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REPORT ON HYDROLOGICAL DATA PROCESSING AND ANALYSIS FOR STUDIES RELATED WITH WATER SURFACE PROFILES, GEOGRAPHICAL INFORMATION SYSTEM AND TWO DIMENSIONAL FINITE ELEMEMT MODELLING IN ESTURINE HYDRO-DYNAMICS

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PREFACE

Hydrometeorological analysis forms an important and integral part of hydrological research. The hydrometeorological analysis comprises of wide range of studies which deal with vast amount of data. Accuracy of these investigations depend upon the quality of data used and hence some extend of data quality control/data processing is necessary before the actual analysis starts.

The aim of data processing is to manipulate the raw data and to put it in a proper form and extract the required information from it. It is necessary to evaluate the data for its accuracy and to prepare it in a form appropriate for subsequent analysis.

This technical report, which consists of three parts, has been prepared by Sh.Chandramohan.T as a part of his 4 months' UNDP training on Data Processing and Analysis, at Texas A&M University, Texas, USA, under the guidance of Dr.W.P.James, Associate Professor, Civil Engineering Department. Part I deals with the features of Modular GIS Environment (MGE PC-1), which is a typical Geographic Information System, the latest data capture, storage and analysis system. Part II explains the Hydrologic Engineering Centre, HEC-2 Water Surface Profile software, its data requirements and its applications. Part III covers a project work which simulates unsteady hydrodynamic flow condition in an estuarine system with the aid of FESWMS-2DH, a finite element two dimensional surface water flow model, using the data from a Texas Gulf coast estuarine system.

DIRECTOR

PART I

GEOGRAPHICAL INFORMATION SYSTEM (GIS)

CONTENTS

ABSTRACT

Geography is part of our everyday world, almost every decision we make is constrained, influenced or dictated by some fact or geography. Geographic Information System (GIS) is a technology that employs the speed and accuracy of a computer to process huge amounts of geographic information. Once a geographic database is established, its analysis allows us to study real world processes by developing and applying models. Such model illuminate underlying trends in the geographic data and thus make new information available.

Hydrology is an area which can benefit from integration with GIS. Hydrologic calculations are based on land use, soil types and local climatic conditions, all of which can be stored within a GIS. The benefit of this technology is to allow designers to test many alternate plans very rapidly and efficiently. Also it provides a level of automation for hydrological analysis that has not been seen before.

In the following pages, functions and applications of a typical GIS software, (MGE PC-1) has been explained briefly. This PC based GIS software is developed by Intergraph Corporation, Huntsville, Alabama, USA.

1.0 INTRODUCTION

A GIS (Geographical Information System) can be defined as an organised collection of computer hardware, software, and geographic data designed to efficiently capture, store, update, manipulate, analyse, and display all forms of geographically referenced information.

GISs can store geographically referenced (cartographic or spatial) data in a raster (grid or cellular-based) data structure or in an x,y coordinate reference based (vector) data structure as points (nodes), lines (arcs), and polygons (bounded by arcs, enclosing an area). GISs make use of a variety of coordinate referencing systems to locate features on the earth relative to others; these coordinate systems, in turn, make use of a variety of map projections to transform earth references onto a two dimensional surface (the map). The information pertaining to the various spatial features (such as ownership, soil type, and vegetation for a land parcel) is stored typically as attributes (characteristics of a mapped feature) in tabular files linked to the feature, often in special database management systems (DBMS).

A geographical information system is a powerful tool for handling spatial data. In a GIS, data are maintained in a digital format. As such the data are in a form more physically compact than that of paper maps, tabulations, or other conventional types. Large quantities of data can also be maintained and retrieved at greater speeds and lower cost per unit when computer based systems are used. The ability to manipulate the spatial data and corresponding attribute information and to integrate different types of data in a single analysis and at high speed are unmatched by any manual methods. The ability to perform complex spatial analyses rapidly provides a quantitative as well as a qualitative advantage. Planning scenarios, decision models, change detection and analysis, and other types of plans can be developed by making refinements to successive analyses. This iterative process only becomes practical because each computer run can be done quickly and at a relatively low cost.

2.0 THE COMPONENTS OF A GIS

2.1 DATA INPUT

The data input component converts data from their existing form into one that can be used by the GIS. Georeferenced data are commonly provided as paper maps, tables of attributes, electronic files of maps and associated attribute data, airphotos, and satellite imagery. Data input is typically the major bottleneck in the implementation of a GIS. Construction of large databases can cost five to ten times that of the GIS hardware and software.

2.2 DATA MANAGEMENT

The data management component of the GIS includes those functions needed to store and retrieve data from the database. The method used to implement these functions affect how efficiently the system performs all operations with the data. The way the data are structured (data structure) and the way files can be related to each other (the organisation of the database) place constraints on the way in which data can be retrieved and the speed of the retrieval operation.

2.3 DATA MANIPULATION AND ANALYSIS

The data manipulation and analysis functions determine the information that can be generated by the GIS. A list of required capabilities should be defined as part of the system requirements. To anticipate the way in which the data in a GIS will be analysed requires that the users be involved in specifying the necessary functions and performance levels.

2.4 DATA OUTPUT

The output or reporting functions of GISs vary more in quality, accuracy and ease of use than in the capabilities available. Reports may be in the form of maps, tables of values, or text in hard copy (such as paper) or soft copy (electronic file). The functions needed are determined by users' needs, and so user involvement is important in specifying the output requirements.

3.0 MODULAR GIS ENVIRONMENT PC-1 (MGE PC-1)

MGE PC-1 is a software production and planning tool for creating, compiling, managing and performing calculations on geographic data. It is the personal computer version of Intergraph Corporations' MGE/SX. It is especially suited for data entry, query, management, review, and editing. It is a full featured Geographical Information System.

As a GIS, MGE PC-1 has three main components:

(a)Hardware - The hardware in a GIS consists of atleast a PC and a graphic input device. It might also include a network card, one or more work stations, servers, or other PCs, a plotter, and some other peripheral devices. The computer is crucial to an efficient GIS because it can accept, integrate and archive enormous amounts of information from different sources rapidly and accurately. It can perform complex calculations very quickly and it is possible to retrieve precisely the combination of information in the required form.

The graphic input device helps to transfer the information from a paper map or aerial photograph into a digital format. This process is called digitizing.

(b)Software - The software in a GIS makes it possible to use the hardware and to enter, manipulate, archive, and retrieve the geographic information. The MGE PC-1 uses the following softwares:

i) DOS is the computer operating system, which communicates with the hardware and with other softwares.
ii) ORACLE is the database management system MGE PC-1 uses to store and retrieve textual information. Oracle is a relational database management system (RDBMS) which stores information in tables.
iii) STRUCTURED QUERY LANGUAGE (SQL) is the industry standard user interface for storing and retrieving information in a database.
iv) MICROSTATION PC provides the graphic capabilities that, among other things, helps in inputting the data and to draw, digitize and output maps to a plotter.
v) MGE PC-1 provides the essential GIS, project management and query capabilities. It also tells ORACLE how to organise the textual information and provides the tools for converting MICRO STATION PC graphics into meaningful geographic information.

(c)Geographic Database - It is a collection of geographic informations that is stored on a computer storage medium, such as disk, and can be retrieved selectively. Geographic information in MGE PC-1 is stored in the database as maps and tables; Graphic information is stored as maps, nongraphic information is stored as tables.

3.1 CHARACTERISTICS OF GEOGRAPHIC INFORMATION

Information is considered as geographic, if it has both size and spatial location, or if it is an attribute of an element with both size and spatial location. The information which is input to MGE PC-1, can come from many sources:

- -Paper maps and drawings. Maps do not have to have the same scale or adjacent areas that match precisely. As long as each map has some points for which accurate geographic coordinates have been measured, it can be entered into MGE PC-1.
- -Records, lists, charts, tables, survey information, or even stacks of applications or forms. This information is generally attached in MGE PC-1 to certain features as attributes.
- -Images and measurements from aerial photographs and satellite based remote sensors. If the hardware system includes scanning equipment, then a photographic image can be entered into MGE PC-1 for reference.
- -MGE PC-1 can transform graphics created in Microstation PC or other digital data source like TIGER and DIME into geographic information.

3.2 THE PROJECT DATABASE

Geographic information from all sources is combined in MGE PC-1 into a project database. A project is a study area, and project database is simply a collection of geographic information related to that area. Each MGE PC-1 project can have its own database, or several projects can share a database.

In an MGE PC-1 project, maps are grouped into thematically or geographically related categories, which are stored on different levels in an index file. A geographic element is represented on a map as a feature. Features are grouped into the same category as the maps on which they appear and are stored on various levels within the category. The following table will illustrates the relationship between categories and features.

CATEGORY	FEATURE
Transportation	Streets
	Centre lines
	Easements

Property	Land parcels Blocks Sub divisions
Utilities	Sanitary sewers Water lines Power lines
Environmental	Slopes Drainage networks Flood plain Landuse pattern
Planning	Zoning districts Landuse outlines School districts

This layering system allows the user to display any combination of features that have been placed on any map in the database. In a manual GIS, a similar result would be achieved with transparent overlays.

Each feature on a map can have a unique look since it is supplied with specific attributes, which are collectively known as its symbology. However, nongraphic attributes of features cannot be represented graphically on a map, and so they are stored in attribute tables.

Linking nongraphic attributes to a feature is called defining attribution, and MGE PC-1 defines attribution automatically for features as they are digitized. This is called intelligent digitizing.

3.3 OUTPUT OF GEOGRAPHIC INFORMATION

Once geographic information is entered and stored in a project database, it can be output in many forms.

- -as an interactive display on the computer screen, in which selectively merging and displaying maps and features, getting coordinate readouts and other measurements, zooming in or out, and manipulation of graphic elements are possible.
- -as map files to be output to a plotter or printer
- -as text files in the form of tables for use in reports and documents
- -as an archive file to be stored on diskette or exported to other systems

If the information has been entered properly, it is possible to overlay and output exactly the combination of features required, to detect changes, match patterns, create scenarios, or generate lists.

3.4 GIS TOOLS IN MGE PC-1

The basis for most GIS analysis derives from the relationship along features and the relationship between features and the surface of the earth. Data that would take days or weeks to compile manually can be processed much faster with MGE PC-1. The following is a list of some of the GIS tools MGE PC-1 offers:

- Tools for automated map production and management, including data collection, verification and maintenance. MGE PC-1 accepts digitized or scanned images, and can use all the capabilities of Microstation PC for manipulating and plotting graphics.
- Interface to Oracle relational database management system with the industry standard SQL.
- Fast and accurate integration of the diverse source data and multiple geographic factors needed for spatial analysis.
- Interactive graphic output to the PC screen. It is possible to select elements for identification, information, or manipulation with a quick press of the data button.
- User friendly interface, including selectable lists, pop-up messages, icons, and system prompts. Key-in commands are available for the more experienced user.
- Selection of graphic elements based on attributes, window area or viewing area for simultaneous manipulation or processing.
- Geographical information overlay based on any combination of features, in the project database, which creates new relationships for analysis.
- Locate and query tools.
- Geographic coordinate referencing and registration of all maps to control points to guarantee geodetic alignment when source maps have different sizes and coverages.
- Precise readout of any coordinate point in the project area.
- Measurement of the distance between any two points in the study area, calculated with relation to the curvature of the earth.
- Conversion between coordinate systems
- Calculation and loading of area and perimeter values to database records.
- Generation of features from user input and graphic elements.
- Tools for cleaning up and generalising lines.
- Automated loading of geographic labels to records.

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PART II

HYDROLOGIC ENGINEERING CENTRE, HEC-2 WATER SURFACE PROFILE MODEL

CONTENTS

ABSTRACT

HEC-2 model calculates water surface profiles for steady gradually varied flow in natural or man made channels. The Hydrologic Engineering Centre (HEC), Davis, California, has developed version of HEC-2 Water Surface Profiles Program for MS/PC-DOS compatible micro-computers. The increased speed, memory and storage capacity of the latest PCs make the use of this, highly practical in the PC environment.

The typical tasks that are required when using batch oriented programs include creating, checking and editing input data; executing the program; and summarising and displaying the results. The HEC has developed a menu driven user interface or shell program to integrate several application programs, an editor and other utility programs to assist the user in accomplishing these tasks. The interface takes the advantage of the unique capabilities and user friendliness found in the PC environment. This integrated package includes a program (SUMPO) for creating summary tables of HEC-2 results, a program (PLOT2) that plots cross sections and water surface profiles, and a PC version of the Corps of Engineers editor (COED), which features full screen editing and on line help screens and documentation.

This part of the technical report explains the methodology and applications of the Hydrologic Engineering Centre, HEC-2 Water Surface Profile software.

1.0 INTRODUCTION

Computer program HEC-2, Water Surface Profiles has originated from a step-backwater program by Bill S Eichert in 1964. This early version was on a GE 225 system at the Corps of Engineers Tulsa District Office, USA. In 1966, the first FORTRAN version of HEC-2 was released by the Hydrologic Engineering Centre (HEC) under the name 'Backwater Any Cross Section'. As the name implies, Backwater Any Cross Section was capable of computing water surface profiles in channels with irregularly shaped cross sections. This program represented a significant step in the development of modern computational techniques of hydraulic analysis.

In 1984, Alfredo Montalvo adapted HEC-2 to the micro computer (PC) environment. The PC release of HEC-2 has been accompanied by the introduction of PC based support programs, SUMPO & PLOT2.

This program is intended for calculating water surface profiles for steady gradually varied flow in natural or man made channels. Both sub critical and super critical flow profiles can be calculated. The effects of various obstructions such as bridges, culverts, weirs and the structures in the flood plain can be considered in the computations. The computational procedure is based on the solution of the 1-dimensional energy equation with energy loss due to friction evaluated with Manning equation. It is generally known as Standard Step Method. The program is also designed for application in flood plain management and flood insurance studies to evaluate floodway encroachments. Also, capabilities are available for assessing the effects of channel improvements and levees on water surface profiles.

A data edit program (EDIT 2) checks the data records for various input errors. An interactive summary printout program (SUMPO) and graphic program (PLOT2) are available for MS DOS computers. An input edit program (COED) is available with an HEC-2 input help file.

2.0 METHODOLOGY

The following two equations are solved by an iterative procedure (the standard step method) to calculate an unknown water surface elevation at a cross section.

$$WS2 + \alpha_2 V_2^2/2g = WS1 + \alpha_1 V_1^2/2g + h_e \quad ....(1)$$

$$h_e = L\overline{S}_f + C \mid \alpha_2 V_2^2/2g - \alpha_1 V_1^2/2g \mid \quad ....(2)$$

V_1, V_2 - mean velocities at two reaches
L - discharge weighted reach length
C - expansion or contraction coefficient
$\overline{S}_f$ - representative friction slope for the reach
α_1, α_2 - velocity correction factor
h_e - friction loss

The determination of total convergence and the velocity coefficient for a cross section requires that flow be subdivided into units for which the velocity is uniformly distributed. The approach used in HEC-2 is to subdivide flow in the overbank areas using the input cross section stations (X coordinates) as the basis for subdivision.

2.1 COMPUTATION PROCEDURE

The unknown water surface elevation at a cross section is determined by an iterative solution of equations 1 and 2. The computational procedure is as follows.

a) Assume a water surface elevation at the upstream cross section (or downstream cross section if a super critical profile is being calculated).
b) Based on the assumed water surface elevation, determine the corresponding total conveyance and velocity head.
c) With value from step 2, compute S and solve equation (2) for h.
d) With values from step 2 and 3, solve equation (1) for WS2.
e) Compare the computed value of WS2 with the values assumed in step 1. Repeat steps 1 through 5 until the values agree within 0.01 feet (or 0.01 meters).

Criteria used to assume water surface elevation in the iterative procedure varies from trial to trial. Generally, the first trial is based on projecting the previous cross section's water surface elevation on the average of the friction slopes from the previous two cross sections. The second trial is an arithmetic average of the computed and assumed elevations from the first trial. The third and subsequent trials are generally based on a 'secant' method of projecting the rate of change of difference between computed and assumed elevations for the previous two trials to zero. The change from one trial to the next is constrained to a maximum of 50% of the assumed depth from the previous trial.

Once a 'balanced' water surface elevation has been obtained for a cross section, checks are made to ascertain the elevation is on the 'right' side of the critical water surface elevation (eg: above the critical elevation if a subcritical profile is being calculated). If the balanced elevation is on the 'wrong' side of the critical water surface elevation, critical depth is assumed for the cross section and a message to that effect is printed by program.

2.2 PROGRAM LIMITATIONS

The following assumptions are implicit in the analytical expressions used in the program.

- -Flow is steady
- -Flow is gradually varied
- -Flow is one dimensional
- -River channels have small slopes (less than 1:10)

The program does not have the capability to deal with movable boundaries (ie. sediment transport) and requires that energy losses be definable with the terms contained in equation(2).

3.0 BASIC DATA REQUIREMENTS

a)Flow regime - Profile computation begins at a cross section with known or assumed starting conditions and proceed upstream for subcritical flow or downstream for supercritical flow. In cases where flow passes from one flow regime to another, it is necessary to compute the profile twice, alternately assuming subcritical and super critical flow. HEC-2 does not contain the capability to determine the position of the hydraulic jump or energy losses associated with the jump.

b)Starting elevation - The water surface elevation for the beginning cross section should be specified in one of four ways: (i)as critical depth, (ii)as a known elevation, (iii)by the slope area method, and (iv)by a rating curve.

c)Discharge - Discharge may be specified and altered in several ways. It is possible to change the discharge for a single profile run at any cross section. Also for a multiple profile run, one to 19 discharge values can be used.

d)Energy loss coefficient - Several types of loss coefficients are utilized by the program to evaluate head losses. (i)Mannings' 'n' or equivalent roughness height 'k' values for friction loss, (ii)contraction and expansion coefficients to evaluate transition losses, and (iii)bridge and culvert loss coefficient to evaluate losses related to weir shape, pier configuration, pressure flow, and entrance and exit conditions.

e)Cross section geometry - Boundary geometry for the analysis of flow in natural streams is specified in terms of ground surface profiles (cross sections) and the measured distances between them (reach lengths). Cross sections are located at intervals along a stream to characterise the flow carrying capability of the stream and its adjacent flood plains. They should extend across the entire flood plain and should be perpendicular to the anticipated flow lines. However, ineffective flow areas of the flood plain such as stream inlet or small ponds in the valley floor should generally not be included in the cross section geometry. Cross sections are required at representative locations throughout a stream reach, at locations where changes occur in discharge, slope, shape or roughness, and at locations where levees begin or end and at bridges or control structures such as weirs. Where abrupt changes occur, several cross sections should be used to describe the change regardless of the distance.

f)Reach lengths - The measured distance between cross sections are referred to as reach lengths. The reach lengths for the left overbank, right overbank and channel have to be specified.

4.0 OPTIONAL CAPABILITIES

HEC-2 has numerous optional capabilities that allow the program user to determine flood plains and floodways, to evaluate energy losses at obstructions such as weirs, culverts and bridges, and to analyse improvements to drainage systems.

a)Multiple Profile Analysis - HEC-2, in a single run can compute upto 14 profiles using the same cross sectional data. After the last profile of a multiple profile run, a summary printout will be generated which provides a concise summary of results for all profiles for each cross section.

b)Calculation of Critical Depth - Several options related to the computation of critical depth are available in HEC-2. Normal tolerance used to terminate critical depth trial calculation is 2.5 % of the depth. Other tolerances can also be specified in data file for critical depth computation.

c)Effective Flow Option - A series of program capabilities are available to restrict flow to the effective flow areas of cross sections. Among these capabilities are option to simulate sediment deposition, to confine flows to leveed channels, to block out road fills and bridge decks, and to analyse flood plain encroachments.

d)Calculation of Bridge Losses - Energy losses caused by structures such as bridges and culverts are computed in two parts. First, the losses due to expansion and contraction of the cross section on the upstream and downstream sides of the structure are computed in the standard step calculation. Secondly, the loss through the structure itself is computed by either the normal bridge, special bridge, or the culvert option.

The normal bridge method handles the cross section at the bridge just as it would be any river cross section with the exception that the area of the bridge below the water surface is subtracted from the total area and the wetted perimeter is increased where the water surface elevation exceeds the low chord.

The special bridge method can be used for any bridge, but should be used for bridges with piers where low flow controls, for pressure flow, and whenever flow passes through critical depth when going through the structure. This method computes losses through the structure for low flow, weir flow and pressure flow or for any combination of these.

The special culvert method is similar to the special bridge method, except that the Federal Highway Administration, USA, standard equation for culvert hydraulics are used to compute losses through the structure.

e)Encroachment Options - Six methods of specifying encroachments for flood way studies can be used.

- Stations and elevations of the right encroachment can be specified for individual cross sections as desired
- A flood way with a fixed top width can be specified which will be used for all cross sections until changed
- Encroachments can be specified by percentages which indicate the desired proportional reduction in the natural discharge carrying capacity of each cross section
- Encroachments can be determined so that each modified cross section will have the same discharge carrying capacity (at some higher elevation) as the natural cross section. This higher elevation is specified as a fixed amount above the natural profile
- This is an optimisation solution of method 'd'. It determines water surface elevation differences between the natural and encroached conditions such that the target difference is obtained as near as possible
- This is also an optimization solution similar to the above method. Here difference is that the energy line elevation is being optimised.

f)Channel Improvement - Cross section data can be modified automatically to analyse improvements made to the natural stream sections. This option simulates channel improvement by trapezoidal elevation. Upto five different bottom widths may be specified for the execution of a single run. Maximum three records may be used at each section.

g)Interpolated Cross Sections - Occasionally it is necessary to insert cross sections between those specified by input, because the change in velocity head is too great to accurately determine the energy gradient. Additional cross sections may be coded manually or a program option may be requested to input interpolated cross sections. A maximum of three interpolations can be possible between two adjacent input cross sections.

h)Tributary Stream Profiles - Subcritical profiles may be computed for tributary stream systems for single or multiple profiles in a single execution of the program.

i)Solving for Manning's n - HEC-2 can be utilised in two ways to solve for Manning's coefficient. It can compute n values automatically from high water data if the discharge, relative ratios of the n values for the channel and overbank and water surface elevation at each cross sections are known. The best estimate of n for the first cross section must be entered on the data record since it is not possible to compute an n value for this cross section. Another method is to specify the discharge and an assumed set of n values, and have the program compute a water surface profile which can be compared with the high water profile.

j)Storage-Outflow Data - The HEC-2 storage outflow option can be used to generate HEC-1 input data for hydrograph routing, using the modified Puls method. The modified Puls method requires stream storage and corresponding discharges. Stream storages should be determined for a range of discharges which cover the anticipated range of flows for routed hydrograph.

k)Split Flow Option - The HEC-2 split flow option provides for the automatic determination of channel discharges and profiles in situations where flow is lost from the main channel. The split flow option can model flow over levees or weirs, overtopping of watershed divides, and flow splits created by diversion structures.

l)Computations for Ice Covered Streams - The HEC-2 ice cover analysis option provides the user with the capability to determine water surface profiles for streams with stationery floating ice cover. The option allows the user to input different ice thickness in the channel and left and right overbanks.

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PART III

APPLICATION OF FESWMS-2DH FOR ESTUARINE MODELLING

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ABSTRACT

In many surface water flow problems of practical engineering concern, the three dimensional nature of the flow is of secondary importance, particularly when the width to depth ratio is large. In such cases, the component of flow quantities in a horizontal plane will be the main interest and depth averaged two dimensional equations can be used to great advantage for solving for components of flow quantities. Shallow rivers, flood plains, estuaries, harbours and even coastal seas are examples of surface water bodies where flows may be essentially two dimensional in nature.

In estuaries,tidal deltas and coastal regions, where complex interaction between physical, chemical or biological processes are found, water circulation is one of the most important factors controlling these processes. Mathematical modelling is the most competitive method in circulation studies and several types of mathematical models for tidal circulation including finite difference and finite element methods, have been developed by many researchers.

This part of the report presents the application of FESWMS-2DH (Finite Element Surface Water Modelling System - two dimensional flow in horizontal plane) in estuarine hydrodynamics and illustrates the capacity of this two dimensional model in simulating unsteady circulation patterns resulting from the combined actions of tides, winds and freshwater inflows to the system.

1.0 INTRODUCTION

The basic equations for the modelling of any surface water problems like tidal flows in estuaries and coastal areas or unsteady flow over flood plains or flow through constrictions etc., are the three dimensional hydrodynamic equations arising from consideration of mass and momentum conservation. In vertically well mixed, shallow bays, the horizontal tidal circulation is normally much more significant than vertical motion. Therefore, with the condition that water pressure is hydrostatic, the vertically integrated form of the hydrodynamic equations or shallow water equations can be employed. These equations are two dimensional dynamic equation of motion which include wind stress and Coriolis acceleration parameters and the unsteady continuity equation.

The numerical models have traditionally employed the finite difference method to solve these governing differential equations. In essence, this method satisfies the governing equations by replacing derivatives of difference approximation. For a problem in two spatial dimensions, this implies a discretization with a constant sized, square grid mesh. Although grids of other shapes are possible, they are usually too inefficient to use. In recent years, a more powerful method, the finite element technique, has emerged. The finite element method seems well suited for solving estuarine type problems, and it has replaced the finite difference method. Finite element methods affords very efficient discretization of the flow domain, since it allows a great versatility and simplicity in the construction of the network grid and in the choice of the shape and size of the elements. This not only gives better adaption to the different gradients of the physical magnitudes and consequently greater accuracy, but also more ease to guarantee overall continuity in the domain.

The study of circulation pattern in estuaries and coastal deltas, where tidal and wind actions are predominant, is one of the important factors in coastal designs, coastal and river engineering techniques for combating pollution, determining friendly habitat for aquaculture etc. It is already proved through numerous studies that two dimensional finite element and finite difference methods are very efficient to simulate such unsteady flow conditions. These types of analyses are useful in Indian conditions where a large extent of coastal area with number of river deltas and estuarine systems is available. In this study, an effort has been made to use one such models to simulate estuarine hydrodynamics, so that it can be useful to tackle similar problems in Indian conditions.

Finite Element Surface Water Modeling System: Two Dimensional Flow in a Horizontal Plane (FESWMS-2DH), (Froelich,1989), is a modular set of computer programs developed to simulate surface water flow where the flow is essentially two dimensional in a horizontal plane. It was developed for the Federal Highway Administration by the U.S.Geological Survey, Water Resources Division. FESWMS-2DH was originally designed to analyse flow at bridge crossings where complicated flow conditions exist, although the program can be used to model many other types of steady and unsteady surface water flows in water bodies that have irregular topography and geometrical features, such as islands, highway embankments, flood plains and estuaries.

FESWMS-2DH calculates depth averaged horizontal velocities and water depth and the time derivatives of these quantities if a time dependent flow is modeled. The equations that govern depth averaged surface water flow account for the effects of bed friction, wind induced stress at the water surface, fluid stresses caused by turbulence and the effect of Earth's rotation.

This report presents the application of FESWMS-2DH in estuarine hydrodynamics and illustrates the capacity of this two dimensional model in simulating unsteady circulation patterns resulting from the combined actions of astronomical tides, winds and freshwater inflows to the system.

2.0 MODEL DESCRIPTION

FESWMS-2DH uses the Galerkin finite element method to solve the governing system of equations for two dimensional flow in a horizontal plane. Galerkin's method of weighted residuals, a Newton-Raphson iteration scheme, numerical integration using seven point Gaussian quadrature, and a frontal solution algorithm using out-of-core storage are used to solve for the nodal values of the velocity components and depths. Time derivatives are handled by an implicit finite difference scheme.

2.1 GOVERNING EQUATIONS

Neglecting vertical velocities and vertical accelerations, the depth averaged velocity may be obtained by integrating the horizontal velocity components from the bed elevation to the water surface. An illustration of the depth averaged velocity is shown in fig 1.

The depth averaged velocity along the X axis is given by,

$$U = 1/H \int_{z}^{z+H} u \, dz$$

and the depth averaged velocity along Y axis is given by,

$$V = 1/H \int_{z}^{z+H} v \, dz$$

The two dimensional depth averaged equations of motion used in FESWMS-2DH to describe the movement of water are:

the conservation of mass,

$$\partial H/\partial t + \partial(HU)/\partial x + \partial(HV)/\partial y = 0$$

the conservation of momentum in X direction,

$$\partial(HU)/\partial t + \partial(\beta_{uu}HUU)/\partial x + \partial(\beta_{uv}HUV)/\partial y + gH\ \partial Z_b/\partial x +$$

$$1/2\ g\ \partial(HH)/\partial x - \Omega\, HV + 1/\rho\ [\tau^{b}_{x} - \tau^{s}_{x} -$$

$$\partial(H\tau_{xx})/\partial x - \partial(H\tau_{xy})/\partial y] = 0$$

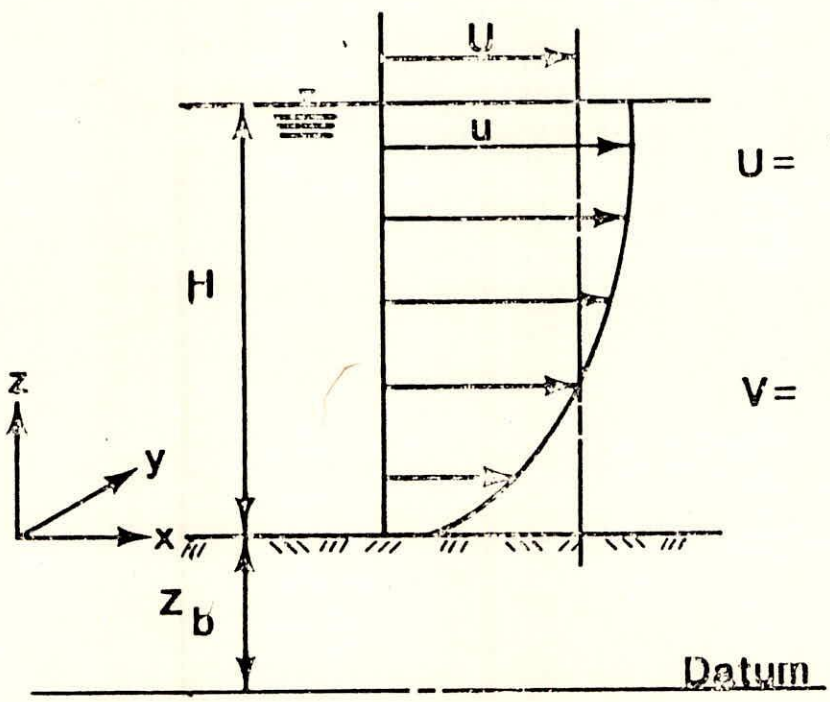
and the conservation of momentum in the Y direction,

$$\partial(HV)/\partial t + \partial(\beta_{vu}HVU)/\partial x + \partial(\beta_{vv}HVV)/\partial y + gH\ \partial Z_b/\partial y +$$

$$1/2\ g\ \partial(HH)/\partial y + \Omega\, HU + 1/\rho\ [\tau^{b}_{y} - \tau^{s}_{y} -$$

$$\partial(H\tau_{yx})/\partial x - \partial(H\tau_{yy})/\partial y] = 0$$

Depth-Averaged Velocities



$$U = \frac{1}{H}\int_{z_b}^{z_b + H} u\,dz$$

$$V = \frac{1}{H}\int_{z_b}^{z_b + H} v\,dz$$

Fig:1 Illustration of Depth Averaged Velocity.

In the conservation of momentum equation, the first three terms describe the inertial force. The fourth and fifth terms describe the pressure gradient resulting from a sloping water surface. The sixth term represents the Coriolis force which acts perpendicular to the velocity. The seventh and eighth terms represent bottom stresses and surface stresses respectively. The ninth and tenth terms represent the effects of the Reynolds stresses. Boussinesque eddy viscosity concept is used where the momentum transfer is proportional to the mean velocity gradients.

FESWMS-2DH uses the Galerkin's finite element method to solve the governing system of differential equations. The solution begins by dividing the physical region of interest into a number of sub regions, which are called elements. An element can either be triangular or quadrangular in shape and is defined by a finite number of node points situated along its boundary or in its interior. A list of nodes connected to each element is easily recorded for identification and use. Values of dependent variables are approximated within each element using values defined at the elements' node points, and a set of interpolation (or shape) functions. Mixed interpolation is used in FESWMS-2DH; quadratic interpolation functions are used to interpolate depth averaged velocities and linear functions are used to interpolate flow depth.

The method of weighted residuals is applied to the governing differential equations next, to form a set of equations for each element. Approximations of the dependent variables are substituted into the governing equations, which generally are not satisfied exactly, to form residuals. The residuals are required to vanish, in an average sense, when they are multiplied by a weighting function and summed at every point in the solution domain. In Galerkin's method, the weighted functions are chosen to be the same as the interpolation functions. By requiring the summation of the weighted residuals to equal zero, the finite element equations take on an integral form. Coefficients of the equations are integrated numerically, and all the element(local) equations are assembled to obtain the complete (global) system of equations. The global set of equations is solved simultaneously.

2.2 INITIAL AND BOUNDARY CONDITIONS

To solve the system of depth averaged flow equations, both initial and boundary conditions need to be specified. From the mathematical point of view, the initial condition and the number and kind of boundary conditions that are specified need to make the problem well-posed (stable). A well-posed problem is one in which increasingly smaller changes to boundary conditions produce increasingly smaller changes in the solutions at points not located on the boundary. The system of equations that exhibits unstable behavior is said to be ill-posed.

2.2.1 Initial Conditions:

To obtain a solution, both the water depth and the depth averaged X and Y velocity components need to be specified as initial conditions throughout the entire solution region. When initial conditions are unknown, a **cold start** procedure is used. During this procedure, the same water surface elevation is assigned to every node point in a finite element network, and velocity are set to zero everywhere. When the results from a previous run are available, they can be used as initial conditions for a subsequent run. The use of results from a previous run as initial condition is referred to as a **hot start.**

2.2.2 Boundary Conditions:

Boundary conditions are specified around the entire boundary of a network for the duration of a simulation. The required boundary information depends on the type of boundary, solid or open and the flow condition, sub critical or super critical.

(a)Solid boundary - The flow across a solid boundary generally equals zero. In addition, either the tangential velocity or tangential stress needs to be specified on a solid boundary. Along solid boundaries, either tangential stresses are assumed to equal zero (a slip condition) or the velocity is set to zero (no slip condition).

(b)Open boundary - An open boundary defines an area where flow is allowed to enter (an inflow boundary) or leave (an outflow boundary) a finite element network.

Usually unit flow in both X and Y directions may be specified at inflow boundary nodes, and water surface elevation may be specified at outflow boundary nodes of a model.

2.3 MODELLING SYSTEM

FESWMS-2DH consists of three distinct but related programs: DINMOD, the data input module; FLOMOD, the depth averaged flow analysis module; and ANOMOD, the output analysis module.

As a preprocessing program, DINMOD checks the input data for errors, generates plots of the finite element network and ground surface contours, and puts the network data in an appropriate form for subsequent analysis. The solution of the 2-D depth averaged flow equations are performed by FLOMOD. The postprocessing program, ANOMOD, generates plots and printed reports from the net work data and the flow data.

2.3.1 DINMOD:

The primary purpose of DINMOD is to generate a two dimensional finite element network (grid). Functions performed by this program include editing of input data, automatic generation of all or part of the finite element network, refinement of an existing network, ordering of elements to enable an efficient equation solution, and graphic display of the finite element network. As such, DINMOD acts as a preprocessor of the finite element network data. Processed network data can be stored in a data file for use by other FESWMS-2DH programs.

2.3.2 FLOMOD:

FLOMOD simulates both steady and unsteady (time-dependent) two dimensional surface water flow. The program numerically solves the vertically integrated equation of motion and continuity, using the finite element method of analysis, to obtain depth averaged velocities and flow depths. The effect of bed friction and turbulent stresses are considered, as are, optionally, surface wind stresses and Coriolis force. The computed two dimensional data can bee written to a data file and stored for further use.

2.3.3 ANOMOD:

Results of flow simulations are presented graphically and in the form of reports by ANOMOD. Plots of velocity and unit flow vectors; ground surface and water surface elevation contours; and time history graphs of velocity, unit flow, or stage (water surface elevation) at a particular computation point can be produced. As such, ANOMOD acts as a post-processor in the modelling.

2.4 NETWORK DESIGN

The basic goal of network is to create a representation of the water body, that provides an adequate approximation of the true solution of the governing equations, at a reasonable cost.

FESWMS-2DH will accept any combination of 6 node triangular, 8 node quadrangular or 9 node quadrangular elements that have straight or curved sides so that complex geometries can be modeled in detail. Curve sided elements can be created by specifying the coordinates of the mid side node as well as the corner nodes of sides that are curved.

2.5 INPUT REQUIREMENTS

Data requirement for FESWMS-2DH can be classified as topographic, network and hydraulic data.

2.5.1 Topographic Data:

a) Contour map of the area to be modeled, at a reasonably close interval.
b) Types of soils, vegetations and topography at different regions of the study area which can be used to estimate fairly accurately, the values of roughness coefficients at these regions.

2.5.2 Network Data:

Once the study area is broken into a finite element network which consists of nodes and elements, it is required to know X and Y co ordinates w.r.t to an origin and ground surface and / or ceiling elevation at each node points of an elements. Node connectivity list has to be prepared for each element, which means listing of nodes, by which an element can be defined, in a counter clockwise direction.

2.5.3 Hydraulic Data:

a) Model parameter values such as Manning's roughness coefficient and kinematic eddy viscosity for each elements.
b) Upstream and downstream boundary conditions such as discharges and water surface elevations (tidal cycle in the case of tidally affected area).
c) Initial conditions (X velocity, Y velocity and water surface elevations) at each node.
d) Wind velocity and direction at each node points.

2.6 MODEL PARAMETERS

The important model parameters are roughness coefficients and kinetic eddy viscosity. Once the sensitivity of the model and its outputs to the changes in these parameters are clearly understood, the model can be used effectively.

2.7 APPLICATIONS

FESWMS-2DH can be used to simulate flow in water bodies that have irregular topography and geometrical features, such as islands and highway embankment. Flow over dams, weirs and highway embankments and through bridges, culverts and gated openings are also can be modeled.

3.0 STUDY AREA AND PROBLEM DEFINITION

A Texas estuary may be defined as the coastal region of the state from the tidally affected reaches of terrestial inflow sources to the Gulf of Mexico. The primary bay of an estuary is directly connected to Gulf of Mexico and having direct flow exchanges between bay and Gulf of Mexico. Secondary bays empty into primary bay of an estuary and are thus away from direct flow exchange with the Gulf. The total water mass is under unsteady flow conditions throughout the estuarine system by inflow, tides and winds. Texas has about 373 miles of open ocean or Gulf shore line and 1419 miles of bay shore line, along which are located seven major estuarine systems and three smaller estuaries. These estuarine systems have a total open water surface area of more than 1.5 million acres. The major estuarine systems along the Texas coast are as shown in fig 2. Lavaca-Tres palacious estuary is one of the major estuarine systems which covers 352 square miles and include several smaller systems. The present study covers a major portion of the Lavaca-Tres Palacious estuary. The location of the study area is shown in fig 3. The study reach includes Matagorda Bay, Lavaca Bay and Tres Palacious Bay which cover about 300 square miles of area.

Main fresh water suppliers to the system are Lavaca River and Colorado River. But most of fresh water inflow from Colorado river is falling into East Matagorda bay which is beyond this study reach. A portion of Colorado river discharge enters to the study reach through the Gulf Intercoastal Water Way (GIWW), Tiger Island Cut and Culvert Cut. Water depth at mean low water varies from 6 ft to 13 ft or less, except in Matagorda ship channel, where the depth goes upto 39 ft. Prevailing winds are towards South West during winter season and towards North East in summer seasons. Wind is a major factor in influencing coastal processes, it can either raise or lower water levels along the Gulf and/or main land shore according to the direction it blows. Astronomical tides are low, ranging from about 0.5 ft in the bay to a maximum of about 2 ft along the Gulf shore line. Tidal effects can reach to estuary through two openings to the Gulf of Mexico, ie. Pass Cavallo and Matagorda ship channel entrance.

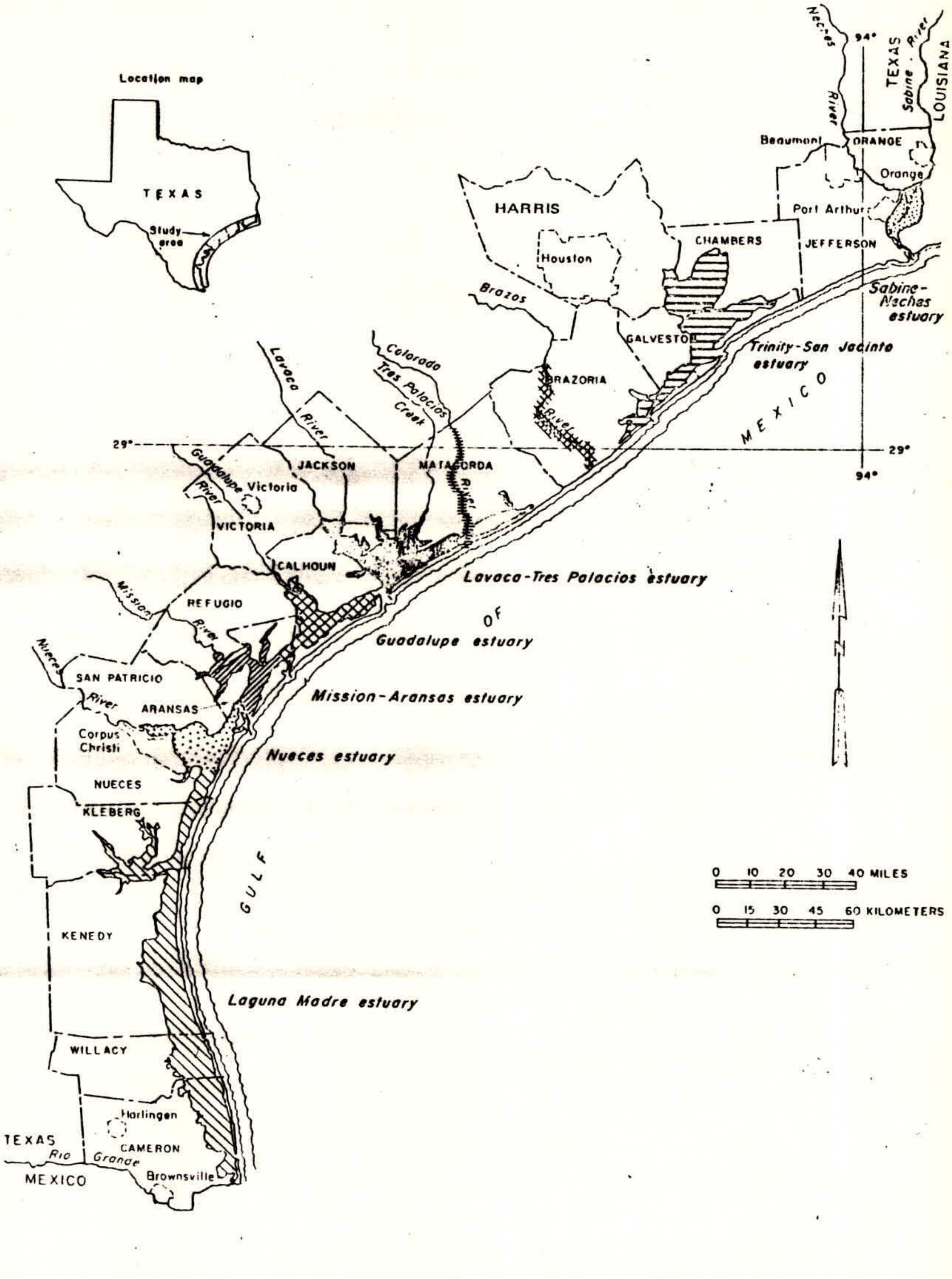


Fig:2 Estuarine Systems Along Texas Coast.

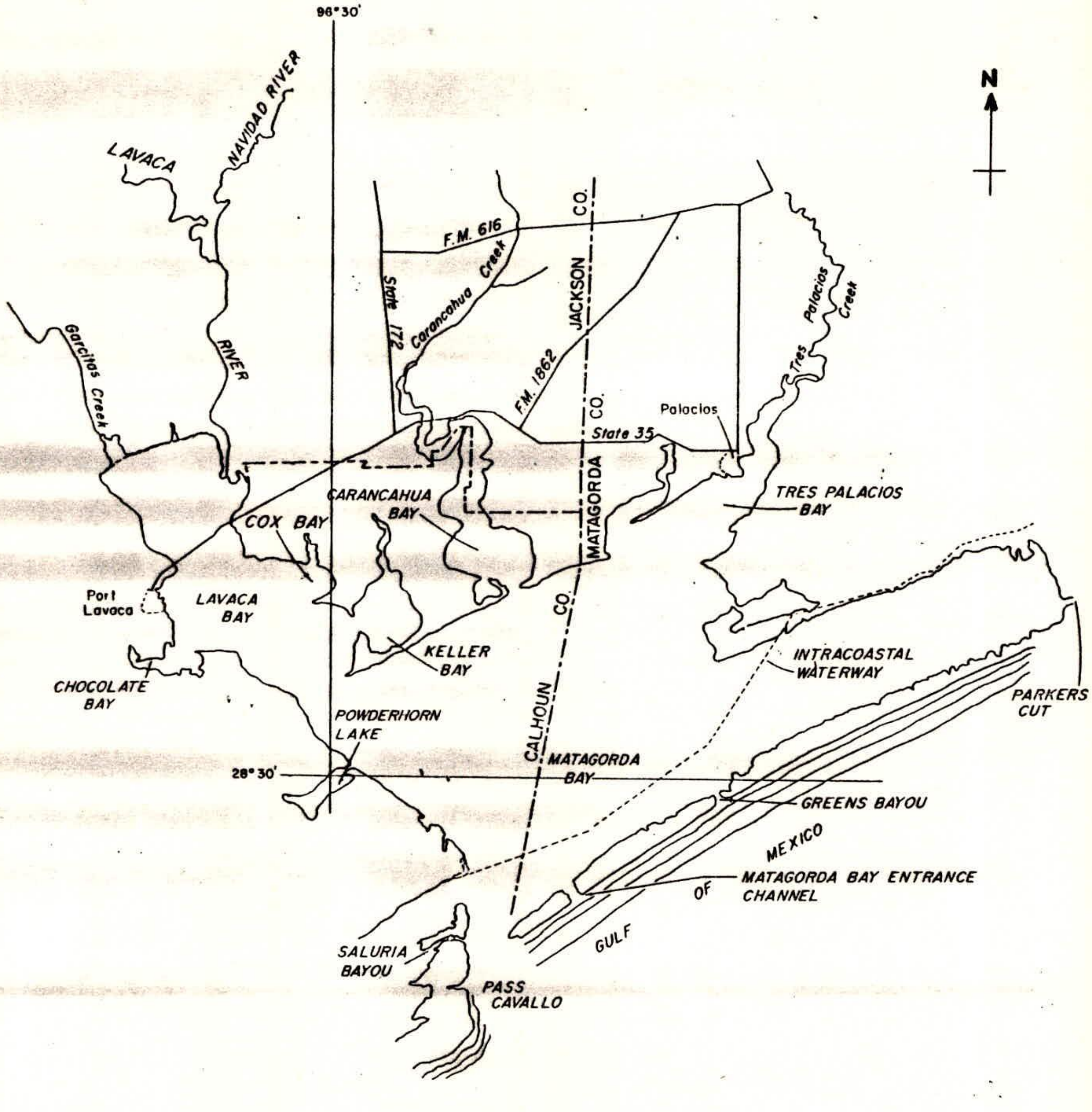


Fig:3 Study Area.

4.0 MODEL APPLICATION

The first and foremost step in applying FESWMS-2DH is to design an efficient finite element network, to create a true representatión of the water body. After defining the limits of the area to be modeled, it was divided into regions of different properties and flow characteristics. Within the study area, except the Matagorda ship channel, the ground surface is at a depth of 6 ft to 13 ft below mean sea level (mean sea level is considered as 100 ft for convenience). Along the ship channel, which passes across the bay, ground surface level reaches upto 36 ft to 39 ft below mean sea level. This area will be having large velocity gradients compared to surrounding regions and had to be modeled carefully. Spoil areas, consisted of dredged materials from the ship channel can be seen along one side of the ship channel. The demarkated study area with locations of spoil banks is shown in figure 4.

So the ship channel and its surrounding area were modeled with smaller elements. Open boundaries near the Gulf of Mexico, where tidal effects are considerable, were also broken up into small elements. The transition region from ship channel to area where larger elements are situated were designed by increasing the element size gradually.

For the creation of finite element network, 6 noded triangular and 9 noded Lagrangian Quadrilateral elements were used. Along the lateral boundaries where the geometric complexity is considerable, curved sided elements were used. The finite element network for this study consisted of 252 elements and 976 nodes, which is shown in fig 5.

4.1 DINMOD DATA

Model topography is described by assuming a ground surface elevation to each node points and letting it to vary linearly within an element. Location of each element are fixed by (a) inputting X and Y coordinates for corner nodes, centre node (for 9 noded elements) and mid side node (for curved element sides), about an assumed origin and (b) by providing node connectivity list for each elements; ie. inputting the list of nodes by which an element can be defined, in anti-clockwise direction.

Since spoil areas, or elements representing spoil areas act as small islands, they had to be specified as no flow zones in DINMOD data file. So each element which represents a spoil area has been assigned a zero property type code which allows FLOMOD module to neglect these areas during calculation of depth averaged water surface elevations and velocities. Since flow properties of ship channel and other areas are different, they have been given property type code of 1 and 2 respectively. Flow

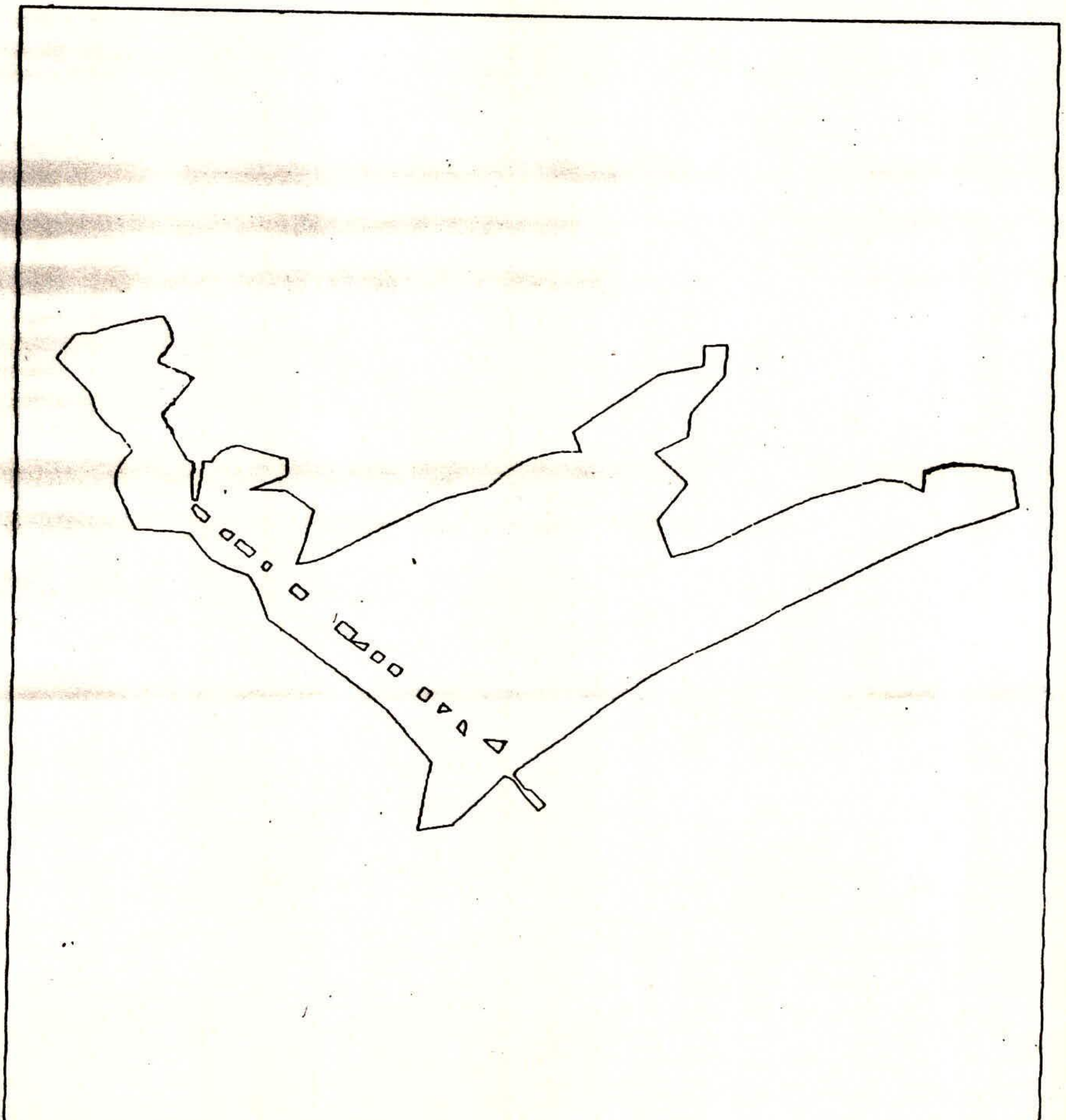


Fig:4 Demarkated Study Area with Spoil Banks.

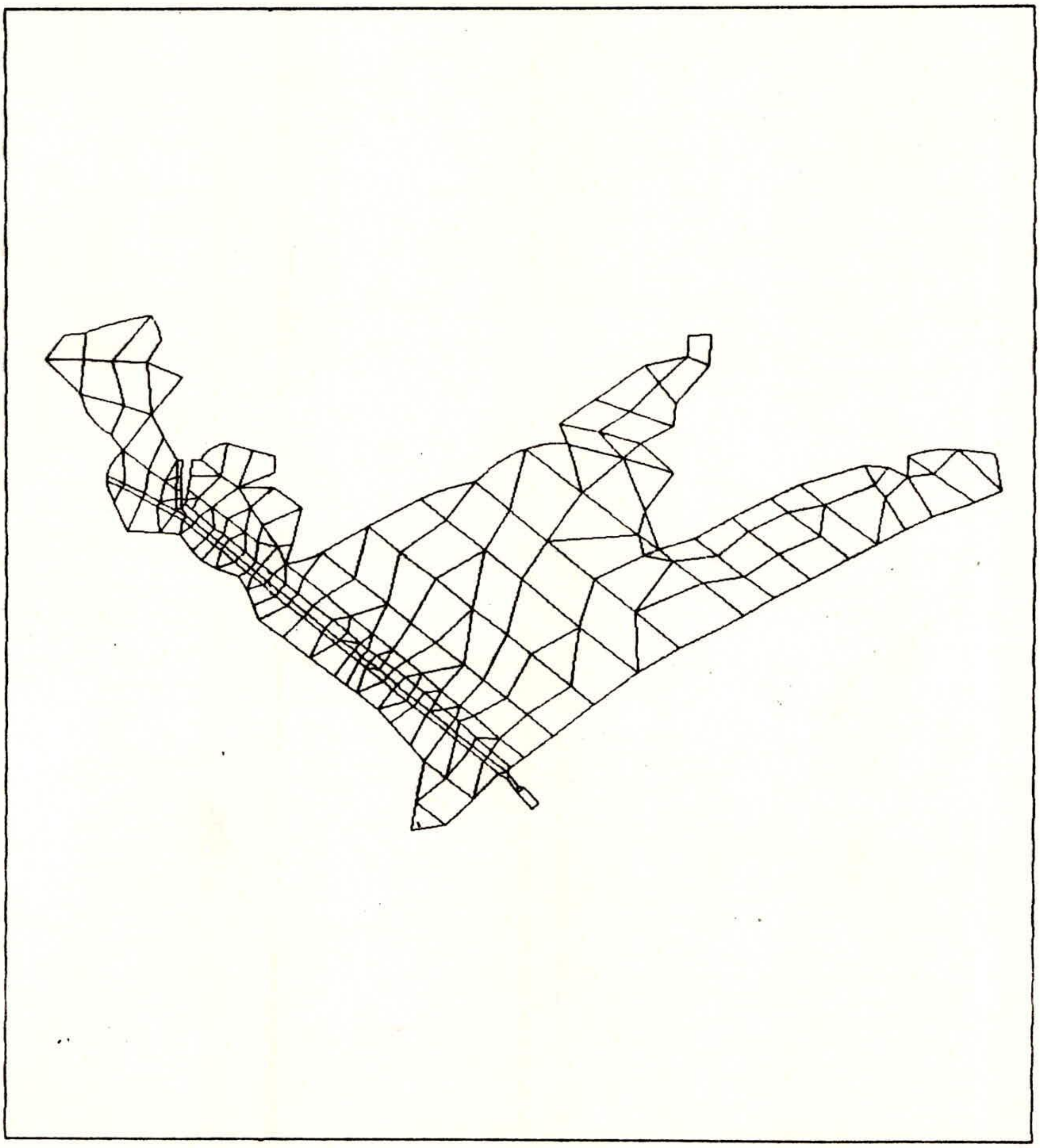


Fig:5 Finite Element Network for the Study Area.

properties of each of these areas are separately given in FLOMOD data file.

DINMOD data file is given in appendix I.

4.2 FLOMOD DATA

Outflow from two rivers (Lavaca and Colorado Rivers) has been provided as the upstream boundary condition at cross section 1 (connected by node numbers 952, 947, 942) and at cross section 2 (connected by node numbers 141, 105, 63). Peak inflow of 12000cfs was applied at section 1, as inflow from Lavaca river and a flow rate of 2000 cfs was applied at section 2, as a percentage inflow from Colorado river. Downstream boundary conditions were provided at the two openings of the estuary to the Gulf of Mexico. An average tidal cycle was applied at section 1 (connected by node numbers 1, 2, 3) and section 2 (connected by 25, 26, 27). The locations of specified boundary conditions are shown in fig 6.

Since the flow characteristics and properties of the ship channel and other areas are different, separate Manning roughness coefficient values have been specified for each property type code given in DINMOD data file. Manning coefficient for the ship channel is taken as 0.01 and for other regions as 0.02. Effect of wind is applied uniformly over all nodes in the network. Average wind velocity for summer season is taken as 14.67 ft/sec which blows in South West direction and average wind velocity for winter season is taken as 17.31 ft/sec which blows in North East direction.

An example FLOMOD data file is given in appendix II.

4.2.1 Cold Start:

Since the initial conditions, values of X and Y velocities and water surface elevations at each node points, are not known, a cold start procedure is to be used to get an approximate initial condition values. For a cold start run, X and Y velocities at all node points were kept to zero and water surface elevations at each node points were assumed to be 100 ft (assumed as mean sea level). At this point of analysis, velocity gradients will be very large and the convergence to a solution becomes difficult. To overcome this, a temporarily high value of kinematic eddy viscosity of 1000 square ft/sec was assumed for the first run which will encourage solution convergence within a few iteration, because of the dampening effect of high viscosity.

4.2.2 Hot Start:

Values of dependent variables u,v and water surface elevation from previous cold start run have been taken as initial condition for next hot start run. Magnitude of eddy viscosity has been gradually reduced to 10 square ft/sec which is physically possible value.

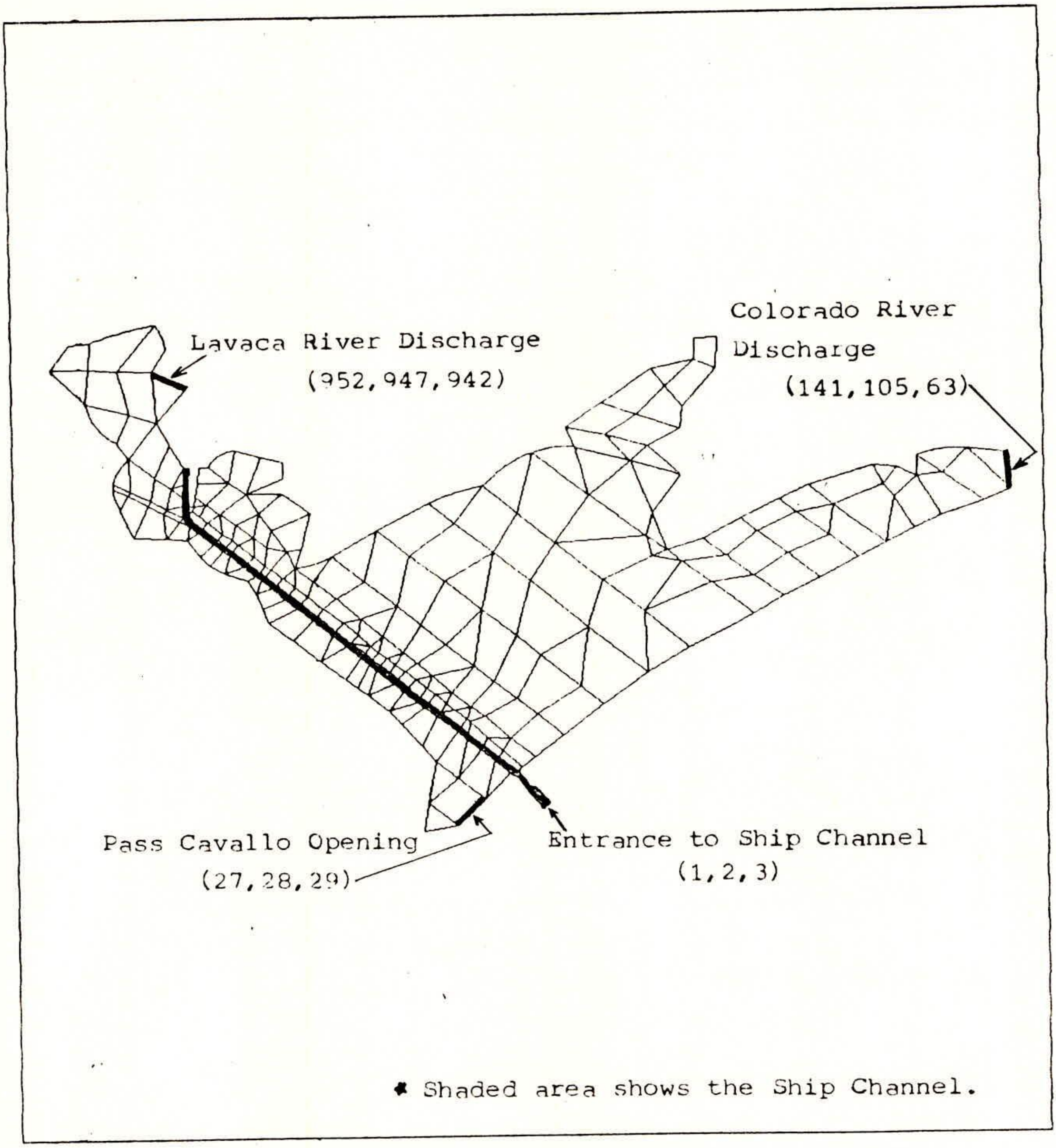


Fig:6 Locations of Specified Boundary Conditions.

4.3 ANOMOD DATA

ANOMOD gives printed outputs for time history report of velocity, unit flow and stage and plots time history graphs for velocity, unit flow and stage at node points. It also gives velocity vector plots and velocity and water surface contour plots for the entire study area.

ANOMOD data file is given in appendix III.

As an initial step in the application of this model, flow was taken as steady, without introducing tidal cycle and by assuming a high eddy viscosity value of 1000 square ft/sec. The program was executed (cold start) by assuming initial conditions and values of independent variables were obtained. These values and an eddy viscosity value of 500 square ft/sec were used for next run, ie., hot start. By repeating this procedure by reducing eddy viscosity upto 10 square ft/sec, the X and Y velocity and water surface elevations were estimated, which will give the steady state results. These steps have been repeated for wind velocities in two directions which will give the magnitudes of dependent variables in those conditions.

Now for each of these three cases, tidal cycles were introduced at sections 1 (node numbers 1,2,3) and 2 (node numbers 27,28,29) which will create the unsteady hydrodynamic situations.

5.0 ANALYSIS OF RESULTS AND DISCUSSIONS

The two dimensional finite element surface water model FESWMS-2DH has been applied for the Matagorda bay and approaches along Texas Gulf coast in U.S.A. Results for the steady state analysis and the effect of wind stresses in two opposite directions on flow parameters are described in the following paragraphs.

During the execution stages, after introducing tidal cycle at the entrance to the ship channel and at the Pass Cavallo opening, convergence problems occurred and a final result has not been obtained for the unsteady condition. In order to obtain a solution, refinement of network (ie, reducing of the size of the elements, thereby increasing the number of elements and nodes) is necessary which requires a great amount of computer time.

Outputs from the FLOMOD analysis gives velocities in X and Y directions and water depths at each node point. Output from ANOMOD run produces plots of velocity and water surface elevation contours for the entire study area.

Three FLOMOD runs have been performed, (a) without wind, (b) with a wind of velocity 14.67 ft/sec blowing in SW direction, and (c) with a wind of velocity 17.31 ft/sec which blows in NE direction.

5.1 ANALYSIS OF RESULTS

Six cross sections were considered for monitoring the effect of wind on flow parameters.

(a) Cross section at the entrance to the ship channel, comprising of node numbers (1,2,3).

At this cross section, the change in water surface elevation is negligibly small. Eventhough there is a considerable variation in the magnitudes of X and Y velocities with wind, that is not according to the wind direction. This may be due to the narrowness of the ship channel.

(b) Cross section at the Pass Cavallo opening, comprising of node numbers (27,28,,29).

Here also the change in water surface elevation is negligible. According to the wind direction, the X and Y velocities are also changing considerably. The variation of X and Y velocities can be seen in figures 7 and 8.

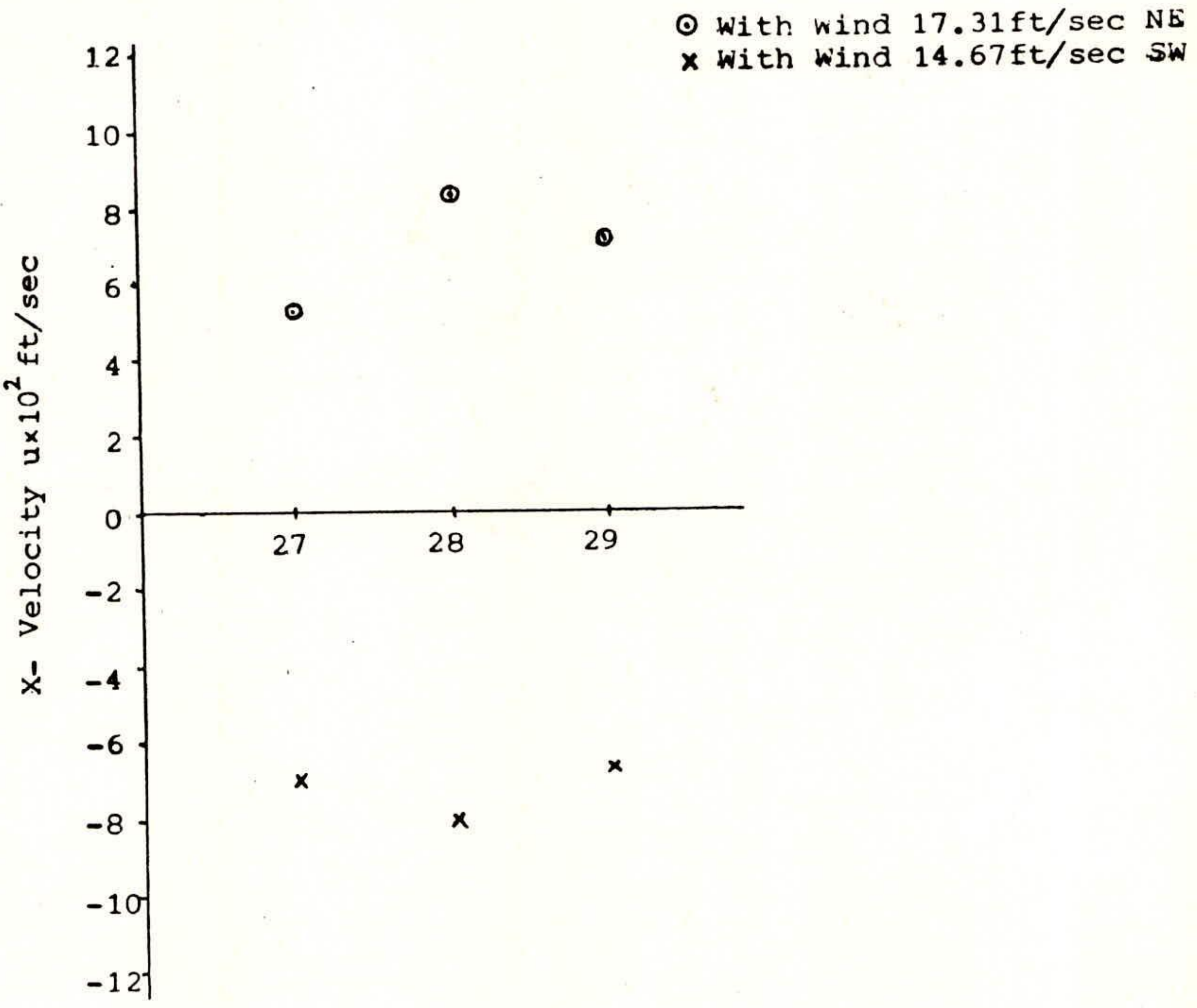


Fig:7 Effect of Wind on X-velocity at Pass Cavallo.

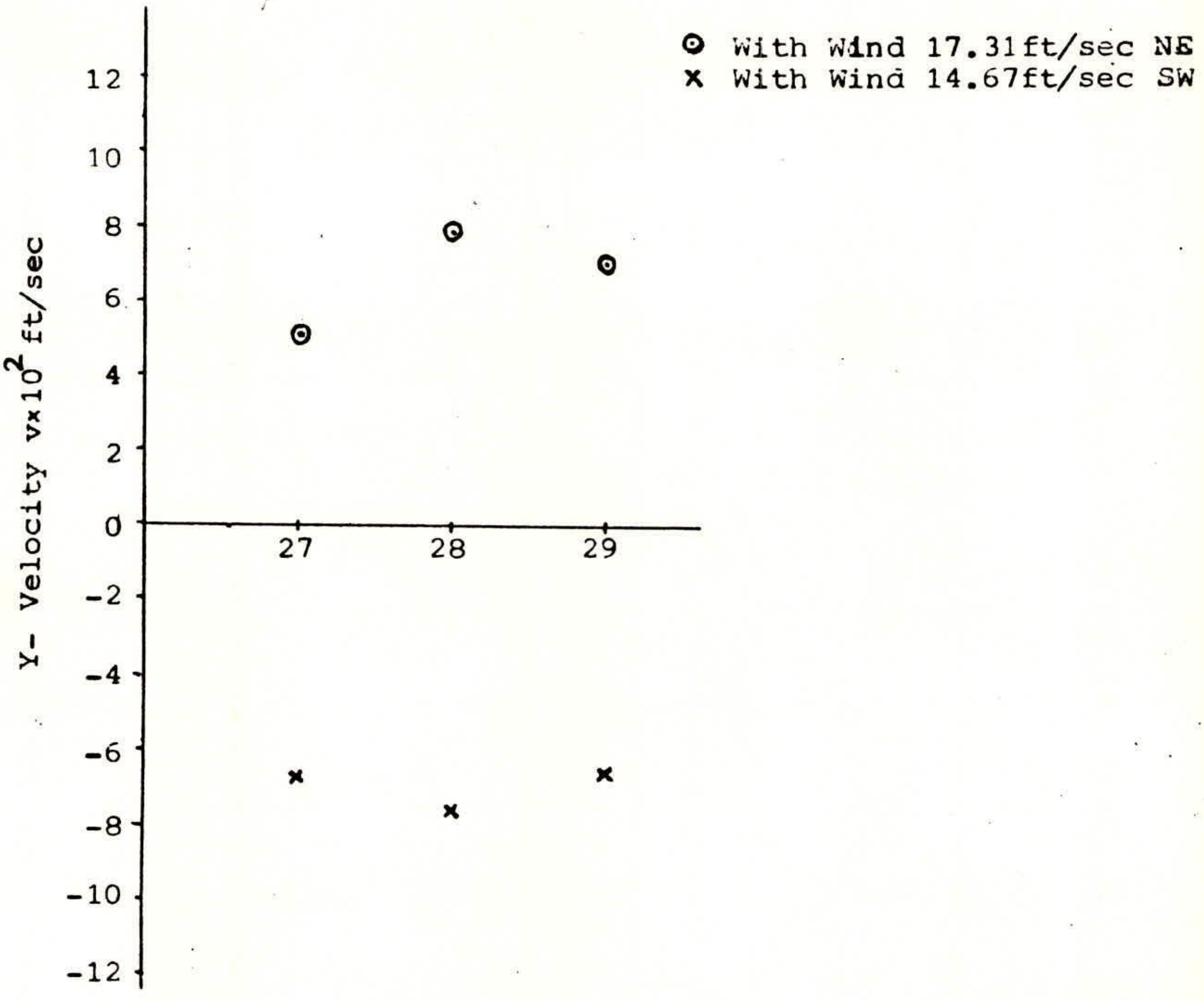


Fig:8 Effect of Wind on Y-Velocity at Pass Cavallo.

(c) Cross section at the mouth of Lavaca River, comprising of node numbers (952,947,942).

(d) Cross section at the mouth of Colorado River, comprising of node numbers (141,105,63).

At these two cross sections, where discharges from Lavaca and Colorado rivers are joining the study reach, there is not much effect for the change in wind velocity and direction on water velocity in X and Y directions. But a variation can be seen, as in figures 9 and 10, in depth of water depending on the wind direction.

(e) Cross section perpendicular to the ship channel, comprising of node numbers (633,642,644,646,632).

(f) Cross section parallel to the ship channel, comprising of node numbers (557,508,469,310,230,178,120,41).

At these cross sections wind does not have any effect on water depth. X and Y velocities are changing according to wind velocity and direction, which can be seen from figures 11, 12, 13 and 14.

From these results, it can be inferred that the circulation patterns reverse when the wind blows in opposite directions.

Results from the ANOMOD run are in the form of velocity contours at an interval 0.05 ft/sec (figures 15, 16, 17), water surface elevation contours at an interval of 0.02 ft (figures 18, 19, 20) and plots of velocity vectors (figures 21, 22, 23).

When there is no wind, velocity variation is negligible throughout the study area except along the ship channel. With the introduction of wind, the velocity gradient along and around the ship channel increase with slight variation at distant areas.

When there is no wind, water surface is almost horizontal except at the two discharging points (mouths of Lavaca and Colorado rivers). After the introduction of wind, water surface elevation changes gradually in the direction of the wind. For the wind with a velocity 14.67 ft/sec in SW direction, water surface contours are almost parallel, minimum (99.7 ft) near the mouth of the Colorado river and maximum (100.2 ft) at the other end. When the direction of wind changes to NE (velocity 17.31 ft/sec), pattern of the contours remains same but the minimum value (99.8 ft) is observed near Pass Cavallo opening and maximum value (100.4 ft) near the mouth of the Colorado river.

5.2 CONCLUSIONS

After the application of FESWMS - 2DH to an estuarine system modelling and analysing the results, following can be noted.

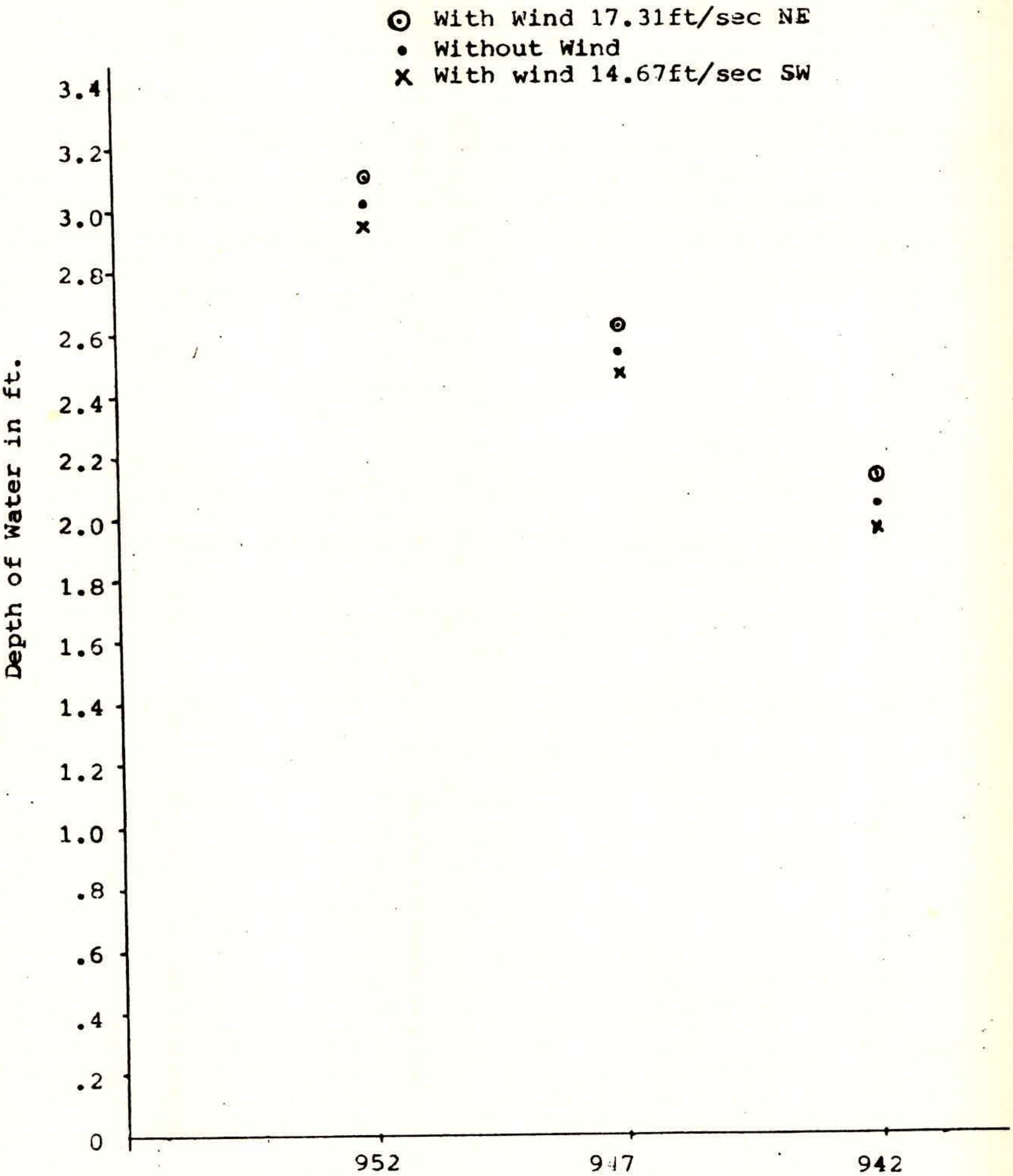


Fig:9 Effect of Wind on Water Depth
at the Mouth of Lavaca River.

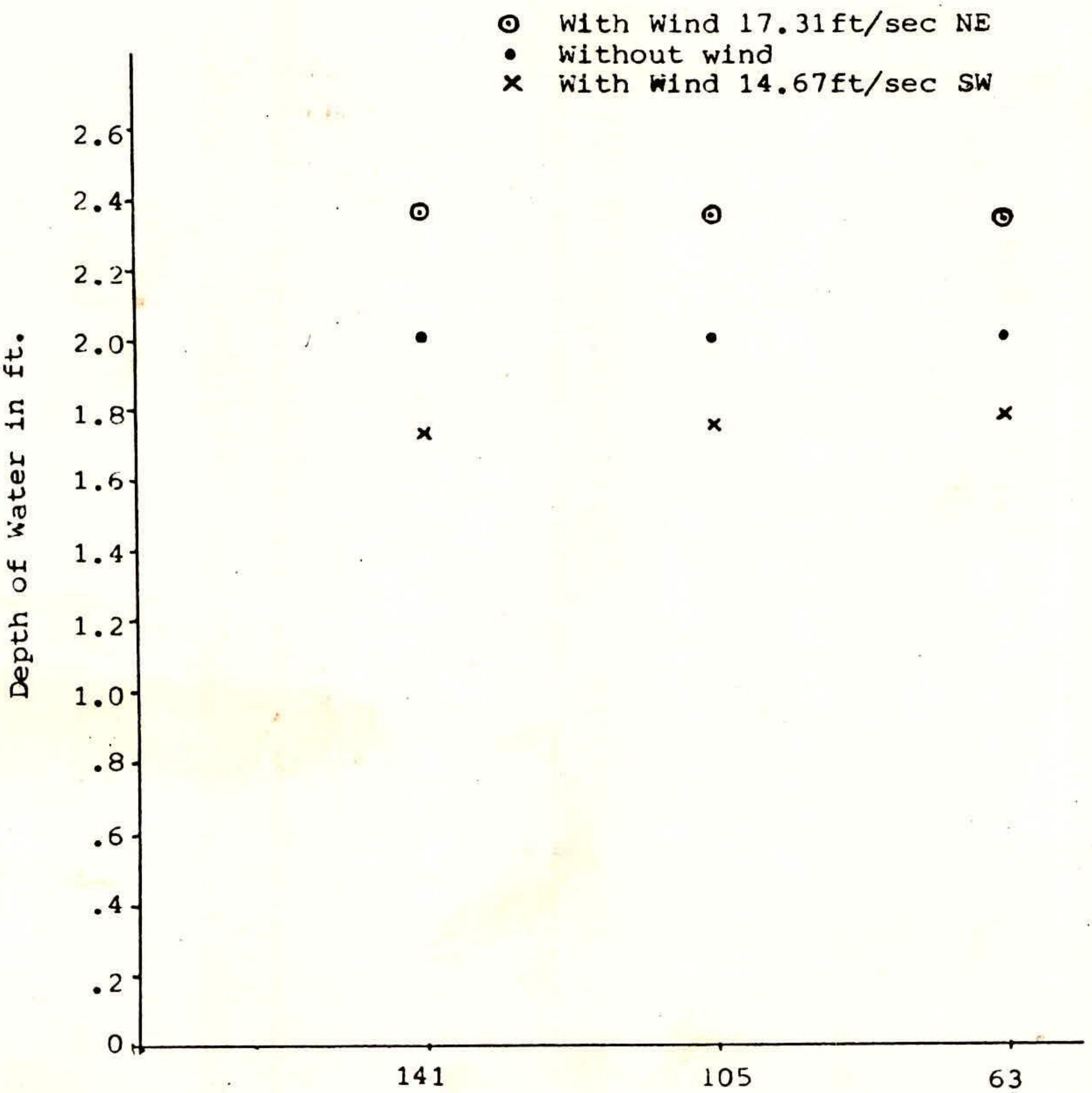


Fig:10 Effect of Wind on Water Depth
at the Mouth of Colorado River.

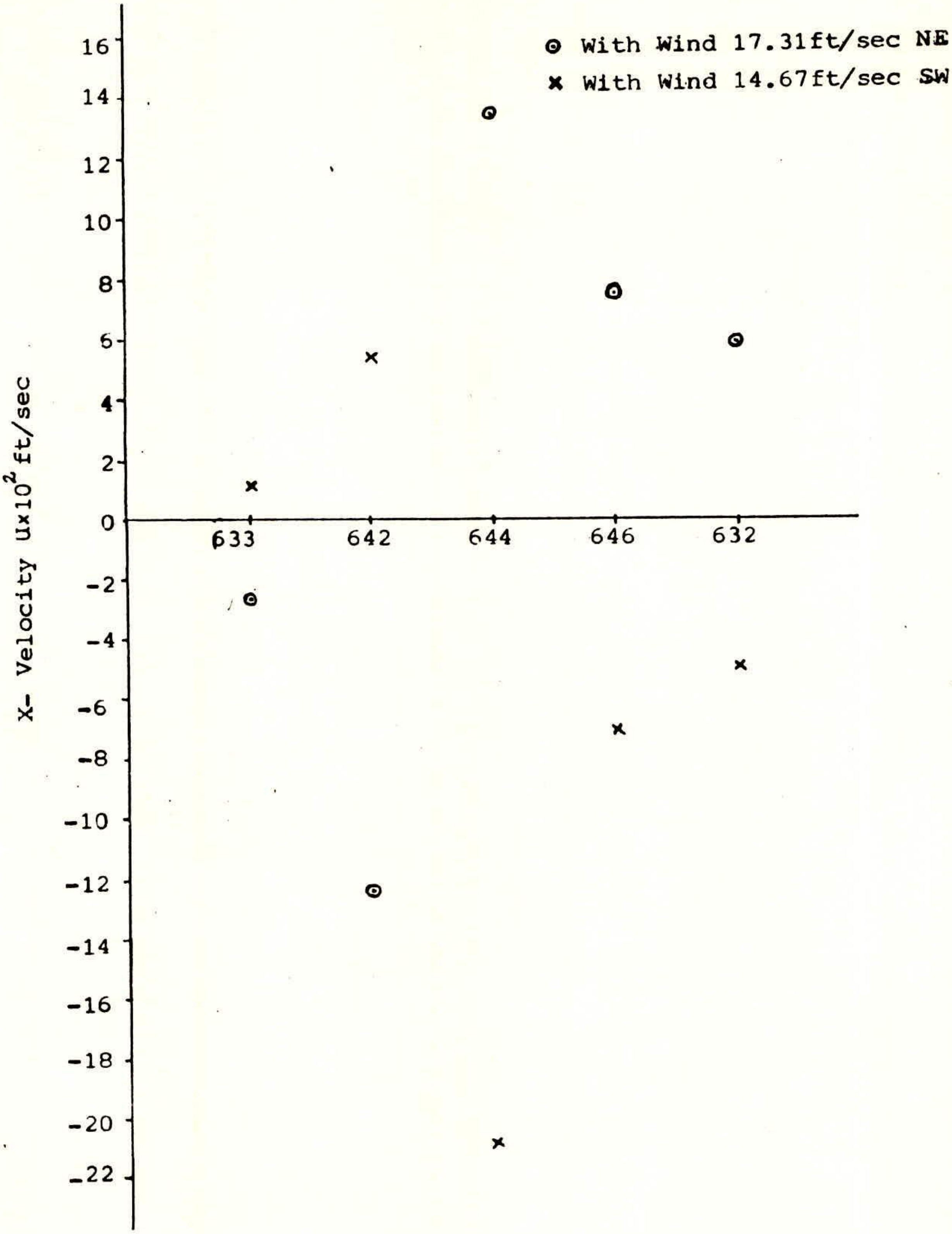


Fig:11 Effect of Wind on X-Velocity at a C/S Perpendicular to Ship Channel.

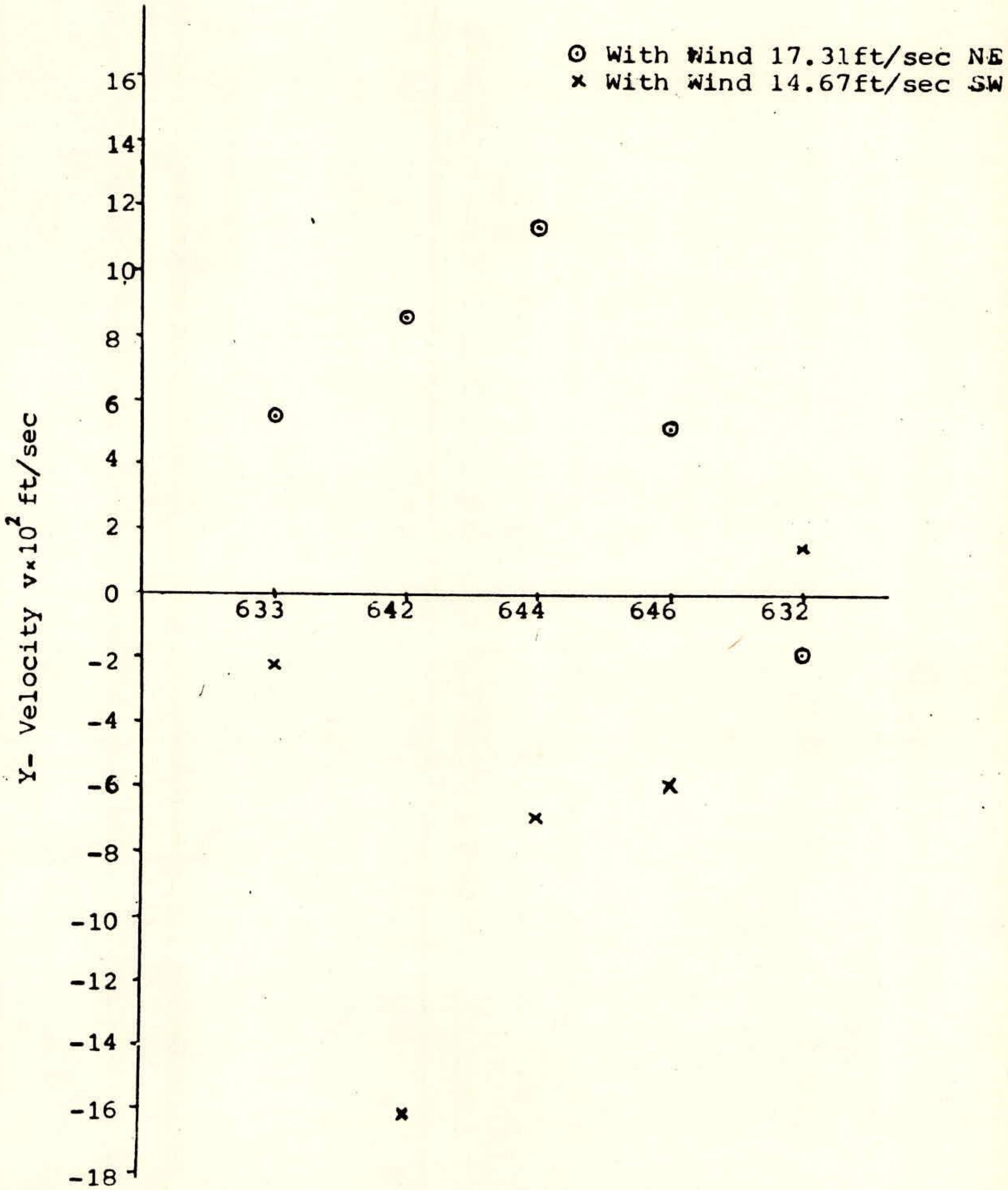


Fig:12 Effect of Wind on Y-Velocity at a C/S Perpendicular to Ship Channel.

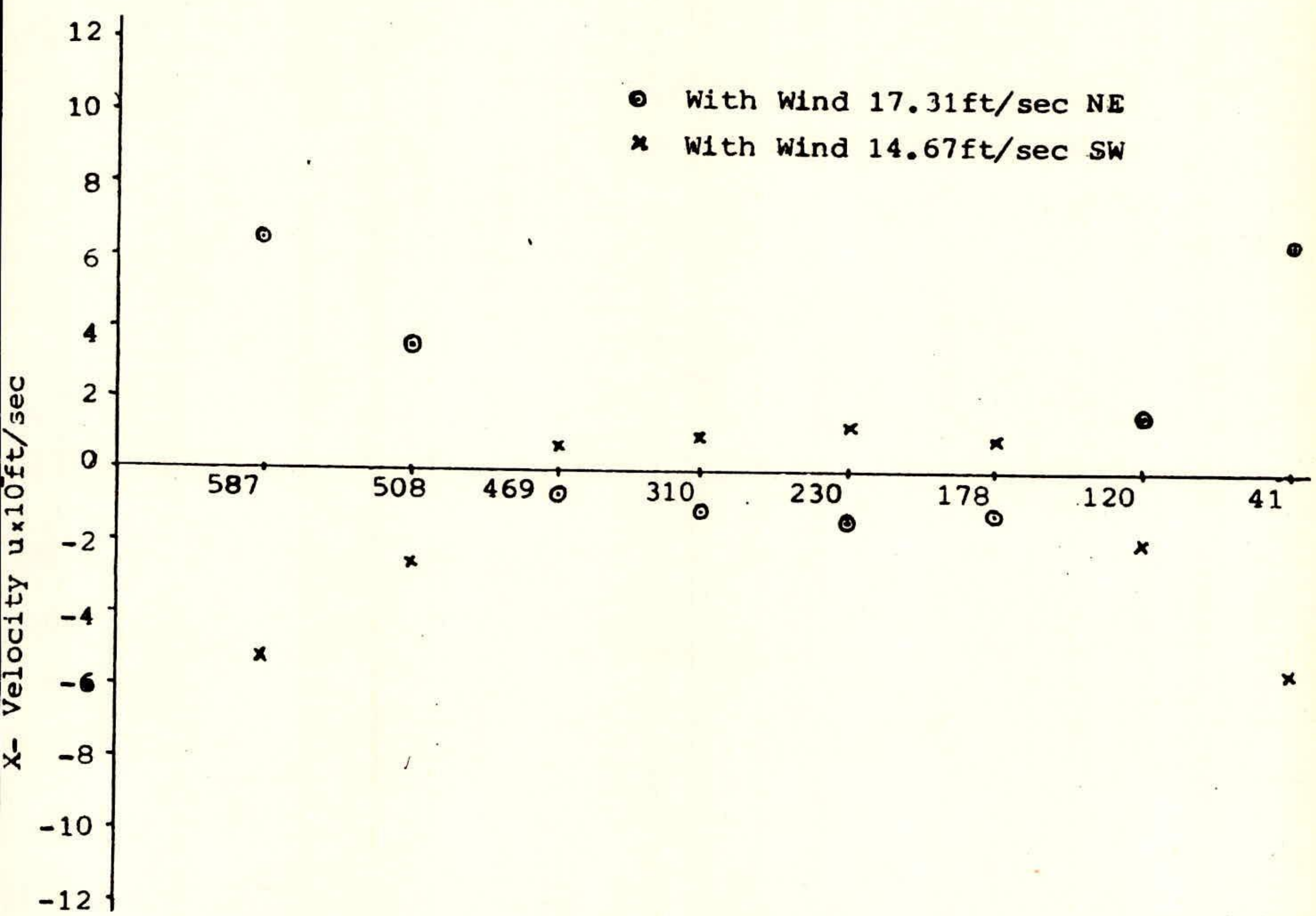


Fig:13 Effect of Wind on X-Velocity at a C/S Parallel to Ship Channel.

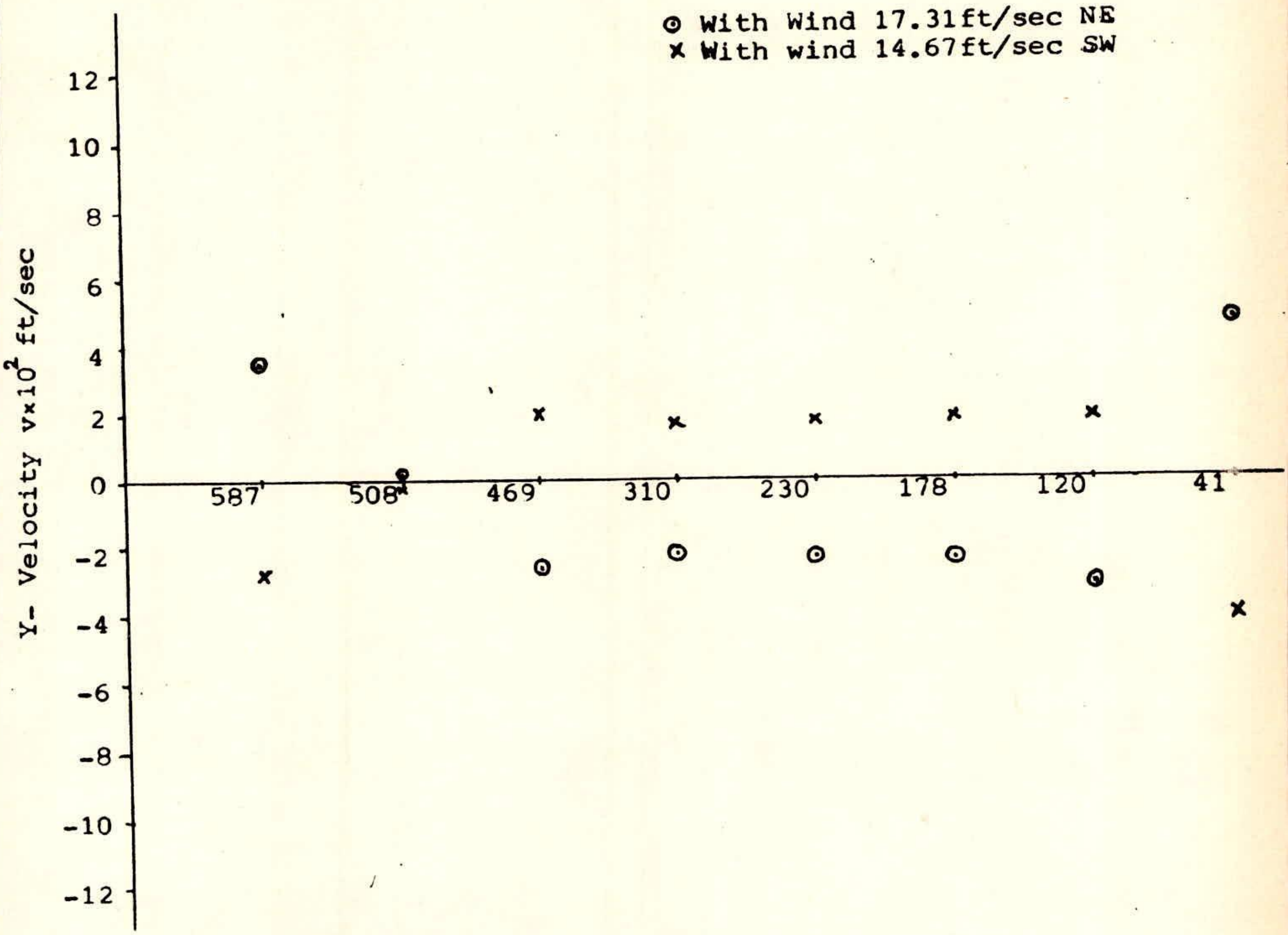


Fig:14 Effect of Wind on Y-Velocity at a C/S Parallel to Ship Channel.

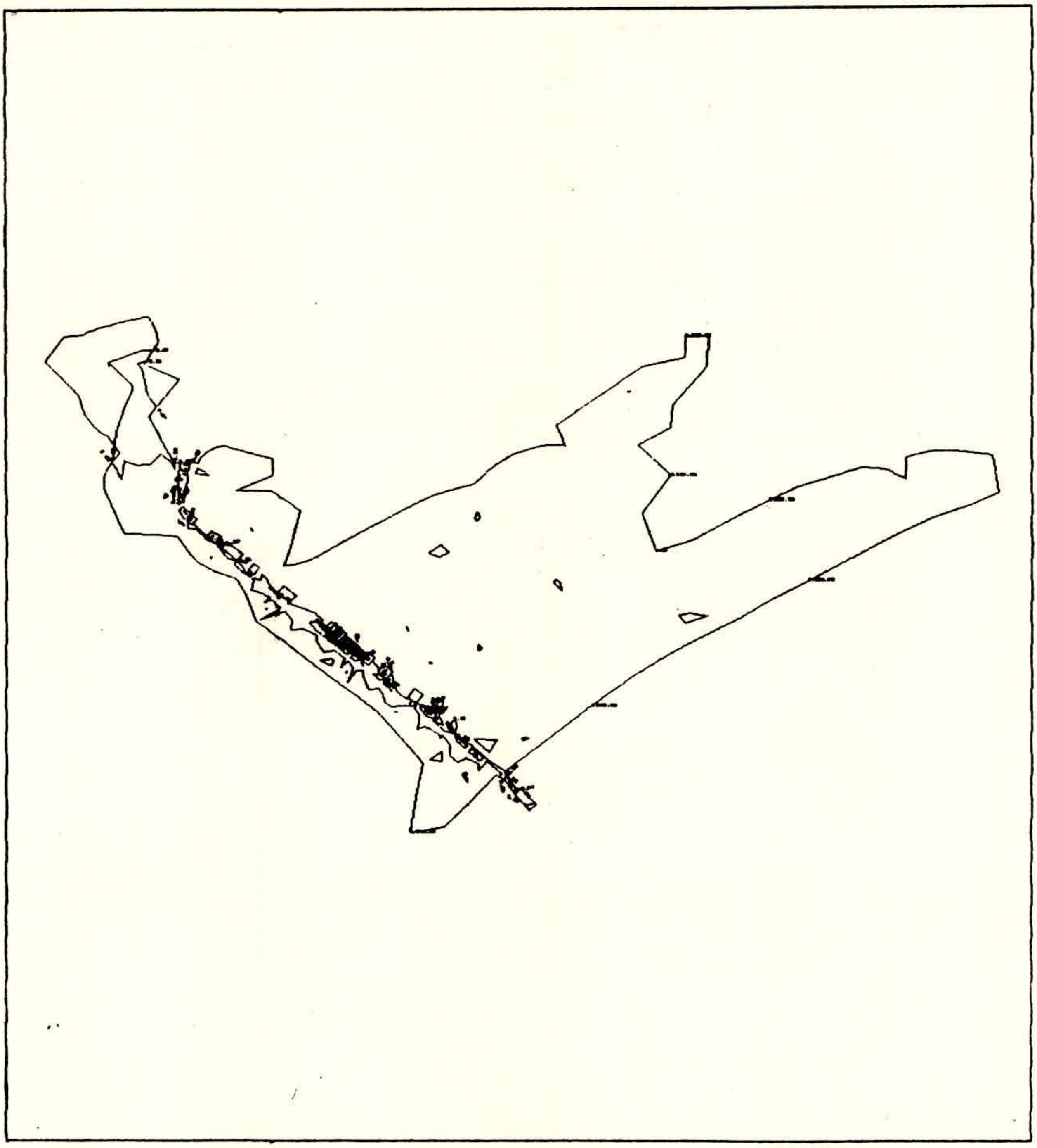


Fig:15 Velocity Contour - Without Wind.

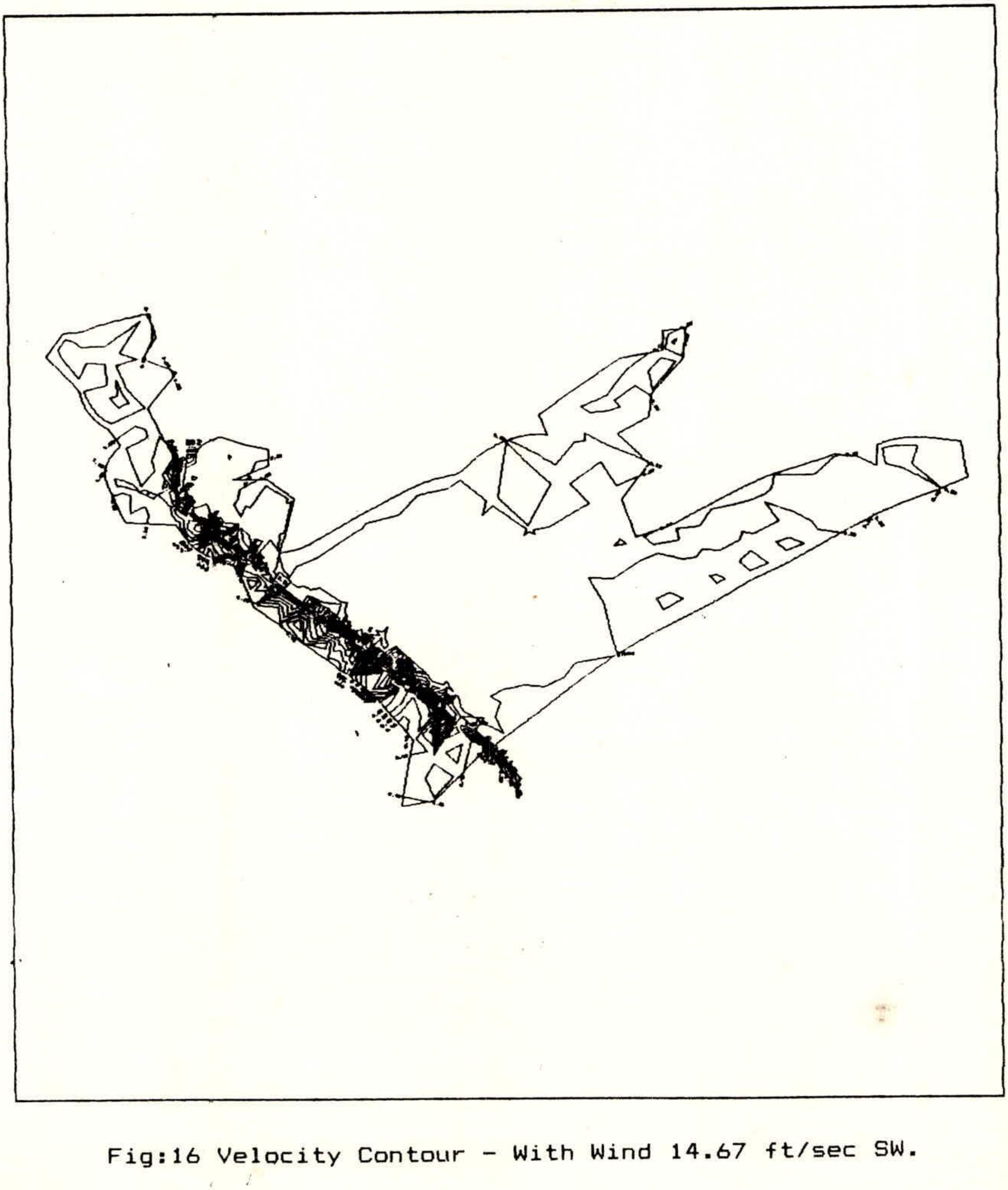


Fig:16 Velocity Contour - With Wind 14.67 ft/sec SW.

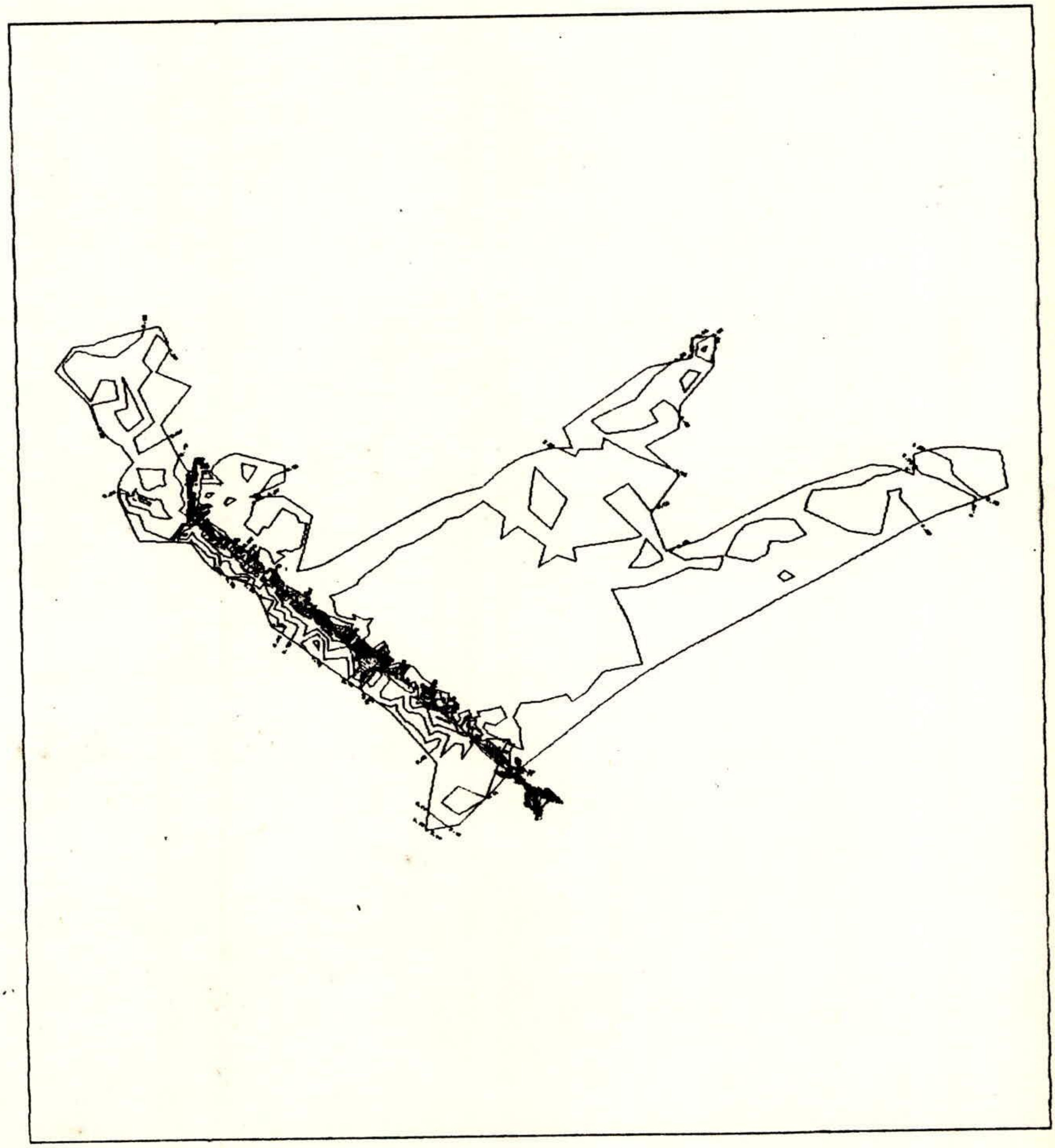


Fig:17 Velocity Contour - With Wind 17.31 ft/sec NE.

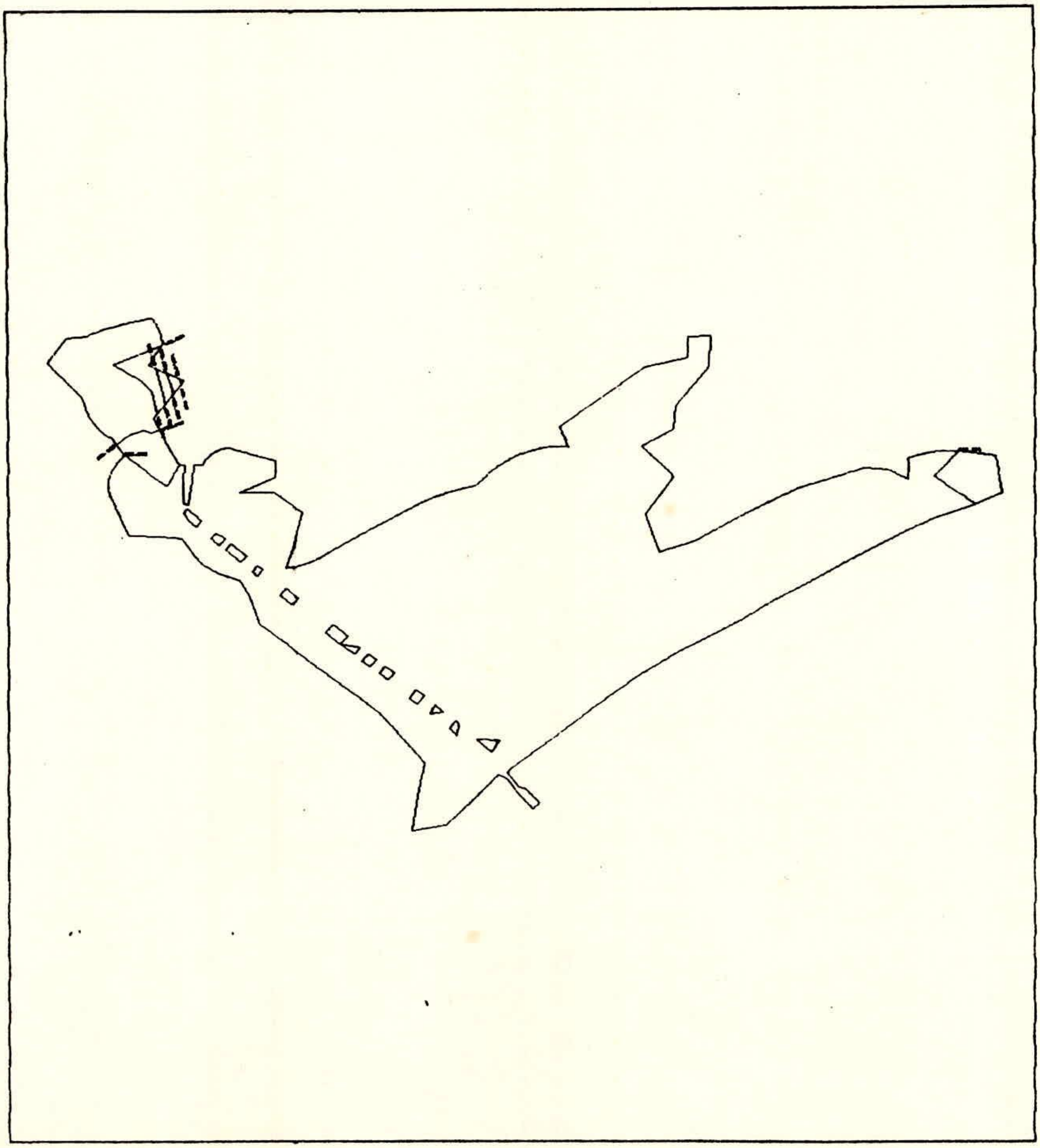


Fig:18 Water Surface Elevation Contours - Without Wind.

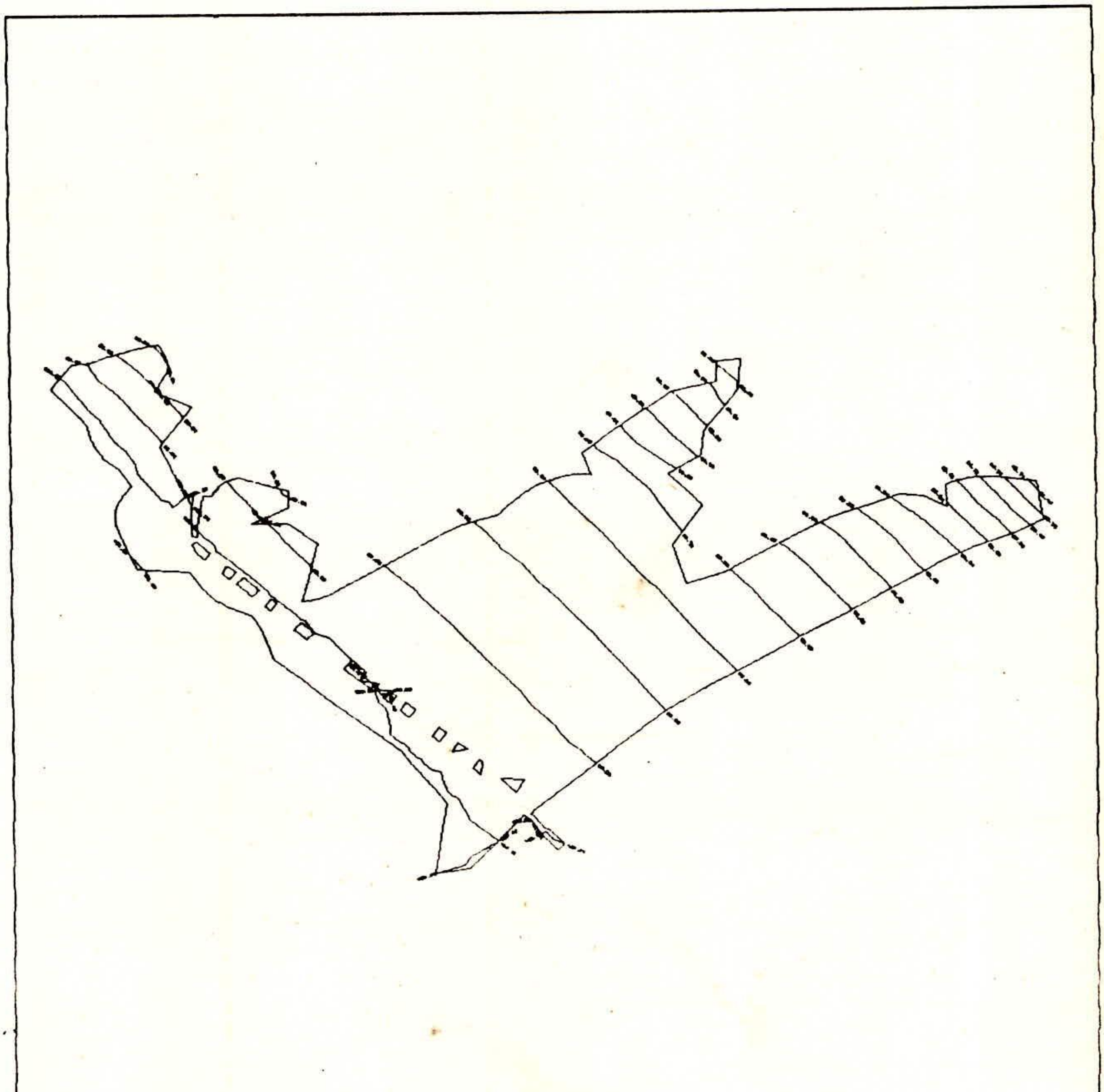


Fig:19 Water Surface Elevation Contours -
With Wind 14.67 ft/sec SW.

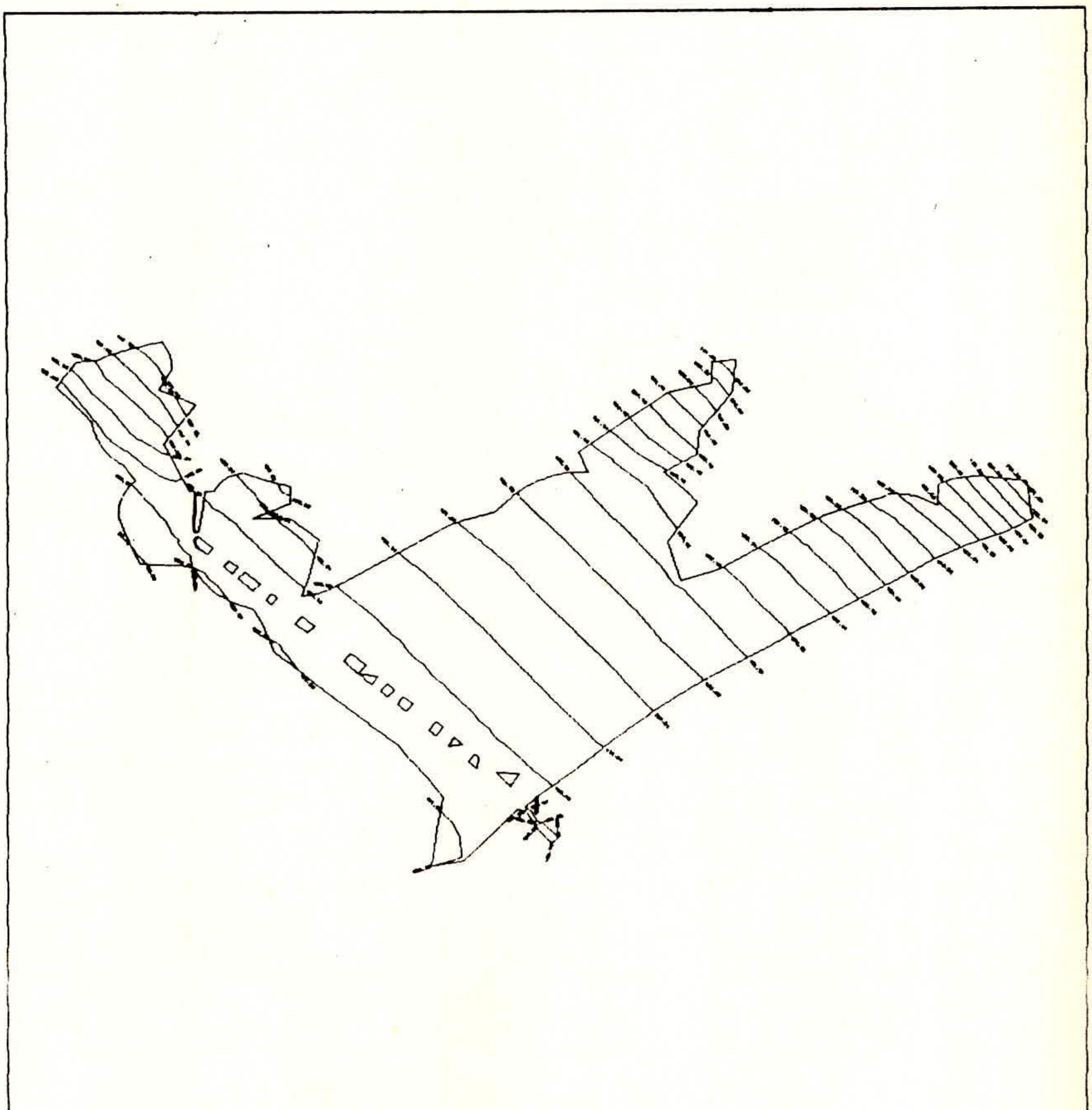


Fig:20 Water Surface Elevation Contours -
With Wind 17.31 ft/sec NE.

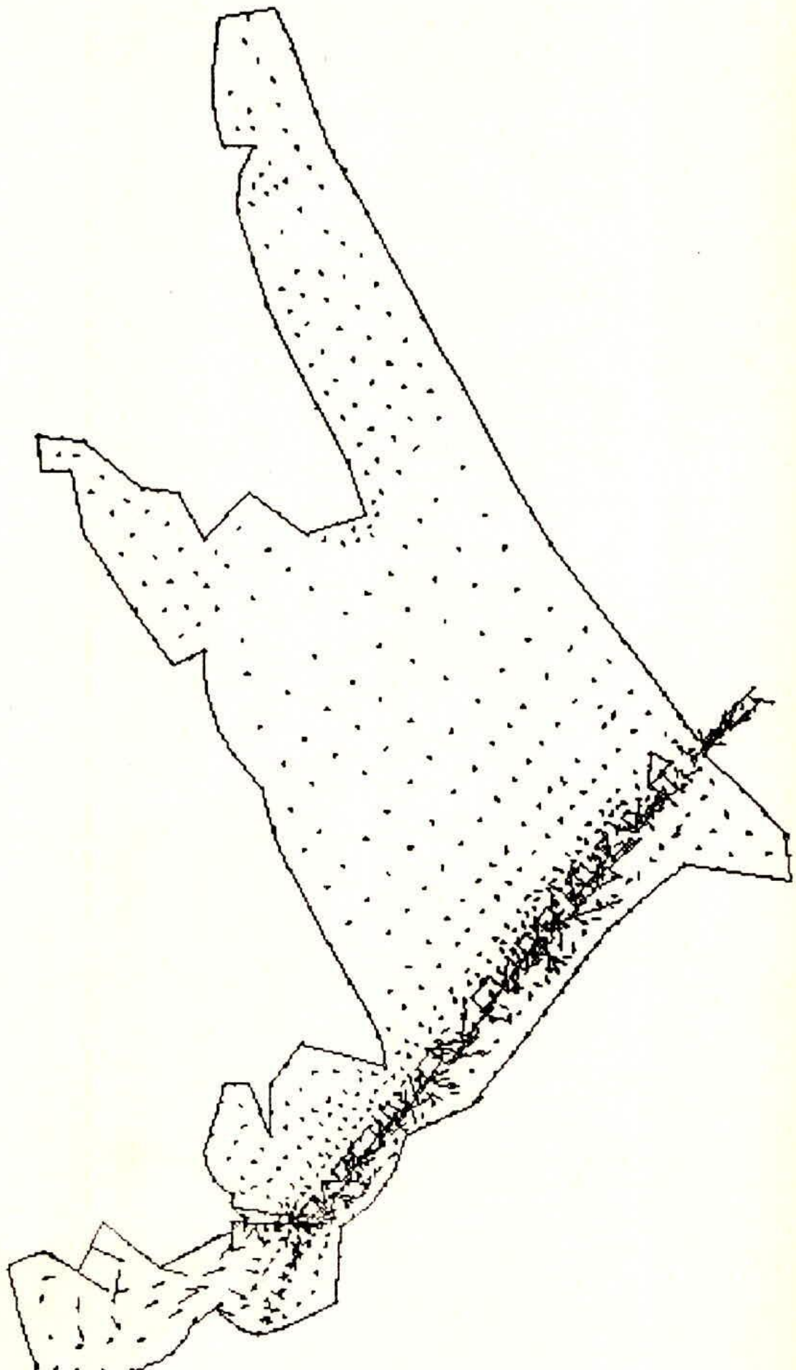


Fig:21 Velocity Vector - Without Wind

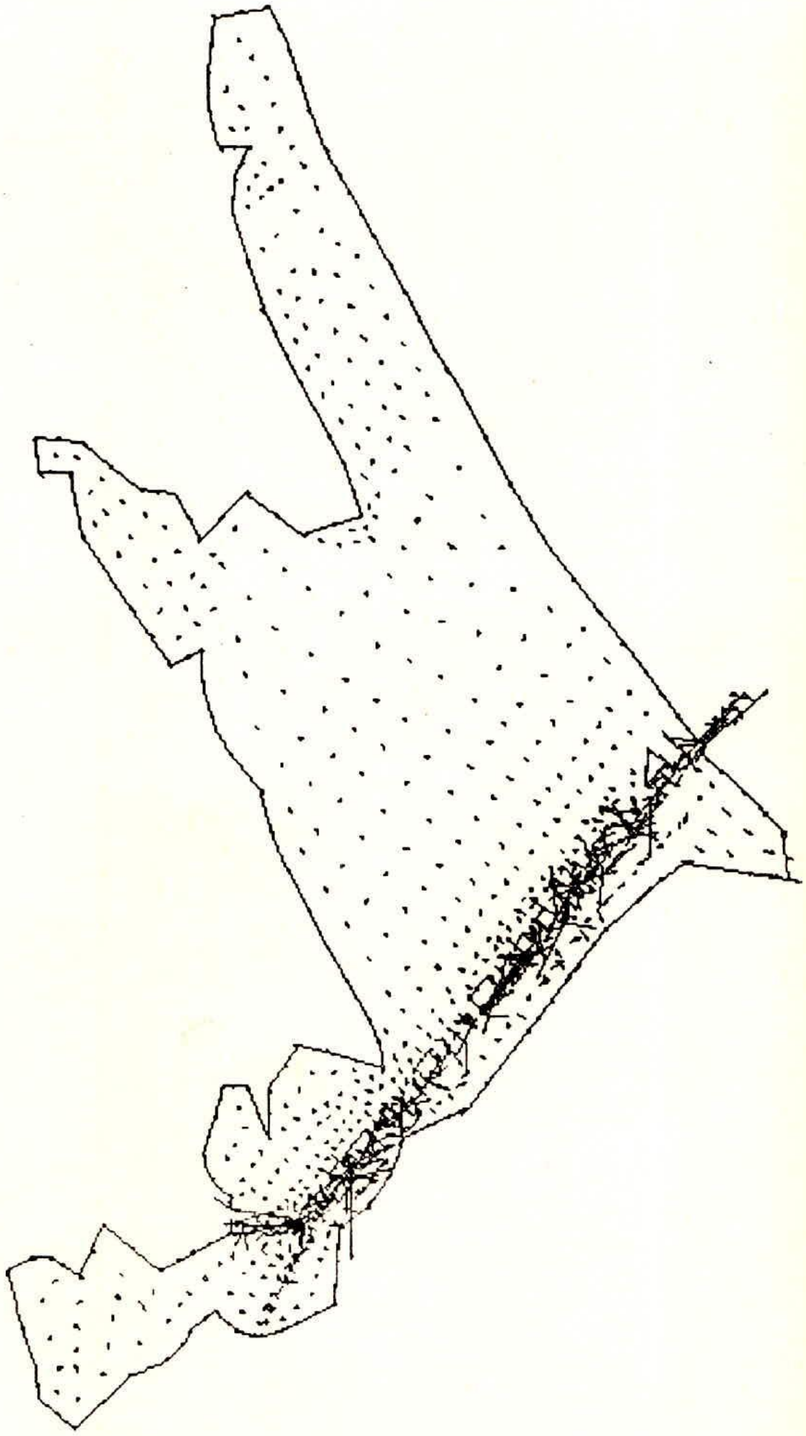


Fig:22 Velocity Vector - With Wind 14.67 ft/sec SW.

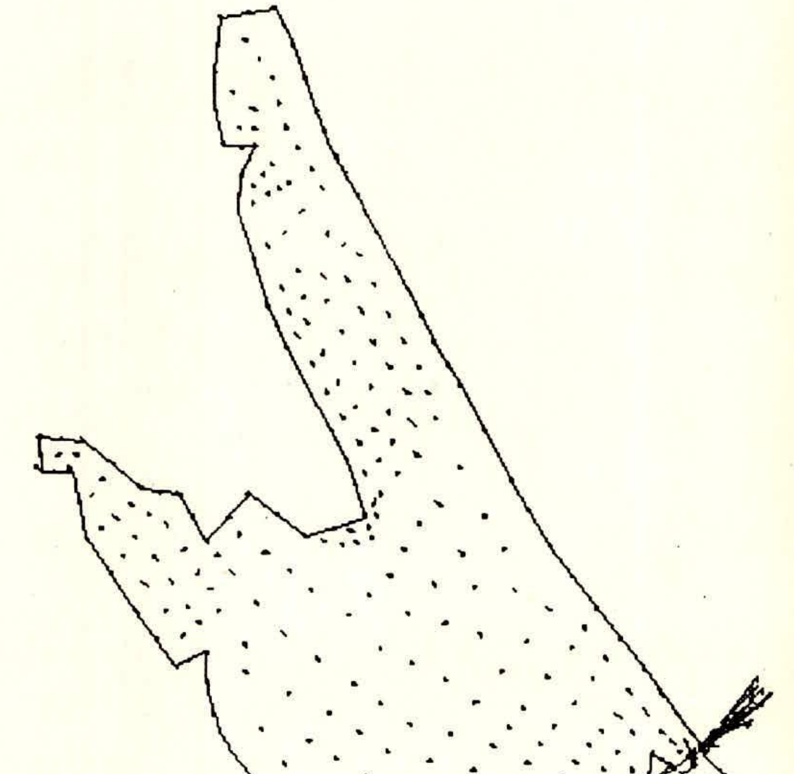


Fig:23 Velocity Vector - With Wind 17.31 ft/sec NE.

1. FESWMS - 2DH can be used effectively for simulating the unsteady hydrodynamic conditions.

2. For unsteady flow conditions, special care should be taken at the network design stage. The areas where the flow parameters change rapidly, should be modeled with comparatively smaller sized elements which encourages the solution to converge easily.

3. The same network could be refined at the area near the ship channel entrance and at Pass Cavallo opening and could be used to simulate the effect of tide.

4. FESWMS - 2DH is very sensitive to the value of Eddy viscosity, initial condition and boundary condition and hence these are to be specified accurately and carefully.

5. FESWMS - 2DH, PC version, takes considerable computer time for a fairly large solution domain (flow field). A network which consists of 252 elements and 976 nodes, takes about 5 to 6 hours on PC 486, to run FLOMOD module.

6. Further studies could be performed in surface water flow problems, in Indian conditions using FESWMS - 2DH.

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CHANDRAMOHAN.T

APPENDIX I

DINMOD DATA FILE

```
SWMS                1        1
MATAGORDA BAY AND SHIP CHANNEL
   0   3   1   0   0   0   0   1
PLOT
MATAGORDA BAY AND APPROACHES
   0   0
     .000      .000      .000      .000      5.000
     .000      .000      .000      .000 80000.000 80000.000        .000
ELEM
   1    9    8    7    4    1    2    3    6    5    1    0
   2   15   14   13   10    7    8    9   12   11    1    0
   3   21   20   19   16   13   14   15   18   17    1    0
   4   33   32   31   22   19   20   21   24   23    1    0
   5  106   64   25   26   27   65    0    0    0    2    0
   6  108  107  106   65   27   28   29   67   66    2    0
   7  146  145  108   67   29   69  110  109   68    2    0
   8  110   69   29   30   31   70    0    0    0    2    0
   9  112  111  110   70   31   32   33   72   71    1    0
  10  114  113  112   72   33   34   35   74   73    2    0
  11  116  115  114   74   35   36   37   76   75    2    0
  12  118  117  116   76   37   38   39   78   77    2    0
  13  120  119  118   78   39   40   41   80   79    2    0
  14  122  121  120   80   41   42   43   82   81    2    0
  15  123   84   43   44   45   85    0    0    0    2    0
  16  125  124  123   85   45   46   47   87   86    2    0
  17  127  126  125   87   47   48   49   89   88    2    0
  18  129  128  127   89   49   50   51   91   90    2    0
  19  131  130  129   91   51   52   53   93   92    2    0
  20  190  446  131   93   53   54   55   95   94    2    0
  21  192  191  190   95   55   97  133  132   96    2    0
  22  133   97   55   56   57   98    0    0    0    2    0
  23  135  134  133   98   57   58   59  100   99    2    0
  24  137  136  135  100   59   60   61  102  101    2    0
  25  137  102   61   62   63  104  139  138  103    2    0
  26  139  104   63  105  141  140    0    0    0    2    0
  27  137  138  139  290  289  291    0    0    0    2    0
  28  137  291  289  288  135  136    0    0    0    2    0
  29  192  132  133  134  135  194  286  249  193    2    0
  30  192  249  286  285  284  248    0    0    0    2    0
  31  190  191  192  248  284  283  282  246  247    2    0
  32  217  218  190  246  282  281  280  244  245    2    0
  33  190  218  217  189  131  446    0    0    0    2    0
  34  215  216  217  244  280  279  278  242  243    2    0
  35  217  216  215  187  129  130  131  189  188    2    0
  36  213  214  215  242  278  277  276  240  241    2    0
  37  127  128  129  187  215  214  213  185  186    2    0
  38  211  212  213  240  276  275  274  238  239    2    0
  39  125  126  127  185  213  212  211  183  184    2    0
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42	211	182	123	124	125	183	0	0	0	2	0
43	209	180	122	82	43	84	123	181	83	2	0
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45	178	177	176	157	118	119	120	159	158	2	0
46	176	175	174	151	116	117	118	157	156	2	0
47	155	149	114	115	116	150	0	0	0	0	0
48	155	154	153	148	112	113	114	149	391	2	0
49	153	152	146	109	110	111	112	148	147	1	0
50	108	143	160	142	106	107	0	0	0	2	0
51	220	219	160	143	108	144	162	195	161	2	0
52	162	144	108	145	146	163	0	0	0	2	0
53	170	169	162	163	146	152	153	165	164	1	0
54	172	171	170	165	153	154	155	167	166	2	0
55	174	173	172	167	155	150	116	151	168	2	0
56	222	221	220	195	162	169	170	197	196	1	0
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63	270	268	233	234	209	235	236	271	269	2	0
64	270	271	236	273	274	272	0	0	0	2	0
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66	317	316	233	268	270	318	0	0	0	2	0
67	326	325	317	318	270	294	293	320	319	2	0
68	326	320	293	321	322	323	0	0	0	2	0
69	326	323	322	324	328	327	0	0	0	2	0
70	297	296	295	250	160	219	220	252	251	2	0
71	299	298	297	252	220	221	222	254	253	1	0
72	301	300	299	254	222	223	224	256	255	2	0
73	301	256	224	225	226	257	0	0	0	2	0
74	303	304	299	300	301	302	0	0	0	0	0
75	306	305	303	302	301	257	226	259	258	2	0
76	308	307	306	259	226	227	228	261	260	2	0
77	310	309	308	261	228	229	230	263	262	2	0
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79	314	313	312	265	232	266	233	315	267	2	0
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82	317	325	326	340	355	339	0	0	0	2	0
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84	356	342	326	327	328	343	0	0	0	2	0
85	356	357	358	367	373	372	371	365	366	2	0
86	358	357	356	343	328	329	330	345	344	2	0
87	358	359	360	369	375	374	373	367	368	2	0
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90	360	347	332	333	334	349	362	361	348	2	0
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97	412	385	306	307	308	386	0	0	0	2	0
98	406	405	404	397	388	389	390	399	398	2	0
99	408	407	406	399	390	392	393	401	400	1	0
100	410	409	408	401	393	394	395	403	402	0	0
101	414	413	404	405	406	415	0	0	0	2	0
102	422	421	414	415	406	407	408	417	416	1	0
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105	436	435	434	427	404	413	414	429	428	2	0
106	438	437	436	429	414	421	422	431	430	1	0
107	440	439	438	431	422	423	424	433	432	2	0
108	442	441	440	433	424	420	412	426	425	2	0
109	444	443	442	426	412	386	308	387	981	2	0
110	310	445	444	387	308	309	0	0	0	2	0
111	448	447	434	435	436	449	0	0	0	2	0
112	461	460	448	449	436	437	438	451	450	1	0
113	463	462	461	451	438	439	440	453	452	0	0
114	465	464	463	453	440	441	442	455	454	2	0
115	467	466	465	455	442	443	444	457	456	2	0
116	469	468	467	457	444	445	310	459	458	2	0
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121	502	501	500	483	475	480	481	485	484	0	0
122	481	480	475	476	461	462	463	478	477	2	0
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129	523	522	521	514	496	497	498	516	515	2	0
130	525	524	523	516	498	499	500	518	517	1	0
131	527	526	525	518	500	501	502	520	519	2	0
132	504	528	527	520	502	503	0	0	0	2	0
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134	543	542	541	531	523	524	525	533	532	1	0
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137	547	546	545	535	527	528	504	537	536	2	0
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139	549	548	539	540	541	550	0	0	0	2	0
140	556	555	549	550	541	542	543	552	551	1	0
141	558	557	556	552	543	544	545	554	553	0	0
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161	610	611	612	623	632	622	0	0	0	2	0
162	642	641	640	633	624	625	626	635	634	2	0
163	644	643	642	635	626	627	628	637	636	1	0
164	646	645	644	637	628	629	630	639	638	2	0
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169	663	662	661	652	646	647	632	654	653	2	0
170	663	654	632	655	665	664	0	0	0	2	0
171	680	679	678	666	640	656	657	668	667	2	0
172	682	681	680	668	657	658	659	670	669	1	0
173	684	683	682	670	659	660	661	672	671	0	0
174	686	685	684	672	661	662	663	674	673	2	0
175	686	674	663	675	688	687	0	0	0	2	0
176	663	664	665	677	690	689	688	675	676	2	0
177	706	705	704	691	678	679	680	693	692	2	0
178	708	707	706	693	680	681	682	695	694	1	0
179	710	709	708	695	682	683	684	697	696	2	0
180	712	711	710	697	684	685	686	699	698	2	0
181	714	713	712	699	686	687	688	701	700	2	0
182	688	689	690	703	716	715	714	701	702	2	0
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184	725	724	723	717	706	707	708	719	718	1	0
185	727	726	725	719	708	709	710	721	720	0	0
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188	742	741	740	731	723	724	725	733	732	1	0
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191	714	747	746	737	712	713	0	0	0	2	0
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193	762	978	761	750	740	741	742	752	751	1	0
194	764	763	762	752	742	743	744	754	753	0	0
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199	783	782	781	774	761	978	762	776	775	1	0
200	785	784	783	776	762	763	764	778	777	2	0
201	766	786	785	778	764	765	0	0	0	2	0
202	801	800	779	780	781	787	0	0	0	2	0
203	803	802	801	787	781	782	783	789	788	1	0
204	805	804	803	789	783	784	785	791	790	0	0
205	807	806	805	791	785	786	766	793	792	2	0
206	809	808	807	793	766	767	768	795	794	2	0
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209	832	831	830	816	779	800	801	818	817	2	0
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212	838	837	836	821	803	804	805	823	822	0	0
213	840	839	838	823	805	806	807	825	824	2	0
214	842	841	840	825	807	826	0	0	0	2	0
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217	809	810	811	849	848	829	0	0	0	2	0
218	859	858	830	831	832	851	0	0	0	2	0
219	861	860	859	851	832	833	834	853	852	1	0
220	861	853	834	854	863	862	0	0	0	2	0
221	863	854	834	835	836	856	865	864	855	1	0
222	865	856	836	837	838	839	840	866	857	2	0
223	506	505	504	487	465	466	467	489	488	2	0
224	873	867	861	862	863	869	875	874	868	2	0
225	875	869	863	864	865	871	877	876	870	1	0
226	877	871	865	866	840	841	842	878	872	0	0
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228	885	881	875	876	877	883	887	886	882	1	0
229	887	883	877	878	842	843	844	888	884	0	0
230	885	886	887	891	895	894	893	889	890	1	0
231	887	888	844	845	846	896	895	891	892	0	0
232	908	907	906	897	830	858	859	899	898	2	0
233	910	909	908	899	859	860	861	901	900	1	0
234	912	911	910	901	861	867	873	903	902	2	0
235	873	879	893	905	914	913	912	903	904	2	0
236	926	925	924	915	906	907	908	917	916	2	0
237	928	927	926	917	908	909	910	919	918	1	0
238	910	911	912	921	930	929	928	919	920	2	0
239	912	913	914	923	932	931	930	921	922	2	0
240	926	934	937	933	924	925	0	0	0	2	0
241	926	927	928	936	939	938	937	934	935	1	0
242	928	929	930	940	939	936	0	0	0	2	0
243	950	949	948	943	930	931	932	945	944	2	0
244	950	956	962	955	948	949	0	0	0	2	0
245	966	971	974	964	962	965	0	0	0	2	0
246	950	957	958	979	966	965	962	956	963	2	0
247	950	945	932	946	952	959	958	957	951	2	0

248	932	941	942	947	952	946	0	0	0	2	0
249	966	980	973	977	976	975	974	971	972	2	0
250	966	979	958	967	968	970	973	980	969	2	0
251	958	959	952	953	954	961	968	967	960	2	0
252	873	880	885	889	893	879	0	0	0	2	0

NODE		80000.000	80000.000	1.000	.000	.000	.000
	1	17.270	1.260	61.000	.000		
	3	17.500	1.400	61.500	.000		
	7	16.770	1.800	61.000	.000		
	9	17.000	1.900	61.500	.000		
	13	16.730	1.900	61.000	.000		
	15	16.830	2.010	61.500	.000		
	19	16.400	2.300	61.000	.000		
	21	16.500	2.400	61.500	.000		
	25	13.250	.520	90.000	.000		
	27	14.370	.700	87.000	.000		
	29	15.310	1.600	97.000	.000		
	31	16.140	2.450	93.000	.000		
	33	16.390	2.500	94.000	.000		
	35	16.520	2.640	97.000	.000		
	37	17.000	3.000	97.000	.000		
	39	18.000	3.720	98.000	.000		
	41	19.400	4.780	96.000	.000		
	43	20.880	5.860	93.000	.000		
	45	22.320	6.700	97.000	.000		
	47	24.500	7.800	98.000	.000		
	49	25.500	8.390	98.000	.000		
	51	26.740	9.000	98.000	.000		
	53	28.040	9.700	99.000	.000		
	55	28.970	10.200	95.000	.000		
	57	29.900	10.700	95.000	.000		
	59	30.840	11.100	97.000	.000		
	61	32.270	11.600	98.000	.000		
	63	33.160	12.000	98.000	.000		
	106	13.400	1.450	98.000	.000		
	108	14.370	2.300	90.000	.000		
	110	15.620	2.870	61.000	.000		
	112	15.760	3.000	61.500	.000		
	114	15.920	3.200	88.000	.000		
	116	16.190	3.630	94.000	.000		
	118	17.100	4.450	87.000	.000		
	120	18.590	5.400	88.000	.000		
	122	18.890	7.400	89.000	.000		
	123	20.800	7.900	88.500	.000		
	125	23.070	8.890	89.000	.000		
	127	24.500	9.100	90.000	.000		
	129	25.650	9.860	92.000	.000		
	131	27.070	10.460	93.000	.000		
	133	29.240	11.760	95.000	.000		
	135	30.030	12.400	97.000	.000		
	137	30.880	12.500	96.500	.000		

139	31.700	13.400	98.000	.000
141	32.940	13.260	98.000	.000
146	15.150	3.250	61.000	.000
153	15.270	3.400	61.500	.000
155	15.410	3.670	87.000	.000
160	13.640	2.850	92.000	.000
162	14.710	3.600	61.000	.000
170	14.760	3.800	61.500	.000
172	14.800	4.200	91.000	.000
174	15.300	4.400	88.000	.000
176	16.400	5.000	88.000	.000
178	17.240	6.480	88.000	.000
190	27.200	11.510	95.500	.000
192	28.920	12.200	96.500	.000
209	19.400	9.000	91.000	.000
211	22.080	9.610	93.000	.000
213	23.580	9.810	92.000	.000
215	24.660	10.620	94.000	.000
217	26.000	11.280	96.000	.000
220	14.370	3.890	61.000	.000
222	14.490	4.020	61.500	.000
224	14.700	4.300	91.000	.000
226	14.850	4.730	88.000	.000
228	15.620	5.600	88.000	.000
230	16.400	7.130	88.000	.000
232	16.900	9.000	88.000	.000
233	17.900	10.300	89.000	.000
236	21.060	9.790	94.000	.000
270	20.910	10.500	93.000	.000
274	21.570	10.000	98.000	.000
276	22.840	10.380	98.000	.000
278	24.100	11.070	97.000	.000
280	25.400	11.720	98.000	.000
282	26.370	12.200	98.000	.000
284	28.520	12.860	98.000	.000
286	29.320	12.800	98.000	.000
289	30.020	13.160	98.000	.000
290	30.840	13.380	98.000	.000
293	21.120	11.300	96.000	.000
295	13.200	3.400	98.000	.000
297	13.700	4.400	61.000	.000
299	13.820	4.550	61.500	.000
301	14.310	4.620	88.000	.000
303	14.020	4.850	92.000	.000
306	14.220	5.230	88.000	.000
308	15.000	6.100	87.000	.000
310	15.270	8.000	88.000	.000
312	15.690	9.980	88.000	.000
314	16.500	11.330	89.000	.000
317	18.960	11.930	90.000	.000
322	22.100	12.600	96.000	.000
326	20.400	13.100	92.000	.000

328	21.000	13.620	97.000	.000
330	22.090	14.200	97.000	.000
332	22.180	15.000	97.000	.000
334	23.300	16.310	98.000	.000
336	23.380	17.340	96.000	.000
353	17.030	13.400	94.000	.000
354	17.800	13.600	94.000	.000
355	18.500	13.600	92.000	.000
356	19.500	14.000	97.000	.000
358	20.610	14.720	98.000	.000
360	21.600	15.700	94.000	.000
362	22.600	16.600	98.000	.000
364	22.600	17.300	98.000	.000
371	18.170	14.300	95.000	.000
373	19.420	15.160	96.000	.000
375	21.130	16.300	96.000	.000
388	12.520	4.150	98.000	.000
390	13.300	4.710	61.000	.000
393	13.410	4.880	61.500	.000
395	13.640	5.200	91.000	.000
404	12.120	4.600	98.000	.000
406	13.060	4.900	61.000	.000
408	13.170	5.070	61.500	.000
410	13.400	5.360	90.000	.000
412	13.560	5.800	88.000	.000
414	12.620	5.250	61.000	.000
422	12.750	5.400	61.500	.000
424	13.000	5.680	90.000	.000
434	11.390	5.150	97.000	.000
436	12.260	5.540	61.000	.000
438	12.420	5.700	61.500	.000
440	12.630	5.950	90.000	.000
442	13.050	6.240	89.000	.000
444	14.020	6.850	87.000	.000
448	11.680	6.000	61.000	.000
461	12.130	5.910	61.500	.000
463	12.340	6.180	88.000	.000
465	12.600	6.600	88.000	.000
467	13.220	7.500	87.000	.000
469	14.000	9.000	88.000	.000
475	11.820	6.160	61.500	.000
481	12.060	6.410	88.000	.000
496	11.060	5.390	98.000	.000
498	11.450	6.200	61.000	.000
500	11.570	6.360	61.500	.000
502	11.800	6.600	88.000	.000
504	11.930	7.150	88.000	.000
506	12.410	8.150	88.000	.000
508	12.820	9.900	89.000	.000
510	14.400	11.000	90.000	.000
512	15.360	12.300	94.000	.000
513	16.200	13.000	93.000	.000

521	10.620	5.710	98.000	.000
523	11.170	6.410	61.000	.000
525	11.300	6.580	61.500	.000
527	11.500	6.820	90.000	.000
539	9.810	6.310	97.000	.000
541	10.700	6.800	61.000	.000
543	10.830	6.920	61.500	.000
545	11.080	7.200	90.000	.000
547	11.200	7.720	88.000	.000
549	10.200	7.180	61.000	.000
556	10.330	7.320	61.500	.000
558	10.600	7.600	94.000	.000
575	8.900	7.020	97.000	.000
577	9.600	7.680	61.000	.000
579	9.720	7.820	61.500	.000
581	9.920	8.100	95.000	.000
583	10.350	8.420	90.000	.000
585	11.310	9.000	89.000	.000
587	11.790	10.770	93.000	.000
589	13.540	11.700	93.000	.000
590	14.400	12.050	96.000	.000
602	8.090	7.610	97.000	.000
604	9.050	8.100	67.500	.000
606	9.160	8.280	67.500	.000
608	9.390	8.500	94.000	.000
610	9.600	9.050	91.000	.000
612	10.200	9.890	94.000	.000
623	9.700	9.660	96.000	.000
624	7.890	8.100	97.000	.000
626	8.630	8.400	67.500	.000
628	8.750	8.570	67.500	.000
630	8.980	8.820	94.000	.000
632	9.000	9.500	97.000	.000
640	7.650	8.600	97.000	.000
642	8.210	8.790	67.500	.000
644	8.350	8.900	67.500	.000
646	8.560	9.170	96.000	.000
657	7.830	9.100	67.500	.000
659	7.980	9.210	67.500	.000
661	8.180	9.480	91.000	.000
663	8.700	10.080	94.000	.000
665	9.200	10.170	96.000	.000
678	7.400	9.060	95.000	.000
680	7.670	9.210	67.500	.000
682	7.800	9.360	67.500	.000
684	8.000	9.600	97.000	.000
686	8.040	10.240	95.000	.000
688	8.200	10.800	94.000	.900
690	9.550	11.400	92.000	.000
704	6.580	9.350	97.000	.000
706	7.250	9.550	67.500	.000
708	7.380	9.700	67.500	.000

710	7.600	9.900	93.000	.000
712	7.600	10.560	93.000	.000
714	7.800	11.400	93.000	.000
716	8.550	12.100	98.000	.000
723	6.770	9.950	67.500	.000
725	6.880	10.100	67.500	.000
727	7.080	10.330	94.000	.000
738	6.120	9.630	94.000	.000
740	6.540	10.100	67.500	.000
742	6.650	10.260	67.500	.000
744	6.860	10.500	94.000	.000
746	7.000	11.020	93.000	.000
759	5.780	9.930	96.000	.000
761	6.250	10.350	67.500	.000
762	6.390	10.490	67.500	.000
764	6.570	10.700	94.000	.000
766	6.450	11.400	93.000	.000
768	7.400	12.100	95.000	.000
771	8.600	12.620	98.000	.000
779	5.350	10.500	98.000	.000
781	5.730	10.750	67.500	.000
783	5.860	10.900	67.500	.000
785	6.040	11.130	93.000	.000
801	5.450	10.990	67.500	.000
803	5.600	11.100	67.500	.000
805	5.800	11.320	94.000	.000
807	6.000	11.720	93.000	.000
809	6.800	12.500	93.000	.000
811	7.000	13.600	93.000	.000
813	7.900	13.330	96.000	.000
815	8.600	13.160	98.000	.000
830	4.680	10.550	98.000	.000
832	5.130	11.140	90.500	.000
834	5.220	11.300	67.500	.000
836	5.400	11.400	67.500	.000
838	5.550	11.500	93.000	.000
840	5.600	11.660	94.000	.000
842	5.630	12.000	94.000	.000
844	5.710	12.480	94.000	.000
846	5.780	13.000	72.500	.000
848	6.090	13.000	94.000	.000
849	6.450	13.400	94.000	.000
859	4.610	11.410	90.500	.000
861	4.700	11.570	90.500	.000
863	5.230	11.690	67.500	.000
865	5.410	11.690	67.500	.000
873	4.860	12.300	94.000	.000
875	5.250	12.000	67.500	.000
877	5.420	12.000	67.500	.000
885	5.260	12.450	67.500	.000
887	5.430	12.450	67.500	.000
893	5.270	13.000	94.000	.000

895	5.450	13.000	72.500	.000
906	3.600	10.600	96.000	.000
908	4.070	11.700	90.500	.000
910	4.160	11.880	90.500	.000
912	4.330	12.670	94.000	.000
914	4.830	13.800	96.000	.000
924	3.140	11.550	97.000	.000
926	3.400	12.080	90.500	.000
928	3.500	12.210	90.500	.000
930	3.450	13.350	97.000	.000
932	4.400	14.600	97.000	.000
933	2.950	12.000	96.000	.000
937	2.890	12.320	96.000	.000
939	2.900	12.500	96.000	.000
940	3.070	12.900	96.000	.000
942	5.480	15.890	98.000	.000
948	3.030	13.900	98.000	.000
950	3.500	14.900	95.000	.000
952	4.280	16.410	97.000	.000
954	4.700	17.080	98.000	.000
955	2.400	14.400	97.000	.000
958	3.060	16.440	95.000	.000
961	4.650	17.500	98.000	.000
962	2.000	15.300	98.000	.000
966	2.100	16.480	96.000	.000
968	4.390	18.000	97.000	.000
970	3.100	17.700	97.000	.000
973	2.140	17.370	97.000	.000
974	.810	16.500	98.000	.000
976	1.490	17.320	98.000	.000

LAST

FLOMOD DATA FILE

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SWMS                 1       1
MATAGORDA BAY AND SHIP CHANNEL
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   1    1    1    0    0    0   98   99
         0         7         0         0      .000   24.000     1.000      .500
   100.000      .000     1.937     1.000      .000  .990E+02      .500     1.000
      .000      .002  .237E-02     1.000      .050      .000     .0000
PROP
         1     .0100   40.0000     .0000     .0000     .0000  .100E+02     .0000
         2     .0200   20.0000     .0000     .0000     .0000  .100E+02     .0000

QSEC
         1  12000.00
  952  947  942   -1
         2   2000.00
   63  105  141   -1

ZSEC
         1   100.000      .000         1
    1    2    3   -1
         2   100.000      .000         1
   25   26   27   -1

TIME
     1.000
ZSEC
         1   100.200      .000         1
    1    2    3   -1
         2   100.200      .000         1
   25   26   27   -1

TIME
     2.000
ZSEC
         1   100.350      .000         1
    1    2    3   -1
         2   100.350      .000         1
   25   26   27   -1

TIME
     3.000
ZSEC
         1   100.500      .000         1
    1    2    3   -1
         2   100.500      .000         1
   25   26   27   -1
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TIME
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ZSEC
          1   100.700      .000        1
   1   2    3   -1
          2   100.700      .000        1
  25  26   27   -1

TIME
    5.000
ZSEC
          1   100.900      .000        1
   1   2    3   -1
          2   100.900      .000        1
  25  26   27   -1

TIME
    6.000
ZSEC
          1   101.150      .000        1
   1   2    3   -1
          2   101.150      .000        1
  25  26   27   -1

TIME
    7.000
ZSEC
          1   101.400      .000        1
   1   2    3   -1
          2   101.400      .000        1
  25  26   27   -1

TIME
    8.000
ZSEC
          1   101.600      .000        1
   1   2    3   -1
          2   101.600      .000        1
  25  26   27   -1

TIME
    9.000
ZSEC
          1   101.800      .000        1
   1   2    3   -1
          2   101.800      .000        1
  25  26   27   -1
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TIME
   10.000

ZSEC
           1  101.650      .000         1
    1    2    3   -1
           2  101.650      .000         1
   25   26   27   -1

TIME
   11.000
ZSEC
           1  101.400      .000         1
    1    2    3   -1
           2  101.400      .000         1
   25   26   27   -1

TIME
   12.000
ZSEC
           1  101.250      .000         1
    1    2    3   -1
           2  101.250      .000         1
   25   26   27   -1

TIME
   13.000
ZSEC
           1  101.100      .000         1
    1    2    3   -1
           2  101.100      .000         1
   25   26   27   -1

TIME
   14.000
ZSEC
           1  100.900      .000         1
    1    2    3   -1
           2  100.900      .000         1
   25   26   27   -1

TIME
   15.000
ZSEC
           1  100.750      .000         1
    1    2    3   -1
           2  100.750      .000         1
   25   26   27   -1
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TIME
16.000
ZSEC

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1	2	3	-1		
	2	100.500	.000	1	
25	26	27	-1		

TIME
17.000
ZSEC

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1	2	3	-1	
	2	100.300	.000	1
25	26	27	-1	

TIME
18.000
ZSEC

	1	100.000	.000	1
1	2	3	-1	
	2	100.000	.000	1
25	26	27	-1	

TIME
19.000
ZSEC

	1	99.800	.000	1
1	2	3	-1	
	2	99.800	.000	1
25	26	27	-1	

TIME
20.000
ZSEC

	1	99.650	.000	1
1	2	3	-1	
	2	99.650	.000	1
25	26	27	-1	

TIME
21.000
ZSEC

	1	99.500	.000	1
1	2	3	-1	
	2	99.500	.000	1
25	26	27	-1	

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TIME
    22.000
ZSEC
         1    99.300      .000         1
    1    2    3   -1
         2    99.300      .000         1
   25   26   27   -1

TIME
    23.000
ZSEC
         1    99.400      .000         1
    1    2    3   -1
         2    99.400      .000         1
   25   26   27   -1

TIME
    24.000
ZSEC
         1    99.600      .000         1
    1    2    3   -1
         2    99.600      .000         1
   25   26   27   -1

LAST
```

APPENDIX III

ANOMOD DATA FILE

```
SWMS              1        1                                       .000      .000
   0   1   1   0   0   0
VECT            /.000                                                          0
MATAGORDA BAY AND SHIP CHANNEL-VECTOR PLOTS
   1   0
  -100.00       .000      1.0       .070
     .140       .070
     .000       .000      .000      .000 80000.000 80000.000       .000
CONT             .000                                                          0
MATAGORDA BAY AND SHIP CHANNEL-CONTOUR PLOTS
   1   1   1
     .000       .000      .000
     .140       .070      .105
     .000       .000      .000      .000 80000.000 80000.000       .000
LAST
```