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FESWMS-TX TWO-DIMENSIONAL ANALYSIS
OF BACKWATER AT BRIDGES:
USER'S GUIDE AND APPLICATIONS

By

Larry W. Mays
Cheng-Kang Taur

Research Report Number 314-1

Modifications of a Hydrodynamic Finite Element Model to a
User Oriented Program for Two-Dimensional Analysis
of Backwater at Bridges
Research Project 3-5-83-314

Conducted for
Texas State Department of Highways
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in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

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August 1983

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PREFACE

This report represents the results of a study to modify, apply, and develop a user's guide for a finite element code for two-dimensional analysis of backwater at bridges.

The authors wish to thank the Texas State Department of Highways and Public Transportation for their sponsorship of the work and express appreciation to the contact members, Mr. Dwight Reagan and Mr. Eric Friedrich. Also we would like to thank Mr. Cliff Powers and Mr. Dan Wiley of the Automation Division for their help and cooperation.

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August 1983

ABSTRACT

The objective of this project has been to modify and apply the computer program (FESWMS-TX) for the two-dimensional hydrodynamic analysis of backwater at bridges. The work performed has been to simplify use of the computer program so that it may eventually become a part of the THYSYS system that is used throughout the Texas State Department of Highways and Public Transportation. Application of the model to a portion of Walnut Creek near Martin Luther King Blvd. in Austin, Texas, was performed to help identify the various needed modifications. A detailed user's manual has been developed, which is a major part of this report.

KEY WORDS: hydraulics, bridges, computer, backwater, two-dimensional

SUMMARY

The objective of this project has been to modify and apply a computer program for the two-dimensional hydrodynamic analysis of backwater at bridges. The computer code used is a model originally developed as a research tool referred to as the RMA model (Resource Management Associates). The U. S. Geological Survey Gulf Coast Hydroscience Center has further modified the RMA model and has performed several major applications of the model. This modified version has been referred to as the FESWMS (Finite-Element Surface-Water Modeling System).

The FESWMS model is not in a user-oriented format and requires a rather sophisticated knowledge of fluid mechanics, hydraulics, and computer science to use. In addition, an extensive amount of detailed data determination and input is required that can be simplified and automated using computer graphics.

The Work performed herein has been to simplify use of the computer program for possible widespread use throughout the Texas State Department of Highways and Public Transportation and other highway departments in the U. S. The emphasis has been on making the program as user oriented as possible, defining what data are necessary, how to assemble the data, and what the output is. In addition, some work has been performed to automate the data determination and the input procedure using the Intergraph IGDS (Interactive Graphics Design System) at the Texas State Department of Highways and Public Transportation. The modified version of the FESWMS model is referred to as the FESWMS-TX model. A user's manual for the FESWMS-TX model is included in this report.

During this project several needed modifications to the program FESWMS were identified and incorporated to simplify the use of the model to the new version.

IMPLEMENTATION STATEMENT

The FESWMS-TX can be applied by the Texas State Department of Highways and Public Transportation. The user's manual should make the application of the model self-explanatory once the model is put on the Texas State Department of Highways and Public Transportation computer facilities.

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CHAPTER I INTRODUCTION

1.1 Purpose

State highway departments are faced daily with the analysis and design of stream crossings that range from small culverts and low-water crossings to highly complex crossings of major rivers with multiple bridges and relief structures. The one-dimensional conventional methods for the hydraulic analysis of bridge openings are often inadequate, especially for bridges located in wide flat floodplains. Because of the inadequacy of the one-dimensional methods, they may eventually be supplanted by the more sophisticated two-dimensional methods. The purpose of this report is to describe a two-dimensional model for analysis of backwater at bridges including a detailed user's manual.

Present and conventional methods for backwater analysis at bridges are based upon one-dimensional analysis and rely on formulas that make use of empirical coefficients for the head losses at highway bridges. These one-dimensional backwater water models include: 1) the U.S. Army Corps of Engineers HEC-II model; b) the U.S. Geological Survey, E431 and J635 models; c) the USDA Soil Conservation Service, WSP2 model; d) the Texas Department of Highways and Public Transportation (DHT) THYSYS hydraulic system which includes the HYDRA model; and e) other models reported by Eichert (1970). These one-dimensional backwater analysis models can only approximate flow conditions at highway bridges assuming that the flow has a predominant velocity in one direction ignoring lateral and vertical velocity components (Fig. 1.1). As a result, the one-dimensional models can only provide average velocities through a bridge opening for various flows, ignoring the actual velocity profiles that occur in the vicinity of bridge abutments. Also the water surface profiles are very approximate as only the one-dimensional aspects are considered. The one-dimensional

methods are used for selecting the distribution of flow through multiple openings in highway embankments and determining backwater.

In the hydraulic design and analysis of highway bridges, there are three major concerns: 1) the economic length of a bridge (or bridges in the case of multi-bridges); (2) an understanding of the backwater effects of the installation; and (3) an understanding of the tailwater conditions. In determining the economic length of bridges, only approximate average velocities of flow through the bridge can be considered because of the one-dimensional backwater analysis. A more important aspect to consider would be the detail of velocities (velocity profiles) through the bridges. Of particular importance is a look at the detailed velocities around bridge abutments for possible scour and for deposition. This is even more important when multi-bridge installations are placed in wide floodplains.

There are two-dimensional models which have considerable potential for solving multi-dimensional hydraulic problems for bridge analysis. The two-dimensional backwater analysis considers the velocity vectors in two dimensions as illustrated in Fig. 1.2. The two-dimensional analysis also provides more accurate estimates of water surface profiles upstream and downstream of bridges.

A two-dimensional finite element surface water model referred to as the RMA (Resource Management Associates) model developed by Norton and King (Norton, et al. 1973; Norton and King 1973; King and Norton 1978) is used as the basic model in the study reported herein. The U.S. Geological Survey Gulf Coast Hydroscience Center has modified the RMA model and has performed several major applications of the RMA model (Lee 1980; Lee and Bennett 1981; Lee, et al. 1982; and Wiche, et al. 1982). A major accomplishment by the United States Geological Survey has been the assessment of the RMA model as a potential operational tool for the backwater analysis of complex highway crossings and other modifications of river floodplains. Particularly interesting has been the capability of the model to simulate flows on a

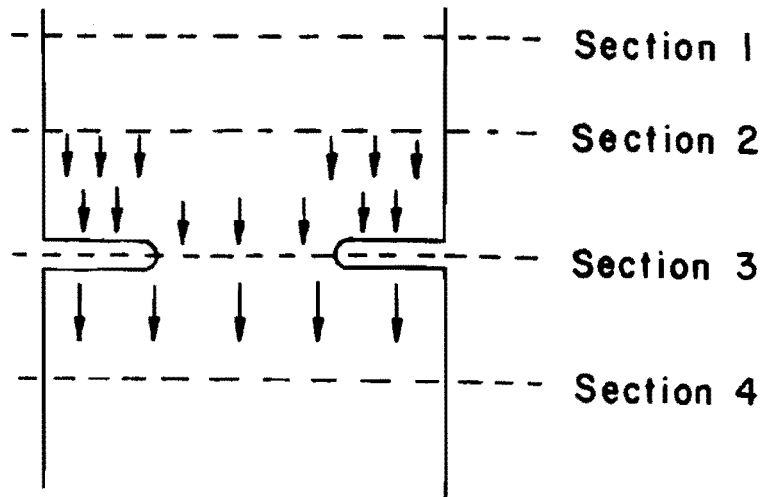


Figure 1.1. Velocity Directions for One-Dimensional Backwater Analysis

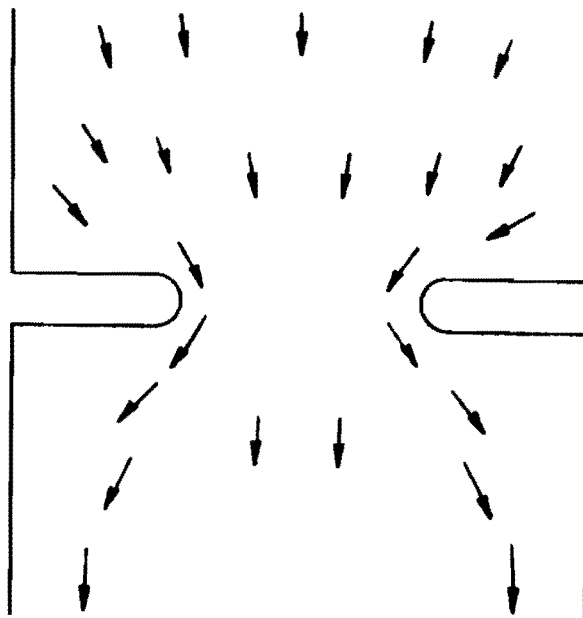


Figure 1.2. Velocity Directions for Two-Dimensional Backwater Analysis.

floodplain with large roughness variations and large changes in depth with distance. The modified version of the RMA model by the USGS is referred to as the FESWMS (Finite-Element Surface Water Modeling System) as listed in the USGS Open-File Report 82-430 (Computer Programs for Modeling Flow and Water Quality of Surface Water Systems).

The USGS Gulf Coast Hydroscience Research Center has been performing research to improve the two-dimensional model. The emphasis of the past work has been a more theoretical effort to improve the computational aspects as opposed to making the model user oriented. The FESWMS model is not in a user-oriented format and requires a rather sophisticated knowledge of fluid mechanics, hydraulics, and computer science to use. In addition, an extensive amount of detailed data determination and input is required that can be simplified and automated using computer graphics.

The work performed herein has been to simplify use of the computer program so that it could possibly become a part of the THYSYS system for widespread use throughout the DHT and other highway departments in the U.S. The emphasis then is to make the program as user oriented as possible, defining what data are necessary, how to assemble the data, and how to interpret the output. Input and output formats would be as similar as possible to that used in THYSYS. In addition, work has been performed to automate most of the data determination and inputting procedure using the IGDS (Interactive Graphics Design System) at the DHT. The modified version of the FESWMS model is referred to as the FESWMS-TX model throughout this report.

1.2 Background

1.2.1 Bridge Backwater Effects

Laursen (1970) has divided the flow region affected by a bridge constriction into four zones, as shown in Fig. 1.3. According to conventional definitions in open-channel hydraulics, zones I and IV are areas of gradually-varied flow in which the flow

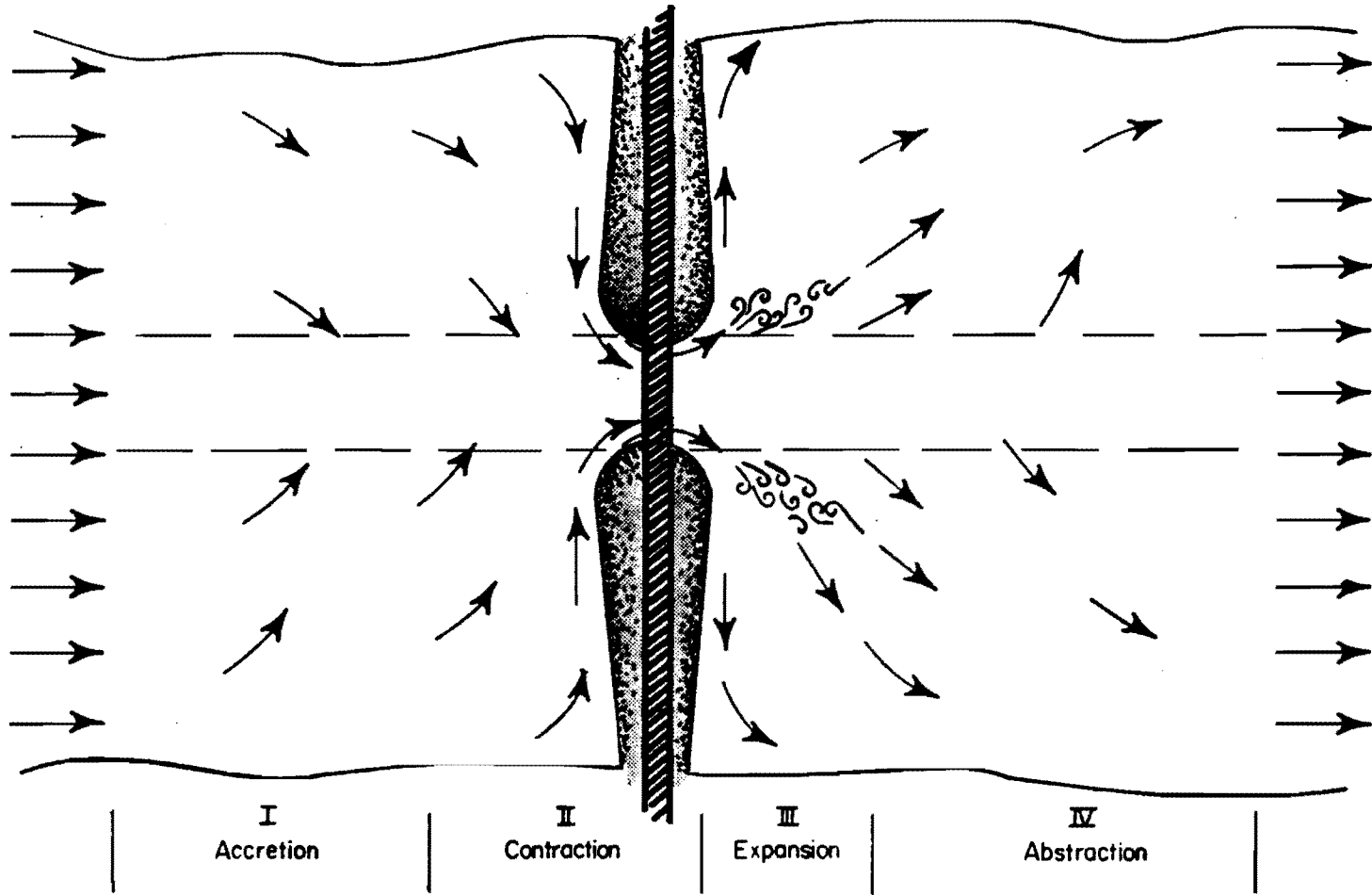


Figure 1.3. Schematic of Flow Region Affected by Bridge Constriction. Tseng (1975)

pattern is essentially governed by the channel resistance. Zones II and III are areas of rapidly-varying flow patterns. The geometry of the bridge constriction causes the flow to contract upstream and expand downstream defining the flow patterns in these zones. Boundaries between zones I and II and zones III and IV may be considered transition zones wherein the channel resistance and the constriction geometry play equally important roles.

Zone I is the reach of river upstream from, but not immediately adjacent to, the bridge. It covers the flow region encompassed by the length of the classic M1 backwater curve and the width of floodplain in which flows move laterally into the main channel. The upper boundary is near the point where the M1 curve meets the normal flow profile.

Zone II characterizes flow contraction and jet formation. The upper boundary of zone II is just upstream from the bridge where the curvature of the water surface starts to increase rapidly in the vertical plane. This zone extends through the bridge to the section where the flow contraction ends. The flow pattern can be approximated by the irrotational flow theory of a slot orifice with a free streamline (Fig. 1.4) separating from the abutment at the end of the embankment.

Zone III is the region in which the jet formed by the contracting flow of zone II is expended through turbulent diffusion or mixing. A large amount of energy is lost in the course of flow expansion. If the channel resistance in zone III is substantial, then the resultant energy loss associated with jet diffusion and the channel resistance may produce a total loss sufficient to cause backwater at the downstream side of the bridge opening.

Zone IV may be considered the downstream counterpart of zone I. In this reach, the flow leaves the main channel and moves laterally across the floodplain. At some distance downstream the flow will be reestablished and resume its natural flow condition in the stream.

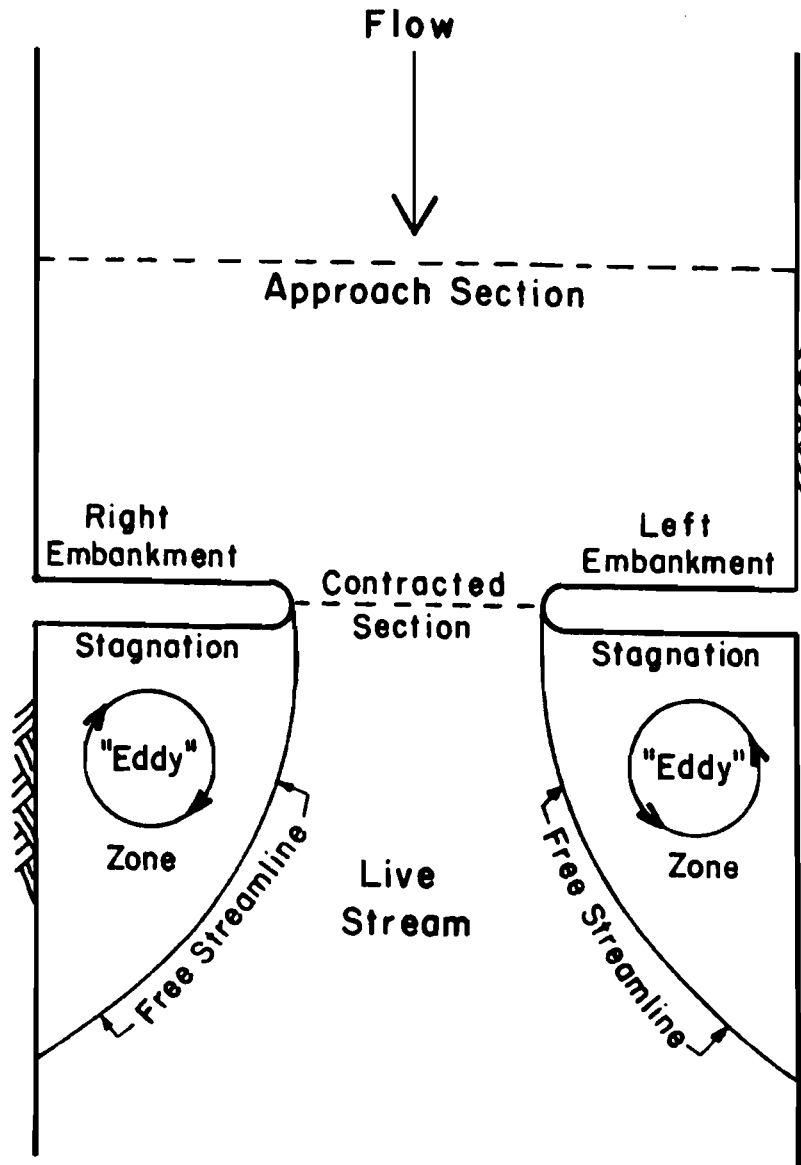


Figure 1.4. Zones of Flow Through Bridge Openings Tseng (1975)

1.2.2 One-Dimensional Approach for Backwater Analysis

Techniques for performing one-dimensional backwater analysis are described in detail by Chow (1959) and Henderson (1966). The differences in conventional one-dimensional methods have partly arisen due to the varying requirements of the problems that are solved. The major distinction between methods is: a) some methods solve for the distance along a channel between a control point and a known or assumed depth and b) others solve for the depth based on a given distance from a known depth.

Backwater analysis methods are based upon the one-dimensional gradually varied flow equation,

$$\frac{dy}{dx} = \frac{S_o - S_f}{1 + \alpha \frac{d(V^2/2g)}{dy}} \quad (1.1)$$

for a given discharge, Q , where y is the depth of flow; x is the distance along the channel; S_o is the slope of the channel bottom; S_f is the energy slope, α is the energy coefficient; V is the mean velocity of flow through a channel section; and g is the acceleration of gravity. The friction slope is usually computed using Manning's equation,

$$S_f = \frac{n^2 V}{2.22 R^{4/3}} \quad (1.2)$$

where n is Manning's roughness factor and R is the hydraulic radius.

The three main types of backwater computation methods are the graphical integration methods, the direct integration methods, and the step methods. Other extensions of these methods include the direct step method, the standard step method, and the Breeze method. Most of the one-dimensional backwater analysis computer programs are based on the standard step method.

The standard step method provides a means for determining the depth of flow when the distance between channel sections is known. This method is a trial and error procedure suited for natural channels. Considering the flow section shown in Fig. 1.5, the energy equation can be written as

$$S_o \cdot \Delta x + y_1 + \alpha_1 \frac{v_1^2}{2g} = y_2 + \alpha_2 \frac{v_2^2}{2g} + \bar{S}_f \cdot \Delta x + h_e \quad (1.3)$$

where h_e is included to account for eddy losses which can be appreciable in natural channels and α is the energy coefficient for nonuniform velocity distribution.

Some of the computer programs that have been developed are summarized in Table 1.1.

1.2.3 Two-Dimensional Approach for Backwater Analysis

Two-dimensional models permit the computation of backwater or water surface elevation in terms of spatial or areawise coordinates and provide spatial distributions of discharge and variations in local velocities. Two-dimensional models do not provide vertical velocity profiles nor do they define separation zones and eddies (Fig. 1.4). The floodplain modeling problem considered herein is a two-dimensional steady state problem.

The two approaches to solving the two-dimensional models are finite differences and finite elements. The general approach for finite difference models is to discretize a flow region or floodplain into a system of grid networks composed of rectangular or square cells (or grids). Size of the grids is governed by the accuracy and stability of the specific numerical scheme applied to the solution of the differential equations describing the flow. In a finite element model the flow region (flood plain) is represented by a grid network of either triangular or polygonal elements.

The set of two-dimensional equations includes the continuity equation and the equations of motion in the two space dimensions. The dependent variables are the

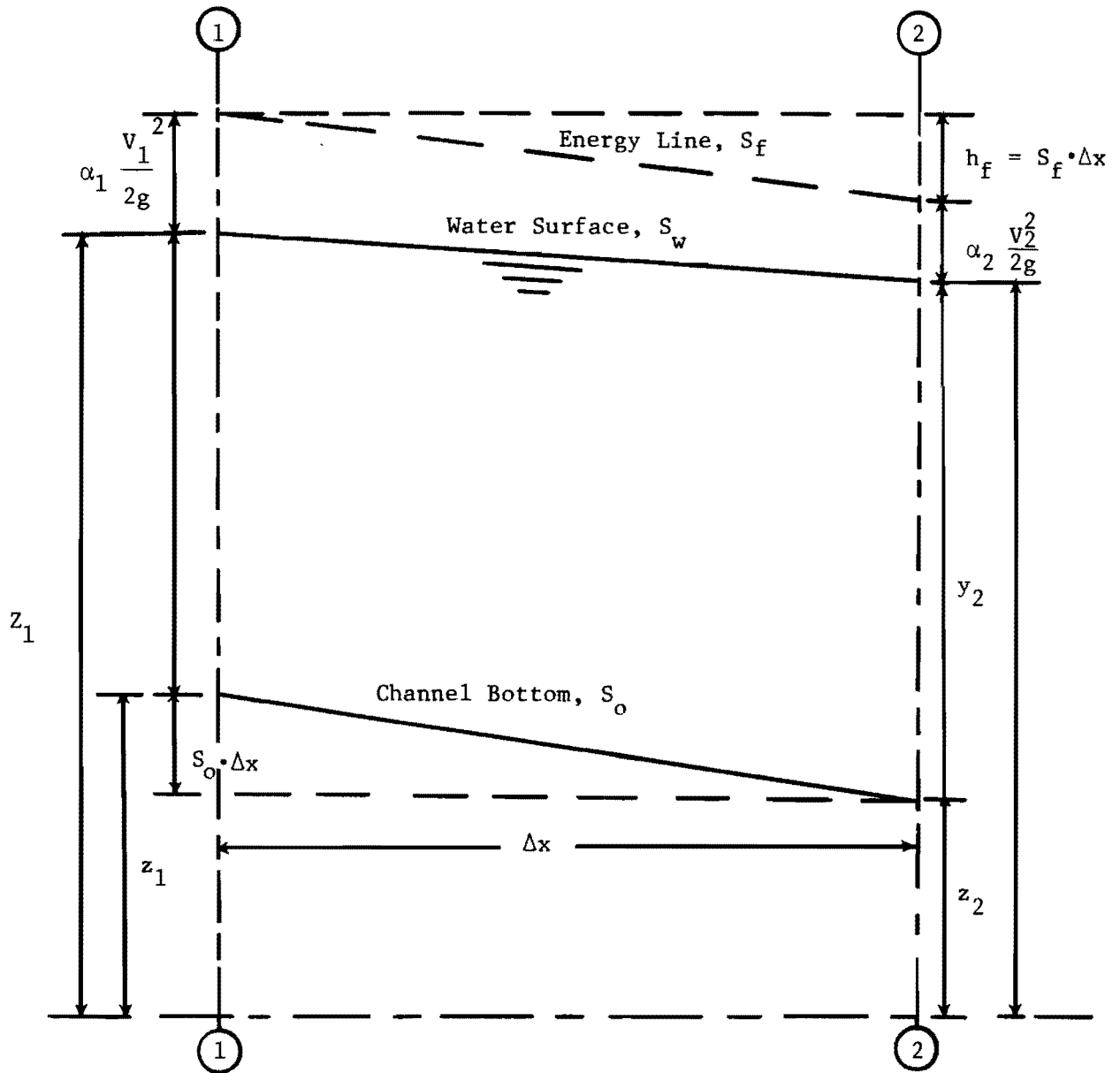


Figure 1.5. Terms in the Energy Equation

TABLE 1.1 Summary of Selected One-Dimensional Backwater Analysis Programs

Agency	Computer Program	Notes	References
1.) U. S. Geological Survey	E 431	Subcritical flow only	Shearman (1976)
2.) U. S. Geological Survey	J 635	Modified version of E 431 to handle both subcritical flow and supercritical flow	
3.) U. S. Army Corps of Engineers Hydrologic Engineering Center	HEC-2	Both sub and supercritical flow	
4.) U. S. Department of Agriculture Soil Conservation Service	WSP-2	Subcritical flow only	Parsley and Lee (1974)
5.) Texas Highway Department	THYSYS (HYDRA)	Similar to U.S.G.S. E431 program.	Texas State Department of Highways and Public Transportation (1977)
6.) U. S. Bureau of Reclamation			U. S. Department of Interior Bureau of Reclamation (1967)
7.) U. S. Bureau of Public Roads	HY-4		U. S. Bureau of Public Roads 1964
8.) Iowa Natural Resources Council and C.I. R. A. S.	WSPPI		Shearman and Dougal (1965)
9.) U. S. Army Corps of Engineers Little Rock District			Thomas (undated)
10.) Department of Sanitation and Flood Control, County of San Diego, California and San Diego State University	FLUVIAL-3	Extension of HEC-2 to handle changes in channel boundary	Chang and Hill (1976)
	DELTA	Same technique as Fluvial-L-3 but developed for delineating flood levels near mouth of a river accounting for erosion, sedimentation, and effects of delta formation	Chang and Hill (1976)

depth and velocity (or discharge) components in each of the two space dimensions. Conceptually finite difference models approximate the solution of differential equations in a discrete manner. Essentially the differential equation is discretized to a set of difference equations. This set of difference equations is then solved using either an explicit or implicit method for prescribed boundary conditions. Finite element methods solve the differential equations without discretization by either: 1) minimizing a functional, an integral quantity which is a function of unknown functions; or by 2) approximating the finite elements directly from the differential equations governing the problem using weighted residual methods over the flow region and part of its boundary.

A major advantage of the finite difference models is that their numerical solution scheme is more conventional and thus better known to program users than the finite element approach. Finite difference models, however, have limited solution efficiency, lack of flexibility in representing irregular flow boundaries, difficulties in treating boundary conditions, and can have numerical stability problems for many schemes. Finite element models can easily represent irregular flow boundaries and have a more efficient solution process. Finite element models are more flexible for laying out grid size and in representing flow boundaries, which is particularly important in bridge backwater computation. A coarse network is sufficient to represent the low variation flow in zones I and IV and a fine network is necessary for rapid variation flow in zones II and III (Fig. 1.3). The major disadvantage of the finite element models is their sophisticated solution technique. One advantage associated with the finite element models is the computation of depths and velocities at specified locations throughout the flow region. Finite element models thus have the potential for computing parameters to describe contraction scour and bridge backwater simultaneously, which is an important feature for design engineers.

1.2.4 Finite Difference Models

The finite difference models are based upon writing the continuity and motion equations for elemental segments that represent a portion of the floodplain or river channel. Many of these segments form a finite difference network or grid. The basic idea is to solve the equation of continuity and motion written in two dimensions using either an explicit or implicit scheme. Most of the two-dimensional models for flood plain analysis were derived from or are extensions of two-dimensional models developed for analyzing flow in estuaries from tidal motion and/or storm surges. As a result of the simplicity of the two-dimensional finite difference models, these models can also simulate unsteady flow. Examples of these models include RIVTID by Brandes and Masch (1973); FLOW2D by Vicens, et al. (1975); and FLOWSIM10 by Bodine (1980).

The model by Bodine (1980) is particularly interesting because in this numerical scheme, the river channel is modeled in a one-dimensional framework and the flood plain is modeled in a two-dimensional framework. The one-dimensional channel flows are coupled with the two-dimensional floodplain flows, allowing for communication between the two regions. The channels are embedded into the two-dimensional finite difference network. An explicit solution scheme is used. The model can allow for levees and barriers anywhere in the modeled system and can be located on one or both sides of a channel. This model can also be used to simulate flows in independent channels and tributary channels to the independent channels and in the floodplain areas. Dry channels or floodplain areas can flood during periods of increasing water levels and dry up again after the passage of a flood wave.

The one-dimensional equations of motion and continuity for river channels are, respectively,

$$\frac{\partial Q}{\partial t} + \beta \frac{Q}{A} \frac{\partial Q}{\partial x} - \frac{Q}{A} \frac{\partial A}{\partial x} + \frac{g n^2 Q Q}{2.21 A R^{4/3}} + g A \frac{\partial H}{\partial x} = q_i u_i - q_o u_o \quad (1.4)$$

$$B \frac{\partial H}{\partial t} + \frac{\partial Q}{\partial x} = q_i - q_o \quad (1.5)$$

in which Q = discharge; t = time; g = gravity; x is the horizontal coordinate along the axis of the channel; n is Manning's roughness coefficient; A is the area of channel cross section; R is the hydraulic radius ($R = A/P_e$); P_e is the wetted perimeter of the cross section; H is the water surface elevation relative to the local mean sea level (msl) datum; B is the water surface width; q_i is the lateral inflow per unit length; q_o is the lateral outflow per unit length; u_i is the channel-directed component of velocity; u_o is the channel velocity (Q/A); and β is a momentum correction coefficient.

The two-dimensional equations of motion and of continuity appropriate for riverine floodplain areas are as follows:

$$\frac{\partial U}{\partial t} + g D \frac{\partial H}{\partial x} + \frac{g n^2 q U}{2.21 D^{7/3}} = 0 \quad (1.6)$$

$$\frac{\partial V}{\partial t} + g D \frac{\partial H}{\partial y} + \frac{g n^2 q V}{2.21 D^{7/3}} = 0 \quad (1.7)$$

$$\frac{\partial H}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0 \quad (1.8)$$

in which x and y are the horizontal Cartesian coordinates; t = time; U and V are the vertically integrated x and y components of transport per unit width; g = gravity; and H is the water level elevation relative to the local msl datum; D is the depth of water at position x, y and time t ; q is the magnitude of the transport per unit width; and n is

Manning's coefficient of roughness. A riverine system is represented in terms of a discrete grid in which all grid elements are taken as uniformly square blocks (Figs. 1.6 and 1.7). The topography of the flood plain is regarded as uniform over each grid square, thus D forms a two-dimensional stairstep type of approximation of the actual topography. Water is allowed to flow onto a dry block during periods when the stage is rising and dry up again during the recession stage, thus allowance is made for a moving boundary in the course of a flood.

1.2.5 Finite Element Models

The formulation and development of finite element models have been reported elsewhere (Norton and others 1973; Norton and King 1973; Tseng 1975; King and Norton 1978 and Driscoll 1981); therefore, only the equations solved and a brief outline of the technique used to solve them are presented here. Two-dimensional, surface-water flow in the horizontal plane is described by two equations for conservation of momentum and one for conservation of mass:

$$\begin{aligned} \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + g \frac{\partial h}{\partial x} + g \frac{\partial z_0}{\partial x} - \frac{\epsilon_{xx}}{\rho} \frac{\partial^2 u}{\partial x^2} - \frac{\epsilon_{xy}}{\rho} \frac{\partial^2 u}{\partial y^2} \\ - 2\omega v \sin \phi + \frac{gu}{C^2 h} (u^2 + v^2)^{1/2} - \frac{\xi}{h} V_a^2 \cos \psi = 0, \end{aligned} \quad (1.9)$$

$$\begin{aligned} \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + g \frac{\partial h}{\partial y} + g \frac{\partial z_0}{\partial y} - \frac{\epsilon_{yx}}{\rho} \frac{\partial^2 v}{\partial x^2} - \frac{\epsilon_{yy}}{\rho} \frac{\partial^2 v}{\partial y^2} \\ 2\omega u \sin \phi + \frac{gv}{C^2 h} (u^2 + v^2)^{1/2} - \frac{\xi}{h} V_a^2 \sin \psi = 0, \end{aligned} \quad (1.10)$$

and

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(uh) + \frac{\partial}{\partial y}(vh) = 0, \quad (1.11)$$

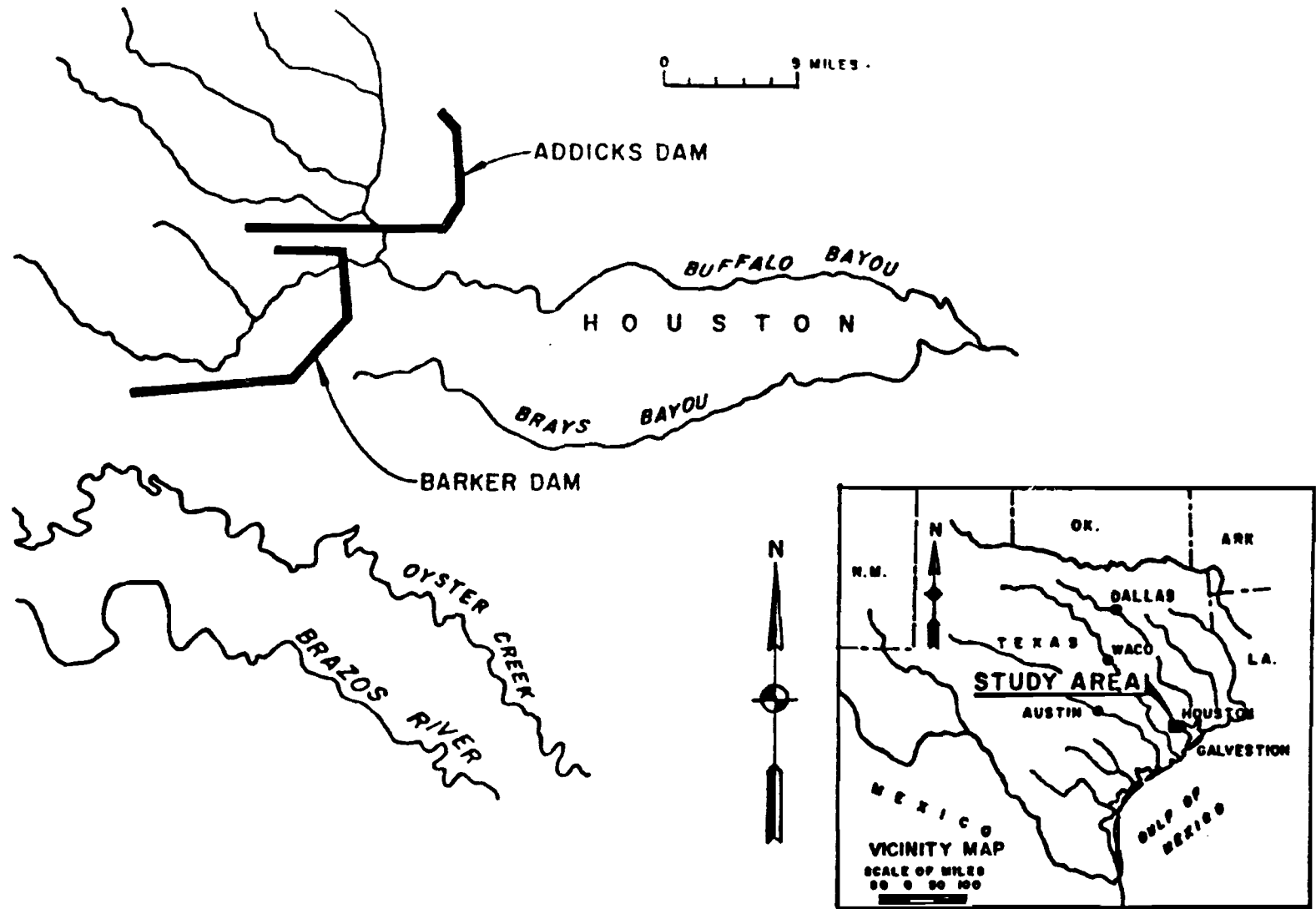


Figure 1.6. LOCATION MAP FOR STREAMS IN HOUSTON TEXAS AND VICINITY Bodine (1980)

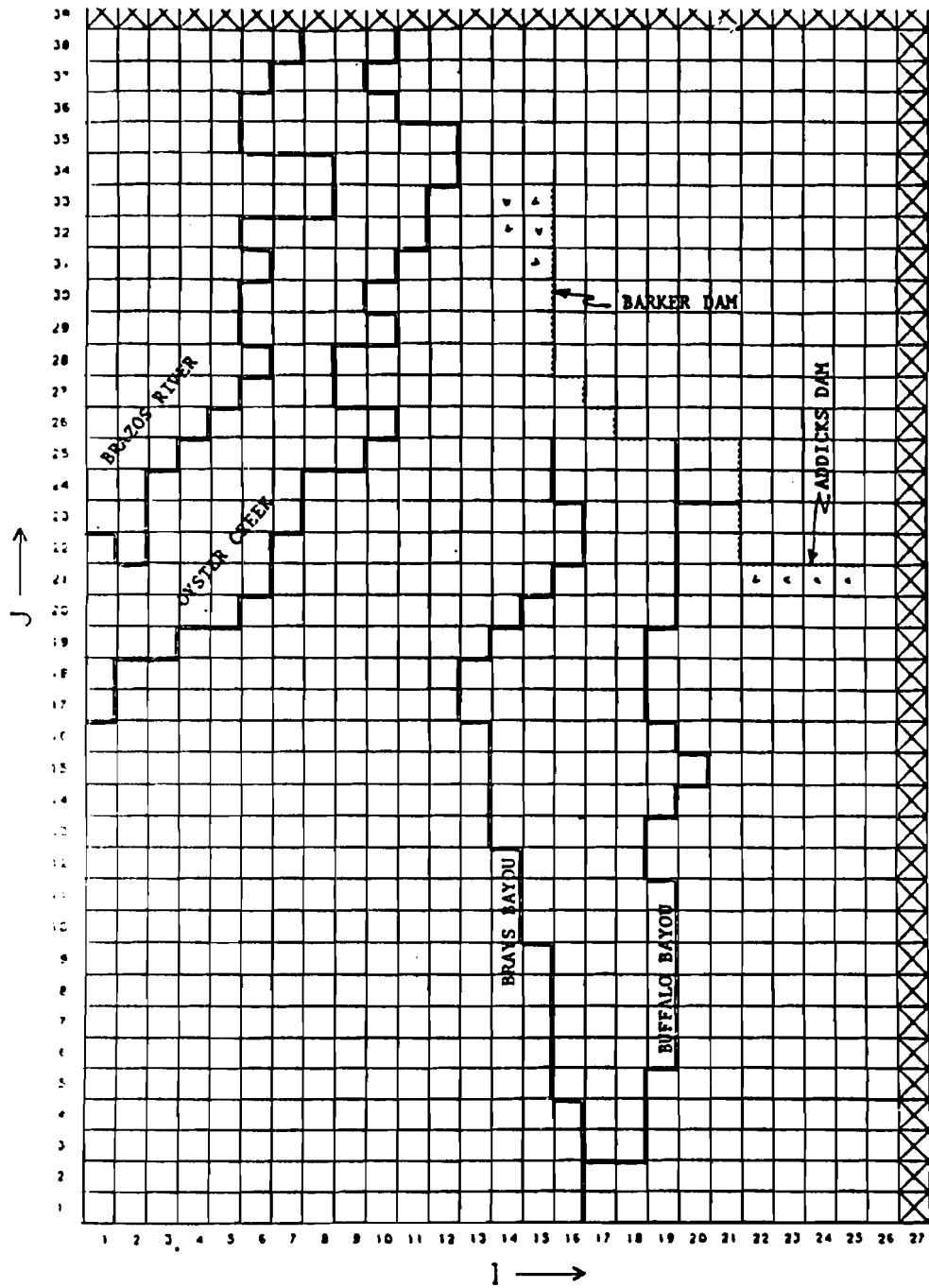


Figure 1.7. Finite Difference Grid for Houston Example
Bodine (1980)

where

x, y = Cartesian coordinates in the positive east and north directions, respectively (feet)

t = time (seconds),

u, v = depth-averaged velocity components in the x and y directions, respectively (feet per second),

h = depth (feet),

z_0 = bed elevation (feet),

ρ = density of water (assumed constant) (slugs per cubic foot),

ω = rate of the Earth's angular rotation (per second),

ϕ = latitude (degrees),

g = gravitational acceleration (feet per square second),

C = Chezy (resistance) coefficient (feet to the one-half power per second),

$\epsilon_{xx}, \epsilon_{xy}, \epsilon_{yx}, \epsilon_{yy}$ = eddy viscosities (pound second per square foot),

ξ = water-surface resistance coefficient (non-dimensional),

V_a = local wind velocity (feet per second), and

ψ = angle between the wind direction and the x axis (degrees).

In the Norton-King development, equations (1.9) through (1.11) are rewritten in terms of the flow variables, $r = uh$, $s = vh$, and depth, h (King and Norton 1978). Boundary conditions consist of the specification of flow components or water-surface elevations at open boundaries and zero flow components or zero normal flow at all other boundaries, called lateral boundaries. Equations (1.9) through (1.11) together with properly specified boundary and initial conditions, comprise a well posed initial-boundary-value problem.

Quadratic basis functions are used to approximate flow components on triangular, six-node, isoparametric elements; and linear basis functions are used to approximate depth (mixed interpolation). Galerkin's method of weighted residuals, a Newton-Raphson iteration scheme, and numerical integration using seven-point Gaussian quadrature (Zienkiewicz 1971) are used to solve for the nodal values of the flow components and depth. The floodplain modeling considered herein is only for steady state conditions so that the terms $\frac{\partial u}{\partial t}$, $\frac{\partial v}{\partial t}$, and $\frac{\partial h}{\partial t}$ in equations (1.9), (1.10), and (1.11), respectively drop out.

Model topography is described by assigning a ground-surface elevation to each element vertex and letting the ground vary linearly within an element. Flow components are specified at inflow boundary nodes, and water-surface elevations are specified at outflow boundary nodes. In this study, zero normal flow is specified at all lateral boundaries. Isoparametric elements permit the use of smooth, curved lateral boundaries. The improvement in accuracy obtained by using such boundaries, together with the specification of zero normal flow (tangential flow) at the boundaries, has been documented by King and Norton (1978), Gee and MacArthur (1978), and Walters and Cheng (1978, 1980) for the mixed-interpolation formulation of the surface-water flow equations.

The model has the capability of integrating the flow across a line following element sides and beginning and ending at element vertices. Thus, conservation of mass, which is not automatically satisfied, can be checked (King and Norton 1978).

Selected applications of two-dimensional finite element models for floodplain analysis are presented in Table 1.2.

1.2.6 Comparison of 1-D and 2-D Models

A brief comparison of 1-D models versus 2-D finite element models such as FESWMS is given in this section. Comparison of the two modeling approaches for the purpose of analysis of bridge backwater in wide, flat flood plains are as follows:

TABLE 1.2 Selected Applications of 2-D Finite Element Models for Floodplain Analysis

Reference/Model	Application—Location	Description
1.) Franques and Yannitell (1974)	Tallahala Creek at Highway 528 near Bay Springs, Miss.	Simulated flood of April 14, 1969 Finite element network shown in Figure 1.8
2.) Tseng (1975)	Tallahala Creek at Highway 528 near Bay Springs, Miss.	Three floods, April 6, 1964; April 14, 1969; and February 21, 1971. 199 nodes and 86 elements. Figure 1.9
3.) King and Norton (1978)	Tallahala Creek at Highway 528 near Bay Springs, Miss.	Considered 7 different level (discretization) of finite element networks. Varied from 199 nodes and 86 elements to 283 nodes and 124 elements. Also considered curved boundaries in same application. Figure 1.10
4.) Gee and Mac Arthur (1978)	Rio Grande de Loiza	Floodplain about 6 mi ² x 6 mi ² . One inlet, two outlets, several islands. Application of (310 nodes, 131 elements), (375 nodes, 162 elements) and (432 nodes, 189 elements.) Figure 1.11
	McNary Dam, Second Powerhouse on Columbia River	Site selection study for a second powerhouse. Studied downstream flow fields. Various levels of finite element networks were applied
5.) Lee and Bennett (1981) FESWMS	Congaree River at I-326 near Columbia, South Carolina	To study the import on flood stages of the Congaree River. Used August 1908 flood in analysis. Several combinations with/without dikes. Different highway embankments tested. Largest network was 2,195 nodes and 1000 elements, shown in Figure 1.12
6.) Lee, et al. (1982) Wiche, et al. (1982) FESWMS	Pearl River at I-10 between Slidell, La. and Bay St. Louis, Miss.	Studied different alternatives for modifying I-10 to reduce flooding. Modeled 1980 flood. I-10 crossing is 4.4 mi long with three bridge openings. Finite element network consisted of 10,771 nodes and 5,224 elements as shown in Figure 1.13
7.) U. S. Army Corps of Engineers Hydrologic Engineering Ctr RMA.-	Harry S. Truman Dam	To simulate horizontal flow fields downstream and to calculate flow velocities to estimate drag forces on fish screens proposed for installation downstream of the powerhouse

1. One-dimensional model solutions do not provide transverse water surface slopes, velocity distribution, or local velocities. One-dimensional approaches assume a constant water surface across the entire floodplain at a particular cross section. One-dimensional approaches also consider a mean velocity for an entire cross section; however, some programs such as HEC-2 allow for a left overbank velocity, a main channel velocity, and a right overbank velocity. On the other hand, two-dimensional, steady-state models: a) permit computation of backwater or water surface elevations in terms of spatial or area-wise coordinates; b) give spatial distribution of discharge (x and y direction); and c) give variations of local velocities (x and y direction). In summary, one-dimensional methods only consider the longitudinal variation in flow; whereas the two-dimensional models account for both the longitudinal and transverse variations in stream velocity, discharges, and water surface elevations.
2. Division of flow around islands in a flood plain can be simulated by two-dimensional models. In fact, the simulation is an integral part of the solution procedure so that the distribution of such flows is determined without having to resort to trial and error procedures that are required of one-dimensional models.
3. The distribution of flow through multiple bridge openings in highway embankments is accomplished in one-dimensional models by assuming that the flow has a predominant (mean) velocity in one direction, ignoring lateral velocity components. The water-surface elevations are assumed constant among the various bridge openings. Two-dimensional models overcome these very limited assumptions placed on the one-dimensional approaches.

4. The one-dimensional methods rely on formulas which consider the longitudinal mean velocity and make use of empirical coefficients for the head loss calculations at highway bridges. The two-dimensional models consider velocity vectors in two dimensions in the horizontal plane and solve the two-dimensional equations of motion eliminating the need for empirical equations to describe energy losses at bridges.
5. The detailed velocity vectors that can be determined in two-dimensional models allow for fairly accurate analysis of scour around bridge abutments and piers. Only an average velocity for the entire bridge opening can be obtained from one-dimensional solutions.
6. A comparison of the prediction, data requirements, and calibration data for the one-dimensional and two-dimensional models is provided in Table 1.3.
7. The two-dimensional models are capable of simulating both subcritical and supercritical flow states within the same finite element network.
8. The two-dimensional model solution consists of vector plots of computed stream velocities which provide the user with unique information on local flow patterns in the floodplain which is impossible for one-dimensional models. Of particular interest are the directions of flow at various locations in the floodplain and flow directions upstream and downstream of highway embankments and bridge openings.

1.3 Scope of Work Accomplished

The work accomplished during this project is summarized below:

1. Several needed modifications to the program FESWMS were identified and incorporated to simplify the use of the model. The new version is referred to as the FESWMS-TX model. The modifications are discussed in detail later in this report in Section 2.3.

TABLE 1.3 Floodplain Modeling Characteristics of 1-D and 2-D

1-Dimensional Models	2-Dimensional Models
<p>PREDICTION</p> <p>Backwater</p>	<p>PREDICTION</p> <p>Backwater Local velocities and their directions Discharge distribution</p>
<p>DATA REQUIREMENTS</p> <p>Cross sections Manning's roughness Upstream discharge</p> <p>Downstream discharge distribution Downstream elevation above highway crossing</p>	<p>DATA REQUIREMENTS</p> <p>Finite element network (x, y coordinates) and ground surface elevation Mannings roughness Turbulent exchange coefficients Upstream discharge and distribution Downstream elevation(s) of the network</p>
<p>CALIBRATION DATA</p> <p>Known water surface elevation Downstream discharge distribution Mannings roughness</p>	<p>CALIBRATION DATA</p> <p>Known water surface elevations Manning's roughness Finite element network Turbulent exchange coefficients</p>

2. The model was applied to Walnut Creek near Martin Luther King Blvd. in Austin, Texas.
3. Use of the Intergraph IGDS (Interactive Graphics Design System) at DHT was explored for use as an automated approach to construct and define the finite element network using computer graphics.
4. A user's manual was written for the FESWMS-TX model for the manual input procedure.

1.4 Definitions

In order to understand many of the concepts and details presented in the remaining part of the report, a basic understanding of the following is necessary:

Elements (or finite elements) - The elements are used to define incremental areas of the floodplain that have similar topography and are defined by nodes. The elements can be three-sided (triangular) or four-sided. (Fig. 1.14).

Finite element network - This is the collection of elements that define the entire floodplain such as that shown in Figs. 1.8-1.12. The network should describe as well as possible the topographical characteristics of the area inundated by a flood of known discharge. Proper determination of finite element network for a given topography requires a knowledge of open channel hydraulics and certain guidance provided by this manual.

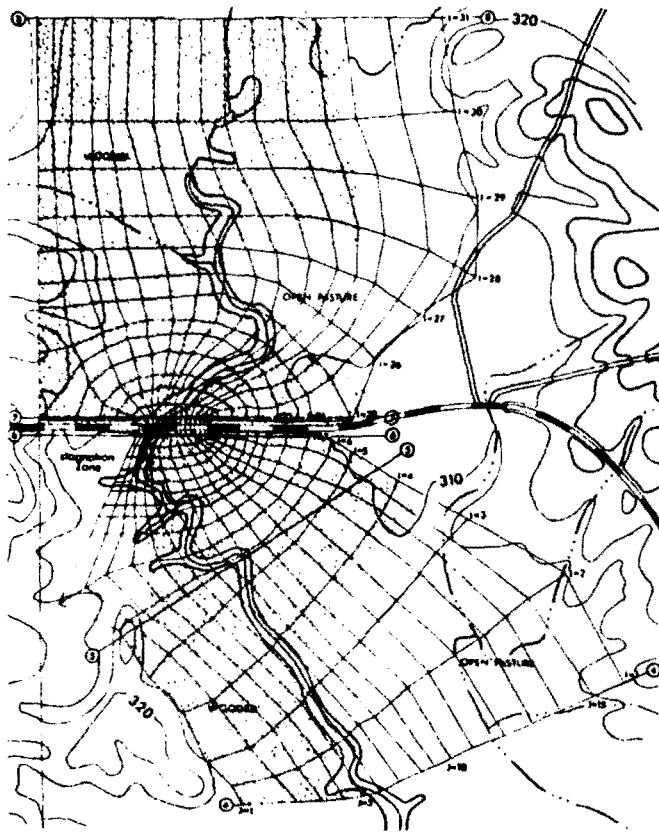


Figure 1.8. Tallahala Creek Example by Franques and Yannitell (1974).

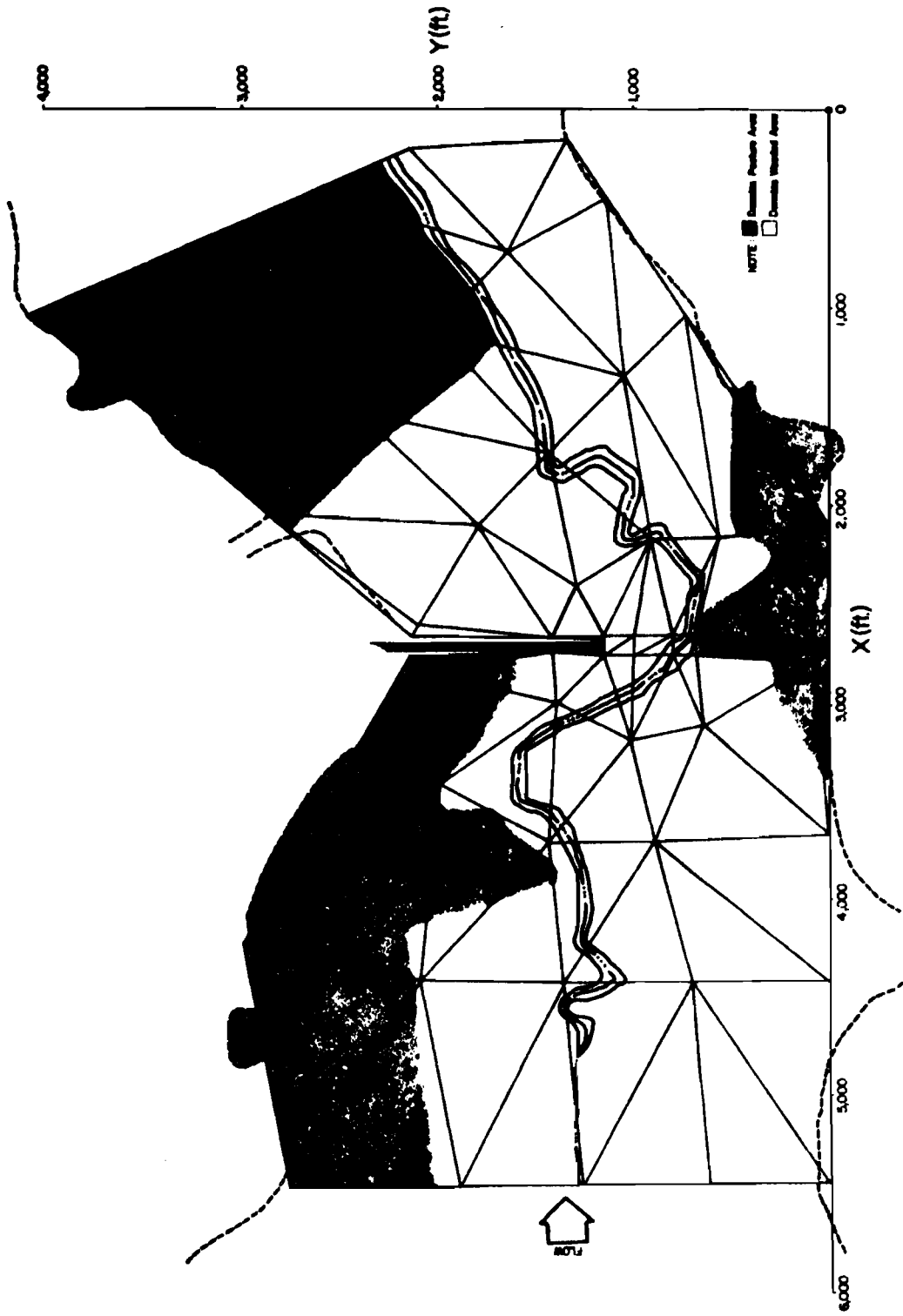


Figure 1.9. Tallahalla Creek Example by Tseng (1975).

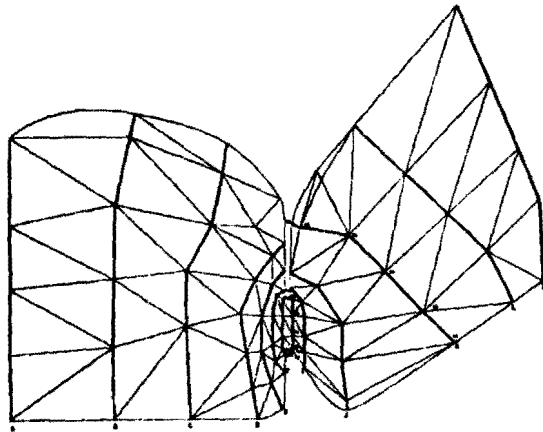
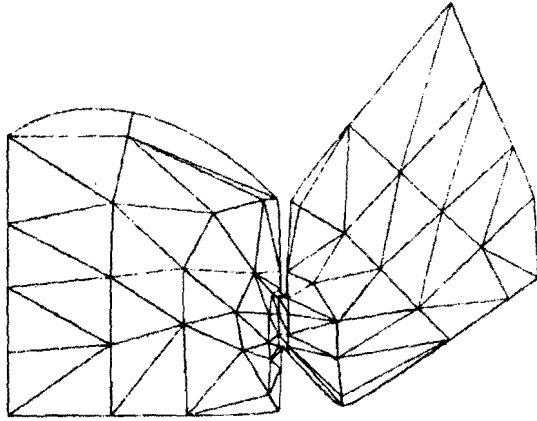
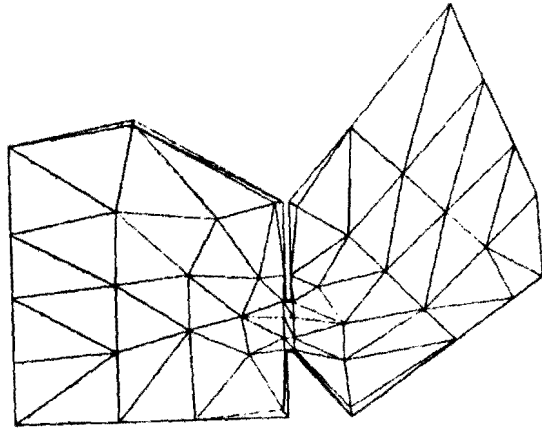


Figure 1.10. Tallahalla Creek Example by King and Norton (1978)

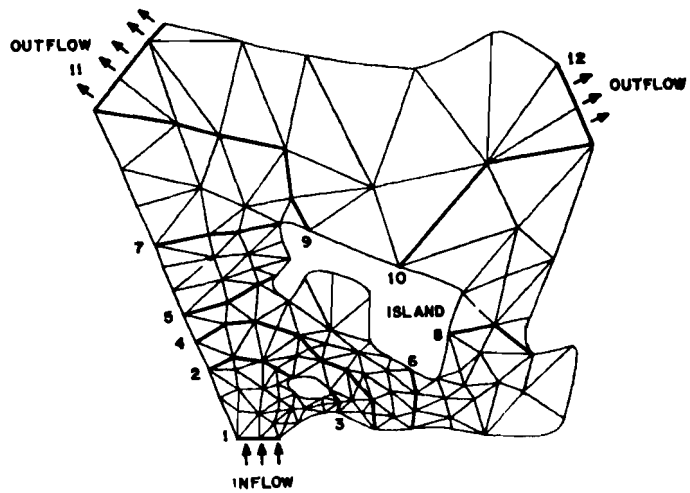
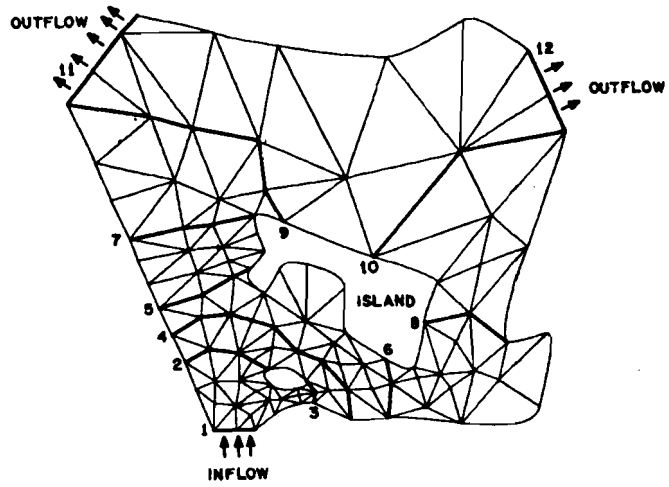
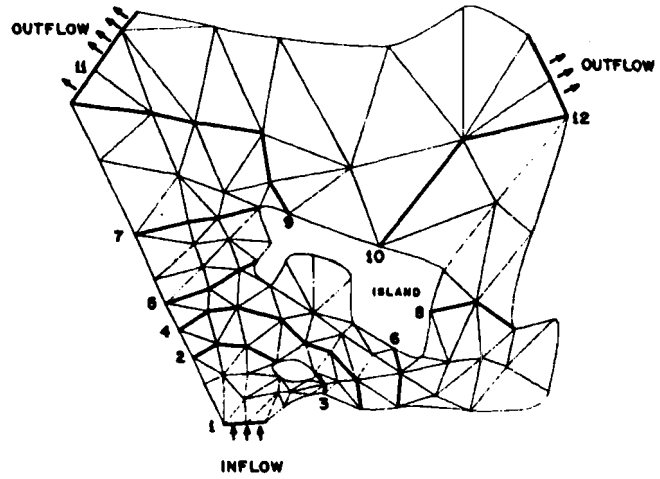


Figure 1.11. Rio Grande de Loiza Example by Gee and Mac Arthur (1978).

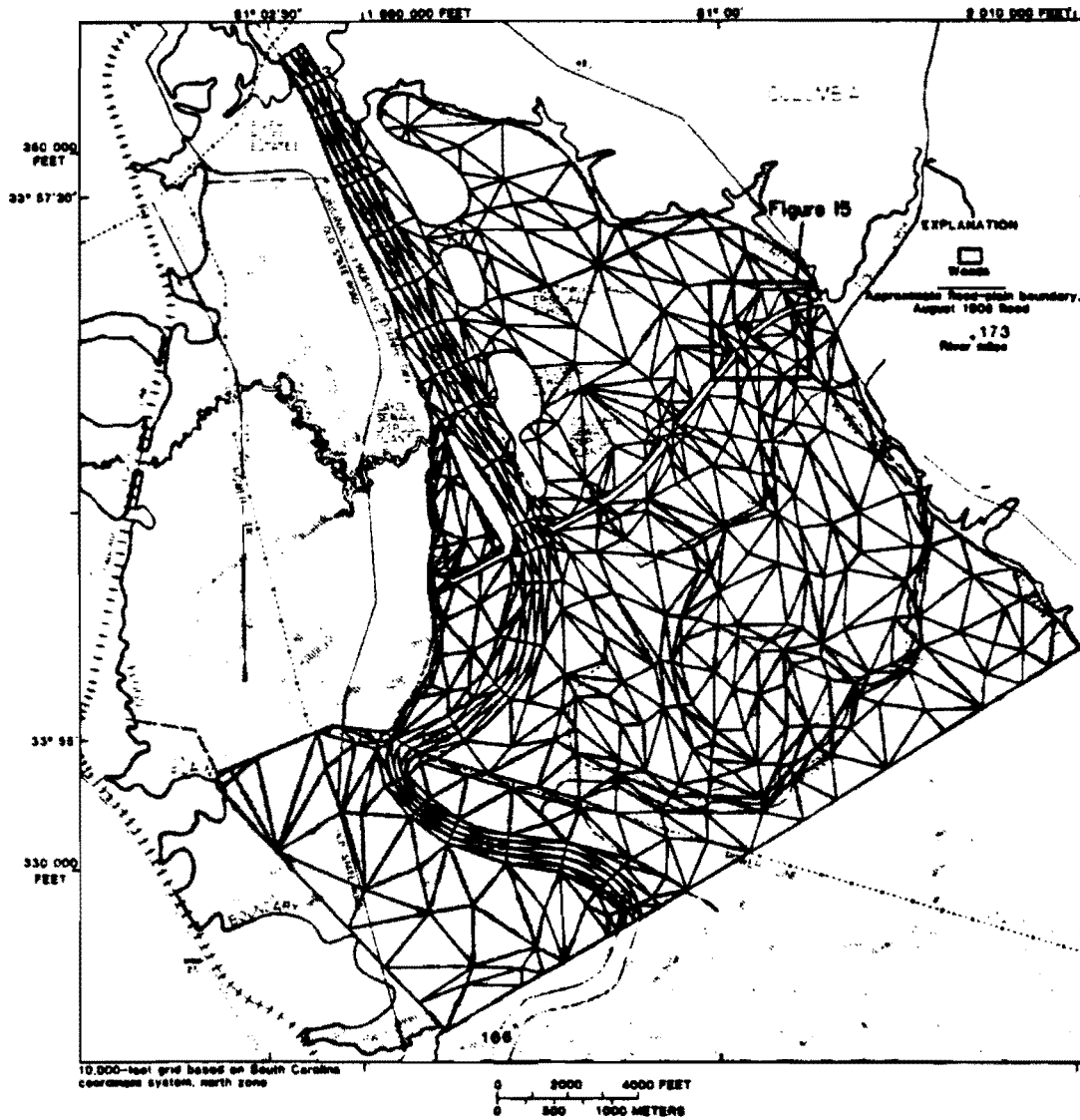


Figure 1.12 Congaree River Example by Lee and Bennett, (1981).

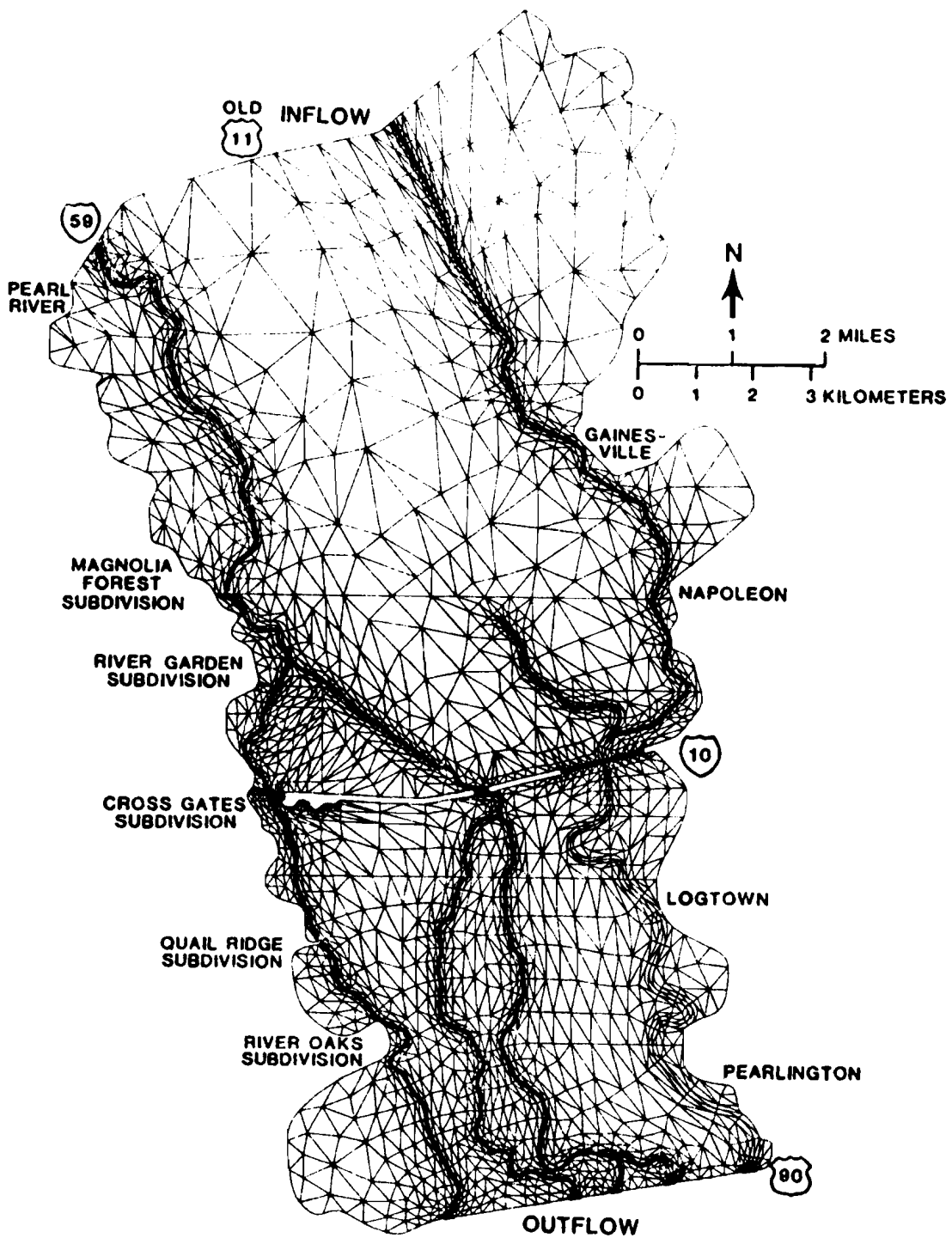


Figure 1.13. Pearl River Example by Lee, et al. (1982) and Wiche, et al. (1982).

Curved element side - Elements can also have curved sides as shown in Fig. 1.14. The curved sides can be used as the outside boundary of the flood plain or could be used to represent the outline of an island.

Boundary conditions

Upstream boundary condition - Specified flow rate for the upstream inlets to the floodplain area. This flowrate can be obtained from known discharge records, using one-dimensional steady flow computation and using known or assumed water surface elevations.

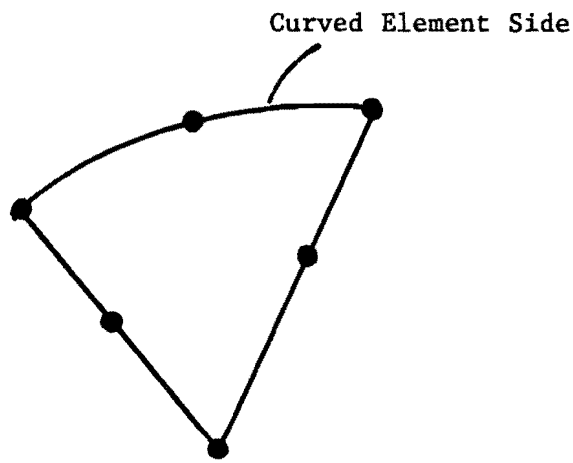
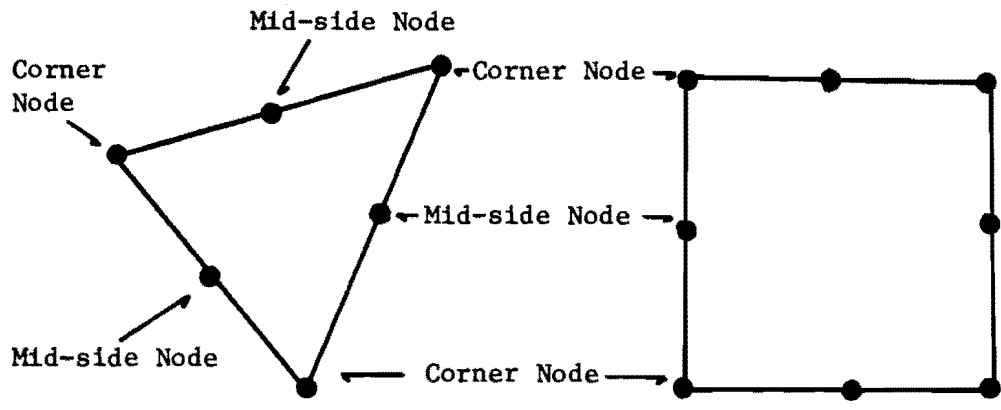
Downstream boundary conditions - Water surface elevations that are specified for nodes on the downstream outlets of the floodplain for known discharges.

Parallel flow boundary - Allows flow to move parallel to fixed boundaries such as around islands or along the boundaries of the area inundated by a flood.

Nodes - The nodes define the location of elements and size of elements.

Corner nodes - Corner nodes are on the vertices of the elements.

Midside nodes - Midside nodes are nodes on the element sides halfway between the corner nodes along the element sides.



Curved Element

Figure 1.14. Finite Element Descriptions

CHAPTER 2 PROGRAM FESWMS DESCRIPTION

2.1. FESWMS Structure

The FESWMS modeling system consists of two major computer programs, RMA-1 (preprocessor) and RMA-2 (processor and postprocessor). In addition, two computer programs RMA1PLT and RMA2PLT are part of the preprocessor and postprocessor for generating calcomp plots. Together these programs constitute the modeling system for simulation of two dimensional (in the horizontal plane) floodplain flows. The RMA-1 program is used to generate the spatial network of finite elements for the simulation. The RMA-2 program is a flood water simulation program which uses the finite element network generated by the preprocessor (RMA-1). The RMA-2 program employs the finite element method of numerical solution to the two-dimensional equations for conservation of mass and momentum in the horizontal plane.

2.1.1 Preprocessor

As described above, the primary purpose of the preprocessor (RMA-1), is to generate the finite element grid network for use by RMA-2. Specific capabilities of RMA-1 include the following:

1. Read, edit, and print all the geometric data required for RMA-2.
2. Refine, update, and modify a finite element network which has been generated by previous runs of RMA-1.
3. Calculate coordinates of mid-side nodes.
4. To produce graphical plots of the user defined finite element network using standard Calcomp library routines.
5. Develop element reorder of the network for more efficient use of the processor (RMA-2).

6. Write a data file which is used as part of the input to the processor (RMA-2).

RMA-1 consists of a master routine, RMA-1, and several subroutines as shown in Fig. 2.1(a). The master routine (RMA-1) reads the input data file and issues calls to various subroutines for specified purposes. Subroutines REORD, ORDER and ADJPT are used to calculate a reordering of the finite element network to reduce (minimize) the computational effort in the processor.

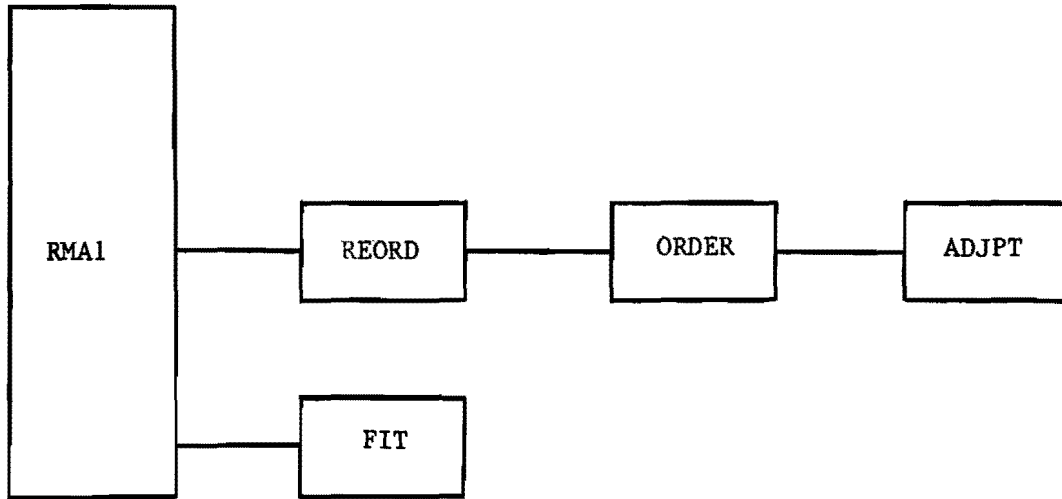
RMA1PLT consists of a master routine and subroutine FIT as shown in Fig. 2.1

2.1.2 Processor

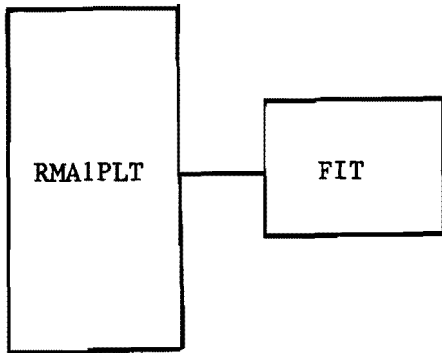
RMA-2 is designed to solve two-dimensional free surface hydrodynamics using the finite element method. The model is capable of solving either steady-state or dynamic problems; however, the descriptions, applications, and discussions herein are only for the purpose of steady-state analysis, since conventional highway drainage designs are based on steady-state conditions.

The computer program, RMA-2, is composed of the master routine, RMA2, and nine subroutines as shown in Fig. 2.2. The master routine, RMA2, performs program initiation, directs calls to various subroutines, performs iteration counts, and normal program terminations. RMA2 first calls subroutine INPUT to read all geometric data and run control data. Then subroutine LOAD is called to set up equation numbers and check the problem size. Subroutine FRONT is then used to form and solve the set of simultaneous equations. Subroutine COEFS is called from FRONT for each element for each iteration to develop the element by element influence of each system variable.

Subroutine XRED is called from FRONT to read information from scratch disk files as written by subroutine XWRIT. Subroutine OUTPUT is either called from the master routine, RMA2, or from subroutine INPUT. OUTPUT performs several tasks depending upon the status of the solution when called. Also, subroutine CHECK is



2.1 (a) RMA-1 Program Organization



2.1 (b) RMA1PLT Program Organization

Figure 2.1. Preprocessor Program Organization

called by OUTPUT and has the function of computing and printing the total flow which crosses a user specified line defined by a list of node numbers. This total flow can be used as a continuity check.

2.1.3 Postprocessor

RMA2PLT is for the purpose of developing vector plots of the flow fields determined in the processor. This computer program consists of a master routine and, RMA2PLT, and three subroutines as shown in Fig. 2.3. Subroutine FIT plots a parabola through three points for curved element sides. Subroutine SUBSC is for scaling the plot. Subroutine AROHD is for the purpose of drawing the vectors, straight lines with arrowheads at the end. This subroutine was written by the investigators of this project. The master routine and each of the subroutines call various Calcomp subroutines to perform the graphics.

2.2 FESWMS Application Procedure

2.2.1 Input

Two sets of input are required for application of FESWMS, input to RMA-1 and input to RMA-2. A detailed description of the input to FESWMS is not given herein but can be found in Norton (1980). A detailed description of the modified modeling system FESWMS-TX is provided in the next chapter.

The basic input to RMA-1 includes:

1. Various input parameters for the running procedure and plotting information.
2. Slopes at corner nodes for defining curved side elements and the mid-side node numbers for the curved elements. Corner node slopes are explained in detail in Section 3.31 and in Figures 3.7 and 3.8.
3. Element numbers, a list of the corner and mid-side nodes of each element, and the element type number.

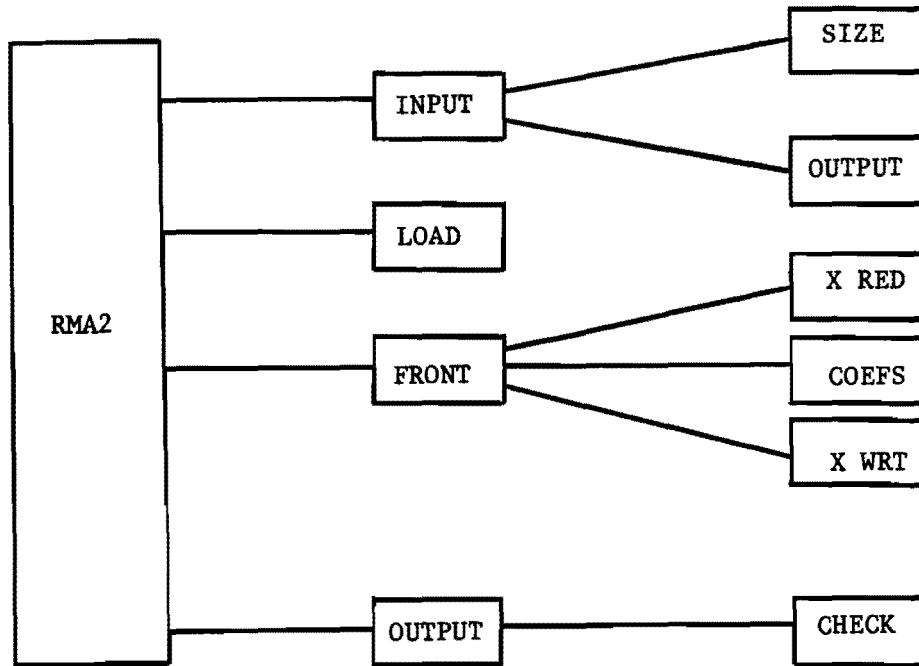


Figure 2.2. Program Structure of RMA2

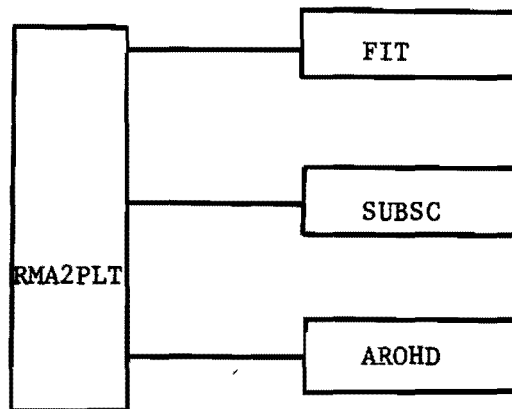


Figure 2.3. Program Structure of RMA2PLT

4. Node numbers with x-coordinate, y-coordinate, and ground surface elevation at each corner node.
5. Nodes defining straight line segments.
6. Lists of nodes for reordering element numbering.

The basic input to RMA-2 includes:

1. Various input parameters for the running procedure and plotting information.
2. Hydraulic information such as turbulent exchange coefficients and Chezy coefficients.
3. List of corner nodes for continuity checks.
4. Boundary conditions for upstream, downstream and parallel flow conditions. The upstream boundary conditions are given as a specified x-direction flow and a specified y-direction flow in terms of $\text{ft}^3/\text{sec}/\text{ft}$ at each upstream boundary node. Downstream boundary conditions are water surface elevations at specified nodes. These upstream and downstream boundary conditions are for subcritical flow.

2.2.2 Operating Procedure

The basic operating procedure for FESWMS (Fig. 2.4) is to first run the RMA-1 model once the input is developed. The RMA-1 model may have to be run more than once to properly define the geometry of the network. The output from RMA-1 has three sets: one set is printed out, one set is a plot of the finite element network, and one set is stored on a scratch disk file and is later used as input to RMA-2. Once RMA-1 has been run successfully then RMA1PLT can be run to obtain additional network plots.

The RMA-2 running procedure starts with a user created input file and an input file on scratch disk file which was an output file from RMA-1 defining the geometry of the finite element network. The running procedure starts with a down-

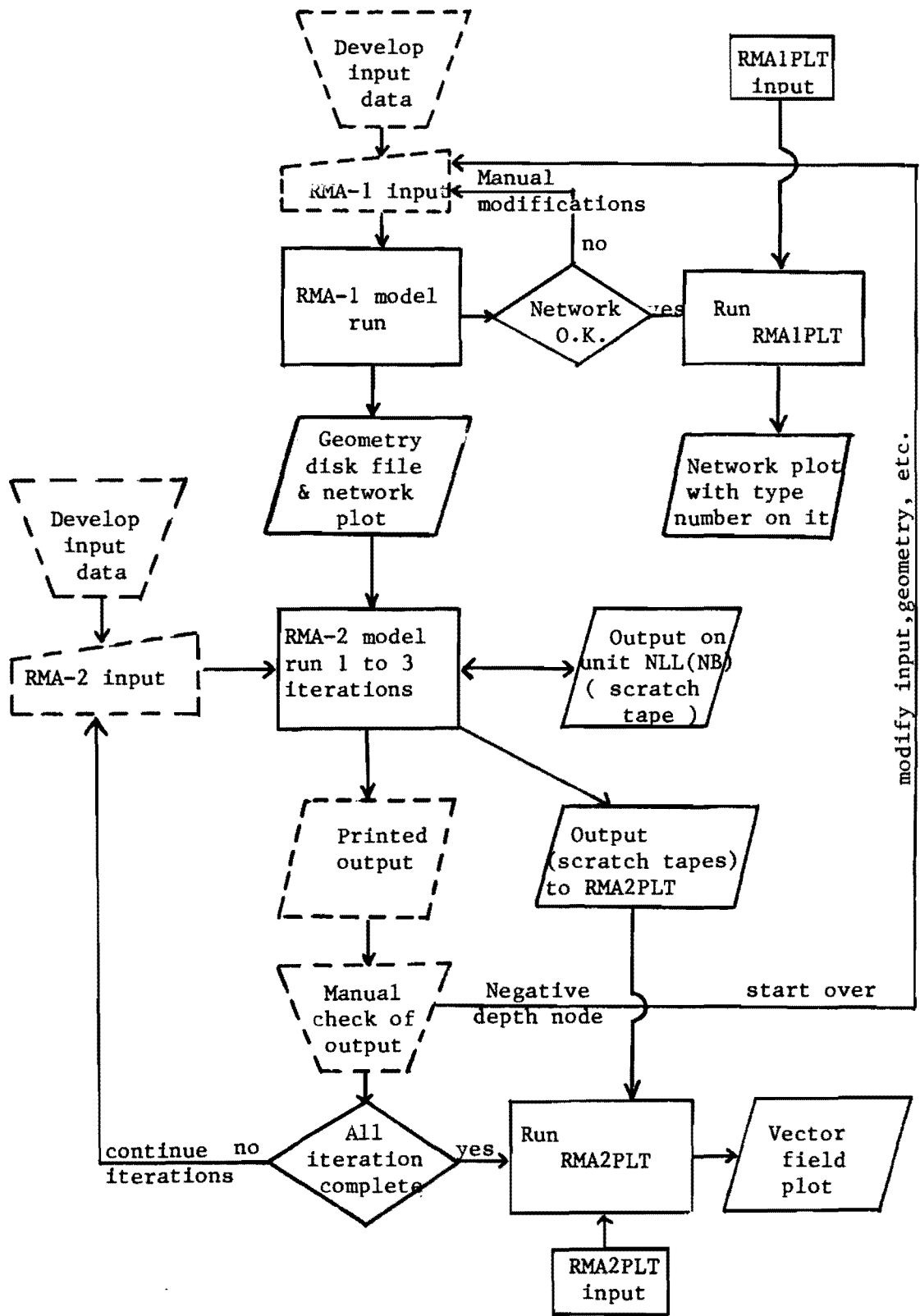


Figure 2.4. Application Procedure for FESWMS

stream water surface elevation (downstream boundary condition) that is higher than the highest expected water surface elevation in the modeled flood plain. The RMA-2 is run for one to three iterations after which the results are put in a file on unit NLL. This file is manually checked to determine if negative depths occur. If negative depths occur, then the RMA-1 and RMA-2 input must be changed and the procedure starts all over again running RMA-1 with the modified network or other modified input.

If the manual check of the RMA-2 output shows no negative depths or other apparent problems, then the RMA-2 input is modified by renumbering the read and write restart files and lowering the downstream water-surface elevation in the RMA-2 input. The switching of the read and write restart files is accomplished by switching the numbers NB and NLL in the RMA-2 input file. The above procedure is continued until the desired downstream water-surface elevation is obtained. Data can be manually modified within reason between iterations such as discharges. Ground surface elevations or element types are changed by starting over and rerunning RMA-1. Once the RMA-2 has been run successfully for the desired downstream water surface elevation, then the RMA2PLT can be run to generate various plots of the results that are described later.

2.3 Needed Modifications

Several modifications (to FESWMS) were identified that could possibly simplify the usage of the modeling system. Each of these modifications are briefly described below and are discussed in more detail in the next chapter. These modifications include:

1. Conversion from use of Chezy's roughness coefficient to Manning's roughness coefficient.
2. Change input of upstream boundary condition from a flow rate per unit depth at each node to a total discharge.

3. Simplify the running process of FESWMS by incorporating routines to check output files for negative depths that would cause non-convergence of the numerical scheme. In addition, these routines would modify the network and input files for RMA-1 and RMA-2 to restart the running process.
4. Automate the manual process of interactively running the RMA-1 and RMA-2 programs.
5. Simplify the input process to RMA-1 and RMA-2.
6. Explore the use of computer graphics to simplify and refine the input process.
7. Provide capability for batch processing of FESWMS system package.

The FESWMS program requires use of the Chezy coefficient, C , as the roughness factor. In the United States, it is customary to use Manning's roughness factor as opposed to Chezy's roughness factor. The Chezy C can be expressed in terms of Manning's n as (Henderson 1966)

$$C = \frac{R^{1/6}}{n} \quad \text{or} \quad C = \frac{y^{1/6}}{n} \quad (2.1)$$

where R is the hydraulic radius which is $R = y$, the depth for discharge per unit width.

The Chezy equation is

$$V = C \sqrt{RS_f} \quad (2.2)$$

where S_f is the friction slope. Manning's equation is then

$$V = \frac{1.49}{n} R^{2/3} S_f^{1/2} \quad (2.3)$$

The upstream boundary condition description requires inputting the unit flow-rate ($\text{ft}^3/\text{sec}/\text{ft}$) in the x-direction and the flow rate in the y-direction for each node. Determination of x- and y-direction flow rates in these terms at each node is a lengthy and cumbersome process. It is a much simpler process to input a total flow rate and trial water surface elevation at the upstream inflow points and let the computer program compute the nodal unit flow rates in the x and y directions.

As depicted in Fig. 2.4, application of the FESWMS model requires a tremendous amount of manual work that also involves a great deal of knowledge about hydraulics. As a result, this makes using FESWMS a rather difficult and time-consuming task for a highway engineer. A modification to simplify the usage of FESWMS would be to automate several manual operations, such as looking through the output files of RMA-2 and then manually correcting the input files to both RMA-1 and RMA-2. These are manual processes that require a great deal of knowledge about the FESWMS model and about hydraulics in general. These manual processes and others are automated in the FESWMS-TX model.

Many of the input parameters to RMA-1 and RMA-2 can be eliminated as input and specified within the computer code. These are the parameters that never really change from one application to the next. Many of these parameters are very confusing to the novice user, and it is difficult to determine their proper value. Program FESWMS-TX incorporates these within the computer code so that the user need not worry about them. However the user does have the option to specify these if values other than the default values are desired.

Application of FESWMS requires manual operations to define and input data to describe the geometry of the system. The user must first draw or define in some manner the network of elements. Next, the user must input the element number and then enter each of the corner and mid-side nodes of that element in a counterclockwise fashion. This is a time-consuming process and is subject to error. The user must

also define the corner node numbers and the x coordinate, the y coordinate, and the ground surface elevation of that node, which also is a very time-consuming process. In addition these processes are very susceptible to error when using manual processes. These two processes to define the elements, node numbering, and the x, y, z coordinate of each node are processes that can be accomplished using computer graphic techniques along with digitized contour maps. A future step would be to use computer graphics capabilities to define and input these data quickly and without error. These proposed graphics capabilities are briefly described in a later section as future work beyond the scope of this project that should be performed.

CHAPTER 3 PROGRAM FESWMS-TX DESCRIPTION

The FESWMS modeling system described in the previous section has been extensively modified to make the modeling system easier to use. This modified version is referred to as FESWMS-TX. The basic input procedure is a manual procedure consisting of inputting the data obtained from constructed finite element networks on contour maps. This process consists of determining the element and node numbering, determination of x, y, z coordinates, etc., from the finite element network placed on the contour map. The user's manual for the manual procedure is given in Chapter 4.

There are basically two running levels for the FESWMS-TX system. One is to use a semi-interactive mode where the user provides various run commands for the different programs through means of a CRT. In other words, the user is presenting commands to the computer system to run the various codes: RMA-1, RMA-2, USNEG, RMA1PLT, and RMA2PLT. The second running level is to use a master program written in control language that systematically presents the various run commands to execute the programs in the proper sequence.

3.1 FESWMS-TX Structure

The FESWMS-TX system is similar in basic structure to the FESWMS system. FESWMS-TX consists of two major computer programs, RMA-1 (preprocessor) and RMA-2 (processor and postprocessor). In addition, two computer programs, RMA1PLT and RMA2PLT, are part of the preprocessor and postprocessor for generating graphical plots. These are identical to those in FESWMS. Another computer program, USNEG, has been added as part of the FESWMS-TX system. The purpose of USNEG is to check the RMA-2 output for negative depth nodes after a specified number of iterations and modifying the RMA-1 input and RMA-2 input to restart the simulation process.

3.1.1. Preprocessor

The purpose of the preprocessor (RMA-1) is to generate the finite element grid network for use by RMA-2. The specific capabilities of RMA-1 have been presented in Chapter 2.1. RMA-1 consists of a master routine, RMA-1, and several subroutines as previously shown in Fig. 2.1(a). The master routine reads the input data file and issues calls to various subroutines for specified purposes. Each of the subroutines is briefly described in Chapter 2.1.

3.1.2 Processor

RMA-2 is the processor which is designed to solve two-dimensional free surface hydrodynamics using the finite element method. The model is capable of solving either steady-state or dynamic problems; however, the emphasis in this report is on steady-state analysis.

The computer program RMA-2 comprises the master routine, RMA2 and the ten subroutines as shown in Fig. 3.1. The major differences between the RMA-2 for FESWMS and the RMA-2 for FESWMS-TX are the following:

1. Conversion from use of Chezy's roughness coefficient to Manning's roughness coefficient.
2. Upstream boundary condition is now inputted as a total discharge and initial water surface elevation at the upstream boundary nodes. A new subroutine, USSET, has been incorporated into RMA-2 to determine the x- and y-coordinate unit flow rates ($\text{ft}^3/\text{sec}/\text{ft}$) using the inputted total discharge and initial water surface elevation. The discharge is distributed based upon water depth assuming a uniform velocity of flow at the upstream boundary.

The master routine, RMA2, of the computer program RMA-2, performs program initiation, directs calls to various subroutines, performs iteration counts and normal program termination. RMA2 first calls subroutine INPUT to read all geometric

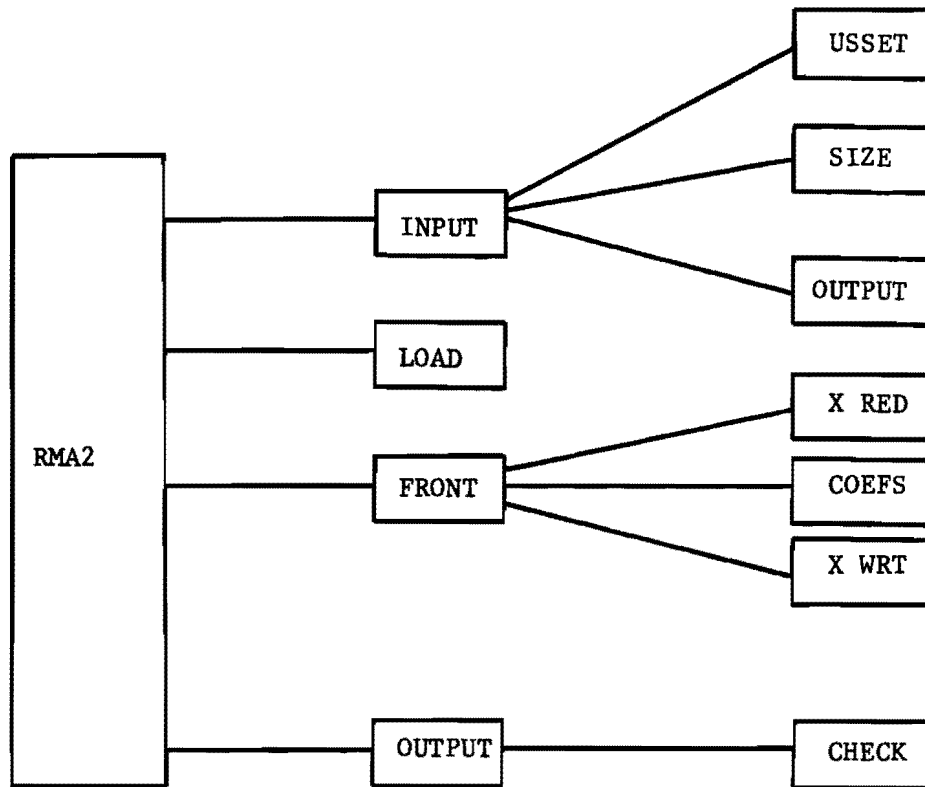


Figure 3.1. Program Structure of RMA-2 in FESWMS-TX.

data and run control data. Subroutine USSET is called from INPUT to set up the upstream boundary conditions. Then subroutine LOAD is called to set up equation numbers and check the problem size. Subroutine FRONT is then used to form and solve the set of simultaneous equations. Subroutine COEFS is called from FRONT for each element for each iteration to develop the element by element influence of each system variable. Subroutine XRED is called from FRONT to read information from scratch disk files as written by XWRIT. Subroutine OUTPUT is either called from the master routine, RMA2, or from subroutine INPUT. Output performs several tasks depending upon the status of the solution when called. Also, subroutine CHECK is called by OUTPUT and has the function of computing and printing the total flow which crosses a user-specified line defined as part of the input by a list of node numbers. Refer to Figure 3.1.

3.1.3 Computer Program USNEG

The purpose of this program is to check the output file of RMA-2 to determine if negative depths have been encountered in the numerical procedure. This computer program is usually run after two or three iterations of the RMA-2 program for a specified downstream water surface elevation. The inputs to USNEG comprise three files: one is the output file from RMA-2 and the others are the input files for RMA-1 and RMA-2. If no negative depths are found, the running process continues with the same network. However, if negative depths are found, the network is modified and the running process restarts with RMA-1 again. The network is modified by eliminating the node with the negative depth from the network. For interior nodes of the network this essentially creates an island. For nodes on the boundary of the network the lateral boundary of the floodplain is changed.

3.2 FESWMS-TX Application Procedure

The FESWMS-TX system can be run in a semi-interactive framework or in a batch framework. The interactive framework is the recommended procedure; however, this running procedure requires some minor knowledge of the control commands for running the programs.

3.2.1 Interactive Application Procedure

The following is a summary of the steps required in running the FESWMS-TX system in the semi-interactive framework (see Fig. 3.2).

1. Develop input for RMA-1, RMA-2, RMA1PLT, and RMA2PLT as described in Chapter 4.
2. Run RMA-1 with the input developed in step 1. Check printed output which also has a network plot and if network and geometry are not correct, modify input appropriately and rerun RMA-1.
3. Run RMA1PLT to check the network. If not correct, modify the network input and rerun RMA-1. Output is a finite network plot with element type number and ground elevations.
4. Next, the RMA-2 program is run using the geometry disk file from the RMA-1 run (step 2) and the input file developed in step 1. The RMA-2 is run for one to three iterations with a specified downstream water surface elevation. Part of the output is stored on a tape file (unit NLL) which is used as input to RMA-2 for the next series of iterations. Also, files are generated from RMA-2 which are input to computer program RMA2PLT for the vector field plot. A printed output file lists the depths, velocities, water surface elevation, and Froude number for each node plus additional information described in Chapter 4.
5. Run computer program USNEG using the same printed output file from RMA-2 to check for negative depth nodes.

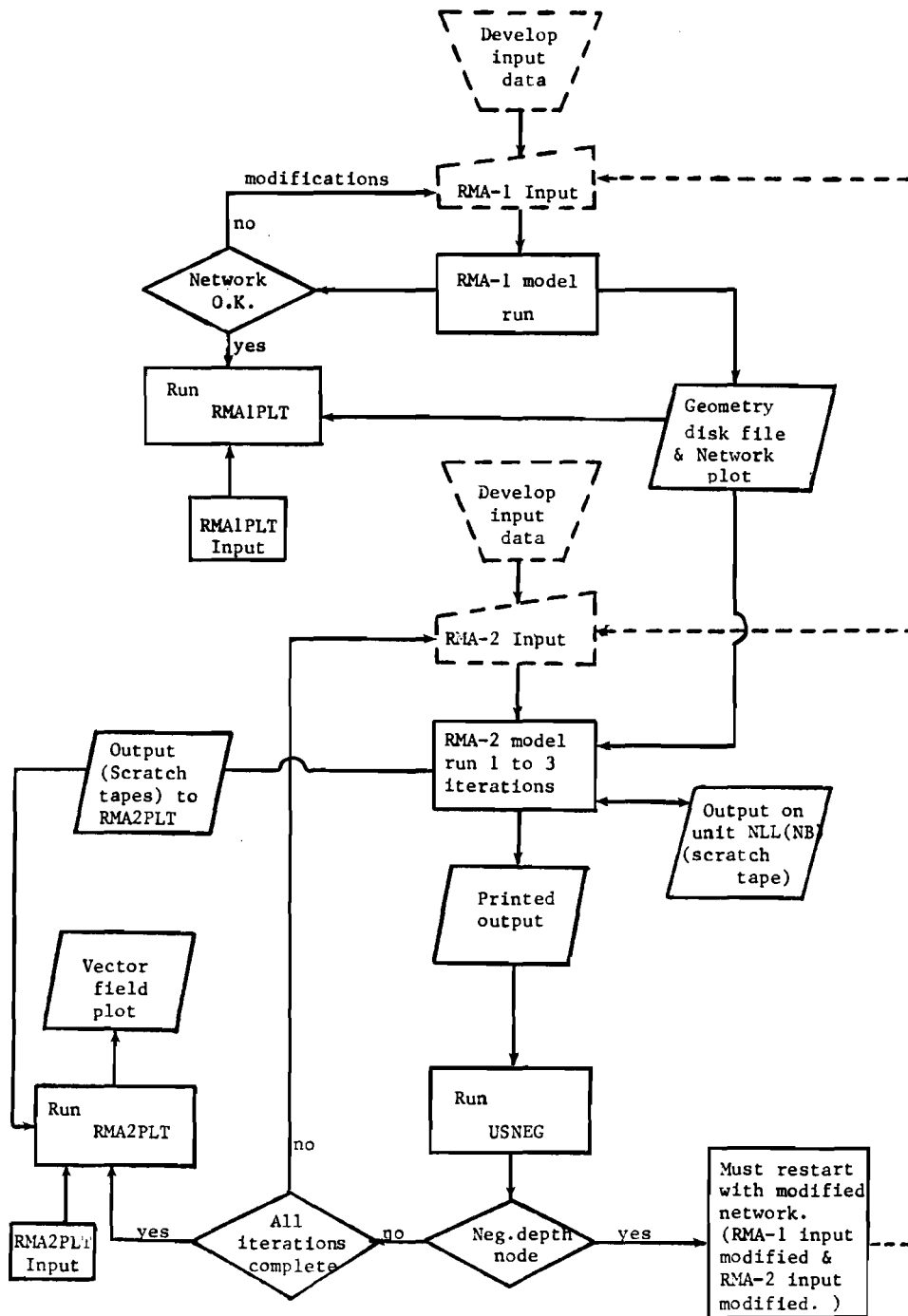


Figure 3.2. Interactive Application Procedure for FESWMS-TX.

- a. If none of the depths are negative, RMA-2 is rerun (go to step 4) using a new downstream boundary condition (i.e., the downstream water surface elevation is lowered). If the final downstream boundary condition (i.e., the desired water surface elevations) have been considered, go to step 6.
 - b. If one or more of the depths are negative, then program USNEG modifies the input to RMA-1 and RMA-2 by eliminating the node with a negative depth from the network. The next step is to return to step 2 and restart the interactive procedure with the modified inputs to RMA-1 and RMA-2.
6. Now the RMA-1 and RMA-2 runs have been successfully completed. RMA2PLT is now run to generate the vector field plots. Input to RMA2PLT is both a manually generated input file, plus tape files generated from the RMA-2 run.
 7. The user may now want to modify the network (modifying RMA-1 and RMA-2 input files) and restart the procedure.

3.2.2 Batch Application Procedure

The batch application procedure involves creating the control command language characteristic of a particular computing system. These control commands should be set up so that the RMA-1 is run first. The next set of commands is to run RMA-2 for a specified number of iterations, then USNEG is run to check for negative depths using the results of the last iteration of RMA-2.

If no negative depths are encountered, RMA-2 is run again for a specified number of iterations using the next downstream boundary condition (water surface elevation). If negative depths are encountered, then the RMA-1 and RMA-2 inputs are modified to delete the node with a negative depth from the network; then RMA-1 is run again. This process is illustrated in Fig. 3.3. The RMA-1 input file and the

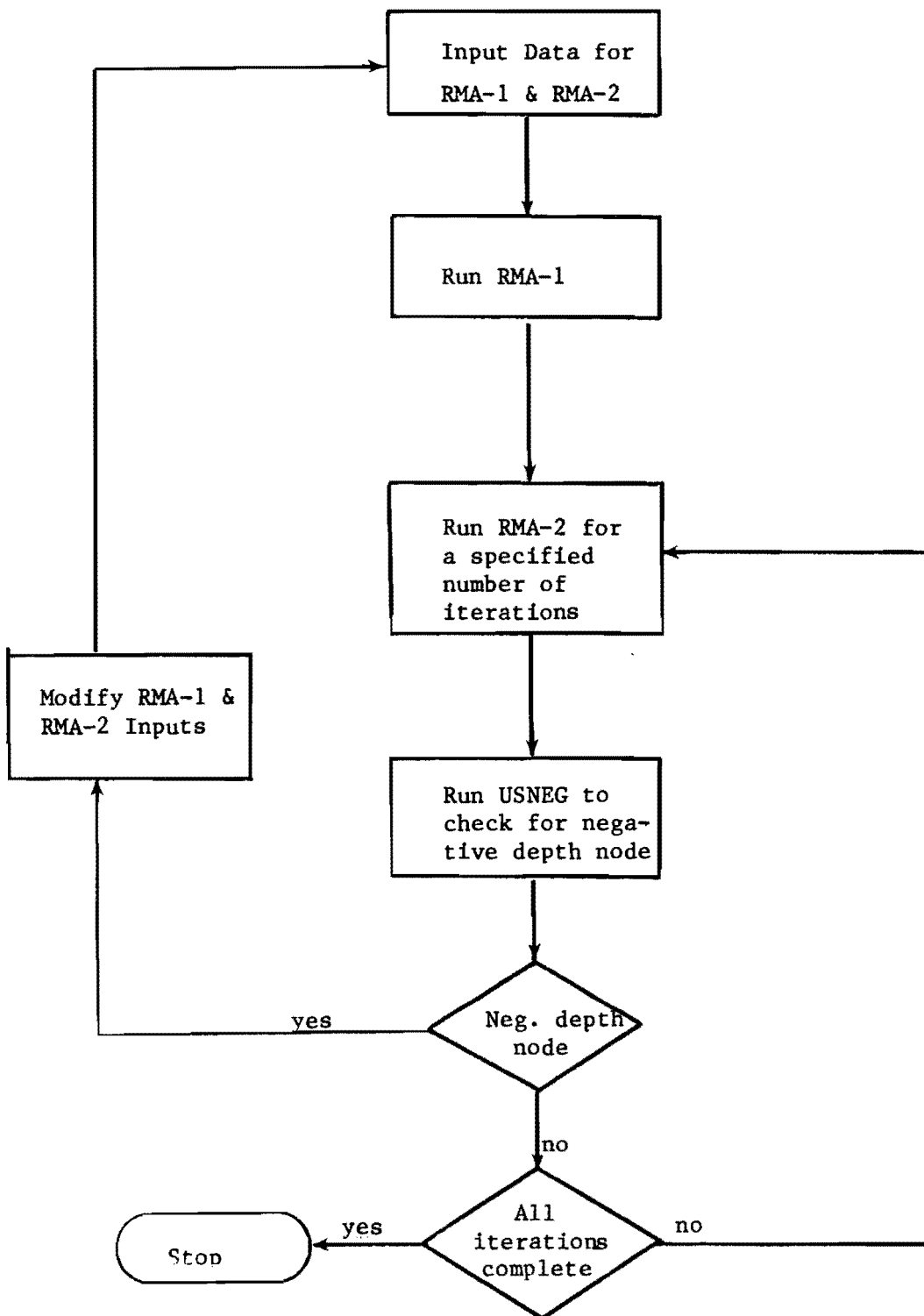


Figure 3.3. Batch Application for FESWMS-TX

RMA-2 input files for each series (group of iterations) of run are established in advance of running the batch process.

Figure 3.4 shows the control language to run FESWMS-TX using the MACRO control language for the CDC Cyber 170/175 system at The University of Texas at Austin. It is recommended that this batch system for running the FESWMS-TX model only be used once an appropriate finite element network has been established for the particular application.

3.3 Guidelines for Input

3.3.1 Developing the Network

In order to model a floodplain, the finite element network must describe the topographical characteristics of the entire floodplain area that would be inundated by a flood of a given magnitude. This description requires both the location of the interior nodes and elements plus the location of the flood boundaries. Each of these two aspects of developing the network are now described.

Selection of nodes to define the finite elements should follow these rules:

1. Interior nodes should be located where they best represent the changing ground surface slope.
2. More rapidly varying slopes require nodes (elements) spaced closer together. As an example, areas of rapidly changing slope, such as channels where steep banks are located, require nodes spaced relatively close together. Areas with gradually changing slope, such as in the floodplain can be represented with much fewer nodes spaced farther apart resulting in large elements. (Refer to Fig. 3.5)
3. The numerical solution is better approximated as the size of the elements decreases (i.e., more elements); however, the user must work within the limits of computer storage available and within the limits of practicality. More elements also imply more computation time.

```

MACRO RMA C=INPUT,L=OUTPUT,CL=INPUT,CRMA1=INPUT,LRMA1=OUTPUT,SKIP=
USERNULL
TRACE
*****
*
*           RMA MACRO
*
*****
*
IFNE /$SKIP// JUMP SKIP
MAXFL B=376000
RFL,376000
REWALLX
READPF 790: RMA15 RMA2NB
** RMA2NB -MANNING EQ. RMA2CZB - CHEZY EQ.
READPF 2287 USNEG3
RFL=77000
INF I=USNEG3 B=BUSNEG L=0
*****
* EXECUTION OF RMA1
*****
LABEL RMA1
LDSET LIB=ZETLTOP
LOAD RMA1B
EXECUTE,,$CRMA1,$LRMA1
*****
* EXECUTION OF RMA2
*****
LABEL RMA2
REWALLX
RMA2NB,$C,$L
SAVEPF 6636 4758 $C $L
*****
* CHECK NEGATIVE DEPTH POINT WITH PROGRAM USNEG3
*****
REWALLX
COPYBF,$L,TAPES1
COPYBF,$C,TAPES2
REWALLX
BUSNEG,$CRMA1,KKK
*
$SO,C=$C,L=$L,$RS SKIP
TERMINATE
LABEL SKIP
*
IFFILE,TAPE61,NOTLO,JUMP CONRUN
REWALLX
COPYBF,KKK,$CRMA1
COPYBF,TAPE62,$C
REWALLX
RETURN TAPES1 TAPES2 TAPE61 TAPE62 KKK
JUMP RMA1
*****
LABEL CONRUN
REWALLX
**SAVEPF 6636 4758 $C $L
IFEQ *$C*$CL* JUMP ENDP
ADVANCE,C
ADVANCE,L
JUMP RMA2
*****
LABEL ENDP

```

Figure 3.4. MACRO Commands to Run FESWMS-TX

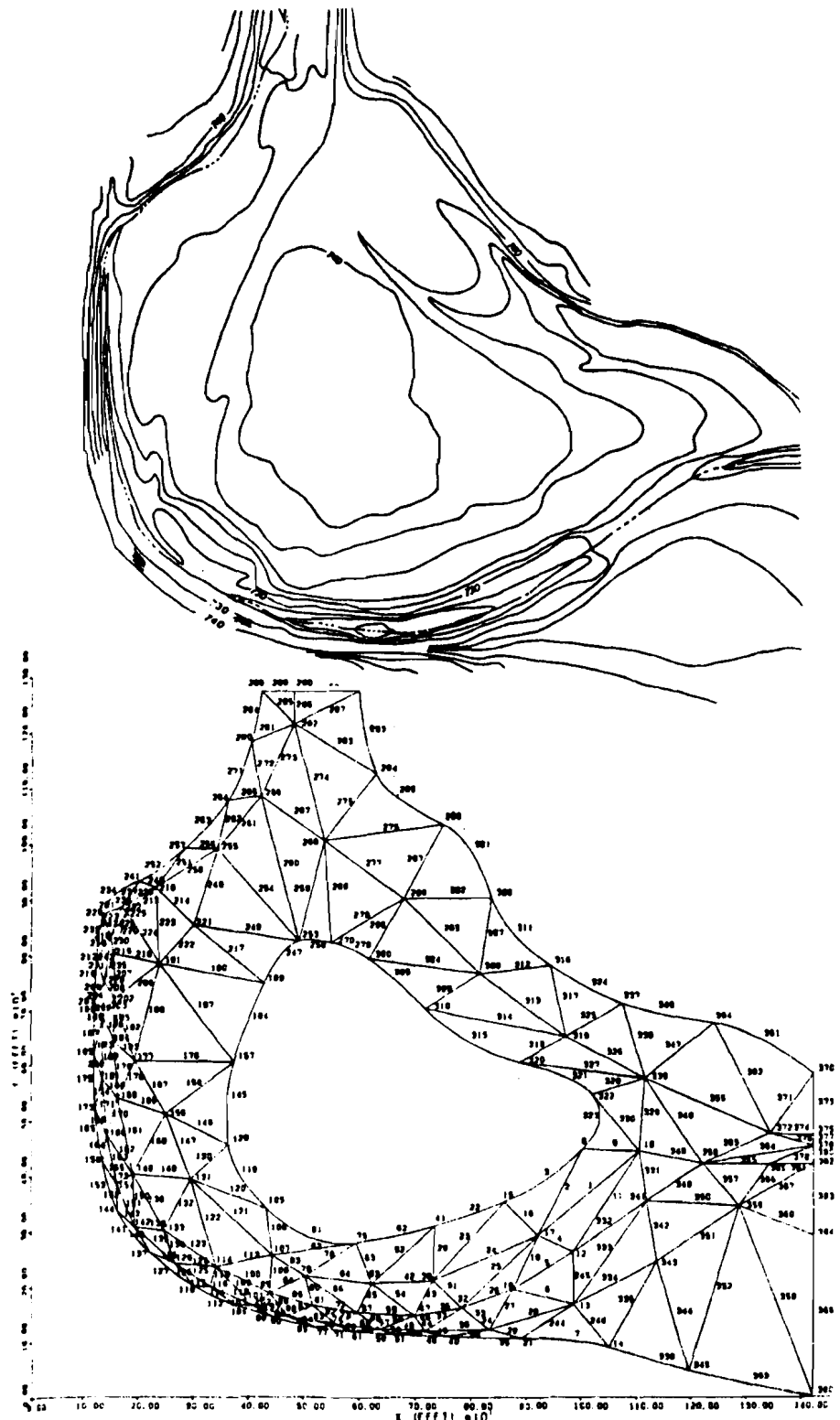


Figure 3.5. Example by Driscoll (1981) Showing Topography and Finite Element Network.

4. Elements can be placed in an orderly fashion starting at the upstream end of the channel and floodplain. Elements are first placed along the upstream extremity going from top to bottom or bottom to top of the contour map. Once this column of elements has been defined, move downstream to define the next column of elements. Proceed in this manner going downstream until the element network has been defined. This procedure has been found to ease the work and makes inputting by the manual procedure systematic.
5. Subdivision lines can be used to divide the network similar to cross-section lines used in one-dimensional backwater analysis. These can be located where abrupt changes in topography or vegetative cover occur. The finite elements are then defined using these subdivision lines as a basis for their construction.
6. Each element should be designed to represent an area of nearly homogeneous vegetative cover and/or physical topography.
7. Areas where the velocity, depth, and water surface gradients are expected to be large should have greater network detail (more and smaller elements) in order to facilitate better simulation of the large gradients. This applies near bridge openings and in areas between overbanks and channel bottoms as shown in Fig. 3.6.
8. Elements used in designing the finite element network for river or stream channels should be placed so that the longest side of the element is aligned with the flow direction of the river or stream channel.
9. Elements with aspect ratios greater than one, make it possible to use the elongated elements to define river channels. Element aspect ratios should not be over ten.
10. If the floodplain is very extensive, such that thousands of elements will be required, then several approximations can be made:

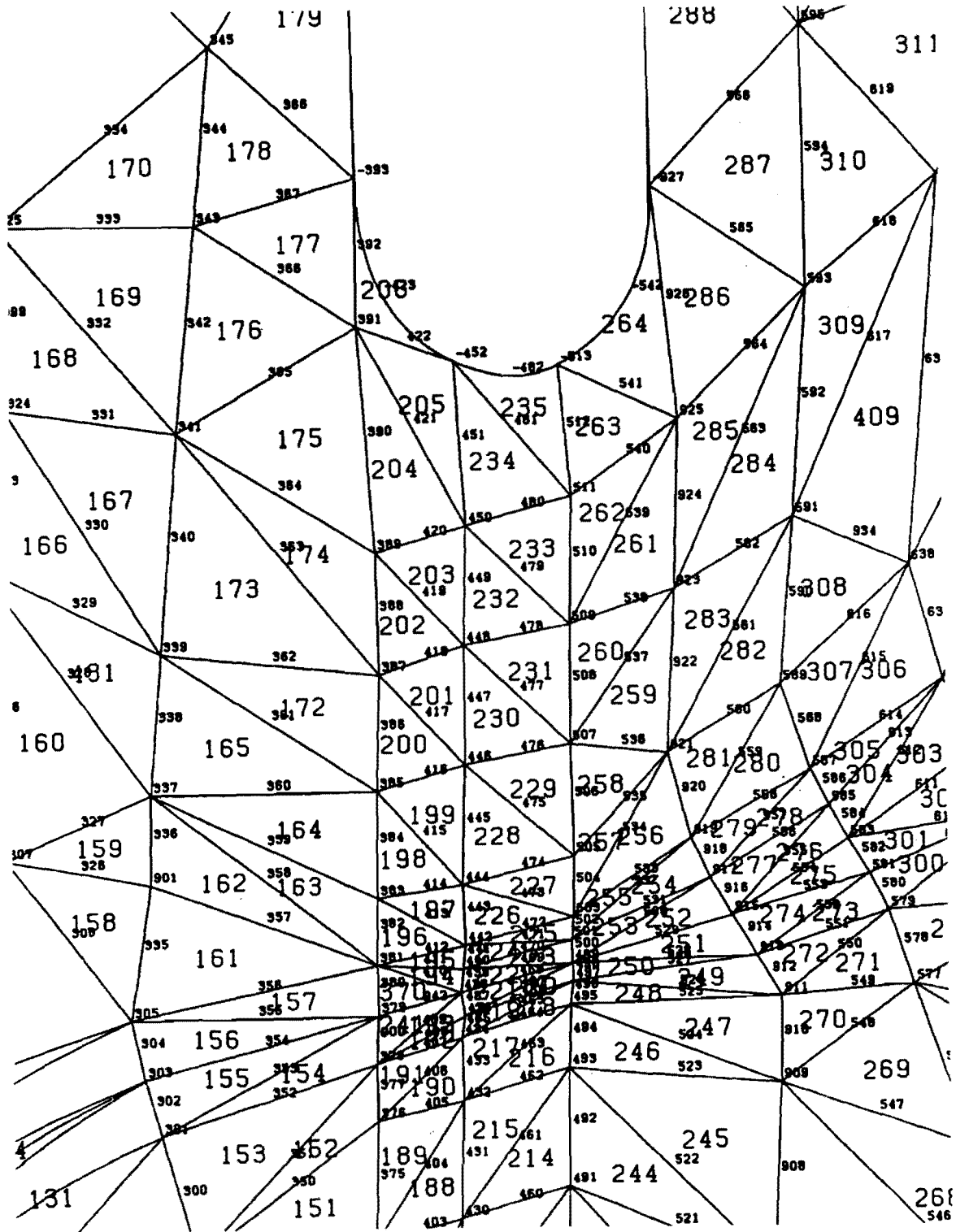


Figure 3.6. Finite Element Construction Around a Highway Embankment.

- a. Only the larger channels can be included in the network.
- b. Elements can be placed to model prototype channel cross-section by triangular or trapezoidal cross-sections with cross-sectional areas equal to the measured areas.
- c. Meandering channel reaches with relatively small flows can be replaced with artificially straightened hydraulically equivalent reaches.

The second major aspect in developing the finite element network is in the specification of the network boundaries, that is, locating the flood boundaries or extent of the floodplain. Location of the network boundaries for rather flat floodplains is a trial and error procedure requiring a certain amount of engineering judgement.

Guidelines for specifying the boundary include:

1. Highwater marks and/or the results of 1-D backwater analysis can be used to estimate the floodplain limits.
2. Curve sided elements should be used for the outer boundaries where the modeler knows that the floodplain limits are irregular as shown in Fig. 3.7.
3. The slope of the tangent (Fig. 3.8) to the curved boundary must be specified at each corner node (along the network boundary) which is on the curved element side.
 - a. The corner node slopes for the curved element sides must be specified so that the mid-side node is located near the center of the curved element side. The mid-side node should be contained within the projection of the middle third of a line connecting the two corner nodes. This is referred to as the middle one-third rule and is shown in Fig. 3.8a.

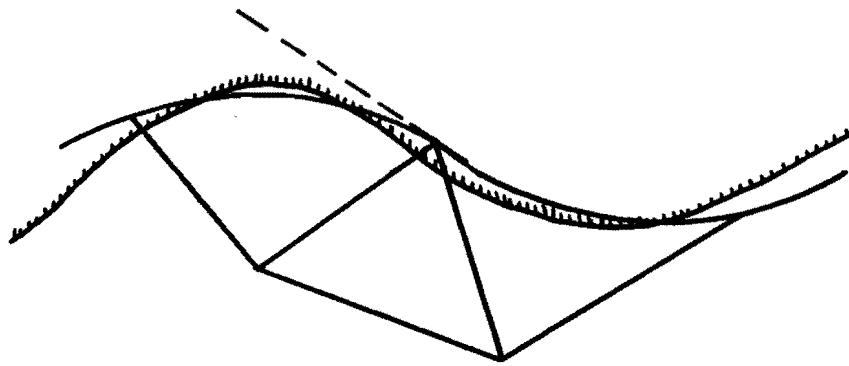
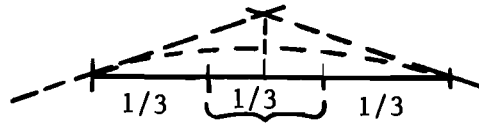
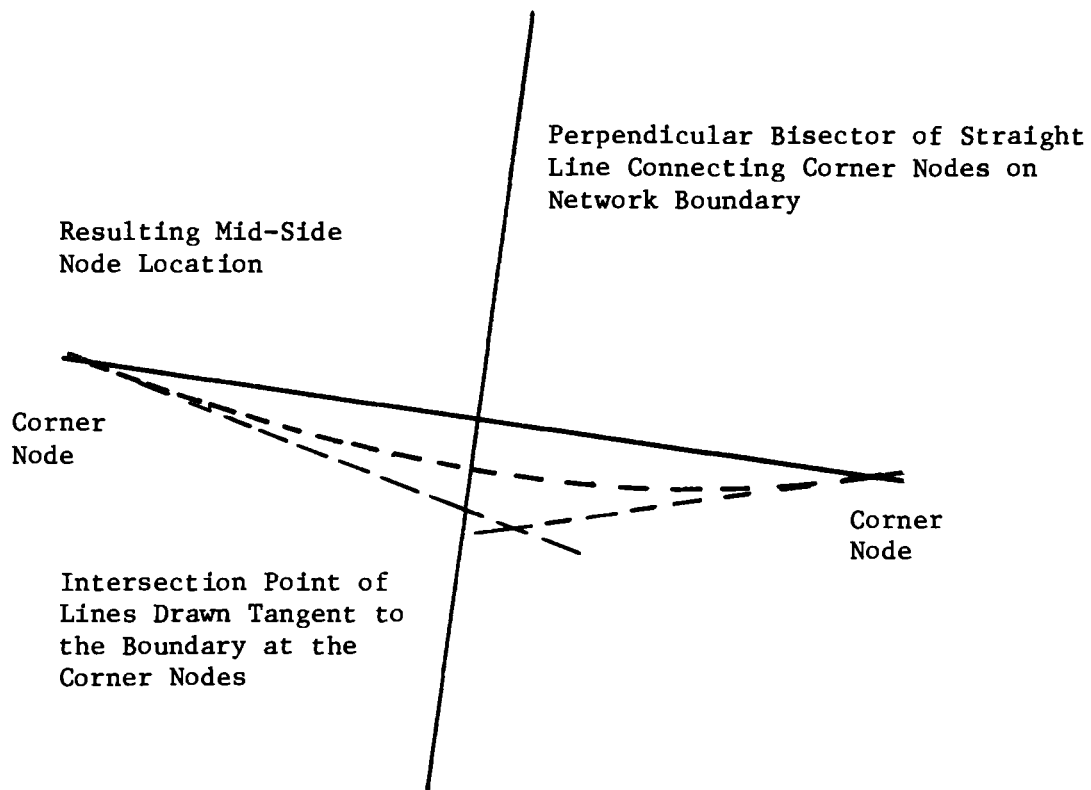


Figure 3.7. Curved Side Elements for Specifying Irregular Floodplain Boundaries



Mid-node
location
must fall
within this
1/3 projected
down.

(a) Middle One-Third Rule



(b) Midnode Location

Figure 3.8. Guidelines for Determining Corner Node Slope for Curved Element Sides

- b. The middle one-third rule should be observed to avoid numerical problems, but slight violations can be tolerated without serious problems.
 - c. RMA-1 calculates the position of the mid-side node using the corner node slopes at the ends of the curved element side. The mid-side node locations are then changed by re-specifying the corner node slopes.
 - d. A rule of thumb is to locate the mid-side node so that the tangents of adjacent corner nodes intersect on or near the perpendicular bisector of a straight line connecting the two corner nodes as shown in Fig. 3.8b.
- 4. The parallel flow boundary condition that specifies flow will be parallel to the curved floodplain side and should be specified for the nodes in the curved boundary. This is explained further in a later section on boundary conditions.
 - 5. Ground slopes along an assumed floodplain boundary should be considered because sharp changes in ground slope in shallow areas can produce exceedingly high velocities that may be unrealistic. This is especially true if the ground slope at the boundary has been poorly represented and this may lead to numerical instability and failure of the model to run.

3.3.2 Numbering the Nodes and Elements

Each triangular element is defined by the three corner node numbers and the three mid-side node numbers. Each element is also given a number. Guidelines for the node and element numbering are:

- 1. The maximum difference in node numbers defining an element is the major factor in determining the amount of computer storage required. As a result the nodes should be numbered so that the difference in nodal numbers common to each element is minimized to the extent possible.

2. The most efficient numbering scheme is to number the nodes across the network so that the minimum number of elements exists between opposite boundaries. The numbering should proceed from one end of the network to the other. It is suggested that the numbering proceed from upstream to downstream, but this is not required.
3. A routine exists within FESWMS-TX which tests several numbering schemes for the most efficient use of computer storage. This routine should be used for the sake of efficiency.
4. Each element is defined by an element number, the corner node numbers, and the mid-side node numbers.

3.3.3 Boundary Conditions

The boundary conditions that can be considered for each node are: 1) no boundary condition; 2) upstream boundary condition; 3) downstream boundary condition; and 4) parallel flow boundary condition.

The no boundary condition is at the internal nodes. This is to say that the flow rate, flow direction, and water surface elevation are all unknown at the node.

The following guidelines should be considered for the upstream boundary condition:

1. For subcritical flow, the boundary condition is a specification of total flow entering the floodplain through a main channel, tributary inflow, or local inflow, and is usually associated with the upstream boundary of the network.
2. For supercritical flow, water surface elevations must be specified at the upstream boundary.
3. The FESWMS-TX (RMA-2) model requires a total flow rate for a group of adjacent nodes that represent an upstream boundary control. As an example, refer to Fig. 3.9, which has two bridge openings that are the

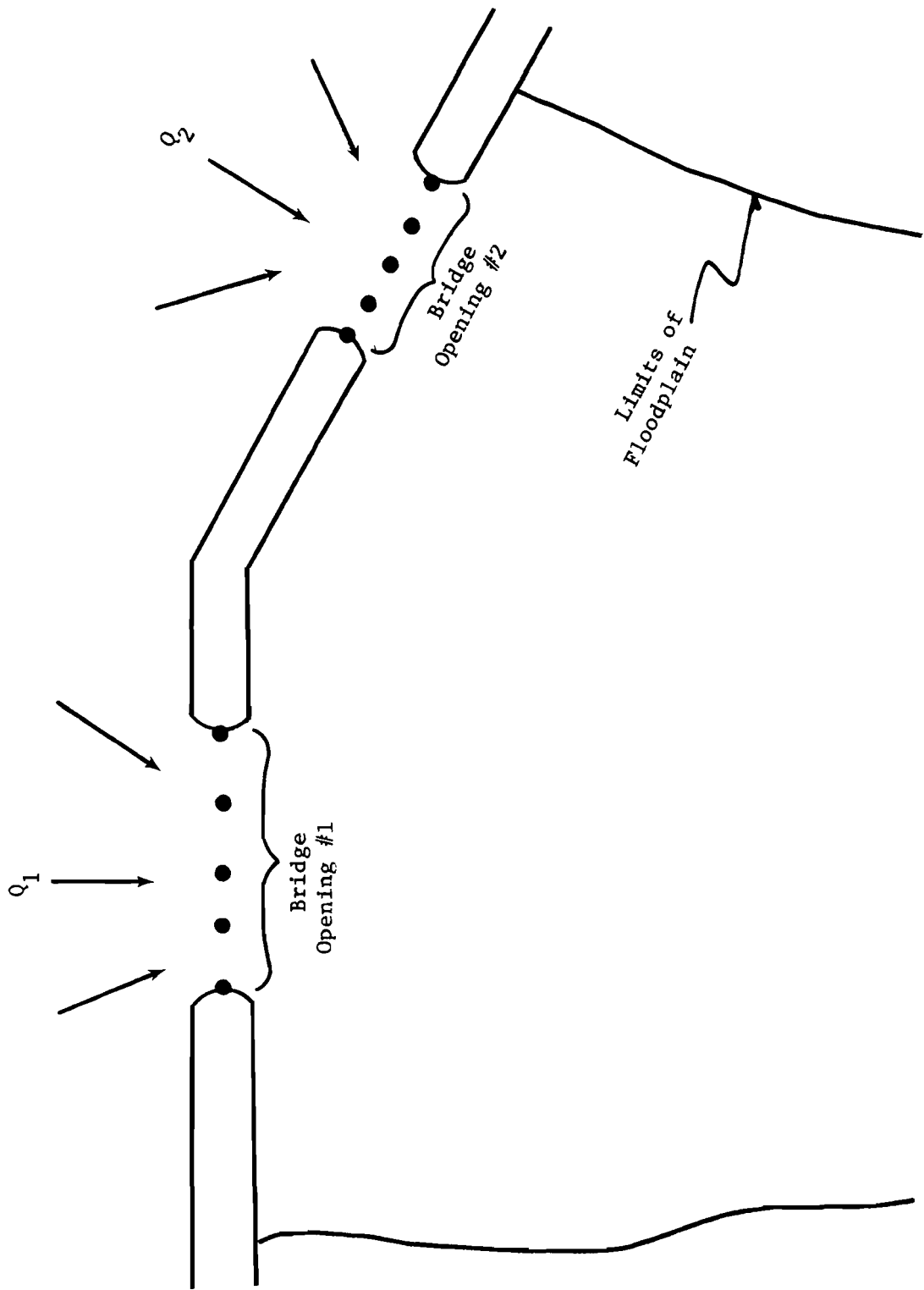


Figure 3.9. Upstream Nodes for Multiple Inlets to Floodplain

inlets to the floodplain and are considered as the upstream boundary locations.

- a. The upstream boundary nodes must be chosen to accurately describe the topographic nature of the upstream boundary. This involves using enough nodes and properly spacing them to define the ground surface. The steeper the ground, the closer the nodes should be spaced.
 - b. The input for each upstream boundary inlet includes: the flow rate for that inlet, the node numbers for that inlet, and an estimate of the water surface elevation.
4. The specified flow rate is used in FESWMS-TX to determine the x and y coordinate unit flow rates. A uniform velocity distribution for a given water surface elevation is assumed at each of the inlets. Therefore, the upstream boundaries should be far enough away (hydraulically) from any particular points of interest (such as a new bridge design that is downstream), so that the assumption of a uniform velocity distribution at the upstream boundary has negligible effect upon the results. The effect will be very minor (negligible) in most instances.
 5. If the uniform velocity distribution assumption for the upstream boundary condition is not negligible or the user wants to be sure it has negligible effect, then the user can put in additional elements and nodes as shown in Fig. 3.10 to move the upstream boundary condition farther upstream. The pattern of elements shown in Fig. 3.10 is only one of several patterns that could be used.
 6. Locate the upstream boundary where it can reasonably well explain the hydraulics. If possible, upstream control locations, such as highway embankments or railroad embankments with bridge openings, levees or dikes

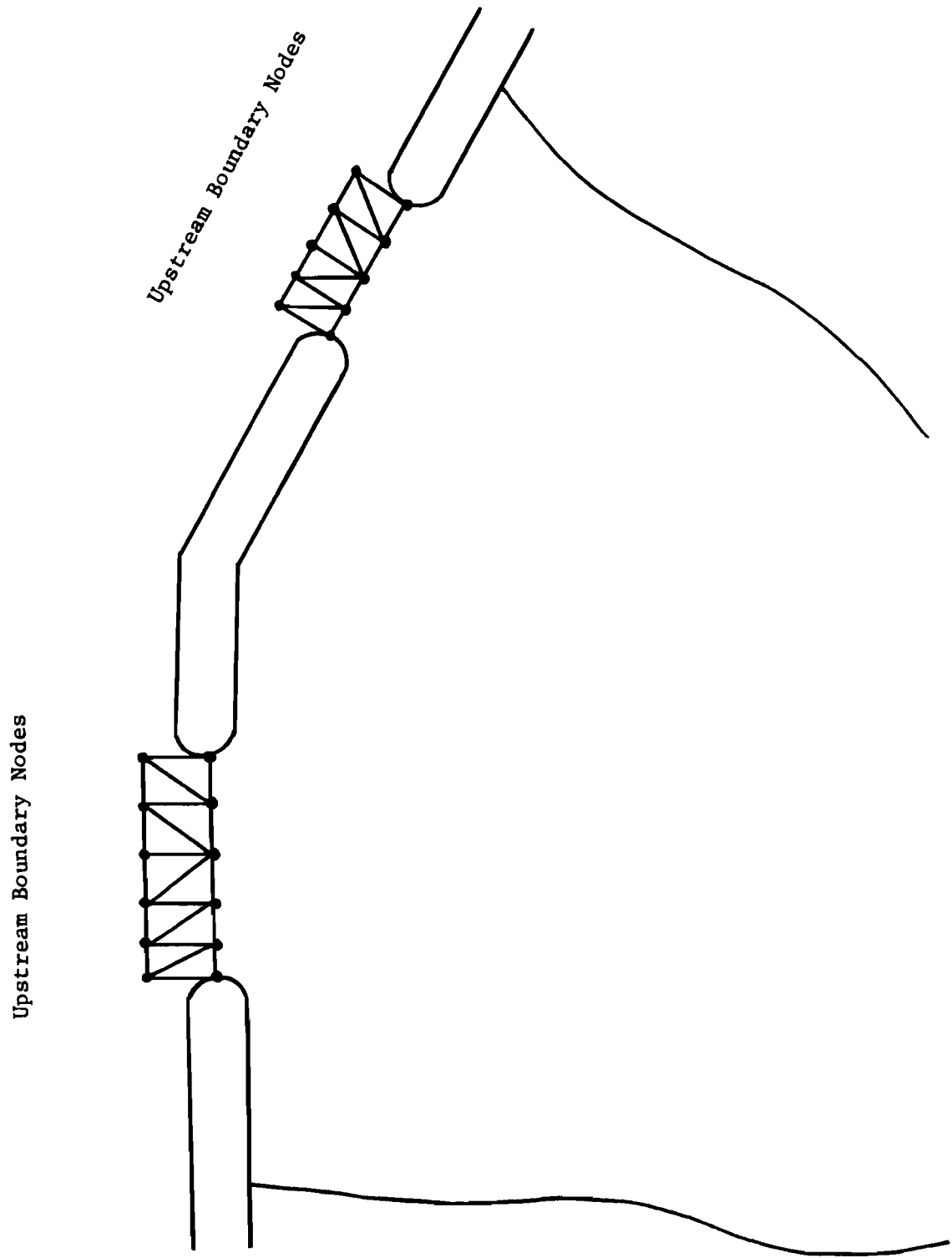


Figure 3.10 Upstream Boundary Nodes for Multiple Inlet to Floodplain

with openings, are excellent for locating upstream boundaries. As an example, Lee, et al. (1980), in the Pearl River application, shown in Fig. 3.11, used Highway I-59 and Highway 11 as the upstream boundary of the finite element network. The hydraulic conditions could be reasonably well specified at these locations.

7. If the upstream boundary is a wide floodplain and not specified bridge openings, then the flow distribution may become a more significant factor in the resultant flow patterns appearing in the final network. Flow behavior in areas of shallow depth in the vicinity of boundaries with specified flow rates is particularly sensitive to the velocity distribution assumed at the boundary.
 - a. The flow patterns observed in these areas may be altered by a change in flow distribution even though the total flow into the system remains the same.
 - b. The user should be aware of this fact and make every effort to specify the upstream boundary condition which leads to the most realistic streamflow velocities.
 - c. As stated above, the upstream boundary should be located such that the estimate of the uniform flow rate distribution has minimal effect upon the primary study area.
 - d. The use of additional elements also requires additional computer storage.

The downstream boundary condition consists of specified water surface elevations at the outlet points at the downstream end of the floodplain.

1. The water surface elevations for the nodes specified at the outlets of the floodplain area are the downstream boundary condition.

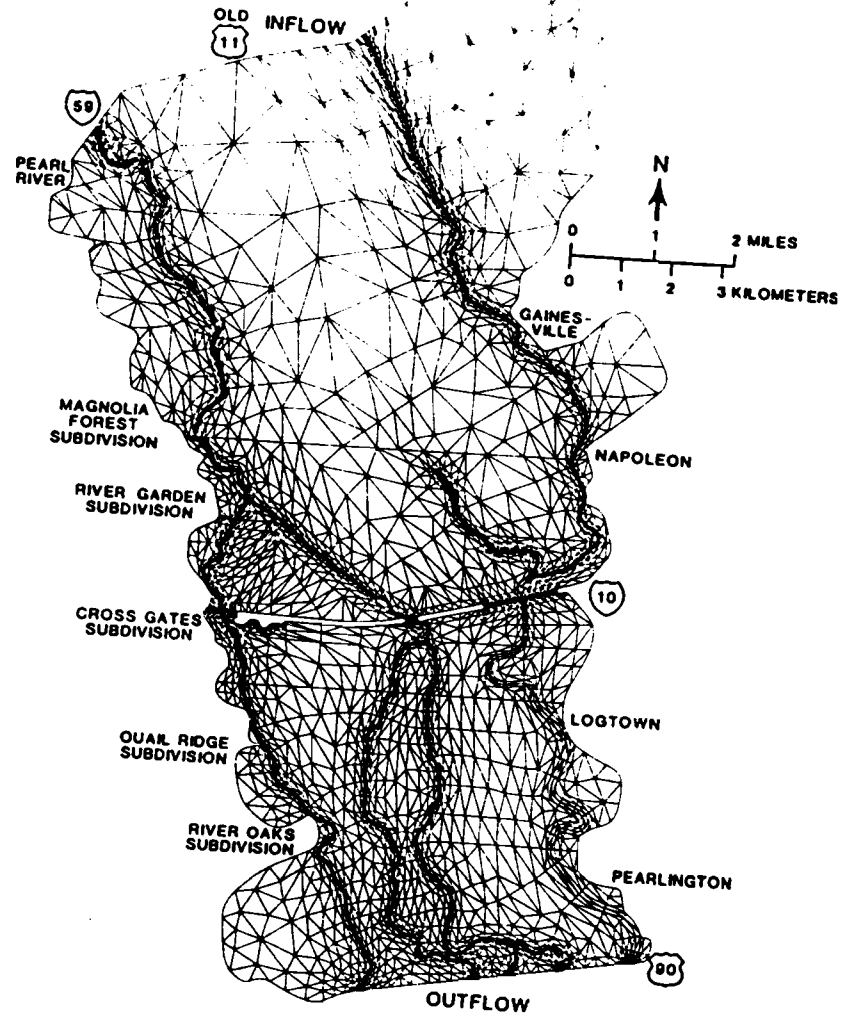
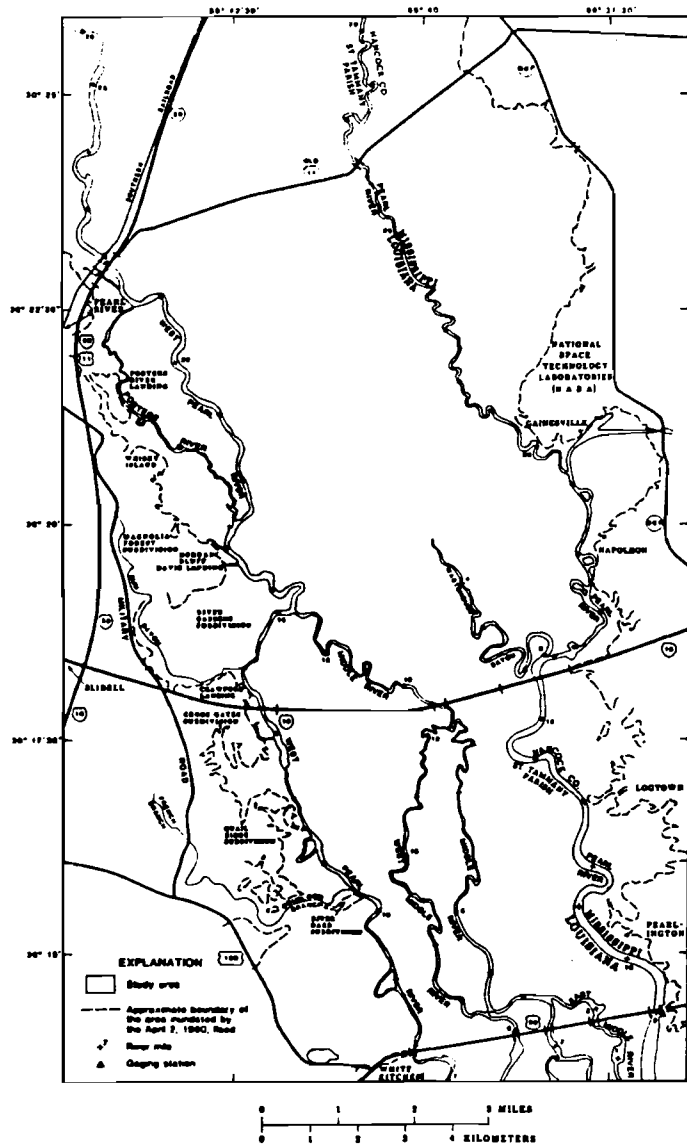


Figure 3.11. Pearl River Example
(Lee, et al., 1972)

2. The water surface elevations are either high water marks or are water surface elevations determined by a backwater analysis downstream of the floodplain area. These water surface elevations are for the discharge specified on the upstream boundary condition for subcritical flow or the downstream boundary condition for supercritical flow.
3. For the consideration of new bridges or the modification of existing bridges in a floodplain, the downstream boundary should not be placed at the location of the new bridges, but should be placed downstream at some control point, if feasible. As an example refer to Fig. 3.12. The Pearl River application shown in Fig. 3.11 used Highway 90 as the downstream boundary.
4. Water surface elevations at the downstream boundary should be based on high-water marks if available.

The parallel flow boundary condition specifies that flow is to move parallel to a fixed boundary. This condition is valuable in reducing the required level of element detail when the lateral boundaries of the floodplains are either straight-sided or are curved boundaries. In each of these cases the flow would be parallel (or tangential) to the boundaries.

1. The parallel flow boundary condition should be specified for all lateral curved boundaries and straight-sided boundaries. All lateral boundaries should be specified in the input as straight sided or curved boundaries.
2. When specifying the parallel flow option it is necessary to insure that the fixed boundary along which the flow is allowed to move is continuous in slope.

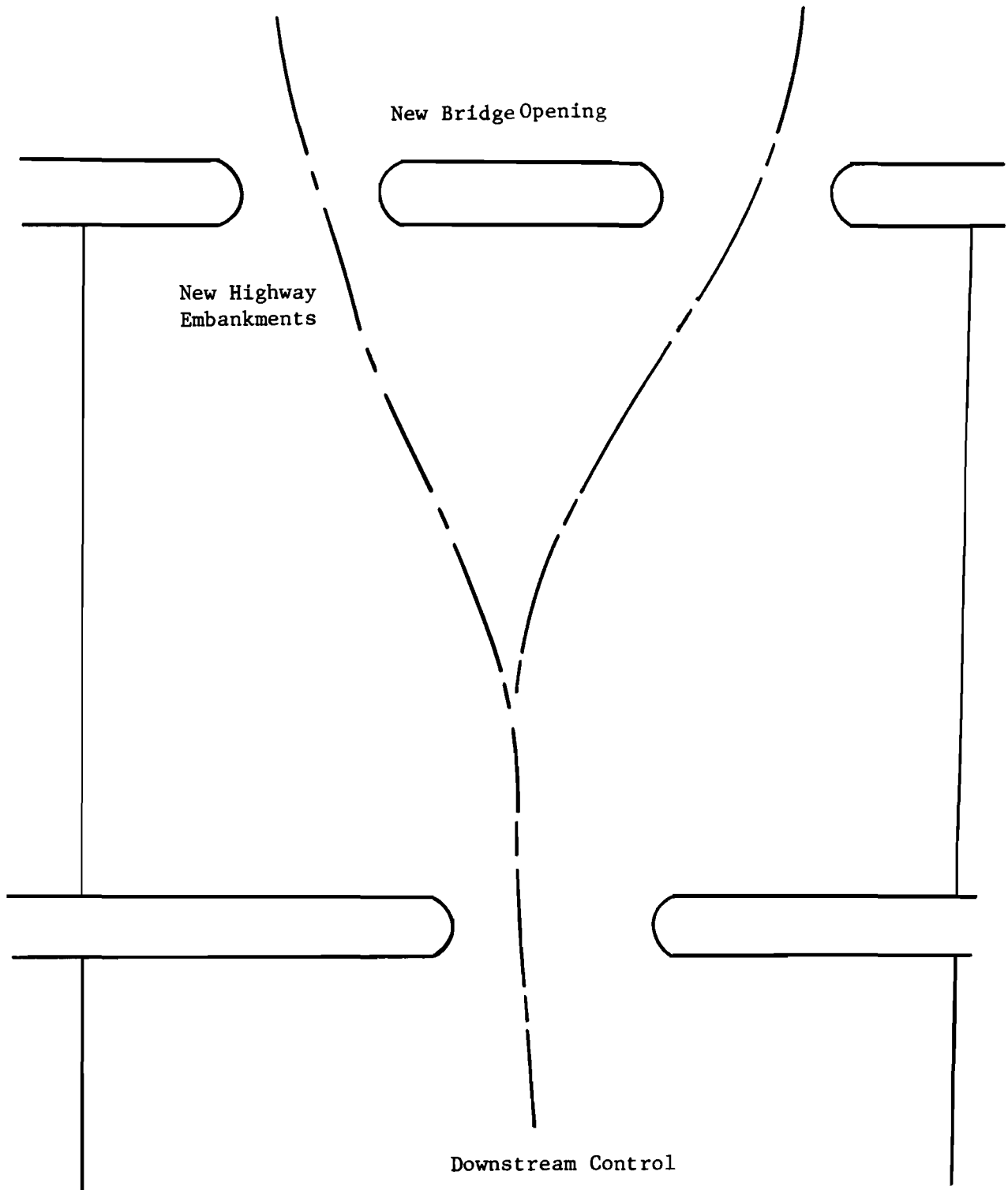


Figure 3.12. Multiple Bridge Openings with Downstream Control.

2. When specifying the parallel flow option it is necessary to insure that the fixed boundary along which the flow is allowed to move is continuous in slope.

CHAPTER 4
FESWMS-TX USER'S MANUAL FOR MANUAL PROCEDURE

4.1 RMA-1 Input

The data forms for the RMA-1 input are shown in Figs. 4.1(a) and (b). Notice that the different data are placed on Card types A through H which are summarized below:

<u>Card</u>	<u>Name</u>	<u>Number of Cards</u>
A	Title card	1
B	Parameter cards	3
C	Corner node slope cards	One for each corner node on a curved element side
D	Mid-side node cards	One for each mid node
E	Element cards	One for each element in network
F	Coordinate cards	One for each corner node in network
G	Straight line segment cards	One for each straight line segment in network
H	Network renumbering cards	Up to 10 cards plus 1 blank card for each list.

A- Title Card

The title card is simply a card used to describe the project being modeled.

B- Parameter Cards

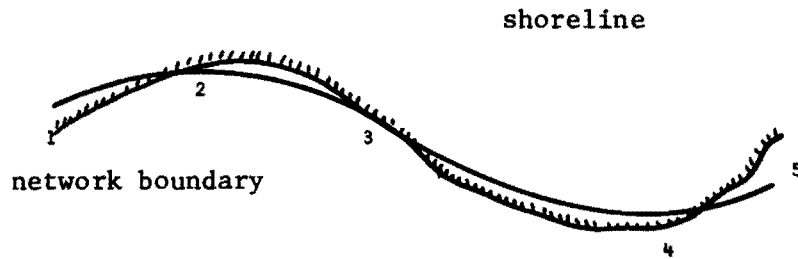
The parameter cards define or specify the parameters for running the program.

C- Corner Node Slope Cards

These cards are used to specify the tangential slopes (Fig. 4.2) of the curved lateral boundaries at the corner node locations. Eight of the corner nodes and their respective corner node slopes can be placed on each card. Specification of curved

FESWMS - TX RMA-1 INPUT																		
1	2		3		4		5		6		7		8		9		10	
ELEMENT CARDS																		
ELEMENT NUMBER	CORNER NODE NUMBER	MIDNODE NUMBER	CORNER NODE NUMBER	MIDNODE NUMBER	CORNER NODE NUMBER	MIDNODE NUMBER							ELEMENT TYPE #					
9999																		
COORDINATE CARDS																		
NODE	X-COORDINATE				Y-COORDINATE				GROUND ELEVATION									
9999																		
STRAIGHT LINE SEGMENT CARDS																		
END CORNER NODE	OTHER END CORNER NODE	LIST OF CORNER NODE NUMBERS BETWEEN THE END CORNER NODES																
9999																		
NETWORK RENUMBERING CARDS - LIST NODE NUMBERS TO REORDER ELEMENT NUMBERING																		
Each list followed by a blank card--a maximum of 160 nodes in each list.																		
9999																		

Figure 4.1b



Specify coordinates (F-cards) and slopes (C-cards) at corner nodes 1, 3 and 5 (these will exist in two elements).

Specify mid-side nodes (D-cards) 2 and 4 for coordinate calculation.

RMA-1 will place nodes 2 and 4 to define the network as shown with a smooth, continuous curve joining the two elements.

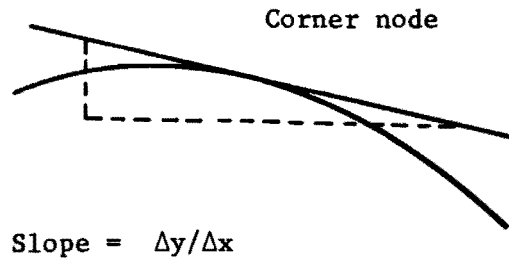


Figure 4.2. Definition of Curved Boundaries.

lateral boundaries requires: a) specification of the corner node slopes on the C-cards; b) specification of the mid-side nodes on the curved element sides on the D-cards; and specification of the corner node coordinates on the F-cards. Figure 4.2 further explains the definition of curved boundaries and calculation of the corner node slopes.

D- Mid-side Node Cards

These D-cards list the mid-side node numbers of the node that are on curved elements on the lateral boundaries.

E- Element Cards

The E-cards are used to define each element by the corner nodes and the mid-side nodes that define each element. Also these cards list the element type number that refers to a specific Manning's roughness factor defined as part of the RMA-2 input. A card exists for each element on which is first placed the element number, then one of the three corner nodes (for triangular elements), then the adjacent mid-node going counterclockwise around the element, then the adjacent corner node going counterclockwise, etc. The element type number is also placed on the element card.

F- Coordinate Cards

The F-card defines the x and y coordinates and the ground surface elevation (z coordinate) for each corner node in the network.

G- Straight Line Segment Cards

These cards are used to define a straight line segment defined by a maximum of 16 corner nodes. The straight line segments are most useful in defining lateral boundaries that can be defined by corner nodes located in a straight line in the finite element network. All lateral flow boundaries should be defined by curved boundaries or by straight line segments.

H- Network Renumbering Cards

An optional routine is built into RMA-1 which tests several numbering schemes. The input on the H-cards consists of lists of node numbers for the program to use to reorder the sequence of elements for the most efficient operation of the program. Each starting location is represented by a new list of node numbers. As a general rule at least two starting locations (one at the upstream of the network, and one at the downstream of the network) should be used. A maximum of 160 nodes for each list can be specified.

Sample Input

A sample of the RMA-1 input is provided in Fig. 4.3.

4.2 RMA-2 INPUT

The data form for the RMA-2 input is shown in Fig. 4.4(a) and (b). Notice that the different data are placed on card types AA through FF, which are summarized below:

<u>Card</u>	<u>Name</u>	<u>Number of Cards</u>
AA	Title card	1
BB	Parameter cards	3
CC	Roughness cards	One for each element type (i.e., Manning's roughness)
DD	Continuity check cards	One for each continuity check line
EE	Boundary condition cards	One for each node having a downstream boundary condition or parallel flow boundary condition
FF	Upstream inflow cards	One card defining number of upstream sections One card defining flow rate in each upstream section

SHOAL CREEK, UPPER PART										30 JUN 83		
2815000	249500	2818000	254500	0.01	0.01	-90.						
2815000	254500											
1	8	4										
554.679	772.924	992.924	121 2.0	143 2.1	165 1.50	111 1.91	133 5.0					
66	110	154	122									
1	1	12	23	24	25	13	1					
2	1	13	25	14	3	2	1					
3	3	14	25	26	27	15	1					
4	3	15	27	16	5	4	1					
5	5	16	27	28	29	17	1					
6	5	17	29	18	7	6	1					
7	7	18	29	30	31	19	1					
8	7	19	31	20	9	8	1					
9	9	20	31	32	33	21	1					
10	9	21	33	22	11	10	1					
11	23	34	45	46	47	35	1					
12	23	35	47	36	25	24	1					
13	25	36	47	48	49	37	1					
14	25	37	49	38	27	26	1					
15	27	38	49	50	51	39	1					
16	27	39	51	40	29	28	1					
17	29	40	51	52	53	41	1					
18	29	41	53	42	31	30	1					
19	31	42	53	54	55	43	1					
20	31	43	55	44	33	32	1					
21	45	56	67	68	69	57	1					
22	45	57	69	58	47	46	1					
23	47	58	69	70	71	59	1					
24	47	59	71	60	49	48	1					
25	49	60	71	72	73	61	1					
26	49	61	73	62	51	50	1					
27	51	62	73	74	75	63	1					
28	51	63	75	64	53	52	1					
29	53	64	75	76	77	65	1					
30	53	65	77	66	55	54	1					
31	67	78	89	90	91	79	1					
32	67	79	91	80	69	68	1					
33	69	80	91	92	93	81	1					
34	69	81	93	82	71	70	1					
35	71	82	93	94	95	83	1					
36	71	83	95	84	73	72	1					
37	73	84	95	96	97	85	1					
38	73	85	97	86	75	74	1					
39	75	86	97	98	99	87	1					
40	75	87	99	88	77	76	1					
41	89	100	111	112	113	101	1					
42	89	101	113	102	91	90	1					
43	91	102	113	114	115	103	1					
44	91	103	115	104	93	92	1					
45	93	104	115	116	117	105	1					
46	93	105	117	106	95	94	1					
47	95	106	117	118	119	107	1					
48	95	107	119	108	97	96	1					
49	97	108	119	120	121	109	1					
50	97	109	121	110	99	98	1					
51	111	122	133	134	135	123	1					
52	111	123	135	124	113	112	1					
53	113	124	135	136	137	125	1					
54	113	125	137	126	115	114	1					

(continued)

Figure 4.3. Example RMA-1 Input.

55	115	126	137	138	139	127	1
56	115	127	139	128	117	116	1
57	117	128	139	140	141	129	1
58	117	129	141	130	119	118	1
59	119	130	141	142	143	131	1
60	119	131	143	132	121	120	1
61	133	144	155	156	157	145	1
62	133	145	157	146	135	134	1
63	135	146	157	158	159	147	1
64	135	147	159	148	137	136	1
65	137	148	159	160	161	149	1
66	137	149	161	150	139	138	1
67	139	150	161	162	163	151	1
68	139	151	163	152	141	140	1
69	141	152	163	164	165	153	1
70	141	153	165	154	143	142	1
9999							
1	2815645.	254068.	652.				
3	2815667.	254060.	648.				
5	2815686.	254058.	645.				
7	2815700.	254052.	646.				
9	2815722.	254048.	650.				
11	2815765.	254035.	654.				
23	2815535.	253793.	650.				
25	2815566.	253785.	646.				
27	2815590.	253779.	642.				
29	2815616.	253772.	644.				
31	2815642.	253764.	650.				
33	2815675.	253758.	654.				
45	2815446.	253575.	650.				
47	2815495.	253557.	646.				
49	2815530.	253544.	642.				
51	2815555.	253534.	644.				
53	2815605.	253515.	650.				
55	2815622.	253510.	654.				
67	2815352.	253335.	650.				
69	2815385.	253320.	646.				
71	2815425.	253300.	644.				
73	2815480.	253275.	642.				
75	2815520.	253254.	650.				
77	2815541.	253243.	654.				
89	2815260.	253105.	646.				
91	2815313.	253081.	642.				
93	2815355.	253059.	640.				
95	2815395.	253040.	644.				
97	2815424.	253028.	650.				
99	2815462.	253012.	654.				
111	2815150.	252895.	646.				
113	2815185.	252877.	644.				
115	2815240.	252851.	640.				
117	2815267.	252840.	640.				
119	2815300.	252825.	644.				
121	2815360.	252796.	652.				
133	2815075.	252650.	646.				
135	2815105.	252638.	640.				
137	2815140.	252624.	635.				
139	2815165.	252610.	640.				
141	2815200.	252595.	644.				
143	2815254.	252573.	646.				
155	2815020.	252375.	650.				
157	2815042.	252375.	646.				

(continued)

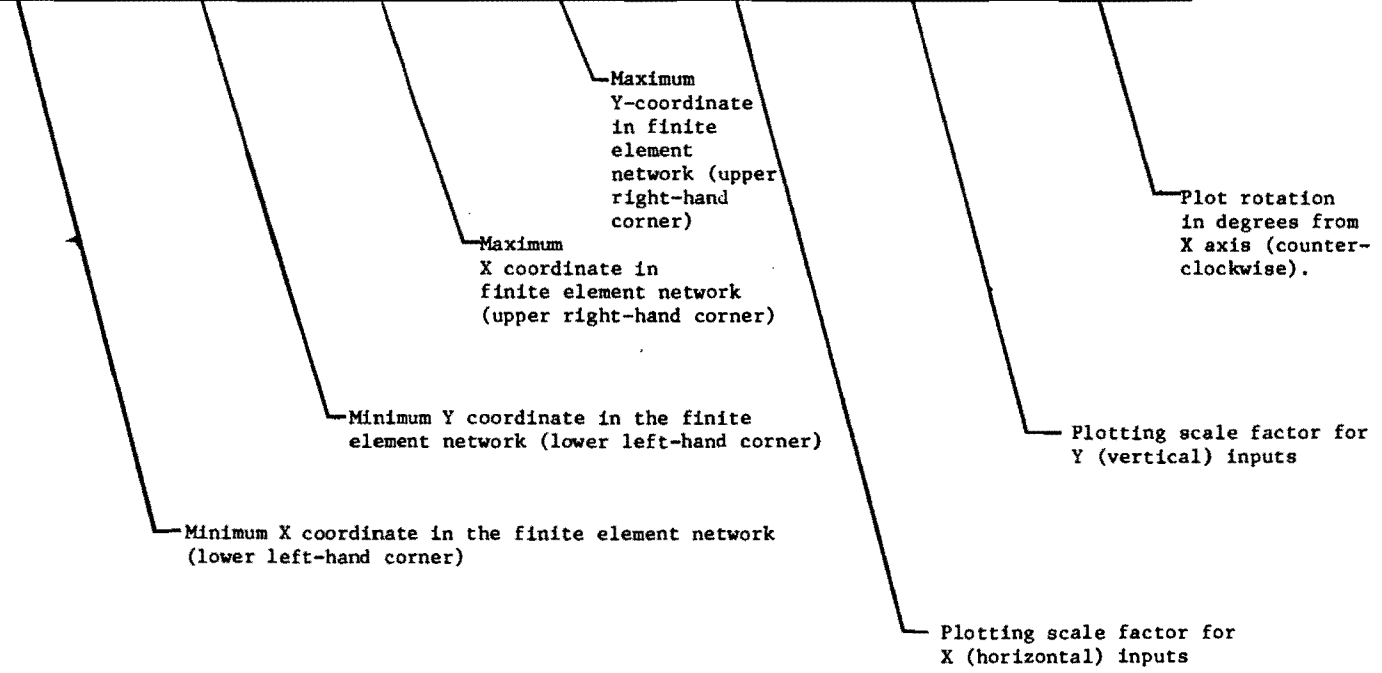
Figure 4.3. (Continued)

159	2815060.	252375.	640.
161	2815080.	252375.	634.
163	2815102.	252375.	640.
165	2815142.	252375.	643.
9999			
1	11	3	5 7 9
9999			
155	156	157	158 159 160 161 162 163 164 165
9999			

Figure 4.3. (Continued)

B-1 Parameter Card

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80



(All entries are right justified)

B-2 Parameter Card (Origin)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

--	--

Y coordinate for origin

X coordinate for origin

B-3 Parameter Cards

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

— Enter the total number of mid-side nodes.

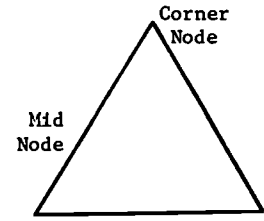
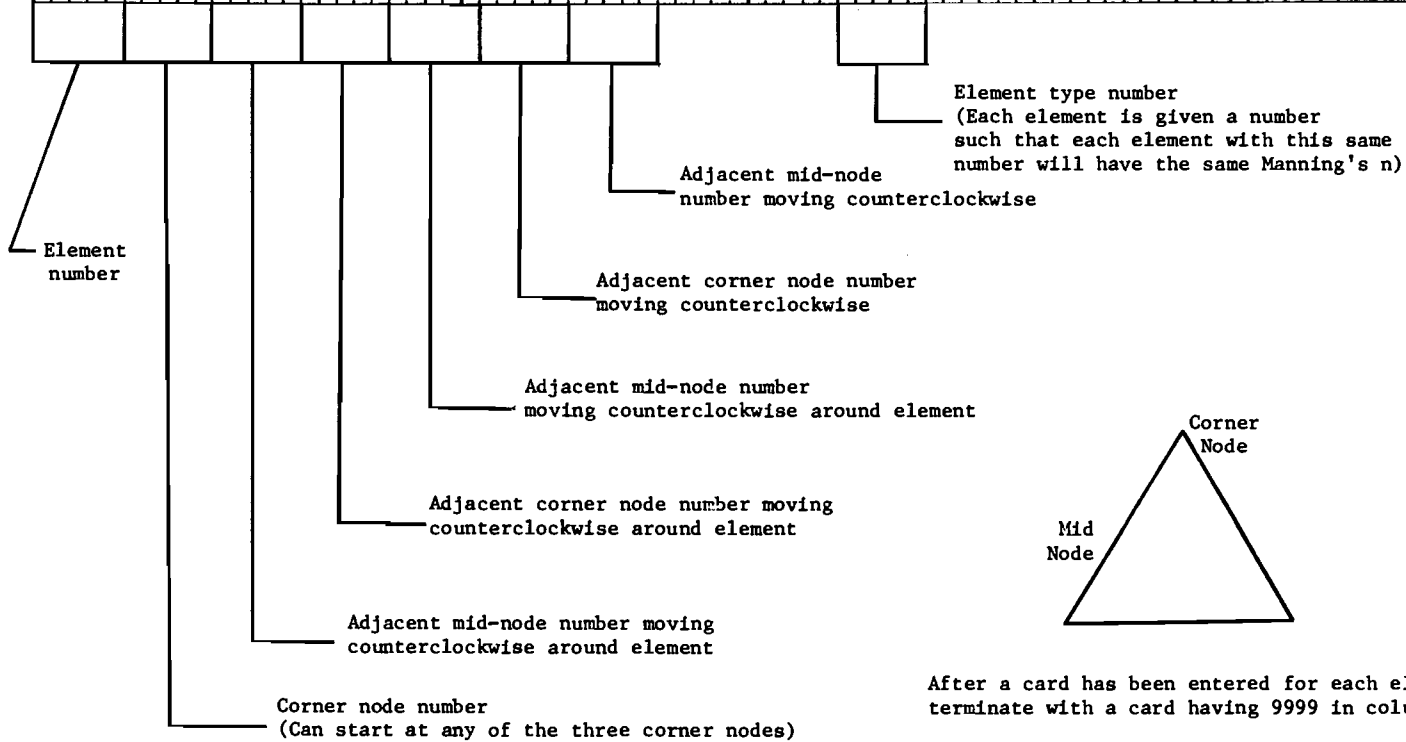
— Enter the number of corner nodes in which the corner node slope will be specified.

— Enter the number of network line segments for which the program will internally calculate exact coordinates to insure a straight line of equal slope. An entry here will require additional input on the G-Card.

(All entries are right justified.)

E-Cards Element Cards

1	2	3	4	5	6	7	8	9	0	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
---	---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

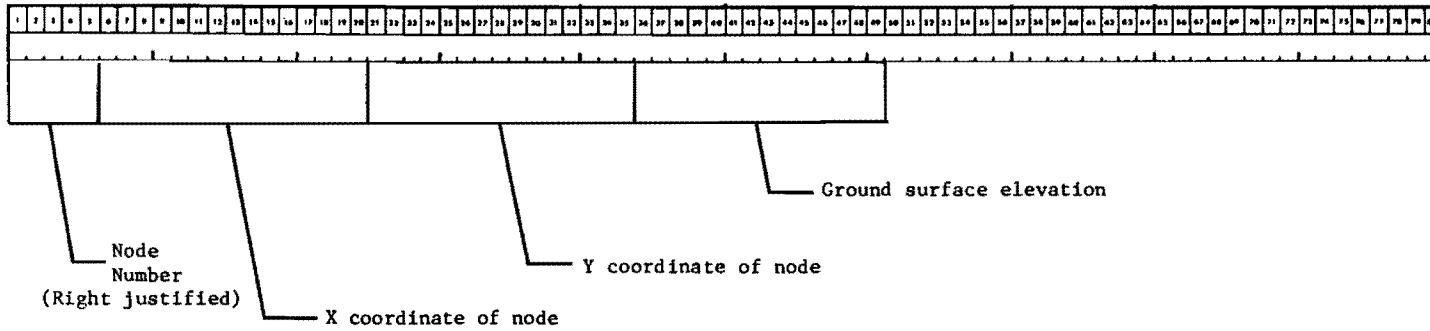


After a card has been entered for each element, terminate with a card having 9999 in columns 2-5.

(All entries on E-cards are right justified.)

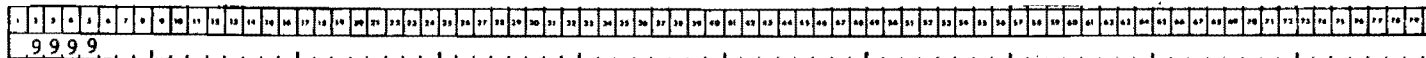
1	2	3	4	5	6	7	8	9	0	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80						
9		9		9																																																																																	

F-Cards Coordinate Cards

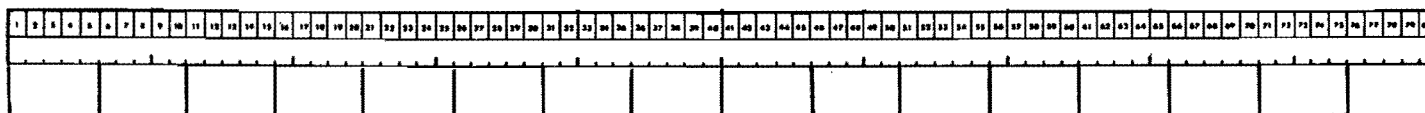


98

After a card has been entered for each corner node, terminate with a card having 9999 in columns 2-5.



G-Cards Straight-Line Segment Cards



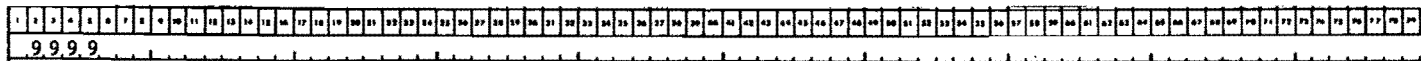
Corner nodes between the two end corner nodes for which the Y coordinates are interpolated using the input values of the X coordinates (up to 14 corner nodes can be entered).

Corner nodes at other end of straight-line segment

Corner node at one end of straight-line segment

(All entries on G-cards are right justified.)

After a card has been entered for each straight line segment, terminate with a card having 9999 in columns 2-5.



FESWMS - TX RMA-2 INPUT										
	1	2	3	4	5	6	7	8	9	10
AA	TITLE CARD									
	PARAMETER CARDS									
BB-1										
BB-2										
BB-3										
CC	ROUGHNESS CARDS ELEMENT TYPE #	TURBULENT EX- CHANGE COEF.	TURBULENT EX- CHANGE COEF.	TURBULENT EX- CHANGE COEF.	TURBULENT EX- CHANGE COEF.	MANNING'S N				
	CONTINUITY CHECK CARDS									
DD	LIST OF CORNER NODES (IN ORDER ACROSS NETWORK) THAT TOTAL FLOW IS TO BE COMPUTED									

Figure 4.4(a)

FESWMS - TX RMA-2 INPUT																																																																																																			
1										2										3										4										5										6										7										8										9										10									
BOUNDARY CONDITION CARDS																																																																																																			
NODE NUMBER OF BOUNDARY CONDITION											ENTER 1 PARALLEL FLOW CONDITION										ENTER 2 IF DOWNSTREAM BOUNDARY CONDITION										ENTER WATER SURFACE ELEV. IF DOWNSTREAM CONDITION																																																																				
EE																																																																																																			
UPSTREAM INFLOW CARDS																																																																																																			
FF																																																																																																			
INFLOW PARAMETERS FOR UPSTREAM SECTION																																																																																																			
FF-1																																																																																																			
FF-2	TOTAL NUMBER OF CORNER NODES AT UP-STREAM SECTION	NUMBER OF CORNER NODES	DISCHARGE AT THIS SECTION IN FT ³ /SEC	AVERAGE WATER SURFACE ELEVATION AT SECTION																																																																																															
LIST OF UPSTREAM BOUNDARY NODES FOR UPSTREAM SECTION (Both Corner and Midnodes are listed)																																																																																																			
FF-3	1 st NODE	2 nd NODE	3 rd NODE	4 th NODE	5 th NODE	6 th NODE	7 th NODE	8 th NODE	9 th NODE	NODE 10	NODE 11	NODE 12	NODE 13	NODE 14	NODE 15	NODE 16																																																																																			
THE FF-2 AND FF-3 CARDS ARE GIVEN FOR EACH UPSTREAM SECTION																																																																																																			

Figure 4.4(b)

At least one card for each
upstream section giving node
numbers

AA-1 Title Card

The title card is simply a card used to describe the project you are modeling.

BB- Parameter Cards

The parameter cards specify the running control information.

CC- Roughness Cards

The roughness cards are used to assign a Manning's roughness factor to each element type number inputted for the RMA-1. Also the user can assign turbulent exchange coefficients for the element types. A brief list of possible values is given in Table 4.1. The turbulent exchange coefficients are optional, and a default value of 100 lb-sec/ft^2 is used by the program if left blank. A list of Manning's roughness factors is provided in Table 4.2.

DD- Continuity Check Cards

These cards are used to identify continuity check lines along which the total discharge is computed for the purpose of continuity checks. A list of corner nodes is given for each line segment. A maximum of 20 nodes can be entered for each continuity check line and cannot contain curved element sides.

EE- Boundary Condition Cards

These cards are used to define the downstream boundary condition and the parallel flow conditions. To specify a downstream boundary condition, the following is required:

Table 4.1 Turbulent Exchange Coefficients

(a) Turbulent Exchange Coefficients (Tseng, 1975)
 (Eddy Viscosity)
 (lb-sec/ft²)

Type of Simulation	Gradually Varied Zone		Flow Contracting Zone		Flow Expansion Zone	
	x direction	y direction	x	x	x	y
Field Site (Tallahalla Creek at Rt. 528, Miss.)	500*	250*	50	50	300	250
	750**	750**				

(b) Turbulent Exchange Coefficients (Norton, 1980)

Type of Simulation Problem	Values of Turbulent Exchange Coefficients (Eddy Viscosity) lb-sec/ft ²
	x direction and y direction
Homogeneous Horizontal Flow Around an Island--Turbulent Range	10 - 100
Homogeneous Horizontal Flow at a Confluence--Turbulent Range	25 - 100
Dynamic Flow in Upper San Francisco Bay	250 - 1000
Steady-State Flow for Thermal Discharge to a Slow Moving River	100 - 1000

Table 4.2. MANNING'S ROUGHNESS COEFFICIENTS (Texas SDHPT, 1970)

NATURAL STREAM CHANNELS	Min.	Max.
I. Minor Streams		
A. Fairly regular section		
1. Some grass and weeds; little or no brush	.030	0.035
2. Dense growth of weeds, depth of flow materially greater than weed height	.035	0.050
3. Some weeds, light brush on banks	.035	0.050
4. Some weeds, heavy brush on banks	.050	0.070
5. Some weeds, dense willows on banks	.060	0.080
6. For trees within channels with branches submerged at high stage, increase all values above by	.010	0.020
B. Irregular section with pools, slight channel meander, use 1A to 5A above, and increase all values by	.010	0.020
C. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage		
1. Bottom; gravel, cobbles and few boulders	.040	0.050
2. Bottom; cobbles with large boulders	.050	0.070
II. Flood Plain (adjacent to natural streams)		
A. Pasture, no brush		
1. Short grass	.030	0.035
2. Tall grass	.035	0.050
B. Cultivated areas		
1. No crop	.030	0.040
2. Mature row crops	.035	0.045
3. Mature field crops	.040	0.050
C. Heavy weeds, scattered brush	.050	0.070
D. Wooded	.075	0.150
<p>This varies depending on undergrowth, height of foliage on trees, etc. The area of "n" = 0.10 and greater indicates an extremely heavily wooded condition. These instances of high "n" values (greater than "n" = 0.10) should be thoroughly investigated (photographs, consultation with experienced engineers, complete knowledge of area, etc.). The D-5 hydraulic section has several references available for "n" value determination.</p>		
III. Major Streams		
<p>Roughness coefficient is usually less than for minor streams of similar description on account of less effective resistance offered by irregular banks or vegetation on banks. Values of "n" for larger streams of mostly regular Sections, with no boulders or brush may be in the range of 0.028 to 0.033.</p>		
LINED CHANNELS		
1. Metal corrugated	.021	0.024
2. Neat cement lined	.012	0.018
3. Concrete	.012	0.018
4. Cement rubble	.017	0.030

TABLE 4.2. (Continued)

GRASS COVERED SMALL CHANNELS, SHALLOW DEPTH

1.	No rank growth .....	.035	0.045
2.	Rank growth .....	.040	0.050

UNLINED CHANNELS

1.	Earth, straight and uniform .....	.017	0.025
2.	Dredged .....	.025	0.033
3.	Winding and sluggish .....	.022	0.030
4.	Stony beds, weeds on bank .....	.025	0.040
5.	Earth bottom, rubble sides .....	.028	0.035
6.	Rock cuts, smooth and uniform .....	.025	0.035
7.	Rock cuts, rugged and irregular .....	.035	0.045

PIPE

1.	Cast iron, coated .....	.010	0.014
2.	Cast iron, uncoated .....	.011	0.015
3.	Wrought iron, galvanized .....	.013	0.017
4.	Wrought iron, black .....	.012	0.015
5.	Steel, riveted and spiral - smooth .....	.013	0.017
6.	Steel, corrugated (1/2") .....	.021	0.024
7.	Steel, corrugated (2" Structural Plate) .....	.034	0.038
8.	Concrete .....	.010	0.017
9.	Vitrified sewer pipe .....	.010	0.017
10.	Clay, common drainage tile .....	.011	0.017

- a) Node number
- b) 2 in column 18
- c) Water surface elevation at boundary for the flow rate specified in the FF Cards

To specify a parallel flow boundary condition (flow is to move parallel to the lateral boundary at the specified node), the following is required:

- a) Node number
- b) 1 in column 17

FF- Upstream Inflow Cards

These cards are used to define the flow into the floodplain at each of the upstream sections. The first card (FF-1) specifies the number of upstream section, followed by the FF-2 and the FF-3 card(s) for each upstream section. As an example the cards are arranged as:

- FF-1
- FF-2 For first upstream section
- FF-3 Nodes defining first upstream section

- FF-2 For second upstream section
- FF-3 Nodes defining second upstream section

Sample Input

A sample of the RMA-2 input is shown in Fig. 4.5.

4.3 RMA-1 Output

The output from RMA-1 consists of a computer plot of the finite element network and printed output. The computer plot shows the element and node numbering (Fig. 4.6). The printed output for RMA-1 is shown in Fig. 4.7.

```

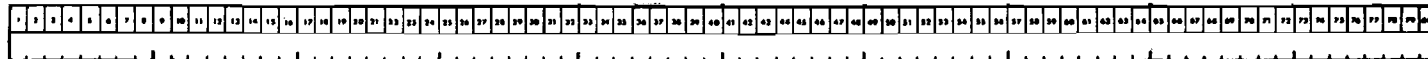
SHOAL CREEK, UPPER (FLOW = 157.0 CFS)      MANNING EQ.      30 JUN 1983
      1      11      8      4      3
      655.0      1.      1.5
      1      100      100      100
      1      3      5      7      9      11
      23      25      27      29      31      33
      45      47      49      51      53      55
      67      69      71      73      75      77
      89      91      93      95      97      99
      111      113      115      117      119      121
      133      135      137      139      141      143
      155      157      159      161      163      165
      155      12      657.0
      156      2      657.0
      157      2      657.0
      158      2      657.0
      159      2      657.0
      160      2      657.0
      161      2      657.0
      162      2      657.0
      163      2      657.0
      164      2      657.0
      165      2      657.0
      1      11      6      16750.0      657.0
      1      2      3      4      5      6      7      8      9      10      11

```

Figure 4.5. Example RMA-2 Input.

BB Parameter Cards

BB-1



Number of different element types, i.e., number of different Manning's n values.

Number of line segments for continuity checks up to 20 can be entered.

Control for output printing:
 = 0; node and element input data suppressed
 = 1; all input data printed
 = 2; print only the initial conditions for velocity and depth

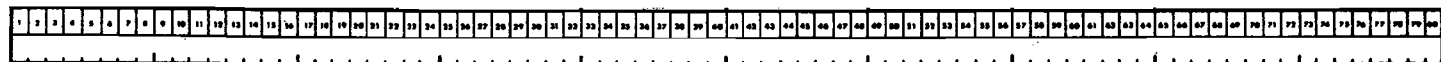
Number of nodes that will have downstream boundary conditions and parallel flow conditions

Logical unit for file containing geometric data created by program RMA-1. (Enter 0 if geometric data are from card input.)

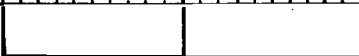
Logical unit for file upon which to write restart conditions (enter 0 if no file is to be written).

Logical unit for file containing initial conditions (enter 0 if initial conditions are not to be input).

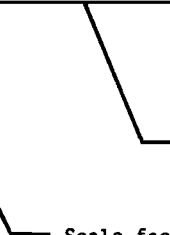
BB-2 Card



Maximum initial water
surface elevation (feet)
respective to datum



Scale factor for X coordinates



Scale factor for Y coordinates

BB-3 Card

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

--

Number of iterations for initial solution (right justified).

CC-Cards Roughness Cards

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

Element type number corresponding to that entered on the element cards (right justified).

Turbulent exchange coefficient to be used in all directions.

Manning's roughness factor.

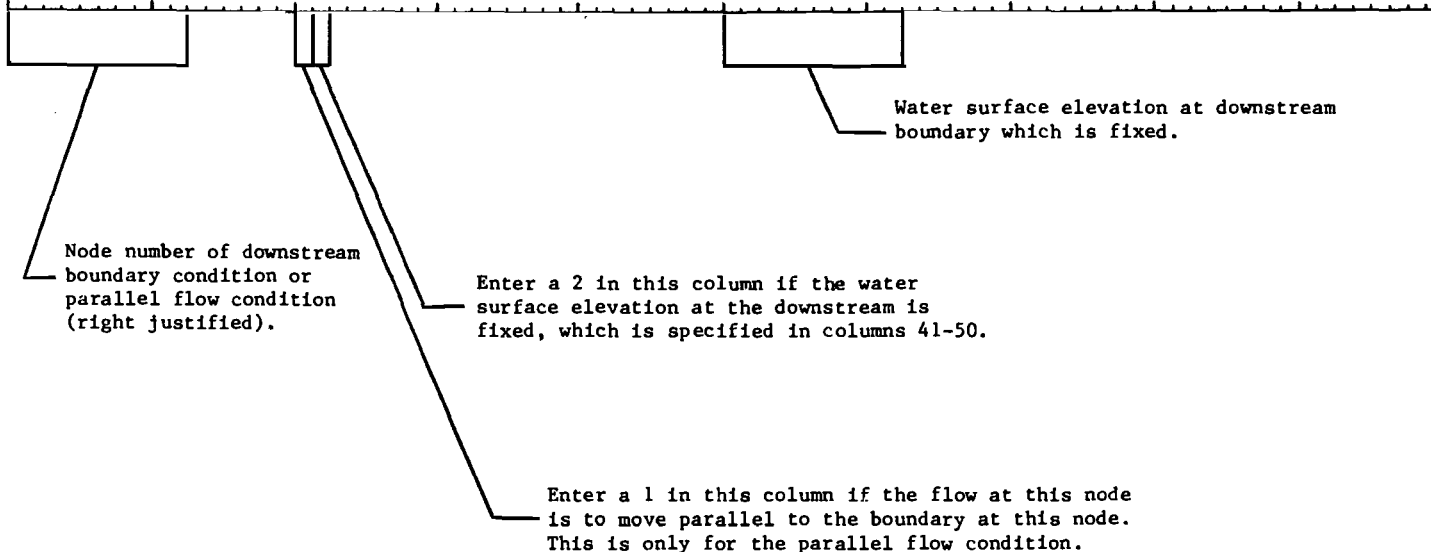
DD-Cards Continuity Check Cards

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

List of corner nodes which define line segments across which total flow is to be computed for continuity checking. This list should be entered in order across the network and should not contain any curved element sides. Up to 20 nodes can be entered. All node numbers are to be right justified (i.e. placing the numbers in the right most columns).

EE-Cards Boundary Condition Cards

1	2	3	4	5	6	7	8	9	0	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
---	---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----



FF-Cards Upstream Inflow Cards

FF-1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

Number of upstream inflow sections.

FF-Cards Upstream Inflow Cards

FF-2 Inflow Parameters for Upstream Section

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----



Upstream average water surface elevation (ft)

Discharge at upstream boundary (cfs)

Number of corner nodes on upstream boundary (right justified)

Total number of nodes--corner and mid-nodes on upstream boundary (right justified)

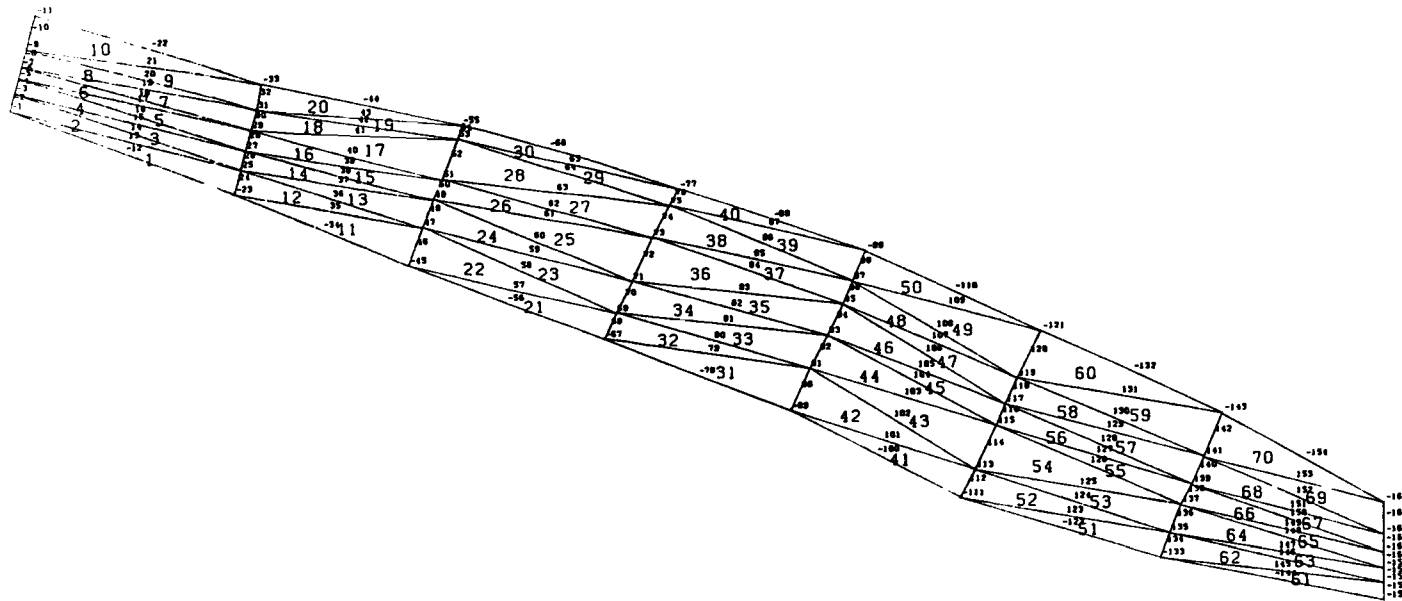


Figure 4.6. RMA-1 Plot Output of Finite Element Network

1

SHOAL CREEK, UPPER PART

30 JUN 83

```

INPUT SLOPES  1
PRINT DATA   1
PLOT NODES    1
PLOT ELTS     1
PLOT NETWORK  2
REORDER ELTS  1
PARTIAL PLOTS 1
NETWORK REFINE 0
GEOM INPUT    0
GEOM OUTPUT   3
INPUT CHECK   0
NUM ST LINES  0
MAX BAND WIDTH 200

```

```

HORIZ SIZE    0.000
VERT SIZE     0.000
X SCALE       .010
Y SCALE       .010
ROTATION      -90.000
X CORD SCALE  0.000
Y CORD SCALE  0.000

```

```

X COORDINATE OF POINT THAT WILL BE LOWER LEFT-HAND CORNER OF PLOT 1 AFTER ROTATION = 281500.
Y COORDINATE OF POINT THAT WILL BE LOWER LEFT-HAND CORNER OF PLOT 1 AFTER ROTATION = 254500.

```

**** INPUT SLOPE SPECS ****

```

1      55      4.679
2      77      2.924
3      99      2.924
4     121      2.000
5     143      2.100
6     165      1.500
7     111      1.910
8     133      5.000

```

*** MID SIDE NODES ***

```

1      66
2     110
3     154
4     122

```

1

SHOAL CREEK, UPPER PART

30 JUN 83

```

ORDER  NUMBER  NODES
1      1      1 12 23 24 25 13 -0 -0 1
2      2      1 13 25 14 3 2 -0 -0 1
3      3      3 14 25 26 27 15 -0 -0 1
4      4      3 15 27 16 5 4 -0 -0 1
5      5      5 16 27 28 29 17 -0 -0 1

```

(continued)

Figure 4.7. RMA-1 Printed Output

6	6	5	17	29	18	7	6	-0	-0	1
7	7	7	18	29	30	31	19	-0	-0	1
8	8	7	19	31	20	9	8	-0	-0	1
9	9	9	20	31	32	33	21	-0	-0	1
10	10	9	21	33	22	11	10	-0	-0	1
11	11	23	34	45	46	47	35	-0	-0	1
12	12	23	35	47	36	25	24	-0	-0	1
13	13	25	36	47	48	49	37	-0	-0	1
14	14	25	37	49	38	27	26	-0	-0	1
15	15	27	38	49	50	51	39	-0	-0	1
16	16	27	39	51	40	29	28	-0	-0	1
17	17	29	40	51	52	53	41	-0	-0	1
18	18	29	41	53	42	31	30	-0	-0	1
19	19	31	42	53	54	55	43	-0	-0	1
20	20	31	43	55	44	33	32	-0	-0	1
21	21	45	56	67	68	69	57	-0	-0	1
22	22	45	57	69	58	47	46	-0	-0	1
23	23	47	58	69	70	71	59	-0	-0	1
24	24	47	59	71	60	49	48	-0	-0	1
25	25	49	60	71	72	73	61	-0	-0	1
26	26	49	61	73	62	51	50	-0	-0	1
27	27	51	62	73	74	75	63	-0	-0	1
28	28	51	63	75	64	53	52	-0	-0	1
29	29	53	64	75	76	77	65	-0	-0	1
30	30	53	65	77	66	55	54	-0	-0	1
31	31	67	78	89	90	91	79	-0	-0	1
32	32	67	79	91	80	69	68	-0	-0	1
33	33	69	80	91	92	93	81	-0	-0	1
34	34	69	81	93	82	71	70	-0	-0	1
35	35	71	82	93	94	95	83	-0	-0	1
36	36	71	83	95	84	73	72	-0	-0	1
37	37	73	84	95	96	97	85	-0	-0	1
38	38	73	85	97	86	75	74	-0	-0	1
39	39	75	86	97	98	99	87	-0	-0	1
40	40	75	87	99	88	77	76	-0	-0	1
41	41	89	100	111	112	113	101	-0	-0	1
42	42	89	101	113	102	91	90	-0	-0	1
43	43	91	102	113	114	115	103	-0	-0	1
44	44	91	103	115	104	93	92	-0	-0	1
45	45	93	104	115	116	117	105	-0	-0	1
46	46	93	105	117	106	95	94	-0	-0	1
47	47	95	106	117	118	119	107	-0	-0	1
48	48	95	107	119	108	97	96	-0	-0	1
49	49	97	108	119	120	121	109	-0	-0	1
50	50	97	109	121	110	99	98	-0	-0	1
51	51	111	122	133	134	135	123	-0	-0	1
52	52	111	123	135	124	113	112	-0	-0	1
53	53	113	124	135	136	137	125	-0	-0	1
54	54	113	125	137	126	115	114	-0	-0	1
55	55	115	126	137	138	139	127	-0	-0	1
56	56	115	127	139	128	117	116	-0	-0	1
57	57	117	128	139	140	141	129	-0	-0	1
58	58	117	129	141	130	119	118	-0	-0	1
59	59	119	130	141	142	143	131	-0	-0	1
60	60	119	131	143	132	121	120	-0	-0	1
61	61	133	144	155	156	157	145	-0	-0	1
62	62	133	145	157	146	135	134	-0	-0	1
63	63	135	146	157	158	159	147	-0	-0	1
64	64	135	147	159	148	137	136	-0	-0	1
65	65	137	148	159	160	161	149	-0	-0	1
66	66	137	149	161	150	139	138	-0	-0	1

(continued)

Figure 4.7. (Continued)

67	67	139	150	161	162	163	151	-0	-0	1
68	68	139	151	163	152	141	140	-0	-0	1
69	69	141	152	163	164	165	153	-0	-0	1
70	70	141	153	165	154	143	142	-0	-0	1

BOUNDARY NODES

1	12	23	3	2	5	4	7	6	9	8	33	22	11	10	34
45	55	44	56	67	77	66	78	89	99	88	100	111	121	110	122
133	143	132	144	155	156	157	158	159	160	161	162	163	164	165	154

1

SHOAL CREEK, UPPER PART

30 JUN 83

ORDER	NODE	X LOC	Y LOC	DEPTH	SLOPE
1	1	2815645.00	254068.00	652.00	-27.500000E-02
2	3	2815667.00	254061.95	648.00	-27.500000E-02
3	5	2815686.00	254056.72	645.00	-27.500000E-02
4	7	2815700.00	254052.88	646.00	-27.500000E-02
5	9	2815722.00	254046.83	650.00	-27.500000E-02
6	11	2815765.00	254035.00	654.00	-27.500000E-02
7	23	2815535.00	253793.00	650.00	25.000000E-01
8	25	2815566.00	253785.00	646.00	-10.000000E+35
9	27	2815590.00	253779.00	642.00	-10.000000E+35
10	29	2815616.00	253772.00	644.00	-10.000000E+35
11	31	2815642.00	253764.00	650.00	-10.000000E+35
12	33	2815675.00	253758.00	654.00	30.777778E-01
13	45	2815446.00	253575.00	650.00	24.494382E-01
14	47	2815495.00	253557.00	646.00	-10.000000E+35
15	49	2815530.00	253544.00	642.00	-10.000000E+35
16	51	2815555.00	253534.00	644.00	-10.000000E+35
17	53	2815605.00	253515.00	650.00	-10.000000E+35
18	55	2815622.00	253510.00	654.00	46.790000E-01
19	66	2815593.16	253403.05	654.00	32.962963E-01
20	67	2815352.00	253335.00	650.00	25.531915E-01
21	69	2815385.00	253320.00	646.00	-10.000000E+35
22	71	2815425.00	253300.00	644.00	-10.000000E+35
23	73	2815480.00	253275.00	642.00	-10.000000E+35
24	75	2815520.00	253254.00	650.00	-10.000000E+35
25	77	2815541.00	253243.00	654.00	29.240000E-01
26	89	2815260.00	253105.00	646.00	25.000000E-01
27	91	2815313.00	253081.00	642.00	-10.000000E+35
28	93	2815355.00	253059.00	640.00	-10.000000E+35
29	95	2815395.00	253040.00	644.00	-10.000000E+35
30	97	2815424.00	253028.00	650.00	-10.000000E+35
31	99	2815462.00	253012.00	654.00	29.240000E-01
32	111	2815150.00	252895.00	646.00	19.100000E-01
33	113	2815185.00	252877.00	644.00	-10.000000E+35
34	115	2815240.00	252851.00	640.00	-10.000000E+35
35	117	2815267.00	252840.00	640.00	-10.000000E+35
36	119	2815300.00	252825.00	644.00	-10.000000E+35
37	121	2815360.00	252796.00	652.00	20.000000E-01
38	133	2815075.00	252650.00	646.00	50.000000E-01
39	135	2815105.00	252638.00	640.00	-10.000000E+35
40	137	2815140.00	252624.00	635.00	-10.000000E+35
41	139	2815165.00	252610.00	640.00	-10.000000E+35
42	141	2815200.00	252595.00	644.00	-10.000000E+35
43	143	2815254.00	252573.00	646.00	21.000000E-01
44	155	2815020.00	252375.00	650.00	50.000000E-01
45	157	2815042.00	252375.00	646.00	00.000000E-01
46	159	2815060.00	252375.00	640.00	00.000000E-01

(continued)

Figure 4.7. (Continued)

47	161	2815080.00	252375.00	634.00	00.000000E-01
48	163	2815102.00	252375.00	640.00	00.000000E-01
49	165	2815142.00	252375.00	643.00	15.000000E-01

1

FOR INITIAL ORDER, REORDERING SUM = 50290
 MAX FRONT WIDTH = 24

SELECTED ELEMENT ORDER IS LISTED BELOW

30	50	70	51	1	2	3	4	5	6
7	8	9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24	25	26
27	28	29	31	32	33	34	35	36	37
38	39	40	41	42	43	44	45	46	47
48	49	52	53	54	55	56	57	58	59
60	61	62	63	64	65	66	67	68	69

XMIN = -253742.23
 XMAX = -252049.29
 YMIN = 2815049.18
 YMAX = 2815794.37

Figure 4.7. (Continued)

The first set of information relates to parameter inputs and default values for the computer plots. The second set of information lists the inputted corner node slopes (C-cards). Next is a list of mid side nodes on the curved element sides (D-cards). The next printed information is the order, element number, nodes of the element, and element type, which is the same as the E-card information. The next information is a list of all the boundary nodes of the network. This is followed by a list of each node with the x, and y coordinates, the ground surface elevation, and the node slopes reading or assigned by the RMA-1 program. The last set of information is the selected element order for running RMA-2 followed by the minimum and maximum x and y coordinates.

4.4 RMA-2 Output

The output from RMA-2 consists of only printed output. The printed output for one iteration is shown in Fig. 4.8 for the previous RMA-1 input and the RMA-2 input. The first set of information is a list of the run control parameters which are either read in or set as default values. This is followed by information of the elements, i.e. turbulent exchange coefficients and Manning's roughness for each element type. The next information is a list of the nodes defining line segments for continuity checks. This information was inputted on the RMA-2 DD-cards. Next is an indication of the completed network input followed by the maximum and minimum element numbers and maximum and minimum node numbers. The next information is a list of the x and y unit discharge values ($\text{ft}^3/\text{sec}/\text{ft}$) for each of the upstream boundary nodes. The next long table lists for each node the x and y direction velocities, the depth, the water surface elevation, and the Froude numbers. The last table lists the results of the continuity checks giving the total flow, x-direction flow, y-direction flow, and percent of the total flow from the first continuity check line.

1

FINITE ELEMENT METHOD FOR FLUID FLOW...PROGRAM RMA-2
TWO-DIMENSIONAL HYDRODYNAMICS IN THE HORIZONTAL PLANE

SHOAL CREEK,UPPER (FLOW = 15700 CFS) MANNING EQ. 30 JUN 1983

RUN CONTROL PARAMETERS

ELEMENT CARDS	0
ELEMENT TYPES	1
COORDINATE CARDS	0
BOUNDARY SPECS	11
PRINT OPTION	0
CONT CHECKS	8
WIND INPUTS	0
INPUT RESTART FILE	-0
OUTPUT RESTART FILE	4
INPUT GEOMETRY FILE	3
FINAL RESULTS FILE	-0
AUG LAT(DEG)	30.30
AUG WS ELEV(FT)	655.00
AUG TEMP(DEG C)	20.00
X-SCALE FACTOR	1.00
Y-SCALE FACTOR	1.00

TIME AND ITERATION CONTROL

CYCLES-FIRST ITERATION	1
CYCLES-NEXT ITERATIONS	0
TIME STEPS/DATA UPDATE	0
STARTING TIME STEP	0
TIME INTERVAL (HOURS)	0.00
TOTAL RUN TIME(HOURS)	0.00

ELEMENT CHARACTERISTICS

NUMBER	X-X EDDY VIS (LB-SEC/FT2)	X-Y EDDY VIS (LB-SEC/FT2)	Y-X EDDY VIS (LB-SEC/FT2)	Y-Y EDDY VIS (LB-SEC/FT2)	MANNING
1	10.000E+01	10.000E+01	10.000E+01	10.000E+01	.09

1

FINITE ELEMENT METHOD FOR FLUID FLOW...PROGRAM RMA-2
TWO-DIMENSIONAL HYDRODYNAMICS IN THE HORIZONTAL PLANE

SHOAL CREEK,UPPER (FLOW = 15700 CFS) MANNING EQ. 30 JUN 1983

CONTINUITY CHECKS TO BE MADE ALONG THE FOLLOWING LINES

LINE	NODES					
1	1	3	5	7	9	11
2	23	25	27	29	31	33
3	45	47	49	51	53	55
4	67	69	71	73	75	77

(continued)

Figure 4.8. RMA-2 Printed Output

```

5      89  91  93  95  97  99
6     111 113 115 117 119 121
7     133 135 137 139 141 143
8     155 157 159 161 163 165

```

....NETWORK INPUT COMPLETE.....

```

MAX ELEMENT NUM = 70
MIN ELEMENT NUM = 1
MAX NODE NUM = 165
MIN NODE NUM = 1

```

... 48 BOUNDARY CONDITIONS NEEDED AT EDGES

- - - - UPSTREAM INFLOW RATE - - - -

ORDER	U/S NODE	FLOW RATE (CFS PER FT WIDTH)	
		X-DIRECTION	Y-DIRECTION
1	1	-25.87	-94.06
2	2	-32.19	-117.06
3	3	-40.81	-148.40
4	4	-48.29	-175.58
5	5	-53.54	-194.69
6	6	-52.88	-192.31
7	7	-49.02	-178.24
8	8	-41.39	-150.50
9	9	-31.20	-113.47
10	10	-22.99	-83.61
11	11	-16.67	-60.62

....TOTAL NUMBER OF ACTIVE SYSTEM EQUATIONS = 341
27 BUFFER BLOCKS WRITTEN

TIME IN COEFS = 0

1

FINITE ELEMENT METHOD FOR FLUID FLOW...PROGRAM RMA-2
TWO-DIMENSIONAL HYDRODYNAMICS IN THE HORIZONTAL PLANE

SHOAL CREEK,UPPER (FLOW = 15700 CFS) MANNING EQ. 30 JUN 1983

RESULTS AT THE END OF 0 TIME STEPS...TOTAL TIME = 0.00 HOURS....ITERATION CYCLE IS 1

CONVERGENCE PARAMETERS

DF	AVG CHG	MAX CHG	LOCATION
1	5.9241	95.8923	11 (X-FLOW)
2	10.0812	-27.2270	17 (Y-FLOW)
3	2.2315	3.7511	9 (DEPTH)

NODAL VELOCITY,DEPTH AND ELEVATION....

(continued)

Figure 4.8. (Continued)

NODE	X-VEL	Y-VEL	DEPTH	ELEV	FR NO	VEL	NODE	X-VEL	Y-VEL	DEPTH	ELEV	FR NO	VEL
	(FPS)	(FPS)	(FT)	(FT)		(FPS)		(FPS)	(FPS)	(FT)	(FT)		(FPS)
1	1.941	7.058	6.675	658.675	.499	7.320	* 84	-3.588	-8.098	14.031	657.031	.417	8.88
2	-1.877	-6.827	8.542	658.542	.427	7.080	* 85	-3.530	-8.215	11.037	657.037	.474	8.91
3	-2.991	-10.877	10.409	658.409	.616	11.280	* 86	-3.392	-8.427	7.037	657.037	.604	9.04
4	-3.335	-12.127	12.010	658.510	.640	12.577	* 87	-3.280	-8.616	5.030	657.030	.724	9.29
5	-3.420	-12.438	13.611	658.611	.616	12.900	* 88	-2.995	-8.758	3.091	657.091	.928	9.26
6	-3.413	-12.412	13.175	658.675	.625	12.873	* 89	-2.909	-7.274	11.019	657.019	.416	7.84
7	-3.184	-11.578	12.738	658.738	.593	12.008	* 90	-2.967	-7.266	13.021	657.021	.383	7.89
8	-2.750	-9.999	10.745	658.745	.558	10.370	* 91	-2.955	-7.324	15.023	657.023	.359	7.87
9	-1.559	-5.668	8.751	658.751	.350	5.879	* 92	-2.923	-7.381	16.012	657.012	.350	7.99
10	-.924	-3.361	5.638	657.638	.259	3.486	* 93	-3.006	-7.407	17.001	657.001	.342	7.94
11	8.756	31.842	2.525	656.525	3.662	33.024	* 94	-3.072	-7.434	15.004	657.004	.366	8.04
12	-7.795	-19.488	6.993	657.993	1.399	20.989	* 95	-3.080	-7.482	13.007	657.007	.395	8.01
13	-7.461	-21.458	9.122	658.122	1.326	22.718	* 96	-3.023	-7.532	10.012	657.012	.452	8.16
14	-8.037	-24.196	10.988	657.988	1.355	25.496	* 97	-2.907	-7.601	7.018	657.018	.541	8.18
15	-8.893	-26.135	13.013	658.013	1.349	27.606	* 98	-2.730	-7.633	5.011	657.011	.638	8.17
16	-9.092	-27.053	14.615	658.115	1.316	28.540	* 99	-2.600	-7.664	3.004	657.004	.817	8.06
17	-9.122	-27.227	13.542	658.042	1.375	28.714	* 100	-3.321	-6.339	11.016	657.016	.380	7.16
18	-9.079	-26.760	13.105	658.105	1.376	28.258	* 101	-3.238	-6.381	12.015	657.015	.364	7.15
19	-8.782	-25.108	10.067	658.067	1.477	26.600	* 102	-3.138	-6.422	14.016	657.016	.336	7.18
20	-8.737	-23.611	8.073	658.073	1.561	25.175	* 103	-2.993	-6.458	16.021	657.021	.313	7.18
21	-6.968	-24.625	6.631	658.631	1.751	25.592	* 104	-2.930	-6.451	17.010	657.010	.303	7.06
22	-15.258	-46.960	3.518	657.518	4.639	49.377	* 105	-2.918	-6.453	17.016	657.016	.303	7.02
23	3.376	8.440	7.311	657.311	.592	9.090	* 106	-2.853	-6.491	15.019	657.019	.322	7.00
24	1.607	9.452	9.439	657.439	.550	9.588	* 107	-2.804	-6.541	13.017	657.017	.348	7.16
25	.780	9.543	11.568	657.568	.496	9.575	* 108	-2.751	-6.602	10.023	657.023	.398	7.12
26	.880	9.599	13.593	657.593	.461	9.640	* 109	-2.834	-6.621	5.998	656.998	.518	7.22
27	1.198	9.857	15.618	657.618	.443	9.930	* 110	-3.078	-6.518	3.991	656.991	.636	7.28
28	1.398	10.295	14.545	657.545	.480	10.390	* 111	-2.997	-5.724	11.013	657.013	.343	6.41
29	1.089	11.356	13.472	657.472	.548	11.408	* 112	-2.919	-5.755	12.012	657.012	.328	6.43
30	.421	13.098	10.434	657.434	.715	13.105	* 113	-2.879	-5.774	13.010	657.010	.315	6.42
31	-.510	15.366	7.396	657.396	.996	15.375	* 114	-2.861	-5.791	15.015	657.015	.294	6.49
32	1.256	20.947	5.953	657.953	1.516	20.984	* 115	-2.796	-5.810	17.019	657.019	.275	6.47
33	8.445	25.991	4.510	658.510	2.268	27.328	* 116	-2.745	-5.829	17.025	657.025	.275	6.43
34	-5.918	-14.496	7.131	657.131	1.033	15.657	* 117	-2.650	-5.870	17.031	657.031	.275	6.40
35	-6.250	-14.558	9.086	657.086	.926	15.842	* 118	-2.514	-5.930	15.030	657.030	.293	6.41
36	-6.163	-14.597	11.214	657.214	.834	15.845	* 119	-2.396	-5.984	13.028	657.028	.315	6.46
37	-5.461	-15.027	13.208	657.208	.775	15.988	* 120	-2.405	-5.974	9.003	657.003	.378	6.40
38	-4.912	-15.136	15.233	657.233	.719	15.913	* 121	-2.875	-5.751	4.978	656.978	.508	6.40
39	-4.279	-15.413	14.222	657.222	.747	15.996	* 122	-1.777	-5.805	11.034	657.034	.322	6.01
40	-3.898	-15.399	13.149	657.149	.772	15.885	* 123	-1.816	-5.802	14.026	657.026	.286	6.00
41	-3.418	-15.683	10.181	657.181	.887	16.052	* 124	-1.896	-5.802	15.025	657.025	.278	6.14
42	-3.043	-15.901	7.143	657.143	1.067	16.190	* 125	-2.016	-5.793	17.521	657.021	.258	6.13
43	-3.727	-16.030	4.829	656.829	1.320	16.458	* 126	-2.188	-5.785	19.525	657.025	.247	6.15
44	-3.542	-16.575	3.387	657.387	1.623	16.950	* 127	-2.238	-5.789	17.027	657.027	.265	6.27
45	-6.317	-15.474	6.951	656.951	1.117	16.714	* 128	-2.261	-5.796	17.033	657.033	.266	6.22
46	-5.162	-16.082	8.906	656.906	.997	16.891	* 129	-2.245	-5.812	15.034	657.034	.283	6.20
47	-4.654	-16.631	10.861	656.861	.923	17.270	* 130	-2.226	-5.815	13.032	657.032	.304	6.27
48	-4.377	-17.033	12.854	656.854	.864	17.586	* 131	-2.271	-5.762	12.022	657.022	.315	6.13
49	-4.109	-17.433	14.848	656.848	.819	17.911	* 132	-2.643	-5.560	7.997	656.997	.384	6.16
50	-3.904	-17.709	13.837	656.837	.859	18.134	* 133	-1.308	-6.542	11.054	657.054	.354	6.61
51	-3.758	-17.975	12.826	656.826	.904	18.364	* 134	-1.352	-6.550	14.047	657.047	.314	6.68
52	-3.226	-18.888	9.858	656.858	1.075	19.162	* 135	-1.458	-6.545	17.039	657.039	.286	6.75
53	-2.057	-20.154	6.891	656.891	1.360	20.259	* 136	-1.632	-6.526	19.535	657.035	.268	6.77
54	-2.467	-21.071	4.577	656.577	1.748	21.215	* 137	-1.842	-6.491	22.031	657.031	.253	6.78
55	-4.676	-21.878	2.263	656.263	2.621	22.372	* 138	-2.004	-6.474	19.532	657.032	.270	6.77
56	-3.274	-8.360	6.972	656.972	.599	8.979	* 139	-2.150	-6.453	17.034	657.034	.290	6.82
57	-2.911	-8.412	8.990	656.990	.523	8.902	* 140	-2.299	-6.409	15.035	657.035	.309	6.89

(continued)

Figure 4.8. (Continued)

58	-2.553	-8.417	10.945	656.945	.469	8.796	* 141	-2.428	-6.351	13.036	657.036	.332	6.79
59	-2.445	-8.233	11.954	656.954	.438	8.588	* 142	-2.599	-6.253	12.026	657.026	.344	6.72
60	-2.350	-8.170	13.948	656.948	.401	8.581	* 143	-2.897	-6.083	11.016	657.016	.358	6.77
61	-2.225	-7.986	14.951	656.951	.378	8.290	* 144	-1.588	-7.941	8.854	656.854	.480	8.08
62	-2.212	-7.917	13.941	656.941	.388	8.220	* 145	-1.614	-7.902	11.048	657.048	.428	8.05
63	-2.295	-7.676	9.941	656.941	.448	8.012	* 146	-1.688	-7.905	14.040	657.040	.380	8.04
64	-2.224	-7.384	6.973	656.973	.515	7.712	* 147	-1.764	-7.849	17.033	657.033	.344	8.05
65	-1.910	-7.202	5.035	657.035	.585	7.451	* 148	-1.994	-7.794	19.529	657.029	.321	8.05
66	-2.372	-7.817	2.721	656.721	.873	8.169	* 149	-2.137	-7.702	22.525	657.025	.297	7.93
67	-2.732	-6.976	6.992	656.992	.499	7.492	* 150	-2.360	-7.646	20.026	657.026	.315	8.02
68	-3.047	-6.856	9.011	657.011	.440	7.502	* 151	-2.534	-7.524	17.025	657.025	.339	7.99
69	-3.174	-6.777	11.029	657.029	.397	7.483	* 152	-2.859	-7.371	15.026	657.026	.359	7.96
70	-3.227	-6.734	12.038	657.038	.379	7.467	* 153	-3.182	-7.088	12.393	655.893	.389	7.79
71	-3.203	-6.733	13.048	657.048	.364	7.456	* 154	-3.790	-6.701	11.383	655.883	.402	7.68
72	-3.179	-6.762	14.052	657.052	.351	7.472	* 155	-2.031	-10.234	6.654	656.654	.713	10.44
73	-3.177	-6.847	15.055	657.055	.343	7.548	* 156	-1.647	-10.178	8.848	656.848	.611	10.30
74	-3.271	-7.033	11.056	657.056	.411	7.756	* 157	-1.638	-10.105	11.041	657.041	.543	10.27
75	-3.428	-7.278	7.056	657.056	.534	8.044	* 158	-1.650	-10.021	14.034	657.034	.478	10.16
76	-3.319	-7.668	5.117	657.117	.651	8.355	* 159	-1.701	-9.922	17.027	657.027	.430	10.07
77	-2.803	-8.197	3.178	657.178	.856	8.663	* 160	-1.796	-9.799	20.023	657.023	.392	9.92
78	-3.035	-7.586	9.006	657.006	.480	8.171	* 161	-1.919	-9.665	23.018	657.018	.362	9.84
79	-3.331	-7.541	11.007	657.007	.438	8.244	* 162	-2.067	-9.521	20.017	657.017	.384	9.73
80	-3.424	-7.580	13.026	657.026	.406	8.318	* 163	-2.225	-9.374	17.016	657.016	.412	9.64
81	-3.504	-7.685	14.015	657.015	.398	8.446	* 164	-2.468	-9.141	14.383	655.883	.440	9.48
82	-3.597	-7.784	15.024	657.024	.390	8.575	* 165	-4.928	-8.911	11.750	654.750	.524	10.13
83	-3.617	-7.908	13.027	657.027	.425	8.696	*						

CONTINUITY CHECKS

LINE	TOTAL	X FLOW	Y FLOW	PERCENT		
1	87.483E+02	65.971E+01	-87.234E+02	100.0	9.383E+03	100.0
2	17.347E+03	-43.745E+01	17.341E+03	198.3	-1.778E+04	-189.5
3	31.860E+03	27.651E+02	-31.740E+03	364.2	3.451E+04	367.7
4	14.802E+03	32.452E+02	-14.442E+03	169.2	1.769E+04	188.5
5	18.404E+03	34.172E+02	-18.084E+03	210.4	2.150E+04	229.1
6	16.410E+03	34.652E+02	-16.040E+03	187.6	1.951E+04	207.9
7	17.974E+03	24.342E+02	-17.808E+03	205.5	2.024E+04	215.7
8	17.893E+03	00.000E-01	-17.893E+03	204.5	1.789E+04	190.7

Figure 4.8. (Continued)

4.5 RMA1PLT Input and Output

4.5.1 Input

The input to RMA1PLT consists of a file on scratch tape generated by running RMA-1 and a short user inputted data file. The user inputted data file is put in the form as shown in Fig. 4.9. The cards are:

<u>Card</u>	<u>Name</u>	<u>Number of Cards</u>
AAA	Title card	1 card
BBB	Scale factor card	1 card
CCC	origin card	1 card

An example of the user inputted file for RMA1PLT is shown in Fig. 4.10a.

4.5.2 Output

The output from RMA1PLT is both a printed output as shown in Fig. 4.11b and the finite element network plot shown in Fig. 4.12 giving the elemental type number for each element and the ground surface elevation of each node.

4.6 RMA2PLT Input and Output

4.6.1 Input

The input to RMA2PLT consists of files on scratch tape generated by both RMA-1 and RMA-2 and a short user inputted data file. The user inputted data file is put in the form as shown in Fig. 4.14. The cards are:

<u>Card</u>	<u>Name</u>	<u>Number of Cards</u>
AAAA	Title card	2 cards
BBBB	Plot information cards	

An example of the user inputted file for RMA2PLT is shown in Fig. 4.15.

4.6.2 Output

The output from RMA2PLT is both a printed output as shown in Fig. 4.15 and plotted output.

FESWMS - TX RMA1PLT INPUT										
1	2	3	4	5	6	7	8	9	10	
TITLE CARD										
AAA										
SCALE FACTOR CARD										
SCALE FACTOR FOR X-DIRECTION					SCALE FACTOR FOR Y-DIRECTION					
BBB										
ORIGIN CARD										
X-COORDINATE OF ORIGIN					Y-COORDINATE OF ORIGIN					
CCC										

Figure 4.9. RMA1PLT Input

```
SHOAL CREEK    22 JAN 83
  .21          .21
2815000.      2545000.
```

Figure 4.10. Example RMA1PLT Input.

119

```
1 SHOAL CREEK    22 JAN 83

PLOT NODES      2
PLOT ELTS       2
PLOT NETWORK    1
PARTIAL PLOTS   1
PLOT INPUT      8

X SCALE          1000
Y SCALE          1000
MAX PLOT LENGTH  1400000

X COORDINATE OF POINT THAT WILL BE LOWER LEFT-HAND CORNER OF PLOT = 2815000.
Y COORDINATE OF POINT THAT WILL BE LOWER LEFT-HAND CORNER OF PLOT = 2545000.
```

Figure 4.11. Example RMA1PLT Output.

REMAIPLT

AAA Card Title Card

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
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BBB Card Scale Factor Card

1	2	3	4	5	6	7	8	9	0	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
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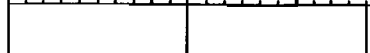
--	--

Plotting scale factor for y direction inputs

Plotting scale factor for x direction inputs

CCC Card Origin Card

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----



y coordinate of origin

x coordinate of origin

This card is the same as the B-2 card for the RMA-1 input

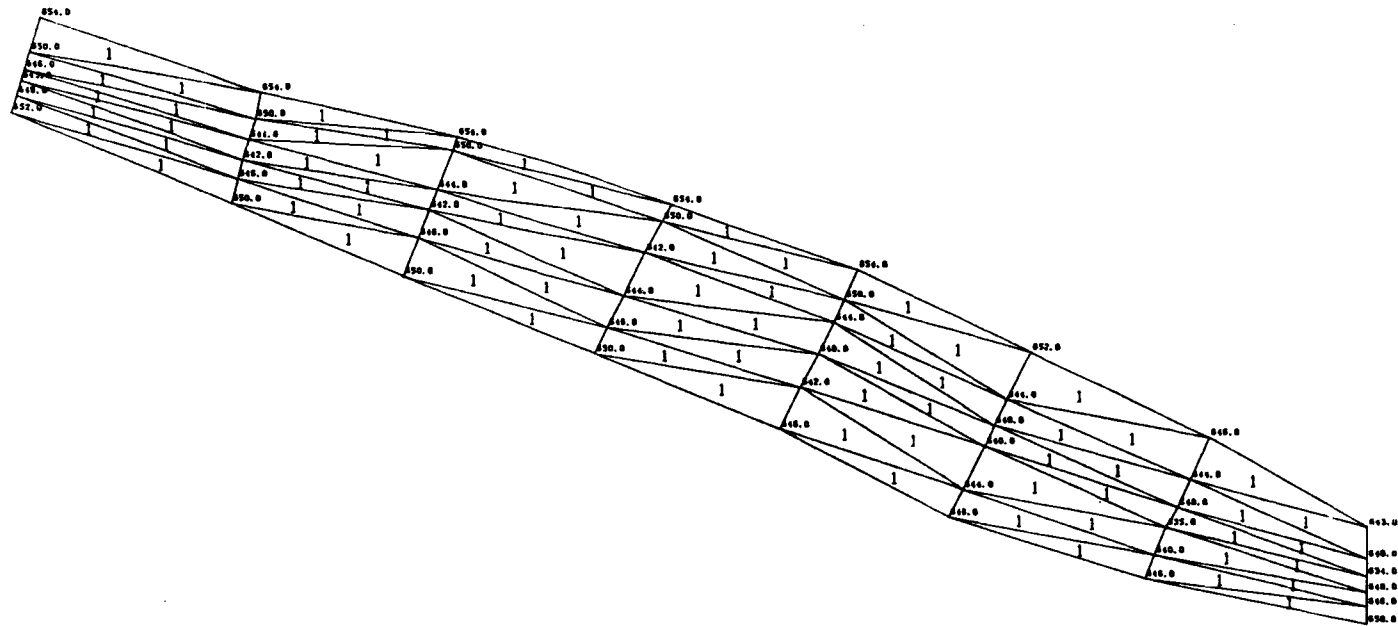


Figure 4.12. RMA1PLT Plotted Output of Finite Element Network and Element Type Numbers

SHOAL CREEK, UPPER PART. TEST FOR RMA2 PLOT
FLOW RATE= 15700 CFS 10 MAR 1983
70 165 2.0 5.0 10.0 15.0 20.0 25.0 28150000 2520000
END OF DATA

Figure 4.14. Example Input for RMA2PLT

AAAA - Title Cards

RMA2PLT

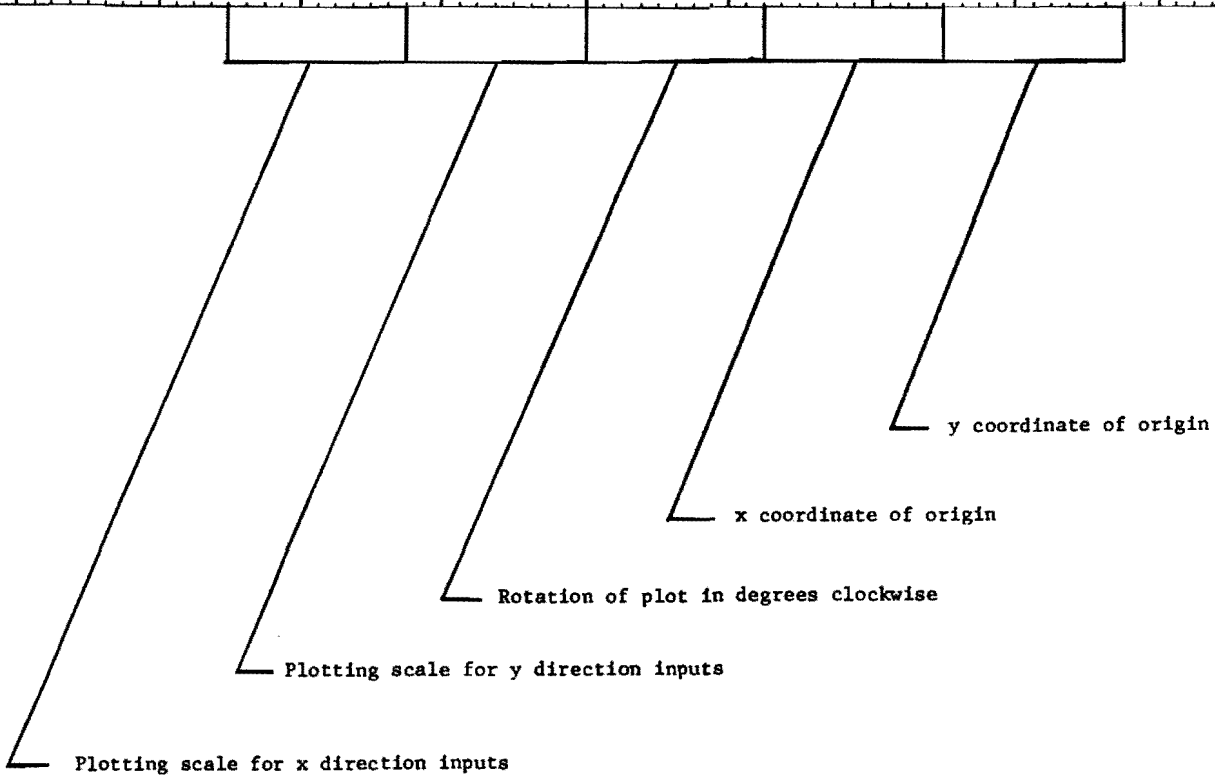
AAAA-1 Title Card

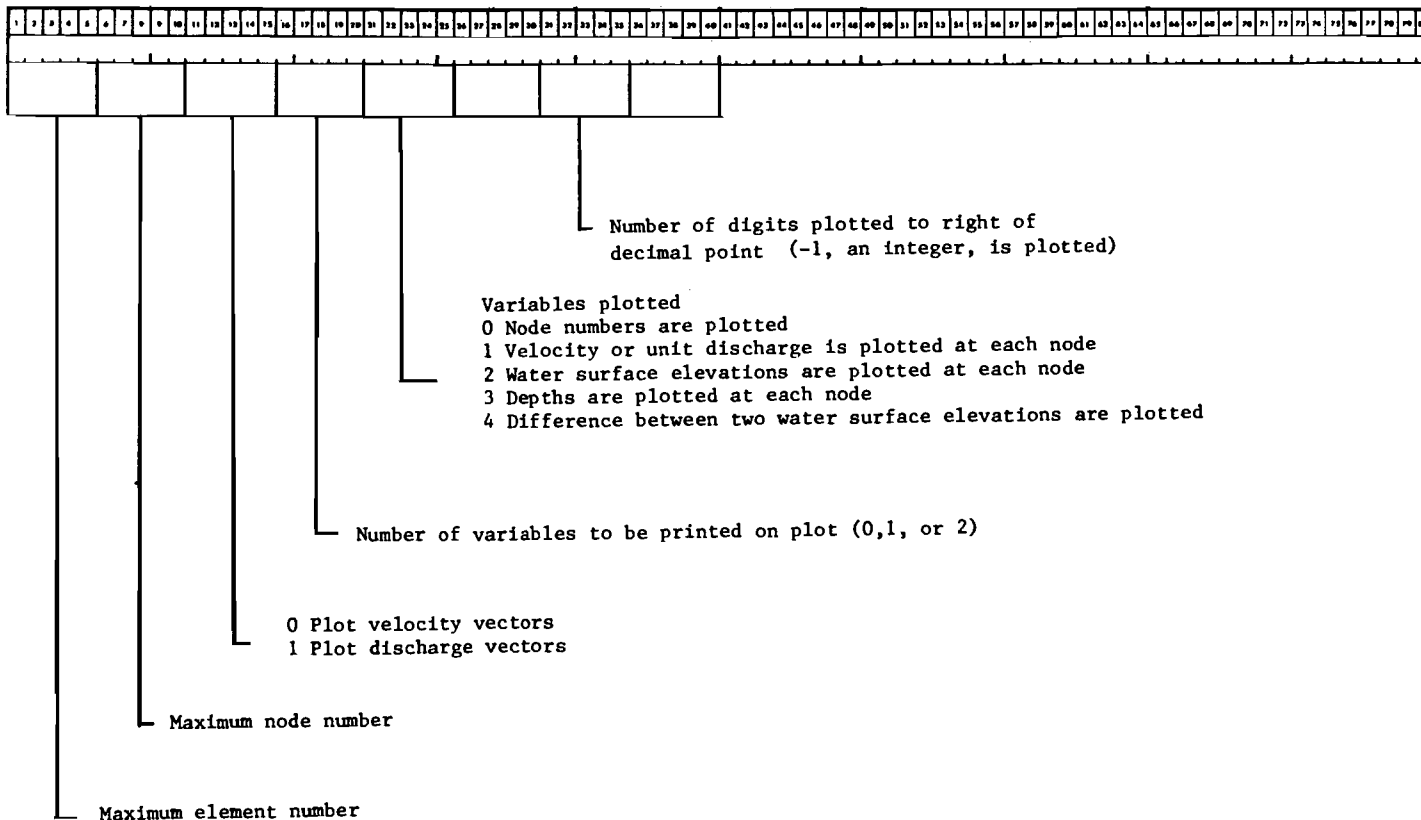
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
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AAAA-2 Subtitle Card

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
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(All entries on this card are right justified)

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Number ft/sec (for velocity) or
cfs/ft (for unit discharge) equal to 1 inch

Length in inches of maximum velocity
or unit discharge vector

0 To scale velocities
1 To scale unit discharges

SHOAL CREEK, UPPER PART. TEST FOR RMA2 PLOT

FLOW RATE= 15740 CFS

10 MAR 1983

HORIZONTAL SIZE (IN) = 25.00
 VERTICAL SIZE (IN) = 25.00
 X-SCALE (IN/FT) = 0.125
 Y-SCALE (IN/FT) = 0.125
 ROTATION (DEG) = 0.00

LEGEND OPTION = 3
 X-COORDINATE FOR TITLE = 25.00
 Y-COORDINATE FOR TITLE = 1.50
 UPPER LIMIT (FT) ON GRID SCALE = 1000.00
 UPPER LIMIT (FT/SEC) ON VELOCITY SCALE = 25.00
 X-COORDINATE FOR NORTH ARROW = 1.50
 Y-COORDINATE FOR NORTH ARROW = 1.50
 NORTH ARROW ROTATION (DEG) = 0.00

NUMBER OF NODES = 165
 VELOCITY OR UNIT DISCHARGE OPTION = 0
 NUMBERS PLOTTED =
 NUMBER PLOTTED ABOVE NODE = 1
 NUMBER PLOTTED BELOW NODE = 2
 NUMBER OF DIGITS PLOTTED ABOVE NODE = 1
 NUMBER OF DIGITS PLOTTED BELOW NODE = 2
 X-SHIFT FOR NUMBER ABOVE NODE = 8.00
 X-SHIFT FOR NUMBER BELOW NODE = 8.00
 HEIGHT (IN) OF NUMBERS = 0.75
 ARROWHEAD TYPE = 16
 ARROWHEAD LENGTH (IN) = 0.75

SCALING OPTION = 0
 LENGTH (IN) OF MAXIMUM VELOCITY VECTOR = 2.00
 NUMBER OF FT/SEC EQUAL TO 1 IN = 5.00

PUNCH OPTION = 1

XM1N = 281522.00
 XMAX = 281576.00
 YMIN = 252375.00
 YMAX = 254268.00

MAXIMUM VELOCITY (FT/SEC) = 49.38

Figure 4.15 . Example Output for RMA2PLT.

CHAPTER 5

FESWMS-TX APPLICATION TO WALNUT CREEK, AUSTIN, TEXAS

The objective of this application is to illustrate the FESWMS-TX model application by simulation of the Memorial Day 1981 flood in the floodplain and main channel of Walnut Creek just upstream of Webberville Road in Austin, Texas. Hopefully through this application, the reader will obtain a better understanding of the use and capabilities of the FESWMS-TX model.

5.1 Description of Study Area

Walnut Creek originates in northern Travis County near the Williamson County line and flows south-southeast to its confluence with the Colorado River. The watershed (Figure 5.1) has an average width of about 4 miles and a length of about 14 miles. The total drainage area is 56.19 mi² including the approximate 13 mi² drainage area of Little Walnut Creek. The natural ground elevations vary from about 950 feet above mean sea level (msl) in the upper portion of the watershed to about 400 ft (msl) at the confluence with the Colorado River.

The reach of Walnut Creek studied in this report is at Webberville Road, shown in Figure 5.2. The study area is shown in detail in Figure 5.3 and extends from 17370 ft to 20850 ft upstream of the confluence with the Colorado River and is bounded by the abandoned Missouri-Kansas-Texas Railroad on the easterly side of Walnut Creek and the Southern Pacific Railroad on the westerly side.

The U. S. Geological Survey maintains five recording stream gages in the Walnut Creek watershed. The gage for Walnut Creek at Webberville Road was established in 1966. Drainage area at the gage is 51.3 square miles, and the gage datum is 425.96 ft msl. According to the USGS records, historical flood information began in 1891. The highest stages since that day occurred 24 May 1981 (27.2 ft), 23 November

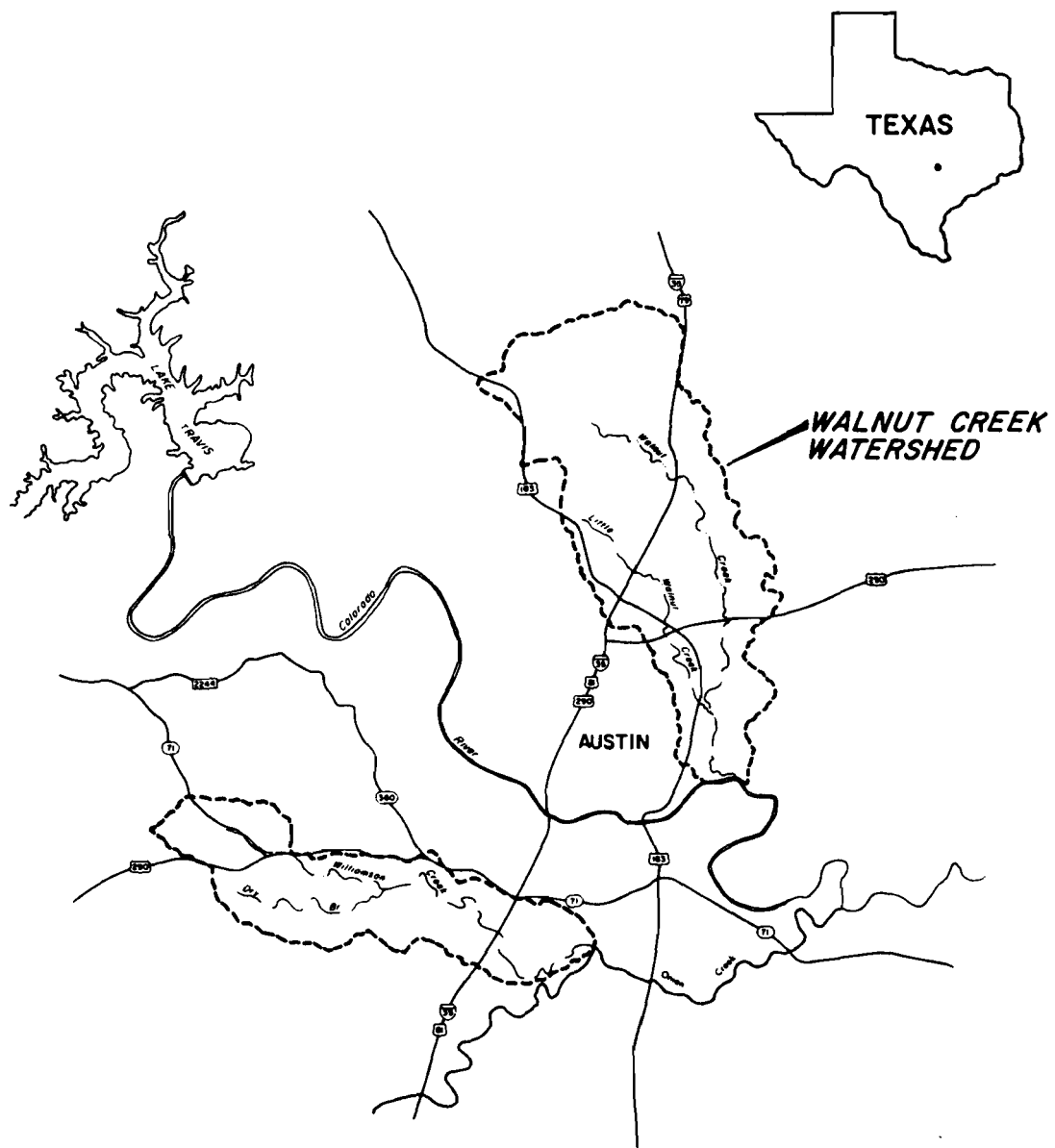


Figure 5.1. Austin, Texas Vicinity Map.

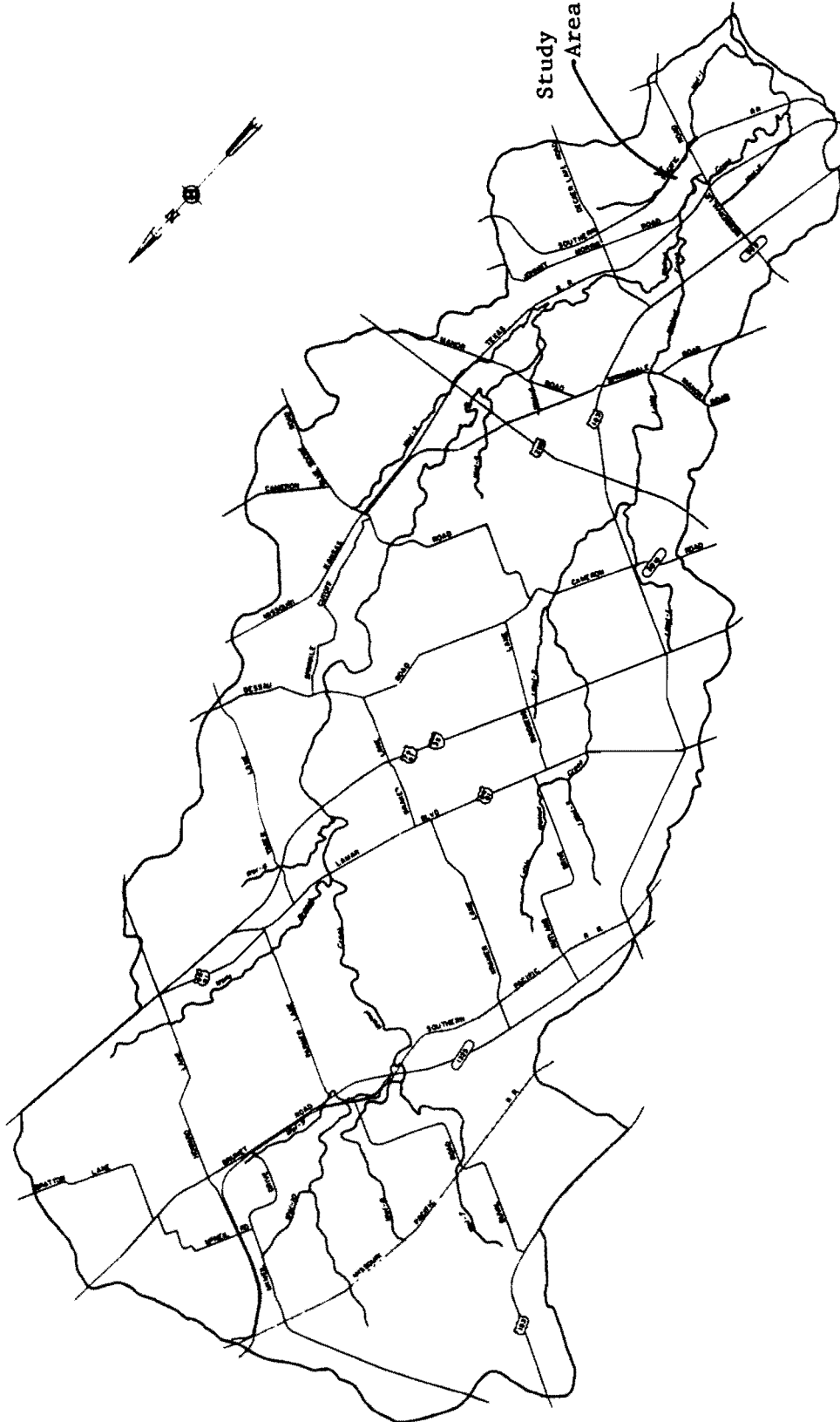


Figure 5.2. Walnut Creek Watershed

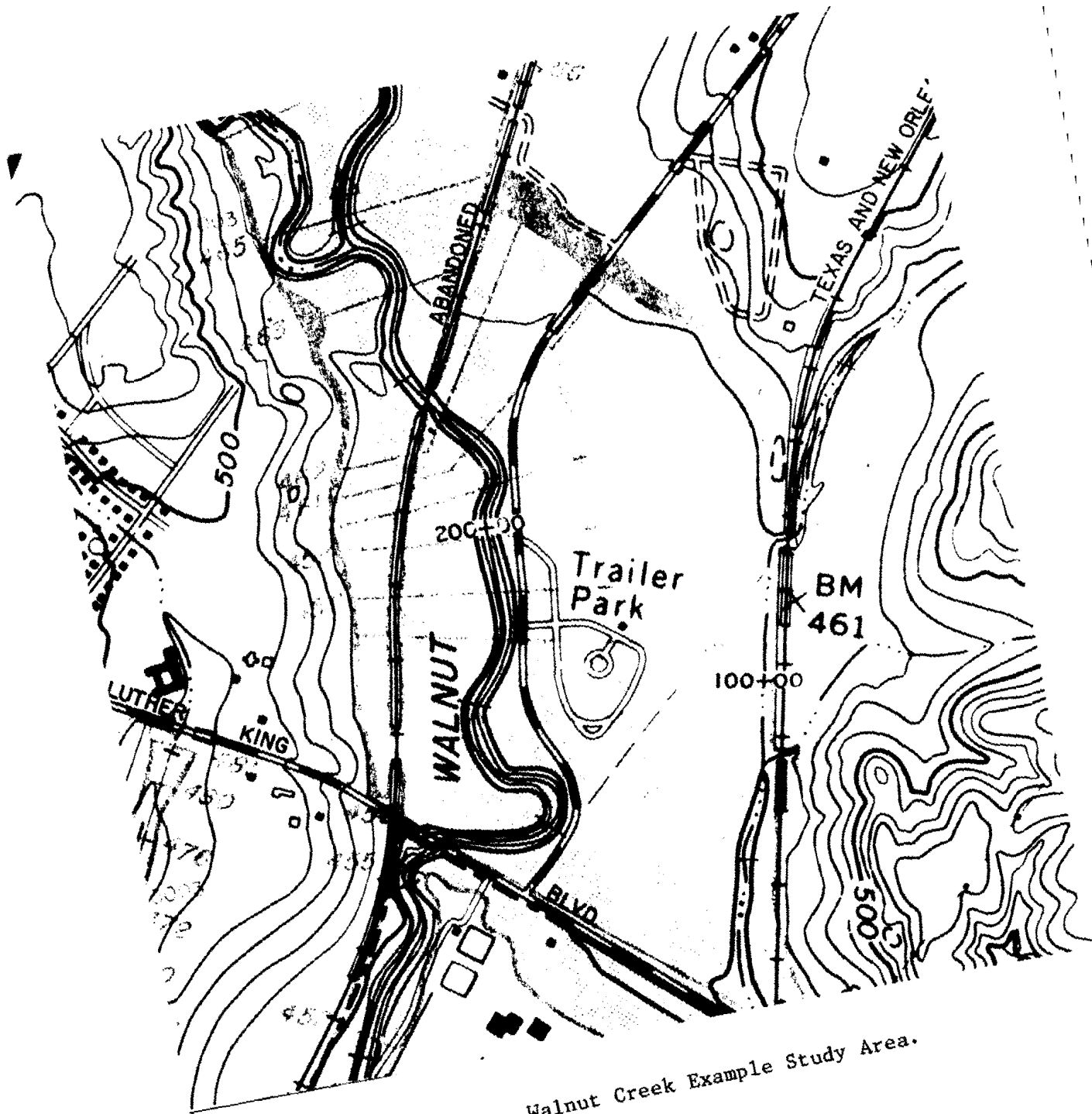


Figure 5.3. Walnut Creek Example Study Area.

1974 (26.16 ft), 21 May 1979 (26.02 ft), 11 October 1973 (25.56 ft), 10 June 1975 (25.24 ft), 15 June 1935 (24 ft) and in 1919 (22 ft). The Austin Sewage Treatment Plant was constructed just down stream from Webberville Road in 1965, and was modified recently to become a joint sewage plant and service center. The highest historical discharge was probably in 1919 before the sewage plant was built; although, the stage was lower than several subsequent floods. Considerable urbanization has occurred in the Walnut Creek Basin above Webberville Road since 1966.

Several studies have been made by the U.S. Army Corps of Engineers, the U.S. Geological Survey, and the City of Austin, Texas of hydrometeorological conditions associated with the storm of 24 May 1981 in the Austin area. Discharges on Walnut Creek at the Webberville Road USGS stream gage station resulting from the storm using the published rating curve were not in agreement with data obtained from a field reconnaissance. Further investigations indicated that auxilliary channel flow and resulting over-bank flow occurs with any discharge of 10,000 cfs or greater on Walnut Creek just upstream of Webberville Road. A revised rating curve was developed as a result.

5.2 Simulation of Memorial Day 1981 Flood

The major objective herein is to illustrate application of the FESWMS-TX model by simulating the Memorial Day 1981 flood in the study area. The flow rate at the Webberville gaging station has been determined by the U. S. Geological Survey to be 14,300 cfs of which approximately 11,500 cfs was through the main channel bridge and approximately 2800 was overflow into the floodplain. Flow enters the study reach through two railroad bridges of the Missouri-Lamar-Texas Railroad. Flow leaves the study area through the main channel of Walnut Creek, over Webberville Road and through the Missouri-Pacific railroad bridge on the southeastern corner of the study area. Several highwater marks for the 1981 Memorial Day were used in the calibration process for the FESWMS-TX model application.

5.2.1 Finite Element Network Design

The finite element network was designed to represent the highly nonuniform boundary of the area inundated by the 1981 Memorial Day Flood. As a part of this study, several networks of varying detail were considered and used to study the accuracy of the model. Figures 5.4, 5.5, 5.6, 5.7, 5.8, and 5.9 represent the various levels of networks considered in this study. In order to check the accuracy of the model for various levels of network discretization continuity lines as indicated in Figures 5.4 - 5.9 were considered. Listed in Table 5.1 are the percentages of the total inflow computed for the respective continuity lines.

Figures 5.10 through 5.15 show the element type numbers for the networks in Figs. 5.4 through 5.9, respectively. Table 5.2 lists the Manning's roughness factor and turbulent exchange coefficient for each element type. Table 5.3 lists the number of elements, the number of nodes, and the execution times for the RMA-2 for each level.

Table 5.4 presents a comparison of water depths at selected locations throughout the finite element networks. The node location is the same for each of the network levels 1 through 6. Note that the same network locations have different node numbers for the different networks because of the element and node renumbering involved for each level.

Figures 5.16, 5.17, and 5.18 show the results of vector plots with Figure 5.17 having the water surface elevations for each node printed and Figure 5.18 having the water depths for each node printed.

5.2.2 Simulation Using Various Manning's Roughness and Turbulent Exchange Coefficients

Using the Level 6 finite element network (Figures 5.9 and 5.15) various simulations were made of the Memorial Day 1981 Flood using the different Manning's roughness factors and turbulent exchange coefficients as listed in Table 5.5. The resulting continuity checks for the various computer runs are listed in Table 5.6 with

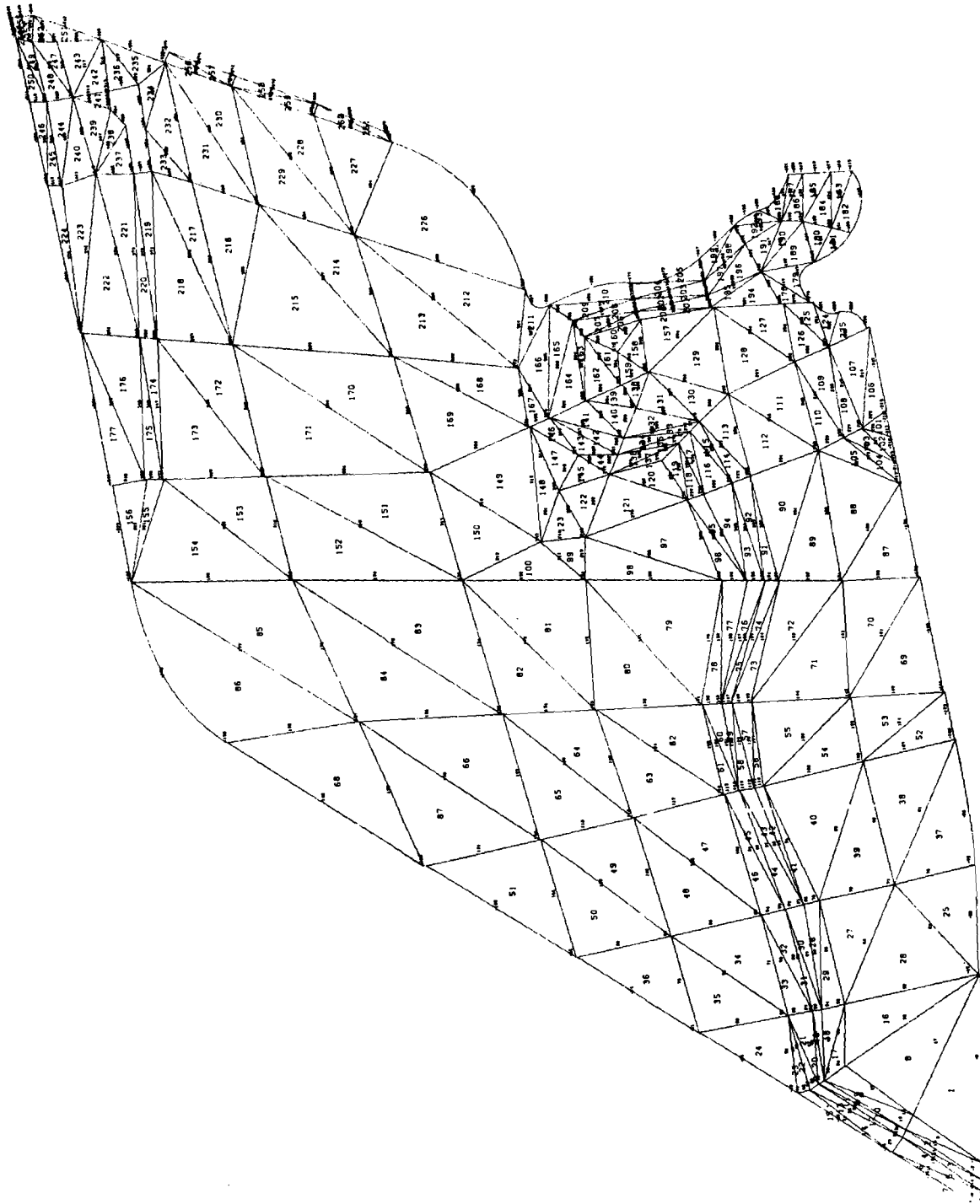


Figure 5.4. Walnut Creek Level 1 Network

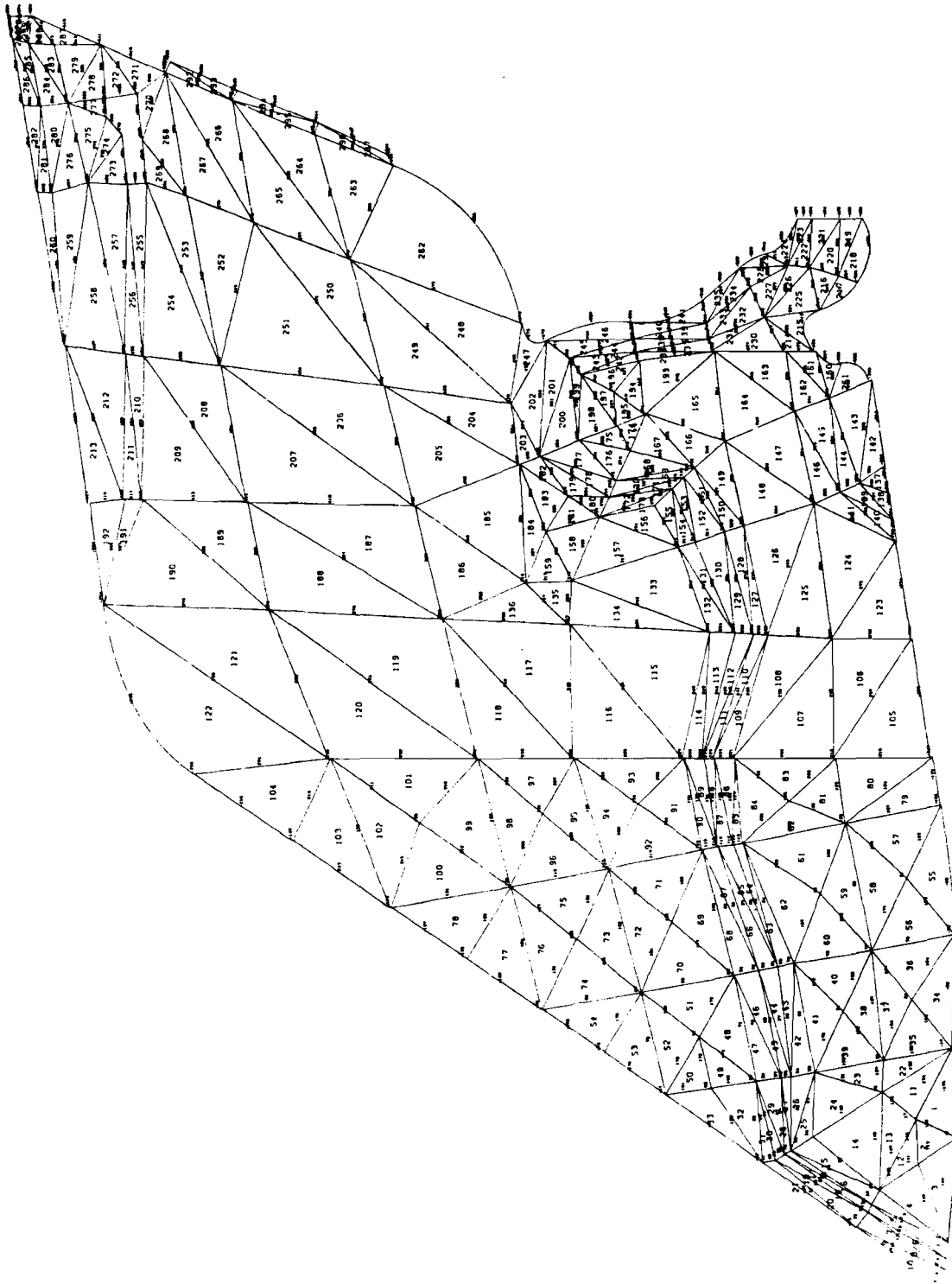


Figure 5.5. Walnut Creek Level 2 Network

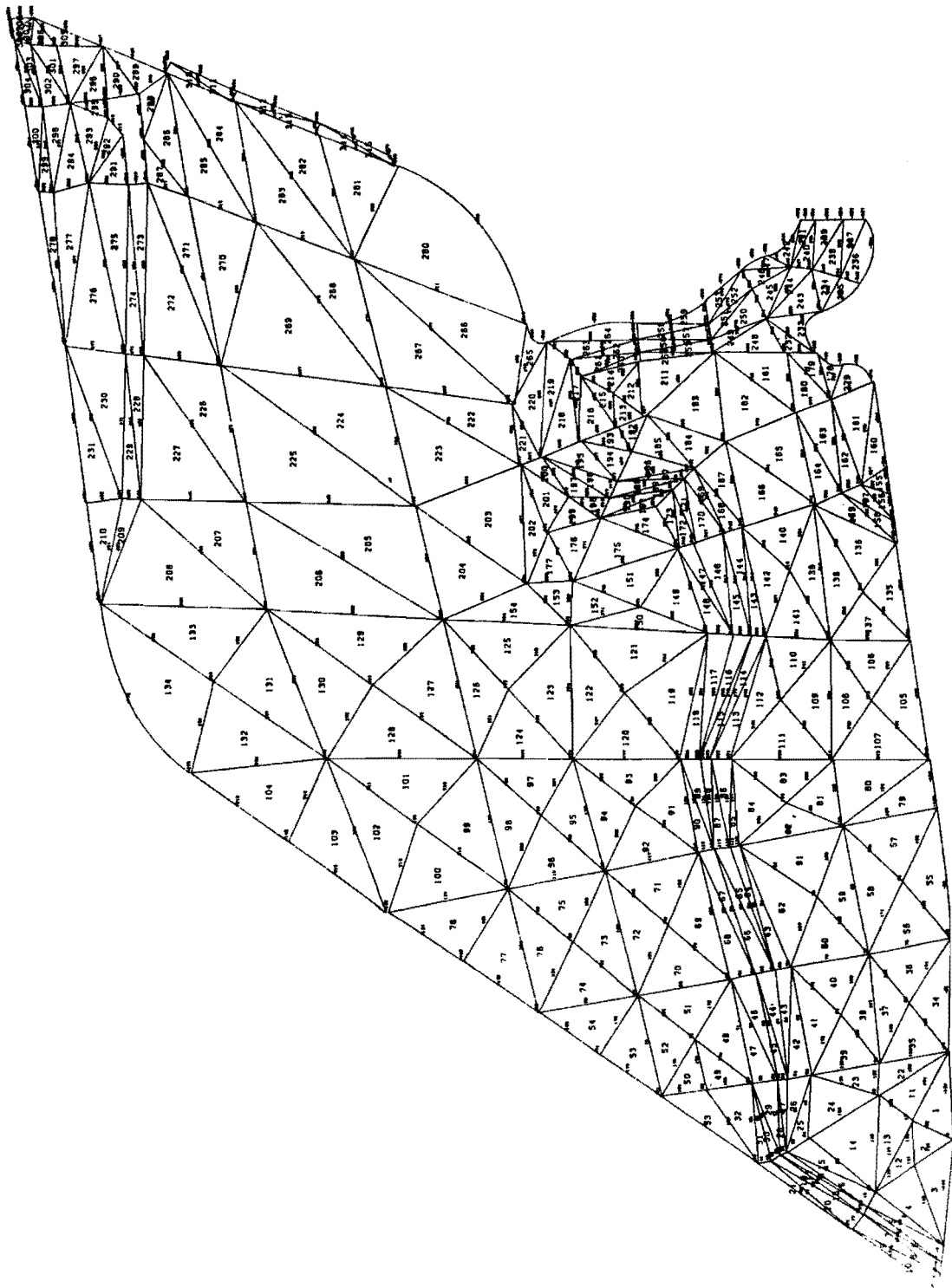


Figure 5.6. Walnut Creek Level 3 Network

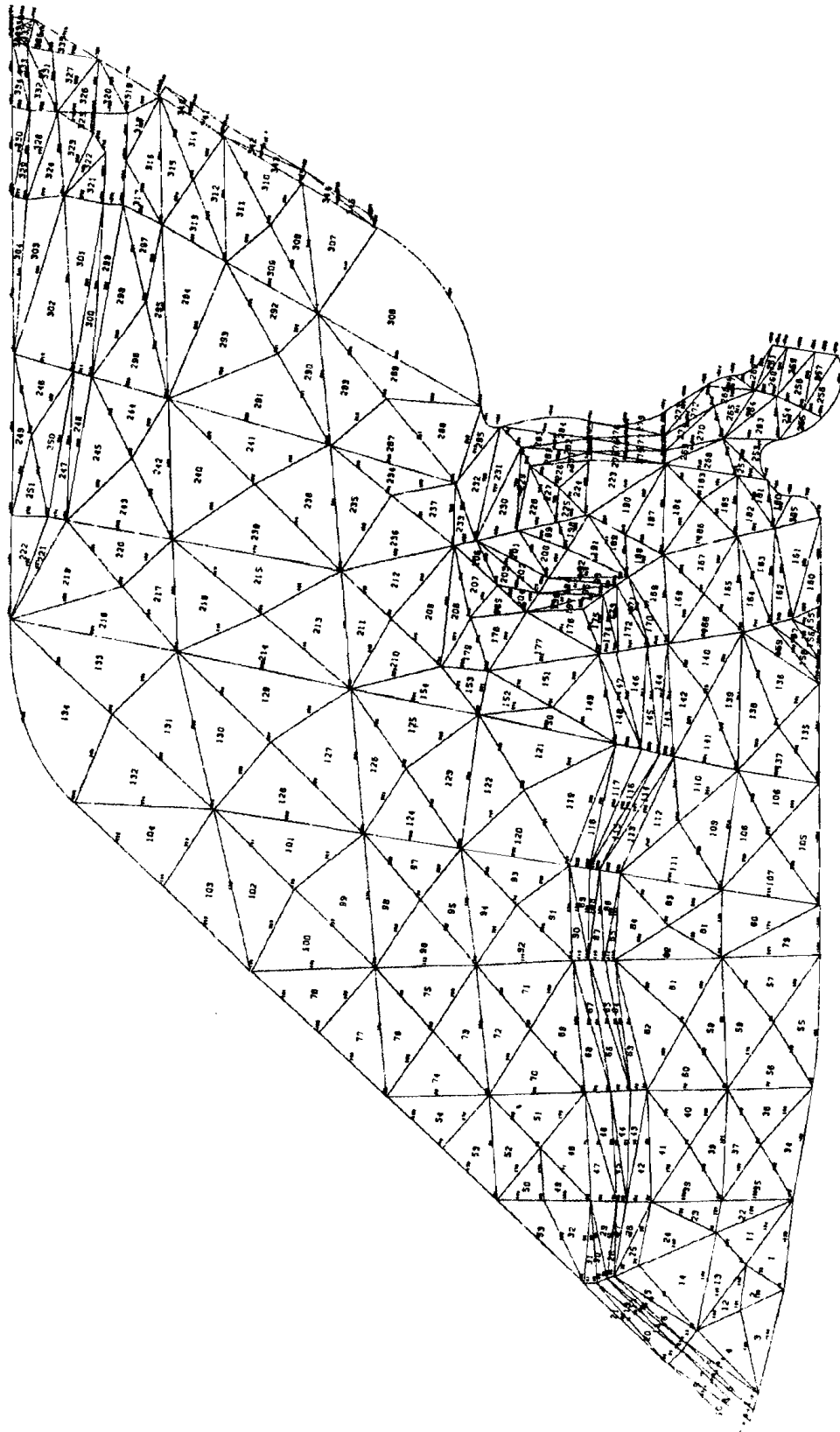


Figure 5.7. Walnut Creek Level 4 Network

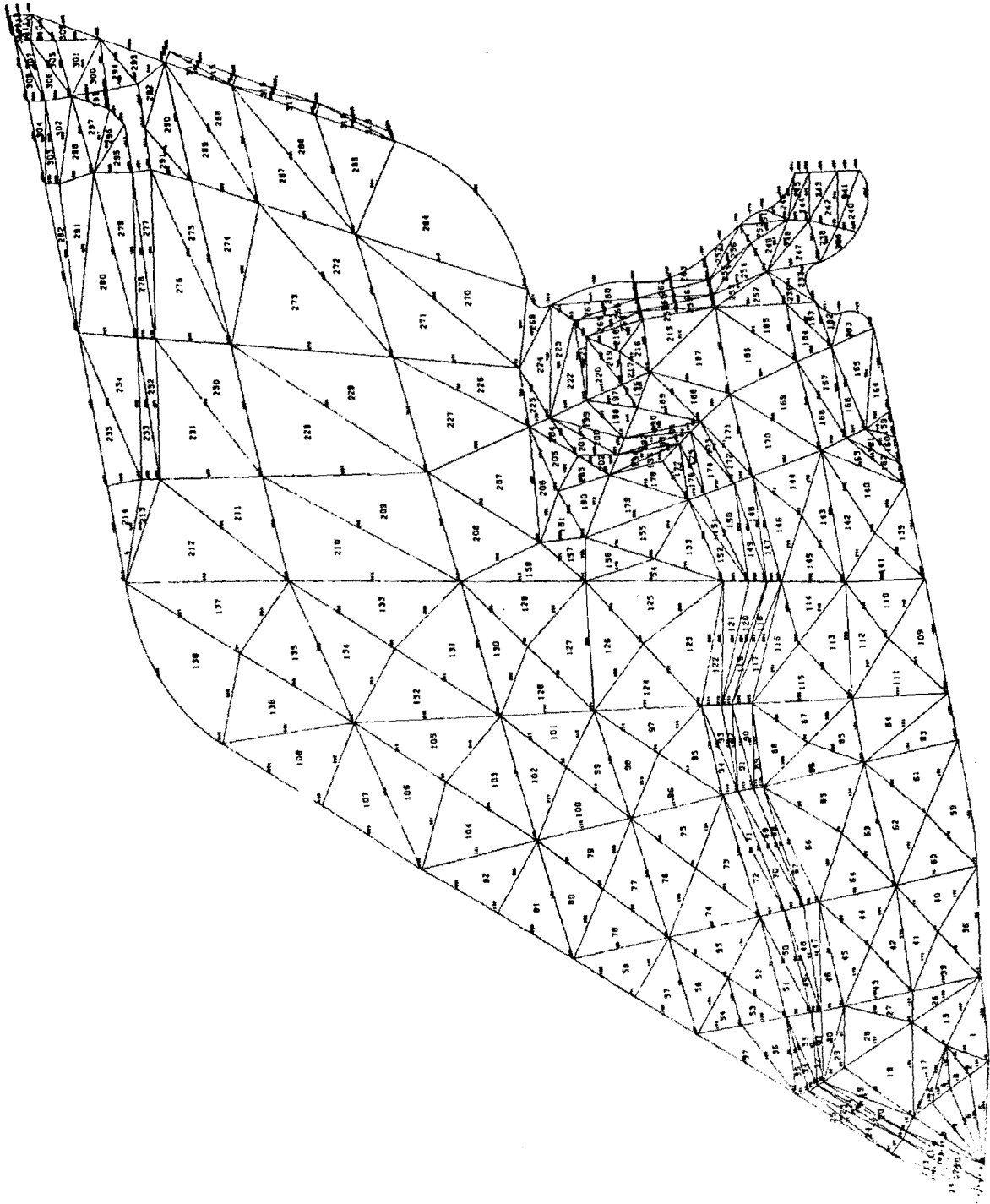


Figure 5.8. Walnut Creek Level 5 Network

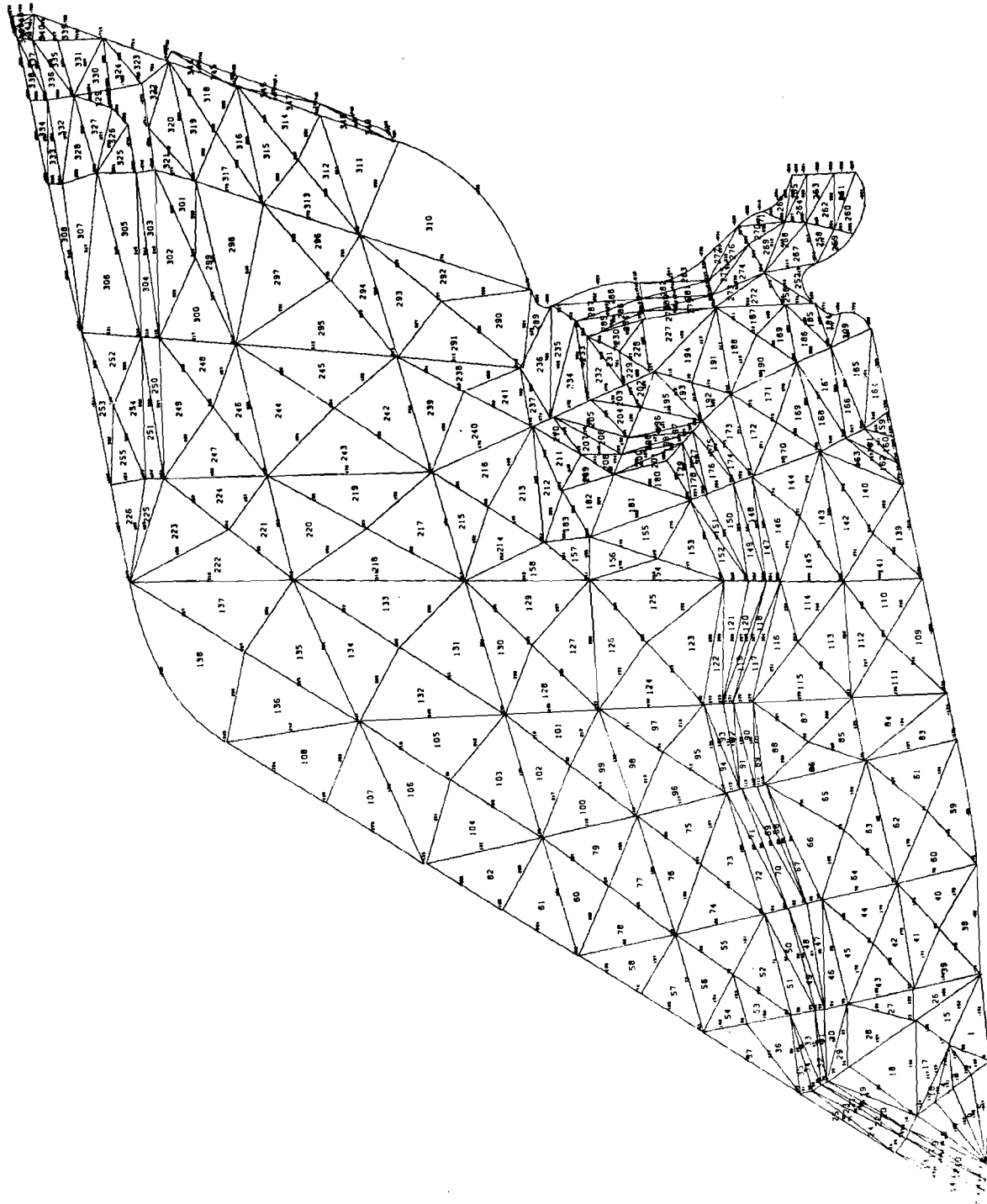


Figure 5.9. Walnut Creek Level 6 Network

Table 5.1. Continuity Checks for Various Levels

Continuity Check Line	Percent of Inflow Network					
	Level 1 Figure 6.4	Level 2 Figure 6.5	Level 3 Figure 6.6	Level 4 Figure 6.7	Level 5 Figure 6.8	Level 6 Figure 6.9
1	100.0	100.0	100.0	100.0	100.0	100.0
2	143.9	117.6	117.6	117.6	117.4	117.4
3	143.7	111.3	111.3	111.3	111.6	111.7
4	130.0	108.5	108.5	108.5	108.0	108.0
5	145.8	116.7	116.7	116.7	116.7	116.7
6	136.6	108.6	111.9	111.9	111.9	111.9
7	149.1	121.3	119.9	117.9	119.9	117.8
8	122.8	99.6	103.2	104.8	103.3	104.9
9	137.9	112.9	112.8	110.2	113.0	110.3
10	139.2	113.8	109.8	109.6	109.8	109.7
11	125.0	106.3	106.2	106.5	106.2	106.5

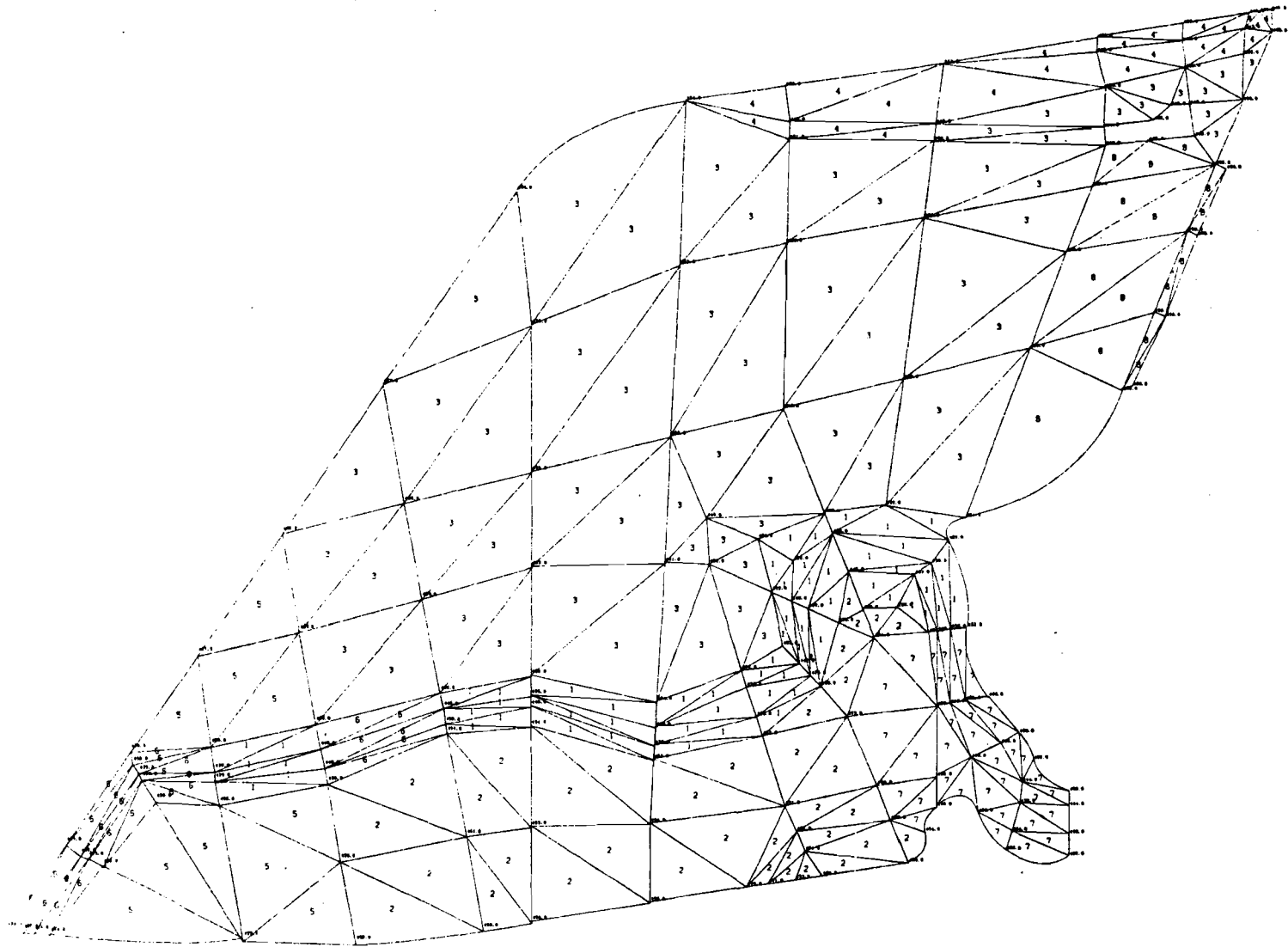


Figure 5.10. Walnut Creek, Level 1 Element Type Number

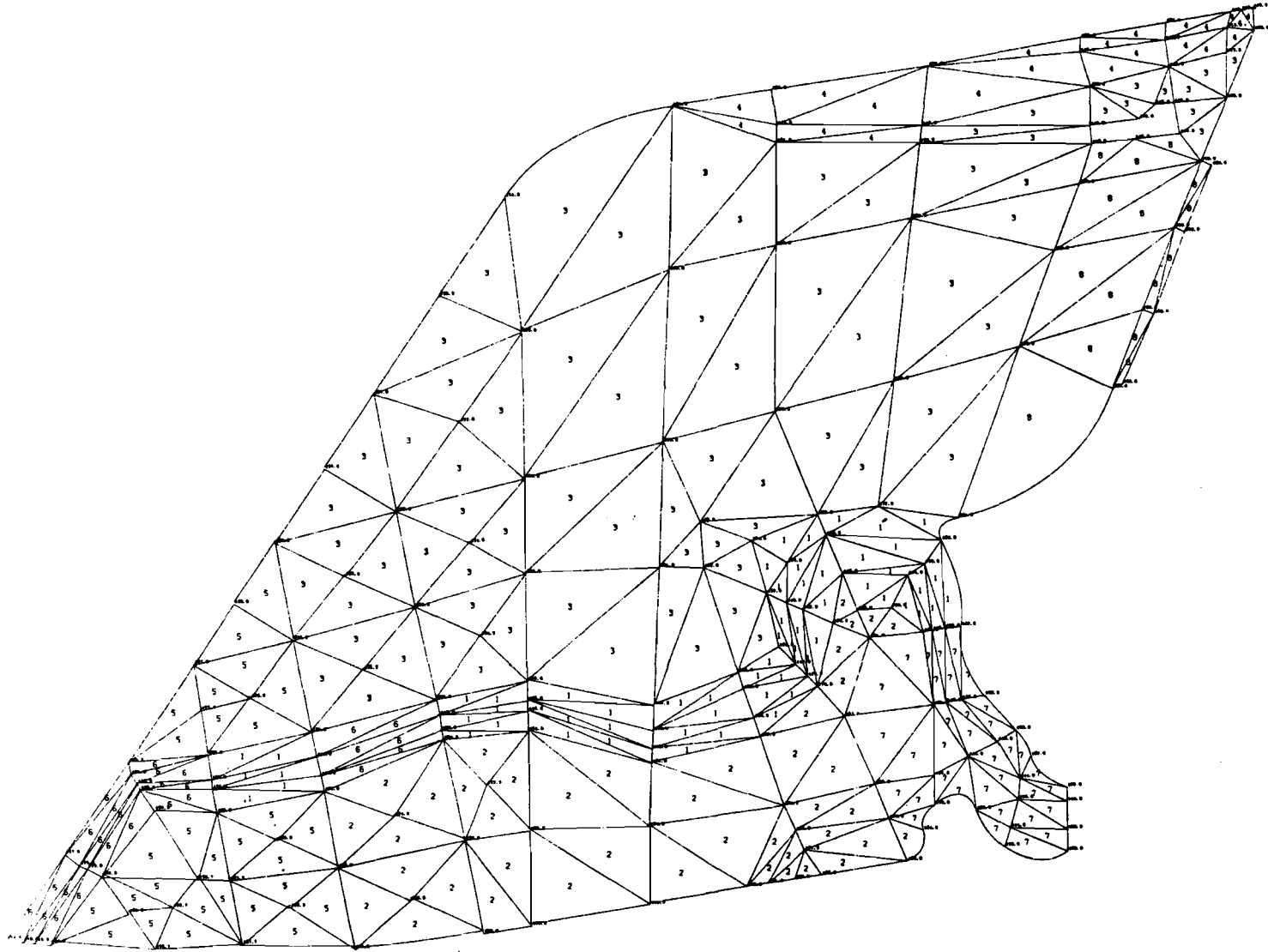


Figure 5.11. Walnut Creek, Level 2 Element Type Number

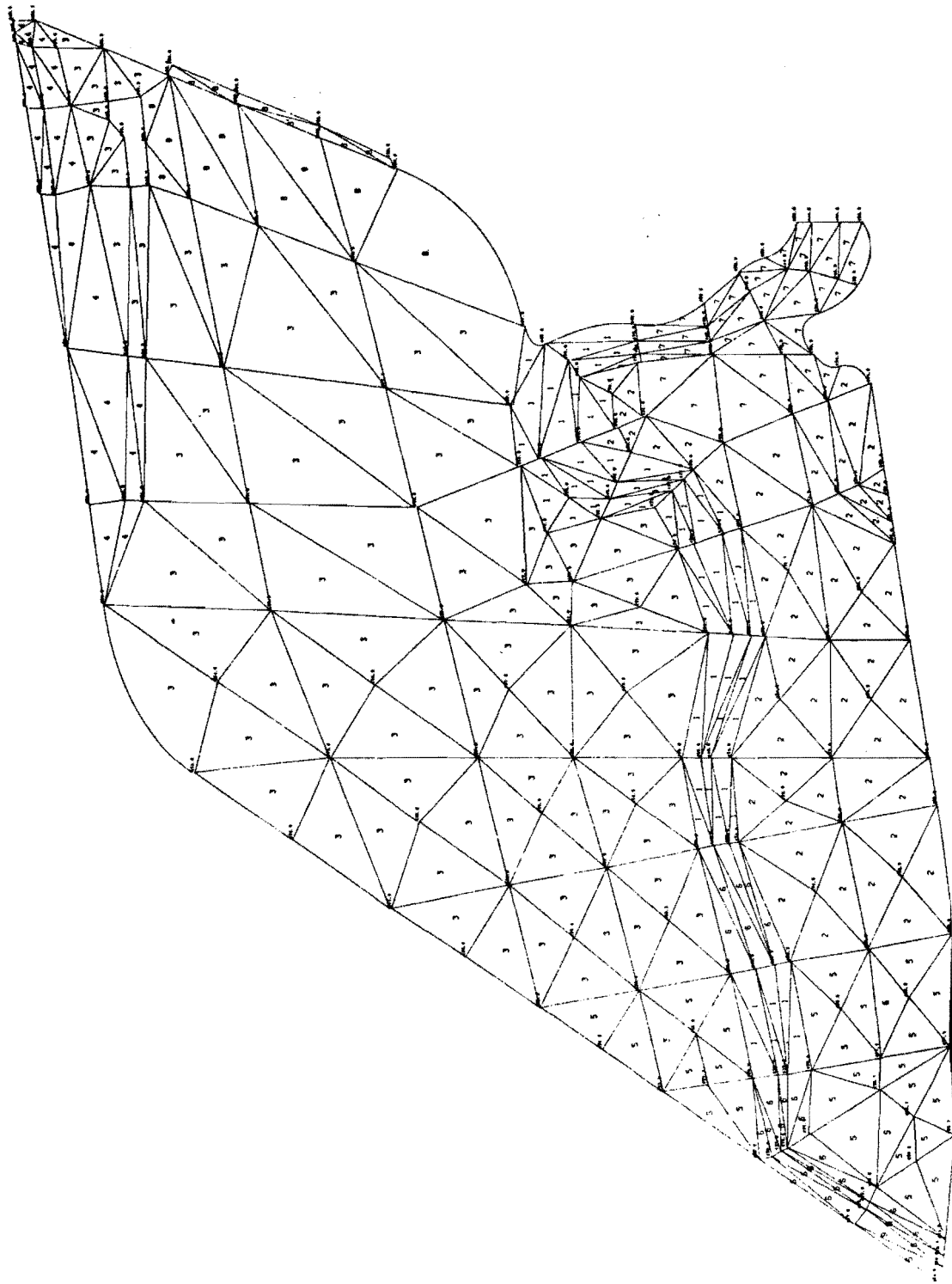


Figure 5.12. Walnut Creek, Level 3 Element Type Number

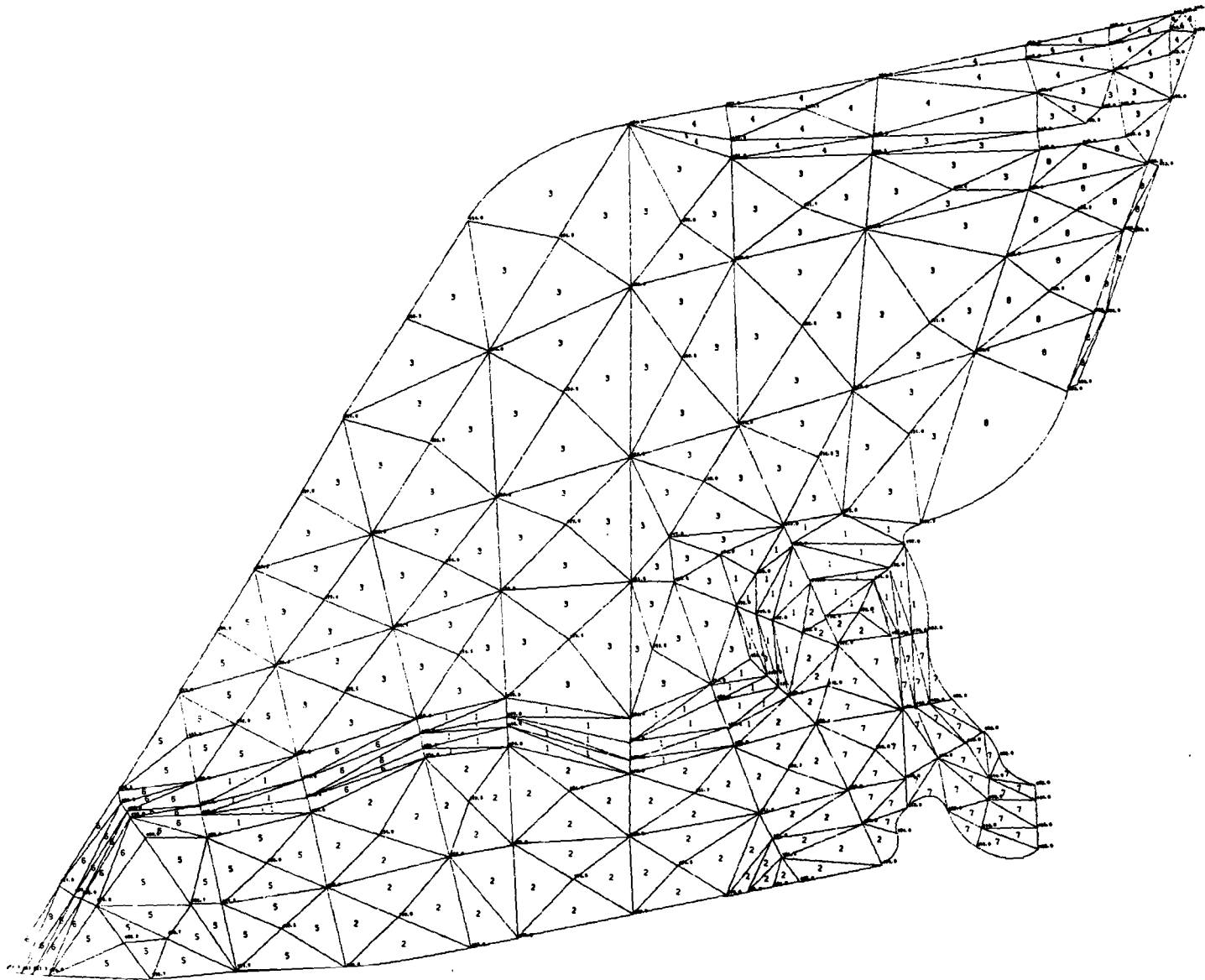


Figure 5.13. Walnut Creek, Level 4 Element Type Number

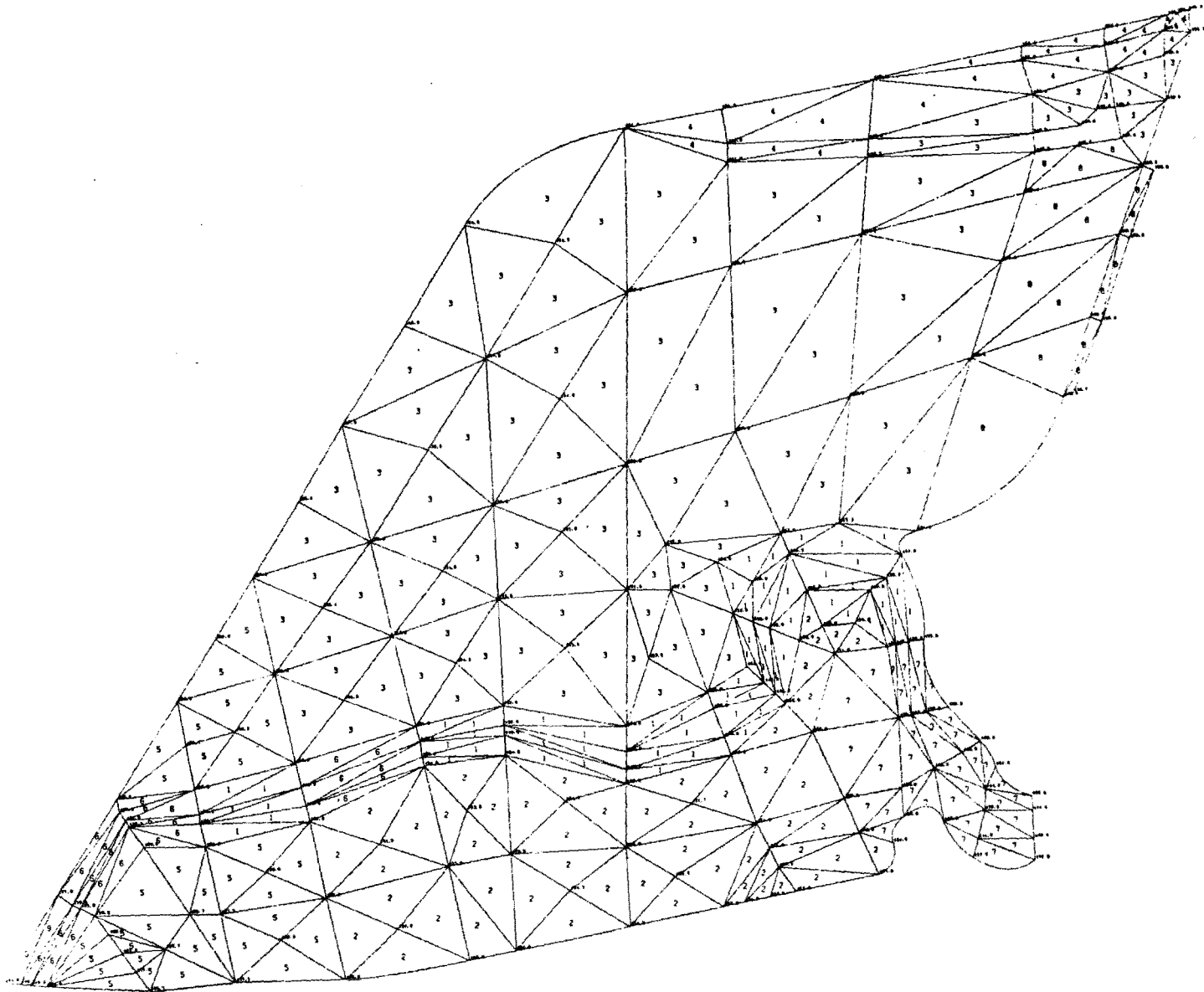


Figure 5.14. Walnut Creek, Level 5 Element Type Number

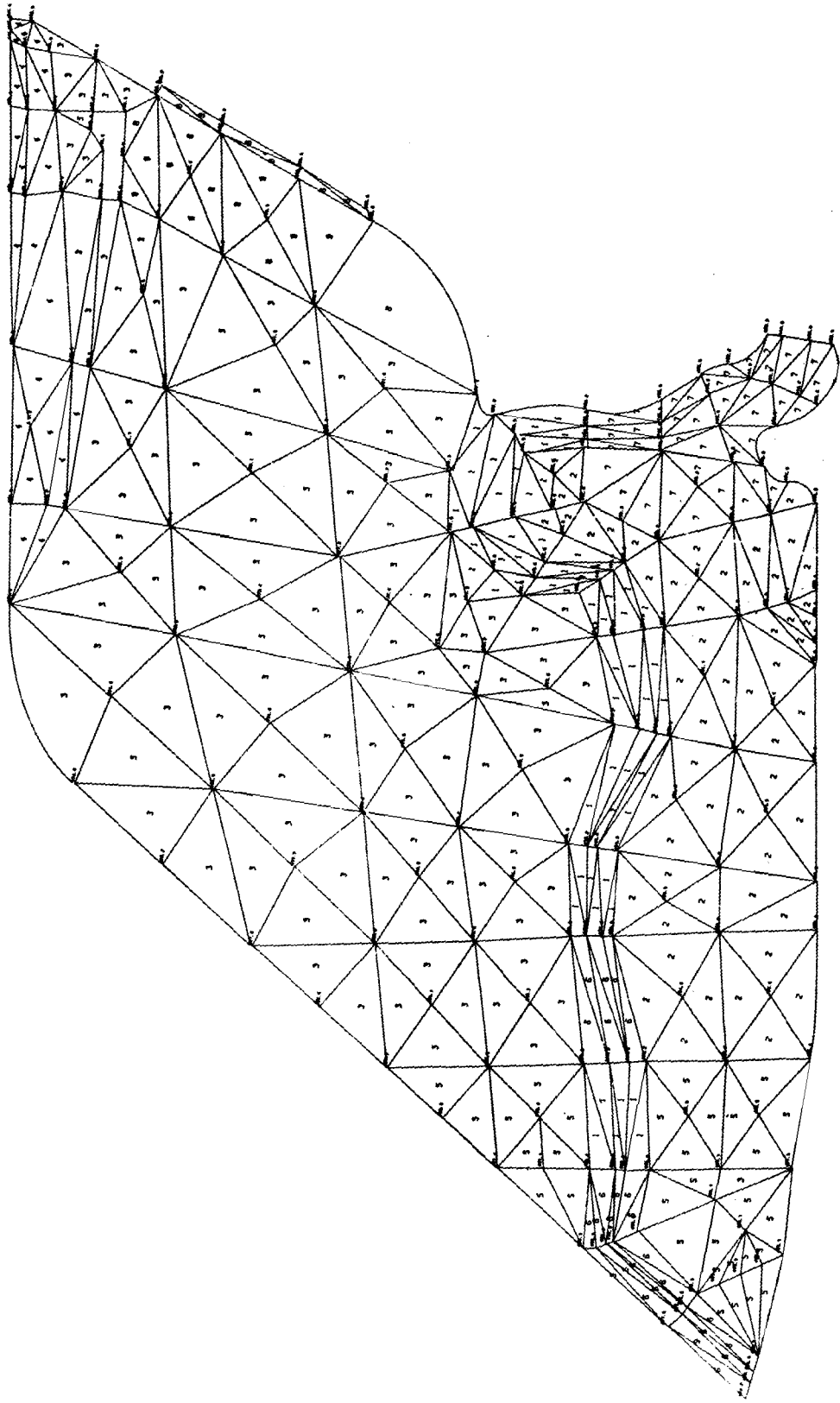


Figure 5.15. Walnut Creek, Level 6 Element Type Number

Table 5.2. Parameters for Element Types

Element Type Number	Turbulent Exchange Coefficient	Manning's Roughness Factor
1	200.	0.06
2	200.	0.10
3	200.	0.10
4	200.	0.08
5	200.	0.10
6	200.	0.06
7	200.	0.06
8	200.	0.10

Table 5.3. Size of Finite Element Networks and RMA-2 Execution Times for Each Level

Level	Number of Elements	Number of Nodes	Execution Time* for RMA2
1	261	593	855.404 (sec)
2	297	669	978.782
3	315	705	1036.041
4	345	765	1125.037
5	319	713	1050.669
6	349	773	1137.793

* CDC CYBER 170/175 System at the University of Texas at Austin

TABLE 5.4. COMPARISON OF WATER DEPTHS AT SELECTED LOCATIONS FOR VARIOUS LEVELS OF NETWORKS

Node Location	Water Depth (ft)					
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
A	5.557	4.709	4.710	4.710	4.713	4.714
B	28.001	27.061	27.061	27.062	27.065	27.065
C	3.740	3.138	3.138	3.139	3.140	3.141
D	26.583	25.872	25.873	25.874	25.874	25.875
E	3.220	2.504	2.505	2.506	2.506	2.507
F	5.351	4.771	4.776	4.780	4.776	4.781
G	19.234	18.624	18.623	18.628	18.624	18.629
H	3.469	2.881	2.872	2.877	2.873	2.880
I	1.731	1.119	1.205	1.214	1.206	1.215
J	3.375	2.825	2.794	2.810	2.795	2.811
K	17.090	16.544	16.542	16.559	16.543	16.560
L	3.260	2.731	2.723	2.735	2.724	2.735
M	0.884	0.490	0.499	0.463	0.499	0.463
N	5.189	4.695	4.682	4.711	4.683	4.712
O	4.739	4.287	4.284	4.314	4.285	3.787
P	11.007	10.524	10.522	10.558	10.522	10.559
Q	3.109	2.848	2.850	2.849	2.851	2.849
R	3.953	3.538	3.537	3.466	3.538	3.467
S	4.423	4.342	4.343	4.236	4.343	4.326
T	5.977	6.060	6.059	6.059	6.059	6.059
U	5.217	5.802	5.799	5.817	5.799	5.817
V	3.861	3.852	3.853	3.851	3.853	3.851
W	3.776	3.828	3.828	3.832	3.828	3.832
X	25.696	25.325	25.233	25.266	25.233	25.266
Y	14.773	14.466	14.465	14.482	14.465	14.482
Z	16.576	16.563	16.563	16.563	16.563	16.563

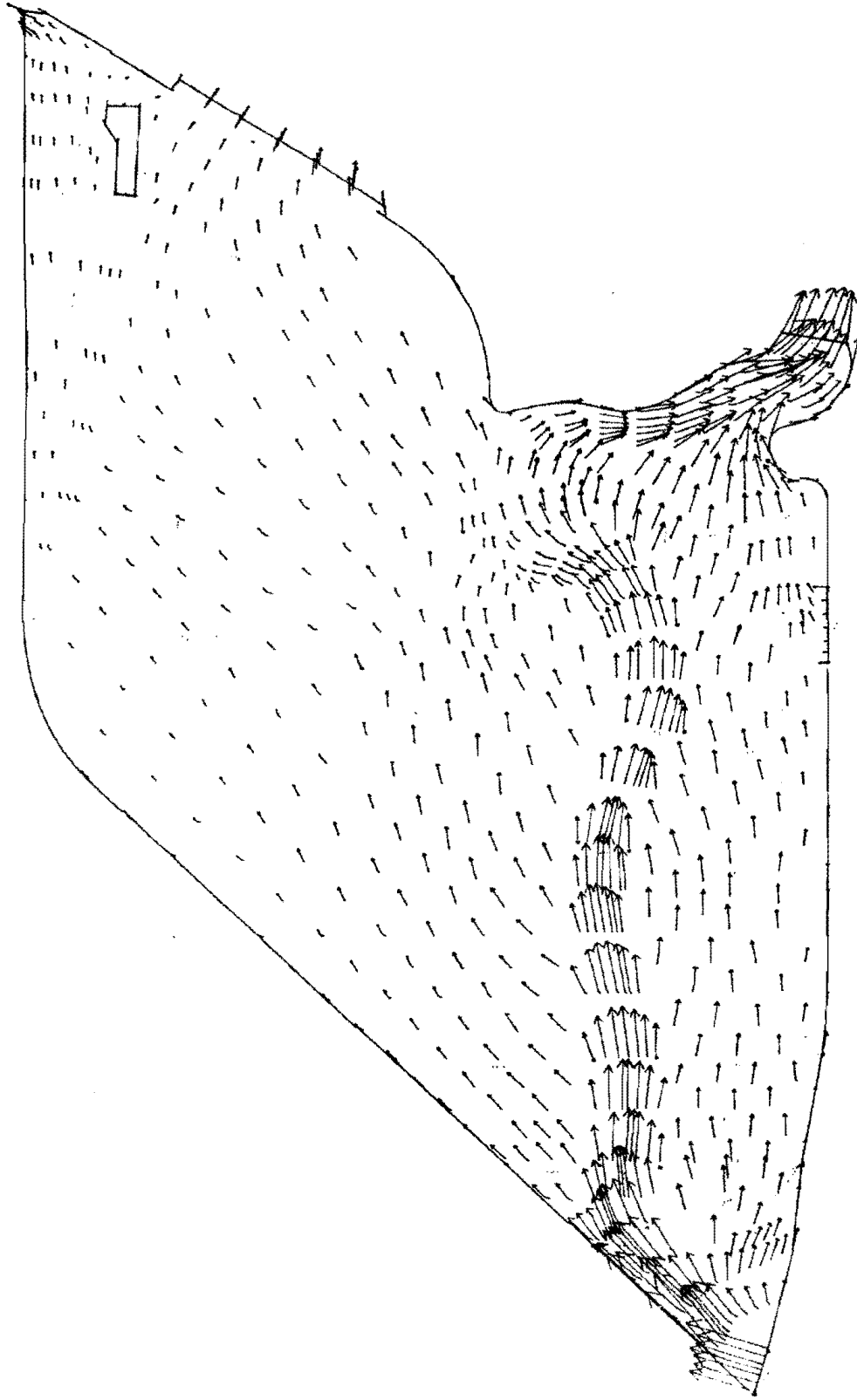


Figure 5.16. Walnut Creek Vector Plot (Level 6)

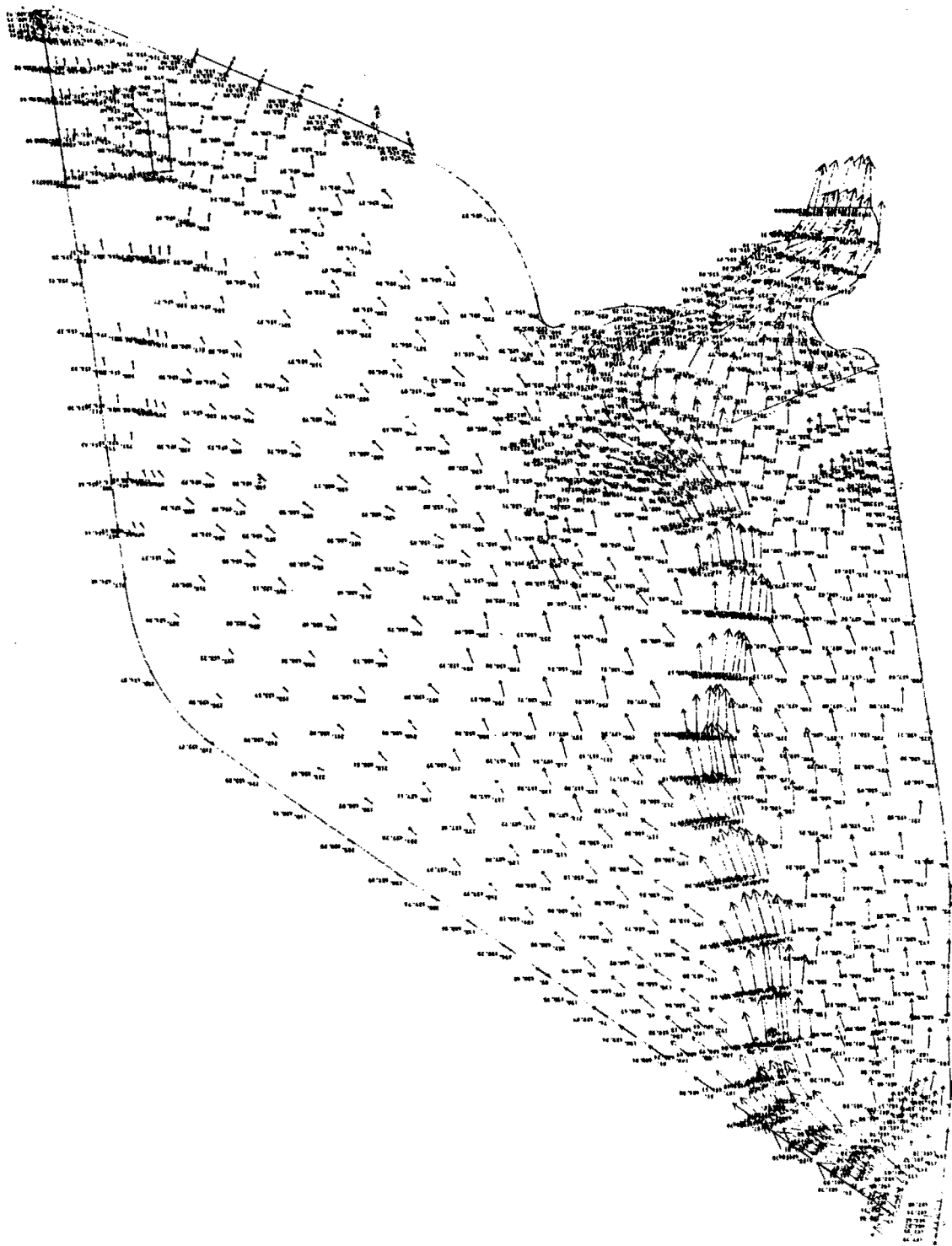


Figure 5.17. Walnut Creek Vector Plot with Water Surface Elevation (Level 6)

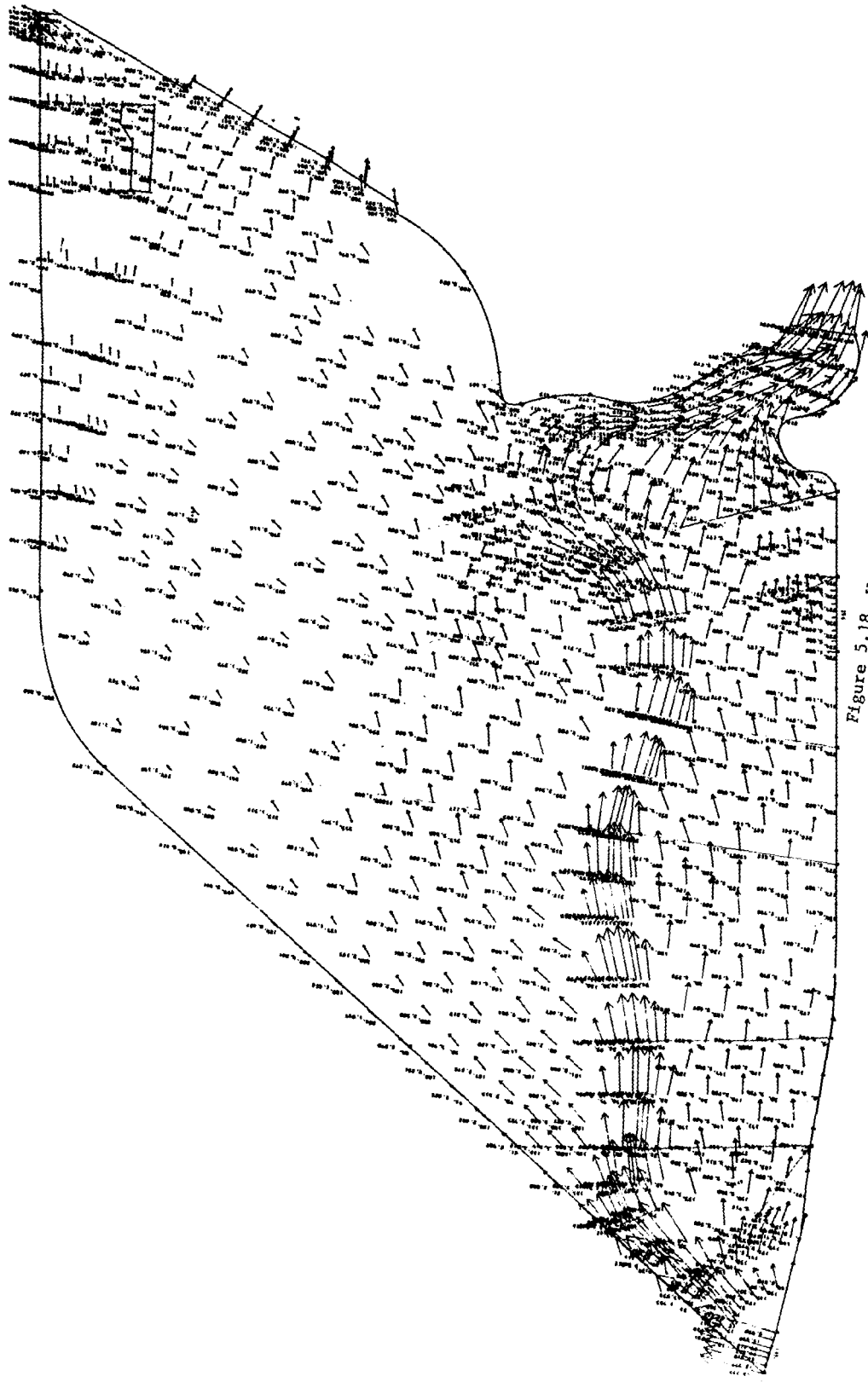


Figure 5.18 Walnut Creek Vector Plot with Water Depths (Level 6)

Figure 5.18. Walnut Creek Vector Plot with Water Depths (Level 6)

Table 5.5. Manning's Roughness Factors for Various Computer Runs

Element Type Number	Computer Runs					
	1	2	3	4	5	6
1	0.06	0.06	0.05	0.05	0.04	0.04
2	0.10	0.10	0.09	0.09	0.08	0.08
3	0.10	0.10	0.09	0.09	0.08	0.08
4	0.08	0.08	0.07	0.07	0.06	0.06
5	0.10	0.10	0.09	0.09	0.08	0.08
6	0.06	0.06	0.05	0.05	0.04	0.04
7	0.06	0.06	0.05	0.05	0.04	0.04
8	0.10	0.10	0.09	0.09	0.08	0.08
Turbulent Exchange Coefficient	200	150	200	150	200	150

Table 5.6. Continuity Checks for Various Levels

Continuity Check Line	Percent of Total Inflow					
	Computer Run Defined in Table 6.5					
	1	2	3	4	5	6
1	100.0	100.0	100.0	100.0	100.0	100.0
2	117.4	118.2	117.0	117.6	116.2	116.8
3	111.7	111.8	111.7	112.2	112.3	113.2
4	108.0	108.0	108.2	108.1	108.2	107.9
5	116.7	116.3	116.4	115.8	115.8	115.2
6	111.9	113.2	111.9	113.2	111.7	113.1
7	117.8	117.6	117.6	117.6	117.4	117.4
8	104.9	104.3	104.1	103.6	103.3	102.9
9	110.3	110.6	109.7	110.2	108.9	109.3
10	109.7	109.3	109.6	109.3	109.5	109.2
11	106.5	106.4	107.2	107.1	108.0	107.7

the various continuity check lines shown in Fig. 5.19. Comparisons of the water surface elevations at various nodes for the various computer runs (Table 5.5) are listed in Table 5.7, and the node locations are shown in Fig. 5.19.

5.2.3 Simulation of Various Discharges

Using the Level 6 finite element network (Figures 5.9 and 5.15) and the roughness factors and turbulent exchange coefficient for computer run 3 (Table 5.5), simulations of the floodplain were made using discharges of 10,400 cfs, 12,715 cfs, 14,300 cfs, 17,380 cfs, and 22,166 cfs. A comparison of water surface elevation at various nodes throughout the floodplain is listed in Table 5.8.

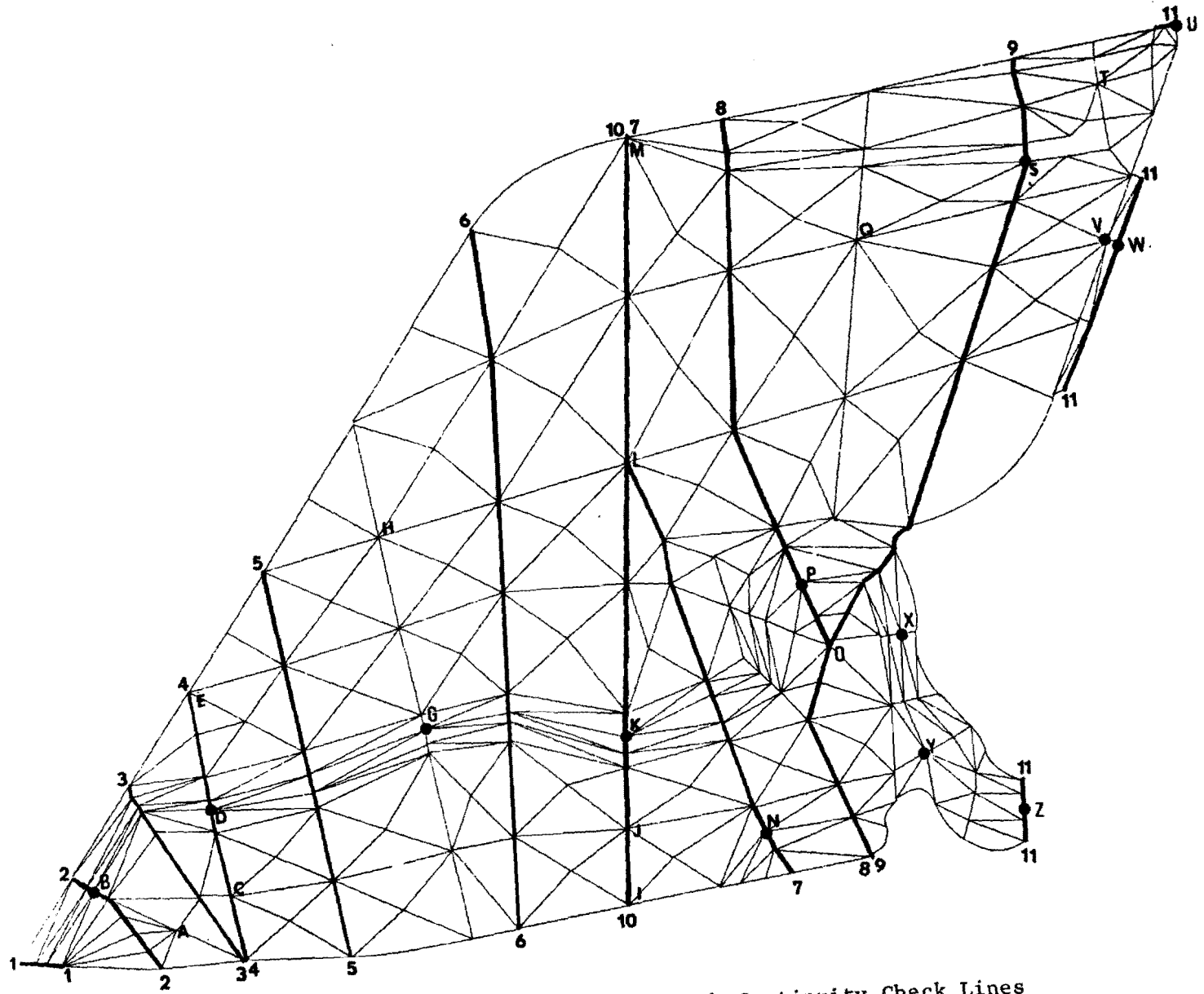


Figure 5.19. Walnut Creek Network with Continuity Check Lines

TABLE 5.7. COMPARISON OF WATER SURFACE ELEVATION FOR VARIOUS MANNING'S ROUGHNESS FACTORS

Computer Runs with Roughness Factor Defined in Table 6.5						
Node Number	1	2	3	4	5	6
A 17	461.464	461.295	461.071	460.894	460.661	460.475
B 20	462.095	461.865	461.628	461.420	461.173	460.958
C 52	460.891	460.728	460.547	460.376	460.190	460.012
D 55	460.875	460.703	460.562	460.379	460.243	460.053
E 61	460.007	459.854	459.707	459.544	459.404	459.235
F 108	458.581	458.472	458.303	458.188	458.017	457.895
G 114	458.629	458.532	458.360	458.257	458.079	457.970
H 120	457.880	457.775	457.620	457.507	457.347	457.224
I 299	457.215	457.110	456.987	456.876	456.759	456.642
J 301	456.811	456.711	456.557	456.452	456.296	456.186
K 307	456.560	456.464	456.309	456.208	456.052	455.947
L 313	455.735	455.672	455.519	455.456	455.303	455.241
M 317	454.463	454.401	454.319	454.264	454.198	454.150
N 348	455.712	455.641	455.483	455.410	455.255	455.180
O 427	455.315	455.248	455.108	455.038	454.902	454.829
P 471	455.559	455.502	455.372	455.316	455.191	455.135
Q 516	454.349	454.299	454.252	454.206	454.169	454.127
R 570	454.967	454.940	454.801	454.776	454.643	454.620
S 578	454.126	454.083	454.083	454.043	454.046	454.010
T 687	454.059	454.015	454.038	453.997	454.019	453.981
U 729	453.817	453.819	453.838	453.838	453.859	453.854
V 711	453.851	453.845	453.845	453.840	453.841	453.837
W 752	453.832	453.825	453.824	453.817	453.815	453.807
X 647	455.266	455.211	455.096	455.041	454.935	454.879
Y 624	454.482	454.454	454.366	454.339	454.256	454.231
Z 590	543.563	453.555	453.560	453.554	453.557	453.553

TABLE 5.8. COMPARISON OF WATER SURFACE ELEVATION FOR VARIOUS DISCHARGES

Node Number	Discharge (cfs)				
	10400	12715	14300	17380	22166
A 17	460.339	460.825	461.071	461.652	462.355
B 20	460.781	461.343	461.628	462.295	463.093
C 52	459.819	460.299	460.547	461.143	461.884
D 55	459.772	460.293	460.562	461.210	462.022
E 61	458.968	459.453	459.707	460.323	461.103
F 108	457.591	458.060	458.303	458.893	459.642
G 114	457.684	458.128	458.360	458.924	459.644
H 120	456.898	457.382	457.620	458.183	458.882
I 299	456.398	456.782	456.987	457.496	458.159
J 301	455.917	456.338	456.557	457.095	457.785
K 307	455.683	456.093	456.309	456.843	457.534
L 313	454.952	455.321	455.519	456.015	456.658
M 317	454.045	454.207	454.319	454.649	455.070
N 348	454.966	455.296	455.483	455.962	456.601
O 427	454.637	454.940	455.108	455.542	456.133
P 471	454.850	455.188	455.372	455.840	456.461
Q 516	454.053	454.174	454.252	454.465	454.663
R 570	454.395	454.652	454.801	455.192	455.708
S 578	453.984	454.047	454.083	454.147	453.913
T 687	454.002	454.031	454.038	453.957	452.643
U 729	453.975	453.909	453.838	453.316	448.000
V 711	453.830	453.839	453.845	453.856	453.820
W 752	453.830	453.828	453.824	453.777	453.509
X 647	454.618	454.925	455.096	455.543	456.158
Y 624	454.077	454.260	454.366	454.654	455.080
Z 590	453.545	453.554	453.560	453.572	453.586

CHAPTER 6

SUMMARY AND FUTURE TASKS

6.1 Summary of Work Accomplished

The objective of this project has been to modify and apply a computer program for the two-dimensional hydrodynamic analysis of backwater at bridges. The computer code used is a model originally developed as a research tool referred to as the RMA model (Resource Management Associates). The U. S. Geological Survey Gulf Coast Hydroscience Center has further modified the RMA model and has performed several major applications of the model. This modified version has been referred to as the FESWMS (Finite-Element Surface-Water Modeling System).

The U.S.G.S. Gulf Coast Hydroscience Center has been performing research to improve the two-dimensional model. The emphasis of this past work has been more of a theoretical effort to improve the computational aspects as opposed to making the model user oriented, which was the objective of this project. The FESWMS model is not in a user-oriented format and requires a rather sophisticated knowledge of fluid mechanics, hydraulics, and computer science to use. In addition, an extensive amount of detailed data determination and input is required that can be simplified and automated using computer graphics.

The work performed herein has been to simplify use of the computer program so that it could possibly become a part of the THYSYS system for widespread use throughout the Texas Highway Department and other highway departments in the U.S. The emphasis then has been to make the program as user oriented as possible, defining what data are necessary, how to assemble the data and what the output is. Input and output formats would be as similar as possible to that used in THYSYS. In addition, some work has been performed to automate the data determination and the input

procedure using the Intergraph IGDS (Interactive Graphics Design System) at the Texas Highway Department. The modified version of the FESWMS model is referred to as the FESWMS-TX model.

The work accomplished during this project is summarized below:

- I. Several needed modifications to the program FESWMS were identified and incorporated to simplify the use of the model to the new version referred to as the FESWMS-TX model. These modifications include:
 1. Conversion from use of Chezy's roughness coefficient to Manning's roughness coefficient.
 2. Change input of upstream boundary condition from a flow rate per unit depth at each node to a total discharge. A routine USSET has been written and incorporated to simplify this process of describing the upstream boundary condition.
 3. Simplify the running process of FESWMS by incorporating routines to check output files for negative depths that would cause non-convergence of the numerical scheme. In addition, these routines modify the network and input files for the preprocessor, RMA-1, and the processor, RMA-2, in order to restart the running process. A computer program USNEG was written which is now part of the FESWMS-TX modeling system.
 4. Automate the manual process of interactively running the computer program, RMA-1, RMA-2, and USNEG programs that make up the FESWMS-TX modeling system.
 5. Simplify the input process to RMA-1 and RMA-2.
 6. Explore the use of computer graphics to simplify and refine the input process which is beyond the scope of work to be accomplished.

II. The model was applied to Walnut Creek near Martin Luther King Blvd. in Austin, Texas to help identify the various needed modifications mentioned above.

III. Use of the Intergraph IGDS (Interactive Graphics Design System) at the DHT was explored for use as an automated approach to construct and define the finite element network using computer graphics.

IV. This report includes a users manual for the FESWMS-TX model.

V. A third application site near Rosebud, Texas was selected for application. The contour maps have been digitized by the DHT Automation Division; however, they were not complete so this application could not be made before the project ended. This application is further described in the next section on new tasks.

It should be emphasized that the objectives of the original project have been completed. The work investigating use of computer graphics on the Intergraph for data development and inputting was beyond the scope of this original project. However, it is felt that this work is of such value that it should be completed.

6.2 Future Tasks

The following are the new tasks beyond the scope and objectives of the present project:

(1) During the course of the project work on refining the FESWMS-TX model it became evident that the data input procedure was very time consuming, especially for large floodplain areas with multiple opening bridges. The most time consuming and difficult information to obtain was (a) the definition of the network or element structures, (b) numbering of the nodes and elements, (c) determining the x and y coordinates

and ground surface elevation, (d) determining corner node slopes, and (e) then inputting this information in the format required by the FESWMS-TX model. It became very apparent in the project that the time and expense of developing the input could be reduced significantly (at least five times) by use of the Intergraph IGDS (Interactive Graphics Design System). Also, the process would be error proof. The IGDS has become an integral part of the DHT Automation (Computer) System and is presently used extensively.

Use of the Intergraph IGDS was beyond the scope of the present project and funding; however, because of its obvious importance to the effective use of the FESWMS-TX model, initial work has been done by both the investigators and TDH Automation Division to explore use of the IGDS. In fact, the TDH Automation Division has developed software that can be used in conjunction with the FESWMS-TX model for inputting the above described data. The work of implementing and refining the computer graphics could not be completed by the project ending date. The computer graphics capability could be expanded and demonstrated using the application described in Task 2 and also a second demonstration described in Task 5.

(2) At the same time the above software was developed, a contour map was developed and digitized by the Automation Division for purposes of (a) demonstrating and further refining the FESWMS-TX model, (b) demonstrating the use of the Intergraph IGDS to develop the input for the FESWMS-TX model, and (c) checking the hydraulics of the new bridge design, in particular effects of backwater. The contour map is of the floodplain upstream and downstream of Highway 53 at the confluence of Pond Creek, Cottonwood Creek, and Salt Creek near Rosebud, Texas. A new bridge is being designed for Highway 53 at this location. The final map was not completed in time for application. The objective of this task is to apply the FESWMS-TX modeling system and the Intergraph computer graphics to satisfy the above purposes.

(3) This report was written to describe the work accomplished for the duration of the present project. This report includes a user's manual for the FESWMS-TX model. However, once the computer graphics Intergraph IGDS is fully accomplished the user's manual will need to be modified. Also further modifications will be required to get it into the same format as the THYSIS models.

(4) Another very important task that has been identified during the present work is the need for incorporation of a one-dimensional backwater code to better define the upstream and downstream boundary conditions for the FESWMS-TX model. This would help considerably in application of the FESWMS-TX model to define bridge-backwater effects.

(5) Another task would be to perform a second demonstration of using the Intergraph IGDS and FESWMS-TX model. This would be an application for an actual (new) bridge design, preferably with multiple openings located in a wide flat floodplain. The digitized contour map would have to be furnished by the Texas Highway Department. Through the demonstration in this task and the Rosebud application, further guidelines on use of the model can be established.

(6) A final task would be to incorporate all improvements or changes made by the U.S.G.S. in the FESWMS model to the FESWMS-TX model. These changes would be those approved by both the investigator and the TDH contact person to this proposed work.

6.3 Interactive Graphics Design System IGDS

The use of the Interactive Graphics Design System (IGDS) automates the process of defining and inputting the data described above. In order to use the IGDS system for defining a finite element network, a contour map of the floodplain must be digitized and stored on the IGDS system.

The Intergraph is an integrated configuration of hardware and software featuring user-controlled interactive graphics. The Interactive Graphics Design System (IGDS) has capabilities that include:

1. Placement, deletion, modification, and movement of design elements such as finite elements and nodes.
2. On-line user definition of any combination of design elements such as a finite element network.
3. Storage and retrieval of intermediate and final designs of the finite element network.
4. Two graphic display screens which allow a large-scale overview (such as an entire floodplain) to be placed on one screen while a magnified (zoomed) detail view (such as one section of a floodplain) is placed on the other.
5. Two-dimensional capability (x and y) so that an x- and y-coordinate system is automatically established by the system and can be modified by the user.
6. Extensive facilities for the support in defining and manipulating non-graphic attribute data. Attribute data can be associated with graphic elements (such as nodes, curves, and finite elements) and interactively reviewed, edited, and reported.
7. The system accepts data and commands through an alphanumeric keyboard and a graphics menu tablet. The keyboard is used for command data entries to the displays. The graphics menu tablet is used both on a function selection device and for indication of x and y coordinates on the graphics screen.

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Appendix A

Listing of Subroutine USSET

```

SUBROUTINE USSET
C
C THE PROGRAM IS DEVELOPED FOR SETTING FLOW RATES FOR U/S NODES
C
COMMON /BLKB/ CORD( 825,2),NBC( 825,3),VEL(3, 825),SPEC( 825,3),
1 ALFA( 825),AO( 825),SIGMA( 825,2),VOLD(3, 825),
2 VDOT(3, 825),NOP( 371,8),IMAT( 371),ORT(50,5),
3 NFIX( 825),NFI( 825),NLOC( 825),VDOTO(3, 825),TH( 371)
C-
COMMON /CNTRL/ LE,LP,NBUS,NNXUS(25)
DIMENSION DEPTH(20),CSAREA(20)
DIMENSION DEM(20),XDEPTH(20),QSEC(20),PROP(20)
DIMENSION A01( 40),CORD1( 40,2),AREA1( 40),DEM1( 40)
DIMENSION A02( 80),CORD2( 80,2),AREA2( 80),DEM2( 80)
DIMENSION A03(160),CORD3(160,2),AREA3(160),DEM3(160)
DIMENSION A04(320),CORD4(320,2),AREA4(320),DEM4(320)
C NBUS : # OF U/S NODES (MID-POINTS INCLUDED)
C NCORD: # OF U/S NODES (MID-POINTS NOT INCLUDED)
C
C **** THE ORDER OF NODES SHOWN ON THE U/S INLET MUST OBEY THE
C **** THE RULE OF INITIAL NODE BEING ON THE RIGHT HAND SIDE WHEN
C **** FACING THE INLET ALONG THE DIRECTION OF FLOW.
C *****
C
C
C Y Y
C Y Y
C Y Y #5 /
C Y Y \ #1 (INITIAL NODE)
C Y >>> FLOW <<<
C Y >>> IN <<<
C Y
C Y #1 /
C Y \ #5
C Y
C O X X X X X X X X X X X X X X X X O X X X X X X X X X X X X X X X X
C
READ 5,NBUS,NCORD,QDISCH,WSELEV
5 FORMAT(2I5,2F10.2)
READ 10,(NNXUS(N),N=1,NBUS)
10 FORMAT(16I5)
C
NLAST=NNXUS(NBUS)
NSTART=NNXUS(1)
C
C
C READ THE COORDINATES FOR U/S NODES
C
DO 12 IK=1,NBUS,2
KK=NNXUS(IK)
C*****READ 7,CORD(KK,1),CORD(KK,2),AO(KK)
7 FORMAT(10X,3F10.2)
12 CONTINUE
C
C CALCULATE COORDINATES FOR MID-POINTS
C
DO 15 ILL=1,NBUS-2,2
IKK=NNXUS(ILL)
IKK1=NNXUS(ILL+1)
IKK2=NNXUS(ILL+2)
CORD(IKK1,1)=0.5*(CORD(IKK,1)+CORD(IKK2,1))
CORD(IKK1,2)=0.5*(CORD(IKK,2)+CORD(IKK2,2))
AO(IKK1)=0.5*(AO(IKK)+AO(IKK2))
15 CONTINUE

```



```

C*****PRINT *, 'NSTART=', NSTART, 'NLSAT=', NLAST
C
C*****PRINT 998
998 FORMAT(/, 'NODE X-COORD Y-COORD ELEV')
C
C*****PRINT 111, (N, CORD(N,1), CORD(N,2), A0(N), N=NSTART, NLAST)
111 FORMAT(14, ' ', 3F10.1)
C
C DETERMINE CROSS-SECTIONAL AREA OF FLOW FOR EACH NODE
C
C*****
C
C DIVIDE EACH NODE TO TWO SUB-NODES. (FIRST)
C
NBUS1=NBUS*2 - 1
LL=0
DO 20 L=1, NBUS1, 2
LL=LL+1
LKK=NXUS(LL)
CORD1(L,1)=CORD(LKK,1)
CORD1(L,2)=CORD(LKK,2)
A01(L)=A0(LKK)
20 CONTINUE
C
DO 30 LI=1, NBUS1-2, 2
CORD1(LI+1,1)=0.5*(CORD1(LI,1)+CORD1(LI+2,1))
CORD1(LI+1,2)=0.5*(CORD1(LI,2)+CORD1(LI+2,2))
A01(LI+1)=0.5*(A01(LI+2)+A01(LI))
30 CONTINUE
C
C*****
C
C DIVIDE EACH SUB-NODE TO TWO SMALL NODES (SECOND)
C
NBUS2=NBUS1*2 - 1
LK=0
DO 40 LI=1, NBUS2, 2
LK=LK+1
CORD2(LI,1)=CORD1(LK,1)
CORD2(LI,2)=CORD1(LK,2)
A02(LI)=A01(LK)
40 CONTINUE
C
DO 50 LII=1, NBUS2-2, 2
CORD2(LII+1,1)=0.5*(CORD2(LII,1)+CORD2(LII+2,1))
CORD2(LII+1,2)=0.5*(CORD2(LII,2)+CORD2(LII+2,2))
A02(LII+1)=0.5*(A02(LII+2)+A02(LII))
50 CONTINUE
C
C*****
C
C DIVIDE EACH SMALL NODE TO TWO SUB-SMALL NODES (THIRD)
C
NBUS3=NBUS2*2 - 1
LK=0
DO 60 LI=1, NBUS3, 2
LK=LK+1
CORD3(LI,1)=CORD2(LK,1)
CORD3(LI,2)=CORD2(LK,2)
A03(LI)=A02(LK)
60 CONTINUE
C
DO 70 LII=1, NBUS3-2, 2
CORD3(LII+1,1)=0.5*(CORD3(LII,1)+CORD3(LII+2,1))
CORD3(LII+1,2)=0.5*(CORD3(LII,2)+CORD3(LII+2,2))

```

```

      A03(LI1+1)=0.5*(A03(LI1+2)+A03(LI1))
70 CONTINUE
C
C *****
C
C DIVIDE EACH SUB-SMALL NODE TO TWO SUB-SUB-SMALL NODES (FOURTH)
C
      NBUS4=NBUS3*2 - 1
      LK=0
      DO 80 LI=1,NBUS4,2
      LK=LK+1
      CORD4(LI,1)=CORD3(LK,1)
      CORD4(LI,2)=CORD3(LK,2)
      A04(LI)=A03(LK)
80 CONTINUE
C
      DO 90 LI1=1,NBUS4-2,2
      CORD4(LI1+1,1)=0.5*(CORD4(LI1,1)+CORD4(LI1+2,1))
      CORD4(LI1+1,2)=0.5*(CORD4(LI1,2)+CORD4(LI1+2,2))
      A04(LI1+1)=0.5*(A04(LI1+2)+A04(LI1))
90 CONTINUE
C
C *****
C
      NSSTT=1
      NLAST1=NBUS1
      NLAST2=NBUS2
      NLAST3=NBUS3
      NLAST4=NBUS4
      DEM4T=0.0
      AREAT=0.0
      DO 500 NSEC=1,NBUS4
      JJM=NSEC
      IF(JJM.GT.NSSTT.AND.JJM.LT.NLAST4) GO TO 100
      IF(JJM.EQ.NSSTT) JR=NSSTT+1
      IF(JJM.EQ.NSSTT) GO TO 110
      IF(JJM.EQ.NLAST4) JL=NLAST4-1
      IF(JJM.EQ.NLAST4) GO TO 120
100 CONTINUE
C
      JL=NSEC-1
      JR=NSEC+1
C
110 CONTINUE
      DXMR=CORD4(JR,1)-CORD4(JJM,1)
      DYMR=CORD4(JR,2)-CORD4(JJM,2)
      DMR=(DXMR*DXMR+DYMR*DYMR)**0.5
      IF(JJM.EQ.NSSTT) DML=DMR
      IF(JJM.EQ.NSSTT) GO TO 140
C
120 CONTINUE
      DXML=CORD4(JJM,1)-CORD4(JL,1)
      DYML=CORD4(JJM,2)-CORD4(JL,2)
      DML=(DXML*DXML+DYML*DYML)**0.5
      IF(JJM.EQ.NLAST4) DMR=DML
C
140 CONTINUE
      DEM4(JJM)=0.5*(DML+DMR)
C
      DEPTH(JJM)=WSELEV-A04(JJM)
      AREA4(JJM)=DEPTH(JJM)*DEM4(JJM)
      AREAT=AREAT+AREA4(JJM)
      DEM4T =DEM4T +DEM4(JJM)
C
C*****PRINT 976,JJM,A04(JJM),DEPTH(JJM),DEM4(JJM),AREA4(JJM)
976 FORMAT(' JJM= ',I3,' ELEV=',F10.3,' DEPTH=',F10.3,' LENGTH= ',

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```

      1      F10.3, ' AREA=' ,F10.3)
C
C 500 CONTINUE
C
C
C*****PRINT 112,AREAT,DEM4T
      112 FORMAT('TOTAL AREA=' ,F10.2,3X, 'TOTAL WIDTH=' ,F10.2)
C
C
C ++++++
C
C      CALCULATE THE AREA UNDER EACH SUB-SMALL NODE
C
      DO 520 M=1,NBUS3
      M2=M*2
      IF(M.EQ.NSSTT) AREA3(M)=AREA4(M2)+0.5*AREA4(M2-1)
      IF(M.EQ.NSSTT) DEM3(M)= DEM4(M2)+0.5*DEM4(M2-1)
      IF(M.EQ.NLAST2) AREA3(M)=AREA4(M2-1)+0.5*AREA4(M2-2)
      IF(M.EQ.NLAST2) DEM3(M)=DEM4(M2-1)+0.5*DEM4(M2-2)
C
      AREA3(M)=AREA4(M2-1)+0.5*AREA4(M2-2)+0.5*AREA4(M2)
      DEM3(M)=DEM4(M2-1)+0.5*DEM4(M2-2)+0.5*DEM4(M2)
C*****PRINT 986,M,AREA3(M),DEM3(M)
      986 FORMAT(' M= ',I5, ' AREA3= ',F10.3, ' DEM3= ',F10.3)
C
      520 CONTINUE
C
C ++++++
C
C      CALCULATE THE AREA UNDER EACH SMALL NODE
C
      DO 530 M=1,NBUS2
      M2=M*2
      IF(M.EQ.NSSTT) AREA2(M)=AREA3(M2)+0.5*AREA3(M2-1)
      IF(M.EQ.NSSTT) DEM2(M)= DEM3(M2)+0.5*DEM3(M2-1)
      IF(M.EQ.NLAST2) AREA2(M)=AREA3(M2-1)+0.5*AREA3(M2-2)
      IF(M.EQ.NLAST2) DEM2(M)=DEM3(M2-1)+0.5*DEM3(M2-2)
C
      AREA2(M)=AREA3(M2-1)+0.5*AREA3(M2-2)+0.5*AREA3(M2)
      DEM2(M)=DEM3(M2-1)+0.5*DEM3(M2-2)+0.5*DEM3(M2)
C*****PRINT 989,M,AREA2(M),DEM2(M)
      989 FORMAT(' M= ',I5, ' AREA2= ',F10.3, ' DEM2= ',F10.3)
C
      530 CONTINUE
C
C ++++++
C
C      CALCULATE THE AREA UNDER EACH SUBNODE
C
      DO 540 M=1,NBUS1
      M2=M*2
      IF(M.EQ.NSSTT) AREA1(M)=AREA2(M2)+0.5*AREA2(M2-1)
      IF(M.EQ.NSSTT) DEM1(M)= DEM2(M2)+0.5*DEM2(M2-1)
      IF(M.EQ.NLAST1) AREA1(M)=AREA2(M2-1)+0.5*AREA2(M2-2)
      IF(M.EQ.NLAST1) DEM1(M)=DEM2(M2-1)+0.5*DEM2(M2-2)
C
      AREA1(M)=AREA2(M2-1)+0.5*AREA2(M2-2)+0.5*AREA2(M2)
      DEM1(M)=DEM2(M2-1)+0.5*DEM2(M2-2)+0.5*DEM2(M2)
C*****PRINT 975,M,AREA1(M),DEM1(M)
      975 FORMAT(' M= ',I5, ' AREA1= ',F10.3, ' DEM1= ',F10.3)
      540 CONTINUE
C
C -----
C
C      RECALCULATE THE AREA UNDER EACH NODE
C

```

```

DO 550 KKM=1,NBUS
MM2=2*KKM
MM=NNXUS(KKM)
IF(MM.EQ.NSSTT) CSAREA(MM)=AREA1(MM2)+0.5*AREA1(MM2-1)
IF(MM.EQ.NSSTT) DEM(MM)=DEM1(MM2)+0.5*DEM1(MM2-1)
IF(MM.EQ.NLAST) CSAREA(MM)=AREA1(MM2-1)+0.5*AREA1(MM2-2)
IF(MM.EQ.NLAST) DEM(MM)=DEM1(MM2-1)+0.5*DEM1(MM2-2)
CSAREA(MM)=AREA1(MM2-1)+0.5*AREA1(MM2-2)+0.5*AREA1(MM2)
DEM(MM)=DEM1(MM2-1)+0.5*DEM1(MM2-2)+0.5*DEM1(MM2)
C*****PRINT 977,MM,CSAREA(MM),DEM(MM)
977 FORMAT('MM=',15,' CSAREA = ',F10.3,' DEM =',F10.3)
550 CONTINUE
C
C *****
C
C*****PRINT 999
999 FORMAT(/,4X,' NODE ',2X,' AREA ',2X,' PROP ',2X,' LENGTH',3X,
2 ' DEPTH FLOW RATE')
C
DO 600 NNSEC=1,NBUS
C
C CALCULATE FLOW RATE FOR EACH SECTION (NODE)
C
JM=NNXUS(NNSEC)
PROP(JM)=CSAREA(JM)/AREAT
XDEPTH(JM)=WSELEV-AO(JM)
QSEC(JM)=PROP(JM)*QDISCH/DEM(JM)
C
C*****PRINT 113,JM,CSAREA(JM),PROP(JM),DEM(JM),XDEPTH(JM),QSEC(JM)
113 FORMAT(I10,6F10.2)
C
C
600 CONTINUE
C
C COMPUTE ANGLE
C
JRR=NNXUS(1)
JLL=NNXUS(NBUS)
DX=CORD(JRR,1)-CORD(JLL,1)
DY=CORD(JRR,2)-CORD(JLL,2)
IF(DX.EQ.0.0) XSIN=1.0
IF(DX.EQ.0.0) XCOS=0.0
IF(DY.EQ.0.0) XSIN=0.0
IF(DY.EQ.0.0) XCOS=1.0
IF(DX.EQ.0.0.OR.DY.EQ.0.0)GO TO 698
C
AN=ABS(DY)/ABS(DX)
ANGLE=ATAN(AN)
XSIN=SIN(ANGLE)
XCOS=COS(ANGLE)
C
698 CONTINUE
C
DO 700 NNSEC=1,NBUS
JM=NNXUS(NNSEC)
SPEC(JM,1)= XSIN*QSEC(JM)
SPEC(JM,2)= XCOS*QSEC(JM)
C
C CONSIDER EIGHT DIFFERENT CONDITIONS
C
C FIRST
IF(DX.GT.0.0.AND.DY.LT.0.0) SPEC(JM,1)=SPEC(JM,1)
IF(DX.GT.0.0.AND.DY.LT.0.0) SPEC(JM,2)=SPEC(JM,2)
C
C SECOND

```

```

C
  IF(DX.LT.0.0.AND.DY.GT.0.0) SPEC(JM,1)=-SPEC(JM,1)
  IF(DX.LT.0.0.AND.DY.GT.0.0) SPEC(JM,2)=-SPEC(JM,2)
C
C THIRD
C
  IF(DX.GT.0.0.AND.DY.GT.0.0) SPEC(JM,1)=-SPEC(JM,1)
  IF(DX.GT.0.0.AND.DY.GT.0.0) SPEC(JM,2)= SPEC(JM,2)
C
C FOURTH
C
  IF(DX.LT.0.0.AND.DY.LT.0.0) SPEC(JM,1)= SPEC(JM,1)
  IF(DX.LT.0.0.AND.DY.LT.0.0) SPEC(JM,2)=-SPEC(JM,2)
C
C FIFTH
C
  IF(DX.EQ.0.0.AND.DY.GT.0.0) SPEC(JM,1)=-SPEC(JM,1)
C SIXTH
  IF(DX.EQ.0.0.AND.DY.LT.0.0) SPEC(JM,1)=SPEC(JM,1)
C
C SEVENTH
C
  IF(DX.GT.0.0.AND.DY.EQ.0.0) SPEC(JM,2)=SPEC(JM,2)
C
C EIGHTH
  IF(DX.LT.0.0.AND.DY.EQ.0.0) SPEC(JM,2)=-SPEC(JM,2)
C
C*****PRINT 699,JM,SPEC(JM,1),SPEC(JM,2)
699 FORMAT(110,5X,'11',3X,2F10.2)
C
700 CONTINUE
C
  RETURN
  END

```

Appendix B
Listing of Program USNEG

```

PROGRAM USNEB1(INPUT,OUTPUT,TAPES=INPUT,TAPE6=OUTPUT,TAPES1,
*          TAPE52,TAPE61,TAPE62)
C
C THE PROGRAM IS DEVELOPED FOR CHECKING THE NEGATIVE-DEPTH
C NODES FROM THE RMA2 OUTPUT, THEN REPLACING THE OLD NETWORK
C WITH NEW NETWORK
C
C
C INPUT INFORMATION : TAPE51 - RMA2 OUTPUT (WITH NEGATIVE-DEPTH NODES)
C                    TAPE5  - OLD RMA1 INPUT
C                    TAPE52 - OLD RMA2 INPUT
C OUTPUT INFORMATION: TAPE61 - LIST OF NEGATIVE-DEPTH NODES
C                    TAPE6  - NEW NETWORK (RMA1 INPUT)
C                    TAPE62 - NEW RMA2 INPUT
C
C
C INTEGER ELEM
C DIMENSION DEP(1000),JSLOPE(100),XSLOPE(100)
C DIMENSION INPA(8),CORD(1000,2),ND(1000),NLTS(100),TITLE(200)
C DIMENSION NOD(100),NCOORD(1000),MSN(100),DPA(2)
C DIMENSION ELEM(500),NOP(500,8),MAT(500)
C
C DIMENSION TITLE2(20),DEFF(10),SLOPE(100),CONNEW(100)
C DIMENSION NYD(200,3),NNEW(200,8),MKND(100),P(100),NNEW2(200,4)
C DIMENSION NE,NMAT,NPN,NEX,NPRTT,NDE,NV,NVINE,NR,NR2,NR3,NRPT
C
C DIMENSION KEY1,KEY2,KEY3,KEY4
C DATA LPRF,LETTER,PR2,NR(PT)
C
C 11999=9999
C
C *****
C SET NEW RMA1 INPUT (DELETE NEGATIVE-DEPTH NODES)
C *****
C
C READ INFORMATION FROM RMA2 OUTPUT
C
C ----- READ FIRST ITERATION OUTPUT
C
500 READ(51,100)(KEY1,KEY2,KEY3,KEY4)
100 FORMAT(9I,45,5X,4E,4X,4A,5X,4A)
IF(KEY1.EQ.LPRF.AND,KEY2.EQ.LPRF)GO TO 600
GO TO 500
600 CONTINUE
C
C -----
C
NRMA2=0
NRNEB=0
INEB=1
500 READ(51,810)(XVEL1,YVEL1,DEP(1),ELEM1)
*          K,XVEL2,YVEL2,DEP(2),ELEM2
600 FORMAT(15,4F10.3,20),3X,15,4F10.3)
IF(J.EQ.0)GO TO 800
IF(DEP(J).LT.0.) NOD(INEB)=J
IF(DEP(J).LT.0.) WRITE(61,222)INEB,NOD(INEB),DEP(J)
222 FORMAT(215,F10.3)

```

```

      IF(DEP(J),LT,0.) INEG=INEG+1
      IF(DEP(K),LT,0.) NNEG=NNEG+1
      IF(DEP(K),LT,0.) NOD(INEG)=K
      IF(DEP(K),LT,0.) WRITE(61,222)INEG,NOD(INEG),DEP(K)
      IF(DEP(K),LT,0.) INEG=INEG+1
      IF(DEP(K),LT,0.) NNEG=NNEG+1
      NRMA2=NRMA2+1
      GO TO 800
805 CONTINUE
      IF(NNEG.NE.0) WRITE(61,224)
224 FORMAT(* THE NODES LISTED ABOVE ARE FROM FIRST ITERATION*)
C
C -----
C
      IF(NNEG.NE.0)GO TO 901
C
C ----- READ SECOND ITERATION OUTPUT
C
820 READ(51,100)KEY1,KEY2,KEY3,KEY4
      IF(KEY1.EG.LFPS.AND.KEY2.EG.LFPS)GO TO 830
      GO TO 820
831 CONTINUE
C
C -----
C
      NRMA2=0
      NNEG=0
      INEG=1
840 READ(51,810)X,XVEL1,YVEL1,DEP(J),ELEM1,
      * K,XVEL2,YVEL2,DEP(K),ELEM2
      IF(X.EQ.0)GO TO 920
      IF(DEP(J),LT,0.) NOD(INEG)=J
      IF(DEP(J),LT,0.) WRITE(61,222)INEG,NOD(INEG),DEP(J)
      IF(DEP(J),LT,0.) INEG=INEG+1
      IF(DEP(J),LT,0.) NNEG=NNEG+1
      IF(DEP(J),LT,0.) NOD(INEG)=K
      IF(DEP(K),LT,0.) WRITE(61,222)INEG,NOD(INEG),DEP(K)
      IF(DEP(K),LT,0.) INEG=INEG+1
      IF(DEP(K),LT,0.) NNEG=NNEG+1
      NRMA2=NRMA2+1
      GO TO 840
901 CONTINUE
      IF(NNEG.NE.0)WRITE(61,225)
225 FORMAT(* THE NODES LISTED ABOVE ARE FROM SECOND ITERATION*)
C
901 CONTINUE
C
C NOD(INEG) : NEGATIVE DEPTH NODES
C
C READ INFORMATION FROM RMA1 INPUT AND REPRINT THE NEW NETWORK
C
      READ(5,5000)TITLE
8001 FORMAT(20A4)
      WRITE(6,5000)TITLE
C
C*UT**READ(5,5010) ISLP,IPRT,IPNW,IPEN,IPQ,IRO,IPP,IRPN,ISIN,LUNIT
C*UT** ,ICHR,MAXL,MAXE
8010 FORMAT(16I5)
C*UT**6,5010) ISLP,IPRT,IPNW,IPEN,IPQ,IRO,IPP,IRPN,ISIN,LUNIT
C*UT**1 ,ICHR,MAXL,MAXE
C

```



```

1*UT**READ(5,5011) HOR12,VERT,XSCALE,YSCALE,AR,XFACT,YFACT
5011 FORMAT(8F10.2)
1*UT**WRITE(6,5011) HOR12,VERT,XSCALE,YSCALE,AR,XFACT,YFACT
C
C   READ(5,5012)XLL,YLL,XUR,YUR,XSCALE,YSCALE,AR
5012 FORMAT(4F10.0,3F10.3)
C   WRITE(6,5012)XLL,YLL,XUR,YUR,XSCALE,YSCALE,AR
C
C   READ(5,5013)X00,Y00
5013 FORMAT(2F10.0)
C   WRITE(6,5013)X00,Y00
C
C-----
C
C   READ(5,5999)NXZL,NDSL0P,NDM10
5999 FORMAT(3I5)
C   WRITE(6,5999)NXZL,NDSL0P,NDM10
C
C-----
C
C   READ NODES WITH SPECIFIED SLOPE
C
C   READ(5,5998)JSLOPE(N),XSLOPE(JSLOPE(N)),N=1,NDSL0P)
5998 FORMAT(8I15,FS,2)
C
C-----
C
C   CHECK THE NEGATIVE-DEPTH NODES
C
C   NLPJ=0
C   DO 130 J=1,NDSL0P
C   DO 132 IK=1,NNEG
C   IF(JSLOPE(IK).EQ.NOD(IK)) JSLOPE(IK)=JSLOPE(IK)+1
132 CONTINUE
130 CONTINUE
C   WRITE(6,5995)(JSLOPE(N),XSLOPE(JSLOPE(N)),N=1,NDSL0P)
C
C-----
C
C   READ MID-POINT
C
C   READ(5,5995)MSN(IN),N=1,NDM10)
5995 FORMAT(3I5)
C
C   CHECK THE NEGATIVE-DEPTH NODES
C
C   DO 140 II=1,NDM10
C   DO 142 III=1,NNEG
C   IF(MSN(III).EQ.NOD(IN)) MSN(III)=0
142 CONTINUE
140 CONTINUE
C   WRITE(6,5995)(MSN(IN),N=1,NDM10)
C
C-----
C
C   READ NODES FROM EACH ELEMENT
C
C   IELEM=1
C   NELEM=0
210 READ(5,5022)J,IXX,IMX
5022 FORMAT(10I5,F10.0)
C   IF(1.0E-9999) GO TO 215
C   ELEM(IELEM)=J

```

```

      DO 212 K=1,8
      NOP(IELM,K)=INX(K)
212 CONTINUE
      IMAT(IELM)=IMX
      NELEM=NELEM+1
      IELM=IELM+1
      GO TO 210
215 CONTINUE
C
C CHECK THE NEGATIVE-DEPTH NODES
C
      DO 250 IMA=1,NELEM
      DO 230 IMB=1,8
      DO 230 IMC=1,8
      IF(NOP(IMA,IMB)/EG.NOD(IMC))GO TO 250
250 CONTINUE
      WRITE(6,5022) IELM(IMA),NOP(IMA),NN=1,8,IMAT(IMA)
250 CONTINUE
      WRITE(6,5023)119999
5022 FORMAT(15)
C
C READ NODES WITH COORDINATES
C
      NCOT=1
      NCOT=0
270 READ(5,5024)O,OX,WOO
5024 FORMAT(15,3F15.2)
      IF(OUGE,9999)GO TO 280
      NCOORD(NCOT)=O
      CORD(NCOT,1)=OX(1)
      CORD(NCOT,2)=OX(2)
      WOOD(NCOT)=WOO
      NCOT=NCOT+1
      GO TO 270
280 CONTINUE
C
C CHECK THE NEGATIVE-DEPTH NODES
C
      DO 300 IAA=1,NCOT
      DO 290 IBB=1,8
      IF(NCOORD(IAA),EB.NOD(1BB))GO TO 300
290 CONTINUE
      WRITE(6,5024) NCOORD(IAA),CORD(IAA,1),CORD(IAA,2),WOD(IAA)
300 CONTINUE
      WRITE(6,5017)119999
5017 FORMAT(15)
C
C -----
C -----
C
C CHECK THE STRAIGHT SECTION
C
      DO 310 KK=1,NXEL
      READ(5,5030)(NLIST(N),N=1,16)
      DO 311 IK1=1,16
      DO 312 IK2=1,8
      IF(NLIST(1K1),EB.NOD(1K2))GO TO 317
312 CONTINUE
311 CONTINUE
      GO TO 318

```

```

317 WRITE(6,5030)NLEF
   GO TO 310
318 WRITE(6,5030)(NLIST(N),N=1,16)
319 CONTINUE
   WRITE(6,5017)119999
-----
-----
0
0
0
   READ(5,5033)179XX
0
0 REPRINT NLIST
0
320 READ(5,5030)(NLIST(N),N=1,16)
5030 FORMAT(16E1)
   IF(NLIST(1).EQ.9999)GO TO 370
   WRITE(6,5030)(NLIST(N),N=1,16)
   GO TO 330
340 CONTINUE
370 WRITE(6,5033)119999
5033 FORMAT(15)
0
0
0 *****
0
0 CHECK RMA2 INPUT AND RESET THE RMA2 INPUT
0 *****
0
0 READ INFORMATION FROM ORIGINAL RMA2 INPUT
0
   READ(52,9000)TITLES
9000 FORMAT(20A4)
   WRITE(62,9000)TITLES
0
0 READ PARAMETERS OF RMA2
0
   READ(51,9001)R0,REX,INPT,INPA,INEX,IPRTT,INCL,OWIND,NB,NCL,IFILE,NOPT
9001 FORMAT(16F15)
0
0 READ ELEVATION AND SCALE FACTORS
0
   READ(52,9002)OMEGA,ELEVA,TEMP,MSCALEE,ZSCALEE
9002 FORMAT(8F10.1)
0
0 READ ITERATION NUMBER
0
   READ(52,9003)NITI,NITN,NCEC,INSTART,DET,TMAX
9003 FORMAT(4I5,2F10.1)
0
0 READ TYPE NUMBER AND COEFFICIENTS
0
   DO 9006 I=1,NMAT
   READ(52,9005)C(I),COEFF(I),N=1,5)
9005 FORMAT(110,4F10.3,6F10.1)
9006 CONTINUE
0
0 READ CHECK CONTINUITY LINE
0
   INCL=1
   NINCL=0

```

```

      DO 9020 I=1,NCL
      READ(52,9008)(LINE(I,K),K=1,10)
9008 FORMAT(1615)
      DO 9010 II=1,10
      DO 9010 JJ=1,NNEG
      IF(LINE(II,II).EQ.NOD(JJ))GO TO 9020
9010 CONTINUE
      DO 9015 IKK=1,10
      LINEW(NNCL,IKK)=LINE(II,IKK)
9015 CONTINUE
      NNCL=NNCL+1
      IWNCL=IWNCL+1
9020 CONTINUE
C
      NCL=NNCL
C
C   READ D/S BOUNDARY
C
      IHNBX=1
      NHNBX=0
      DO 9040 M=1,NBX
      READ(52,9025)(MXYZ(M,K),K=1,4),MXYZ(M,NN),M=1,3)
9025 FORMAT(110,16,11,11,2X,3F10.3)
      DO 9030 IM=1,NNEG
      IF(MXYZ(M,1).EQ.NGD(IM)) GO TO 9040
9030 CONTINUE
      MXYZNEW(IHNBX,1)=MXYZ(M,1)
      MXYZNEW(IHNBX,2)=MXYZ(M,2)
      MXYZNEW(IHNBX,3)=MXYZ(M,3)
      MXYZNEW(IHNBX,4)=MXYZ(M,4)
      XYZNEW(IHNBX,1)=XYZ(M,1)
      XYZNEW(IHNBX,2)=XYZ(M,2)
      XYZNEW(IHNBX,3)=XYZ(M,3)
      IHNBX=IHNBX+1
      NHNBX=NHNBX+1
9040 CONTINUE
C
      NBX=NHNBX
C
C   PRINT NEW RMA2 INPUT
C
      WRITE(62,9001)NE,NMAT,NPH,NBA,I,PRTT,NCL,IAT,NO,NB,NL,IFILE,NOFT
      WRITE(62,9002)OMEGA,E,LEW,TEMP,XSCALE,ZSCALE
      WRITE(62,9003)NTIC,NTIN,NCBS,NSTART,ZET,THA
      WRITE(62,9005)(XCOEFF(I,K),K=1,5),I=1,NMAT
C
      DO 9060 I=1,NCL
      WRITE(62,9006)(LINEW(I,K),K=1,10)
9060 CONTINUE
C
      DO 9070 IM=1,NBX
      WRITE(62,9025)(MXYZNEW(M,K),K=1,4),M=1,3)
9070 CONTINUE
C
      RETURN
      END

```