Applying Computer Programming to Unsteady Stream Flow (FEQ)

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APPLYING COMPUTER PROGRAMMING TO UNSTEADY STREAM FLOW (FEQ)

MARCH 19 - 22, 1990

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APPLYING COMPUTER PROGRAMMING TO UNSTEADY STREAM FLOW (FEQ)

March 19–22, 1990

This outline presents the major topic to be presented during the short course. The outline is subject to adjustment during the course depending on the background, interests, and abilities of the class members.

DAY 1–Morning

Session 1–**Introduction to Unsteady Flow.** Present examples and comparisons to steady flow, data requirements, assumptions in the analysis, and when unsteady flow analyses are required.

Session 2–**Describing a Stream System: Part I.** Introduce the world view of the computer program, FEQ, and the terms used to describe the stream systems. These include cross sections, functions, function tables, computational elements, branches, nodes, and control structures, land uses, tributary area, *etc.* Introduce the flow sign convention.

DAY 1–Afternoon

Session 1–**Program FEQUTL: Part I.** Introduce FEQUTL, its world view, purpose, and basic operations.

Session 2–**Program FEQUTL: Part II.** Introduce the more complex operations performed by FEQUTL: Flow over embankments, flow through bridges, flow through culverts, dam-break related functions.

DAY 1–Evening

Laboratory. Introduce students to computer using FEQUTL input examples. Students experiment with options.

DAY 2–Morning

Session 1–**Describing a Stream System: Part II.** Through simple examples show how the various pieces introduced in the previous session are put together to describe a stream system to FEQ.

Session 2–**Control Structure Options: Part I.** Describe in detail the fixed geometry control structure options and show how the parts of a real stream system are represented by these control structures.

DAY 2–Afternoon

Session 1–**Control Structure Options: Part II.** Continue with the fixed geometry options. Describe branch options which might serve as substitutes for control structures in some cases.

Session 2–**Fixed Geometry Control Structure Examples.** Give a series of examples demonstrating the use of the control structure options already presented.

DAY 2–Evening

Unsteady Flow Laboratory. Students will modify an existing input for FEQUTL and FEQ to describe a simple system. These inputs would be run and debugged to illustrate hands-on operation of the software.

DAY 3–Morning

Session 1–**An Approach to Unsteady Flow Analysis.** Present the various steps such as data assembly, data review, constructing a schematic, numbering the parts of the system, describing connections, debugging, etc. Also outline some operational details such as multiple files for cross section tables, choice of directory structure and file names, and using the identification field.

Session 2–**Control Structure Options: Part III.** Describe the variable geometry options for control structures.

DAY 3–Afternoon

Session 1–**Basic Theory: Part I.** Develop the theory used for selected options in FEQUTL. Present an introduction to unsteady flow governing equations.

Session 2–**Basic Theory: Part II.** Continue with unsteady flow governing equations and their solution.

DAY 3–Evening

Unsteady Flow Laboratory. Students will create inputs for simple streams which differ from previous examples to give them further opportunity for testing and improving their skill level.

DAY 4–Morning

Session 1–**Complex Example.** Use Spring Brook from the Salt Creek study as an example. Outline the stream system and how it was represented. Show some simple results illustrating reverse flow and the dynamic operation of the control gate and pump.

Session 2–**Recent Examples and Discussion.** Outline recent applications of FEQ. Answer questions from students on representation alternatives.

DAY 4–Afternoon

Session 1–**The HIP System.** Provide an overview of the role played by each component of the HIP system and their interaction.

Session 2–**Concluding Comments and Discussion.** Give concluding comments on approach and philosophy allowing time for questions and discussion.

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DELBERT FRANZ

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Delbert D. Franz, Ph.D., P.E. is Vice President of Linsley, Kraeger Associates Ltd., in Mountain View, California. He has more than 20 years of experience in hydrology, hydraulics, and software development. His areas of expertise include computer software development for science and engineering, dynamic flood routing, bridge and culvert hydraulics, stochastic hydrology, and hydrologic simulation.

His accomplishments in these areas are numerous. Dr. Franz applied a hydrologic simulation model for the Federal Highway Administration study, Flood Frequency Estimates for Small Watersheds. He supervised a project, Studies in the Application of Digital Simulation to Urban Hydrology, which was conducted for the Office of Water Resources Research. He developed and applied a FORTRAN program for unsteady open channel flow using the specified-time interval method of characteristics. The program has been used to predict the movement of dam-break flood waves at about 50 sites in northern California. Dr. Franz developed, applied, maintained, and extended another FORTRAN program that simulates unsteady flow in open channels by using an implicit four-point scheme. The current version incorporates bridges, culverts, reservoirs, expansions, contractions, critical depth, flow over side weirs, and momentum effects at junctions. It is in use at more than six locations across the United States.

DELBERT D. FRANZ
Vice President

Linsley, Kraeger Associates Ltd

Dr. Franz has 19 years of experience in hydrology, hydraulics and software development. His fields of expertise include:

Computer software development for science and engineering
Dynamic flood routing
Bridge and culvert hydraulics
Stochastic hydrology
Hydrologic simulation

Education

1965 BS in Civil Engineering, University of Kansas
1966 MS in Water Resources Engineering, University of Kansas
1970 PhD in Civil Engineering, Stanford University
1974 Advanced Programming Short Course, University of California, Santa Cruz

Experience

1968-69 Acting Assistant Professor, Stanford University
1970-72 Research Hydrologist, Hydrocomp, Palo Alto, CA
1973-80 Vice President, Hydrocomp, Palo, Alto, CA
1980-81 Visiting Associate Professor, University of Kansas
1981- Vice President, Linsley, Kraeger Associates

Projects

Designed, implemented, and used interactive graphics system on a PDP 8/I minicomputer to display time series data for a large hydrologic simulation program executing on a mainframe computer.

Applied a hydrologic simulation model for a Federal Highway Administration study titled, "Flood Frequency Estimates for Small Watersheds".

Project manager for Office of Water Resources Research study titled, "Studies in the Application of Digital Simulation to Urban Hydrology."

Principal investigator for study titled, "Prediction of Dew Point Temperature, Solar Radiation, and Wind Movement Data for Simulation and Operations Research Models." Project funded by the Office of Water Resources Research.

Modified and extended a large PL/1 hydrologic simulation program to support improved time series data management, to forecast snowmelt floods, and to predict water quality in streams and reservoirs. Also provided maintenance, on site support, and telephone support to clients using the simulation program.

Developed and applied FORTRAN program for unsteady open channel flow using the specified-time interval method of characteristics. Predicted movement of dam-break flood waves at about 50 sites in northern California using this program.

Developed, applied, maintained, and extended a FORTRAN program simulating unsteady flow in open channel networks using an implicit four-point scheme. Current version incorporates bridges,

culverts, reservoirs, expansions, contractions, critical depth, flow over side weirs, momentum effects at junctions, etc. Current version in use six or more locations across the United States.

Co-designer of HSPF, a large FORTRAN program(over 75,000 statements) simulating the flow of water and pollutants in a river basin. Designed and implemented the time series management system for the program. HSPF is in active use by a variety groups across the United States.

Developed and tested a FORTRAN program for computing best spline approximations to tabulated functions derived from stream and river cross sections. Utilized linear programming with an efficient method for representing polynomial splines. First versions of program were developed in BASIC on a microcomputer and then translated and expanded in FORTRAN for mainframe computers.

Developed and applied a BASIC program on a microcomputer to compute steady flow water surface profiles in open channels containing culverts and pipe crossings.

Developed and applied a C program on a microcomputer to simulate water temperature in small streams under steady flow conditions.

Developed and applied a suite of programs for stochastic modeling of hourly rainfall data for use in studies for floods of long return period via hydrologic simulation. Work done for the Nuclear Regulatory Commission.

Memberships

American Society of Civil Engineers
American Geophysical Union
American Institute of Hydrology
Society of Sigma Xi
Registered Civil Engineer, California C022983

Selected Publications

"Hourly Rainfall Synthesis for a Network of Stations", Technical Report 126, Department of Civil Engineering, Stanford University, 1970.

"An Interactive Time Series Plotting System for Classroom Instruction in Hydrology", Technical Report 143, Department of Civil Engineering, Stanford University, 1971(with Linsley).

"Studies in the Application of Digital Simulation to Urban Hydrology", report to Office of Water Resources Research, 1971.

"Prediction of Dew Point Temperature, Solar Radiation, and Wind Movement Data for Simulation and Operations Research Models", report to Office of Water Resources Research.

"Long Waves in Open Channels and Dam-Failure Analysis". Report to Pacific Gas and Electric Company, 1977.

"Dam-Break Flood Wave Analysis: Problems, Pitfalls, and Partial Solutions", *Proceedings of Dam-Break Flood Routing Model Workshop*, Bethesda, Maryland, 1979.

"Streamflow Routing", in Hydrology for Engineers by Linsley, Kohler, and Paulhus, 1982.

"Representation of Cross-Sectional Elements", *Journal of the Hydraulics Division*, ASCE, October, 1982.

"Geometric and Frictional Characteristics of Open Channels", report to SCS National Engineering Staff Hydrology Unit. Lanham, Maryland, 1982.

"Capacity Determination for Hopper Creek, Yountville, California", report to Nowack and Associates, Santa Clara, CA 1982.

"A System for Generating Long Streamflow Records for Study of Floods of Long Return Periods", NUREG/CR-4496 Vol. 2, prepared for Waste Management Branch, Office of Nuclear Regulatory Research, U. S. Nuclear Regulatory Commission, Washington, D. C., 1988(with Kraeger and Linsley).

UNSTEADY FLOW SOLUTIONS

Notes for Short Course on FEQ and Unsteady Flow

Date: 5 March 1990

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INTRODUCTION TO UNSTEADY FLOW

An unsteady flow is any flow in which some aspect of the flow is changing with time. We restrict our attention to flows with a free surface taking place in open channels such as canals, rivers, streams, brooks, sewers, pipes, *etc.* Many of these flows can be analyzed successfully by treating the flow as if it were one dimensional. If the flow is one dimensional, then only acceleration along the channel length(longitudinal acceleration) is important. When vertical and lateral accelerations are small, the movement of water is described as a shallow-water wave. In a shallow-water wave the wave length of a disturbance is much larger than the depth of water. In contrast a deep-water wave has a wave length much smaller than the depth. For a shallow-water wave, the disturbance reaches the bottom of the channel, whereas in the deep-water wave the disturbance remains near the surface. Waves of either type may occur in water of any reasonable depth.

Most real flows are unsteady; but most flow analyses assume steady flow. Practically, many real flows can be approximated by steady flow. This is true in those cases where the goal is to maintain essentially steady flow for long periods of time such as in irrigation canals. However, the principal reason for the predominance of steady flow analysis is that it is simpler to understand and it requires less computational power. As a practical matter, the computations for unsteady flow were too expensive or impossible to do by hand computations except for some simplified cases. Clearly widespread use of unsteady flow analysis could not begin until the power of the modern digital computer became available.

A classification scheme for both steady and unsteady flow is useful in describing the flows of interest to us. The simplest steady flow is uniform flow in which no flow variable changes with distance. In a uniform steady flow every flow variable is a constant with respect to both distance and time. If the flow is not uniform then it is non-uniform. In this case the flow is further divided into gradually varied or rapidly varied flow. Gradually varied steady flow may have variations in the flow variables with distance but all variables are constant in time. Furthermore the variations with distance are gradual as the name implies. The series of backwater profiles discussed in the typical open channel hydraulics course are all gradually varied flows. Finally the flow may be rapidly varied meaning that there are significant variations in flow in other than the longitudinal direction. An extreme example is a hydraulic jump below a dam. This flow can still be analyzed using the assumption of one dimensional flow but such an analysis must recognize and isolate the rapidly varied flow portion. Additional examples of rapidly varied flow include flows through culverts and bridges as well as flow over weirs and spillways.

If the flow is unsteady, uniform flow is impossible so that only non-uniform flow exists for unsteady flow. Both gradually varied and rapidly varied flow exist and the same general rules for analysis apply. We must isolate the regions of rapidly varied flow before we can analyze them using the one-dimensional flow assumption. As a result the method of analysis of steady and unsteady flow is the same in this respect. There are many other similarities between the analyzes of these flows. Because steady flow is much more widely used and because I assume you are familiar with steady flow, I will use it as a springboard to introduce some aspects of the analysis of unsteady flow.

Comparison of Steady and Unsteady Flow Analysis

In steady flow we have a governing equation that describes how the flow varies. This is most often written as an energy equation but a momentum equation can be used as well. In either case, this equation is a differential or integral equation having a solution but the solution cannot be found without recourse to numerical methods. We can only obtain an approximate solution to the governing equation as a result. To find this solution we subdivide the channel into short pieces. Then for each short piece we approximate the differential or integral terms in the governing

equations algebraically and obtain an algebraic equation that approximates the governing equation in the short channel pieces. The channel pieces I will call computational elements. They are called computational because they have been introduced for purely computational reasons and they are called elements because from them the whole solution scheme proceeds. Therefore they are truly elemental.

The ends of the computational element, called nodes, are defined by cross sections either measured or estimated from measurements. The cross section is taken at right angles to the direction of flow in so far as we can predict the direction of flow. One way to visualize a computational element is as a slice of the channel taken at right angles to the longitudinal axis of the channel. Adjacent computational elements have a cross section and therefore a node in common. As a result a length of channel divided into 10 computational elements will have 11 nodes. There will always be one more node(cross section) than the number of computational elements.

The values of interest in the cross sections at the end of the computational element, also called elements, in this case cross sectional elements, are the width of the water surface, the flow area, the first moment of area, the conveyance, and perhaps an energy or momentum flux coefficient all computed at any given elevation. Please note that the governing equation does not explicitly know anything of the shape of the cross section beyond the information on shape reflected in these cross sectional elements. This is why they are called cross sectional elements because they convey all the information that the governing equation can comprehend about the cross section. Therefore they are truly elemental.

In steady flows, except for flow over a side weir, the flow is known at all points in the channel. Now we have been careful to write the algebraic approximations such that they involve values at the ends of the computational element only. Consequently we have two unknowns in each computational element: the elevation of the water surface at each end. If we are given an initial elevation we can compute the unknown elevations along the channel sequentially and we never have to solve for more than one unknown at a time. The direction of solution must be from a point of known or assumed elevation to points of unknown elevation. In general if the flow is subcritical the direction of solution is upstream and if the flow is supercritical the direction of solution is downstream.

An important factor in a steady flow analysis is determining points where the elevation can be computed once the steady flow is selected. These points, of known or knowable relationship between flow and elevation, are called control points. Consequently in a steady flow analysis one of the first things done is to determine the location and nature of the control points. Additionally the algebraic governing equation for steady flow does not apply to rapidly varied flow that occurs at bridges, culverts, falls, rapids, dams, *etc.* Furthermore it does not apply to junctions of two or more channels or to abrupt expansions or contractions in channel size or shape. These features must be isolated and analyzed using equations other than the equations used for each computational element.

Another feature of steady flow analysis that is important is that our first selection of the length of one or more computational elements may be too long. We may find that the non-linear equation that we must solve in each computational element has no solution. The only recourse is to subdivide the computational element into two or more shorter computational elements. We also may find that occasionally our solution process may find an elevation such that the flow is supercritical at the upstream end of the computational element when we started with an elevation at the downstream end at which the flow was subcritical. This is incorrect! In steady flow, such a pattern indicates that there is a hydraulic jump present at some point in the computational element. Several possibilities present themselves to the analyst at this point in a steady flow analysis. First, the incorrect result may be purely a computational artifact and results only from the failure of the solution process to find the subcritical solution at the upstream end of the computational element. The solution process should be changed to seek a subcritical solution so that this case should not arise frequently.

Second, there may not be a subcritical solution to the unknown in the computational element. This also can be a computational artifact because the computational element is too long so that the errors in our approximation of the differential or integral terms are falsifying the solution. We must then subdivide the computational element and try the solution again. The final possibility is that the flow is physically supercritical near the computational element yielding the invalid solution. If this is the case, then we must find the control point for the supercritical flow and compute that profile downstream from the control point and locate the hydraulic jump by computing another profile upstream from the subcritical control point until the conditions for a jump are found. This process normally requires several trial and error attempts.

A final feature of steady flow is that we must provide the hydraulics of the special features such as junctions, bridges, *etc.* These are not adequately described by the algebraic governing equation used for the computational elements along the channel. Appropriate assumptions must be made to develop equations relating flows and elevations at junctions, bridges, dams, *etc.* It is then possible for us to compute the hydraulic effects so that we can find the initial conditions for the channels upstream of these special features. Of course, there must be at least one point at which we know the elevation to start the computations. This point, in subcritical flow will be at the downstream end of the stream system we are analyzing. It is at the downstream boundary of the region of interest to us and is called an initial condition.

This outline of a steady flow analysis gives the background for introducing some concepts of unsteady flow analysis. We can expect some similarities because steady flow is a special case of unsteady flow. There will be some differences also because unsteady flow must describe conditions not comprehended by the steady flow governing equations.

In unsteady flow we need two governing equations because both the flow and the elevation of the water surface are unknown. One of the governing equations is based on the conservation of water volume and the other is based on the conservation of water momentum. In steady flow the principle of conservation of water volume was trivial because the flows were constant and we used it to solve for the flows everywhere *without* having to know the elevations *anywhere*! We can no longer do this in unsteady flow. Therefore the conservation of water volume becomes a governing equation involving both flows and elevations.

We again must use computational elements in the unsteady flow analysis and we use algebraic approximations to the differential or integral terms involved in the governing equations to develop two algebraic equations for each computational element written in terms of elevations and flows at the ends of the element. But these governing equations are not only more in number they are more complex. In the unsteady flow case we must also introduce a "computational element" with respect to time. This was not needed in steady flow because no value changed with time. Fortunately, the "computational element" with respect to time is very simple. We merely divide the time axis into finite time increments that we hope will be short enough so that the algebraic approximations to the differential and integral terms will be sufficiently accurate. Because of this dependence on time the algebraic governing equation involve not only the unknown flow and elevation at two points along the channel but also at two points in time.

We need to identify control points of known relationship between elevation and flow as well as all the other points of rapidly varied flow or of interaction between channels not described by the algebraic governing equations. Just as in steady flow, these points establish the limits of applicability of the governing equations with respect to distance along the channel as well as providing known values for the analysis. However, in unsteady flow we have an additional requirement in that we must have some starting time to begin the computations. We must start at some point in time and we must know all the flow values at this point in time! That at first sight sounds impossible. How will we ever start if we need to know the flows and elevations at a time point and that is just the purpose of the unsteady flow analysis? We need to make some assumption to break the circle

so that we can start. The way we do this is that we assume that the flow is steady at the starting time everywhere in the system. This is the first major difference between steady flow and unsteady flow: we must complete a steady flow analysis to establish the initial condition for the unsteady flow analysis.

A second major difference between unsteady flow analysis and steady flow is the nature of the information we need at the boundaries of the stream system. In steady flow we need only know one elevation at the downstream boundary to start the computations. However, a cursory analysis of the number of equations we have available so far in unsteady flow shows that we will need more information for unsteady flow analysis. Let us assume that we have a single channel with no special features. We divide this channel into 9 computational elements yielding 10 nodes. With 2 unknowns at each node we have 20 unknowns but only 18 equations(2 per computational element). Thus we cannot possibly solve for the unknowns unless we have some additional information. We need additional information at the boundaries of the system we are analyzing. When the flow is subcritical, we need information at both the upstream and downstream boundary of the system. This information can be in one of three forms: flow known as a function of time, elevation known as a function of time, or a relationship between flow and elevation. The upstream boundary will often be flow known as a function of time and the downstream boundary will often be a known relationship between flow and elevation. The information we supply at a boundary is called a boundary condition.

The information supplied at special features internal to the system is often called an internal boundary condition. In unsteady flow these are approximated as steady flow relationships because the special features are usually sufficiently short so that the changes in momentum and volume of the water within the special features are small. We will discover as we continue in the study of unsteady flow analysis that the isolation and description of the special features is a major component of the analysis.

Major differences between the two analyses are not in the hydraulic geometry because that can be identical but are in the number and complexity of the governing equations, the initial conditions required, and the addition of boundary conditions. The same problems can arise computationally because both use algebraic approximations to the differential and integral terms. These approximations are developed for the computational element of finite length. The computational element may be too long. The difference is that in unsteady flow analysis the computational problems are both more complex and more frequent. The increased frequency comes about primarily because unsteady flow analysis involves computations over a wide range of elevation whereas most steady flow analysis involves computations over a narrow range of elevations. Furthermore, the time dimension has been added and this brings its own set of problems. We will discuss some of these problems and their solution as we go through the course.

Major Assumptions in Unsteady Flow Analysis

To complete an analysis of flow in open channels we must make many assumptions. Some major ones are:

1. The wave length of the disturbance is very long relative to the depth of the flow. This is the shallow-water wave assumption. This implies that the pressure distribution does not deviate significantly from hydrostatic. This also implies that lateral and vertical accelerations are insignificant compared to the longitudinal accelerations.
2. The channel geometry is fixed so that effects of deposition or scour of sediment is insignificant.
3. The bed of the channel has only a small slope so that the tangent and sine of an angle and the angle are nearly the same value.
4. The effect of friction can be estimated by using a relationship derived from steady uniform flow.

We assume that non-uniformity and unsteadiness have an insignificant effect on the friction losses.

5. The water surface in any cross section of the stream is assumed to be horizontal. This cannot be true in many cases so we assume again that the deviations from horizontal have only a small effect on the results.
6. We assume that the effects of variations in velocity across a cross section can be approximated by using flux correction coefficients that are functions of water surface elevation only.

Using these assumptions we can develop formal statements of the conservation of water volume(mass) and conservation of water momentum. We will develop these mathematical statements later in the course. For now I want to concentrate on some basic ideas so that the mathematics presented later will be able to build on them with a minimum of confusion.

The conservation of volume(mass) principle relates to flows and changes in the quantity of water stored in the channels and reservoirs. It is not concerned with forces of any kind. On the other hand the conservation of momentum principle relates forces, momentum fluxes, and the momentum of water in storage. The factors involved in this equation are:

1. Gravity force on the water in the channel.
2. Friction force on the wetted perimeter of the channel.
3. Pressure force on the boundaries.
4. Inertia of the water.

Some of these factors can be or are ignored to simplify the unsteady flow computations. If these factors are included we have what are called the complete, full, dynamic, St. Venant, or shallow-water equations. Various names are used but they refer to equations in which these factors are included in the analysis. If the inertia of the water is ignored we have what is called the zero-inertia form of the governing equation. If the variations of pressure force along the channel are ignored because they are thought to be small we obtain what is called the kinematic form of the governing equation. Reservoir routing is also a form of unsteady flow analysis in which the governing equation degenerates to a simple relationship between water surface elevation and the flow. In a certain sense reservoir routing ignores all four factors though some or all are implicit in the relationship between flow and water surface elevation. In each case one of the factors is dropped from the momentum equation and to be precise we should call the governing equation a motion equation. The unsteady flow analysis program to be discussed here, called FEQ(Full EQuations), includes three of the four forms of governing equation for unsteady flow: (1) the so-called full equation form involving all four factors, (2) the zero-inertia form in which the inertia of the water is ignored, and (3) the reservoir routing form in which the motion equation is reduced to a relationship between water surface elevation and flow.

Unsteady Flow Analysis Examples

There are many possible examples of unsteady flow analysis. I mention only a few here.

1. Passage of a Flood Wave. In flood insurance studies the presumed maximum elevation envelope caused by a flood wave is computed assuming steady flow. Of course the flow is really unsteady and this is only an approximation and little work has been done to evaluate the accuracy of the approximation. The effect of flood plain filling and obstruction is also often analyzed using steady flow. Steady flow analysis can only evaluate the effects of changes in the ability of the stream to convey water and does not reflect the effects of changes in the ability of the stream to store water. This latter change may be large in some cases.
2. Operation of Irrigation and Power Canals. Unsteady flow analysis is required to design these canals properly because the flow variations can often be abrupt. Allowance must be made for the wave heights that might result. Furthermore, the time of travel of transients becomes important in the design and operation of structures intended to reduce or control transients.

3. Tidal Influence. Analysis of the influence of tides on streams requires unsteady flow analysis. Steady flow analysis is often used to approximate the envelope of maximum elevations but again little work has been reported on the accuracy of this approximation.
4. Junctions. The complex interactions at junctions among streams often require unsteady flow analysis. For example, a large flood or failure of a dam on a tributary stream to a second larger stream can sometimes result in upstream flow at the junction in the receiving stream. This can lead to a very rapid rise in water surface elevation because not only does the influx of water serve as a temporary dam it also provides another source of inflow.

DESCRIBING THE STREAM SYSTEM-PART I

World View of FEQ

We have already introduced part of the world view of FEQ without giving it a name. What is a world view and why use the term? A world view is simply an explicit description of how the software looks at the stream system and how it describes it. The idea of a world view is important because unless we know the world view of a piece of software or of an analysis we do not know what the software can do and if it can give us answers to our questions. The world view tries to define which systems can be described meaningfully in general terms without describing any particular stream system. As a result some of the concepts are a bit abstract without examples. Examples will be presented when enough of the world view is presented to start doing so.

We are interested in describing stream channels, reservoirs, lakes, bridges, weirs, and any other aspect of an open channel flow system that has an influence on the flow and its elevation. We must pick names for things so we can talk about them. We must also be able to describe these things quantitatively. We have already talked about the stream channels and the special features where the stream channels interact with other channels or with other physical structure.

Branches

I call the length of channel between special features a branch. The key idea of a branch is that its flow is described by the governing equations and in this sense every branch is identical. The branch has many related values that we must define. A branch is subdivided into computational elements for purposes of developing the approximate algebraic governing equations. A branch also has nodes at the boundaries of these computational elements and each node on the branch has a cross section associated with it. The nodes at the two ends of the branch are called exterior nodes because they are used to describe interactions between the branch and the world exterior to the branch. The nodes on the branch not on the ends are called interior nodes. The branch has an upstream end and a downstream end that the user must assign. For example, the exterior node at the upstream end is called the upstream exterior node. The nodes on a branch are numbered for identification with the numbers increasing and consecutive from the upstream end to the downstream end. Each node on the branch has a station associated with it where the station is the distance measured along the stream from some convenient reference point. Each node on a branch also has associated with it the elevation of the minimum point in the cross section at that node. The station-elevation pair for each node defines the bottom profile of the stream channel. The absolute value of the difference in the stations of two consecutive nodes on a branch gives the length of the computational element between the two nodes.

There are only three ways for water to enter a branch: inflow at the ends or inflow from the area tributary to the branch. Thus a branch and also a computational element may have a tributary area associated with it. The tributary area for a computational element is that area that will contribute inflow to the computational element by some means other than at the ends of the channel. Generically this inflow is referred to as lateral inflow but it might enter at only selected inflow points if a storm sewer is involved. Most often the lateral inflow from a tributary area is estimated using a hydrologic model that produces unit values of runoff for one or more land uses. For example, the area tributary to a computational element might consist of agricultural land, forested land, and part of a city. Each of these land uses or cover types would have a different rainfall-runoff relationship in the hydrologic model. It is therefore convenient to allow the subdivision of the tributary area into the different cover types used in the hydrologic model.

An additional parameter related to the estimation of lateral inflow into the computational element is the gage. The gage refers to the precipitation gage used to define the rainfall from

which the runoff was computed. More than one rainfall gage may be available in a watershed being analyzed. To allow this variability in the operation of FEQ the tributary area for each computational element must be associated with the gage used to compute the unit area runoff for that tributary area.

Special Features

Recall that a branch was defined as the length of stream between special features. We now must come to grips with special features. They can be grouped into several classes:

1. Junctions. These are locations where two or more channels meet and combine to form a single channel. This could also be the case where a single channel splits and forms two or more channels.
2. Boundary conditions at the boundaries of the system under analysis.
3. Control structures. This is any physical feature that exerts a measure of control or influence on the flow. The control might be complete so that a unique relationship between flow and water surface elevation is established by the structure. In that case we call the structure a one-node control structure because only the value of flow or elevation need be known at one exterior node to define fully the other value. The control might be incomplete in that we need to know the water surface elevation at two exterior nodes before the flow is defined. Such control structures are called two-node control structures. As you will see a major challenge of unsteady flow is often the identification of the control structures and their description.
4. Level-Pool Reservoirs. A level-pool reservoir is a reservoir of a size and shape relative to the flows through it that its surface departs insignificantly from the horizontal. Level-pool reservoirs are often configured such that meaningful cross sections for one-dimensional flow analysis cannot be defined. These reservoirs are considered special features because they can be analyzed using governing equations far simpler than those used for branches. Long and narrow reservoirs or lakes are often not level-pool and should be treated as a branch.

Functions and Function Tables

Another part of the world view of FEQ is functions and function tables. A function is a mapping from one set of numbers called the domain of the function to another set of numbers called the range of the function. The mapping must be such that for any number in the domain there is only one number in the range. This assures that the function will be single valued. This definition is abstract but it is the basis for the traditional function idea that most engineers and scientists have. We tend to think of some mathematical expression with some variable, say x denoting the domain of the function, and another variable, say y, denoting the range of the function. The variable denoting the domain is called the argument of the function. An example is the square root function defined for all positive real numbers. If we are given a positive number we can compute the square root that is either a positive or negative number. To make this function follow the rule we must always specify in advance which of the two values we have in mind. The square root function on calculators and in computer software gives the positive value. An even simpler function is $y = 3x$ that indicates that each value in the domain, x, is to be multiplied by 3 to yield the corresponding value in the range, y.

This is enough of formal details and we move on to examples from open channel flow. An important example is the top width function for a cross section. The top width for a cross section is the width of the water surface at any elevation in the cross section from the minimum point to some user established maximum point. Given a valid elevation the top width function will return a single value of topwidth. There are many other functions associated with a cross section. These

include the area function, conveyance function, *etc.* In fact, we view any element of the cross section as a function because these are the aspects of a cross section used by the governing equations.

There are other functions of interest to us. These include stage-discharge relationships at gaging stations, head-discharge relationships for a wide variety of physical features, elevation-area-storage relationships for reservoirs, inflow hydrographs, *etc.* A major effort in any analysis is to define these functions for the stream system. Hundreds of functions may be involved in even a modest sized stream system.

Most of these functions are not known as a simple mathematical expression and we are faced with describing a variety of functions consistently in a way that is both flexible and convenient. To do this I decided to use function tables for nearly all functions encountered in unsteady flow analysis. A function table consists of a set of selected argument values(the tabulated argument set) and the corresponding set of function values, and a rule for defining the function values for arguments not in the tabulated argument set. This approach was taken because most functions of interest to us are only known approximately, and we can allow some error in the function value in the rule used to compute the values not found in the table. Consequently the elements of the cross sections needed by FEQ are computed by a utility program called FEQUTL and placed in specially designed function tables called cross section tables. Thus FEQ does not know anything about the cross section unless it is reflected in the cross section function table.

This is another major difference between steady and unsteady flow analysis. Many steady flow programs compute the elements of the cross section from the definition of the cross section. The cross section is normally defined by giving the location of selected points on the periphery of the cross section in some convenient co-ordinate system and then assuming that adjacent points may be connected with straight lines without introducing significant error. The points should be measured in the field or taken from a topographic with this assumption in mind. The cross section may be subdivided by vertical frictionless fictional walls to account for the problems that the hydraulic radius encounters in describing the shape of the cross section when computing the conveyance. Each subdivision may also have a separate value of Manning's n to account for variations in roughness along the periphery of the cross section.

The approach of computing the elements as required from the fundamental or raw cross section is no longer efficient for unsteady flow. The cross sectional element values need be computed only a few times for each steady flow analysis. This is in stark contrast to the needs of unsteady flow analysis. The cross sectional element values may be needed many thousands of times for each analysis. Therefore it is economical of computer time to compute the cross sectional elements and place them in a well designed cross section table for later access.

Exterior Nodes

Exterior nodes have already be introduced as the nodes on a branch at the ends of the branch. In simple stream systems these nodes are all that are needed to specify the system completely. However, in more complex systems we need to introduce additional nodes that are not on a branch. The first such node is a level-pool reservoir node or more concisely a reservoir node. We do not associate a cross section with this node because no cross section is defined for level-pool reservoirs. However, we do associate an analogous entity, the elevation-area-storage relationship for the reservoir with the reservoir node. We visualize the reservoir node as being at the downstream end of a degenerate branch of zero length. As a result the reservoir node inherits the characteristics of the downstream exterior node on a branch when it is involved in a special feature such as a junction.

The second kind of exterior node not on a branch that we need in some cases is a free node. This is an exterior node not associated with either a cross section or an elevation-area-storage relationship but is associated with a flow path for which we wish to identify the flow and we either

do not wish to or cannot define the flow path as a branch or a level-pool reservoir. Examples for free nodes cannot be given until we have discussed simpler examples of flow systems. The best way to visualize a free node is as a branch of zero length with an undefined cross section but yet having an upstream and a downstream end or face. The user must decide on which end of the virtual branch the free node is to be by default. The user must then also indicate in context when the free node should be treated as being on the other end of the virtual branch. These ideas lead naturally into the very important definition of the flow sign convention used in FEQ.

Flow Sign Convention

A precise and general flow sign convention is essential for an efficient and comprehensible solution of the complex flow systems for which FEQ was designed. We normally think of the flow in a stream as a positive variable just as we think of most variables we use as positive. However, when we do think of flow as positive we have an implicit knowledge or assumption about its direction. Flow in FEQ always has a direction. There are two possibilities: upstream or downstream. If the flow is zero it makes no difference what direction we agree to say the flow has. The basis for the entire sign convention is the choice of defining flow moving in the direction from the upstream node to the downstream node of a branch as positive. Flow movement in the other direction is then negative. Be advised that in a program like FEQ the designations of upstream and downstream flow for a branch are purely nominal. The natural downstream direction need not be the downstream direction defined in FEQ and the user should pick the downstream direction to be that direction for which FEQ is supposed to print positive flow values.

With this basic designation we move to the sign associated with each exterior node in the system. First we begin with nodes on a branch because they are the next step in the convention. We would like to be able to tell, at least inside the program, when flow is leaving a branch and when it is entering a branch. The usage in FEQ is arbitrary but it is used consistently. We say that the sign of the downstream node on the branch is positive and that the sign of the upstream node on a branch is negative. Then the product of the sign of the exterior node and the sign of the flow at the exterior node will determine whether the flow is leaving or entering the branch. If the product(we take the sign to have an implicit absolute value of unity) is positive then the flow is leaving the branch and if it is negative flow is entering the branch. For a node not on a branch the same convention is used but in this case the current conceptual position and role of the node must be kept in mind because free nodes can shift from one end of a virtual branch to the other at the discretion of the user.

An Analogy

An analogy is useful in putting these ideas into context. As a child you may have had or been aware of what are called tinker toys; a building toy composed of slender pencil-like sticks and round knobs with holes on their periphery and a hole in the center of the knob. A wide variety of stick structures could be built by inserting the sticks into the holes of the knobs. In a sense, FEQ has a tinker toy view of the world of open channel hydraulics. The branches are like the sticks and the special features are like the knobs. We are able to build a model of an open channel system using these parts. Consequently there are few predefined limits in FEQ. The limit to the complexity is usually set by the memory and computer time requirements rather than the structure of the program. As a result, a variety of stream systems and conditions can be described without requiring changes to the program.

In keeping with the tinker toy analogy, FEQ describes the parts of the system more or less separately. For example, the branches are completely described in terms of nodes, stations, elevation, and cross sections before any description of the special features are given. Furthermore, the

cross sections are only described in terms of their table number and the contents of the table are given later. This is a rule: all references to functions are given by the table number containing the description of the table. This is done because we can focus on how the various pieces are connected without concern for the location, size, or shape of the cross sections. This layered approach to describing the system attempts to reduce the number of details that must be comprehended simultaneously to make management of the details simpler.

THE UTILITY PROGRAM: FEQUTL

Function tables are an integral part of any stream system description using FEQ. Some of the functions we need may already exist in the form of function tables and all we must do is convert their format to that required by FEQ. However, in many cases the function table must be computed from other more basic information. A utility program, called FEQUTL, is the primary tool available for computing a variety of tables for FEQ. This program proves essential in the description of the stream system.

The input to FEQUTL is organized around commands. Each command has its own input requirements. These commands are defined internally as to their operations but the names for the commands are supplied in a header block that must appear at the start of each input. An example of the header block appears in lines 1–26 of page 2 in the section FEQUTL Examples. Of this header block lines 6-21 associate command names with the internal parts of the program. For example, in line 9 we see the command name "CULVERT" followed after a few intervening spaces by the numeral "4". Internal to FEQUTL there exists a call to a subroutine CULVRT that is number 4 in a list of commands. Thus in the example input the appearance of the command "CULVERT", as in line 38 of page 7, causes FEQUTL to carry out the computations defined in the subroutine CULVRT. The name for the command can be changed by changing line 9 on page 2 to some other name, with 8 or fewer characters. The action taken by the command can only be changed by changing the CULVRT subroutine.

This approach to defining command names results in an interesting error on the part of the user. Assume that you currently have version 1.0 of FEQUTL and that you have just received version 2.7. All of your old input streams to version 1.0 will likely run without change. However, if you add a request to compute a table for a culvert to a version 1.0 input stream and fail to modify the header block, FEQUTL will issue an error message indicating that "CULVERT" is an unknown command. What has happened is that version 2.7 contains the culvert subroutine but that the version 1.0 header block did not reference it. Thus the header block must be changed to reference the new commands in the new version. Otherwise, FEQUTL does not know that they exist. To avoid this problem, I am in the habit of copying the latest version's header block into old input streams.

As well as commands, FEQUTL recognizes comments. A comment is any line, appearing where a command could appear, that has at least it first eight characters blank. Lines 27–42 are comments, some of them just blank lines, on page 2 of "FEQUTL Examples". Basically comments can only appear between commands and never within the input for a command. As the example shows, comments can be added to document what is being done as well as to provide some blank space so that the input and the output is more easily read.

FEQUTL requires three files for its proper operation. The first file is the input file, containing the header block and commands. The second file is the output file. FEQUTL uses this file for echoing its input and for messages to the user. It also contains results of the computations for some of the commands. The third file is the function table file. FEQUTL places the final function tables in this file in a form that is readable by FEQ *without* change. "FEQUTL Examples" contains an example of each of these files.

The first four example commands in "FEQUTL Examples" illustrate some variations on the commands which compute a cross section table from the cross section description. A cross section is described by giving the coordinates of the points along the boundary of the section. The section can be divided into subsections to account for the variation of shape as well as roughness. The user must supply a unique table number for each cross section table to be used by FEQUTL as an identifying number. Here we will discuss the major aspects of the commands with the details

to be found in the input description to be discussed later or explored in the computer laboratory sessions.

To shorten references to pages and lines I will use the following shorthand notation: x–yy where the x will denote a page number and the yy will denote a line number. Using this notation, 2–43, refers to page 2, line 43.

At 2–43 is an example of the command FEQX. FEQX computes a cross section table from input in a fixed format. The points on the boundary of the cross section are given in the columns following line 2–48. The offset gives the horizontal distance to the point from some convenient reference point. As shown the offset can be positive or negative. The elevation gives the elevation of the point again from some convenient reference. The last column, SUBS, gives the subsection number. In this example, the line segments from offset -750 through -47 are in subsection 1 and from line 2–47 the Manning's n for subsection 1 is 0.140. Thus subsection 1 is a flood plain with dense brush or trees on it. Using FEQX only the subsection number for the first point of the subsection need be given. FEQUTL will assume that blank lines in the SUBS column are to be filled by propagation from previous lines. The subsection number for the last point on the boundary of the cross section is given as -1 to signal the end of the input.

At 2–70 is an example of the command FEQXLST. This command is similar to FEQX but the fixed input format is relaxed somewhat. FEQXLST allows the input of offset, elevation, and subsection number to be in what is called list format. Each number must be given but they do not need to fall into a fixed number of columns but can be given in order separated by one or more spaces. Thus following line 2–75 we have each line containing the three values required for each point on the boundary of a cross section: offset, elevation, and subsection number. In this command the subsection number *cannot* be omitted.

At lines 3–2 and 3–50 are further examples of cross section processing. These two examples show the use of the SCALE option to adjust the offsets. When cross sections are taken from a topographic map, it is often convenient to give the offset in some unit convenient to the map. The example at line 3–2 gives the value of scale as 50 and that means that the values in the offset column will be multiplied by 50 before they are used to compute the cross section table. The example at line 3–50 gives the value of scale as 0.8 and is used, not to reflect a map scale, but to reduce the size of the cross section slightly. Output for FEQXLST at line 3–2 appears at starts at line 11-28. This shows the offset as multiplied by the scale.

In these examples various options like "NOOUT", "MONOTONE", "SAVE1", *etc.* have been given after the table number. These are optional specifications used to control the action of FEQUTL. A complete list of options is given on page 22 of "Input Description for FEQUTL: Version 2.70". NOOUT requests that the function table not be output to the table file, MONOTONE requests that FEQUTL check to make sure that the offsets never decrease, and SAVE1 requests that the function table be saved internally in FEQUTL as a cross section table of type 1. MONOTONE should be used to check every cross section that is thought to represent a natural channel section. Generally, natural channels as well as manmade channels do not have overhanging banks. Therefore, the offsets for points on the boundary of the cross section should never decrease. If they do it indicates an error in the field or an error in typing the input.

NEWBETA requests that the values for the momentum and kinetic energy flux correction coefficients be computed differently than the default. This new method is discussed in the "Governing Equation Summary" section. This method holds much promise for solving or reducing the inconsistencies in the traditional method and some variation of NEWBETA will likely become the method of choice in the future in FEQUTL.

The output on pages 10–12 of "FEQUTL Examples" illustrates some warning messages that will appear frequently in computing cross section tables. WRN:504 at lines 10–41 and 10–44 is issued because FEQUTL has found a line segment on the boundary of the cross section that is not

at the minimum or maximum elevation for the cross section. Such horizontal line segments are invalid because they indicate a mathematical discontinuity in the top width. Such a discontinuity is incompatible with the function table, because a function is required to have a single value at each argument in its domain of definition. It maybe that the measurements in the field indicate that the line segment is horizontal. However, FEQUTL will adjust one end by the arbitrary amount given to prevent an exactly horizontal line segment. At lines 11–70 and 11–71 WRN:505 complains that the conveyance in the given subsection is decreasing. This indicates that there maybe an error in the subsection definition. If the cross section is such that each subsection always has a constant or increasing top width with increases in elevation, then the conveyance, when properly computed should never decrease in any subsection. The way we have subdivided the cross section, could however, result in there being a decrease.

The warning message at line 12–8 indicates that there is a decrease in the conveyance for the entire cross section at depth 9.03. Looking at the fourth column(excluding the column of line numbers that are not part of the output from FEQUTL) at depth 9.20001 we see that the square root of conveyance is 4.150E+02 and at depth 9.29999 we see that the square root of conveyance is 4.087E+02. This decrease is small and can perhaps be ignored without serious damage to the results. However, decreases as large as 25 *per cent* occur and should not be ignored.

Examples of the function table formats for cross sections appear in the listing of the table file on pages 24–26 of "FEQUTL Examples". Lines 24–1 through 24–27 give a cross section table of type 12. This table type is currently used by the CULVERT command only. It gives the area, top width, the square root of conveyance, the momentum flux correction coefficient, the first moment of area about the water surface, the kinetic energy flux correction coefficient, and the critical flow rate at each tabulated value of depth. The depths are defined by the unique breakpoints in the description of the points on the boundary of the cross section. Thus the top width function is represented exactly in the table. The area is the integral of the top width and is also represented exactly in the table. The first moment of area is the integral of the area and is also represented exactly in the table. By exactly I mean that if you used the cross section description and computed the top width at any depth by appropriate linear interpolation of the line segments comprising the boundary of the cross section you would find agreement within roundoff with the value of the top width interpolated linearly in the cross section table. The same meaning applies to area and first moment of area with the proviso that instead of linear interpolation in the table that the methods outlined in the "Governing Equation Summary" are used to find the area and first moment of area in the table.

The conveyance is tabulated as the square root of conveyance because the square root of conveyance generally varies more nearly linearly than does the conveyance itself. Thus there is an improvement in interpolation accuracy by using linear interpolation in the square root of conveyance. To improve on the accuracy of interpolation for conveyance, FEQUTL may add additional points to the cross section table. The option NRZERO in the header block for the input gives the depth at which an additional point that is at near zero depth should be added. The addition of this near zero depth point greatly increases the accuracy of interpolation for conveyance when the depths are small. The option DZLIM in the header block gives the maximum change in elevation that is to be allowed in the final cross section table. If the vertical distance between breakpoints in the cross section description exceeds the value of DZLIM, then FEQUTL subdivides the distance until the maximum vertical distance is less than DZLIM. The value of DZLIM depends to some extent on the size of the cross sections and to the range of depths that will be experienced in the unsteady flow computations. If there are adequate points at small depths in the cross section description so that conveyance is well represented then DZLIM can be large so that it causes no additional points in the table. On the other hand, if the cross sections are some simple shape, such as trapezoidal, and only the breakpoints of the trapezoid are given, then DZLIM should be set

to add several intermediate points so that the vertical distances between points in the trapezoidal channel are close enough to permit reasonable interpolation for the untabulated conveyance values.

Interpolation for the flux coefficients is linear. Critical flow is interpolated linearly in terms of the logarithms of the depth and critical flow. This implies that the critical flow varies as some power of the depth. This is approximately true over restricted depth ranges for all cross sections and is exact for triangular, rectangular and parabolic cross sections.

An example of table type 1 appears in lines 24–68 through 26–2. Tables of type 1 are similar to tables of type 12 except that they do not tabulate values for the kinetic energy flux coefficient and for the critical flow. This particular table was created by the MULCON command that computes a table for one or more closed conduits. You will notice that there are many tabulated depth values in the resulting table. This follows because MULCON approximates each conduit by a polygon with 40 sides such that the full flow area is matched. In this example, a wide variety of different conduit shapes where combined into one unit. Consequently, there are many distinct breakpoints defining the effective boundary of the cross section.

Examples for computing cross section tables for closed conduits appear in lines 5–57 through 6–18. SEWER computes a table for a single circular pipe; MULPIPES computes a table for multiple circular pipes: and MULCON computes a table for multiple conduits not necessarily the same shape. MULCON can do all that SEWER and MULPIPES can do. Only the MULCON command at line 5–84 produces output in the table file. This output in lines 24–68 through 26–2 has already been referenced as an example of table type 1.

FEQ treats closed conduits like open channels by adding a narrow vertical slot to the top of each conduit. Thus there is always a free surface and the error introduced by the slot is negligible if it is small enough. The width of the slot can be sized so that the free surface wave celerity approximates the celerity of the water-hammer wave in a closed conduit. This need be done only in long closed conduits and then only in those cases where details of wave propagation are significant. Note also that the value for the flux correction coefficients is forced to be exactly 1.0 for closed conduits. When multiple conduits are present in one cross section and they are not all of the same size, shape, roughness, and invert elevation, the flux coefficients as computed by the cross section processing computer code differ from unity slightly. This slight deviation from unity does not cause problems until the conduits are flowing nearly full. Then problems with undefined critical flow can arise. Secondly, note that the maximum depth for a closed conduit table is always 500.0 without regard to what you requested in the input. Furthermore, the value of DZLIM is ignored in the slot because the conveyance and top width are constant. Thus only two points are required to define the value in the slot. FEQUTL decides that the table is for a closed conduit if two consecutive values of top width are equal and if they are both less than or equal to 0.07.

Lines 5–26 through 5–52 give an example of computing a table to describe the flow over an embankment shaped weir. Such flows occur frequently because most roadways are embankment shaped. This example shows a reference to tables that have been stored in FEQUTL previously. EMBANKQ refers to six tables to define the weir coefficients and the submergence relationships for the flow. These tables must have been input before EMBANKQ is encountered. The command before EMBANKQ, FTABIN, at line 4–13 inputs the required tables. The output for this command does not include a copy of the table. The table produced only appears in the table file. This has been done, because the table type currently supported in version 6 of FEQ, type 6, uses many lines of output. Table type 5, the one shown in lines 24-40 through 24–67 is much more compact. This type will be supported in FEQ in the near future.

In this table the information that is not self explanatory is as follows: NHUP gives the number of upstream heads in the table; NPFD gives the number of partial free drops in the table; HUP gives the sequence of upstream heads; FDROP gives the sequence of free drops corresponding to each upstream head; PFD labels the column giving the partial free drops in decimal fraction form;

and the body of the table gives the flows corresponding to the upstream head and the partial free drop. In the table, non-integer numbers are written in a special compact notation to save space and to also preserve a constant precision for the values. The first four numerals of the number are to be multiplied by the power of ten given by the sign and the last number. Thus 2000-4 means a value of 0.2. The table indicates that at an upstream head of 0.3 and a partial free drop of 0.25 the flow over the weir is 323.9. The free flow values are the last row of the table in line 24–67.

EMBANKQ computes the flow for the sloping crest using integration of the unit width weir equation. Thus variation in head, approach velocity, weir coefficient, and submergence is approximated. The velocity head is the velocity head local to that portion of the weir crest and not the velocity head averaged across the approach section. This introduces a slight inconsistency with FEQ. See the "Governing Equation Summary" section for more details.

The range of heads used for EMBANKQ should be selected with some care. Where the flow is changing rapidly and the head is small the head interval should be small so that linear interpolation will be reasonable. At larger heads the interval can be quite large and still obtain reasonable results for intermediate flows via linear interpolation. Furthermore, care must be exercised in not making the heads too high because FEQUTL assumes that vertical frictionless walls exist at the ends of the definition of the profile of the embankment. The choice of the APPROACH value determines the velocity head. If the coefficients used for the flow over the weir were defined ignoring the velocity head of the approaching flow, then the approach elevation should be given as a large negative number so that the velocity head will be negligible. In the example, the tables are derived from USGS-Dams and therefore assume that the velocity head is included in the head on the crest.

Please note that by an appropriate choice of tables and values of head to embankment width ratio, EMBANKQ can be used to compute tables for sloping weirs with shapes differing from embankments. Thus EMBANKQ can compute estimates of the flow over a wide variety of overflow structures in which the flow at a point can be approximated by the weir flow relationship.

Lines 6–25 through 7–30 illustrate the computation of a bridge head loss table. The BRIDGE command predates the facility for saving tables internally or inputing previously computed tables. Therefore BRIDGE requires that the upstream and downstream cross sections be input in a particular order. Additional details on the input are given in the "Input Description for FEQUTL: Version 2.70".

Lines 7–38 through 8–2 give an example of the computation of a table for flow through a culvert. The CULVERT command assumes that the tables it needs have already been stored in FEQUTL. It will complain if such is not the case. Additional discussion will be found in the "Input Description for FEQUTL: Version 2.70" and in the "Governing Equation Summary".

The output from the CULVERT command appears in lines 20–59 through 22–46. For each upstream head, the CULVERT command produces a table giving some of the details of the results. The free drop is given after the upstream head as shown in line 21–46. The next line gives the headings for the subsequent columns. The meanings are as follows: PFD gives the partial free drop in decimal fraction form; HD2 gives the head at section 2(in culvert at entrance); HD3 gives the head at section 3(in culvert at exit); HD3P gives the piezometric head at section 3(may differ from head computed from water surface elevation in some cases); HD43 gives the head at section 43(in departure reach at exit of culvert); HD4 gives head in the section 4(downstream end of departure reach); TYP give the flow type(0, 1, 2, 3, 4, 5, 6, 7, 41, 42, 61, and 62 currently supported); QCLV give the flow through the culvert barrel; QRD gives the flow over the road way; QTOT gives the total flow; CL34 gives the coefficient on velocity head change required to match the change in total energy line elevation between sections 3 and 4; DE34 gives the drop in total energy line elevation between sections 3 and 4; and DE14 gives the drop in total energy line elevation between sections 1 and 4. All heads are measured relative to the datum for head given in line 21–43.

DESCRIBING THE STREAM SYSTEM-PART II

The best way to understand the world view of FEQ is to study some examples of input and output. These examples will contain much material that has not been described yet. Thus you should focus on the ideas involved in describing the major features of the system and delay concern about the details until later in the discussion. The examples of input and output for FEQ are contained in a section titled, "FEQ Examples".

The first example given in the example section, called FEQEX1, is the simplest possible stream system. It has a single branch with a hydrograph given as the inflow at the upstream end and with a discharge versus stage relationship given at the downstream end. Even though simple, this example illustrates many basic principles and is relevant to some applications. The upstream inflow can be viewed as a release from a high dam into the stream. This dam has controllable gates so that the outflow can be varied by the dam operator. Some miles downstream is another dam that has a fixed overflow spillway that cannot be varied or that is only varied in special circumstances. We wish to study how the release pattern at the upstream dam affects the outflow from the downstream dam to provide adequate free board, warning time, or some other factor that is germane to the proper operation of these dams.

In the input listing we skip over the Run Control Block that extends from the first line of the input giving the title of the example through the line starting with 'EXTTOL'. We wish to focus attention on the section titled BRANCH DESCRIPTION TABLES starting at line 5–37. We will reference information in the example section by giving the page number followed by the linen umber on that page. Thus line 5–37 refers to the 37-*th* line on page 5. We assign a number to each branch where the branch numbers must begin at one and be consecutive. Following the identification of the branch number is the heading for the subsequent lines of information describing each node on the branch starting at the upstream end of the branch. Note that you, the user, define which direction of flow is to be downstream. Usually there is a natural or normal flow direction that should be taken as downstream. However, in some cases no such natural or normal direction exists. Then you must make some choice to define which direction is to be downstream. Once you have selected this direction, FEQ will print flows as positive numbers if the flow direction is downstream but FEQ will print flows as negative numbers if the flow direction is upstream. The upstream node on the branch in this example was assigned the number 100. Any positive number that would fit in the available field would be suitable. However, I have found it most helpful to 'design' the node numbers to convey both the branch number and the location of the node on the branch. In this case the first digit of the node number is the branch number and the following two digits are used to identify the position of the node on the branch. Thus 100 denotes the upstream node on branch 1 and 102 would denote the third node on branch 1. If the system were large and required 50 branches the upstream node on branch 50 would by this system be 5000.

Note however that we have only given the node number for the first node on the branch and furthermore we have only given information for the first and last node on the branch. (The -1 in the node column at line 5–51 indicates the end of information for a branch.) The blank lines in the description for branch 1 are not ignored and in fact each blank line represents another node on the branch. FEQ numbers the nodes sequentially starting at the first node given on the branch. This removes the burden of sequential numbering from the user and is the preferred method of input. You can supply all the node numbers but they must be sequential. This could cause you some grief later if you already have 50 node numbers on the branch and you later must interpolate another cross section because one of the computational elements proves to be too long. You would then have to renumber all the nodes on that branch that are downstream of the point of insertion of the new node. Thus it is better to let FEQ number the nodes for you starting with your initial node number.

If the cross section table column is left blank FEQ assumes you want to use the same cross section as at the previous node. This option is useful and should only be used if the stream channel between the points of given table numbers is prismatic, that is, it does not change size or shape along the branch. The station field if left blank instructs FEQ to assign a station to that node by distributing the nodes having blank stations uniformly between the nodes at which the station is given. In the current example that means that each computational element on branch 1 will have the same length and if you turn to the output you will find that each element is 0.1 mile in length. The station is in miles because in the Run Control Block, the variable called SFAC was given the value 5280 that gives the number of feet in a mile. FEQ uses feet for all length units because again in the Run Control Block, the variable GRAV is given the value 32.2, the acceleration of gravity when distance is in feet and time is in seconds.

The final item of interest for the nodes on branch 1 is the elevation of the minimum point in the channel. If this field is left blank, then FEQ interpolates linearly to find the bottom elevation for that node. The closest upstream node and the closest downstream node having elevations given by the user are used in this interpolation.

The branch description table in this example gives the minimum possible information. Additional information can be given. The branch may have a change of bottom slope at one or more points but have essentially constant slope between these points. In this case you need only enter the nodes with their stations and elevations at these points of slope change. FEQ will then interpolate for the remaining values. You can also request that FEQ create a new cross section table by interpolating linearly from the closest upstream and downstream cross section table supplied by you. In this case you supply a unique table number for the cross section table and prefix it with a minus sign or more conveniently supply a minus sign in the rightmost column of the input field. An example of this option appears in branch 3 of FEQEX2, the next example in order.

Given below the branch description table is the branch-exterior node table. This table defines the relationship between branches and exterior nodes. In the system schematic for FEQEX1 the branch number is shown circled and the exterior node numbers are shown adjacent to the ends of the branch. The nodes interior to the branch are not shown on the schematic and as a general rule I do not show the interior nodes on any of my schematics because they are non-essential at that level of detail. Recall from the discussion above that the exterior nodes are the means of communication between branches. This means that the nodes at each end of a branch have two numbers. One of these numbers is the node number on the branch. In this case for the upstream node this is 100. This number is known only to that branch and only makes sense in the context of the branch. In a multi-branch system we could, if we liked, number the nodes on each branch from the same number. Thus there could be a node 100 on branch 1, a node 100 on branch 2, and so on. FEQ would work fine. We might become confused but FEQ would not be confused! The second number associated with the nodes on the end of the branch is the exterior node number. These numbers must begin with 1 and be consecutive. Thus they uniquely identify a node. The branch-exterior node table establishes the correspondence between the exterior node numbers and the nodes on the ends of the branches. In the current example, I arbitrarily gave the exterior node number 1 to the upstream end of branch 1 and the exterior node number 2 to the downstream end of branch 1. Therefore the number 1 appears under the heading UEXN(Upstream EXterior Node) and the number 2 appears under the heading DEXN(Downstream EXterior Node). The order of the exterior node numbers could have been reversed and then the upstream exterior node would be given the number 2 and the downstream exterior node would be given the number 1. In this example the choice is immaterial but in other examples it is not.

With the branch described and with the exterior node numbers assigned we are now ready to tell FEQ how the system is connected and what the boundary conditions are. Of course, no connections exist between branches in a one branch system so all we can give for this example are the

boundary conditions. This information is presented in the Exterior-Matrix Control Input starting at line 5–55. This input, as its name implies relates to a matrix. This matrix is internal to FEQ and is one of several matrices used in the solution of the governing equations. Each branch has a matrix associated with it called an interior matrix. The interior matrix contains relationships developed from the governing equations written for each of the computational elements on the branch. Thus the interior matrix is concerned with values within the branch. In contrast the exterior matrix is concerned only with relationships among exterior nodes. Each branch is represented in this matrix but only via its exterior nodes. Conceptually, all the details of the branch have been summarized by special relationships involving only the values at the nodes at the end of each branch.

FEQ can create the interior matrices using the information in the branch description tables because each branch is like every other branch with the only difference being the number of nodes. The details of elevation, slope, cross section, *etc.* are used but do not make one branch different from any other branch insofar as the structure of the interior matrices are concerned. This was of course the motivation for defining the branch as I did. The exterior matrix, in graphic contrast, cannot be automated because it must reflect the structure of the system defined by the connections between the branches, the reservoirs, the control structures, *etc.* that make each stream system different from any other stream system.

Therefore, the exterior matrix defines the control structures, the connections among branches and control structures, and the order of the information in the exterior matrix. As such it is the most complex part of the input to FEQ to understand. In return for this complexity we gain generality, and in my experience generality is needed. At the base of the exterior-matrix control input design is the code number denoting which entity is being described. Code 1 references a branch number as shown in the second line of the exterior-matrix control input following the heading for each column. This is the method used to inform FEQ that the two equations required to represent a branch are to be entered into the exterior matrix. Each branch always generates two equations in the exterior matrix. In this case the equations will be the second and third in the matrix. All other codes generate only one equation.

The first equation in the exterior matrix is given by Code 6. You should turn to page 24 of the "Input Description for FEQ: Version 6.0" to find the description of Code 6. This code specifies that the exterior node referenced in the subsequent input will have a value of either flow or elevation specified as a function of time. FEQ will force this value at that node at each time point encountered in the computations.

The input description indicates that the type is 1 meaning that flow versus time is specified at the boundary and therefore FEQ will define the flow at exterior node 1(given in the next input field on the line) by looking up the value in the function table given in the fifth input field. Thus table number 100 will contain a definition of the inflow hydrograph that represents the flow out of the upstream dam. This flow **must** be the value at the upstream node and FEQ will force it to be so no matter what the downstream conditions become. The direction of this flow must also be given in the fourth field. Flow is into the system so that the direction is given as 1. As a side observation it is possible that it is hydraulic nonsense to force the value of the flow at a given node in a system. The only way to tell if that is so is to force the flow and then examine the resulting elevation of the water surface at that node to determine if the forced flow is physically possible or reasonable. Downstream controls could be such that the assumption of forced flow is unreasonable. If this is the case then the upstream boundary must be moved farther upstream in some manner to a point where the flow can be forced to have a known value.

The downstream boundary for the single branch is specified by the remaining line in the exterior-matrix control input. Code 4 is described on page 20 of the input description as representing a one-node head discharge relationship at a node. Thus we are assuming that the spillway on the dam at the downstream end of our example stream system is too high for there to be any influence

on the flow from the water surface elevation below the dam. The Type is 1 which denotes flow over any structure described by the equations for flow over a weir. The node for flow and the node for head are both node 2. The table number giving the variation of the weir coefficient with head is 110. Under the headings FA and FB we find that the reference elevation for computing the head is 102.0 feet and that the weir length is 32 feet.

The remainder of the input involves specifying output options, function tables, initial conditions, *etc.* The meaning of much of this input can be determined from examining the corresponding input description. The best way to learn the system is to make minor changes to an existing input and see what happens and the opportunity to do so will be provided in the short course.

The output for the first example starts on page 8. Note that the branch description table is fully expanded following the instructions as outlined above. The exterior-matrix input is also expanded with some additional explanatory detail. On the fourth page of the output the pattern of zero and non-zero values in the exterior matrix is displayed. The exterior matrix is banded and the pattern is displayed relative to the main diagonal located under the numeral zero in the heading.

The output of the simulation results is given every eighth time step to reduce the volume of output. This output interval is controlled by the variable PRTINT in the run control block that is set to 8 in the input. There is a standard heading printed whether the results are printed or not. This heading gives a summary of each iteration required to find the solution at each time step. The solution at each time step must be found by iteration because Newton's method for the solution of a system of non-linear equations is used. This method starts from an initial estimate of the solution and improves this first estimate by repeatedly solving a linear system of equations derived from the non-linear equations. Eventually, if all goes well, the corrections will become small at which time we say that the solution process has converged. The convergence criterion requires that the correction relative to the value being corrected should not exceed a user supplied tolerance specified in EPSSYS in the run control block. This convergence tolerance is 0.05 for FEQEX1. For example, the output at 3.5 hours on January 1, 1990, starting at line 12–75 shows that after the second iteration the maximum relative correction, given under the heading RERROR, was 0.00052 and it occurred at exterior node 1 and was obtained from depth. The negative node number indicates that the error is in depth and the branch number being zero indicates that the node number is an exterior node number.

At the first iteration the maximum relative correction occurred at branch 0 and node 1 and was in the flow rate because the node number is positive. Thus the maximum relative correction at the end of the first iteration was 0.25 and it occurred in the flow rate at that exterior node. The other columns of the header information relate to the equation systems involved. Under the heading MXRES we have the maximum relative residual occurring in the equation systems. If the value under the heading LOC is negative it denotes the number of the equation in the exterior matrix and if it is positive it denotes the equation number in the interior matrix. The final value SUMSQR gives the sum of the squares of the residuals for all equations in both the interior and exterior matrices. In the column NUMGT is the number of the variables that have not yet met the primary convergence tolerance given by EPSSYS. After the first iteration for the solution at 3.5 hours on 1 January 1990 there were 8 variables not yet meeting the primary convergence tolerance. ERRP is used to report status of the ponding calculations when storm sewers are being simulated. ERRQ gives a measure of flow unsteadiness. ERRQ gives the maximum absolute value of the rate of change of storage in an element taken relative to the average flow existing in the element at the start of the time step. If the flow is completely steady, ERRQ is zero and if large inflows enter from lateral inflow. ERRQ becomes large. The branch/node combination gives the node at the downstream end of the element for which this maximum was found for the current time step.

Line 12–81 through 13–18 show an example of the results for a branch. The results for each branch, when printed, give from left to right, the node number, node id string given by the user,

the station in the same units as given by the user, the discharge, the flow area, the average velocity, the depth of flow measured from the low point in the cross section, the water surface elevation, the top width of the water surface elevation, the square of the Froude number, and the average rate of lateral inflow to the element. The output format for the flow, area, and top width is a non-standard format to save space. The traditional 'E' that denotes that a power of ten follows has been omitted. Furthermore, the power of ten is limited to the range $(-9, +9)$. However, no stream exceeds a flow of 10 billion ft^3/sec. Some large dambreak flood peak may do so but on the whole the range for flows is large enough. This form of output is accepted by FORTRAN on input so that the new format can be read by FORTRAN programs if that proves useful.

The volume of ponding for each branch and for the system as a whole is given after all the branch results are printed. This becomes significant if storm sewers are being simulated and water is ponded on the land surface. A summary of values is also given for each exterior node with the values from left to right being the exterior node number, the node id string given by the user, the flow at the exterior node, the depth of flow at the exterior node, the elevation at the exterior node, the storage in cubic feet, and the storage in acre-feet. The final part of the output for each time step is a water balance check labeled BC. S1 gives the initial storage in the stream system in cubic feet, S2 gives the storage at the end of the current time step in cubic feet, I gives the inflow volume in cubic feet from the start of the run, Q gives the outflow in cubic feet from the start of the run, D gives the error in the water balance for the system, and R gives the error in the water balance relative to the sum of the initial storage and the total inflow.

The subsequent examples illustrate other features of the FEQ system. I will only outline these here and leave the details to lecture, personal research, or questions.

FEQEX2, a three-branch system, illustrates how Code 2, requiring that the sum of flows at the involved exterior nodes be zero, and Code 3, requiring that the elevation be the same at the two given nodes, combine to represent a junction of two or more branches. Several variations on the branch description input are also illustrated including interpolation for intermediate cross sections.

FEQEX3 is also a three-branch system but places a level-pool reservoir at the junction to illustrate how that hydraulic feature is described. Table number 250 gives the elevation-storage-area relationship for the reservoir and illustrates the use of a table type(Type 3) not appearing in the previous two examples. This table type is often convenient for representing reservoirs because it permits the input of the surface area as well as the storage. This example also introduces a free node used to represent a reservoir.

FEQEX4 is the most complex example given. It represents an off-line reservoir(exterior node 4) used for flood control. This reservoir is excavated below the elevation of the stream bed and if the flow in the stream is high enough water is diverted into the reservoir. If the water in the reservoir rises high enough it begins to flow over an emergency spillway and reenters the stream between nodes 5 and 7. After the high flows recede, and the flow at the diversion point falls far enough below the diversion weir, the water is pumped out of the reservoir at a constant rate to dewater the reservoir and prepare for the next flood. This example illustrates the use of a free node to represent the flow over the emergency spillway and also illustrates the application of the Code 5 Type 2 control structure that can represent bidirectional flow as well as the pumping of the water from the reservoir.

The examples have been kept simple to reduce the length of the presentation of the basic principles and to make it easier to understand the process of using FEQ. Never-the-less, the fourth example gives a little flavor of the power and flexibility of the unsteady flow analysis program. Systems have been modeled that involve 70 or more branches, several off-line and on-line reservoirs, some with dynamically operated gates to better control the flows, as well as bridges and culverts. Other systems have involved forcing a known elevation as a function of time at the downstream

boundary to represent tidal fluctuations. If time permits in the short course I will discuss a more complex example in greater detail.

EXTERIOR-MATRIX CONTROL OPTIONS

A clear understanding of the options available for defining both the control structures and the relationships between control structures, branches, boundary conditions, and reservoirs is needed to make best use of the flexibility of FEQ. The required format and explanatory notes for each option are given in the input description starting on page 20. These explanations are generally complete as they stand but some nuances of their use will be presented here. It proves convenient to divide the options into two groups. Control structures form one group and the other group is the collection of all other options some of which are control-structure like but are much more restrictive in their application. We start with the non-control structure group because some of these options are needed to help explain the nuances of the application of the control structure options.

Non-Control Structure Options

These options are Codes 1, 2, 3, 6, 7, 8, 10, 11, 12, and 13. Of these, Code 1 is the simplest requiring only that the branch number be given. This code places the two internally generated equations for the branch into the exterior matrix to represent the effects of the branch on the exterior nodes.

Codes 2 and 3 are much used. Code 2 is used to ensure continuity of flow at junctions of two or more exterior nodes. This code is heavily used and appears at every junction. Code 3 establishes equality of elevation of water surface between any two nodes. These codes in combination represent a junction. For example, assume that nodes 2, 3, and 4 are involved at a junction between three branches. Then a Code 2 involving all three nodes and two Code 3's define the junction. The first Code 3 would require water surface equality between nodes 2 and 3 and the second would require water surface equality between nodes 3 and 4. This is preferred to any other of the possible patterns because it minimizes the bandwidth of the equations in the exterior matrix that in turn reduces the computational effort. It is also possible to have a junction between two branches. Such a junction may be placed in the stream channel to allow for the later addition of a proposed dam. When the dam is not present but the junction is present the use of Codes 2 and 3 will result in the junction having no effect on the flow if the cross section at the downstream end of the upstream branch is identical to the cross section at the upstream end of the downstream branch. If this is not so, then an explicit loss due to the contraction or expansion of the flow should be represented using one of the control structure options described below, Code 5 Type 1. If this is not done and the cross section at the upstream end of the downstream branch is smaller than the cross section at the downstream end of the upstream branch, there will be a net energy input at the junction as if there were a pump present. This follows because the elevations of water surface are forced to be the same and the flows are forced to be the same but the velocity head in the downstream cross section will be larger than in the upstream cross section because of the differing areas available for flow. If this falsification of energy is small no problems will result but if it is large either the results will be invalid or computational problems may arise.

Code 6 represents boundary conditions in which one of the flow variables (discharge or water surface elevation) is forced to have a given value. Recall that there are only three boundary conditions possible: flow rate versus time, water surface elevation versus time, and flow rate versus water surface elevation. The latter boundary condition is represented by either a one-node control structure option(Code 4) or by the critical depth option(Code 8). Code 8 is in a sense a control structure option but for historical reasons it exists by itself and is a convenient option for representing a free overfall. There are three types given for Code 6 but only types 1 and 2 should be used. Type 3 may be used but the caution given in the input description should be followed. The direction in which the flow is going for a positive value found in the flow table must be given because an isolated flow value does not give a direction. Normally the flow is into the system when

flow is specified. If flow is specified out of the system problems can arise because the upstream conditions as simulated may not be able to support the forced value of flow. This can lead to unexpected computational problems. Complete disaster can result if the flow is forced at both the upstream and downstream boundary because any error in the flows must be reflected in the depths of water in the system. If the error is for some reason larger than expected there is no possible compensation and computation problems will result. Thus it is better to have at least one outflow that relates to the elevation of the water surface as simulated by FEQ. Then some compensation in the simulated flow can take place.

In some applications a constant flow must be forced at a node and a special option is provided to do this conveniently without having to specify a table of flow values. If the source field for the forcing values is zero then the constant flow is found in the first floating point input position. The forced value of flow can be zero at a boundary only if there will always be water present at the boundary. Otherwise, some nonzero value of flow must be given. Code 2 can be used to force a flow of zero at a boundary by specifying only one node.

Forcing a value of water surface elevation at a boundary to represent tidal fluctuations is straightforward. The direction of the flow should be given as -1 if a positive flow is out of the system. FEQ automatically checks for critical depth at the outfall location. Critical depth can be reached at the outfall location if the tide level falls low enough relative to flow so that free outflow conditions exist at the outfall.

Code 7 is used to represent level pool reservoirs. This code only relates to the characteristics of the reservoir and how it is connected to the rest of the system. The characteristics of any discharges from the reservoir are specified using other exterior matrix control options. Thus at a minimum Code 7 must be supplemented with one other relationship to complete the specification of the reservoir together with its spillway or outlet works. The sign of the reservoir node is always positive because the node is visualized as being the downstream node on a degenerate or virtual branch having zero length but still retaining its other properties. The reservoir node is also treated as the outflow point from the reservoir. This follows from its being on the downstream end of the branch. However, this is only a nominal designation and it is possible to have the water physically enter the reservoir through its outflow node and physically leave the reservoir through one or more of its inflow nodes.

Some special computational problems exist for reservoirs. It is often true that a reservoir has dead storage, that is storage below a spillway or any other outlet so that the water below that level cannot be released. For certain analyses it is convenient to assume that there will be no need for FEQ to find values of storage below the spillway level and therefore the user needs to define the storage above the spillway level only. This proves unwise for the following reasons. First, it may be that in the course of the iterative solution FEQ does need to find a value of storage below the spillway level though the final answer will be at or above the spillway level. A warning message will be issued and the value of storage will be set to the minimum value given in the table. The minimum value will often be zero and to avoid problems in computing the relative correction when the base value is zero, FEQ makes default assumptions to compute the relative correction in the storage in the reservoir. If the surface area obtained from the table describing the reservoir is greater than 1000 square feet then FEQ assumes that the correction should be taken relative to a volume of water represented by a depth of one foot over the surface area of the reservoir. If the surface area is less than 1000 square feet, either because the reservoir has no dead storage or because the user made a mistake in the input for the area, FEQ then takes the correction relative to 1000 cubic feet. Second, the user may be mistaken in believing that the simulated water level should never go below the spillway level either because the system is not properly understood or because there is an error in the input at some point that permits the water level to fall below the spillway level. Again in this case FEQ takes the same course of action with the resultant possible problems. The

best approach is to represent the entire physically feasible range of storage in the reservoir. The range not expected to be used can be represented using a gross approximation but the entire range should be represented. For example, if Lake Mead behind Hoover Dam could be represented by a level pool reservoir(it likely cannot because it is too long relative to its width) then it is unlikely that the water level will fall much below some minimum elevation based on past experience in the operation of the reservoir. It might prove an onerous task to define the elevation-area-storage table for the entire range of possible elevations. All that needs to be done is to define the expected range with the desired accuracy and to represent the remainder of the range of water surface elevation in a manner that is still physically realistic but might be grossly inaccurate.

The tables giving reservoir storage versus elevation should be of Type 3 or Type 4 so that the surface area of the reservoir is also tabulated. Type 3 is most convenient because it implements a function computed as the integral of another function using the trapezoidal rule to approximate the integration. In a reservoir the storage volume is the integral of the surface area and the trapezoidal rule is both convenient and accurate for computing the storage in a reservoir. Tables of type 2, using linear interpolation, can also be used for the reservoir storage function. However, tables of type 2 assume linear variation between tabulated points. This implies that the surface area of the reservoir is constant between tabulated points and experiences a potential discontinuity at each tabulated elevation. This is of course not true. If the reservoir is large, and the volume changes over a time step are small, there should be no problem. However, if the volume changes are large and the storage is small problems can be expected. There have been two cases of completely nonsense results being computed by FEQ in such cases when tables of type 2 were used for reservoir storage. Thus I recommend that tables of type 3 always be used.

Code 10 should be used with care because no checking for critical depth is done. Using Code 5 Type 1 to represent an expansion or a contraction is probably a better choice. Code 10 will be expanded in the near future to include optional energy losses in the direction of flow.

Code 11 represents the approximate effect of lateral inflow or outflow assuming that the inflow take place at right angles to the stream channel. When inflow is occurring FEQ uses conservation of momentum and when outflow is occurring FEQ assumes that the water surface elevation is conserved. This implies an energy loss of the change in velocity head at the point of inflow. Code 11 is currently simple and it has several restrictions. More complex options or extensions are planned for the future to approximate a wider range of junction interactions.

Code 12 involves three nodes at a junction and is usually used with codes 11 or 13. It can happen that the flow into or out of a main channel junction is regulated by some structure. If code 11 or 13 is used to represent the effect of this flow on the main channel, then the water surface elevations at the exterior nodes at the main channel junction will not be the same. However, the control structure or other exterior matrix control input option used to define the flow may be a two node relationship requiring both an upstream and a downstream node for the computation of head. Which of the two available elevations in the main channel should then be used? To avoid this question code 12 allows you to take an average of the two main channel exterior nodes and have that average forced at a third exterior node. Thus the elevation for computing head for the control structure can then be an average value of the elevations in the main channel. This should prove to be a better representation of the flow pattern.

Code 13 is closely related to code 11 in that it conserves momentum when there is an inflow to the main channel and energy when there is an outflow from the main channel. Code 11 assumes the *maximum* loss of energy on outflow but code 13 assumes the *minimum* loss of energy on outflow. Plans are underway to expand code 13 to include a user selected loss of the change in velocity head or some similar relationship that might depend on the outflow relative to the total flow in the main channel. Also the conservation of momentum will also be revised to include at least approximately the effect of cross slope of the water surface in the channel discharging into the main

channel junction. A major uncertainty in both code 11 and code 13 is the effect of the distortion of the velocity distribution at the downstream exterior node in the main channel. A literature search is underway to seek information on approximating that effect also.

Control Structure Options

A control structure is any feature or device present in the flow that exerts either partial or complete control over the flow value. By control I do not mean the ability to regulate the flow or force the flow to take on a given value. In fact, an uncontrolled spillway often exerts complete control over the flow value. What I mean by control is the ability to compute the flow given the elevation of the water surface at either one or two points. If the elevation of the water surface at one point allows me to compute the flow then I say that the control structure is a one-node control structure. If I need to know the elevation of the water surface at two distinct points, then I say that the control structure is a two-node control structure. Finally there are some cases in which knowledge of the water surface elevation or at least flow conditions are needed at three nodes to define the flow completely. This classification relating to the information needed for computing the flow is supplemented by another classification relating to the changes that are possible in the geometric configuration of the control structure. Control structures for which the geometry cannot be changed with the purpose of changing the relationship between water surface elevations and flow are called fixed geometry control structures.

An example of a fixed geometry control structure, in this case manmade, is an ungated spillway on a dam. If the spillway crest is elevated above the tail water such that it is never subject to submergence then the control structure is also a one-node control structure. However, if the spillway is on a low dam the spillway may be subject to submergence from high tailwater and it becomes a two-node control structure. Another example of a control structure, natural is this case, is a waterfall or steep rapids. Again the height of the waterfall or rapids relative to the expected range of water surface elevations at its foot determines if the control is one-node or two-node. A variable geometry control structure will have some means of changing the relationship between flow and water surface elevation by moving some form of gate or valve. A spillway with Tainter gates is a typical example. A control structure that involves information at three nodes is flow over a side weir sometimes used for diverting water to an off-channel storage reservoir. Flow over a levee during a flood is of a similar character with an option for variable geometry as the levee erodes or collapses.

One-Node Control Structures

The one-node control structures assume that there is never an influence on the flow from downstream. FEQ does not check for the possibility of such an influence and the user must make the appropriate checks to make sure that the flow has not been affected by the water surface elevation downstream of the structure. If there is any doubt, use a two-node option so that submergence will be properly taken into account should it occur.

The head node and the flow node are specified separately even though the node for head and flow is often the same. A typical example would be flow over a high dam that cannot be submerged from downstream, at least for the flows being considered. Further assume that the reservoir formed behind the dam is long relative to the cross section available for flow so that its surface during the high flows has an appreciable slope. Then the reservoir should be represented as a branch with cross sections defining its volume. It is then no different from the point of view of FEQ than the stream channel without the dam. In this case the flow node and the head node for the spillway if the spillway is the only path available for water to pass by or over the dam would be the exterior node on the downstream end of the branch.

Now, however, if there is more than one path for the water to pass downstream and these paths are to be kept distinct, then there would have to be two or more control structures with one control structure for each path. Of course the hydraulics of the control structure are governed by the flow passing through the control structure. Thus the downstream node on the branch can no longer be used to represent the flow through either control structure because it should represent the total flow passing the dam. To make the example specific, assume that one purpose of the dam is to divert water into a canal. Thus part of the flow passing the dam continues downstream in the natural stream channel and the rest enters the canal. The canal would be represented by one or more branches as would the natural channel downstream of the dam. In this case the head node for each of the two control structures would be the downstream node on the branch representing the reservoir. The flow node for the control structure determining how much water is released to the natural channel would be the upstream node on the branch representing that flow path. In the same way the flow node for the control structure determining how much water was released to the canal would be the upstream node on the branch representing that flow path. Such multiple flow paths require that the head node and the flow node for a one-node control structure be specified individually so that they can differ if necessary.

One-node control structures are often a natural means to represent a downstream boundary. To maintain an overall water balance and to satisfy the flow sign convention, the user must inform FEQ in which direction the water is flowing relative to that part of the system that has the head node. In the first example in which the flow all went to the natural downstream channel the direction of flow would be given as -1 because the flow is leaving the branch on which the flow node is located. In the second example, in which the flow was split between two downstream paths, the direction of flow for each control structure would be $+1$ because water is entering each of the branches on which the flow nodes are located.

Fixed Geometry Structures

Fixed geometry one-node control is the simplest option available for representing hydraulic structures. In each case involving head the head is always taken to be positive and it is defined as the difference between the water surface elevation and the elevation of the reference point. If the head is negative, it is set to zero before the flow is computed or the table is entered to find the flow. Type 2 is the most general option allowing the user to compute a table of flows that could represent the combination of flow through several different parts of the control structure. For example, the same table could be used to define the flow through a combination of an orifice and a weir or spillway.

The channel control of flow option(Type 3) can only be specified at the downstream end of a branch because only exterior nodes on a branch have a cross sectional area and such a control only makes sense at the downstream end of a branch. Using the water surface slope from the previous time step approximates the influence of water surface slope at the boundary when no other convenient boundary condition exists but the computations may become unstable under conditions of rapid variation of flow. In addition, if you supply a slope do not have this slope deviate too much from the actual slope at that point in the profile as defined in the branch description tables. Computational problems, mainly with supercritical flow could result if the given slope is able to move water more rapidly than the upstream channel can deliver it and still retain subcritical flow.

Variable Geometry Structures

Variable geometry one-node control is the next most complex representation for a hydraulic structure. To represent a variety of possible structures without burdening FEQ with the onerous detail of representing each case separately, a generalized representation was developed. This

representation approximates a variety of structures by assuming that the flow through any one-node variable geometry structure can be computed by the product of the maximum capacity of the structure at the current head and the proportion of the maximum capacity that is currently available. That is, FEQ assumes that the capacity to release water is given by a variable, P, such that when $P = 1$ the structure is set so that the flow is retarded by the minimum possible amount. Thus $P = 1$ represents the setting of the variable geometry such that the maximum flow of water is obtained at any head. Any lesser capacity than the maximum capacity is represented in FEQ by a value of $P < 1$. If $P = 0$ then the structure is set such that no water can pass through it. Any value of P such that $0 < P < 1$ represents some intermediate setting of the structure. The value of P may or may not represent structure setting directly but it is always possible to set the structure so that the flow computed by FEQ using the product of P and the maximum capacity at the given head is obtained. Thus by using the maximum capacity, FEQ ensures that all flows passing the control structure are physically possible.

For Type 4 the user gives the proportion of maximum flow as a function of time explicitly. Computational problems with supercritical flow can result if the stream channel upstream of the structure cannot deliver enough water while remaining subcritical to satisfy the current capacity of the structure. For Type 5 FEQ computes the proportion of maximum flow based on the conditions at user defined control points as outlined in the Operation of Control Structures section on page 34 of the input description for FEQ.

Type 6 is an operation rule that was specific to a given project. It is unlikely that another project will use such a rule, however it is being retained for the near future in case another application arises for it.

Two-Node Control Structures

In contrast to one-node control, two-node control assumes that the downstream water surface elevation may influence the flow in the structure. Consequently, two-node control structures are more general and can represent one-node control structures as a special case. Never-the-less one-node control structures are still useful because they are often an adequate representation of the flow.

The degree of downstream influence may not only retard the flow below that which would be obtained without the influence but may also cause the flow to reverse direction. In some cases the occurrence of reverse flow is not allowed by a particular structure or if reverse flow is present additional information must be supplied so that FEQ can compute the flow properly.

Two-node control structures require specification of an upstream node, a downstream node, and a flow node. The usage of upstream and downstream is again nominal but there are certain natural usages that help to minimize user confusion and error. Recall that each branch has an upstream and a downstream node. Now the natural mode of connecting one branch to another is to connect the downstream node of the upstream branch to the upstream node of the downstream branch. In this case at the junction we will find two distinct nodes. Now a control structure is best conceptualized as being like a branch in that it represents a flow path of water but it has no nodes. The control structure in a sense is a parasite in that it can only exist by using the exterior nodes already defined for some other purpose. As a result, a natural assignment of upstream and downstream leads to the upstream node of the control structure being the same as the downstream node on the branch upstream of the control structure. Also the downstream node of the control structure is the upstream node of the branch downstream of the control structure. This sharing of nodes by the control structure, far from being parasitic, is essential because it makes up part of the connection between branches. The other part is of course the continuity of flow specified by Code 2.

A flow node must be assigned just as for one-node control but in this case the flow mode must the same as either the upstream or the downstream node. The flow node again gives the flow through the structure. As a consequence a node can only be used as a flow node once. Thus each control structure must have a unique flow node.

Fixed Geometry Structures

Type 1 represents an expansion or a contraction in the channel size. The usage of contraction or expansion includes flow over a drop or a step. The table defining the elements of the cross section for the critical flow computation is the same as any other cross section table. Generally critical flow will occur at the smaller of the two sections but it might be that some other section would better represent the critical flow section. There have been some recent computational problems with type 1. There has been one case where FEQ failed to detect critical depth properly. As a result, a completely nonsense solution was obtained. Plans are underway to replace type 1 with a more general option for rapid expansions and contractions.

Type 2 can represent several hydraulic features by appropriate choice of its parameters. The basic function is bidirectional flow as computed from tables. The flow is computed as follows. First the direction of flow is set from the higher head to the lower head. Second, the unsubmerged flow is found in the proper flow table. Third, the ratio of the smaller head to the larger head is then used to find the submergence factor in the proper submergence reduction table. Finally, the flow is computed as the product of the unsubmerged flow and the submergence factor. If both heads are negative then the flow is zero. This option can represent bidirectional flows over weirs, roadways, spillways, *etc.*

The pump option can be used alone or with the bidirectional flow option. The pump option was designed to represent the pumping from an off-line reservoir where the pumping is controlled by the flow state at the destination node and by the water level in the off-line reservoir. Obviously the pump should be turned off if the water level at its source node is below the intake. Also the pump should be turned off when the water at its destination node is considered to be at flood stage and this stage must be set so that turning the pump on does not cause the flood stage to be reached.

The conveyance option represents flow between the upstream and the downstream node by using the Manning equation between the nodes with the slope computed from the difference in water surface elevation and the flow distance between the nodes. This option has not been used much and should be used with caution because its characteristics have not been well established.

Type 4 is one way of representing flow through bridges and culverts. The method is based on the Bureau of Public Roads methodology as reported in "Hydraulics of Bridge Waterways". The method as presented is restrictive in that it assumes that the cross section of the stream upstream and downstream of the bridge is the same and that a meaningful normal depth can be computed. The utility program, FEQUTL, computes a loss table that is then used by FEQ. Computational problems can result when the flow passes from part full flow to full flow and options can be selected to force FEQ to approximate the full flow by using the part full flow equations to avoid these problems. Type 3 should not be used as noted in the input summary. It is being retained for compatibility with past projects that may require its use. Type 4 will be replaced in the future with a much improved methodology based on Code 5 Type 6.

There is an alternative method for approximating the hydraulic effect of bridges and culverts without using the bridge routines. This alternative method is based on the observation that the hydraulic losses for flow through a bridge or culvert occur, at least conceptually, at the contraction at the entrance, by friction of the flow path through the structure, and at the expansion at the exit from the structure. Thus the bridge or culvert can be represented by a branch with cross sections

given by the shape of the opening. At the entrance a Code 5 Type 1 option is used to represent the contraction and at the exit another Code 5 Type 1 is used to represent the expansion of the flow. If flow occurs over the roadway a Code 5 Type 2 can be added with some extra exterior nodes to represent that flow path. This approach involves more computational effort in FEQ than do the bridge routines but it can be used for special situations not well represented by the bridge routines. For example, long culverts are sometimes used to convey water under multi-lane highways and the friction losses in the culvert may be of the same magnitude or larger than the entrance and exit losses. In some cases the inertia of the water in the culvert or bridge may be significant but this would likely only happen on flat slopes involving reverse flow.

Type 5 represents an abrupt expansion in flow with possible inflow-outflow taking place within the expansion. This option is designed to represent a range of hydraulic structures used to divert and return water to an off-line reservoir. The critical flow table differs from the one used for Type 1 in that the table gives the critical flow and not the elements from which critical flow is to be computed. This approach has been taken to provide for the possibility that the cross section at which critical flow is being computed is shaped such that the simple formula for critical flow no longer yields a meaningful value. It then becomes possible for the user to compute the critical flow in some other manner so that the critical flow makes hydraulic sense. As currently implemented Type 5 does not permit reverse flow but that restriction will be removed in the future.

Type 6 can be used as either fixed or variable geometry and is in a sense is the most general option for describing flow. It uses a two-dimensional table to represent the flow through a variety of structures. Page 39 of the input description begins an extensive discussion of how to compute the contents of these tables. The only restriction at this time is the requirement that there be a drop in the water surface elevation in the direction of flow. In some cases this is not true because there is a transformation of kinetic energy into potential energy so that the downstream water surface elevation is higher than the upstream water surface elevation. However, an extension of Type 6 involving the velocity head of approach is being planned and will be implemented soon. FEQUTL, in Version 2.7 has two commands that create tables of type 6: EMBANKQ, for flow over embankment shaped weirs, and CULVERT, for flow through culverts.

Type 6 has the option to both vary the elevation used for computing the head as well as a time dependent factor to apply to the flow derived from the tables as given. To some degree these options can be used to represent the effect of erosion of a levee as a function of time. Some *a priori* knowledge of erosion must be assumed because FEQ has no current mechanism of linking the flow over the levee with the erosion. Thus the variable crest elevation option must be used with care. Finally type 6 can have more than one set of tables given so that multiple flow paths between the upstream and downstream node can be represented. It is always possible to compute a table representing the total flow but the construction of such a table may be difficult. It is often simpler to construct a table for each flow path and let FEQ compute the net result of all the tables. There will be an interaction among the flow paths in general that implies that the flow tables for each of the paths must be computed simultaneously. Currently there are no utility programs to do that. However, often the interaction among flow tables is reflected primarily in the approach velocity head to the entrances of the flow paths. Sometimes a good first approximation to the flow can be computed by assuming that the velocity head of approach is small enough to be neglected in the computations. This then implies that the flow in each flow path is unaffected by the flows in the other paths. Flow through culverts can already be computed using FEQUTL and an improved facility for flow computations through bridges is being planned. However, there will always be structures in the field that require the construction of a special purpose program.

Variable Geometry Structures

The only explicit variable geometry two-node control structure is a representation of a variable height weir. The weir can either be vertical or it can be sloped and the user supplied variation of the weir coefficient reflects the difference. Type 7 implements this option. The opening fraction, P, has the same range as for the one-node variable geometry control structures but it plays a more direct role in that it does represent via one of the input tables the height of the weir.

Type 6 also offers some variable geometry features but the relationship between the geometry and the hydraulics of the flow is not explicit. Also at this time(Version 6.0) type 6 cannot reference an Operation Control Block. This facility can be provided should a project require the ability to dynamically control a two-node control structure.

Three-Node Control Structures

The only three-node control structure is code 14 that is used to approximate flow over side weirs. The input description contains an extensive description of the current capability of FEQ to represent flow over side weirs. In brief, the discharge must take place at junctions placed in the source channel to represent the outflow at a distinct point even though this discharge has occurred over a significant length of channel. The input description gives some methods for approximating side weir flow more accurately by using several code 14 options to represent one weir. Plans are underway for creating new options for branches to include the side weir flow explicitly in the branch equations. In this case the side weir flow would be distributed over the length of the branch and would more accurately reflect the true flow geometry.

Closing Comments

Sometimes the special conditions need not be represented outside a branch because FEQ allows isolated losses to be represented within a branch. The losses caused by one or more piers of a bridge that is so high that the low chord is never submerged and designed such that no contraction or expansion of flow is caused can be represented by computing a loss table giving the multiplying factor to apply to the velocity head in the computational element in which the pier or piers are located. Other so-called point losses can be represented in the same way. The losses in excess of those caused by friction generally called eddy losses and attributed to the expansions and contractions in the flow area caused by the irregular geometry of the channel can also be represented by branch options. These coefficients are constants and are applied to the change in velocity head in the computational element. However, these special options defined for computational elements in a branch should not be used for major structures or for the more abrupt changes in channel geometry.

FEQ has the current ability to represent a variety of special conditions but there will be some special conditions that will not be well represented by the current repertoire of options. An intrinsic part of the design of the FEQ software was to make addition of new exterior matrix options easier to implement. That goal has been achieved. The software has been used and expanded for more than twelve years and many options have been added during that time span. In the future more options will be added as the applications require.

INPUT PREPARATION CONSIDERATIONS

This section will discuss briefly a number of issues that relate to the details of conducting an unsteady flow analysis project. These are more in the form of recommendations than requirements and are based on more than ten years of experience with FEQ and its earlier versions as well as on fifteen years of experience with unsteady flow programs.

Function Tables

A ubiquitous feature of any unsteady flow analysis project is the large number of functions involved. As should be clear now almost all functions are represented by tables in FEQ. The table types available in FEQ can represent almost every conceivable function that will be encountered in an application. Thus generality is not a problem. Keeping track of the resulting tables, however, can become a problem if it is not approached in an organized manner. The range of function table numbers can be made quite large now that large memories are available on personal computers as well as mainframes. Currently the limit is 10000 so that different ranges of numbers can be assigned to different classes of tables. The particular pattern should be designed to be meaningful for a specific application. One possible approach, if there will be fewer than 100 cross sections on a branch, is to assign a four digit number to each cross section with the first two digits being the branch number and the second two digits being used to distinguish cross sections on that branch. Then the location of the cross section is defined at least approximately by the table number.

Other table numbers, such as those for reservoir storage, spillway ratings, *etc.* can be assigned similar ranges of table numbers so that they too, can be approximately located or associated via their table numbers.

The next level of organization is the input of the tables to FEQ. Some tables, notably cross section tables, bridge loss tables, and flow over the roadway tables, are produced by FEQUTL from the description of the basic geometry. FEQUTL is designed to produce a file containing only the resulting function tables in a format suitable for input to FEQ without any changes. FEQ can input one or more separate files to obtain its needed function tables. Thus it proves efficacious to classify the function tables into at least two classes: those produced as output from FEQUTL and those derived from other sources. Then when some change is made in one or more of the basic descriptions defining the cross section tables, the bridge loss tables, or the flow over the roadway tables, the change can be made in the input file to FEQUTL and the entire set of tables can be recomputed and the file for this class of tables can be replaced in its entirety without affecting any other tables. FEQUTL takes little time to recompute all the tables and to do so for even the smallest change avoids confusion and keeps all the tables in order. It is common to have several files describing the input to FEQUTL and several files describing the corresponding function table files. The tables derived from other sources should also be divided into subcategories so that similar tables are stored together. It matters little what aspect of the tables is used to define the similarity so long as the classification is applied consistently and so long as it is meaningful to the user.

A final level of organization makes use of the tree-structured directories available under MS-DOS and other operating systems available on personal computers. A carefully designed set of subdirectories can aid greatly in reducing the number of separate file names that must be used. Again the specific design depends on the problem at hand.

The use of these three approaches to organizing the function tables has many advantages. First, it reduces the chance for major blunders in managing the files. Secondly, it can help reduce errors in the input because tables that are related will tend to have their table numbers close together in the input. This makes it easier to find typing errors, that may cause a reference to an existing but incorrect table. Thirdly a well thought out structure tends to be self documenting and makes it possible for several people, not necessarily working on the project at the same time or in

the same office, to maintain familiarity with where things are stored and what is contained in each of the files. This can prove invaluable for even a modest sized project and becomes essential for a large project.

Exterior-Matrix Control Input

As mentioned earlier the preparation of the exterior-matrix control input is the most challenging part of the input preparation because it involves the subtleties of the connections between and among branches, reservoirs, and a host of special conditions. It is at once the source of the generality of FEQ and the source of the challenge of using FEQ. However, once several examples have been understood and some simple cases done the idea is grasped and one can move on to more complex situations.

The first step in the analysis of a stream system using FEQ must begin with the construction of what I call a schematic. This is a diagram that shows the branches and the exterior nodes and how they are connected. Sample schematics appear in the examples FEQEX1 through FEQEX4 in the set of examples supplied with these notes. To draw the schematic we must determine the location and the nature of any special features in the stream system that cannot be part of a branch. The following is a partial list of special features given as an aid to this process.

1. Any change in bottom slope that might be great enough to cause a critical control. These must be isolated because branches that have supercritical flow must be treated differently than those with subcritical flow and in any case locations of potential critical flow must be isolated.
2. Any abrupt change in channel shape or roughness. These transitions must be isolated to account for the additional losses.
3. Dams, control weirs, large pumping stations, and similar features that can have a major effect on the water surface elevation or the amount of water flowing in the stream.
4. Level-pool reservoirs, lakes, and ponds.
5. Junctions between or among tributaries or distributaries.
6. Drop structures, falls, or rapids. These will be control points at least at certain flow levels. FEQ can have these control points be drowned out at high flows and to be re-established at lower flows.
7. Bridges and culverts that are to be represented explicitly.
8. Points of known water surface elevation or of known or knowable flow. These will often be the logical places for boundary conditions. These values can be functions of time and need not be constants.
9. Points of known relationships between water surface elevation and flow rate such as gaging stations.
10. Points at which a special feature of some kind may be added to improve the control of the stream system in some way.

Some of these categories overlap and there may be some feature that has been missed. The rule for defining a special feature is that anything that has an influence on the flow and cannot be represented by gradually varying unsteady flow in a stream channel is a special feature.

Once the schematic has been drawn the branches and the exterior nodes must be numbered. The only requirement for numbering the branches is that their numbers start at 1 and be consecutive. The requirements on the exterior node numbers are more stringent because the order of numbering determines the bandwidth of the exterior matrix. The computational effort in solving the exterior matrix, which must be done thousands of times in a typical simulation, varies as the square of the bandwidth. Thus reducing the bandwidth by a factor of 2 can reduce the computational effort by a factor of 4.

The band width is determined by the maximum difference between exterior node numbers appearing in any equation in the exterior matrix. The first example is the branch. The upstream

node and the downstream node appear in the pair of equations generated for each branch. The lines of input not involving a branch generate one equation in the exterior matrix. The bandwidth is generally $2n_d + 3$ where n_d is the maximum difference between the node numbers appearing in any of the equations.

Any scheme of numbering that will keep the maximum difference small is acceptable. The following manual technique has worked well in the past and is the current preferred method for manual numbering of the exterior nodes.

1. Visualize what the schematic would look like if each branch were given the same length and each point of connection were connected with some flexible material and then hung as a mobile. The connections should be such that the branches that happen to be the same distance from the point of suspension would hang parallel to each other.
2. Begin numbering the exterior nodes at the point of suspension always moving in a consistent direction; either left to right or right to left along nodes at the same distance from the point of suspension.
3. This can be done for several suspension points to see which one yields the smallest maximum difference.

This general technique is straightforward when no loops in the stream system are present and when there are no free nodes. If free nodes are present(level-pool reservoirs and other nodes not on any branch) they should be treated as being the same length as the branches but having a node at only one end. However, remember that a reservoir has inflow nodes and all the inflow nodes take part in one equation. Furthermore, the reservoir node will also be involved in some other equation connecting the default outflow point of the reservoir with the rest of the system. Loops make the pattern to follow in the numbering scheme uncertain. Some trial and error may be required before a reasonable minimum value of the maximum difference can be found.

Once the exterior nodes are numbered the numbering should be checked to make sure that one or more numbers have not been left out. The number of exterior nodes is always twice the number of branches plus the number of free nodes.

The writing of the lines of input should begin with the smallest exterior node number and move to the large exterior node numbers. The order of writing is not critical because FEQ has the ability to reorder the input to minimize the bandwidth. The number of equations should be checked to make sure that none have been omitted or that none have been given twice. The number of equations is always twice the number of exterior nodes. FEQ checks for agreement and will report an error and stop if the incorrect number of equations has been supplied. In counting the equations make sure to count two for every Code 1 and one for all other codes in the exterior-matrix input.

For larger models I have found it useful to construct an explicit representation of the schematic out of strips of cardboard. A convenient source of cardboard is the backing sheet that comes with note pads. This has dimensions of 8.5 by 11 inches. A length of 4.25 inches and a width of 5/8 inches for each link in the schematic have proved practical. Each link has a hole punched near each end so that they can be fastened using brass fasteners. Thus the mobile mentioned earlier is actually built. It may seem strange to use a structure made of cardboard to help prepare input for a large and complex computer program. However, we should never disdain any aid we can use in helping us to keep track of the many details of an unsteady flow model.

Each branch should have a name of seven or fewer characters in length. Again the names are anything that is meaningful to the user. However, I have found it useful to use the name of the stream or tributary on which the branch is located and to add a letter suffix to it. For example, the downstream most branch on the Fox River would be called "FOXA" and the next branch upstream would be called "FOXB" and so forth. If there are more than 26 branches add another letter so that the 27-*th*branch on the Fox River would be "FOXAA". The exterior nodes on each branch also are named but they inherit their name from the branch name. The upstream node on a branch

is given the name of the branch with a "U" appended to designate upstream. The downstream node on a branch is named by appending a "D" to the branch name. The goal is to keep the node names at eight characters or less so that they can be placed in the node id column for FEQ. Each level-pool reservoir and free node must also be given a name.

The branch names, level-pool reservoir names, and free node names are written on the pieces of cardboard that represents them in the schematic. The name is always written from the upstream end to the downstream end of the cardboard strip. Thus not only does the name denote the relative position of the physical entity, but it also denotes the direction of downstream flow. The schematic is constructed link by link without numbers assigned to it. Links can added or deleted easily to change the representation as the model is being designed. Once a final model is complete, we can physically manipulate the links to minimize the maximum difference between associated nodes.

Once the best arrangement of the schematic is found, we then systematically number the exterior nodes. In complex models, I have found it convenient to assign two exterior nodes to every link in the schematic. Thus level-pool reservoirs as well as free nodes are given both an upstream and a downstream node number. This makes the numbering much simpler and often reduces the bandwidth significantly. We also may have to add some extra free nodes to make the bandwidth smaller. These are added in pairs and the link created by these free nodes is called a null branch.

Once the branches and exterior nodes are numbered the schematic serves as a memory device for keeping track of the progress made in writing the Exterior-Matrix Control Input. Keep in mind that a large model may have more than 70 branches and more than 200 exterior nodes. Thus there are hundreds of entries in the Exterior-Matrix Control Input. If periodic checks are not made as the input is written, it becomes difficult to find the location of an error if the incorrect number of equations is obtained at the end. Thus, periodic checks on the number of equations already written need to be made. To make these checks the entries in the Exterior-Matrix Control Input must be written in a systematic order.

This order follows the numbering of the exterior nodes. The cardboard schematic is placed on a long table with the links arranged so that all the links are parallel and that all junction points are aligned at right angles to the links. Then the Exterior-Matrix Control Input entries are written in the sequence of the exterior node numbering. The pattern becomes that of writing the conditions at a row of junctions(or boundary nodes if no junction exists at the end of a branch or other link in the schematic) followed by the entries for each branch, null branch, or level-pool reservoir. It is convenient to check the number of equations after the link entries have been made. We then imagine that the model has been truncated at the end of these links, thus creating the need for as many boundary conditions as there are links. The number of equations required in this truncated model is twice the number of the maximum exterior node in the truncated model. The check is then as follows: the number of equations represented by the Exterior-Matrix Control Input plus the number of links at the point of checking must equal the number of equations required for the truncated model. Any error in this check reveals that a mistake has been made between the current and previous checking location.

Steady Flow Analysis Input

The input for the steady flow analysis(also called backwater analysis) must move from points of known elevation to points of unknown elevation. The flow is always considered to be subcritical so that the general direction of the input is from downstream to upstream. The elevation information is transmitted from branch to branch via the exterior nodes on the ends of the branch. A variety of codes exists to represent the major features of the system but some features are ignored. For example, losses through bridges are ignored in the backwater computations. It may prove necessary to add some elevation increments at the bridges and culverts to get close enough for the unsteady

flow computations to get started properly. Another technique that is sometimes useful is to compute the initial conditions at some high level of elevation so that the losses through any culvert or bridge relative to the flow depth is small. Then apply hydrographs at the boundary points that reduce the flow to the desired initial level. In some stream systems, with little relief, it is possible to start with the water level initially horizontal and all flows zero. The boundary conditions are then adjusted over time to reach the desired initial state.

Trial and error may be required if loops are present because FEQ does not now have the ability to balance the losses along different flow paths in the steady flow computations. Once the losses are approximately balance, FEQ can be used, with the forced flow boundaries held constant, to compute the initial steady flow profile and the distribution of flows among parallel paths. These flows can then be manually entered into the backwater input to enable subsequent runs to dispense with the computation of steady flow using the unsteady flow model!

The purpose of the backwater computations is to get a good first approximation to the initial water surface elevations. This first approximation is then refined by "freezing" time for several time steps before beginning the actual simulation. During frozen time, all the unsteady flow computations are made with an ever increasing sequence of time steps but the time is never changed. Thus the time-dependent boundary conditions are fixed during frozen time. At the end of the frozen time period the water surface elevations and the initial flows have adjusted to all special features in the system.

These introductory notes on the application of FEQ to unsteady flow problems have focused on the details of the unsteady flow and have assumed that some other source will be available for defining the flows at the boundaries and the lateral inflows to the stream. FEQ is indifferent as to the source of these inflows. FEQ functions in two modes depending on the source of the inflow information.

The mode that we have discussed so far in the course involves specifying hydrographs in function tables at all flow boundary points. We have assumed that the flows entering the stream from the adjacent tributary area is small so that we can ignore them or that we can add additional points of inflow at intervals along the stream to represent them. This is a perfectly satisfactory means of analyzing a stream if only a few flow events are of interest but it becomes cumbersome if many flow events are to be analyzed. This option is selected by specifying DIFFUS=NO in the Run Control Block.

HIP, an acronym for Hydrologic Information Program, is a collection of programs and data files designed to make the analysis of many flow events both possible and convenient. This option is selected by specifying DIFFUS=YES in the Run Control Block. With this option additional files are required by FEQ. The major file, called a diffuse time series file (DTSF or merely TSF) is used to store information on runoff intensities from the watershed so that FEQ can compute the lateral inflow that enters branches and reservoirs along their length. This file also allows us to store many different flow events for analysis of their effect on the stream system.

You may wonder why we would like to analyze many flow events. We would like to do so because current and future problems in water resources management are too complex for the traditional methods to function properly. Traditional methods typically limit themselves to one or at most a small number of events called design events. The selection of the proper events to use in complex cases is at best difficult and most likely impossible to do on a defensible hydrologic basis. To provide some context for this assertion I briefly review traditional methods and their areas of weakness.

Traditional Hydrologic Methods

Traditional hydrologic design has three major components: selection of a synthetic rainfall event, transformation of this synthetic rainfall event into a flow or a hydrograph, and an assignment of a probability of exceedance to the synthetic flow hydrograph.

Selection of Rainfall Event

The rainfall event is most often selected from the results of an available rainfall frequency analysis. Such an analysis assumes that it is meaningful to categorize rainfall based on duration. Consequently, frequency analysis is unable to reflect the distribution of rainfall intensities within a given duration. Only the total rainfall for the duration enters the analysis. This loss of rainfall intensity pattern is serious because runoff intensity is dependent on the rainfall intensity. Some methods partially recover this information by using a standard distribution for the rainfall. This *ad hoc* adjustment presumably leaves the frequency of the event unchanged.

Selecting the duration to use for a particular case assumes that there is a single critical duration for a watershed for a given return period. Generally a time of concentration or a time to equilibrium approximates this critical duration. If significant detention storage is present, the critical duration may have to be estimated by trial and error retaining the duration that results in the maximum for the peak flow or volume of the hydrograph.

Transformation of the Rainfall Event

The transformation of the rainfall event into a hydrologic event is the next step in the process. This transformation can be simple or complex and thus I limit myself to the assumption common to these methods. The key assumption of these methods is the belief that the initial conditions can be set *a priori*. These initial conditions relate to the initial storages in the watershed: soil moisture, reservoirs, and stream channels. These values are stochastic because they depend on the antecedent rainfall. Clearly it is difficult or impossible to set the initial conditions *a priori* meaningfully. In practice, it is done, sometimes with careful thought, but most often following some standard that has been accepted by the group doing the analysis or by the agency that will review the analysis in some permit application procedure.

Assignment of Frequency

The result for traditional hydrologic design is a peak flow, or a hydrograph, or elevations for reservoirs. These results are the hydrologic response of the model system to the synthetic rainfall event when the assumed initial conditions prevail. To assign a frequency to these results the hydrologist invokes what I call the principle of conservation of rainfall frequency. The principle of conservation of rainfall frequency says that no matter what the transformations and assumptions, the outcome of the analysis will have the same frequency as the synthetic rainfall event. Furthermore, all parts of the outcome will be given this frequency. That is, the hydrograph produced by the model will be given the same frequency as the rainfall. To assign a frequency to some event that event must be capable of being ranked relative to other similar events. Hydrographs cannot be ranked and therefore they cannot have a probability of exceedance. Only single-valued outcomes like peak flows or hydrograph volumes can be ranked and assigned a probability of exceedance. Therefore, the assignment of a frequency to the entire hydrograph is either meaningless or the hydrologist has implicitly restricted the hydrographs so that they can be ranked in some sense. The latter case then raises the related problem of justifying the restriction on the hydrographs.

At face value the principle of conservation of rainfall frequency is false. The same flood peak could have resulted from a variety of combinations of antecedent conditions and rainfall events with return periods differing from the design return period. The principle of conservation of rainfall frequency fails because it does not integrate the probabilities of outcomes over the space of possible combinations of rainfall intensities, durations, and antecedent conditions.

An Alternative

The shortcomings of traditional hydrologic design and analysis become most acute as development increases and the stream system becomes more complex. The addition of detention storages to compensate for changes in imperviousness and to compensate for the reduction in flood plain storage are commonplace changes that make assignment of initial conditions difficult and subject to large error. Experience has shown that the sequence of floods is often the determining factor in the performance of modern urban drainage systems. No single event determines the required storage but rather a sequence of moderate to large events does. Thus it is also difficult if not impossible to *a priori* select one or more design events to design and evaluate urban drainage system comprehensively.

Some shortcomings of traditional hydrologic design can be overcome. The weakest parts of this approach are those involving frequency. Thus the best hope for improving hydrologic design is to improve our ability to assign frequencies to the synthetic streamflow produced by our rainfall-runoff models. We can improve our results if we examine a complete sequence of events and not only a single event with *a priori* initial conditions. This is the goal of HIP, to provide a sequence of events

that represents the range of events that are likely to occur in the future. Using HIP, a user can evaluate the performance of a proposed change with many events and not just one design event.

An Overview of HIP

HIP involves several programs and data files. Development of a HIP system for a stream is a major undertaking involving several major steps. This steps are outlined here.

1. Collection of meteorologic data. These data include daily rainfall, hourly rainfall, evaporation, solar radiation, *etc.*, that is, any data series required by the rainfall-runoff model. The rainfall-runoff model will be such that it simulates both high and low flows, both wet and dry periods. Such a model is often called a continuous rainfall-runoff model to distinguish it from single-event rainfall-runoff models. These continuous rainfall-runoff models eliminate the problem of establishing arbitrary initial conditions that is inherent in the traditional methods of hydrologic analysis.
2. Collection of watershed data. These data include areas, land uses, channel cross sections, bridges, culverts, storm sewers, dams, reservoirs, *etc.* required to describe the watershed and stream system for both the rainfall-runoff model and FEQ.
3. Collection of stage and flow data. These data include daily streamflow, detailed flood hydrographs, and stages in both streams and reservoirs. They will be used in the process of calibrating and verifying the HIP system.
4. Calibration of the rainfall-runoff model. Key parameters of all useful rainfall-runoff models depend on calibration to observed data. The HIP model has used HSPX in the past, an outgrowth of the Stanford Watershed Model developed in the 1960's. This model requires that the watershed be broken into segments for which one rain gage is assumed to represent the rainfall on a segment. Thus if there are three rain gages available with long records, the watershed would be broken into at least three segments. In the future HIP will use HSPF instead of HSPX. HSPF is based on HSPX but contains many extensions and improvements and can also be used on larger microcomputers.
5. Selection of design basis conditions. The rainfall-runoff model is calibrated to data that has been observed. Some of the watershed characteristics are changing with time, *e. g.* land use. During calibration either a period of nearly constant land use must be found or the land use must be changed so that the parameters will be properly defined. Before design basis or regulatory basis analyses can be done the land use must be defined for the hydrology. This might be an estimate of the future land use or it might be useful to have more than one basis for testing existing facilities or for designing future facilities.
6. Computation of unit area runoff intensities. In this step, a time series of unit area runoff intensities are computed using the rainfall-runoff model and the longest period of rainfall record that can be constructed. For example, if there are 3 land uses: undeveloped, moderately developed, and completely developed, and if there are 3 segments(rain gages) then there will be 9 time series of unit area runoff intensities.
7. Selection of critical events. In principle, the entire series of runoff intensities could be used in an unsteady flow analysis. However, the computer time required is large. Furthermore, most of the time nothing of significance is happening in the watershed. Thus as a practical matter, we must select time periods of significant flow. In the past one or more events from each water year of the simulation record have been selected for inclusion in the set of critical events. Each of these events should have a period of low flow preceding it so that the storages in the watershed can be properly initialized prior to the occurrence of the main part of the event.
8. Create the time series file for FEQ. The time series file or TSF is a file designed to make access

to the many separate values of unit area runoff intensity convenient and efficient. This file is created from the rainfall-runoff model's time series storage system using a utility program.

9. Selection of the standard initial condition. A standard initial condition for the unsteady flow analysis is needed to make sure that each event begins from the same point so that the runs with differing alternatives will be comparable.
10. Develop the streamflow model. This task involves all the aspects of describing the stream system to FEQ. The tributary area for each land use in each segment for each branch or reservoir must be defined so that FEQ can compute estimates of the inflow to the stream system.

Once complete, the TSF for a large watershed can be used for smaller subwatersheds and for adjacent streams if the rainfall patterns are similar. Some of the steps as outlined above may have to be modified. For example it may be necessary to have the streamflow model take part in the calibration process to make the proper distinction between the effect of the channel system and the effect of the land surface on streamflow.

This approach is better able to represent the complex interactions in a watershed because many different events are used. However, the major difficulty is the limited number of events. The existing records of rainfall suitable for rainfall-runoff modeling are limited to a maximum of 40 years or less. Consequently, it may be that none of the events in the TSF really represent the larger return period flows. Thus we would like a means of creating synthetic events that none-the-less still retain the characteristics of observed events and that are larger than any observed event.

One promising approach to attain this goal has already been mentioned in the FEQUTL input documentation under the FLOODWAY command. This approach uses a stochastic rainfall data simulation model to create synthetic rainfall data with the key characteristics of the observed data being mimicked. A long series of synthetic rainfall data would contain extreme events consistent with what has been observed in a region. This synthetic rainfall data would be used to derive runoff estimates using a rainfall-runoff model. Instead of using about 40 years of data we could, in principle, use hundreds or thousands of years of synthetic data to obtain reasonable extrapolations to events larger than any observed. This combination of stochastic rainfall generation with deterministic rainfall-runoff simulation holds much promise.

The combination method outlined here is not really new. Work has been done at Stanford University since as early as 1965 on this approach. Three dissertations at Stanford dealt with this approach and Linsley, Kraeger and Associates has recently completed a major project for the Nuclear Regulatory Commission examining it also. A report of some ten years ago from Colorado State University also proposed the use of synthetic rainfall for this purpose. I am sure that the idea has been entertained and even explored more than once in the past 20 years.

Technological Objections

With such a long history why has it not been used more widely?

A reason of some validity is that the technology for generating synthetic rainfall is just emerging. Some very general but not site specific models and some site specific models have appeared over the past 25 years. What is needed in the near term is a stochastic rainfall model that can use existing sequences of both daily and hourly rainfall in its parameter estimation process so that it can be region specific but simultaneously retain as much of the current knowledge of rainfall processes as possible. Any such model must have a structure that makes it possible to regionalize the parameter estimation process. Such a model does not now exist but I think the seminal ideas for such a model are available.

Other reasons, of a technological nature, involve the requirement to extrapolate in both the rainfall model and the rainfall-runoff model to values larger than any observed. However, this

objection applies with equal or greater force to the traditional methods as well. The question of extrapolation in the rainfall-runoff model merits more attention in the future. Any design method involves extrapolation. The question really is, 'How will we extrapolate?'; not if we will extrapolate!

Legal-Administrative Objections

Another rich source of objections to any new method in hydrology is the combination of legal and administrative concerns. Our legal system evaluates current practice by past practice. Stated negatively, the courts protect you if you practice mediocrity among the mediocre, and stated positively they protect you if you practice excellence among the excellent! The courts refuse to evaluate technology and leave it to the practice of the profession to determine what is accepted. Carried to it logical extreme this policy prevents the acceptance of any new methods.

The concern for administrative simplicity also favors traditional methods because they require much less skill to use. Much of hydrologic design is done by individuals not trained in hydrology. Much of what is done must be reviewed by one or more governmental agencies. Thus simple traditional methods, even when their technological shortcomings are obvious, may be preferred for these reasons.

Clearly some standards must exist. Unfortunately, there is the universal tendency for standards to become substitutes for thought. Thus methods are applied incorrectly or to situations for which they were not designed. Tragically the hydrologist and those they serve are often unaware of this misuse of a standard method.

Financial Constraints

A third source of objections falls under the heading of financial constraints. The combination method clearly exchanges simplifying assumptions for computational complexity. But that is exactly the reason we have digital computers: to help us with computational complexity. The current generation of micro-computers and work stations is more than powerful enough to implement this emerging technology. After nearly two decades of using computers to do analyses faster perhaps it is time to try to do them better as well. The radical changes wrought by urbanization will eventually require some form of the combination method. The traditional methods are already inadequate for many basin-wide problems. The result is costly projects that do not function properly.

Conclusions

HIP is an early step in the direction of a new approach to basin-wide analysis of urbanizing stream systems. Much progress has been made; much more remains to be accomplished. Every new technology raises new questions that were not asked using the old technology. Over time these questions will be answered. Eventually some technology like HIP will have to be used with synthetic rainfall to design and evaluate the growing complexity of urbanizing watersheds.

UNSTEADY FLOW ANALYSIS: PROBLEM OF ROBUSTNESS

One of the early experiences of anyone undertaking the analysis of unsteady flow in a system of one-dimensional open channels is the frequent inability to complete an analysis straightforwardly because the computations breakdown at one or more points. We have the notion, primarily gained from steady flow analysis, that we should be able to describe the stream system and then have the program complete an analysis successfully with the only changes required being the nearly inevitable errors in typing or sequence of data. This is often the case in steady flow. However, it is the rare case in unsteady flow that is completed in this manner.

More typically the stream system is described with the available cross sections with interpolated cross sections requested in those reaches of the stream where the spacing of the measured cross sections seems to be too large. Furthermore, we try to isolated points at which special flow features might appear. We then begin the computations. First of all we must get a steady flow analysis completed for the assumed initial flows to serve as the starting condition for the unsteady flow. This may require the addition of some more interpolated cross sections so that the iterations used to solve the non-linear steady-flow equations will converge to a solution. Once the steady flow computation is completed successfully we have hopes of being able to proceed to completion of the unsteady flow computations. But this generally will require many more trials before a complete analysis is obtained. As the flow varies, hydraulic geometry not encountered in the initial conditions may result in the iterations not converging and a failure of the run. The problem can stem from a variety of sources. In what follows I will be discussing some of these sources but first I wish to discuss robustness and what changes can be made to the software to increase the robustness of the analysis.

In general terms robustness is the ability to complete computations in less than ideal situations in such a manner that the final results are still acceptable. The ideal situation is a rectangular, prismatic, horizontal channel in which the variation of flow is such that the depth of water is always large relative to the fluctuations in depth. Furthermore the variations in flow are relatively smooth. Such a stream channel can be analyzed in a predictable fashion. However, such a stream system rarely occurs. The next most ideal situation would be a prismatic channel of some simple shape with a very flat slope. The most difficult situations usually involve natural channels with erratic cross sectional shape as well as an erratic profile coupled with the flow being derived primarily from lateral inflows. Some of the stream slopes will be steep having supercritical flow at moderate and low flow levels but will be drowned from downstream at high flows so that the Froude number ranges from nearly 0 to perhaps 2 or 3. It is in natural stream systems where robustness becomes a problem with many trial runs required before a complete run is obtained. In addition the presence of culverts, bridges, dams, *etc.* add to the potential computational problems. This lack of predictability not only causes additional expense but also leads to frustration on the part of the analyst.

Robustness problems are of two kinds. The first kind is what I will call algorithmic. It results from the particular solution scheme adopted for various parts of the system. This relates to how we approximate the real system and how we solve the algebraic equations that result. The second kind is what I will call inherent. It results from the nature of the system and cannot be eliminated by changing the algorithm used in the solution scheme.

Algorithmic Robustness

A whole host of potential problems exists in the algorithms used in a program like FEQ. FEQ uses an implicit approach to the governing equation solution that is robust against certain computational instabilities that plague the simpler explicit approaches. However, stability in this sense does not assure us that the computations will converge in a practical sense in all cases. As an example the current bridge routine, in use for a number of years, has been a rich source of

computational problems. This comes about because there are several distinct flow patterns through a bridge or culvert opening. Each of these patterns has its own relationship between water surface elevation and flow through the opening. However, the transition between these flow patterns is not smooth because the relationships do not exactly match each other at their boundaries. Thus the computed flow can experience a discontinuity at this transition. The current bridge routine represents these flow patterns in the unsteady flow program and solves them at each time step as the computations progress. The transitions between flow patterns often result in computational problems because the jump in flow rate can often cause the computations to fail to converge.

An alternative approach to bridges and culverts currently under development avoids these problems completely by representing the flow through bridge and culvert openings using specially designed two-dimensional tables to represent all possible flow patterns. This table is computed using a utility program and all discontinuities in flow are resolved as the table is developed. Thus none are possible in the unsteady flow computations. In two years of experience using these tables no computational problems have been found. Thus careful design of the various components of the program can greatly increase robustness.

We have been speaking about convergence of the iterations as if convergence is defined simply. This is not the case. There are many complications to deciding how close we have to be to be close enough! FEQ tends to favor relative criteria for closeness if the quantity used to define the relativity is not too small. If it becomes too small then the relative criteria must be modified or supplanted by others. For example, the relative change in flow rate is meaningful so long as the flow does not become too small. The user must define what too small is because FEQ could be used to model the lower Mississippi or it could be used to model a brook hardly 5 feet wide! Thus the user supplies a value called QSMALL that is added to the absolute value of the flow to yield the quantity defining the relative change in flow given the change in flow. If QSMALL is too small, and the relative change criterion, EPSSYS, is too small, then the computations will not converge. QSMALL is usually some small fraction of the flow range of interest. For example, if the flows of interest are greater than 100 f^3/s then it would make little sense to have QSMALL at 0.1 f^3/s because the flows are only known at best to within 5 *per cent*! Thus a QSMALL value of 5 or even 10 f^3/s or more might be reasonable. This means of course that the relative change accepted for the low initial flows might be considerable larger than EPSSYS.

The convergence criterion for depth values at locations having a cross sectional area is defined in terms of the relative change in area. This works fine so long as the depth and area are not too small. The smallness here is handled a bit differently than for flow. If the correction to depth is less than an input value, ABSTOL, then the computations are declared converged at that point and the relative change is taken to be zero. Otherwise the relative change in the area is computed and this must be less than EPSSYS before convergence is declared. Again this means that the relative change in area accepted for small areas is larger than for the large areas.

The rule for declaring convergence for the equation system is that each variable being computed must satisfy convergence simultaneously. Thus the maximum value of all relative changes must be less than EPSSYS before convergence is declared. Studies have shown that in many cases only one or two variables will prevent convergence while all other variables have relative changes that are only a small fraction of EPSSYS. This is often the case when convergence is slow and the time step is being reduced for some computational problem. To increase robustness yet another convergence criterion is added. This criterion declares convergence if no more than a user input number, NUMGT, of variables does not meet the current convergence criteria but do meet a less restrictive secondary convergence criterion. Thus EPSSYS with ABSTOL become the primary convergence criteria. Then NUMGT and the secondary relative change criterion become the secondary criteria for convergence. FEQ displays the number of variables not yet meeting the primary convergence criteria at each iteration. In most cases all variables meet the criteria but the ability to ignore local

convergence for small flows and depths can greatly increases the robustness of the unsteady flow analysis.

Because the affected flows and depths are small relative to the flows and depths of primary interest, the effect on the final results of these additional convergence criteria is small. Limited testing has shown that the maximum flows and stages obtained are usually the same or within the uncertainty implied by the convergence criteria.

A further increase in robustness has been obtained by implementing a small or shallow depth adjustment to the computation of the friction slope in a computational element. This adjustment was adapted from work done at SOGREAH in Franc and reported on p. 176 of *Practical Aspects of Computational River Hydraulics*, by Cunge, Holly, and Verwey. Basically at shallow depths there are two values of depth that will satisfy the governing equations and this duplicity is caused by the interaction of friction slope and conveyance. If the inertial terms are ignored, and they are usually small for shallow depths, the friction slope is given by the slope of the water surface. As the water surface slope increases the flow should increase but when the depths are small a change in water surface slope also results in a decrease in the conveyance in the algebraic equations used to approximate the flows. Eventually the decrease in conveyance causes the flow to decrease as the slope increases. Thus the solution may oscillate between the two depths and never converge. The remedy to this problem is to depart from using the arithmetic average of the conveyance at each end of the computational element as the mean conveyance in the element by using a weighted average of these end of element conveyances with the greater weight being given to the physically upstream end of the computational element. This weight can be computed so that the multiple solution problem is eliminated at shallow depths. The effect on the results is small because the depths and flows are small.

Inherent Robustness

The robustness problems that are primarily resident in the physical system itself are those relating to channel geometry, lateral inflows, and steep bottom profiles. There is of course an interaction between these two kinds of robustness problems in that an algorithmic change can sometimes reduce the significance of the inherent robustness problems. For example, the shallow depth adjustment reduces the effect of shallow depths.

Channel Geometry

Channel geometry is the most pervasive influence on robustness. We must distinguish, in so far as possible, between the channel geometry as represented by the available cross sections and the channel geometry that is actually present in the physical system. This means we have to be aware of both the precision and accuracy of the cross section measurements. In most cases the precision of the measurements is an order of magnitude greater than the accuracy, especially for elevations. With modern surveying equipment it is often no more difficult to record the elevation to the nearest hundredth of foot than to the nearest tenth of foot but a moment's reflection tells us that the elevation of a point on the bottom of a channel or flood plain has an uncertainty of more than a tenth of foot unless it is rock or concrete! Thus slavish adherence to the reported precision of the measurements can be counter productive to the goal of completing the analysis. Judicious adjustments within the estimated uncertainty of the data can sometimes increase robustness significantly. Smoothing the bottom profile is always useful and is almost mandatory if the very low flows are to be simulated.

The principal problem caused by channel geometry is the variation of this geometry longitudinally. Expansion and contraction in the size of a natural stream channel is to be expected and these changes can be surprisingly large. Changes of a factor of two in the cross sectional area at constant depth over a distance of a typical computational element are common. Of course the conveyance

also can change rapidly along the stream channel. These changes cause problems with the approximations we use in converting the integral or differential equations into algebraic equations. These approximations generally assume that the variation over a short time or distance span is linear. The error committed depends on the departure of the variation from linear and this departure is usually greater when the channel characteristics vary rapidly longitudinally.

The only practical solution to the variation of channel geometry is to reduce the length of the computational elements where the channel geometry is varying rapidly. Reduction in the element length in problem areas will generally eliminate most of the computational problems. The principal difficulty is determining where and how many additional interpolated cross sections must be added to avoid the problem. If CHKGEO=YES is used in the Run Control Block, FEQ will report areas of the channel where rapid variations are taking place. These can be used as a first estimate of the potential problem areas. However, trial and error analysis is the final method that must be used to eliminate computational problems caused by channel geometry variations.

Lateral Inflows

Extensive experiments with lateral inflows have shown that they are another rich source of computational problems in the current methods used in HIP. Currently the lateral inflows are assumed to be constant over each time interval in the hydrologic simulation. Thus if the time step of the hydrologic simulation was one hour, then the lateral inflows will be taken as constant over one hour. FEQ computes the average rate of flow over each of its time steps always exactly conserving water volume. Thus when FEQ encounters computational difficulty and reduces its time step the volume of water introduced into the stream during the time step is most likely reduced. However, most often the rate at which the water enters is not reduced.

The lateral inflows are assumed to enter at approximately right angles to the flow in the stream so that any downstream component of momentum flux from the lateral inflows can be ignored. Thus there are two effects of the incoming water: a change in the volume of water in the stream and the related change in the momentum of the water in the stream. Experimental efforts to isolated these two effects were not successful. However, some insight has been gained from using simplified cases so that they can be analyzed without resort to computation. If we assume steady flow in a frictionless, horizontal, rectangular channel with constant lateral inflow, then we find that the second derivative of depth with respect to distance along the channel is directly proportional to $(q/Q)^2$ where q = lateral inflow; and Q = flow in the channel. Thus we see that the curvature of the water surface increases rapidly as the ratio of lateral inflow to the flow in the stream increases. The algebraic governing equations that we are using will have small errors if the curvature is small. If large errors occur we cannot even be sure that the algebraic governing equations will make sense. Thus it should not be surprising to us if large errors in approximation result in failure to converge. We also see that sudden large inflows to an initially small base flow could lead to computational problems. This approximate analysis corroborates qualitatively what has been observed practically. It also shows that a reduction in time step that reduces the volume of inflow but does not reduce the lateral inflow to current flow ratio will not solve the computational problem. Thus there are three actions that will reduce the computational problems: reduce the length of the computational element, reduce the rate of lateral inflow, or increase the baseflow. The later course of action is often effective but undesirable because the results might be distorted when the base flow is greatly increased over that which is physically present. This then leaves us with the choice of decreasing the computational element length in reaches that experience high rates of inflow when the baseflow is small or to reduce the high rates of inflow.

Adding computational elements to a branch is simple using the interpolation options of FEQ but it does add to the computational effort. The option of reducing the high rates of inflow should be examined carefully because the rates of lateral inflow are not normally measured but are

computed from some hydrologic model. This model may make assumptions that cause artificially high lateral inflows leading to unnecessary computational problems. As an example, hydrologic models often assume that runoff from impervious areas directly connected to the stream system enters the stream within the time interval of the rainfall causing the runoff. This is the assumption in HSPX. This is often realistic if the impervious areas are small and are closely connected to one of the stream channels being represented in FEQ. However, if the impervious area is large or if the water originating therefrom must first flow through a storm sewer, gutter, or natural channel not represented in FEQ then the assumption of rapid entry is greatly weakened.

The lateral inflow can also be distorted by not carefully allocating the tributary area to computational elements. This must again be done physically meaningfully. If a physically unrealistic tributary area is assigned to a computational element, then computational problems can be expected. As an example, in one case of computational problems, I computed the average depth of water that would have to flow over the bank of the channel in order for the assigned amount of water to enter the channel. Water would have to have been more than one foot deep on both sides of the channel for one hour to have permitted the assigned amount of runoff to enter the stream channel. This is rather unlikely. It is more likely that a small stream or a large storm sewer discharged into the stream at this point and contributed most of the inflow.

This should be kept in mind when designing the schematic of the stream system. There will be tributaries that will not be represented as channels in the hydraulic model. However, these tributaries will contribute concentrated flow that could cause computational problems if the tributary area is assigned to one computational element. A better approach is to assign the tributary area of this tributary to a reservoir designed to approximate the time delay and attenuation that the diffuse runoff will experience as it traverses the unrepresented tributary. The concentrated inflow will then enter at a junction resulting in a much more realistic representation of the stream system and avoid the unduly large lateral inflows. The reservoir can be made linear, that is a reservoir such that $S = KQ$ where S = storage in the reservoir; Q = the outflow from the reservoir; and K = a storage constant in time units relating the storage to the outflow. The storage constant, K, can be shown to be the time difference between the centroid of the inflow and the outflow. Thus if some estimate of the time delay between peak inflow and outflow can be made this can serve as a surrogate for the time difference between centroids and therefore gives as estimate of the storage constant. A non-linear storage can be used if there is some means for defining its characteristics. However, we are not looking for a complex solution to the problem, because if we wanted that we could represent the tributary explicitly and solve the problem that way. This reservoir is only an approximation to the effect of the unrepresented flow paths and also a correction for the delays not properly included in the hydrologic model.

Steep Slopes

The robustness problems of steep slopes arises primarily from the transition between steep slopes and mild slopes. If the slopes are always steep and are never drowned from downstream, then FEQ will be able to simulate them albeit using the zero inertia assumption. The transition from supercritical flow to subcritical flow is always more or less abrupt with a concomitant loss of energy via turbulence. If the transition were confined to one region we could force a hydraulic jump at that point and solve the problem. Unfortunately, in unsteady flow the transition points are not often restricted to one region. Thus without explicitly representing the position of the moving hydraulic jump we must resort to other means to accommodate this situation.

Basically we must dissipate energy where the flow variables are changing rapidly. Thus one approach is to increase the acceleration losses to values higher than physically reasonable. This will work if the transition is not too abrupt. Another approach is to increase the roughness in the area where the transition is likely to be restricted. Both of these approaches distort physical reality

locally but we have little other recourse because the transition from supercritical to subcritical flow is not represented properly either. However, unless we are interested in the details of the location and movement of the transition, there seems little reason to complicate the computations by trying to track the moving hydraulic jump. If a means can be found, and some thinking along these lines has been done, to represent the hydraulic jump approximately, it will be implemented to reduce this problem.

Conclusions

The easiest solution to most problems of robustness is to reduce the length of the computational elements in the model. This has proved to be the most powerful and effective tool in practice. The reduction in computational element length reduces the errors in approximation. The smaller these errors the less likely that they will cause computational problems. Unfortunately, the smaller the computational element length the greater is the computer capacity required to do the analysis. Thus we are in practice, forced to strike an empirical and somewhat subjective balance among the alternatives of reducing computational element lengths, smoothing the bottom profile, raising the base flow, and reducing the peak rates of lateral inflow.

UNSTEADY FLOW SOLUTIONS

Input Description for FEQUTL: Version 2.70

Date: 5 March 1990

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INPUT DESCRIPTION FOR FEQUTL: VERSION 2.70

The input to FEQUTL consists of a command followed by one or more lines of output specific to that command. The following commands are currently available in FEQUTL:(page numbers giving details follow each command name).

BRIDGE–5: Compute the tables required for representing flow through a bridge. Based on the FHA methodology.

CRITQ–8: Computes critical flow in a given cross section on the assumption that this cross section represents a constriction to the flow. The velocity head of approach is computed from an approach cross section. The resulting flow table contains the flow as defined by critical flow at the constriction but uses the height of the water in the approach section above the low point of the critical section as the head argument. Thus in an application to FEQ, the approach cross section and the flow table would appear explicitly in the input but the constricted cross section would not because its effect is already implicit in the two tables.

CULVERT–10: Computes flow through culverts and over the associated roadway using the methods developed by the USGS and summarized in "Measurement of Peak Discharge at Culverts by Indirect Methods", Chapter A3, Book3, *Techniques of Water-Resources Investigations of the United States Geological Survey*, 1968. For brevity this publication will be referred to as USGS-Culvert below. CULVERT can only represent standard culverts and small deviations from standard culverts. Culverts with drop inlets or other special structural features that are uncommon in practice cannot be analyzed using CULVERT. Extensions to CULVERT are already planned to represent some forms of drop inlets.

EMBANKQ–19: Computes flow over embankments or other weir-like structures. Can also compute flow over weirs if the proper table are provided. Currently supports the method developed by the USGS and summarized on pp. 26–27 of "Measurement of Peak Discharge at Dams by Indirect Methods", Chapter A5, Book 3, *Techniques of Water-Resources Investigations of the United States Geological Survey*, 1967. This document is referred to as USGS-Dams below.

FEQX–22: Compute elements of a cross section and output a cross section table. Co-ordinate points on the boundary of the cross section are given in a fixed format.

FEQXLST–24: Compute elements of a cross section and output a cross section table. The co-ordinate points on the boundary of the cross section are given in a list format.

FINISH–25: Used to terminate the input to FEQUTL.

FLOODWAY–26: Inputs a table of values giving the information to be used later by FEQX or FEQXLST in defining the cross section elements for a floodway analysis.

FTABIN–30: Inputs one or more function tables in the same format as used by FEQ. Time dependent tables cannot be input because there is currently no need for them.

GRITTER–31: Solves the generalized Ritter dam break problem for the flood peak and the stage at the dam site. Useful for obtaining estimates of reasonable maximum dambreak peak flow rates.

JUMP–33: Computes a special sequent depth table for a given cross section. Not currently used by FEQ but retained in FEQUTL for possible future use.

MULCON–35: Computes the elements for one or more conduits that may be circular, box, true elliptical, nominal elliptical, or reinforced concrete arch pipe.

MULPIPES–37: Computes the elements for one or more circular sections.

ROADFLOW–39: Compute a flow table from a cross section assuming the flow is critical in the section. The head in the flow table is the head upstream of the cross section. Useful for estimating the flow over a roadway when the roadway is not horizontal.

SAME–40: Reproduce the most recent cross section with a possible shift in elevations. Sometimes useful in bridge table computations.

SEWER–41: Computes the elements for a circular section.

Each command must begin in column 1 of a line. The first 8 columns of the command line are reserved for the command but the remainder of the line may contain a comment. The input associated with a command begins on the line following the command line. The lines(cards) of input are numbered from the first line of input and not the command line in the descriptions given below. The null command, consisting of all blanks in the first eight columns of a line, may be used to add comments and blank lines to the input. These blank lines cannot appear within the input for any command. They can only appear between the end of the input for a command and the subsequent command.

Standard Header

The command names as well as the unit numbers for the three files used by FEQUTL always appear first in the input. Since these values change only when a command is added or a command name is changed, they may be copied from a previous FEQUTL input file. The name for any command can be changed by the user if so desired. For example, in the list below changing SEWER to PIPE changes the name of the command for computing the elements of a single circular section from SEWER to PIPE. In the subsequent input the PIPE command must be used to select this option.

```
STDIN=   5   Unit number for input
STDOUT=  6   Unit number for user output
STDTAB=  7   Unit number for table output
UNITS= ENGLISH   Selects measurement units
NCMD=   16   Number of commands present in FEQUTL
FEQX          1
FLOODWAY      2
BRIDGE        3
CULVERT       4
SAME          6
FINISH        5
FEQXLST       8
ROADFLOW      9
SEWER        10
MULPIPES     11
FTABIN       12
EMBANKQ      13
JUMP         14
CRITQ        15
GRITTER      16
MULCON       18
DZLIM= 1.0   Minimum depth increment in output table
NRZERO= 0.08   Minimum non-zero depth in the table
USGSBETA=NO   Selection of computation of BETA
EPSARG=4.E-5   Convergence criterion for CULVERT
EPSF=1.e-4  quad Convergence criterion for CULVERT
```

The parameters DZLIM and NRZERO are used to control the spacing of the arguments in the cross section tables. The list of arguments in a cross section table is first constructed from the unique depth values defined by the breakpoints along the boundary of the cross section. This list is then checked for an argument near zero. If none exists the value given by NRZERO is inserted as an argument. The list of arguments is also checked to ensure that the distance between successive arguments in the table is never greater than DZLIM. Both of these parameters are provided to help control the errors of interpolation in conveyance for the cross section. The near zero point is needed because the conveyance varies rapidly near zero depth and linear interpolation in the square root of conveyance at small depths is inaccurate if a near zero argument is not in the table.

The parameter USGSBETA selects the method used in computing the momentum correction coefficient, β, in cross section. If USGSBETA=NO then $\beta = 1.0$ in each subsection of the cross section. On the other hand if USGSBETA=YES then the value of β in each subsection is computed from

$$\alpha = 14.8n + 0.884$$
$$\beta = 1 + 0.3467(\alpha - 1)$$

where α = the velocity head correction factor, $1 \leq \alpha \leq 2$, and n = Manning's $n-$value. The relationship for α was taken from "Velocity-Head Coefficient in Open Channels", *Geological Survey Water Supply Paper 1869-C*, by Harry Hulsing, Winchell Smith, and Earnest D. Cobb. The relationship between β and α was

computed by linear regression using unpublished data on β from the USGS that was computed but did not appear in the named water supply paper. Only the values from the compact cross sections were used. The first relationship was subject to considerable scatter but its use was shown to greatly improve the computation of the value of α for the cross section. The second relationship is well defined by the data with a correlation of 0.996 and a standard error of estimate of 0.0066 using 87 pairs of values computed from current meter measurements in a variety of streams. Testing has revealed that USGSBETA=YES should be used with caution. An alternative that seems to have better consistency is the NEWBETA option available for most non-conduit channels. NEWBETA is discussed under command FEQX.

COMMAND NAME: BRIDGE

CARD 1

Variable: LABEL

Format: A80

Example: Bridge over Route 355

Explanation: User label to identify the bridge.

CARD 2

Variable: TYPE

Format: 5X, A8

Example: TYPE= RDFLOW

Explanation: Selects the bridge loss option. FEQ only supports the RDFLOW option and thus it is the only valid option.

CARD 3

Variable: BSCURV

Format: 12X, I5

Example: BASE CURVE#=00002

Explanation: Gives the base curve number for the backwater coefficient in the FHA procedure from Figure 6 in **Hydraulics of Bridge Waterways** from the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, 1970. The curves are numbered for purposes of identification from lower left to upper right. The range of curve numbers is from 1 to 3.

CARD 4

Variable: ABTYPE

Format: 19X, I5

Example: ABUTMENT ALIGNMENT= 0

Explanation: Specifies the alignment of the abutments relative to the flow through the bridge opening. If ABTYPE = 0, the abutment faces are parallel to the flow and if ABTYPE = 1, the abutment faces are not parallel to the flow.

CARD 5

Variable: BSKEW

Format: 12X, F10.0

Example: BRIDGE SKEW= 0.0

Explanation: Gives the bridge skew in degrees. A bridge at right angles to the flow has a skew of 0.0.

CARD 6

Variable: ADJFAC

Format: 18X, F10.0

Example: ADJUSTMENT FACTOR= 1.0

Explanation: Provides for adjustment of the computed loss for the bridge. Normally has value of 1.0

CARD 7

Variable: CNTRU

Format: 16X, F10.0

Example: UPSTREAM OFFSET= 50.5

Explanation: Establishes the location of the center of the bridge opening in the cross section upstream of the bridge. For, example, if the center of the bridge opening is immediately downstream of offset 50.5 in

the description of the upstream cross section then the upstream offset is 50.5. This information is needed to compute the bridge opening ratio as outlined in the BPR bridge backwater procedure.

CARD 8

Variable: CNTRD

Format: 18X, F10.0

Example: DOWNSTREAM OFFSET= 35.5

Explanation: Same definition as for CNTRU but for the cross section downstream of the bridge.

CARD 9

Variable: PTYPE

Format: 10X, I5

Example: PIER TYPE= 1

Explanation: Indicates presence of piers and the type of pier. If PTYPE = 0 then no piers are present in the bridge opening. Otherwise if $1 \leq$ PTYPE ≤ 8, then piers of the given type are present in the bridge opening. The type number is defined by numbering the curves in Figure 7 of **Hydraulics of Bridge Waterways** from the lower right to the upper left.

If PTYPE > 0, then the pier description must be given using the following cards. Otherwise skip to Card 15.

CARD 10

Variable: PLEN

Format: 12X, F10.0

Example: PLEN= 50.0

Explanation: Gives the length of the pier. Used only if the piers are skewed with respect to the flow.

CARD 11

Variable: PSKEW

Format: 10X, F10.0

Example: PSKEW= 0.0

Explanation: Provides value of pier skew in degrees, where skew is 0.0 if the pier is parallel to the flow direction through the bridge opening.

CARD 12

Variable: HEAD

Format: A80

Example: PIER TABLE FOR ROUTE 355 BRIDGE

Explanation: Descriptive heading for the pier table.

CARD 13

Variable: HEAD

Format: A80

Example: HEIGHT NUMB WIDTH

Explanation: Headings for the pier description table.

CARD 14

Variables: PZ(i), PNUM(i), PWIDTH(i)

Format: F10.0, I5, F10.0

Explanation: In a bridge opening it is possible that there are several piers across the opening. These piers will not all start at the same elevation. We need to know the total width of the piers in the opening as a function of the height above the minimum point in the bridge opening. Thus at each change in total

pier width we need a line in the pier table. The value PZ(i) gives the height above the minimum point in the bridge opening at which the number of piers, given by PNUM(i) exist, with the average width given by PWIDTH(i). The end of the table is signaled by a final line with a negative pier width. Card 14 is repeated as needed to describe the variation of pier width in the bridge opening with respect to height above the minimum point in the opening.

CARD 15

Explanation: Card 15 is the start of the description of the bridge opening using the same format as for FEQX. Card 15 should be the table number for the bridge opening cross section followed by the cards required to describe the perimeter of the bridge opening.

CARD 16

Variable: HEAD

Format: A80

Example: NUMBER FOR HEAD LOSS TABLE

Explanation: Descriptive heading for the following table number.

CARD 17

Variable: TAB

Format: 7X, I5

Example: TABLE#= 5

Explanation: Gives the table number to use for the bridge head loss table.

Note: The computation of bridge losses assumes the presence of upstream and downstream cross section. These must be defined before the bridge losses can be computed. The order of input defines these cross sections. The order of entry is as follows: downstream cross section, upstream cross section, bridge loss computation.

COMMAND NAME: CRITQ

The flow and head in the flow table are computed as follows: For each non-zero depth entry in the cross section table for the constricted section compute the critical flow rate as

$$Q_c = A_c\sqrt{gA_c/T_c} \qquad \text{(CRITQ–1)}$$

where Q_c = the critical flow rate at critical depth, y_c; g = acceleration due to gravity; A_c = the flow area at critical depth; and T_c = top width of the water surface at critical depth. Note that no account is taken of the non-uniform distribution of velocity. Thus the critical flow computations are only applicable to compact cross sections.

Given the critical flow rate at each depth in the constricted section compute the depth that would have to exist in the approach cross section to produce this flow by applying an energy balance between the approach section and the constricted section. That is solve

$$z_a + y_a + \frac{Q_c^2}{2gA_a^2} = z_c + y_c + \frac{Q_c^2}{2gC_d^2A_c^2} \qquad \text{(CRITQ–2)}$$

for y_a. Here z_a and z_c give the bottom elevations of the approach and constricted section respectively. The approaching flow must be subcritical for a meaningful solution to exist. FEQUTL seeks a subcritical solution and will report an error if it thinks no subcritical solution exists. A subcritical solution will exist if the constricted section is actually restrictive at all depths. The computational procedure uses the depth entries in the constricted flow table to define the number and spacing of the entries in the critical flow table. The DZLIM value used in computing the constricted cross section table can be used to vary minimum spacing for this table to produce a spacing that will be suitable for the constricted flow table.

CARD 1

Variables: TABLE, SAVEIT

Format: 7X, I5, 1X, A4

Example: TABLE#= 9900 SAVE

Explanation: Gives table number for the table to be computed by FEQUTL. The user has the option of saving the resulting table internally within FEQUTL so that the table can be referenced for use in later commands. If the SAVE option is omitted FEQUTL does not save the table and it cannot be referenced in later commands.

CARD 2

Variables: NAME, APPTAB

Format: A8, I5

Example: APPTAB#= 25

Explanation: Gives the table number for the cross section table describing the shape of the channel conveying water to the critical section. This is called the approach cross section or just the approach section. The bottom elevation of the approach cross section cannot be higher than the bottom elevation of the critical section. The elevations of the bottom of each cross section are taken from the elevation entry in the cross section table.

CARD 3

Variables: NAME, CONTAB

Format: A8, I5

Example: CONTAB#= 29

Explanation: Gives the table number for cross section table defining the cross section at which critical flow is assumed to be present. The bottom of the constricted cross section must be at or above the elevation of the approach section. The elevations are taken from the elevation entry in the heading of the cross section table. The constricted cross section must not be larger than the approach cross section. However,

it can be the same shape and size. If the same table number is used for both the approach and the constricted section FEQUTL will complain that the cross section is not high enough. This occurs because FEQUTL computes an entry in the critical flow table for each entry in the constricted section. The water surface elevation required in the approach section to produce critical flow in the constricted section is always higher than the water surface elevation in the constricted section. Therefore the computations for the depth in the approach section must overtop the cross section table when computing the larger depth values in the critical section. Extending the cross section table does not help the problem because this also causes the computations for critical flow to go to higher depths! The solution is to copy the cross section table in the input to FTABIN and change the table number and then extend this copy to a value high enough to avoid the table overflow problem.

CARD 4

Variables: NAME, CD

Format: A8, I5

Example: DISCOEF= 0.95

Explanation: Gives the discharge coefficient for the opening. Since the flow is critical and the opening is at least as efficient as a square edged box culvert, coefficients close to 0.95 are likely reasonable. The discharge coefficient applies to the flow in the constricted section.

CARD 5

Variable: LABEL

Format: A50

Example: Flow at partial failure of Upper Baker Dam.

Explanation: Gives up to a 50 character long label that will appear to the left of the column headings in the constricted flow table produced by CRITQ.

COMMAND NAME: CULVERT

CARD 1

Variable: TABLE

Format: 7X, I5

Example: TABLE#= 9900

Explanation: Gives table number of the table culvert flow table to be computed by FEQUTL.

CARD 2

Variable: CHAR4, TABTYP

Format: A4, 1X, I5

Example: TYPE= 6

Explanation: Specifies the table type. Type 6 is the currently supported in FEQ. Type 5 is supported by FEQUTL but is not yet supported by FEQ(Version 6.0). Both contain the same information but Type 5 is more compact and reduces storage space significantly

CARD 3

Variable: CHAR6, LABEL

Format: A5, 1X, A50

Example: LABEL= Twin barrel 54 inch culvert at El Monte Road

Explanation: Gives a user defined label that will appear in the table for identification purposes.

CARD 4

Variable: HEAD

Format: A80

Example: Approach Section Data

Explanation: Sub-heading to break the input into logical components. Heading may be anything but it should describe the data that follows.

CARD 5

Variable: CHAR6, APPTAB

Format: A6, 2X, I5

Example: APPTAB#= 342

Explanation: Gives the table number for the cross section table giving the description of the approach section for the culvert. This table must have been input by FTABIN or have been computed with the SAVE option in this input. Furthermore, this table must be of TYPE 12, a new table type for cross section descriptions introduced in Version 2.7 of FEQUTL.

CARD 6

Variable: CHAR6, APPELV

Format: A6, 1X, F10.0

Example: APPELV= 723.10

Explanation: Supplies the elevation of minimum point of the cross section given in APPTAB. This elevation should match the bottom profile elevation at the downstream end of the branch upstream of the culvert in the FEQ input.

CARD 7

Variable: CHAR6, APPLEN

Format: A6, 1X, F10.0

Example: APPLEN= 24.0

Explanation: Gives the distance between the approach cross section and the entrance to the culvert. This

distance should be about the same as the opening width of the culvert. USGS-Culvert indicates that this distance should vary slightly depending on the headwater elevation and the nature of the culvert opening. These refinements have not been included but could be included as an option if they are found to be important.

CARD 8

Variable: CHAR6, APPLOS

Format: A6, 1X, F10.0

Example: APPLOS= 0.1

Explanation: Gives the hydraulic energy loss caused by special approach conditions in terms of the fraction of the velocity head in the approach cross section. Normally is 0 but can be used to approximate the losses caused by trash racks, right angle bends upstream of the culvert entrance, *etc.*

CARD 9

Variable: CHAR6, APPEXP

Format: A6, 1X, F10.0

Example: APPEXP= 0.5

Explanation: Gives a coefficient to be applied to the difference between the approach velocity head and the velocity head in the culvert entrance should the culvert provide an expansion in flow area instead of a contraction in flow area. All known culvert loss descriptions assume that the culvert causes a contraction in the available flow area. At high flows this is often the case. However, at low and moderate flows, culverts can provide a greater flow area than the approaching channel. The equations used for the loss computations, assuming a contraction of flow, fail computationally if there is no contraction in flow. Therefore, CULVERT checks for an expansion in flow in the approach to the culvert entrance and then applies the loss coefficient given by APPEXP to represent the loss of hydraulic energy occurring in the expansion. The discharge coefficient for the entrance loss for the culvert is set to the USGS maximum value for no contraction, 0.98.

CARD 10

Variable: HEAD

Format: A80

Example: Culvert Description

Explanation: Provides sub-heading for the culvert cross section, elevation, and length description.

CARD 11

Variables: CHAR6, NODEID

Format: A6, 1X, A4

Explanation: The culvert description is the same as the description of a branch with some options deleted. Thus the option exists to include an identifying string for each node along the culvert. At a minimum, each culvert will have two nodes: one at the entrance, and the other at the exit of the culvert. However, more nodes may be needed if the culvert changes shape or slope along its course. Also, additional nodes may be needed to compute the flow through the culvert. If NODEID is YES then identifying strings are present and otherwise they are omitted. NODEID=YES is recommended because NODEID=NO will be removed in the future.

CARD 12

Variable: CHAR4, SFAC

Format: A4, 1X, F10.0

Example: SFAC= 1.0

Explanation: Gives the multiplying factor to use in converting the stations in the input to distances in feet as required by FEQUTL.

CARD 13

Variable: HEAD

Format: A80

Example: NODE XNUM STATION ELEVATION KA KD HTAB AZM CF YC STD

Explanation: Gives user definable heading to describe the information on subsequent cards.

CARD 14

If NODEID=NO then

Variables: NODE, XTAB, X, Z, CA, CD, HL

Format: 2I5, 2F10.0, 2F5.0, I5

If NODEID=YES then

Variables: NODE, NAME, XTAB, X, Z, CA, CD, HL

Format: I5, 1X, A8, 1X, I5, 2F10.0, 2F5.0, I5

Explanation: Gives the values describing each node on a culvert where NODE = node number on the current culvert; NAME = the identification string for the node; XTAB = number of the table giving the elements of the cross section at the node; X = station of the node; Z = elevation of the minimum point in the stream at the node; CA = loss factor to apply to differential velocity head in the computational element upstream of the node when the flow is accelerating with respect to distance; CD = loss factor to apply to differential velocity head in the computational element upstream of the node when the flow is decelerating with respect to distance; and HL = number of table giving factor to apply to the mean velocity head in the element as an estimate of point losses. Note: CA, CD, and HL area not currently implemented(Version 2.70).

Card 13 is repeated as needed for each node on the culvert. Not all the values need be given for each node. The required values that must be defined either explicitly by the user or implicitly by FEQUTL following user directions are the node number, the cross section table number, the station, and the elevation of the bottom profile. The other fields on the line can be left blank if the feature is not needed in the analysis.

The end of a culvert description is indicated by giving a negative value for the NODE entry. The remainder of the card containing the terminating node number may be blank. The number for the first node on each branch must be given. The NODE column may be left blank for the other nodes and FEQUTL will compute the node number. If node numbers are given they must be consecutive and increasing. The first node appearing in the table is taken to be the entrance to the culvert.

A culvert may be too long to compute a steady flow profile using cross sections at its entrance and exit only. Thus additional nodes and cross sections must be added to reduce the length of one or more computational elements. FEQUTL offers two methods for adding intermediate cross sections. The first method is simple propagation of the last known cross section at equal station intervals and with linear interpolation for the profile elevation. This method is requested by leaving one or more blank lines in the branch table input. There must be a line of complete information above the blank lines and a line of complete information below the blank lines. The upstream table number is assigned to each blank line and the stations and elevations are distributed uniformly between the two lines of known values. The second method uses linear interpolation of cross section characteristics between two known cross sections. This method is selected by giving a negative table number for the cross section table or more conveniently merely giving a minus sign in the right most column of the field for the table number. FEQ will then select an available table number and supply it at the proper time. This avoids the problem of trying to remember which table numbers are available for interpolated cross sections. If the station and elevation values are given they will be used. If they are omitted FEQ will distribute the station values uniformly and interpolate linearly for the elevation. The first method should only be used if the channel is prismatic over the interval of addition of cross sections. The second method should be used when the channel characteristics vary over the interval between the known cross sections.

Another interpolation feature for cross sections involves the computation of bottom profile elevations when the location of the cross section is known. This occurs when cross sections have been measured at some time in the past and the bottom profile has changed but only sparse information on the changes is available

either by measurement or by estimation. The cross section data is then adjusted using some rule, usually linear interpolation between points of known or estimated bottom profile elevation. Since the bottom profile in the adjusted cross sections varies in a piecewise linear fashion, it proves useful to have FEQUTL do the linear interpolations between points with known bottom profile elevation also. This can save much typing and reduces the chance for mistakes. The elevation of the bottom profile at the first and last node on the branch together with the corresponding stations must always be given. None of these values can be 0.0 because FEQUTL interprets an exact zero as a request for interpolation. If per chance an elevation or station is 0.0 it can be changed to some small non-zero value with insignificant effect on the profile. With these first and last values given, FEQUTL first finds the bottom profile elevations at the nodes for which non-zero station values were given and for which the bottom profile elevation field was left blank. Then the station and the bottom profile elevation for the nodes for which both the station and the bottom profile elevation were left blank are computed.

All cross sections given in the culvert description must be of table type 12 and must have a vertical slot so that there is always a free surface.

CARD 15

Variable: CHAR6, CULCLS

Format: A6, 1X, A8

Example: CULCLS= BOX

Explanation: Gives the general class of the culvert for the purposes of selecting the discharge coefficient. Note that the culvert class does not determine the shape of the culvert. Thus if an irregular shaped culvert is judged to be best described as a box culvert for the purpose of determining its hydraulic characteristics, then the culvert class should be given as BOX even though the culvert is not strictly a box culvert. The available options are: BOX, PIPE, MITER, RCPTG. BOX- box culverts, PIPE- circular, elliptical, arch pipes, MITER- mitered entrance for pipe culverts, RCPTG- reinforced concrete pipe with machine tongue-and-groove construction and also pipes with commercially flared entrances.

CARD 16

Variable: HEAD

Format: A80

Example: Departure Section Description

Explanation: Sub-heading for the departure section data that follows.

CARD 17

Variable: CHAR6, DEPTAB, BEGTAB, RMFFAC

Format: A6, 1X, I5, A5, A5

Example: DEPTAB#= 341

Explanation: Gives the table number of the cross section table describing the departure section for the culvert. This section represents the stream cross section where the flow concentration caused by the culvert in the downstream flow has essentially dissipated. An optional table number for the cross section table describing the departure reach at the exit from the culvert can also be given. The final optional entry, RMFFAC, gives a multiplying factor on the estimated momentum flux over the roadway. If omitted the value for BEGTAB is set to the value of DEPTAB and RMFFAC is 1.0.

CARD 18

Variable: CHAR6, DEPELV, BEGELV, DSFFAC, WIDFAC

Format: A6, 1X, F10.0, A10, A5, A5

Example: DEPELV= 629.05

Explanation: Gives the elevation of the bottom of the departure section. This elevation must should the elevation of the bottom profile of the upstream end of the branch downstream of the culvert in the FEQ input. The value of BEGELV gives the elevation of the bottom of the beginning cross section for the departure reach. DSFFAC is a loss coefficient applied to the difference in velocity head between the

culvert exit and the departure section to force additional losses in the departure reach, and WIDFAC is a width factor for checking the beginning cross section of the departure reach. The beginning elevation, if omitted, is set as follows: if DEPELV > culvert exit invert elevation then BEGELV is set to the culvert exit invert elevation; otherwise FEQUTL sets BEGELV to the same elevation as DEPELV. The default value for DSFFAC is 0.0 and for WIDFAC is 1.10.

WIDFAC is used to check the validity of BEGTAB. BEGTAB, representing the cross section of the departure reach at the culvert exit, must always be at least a factor of WIDFAC wider than the culvert exit. FEQUTL checks at each tabulated level in the cross section table for the culvert barrel and if the test fails at any level, FEQUTL rejects the cross section in BEGTAB and generates a rectangular section that does satisfy the requirement. This rectangular section has the same base elevation as BEGTAB.

CARD 19

Variable: CHAR6, LOSOPT, VHFAC

Format: A6, 1X, A8, F10.0

Example: LOSOPT=ENERGY 0.7

Explanation: Gives the loss option he expansion of the flow into the departure reach. Note that the USGS procedure for culvert flow in es in the culvert losses only the losses caused by contraction and subsequent expansion in the culver rrel. The two-dimensional flow tables in FEQ must include the expansion losses in the departure reach as well.

Two loss options exist in CULVERT. The first, ENERGY, uses the hydraulic energy relationship to relate the flow at the exit of the culvert to the flow in the departure reach. The value of VHFAC is the coefficient used as a multiplier on the difference in velocity heads between the exit and the departure section to estimate the hydraulic energy losses due to the expanding flow in the departure reach. The second loss option, MOMENTUM, uses a simple momentum balance in the departure reach to estimate the losses in the expanding flow. The momentum flux of the jet of water exiting the culvert is isolated from the momentum flux that may be contributed by flow over the roadway. If the conditions are suitable this option gives the best representation of the expansion losses. The momentum option is most applicable when the departure reach is approximately prismatic and horizontal. Note: Loss option ENERGY is not yet available in Version 2.7.

The momentum option can also approximate the effect of an abrupt drop or step at the exit of the culvert. In this case the departure section elevation should give the elevation of the bottom of the drop. This analysis assumes that the pressure distribution on the face of the step is hydrostatic and that the pressure is given by the depth of water above the base of the step.

CARD 20

Variable: CHAR6, DEPCON

Format: A6, 1X, F10.0

Example: DEPCON= 0.3

Explanation: The loss options for the departure section assume that the flow will expand upon leaving the culvert. However, this is not always the case at all flows encountered in the analysis. If a contraction in flow occurs CULVERT will assume that DEPCON gives the portion of the velocity head difference to be assigned to loss of hydraulic energy. Not currently implemented in Version 2.7. Thus it does not appear in the input but will appear at this relative location when implemented.

CARD 21

Variable: HEAD

Format: A80

Example: Discharge Coefficient Data

Explanation: Sub-heading for discharge coefficient information. The selection of the discharg efficient involves several factors. Some of these factors are purely geometric and are not changed by ne depth or flow of water in the culvert. Some of the factors are hydraulic and depend on the depth or flow of water. Consequently, some discharge coefficients are determined by geometric factors alone and some

are determined by a combination of geometric and hydraulic factors. In order to allow for the greatest flexibility and to simplify the input for CULVERT the discharge coefficients dependent on hydraulic factors are determined internally. Discharge factors and adjustment factors that depend on geometry only must be supplied in the input.

CARD 22

Variable: CHAR3, KRB

Format: A3, 1X, F10.0

Example: KRB= 1.05

Explanation: Multiplying factor to adjust base discharge coefficient for flow types 1, 2, and 3 for the effect of rounding or beveling of the entrance to the culvert. The base coefficient is selected based on the culvert class. Figure 20(all references to figures here are to USGS-Culvert given above) is selected if the class is PIPE and Figure 23 is selected if the class is BOX. KRB is taken from either Figure 21 or Figure 22 depending whether rounding or beveling is present at the entrance of the culvert.

CARD 23

Variable: CHAR5, KWING

Format: A5, 1X, F10.0

Example: KWING= 1.10

Explanation: Gives the adjustment factor for the effect of wingwalls on the discharge coefficient for flow types 1, 2, and 3 when wingwalls are present for box culverts. Values are given in Figure 24. Note that wingwalls do note change the discharge coefficient for a pipe culvert set flush with a vertical headwall.

CARD 24

Variable: CHAR5, KPROJ

Format: A5, 1X, F10.0

Example: KPROJ= 0.96

Explanation: Gives the effect for projecting entrances for flow types 1, 2, and 3. See page 41 and 42 of the USGS-Culvert.

CARD 25

Variable: CHAR3, C46

Format: A3, 1X, F10.0

Example: C46= 0.85

Explanation: Gives the discharge coefficient for type 4 and 6 flow. This coefficient is purely a function of geometry and must therefore contain all the adjustments for wingwalls, projecting entrance, rounding, beveling, *etc.* discussed on pages 42 and 43 of USGS-Culvert.

CARD 26

Variable: HEAD

Format: A80

Example: Roadway Description

Explanation: Sub-heading for roadway description. Much the same format as used in EMBANKQ is used here.

CARD 27

Variable: TAB(1)

Format: 7X, I5

Example: PLCWTB= 9994

Explanation: Gives the table number for the function table giving the paved low-head weir coefficient in the USGS procedure for computing flow over embankment shaped weirs.

CARD 28

Variable: TAB(2)

Format: 7X, I5

Example: GLCWTB= 9995

Explanation: Gives the table number for the function table giving the gravelled low-head weir coefficient in the USGS procedure for computing flow over embankment shaped weirs.

CARD 29

Variable: TAB(3)

Format: 7X, I5

Example: PHCWTB= 9996

Explanation: Gives the table number for the function table giving the paved high-head weir coefficient in the USGS procedure for computing flow over embankment shaped weirs.

CARD 30

Variable: TAB(4)

Format: 7X, I5

Example: GHCWTB= 9997

Explanation: Gives the table number for the function table giving the gravelled high-head weir coefficient in the USGS procedure for computing flow over embankment shaped weirs.

CARD 31

Variable: TAB(5)

Format: 7X, I5

Example: PSUBTB= 9998

Explanation: Gives the table number for the function table giving the submergence correction factor for the paved weir surface.

CARD 32

Variable: TAB(6)

Format: 7X, I5

Example: GSUBTB= 9998

Explanation: Gives the table number for the function table giving the submergence correction factor for the gravelled weir surface.

CARD 33

Variable: HEAD

Format: A80

Example: OFFSET CREST WIDTH APPROACH SURFACE

Explanation: Gives heading for subsequent columns of input.

CARD 34

Variables: OFF(I), CREST(I), WIDTH(I), APPROC(I), SURF(I)

Format: 4F10.0, 1X, A8

Explanation: These values define the crest of the weir used in computing the flow by giving the horizontal offset(OFF), the crest elevation(CREST), the width of the crest in the direction of flow(WIDTH), the elevation of the approach channel(APPROC), and the nature of the surface(SURF). The variation of the crest elevation, crest width, and approach channel elevation is assumed to be linear between the given points on the crest. The nature of the surface is given by SURF and the designation applies to the line segment beginning at the offset for which the surface nature is given. For example, if the first line of the weir crest specification gives the nature of the surface as GRAVEL and the second line of the weir crest specification gives the nature of the surface as PAVED then the weir crest between the first and second offset is taken to be of a roughness similar to a gravelled roadway. The end of the weir specification is indicated by giving END for the nature of the surface. Thus if the third line of the input had END for the nature of the surface, then the weir crest between the second and third offset would be taken to be of a roughness similar to a paved roadway.

If the approach velocity is to be ignored then supply an approach elevation that is much lower than the crest elevation so that the computed velocity head will be very small. To make input easier the values for width, approach channel, and surface propagate downward into fields left blank. Thus if the elevation of the approach channel is constant and the width is constant, only the first line of the specification need contain the elevation of the channel and the width of the weir crest. The surface value also propagates so that for constant surface only the first line need have PAVED or GRAVEL. The final line of the specification then has the END to indicate the end of the specification.

CARD 35

Variable: HEAD

Format: A80

Example: Head Sequence Definition

Explanation: Parameters defining the sequence of upstream heads and the distribution of the partial free drops used to define the downstream heads for the two-dimensional table.

CARD 36

Variable: CHAR5, NFRAC

Format: A5, 1X, I5

Example: NFRAC= 11

Explanation: Number of partial free drops used in computing the table. The partial free drops vary from 0 to 1. Thus the first partial free drop is no drop at all and the final partial free drop is not partial because it is the complete free drop.

CARD 37

Variable: CHAR6, POWER

Format: A6, 1X, F10.0

Example: POWER= 2.5

Explanation: Gives the power used to distribute the proportion of free drop from a value of 0 to 1. The proportion of free drop is given by

$$P_i = (i-1)/(NFRAC-1)^{POWER}$$

for $i = 1, \cdots, NFRAC$.

CARD 38

Variable: HUVEC(I)

Format: F10.0

Example: 2.0

Explanation: Gives the upstream heads to use. Card 37 is repeated as many times as needed to read the ascending sequence of upstream heads. The input of the list is terminated when a negative head is

encountered.

Note: The CULVERT command has not been extensively tested. Thus it should be used with caution until it has undergone additional testing.

COMMAND NAME: EMBANKQ

CARD 1

Variable: TABLE, TYPE, HLCRIT, HLMAX

Format: 7X, I5, I5, A5, A5

Example: TABLE#= 9900

Explanation: Gives table number for the table to be computed by FEQUTL and several optional parameters. TYPE can be either 5 or 6 with 6 taken by default if TYPE is omitted. Type 5 tables are supported by FEQUTL but not yet supported in FEQ. HLCRIT gives the critical ratio between approach head and embankment width that distinguishes between low head and high head flow. Ratios less than HLCRIT are taken to be low head flow and ratios at or greater than HLCRIT are taken to be high head flow. HLMAX gives the maximum ratio of approach head to embankment width that can be used without generating a warning message from EMBANKQ. This warning message alerts the user to the possibility that the weir coefficients may no longer be valid at head ratios greater than HLMAX. If omitted HLCRIT defaults to 0.15 and HLMAX to 0.32, the values derived from the USGS-Dams

CARD 2

Variable: TAB(1)

Format: 7X, I5

Example: PLCWTB= 9994

Explanation: Gives the table number for the function table giving the paved low-head weir coefficient in the USGS procedure for computing flow over embankment shaped weirs.

CARD 3

Variable: TAB(2)

Format: 7X, I5

Example: GLCWTB= 9995

Explanation: Gives the table number for the function table giving the gravelled low-head weir coefficient in the USGS procedure for computing flow over embankment shaped weirs.

CARD 4

Variable: TAB(3)

Format: 7X, I5

Example: PHCWTB= 9996

Explanation: Gives the table number for the function table giving the paved high-head weir coefficient in the USGS procedure for computing flow over embankment shaped weirs.

CARD 5

Variable: TAB(4)

Format: 7X, I5

Example: GHCWTB= 9997

Explanation: Gives the table number for the function table giving the gravelled high-head weir coefficient in the USGS procedure for computing flow over embankment shaped weirs.

CARD 6

Variable: TAB(5)

Format: 7X, I5

Example: PSUBTB= 9998

Explanation: Gives the table number for the function table giving the submergence correction factor for the paved weir surface.

CARD 7

Variable: TAB(6)

Format: 7X, I5

Example: GSUBTB= 9998

Explanation: Gives the table number for the function table giving the submergence correction factor for the gravelled weir surface. If PSUBTB and GSUBTB are given as zero then no submergence computations are done and the resulting function table will be Type 2. If they are non-zero then submergence computations are done and the resulting function table will be Type 6.

CARD 8

Variable: LABEL

Format: 6X, A80

Example: LABEL=FLOW OVER BUTTERFIELD ROAD AT DRY CREEK

Explanation: Specifies user supplied label that will be output as part of the heading for the table produced by FEQUTL.

CARD 9

Variable: HEAD

Format: A80

Example: OFFSET CREST WIDTH APPROACH SURFACE

Explanation: Gives heading for subsequent columns of input.

CARD 10

Variables: OFF(I), CREST(I), WIDTH(I), APPROC(I), SURF(I)

Format: 4F10.0, 1X, A8

Explanation: These values define the crest of the weir used in computing the flow by giving the horizontal offset(OFF), the crest elevation(CREST), the width of the crest in the direction of flow(WIDTH), the elevation of the approach channel(APPROC), and the nature of the surface(SURF). The variation of the crest elevation, crest width, and approach channel elevation is assumed to be linear between the given points on the crest. The nature of the surface is given by SURF and the designation applies to the line segment beginning at the offset for which the surface nature is given. For example, if the first line of the weir crest specification gives the nature of the surface as GRAVEL and the second line of the weir crest specification gives the nature of the surface as PAVED then the weir crest between the first and second offset is taken to be of a roughness similar to a gravelled roadway. The end of the weir specification is indicated by giving END for the nature of the surface. Thus if the third line of the input had END for the nature of the surface, then the weir crest between the second and third offset would be taken to be of a roughness similar to a paved roadway.

If the approach velocity is to be ignored then supply an approach elevation that is much lower than the crest elevation so that the velocity head computed will be very small. To make input easier the values for width, approach channel, and surface propagate downward into fields left blank. Thus if the elevation of the approach channel is constant and the width is constant, only the first line of the specification need contain the elevation of the channel and the width of the weir crest. The surface value also propagates so that for constant surface only the first line need have PAVED or GRAVEL. The final line of the specification then has the END to indicate the end of the specification.

CARD 11

Variable: HEAD

Format: A80

Example: UPSTREAM HEADS TO USE IN COMPUTING THE TABLE

Explanation: Gives heading for subsequent column of input.

CARD 12

Variable: HUVEC(*)

Format: F10.0

Explanation: Gives the upstream head values to use in computing the table. The heads should be positive and strictly increasing. The end of head input is signaled by a negative value for head. The heads given here will be the heads that appear in the table. It is the user's responsibility to choose the spacing that is appropriate to nature of the problem. Generally the spacing should be small for the small heads and larger for the large heads. A spacing of 0.1 foot or even 0.01 foot may be needed to define the low range of the table if the range of heads is small. Generally no more than about 20 subdivisions should be used to represent the range of heads expected. More subdivisions can be used but at the expense of larger tables.

Notes: In the USGS procedure the relationship between the weir coefficient and the head on the weir is broken into two classes: low head and high head. The low head relationship is a function of the head on the crest and applies for heads less than 0.15 of the width of the crest. The high head relationship is defined as a function of the ratio of head to crest width. Different relationships are presented for gravelled and paved highways.

The flow over the weir is computed by using numerical integration to include the effect of the variation of head on the crest caused by the typical non-horizontal roadway crest. FEQUTL determines the portion of the weir crest that is submerged for each of the heads supplied by the user. The flow per unit length is computed for the ends and the midpoint of each line segment of the submerged portion of the weir. The total flow for each segment is then computed by using Simpson's rule to approximate the value of the integral of flow per unit length with respect to crest length. This procedure then takes into account both the variation of upstream head as well as the variation of the downstream head. In order to avoid integration errors additional intermediate points should be inserted if the difference in elevation from one end of a line segment to the other end is greater than about 2 feet.

COMMAND NAME: FEQX

CARD 1

Variable: TAB, CIN

Format: 7X, I5, A50

Example: TABLE#=00025 MONOTONE SAVE1

Explanation: Gives the table number that will be used to identify the cross section table computed from the cross section defined here. The user may specify several options after the table number. The options are as follows:

MONOTONE: FEQUTL checks to make sure that the offsets for the cross section are strictly increasing. This is useful in preliminary checking of cross sections for natural streams.

SAVE1: Requests that FEQUTL retain an internal copy of the resulting table in the Type 1 format.

SAVE12: Requests that FEQUTL retain an internal copy of the resulting table in the Type 12 format. Currently only the CULVERT command requires this format.

SAVE: Same as SAVE1. Included to be consistent with previous versions.

NOSAVE: Requests that FEQUTL not retain a copy of the table. This is the default action if none of the save options are given.

OUT1: Requests that FEQUTL output a copy of the table to the standard table file in the Type 1 format. This is the default option if none of the output options are given.

OUT12: Requests that FEQUTL output a copy of the table to the standard table file in the Type 12 format.

NEWBETA: Requests the computation of the momentum flux correction coefficient, β, and the kinetic energy flux correction coefficient, α, using a method suggested by J. C. Schönfeld, "Propagation of tides and similar waves", *Thesis*, Technical University, Delft, The Netherlands, 1951. This method integrates the depth averaged velocities in the cross section as computed by locally applying Manning's equation at each point across the cross section. This estimates the variation of velocity across the section but ignores the variation of velocity in the vertical. Preliminary testing shows that this method produces greater consistency between critical flow estimates than does the use of USGSBETA and the traditional subsection conveyance estimation methods used in FEQX.

NEWBETA can only be used for cross sections that do not have any converging boundary. Thus NEWBETA implies checking for monotonicity.

NOOUT: Suppresses output of the table to the standard table file.

CARD 2

Variables: STAT, LEFT, RIGHT

Format: 8X, F10.0, 6X, F10.0, 7X, F10.0

Example: STATION= 8.256 LEFT= 100.0 RIGHT= 967.

Explanation: Gives the station of the cross section and the left and right truncation points for the cross section. The station is used for identification only. The right and left truncation points indicate the offsets at which a vertical frictionless wall is to be assumed in computing the cross section. Thus encroachments on the cross section can be indicated without changing the cross section. If LEFT $\geq$ RIGHT, then the encroachments are not calculated. LEFT = RIGHT by default if the input is omitted.

CARD 3

Variables: NAVM, SCALE, SHIFT

Format: 5X, I5, 7X, F10.0, 7X, F10.0

Example: NAVM=00001 SCALE= 1.0 SHIFT= 0.2

Explanation: Selects the methodology for computing the effective roughness of a compound cross section and also provides optional values for scaling of the offsets and shifting of the elevations. If NAVM= 0, FEQUTL computes the total conveyance from the sum of the subsection conveyances. This is the method

of choice for most open channels. If NAVM=1, FEQUTL computes a weighted Manning's n value using the wetted perimeter in each subsection as the weight. Then the conveyance for the cross section is computed using the weighted average n value. This is the method of choice for closed conduits having abrupt variation of roughness around their perimeter.

The value of SCALE multiplies the offsets and can be used to adjust for scaled measurements from a map. The value of SHIFT is added to elevation of each point on the boundary of the cross section. If omitted, SCALE = 1.0 and SHIFT = 0.0.

CARD 4

Variables: NSUB, N(1),...,N(NSUB)

Format: 4X, I5, 6F10.0,/,(9X, 6F10.0)

Example: NSUB 3 0.03 0.02 0.04

Explanation: Specifies the number of subsections and the Manning's n for each subsection for the cross section. The valid range for NSUB is from 1 to 18. The divisions between subsections are defined by frictionless vertical lines.

CARD 5

Variable: HEAD

Format: A80

Example: OFFSET ELEVATION SUB

Explanation: Gives user definable heading to describe the information on subsequent cards.

CARD 6

Variables: X(i), Z(i), SB(i)

Explanation: Specifies the offset, elevation, and subsection number for the i-th co-ordinate point on the boundary of the cross section. The boundary is assumed to be adequately defined by connecting these co-ordinate points by straight lines. Card 6 is repeated for each point on the boundary. The last point on the cross section boundary is indicated by a subsection number of -1. This convention means that the subsection number for a point applies to the line segment connecting the point to the subsequent point. Thus there is no need for a subsection assignment to the last point because there is no line segment between it and a subsequent point because there is no subsequent point. Therefore, FEQUTL uses the subsection for the last point as a flag to signal the end of the cross section specification. If SB(i) is left blank it will be taken as zero and the subsection number from the previous point will be assigned to the current point.

A closed section can be specified by defining the offsets and elevations of points around the perimeter of the section. The description should begin at the high point of the section and should not quite close so that a free surface remains.

COMMAND NAME: FEQXLST

The input for this command is the same as for FEQX except that the input of the offset, elevation, and subsection is in list format. That is, each line must have exactly three entries separated by one or more spaces and the subsection must be given in each case. This form of the input is often faster for data entry.

COMMAND NAME: FINISH

This command should be the last in the input. It closes the files and terminates execution of FEQUTL.

the floodway, and key items of information required to implement that method. The table number of the cross section description is used to associate the floodway information with the cross section description. If no floodway information is given in the floodway table for a cross section that appears in the subsequent input, then the cross section table is computed unchanged. Conversely, floodway information given in the floodway table for a cross section that does not appear in the subsequent input is read by FEQUTL but not used. Thus only those tables for which floodway information is given AND that also appear in the subsequent input are changed. However, the complete input should always be processed in order to simplify the bookkeeping for files because the time taken by FEQUTL to compute the function tables is minimal.

The floodway table is stored in its own file and is referenced via the floodway command. In this way only one copy of the floodway table need exist for a stream system. This reduces errors and helps maintain consistency. Only two lines need be added to the existing input files for FEQUTL to invoke the floodway option. These two lines are the command 'FLOODWAY' given above and the file name as defined on card 1.

CARD 1

Variable: FILNAM

Format: 5X, A48

Example: FILE=FLOODWAY.UMS

Explanation: Gives the file name containing the floodway table specifying which cross sections are to be used and the method to be used in defining the encroachment limits.

The floodway table itself consists of:

CARD 1

Variable: HEAD

Format: A80

Example: Floodway specification for West Branch Salt Creek

Explanation: Descriptive heading given by user.

CARD 2

Variable: GLBCON

Format: 16X, F10.0

Example: Conveyance Loss= 0.05

Explanation: Gives the global value for the fraction of total conveyance lost on one side of the stream. Thus the total loss is twice the given value. This value is used if the loss field for a cross section is left blank and the option field contains CONV.

CARD 3

Variable: GLBELV

Format: 15X, F10.0

Example: Elevation Loss= 0.7

Explanation: Gives the global value for the decrement in elevation from the standard flood level for defining the floodway using the elevation option. This value is used if the loss field for a cross section is left blank and the option field contains ELEV.

CARD 4

Variable: HEAD

Format: A80

Example: XSEC OPTN ELEV FEQBOT LEFT RIGHT LOSS

Explanation: User headings for subsequent columns in the floodway table.

CARD 5

Variables: TAB, OPT, ELEV, BOT, LEFT, RIGHT, LOSS

Format: I5, 1X, A4, 1X, F8.0, 4A8

Explanation: Gives variables specifying which method to use on which cross sections. TAB gives the table number of the cross section being referenced. If a cross section description with the given table number appears in subsequent input, then that cross section is analyzed using the information in the remainder of the line to define a floodway cross section table. If TAB gives a table number and no subsequent cross section description with a matching number exists in the input, then the information is read but not used. If a cross section description is encountered without an entry in the floodway table, then the cross section is processed as usual.

OPT gives the options. Valid options are: ELEV, CONV, and USET. The ELEV option defines the flood way by giving a decrement from the standard flood elevation given in ELEV in the LOSS column. A decrement is positive. Thus if the floodway is to start at an elevation of 672 and the standard flood elevation at this cross section is 672.7 then the value in the loss column should be given as 0.7. If the loss column is left blank FEQUTL will use the global value of the decrement. The CONV option uses the water surface elevation given in ELEV to compute the conveyance in the cross section and then uses the loss fraction given in the LOSS column to determine the loss of conveyance on each side of the channel to determine the encroachment limits. Just as for ELEV, a blank in the LOSS column results in FEQUTL using the global loss value for conveyance. The USET option indicates by it name that the user sets the limits by giving the LEFT and RIGHT limits for the floodway encroachment. The co-ordinate system for each cross section is the same as for the offset and elevation values for that cross section. Obviously it is an error to leave the RIGHT and LEFT columns blank if the USET option is selected.

ELEV, as already noted, gives the elevation of the water surface at this cross section for the standard flood. Normally the standard flood is the 100-year flood elevation but FEQUTL doesn't know that and doesn't care! The elevation in ELEV must be given and it is an error if the ELEV is lower than the minimum point of the cross-section or if it is higher than the last point on either the left or right end of the cross section boundary description. IMPORTANT: This is different from the usual rule for computing cross section tables. FEQUTL normally extends whichever end of the cross section boundary is lower to match the higher elevation. This extension is assumed to be vertical and frictionless. This will not be done for floodway determination because automatic extension could lead to unrealistic results.

BOT gives the elevation of the bottom of the cross section as specified in the profile for FEQ. This need be given only if it differs from the elevation of the minimum point in the cross section boundary description. If left blank, FEQUTL assumes that the bottom profile as given in FEQ for this cross section matches the minimum elevation in the cross section boundary description. FEQUTL prints out the symbol 'same' if the field is left blank.

LEFT gives the limit of the encroachment from the left of the main channel. If the option produces a value that is less than the offset given by LEFT then that value is retained. Otherwise, the value given by the floodway option is replaced by the value of LEFT. If left blank the encroachment is unlimited and FEQUTL prints out the symbol '+inf', denoting positive infinity, as the limit.

RIGHT gives the limit of the encroachment from the right of the main channel. If the option produces a value that is greater than the offset given by RIGHT then that offset is retained. Otherwise, the value given by the floodway option is replaced by the value of RIGHT. If left blank the encroachment is unlimited and FEQUTL prints out the symbol '-inf', denoting negative infinity, as the limit.

LOSS gives 'loss' used to define the encroachment limits. The methods of definition have already been given above.

The fields BOT, LEFT, RIGHT, and LOSS are optional and may be left blank if the default values are the ones you want used.

Card 5 is repeated as required to complete the floodway specification. The input is terminated by giving a negative value for the table number.

FEQUTL prints a summary of the floodway table at the completion of the output with the values of LEFT and RIGHT replaced by the limits computed by the selected option.

COMMAND NAME: FTABIN

The input for FTABIN consists of function tables in the exact format used by FEQ. Currently any of the explicitly time dependent tables, Types 7, 8, and 9, cannot be entered because FEQUTL has no need of time dependent tables. The table input is terminated with a table number of -1. No auxiliary files can be used for the input of tables.

The table numbers used for the tables input under FTABIN should be unique. They can be referenced by subsequent commands as required. Table stored in separate files can be accessed by providing a negative table number that differs from -1 with the number followed immediately by the file name or by the ddname for IBM mainframes. This feature works the same as the file references for tables in FEQ.

COMMAND NAME: GRITTER

GRITTER computes a generalization of the Ritter solution for the peak outflow following the instantaneous failure of a dam. GRITTER assumes that the reservoir cross section is prismatic, horizontal and frictionless. Furthermore there can be an initial flow in the reservoir and the cross section of the failure site need not match the cross section of the reservoir. Although restrictive, the assumptions for the generalized solution allow reasonable estimates to be made of the physically possible peak flows caused by a variety of failures. These estimates can be used to assess the reasonableness of the results obtained via solution of the dambreak problem using the options available in FEQ.

The generalization to a non-rectangular channel cross section involves the introduction of the Escoffier stage variable, ω, defined as

$$\omega(y) = \int_0^y \frac{g}{c(z)}\, dz \qquad \text{(GRITTER–1)}$$

where y = height of water surface from the minimum point in the cross section(also called depth); g = acceleration due to gravity; $c(z)$ = celerity at height $z = \sqrt{gA(z)/T(z)}$, $A(z)$ = flow area at height z; and $T(z)$ = top width of the water surface at height z. The Escoffier stage variable transforms the characteristic form of the governing equations(not shown here) into a convenient form for solution. The solution for the relationship between the depth and velocity at the dam site after the failure is

$$V + \omega = V_1 + \omega_1 \qquad \text{(GRITTER–2)}$$

where V = velocity at the dam site after the failure; ω = Escoffier stage variable at the dam site after the failure; and the subscript of 1 denotes corresponding values at the dam site before the failure. Equation 2 contains two unknowns: water height and water velocity at the dam site after the failure. If the dam fails completely and the cross section at the dam is identical to the cross section in the reservoir then the Ritter solution finds that the flow at the dam site is critical. Thus it seems reasonable, and testing bears this out, to assume that the flow at the dam site will be critical for a partial failure with perhaps some allowance for the associated contraction losses. The critical flow relationship at the dam site for the dam breach provides another equation relating the velocity to water height at the dam site in the reservoir cross section. Thus define a function, $f(y)$, which gives the flow through the breach for each water height in the reservoir. Please note that the water height in the reservoir is not the same as the water height in the breach if the breach is partial. Therefore $f(y)$ gives the critical flow in the breach for the corresponding heights in the reservoir. We are assuming that the distance between the breach and the upstream point in the reservoir is a small part of the length of the reservoir and that the use of a steady flow relationship will not unduly affect the results.

The depth and velocity in the reservoir at the dam site must be the same for both Eq. 2 and for $f(y)$. Therefore we can substitute $f(y)/A(y)$ for V in Eq. 2 to yield

$$f(y)/A(y) + \omega(y) = V_1 + \omega_1 \qquad \text{(GRITTER–3)}$$

the governing equation for the generalized Ritter solution. FEQUTL solves Eq. 3 using a modified *regula falsi* technique.

The Escoffier stage variable table is computed internally by FEQUTL and is output to STDOUT but not to STDTAB because there is no current need for such a table in FEQ.

CARD 1

Variables: NAME, APPTAB

Format: A8, I5

Example: APPTAB#= 731

Explanation: Gives the table number for the approach cross section to the dam site. This cross section is the cross section of the prismatic, horizontal, frictionless reservoir presumed to exist upstream of the

dam before the instantaneous removal of the dam occurs. In the course of the computations this table is replaced by a table containing the Escoffier stage variable. Thus the table is lost to subsequent commands.

CARD 2

Variables: NAME, CONTAB

Format: A8, I5

Example: CONTAB#= 25

Explanation: Gives the table number for the constricted flow relationship produced by CRITQ or some similar computation. The table must give the flow for each head in the reservoir where the head is measured from the water surface elevation in the reservoir upstream of the breach to the base of the breach opening.

CARD 3

Variables: NAME, Z0

Format: A8, F10.0

Example: BRCHHGT= 0.0

Explanation: Gives the height of the base of the breach from the bottom point of the reservoir cross section. Must be ≥ 0. This height should agree with the elevation difference used in computing the critical flow table using CRITQ.

CARD 4

Variables: LABEL

Format: A79

Example: DEPTH DISCHARGE Test of the Ritter solution.

Explanation: Provides a heading for the subsequent values of depth and discharge in the reservoir before the failure and a descriptive label for the dam being analyzed.

CARD 5

Variables: Y1, Q1

Format: 2F10.0

Explanation: Gives the before failure depth and flow rate in the reservoir. Card 5 is repeated as many times as needed to represent the range of depths and flows required for the analysis of various failures. The sequence is terminated by giving a negative value for the depth.

COMMAND NAME: JUMP

The JUMP command produces a table giving the ratio of the downstream depth to the upstream depth for each combination of upstream depth and upstream Froude number given by the user. It is the user's responsibility to have the cross section defined high enough so that the downstream depth can be computed. If the cross section is not high enough, FEQUTL issues a warning message and then uses the maximum value in the cross section for the sequent depth. The table is still produced but the larger sequent depth ratios will be invalid. FEQUTL computes the depth ratio using a momentum balance between the upstream and downstream cross section ignoring bottom slope and friction but including the momentum flux correction coefficient.

The computations for the JUMP command are robust but there may be compound cross sections for which the computations will fail. The hydraulic jump computations are only meaningful in compact cross sections in any case so these problems should not restrict application of the command.

CARD 1

Variable: TABLE

Format: 7X, I5

Example: TABLE#= 9900

Explanation: Gives table number for the table to be computed by FEQUTL.

CARD 2

Variable:

Format: 8X, I5

Example: XTABLE#= 7890

Explanation: Gives the table number defining the cross section of the channel for which the hydraulic jump relationships are to be computed. For the purposes of computing the jump relationships, FEQUTL assumes the channel is prismatic, horizontal, and frictionless.

CARD 3

Variable: LABEL

Format: A80

Example: Hydraulic jump relationships upstream of culvert on Medinah Road.

Explanation: Gives a user label to identify the resulting table.

CARD 4

Variable: HEAD

Format: A80

Example: Values of upstream depth to use in constructing the table.

Explanation: Gives a descriptive heading for the upstream depths to use in computing the table.

CARD 5

Variable: YUPVEC(I)

Format: F10.0

Explanation: Gives the sequence of upstream depths to use in computing the table. The depths should be in ascending order and all depths must be positive. Card 5 is repeated as many times as required to input the sequence of depths. The sequence is terminated by giving a negative depth.

CARD 6

Variable: HEAD

Format: A80

Example: Values of upstream Froude number to use in computing the table.

Explanation: Gives descriptive heading for the Froude numbers used in computing the table.

CARD 7

Variable: FRVEC(I)

Format: F10.0

Explanation: Gives the sequence of upstream Froude numbers to use in computing the table. The Froude numbers should be in ascending order and beginning with a Froude number of 1.0. Card 5 is repeated as many times as required to input the sequence of Froude numbers. The sequence is terminated by giving a negative Froude number.

COMMAND NAME: MULCON

CARD 1

Variable: TAB, CIN

Format: 7X, I5, A50

Example: TABLE#= 9 OUT12

Explanation: Gives the table number of the cross section table computed by FEQUTL. The user may specify the same options after the table number as in FEQX.

CARD 2

Variable: WSLOT

Format: 6X, F10.0

Example: WSLOT= 0.01

Explanation: Specifies the width of the slot to use to maintain a free surface in the conduit. This width is used for each conduit and the final slot for the table is the sum of the slot widths. That is, the final slot width is NPIPES*WSLOT where NPIPES is the number of conduits involved.

CARD 3

Variable: HSLOT

Format: 6X, F10.0

Example: HSLOT= 50.0

Explanation: Gives the height of the slot above the invert of the conduit with the minimum elevation.

CARD 4

Variable: NPIPES

Format: 7X, F10.0

Example: NPIPES= 3

Explanation: Specifies the number of conduits involved. Valid range is: $1 \leq \text{NPIPES} \leq 18$.

CARD 5

Variables: TYPE(i)

Format: 5X, 6A10,/,(5X, 6A10)

Example: TYPE= CIRC NHE

Explanation: Gives the type of conduit. Valid types are: CIRC for circular pipe; NHE for nominal horizontal elliptical for standard elliptical pipe designed for placement with the major axis horizontal; NVE for standard elliptical pipe designed for placement with the major axis vertical; TE for true elliptical pipe; and RCPA for the standard reinforced concrete pipe arch. The nominal elliptical pipe is called nominal because it is elliptical in name only being composed of four circular arcs that approximate an elliptical shape.

CARD 6

Variables: SPAN(i)

Format:5X, 6F10.0,/,(5X, 6F10.0)

Example: SPAN= 4.0 4.5 4.0

Explanation: Give the maximum horizontal dimension of the opening in each of the conduits.

CARD 7

Variables: RISE(i)

Format: 5X, 6F10.0,/,(5X, 6F10.0)

Example: RISE= 3.0 2.5 5.0

Explanation: Give the maximum vertical dimension of the opening in each conduit. The combination of

SPAN and RISE defines the size of the conduit. The required information depends on the TYPE of the conduit. If TYPE is CIRC then SPAN defines the diameter and RISE is ignored. If TYPE is NHE either RISE or SPAN or both may be given. FEQUTL computes the equivalent diameter circular pipe from the RISE or SPAN and from both if both are given. If only one of the two values is given then that value defines the equivalent diameter. If both values are given then the RISE is taken as the defining value and a warning message is issued if the equivalent diameter computed from the SPAN differs from the equivalent diameter computed from the RISE by more than about 3 *per cent.* If TYPE is NVE the same rules as for NHE apply. If TYPE is TE then both the SPAN and the RISE must be given because there is no "standard" shape for true elliptical pipe. Finally if TYPE is RCPA either RISE or SPAN or both may be given. If RISE or both are given FEQUTL computes the SPAN from the RISE and if the SPAN is given issues a warning message if the SPAN computed from the RISE differs by more than about 2 *per cent* from the SPAN as given. If only the SPAN is given then the RISE is computed from the SPAN. The priority given to value of RISE is based on the belief that this dimension is often easier to measure in the field than is the SPAN.

For RCPA pipe only certain standard sizes exist and these sizes do not have a constant scale relationship. That is any given size cannot be scaled to represent a larger or smaller size. However, FEQUTL interpolates between the standard sizes linearly for the dimensions so that non-standard sizes can be approx mated. The true elliptical shape is provided so that non-standard elliptical pipe should it be encountered an be represented in a cross section table.

In MULCON as in MULPIPES each pipe is considered a different subsection of a cross section. Thus the values of ALPHA and BETA computed by FEQUTL may differ from 1.0 even if USGSBETA=NO is the selected option. The number of sides of the polygon is fixed at 40 by MULCON. Furthermore the datum point for the cross section description is the invert of the conduit with minimum invert elevation. The polygon is adjusted so that the full flow area is matched. As a result the invert of the polygon will be slightly below the invert of the conduit and thus the elevation reported for the cross section table will be a small negative value and the maximum depth before entering the slot will be slightly larger than the RISE of the conduit. These differences are always much smaller than the manufacturing tolerances for the conduit!

In closed conduits the conveyance will decrease with depth in the conduit as the conduit approaches the nearly full flow condition. FEQUTL allows two options. The first option, selected by giving the table number as positive, is to propagate the maximum conveyance so that the conveyance never decreases. The second option, selected by giv he table number as negative, reports warning messages for decreasing conveyance but retains the con ce as co puted. The conveyance in the slot is forced to be a constant with its value given by either t aximum nveyance in the irst option or the c eyance reached at the entrance to the slot in the s nd option.

CARD 8

Variables: BOTTOM(i)

Format: 5X, 6F10.0,/,(5X, 6F10.0)

Example: BOTT= 0.5 0.0 0.5

Explanation: Gives the height of the invert of each conduit above the invert of the conduit with the smallest invert elevation. In the example the invert of two conduits is 0.5 foot above the invert of the remaining conduit.

CARD 9

Variables: ROUGH(i)

Format: 5X, 6F10.0,/,(5X, 6F10.0)

Example: ROUG= 0.02 0.03 0.02

Explanation: Gives the Manning's n for each of the conduits

COMMAND NAME: MULPIPES

CARD 1

Variable: TAB, CIN

Format: 7X, I5, A50

Example: TABLE#= 9 OUT1

Explanation: Gives the table number of the cross section table computed by FEQUTL. The user may specify the same options after the table number as in FEQX.

CARD 2

Variable: NSIDES

Format: 7X, I5

Example: NSIDES= 30

Explanation: Gives the number of sides in the polygon used to approximate the pipes. The polygon is sized so that the area of the polygon and the pipe is the same when the pipe is flowing full. FEQUTL adds a slot to the cross section table to maintain a free surface at all stage levels.

CARD 3

Variable: WSLOT

Format: 6X, F10.0

Example: WSLOT= 0.01

Explanation: Specifies the width of the slot to use to maintain a free surface in the pipe. This width is used for each pipe and the final slot for the table is the sum of the slot widths. That is, the final slot width is NPIPES*WSLOT where NPIPES is the number of pipes involved.

CARD 4

Variable: HSLOT

Format: 6X, F10.0

Example: HSLOT= 50.0

Explanation: Gives the height of the slot above the conduit invert. The presence of multiple pipes can lead to some unexpected results near the depth of HSLOT in the table. To eliminate this problem FEQUTL deletes the two last values in the table. Therefore make the height of the slot large enough so that the table will not be overtopped even when a length perhaps as much as DZLIM is deleted from the table.

CARD 5

Variable: NPIPES

Format: 7X, F10.0

Example: NPIPES= 3

Explanation: Specifies the number of pipes involved. Valid range is: $1 \leq \text{NPIPES} \leq 18$.

CARD 6

Variables: DIAM(i)

Format: 5X, 6F10.0,/,(5X, 6F10.0)

Example: DIAM= 4.0 4.5 4.0

Explanation: Give the diameter of each of the NPIPES pipes in feet or meters.

CARD 7

Variables: BOTTOM(i)

Format: 5X, 6F10.0,/,(5X, 6F10.0)

Example: BOTT= 0.5 0.0 0.5

Explanation: Gives the height of the invert of each pipe above the invert of the pipe with the smallest

invert elevation. In the example the invert of two pipes is 0.5 foot above the invert of the remaining pipe.

CARD 8

Variables: ROUGH(i)

Format: 5X, 6F10.0,/,(5X, 6F10.0)

Example: ROUG= 0.02 0.03 0.02

Explanation: Gives the Manning's n for each of the pipes.

COMMAND NAME: ROADFLOW

CARD 1

Variable: LABEL

Format: A80

Example: Flow table for Zanker Road

Explanation: Provides description of the table being computed.

CARD 2

Variable: DZLIM

Format: 6X, F10.0

Example: DZLIM= 0.25

Explanation: Provides maximum spacing in the table produced by ROADFLOW. Does not change the value of DZLIM established in the standard header.

CARD 3

Variable: NRZERO

Format: 7X, F10.0

Example: NRZERO= 0.05

Explanation: Forces a table value near zero to improve interpolation accuracy.

CARD 4

Variable: FACTOR

Format: 7X, F10.0

Example: FACTOR= 0.95

Explanation: Provides a reduction factor for the critical flow to approximate hydraulic losses.

CARD 5

At card 5 give the road cross section in the same format as for FEQX. FEQUTL will compute a cross section table internally and then from this table compute the flow at critical depth. In these computations, FEQUTL assumes that the approach velocity head is small enough to be neglected. If this is not true then the flow over the roadway should not be computed using ROADFLOW.

COMMAND NAME: SAME

CARD 1

Variable: SHIFT

Format: 6X, F10.0

Example: SHIFT= 1.0

Explanation: Takes the previous cross section to be the current cross section adding the value given by SHIFT to the each elevation.

COMMAND NAME: SEWER

CARD 1

Variable: TAB, CIN

Format: 7X, I5, A50

Example: TABLE#= 9 NOOUT

Explanation: Gives the table number of the cross section table computed by FEQUTL. The user may specify the same options after the table number as in FEQX.

CARD 2

Variable: D

Format: 9X, F10.0

Example: DIAMETER= 3.5

Explanation: Specifies the diameter of the pipe in feet or meters.

CARD 3

Variable: NSIDES

Format: 7X, I5

Example: NSIDES= 30

Explanation: Gives the number of sides in the polygon used to approximate the circular conduit. The polygon is sized so that the area of the polygon and the circular conduit is the same when the conduit is flowing full. FEQUTL adds a slot to the cross section table to maintain a free surface at all stage levels.

CARD 4

Variable: WSLOT

Format: 6X, F10.0

Example: WSLOT= 0.01

Explanation: Specifies the width of the slot to use to maintain a free surface in the pipe.

CARD 5

Variable: HSLOT

Format: 6X, F10.0

Example: HSLOT= 50.0

Explanation: Gives the height of the slot above the conduit invert.

CARD 6

Variable: N

Format: 2X, F10.0

Example: N= 0.025

Explanation: Gives Manning's n for the conduit.

UNSTEADY FLOW SOLUTIONS

FEQUTL Messages: Version 2.70

Date: 5 March 1990

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FEQUTL MESSAGES: Version 2.70

FEQUTL issues messages to the user in three categories. The first category consists of error messages describing some condition in the input which makes it impossible for FEQUTL to understand the intent of the user. FEQUTL will in many cases stop processing the current command, read the subsequent input for the current command and attempt to continue processing with the following command. Thus each command in the input will be processed but only those without detected errors will be completed. Therefore, you must always check for detected errors before assuming that all the commands have been processed correctly.

The second category of messages consists of warning messages reporting conditions which may indicate a user error or which highlight the possibility of some later computational problem. Usually FEQUTL makes some assumption to circumvent the problem and then continues the computations. The user should always check the warning messages to make sure that the default action taken by FEQUTL has not affected the results.

The third category of messages consists of bug messages reporting conditions which should not occur. They are usually indicative of some problem in the computer code and should not be seen often. However, conditions not tested may occur in an application and a bug may be revealed.

Some parts of the software in FEQUTL are taken from FEQ. The parts of FEQUTL which are taken from FEQ bring their error, warning, and bug messages with them. A message with a number less than 500 is from FEQ software and will be described in the FEQ message summary. Its description may not refer directly to FEQUTL but the nature of the error is the same. The principal operations copied from FEQ involve the storage of and the lookup from function tables. Thus errors of argument out of range or missing tables will be reported using messages from FEQ. All messages with numbers greater than 500 are described here.

ERR:nn MESSAGES

FEQUTL contains a fairly extensive set of error messages to detect errors in the input as early as possible. However, there are errors which could be detected but which are not yet detected. Over a period of time these undetected errors will result in program code changes so that they will be found before they cause computational problems or incorrect results. However, it is possible to correctly specify the input so that FEQUTL detects no errors and still have improperly defined input through some error on the part of the user. As a simple example, the offsets used for the boundary points on a cross section may be given in a valid from and also specify a valid cross section. However, the cross section may not be the correct size because the user applied the incorrect map scale to the measurements, FEQUTL has no way of detecting this error because the input is valid but yet incorrect for the application. Thus there are three types of errors possible: an error which can be detected by FEQUTL and is detected, an error which could have been detected by FEQUTL but no code for the detection exists, and an error which by its nature cannot be detected by FEQUTL now or in the future. Over time the number of errors included in the first set will increase and the number of errors included in the second set will decrease. However, the number of errors in the third set will stay the same.

The error messages are given in numerical order below. There may be gaps in the order as changes are made so that the absence of a numbered message does not necessarily imply that some message has been omitted. Furthermore, the order of numbering is arbitrary.

In many cases the message includes numbers and in a few cases character strings. These numbers and character strings will have a value which depends on the specific occurrence of the error. The positions of these occurrence-dependent values are denoted by 'nn' for an integer number, 'ff' for a floating point number(i.e. one containing a decimal point or in the so-called floating point format), and 'aa' for a character string.

ERR:501 UNKNOWN COMMAND.

Notes: A command has been found which cannot be found in the current list of commands. The current list of commands is defined by the header information which appears at the head of each input to FEQUTL. It might be that the current version of FEQUTL supports the command you have invoked but that the header information you used is from a previous version which does not support the command. You must correct the header information and attempt the run again. Of course it is always possible that the command was merely mistyped and therefore could not be found.

ERR:502 INVALID VALUES FOR NRZERO OR DZLIM BOTH MUST BE > 0.0

Notes: The input values for NRZERO, the depth for the near zero values, and DZLIM, the maximum change in argument both applying to cross section tables only, must both be > 0. At least one of the values has been given as zero.

ERR:503 TOO MANY COMMANDS IN SYSTEM FILE. LIMIT= nn

Notes: More commands have appeared in the header to the input than are allowed in FEQUTL. In the INCLUDE file ARSIZE.FOR increase the value of the parameter MAXCMD and recompile FEQUTL to allow for more commands.

ERR:504 NUMBER OF SUBSECTIONS= nn > nn

Notes: The number of subsections for a cross section specification has exceeded the number allowed in FEQUTL. Change the parameter PMXSUB in the INCLUDE file ARSIZE.FOR and recompile to permit more subsections.

ERR:505 SUBSECTION NUMBER TOO LARGE AT OFFSET= ff

Notes: A line segment of the cross section boundary has been assigned to a subsection number which is larger than the number of subsections given earlier in the input when the Manning's "n" values were

given. Thus FEQUTL cannot process the cross section because the line segment is an 'orphan' and has no assigned value of "n".

ERR:506 ONLY ONE POINT GIVEN ON BOUNDARY OF THE CROSS SECTION.

Notes: At a minimum two points must exist on the boundary of the cross section before the cross section is defined. A mistake has likely been made in a subsection number so that FEQUTL has concluded that the input of the cross section is complete when in fact it is not.

ERR:507 NUMBER OF POINTS IN CROSS SECTION > nn

Notes: The number of points given on a cross section is larger than the current internal maximum allowed by FEQUTL. Increase the size of the parameter PMXPNT in the INCLUDE file ARSIZE.FOR and recompile the program.

ERR:508 SECTION VIOLATES MONOTONICITY AT OFFSET= ff

Notes: The user has stated that the cross section offsets should be strictly increasing and FEQUTL has found an offset which violates this condition. Either the request for checking monotonicity of offsets is incorrect or there is an error in the cross section.

ERR:509 TABLE# < 0 OR TABLE# > nn

Notes: A function table number is out of range. If the upper range is too small change the parameter PMXTAB in the INCLUDE file ARSIZE.FOR to the new value and recompile.

ERR:510 DUPLICATE TABLE NUMBER.

Notes: A table number already in use has been found. Change the numbers so that each table in a run of FEQUTL is unique.

ERR:511 UPSTREAM CROSS SECTION MISSING FOR BRIDGE

Notes: The bridge routine requires that an upstream cross section be present and no upstream cross section has been found. Make sure that the last cross section processed before the bridge routine is the upstream cross section for the bridge.

ERR:512 DOWNSTREAM CROSS SECTION MISSING FOR BRIDGE

Notes: The bridge routine requires that a downstream cross section be present and no downstream cross section has been found. Make sure that the downstream cross section for the bridge appears before the input of the upstream cross section for the bridge. The upstream cross section for the bridge should appear immediately before the input for the bridge.

ERR:513 BASE CURVE# > 3 OR < 1.

Notes: In the FHA bridge loss method there are exactly three base curves available for the loss coefficient. A base curve number outside this range has been found.

ERR:514 PIER TYPE < 0 OR > 8.

Notes: The pier type for the FHA bridge loss method must be in the given range. A pier type has been found which is outside this range.

ERR:515 NUMBER OF ENTRIES IN PIER NUMBER-WIDTH TABLE > nn

Notes: The number of entries in the pier description is too large. The current limit is 25 and cannot easily be changed.

ERR:506 ELEVATION FOR PIER NUMBER-WIDTH TABLE IS DECREASING AT: ff

Notes: The elevation in the pier description is decreasing and is therefore invalid.

ERR:517 ONLY TYPE RDFLOW IS VALID FOR A BRIDGE

Notes: Only the bridge option RDFLOW is supported for the FHA method. If no flow over the roadway is to occur make the top of road elevation very large so that water will never overtop the road and supply flow tables which yield zero flow.

ERR:518 SUBSET AND SECTION ARE DISJOINT

Notes: A subset from a cross section has been specified, either in the bridge computations or in a floodway specification. The subset is such that it is not contained within the cross section. Thus the subset cannot be computed. Check the specification of the subset for the location of the center of the bridge opening relative to the upstream cross section.

ERR:519 ACTION REQUESTED REQUIRES PREVIOUS CROSS SECTION BUT PREVIOUS CROSS SECTION DOES NOT EXIST

Notes: The SAME command has been issued but no previous cross section exists. SAME can only be given if one or more cross sections have already been processed.

ERR:525 SPACE FOR ELEVATION ARGUMENTS EXHAUSTED

Notes: FEQUTL adds arguments to those defined by the unique breakpoint elevations which are found in the cross section specification in order to improve the accuracy of the conveyance. In this process the space allocated for these arguments has been exhausted. The space allocated for arguments is the same as the number of points in the cross section. Therefore, increase the value of PMXPNT in INCLUDE file ARSIZE.FOR and recompile.

ERR:526 INVALID VALUES OF NRZERO OR DZLIM IN SUBROUTINE FNDRF.

Notes: Subroutine FNDRF is used to compute flow over a roadway for the FHA bridge routine and must still be used for that purpose. It constructs a table containing critical flow and allows values for NRZERO and DZLIM to be given which differ from those used for computing the cross section tables. These values are only used for the computation of flow over the road and do not supplant the values used for cross sections. Both must be > 0 and at least one of them has been found to be zero.

ERR:527 CRITICAL FLOW DECREASES AT HEAD= ff

Notes: In the computation of flow over the roadway assuming critical flow FEQUTL has found that the computed critical flow decreases with an increase of head. This is considered to be an error and the road profile must be adjusted so that the top width does not increase so rapidly relative to the area of flow. If the flow over the road is not involved with a FHA method bridge than using the command EMBANKQ provides a better alternative which is not subject to this problem.

ERR:528 NUMBER OF CONDUITS= nn > nn

Notes: The number of pipes in a multiple pipe installation has exceeded the number allowed in FEQUTL. The maximum number of pipes allowed is the same as the number of subsections. Thus increase the value of the parameter PMXSUB in the INCLUDE file ARSIZE.FOR and recompile.

ERR:529 TWO FEW INTERSECTIONS. FLOOD WAY ELEVATION LIKELY BELOW SECTION. IL = nn IR = nn

Notes: The defining elevation for the floodway specified by a given decrement in elevation proves to not intersect the cross section boundary. Message may not appear because the condition should be detected by ERR:530.

ERR:530* DEFINING ELEVATION BELOW CHANNEL BOTTOM.

Notes: The defining elevation for the floodway specified by a given decrement in elevation proves to be below the current channel bottom. Either the cross section is too high or the defining elevation is too low!

ERR:531 FLDWAY ELEV= ff HIGHER THAN LEFT END ELEV= ff

Notes: The defining elevation for the elevation specified floodway is higher than the left end of the cross section. FEQUTL requires that the cross section always be defined to an elevation at least as high as the defining elevation.

ERR:532 FLDWAY ELEV= ff HIGHER THAN RIGHT END ELEV= ff

Notes: The defining elevation for the elevation specified floodway is higher than the right end of the cross section. FEQUTL requires that the cross section always be defined to an elevation at least as high as the defining elevation.

ERR:533 INVALID FLOODWAY OPTION IN ABOVE LINE

Notes: A floodway option has been given and FEQUTL does not support that option. Likely an error in giving the option.

ERR:534 IN LINE ABOVE, USET SELECTED BUT ONE OR BOTH LIMITS MISSING.

Notes: In the USET option for the floodway the user must give both limits and one or both are missing from the input.

ERR:537 STANDARD FLOOD ELEVATION BELOW CHANNEL BOTTOM.

Notes: The standard flood elevation given for the conveyance defined floodway proves to be below the current channel bottom. Either the cross section is too high or the standard flood elevation is too low!

ERR:538 NO INTERVAL FOUND FOR KTAR ON RIGHT

Notes: In a conveyance defined floodway FEQUTL computes the target conveyance and searches from left to right to find an interval of the cross section boundary which will contain that value of the reduced conveyance. No such interval could be found. This means that there is some problem in the search method or that there is something rather strange about either the shape or the roughness distribution for the cross section.

ERR:539 NO INTERVAL FOUND FOR KTAR ON LEFT

Notes: In a conveyance defined floodway FEQUTL computes the target conveyance and searches from right to left to find an interval of the cross section boundary which will contain that value of the reduced conveyance. No such interval could be found. This means that there is some problem in the search method or that there is something rather strange about either the shape or the roughness distribution for the cross section.

ERR:540 TABLE NUMBER= nn NOT FOUND

Notes: A referenced table number intended to supply information for the command could not be found. Make sure that the referenced function table has been input using command FTABIN before the current command is encountered in the input.

ERR:543 CREST BELOW APPROACH INVALID.

Notes: In computing the flow over embankment shaped weirs using command EMBANKQ, FEQUTL has found that the given crest elevation is below the bottom of the approach channel. This is clearly hydraulic nonsense. Check the crest and approach channel elevations.

ERR:544 WEIR WIDTH MUST BE POSITIVE

Notes: In computing the flow over embankment shaped weirs using command EMBANKQ, FEQUTL has found that the width of the crest is ≤ 0. This is invalid. The crest must always have a positive width so that the head relative to the crest can be computed.

ERR:545 MORE THAN nn OFFSETS FOR EMBANKMENT

Notes: The number of offsets for specifying the embankment crest and approach channel has exceeds the space allowed. Increase the parameter PMXOFF in INCLUDE file ARSIZE.FOR and recompile.

ERR:546 INVALID SURFACE OPTION: NEED PAVED OR GRAVEL

Notes: The only two valid surface options for EMBANKQ are PAVED or GRAVEL and FEQUTL has found some other option(other the END).

ERR:547 CRITICAL FLOW UNDEFINED IN TABLE#: nn AT DEPTH= nn

Notes: The critical flow for the cross section is computed for the JUMP command and the critical flow for this cross section is undefined because the variation of the momentum flux correction coefficient is such that the argument of the square root defining critical flow is negative. Change the shape of the cross section or redefine the variation of the momentum flux correction coefficient so that the critical flow is always defined.

ERR:548 MORE THAN nn UPSTREAM HEADS

Notes: More than the allowed number of upstream heads has been requested for EMBANKQ. Increase the parameter PMXNHU in the INCLUDE file ARSIZE.FOR and recompile.

ERR:549 MORE THAN nn FRACTIONS OF FREE DROP

Notes: More than the allowed number of fractions of free drop has been requested. Not now active but could be activated by allowing the user to specify the number of free drops to use for the flow over an embankment shaped weir.

ERR:550 SEQUENT DEPTH ABOVE TABLE#: nn MAXIMUM DEPTH IN TABLE ff USED FOR SEQUENT DEPTH

Notes: The sequent depth for the given upstream condition will be larger than the largest depth in the table defining the cross section properties. The sequent depth computations are suppressed and the maximum depth available from the cross section table is inserted in the sequent depth table.

ERR:551 Unassigned.

ERR:552 NO APPARENT SOLUTION. DEPTH= ff F= ff DF= ff

Notes: FEQUTL has not been able to find a solution for the sequent depth for the given upstream depth. The value of F gives the current residual for Newton's method and DF gives the current derivative of the residual. This problem may arise if the channel has overbank flow areas which differ significantly in depth and velocity from the flow in the principal channel.

ERR:553 ITERATION COUNT OF nn EXCEEDED.

Notes: In the JUMP command FEQUTL has exceeded the allowed number of iterations for a solution. The current limit of 99 should be more than adequate. When this error occurs FEQUTL restarts the computations and prints out intermediate values in an attempt to display the nature of the problem.

ERR:554* TABLE TYPE NOT 1 IN COMMAND: JUMP

Notes: The cross section table given for the computation of the sequent depth table is not in fact a cross section table.

ERR:555 MORE THAN nn UPSTREAM DEPTHS

Notes: More than the current maximum number of upstream depths has been given for the sequent depth table computed by command JUMP. Increase the parameter PMXNUP in the INCLUDE file ARSIZE.FOR and recompile.

ERR:556 MORE THAN nn UPSTREAM FROUDE NUMBERS

Notes: More than the current maximum number of upstream Froude numbers has been given for the sequent depth table computed by command JUMP. Increase the parameter PMXNFR in the INCLUDE file ARSIZE.FOR and recompile.

ERR:557 ERRORS PREVENT COMPUTATION OF JUMP TABLE

Notes: One or more errors have occurred in the input for the JUMP command and the sequent depth table cannot be computed.

ERR:558 DIGITIZED INPUT NOT SUPPORTED

Notes: FEQUTL does not currently support a special form of input created by the digitizer.

ERR:559 COEFFICIENT OF DISCHARGE <= 0.0 OR > 1.0

Notes: A coefficient of discharge input by the user has been found to be invalid.

ERR:560 APPROACH SECTION TABLE NUMBER DOES NOT REPRESENT A CROSS SECTION.

Notes: FEQUTL has found that the approach section table given in CRITQ or GRITTER is not a cross section table. Some mistake exists in either the number given or in the number assigned to the cross section table when it was computed.

ERR:561 CONSTRICTED SECTION TABLE NUMBER DOES NOT REPRESENT A CROSS SECTION.')

Notes: FEQUTL has found that the constricted section table given in CRITQ is not a cross section table. Some mistake exists in either the number given in CRITQ or in the number assigned to the cross section table when it was computed.

ERR:562 SOLUTION DOES NOT EXIST AT DEPTH= ff
CONSTRICTED SECTION IS NOT A CONSTRICTION!

Notes: In computing a critical flow table using CRITQ, FEQUTL has found super critical flow in the approach section. The computations have not been completed at the given depth. It is likely that the cross section given as the constricted cross section is not in fact a constriction relative to the approach cross section at all depths.

ERR:563 CONSTRICTED FLOW TABLE NUMBER IS INVALID. TYPE MUST BE 2, 3, OR 4.

Notes: The constricted flow table in GRITTER is of the wrong type. The wrong table number has been given or there has been a mistake in typing the table type.

ERR:564 BREACH OFFSET NEGATIVE FOR GRITTER. MUST BE >= 0.0

Notes: The base of the breach opening can be offset from the bottom of the reservoir cross section but the offset cannot be negative. This helps insure that the constricted flow section is really a constriction!

ERR:565 BOTTOM ELEV. OF APPROACH SECTION ABOVE BOTTOM ELEV. OF CONSTRICTED SECTION.

Notes: The bottom of the approach section must not be at a higher elevation than the bottom of the constricted section. Gravity and friction forces are ignored and as a result any drop in elevation in the downstream direction causes problems.

ERR:566 INSUFFICIENT SPACE IN ITAB/FTAB TO SAVE TABLE IN CRITQ. NEED nn MORE ELEMENTS.

Notes: You have requested that the critical flow table be saved internally in FEQUTL so that it can be referenced after it is computed just like a table entered using the FTABIN command and FEQUTL has found that there is not enough space in the function table storage system. Increase the size of the parameter, MRFTAB, in the include file ARSIZE.FOR and recompile the programs.

ERR:567 FIRST FROUDE NUMBER IS NOT 1.0 BUT: ff

Notes: The first Froude number given in command JUMP must be 1.0.

ERR:568 INITIAL DEPTH IN RESERVOIR BELOW LOW POINT OF BREACH.

Notes: The initial depth in the reservoir in GRITTER must be higher than the low point of the breach given by Z0 if there is to be any flow when the dam fails!

ERR:569 INSUFFICIENT SPACE IN ITAB/FTAB TO SAVE CROSS SECTION TABLE. NEED nn MORE ELEMENTS

Notes: Saving a cross section table within FEQUTL has been requested but the space in the FTAB/ITAB system is exhausted. Increase the size of the parameter MRFTAB in the include file ARSIZE.FOR and recompile.

ERR:570 INVALID OPTION FOR MONOTONICITY.

Notes: A request for checking for offset monotonicity in a cross section must be 'MONOTONE', 'SAVE', or it must be blank. This is flagged as an error because you might think you have requested monotonicity checking when you have not and FEQUTL would not issue any errors for the cross sections.

ERR:571 RISE= ff < MIN RISE= ff OR > MAX RISE= ff

Notes: The value of rise given for a reinforced concrete pipe arch is either greater than the minimum value of rise for standard pipe or it is greater than the maximum value for standard pipe. If the measurement is not in error than the internal tables in FEQUTL must be extended or detailed measurements must be taken of the dimensions of the conduit so that its shape can be defined and a cross section table computed using FEQX or FEQXLST.

ERR:572 SPAN= < MIN SPAN= ff OR > MAX SPAN= ff

Notes: Same meaning as ERR:571 except that the span was given as the defining dimension.

ERR:573 OFFSET SPACE FILLED IN MULCON.

Notes: The space for storing offsets has been filled in MULCON when processing a request for analysis of multiple conduits. This message should not appear unless the maximum number of pipes, which is the same as the maximum number of subsections, has been increased from the standard value of 18.

ERR:574 SPAN <= 0.0 INVALID FOR TYPE=CIRC.

Notes: The value of span is used as the diameter of the pipe and therefore it may not be omitted if the type is CIRC.

ERR:575* RISE AND SPAN ARE 0.0. ONE MUST BE > 0.0

Notes: Either rise or span must be given. FEQUTL has found a case where neither value was given.

ERR:576 TYPE= aa UNKNOWN

Notes: The given pipe type is not known to command MULCON. The type may be mistyped.

ERR:577 RISE AND SPAN MUST BE > 0.0 FOR TYPE TE

Notes: Both the rise and span must be given for true elliptical pipe because there are no standard dimensions to use to infer one dimension from the other when only one of rise or span is given.

ERR:578 APPROACH REACH LENGTH= ff < 0.

Notes: The approach reach length must be positive.

ERR:579 APPROACH LOSS COEF. < 0 OR > 1.

Notes: Loss coefficient is only meaningful if it is between 0 and 1.

ERR:580 VELOCITY HEAD LOSS FACTOR < 0 OR > 1.'

Notes: Loss coefficient is only meaningful if it is between 0 and 1.

ERR:581 APPROACH EXPANSION COEF. < 0 OR > 1.'

Notes: Loss coefficient is only meaningful if it is between 0 and 1.

ERR:582 ROUNDING/BEVELING FACTOR < 1 OR > 1.5.

Notes: The factor to account for rounding/beveling of a culvert entrance is outside the range established by the USGS.

ERR:583 DEPARTURE CONTRACTION COEF. < 0 OR > 1.

Notes: Loss coefficient is only meaningful if it is between 0 and 1.

ERR:584 WINGWALL FACTOR < 1 OR > 1.25.

Notes: The factor to account for wingwalls is outside the range established by the USGS.

ERR:585 PROJECTION ADJUSTMENT < 0.90 OR > 1.

Notes: The factor to account for a projecting entrance is outside the range established by the USGS,

ERR:586 LOSS OPTION: ',A8,' INVALID.

Notes: The only loss option supported in Version 2.7 is MOMENTUM.

ERR:587 CULVERT CLASS:', A8,' INVALID.

Notes: Culvert class must be: BOX, PIPE, MITER, or RCPTG.

ERR:588 TYPE 4-6 COEF.: ff < 0.80 OR > 1.

Notes: The discharge coefficient is outside the range established by the USGS.

ERR:589 TABLE TYPE < 5 OR > 6.

Notes: Only types 5 or 6 can be computed by CULVERT. Type 5 is not supported by FEQ Version 6.0.

ERR:590 TABLE NUMBER: nn IS NOT OF A CLOSED CONDUIT.

Notes: FEQUTL has decided that the given table number does not represent a closed conduit when FEQUTL requires a table number for a closed conduit.

ERR:591 aa IS A BAD SAVE OR OUTPUT OPTION.

Notes: The save or output option for FEQX is invalid. Valid options are: SAVE, SAVE1, SAVE12, NOSAVE, OUT1, OUT12, NOOUT, and MONOTONE.

ERR:592 TYPE= nn INVALID FOR 2-D FLOW TABLES.

Notes: Only types 5 and 6 are valid for 2-D tables.

ERR:593 WEIR COEF. TABLE NUMBER MUST BE GIVEN.

Notes: A weir coefficient table number for flow over embankment shaped weirs does not exist in FEQUTL storage. It must be input using FTABIN.

ERR:594 TABLE#= nn OVERFLOW SEEKING SOLUTION IN FRFT0. MAXARG= ff

Notes: CULVERT has not found a solution for Type 0 flow(control at the approach section) even though it has reached the top of the given table. Increase the height of the table if possible and try again. Otherwise there may be some other problem in the input or a computational failure of the method used for the solution.

ERR:595 TAB#= nn OVERFLOW SEEKING CRIT. DEPTH FOR FLOW= ff TABLE MAXARG= ff

Notes: FEQUTL has not been able to find critical depth in the given table even though it has reached the top of the table. Either the flow is in error or the table must be extended.

ERR:596 TAB#= nn UNDERFLOW SEEKING CRIT. DEPTH FOR FLOW=ff

Notes: FEQUTL has not been able to find critical depth in the given table even though it has reached the bottom of the table. The flow is likely invalid(i. e. equal to 0) or there is a problem in the solution method.

ERR:597 INITIAL DEPTH= ff $\leq$ 0 IN SFPSBE.

Notes: The initial depth for the computation of a steady flow profile for subcritical flow is negative which indicates an undetected input error or a problem with the solution method.

ERR:598 TAB#= nn OVERFLOW SEEKING SUBCRITICAL SOLUTION. MAXARG= ff

Notes: A subcritical solution could not be found before the top of the table was reached. The flow is likely too large for the conduit or there is a problem with the solution method.

ERR:599 INITIAL DEPTH= ff $\leq$ 0 IN SFPSPE.

Notes: The initial depth for the computation of a steady flow profile for super critical flow is negative which indicates an undetected input error or a problem with the solution method.

ERR:600 TYPE= nn INVALID TYPE FOR SUBMERGENCE TABLE.

Notes: The table type for a submergence table must be 2, 3, or 4.

ERR:601 TABLE#= nn INVALID SUBMERGENCE VALUES AT TABLE START.

Notes: A submergence table must start with an argument of 0.0 and a function value of 1.0 indicating that there is no reduction in free flow when there is no submergence.

ERR:602 TABLE#= nn NO SUBMERGENCE IN SUBMERGENCE TABLE.

Notes: A table given as a submergence table never indicates any submergence of the flow. A submergence table must indicate at some point a reduction in flow due to tailwater head on the overflow crest elevation.

ERR:603 ROADWAY MOMENTUM FLUX FACTOR= ff < 0 OR > 1.

Notes: The roadway momentum flux factor must always be positive but not exceed 1.0.

ERR:604 WIDTH FACTOR FOR DEPARTURE REACH ¡= 1.0

Notes: The width factor for testing the cross section for the beginning of the departure reach must always exceed 1.0.

ERR:605 BEGINNING ELEV. FOR DEP. RCH.=' ff > CLVRT EXIT ELEV. ff

Notes: The elevation of the beginning of the departure reach must not be higher than the culvert invert. That is, there can be no abrupt positive step at the exit of the culvert.

ERR:606 DSF WEIGHT FACTOR= ff < −1 OR *gt*1.

Notes: The downstream force weight factor must have an absolute value not greater than 1.

ERR:607 TABLE# ≤ 0

Notes: A table number must always be positive in this context.

ERR:608 SUBMERGED ROAD FLOW WITH FREE CULVERT FLOW NOT YET SUPPORTED.

Notes: Submerged road flow occurring before the flow through the culvert is also submerged is not yet supported. It may be supported in the future should such flows occur in practice.

ERR:609 ROAD CREST ELEV. ≤ HEAD DATUM INVALID.

Notes: Probable user error. A road crest below the head datum indicates that water is flowing over the road before water will flow through the culvert. This is not a normal road crossing. If the culvert code is being used for a non-road crossing for which this relationship in elevations is true then the culvert flow and the flow over the weir crest must be computed in separate tables and then combined via Code 5 Type 6 in FEQ.

ERR:610 FREE DROP= ff ≤ 0 NOT YET SUPPORTED.

Notes: A negative free drop indicates velocity head recovery through the culvert system. Increase the approach losses to force a drop in water surface elevation. Increasing APPEXP to 1.0 is one option.

ERR:611 H/L CRIT RATIO *lt*0 IN EMBANK.

Notes: The critical ratio of head to embankment width used to distinguish high head flow from low head flow is negative. This makes no sense and the ratio is set to the default of 0.15 for flow over embankment shaped weirs.

ERR:612 H/L MAX RATIO < 0 IN EMBANK.

Notes: The maximum ratio for head to embankment width used to generate a warning message is negative. This makes no sense and the ratio is set to the default of 0.32 for flow over embankment shaped weirs.

ERR:613 aa IS AN UNKNOWN UNITS OPTION.

Notes: The units option must be either METRIC or ENGLISH and the input must begin in column 9.

ERR:614 MAXIMUM NUMBER OF SUBSECTIONS= nn EXCEEDED IN REASUB.

Notes: In the process of reassigning subsection numbers to avoid non- contiguous occurrences of the same subsection, REASUB has added more subsection numbers than can be currently stored in FEQUTL. Increase PMXSUB in ARSIZE.FOR.FOR and recompile FEQUTL.

ERR:615 NEWBETA FAILURE. VALUE *LT*1

Notes: The NEWBETA option computes estimates of the kinetic energy flux and the momentum flux correction coefficients. These coefficients should never be less than 1.0 but NEWBETA has computed a value less than 1.0.

ERR:616 RISE AND SPAN MUST BE > 0 FOR TYPE: BOX

Notes: Both the rise and span for a box culvert must be given. FEQUTL has found one or both to be missing.

WRN:nn MESSAGES

FEQUTL detects a variety of conditions which may or may not cause problems in the computations. However, the conditions are such that the user is made aware of their presence so that corrective action, if required, can be taken.

WRN:501 SUBSECTION VALUE FOR FIRST POINT IS MISSING. SUBSECTION = 1 ASSUMED.

Notes: The subsection for the first point on the cross section boundary is missing. FEQUTL assumes that subsection 1 is meant and continues with the computations.

WRN:502 UNEXPECTED SLOPE AT LEFT END. SLOPE EXPECTED TO BE < 0 AT LEFT BOUNDARY

Notes: The left end of the cross section would normally have a downward slope as the channel is entered with the left-most point being higher than any nearby point. A cross section has been found for which this is not true. If the cross section is a natural or a manmade channel but not a closed conduit, check to make sure that it is meaningful to have the left-most point of the cross section boundary be lower than the second from the left-most point. In most cases such a condition does not make sense.

WRN:503 UNEXPECTED SLOPE AT RIGHT END. SLOPE EXPECTED TO BE > 0 AT RIGHT BOUNDARY

Notes: The right end of the cross section would normally have an upward slope as the channel is exited with the right-most point being higher than any nearby point. A cross section has been found for which this is not true. If the cross section is a natural or manmade channel but not a closed conduit, check to make sure that it is meaningful to have the right-most point of the cross section boundary be lower than the second from the right-most point. In most cases such a condition does not make sense.

WRN:504 LINE SEGMENT ENDING AT (ff, ff) IS HORIZONTAL AND NOT AT MINIMUM OR MAXIMUM ELEVATION. RIGHT HAND END INCREMENTED BY ff

Notes: FEQ requires that every function given in a function table be strictly continuous. Therefore, it is not possible to have a horizontal line at any other than the minimum or maximum(in case of some closed conduits) elevation in the cross section. Every invalid horizontal line segment is incremented at its right-hand end by the given amount. If this action is not acceptable increment one end point yourself so that the line is not horizontal.

WRN:505 DECREASE IN CONVEYANCE IN SUBSECTION nn AT ELEVATION = ff

Notes: The conveyance as computed in the given subsection at the given elevation has been found to be smaller than the conveyance at the previous elevation in this subsection. This does not make hydraulic sense unless the cross section has converging walls. Therefore in a natural channel the conveyance should always increase with an increase in the water surface elevation. Additional subsections may need to be added to the cross section specification.

WRN:506 CONVEYANCE NON-INCREASING AT DEPTH= ff

Notes: The conveyance for the whole cross section is non-increasing at the given depth. This message may not appear even though WRN:505 does appear because the increase of the conveyance in one subsection is larger than the corresponding decrease in conveyance of some other subsection. A decrease in conveyance with an increase of water surface elevation only makes sense if the walls of the section are converging. Again additional subsections may be needed to properly represent the conveyance for the cross section.

WRN:507 BRIDGE SKEW < 0 OR > 45. RESET TO: ff DEGREES.

Notes: The bridge skew for the FHA bridge method is outside its valid range. FEQUTL resets the value to be valid.

WRN:508 PIER SKEW < 0. RESET TO: ff

Notes: The pier skew is invalid and FEQUTL resets it to a valid value.

WRN:509 M > 1 IN MCOMP. K = ff KSUB= ff

Notes: The contraction ratio, M, has been found to be larger than 1.0 which is nonsense. This may arise merely from the vagaries of computing the conveyance for a subset of a cross section. The value will not in general differ much from 1.0 and FEQUTL resets the value to 1.0.

WRN:511 NUMBER OF SIDES= nn TOO SMALL. NSIDES RESET TO 10

Notes: The number of sides requested for the polygon approximation to a pipe is too small. FEQUTL resets the value to the value given.

WRN:512 NUMBER OF SIDES= nn TOO LARGE. NSIDES RESET TO nn

Notes: The number of sides requested for the polygon approximation to a pipe is too large. FEQUTL resets the number of sides to the value given. The number of sides is set to the number of points in a cross section less 4. This number is more than adequate to approximate a pipe. In fact 20 to 30 sides yields an approximation which is within a fraction of a per cent of the true values computed from a perfect circle. Most commercial pipes are not made to that accuracy to begin with!

WRN:513 NUMBER OF SIDES= nn TOO SMALL. NSIDES RESET TO 10

Notes: See WRN:511.

WRN:514 NUMBER OF SIDES= nn TOO LARGE NSIDES RESET TO nn

Notes: See WRN:512.

WRN:515 Unassigned.

WRN:516 MORE THAN ONE LEFT BOUNDARY. ONLY FIRST ONE RETAINED.

Notes: In the elevation defined floodway more than one left boundary has been found at the given elevation. Only the left-most one has been retained and the others are taken to be the boundaries of islands.

WRN:517 MORE THAN ONE RIGHT BOUNDARY. ONLY LAST ONE RETAINED.

Notes: In the elevation defined floodway more than one right boundary has been found at the given elevation. Only the right-most one has been retained and the others are taken to be the boundaries of islands.

WRN:518 ONE OR MORE ERRORS FOUND. TABLE FILE IS INCOMPLETE OR INVALID.

Notes: FEQUTL skips to the next command if an error is detected in processing the current command. When this happens the table which you thought the command was going to produce was *not* produced but the table file you specified will contain all the tables from the successfully completed commands but there will be no indication that the table file is incomplete. Please search the output for the string '*ERR:' to find all reported errors.

WRN:519 Unassigned.

WRN:520 CELERI DECREASES BY ff PER CENT AT DEPTH= ff

Notes: In compact cross sections, that is cross sections in which the hydraulic radius and the hydraulic depth increase with the maximum depth in the cross section, the celerity will never decrease as the

maximum depth increases. The meaning of celerity and the related concepts of critical depth and critical flow in non-compact cross sections in unclear. A decrease in celerity with depth may or may not cause subsequent computational problems. Therefore, it is important in the computation of critical flow tables and in the computation of the generalized Ritter dambreak flood peak to be aware of cross sections in which the celerity decreases.

WRN:521 CRITICAL FLOW DECREASES BY ff PER CENT AT DEPTH= ff

Notes: In compact cross sections, that is cross sections in which the hydraulic radius and the hydraulic depth increase with the maximum depth in the cross section, the flow rate at critical flow will never decrease as the maximum depth increases. In non-compact cross sections the critical flow as computed can decrease. It is not yet clear what this means. Therefore, in the computation of a critical flow table it is unwise to use a cross section for which the critical flow decreases.

WRN:522 ESCOF. TABLE BELOW RANGE IN XLOOKW
TABLE NUMBER = nn
STATION NUMBER = ff
DEPTH = ff

Notes: Subroutine XLOOKW has found that the depth is less than the minimum depth available in the Escoffier table. This message should not appear and may indicate a bug in command GRITTER.

WRN:523 ESCOF. TABLE ABOVE RANGE IN XLOOKW
TABLE NUMBER = nn
STATION NUMBER = ff
DEPTH = ff

Notes: Subroutine XLOOKW has found that the depth is greater then the maximum depth in the Escoffier table. Recompute the cross section for the reservoir in GRITTER so that it is somewhat higher than the maximum dam height to be simulated.

WRN:524 LEFT HAND SUBSET REQUEST OF ff IS LEFT
OF CROSS SECTION BOUNDARY OF ff
SUBSET REQUEST SET TO THE CROSS SECTION BOUNDARY

Notes: In computing a floodway, in computing an explicit request for a subset of the cross section, or in computing the contraction ratio in the FHA bridge loss method, FEQUTL has found that the offset for the left hand end of the subset is off the cross section on the left end. FEQUTL resets the subset boundary to the left end of the cross section and continues the computations.

WRN:525 RIGHT HAND SUBSET REQUEST OF ff IS RIGHT
OF CROSS SECTION BOUNDARY OF ff
SUBSET REQUEST SET TO THE CROSS SECTION BOUNDARY

Notes: In computing a floodway, in computing an explicit request for a subset of the cross section, or in computing the contraction ratio in the FHA bridge loss method, FEQUTL has found that the offset for the right hand end of the subset is off the cross section on the right end. FEQUTL resets the subset boundary to the right end of the cross section and continues the computations.

WRN:526 INVALID RESPONSE FOR USGSBETA. TAKEN AS:NO

Notes: The valid responses to the USGSBETA are 'YES' or 'NO'. All requests other than 'YES' are taken to be 'NO' but this warning is issued to alert you to the possibility of a typing mistake.

WRN:527 GIVEN SPAN= ff DIFFERS FROM TABLE SPAN= ff BY > 2%

Notes: The span inferred from the given rise for a reinforced concrete arch pipe differs by more than 2 % from the span given in the input. This might indicate an input error or it might also indicate that the pipe is not a pipe arch or that the pipe does not conform to the standard dimensions built into FEQ.

WRN:528 EQIV. DIA. FROM SPAN= ff DIA. FROM RISE= ff DIFFERENCE INDICATES POSSIBLE ERROR.

Notes: The equivalent diameter of a nominal elliptical pipe computed from the given span and also computed from the given rise differ by more than about 3 %.

WRN:529 TABLE NUMBER: nn HAS SLOT WIDTH= ff. MAY NOT BE OF A CLOSED CONDUIT.

WRN:530 TEL AT SEC. 2= ff > TEL AT SEC. 1=ff

Notes: CULVERT checks the elevation of the total energy line and reports any increases in the downstream direction. If the error is small it may be reasonable to ignore it. The check is sometimes invalid or misleading when the flow over the roadway is large relative to the flow through the culvert. Further testing will be needed to develop a more refined test.

WRN:531 TEL AT SEC. 3= ff > TEL AT SEC. 2= ff

Notes: CULVERT checks the elevation of the total energy line and reports any increases in the downstream direction. If the error is small it may be reasonable to ignore it. The check is sometimes invalid or misleading when the flow over the roadway is large relative to the flow through the culvert. Further testing will be needed to develop a more refined test.

WRN:532 TEL AT SEC. 4= ff > TEL AT SEC. 3= ff

Notes: CULVERT checks the elevation of the total energy line and reports any increases in the downstream direction. If the error is small it may be reasonable to ignore it. The check is sometimes invalid or misleading when the flow over the roadway is large relative to the flow through the culvert. Further testing will be needed to develop a more refined test.

WRN:533 INVALID HEADWATER RATIO= ff IN FCD123 AT Z1= ff
RESET TO MAXIMUM.

Notes: The headwater ratio for a pipe culvert for flow types 1, 2, and 3 exceeds the maximum of about 1.6 in the figures in USGS.

WRN:534 TOP SLOT= ff IN TABLE#= nn MAY BE TOO LARGE.

Notes: The top slot in a closed conduit should be small. Widths on the order of 0.01 to 0.03 feet have worked well in the past.

WRN:535 TEL AT SEC. 4= ff > TEL AT SEC. 1= ff

Notes: CULVERT checks the elevation of the total energy line and reports any increases in the downstream direction. If the error is small it may be reasonable to ignore it. The check is sometimes invalid or misleading when the flow over the roadway is large relative to the flow through the culvert. Further testing will be needed to develop a more refined test.

WRN:536 NO EXPANSION OF FLOW IN DEPARTURE REACH.

Notes: FEQUTL has determined that there is a contraction of flow in the departure reach. Current experience indicates that this is a frequent occurrence at low to moderate flow rates. However, this is a departure from the standard culvert tests used to determine losses. Therefore, *ad hoc* judgments have been made in computing the losses in this case. The departure section may not represent the departure reach or there may be an error in the cross sections or in an elevation in the CULVERT input.

WRN:537 TAB#= nn OVERFLOW SEEKING XS1 DEPTH FOR FLOW= ff IN APPRO.

Notes: The CULVERT command has not found a solution for the approach reach even though the approach cross section has been overtopped. This sometimes happens in the process of finding a solution.

If the warning persists then try extending the cross section to some high value or review the CULVERT input for errors. Too much flow over the roadway could be a possible cause for the message.

WRN:538 FRD. NUM.= ff > 1 FOR BOX CULV TYPE 3 FLOW. AT DEPTH= ff

Notes: A Froude number greater than 1 by an internal tolerance has been found when computing the Type 3 loss in a box culvert. This can happen especially at the onset of submergence when the loss coefficients have small inconsistencies. FEQUTL sets the value to 1.0 and uses the discharge coefficient for free flow.

WRN:539 NO ROOT FOR TYPE 1 FLOW. TRYING TYPE 2.

Notes: The CULVERT command has not been able to find a root for Type 1 flow and is trying Type 2. This message may indicate some special problems with the computations. However, the flows often look reasonable when this message appears.

WRN:540 NO POSITIVE RESIDUAL FOR TYPE 2 FLOW.

Notes: Informative message showing some aspects of the decision process. May indicate special problems in some cases.

WRN:541 NO NEGATIVE RESIDUAL FOR TYPE 2 FLOW.

Notes: Informative message showing some aspects of the decision process. May indicate special problems in some cases.

WRN:542 AT UPSTREAM HEAD= ff FREE FLOW TYPE UNCLEAR.

Notes: In some cases the free flow type may not be determined because of inconsistencies in the losses. For example, we may assume flow type 2 and find that this assumption shows that the inlet is submerged indicating that the flow type should be 6. Using flow type 6 losses then shows that the flow type should be type 2. FEQUTL then uses flow type 7 which may not be correct. Some interpolation between flow types has been implemented to avoid these problems but more may have to be added if this warning appears frequently and the if flow type 7 is an inappropriate choice.

WRN:543 SUBMERGED FLOW VALUE MAY BE INVALID. RESIDUAL=ff
EXCEEDS ff

Notes: In the process of finding a submerged flow value, CULVERT has encountered an equation with a discontinuity and the apparent root is at the discontinuity. The residual, which in theory is zero at a root, cannot be made small in this case. You must judge if the residual is too large for your purposes.

WRN:544 INITIAL FLOW FOR TYPE 7 IS PHYSICALLY IMPOSSIBLE.

Notes: Informative message. CULVERT will try to reduce the flow in a meaningful manner to find a solution.

WRN:545 HEAD TO WIDTH RATIO= ff > MAX RATIO= ff

Notes: The head to embankment width ratio for an embankment shaped weir has exceeded the maximum ratio. This warning is given only once even though the condition may occur more than once for a given embankment. This message indicates that the heads may be large enough to invalidate the flows because nature of the flow over the embankment at high heads may not be properly reflected in the weir coefficient tables. The maximum ratio of 0.32 for embankment shaped weirs is the approximate limit of experimental verification of the weir coefficient variation with head.

WRN:546 SUBMERGED FLOW VALUE MAY BE INVALID. FLOW RESIDUAL= ff
EXCEEDS' ff

Notes: In the process of finding a submerged flow value, CULVERT has encountered an equation with a discontinuity and the apparent root is at the discontinuity. The residual, which in theory is zero at a root, cannot be made small in this case. You must judge if the residual is too large for your purposes.

WRN:547 ROAD IS LOWER THAN A CULVERT SOFFIT ELEVATION.

Notes: May indicate an input error in certain cases.

WRN:547 UNWISE USE OF SUBSECTION NUMBERS
SUBSECTIONS HAVE BEEN ADDED TO AVOID REPEATED USAGES.
OLD NSUB= nn NEW NSUB= nn PLEASE CHECK FOR VALIDITY

Notes: A unique subsection number must be assigned to each portion of the cross section periphery which has a different roughness or a non-compact shape or both. Thus repeated subsection numbers can only appear in an unbroken sequence in the input. FEQUTL will add new subsection numbers to meet this requirement. The roughness values for the new subsection numbers are inherited from the old subsection. For example, a concrete lined channel with a concrete covered berm must have at least two subsections to account for the non-compact shape created by the berm. The roughness is the same for each subsection. A wide rectangular channel with only part of its bottom paved will also require more than one subsection to account for the change of roughness without a change in shape.

WRN:548 BETA OPTION MUST BE "OLDBETA". THE OPTION HAS BEEN RESET TO "OLDBETA".

Notes: NEWBETA can only be used on cross section which never have a decrease in its offsets.

BUG:nn MESSAGES

FEQUTL contains code designed to detect mistakes in the program. Normally you should not see these messages but there is always the chance that some programming change has not been made properly and the testing process has not used the erroneous program code. A BUG message almost always requires a change in the program code.

BUG:501 INVALID ADDRESS FOR A COMMAND

Notes: A command read from the standard header portion of the input has an address given which is outside the range for the version of FEQUTL used to read the input. Make sure that the header and the version of FEQUTL you are using are compatible. Otherwise there must be a mistake in the address as given. Correcting this mistake requires knowledge of the pattern followed in the computed GOTO used to branch to the proper part of the program to process each command.

BUG:502 ZERO DIFFERENCE IN ELEVATIONS

Notes: A zero difference in the computations involved in an elevation based floodway has been found where a zero difference should be impossible.

BUG:503 GUESSED DEPTH IN SUB. CRITQ IS NOT POSITIVE

Notes: The guessed depth passed to subroutine CRITQ must be positive in order for the computations to continue. Some mistake exists in the computations of the initial guessed depth.

BUG:504 NO SOLUTION FOR COMMAND GRITTER. UPPER DEPTH= ff LOWER DEPTH=ff

Notes: No solution could be found for the generalized Ritter dam failure peak flow. Make sure that the celerity and critical flow for the reservoir cross section are monotone increasing. Also check to make sure that the critical flow table is the correct one for the reservoir cross section. If the flows in this table are too large relative to the reservoir cross section there might not be a solution. The constricted flow table must not have been computed from a cross section larger than the reservoir cross section.

BUG:505 SPAN AND RISE=0.0 IN SUBROUTINE RCARCH.

Notes: Both span and rise cannot be 0.0. One of the two values must be given as nonzero.

FEQUTL EXAMPLES

The following pages illustrate input, and output from FEQUTL. The input to FEQUTL is shown with each line numbered for reference. The line numbers and page numbers are not part of the input to FEQUTL and have been added before printing.

```
STDIN=      5
STDOUT=     6
STDTAB=     7
UNITS=  ENGLISH
NCMD=      16
FEQX        1
FLOODWAY    2
BRIDGE      3
CULVERT     4
FINISH      5
SAME        6
FEQXLST     8
ROADFLOW    9
SEWER      10
MULPIPES   11
FTABIN     12
EMBANKQ    13
JUMP       14
CRITQ      15
GRITTER    16
MULCON     18
DZLIM= 5.0
NRZERO= 0.08
USGSBETA=NO
EPSARG=5.E-4
EPSX=1.E-3

        Example file for FEQUTL illustrating many of its features.

        Note: DZLIM is set to 5.0 to make some of the tables smaller.
        Generally DZLIM should be smaller so that conveyance is
        interpolated more precisely in the cross section tables.


        These comments are an example of the way comments can be placed
        in the input to FEQUTL.  Comments can only appear between
        commands and then must begin in at or after column 9.  No comments
        are allowed within the body of a command.

        Example of table in FEQX format illustrating the
        propagation of subsection numbers into blank fields.

FEQX
TABLE#=  153 NOOUT
STATION=     1.070
NAVM=    0
NSUB     3      .140      .050      .140
    OFFSET ELEVATION SUBS
    -750.     720.      1
    -400.     710.
    -100.     704.08
     -47.     704.08    2
     -20.     695.08
       0.0    695.08
      20.     695.08
      47.     704.08    3
     100.     704.08
     300.     710.
     700.     720.   -1

        Example of cross section table in FEQXLST format.
        Shows example of checking that the offsets never
        decrease to help check for errors when keying in natural
        channel cross sections and also shows a request to save
        the resulting cross section table in the memory of FEQUTL
        so that we can refer to this table later.


FEQXLST
TABLE#=   18 MONOTONE SAVE1 NOOUT
STATION= 2.412
NAVM=0     SCALE=1.0
NSUB     1       0.03
    OFFSET ELEVATION  SUB
0.0  40.0  1
0.0 0.0    1
100.0 0.0   1
100.0 40.0 -1

        Shows example of multiple subsections.  Note that the subsection
        number is given at the start of the line segment because the
        last subsection number is used to terminate the input.
        That is, the line segment from offset 663 to 664 is in
        subsection 1.  The line segment from 659.2 to 661.2 is in
        subsection 2 and  the line segment from 661.2 to 665 is in
        subsection 3.  Finally the subsection value of -1 at offset
        674 signals the end of the cross section.
```

option to input measured values (units) or multiples of it by scale

```
1
2 FEQXLST
3 TABLE#=    4  SAVE12  NEWBETA  OUT12
4 STATION= 2.095
5 NAVM=0      SCALE=50.0
6 NSUB    3       0.08      0.055       0.09
7 HEADING
8 0.0 674.0 1
9 0.6 670.0 1
10 2.3 664.0 1
11 4.0 663.8 1
12 5.4 664.0 1
13 5.7 666.0 1
14 6.4 667.0 1
15 7.2 667.3 1
16 7.8 667.0 1
17 8.5 666.0 1
18 9.0 666.1 1
19 10.8 668.0 1
20 11.6 670.0 1
21 12.2 670.1 1
22 13.0 668.0 1
23 15.0 668.1 1
24 16.0 667.0 1
25 25.6 667.1 1
26 25.7 666.0 1
27 28.8 665.0 1
28 32.5 665.1 1
29 33.2 664.0 1
30 33.6 663.0 1
31 33.8 664.0 2
32 34.7 658.6 2
33 35.1 657.8 2
34 35.8 658.1 2
35 36.1 658.6 2
36 36.4 659.2 2
37 36.9 661.2 3
38 38.3 665.0 3
39 38.4 666.0 3
40 39.2 667.0 3
41 39.8 674.0 -1
42
43
44          Shows use of scale option to adjust the horizontal scale
45          of the cross section.
46          Also shows how we can ask to save the cross section without
47          requesting monotonicity checking and at the same time suppress
48          output to the table file.
49
50 FEQXLST
51 TABLE#=   19 SAVE NOOUT
52 STATION= 2.412
53 NAVM=0      SCALE=0.8
54 NSUB    1       0.03
55      OFFSET ELEVATION  SUB
56 0.0  20.0  1
57 0.0 0.0   1
58 100.0 0.0   1
59 100.0 20.0 -1
60
61
62          Example of computing a critical flow table using the just
63          computed cross section tables.  We also request saving of
64          the critical flow table so we can use it later in the input.
65
66
67 CRITQ
68 TABLE#=   50 SAVE
69 APPTAB#=   18
70 CONTAB#=   19
71 DISCOEF=  0.98
72 TEST OF CRITICAL FLOW TABLE
73
74          Example of use of the just computed critical flow table
75          for the generalized Ritter solution to the classical
76          dam break problem.
77
78 GRITTER
79 APPTAB#=   18
80 CONTAB#=   50
81 BRCHHGT=   0.0
82       DEPTH DISCHARGE   TEST OF GRITTER SOLUTION
83         15.       0.0
84         15.     100.0
85         15.     200.0
86         15.0    500.0
87        -1.0
88
89
```

```
         Example of input of tables either created manually or
         computed by FEQUTL in a previous run for subsequent
         use.  These tables are the standard tables for the
         computation of flow over embankment shaped weirs.
         They must be entered before the EMBANKQ command is
         used.

         Please note that tables for which TYPE is negative
         have only their header information echoed to the output
         file.  This is often a convenient way to reduce the size
         of the output.

FTABIN
TABLE#= 9994
TYPE=   -2
REFL=0.0
      HEAD WEIR COEF  PAVED LOW HEAD WEIR COEFFICIENT
       0.0       2.83
       0.1       2.93
       0.2       2.97
       0.3       2.99
       0.4       3.01
       0.5       3.02
       0.7       3.03
       1.0      3.035
       2.0       3.04
       4.0       3.05
      10.0       3.05
-1.0
TABLE#= 9995
TYPE=   -2
REFL=0.0
      HEAD WEIR COEF GRAVEL LOW HEAD WEIR COEFFICIENT
       0.0       2.50
       0.3       2.61
       0.6       2.68
       0.9       2.80
       1.2       2.87
       1.5       2.92
       2.0       2.98
       2.5       3.02
       3.0       3.04
       3.2      3.046
       4.0       3.05
      10.0       3.05
-1.0
TABLE#= 9996
TYPE=   -2
REFL=0.0
     RATIO WEIR COEF PAVED HIGH HEAD WEIR COEFFICIENT
      0.15       3.05
      0.17      3.062
      0.19      3.071
      0.22      3.081
      0.26      3.088
      0.28      3.090
     10.00      3.090
-1.0
TABLE#= 9997
TYPE=   -2
REFL=0.0
     RATIO WEIR COEF GRAVEL HIGH HEAD WEIR COEFFICIENT
      0.15       2.95
      0.26      3.072
      0.28      3.078
      0.30      3.088
      0.31       3.09
     10.0        3.09
-1.0
TABLE#= 9998
TYPE=   -2
REFL=0.0
     RATIO  FRACTION  PAVED SUBMERGENCE REDUCTION FACTOR
       0.0        1.0
       0.8        1.0
      0.82      0.997
      0.84      0.987
      0.86      0.975
      0.88      0.956
      0.90      0.928
      0.92      0.887
      0.94      0.820
      0.96      0.720
      0.98       0.57
     0.984       0.50
       1.0        0.0
-1.0
TABLE#= 9999
TYPE=   -2
```

```
REFL=0.0
      RATIO  FRACTION  GRAVELED SUBMERGENCE REDUCTION FACTOR
        0.0       1.0
        0.7       1.0
       0.74     0.998
       0.78     0.992
       0.84      0.96
       0.86      0.94
       0.88     0.915
       0.90      0.88
       0.92      0.82
       0.94     0.732
       0.96     0.612
      0.975     0.500
        1.0       0.0
-1.0
TABLE#=   -1


        Example of flow over an embankment shaped weir.
        The table will not be echoed to the output file
        because the table is long and not very readable by
        a human.  It does appear in the table file.

EMBANKQ
TABLE#=  500  5
PLCWTB= 9994
GLCWTB= 9995
PHCWTB= 9996
GHCWTB= 9997
PSUBTB= 9998
GSUBTB= 9999
LABEL= MTPPOOL TO PENPOOL
     OFFSET     CREST     WIDTH  APPROACH SURFACE
        0.0      11.8       25.       9.0 PAVED
      235.0      11.4                 8.9
      630.0      11.3                 8.7
      995.0      11.3                 8.4
     1410.0      11.7                 8.2
     1780.0      11.7                 8.0 END
UPSTREAM HEADS TO USE IN COMPUTING THE TABLE
0.01
0.05
0.10
0.15
0.20
0.30
0.40
0.75
1.0
-1.


        Example of SEWER option.

SEWER
TABLE#=  636  NOOUT
DIAMETER= 3.0
NSIDES=  30
WSLOT= 0.01
HSLOT=200.0
N= 0.020


        Example of MULPIPES option.


MULPIPES
TABLE#=  650   NOOUT
NSIDES=  30
WSLOT= 0.01
HSLOT= 20.0
NPIPES=    3
DIAM=       3.5       4.0       3.5
BOTT=       0.5       0.0       0.5
ROUG=     0.020     0.020     0.020


        Example of MULCON option.  The MULCON option is a generalization
        of the MULPIPES option and therefore can do all that MULPIPES can
        do and more.

MULCON
TABLE#= -107  OUT1
WSLOT= 0.01
HSLOT= 25.0
NPIPES=    5
TYPE:      RCPA      NHE       NVE      CIRC        TE
```

```
SPAN:                              12.00      12.00       3.15
RISE:       2.00       12.00                   2.00      12.00
BOTT:        1.0         2.0        0.0         0.4        0.8
ROUG:       0.02        0.02       0.02        0.02       0.02

        Example of MULCON computing a cross section table for
        a box culvert.

MULCON
TABLE#= -999 SAVE12  NOOUT
WSLOT= 0.01
HSLOT= 25.0
NPIPES=    1
TYPE:       BOX
SPAN:        3.
RISE:        3.
BOTT:       0.0
ROUG:     0.018


        Example of computing a bridge loss table.
        The following cross section is downstream of the bridge and
        must be given first.

FEQX
TABLE#=  800 NOOUT
STATION=
NAVM    0
NSUB    3       .080       .065       .080
RJS SEGMENT NO. LS1417, D.S. OF CERMAK ROAD
   -900.00     659.00     1
   -850.00     658.00     1
   -700.00     656.00     1
      .00      654.40     1
    50.00      655.10     1
   100.00      655.40     1
   113.00      657.40     1
   120.00      657.50     1
   135.00      657.10     1
   140.00      656.00     1
   147.00      654.90     2
   160.00      648.00     2
   165.00      646.10     2
   170.00      644.80     2
   180.00      644.20     2
   190.00      644.50     2
   200.00      644.90     2
   210.00      644.60     2
   215.00      645.60     2
   218.00      648.00     2
   221.00      650.90     3
   271.00      656.90     3
   321.00      662.00     3
   370.00      664.40    -1

        The following cross section is upstream of the bridge and is
        given next.
FEQX
TABLE#=  804 NOOUT
STATION=
NAVM    0
NSUB    3       .100       .060       .100
RJS SEGMENT NO. LS1420, U.S. OF CERMAK ROAD
    50.00      652.80     1
    78.00      651.90
   103.00      651.50
   125.00      650.90     2
   133.00      647.80
   142.00      646.80
   150.00      645.70
   160.00      645.20
   170.00      643.60
   175.00      645.60
   179.00      647.80
   185.00      650.00     3
   204.00      657.20
   219.00      658.40
   223.00      661.40
   283.00      664.00    -1

        The request for computation of a bridge table is next.
        This command is old and predates the feature for saving tables
        internally or of reading precomputed tables from a file.

BRIDGE
CERMAK ROAD
TYPE=RDFLOW
BASE CURVE#=00001
ABUTMENT ALIGNMENT=0
```

```
BRIDGE SKEW=0.0
ADJUSTMENT FACTOR=1.0
UPSTREAM OFFSET=170.0
DOWNSTREAM OFFSET=180.0
PIER TYPE=    2
PIER LENGTH= 00.0
PIER SKEW= 00.0
PIER TABLE
ELEV        PNUM PWITH
0.00           1   3.0
0.01           1   3.0
5.69           1   3.0
5.70           2   3.0
42.00          2   3.0
42.00          1  -1.0
TABLE#=  801
STATION=
NAVM=   0
NSUB    1 0.024
 OFFSET    ELEVATION  SUB  CERMAK ROAD BRIDGE OPENING
      0.      660.80    1
      0.      651.30    1
     52.      649.20    1
     62.      647.80    1
    105.      643.50    1
    156.      649.00    1
    156.      661.00    1
      0.      660.80   -1
HLCOEF TABLE NUMBER
TABLE#=  802


       Example of a simple culvert.  FEQUTL can create table of
       type 5 but FEQ is not yet able to use them.  Type 5 tables
       are more compact than type 6 and are more easily read by a
       human.  They will also take less space to store in FEQ.

CULVERT
TABLE#= 128
TYPE=    5
LABEL=SIMPLE CULVERT EXAMPLE
Approach Section Data
APPTAB#=   4
APPELV=  100.
APPLEN=  4.0
APPLOS= 0.0
APPEXP= 0.5
Culvert Description
NODEID=YES
SFAC= 1.0
 NODE    NODEID  XNUM   STATION ELEVATION   KA   KD HTAB
  100 TESTCLVU   999      0.00     100.0  0.0  0.0    0




      TESTCLVD   999     50.00     099.9  0.0  0.0
   -1
CULCLS=BOX
Departure Section Data
DEPTAB#=   4
DEPELV= 99.5
LOSOPT=MOMENTUM
Discharge Coefficient Data
KRB= 1.0
KWING= 1.0
KPROJ= 1.0
C46= 0.84
Roadway Description
PLCWTB= 9994
GLCWTB= 9995
PHCWTB= 9996
GHCWTB= 9997
PSUBTB= 9998
GSUBTB= 9999
    OFFSET     CREST      WIDTH  APPROACH SURFACE
       0.0    105.30        25. -999999.0 PAVED
      50.0    105.00                      END
Head Sequence Definition
NFRAC= 11
POWER= 2.5
0.5
1.0
2.0
3.0
4.0
5.0
```

```
5.5
-1.

FINISH
```

The following pages show the output written by FEQUTL to the standard output file for the input given on pages 2–8. Again the line numbers and page numbers have been added before printing but other than these additions the output is that produced by FEQUTL.

```
FEQUTL Version 2.70  15 March 1990

DZLIM=      5.00 NRZERO=       .08 USGSBETA=NO
EPSARG=   .000500
EPSF=   .001000

        Example file for FEQUTL illustrating many of its features.

        Note: DZLIM is set to 5.0 to make some of the tables smaller.
        Generally DZLIM should be smaller so that conveyance is
        interpolated more precisely in the cross section tables.


        These comments are an example of the way comments can be placed
        in the input to FEQUTL.  Comments can only appear between
        commands and then must begin in at or after column 9.  No comments
        are allowed within the body of a command.

        Example of table in FEQX format illustrating the
        propagation of subsection numbers into blank fields.

FEQX

TABLE#=  153  NOOUT
STATION=     1.070
NAVM=    0  SCALE=     1.000 SHIFT=      .000
NSUB    3  .140  .050  .140
    OFFSET ELEVATION SUBS
    -750.0    720.00    1
    -400.0    710.00    1
    -100.0    704.08    1
     -47.0    704.08    2
     -20.0    695.08    2
        .0    695.08    2
      20.0    695.08    2
      47.0    704.08    3
     100.0    704.08    3
     300.0    710.00    3
     700.0    720.00   -1

*WRN:504*LINE SEGMENT ENDING AT (    -47.00    704.08) IS HORIZONTAL AND NOT AT MINIMUM OR MAXIMUM ELEVATION.
     RIGHT HAND END INCREMENTED BY      .053

*WRN:504*LINE SEGMENT ENDING AT (    100.00    704.08) IS HORIZONTAL AND NOT AT MINIMUM OR MAXIMUM ELEVATION.
     RIGHT HAND END INCREMENTED BY      .053

ELEMENTS FOR SECTION NUMBER  153

TABLE#=  153
TYPE=    1
STATION= 1.07000E+00
ELEVATION= 6.95080E+02

     DEPTH TOP WID      AREA SQRT(CNV)   BETA     YBARA  ALPHA     CRITQ
    .00000    40.0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
    .08002    40.5 3.220E+00 4.212E+00  1.000 1.286E-01  1.000 5.153E+00
   4.50000    66.9 2.406E+02 1.288E+02  1.000 4.959E+02  1.000 2.588E+03
   9.00000    93.8 6.023E+02 2.464E+02  1.000 2.347E+03  1.000 8.658E+03
   9.05298   202.7 6.101E+02 2.480E+02  1.005 2.379E+03  1.009 6.007E+03
  11.98651   451.3 1.569E+03 3.551E+02  1.492 5.398E+03  2.388 1.661E+04
  14.91998   700.0 3.258E+03 4.813E+02  1.783 1.230E+04  3.766 3.989E+04
  18.25329   950.0 6.008E+03 6.449E+02  1.873 2.751E+04  4.587 8.574E+04
  21.58667  1200.0 9.592E+03 8.229E+02  1.865 5.328E+04  4.890 1.539E+05
  24.91998  1450.0 1.401E+04 1.013E+03  1.823 9.238E+04  4.932 2.471E+05

        Example of cross section table in FEQXLST format.
        Shows example of checking that the offsets never
        decrease to help check for errors when keying in natural
        channel cross sections and also shows a request to save
        the resulting cross section table in the memory of FEQUTL
        so that we can refer to this table later.


FEQXLST

TABLE#=   18  MONOTONE SAVE1 NOOUT
STATION=     2.412
NAVM=    0  SCALE=     1.000 SHIFT=      .000
NSUB    1  .030
    OFFSET ELEVATION  SUB
        .0     40.00    1
        .0       .00    1
     100.0       .00    1
     100.0     40.00   -1

ELEMENTS FOR SECTION NUMBER   18

TABLE#=   18
```

```
TYPE=    1
STATION= 2.41200E+00
ELEVATION= 0.00000E+00

     DEPTH TOP WID      AREA SQRT(CNV)   BETA      YBARA  ALPHA      CRITQ
    .00000   100.0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
    .08000   100.0 8.000E+00 8.584E+00  1.000 3.200E-01  1.000 1.284E+01
   4.44444   100.0 4.444E+02 2.374E+02  1.000 9.877E+02  1.000 5.317E+03
   8.88889   100.0 8.889E+02 4.121E+02  1.000 3.951E+03  1.000 1.504E+04
  13.33333   100.0 1.333E+03 5.640E+02  1.000 8.889E+03  1.000 2.763E+04
  17.77778   100.0 1.778E+03 7.007E+02  1.000 1.580E+04  1.000 4.253E+04
  22.22222   100.0 2.222E+03 8.263E+02  1.000 2.469E+04  1.000 5.944E+04
  26.66667   100.0 2.667E+03 9.429E+02  1.000 3.556E+04  1.000 7.814E+04
  31.11111   100.0 3.111E+03 1.052E+03  1.000 4.840E+04  1.000 9.847E+04
  35.55556   100.0 3.556E+03 1.155E+03  1.000 6.321E+04  1.000 1.203E+05
  40.00000   100.0 4.000E+03 1.253E+03  1.000 8.000E+04  1.000 1.436E+05

       Shows example of multiple subsections.  Note that the subsection
       number is given at the start of the line segment because the
       last subsection number is used to terminate the input.
       That is, the line segment from offset 663 to 664 is in
       subsection 1.  The line segment from 659.2 to 661.2 is in
       subsection 2 and  the line segment from 661.2 to 665 is in
       subsection 3.  Finally the subsection value of -1 at offset
       674 signals the end of the cross section.


FEQXLST

TABLE#=    4   SAVE12  NEWBETA  OUT12
SELECTION OF BETA OPTION "NEWBETA" IMPLIES CHECKING FOR MONOTONICITY.
STATION=     2.095
NAVM=    0  SCALE=    50.000 SHIFT=      .000
NSUB    3  .080  .055  .090
HEADING
        .0    674.00    1
      30.0    670.00    1
     115.0    664.00    1
     200.0    663.80    1
     270.0    664.00    1
     285.0    666.00    1
     320.0    667.00    1
     360.0    667.30    1
     390.0    667.00    1
     425.0    666.00    1
     450.0    666.10    1
     540.0    668.00    1
     580.0    670.00    1
     610.0    670.10    1
     650.0    668.00    1
     750.0    668.10    1
     800.0    667.00    1
    1280.0    667.10    1
    1285.0    666.00    1
    1440.0    665.00    1
    1625.0    665.10    1
    1660.0    664.00    1
    1680.0    663.00    1
    1690.0    664.00    2
    1735.0    658.60    2
    1755.0    657.80    2
    1790.0    658.10    2
    1805.0    658.60    2
    1820.0    659.20    2
    1845.0    661.20    3
    1915.0    665.00    3
    1920.0    666.00    3
    1960.0    667.00    3
    1990.0    674.00   -1
*WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=   665.100
*WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=   667.100

ELEMENTS FOR SECTION NUMBER    4

TABLE#=    4
TYPE=  -12
STATION= 2.09500E+00
ELEVATION= 6.57800E+02

     DEPTH TOP WID      AREA SQRT(CNV)   BETA      YBARA  ALPHA      CRITQ
    .00000      .0 0.000E+00 0.000E+00  1.067 0.000E+00  1.185 0.000E+00
    .08002     11.3 4.535E-01 1.199E+00  1.067 1.210E-02  1.185 4.855E-01
    .29999     42.5 6.375E+00 6.982E+00  1.067 6.374E-01  1.185 1.321E+01
    .79999     70.0 3.450E+01 2.415E+01  1.040 1.028E+01  1.107 1.330E+02
   1.40002     90.0 8.250E+01 4.591E+01  1.036 4.479E+01  1.097 4.343E+02
   3.40002    131.7 3.042E+02 1.199E+02  1.035 4.176E+02  1.092 2.556E+03
   5.20001    179.8 5.845E+02 1.920E+02  1.058 1.204E+03  1.149 5.859E+03
   6.00000    225.2 7.465E+02 2.243E+02  1.081 1.734E+03  1.207 7.671E+03
   6.20001    391.6 8.082E+02 2.325E+02  1.107 1.889E+03  1.269 7.811E+03
```

```
    7.20001   463.5 1.236E+03 2.844E+02  1.219 2.905E+03  1.596 1.046E+04
    7.29999   669.8 1.292E+03 2.873E+02  1.233 3.031E+03  1.638 1.062E+04
    8.20001   833.3 1.969E+03 3.448E+02  1.335 4.488E+03  2.009 1.425E+04
    8.29999   871.2 2.054E+03 3.509E+02  1.340 4.689E+03  2.034 1.481E+04
    9.20001  1029.7 2.909E+03 4.150E+02  1.352 6.912E+03  2.143 2.126E+04
    9.29999  1544.6 3.038E+03 4.087E+02  1.361 7.209E+03  2.178 2.164E+04

*WRN:506* CONVEYANCE NON-INCREASING AT DEPTH=      9.30
    9.50000  1613.5 3.354E+03 4.267E+02  1.388 7.848E+03  2.287 2.275E+04
   10.20001  1691.4 4.511E+03 4.963E+02  1.404 1.060E+04  2.411 3.028E+04
   10.29999  1801.7 4.685E+03 5.030E+02  1.402 1.106E+04  2.411 3.155E+04
   12.20001  1911.0 8.212E+03 7.112E+02  1.293 2.328E+04  2.082 6.865E+04
   12.29999  1944.0 8.405E+03 7.202E+02  1.287 2.411E+04  2.062 7.114E+04
   16.20001  1990.0 1.608E+04 1.158E+03  1.145 7.179E+04  1.534 2.079E+05

 ESTIMATES OF CRITICAL FLOW.
      DEPTH    DBETADY  DALPHADY      QBETA     QALPHA      QCRIT
     .00000     .00000    .00000         .0         .0         .0
     .08002     .00000    .00000         .5         .5         .5
     .29999     .00000    .00000        13.6       12.9       14.0
     .79999     .01008    .02124       135.1      130.9      137.4
    1.40002     .00112    .00084       440.6      428.1      448.2
    3.40002     .00353    .00893      2589.5     2522.5     2623.4
    5.20001     .01679    .04228      5968.5     5752.2     5979.9
    6.00000     .03492    .08988      7848.6     7497.9     7712.4
    6.20001     .20740    .50693      7996.5     7629.5     6588.8
    7.20001     .05348    .19535     11034.1     9908.2    11449.9
    7.29999     .21199    .63129     11221.9    10042.7    10186.9
    8.20001     .04792    .24010     15535.1    13072.5    17172.5
    8.29999     .04958    .24516     16182.6    13550.0    17897.1
    9.20001    -.01093    .02957     23600.8    19145.6    27752.2
    9.29999     .17726    .64913     24034.9    19485.5    24178.8
    9.50000     .10634    .45772     25397.8    20386.4    27439.8
   10.20001    -.03065   -.02440     34291.0    26742.6    41799.6
   10.29999    -.01349    .02999     35765.0    27838.1    42874.3
   12.20001    -.05933   -.21054     77659.7    60683.8    96606.8
   12.29999    -.05426   -.19481     80401.6    62938.1    99172.2
   16.20001    -.02039   -.07767    226550.4   190741.5   259292.1


        Shows use of scale option to adjust the horizontal scale
        of the cross section.
        Also shows how we can ask to save the cross section without
        requesting monotonicity checking and at the same time suppress
        output to the table file.

FEQXLST

TABLE#=   19  SAVE NOOUT
STATION=     2.412
NAVM=    0  SCALE=      .800 SHIFT=      .000
NSUB    1  .030
    OFFSET ELEVATION  SUB
        .0     20.00    1
        .0       .00    1
      80.0       .00    1
      80.0     20.00   -1

ELEMENTS FOR SECTION NUMBER   19

TABLE#=   19
TYPE=    1
STATION= 2.41200E+00
ELEVATION= 0.00000E+00

     DEPTH TOP WID      AREA SQRT(CNV)   BETA     YBARA  ALPHA     CRITQ
    .00000    80.0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
    .08000    80.0 6.400E+00 7.677E+00  1.000 2.560E-01  1.000 1.027E+01
   4.00000    80.0 3.200E+02 1.939E+02  1.000 6.400E+02  1.000 3.632E+03
   8.00000    80.0 6.400E+02 3.356E+02  1.000 2.560E+03  1.000 1.027E+04
  12.00000    80.0 9.600E+02 4.581E+02  1.000 5.760E+03  1.000 1.887E+04
  16.00000    80.0 1.280E+03 5.679E+02  1.000 1.024E+04  1.000 2.905E+04
  20.00000    80.0 1.600E+03 6.685E+02  1.000 1.600E+04  1.000 4.060E+04


        Example of computing a critical flow table using the just
        computed cross section tables.  We also request saving of
        the critical flow table so we can use it later in the input.


CRITQ
TABLE#=   50 SAVE
APPTAB#=   18
CONTAB#=   19
DISCOEF=      .980
TEST OF CRITICAL FLOW TABLE

TESTING TABLE#=   19 FOR MONOTONE CELERITY AND CRITICAL FLOW.
TABLE TESTS OK.
```

```
1
2 TABLE#=   50
3 TYPE=     2
4 REFL=0.0
5       HEAD DISCHARGE  TEST OF CRITICAL FLOW TABLE
6        .000        .0
7        .107       10.3
8       5.373    3631.7
9      10.746   10271.9
10     16.119   18870.8
11     21.492   29053.5
12     26.865   40603.4
13
14          Example of use of the just computed critical flow table
15          for the generalized Ritter solution to the classical
16          dam break problem.
17
18 GRITTER
19 APPTAB#=   18
20 CONTAB#=   50
21 BRCHHGT=       .000
22
23 TESTING TABLE#=   18 FOR MONOTONE CELERITY AND CRITICAL FLOW.
24 TABLE TESTS OK.
25
26 TABLE FOR CELERITY AND ESCOFFIER VARIABLE FOR RESERVOIR
27
28       DEPTH       TOP       AREA  CELERITY ESCOFFIER
29        .000     100.0 0.000E+00      .000 0.000E+00
30        .080     100.0 8.000E+00     1.605 3.210E+00
31       4.444     100.0 4.444E+02    11.963 2.393E+01
32       8.889     100.0 8.889E+02    16.918 3.384E+01
33      13.333     100.0 1.333E+03    20.720 4.144E+01
34      17.778     100.0 1.778E+03    23.926 4.785E+01
35      22.222     100.0 2.222E+03    26.750 5.350E+01
36      26.667     100.0 2.667E+03    29.303 5.861E+01
37      31.111     100.0 3.111E+03    31.651 6.330E+01
38      35.556     100.0 3.556E+03    33.836 6.767E+01
39      40.000     100.0 4.000E+03    35.889 7.178E+01
40       DEPTH DISCHARGE   TEST OF GRITTER SOLUTION
41
42  INITDEPTH  INITFLOW PEAKDEPTH    PEAKFLOW
43     15.000        .0     9.401 8.60907E+03
44     15.000      100.0    9.431 8.64672E+03
45     15.000      200.0    9.462 8.68445E+03
46     15.000      500.0    9.554 8.79819E+03
47
48
49          Example of input of tables either created manually or
50          computed by FEQUTL in a previous run for subsequent
51          use.  These tables are the standard tables for the
52          computation of flow over embankment shaped weirs.
53          They must be entered before the EMBANKQ command is
54          used.
55
56          Please note that tables for which TYPE is negative
57          have only their header information echoed to the output
58          file.  This is often a convenient way to reduce the size
59          of the output.
60
61 FTABIN
62
63 TABLE#= 9994
64 TYPE=   -2
65 REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.
66
67       HEAD WEIR COEF  PAVED LOW HEAD WEIR COEFFICIENT
68
69 TABLE#= 9995
70 TYPE=   -2
71 REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.
72
73       HEAD WEIR COEF GRAVEL LOW HEAD WEIR COEFFICIENT
74
75 TABLE#= 9996
76 TYPE=   -2
77 REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.
78
79      RATIO WEIR COEF PAVED HIGH HEAD WEIR COEFFICIENT
80
81 TABLE#= 9997
82 TYPE=   -2
83 REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.
84
85      RATIO WEIR COEF GRAVEL HIGH HEAD WEIR COEFFICIENT
86
87 TABLE#= 9998
88 TYPE=   -2
89 REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.
```

```
1
2       RATIO  FRACTION  PAVED SUBMERGENCE REDUCTION FACTOR
3
4  TABLE#= 9999
5  TYPE=    -2
6  REFERENCE LEVEL=         0. FAC=      1.000 SHIFT=         0.
7
8       RATIO  FRACTION  GRAVELED SUBMERGENCE REDUCTION FACTOR
9
10 THERE ARE NOW    6 FUNCTION TABLES STORED
11     468 LOCATIONS OUT OF  100000 ARE USED
12
13
14
15          Example of flow over an embankment shaped weir.
16          The table will not be echoed to the output file
17          because the table is long and not very readable by
18          a human.  It does appear in the table file.
19
20 EMBANKQ
21 TABLE#=  500 TYPE=    5 H/L CRIT RATIO=     .15 H/L MAX RATIO=     .32
22 PLCWTB= 9994
23 GLCWTB= 9995
24 PHCWTB= 9996
25 GHCWTB= 9997
26 PSUBTB= 9998
27 GSUBTB= 9999
28 LABEL= MTPPOOL TO PENPOOL
29      OFFSET      CREST      WIDTH  APPROACH SURFACE
30          .0      11.80       25.0        9.0 PAVED
31       235.0      11.40       25.0        8.9 PAVED
32       630.0      11.30       25.0        8.7 PAVED
33       995.0      11.30       25.0        8.4 PAVED
34      1410.0      11.70       25.0        8.2 PAVED
35      1780.0      11.70       25.0        8.0 END
36
37 MINIMUM CREST ELEVATION=     11.30
38 MINIMUM CREST LOCATION=     630.0
39 UPSTREAM HEADS TO USE IN COMPUTING THE TABLE
40         .01
41         .05
42         .10
43         .15
44         .20
45         .30
46         .40
47         .75
48        1.00
49       -1.00
50
51
52          Example of SEWER option.
53
54 SEWER
55
56 TABLE#=  636  NOOUT
57 DIAMETER=   3.00
58 POLYGON APPROX HAS 30 SIDES
59 WIDTH OF SLOT=    .010
60 HEIGHT OF SLOT=    200.
61 MANNING N=    .020
62
63 ELEMENTS FOR SECTION NUMBER  636
64
65 TABLE#=  636
66 TYPE=    1
67 STATION= 0.00000E+00
68 ELEVATION=-5.50122E-03
69
70       DEPTH TOP WID       AREA SQRT(CNV)   BETA      YBARA  ALPHA      CRITQ
71      .00000       .0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
72      .03290       .6 1.030E-02 2.223E-01  1.000 1.129E-04  1.000 7.495E-03
73      .13016      1.2 1.003E-01 1.176E+00  1.000 5.019E-03  1.000 1.629E-01
74      .28753      1.8 3.359E-01 2.813E+00  1.000 3.822E-02  1.000 8.304E-01
75      .49812      2.2 7.579E-01 5.036E+00  1.000 1.517E-01  1.000 2.503E+00
76      .75275      2.6 1.375E+00 7.679E+00  1.000 4.212E-01  1.000 5.664E+00
77     1.04028      2.9 2.161E+00 1.053E+01  1.000 9.278E-01  1.000 1.065E+01
78     1.34813      3.0 3.063E+00 1.338E+01  1.000 1.731E+00  1.000 1.758E+01
79     1.66287      3.0 4.006E+00 1.601E+01  1.000 2.843E+00  1.000 2.629E+01
80     1.97073      2.9 4.907E+00 1.823E+01  1.000 4.216E+00  1.000 3.645E+01
81     2.25825      2.6 5.694E+00 1.992E+01  1.000 5.742E+00  1.000 4.774E+01
82     2.51288      2.2 6.311E+00 2.102E+01  1.000 7.272E+00  1.000 6.014E+01
83     2.72348      1.8 6.733E+00 2.155E+01  1.000 8.648E+00  1.000 7.452E+01
84     2.88085      1.2 6.968E+00 2.160E+01  1.000 9.727E+00  1.000 9.432E+01
85     2.97810       .6 7.058E+00 2.160E+01  1.000 1.041E+01  1.000 1.345E+02
86     3.01048       .0 7.069E+00 2.160E+01  1.000 1.064E+01  1.000 1.066E+03
87   500.00000       .0 1.204E+01 2.160E+01  1.000 4.759E+03  1.000 1.066E+03
88
89
```

```
1         Example of MULPIPES option.
2
3
4 MULPIPES
5
6 TABLE#=  650   NOOUT
7 POLYGON APPROX HAS  30 SIDES
8 WIDTH OF SLOT=   .010
9 HEIGHT OF SLOT ABOVE DATUM=    20.
10 NUMBER OF PIPES=    3
11 DIAMETERS=   3.50   4.00   3.50
12 BOTTOMS=    .50    .00    .50
13 ROUGNESS=   .020   .020   .020
14
15 ELEMENTS FOR SECTION NUMBER  650
16
17 TABLE#=  650
18 TYPE=    1
19 STATION= 0.00000E+00
20 ELEVATION=-7.33495E-03
21
22      DEPTH TOP WID       AREA SQRT(CNV)   BETA      YBARA  ALPHA      CRITQ
23     .00000      .0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
24     .04387      .8 1.831E-02 3.263E-01  1.000 2.677E-04  1.000 1.538E-02
25     .17354     1.6 1.783E-01 1.726E+00  1.000 1.190E-02  1.000 3.343E-01
26     .38337     2.4 5.972E-01 4.129E+00  1.000 9.059E-02  1.000 1.705E+00
27     .50092     2.6 8.899E-01 5.512E+00  1.000 1.777E-01  1.000 2.943E+00
28     .53930     4.2 1.020E+00 5.969E+00  1.000 2.142E-01  1.000 2.864E+00
29     .65277     5.8 1.587E+00 7.542E+00  1.000 3.603E-01  1.000 4.702E+00
30     .66417     5.9 1.653E+00 7.718E+00  1.000 3.787E-01  1.000 4.958E+00
31     .83636     7.4 2.797E+00 1.058E+01  1.000 7.584E-01  1.000 9.783E+00
32    1.00367     8.3 4.112E+00 1.355E+01  1.000 1.334E+00  1.000 1.637E+01
33    1.08206     8.8 4.782E+00 1.497E+01  1.000 1.682E+00  1.000 2.004E+01
34    1.37913     9.9 7.555E+00 2.035E+01  1.000 3.507E+00  1.000 3.746E+01
35    1.38703     9.9 7.633E+00 2.050E+01  1.000 3.567E+00  1.000 3.800E+01
36    1.71457    10.6 1.100E+01 2.625E+01  1.000 6.612E+00  1.000 6.346E+01
37    1.79751    10.7 1.189E+01 2.766E+01  1.000 7.561E+00  1.000 7.094E+01
38    2.07374    11.0 1.489E+01 3.216E+01  1.000 1.126E+01  1.000 9.836E+01
39    2.21716    11.0 1.646E+01 3.437E+01  1.000 1.350E+01  1.000 1.144E+02
40    2.44093    10.9 1.891E+01 3.761E+01  1.000 1.746E+01  1.000 1.414E+02
41    2.62764    10.6 2.092E+01 4.010E+01  1.000 2.118E+01  1.000 1.664E+02
42    2.80010    10.3 2.273E+01 4.222E+01  1.000 2.495E+01  1.000 1.911E+02
43    3.01100     9.8 2.485E+01 4.452E+01  1.000 2.996E+01  1.000 2.247E+02
44    3.13554     9.4 2.604E+01 4.571E+01  1.000 3.313E+01  1.000 2.463E+02
45    3.35050     8.4 2.796E+01 4.744E+01  1.000 3.894E+01  1.000 2.887E+02
46    3.43261     8.0 2.864E+01 4.798E+01  1.000 4.127E+01  1.000 3.070E+02
47    3.63130     6.7 3.010E+01 4.890E+01  1.000 4.711E+01  1.000 3.620E+02
48    3.67831     6.3 3.040E+01 4.904E+01  1.000 4.853E+01  1.000 3.782E+02
49    3.84113     4.6 3.130E+01 4.911E+01  1.000 5.355E+01  1.000 4.615E+02
50    3.86190     4.4 3.139E+01 4.911E+01  1.000 5.421E+01  1.000 4.778E+02
51    3.97080     2.4 3.176E+01 4.911E+01  1.000 5.765E+01  1.000 6.622E+02
52    3.97537     2.2 3.177E+01 4.911E+01  1.000 5.779E+01  1.000 6.836E+02
53    4.01323      .0 3.181E+01 4.911E+01  1.000 5.899E+01  1.000 4.674E+03
54    4.01414      .0 3.181E+01 4.911E+01  1.000 5.902E+01  1.000 5.877E+03
55  500.00000      .0 4.669E+01 4.911E+01  1.000 1.953E+04  1.000 5.877E+03
56
57
58         Example of MULCON option.  The MULCON option is a generalization
59         of the MULPIPES option and therefore can do all that MULPIPES can
60         do and more.
61
62 MULCON
63
64 TABLE#= -107  OUT1
65 WIDTH OF SLOT=    .010
66 HEIGHT OF SLOT ABOVE DATUM=    25.
67 NUMBER OF CONDUITS=    5
68 TYPE=          RCPA      NHE       NVE      CIRC       TE
69 SPAN=           .00       .00     12.00     12.00     3.15
70 RISE=          2.00     12.00       .00      2.00    12.00
71 BOTTOM=        1.00      2.00       .00       .40      .80
72 ROUGNESS=      .020      .020      .020      .020      .020
73 PROCESSING  TYPE: RCPA
74     USING SPAN=   3.25 AND RISE=   2.00
75 PROCESSING  TYPE: NHE
76     USING SPAN=  18.90 AND RISE=  12.00
77 PROCESSING  TYPE: NVE
78     USING SPAN=  12.00 AND RISE=  18.90
79 PROCESSING  TYPE: CIRC
80     USING SPAN=  12.00 AND RISE=  12.00
81 PROCESSING  TYPE: TE
82     USING SPAN=   3.15 AND RISE=  12.00
83 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=     2.866
84 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=     2.937
85 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=     2.986
86 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=     2.987
87 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=     2.997
88 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=     3.004
89 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   4 AT ELEVATION=    11.963
```

```
 1 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     11.996
 2 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     12.118
 3 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     12.320
 4 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     12.320
 5 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     12.338
 6 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     12.338
 7 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     12.412
 8 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     12.412
 9 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     12.591
10 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     12.591
11 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     12.863
12 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     12.863
13 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     13.003
14 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     13.003
15 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    2 AT ELEVATION=     13.442
16 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     13.442
17 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     13.442
18 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    2 AT ELEVATION=     13.726
19 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     13.726
20 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     13.726
21 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    2 AT ELEVATION=     13.759
22 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     13.759
23 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     13.759
24 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    2 AT ELEVATION=     13.949
25 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     13.949
26 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     13.949
27 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    2 AT ELEVATION=     14.013
28 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     14.013
29 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     14.013
30 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     15.100
31 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     15.100
32 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     16.147
33 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     16.147
34 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     17.080
35 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     17.080
36 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     17.856
37 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     17.856
38 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    3 AT ELEVATION=     18.438
39 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     18.438
40 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     18.438
41 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    3 AT ELEVATION=     18.798
42 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     18.798
43 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     18.798
44 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    3 AT ELEVATION=     18.920
45 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     18.920
46 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     18.920
47 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     21.960
48 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     21.960
49 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     25.000
50 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     25.000
51 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    1 AT ELEVATION=     25.010
52 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    2 AT ELEVATION=     25.010
53 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    3 AT ELEVATION=     25.010
54 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    4 AT ELEVATION=     25.010
55 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION    5 AT ELEVATION=     25.010
56
57 ELEMENTS FOR SECTION NUMBER  107
58
59 TABLE#=  107
60 TYPE=   -1
61 STATION= 0.00000E+00
62 ELEVATION=-2.04239E-02
63
64       DEPTH TOP WID       AREA SQRT(CNV)   BETA      YBARA  ALPHA      CRITQ
65      .00000       .0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
66      .08000       1.5 5.865E-02 7.135E-01  1.000 1.564E-03  1.000 6.656E-02
67      .12207       2.2 1.365E-01 1.253E+00  1.000 5.556E-03  1.000 1.914E-01
68      .40806       3.9 1.018E+00 5.503E+00  1.000 1.592E-01  1.000 2.942E+00
69      .48209       6.2 1.395E+00 6.655E+00  1.000 2.474E-01  1.000 3.740E+00
70      .48252       6.3 1.398E+00 6.662E+00  1.000 2.480E-01  1.000 3.749E+00
71      .70233       8.8 3.053E+00 1.090E+01  1.000 7.269E-01  1.000 1.020E+01
72      .75185       9.2 3.500E+00 1.193E+01  1.000 8.891E-01  1.000 1.224E+01
73     1.01965      11.9 6.327E+00 1.767E+01  1.000 2.189E+00  1.000 2.618E+01
74     1.03921      12.9 6.570E+00 1.810E+01  1.000 2.315E+00  1.000 2.656E+01
75     1.06337      13.5 6.890E+00 1.864E+01  1.000 2.478E+00  1.000 2.790E+01
76     1.06439      13.6 6.904E+00 1.866E+01  1.000 2.485E+00  1.000 2.796E+01
77     1.09771      14.3 7.367E+00 1.945E+01  1.000 2.722E+00  1.000 3.004E+01
78     1.19405      15.8 8.816E+00 2.177E+01  1.000 3.501E+00  1.000 3.738E+01
79     1.23141      16.3 9.414E+00 2.269E+01  1.000 3.841E+00  1.000 4.066E+01
80     1.28698      16.8 1.033E+01 2.408E+01  1.000 4.390E+00  1.000 4.595E+01
81     1.35856      17.5 1.156E+01 2.589E+01  1.000 5.173E+00  1.000 5.333E+01
82     1.44329      18.2 1.308E+01 2.805E+01  1.000 6.216E+00  1.000 6.284E+01
83     1.53780      19.0 1.483E+01 3.048E+01  1.000 7.535E+00  1.000 7.440E+01
84     1.55632      19.1 1.519E+01 3.095E+01  1.000 7.813E+00  1.000 7.678E+01
85     1.62441      19.6 1.651E+01 3.273E+01  1.000 8.891E+00  1.000 8.597E+01
86     1.63834      19.7 1.678E+01 3.310E+01  1.000 9.123E+00  1.000 8.794E+01
87     1.74091      20.2 1.882E+01 3.577E+01  1.000 1.095E+01  1.000 1.031E+02
88     1.84029      20.6 2.085E+01 3.833E+01  1.000 1.292E+01  1.000 1.189E+02
89     1.84142      20.6 2.087E+01 3.836E+01  1.000 1.294E+01  1.000 1.191E+02
```

```
 1    2.00746    21.2 2.435E+01 4.264E+01  1.000 1.670E+01  1.000 1.480E+02
 2    2.06227    23.9 2.559E+01 4.403E+01  1.000 1.806E+01  1.000 1.502E+02
 3    2.07119    24.3 2.580E+01 4.426E+01  1.000 1.829E+01  1.000 1.508E+02
 4    2.16904    26.1 2.827E+01 4.678E+01  1.000 2.094E+01  1.000 1.669E+02
 5    2.26189    27.7 3.077E+01 4.923E+01  1.000 2.368E+01  1.000 1.839E+02
 6    2.26883    27.8 3.096E+01 4.941E+01  1.000 2.389E+01  1.000 1.854E+02
 7    2.45700    29.9 3.639E+01 5.446E+01  1.000 3.022E+01  1.000 2.279E+02
 8    2.57806    31.2 4.009E+01 5.773E+01  1.000 3.485E+01  1.000 2.580E+02
 9    2.62303    31.5 4.150E+01 5.896E+01  1.000 3.669E+01  1.000 2.702E+02
10    2.76363    32.5 4.600E+01 6.281E+01  1.000 4.283E+01  1.000 3.104E+02
11    2.77369    32.6 4.633E+01 6.308E+01  1.000 4.330E+01  1.000 3.134E+02
12    2.87600    33.2 4.969E+01 6.589E+01  1.000 4.821E+01  1.000 3.451E+02
13    2.88645    33.2 5.004E+01 6.618E+01  1.000 4.873E+01  1.000 3.485E+02
14    2.95790    33.5 5.242E+01 6.813E+01  1.000 5.239E+01  1.000 3.723E+02
15    3.00675    33.4 5.405E+01 6.943E+01  1.000 5.499E+01  1.000 3.900E+02
16    3.00769    33.4 5.409E+01 6.945E+01  1.000 5.504E+01  1.000 3.904E+02
17    3.01724    33.2 5.440E+01 6.968E+01  1.000 5.556E+01  1.000 3.949E+02
18    3.02405    33.1 5.463E+01 6.984E+01  1.000 5.593E+01  1.000 3.982E+02
19    3.42952    36.1 6.866E+01 8.135E+01  1.000 8.089E+01  1.000 5.372E+02
20    3.69087    37.5 7.829E+01 8.899E+01  1.000 1.001E+02  1.000 6.418E+02
21    3.82066    38.2 8.320E+01 9.280E+01  1.000 1.106E+02  1.000 6.972E+02
22    4.04114    39.2 9.172E+01 9.928E+01  1.000 1.298E+02  1.000 7.961E+02
23    4.05791    39.3 9.238E+01 9.977E+01  1.000 1.314E+02  1.000 8.039E+02
24    4.56250    41.1 1.127E+02 1.146E+02  1.000 1.831E+02  1.000 1.058E+03
25    4.75831    41.7 1.208E+02 1.204E+02  1.000 2.059E+02  1.000 1.166E+03
26    4.87283    42.1 1.256E+02 1.237E+02  1.000 2.200E+02  1.000 1.231E+03
27    5.19401    42.9 1.392E+02 1.330E+02  1.000 2.625E+02  1.000 1.423E+03
28    5.27963    43.1 1.429E+02 1.355E+02  1.000 2.746E+02  1.000 1.477E+03
29    5.47988    43.6 1.516E+02 1.412E+02  1.000 3.041E+02  1.000 1.605E+03
30    5.68353    43.9 1.605E+02 1.470E+02  1.000 3.359E+02  1.000 1.740E+03
31    5.83592    44.2 1.672E+02 1.513E+02  1.000 3.609E+02  1.000 1.845E+03
32    6.01591    44.5 1.752E+02 1.563E+02  1.000 3.917E+02  1.000 1.973E+03
33    6.30470    44.9 1.881E+02 1.642E+02  1.000 4.441E+02  1.000 2.185E+03
34    6.42042    45.0 1.933E+02 1.674E+02  1.000 4.662E+02  1.000 2.273E+03
35    6.56834    45.2 2.000E+02 1.714E+02  1.000 4.953E+02  1.000 2.387E+03
36    6.60078    45.2 2.014E+02 1.723E+02  1.000 5.018E+02  1.000 2.413E+03
37    6.82042    45.4 2.114E+02 1.781E+02  1.000 5.471E+02  1.000 2.589E+03
38    6.90185    45.4 2.151E+02 1.802E+02  1.000 5.645E+02  1.000 2.655E+03
39    7.07251    45.5 2.228E+02 1.847E+02  1.000 6.018E+02  1.000 2.799E+03
40    7.33615    45.6 2.348E+02 1.915E+02  1.000 6.622E+02  1.000 3.025E+03
41    7.36096    45.6 2.360E+02 1.921E+02  1.000 6.680E+02  1.000 3.047E+03
42    7.62493    45.6 2.480E+02 1.988E+02  1.000 7.319E+02  1.000 3.283E+03
43    7.95731    45.5 2.631E+02 2.069E+02  1.000 8.168E+02  1.000 3.589E+03
44    8.02042    45.5 2.660E+02 2.085E+02  1.000 8.335E+02  1.000 3.649E+03
45    8.02997    45.5 2.664E+02 2.087E+02  1.000 8.361E+02  1.000 3.658E+03
46    8.27834    45.3 2.777E+02 2.146E+02  1.000 9.037E+02  1.000 3.900E+03
47    8.36122    45.3 2.815E+02 2.166E+02  1.000 9.268E+02  1.000 3.984E+03
48    8.88253    44.7 3.049E+02 2.284E+02  1.000 1.080E+03  1.000 4.521E+03
49    9.13900    44.4 3.163E+02 2.340E+02  1.000 1.159E+03  1.000 4.793E+03
50    9.14998    44.3 3.168E+02 2.342E+02  1.000 1.163E+03  1.000 4.805E+03
51    9.47042    43.7 3.309E+02 2.409E+02  1.000 1.267E+03  1.000 5.168E+03
52    9.59971    43.4 3.366E+02 2.435E+02  1.000 1.310E+03  1.000 5.318E+03
53    9.95440    42.6 3.518E+02 2.505E+02  1.000 1.432E+03  1.000 5.739E+03
54   10.20492    41.9 3.624E+02 2.551E+02  1.000 1.521E+03  1.000 6.050E+03
55   10.63410    40.4 3.801E+02 2.626E+02  1.000 1.681E+03  1.000 6.612E+03
56   10.67180    40.3 3.816E+02 2.632E+02  1.000 1.695E+03  1.000 6.663E+03
57   10.91088    39.3 3.911E+02 2.670E+02  1.000 1.787E+03  1.000 7.002E+03
58   11.16801    38.1 4.010E+02 2.709E+02  1.000 1.889E+03  1.000 7.379E+03
59   11.28453    37.6 4.055E+02 2.726E+02  1.000 1.936E+03  1.000 7.560E+03
60   11.77747    34.6 4.232E+02 2.787E+02  1.000 2.141E+03  1.000 8.402E+03
61   11.98294    33.0 4.302E+02 2.808E+02  1.000 2.228E+03  1.000 8.811E+03
62   12.01644    32.7 4.313E+02 2.811E+02  1.000 2.243E+03  1.000 8.884E+03
63   12.13852    31.5 4.352E+02 2.821E+02  1.000 2.296E+03  1.000 9.178E+03
64   12.34007    28.8 4.413E+02 2.832E+02  1.000 2.384E+03  1.000 9.802E+03
65   12.35876    28.5 4.418E+02 2.833E+02  1.000 2.392E+03  1.000 9.863E+03
66   12.43239    26.3 4.438E+02 2.829E+02  1.000 2.425E+03  1.000 1.035E+04
67   12.61133    25.3 4.484E+02 2.843E+02  1.000 2.505E+03  1.000 1.071E+04
68   12.88369    23.3 4.551E+02 2.855E+02  1.000 2.628E+03  1.000 1.141E+04
69   13.02361    22.5 4.583E+02 2.861E+02  1.000 2.692E+03  1.000 1.173E+04
70   13.46279    19.6 4.675E+02 2.870E+02  1.000 2.895E+03  1.000 1.296E+04
71   13.74684    16.9 4.727E+02 2.866E+02  1.000 3.028E+03  1.000 1.417E+04
72   13.77896    16.6 4.733E+02 2.865E+02  1.000 3.044E+03  1.000 1.432E+04
73   13.96966    13.7 4.761E+02 2.850E+02  1.000 3.134E+03  1.000 1.596E+04
74   14.03317    10.7 4.769E+02 2.829E+02  1.000 3.164E+03  1.000 1.803E+04
75   15.12018    10.0 4.882E+02 2.859E+02  1.000 3.689E+03  1.000 1.931E+04
76   16.16715     9.2 4.983E+02 2.884E+02  1.000 4.206E+03  1.000 2.079E+04
77   17.10056     8.0 5.063E+02 2.899E+02  1.000 4.675E+03  1.000 2.291E+04
78   17.87646     6.3 5.119E+02 2.902E+02  1.000 5.070E+03  1.000 2.611E+04
79   18.45833     4.4 5.150E+02 2.895E+02  1.000 5.368E+03  1.000 3.158E+04
80   18.81878     2.3 5.162E+02 2.879E+02  1.000 5.554E+03  1.000 4.410E+04
81   18.94030      .1 5.163E+02 2.861E+02  1.000 5.617E+03  1.000 2.977E+05
82  500.00000      .1 5.404E+02 2.861E+02  1.000 2.598E+05  1.000 2.977E+05
83
84          Example of MULCON computing a cross section table for
85          a box culvert.
86
87 MULCON
88
89 TABLE#= -999 SAVE12  NOOUT
```

```
 1 WIDTH OF SLOT=   .010
 2 HEIGHT OF SLOT ABOVE DATUM=    25.
 3 NUMBER OF CONDUITS=    1
 4 TYPE=           BOX
 5 SPAN=          3.00
 6 RISE=          3.00
 7 BOTTOM=         .00
 8 ROUGNESS=      .018
 9 PROCESSING  TYPE: BOX
10 *WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=     3.010
11
12 ELEMENTS FOR SECTION NUMBER  999
13
14 TABLE#=  999
15 TYPE=    1
16 STATION= 0.00000E+00
17 ELEVATION= 0.00000E+00
18
19      DEPTH TOP WID       AREA SQRT(CNV)   BETA      YBARA  ALPHA      CRITQ
20     .00000      3.0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
21     .08000      3.0 2.400E-01 1.888E+00  1.000 9.600E-03  1.000 3.852E-01
22    2.99000      3.0 8.970E+00 2.724E+01  1.000 1.341E+01  1.000 8.801E+01
23    3.01000       .0 9.000E+00 2.482E+01  1.000 1.359E+01  1.000 1.532E+03
24  500.00000       .0 1.397E+01 2.482E+01  1.000 5.722E+03  1.000 1.532E+03
25
26
27          Example of computing a bridge loss table.
28          The following cross section is downstream of the bridge and
29          must be given first.
30
31 FEQX
32
33 TABLE#=  800  NOOUT
34 STATION=      .000
35 NAVM=    0  SCALE=     1.000 SHIFT=      .000
36 NSUB    3  .080  .065  .080
37 RJS SEGMENT NO. LS1417, D.S. OF CERMAK ROAD
38      -900.0    659.00    1
39      -850.0    658.00    1
40      -700.0    656.00    1
41          .0    654.40    1
42        50.0    655.10    1
43       100.0    655.40    1
44       113.0    657.40    1
45       120.0    657.50    1
46       135.0    657.10    1
47       140.0    656.00    1
48       147.0    654.90    2
49       160.0    648.00    2
50       165.0    646.10    2
51       170.0    644.80    2
52       180.0    644.20    2
53       190.0    644.50    2
54       200.0    644.90    2
55       210.0    644.60    2
56       215.0    645.60    2
57       218.0    648.00    2
58       221.0    650.90    3
59       271.0    656.90    3
60       321.0    662.00    3
61       370.0    664.40   -1
62
63 ELEMENTS FOR SECTION NUMBER  800
64
65 TABLE#=  800
66 TYPE=    1
67 STATION= 0.00000E+00
68 ELEVATION= 6.44200E+02
69
70      DEPTH TOP WID       AREA SQRT(CNV)   BETA      YBARA  ALPHA      CRITQ
71     .00000        .0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
72     .08002       4.0 1.601E-01 6.550E-01  1.000 4.270E-03  1.000 1.817E-01
73     .29999      15.0 2.250E+00 3.815E+00  1.000 2.250E-01  1.000 4.945E+00
74     .39996      19.2 3.958E+00 5.628E+00  1.000 5.318E-01  1.000 1.021E+01
75     .59998      35.2 9.391E+00 9.444E+00  1.000 1.813E+00  1.000 2.754E+01
76     .70001      41.9 1.325E+01 1.186E+01  1.000 2.940E+00  1.000 4.227E+01
77    1.39996      48.1 4.473E+01 3.121E+01  1.000 2.298E+01  1.000 2.448E+02
78    1.89996      50.6 6.941E+01 4.417E+01  1.000 5.146E+01  1.000 4.611E+02
79    3.79999      58.0 1.726E+02 8.971E+01  1.000 2.791E+02  1.000 1.690E+03
80    6.70001      66.5 3.531E+02 1.544E+02  1.000 1.035E+03  1.000 4.618E+03
81   10.20001     102.2 6.483E+02 2.342E+02  1.040 2.751E+03  1.094 9.264E+03
82   10.70001     361.8 7.643E+02 2.470E+02  1.124 3.099E+03  1.291 6.303E+03
83   10.89996     466.5 8.471E+02 2.535E+02  1.188 3.260E+03  1.455 6.477E+03
84   11.20001     652.2 1.015E+03 2.646E+02  1.303 3.538E+03  1.787 7.184E+03
85   11.79999     927.4 1.489E+03 2.936E+02  1.497 4.281E+03  2.508 1.070E+04
86   12.70001    1012.3 2.362E+03 3.541E+02  1.499 6.008E+03  2.743 2.047E+04
87   12.89996    1031.5 2.566E+03 3.687E+02  1.481 6.500E+03  2.710 2.297E+04
88   13.20001    1070.2 2.881E+03 3.907E+02  1.455 7.317E+03  2.655 2.683E+04
89   13.29999    1089.4 2.989E+03 3.979E+02  1.449 7.611E+03  2.643 2.810E+04
```

```
  13.79999  1131.8 3.545E+03 4.372E+02  1.394 9.243E+03  2.475 3.560E+04
  14.79999  1191.6 4.706E+03 5.199E+02  1.294 1.336E+04  2.123 5.307E+04
  17.79999  1221.0 8.325E+03 7.830E+02  1.125 3.289E+04  1.464 1.234E+05
  20.20001  1270.0 1.131E+04 9.869E+02  1.082 5.643E+04  1.296 1.916E+05

       The following cross section is upstream of the bridge and is
       given next.
FEQX

TABLE#=  804  NOOUT
STATION=      .000
NAVM=    0  SCALE=     1.000 SHIFT=      .000
NSUB     3  .100  .060  .100
RJS SEGMENT NO. LS1420, U.S. OF CERMAK ROAD
      50.0    652.80    1
      78.0    651.90    1
     103.0    651.50    1
     125.0    650.90    2
     133.0    647.80    2
     142.0    646.80    2
     150.0    645.70    2
     160.0    645.20    2
     170.0    643.60    2
     175.0    645.60    2
     179.0    647.80    2
     185.0    650.00    3
     204.0    657.20    3
     219.0    658.40    3
     223.0    661.40    3
     283.0    664.00   -1

ELEMENTS FOR SECTION NUMBER  804

TABLE#=  804
TYPE=    1
STATION= 0.00000E+00
ELEVATION= 6.43600E+02

     DEPTH TOP WID      AREA SQRT(CNV)   BETA     YBARA  ALPHA     CRITQ
    .00000      .0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
    .08002      .7 2.801E-02 2.824E-01  1.000 7.471E-04  1.000 3.179E-02
   1.60004    14.0 1.120E+01 1.532E+01  1.000 5.974E+00  1.000 5.685E+01
   2.00000    23.0 1.860E+01 1.987E+01  1.000 1.181E+01  1.000 9.491E+01
   2.10004    25.2 2.101E+01 2.135E+01  1.000 1.379E+01  1.000 1.089E+02
   3.20001    35.2 5.421E+01 4.202E+01  1.000 5.415E+01  1.000 3.818E+02
   4.20001    46.0 9.480E+01 6.121E+01  1.000 1.278E+02  1.000 7.723E+02
   6.40002    57.7 2.088E+02 1.093E+02  1.000 4.571E+02  1.000 2.255E+03
   7.30005    62.4 2.629E+02 1.302E+02  1.003 6.690E+02  1.007 3.062E+03
   7.90002    86.0 3.074E+02 1.452E+02  1.025 8.394E+02  1.053 3.298E+03
   8.30005   112.0 3.470E+02 1.554E+02  1.058 9.699E+02  1.128 3.465E+03
   9.20001   142.4 4.614E+02 1.796E+02  1.139 1.332E+03  1.334 4.714E+03
  13.60004   154.0 1.114E+03 3.099E+02  1.178 4.778E+03  1.510 1.699E+04
  14.80005   169.0 1.307E+03 3.446E+02  1.184 6.228E+03  1.534 2.063E+04
  17.80005   173.0 1.820E+03 4.341E+02  1.170 1.092E+04  1.508 3.351E+04
  20.40002   233.0 2.348E+03 5.073E+02  1.210 1.630E+04  1.626 4.230E+04

       The request for computation of a bridge table is next.
       This command is old and predates the feature for saving tables
       internally or of reading precomputed tables from a file.

BRIDGE
CERMAK ROAD
BRIDGE TYPE=RDFLOW
BASE CURVE#=    1
ABUTMENT ALIGNMENT=    0
BRIDGE SKEW=        .00
ADJUSTMENT FACTOR=      1.00
UPSTREAM OFFSET=    170.00
DOWNSTREAM OFFSET=    180.00
PIER TYPE=    2
PIER LENGTH=        .00
PIER SKEW=       .00
PIER TABLE
ELEV        PNUM PWITH
       .00    1      3.00
       .01    1      3.00
      5.69    1      3.00
      5.70    2      3.00
     42.00    2      3.00
     42.00    1     -1.00

TABLE#=  801
STATION=      .000
NAVM=    0  SCALE=     1.000 SHIFT=      .000
NSUB     1  .024
 OFFSET    ELEVATION  SUB  CERMAK ROAD BRIDGE OPENING
       .0    660.80    1
       .0    651.30    1
      52.0   649.20    1
```

```
      62.0    647.80    1
     105.0    643.50    1
     156.0    649.00    1
     156.0    661.00    1
        .0    660.80   -1
*WRN:505* DECREASE IN CONVEYANCE IN SUBSECTION   1 AT ELEVATION=   661.000

ELEMENTS FOR SECTION NUMBER  801

TABLE#=  801
TYPE=   -1
STATION= 0.00000E+00
ELEVATION= 6.43500E+02

      DEPTH TOP WID       AREA SQRT(CNV)   BETA      YBARA  ALPHA      CRITQ
    .00000       .0 0.000E+00 0.000E+00  1.000 0.000E+00  1.000 0.000E+00
    .08002      1.5 6.170E-02 6.682E-01  1.000 1.646E-03  1.000 7.003E-02
   4.29999     82.9 1.782E+02 1.355E+02  1.000 2.554E+02  1.000 1.483E+03
   5.50000    102.6 2.894E+02 1.891E+02  1.000 5.336E+02  1.000 2.759E+03
   5.70001    104.0 3.101E+02 1.992E+02  1.000 5.935E+02  1.000 3.039E+03
   7.79999    156.0 5.831E+02 2.934E+02  1.000 1.512E+03  1.000 6.397E+03
  12.54999    156.0 1.324E+03 5.701E+02  1.000 6.042E+03  1.000 2.189E+04
  17.29999    156.0 2.065E+03 8.107E+02  1.000 1.409E+04  1.000 4.264E+04
  17.50000       .0 2.081E+03 6.612E+02  1.000 1.451E+04  1.000 0.000E+00
HLCOEF TABLE NUMBER
TABLE#=  802
TABLE#=  802
TYPE=    2
REFL=   643.500
     DEPTH     HLCOEF  CERMAK ROAD
      .000      .7866
      .875      .7866
     1.750      .3792
     2.625      .2434
     3.500      .1755
     4.375      .1347
     5.250      .1082
     6.125      .0981
     7.000      .0945
     7.875      .0926
     8.750      .1023
     9.625      .1133
    10.500      .1266
    11.375      .1445
    12.250      .1644
    13.125      .1842
    14.000      .2047
    14.875      .2251
    15.750      .2400
    16.625      .2527
    17.500      .2646


        Example of a simple culvert.  FEQUTL can create table of
        type 5 but FEQ is not yet able to use them.  Type 5 tables
        are more compact than type 6 and are more easily read by a
        human.  They will also take less space to store in FEQ.

CULVERT

TABLE#=  128
TYPE=    5

LABEL=SIMPLE CULVERT EXAMPLE

Approach Section Data

APPTAB#=    4
APPELV=    100.00
APPLEN=       4.0
APPLOS=       .00
APPEXP=       .50

Culvert Description
NODEID=YES
SFAC=      1.00

 NODE   NODEID  XNUM   STATION ELEVATION   KA   KD HTAB
  100 TESTCLVU   999        .0   100.000  .00  .00    0
  101            999       7.1    99.986  .00  .00    0
  102            999      14.3    99.971  .00  .00    0
  103            999      21.4    99.957  .00  .00    0
  104            999      28.6    99.943  .00  .00    0
  105            999      35.7    99.929  .00  .00    0
  106            999      42.9    99.914  .00  .00    0
  107 TESTCLVD   999      50.0    99.900  .00  .00    0

CULCLS=BOX

```

```
Departure Section Data

DEPTAB#=     4
DEPELV=     99.50
LOSOPT=MOMENTUM

Discharge Coefficient Data
KRB=        1.00
KWING=       1.00
KPROJ=       1.00
C46=          .84

Roadway Description
PLCWTB= 9994
GLCWTB= 9995
PHCWTB= 9996
GHCWTB= 9997
PSUBTB= 9998
GSUBTB= 9999
     OFFSET      CREST      WIDTH  APPROACH SURFACE
         .0     105.30       25.0 -999999.1 PAVED
       50.0     105.00       25.0 -999999.1 END

MINIMUM CREST ELEVATION=     105.00
MINIMUM CREST LOCATION=       50.0

Head Sequence Definition

NFRAC=   11
POWER=       2.50
         .50
        1.00
        2.00
        3.00
        4.00
        5.00
        5.50
       -1.00

INPUT COMPLETE. BEGIN COMPUTATATIONS
 UPSTREAM OPENING=   3.01 DOWNSTREAM OPENING=   3.01

DATUM FOR HEADS IS:     100.00
OBEGTAB ACCEPTED.

Upstream Head=      .50  Free Drop=      .393
     PFD     HD2     HD3    HD3P    HD43     HD4 TYP     QCLV      QRD     QTOT    CL34    DE34    DE14
 1.00000    .468    .102    .102    .102    .107   2      1.5       .0      1.5    .946    .095    .393
  .76843    .466    .195    .195    .195    .198   3      1.5       .0      1.5    .938    .043    .302
  .57243    .469    .273    .273    .273    .275   3      1.5       .0      1.5    .934    .025    .225
  .40996    .474    .338    .338    .338    .339   3      1.4       .0      1.4    .932    .016    .161
  .27885    .480    .390    .390    .390    .390   3      1.3       .0      1.3    .931    .011    .110
  .17678    .487    .430    .430    .430    .431   3      1.0       .0      1.0    .930    .006    .070
  .10119    .491    .460    .460    .460    .460   3       .8       .0       .8    .929    .004    .040
  .04930    .495    .481    .481    .481    .481   3       .6       .0       .6    .930    .002    .019
  .01789    .499    .493    .493    .493    .493   3       .3       .0       .3    .931    .000    .008
  .00316    .499    .499    .499    .499    .499   3       .3       .0       .3    .921    .000    .001

Upstream Head=     1.00  Free Drop=      .621
     PFD     HD2     HD3    HD3P    HD43     HD4 TYP     QCLV      QRD     QTOT    CL34    DE34    DE14
 1.00000    .915    .363    .363    .363    .379   2      5.4       .0      5.4    .932    .216    .622
  .76843    .909    .514    .514    .514    .523   3      5.3       .0      5.3    .930    .119    .477
  .57243    .916    .639    .639    .639    .645   3      5.1       .0      5.1    .929    .077    .355
  .40996    .929    .742    .742    .742    .745   3      4.8       .0      4.8    .929    .051    .255
  .27885    .945    .824    .824    .824    .827   3      4.3       .0      4.3    .929    .034    .173
  .17678    .959    .889    .889    .889    .890   3      3.7       .0      3.7    .930    .022    .110
  .10119    .975    .936    .936    .936    .937   3      2.8       .0      2.8    .931    .012    .062
  .04930    .987    .969    .969    .969    .969   3      2.0       .0      2.0    .930    .006    .030
  .01789    .995    .989    .989    .989    .989   3      1.2       .0      1.2    .932    .002    .011
  .00316    .999    .998    .998    .998    .998   3       .7       .0       .7    .929    .001    .002

Upstream Head=     2.00  Free Drop=      .985
     PFD     HD2     HD3    HD3P    HD43     HD4 TYP     QCLV      QRD     QTOT    CL34    DE34    DE14
 1.00000   1.732    .978    .978    .978   1.015   2     19.1       .0     19.1    .932    .501    .985
  .76843   1.726   1.220   1.220   1.220   1.243   3     18.7       .0     18.7    .933    .321    .757
  .57243   1.750   1.420   1.420   1.420   1.436   3     17.8       .0     17.8    .934    .222    .564
  .40996   1.792   1.585   1.585   1.585   1.596   3     16.5       .0     16.5    .935    .153    .404
  .27885   1.843   1.718   1.718   1.718   1.725   3     14.5       .0     14.5    .936    .103    .274
  .17678   1.896   1.822   1.822   1.822   1.826   3     11.9       .0     11.9    .936    .062    .174
  .10119   1.935   1.898   1.898   1.898   1.900   3      9.4       .0      9.4    .937    .036    .099
  .04930   1.967   1.950   1.950   1.950   1.951   3      6.6       .0      6.6    .937    .017    .048
  .01789   1.988   1.982   1.982   1.982   1.982   3      4.0       .0      4.0    .938    .006    .018
  .00316   1.998   1.997   1.997   1.997   1.997   3      1.7       .0      1.7    .943    .001    .003

Upstream Head=     3.00  Free Drop=     1.314
     PFD     HD2     HD3    HD3P    HD43     HD4 TYP     QCLV      QRD     QTOT    CL34    DE34    DE14
 1.00000   2.486   1.631   1.631   1.631   1.686   2     38.8       .0     38.8    .936    .809   1.313
  .76843   2.487   1.954   1.954   1.954   1.990   3     37.9       .0     37.9    .938    .549   1.009
  .57243   2.542   2.223   2.223   2.223   2.248   3     35.9       .0     35.9    .939    .387    .751
```

.40996	2.631	2.444	2.444	2.444	2.461	3	32.8	.0	32.8	.940	.269	.538
.27885	2.729	2.622	2.622	2.622	2.634	3	28.6	.0	28.6	.941	.179	.366
.17678	2.819	2.761	2.761	2.761	2.768	3	23.5	.0	23.5	.942	.110	.232
.10119	2.893	2.863	2.863	2.863	2.867	3	18.2	.0	18.2	.942	.061	.134
.04930	2.949	2.934	2.934	2.934	2.935	3	12.3	.0	12.3	.943	.027	.064
.01789	2.982	2.976	2.976	2.976	2.976	3	7.2	.0	7.2	.945	.009	.023
.00316	2.997	2.996	2.996	2.996	2.996	3	3.0	.0	3.0	.946	.002	.005

Upstream Head= 4.00 Free Drop= 1.776

PFD	HD2	HD3	HD3P	HD43	HD4	TYP	QCLV	QRD	QTOT	CL34	DE34	DE14
1.00000	3.362	2.156	2.156	2.156	2.224	61	57.7	.0	57.7	.939	1.058	1.775
.76843	3.367	2.590	2.590	2.590	2.636	42	57.4	.0	57.4	.941	.740	1.364
.57243	3.504	2.910	2.956	2.956	2.984	4	50.9	.0	50.9	.944	.468	1.016
.40996	3.646	2.910	3.255	3.255	3.272	4	43.0	.0	43.0	.950	.336	.728
.27885	3.760	2.910	3.494	3.494	3.505	4	35.4	.0	35.4	.955	.230	.496
.17678	3.848	2.910	3.680	3.680	3.686	4	28.2	.0	28.2	.958	.146	.314
.10119	3.913	2.910	3.817	3.817	3.820	4	21.4	.0	21.4	.960	.084	.181
.04930	3.958	2.910	3.911	3.911	3.912	4	14.9	.0	14.9	.961	.041	.088
.01789	3.985	2.910	3.968	3.968	3.968	4	9.0	.0	9.0	.962	.015	.032
.00316	3.997	2.910	3.994	3.994	3.994	4	3.8	.0	3.8	.962	.003	.006

Upstream Head= 5.00 Free Drop= 2.550

PFD	HD2	HD3	HD3P	HD43	HD4	TYP	QCLV	QRD	QTOT	CL34	DE34	DE14
1.00000	3.746	2.910	2.360	2.360	2.450	6	80.9	.0	80.9	.928	1.163	2.548
.76843	4.045	2.910	2.988	2.988	3.041	4	70.6	.0	70.6	.945	.903	1.959
.57243	4.292	2.910	3.509	3.509	3.540	4	60.8	.0	60.8	.955	.677	1.458
.40996	4.495	2.910	3.935	3.935	3.955	4	51.4	.0	51.4	.961	.487	1.045
.27885	4.657	2.910	4.277	4.277	4.289	4	42.4	.0	42.4	.965	.332	.711
.17678	4.783	2.910	4.542	4.542	4.549	4	33.7	.0	33.7	.968	.211	.451
.10119	4.876	2.910	4.738	4.738	4.742	4	25.5	.0	25.5	.970	.121	.258
.04930	4.940	2.910	4.873	4.873	4.874	4	17.8	.0	17.8	.971	.059	.126
.01789	4.978	2.910	4.954	4.954	4.954	4	10.7	.0	10.7	.972	.021	.045
.00316	4.996	2.910	4.992	4.992	4.992	4	4.5	.0	4.5	.973	.004	.008

Upstream Head= 5.50 Free Drop= 3.069

PFD	HD2	HD3	HD3P	HD43	HD4	TYP	QCLV	QRD	QTOT	CL34	DE34	DE14
1.00000	3.984	2.910	2.307	2.307	2.431	6	89.0	31.8	120.8	.918	1.390	3.065
.76843	4.347	2.910	3.070	3.070	3.142	4	77.6	31.8	109.5	.938	1.082	2.357
.57243	4.646	2.910	3.699	3.699	3.743	4	66.9	31.8	98.7	.948	.812	1.757
.40996	4.890	2.910	4.213	4.213	4.242	4	56.5	31.8	88.3	.953	.583	1.258
.27885	5.085	2.910	4.625	4.625	4.644	4	46.6	31.8	78.4	.953	.397	.856
.17678	5.236	2.910	4.944	4.944	4.957	4	37.2	31.8	69.0	.949	.251	.543
.10119	5.348	2.910	5.180	5.180	5.189	4	28.2	31.8	60.0	.936	.143	.311
.04930	5.425	2.910	5.341	5.341	5.349	4	19.8	31.8	51.6	.902	.068	.151
.01789	5.472	2.910	5.442	5.442	5.445	4	12.0	31.0	43.0	.879	.024	.055
.00316	5.495	2.910	5.489	5.489	5.490	4	5.1	19.7	24.8	.792	.004	.009

FINISH

The following pages show the output written by FEQUTL to the standard table file for the input given on pages 2–8. Again the line numbers and page numbers have been added before printing but other than these additions the output is that produced by FEQUTL.

Fudge Factors

TABLE#= 4
TYPE= -12
STATION= 2.09500E+00
ELEVATION= 6.57800E+02 EXT=00.00 FAC=1.000

DEPTH	TOP WIDTH	AREA	SQRT(CONV)	BETA	YBARA	ALPHA	CRITQ
.00000	.000	0.00000E+00	0.00000E+00	1.0667	0.00000E+00	1.1852	0.00000E+00
.08002	11.336	4.53544E-01	1.19880E+00	1.0667	1.20971E-02	1.1852	4.85478E-01
.29999	42.500	6.37472E+00	6.98193E+00	1.0667	6.37446E-01	1.1852	1.32121E+01
.79999	70.000	3.44997E+01	2.41456E+01	1.0396	1.02831E+01	1.1071	1.33005E+02
1.40002	90.000	8.25027E+01	4.59130E+01	1.0358	4.47859E+01	1.0967	4.34315E+02
3.40002	131.667	3.04170E+02	1.19918E+02	1.0345	4.17570E+02	1.0919	2.55575E+03
5.20001	179.825	5.84511E+02	1.92020E+02	1.0584	1.20437E+03	1.1495	5.85933E+03
6.00000	225.227	7.46529E+02	2.24298E+02	1.0813	1.73436E+03	1.2070	7.67124E+03
6.20001	391.579	8.08213E+02	2.32506E+02	1.1070	1.88929E+03	1.2689	7.81086E+03
7.20001	463.486	1.23575E+03	2.84399E+02	1.2194	2.90528E+03	1.5958	1.04560E+04
7.29999	669.829	1.29240E+03	2.87337E+02	1.2331	3.03148E+03	1.6379	1.06159E+04
8.20001	833.333	1.96884E+03	3.44760E+02	1.3351	4.48804E+03	2.0093	1.42507E+04
8.29999	871.201	2.05404E+03	3.50888E+02	1.3400	4.68910E+03	2.0336	1.48079E+04
9.20001	1029.678	2.90946E+03	4.15017E+02	1.3518	6.91205E+03	2.1429	2.12568E+04
9.29999	1544.586	3.03815E+03	4.08750E+02	1.3607	7.20892E+03	2.1782	2.16409E+04
9.50000	1613.514	3.35397E+03	4.26669E+02	1.3883	7.84794E+03	2.2874	2.27545E+04
10.20001	1691.408	4.51072E+03	4.96296E+02	1.4041	1.05975E+04	2.4105	3.02826E+04
10.29999	1801.701	4.68533E+03	5.02959E+02	1.4020	1.10571E+04	2.4110	3.15536E+04
12.20001	1910.953	8.21240E+03	7.11162E+02	1.2925	2.32772E+04	2.0820	6.86490E+04
12.29999	1944.035	8.40510E+03	7.20203E+02	1.2868	2.41078E+04	2.0617	7.11359E+04
16.20001	1990.000	1.60765E+04	1.15850E+03	1.1452	7.17890E+04	1.5342	2.07876E+05
-1.00000	.000	0.00000E+00	0.00000E+00	.0000	0.00000E+00	.0000	0.00000E+00

TABLE#= 50
TYPE= 2
REFL=0.0

HEAD	DISCHARGE	TEST OF CRITICAL FLOW TABLE
.000	.0	
.107	10.3	
5.373	3631.7	
10.746	10271.9	
16.119	18870.8	
21.492	29053.5	
26.865	40603.4	
-1.000	.0	

TABLE#= 500
TYPE= -5
LABEL= MTPPOOL TO PENPOOL
NHUP= 9
NPFD= 20

HUP	1000-5	5000-5	1000-4	1500-4	2000-4	3000-4	4000-4	7500-4	1000-3
FDROP	2000-6	9998-6	1999-5	2995-5	3989-5	5964-5	7919-5	1456-4	1909-4
PFD	Flows for HUP and Proportion of FDROP								
2500-6	1760-5	2631-4	9827-4	2113-3	3561-3	7487-3	1286-2	4575-2	7275-2
1000-5	7042-5	1053-3	3931-3	8455-3	1426-2	3000-2	5160-2	1844-1	2946-1
2250-5	1585-4	2369-3	8849-3	1899-2	3209-2	6770-2	1167-1	4205-1	6777-1
4000-5	2817-4	4211-3	1574-2	3338-2	5678-2	1198-1	2071-1	7569-1	1247+0
6250-5	4344-4	6255-3	2274-2	4960-2	8470-2	1793-1	3082-1	1138+0	1973+0
9000-5	5902-4	8300-3	2963-2	6346-2	1083-1	2298-1	3958-1	1427+0	2428+0
1225-4	6656-4	9340-3	3327-2	7123-2	1212-1	2562-1	4399-1	1572+0	2672+0
1600-4	7275-4	1021-2	3634-2	7776-2	1327-1	2806-1	4817-1	1721+0	2930+0
2025-4	7956-4	1113-2	3953-2	8460-2	1441-1	3044-1	5220-1	1858+0	3160+0
2500-4	8473-4	1182-2	4192-2	8978-2	1531-1	3239-1	5551-1	1976+0	3369+0
3025-4	9030-4	1255-2	4438-2	9498-2	1621-1	3422-1	5864-1	2080+0	3545+0
3600-4	9446-4	1310-2	4620-2	9887-2	1687-1	3565-1	6110-1	2165+0	3694+0
4225-4	9832-4	1359-2	4784-2	1023-1	1746-1	3689-1	6315-1	2231+0	3808+0
4900-4	1013-3	1397-2	4907-2	1050-1	1791-1	3784-1	6474-1	2284+0	3901+0
5625-4	1036-3	1425-2	4998-2	1069-1	1824-1	3855-1	6594-1	2323+0	3974+0
6400-4	1055-3	1449-2	5073-2	1085-1	1852-1	3912-1	6691-1	2354+0	4027+0
7225-4	1070-3	1468-2	5131-2	1097-1	1872-1	3955-1	6765-1	2377+0	4065+0
8100-4	1081-3	1481-2	5174-2	1105-1	1885-1	3985-1	6818-1	2393+0	4093+0
9025-4	1090-3	1493-2	5212-2	1112-1	1896-1	4008-1	6856-1	2405+0	4112+0
1000-3	1094-3	1497-2	5224-2	1114-1	1900-1	4015-1	6867-1	2408+0	4118+0

TABLE#= 107
TYPE= -1
STATION= 0.00000E+00
ELEVATION=-2.04239E-02 EXT=00.00 FAC=1.000

DEPTH	TOP WIDTH	AREA	SQRT(CONV)	BETA	YBARA
.00000	.000	0.00000E+00	0.00000E+00	1.0000	0.00000E+00
.08000	1.466	5.86470E-02	7.13451E-01	1.0000	1.56392E-03
.12207	2.237	1.36542E-01	1.25327E+00	1.0000	5.55578E-03
.40806	3.929	1.01824E+00	5.50346E+00	1.0000	1.59158E-01
.48209	6.248	1.39487E+00	6.65505E+00	1.0000	2.47411E-01
.48252	6.254	1.39758E+00	6.66235E+00	1.0000	2.48017E-01
.70233	8.812	3.05343E+00	1.08999E+01	1.0000	7.26903E-01
.75185	9.216	3.49985E+00	1.19299E+01	1.0000	8.89096E-01
1.01965	11.900	6.32726E+00	1.76675E+01	1.0000	2.18890E+00
1.03921	12.942	6.57017E+00	1.80983E+01	1.0000	2.31498E+00
1.06337	13.531	6.88998E+00	1.86370E+01	1.0000	2.47756E+00
1.06439	13.554	6.90379E+00	1.86603E+01	1.0000	2.48459E+00
1.09771	14.273	7.36740E+00	1.94475E+01	1.0000	2.72228E+00
1.19405	15.792	8.81566E+00	2.17722E+01	1.0000	3.50066E+00
1.23141	16.254	9.41421E+00	2.26931E+01	1.0000	3.84111E+00
1.28698	16.829	1.03334E+01	2.40801E+01	1.0000	4.38965E+00
1.35856	17.495	1.15618E+01	2.58877E+01	1.0000	5.17294E+00

1	1.44329	18.225	1.30751E+01	2.80487E+01	1.0000	6.21625E+00
2	1.53780	18.990	1.48338E+01	3.04763E+01	1.0000	7.53460E+00
3	1.55632	19.132	1.51868E+01	3.09536E+01	1.0000	7.81259E+00
4	1.62441	19.590	1.65050E+01	3.27310E+01	1.0000	8.89134E+00
5	1.63834	19.666	1.67785E+01	3.30952E+01	1.0000	9.12320E+00
6	1.74091	20.183	1.88221E+01	3.57663E+01	1.0000	1.09485E+01
7	1.84029	20.644	2.08508E+01	3.83322E+01	1.0000	1.29195E+01
8	1.84142	20.648	2.08742E+01	3.83617E+01	1.0000	1.29431E+01
9	2.00746	21.232	2.43509E+01	4.26364E+01	1.0000	1.66962E+01
10	2.06227	23.902	2.55878E+01	4.40320E+01	1.0000	1.80641E+01
11	2.07119	24.333	2.58030E+01	4.42596E+01	1.0000	1.82933E+01
12	2.16904	26.110	2.82711E+01	4.67805E+01	1.0000	2.09376E+01
13	2.26189	27.737	3.07707E+01	4.92263E+01	1.0000	2.36773E+01
14	2.26883	27.816	3.09635E+01	4.94112E+01	1.0000	2.38915E+01
15	2.45700	29.890	3.63928E+01	5.44556E+01	1.0000	3.02226E+01
16	2.57806	31.164	4.00885E+01	5.77286E+01	1.0000	3.48506E+01
17	2.62303	31.518	4.14980E+01	5.89604E+01	1.0000	3.66851E+01
18	2.76363	32.530	4.60006E+01	6.28075E+01	1.0000	4.28346E+01
19	2.77369	32.592	4.63282E+01	6.30816E+01	1.0000	4.32991E+01
20	2.87600	33.169	4.96921E+01	6.58916E+01	1.0000	4.82102E+01
21	2.88645	33.210	5.00388E+01	6.61752E+01	1.0000	4.87312E+01
22	2.95790	33.456	5.24204E+01	6.81270E+01	1.0000	5.23914E+01
23	3.00675	33.435	5.40543E+01	6.94258E+01	1.0000	5.49922E+01
24	3.00769	33.434	5.40860E+01	6.94509E+01	1.0000	5.50434E+01
25	3.01724	33.246	5.44042E+01	6.96750E+01	1.0000	5.55610E+01
26	3.02405	33.104	5.46302E+01	6.98370E+01	1.0000	5.59325E+01
27	3.42952	36.119	6.86640E+01	8.13529E+01	1.0000	8.08871E+01
28	3.69087	37.510	7.82855E+01	8.89861E+01	1.0000	1.00082E+02
29	3.82066	38.150	8.31956E+01	9.28001E+01	1.0000	1.10561E+02
30	4.04114	39.204	9.17231E+01	9.92781E+01	1.0000	1.29839E+02
31	4.05791	39.283	9.23812E+01	9.97702E+01	1.0000	1.31383E+02
32	4.56250	41.100	1.12661E+02	1.14636E+02	1.0000	1.83076E+02
33	4.75831	41.737	1.20771E+02	1.20360E+02	1.0000	2.05928E+02
34	4.87283	42.102	1.25572E+02	1.23689E+02	1.0000	2.20033E+02
35	5.19401	42.902	1.39223E+02	1.33014E+02	1.0000	2.62549E+02
36	5.27963	43.099	1.42904E+02	1.35480E+02	1.0000	2.74626E+02
37	5.47988	43.551	1.51580E+02	1.41206E+02	1.0000	3.04111E+02
38	5.68353	43.945	1.60490E+02	1.46977E+02	1.0000	3.35886E+02
39	5.83592	44.234	1.67208E+02	1.51253E+02	1.0000	3.60855E+02
40	6.01591	44.481	1.75192E+02	1.56284E+02	1.0000	3.91669E+02
41	6.30470	44.868	1.88094E+02	1.64240E+02	1.0000	4.44122E+02
42	6.42042	45.020	1.93295E+02	1.67390E+02	1.0000	4.66189E+02
43	6.56834	45.168	1.99965E+02	1.71382E+02	1.0000	4.95273E+02
44	6.60078	45.200	2.01431E+02	1.72252E+02	1.0000	5.01784E+02
45	6.82042	45.375	2.11378E+02	1.78101E+02	1.0000	5.47119E+02
46	6.90185	45.438	2.15075E+02	1.80247E+02	1.0000	5.64480E+02
47	7.07251	45.492	2.22834E+02	1.84719E+02	1.0000	6.01849E+02
48	7.33615	45.570	2.34838E+02	1.91513E+02	1.0000	6.62178E+02
49	7.36096	45.577	2.35969E+02	1.92145E+02	1.0000	6.68019E+02
50	7.62493	45.563	2.47998E+02	1.98784E+02	1.0000	7.31895E+02
51	7.95731	45.536	2.63138E+02	2.06946E+02	1.0000	8.16841E+02
52	8.02042	45.529	2.66011E+02	2.08472E+02	1.0000	8.33539E+02
53	8.02997	45.524	2.66446E+02	2.08702E+02	1.0000	8.36081E+02
54	8.27834	45.343	2.77730E+02	2.14622E+02	1.0000	9.03661E+02
55	8.36122	45.253	2.81484E+02	2.16559E+02	1.0000	9.26834E+02
56	8.88253	44.669	3.04923E+02	2.28374E+02	1.0000	1.07970E+03
57	9.13900	44.364	3.16340E+02	2.33967E+02	1.0000	1.15937E+03
58	9.14998	44.346	3.16827E+02	2.34202E+02	1.0000	1.16284E+03
59	9.47042	43.692	3.30933E+02	2.40874E+02	1.0000	1.26663E+03
60	9.59971	43.405	3.36563E+02	2.43492E+02	1.0000	1.30978E+03
61	9.95440	42.577	3.51811E+02	2.50455E+02	1.0000	1.43187E+03
62	10.20492	41.872	3.62390E+02	2.55118E+02	1.0000	1.52134E+03
63	10.63410	40.436	3.80052E+02	2.62586E+02	1.0000	1.68068E+03
64	10.67180	40.300	3.81574E+02	2.63216E+02	1.0000	1.69504E+03
65	10.91088	39.286	3.91087E+02	2.67030E+02	1.0000	1.78740E+03
66	11.16801	38.149	4.01043E+02	2.70934E+02	1.0000	1.88925E+03
67	11.28453	37.554	4.05453E+02	2.72576E+02	1.0000	1.93623E+03
68	11.77747	34.578	4.23232E+02	2.78708E+02	1.0000	2.14054E+03
69	11.98294	33.016	4.30176E+02	2.80805E+02	1.0000	2.22822E+03
70	12.01644	32.725	4.31277E+02	2.81099E+02	1.0000	2.24265E+03
71	12.13852	31.510	4.35198E+02	2.82118E+02	1.0000	2.29554E+03
72	12.34007	28.799	4.41275E+02	2.83211E+02	1.0000	2.38388E+03
73	12.35876	28.544	4.41811E+02	2.83302E+02	1.0000	2.39213E+03
74	12.43239	26.282	4.43830E+02	2.82924E+02	1.0000	2.42474E+03
75	12.61133	25.332	4.48448E+02	2.84274E+02	1.0000	2.50457E+03
76	12.88369	23.313	4.55072E+02	2.85549E+02	1.0000	2.62763E+03
77	13.02361	22.539	4.58280E+02	2.86124E+02	1.0000	2.69153E+03
78	13.46279	19.595	4.67532E+02	2.87020E+02	1.0000	2.89487E+03
79	13.74684	16.940	4.72721E+02	2.86555E+02	1.0000	3.02843E+03
80	13.77896	16.633	4.73260E+02	2.86485E+02	1.0000	3.04362E+03
81	13.96966	13.653	4.76148E+02	2.84962E+02	1.0000	3.13416E+03
82	14.03317	10.742	4.76923E+02	2.82887E+02	1.0000	3.16442E+03
83	15.12018	10.046	4.88221E+02	2.85933E+02	1.0000	3.68905E+03
84	16.16715	9.222	4.98308E+02	2.88434E+02	1.0000	4.20556E+03
85	17.10056	7.965	5.06329E+02	2.89933E+02	1.0000	4.67452E+03
86	17.87646	6.335	5.11877E+02	2.90248E+02	1.0000	5.06961E+03
87	18.45833	4.409	5.15003E+02	2.89471E+02	1.0000	5.36842E+03
88	18.81878	2.277	5.16208E+02	2.87935E+02	1.0000	5.55430E+03
89	18.94030	.050	5.16349E+02	2.86150E+02	1.0000	5.61704E+03

```
 500.00000      .050  5.40403E+02  2.86150E+02     1.0000  2.59798E+05
  -1.00000      .000  0.00000E+00  0.00000E+00      .0000  0.00000E+00
TABLE#=  801
TYPE=   -1
STATION= 0.00000E+00
ELEVATION= 6.43500E+02                EXT=00.00       FAC=1.000
     DEPTH TOP WIDTH          AREA   SQRT(CONV)        BETA          YBARA
     .00000      .000  0.00000E+00  0.00000E+00     1.0000  0.00000E+00
     .08002     1.542  6.16990E-02  6.68191E-01     1.0000  1.64566E-03
    4.29999    82.873  1.78176E+02  1.35503E+02     1.0000  2.55384E+02
    5.50000   102.571  2.89443E+02  1.89066E+02     1.0000  5.33594E+02
    5.70001   104.000  3.10102E+02  1.99194E+02     1.0000  5.93548E+02
    7.79999   156.000  5.83098E+02  2.93440E+02     1.0000  1.51229E+03
   12.54999   156.000  1.32410E+03  5.70073E+02     1.0000  6.04188E+03
   17.29999   156.000  2.06510E+03  8.10660E+02     1.0000  1.40912E+04
   17.50000      .000  2.08070E+03  6.61223E+02     1.0000  1.45063E+04
   -1.00000      .000  0.00000E+00  0.00000E+00      .0000  0.00000E+00
TABLE#=  802
TYPE=    2
REFL=   643.500
      DEPTH    HLCOEF  CERMAK ROAD
       .000     .7866
       .875     .7866
      1.750     .3792
      2.625     .2434
      3.500     .1755
      4.375     .1347
      5.250     .1082
      6.125     .0981
      7.000     .0945
      7.875     .0926
      8.750     .1023
      9.625     .1133
     10.500     .1266
     11.375     .1445
     12.250     .1644
     13.125     .1842
     14.000     .2047
     14.875     .2251
     15.750     .2400
     16.625     .2527
     17.500     .2646
     42.500     .2646
     -1.000   -1.0000
TABLE#=  128
TYPE=   -5
LABEL=SIMPLE CULVERT EXAMPLE
NHUP=    7
NPFD=   10
HUP     5000-4 1000-3 2000-3 3000-3 4000-3 5000-3 5500-3
FDROP   3928-4 6208-4 9853-4 1314-3 1776-3 2550-3 3069-3
   PFD          Flows for HUP and Proportion of FDROP
 3162-6 2906-4 6651-4 1700-3 2988-3 3756-3 4492-3 2478-2
 1789-5 3141-4 1231-3 4000-3 7153-3 8955-3 1070-2 4299-2
 4930-5 5982-4 2021-3 6634-3 1231-2 1495-2 1779-2 5165-2
 1012-4 8336-4 2814-3 9385-3 1818-2 2137-2 2549-2 6003-2
 1768-4 1013-3 3687-3 1187-2 2353-2 2818-2 3370-2 6898-2
 2789-4 1256-3 4260-3 1450-2 2856-2 3545-2 4235-2 7844-2
 4100-4 1391-3 4769-3 1645-2 3278-2 4298-2 5140-2 8835-2
 5724-4 1484-3 5108-3 1784-2 3592-2 5087-2 6081-2 9870-2
 7684-4 1530-3 5291-3 1866-2 3786-2 5743-2 7063-2 1095-1
 1000-3 1543-3 5372-3 1905-2 3876-2 5768-2 8090-2 1208-1
```

UNSTEADY FLOW SOLUTIONS

Input Description for FEQ: Version 6.0

Date: 5 March 1990

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INPUT DESCRIPTION FOR FEQ: VERSION 6.0

The input to FEQ is broken into what are called blocks. A block consists of one or more tables. A table is a series of lines(cards in the days of card input) grouped on some basis. Each block begins with one or more lines of alpha-numeric information(called a heading or headings) that serves to delimit the block from the previous input. This is followed with the table or tables of information relevant to that block. The order of the blocks is fixed and cannot be varied by the user. Furthermore, a value input in one block may require that a block of related information appear later in the input sequence to FEQ. For example, the Wind Information Block is only given if WIND=YES in the run control block. Each block of input is described briefly below so that an overview of the complete input sequence is obtained. Subsequent sections provide details for each of these blocks.

The order of presentation is the order in which the blocks must be given in the input sequence. Note that the word "line" and "card" are used to mean the same thing. No line may be longer than 80 characters. The page number giving the details for each block follows the block name.

BLOCK NAME: Run Control–4

Headings: Exactly three lines(cards) of user selected information to identify the input sequence.

Purpose: This block supplies parameters that are used to control the time span to be simulated, to specify the convergence tolerances, to specify the number of iterations allowed in the computations, etc.

BLOCK NAME: Branch Description–13

Heading: One line of user selected information. Suggested string is: BRANCH DESCRIPTION.

Purpose: This block supplies a description of the nodes on each branch. The location of each node on the branch is given together with the elevation of the minimum point in the stream channel. Additional data such as special loss coefficients or tables also can be given.

BLOCK NAME: Tributary Area–16

Heading: One line of user selected information. Suggested string is: TRIBUTARY AREA.

Purpose: Supplies the areas for each land use that are tributary to each computational element. This block only appears if DIFFUS=YES in the Run Control Block. The unit number of the Diffuse Time Series File(DTSF) containing the runoff intensity for each land use as a function of time is also given in this block.

BLOCK NAME: Branch-Exterior Node–19

Heading: One line of user selected information. Suggested string is: BRANCH-EXTERIOR NODE.

Purpose: Supplies the relationship between the branches and the exterior nodes on the ends of these branches so that the information in the Exterior Matrix Control Block will properly define a system of equations describing the flow in the stream system.

BLOCK NAME: Exterior Matrix Control–20

Heading: One line of user selected information. Suggested string is: EXTERIOR MATRIX CONTROL.

Purpose: Defines the equations relating the flow and depth values at all the exterior nodes in the system. The input in this block specifies how the exterior nodes are connected to represent the stream system.

BLOCK NAME: Point Flows–28

Heading: One line of user selected information. Suggested string is: POINT FLOWS.

Purpose: The inflows and outflows from the stream system that can be localized to a point or at least a small section of the stream are specified here. These flows might be water intakes for a city or a discharge point for a treatment plant. This block is present only when POINT=YES in the Run Control Block.

BLOCK NAME: Wind Information–29

Heading: One line of user selected information. Suggested string is: WIND INFORMATION.

Purpose: Supplies the information on wind such as wind shear coefficient, air density, wind velocity table, *etc.*. This block is present only when WIND=YES in the Run Control Block. If used, the azimuth

information in the Branch Description Block should be specified. If the azimuth information is not specified then all elements will be given an azimuth of 0 meaning that the computational elements have their downstream direction pointing due north.

BLOCK NAME: Special Output Locations–31

Heading: One line of user selected information. Suggested string is: SPECIAL OUTPUT LOCATIONS

Purpose: Used to specify the nodes where output to a designated file is desired. This block is present even if no special output is needed. No nodes are specified in this case but a null block is still present in the input.

BLOCK NAME: Input Files–32

Heading: One line of user selected information. Suggested string is: INPUT FILES.

Purpose: Used to specify the information describing files used to input flow or elevation at an exterior node. These files are called Point Time Series Files(PTSF's) to distinguish them from the single DTSF used to specify the diffuse flows into the stream system. This block is present at all times and if no files are input a null block is present.

BLOCK NAME: Output Files–33

Heading: One line of user selected information. Suggested string is: OUTPUT FILES.

Purpose: Used to specify the information describing files used to output flow or elevation at any node in the system. These files can later be used for input to another stream system using the Input Files Block. This block is always present and if no files are output a null block must be present.

BLOCK NAME: Operation of Control Structures–34

Heading: One line of user selected information. Suggested string is: OPERATION OF CONTROL STRUCTURES.

Purpose: Gives the operation rules for any dynamically operated control structures. This block is only present if SOPER=YES in the Run Control Block.

BLOCK NAME: Function Tables–36

Heading: One line of user selected information. Suggested string is: FUNCTION TABLES.

Purpose: All function tables are given here in a user selected order. Each table has a unique identifying number so that order is immaterial. It is possible to store some or all tables in one or more files and have FEQ obtain the table information from these files.

BLOCK NAME: Free Node Initial Conditions–43

Heading: One line of user selected information. Suggested string is: FREE NODE INITIAL CONDITIONS.

Purpose: Used to give the sign, elevation, and initial values of any free nodes present. Present only if the system has free nodes. There are free nodes whenever twice the number of branches is less than the number of exterior nodes.

BLOCK NAME: Backwater Analysis–44

Heading: One line of user selected information. Suggested string is: BACKWATER ANALYSIS.

Purpose: Used to specify the initial flows and the starting depth at the control point to estimate the initial conditions at all nodes using a steady flow backwater analysis.

Note on the format descriptions: The format descriptions use the same format codes as the FORTRAN language. An 'X' format code indicates skipping the number of spaces given by the number preceding the X. The 'A' format code indicates that a character string of the length given by the number following the A is to be entered. A character string is any sequence of characters that can be printed. Thus numbers, letters, and most special characters can be used in character strings. Character strings should be left justified in their available field on the input line. The 'I' format indicates an integer number with the maximum number of digits given by the number following the I. No decimal point should appear in the number. The number

can appear anywhere within the field assigned to it. The 'F' format code indicates a so-called floating point number that can contain a decimal point and in FEQ should always contain a decimal point unless the number completely fills the field. The field width is again given by the number following the F. A number preceding the A, I, or F format codes denotes repetition of that field width and type the given number of times. Thus 8F5.0 indicates 8 fields each 5 columns wide and containing a number with a decimal point present.

RUN CONTROL BLOCK: Run Control Table

CARD 1

Variable: NBRA

Format: 5X, I5

Example: NBRA=00005

Explanation: NBRA gives the number of branches in the stream system. Branches must be numbered consecutively starting at 1. There must be at least one branch in the system.

CARD 2

Variable: NEX

Format: 4X, I5

Example: NEX=00010

Explanation: NEX give the number of exterior nodes in the stream system. Exterior nodes must be numbered consecutively starting at 1. The pattern followed in numbering exterior nodes has a critical impact on the feasibility of solution and the time required for the solution.

CARD 3

Variable: SOPER

Format: 6X, A4

Example: SOPER=YES

Explanation: SOPER=YES means that there are control structures present that will be operated dynamically by FEQ and therefore the Operation of Control Structures Block must be present in the input sequence. SOPER=NO means that the Operation of Control Structures Block is not present.

CARD 4

Variable: POINT

Format: 6X, A4

Example: POINT=NO

Explanation: POINT=NO means that point flows are not present and that the Point Flows Block will not appear. POINT=YES means that point flows are present and the Point Flows Block will appear.

CARD 5

Variables: DIFFUS, MINPRT, LAGTSF

Format: 7X, A4, I1, I1

Example: DIFFUS=YES 10

Explanation: DIFFUS=YES means that diffuse inflows from the land area tributary to the stream system is to be computed and used in the simulation. The Tributary Area Block must be present and a DTSF must exist in the format required by FEQ. DIFFUS=NO means that diffuse inflows will not be simulated. The Tributary Area Block should not be present in the input sequence in this case.

The interpretation of the starting and ending times(given on cards 9 and 10) is influenced by the presence of the DTSF. The DTSF contains one or more disjoint time segments with the unit runoff for one or more land cover types or land uses. These unit runoffs are multiplied by areas given in the Tributary Area Block to derive the inflow from these land uses into the stream system. The time segments in the DTSF are given in ascending order of time. The first time segment must always be run to establish the initial conditions to be used for all subsequent time segments. FEQ ensures that this takes place and thus the user only has control over subsequent time segments. These subsequent time segments are independent of each other and need not be run in any particular sequence. Thus it is possible to skip over time segments to get to the one of interest. To do this, specify a starting time equal to or less than the starting time of the time segment of interest. The program will scan for the first segment that has a starting time equal to or greater than the start time given by the user. The ending time is also checked and computations

will end at the ending time given even if that time is within one of the time segments stored in the DTSF. The program stops at the end of a time segment or at the end time given by the user. Thus if the whole DTSF is to be run, give an end time known to be beyond the end time of the last time segment stored in the DTSF.

MINPRT is used to control the output of the normal summary information given at the completion of each time step when DIFFUS=YES. This output is currently not controlled by PRTINT given on card 18. If MINPRT=0 then these summaries are printed. Thus old input streams do not need to be changed if the user desires the summary output. MINPRT=1 suppresses the summary output. Error and warning messages are never suppressed!

LAGTSF if non-zero requests lagging the data in the time series file to allow for greater delay in water reaching the stream channels. The lagging is always by one time interval, whatever the time interval of the TSF happens to be. Instead of each time interval's runoff value being treated as a constant the runoff is lagged so that for an isolated interval with runoff the runoff increases from zero to its peak value over the interval. The runoff then decreases to zero from it peak over the subsequent time interval. Thus the volume is not changed but the average delay time, that is the time measured from centroid of runoff before and after lagging, is one-half the time interval. Adjacent time intervals are treated in the same manner and superposition is used in combining the overlapping flows that result. This adjustment to the TSF is simple and consistent but may not be realistic. However, lagging the flows greatly increases the robustness of the computations because the current assumption for the inflow is physically unrealistic and some reasonable alternative must be found to distribute the runoff over the time interval in a more reasonable manner.

CARD 6

Variable: WIND

Format: 5X, A4

Example: WIND=NO

Explanation: WIND=NO means that the effect of wind shear stress on the water surfaces of the streams will not be simulated. WIND=YES means that the wind shear stress on the water surfaces of the streams will be simulated. The Wind Information block must be present in this case. Note that wind shear stress is computed for branches only and cannot be computed for level pool reservoirs.

CARD 7

Variable: UNDERFLOW

Format: 10X, A4

Example: UNDERFLOW=NO

Explanation: Used to suppress underflow messages. Should always be UNDERFLOW=NO. Not currently used in FEQ but needed in the past for some compilers and computer systems. It may be needed in the future.

CARD 8

Variable: ZL

Format: 3X, F10.0

Example: ZL=1.200

Explanation: Gives cutoff depth for using zero inertia in an element to avoid spurious(computational) supercritical flows. Inertia terms in the governing equations are suppressed whenever the depth at either end of the computational element is less than ZL. Probably should be set to zero if GEQOPT=STDX is used based on limited experience.

CARD 9

Variables: SYR, SMN, SDY, SFRAC

Format: 6X, I4, 1X, I2, 1X, I2, 1X, F12.0

Example: STIME=1980/01/20:0.500

Explanation: Specifies the starting time for the current analysis. SYR = year(all four digits); SMN =

number of the month(two digits); SDY = day of month(two digits); and SFRAC = fraction of the day. The example gives noon on the 20th day of January 1980 as the starting time.

CARD 10

Variables: EYR, EMN, EDY, EFRAC

Format: 6X, I4, 1X, I2, 1X, I2, 1X, F12.0

Example: ETIME=1981/12/31:0.9999

Explanation: Gives ending time for the current analysis. Values are defined analogously to the starting time values on card 9. The fraction of the day in both the starting and ending time should satisfy $0 \leq fraction \leq 1$. This convention permits two different time designations for the boundary between consecutive days. For example: 1982/06/21:0.0 and 1982/06/20:1.0 refer to the same time point. As another example, the year can differ if the day boundary is also a year boundary: 1982/12/31/1.0 and 1983/01/01/0.0 refer to the same time point. The time designation to use in a given context is user dependent. Starting times using a fraction of zero and ending times a fraction of 1.0 seems most natural in many cases.

CARD 11

Variable: GRAV

Format: 5X, F10.0

Example: GRAV=32.2

Explanation: Gives the acceleration due to gravity in the proper system of units. FEQ is not currently able to support non-English units without modification.

CARD 12

Variable: NODEID

Format: 7X, A4

Example: NODEID=YES

Explanation: NODEID=YES means that an identification string of up to 8 characters is given in the Branch Tables for each node on a branch. Free nodes described in the Free Node Initial Conditions Block also have an identification string of the same length. The string may be left blank if no printed node identification is desired. The identification string is printed with the node when results are reported to the user. NODEID=NO means that no identification string can be given with the nodes.

CARD 13

Variable: SSEPS

Format: 6X, F10.0

Example: SSEPS=0.10

Explanation: Once used for cross section lookup with area as an argument. Now used to give the convergence tolerance for the volume of water in ponding storage when sewers are simulated. Gives the maximum relative change in surcharge storage volume allowed anywhere in the system.

CARD 14

Variable: NAME, PAGESP

Format: A4, 1X, I5

Example: PAGE=00022

Explanation: Used to specify the number of lines per page for the special output file. Please see the Special Output Locations Block input description.

CARD 15

Variable: EPSSYS, ABSTOL, FAC

Format: 7X, 3F5.0

Example: EPSSYS=0.050 0.010

Explanation: Gives the convergence tolerances for the system solution. EPSSYS is the primary relative tolerance and gives the maximum relative change in the value of an unknown (flow, or depth depending on context). The maximum relative change as computed is based on the last correction from Newton's method. The last correction is made so that the relative error in the unknowns is likely much less than the stated tolerance. Therefore, the tolerance should not be made too small. Limited experiments have shown that a change from 0.05 to 0.005 for EPSSYS changed the computed maximum water surface elevations by about 0.02 feet or less. The flows differed by at most a few percent. The execution time with EPSSYS=0.05 was about 30 percent less than the execution time with EPSSYS=0.005.

ABSTOL is an absolute tolerance that is used only if GEQOPT $\neq$ STD. The given value of ABSTOL is used as a tolerance on the change in any depth(elevation) in the system. If the absolute value of the change is less than ABSTOL then the relative change for that variable is treated as if it were zero. ABSTOL must be non-zero if shallow depths are to be simulated if there is to be any hope of convergence. ABSTOL plays a role for depths similar to the role played by QSMALL for flow rates.

FAC is used to create a secondary relative tolerance if GEQOPT $\neq$ STD. If input for FAC is omitted, FAC is taken to be 2.0. The secondary tolerance is computed by multiplying the primary relative tolerance by FAC. This secondary relative tolerance is used when NUMGT(given in next input line) is positive. Convergence is declared if all but NUMGT variables satisfy the primary relative tolerance and the NUMGT variables that exceed the primary relative tolerance all are less than the secondary relative tolerance

CARD 16

Variable: MKNT, NUMGT

Format: 5X, 2I5

Example: MKNT=00005 1

Explanation: Gives the maximum number of iterations for the system solution. If MKNT is exceeded, FEQ reduces the time step using the LFAC value given on card 28 and tries to obtain convergence again. This process will continue until either convergence is obtained or the time step becomes less than the minimum time step given on card 28.

NUMGT is a value added in version 4.5 to solve a problem of robustness that occurs frequently. I have noticed that frequently convergence will be prevented by problems at only one or two nodes with all other nodal variables meeting the convergence criterion for relative change by a large margin. Yet convergence cannot be declared for the system until all nodal variables meet the criterion. The addition of ABSTOL helps but does not solve the problem. Test runs in which statistics on the relative change for the nodal variables were printed supported the observation that often one or only a few nodes can often greatly delay or prevent convergence. FEQ, when GEQOPT $\neq$ STD permits convergence being declared if the number of variables not meeting the current convergence criteria does not exceed NUMGT and if these variables satisfy the secondary relative tolerance defined above. The number of variables not meeting the current convergence criteria is printed out in the iteration log so that you can get a feeling of how this aspect of convergence is progressing. In experiments so far the value NUMGT should be small. A value of 1 often greatly increases the robustness with only minor effects on the final results. In some cases the only way to obtain final results without greatly modifying the stream system representation is to use positive NUMGT! It is always wise, however, to check the iteration log to determine when, where, and how often FEQ has made use of NUMGT. In most cases no relative changes will exceed the convergence criterion. Often those cases that do exceed the criterion at one node will be during low flow periods and will have little effect on the larger flows and depths.

CARD 17

Variables: OUTPUT

Format: 7X, I5

Example: OUTPUT=00001

Explanation: OUTPUT controls the level of detail in the output. OUTPUT=0 yields the minimum detail and OUTPUT=5 yields the maximum detail for debugging. A value of 0 is used in normal operation. A

value of 1 gives a complete echo of the cross section tables instead of just the headings as for OUTPUT=0. A dump of some internal table values is also given at OUTPUT=1 for checking purposes. Values greater than 1 output details of the actual computations. OUTPUT=5 should be used sparingly because it can produce large amounts of output. If OUTPUT > 1 then cards 19 and 20 must be present in the input sequence.

CARD 18

Variable: PRTINT

Format: 7X, I5

Example: PRTINT=00005

Explanation: PRTINT controls the frequency of output of the system results. PRTINT=1 means output every time step, PRTINT=2 means output every second time step, PRTINT=3 means output every third time step, etc.

CARD 19

Variable: STPRNT

Format: 7X, I5

Example: STPRNT=00010

Explanation: Gives the number of the time step at which detailed output is to start when OUTPUT > 1.

CARD 20

Variable: EDPRNT

Format: 7X, I5

Example: EDPRNT=00100

Explanation: Gives the number of the time step at which detailed output is to stop when OUTPUT > 1.

CARD 21

Variables: NAME7, NAME

Format: A7, A4

Example: GEQOPT=STDX

Explanation: GEQOPT(Governing EQuation OPTion) replaces the no longer used BACKW option. The string GEQOPT must be used because the program reads both parts of the input and if the first six characters are not GEQOPT a warning message is issued and the option STD is selected. The options for the governing equations are: STD, and STDX. STD is a close approximation to the form in use in the past with FEQ. With this option ABSTOL, and NUMGT are ignored even if they are input. Thus STD should produce nearly the results that were obtained with earlier versions. STDX is a generalization of STD that includes ABSTOL and NUMGT as well as an upstream weighting for the friction slope when the depths are very shallow. This upstream weighting has permitted the computation of depths on the order of 0.05 feet with only modest increases in computation time. The recommended option to use is STDX because it proves to be more robust for most systems.

CARD 22

Variable: EPSB

Format: 5X, F10.0

Example: EPSB=0.00001

Explanation: EPSB gives the convergence tolerance for the steady state flow analysis used to define the initial conditions in the stream system. This value should be small to force small residuals in the steady flow governing algebraic equations because this residual is in effect multiplied by the time step in the unsteady flow solution. A large residual may require extra computational effort during the frozen time stage of the FEQ computations.

CARD 23

Variable: MAXIT

Format: 6X, I5

Example: MAXIT=00020

Explanation: Gives the maximum number of iterations permitted in the steady state flow analysis.

CARD 24

Variable: SFAC

Format: 5X, F10.0

Example: SFAC=5280.0

Explanation: SFAC gives the multiplying factor for converting the stations for the nodes given in the Branch Description Block to the internal units. The combination of SFAC and GRAV determine the internal units. If GRAV=32.2 FEQ uses the so-called English system of units. FEQ is consistent. Thus internally lengths are in feet, areas in $feet^2$, and volumes in $feet^3$. Time is in seconds. For convenience, SFAC is used to allow different units for the stations along the stream and for tributary areas. SFAC is used to multiply whatever values are used for the stations and SFAC*SFAC is used to multiply whatever values are used for tributary areas. If GRAV=32.2 and SFAC=5280, then stations along the stream are given in miles and tributary areas are given in square miles. GRAV=9.8 should not be used currently because certain features of FEQ are not unit independent. This will be changed in the future.

CARD 25

Variable: QSMALL

Format: 7X, F10.0

Example: QSMALL=50.0

Explanation: QSMALL gives the value of flow rate to add to a flow before computing a relative change in the flow to prevent a zero divide if the flow is zero. QSMALL should be small relative to the flows of interest. QSMALL should not be made too small either because unneeded computational effort is expended in reducing the changes to a value smaller than needed. A value on the order of a few percent of the maximum flows expected is often reasonable.

CARD 26

Variable: IFRZ

Format: 5X, I5

Example: IFRZ=00005

Explanation: Losses from flow through bridges, and expansions-contractions are not currently included in the steady flow analysis. Therefore, simulated time is "frozen" for the number of time steps given by IFRZ to yield initial conditions that do include these losses. Since time is frozen, all the inflows and outflows that are functions of time will remain constant. The following card gives the time steps to be used during this process.

CARD 27

Variables: DTVEC(*)

Format: 10F8.0

Explanation: This card gives the IFRZ time step values to use while time is "frozen". The first time step is given last and the last time step is given first. Normally the time steps should start at small values and become larger from step to step. This card is not present if IFRZ=0.

CARD 28

Variables: MAXDT, MINDT, AUTO, SITER, HIGH, LOW, HFAC, LFAC

Format: 8F5.0

Explanation: Specifies the parameters used to select time steps. FEQ computes a weighted sum of the

number of iterations required to reach convergence, SITER. The value given for AUTO, gives the weighting factor to apply to SITER before adding the current iteration count to it. That is, SITER = AUTO*SITER +(1− AUTO)*ITER, where ITER is the current number of iterations. Therefore, 0 < AUTO < 1.0. The current time step is unchanged if LOW ≤ SITER ≤ HIGH. If SITER > HIGH then the time step is multiplied by LFAC to reduce it. If SITER < LOW then the time step is multiplied by HFAC to increase it. The goal is to keep the number of iterations between 2 to 3. There is no point in having the time steps so large that the number of iterations is larger than this because convergence of the iterations does not mean that an accurate solution has been obtained. Values used in the past have been AUTO=0.7, HIGH=3.2, LOW=2.4, HFAC=1.5, LFAC=0.5. The value given for SITER should be midway between HIGH and LOW. MAXDT should be selected based on the expected rate of change of flow during the simulation. If it is too large, major events may be missed and if it is too small, time will be wasted in making unneeded computations. MINDT should be set small so that short duration computational problems will not cause the simulation to terminate prematurely. Values of MINDT about 1 second or less have been used in the past.

CARD 29

Variables: MRE, FAC, HSLOT, WSLOT, NSLOT

Format: 4X, 5F10.0

Example: MRE= 0.1 1.0 5.0 0.2 0.015

Explanation: FAC regulates the degree of extrapolation from past values to aid in the solution of the equations. If FAC=1.0 then full linear extrapolation in time from the two previous values at each node is used to estimate the unknowns at the end of the current time step. FAC=0.5 uses one-half the extrapolation and so on. If diffuse flows are being used and are the predominant source of flows, then FAC=0.0 seems to give the best results. If diffuse flows are not used FAC=1.0 often reduces the time required to complete the computations. MRE gives the maximum relative change permitted during extrapolation.

HSLOT, WSLOT, and NSLOT define a bottom slot in every branch to allow for small flows without the depth becoming too small. Each cross section table is adjusted to include the slot. The depths as printed in results are the depth measured from the original channel bottom. Thus it is possible to have a negative depth printed in the results that means that the water surface was in the slot. Depths printed in error or warning messages, however, are measured from the bottom of the slot and will not be negative. The use of the slot is experimental. It has worked reasonably well in some cases. The principal problem with the slot is the transition from the slot to the real cross section. The rapid change in top width causes computational problems in many cases. To date using STDX without a bottom slot seems to work better than using STDX with a bottom slot. However, in time we may gather enough information to adjust the shape of the slot so that the computational problems will be minimized.

If HSLOT is zero then no slot is added to any cross section.

CARD 30

Variable: DWT

Format: 4X, F10.0

Example: DWT=0.1

Explanation: FEQ uses an implicit set of discrete algebraic governing equations to approximate the continuous integral equations governing the flow. Linear analysis of the stability properties of this approach reveals that it is unconditionally stable for all time steps. However, the algebraic equations used in the computations are not linear. Therefore, experience has shown that instabilities can still arise and these appear to be generated by the non-linear terms. Experience has also shown that these non-linear stability problems can sometimes, but not always, be reduced or eliminated by using an unequally weighted integration rule to approximate the time integrals in the integral equations. In FEQ the variable WT gives the weight to be applied to any integrand value at the time point where the values are unknown. A weight of 1 − WT is then applied to any integrand values at the known time point. If WT=0.5 the integrals with respect to time are estimated by the trapezoidal rule that gives the maximum nominal accuracy. Therefore,

values of WT close to 0.5 should be used but a fixed value may lead to failure of the computations during a simulation.

Therefore FEQ uses DWT and BWT(given on the following card) to vary the value of WT depending on the conditions encountered in the computations. Whenever the time step must be reduced because convergence was not obtained within MKNT iterations, the current value of WT is incremented by DWT. If the resulting value for WT > 1.0 then WT=1.0. Whenever the time step is decreased because SITER < LOW, then the current value of WT is decremented by DWT. If the resulting value of WT < BWT then WT=BWT. Varying WT as the computation proceeds strikes a balance between accuracy and the need to damp non-linear oscillations. A fixed value of WT can still be used throughout the simulation by using DWT=0.0.

CARD 31

Variable: BWT

Format: 4X, F10.0

Example: BWT=0.5

Explanation: Gives base value of WT discussed above where $0.5 \leq \text{BWT} \leq 1.0$.

CARD 32

Variables: BWFDSN, BWFNAM

Format: 7X, I2, A32

Example: BWFDSN=15

Explanation: Gives the FORTRAN unit number for the file used to save the initial conditions when DIFFUS=YES. Value read but not used by FEQ when DIFFUS=NO. If BWFNAM is non-blank, FEQ will attempt to open a file with name given by the contents of BWFNAM(most micro-computers) to store the initial conditions needed for events in the DTSF. On IBM mainframes the name given by BWFNAM will be the ddname for the DD statement defining the dataset. If the BWFNAM is blank IBM mainframes will attempt an implicit open if the proper DD statement defining the unit number given by BWFDSN is present. Some micro-computer environments will prompt the user for the file name in this case and some will abort execution.

This file is written at the end of the dummy event in the TSF. This event is always the first event and traditionally has been set in 1925. Should a real event exist with a date earlier than 1925, then some changes will need to be made to FEQ. The dummy event should have either zero runoff or constant small runoff so that the system attains a steady state at the levels that will serve as the initial condition for all subsequent events.

CARD 33

Variable: CHKGEO

Format: 7X, A4

Example: CHKGEO=YES

Explanation: Used to select geometric checking. If selected execution is terminated at the end of the checking so that changes to the input can be made.

The unsteady flow computations in FEQ are often sensitive to the variations in channel geometry. If the variations are too large, FEQ may fail to find a solution or may find an invalid solution containing very large Froude numbers that have no basis in physical reality. The governing equations are approximated using simple rules of numerical integration in each computational element. If the changes in top width, area, or conveyance from the upstream node to the downstream node of the element are too large then large errors in the approximations are introduced. Thus CHKGEO finds the list of depths that appear in the cross section tables at each end of each computational element in the system. Then for each of these depths it computes the ratio of the downstream element to the upstream element where the element refers to top width, area, or conveyance. If this ratio is too small or too large a message is printed alerting the user to the value of the ratio.

Not only the absolute change in the cross-sectional elements from one end of the computational element to the other is important but also the rate of change of these elements with distance at a constant depth. Natural channels often contain rapidly expanding or contracting reaches. The Manning's roughness values used to define the conveyance of the channels normally relates to the losses encountered in straight reaches. Additional losses need to be included in reaches which are rapidly expanding or contracting. FEQ provides for this input and CHKGEO computes the rate of change of top width and the rate of change of area normalized to be in the same units as the rate of change of top width, as indicators of the need for these additional losses. If these rates of change are too large or too small a message is printed alerting the user to the value of the ratio.

CARD 34

Variable: MINBND

Format: 7X, A4

Example: MINBND=YES

Explanation: MINBND=YES attempts to reduce the band width of the exterior matrix by rearranging rows of the input internally. If a reduction is possible the routines used by MINBND will likely find a reduction but there is no guarantee that the smallest possible band width will be found. MINBND=NO does not reorder the equation in the exterior matrix and the band width remains unchanged.

As an adjunct to band width reduction, the output of the exterior matrix and the pattern of the non-zero entries in the matrix have also been changed. Both the entry number and the equation number or numbers associated with each line of input to the exterior matrix are given in the output of the exterior matrix. Each line of the band width pattern output also has its corresponding equation number and entry number given so that you can manually reorder the input if you wish. This numbers are also useful in tracing some difficult problems with the exterior matrix solution, should such problems arise.

CARD 35

Variable: EXTTOL

Format: 7X, F10.0

Example: EXTTOL= 0.5

Explanation: Gives the distance above the top of section that can be extrapolated during the unsteady flow computations before a warning message will be issued at the completion of the run. FEQ checks if and cross sections extended by the EXT option on input have a maximum elevation of water that exceeds the unextented top of the cross section by more than EXTTOL.

CARD 1

Variable: BNUM, INERT, CFRATE, WDFAC

Format: 5X, I5, 9X, A5, 8X, F5.0, 9X, A5

Example 1: BNUM=00020

Example 2: BNUM=0020 INERTIA= 0.0 CFRATE= 100. WINDFAC= 1.2

Explanation: Gives the branch number being described by the branch table several optional parameters applicable to this branch. If omitted as in Example 1, INERTIA will take a default value of 1.0 meaning that the full inertial terms will be included in the governing equations; CFRATE will be taken as 0.0; and WINDFAC will be taken as 1.0. In example 2 the zero-inertia form of the equations has been requested for branch number 20. Partial inertial terms can be requested but there is no experience with their use. The branch tables must be given in ascending order of branch number. CFRATE gives the number of square feet of effective inflow area, CF, per unit length of sewer where SFAC in the Run Control Block gives the unit length. This permits assigning CF to each element in a branch in proportion to the element length. If CFRATE is nonzero then any values of CF given explicitly for the branch will be ignored. WINDFAC is an adjustment factor for the wind shear stress on the water surface in the branch. This permits adjustment of the effective wind shear to represent differences in exposure to wind among the branches in the stream system.

CARD 2

Variable: HEAD

Format: A80

Example: NODE XNUM STATION ELEVATION KA KD HTAB AZM CF YC STD

Explanation: Gives user definable heading to describe the information on subsequent cards.

CARD 3

If NODEID=NO then

Variables: NODE, XTAB, X, Z, CA, CD, HL, AZM, CF, YC, STD

Format: 2I5, 2F10.0, 2F5.0, I5, 3F5.0, F10.0

If NODEID=YES then

Variables: NODE, NAME, XTAB, X, Z, CA, CD, HL, AZM, CF, YC, STD

Format: I5, 1X, A8, 1X, I5, 2F10.0, 2F5.0, I5, 3F5.0, F10.0

Explanation: Gives the values describing each node on a branch, where NODE = node number on the current branch; NAME = the identification string for the node; XTAB = number of the table giving the elements of the cross section at the node; X = station of the node; Z = elevation of the minimum point in the stream at the node; CA = loss factor to apply to differential velocity head in the computational element upstream of the node when the flow is accelerating with respect to distance; CD = loss factor to apply to differential velocity head in the computational element upstream of the node when the flow is decelerating with respect to distance; HL = number of table giving factor to apply to the mean velocity head in the element as an estimate of point losses; AZM = azimuth of the downstream flow direction for the computational element upstream of the node given in degrees clockwise from north; CF = effective area for inflow and outflow of water from the storm sewer; YC = depth of water(distance of hydraulic grade line above invert) when ponding begins to take place; and STD = standard flood elevation for computation of the valley storage for floodway computations.

Card 3 is repeated as needed for each node on the branch. Cards 1 and 2 are given for each branch followed by three or more card 3's. The station and elevation given here are used by FEQ. The station and elevation field in the cross-section table are not used by FEQ. Not all the values need be given for each node. The required values that must be defined either explicitly by the user or implicitly by FEQ following user directions are the node number, the cross section table number, the station, and the elevation of the bottom profile. The other fields on the line can be left blank if the feature is not needed in the analysis.

The end of a branch table is indicated by giving a negative value for the NODE entry. The remainder of the card containing the terminating node number may be blank. The number for the first node on each branch must be given. The NODE column may be left blank for the other nodes and FEQ will compute the node number. If node numbers are given they must be consecutive and increasing. The first node appearing in the table is taken to be the upstream end of the branch. Flow in the direction of upstream node to downstream node is reported as positive and flow in the opposite direction is reported as negative.

Frequently the spacing of measured cross sections is too large for computation of the unsteady flows. Thus cross sections must be added to reduce the length of one or more computational elements. FEQ offers two methods for adding intermediate cross sections. The first method is simple propagation of the last known cross section at equal station intervals and with linear interpolation for the profile elevation. This method is requested by leaving one or more blank lines in the branch table input. There must be a line of complete information above the blank lines and a line of complete information below the blank lines. The upstream table number is assigned to each blank line and the stations and elevations are distributed uniformly between the two lines of known values. The second method uses linear interpolation of cross section characteristics between two known cross sections. This method is selected by giving a negative table number for the cross section table or more conveniently merely giving a minus sign in the right-most column of the field for the table number. FEQ will then select an available table number and supply it at the proper time. This avoids the problem of trying to remember which table numbers are available for interpolated cross sections. If the station and elevation values are given they will be used. If they are omitted FEQ will distribute the station values uniformly and interpolate linearly for the elevation. The first method should only be used if the channel is prismatic over the interval of addition of cross sections. The second method should be used when the channel characteristics vary over the interval between the known cross sections.

Another interpolation feature for cross sections involves the computation of bottom profile elevations when the location of the cross section is known. This occurs when cross sections have been measured at some time in the past and the bottom profile has changed but only sparse information on the changes is available either by measurement or by estimation. The cross section data is then adjusted using some rule, usually linear interpolation between points of known or estimated bottom profile elevation. Since the bottom profile in the adjusted cross sections varies in a piecewise linear fashion, it proves useful to have FEQ do the linear interpolations between points with known bottom profile elevation also. This can save much typing and reduces the chance for mistakes. The elevation of the bottom profile at the first and last node on the branch together with the corresponding stations must always be given. None of these values can be 0.0 because FEQ interprets an exact zero as a request for interpolation. If per chance an elevation or station is 0.0 it can be changed to some small non-zero value with insignificant effect on the profile. With these first and last values given, FEQ first finds the bottom profile elevations at the nodes for which non-zero station values were given and for which the bottom profile elevation field was left blank. Then the station and the bottom profile elevation for the nodes for which both the station and the bottom profile elevation were left blank are computed.

Storm sewers present several special problems. These problems are solvable and FEQ can represent flow in storm and combined sewers. However, the user must supply additional information for these solutions to be possible. The first problem is that the free surface disappears in a closed conduit when it is flowing full. The governing equations as written for FEQ are then invalid. The solution to this problem is to add a narrow slot to the top of each closed conduit cross section so that the conduit is never closed. The slot need be only a fraction of an inch wide so that the falsification of cross sectional elements is negligible. Wave propagation speed in a closed conduit is large, and is infinite if the water is treated as being incompressible as we do in FEQ. The narrow slot will result in not an infinite celerity but a very large celerity in the closed conduit when it is flowing full and that is all we need for physical realism. The slot must be made high enough so that the section is never overtopped. The depth as printed in the output will be the distance from the invert of the conduit to the hydraulic grade line in the conduit. The problem of no free surface is solved by always providing a free surface!

The second problem with closed conduits is that there is no storage (negligible storage with the slotted form) available when they are flowing full. As a convenience in analysis the inflow from the watershed surfaces into the storm sewers is simulated separately using a hydrologic model. This model produces the

runoff generated by rainfall and snowmelt on the land surface. This water will reach the channel and flow downstream. However, the hydrologic model has no knowledge of the state of flow in the channel system and cannot know that downstream conditions have led to the storm sewer being surcharged. Therefore FEQ must make provision for some nominal storage mechanism to represent at least approximately the ponding of water in streets, parking lots, basements, and other forms of depression and detention storage present in the watershed. To do this the user must provide two additional parameters for each computational element representing a sewer that is receiving inflow from the land surface. If this is not done, FEQ will try to force all inflow appearing in a time interval into the conduit. This will then cause the depth to become very large(order of hundreds of feet) and will result in either nonsense results or computational failure.

The first parameter, CF, gives an estimated effective inflow area into the storm sewer for the computational element. This effective area should be viewed as the product of some discharge coefficient and an approximate area of inlets to the storm sewer in the computational element. This is only an approximation because the equations used to represent the inflow and outflow from the storm sewer assume orifice flow. In truth, the flow in the inlets is orifice flow only when the ponding is deep enough to completely submerge the inlets. Again, we must strive for sufficient physical realism to avoid major errors and at the same time avoid becoming lost in the mass of details that cannot be represented economically. The second parameter, YC, gives the distance between the water surface when ponding is present in the element and the invert of the conduit. This is a constant value and again must be an approximate value that relates to the depth of the invert below the ground surface and the nature of the assumed or actual ponding areas.

FEQ uses these two parameters to determine the rate at which water can enter or leave the conduit via its inlets. Thus the inflow capacity is given by orifice flow computed from the difference between the YC and the current depth in the conduit. Thus when the current depth is the same as the cutoff depth, there is no flow into the conduit. An excess of inflow over the inflow capacity is stored in the ponding area. The ponding area always ponds water such that the water surface is YC above the conduit invert. The capacity of the ponding area to store water is unlimited and of undefined extent and location. The ponded water will all be retained until the inflow decreases such that the sewer can again accept inflow. Thus the water is retained without loss.

This model is very simple and gives only a rough approximation to the many details present in a storm sewer system. It is adequate, however, to yield a realistic representation of the major features of storm sewer system without becoming lost in the details.

The azimuth need only be given if the effect of wind shear stress on the water surface is to be simulated. A value of azimuth propagates into blank fields. Thus if the azimuths for all elements in a branch are the same only the azimuth for the first element need be given. Note that the azimuth applies to a computational element and not a node. Thus the azimuth for the first element is given at the second node on the branch. However, if the azimuth is the same for all elements, a value given for the first node on the branch will propagate to all subsequent elements even though an azimuth for the first node on the branch has no meaning. After propagation, FEQ ignores its value.

The standard flood elevation if given will result in the computation of the valley storage below that elevation and the storage will be reported for each branch and for the entire stream system and the FEQ will stop. If the standard flood elevation for the first node on the first branch is set to zero, then the valley storage will not be computed and FEQ will continue with its normal computations. The minimum input for the standard flood elevation is at the upstream and downstream node of each branch. FEQ will then interpolate linearly for the missing values. Intermediate values can be given between the upstream and downstream nodes on the branch and FEQ will interpolate linearly for any missing values using the given standard flood elevations.

TRIBUTARY AREA BLOCK: Tributary Area Tables

CARD 1

Variable: TSFDSN, TSFNAM

Format: 7X, I5, A32

Example: TSFDSN=00012\SALT\TSFLONG

Explanation: Supplies the FORTRAN unit number and name for the DTSF giving the runoff intensities on the tributary areas. If TSFNAM is non-blank, FEQ will attempt to open a file with name given by the contents of TSFNAM(most micro-computers) as the DTSF. On IBM mainframes the name given by TSFNAM will be the ddname for the DD statement defining the dataset. If the TSFNAM is blank IBM mainframes will attempt an implicit open if the proper DD statement defining the unit number given by TSFDSN is present. Some micro-computer environments will prompt the user for the file name in this case and some will abort execution.

In Version 4.41 and later a negative value of TSFDSN is used to signal rain gage input of tributary areas. This mode of input for tributary area will be the only mode of input in future versions because it is more convenient and flexible and it also reflects the manner in which the unit area runoff values are computed.

In the new approach one or more gage numbers are defined with the numbers required to start at 1 and be consecutive thereafter. Associated with the gage number are cover types used in the hydrologic analysis. The gage number refers to the rainfall gage from which the rainfall data was derived for the runoff computations on these cover types. For example, there might be three rain gages used for a given watershed and there might be five different cover types: impervious, flat slope grassland, medium slope grassland, steep slope grassland, and forest. There are then fifteen different combinations of rain gage and cover type. For each time interval used in the hydrologic computations, there are fifteen numbers defining the runoff from the watershed. These numbers are stored in the DTSF in an order defined by the input to the utility program used to create the DTSF. The order is under the control of the user but a logical ordering should be used because the order of input for tributary area is tied to the order of appearance of the runoff values in the DTSF. Giving the runoff values in land-cover-type order for each gage has worked well in the past.

The user must specify the number of land cover types to be associated with each gage. This number is often the same for each gage but it could vary. Also the land cover types do not have to be the same for each gage but the user must make sure that the order of storing the runoff values in the DTSF is the same as the order in which the tributary areas are given for the land cover types in the input below.

Each computational element is assigned the runoff from one and only one gage. This is not as restrictive as it might first seem. First the tributary area for a computational element should be kept small to prevent computational problems. Secondly, additional computational elements can be added if multiple gages are required for one or more reaches in the stream.

The tributary areas in a branch can be given in three different ways. The simplest and least flexible requires that the user give the total area for each land cover type for the entire branch. FEQ will then distribute this area to each element in proportion to the ratio of the length of the element to the length of the branch. This branch mode of input assumes that the tributary area is uniformly distributed over the length of the branch.

The second input mode requires that the user specify a series of upstream and downstream stations along the branch and for each such station interval give the total area for each cover type. FEQ will then distribute the area over that station interval in proportion to element length. In this mode a non-uniform distribution of tributary area over the length of the branch can be specified. The upstream and downstream stations given must match existing computational element boundaries.

The final mode of input, the node mode, requires that the user give the tributary area for each element explicitly. This gives complete freedom of assignment but the user must input the tributary area for each element on the branch. Furthermore, if additional elements are added in the branch description table to overcome computational problems, the user must remember to update the tributary area input accordingly.

On completion of tributary area input, FEQ outputs the areas as assigned to each branch and element so that the user can verify that the proper result has been obtained. Furthermore, a complete summary of tributary area is given for each branch and for the system as a whole. The total area for each cover type, gage, branch, and system is given to help in verifying the input.

CARD 2

Variable: FFFDSN, FFFNAM

Format: 7X, I5, A32

Example: FFFDSN=00011\SALT\UPMS\FFF

Explanation: Supplies the FORTRAN unit number for the file to be used to store the flows and stages required for making a flood frequency analysis. If FFFNAM is non-blank, FEQ will attempt to open a file with name given by the contents of FFFNAM(most micro-computers) to store the values needed for flood frequency analysis. On IBM mainframes the name given by FFFNAM will be the ddname for the DD statement defining the dataset. If the FFFNAM is blank IBM mainframes will attempt an implicit open if the proper DD statement defining the unit number given by FFFDSN is present. Some micro-computer environments will prompt the user for the file name in this case and some will abort execution

FEQ in versions 4.5 and later stores the maximum value summary in FFFNAM. This summary is the same as the summary printed at the end of each event in the standard output file. The data is in character form so that it can be examined and printed easily. Earlier versions of FEQ wrote the file in binary and stored additional information.

CARD 3

Variable: NLUSE

Format: 6X, I5

Example: NLUSE=00006

Explanation: Gives the number of cover type and rain gage combinations represented by the tributary areas. For example, if there are three land uses in each of two segments in the hydrologic simulation then NLUSE=6.

CARD 4

Variable: NGAGE

Format: 6X, I5

Example: NGAGE=00003

Explanation: Gives the number of gages used to define the runoff intensities on the tributary area for the watershed.

CARD 5

Variable: HEAD

Format: A80

Example: GAGE NCOV

Explanation: Heading for the gage number cover type table.

CARD 6

Variable: GAGE, NCOV

Format: 2I5

Example: Gives the gage number(in ascending order) and its number of cover types. There must be a card for each gage and the sum of the number of cover types must be the same as the value of NLUSE given on card 3. Card 6 is repeated as required to specify the number of cover types for each gage in the watershed.

CARD 7

Variable: BRA, FAC

Format: 7X, I5, 5X, F10.0

Example: BRANCH=00001 FAC= 1.05

Explanation: Gives the branch number for the tributary area table. If the branch number is zero it indicates that the table will be describing the areas tributary to reservoirs. If the branch number is negative it denotes that the station interval mode of specifying tributary areas will be used. Otherwise, the branch total mode of input will be used. The tables must be presented in ascending order of branch number. The value given for FAC is used as a multiplier on each tributary areas given in the branch. If omitted, the default is FAC=1.0.

CARD 8

Variable: HEAD

Mode: Node and branch

Format: A80

Example: NODE GAGE AREA1 AREA2 AREA3 AREA4 AREA5 etc.

Mode: Station interval

Format: A80

Example: USTAT DSTAT GAGE AREA1 AREA2 AREA etc..

Example: Explanation: User supplied headings descriptive of the tributary areas.

CARD 9

Modes: Node and branch

Variables: NODE, GAGE, TRIBA(*)

Format: I5, I5, 10F6.0

Explanation: Specifies the tributary area for all computational elements on the branch. In node mode all nodes(but the upstream node) must appear explicitly even if the tributary area for that branch is zero. If the branch number on card 7 is zero then the node number given is the exterior node number of the reservoir involved. In this latter case the node number list must be terminated by a -1 because only those reservoirs having tributary area need be entered in the table. As a result FEQ does know in advance how many reservoirs will appear. If the value for NODE is zero it denotes the branch mode of input for tributary area and the tributary areas given will be the total for the branch in each land cover type. Note that there is a current limit of 10 on the number of land cover types that may contribute to a stream element. Card 9 is repeated as needed to complete the table for the branch. Note that the same mode of input must be used to complete the input for any branch.

CARD 9a

Modes: Station interval

Variables: USTAT, DSTAT, GAGE, TRIBA(*)

Format: F10.0, F10.0, I5, 10F6.0

Explanation: Gives the tributary area specification for the station interval mode. The branch number given on card 7 must be negative in this case. Both the upstream and downstream station must exist in the branch description table for the branch. Any station interval left out will have zero tributary area. Card 9a is repeated as required to describe the tributary area for the branch. The last card must be a null tributary area card with the upstream and downstream stations being the same. This tells FEQ that input for this branch is complete.

BRANCH-EXTERIOR NODE BLOCK: Branch-Exterior Node Table

CARD 1

Variable: HEAD

Format: A80

Example: BRAN UEXN DEXN

Explanation: User supplied heading for the subsequent cards of information.

CARD 2

Variables: BNUM, UEXN, DEXN

Format: 3I5

Explanation: Gives the branch number, BNUM, the upstream exterior node number, UEXN, and the downstream exterior node number, DEXN for each branch. The branches must be given in ascending order.

EXTERIOR-MATRIX CONTROL BLOCK: Exterior Matrix Table

CARD 1

Variable: HEAD

Format: A80

Explanation: User selected heading. See the example input.

CARD 2

Variables: CODE, N(1),...,N(10), F(1),...,F(5)

Format: I5, 10I4, 5F7.0

Example: See example input.

Explanation: This card specifies the information used to define an equation or equations in the matrix relating the exterior nodes and branches. CODE defines the nature of the relationship and the meaning of the remainder of the card depends on CODE. Note that all fields on the card are read whether needed or not. The following sections describe the meaning for each code.

If **CODE = 1 (Branch Equations):**

N(1) = the branch number. Each branch generates two equations in the matrix. All other codes, at present, generate only one equation.

If **CODE = 2 (Sum of flows = 0 i. e. a junction):**

N(1) = number of exterior nodes at the junction.

N(2),...,N(N(1)) = the exterior nodes at the junction given in ascending order.

If **CODE = 3 (Equality of water surface elevation between nodes):**

N(1) = first exterior node(the smaller value).

N(2) = second exterior node(the larger value).

If **CODE = 4 (One-node head-discharge relationship at a node):**

N(1) = type number for the relationship with $1 \leq N(1) \leq 6$.

N(2) = number of the exterior node giving the head.

N(3) = direction of positive flow, +1 means flow into the system and −1 means flow out of the system where the system is that part that has the ~~head~~ flow node.

N(4) = number of the exterior node giving the flow.

In most cases the node giving the head and the node giving the flow will be the same. Separate specification is allowed, however, to include any exceptional cases. These four values must always appear if CODE=4. The remainder of the card depends on the value of N(1) giving the TYPE.

If **TYPE = 1 (Flow over a weir):**

N(5) = table number giving the weir coefficient as a function of head.

F(1) = elevation of the reference point used for defining head.

F(2) = weir length.

If **TYPE = 2 (Flow given in a table as function of head):**

N(5) = table number of table giving flow versus head.

F(1) = elevation of the reference point used for defining head.

If **TYPE = 3 (Channel control of flow):**

N(5) = slope source for defining flow. If N(5) = −1 then the slope is given in F(1), if N(5) = 0 then the bottom slope of the stream channel is used, and if N(5) = 1 then the water surface slope at the previous time point is used.

F(1) = value of slope if N(5) = −1.

If **TYPE = 4 (Structure capacity given as a function of time):**

N(5) = table number of table giving the maximum flow through the structure versus head.

N(6) = table number of table giving proportion of maximum flow versus time.

F(1) = elevation of the reference point used to define head.

It is assumed that the time varying flow can be represented by the product of two functions. The first gives the proportion of the maximum flow rate as a function of time. The second gives the maximum flow rate as a function of head at the head node. These two functions are simple to define given records of the operation of the facility.

If **TYPE = 5 (Structure capacity varied dynamically by FEQ):**

N(5) = table number of table giving maximum flow through the structure versus head.

N(6) = number of the operation table controlling the operation of the structure. The operation table appears in the Operation of Control Structures Block.

F(1) = elevation of the reference point used to define head.

If **TYPE = 6 (Busse Woods Reservoir Operation):**

N(5) = table number of table giving maximum flow through the structure versus head.

N(6) = table number of table giving head-discharge relationship when stage is rising.

F(1) = elevation of the reference point used to define head.

If **CODE = 5 (Two- node Head-discharge relationship):**

N(1) = type of relationship where $1 \leq N(1) \leq 7$.

N(2) = upstream node of the two nodes involved.

N(3) = downstream node of the two nodes involved.

N(4) = the node giving the flow through the structure. Must be either N(2) or N(3).

Each structure of CODE = 5 has two nodes and a nominal downstream direction of flow used to establish the designation of upstream and downstream node. The upstream node should be placed where the water approaches the structure when it is flowing in its nominal downstream direction. The downstream node should be placed at the exit point from the structure when the water is flowing in its nominal downstream direction.

If **TYPE = 1 (Expansion or contraction with critical flow possible):**

N(5) = sign of the transition. Sign = +1 if expansion in flow takes place when flow is from upstream node to downstream. Sign = −1 otherwise.

N(6) = table number of table giving the elements of the cross section where critical flow, if it occurs, is to be computed.

F(1) = loss factor on velocity head change for positive flow.

F(2) = loss factor on velocity head change for negative flow.

F(3) = elevation to use in defining depth in the critical section.

If **TYPE = 2 (Bidirectional flow given by tables plus pumping):**

N(5) = table number of table giving flow in positive direction i. e. from upstream node to downstream node. If N(6) = 0 then gives table number of table containing square root of conveyance as a function of depth.

N(6) = table number of table giving submergence reduction for positive flow. N(6) = 0 selects the conveyance option. The pumping parameters are ignored if the conveyance option is selected.

N(7) = table number of table giving flow in the negative direction.

N(8) = table number of table giving submergence reduction for negative flow.

N(9) = 0 requests sensing of water surface elevation at the destination node for control of the pump.

N(9) = 1 requests sensing of the flow rate at the destination node for control of the pump.

N(10) = node to sense if pump is to be switched off whenever flow at the exterior node given by N(10) is > 0.

F(1) = elevation for the reference point used in computing head.

F(2) = flow distance for conveyance option.

F(3) = pumping rating. If F(3) = 0 then no pump is present. If F(3) > 0 then pumping takes place from the upstream node to the downstream node. If F(3) < 0 then pumping takes place from the downstream node to the upstream node. The node from which water is pumped is the source node and the node to which water is pumped is the destination node.

F(4) = inlet elevation for the pump. The water surface elevation at the source node must exceed the inlet elevation before the pump can be turned on. Once on the pump will be turned off if the water surface elevation at the source node is at least 0.1 foot below the inlet elevation.

F(5) = the cutoff value at the destination node. F(5) is either flow or elevation as defined by the value of N(9). The cutoff value is used to decide when to turn the pump on or off based on conditions at the destination node. If this values gives a cutoff elevation then F(5) < F(1) to prevent convergence problems caused by the pump cycling on and off in subsequent iterations of the computations for a solution at a time step.

Discussion: This exterior matrix control option is designed to represent a variety of structures. The conveyance option can be used to represent flows into and out of extensive slack water areas next to a channel for which the storage is represented by a level pool reservoir and the inflow and outflow are controlled primarily by boundary friction and the inertial terms are negligible. The bidirectional flow option can represent flow over a weir, a road, a spillway, etc. The flow is zero if both the upstream and downstream elevations are below the elevation used for defining head. Otherwise the flow is given by the product of the flow from the flow table with the larger head and the submergence reduction factor from the corresponding submergence table. The head used does not include the velocity head of approach.

The pump option is used to represent the simple on-off operation of a constant flow pump. The pump always moves water in the direction given by the sign of the constant pumping rate defined by F(3). The pump is either on or off. If the pump is off it is turned on whenever both the inlet elevation is exceeded by the water surface elevation at the source node and the sensed value at the destination node is in the proper range. If the value being sensed at the destination node is water surface elevation, then the water surface elevation at the destination node must be less than the cutoff value given in F(5) to be in the proper range for turning the pump on. If the value being sensed at the destination node is flow rate then the flow rate at the destination node must be positive and less than the cutoff value given in F(5) to be in the proper range for turning the pump on.

If the pump is on some similar set of rules must be used to decide when to turn the pump off. The action of the pump will influence the values at the destination node and some tolerance region or null region must be provided to prevent endless on-off cycling of the pump. The pump is turned off if the water surface elevation at the inlet is at least 0.1 ft. below the pump inlet elevation given in F(4). If the value being sensed at the destination node is elevation, then the pump is turned off if the water surface elevation at the destination node is greater than the elevation given in F(1). If the value being sensed at the destination node is flow rate, then the pump is turned off if the flow at the destination node is greater than the turn-on value plus twice the absolute value of the pumping rate. Finally, if N(10) > 0, then the pump is turned off if the flow at exterior node N(10) > 0.

If **TYPE = 3 (Bridge with no flow over roadway):** Do not use. Use TYPE = 4 and make the low point of the roadway so high that it will never be reached.

N(5) = table number of table giving bridge loss coefficient versus nominal depth in the bridge opening for positive flow. This table is created by FEQUTL.

N(6) = table number of table giving bridge loss coefficient versus nominal depth in the bridge opening for negative flow. This table is created by FEQUTL.

F(1) = maximum flow area through the bridge.

F(2) = elevation of the high point of the bridge opening.

F(3) = Submerged flow discharge coefficient for the bridge.

If **TYPE = 4 (Bridge with flow over the roadway):**

N(5) = table number of table giving bridge loss coefficient versus depth in bridge opening for positive flow.

N(6) = table number of table giving bridge loss coefficient versus depth in bridge opening for negative flow.

N(7) = table number of table giving area of bridge opening versus depth in the bridge opening.

N(8) = table number of table giving flow over the roadway versus head for positive flow.

N(9) = table number of table giving flow over the roadway versus head for negative flow.

N(10) = table number of table giving submergence effect versus head ratio for flow over the roadway.

F(1) = maximum flow area through the bridge.

F(2) = elevation of high point of the bridge opening. There are two option for this elevation. The first gives the true elevation of the high point of the bridge opening and the second gives a value that is false and at least 1 foot higher than the true value. If the true value is given, then FEQ will use a submerged flow equation if the upstream end of the bridge becomes submerged. Otherwise, the free flow equation will be used with the free flow loss adjusted to match closely the submerged flow loss. This later option is used to avoid the inevitable discontinuities in flow that occur during the transition from free flow to submerged flow. These discontinuities can cause severe computational problems.

F(3) = submerged flow discharge coefficient for the bridge.

F(4) = elevation for computing head on the roadway. This value can be set so large that flow over the roadway will never occur. This should be done to model bridges for which flow over the roadway is impossible instead of using the TYPE = 3 option.

If **TYPE = 5 (Abrupt expansion with possible inflow-outflow):**

N(5) = table number of table giving the critical flow as a function of depth at the upstream node for the abrupt expansion.

Discussion: An abrupt expansion can be any feature that yields an abrupt increase in the area available for flow at all depths. Thus a hydraulic drop is an abrupt expansion as is a sudden increase in channel size. Critical depth may occur at the upstream node only. The user must supply a critical flow table so that this condition can be detected. Inflow-outflow of water may occur between the upstream and downstream node of the abrupt expansion. The direction of this flow is taken to be at right angles to the direction of flow from the upstream node to the downstream node. These features make it possible to represent structures used to divert water from the side of a channel. Frequently an abrupt expansion is used to reduce the velocity of the water so that the performance of the side discharge is easier to evaluate and more efficient in diverting water.

This option has several restrictions. First, the nodes must be on branches in their natural sense. That is the upstream node for the abrupt expansion must be the downstream node on a branch upstream and the downstream node for the abrupt expansion must be the upstream node for the branch downstream. Second, the flow node for the abrupt expansion must be the upstream node of the abrupt expansion. Third, the flow cannot reverse at the flow node. It may reverse at the downstream node of the abrupt expansion. Fourth, gravity and friction forces are ignored in the momentum balance.

If **TYPE = 6 (Two dimensional tables):**

N(5) = table number for table defining flow from the upstream node to the downstream node.

N(6) = table number for table defining flow from the downstream node to the upstream node.

N(7) = optional table number for the table giving a multiplying factor to apply to the values derived from the tables given in N(5) and N(6). If left blank, the multiplying factor is taken to be 1.0.

N(8) = optional table number for the table giving the elevation for computing heads as a function of time. If left blank the elevation for computing heads remains fixed the value given in F(1).

N(10) = continuation field. If N(10) > 0 then the next line of input gives another set of values N(5) through F(1) so that more than one set of flow relationships can exist between the two nodes. A value of N(10) = 0 then signals the end of the input. The number of sets of tables input is limited only by

the memory allocated for the storage of the exterior control matrix input.

F(1) = elevation for computing heads.

Discussion: This option represents bidirectional flow through a structure with fixed geometry with the flow defined by the elevation of the water surface upstream and downstream of the structure. Currently the flow is always taken to be in the direction of drop of the water surface elevation. Thus cases in which velocity head recovery takes place cannot be represented. This restriction will be relaxed in the future. The structure of the tables is described in the Function Tables Block.

More than one set of tables can be used to describe the flow between the two nodes. For example there may be several opening through a long highway or railroad fill crossing the flood plain. Each opening could be represented by its own set of tables. FEQ reports the sum of the flows through all the active openings when the results are given.

If **TYPE = 7 (Variable height weir):**

N(5) = operation block number if N(5) > 0. Table giving the opening fraction as a function of time if N(5) < 0.

N(6) = table number of the table giving the elevation of the weir crest as a function of the opening fraction.

N(7) = table number of the table giving the weir coefficient for flow from the upstream node to the downstream node(positive flow) as a function of the opening fraction.

N(8) = table number of the table giving the weir coefficient for flow from the downstream node to the upstream node(negative flow) as a function of the opening fraction.

N(9) = table number of the table giving the submergence correction for flow over the weir.

F(1) = weir length

F(2) = factor to apply to velocity head when computing the total head for use in the weir equation.

Discussion: This option may be used to represent flow for overflow gates. The opening fraction, P, is taken to be 0.0 when the gate is fully raised and 1.0 when the gate is fully lowered. The value of P is set by the rules given in the operation block or table referenced in N(5). The velocity head factor can be used to eliminate the velocity head from the weir equation by making F(2) = 0. On the other hand, the velocity head factor can be used to reduce the effect of weir height on the weir coefficient.

If **CODE = 6 (Node with a forced value of flow or elevation):**

N(1) = TYPE of the forced value. TYPE = 1 if flow versus time is forced, TYPE = 2 if elevation versus time is forced, and TYPE = 3 if mean flow versus time is forced at the exterior node. TYPE = 3 must be used with caution. This option is inherently unstable if the rate of change of flow at the boundary is large and WT is too close to 0.5. If WT = 0.5 then any rate of change at the boundary will eventually cause large oscillations of the computed flow value at the boundary.

N(2) = number of the exterior node where forcing takes place.

N(3) = direction of positive flow at the node. Direction is given as 1 if a positive value from the flow source is into the system and −1 if out of the system.

N(4) = source for the forcing values. If N(4) > 0 then the source is the table number given by N(4). If N(4) = 0 then the source is the constant value given in F(1). If N(4) < 0 then the source is the file referenced by the FORTRAN unit number given by the absolute value of N(4).

F(1) = value of constant flow if N(4) = 0 and TYPE = 1 or 3.

If **CODE = 7 (Level pool reservoir):**

N(1) = node number of the reservoir.

N(2) = table number of table giving storage versus elevation for the reservoir.

N(3) = number of inflow nodes. Reservoir node is always treated as an outflow node. May be 0.

N(4),...,N(N(3)) = inflow node numbers in ascending order.

If **CODE = 8 (Critical depth):**

N(1) = number of the exterior node. This node must be on a branch so that the cross sectional elements are defined.

If **CODE = 9 (Not now used)**

If **CODE = 10 (Energy line equality between exterior nodes):**

N(1) = smaller of the two node numbers.

N(2) = larger of the two node numbers.

If **CODE = 11 (Conservation of momentum/elevation):**

N(1) = upstream node

N(2) = downstream node

Discussion: The option is used to represent the influence of an inflow or outflow at right angles to the channel. If there is an inflow of water between the two nodes, conservation of momentum is used to allow for a difference in water surface elevation. If there is an outflow of water between the two nodes, the two nodes are forced to have the same elevation.

There are several restrictions for the option. The cross sections at both nodes must be identical and must be given by the same table number. Furthermore, the bottom elevations must be identical. There also should be a change in flow rate otherwise CODE = 3 is a better choice.

If **CODE = 12 (Match the average elevation at two nodes):**

N(1) = upstream source node for averaging

N(2) = downstream source node for averaging

N(3) = node at which average elevation of nodes N(1) and N(2) will be forced

F(1) = the weight to be used in computing the average. The weight is applied to N(1) and the complement of the weight is applied to N(2). The weight W must satisfy $0 \leq W \leq 1$.

Discussion: Used to attach a branch or free node to a junction defined by code 11 or code 13 so that there is a difference in water surface elevation between the two nodes.

If **CODE = 13 (Conservation of momentum or energy):**

N(1) = upstream node

N(2) = downstream node

Discussion: This option is the preferred option for representing an inflow or outflow that takes place at right angles to another stream. If there is inflow then conservation of momentum is used and if there is outflow conservation of specific energy is used. There are several restrictions on this option. The nodes must be on branches in the normal manner. That is, the upstream node for this option must be the downstream node on the branch upstream of the junction and the downstream node for this option must be the upstream node for the branch downstream of the junction. Also the bottom elevations must match and the cross section table numbers must be identical.

If **CODE = 14 (Side-Weir flow):**

N(1) = the upstream node on the source channel

N(2) = the downstream node on the source channel

N(3) = the node used to represent the outflow or inflow to the source channel.

N(4) = the flow table of Type 6 representing the outflow over the side weir. This flow is computed as if the weir were not a side weir but a normal weir. Adjustments are made, based on flow conditions, for the side weir flow.

N(5) = the flow table of Type 6 representing inflow over the side weir into the source channel. This flow is taken to be for a normal weir and no adjustment is made.

F(1) = the weight coefficient used in computing the average depth, elevation, and flow rate in the source channel.

F(2) = the elevation from which the heads appearing in the flow tables are measured.

Discussion: Flow over a side weir is one of the more complex flows to compute even in steady flow. Various approximations have been used and there does not seem to be any consensus in the literature about the best method to use. In FEQ we cannot do a detailed integration along the side weir to estimate the flow. However, we do want to include the major features of side weir flow for subcritical flow throughout the length of the weir. Please be aware that many different flow profiles along the weir are possible. FEQ does not check for critical flow upstream of the side weir. If the weir is long enough and the hydraulic conditions are proper, then critical depth can occur upstream of the side weir and a hydraulic jump will form at some point along the weir. This condition is usually avoided in design if possible.

Let x = the distance measured along the side weir with $x = 0$ being at the upstream end of the weir; $h(x)$ = the head on the side weir given by $y(x) - s(x)$ where $y(x)$ = height of water surface above the channel bottom and $s(x)$ = the height of the weir crest above the channel bottom; $C(x)$ = side weir coefficient that varies with distance; $q(x)$ = rate of outflow per unit length of weir; L = the length of the weir; and Q = the total flow over the side weir. Then we can say

$$Q = \int_0^L q(x)\,dx = \int_0^L C(x)h(x)^{3/2}\,dx$$

In steady flow, this equation is combined with some form of the energy or momentum conservation equation to solve for the water surface profile along the weir and the flow over the weir. One assumption made to solve the problem is that the loss of energy along the length of the weir is small. For nearly horizontal channels, those of interest to us, the specific energy is then nearly a constant. As a result, the decrease in flow in the channel as water flows over the weir results in an increase in the depth of the flow in the channel in the direction of the flow for subcritical flow. In FEQ we approximate the above integral using one or more intermediate points along the weir. Each point is assigned a length of weir. Thus if a single point is used then the entire length of the weir is assigned to that point. This point is taken to be the midpoint of the weir length and two branches are assumed to join at that point. Thus the friction loss in the channel is still approximated. The representation proceeds as follows:

1. Decide how many equal-length segments to use to represent the side weir. The number selected should be an integral small power of 2. More than eight segments makes the model input too complicated. No guidelines are currently available for deciding how many pieces should be used.
2. Mark the mid-point of each segment of the weir.
3. Place a branch division at each mid-point. Thus if there is one segment there will be two branches: one coming from upstream to the midpoint and the other leading downstream from the midpoint. If there are two segments then there are three branches: one coming from upstream to the upstream midpoint, one connecting the two midpoints, and one leading downstream from the downstream mid-point. The branches represent the channel shape and frictional characteristics. At each junction between branches we will use code 13 to include the effect of water leaving or entering the channel. If water is leaving we assume that specific energy is conserved so that there will be an increase in the elevation of the water surface. Actually this increase takes place over the length of each weir segment but we treat the increase as taking place at the mid-point of the weir segment. The flow over the weir is computed using the head computed from the average elevations at the ends of the branch at each weir segment mid-point. The flow over the weir is given by a table. This table contains flows over the weir segment assuming that the water surface is horizontal and assuming that the weir is normal to the flow. The velocity of approach is assumed to be small in this computation. The flow over the side weir is different than the flow over a normal weir for the same water surface elevation because the component of velocity along the side weir tends to retard water from flowing over the side weir. Thus some correction must be made that depends on the flow characteristics at the midpoint of the weir segment.
4. Use code 14 for each weir segment and collect the flow from each segment in a manner appropriate to the application. The correction for normal weir flow given in the tables is computed at the mid-point of each weir segment. FEQ uses a correction developed by W. Hager reported in, "Lateral Outflow Over Side Weirs", **Journal of Hydraulic Engineering**, Vol. 113, No. 4, July 1987, pp. 491–504. He develops a correction factor to apply to the normal weir coefficient to approximate the coefficient for

each location along the side weir. This factor is

$$\omega = \left\{ \frac{\mathbf{F}_w^2 + 2}{3\mathbf{F}_w^2 + 2} \right\}^{1/2}$$

where $\mathbf{F}_w$ = Froude number of the channel flow relative to the head on the weir = $V(x)/\sqrt{gh(x)}$; and g = acceleration due to gravity. This form of the correction assumes that the bottom slope of the channel is small and that the channel along the weir is prismatic. Thus the flow tables reflect the nature of the weir crest and possible weir crest slope along the channel while the correction factor adjusts for the state of the flow at the mid-point of each weir segment. Thus the continuous variation of the hydraulic characteristics along the side weir is approximated by FEQ in a series of steps. The correction factor is always less than 1.0 for positive Froude numbers. Thus the flow over the side weir is always less than the flow over a normal weir for the same upstream head.

When analyzing side weirs with FEQ remember that the steady flow computations in FEQ cannot compute side weir flows. Thus the initial conditions in the system must be such that the side weirs are not active. Then the hydraulic conditions can be changed at the boundaries of the system to cause the water to begin flowing over the side weir.

If **CODE = −1 (Input for exterior matrix table is complete).**

POINT FLOWS BLOCK: Point Flow Table

CARD 1

Variable: HEAD

Format: A80

Example: BRAN NODE TYPE TABN MFAC

Explanation: User supplied headings for subsequent information.

CARD 2

Variables: BRA, NODE, TYPE, TABLE, MFAC

Format: 4I5, F10.0

Explanation: Gives information for a point flow where BRA = the branch number; NODE = the number of node on the branch at the downstream end of the element involved with the point flow; TYPE = 1 if it is an inflow and TYPE = 2 if it is an outflow; TABLE = table number of the table giving the flow as a function of time; and MFAC gives the multiplying factor to apply to the flow to approximate the downstream component of momentum flux.

Card 2 is given for each point flow. The same branch and node number may appear as many times as needed for multiple point flows in a given element. The end of the table is indicated by giving a negative value for the branch number.

This means of specifying point flows is primarily designed for use when the DTSF is not used. The point flows referenced here can only be in a function table and not a file and their duration is thereby limited. The argument for function tables representing a time series is the elapsed time in seconds from the start of the analysis. A DTSF may contain several distinct non-overlapping time periods to be simulated. The elapsed time is set to zero at the start of each period in the DTSF. Thus any time series given in a function table will be reused for each time segment. Input and output files are a better means of specifying point flows for an extended period of time or when using a DTSF.

CARD 1

Variable: WINTAB

Format: 7X, I5

Example: WINTAB=00007

Explanation: Table number of table giving wind velocity and direction as a function of time. Function table type 11 is reserved for this purpose. Note that there is an inconsistency in common practice for the designation of wind direction. The direction for wind has traditionally been the point from which the wind is coming and not the direction the wind is going. FEQ retains this traditional designation and adjusts for it internally. Thus the direction of the wind is in degrees clockwise from north for the direction from which the wind is coming. For example, an east wind is given an azimuth of 90 degrees, a south wind an azimuth of 180 degrees, a west wind an azimuth of 270 degrees and a north wind an azimuth of 0 degrees. The azimuth for the orientation of an element in a branch is based on the direction that water flowing downstream is *going* not the direction from which it is *coming*. Therefore an element with downstream flow going east is given an azimuth of 90 degrees also. In this case an east wind will be going in the opposite direction even though the wind and the downstream flow direction are given the identical value for azimuth. FEQUTL adds 180 degrees *modulo* 360 degrees internally to convert the wind direction to the same basis as the flow direction.

Wind shear stress on the water surface is computed using the results collected by Basil W. Wilson in "Note on Surface Wind Stress over Water at Low and High Wind Speeds", *Journal of Geophysical Research*, Vol. 65, No. 10, October, 1960, pp. 3377-3382. He defines the shear stress as

$$\tau_0 = C_d \rho_a U^2$$

where τ_0 = shear stress; C_d = a dimensionless drag coefficient; ρ_a = mass density of air; and U = the wind velocity at a 10-meter height above the water surface. Wilson indicates that the drag coefficient depends on the wind velocity with the coefficient increasing to a limit at the wind velocity increases. He also stated that there is evidence that the drag coefficient decreases slightly to a minimum at about 4 or 5 meters/second for low wind speeds. The variation between low wind and high wind speeds is non-linear but not well established. FEQ supports this variation by requiring you to input the following values for the drag coefficient: the wind speed at minimum drag coefficient; VAMIN; the minimum drag coefficient, CDMIN; the wind speed at maximum drag coefficient, VAMAX; and the maximum drag coefficient, CDMAX. FEQ then applies the minimum drag coefficient to all wind speeds less than VAMIN and the maximum drag coefficient to all wind speeds greater than VAMAX. The drag coefficient for intermediate wind speeds is interpolated using a cubic polynomial between the minimum and maximum points assuming that the slope of the function is zero at both its extremes.

The wind speed can be adjusted to the standard height by assuming an appropriate variation for velocity. See *Hydrology for Engineers* by Linsley, Kohler and Paulhus, 3rd ed., 1982.

CARD 2

Variable: AIRSPW

Format: 7X, F10.0

Example: AIRSPW= 0.075

Explanation: The specific weight of air in pounds per cubic foot. The specific weight of air varies slightly with temperature, moisture content and atmospheric pressure. These variations over the course of the simulation are taken to be negligible. The specific weight of air can be estimated from

$$\gamma_a = 0.0807 \frac{491.6}{T + 491.6} \frac{P_a - .3783e}{1013.3}$$

where γ_a = specific weight of air in pounds for cubic foot; T = air temperature in degrees Fahrenheit; P_a = atmospheric pressure in millibars; and e = vapor pressure of water in air in millibars. The specific weight

at standard atmospheric pressure varies from 0.075 lbs/ft^3 in dry air at 40 °F to 0.0654 in fully saturated air at 100 °F. The variation is small but might be detectable in a carefully controlled experiment in a laboratory setting. It is unlikely that a field test would require any more than a possible adjustment to average conditions of atmospheric pressure, temperature, and humidity.

CARD 3

Variable: WATSPW

Format: 7X, F10.0

Example: WATSPW= 62.4

Explanation: Gives the specific weight water in pounds per cubic foot. FEQ only uses the ratio of the specific weight of air to the specific weight of water. Thus you can supply them in any convenient units so long as the ratio is correct. The specific weight of water varies slightly with temperature but the variation from 62.4 over the range of possible temperatures is less than 1 *per cent.*

CARD 4

Variable: VAMIN

Format: 6X,F10.0

Example: VAMIN= 15

Explanation: Gives the velocity of the wind where the drag coefficient reaches an approximate minimum value. Based on Wilson, this value is recommended to be about 15 ft/sec.

CARD 5

Variable: CDMIN

Format: 6X,F10.0

Example: CDMIN= 0.0015

Explanation: Gives the minimum value of the drag coefficient. The value recommended is 0.0015.

CARD 6

Variable: VAMAX

Format: 6X,F10.0

Example: VAMAX= 75

Explanation: Gives the velocity of the wind where the drag coefficient reaches an approximate maximum. Based on Wilson a value of 75 ft/sec (about 50 miles/hour) is recommended.

CARD 7

Variable: CDMAX

Format: 6X,F10.0

Example: CDMAX= 0.0025

Explanation: Gives the maximum drag coefficient. The value recommended is 0.0025.

SPECIAL OUTPUT LOCATIONS BLOCK: Special Output Table

CARD 1

Variable: UNIT, OUTNAM

Format: 5X, I5, A32

Example: UNIT=00009SPOUT

Explanation: Supplies the FORTRAN unit number and name for the file to use for storing the special output. If OUTNAM is non-blank, FEQ will attempt to open a file with name given by the contents of OUTNAM(most micro-computers). On IBM mainframes the name given by OUTNAM will be the ddname for the DD statement defining the dataset. If the OUTNAM is blank, IBM mainframes will attempt an implicit open if the proper DD statement defining the unit number given by UNIT is present. Some micro-computer environments will prompt the user for the file name in this case and some will abort execution.

CARD 2

Variable: HEAD

Format: A80

Example: BRAN NODE IDENTIFICATION

Explanation: User supplied heading for subsequent information.

CARD 3

Variables: BRA, NODE, HEAD1, HEAD2

Format: 2I5, 1X, 2A7

Explanation: Specifies output node locations where BRA = branch number; and NODE = the node number. If BRA = 0 then the node number is an exterior node. FEQ outputs two lines for each time point in the simulation run. The first line gives the year, month, and day followed by the water surface elevations at the output locations you have requested. The second line gives the hour of the day in fractional form followed by the flows at the requested locations. If the node number is negative FEQ will output the diffuse inflows to either the reservoir or the computational element specified by the node with the elevation values set to zero. It is an error to ask for diffuse inflows for reservoirs not having tributary area. Card 3 is repeated for each node at which special output is desired. The table is terminated if the branch number is given as negative. This table must always be present even if no output is needed. The headings must be given and the input terminated as usual resulting in a null table i. e. a table with no body. Up to 14 characters of identification information can be given for each output location. This identification will be broken into two strings, each 7 characters long, and will serve as a two line heading for each column of hydraulic data in the special output file. These heading will be repeated every PAGESP lines where PAGESP is input as PAGE in the Run Control Block. PAGESP gives the number of lines per page and includes the two heading lines. Thus if you always want at least one heading visible while reviewing the special output on the screen using the BRIEF editor then PAGESP should be set to 22. If you want only the headings at the top of the file then set PAGESP to a number larger than the maximum number of lines expected in the special output file. Then only three extra lines will appear in the special output file. The first line will give the value of PAGESP. The following two lines will give the identification information. PAGESP is output to the special output file so that other programs that read the special output file can be modified to read the number of lines per page and then skip over the headings as they read the file. This modification is simple and should be made on all programs designed to read the special output file. When DIFFUS=YES the headings are given at the beginning of each event even though PAGESP lines have not been used.

INPUT FILES BLOCK: Input File Table

CARD 1

Variable: HEAD

Format: A80

Example: UNIT NAME

Explanation: User supplied heading for subsequent information.

CARD 2

Variables: UNIT, NAME

Format: I5, 1X, A32

Explanation: Defines the Point Time Series Files to be read by FEQ where UNIT = the FORTRAN unit number of the file, and NAME = the left justified file name for the file. Card 2 is repeated for each input file required. The table is terminated if a negative value for UNIT is given. The table must be present even if there are no input files. The table is then null consisting of only the heading and a – in the UNIT column. Each input file is associated with a single exterior node by giving the negative of the unit number in the source field for a forced boundary condition(CODE = 6) in the Exterior Matrix Table.

This means of specifying point inflows can be used with or without a DTSF present. If a DTSF is used it is the responsibility of the user to ensure that all needed time segments are in the file. The input/output file system was designed to permit subdivision of a large system at points of known hydraulic control such that a series of smaller systems could be analyzed in sequence from upstream to downstream to represent the larger system. The output from an upstream subsystem would be stored in a file for later use as input to the downstream system. For this approach to work properly several conditions must be satisfied. First, the same DTSF must be used for all subsystems to ensure that the same length and sequence of time segments appears in all input/output files. Second, the points of subdivision must be at points of known relationship between flow and stage in the stream. If this is not the case, then the subdivision of the system into smaller parts will distort the results. If such points cannot be found then the system should not be subdivided.

OUTPUT FILES BLOCK: Output File Table

CARD 1

Variables: HEAD

Format: A80

Example: UNIT BRAN NODE ITEM TYPE NAME

Explanation: User supplied heading for subsequent information.

CARD 2

Variables: UN, BRA, NODE, ITEM, TYPE, NAME

Format: 3I5, 1X, A4, 1X, A4, 1X, A32

Explanation: Specifies the location and nature of information output to create a Point Time Series File(PTSF) where UNIT = FORTRAN unit number for the file; BRA = the branch number; NODE = the node number; ITEM = FLOW for output of flow and ITEM = ELEV for output of elevation; TYPE = PNT if instantaneous values are to be output and TYPE = MEAN if average values are to be output; and NAME = the left justified name of the file. TYPE = MEAN is invalid if ITEM = ELEV. The table is terminated if the UNIT is given as negative. A null table must be present just as for the Input File Table.

OPERATION OF CONTROL STRUCTURES BLOCK: Operation Table

CARD 1

Variable: BLK

Format: 4X, I5

Example: BLK=00001

Explanation: Gives the number of the operation table. BLK $= -1$ terminates input of operation blocks.

CARD 2

Variable: PINIT

Format: 6X, F5.0

Example: PINIT=0.62

Explanation: Initial value for the opening fraction.

CARD 3

Variable: HEAD

Format: A80

Example: BRAN NODE KEY MODE MNRATE LRATE LOWLIM HGHLIM HRATE LPRI NPRI HPRI DPDT

Explanation: User supplied headings for subsequent information.

CARD 4

Variables: BRA, NODE, KEY, MODE, MNRATE, ML, LL, LU, MU, LPRI, NPRI, HPRI, DPDT

Format: 4I5, 5F7.0, 3I5, F5.0

Explanation: Specifies the parameters defining a control point used in the operation of a structure. The values are:

BRA = branch number for the control point. BRA=0 if the node is an exterior node.

NODE = node number for the control point.

KEY = 0 if control point senses water surface elevation and KEY = 1 if control point senses flow rate.

MODE = 0 means that the structure opening is changed whenever the value being sensed at the control point is outside its null region. MODE = 1 means structure opening is changed only if the value being sensed at the control point is outside the null region and is not moving in the right direction with sufficient speed.

MNRATE = the minimum change per hour under MODE = 1 required to avoid changing the structure opening. For example, if KEY = 0 indicating that water surface elevation is being sensed and if MNRATE = 0.01 then the elevation at the sensing point must be moving toward the null region at a rate exceeding 0.01 foot/hour to avoid having the structure opening changed.

ML = rate factor for the rate of change of opening when the control point is below the null region. This rate factor is a multiplier on the distance that the sensed value is from the closest boundary of the null region. The resulting rate is the change per hour of the structure opening as measured by an opening fraction, P, which is taken as zero when the structure opening is such as to restrict the flow by the maximum amount and as one when the structure opening is such to restrict the flow by the minimum possible amount.

LL = lower limit for the null region.

LU = upper limit for the null region.

MU = rate factor for the rate of change of opening when the control point is above the null region.

LPRI = the priority of the action for this control point when the sensed value is below the null region.

NPRI = the priority of the action for this control when the sensed value is in the null region.

HPRI = the priority of the action for this control when the sensed value is above the null region.

DPDT = the absolute value of the maximum permitted rate of change in the opening fraction for the structure.

Card 4 is repeated for each control point given for each table. A table is terminated by a negative branch number. Input of tables is terminated by a negative value for BLK.

A given dynamically operated structure can have more then one control point and the control points may recommend different actions. Some method must be devised to decide which control point's action should be taken. The method used here is to attach a priority to each of the three possible actions requested by the control point. The highest priority action for all the control points is then the action taken.

The null region is needed to prevent or minimize "hunting" of the structure opening fraction. Thus the action requested when in the null region is no change in the opening fraction. Experience to date has indicated that MODE = 1 is the best choice because the response at the control point to the structure opening change can be delayed so that the control point is still out of the null region but is moving in the right direction. If MODE = 0 is used the structure opening fraction will increase to its maximum value resulting in a large overshoot of the desired result. This will then be followed by the structure opening decreasing to its minimum possible value with a subsequent overshoot of the desired result. Using MODE = 1 and a properly sized null region can eliminate this illogical hunting behavior of the system.

The simple priority method for selecting the action to take ignores the direction of motion of the sensed values. Sometimes the action taken when the sensed value is increasing differs from the action taken when the sensed value is decreasing. This complication has not been included here. Of course the number of rules used for the operation of control structures is essentially unlimited. Thus changes will need to be made for specific examples that do not fit the current generalized scheme.

CARD 1

Variable: TABLE, FNAME

Format: 7X, I5, A32

Example: TABLE#=00029

Explanation: Gives the identification number of the function table. If TABLE# = −1, then input of function tables is terminated. If TABLE# = −n where n is an integer > 1, FEQ continues function table input from a file specified by FORTRAN unit number n. In this case if FNAME is non-blank, FEQ will attempt to open a file (called an auxiliary file) with name given by the contents of FNAME(most micro-computers) to continue input of the function tables. On IBM mainframes the name given by FNAME will be the ddname for the DD statement defining the dataset. If the FNAME is blank IBM mainframes will attempt an implicit open if the proper DD statement defining the unit number given by BWFDSN is present. Some micro-computer environments will prompt the user for the file name in this case and some will abort execution.

Each file encountered is opened, read, and then closed so that the function tables can be divided into many groups for convenience in creation and adjustment. The relationship between the files varies depending on how each of the auxiliary files is ended. If the last line of the file gives a negative table number other than −1 then the current auxiliary file is closed and the file specified explicitly or implicitly by this last line is opened and function tables are read from this new auxiliary file. There is no limit to the number of separate files that can be used because each file points to the next file. The last file in the sequence is of course terminated with the TABLE# = −1 option.

If the auxiliary file ends without a negative table number, then the auxiliary file is closed and the next table number is read from the input file. Thus one or more auxiliary files can be given in sequence in the input file to complete the input of the function tables. This technique is preferred because all the auxiliary file names appear in one place. The first method is inconvenient in that the next auxiliary file name appears at the end of the current auxiliary file and this requires that all of the auxiliary files be scanned in order to establish the files being used. In order to avoid confusion and to keep the programming simpler, only table numbers giving additional auxiliary files or giving the −1 terminator can appear after an auxiliary file has been given. This means that function table input from the input file must be completed before auxiliary files are referenced to provide the remainder of the function tables.

CARD 2

Variable: TYPE

Format: 5X, I5

Example: TYPE=00001

Explanation: Gives the type of function table. The type defines the format and role of the table.

If TYPE = 1 (Cross sectional elements):

CARD 3

Variable: STAT

Format: 8X, F10.0

Example: STATION = 1.456

Explanation: Gives the station of the cross section. Read but not used by FEQ.

CARD 4

Variables: ELEV, CUTOFF, EXT, FAC

Format: 10X, E12.0, 7X, F10.0, 5X, F10.0, 5X, F5.0

Explanation:

ELEV = the elevation of the minimum point in the cross section.

CUTOFF = elevation below which information in the cross-section table is input but discarded.

EXT = maximum extent of extrapolation allowed from the last two entries in the table. If EXT < 0 then the top width is held constant at its maximum tabulated value during the extrapolation. If EXT > 0 then the top width is extrapolated linearly.

FAC = value used to adjust all values of conveyance in the table. The stored value is given by the input value divided by FAC. If FAC is not given it defaults to 1.0.

CARD 5

Variable: HEAD

Format: A80

Explanation: User selected headings for subsequent information. Tables of TYPE = 1 are computed by FEQUTL which also produces the headings.

CARD 6

Variables: Y, T, A, KH, BETA, YB

Format: 2F10.0, 2E13.0, F10.0, E13.0

Explanation:

Y = the values of depth used in the tabulation of the elements. Depth is defined relative to the point of minimum elevation in the cross section.

T = the top width of the water surface at depth Y.

A = the area of the cross section at depth Y.

KH = the square root of the conveyance of the cross section at depth Y.

BETA = the momentum flux correction factor of the cross section at depth Y.

YB = the first moment of area about the water surface at depth Y.

A negative value of depth terminates the table. Card 6 is repeated for as many depth levels as needed to represent the cross section.

If TYPE = 2 (Single function linear):

CARD 3

Variable: REFLEV, FAC

Format: 5X, F10.0, 5X, F10.0

Example: REFL=0.0 FAC= 43560.0

Explanation: Reference level read by FEQ but not now used. FAC is used as a multiplier on the function values in the table. If FAC entry is omitted the multiplier defaults to 1.0.

CARD 4

Variable: HEAD

Format: A80

Explanation: User selected heading for subsequent information.

CARD 5

Variables: ARG, F(1)

Format: 2F10.0

Explanation:

ARG = the argument for the function being tabulated.

F(1) = the value of the function at argument ARG.

The table is terminated by an argument value being less than the argument value on the previous card. This means that negative values can be used for an argument. Values are found by linear interpolation.

If TYPE = 3 (Dual function quadratic):

CARD 3

Variable: REFLEV, FAC

Format: 5X, F10.0, 5X, F10.0

Example: REFL=0.0 FAC= 43560.0

Explanation: Reference level read by FEQ but not now used. FAC is used as a multiplier on the function values in the table. If FAC entry is omitted the multiplier defaults to 1.0.

CARD 4

Variable: HEAD

Format: A80

Explanation: User selected heading for subsequent information.

CARD 5

Variables: ARG, F(1), F(2)

Format: 3F10.0

Explanation:

ARG = the argument for the functions tabulated.

F(1) = the value of the first function at argument ARG.

F(2) = the value of the second function at the argument ARG.

F(1) and F(2) must be related via the trapezoidal rule with F(1) being given by F(2). Card 5 is repeated for each argument in the table. The table is terminated if the argument value given is smaller than the argument value on the previous card.

If TYPE = 4 (Dual function cubic):

Same as for TYPE = 3 except that F(2) is the derivative of the function tabulated in F(1).

If TYPE = 6 (Two dimensional):

CARD 3

Variable: HEAD

Format: A80

Example: HEADUP FREEDROP

Explanation: Heading for the first part of the table.

CARD 4

Variable: HU, FDROP

Format: 2F10.0

Explanation: Values of upstream head and the corresponding drop in water surface elevation required from the upstream node to the downstream node for the maximum physically possible flow to occur. The maximum physically possible flow is called the free flow and the drop in elevation is called the free drop. The values of upstream head and free drop should be entered in ascending order of upstream head. Card 4 is repeated as needed to represent the range of flows. A value of HU < 0 terminates input of this part of the table.

CARD 5

Variables: HEAD

Format: A80

Explanation: Heading for the second part of the table.

Example: PROPORTION OF FREE DROP AND FLOW FOR CONSTANT UPSTREAM HEAD

CARD 6

Variable: P, Q

Format: 2F10.0

Explanation: Values of the proportion of free drop and the corresponding flow for constant upstream head. Values must be given for each of the upstream heads given in the first part of the table. The first line for each upstream head must be P = 0 and Q = 0. Subsequent lines for each upstream head must give P and Q in ascending order of P until the final value with P = 1.0 and Q = maximum physically possible flow for the given upstream head is reached. Thus each upstream head in the first part of the table has a minimum of two lines in the second part of the table. The sets of lines for the upstream heads appear in the same order as the upstream heads. Each of the sets must end with a value of P = 1.0.

The control structure is located between an approach section and a departure section. The length of channel between the approach section and the entrance to the control structure is called the approach reach and the length of channel between the exit of the control structure and the departure section is called the departure reach. The approach section and the departure section will be the sections appearing in the input to FEQ. Thus the two dimensional table represents the relationship between the water surface elevations at these sections and the flow through the control structure. The lengths of these reaches must be selected with the possible flow directions in mind. If the flow through the control structure is unidirectional then the approach section should be located sufficiently far upstream so that it is upstream of the drawdown local to the structure. In the case of culvert or bridge openings the approach reach should be at least as long as the total opening width. The length of the departure reach should be such that the velocity distribution in the channel is nearly fully developed. One approach for selecting a length is to use the rate of expansion of a free jet in the range of 1:4 to 1:5. This is the rate of expansion on one side of the jet so that the expansion in width is really about 1:2 to 1:2.5. Using this rate of expansion and the width of the structure opening the length of the departure reach required such that the jet will completely fill the departure section can be computed. We assume that the velocity distribution in the departure section so located will be essentially the same as the velocity distribution in that section if the control structure were not present.

This requirement often leads to departure reach lengths which are much longer than the approach reach. Furthermore, bidirectional flow through the control structure results in approach and departure reaches switching roles as the flow reverses direction. It is not practical to vary the length of the corresponding branch lengths with changes in direction of flow. The solution to this problem is found in making the assumption that the two-dimensional table should represent, in the departure reach, losses in excess of those caused by the normal frictional resistance that would obtain if the structure were not there. Thus we can then compress the departure reach to the same length as the approach reach and only concern ourselves with the local losses. The frictional losses are then approximated in the branch which no extends into the area of disturbed flow downstream of the structure.

A two-dimensional table represents all physically possible flows for a range of elevations in the approach and departure sections. It is convenient to define an upstream head(in the approach section) and a downstream head(in the departure section) where upstream and downstream denote the actual flow direction and not just the nominal location of a node. Thus the flow is always from approach section to control structure entrance to control structure exit to departure section. The upstream and downstream head are referred to the same datum and equality of upstream and downstream head yields zero flow. Thus there must always be some head loss through the control structure.

The table is constructed by computing the flow that results for a range of downstream heads with the upstream head held constant. When the downstream head equals the upstream head the flow is zero and the drop in water surface elevation from upstream to downstream is also zero. As the downstream head is reduced the flow increases as does the drop in water surface elevation. Eventually an additional decrease in the downstream head will result in either critical flow at some point in the control structure or in critical flow in the departure section or in some section in the departure reach. At this point the physically maximum flow through the control structure for the given upstream head

has been reached and further decreases in downstream head result in no increase in flow or in a physically impossible flow situation. The drop in water surface elevation at this point is called the free drop and the flow is called the free flow because the upstream head and the flow are free of any downstream influence.

Instead of tabulating the actual drops for a given upstream head it is convenient to normalize the drops with the free drop. This then gives the proportion of free drop that varies from 0.0 to 1.0. Knowledge of the free drop for each upstream head then defines the entire table.

Two-dimensional tables with this definition are limited to control structure for which there is a drop in water surface elevation in the direction of flow for all flows. Control structures exist for which this is not true. For example, a carefully designed expansion in channel size will result in an increase in water surface elevation for all expanding flows. Such a structure cannot be represented by the current method. A generalization of the current method is under consideration in which the direction of flow will be defined by the drop in the elevation of the total energy line. In this case the drop in the water surface elevation may be negative.

Two tables must be computed to represent both directions of flow through a control structure. The roles of entrance and exit and approach and departure are reversed and the second table is defined as the first. The range of head values does not need to be the same but the datum for defining the heads must be the same for both tables.

It should be noted that the tables are to define all flows and some ingenuity is required in adequately defining the tables for the more complex control structures. Transitions between flow regimes will occur and some of these transitions must be smoothed because the approximating equations for the regimes may give different flow values at the boundary between the regimes. The user must use judgment in deciding how to smooth the transition.

The table lookup is linear in the upstream head and in the proportion of free drop. This has the advantage of being simple and of always giving reasonable values. The lookup procedure will never return a flow that exceeds the free flow for the given upstream head. The choice of the proportions of free drop must be selected so that linear interpolation yields acceptable results. The rate of change of flow is theoretically infinite when the drop approaches zero. Thus the values of proportion of free drop should be closely spaced for small values of drop and more widely spaced for large values of drop. In this way the flows can be represented adequately for the range of drops that will likely occur in FEQ.

In many cases the downstream flow conditions will be such that the flow never comes close to being free. Thus the computation of the whole range of physically possible flows for a control structure may appear to be wasted effort. This is not so for the following reasons. First, it is difficult to predict what the range of downstream flows and stages will be in an unsteady flow analysis. Second, the manner in which the user has represented the flow system may yield results totally unexpected and perhaps unrealistic. Thus the flows as modeled may result in free flow because of some error in representation. If the free flow limit were not included, the computations might break down with the true nature of the problem being obscured. Third, the computations of the two-dimensional tables should normally be done using a computer program and the additional computations are not costly. Fourth, the computation of the entire range of physically possible flows is a good lesson in hydraulic analysis and should provide additional insight into the hydraulics of the control structure. Fifth, computation of the whole range of flows provides a check against blunders in computation or analysis.

If TYPE = 7, 8, or 9 (Alternative time argument for types 2, 3, or 4):

These three types use a time argument that differs from the argument given in types 2, 3, and 4. The time argument is given in the form of year, month, day, and hour. Card 3 is exactly the same as for types 2, 3, and 4 but cards 4 and 5 differ.

CARD 4

Variable: HEAD

Format: A80

Explanation: User selected heading for subsequent information.

Example: YEAR MN DY HOUR F(1) F(2)

CARD 5

Variables: YR, MN, DY, HR, F(1), [F(2)]

Format: I4, 1X, I2, 1X, I2, 3F10.0

Explanation:

YR = the year in which the function values occur. All four digits must be given.

MN = the month(1–12) in which the function values occur.

DY = the day of the month(1–31) in which the function values occur.

HR = the hour of the day including any fractional hour at which the function values occur.

F(1) = the value of the first function at the given time argument.

F(2) = the value of the second function at the given time argument.

The values for year, month, and day need only be given for the first argument in the table and whenever they change. FEQ replaces blank fields found for these three values with the most recent non-blank values. That is, the values of year, month, and day propagate into blank fields. The hour of the day must be given for each entry because it will always differ. The year, month, and day must be valid calendar dates and FEQ reports an error if they are not. Also the year must be between 1901 and 2099 in order for the internal date computations to function properly. Again FEQ reports an error if the year falls outside its valid range.

The end of input for a table with the year, month, and day argument is indicated by giving a year, month, day argument that is earlier in time than its predecessor.

If TYPE = 11 (Dual function wind speed and direction):

CARD 3

Variable: REFLEV, FAC

Format: 5X, F10.0, 5X, F10.0

Example: REFL=0.0 FAC= 43560.0

Explanation: Reference level read by FEQ but not now used. FAC is used as a multiplier on the wind sped values in the table but not the direction. Thus FAC can be used to adjust measured wind speeds to the correct units and measurement level.

CARD 4

Variable: HEAD

Format: A80

Explanation: User selected heading for subsequent information.

Example: YEAR MN DY HOUR SPEED AZIMUTH

CARD 5

Variables: YR, MN, DY, HR, F(1), F(2)

Format: I4, 1X, I2, 1X, I2, 3F10.0

Explanation:

YR = the year in which the wind values occur. All four digits must be given.

MN = the month(1–12) in which the wind values.

DY = the day of the month(1–31) in which the wind values occur.

HR = the hour of the day including any fractional hour at which the wind values occur.

F(1) = the speed in the wind at the given time argument.

F(2) = azimuth of the wind direction measured clockwise from north in degrees. Corresponds to the tradition of wind direction being the point from which the wind is coming. For example, an east wind has an azimuth of 90 degrees.

The values for year, month, and day need only be given for the first argument in the table and whenever they change. FEQ replaces blank fields found for these three values with the most recent non-blank values. That is, the values of year, month, and day propagate into blank fields. The hour of the day must be given for each entry because it will always differ. The year, month, and day must be valid calendar dates and FEQ reports an error if they are not. Also the year must be between 1901 and 2099 in order for the internal date computations to function properly. Again FEQ reports an error if the year falls outside its valid range.

The end of input for a table with the year, month, and day argument is indicated by giving a year, month, day argument that is earlier in time than its predecessor.

If TYPE = 12 (Cross sectional elements):

Tables of type 12 are used in FEQUTL for culvert computations. FEQ can read these tables but can make no use of them. Plans are underway to design a cross sectional elements table to supplant by types 1 and 12 so that the same table will again be used by all programs.

A negative TYPE value for TYPE's 2, 3, 4, 6, 7, 8, 9, 11, or 12 suppresses echoing of the table values. Only the header information will be output by FEQ in this case.

FREE NODE INITIAL CONDITIONS BLOCK: Free Node Table

CARD 1

Variable: HEAD

Format: A80

Example: NODE DEPTH DISCHARGE ELEVATION SIGN

Explanation: User selected heading for subsequent information.

CARD 2

If NODEID = NO then

Variables: NODE, DEPTH, DISCH, ELV, SIGN

Format: I5, 3F10.0, I5

If NODEID = YES then

Variables: NODE, NAME, DEPTH, DISCH, ELV, SIGN

Format: I5, 1X, A8, 1X, 3F10.0, I5

Explanation:

NODE = the exterior node number of the free node.

NAME = optional name for the free node.

DEPTH = the initial depth of water at the free node.

DISCH = the initial discharge at the free node.

ELV = the elevation of the reference point used for defining depth at the free node.

SIGN = the sign of the free node(+1 or −1). If the free node is a reservoir, FEQ reads the sign but ignores its value because the sign of a reservoir node is always +1.

Card 2 is repeated for each free node. No terminator is needed because FEQ knows the number of free nodes at this point in the analysis of the input.

CARD 1

Variable: NBR

Format: 14X, I5

Example: BRANCH NUMBER=00001

Explanation: Gives the branch number identification for the flow specification table for a branch. Branch numbers must be given in ascending order.

If NBR < 0 on card 1 then

CARD 2

Variable: DISCH

Format: 10X, F10.0

Example: DISCHARGE=250.0

Explanation: Gives the flow in the branch if the flow is the same for all nodes on the branch. If the flowa are different, then a more detailed input is required.

If NBR > 0 on card 1 then

CARD 2

Variable: HEAD

Format: A80

Example: NOD1 NOD2 DISCHARGE

Explanation: User selected heading for subsequent information.

CARD 3

Variables: ND1, ND2, DISCH

Format: 2I5, F10.0

Explanation:

ND1 = first node in range of node numbers.

ND2 = second node in range of node numbers.

DISCH = discharge to use for ND1 through ND2.

Card 3 is repeated as needed to define a flow for each node on the branch. The first and last node in the range must be given even if they are the same number.

CARD 4

Variable: HEAD

Format: A80

Example: BRAN CODE ELEVATION EXN

Explanation: User selected headings for subsequent information.

CARD 5

Variables: BRA, CODE, ELEV, EXN

Format: 2I5, F10.0, I5

Explanation:

BRA = branch number to be analyzed. If BRA = 0 and if CODE > 0 then the exterior node given in CODE is given the elevation of the exterior node given in EXN.

CODE = code defining the operation to be done:

CODE = 0 indicates that the starting elevation for the branch given by BRA is given by the sum of the elevation of the water surface at the exterior node given in EXN and the value given for ELEV. Note that the value given for ELEV in this case may not be an elevation. It will likely be an increment in water surface elevation.

CODE> 0 then the starting elevation is taken from ELEV. The starting elevation may be a first guess to be refined by FEQ.

CODE = 2 computes the critical depth at the downstream end of the branch using the elevation given in ELEV as a first estimate. The resulting elevation at critical depth is then used as the starting elevation for the branch.

CODE = 3 computes the depth from a stage-discharge relationship as given in the Exterior Matrix Control Block for CODE = 4, TYPE = 1, 2 or 3 using the elevation in ELEV as a first estimate. The resulting elevation is then used as the starting elevation for the branch.

CODE = −3 computes the depth from a stage-discharge relationship specified at the free node given in EXN in the same manner as for CODE = 3. BRA = 0 in this case.

CODE = 5 computes critical depth at the downstream end of the branch using the elevation in ELEV as a first estimate. Then it compares the resulting water surface elevation with the elevation at the node given in EXN. It then uses the elevation at critical depth if it is greater than the elevation given in EXN. Otherwise, it uses the elevation at the node in EXN.

Card 5 is repeated for each branch in the system but not necessarily in branch number order. The order is defined by the requirement that the water surface elevation be known at the downstream end of the branch. Thus the first branch appearing in the input will be the most downstream branch where a boundary condition will define the water surface elevation directly or indirectly. The branches are then given in an order such that the result of the analysis of one branch will provide an elevation for one or more upstream branches.

A value of −1 in the BRA column terminates input for the backwater computations and indicates that all flow depths have been defined.

UNSTEADY FLOW SOLUTIONS

FEQ Messages: Version 6.0

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FEQ MESSAGES: Version 6.0

FEQ issues messages to the user in three categories. The first category of messages consists of messages describing some condition in the input which makes it impossible for FEQ to understand the intent of the user. Some errors are simple enough that FEQ takes some standard corrective action and continues reading and checking the input to search for additional errors. FEQ will, however, terminate the run when the input has been checked. Some errors may only be detected during execution of the unsteady flow computations. These errors are not corrected and in most cases the computations are terminated.

The second category consists of warning messages reporting conditions which may indicate a user error or which highlight the possibility of some later computational problem. Usually FEQ makes some assumption to circumvent the problem and then continues the computations. The user should always check the warning messages to make sure that the default action taken by FEQ has not affected the results.

The third category of messages consists of bug messages reporting conditions which should not occur. They are usually indicative of some problem in the computer code and should not be seen often. However, conditions not tested may occur in an application and a bug may be revealed.

ERR:nn MESSAGES

FEQ contains a fairly extensive set of error messages to detect errors in specification of the hydraulic system as early as possible. However, there are errors which could be detected but which are not yet detected. Over a period of time these undetected errors will result in program code changes so that they will be found before they cause computational problems or incorrect results. However, it is possible to correctly specify the hydraulic system so that FEQ detects no errors and still have the system improperly defined through some error on the part of the user. As a simple example, the stationing used for the node locations on a branch might be in river miles but by some mistake the person typing the input thought the stationing was in thousands of feet. FEQ has no way of detecting this error because SFAC will have a proper value in either case. However, the results of the run, should it go to completion, would be incorrect. Thus there are three types of errors possible: an error which can be detected by FEQ and is detected, an error which could have been detected by FEQ but no code for the detection exists, and an error which by its nature cannot be detected by FEQ now or in the future. Over time the number of errors included in the first set will increase and the number of errors included in the second set will decrease. However, the number of errors in the third set will stay the same.

The error messages are given in numerical order below. There may be gaps in the order as changes are made so that the absence of a numbered message does not necessarily imply that some message has been omitted. Furthermore, the order of numbering is arbitrary.

Messages with numbers of 60 or less are reported by a special subroutine, KILL, and relate to the early processing of the input to FEQ. Each message includes a separate line, not shown here, giving a reference number. This number obtains its meaning from the context of the following message. For example, message 2, "NODE ON A BRANCH OUTSIDE VALID RANGE", will have the errant node number appearing in its reference value line.

In many cases the message includes numbers and in a few cases character strings. These numbers and character strings will have a value which depends on the specific occurrence of the error. The positions of these occurrence dependent values are denoted by 'nn' for an integer number, 'ff' for a floating point number(i.e. one containing a decimal point or in the so-called floating point format), and 'aa' for a character string.

ERR: 1 BRANCH NUMBERS OUT OF SEQUENCE OR RANGE

Notes: Branch numbers must be given in ascending numerical order. This message indicates that a branch number has been given out of order, a branch number which is zero or less or has been found, or that a branch number which is greater than the number of branches given in the Run Control Block has been found.

ERR: 2 NODE ON A BRANCH OUTSIDE VALID RANGE

Notes: A node on a branch has been found ≤ 0.

ERR: 3 NODE ON A BRANCH OUT OF SEQUENCE OR A DUPLICATE

Notes: Nodes on a branch must have node numbers assigned in ascending consecutive order. A node has been found which does not follow this sequence or is a duplicate on the branch. Note that only the upstream node on a branch need be given a node number. Subsequent nodes will then be automatically numbered by FEQ to satisfy its requirements. This is the preferred method of input to minimize errors and confusion. Further note that the node numbers for nodes on a branch need only be unique for a given branch. Thus the same number can be used for nodes on different branches. This is possible but not advisable. I have found it to be efficacious to use four digit numbers for node numbers. The first two digits are the branch number and the second two digits are the node number on the branch. This of course assumes that there are not more than 99 branches with no branch having more than 100 nodes on it. Most systems will fit these assumptions! For example, the first node on branch 10 would by this system be given the number 1000 or 1001 depending on your preference of numbering from 1 or from 0. This method yields a self-identifying number for a node on a branch giving its branch number as well as its location on the branch. This can be a great time and mistake saver!

ERR: 4 UPSTREAM EXTERIOR NODE NUMBER OUT OF RANGE

Notes: An exterior node number for the upstream node on a branch has been found which is either ≤ 0 or which is greater than the number of exterior nodes, NEX, given in the Run Control Block.

ERR: 5 DOWNSTREAM EXTERIOR NODE NUMBER OUT OF RANGE

Notes: An exterior node number for the downstream node on a branch has been found which is either ≤ 0 or which is greater than the number of exterior nodes, NEX, given in the Run Control Block.

ERR: 6 ONLY NON-RESERVOIR FREE NODES MAY BE < 0

Notes: In order to represent certain connections efficiently, it is possible to prefix the number of a non-reservoir free node with a minus sign when giving that node number in the Exterior Matrix Control Input to indicate that it is to have its node sign reversed for that particular relationship only. A reservoir node, although also a free node, cannot be treated in this manner because a reservoir node is always taken to be at the downstream end of a virtual branch. This message appears if FEQ detects that a reservoir node has been prefixed with a minus sign in the Exterior Matrix Control Input.

ERR: 7 INVALID DEVICE TYPE FOR A CONTROL STRUCTURE

Notes: Each control structure category, Code 4 or Code 5, has its valid range of device type number. A type number has been found which is outside the valid range for the control structure category.

ERR: 8 I/O UNIT NUMBER ALREADY IN USE

Notes: FEQ keeps track of the input/output units already specified either explicitly or implicitly by the user. FEQ has detected a unit number which is the same as one already given by the user.

ERR: 9 TABLE NUMBER OUT OF VALID RANGE

Notes: A table number for a function table to be supplied by the user must be greater than zero and less than the compile time variable, MFTNUM (Maximum Function Table NUMber), given in the INCLUDE file named ARSIZE.FOR. The current standard maximum function table number is 10,000. This number may be set to any desired positive value by the user. The new number does not take effect until FEQ is recompiled and linked.

ERR:10 FUNCTION TABLE SPACE EXCEEDED

Notes: FEQ maintains an area of computer memory for the storage of all function tables encountered in its input. The size of this area is given by the compile time variable, MRFTAB(Maximum Row Function TABle), in the INCLUDE file named ARSIZE.FOR. This value must be large enough for the hydraulic system being simulated. This number may be set to any desired positive value by the user. The new number does not take effect until FEQ is recompiled and linked. The typical range of values is 40,000 to 150,000 elements. Each element, on byte oriented computers, takes 4 bytes. Thus a request for 150,000 elements will used 600,000 bytes in one array.

ERR:11 INVALID CODE FOR EXTERIOR MATRIX CONTROL

Notes: FEQ has detected a code value in the Exterior Matrix Control Input which is not defined by FEQ. The current defined code values are given in the input summary for FEQ.

ERR:12 BRANCH NUMBER OUT OF RANGE

Notes: FEQ has detected a branch number which is ≤ 0 or $>$ NBRA, the number of branches given in the Run Control Block.

ERR:13 EXTERIOR MATRIX CONTROL SPACE EXCEEDED

Notes: FEQ allocates a predetermined amount of space for storage of the exterior matrix control information. This space is given by the compile time variable, MREMC(Maximum Row Exterior Matrix Control), in the INCLUDE file named ARSIZE.FOR. This number may be set to any desired positive value by the user. The new number does not take effect until FEQ is recompiled and linked. Typical range is 2000 to 3000 elements.

ERR:14 NUMBER OF NODES AT A JUNCTION > 9 OR < 1

Notes: The number of nodes found at a junction(Code = 2) is outside the valid range indicated in the message.

ERR:15 EXTERIOR NODE NUMBER OUT OF RANGE OR SEQUENCE

Notes: FEQ has encountered an exterior node number which is ≤ 0 or $>$ NEX, the number of exterior nodes given in the Run Control Block.

ERR:16 TYPE MUST BE 1, 2, OR 3 FOR A FORCED BOUNDARY

Notes: An invalid type has been found for a forced boundary(Code = 6).

ERR:17 NUMBER OF RESERVOIR FLOW NODES> 7 OR < 0

Notes: The number of flow nodes for a reservoir is either too large or is negative. It is valid to have no flow nodes for a reservoir because the reservoir node itself is always excluded from the count of flow nodes. The flow nodes are nominally inflow nodes but this is only a nominal designation because the flow may enter or leave the reservoir at these nodes depending upon the hydraulic conditions.

ERR:18 TYPE FOR POINT FLOWS > 2 OR < 1

Notes: The Type for point flows must be either 1 or 2 and FEQ has encountered a different value.

ERR:19 TOO MANY POINT FLOWS GIVEN

Notes: :FEQ maintains a predefined space for the point flows and this space is too small. The size of this space is given by the compile time variable, MRPFPNT(Maximum Row Point Flow PoiNter), in the INCLUDE file named ARSIZE.FOR.This number may be set to any desired positive value by the user. The new number does not take effect until FEQ is recompiled and linked. The current value is 3 because the point flow option is rarely used.

ERR:20 TYPE FOR FUNCTION TABLES > 12 OR < 1

Notes: FEQ has found a function table type which is outside the range given in the error message.

ERR:21 INVALID ARG SEQ OR INTERVAL FOR FUNCTION TABLE TYPE 5

Notes: Function table type 5 is an undocumented function table type which is used only under special circumstances. Its function has been supplanted for the most part by the INFLOW FILES option.

ERR:22 THE NODES FOR HEAD MUST BE DISTINCT

Notes: FEQ has detected that the two nodes for head in a two-node control structure are the same node which is invalid and meaningless.

ERR:23 THE NODE FOR FLOW MUST EQUAL ONE OF THE HEAD NODES

Notes: FEQ has found that the flow node for a two-node control structure is different than either of the head nodes. The flow node must match one of the two head nodes.

ERR:24 RESERVOIR NODE DUPLICATES AN EXISTING NODE

Notes: A reservoir node number duplicates a number already given to a previous exterior node.

ERR:25 DUPLICATE FUNCTION TABLE NUMBER

Notes: A function table number duplicates a number already used for a previous function table.

ERR:26 Unassigned.

ERR:27 TOO MANY NODES

Notes: The number of nodes on branches has exceeded the space predefined in FEQ. The compile time variable, MNBN(Maximum Number Branch Nodes), in the INCLUDE file ARSIZE.FOR defines the size of this space. This number may be set to any desired positive value by the user. The value of MNBN must always include the exterior nodes at each end of each branch and any other nodes not on the ends of the branch. The variable MEXTRA in ARSIZE.FOR gives the count of these extra nodes on a branch. The new number does not take effect until FEQ is recompiled and linked. The range of values in current use for MEXTRA is 400 to 700.

ERR:28 POINT FLOW INVALID FOR UPSTREAM NODE

Notes: It only makes sense for a point flow to enter a computational element. Computational elements are identified and referenced by giving the number of their downstream node. The upstream node on a branch cannot therefore refer to any computational element and FEQ must report any such reference as an error.

ERR:29 TOO MANY BRANCHES

Notes: FEQ allocates a predefined space for branches. The size of this space is given by the compile time variable, MNBRA(Maximum Number BRAnchs), in the INCLUDE file, ARSIZE.FOR. This number may be set to any desired positive value by the user. The new number does not take effect until FEQ is recompiled and linked.

ERR:30 TOO MANY EXTERIOR NODES

Notes: FEQ allocates a predefined space for storage of exterior node information. The size of this space is given by the compile time variable, MNEX(Maximum Number EXterior nodes), in the INCLUDE file ARSIZE.FOR. This number may be set to any desired positive value by the user. The new number does not take effect until FEQ is recompiled and linked.

ERR:31 INVALID OPERATION BLOCK NUMBER IN CHKEX

Notes: Operation block numbers must be positive but not greater than the number of blocks given in the Operation of Control Structures Block. This means that the blocks should be numbered consecutively starting at 1.

ERR:32 INTERIOR MATRIX CONTROL VECTOR (IMPV) SPACE EXCEEDED

Notes: FEQ has detected that the interior matrix control vector is too small for the current hydraulic system. The size of this vector is given by the compile time variable, MRAPD(Maximum Row Array of Partial Derivatives), in the INCLUDE file ARSIZE.FOR. This number may be set to any desired positive value by the user. The new number does not take effect until FEQ is recompiled and linked.

ERR:33 ARRAY OF PARTIAL DERIVATIVES (APD,RHS) SPACE EXCEEDED

Notes: FEQ has detected that the arrays used to store the interior matrix are too small for the current hydraulic system. The size of these arrays is given by the compile time variable, MRAPD(Maximum Row Array of Partial Derivatives), in the INCLUDE file ARSIZE.FOR. This number may be set to any

desired positive value by the user. The new number does not take effect until FEQ is recompiled and linked.

ERR:34 EXTERIOR MATRIX (EXTMAT,EXTRHS) SPACE EXCEEDED

Notes: FEQ has detected that the arrays used to store the exterior matrix are too small for the current hydraulic system. The size of these arrays is given by the compile time variable, MREXT(Maximum Row EXTerior matrix), in the INCLUDE file ARSIZE.FOR.

ERR:35 INVALID PRINT OUT OPTION

Notes: A value for OUTPUT in the Run Control Block < 0 or > 5 has been found by FEQ. Values greater than 1 are designed for use in debugging and should be used with care because they can produce large amounts of output.

ERR:36 INVALID OPTION FOR POINT FLOWS

Notes: The option for POINT in the Run Control Block must be YES or NO. Any other response will result in this error message.

ERR:37 INVALID OPTION FOR DIFFUSE FLOWS

Notes: The option for DIFFUSE in the Run Control Block must be YES or NO. Any other response will result in this error message.

ERR:38 INVALID OPTION FOR WIND LOADING

Notes: The option for WIND in the Run Control Block must be YES or NO. Any other response will result in this error message.

ERR:39 Unassigned.

ERR:40 I/O UNIT NUMBER OUT OF RANGE

Notes: FEQ uses a predefined range for input/output unit numbers. The minimum unit number is 1 and the maximum number is given by the compile time variable, MUNIT(Maximum UNIT number), in the INCLUDE file named ARSIZE.FOR.

ERR:41 SPECIAL OPERATION BLOCK NUMBER OUT OF RANGE

Notes: Operation block numbers must be positive but not greater than the maximum number of blocks given by the compile time variable, MNBLK(Maximum Number of BLocKs), in the INCLUDE file ARSIZE.FOR. This number may be set to any desired positive value by the user. The new number does not take effect until FEQ is recompiled and linked.

ERR:42 INVALID OPTION FOR SPECIAL OPERATIONS

Notes: The option for SOPER in the Run Control Block must be YES or NO. Any other response will result in this error message.

ERR:43 EXTER NODE USED AS A FLOW NODE IN A CONTROL STRUCTURE MORE THAN ONCE

Notes: An exterior node has been used as flow node in more than one control structure. A flow node must be unique and therefore more than one use is invalid.

ERR:44 EXTERIOR NODE APPEARS ON MORE THAN ONE BRANCH

Notes: An exterior node has been assigned to more than one branch. The exterior node numbers assigned to the upstream and downstream node on each branch must be unique.

ERR:45 INVALID SLOPE SOURCE FOR CHANNEL CONTROL:-1,0,1, ARE VALID

Notes: A slope source code number other than the possible values given in the error message has been found.

ERR:46 THIS NODE MATCHES ANOTHER WHEN NODES MUST BE DISTINCT.

Notes: Duplicate exterior node numbers have appeared in a context requiring that the nodes be distinct. This could happen in several of the Exterior Matrix Input Control options.

ERR:47 OPTION DISCONTINUED. ALTERNATIVE IN INPUT DESCRIPTION.

Notes: The requested option is not available in this version of FEQ or FEQUTL. An alternative can be found in the input description for the current version.

ERR:48 TOO MANY FORCED NODES WITH TABLES OR FILES.

Notes: Increase MNCD6 in ARSIZE.FOR.FOR and recompile FEQ.

ERR:49 TOO MANY INPUT FILES.

Notes: Increase MNFIN in ARSIZE.FOR.FOR and recompile FEQ.

ERR:50 INVALID DIRECTION: 1 OR -1 ARE VALID

Notes: An invalid direction has been given in the Exterior Matrix Control Input.

ERR:51 BRANCH HAS ALREADY APPEARED IN EMC INPUT.

Notes: The branch number has already been read. Indicates an error in typing one of the branch numbers or an error in labeling the schematic or in writing the Exterior Matrix Control Input.

ERR:61 ELEMENT LENGTH IS ZERO

Notes: The computational element length is given by the absolute value of the difference in the stations at its upstream and downstream end. This length must be positive, but FEQ has found an element with zero length indicating that two consecutive nodes on a branch were given the same station value.

ERR:62 TABLE#= nn SHOULD BE TYPE 6 BUT TYPE= nn FOUND INSTEAD.

Notes: A table number of Type 6 is required by FEQ but you have supplied a table with a different type.

ERR:68 TABLE# = nn SHOULD BE TYPE 1 BUT TYPE = nn FOUND INSTEAD.

Notes: Only tables of type 1 contain cross section elements. FEQ has found a table which is not a cross section table in a context which requires a cross section table.

ERR:69 TABLE#= nn SHOULD BE TYPE 2:4 OR 7:9BUT TYPE= nn FOUND INSTEAD.

Notes: FEQ has found a table of invalid type in a context which requires a 1-D table. Table types of 2 through 4 and 7 through 9 are valid in the context of this table reference.

ERR:70 ARGUMENT BELOW RANGE IN LKTAB
TABLE NUMBER = nn
TIME = ff
ARGUMENT = ff

Notes: Each table has a minimum value of its argument for which the function value is defined. FEQ has encountered an argument less than this minimum for the given table and at the given time. Check

to see if the correct table has been given and that it has an adequate range. In some contexts this error requires that the computations be terminated and in other contexts the minimum value in the table is used and the computations continue.

ERR:71 ARGUMENT ABOVE RANGE IN LKTAB
TABLE NUMBER = nn
TIME = ff
ARGUMENT = ff

Notes: Each table has a maximum value of an argument for which the function value is defined. FEQ has encountered an argument greater than this maximum value. Check to see if the correct table has been given and that it has an adequate range. In some contexts this error requires that the computations be terminated and in other contexts the maximum value in the table is used and the computations continue.

ERR:72 EU < ED IN TWO-D TABLE# = nn EU = ff, ED = ff

Notes: In two-dimensional tables of type 6 the upstream level can never be less than the downstream level. FEQ has encountered a pair of levels which does not satisfy this relationship and therefore cannot continue with its computations. This error indicates a major problem with the table or a bug in the software.

ERR:73 UNEXPECTED TYPE IN TWO-D TABLE# = nn TYPE = nn EXPECTED TYPE = nn

Notes: FEQ has encountered a table type which is incorrect for a two- dimensional table. This means that an incorrect table number has been given.

ERR:74 INVALID MONTH IN TABLE# = nn

Notes: An invalid month number has been found while processing the time argument for a table of type 7, 8, or 9. Check to make sure that all months are in the range of 1 to 12.

ERR:75 INVALID DAY IN TABLE# = nn

Notes: An invalid day of the month has been found while processing the time argument for a table of type 7, 8, or 9. Check to make sure that all days are in the proper range for the given month.

ERR:76 INVALID YEAR IN TABLE# = nn

Notes: The year for the time argument for a table of type 7, 8, or 9 must be greater then 1900 but less than 2100 for the internal date computations to be valid.

ERR:77 FIRST VALUE OF P FOR CONSTANT HEAD LINE NOT ZERO. P = ff

Notes: In tables of type 6 the first value of P, the fraction of the drop to free flow, must always be zero. A table has been found for which this is not true.

ERR:78 P DECREASES. P = ff POLD = ff

Notes: In tables of type 6 the values of P, the fraction of the drop to free flow, must always be increasing. A table has been found for which this is not true. POLD gives the previous value of P and P gives the current value of P.

ERR:79 VALUES OF UPSTREAM HEAD ARE DECREASING IN 2-D TABLE.

Notes: In tables of type 6 the values of upstream head must always be increasing. A table has been found for which this is not true.

ERR:80 INVALID ROADWAY FLOW. ZU = ff ZD = ff RDELEV = ff RS = ff

Notes: Flow over the roadway in the bridge flow computations using Code 5, Type 4, must always flow from a higher elevation to a lower elevation. FEQ has detected a situation in which the direction of flow and the relationship of elevations for the computation of flow over the roadway are contradictory. If the problem can not be resolved by modifying the input, the error detection code will have to be modified to permit small discrepancies in the elevation-direction relationship.

ERR:81 TABLE# = nn DOES NOT EXIST.

Notes: FEQ has encountered a table number which cannot be found in the list of table numbers indicating that the input to FEQ referenced a table number but the table for that number was not included in the input.

ERR:82 TABLE# = nn TOO LARGE. SET TO CURRENT MAXIMUM OF: nn

Notes: The current maximum table number has been exceeded by a table number given in the input to FEQ. The current maximum table number can be increased by changing MFTNUM (Maximum Function Table NUMber) in the file ARSIZE.FOR to the maximum value desired. The only limit to the maximum is the available memory for the computer program and the space allowed for input of a table number. Table numbers appearing in the Exterior-Matrix Control Input are currently limited to four digits and those for the cross section table number in the Branch Description Tables are currently limited to five digits.

ERR:83 NODE FOR CHANNEL CONTROL DEPTH nn NOT ON A BRANCH

Notes: Channel control of the relationship between flow and depth can only be requested for a node on a branch.

ERR:84 CHANNEL CONTROL NODE nn NOT AT DOWNSTREAM END OF BRANCH

Notes: Channel control of the relationship between flow and depth can only be requested at the downstream node on a branch.

ERR:85 NUMERIC PROBLEM IN SUBROUTINE EXCON. 3nn,ff,6(ff))

Notes: This error message should not occur because subroutine EXCON currently computes critical depth ignoring the effect of the momentum flux correction coefficient. If this restriction is removed then it possible that the critical flow cannot be computed because the variation of the momentum flux coefficient with depth is such that the critical flow is mathematically undefined. This results because the currently available techniques for estimating the momentum flux coefficient can be greatly in error especially for the computation of critical flow.

ERR:86 INVALID CROSS-SECTION INTERPOLATION REQUEST XL = ff XM = ff XR = ff

Notes: An interpolation request for an intermediate cross section has been found with the station of the intermediate cross section falling outside of the station interval given by the next available upstream and downstream cross section.

ERR:87 MORE THAN nn DEPTH VALUES BETWEEN TABLE#'S nn AND nn

Notes: The maximum number of depth values currently allowed for intermediate cross sections is nn. If this value too small, then the cross sections given by the table numbers in the message should be adjusted such that there are either fewer depth values in each table or that there are a greater number of coincident depth values in the tables. If this is not satisfactory then the maximum must be increased by changing MNDEP in the include file ARSIZE.FOR to the desired value and recompiling FEQ.

ERR:88 CUBIC INTERPOLATION FOR ELEV NOT YET SUPPORTED

Notes: Cubic interpolation has been requested for an input file containing elevations when this interpolation option it not supported.

ERR:89 EXTERIOR NODE = nn NOT FOUND IN EXTERIOR MATRIX CONTROL WITH CODE = 4

Notes: FEQ has been requested to compute a one-node stage-discharge relationship at the given exterior node but no such relationship appears in the Exterior-Control Matrix input. Most likely source of the error is an incorrect specification of the options for the computation of the backwater profiles.

ERR:90 BRANCH NUMBER nn EXPECTED, BRANCH NUMBER nn FOUND

Notes: A branch number is out of order in the section of the Backwater Input giving the discharges for the branches.

ERR:91 INVALID NODE NUMBER ORDER nn

Notes: The nodes on a branch in the Backwater Input are out of order.

ERR:92 NODE NUMBER nn OUT OF RANGE

Notes: A node number has been found in the Backwater Input which is out of the range for its branch.

ERR:93 OVERLAPPING OR MISSING NODE NUMBER INTERVAL ND1 = nn OLD ND2 = nn

Notes: The node number intervals given for the assignment of initial flows on a branch in the Backwater Input must not be overlapping and both numbers of the range must be given.

ERR:94 DOWNSTREAM DEPTH MISSING FOR BRANCH nn

Notes: The downstream depth to start the computations of backwater appears to be missing. The depth may have been given or may have been obtained from an exterior node for which the depth has already been computed but the bottom elevation of the downstream end of the current branch is greater than the water surface elevation known at the source node.

ERR:95 MAXIMUM ITERATIONS EXCEEDED FOR BACKWATER ANALYSIS

Notes: The computations for the unknown depth in the backwater analysis have not converged within the allowed number of iterations. There are many potential explanations for the lack of convergence. The most common source is that the length of the computational element is too long. Thus most such convergence problems are corrected by interpolating one or more intermediate cross sections in the current computational element. The downstream node for the element in question is given by the last node printed for the branch in the backwater analysis block. If the slope and roughness of the branch make supercritical flow possible it may be necessary to request that the inertial terms be ignored in the branch by setting INERTIA to 0.0 in the branch heading information.

ERR:96 FATAL ERRORS ENCOUNTERED

Notes: This message is printed before the execution of the program is terminated because errors have been detected in the input which make continuation of the program computations impossible. One or more error messages will appear in the output describing the nature and location of the errors.

ERR:97 ELEVATION UNDEFINED AT EXN = nn

Notes: An exterior node has been referenced as a source of water surface elevation in the Backwater Analysis Block but the elevation at that node has not been defined. Some error has been made in either the node number or there is an error in the order of computation of the branches.

ERR:98 INVALID BRANCH NUMBER. BNUM = nn

Notes: A branch number less than 1 or greater than the number of branches has been encountered in the Backwater Analysis Block.

ERR:99 INVALID EXTERIOR NODE. EXN = nn

Notes: An exterior node number less than 1 or greater than the number of exterior nodes has been encountered in the Backwater Analysis Block.

ERR:100 EXN# WITH BRA = 0 AND ICODE = -3 IS NOT A FREE NODE. EXN# = nn

Notes: An exterior node has been referenced in the Backwater Analysis Block in a context which requires the node to be a free node but the node is found by FEQ to be on a branch.

ERR:101 INVALID EXTERIOR NODE GIVEN IN C/ND WHEN BRA = 0. C/ND = nn

Notes: An exterior node has been referenced in the Backwater Analysis Block in the code/node column which is either less than 1 or greater than the number of exterior nodes.

ERR:102 INVALID EXTERIOR NODE GIVEN WHEN BRA = 0 EXN = nn

Notes: An exterior node has been referenced in the Backwater Analysis Block when the branch column is zero and the exterior node is either less than 1 or greater than the number of exterior nodes.

ERR:103 INCORRECT NO. OF EQUATIONS SPECIFIED FOR EXTERIOR MATRIX,
NO. OF EQUATIONS SPECIFIED = nn
NO. OF EQUATIONS REQUIRED = nn

Notes: There must be exactly twice as many equations as there are exterior nodes in the exterior matrix. Too few or too many equations may have been given. Review the schematic and the equations to find the error.

ERR:104 INSUFFICIENT SPACE IN EXTERIOR MATRIX,
NO. OF COLUMNS REQUIRED = nn
NO. OF COLUMNS AVAILABLE = nn

Notes: If the bandwidth has already been minimized by rearranging equations then the bandwidth must be increased by changing the parameter MCEXT (Maximum Columns in the EXTerior matrix) in ARSIZE.FOR to the number of columns required and recompiling the program.

ERR:105 INSUFFICIENT SPACE IN LOWER TRIANGULAR MATRIX
NO. OF COLUMNS REQUIRED = nn
NO. OF COLUMNS AVAILABLE = nn

Notes: If the bandwidth has already been minimized by rearranging equations then the width of the lower triangular matrix must be increased by changing MCLTM (Maximum Columns in Lower Triangular Matrix) in ARSIZE.FOR to the number of columns required and recompiling the program.

ERR:106 CODE nn NOT IMPLEMENTED

Notes: A code found in the Exterior-Matrix Control Input has not been implemented.

ERR:107 EXTERIOR NODES ARE THE SAME ON BRA = nn

Notes: The upstream and downstream nodes on the given branch have the same node number. FEQ requires that these numbers be distinct.

ERR:108 CROSS SECTION TABLE NUMBER MUST BE > 0 AT FIRST NODE ON BRANCH

Notes: The first node on the branch must always have a cross section table given which does not require interpolation.

ERR:109 INLET AREA GIVEN BUT INLET CUTOFF HEIGHT IS MISSING FOR NODE: nn

Notes: If the inlet area is given for a sewer than the cutoff height must also be given.

ERR:110 TABLE# = nn DOES NOT EXIST.

Notes: FEQ cannot find the table number given as a cross section table on a branch.

ERR:111 TABLE# = nn DOES NOT EXIST.

Notes: FEQ cannot find the table number given as a table in the Exterior-Matrix Control Input.

ERR:112 CRITICAL DEPTH INVALID FOR THIS NODE: nn

Notes: Critical depth can only be requested at a node on a branch. The node given is not on a branch.

ERR:113 RESERVOIR TRIB AREA GIVEN FOR NODE nn BUT NODE IS NOT A RESERVOIR.

Notes: An exterior node has been referenced in the Tributary Input in a context implying that it is a reservoir node. The node however, is not a reservoir node.

ERR:114 CODE = 9 SELECTED WHEN NOT SUPPORTED

Notes: Code = 9 in the Exterior-Matrix Control Input is not yet supported. It is under development and the code number is reserved and will be made available in the future.

ERR:115 NODE = nn NOT ON A BRANCH FOR CODE = nn

Notes: The exterior nodes involved with Code = nn in the Exterior-Matrix Control Input must all be on a branch. The given node is not on a branch and is therefore invalid.

ERR:116 CROSS SECTIONS NOT THE SAME FOR CODE = nn BETWEEN NODES nn AND nn

Notes: Code = nn in the Exterior-Matrix Control Input requires that the cross sections at its upstream and downstream nodes be identical and that they be given by the same table number. The table numbers are different and FEQ therefore assumes that the cross sections are different also.

ERR:117 BOTTOM ELEVATIONS NOT THE SAME FOR CODE = nn BETWEEN NODES nn AND nn

Notes: Code = nn in the Exterior-Matrix Control Input requires that the bottom elevations be the same for the two exterior nodes involved. The bottom elevations as given by the user are not the same and therefore the input is invalid.

ERR:118 INVALID TYPE = nn IN POINT FLOW TABLE

Notes: Only point flow types of 1 or 2 are valid and a type different than either of these valid numbers has been found in processing a point flow table.

ERR:119 TABLE NUMBER = nn OUT OF RANGE FOR POINT FLOW NO.: nn

Notes: The given table number is out of the valid range for table numbers in the given point flow specification. The point flow number is current count of point flow specifications processed.

ERR:120 TABLE# = nn DOES NOT EXIST

Notes: A table number given in the Wind Input cannot be found in the input.

ERR:121 BOTTOM SLOPE FOR NORMAL DEPTH < 0. S = ff

Notes: The user supplied bottom slope for the computation of normal depth is negative and therefore invalid.

ERR:122 UPSTREAM NODE: nn FOR CODE 5 TYPE 5 MUST BE ON DOWNSTREAM END OF A BRANCH.

Notes: Type = 5 of Code = 5 in the Exterior-Matrix Control Input requires that the upstream node be on the downstream end of a branch. The node given by the user is not on the downstream end of a branch and is therefore invalid.

ERR:123 DOWNSTREAM NODE: nn FOR CODE 5 TYPE 5 MUST BE ON UPSTREAM END OF A BRANCH.

Notes: Type = 5 of Code = 5 in the Exterior-Matrix Control Input requires that the downstream node be on the upstream end of branch. The node given by the user is not on the upstream end of a branch and is therefore invalid.

ERR:124 FLOW NODE FOR CODE 5 TYPE 5 MUST BE THE UPSTREAM NODE

Notes: Type = 5 of Code = 5 in the Exterior-Matrix Control Input requires that the flow node be the upstream node. The flow node given by the user is not the upstream node and is therefore invalid.

ERR:125 INVALID NODE NUMBER nn

Notes: An exterior node number < 0 or > NEX, the number of exterior nodes given in the Run Control Block, has been found in the Free Node Initial Conditions Input.

ERR:126 INVALID INITIAL DEPTH ff DEPTH MUST BE POSITIVE NON-ZERO

Notes: A depth has been given in the Free Node Initial Conditions Input which is zero or negative and is therefore invalid.

ERR:127 NUMBER OF EXTERIOR NODES GIVEN BY BRANCHES EXCEEDS EXPECTED NUMBER OF nn

Notes: The number of exterior nodes given by the twice the number of branches is larger than the number of exterior nodes specified by the user in the Run Control Input. Either the number of branches given is too large or the number of exterior nodes given is too small.

ERR:128 EXTERIOR NODE nn PREVIOUSLY INITIALIZED TO ff CHECK BRANCH-EXTERIOR NODE TABLE

Notes: An exterior node listed in the Free Node Initial Conditions Input has already been initialized. It is likely not a free node or it has already appeared in the previous input for this block.

ERR:129 EXTERIOR NODE nn IS NOT FREE. IT IS ON BRANCH# nn

Notes: An exterior node listed in the Free Node Initial Conditions Input is not a free node and is therefore invalid.

ERR:130 Not now in use.

ERR:131 INVALID USE OF AUXILIARY TABLE FILES. FEQIN TABLE INPUT MUST BE COMPLETE BEFORE USING AUXILIARY FILES.

Notes: Auxiliary table files for the input of function tables can only be used after table input from the principal input(called FEQIN in the message) is complete. FEQ has found a function table in the

principal input after an auxiliary table file has been processed. To correct the error move the offending table or tables in the principal input above the first reference to an auxiliary table file.

ERR:132 ONLY nn EXTERIOR NODES GIVEN BUT AT LEAST 2*NBRA = nn REQUIRED.

Notes: The number of exterior nodes on branches exceeds the given number of exterior nodes. Either the number of branches or the number of exterior nodes is in error.

ERR:133 NBRA = 0 INVALID. NBRA > 0 REQUIRED.

Notes: FEQ always requires that at least one branch be present.

ERR:134 BRANCH NUMBERS OUT OF RANGE OR SEQUENCE IN TRIB. AREA INPUT

Notes: The branch numbers in the Tributary Area Input must be given in ascending order with no omissions. A branch number in this input has been found which is out of the valid range for branch numbers or is out of numerical sequence.

ERR:135 NODES ON A BRANCH OUT OF RANGE OR SEQUENCE IN TRIB. AREA INPUT

Notes: If the nodes on a branch are given in the Tributary Area Input they must be in ascending order. A node has been found which is either out of range or is not in ascending order.

ERR:136 TRIB AREA FOR RESERVOIRS REQUIRES nn LOCATIONS IN QPVEC BUT ONLY nn ARE AVAILABLE.

Notes: FEQ cannot find adequate space for storage of the tributary area for reservoirs. Increase the size of MEXTRA in ARSIZE.FOR and recompile the program.

ERR:137 BRANCH NUMBER = 0 HAS BEEN FOUND MORE THAN ONCE IN TRIB AREA INPUT.

Notes: A branch number of 0 is used in the Tributary Area Input to reference input of the areas tributary to reservoirs. All reservoirs having tributary area must have their tributary area given when the branch number is 0. A second occurrence of a branch number of 0 has been found. Some error has occurred in the branch number sequence.

ERR:138 NUMBER OF GAGES < 1 OR > nn

Notes: The number of gages is out of range. If the number is correct then change MXGAGE in ARSIZE.FOR and recompile the program.

ERR:139 GAGE NUMBER: nn OUT OF SEQUENCE

Notes: The gage numbers must be given in ascending order and a gage number has been found which is out of order.

ERR:140 SUM OF GAGE LAND USES IN ERROR

Notes: The summation of land uses from the gages does not match the number of land uses given in the input.

ERR:141 GAGE NUMBER: nn OUT OF RANGE

Notes: The gage number is outside the valid range. See ERR:138.

ERR:142 UPSTREAM STATION: ff NOT FOUND IN BRANCH: nn

Notes: The option to distribute tributary area by station interval has been invoked but the upstream station of the interval cannot be found in the list of stations given in the Branch Description Input.

ERR:143 DOWNSTREAM STATION: ff NOT FOUND IN BRANCH: nn

Notes: The option to distribute tributary area by station interval has been invoked but the downstream station of the interval cannot be found in the list of stations given in the Branch Description Input.

ERR:144 UPSTREAM NODE = nn >= DOWNSTREAM NODE = nn FOR TRIB. AREA.

Notes: The stations for the station interval method for distributing tributary area are given in reverse order so that the node corresponding to the downstream station is upstream of the node corresponding to the upstream station. As a result the tributary area cannot be distributed because the nodes are reversed.

ERR:145 NUMBER OF LAND USES < 1 OR > nn

Notes: The number of land uses must be at least 1 if the diffuse flows option is invoked in the Run Control Block. The number of land uses must not be larger than the maximum number of uses established in ARSIZE.FOR. If the current maximum number is too small change MNDIFA in ARSIZE.FOR to the new maximum number and recompile FEQ.

ERR:146 REQUEST FOR AUTOMATIC TRIB. AREA ALLOCATION INVALID. MUST BE FIRST AND ONLY ENTRY FOR THE BRANCH

Notes: If the automatic area allocation for the tributary area to a branch is selected then only one line of area information for each gage should appear for each branch. FEQ has detected that more than one line of information has been given for a branch and cannot do the allocation.

ERR:147 OUTPUT REQUESTED AT TOO MANY NODES. NOUT = nn

Notes: The limit for the number of output locations for the special output option has been exceeded. If the number must be increased change the value of MNSOUT in ARSIZE.FOR to the new value. Furthermore the specification of the number of floating point numbers to output in subroutine OUTSP in formats 10 and 11 must be changed to correspond to the new limit. Please be aware of the limit on the record size in the operating system used to control the computer system. Under MS-DOS the limit is 512 bytes. This limits the number of special outputs to about 62 locations.

ERR:148 IN BRANCH nn THERE HAVE BEEN nn CONSECUTIVE INTERPOLATION REQUESTS. ONLY nn ARE ALLOWED.

Notes: More than the allowed number of consecutive interpolated sections have been requested in a branch. The allowed number is increased by changing the value of MNMID in the include file ARSIZE.FOR and recompiling the program.

ERR:149 STAND FLD LVL AT OR BELOW MINIMUM POINT IN CHANNEL AT BRANCH nn NODE nn

Notes: The standard flood level given for the node has an elevation which is at or below the minimum point in the cross section and is therefore invalid.

ERR:150 NUMBER OF INPUT FILES REQUESTED IS LARGER THEN THE CURRENT MAXIMUM OF: nn

Notes: Too many input files have been requested. The limit can be increased by changing MNFIN in ARSIZE.FOR to the new limit and recompiling FEQ. The parameter MRRBUF in ARSIZE.FOR should also be increased to allow more buffer space for the input files. The available buffer space is divided equally among the input files.

ERR:151 FILE NUMBER IN INPUT LIST NOT IN FORCED BOUNDARY LIST. UNIT = nn

Notes: An input file has been specified but it has not been associated with any forced boundary condition(Code = 6 in the Exterior-Matrix Control Input). Please make sure that all the files listed in the File Input Block are being used in the current run.

ERR:152 INPUT FILE nn HAS A START TIME = ff > RUN START TIME = ff

Notes: An input file has been found with a start time which is later than the start time of the run. Thus the run cannot be made because the data in the file is incomplete.

ERR:153 FILE NUMBER IN FORCED BOUNDARY NOT IN INPUT LIST. UNIT = nn

Notes: A file number has been referenced in a forced boundary(Code = 6 in the Exterior-Matrix Control Input) but the file number could not be found in the list of input files. Supply the missing file information and try the run again.

ERR:154 THERE ARE nn VALUES IN EACH RECORD OF THE DIFFUSE TSF BUT ONLY nn VALUES ALLOWED IN FEQ.

Notes: The record length of the diffuse time series file being used is larger than the record length allowed in FEQ. Change the value of MNDIFA in ARSIZE.FOR and recompile FEQ to change the number of values allowed in FEQ.

ERR:155 THERE ARE nn DIFFUSE FLOWS IN THE DIFFUSE FLOW FILE BUT nn LAND USES IN FEQ.

Notes: The number of land uses specified in the Tributary Area Input is not the same as the number of diffuse flows in the diffuse time series file. These two numbers must agree. If all the land uses in the diffuse time series file are not of interest give a tributary area of zero for those land uses to be skipped. This will then give the correct total for land uses and will yield the desired result.

ERR:156 ITEM FIELD MUST BE: "ELEV" OR "FLOW"

Notes: In the Output Files Block the item to be output must be either elevation or flow. Check spelling and spacing and resubmit.

ERR:157 TYPE FIELD MUST BE: "PNT " OR "MEAN"

Notes: In the Output Files Block the recording type must be either point or mean value. Check spelling and spacing and resubmit.

ERR:158 NUMBER OF OUTPUT FILES REQUESTED LARGER THAN THE CURRENT MAXIMUM OF: nn

Notes: More than the current maximum number of output files has been requested. Change MNFOUT in ARSIZE.FOR to the new maximum and recompile FEQ.

ERR:159 MEAN VALUED ELEVATIONS CANNOT BE OUTPUT

Notes: It is meaningless to output mean values of elevations and FEQ does not allow that recording type for elevations.

ERR:160 ZERO PIVOT IN BANDET SOLUTION

Notes: In the course of computations FEQ has encountered a singular exterior matrix. The solution is undefined and computations must halt. This error can arise if two identical equations have been specified in the Exterior-Matrix Control Input. Check the input carefully to make sure that the proper equations have been specified.

ERR:161 UNABLE TO SET UP VECTORS QPVEC, FPVEC, WSVEC IN SUBROUTINE LOAD

Notes: An error has already been detected and reported in subroutine LOAD which makes it impossible to complete the subroutine properly. Therefore the computations must stop.

ERR:162 EXECUTION TERMINATED BECAUSE OF PREVIOUS ERRORS

Notes: One or more errors requiring termination of the computations have been found.

ERR:163 CONVERGENCE CRITERION FOR SURCHARGE STORAGE IS TOO SMALL.
MUST BE LARGER THAN 0.01

Notes: The current version of FEQ no longer uses the old value of EPSXS, the convergence criterion for cross section tables because the current version of FEQ no longer uses the flow area as the dependent variable. Thus the string 'EPSXS' should be replaced by the string 'SSEPS' in the input to give the convergence criterion for surcharge storage. This convergence criterion is active whenever there are sewers present and there is surcharge storage. The criterion should be in the range of 0.1 to 0.25. If the criterion is too large then the water balance will have large errors and if it is too small there will be convergence problems.

ERR:164 TABLE NUMBERS EXHAUSTED IN NEXTN

Notes: All available table numbers have been used for the interpolation of cross section tables. Increase the maximum number of table numbers by increasing the parameter MFTNUM in the include file ARSIZE.FOR and recompiling the program.

ERR:165 Value of MORG wrong in ARSIZE.FOR. Must be 0 or 1.

Notes: MORG gives the origin for the retrieval of the command line arguments when command line arguments are retrieved using the standard function names from UNIX. Not all compilers support this option. Compilers which do support the option differ in how they count command line arguments. Some will label the command itself as argument 0 with the first argument labeled as 1. Others will label the command itself as the first argument and so the first command line argument is labeled as 2. In the first case MORG = 0 and in the second case MORG = 1. Any other value for MORG is invalid.

ERR:166 WEIGHT COEFFICIENT FOR AVERAGING ELEVATION IS INVALID.
MUST BE >= 0 AND <= 1.0. WEIGHT= ff

Notes: The weight coefficient for averaging elevations in those Exterior Matrix Control Input options which use an average elevation is outside its valid range.

ERR:167 RESERVOIR NODE nn HAS WRONG SIGN. MUST BE +1.

Notes: The sign given to a reservoir node must be +1. FEQ checks to make sure this is true. An error in this sign is either a clerical input error or a more serious misunderstanding of the role of a reservoir. Therefore FEQ requires the input of the sign even though the sign is always +1.

ERR:168 SIDE NODE nn FOR SIDE WEIR MUST HAVE SIGN OF −1.

Notes: The current side weir option must have a sign of −1 for the side weir node in order for flows to be represented properly.

ERR:169 NUMBER OF GAGE LAND USES= nn EXCEEDS MAX OF nn AT GAGE nn.

Notes: Too many gage land uses have been assigned to a gage. Increase MXGLU in the include file ARSIZE.FOR and recompile the program.

ERR:170 NUMBER OF GAGE LAND USES= nn IS INVALID.

Notes: The number of gage land uses is either negative or zero. Only positive numbers are meaningful.

ERR:171 IF GEQOPT=FCON THEN XSTOFF MUST= 7. XSTOFF= nn INSTEAD.

Notes: In order to use the governing equation option for the full conservation form approximation to the governing equations XSTOFF must be set in the include file ARSIZE.FOR at compile time to the

proper value. Using XSTOFF= 7 will still allow using the options STD or STDX but more storage will be required for the cross section tables. If storage is at a premium and there is no need to use FCON then compile the program using XSTOFF= 6.

ERR:172 EXTERIOR NODE nn DOES NOT HAVE TRIB. AREA OR IS NOT A RESERVOIR.

Notes: You have requested output of the diffuse land surface runoff value at an exterior node. The node given must be a reservoir node having tributary area assigned to it. The node given in the message is invalid because it does not meet these requirements.

ERR:173 MORE THAN nn ITERATIONS FOR BANDWIDTH REDUCTION.

Notes: More than the given number of iterations has been used and the band width for the exterior matrix has not reached a minimum. The current limit is set at 500 and this error message indicates a probable bug in the system or an extremely perverse pattern for the exterior matrix!

ERR:174 TABLE#= nn IS TYPE 12. NOT YET SUPPORTED IN FEQ.

Notes: Table Type 12 is currently used by FEQUTL but is not yet supported by FEQ. Only cross section tables of Type 1 can be used in FEQ at this time.

ERR:175 Band width minimization option: MINBND is missing.
Add after option:CHKGEO.

Notes: The band width minimization option must be added to input streams for older versions of FEQ.

ERR:176 TABLE#= nn SHOULD BE TYPE 12 BUT TYPE= nn FOUND INSTEAD.

Notes: A table of Type 12 is required by the context but a table of the given type was found.

ERR:177 TABLE#= nn SHOULD BE TYPE 11 BUT TYPE= nn FOUND INSTEAD.

Notes: A table of Type 11 is required by the context but a table of the given type was found.

ERR:178 FEQ FINDS nn EQNS IN EXTERIOR MATRIX BUT EXPECTS nn EQNS.

Notes: The incorrect number of equations has been given in the Exterio atrix Control Input. Other error messages may appear earlier and may relate to the incorrect numb f equations.

ERR:179 BRANCH NUMBER= nn DOES NOT APPEAR IN EMC INPUT.

Notes: The given branch number has not been found in the Exterior Matrix Control Input. All branches must be referenced exactly once in the input.

ERR:180 EXPECTED nn ENTRIES IN EMC INPUT BUT FOUND nn ENTRIES.

Notes: An incorrect number of entries exists in the Exterior Matrix Control Input. The number of entries should be exactly twice the number of exterior nodes less the number of branches. Some error has been made in the input.

ERR:181 EXTERIOR NODE= nn APPEARS IN CODES 2, 6,OR 7 MORE THAN ONCE.

Notes: An exterior node which is on a branch or is a reservoir node can only appear once in one of the above contexts.

ERR:182 EXTERIOR NODE= nn APPEARS IN CODES 2, 6, OR 7 MORE THAN TWICE OR NOT AT ALL.

Notes: Non-reservoir free nodes must appear at least once but not more than twice in the above context. appeared more than two times in the input.

ERR:183 Extrapolation tolerance: EXTTOL is missing.
Add after option:MINBND.

Notes: FEQ remembers the maximum depth in each cross section before making any extrapolation requested by the user. FEQ checks the resulting maximum elevations in each cross section against the maximum depth in the cross sections and issues a warning message for each cross section which is overtopped by more than EXTTOL. EXTTOL should be picked so that minor extrapolations are not reported but that major ones are.

ERR:184 EXTERIOR NODE= nn IMPROPERLY CONNECTED.

Notes: A non-reservoir free node must appear exactly twice in flow defining relationships in order to be connected properly. At least one of these appearances must be in codes 2, 6, or 7. Both can be in codes 2 or 7 but not in 6. If the node appears twice in code 6 FEQ will issue an error because a node has been used twice as a flow node. If the node appears only once in codes 2, 6, or 7, then it must also appear in either codes 4 or 8. An example is a downstream boundary node on a null branch. Such usage is unusual but possible.

ERR:185 EXTERIOR NODE= nn NEVER APPEARS IN CODES 2, 4, 6, 7, OR 8.

Notes: An exterior node must appear at least once in one of the above codes to be properly connected.

ERR:186 TWO STATIONS MATCH IN BRANCH nn STATION= ff

Notes: Each station along a branch must be unique so that each element has a nonzero length.

WRN:nn MESSAGES

FEQ detects a variety of conditions which may or may not cause problems in the computations. However, the conditions are such that the user is made aware of their presence so that corrective action, if required, can be taken.

WRN:01 EXTRAPOLATION NOT DONE. TOP WIDTH < 0. EXT = ff

Notes: An extrapolation request for a cross section results in a negative top width. The extrapolation is not done.

WRN:02 X-SECTION BELOW RANGE IN XLOOKY
TABLE NUMBER = nn
STATION NUMBER = ff
TIME = ff
DEPTH = ff

Notes: Subroutine XLOOKY has found that the depth is less than the minimum depth available in the cross section. This message should not appear if the CUTOFF option for cross sections has not been used.

WRN:03 X-SECTION ABOVE RANGE IN XLOOKY
TABLE NUMBER = nn
STATION NUMBER = ff
TIME = ff
DEPTH = ff

Notes: Subroutine XLOOKY has found that the depth is greater then the maximum depth in the cross section. If this warning appears only a few times and if the resulting maximum depth at the conclusion of the run is less than the maximum no action is required. However, if the warning appears many times and the run terminates early or the maximum depth at the conclusion of the run is the same as the maximum depth in the cross section then either extend the cross section using the EXT option or obtain additional data to further define the cross section and recompute the table using FEQUTL.

WRN:04 HU > HMAX IN TWO-D TABLE# = nn HU = ff HMAX = ff

Notes: The upstream head for a two-dimensional table of Type = 6 is greater than the maximum upstream head stored in the table. FEQ uses the maximum stored upstream head and continues the computations. If this message appears many times and if the limitation appears to have affected the flow then you must extend the table so that the message no longer appears.

WRN:05 ABRUPT EXPANSION CANNOT ALLOW REVERSE FLOW AT TIME = ff WITH FLOW = ff UPS NODE = nn, AND DNS NODE = nn

Notes: The current implementation for an abrupt expansion cannot allow reverse flow and FEQ has determined that such a flow occurs. FEQ forces the flow to be zero and continues with the computations.

WRN:06 INVALID CRITICAL DEPTH FACTOR AT UPS NODE = nn IN ABRUPT EXPANSION. DEPTH = ff

Notes: The computation of critical flow when the correction coefficient for momentum flux is included is not always possible. An invalid condition has been found but FEQ will try to continue. This problem will not arise if the momentum flux correction factor is a constant.

WRN:07 INVALID CRITICAL DEPTH FACTOR AT DNS NODE = nn IN ABRUPT EXPANSION. DEPTH = ff

Notes: The computation of critical flow when the correction coefficient for momentum flux is included is not always possible. An invalid condition has been found but FEQ will try to continue. This problem will not arise if the momentum flux correction factor is a constant.

WRN:08 EXP-CON WITH FLOW NODE = nn CANNOT ALLOW REVERSE FLOW AT TIME = ff WITH FLOW = ff AT UPS DEPTH = ff AND DNS DEPTH = ff

Notes: The computed flow in an expansion-contraction indicates reversal when the physical conditions are such that a reversal is impossible. FEQ forces the reverse flow to zero and continues.

WRN:09 CONVEYANCE NONINCREASING AT DEPTH = ff

Notes: Conveyance should always be increasing with depth in an open channel with diverging walls. This message occurs if the drop in conveyance over the depth interval is less than 0.5 per cent.

WRN:10 CRIT. FLOW NONINCREASING AT DEPTH = ff

Notes: Critical flow, computed ignoring the momentum flux correction factor, is decreasing with an increase in depth. Computational problems may occur in the region of decrease.

WRN:11 DROP OF ff PER CENT IN CONVEYANCE AT DEPTH = ff

Notes: Conveyance should always be increasing with depth in an open channel with diverging walls. This message occurs if the drop in conveyance is greater than 0.5 percent. The corrective action to take is to further subdivide the cross-section to compensate for the inability of the hydraulic radius to properly reflect the effect of cross section shape.

WRN:12 BOTTOM ELEVATION DIFFERENCE BETWEEN NODE nn , aa, AND NODE nn, aa, IS ff

Notes: The bottom elevation difference may be real but it could also be the result of an error. If the difference is large enough relative to the flow FEQ will encounter problems at the difference with critical or super critical flow. This message will also appear in some cases when a branch discharges into a level-pool reservoir. In general I represent reservoirs such that the depth and the elevation of the water surface are the same. To do this FEQ is led to believe that the bottom of the reservoir is at the datum for elevations which is usually far below the bottom elevation of the branch. This warning will appear for each such case but can be ignored because the discontinuity in bottom elevation between a reservoir and a branch does not have the same effect as does a discontinuity in the bottom elevations at a junction among branches.

WRN:13 BAL CHK WILL BE INCORRECT. AVOID FREE NODE SIGN CHANGE FOR CODE = 6.

Notes: This is one of the situations where FEQ cannot properly interpret the balance check. Free nodes serving as locations where either flow or elevation is forced should always be given a sign which would be in the natural sense for that node if that node were on a branch serving the same function as the free node. For example, inflows of water to a system would normally occur at the upstream node on a branch. Therefore if a free node is used for the inflow it should be given a sign of -1 to make its default nature that of an upstream node on a branch.

WRN:14 BAL CHK WILL BE INCORRECT. AVOID FREE NODE SIGN CHANGE FOR CODE = 4 WHEN ON SYSTEM BOUNDARY.

Notes: This is the other situation where FEQ cannot properly interpret the balance check. The same recommendation applies here as for WRN:13.

WRN:15 nn ITERATIONS REQUESTED FOR SYSTEM SOLUTION BUT ONLY nn ALLOWED.

Notes: More iterations have been requested for the maximum allowed for system solution than have been provided in ARSIZE.FOR. Change the parameter, MNITER, in ARSIZE.FOR and recompile the program.

WRN:16 OLD FORM OF TRIB AREA INPUT IS BEING DISCONTINUED. PLEASE CONVERT OLD FILES TO NEW FORM TO ESTABLISH COMPATIBILITY WITH FUTURE VERSIONS

Notes: Your input is using the old form for Tributary Area Input. This form will be discontinued at some point in the future and you should convert to the new forms because they are more flexible and more convenient than the old form. See the current Input Description for FEQ.

WRN:17 CONTINUITY ERROR OF ff IN INITIAL CONDITIONS AT NODES:

Notes: An error in continuity of flow in the initial conditions has been found at a junction involving the listed exterior nodes. If this error is large enough it could cause computational problems. The error can be corrected by changing the flow assignments in the backwater computations.

WRN:18 WS ELEV DIF BTWN NODE nn, aa, & NODE nn , aa, : ff

Notes: A difference in water surface elevation at the listed exterior nodes has been found. A difference large relative to the depths of water could cause computational problems. The error can be corrected by making appropriate adjustments in the backwater computations.

WRN:19 POSS. FLOW DISCON. AT FULL FLOW AT BRIDGE BETWEEN NODES nn , aa, AND nn ,aa

Notes: The current bridge routine often encounters computational problems in the transition to full flow. This warning message is issued if the estimated discontinuity is greater than an internal threshold.

WRN:20 MAX. FLOW AREA FOR BRIDGE AND AREA AT MAX. DEPTH DISAGREE FOR BRIDGE BETWEEN NODES nn, aa, AND nn ,aa
MAXIMUM FLOW AREA = ff AREA AT MAXIMUM DEPTH = ff
MAX. AREA USED IS ff MAKE INPUT CHANGE IF UNSATISFACTORY

Notes: The maximum flow area for the bridge given in the Exterior-Matrix Control Input does not agree with the maximum flow area derived from the cross section table describing the bridge opening.

WRN:21 DISCREPANCY IN MAX. ELEV. OF BRIDGE OPENING FOR BRIDGE BETWEEN NODES nn ,aa, AND nn, aa
MAX. ELEV. IN EXTERIOR MATRIX = ff MAX ELEV IN TABLE# nn IS ff
MAX. ELEV. USED IS ff MAKE INPUT CHANGES IF UNSATISFACTORY

Notes: The maximum elevation of the bridge opening given in the Exterior-Matrix Control Input and the maximum elevation of the bridge opening inferred from the cross section table for the opening do not agree. This may not be an error because you may have requested that FEQ simulate submerged flow hydraulics using the free-flow hydraulic equations. If FEQ thinks you have done so it will print a message.

WRN:22 FLOW DISCONTINUITY AT CONSTANT FLOW BOUNDARY AT NODE nn, aa

Notes: The flow assigned to a branch or a free node in the backwater computations does not match the flow forced at the node by Code = 6.

WRN:23 FOR BRIDGE BETWEEN NODES nn, aa, AND nn, aa, DOWNSTREAM AREA < MAX BRIDGE AREA. AB/AD = ff VIOLATES BPR BRIDGE LOSS METHOD ASSUMPTIONS

Notes: The BPR bridge loss method assumes that the area downstream of the bridge is larger than the area of the bridge opening. FEQ has found that this requirement is not met when computing the

adjustments to the free-flow loss table in order to mimic the submerged flow loss using the free-flow loss equations.

WRN:24 NON-CONVERGENCE. TIME STEP WILL BE REDUCED.

Notes: The system solution has not converged in the number of iterations allowed. FEQ will reduce the time step according to user instructions and will try to continue the computations. Eventually this process is terminated either by convergence or by reduction of the time step to a value less than a user given minimum value.

WRN:25 DF = 0.0 IN CHKGEO

Notes: The value of the derivative in the single step steady flow computation in CHKGEO is zero. FEQ resets the value to 1.0 and continues the computations.

WRN:26 COMPUTATIONAL PROBLEMS LIKELY: CUTOFF ELEVATION= ff
SHOULD BE LESS THAN ELEVATION FOR HEAD= ff

Notes: For Code 5 Type 2 in the exterior control matrix the elevation at which the pump is turned on based on conditions at the destination node should be less than the elevation used for computing the head for the diversion of water into the offline reservoir. If the cutoff elevation is higher than the elevation for head then the pump is being turned on while the diversion structure is still diverting water into the offline storage reservoir. If the two elevation are equal the pumping of the water could cause the water surface elevation at the destination node to exceed the cutoff elevation. This feedback can result in convergence problems because the pump is being turned on and off at successive iterations so that convergence cannot occur.

WRN:27 XKNT= HAS BEEN REPLACED BY PAGE=. PLEASE CHECK RUN
CONTROL BLOCK INPUT DESCRIPTION.

Notes: FEQ has not used XKNT for some time. The space used by XKNT in the input has now been replaced by page size for the special output file so that headings can be placed in the file to help make the file easier to use. See the Run Control Block input description and the description for the Special Output Locations input.

WRN:28 FIRST DEPTH INCREMENT IN TABLE IS LARGE.

Notes: The first depth increment in a table to which a bottom slot is to be added is larger than 0.1. Check to make sure that NRZERO in FEQUTL has been set to the value you want. Large NRZERO values increase the effect of adding the bottom slot to the cross section.

WRN:29 BACKW NO LONGER USED. REPLACED BY GEQOPT.

Notes: The backwater option has not been in use for some time. It has remained in the input for consistency. It has now been replaced by GEQOPT in order to allow for the option of different sets of governing equations. See the discussion in the input description for the Run Control Block.

WRN:30 UNKNOWN OPTION= aa FOR GEQOPT. STD OPTION ASSUMED.

Notes: An unknown value for the selection of governing equations has been found for GEQOPT. FEQ assumes that the STD option was meant and continues the computations with that option.

WRN:31 X-SECTION BELOW RANGE IN XLKT11
TABLE NUMBER = nn
STATION NUMBER = ff
TIME = ff

DEPTH = ff

Notes: Subroutine XLKT11 has found that the depth is less than the minimum depth available in the cross section. This message should not appear if the CUTOFF option for cross sections has not been used. Note that XLKT11 looks up elements in a table of Type 12 but does not lookup the critical flow. This results primarily from the pattern of historical development of the program.

WRN:32 X-SECTION ABOVE RANGE IN XLKT11
TABLE NUMBER = nn
STATION NUMBER = ff
TIME = ff
DEPTH = ff

Notes: Subroutine XLKT11 has found that the depth is greater then the maximum depth in the cross section. If this warning appears only a few times and if the resulting maximum depth at the conclusion of the run is less than the maximum no action is required. However, if the warning appears many times and the run terminates early or the maximum depth at the conclusion of the run is the same as the maximum depth in the cross section then either extend the cross section using the EXT option or obtain additional data to further define the cross section and recompute the table using FEQUTL.

WRN:33 X-SECTION BELOW RANGE IN XLKT12
TABLE NUMBER = nn
STATION NUMBER = ff
TIME = ff
DEPTH = ff

Notes: Subroutine XLKT11 has found that the depth is less than the minimum depth available in the cross section. This message should not appear if the CUTOFF option for cross sections has not been used.

WRN:34 X-SECTION ABOVE RANGE IN XLKT12
TABLE NUMBER = nn
STATION NUMBER = ff
TIME = ff
DEPTH = ff

Notes: Subroutine XLKT11 has found that the depth is greater then the maximum depth in the cross section. If this warning appears only a few times and if the resulting maximum depth at the conclusion of the run is less than the maximum no action is required. However, if the warning appears many times and the run terminates early or the maximum depth at the conclusion of the run is the same as the maximum depth in the cross section then either extend the cross section using the EXT option or obtain additional data to further define the cross section and recompute the table using FEQUTL.

WRN:35 X-SECTION BELOW RANGE IN LKTQC
TABLE NUMBER = nn
STATION NUMBER = ff
TIME = ff
DEPTH = ff

Notes: Subroutine LKTQC has found that the depth is less than the minimum depth available in the cross section. This message should not appear if the CUTOFF option for cross sections has not been used. LKTQC looks up only the critical flow in tables of Type 12.

WRN:36 X-SECTION ABOVE RANGE IN LKTQC
TABLE NUMBER = nn
STATION NUMBER = ff

TIME = ff
DEPTH = ff

Notes: Subroutine LKTQC has found that the depth is greater then the maximum depth in the cross section. If this warning appears only a few times and if the resulting maximum depth at the conclusion of the run is less than the maximum no action is required. However, if the warning appears many times and the run terminates early or the maximum depth at the conclusion of the run is the same as the maximum depth in the cross section then either extend the cross section using the EXT option or obtain additional data to further define the cross section and recompute the table using FEQUTL. LKTQC looks up only the critical flow in tables of Type 12.

WRN:37 TABLE OVERFLOW AT EXT. NODE= nn ARGUMENT= ff

Notes: FEQ has predicted an argument at a reservoir node which will exceed the maximum value in the table. To prevent going beyond the maximum level in the table, FEQ takes the arithmetic average of the last valid argument and the maximum argument in the table as the argument value to use. If the message persists and the FEQ fails to complete its computations, the table may have to be extended to higher values. In some cases these values will be false but they must be supplied in any case. Occasionally FEQ must find a very large value of storage in the table in order to find the solution. If the maximum value resulting from convergence of the iterations is below the true maximum of the table, then the solution is valid. However, if the maximum value obtained is physically higher than the true maximum in the table, then some changes must be made in the flows, cross sections, *etc.*

WRN:38 TABLE OVERFLOW AT: nn:nn ARGUMENT= ff

Notes: Same as WRN:37 except that the problem is at a node on a branch.

WRN:39 DEPTH AT NODE: nn : nn OVERTOPS TABLE#= nn BY ff

Notes: FEQ remembers the maximum depth in a cross section table before doing any requested extrapolation via the EXT option. FEQ then checks to see which cross sections are overtopped by more than EXTTOL. EXTTOL should be set so that excessive use of extrapolated information is avoided.

BUG:nn MESSAGES

FEQ contains code designed to detect mistakes in the program. Normally you should not see these messages but there is always the chance that some programming change has not been made properly and the testing process has not used the erroneous program code. A BUG message almost always requires a change in the program code.

Many of the messages are similar because the same check is done in separate subroutines in the same context. FEQ makes extensive use of computed GOTO statements and includes code to detect an improper index for these statements. This extra code makes sure that an improper value of the index will be detected and reported instead of allowing the program to take the default action for an improper index.

BUG:01 INVALID GOTO CODE IN KILL. CODE= nn

Notes: A call to the error reporting subroutine KILL has included an error code number which is either greater than or less than the range provided in the computed GOTO used to branch to the output of each of the error messages.

BUG:02 INVALID TYPE IN CONTRL. TYPE= nn

Notes: Subroutine CONTRL computes most of the one-node control structure relationships. A type has been found which is either less than 1 or greater than the current maximum valid type number.

BUG:03 INVALID INTERNAL CODE: nn IN RDGET

Notes: An invalid code representing the data in an input file has been found by subroutine RDGET. This may mean that a file referenced in the Input Files Block was not created by FEQ in a previous run.

BUG:04 INVALID JTIME FOR TSF RECORD JTIME = ff

Notes: A problem exists in the time series file in the first data record. The Julian time for this record has been found to be positive when it should have been either 0 or negative.

BUG:05 INVALID EMC CODE IN BNDSIZ. CODE= nn

Notes: A code in the Exterior Matrix Control vector which falls outside the current range has been found in subroutine BNDSIZ.

BUG:06 EMC ENDS AT ELEMENT: nn BUT SHOULD END AT: nn IN CHKEX.

Notes: Subroutine CHKEX has found a problem in the internal addressing scheme in the Exterior Matrix Control vector.

BUG:07 ERROR IN OPERATION BLOCK ADDRESSING IN CHKEX nn nn nn

Notes: Subroutine CHKEX has found a problem in the internal addressing scheme for operation blocks.

BUG:08 INVALID EMC CODE IN CHKEX. CODE= nn

Notes: A code in the Exterior Matrix Control vector which falls outside the current range has been found in subroutine CHKEX.

BUG:09 INVALID TYPE FOR CODE=4 IN CHKEX. TYPE=nn

Notes: An invalid type for a one-node control structure has been found in subroutine CHKEX.

BUG:10 INVALID CODE 5 TYPE IN CHKEX. TYPE=nn

Notes: An invalid type for a two-node control structure has been found in subroutine CHKEX.

BUG:11 INVALID EMC CODE IN EXIN. CODE= nn

Notes: An Exterior-Matrix Control Input code outside the valid range has been found in subroutine EXIN.

BUG:12 INVALID CODE=4 TYPE IN EXIN. TYPE=nn

Notes: A type for one-node control structures outside the valid range has been found in subroutine EXIN.

BUG:13 INVALID CODE=5 TYPE IN EXIN. TYPE=nn

Notes: A type for two-node control structures outside the valid range has been found in subroutine EXIN.

BUG:14 INVALID TABLE TYPE IN FTABIN. TYPE=nn

Notes: A table type outside the valid range has been found in subroutine FTABIN.

BUG:15 INVALID EMC CODE IN SETCON. CODE=nn

Notes: An invalid code in the Exterior-Matrix Control vector has been found in subroutine SETCON.

BUG:16 INVALID EMC CODE IN SETEXT. CODE=nn

Notes: An invalid code in the Exterior-Matrix Control vector has been found in subroutine SETEXT.

BUG:17 INVALID CODE=5 TYPE IN SETEXT. TYPE=nn

Notes: An invalid type for two-node control structures has been found in subroutine SETEXT.

BUG:18 INVALID EMC CODE IN SETSTA. CODE=nn

Notes: An invalid code in the Exterior-Matrix Control vector has been found in subroutine SETSTA.

BUG:19 ERROR IN BRPT OR INNODE DETECTED IN FBRND.

Notes: An internal addressing problem has found in subroutine FBRND.

BUG:20 INVALID EMC CODE IN FINCHK. CODE=nn

Notes: An invalid code in the Exterior-Matrix Control vector has been found in subroutine FINCHK.

BUG:21 INVALID CODE=5 TYPE IN FINCHK. TYPE=nn

Notes: An invalid type for two-node control structures has been found in subroutine FINCHK.

BUG:22 ADDRESSING BUG FOR TABLES nn, nn

Notes: An addressing problem for function tables has been found when attempting to output the tables.

BUG:23 TABLE TYPE INVALID: nn

Notes: An invalid table type has been found when attempting to output the tables. Subroutine FTOUT currently supports only types 1 through 4.

BUG:24 INVALID TABLE TYPE IN FTOUT. TYPE=nn

Notes: An invalid table type has been found when attempting to output the tables. Subroutine FTOUT currently supports only types 1 through 4.

BUG:25 INVALID EMC CODE IN RSTSTA. CODE= nn

Notes: An invalid code in the Exterior-Matrix Control vector has been found in subroutine RSTSTA.

BUG:26 INVALID VALUE OF INTERNAL CODE FOR OUTPUT FILES: nn

Notes: An invalid code for output files has been found in subroutine WROUT.

BUG:27 INTERNAL CODE = 2 SHOULD NOT APPEAR FOR OUTPUT

Notes: Internal code = 2 although in the valid range for output files should not be used for output files in the current version of FEQ.

BUG:28 TL = 0

BUG:29 AL = 0

BUG:30 KL = 0

BUG:31 YL = 0

BUG:32 AR = 0

BUG:33 TR = 0

Notes: Messages 28-33 are issued by subroutine FINCHK when computing slope and ratio tests for a computational element in CHKGEO.

BUG:34 SUBROUTINE LKTSF:PASSING LIST HEAD COUNTER CLOCKWISE. JTIME =ff

Notes: FEQ has passed the list head for the circular buffer list when searching backward in time for an interval. May be caused by not having enough space in the buffer. The buffer space must always be large enough so that no time step will have a time span larger than the time span of the buffer. If this is found to be the cause then increasing the parameter MNDBUF in the INCLUDE file ARSIZE.FOR and recompiling FEQ should eliminate the problem.

BUG:35 SUBROUTINE LKTSF: UNEXPECTED END OF FILE READING FROM DTSF. FILE JTIME= ff
YEAR= nn MONTH=nn DAY=nn DAYFRAC=ff
RUN JTIME= ff SEGMENT EJTIME= ff

Notes: Something is incorrect in either the structure of the diffuse TSF or in the reading of the diffuse TSF because an end of file should not be encountered in LKTSF.

BUG:36 UNEXPECTED END OF FILE IN DTSF IN BFINIT.
RUN JTIME= ff RUN EJTIME= ff

Notes: In filling the diffuse TSF buffer for the first time for an event in the TSF, FEQ has encountered an end of file. Could be caused by the buffer being too small or could reflect some error in the structure of the TSF or in the processing of the TSF by FEQ. If the buffer is too small increase the parameter MNDBUF in the INCLUDE file ARSIZE.FOR and recompile FEQ.

BUG:37 INVALID CODE 5 TYPE IN SETSTA. TYPE= nn

Notes: A new Code 5 type has been added but not included in subroutine SETSTA.

BUG:38 INVALID CODE 5 TYPE IN RSTSTA. TYPE= nn

Notes: A new Code 5 type has been added but not included in subroutine RSTSTA.

BUG:39 INVALID CODE 5 TYPE IN BNDSIZ. TYPE= nn

Notes: A new Code 5 type has been added but not included in subroutine BNDSIZ.

BUG:40 INVALID CODE 5 TYPE IN SETCON. TYPE= nn

Notes: A new Code 5 type has been added but not included in subroutine SETCON.

BUG:41 INVALID CODE 5 TYPE IN SCNEMC. TYPE= nn

Notes: A new Code 5 type has been added but not included in subroutine SCNEMC.

BUG:42 CTYPE= nn IS INVALID IN SUBROUTINE CHKTYP

Notes: An error has been made in adding a new type to the list to be checked if CHKTYP.

BUG:43 DEQ DOES NOT = 2.

Notes: An error in the number of equations has been found in ENTSWP.

BUG:44 DEQ DOES NOT = 1.

Notes: An error in the number of equations has been found in ENTSWP.

BUG:45 INVALID EMC CODE IN SCNBND. CODE= CODE

Notes: An EMC code exists but has not been added to SCNBND.

BUG:46 FMXARG INVALID WITH 2-D TABLE. TAB#=nn IS A 2-D TABLE.

Notes: A request for the maximum argument in a table has been made for a 2-D table and FMXARG does not support 2-D tables at this time.

FEQ EXAMPLES

The following pages show four simple examples of input and output for FEQ. The examples are as follows:

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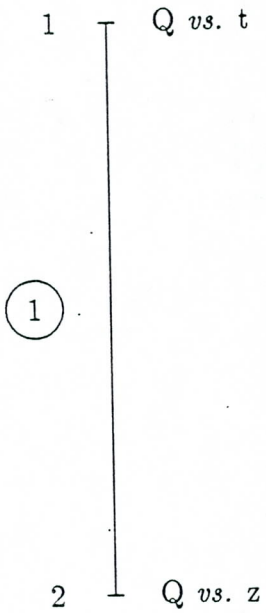
Each input and output has numbers added on the left for ease in reference. These numbers are not a part of the input or of the output.

FEQEX1-Single Branch System

SYSTEM SCHEMATIC SKETCH: FEQEX1



Listing of Input: FEQEX1

```
 1 Unsteady Flow- Example 1
 2 Single Branch System
 3 March 5, 1990
 4 NBRA=00001
 5 NEX=00002
 6 SOPER=NO
 7 POINT=NO
 8 DIFFUS=NO
 9 WIND=NO
10 UNDERFLOW=NO
11 ZL=0.0
12 STIME=1990/01/01:0.00
13 ETIME=1990/01/01:0.75
14 GRAV=32.2
15 NODEID=YES
16 SSEPS=0.1
17 PAGE=   22
18 EPSSYS=0.05
19 MKNT=   05
20 OUTPUT=    0
21 PRTINT=    8
22 GEQOPT=STDX
23 EPSB=0.000005
24 MAXIT=   30
25 SFAC=5280.
26 QSMALL=0.01
27 IFRZ=00001
28    1800.   1400.   1000.    850.    700.    500.    350.    100.    450.
29  1800 01.0  0.7  2.8  3.2  3.0  2.0  0.5
30 MRE=      0.20       0.5
31 DWT=0.05
32 BWT=0.50
33 BWFDSN=   00
34 CHKGEO=NO
35 MINBND=YES
36 EXTTOL= 0.0
37 BRANCH DESCRIPTION TABLES
38 BNUM=    1
39  NODE    NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
40   100 UPSTREAM  5000        0.0     100.
41
42
43
44
45
46
47
48
49
50       DNSTREAM  5000        1.0     100.
51    -1
52 BRANCH-EXTERIOR NODE TABLE
53  BRA# UEXN DEXN
54     1    1    2
55 EXTERIOR-MATRIX CONTROL INPUT
56  CODE    A   B    C   D   E   F   G   H   I   J     FA     FB     FC     FD
57     6    1   1    1 100
58     1    1
59     4    1   2   -1   2 110                        102.0   32.0
60    -1
61 SPECIAL OUTPUT LOCATIONS
62 UNIT=    3\FEQ68\TEST\EX1SPOUT
63   BRA NODE
64     1  100 NOD 100
65     1  101 NOD 101
66     1  102 NOD 102
67     1  103 NOD 103
68     1  104 NOD 104
69     1  105 NOD 105
70     1  106 NOD 106
71     1  107 NOD 107
72     1  108 NOD 108
73     1  109 NOD 109
74     1  110 NOD 110
75    -1
76 INPUT FILE SPECIFICATION
77  UNIT NAME
78    -1
79 OUTPUT FILE SPECIFICATION
80  UNIT  BRA NODE ITEM TYPE NAME
81    -1
82 FUNCTION TABLES
83 TABLE#=  100
84 TYPE=   -7
85 REFL=0.0        FAC=1.0
86 YEAR MN DY      HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END
87 1990 01 01       0.0       9.
88                  1.0      32.
89                  2.0     100.
```

```
                    3.0       151.
                    4.0        94.
                    5.0       145.
                    6.0       220.
                    7.0       178.
                    8.0       104.
                    9.0        77.
                   10.0        57.
                   11.0        38.
                   12.0        28
                   13.0        19.
                   14.0        10.
         02        24.0        10.
                   23.0
TABLE#=  110
TYPE=   -2
REFL=0.0
       HEAD WEIR COEF
        0.0       3.2
       50.0       3.2
       -1.0
TABLE#= 5000
TYPE=   -1
STATION= 2.41200E+00
ELEVATION= 0.00000E+00                    EXT=00.00      FAC=1.000
      DEPTH TOP WIDTH          AREA   SQRT(CONV)       BETA         YBARA
       .000    20.000  0.00000E+00  0.00000E+00     1.0000  0.00000E+00
       .080    20.480  1.61920E+00  4.21451E+00     1.0000  6.45120E-02
       .938    25.625  2.13867E+01  3.34821E+01     1.0000  9.61304E+00
     1.875    31.250  4.80469E+01  6.13671E+01     1.0000  4.17480E+01
     2.812    36.875  7.99805E+01  8.86460E+01     1.0000  1.01349E+02
     3.750    42.500  1.17188E+02  1.16093E+02     1.0000  1.93359E+02
     4.688    48.125  1.59668E+02  1.43993E+02     1.0000  3.22723E+02
     5.625    53.750  2.07422E+02  1.72467E+02     1.0000  4.94385E+02
     6.563    59.375  2.60449E+02  2.01568E+02     1.0000  7.13287E+02
     7.500    65.000  3.18750E+02  2.31316E+02     1.0000  9.84375E+02
     8.437    70.625  3.82324E+02  2.61712E+02     1.0000  1.31259E+03
     9.375    76.250  4.51172E+02  2.92750E+02     1.0000  1.70288E+03
    10.312    81.875  5.25293E+02  3.24420E+02     1.0000  2.16019E+03
    11.250    87.500  6.04687E+02  3.56707E+02     1.0000  2.68945E+03
    12.187    93.125  6.89355E+02  3.89597E+02     1.0000  3.29562E+03
    13.125    98.750  7.79297E+02  4.23074E+02     1.0000  3.98364E+03
    14.062   104.375  8.74512E+02  4.57123E+02     1.0000  4.75845E+03
    15.000   110.000  9.75000E+02  4.91730E+02     1.0000  5.62500E+03
    15.909   115.455  1.07748E+03  5.25807E+02     1.0000  6.55757E+03
    16.818   120.909  1.18492E+03  5.60383E+02     1.0000  7.58556E+03
    17.727   126.364  1.29731E+03  5.95444E+02     1.0000  8.71347E+03
    18.636   131.818  1.41467E+03  6.30980E+02     1.0000  9.94581E+03
    19.545   137.273  1.53698E+03  6.66980E+02     1.0000  1.12871E+04
    20.455   142.727  1.66426E+03  7.03433E+02     1.0000  1.27418E+04
    21.364   148.182  1.79649E+03  7.40329E+02     1.0000  1.43145E+04
    22.273   153.636  1.93368E+03  7.77659E+02     1.0000  1.60097E+04
    23.182   159.091  2.07583E+03  8.15414E+02     1.0000  1.78318E+04
    24.091   164.545  2.22293E+03  8.53584E+02     1.0000  1.97854E+04
    25.000   170.000  2.37500E+03  8.92162E+02     1.0000  2.18750E+04
    -1.000      .000  0.00000E+00  0.00000E+00      .0000  0.00000E+00
TABLE#=   -1
BACKWATER ANALYSIS
BRANCH NUMBER=   -1
DISCHARGE=  9.0
  BRA CODE ELEVATION EXN#
    1    3     102.1
   -1
```

Listing of Output: FEQEX1

```
1
2
3
4
5  ********************************************************************************
6  *                                                                              *
7  *                          FULL EQUATIONS FLOW ROUTING                         *
8  *                                                                              *
9  *                                                                              *
10 ********************************************************************************
11
12 VERSION: 6.0 15 MARCH  1990
13
14  WARNING: This program is large and complex.
15  User is totally responsible for any
16  consequences resulting from application
17  of this program.  Read disclaimer in the
18  source code.
19
20  This program is not to be sold in any form.
21
22
23 THE SIZE LIMITS SET FOR THIS PROGRAM ARE:
24 NUMBER OF BRANCHES:   85
25 NUMBER OF EXTERIOR NODES:  220
26 NUMBER OF NODES ON BRANCHES: 1170
27 NUMBER OF OPERATION BLOCKS:   10
28 FUNCTION TABLE NUMBER:10000
29 LENGTH OF THE FUNCTION TABLE:250000
30 NUMBER OF POINT FLOWS:   10
31 LENGTH OF EXTERIOR MATRIX CONTROL: 2000
32 NUMBER OF ROWS IN ARRAY OF PARTIAL DERIV.: 2340
33 LENGTH OF INTERIOR MATRIX POINTER VECTOR :  170
34 NUMBER OF ROWS IN EXTERIOR MATRIX :  440
35 NUMBER OF LAND USES FOR TRIB. AREA:   20
36 NUMBER OF POINT INFLOW FILES:   10
37 NUMBER OF POINT OUTFLOW FILES:    4
38 NUMBER OF SPECIAL OUTPUTS:   45
39 NUMBER OF CODE=6 EX NODES WITH FILES OR TABLES:   20
40 MAX. UNIT NUMBER FOR FILES:   50
41 TOTAL BANDWIDTH OF EXTERIOR MATRIX :   16
42 NUMBER OF SUBDIAGONALS IN EXTERIOR MATRIX :   10
43
44 Unsteady Flow- Example 1
45
46 Single Branch System
47
48 March 5, 1990
49
50 NUMBER OF BRANCHES =     1
51
52 NUMBER OF EXTERIOR NODES =     2
53
54 SPECIAL OPERATION BLOCK OPTION = NO
55
56 POINT FLOW OPTION = NO
57
58 DIFFUSE FLOW OPTION = NO   MINPRT=0 LAGTSF=0
59
60 WIND LOADING OPTION = NO
61
62 UNDERFLOW MESSAGES ARE : NO
63
64 ZERO INERTIA LIMIT =        .00 FEET
65
66 START TIME =  1990/ 1/ 1:  .000000000
67
68 END TIME =  1990/ 1/ 1:  .750000000
69
70 GRAVITY =      32.20
71
72 NODE ID STRING PRESENT? YES
73
74 CONVERGENCE LIMIT(SURCHARGE STORAGE)  =  1.000E-01
75
76 PAGE=    22
77
78 CONVERGENCE LIMITS(SYSTEM SOLUTION):
79           PRIMARY =  5.000E-02
80           SECONDARY = 1.000E-01
81           ABSOLUTE =   .000
82
83 MAXIMUM NO. OF ITERATIONS IN SYSTEM SOLUTION  =     5 MAX. NUMGT=    0
84
85 PRINT OUT OPTION IS OUTPUT       0
86
87 PRINT OUT WILL BE GIVEN EVE.      8 TIME STEPS
88
89 STANDARD GOVERNING EQUATIONS SELECTED. WX VARIABLE
```

```

 CONVERGENCE CRITERION FOR BACKWATER = 5.000E-06

 MAX.NO. ITERATIONS FOR BACKWATER ANALYSIS =    30

 STATIONING FACTOR = 5.28000E+03

 Q SMALL FOR RELATIVE ERROR =     .01

 IFRZ =     1
    1800.00      1.00       .70      2.80      3.20      3.00      2.00       .50

 MRE =    .20 FAC =    .50 HSLOT=   .00 WSLOT=   .00 NSLOT=   .000
 WT INCREMENT/DECREMENT =   .050
 BASE VALUE FOR WT =        .50
 BWFDSW =     0 NAME=
 GEOMETRY WILL NOT BE CHECKED
 REDUCTION OF BAND WIDTH WILL BE ATTEMPTED.
 EXTRAPOLATION TOLERANCE=      .000

 BRANCH DESCRIPTION TABLES

 BRANCH NUMBER=    1 INERTIA=  1.0 CFRATE=    .0 WINDFAC= 1.00

  NODE   NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
   100 UPSTREAM 5000      .0000   100.000  .00  .00    0   0.    .0    .0       .00
   101          5000      .1000   100.000  .00  .00    0   0.    .0    .0       .00
   102          5000      .2000   100.000  .00  .00    0   0.    .0    .0       .00
   103          5000      .3000   100.000  .00  .00    0   0.    .0    .0       .00
   104          5000      .4000   100.000  .00  .00    0   0.    .0    .0       .00
   105          5000      .5000   100.000  .00  .00    0   0.    .0    .0       .00
   106          5000      .6000   100.000  .00  .00    0   0.    .0    .0       .00
   107          5000      .7000   100.000  .00  .00    0   0.    .0    .0       .00
   108          5000      .8000   100.000  .00  .00    0   0.    .0    .0       .00
   109          5000      .9000   100.000  .00  .00    0   0.    .0    .0       .00
   110 DNSTREAM 5000     1.0000   100.000  .00  .00    0   0.    .0    .0       .00

 BRANCH-EXTERIOR NODE TABLE

  BRA# UEXN DEXN
     1    1    2

 EXTERIOR-MATRIX CONTROL INPUT

  CODE   A   B   C   D   E   F   G   H   I   J     FA      FB      FC      FD

 CODE=    6 EQN#=    1. ENTRY#=    1
    TYPE=    1 UPN=    1 DIR=    1 TAB#=  100 FLOW=       .00

 CODE=    1 EQN#S=    2 AND    3. ENTRY#=    2
    BRANCH=    1

 CODE=    4 EQN#=    4. ENTRY#=    3
    TYPE=    1 UPN=    2 DIR=   -1 QNODE=    2
    WEIR COEF. TAB#=  110 WEIR ELEV.=    102.00 WEIR LENGTH=      32.0
```

BANDWIDTH REDUCTION LOG

ITER	MAXSUB	MAXSUP	BANDW	DECSUB	DECSUP	SWPFLG
0	2	2	5			
1	2	2	5	0	0	0
2	2	2	5	0	0	0
3	2	2	5	0	0	0
4	2	2	5	0	0	0
5	2	2	5	0	0	0
6	2	2	5	0	0	0

```
ARRANGEMENT OF NON-ZERO ELEMENTS IN EXTERIOR MATRIX

  EQN ENTRY   C9876543218987654321A98765432101234567891A123456789B123456789C123456789
    1     1                                        .X..
    2     2                                       XXXX
    3                                             XXXX
    4     3                                      ..XX


TOTAL BAND WIDTH M3 =    5

NO. OF SUBDIAGONALS M1 =    2 NO. OF SUPER DIAGONALS M2 =   2

SPECIAL OUTPUT LOCATIONS
UNIT=    3 NAME=\FEQ68\TEST\EX1SPOUT
  BRA NODE
    1  100 NOD 100
    1  101 NOD 101
    1  102 NOD 102
    1  103 NOD 103
    1  104 NOD 104
    1  105 NOD 105
    1  106 NOD 106
    1  107 NOD 107
    1  108 NOD 108
    1  109 NOD 109
    1  110 NOD 110

INPUT FILE SPECIFICATION

 UNIT NAME

OUTPUT FILE SPECIFICATION

 UNIT  BRA NODE ITEM TYPE NAME

FUNCTION TABLES

TABLE#=  100
TYPE=   -7
REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.

YEAR MN DY      HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END

TABLE#=  110
TYPE=   -2
REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.

       HEAD WEIR COEF

TABLE#= 5000
TYPE=   -1

TRUE SIZES:
NUMBER OF BRANCHES:    1
NUMBER OF EXTERIOR NODES:    2
NUMBER OF NODES ON BRANCHES:   11
NUMBER OF OPERATION BLOCKS:    0
FUNCTION TABLE NUMBER:    3
LENGTH OF THE FUNCTION TABLE:    227
NUMBER OF POINT FLOWS:    0
LENGTH OF EXTERIOR MATRIX CONTROL:   35
NUMBER OF ROWS IN ARRAY OF PARTIAL DERIV.:   20
LENGTH OF INTERIOR MATRIX POINTER VECTOR :    2
NUMBER OF ROWS IN EXTERIOR MATRIX:    4
NUMBER OF LAND USES FOR TRIB. AREA:    0
NUMBER OF POINT INFLOW FILES:    0
NUMBER OF POINT OUTFLOW FILES:    0
NUMBER OF SPECIAL OUTPUTS:   11
NUMBER OF CODE=6 EX NODES WITH FILES OR TABLES:    1

SRLIM= 6.00000E-04
```

```
 1 BACKWATER ANALYSIS
 2
 3 BRANCH NUMBER =      1
 4 DISCHARGE =         9.0
 5
 6   BRA CODE ELEVATION EXN#
 7     1    3    102.10    0
 8
 9 BACKWATER ANALYSIS BRANCH#     1
10  STATION IT      YL       QL       AL      TL      DZ      DX      ELEV       RES   FR
11   1.0000  0  2.198      9.0     58.5    33.2    .00      .0   102.198  0.0E+00   .0
12    .9000  2  2.200      9.0     58.5    33.2    .00    528.0  102.200 -1.5E-03   .0
13    .8000  2  2.202      9.0     58.6    33.2    .00    528.0  102.202 -1.4E-03   .0
14    .7000  2  2.203      9.0     58.6    33.2    .00    528.0  102.203 -1.4E-03   .0
15    .6000  2  2.205      9.0     58.7    33.2    .00    528.0  102.205 -1.7E-03   .0
16    .5000  2  2.207      9.0     58.7    33.2    .00    528.0  102.207 -1.5E-03   .0
17    .4000  2  2.208      9.0     58.8    33.3    .00    528.0  102.208 -1.7E-03   .0
18    .3000  2  2.210      9.0     58.9    33.3    .00    528.0  102.210 -1.4E-03   .0
19    .2000  2  2.212      9.0     59.0    33.3    .00    528.0  102.212 -1.5E-03   .0
20    .1000  2  2.213      9.0     59.0    33.3    .00    528.0  102.213 -1.6E-03   .0
21    .0000  2  2.215      9.0     59.0    33.3    .00    528.0  102.215 -1.6E-03   .0
22
23 IFRZ =      1
24
25 SIMULATION ENDING AT  1990/ 1/ 1/    .000 WITH TIME STEP OF      1800.0 SEC
26 ITER  RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
27    1 2.6E-03     0     2 5.1E-04   -4 2.6E-07      0
28 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 0.00E+00 AT ND=  0:    0 DT/ITER=       .0
29
30 IFRZ =      0
31      TIME STEP RESET TO    1800.00 SEC WT =  .500
32
33 SIMULATION ENDING AT  1990/ 1/ 1/    .500 WITH TIME STEP OF      1800.0 SEC
34 ITER  RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
35    1 1.3E+00     0     1 1.1E+01   -1 1.3E+02     11
36    2 7.3E-03     1   105 3.2E-03   -3 2.9E-05      0
37 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 7.36E-02 AT ND=  1: 100 DT/ITER=    900.0
38      TIME STEP RESET TO    1800.00 SEC WT =  .500
39
40 SIMULATION ENDING AT  1990/ 1/ 1/   1.000 WITH TIME STEP OF      1800.0 SEC
41 ITER  RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
42    1 4.9E-01     0     2 5.8E+00   -1 3.3E+01     18
43    2 8.5E-03     0     2 5.3E-03   -4 5.7E-05      0
44 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 8.12E-02 AT ND=  1: 109 DT/ITER=    900.0
45      TIME STEP RESET TO    1800.00 SEC WT =  .500
46
47 SIMULATION ENDING AT  1990/ 1/ 1/   1.500 WITH TIME STEP OF      1800.0 SEC
48 ITER  RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
49    1 7.5E-01     0     1 2.8E+01   -1 8.0E+02     22
50    2 6.9E-03     0     2 1.0E-02    1 4.2E-04      0
51 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 1.04E-01 AT ND=  1: 100 DT/ITER=    900.0
52      TIME STEP RESET TO    1800.00 SEC WT =  .500
53
54 SIMULATION ENDING AT  1990/ 1/ 1/   2.000 WITH TIME STEP OF      1800.0 SEC
55 ITER  RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
56    1 4.7E-01     0     2 1.7E+01   -1 2.9E+02     22
57    2 6.4E-03     0     2 1.1E-02    3 8.9E-04      0
58 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 7.97E-02 AT ND=  1: 105 DT/ITER=    900.0
59      TIME STEP RESET TO    1800.00 SEC WT =  .500
60
61 SIMULATION ENDING AT  1990/ 1/ 1/   2.500 WITH TIME STEP OF      1800.0 SEC
62 ITER  RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
63    1 2.6E-01     0     2 8.5E+00   -1 7.4E+01     22
64    2 1.8E-03     0     2 4.2E-03   -4 1.4E-04      0
65 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 4.71E-02 AT ND=  1: 106 DT/ITER=    900.0
66      TIME STEP RESET TO    1800.00 SEC WT =  .500
67
68 SIMULATION ENDING AT  1990/ 1/ 1/   3.000 WITH TIME STEP OF      1800.0 SEC
69 ITER  RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
70    1 1.2E-01     1   103 1.3E+01   -1 1.6E+02     11
71    2 5.5E-04     1  -101 2.1E-03    1 3.0E-05      0
72 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 3.03E-02 AT ND=  1: 102 DT/ITER=    900.0
73      TIME STEP RESET TO    1800.00 SEC WT =  .500
74
75 SIMULATION ENDING AT  1990/ 1/ 1/   3.500 WITH TIME STEP OF      1800.0 SEC
76 ITER  RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
77    1 2.5E-01     0     1 4.1E+01   -1 1.7E+03      9
78    2 5.2E-04     0    -1 2.9E-03    1 2.0E-05      0
79 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 8.61E-03 AT ND=  1: 107 DT/ITER=    900.0
80
81 RESULTS AT TIME      12600. JTIME =      47892.1458333334
82
83 BRANCH NUMBER =      1
84
85 NODE   NODEID     STAT     FLOW     AREA   VEL  DEPTH     ELEV      TOP  FR LAT INF
86  100 UPSTREAM    .0000 1.225+2 1.206+2  1.02   3.83  103.83 4.298+1  .0 0.000+0
87  101             .1000 1.253+2 1.189+2  1.05   3.79  103.79 4.274+1  .0 0.000+0
88  102             .2000 1.280+2 1.171+2  1.09   3.75  103.75 4.249+1  .0 0.000+0
89  103             .3000 1.303+2 1.151+2  1.13   3.70  103.70 4.220+1  .0 0.000+0
```

```
 104             .4000 1.321+2 1.129+2  1.17   3.65  103.65 4.189+1  .0 0.000+0
 105             .5000 1.335+2 1.105+2  1.21   3.59  103.59 4.155+1  .0 0.000+0
 106             .6000 1.345+2 1.079+2  1.25   3.53  103.53 4.117+1  .0 0.000+0
 107             .7000 1.351+2 1.051+2  1.29   3.46  103.46 4.076+1  .0 0.000+0
 108             .8000 1.355+2 1.020+2  1.33   3.38  103.38 4.030+1  .0 0.000+0
 109             .9000 1.357+2 9.868+1  1.37   3.30  103.30 3.980+1  .0 0.000+0
 110 DNSTREAM   1.0000 1.357+2 9.498+1  1.43   3.21  103.21 3.924+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

    NETWORK PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

EXTERIOR NODES

NODE    NODEID          QE1      YE1    ELEV     STORAGE     STORAGE
   1 UPSTREAM  1.225E+02    3.83  103.83
   2 DNSTREAM  1.357E+02    3.21  103.21
BC:S1=3.101E+05 S2=5.787E+05 I=1.009E+06 Q=7.408E+05 D= 1.005E+00 R= 7.61E-07
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  4.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 2.0E-01    1  105 1.4E+01   -1 2.1E+02     22
   2 2.2E-03    0    2 6.5E-03    5 3.5E-04      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.08E-02 AT ND=  1: 100 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  4.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 5.0E-01    0    1 4.0E+01   -1 1.6E+03      8
   2 2.5E-03    1  104 6.5E-03   -3 9.0E-05      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 8.47E-03 AT ND=  1: 107 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  5.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 2.1E-01    0    2 1.3E+01   -1 1.6E+02     22
   2 2.0E-03    0    2 5.4E-03    3 2.6E-04      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 1.98E-02 AT ND=  1: 100 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  5.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.6E-01    0    1 2.5E+01   -1 6.1E+02     21
   2 1.7E-03    0   -1 5.4E-03    1 2.1E-04      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.59E-02 AT ND=  1: 100 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  6.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.4E-01    1  107 1.9E+01   -1 3.5E+02     21
   2 1.1E-03    0    2 4.2E-03    3 1.6E-04      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.38E-02 AT ND=  1: 101 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  6.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.7E-01    0    1 4.0E+01   -1 1.6E+03      6
   2 1.8E-04    1  104 1.1E-03    1 2.3E-06      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 8.81E-03 AT ND=  1: 107 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  7.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.1E-01    1  106 1.0E+01   -1 1.1E+02     15
   2 8.9E-04    0    2 3.3E-03    7 1.0E-04      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 8.04E-03 AT ND=  1: 100 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  7.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.6E-01    0    1 2.7E+01   -1 7.0E+02     14
   2 1.4E-03    0   -1 4.1E-03    1 1.2E-04      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 1.77E-02 AT ND=  1: 100 DT/ITER=   900.0

RESULTS AT TIME     27000. JTIME =     47892.3125000000

BRANCH NUMBER =     1

NODE    NODEID     STAT     FLOW     AREA    VEL   DEPTH     ELEV      TOP   FR LAT INF
 100 UPSTREAM    .0000 1.410+2 1.335+2  1.06    4.12  104.12 4.474+1  .0 0.000+0
 101             .1000 1.459+2 1.317+2  1.11    4.08  104.08 4.450+1  .0 0.000+0
 102             .2000 1.504+2 1.297+2  1.16    4.04  104.04 4.423+1  .0 0.000+0
 103             .3000 1.544+2 1.275+2  1.21    3.99  103.99 4.393+1  .0 0.000+0
 104             .4000 1.578+2 1.250+2  1.26    3.93  103.93 4.359+1  .0 0.000+0
 105             .5000 1.608+2 1.223+2  1.32    3.87  103.87 4.321+1  .0 0.000+0
 106             .6000 1.634+2 1.192+2  1.37    3.80  103.80 4.278+1  .0 0.000+0
 107             .7000 1.658+2 1.158+2  1.43    3.72  103.72 4.231+1  .0 0.000+0
 108             .8000 1.679+2 1.121+2  1.50    3.63  103.63 4.177+1  .0 0.000+0
```

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 109            .9000 1.698+2 1.079+2  1.57   3.53  103.53 4.117+1  .0 0.000+0
 110 DNSTREAM  1.0000 1.715+2 1.031+2  1.66   3.41  103.41 4.046+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

    NETWORK PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

EXTERIOR NODES

NODE   NODEID        QE1      YE1    ELEV    STORAGE    STORAGE
   1 UPSTREAM  1.410E+02    4.12  104.12
   2 DNSTREAM  1.715E+02    3.41  103.41
BC:S1=3.101E+05 S2=6.386E+05 I=3.295E+06 Q=2.966E+06 D= 1.803E+00 R= 5.00E-07
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  8.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.8E-01    1  103 1.9E+01   -1 3.4E+02     21
   2 1.6E-03    0    2 5.7E-03    3 2.4E-04      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.89E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  8.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.1E-01    0    2 5.0E+00   -1 2.6E+01      6
   2 6.4E-04    1 -108 1.9E-03   -4 2.7E-05      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.96E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  9.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 8.9E-02    1  102 6.8E+00   -1 4.6E+01      6
   2 1.8E-04    1  106 5.2E-04    1 1.3E-06      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.41E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/  9.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 7.8E-02    1  107 3.2E+00   -1 1.1E+01      7
   2 2.3E-04    0    2 4.8E-04   -4 2.0E-06      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.21E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 10.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 8.7E-02    1  101 5.0E+00   -1 2.5E+01      6
   2 3.1E-04    0    2 5.7E-04    1 1.9E-06      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.25E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 10.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.1E-01    1  106 4.5E+00   -1 2.0E+01     11
   2 2.1E-04    1  105 6.0E-04    1 2.4E-06      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.49E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 11.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.2E-01    1  101 4.8E+00   -1 2.3E+01     10
   2 6.5E-04    0    2 6.8E-04    1 3.0E-06      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.92E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 11.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.1E-01    1  106 2.5E-01   -1 2.3E-01      8
   2 2.6E-04    1  104 3.7E-04   -4 9.7E-07      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.94E-02 AT ND=  1: 100 DT/ITER=   900.0

RESULTS AT TIME     41400. JTIME =     47892.4791666667

BRANCH NUMBER =     1

NODE   NODEID     STAT    FLOW    AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
 100 UPSTREAM    .0000 3.300+1 7.576+1   .44   2.70  102.70 3.618+1  .0 0.000+0
 101             .1000 3.403+1 7.537+1   .45   2.69  102.69 3.612+1  .0 0.000+0
 102             .2000 3.482+1 7.494+1   .46   2.67  102.67 3.605+1  .0 0.000+0
 103             .3000 3.540+1 7.445+1   .48   2.66  102.66 3.597+1  .0 0.000+0
 104             .4000 3.599+1 7.394+1   .49   2.65  102.65 3.588+1  .0 0.000+0
 105             .5000 3.672+1 7.341+1   .50   2.63  102.63 3.579+1  .0 0.000+0
 106             .6000 3.759+1 7.288+1   .52   2.62  102.62 3.570+1  .0 0.000+0
 107             .7000 3.857+1 7.232+1   .53   2.60  102.60 3.561+1  .0 0.000+0
 108             .8000 3.956+1 7.173+1   .55   2.58  102.58 3.551+1  .0 0.000+0
 109             .9000 4.049+1 7.109+1   .57   2.57  102.57 3.540+1  .0 0.000+0
 110 DNSTREAM  1.0000 4.140+1 7.039+1   .59   2.55  102.55 3.528+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT
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    NETWORK PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

EXTERIOR NODES

NODE   NODEID         QE1      YE1    ELEV     STORAGE     STORAGE
   1 UPSTREAM  3.300E+01     2.70  102.70
   2 DNSTREAM  4.140E+01     2.55  102.55
BC:S1=3.101E+05 S2=3.871E+05 I=4.317E+06 Q=4.240E+06 D= 1.979E+00 R= 4.28E-07
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 12.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 8.4E-02    1  101 2.5E+00   -1 6.3E+00      5
   2 3.5E-04    0    2 3.2E-04   -4 2.7E-07      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.68E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 12.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.4E-01    1  105 2.0E+00   -1 4.1E+00     10
   2 6.1E-04    1  104 2.5E-04   -3 3.7E-07      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.80E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 13.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.1E-01    1  101 2.2E+00   -1 5.1E+00      8
   2 6.9E-04    0    2 5.3E-04   -4 5.4E-07      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 3.02E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 13.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.7E-01    1  104 2.2E+00   -1 5.1E+00     11
   2 6.0E-04    1  103 2.3E-04   -4 4.3E-07      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 3.70E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 14.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.9E-01    1  101 2.2E+00   -1 5.1E+00     11
   2 1.3E-03    0    2 8.4E-04   -4 1.3E-06      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 4.65E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 14.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 2.9E-01    0    1 2.2E+00   -1 5.1E+00      4
   2 4.7E-04    0    2 1.6E-04   -4 8.1E-08      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 4.23E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 15.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.3E-01    1  103 7.3E-02   11 2.3E-02      6
   2 2.5E-04    1  104 5.6E-05   -3 7.1E-09      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.25E-02 AT ND=  1: 100 DT/ITER=   900.0
     TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 15.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.1E-01    1  108 8.5E-02   11 2.6E-02      7
   2 3.4E-04    1  106 7.5E-05   -3 9.9E-09      0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 1.10E-02 AT ND=  1: 103 DT/ITER=   900.0

RESULTS AT TIME     55800. JTIME =     47892.6458333334

BRANCH NUMBER =     1

NODE   NODEID     STAT     FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
 100 UPSTREAM   .0000 1.000+1 5.994+1   .17   2.24  102.24 3.346+1  .0 0.000+0
 101            .1000 1.000+1 5.986+1   .17   2.24  102.24 3.344+1  .0 0.000+0
 102            .2000 9.869+0 5.977+1   .17   2.24  102.24 3.343+1  .0 0.000+0
 103            .3000 9.786+0 5.968+1   .16   2.24  102.24 3.341+1  .0 0.000+0
 104            .4000 9.939+0 5.962+1   .17   2.23  102.23 3.340+1  .0 0.000+0
 105            .5000 1.027+1 5.957+1   .17   2.23  102.23 3.339+1  .0 0.000+0
 106            .6000 1.061+1 5.952+1   .18   2.23  102.23 3.338+1  .0 0.000+0
 107            .7000 1.084+1 5.946+1   .18   2.23  102.23 3.337+1  .0 0.000+0
 108            .8000 1.090+1 5.939+1   .18   2.23  102.23 3.336+1  .0 0.000+0
 109            .9000 1.079+1 5.931+1   .18   2.22  102.22 3.334+1  .0 0.000+0
 110 DNSTREAM  1.0000 1.065+1 5.922+1   .18   2.22  102.22 3.333+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

    NETWORK PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

EXTERIOR NODES

NODE   NODEID         QE1      YE1    ELEV     STORAGE     STORAGE
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```
    1 UPSTREAM  1.000E+01    2.24  102.24
    2 DNSTREAM  1.065E+01    2.22  102.22
BC:S1=3.101E+05 S2=3.146E+05 I=4.563E+06 Q=4.559E+06 D= 1.970E+00 R= 4.04E-07
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 16.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.3E-01    1  103 8.6E-02   11 2.9E-02     7
   2 3.9E-04    1  107 7.8E-05   -3 1.1E-08     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 5.67E-03 AT ND=  1: 106 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 16.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.3E-01    1  107 8.4E-02    9 3.0E-02     7
   2 3.9E-04    1  106 8.0E-05   -3 1.1E-08     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 3.56E-03 AT ND=  1: 102 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 17.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.2E-01    1  103 8.6E-02    9 2.9E-02     6
   2 3.7E-04    1  106 7.3E-05   -3 9.1E-09     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.87E-03 AT ND=  1: 106 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION ENDING AT  1990/ 1/ 1/ 17.500 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.2E-01    1  107 8.5E-02    9 2.7E-02     5
   2 2.9E-04    1  106 6.2E-05   -3 6.6E-09     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.22E-03 AT ND=  1: 109 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

TIME STEP RESET IN MANTIM TO   1800.00 SECS TO MATCH EVENT END

SIMULATION ENDING AT  1990/ 1/ 1/ 18.000 WITH TIME STEP OF     1800.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 8.9E-02    1  107 7.9E-02    9 2.2E-02     5
   2 2.1E-04    1  106 4.8E-05   -3 4.1E-09     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.63E-03 AT ND=  1: 105 DT/ITER=   900.0
      TIME STEP RESET TO   1800.00 SEC WT =  .500

SIMULATION COMPLETE AT     64800. SECS.



SIMULATION ENDING AT  1990/  1/  1/ 18.000

RESULTS AT TIME     64800. JTIME =     47892.7500000000

BRANCH NUMBER =     1

NODE   NODEID     STAT     FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
 100 UPSTREAM   .0000 1.000+1 5.961+1   .17   2.23  102.23 3.340+1  .0 0.000+0
 101            .1000 1.007+1 5.955+1   .17   2.23  102.23 3.339+1  .0 0.000+0
 102            .2000 1.022+1 5.949+1   .17   2.23  102.23 3.338+1  .0 0.000+0
 103            .3000 1.025+1 5.941+1   .17   2.23  102.23 3.337+1  .0 0.000+0
 104            .4000 1.008+1 5.932+1   .17   2.22  102.22 3.336+1  .0 0.000+0
 105            .5000 9.856+0 5.923+1   .17   2.22  102.22 3.333+1  .0 0.000+0
 106            .6000 9.736+0 5.915+1   .16   2.22  102.22 3.332+1  .0 0.000+0
 107            .7000 9.751+0 5.911+1   .16   2.22  102.22 3.331+1  .0 0.000+0
 108            .8000 9.862+0 5.907+1   .17   2.22  102.22 3.330+1  .0 0.000+0
 109            .9000 1.003+1 5.903+1   .17   2.22  102.22 3.329+1  .0 0.000+0
 110 DNSTREAM  1.0000 1.012+1 5.898+1   .17   2.21  102.21 3.328+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

    NETWORK PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

EXTERIOR NODES

NODE   NODEID        QE1     YE1    ELEV    STORAGE    STORAGE
   1 UPSTREAM  1.000E+01    2.23  102.23
   2 DNSTREAM  1.012E+01    2.21  102.21

SIMULATION COMPLETED
```

SUMMARY OF MAXIMUM ELEVATIONS

Unsteady Flow- Example 1
Single Branch System
March 5, 1990

MAXIMUM ELEVATIONS ACHIEVED BY TIME 64800.

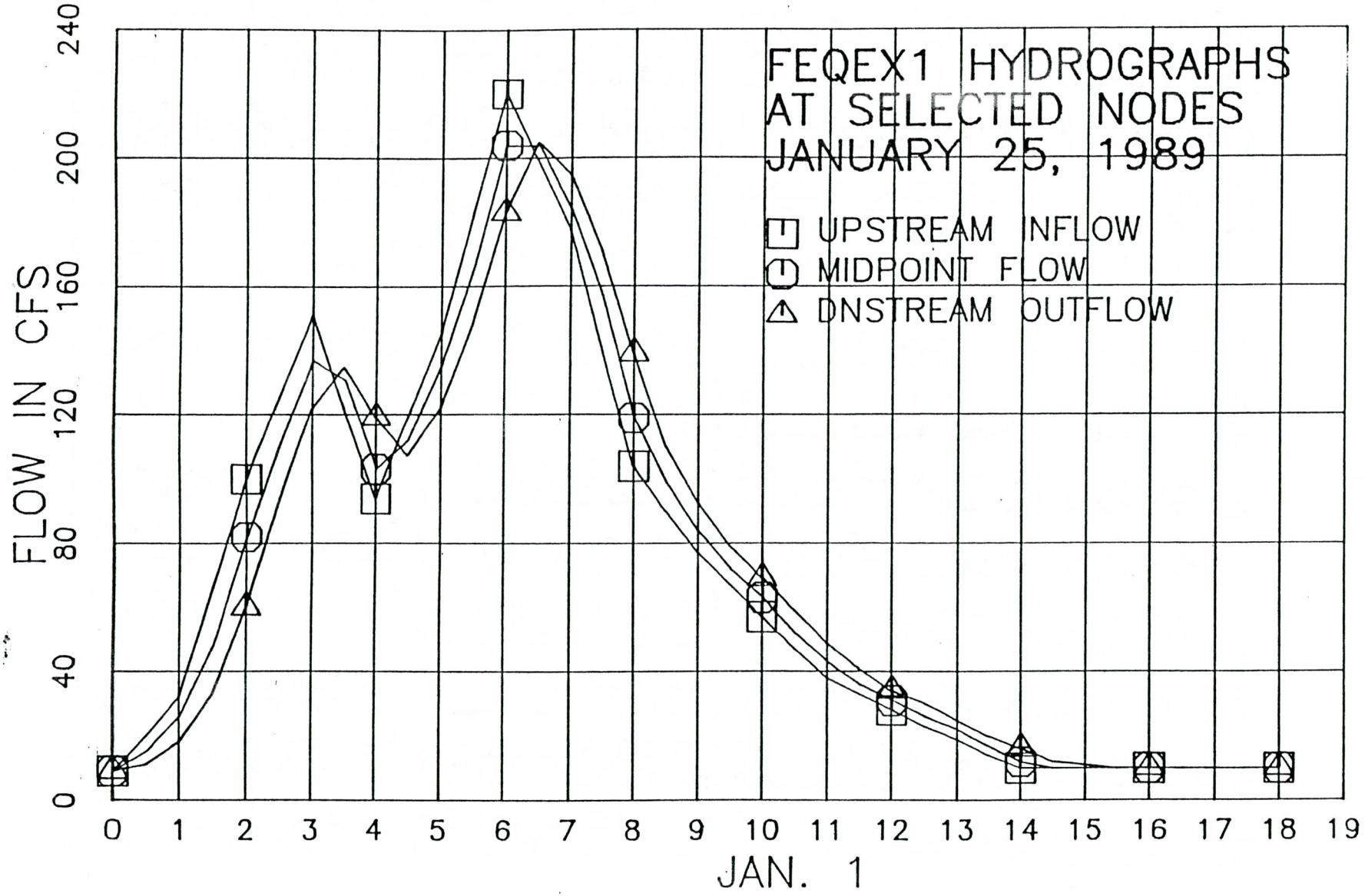
BRANCH NUMBER = 1

NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
100	UPSTREAM	.0000	4.49	104.49	1.49	2.2000E+02	9.0000E+00
101		.1000	4.43	104.43	1.50	2.1643E+02	9.0020E+00
102		.2000	4.37	104.37	1.51	2.1248E+02	9.0040E+00
103		.3000	4.30	104.30	1.52	2.0847E+02	9.0060E+00
104		.4000	4.23	104.23	1.54	2.0480E+02	9.0081E+00
105		.5000	4.15	104.15	1.56	2.0548E+02	9.0102E+00
106		.6000	4.06	104.06	1.58	2.0588E+02	9.0125E+00
107		.7000	3.96	103.96	1.63	2.0608E+02	9.0149E+00
108		.8000	3.86	103.86	1.69	2.0612E+02	9.0175E+00
109		.9000	3.73	103.73	1.77	2.0607E+02	9.0204E+00
110	DNSTREAM	1.0000	3.59	103.59	1.86	2.0601E+02	9.0235E+00

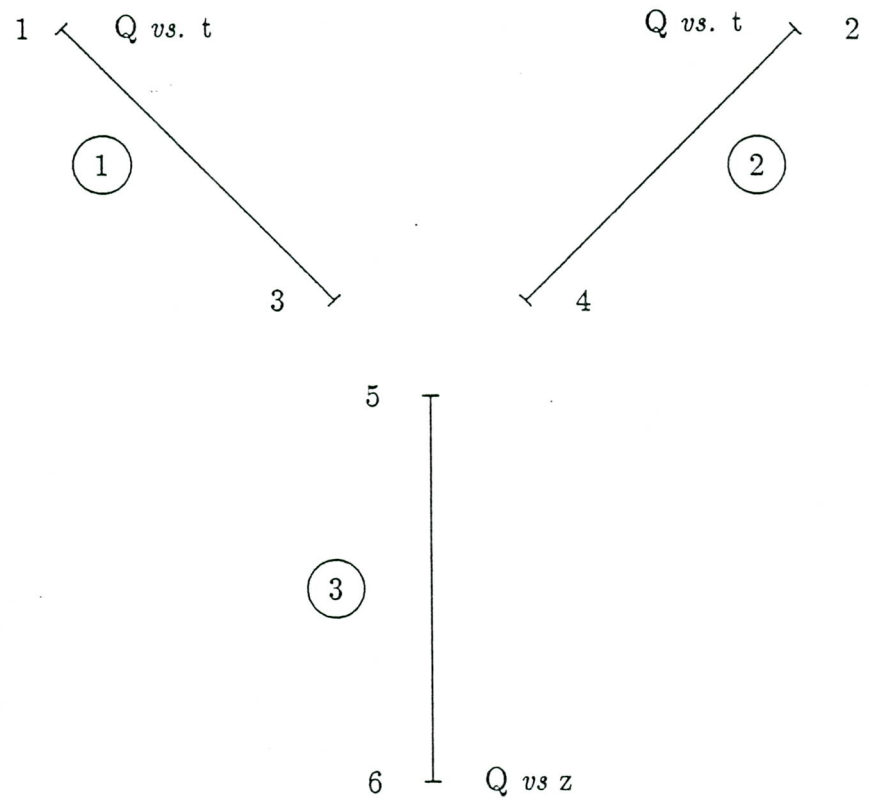
COMPUTATION TIME= 5.08 SECS OR .0847 MINS

Listing of Special Output: FEQEX1

22													
	NOD 100	NOD 101	NOD 102	NOD 103	NOD 104	NOD 105	NOD 106	NOD 107	NOD 108	NOD 109	NOD 110		
1990/ 1/ 1	102.21	102.21	102.21	102.21	102.21	102.21	102.20	102.20	102.20	102.20	102.20		
.000000	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0		
1990/ 1/ 1	102.29	102.28	102.27	102.26	102.26	102.25	102.25	102.24	102.24	102.23	102.23		
.500000	20.5	19.1	17.8	16.7	15.7	14.8	14.0	13.2	12.5	11.9	11.2		
1990/ 1/ 1	102.43	102.41	102.40	102.39	102.38	102.36	102.35	102.34	102.34	102.33	102.32		
1.000000	32.0	30.7	29.3	27.9	26.5	25.1	23.7	22.3	21.0	19.8	18.5		
1990/ 1/ 1	102.76	102.71	102.68	102.64	102.61	102.58	102.56	102.53	102.51	102.49	102.47		
1.500000	66.0	60.8	56.3	52.3	48.7	45.5	42.6	40.0	37.6	35.4	33.4		
1990/ 1/ 1	103.17	103.12	103.07	103.02	102.97	102.92	102.87	102.83	102.79	102.74	102.71		
2.000000	100.0	96.0	91.8	87.4	83.0	78.7	74.6	70.7	67.0	63.7	60.6		
1990/ 1/ 1	103.53	103.48	103.42	103.36	103.30	103.25	103.19	103.13	103.07	103.00	102.94		
2.500000	125.5	121.1	117.2	113.6	110.2	107.0	104.0	101.0	98.3	95.7	93.4		
1990/ 1/ 1	103.84	103.77	103.71	103.65	103.58	103.51	103.44	103.37	103.29	103.21	103.12		
3.000000	151.0	148.0	144.7	141.3	138.0	134.8	131.7	128.9	126.4	124.1	122.0		
1990/ 1/ 1	103.83	103.79	103.75	103.70	103.65	103.59	103.53	103.46	103.38	103.30	103.21		
3.500000	122.5	125.3	128.0	130.3	132.1	133.5	134.5	135.1	135.5	135.7	135.7		
1990/ 1/ 1	103.62	103.58	103.55	103.51	103.47	103.43	103.38	103.32	103.26	103.19	103.11		
4.000000	94.0	96.4	98.7	101.1	103.8	106.5	109.3	112.1	114.9	117.5	119.8		
1990/ 1/ 1	103.62	103.57	103.52	103.47	103.41	103.36	103.30	103.24	103.17	103.11	103.03		
4.500000	119.5	117.3	115.5	113.9	112.5	111.2	110.1	109.2	108.4	107.8	107.3		
	NOD 100	NOD 101	NOD 102	NOD 103	NOD 104	NOD 105	NOD 106	NOD 107	NOD 108	NOD 109	NOD 110		
1990/ 1/ 1	103.81	103.76	103.70	103.63	103.57	103.50	103.44	103.37	103.29	103.21	103.13		
5.000000	145.0	142.6	140.0	137.4	134.9	132.5	130.2	128.0	126.0	124.1	122.3		
1990/ 1/ 1	104.11	104.04	103.97	103.89	103.82	103.74	103.66	103.57	103.48	103.39	103.28		
5.500000	182.5	177.5	173.1	169.1	165.3	161.8	158.5	155.5	152.8	150.5	148.4		
1990/ 1/ 1	104.43	104.36	104.28	104.20	104.11	104.02	103.93	103.83	103.72	103.61	103.48		
6.000000	220.0	216.4	212.5	208.5	204.5	200.7	196.9	193.3	189.9	186.7	183.8		
1990/ 1/ 1	104.49	104.43	104.37	104.30	104.23	104.15	104.06	103.96	103.86	103.73	103.59		
6.500000	199.0	200.7	202.4	203.8	204.8	205.5	205.9	206.1	206.1	206.1	206.0		
1990/ 1/ 1	104.37	104.32	104.26	104.19	104.13	104.05	103.97	103.88	103.78	103.67	103.54		
7.000000	178.0	179.5	180.9	182.5	184.3	186.2	188.1	190.1	192.0	193.7	195.2		
1990/ 1/ 1	104.12	104.08	104.04	103.99	103.93	103.87	103.80	103.72	103.63	103.53	103.41		
7.500000	141.0	145.9	150.4	154.4	157.8	160.8	163.4	165.8	167.9	169.8	171.5		
1990/ 1/ 1	103.80	103.76	103.73	103.69	103.64	103.59	103.54	103.48	103.41	103.33	103.23		
8.000000	104.0	107.5	111.0	114.8	118.8	122.9	126.8	130.6	134.1	137.2	140.0		
1990/ 1/ 1	103.54	103.51	103.48	103.44	103.40	103.35	103.30	103.25	103.19	103.12	103.05		
8.500000	90.5	93.3	95.9	98.1	100.0	101.8	103.6	105.3	107.0	108.7	110.3		
1990/ 1/ 1	103.35	103.33	103.30	103.26	103.23	103.19	103.15	103.11	103.06	103.00	102.94		
9.000000	77.0	78.7	80.4	82.4	84.5	86.5	88.4	90.1	91.5	92.7	93.6		
1990/ 1/ 1	103.20	103.18	103.15	103.12	103.09	103.06	103.02	102.98	102.94	102.90	102.85		
9.500000	67.0	68.8	70.3	71.6	72.7	73.7	74.8	76.0	77.3	78.5	79.8		
	NOD 100	NOD 101	NOD 102	NOD 103	NOD 104	NOD 105	NOD 106	NOD 107	NOD 108	NOD 109	NOD 110		
1990/ 1/ 1	103.07	103.05	103.02	103.00	102.97	102.95	102.92	102.88	102.85	102.81	102.77		
10.000000	57.0	58.3	59.7	61.3	63.0	64.5	65.8	66.9	67.7	68.4	69.0		
1990/ 1/ 1	102.94	102.92	102.90	102.88	102.86	102.84	102.81	102.78	102.76	102.73	102.69		
10.500000	47.5	49.1	50.4	51.4	52.4	53.3	54.4	55.6	56.8	58.0	59.1		
1990/ 1/ 1	102.80	102.79	102.78	102.76	102.75	102.73	102.71	102.69	102.67	102.64	102.61		
11.000000	38.0	39.2	40.7	42.3	43.8	45.2	46.4	47.3	48.1	48.8	49.4		
1990/ 1/ 1	102.70	102.69	102.67	102.66	102.65	102.63	102.62	102.60	102.58	102.57	102.55		
11.500000	33.0	34.0	34.8	35.4	36.0	36.7	37.6	38.6	39.6	40.5	41.4		
1990/ 1/ 1	102.61	102.60	102.59	102.58	102.57	102.56	102.55	102.53	102.52	102.50	102.49		
12.000000	28.0	28.8	29.7	30.8	31.8	32.6	33.2	33.7	34.1	34.5	34.8		
1990/ 1/ 1	102.53	102.53	102.52	102.51	102.50	102.49	102.48	102.47	102.46	102.45	102.44		
12.500000	23.5	24.3	24.9	25.3	25.8	26.4	27.2	28.0	28.8	29.5	30.1		
1990/ 1/ 1	102.46	102.46	102.45	102.45	102.44	102.43	102.43	102.42	102.41	102.40	102.39		
13.000000	19.0	19.6	20.5	21.4	22.2	22.7	23.2	23.5	23.9	24.4	24.9		
1990/ 1/ 1	102.39	102.39	102.38	102.38	102.37	102.37	102.37	102.36	102.36	102.35	102.35		
13.500000	14.5	15.3	15.9	16.3	16.9	17.6	18.4	19.2	19.9	20.4	20.8		
1990/ 1/ 1	102.32	102.32	102.32	102.32	102.31	102.31	102.31	102.30	102.30	102.29	102.29		
14.000000	10.0	10.6	11.4	12.2	12.9	13.4	13.8	14.2	14.7	15.4	16.1		
1990/ 1/ 1	102.28	102.27	102.27	102.27	102.26	102.26	102.26	102.26	102.26	102.25	102.25		
14.500000	10.0	10.3	10.4	10.5	10.8	11.2	11.8	12.3	12.6	12.7	12.9		
	NOD 100	NOD 101	NOD 102	NOD 103	NOD 104	NOD 105	NOD 106	NOD 107	NOD 108	NOD 109	NOD 110		
1990/ 1/ 1	102.25	102.25	102.25	102.25	102.25	102.24	102.24	102.24	102.23	102.23	102.23		
15.000000	10.0	10.2	10.5	10.8	10.9	10.8	10.7	10.6	10.7	11.0	11.3		
1990/ 1/ 1	102.24	102.24	102.24	102.24	102.23	102.23	102.23	102.23	102.23	102.22	102.22		
15.500000	10.0	10.0	9.9	9.8	9.9	10.3	10.6	10.8	10.9	10.8	10.7		
1990/ 1/ 1	102.24	102.23	102.23	102.23	102.23	102.23	102.22	102.22	102.22	102.22	102.22		
16.000000	10.0	10.1	10.3	10.5	10.4	10.2	9.9	9.8	9.9	10.1	10.3		
1990/ 1/ 1	102.23	102.23	102.23	102.23	102.23	102.23	102.22	102.22	102.22	102.22	102.21		
16.500000	10.0	9.9	9.8	9.7	9.8	10.1	10.4	10.5	10.5	10.3	10.1		
1990/ 1/ 1	102.23	102.23	102.23	102.23	102.23	102.22	102.22	102.22	102.22	102.22	102.21		
17.000000	10.0	10.1	10.3	10.4	10.2	9.9	9.7	9.7	9.8	10.0	10.1		
1990/ 1/ 1	102.23	102.23	102.23	102.23	102.23	102.22	102.22	102.22	102.22	102.21	102.21		
17.500000	10.0	9.9	9.8	9.7	9.9	10.2	10.3	10.4	10.3	10.1	9.9		
1990/ 1/ 1	102.23	102.23	102.23	102.23	102.22	102.22	102.22	102.22	102.22	102.22	102.21		
18.000000	10.0	10.1	10.2	10.2	10.1	9.9	9.7	9.8	9.9	10.0	10.1		


FEQEX1 HYDROGRAPHS
AT SELECTED NODES
JANUARY 25, 1989
UPSTREAM INFLOW
MIDPOINT FLOW
DNSTREAM OUTFLOW
FLOW IN CFS
0
40
80
120
160
200
240
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
JAN. 1

SYSTEM SCHEMATIC SKETCH: FEQEX2



Listing of Input: FEQEX2

```
Unsteady Flow --Example 2
THREE BRANCH SYSTEM
March 5, 1990
NBRA=00003
NEX=00006
SOPER=NO
POINT=NO
DIFFUS=NO
WIND=NO
UNDERFLOW=NO
ZL=0.0
STIME=1990/01/01:0.00
ETIME=1990/01/01:0.75
GRAV=32.2
NODEID=YES
SSEPS=0.1
PAGE=   22
EPSSYS=0.010 0.010
MKNT=   05   1
OUTPUT=    0
PRTINT=   72
GEQOPT=STDX
EPSB=0.000005
MAXIT=   30
SFAC=5280.
QSMALL=0.01
IFRZ=00001
   1800.   1400.   1000.    850.    700.    500.    350.    100.  0450.
 450. 01.0  0.7  2.8  3.2  3.0  2.0  0.5
MRE=     0.0       0.5
DWT=0.1
BWT=0.6
BWFDSN=   00
CHKGEO=NO
MINBND=YES
EXTTOL= 0.0
BRANCH DESCRIPTION TABLES
BNUM=    1
 NODE   NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
  100 UPSTREAM  5000       0.0     101.
      DNSTREAM  5000       1.0     100.0
   -1
BNUM=    2
 NODE   NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
  200 UPSTREAM  5000       0.0     101.
  201
  202
  203
  204
  205
  206
  207
  208
  209
  210 DNSTREAM  5000       1.0     100.0
   -1
BNUM=    3
 NODE   NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
  300 UPSTREAM  4990       0.0     100.
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
      DNSTREAM  5000       1.0     101.
   -1
BRANCH-EXTERIOR NODE TABLE
 BRA# UEXN DEXN
    1    1    3
    2    2    4
    3    5    6
EXTERIOR-MATRIX CONTROL INPUT
 CODE   A   B   C   D   E   F   G   H   I   J     FA     FB     FC     FD
    6   1   1   1 100
    1   1
    1   2
```

```
    6   1   2   1 102
    3   3   4
    2   3   3   4   5
    3   4   5
    1   3
    4   1   6  -1   6 110                          103.0   32.0
   -1
SPECIAL OUTPUT LOCATIONS
UNIT=    3\FEQ68\TEST\EX2SPOUT
  BRA NODE
    0    3 EXNOD 3
    0    4 EXNOD 4
    0    5 EXNOD 5
   -1
INPUT FILE SPECIFICATION
 UNIT NAME
   -1
OUTPUT FILE SPECIFICATION
 UNIT  BRA NODE ITEM TYPE NAME
   -1
FUNCTION TABLES
TABLE#=  100
TYPE=   -7
REFL=0.0         FAC=1.0
YEAR MN DY       HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END
1990 01 01        0.0        9.
                  1.0       32.
                  2.0      100.
                  3.0      151.
                  4.0       94.
                  5.0      145.
                  6.0      220.
                  7.0      178.
                  8.0      104.
                  9.0       77.
                 10.0       57.
                 11.0       38.
                 12.0       28
                 13.0       19.
                 14.0       10.
         02      24.0       10.
                 23.0
TABLE#=  102
TYPE=   -7
REFL=0.0         FAC=2.0
YEAR MN DY       HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END
1990 01 01        0.0        9.
                  1.0       32.
                  2.0      100.
                  3.0      151.
                  4.0       94.
                  5.0      145.
                  6.0      220.
                  7.0      178.
                  8.0      104.
                  9.0       77.
                 10.0       57.
                 11.0       38.
                 12.0       28
                 13.0       19.
                 14.0       10.
         02      24.0       10.
                 23.0
TABLE#=  110
TYPE=   -2
REFL=0.0
       HEAD WEIR COEF
        0.0       3.2
       50.0       3.2
       -1.0
TABLE#= 4990
TYPE=   -1
STATION= 2.41200E+00                              EXT=00.00      FAC=1.000
ELEVATION= 0.00000E+00
      DEPTH TOP WIDTH          AREA   SQRT(CONV)      BETA        YBARA
       .000    40.000  0.00000E+00  0.00000E+00    1.0000  0.00000E+00
       .080    40.960  3.23840E+00  5.96209E+00    1.0000  1.29024E-01
      1.875    62.500  9.60937E+01  8.72018E+01    1.0000  8.34961E+01
      3.750    85.000  2.34375E+02  1.65332E+02    1.0000  3.86719E+02
      5.625   107.500  4.14844E+02  2.45929E+02    1.0000  9.88770E+02
      7.500   130.000  6.37500E+02  3.30116E+02    1.0000  1.96875E+03
      9.375   152.500  9.02344E+02  4.18033E+02    1.0000  3.40576E+03
     11.250   175.000  1.20938E+03  5.09580E+02    1.0000  5.37891E+03
     13.125   197.500  1.55859E+03  6.04590E+02    1.0000  7.96728E+03
     15.000   220.000  1.95000E+03  7.02889E+02    1.0000  1.12500E+04
     16.667   240.000  2.33333E+03  7.92889E+02    1.0000  1.48148E+04
     18.333   260.000  2.75000E+03  8.85244E+02    1.0000  1.90463E+04
     20.000   280.000  3.20000E+03  9.79852E+02    1.0000  2.40000E+04
     21.667   300.000  3.68333E+03  1.07662E+03    1.0000  2.97315E+04
```

```
    23.333   320.000  4.20000E+03  1.17547E+03    1.0000  3.62963E+04
    25.000   340.000  4.75000E+03  1.27631E+03    1.0000  4.37500E+04
    -1.000      .000  0.00000E+00  0.00000E+00     .0000  0.00000E+00
TABLE#= 5000
TYPE=   -1
STATION= 2.41200E+00
ELEVATION= 0.00000E+00                    EXT=00.00      FAC=1.000
      DEPTH TOP WIDTH          AREA   SQRT(CONV)      BETA          YBARA
       .000    20.000  0.00000E+00  0.00000E+00    1.0000  0.00000E+00
       .080    20.480  1.61920E+00  4.21451E+00    1.0000  6.45120E-02
       .938    25.625  2.13867E+01  3.34821E+01    1.0000  9.61304E+00
      1.875    31.250  4.80469E+01  6.13671E+01    1.0000  4.17480E+01
      2.812    36.875  7.99805E+01  8.86460E+01    1.0000  1.01349E+02
      3.750    42.500  1.17188E+02  1.16093E+02    1.0000  1.93359E+02
      4.688    48.125  1.59668E+02  1.43993E+02    1.0000  3.22723E+02
      5.625    53.750  2.07422E+02  1.72467E+02    1.0000  4.94385E+02
      6.563    59.375  2.60449E+02  2.01568E+02    1.0000  7.13287E+02
      7.500    65.000  3.18750E+02  2.31316E+02    1.0000  9.84375E+02
      8.437    70.625  3.82324E+02  2.61712E+02    1.0000  1.31259E+03
      9.375    76.250  4.51172E+02  2.92750E+02    1.0000  1.70288E+03
     10.312    81.875  5.25293E+02  3.24420E+02    1.0000  2.16019E+03
     11.250    87.500  6.04687E+02  3.56707E+02    1.0000  2.68945E+03
     12.187    93.125  6.89355E+02  3.89597E+02    1.0000  3.29562E+03
     13.125    98.750  7.79297E+02  4.23074E+02    1.0000  3.98364E+03
     14.062   104.375  8.74512E+02  4.57123E+02    1.0000  4.75845E+03
     15.000   110.000  9.75000E+02  4.91730E+02    1.0000  5.62500E+03
     15.909   115.455  1.07748E+03  5.25807E+02    1.0000  6.55757E+03
     16.818   120.909  1.18492E+03  5.60383E+02    1.0000  7.58556E+03
     17.727   126.364  1.29731E+03  5.95444E+02    1.0000  8.71347E+03
     18.636   131.818  1.41467E+03  6.30980E+02    1.0000  9.94581E+03
     19.545   137.273  1.53698E+03  6.66980E+02    1.0000  1.12871E+04
     20.455   142.727  1.66426E+03  7.03433E+02    1.0000  1.27418E+04
     21.364   148.182  1.79649E+03  7.40329E+02    1.0000  1.43145E+04
     22.273   153.636  1.93368E+03  7.77659E+02    1.0000  1.60097E+04
     23.182   159.091  2.07583E+03  8.15414E+02    1.0000  1.78318E+04
     24.091   164.545  2.22293E+03  8.53584E+02    1.0000  1.97854E+04
     25.000   170.000  2.37500E+03  8.92162E+02    1.0000  2.18750E+04
     -1.000      .000  0.00000E+00  0.00000E+00     .0000  0.00000E+00
TABLE#=   -1
BACKWATER ANALYSIS
BRANCH NUMBER=   -1
DISCHARGE=  9.0
BRANCH NUMBER=   -2
DISCHARGE= 19.0
BRANCH NUMBER=   -3
DISCHARGE= 27.0
  BRA CODE ELEVATION EXN#
    3    3     103.1
    1    0          5
    2    0          5
   -1
```

Listing of Output: FEQEX2

```
1
2
3
4
5  ********************************************************************************
6  *                                                                              *
7  *                          FULL EQUATIONS FLOW ROUTING                         *
8  *                                                                              *
9  *                                                                              *
10 ********************************************************************************
11
12 VERSION: 6.0 15 MARCH  1990
13
14  WARNING: This program is large and complex.
15  User is totally responsible for any
16  consequences resulting from application
17  of this program.  Read disclaimer in the
18  source code.
19
20  This program is not to be sold in any form.
21
22
23 THE SIZE LIMITS SET FOR THIS PROGRAM ARE:
24 NUMBER OF BRANCHES:   85
25 NUMBER OF EXTERIOR NODES:  220
26 NUMBER OF NODES ON BRANCHES: 1170
27 NUMBER OF OPERATION BLOCKS:   10
28 FUNCTION TABLE NUMBER:10000
29 LENGTH OF THE FUNCTION TABLE:250000
30 NUMBER OF POINT FLOWS:   10
31 LENGTH OF EXTERIOR MATRIX CONTROL: 2000
32 NUMBER OF ROWS IN ARRAY OF PARTIAL DERIV.: 2340
33 LENGTH OF INTERIOR MATRIX POINTER VECTOR :  170
34 NUMBER OF ROWS IN EXTERIOR MATRIX :  440
35 NUMBER OF LAND USES FOR TRIB. AREA:   20
36 NUMBER OF POINT INFLOW FILES:   10
37 NUMBER OF POINT OUTFLOW FILES:    4
38 NUMBER OF SPECIAL OUTPUTS:   45
39 NUMBER OF CODE=6 EX NODES WITH FILES OR TABLES:   20
40 MAX. UNIT NUMBER FOR FILES:   50
41 TOTAL BANDWIDTH OF EXTERIOR MATRIX :   16
42 NUMBER OF SUBDIAGONALS IN EXTERIOR MATRIX :   10
43
44 Unsteady Flow --Example 2
45
46 THREE BRANCH SYSTEM
47
48 March 5, 1990
49
50 NUMBER OF BRANCHES =     3
51
52 NUMBER OF EXTERIOR NODES =     6
53
54 SPECIAL OPERATION BLOCK OPTION = NO
55
56 POINT FLOW OPTION = NO
57
58 DIFFUSE FLOW OPTION = NO   MINPRT=0 LAGTSF=0
59
60 WIND LOADING OPTION = NO
61
62 UNDERFLOW MESSAGES ARE : NO
63
64 ZERO INERTIA LIMIT =        .00 FEET
65
66 START TIME =  1990/ 1/ 1:  .000000000
67
68 END TIME =  1990/ 1/ 1:  .750000000
69
70 GRAVITY =      32.20
71
72 NODE ID STRING PRESENT? YES
73
74 CONVERGENCE LIMIT(SURCHARGE STORAGE)  =  1.000E-01
75
76 PAGE=    22
77
78 CONVERGENCE LIMITS(SYSTEM SOLUTION):
79           PRIMARY =  1.000E-02
80           SECONDARY = 2.000E-02
81           ABSOLUTE =   .010
82
83 MAXIMUM NO. OF ITERATIONS IN SYSTEM SOLUTION  =     5 MAX. NUMGT=    1
84
85 PRINT OUT OPTION IS OUTPUT =     0
86
87 PRINT OUT WILL BE GIVEN EVERY    72 TIME STEPS
88
89 STANDARD GOVERNING EQUATIONS SELECTED. WX VARIABLE
```

```
1
2 CONVERGENCE CRITERION FOR BACKWATER =  5.000E-06
3
4 MAX.NO. ITERATIONS FOR BACKWATER ANALYSIS =    30
5
6 STATIONING FACTOR =  5.28000E+03
7
8 Q SMALL FOR RELATIVE ERROR =      .01
9
10 IFRZ =     1
11     450.00      1.00       .70      2.80      3.20      3.00      2.00       .50
12
13 MRE =     .20 FAC =     .50 HSLOT=    .00 WSLOT=    .00 NSLOT=    .000
14 WT INCREMENT/DECREMENT =    .100
15 BASE VALUE FOR WT =         .60
16 BWFDSN =      0 NAME=
17 GEOMETRY WILL NOT BE CHECKED
18 REDUCTION OF BAND WIDTH WILL BE ATTEMPTED.
19 EXTRAPOLATION TOLERANCE=       .000
20
21 BRANCH DESCRIPTION TABLES
22
23 BRANCH NUMBER=     1 INERTIA=  1.0 CFRATE=     .0 WINDFAC= 1.00
24
25   NODE    NODEID  XNUM    STATION ELEVATION    KA    KD HTAB  AZM
26    100 UPSTREAM  5000      .0000   101.000   .00   .00    0   0.    .0    .0        .00
27    101           5000      .1000   100.900   .00   .00    0   0.    .0    .0        .00
28    102           5000      .2000   100.800   .00   .00    0   0.    .0    .0        .00
29    103           5000      .3000   100.700   .00   .00    0   0.    .0    .0        .00
30    104           5000      .4000   100.600   .00   .00    0   0.    .0    .0        .00
31    105           5000      .5000   100.500   .00   .00    0   0.    .0    .0        .00
32    106           5000      .6000   100.400   .00   .00    0   0.    .0    .0        .00
33    107           5000      .7000   100.300   .00   .00    0   0.    .0    .0        .00
34    108           5000      .8000   100.200   .00   .00    0   0.    .0    .0        .00
35    109           5000      .9000   100.100   .00   .00    0   0.    .0    .0        .00
36    110 DNSTREAM  5000     1.0000   100.000   .00   .00    0   0.    .0    .0        .00
37
38 BRANCH NUMBER=     2 INERTIA=  1.0 CFRATE=     .0 WINDFAC= 1.00
39
40   NODE    NODEID  XNUM    STATION ELEVATION    KA    KD HTAB  AZM
41    200 UPSTREAM  5000      .0000   101.000   .00   .00    0   0.    .0    .0        .00
42    201           5000      .1000   100.900   .00   .00    0   0.    .0    .0        .00
43    202           5000      .2000   100.800   .00   .00    0   0.    .0    .0        .00
44    203           5000      .3000   100.700   .00   .00    0   0.    .0    .0        .00
45    204           5000      .4000   100.600   .00   .00    0   0.    .0    .0        .00
46    205           5000      .5000   100.500   .00   .00    0   0.    .0    .0        .00
47    206           5000      .6000   100.400   .00   .00    0   0.    .0    .0        .00
48    207           5000      .7000   100.300   .00   .00    0   0.    .0    .0        .00
49    208           5000      .8000   100.200   .00   .00    0   0.    .0    .0        .00
50    209           5000      .9000   100.100   .00   .00    0   0.    .0    .0        .00
51    210 DNSTREAM  5000     1.0000   100.000   .00   .00    0   0.    .0    .0        .00
52
53 BRANCH NUMBER=     3 INERTIA=  1.0 CFRATE=     .0 WINDFAC= 1.00
54
55   NODE    NODEID  XNUM    STATION ELEVATION    KA    KD HTAB  AZM
56    300 UPSTREAM  4990      .0000   100.000   .00   .00    0   0.    .0    .0        .00
57    301           -         .1000   100.100   .00   .00    0   0.    .0    .0        .00
58    302           -         .2000   100.200   .00   .00    0   0.    .0    .0        .00
59    303           -         .3000   100.300   .00   .00    0   0.    .0    .0        .00
60    304           -         .4000   100.400   .00   .00    0   0.    .0    .0        .00
61    305           -         .5000   100.500   .00   .00    0   0.    .0    .0        .00
62    306           -         .6000   100.600   .00   .00    0   0.    .0    .0        .00
63    307           -         .7000   100.700   .00   .00    0   0.    .0    .0        .00
64    308           -         .8000   100.800   .00   .00    0   0.    .0    .0        .00
65    309           -         .9000   100.900   .00   .00    0   0.    .0    .0        .00
66    310 DNSTREAM  5000     1.0000   101.000   .00   .00    0   0.    .0    .0        .00
67
68 BRANCH-EXTERIOR NODE TABLE
69
70   BRA# UEXN DEXN
71      1    1    3
72      2    2    4
73      3    5    6
74
75 EXTERIOR-MATRIX CONTROL INPUT
76
77   CODE    A    B    C    D    E    F    G    H    I    J      FA      FB      FC      FD
78
79 CODE=     6 EQN#=     1.  ENTRY#=     1
80     TYPE=     1 UPN=     1 DIR=     1 TAB#=   100 FLOW=         .00
81
82 CODE=     1 EQN#S=     2 AND     3.  ENTRY#=     2
83     BRANCH=     1
84
85 CODE=     1 EQN#S=     4 AND     5.  ENTRY#=     3
86     BRANCH=     2
87
88 CODE=     6 EQN#=     6.  ENTRY#=     4
89     TYPE=     1 UPN=     2 DIR=     1 TAB#=   102 FLOW=         .00
```

```
 1
 2 CODE=    3 EQN#=    7.  ENTRY#=    5
 3    ELEVATION EQUALITY BETWEEN NODE    3 AND    4
 4
 5 CODE=    2 EQN#=    8.  ENTRY#=    6
 6    THE    3 NODES FOR SUM OF Q ARE    3    4    5
 7
 8 CODE=    3 EQN#=    9.  ENTRY#=    7
 9    ELEVATION EQUALITY BETWEEN NODE    4 AND    5
10
11 CODE=    1 EQN#S=   10 AND   11.  ENTRY#=    8
12    BRANCH=    3
13
14 CODE=    4 EQN#=   12.  ENTRY#=    9
15    TYPE=    1 UPN=    6 DIR=   -1 QNODE=    6
16    WEIR COEF. TAB#=  110 WEIR ELEV.=    103.00 WEIR LENGTH=      32.0
```

BANDWIDTH REDUCTION LOG

ITER	MAXSUB	MAXSUP	BANDW	DECSUB	DECSUP	SWPFLG
0	2	4	7			
1	2	4	7	0	0	0
2	2	4	7	0	0	0
3	2	4	7	0	0	0
4	2	4	7	0	0	0
5	2	4	7	0	0	0
6	2	4	7	0	0	0
7	2	4	7	0	0	0
8	2	4	7	0	0	0

```
ARRANGEMENT OF NON-ZERO ELEMENTS IN EXTERIOR MATRIX

  EQN ENTRY   C987654321B987654321A9876543210123456789A123456789B123456789C123456789
    1     1                                    .X.........
    2     2                                   XX..XX......
    3                                       XX..XX......
    4     3                                ..XX..XX....
    5                                    ..XX..XX....
    6     4                             ...X........
    7     5                            ....X.X.....
    8     6                           .....X.X.X..
    9     7                          ......X.X...
   10     8                        ........XXXX
   11                            ........XXXX
   12     9                     ..........XX


TOTAL BAND WIDTH M3 =    7

NO. OF SUBDIAGONALS M1 =    2 NO. OF SUPER DIAGONALS M2 =   4

SPECIAL OUTPUT LOCATIONS
UNIT=    3 NAME=\FEQ68\TEST\EX2SPOUT
  BRA NODE
    0    3 EXNOD 3
    0    4 EXNOD 4
    0    5 EXNOD 5

INPUT FILE SPECIFICATION

 UNIT NAME

OUTPUT FILE SPECIFICATION

 UNIT  BRA NODE ITEM TYPE NAME

FUNCTION TABLES

TABLE#=  100
TYPE=   -7
REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.

YEAR MN DY      HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END

TABLE#=  102
TYPE=   -7
REFERENCE LEVEL=        0. FAC=     2.000 SHIFT=        0.

YEAR MN DY      HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END

TABLE#=  110
TYPE=   -2
REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.

      HEAD WEIR COEF

TABLE#= 4990
TYPE=   -1

TABLE#= 5000
TYPE=   -1

TRUE SIZES:
NUMBER OF BRANCHES:    3
NUMBER OF EXTERIOR NODES:    6
NUMBER OF NODES ON BRANCHES:   33
NUMBER OF OPERATION BLOCKS:    0
FUNCTION TABLE NUMBER:    5
LENGTH OF THE FUNCTION TABLE:    366
NUMBER OF POINT FLOWS:    0
LENGTH OF EXTERIOR MATRIX CONTROL:   58
NUMBER OF ROWS IN ARRAY OF PARTIAL DERIV.:   60
LENGTH OF INTERIOR MATRIX POINTER VECTOR :    6
NUMBER OF ROWS IN EXTERIOR MATRIX:   12
NUMBER OF LAND USES FOR TRIB. AREA:    0
NUMBER OF POINT INFLOW FILES:    0
NUMBER OF POINT OUTFLOW FILES:    0
NUMBER OF SPECIAL OUTPUTS:    3
NUMBER OF CODE=6 EX NODES WITH FILES OR TABLES:    2

    9 X-SECTIONS INTERPOLATED BETWEEN  STATIONS      .000 AND     1.000
      MAX. DEPTH =     25.000 NUMBER OF DEPTH VALUES =    34
  THERE ARE NOW    14 FUNCTION TABLES AND    2256 LOCATIONS USED IN FTAB.

SRLIM= 7.20000E-05
```

```
 BACKWATER ANALYSIS

 BRANCH NUMBER =      1
 DISCHARGE =         9.0

 BRANCH NUMBER =      2
 DISCHARGE =        19.0

 BRANCH NUMBER =      3
 DISCHARGE =        27.0

   BRA CODE ELEVATION EXN#
     3    3    103.10    0

 BACKWATER ANALYSIS BRANCH#     3
  STATION IT      YL        QL        AL      TL      DZ      DX      ELEV        RES     FR
  1.0000  0  2.411     27.0     65.7    34.5    .00       .0  103.411  0.0E+00   .0
   .9000  3  2.521     27.0     76.4    38.6    .10    528.0  103.421 -7.0E-03   .0
   .8000  3  2.628     27.0     88.0    42.9    .10    528.0  103.428 -6.5E-03   .0
   .7000  3  2.734     27.0    100.2    47.3    .10    528.0  103.434 -6.1E-03   .0
   .6000  3  2.838     27.0    113.3    51.8    .10    528.0  103.438 -6.0E-03   .0
   .5000  3  2.941     27.0    127.1    56.5    .10    528.0  103.441 -6.0E-03   .0
   .4000  3  3.043     27.0    141.8    61.2    .10    528.0  103.443 -6.2E-03   .0
   .3000  3  3.145     27.0    157.3    66.1    .10    528.0  103.445 -6.3E-03   .0
   .2000  3  3.246     27.0    173.8    71.1    .10    528.0  103.446 -5.6E-03   .0
   .1000  3  3.347     27.0    191.0    76.2    .10    528.0  103.447 -5.5E-03   .0
   .0000  3  3.448     27.0    209.2    81.4    .10    528.0  103.448 -5.5E-03   .0
    1    0        .00    5

 BACKWATER ANALYSIS BRANCH#     1
  STATION IT      YL        QL        AL      TL      DZ      DX      ELEV        RES     FR
  1.0000  0  3.448      9.0    104.6    40.7    .00       .0  103.448  0.0E+00   .0
   .9000  3  3.348      9.0    100.6    40.1   -.10    528.0  103.448 -2.3E-03   .0
   .8000  3  3.249      9.0     96.6    39.5   -.10    528.0  103.449 -2.3E-03   .0
   .7000  3  3.149      9.0     92.7    38.9   -.10    528.0  103.449 -2.2E-03   .0
   .6000  3  3.050      9.0     88.9    38.3   -.10    528.0  103.450 -2.9E-03   .0
   .5000  3  2.950      9.0     85.1    37.7   -.10    528.0  103.450 -2.5E-03   .0
   .4000  3  2.851      9.0     81.4    37.1   -.10    528.0  103.451 -2.5E-03   .0
   .3000  3  2.751      9.0     77.7    36.5   -.10    528.0  103.451 -2.6E-03   .0
   .2000  3  2.652      9.0     74.1    35.9   -.10    528.0  103.452 -2.7E-03   .0
   .1000  3  2.553      9.0     70.6    35.3   -.10    528.0  103.453 -3.0E-03   .0
   .0000  3  2.454      9.0     67.1    34.7   -.10    528.0  103.454 -3.4E-03   .0
    2    0        .00    5

 BACKWATER ANALYSIS BRANCH#     2
  STATION IT      YL        QL        AL      TL      DZ      DX      ELEV        RES     FR
  1.0000  0  3.448     19.0    104.6    40.7    .00       .0  103.448  0.0E+00   .0
   .9000  3  3.349     19.0    100.6    40.1   -.10    528.0  103.449 -2.3E-03   .0
   .8000  3  3.251     19.0     96.7    39.5   -.10    528.0  103.451 -2.6E-03   .0
   .7000  3  3.153     19.0     92.9    38.9   -.10    528.0  103.453 -2.4E-03   .0
   .6000  3  3.055     19.0     89.1    38.3   -.10    528.0  103.455 -2.3E-03   .0
   .5000  3  2.957     19.0     85.4    37.7   -.10    528.0  103.457 -2.2E-03   .0
   .4000  3  2.860     19.0     81.7    37.2   -.10    528.0  103.460 -2.6E-03   .0
   .3000  3  2.763     19.0     78.2    36.6   -.10    528.0  103.463 -2.6E-03   .0
   .2000  3  2.666     19.0     74.7    36.0   -.10    528.0  103.466 -2.7E-03   .0
   .1000  3  2.570     19.0     71.2    35.4   -.10    528.0  103.470 -2.8E-03   .0
   .0000  3  2.475     19.0     67.9    34.9   -.10    528.0  103.475 -2.5E-03   .0

 *WRN:17* CONTINUITY ERROR OF        1.0 IN INITIAL CONDITIONS AT NODES:
               3 ON BRA   1
               4 ON BRA   2
               5 ON BRA   3

 IFRZ =      1

 SIMULATION ENDING AT  1990/ 1/ 1/   .000 WITH TIME STEP OF      1800.0 SEC
 ITER   RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
    1 5.3E-02    0    2 1.0E+00   -6 2.0E+00     11
    2 1.2E-04    0    3 3.7E-05   -5 2.4E-09      0
 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 1.69E-03 AT ND=  2: 200 DT/ITER=       .0

 IFRZ =      0
       TIME STEP RESET TO    450.00 SEC WT =  .600

 SIMULATION ENDING AT  1990/ 1/ 1/   .125 WITH TIME STEP OF       450.0 SEC
 ITER   RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
    1 3.3E-01    0    2 5.9E+00   -6 4.3E+01     26
    2 5.5E-04    2  203 1.5E-04   -4 5.7E-08      0
 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 4.57E-02 AT ND=  2: 200 DT/ITER=    225.0
       TIME STEP RESET TO    450.00 SEC WT =  .600

 SIMULATION ENDING AT  1990/ 1/ 1/   .250 WITH TIME STEP OF       450.0 SEC
 ITER   RERROR  BRA NODE    MXRES  LOC  SUMSQR NUMGT
    1 2.1E-01    2  203 2.9E+00   -6 1.0E+01     31
    2 2.1E-03    2  205 3.9E-04   -4 3.5E-07      0
 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 4.99E-02 AT ND=  2: 201 DT/ITER=    225.0
       TIME STEP RESET TO    450.00 SEC WT =  .600

 SIMULATION ENDING AT  1990/ 1/ 1/   .375 WITH TIME STEP OF       450.0 SEC
```

```
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.6E-01    2  209 2.9E+00   -6 1.0E+01    33
   2 1.6E-03    2  208 1.9E-04   -5 8.5E-08     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 6.27E-02 AT ND=  1: 109 DT/ITER=   225.0
      TIME STEP RESET TO    450.00 SEC WT =  .600

SIMULATION ENDING AT  1990/ 1/ 1/   .500 WITH TIME STEP OF      450.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 8.5E-02    2  201 2.9E+00   -6 1.0E+01    33
   2 4.9E-04    0    4 7.3E-05   -5 3.8E-08     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 7.62E-02 AT ND=  1: 109 DT/ITER=   225.0
      TIME STEP RESET TO    450.00 SEC WT =  .600

SIMULATION ENDING AT  1990/ 1/ 1/   .625 WITH TIME STEP OF      450.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 6.7E-02    2  203 2.9E+00   -6 1.0E+01    34
   2 1.8E-04    2  204 7.6E-05  -12 4.6E-08     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 8.42E-02 AT ND=  1: 109 DT/ITER=   225.0
      TIME STEP RESET TO    450.00 SEC WT =  .600

SIMULATION ENDING AT  1990/ 1/ 1/   .750 WITH TIME STEP OF      450.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 6.2E-02    1  106 2.9E+00   -6 1.0E+01    36
   2 1.2E-04    2  206 9.9E-05   21 7.1E-08     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 9.74E-02 AT ND=  1: 109 DT/ITER=   225.0
      TIME STEP RESET TO    450.00 SEC WT =  .600

SIMULATION ENDING AT  1990/ 1/ 1/   .875 WITH TIME STEP OF      450.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 5.7E-02    0    3 2.9E+00   -6 1.0E+01    37
   2 1.3E-04    2  209 1.2E-04   21 1.1E-07     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 1.06E-01 AT ND=  1: 109 DT/ITER=   225.0
      TIME STEP RESET TO    450.00 SEC WT =  .600

SIMULATION ENDING AT  1990/ 1/ 1/  1.000 WITH TIME STEP OF      450.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 5.1E-02    2  206 2.9E+00   -6 1.0E+01    39
   2 1.3E-04    0    4 1.3E-04   21 1.5E-07     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 1.09E-01 AT ND=  1: 109 DT/ITER=   225.0
      TIME STEP RESET TO    450.00 SEC WT =  .600

SIMULATION ENDING AT  1990/ 1/ 1/  1.125 WITH TIME STEP OF      450.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 2.1E-01    0    2 1.4E+01   -6 2.5E+02    48
   2 2.6E-04    1  103 8.0E-04   21 1.7E-06     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 1.17E-01 AT ND=  1: 109 DT/ITER=   225.0
      TIME STEP RESET TO    450.00 SEC WT =  .600

    ****************************************
    Lines deleted to save space
    ****************************************

SIMULATION ENDING AT  1990/ 1/ 1/  8.750 WITH TIME STEP OF      450.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 2.0E-02    2  203 3.4E+00   -6 1.4E+01    33
   2 2.2E-05    0    3 1.4E-04   21 4.1E-07     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 4.50E-02 AT ND=  1: 100 DT/ITER=   225.0
      TIME STEP RESET TO    450.00 SEC WT =  .600

SIMULATION ENDING AT  1990/ 1/ 1/  8.875 WITH TIME STEP OF      450.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 2.1E-02    0    2 3.4E+00   -6 1.4E+01    33
   2 3.1E-05    3  304 1.4E-04   21 4.1E-07     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 4.64E-02 AT ND=  1: 100 DT/ITER=   225.0

RESULTS AT TIME     31950. JTIME =     47892.3697916668

BRANCH NUMBER =     1

NODE   NODEID     STAT     FLOW     AREA   VEL  DEPTH     ELEV      TOP  FR LAT INF
 100 UPSTREAM   .0000 8.038+1 1.827+2   .44   5.15  106.15 5.091+1  .0 0.000+0
 101            .1000 8.434+1 1.876+2   .45   5.25  106.15 5.148+1  .0 0.000+0
 102            .2000 8.835+1 1.924+2   .46   5.34  106.14 5.205+1  .0 0.000+0
 103            .3000 9.239+1 1.974+2   .47   5.44  106.14 5.262+1  .0 0.000+0
 104            .4000 9.645+1 2.024+2   .48   5.53  106.13 5.318+1  .0 0.000+0
 105            .5000 1.005+2 2.074+2   .48   5.63  106.13 5.375+1  .0 0.000+0
 106            .6000 1.047+2 2.125+2   .49   5.72  106.12 5.431+1  .0 0.000+0
 107            .7000 1.088+2 2.176+2   .50   5.81  106.11 5.488+1  .0 0.000+0
 108            .8000 1.130+2 2.228+2   .51   5.91  106.11 5.544+1  .0 0.000+0
 109            .9000 1.172+2 2.281+2   .51   6.00  106.10 5.601+1  .0 0.000+0
 110 DNSTREAM  1.0000 1.215+2 2.333+2   .52   6.10  106.09 5.657+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

BRANCH NUMBER =     2

NODE   NODEID     STAT     FLOW     AREA   VEL  DEPTH     ELEV      TOP  FR LAT INF
 200 UPSTREAM   .0000 1.607+2 1.891+2   .85   5.28  106.28 5.167+1  .0 0.000+0
 201            .1000 1.650+2 1.933+2   .85   5.36  106.26 5.215+1  .0 0.000+0
```

```
 202             .2000 1.692+2 1.976+2   .86   5.44  106.24 5.264+1  .0 0.000+0
 203             .3000 1.735+2 2.019+2   .86   5.52  106.22 5.313+1  .0 0.000+0
 204             .4000 1.777+2 2.062+2   .86   5.60  106.20 5.361+1  .0 0.000+0
 205             .5000 1.820+2 2.106+2   .86   5.68  106.18 5.410+1  .0 0.000+0
 206             .6000 1.862+2 2.150+2   .87   5.77  106.17 5.459+1  .0 0.000+0
 207             .7000 1.904+2 2.195+2   .87   5.85  106.15 5.508+1  .0 0.000+0
 208             .8000 1.947+2 2.241+2   .87   5.93  106.13 5.558+1  .0 0.000+0
 209             .9000 1.990+2 2.287+2   .87   6.01  106.11 5.607+1  .0 0.000+0
 210 DNSTREAM   1.0000 2.033+2 2.333+2   .87   6.10  106.09 5.657+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

BRANCH NUMBER =     3

NODE   NODEID     STAT     FLOW     AREA    VEL  DEPTH     ELEV      TOP  FR LAT INF
 300 UPSTREAM    .0000 3.248+2 4.667+2   .70   6.10  106.09 1.131+2  .0 0.000+0
 301             .1000 3.331+2 4.312+2   .77   5.98  106.08 1.062+2  .0 0.000+0
 302             .2000 3.408+2 3.968+2   .86   5.86  106.06 9.933+1  .0 0.000+0
 303             .3000 3.479+2 3.633+2   .96   5.74  106.04 9.256+1  .0 0.000+0
 304             .4000 3.544+2 3.307+2  1.07   5.61  106.01 8.587+1  .0 0.000+0
 305             .5000 3.604+2 2.990+2  1.21   5.47  105.97 7.925+1  .0 0.000+0
 306             .6000 3.658+2 2.679+2  1.37   5.32  105.92 7.270+1  .0 0.000+0
 307             .7000 3.707+2 2.375+2  1.56   5.15  105.85 6.618+1  .0 0.000+0
 308             .8000 3.750+2 2.073+2  1.81   4.96  105.76 5.968+1  .0 0.000+0
 309             .9000 3.787+2 1.772+2  2.14   4.72  105.62 5.313+1  .0 0.000+0
 310 DNSTREAM   1.0000 3.817+2 1.463+2  2.61   4.40  105.40 4.642+1  .1 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

    NETWORK PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

EXTERIOR NODES

NODE   NODEID         QE1      YE1    ELEV     STORAGE     STORAGE
   1 UPSTREAM   8.038E+01     5.15  106.15
   2 UPSTREAM   1.607E+02     5.28  106.28
   3 DNSTREAM   1.215E+02     6.10  106.09
   4 DNSTREAM   2.033E+02     6.10  106.09
   5 UPSTREAM   3.248E+02     6.10  106.09
   6 DNSTREAM   3.817E+02     4.40  105.40
BC:S1=1.593E+06 S2=3.803E+06 I=1.143E+07 Q=9.217E+06 D= 4.014E-01 R= 3.08E-08
     TIME STEP RESET TO    450.00 SEC WT =  .600

    ****************************************
    Lines deleted to save space
    ****************************************

SIMULATION ENDING AT  1990/ 1/ 1/ 17.875 WITH TIME STEP OF      450.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 6.6E-03    0    6 5.9E-03    7 1.0E-03     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.57E-02 AT ND=  1: 100 DT/ITER=   234.0

RESULTS AT TIME     64350. JTIME =     47892.7447916670

BRANCH NUMBER =     1

NODE   NODEID     STAT     FLOW     AREA    VEL  DEPTH     ELEV      TOP  FR LAT INF
 100 UPSTREAM    .0000 1.000+1 7.220+1   .14   2.60  103.60 3.559+1  .0 0.000+0
 101             .1000 1.025+1 7.575+1   .14   2.70  103.60 3.618+1  .0 0.000+0
 102             .2000 1.051+1 7.936+1   .13   2.80  103.60 3.678+1  .0 0.000+0
 103             .3000 1.077+1 8.304+1   .13   2.89  103.59 3.737+1  .0 0.000+0
 104             .4000 1.103+1 8.677+1   .13   2.99  103.59 3.797+1  .0 0.000+0
 105             .5000 1.130+1 9.057+1   .12   3.09  103.59 3.856+1  .0 0.000+0
 106             .6000 1.158+1 9.443+1   .12   3.19  103.59 3.916+1  .0 0.000+0
 107             .7000 1.185+1 9.835+1   .12   3.29  103.59 3.975+1  .0 0.000+0
 108             .8000 1.213+1 1.023+2   .12   3.39  103.59 4.035+1  .0 0.000+0
 109             .9000 1.242+1 1.064+2   .12   3.49  103.59 4.095+1  .0 0.000+0
 110 DNSTREAM   1.0000 1.271+1 1.105+2   .12   3.59  103.59 4.154+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

BRANCH NUMBER =     2

NODE   NODEID     STAT     FLOW     AREA    VEL  DEPTH     ELEV      TOP  FR LAT INF
 200 UPSTREAM    .0000 2.000+1 7.292+1   .27   2.62  103.62 3.571+1  .0 0.000+0
 201             .1000 2.025+1 7.637+1   .27   2.71  103.61 3.629+1  .0 0.000+0
 202             .2000 2.051+1 7.989+1   .26   2.81  103.61 3.686+1  .0 0.000+0
 203             .3000 2.077+1 8.348+1   .25   2.91  103.61 3.744+1  .0 0.000+0
 204             .4000 2.103+1 8.714+1   .24   3.00  103.60 3.802+1  .0 0.000+0
 205             .5000 2.130+1 9.086+1   .23   3.10  103.60 3.861+1  .0 0.000+0
 206             .6000 2.158+1 9.465+1   .23   3.20  103.60 3.919+1  .0 0.000+0
 207             .7000 2.185+1 9.851+1   .22   3.30  103.60 3.978+1  .0 0.000+0
 208             .8000 2.213+1 1.024+2   .22   3.39  103.59 4.036+1  .0 0.000+0
 209             .9000 2.242+1 1.064+2   .21   3.49  103.59 4.095+1  .0 0.000+0
 210 DNSTREAM   1.0000 2.271+1 1.105+2   .21   3.59  103.59 4.154+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

BRANCH NUMBER =     3
```

```
 1
 2 NODE   NODEID    STAT    FLOW    AREA    VEL  DEPTH    ELEV     TOP  FR LAT INF
 3  300 UPSTREAM   .0000 3.541+1 2.209+2   .16   3.59  103.59 8.308+1  .0 0.000+0
 4  301            .1000 3.598+1 2.020+2   .18   3.49  103.59 7.777+1  .0 0.000+0
 5  302            .2000 3.650+1 1.839+2   .20   3.39  103.59 7.258+1  .0 0.000+0
 6  303            .3000 3.699+1 1.667+2   .22   3.29  103.59 6.751+1  .0 0.000+0
 7  304            .4000 3.743+1 1.505+2   .25   3.18  103.58 6.255+1  .0 0.000+0
 8  305            .5000 3.784+1 1.350+2   .28   3.08  103.58 5.771+1  .0 0.000+0
 9  306            .6000 3.822+1 1.204+2   .32   2.97  103.57 5.298+1  .0 0.000+0
10  307            .7000 3.855+1 1.066+2   .36   2.87  103.57 4.837+1  .0 0.000+0
11  308            .8000 3.885+1 9.359+1   .42   2.76  103.56 4.386+1  .0 0.000+0
12  309            .9000 3.911+1 8.131+1   .48   2.65  103.55 3.947+1  .0 0.000+0
13  310 DNSTREAM  1.0000 3.933+1 6.974+1   .56   2.53  103.53 3.517+1  .0 0.000+0
14
15       BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT
16
17     NETWORK PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT
18
19 EXTERIOR NODES
20
21 NODE   NODEID        QE1        YE1     ELEV     STORAGE    STORAGE
22    1 UPSTREAM  1.000E+01       2.60   103.60
23    2 UPSTREAM  2.000E+01       2.62   103.62
24    3 DNSTREAM  1.271E+01       3.59   103.59
25    4 DNSTREAM  2.271E+01       3.59   103.59
26    5 UPSTREAM  3.541E+01       3.59   103.59
27    6 DNSTREAM  3.933E+01       2.53   103.53
28 BC:S1=1.593E+06 S2=1.692E+06 I=1.395E+07 Q=1.385E+07 D= 9.346E+00 R= 6.02E-07
29      TIME STEP RESET TO    450.00 SEC WT =  .600
30
31 TIME STEP RESET IN MANTIM TO    450.00 SECS TO MATCH EVENT END
32
33 SIMULATION ENDING AT  1990/ 1/ 1/ 18.000 WITH TIME STEP OF      450.0 SEC
34 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
35    1 6.3E-03    0    6 5.6E-03    5 9.3E-04     0
36 ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 2.42E-02 AT ND=  1: 100 DT/ITER=   234.8
37      TIME STEP RESET TO    450.00 SEC WT =  .600
38
39 SIMULATION COMPLETE AT     64800. SECS.
40
41
42
43 SIMULATION ENDING AT  1990/  1/  1/ 18.000
44
45 RESULTS AT TIME     64800. JTIME =     47892.7500000000
46
47 BRANCH NUMBER =     1
48
49 NODE   NODEID    STAT    FLOW    AREA    VEL  DEPTH    ELEV     TOP  FR LAT INF
50  100 UPSTREAM   .0000 1.000+1 7.200+1   .14   2.59  103.59 3.555+1  .0 0.000+0
51  101            .1000 1.024+1 7.554+1   .14   2.69  103.59 3.615+1  .0 0.000+0
52  102            .2000 1.048+1 7.915+1   .13   2.79  103.59 3.674+1  .0 0.000+0
53  103            .3000 1.073+1 8.282+1   .13   2.89  103.59 3.734+1  .0 0.000+0
54  104            .4000 1.098+1 8.655+1   .13   2.99  103.59 3.793+1  .0 0.000+0
55  105            .5000 1.123+1 9.035+1   .12   3.09  103.59 3.853+1  .0 0.000+0
56  106            .6000 1.149+1 9.420+1   .12   3.19  103.59 3.912+1  .0 0.000+0
57  107            .7000 1.175+1 9.812+1   .12   3.29  103.59 3.972+1  .0 0.000+0
58  108            .8000 1.201+1 1.021+2   .12   3.39  103.59 4.031+1  .0 0.000+0
59  109            .9000 1.228+1 1.061+2   .12   3.48  103.58 4.091+1  .0 0.000+0
60  110 DNSTREAM  1.0000 1.256+1 1.102+2   .11   3.58  103.58 4.151+1  .0 0.000+0
61
62       BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT
63
64 BRANCH NUMBER =     2
65
66 NODE   NODEID    STAT    FLOW    AREA    VEL  DEPTH    ELEV     TOP  FR LAT INF
67  200 UPSTREAM   .0000 2.000+1 7.271+1   .28   2.61  103.61 3.568+1  .0 0.000+0
68  201            .1000 2.024+1 7.616+1   .27   2.71  103.61 3.625+1  .0 0.000+0
69  202            .2000 2.048+1 7.968+1   .26   2.80  103.60 3.683+1  .0 0.000+0
70  203            .3000 2.072+1 8.326+1   .25   2.90  103.60 3.741+1  .0 0.000+0
71  204            .4000 2.097+1 8.692+1   .24   3.00  103.60 3.799+1  .0 0.000+0
72  205            .5000 2.123+1 9.064+1   .23   3.10  103.60 3.857+1  .0 0.000+0
73  206            .6000 2.149+1 9.443+1   .23   3.19  103.59 3.916+1  .0 0.000+0
74  207            .7000 2.175+1 9.828+1   .22   3.29  103.59 3.974+1  .0 0.000+0
75  208            .8000 2.201+1 1.022+2   .22   3.39  103.59 4.033+1  .0 0.000+0
76  209            .9000 2.228+1 1.062+2   .21   3.49  103.59 4.092+1  .0 0.000+0
77  210 DNSTREAM  1.0000 2.256+1 1.102+2   .20   3.58  103.58 4.151+1  .0 0.000+0
78
79       BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT
80
81 BRANCH NUMBER =     3
82
83 NODE   NODEID    STAT    FLOW    AREA    VEL  DEPTH    ELEV     TOP  FR LAT INF
84  300 UPSTREAM   .0000 3.511+1 2.205+2   .16   3.58  103.58 8.301+1  .0 0.000+0
85  301            .1000 3.564+1 2.015+2   .18   3.48  103.58 7.771+1  .0 0.000+0
86  302            .2000 3.614+1 1.835+2   .20   3.38  103.58 7.252+1  .0 0.000+0
87  303            .3000 3.659+1 1.664+2   .22   3.28  103.58 6.745+1  .0 0.000+0
88  304            .4000 3.702+1 1.501+2   .25   3.18  103.58 6.250+1  .0 0.000+0
89  305            .5000 3.741+1 1.347+2   .28   3.07  103.57 5.766+1  .0 0.000+0
```

```
 306             .6000 3.776+1 1.201+2   .31   2.97  103.57 5.294+1   .0 0.000+0
 307             .7000 3.808+1 1.064+2   .36   2.86  103.56 4.833+1   .0 0.000+0
 308             .8000 3.836+1 9.336+1   .41   2.75  103.55 4.382+1   .0 0.000+0
 309             .9000 3.860+1 8.111+1   .48   2.64  103.54 3.943+1   .0 0.000+0
 310 DNSTREAM   1.0000 3.881+1 6.958+1   .56   2.52  103.52 3.514+1   .0 0.000+0

      BRANCH PONDING VOLUME =    0.0000E+00 FT**3          .0 AC-FT

    NETWORK PONDING VOLUME =    0.0000E+00 FT**3          .0 AC-FT

EXTERIOR NODES

NODE    NODEID          QE1       YE1    ELEV     STORAGE     STORAGE
   1 UPSTREAM    1.000E+01      2.59  103.59
   2 UPSTREAM    2.000E+01      2.61  103.61
   3 DNSTREAM    1.256E+01      3.58  103.58
   4 DNSTREAM    2.256E+01      3.58  103.58
   5 UPSTREAM    3.511E+01      3.58  103.58
   6 DNSTREAM    3.881E+01      2.52  103.52

SIMULATION COMPLETED
```

SUMMARY OF MAXIMUM ELEVATIONS

Unsteady Flow --Example 2
THREE BRANCH SYSTEM
March 5, 1990

MAXIMUM ELEVATIONS ACHIEVED BY TIME 64800.

BRANCH NUMBER = 1

NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
100	UPSTREAM	.0000	5.95	106.95	1.06	2.2000E+02	9.0000E+00
101		.1000	6.04	106.94	1.01	2.1363E+02	8.9945E+00
102		.2000	6.13	106.93	.96	2.0721E+02	8.9889E+00
103		.3000	6.22	106.92	.91	2.0152E+02	8.9830E+00
104		.4000	6.31	106.91	.86	1.9626E+02	8.9768E+00
105		.5000	6.40	106.90	.82	1.9071E+02	8.9704E+00
106		.6000	6.49	106.89	.77	1.8493E+02	8.9636E+00
107		.7000	6.58	106.88	.73	1.7943E+02	8.9566E+00
108		.8000	6.67	106.87	.69	1.7720E+02	8.9491E+00
109		.9000	6.76	106.86	.65	1.7546E+02	8.9413E+00
110	DNSTREAM	1.0000	6.85	106.85	.63	1.7473E+02	8.9330E+00

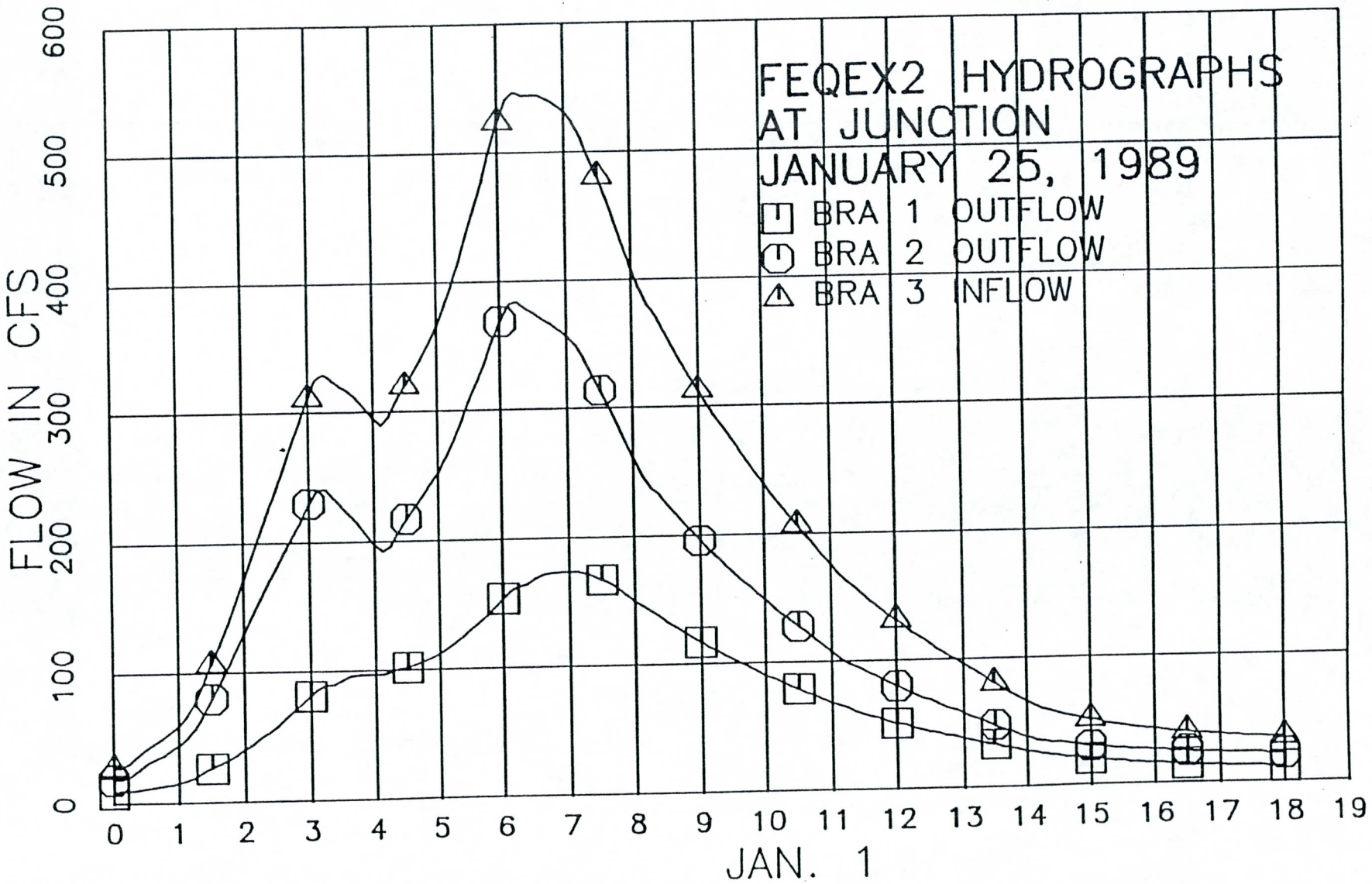
BRANCH NUMBER = 2

NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
200	UPSTREAM	.0000	6.26	107.26	1.88	4.4000E+02	1.8000E+01
201		.1000	6.31	107.21	1.84	4.3274E+02	1.8053E+01
202		.2000	6.36	107.16	1.80	4.2552E+02	1.8097E+01
203		.3000	6.42	107.12	1.76	4.2103E+02	1.8133E+01
204		.4000	6.47	107.07	1.72	4.1662E+02	1.8161E+01
205		.5000	6.53	107.03	1.67	4.1169E+02	1.8183E+01
206		.6000	6.59	106.99	1.63	4.0633E+02	1.8198E+01
207		.7000	6.65	106.95	1.59	4.0065E+02	1.8207E+01
208		.8000	6.72	106.92	1.55	3.9470E+02	1.8211E+01
209		.9000	6.78	106.88	1.51	3.8909E+02	1.8210E+01
210	DNSTREAM	1.0000	6.85	106.85	1.47	3.8424E+02	1.8204E+01

BRANCH NUMBER = 3

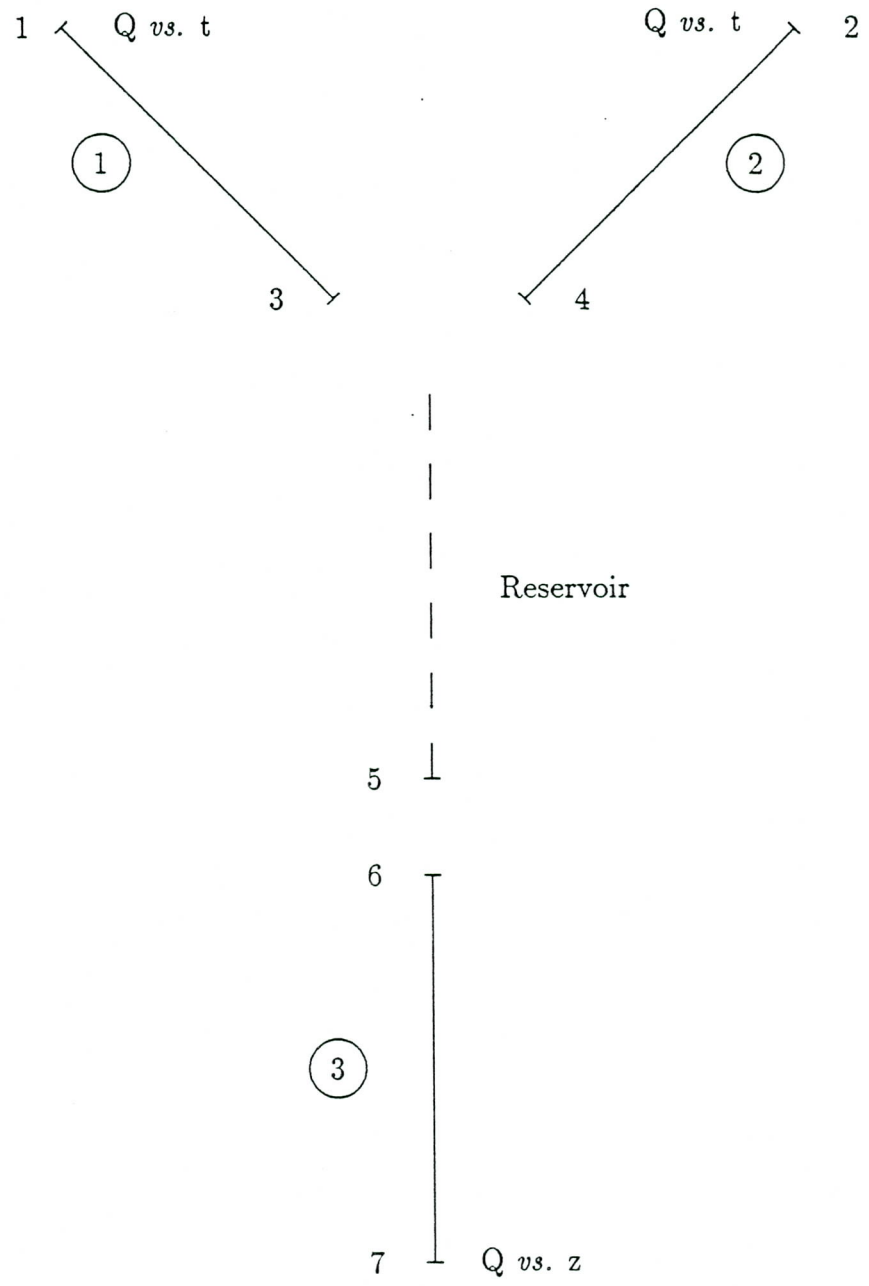
NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
300	UPSTREAM	.0000	6.85	106.85	1.04	5.4759E+02	2.7137E+01
301		.1000	6.73	106.83	1.10	5.3959E+02	2.7120E+01
302		.2000	6.60	106.80	1.17	5.3515E+02	2.7106E+01
303		.3000	6.47	106.77	1.26	5.3215E+02	2.7092E+01
304		.4000	6.33	106.73	1.36	5.2961E+02	2.7081E+01
305		.5000	6.18	106.68	1.49	5.2798E+02	2.7070E+01
306		.6000	6.01	106.61	1.65	5.2712E+02	2.7061E+01
307		.7000	5.82	106.52	1.86	5.2637E+02	2.7053E+01
308		.8000	5.60	106.40	2.13	5.2588E+02	2.7046E+01
309		.9000	5.33	106.23	2.49	5.2578E+02	2.7041E+01
310	DNSTREAM	1.0000	4.98	105.98	3.02	5.2567E+02	2.7036E+01

COMPUTATION TIME= 26.85 SECS OR .4475 MINS


FEQEX2 HYDROGRAPHS
AT JUNCTION
JANUARY 25, 1989
BRA 1 OUTFLOW
BRA 2 OUTFLOW
BRA 3 INFLOW
FLOW IN CFS
0
100
200
300
400
500
600
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
JAN. 1

FEQEX3-Three Branch System with Reservoir

SYSTEM SCHEMATIC SKETCH: FEQEX3



Listing of Input: FEQEX3

```
UNSTEADY FLOW-EXAMPLE 3
THREE BRANCH SYSTEM WITH LEVEL-POOL RESERVOIR AT JUNCTION
MARCH 5, 1990
NBRA=00003
NEX=00007
SOPER=NO
POINT=NO
DIFFUS=NO
WIND=NO
UNDERFLOW=NO
ZL=0.5
STIME=1990/01/01:0.00
ETIME=1990/01/01:1.0
GRAV=32.2
NODEID=YES
SSEPS=0.1
PAGE=   22
EPSSYS=0.002 .003
MKNT=   05  1
OUTPUT=    0
PRTINT=  144
GEQOPT=STDX
EPSB=0.000005
MAXIT=   30
SFAC=5280.
QSMALL=0.01
IFRZ=00001
   0300.   1400.   1000.    850.    700.    500.    350.    100.  0300.
 0300 01.0  0.7  2.8  3.2  3.0  2.0  0.5
MRE=     0.20       0.5
DWT=0.1
BWT=0.7
BWFDSN=   00
CHKGEO=NO
MINBND=YES
EXTTOL= 0.0
BRANCH DESCRIPTION TABLES
BNUM=    1
 NODE   NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
  100 UPSTREAM  5000       0.0     101.




      DNSTREAM  5000       1.0     100.0
   -1
BNUM=    2
 NODE   NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
  200 UPSTREAM  5000       0.0     101.
  201
  202
  203
  204
  205
  206
  207
  208
  209
  210 DNSTREAM  5000       1.0     100.0
   -1
BNUM=    3
 NODE   NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
  300 UPSTREAM  4990       0.0     100.
                   -
                   -
                   -
                   -
                   -
                   -
                   -
                   -
                   -
      DNSTREAM  5000       1.0     101.
   -1
BRANCH-EXTERIOR NODE TABLE
 BRA# UEXN DEXN
    1    1    3
    2    2    4
    3    6    7
EXTERIOR-MATRIX CONTROL INPUT
 CODE   A   B   C   D   E   F   G   H   I   J     FA     FB     FC     FD
    6   1   1   1 100
    1   1
    1   2
```

```
    6   1   2   1 102
    3   3   4
    7   5 250   2   3   4
    3   4   5
    4   1   5  -1   5 110                        106.0   10.0
    2   2   5   6
    1   3
    4   1   7  -1   7 110                        103.0   32.0
   -1
SPECIAL OUTPUT LOCATIONS
UNIT=    3EX3SPOUT
  BRA NODE
    0    3 EXNOD 3
    0    4 EXNOD 4
    0    5 EXNOD 5
   -1
INPUT FILE SPECIFICATION
 UNIT NAME
   -1
OUTPUT FILE SPECIFICATION
 UNIT  BRA NODE ITEM TYPE NAME
   -1
FUNCTION TABLES
TABLE#=  100
TYPE=   -7
REFL=0.0         FAC=1.0
YEAR MN DY       HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END
1990 01 01        0.0        9.
                  1.0       32.
                  2.0      100.
                  3.0      151.
                  4.0       94.
                  5.0      145.
                  6.0      220.
                  7.0      178.
                  8.0      104.
                  9.0       77.
                 10.0       57.
                 11.0       38.
                 12.0       28
                 13.0       19.
                 14.0       10.
         02      24.0       10.
                 23.0
TABLE#=  102
TYPE=   -7
REFL=0.0         FAC=2.0
YEAR MN DY       HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END
1990 01 01        0.0        9.
                  1.0       32.
                  2.0      100.
                  3.0      151.
                  4.0       94.
                  5.0      145.
                  6.0      220.
                  7.0      178.
                  8.0      104.
                  9.0       77.
                 10.0       57.
                 11.0       38.
                 12.0       28
                 13.0       19.
                 14.0       10.
         02      24.0       10.
                 23.0
TABLE#=  110
TYPE=   -2
REFL=0.0
       HEAD WEIR COEF
        0.0       3.2
       50.0       3.2
       -1.0
TABLE#=  250
TYPE=   -3
REFL=0.00000000 FAC=43560.
 ELEVATION    STORAGE      AREA
      95.0        0.0      20.0
     100.0      112.5      25.0
     105.0      265.0      36.0
     115.0      695.0      50.0
      -1.0
TABLE#= 4990
TYPE=   -1
STATION= 2.41200E+00
ELEVATION= 0.00000E+00                    EXT=00.00       FAC=1.000
      DEPTH TOP WIDTH          AREA   SQRT(CONV)       BETA         YBARA
       .000    40.000  0.00000E+00  0.00000E+00     1.0000  0.00000E+00
       .080    40.960  3.23840E+00  5.96209E+00     1.0000  1.29024E-01
     1.875    62.500  9.60937E+01  8.72018E+01     1.0000  8.34961E+01
```

```
 1      3.750    85.000  2.34375E+02  1.65332E+02    1.0000  3.86719E+02
 2      5.625   107.500  4.14844E+02  2.45929E+02    1.0000  9.88770E+02
 3      7.500   130.000  6.37500E+02  3.30116E+02    1.0000  1.96875E+03
 4      9.375   152.500  9.02344E+02  4.18033E+02    1.0000  3.40576E+03
 5     11.250   175.000  1.20938E+03  5.09580E+02    1.0000  5.37891E+03
 6     13.125   197.500  1.55859E+03  6.04590E+02    1.0000  7.96728E+03
 7     15.000   220.000  1.95000E+03  7.02889E+02    1.0000  1.12500E+04
 8     16.667   240.000  2.33333E+03  7.92889E+02    1.0000  1.48148E+04
 9     18.333   260.000  2.75000E+03  8.85244E+02    1.0000  1.90463E+04
10     20.000   280.000  3.20000E+03  9.79852E+02    1.0000  2.40000E+04
11     21.667   300.000  3.68333E+03  1.07662E+03    1.0000  2.97315E+04
12     23.333   320.000  4.20000E+03  1.17547E+03    1.0000  3.62963E+04
13     25.000   340.000  4.75000E+03  1.27631E+03    1.0000  4.37500E+04
14     -1.000      .000  0.00000E+00  0.00000E+00     .0000  0.00000E+00
15 TABLE#= 5000
16 TYPE=   -1
17 STATION= 2.41200E+00
18 ELEVATION= 0.00000E+00                    EXT=00.00      FAC=1.000
19      DEPTH TOP WIDTH          AREA   SQRT(CONV)      BETA        YBARA
20       .000    20.000  0.00000E+00  0.00000E+00    1.0000  0.00000E+00
21       .080    20.480  1.61920E+00  4.21451E+00    1.0000  6.45120E-02
22       .938    25.625  2.13867E+01  3.34821E+01    1.0000  9.61304E+00
23      1.875    31.250  4.80469E+01  6.13671E+01    1.0000  4.17480E+01
24      2.812    36.875  7.99805E+01  8.86460E+01    1.0000  1.01349E+02
25      3.750    42.500  1.17188E+02  1.16093E+02    1.0000  1.93359E+02
26      4.688    48.125  1.59668E+02  1.43993E+02    1.0000  3.22723E+02
27      5.625    53.750  2.07422E+02  1.72467E+02    1.0000  4.94385E+02
28      6.563    59.375  2.60449E+02  2.01568E+02    1.0000  7.13287E+02
29      7.500    65.000  3.18750E+02  2.31316E+02    1.0000  9.84375E+02
30      8.437    70.625  3.82324E+02  2.61712E+02    1.0000  1.31259E+03
31      9.375    76.250  4.51172E+02  2.92750E+02    1.0000  1.70288E+03
32     10.312    81.875  5.25293E+02  3.24420E+02    1.0000  2.16019E+03
33     11.250    87.500  6.04687E+02  3.56707E+02    1.0000  2.68945E+03
34     12.187    93.125  6.89355E+02  3.89597E+02    1.0000  3.29562E+03
35     13.125    98.750  7.79297E+02  4.23074E+02    1.0000  3.98364E+03
36     14.062   104.375  8.74512E+02  4.57123E+02    1.0000  4.75845E+03
37     15.000   110.000  9.75000E+02  4.91730E+02    1.0000  5.62500E+03
38     15.909   115.455  1.07748E+03  5.25807E+02    1.0000  6.55757E+03
39     16.818   120.909  1.18492E+03  5.60383E+02    1.0000  7.58556E+03
40     17.727   126.364  1.29731E+03  5.95444E+02    1.0000  8.71347E+03
41     18.636   131.818  1.41467E+03  6.30980E+02    1.0000  9.94581E+03
42     19.545   137.273  1.53698E+03  6.66980E+02    1.0000  1.12871E+04
43     20.455   142.727  1.66426E+03  7.03433E+02    1.0000  1.27418E+04
44     21.364   148.182  1.79649E+03  7.40329E+02    1.0000  1.43145E+04
45     22.273   153.636  1.93368E+03  7.77659E+02    1.0000  1.60097E+04
46     23.182   159.091  2.07583E+03  8.15414E+02    1.0000  1.78318E+04
47     24.091   164.545  2.22293E+03  8.53584E+02    1.0000  1.97854E+04
48     25.000   170.000  2.37500E+03  8.92162E+02    1.0000  2.18750E+04
49     -1.000      .000  0.00000E+00  0.00000E+00     .0000  0.00000E+00
50 TABLE#=   -1
51 FREE NODE TABLE
52  NODE NODEID         DEPTH DISCHARGE ELEVATION SIGN
53     5 RESERV         106.9      28.0       0.0   +1
54 BACKWATER ANALYSIS
55 BRANCH NUMBER=   -1
56 DISCHARGE=  9.0
57 BRANCH NUMBER=   -2
58 DISCHARGE= 19.0
59 BRANCH NUMBER=   -3
60 DISCHARGE= 28.0
61    BRA CODE ELEVATION EXN#
62      3    3     103.1
63      0   -3     106.9    5
64      1    0              5
65      2    0              5
66     -1
```

Listing of Output: FEQEX3

```
1
2
3
4
5  ********************************************************************************
6  *                                                                              *
7  *                          FULL EQUATIONS FLOW ROUTING                         *
8  *                                                                              *
9  *                                                                              *
10 ********************************************************************************
11
12 VERSION: 6.0 15 MARCH  1990
13
14  WARNING: This program is large and complex.
15  User is totally responsible for any
16  consequences resulting from application
17  of this program.  Read disclaimer in the
18  source code.
19
20  This program is not to be sold in any form.
21
22
23 THE SIZE LIMITS SET FOR THIS PROGRAM ARE:
24 NUMBER OF BRANCHES:   85
25 NUMBER OF EXTERIOR NODES:  220
26 NUMBER OF NODES ON BRANCHES: 1170
27 NUMBER OF OPERATION BLOCKS:   10
28 FUNCTION TABLE NUMBER:10000
29 LENGTH OF THE FUNCTION TABLE:250000
30 NUMBER OF POINT FLOWS:   10
31 LENGTH OF EXTERIOR MATRIX CONTROL: 2000
32 NUMBER OF ROWS IN ARRAY OF PARTIAL DERIV.: 2340
33 LENGTH OF INTERIOR MATRIX POINTER VECTOR :  170
34 NUMBER OF ROWS IN EXTERIOR MATRIX :  440
35 NUMBER OF LAND USES FOR TRIB. AREA:   20
36 NUMBER OF POINT INFLOW FILES:   10
37 NUMBER OF POINT OUTFLOW FILES:    4
38 NUMBER OF SPECIAL OUTPUTS:   45
39 NUMBER OF CODE=6 EX NODES WITH FILES OR TABLES:   20
40 MAX. UNIT NUMBER FOR FILES:   50
41 TOTAL BANDWIDTH OF EXTERIOR MATRIX :   16
42 NUMBER OF SUBDIAGONALS IN EXTERIOR MATRIX :   10
43
44 UNSTEADY FLOW-EXAMPLE 3
45
46 THREE BRANCH SYSTEM WITH LEVEL-POOL RESERVOIR AT JUNCTION
47
48 MARCH 5, 1990
49
50 NUMBER OF BRANCHES =     3
51
52 NUMBER OF EXTERIOR NODES =     7
53
54 SPECIAL OPERATION BLOCK OPTION = NO
55
56 POINT FLOW OPTION = NO
57
58 DIFFUSE FLOW OPTION = NO   MINPRT=0 LAGTSF=0
59
60 WIND LOADING OPTION = NO
61
62 UNDERFLOW MESSAGES ARE : NO
63
64 ZERO INERTIA LIMIT =        .50 FEET
65
66 START TIME =  1990/ 1/ 1:  .000000000
67
68 END TIME =  1990/ 1/ 1: 1.000000000
69
70 GRAVITY =      32.20
71
72 NODE ID STRING PRESENT? YES
73
74 CONVERGENCE LIMIT(SURCHARGE STORAGE)  =  1.000E-01
75
76 PAGE=    22
77
78 CONVERGENCE LIMITS(SYSTEM SOLUTION):
79           PRIMARY =  2.000E-03
80           SECONDARY = 4.000E-03
81           ABSOLUTE =   .003
82
83 MAXIMUM NO. OF ITERATIONS IN SYSTEM SOLUTION  =     5 MAX. NUMGT=    1
84
85 PRINT OUT OPTION IS OUTPUT =     0
86
87 PRINT OUT WILL BE GIVEN EVERY   144 TIME STEPS
88
89 STANDARD GOVERNING EQUATIONS SELECTED. WX VARIABLE
```

CONVERGENCE CRITERION FOR BACKWATER = 5.000E-06

MAX.NO. ITERATIONS FOR BACKWATER ANALYSIS = 30

STATIONING FACTOR = 5.28000E+03

Q SMALL FOR RELATIVE ERROR = .01

IFRZ = 1
300.00 1.00 .70 2.80 3.20 3.00 2.00 .50

MRE = .20 FAC = .50 HSLOT= .00 WSLOT= .00 NSLOT= .000
WT INCREMENT/DECREMENT = .100
BASE VALUE FOR WT = .70
BWFDSN = 0 NAME=
GEOMETRY WILL NOT BE CHECKED
REDUCTION OF BAND WIDTH WILL BE ATTEMPTED.
EXTRAPOLATION TOLERANCE= .000

BRANCH DESCRIPTION TABLES

BRANCH NUMBER= 1 INERTIA= 1.0 CFRATE= .0 WINDFAC= 1.00

NODE	NODEID	XNUM	STATION	ELEVATION	KA	KD	HTAB	AZM			
100	UPSTREAM	5000	.0000	101.000	.00	.00	0	0.	.0	.0	.00
101		5000	.1000	100.900	.00	.00	0	0.	.0	.0	.00
102		5000	.2000	100.800	.00	.00	0	0.	.0	.0	.00
103		5000	.3000	100.700	.00	.00	0	0.	.0	.0	.00
104		5000	.4000	100.600	.00	.00	0	0.	.0	.0	.00
105		5000	.5000	100.500	.00	.00	0	0.	.0	.0	.00
106		5000	.6000	100.400	.00	.00	0	0.	.0	.0	.00
107		5000	.7000	100.300	.00	.00	0	0.	.0	.0	.00
108		5000	.8000	100.200	.00	.00	0	0.	.0	.0	.00
109		5000	.9000	100.100	.00	.00	0	0.	.0	.0	.00
110	DNSTREAM	5000	1.0000	100.000	.00	.00	0	0.	.0	.0	.00

BRANCH NUMBER= 2 INERTIA= 1.0 CFRATE= .0 WINDFAC= 1.00

NODE	NODEID	XNUM	STATION	ELEVATION	KA	KD	HTAB	AZM			
200	UPSTREAM	5000	.0000	101.000	.00	.00	0	0.	.0	.0	.00
201		5000	.1000	100.900	.00	.00	0	0.	.0	.0	.00
202		5000	.2000	100.800	.00	.00	0	0.	.0	.0	.00
203		5000	.3000	100.700	.00	.00	0	0.	.0	.0	.00
204		5000	.4000	100.600	.00	.00	0	0.	.0	.0	.00
205		5000	.5000	100.500	.00	.00	0	0.	.0	.0	.00
206		5000	.6000	100.400	.00	.00	0	0.	.0	.0	.00
207		5000	.7000	100.300	.00	.00	0	0.	.0	.0	.00
208		5000	.8000	100.200	.00	.00	0	0.	.0	.0	.00
209		5000	.9000	100.100	.00	.00	0	0.	.0	.0	.00
210	DNSTREAM	5000	1.0000	100.000	.00	.00	0	0.	.0	.0	.00

BRANCH NUMBER= 3 INERTIA= 1.0 CFRATE= .0 WINDFAC= 1.00

NODE	NODEID	XNUM	STATION	ELEVATION	KA	KD	HTAB	AZM			
300	UPSTREAM	4990	.0000	100.000	.00	.00	0	0.	.0	.0	.00
301		-	.1000	100.100	.00	.00	0	0.	.0	.0	.00
302		-	.2000	100.200	.00	.00	0	0.	.0	.0	.00
303		-	.3000	100.300	.00	.00	0	0.	.0	.0	.00
304		-	.4000	100.400	.00	.00	0	0.	.0	.0	.00
305		-	.5000	100.500	.00	.00	0	0.	.0	.0	.00
306		-	.6000	100.600	.00	.00	0	0.	.0	.0	.00
307		-	.7000	100.700	.00	.00	0	0.	.0	.0	.00
308		-	.8000	100.800	.00	.00	0	0.	.0	.0	.00
309		-	.9000	100.900	.00	.00	0	0.	.0	.0	.00
310	DNSTREAM	5000	1.0000	101.000	.00	.00	0	0.	.0	.0	.00

BRANCH-EXTERIOR NODE TABLE

BRA#	UEXN	DEXN
1	1	3
2	2	4
3	6	7

EXTERIOR-MATRIX CONTROL INPUT

CODE	A	B	C	D	E	F	G	H	I	J	FA	FB	FC	FD

CODE= 6 EQN#= 1. ENTRY#= 1
TYPE= 1 UPN= 1 DIR= 1 TAB#= 100 FLOW= .00

CODE= 1 EQN#S= 2 AND 3. ENTRY#= 2
BRANCH= 1

CODE= 1 EQN#S= 4 AND 5. ENTRY#= 3
BRANCH= 2

CODE= 6 EQN#= 6. ENTRY#= 4
TYPE= 1 UPN= 2 DIR= 1 TAB#= 102 FLOW= .00

```
 1
 2 CODE=    3 EQN#=    7.  ENTRY#=    5
 3    ELEVATION EQUALITY BETWEEN NODE    3 AND    4
 4
 5 CODE=    7 EQN#=    8.  ENTRY#=    6
 6    RESERVOIR NODE=    5 STORAGE TABLE#=  250 NUMBER OF INFLOW NODES=    2
 7    INFLOW NODES=    3    4
 8
 9 CODE=    3 EQN#=    9.  ENTRY#=    7
10    ELEVATION EQUALITY BETWEEN NODE    4 AND    5
11
12 CODE=    4 EQN#=   10.  ENTRY#=    8
13    TYPE=    1 UPN=    5 DIR=   -1 QNODE=    5
14    WEIR COEF. TAB#=  110 WEIR ELEV.=    106.00 WEIR LENGTH=      10.0
15
16 CODE=    2 EQN#=   11.  ENTRY#=    9
17    THE    2 NODES FOR SUM OF Q ARE    5    6
18
19 CODE=    1 EQN#S=   12 AND   13.  ENTRY#=   10
20    BRANCH=    3
21
22 CODE=    4 EQN#=   14.  ENTRY#=   11
23    TYPE=    1 UPN=    7 DIR=   -1 QNODE=    7
24    WEIR COEF. TAB#=  110 WEIR ELEV.=    103.00 WEIR LENGTH=      32.0
```

BANDWIDTH REDUCTION LOG

ITER	MAXSUB	MAXSUP	BANDW	DECSUB	DECSUP	SWPFLG
0	2	4	7			
1	2	4	7	0	0	0
2	2	4	7	0	0	0
3	2	4	7	0	0	0
4	2	4	7	0	0	0
5	2	4	7	0	0	0
6	2	4	7	0	0	0
7	2	4	7	0	0	0
8	2	4	7	0	0	0

```
ARRANGEMENT OF NON-ZERO ELEMENTS IN EXTERIOR MATRIX

  EQN ENTRY   C98765432198765432198765432101234567891234567891234567891234567890
    1     1                                      .X..........
    2     2                                     XX..XX........
    3                                          XX..XX........
    4     3                                   ..XX..XX......
    5                                       ..XX..XX......
    6     4                                ...X..........
    7     5                             ....X.X.......
    8     6                          .....X.XXX....
    9     7                       .......X.X.....
   10     8                    .........XX....
   11     9                 ..........X.X..
   12    10              ...........XXXX
   13                 ...........XXXX
   14    11        ............XX


TOTAL BAND WIDTH M3 =    7

NO. OF SUBDIAGONALS M1 =    2 NO. OF SUPER DIAGONALS M2 =   4

SPECIAL OUTPUT LOCATIONS
UNIT=    3 NAME=EX3SPOUT
  BRA NODE
    0    3 EXNOD 3
    0    4 EXNOD 4
    0    5 EXNOD 5

INPUT FILE SPECIFICATION

 UNIT NAME

OUTPUT FILE SPECIFICATION

 UNIT  BRA NODE ITEM TYPE NAME

FUNCTION TABLES

TABLE#=  100
TYPE=   -7
REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.

YEAR MN DY      HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END

TABLE#=  102
TYPE=   -7
REFERENCE LEVEL=        0. FAC=     2.000 SHIFT=        0.

YEAR MN DY      HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END

TABLE#=  110
TYPE=   -2
REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.

      HEAD WEIR COEF

TABLE#=  250
TYPE=   -3
REFERENCE LEVEL=        0. FAC= 43560.000 SHIFT=        0.

 ELEVATION   STORAGE      AREA

TABLE#= 4990
TYPE=   -1

TABLE#= 5000
TYPE=   -1


FREE NODE TABLE


 NODE NODEID        DEPTH DISCHARGE ELEVATION SIGN
    5 RESERV       106.90     28.00       .00    1

TRUE SIZES:
NUMBER OF BRANCHES:    3
NUMBER OF EXTERIOR NODES:    7
NUMBER OF NODES ON BRANCHES:   33
NUMBER OF OPERATION BLOCKS:    0
FUNCTION TABLE NUMBER:    6
LENGTH OF THE FUNCTION TABLE:    383
NUMBER OF POINT FLOWS:    0
LENGTH OF EXTERIOR MATRIX CONTROL:   73
NUMBER OF ROWS IN ARRAY OF PARTIAL DERIV.:   60
LENGTH OF INTERIOR MATRIX POINTER VECTOR :    6
NUMBER OF ROWS IN EXTERIOR MATRIX:   14
```

```
 1 NUMBER OF LAND USES FOR TRIB. AREA:     0
 2 NUMBER OF POINT INFLOW FILES:     0
 3 NUMBER OF POINT OUTFLOW FILES:     0
 4 NUMBER OF SPECIAL OUTPUTS:     3
 5 NUMBER OF CODE=6 EX NODES WITH FILES OR TABLES:     2
 6
 7 *WRN:12* BOTTOM ELEVATION DIFFERENCE BETWEEN
 8     NODE     4 ON BRA    2 AND NODE     5 RESERVOIR  IS 100.00
 9
10      9 X-SECTIONS INTERPOLATED BETWEEN  STATIONS       .000 AND      1.000
11       MAX. DEPTH =      25.000 NUMBER OF DEPTH VALUES =     34
12   THERE ARE NOW     15 FUNCTION TABLES AND     2273 LOCATIONS USED IN FTAB.
13
14 SRLIM= 2.96000E-06
```

```
 1 BACKWATER ANALYSIS
 2
 3 BRANCH NUMBER =      1
 4 DISCHARGE =         9.0
 5
 6 BRANCH NUMBER =      2
 7 DISCHARGE =        19.0
 8
 9 BRANCH NUMBER =      3
10 DISCHARGE =        28.0
11
12   BRA CODE ELEVATION EXN#
13     3    3    103.10    0
14
15 BACKWATER ANALYSIS BRANCH#     3
16  STATION IT      YL       QL       AL       TL      DZ      DX      ELEV       RES   FR
17   1.0000  0  2.421     28.0     66.0     34.5    .00      .0   103.421  0.0E+00   .0
18    .9000  3  2.532     28.0     76.9     38.7    .10   528.0   103.432 -7.2E-03   .0
19    .8000  3  2.640     28.0     88.4     43.0    .10   528.0   103.440 -6.5E-03   .0
20    .7000  3  2.745     28.0    100.8     47.4    .10   528.0   103.445 -6.0E-03   .0
21    .6000  3  2.849     28.0    113.9     51.9    .10   528.0   103.449 -6.2E-03   .0
22    .5000  3  2.952     28.0    127.8     56.6    .10   528.0   103.452 -5.9E-03   .0
23    .4000  3  3.055     28.0    142.6     61.3    .10   528.0   103.455 -6.3E-03   .0
24    .3000  3  3.157     28.0    158.1     66.2    .10   528.0   103.457 -5.7E-03   .0
25    .2000  3  3.258     28.0    174.6     71.2    .10   528.0   103.458 -5.3E-03   .0
26    .1000  3  3.359     28.0    192.0     76.3    .10   528.0   103.459 -5.2E-03   .0
27    .0000  3  3.460     28.0    210.2     81.5    .10   528.0   103.460 -6.6E-03   .0
28     0   -3    106.90     5
29
30 BACKWATER ANALYSIS BRANCH#     0
31  STATION IT      YL       QL       AL       TL      DZ      DX      ELEV       RES   FR
32     1    0        .00     5
33
34 BACKWATER ANALYSIS BRANCH#     1
35  STATION IT      YL       QL       AL       TL      DZ      DX      ELEV       RES   FR
36   1.0000  0  6.915      9.0    281.7     61.5    .00      .0   106.915  0.0E+00   .0
37    .9000  3  6.815      9.0    275.6     60.9   -.10   528.0   106.915 -1.6E-03   .0
38    .8000  3  6.715      9.0    269.6     60.3   -.10   528.0   106.915 -2.7E-03   .0
39    .7000  3  6.615      9.0    263.6     59.7   -.10   528.0   106.915 -2.9E-03   .0
40    .6000  3  6.515      9.0    257.6     59.1   -.10   528.0   106.915 -2.1E-03   .0
41    .5000  3  6.415      9.0    251.8     58.5   -.10   528.0   106.915 -5.7E-04   .0
42    .4000  3  6.315      9.0    245.9     57.9   -.10   528.0   106.915 -1.9E-03   .0
43    .3000  3  6.215      9.0    240.2     57.3   -.10   528.0   106.915 -2.1E-03   .0
44    .2000  3  6.115      9.0    234.5     56.7   -.10   528.0   106.915 -1.1E-03   .0
45    .1000  3  6.015      9.0    228.8     56.1   -.10   528.0   106.915 -2.3E-03   .0
46    .0000  3  5.915      9.0    223.3     55.5   -.10   528.0   106.915 -2.2E-03   .0
47     2    0        .00     5
48
49 BACKWATER ANALYSIS BRANCH#     2
50  STATION IT      YL       QL       AL       TL      DZ      DX      ELEV       RES   FR
51   1.0000  0  6.915     19.0    281.7     61.5    .00      .0   106.915  0.0E+00   .0
52    .9000  3  6.815     19.0    275.6     60.9   -.10   528.0   106.915 -2.5E-03   .0
53    .8000  3  6.715     19.0    269.6     60.3   -.10   528.0   106.915 -1.8E-03   .0
54    .7000  3  6.615     19.0    263.6     59.7   -.10   528.0   106.915 -1.2E-03   .0
55    .6000  3  6.515     19.0    257.6     59.1   -.10   528.0   106.915 -7.3E-04   .0
56    .5000  3  6.415     19.0    251.8     58.5   -.10   528.0   106.915 -4.5E-04   .0
57    .4000  3  6.316     19.0    246.0     57.9   -.10   528.0   106.916  3.0E-04   .0
58    .3000  3  6.216     19.0    240.2     57.3   -.10   528.0   106.916 -1.5E-03   .0
59    .2000  3  6.116     19.0    234.5     56.7   -.10   528.0   106.916 -1.4E-03   .0
60    .1000  3  6.016     19.0    228.9     56.1   -.10   528.0   106.916 -2.7E-03   .0
61    .0000  3  5.916     19.0    223.3     55.5   -.10   528.0   106.916 -1.2E-03   .0
62
63 IFRZ =      1
64
65 SIMULATION ENDING AT  1990/ 1/ 1/   .000 WITH TIME STEP OF      300.0 SEC
66 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
67    1 5.3E-02    0    2 1.0E+00   -6 1.0E+00     12
68    2 2.8E-04    0    3 2.3E-06   -8 2.3E-11      0
69 ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 6.96E-03 AT ND=  2: 200 DT/ITER=       .0
70
71 IFRZ =      0
72       TIME STEP RESET TO    300.00 SEC WT =  .700
73
74 SIMULATION ENDING AT  1990/ 1/ 1/   .083 WITH TIME STEP OF      300.0 SEC
75 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
76    1 2.5E-01    0    2 4.3E+00   -6 2.2E+01     22
77    2 3.2E-05    0    4 4.1E-06   21 4.3E-11      0
78 ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 2.81E-02 AT ND=  2: 200 DT/ITER=    150.0
79       TIME STEP RESET TO    300.00 SEC WT =  .700
80
81     ****************************************
82     Lines deleted to save space
83     ****************************************
84
85 SIMULATION ENDING AT  1990/ 1/ 1/ 11.833 WITH TIME STEP OF      300.0 SEC
86 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
87    1 1.4E-02    0    2 8.3E-01   -6 8.7E-01     34
88    2 1.1E-04    0    3 5.5E-06   21 4.7E-10      0
89 ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 5.81E-02 AT ND=  1: 100 DT/ITER=    150.0
```

```
     TIME STEP RESET TO    300.00 SEC WT =  .700

SIMULATION ENDING AT  1990/ 1/ 1/ 11.917 WITH TIME STEP OF      300.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 1.4E-02    0    2 8.3E-01   -6 8.7E-01    34
   2 2.0E-05    0    3 5.5E-06   39 5.2E-10     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 6.00E-02 AT ND=  1: 100 DT/ITER=   150.0

RESULTS AT TIME     42900. JTIME =     47892.4965277773

BRANCH NUMBER =     1

NODE   NODEID     STAT    FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
 100 UPSTREAM   .0000 2.883+1 3.910+2   .07   8.56  109.56 7.136+1  .0 0.000+0
 101            .1000 3.068+1 3.982+2   .08   8.66  109.56 7.196+1  .0 0.000+0
 102            .2000 3.254+1 4.054+2   .08   8.76  109.56 7.256+1  .0 0.000+0
 103            .3000 3.441+1 4.127+2   .08   8.86  109.56 7.316+1  .0 0.000+0
 104            .4000 3.630+1 4.201+2   .09   8.96  109.56 7.376+1  .0 0.000+0
 105            .5000 3.821+1 4.275+2   .09   9.06  109.56 7.436+1  .0 0.000+0
 106            .6000 4.013+1 4.349+2   .09   9.16  109.56 7.496+1  .0 0.000+0
 107            .7000 4.207+1 4.424+2   .10   9.26  109.56 7.556+1  .0 0.000+0
 108            .8000 4.402+1 4.500+2   .10   9.36  109.56 7.616+1  .0 0.000+0
 109            .9000 4.599+1 4.577+2   .10   9.46  109.56 7.676+1  .0 0.000+0
 110 DNSTREAM  1.0000 4.798+1 4.654+2   .10   9.56  109.56 7.736+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

BRANCH NUMBER =     2

NODE   NODEID     STAT    FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
 200 UPSTREAM   .0000 5.767+1 3.911+2   .15   8.56  109.56 7.137+1  .0 0.000+0
 201            .1000 5.953+1 3.983+2   .15   8.66  109.56 7.197+1  .0 0.000+0
 202            .2000 6.141+1 4.055+2   .15   8.76  109.56 7.257+1  .0 0.000+0
 203            .3000 6.330+1 4.128+2   .15   8.86  109.56 7.317+1  .0 0.000+0
 204            .4000 6.521+1 4.201+2   .16   8.96  109.56 7.377+1  .0 0.000+0
 205            .5000 6.713+1 4.275+2   .16   9.06  109.56 7.437+1  .0 0.000+0
 206            .6000 6.906+1 4.350+2   .16   9.16  109.56 7.496+1  .0 0.000+0
 207            .7000 7.100+1 4.425+2   .16   9.26  109.56 7.556+1  .0 0.000+0
 208            .8000 7.296+1 4.500+2   .16   9.36  109.56 7.616+1  .0 0.000+0
 209            .9000 7.493+1 4.577+2   .16   9.46  109.56 7.676+1  .0 0.000+0
 210 DNSTREAM  1.0000 7.692+1 4.654+2   .17   9.56  109.56 7.736+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

BRANCH NUMBER =     3

NODE   NODEID     STAT    FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
 300 UPSTREAM   .0000 2.149+2 3.680+2   .58   5.18  105.18 1.021+2  .0 0.000+0
 301            .1000 2.163+2 3.389+2   .64   5.07  105.17 9.577+1  .0 0.000+0
 302            .2000 2.176+2 3.108+2   .70   4.95  105.15 8.949+1  .0 0.000+0
 303            .3000 2.189+2 2.837+2   .77   4.84  105.14 8.332+1  .0 0.000+0
 304            .4000 2.200+2 2.574+2   .85   4.71  105.11 7.724+1  .0 0.000+0
 305            .5000 2.210+2 2.321+2   .95   4.58  105.08 7.125+1  .0 0.000+0
 306            .6000 2.219+2 2.075+2  1.07   4.45  105.05 6.535+1  .0 0.000+0
 307            .7000 2.227+2 1.837+2  1.21   4.30  105.00 5.951+1  .0 0.000+0
 308            .8000 2.234+2 1.604+2  1.39   4.13  104.93 5.372+1  .0 0.000+0
 309            .9000 2.240+2 1.375+2  1.63   3.93  104.83 4.794+1  .0 0.000+0
 310 DNSTREAM  1.0000 2.245+2 1.145+2  1.96   3.69  104.69 4.213+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

    NETWORK PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

EXTERIOR NODES

NODE   NODEID        QE1      YE1    ELEV    STORAGE    STORAGE
   1 UPSTREAM  2.883E+01     8.56  109.56
   2 UPSTREAM  5.767E+01     8.56  109.56
   3 DNSTREAM  4.798E+01     9.56  109.56
   4 DNSTREAM  7.692E+01     9.56  109.56
   5 RESERV    2.149E+02   109.56  109.56  1.933E+07  4.437E+02
   6 UPSTREAM  2.149E+02     5.18  105.18
   7 DNSTREAM  2.245E+02     3.69  104.69
BC:S1=1.801E+07 S2=2.509E+07 I=1.309E+07 Q=6.020E+06 D= 4.418E+01 R= 1.42E-06
     TIME STEP RESET TO    300.00 SEC WT =  .700

    ****************************************
    Lines deleted to save space
    ****************************************

SIMULATION ENDING AT  1990/ 1/ 1/ 24.000 WITH TIME STEP OF      300.0 SEC
ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
   1 2.6E-03    0    7 6.3E-03   17 1.0E-03    12
   2 6.6E-05    0    3 2.0E-06   37 3.7E-11     0
ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 6.60E-02 AT ND=  1: 100 DT/ITER=   150.0
     TIME STEP RESET TO    300.00 SEC WT =  .700

TIME STEP RESET IN MANTIM TO       .00 SECS TO MATCH EVENT END
```

```
 SIMULATION COMPLETE AT     86400. SECS.


 SIMULATION ENDING AT  1990/  1/  1/ 24.000

 RESULTS AT TIME     86400. JTIME =     47892.9999999991

 BRANCH NUMBER =     1

 NODE   NODEID     STAT     FLOW     AREA    VEL   DEPTH     ELEV      TOP   FR LAT INF
  100 UPSTREAM   .0000 1.000+1 2.785+2   .04    6.86   107.86 6.117+1   .0 0.000+0
  101            .1000 1.069+1 2.846+2   .04    6.96   107.86 6.177+1   .0 0.000+0
  102            .2000 1.138+1 2.908+2   .04    7.06   107.86 6.237+1   .0 0.000+0
  103            .3000 1.208+1 2.971+2   .04    7.16   107.86 6.297+1   .0 0.000+0
  104            .4000 1.279+1 3.034+2   .04    7.26   107.86 6.357+1   .0 0.000+0
  105            .5000 1.351+1 3.098+2   .04    7.36   107.86 6.417+1   .0 0.000+0
  106            .6000 1.423+1 3.163+2   .04    7.46   107.86 6.477+1   .0 0.000+0
  107            .7000 1.496+1 3.228+2   .05    7.56   107.86 6.537+1   .0 0.000+0
  108            .8000 1.569+1 3.293+2   .05    7.66   107.86 6.597+1   .0 0.000+0
  109            .9000 1.643+1 3.360+2   .05    7.76   107.86 6.657+1   .0 0.000+0
  110 DNSTREAM  1.0000 1.718+1 3.426+2   .05    7.86   107.86 6.717+1   .0 0.000+0

       BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

 BRANCH NUMBER =     2

 NODE   NODEID     STAT     FLOW     AREA    VEL   DEPTH     ELEV      TOP   FR LAT INF
  200 UPSTREAM   .0000 2.000+1 2.785+2   .07    6.86   107.86 6.117+1   .0 0.000+0
  201            .1000 2.069+1 2.847+2   .07    6.96   107.86 6.177+1   .0 0.000+0
  202            .2000 2.138+1 2.909+2   .07    7.06   107.86 6.237+1   .0 0.000+0
  203            .3000 2.208+1 2.971+2   .07    7.16   107.86 6.297+1   .0 0.000+0
  204            .4000 2.279+1 3.035+2   .08    7.26   107.86 6.357+1   .0 0.000+0
  205            .5000 2.350+1 3.098+2   .08    7.36   107.86 6.417+1   .0 0.000+0
  206            .6000 2.423+1 3.163+2   .08    7.46   107.86 6.477+1   .0 0.000+0
  207            .7000 2.495+1 3.228+2   .08    7.56   107.86 6.537+1   .0 0.000+0
  208            .8000 2.569+1 3.293+2   .08    7.66   107.86 6.597+1   .0 0.000+0
  209            .9000 2.643+1 3.360+2   .08    7.76   107.86 6.657+1   .0 0.000+0
  210 DNSTREAM  1.0000 2.718+1 3.426+2   .08    7.86   107.86 6.717+1   .0 0.000+0

       BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

 BRANCH NUMBER =     3

 NODE   NODEID     STAT     FLOW     AREA    VEL   DEPTH     ELEV      TOP   FR LAT INF
  300 UPSTREAM   .0000 8.129+1 2.623+2   .31    4.07   104.07 8.886+1   .0 0.000+0
  301            .1000 8.194+1 2.405+2   .34    3.97   104.07 8.323+1   .0 0.000+0
  302            .2000 8.254+1 2.196+2   .38    3.86   104.06 7.771+1   .0 0.000+0
  303            .3000 8.310+1 1.996+2   .42    3.76   104.06 7.231+1   .0 0.000+0
  304            .4000 8.361+1 1.806+2   .46    3.65   104.05 6.701+1   .0 0.000+0
  305            .5000 8.408+1 1.624+2   .52    3.54   104.04 6.183+1   .0 0.000+0
  306            .6000 8.450+1 1.450+2   .58    3.42   104.02 5.674+1   .0 0.000+0
  307            .7000 8.488+1 1.284+2   .66    3.30   104.00 5.176+1   .0 0.000+0
  308            .8000 8.521+1 1.125+2   .76    3.18   103.98 4.687+1   .0 0.000+0
  309            .9000 8.549+1 9.737+1   .88    3.04   103.94 4.206+1   .0 0.000+0
  310 DNSTREAM    0000 8.572+1 8.279+1  1.04    2.89   103.89 3.733+1   .0 0.000+0

       BRANCH     ING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

     NETWORK PO ING VOLUME =   0.0000E+00 FT**3         .0 AC-FT

 EXTERIOR NODES

 NODE   NODEID         QE1       YE1     ELEV     STORAGE     STORAGE
    1 UPSTREAM  1.000E+01      6.86   107.86
    2 UPSTREAM  2.000E+01      6.86   107.86
    3 DNSTREAM  1.718E+01      7.86   107.86
    4 DNSTREAM  2.718E+01      7.86   107.86
    5 RESERV    8.129E+01    107.86   107.86  1.628E+07  3.738E+02
    6 UPSTREAM  8.129E+01      4.07   104.07
    7 DNSTREAM  8.572E+01      2.89   103.89

 SIMULATION COMPLETED
```

SUMMARY OF MAXIMUM ELEVATIONS

UNSTEADY FLOW-EXAMPLE 3
THREE BRANCH SYSTEM WITH LEVEL-POOL RESERVOIR AT JUNCTION
MARCH 5, 1990

MAXIMUM ELEVATIONS ACHIEVED BY TIME 86400.

BRANCH NUMBER = 1

NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
100	UPSTREAM	.0000	8.90	109.90	.61	2.2000E+02	9.0000E+00
101		.1000	9.00	109.90	.58	2.1303E+02	9.0011E+00
102		.2000	9.10	109.90	.56	2.0602E+02	9.0023E+00
103		.3000	9.20	109.90	.53	1.9908E+02	9.0036E+00
104		.4000	9.30	109.90	.50	1.9267E+02	9.0050E+00
105		.5000	9.40	109.90	.47	1.8604E+02	9.0065E+00
106		.6000	9.50	109.90	.45	1.7921E+02	9.0084E+00
107		.7000	9.60	109.90	.42	1.7220E+02	9.0107E+00
108		.8000	9.70	109.90	.40	1.6503E+02	9.0133E+00
109		.9000	9.80	109.90	.37	1.5772E+02	9.0167E+00
110	DNSTREAM	1.0000	9.90	109.90	.35	1.5027E+02	9.0206E+00

BRANCH NUMBER = 2

NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
200	UPSTREAM	.0000	8.91	109.91	1.20	4.4000E+02	1.8000E+01
201		.1000	9.01	109.91	1.16	4.3259E+02	1.8190E+01
202		.2000	9.11	109.91	1.12	4.2519E+02	1.8341E+01
203		.3000	9.21	109.91	1.09	4.1894E+02	1.8460E+01
204		.4000	9.31	109.91	1.05	4.1319E+02	1.8555E+01
205		.5000	9.41	109.91	1.02	4.0704E+02	1.8628E+01
206		.6000	9.50	109.90	.99	4.0058E+02	1.8685E+01
207		.7000	9.60	109.90	.96	3.9384E+02	1.8727E+01
208		.8000	9.70	109.90	.93	3.8685E+02	1.8757E+01
209		.9000	9.80	109.90	.89	3.7965E+02	1.8776E+01
210	DNSTREAM	1.0000	9.90	109.90	.86	3.7223E+02	1.8785E+01

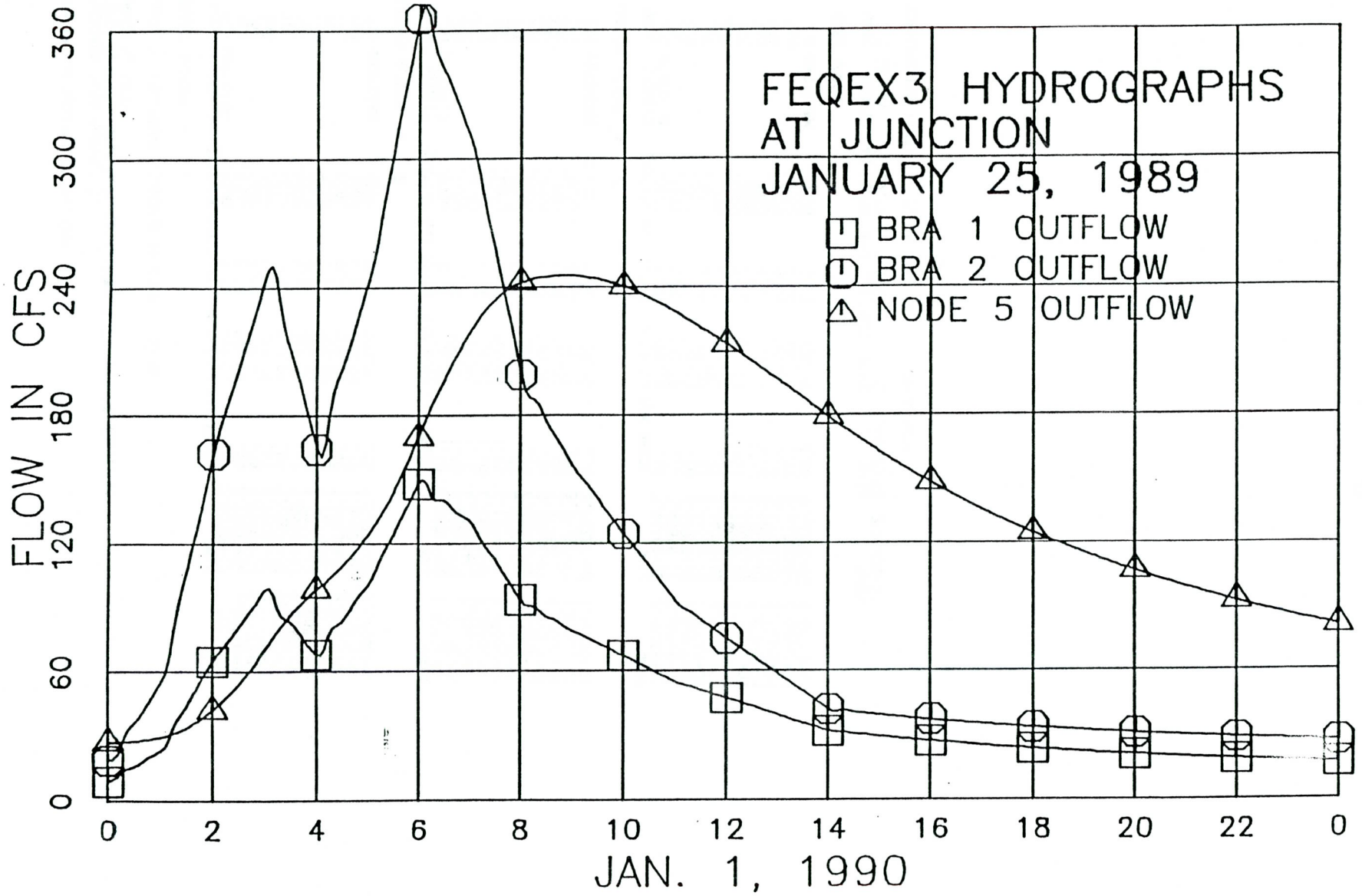
BRANCH NUMBER = 3

NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
300	UPSTREAM	.0000	5.32	105.32	.66	2.4640E+02	2.8002E+01
301		.1000	5.20	105.30	.70	2.4558E+02	2.8002E+01
302		.2000	5.09	105.29	.76	2.4498E+02	2.8003E+01
303		.3000	4.97	105.27	.83	2.4455E+02	2.8003E+01
304		.4000	4.84	105.24	.91	2.4425E+02	2.8003E+01
305		.5000	4.71	105.21	1.01	2.4404E+02	2.8004E+01
306		.6000	4.57	105.17	1.13	2.4391E+02	2.8004E+01
307		.7000	4.41	105.11	1.28	2.4383E+02	2.8005E+01
308		.8000	4.24	105.04	1.46	2.4377E+02	2.8006E+01
309		.9000	4.04	104.94	1.71	2.4375E+02	2.8008E+01
310	DNSTREAM	1.0000	3.78	104.78	2.06	2.4373E+02	2.8010E+01

FREE NODES

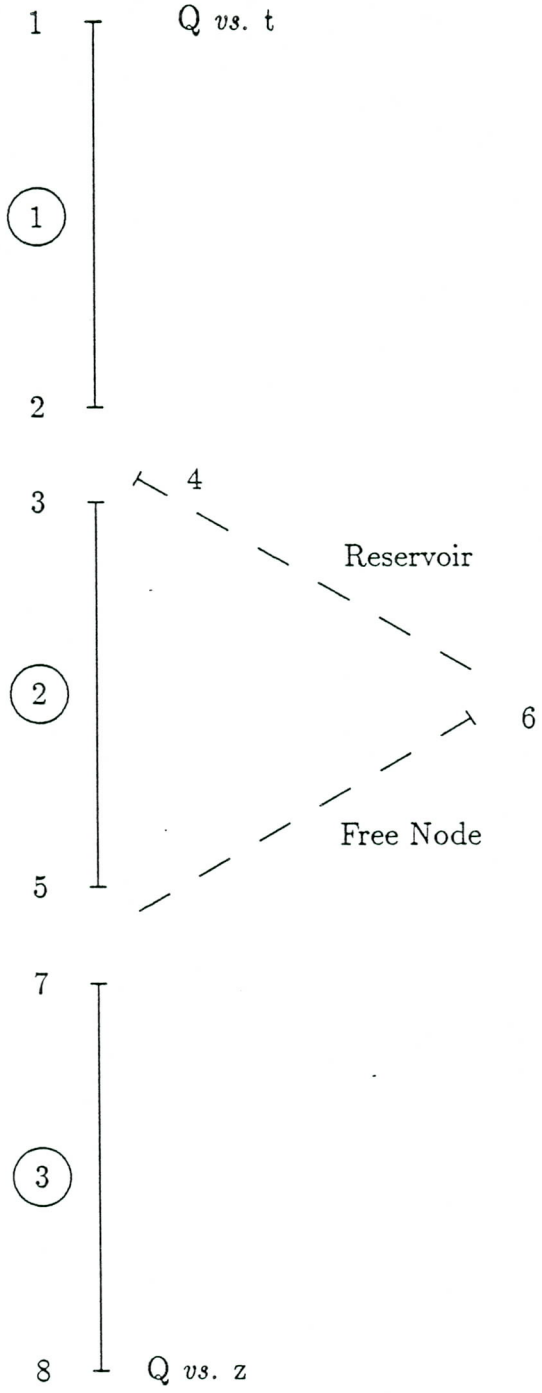
NODE	NODEID	MAX DEPTH	MAX ELEV	BOTM ELEV	QMAX	QMIN
5	RESERV	109.90	109.90	.00	2.4640E+02	2.8002E+01

COMPUTATION TIME= 53.10 SECS OR .8850 MINS


FEQEX3 HYDROGRAPHS
AT JUNCTION
JANUARY 25, 1989
BRA 1 OUTFLOW
BRA 2 OUTFLOW
NODE 5 OUTFLOW
FLOW IN CFS
0
60
120
180
240
300
360
0
2
4
6
8
10
12
14
16
18
20
22
0
JAN. 1, 1990

FEQEX4-Three Branch System with Offline Reservoir
Illustrating Dual Connection to Stream

SYSTEM SCHEMATIC SKETCH: FEQEX4



Listing of Input: FEQEX4

```
UNSTEADY FLOW-EXAMPLE 4
THREE BRANCH SYSTEM WITH OFFLINE RESERVOIR WITH DUAL CONNECTION TO STREAM
MARCH 5, 1990
NBRA=00003
NEX=00008
SOPER=NO
POINT=NO
DIFFUS=NO
WIND=NO
UNDERFLOW=NO
ZL=0.0
STIME=1990/01/01:0.00
ETIME=1990/01/01:1.00
GRAV=32.2
NODEID=YES
SSEPS=0.1
PAGE=   22
EPSSYS=0.010 0.01
MKNT=   05  1
OUTPUT=    0
PRTINT=  144
GEQOPT=STDX
EPSB=0.000005
MAXIT=   30
SFAC=5280.
QSMALL=20.
IFRZ=00001
    900.    900.    900.    850.    700.    500.    350.    100.   300.
  300 01.0  0.7  2.8  3.2  3.0  2.0  0.5
MRE=     0.20       0.5
DWT=0.1
BWT=0.51
BWFDSN=   00
CHKGEO=NO
MINBND=YES
EXTTOL= 0.0
BRANCH DESCRIPTION TABLES
BNUM=    1
 NODE    NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
  100 UPSTREAM  5000       0.0     101.
      DNSTREAM  5000       1.0     100.0
   -1
BNUM=    2
 NODE    NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
  200 UPSTREAM  5000       0.0     100.
      DNSTREAM  5000       1.0      95.0
   -1
BNUM=    3
 NODE    NODEID  XNUM   STATION ELEVATION   KA   KD HTAB  AZM
  300 UPSTREAM  5000       0.0      95.
      DNSTREAM  5000       1.0      95.
   -1
BRANCH-EXTERIOR NODE TABLE
 BRA# UEXN DEXN
    1    1    2
    2    3    5
    3    7    8
EXTERIOR-MATRIX CONTROL INPUT
 CODE   A   B   C   D   E   F   G   H   I   J     FA     FB     FC     FD     FE
    6   1   1   1 100
    1   1
   11   2   3
```

```
    2   3   2   3   4
    7   4 250   1   6
    5   2   4   2   4 400 500 400 500   0      103.0          30.0   95.5  102.9
    1   2
    3   5   6
    3   6   7
    2   3   5  -6   7
    5   2   4   6   6 400 500 400 500          106.0
    1   3
    4   1   8  -1   8 110                       97.0   32.0
   -1
SPECIAL OUTPUT LOCATIONS
UNIT=    3EX4SPOUT
  BRA NODE
    0    2 EXNOD 2
    0    4 EXNOD 4
    0    6 EXNOD 6
   -1
INPUT FILE SPECIFICATION
 UNIT NAME
   -1
OUTPUT FILE SPECIFICATION
 UNIT  BRA NODE ITEM TYPE NAME
   -1
FUNCTION TABLES
TABLE#=  100
TYPE=   -7
REFL=       0.0 FAC=6.0
YEAR MN DY      HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END
1990 01 01       0.0        9.
                 1.0       32.
                 2.0      100.
                 3.0      151.
                 4.0       94.
                 5.0      145.
                 6.0      220.
                 7.0      300.
                 8.0      382.
                 9.0      450.
                10.0      350.
                11.0      280.
                12.0      200
                13.0      150.
                14.0      110.
                15.0       80.
                16.0       60.
                17.0       45.
                18.0       35.
                19.0       30.
                20.0       26.
          31    24.0       20.
                23.0
TABLE#=  110
TYPE=   -2
REFL=0.0
       HEAD WEIR COEF
        0.0       3.2
       50.0       3.2
       -1.0
TABLE#=  250
TYPE=   -3
REFL=0.00000000 FAC=43560.
 ELEVATION   STORAGE      AREA
       95.0       0.0      20.0
      100.0     112.5      25.0
      105.0     265.0      36.0
      115.0     695.0      50.0
       -1.0
TABLE#=  400
TYPE=   -2
REFL=0.0        FAC= 3.0
       HEAD DISCHARGE
        0.0       0.0
       0.01      0.06
      0.015      0.11
       0.02      0.17
       0.03      0.31
       0.04      0.48
       0.05      0.67
       0.07      1.11
        0.1       1.9
        0.2       5.4
        0.4      15.2
        0.8      42.9
        1.0      60.0
        1.5     110.0
        2.0     170.0
        3.0     312.0
        4.0     480.0
```

```
 1        5.0      670.0
 2        6.0      880.0
 3        7.0     1110.0
 4        8.0     1360.0
 5        9.0     1620.0
 6       -1.0
 7 TABLE#=  500
 8 TYPE=   -2
 9 REFL=0.0
10  HEADRATIO FLOWRATIO
11        0.0        1.0
12        0.8        1.0
13      1.000        0.0
14       -1.0
15 TABLE#= 5000
16 TYPE=   -1
17 STATION= 2.41200E+00
18 ELEVATION= 0.00000E+00                    EXT=00.00      FAC=1.000
19       DEPTH TOP WIDTH          AREA   SQRT(CONV)       BETA        YBARA
20        .000    20.000  0.00000E+00  0.00000E+00     1.0000  0.00000E+00
21        .080    20.480  1.61920E+00  4.21451E+00     1.0000  6.45120E-02
22        .938    25.625  2.13867E+01  3.34821E+01     1.0000  9.61304E+00
23      1.875     31.250  4.80469E+01  6.13671E+01     1.0000  4.17480E+01
24      2.812     36.875  7.99805E+01  8.86460E+01     1.0000  1.01349E+02
25      3.750     42.500  1.17188E+02  1.16093E+02     1.0000  1.93359E+02
26      4.688     48.125  1.59668E+02  1.43993E+02     1.0000  3.22722E+02
27      5.625     53.750  2.07422E+02  1.72467E+02     1.0000  4.94368E+02
28      6.563     59.375  2.60449E+02  2.01568E+02     1.0000  7.13287E+02
29      7.500     65.000  3.18750E+02  2.31316E+02     1.0000  9.84375E+02
30      8.437     70.625  3.82324E+02  2.61712E+02     1.0000  1.31259E+03
31      9.375     76.250  4.51172E+02  2.92750E+02     1.0000  1.70288E+03
32     10.312     81.875  5.25293E+02  3.24420E+02     1.0000  2.16019E+03
33     11.250     87.500  6.04687E+02  3.56707E+02     1.0000  2.68945E+03
34     12.187     93.125  6.89355E+02  3.89597E+02     1.0000  3.29562E+03
35     13.125     98.750  7.79297E+02  4.23074E+02     1.0000  3.98364E+03
36     14.062    104.375  8.74512E+02  4.57123E+02     1.0000  4.75845E+03
37     15.000    110.000  9.75000E+02  4.91730E+02     1.0000  5.62500E+03
38     15.909    115.455  1.07748E+03  5.25807E+02     1.0000  6.55757E+03
39     16.818    120.909  1.18492E+03  5.60383E+02     1.0000  7.58556E+03
40     17.727    126.364  1.29731E+03  5.95444E+02     1.0000  8.71347E+03
41     18.636    131.818  1.41467E+03  6.30980E+02     1.0000  9.94581E+03
42     19.545    137.273  1.53698E+03  6.66980E+02     1.0000  1.12871E+04
43     20.455    142.727  1.66426E+03  7.03433E+02     1.0000  1.27418E+04
44     21.364    148.182  1.79649E+03  7.40329E+02     1.0000  1.43145E+04
45     22.273    153.636  1.93368E+03  7.77659E+02     1.0000  1.60097E+04
46     23.182    159.091  2.07583E+03  8.15414E+02     1.0000  1.78318E+04
47     24.091    164.545  2.22293E+03  8.53584E+02     1.0000  1.97854E+04
48     25.000    170.000  2.37500E+03  8.92162E+02     1.0000  2.18750E+04
49     -1.000       .000  0.00000E+00  0.00000E+00      .0000  0.00000E+00
50 TABLE#=   -1
51 FREE NODE TABLE
52  NODE NODEID         DEPTH DISCHARGE ELEVATION SIGN
53     4 RESERV          95.5      0.00       0.0   +1
54     6 OVERFLOW         2.0      0.00      95.0   -1
55 BACKWATER ANALYSIS
56 BRANCH NUMBER=   -1
57 DISCHARGE=  54.0
58 BRANCH NUMBER=   -2
59 DISCHARGE= 54.0
60 BRANCH NUMBER=   -3
61 DISCHARGE= 54.0
62   BRA CODE ELEVATION EXN#
63     3    3      97.1
64     0    6                7
65     2                     7
66     1                     3
67    -1
```

Listing of Output: FEQEX4

```
1
2
3
4
5  ********************************************************************************
6  *                                                                              *
7  *                          FULL EQUATIONS FLOW ROUTING                         *
8  *                                                                              *
9  *                                                                              *
10 ********************************************************************************
11
12 VERSION: 6.0 15 MARCH  1990
13
14  WARNING: This program is large and complex.
15  User is totally responsible for any
16  consequences resulting from application
17  of this program.  Read disclaimer in the
18  source code.
19
20  This program is not to be sold in any form.
21
22
23 THE SIZE LIMITS SET FOR THIS PROGRAM ARE:
24 NUMBER OF BRANCHES:    85
25 NUMBER OF EXTERIOR NODES:  220
26 NUMBER OF NODES ON BRANCHES: 1170
27 NUMBER OF OPERATION BLOCKS:   10
28 FUNCTION TABLE NUMBER:10000
29 LENGTH OF THE FUNCTION TABLE:250000
30 NUMBER OF POINT FLOWS:   10
31 LENGTH OF EXTERIOR MATRIX CONTROL: 2000
32 NUMBER OF ROWS IN ARRAY OF PARTIAL DERIV.: 2340
33 LENGTH OF INTERIOR MATRIX POINTER VECTOR :  170
34 NUMBER OF ROWS IN EXTERIOR MATRIX :  440
35 NUMBER OF LAND USES FOR TRIB. AREA:   20
36 NUMBER OF POINT INFLOW FILES:   10
37 NUMBER OF POINT OUTFLOW FILES:    4
38 NUMBER OF SPECIAL OUTPUTS:   45
39 NUMBER OF CODE=6 EX NODES WITH FILES OR TABLES:   20
40 MAX. UNIT NUMBER FOR FILES:   50
41 TOTAL BANDWIDTH OF EXTERIOR MATRIX :   16
42 NUMBER OF SUBDIAGONALS IN EXTERIOR MATRIX :   10
43
44 UNSTEADY FLOW-EXAMPLE 4
45
46 THREE BRANCH SYSTEM WITH OFFLINE RESERVOIR WITH DUAL CONNECTION TO STREAM
47
48 MARCH 5, 1990
49
50 NUMBER OF BRANCHES =     3
51
52 NUMBER OF EXTERIOR NODES =     8
53
54 SPECIAL OPERATION BLOCK OPTION = NO
55
56 POINT FLOW OPTION = NO
57
58 DIFFUSE FLOW OPTION = NO   MINPRT=0 LAGTSF=0
59
60 WIND LOADING OPTION = NO
61
62 UNDERFLOW MESSAGES ARE : NO
63
64 ZERO INERTIA LIMIT =        .00 FEET
65
66 START TIME =  1990/ 1/ 1:  .000000000
67
68 END TIME =  1990/ 1/ 1: 1.000000000
69
70 GRAVITY =      32.20
71
72 NODE ID STRING PRESENT? YES
73
74 CONVERGENCE LIMIT(SURCHARGE STORAGE)  =  1.000E-01
75
76 PAGE=    22
77
78 CONVERGENCE LIMITS(SYSTEM SOLUTION):
79           PRIMARY =  1.000E-02
80           SECONDARY = 2.000E-02
81           ABSOLUTE =   .010
82
83 MAXIMUM NO. OF ITERATIONS IN SYSTEM SOLUTION  =     5 MAX. NUMGT=    1
84
85 PRINT OUT OPTION IS OUTPUT =     0
86
87 PRINT OUT WILL BE GIVEN EVERY   144 TIME STEPS
88
89 STANDARD GOVERNING EQUATIONS SELECTED. WX VARIABLE
```

CONVERGENCE CRITERION FOR BACKWATER = 5.000E-06

MAX.NO. ITERATIONS FOR BACKWATER ANALYSIS = 30

STATIONING FACTOR = 5.28000E+03

Q SMALL FOR RELATIVE ERROR = 20.00

IFRZ = 1
300.00 1.00 .70 2.80 3.20 3.00 2.00 .50

MRE = .20 FAC = .50 HSLOT= .00 WSLOT= .00 NSLOT= .000
WT INCREMENT/DECREMENT = .100
BASE VALUE FOR WT = .51
BWFDSN = 0 NAME=
GEOMETRY WILL NOT BE CHECKED
REDUCTION OF BAND WIDTH WILL BE ATTEMPTED.
EXTRAPOLATION TOLERANCE= .000

BRANCH DESCRIPTION TABLES

BRANCH NUMBER= 1 INERTIA= 1.0 CFRATE= .0 WINDFAC= 1.00

NODE	NODEID	XNUM	STATION	ELEVATION	KA	KD	HTAB	AZM			
100	UPSTREAM	5000	.0000	101.000	.00	.00	0	0.	.0	.0	.00
101		5000	.1000	100.900	.00	.00	0	0.	.0	.0	.00
102		5000	.2000	100.800	.00	.00	0	0.	.0	.0	.00
103		5000	.3000	100.700	.00	.00	0	0.	.0	.0	.00
104		5000	.4000	100.600	.00	.00	0	0.	.0	.0	.00
105		5000	.5000	100.500	.00	.00	0	0.	.0	.0	.00
106		5000	.6000	100.400	.00	.00	0	0.	.0	.0	.00
107		5000	.7000	100.300	.00	.00	0	0.	.0	.0	.00
108		5000	.8000	100.200	.00	.00	0	0.	.0	.0	.00
109		5000	.9000	100.100	.00	.00	0	0.	.0	.0	.00
110	DNSTREAM	5000	1.0000	100.000	.00	.00	0	0.	.0	.0	.00

BRANCH NUMBER= 2 INERTIA= 1.0 CFRATE= .0 WINDFAC= 1.00

NODE	NODEID	XNUM	STATION	ELEVATION	KA	KD	HTAB	AZM			
200	UPSTREAM	5000	.0000	100.000	.00	.00	0	0.	.0	.0	.00
201		5000	.1000	99.500	.00	.00	0	0.	.0	.0	.00
202		5000	.2000	99.000	.00	.00	0	0.	.0	.0	.00
203		5000	.3000	98.500	.00	.00	0	0.	.0	.0	.00
204		5000	.4000	98.000	.00	.00	0	0.	.0	.0	.00
205		5000	.5000	97.500	.00	.00	0	0.	.0	.0	.00
206		5000	.6000	97.000	.00	.00	0	0.	.0	.0	.00
207		5000	.7000	96.500	.00	.00	0	0.	.0	.0	.00
208		5000	.8000	96.000	.00	.00	0	0.	.0	.0	.00
209		5000	.9000	95.500	.00	.00	0	0.	.0	.0	.00
210	DNSTREAM	5000	1.0000	95.000	.00	.00	0	0.	.0	.0	.00

BRANCH NUMBER= 3 INERTIA= 1.0 CFRATE= .0 WINDFAC= 1.00

NODE	NODEID	XNUM	STATION	ELEVATION	KA	KD	HTAB	AZM			
300	UPSTREAM	5000	.0000	95.000	.00	.00	0	0.	.0	.0	.00
301		5000	.1000	95.000	.00	.00	0	0.	.0	.0	.00
302		5000	.2000	95.000	.00	.00	0	0.	.0	.0	.00
303		5000	.3000	95.000	.00	.00	0	0.	.0	.0	.00
304		5000	.4000	95.000	.00	.00	0	0.	.0	.0	.00
305		5000	.5000	95.000	.00	.00	0	0.	.0	.0	.00
306		5000	.6000	95.000	.00	.00	0	0.	.0	.0	.00
307		5000	.7000	95.000	.00	.00	0	0.	.0	.0	.00
308		5000	.8000	95.000	.00	.00	0	0.	.0	.0	.00
309		5000	.9000	95.000	.00	.00	0	0.	.0	.0	.00
310	DNSTREAM	5000	1.0000	95.000	.00	.00	0	0.	.0	.0	.00

BRANCH-EXTERIOR NODE TABLE

BRA#	UEXN	DEXN
1	1	2
2	3	5
3	7	8

EXTERIOR-MATRIX CONTROL INPUT

CODE	A	B	C	D	E	F	G	H	I	J	FA	FB	FC	FD	FE

CODE= 6 EQN#= 1. ENTRY#= 1
TYPE= 1 UPN= 1 DIR= 1 TAB#= 100 FLOW= .00

CODE= 1 EQN#S= 2 AND 3. ENTRY#= 2
BRANCH= 1

CODE= 11 EQN#= 4. ENTRY#= 3
IMPULSE+MOMENTUM EQUALITY BETWEEN NODES 2 AND 3

CODE= 2 EQN#= 5. ENTRY#= 4
THE 3 NODES FOR SUM OF Q ARE 2 3 4

```
 1
 2 CODE=    7 EQN#=    6.  ENTRY#=    5
 3    RESERVOIR NODE=    4 STORAGE TABLE#=  250 NUMBER OF INFLOW NODES=    1
 4    INFLOW NODES=    6
 5
 6 CODE=    5 EQN#=    7.  ENTRY#=    6
 7    TYPE=    2 UPS HEAD NODE=    4 DWNS HEAD NODE=    2 Q NODE=    4
 8    TAB# FOR POS FLOW=  400 TAB# FOR SUB. CORR.=  500
 9    TAB# FOR NEG FLOW=  400 TAB# FOR SUB.CORR.=  500
10    BASE ELEV.=    103.00 DIST. FOR SLOPE=        .0
11    PUMP RATE=      30.0 INLET ELEV.=     95.50 TURNON ELEV.=    102.90
12
13 CODE=    1 EQN#S=    8 AND    9.  ENTRY#=    7
14    BRANCH=    2
15
16 CODE=    3 EQN#=   10.  ENTRY#=    8
17    ELEVATION EQUALITY BETWEEN NODE    5 AND    6
18
19 CODE=    3 EQN#=   11.  ENTRY#=    9
20    ELEVATION EQUALITY BETWEEN NODE    6 AND    7
21
22 CODE=    2 EQN#=   12.  ENTRY#=   10
23    THE    3 NODES FOR SUM OF Q ARE    5   -6    7
24
25 CODE=    5 EQN#=   13.  ENTRY#=   11
26    TYPE=    2 UPS HEAD NODE=    4 DWNS HEAD NODE=    6 Q NODE=    6
27    TAB# FOR POS FLOW=  400 TAB# FOR SUB. CORR.=  500
28    TAB# FOR NEG FLOW=  400 TAB# FOR SUB.CORR.=  500
29    BASE ELEV.=    106.00 DIST. FOR SLOPE=        .0
30    PUMP RATE=        .0 INLET ELEV.=       .00 TURNON ELEV.=       .00
31
32 CODE=    1 EQN#S=   14 AND   15.  ENTRY#=   12
33    BRANCH=    3
34
35 CODE=    4 EQN#=   16.  ENTRY#=   13
36    TYPE=    1 UPN=    8 DIR=   -1 QNODE=    8
37    WEIR COEF. TAB#=  110 WEIR ELEV.=     97.00 WEIR LENGTH=      32.0
```

BANDWIDTH REDUCTION LOG

ITER	MAXSUB	MAXSUP	BANDW	DECSUB	DECSUP	SWPFLG
0	6	6	13			
1	4	3	8	1	1	3
2	3	3	7	1	0	0
3	3	3	7	0	0	0
4	3	3	7	0	0	0
5	3	3	7	0	0	0
6	3	3	7	0	0	0
7	3	3	7	0	0	0
8	3	3	7	0	0	0
9	3	3	7	0	0	0
10	3	3	7	0	0	0

```
ARRANGEMENT OF NON-ZERO ELEMENTS IN EXTERIOR MATRIX

  EQN ENTRY   C987654321B987654321A9876543210123456789A123456789B123456789C123456789
    1     1                                    .X.............
    2     2                                   XXXX............
    3                                         XXXX............
    4     3                                  ..XXXX..........
    5     6                                 ..XX..XX........
    6     4                                ...X.X.X........
    7     7                               ....XX..XX......
    8                                     ....XX..XX......
    9     5                              ......XX...X....
   10    11                             ......XX..XX....
   11     8                            .........X.X.....
   12    10                           .........X.X.X..
   13     9                          ..........X.X...
   14    12                         ............XXXX
   15                              ............XXXX
   16    13                       ..............XX


TOTAL BAND WIDTH M3 =    7

NO. OF SUBDIAGONALS M1 =    3 NO. OF SUPER DIAGONALS M2 =   3

SPECIAL OUTPUT LOCATIONS
UNIT=    3 NAME=EX4SPOUT
  BRA NODE
    0    2 EXNOD 2
    0    4 EXNOD 4
    0    6 EXNOD 6

INPUT FILE SPECIFICATION

 UNIT NAME

OUTPUT FILE SPECIFICATION

 UNIT  BRA NODE ITEM TYPE NAME

FUNCTION TABLES

TABLE#=  100
TYPE=   -7
REFERENCE LEVEL=        0. FAC=     6.000 SHIFT=        0.

YEAR MN DY      HOUR DISCHARGE  INFLOW HYDROGRAPH AT UPSTREAM END

TABLE#=  110
TYPE=   -2
REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.

      HEAD WEIR COEF

TABLE#=  250
TYPE=   -3
REFERENCE LEVEL=        0. FAC= 43560.000 SHIFT=        0.

 ELEVATION   STORAGE      AREA

TABLE#=  400
TYPE=   -2
REFERENCE LEVEL=        0. FAC=     3.000 SHIFT=        0.

      HEAD DISCHARGE

TABLE#=  500
TYPE=   -2
REFERENCE LEVEL=        0. FAC=     1.000 SHIFT=        0.

 HEADRATIO FLOWRATIO

TABLE#= 5000
TYPE=   -1


FREE NODE TABLE


 NODE NODEID        DEPTH DISCHARGE ELEVATION SIGN
    4 RESERV        95.50       .00       .00    1
    6 OVERFLOW       2.00       .00     95.00   -1

TRUE SIZES:
NUMBER OF BRANCHES:    3
NUMBER OF EXTERIOR NODES:    8
NUMBER OF NODES ON BRANCHES:   33
NUMBER OF OPERATION BLOCKS:    0
FUNCTION TABLE NUMBER:    6
```

```
 1 LENGTH OF THE FUNCTION TABLE:    316
 2 NUMBER OF POINT FLOWS:     0
 3 LENGTH OF EXTERIOR MATRIX CONTROL:  100
 4 NUMBER OF ROWS IN ARRAY OF PARTIAL DERIV.:    60
 5 LENGTH OF INTERIOR MATRIX POINTER VECTOR :     6
 6 NUMBER OF ROWS IN EXTERIOR MATRIX:    16
 7 NUMBER OF LAND USES FOR TRIB. AREA:     0
 8 NUMBER OF POINT INFLOW FILES:     0
 9 NUMBER OF POINT OUTFLOW FILES:     0
10 NUMBER OF SPECIAL OUTPUTS:     3
11 NUMBER OF CODE=6 EX NODES WITH FILES OR TABLES:     1
12
13 SRLIM= 7.60000E-05
```

```
 1 BACKWATER ANALYSIS
 2
 3 BRANCH NUMBER =     1
 4 DISCHARGE =        54.0
 5
 6 BRANCH NUMBER =     2
 7 DISCHARGE =        54.0
 8
 9 BRANCH NUMBER =     3
10 DISCHARGE =        54.0
11
12   BRA CODE ELEVATION EXN#
13     3    3     97.10    0
14
15 BACKWATER ANALYSIS BRANCH#     3
16  STATION IT      YL       QL       AL       TL       DZ       DX       ELEV       RES   FR
17   1.0000  0  2.653     54.0     74.2     35.9     .00       .0     97.653  0.0E+00   .0
18    .9000  3  2.683     54.0     75.3     36.1     .00     528.0    97.683 -6.3E-05   .0
19    .8000  3  2.712     54.0     76.3     36.3     .00     528.0    97.712  4.9E-05   .0
20    .7000  3  2.741     54.0     77.3     36.4     .00     528.0    97.741 -3.0E-04   .0
21    .6000  3  2.768     54.0     78.3     36.6     .00     528.0    97.768  5.4E-05   .0
22    .5000  3  2.794     54.0     79.3     36.8     .00     528.0    97.794 -3.2E-05   .0
23    .4000  3  2.819     54.0     80.2     36.9     .00     528.0    97.819 -1.9E-04   .0
24    .3000  3  2.844     54.0     81.1     37.1     .00     528.0    97.844 -1.2E-04   .0
25    .2000  3  2.867     54.0     82.0     37.2     .00     528.0    97.867 -8.8E-05   .0
26    .1000  3  2.890     54.0     82.9     37.3     .00     528.0    97.890 -8.9E-05   .0
27    .0000  3  2.913     54.0     83.7     37.5     .00     528.0    97.913 -4.6E-05   .0
28     0     6        .00     7
29
30 BACKWATER ANALYSIS BRANCH#     0
31  STATION IT      YL       QL       AL       TL       DZ       DX       ELEV       RES   FR
32     2    0        .00     7
33
34 BACKWATER ANALYSIS BRANCH#     2
35  STATION IT      YL       QL       AL       TL       DZ       DX       ELEV       RES   FR
36   1.0000  0  2.913     54.0     83.7     37.5     .00       .0     97.913  0.0E+00   .0
37    .9000  4  2.439     54.0     66.6     34.6    -.50     528.0    97.938  3.7E-05   .0
38    .8000  4  1.991     54.0     51.7     31.9    -.50     528.0    97.991 -1.2E-04   .0
39    .7000  4  1.604     54.0     39.8     29.6    -.50     528.0    98.104 -8.2E-05   .0
40    .6000  4  1.344     54.0     32.3     28.1    -.50     528.0    98.344 -5.3E-05   .1
41    .5000  3  1.243     54.0     29.5     27.5    -.50     528.0    98.743 -3.2E-03   .1
42    .4000  3  1.223     54.0     29.0     27.3    -.50     528.0    99.223 -3.4E-05   .1
43    .3000  2  1.221     54.0     28.9     27.3    -.50     528.0    99.721 -2.4E-03   .1
44    .2000  2  1.221     54.0     28.9     27.3    -.50     528.0   100.221 -4.6E-05   .1
45    .1000  2  1.221     54.0     28.9     27.3    -.50     528.0   100.721 -8.4E-05   .1
46    .0000  1  1.221     54.0     28.9     27.3    -.50     528.0   101.221 -6.2E-03   .1
47     1     0        .00     3
48
49 BACKWATER ANALYSIS BRANCH#     1
50  STATION IT      YL       QL       AL       TL       DZ       DX       ELEV       RES   FR
51   1.0000  0  1.221     54.0     28.9     27.3     .00       .0     101.221  0.0E+00   .1
52    .9000  4  1.484     54.0     36.3     28.9    -.10     528.0    101.584 -2.7E-05   .1
53    .8000  3  1.607     54.0     39.9     29.6    -.10     528.0    101.807 -9.9E-03   .0
54    .7000  3  1.684     54.0     42.2     30.1    -.10     528.0    101.984 -1.5E-03   .0
55    .6000  3  1.737     54.0     43.8     30.4    -.10     528.0    102.137 -2.7E-04   .0
56    .5000  3  1.776     54.0     45.0     30.7    -.10     528.0    102.276 -5.7E-05   .0
57    .4000  3  1.805     54.0     45.9     30.8    -.10     528.0    102.405 -3.3E-05   .0
58    .3000  3  1.828     54.0     46.6     31.0    -.10     528.0    102.528 -8.6E-06   .0
59    .2000  3  1.845     54.0     47.1     31.1    -.10     528.0    102.645 -8.1E-05   .0
60    .1000  3  1.859     54.0     47.5     31.2    -.10     528.0    102.759  1.4E-05   .0
61    .0000  3  1.870     54.0     47.9     31.2    -.10     528.0    102.870 -1.0E-05   .0
62
63 IFRZ =     1
64
65 SIMULATION ENDING AT  1990/ 1/ 1/    .000 WITH TIME STEP OF      900.0 SEC
66 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
67    1 6.4E-06    1  109 1.7E-05   -3 6.1E-10      0
68 ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 0.00E+00 AT ND=  0:   0 DT/ITER=       .0
69
70 IFRZ =     0
71      TIME STEP RESET TO    300.00 SEC WT =  .510
72
73 SIMULATION ENDING AT  1990/ 1/ 1/    .083 WITH TIME STEP OF      300.0 SEC
74 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
75    1 1.6E-01    0    1 1.1E+01   -1 1.3E+02      7
76    2 3.3E-04    1  101 1.0E-03    2 2.5E-06      0
77 ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 5.44E-02 AT ND=  1: 100 DT/ITER=    150.0
78      TIME STEP RESET TO    300.00 SEC WT =  .510
79
80     ****************************************
81     Lines deleted to save space
82     ****************************************
83
84 SIMULATION ENDING AT  1990/ 1/ 1/ 11.833 WITH TIME STEP OF      300.0 SEC
85 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
86    1 1.3E-01    0    4 2.0E+01   -1 4.0E+02     13
87    2 3.8E-05    0    4 2.0E-04    1 3.7E-07      0
88 ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 9.40E-03 AT ND=  1: 100 DT/ITER=    148.4
89      TIME STEP RESET TO    300.00 SEC WT =  .510
```

```
1
2 SIMULATION ENDING AT  1990/ 1/ 1/ 11.917 WITH TIME STEP OF      300.0 SEC
3 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
4    1 1.5E-01    0    4 2.0E+01   -1 4.0E+02    13
5    2 1.2E-04    0    4 2.1E-04    1 4.3E-07     0
6 ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 9.79E-03 AT ND=  1: 100 DT/ITER=   148.4
7
8 RESULTS AT TIME     42900. JTIME =     47892.4965277773
9
10 BRANCH NUMBER =     1
11
12 NODE   NODEID     STAT     FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
13  100 UPSTREAM   .0000 1.240+3 3.996+2  3.10   8.68 109.68 7.208+1  .1 0.000+0
14  101            .1000 1.253+3 3.953+2  3.17   8.62 109.52 7.172+1  .1 0.000+0
15  102            .2000 1.265+3 3.902+2  3.24   8.55 109.35 7.129+1  .1 0.000+0
16  103            .3000 1.277+3 3.845+2  3.32   8.47 109.17 7.081+1  .1 0.000+0
17  104            .4000 1.288+3 3.779+2  3.41   8.37 108.97 7.025+1  .1 0.000+0
18  105            .5000 1.299+3 3.704+2  3.51   8.27 108.77 6.961+1  .1 0.000+0
19  106            .6000 1.309+3 3.617+2  3.62   8.14 108.54 6.885+1  .1 0.000+0
20  107            .7000 1.319+3 3.517+2  3.75   8.00 108.30 6.797+1  .1 0.000+0
21  108            .8000 1.328+3 3.400+2  3.91   7.82 108.02 6.693+1  .1 0.000+0
22  109            .9000 1.336+3 3.260+2  4.10   7.61 107.71 6.567+1  .1 0.000+0
23  110 DNSTREAM  1.0000 1.343+3 3.090+2  4.35   7.35 107.35 6.409+1  .1 0.000+0
24
25       BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT
26
27 BRANCH NUMBER =     2
28
29 NODE   NODEID     STAT     FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
30  200 UPSTREAM   .0000 1.307+3 3.090+2  4.23   7.35 107.35 6.409+1  .1 0.000+0
31  201            .1000 1.313+3 3.215+2  4.08   7.54 107.04 6.525+1  .1 0.000+0
32  202            .2000 1.319+3 3.365+2  3.92   7.77 106.77 6.662+1  .1 0.000+0
33  203            .3000 1.326+3 3.542+2  3.75   8.03 106.53 6.819+1  .1 0.000+0
34  204            .4000 1.333+3 3.745+2  3.56   8.33 106.33 6.996+1  .1 0.000+0
35  205            .5000 1.342+3 3.976+2  3.37   8.65 106.15 7.191+1  .1 0.000+0
36  206            .6000 1.349+3 4.232+2  3.19   9.00 106.00 7.401+1  .1 0.000+0
37  207            .7000 1.357+3 4.513+2  3.01   9.38 105.88 7.626+1  .0 0.000+0
38  208            .8000 1.366+3 4.818+2  2.84   9.77 105.77 7.863+1  .0 0.000+0
39  209            .9000 1.375+3 5.146+2  2.67  10.18 105.68 8.109+1  .0 0.000+0
40  210 DNSTREAM  1.0000 1.385+3 5.496+2  2.52  10.61 105.61 8.364+1  .0 0.000+0
41
42       BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT
43
44 BRANCH NUMBER =     3
45
46 NODE   NODEID     STAT     FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
47  300 UPSTREAM   .0000 1.664+3 5.496+2  3.03  10.61 105.61 8.364+1  .0 0.000+0
48  301            .1000 1.673+3 5.391+2  3.10  10.48 105.48 8.288+1  .0 0.000+0
49  302            .2000 1.683+3 5.279+2  3.19  10.34 105.34 8.207+1  .0 0.000+0
50  303            .3000 1.692+3 5.159+2  3.28  10.20 105.20 8.119+1  .1 0.000+0
51  304            .4000 1.701+3 5.032+2  3.38  10.04 105.04 8.024+1  .1 0.000+0
52  305            .5000 1.709+3 4.894+2  3.49   9.87 104.87 7.921+1  .1 0.000+0
53  306            .6000 1.718+3 4.745+2  3.62   9.68 104.68 7.807+1  .1 0.000+0
54  307            .7000 1.726+3 4.582+2  3.77   9.47 104.47 7.680+1  .1 0.000+0
55  308            .8000 1.734+3 4.401+2  3.94   9.23 104.23 7.538+1  .1 0.000+0
56  309            .9000 1.742+3 4.198+2  4.15   8.96 103.96 7.374+1  .1 0.000+0
57  310 DNSTREAM  1.0000 1.750+3 3.964+2  4.42   8.64 103.64 7.181+1  .1 0.000+0
58
59       BRANCH PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT
60
61     NETWORK PONDING VOLUME =   0.0000E+00 FT**3         .0 AC-FT
62
63 EXTERIOR NODES
64
65 NODE   NODEID         QE1      YE1    ELEV     STORAGE     STORAGE
66    1 UPSTREAM  1.240E+03     8.68  109.68
67    2 DNSTREAM  1.343E+03     7.35  107.35
68    3 UPSTREAM  1.307E+03     7.35  107.35
69    4 RESERV   -3.592E+01   107.33  107.33  1.536E+07  3.527E+02
70    5 DNSTREAM  1.385E+03    10.61  105.61
71    6 OVERFLOW  2.790E+02    10.61  105.61
72    7 UPSTREAM  1.664E+03    10.61  105.61
73    8 DNSTREAM  1.750E+03     8.64  103.64
74 BC:S1=1.294E+06 S2=2.200E+07 I=5.598E+07 Q=3.527E+07 D= 2.789E+01 R= 4.87E-07
75       TIME STEP RESET TO    300.00 SEC WT =  .510
76
77 SIMULATION ENDING AT  1990/ 1/ 1/ 12.000 WITH TIME STEP OF      300.0 SEC
78 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
79    1 2.4E-01    0    4 2.0E+01   -1 4.0E+02    13
80    2 3.2E-04    0    4 2.2E-04    1 4.8E-07     0
81 ERRP= 0.00E+00 AT ND=  0:   0 ERRQ= 1.02E-02 AT ND=  1: 100 DT/ITER=   148.5
82       TIME STEP RESET TO    300.00 SEC WT =  .510
83
84     ****************************************
85     Lines deleted to save space
86     ****************************************
87
88
89 SIMULATION ENDING AT  1990/ 1/ 1/ 24.000 WITH TIME STEP OF      300.0 SEC
```

```
ITER   RERROR   BRA NODE    MXRES   LOC   SUMSQR NUMGT
   1 2.7E-03     0     4 1.2E-02    35 1.0E-03     0
ERRP= 0.00E+00 AT ND=  0:    0 ERRQ= 3.66E-03 AT ND=  2: 207 DT/ITER=   162.1
      TIME STEP RESET TO    300.00 SEC WT =  .510

TIME STEP RESET IN MANTIM TO       .00 SECS TO MATCH EVENT END

SIMULATION COMPLETE AT     86400. SECS.


SIMULATION ENDING AT  1990/  1/  1/ 24.000

RESULTS AT TIME     86400. JTIME =     47892.9999999991

BRANCH NUMBER =     1

NODE    NODEID     STAT     FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
 100 UPSTREAM    .0000 1.558+2 9.644+1  1.62   3.24  104.24 3.946+1  .0 0.000+0
 101             .1000 1.559+2 9.553+1  1.63   3.22  104.12 3.933+1  .0 0.000+0
 102             .2000 1.559+2 9.438+1  1.65   3.19  103.99 3.915+1  .0 0.000+0
 103             .3000 1.559+2 9.308+1  1.68   3.16  103.86 3.895+1  .0 0.000+0
 104             .4000 1.561+2 9.153+1  1.71   3.12  103.72 3.871+1  .0 0.000+0
 105             .5000 1.562+2 8.969+1  1.74   3.07  103.57 3.842+1  .0 0.000+0
 106             .6000 1.563+2 8.745+1  1.79   3.01  103.41 3.807+1  .0 0.000+0
 107             .7000 1.564+2 8.470+1  1.85   2.94  103.24 3.764+1  .0 0.000+0
 108             .8000 1.565+2 8.122+1  1.93   2.85  103.05 3.708+1  .1 0.000+0
 109             .9000 1.567+2 7.664+1  2.04   2.72  102.82 3.633+1  .1 0.000+0
 110 DNSTREAM   1.0000 1.569+2 7.015+1  2.24   2.54  102.54 3.524+1  .1 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

BRANCH NUMBER =     2

NODE    NODEID     STAT     FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
 200 UPSTREAM    .0000 1.884+2 6.738+1  2.80   2.46  102.46 3.477+1  .1 0.000+0
 201             .1000 1.886+2 6.762+1  2.79   2.47  101.97 3.481+1  .1 0.000+0
 202             .2000 1.889+2 6.814+1  2.77   2.48  101.48 3.490+1  .1 0.000+0
 203             .3000 1.891+2 6.926+1  2.73   2.51  101.01 3.509+1  .1 0.000+0
 204             .4000 1.894+2 7.163+1  2.64   2.58  100.58 3.549+1  .1 0.000+0
 205             .5000 1.898+2 7.622+1  2.49   2.71  100.21 3.626+1  .1 0.000+0
 206             .6000 1.901+2 8.397+1  2.26   2.92   99.92 3.752+1  .1 0.000+0
 207             .7000 1.907+2 9.526+1  2.00   3.21   99.71 3.928+1  .1 0.000+0
 208             .8000 1.911+2 1.098+2  1.74   3.58   99.58 4.145+1  .0 0.000+0
 209             .9000 1.917+2 1.273+2  1.51   3.98   99.48 4.391+1  .0 0.000+0
 210 DNSTREAM   1.0000 1.923+2 1.472+2  1.31   4.42   99.42 4.655+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

BRANCH NUMBER =     3

NODE    NODEID     STAT     FLOW     AREA   VEL  DEPTH    ELEV     TOP  FR LAT INF
 300 UPSTREAM    .0000 1.923+2 1.472+2  1.31   4.42   99.42 4.655+1  .0 0.000+0
 301             .1000 1.928+2 1.445+2  1.33   4.37   99.37 4.619+1  .0 0.000+0
 302             .2000 1.934+2 1.416+2  1.37   4.30   99.30 4.581+1  .0 0.000+0
 303             .3000 1.940+2 1.385+2  1.40   4.23   99.23 4.540+1  .0 0.000+0
 304             .4000 1.946+2 1.352+2  1.44   4.16   99.16 4.497+1  .0 0.000+0
 305             .5000 1.951+2 1.317+2  1.48   4.08   99.08 4.450+1  .0 0.000+0
 306             .6000 1.956+2 1.279+2  1.53   4.00   99.00 4.399+1  .0 0.000+0
 307             .7000 1.961+2 1.238+2  1.58   3.90   98.90 4.343+1  .0 0.000+0
 308             .8000 1.966+2 1.193+2  1.65   3.80   98.80 4.280+1  .0 0.000+0
 309             .9000 1.970+2 1.144+2  1.72   3.68   98.68 4.210+1  .0 0.000+0
 310 DNSTREAM   1.0000 1.974+2 1.088+2  1.81   3.55   98.55 4.129+1  .0 0.000+0

      BRANCH PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

    NETWORK PONDING VOLUME =   0.0000E+00 FT**3        .0 AC-FT

EXTERIOR NODES

NODE    NODEID          QE1      YE1    ELEV     STORAGE     STORAGE
   1 UPSTREAM   1.558E+02     3.24  104.24
   2 DNSTREAM   1.569E+02     2.54  102.54
   3 UPSTREAM   1.884E+02     2.46  102.46
   4 RESERV     3.147E+01   103.04  103.04   8.655E+06   1.987E+02
   5 DNSTREAM   1.923E+02     4.42   99.42
   6 OVERFLOW   0.000E+00     4.42   99.42
   7 UPSTREAM   1.923E+02     4.42   99.42
   8 DNSTREAM   1.974E+02     3.55   98.55

SIMULATION COMPLETED
```

SUMMARY OF MAXIMUM ELEVATIONS

UNSTEADY FLOW-EXAMPLE 4
THREE BRANCH SYSTEM WITH OFFLINE RESERVOIR WITH DUAL CONNECTION TO STREAM
MARCH 5, 1990

MAXIMUM ELEVATIONS ACHIEVED BY TIME 86400.

BRANCH NUMBER = 1

NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
100	UPSTREAM	.0000	11.29	112.29	4.44	2.7000E+03	5.4000E+01
101		.1000	11.14	112.04	4.52	2.6907E+03	5.4000E+01
102		.2000	10.99	111.79	4.62	2.6818E+03	5.4000E+01
103		.3000	10.81	111.51	4.74	2.6728E+03	5.4000E+01
104		.4000	10.60	111.20	4.88	2.6657E+03	5.4000E+01
105		.5000	10.36	110.86	5.05	2.6634E+03	5.4000E+01
106		.6000	10.08	110.48	5.27	2.6598E+03	5.4000E+01
107		.7000	9.73	110.03	5.56	2.6554E+03	5.4000E+01
108		.8000	9.30	109.50	5.98	2.6511E+03	5.4000E+01
109		.9000	8.68	108.78	6.73	2.6423E+03	5.4000E+01
110	DNSTREAM	1.0000	7.99	107.99	9.42	2.6312E+03	5.4000E+01

BRANCH NUMBER = 2

NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
200	UPSTREAM	.0000	7.99	107.99	5.03	1.6751E+03	5.4000E+01
201		.1000	8.17	107.67	4.93	1.6690E+03	5.4000E+01
202		.2000	8.39	107.39	4.82	1.6627E+03	5.4000E+01
203		.3000	8.64	107.14	4.66	1.6529E+03	5.4000E+01
204		.4000	8.94	106.94	4.47	1.6427E+03	5.4000E+01
205		.5000	9.26	106.76	4.25	1.6321E+03	5.4000E+01
206		.6000	9.61	106.61	4.00	1.6195E+03	5.4000E+01
207		.7000	9.99	106.49	3.73	1.6085E+03	5.4000E+01
208		.8000	10.39	106.39	3.46	1.5961E+03	5.4000E+01
209		.9000	10.80	106.30	3.19	1.5857E+03	5.4000E+01
210	DNSTREAM	1.0000	11.23	106.23	2.94	1.5765E+03	5.4000E+01

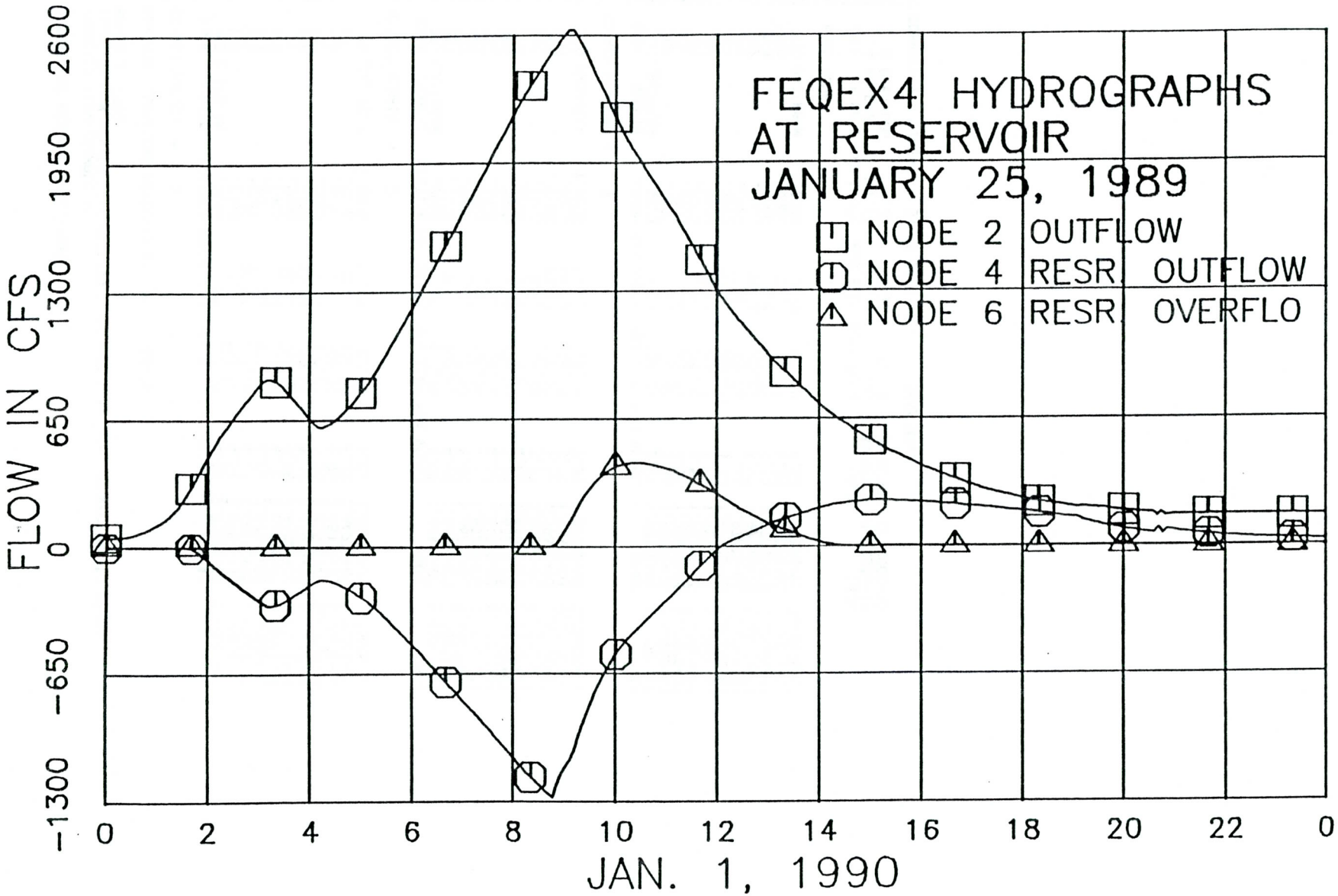
BRANCH NUMBER = 3

NODE	NODEID	STATION	MAX DEPTH	MAX ELEV	MAX VELOC	QMAX	QMIN
300	UPSTREAM	.0000	11.23	106.23	3.41	1.9931E+03	5.4000E+01
301		.1000	11.09	106.09	3.46	1.9895E+03	5.4000E+01
302		.2000	10.94	105.94	3.51	1.9865E+03	5.4000E+01
303		.3000	10.79	105.79	3.57	1.9835E+03	5.4000E+01
304		.4000	10.62	105.62	3.64	1.9818E+03	5.4000E+01
305		.5000	10.44	105.44	3.73	1.9798E+03	5.4000E+01
306		.6000	10.24	105.24	3.83	1.9783E+03	5.4000E+01
307		.7000	10.02	105.02	3.95	1.9774E+03	5.4000E+01
308		.8000	9.78	104.78	4.10	1.9763E+03	5.4000E+01
309		.9000	9.51	104.51	4.28	1.9759E+03	5.4000E+01
310	DNSTREAM	1.0000	9.19	104.19	4.52	1.9759E+03	5.4000E+01

FREE NODES

NODE	NODEID	MAX DEPTH	MAX ELEV	BOTM ELEV	QMAX	QMIN
4	RESERV	107.76	107.76	.00	2.3539E+02	-1.2803E+03
6	OVERFLOW	11.23	106.23	95.00	4.2415E+02	0.0000E+00

COMPUTATION TIME= 51.98 SECS OR .8663 MINS


FEQEX4 HYDROGRAPHS
AT RESERVOIR
JANUARY 25, 1989
NODE 2 OUTFLOW
NODE 4 RESR. OUTFLOW
NODE 6 RESR. OVERFLO
FLOW IN CFS
2600
1950
1300
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UNSTEADY FLOW SOLUTIONS

Governing Equations Summary

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INTRODUCTION

FEQ and FEQUTL use a variety of equations in computing the results for unsteady flow. In a generic sense all these equations are governing equations because they directly or indirectly influence the results produced by these programs. An awareness of these equations and of the assumptions used in deriving them and solving them is important to the proper use of these programs.

I will begin with the basic definitions and relationships for a stream channel and then move to the various forms of the governing equations for one-dimensional flow. Next in order an outline of the solution schemes will be given followed by the solution scheme used in the branches in FEQ. This will be followed by the various steady flow relationships comprising the special features used in the exterior matrix. Operations from FEQUTL will be introduced where appropriate. Note that FEQUTL exists solely to provide convenient information for FEQ and therefore its operations will be presented at the point where the information is used in FEQ.

I am assuming several things on the part of the reader of this information. To begin with, I assume that you are familiar and conversant with one-dimensional steady flow hydraulics in open channels. I also assume that you are familiar with and not intimidated by derivatives and integrals. You should also be familiar with a variety of standard numerical techniques: numerical integration using the trapezoidal, mid-point, and Simpson's rules, linear, quadratic, and cubic interpolation in a table of values, and root finding methods including *regula falsi* and Newton's method. If you are not familiar with these then you should be willing to spend some time to become familiar with them. These and other related topics will be used or referenced throughout this summary. Some of these topics will be sketched briefly but other sources must be consulted for a fuller understanding of them.

Relationships for a Cross Section

The elements for a cross section can be placed into two classes. I call the first class static because they relate to elements which are important when the water in the channel is at rest. The static elements are the top width, wetted perimeter, area, and first moment of area about the water surface and their derivatives with respect to distance along the channel. The second class I call dynamic because they are needed when the water is in motion. The dynamic elements are the conveyance, the momentum flux coefficient, and the kinetic energy flux coefficient. I begin with the static elements because they are basic to the dynamic elements.

The Static Elements

Figure 1 shows a typical cross section in outline form. The top width, denoted by $T(x, y)$ is taken to be a function of the distance along the channel, x, and the maximum depth(or height), y, of the water in the channel. In keeping with the assumptions of one-dimensional open channel flow, the water surface is assumed to be horizontal. We generalize the top width to include also the width that the water surface would have if it were at a height z above the invert of the cross section. The area of flow is defined as the integral of the top width function yielding

$$A(x, y) = \int_0^y T(x, z)\, dz \tag{1}$$

where z =dummy variable of integration. The hydrostatic pressure force on the narrow horizontal strip centered on z in Fig. 1 is approximately $\rho g(y - z)T(x, z)\Delta z$ where ρ = the density of water; and g = acceleration of gravity. Thus the pressure force on the cross-section below y is given by the limit of the sum of the pressure forces on many small horizontal strips, that is by

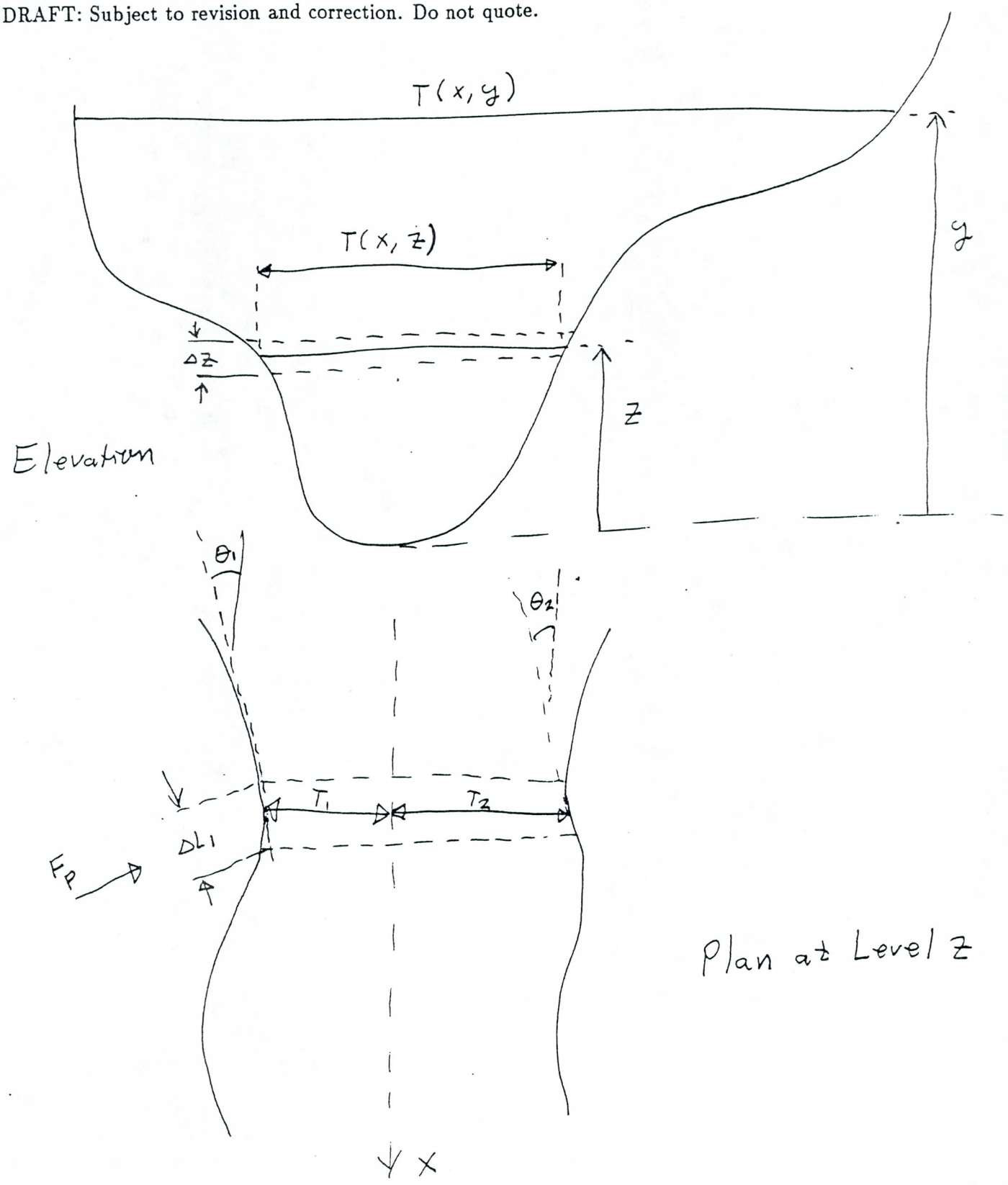


Figure 1: Definition of Cross Section Elements

$$F_p = \rho g \int_0^y (y - z) T(x, z)\, dz \tag{2}$$

Dividing Eq.2 by ρg gives the first moment of area about the water surface:

$$J(x, y) = \int_0^y (y - z) T(x, z)\, dz \tag{3}$$

Expansion of Eq. 3 and integration by parts yields

$$J(x, y) = \int_0^y A(x, z)\, dz \tag{4}$$

as a simpler relationship for the first moment of area.

The wetted perimeter is the length of the boundary of the cross section which is under water for a given depth of water y. It can be defined in terms of an integral involving derivatives of the boundary shape. However, the mathematics will only serve to obscure a simple precise concept. The wetted perimeter, $P(x, y)$, is never less than the top width and is often not much different than the top width. However, there are cross sections for which the difference between top width and wetted perimeter is significant. Therefore, FEQ and FEQUTL make use of the conveyance which includes the wetter perimeter implicitly. See the Dynamic Element discussion below.

Partial derivatives of the area and the first moment of area are needed for some derivations and for an understanding of some of the terms in the equations. Care must be used in notation to avoid confusion. The notation already used for the arguments for top width, area, and first moment of area(I will assume in the following that the first moment is always to be taken about the water surface to avoid the constant pedantic reference to the water surface) are simplified. To show the full dependence of the terms I should really write $T[x, y(x)]$ for steady flow and $T[x, y(x, t)]$ where t denotes time. In unsteady flow we could also write $T(x, t)$ with the intermediary role played by the depth of water suppressed. These notations are simpler but they can be confusing when partial derivatives are involved.

A partial derivative of a function of more than one variable is the same as the ordinary derivative of the function which results when all variables but the differentiating variable are held fixed. Thus, using this convention, $\partial T(x, t)/\partial x$ means that time is to be held constant when the derivative is taken. Thus we imagine a snapshot of the water surface at a given time which then defines a function of the single variable x. The value of depth used in defining the top width does not enter the relationship but we would like relationships which make the role of depth evident. Thus a different notation for showing which variables are being held constant must be used. For example

$$\left.\frac{\partial T}{\partial x}\right|_y$$

indicates that T is a function of y and x and that y is being held constant during the differentiation. Note that if I wrote

$$\frac{\partial}{\partial x} T(x, y)$$

the meaning is unclear because the depth, y, is also a function of x as well as t in unsteady flow. Thus to be clear, the extra notation should be used. A shorthand form for this notation is T_x^y where the subscript denotes the variable being used in taking the derivative and the superscript denotes the variable being held constant. With this background the meaning of the statement

$$\frac{\partial T}{\partial x} = \left.\frac{\partial T}{\partial x}\right|_y + \frac{\partial T}{\partial y}\frac{\partial y}{\partial x} \tag{5}$$

is clear. The top width functions on the right hand side of Eq. 5 are functions of x and y with y being a function of x and t. The T value on the left hand side is a function of x and t without the intermediate role of y.

It is convenient to make use of the definitions of the area and first moment of area in order to compute their partial derivatives. What makes this convenient is the availability of Leibniz's rule or theorem for the derivative of a definite integral when the integrand and the limits are functions of the differentiating variable. This rule, stated for a function of two variables, is

$$\frac{d}{dx}\int_{a(x)}^{b(x)} f(x,z)\,dz = \int_{a(x)}^{b(x)} \frac{\partial}{\partial x} f(x,z)\,dz + f(x,b)\frac{db}{dx} - f(x,a)\frac{da}{dx} \tag{6}$$

This rule, applied to the definitions of area and first moment of area, yields

$$\frac{\partial A}{\partial x} = \frac{\partial A}{\partial y}\frac{\partial y}{\partial x} + \int_0^y \frac{\partial}{\partial x} T(x,z)\,dz = T(x,y)\frac{\partial y}{\partial x} + A_x^y \tag{7}$$

$$\frac{\partial J}{\partial x} = \frac{\partial J}{\partial y}\frac{\partial y}{\partial x} + \int_0^y \frac{\partial}{\partial x} A(x,z)\,dz = A(x,y)\frac{\partial y}{\partial x} + J_x^y \tag{8}$$

The terms, A_x^y and J_x^y vanish if the channel is prismatic.

The last term in Eq. 8, J_x^y, is related to the downstream component of the pressure force on the sides of a channel. Figure 1 shows a plan view of the intersection of the walls of the channel with a plane surface at a constant level z from the invert of the channel. Consider a small vertical element of size Δz by ΔL at level z. The hydrostatic pressure at the mid-point of this rectangular element is $\rho g(y-z)$. The angle θ_1 is given by

$$\tan\theta_1 = \left.\frac{\partial T_1}{\partial x}\right|_z \tag{9}$$

That is, the element is tangent to the line given by the intersection of the channel wall and the place at constant z cutting the channel. The pressure force on the element is then

$$\Delta F_p = \Delta L \Delta z \rho g(y-z) \tag{10}$$

The component of this force in the downstream(x direction) is

$$\Delta F = \Delta F_p \sin\theta_1 = \Delta L \Delta z \rho g(y-z)\sin\theta_1 \tag{11}$$

We wish to find the force on the side of the channel per unit length of channel. To that end substitute for ΔL from $\Delta x = \Delta L\cos\theta_1$ in Eq. 11 to get

$$\Delta F = \Delta x \Delta z \rho g(y-z)\tan\theta_1 \tag{12}$$

for the force in the downstream direction from one side of the channel. A force acts on both sides of the channel so that the total force is

$$\Delta F_T = \Delta x \Delta z \rho g(y-z)(\tan\theta_1 + \tan\theta_2) \tag{13}$$

Now the tangents of the angles can be replaced using Eq. 9 to yield

$$\Delta F_T = \Delta x \Delta z \rho g (y - z) \left. \frac{\partial T}{\partial x} \right|_z \tag{14}$$

because $T = T_1 + T_2$. Dividing both sides of Eq. 14 by Δx then gives the force per unit length for an element of vertical height Δz

$$\frac{\Delta F_T}{\Delta x} = \rho g (y - z) \left. \frac{\partial T}{\partial x} \right|_z \tag{15}$$

and after appropriate limiting processes and integration we get the force per unit length for the channel over the depth y as

$$F_x^y = \rho g \int_0^y (y - z) \frac{\partial}{\partial x} T(x, z)\, dz \tag{16}$$

Dividing both sides by ρg yields the term we have been seeking as

$$J_x^y = \int_0^y (y - z) \frac{\partial}{\partial x} T(x, z)\, dz = \int_0^y \frac{\partial}{\partial x} A(x, z)\, dz \tag{17}$$

Therefore, the downstream component of the pressure force on the sides of the channel are given by the product of ρg and the derivative of the first moment of area at constant depth with respect to distance along the channel.

The Dynamic Elements

The static elements are used to define the dynamic elements with the addition of information relating to the movement of water. The conveyance is the simplest, at least if the Manning friction loss relationship is used. The conveyance for a compact channel, where a compact channel is shaped such that the ratio of the flow area to the wetted perimeter, the hydraulic radius, adequately describes the effect of channel shape on the friction losses, is

$$K(x, y) = \frac{1.49}{n} A(x, y) R(x, y)^{2/3} \tag{18}$$

where $R(x, y)$ = hydraulic radius = $A(x, y)/P(x, y)$; and n = Manning's roughness coefficient. If the cross section is non-compact, it must be subdivided. This is discussed below when the approximations to the cross section elements are discussed.

The other dynamic elements, the momentum and kinetic energy flux coefficients, correct for the effect of non-uniform velocity distributions. In one-dimensional flow, we use the average velocity to compute the flux of momentum and kinetic energy. However, these fluxes involve powers of the velocity at each point of the cross section so that an error is committed if the average velocity is used. Stated roughly the square of the average velocity does not equal the sums of the squares of the velocities used to define the average.

The average velocity is defined so that continuity is preserved. That is, the flow rate Q for the cross section is defined by

$$Q = \int_A v\, dA \tag{19}$$

where v is the velocity at each point in the cross section. The average velocity is then simply defined as $V = Q/A$. The flux of momentum is defined similarly. First, however, let us address the concept of a flux of momentum. Flux is another word for flow. Flow gets overworked in most

fluid dynamic contexts so it is useful to have another word which means the same thing. Since the water is the medium which is transporting the momentum, it is perhaps most meaningful to try to define the concept of the momentum content of the water per unit volume and then multiply by the rate of flow to develop the concept of momentum flux. That is

$$momentum\ flux = (momentum/unit\ volume) \times (flow\ rate)$$

Now it seems evident that

$$momentum/unit\ volume = (mass/unit\ volume) \times\ velocity$$

because the basic definition of momentum is $mass \times velocity$. Furthermore $flow\ rate = area \times velocity$. Therefore

$$momentum\ flux = (mass/unit\ volume) \times velocity \times velocity \times area$$

Thus the momentum flux through a small area, ΔA, is $\rho v^2 \Delta A$. The limit of the sum of these fluxes for the cross section becomes

$$M_F = \rho \int_A v^2\, dA \tag{20}$$

We want the momentum flux computed using the average velocity to be the same as the momentum flux as computed from the point velocities in the cross section. Thus we introduce a coefficient, β, which is supposed to correct for the errors introduced by using the average velocity instead of the true velocity field in the cross section. The defining equation for, β, the momentum flux coefficient, is then

$$\beta V^2 A = \int_A v^2\, dA \tag{21}$$

where ρ is assumed to be constant and therefore vanishes from the relationship. Solving for β yields

$$\beta = \frac{1}{QV} \int_A v^2\, dA \tag{22}$$

The kinetic energy coefficient, α, is defined in a similar manner. Kinetic energy replaces momentum in the concept development and we get a defining equation

$$\alpha = \frac{1}{QV^2} \int_A v^3\, dA \tag{23}$$

where again ρ vanishes.

If we assume that the velocities are uni-directional(all downstream) but non-uniform across the section we find that

$$\alpha - 1 = 3(\beta - 1) + \frac{1}{QV^2} \int_A (\delta v)^3\, dA \tag{24}$$

Here $\delta v = v - V$ = the deviation of the point velocity from the average velocity. Equations 22 and 23 show that $\alpha > \beta$. I developed Eq. 24 from results on page 115 of **Engineering Fluid Mechanics** by Charles Jaeger as translated by P. O. Wolf.

Approximating the Elements of a Cross Section

The definitions of the elements of a cross section are rigorous and exact if the boundary of the cross section is known exactly. This is only true for design computations for artificial channels. It is not even true for artificial channels as constructed because there are always acceptable variations from the design computations. Concrete and steel closed conduits also have manufacturing tolerances as large as 2 *per cent* from the nominal dimensions. Therefore, we are always approximating the elements of a cross section. Therefore, we need to seek some means of defining the elements for a cross section so that the approximation will be both convenient, consistent, and sufficiently accurate.

Channels of regular shape, such as trapezoidal, rectangular, circular, *etc.* can be represented by simple formulas. However, cross sections of that shape appear infrequently in most stream systems(excluding storm sewers) and furthermore it proves convenient to represent all cross sections in the same way. FEQ accomplishes this by using a lookup table for the cross sectional elements. A carefully defined table is not only convenient but also consistent and accurate. The construction of such a table begins with a definition of the practical boundary of a cross section.

Figure 2 shows a sketch of a possible cross section boundary with selected points on the boundary marked and connected with straight lines. In practice the boundary of a cross section is found by measuring the horizontal distance to points on its periphery at which elevation is measured. These points should, in theory, be selected so that the variation of the boundary between these points is approximately linear so that the assumption of linear variation is accurate. In all subsequent work the boundary of the cross section is taken to be given by the polygonal shape established by connecting the surveyed points by straight lines. The degree of approximation depends on the skill of the survey crew and can only be estimated by making another more detailed survey of the cross section with more points.

Figure 2 shows points of subdivision to take into account changes in shape or boundary roughness. The boundaries between the subsections must occur at a measured point on the cross section boundary. FEQUTL computes the cross section element values in the following sequence of steps.

1. Rank the elevations, $\{z_i : i = 1, \ldots, n_p\}$, from smallest to largest, delete repeated values, and subtract the smallest value from each distinct elevation to produce a sequence of ascending depths, $\{y_i : i = 1, \ldots, n_p\}$. Here, n_p = the number of points on the boundary.

2. Scan the depth sequence and insert the NRZERO value given by the user as well as additional depth values to make the largest depth interval less than or equal to the user value of DZLIM. NRZERO and DZLIM are user supplied parameters for FEQUTL. A depth value near to zero depth may not exist in the depth sequence computed in item 1. A near zero depth value (NRZERO) is needed to improve the accuracy of the interpolation for conveyance at small depths. DZLIM gives the maximum depth interval to be allowed in the table to again improve the accuracy of the interpolation for conveyance.

3. For each depth value in the depth sequence established in item 2, compute the top width, T_i, wetted perimeter, P_i, area, A_i, and first moment of area, J_i, for each of the m subsections in the cross section where i denotes the subsection number. FEQUTL does this by scanning the cross section boundary from left to right and computing these values for each line segment which would be partially or completely under water if the cross section held water at the specified depth value. The values for each line segment are added to totals maintained for each distinct subsection number. It is imperative that each subsection be given a unique number even if the roughnesses are the same. If this is not done FEQUTL will combine totally disjoint and disparate parts of the cross section into one subsection. This can lead to significant errors in the conveyance. FEQUTL also extends the low end of the cross section vertically with a

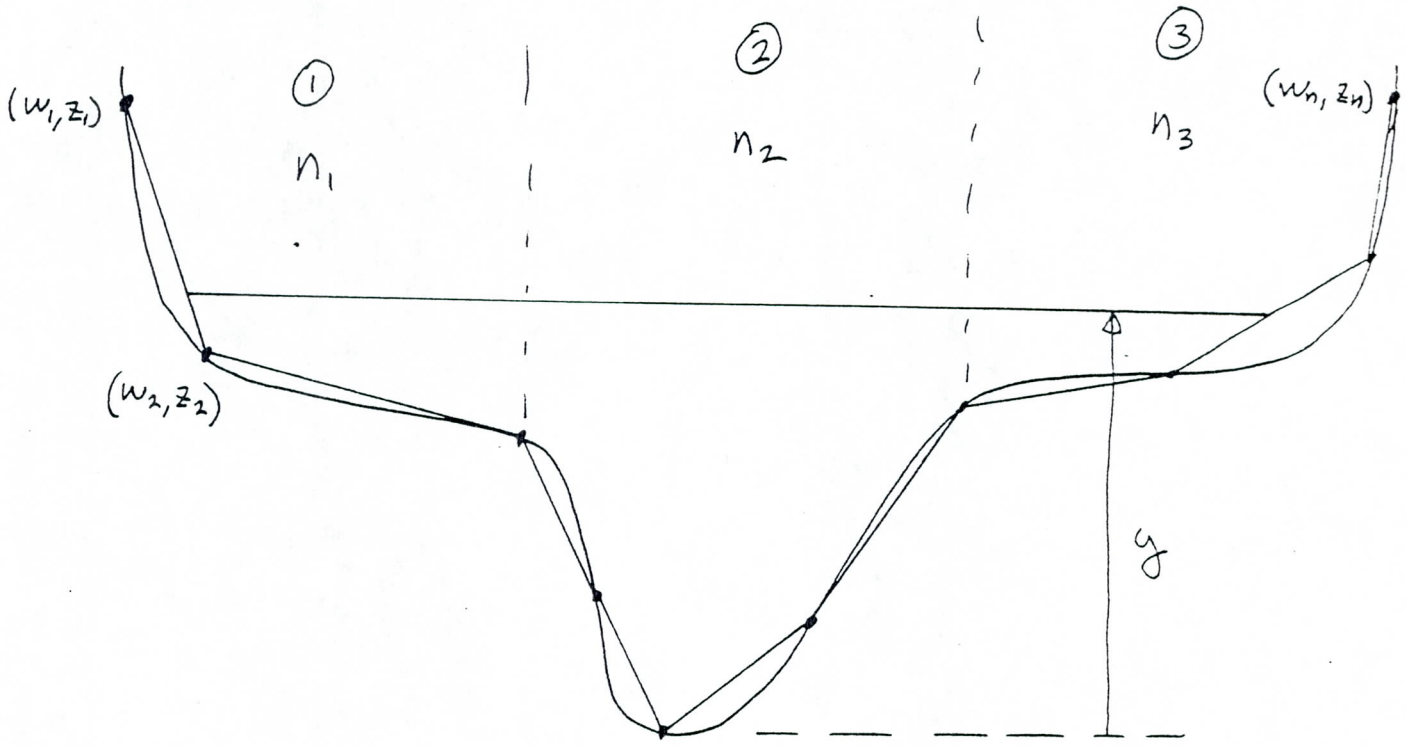


Figure 2: Approximation to Cross Section Elements

frictionless wall so that the elements can be computed to the maximum depth in the sequence of depths. FEQUTL currently(Version 2.7) gives no warning that this has been done.

4. Compute the element values at each depth value in the depth sequence. The following sequence of equations defines the elements at the current depth in the depth sequence:

$$T = \sum_{i=1}^{m} T_i \tag{25}$$

$$A = \sum_{i=1}^{m} A_i \tag{26}$$

$$J = \sum_{i=1}^{m} J_i \tag{27}$$

$$K_i = \frac{1.49}{n} A_i (A_i/P_i)^{2/3} \tag{28}$$

$$K = \sum_{i=1}^{m} K_i \tag{29}$$

$$\alpha = \frac{A^2}{K^3} \sum_{i=1}^{m} \alpha_i \frac{K_i^3}{A_i^2} \tag{30}$$

$$\beta = \frac{A}{K^2} \sum_{i=1}^{m} \beta_i \frac{K_i^2}{A_i} \tag{31}$$

Equations 30 and 31 are based on approximating the integrals in Eqs. 22 and 23 by assuming that the velocity in each subsection is given by $K_i S_f^{1/2}/A_i$ and that the average velocity for the cross section is given by $K S_f^{1/2}/A$. The friction slope, S_f, is assumed to be the same for all subsections and therefore vanishes from the final relationships. In addition, FEQUTL allows for an estimated value for the flux coefficients in each subsection. If USGSBETA=YES, then FEQUTL estimates subsection values of these coefficients as described in the Input Description for FEQUTL. If USGSBETA=NO, then FEQUTL sets the subsection flux coefficients to 1.0.

5. Place the elements in a table for later use by either FEQ or FEQUTL. Tables of type 1 or 12 represent the cross sectional elements. Tables of type 1 do not tabulate the kinetic energy flux coefficient.

Once the table is complete it can be used to find values of the elements at any depth in the range of the table. Only a finite number of depth values are tabulated and FEQ uses the following rules for finding values of the elements corresponding to depths intermediate to the tabulated depths.

1. Interpolate linearly for the top width. Let y_1 and y_2 be two consecutive depth values defining the depth interval containing the depth, y, at which we wish to find the cross sectional elements. That is, it is true that $y_1 \leq y \leq y_2$. Then the top width at depth y is given by $T_y = T_1 + h(T_2 - T_1)/\Delta y$ where $h = y - y_1$ and $\Delta y = y_2 - y_1$. All elements with the subscript 1 are at depth y_1 and all elements with the subscript 2 are at depth y_2. The interpolated value is exactly in agreement with the value which would have been obtained by FEQUTL in its computations if the depth value y were in the sequence of depth values defined by FEQUTL. The assumption of linear variation of the cross section boundary between points

on its periphery implies linear variation between the distinct depth values derived from these points. Thus the interpolation introduces no additional error into the top width value.

2. Use the trapezoidal rule for computing the area. That is, the area at depth y is given by $A_y = A_1 + h(T_1 + T_y)/2$. This is also in exact agreement with the values obtained from FEQUTL because the trapezoidal rule integrates a linear function exactly. Thus the value of area is consistent with the values of area computed in FEQUTL.

3. Use the corrected trapezoidal rule for computing the first moment of area. That is, the first moment of area at depth y is given by $J_y = J_1 + h(A_1 + A_y)/2 - h^2(T_y - T_1)/12$. The values of first moment given by this equation are again in exact agreement with those from FEQUTL because the corrected trapezoidal rule integrates cubic functions exactly and the variation of area in the interval between tabulated depths is only quadratic.

4. Interpolate for the conveyance assuming that the square root of conveyance varies linearly between tabulated points. This is only approximately true but the error can be made small by requesting that a few additional points be tabulated in the table.

5. Interpolate linearly for the flux coefficients. This is again only approximate but seems consistent with the approximate nature of the tabulated flux coefficients.

Tables of type 12, currently used only in the CULVERT command of FEQUTL, also tabulate the critical flow. Plans are underway to require tables of type 12 for some locations in FEQ also to make computations not only more accurate but more robust. The computation of critical flow in a consistent manner is difficult and has not yet been solved to my satisfaction.

Consistent Definition of Critical Flow

Critical flow is an important concept in open channel hydraulics because it is the boundary between two broad classes of flow which must often be distinguished in order to understand what is happening and to compute estimates of the flow variables. I will discuss critical flow in terms of steady flow since unsteady flow only complicates the derivations without adding much insight. Traditionally critical flow is defined as the point at which the specific energy is a minimum when the flow rate is held constant, where the specific energy, $E(Q, y)$ is defined as the sum of the velocity head and the depth of flow. That is

$$E(y, Q) = \frac{Q^2}{2gA(y)^2} + y \tag{32}$$

I have used explicit functional notation to emphasize the dependence on depth and on flow rate in Eq. 32. Subsequent equations will only introduce explicit arguments when necessary to show the function dependence. Otherwise, any cross sectional element appearing in an equation should be assumed to be a function of the maximum depth in the cross section. Setting the partial derivative of specific energy with respect to depth to zero yields

$$Q_c = \sqrt{\frac{gA^3}{T}} = A\sqrt{gA/T} \tag{33}$$

Here Q_c = critical flow rate which is the flow that would cause the given depth, y, to produce a minimum in the specific energy. It proves more convenient to work with critical flow than the depth at critical flow in the current discussion. Most introductory treatments go on to develop the concept of force plus momentum, M, which is the sum of the hydrostatic pressure force on a section and the momentum flux for the section(treating the density of water as 1 since it is constant). Thus we get

$$M(y,Q) = gJ + \frac{Q^2}{A} \tag{34}$$

as the definition of force plus momentum. Setting the partial derivative of force plus momentum with respect to depth to zero yields

$$Q_c = \sqrt{\frac{gA^3}{T}} = A\sqrt{gA/T} \tag{35}$$

which is exactly equal to the result obtained from minimization of specific energy.

Much is made of this equivalence in some introductory texts and with good reason. If we can assume that the cross sections are compact and the velocity distribution is essentially uniform, then this result follows. However, as soon as we introduce the flux coefficients to at least partially represent the effect of the non-uniformity, we have opened a Pandora's Box of one-dimensional hydraulics. Most treatments, if they discuss the effect of non-uniformity of velocity at all, ignore or are unaware of the inconsistencies introduced by admitting that $\alpha \neq \beta \neq 1$. All treatments of which I am aware, save one, ignore the inconsistency completely. What is the inconsistency?

Briefly, if the flux coefficients are included in the analysis, and if they are estimated by the usual means, *e. g.* as outlined above, then the critical flow values, as computed, are no longer the same. The difference is not small and can be larger than 30 *per cent.* We should recognize immediately that we cannot compute the flux coefficients exactly in any case and this difference may be a sign of the error in the our understanding of the problem. The flux coefficients depend on the velocity distribution which is only approximately known. However, it makes sense to approximate the flux coefficients in a manner which is at least approximately consistent. Furthermore, the inconsistency between critical flows causes problems within computer programs which make use of both the conservation of energy and the conservation of momentum.

Generalizing the specific energy and the force plus momentum values to include the flux coefficients yields

$$E(y,Q) = \alpha(y)\frac{Q^2}{2gA^2} + y \tag{36}$$

$$M(y,Q) = gJ + \beta(y)\frac{Q^2}{A} \tag{37}$$

As indicated in Eqs. 36 and 37, the flux coefficients are assumed to vary with the maximum depth in the cross section. This seems to be the minimum reasonable assumption. It makes no sense to assume that they are constant because then there is no way that the critical flows can be the same as I now show. Again setting the partial derivatives with respect to depth to zero and solving for the critical flow yields

$$Q_E = A\sqrt{\frac{gA}{\alpha T - \frac{A}{2}\frac{d\alpha}{dy}}} \tag{38}$$

$$Q_M = A\sqrt{\frac{gA}{\beta T - A\frac{d\alpha}{dy}}} \tag{39}$$

where Q_E = the critical flow defined using specific energy; and Q_M = the critical flow defined using force plus momentum. From these results it is clear that the functions representing the flux coefficients must follow certain restrictions in order for these two values to be the same at all depths.

Jaeger, in the book cited above, has an extensive discussion of the equivalence of these two definitions of critical flow. He included correction coefficients for potential energy and hydrostatic pressure force to include the effect of streamline curvature and was able to show that the two values of critical flow are the same. This assumes that the correct correction coefficients have been used. In our case only the flux coefficients are being used. So some of the difference could be the result of streamline curvature. Some of the difference can be attributed to this source but much of it cannot. There are flows for which streamline curvature is small and we still get the large difference in computed values.

For critical flow to be physically meaningful, the two values must be the same. Jaeger's results shows that mathematically they can be shown to be the same. This highlights the dual role of the concept of critical flow: it is both a mathematical result and a physical result. Mathematically, critical flow takes on a form dictated by the governing equation. This must be because when the flow is at critical, mathematical problems occur. Divisions by zero or a result of zero divided by zero occurs in the governing equation. As an example I derive an ordinary differential equation for the steady flow profile in a prismatic channel using both the conservation of energy and the conservation of momentum principles. The limitation to a prismatic channel minimizes the notational details and illustrates the problem of consistency adequately for my purposes.

The starting point for the derivation is the conservation of energy equation

$$\frac{dE}{dx} = S_0 - S_f \tag{40}$$

in which E is given by Eq. 36 and S_0 = the inclination of the bottom(or bottom slope taken as positive if the elevation decreases in the downstream direction); and S_f = the friction slope. Expanding the derivative on the left-hand side yields

$$\frac{dy}{dx}(1 + \frac{A}{2}\frac{d\alpha}{dy}\frac{Q^2}{gA^3} - \frac{\alpha Q^2 T}{gA^3}) = S_0 - S_f \tag{41}$$

Here we are assuming that the variation of α with distance at constant depth is zero. Re-arranging the left-hand side shows that

$$\frac{dy}{dx}[1 - Q^2(\frac{\alpha T - \frac{A}{2}\frac{d\alpha}{dy}}{gA^3})] = S_0 - S_f \tag{42}$$

The factor on Q^2 is just the inverse square of Q_E from Eq. 38 so that the product is the square of a Froude number, F_E^2. Making this substitution yields the final form

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - \mathrm{F}_E^2} \tag{43}$$

Note that if $\alpha = 1$, this reduces to the form normally presented in textbooks on open channel flow.

The conservation of momentum for this special case becomes simply

$$\frac{dM}{dx} = gA(S_0 - S_f) \tag{44}$$

where M is given by Eq. 37. Carrying out the same operations as for the energy conservation form yields a final form

$$\frac{dy}{dx} = \frac{S_0 - S_f}{1 - \mathrm{F}_M^2} \tag{45}$$

with

$$F_M^2 = Q^2\left[\frac{\beta T - A\frac{d\beta}{dy}}{gA^3}\right] \tag{46}$$

Again if $\beta = 1$ the form normally presented in textbooks on open channel flow is obtained.

All of these forms are identical except for the definition of the Froude number. For the case of steady flow in a prismatic channel there is no good reason for preferring one conservation principle over the other. It is only tradition which prefers the energy conservation principle in this case. Thus there are potentially three different differential equations giving three different profiles. These profiles will differ significantly if the Froude numbers for a given depth and flow differ significantly. Of course there is only one real profile that the water follows. The three equations are all designed to approximate the true water surface profile. Of course the equation that assumes $\alpha = \beta = 1$ is invalid if the flux coefficients differ from 1 by too much. How much is too much cannot be specified but likely a deviation of 10 *per cent* from 1 for β is cause for some concern. About 36 out of the 62 values of β computed by the USGS from current meter measurements for channels of Type A exceed this value. Type A channels are described as, "A natural trapezoidal-shaped channel without overbank flow and no bridge piers or other manmade obstructions." Thus these channels were compact by any sense of the meaning of a compact channel and yet more than one-half of them had a computed $\beta > 1.1$. Eight out of the 62 type A channel measurements had $\beta > 1.2$. Using the linear relationship established between α and β in the Input Description for FEQUTL the corresponding limits for α are about 1.29 and 1.58. The average values for α for the 62 measurements was 1.36 and the average for β was 1.12. These measurements show that the flux coefficients may be significantly different than 1 even in compact natural channels. The inclusion of extensive overbank flow could make the values much higher. Therefore, the inconsistency in critical flow and the resulting difference in water surface profiles is not an occasional occurrence.

A further practical problem with the critical flow estimates which use the flux coefficients is that the critical flow may become undefined because its square is negative. This comes about when there are large inconsistencies between the estimated value of the flux coefficient and its estimated rate of change. The rates of change of the estimates given in Eqs. 30 and 31 when computed rigorously show a discontinuity at each change in the slopes of the lines comprising the boundary of the measured cross section. This follows because the rate of change of the wetted perimeter with depth is discontinuous at each change in slope. Thus there are two values of critical flow at each tabulated point at which the slope of the cross section boundary changes. This is hardly a heartening finding! Thus we must develop methods for estimating the flux coefficients that will at least have continuous first derivatives with respect to changes in maximum depth.

These inconsistencies imply that there is good reason to develop a means for estimating the flux coefficients that will reduce the inconsistency and if possible make them small enough to be of little concern. As a first step in that direction FEQUTL offers an option for computing the flux coefficients for natural open channels which so far has shown promise. It is based on a method suggested by J. C. Schönfeld, "Propagation of tides and similar waves", *Thesis*, Technical University, Delft, The Netherlands, 1951. This method integrates the depth averaged velocities obtained by locally applying Manning's equation at each point across the cross section.

Figure 3 shows a typical line segment on the boundary of the cross section and the water surface above it. Let m = slope of the boundary line with m defined as

$$m = \frac{z_R - z_L}{x_R - x_L} \tag{47}$$

then the elevation of a point on the boundary line at offset x where $x_L \leq x \leq x_R$ is

$$z = z_L + m(x - x_L) \tag{48}$$

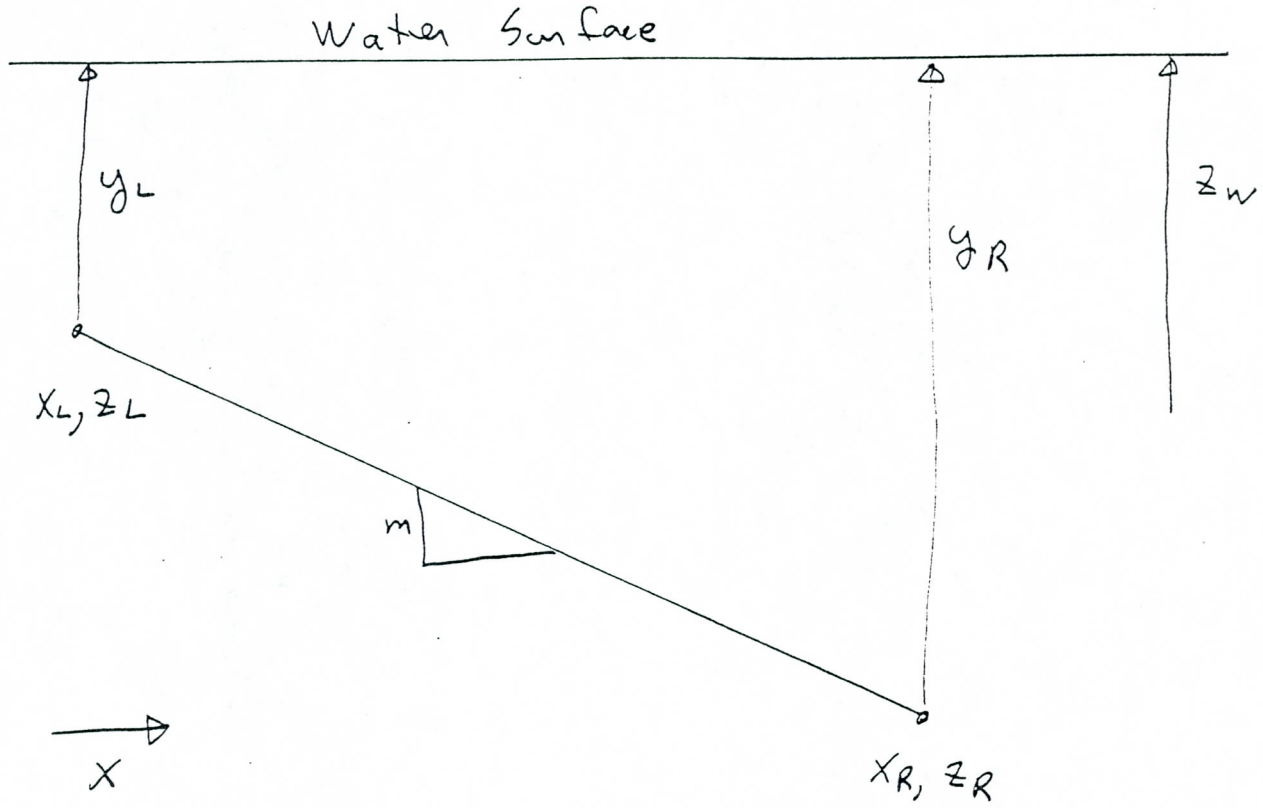


Figure 3: Typical Line Segment for NEWBETA Method

and the local depth, y, is given by

$$y(x) = z_w - z = z_w - z_L - m(x - x_L) \tag{49}$$

In each vertical we assume that the mean velocity is given by

$$V(x) = \frac{1.49}{n} R(x)^{2/3} \tag{50}$$

with the hydraulic radius being given by

$$R(x) = \frac{y(x)}{\sqrt{1+m^2}} \tag{51}$$

The inclusion of the slope of the boundary line approximately represents the reduced velocity at shallow depths with sloping boundaries. On the steeper slopes the hydraulic radius is significantly smaller than the depth using this approximation. I have also suppressed the friction slope term in Eq. 50 because it is the same everywhere and would not appear in the final equation.

The following steps are used in this method to estimate the flux coefficients and the critical flow rate:

1. Compute the flow rate above each line segment and below the water surface by integrating the velocity given in Eq. 50 from x_L to x_R. Compute the sum of the flow for each line segment to get the total flow for the cross section. Let

$$C = \frac{1.49}{n}\left(\frac{1}{\sqrt{1+m^2}}\right)^{2/3} \tag{52}$$

and then the flow for a typical line segment, Q_i, becomes

$$Q_i = C \int_{x_L}^{x_R} [z_w - z_L - m(x - x_L)]^{5/3}\, dx \tag{53}$$

where the subscript i is omitted from the terms on the right hand side to simplify notation. The integral in Eq. 53 evaluates to

$$Q_i = -\frac{3C}{8m}(y_R^{8/3} - y_L^{8/3}) \tag{54}$$

with a derivative of

$$\frac{dQ_i}{dz_w} = -\frac{C}{m}(y_R^{5/3} - y_L^{5/3}) \tag{55}$$

if $m \neq 0$ and to

$$Q_i = C y_L^{5/3}(x_R - x_L) \tag{56}$$

with a derivative of

$$\frac{dQ_i}{dz_w} = \frac{5C}{3} y_L^{2/3}(x_R - x_L) \tag{57}$$

if $m = 0$ because $y_L = y_R$. The total flow for the cross section then becomes

$$Q = \sum_{i=1}^{n_s} Q_i \tag{58}$$

with a derivative of

$$\frac{dQ}{dz_w} = \sum_{i=1}^{n_s} \frac{dQ_i}{dz_w} \tag{59}$$

where n_s = number of line segments below the water surface. This flow estimate is used only for the estimation of the flux coefficients and never for estimating the conveyance of the cross section.

2. Compute the flux of kinetic energy above each line segment and below the water surface by integrating the local flux and sum the fluxes for each line segment to get the flux for the cross section. To simplify notation drop the factor of 1/2 from the kinetic energy. Then the flux of kinetic energy, F_{E_i}, for a typical line segment is given by

$$F_{E_i} = \int_{x_L}^{x_R} y(x)V(x)^3\,dx \tag{60}$$

Substituting for the depth and velocity from Eq. 49 and 50 yields

$$F_{E_i} = C^3 \int_{x_L}^{x_R} [z_w - z_L - m(x - x_L)]^3\,dx \tag{61}$$

which simplifies to

$$F_{E_i} = -\frac{C^3}{4m}(y_R^4 - y_L^4) \tag{62}$$

with a derivative of

$$\frac{dF_{E_i}}{dz_w} = -\frac{C^3}{m}(y_R^3 - y_L^3) \tag{63}$$

if $m \neq 0$ and to

$$F_{E_i} = C^3 y_L^3 (x_R - x_L) \tag{64}$$

with a derivative of

$$\frac{dF_{E_i}}{dz_w} = 3C^3 y_L^2 (x_R - x_L) \tag{65}$$

if $m = 0$. The total flux of kinetic energy for the cross section becomes

$$F_E = \sum_{i=1}^{n_s} F_{E_i} \tag{66}$$

with a derivative of

$$\frac{dF_E}{dz_w} = \sum_{i=1}^{n_s} \frac{dF_{E_i}}{dz_w} \tag{67}$$

3. Compute the momentum flux for each line segment and sum the fluxes to get the total momentum flux for the cross section. The flux of momentum, F_{M_i}, for a typical line segment is given by

$$F_{M_i} = \int_{x_L}^{x_R} y(x)V(x)^2\,dx \tag{68}$$

Substituting for the depth and velocity from Eq. 49 and 50 yields

$$F_{M_i} = C^2 \int_{x_L}^{x_R} [z_w - z_L - m(x - x_L)]^{7/3}\,dx \tag{69}$$

which simplifies to

$$F_{M_i} = -\frac{3C^2}{10m}(y_R^{10/3} - y_L^{10/3}) \tag{70}$$

with a derivative of

$$\frac{dF_{M_i}}{dz_w} = -\frac{C^2}{m}(y_R^{7/3} - y_L^{7/3}) \tag{71}$$

if $m \neq 0$ and to

$$F_{M_i} = C^2 y_L^{7/3}(x_R - x_L) \tag{72}$$

with a derivative of

$$\frac{dF_{M_i}}{dz_w} = \frac{7C^2}{3} y_L^{4/3}(x_R - x_L) \tag{73}$$

if $m = 0$. The total flux of momentum for the cross section becomes

$$F_M = \sum_{i=1}^{n_s} F_{M_i} \tag{74}$$

with a derivative of

$$\frac{dF_M}{dz_w} = \sum_{i=1}^{n_s} \frac{dF_{M_i}}{dz_w} \tag{75}$$

4. Compute the estimates of the flux coefficients and their derivatives using

$$\alpha = \frac{A^2}{Q^3} F_E \tag{76}$$

$$\beta = \frac{A}{Q^2} F_M \tag{77}$$

$$\frac{d\alpha}{dz_w} = \frac{2ATF_E}{Q^3} - \frac{3A^2F_E}{Q^4}\frac{dQ}{dz_w} + \frac{A^2}{Q^3}\frac{dF_E}{dz_w} \tag{78}$$

$$\frac{d\beta}{dz_w} = \frac{TF_M}{Q^2} - \frac{2AF_M}{Q^3}\frac{dQ}{dz_w} + \frac{A}{Q^2}\frac{dF_M}{dz_w} \tag{79}$$

5. Compute the critical flow rate using Eqs. 38 and 39. Use the geometric mean of these two values if both are defined. That is, the tabulated critical flow in table type 12 is $\sqrt{Q_M Q_E}$. If either of these critical flow estimates is undefined, FEQUTL uses Q_c which is always defined.

This method has not encountered an undefined critical flow in testing with over 300 natural cross sections. The method still needs improvement because the two estimates of critical flow can still be far apart and the values of the flux coefficients are constant for some channel shapes. The current implementation of the method assumes that the local flux coefficient for each vertical is 1. Experiments are being planned to add a vertical velocity distribution based on one of the law-of-the-wall velocity distributions based on Prandtl's mixing length theory of turbulent momentum transfer. These distributions have one or two parameters which can be varied to represent different conditions of roughness of the wall and different assumptions on the nature of the turbulence. Perhaps variation of these parameters can force the estimates of critical flow to agree more closely. A final approach to try is to replace the vertical velocity distribution with the velocity distribution which is locally perpendicular to the wall. This is likely closer to reality but is much more difficult to implement because the cross section then must be broken into polygonal subregions which can become quite complex. The goal throughout is to compute reasonable estimates of the flux coefficients and at the same time have values of critical flow from the momentum and energy principles that nearly match.

Unsteady Open Channel Flow Equations

With the definitions and the approximation to the cross sectional elements established, we can now turn to the development of the unsteady open channel flow equations used in FEQ. I will not limit myself to the equations used in FEQ because other forms of the equations are required to better understand the nature of one-dimensional open channel flow. The reader should be warned that there are many different forms for these equations. Only a few of them will be outlined here. I will start with what I call the integral form of the equations because I find it to be the most closely related to the basic physical principles involved. Not many treatments use this form but I prefer it to the differential forms. Differential forms will be presented but without detailed derivation.

Integral Form of the Equations

The integral form is a macroscopic statement of the principles of conservation of mass and momentum for what is called a control volume. A control volume is a conceptual device for clearly describing the various fluxes and forces present in an open channel flow. Figure 4 shows a sketch of the control volume we will be using. The upstream face of the control volume at station, x_L, is assumed to be taken perpendicular to the flow direction at that point in the channel. The downstream face of the control volume at station, x_R, is also assumed to be perpendicular to the flow direction. The sides and bottom of the control volume are formed by the sides and bottom of the stream channel. The top of the control volume is formed by the water surface. The length of the control volume, $\Delta x = x_R - x_L$, does not have to be small.

We make the following major assumptions about the flow in making the derivation:

1. The direction of the mean velocity at each section is closely parallel to the direction of the channel. That is, the flow is principally one dimensional and essentially parallel to the walls and bottom forming the channel.

2. The channel boundary is fixed.

3. The pressure distribution is hydrostatic. This implies that the wave length of a disturbance in the channel is much longer than the depth of the water. Therefore the equations we derive

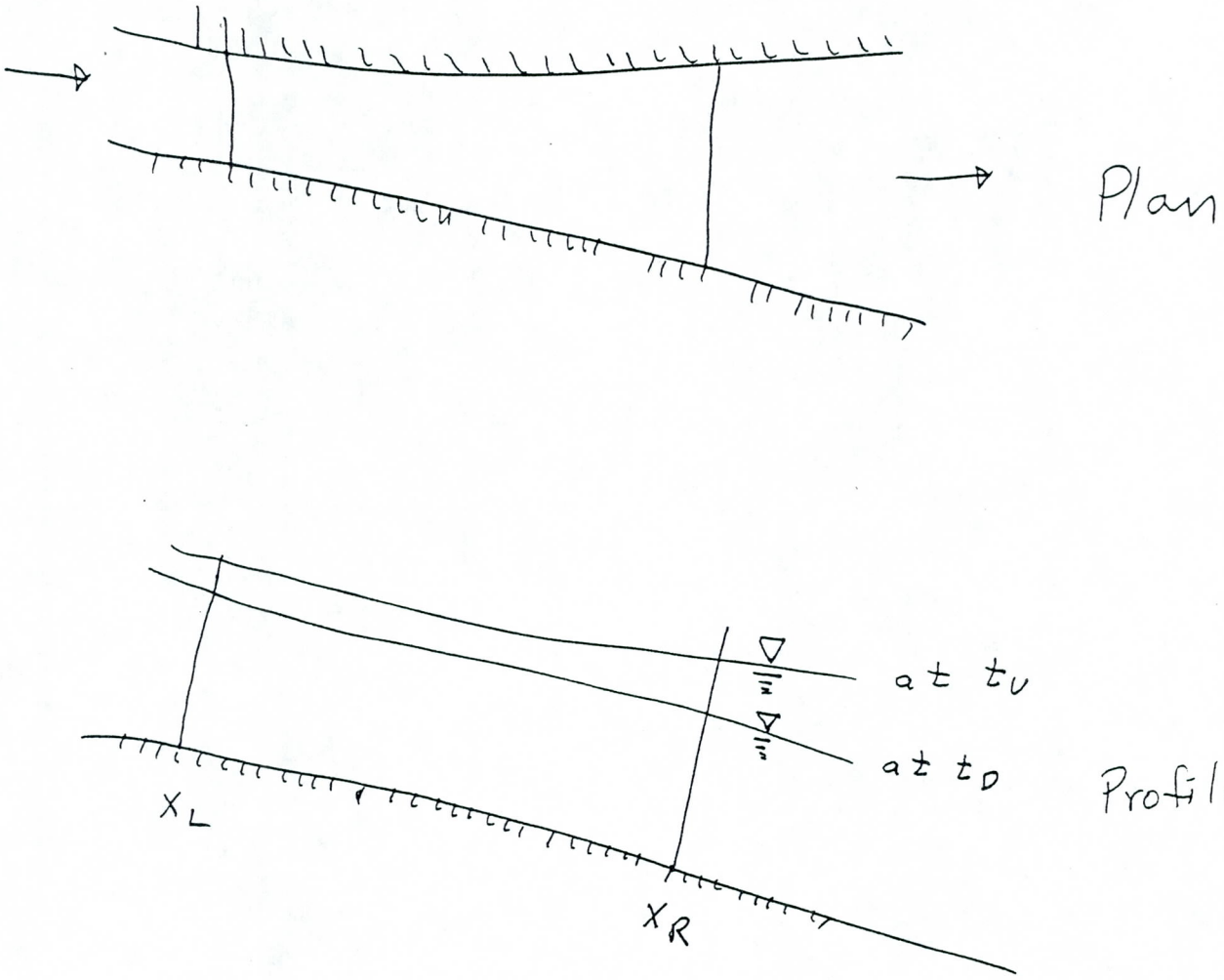


Figure 4:Control Volume for Unsteady Flow Equations

from these assumptions are often called the shallow-water equations and the resulting wave motions are called shallow-water waves. A shallow-water wave is a disturbance in the water which affects the entire vertical column of water from the channel bottom to the surface. The depth of the water is immaterial: it may be thousands of feet deep as in a tsunami in the ocean or it may be less than one foot deep in a small brook. In the oceans the wave length of a tsunami is hundreds of miles and in a small brook the wave length may be hundreds of feet. In both cases the disturbance is a shallow-water wave because the depth is small relative to the wave length. Deep-water waves, in contrast only affect the surface region of the water and pressure distribution deviates appreciably from hydrostatic.

4. The slope of the channel is small enough so that $\sin\theta \approx \tan\theta \approx \theta$ and $\cos\theta \approx 1$ where θ is the angle that the bottom makes with the horizontal.

5. The channel alignment may be treated as if it were rectilinear even though the channel is curvilinear. This implies that the water surface across the channel is treated as horizontal.

6. The boundary friction force may be estimated with a steady uniform flow formula.

The Conservation of Mass

The conservation of mass principle for the control volume is

$$\int_{x_L}^{x_R} [A(x,t_U) - A(x,t_D)]\, dx = \int_{t_D}^{t_U} [Q(x_L,t) + I(t) - Q(x_R,t)]\, dt \tag{80}$$

The density does not appear in Eq. 80 because it would appear on each term as a constant multiplier and cancel from the relationship. Thus the conservation of mass is equivalent to conservation of water volume in FEQ. Equation 80 is a precise statement of a simple concept. The left hand side of Eq. 80 gives the change in volume of water contained in the control volume during the time interval (t_D, t_U). The meaning of the subscripts on time will be explained below, but for now they represent two time points with $t_U > t_D$. The integral of flow area with respect to distance at a fixed time defines the volume of water in the control volume at that time. The right hand side of Eq. 80 gives the difference in flow volume during the time interval. Water enters from upstream, $Q(x_L,t)$, and exits downstream, $Q(x_R,t)$, as well as entering over or through the sides of the channel, $I(t)$. Thus in words, Eq. 80 states that the change in volume of the water in the control volume during any time interval is equal to the difference between the volume of inflow and the volume of outflow during that time interval. The term, $I(t)$, is often called the lateral inflow and could come from several sources. Runoff from the land surface, discharges from sewers, outflows of water from pumping, *etc.* If the flow is out of the channel then $I(t)$ is negative.

The Conservation of Momentum

The principle of conservation of water volume involves only the flows and changes in volumes. The conservation of momentum involves the momentum flux as well as a variety of forces which are present on the boundaries of the control volume. Because forces are vectors, the momentum equation is vectorial. Therefore, we write the terms relative to the direction assigned to downstream flow in the channel. The conservation principle asserts that the change in momentum of the water in the control volume over any time period is given by the net downstream impulse during the time period plus the influx of momentum during the time period and less the efflux of momentum during the time period. Recall that impulse is a time integral of a force. The forces included are: pressure forces on the upstream and downstream face, downstream component of the pressure force on the

sides of the channel, the gravity force, channel friction, and wind shear stress on the water surface. The conservation of momentum for the control volume then becomes:

$$\rho \int_{x_L}^{x_R} [Q(x,t_U) - Q(x,t_D)]\, dx = \rho \int_{t_D}^{t_U} [\beta QV(x_L,t) - \beta QV(x_R,t)]\, dt + \rho g \int_{t_D}^{t_U} \left[J(x_L,t) + \int_{x_L}^{x_R} J_x^y\, dx - J(x_R,t) \right] dt + \rho g \int_{t_D}^{t_U} \int_{x_L}^{x_R} S_0 A\, dt dx - \int_{t_D}^{t_U} \int_{x_L}^{x_R} \tau_0 P\, dt dx + \int_{t_D}^{t_U} \int_{x_L}^{x_R} C_D \rho_a U^2 T \cos\phi\, dt dx \tag{81}$$

Here τ_0 = the friction force of the channel boundary on the water in the control volume; $C_D\rho_a U^2$ = the wind induced shear stress on the water surface in the direction of the wind velocity vector; ρ_a = density of air; U = wind velocity; C_D = dimensionless drag coefficient for wind shear stress; and ϕ = angle between the downstream flow velocity in the channel and the velocity of the wind. The integral on the left hand side of Eq. 81 gives the change in momentum. The product of flow rate and density gives the momentum per unit length of channel(mass/unit volume × unit area × velocity) and its integral with respect to distance gives the total momentum of the water in the control volume. The downstream component of force from the pressure force on the sides of the channel is also given by integration with respect to distance of the force per unit length derived earlier. The gravity force is represented by the integration of the product of density and area, the mass per unit length of channel, and the bottom slope of the channel. In Eq. 81 those elements which are integrated with respect to both time and distance do not have their arguments shown to simplify the notation. Both the argument of time and of distance are implicit in these instances.

The friction force term simplifies if we assume that the relationship between slope and boundary friction from steady uniform flow,

$$S_0 = \frac{\tau_0 P}{\rho g A} \tag{82}$$

can be generalized to non-unsteady flow by replacing the bottom slope with the friction slope, S_f. Using this result and dividing Eq. 81 by ρ yields

$$\int_{x_L}^{x_R} [Q(x,t_U) - Q(x,t_D)]\, dx = \int_{t_D}^{t_U} [\beta QV(x_L,t) - \beta QV(x_R,t)]\, dt + g \int_{t_D}^{t_U} \left[J(x_L,t) + \int_{x_L}^{x_R} J_x^y\, dx - J(x_R,t) \right] dt + g \int_{t_D}^{t_U} \int_{x_L}^{x_R} A(S_0 - S_f)\, dt dx + \int_{t_D}^{t_U} \int_{x_L}^{x_R} C_D \frac{\rho_a}{\rho} U^2 T \cos\phi\, dt dx \tag{83}$$

as the integral form for the conservation of momentum equation for open channel flow. In this equation we have ignored the momentum contribution from the lateral inflow. We rarely have good information about the velocity of the these flows and they are often nearly perpendicular to the flow in the channel.

You might wonder why the conservation of momentum equation is used in unsteady flow whereas the conservation of energy equation is often used in steady flow profile computations. One reason for the selection of the momentum equation is that it gives a better approximation to the effect of the incoming lateral inflows. This can become important during floods when the lateral inflows become large relative to the flow in the stream. The large energy losses associated with such flows are difficult to estimate. These losses would have to be estimated if a conservation of energy equation were used. We can avoid much of this problem by using a conservation of momentum equation which is concerned with the forces on the control volume and not the internal turbulence of the water in the control volume. It is true that the internal turbulence affects the shear stresses on the boundary but experiments with lateral inflow have shown that this effect is secondary and that the assumption of conservation of momentum gives a reasonable approximation to the flow. There are other reasons to prefer the mass-momentum formulation over a mass-energy formulation but these must be taken up later when the solution process is developed.

The integral form of the equations forms a basis for all other forms of the governing equations for unsteady open channel flow. These other forms involve differential equations derived by manipulating the integral form or an approximation to it by limits as the time and distance intervals approach zero. The wind stress terms will be omitted in these developments to simplify the equations because these terms add nothing to the role to be played by these equations in our discussion. Furthermore the momentum flux coefficients will be taken as 1.

The Conservation Form

Approximating the integrals in Eqs. 80 and 83 by finite differences and taking limits properly yields

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \tag{84}$$

$$\frac{\partial Q}{\partial t} + g\frac{\partial J}{\partial x} + \frac{\partial}{\partial x}(QV) = gA(S_0 - S_f) + gJ_x^y \tag{85}$$

where q is defined a function of distance and time such that

$$I(t) = \int_{x_l}^{x_R} q(x,t)dx \tag{86}$$

These are a pair of partial differential equations known as the conservation form.

The St. Venant Form

Expanding the derivatives in the conservation form and simplifying the equations yields

$$A\frac{\partial V}{\partial x} + VT\frac{\partial y}{\partial x} + T\frac{\partial y}{\partial t} + VA_x^y = q \tag{87}$$

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} + g\frac{\partial y}{\partial x} = g(S_0 - S_f) - \frac{Vq}{A} \tag{88}$$

which is often called the St. Venant form. This form of the equation or close relatives of it is the most common form in the literature but it is not always the best form to use in constructing a numerical solution.

The Characteristic Form

The final form of the equations to be presented here is obtained by transforming the St. Venant form so that derivatives taken in the proper directions, called characteristic directions, can be written as ordinary derivatives and not partial derivatives. The result of this transformation is

$$\left[\frac{\partial V}{\partial t} + \frac{dx}{dt}\frac{\partial V}{\partial x}\right] \pm \frac{g}{c}\left[\frac{\partial y}{\partial t} + \frac{dx}{dt}\frac{\partial y}{\partial x}\right] = g(S_0 - S_f) - \frac{Vq}{A} \mp \frac{c}{A}(VA_x^y - q) \tag{89}$$

$$\frac{dx}{dt} = V \pm c \tag{90}$$

where c = celerity. The celerity is the speed of an infinitesimal disturbance in the channel relative to the water. If the flux coefficients are taken to be unity, then the celerity turns out to be equal to Q_c/A with Q_c given by Eq. 33 above. If the characteristic form is derived from a mass-energy formulation the celerity is given by Q_E/A with Q_E. given by Eq. 38 and if it is derived from a mass-momentum formulation the celerity is given by Q_M/A with Q_M given by Eq. 39. This connection between the steady flow and unsteady flow should not be surprising because the steady flow equations are special cases of the unsteady flow equations. This result also shows that the consistency problems with critical flow carry over into unsteady flow as well. These unsteady flow results also show that the non-prismatic terms and the friction terms do not affect the celerity and justify ignoring them in deriving the steady flow relationships for critical flow.

The bracketed terms in Eq. 89 represent the ordinary derivatives of velocity and maximum depth when these derivatives are taken in the directions given by Eq. 90. Then Eq. 89 becomes

$$\frac{dV}{dt} \pm \frac{g}{c}\frac{dy}{dt} = g(S_0 - S_f) - \frac{Vq}{A} \mp \frac{c}{A}(VA_x^y - q) \tag{91}$$

Equation 91 is best understood as representing the rate of change of velocity and depth which an observer moving in the direction and velocity given by Eq. 90 would experience.

The various forms for the governing equations show a progression from the physical to the mathematical. The integral form and to some to a large extent the conservation form relate closely to the fluxes and forces involved in the flow. On the other hand, the St. Venant form and especially the characteristic form obscure or even eliminate this connection to the forces and fluxes. The characteristic form has lost almost all reference to its physical basis. However, the characteristic form provides insight into the phenomena of wave motion which is not at all evident in the other forms. This insight is vital to understanding the requirements which must be met as we try to find approximate solutions to these equations.

Nature of Shallow-Water Waves

The insight to be gained from the characteristic form of the governing equations is best visualized by tracking small identifiable disturbances in a stream channel. Imagine a long rectangular stream channel with no special features, a branch in the world view of FEQ. Also imagine that the flow is steady and subcritical but non-uniform. We wish to introduce small shallow-water wave disturbances. One way to do this is to imagine that a short segment of the channel bottom is made of some flexible material which can be given a sudden sharp but small displacement upward. This disturbs the whole column of water above the location of the flexible strip and is analogous to

the mechanism thought to initiate tsunamis in the Pacific Ocean. Because the flow is subcritical a shallow-water wave will move upstream and downstream. To keep track of the location of each of these small waves, we measure the location of the wave along the channel at periodic intervals. Then we can depict the path or trajectory followed by the wave or waves using a co-ordinate system in which the distance along the channel, x, is shown on the horizontal axis and the time, t, is shown on the vertical axis as in Fig. 5. This co-ordinate system defines the xt plane. Suppose that the disturbance was introduced at station x_L at time $t = t_0$. Small shallow-water waves will travel upstream and downstream from this station. The upstream wave will have a velocity $V - c$ and the downstream wave a velocity of $V + c$. In Fig. 5 the trajectory of the upstream wave is labeled $C-$ and the downstream wave is labeled $C+$. The region of the xt plane between these two trajectories is the region of influence of the disturbance at point x_L at time $t = t_0$. Outside this region the disturbance has no influence on the flow. Imagine further, that another disturbance has been introduced at a station, x_R, some distance downstream of x_L. The $C+$ and $C-$ trajectories for this disturbance are shown on Fig. 5 also. The region of the xt plane between the $C+$ trajectory of the disturbance at x_L and the $C-$ trajectory of the disturbance at x_R is called the domain of uniqueness because the flows in this region cannot be affected by disturbances upstream of X_L or downstream of x_R originating at any time $t \geq t_0$. The distance interval from x_L to x_R is called the interval of dependence for point P because what happens at point P is dependent on knowledge of the flow on this interval at time $t = t_0$.

These features of shallow-water wave motion are important in designing methods to compute approximations to the motion. All of these methods, for a variety of practical reasons, start from a known condition in the stream channel at a time we can call $t = t_0$, and then attempt to predict the conditions in the channel at some later time. The known conditions from which the computations start are called initial conditions. Again for practical reasons, the initial condition is almost always assumed to be a steady flow. To have any hope of adequately predicting what is happening at point P from information at $t = t_0$, we must have information about the flow on the interval of dependence for point P. If that information is not available to us, we cannot make a meaningful prediction because conditions unknown to us has the potential to affect the values at point P. Thus to predict the conditions at any point on the xt plane we must have available to us information about the interval of dependence for that point.

This requirement has implications at the boundaries of the channel. Now every channel is of finite length and at some point we start the analysis and at some point we must end the analysis so that boundaries are inevitable. Figure 6 shows possible conditions at the boundaries of channel. If the flow is subcritical the interval of dependence for the upstream-most point on the channel is partially upstream of the boundary point. Thus we cannot predict what happens at this boundary point unless we have some information about the flow conditions at that point. The $C+$ trajectory brings information to the flow at that point in the xt plane and yet our analysis for this channel stops at the boundary. Therefore, we must specify a single condition at that point. This condition, called a boundary condition, may be one of three types: flow given as a function of time, elevation given as a function of time, or a relationship between flow and elevation. This condition, then supplies the information which is lacking along the upstream boundary for the channel. The same is true at a downstream boundary if the flow is subcritical. Again part of the interval of dependence falls outside the channel length we are analyzing and a downstream boundary condition must be supplied.

If the flow is super critical at a boundary the required number of conditions we must supply changes. At an upstream boundary, we must supply both the flow and the elevation of the water because as Fig. 6 shows the interval of dependence of points on the upstream boundary in the xt plane fall completely outside the length of channel being analyzed. At the downstream end, no conditions are required because the interval of dependence falls completely within the length of

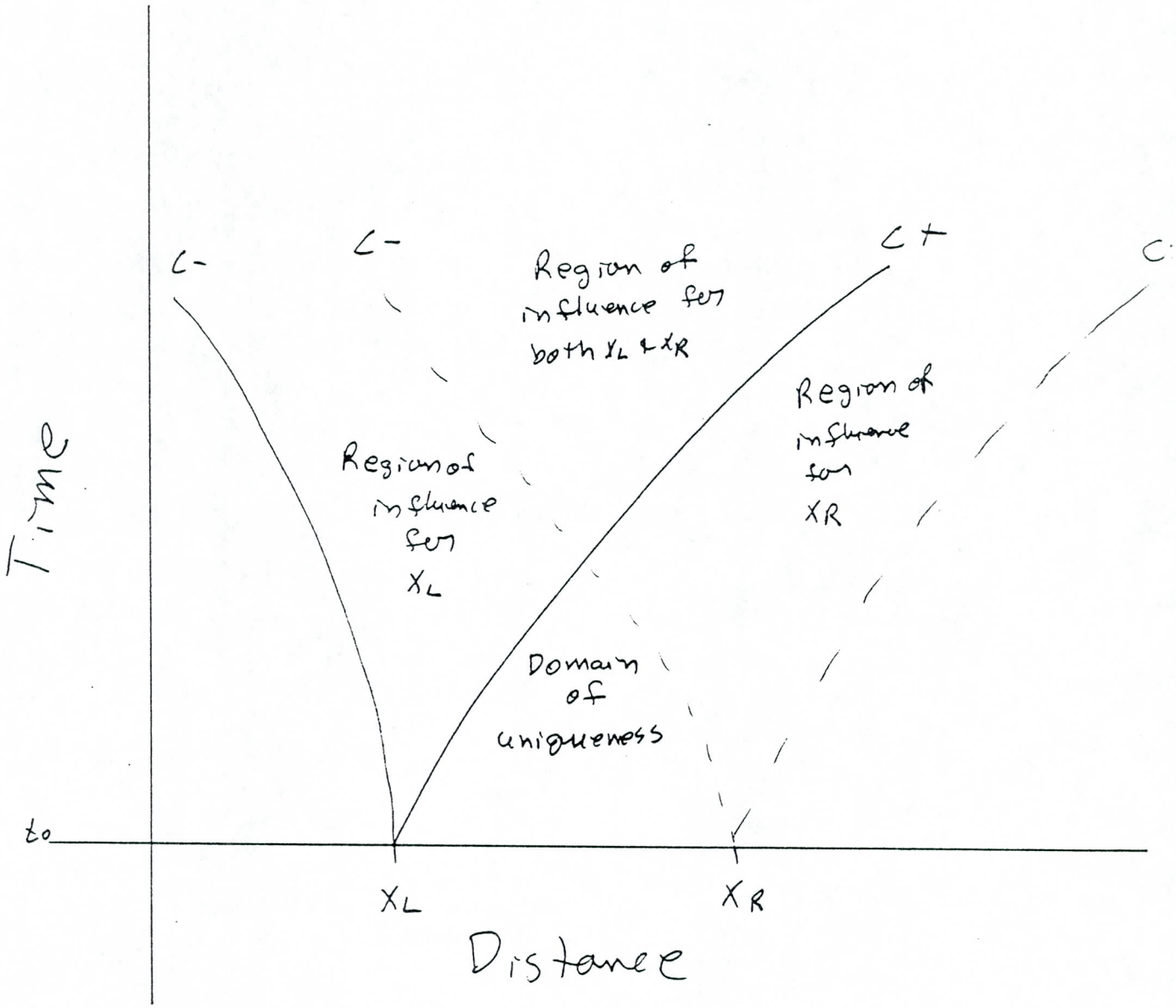
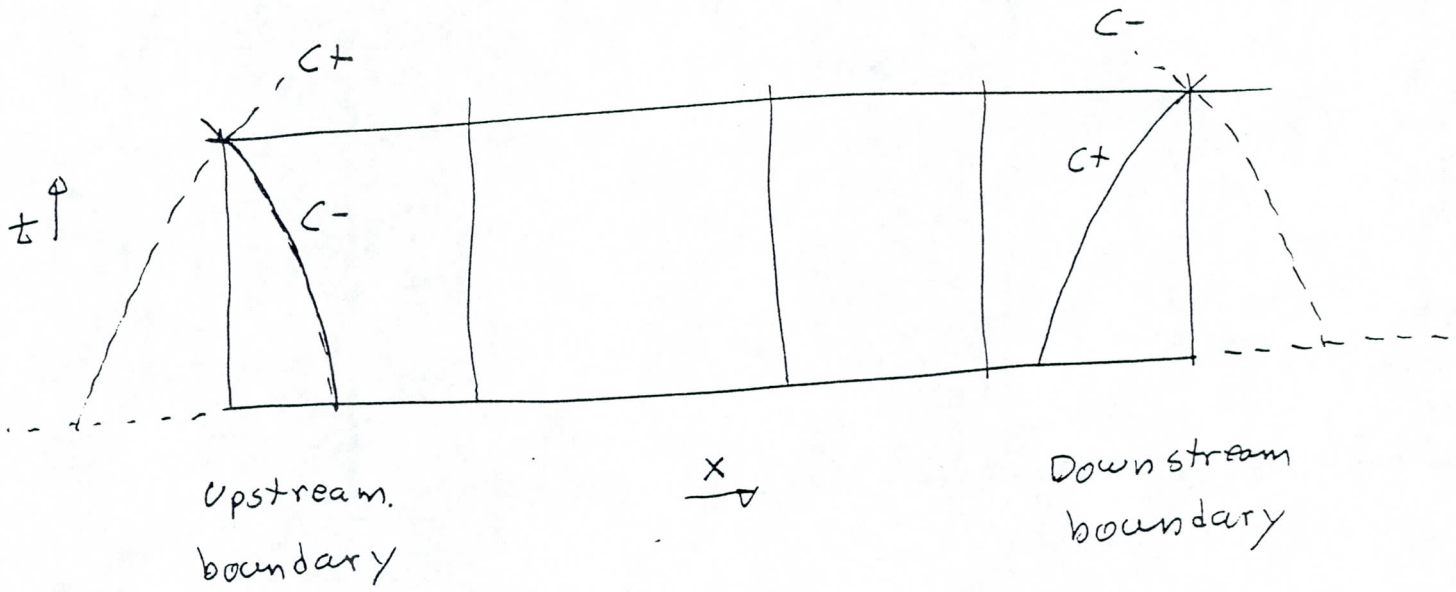
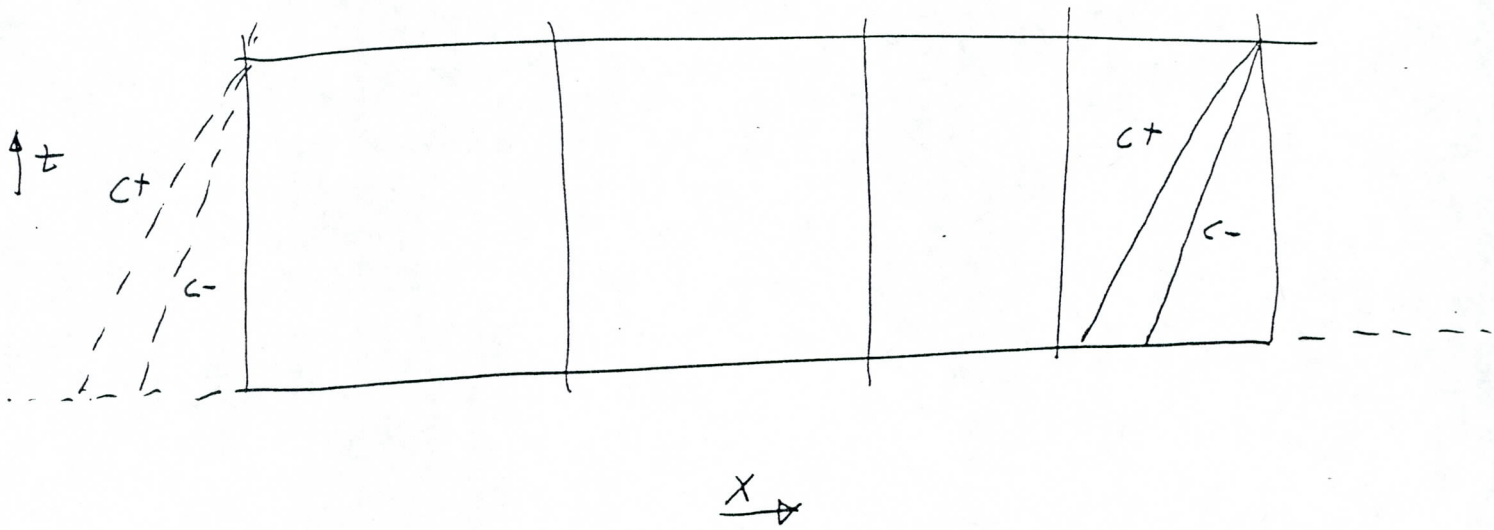


Figure 5: Regions of Influence and Domain of Uniqueness



Subcritical Flow at Boundaries



Super Critical Flow at Boundaries

Figure 6: Required Boundary Conditions

channel being analyzed. Thus the number of boundary conditions required depends on the state of the flow, subcritical or super critical, at the boundary.

Approximating the Governing Equations in a Branch

Any method for the solution of the governing equations must take into account the requirements imposed by the nature of shallow-water waves. We must be content with approximate solutions found using numerical methods because exact solutions of the equations are limited to a few special cases. In computing these solutions we are of necessity limited to computing them at a finite number of points along the branch. The approaches to computing approximate solutions to these equations can be broken into two broad classes: those which fix the location of the points along the channel in advance, and those which adjust the locations as needed in the solution. The latter class, includes the broad range of methods of characteristics that solve the characteristic form of the equations by explicitly tracing the trajectories defined by Eq. 90 in whole or in part on the xt plane. The locations and times at which flows and elevations are computed is irregular and varies as the flow conditions vary. This has some advantages in accuracy but becomes complex and impractical in prototype stream systems. Therefore methods based on the characteristic form of the equations will not be considered further here because they are not used in FEQ.

The class of methods using a fixed set of locations(called nodes) along the stream channel is also broad. This class divides into two sub-classes: explicit methods and implicit methods. These methods offer practical advantages in that the locations at which the solution values are found is fixed and they also solve for these values at the same time at all points. Thus analysis and presentation of the results is simplified. All of these methods assume knowledge of the flow and elevation at all locations prior to some initial time $t = t_0$ and solve for the values at some time $t = t_1 > t_0$. Thus these methods develop the solution for the time period of interest step wise.

An explicit method computes the solution at time $t = t_1$ at each node in turn using information at $t = t_0$ within one or two distance intervals of the node. Figure 7 shows a pattern of points on the xt plane used in some simple explicit methods. The values are known at points L, M, and R at time t_0 and the goal of the method is to predict values at point P_1 or point P_2. The dashed trajectories show that the interval of dependence for point P_1 is contained within the interval defined by L and R. Therefore, it makes physical sense to try to compute the flow conditions at point P_1. However, the interval of dependence for point P_2 is larger than the interval defined by L and R. Thus it is physical nonsense to compute the flow conditions at P_2 given the information on the interval from L to R at time t_0. The time step in the latter case is too large. In general explicit methods have limitations on time steps. If these limitations are exceeded, the resulting flows and elevation will develop large non-physical oscillations and eventually the oscillations become so large that the computations fail for some reason(negative depth, square root of a negative number, numerical overflow, *etc.*. We then say that the computations are unstable or that the method is unstable. Since the method is stable if the time step meets the constraints, explicit methods are conditionally stable. The condition which generally applies is that the distance travelled by an infinitesimal wave in one time step must never exceed the distance between nodes. This condition is known as the Courant condition and is given by

$$\Delta t \leq \frac{\Delta x}{V \pm c} \tag{92}$$

This condition proves to be restrictive so that the time step is often limited to a few seconds. It is impractical to make extensive unsteady flow computations using explicit methods if more than short time periods must be simulated. Consequently FEQ does not use an explicit method.

Implicit methods solve for all of the unknowns at time t_1 simultaneously. They are thus much more complex than are explicit methods which solve each non-boundary point independently of any

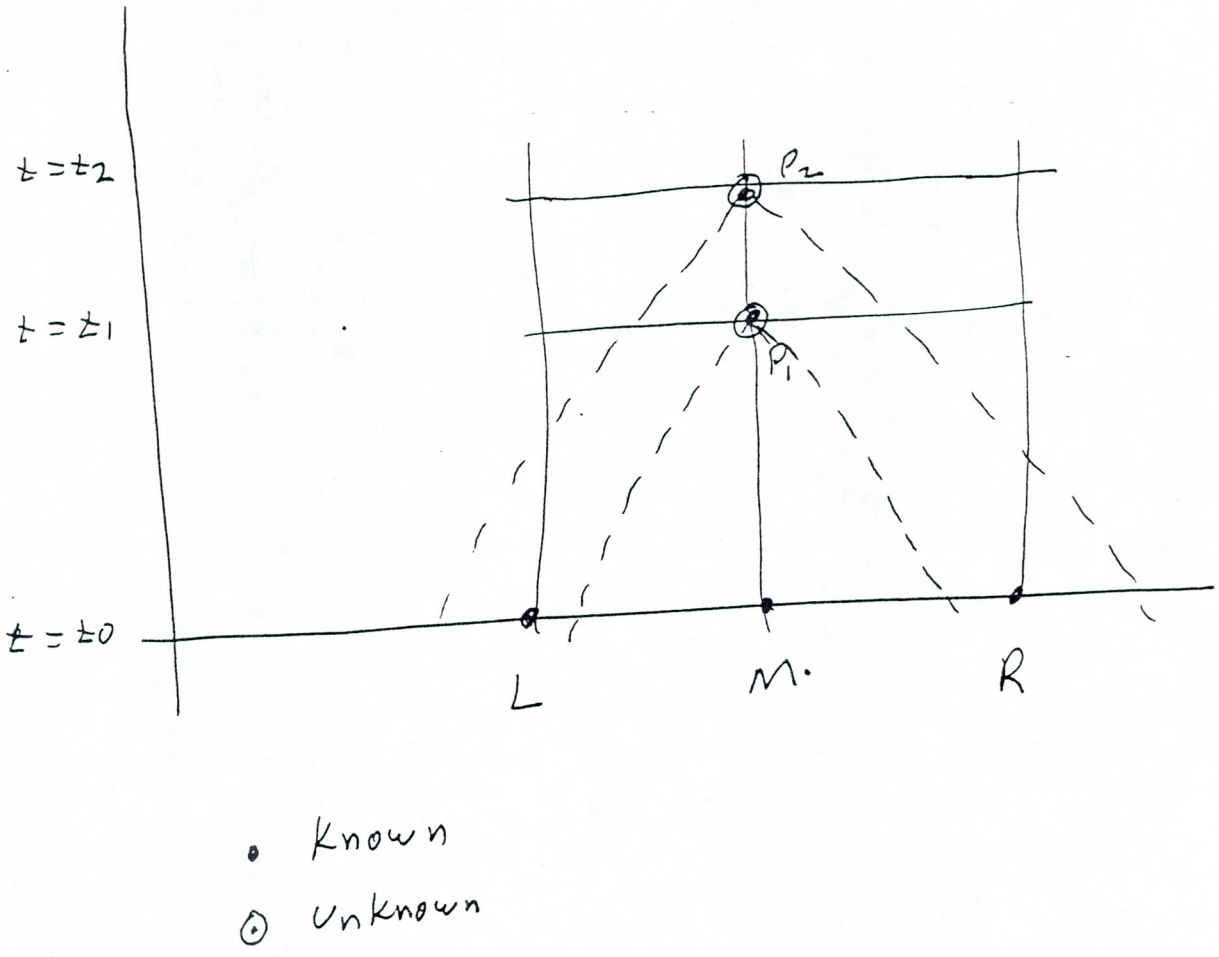


Figure 7: Explicit Method on xt Plane

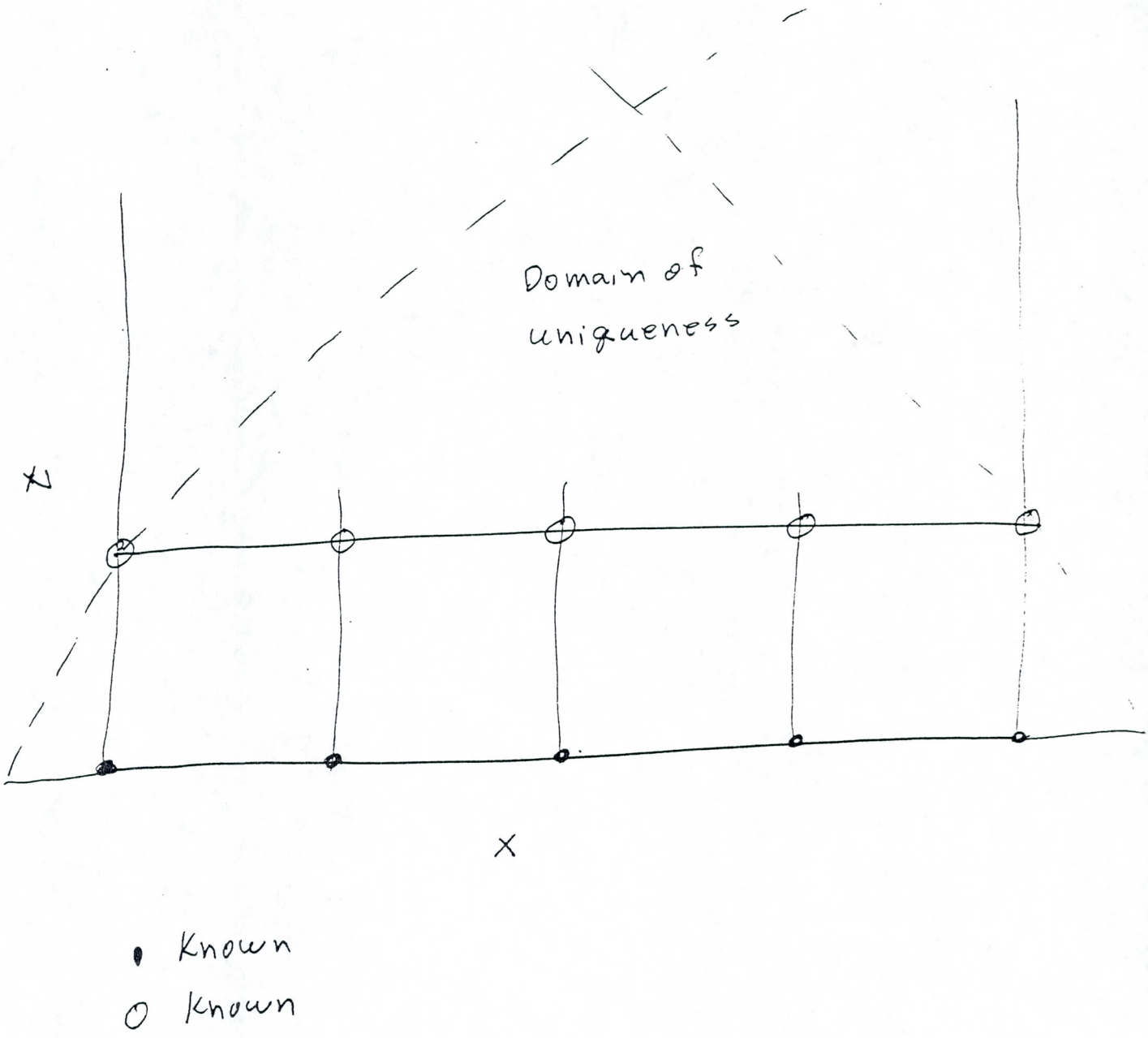


Figure 8: Implicit Method on xt Plane

other non-boundary point. Figure 8 depicts the trajectories defined for an implicit method. The interval of dependence is larger than the interval of known conditions at time t_0 but the boundary conditions supply the needed information. Thus all the unknown points fall within the domain of uniqueness established by the characteristic trajectories emanating from the boundary points. Therefore, there is no restriction on the time step caused by the nature of the shallow-water waves like there is in an explicit method. Implicit methods are not subject to the Courant condition for stability and are sometimes called unconditionally stable.

This stability allows us to use large time steps in the solution. The time step may still be limited in terms of accuracy of results but we can adjust the time step to suit the nature of the flows and not the Courant condition. Implicit methods make it possible to simulate long time periods economically with acceptable accuracy. Therefore FEQ uses an implicit method, called the Preissman four-point scheme or method. This scheme has been used for many years with variations from the original. Thus the scheme as implemented in FEQ uses only some of the concepts and might better be called a weighted four-point scheme.

Approximating the Integrals in the Integral Form

The weighted four-point scheme uses four points in the xt plane to develop the system of equations which must be solved for a branch. Figure 9 shows these points. The subscripts are chosen to assist in coding the computer program. The subscript L denotes the station on the left end of the control volume and the subscript R denotes the station on the right. The subscript U denotes the time point that is up and the subscript D denotes the time point that is down relative to the center of the rectangular box on the xt plane used to define the scheme. These subscripts are carried over to the computer program code by composing variable names for the various elements and values needed. For example, the Fortran name 'ALU' specifies the area of flow at the left end of the control volume and at the upper time. The last two letters of the variable name are reserved to refer to the point on the xt plane. This proves to be much simpler and cleaner than using the cumbersome and error-prone indices for subscripts. The equations are written for a typical control volume corresponding to the computational element on the branch which lies between adjacent cross sections.

To be continued.

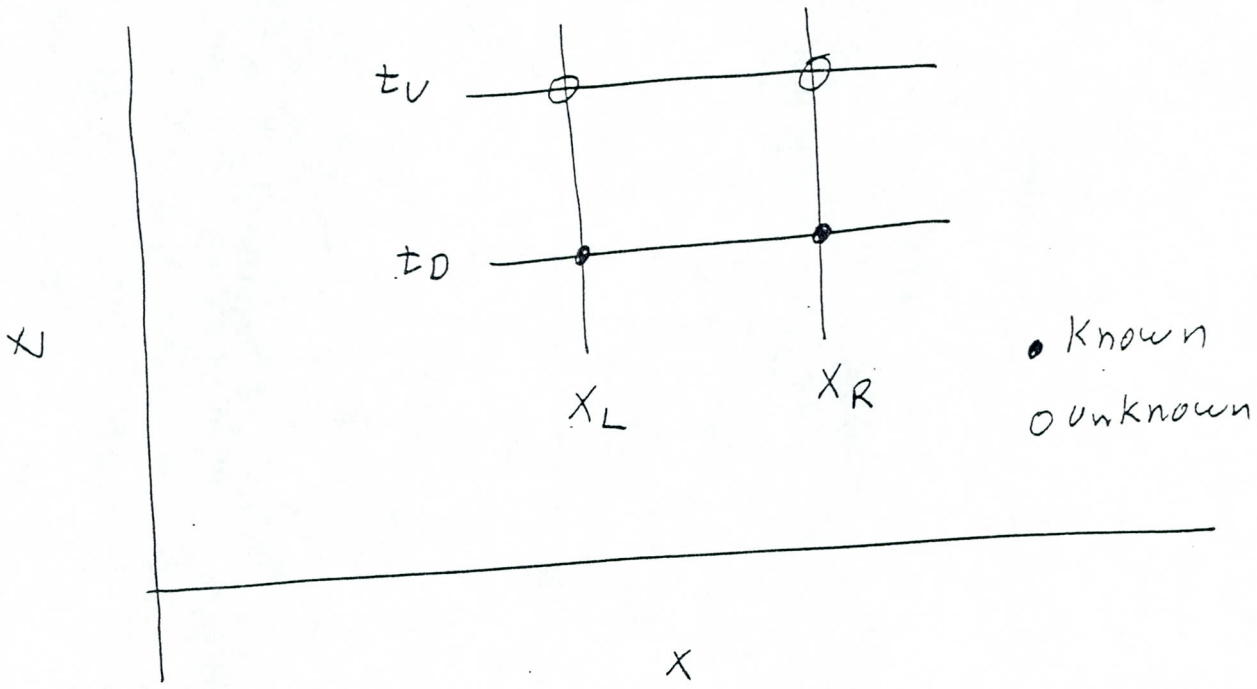


Figure 9: Points on xt Plane for FEQ

INTRODUCTION TO UNSTEADY FLOW

- Flow Classification
- Comparison of Steady and Unsteady Flow
- Assumptions in Unsteady Flow Analysis
- Unsteady Flow Examples

DESCRIBING THE STREAM SYSTEM

Part I

- World View
- Branches
- Special Features
  - Junctions
  - Boundary Conditions
  - Control Structures
  - Level-Pool Reservoirs
- Functions and Function Tables
- Exterior Nodes
- Flow Sign Convention

THE UTILITY PROGRAM: FEQUTL

Part I

- **World View**

- **Cross Section Tables**
  - User Specified
  - Standard Shapes
  - Checking Options
  - Output and Save Options
  - Key Messages

- **Flow Over Embankments**

THE UTILITY PROGRAM: FEQUTL

Part II

- **Bridge Flow Head Loss**

- **Culvert Flow Tables**
  - Section Locations
  - Flow Types
  - General Solution Method
  - Problems
  - Future

DESCRIBING A STREAM SYSTEM

Part II

- Developing a Schematic
- Numbering Exterior Nodes
- Branch and Branch-Exterior Node Description
- Exterior Matrix Control Input
- Output from FEQ

CONTROL STRUCTURE OPTIONS

Fixed Geometry

- **One-Node Control**
  - Code 4–General Rating
  - Code 8–Critical Depth

- **Two-Node Control-Code 5**
  - Type 1–Expansion-Contraction
  - Type 2–Bidirectional Flow with Pumping
  - Type 4–Bridge Losses
  - Type 5–Abrupt Expansion
  - Type 6–General Rating

N APPROACH TO UNSTEADY FLOW ANALYSIS

- **Function Tables**
  - Numbering
  - Storage and Recomputation
  - Tree Structured Directory
  - Files and Input

- **Constructing a Physical Schematic**
  - Why Do It?
  - Branch Names
  - Exterior Node Names
  - Reservoir Names
  - Numbering Nodes and Branches

- **Exterior Matrix Input**
  - Coding
  - Checking

CONTROL STRUCTURE OPTIONS

Variable Geometry

- **One-Node Control-Code 4**
  - Type 4–A Priori Variation
  - Type 5–Dynamic Variation

- **Two-Node Control-Code 5**
  - Type 6–A Priori Variation
  - Type 7–Dynamic Variation

BASIC THEORY

- **Cross Sections**
  - Definition of Elements
  - Approximation to Elements

- **Critical Flow Consistency**

- **Unsteady Flow Equations**
  - Control Volume and Integral Form
  - Conservation Form
  - St. Venant Form
  - Characteristic Form

UNSTEADY FLOW ANALYSIS THEORY

- **Governing Equation: Integral Form**

$$\int_{x_L}^{x_R} [A(x,t_U) - A(x,t_D)]\, dx =$$

$$\int_{t_D}^{t_U} [Q(x_L,t) + I(t) - Q(x_R,t)]\, dt$$

$$\int_{x_L}^{x_R} [Q(x,t_U) - Q(x,t_D)]\, dx =$$

$$\int_{t_D}^{t_U} [\beta QV(x_L,t) - \beta QV(x_R,t)]\, dt$$

$$+g \int_{t_D}^{t_U} \left[J(x_L,t) + \int_{x_L}^{x_R} J_x^y\, dx - J(x_R,t) \right] dt$$

$$+g \int_{t_D}^{t_U} \int_{x_L}^{x_R} A(S_0 - S_f)\, dtdx$$

$$+ \int_{t_D}^{t_U} \int_{x_L}^{x_R} C_D \frac{\rho_a}{\rho} U^2 T \cos\phi\, dtdx$$

UNSTEADY FLOW ANALYSIS THEORY

- **Governing Equation: Conservation Form**

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q$$

$$\frac{\partial Q}{\partial t} + g\frac{\partial J}{\partial x} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) = gA\left(S_0 - S_f\right) + gJ_x^y$$

where

$$I(t) = \int_{x_1}^{x_2} q(x,t)\,dx$$

- **Governing Equation: St. Venant Form**

$$A\frac{\partial V}{\partial x} + VT\frac{\partial y}{\partial x} + T\frac{\partial y}{\partial t} + VA_x^y = q$$

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} + g\frac{\partial y}{\partial x} = g(S_0 - S_f) - \frac{Vq}{A}$$

where

$$A_x^y = \int_0^y \frac{\partial T}{\partial x}(x,z)\,dz$$

UNSTEADY FLOW ANALYSIS THEORY

- **Governing Equation: Characteristic Form**

$$\left[\frac{\partial V}{\partial t} + \frac{dx}{dt}\frac{\partial V}{\partial x}\right] \pm \frac{g}{c}\left[\frac{\partial y}{\partial t} + \frac{dx}{dt}\frac{\partial y}{\partial x}\right] =$$

$$g(S_0 - S_f) - \frac{Vq}{A} \mp \frac{c}{A}(VA_x^y - q)$$

where

$$\frac{dx}{dt} = V \pm c$$

and

$$c = \sqrt{\frac{gA}{T}}$$

UNSTEADY FLOW ANALYSIS THEORY

- **The x-t Plane and Wave Motion**
  - Region of Influence
  - Domain of Uniqueness
  - Interval of Dependence
  - Implications for Boundary Conditions

- **Explicit and Implicit Schemes**

- **Preissman Weighted Four-Point Scheme**

- **Nonlinear Equations and Newton's Method**

- **Branched and Looped Stream Systems**

```
GGGGGGGGGG    4444444444444444444444444444444444444444444444444444444444444444444444444444444444444444
GGGGGGGGGG    44444444444444444444444  VAX8                                                    Donohue  4444
GGGGGGGGGG    4444444444444444444444444444444444444444444444444444444444444444444444444444444444444444
```

```
L       OOO   U   U   CCCC  K   K   SSSS
L      O   O  U   U  C      K   K  S
L      O   O  U   U  C      K  K   S
L      O   O  U   U  C      KKK     SSS
L      O   O  U   U  C      K  K       S
L      O   O  U   U  C      K   K      S
LLLLL   OOO   UUUUU   CCCC  K   K  SSSS
```

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  11        999999      888888    77777777    FFFFFFFFFF  UU
1111      99      99  88      88          77  FF          UU
1111      99      99  88      88          77  FF          UU
  11      99      99  88      88          77  FF          UU
  11      99      99  88      88          77  FF          UU
  11        99999999    888888          77    FFFFFFFF    UU
  11        99999999    888888          77    FFFFFFFF    UU
  11              99  88      88      77      FF          UU
  11              99  88      88      77      FF          UU
  11              99  88      88    77        FF          UU
  11              99  88      88    77        FF          UU
111111      999999      888888    77          FF          UUUUU
111111      999999      888888    77          FF          UUUUU
```

```
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                DDDDDDDD      AAAAAA    TTTTTTTTTT      ;;;;        1
                DD      DD  AA      AA      TT          ;;;;      111
                DD      DD  AA      AA      TT          ;;;;      111
                DD      DD  AA      AA      TT                      1
                DD      DD  AA      AA      TT                      1
                DD      DD  AA      AA      TT          ;;;;        1
                DD      DD  AA      AA      TT          ;;;;        1
                DD      DD  AAAAAAAAAA      TT          ;;;;        1
                DD      DD  AAAAAAAAAA      TT          ;;;;        1
                DD      DD  AA      AA      TT            ;;        1
....            DD      DD  AA      AA      TT            ;;        1
....            DDDDDDDD    AA      AA      TT          ;;        111
....            DDDDDDDD    AA      AA      TT          ;;        111
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[300,311]. The records are stream-LF with implied (CR) carriage control. The longest record is

Job 1987FU (42) queued to P011 on 21-FEB-1991 12:53 by user LOUCKS, UIC [300,311], under account
printer LTA9080: on 21-FEB-1991 12:53 from queue P011.

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GGGGGGGGGG    44444444444444444444  Digital Equipment Corporation - VAX/VMS Version V5.3-1  4
GGGGGGGGGG    4444444444444444444444444444444444444444444444444444444444444444444444444444444444444444
```

Input 1

```
GINGER CREEK EXISTING CONDITIONS IMPROVED MODEL N OF TOLLWAY
LAST UPDATE: JANUARY 15, 1991 BY EDL
AUGUST, 1987 HISTORICAL STORM EVENT OHARE RAINFALL, FUTURE LANDUSE
NBRA=00043
NJCT=00129
JOPER=NO
POINT=NO
DIFFUS=YES
WIND=NO
UNDERFLOW=NO
ZL=2.0
STIME=1925/01/01:0.00
ETIME=1987/08/20:0.00
GRAV=32.2
NODEID=YES
EPSXS=10.0
PAGE=99999
EPSSYS=0.5
MKNT=  05
OUTPUT=     0
PRTINT=99999
GEQOPT=STDX
EPSB=0.00005
MAXIT=   30
SFAC=5280.00
QSMALL=10.0
IFRZ=   9
    900.    750.    600.    450.    300.    200.    100.     50.     25.
 900.  2.0  0.7  2.9  3.2  2.4  2.0  0.5
MRE=     0.100       0.0
 T=0.1
 T=0.67
BWFDSM=   04BWF
CHKGEO=NO
MINBND=YES
EXTTOL=1.0
SQREPS=0.0
BRANCH DESCRIPTION BLOCK
BNUM=1    INERTIA= 1.0
 NODE NAME       XNUM   STATION ELEVATION
  100 SCUPUP     2800     1.922    643.50
                 2715     1.861    643.40
                 2714     1.742    643.10
                 2713     1.373    642.60
                 2712     0.819    642.00
                 2711     0.743    642.00
                 2710     0.222    640.40
       SCUPDN    2009     0.000    638.50
   -1
BNUM=2    INERTIA= 1.0
NODE NAME       XNUM   STATION ELEVATION
 200  SCDOWNU   2009     2.898    638.50
                2008     2.599    639.00
                2007     2.211    638.80
                2006     2.069    636.20
                2005     1.965    632.70
                2004     1.368    632.00
                2003     0.814    630.50
                2002     0.426    627.70
                2001     0.014    625.30
```

Input 2

```
      SCDOWND   2617      0.000     625.10
   -1
BNUM=3     INERTIA= 0.0
 NODE NAME       XNUM    STATION ELEVATION
  300 SCAPPUP     101      0.023     643.94

      SCAPPDN     101      0.000     641.50
   -1
BNUM=4     INERTIA= 0.0
 NODE NAME       XNUM    STATION ELEVATION
  400 EDOUTU      103      0.043     644.65

      EDOUTD      103      0.027     644.00
   -1
BNUM=5     INERTIA= 0.0
 NODE NAME       XNUM    STATION ELEVATION
  500 MCD01UP     305      0.219     652.59


                 305      0.189     649.72


                 305      0.171     648.00
      MCD01DN     305      0.170     646.30
   -1
BNUM=6     INERTIA= 0.0
 NODE NAME       XNUM    STATION ELEVATION
  600 MCD02UP     396      0.361     659.83


                 396      0.257     655.00


      MCD02DN     396      0.229     653.29
   -1
BNUM=7     INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
  700 EDINU       106      0.211     646.30


      EDIND       106      0.196     646.30
   -1
BNUM=8     INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
  800 FREDOUTU    108      0.224     646.30

      FREDOUTD    108      0.217     646.30
   -1
BNUM=9     INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
  900 FREDINUP    111      0.437     652.76
                  111      0.433     652.76
                    -
                    -
                  110      0.386     650.10
      FREDINDN    110      0.380     650.00
   -1
BNUM=10    INERTIA= 1.0
```

```
NODE NAME       XNUM    STATION ELEVATION
1000 JORAPPU     192      0.476    652.76
                 192      0.464
                   -
                   -
                 112      0.456
     JORAPPD     112      0.453    652.76
   -1
BNUM=11   INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 1100 POND1U      115      0.666    655.34

                 115      0.577    654.28
                   -
                   -
                   -
                   -
                 114      0.520    653.81

      POND1D     114      0.477    656.19
   -1
BNUM=12   INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 1200 POND2U      120      0.875    658.44

                 120      0.859    656.65
                   -
                   -
                   -
                 119      0.804    656.11
                   -
                   -
                   -
                   -
                 118      0.741    655.87
                   -
                   -
                   -
                 117      0.689    655.71

      POND2D     117      0.669    657.69
   -1
 BNUM=13   INERTIA= 1.0
  NODE NAME       XNUM    STATION ELEVATION
  1300 R83APPU     221      0.921    662.00

       R83APPD     221      0.911    661.76
    -1
  BNUM=14   INERTIA= 1.0
   NODE NAME       XNUM    STATION ELEVATION
   1400 BRCAPPU     221      0.949    662.12

        BRCAPPD     221      0.927    662.00
    -1
  BNUM=15   INERTIA= 1.0
   NODE NAME       XNUM    STATION ELEVATION
   00 MLPOOL1U     371      1.267    665.62


                   371      1.257    666.14
```

MLPOOL1D	371	1.231	666.41

-1

BNUM=16 INERTIA= 1.0

NODE	NAME	XNUM	STATION	ELEVATION
[illegible]0	MLPOOL2U	328	1.315	674.37
		328	1.291	672.22
	MLPOOL2D	328	1.267	676.29

-1

BNUM=17 INERTIA= 1.0

NODE	NAME	XNUM	STATION	ELEVATION
1700	MLPOOL3U	326	1.358	678.53
		326	1.339	675.24
	MLPOOL3D	326	1.315	678.14

-1

BNUM=18 INERTIA= 1.0

NODE	NAME	XNUM	STATION	ELEVATION
1800	MLRCHU	358	1.748	697.50
		358	1.509	690.18
		-		
		-		
		357	1.488	689.42
	MLRCHD	357	1.477	689.90

-1

BNUM=19 INERTIA= 1.0

NODE	NAME	XNUM	STATION	ELEVATION
1900	BDFATU	369	1.286	665.83
		369	1.270	664.96
		-		
		-		
		-		
		-		
		342	1.231	658.44
		342	1.195	658.44
		-		
		-		
		-		
		343	1.168	657.73
	BDFATD	343	1.155	657.33

-1

BNUM=20 INERTIA= 1.0

NODE	NAME	XNUM	STATION	ELEVATION
2000	BDDITCHU	373	1.575	670.80

```
                373      1.386     665.83

      BDDITCHD  373      1.286     665.83
   -1
BNUM=21   INERTIA= 1.0
 NODE NAME      XNUM    STATION ELEVATION
 2100 TWAYU      397      1.943     676.87

      TWAYD      397      1.594     670.80
   -1
BNUM=22   INERTIA= 1.0
 NODE NAME      XNUM    STATION ELEVATION
 2200 BRLKAPPU   230      1.246     662.60

      BRLKAPPD   230      1.195     661.58
   -1
BNUM=23   INERTIA= 1.0
 NODE NAME      XNUM    STATION ELEVATION
 2300 REGDEPU    233      1.346     664.46

                233      1.318     663.96
                  -
                  -
                  -
                  -
                232      1.273     663.11

      REGDEPD   232      1.246     662.60
   -1
BNUM=24   INERTIA= 1.0
 NODE NAME      XNUM    STATION ELEVATION
```

```
 2400 REGAPPUP    235      1.403     665.95


      REGAPPDN    235      1.354     664.46
   -1
BNUM=25    INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 2500 BRKFATU     238      1.526     666.84


                  238      1.473     665.86
                    -
                    -
                    -
                  237      1.428     662.91


      BRKFATD     237      1.403     666.00
   -1
BNUM=26    INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 2600 BRKTHINU    239      1.619     669.08


      BRKTHIND    239      1.526     666.84
   -1
BNUM=27    INERTIA=  1.0 CFRATE= 200.
 NODE NAME       XNUM    STATION ELEVATION
 2700 SUMSWRUP    636      2.277     700.50                              5.0


                  636      1.895     678.08                              6.92


                  636      1.844     676.01                              6.80
                    -
                  648      1.841     675.98                              6.76
```

```
      SUMSWRD     648      1.619     670.69                          4.0
   -1
BNUM=28    INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 2800 SUMDEPU     291      1.671     675.0
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                   241      1.644     669.47
                    -
                    -
                    -
                    -
                    -
                    -
      SUMDEPD     240      1.619     674.42
   -1
BNUM=29    INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 2900 BUTTERUP    267      2.181     689.15
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
                    -
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```

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-
246 1.977 686.39
-
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-
250 1.856 683.87
-
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-
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-
-
-
-
-
-
-
-
-
-
-
-
249 1.761 681.55

BUTTERDN 249 1.692 680.75

-1

BNUM=30 INERTIA= 1.0

NODE	NAME	XNUM	STATION	ELEVATION
3000	MWBUTTUP	362	2.649	696.48

362 2.617 695.07
-
-
-
-

```
                -
                -
                -
                -
                -
                -
              363      2.535     692.18
                -
                -
                -
                -
                -
                -
                -
                -
              364      2.461     691.59
                -
                -
                -
                -
                -
                -
                -
                -
                -
                -
              365      2.367     691.60
                -
                -
                -
                -
                -
                -
                -
                -
                -
                -
                -
                -
              366      2.272     690.60
```

```
      MWBUTTDN   366      2.181     689.15
   -1
BNUM=31   INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 3100 BUENTRUP    268      2.304     692.11
```

```
                268      2.253     690.88


                268      2.191     689.39
                  -
      BUENTRDN  267      2.181     689.15
   -1
BNUM=32   INERTIA= 1.0
 NODE NAME      XNUM    STATION ELEVATION
 3200 GCLOUTUP  253      2.366     690.05


                253      2.338     691.17


      GCLOUTDN  253      2.313     692.42
   -1
BNUM=33   INERTIA= 1.0
 NODE NAME      XNUM    STATION ELEVATION
 3300 LOMB01UP  354      2.472     692.20




      LOMB01DN  354      2.430     690.95
   -1
BNUM=34   INTERIA= 0.0
 NODE NAME      XNUM    STATION ELEVATION
 3400 LOMB02UP  356      2.601     697.70




      LOMB02DN  356      2.480     693.10
   -1
BNUM=35   INERTIA= 1.0
 NODE NAME      XNUM    STATION ELEVATION
 3500 UPPGCLUP  251      3.125     689.00

                251      3.076     689.
                  -
                  -
                247      2.898     689.

      UPPGCLDN  247      2.875     689.00
   -1
BNUM=36   INERTIA= 1.0
 NODE NAME      XNUM    STATION ELEVATION
 3600 HOAKFATU  344      3.250     690.00

      HOAKFATD  344      3.125     689.00
   -1
```

```
BNUM=37   INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 3700 MEYDEPUP    245      3.182    690.58

      MEYDEPDN    245      3.125    690.00
   -1
BNUM=38   INERTIA= 1.0                                          CF    YC
 NODE NAME       XNUM    STATION ELEVATION
 3800 66INCHUP    666      3.301    691.49                        6.0

                  666      3.193    690.58                        6.0
                    -
                    -
                    -
                    -
                    -
      66INCHDN    645      3.182    690.58                        6.0
   -1
BNUM=39   INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 3900 CHATWDUP    276      3.392    696.69

                  276      3.351    696.25
                    -
                  275      3.347    696.22

      CHATWDDN    275      3.301    696.02
   -1
BNUM=40   INERTIA= 1.0  CFRATE= 200.
 NODE NAME       XNUM    STATION ELEVATION                      CF    YC
 4000 HOAKCCUP    697      3.513    696.82                        5.00

                  697      3.385    695.46                        5.00
                  618      3.384    695.46                        5.00

                  618      3.354    694.68                        5.00
                  624      3.353    694.68                        5.00
```

```
   HOAKCCDN    624      3.250     693.32                          5.00
   -1
BNUM=41    INERTIA= 1.0  CFRATE= 200.
 NODE NAME       XNUM    STATION ELEVATION
 4100 TLTREESU    622      3.555     698.52                          5.0

                  622      3.504     697.15                          5.0

                  696      3.503     697.15                          5.0

      TLTREESD    696      3.392     696.69                          5.0
   -1
BNUM=42    INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 4200 HOAKCHNU    394      3.657     701.00

      HOAKCHND    394      3.513     698.70
   -1
BNUM=43    INERTIA= 1.0
 NODE NAME       XNUM    STATION ELEVATION
 4300 MW13UP      361      2.731     697.85

                  361      2.682     697.34
                    -
                  638      2.680     697.34
```

```
      MW13DN      638      2.649     696.48
   -1
TRIBUTARY AREA SPECIFICATION
TSFDSN=    -9\FEQ\TSF\TSF87
[redacted]SN=    02\GINGER\FEQ\1987FU.FFF
NLUSE=    20
NGAGE=     4
 GAGE  NLU
    1    5
    2    5
    3    5
    4    5
BRANCH=     0 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
  04    2  18.38     0 26.44 53.36  4.73
  10    2  15.15     0  4.50 15.99  1.37
  15    2   8.96     0  4.69  7.48  0.63
  23    2  49.10     0 33.07 38.04  4.89
  26    2  27.25     0     0 49.84  3.96
  30    2   8.29     0  1.66 16.82  5.23
  34    2  33.16     0  6.63 67.29 20.9
  42    2   7.45     0  3.54 11.97  0.79
  51    2  35.78 17.51  8.51 65.16  5.40
  67    2  64.17     0 13.23  3.90     0
  72    2   5.94     0     0 50.49  2.97
  79    2  64.25  2.89 39.43 23.67  5.89
  80    2   44.2  3.72 12.19 0.917  3.00
  82    2   88.5  7.45 24.38  1.83  6.00
  83    2  64.25  2.89 39.43 23.67  5.89          128.5  5.78 78.86 47.34 11.78
  85    2   14.7  1.24  4.06  0.31  1.00
[redacted]    2   32.1  1.44 19.72 11.84  2.94
[redacted]0    2  39.44  0.65  6.32     0     0
 100    2  125.6 41.10 139.2 41.22  9.31
 107    2  44.4     0     0 154.3 17.0
 106    2   7.95     0  9.28 33.12  5.25
 125    2  21.53 23.73 19.30 14.65 10.8
 126    2  26.73     0 23.20 89.98  7.59
 -1
BRANCH=     1
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2 0.69  0.14  1.35  2.35   1.17
BRANCH=     2
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  0.1  0.02  0.20  0.35   0.17
BRANCH=     3 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=     4 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=     5 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=     6 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2 10.10     0  3.00 10.66  0.92
[redacted]NCH=     7 FAC=1.5625E-3
 [redacted]DE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=     8 FAC=1.5625E-3
```

```
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=    9 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  2.24     0  1.17  1.87  1.58
BRANCH=   10 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=   11 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2 23.44     0  2.91  3.36     0
BRANCH=   12 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2 44.71     0 19.22 51.45   .93
BRANCH=   13 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=   14 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=   15 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  1.24     0  0.59  2.00  0.13
BRANCH=   16 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  1.24     0  0.59  2.00  0.13
BRANCH=   17 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  1.24     0  0.59  2.00  0.13
BRANCH=   18 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2 12.94     0 15.01 69.33  2.42
BRANCH=   19 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  3.12  1.95  0.10  3.97  0.35
BRANCH=   20 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  9.61     0 14.19 20.34  1.92
BRANCH=   21 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  4.12     0  6.08  8.72  0.82
BRANCH=   22 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  0.35     0  0.60  1.03  0.10
BRANCH=   23 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  5.27     0  9.00 15.48  1.53
BRANCH=   24 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  7.24     0  8.98 14.93  1.49
BRANCH=   25 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2 11.05     0  7.42 42.32  3.11
BRANCH=   26 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  3.48     0     0 18.52  1.16          6.95     0     0 37.04  2.32
BRANCH=   27 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  3.48     0     0 18.52  1.16
BRANCH=   28 FAC=1.5625E-3
```

```
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=   29 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2 21.38     0     0 127.7     0
BRANCH=   30 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  5.95     0 38.95 37.82  1.74
BRANCH=   31 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  0.55     0  4.89  7.23  0.24
BRANCH=   32 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=   33 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=   34 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  0.28     0 12.92     0  0.70
BRANCH=   35 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  5.87 10.76 19.42     0  1.63
BRANCH=   36 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  3.91  7.18 12.94     0  1.08
BRANCH=   37 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=   38 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH=   39 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  2.45  2.13  7.48 11.22  1.23
BRANCH=   40 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  1.47 11.77 11.26  3.74  1.49
BRANCH=   41 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2 53.01  9.75 10.48 62.97  4.10
BRANCH=   42 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2  1.47 11.77 11.26  3.74  1.49
BRANCH=   43 FAC=1.5625E-3
 NODE GAGE IMPRV FGRSS MGRSS SGRSS FORST
    0    2     0     0     0     0     0
BRANCH-EXTERIOR NODE TABLE
 BRA# UEXN DEXN
    1    8    5
    2    3    1
    3    9    6
    4   13   11
    5   16   18
    6   12   14
    7   20   19
    8   22   21
    9   29   27
   10   33   31
   11   37   35
```

Input 4

```
 12   41   39
 13   45   43
 14   49   47
 15   52   54
 16   48   50
 17   44   46
 18   36   38
 19   57   55
 20   61   59
 21   65   63
 22   58   56
 23   62   60
 24   66   64
 25   71   68
 26   75   73
 27   74   76
 28   81   78
 29   86   84
 30   98   95
 31   91   88
 32   97   94
 33   99  102
 34   93   96
 35  108  105
 36  113  111
 37  112  110
 38  118  115
 39  122  120
 40  119  116
 41  127  124
 42  123  121
 43  104  101
EXTERIOR MATRIX CONTROL INPUT
 CODE   A   B   C   D   E   F   G   H   I   J     FA     FB     FC     FD     FE
    4   2   1  -1   1 550                        625.10
    6   1   2   1   0                            5.00
    1   2
    7   4 533   1  -2
    3   2   4
    2   3   3   5   6
   11   5   3
    3   5   6
    2   2   4   7
    4   2   4  -1   4 551                        684.62
    1   1
    1   3
    7  10 536   1  -7
    3   7  10
    6   1   8   1 -14
    5   6  11   9   9 401 401                    644.00
    2   2   9  11
    4   2  10  -1  10 563                        662.10
    2   2  10  12
    1   4
    1   6
    5   6  15  13  13 502 502                    648.45
    2   2  13  15
    5   6  14  16  16 402 402                    653.29
    2   2  14  16
    7  15 535   1 -17
```

Input 5

```
3  15  17
1   5
2   3  17  18  19
3  17  18
3  18  19
1   7
5   6  21  20  20 403 403                    646.34
2   2  20  21
1   8
5   6  23  22  22 504 504                    652.32
2   2  22  23
6   1  24   1   0                              1.00
7  23 534   1 -25
3  23  25
7  26 545   1 -24
3  24  26
2   2  25  27
5   1  27  25  25  1  110                       1.0    0.8 650.13
2   2  26  28
4   2  26  -1  26 552                        721.5
1   9
7  30 531   1 -28
3  28  30
5   6  31  29  29 405 405                  1 652.76
                   406 406                    655.66
2   2  29  31
4   2  30  -1  30 553                        715.00
2   2  30  32
1  10
3  32  34
7  34 532   1 -32
2   2  33  35
5   6  35  33  33 507 507                    656.39
2   2  34  36
4   2  34  -1  34 554                        699.15
1  11
1  18
5   6  39  37  37 509 509                    658.98
2   2  37  39
4   2  38  -1  38 407                        689.90
2   2  38  40
1  12
7  42 548   1 -40
3  40  42
5   6  43  41  41 411 411                    661.76
2   2  41  43
5   6  42  44  44 505 505                    683.01
2   2  42  44
1  13
1  17
5   4  47  45  47 483 483 484 485 485 798 406.0  673.99    0.8 674.83
2   2  45  47
4   2  46  -1  46 594                        681.05
2   2  46  48
1  14
1  16
2   2  49  51
5   6  51  49  51 513 513                  1 666.30
                   514 514                  1 667.58
                   515 515                    666.30
```

```
2   2  50  52
4   2  50  -1  50 593                    677.96
7  51 542   1 -53
3  51  53
1  15
4   2  54  -1  54 592                    669.70
5   1  56  53  56   1 230                   1.0    0.8 658.78
3  53  55
2   4  53  54  55  56
1  19
1  22
2   2  57  59
5   1  59  57  59   1 373                   1.0    0.8 658.35
2   2  58  60
5   1  60  58  58  -1 231                   0.8    1.0 661.87
1  20
1  23
5   6  63  61  61 493 493                 670.80
2   2  61  63
5   1  64  62  64  +1 235                   1.0    0.8 664.46
2   2  62  64
1  21
1  24
2   2  65  67
4   2  67  -1  67 555                    677.00
2   2  66  68
5   6  68  66  66 520 520                 670.51
6   1  69   1   0                         4.00
7  67 547   1 -70
3  67  70
1  25
7  72 541   1 -69
3  69  72
6   1  70   1   0                         1.00
2   2  71  73
5   1  73  71  71   1 369                   1.0    0.8 666.39
2   2  72  74
4   2  72  -1  72 556                    700.50
1  26
1  27
2   3  75  76  78
5   1  76  75  76   1 648                   1.0    0.8 670.69
5   6  78  75  78 523 523                 674.92
6   1  77   1   0                         1.00
7  82 528   1  80
1  28
7  79 546   1 -77
7  80 527   0
3  77  79
4   1  79  -1  79 991                    730.00   4.0
4   1  80  -1  80 991                    730.00   4.0
7  83 549   1  79
4   2  82  -1  82 582                    723.30
2   2  81  84
5   6  84  81  81 424 424                 680.75
7  85 529   0
4   2  85  -1  85 585                    723.40
7  87 530   3  82  83  85
4   2  83  -1  83 583                    718.80
1  29
```

```
4   2  87  -1  87 558                    709.00
2   3  86  88  89
3  86  89
3  88  86
7  90 538   1  87
1  31
2   2 -89 -92
3  89  92
2   2  90  93
4   2  90  -1  90 559                    700.00
2   2  91  94
5   6  94  91  94 441 441                692.42
2   2  92  95
3  92  95
1  34
1  32
1  30
2   2  96  99
5   6  96  99  96 400 400                693.10
2   2  97 100
3  97 100
2   2  98 101
5   1 101  98 101  +1 638                  1.00    0.8 696.48
1  33
7 100 540   1-103
3 100 103
1  43
2   3 102 103 105
3 102 103
5   6 105 103 105 444 444                689.72
2   3 104 106 107
4   2 106  -1 106 560                    700.72
4   2 107  -1 107 565                    698.00
1  35
7 106 537   1-109
3 106 109
6   1 109   1   0                        1.00
7 107 543   0
2   3 108 110 111
3 108 110
3 108 111
1  37
1  36
2   3 112 114 115
5   5 115 112 115 700
3 112 114
2   2 113 116
5   1 116 113 116  +1 624                  1.0    1.0 693.32
2   2-114-117
5   6 117 114-117 866 866                690.58
1  38
1  40
2   3 117 118 120
5   6 120 118 118 847 847                691.49
3 117 120
2   2 119 121
5   6 121 119 121 818 818                698.70
1  39
1  42
2   3 122 124 125
```

Input 6

```
   3 122 124
   4   2 125  -1 125 561                    697.33
   2   2 123 126
   4   2 126  -1 126 562                    701.00
   1  41
   7 125 544   1-128
   3 125 128
   7 126 539   1-129
   3 126 129
   6   1 127   1   0                         3.00
   6   1 128   1   0                         0.00
   6   1 129   1   0                         4.00
 -1
SPECIAL OUTPUT LOCATIONS
UNIT=   231987FU.SPO
  BRA NODE
    0   15
    0   23
   11 1104
   12 1208
    0   51
   24 2405
   25 2505
   26 2603
   28 2810
   29 2962
   29 2910
   30 3040
   31 3108
    0  100
   39 3903
   -1
INPUT FILE SPECIFICATION
 UNIT NAME
   14 \FEQ\TSF\FLOWOUT.87
   -1
OUTPUT FILE SPECIFICATION
 UNIT   BRA NODE ITEM TYPE NAME
   -1
FUNCTION TABLES
TABLE#=  -15\GINGER\FEQ\TABLES\XSEC.TAB
TABLE#=  -15\GINGER\FEQ\TABLES\SALTXSEC.TAB
TABLE#=  -15\GINGER\FEQ\TABLES\MULCON.TAB
TABLE#=  -15\GINGER\FEQ\TABLES\CULVERT.TAB
TABLE#=  -15\GINGER\FEQ\TABLES\ONEDIM.TAB
TABLE#=  -15\GINGER\FEQ\TABLES\AUXIL.TAB
TABLE#=  -15\GINGER\FEQ\TABLES\EMBANKQ.TAB
TABLE#=  -15\GINGER\FEQ\TABLES\BRIDGE.TAB
TABLE#=   -1
FREE NODE INITIAL CONDITIONS
 NODE      NAME      STAGE DISCHARGE      DATUM SIGN
    2 HUNTERFR    687.77       5.0        0.0   -1
    4 HUNTER      687.77       5.0        0.0   +1
    7 MDLAKEFR    662.60       5.0        0.0   -1
   10 MDLAKE      662.60       5.0        0.0   +1
   15 LAKEED      649.55      20.0        0.0   +1
   17 LAKEEDFR    649.55      20.0        0.0   -1
   23 LAKEFRED    652.70      15.0        0.0   +1
   24 TRINITYF    721.70       1.0        0.0   -1
   25 FREDFR      652.70      15.0        0.0   -1
```

26	TRINITY1	721.70	1.0	0.0	+1
28	MAYSIFR	715.40	1.0	0.0	-1
30	MAYSI	715.40	1.0	0.0	+1
32	MAYSIIFR	699.35	1.0	0.0	-1
34	MAYSII	699.35	1.0	0.0	+1
40	MLPOOLFR	683.76	1.0	0.0	-1
42	MLPOOL4	683.76	1.0	0.0	+1
51	BRWOODLK	666.38	15.0	0.0	+1
53	BRWOODFR	666.38	15.0	0.0	-1
67	TOLLWAY	677.10	1.0	0.0	+1
69	TRIN2FR	703.39	4.0	0.0	-1
70	TWAYFREE	677.10	1.0	0.0	-1
72	TRINITY2	703.39	4.0	0.0	+1
77	LOMBFREE	730.20	1.0	0.0	-1
79	LOMBDET	730.20	1.0	0.0	+1
80	YORKLINR	730.00	0.0	0.0	+1
82	YORKTOWN	723.30	0.0	0.0	+1
83	LOMBWET	719.00	1.0	0.0	+1
85	SEMINARY	723.40	0.0	0.0	+1
87	WMI DET	709.32	1.0	0.0	+1
89	BTJUNCDN	689.65	1.0	0.0	+1
90	IBM DET	700.48	1.0	0.0	+1
92	BTJUNCUP	689.65	1.0	0.0	-1
100	GCLAKE	693.53	8.0	0.0	+1
103	GCLAKEFR	693.53	8.0	0.0	-1
106	MWPONDI	701.10	1.0	0.0	+1
107	MWPONDII	698.01	0.0	0.0	+1
109	MWPONDIF	701.10	1.0	0.0	-1
114	CHWOODDN	693.53	0.0	0.0	+1
117	CHWOODUP	696.22	0.0	0.0	-1
125	WETLAND	697.33	0.0	0.0	+1
126	HERITAGE	702.23	4.0	0.0	+1
128	WETLANDF	697.33	0.0	0.0	-1
129	HOAKSFR	702.23	4.0	0.0	-1

BACKWATER ANALYSIS
BRANCH NUMBER= -1
DISCHARGE=280.
BRANCH NUMBER= -2
DISCHARGE=300.
BRANCH NUMBER= -3
DISCHARGE=20.0
BRANCH NUMBER= -4
DISCHARGE=20.0
BRANCH NUMBER= -5
DISCHARGE= 5.0
BRANCH NUMBER= -6
DISCHARGE= 5.0
BRANCH NUMBER= -7
DISCHARGE=15.0
BRANCH NUMBER= -8
DISCHARGE=15.0
BRANCH NUMBER= -9
DISCHARGE=15.0
BRANCH NUMBER= -10
DISCHARGE=15.0
BRANCH NUMBER= -11
DISCHARGE=15.0
BRANCH NUMBER= -12
DISCHARGE=15.0
BRANCH NUMBER= -13

DISCHARGE=15.0
BRANCH NUMBER= -14
DISCHARGE=15.0
BRANCH NUMBER= -15
DISCHARGE= 1.0
BRANCH NUMBER= -16
DISCHARGE= 1.0
BRANCH NUMBER= -17
DISCHARGE= 1.0
BRANCH NUMBER= -18
DISCHARGE= 1.0
BRANCH NUMBER= -19
DISCHARGE= 1.0
BRANCH NUMBER= -20
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BRANCH NUMBER= -25
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BRANCH NUMBER= -26
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BRANCH NUMBER= -27
DISCHARGE= 4.0
BRANCH NUMBER= -28
DISCHARGE= 9.0
BRANCH NUMBER= -29
DISCHARGE= 9.0
BRANCH NUMBER= -30
DISCHARGE= 1.0
BRANCH NUMBER= -31
DISCHARGE= 8.0
BRANCH NUMBER= -32
DISCHARGE= 8.0
BRANCH NUMBER= -33
DISCHARGE= 1.0
BRANCH NUMBER= -34
DISCHARGE= 1.0
BRANCH NUMBER= -35
DISCHARGE= 7.0
BRANCH NUMBER= -36
DISCHARGE= 4.0
BRANCH NUMBER= -37
DISCHARGE= 3.0
BRANCH NUMBER= -38
DISCHARGE= 3.0
BRANCH NUMBER= -39
DISCHARGE= 3.0
BRANCH NUMBER= -40
DISCHARGE= 4.0
BRANCH NUMBER= -41
DISCHARGE= 3.0
BRANCH NUMBER= -42
DISCHARGE= 4.0
BRANCH NUMBER= -43

DISCHARGE= 1.0

BRA	CODE	ELEV	EXN
2	3	628.50	
1			03
3			03
4			09
5	1	649.55	
6	1	653.63	
7	1	649.55	
8			20
9			23
10			29
11	1	656.90	507
12	1	659.48	509
13	1	662.27	411
14			45
15	3	669.80	592
16	3	678.05	593
17	3	681.15	594
18	1	690.30	
19	1	666.38	
20			57
21			61
22	1	666.38	
23			58
24			62
25	1	670.98	
26			71
27	1	671.34	
28	1	675.32	
29	1	681.35	
30			86
43			98
31			86
0	89		86
0	92		86
32	1	693.50	
33	1	693.53	
34			99
35	1	693.53	
36			108
37			108
38			112
39	1	696.22	
40	1	694.10	
41			122
42	1	699.00	

-1

Exterior Matrix Control Input

CODE	N_1 A	N_2 B	N_3 C	N_4 D	N_5 E	N_6 F	N_7 G	N_8 H	N_9 I	N_{10} J	F_1 FA	F_2 FB	F_3 FC	F_4 FD	F_5 FE
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															

Exterior Matrix Control Input

CODE	N_1 A	N_2 B	N_3 C	N_4 D	N_5 E	N_6 F	N_7 G	N_8 H	N_9 I	N_{10} J	F_1 FA	F_2 FB	F_3 FC	F_4 FD	F_5 FE
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															

Exterior Matrix Control Input

CODE	N_1 A	N_2 B	N_3 C	N_4 D	N_5 E	N_6 F	N_7 G	N_8 H	N_9 I	N_{10} J	F_1 FA	F_2 FB	F_3 FC	F_4 FD	F_5 FE
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															

Exterior Matrix Control Input

	CODE	N_1 A	N_2 B	N_3 C	N_4 D	N_5 E	N_6 F	N_7 G	N_8 H	N_9 I	N_{10} J	F_1 FA	F_2 FB	F_3 FC	F_4 FD	F_5 FE
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																

```
AAAAAAAAAA  0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
AAAAAAAAAA  00000000000000000000000  VAX8                                                    Donohue  0000
AAAAAAAAAA  0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
```

```
   L       OOO   U   U   CCCC  K   K   SSSS
   L      O   O  U   U  C      K   K  S
   L      O   O  U   U  C      K  K   S
   L      O   O  U   U  C      KKK     SSS
   L      O   O  U   U  C      K  K       S
   L      O   O  U   U  C      K   K      S
   LLLLL   OOO   UUUUU   CCCC  K   K  SSSS


    OOOOOO    UU      UU  TTTTTTTTTT      11
    OOOOOO    UU      UU  TTTTTTTTTT      11
  OO      OO  UU      UU      TT         1111
  OO      OO  UU      UU      TT         1111
  OO      OO  UU      UU      TT           11
  OO      OO  UU      UU      TT           11
  OO      OO  UU      UU      TT           11
  OO      OO  UU      UU      TT           11
  OO      OO  UU      UU      TT           11
  OO      OO  UU      UU      TT           11
  OO      OO  UU      UU      TT           11
  OO      OO  UU      UU      TT           11
    OOOOOO    UUUUUUUUUU      TT         111111
    OOOOOO    UUUUUUUUUU      TT         111111
```

```
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     SSSSSSSS  MM      MM  PPPPPPPP        ;;;;         1
   SS          MMMM  MMMM  PP      PP      ;;;;       111
   SS          MMMM  MMMM  PP      PP      ;;;;       111
   SS          MM  MM  MM  PP      PP                   1
   SS          MM  MM  MM  PP      PP                   1
     SSSSSS    MM      MM  PPPPPPPP        ;;;;         1
     SSSSSS    MM      MM  PPPPPPPP        ;;;;         1
           SS  MM      MM  PP              ;;;;         1
           SS  MM      MM  PP              ;;;;         1
....       SS  MM      MM  PP                ;;         1
....       SS  MM      MM  PP                ;;         1
....  SSSSSSSS  MM      MM  PP              ;;         111
....  SSSSSSSS  MM      MM  PP              ;;         111
```

File _DUA0:[SYS0.DQS$SERVER]OUT1.SMP;1 (3046,84,0), last revised on 24-FEB-1991 20:09, is a 28 b
[300,311]. The records are stream-LF with implied (CR) carriage control. The longest record is

Job OUT1 (122) queued to P011 on 24-FEB-1991 20:09 by user LOUCKS, UIC [300,311], under account
printer LTA9080: on 24-FEB-1991 20:09 from queue P011.

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AAAAAAAAAA  00000000000000000000  Digital Equipment Corporation - VAX/VMS Version V5.3-1  0
AAAAAAAAAA  0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
```

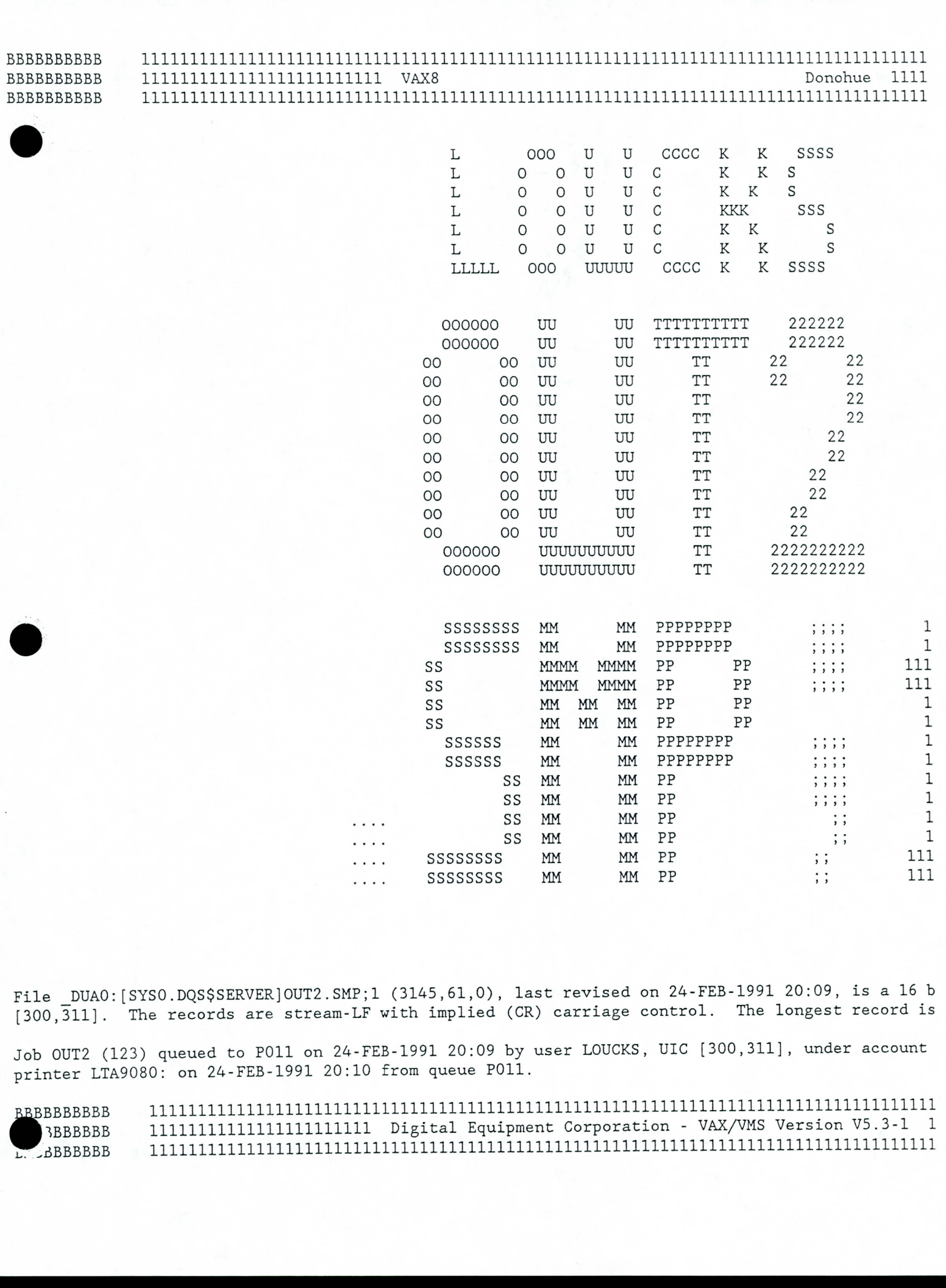
BBBBBBBBBB 1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111
BBBBBBBBBB 11111111111111111111 VAX8 Donohue 1111
BBBBBBBBBB 1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111
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L O O U U C K K S
L O O U U C K K S
L O O U U C KKK SSS
L O O U U C K K S
L O O U U C K K S
LLLLL OOO UUUUU CCCC K K SSSS
OOOOOO UU UU TTTTTTTTTT 222222
OOOOOO UU UU TTTTTTTTTT 222222
OO OO UU UU TT 22 22
OO OO UU UU TT 22 22
OO OO UU UU TT 22
OO OO UU UU TT 22
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OO OO UU UU TT 22
OO OO UU UU TT 22
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OO OO UU UU TT 22
OOOOOO UUUUUUUUUU TT 2222222222
OOOOOO UUUUUUUUUU TT 2222222222
SSSSSSSS MM MM PPPPPPPP ;;;; 1
SSSSSSSS MM MM PPPPPPPP ;;;; 1
SS MMMM MMMM PP PP ;;;; 111
SS MMMM MMMM PP PP ;;;; 111
SS MM MM MM PP PP 1
SS MM MM MM PP PP 1
SSSSSS MM MM PPPPPPPP ;;;; 1
SSSSSS MM MM PPPPPPPP ;;;; 1
SS MM MM PP ;;;; 1
SS MM MM PP ;;;; 1
.... SS MM MM PP ;; 1
.... SS MM MM PP ;; 1
.... SSSSSSSS MM MM PP ;; 111
.... SSSSSSSS MM MM PP ;; 111
File _DUA0:[SYS0.DQS$SERVER]OUT2.SMP;1 (3145,61,0), last revised on 24-FEB-1991 20:09, is a 16 b
[300,311]. The records are stream-LF with implied (CR) carriage control. The longest record is
Job OUT2 (123) queued to P011 on 24-FEB-1991 20:09 by user LOUCKS, UIC [300,311], under account
printer LTA9080: on 24-FEB-1991 20:10 from queue P011.
BBBBBBBBBB 1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111
BBBBBBB 1111111111111111111111 Digital Equipment Corporation - VAX/VMS Version V5.3-1 1
BBBBBBBBB 1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111

```
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 4.5E-01   88 8827 2.5E+00 -168 3.8E+01    81
    2 2.5E-02   88 8822 6.0E-02 3435 3.3E-02     0
 ERRP= 4.76E-04 AT ND= 42:4216 ERRQ= 1.53E+01 AT ND= 88:8828 DT/ITER=  1285.6
0SIMULATION ENDING AT  1987/ 8/13/ 20.297 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 4.5E-01   82 8208 2.5E+00 -168 3.6E+01   104
    2 2.8E-02    0   85 5.9E-02 2856 2.1E-02     0
 ERRP= 5.06E-04 AT ND= 42:4216 ERRQ= 3.39E+01 AT ND= 82:8207 DT/ITER=  1265.6
0SIMULATION ENDING AT  1987/ 8/13/ 20.313 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 4.5E-01   82 8205 2.5E+00 -168 3.5E+01   102
    2 7.7E-02   33 3307 8.4E-02 2856 2.3E-02     0
 ERRP= 5.45E-04 AT ND= 42:4229 ERRQ= 9.24E+01 AT ND= 64:6403 DT/ITER=  1246.3
0SIMULATION ENDING AT  1987/ 8/13/ 20.328 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 3.8E-01   82 8201 2.5E+00 -168 3.4E+01    64
    2 3.0E-02   33 3306 2.9E-02 3413 1.1E-02     0
 ERRP= 4.77E-04 AT ND= 42:4229 ERRQ= 2.94E+01 AT ND= 92:9204 DT/ITER=  1227.5
0SIMULATION ENDING AT  1987/ 8/13/ 20.344 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 2.8E-01    0  196 2.5E+00 -168 3.3E+01    62
    2 1.3E-02   80 8045 2.5E-02 3409 8.6E-03     0
 ERRP= 4.36E-04 AT ND= 40:4114 ERRQ= 3.53E+01 AT ND= 92:9204 DT/ITER=  1209.4
0SIMULATION ENDING AT  1987/ 8/13/ 20.359 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 2.4E-01   64 6404 2.5E+00 -168 3.3E+01    58
    2 8.4E-02   86-8602 1.1E-01 5359 5.3E-02     0
 ERRP= 4.63E-04 AT ND= 40:4114 ERRQ= 1.74E+01 AT ND= 92:9204 DT/ITER=  1191.7
0SIMULATION ENDING AT  1987/ 8/13/ 20.375 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 2.6E-01   63 6301 2.5E+00 -168 3.3E+01    53
    2 5.9E-02   86 8603 6.7E-02 3105 8.3E-02     0
 ERRP= 5.39E-04 AT ND= 40:4111 ERRQ= 1.66E+01 AT ND= 92:9204 DT/ITER=  1174.6
0SIMULATION ENDING AT  1987/ 8/13/ 20.391 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 2.6E-01   63 6303 2.4E+00 -124 3.6E+01    47
    2 7.3E-02   40 4102 4.3E-01 3099 3.0E+00     0
 ERRP= 7.95E-04 AT ND= 40:4112 ERRQ= 2.58E+01 AT ND= 92:9204 DT/ITER=  1158.0
0SIMULATION ENDING AT  1987/ 8/13/ 20.406 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 2.6E-01   63 6305 2.4E+00 -124 4.3E+01    46
    2 1.0E-01   40 4091 2.1E+00 -254 1.0E+01     1
 ERRP= 2.96E-03 AT ND= 40:4102 ERRQ= 1.66E+02 AT ND= 92:9204 DT/ITER=  1141.9
0SIMULATION ENDING AT  1987/ 8/13/ 20.422 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 2.6E-01   63 6307 4.6E+00 -124 6.2E+01    47
    2 9.2E-02   40 4085 1.2E+00 3053 3.6E+00     0
 ERRP= 2.28E-03 AT ND= 40:4109 ERRQ= 5.61E+01 AT ND= 88:8821 DT/ITER=  1126.2
0SIMULATION ENDING AT  1987/ 8/13/ 20.438 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 2.7E-01   88 8822 2.2E+00 -416 3.5E+01    49
    2 7.2E-02   40 4081 9.4E-01 3043 1.8E+00     0
 ERRP= 2.97E-03 AT ND= 40:4105 ERRQ= 2.51E+01 AT ND= 92:9204 DT/ITER=  1110.9
0SIMULATION ENDING AT  1987/ 8/13/ 20.453 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 4.2E-01   88 8823 2.2E+00 -416 3.0E+01    46
    2 4.7E-02   40 4078 7.1E-01 3037 7.6E-01     0
 ERRP= 2.08E-03 AT ND= 40:4097 ERRQ= 2.98E+01 AT ND= 92:9204 DT/ITER=  1096.1
0SIMULATION ENDING AT  1987/ 8/13/ 20.469 WITH TIME STEP OF       56.3 SEC
```

```
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 4.6E-01   88 8829 2.2E+00 -416 2.7E+01    40
    2 3.8E-02   40 4075 5.8E-01 3033 5.1E-01     0
 ERRP= 1.77E-03 AT ND= 40:4094 ERRQ= 4.16E+01 AT ND= 92:9204 DT/ITER=  1081.7
0SIMULATION ENDING AT  1987/ 8/13/ 20.484 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 4.4E-01   88 8830 2.2E+00 -416 2.3E+01    36
    2 4.4E-02   82 8210 5.4E-01 3029 4.9E-01     0
 ERRP= 1.71E-03 AT ND= 40:4091 ERRQ= 4.61E+01 AT ND= 92:9204 DT/ITER=  1067.6
0SIMULATION ENDING AT  1987/ 8/13/ 20.500 WITH TIME STEP OF       56.3 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 4.7E-01   87 8702 2.2E+00 -416 2.4E+01    32
    2 4.2E-02   40 4034 2.6E-01 2955 3.6E-01     0
```

```
CCCCCCCCCC     2222222222222222222222222222222222222222222222222222222222222222222222222222222222
CCCCCCCCCC     2222222222222222222222  VAX8                                                Donohue  2222
CCCCCCCCCC     2222222222222222222222222222222222222222222222222222222222222222222222222222222222
```

```
                L       OOO   U   U   CCCC  K   K   SSSS
                L      O   O  U   U  C      K   K  S
                L      O   O  U   U  C      K  K   S
                L      O   O  U   U  C      KKK     SSS
                L      O   O  U   U  C      K  K       S
                L      O   O  U   U  C      K   K      S
                LLLLL   OOO   UUUUU   CCCC  K   K  SSSS


              OOOOOO    UU      UU  TTTTTTTTTT    333333
              OOOOOO    UU      UU  TTTTTTTTTT    333333
            OO      OO  UU      UU      TT      33      33
            OO      OO  UU      UU      TT      33      33
            OO      OO  UU      UU      TT              33
            OO      OO  UU      UU      TT              33
            OO      OO  UU      UU      TT            33
            OO      OO  UU      UU      TT            33
            OO      OO  UU      UU      TT              33
            OO      OO  UU      UU      TT              33
            OO      OO  UU      UU      TT      33      33
            OO      OO  UU      UU      TT      33      33
              OOOOOO    UUUUUUUUUU      TT        333333
              OOOOOO    UUUUUUUUUU      TT        333333
```

```
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              SSSSSSSS  MM      MM  PPPPPPPP        ;;;;        1
            SS          MMMM  MMMM  PP      PP      ;;;;      111
            SS          MMMM  MMMM  PP      PP      ;;;;      111
            SS          MM  MM  MM  PP      PP                  1
            SS          MM  MM  MM  PP      PP                  1
              SSSSSS    MM      MM  PPPPPPPP        ;;;;        1
              SSSSSS    MM      MM  PPPPPPPP        ;;;;        1
                    SS  MM      MM  PP              ;;;;        1
                    SS  MM      MM  PP              ;;;;        1
....                SS  MM      MM  PP                ;;        1
....                SS  MM      MM  PP                ;;        1
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....        SSSSSSSS    MM      MM  PP              ;;        111
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File _DUA0:[SYS0.DQS$SERVER]OUT3.SMP;1 (3147,26,0), last revised on 24-FEB-1991 20:09, is a 11 b
[300,311]. The records are stream-LF with implied (CR) carriage control. The longest record is

Job OUT3 (124) queued to P011 on 24-FEB-1991 20:09 by user LOUCKS, UIC [300,311], under account
printer LTA9080: on 24-FEB-1991 20:10 from queue P011.

```
CCCCCCCCCC     2222222222222222222222222222222222222222222222222222222222222222222222222222222222
CCCCCCCCCC     2222222222222222222222  Digital Equipment Corporation - VAX/VMS Version V5.3-1  2
CCCCCCCCCC     2222222222222222222222222222222222222222222222222222222222222222222222222222222222
```

```
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 3.0E-01   24-2401 6.6E+00 -244 1.2E+02   118
    2 9.9E-02    0  -39 8.4E-02 2481 3.7E-02     0
 ERRP= 8.79E-04 AT ND= 40:4132 ERRQ= 2.55E+00 AT ND= 74:7400 DT/ITER=   674.0
 SIMULATION ENDING AT  1987/ 8/13/ 22.507 WITH TIME STEP OF      284.8 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 2.3E-01   24-2402 6.2E+00 -244 1.2E+02   120
    2 3.6E-02   24-2401 3.9E-02 2053 2.0E-02     0
 ERRP= 3.65E-03 AT ND= 40:4005 ERRQ= 2.54E+00 AT ND= 74:7400 DT/ITER=   669.7
0SIMULATION ENDING AT  1987/ 8/13/ 22.586 WITH TIME STEP OF      284.8 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 1.7E-01   24-2403 4.5E+00 -372 8.0E+01   112
    2 1.7E-02   24-2402 3.7E-02 2897 1.6E-02     0
 ERRP= 4.77E-03 AT ND= 40:4008 ERRQ= 2.54E+00 AT ND= 74:7400 DT/ITER=   665.5
0SIMULATION ENDING AT  1987/ 8/13/ 22.665 WITH TIME STEP OF      284.8 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 1.5E-01    0  -45 5.1E+00 -372 8.1E+01    91
    2 1.5E-02   35-3516 4.2E-02 2901 1.5E-02     0
 ERRP= 4.99E-03 AT ND= 40:4011 ERRQ= 2.55E+00 AT ND= 74:7400 DT/ITER=   661.4
0SIMULATION ENDING AT  1987/ 8/13/ 22.744 WITH TIME STEP OF      284.8 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 1.7E-01    0  -35 5.5E+00 -372 8.1E+01    51
    2 1.4E-02    0  -97 4.7E-02 2905 1.5E-02     0
 ERRP= 5.11E-03 AT ND= 40:4013 ERRQ= 2.53E+00 AT ND= 74:7400 DT/ITER=   657.3
0SIMULATION ENDING AT  1987/ 8/13/ 22.823 WITH TIME STEP OF      284.8 SEC
 ITER  RERROR  BRA NODE   MXRES  LOC  SUMSQR NUMGT
    1 1.7E-01   23-2392 5.6E+00 -372 8.0E+01    27
    2 1.7E-02   23-2390 6.7E-02 2465 2.5E-02     0
 ERRP= 5.13E-03 AT ND= 40:4016 ERRQ= 2.54E+00 AT ND= 74:7400 DT/ITER=   653.3
```

335		8.3667	16.98	643.27	0.85	3.5164E+03	1.2347E+02
336		8.3643	17.24	643.27	0.82	3.5164E+03	1.2347E+02
337		8.3619	17.49	643.27	0.79	3.5164E+03	1.2347E+02
338		8.3595	17.75	643.27	0.76	3.5164E+03	1.2347E+02
339		8.3571	18.00	643.27	0.74	3.5164E+03	1.2347E+02
340		8.3548	18.26	643.27	0.71	3.5164E+03	1.2347E+02
341		8.3524	18.51	643.27	0.69	3.5164E+03	1.2347E+02
342		8.3500	18.77	643.27	1.00	3.5164E+03	1.2347E+02
343		8.3466	18.46	643.26	1.03	3.5164E+03	1.2347E+02
344		8.3433	18.16	643.26	1.07	3.5164E+03	1.2347E+02
345		8.3399	17.86	643.26	1.12	3.5164E+03	1.2347E+02
346		8.3365	17.55	643.25	1.16	3.5164E+03	1.2347E+02
347		8.3332	17.25	643.25	1.21	3.5164E+03	1.2347E+02
348		8.3298	16.94	643.24	1.26	3.5164E+03	1.2347E+02
349		8.3265	16.64	643.24	1.32	3.5164E+03	1.2347E+02
350		8.3231	16.33	643.23	1.38	3.5164E+03	1.2347E+02
351		8.3197	16.03	643.23	1.44	3.5164E+03	1.2347E+02
352		8.3164	15.72	643.22	1.52	3.5164E+03	1.2347E+02
353	HINSDAM	8.3130	15.44	643.24	0.66	3.5164E+03	1.2347E+02

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UUUUUUUUUU    7777777777777777777777777777777777777777777777777777777777777777777777777777
UUUUUUUUUU    77777777777777777777  VAX8                                          Donohue  7777
UUUUUUUUUU    7777777777777777777777777777777777777777777777777777777777777777777777777777
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L       OOO   U   U   CCCC  K   K   SSSS
L      O   O  U   U  C      K   K  S
L      O   O  U   U  C      K  K   S
L      O   O  U   U  C      KKK     SSS
L      O   O  U   U  C      K  K       S
L      O   O  U   U  C      K   K      S
LLLLL   OOO   UUUUU   CCCC  K   K  SSSS
```

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  SSSSSSSS  PPPPPPPP      000000        11
SS          PP      PP  00      00    1111
SS          PP      PP  00      00    1111
SS          PP      PP  00      00      11
SS          PP      PP  00      00      11
  SSSSSS    PPPPPPPP    00      00      11
  SSSSSS    PPPPPPPP    00      00      11
        SS  PP          00      00      11
        SS  PP          00      00      11
        SS  PP          00      00      11
        SS  PP          00      00      11
SSSSSSSS    PP            000000      111111
SSSSSSSS    PP            000000      111111
```

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SS          MMMM  MMMM  PP      PP      ;;;;      111
SS          MM  MM  MM  PP      PP                  1
SS          MM  MM  MM  PP      PP                  1
  SSSSSS    MM      MM  PPPPPPPP        ;;;;        1
  SSSSSS    MM      MM  PPPPPPPP        ;;;;        1
        SS  MM      MM  PP              ;;;;        1
        SS  MM      MM  PP              ;;;;        1
....    SS  MM      MM  PP                ;;        1
....    SS  MM      MM  PP                ;;        1
....  SSSSSSSS  MM      MM  PP            ;;      111
....  SSSSSSSS  MM      MM  PP            ;;      111
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File _DUA0:[SYS0.DQS$SERVER]SPO1.SMP;1 (2930,91,0), last revised on 22-FEB-1991 12:54, is a 9 bl
[300,311]. The records are stream-LF with implied (CR) carriage control. The longest record is

Job SPO1 (758) queued to P011 on 22-FEB-1991 12:54 by user LOUCKS, UIC [300,311], under account
printer LTA9080: on 22-FEB-1991 12:55 from queue P011.

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UUUUUUUUUU    7777777777777777777777777777777777777777777777777777777777777777777777777777
UUUUUUUUUU    77777777777777777777  Digital Equipment Corporation - VAX/VMS Version V5.3-1  7
UUUUUUUUUU    7777777777777777777777777777777777777777777777777777777777777777777777777777
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VVVVVVVVVV    8888888888888888888888888888888888888888888888888888888888888888888888888888888888
VVVVVVVVVV    88888888888888888888  VAX8                                                  Donohue  8888
VVVVVVVVVV    8888888888888888888888888888888888888888888888888888888888888888888888888888888888
```

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L       OOO   U   U   CCCC  K   K   SSSS
L      O   O  U   U  C      K   K  S
L      O   O  U   U  C      K  K   S
L      O   O  U   U  C      KKK     SSS
L      O   O  U   U  C      K  K       S
L      O   O  U   U  C      K   K      S
LLLLL   OOO   UUUUU   CCCC  K   K  SSSS
```

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SS          PP      PP  00      00  22      22
SS          PP      PP  00      00          22
SS          PP      PP  00      00          22
  SSSSSS    PPPPPPPP    00      00        22
  SSSSSS    PPPPPPPP    00      00        22
        SS  PP          00      00      22
        SS  PP          00      00      22
        SS  PP          00      00    22
        SS  PP          00      00    22
SSSSSSSS    PP            000000    2222222222
SSSSSSSS    PP            000000    2222222222
```

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SS          MM  MM  MM  PP      PP                  1
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        SS  MM      MM  PP              ;;;;        1
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....  SSSSSSSS  MM      MM  PP            ;;      111
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File _DUA0:[SYS0.DQS$SERVER]SPO2.SMP;1 (2931,69,0), last revised on 22-FEB-1991 12:54, is a 131
[300,311]. The records are stream-LF with implied (CR) carriage control. The longest record is

Job SPO2 (759) queued to P011 on 22-FEB-1991 12:54 by user LOUCKS, UIC [300,311], under account
printer LTA9080: on 22-FEB-1991 12:56 from queue P011.

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VVVVVVVVVV    8888888888888888888888888888888888888888888888888888888888888888888888888888888888
VVVVVVVVVV    88888888888888888888  Digital Equipment Corporation - VAX/VMS Version V5.3-1  8
VVVVVVVVVV    8888888888888888888888888888888888888888888888888888888888888888888888888888888888
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1987/ 8/13	671.39	669.44	664.89	661.33	661.24	661.16	480.00	480.00	480.00	649.88
20.000000	26.4	26.5	1.7	38.9	38.9	38.9	0.0	0.0	0.0	97.9
1987/ 8/13	671.58	669.50	665.05	661.56	661.40	661.26	480.00	480.00	480.00	649.89
20.062500	31.5	27.9	-3.8	59.0	62.0	45.7	0.0	0.0	0.0	101.1
1987/ 8/13	671.69	669.53	665.11	661.66	661.49	661.33	480.00	480.00	480.00	649.90
20.093750	36.8	28.7	-6.1	67.8	70.6	49.5	0.0	0.0	0.0	103.6
1987/ 8/13	671.74	669.54	665.14	661.71	661.53	661.37	480.00	480.00	480.00	649.90
20.109380	40.2	29.3	-6.9	70.9	73.9	51.3	0.0	0.0	0.0	105.1
1987/ 8/13	671.77	669.55	665.16	661.73	661.55	661.39	480.00	480.00	480.00	649.90
20.117190	42.1	29.6	-7.2	72.6	75.4	52.1	0.0	0.0	0.0	105.9
1987/ 8/13	671.78	669.55	665.16	661.74	661.56	661.40	480.00	480.00	480.00	649.91
20.121090	43.0	29.7	-7.4	73.4	76.1	52.5	0.0	0.0	0.0	106.3
1987/ 8/13	671.80	669.56	665.17	661.76	661.57	661.41	480.00	480.00	480.00	649.91
20.125000	44.0	29.9	-7.5	74.3	76.9	52.8	0.0	0.0	0.0	106.8
1987/ 8/13	671.81	669.56	665.18	661.77	661.58	661.42	480.00	480.00	480.00	649.91
20.128910	45.0	30.1	-7.6	75.2	77.6	53.2	0.0	0.0	0.0	107.2
1987/ 8/13	671.83	669.56	665.18	661.78	661.59	661.43	480.00	480.00	480.00	649.91
20.132810	46.0	30.3	-7.7	76.0	78.3	53.5	0.0	0.0	0.0	107.7
1987/ 8/13	671.84	669.57	665.19	661.79	661.60	661.44	480.00	480.00	480.00	649.91
20.136720	47.0	30.5	-7.9	76.8	79.1	53.8	0.0	0.0	0.0	108.2
1987/ 8/13	671.86	669.57	665.20	661.80	661.61	661.45	480.00	480.00	480.00	649.91
20.140630	48.0	30.7	-7.9	77.7	79.8	54.1	0.0	0.0	0.0	108.7
1987/ 8/13	671.87	669.58	665.21	661.81	661.62	661.46	480.00	480.00	480.00	649.91
20.144530	49.1	30.9	-8.1	78.5	80.5	54.4	0.0	0.0	0.0	109.2
1987/ 8/13	671.89	669.58	665.21	661.83	661.63	661.47	480.00	480.00	480.00	649.92
20.148440	50.1	31.1	-8.1	79.3	81.3	54.7	0.0	0.0	0.0	109.7
1987/ 8/13	671.91	669.59	665.22	661.84	661.65	661.49	480.00	480.00	480.00	649.92
20.154300	51.7	31.5	-8.3	80.3	82.3	55.2	0.0	0.0	0.0	110.5
1987/ 8/13	671.93	669.59	665.23	661.86	661.67	661.50	480.00	480.00	480.00	649.92
20.160160	53.1	31.9	-8.4	81.3	83.3	55.8	0.0	0.0	0.0	111.4
1987/ 8/13	671.95	669.60	665.24	661.88	661.68	661.52	480.00	480.00	480.00	649.92
20.166020	54.4	32.3	-8.6	82.3	84.3	56.4	0.0	0.0	0.0	112.3
1987/ 8/13	671.97	669.61	665.25	661.89	661.70	661.54	480.00	480.00	480.00	649.93
20.171880	55.5	32.7	-8.7	83.2	85.1	57.1	0.0	0.0	0.0	113.2
1987/ 8/13	672.00	669.61	665.26	661.91	661.72	661.56	480.00	480.00	480.00	649.93
20.177730	56.6	33.2	-8.9	84.0	85.9	57.8	0.0	0.0	0.0	114.2
1987/ 8/13	672.02	669.62	665.27	661.93	661.73	661.57	480.00	480.00	480.00	649.93
20.183590	57.7	33.6	-9.1	84.8	86.7	58.5	0.0	0.0	0.0	115.2
1987/ 8/13	672.04	669.63	665.28	661.94	661.75	661.59	480.00	480.00	480.00	649.94
20.189450	58.7	34.2	-9.2	85.6	87.5	59.3	0.0	0.0	0.0	116.2
1987/ 8/13	672.06	669.64	665.29	661.96	661.76	661.61	480.00	480.00	480.00	649.94
20.195310	59.2	34.7	-9.3	86.3	88.1	60.0	0.0	0.0	0.0	117.2
1987/ 8/13	672.08	669.65	665.30	661.97	661.78	661.63	480.00	480.00	480.00	649.95
20.201170	59.5	35.3	-9.5	86.9	88.8	60.6	0.0	0.0	0.0	118.3
1987/ 8/13	672.09	669.65	665.31	661.99	661.80	661.64	480.00	480.00	480.00	649.95
20.207030	59.5	35.8	-9.5	87.6	89.4	61.2	0.0	0.0	0.0	119.4
1987/ 8/13	672.11	669.66	665.32	662.00	661.81	661.66	480.00	480.00	480.00	649.95
20.212890	59.4	36.4	-9.6	88.2	90.1	61.7	0.0	0.0	0.0	120.5
1987/ 8/13	672.13	669.67	665.33	662.02	661.83	661.68	480.00	480.00	480.00	649.96
20.218750	59.2	37.0	-9.6	88.8	90.7	61.9	0.0	0.0	0.0	121.7
1987/ 8/13	672.14	669.68	665.34	662.03	661.84	661.70	480.00	480.00	480.00	649.96
20.224610	58.9	37.7	-9.6	89.4	91.3	61.9	0.0	0.0	0.0	122.9
1987/ 8/13	672.16	669.69	665.35	662.05	661.86	661.72	480.00	480.00	480.00	649.97
20.230470	58.7	38.3	-9.5	90.0	91.9	62.1	0.0	0.0	0.0	124.2
1987/ 8/13	672.17	669.70	665.36	662.06	661.88	661.74	480.00	480.00	480.00	649.97
20.236330	58.4	39.0	-9.4	90.5	92.3	62.3	0.0	0.0	0.0	125.6
1987/ 8/13	672.19	669.71	665.37	662.08	661.89	661.76	480.00	480.00	480.00	649.98
20.242190	58.1	39.6	-9.2	91.0	92.7	62.7	0.0	0.0	0.0	126.9
1987/ 8/13	672.20	669.72	665.38	662.09	661.91	661.78	480.00	480.00	480.00	649.98
20.248050	57.8	40.4	-9.1	91.4	93.0	63.0	0.0	0.0	0.0	128.3

1987/ 8/13	672.22	669.73	665.39	662.11	661.93	661.80	480.00	480.00	480.00	649.99
20.253910	57.6	41.1	-8.9	91.8	93.3	63.3	0.0	0.0	0.0	129.6
1987/ 8/13	672.23	669.74	665.40	662.12	661.94	661.81	480.00	480.00	480.00	650.00
[illegible].259770	57.4	41.8	-8.7	92.2	93.7	63.6	0.0	0.0	0.0	131.0
[illegible]/ 8/13	672.24	669.75	665.41	662.13	661.96	661.83	480.00	480.00	480.00	650.00
20.265630	57.3	42.5	-8.5	92.5	94.0	63.9	0.0	0.0	0.0	132.2
1987/ 8/13	672.26	669.76	665.42	662.15	661.98	661.85	480.00	480.00	480.00	650.01
20.271480	57.2	43.3	-8.3	92.7	94.2	64.3	0.0	0.0	0.0	133.5
1987/ 8/13	672.27	669.77	665.43	662.16	661.99	661.87	480.00	480.00	480.00	650.01
20.277340	57.2	44.0	-8.1	93.0	94.5	64.7	0.0	0.0	0.0	134.7
1987/ 8/13	672.28	669.78	665.44	662.18	662.01	661.89	480.00	480.00	480.00	650.02
20.283200	57.2	44.8	-7.8	93.2	94.7	64.9	0.0	0.0	0.0	135.9
1987/ 8/13	672.29	669.79	665.45	662.19	662.03	661.91	480.00	480.00	480.00	650.03
20.289060	57.2	45.6	-7.5	93.4	94.9	65.3	0.0	0.0	0.0	137.2
1987/ 8/13	672.31	669.80	665.46	662.20	662.04	661.93	480.00	480.00	480.00	650.03
20.294920	57.3	46.4	-7.1	93.6	95.1	65.5	0.0	0.0	0.0	138.4
1987/ 8/13	672.32	669.81	665.47	662.22	662.06	661.94	480.00	480.00	480.00	650.04
20.300780	57.5	47.2	-6.7	93.7	95.2	65.6	0.0	0.0	0.0	139.6
1987/ 8/13	672.33	669.83	665.48	662.23	662.07	661.96	480.00	480.00	480.00	650.05
20.306640	57.7	48.1	-6.3	94.0	95.4	65.7	0.0	0.0	0.0	140.8
1987/ 8/13	672.34	669.84	665.50	662.24	662.09	661.98	480.00	480.00	480.00	650.05
20.312500	57.9	48.9	-5.7	94.2	95.6	65.7	0.0	0.0	0.0	142.1
1987/ 8/13	672.35	669.85	665.51	662.26	662.11	662.00	480.00	480.00	480.00	650.06
20.318360	58.1	49.8	-5.2	94.3	95.8	65.7	0.0	0.0	0.0	143.3
1987/ 8/13	672.36	669.86	665.52	662.27	662.12	662.02	480.00	480.00	480.00	650.07
20.324220	58.4	50.6	-4.6	94.5	95.9	65.7	0.0	0.0	0.0	144.5
1987/ 8/13	672.37	669.87	665.53	662.28	662.14	662.04	480.00	480.00	480.00	650.07
20.330080	58.7	51.5	-3.9	94.6	95.9	65.8	0.0	0.0	0.0	145.8
1987/ 8/13	672.39	669.89	665.54	662.30	662.15	662.06	480.00	480.00	480.00	650.08
20.335940	59.0	52.4	-3.2	94.7	96.0	65.9	0.0	0.0	0.0	147.2
[illegible]/ 8/13	672.40	669.90	665.55	662.31	662.17	662.07	480.00	480.00	480.00	650.09
20.341800	59.3	53.3	-2.5	94.7	96.0	66.0	0.0	0.0	0.0	148.5
1987/ 8/13	672.41	669.91	665.57	662.32	662.19	662.09	480.00	480.00	480.00	650.10
20.347660	59.6	54.2	-1.8	94.8	96.0	66.1	0.0	0.0	0.0	149.8
1987/ 8/13	672.42	669.92	665.58	662.34	662.20	662.11	480.00	480.00	480.00	650.11
20.353520	60.0	55.1	-1.0	94.8	96.0	66.1	0.0	0.0	0.0	151.2
1987/ 8/13	672.43	669.94	665.59	662.35	662.22	662.13	480.00	480.00	480.00	650.11
20.359380	60.4	56.0	-0.2	94.8	96.0	66.2	0.0	0.0	0.0	152.6
1987/ 8/13	672.44	669.95	665.60	662.36	662.23	662.15	480.00	480.00	480.00	650.12
20.365230	60.8	57.0	0.5	94.8	96.0	66.1	0.0	0.0	0.0	154.0
1987/ 8/13	672.45	669.96	665.61	662.38	662.25	662.17	480.00	480.00	480.00	650.13
20.371090	61.2	57.9	1.3	94.8	96.0	66.1	0.0	0.0	0.0	155.5
1987/ 8/13	672.46	669.98	665.63	662.39	662.27	662.18	480.00	480.00	480.00	650.14
20.376950	61.6	58.8	2.1	94.7	95.9	66.1	0.0	0.0	0.0	157.0
1987/ 8/13	672.47	669.99	665.64	662.40	662.28	662.20	480.00	480.00	480.00	650.15
20.382810	62.1	59.7	2.9	94.7	95.9	66.4	0.0	0.0	0.0	158.5
1987/ 8/13	672.48	670.00	665.65	662.42	662.30	662.22	480.00	480.00	480.00	650.16
20.388670	62.5	60.7	3.8	94.6	95.7	66.6	0.0	0.0	0.0	160.1
1987/ 8/13	672.49	670.01	665.67	662.43	662.31	662.24	480.00	480.00	480.00	650.17
20.394530	63.0	61.6	4.6	94.6	95.7	66.6	0.0	0.0	0.0	161.6
1987/ 8/13	672.50	670.03	665.68	662.44	662.33	662.25	480.00	480.00	480.00	650.18
20.400390	63.5	62.5	5.4	94.6	95.7	66.8	0.0	0.0	0.0	163.3
1987/ 8/13	672.51	670.04	665.69	662.46	662.35	662.27	480.00	480.00	480.00	650.18
20.406250	63.9	63.5	6.3	94.6	95.8	67.4	0.0	0.0	0.0	164.9
1987/ 8/13	672.52	670.06	665.71	662.47	662.36	662.28	480.00	480.00	480.00	650.19
[illegible].412110	64.4	64.4	7.1	94.7	95.7	67.8	0.0	0.0	0.0	166.6
[illegible]7/ 8/13	672.53	670.07	665.72	662.48	662.38	662.30	480.00	480.00	480.00	650.20
[illegible].417970	64.9	65.3	8.0	94.8	95.9	67.7	0.0	0.0	0.0	168.3
1987/ 8/13	672.54	670.08	665.73	662.50	662.39	662.32	480.00	480.00	480.00	650.21
20.423830	65.4	66.3	8.9	94.9	96.2	67.4	0.0	0.0	0.0	170.0

1987/ 8/13	672.55	670.10	665.75	662.51	662.41	662.34	480.00	480.00	480.00	650.23
20.429690	65.9	67.2	9.9	95.0	96.4	67.2	0.0	0.0	0.0	171.8
1987/ 8/13	672.56	670.11	665.76	662.52	662.42	662.35	480.00	480.00	480.00	650.24
20.435550	66.5	68.1	10.8	95.1	96.4	67.2	0.0	0.0	0.0	173.6
1987/ 8/13	672.57	670.12	665.77	662.54	662.44	662.37	480.00	480.00	480.00	650.25
20.441410	67.0	69.0	11.8	95.2	96.2	67.2	0.0	0.0	0.0	175.4
1987/ 8/13	672.58	670.14	665.79	662.55	662.45	662.39	480.00	480.00	480.00	650.26
20.447270	67.6	69.9	12.8	95.2	96.2	67.3	0.0	0.0	0.0	177.4
1987/ 8/13	672.59	670.15	665.80	662.56	662.47	662.40	480.00	480.00	480.00	650.27
20.453130	68.2	70.8	13.9	95.2	96.1	67.4	0.0	0.0	0.0	179.4
1987/ 8/13	672.60	670.16	665.81	662.58	662.48	662.42	480.00	480.00	480.00	650.28
20.458980	68.8	71.8	14.9	95.2	96.1	67.5	0.0	0.0	0.0	181.3
1987/ 8/13	672.61	670.18	665.83	662.59	662.50	662.44	480.00	480.00	480.00	650.29
20.464840	69.4	72.7	16.0	95.2	96.1	67.6	0.0	0.0	0.0	183.2
1987/ 8/13	672.62	670.19	665.84	662.60	662.52	662.45	480.00	480.00	480.00	650.30
20.470700	70.0	73.6	17.1	95.2	96.2	67.8	0.0	0.0	0.0	185.0
1987/ 8/13	672.63	670.20	665.86	662.62	662.53	662.47	480.00	480.00	480.00	650.31
20.476560	70.6	74.5	18.2	95.1	96.2	67.9	0.0	0.0	0.0	186.7
1987/ 8/13	672.64	670.22	665.87	662.63	662.55	662.49	480.00	480.00	480.00	650.33
20.482420	71.2	75.3	19.3	95.1	96.2	68.1	0.0	0.0	0.0	188.5
1987/ 8/13	672.65	670.23	665.88	662.64	662.56	662.50	480.00	480.00	480.00	650.34
20.488280	71.8	76.2	20.4	95.1	96.2	68.2	0.0	0.0	0.0	190.3
1987/ 8/13	672.66	670.24	665.90	662.66	662.58	662.52	480.00	480.00	480.00	650.35
20.494140	72.4	77.1	21.5	95.2	96.2	68.4	0.0	0.0	0.0	192.0
1987/ 8/13	672.67	670.26	665.91	662.67	662.59	662.53	480.00	480.00	480.00	650.36
20.500000	73.0	78.0	22.6	95.2	96.3	68.5	0.0	0.0	0.0	193.8
1987/ 8/13	672.68	670.27	665.93	662.69	662.61	662.55	480.00	480.00	480.00	650.37
20.505860	73.6	78.8	23.7	95.4	96.4	68.6	0.0	0.0	0.0	195.6
1987/ 8/13	672.69	670.28	665.94	662.70	662.62	662.57	480.00	480.00	480.00	650.38
20.511720	74.3	79.7	24.8	95.5	96.5	68.6	0.0	0.0	0.0	197.4
1987/ 8/13	672.70	670.30	665.96	662.71	662.64	662.58	480.00	480.00	480.00	650.40
20.517580	74.9	80.5	25.9	95.6	96.6	68.7	0.0	0.0	0.0	199.2
1987/ 8/13	672.71	670.31	665.97	662.73	662.65	662.60	480.00	480.00	480.00	650.41
20.523440	75.5	81.4	27.0	95.7	96.7	68.7	0.0	0.0	0.0	201.1
1987/ 8/13	672.72	670.32	665.99	662.74	662.67	662.61	480.00	480.00	480.00	650.42
20.529300	76.2	82.2	28.1	95.9	96.8	68.8	0.0	0.0	0.0	202.9
1987/ 8/13	672.72	670.34	666.00	662.75	662.68	662.63	480.00	480.00	480.00	650.43
20.535160	76.8	83.1	29.2	96.0	96.9	68.8	0.0	0.0	0.0	204.7
1987/ 8/13	672.73	670.35	666.02	662.77	662.70	662.64	480.00	480.00	480.00	650.45
20.541020	77.5	83.9	30.3	96.0	96.9	69.1	0.0	0.0	0.0	206.5
1987/ 8/13	672.74	670.36	666.03	662.78	662.71	662.66	480.00	480.00	480.00	650.46
20.546880	78.1	84.7	31.4	96.1	97.0	69.0	0.0	0.0	0.0	208.3
1987/ 8/13	672.75	670.38	666.05	662.79	662.73	662.68	480.00	480.00	480.00	650.47
20.552730	78.8	85.5	32.5	96.2	97.1	67.9	0.0	0.0	0.0	210.1
1987/ 8/13	672.76	670.39	666.06	662.81	662.74	662.69	480.00	480.00	480.00	650.49
20.558590	79.4	86.3	33.6	96.2	97.2	68.1	0.0	0.0	0.0	211.8
1987/ 8/13	672.77	670.40	666.08	662.82	662.76	662.71	480.00	480.00	480.00	650.50
20.564450	80.1	87.1	34.7	96.3	97.0	70.4	0.0	0.0	0.0	213.6
1987/ 8/13	672.78	670.41	666.09	662.84	662.77	662.72	480.00	480.00	480.00	650.51
20.570310	80.7	88.0	35.7	96.3	96.5	71.7	0.0	0.0	0.0	215.4
1987/ 8/13	672.79	670.43	666.11	662.85	662.79	662.73	480.00	480.00	480.00	650.53
20.576170	81.4	88.8	36.6	96.2	96.8	71.6	0.0	0.0	0.0	217.2
1987/ 8/13	672.80	670.44	666.12	662.86	662.80	662.75	480.00	480.00	480.00	650.54
20.582030	82.0	89.6	37.5	96.2	97.9	71.6	0.0	0.0	0.0	219.0
1987/ 8/13	672.81	670.45	666.14	662.88	662.81	662.76	480.00	480.00	480.00	650.55
20.587890	82.7	90.3	38.2	96.5	98.5	71.8	0.0	0.0	0.0	220.8
1987/ 8/13	672.81	670.47	666.15	662.89	662.83	662.78	480.00	480.00	480.00	650.57
20.593750	83.3	91.1	38.9	96.9	98.6	72.0	0.0	0.0	0.0	222.7
1987/ 8/13	672.83	670.48	666.17	662.91	662.85	662.80	480.00	480.00	480.00	650.59
20.602540	84.3	92.3	40.0	97.3	98.6	72.4	0.0	0.0	0.0	225.4

1987/ 8/13	672.84	670.50	666.19	662.93	662.87	662.82	480.00	480.00	480.00	650.61
20.611330	85.2	93.5	41.0	97.4	98.7	72.7	0.0	0.0	0.0	228.2
1987/ 8/13	672.86	670.53	666.23	662.96	662.90	662.85	480.00	480.00	480.00	650.64
20.624510	86.7	95.2	42.5	97.6	99.0	73.1	0.0	0.0	0.0	232.3
1987/ 8/13	672.88	670.56	666.26	662.99	662.93	662.89	480.00	480.00	480.00	650.67
20.637700	88.1	96.9	44.0	97.8	99.3	73.5	0.0	0.0	0.0	236.5
1987/ 8/13	672.90	670.59	666.29	663.02	662.96	662.92	480.00	480.00	480.00	650.70
20.650880	89.5	98.6	45.4	98.1	99.6	74.0	0.0	0.0	0.0	240.8
1987/ 8/13	672.92	670.61	666.32	663.04	662.99	662.95	480.00	480.00	480.00	650.73
20.664060	90.9	100.4	46.7	98.4	99.9	74.4	0.0	0.0	0.0	245.1
1987/ 8/13	672.94	670.64	666.35	663.07	663.02	662.98	480.00	480.00	480.00	650.77
20.677250	92.4	102.0	48.0	98.6	100.2	74.9	0.0	0.0	0.0	249.4
1987/ 8/13	672.95	670.67	666.38	663.10	663.05	663.01	480.00	480.00	480.00	650.80
20.690430	93.8	103.7	49.2	98.9	100.5	75.5	0.0	0.0	0.0	253.9
1987/ 8/13	672.97	670.69	666.41	663.13	663.08	663.04	480.00	480.00	480.00	650.83
20.703610	95.3	105.4	50.4	99.3	100.9	76.4	0.0	0.0	0.0	258.5
1987/ 8/13	672.99	670.72	666.43	663.16	663.11	663.07	480.00	480.00	480.00	650.86
20.716800	96.8	107.1	51.5	99.7	101.5	77.3	0.0	0.0	0.0	263.2
1987/ 8/13	673.01	670.75	666.46	663.18	663.14	663.10	480.00	480.00	480.00	650.90
20.729980	98.2	108.8	52.6	100.2	102.1	78.4	0.0	0.0	0.0	268.0
1987/ 8/13	673.03	670.77	666.49	663.21	663.16	663.12	480.00	480.00	480.00	650.93
20.743160	99.7	110.4	53.7	100.8	102.8	79.4	0.0	0.0	0.0	272.9
1987/ 8/13	673.04	670.80	666.52	663.24	663.19	663.15	480.00	480.00	480.00	650.97
20.756350	101.2	112.1	54.9	101.4	103.6	80.5	0.0	0.0	0.0	277.8
1987/ 8/13	673.06	670.82	666.55	663.26	663.22	663.18	480.00	480.00	480.00	651.00
20.769530	102.7	113.7	56.0	102.1	104.4	81.5	0.0	0.0	0.0	283.0
1987/ 8/13	673.08	670.85	666.58	663.29	663.25	663.21	480.00	480.00	480.00	651.04
20.782710	104.2	115.4	57.2	102.8	105.2	82.6	0.0	0.0	0.0	288.2
1987/ 8/13	673.10	670.87	666.60	663.32	663.27	663.23	480.00	480.00	480.00	651.07
20.795900	105.8	117.0	58.5	103.6	106.1	83.8	0.0	0.0	0.0	293.5
1987/ 8/13	673.11	670.90	666.63	663.34	663.30	663.26	480.00	480.00	480.00	651.11
20.809080	107.3	118.6	59.8	104.5	107.0	85.0	0.0	0.0	0.0	299.0
1987/ 8/13	673.13	670.92	666.66	663.37	663.32	663.28	480.00	480.00	480.00	651.15
20.822270	108.9	120.3	61.0	105.4	108.0	86.2	0.0	0.0	0.0	304.7
1987/ 8/13	673.15	670.95	666.68	663.39	663.35	663.31	480.00	480.00	480.00	651.19
20.835450	110.5	121.9	62.3	106.4	109.0	87.3	0.0	0.0	0.0	310.5
1987/ 8/13	673.17	670.97	666.71	663.42	663.37	663.33	480.00	480.00	480.00	651.22
20.848630	112.1	123.5	63.5	107.4	110.1	88.4	0.0	0.0	0.0	316.3
1987/ 8/13	673.18	671.00	666.74	663.44	663.40	663.36	480.00	480.00	480.00	651.26
20.861820	113.6	125.1	64.7	108.4	111.1	89.5	0.0	0.0	0.0	322.2
1987/ 8/13	673.20	671.02	666.76	663.47	663.42	663.38	480.00	480.00	480.00	651.30
20.875000	115.2	126.7	65.8	109.4	112.1	90.7	0.0	0.0	0.0	328.1
1987/ 8/13	673.22	671.04	666.79	663.49	663.45	663.41	480.00	480.00	480.00	651.34
20.888180	116.8	128.3	66.9	110.5	113.3	92.2	0.0	0.0	0.0	334.0
1987/ 8/13	673.23	671.07	666.81	663.52	663.47	663.43	480.00	480.00	480.00	651.38
20.901370	118.4	129.9	68.1	111.6	114.5	93.8	0.0	0.0	0.0	339.8
1987/ 8/13	673.25	671.09	666.84	663.54	663.50	663.46	480.00	480.00	480.00	651.42
20.914550	120.0	131.5	69.2	112.9	115.9	95.4	0.0	0.0	0.0	345.6
1987/ 8/13	673.27	671.11	666.86	663.56	663.52	663.48	480.00	480.00	480.00	651.46
20.927730	121.5	133.1	70.3	114.2	117.3	97.0	0.0	0.0	0.0	351.4
1987/ 8/13	673.28	671.14	666.88	663.59	663.54	663.50	480.00	480.00	480.00	651.50
20.940920	123.1	134.7	71.5	115.6	118.7	98.6	0.0	0.0	0.0	357.2
1987/ 8/13	673.30	671.16	666.91	663.61	663.57	663.53	480.00	480.00	480.00	651.54
20.954100	124.7	136.2	72.6	116.9	120.1	100.2	0.0	0.0	0.0	362.9
1987/ 8/13	673.32	671.18	666.93	663.63	663.59	663.55	480.00	480.00	480.00	651.58
20.967290	126.2	137.8	73.7	118.3	121.6	101.8	0.0	0.0	0.0	368.7
1987/ 8/13	673.33	671.21	666.96	663.66	663.61	663.57	480.00	480.00	480.00	651.62
20.980470	127.7	139.4	74.8	119.7	123.0	103.3	0.0	0.0	0.0	374.5
1987/ 8/13	673.35	671.23	666.98	663.68	663.64	663.59	480.00	480.00	480.00	651.66
20.993650	129.2	141.0	75.9	121.0	124.4	104.9	0.0	0.0	0.0	380.2

1987/ 8/13	673.37	671.25	667.00	663.70	663.66	663.61	480.00	480.00	480.00	651.71
21.006840	130.4	142.6	77.2	122.7	126.4	106.5	0.0	0.0	0.0	386.1
1987/ 8/13	673.38	671.27	667.03	663.73	663.68	663.64	480.00	480.00	480.00	651.76
21.020020	131.2	144.2	78.7	124.9	128.9	108.5	0.0	0.0	0.0	392.2
[redacted] 8/13	673.40	671.30	667.05	663.75	663.71	663.66	480.00	480.00	480.00	651.80
21.033200	132.0	145.9	80.3	127.2	131.2	110.8	0.0	0.0	0.0	398.5
1987/ 8/13	673.42	671.32	667.07	663.77	663.73	663.68	480.00	480.00	480.00	651.85
21.046390	133.1	147.6	82.0	129.4	133.5	113.3	0.0	0.0	0.0	404.5
1987/ 8/13	673.43	671.34	667.09	663.80	663.75	663.70	480.00	480.00	480.00	651.90
21.059570	134.3	149.4	83.9	131.5	135.7	115.7	0.0	0.0	0.0	410.5
1987/ 8/13	673.45	671.36	667.12	663.82	663.78	663.73	480.00	480.00	480.00	651.94
21.072750	135.6	151.2	85.8	133.4	137.8	118.1	0.0	0.0	0.0	416.4
1987/ 8/13	673.47	671.39	667.14	663.84	663.80	663.75	480.00	480.00	480.00	651.99
21.085940	137.0	153.0	87.6	135.3	139.8	120.3	0.0	0.0	0.0	422.4
1987/ 8/13	673.48	671.41	667.16	663.87	663.82	663.77	480.00	480.00	480.00	652.04
21.099120	138.4	154.8	89.3	137.2	141.7	122.4	0.0	0.0	0.0	428.4
1987/ 8/13	673.50	671.43	667.18	663.89	663.84	663.79	480.00	480.00	480.00	652.08
21.112300	139.9	156.6	91.1	139.0	143.6	124.4	0.0	0.0	0.0	434.4
1987/ 8/13	673.52	671.45	667.20	663.91	663.86	663.81	480.00	480.00	480.00	652.13
21.125490	141.4	158.4	92.8	140.7	145.4	126.4	0.0	0.0	0.0	440.4
1987/ 8/13	673.54	671.49	667.23	663.94	663.90	663.84	480.00	480.00	480.00	652.20
21.145260	143.6	161.1	95.4	143.2	148.0	129.3	0.0	0.0	0.0	449.4
1987/ 8/13	673.56	671.52	667.26	663.97	663.93	663.87	480.00	480.00	480.00	652.27
21.165040	145.9	163.8	97.9	145.8	150.6	132.2	0.0	0.0	0.0	458.5
1987/ 8/13	673.59	671.55	667.29	664.00	663.96	663.90	480.00	480.00	480.00	652.34
21.184810	148.0	166.4	100.3	148.3	153.3	135.1	0.0	0.0	0.0	467.6
1987/ 8/13	673.61	671.58	667.31	664.04	663.99	663.93	480.00	480.00	480.00	652.41
21.204590	149.9	169.0	102.5	150.8	156.0	138.1	0.0	0.0	0.0	476.7
1987/ 8/13	673.63	671.61	667.34	664.07	664.02	663.96	480.00	480.00	480.00	652.48
21.224370	151.8	171.6	104.7	153.4	158.7	141.2	0.0	0.0	0.0	485.8
[redacted] 8/13	673.65	671.64	667.37	664.09	664.05	663.99	480.00	480.00	480.00	652.55
21.244140	153.6	174.1	106.9	156.1	161.5	144.4	0.0	0.0	0.0	494.7
1987/ 8/13	673.68	671.67	667.39	664.12	664.08	664.02	480.00	480.00	480.00	652.62
21.263920	155.6	176.7	109.2	158.8	164.3	147.6	0.0	0.0	0.0	503.5
1987/ 8/13	673.70	671.70	667.42	664.15	664.10	664.04	480.00	480.00	480.00	652.69
21.283690	157.6	179.3	111.6	161.5	167.2	150.8	0.0	0.0	0.0	512.0
1987/ 8/13	673.72	671.73	667.44	664.18	664.13	664.07	480.00	480.00	480.00	652.75
21.303470	159.9	181.8	114.1	164.3	170.1	153.9	0.0	0.0	0.0	520.4
1987/ 8/13	673.74	671.76	667.47	664.21	664.16	664.10	480.00	480.00	480.00	652.82
21.323240	162.1	184.3	116.7	167.1	173.0	157.0	0.0	0.0	0.0	528.6
1987/ 8/13	673.76	671.79	667.49	664.23	664.18	664.12	480.00	480.00	480.00	652.89
21.343020	164.5	186.7	119.2	169.9	175.9	160.2	0.0	0.0	0.0	536.8
1987/ 8/13	673.79	671.83	667.53	664.27	664.22	664.16	480.00	480.00	480.00	652.99
21.372680	168.1	190.4	122.8	174.1	180.2	164.8	0.0	0.0	0.0	549.0
1987/ 8/13	673.83	671.87	667.56	664.31	664.26	664.20	480.00	480.00	480.00	653.08
21.402340	171.7	194.1	126.0	178.3	184.5	169.4	0.0	0.0	0.0	561.1
1987/ 8/13	673.86	671.91	667.59	664.35	664.30	664.23	480.00	480.00	480.00	653.18
21.432010	175.3	197.7	129.1	182.5	188.8	173.8	0.0	0.0	0.0	572.8
1987/ 8/13	673.89	671.95	667.63	664.39	664.33	664.27	480.00	480.00	480.00	653.28
21.461670	178.5	201.4	132.2	186.7	193.1	178.3	0.0	0.0	0.0	584.2
1987/ 8/13	673.92	671.99	667.66	664.42	664.37	664.30	480.00	480.00	480.00	653.37
21.491330	181.5	205.0	135.2	190.9	197.3	182.7	0.0	0.0	0.0	595.2
1987/ 8/13	673.95	672.03	667.69	664.46	664.41	664.34	480.00	480.00	480.00	653.46
21.521000	185.0	208.6	138.0	195.2	201.7	187.2	0.0	0.0	0.0	606.0
1987/ 8/13	673.98	672.06	667.72	664.50	664.44	664.37	480.00	480.00	480.00	653.55
21.550660	189.2	212.1	140.2	199.4	206.0	191.7	0.0	0.0	0.0	616.5
[redacted] 8/13	674.01	672.10	667.75	664.53	664.48	664.40	480.00	480.00	480.00	653.64
21.580320	193.4	215.6	142.2	203.7	210.3	196.1	0.0	0.0	0.0	627.0
1987/ 8/13	674.04	672.14	667.78	664.57	664.51	664.44	480.00	480.00	480.00	653.73
21.609990	197.6	219.2	144.2	207.9	214.5	200.6	0.0	0.0	0.0	637.4

1987/ 8/13	674.81	672.92	668.56	665.09	665.03	664.94	480.00	480.00	480.00	655.87
22.944820	328.1	300.9	245.3	270.5	270.6	267.7	0.0	0.0	0.0	907.9
1987/ 8/13	674.83	672.94	668.57	665.10	665.04	664.95	480.00	480.00	480.00	655.90
[illegible]89320	330.7	303.2	245.9	273.1	273.2	270.1	0.0	0.0	0.0	909.7
[illegible] 8/13	674.85	672.96	668.58	665.11	665.05	664.96	480.00	480.00	480.00	655.93
23.033810	332.2	305.8	245.9	277.7	278.1	273.9	0.0	0.0	0.0	910.7
1987/ 8/13	674.86	672.98	668.60	665.13	665.07	664.97	480.00	480.00	480.00	655.96
23.078310	334.2	308.7	245.2	282.1	282.7	278.3	0.0	0.0	0.0	911.8
1987/ 8/13	674.88	673.01	668.61	665.15	665.08	664.99	480.00	480.00	480.00	655.99
23.122800	337.0	311.6	245.0	285.6	286.2	281.9	0.0	0.0	0.0	913.2
1987/ 8/13	674.90	673.03	668.62	665.16	665.10	665.00	480.00	480.00	480.00	656.01
23.167300	340.1	314.4	244.7	288.7	289.3	285.0	0.0	0.0	0.0	914.8
1987/ 8/13	674.92	673.05	668.64	665.18	665.11	665.02	480.00	480.00	480.00	656.03
23.211790	343.5	317.3	244.4	291.7	292.4	288.1	0.0	0.0	0.0	916.3
1987/ 8/13	674.94	673.07	668.65	665.20	665.13	665.03	480.00	480.00	480.00	656.05
23.256290	347.1	320.1	244.2	294.7	295.4	291.2	0.0	0.0	0.0	917.6
1987/ 8/13	674.96	673.10	668.66	665.21	665.14	665.04	480.00	480.00	480.00	656.07
23.300780	350.7	322.9	244.0	297.8	298.4	294.2	0.0	0.0	0.0	918.6
1987/ 8/13	674.99	673.12	668.67	665.23	665.16	665.06	480.00	480.00	480.00	656.09
23.345280	354.5	325.8	243.9	301.1	301.9	298.2	0.0	0.0	0.0	919.5
1987/ 8/13	675.01	673.14	668.69	665.24	665.17	665.07	480.00	480.00	480.00	656.10
23.389770	358.4	328.7	243.8	304.5	305.3	301.4	0.0	0.0	0.0	920.2
1987/ 8/13	675.03	673.16	668.70	665.26	665.19	665.08	480.00	480.00	480.00	656.12
23.434270	362.4	331.7	243.7	307.6	308.3	304.3	0.0	0.0	0.0	921.0
1987/ 8/13	675.05	673.18	668.71	665.27	665.20	665.10	480.00	480.00	480.00	656.13
23.478760	366.5	334.7	243.7	310.7	311.4	307.4	0.0	0.0	0.0	921.6
1987/ 8/13	675.07	673.21	668.72	665.29	665.21	665.11	480.00	480.00	480.00	656.14
23.523250	370.7	337.8	243.8	313.7	314.4	310.3	0.0	0.0	0.0	922.5
1987/ 8/13	675.10	673.23	668.73	665.30	665.23	665.12	480.00	480.00	480.00	656.16
23.567750	374.9	341.0	243.8	316.7	317.4	313.2	0.0	0.0	0.0	923.5
[illegible] 8/13	675.12	673.25	668.74	665.32	665.24	665.14	480.00	480.00	480.00	656.17
23.612240	379.2	344.2	243.9	319.7	320.3	316.1	0.0	0.0	0.0	924.6
1987/ 8/13	675.15	673.29	668.76	665.34	665.27	665.16	480.00	480.00	480.00	656.18
23.678990	385.8	349.1	244.1	324.1	324.7	320.5	0.0	0.0	0.0	926.7
1987/ 8/13	675.19	673.32	668.78	665.36	665.29	665.18	480.00	480.00	480.00	656.20
23.745730	392.5	354.2	244.3	328.4	329.0	324.8	0.0	0.0	0.0	928.9
1987/ 8/13	675.23	673.36	668.79	665.39	665.31	665.20	480.00	480.00	480.00	656.22
23.812470	399.2	359.5	244.4	332.7	333.3	329.1	0.0	0.0	0.0	931.4
1987/ 8/13	675.26	673.39	668.81	665.41	665.33	665.22	480.00	480.00	480.00	656.23
23.879210	406.1	364.8	244.7	337.0	337.6	333.4	0.0	0.0	0.0	934.1
1987/ 8/13	675.30	673.43	668.83	665.43	665.36	665.24	480.00	480.00	480.00	656.25
23.945950	413.0	370.4	245.0	341.2	341.9	337.6	0.0	0.0	0.0	937.5
1987/ 8/14	675.34	673.47	668.86	665.47	665.39	665.27	480.00	480.00	480.00	656.27
0.012695	415.4	377.6	244.4	351.9	353.8	346.2	0.0	0.0	0.0	942.0
1987/ 8/14	675.41	673.55	668.92	665.58	665.48	665.34	480.00	480.00	480.00	656.29
0.079437	401.4	391.8	239.5	386.6	393.8	374.5	0.0	0.0	0.0	948.5
1987/ 8/14	675.47	673.63	668.94	665.65	665.56	665.42	480.00	480.00	480.00	656.31
0.146179	405.0	407.2	235.8	402.9	410.2	396.5	0.0	0.0	0.0	957.3
1987/ 8/14	675.53	673.71	668.98	665.72	665.63	665.48	480.00	480.00	480.00	656.34
0.212921	413.0	420.6	237.3	411.4	419.5	405.9	0.0	0.0	0.0	966.3
1987/ 8/14	675.59	673.78	669.01	665.79	665.69	665.55	480.00	480.00	480.00	656.38
0.279663	421.8	432.6	238.3	421.2	429.4	416.5	0.0	0.0	0.0	974.2
1987/ 8/14	675.64	673.85	669.05	665.85	665.76	665.61	480.00	480.00	480.00	656.41
0.346405	431.2	444.0	241.8	430.3	438.9	427.0	0.0	0.0	0.0	982.2
1987/ 8/14	675.70	673.92	669.09	665.91	665.81	665.67	480.00	480.00	480.00	656.45
0.413147	441.2	455.1	246.4	439.5	448.3	436.7	0.0	0.0	0.0	990.7
[illegible] 8/14	675.76	673.98	669.13	665.96	665.87	665.72	480.00	480.00	480.00	656.49
[illegible].479889	452.2	465.9	251.8	448.3	457.4	446.3	0.0	0.0	0.0	999.7
1987/ 8/14	675.82	674.04	669.17	666.02	665.92	665.77	480.00	480.00	480.00	656.53
0.546631	464.0	476.4	257.8	457.3	466.5	455.8	0.0	0.0	0.0	1009.3

1987/ 8/14	675.87	674.09	669.21	666.07	665.98	665.82	480.00	480.00	480.00	656.57
0.613373	476.1	486.8	264.2	466.1	475.4	465.0	0.0	0.0	0.0	1019.7
1987/ 8/14	675.93	674.15	669.26	666.12	666.03	665.87	480.00	480.00	480.00	656.62
0.680115	488.5	497.5	270.9	474.7	484.2	474.3	0.0	0.0	0.0	1030.4
8/14	675.99	674.21	669.30	666.17	666.07	665.92	480.00	480.00	480.00	656.66
0.746857	501.1	508.2	278.0	483.5	493.2	483.7	0.0	0.0	0.0	1041.2
1987/ 8/14	676.04	674.26	669.35	666.22	666.12	665.96	480.00	480.00	480.00	656.70
0.813599	513.6	519.1	285.1	492.3	502.2	493.1	0.0	0.0	0.0	1052.2
1987/ 8/14	676.10	674.32	669.40	666.26	666.16	666.00	480.00	480.00	480.00	656.75
0.880341	526.1	530.9	292.6	501.0	511.0	502.2	0.0	0.0	0.0	1063.6
1987/ 8/14	676.16	674.37	669.44	666.30	666.21	666.04	480.00	480.00	480.00	656.79
0.947083	538.7	542.7	300.5	509.6	519.6	511.0	0.0	0.0	0.0	1076.2
1987/ 8/14	676.22	674.45	669.52	666.38	666.27	666.10	480.00	480.00	480.00	656.84
1.013824	534.4	561.4	307.9	533.3	546.4	531.5	0.0	0.0	0.0	1090.6
1987/ 8/14	676.33	674.59	669.65	666.56	666.43	666.21	480.00	480.00	480.00	656.90
1.080566	474.8	607.5	309.4	605.0	629.7	593.9	0.0	0.0	0.0	1108.4
1987/ 8/14	676.42	674.71	669.72	666.68	666.55	666.34	480.00	480.00	480.00	656.96
1.147308	474.6	646.7	304.7	634.8	661.2	639.4	0.0	0.0	0.0	1128.8
1987/ 8/14	676.52	674.82	669.81	666.79	666.66	666.44	480.00	480.00	480.00	657.03
1.214050	486.0	680.8	318.8	652.5	680.4	658.8	0.0	0.0	0.0	1148.9
1987/ 8/14	676.61	674.91	669.89	666.89	666.76	666.53	480.00	480.00	480.00	657.11
1.280792	502.8	708.2	334.5	673.9	701.6	680.4	0.0	0.0	0.0	1168.1
1987/ 8/14	676.70	675.00	669.96	666.98	666.85	666.63	480.00	480.00	480.00	657.19
1.347534	523.4	734.3	362.0	693.2	721.6	701.9	0.0	0.0	0.0	1188.4
1987/ 8/14	676.79	675.07	670.04	667.07	666.94	666.71	480.00	480.00	480.00	657.28
1.414276	546.1	759.0	389.4	713.0	741.6	722.3	0.0	0.0	0.0	1210.8
1987/ 8/14	676.88	675.15	670.12	667.16	667.03	666.80	480.00	480.00	480.00	657.36
1.481018	570.6	783.7	421.6	732.1	760.9	742.0	0.0	0.0	0.0	1234.9
1987/ 8/14	676.96	675.22	670.20	667.25	667.12	666.88	480.00	480.00	480.00	657.45
1.547760	596.8	808.2	454.0	750.9	779.8	761.3	0.0	0.0	0.0	1265.2
8/14	677.05	675.29	670.28	667.33	667.20	666.96	480.00	480.00	480.00	657.54
1.614502	624.6	833.2	483.2	769.5	798.6	780.4	0.0	0.0	0.0	1297.4
1987/ 8/14	677.15	675.35	670.36	667.41	667.28	667.04	480.00	480.00	480.00	657.63
1.681244	653.1	858.5	513.7	788.0	817.2	799.3	0.0	0.0	0.0	1332.8
1987/ 8/14	677.24	675.42	670.45	667.49	667.36	667.12	480.00	480.00	480.00	657.73
1.747986	682.7	886.1	545.3	806.6	835.6	818.0	0.0	0.0	0.0	1371.4
1987/ 8/14	677.33	675.48	670.53	667.57	667.43	667.19	480.00	480.00	480.00	657.83
1.814728	713.7	913.8	577.5	825.0	854.0	836.6	0.0	0.0	0.0	1412.6
1987/ 8/14	677.42	675.53	670.61	667.64	667.51	667.26	480.00	480.00	480.00	657.94
1.881470	745.8	941.9	609.5	843.8	872.7	855.8	0.0	0.0	0.0	1455.3
1987/ 8/14	677.51	675.59	670.70	667.72	667.58	667.33	480.00	480.00	480.00	658.05
1.948212	778.7	968.7	643.1	862.9	891.5	874.9	0.0	0.0	0.0	1499.4
1987/ 8/14	677.59	675.63	670.77	667.74	667.62	667.38	480.00	480.00	480.00	658.15
2.014954	835.6	982.6	669.1	856.1	880.9	874.5	0.0	0.0	0.0	1544.5
1987/ 8/14	677.62	675.63	670.79	667.64	667.54	667.34	480.00	480.00	480.00	658.25
2.081696	945.9	960.8	675.8	777.0	787.6	810.5	0.0	0.0	0.0	1588.6
1987/ 8/14	677.66	675.63	670.85	667.61	667.50	667.30	480.00	480.00	480.00	658.34
2.148438	983.2	957.2	716.8	765.7	770.8	773.3	0.0	0.0	0.0	1629.5
1987/ 8/14	677.71	675.64	670.90	667.59	667.49	667.29	480.00	480.00	480.00	658.43
2.215179	1011.7	959.2	744.8	767.2	771.4	774.4	0.0	0.0	0.0	1668.7
1987/ 8/14	677.75	675.66	670.95	667.58	667.47	667.28	480.00	480.00	480.00	658.51
2.281921	1034.9	968.3	766.6	764.3	768.8	772.2	0.0	0.0	0.0	1706.9
1987/ 8/14	677.79	675.68	671.00	667.57	667.47	667.27	480.00	480.00	480.00	658.58
2.348663	1055.3	978.7	783.7	766.3	769.9	771.8	0.0	0.0	0.0	1736.5
1987/ 8/14	677.84	675.70	671.04	667.56	667.46	667.26	480.00	480.00	480.00	658.66
2.415405	1074.6	990.7	794.7	768.1	771.6	773.5	0.0	0.0	0.0	1761.6
8/14	677.88	675.72	671.09	667.56	667.45	667.25	480.00	480.00	480.00	658.73
2.482147	1093.0	1003.0	802.6	771.5	774.7	776.0	0.0	0.0	0.0	1784.9
1987/ 8/14	677.93	675.75	671.12	667.56	667.45	667.24	480.00	480.00	480.00	658.80
2.548889	1111.1	1015.9	807.6	775.6	778.6	779.6	0.0	0.0	0.0	1804.6

1987/ 8/14	677.97	675.78	671.16	667.56	667.45	667.24	480.00	480.00	480.00	658.86
2.615631	1128.8	1028.9	810.6	780.4	783.2	783.9	0.0	0.0	0.0	1820.8
1987/ 8/14	678.02	675.81	671.19	667.56	667.45	667.24	480.00	480.00	480.00	658.91
[illegible]82373	1146.4	1042.1	812.2	785.8	788.4	788.8	0.0	0.0	0.0	1833.9
[illegible] 8/14	678.06	675.83	671.22	667.56	667.45	667.23	480.00	480.00	480.00	658.96
2.749115	1163.9	1055.4	812.9	791.7	794.1	794.1	0.0	0.0	0.0	1844.3
1987/ 8/14	678.11	675.86	671.25	667.57	667.45	667.23	480.00	480.00	480.00	659.01
2.815857	1181.4	1068.6	812.7	798.0	800.2	799.7	0.0	0.0	0.0	1852.5
1987/ 8/14	678.15	675.89	671.28	667.57	667.46	667.24	480.00	480.00	480.00	659.05
2.882599	1199.5	1082.8	811.1	804.5	806.4	805.5	0.0	0.0	0.0	1859.0
1987/ 8/14	678.20	675.92	671.30	667.58	667.46	667.24	480.00	480.00	480.00	659.08
2.949341	1217.9	1098.1	808.6	811.3	813.0	811.7	0.0	0.0	0.0	1864.3
1987/ 8/14	678.24	675.96	671.32	667.59	667.47	667.24	480.00	480.00	480.00	659.11
3.016083	1238.9	1113.5	804.9	816.6	817.9	816.9	0.0	0.0	0.0	1868.7
1987/ 8/14	678.28	675.98	671.34	667.59	667.47	667.24	480.00	480.00	480.00	659.13
3.082825	1265.9	1126.1	801.0	817.9	818.0	818.5	0.0	0.0	0.0	1872.8
1987/ 8/14	678.32	676.01	671.35	667.59	667.47	667.24	480.00	480.00	480.00	659.15
3.149567	1285.0	1140.6	799.9	823.4	823.2	822.1	0.0	0.0	0.0	1874.6
1987/ 8/14	678.36	676.04	671.36	667.60	667.48	667.25	480.00	480.00	480.00	659.16
3.216309	1302.4	1155.2	797.9	829.9	829.4	828.1	0.0	0.0	0.0	1874.9
1987/ 8/14	678.40	676.08	671.37	667.61	667.49	667.25	480.00	480.00	480.00	659.17
3.283051	1318.8	1170.8	797.2	836.3	835.7	834.1	0.0	0.0	0.0	1874.6
1987/ 8/14	678.44	676.11	671.38	667.62	667.50	667.26	480.00	480.00	480.00	659.18
3.349792	1334.3	1186.5	799.0	842.8	842.1	840.2	0.0	0.0	0.0	1873.4
1987/ 8/14	678.47	676.14	671.38	667.63	667.51	667.27	480.00	480.00	480.00	659.19
3.416534	1349.1	1202.2	801.7	849.4	848.5	846.3	0.0	0.0	0.0	1871.7
1987/ 8/14	678.51	676.17	671.38	667.64	667.52	667.27	480.00	480.00	480.00	659.19
3.483276	1363.3	1217.9	802.2	855.9	854.9	852.5	0.0	0.0	0.0	1869.3
1987/ 8/14	678.55	676.20	671.39	667.66	667.53	667.28	480.00	480.00	480.00	659.19
3.550018	1376.8	1233.3	800.1	862.3	861.2	858.6	0.0	0.0	0.0	1866.5
[illegible] 8/14	678.58	676.24	671.39	667.67	667.54	667.29	480.00	480.00	480.00	659.19
3.616760	1389.7	1248.9	798.5	868.6	867.4	864.7	0.0	0.0	0.0	1863.2
1987/ 8/14	678.62	676.27	671.39	667.68	667.55	667.31	480.00	480.00	480.00	659.18
3.683502	1402.2	1264.3	797.6	874.7	873.4	870.6	0.0	0.0	0.0	1859.5
1987/ 8/14	678.65	676.30	671.39	667.70	667.57	667.32	480.00	480.00	480.00	659.18
3.750244	1410.1	1278.8	797.7	880.7	879.3	876.4	0.0	0.0	0.0	1855.4
1987/ 8/14	678.68	676.32	671.39	667.71	667.58	667.33	480.00	480.00	480.00	659.17
3.816986	1418.8	1291.7	798.9	886.4	885.0	882.0	0.0	0.0	0.0	1850.9
1987/ 8/14	678.71	676.35	671.39	667.73	667.59	667.34	480.00	480.00	480.00	659.16
3.883728	1434.7	1303.2	807.4	892.0	890.5	887.4	0.0	0.0	0.0	1846.2
1987/ 8/14	678.74	676.38	671.38	667.74	667.61	667.35	480.00	480.00	480.00	659.15
3.950470	1448.5	1314.5	821.0	897.3	895.8	892.7	0.0	0.0	0.0	1841.1
1987/ 8/14	678.77	676.41	671.37	667.76	667.62	667.37	480.00	480.00	480.00	659.14
4.017212	1460.5	1326.4	831.1	902.3	900.9	897.8	0.0	0.0	0.0	1835.8
1987/ 8/14	678.80	676.43	671.35	667.77	667.64	667.38	480.00	480.00	480.00	659.13
4.083954	1471.5	1338.5	838.7	907.1	905.7	902.6	0.0	0.0	0.0	1830.3
1987/ 8/14	678.83	676.46	671.34	667.78	667.65	667.39	480.00	480.00	480.00	659.12
4.150696	1481.7	1350.5	843.8	911.7	910.3	907.2	0.0	0.0	0.0	1824.6
1987/ 8/14	678.85	676.49	671.34	667.80	667.66	667.40	480.00	480.00	480.00	659.11
4.217438	1491.1	1362.4	847.1	915.9	914.5	911.6	0.0	0.0	0.0	1818.7
1987/ 8/14	678.88	676.52	671.33	667.81	667.67	667.41	480.00	480.00	480.00	659.10
4.284180	1495.4	1372.9	850.2	919.8	918.5	915.6	0.0	0.0	0.0	1812.6
1987/ 8/14	678.91	676.55	671.32	667.82	667.69	667.43	480.00	480.00	480.00	659.08
4.350922	1498.1	1381.1	853.2	923.4	922.2	919.4	0.0	0.0	0.0	1806.3
1987/ 8/14	678.93	676.57	671.32	667.83	667.70	667.44	480.00	480.00	480.00	659.07
4.417664	1505.6	1387.7	854.8	926.6	925.4	922.8	0.0	0.0	0.0	1800.0
[illegible] 8/14	678.95	676.60	671.31	667.84	667.71	667.45	480.00	480.00	480.00	659.06
[illegible].484406	1516.2	1394.8	855.9	929.5	928.4	925.9	0.0	0.0	0.0	1793.7
1987/ 8/14	678.98	676.62	671.31	667.85	667.72	667.46	480.00	480.00	480.00	659.04
4.551147	1525.9	1403.4	857.2	932.0	931.0	928.7	0.0	0.0	0.0	1787.2

1987/ 8/14	679.00	676.65	671.31	667.86	667.73	667.47	480.00	480.00	480.00	659.03
4.617889	1534.1	1411.9	858.6	934.2	933.3	931.1	0.0	0.0	0.0	1780.1
1987/ 8/14	679.02	676.68	671.31	667.87	667.74	667.47	480.00	480.00	480.00	659.01
[redacted]84631	1541.3	1420.5	860.1	936.2	935.4	933.3	0.0	0.0	0.0	1772.7
[redacted] 8/14	679.04	676.70	671.30	667.88	667.75	667.48	480.00	480.00	480.00	658.99
4.751373	1547.7	1429.1	861.8	937.9	937.2	935.3	0.0	0.0	0.0	1765.1
1987/ 8/14	679.06	676.73	671.30	667.89	667.75	667.49	480.00	480.00	480.00	658.98
4.818115	1553.5	1437.4	863.6	939.4	938.8	937.0	0.0	0.0	0.0	1757.7
1987/ 8/14	679.08	676.76	671.30	667.89	667.76	667.50	480.00	480.00	480.00	658.96
4.884857	1558.6	1445.4	865.5	940.7	940.2	938.5	0.0	0.0	0.0	1750.7
1987/ 8/14	679.10	676.78	671.30	667.90	667.77	667.50	480.00	480.00	480.00	658.95
4.951599	1563.2	1453.0	867.5	941.9	941.5	939.9	0.0	0.0	0.0	1744.1
1987/ 8/14	679.11	676.81	671.31	667.91	667.77	667.51	480.00	480.00	480.00	658.93
5.018341	1564.9	1458.5	869.6	943.0	942.6	941.2	0.0	0.0	0.0	1737.8
1987/ 8/14	679.13	676.83	671.31	667.91	667.78	667.52	480.00	480.00	480.00	658.91
5.085083	1564.7	1461.4	871.8	943.9	943.6	942.3	0.0	0.0	0.0	1731.9
1987/ 8/14	679.15	676.86	671.31	667.92	667.78	667.52	480.00	480.00	480.00	658.90
5.151825	1565.4	1463.7	874.2	944.8	944.5	943.3	0.0	0.0	0.0	1726.1
1987/ 8/14	679.16	676.88	671.31	667.92	667.79	667.53	480.00	480.00	480.00	658.88
5.218567	1568.7	1467.3	876.8	945.6	945.4	944.2	0.0	0.0	0.0	1720.5
1987/ 8/14	679.18	676.91	671.31	667.93	667.79	667.53	480.00	480.00	480.00	658.87
5.285309	1573.2	1472.3	879.6	946.3	946.1	945.0	0.0	0.0	0.0	1715.0
1987/ 8/14	679.19	676.93	671.32	667.93	667.80	667.53	480.00	480.00	480.00	658.85
5.352051	1577.0	1477.7	882.5	946.9	946.7	945.6	0.0	0.0	0.0	1709.6
1987/ 8/14	679.21	676.95	671.32	667.94	667.80	667.54	480.00	480.00	480.00	658.84
5.418793	1580.2	1483.0	885.5	947.4	947.2	946.1	0.0	0.0	0.0	1704.3
1987/ 8/14	679.22	676.98	671.33	667.94	667.81	667.54	480.00	480.00	480.00	658.82
5.485535	1582.8	1488.0	888.7	947.9	947.7	946.5	0.0	0.0	0.0	1699.0
1987/ 8/14	679.23	677.00	671.33	667.94	667.81	667.55	480.00	480.00	480.00	658.81
5.552277	1584.9	1492.9	892.0	948.4	948.1	947.0	0.0	0.0	0.0	1694.0
[redacted] 8/14	679.24	677.03	671.33	667.95	667.82	667.55	480.00	480.00	480.00	658.80
5.619019	1586.7	1497.5	895.4	948.8	948.6	947.4	0.0	0.0	0.0	1689.1
1987/ 8/14	679.26	677.05	671.34	667.95	667.82	667.56	480.00	480.00	480.00	658.78
5.685760	1588.2	1501.8	899.0	949.2	949.0	947.8	0.0	0.0	0.0	1684.2
1987/ 8/14	679.27	677.07	671.34	667.96	667.82	667.56	480.00	480.00	480.00	658.77
5.752502	1589.4	1506.0	902.6	949.7	949.4	948.3	0.0	0.0	0.0	1679.5
1987/ 8/14	679.28	677.09	671.35	667.96	667.83	667.57	480.00	480.00	480.00	658.76
5.819244	1590.6	1509.9	906.3	950.2	949.9	948.7	0.0	0.0	0.0	1674.8
1987/ 8/14	679.29	677.12	671.36	667.97	667.83	667.57	480.00	480.00	480.00	658.74
5.885986	1591.6	1513.5	905.5	950.7	950.4	949.3	0.0	0.0	0.0	1670.2
1987/ 8/14	679.30	677.14	671.37	667.97	667.84	667.58	480.00	480.00	480.00	658.73
5.952728	1592.7	1516.9	899.4	951.3	951.0	949.8	0.0	0.0	0.0	1666.2
1987/ 8/14	679.32	677.17	671.41	668.03	667.89	667.61	480.00	480.00	480.00	658.72
6.019470	1576.7	1536.5	904.2	989.3	992.3	977.2	0.0	0.0	0.0	1663.0
1987/ 8/14	679.37	677.22	671.47	668.21	668.04	667.72	480.00	480.00	480.00	658.72
6.086212	1535.5	1584.2	922.6	1089.7	1102.0	1061.6	0.0	0.0	0.0	1663.0
1987/ 8/14	679.42	677.27	671.54	668.32	668.15	667.83	480.00	480.00	480.00	658.73
6.152954	1539.2	1616.9	884.5	1119.6	1139.6	1117.6	0.0	0.0	0.0	1668.4
1987/ 8/14	679.47	677.32	671.60	668.40	668.24	667.92	480.00	480.00	480.00	658.75
6.219696	1548.8	1650.1	873.0	1138.3	1159.8	1138.7	0.0	0.0	0.0	1674.4
1987/ 8/14	679.52	677.36	671.66	668.48	668.32	668.00	480.00	480.00	480.00	658.77
6.286438	1565.0	1677.2	885.9	1159.0	1180.6	1160.1	0.0	0.0	0.0	1679.7
1987/ 8/14	679.56	677.41	671.71	668.56	668.40	668.07	480.00	480.00	480.00	658.80
6.353180	1585.2	1702.9	902.7	1175.7	1197.9	1178.9	0.0	0.0	0.0	1686.6
1987/ 8/14	679.61	677.45	671.77	668.63	668.47	668.14	480.00	480.00	480.00	658.83
6.419922	1608.0	1723.5	924.6	1193.1	1215.2	1196.4	0.0	0.0	0.0	1696.1
[redacted] 8/14	679.66	677.49	671.83	668.70	668.54	668.21	480.00	480.00	480.00	658.86
6.486664	1633.2	1747.6	946.9	1209.7	1231.9	1213.8	0.0	0.0	0.0	1708.2
1987/ 8/14	679.70	677.53	671.88	668.76	668.60	668.28	480.00	480.00	480.00	658.90
6.553406	1660.0	1771.9	972.6	1226.6	1248.7	1230.9	0.0	0.0	0.0	1723.6

1987/ 8/14	679.75	677.57	671.94	668.83	668.67	668.35	480.00	480.00	480.00	658.94
6.620148	1687.7	1796.5	1000.0	1243.2	1265.4	1248.0	0.0	0.0	0.0	1742.1
1987/ 8/14	679.80	677.61	672.00	668.89	668.73	668.41	480.00	480.00	480.00	658.98
6.686890	1716.1	1821.4	1026.8	1259.6	1281.8	1264.7	0.0	0.0	0.0	1763.9
[redacted] 8/14	679.85	677.65	672.06	668.95	668.80	668.47	480.00	480.00	480.00	659.03
6.753632	1745.5	1845.2	1054.6	1276.1	1298.2	1281.5	0.0	0.0	0.0	1788.6
1987/ 8/14	679.90	677.69	672.12	669.01	668.86	668.53	480.00	480.00	480.00	659.08
6.820374	1773.8	1867.1	1084.5	1290.0	1312.9	1297.1	0.0	0.0	0.0	1816.0
1987/ 8/14	679.95	677.72	672.18	669.07	668.91	668.59	480.00	480.00	480.00	659.14
6.887115	1801.1	1885.8	1115.1	1304.5	1327.5	1312.1	0.0	0.0	0.0	1845.4
1987/ 8/14	680.00	677.76	672.24	669.12	668.97	668.64	480.00	480.00	480.00	659.20
6.953857	1829.0	1903.7	1144.6	1319.9	1342.8	1327.7	0.0	0.0	0.0	1876.4
1987/ 8/14	680.02	677.77	672.27	669.15	668.99	668.67	480.00	480.00	480.00	659.24
6.987228	1843.7	1912.8	1158.7	1327.6	1350.5	1335.7	0.0	0.0	0.0	1892.4
1987/ 8/14	680.04	677.78	672.29	669.15	669.00	668.69	480.00	480.00	480.00	659.28
7.020599	1876.8	1914.8	1160.0	1319.8	1337.3	1333.5	0.0	0.0	0.0	1906.0
1987/ 8/14	680.05	677.79	672.31	669.14	669.00	668.69	480.00	480.00	480.00	659.33
7.053970	1907.4	1915.9	1164.2	1304.7	1318.8	1320.6	0.0	0.0	0.0	1917.7
1987/ 8/14	680.06	677.80	672.33	669.14	669.00	668.69	480.00	480.00	480.00	659.38
7.087341	1927.2	1917.7	1179.8	1297.3	1310.4	1310.3	0.0	0.0	0.0	1929.9
1987/ 8/14	680.07	677.81	672.35	669.14	669.00	668.69	480.00	480.00	480.00	659.42
7.120712	1944.4	1919.9	1194.9	1295.3	1306.7	1305.7	0.0	0.0	0.0	1944.5
1987/ 8/14	680.09	677.82	672.38	669.14	669.00	668.69	480.00	480.00	480.00	659.45
7.154083	1960.0	1923.3	1206.9	1294.4	1305.0	1303.5	0.0	0.0	0.0	1960.6
1987/ 8/14	680.10	677.83	672.40	669.15	669.00	668.70	480.00	480.00	480.00	659.49
7.187454	1974.4	1927.6	1217.7	1294.6	1304.7	1302.9	0.0	0.0	0.0	1977.2
1987/ 8/14	680.11	677.84	672.42	669.15	669.01	668.70	480.00	480.00	480.00	659.52
7.220825	1987.9	1932.6	1227.1	1295.7	1305.3	1303.1	0.0	0.0	0.0	1993.5
1987/ 8/14	680.13	677.85	672.44	669.15	669.01	668.71	480.00	480.00	480.00	659.56
7.254196	2000.6	1938.2	1234.6	1297.4	1306.6	1304.1	0.0	0.0	0.0	2009.4
[redacted] 8/14	680.14	677.86	672.47	669.16	669.01	668.71	480.00	480.00	480.00	659.59
7.287567	2012.8	1944.2	1240.8	1299.5	1308.5	1305.9	0.0	0.0	0.0	2024.9
1987/ 8/14	680.16	677.87	672.49	669.16	669.02	668.71	480.00	480.00	480.00	659.62
7.320938	2024.5	1950.7	1246.3	1302.1	1310.9	1308.2	0.0	0.0	0.0	2040.0
1987/ 8/14	680.17	677.88	672.51	669.17	669.03	668.72	480.00	480.00	480.00	659.66
7.354309	2035.8	1957.7	1251.9	1305.2	1313.8	1311.0	0.0	0.0	0.0	2054.6
1987/ 8/14	680.18	677.89	672.53	669.18	669.03	668.72	480.00	480.00	480.00	659.69
7.387680	2046.9	1965.0	1258.0	1308.5	1317.0	1314.1	0.0	0.0	0.0	2068.4
1987/ 8/14	680.20	677.90	672.55	669.18	669.04	668.73	480.00	480.00	480.00	659.72
7.421051	2057.9	1972.5	1264.0	1312.1	1320.4	1317.4	0.0	0.0	0.0	2081.9
1987/ 8/14	680.21	677.91	672.57	669.19	669.04	668.73	480.00	480.00	480.00	659.75
7.454422	2068.7	1980.2	1270.3	1315.9	1324.1	1321.0	0.0	0.0	0.0	2094.9
1987/ 8/14	680.23	677.92	672.59	669.19	669.05	668.74	480.00	480.00	480.00	659.78
7.487793	2079.5	1988.0	1277.0	1320.0	1327.9	1324.7	0.0	0.0	0.0	2107.4
1987/ 8/14	680.24	677.93	672.61	669.20	669.06	668.74	480.00	480.00	480.00	659.81
7.521164	2090.2	1996.0	1283.2	1324.1	1332.0	1328.7	0.0	0.0	0.0	2119.2
1987/ 8/14	680.25	677.94	672.63	669.21	669.06	668.75	480.00	480.00	480.00	659.84
7.554535	2101.0	2004.2	1288.9	1328.5	1336.2	1332.8	0.0	0.0	0.0	2130.3
1987/ 8/14	680.27	677.95	672.65	669.22	669.07	668.75	480.00	480.00	480.00	659.87
7.587906	2111.9	2012.6	1294.8	1333.0	1340.6	1337.0	0.0	0.0	0.0	2140.9
1987/ 8/14	680.28	677.96	672.67	669.22	669.08	668.76	480.00	480.00	480.00	659.89
7.621277	2123.0	2021.7	1300.1	1337.7	1345.1	1341.4	0.0	0.0	0.0	2150.7
1987/ 8/14	680.30	677.97	672.69	669.23	669.08	668.77	480.00	480.00	480.00	659.92
7.654648	2134.3	2030.7	1304.7	1342.4	1349.7	1345.9	0.0	0.0	0.0	2160.2
1987/ 8/14	680.31	677.98	672.71	669.24	669.09	668.77	480.00	480.00	480.00	659.95
7.688019	2145.6	2039.6	1309.5	1347.3	1354.4	1350.5	0.0	0.0	0.0	2169.1
[redacted] 8/14	680.32	677.99	672.73	669.25	669.10	668.78	480.00	480.00	480.00	659.97
7.721390	2157.1	2048.6	1313.7	1352.3	1359.3	1355.3	0.0	0.0	0.0	2177.7
1987/ 8/14	680.34	678.00	672.75	669.26	669.11	668.79	480.00	480.00	480.00	660.00
7.754761	2168.6	2057.6	1317.5	1357.3	1364.1	1360.0	0.0	0.0	0.0	2185.9

1987/ 8/14	680.35	678.01	672.77	669.26	669.11	668.79	480.00	480.00	480.00	660.02
7.788132	2180.2	2066.7	1321.6	1362.3	1369.0	1364.8	0.0	0.0	0.0	2193.7
1987/ 8/14	680.37	678.02	672.79	669.27	669.12	668.80	480.00	480.00	480.00	660.04
7.821503	2191.9	2075.9	1325.3	1367.4	1373.9	1369.6	0.0	0.0	0.0	2201.2
[redacted] 8/14	680.38	678.03	672.81	669.28	669.13	668.81	480.00	480.00	480.00	660.06
7.854874	2203.6	2085.1	1327.5	1372.4	1378.7	1374.3	0.0	0.0	0.0	2208.4
1987/ 8/14	680.40	678.04	672.83	669.29	669.14	668.81	480.00	480.00	480.00	660.09
7.888245	2215.3	2094.4	1328.1	1377.3	1383.4	1378.8	0.0	0.0	0.0	2215.3
1987/ 8/14	680.41	678.05	672.85	669.30	669.15	668.82	480.00	480.00	480.00	660.11
7.921616	2227.1	2103.7	1326.7	1382.3	1388.2	1383.4	0.0	0.0	0.0	2221.9
1987/ 8/14	680.43	678.07	672.88	669.32	669.16	668.83	480.00	480.00	480.00	660.14
7.971672	2244.9	2117.8	1325.8	1390.0	1395.5	1390.4	0.0	0.0	0.0	2231.5
1987/ 8/14	680.45	678.08	672.90	669.33	669.17	668.84	480.00	480.00	480.00	660.15
8.021729	2267.6	2130.3	1328.7	1396.1	1400.4	1396.1	0.0	0.0	0.0	2243.5
1987/ 8/14	680.47	678.09	672.93	669.34	669.18	668.85	480.00	480.00	480.00	660.16
8.071785	2292.4	2141.3	1331.0	1400.3	1403.1	1399.8	0.0	0.0	0.0	2257.4
1987/ 8/14	680.49	678.11	672.95	669.35	669.19	668.86	480.00	480.00	480.00	660.17
8.121841	2311.0	2152.7	1335.4	1405.7	1408.2	1404.2	0.0	0.0	0.0	2267.5
1987/ 8/14	680.51	678.12	672.98	669.37	669.20	668.87	480.00	480.00	480.00	660.19
8.171898	2328.2	2164.0	1339.4	1412.1	1414.2	1409.7	0.0	0.0	0.0	2274.9
1987/ 8/14	680.53	678.13	673.00	669.38	669.22	668.88	480.00	480.00	480.00	660.21
8.221954	2344.7	2175.7	1342.8	1418.6	1420.2	1415.4	0.0	0.0	0.0	2281.9
1987/ 8/14	680.54	678.14	673.03	669.39	669.23	668.90	480.00	480.00	480.00	660.22
8.272011	2360.6	2187.8	1346.1	1425.2	1426.4	1421.2	0.0	0.0	0.0	2288.4
1987/ 8/14	680.56	678.16	673.05	669.41	669.25	668.91	480.00	480.00	480.00	660.24
8.322067	2376.3	2200.2	1348.7	1432.5	1433.4	1427.7	0.0	0.0	0.0	2294.7
1987/ 8/14	680.59	678.17	673.09	669.43	669.27	668.93	480.00	480.00	480.00	660.26
8.397152	2399.3	2220.6	1352.1	1443.2	1443.6	1437.5	0.0	0.0	0.0	2304.1
1987/ 8/14	680.62	678.19	673.13	669.46	669.30	668.95	480.00	480.00	480.00	660.28
8.472237	2422.0	2241.0	1356.3	1454.3	1454.2	1447.6	0.0	0.0	0.0	2312.8
[redacted] 8/14	680.65	678.21	673.16	669.49	669.32	668.97	480.00	480.00	480.00	660.30
8.547321	2445.2	2262.3	1362.3	1465.5	1465.0	1457.9	0.0	0.0	0.0	2320.3
1987/ 8/14	680.67	678.23	673.19	669.52	669.35	669.00	480.00	480.00	480.00	660.32
8.622406	2468.7	2284.3	1365.8	1477.4	1476.7	1468.9	0.0	0.0	0.0	2326.4
1987/ 8/14	680.69	678.24	673.21	669.53	669.37	669.01	480.00	480.00	480.00	660.32
8.659948	2480.3	2295.5	1366.4	1483.5	1482.6	1474.6	0.0	0.0	0.0	2329.2
1987/ 8/14	680.69	678.25	673.22	669.54	669.37	669.01	480.00	480.00	480.00	660.33
8.678720	2486.1	2301.1	1366.7	1486.5	1485.5	1477.5	0.0	0.0	0.0	2330.6
1987/ 8/14	680.70	678.25	673.22	669.54	669.38	669.02	480.00	480.00	480.00	660.33
8.697491	2491.9	2306.7	1367.0	1489.6	1488.5	1480.4	0.0	0.0	0.0	2332.0
1987/ 8/14	680.71	678.26	673.23	669.55	669.39	669.03	480.00	480.00	480.00	660.34
8.716262	2497.6	2312.3	1367.4	1492.7	1491.5	1483.4	0.0	0.0	0.0	2333.5
1987/ 8/14	680.71	678.26	673.24	669.56	669.40	669.03	480.00	480.00	480.00	660.34
8.735033	2503.3	2317.9	1368.0	1495.8	1494.6	1486.3	0.0	0.0	0.0	2334.8
1987/ 8/14	680.72	678.27	673.25	669.57	669.40	669.04	480.00	480.00	480.00	660.34
8.753804	2508.9	2323.5	1368.5	1498.9	1497.6	1489.3	0.0	0.0	0.0	2336.1
1987/ 8/14	680.73	678.27	673.26	669.58	669.41	669.05	480.00	480.00	480.00	660.35
8.781961	2517.3	2332.0	1368.8	1503.6	1502.2	1493.8	0.0	0.0	0.0	2338.1
1987/ 8/14	680.74	678.29	673.28	669.60	669.43	669.06	480.00	480.00	480.00	660.36
8.824196	2529.9	2344.7	1368.9	1510.8	1509.2	1500.6	0.0	0.0	0.0	2340.9
1987/ 8/14	680.77	678.30	673.31	669.62	669.46	669.09	480.00	480.00	480.00	660.37
8.887548	2548.3	2363.5	1369.7	1522.0	1520.4	1511.8	0.0	0.0	0.0	2345.1
1987/ 8/14	680.79	678.32	673.33	669.65	669.48	669.11	480.00	480.00	480.00	660.38
8.950902	2566.3	2381.4	1370.3	1533.5	1531.9	1523.1	0.0	0.0	0.0	2348.9
1987/ 8/14	680.81	678.34	673.36	669.67	669.51	669.13	480.00	480.00	480.00	660.38
9.014255	2582.8	2398.2	1369.8	1543.2	1540.8	1532.8	0.0	0.0	0.0	2353.0
[redacted] 8/14	680.82	678.35	673.38	669.69	669.52	669.15	480.00	480.00	480.00	660.39
9.077607	2594.2	2412.5	1368.3	1547.0	1542.3	1537.5	0.0	0.0	0.0	2357.6
1987/ 8/14	680.84	678.36	673.41	669.70	669.54	669.16	480.00	480.00	480.00	660.39
9.140960	2602.1	2426.0	1371.3	1552.9	1548.6	1542.8	0.0	0.0	0.0	2360.9

1987/ 8/14	680.85	678.38	673.43	669.72	669.55	669.18	480.00	480.00	480.00	660.40
9.204312	2611.1	2438.7	1373.1	1560.8	1556.0	1550.2	0.0	0.0	0.0	2363.2
1987/ 8/14	680.86	678.39	673.45	669.74	669.57	669.20	480.00	480.00	480.00	660.40
[illegible]67665	2619.8	2451.1	1373.5	1568.7	1563.8	1557.9	0.0	0.0	0.0	2365.3
[illegible]8/14	680.88	678.40	673.47	669.75	669.59	669.21	480.00	480.00	480.00	660.40
9.331017	2628.4	2463.1	1373.2	1577.3	1572.2	1566.1	0.0	0.0	0.0	2367.0
1987/ 8/14	680.89	678.42	673.49	669.77	669.61	669.23	480.00	480.00	480.00	660.40