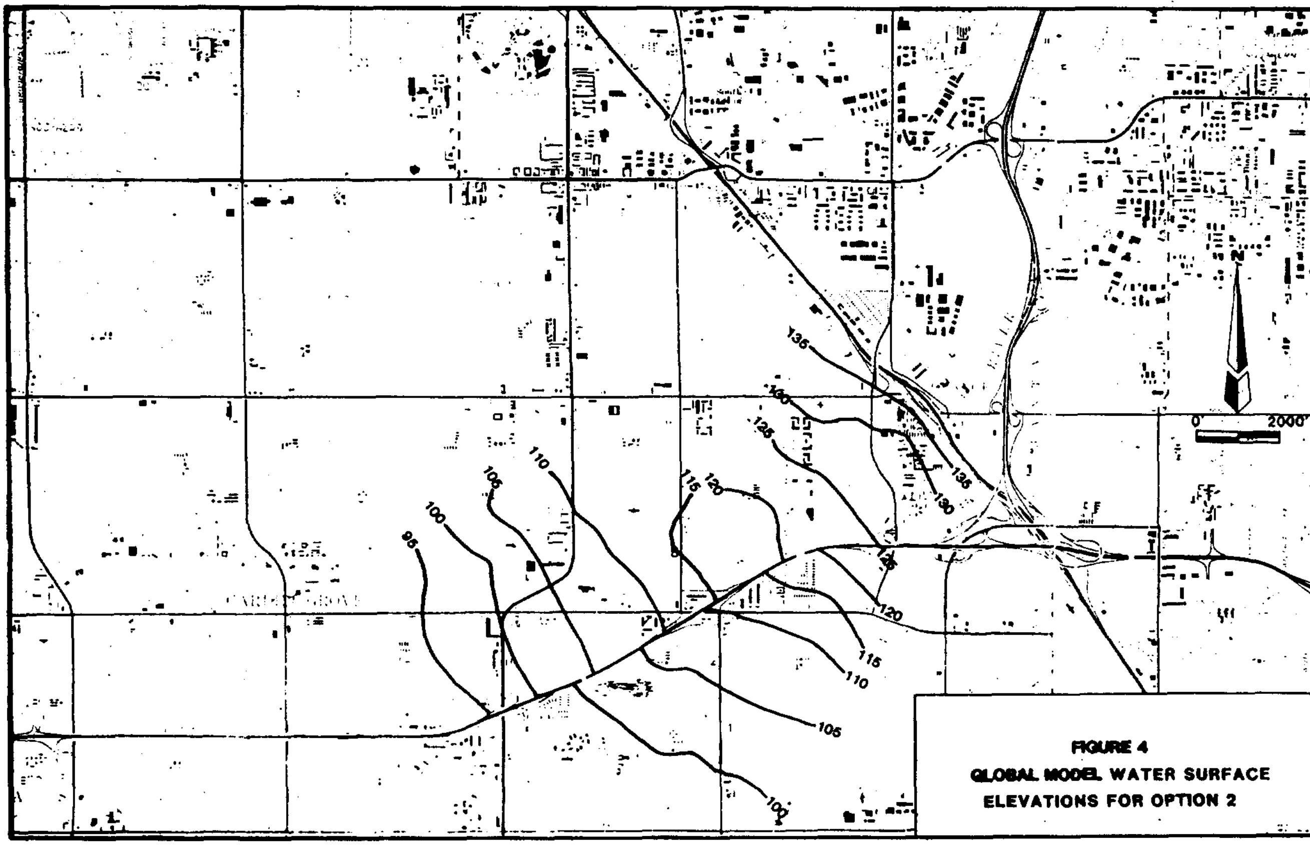
FIGURE 4
GLOBAL MODEL WATER SURFACE
ELEVATIONS FOR OPTION 2
0'
2000'

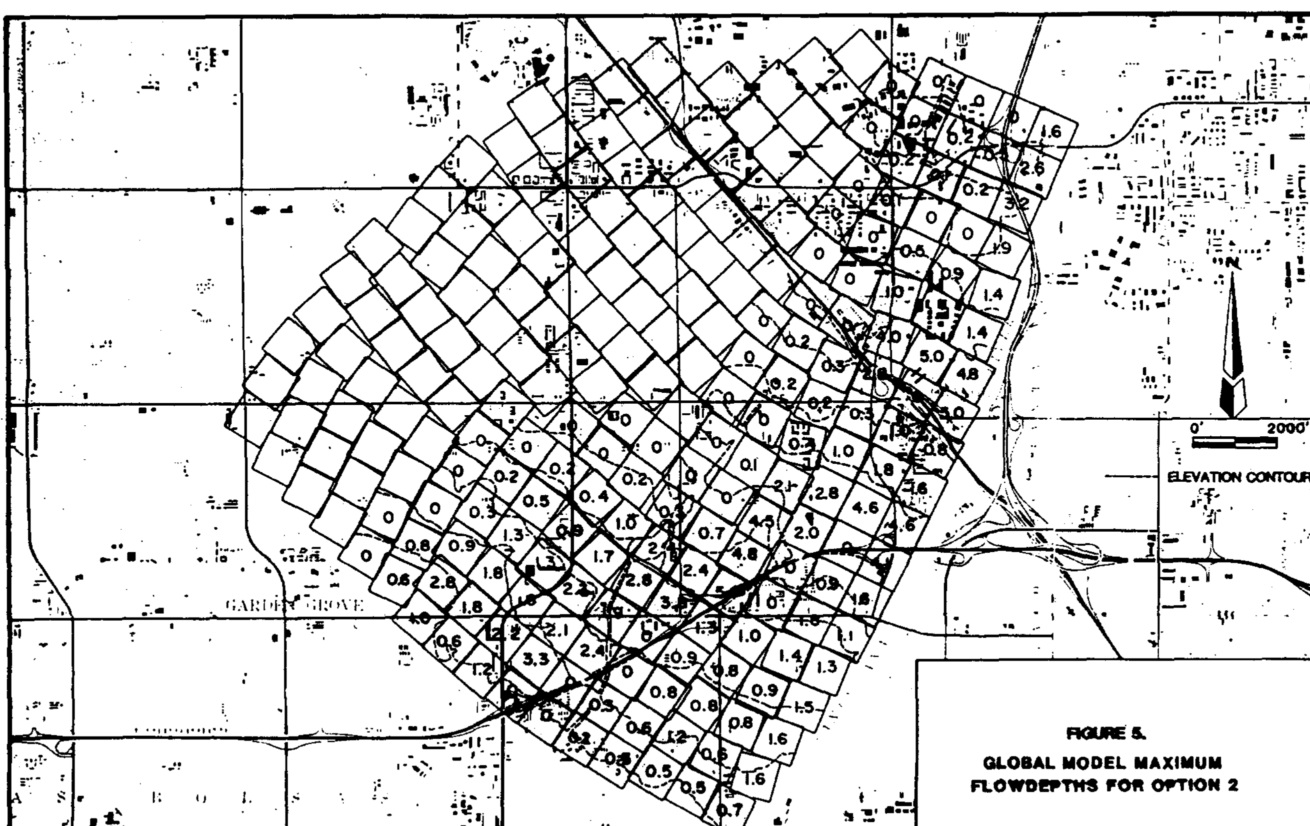
FIGURE 5.
GLOBAL MODEL MAXIMUM
FLOWDEPTHS FOR OPTION 2
0'
2000'
ELEVATION CONTOUR

flow. The first model is a global DHM schematic where an entire region is studied in order to develop broad based flow characteristics of the hypothesized massive outflows. The second model used is a detailed DHM schematic where a small portion of the global model is finely detailed DHM, using the global model results to define the detailed model's boundary conditions of inflow. The limits of the detailed model's domain is developed by using successively larger domains until the foow characteristics identified at the study site do not change with further increase in the size of the domain. In this way, the backwater effects of the downstream floodplain are included in the flowdepth predictions.

The flow boundary conditions of the global DHM model are obtained from use of two assumptions:

(1) all storm drain systems at the study site are flowing at capacity and accommodate the storm runoff occurring simultaneously with the Santa Ana River flow outbreak; and

(2) the Santa Ana River flow outbreak follows the hudrographs shown in Fig. 2. These hydrographs were obtained by use of an available study prepared by the U.S. Army Corps of Engineers, Los Angeles District Office (COE), (Ref. 12). The study indicates out flows of peaks 19,000 and 5,000 cfs (cubic feet per second) at the two locations of the Garden Grove Freeway (Node 99) and Katella Avenue (Node 1), respectively. In this study, the runoff hydrographs were obtained by simply utilizing the peak 24000 cfs of the Santa Ana River design 100-year runoff hydrograph as shown in Fig. 2.

Another boundary condition of the two-dimensional flood plain is the flow release at the Garden Grove Freeway and Garden Grove Boulevard. The DHM includes this flow characteristic by diffusion routing according to the width of the underpass. That is, the topographic model accommadated this restricted outflow by using the appropriate hydraulic flow-width and Manning's friction factor as calculated in Table 1.

Figure 3 shows the DHM global model finite element schematic with grid spacing. Topographic data (obtained rom published U.S.G.S. maps) are used for elevation information. Several options were considered in order to evaluate modeling sensitivity. Table 1 lists the several options considered. (See next page)

The detailed model is based on aerial topography data obtained for this study. Using an inflow hydrograph (Fig. 7) obtained from Node 117 of the global model study, the detailed model better represents the local topography and therfore better desvribes the flow characteristics at the study site. Figure 8a shows the detailed model finite element schematic. Figure 8b shows the boundary of the detailed model within the global model schematic.

Figures 9, 10, and 11 show the detailed model water surface elevations, maximum flow depths, and stream flow velocities, respectively.

For the detailed model, effective areas are used which represent that area where rapid water volume changes are available. Additionally, effective flowpaths are used which represent the length of each grid boundary where flows can cross. In all cases,the buildings are assumed to "survive" the flood which represent a conservative condition in that with less volume available, higher flood depths will be predicted. Block walls are assumed to fail as is customarily assumed in such catastrophic flood events. From the detailed study, the study site is anticipated to have a maximum flood depth of about 3.3 feet.

CONCLUSIONS

The DHM has been applied to two modeling schematics in order to predict the maximum flood depth corresponding to the 100-year storm Santa Ana River flow outbreak. The results of this preliminary study is that the maximum flood depth is less than approximately 5 feet.

In a previously prepared flood plain study (see Ref 13), developed by use of standard one- dimensional model, the flood plain indicates a maximum flood depth of about 10 feet. Figure 12 compares the one-dimensional (HEC-2) flood plain and the global DHM flood plain. From the figure, it is seen that the differences in predictions are significant.

The main differences in the predicted flood plain depths, are due to the dimensionality of the two studies, and the neglect of unsteady flow in the one-dimensional study.

REFERENCES

1. Hromadka II, T.V., Predicting Dam-Break Flood Depths Using a One-Dimensional Diffusion Model: Microsoftware for Engineers, 1985, 1, 1
2. Hromadka II, T.V., Berenbrock, C.E., Freckleton, J.R. and Guymon, G.L., A Two-Dimensional Dam-Break Flood Plain Model: Advances in Water Resources, 1985, 8, 1, 7-14
3. Guymon, G.L. and Hromadka II, T.V., Two-Dimensional Diffusion Probabilistic Model of a Slow Dam Break: Water Resources Bulletin, 1986, 22, 2, 257-265
4. Hromadka II, T.V. and Durbin, T.J., Two-Dimensional Dam-Break Flood Flow Aanalysis for Orange County Reservoir; Wat. Res. Bulletin, 1986, 22, 2, 249-255
5. Hromadka II, T.V. and Nestlinger, A.J., Using a Two-Dimensional Diffusion Dam-Break Model in Engineering Planning, Proceedings: ASCE Workshop on Urban Hydrology and Stormwater Management, Los Angeles County

Flood Control District Office, Los Angeles, Calif., May 1985
6. Hromadka II, T.V., and Yen, C.C., A Diffusion Hydrodynamic Model: I. Model Development, Advances in Water Resources, 1986, 9, 3, 118-121
7. Hromadka II, T.V., and Yen, C.C., A Diffusion Hydrodynamic Model (DHM), Advances in Water Resources, 1986, 9, 3, 122-131
8. Hromadka II, T.V., and Yen, C.C., A Diffusion Hydrodynamic Model: III. Program Description of DHM Model, Advances in Water Resources, 1986, 9, 3, 131-135
9. Hromadka II, T.V., and Yen, C.C., A Diffusion Hydrodynamic Model: IV. Applications of the DHM, Advances in Water Resources, 1986, 9, 3, 136-155
10. Hromadka II, T.V., and Yen, C.C., A Diffusion Hydrodynamic Model: V. Comparison Between Kinematic Routing and DHM Model, Advances in Water Resources, 1986, 9, 3, 156-170
11. Hromadka II, T.V., and Yen, C.C., A Diffusion Hydrodynamic Model, Water Resources Investigations Report, 87-4137, US Geological Survey, 1987. (Available for Public Release)
12. US Army Corps of Engineers, Los Angeles District Office, Santa Ana River Phase 1 - General Design Memorandum, 1985
13 Federal Emergency Management Agency, Flood Insurance Study, City of Garden Grove, California, 1982

TABLE 1. DHM GLOBAL MODEL SCHEMATIC RESULTS

OPTION	DESCRIPTION	DEPTH AT STUDY SITE
1	n=0.045, except at freeway undercrossings where $n = 0.02 \times \dfrac{1000\text{ ft.}}{\text{width of undercrossing (ft.)}}$	3.6 ft.
2	same as option 1, except n= 0.20 at site	3.8 ft.
3	n=0.010, except at freeway undercrossings where $n = 0.02 \times \dfrac{1000\text{ ft.}}{\text{width of undercrossing (ft.)}}$	4.2 ft.
4	same as option 3, except n=0.20 at site	4.3 ft.
5	same as option 4, with project flood hydrograph	8.2 ft.
6	n=0.50, except at freeway undercrossings where $n = 0.02 \times \dfrac{1000\text{ ft.}}{\text{width of undercrossing (ft.)}}$	6.3 ft.

Note: n is Manning's friction factor

For the case of Option 2, Fig. 4 shows the anticipated water surface elevations, while Figs. 5 and 6 show maximum flowdepths and stream flow velocities, respectively.

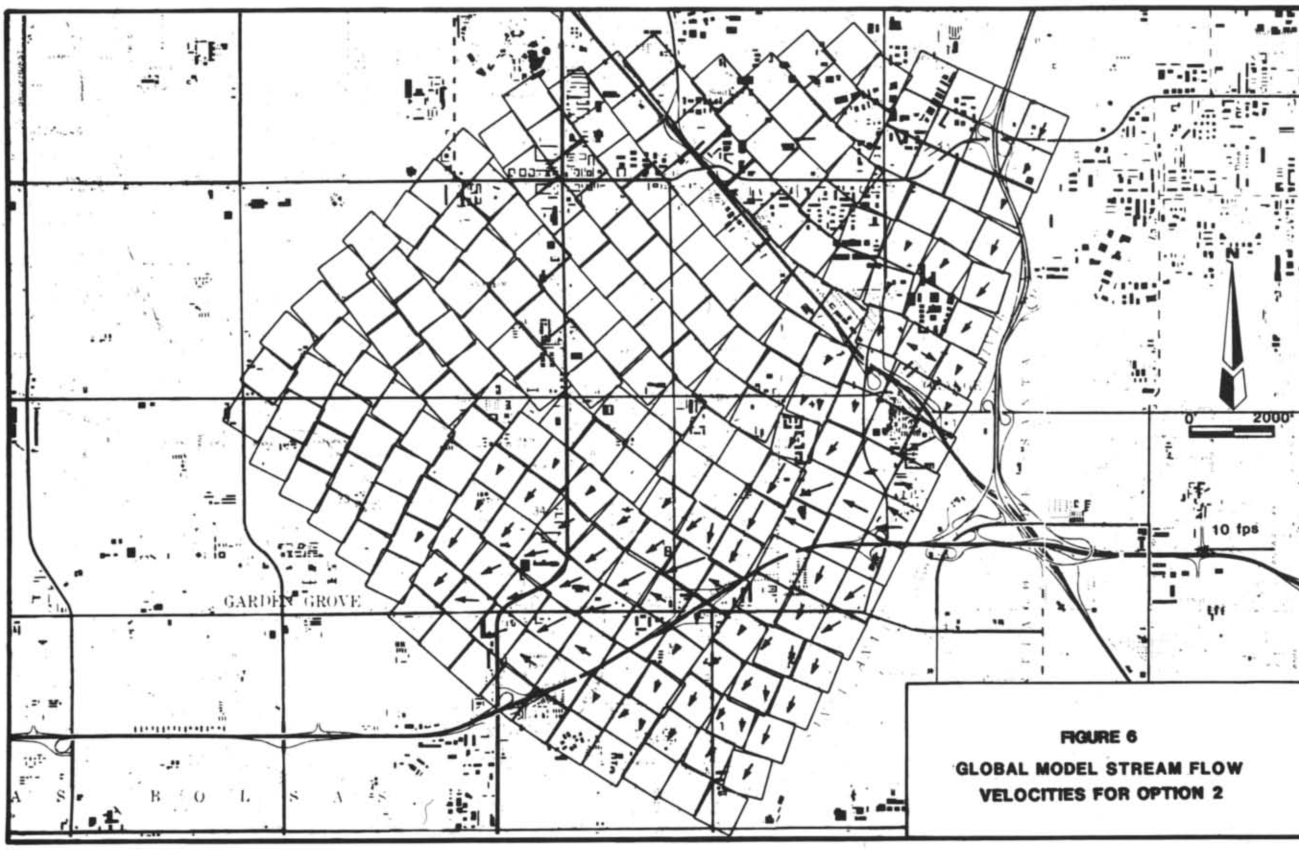

FIGURE 6
GLOBAL MODEL STREAM FLOW VELOCITIES FOR OPTION 2

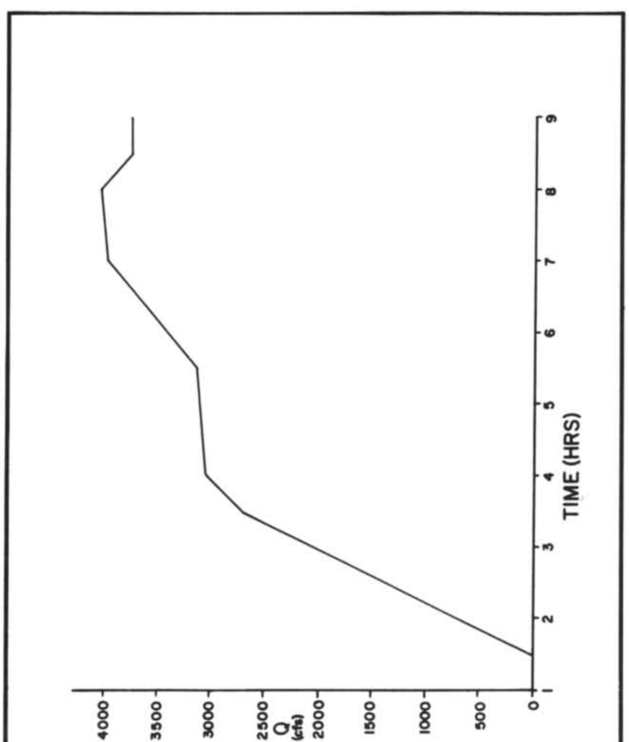

FIGURE 7.
INFLOW HYDROGRAPH AT NODES 1, 2, 3, 4 OF DETAILED DHM MODEL

FIGURE 8a.
DETAILED DHM MODEL FINITE ELEMENT SCHEMATIC

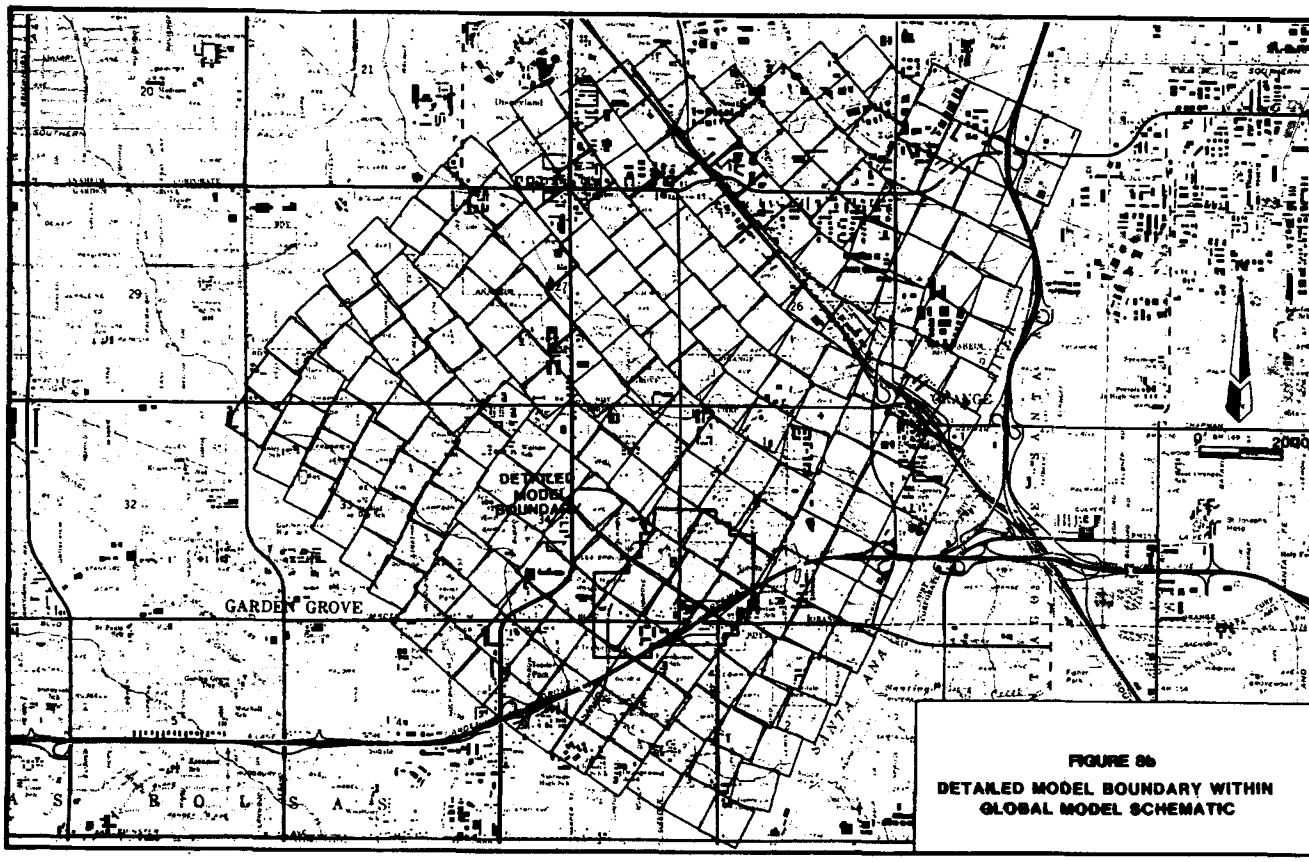

FIGURE 8b

DETAILED MODEL BOUNDARY WITHIN GLOBAL MODEL SCHEMATIC

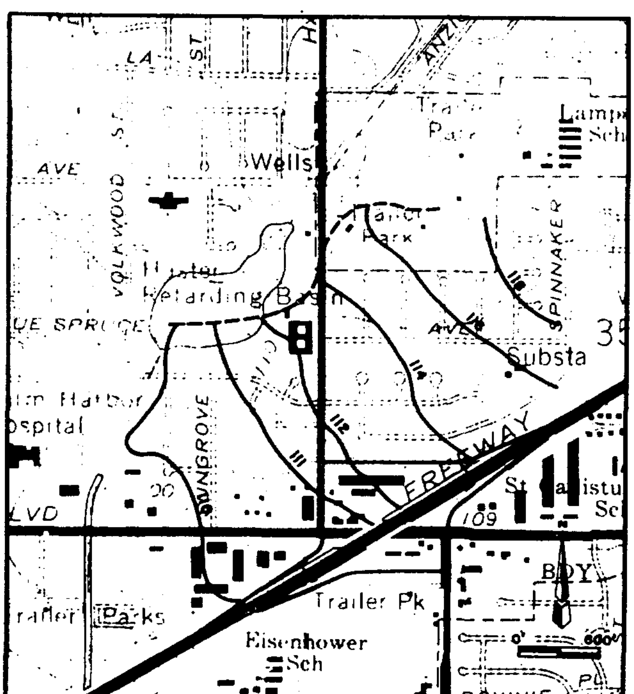

FIGURE 9.

DETAILED MODEL WATER SURFACE ELEVATIONS

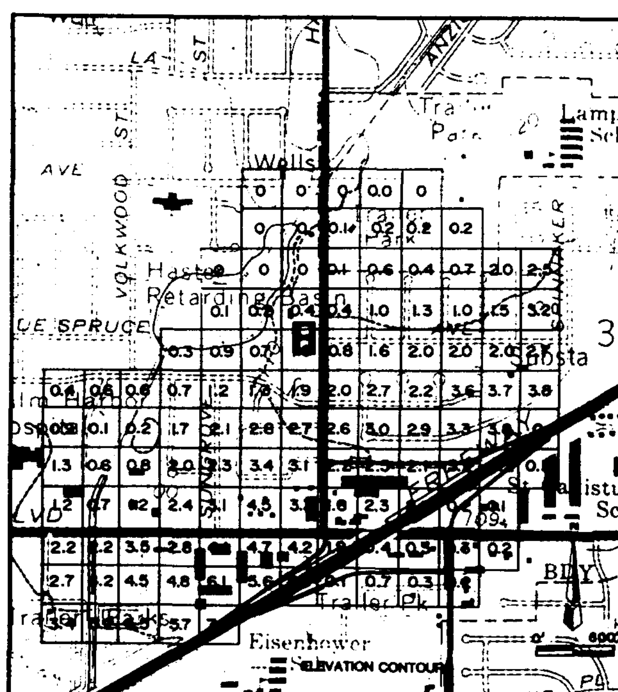

FIGURE 10

MAXIMUM FLOWDEPTHS FOR DETAILED MODEL

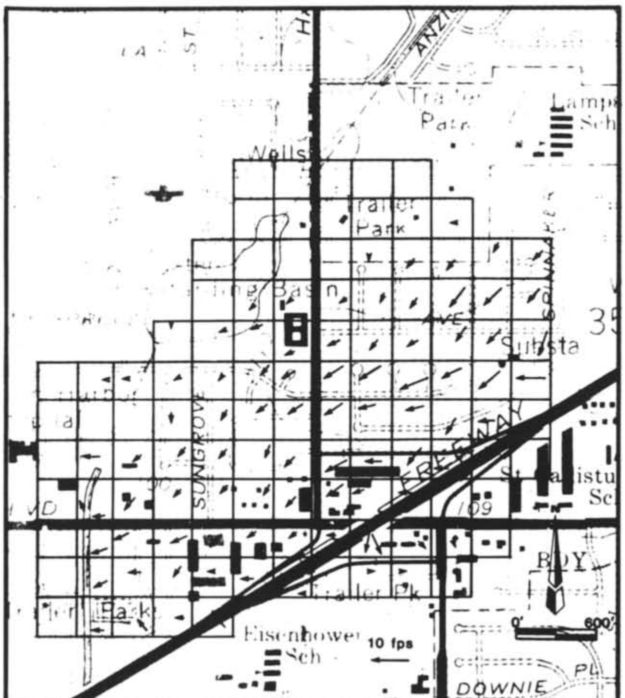

FIGURE 11

DETAILED MODEL STREAMFLOW VELOCITIES

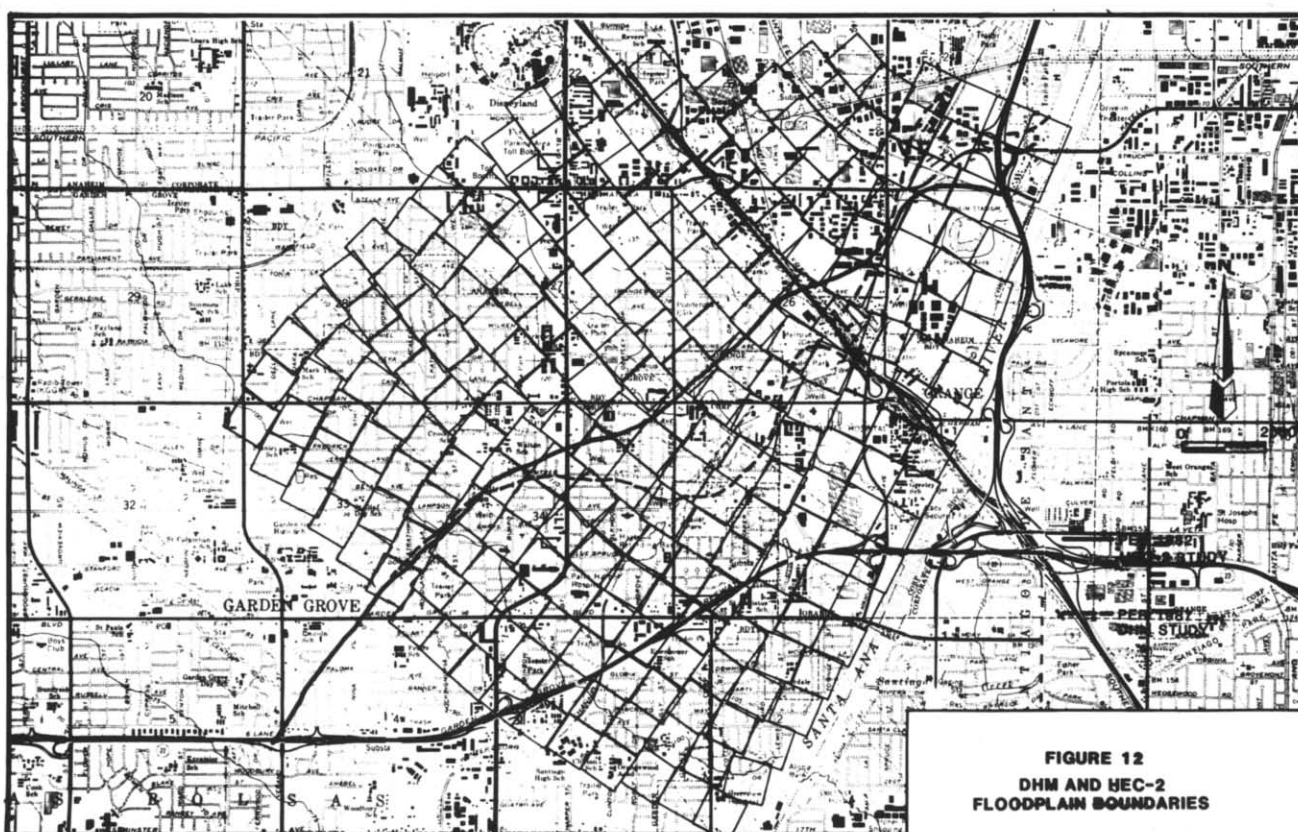

FIGURE 12
DHM AND HEC-2
FLOODPLAIN BOUNDARIES