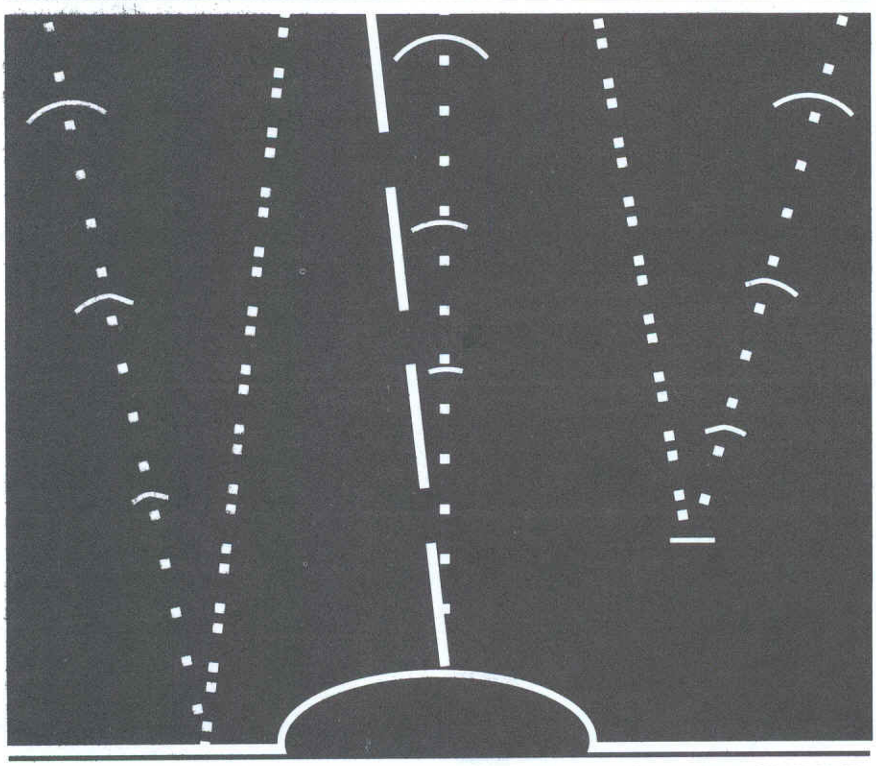
28,

# SYMPOSIUM ON INVERSE PROBLEMS:



# GEOPHYSICAL APPLICATIONS

## Marriott Tenaya Lodge at Yosemite
## Fish Camp, California
## December 16 - 19, 1995

*Conducted by SIAM with the cooperation of Gesellschaft für Angewandte Mathematik und Mechanik (GAMM)*

## CONFERENCE SERIES ORGANIZING COMMITTEE

**Heinz W. Engl (Co-chair)**
*Johannes-Kepler Universität, Austria*

**William Rundell (Co-chair)**
*Texas A&M University, College Station*

**David L. Colton**
*University of Delaware*

**Alfred Louis**
*Universität Saarlandes, Germany*

## CONTENTS

## SYMPOSIUM THEMES

Groundwater Flow

Seismology

Geophysical Prospecting

Electromagnetic Waves

siam®
Society for Industrial and Applied Mathematics
FINAL Program

# PROGRAM-AT-A-GLANCE

## Friday Evening, December 15

**7:00 AM-6:00 PM** **Registration opens**
*Tenaya Ballroom Foyer*

**7:00-9:00** **Welcoming Reception**
*Tenaya 4*

## Saturday Morning, December 16

**7:00 AM-6:00 PM** **Registration opens**
*Tenaya Ballroom Foyer*

**8:45** **Welcoming Remarks**
William Rundell and Heinz Engl
*Tenaya 1*

---

**9:00** **IP1** **The Mathematics of Velocity Analysis**
William W. Symes
*Tenaya 1*

---

**10:00** **Coffee**
*Tenaya 4*

**10:30 AM-12:30 PM** **Concurrent Sessions**

**CP1** **Regularization Techniques I**
*Tenaya 1*

**CP2** **Travel-Time Seismology**
*Tenaya 2*

## Saturday Afternoon, December 16

**12:30** **Lunch**

---

**2:00** **IP2** **Inverse Problems for Groundwater Contamination and Petroleum Applications**
Richard E. Ewing
*Tenaya 1*

---

**3:00** **Coffee**
*Tenaya 4*

**3:30-5:30** **Concurrent Sessions**

**CP3** **Inverse Scattering**
*Tenaya 2*

**CP4** **Remote Sensing**
*Tenaya 1*

**CP4A** **Seismic Velocities**
*Madera*

---

**5:45** **IP3** **The Inversion of Body Wave Attributes Derived from Seismic Refraction Data**
Robert L. Nowack
*Tenaya 1*

---

## Sunday Morning, December 17

**7:30-11:00** **Registration opens**
*Tenaya Ballroom Foyer*

**8:30-11:00** **Concurrent Sessions**

**CP5** **Earth Structure and Tectonics**
*Tenaya 1*

**CP6** **Groundwater and Hydrology I**
*Tenaya 2*

**11:00** **Coffee**
*Tenaya 4*

---

**11:30** **IP4** **Underground Imaging of Electrically Conducting Plumes**
James G. Berryman
*Tenaya 1*

---

**12:30** **Lunch**

**Afternoon is free or join the Yosemite Valley Mariposa Grove Tour.**

## Sunday Evening, December 17

---

**7:00** **IP5** **A Geometrical Analysis of the MBTT Approach to Inversion of Seismic Data**
Guy Chavent
*Tenaya 1*

---

**8:00-10:00** **Concurrent Sessions**

**CP7** **Seismology I**
*Tenaya 1*

**CP8** **Regularization Techniques II**
*Tenaya 2*

**CP9** **Spectral Methods**
*Madera*

## Monday Morning, December 18

**7:30-11:00** **Registration opens**
*Tenaya Ballroom Foyer*

**8:30-11:00** **Concurrent Sessions**

**CP10** **Data Inversion**
*Tenaya 1*

**CP11** **Geo-Electrical Techniques**
*Tenaya 2*

**11:00** **Coffee**
*Tenaya 4*

---

**11:30** **IP6** **Inverse Boundary Value Problems Arising in Geophysics**
Gunther Uhlmann
*Tenaya 1*

---

**12:30** **Lunch**

**Afternoon is free.**

## Monday Evening, December 18

---

**7:00** **IP7** **Inverse Problems in Geodesy**
Willi Freeden
*Tenaya 1*

---

**8:00-10:00** **Concurrent Sessions**

**CP12** **Groundwater and Hydrology II**
*Tenaya 2*

**CP13** **Wave Propagation Methods**
*Madera*

**CP14** **Gravimetry**
*Tenaya 1*

## Tuesday Morning, December 19

**7:30-11:00** **Registration opens**
*Tenaya Ballroom Foyer*

---

**8:30** **IP8** **Geologically Constrained Reflection Tomography**
Kurt J. Marfurt
*Tenaya 1*

---

**9:30** **Coffee**
*Tenaya 4*

**10:00 AM-12:30 PM** **Concurrent Sessions**

**CP15** **Seismology II**
*Tenaya 1*

**CP16** **Heat Transfer and Diffusion**
*Tenaya 2*

**CP17** **Acoustics**
*Madera*

**CP18** **Groundwater and Hydrology III**
*Mariposa*

**12:30 PM** **Conference adjourns**

---

*Times allowed for each presentation, including discussion:*

*30 minutes for a contributed presentation (CP)*

*60 minutes for an invited presentation (IP)*

*The organizing committee expects every speaker of a scheduled presentation to register and attend the conference. If it becomes inevitable for a speaker to cancel the presentation, the speaker is expected to find an alternate presenter or one of the speaker's co-authors should give the presentation.*

*A canceled presentation can cause serious inconvenience to the attendees and conference organizers.*

***NOTE: For papers with multiple authors, the speaker is shown in italics if known at press time.***

## PROCEEDINGS

The proceedings will be available in August 1996. All attendees will be notified and will be offered a special discount. The proceedings is not included in the registration fee.

*10:00 AM-12:30 PM*

## Concurrent Sessions

*CP15/Tenaya 1*

### *Seismology II*

Chair: Kurt J. Marfurt, Amoco Exploration and Production Technology

**10:00 Development of Three-Dimensional Finite Element Models for Geologic Structures**
Lawrence D. Porter, Autonnic Research, Inc., Alamo, California

**10:30 Time-Pulse Propagation and Inverse Problem Solution for Layered Medium**
*V.I. Klyatskin*, K.V. Koshel and B.M. Shevtsov, Russian Academy of Sciences, Russia

**11:00 Inverse Problem for Buried in Nonisotropic Medium Moving Oscillating Source**
*Vladimir A. Pozdnyakov*, Alexandr A. Tuzovsky, and Dmitry V. Safonov, State University of Krasnoyarsk, Russia

**11:30 Application of the Results of Analytical Function Approximation by Means of Rational Function with Prescribed Poleses and Quasi-Analytical Continuation to Decision Inverse Problem of Potential Two-Dimension Fields**
G.C. Tumarkin, Moscow State Geology-Prospecting Academy, Russia

**12:00 Regularizing an Inverse Seismic Problem for Oil Prospection**
Susana Gomez, IIMAS National University of Mexico, Mexico

*CP16/Tenaya 2*

### *Heat Transfer and Diffusion*

Chair: To be determined

**10:00 Determination of the Surface Temperature from Interior Observations**
Dinh Nho Hao, Universität GH Siegen, Germany

**10:30 A Numerical Algorithm for Parameter Estimations**
Jianping Zhu, Mississippi State University

**11:00 Determining Heat Sources in Rock Dumps**
Jerard M. Barry, Australian Nuclear Science and Technology Organisation, Australia

**11:30 Inverse Approximation of a Hydrodynamic Flooding Problem**
Theodore V. Hromadka, California State University, Fullerton

**12:00 Inverse Problem of Heat Transfer in Geological Surrounding**
*L.S. Monastyrsky*, A.S. Kokodyniak, and R.M. Kovtun, Lviv State University, Ukraine

*CP17/Madera*

### *Acoustics*

Chair: Pierre C. Sabatier, Université Montpellier 2, France

**10:00 A Patchwork Approach to Inverse Problems**
Pierre C. Sabatier, Université Montpellier 2, France

**10:30 Globally Convergent Layer Stripping Method in Diffusion Tomography and Inverse Acoustics**
Michael V. Klibanov, University of North Carolina, Charlotte

**11:00 Multipath Identification and Truncated Total Least Squares Solution for Ocean Acoustic Tomography**
*Longji Tang*, J. L. Barlow, S. Draganov, A. Fabrikant, and J. Spiesberger, Penn State University

**11:30 The Inverse Problem of a Fourth Order Self-Adjoint Binomial Operator**
Alan Elcrat and *Vassilis G. Papanicolaou*, Wichita State University

*CP18/Mariposa*

### *Groundwater and Hydrology III*

Chair: Giovanni F. Crosta, Universita degli Studi di Milano, Italy

**10:00 Applying Neural Networks to Groundwater Inverse Problems**
*Donna M. Rizzo* and David E. Dougherty, University of Vermont

**10:30 A Multi-Resolution Approach to Hydraulic Conductivity Estimation**
*Michael M. Daniel*, Alan S. Willsky, and Dennis M. McLaughlin, Massachusetts Institute of Technology; and David J. Rossi, Schlumberger-Doll Research

**11:00 A Hybrid Numerical Method for High Contrast Conductivity Problems**
*Liliana Borcea* and George C. Papanicolaou, Stanford University

*12:30*

### *Conference Adjourns*

## SPEAKER INDEX

* Evening Sessions
CP = Contributed Presentation
IP = Invited Presentation

Dinh Nho Hào
Universität- GH Siegen
FB Mathematik
Hölderlinstr. 3
*57068 Siegen, Germany*
E-Mail: hao@numerik.fb6.uni-siegen.de

### A Numerical Algorithm for Parameter Estimations

In this presentation, we will discuss a numerical algorithm for estimating unknown paramters in diffusion equations. The method is based on the first order pertubations. The senstivity coefficients are obtained efficiently without using either the adjoint equations or repeated simulation runs. Applications of this method to the estimation of conductivity coefficient in the heat equation and the permeability distribution in a porous media flow model will also be disccussed.

Jianping Zhu
Department of Mathematics and Statistics
& NSF Engineering Research Center
Mississippi State University
Mississippi State, MS 39762
E-mail: jzhu@math.msstate.edu

### Determining Heat Sources in Rock Dumps

The rate of generation of pollutants in rock dumps may be estimated by solving the inverse problem to determine the strength and location of pockets of oxidisation. A one-dimensional model is solved with regularisation. In this situation temperature data recorded in the dumps is very sparse, and the boundary conditions at the top and bottom of the dumps were not clearly identified. The inverse solution is compared to oxygen depletion readings taken in the dump.

Jerard M. Barry
Australian Nuclear Science and Technology Organisation
Locked Mail Bag 1
Menai NSW 2234, Australia
*Email: jmb@atom.ansto.gov.au*

### Inverse Approximation of a Hydrodynamic Flooding Problem

Currently, little attention has been paid towards developing approximation of the source of flooding, given flood depth versus time data. In this paper, the inverse problem is approximated by use of the United States Geological Survey Diffusion Hydrodynamic Model (DHM), as originally developed by this author in 1986. The DHM is extended to solve the inverse problem, i.e., the source of flooding, given flow hydrographs at specified locations in the flood plain. This approach may be important to flood plain managers who deal with issues regarding flood protection, and who work with flood mitigation measures.

Theodore Vincent Hromadka, Ph.D., Ph.D., PH, PE,
Professor of Mathematics and Environmental Studies,
California State University, Fullerton
Fullerton, California 92634

### Inverse Problem of Heat Transfer in Geological Surrounding

One of the inverse problems of heat-transfer is founding parameters of surrounding if we know temperature-coordinate dependence in it. Such distribution may be obtained in experiment or by numerical solving nonlinear nonstationary differential heat-transfer equation for set means of diffusivity of heat. In inverse heat problems, such as in inverse diffusion problems for research temperatures dependence of diffusivity of heat a(T) may be used Matano method (grafical of numerical).

L.S. Monastyrsky, A.S. Kokodyniak and R.M. Kovtun
Lviv State University
50 Dragomanova Str
Lviv, Ukraine

## CP 17

### A Patchwork Approach to Inverse Problems

In many problems of Ocean geophysics, a three dimensional phenomenon is reconstructed from boundary measurements seated locally, close to the phenomenon. Yet, the basin extends far away, and a global analysis justifying uniqueness theorems should involve far away information. In the present lecture, it is shown when and how the coupling of subdomains can be treated to justify the local analysis.

Pierre C. Sabatier
Universite Montpellier 2
Department of Physique Mathematique
Pl. Eugene Bataillon
34095 Montpellier Cx 05, France
E-Mail: sabatier@lpm.univ-montp2.fr

### Globally Convergent Layer Stripping Method in Diffusion Tomography and Inverse Acoustics

We present an essentially novel approach to multi-dimensional Inverse Scattering Problems (ISP) arising in Diffusion Tomography and Inverse Acoustics. Applications:
(i) ground penetrating radars, (ii) acoustical imaging, and (iii) early non-ionising breast cancer diagnosis. Sources of radiation are (i) electropragmatic, (ii) acoustical, and (iii) lasers respectively.

Our approach is based on the so-called Carleman's Weight Method, which provides a stable layer stripping procedure with guaranteed global convergence, c. f. SIAM J. Math. Anal, 26 (1995), 147-174.

Michael V. Klibanov, Department of Mathematics
University of North Carolina at Charlotte
Charlotte, NC 28223

### Multipath Identification And Truncated Total Least Squares Solution for Ocean Acoustic Tomography

Ocean acoustic tomography is a technique where travel time measurements in the ocean are used to infer ocean properties such as temperature and current velocity. Large-scale fluctuations of temperature in the ocean affect the weather, climate, ocean circulation and the distribution of marine organisms. Therefore, solving this problem by using modern computing methods is an important research project. Mathematically, the ocean acoustic tomography leads to a nonlinear ill-posed integral equation. To solve it, An adjoint algorithm for multiraypath identification and a truncated total least squares algorithm for solving linearized travel time equation are given, regularization effect on TLS algorithm and numerical simulation is discussed.

## INTRODUCTION

In general, flood plain studies are based on an one-dimensional steady-state flow analysis. Flood depths are calculated by assuming normal depth in wide, shallow rectangular sections taken parallel to major contour lines. The overflow boundaries are determined by judgment, and inspection of overflow maps and aerial photographs of historical floods. The above procedures are strictly subjective to the analyst. The DHM computer program used in the current study is a two-dimensional, unsteady flow model which simplifies the two-dimensional St. Venant equations to eliminate local acceleration and inertial terms, and combines the simplified flow equations with the equation of continuity to form a set of diffusion-type partial differential equations. Because the DHM provides a two-dimensional hydrodynamic response, use of the model eliminates the uncertainty in predicted flood depth due to variability in the choice of cross-sections used in the one-dimensional models. Additionally, the DHM accommodates storage, backwater effects, and unsteady flow. In this study, all of the local pipe flow drainage systems, pump stations, and retarding basins were modeled by the DHM as one-dimensional unsteady flow elements. For details regarding the development and verification of the DHM, the reader should refer to the U.S.G.S. Water Resources Investigations Report 87-4137 (Hromadka and Yen,1987).

## STUDY AREA

The Orange County Flood Control District's East Garden Grove-Wintersburg Channel(facility C05) and its tributary Ocean View Channel(C06), drain an area of approximately 18,000 acres (28.13 square miles) within the cities of Anaheim, Fountain Valley, Garden Grove, Huntington Beach, Orange, Santa Ana, and Westminster. The watershed (see Figures 1 and 2) lies on a flat coastal plain and is generally bounded by the Santa Ana River to the east, Talbert Valley watershed (facilities D01, D02, and D05) to the south, the Pacific Ocean to the west and the Westminster Channel watershed (facility C04) to the north.

## DHM MODELING APPROACHES

In this inundation study, a DHM model was used to analyze the existing flood control systems for t-year events (i.e., 100-, 50-, 25-, and 10-year design storms). The DHM model encompasses the entire C05/C06 watershed. The local terrain slopes southwesterly at a mild gradient (about 0.1% to 0.4%) and is fully developed with mixed residential and commercial land development. The storm runoff is collected by the local storm drain systems and then transported to the C05/C06 channel system, which in turn conveys the storm water into Bolsa Chica Marsh and ultimately the Pacific Ocean at Anaheim Bay.

The DHM flood plain grid schematic, using a 1000-foot grid discretization, is shown on Figure 3. Mean ground elevations for each grid were estimated from U.S.G.S. topographic 7.5 minute quadrangle maps (2000 scale). Not all of the grid area is assumed to carry storm flow. to Account for flow obstructions such ad buildings, an average value of 30-percent of the total grid area is used as the effective grid area for fully developed areas. Average street section flow widths within each grid element are estimated to be a total of 100 feet with a Manning's roughness coefficient of 0.02. Thus, the global Manning's roughness coefficient for each 1000-foot grid is 0.20 (i.e., 0.02*1000 feet/ 100 feet) except in locations including open areas where a Manning's roughness coefficient of 0.05 is used, and freeway underpasses where an effective flow path factor and Manning's roughness coefficient of 0.02 are used.

The DHM model was developed with the following elements:

Freeway Element

The Santa Ana Freeway, the Garden Grove Freeway, and the San Diego Freeway are major topographic features in the watershed. In addition to flowing through flood control channels, storm runoff may flow through freeway underpasses, which carry streets and railroads. An effective flow path and the roughness coefficient of n = 0.02, was used to simulate the hydraulic characteristics for all the freeway underpasses. Table 1 lists the effective widths and freeway elements at each freeway underpass which conveys surface runoff under the freeway embankments.

Table 1.
FREEWAY UNDERPASSES AND GRID ELEMENTS

| Location | Grid Element Number | Width of Underpass |
|---|---|---|
| Old Southern Pacific Railroad at I-5 Freeway | (786,769) | 20 feet |
| Garden Grove Boulevard at 22 Freeway | (714,618) | 100 feet |
| Harbor Boulevard at 22 Freeway | (675,833) | 120 feet |
| Trask Avenue at 22 Freeway | (622,563) | 80 feet |
| Newhope Street at 22 Freeway | (649,527) | 200 feet |
| Euclid Street at 22 Freeway | (823,827) | 100 feet |
| Taft Avenue at 22 Freeway | (824,919) | 60 feet |
| Brookhurst Street at 22 Freeway | (903,915) | 100 feet |
| Magnolia Street at 22 Freeway | (898,910) | 100 feet |
| Beach Boulevard at 405 Freeway | (280,255) | 120 feet |

Culverts that convey storm runoff through the freeways are identified in Table 2. Estimated depth-versus-discharge relationships are used to represent freeway culvert hydraulics.

Table 2.
FREEWAY CULVERTS AND GRID ELEMENTS

| Location | Grid Element Number |
|---|---|
| State College Boulevard at I-5 Freeway | (786,759) |
| Katella Avenue at I-5 Freeway | (762,745) |
| Orangewood Avenue at I-5 Freeway | (773,752) |
| C05 at 22 Freeway | (700,601) |
| C05 at 405 Freeway | (309,260) |
| C06 at 405 Freeway | (353,267) |
| Newland Avenue at C06 | (245,246) |
| C05 at Tide Gate | (1) |

## Storage Element

A storage element is a special flood plain element which has a specified depth versus storage relationship other than the ordinary grid flood plain element. For an ordinary flood plain element, the flood depth is calculated by dividing its flood flow volume by its effective area. On the other hand, the flood depth at storage element is determined from a user-specified depth-versus-storage relationship. The outflow from the storage element is based upon the specified depth-versus-discharge relationship which differs from the regular flood plain element which conveys flood flow based on the two-dimensional unsteady flow equations.

There are two retarding basins (Haster and West Street Basins) on the north side of the Garden Grove Freeway, and three storage facilities (Talbert Lake, Huntington Lake and Sand and Gravel Pit) in the City of Huntington Beach. The storage-elevation-discharge relationships were obtained from the feasibility study of the East Garden Grove-Wintersburg Channel by the U.S. Army Corps of Engineers (1988). In this study, the initial water elevations for the Haster and West Street Basins are assumed to be flow line elevations at the outlet structures. For other storage facilities (Talbert Lake, Huntington Lake and Sand and Gravel Pit) which are not Orange County Flood Control District Facilities, the initial water surface elevations are assumed to be at spillway elevation, i.e. no flood control storage was assumed.

## Channel Element

A Channel element can be described as a trapezoidal section which is situated at the center of a flood plain element. The relative depth of the channel is defined as the difference between the representative flood plain and channel bottom elevations as shown in Figure 4. The relative levee height of the channel is defined as the difference between the top-of-berm elevation and the representative flood plain elevation. It is assumed in the flood plain and channel interface model that overflow from the channel is evenly distributed to the associated flood plain element, and the overland flow that enters the channel is tributary from the entire flood plain element. Thus, the interface model serves as a source/sink model for an associated DHM grid element.

### Surcharged Pipe Element

The surcharged pipe element can be used to model the closed conduit drainage systems. It assumes a circular pipe system flowing under pressure with a hydraulic grade line that coincides with the water surface elevations of the connecting flood plain elements or flood plain and channel elements as shown in Figure 5. Non-circular pipe systems were converted into equivalent circular pipe systems for the entire study area. Flood water is transported in a surcharged pipe element by first calculating the friction slope corresponding to the water surface elevations of two connecting elements. By Manning's equation, flood water is transported between these two connecting elements and results in a discrete instantaneous change in water surface elevation at both connecting elements.

### Pump Stations

There are five pump stations in the Cities of Huntington Beach and Fountain Valley. The Slater, Shields, and Marilyn Pump Stations convey storm water directly into the C05 Channel system. The Heil and Sandalwood Pump Stations pump storm water into a local storm drain system which eventually connects to the C05 Channel System. Simplified rating curves were used to model all pump stations.

### T-Year Storm Events and Storm Centers

The temporal and spatial variabilities of a t-year storm event are simulated by applying different storm centerings over the entire C05/C06 watershed for each event. Due to the uncertainties of storm locations, six storm centers, which progressed from the top of the watershed to the C05 Bolsa Chica outlet, were used for each event to analyze the entire watershed response. Data from the Hydrology Report of East Garden Grove-Wintersburg Channel by Orange County Environmental Agency (OCEMA) were used to obtain effective rainfall information for the above-mentioned storm events and storm centerings.

### Initial Conditions and Boundary Conditions

If the initial condition of the DHM modeling area is "dry" (e.g. zero flooding depth), the computer program initially advances its time domain in less than 1-second increments. This results in unreasonably long computation time. To speed computation, yet introduce negligible change in final calculated flooding depths, an initial flooding depth of 0.15 feet was assigned to the entire DHM modeling area. This depth is the average gutter-hike depth and allows the minimum modeling time to be set at 5 seconds.

Three types of outflow boundary conditions are used in the modeling area. "No flow" boundary conditions are assigned to the flood plain boundaries where no flow is allowed to cross. Surface water that migrates into neighboring watersheds without returning to the modeling area is modeled by critical depth boundary conditions. The third boundary conditions uses the specified rating curve (i.e. a depth-versus-discharge relationship) to model a control outlet structure. Rating curves are used to model the flow conditions at the C05 Bolsa Chica outlet, Haster Basin, West Street Basin, and channel undercrossings at various freeways and pump stations.

## DHM MODELING RESULTS

For each t-year event, the maximum flood depths from all six storm centerings were compiled to model the worst possible flooding within the entire watershed. Figure 6 depicts the maximum flood depths in the study area for the 100-year event. Flooding may occur either by inadequate local storm drain system capacity or by inadequate regional (C05/C06) system Capacity, or a combination of both. The model showed that inadequate local storm drain system would cause local ponding and storage, in most cases less than 0.5 foot deep. Sufficient storm volume would be stored locally to significantly decrease the load on regional flood control facilities.

Even with this local storage, the model showed that West Street Basin would be overtopped during any t-year event. Haster Basin would not be overtopped, but would experience emergency spillway flow during the 25-, 50-, and 100-year events.

The model also showed two types of channel overtopping which might occur for the estimated flooded areas due to the interface between channel and flood plain elements. Type I overtopping indicates that the channel has limited capacity and the water surface elevations are the same for both the channel and flood plain elements. Type II overtopping indicates that water overtops the channel levee from flood plain element. Modeled regional type I overtopping areas along the C05 channel system are: near Anthony School in the City of Westminster, between Bushard Street and Brookhurst Avenue, downstream of 405 Freeway, between Golden West Street and Springdale Avenue, and Slater Pump Station. Modeled local type I overtopping areas are: Heil street storm channel (C5-SC-2) and Slater storm channel in the City of Huntington Beach. Most of the type I overtopping along the C05 channel system occurred for the t-year events. No type I or type II overtopping was modeled for the C06 Channel system for the t-year events. The causes of the type II overtopping may be due to either the deficiencies of the local storm drain systems or the cascaded flows from type I overtopping areas, or both. Modeled regional type II overtopping areas along the C05 channel system are: south of Bushard Street, upstream of 405 Freeway, and downstream of 405 Freeway.

The Corps of Engineers 1988 feasibility study reported five areas of significant potential flooding: C05 downstream of I-405 Freeway, Slater Pump Station, Edwards Street and Heil Avenue intersection, Newland Street and Warner Avenue intersection, and C06 downstream of I-405 Freeway. Because of different methodology used by the Corps study, inundated areas and flooding depths were different from the DHM modeling results.

Nevertheless, the same number of areas subject to potential flooding were identified by both studies. In general, DHM reported a greater number of local flood areas with shallower flooding.

## CONCLUSION

DHM, a fully dynamic unsteady two-dimensional flow model was used to model a major regional drainage area. The DHM accommodates pipe flow drainage, pump stations, and retarding basins as one-dimensional unsteady flow elements; regional and overland flow as two-dimensional unsteady flow elements; and temporal and spatial storm centering over the watershed area. By applying different storm centering over the watershed area, the watershed response was analyzed under conditions of uncertainty of storm locations.

DHM proved to be a versatile and practical tool in modeling surface runoff problems related to regional flood protection. DHM significantly advances the current of the art for flood control system modeling and regional flood plain mapping.

areal

A significant advantage conferred by the DHM analysis is the display of the aerial extent and depth of flooding under a wide range of recurrence intervals without the necessity of assigning, *a priori*, the flow paths for overbank flows. Such *a priori* flow path designation is a significant source of uncertainty in the results of non-dynamic models for the analysis of flood plains and is especially critical in watersheds with very flat transverse slopes or on alluvial fans where overbank flows may be spread widely and unpredictably from the main channel.

## REFERENCES

1. East Garden Grove-Wintersburg (C05) and Oceanview (C06) Channels Inundation Studies prepared by Williamson and Schmid, 1992.

2. Hromadka II, T.V. and Yen, C. C., A Diffusion Hydrodynamic Model (DHM), U.S.G.S. Water Resources Investigations Report 87-4137, 1987.

3. Hydrologic Documentation for Feasibility Study, Santa Ana River Basin and Orange County, Interim 3, East Garden Grove-Wintersburg Channel, U.S. Army Corps of Engineers, Los Angeles District, 1988.

4. Hydrology Report for East Garden Grove-Wintersburg Channel, Orange County Environmental Management Agency, 1991.

5. Orange County Hydrology Manual, Orange County Environmental Management Agency, 1986.

6. Storm Drain Pump Station Analysis prepared for the City of Huntington Beach by L.D. King Engineering, 1979.

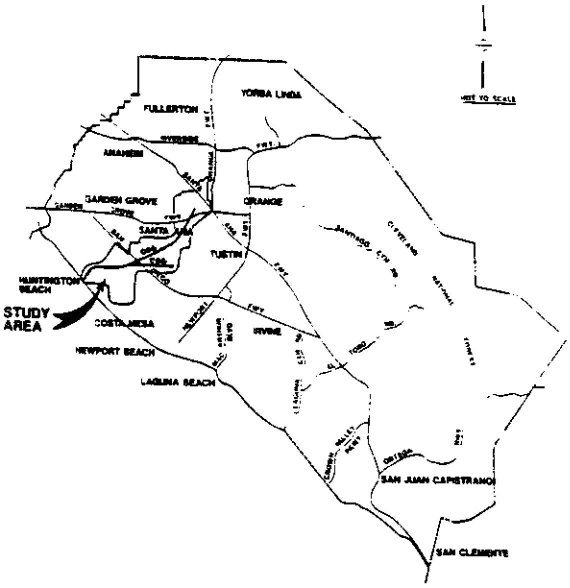


FIGURE 1. REGIONAL LOCATION MAP

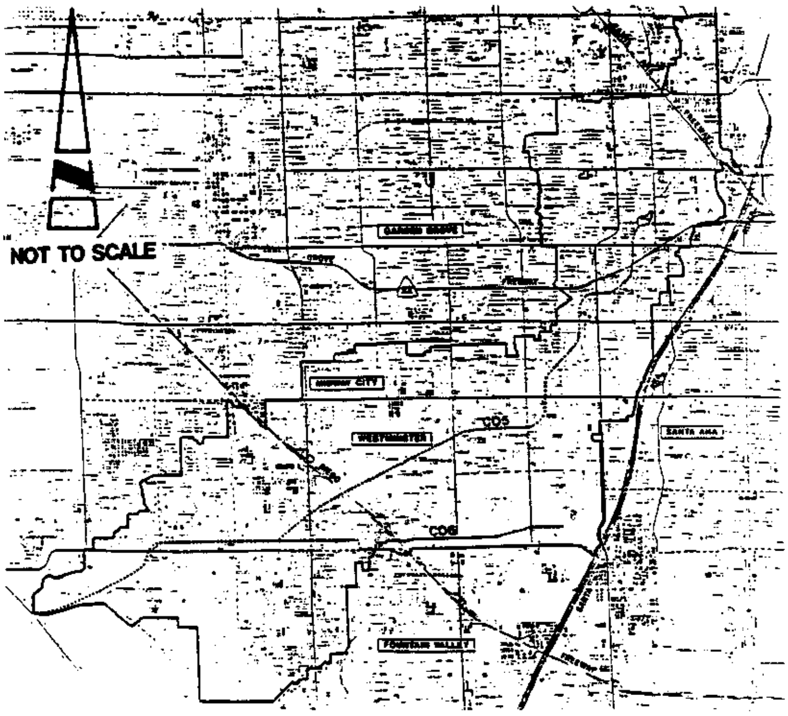


FIGURE 2. VICINITY MAP

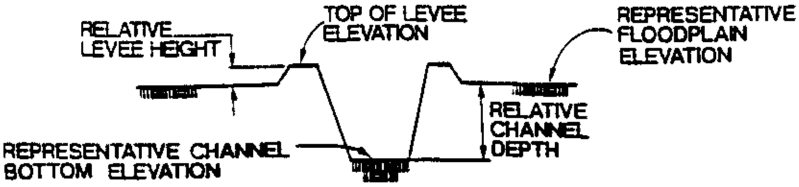
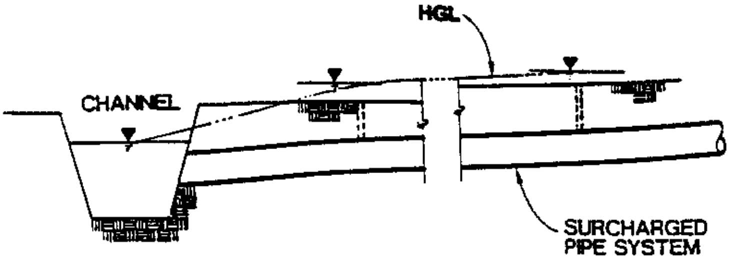


FIGURE 4. DHM MODEL TRAPEZOIDAL LEVEED CHANNEL ELEMENT



FIRGURE 5. DHM MODEL SURCHARGED PIPE ELEMENT

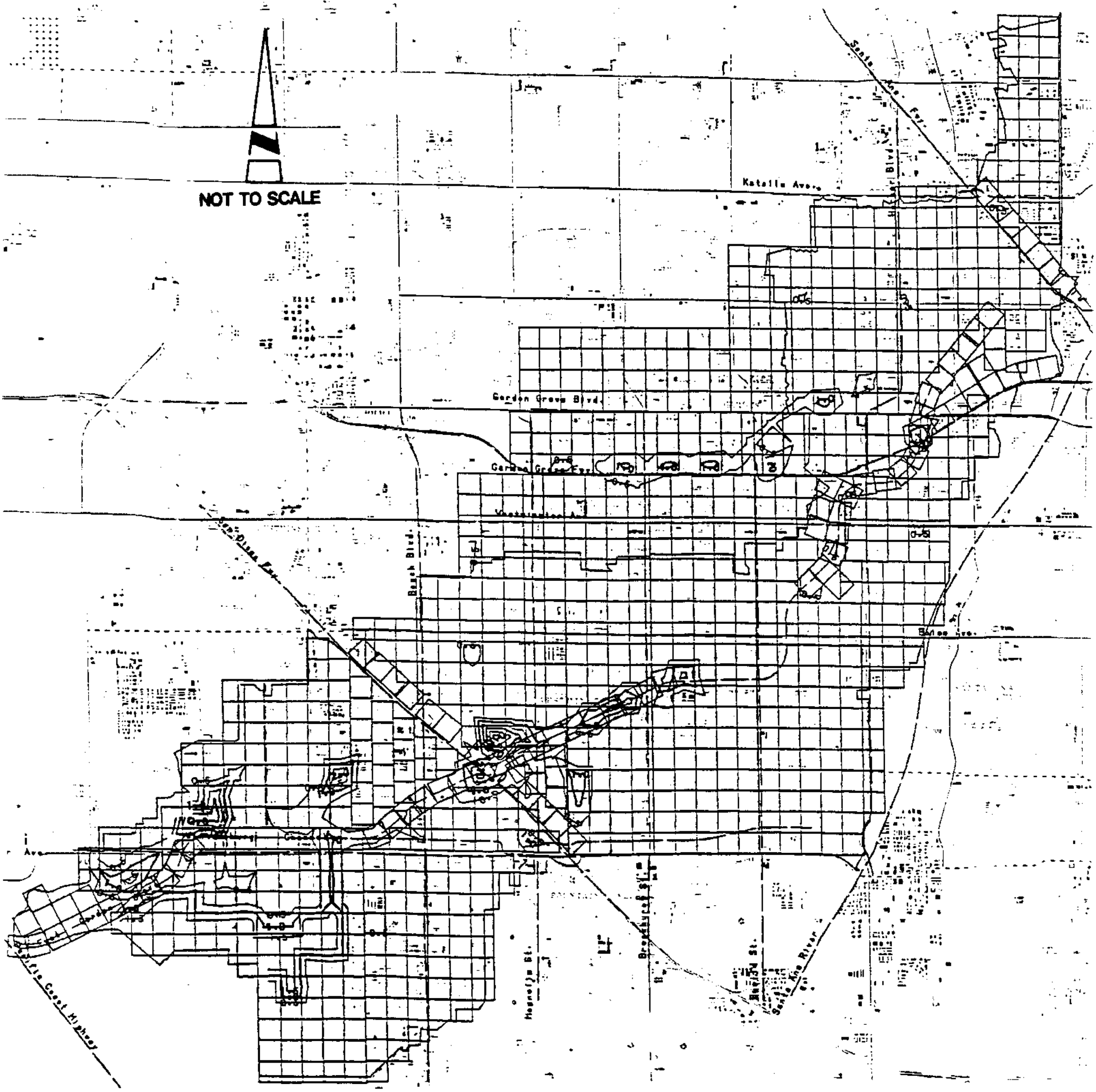


FIGURE 6. DHM MODEL RESULTS, 100-YEAR MAXIMUM FLOODING DEPTHS