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16. Abstract

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FESWMS-TX TWO-DIMENSIONAL ANALYSIS OF BACKWATER AT BRIDGES:

USER'S GUIDE AND APPLICATIONS—PHASE TWO

By

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and

Cheng-Kang Taur

Research Report Number 314-2F

Modifications of a Hydrodynamic Finite Element Model to a User Oriented Program for Two-Dimensional Analysis of Backwater at Bridges

Research Project 3-5-84-314

Conducted for

Texas State Department of Highways and Public Transportation

In Cooperation with the
U.S. Department of Transportation Federal Highway Administration

by the

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The University of Texas at Austin

November 1984

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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 Friedrick. Also, we would like to thank Mr. Cliff Powers and Mr. Dan Wiley of the Automation Division for their help and cooperation.

The manuscript was typed at the Center for Research in Water Resources, and appreciation is extended to their staff.

Larry W. Mays
Cheng-Kang Taur

November 1984

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 second objective was to demonstrate the use of Intergraph graphic capabilities to develop input for the FESWMS-TX model. An application to the confluence of two streams near Rosebud, Texas, was used to demonstrate the graphics procedure. A detailed user's manual has been developed, which is a major part of this report.

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 objective of this phase of the project has been to extend the previous application of the FESWMS-TX model to the Walnut Creek example. The purpose was to analyze the effect of very minor modifications to Martin Luther King Boulevard and to show the flow pattern that results in the floodplain due to putting flow barriers such as embankments, stacks of lumber and buildings in the flood plain. The major reason for extending the original application was to demonstrate the capabilities of this model to consider very detailed aspects of the two dimensional flow pattern. The second major objective has been to demonstrate that the use of the Intergraph (IDGS) System can be used to develop input for the FESWMS-TX model. This procedure has the potential to be a very valuable tool in the use of the FESWMS-TX model; tremendously reducing the time required and eliminating errors from the highly error prone process of manually developing the input directly from topography maps. Several needed improvements to the IDGS software developed by the Automation Division were identified. Hopefully, future funded research will improve the process and the software. 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 1

INTRODUCTION

1.1 Purpose

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 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. 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. The two-dimensional analysis also provides more accurate estimates of water surface profiles upstream and downstream of bridges.

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 use by 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, 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.

1.2 Work Accomplished During Phase I

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 was 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. Automated 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. Simplified the input process to RMA-1 and RMA-2.

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. Extensive analysis were performed using the Walnut Creek example.

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. A user's manual for the FESWMS-TX model was written.

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 first phase of the project ended.

1.3 Scope of Work Accomplished During Phase II

The work accomplished during Phase II of this project is summarized below:

(1) The previous application of the FESWMS-TX model to the Walnut Creek example in Phase I was extended for two purposes: (a) To analyze the effect of very minor modification to the Martin Luther King Blvd., and (b) To show the flow pattern that results in the flood plain due to putting flow barriers such as embankments, stacks of lumber and buildings in the flood plain. The major reason for extending this original application was to demonstrate the capabilities of this model to consider very detailed aspects of the two-dimensional flow pattern. This is especially important for floodprone areas such as this application location which is subject to repeated floodings. This work is described in detail in Chapter 3 of this report.

(2) During the course of the Phase I 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 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 extensively used.

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 was performed under the Phase II. The computer graphics capability was demonstrated using the application described in Task 3.

(3) 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 objective of this task was to apply the FESWMS-TX modeling system and the Intergraph computer graphics to satisfy the above purposes.

This report was written to describe the work accomplished for the duration of the Phase II project. This report includes a user's manual for the FESWMS-TX model with a more detailed manual in the Phase I project report.

1.4 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 (Figure 1.1) 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 cabability (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 nongraphic 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 (Figure 1.2). 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.

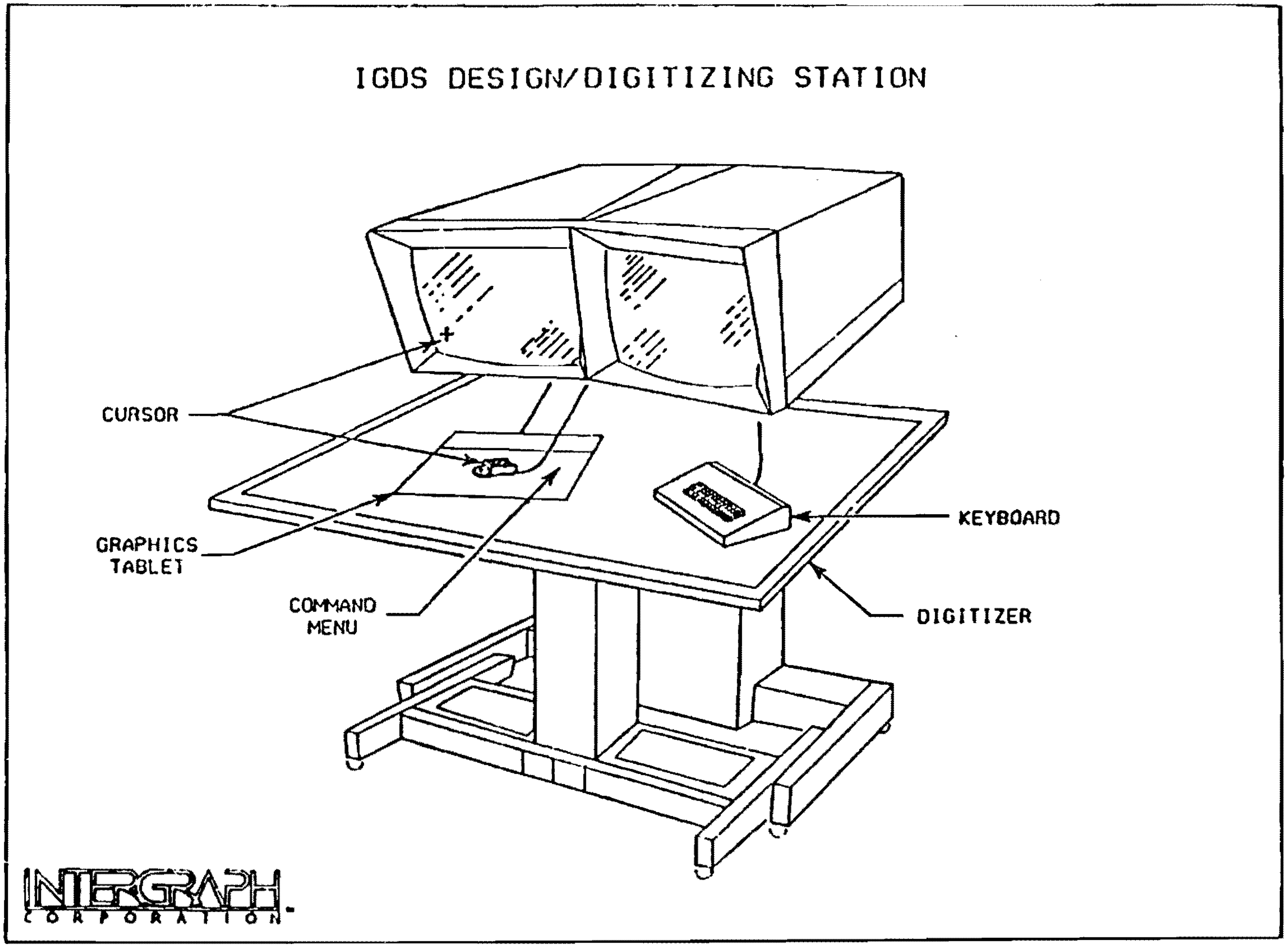


Figure 1.1 IGDS Design/Digitizing Station

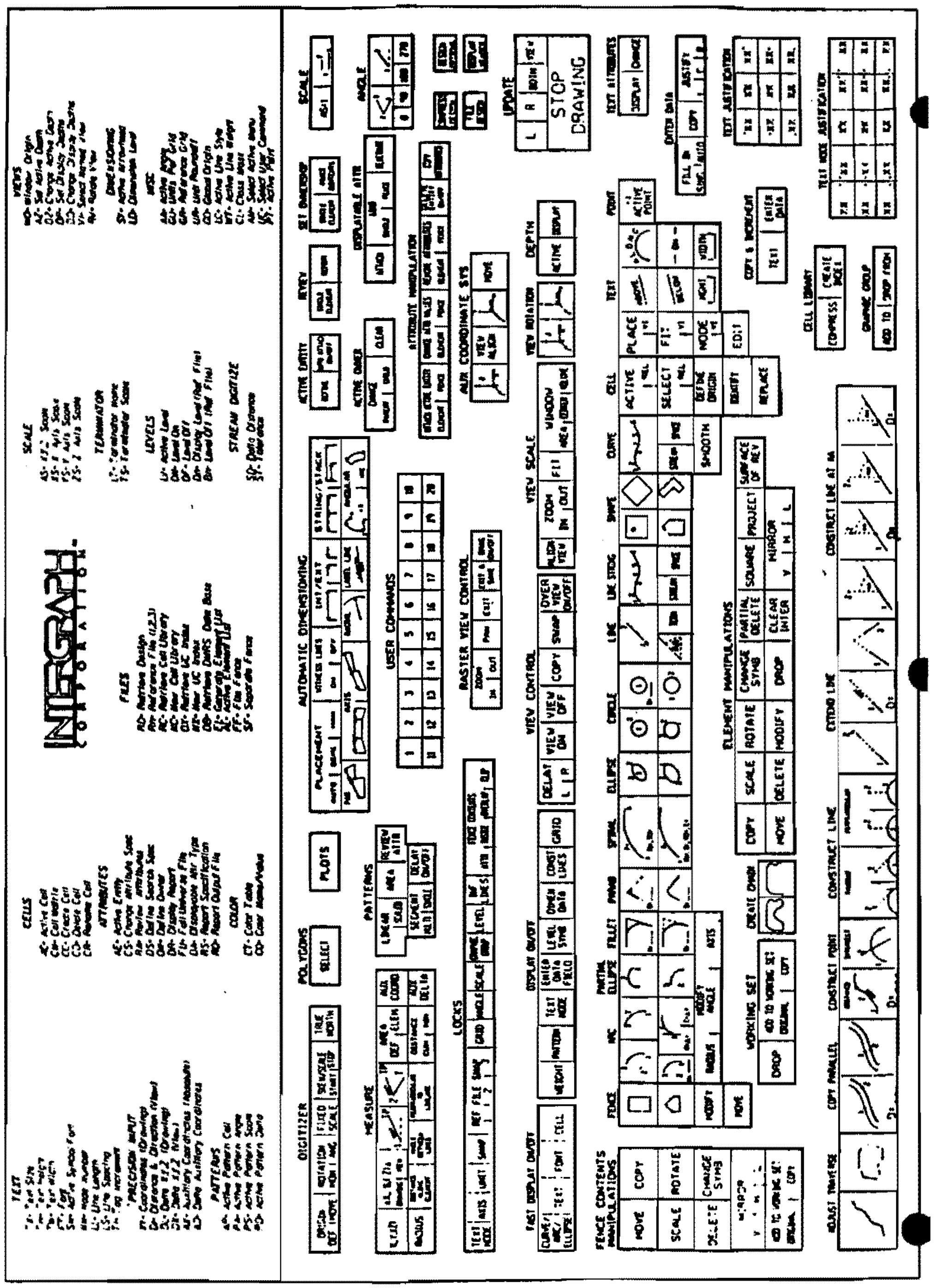


Figure 1.2 Graphics Tablet

CHAPTER 2

FESWMS-TX System Description

2.1 Finite Element Models

The formulation and development of finite element models have been reported elsewhere (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:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial h}{\partial x} + g\frac{\partial z_o}{\partial x} - \frac{\varepsilon_{xx}}{\rho}\frac{\partial^2 u}{\partial x^2} - \frac{\varepsilon_{xy}}{\rho}\frac{\partial^2 u}{\partial y^2}$$

$$- 2\,wv \sin\phi + \frac{gu}{C^2 h}(u^2 + v^2)^{1/2} - \frac{\varepsilon}{h} V_a^2 \cos\psi = 0, \qquad (2.1)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial h}{\partial y} + g\frac{\partial z_o}{\partial y} - \frac{\varepsilon_{yx}}{\rho}\frac{\partial^2 v}{\partial x^2} - \frac{\varepsilon_{yy}}{\rho}\frac{\partial^2 v}{\partial y^2}$$

$$2\,wu \sin\phi + \frac{gv}{C^2 h}(u^2 + v^2)^{1/2} - \frac{\varepsilon}{h} V_a^2 \sin\psi = 0, \qquad (2.2)$$

and

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(uh) + \frac{\partial}{\partial y}(vh) = 0, \qquad (2.3)$$

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_o = bed elevation (feet),

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

w = 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),
$\varepsilon_{xx}, \varepsilon_{xy}, \varepsilon_{yx}, \varepsilon_{yy}$	=	eddy viscosities (pound second per square foot),
ζ	=	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 (2.1) through (2.2) 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 (2.1) through (2.2) 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 (2.1), (2.2), and (2.3), respectively drop out.

The 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).

Previous applications of two-dimensional finite element models for floodplain analysis are presented in Table 2.1.

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. 2.1).

TABLE 2.1 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.)
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.

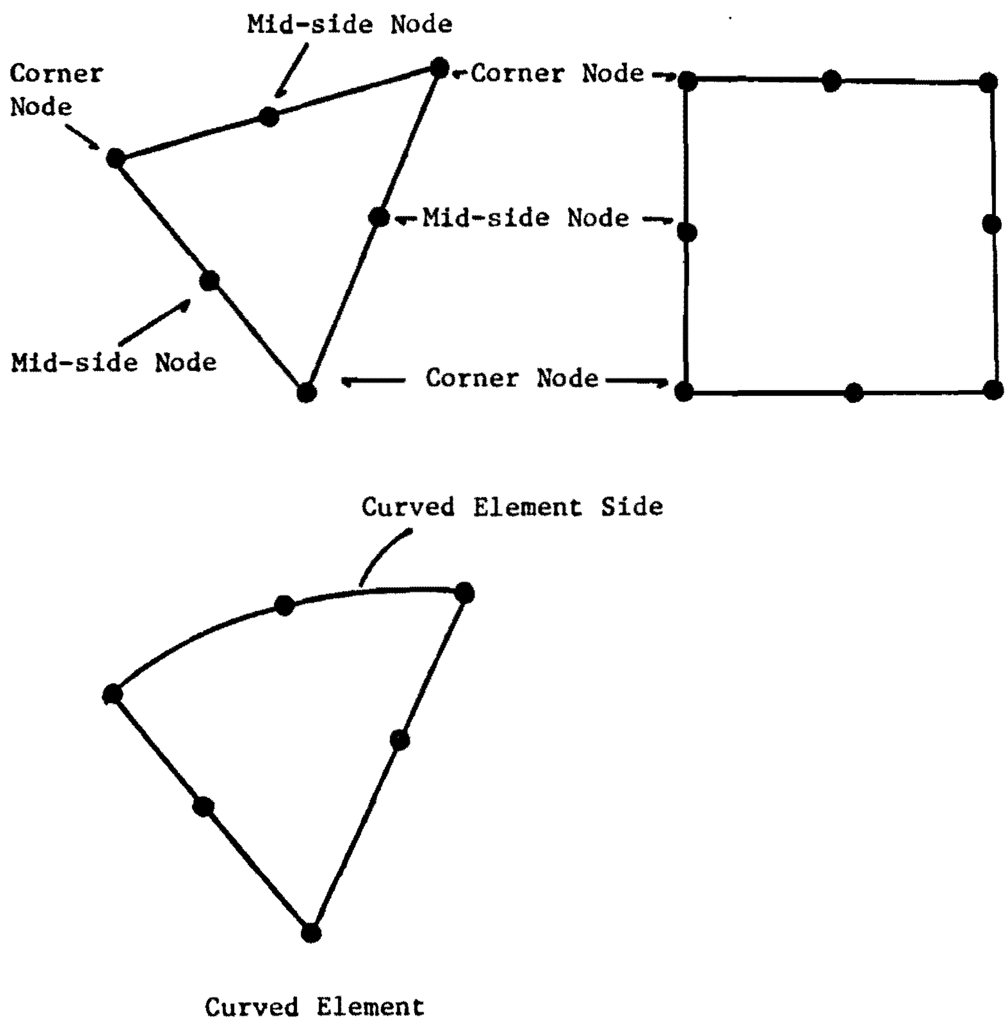


Figure 2.1 Finite Element Descriptions

Finite element network - This is the collection of elements that define the entire floodplain. 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.

Curved element side - Elements can also have curved sides as shown in Fig. 2.1. 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 flow rate 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 locations 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.

2.2 FEWSMW-TX Description

The FESWMS modeling system has been 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 Section 2.3 and 2.4.

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.

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.

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 Mays and Taur (1984). RMA-1 consists of a master routine, RMA-1, and several subroutines. The master routine reads the input data file and issues calls to various subroutines for specific purposes. Each of the subroutines is briefly described in Mays and Taur (1984).

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, RMA-2 and the ten subroutines as shown in Fig. 2.2. 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 (ft^3/sec/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 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-specific line defined as part of the input by a list of node numbers. Refer to Figure 2.2.

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 specific 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

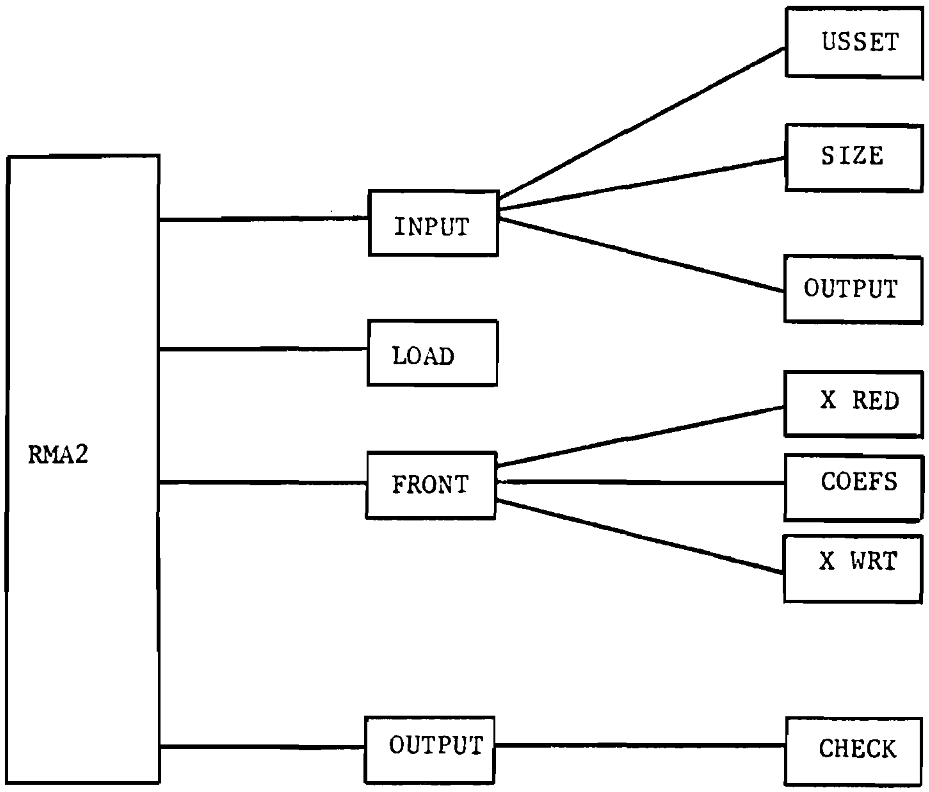


Figure 2.2 Program Structure of RMA-2 in FESWMS-TX.

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.

2.3 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.

2.3.1 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. 2.3).

1. Develop input for RMA-1, RMA-2, RMA1PLT, and RMA2PLT as described in Sections 2.4 and 2.5.

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 specific 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 Sections 2.4 and 2.5.

5. Run computer program USNEG using the same printed output file from RMA-2 to check for negative depth nodes.

   a. If none of the depths are negative, RMA-2 is rerun (go to step 4) using a new dowmstream 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.

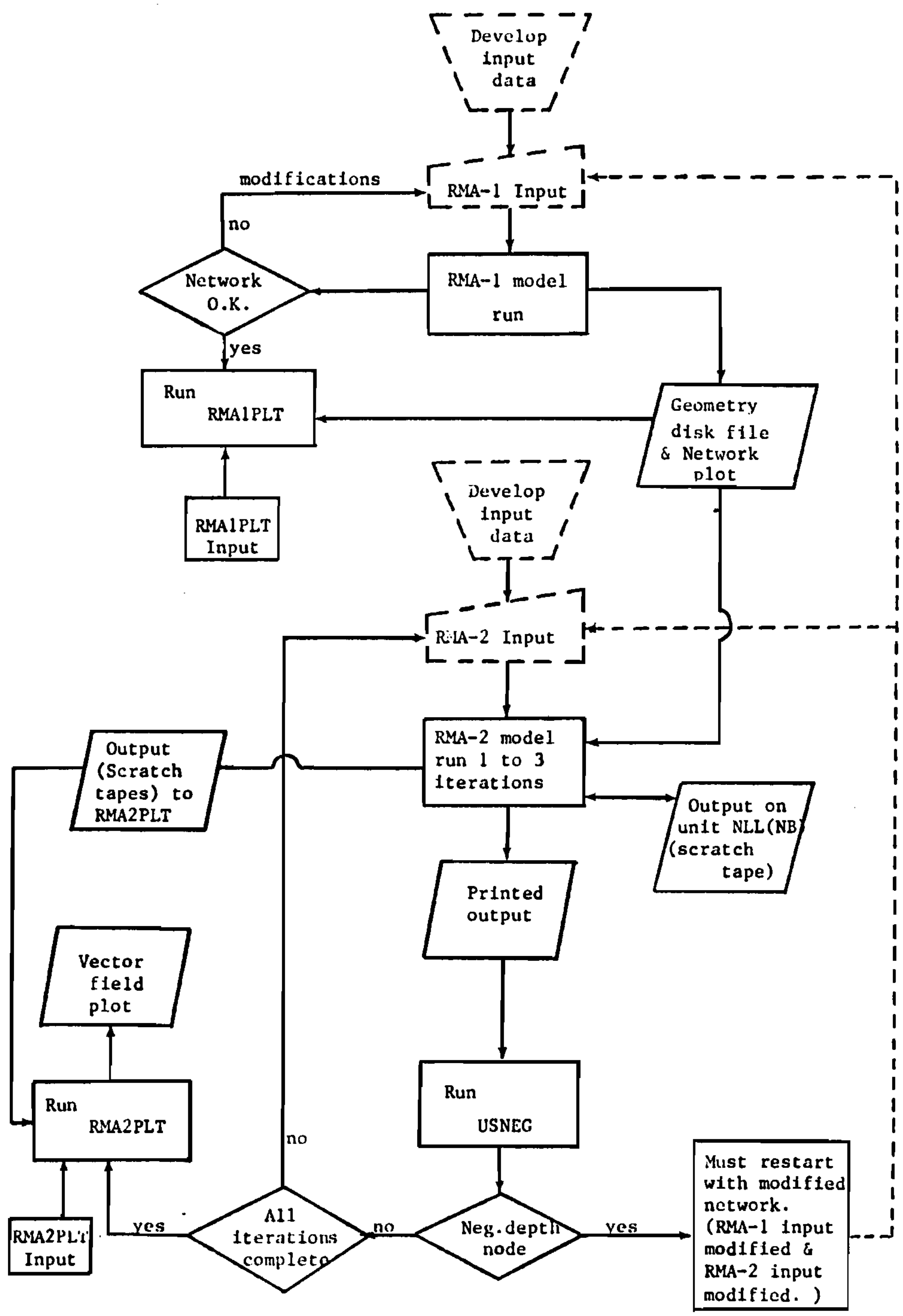


Figure 2.3 Interactive Application Procedure for FESWMS-TX

7. The user may now want to modify the network (modifying RMA-1 and RMA-2 input files) and restart the procedure.

2.3.2 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. 2.4. The RMA-1 input file and the RMA-2 input files for each series (group of iterations) of run are established in advance of running the batch process.

2.4 Guidelines for Input

2.4.1 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 blood 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.
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.
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

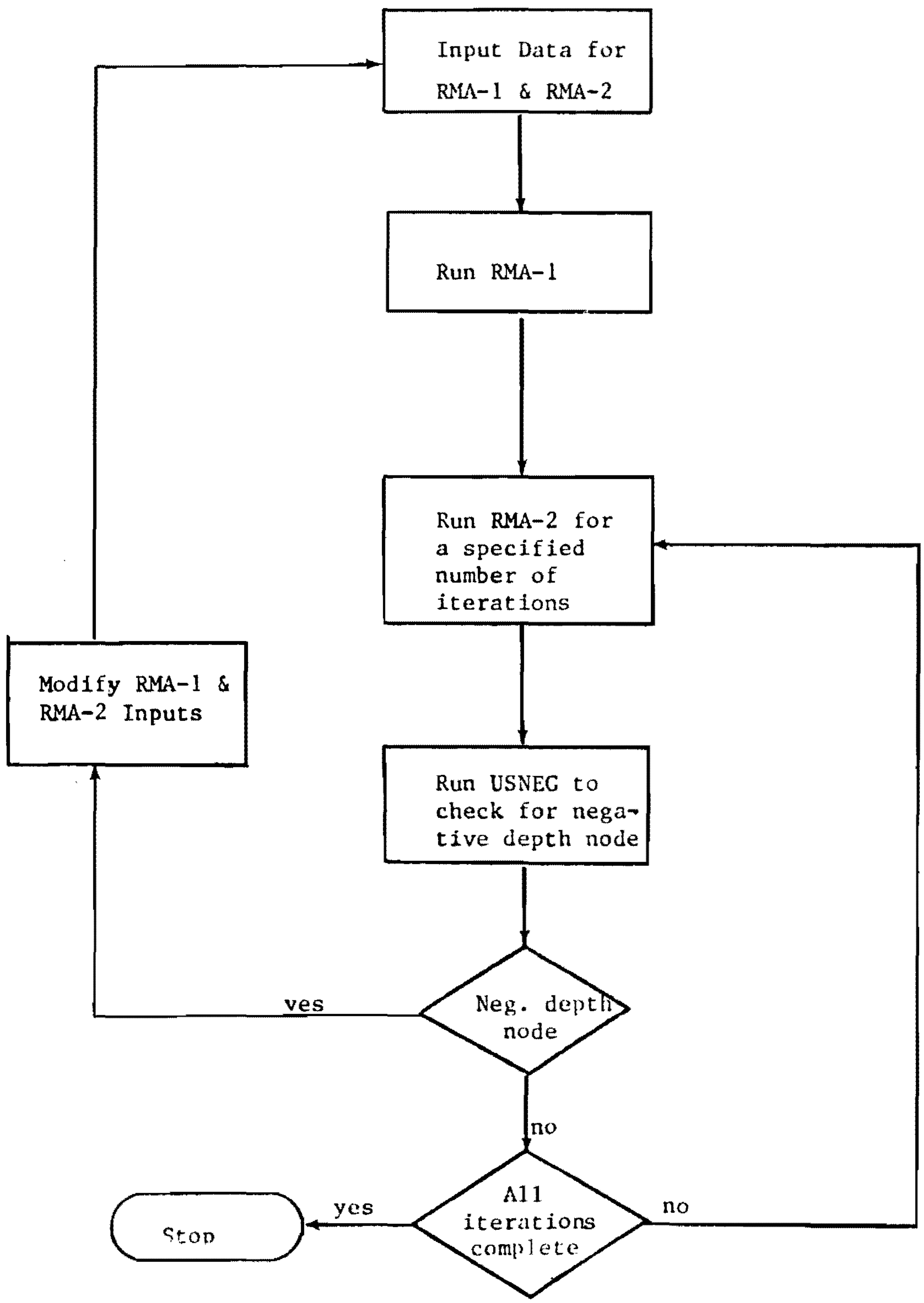


Figure 2.4 Batch Application for FESWMS-TX

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 raea 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.

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:

    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. 2.5.

3. The slope of the tangent (Fig. 2.6) 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. 2.6a.

    b. The middle one-third rule should be observed to avoid numerical problems, but slight violations can be tolerated without serious problems.

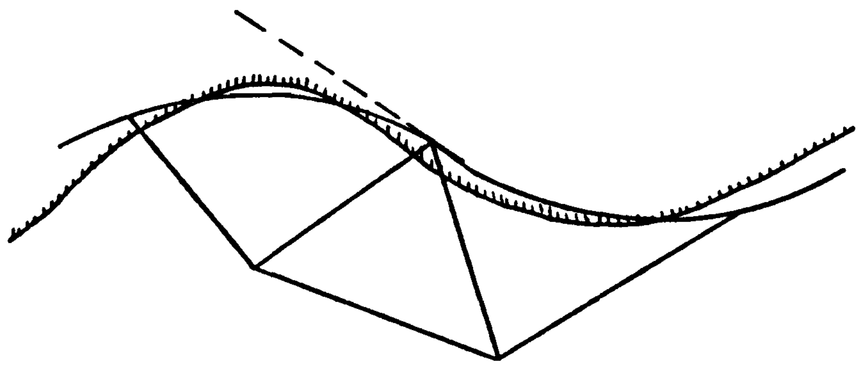
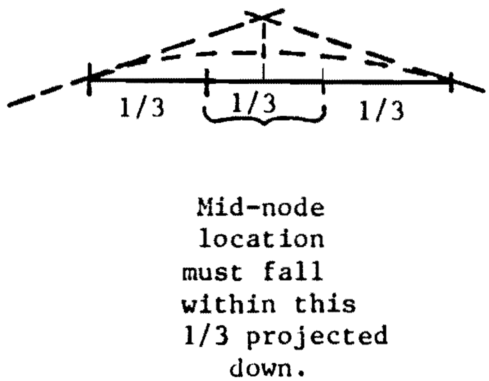
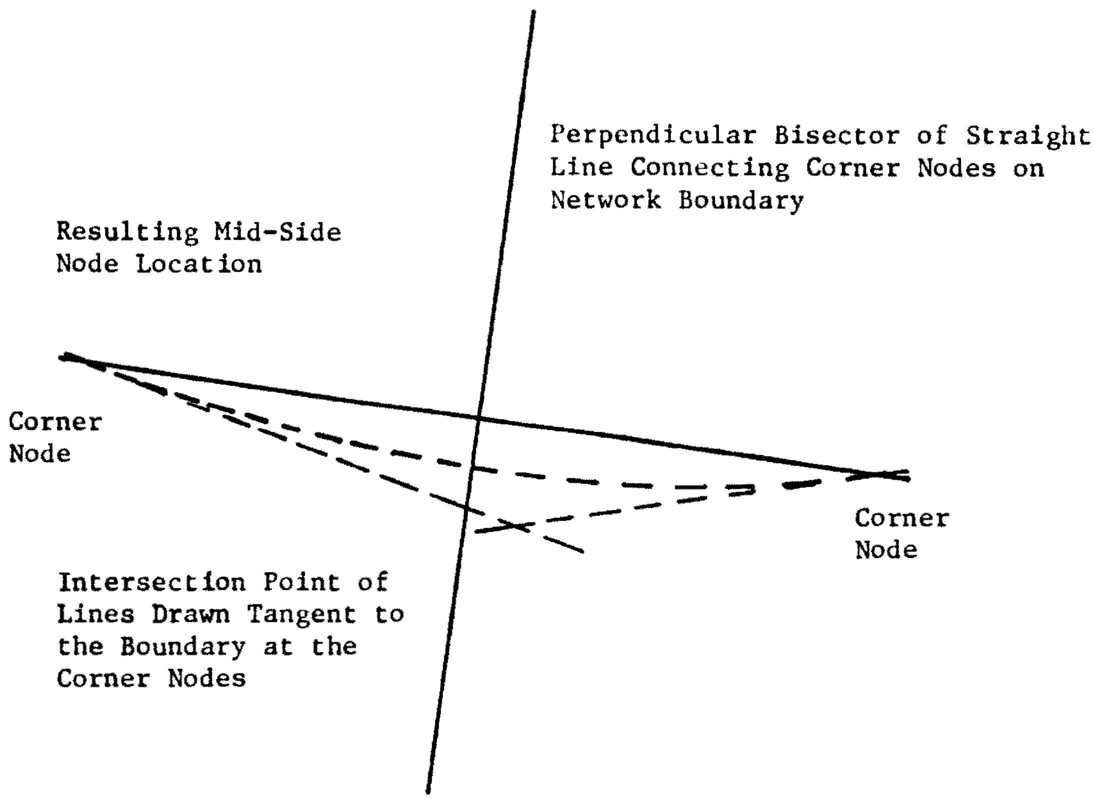


Figure 2.5 Curved Side Elements for Specifying Irregular Floodplain Boundaries



(a) Middle One-Third Rule



(b) Midnode Location

Figure 2.6 Guidelines for Determining Corner Node Slope for Curved Element Sides

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. 2.6b.

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 exceedingsly 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.

2.4.2 Numbering and 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.

2.4.3 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. 2.7, which has two bridge openings that are the 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. 2.8 to move the upstream boundary condition farther upstream. The pattern of elements shown in Fig. 2.8 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 with openings, are excellent for locating upstream boundaries. 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.

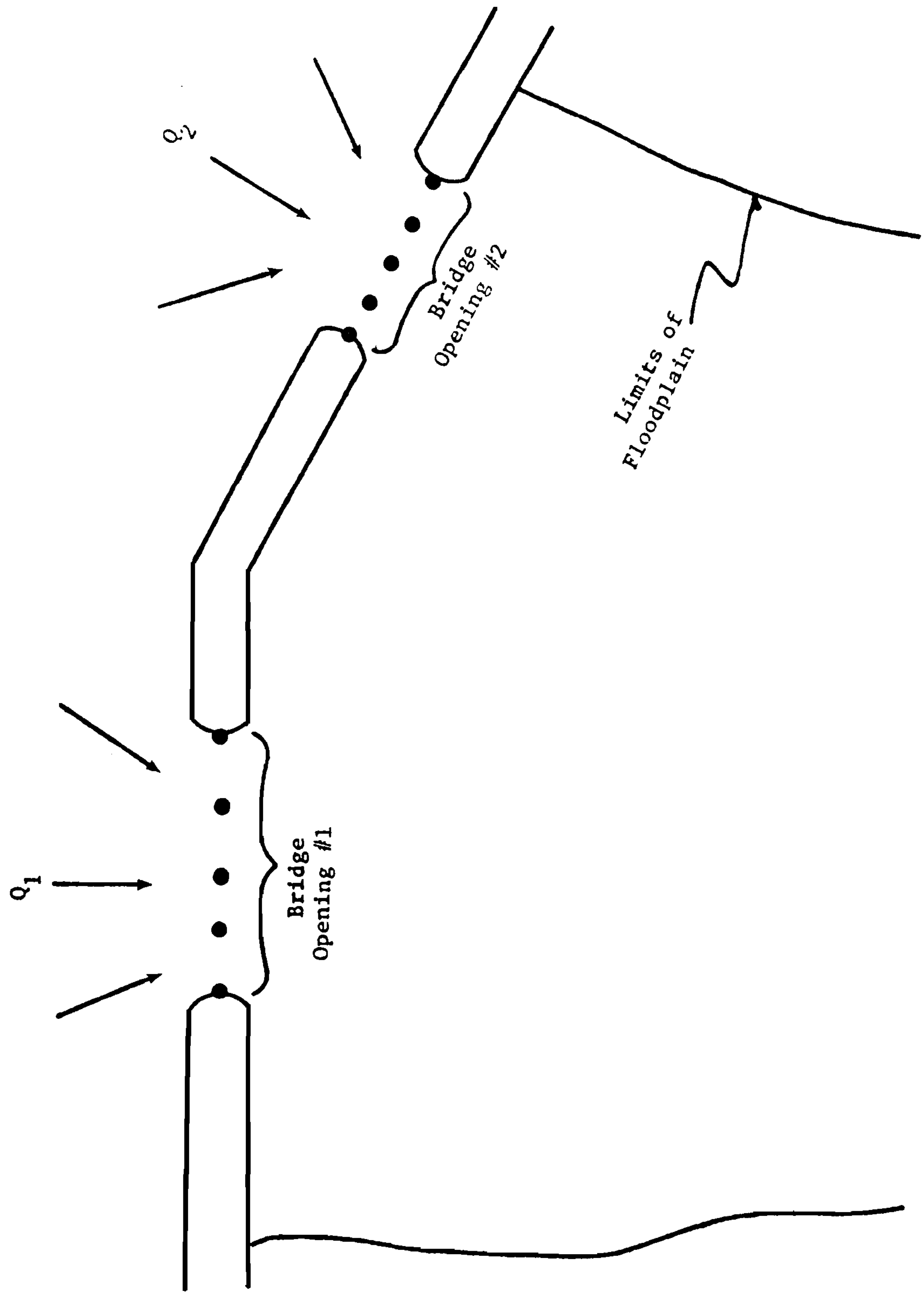


Figure 2.7 Upstream Nodes for Multiple Inlets to Floodplain

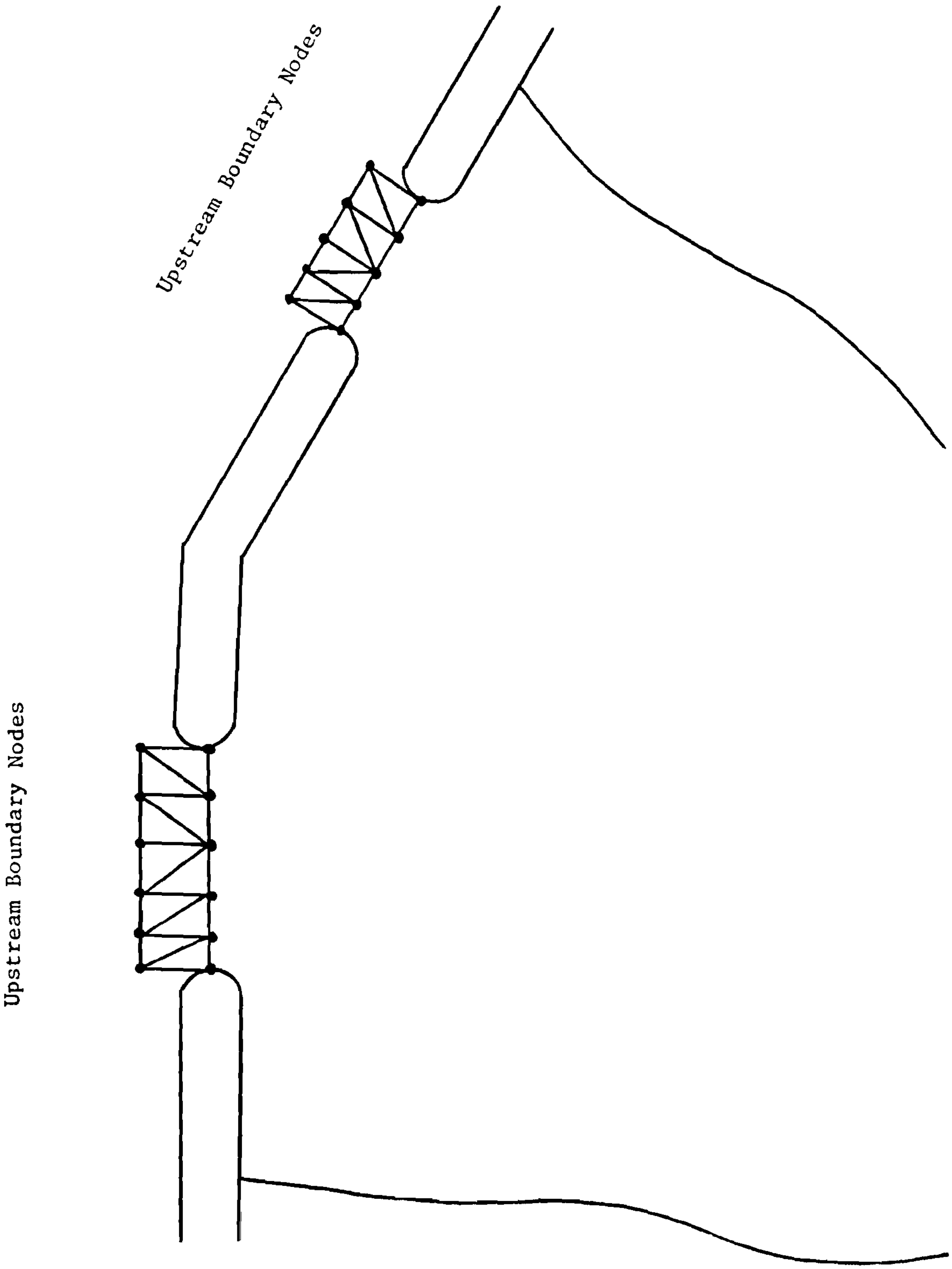


Figure 2.8 Upstream Boundary Nodes for Multiple Inlet to Floodplain

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.
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. 2.9.
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.

2.5 User's Manual for RMA-1 Input

The data forms for the RMA-1 input are shown in Figs. 2.10(a) and (b). Notice that the different data are placed on Card types A through H which are summarized below:

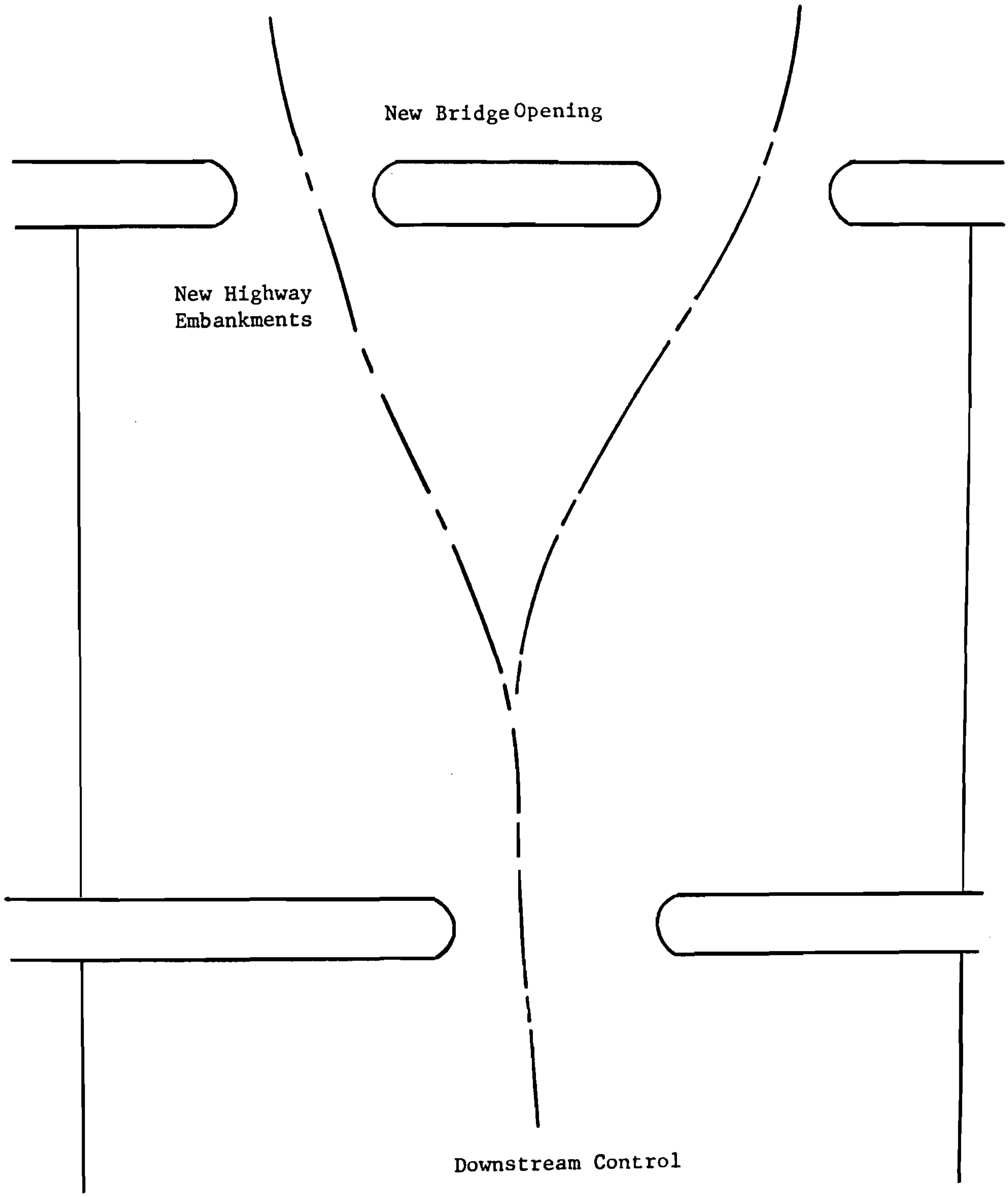


Figure 2.9 Multiple Bridge Openings with Downstream Control.

FESWMS - TX RMA-1 INPUT

TITLE CARD

A

PARAMETER CARDS

B-1

B-2

B-3

CORNER NODE SLOPE CARDS

C

CORNER NODE NUMBER	CORNER NODE SLOPE	CORNER NODE NUMBER	CORNER NODE SLOPE	CORNER NODE NUMBER	CORNER NODE SLOPE	CORNER NODE NUMBER	CORNER NODE SLOPE	CORNER NODE NUMBER	CORNER NODE SLOPE	CORNER NODE NUMBER	CORNER NODE SLOPE	CORNER NODE NUMBER	CORNER NODE SLOPE	CORNER NODE NUMBER	CORNER NODE SLOPE

MIDSIDE NODE CARDS

D

NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER	NODE NUMBER

(continued)

Figure 2.10 RMA-1 Input

FESWMS - TX RMA-1 INPUT

1	2	3	4	5	6	7	8	9	10

E

ELEMENT CARDS

ELEMENT NUMBER	CORNER NODE NUMBER	MIDNODE NUMBER	CORNER NODE NUMBER	MIDNODE NUMBER	CORNER NODE NUMBER	MIDNODE NUMBER		ELEMENT TYPE
9999								

F

COORDINATE CARDS

NODE	X-COORDINATE	Y-COORDINATE	GROUND ELEVATION
9999			

G

STRAIGHT LINE SEGMENT CARDS

END CORNER NODE	OTHER END CORNER NODE	LIST OF CORNER NODE NUMBERS BETWEEN THE END CORNER NODES
9999		

H

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 2.10 (Continued)

Card	Name	Number of Cards
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

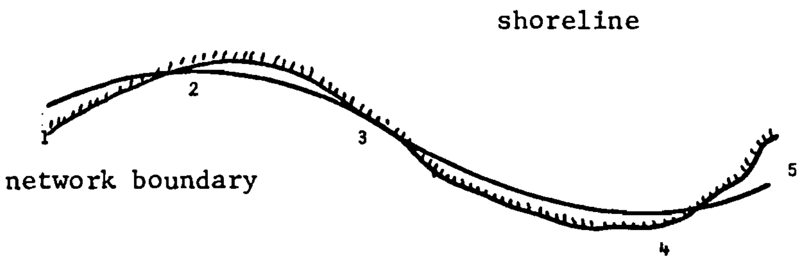
These cards are used to specify the tangential slopes (Fig. 2.11) of the curved lateral boundaries at the corner node locations. Eight of the corner nodes and their respective corner node slopes can be placed on each card. Specification of curved lateral boundaries requires: a) specification of the corner 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 2.11 further explains the definition of curved boundaries and calculation of the corner node slopes.

D- Mid-side Node Cards

The 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.



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.

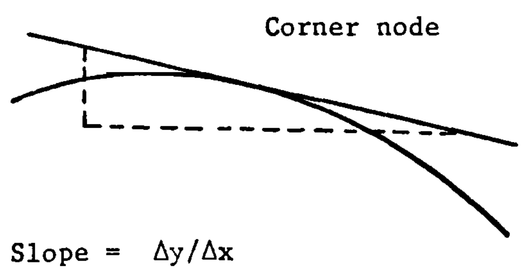


Figure 2.11 Definition of Curved Boundaries.

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 locations 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.

2.6 User's Manual for RMA-2 Input

The data form for the RMA-2 input is shown in Fig. 2.12(a) and (b). Notice that the different data are placed on card types AA through FF, which are summarized below:

Card	Name	Number of Cards
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 At least one card for each upstream section giving node numbers

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

DD

CONTINUITY CHECK CARDS

LIST OF CORNER NODES (IN ORDER ACROSS NETWORK) THAT TOTAL FLOW IS TO BE COMPUTED

(continued)

Figure 2.12 RMA-2 Input

FESWMS - TX RMA-2 INPUT

1 2 3 4 5 6 7 8 9 10

EE

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

FF

UPSTREAM INFLOW CARDS

NUMBER OF UP-STREAM INFLOW SECTIONS

FF-1

INFLOW PARAMETERS FOR UPSTREAM SECTION

TOTAL NUMBER NODES AT UP-STREAM SECTION	NUMBER OF CORNER NODES	DISCHARGE AT THIS SECTION IN FT^3/SEC	AVERAGE WATER SURFACE ELEVATION AT SECTION

FF-2

LIST OF UPSTREAM BOUNDARY NODES FOR UPSTREAM SECTION (Both Corner and Midnodes are listed)

1st NODE	2nd NODE	3rd NODE	4th NODE	5th NODE	6th NODE	7th NODE	8th NODE	9th NODE	NODE 10	NODE 11	NODE 12	NODE 13	NODE 14	NODE 15	NODE 16

FF-3

THE FF-2 AND FF-3 CARDS ARE GIVEN FOR EACH UPSTREAM SECTION

Figure 2.12 (Continued)

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 2.2. 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 2.3.

DD- Continuity Check Card

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:

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,

Table 2.2 Turbulent Exchange Coefficients

(a) Turbulent Exchange Coefficients (Tseng, 1975)
(Eddy Viscosity)
($lb\text{-}sec/ft^2$)

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

(b) Turbulent Exchange Coefficients (Norton, 1980)

Type of Simulation Problem	Values of Turbulent Exchange Coefficients (Eddy Viscosity) $lb\text{-}sec/ft^2$ 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 2.3 MANNING'S ROUGHNESS COEFFICIENTS (Texas Dept.of Highway, 1970)

NATURAL STREAM CHANNELS	Min.	Max.
I. Minor Streams		
A. Fairly regular section		
1. Some grass and weeds; little or no brush	0.030	0.035
2. Dense growth of weeds, depth of flow materially greater than weed height	0.035	0.050
3. Some weeds, light brush on banks	0.035	0.050
4. Some weeds, heavy brush on banks	0.050	0.070
5. Some weeds, dense willows on banks	0.060	0.080
6. For trees within channels with branches submerged at high stage, increase all values above by	0.010	0.020
B. Irregular section with pools, slight channel meander, use 1A to 5A above, and increase all values by	0.010	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	0.040	0.050
2. Bottom; cobbles with large boulders	0.050	0.070
II. Flood Plain (adjacent to natural streams)		
A. Pasture, no brush		
1. Short grass	0.030	0.035
2. Tall grass	0.035	0.050
B. Cultivated areas		
1. No crop	0.030	0.040
2. Mature row crops	0.035	0.045
3. Mature field crops	0.040	0.050
C. Heavy weeds, scattered brush	0.050	0.070
D. Wooded	0.075	0.150

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.

III. Major Streams

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.

LINED CHANNELS	Min.	Max.
1. Metal corrugated	0.021	0.024
2. Neat cement lined	0.012	0.018
3. Concrete	0.012	0.018
4. Cement rubble	0.017	0.030

Table 2.3 (Continued)

GRASS COVERED SMALL CHANNELS, SHALLOW DEPTH

1.	No rank growth	0.035	0.045
2.	Rank growth	0.040	0.050

UNLINED CHANNELS

1.	Earth, straight and uniform	0.017	0.025
2.	Dredged	0.025	0.033
3.	Winding and sluggish	0.022	0.030
4.	Stony beds, weeds on bank	0.025	0.040
5.	Earth bottom, rubble sides	0.028	0.035
6.	Rock cuts, smooth and uniform	0.025	0.035
7.	Rock cuts, rugged and irregular	0.035	0.045

PIPE

1.	Cast iron, coated	0.010	0.014
2.	Cast iron, uncoated	0.011	0.015
3.	Wrought iron, galvanized	0.013	0.017
4.	Wrought iron, black	0.012	0.015
5.	Steel, riveted and spiral - smooth	0.013	0.017
6.	Steel, corrugated (1/2")	0.021	0.024
7.	Steel, corrugated (2" Structural Plate)	0.034	0.038
8.	Concrete	0.010	0.017
9.	Vitrified sewer pipe	0.010	0.017
10.	Clay, common drainage tile	0.011	0.017

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

CHAPTER 3

FURTHER 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. The model application was originally reported by Mays and Taur (1984). This application reported herein expands upon the original application to look at the detailed effect of modifications to the downstream road and the detailed flow pattern around buildings in the flood plain.

3.1 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 3.1) has an average width of about 4 miles and a length of about 14 miles. The total drainage area is 56.19 mi^2 including the approximate 13 mi^2 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 Martin Luther King Blvd. (Webberville Road), shown in Figure 3.2. The study area is shown in detail in Figure 3.3 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 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 downstream 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.

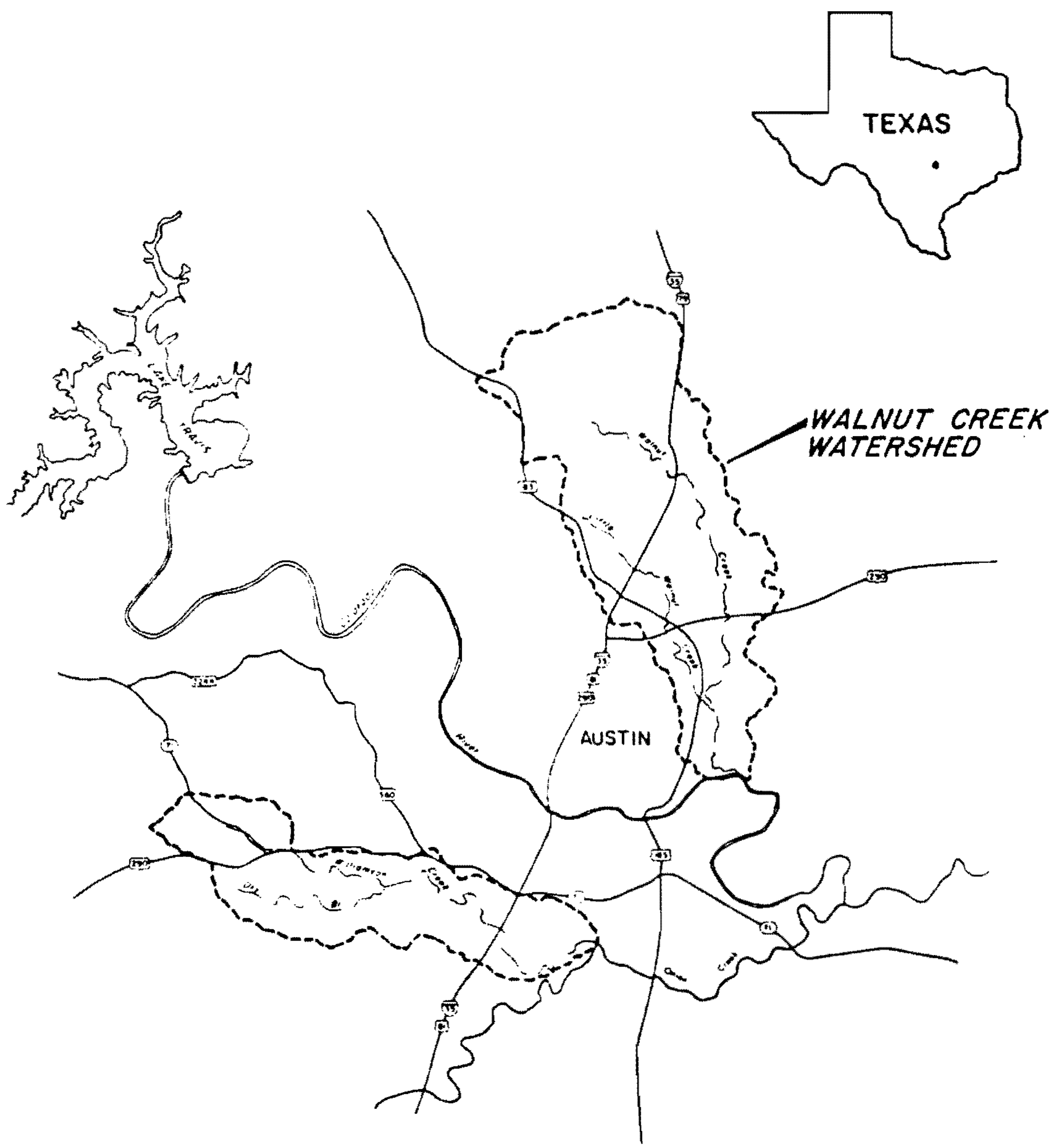


Figure 3.1. Austin, Texas Vicinity Map.

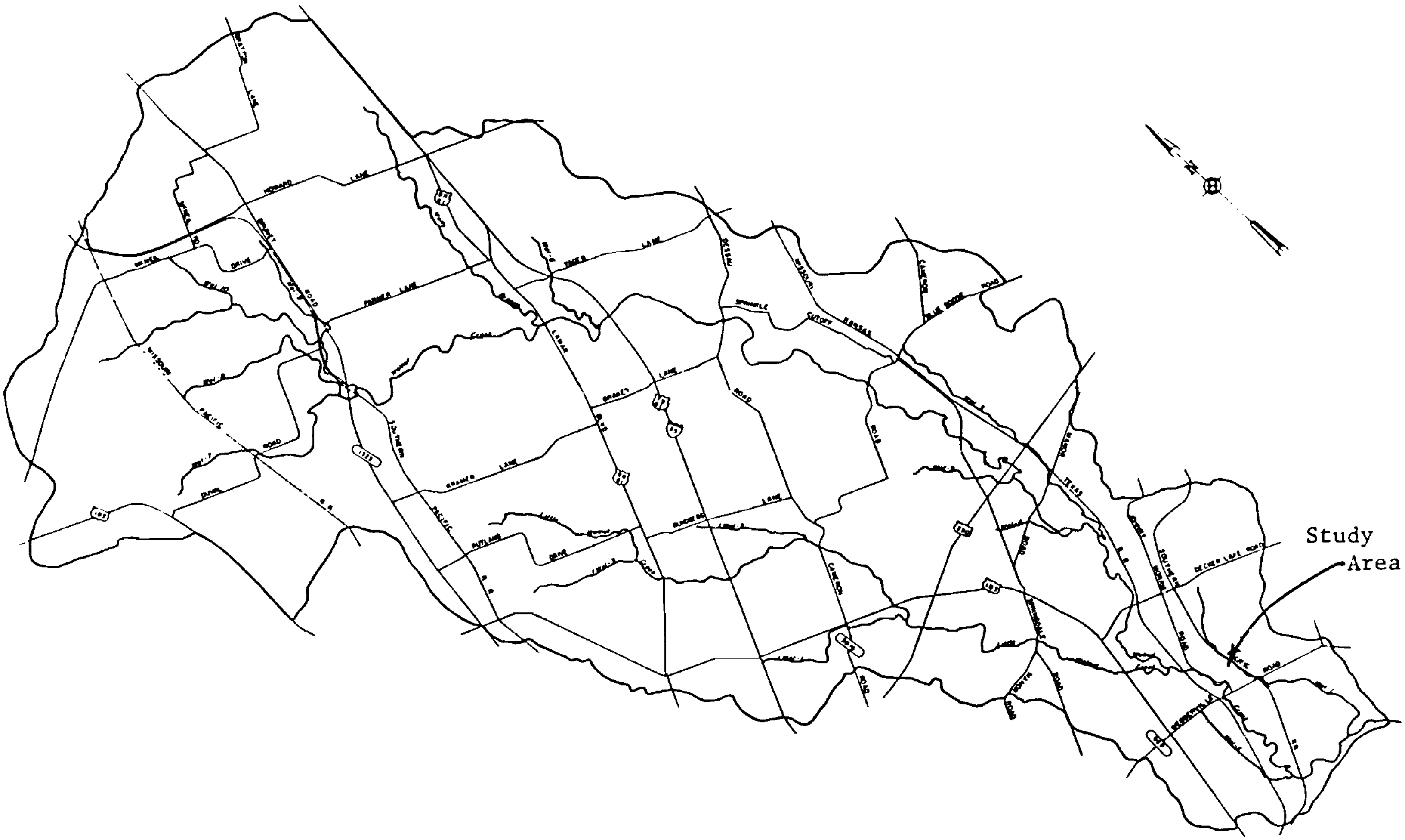


Figure 3.2. Walnut Creek Watershed

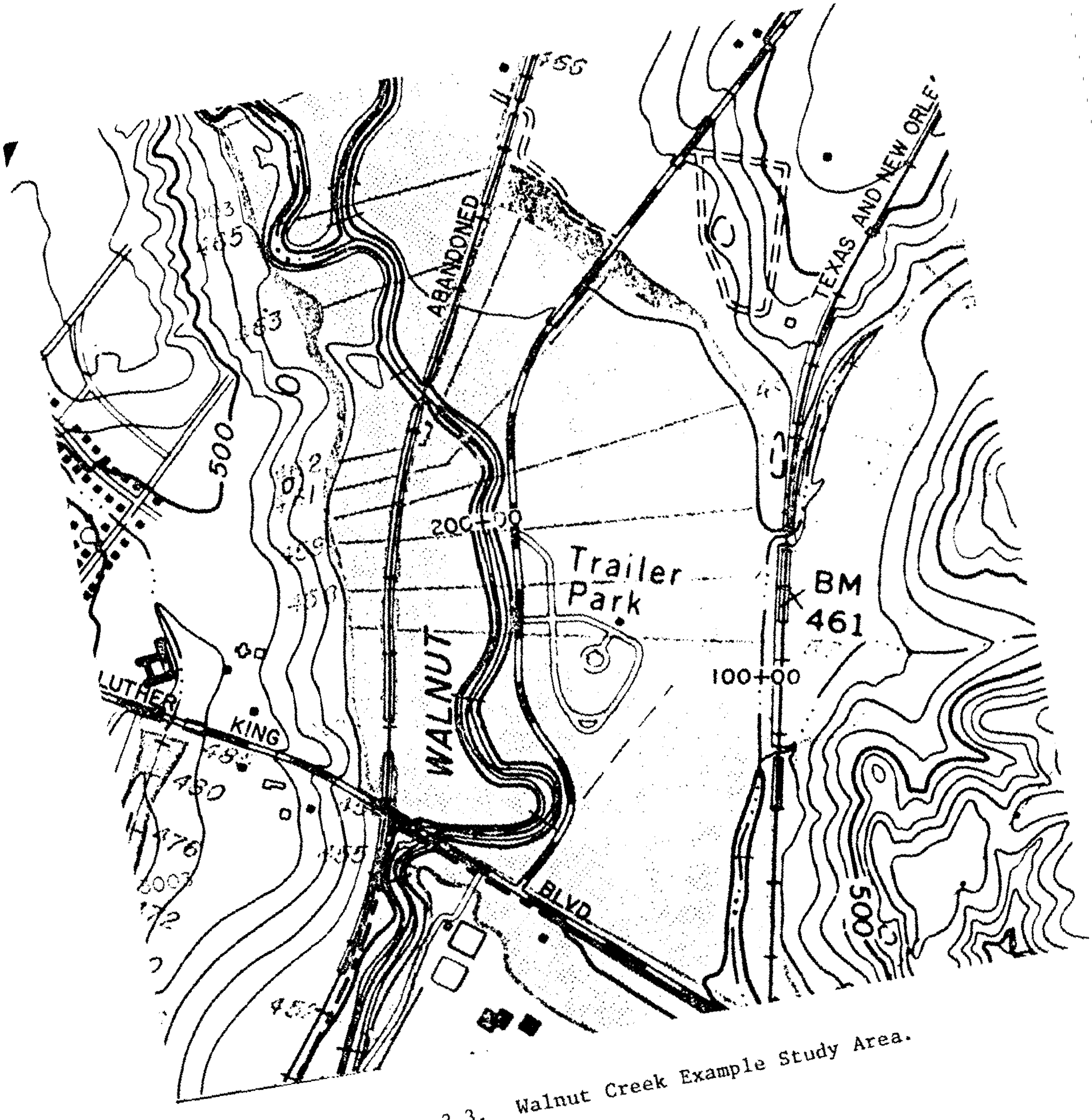


Figure 3.3. Walnut Creek Example Study Area.

3.2 Summary of Previous Work

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-Kansas-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.

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. Various levels of networks were considered in the work by Mays and Taur (1984). In order to check the accuracy of the model for various levels of network discretization continuity lines as indicated were considered. The highest level of discretization is shown in Figure 3.4. Table 3.1 lists the Manning's roughness factor and turbulent exchange coefficient for each element type. Table 3.2 lists the number of elements, the number of nodes, and the execution times for the RMA-2 for each level.

A comparison of water depths at selected locations throughout the finite element networks was performed. The node location is the same for each of the network levels 1 through 6. Using the Level 6 finite element network various simulations were made of the Memorial Day 1981 Flood using the different Manning's roughness factors and turbulent exchange coefficients. The resulting continuity checks for the various computer runs were analyzed. Comparisons of the water surface elevations at various nodes for the various computer runs were also analyzed.

Using the Level 6 finite element network (Figure 3.4) 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 elevations at the various nodes throughout the floodplain was made (Mays and Taur, 1984).

3.3 New Application of Walnut Creek Example

The previous application of the FESWMS-TX model to the Walnut Creek example was extended for two purposes:

(1) To analyze the effect of very minor modification to the Martin Luther King Blvd., and

(2) To show the flow pattern that results in the flood plain due to putting flow barriers such as embankments, stacks of lumber and buildings in the flood plain.

The major reason for extending this original application was to demonstrate the capabilities of this model to consider very detailed aspects of the two-dimensional flow pattern. This is especially important for floodprone areas such as this application location which are subject to repeated floodings.

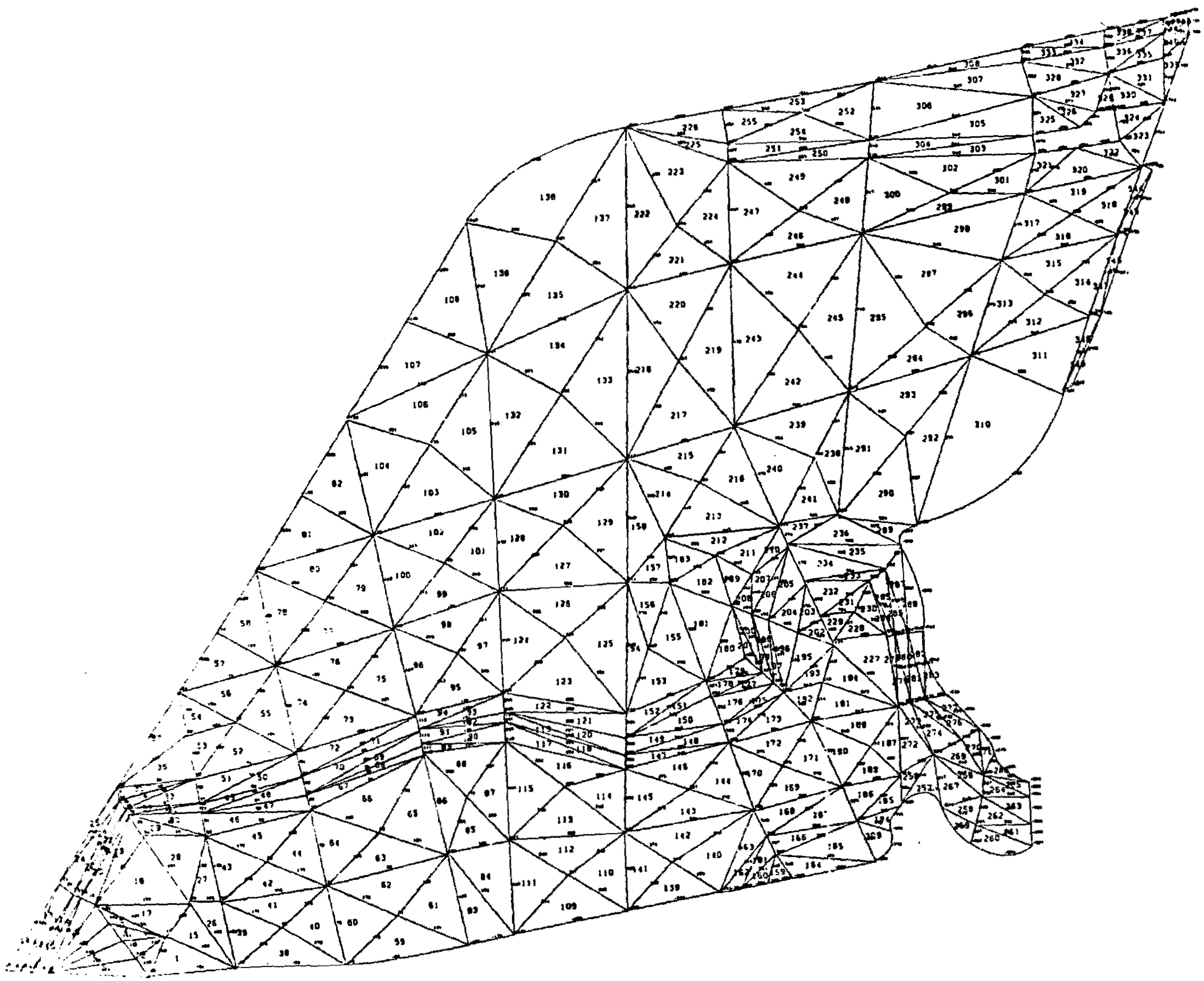


Figure 3.4 Walnut Creek Level 6 Network

Table 3.1 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 3.2 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

The new networks considered are shown in Figures 3.5, 3.6, and 3.7. Figure 3.5 is the network used to determine the effect of removing a small dip from Martin Luther King Blvd. without any buildings upstream of the dip. The road is represented by the long, narrow elements as shown in Figure 3.5. Figure 3.6 is the network used to analyze the effect of a building just upstream of the road considering condition with and without the dip in place. Figure 3.7 is the network used to look at more detail including an embankment and additional obstruction to the flow as shown in the figure.

Several computer simulations were performed considering the various conditions with and without the dip in the road and with and without the additional obstruction in the floodplain. The simulations were made using the Memorial Day 1981 flood with a peak discharge of 14,300 cfs.

The resulting flow pattern under conditions of no buildings with and without the dip in the road are shown in Figures 3.8 and 3.9, respectively. The resulting flow pattern with all the existing obstructions, with and without the dip are shown in Figures 3.10 and 3.11.

The results are further summarized in Table 3.3 which compares water surface elevation with and without the dip and with and without the buildings for iteration 10 and 11 of the simulation. The node locations are given in detail in Figure 3.12.

Table 3.4 shows a comparison of the flow depths along Martin Luther King Blvd. with and without the dip and with and without the floodplain obstruction (buildings) for iterations 10 and 11 of the simulations.

One of the major difficulties in using this model is to satisfy flow continuity within the network. Even with the detailed networks shown in Figure 3.5 to 3.7, continuity estimates for various portions of the network were in error from 4 to 22 percent. This indicates that even a more detailed network would be advisable. The errors in flow continuity tend to be local effects and probably would not significantly influence the results at remote locations. This is important in determining the minimum level of detail needed in a large network where different spatial locations may have different relative importance. With the careful use of increased element density and smooth-sided networks, in most cases it should be possible to reduce the flow continuity error to acceptable levels.

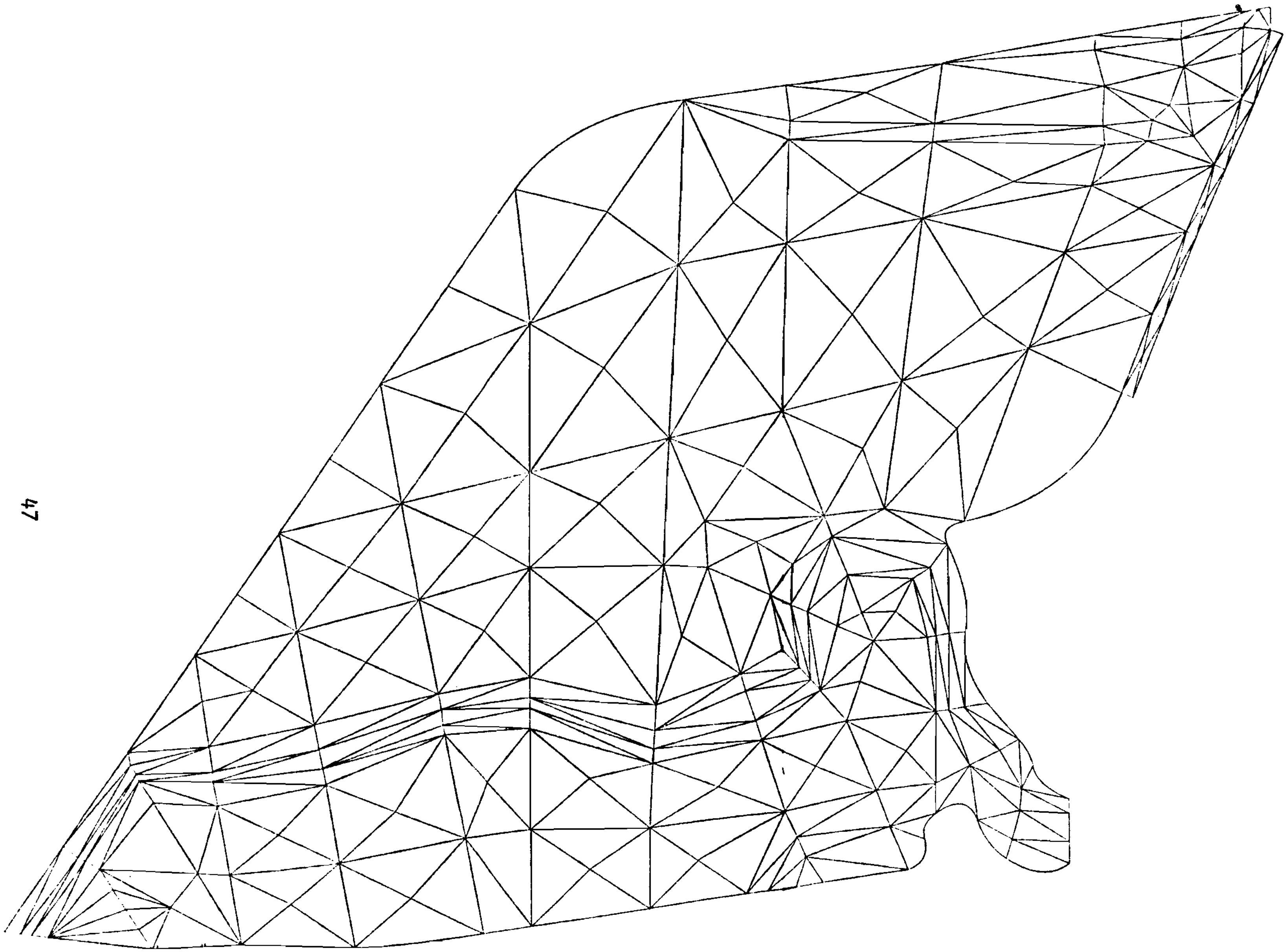


Figure 3.5 Network Without Lumberyard

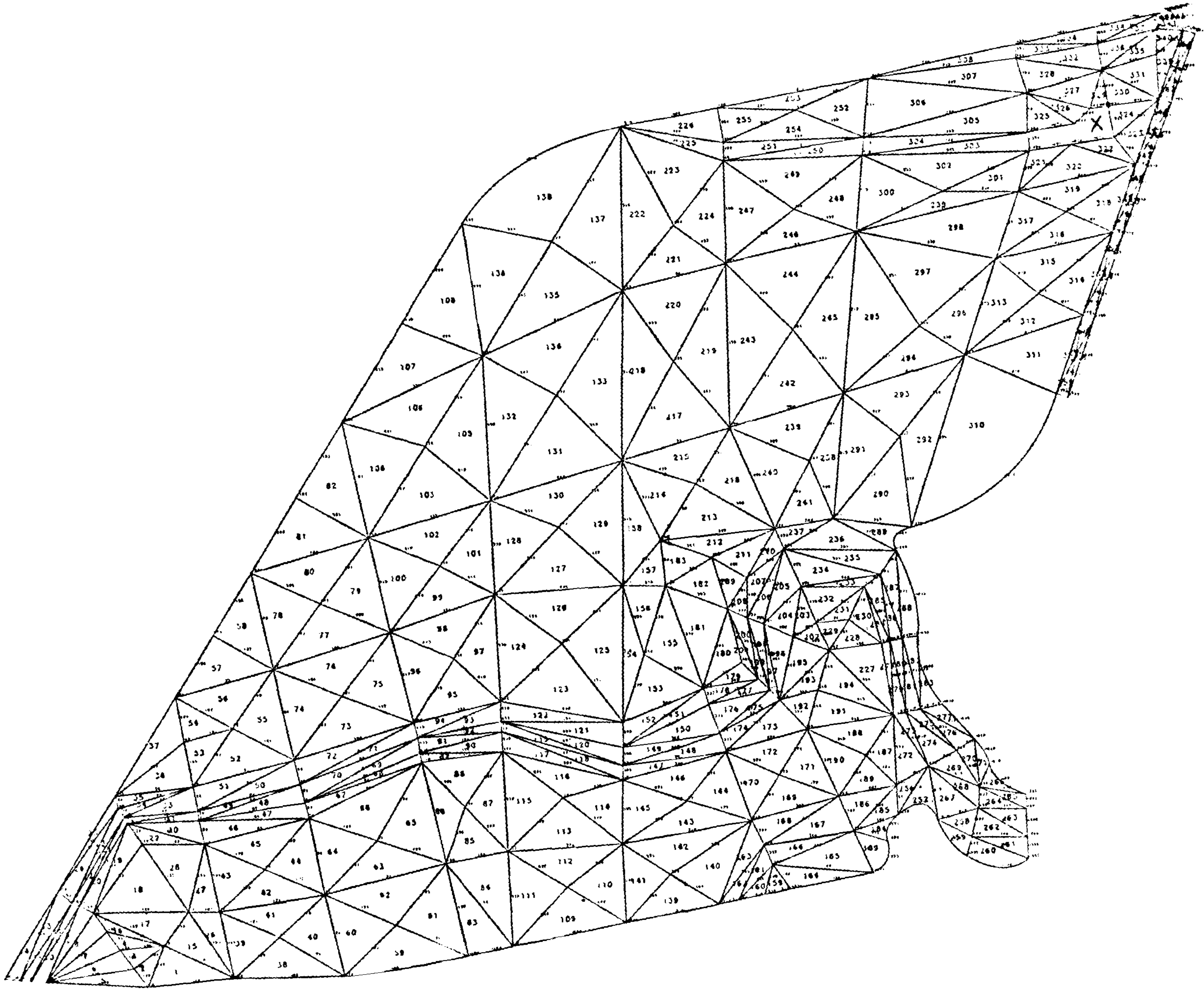


Figure 3.6 Network With Building at Lumberyard

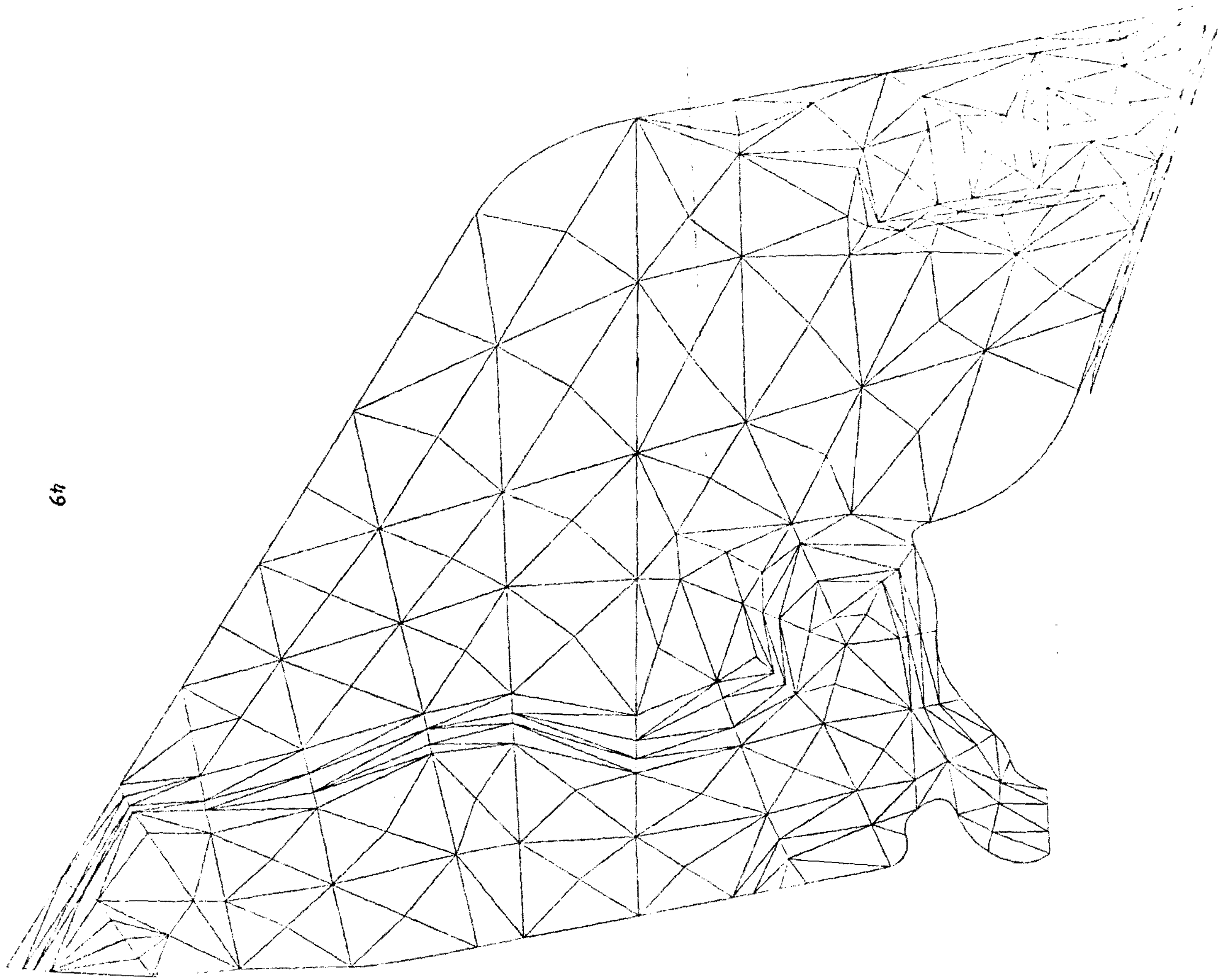


Figure 3.7 Network With Lumberyard Buildings and Embankment

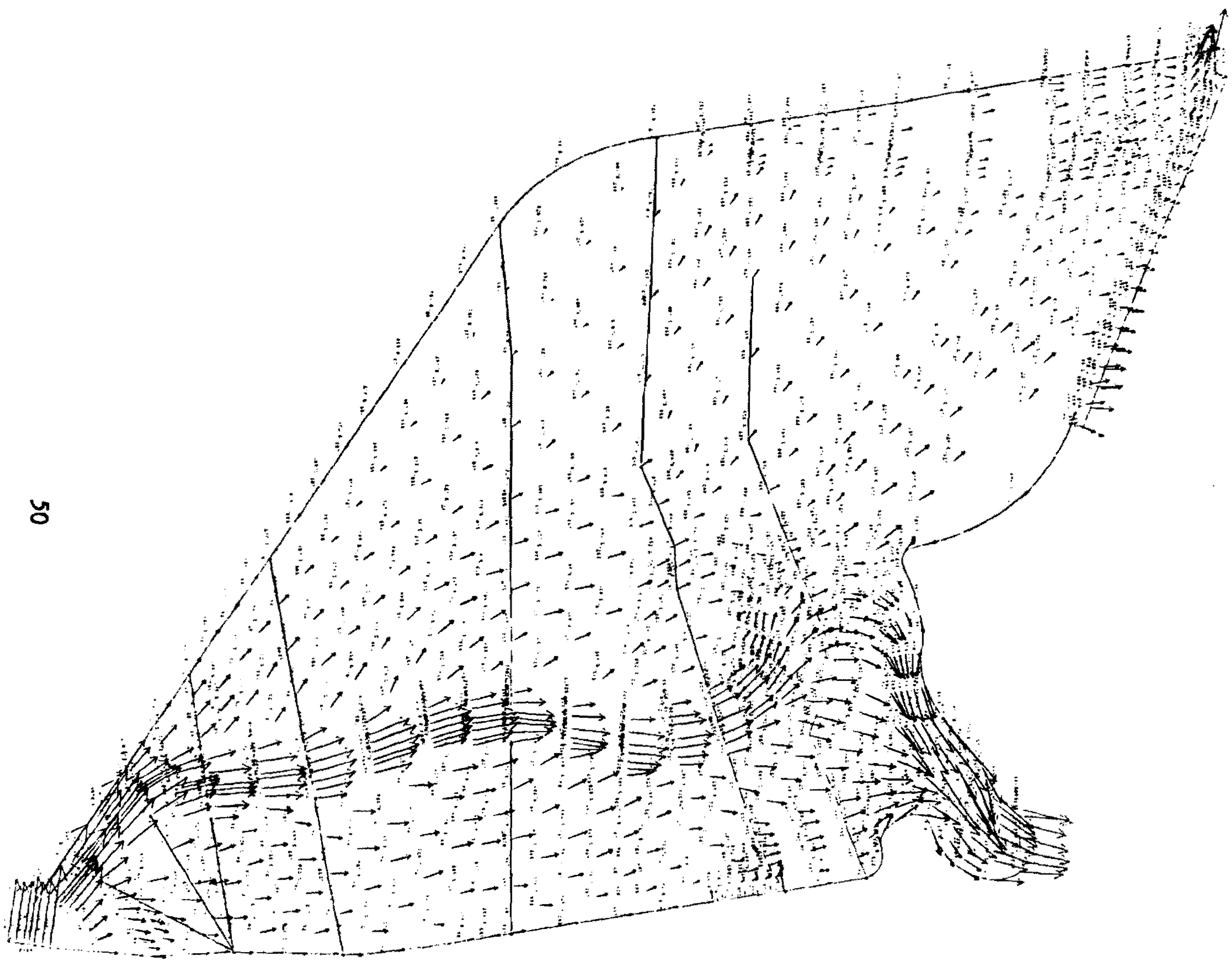


Figure 3.8 Walnut Creek Vector Plot With Dip in Road and Without Lumberyard

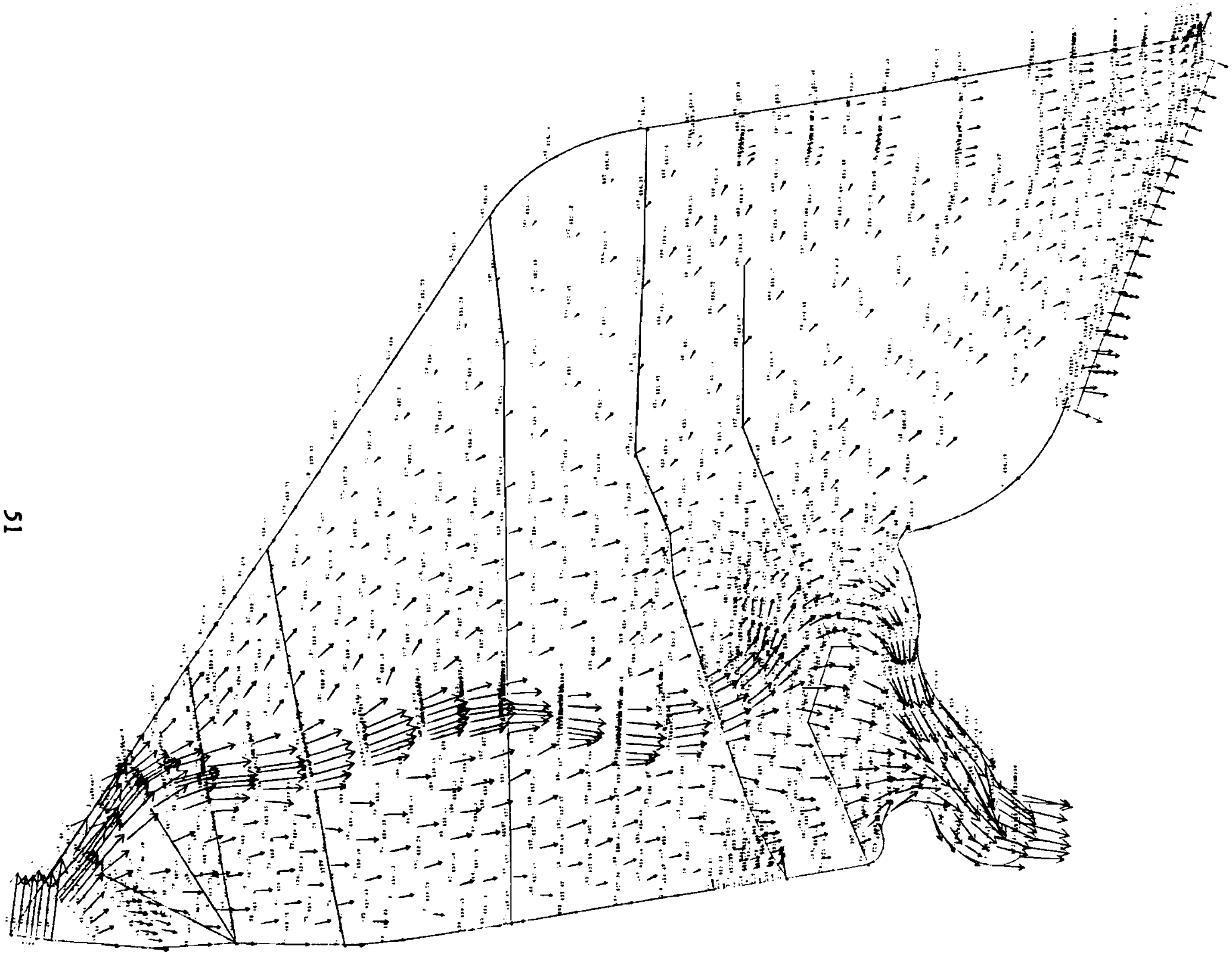


Figure 3.9 Walnut Creek Vector Plot Without Dip in Road and Without Lumberyard

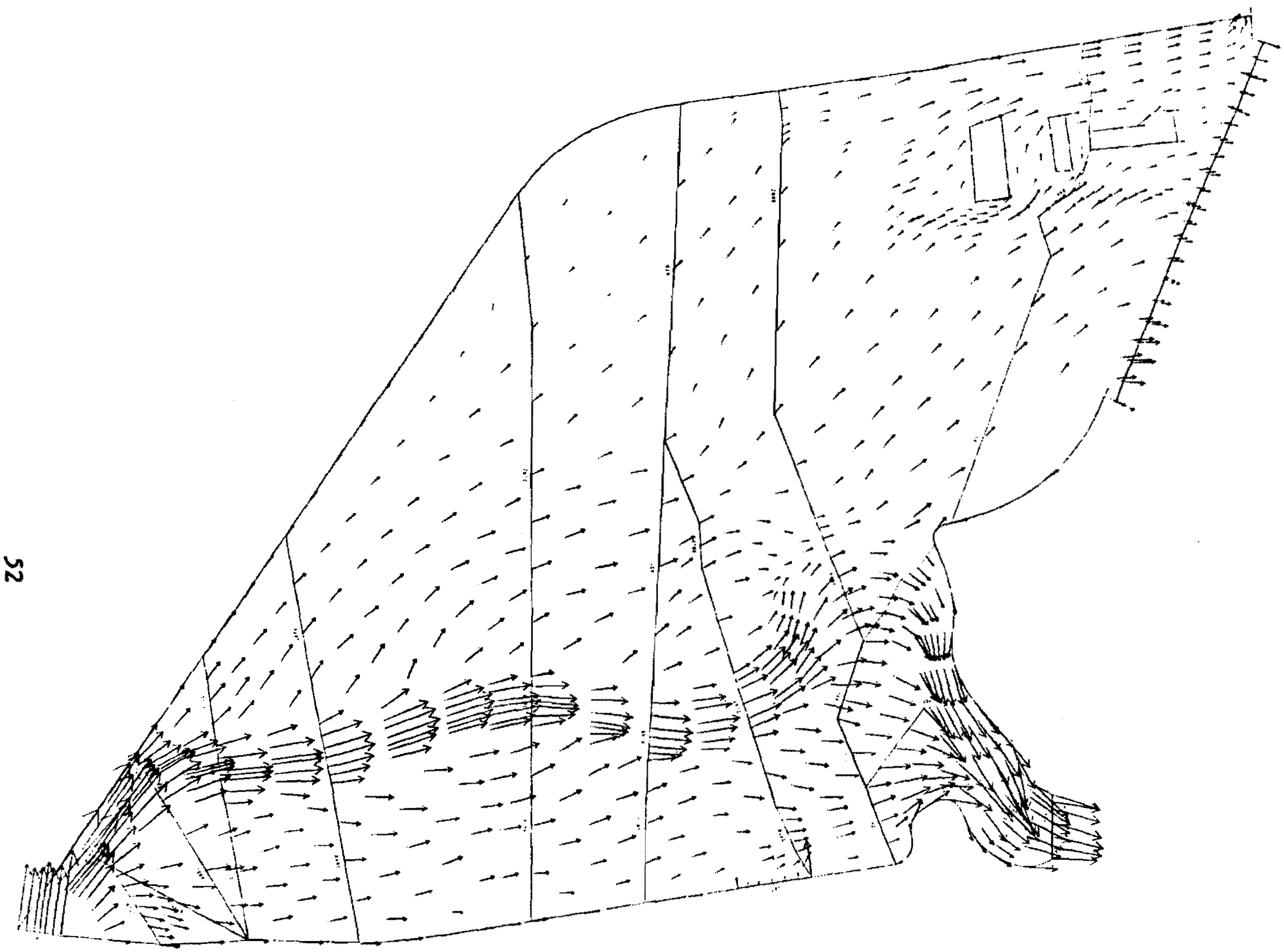


Figure 3.10 Walnut Creek Vector Plot With Dip in Road With Lumberyard

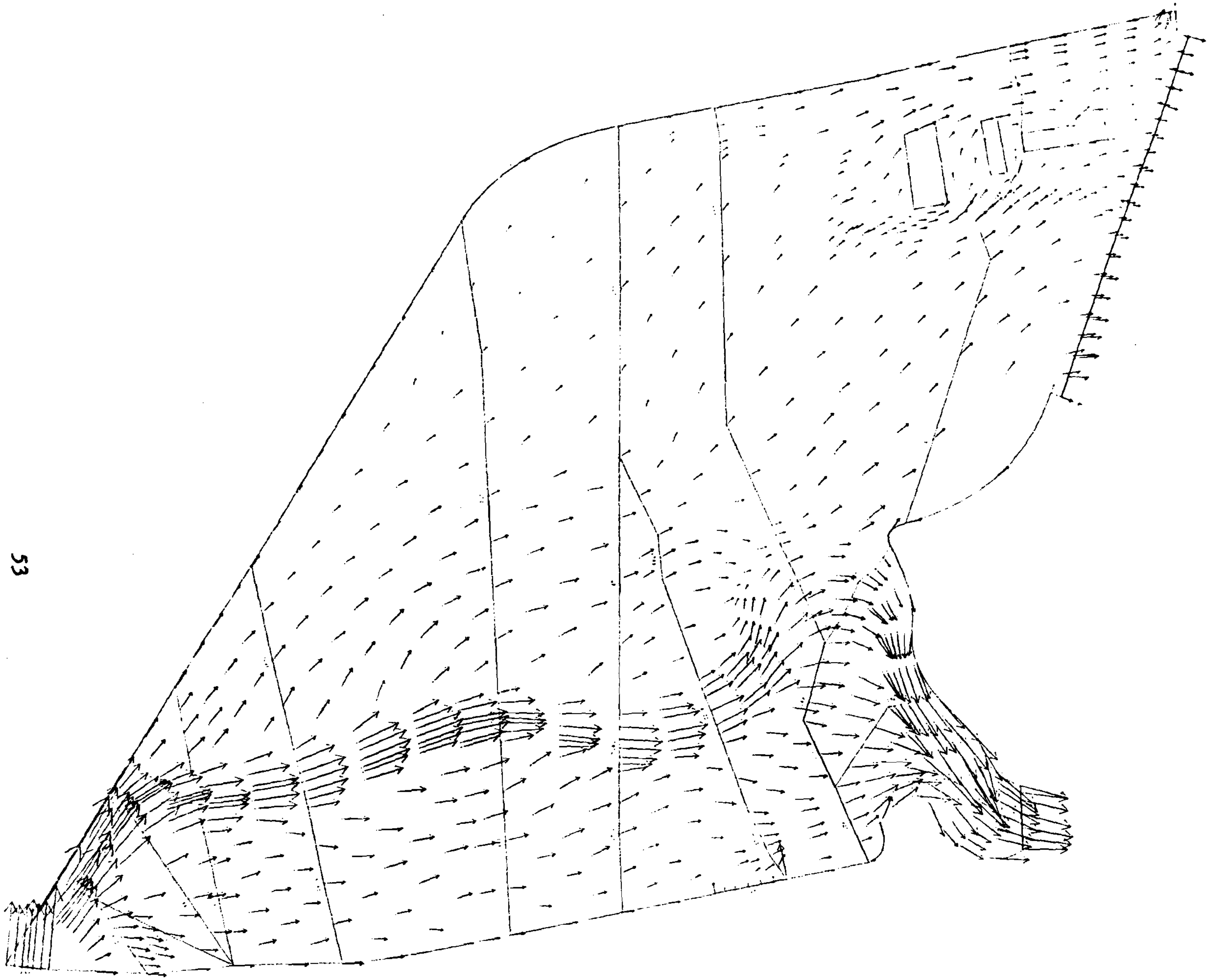


Figure 3.11 Walnut Creek Vector Plot Without Dip in Road With Lumberyard

Table 3.3. Water Surface Elevations at Building Location

Iteration 10

	With lumberyard		Without lumberyard	
Node	w/dip	w/o dip	w/dip	w/o dip
693	452.835	452.934	452.898	453.000
703	452.947	453.007	452.933	453.012
578	453.164	453.290	453.033	453.133
580	453.125	453.255	453.022	453.122

Iteration 11

	With lumberyard		Without lumberyard	
Node	w/dip	w/o dip	w/dip	w/o dip
693	452.500	452.651	452.542	452.710
703	452.542	452.673	452.567	452.717
578	452.873	453.082	452.727	452.916
580	452.862	453.062	452.722	452.906

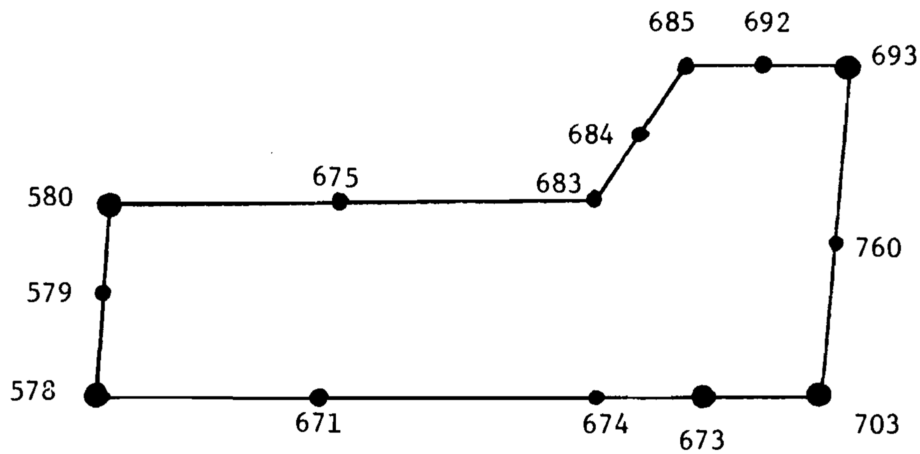


Figure 3.12 Node Numbers for Building

Table 3.4. Comparison of Flow Depths Along MLK Blvd.

Iteration 10

	With lumberyard		Without lumberyard	
Node	w/dip	w/o dip	w/dip	w/o dip
775	4.500	2.485	4.554	2.491
774	4.098	2.532	4.027	2.457
756	3.696	2.578	3.500	2.400

Iteration 11

	With lumberyard		Without lumberyard	
Node	w/dip	w/o dip	w/dip	w/o dip
775	4.431	2.282	4.369	2.254
774	3.967	2.336	3.939	2.307
756	3.503	2.390	3.508	2.361

Ground Surface Elevations

Node	w/dip	w/o dip
775	447.9	450.2
774	448.5	450.25
756	449.1	450.3

CHAPTER 4

APPLICATION TO ROSEBUD

The objective of this application was to demonstrate the use of the Interactive Graphics Design System (IGDS) to define the finite element network from a digitized contour map and develop the appropriate input data for the RMA models. Through this application it was shown that such a procedure could be successfully performed. This application also showed several needed improvements to the software for defining the finite element network and input.

4.1 Description of Study Area

This application study area is located west of Rosebud, Texas as shown in Figure 4.1. The particular area of interest is the floodplain upstream of Highway 53. In particular, the area is between the old Highway 53 and the new relocated Highway 53 which is approximately 0.75 mile upstream from the old highway. The relocated highway is also shown in Figures 4.2 and 4.3.

Pond Creek watershed has a drainage area of approximately 81 square miles upstream of the relocated Highway 53. The average stream slope is 8.8 ft/mile. The flood plain upstream of relocated Highway 53 has a main channel and an east and west auxiliary channel. The land use of Pond Creek watershed consists of 60% cropland, 35% grassland, and 5% miscellaneous land uses. The State Department of Highways and Public Transportation has computed the 25 year, 50 year, and 100 year peak discharge at the relocated Highway 53 as 15,200 cfs, 19,100 cfs, and 23,300 cfs, respectively.

The Cottonwood Creek watershed has a drainage area of approximately 10.5 square miles and is long and narrow as shown in Figure 4.3. The average stream slope is 13.7 ft/mile. This watershed is relatively flat and is under cultivation except for the brushy areas along the creek channel. The State Department of Highways and Transportation has computed the 25 year, 50 year, and 100 year peak discharge at the relocated Highway 53 as 4,300 cfs, 5,300 cfs, and 6,400 cfs, respectively.

Downstream of the old Highway 53 is the Confluence of Pond Creek, Cottonwood Creek, and Salt Creek as shown in Figure 4.1. A new bridge has also been constructed for the Cottonwood Creek crossing on the old Highway 53. For the purpose of this demonstration application only the flood plain areas of Pond and Cottonwood Creek between the old and new Highway 53 will be considered.

4.2 Description of Application

The Texas Department of Highways and Public Transportation developed aerial photography of the area. This aerial photography was used to develop a digitized contour map of the study area. The contour map was digitized on the Intergraph System. The Automation Division of Texas Department of Highways and Public Transportation developed software for the IGDS system that can be used to define the finite element network. Definition of the network requires locating the finite element nodes at appropriate locations with the cursor, entering the ground surface elevation manually, then moving to the next finite element node of the triangular element. This process must be carried on in a particular order. Because the major purpose here is to demonstrate that such a process can be used to define the input for FESWMS-TX, and

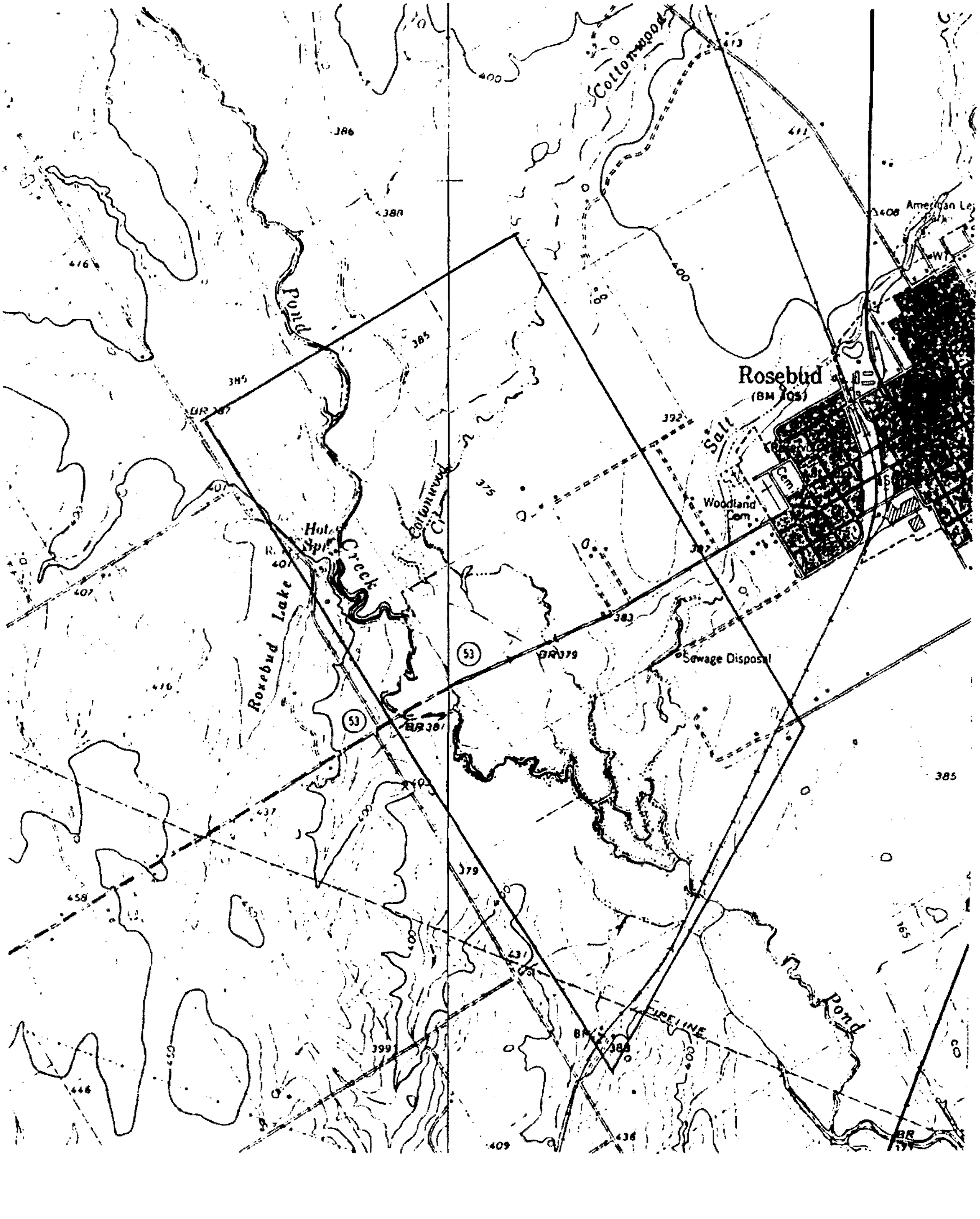


Figure 4.1 Application Area Near Rosebud, Texas

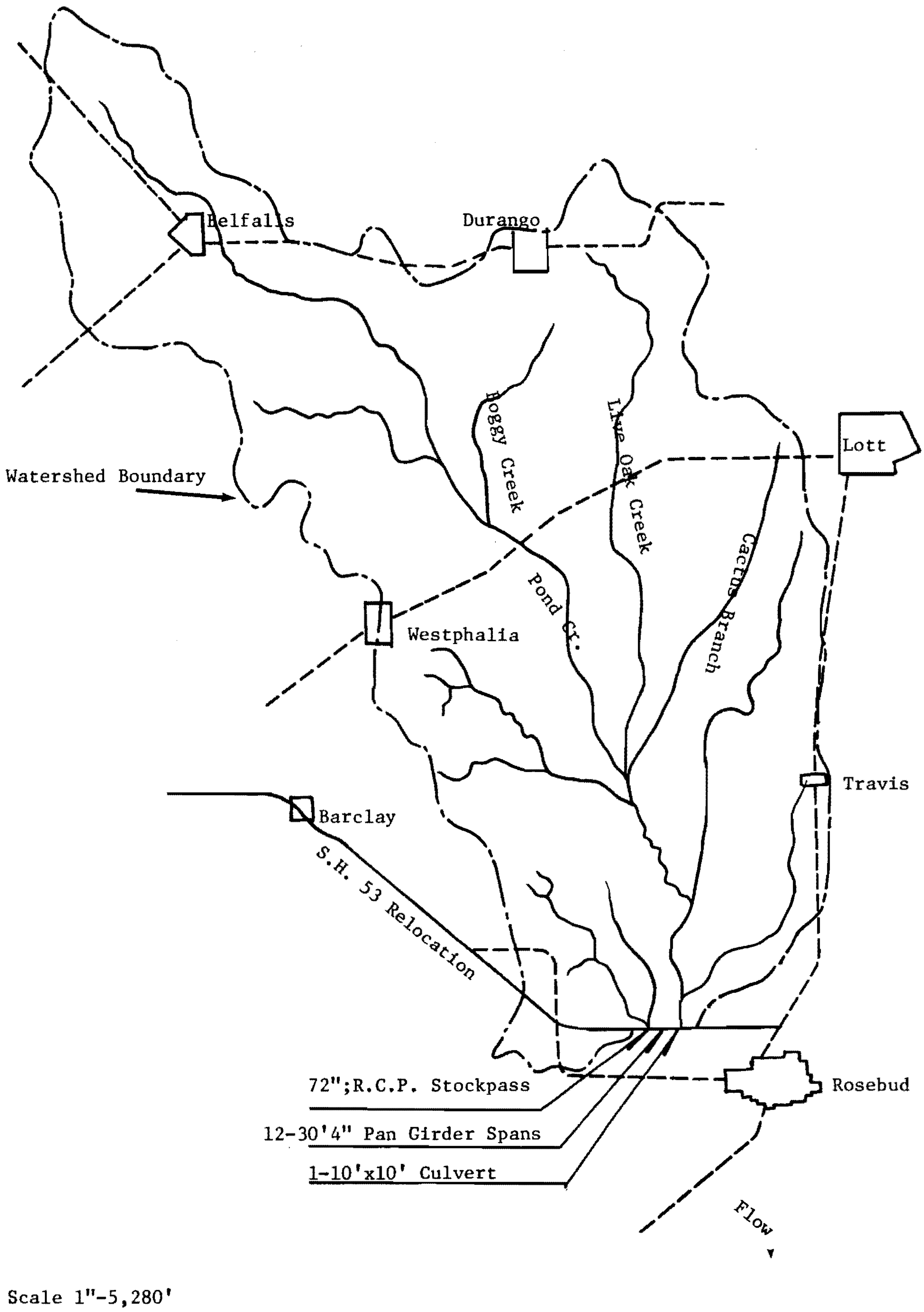


Figure 4.2 Pond Creek Watershed

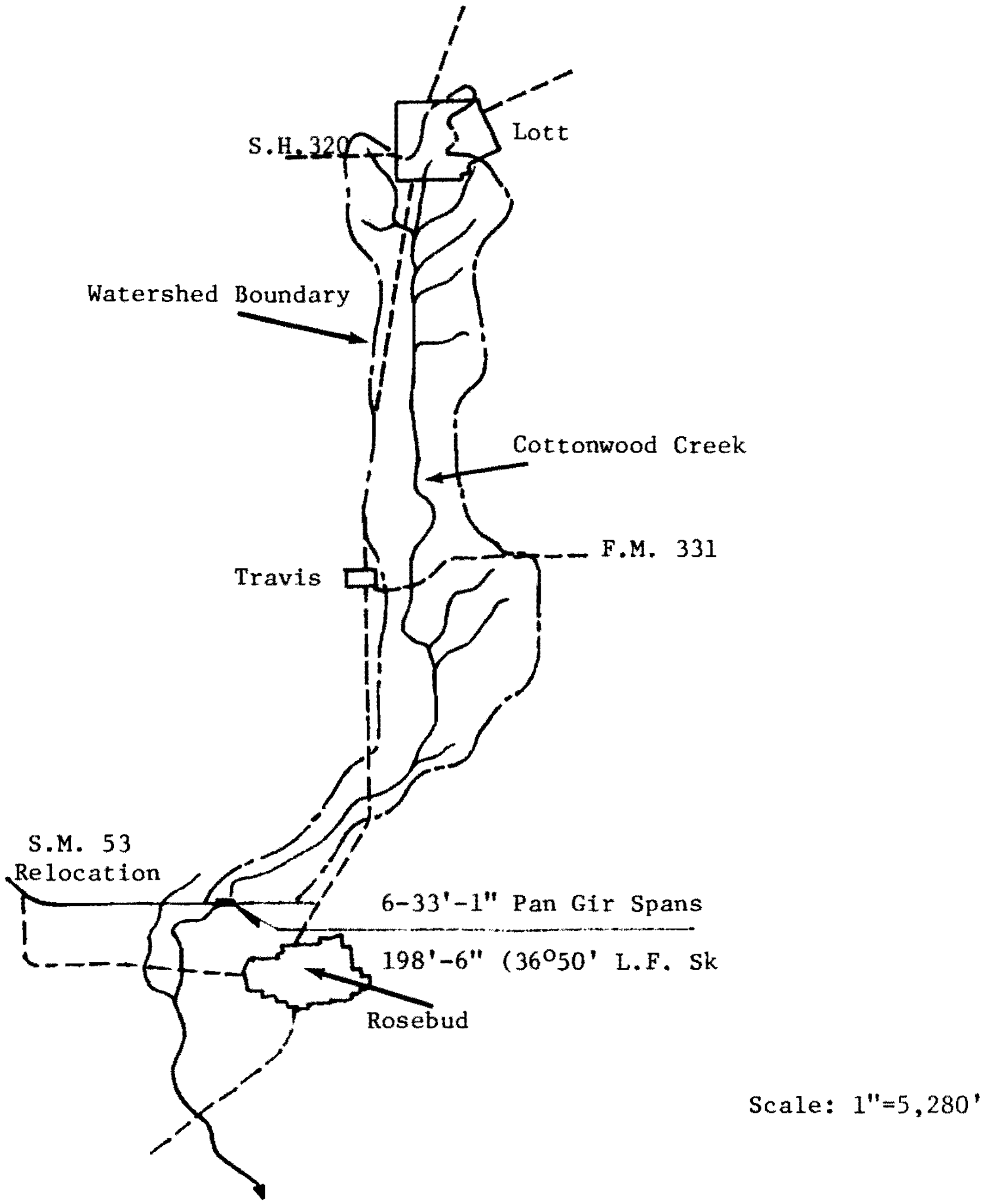


Figure 4.3 Cottonwood Creek Watershed

that several needed improvements to the Intergraph software were identified, a detailed description of the procedure to develop the finite element network using IGDS will not be presented.

Hopefully, future funded research will improve the process and software. The important fact here is that such a process has been successfully demonstrated and further work is needed. The generated finite element network for this application is presented in Figure 4.4. The 100-year peak discharges of 23,300 cfs for Pond Creek and 6,400 cfs for Cottonwood Creek were used. This application is intended only for application.

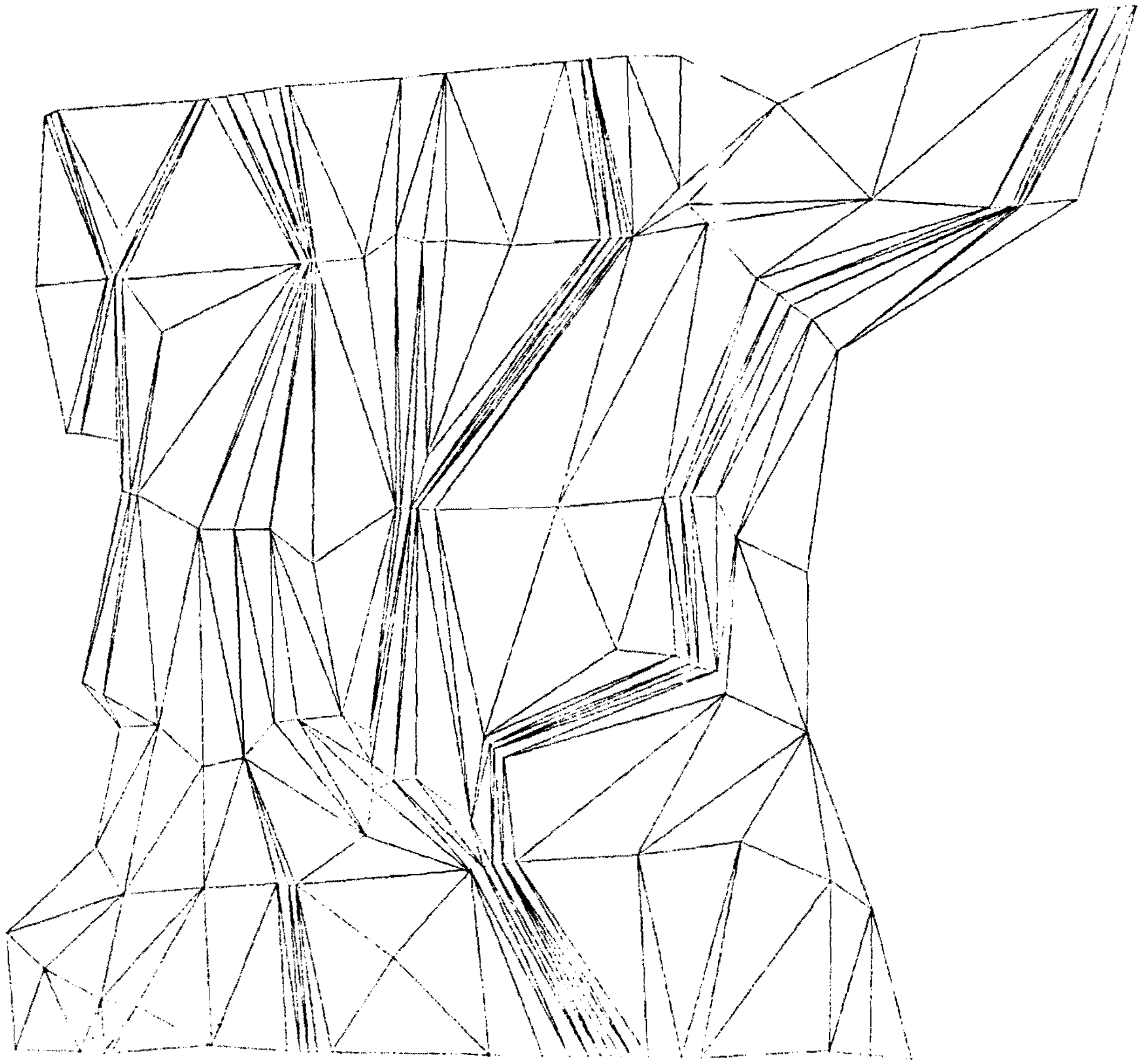


Figure 4.4 Finite Element Network for Application

CHAPTER 5

SUMMARY AND CONCLUSIONS

The objective of this phase of the project has been to extend the previous application of the FESWMS-TX model to the Walnut Creek example. The purpose was to analyze the effect of very minor modifications to Martin Luther King Boulevard and to show the flow pattern that results in the floodplain due to putting flow barriers such as embankments, stacks of lumber and buildings in the flood plain. The major reason for extending the original application was to demonstrate the capabilities of this model to consider very detailed aspects of the two dimensional flow pattern. The second major objective has been to demonstrate that the use of the Intergraph (IDGS) System can be used to develop input for the FESWMS-TX model. This procedure has the potential to be a very valuable tool in the use of the FESWMS-TX model; tremendously reducing the time required and eliminating errors from the highly error prone process of manually developing the input directly from topography maps. Several needed improvements to the IDGS software developed by the Automation Division were identified. Hopefully future funded research will improve the process and the software.

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