Attachment 02.04.03-08C
TVA letter dated February 3, 2010
RAI Response

ASSOCIATED ATTACHMENTS/ENCLOSURES:

Attachment 02.04.03-8C: SOCH Version 1 SRS, Rev 0

(64 Pages including Cover Sheet)

L58 090528 001

Tennessee Valley Authority

SOFTWARE REQUIREMENTS SPECIFICATION

(SRS)

Simulated Open Channel Hydraulics (SOCH)

Version 1.0

	R0	R1	R2	R3
Prepared	Helder de Almeida			
	[signature]			
Reviewed	Angelos Findikakis			
	[signature]			
Approved	K.R. Spates			
[signature] 5-26-09 [initials] 5-28-09	[signature]			
Issue Date	5-27-09			

Tennessee Valley Authority

SOFTWARE REQUIREMENTS SPECIFICATION

(SRS)

Simulated Open Channel Hydraulics (SOCH)

Version 1.0

	R0	R1	R2	R3
Prepared	Helder de Almeida			
Reviewed	Angelos Findikakis			
Approved				
Issue Date				

	REVISION LOG	
Revision Number	**Description of Revision**	**Date Approved**
0	Original Issue - Issued in support of the SOCH computer code, Version 1.0	

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS & ABBREVIATIONS

A	area
B	width
cfs	cubic feet per second
ft	feet
ft^2	square feet
$R^{2/3}$	hydraulic radius to the power of two thirds

ACRONYMS

ANSI	American National Standards Institute
BLN	Bellefonte Nuclear Plant
SDD	Software Design Description
SRS	Software Requirements Specification
SVVR	Software Verification and Validation Report
TVA	Tennessee Valley Authority

1. INTRODUCTION

1.1 Description

SOCH is an unsteady hydraulic flow analysis code in open channels used to develop, calibrate, and verify the runoff and stream course models needed to compute elevations and discharges at TVA Nuclear Plant sites. SOCH requires several blocks of input data, which can be prepared using a suite of computer programs. Seven auxiliary codes, UNITGRPH, FLDHYDRO, TRBROUTE, CHANROUT, DBREACH, CONVEY, and WWIDTH, prepare the required input data to SOCH (Reference 19, 20 and 21). Table 1 gives a brief description of the seven codes used together with SOCH. These computer programs are used to meet United States Nuclear Regulatory Commission guidance set forth in Nuclear Regulatory Guide 1.59 (American National Standards Institute [ANSI] ANSI/ANS-2.8-1992) and TVA SPP-2.6, R12, Computer Software Control.

Table 1 Summary of TVA's flood analysis codes

Computer Code	Description
UNITGRPH	Computes unit hydrographs from historical flood data.
FLDHYDRO	Determines inflows from unit hydrographs and rainfall.
TRBROUTE	Routes hydrographs from one point to another using different routing procedures (channel & reservoir).
CHANROUT	Determines channel routing method coefficients.
DBREACH	Determines time of failure of an overtopped earth embankment based on soil type and time and depth of overtopping during a flood.
WWIDTH	Determines equivalent weighted width (B) to account for reservoir volume in SOCH geometry.
CONVEY	Determines cross sectional area (A) and composite conveyance for SOCH geometry.
SOCH	One dimensional unsteady flow model that computes elevation, discharge, and average velocity at selected locations.

Figure 1 illustrates the sequence of use of the codes described in Table 1.

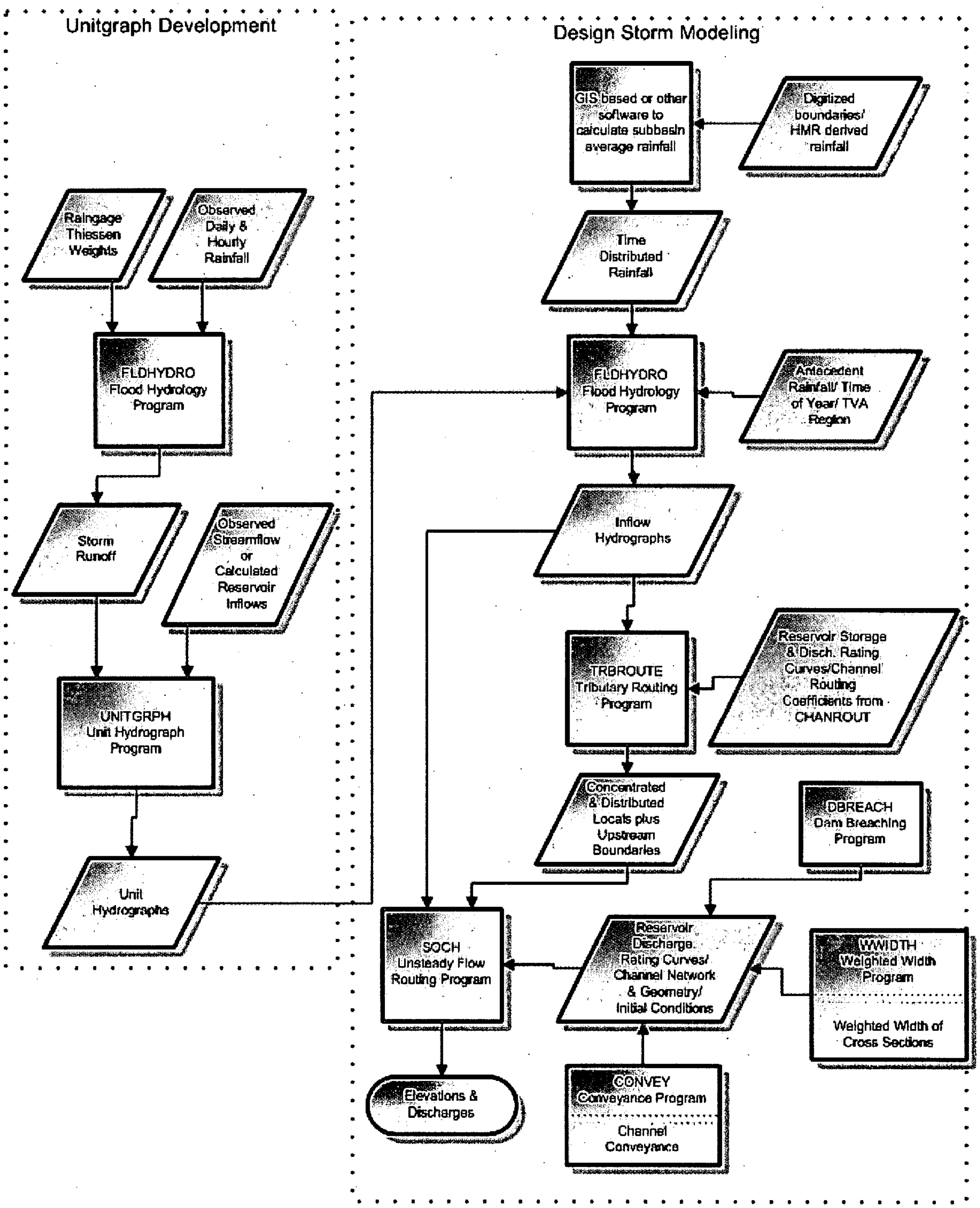


Figure 1 TVA's flood analysis computer codes

1.2 Purpose

The quality-assured purpose of the SOCH computer code is to perform flood routing calculations for the TVA reservoir system. SOCH is applicable to one-dimensional unsteady flow in open channels.

The theory for the model formulation is included in Section 2. Section 3 described the Input and Output features of SOCH. The plan for testing the functionality of SOCH is described in Section 4 and references are listed in Section 5.

1.3 Limitations

The use of SOCH is subject to the following limitations.

1. SOCH is restricted to computations in the U. S. Standard system of units.
2. The time step used in SOCH should be selected as close to the limit of numerical stability as practicable in order to obtain an accurate solution. The numerical stability criterion is discussed in Section 2.2.2. In setting up SOCH, particular attention must be given to the spacing of the cross-sections defining the channel geometry, especially at the location of boundary conditions to assure that inaccuracies are not introduced by the boundary conditions themselves.
3. There must be an odd number of cross-sections in each channel reach used in SOCH.
4. SOCH will not propagate flood waves into channels with initially low flows or low water depths in the channel. This is a limitation of the explicit finite difference scheme used in SOCH. How low a flow or depth can be used depends on the channel or reservoir slope, cross-section geometry, cross-section spacing (Δx), and time step (Δt). A trial and error process may be necessary to establish initial depths and flow that will provide a stable and accurate solution.
5. The initial condition generator for SOCH does not generate a solution to the steady-state condition for a given flow rate, but rather an initial starting condition which eliminates the need for the user to estimate the initial elevation and flow at each cross section. Therefore, a warm-up period is required to dampen out false transients caused by the initial condition generator and to establish a truly steady-state initial condition for the model. It is noted that TVA practice requires a warm-up period for SOCH regardless of the source of the initial conditions so that this is not a restrictive limitation. The length of this warm-up period can be easily determined by the user by observing the computed profile in the model over the last several time steps of the warm-up period prior to the actual simulation period ensuring that very little or no change is occurring in the computed elevation and flow at each cross section.
6. SOCH prints the name of the geometry input file used in each run rather than printing an "echo check" of the input geometry file. SOCH does not produce an echo check of the channel geometry data. The user must verify that the data in this file have been entered correctly and that they conform to the FORTRAN format specification for each piece of data. Since the column positions of each value in the input data files must be correct, the user is responsible for ensuring that problems associated with stability, accuracy and calibration are not due to incorrect input data.

7. Since a direct check of the interpolated sections is not possible because SOCH does not print out the geometric data of the channel sections, the user should exercise caution in the utilization of the SOCH interpolation feature. The most common interpolation approach utilized is the interpolation of a new section between each of the original sections in the reach. For this approach, the SOCH interpolation feature provides an intermediate section consistent with the expected transition section between the two original sections. If alternate methodologies (such as interpolation between separate and distinct sections) are utilized, the user should carefully examine the SOCH results for anomalus conditions. A potential source of an observed anomaly is the number and location of sections interpolated.

8. SOCH does not specifically warn the user for any type of abnormal input.

1.4 Network Size Limits

The system simulated by SOCH can be a complex reservoir or stream network with multiple junctions. Key limitations on the network configuration are:

- Maximum of 999 total number of cross sections.
- Maximum of 999 total number of nodes. This must be an **odd** number.
- Maximum of 999 data pairs in any of the Rating Tables.
- Maximum of 999 elevation entries per cross section in the geometry file.
- Only one channel in the network can have special KSPL/LSPL operation at the downstream boundary.
- Maximum of 8 interpolated node points between two cross sections.

1.5 Computer System Requirements

SOCH was originally programmed to run on a mainframe computer and was later transferred to the personal computer (PC). The latest version of this code has been compiled using the Compaq Visual FORTRAN compiler, Professional Edition 6.6A.

The SOCH application owner is the Nuclear Power Group (NPG) Corporate Civil Engineering. User support needs will be arranged through the NPG Corporate Civil Engineering with the technically cognizant TVA organization or vendor. Any problems identified with the software should be reported to NPG Corporate Civil Engineering.

2. SOCH THEORETICAL BASIS

The SOCH computer code, when properly applied, will give satisfactory numerical results that can be used with confidence in the determination of flood stages and flows in the TVA system. "Proper application" indicates that the user must understand the theoretical basis of the SOCH code and know how to apply SOCH to the analysis of flows in the TVA river and reservoir system in order to produce correct solutions. This section describes the theoretical basis of SOCH and discusses the procedures that must be followed to obtain satisfactory numerical results. Also in this section, the choice of the spacing between cross-sections, Δx, and the time step used in SOCH, Δt, is discussed in the light of requirements for accuracy and stability of the solution. For a given set of cross-sections, if the time step is not chosen properly, it is possible to generate solutions that are inaccurate.

2.1 Basic Equations and Assumptions

SOCH solves the Saint-Venant equations of continuity and momentum for one-dimensional, unsteady flow in open channels. The basic equations are discussed in detail in References 1, 6, 10 and 14. The independent variables in the equations are the flow depth, h, and the velocity, V. The dependent variables are the distance along the channel, x, and time, t. The flow depth, h, and velocity, V, therefore vary only with the longitudinal (x) direction and time, t.

As a consequence of the one-dimensional flow assumption, the following simplifications are introduced:

1. The velocity is uniform across each cross section.
2. The transverse water surface is horizontal at any cross section.
3. The axis of the river is a straight line.

In the development of the mathematical model, the following assumptions are also made:

1. The flow is gradually varied so that the vertical acceleration of the water may be neglected, and therefore the pressure distribution in any cross section is hydrostatic.
2. The bottom slope of the channel is small. This implies that $\sin\alpha \sim \tan\alpha$ and $\cos\alpha \sim 1$, where α is the angle between the channel bottom and the horizontal.
3. The resistance coefficient, as determined for uniform turbulent flow at any given channel cross section, is the same for the given water surface elevation and mean velocity regardless of whether the flow is uniform or non-uniform, steady or unsteady.
4. The mass density, ρ, is a constant, i.e., no density stratification exists.

SOCH solves the St. Venant equations of unsteady flow in open channels, (the continuity equation and the momentum equation), expressed in the following form:

$$\frac{\partial (AV)}{\partial x} + B\frac{\partial h}{\partial t} - q = 0 \qquad \text{Continuity} \qquad (1)$$

$$g\frac{\partial h}{\partial x} + V\frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} + gS_f + V\frac{q}{A} = 0$$ Momentum (2)

where:

A = flow area in ft^2;
V = mean velocity in ft/s;
x = distance in feet;
B = water-surface width in feet;
h = water surface elevation in feet;
t = time in seconds;
q = lateral local inflow per unit distance;
g = the gravitational constant (ft/s^2); and
S_f = the energy gradient given by the Manning's equation (ft/ft):

$$S_f = \frac{n^2 V|V|}{2.21\ R^{4/3}} \quad (3)$$

where:

n = Manning's n; and
R = the hydraulic radius in feet and R = A/P, where A is the flow area in ft^2
P = the wetted perimeter in feet.

Units in this manual are U. S. Standard units (pounds, feet, and seconds). Since SOCH was coded with dimensional constants that are applicable only to U. S. Standard units, correct results will not be achieved with SI units.

2.2 Numerical Solution Scheme

2.2.1 Method

SOCH implements an explicit finite-difference scheme in the solution of the St. Venant equations using the leapfrog method, which employs a staggered time-distance grid and centered differences in space and time to compute the spatial and temporal derivatives in the equations of continuity and momentum. The variables at a spatial position x and for time t +Δt are computed with data at time t and time t-Δt as indicated in Figure 2. The method is described in detail in Reference 12. The staggered grid used in the leapfrog method as programmed in SOCH requires that the number of cross-sections in each channel reach be an odd number. SOCH thus computes water-surface elevations, discharges, and velocities, along the river or reservoir at the specified grid points in space (the cross-sections) at time t +Δt using the known conditions at time t and time t-Δt and the geometric parameters at each cross-section as read in from the SOCH input geometry files.

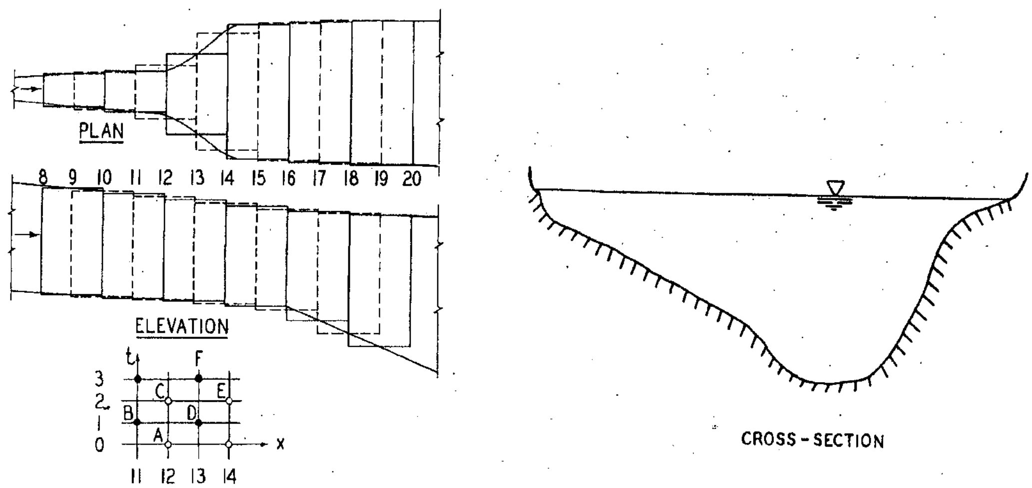


Figure 2. Net Scheme and Channel Geometry

2.2.2 Stability

All classic analyses for stability of explicit finite difference methods for solution of the Saint-Venant equations lead to the condition

$$\left(V+\sqrt{g\frac{A}{B}}\right)\frac{\Delta t}{\Delta x}\leq 1 \qquad (4)$$

A = cross-sectional flow area in ft^2;
V = mean velocity in ft/s;
B = water-surface width in feet;
Δx = distance between cross-sections in feet;
Δt = time step in seconds
g = acceleration of gravity, ft/s^2 ;

This condition is known as the Courant condition and the value of the left-hand side of the equation is called the Courant number. However, this expression was obtained by ignoring the effects of channel resistance. A re-analysis of the stability of the method including friction was performed in 1968 by Perkins who showed that the stability criterion for the leapfrog method including friction is

$$\left(V+\sqrt{g\frac{A}{B}}\right)\frac{\Delta t}{\Delta x}\leq 1-\frac{gn^2|V|}{2.21R^{4/3}}\Delta t \qquad (5)$$

with the quantities in Equation (5) as defined previously (Reference 13).

2.2.3 Accuracy

Accuracy in the solution is related to the spatial resolution used to define the variation in flow along the channel. The cross-sections used in SOCH should be located so that changes in channel characteristics such as cross-sectional area, Manning's n and off-channel storage are represented adequately in SOCH. The leapfrog method is a method that is second-order accurate in space with equal spacing. It is a characteristic of numerical methods using fixed grids that the order of the accuracy is diminished if the spacing of the grids is unequal (Reference 5, p. 197). Therefore, the cross-section spacing should not be highly variable. As an example, a spacing of 2000 feet should not be followed by one of 20 feet. For large spacing variations, spacing sensitivity studies should be considered to validate the SOCH model results A second factor affecting accuracy is the relationship between Δx, and Δt. For explicit methods, the most accurate solution is obtained when

$$\left(V+\sqrt{g\frac{A}{B}}\right)\frac{\Delta t}{\Delta x} \quad \text{is less than but very close to 1} \qquad (6)$$

Here V is the velocity in the channel, A is the cross-sectional area in ft^2, B is the top width in feet, Δx is the spacing between cross-sections in feet, and Δt is the time step in seconds.

This expression is the Courant number, which was introduced in the previous discussion of stability . For a fixed grid , the analysis should be conducted with Δt as close to the stability limit as possible, or equivalently with a Courant number as close to 1 as practicable [Reference 16, p. 320 and Reference 14]. When this condition is met with the leapfrog method and equal grid spacing, there is neither damping nor dispersion(i.e., the amplitude of the perturbations is not damped, and the wave speed of the Fourier components is not changed).

The effects of unequal grid spacing are that the Courant number for different spacing of the cross-sections is different. Consequently, a wide range of spacing of cross-sections along the river or reservoir can result in a small Δt that is necessary for stability in one part of the system, but that leads to inaccuracy in other parts of the system. For SOCH, this problem also requires particular attention to the boundary conditions as discussed below.

2.2.4 Boundary Conditions

SOCH handles a range of boundary conditions that can be used to describe the operation of gates, spillway gates, turbines, overflow sections, inflows and outflows. In this section, a discussion is presented on the potential for significant errors to occur with the formulation of boundary conditions if Δt is not close to the stability limit for the system being analyzed.

The formulation of boundary conditions for explicit finite difference schemes is difficult. Liggett and Cunge (Reference 12) and Sturm (Reference 16, p. 312) discuss some of the pitfalls. If the Courant number for the Δx between the boundary and the next upstream (or downstream as the case may be) cross-section is not close to one, then errors are introduced at the boundary and these errors increase as the Δt becomes smaller and smaller.

2.2.5 Initial Conditions

SOCH is equipped with an initial condition feature that allows the user to either specify the initial conditions through the input files or automatically establish the initial water-surface elevation and flow rate at each cross-section to start the computations. A feature is also available so that the end computation of one run may be saved in a special file to be used as initial conditions for the next run, if needed

The automatic computation of initial conditions for SOCH uses a method that approximates the steady-state water surface profile in the system. It must be emphasized that the internal calculation of the initial conditions is not the steady-state water-surface profile. Consequently, using this initial condition generator is an estimate only and may introduce false transients. However, the standard approach is to require an initial "warm-up" period prior to routing the inflow hydrograph through a river segment. This warm-up period dampens out any false transients and tests that the initial boundary conditions have been set correctly. Since SOCH does not automatically perform this initial condition check, it is the responsibility of the user to use a warm-up period to establish the correct initial conditions for each run. The length of this warm-up period can be easily determined by the user by observing the computed profile in the model over the last several time steps prior to the actual simulation period ensuring that very little or no change is occurring in the computed elevation and flow at each cross section.

2.3 Geometric Representation of Cross-section Data

Cross-sections used to develop input for SOCH are not, in general, the same as would be obtained from field topography at that location. Each cross-section used in SOCH defines the effective flow area for the cross-section. This means that the cross-section used in SOCH defines the conveyance characteristics at that section only. The storage characteristics are handled separately. This approach is a consequence of channel sections that have extensive overbank areas or have extensive off-channel storage. Treating the conveyance and storage characteristics separately is possible because the storage effects as embodied in the top-width, B, are isolated in one term in the Saint-Venant equations, while the conveyance characteristics, embodied in the Manning's equation, are isolated in another term. The basic concept is outlined by Liggett (Reference 11, page 40).

The primary geometric input to SOCH therefore includes:

1. a description of the hydraulic conveyance characteristics at each cross-section
2. a description of the reservoir storage characteristics for each reach of the reservoir (between cross-sections)

The conveyance for a channel cross-section is defined (Reference 2 , p. 128) as

$$C = \frac{1.486AR^{2/3}}{n} \qquad (7)$$

C is a measure of the carrying capacity of the channel, since the conveyance is directly proportional to the discharge in the channel. Here A is the cross-sectional area in ft^2, R is the hydraulic radius in feet, and n is Manning's "n". Equation (7) is valid only for U. S. Standard Units. The term "conveyance", refers to the conveyance characteristics for a cross-section such as the area, A, or hydraulic radius, R, or to the conveyance for the cross-section (or segments thereof), C, as defined by Equation 7.

The hydraulic conveyance characteristics that are established for a given cross-section for input to the SOCH model are:

1. a table of cross-sectional area versus water-surface elevation
2. a corresponding table of $R^{2/3}$ versus water-surface elevation

All cross sections must have the same number of entries (the number of elevation entries [NSTP] is usually 21) but there is no restriction on the elevation intervals for entries. The first entry should be the streambed elevation in order to properly compute the depth. An option is available to use or skip any cross section, duplicate a section when necessary, or interpolate between sections.

It should be noted that the value of $R^{2/3}$ as computed for use in the SOCH model is based on the total conveyance for the cross-section. The total conveyance for the cross-section is the sum of the individual conveyances as specified by the variation in Manning's n across the cross-section. Consequently, computing $R^{2/3}$ from Equation 7 results in a value that does not exist physically, unless Manning's n is a constant for the entire cross-section. The user generates the input file for SOCH with the conveyance characteristics for the cross-sections using the CONVEY program (Reference 21). This program computes the total conveyance, C, for the cross-section, and then given a user-specified value of Manning's n, it then computes the parameter $R^{2/3}$ using Equation (7). Changing the value of Manning's n effectively changes the conveyance for the cross-section. SOCH therefore allows the user to specify three changes in Manning's n with elevation or discharge to permit calibration for various flow rates. The value of Manning's n is then interpolated for intermediate elevations or discharges.

The reservoir/channel storage characteristics are represented by a table of weighted width values at that cross-section as a function of water-surface elevation. The weighted width is the quantity that SOCH uses to represent the storage in the reach of the reservoir or river channel $\Delta x/2$ upstream and $\Delta x/2$ downstream from the location of the cross-section. In general, the weighted width is not equal to the top width of the cross-section.

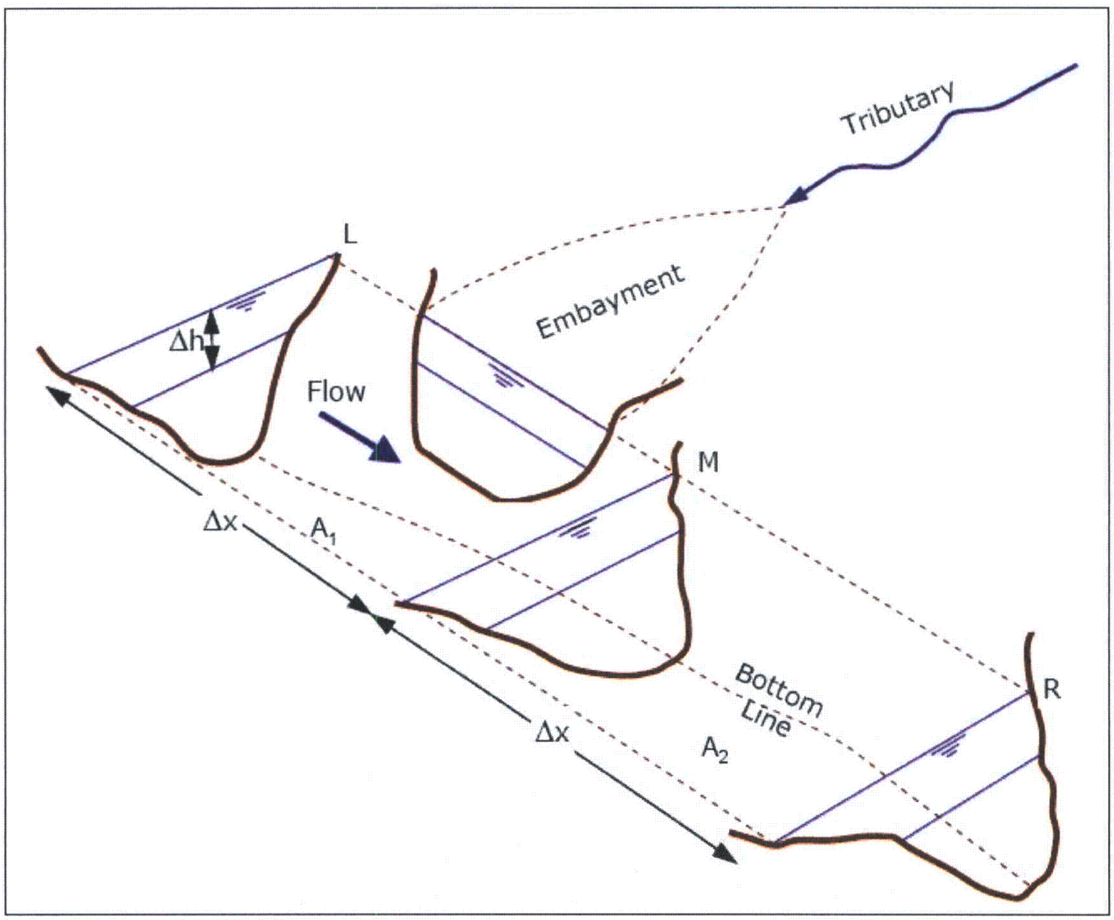


Figure 3. Definition Sketch for Calculation of Weighted Width

Referring to Figure 3, if the surface area at a given elevation between cross-sections L and M is A_1, and the surface area at the same elevation between cross-section M and R is A_2, then the width of a rectangle, B_1, with area A_1 and length Δx is given by Equation 8:

$$B_1 = \frac{A_1}{\Delta x} \tag{8}$$

The width, B_2, of the rectangle with area A_2, and length Δx is given by Equation 9:

$$B_2 = \frac{A_2}{\Delta x} \tag{9}$$

The weighted width, B_w, at cross-section M is then given by Equation 10

.

$$B_w = \frac{(B_1 + B_2)}{2} \tag{10}$$

The quantities B_1, B_2, B_w and Δx are in feet and the areas A_1 and A_2 are in ft^2.

If the weighted width at cross-section M is multiplied by Δx, then this is the area at the given elevation for cross-section M in the reach $\Delta x/2$ upstream and $\Delta x/2$ downstream from M. Integrating the areas at cross-section M as a function of elevation gives the volume for the reach represented by cross-section M. Details for preparation of the input files for the weighted width are given in the user's manual for WWIDTH (Reference 21). Here it is necessary to know only what the weighted width is so that the formulation of the equations and the treatment of the conveyance and storage terms in the basic equations used in SOCH are documented and that the user then prepares and utilizes the data in accordance with the requirements of these equations.

3. SOCH FUNCTIONALITY

By default, SOCH uses two main user-specified input files for all the required data input, Unit 3 and Unit 5, for geometry parameters and all others, respectively. Optionally, some input data can be specified in separate input files, Unit 1, Unit 8 and Unit 9, for initial conditions, local inflows and upstream boundary inputs, respectively.

By default, a given SOCH simulation will produce three output files Unit 4, Unit 6 and the file ".run" with no assigned Unit, for the downstream most node discharge hydrograph, general output, and name and path of all the files used, respectively.

SOCH input and output files are associated with specific Unit numbers in the standard FORTRAN language terminology, except the file with the extension ".run".

3.1 Input Features

To obtain the SOCH solution for a reservoir system, a sequence of SOCH datasets are needed to complete each particular simulation. Typically, each dataset specifies a change in dam operating rules and conditions that can't be accomplished within one dataset for the entire system throughout the entire duration of a given event. The overall sequence of the preparation of the input data to run SOCH is illustrated in Figure 1.

The SOCH code requires the following input files:

- ".sln" – This file (Unit 1) specifies the initial conditions of the system to be modeled. It can contain stages, discharges or both for the downstream most node or every node in the system. (optional separate file)
- ".geo" – SOCH input channel geometry parameters are read from files with this extension (Unit 3). The geometry is tabulated by Area, $R^{2/3}$ and Storage Width as a function of the elevation.
- ".dat" – SOCH input data are read from files with this extension (Unit 5). The overall input data required, except for the channel geometry, are included in the".dat" file. There are options that allow a separation of the data in the ".dat" file throughout other independent input units.
- ".loc" – This file (Unit 8) specifies the local point source or distributed local inflows to be included in a given simulation. The requirement to specify local inflows in this input file is that a constant time interval must be used. (optional separate file)
- ".bnd" – This file (Unit 9) specifies the upstream boundaries to be included in a given simulation. The hydrographs can be specified in the same way as in Unit 5 and the time interval can be constant or variable. (optional separate file)

For any SOCH unsteady flow simulation, it is necessary to specify the following parameters:

- Upstream boundary condition – Specified at the upstream most node of a channel/reservoir. There are four types of upstream boundary conditions, namely, stage hydrograph, flow hydrograph, rating curve or junction with free surface. A network can have all but the upstream most channel upstream boundary condition set as a junction with free surface or rating curve. It is mandatory that the upstream most channel in the network have an upstream boundary set to stage hydrograph or flow hydrograph. The time-dependent boundary types must be specified at fixed or variable time intervals and they cannot include negative values neither as ordinates nor as abscissae.

Upstream boundary data can be specified in a separate file with the extension ".bnd".

- Downstream boundary condition – Specified at the downstream most node of a channel/reservoir. There are four types of downstream boundary conditions, namely, stage hydrograph, flow hydrograph, rating curve or junction with free surface. A network can have all but the downstream most channel downstream boundary condition set as a junction with free surface. It is mandatory that the downstream most channel in the network have a downstream boundary set to stage hydrograph, flow hydrograph or rating curve. The time-dependent boundary types must be specified at fixed or variable time intervals and cannot include negative values neither as ordinate, nor as abscissae.

If the downstream boundary in a given channel is set according to the above mentioned, SOCH allows optional additional specifications for the downstream boundary, namely:

- Hold a given stage until a certain discharge occurs (KSPL)
- Hold a given discharge until a given stage occurs (LSPL)
- Partial Failure at a given stage, discharge or time.
- Total Failure at a given stage, discharge or time.

The key limitations in the usage of these optional specifications are that only one channel can have KSPL or HSPL operation at the downstream boundary, and that in the case of Total Failure there must be a channel/reservoir downstream of the location of the Total Failure.

- Initial conditions – Specified for the beginning of a simulation at every node. A steady-flow profile, a flat pool-zero flow profile or a transient flow profile from previous computations may be used as the initial conditions. The initial conditions provide an elevation and discharge for each node in the reach. The end computation of one run may be saved in a special file (".sav" described in Section 3.2) to be used as initial conditions for another run if needed. Optionally, a simulation can use the steady state solver included in SOCH that, given a flow or a stage-flow data pair at the downstream end node, computes an approximation of the initial profile for the remaining upstream extension of the channel/reservoir. The use of this option requires the specification of a warm-up period in the consequent unsteady simulation so that the solution is not affected by potential initial false transients.

Initial conditions (or starting lines) can be included in a separate SOCH input file with the extension ".sln".

- Local inflows – Local inflows to the model generated by the FLDHYDRO code (with inputs from UNITGRPH, TRBROUTE, and CHANROUT) can be entered as point source or distributed locals over a given extension of a reach or multiple reaches. The time-dependent flow hydrograph must be specified at fixed or variable time intervals and cannot include negative values neither as ordinate nor as abscissae.

  The ordinates of local inflow hydrographs with constant time interval can be included in a separate SOCH input file with the extension ".loc".

- Channel geometry – Channel geometry for each cross section is generated by the WTDWIDTH and CONVEYANCE codes. The geometric table for each cross section discretizes the Area and $R^{2/3}$, from CONVEYANCE, and Storage width from WTDWIDTH, as a function of elevation, always starting at the channel invert. The elevation increments can vary in magnitude but the total number of increments must be the same for all the cross sections. The SOCH program interpolates values for these parameters from these geometry tables.

  Geometry parameters are included in the SOCH input file with the extension ".geo".

- Manning's n values – The Manning's n values are developed from field estimates and then adjusted based on calibration of the backwater/HEC2 model profiles and/or with historical flood events. These must be specified for every node in the system

  The Manning's n values are included in the general ".dat" file.

If the flood scenario analyzed involves one or multiple dam breaks the code DBREACH is used to obtain the time, discharge or stage at which the dam breaks occur.

In the cases of partial failure, the rating curve characterizing the stage-discharge relationship over the failed portion of the dam is also obtained with DBREACH. This rating curve is combined with the rating curve that describes the stage-discharge relationship for other elements of the dam and originates Rating Table 4.

Rating Table 4 is used in SOCH to characterize the post failure stage-discharge relationship over the partially failed dam and is included in the ".dat" file.

The triggers for failure are specified in the ".dat" file for the corresponding channels.

3.2 Output Features

The output produced by the SOCH model at every node is specified at selected time intervals. The output from SOCH is saved in files with the following extensions:

- **".out"** – SOCH output listing is written to files with this extension, which includes the resulting flows, average velocities, and water surface elevations. This file contains all the "echoed" input except the geometry parameters from the ".geo" file. Similarly, it does not contain the geometry parameters for interpolated cross sections, in case cross section interpolation is used.

- **".sto"** – The discharge hydrograph at the downstream most node is saved in a separate file with this extension and also in the end of the ".out" file. There is no option to eliminate the redundancy.

- "**.sav**" – Ending lines are saved to files with this extension (optional separate file)
- "**.run**" – Name and path to all the input/output files used in a given run.
- "**.prt**" – Stage and flow hydrographs at specific locations at the specified output print interval (optional separate file)

The results at the nodes are grouped by channels (in proper sequence) and show: River Mile (mi), stage (ft) , discharge (cfs) , velocity (ft/s) , flow area (ft^2) , storage width (ft), $R^{2/3}$, Manning's n assigned to this node, local inflow (cfs), depth (ft), and Froude number (non-dimensional). Example output files are presented in Appendix B.

A tabulation of maximum elevation, discharge, and velocity at all nodes, with the exact time and day of occurrence follows the computation. It can be used to plot envelope maximum profiles of these three variables along the extension of the channels/reservoirs.

4. PLAN FOR TESTING SOCH CODE FUNCTIONALITY

4.1 Overview of the SOCH Test Plan

The SOCH Test Plan consists of a comparison of the solution of several test problems obtained with SOCH to independent calculations performed with the computer code HEC-RAS (References 7, 8, 9 and 22). The test plan serves to evaluate SOCH's capabilities and limitations as related to TVA's flood design analyses. The test problems, which are described in Section 4.2, were selected to be representative of typical TVA applications of SOCH.

The validation of SOCH after changes and modifications to the computer code in the future shall be documented as required by Section 3.3, Reference 17.

The test problems specified herein are intended to assess the extent of possible program features and options likely to be required for safety-related design analysis.

The SOCH Test Plan includes 28 Test Problems. Table 2 provides a cross-reference index to all SOCH features and options verified by each of these test problems.

Table 2. Test Problem Cross Reference Index

SOCH Feature	Test Problem
Unsteady convergence to a steady state problem	1-3
Unsteady flow in single channel	4-6
SOCH specific options:	7-10
• Cross section interpolation	7
• Initial conditions solver/estimator	8
• Extrapolation on downstream rating curve	9
• Composite cross section	10
Unsteady flow in channels with tributaries	11-13
Unsteady flow in channels with local inflows	14-16
Vertical variation of roughness as a function of the water surface level	17
Vertical variation of roughness as a function of discharge	18
Holding water elevation constant at the downstream end	19
Holding discharge constant at the downstream end	20
Partial dam failure at the downstream end of a channel	21
Total dam failure at the downstream end of a channel	22
Dam failure at the upstream end of a channel	23-27
Cross section interpolation in a natural section (irregular geometry)	28

4.2 SOCH TEST PROBLEMS

4.2.1 Steady-Flow

4.2.1.1 Test Problem 1

The test problem considers the case of steady-state flow in a prismatic channel, i.e. with uniform trapezoidal cross section and uniform invert slope. Boundary conditions are constant discharge at the upstream end and constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections. The boundary conditions for Test Problem 1 are defined in Table 3

Channel Characteristics:

- Length: 75.76 mi (400,000 ft)
- Longitudinal slope: 0.01%
- Cross section bottom width: 2,000 ft
- Bank slope: 2:1 (H:V)
- Distance between cross sections: 10,000 ft

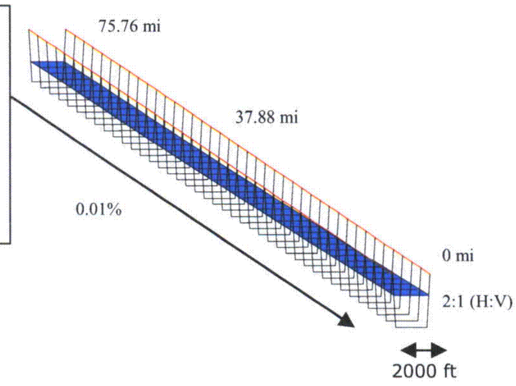


Figure 4. Test Problem 1

Table 3. Prescribed boundary conditions in Test Problem 1

Boundary conditions			
Upstream		Downstream	
Time (hr)	Flow (cfs)	Time (hr)	Stage (ft)
0	500,000	0	60
48	500,000	48	60

The steady-state solution for this problem is obtained by running SOCH in transient mode until the SOCH solution converges to steady state. The simulation period used for this purpose is 48 hours.

4.2.1.2 Test Problem 2

This test problem considers the case of steady-state flow in a channel with uniform trapezoidal cross section with two reaches, each with a different invert slope. Boundary conditions are constant discharge at the upstream end and constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections.

Channel Characteristics:

Upstream reach length: 37.88 mi (200,000 ft)
Upstream reach longitudinal slope: 0.005%
Downstream reach length: 37.88 mi (200,000 ft)
Downstream reach longitudinal slope: 0.015%
Cross sectional bottom width: 2,000 ft
Bank slope: 2:1 (H:V)
Distance between cross sections: 10,000 ft

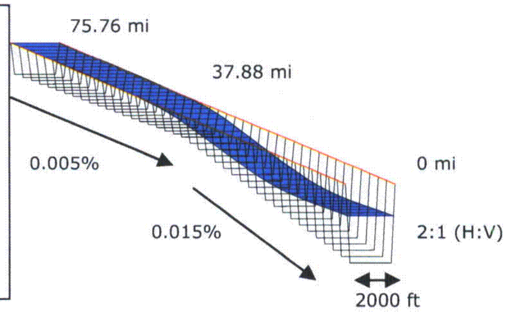


Figure 5. Test Problem 2

The boundary conditions for Test Problem 2 are defined in Table 4.

Table 4. Prescribed boundary conditions in Test Problem 2

Boundary conditions			
Upstream		Downstream	
Time (hr)	Flow (cfs)	Time (hr)	Stage (ft)
0	500,000	0	60
48	500,000	48	60

The steady-state solution for this problem is obtained by running SOCH in the transient mode until the SOCH solution converges to steady state. The simulation period used for this purpose is 48 hours.

4.2.1.3 Test Problem 3

This test problem considers the case of steady-state flow in a channel with variable trapezoidal cross section with two reaches, each with a different invert slope. Boundary conditions are constant discharge at the upstream end and constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections.

Channel Characteristics:

Upstream reach length: 37.88 mi (200,000 ft)
Upstream reach longitudinal slope: 0.005%
Upstream reach cross sectional bottom width:
- Gradual expansion from 2,000 ft to 4,000 ft.
Upstream bank slope: 2:1 (H:V)
Downstream reach length: 37.88 mi (200,000 ft)
Downstream reach longitudinal slope: 0.015%
Downstream reach cross sectional bottom width:
- Gradual contraction from 4,000 ft to 2,000 ft.
Downstream bank slope: 2:1 (H:V)
Distance between cross sections: 10,000 ft

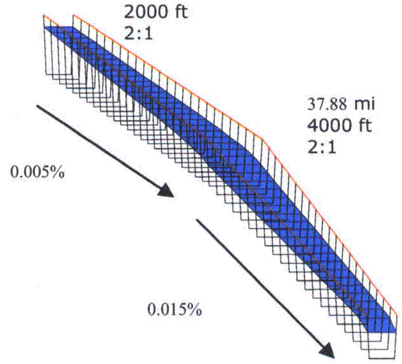


Figure 6. Test Problem 3

The boundary conditions for Test Problem 3 are defined in Table 5.

Table 5. Prescribed boundary conditions in Test Problem 3

Boundary conditions			
Upstream		Downstream	
Time (hr)	Flow (cfs)	Time (hr)	Stage (ft)
0	500,000	0	60
48	500,000	48	60

The steady-state solution for this problem is obtained by running SOCH in the transient mode until the SOCH solution converges to steady state. The simulation period used for this purpose is 48 hours.

4.2.2 Unsteady Flow in Single Channels

4.2.2.1 Test Problem 4

This test problem considers the case of unsteady-state flow in a prismatic channel, i.e. a channel with uniform trapezoidal cross section and uniform invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections. The channel geometry in Test Problem 4 is the same as that in Test Problem 1.

The boundary conditions for Test Problem 4 are defined in Table 6. The hydrograph defining the upstream boundary condition is shown in Figure 8.

Channel Characteristics:

Reach length: 75.75 mi (400,000 ft)
Reach longitudinal slope: 0.01%
Cross section bottom width: 2,000 ft
Bank slope: 2:1 (H:V)
Distance between cross sections: 10,000 ft

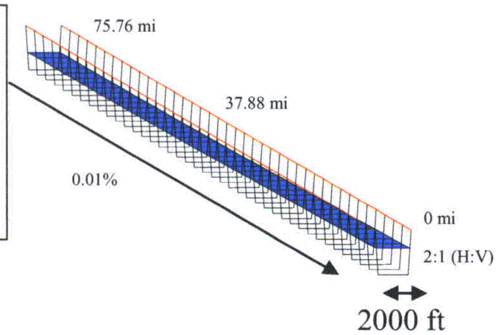


Figure 7. Test Problem 4

Table 6. Prescribed boundary conditions in Test Problem 4

Boundary conditions			
Upstream		Downstream	
Time (hr)	Flow (cfs)	Time (hr)	Stage (ft)
0	30,000	0	60
24	30,000	24	60
30	500,000	30	60
36	30,000	36	60
60	30,000	60	60

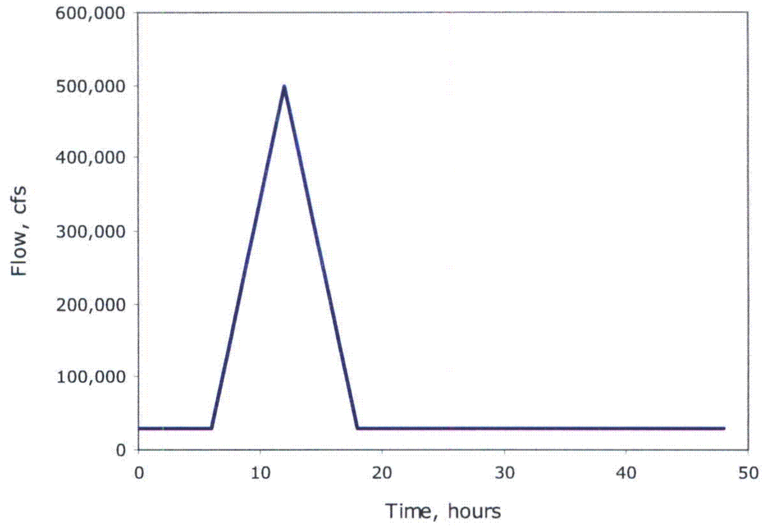


Figure 8. Hydrograph defining the upstream boundary condition for Test Problem 4, Test Problem 5, Test Problem 6 and Test Problem 7 .

4.2.2.2 Test Problem 5

This test problem considers the case of unsteady-state flow in a channel with uniform trapezoidal cross section with two reaches, each with a different invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections.

The channel geometry in Test Problem 5 is the same as that in Test Problem 2. The inflow hydrograph that defines the upstream boundary condition for this problem is the same as that for Test Problem 4.

Channel Characteristics

- Upstream reach length: 37.88 mi (200,000 ft)
- Upstream reach longitudinal slope: 0.005%
- Downstream reach length: 37.88 mi (200,000 ft)
- Downstream reach longitudinal slope: 0.015%
- Cross sectional bottom width: 2,000 ft
- Bank slope: 2:1 (H:V)
- Distance between cross sections: 10,000 ft

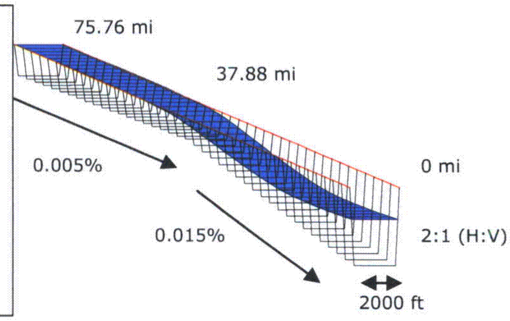


Figure 9. Test Problem 5

The boundary conditions for Test Problem 5 are defined in Table 6. The hydrograph defining the upstream boundary condition is shown in Figure 8.

.

4.2.2.3 Test Problem 6

This test problem considers the case of unsteady-state flow in a channel with variable trapezoidal cross section with two reaches, each with a different invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections.

The channel geometry in Test Problem 6 is the same as that in Test Problem 3. The inflow hydrograph that defines the upstream boundary condition for this problem is the same as for Test Problem 4.

Channel *Characteristics*

Upstream reach length: 37.88 mi (200,000 ft)
Upstream reach longitudinal slope: 0.005%
Upstream reach cross sectional bottom width:
- Gradual expansion from 2,000 ft to 4,000 ft.
Upstream bank slope: 2:1 (H:V)
Downstream reach length: 37.88 mi (200,000 ft)
Downstream reach longitudinal slope: 0.015%
Downstream reach cross sectional bottom width:
- Gradual contraction from 4,000 ft to 2,000 ft.
Downstream bank slope: 2:1 (H:V)
Distance between cross sections: 10,000 ft

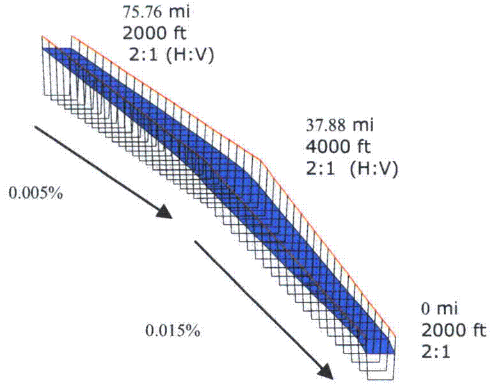


Figure 10. Test Problem 6

The boundary conditions for Test Problem 6 are defined in Table 6. The hydrograph defining the upstream boundary condition is shown in Figure 8.

.

4.2.3 Specific SOCH Options

4.2.3.1 Test Problem 7

This test problem considers the case of unsteady-state flow in a channel with variable trapezoidal cross section with two reaches, each with a different invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections, but the flow routing is performed using 81 equally spaced nodes. SOCH interpolates the geometry between the 41 Cross sections defined in the input to the model.

The channel geometry and boundary conditions for Test Problem 7 are the same as those in Test Problem 6.

The boundary conditions for Test Problem 7 are defined in Table 6. The hydrograph defining the upstream boundary condition is shown in Figure 8.

In interpolating between the input channel geometry data, one new cross section is added midway between every two cross sections defined as part of the input, both in HEC-RAS and in SOCH. Since SOCH does not "echo" neither the geometry file containing the parameters of the original cross sections, nor the interpolated Cross sections, the only way to check the accuracy of the interpolation in SOCH is to compare the computed stage and discharges for this problem with those computed by HEC-RAS.

Channel Characteristics:

Upstream reach length: 37.88 mi (200,000 ft)
Upstream reach longitudinal slope: 0.005%
Upstream reach cross sectional bottom width:
- Gradual expansion from 2,000 ft to 4,000 ft.
Upstream bank slope: 2:1 (H:V)
Downstream reach length: 37.88 mi (200,000 ft)
Downstream reach longitudinal slope: 0.015%
Downstream reach cross sectional bottom width:
- Gradual contraction from 4,000 ft to 2,000 ft.
Downstream bank slope: 2:1 (H:V)
Distance between cross sections: 5,000 ft

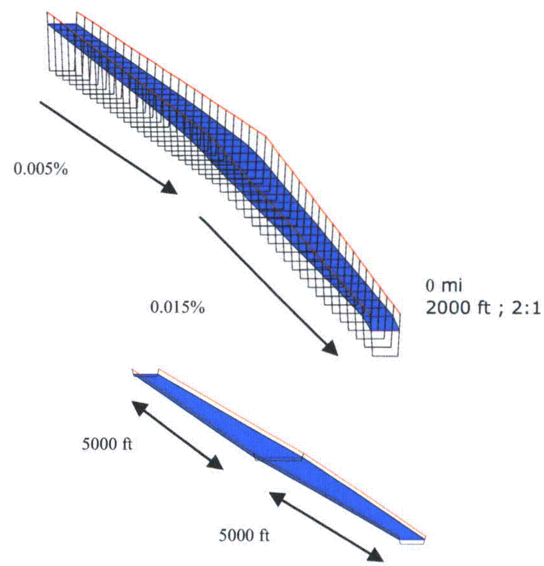


Figure 11. Test Problem 7

4.2.3.2 Test Problem 8

This test problem considers the case of steady-state flow in a prismatic channel with uniform trapezoidal cross section and uniform invert slope. Boundary conditions are a constant discharge at the upstream end and a constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections.

The channel geometry and boundary conditions used in Test Problem 8 are the same as those in Test problem 1 and shown in Table 7. The difference between the two problems is that in Test Problem 8 the steady-state solution is obtained by SOCH directly by performing a backwater calculation, not by marching through time as in Test Problem 1.

Main Characteristics:

- Reach length: 75.76 mi (400,000 ft)
- Reach longitudinal slope: 0.01%
- Cross section bottom width: 2,000 ft
- Bank slope: 2:1 (H:V)
- Distance between cross sections: 10,000 ft

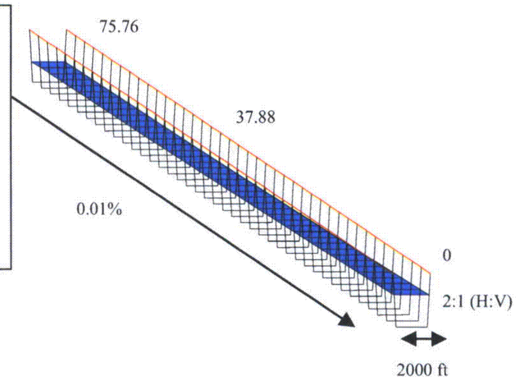


Figure 12. Test Problem 8

Table 7. Prescribed boundary conditions in Test Problem 8

Boundary conditions			
Upstream		Downstream	
Time (hr)	Flow (cfs)	Time (hr)	Stage (ft)
0	500,000	0	60
48	500,000	48	60

To perform the backwater calculation with SOCH the user must provide the initial elevation at the most downstream node leaving all other node flow and stage fields blank in the *.sln* file. The resultant initial stages, obtained from the backwater calculation, are compared with the initial stage computations performed with HEC-RAS and with the stage computed by running SOCH in the transient mode to obtain the steady state solution described in Test Problem 1.

4.2.3.3 Test Problem 9

This test problem considers the case of unsteady-state flow in a prismatic channel with trapezoidal cross section. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a rating curve at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections.

Channel Characteristics:

- Reach length: 75.76 mi (400,000 ft)
- Reach longitudinal slope: 0.01%
- Cross section bottom width: 2,000 ft
- Bank slope: 2:1 (H:V)
- Distance between cross sections: 10,000 ft

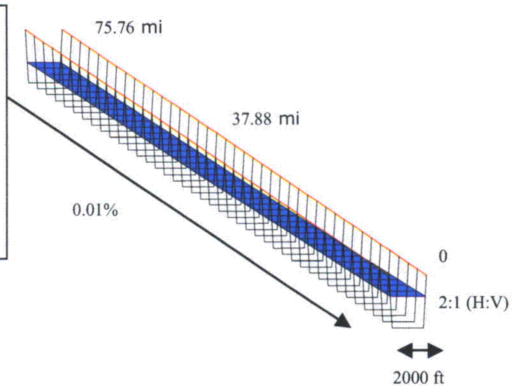


Figure 13. Test Problem 9

The upstream boundary condition for Test Problem 9 is defined in Table 6. The rating curve that defines the downstream boundary condition is shown in Table 8.

Table 8. Prescribed downstream boundary condition in Test Problem 9

Downstream Rating Curve	
Stage (ft)	Flow (cfs)
59.9	30,000
60.1	500,000

4.2.3.4 Test Problem 10

This test problem considers the case of steady-state flow in a prismatic channel with trapezoidal cross section. Manning's n varies across the cross section, with a lower value in the main channel than in the overbank portion of the cross section. Boundary conditions are a constant discharge at the upstream end and a constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections.

The steady-state solution of Test Problem 10 is obtained by SOCH both directly by performing a backwater calculation, and by marching through time.

Channel Characteristics:

- Length: 75.76 mi (400,000 ft)
- Longitudinal slope: 0.01%
- Main channel bottom width: 1,000 ft
- Overbanks bottom width: 2 x 500 ft
- Bank slope: 2:1 (H:V)
- Distance between cross sections: 10,000 ft

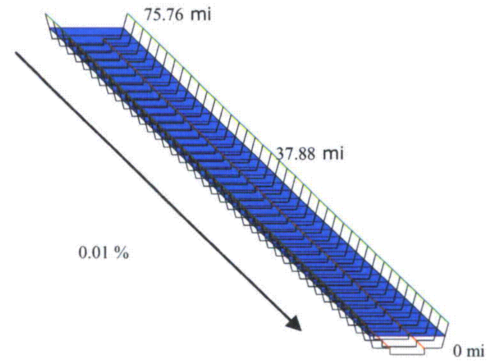


Figure 14. Test Problem 10

Figure 14 illustrates the key characteristics of the channel used in Test Problem 10. Figure 15 shows the channel cross section used in this problem. The boundary conditions for Test Problem 10 are defined in Table 3.

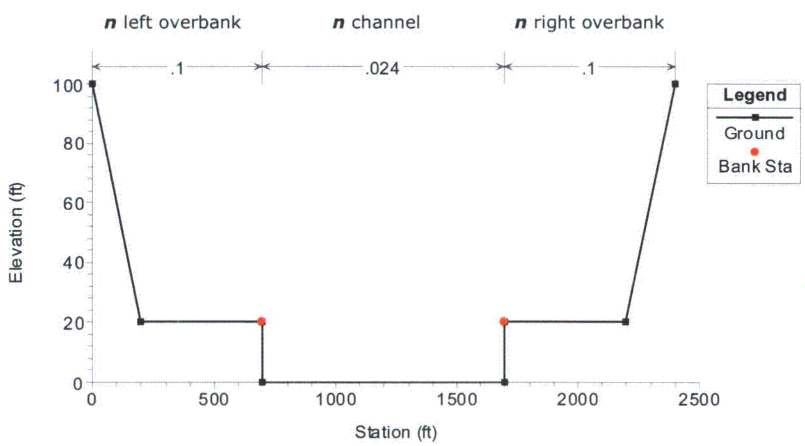


Figure 15. Channel cross section used in Test Problem 10

4.2.4 Unsteady Flow in Channels with Tributaries

4.2.4.1 Test Problem 11

This test problem considers the case of unsteady-state flow in a network of two prismatic channels with trapezoidal cross section. Boundary conditions are a time-dependent discharge at the upstream end of the main stem and tributary, in the form of a triangular hydrograph, and a constant water level at the downstream end of the main stem. The geometry of the channels is defined at 41 equally spaced cross sections for the main stem and at 21 equally spaced cross sections for the tributary.

The main-stem channel geometry in Test Problem 11 is the same as that in Test Problem 1. The tributary channel in Test Problem 11 is 37.88 miles long, with the same cross sectional geometry as the main stem channel.

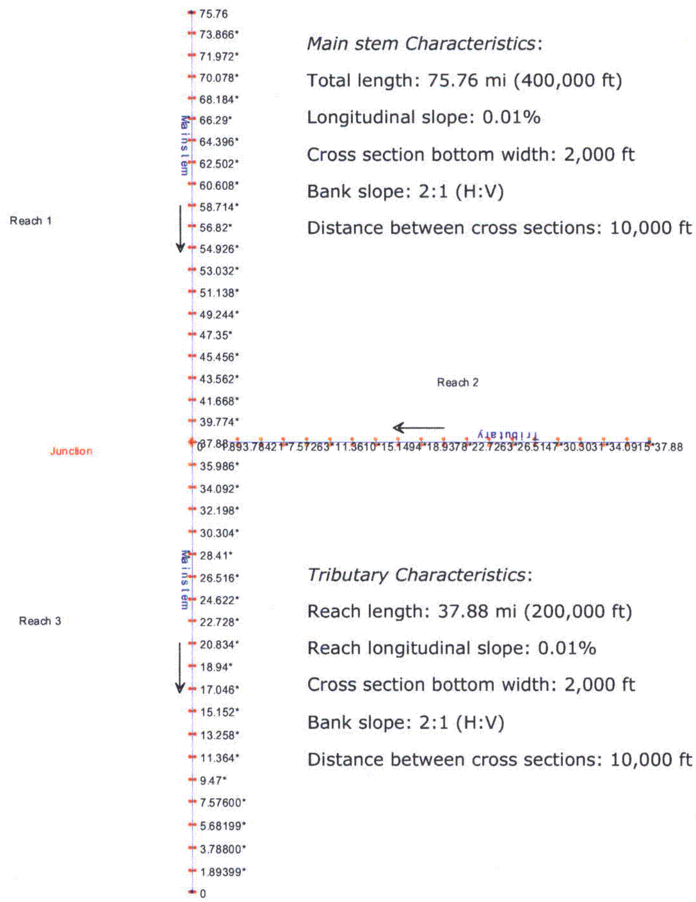


Figure 16. Network used in Test Problem 11.

The boundary conditions for this problem are defined in Table 9. The hydrograph defining the upstream boundary conditions is shown in Figure 8.

.

Table 9. Prescribed boundary conditions in Test Problem 11

Main-stem boundary conditions				Tributary boundary conditions	
Upstream		Downstream		Upstream	
Time (hr)	Flow (cfs)	Time (hr)	Stage (ft)	Time (hr)	Flow (cfs)
0	30,000	0	60	0	30,000
24	30,000	24	60	24	30,000
30	500,000	30	60	30	500,000
36	30,000	36	60	36	30,000
48	30,000	48	60	48	30,000

In HEC-RAS, the initial flow optimization at junctions is disabled, because SOCH does not have a similar capability. The initial water surface elevations along all channel reaches used in SOCH are imported from the HEC-RAS initial stage computation in order to use the same initial condition in both SOCH and HEC-RAS.

4.2.4.2 Test Problem 12

This test problem considers the case of unsteady-state flow in a network of three prismatic channels with trapezoidal cross section. Boundary conditions are time-dependent discharge at the upstream end of the main stem and tributary, in the form of a triangular hydrograph, and a constant water level at the downstream end of the main stem. The geometry of the channels is defined at 41 equally spaced cross sections for the main stem, at 22 equally spaced cross sections for the tributary and at 11 equally spaced cross sections for the bypass.

The network is defined by three junctions: Two confluences and one diversion. The main-stem channel geometry in Test Problem 12 is the same as that in Test Problem 1. The tributary channel in Test Problem 12 is 37.88 miles long, with the same geometry characteristics of the channel for the main stem. The bypass channel is 27.52 miles long and has longitudinal slope of 0.015%. Its cross section geometry is the same as the main stem.

The boundary conditions for this problem are defined in Table 9.

As in Test Problem 11 , the initial flow optimization at junctions is disabled in the HEC-RAS run. The initial water surface elevations along all channel reaches used in SOCH are imported from the HEC-RAS initial stage computation in order to use the same initial condition in both SOCH and HEC-RAS.

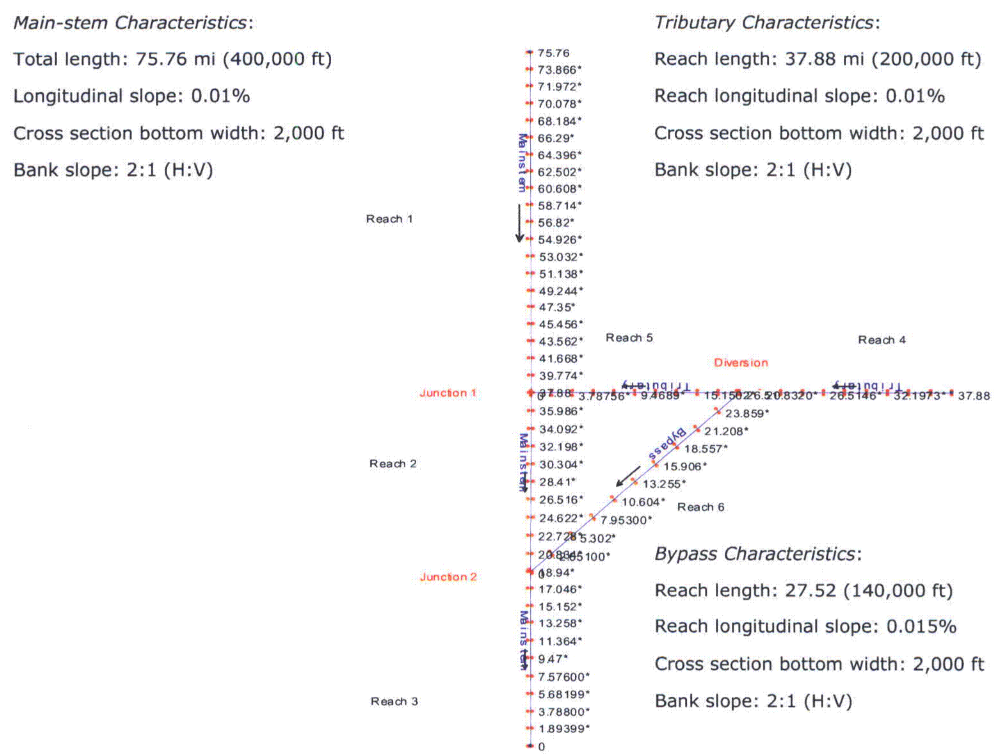


Figure 17. Looped network used in Test Problem 12

4.2.4.3 Test Problem 13

This test problem considers the case of unsteady-state flow in a network of four prismatic channels. Boundary conditions are time-dependent discharge at the upstream end of the main stem and each tributary and a constant water level at the downstream end of the main stem. The geometry is defined at 41 equally spaced cross sections in the main stem, and at 21 equally spaced cross sections in each of the tributaries.

The network is defined by three junctions, each representing a confluence. The main-stem channel geometry in Test Problem 13 is the same as that in Test Problem 1. The tributaries are 18.94 miles long, with the same channel cross section and longitudinal slope as the main stem.

The boundary conditions for this problem are defined in Table 9. Tributaries 1, 2 and 3 all have the same boundary conditions as Tributary 1 in Test Problem 11.

As in the last two test problems, the initial flow optimization at junctions is disabled in the HEC-RAS run. The initial water surface elevations along all channel reaches used in SOCH are imported from the HEC-RAS initial stage computation in order to use the same initial condition in both SOCH and HEC-RAS.

Main stem Characteristics:

Total length: 75.76 mi (400,000 ft)

Longitudinal slope: 0.01%

Cross section bottom width: 2,000 ft

Bank slope: 2:1 (H:V)

Distance between cross sections: 10,000 ft

Tributaries 1,2 and 3 characteristics:

Reach length: 18.94 mi (100,000 ft)

Reach longitudinal slope: 0.01%

Cross section bottom width: 2,000 ft

Bank slope: 2:1 (H:V)

Distance between cross sections: 10,000 ft

Figure 18. Network used in Test Problem 13

4.2.5 Unsteady Flow in Channels with local inflows

4.2.5.1 Test Problem 14

This problem involves unsteady-state flow in a prismatic channel, i.e. a channel with uniform trapezoidal cross section and uniform invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a rating curve at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections. The purpose of this problem is to test the SOCH solution for the case that a local inflow is specified at a given cross section.

The geometry used is the same as that in Test Problem 4, shown in Figure 7. The upstream and downstream boundary conditions are also the same as in Test Problem 4 , shown in Table 6. The local inflow enters the channel at RM 37.88 and is given in Table 10.

Table 10. Prescribed local inflow at RM 37.88 in Test Problem 14.

Time (hr)	Flow (cfs)
0	30,000
24	30,000
30	250,000
36	30,000
60	30,000

Channel Characteristics:

- Reach length: 75.75 mi (400,000 ft)
- Reach longitudinal slope: 0.01%
- Cross section bottom width: 2,000 ft
- Bank slope: 2:1 (H:V)
- Distance between cross sections: 10,000 ft

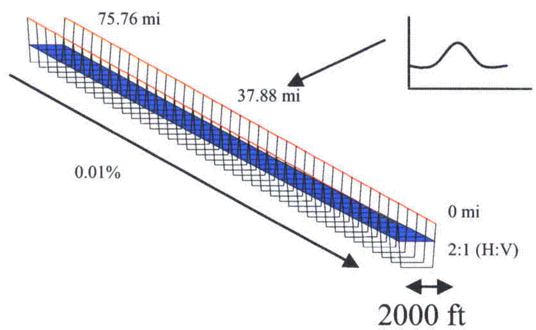


Figure 19. Test Problem 14

4.2.5.2 Test Problem 15

This problem involves unsteady-state flow in a prismatic channel, i.e. a channel with uniform trapezoidal cross section and uniform invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a rating curve at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections. This problem tests the SOCH solution for the case that a local inflow is distributed along a part of a single reach.

The geometry used in this test problem is the same as that in Test Problem 4 , shown in Figure 7. The upstream and downstream boundary conditions are also the same as in Test Problem 4 , shown in Table 6. The local inflow is the same as in Test Problem 14, shown in Table 10, and enters the channel between RM 37.88 and RM 30.30.

Channel Characteristics:

- Reach length: 75.75 mi (400,000 ft)
- Reach longitudinal slope: 0.01%
- Cross section bottom width: 2,000 ft
- Bank slope: 2:1 (H:V)
- Distance between cross sections: 10,000 ft

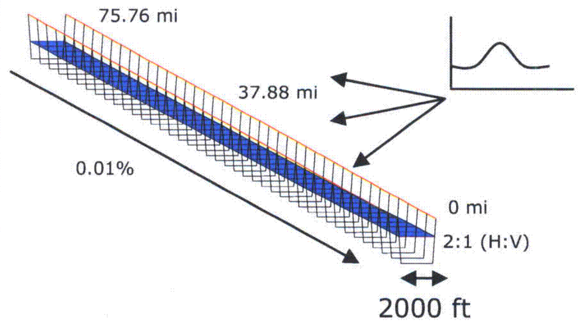


Figure 20. Test Problem 14

4.2.5.3 Test Problem 16

This problem involves unsteady-state flow in a network of two prismatic channels with trapezoidal cross section. Boundary conditions are a time-dependent discharge at the upstream end of the main stem and tributary, in the form of a triangular hydrograph, and a constant water level at the downstream end of the main stem. The geometry of the channel is defined at 41 equally spaced cross sections for the main stem and at 21 equally spaced cross sections for the tributary. This problem tests the SOCH solution for the case that a local inflow is distributed along multiple reaches.

The main-stem channel geometry in Test Problem 16 is the same as that in Test Problem 1. The tributary channel in Test Problem 16 is 37.88 miles long, with the same cross sectional geometry as the main stem channel.

The boundary conditions for the main stem and the tributary are the same as in Test Problem 11 and are shown in Table 9. The local inflow is the same as in Test Problem 14, shown in Table 10, and is distributed between RM 58.71 and RM 28.41 in the main stem and along the complete extension of the tributary.

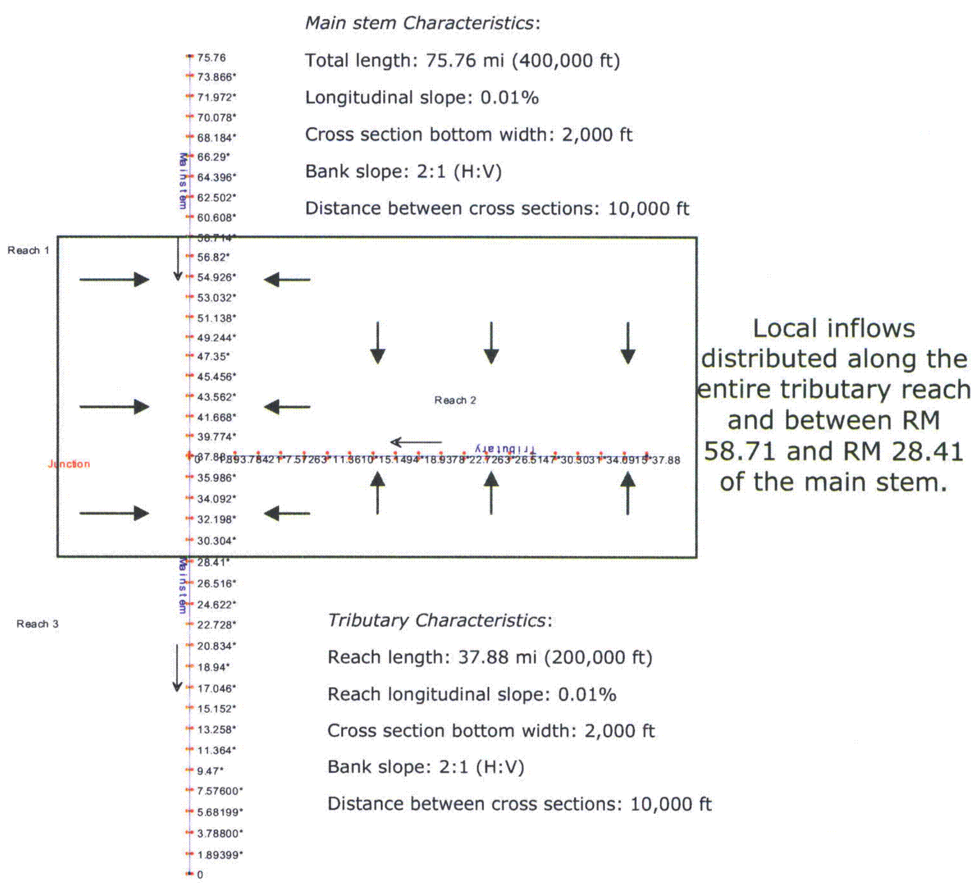


Figure 21. Setting used in Test Problem 16.

HEC-RAS does not handle a local inflow distributed along multiple reaches, thus, the local inflows in HEC-RAS are distributed in separate reaches according to the flow distribution length. Weighted hydrographs generated in an auxiliary computation are shown in Table 11.

Reach 1 represents the main stem upstream of RM 37.88, Reach 2 represents the tributary and Reach 3 represents the main stem downstream of RM 37.88.

Table 11. Distribution length weighted hydrographs

		Local inflow (cfs)	Reach 1 (cfs)	Reach 2 (cfs)	Reach 3 (cfs)
Time (hr)	0	30,000	9,167	16,670	4,163
	24	30,000	9,167	16,670	4,163
	30	250,000	76,390	138,917	34,693
	36	30,000	9,167	16,670	4,163
	84	30,000	9,167	16,670	4,163
	Length (mi)	68.18	20.83	37.88	9.47
		Length ratio	0.305	0.556	0.139

HEC-RAS does not allow a local inflow to be distributed along the entire extension of a given reach (no local inflows at the boundaries are allowed). Some fictitious cross sections can be generated 1 ft apart from the boundaries. An auxiliary run without the local inflows can be conducted and compared against the results of Test Problem 11 to demonstrate that the introduction of the fictitious cross sections does not change the solution.

4.2.6 Unsteady Flow in Channels with vertical variation of roughness coefficient

4.2.6.1 Test Problem 17

This problem involves unsteady-state flow in a prismatic channel, i.e. a channel with uniform rectangular cross section and uniform invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections. This test problem tests the SOCH solution for the case that a vertical variation of Manning's n value with stage is used. Figure 22 illustrates the channel characteristics used in this test problem.

A Manning's n value varying vertically with stage is specified in 8 cross sections between RM 45.456 to RM 32.198. An example of this variation is shown in Figure 23.

Channel Characteristics:

Reach length: 75.75 mi (400,000 ft)
Reach longitudinal slope: 0.01%
Cross section bottom width: 2,000 ft
Bank slope: 2:1 (H:V)
Distance between cross sections: 10,000 ft

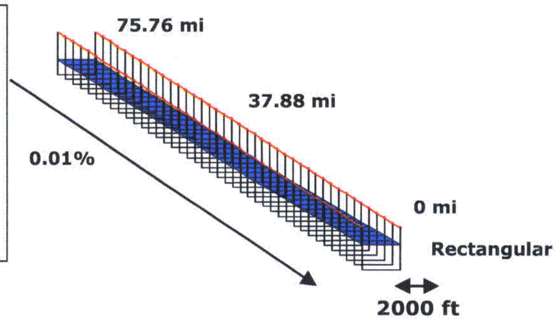


Figure 22. Test Problem 17

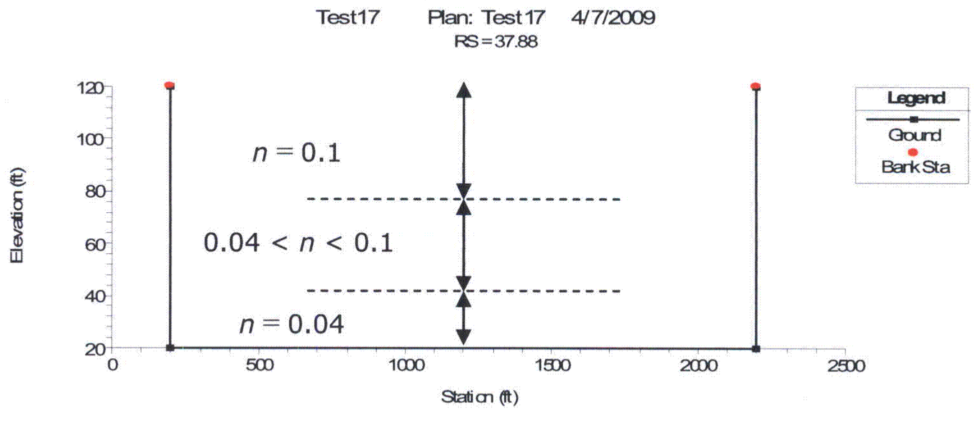


Figure 23. Vertical variation of Manning's n value

The boundary conditions for Test Problem 17 are defined in Table 12. The hydrograph defining the upstream boundary condition is shown in Figure 24.

Table 12. Prescribed boundary conditions in Test Problem 17

Boundary conditions			
Upstream		Downstream	
Time (hr)	Flow (cfs)	Time (hr)	Stage (ft)
0	30,000	0	60
24	30,000	24	60
30	300,000	30	60
36	30,000	36	60
60	30,000	60	60

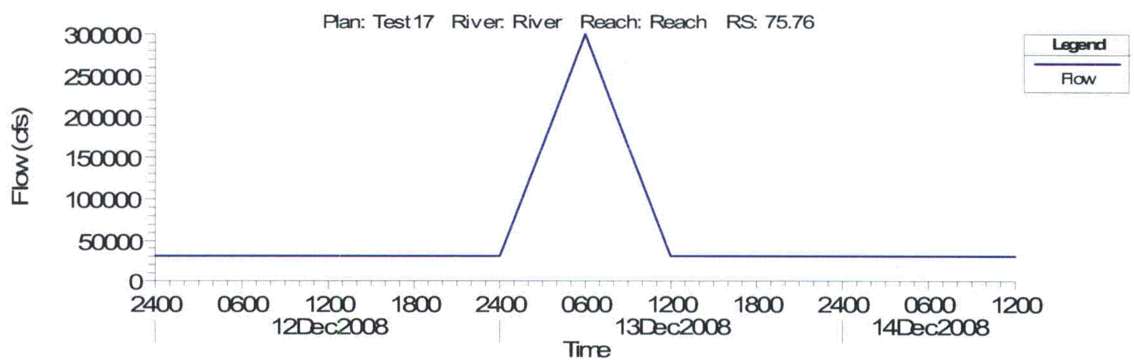


Figure 24. Hydrograph defining the upstream boundary condition for Test Problem 17.

This test problem can be set up taking advantage of the fact that HEC-RAS adjusts the conveyance of the cross sections accordingly to the specified vertical variation of Manning's *n* values on a pre-simulation basis, as soon as the geometry pre-processor runs. Considering the same vertical variation in Manning's n values, the column of $R^{2/3}$ can be built so that the conveyance for a given elevation in both models is conserved.

SOCH interpolates Manning's n values for the middle of 3 elevation bands of roughness. As a result the specified variation within the middle block is linear so that the exact same variation can be specified in both models in an expeditious manner.

4.2.6.2 Test Problem 18

This problem involves unsteady-state flow in a prismatic channel, i.e. a channel with uniform rectangular cross section and uniform invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a constant water level at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections. This test problem analyzes SOCH solution when a vertical variation of Manning's n value with discharge is used. Figure 25 illustrates the channel characteristics used in this test problem.

A Manning's n value varying vertically with discharge is specified in 8 cross sections between RM 45.456 to RM 32.198. An example of this variation is shown in Figure 26.

HEC-RAS does not consider the vertical variation in roughness with discharge in the geometry pre-processor, thus, this variation is not considered when computing $R^{2/3}$ used in SOCH.

SOCH interpolates Manning's n values for the middle of 3 discharge bands of roughness. As a result the specified variation within the middle block is linear so that the exact same variation can be specified in both models expeditiously.

Channel Characteristics:

Reach length: 75.75 mi (400,000 ft)
Reach longitudinal slope: 0.01%
Cross section bottom width: 2,000 ft
Bank slope: 2:1 (H:V)
Distance between cross sections: 10,000 ft

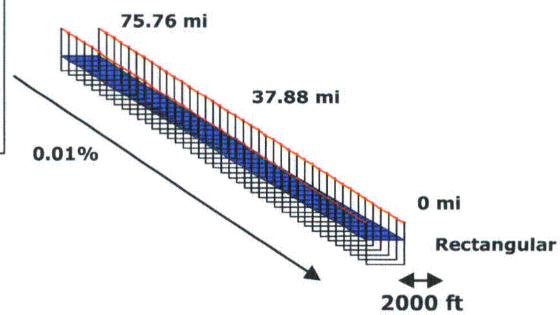


Figure 25. Test Problem 18

The boundary conditions for Test Problem 18 are defined in Table 12. The hydrograph defining the upstream boundary condition is shown in Figure 24.

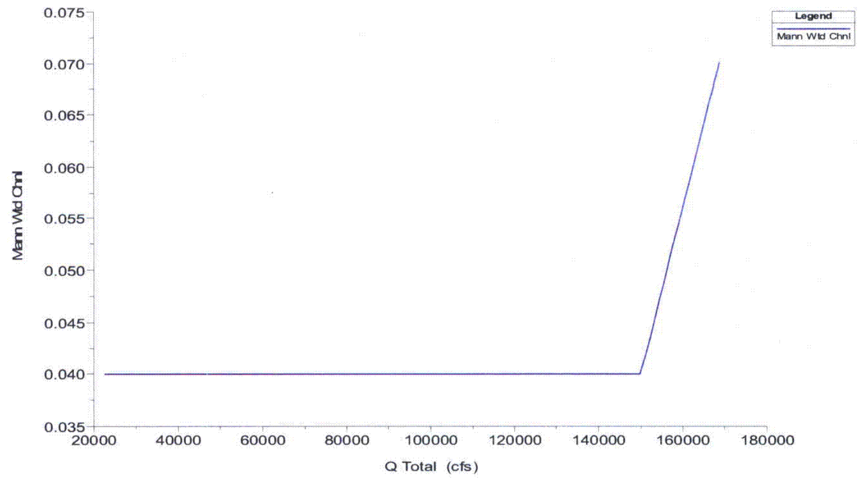


Figure 26. Manning's n variation with discharge at RM 37.88

4.2.7 Unsteady Flow in Channels with special rules

4.2.7.1 Test Problem 19

Unsteady-state flow in a prismatic channel, i.e. a channel with uniform trapezoidal cross section and uniform invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a rating curve at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections. This problem tests the SOCH option of holding a given stage until a certain discharge occurs at the downstream boundary of a channel defined by the SOCH variable KSPL. This option also affects the receding side of the hydrograph.

The geometry used is the same as that in Test Problem 4 , shown in Figure 7, the upstream boundary condition is shown in Table 13, and the downstream boundary condition is shown in Table 14.

Table 13. Prescribed boundary conditions in Test Problem 19

Upstream boundary condition	
Time (hr)	Flow (cfs)
0	30,000
90	30,000
96	75,000
102	30,000
108	100,000
114	30,000
120	500,000
126	30,000

Table 14. Downstream Boundary Rating Curves used in Test Problem 19

Downstream Rating Curve			
HEC-RAS		SOCH	
Stage (ft)	Flow (cfs)	Stage (ft)	Flow (cfs)
64.99	30,000	60	30,000
65.00	250,000	65	250,000
100.00	500,000	100	500,000

In SOCH, the KSPL option is used and it is specified that the stage be held at the downstream boundary at the elevation of 65 ft until the discharge reaches 250,000 cfs. In HEC-RAS this effect is built-in in the Rating Curve for the downstream boundary.

4.2.7.2 Test Problem 20

Unsteady-state flow in a prismatic channel, i.e. a channel with uniform trapezoidal cross section and uniform invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a rating curve at the downstream end. The geometry of the channel is defined at 41 equally spaced cross sections. This test problem tests the SOCH option of holding a given discharge until a certain stage occurs at the downstream boundary of a channel defined by the SOCH variable LSPL. This option also affects the receding side of the hydrograph.

The geometry used is the same as that in Test Problem 4, shown in Figure 7, the upstream boundary condition is shown in Table 15, and the downstream boundary condition is shown in Table 16.

Table 15. Prescribed upstream boundary condition in Test Problem 20.

Upstream boundary condition	
Time (hr)	Flow (cfs)
0	30,000
24	30,000
30	500,000
36	10,000
48	10,000

Table 16. Downstream Boundary Rating Curves used in Test Problem 20

Downstream Rating Curve			
HEC-RAS		SOCH	
Stage (ft)	Flow (cfs)	Stage (ft)	Flow (cfs)
60.00	30,000	60.00	30,000
65.00	30,000	65.01	50,000
65.01	50,000		
100.00	500,000	100.00	500,000

In SOCH, the LSPL option is used and it is specified that the flow be held at the downstream boundary at the discharge of 30,000 cfs until the stage reaches the elevation of 65 ft. In HEC-RAS this effect is built-in in the Rating Curve for the downstream boundary.

4.2.8 Unsteady Flow in Channels assuming failure at the downstream end.

4.2.8.1 Test Problem 21

This problem involves unsteady-state flow in a prismatic channel, i.e. a channel with uniform trapezoidal cross section and uniform invert slope. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a rating curve at downstream end. The geometry of the channel is defined at 41 equally spaced cross sections. This problem tests the SOCH option when the option of simulating a **partial** failure at the downstream boundary of the channel defined by the SOCH variable KTOTFL.

The geometry used is the same as that in Test Problem 4 , shown in Figure 7, the upstream boundary condition is shown in Table 17, and the downstream boundary condition is shown in Table 18.

Table 17. Prescribed boundary condition in Test Problem 21

Upstream boundary hydrograph	
Time (hr)	Flow (cfs)
0	30,000
48	30,000
54	500,000
60	30,000
168	30,000

Table 18. Downstream Boundary Rating Curves used in Test Problem 21

<table>
<tr><th colspan="6">Downstream Rating Curve</th></tr>
<tr><th colspan="2">HEC-RAS</th><th colspan="2">SOCH Table 1</th><th colspan="2">SOCH Table 4</th></tr>
<tr><th>Stage (ft)</th><th>Flow (cfs)</th><th>Stage (ft)</th><th>Flow (cfs)</th><th>Stage (ft)</th><th>Flow (cfs)</th></tr>
<tr><td>60.00</td><td>20,000</td><td>60.00</td><td>20000</td><td>77.97</td><td>460,264</td></tr>
<tr><td>77.97</td><td>460,264</td><td rowspan="2">100.00</td><td rowspan="2">1,000,000</td><td rowspan="2">80.00</td><td rowspan="2">1,000,000</td></tr>
<tr><td>80.00</td><td>1,000,000</td></tr>
</table>

In HEC-RAS, the downstream rating curve is a combination of tables 1 and 4 rating curves in SOCH, considering a given transition point.

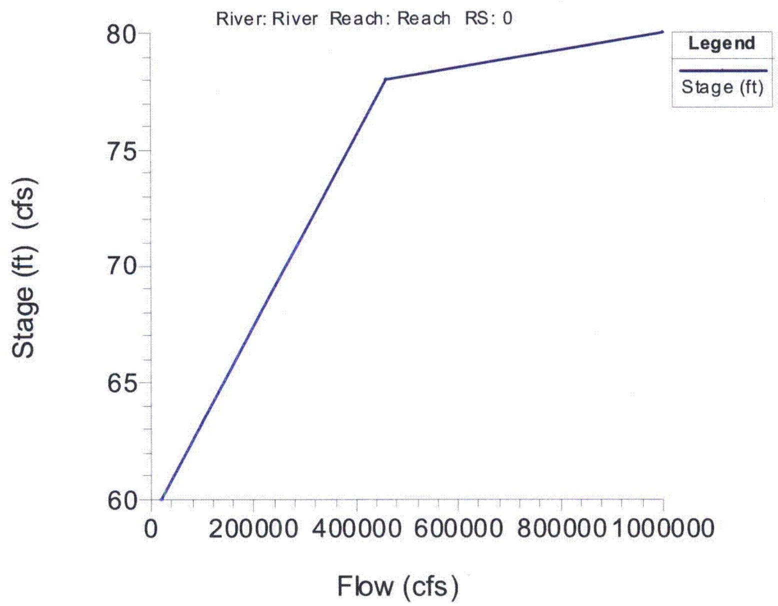


Figure 27. Composite rating curve used in HEC-RAS.

The partial failure in SOCH will be tested considering three distinct partial failure modes, namely, partial failure if the stage reaches the elevation of 77.97 ft, partial failure if the discharge reaches 460,264 cfs and partial failure at the time of failure obtained from the HEC-RAS solution. These three SOCH solutions should be in agreement between themselves and with the HEC-RAS solution using the combined Rating Curve shown in Table 18.

4.2.8.2 Test Problem 22

This test problem considers unsteady-state flow in a prismatic channel with trapezoidal cross section. Boundary conditions are a time-dependent discharge at the upstream end, in the form of a triangular hydrograph, and a stage hydrograph at the downstream end. The geometry of the channels is defined at 978 equally spaced cross sections. This test problem analyses SOCH solution when the option of simulating a total failure at the downstream boundary is used, defined when the SOCH variable KTOTFL is set equal to 1.

The geometry of the channel used in this test problem is shown in Figure 28 and the boundary conditions used in HEC-RAS are shown in Table 19. The inline structure used to represent the dam in this test problem is shown in Figure 29.

Main Characteristics:

- Reach length: 75.76 mi (400,000 ft)
- Reach longitudinal slope: 0.01%
- Cross section bottom width: 2,000 ft
- Bank slope: 2:1 (H:V)
- Distance between cross sections: 409 ft

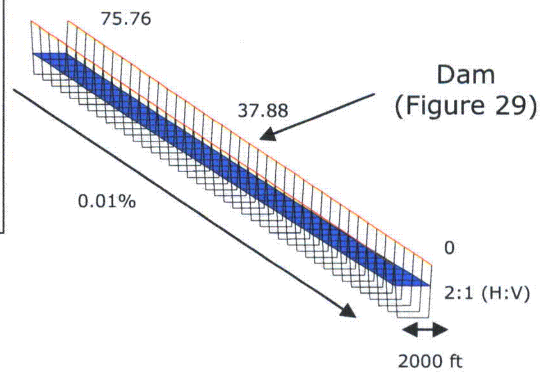


Figure 28. Test Problem 22

Table 19. Prescribed boundary condition in Test Problem 22

Boundary conditions			
Upstream		Downstream	
Time (hr)	Flow (cfs)	Time (hr)	Stage (ft)
0	30,000	0	40
48	30,000	48	40
54	500,000	54	40
60	30,000	60	40
168	30,000	168	40

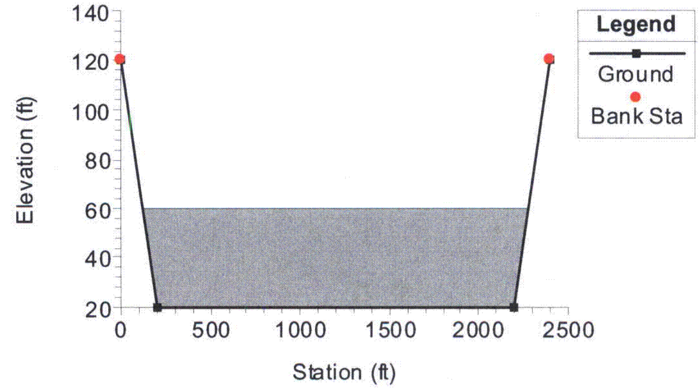


Figure 29. Dam used in Test Problem 22

To solve exactly the same problem with HEC-RAS as when the total failure option is used in SOCH, HEC-RAS is set up with the breach characteristics shown in Figure 30. It is considered an instantaneous failure, given that the breaching of the dam progresses in less than a second and this breaching time is smaller than the computational time step that will be used to run the simulation, in RAS and in SOCH.

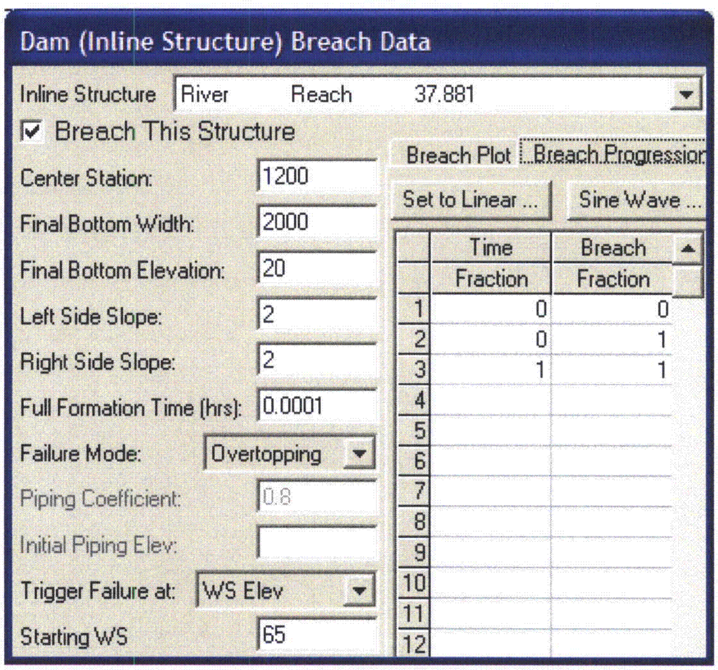


Figure 30. Stage triggered breach in RAS.

In this case, in SOCH it assumed that under a total failure scenario the flow is controlled by the first cross section downstream of the dam. Therefore there is no need to specify an additional rating table to represent the stage-discharge relationship after failure, but the downstream channel geometry must be defined.

To meet the above-mentioned requirement, the 75.76-mile long reach is split into two channels in SOCH, connected by a junction. A separate run will be conducted to ensure that these modifications do not affect the solution for a non-failure scenario.

The dam that fails is represented in HEC-RAS by the inline structure shown in Figure 29, located at RM 37.88 (location of the junction in SOCH). An auxiliary HEC-RAS run without breaching the inline weir is conducted to extract the rating curve that describes the hydraulic behavior of the structure without breaching. This represents the normal operation of the structure in SOCH for the entire pre-failure period. This is Rating Table 1 in SOCH, and is given in Table 20.

Table 20. Rating Table 1 used in SOCH.

Stage (ft)	Discharge (cfs)	Stage (ft)	Discharge (cfs)
63.049	29,989	63.420	35,656
63.054	30,070	63.525	37,300
63.055	30,090	63.659	39,457
63.059	30,145	63.834	42,309
63.062	30,185	64.058	46,118
63.065	30,235	64.351	51,261
63.070	30,299	64.745	58,304
63.075	30,381	65.260	68,107
63.082	30,485	65.480	72,431
63.091	30,618	65.950	82,015
63.099	30,787	66.881	102,166
63.116	31,004	68.165	132,318
63.134	31,281	68.870	150,086
63.159	31,635	69.901	177,355
63.191	32,089	72.424	250,235
63.225	32,673	72.733	259,801
63.277	33,424	73.711	290,956
63.317	34,050	73.742	291,939
63.340	34,396	---	---

To create the downstream channel required by SOCH, the 75.76-mile long reach is split into two channels in SOCH, connected by a junction at RM 37.88.

As mentioned above, in SOCH, the rating curve extracted from HEC-RAS shown in Table 20 is specified as the downstream boundary condition of the upstream channel. The upstream boundary condition of the downstream channel is not controlled and set to behave as a junction. The downstream boundary condition of the downstream channel and the upstream boundary condition of the upstream channel are the same as in HEC-RAS and are shown in Table 19.

An auxiliary run without breaching the weir will be conducted in SOCH to ensure that the inline structure is being properly represented in SOCH by Rating Table 1.

Three SOCH runs are set up for the different ways of describing the start of the dam failure, i.e. by defining the same stage, discharge or time of the failures. The results of these three SOCH runs will be compared against each other, and with the HEC-RAS solution.

4.2.9 Dam break problems

4.2.9.1 Test problem 23

This test problem considers the case of flow in a straight channel with prismatic rectangular channel (uniform cross section and uniform bottom slope) with a rapid increase of the flow entering the channel by a factor of 20, from 10,000 cfs to 200,000 cfs, which causes the propagation of a wave down the channel. The channel is 15.23 miles long and its slope is 0.000679. The Manning's n is 0.07 and the width of the rectangular channel cross section is 2000 ft. The bottom at the downstream end of the channel is at elevation 529.34 and at the upstream end it is at elevation 583.84 ft. Flow at the downstream end is controlled by the rating curve shown in Figure 31, which corresponds to normal flow at all depths.

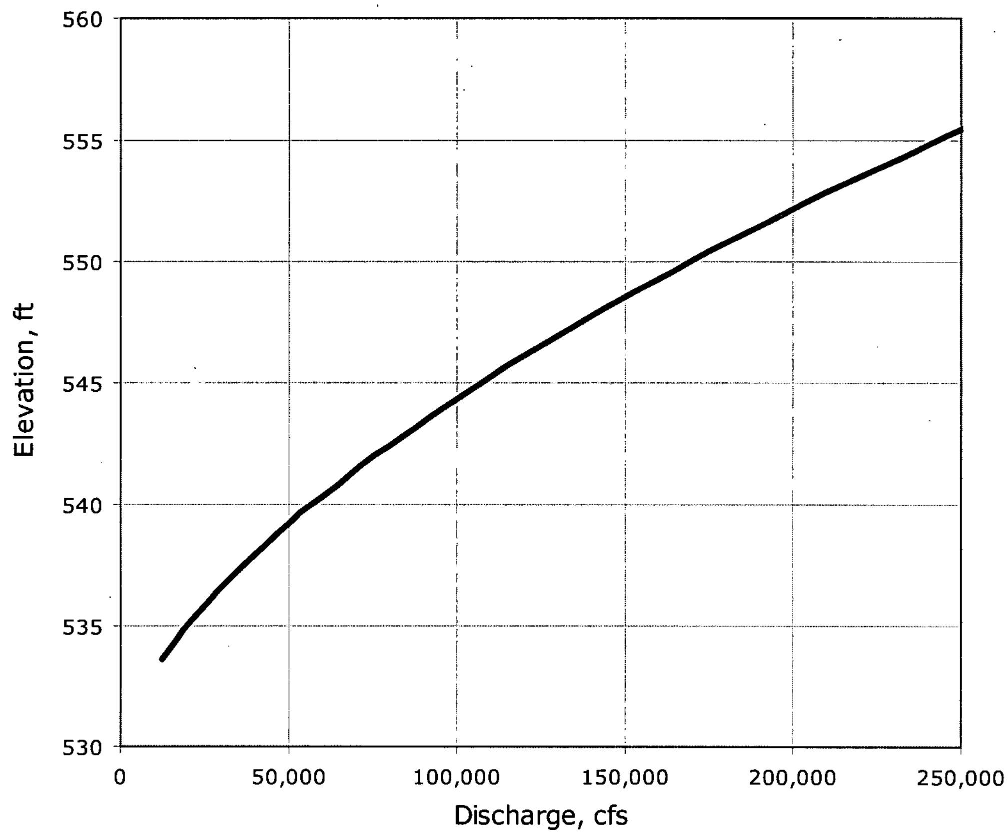


Figure 31. Rating curve defining the downstream boundary condition in Test problem 23

Initially the flow in the channel is uniform and steady, with discharge equal to 10,000 cfs. After 117 hours (a little under 5 days) of steady flow, the flow at the upstream end of the channel increases within 10 minutes from 10,000 to 200,000 cfs and is maintained at that level over the next 3 days, which is the remaining of the simulation period for this problem.

4.2.9.2 Test Problem 24

This test problem considers the case of routing a dambreak hydrograph in a straight trapezoidal prismatic channel (uniform cross section and uniform bottom slope). The channel is 15.23 miles long and its slope is 0.000679. The Manning's n is equal to 0.07 throughout the entire channel. The bottom width of the trapezoidal channel cross section is 2000 ft, and the side slopes are 2 to 1 (horizontal to vertical). The bottom at the downstream end of the channel is at elevation 529.34 and at the upstream end it is at elevation 583.84 ft. Flow at the downstream end is controlled by the rating curve shown in Figure 32. The values defining the rating curve plotted in Figure 32 are given in Table 21.

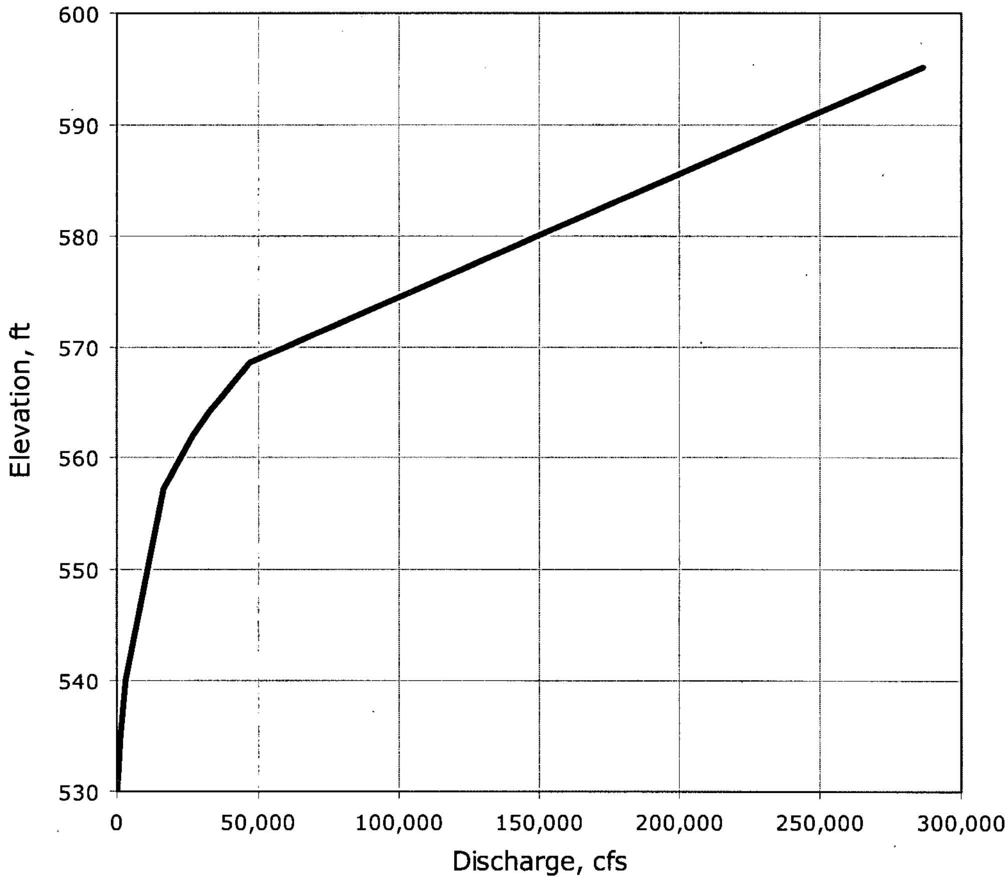


Figure 32. Rating curve defining the downstream boundary condition in Test Problem 24

Table 21. Rating curve at the downstream end of the reach

Stage (ft)	Discharge(cfs)
529.2	0.
535.0	1,000
540.0	3,000
557.3	16,500
562.1	27,000
564.1	32,500
568.6	47,000
581.9	166,930
595.2	286,860

Figure 33 shows the upstream flow hydrograph used in this problem.

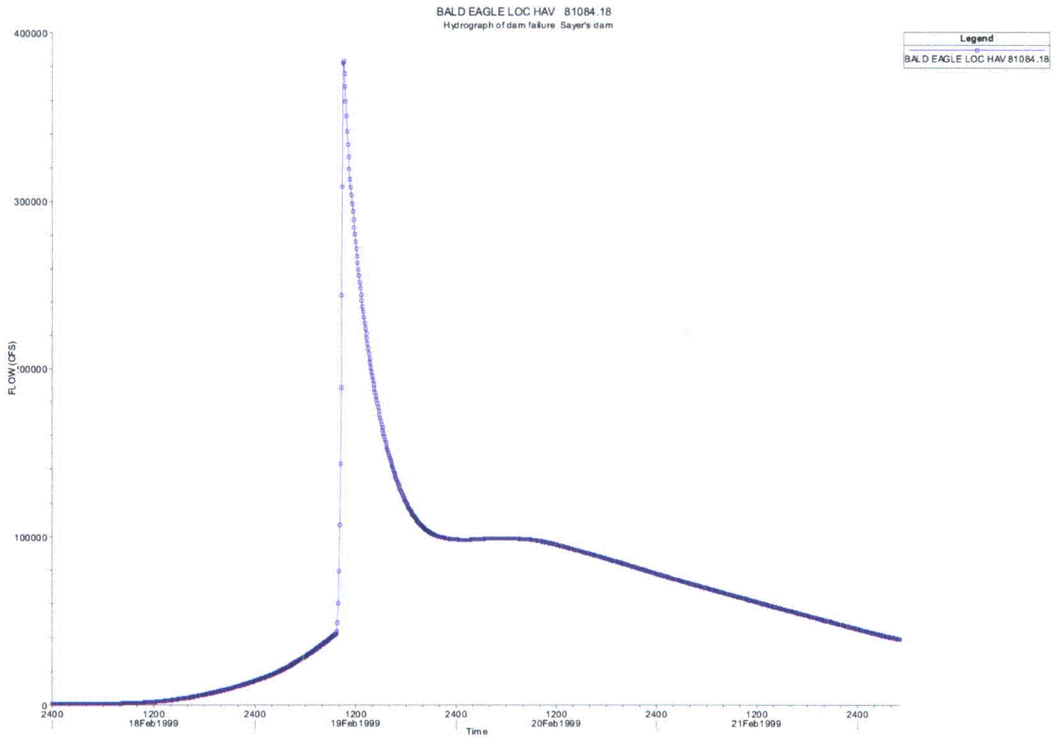


Figure 33. Hydrograph generated by the failure of Sayer's dam.

The flow hydrograph shown in Figure 33 is the flow hydrograph generated by the failure of Sayer's dam located in Bald Eagle Creek, Lock Haven, Pennsylvania. This problem using the actual channel geometry of Bald Eagle Creek is used as Test Problem 24. The rating curve shown in Figure 32, which is used in Test Problem 15, is also the rating curve controlling the flow at the downstream end of Bald Eagle Creek.

4.2.9.3 Test Problem 25

This test problem considers the case of routing of the unsteady-state flow generated by the failure of Sayer's dam located in Bald Eagle Creek, Lock Haven, Pennsylvania. This problem is taken from Reference 3 , which also compares the HEC-RAS solution of this problem with that produced by the code NWS-FLDWAV (Reference 4). The input data for this problem are available as an example distributed with the standard HEC-RAS package available from the U.S. Army Corps of Engineers (Reference 22).

The input data file for this problem that comes with the HEC-RAS package is very close but not exactly identical to the Sayer's Dam failure problem in Reference 4. To match the problem described in Reference 4 it is necessary to edit the input data file distributed with HEC-RAS to remove some extra features like bridges, hydraulic controls from the cross sections, ineffective flow areas and levees, etc. Figure 34 shows a typical cross section Bald Eagle Creek channel downstream of Sayer's Dam.

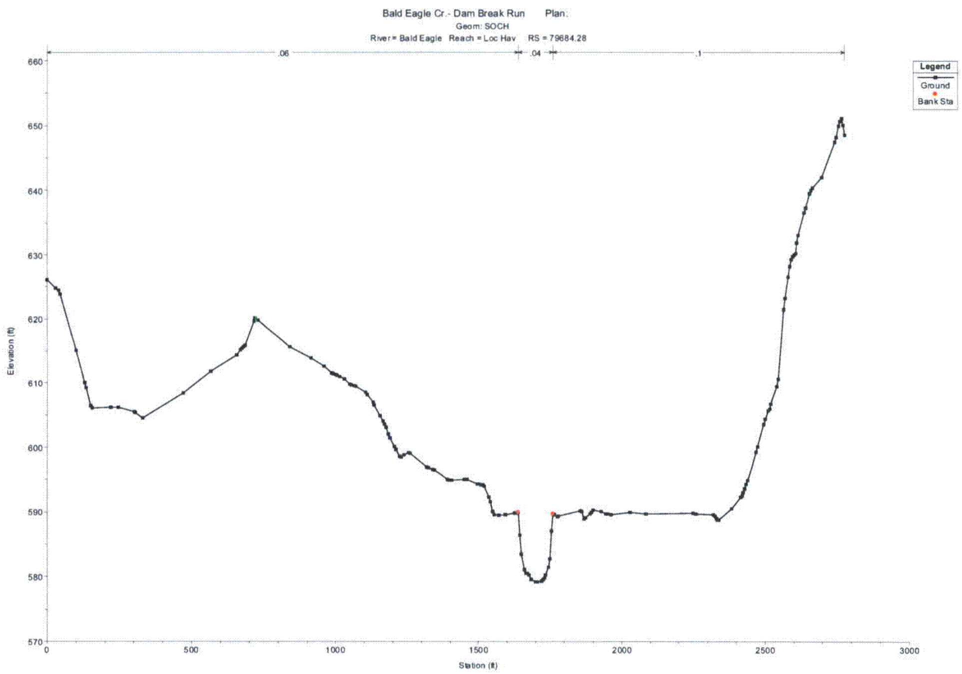


Figure 34. Typical cross section in Bald Eagle Creek

To ensure that both HEC-RAS and SOCH use the same upstream boundary condition for the solution of this problem, the hydrograph resulting from the failure of the dam at the first cross section immediately downstream of the dam is used as the upstream inflow hydrograph in SOCH. This hydrograph is shown in Figure 33.

Flow at the downstream end is controlled by the rating curve shown in Figure 32. The values defining the rating curve plotted in Figure 32 are given in Table 21.

This Test Problem also shows the possible implications of not considering the separate effect of friction forces in the main channel and floodplain in the solution of certain Dam Break scenarios. Thus two HEC-RAS simulations are set up. See Reference 7, page 35. At each cross section, one simulation considers the original high roughness coefficient variability between main channel and overbanks, Manning's n from 0.04 to 0.5, respectively, whereas the other resets the overbanks Manning's n values to a maximum of 0.1 (less variability between main channel and overbank).

All downstream reach lengths are set equal for main channel and overbanks to eliminate other possible sources of differences, described in the next test problem.

The results are again compared with the results reported in Reference 4 to ensure that the geometry illustrated in Figure 34, the upstream boundary condition shown in Figure 33 and the downstream boundary condition tabulated in Table 21, still recreate the original results.

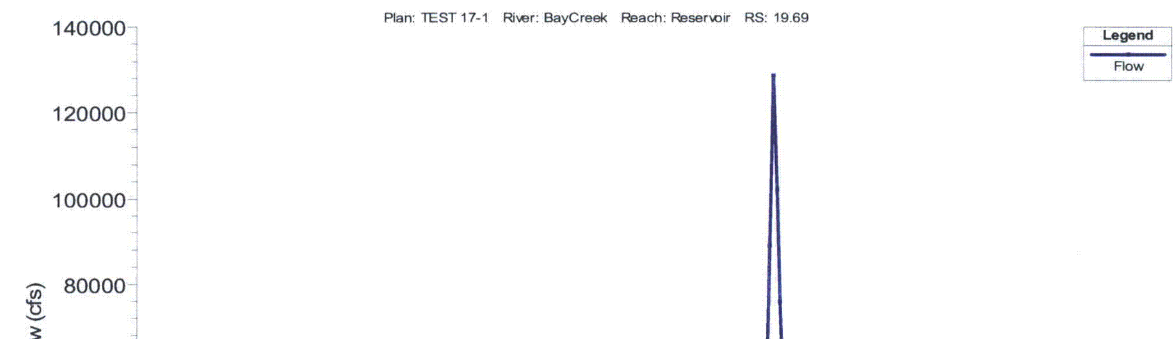
4.2.9.4 Test Problem 26

This test problem considers the case of routing of the unsteady-state flow generated by the failure of Big Bay dam located in Lamar County, Mississippi. This problem is taken from Reference 15. The input data for this problem were provided by the authors of Reference 15.

To ensure that both HEC-RAS and SOCH use the same upstream boundary condition for the solution of this problem, the hydrograph resulting from the failure of the dam at the first cross section immediately downstream of the dam was obtained by running HEC-RAS and saved for use as the upstream inflow hydrograph in SOCH.

This Test Problem also demonstrates the possible implications of not considering the sinuosity in the solution of certain Dam Break scenarios. Thus, two distinct HEC-RAS simulations were conducted. See Reference 7, page 29. One simulation considers the original different downstream reach lengths for main channel and overbanks whereas the second simulation resets the overbanks downstream reach lengths to the same values as for the main channel.

Figure 35 shows the upstream boundary condition and Table 22 defines the downstream boundary condition, used for this test problem by both HEC-RAS and SOCH.



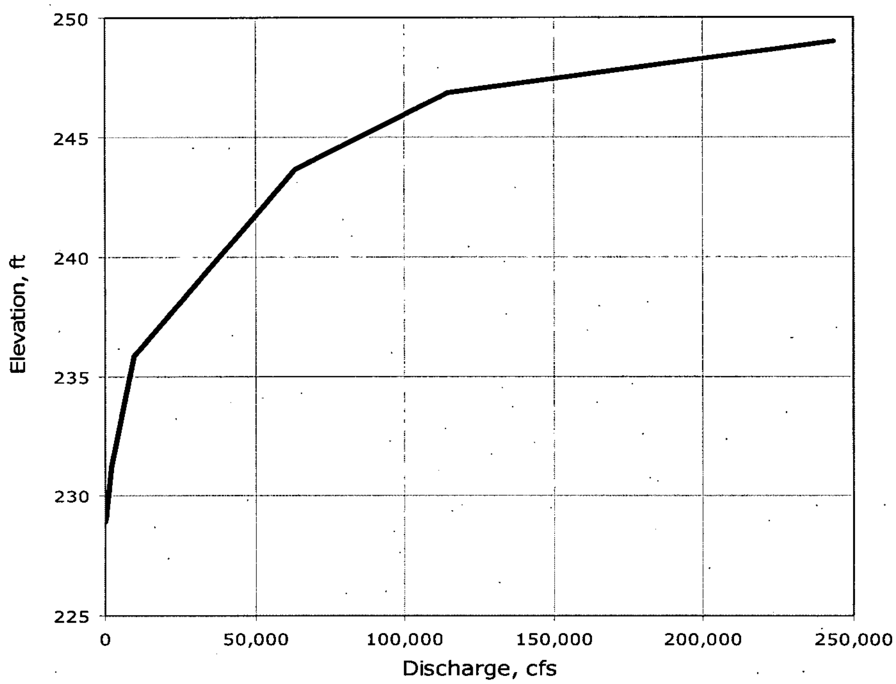


Figure 36. Downstream Rating curve used in Test Problem 26.

Table 22. Rating curve at the downstream end of the selected reach

Discharge(cfs)	Stage (ft)
0.000	228.890
468.515	229.218
471.056	229.230
481.483	229.250
541.592	229.398
797.506	229.945
2,095.022	231.230
9,744.426	235.885
63,175.360	243.674
114,551.400	246.874
243,315.600	248.989

4.2.9.5 Test Problem 27

This test problem considers the case of routing of the unsteady-state flow generated by the hypothetical failure of Norris dam on the Clinch River. The parameters and other data defining this problem were provided by TVA (Reference 18).

No modifications were required to the geometry data and upstream hydrograph generated by the dam failure. The downstream rating curve was extended through linear extrapolation and one additional stage-discharge data-pair was generated for high flows.

Figure 37 shows the inflow hydrograph generated by the hypothetical dam failure of Norris dam, which defines the upstream boundary condition of Test Problem 27. Table 23 gives the values of the rating curve that defines the downstream boundary condition for this test problem.

As a typical TVA application, this test problem offers also the opportunity to assess the implications of not considering an area weighted velocity distribution factor representative of the different friction forces acting on the fluid for the main channel and the overbank areas, as illustrated in Test Problem 25. It also tests the implications of not taking into account the effects of sinuosity by not carrying a separate conveyance weighted flow distribution for main channel and overbanks throughout the computations, as shown in Test Problem 26.

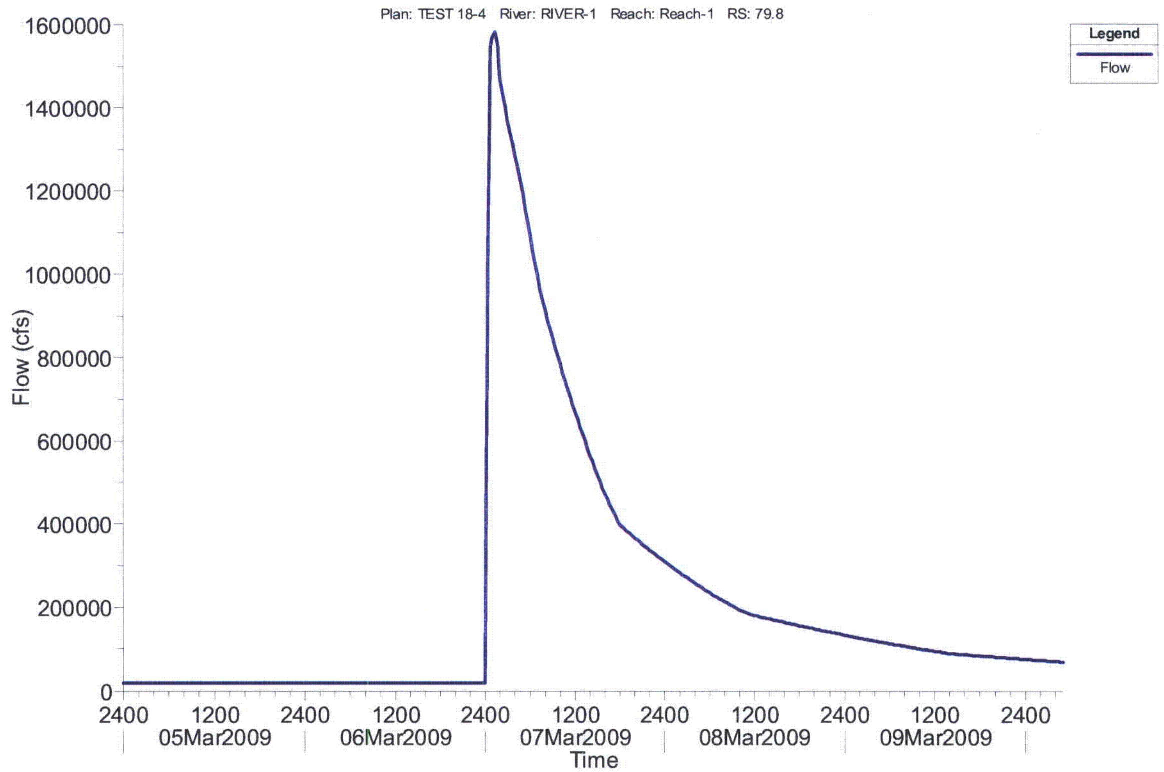


Figure 37. Hydrograph generated by the failure of Norris Dam.

Table 23. Rating curve at the downstream end of the channel of Test Problem 27

Stage (ft)	Discharge(cfs)	Stage (ft)	Discharge(cfs)
793.	0.	813.	210471.
794.	20000.	814.	222650.
798.	115955.	815.	235455.
800.	119973.	816.	248835.
800.4	120842.	816.5	255172.
802.	124310.	818.	277328.
803.	127957.	819.	292406.
804.	132726.	820.	307986.
804.9	137947.	822.	338986.
805.	138239.	824.	369986.
805.5	141184.	826.	400986.
806.	144683.	828.	431986.
807.	152121.	830.	462986.
808.	160308.	832.	493986.
809.	169141.	834.	524986.
810.	178555.	836.	555986.
811.	188504.	838.	586986.
811.7	195766.	840.	617986.
812.	199018.		

4.2.10 SOCH interpolation of irregular cross sections

4.2.10.1 Test Problem 28

This test problem uses the same geometry as Test Problem 27 , provided by TVA (Reference 18), and the same downstream rating curve shown in Table 23. In this problem the channel geometry is defined by 31 unequally spaced cross sections. The upstream inflow hydrograph used in this problem is shown in Figure 38. This hydrograph is of the order of the Probable Maximum Flood for this part of the TVA system.

Test Problem 28 tests the SOCH interpolation routine for natural channels with irregular geometry. Two simulations will be set up in SOCH. One of the simulations will require SOCH to interpolate 4 cross sections downstream of RM 51.00 and 6 cross sections downstream of RM 42.91 . The other simulation will have the interpolated cross sections, pre-computed externally, included in the geometry file,. Figure 39 illustrates the relative location of the interpolated cross sections. In Figure 39 one can observe that some of the interpolated cross sections are located in a positive slope of the river invert and some others are located in a negative slope of the river invert.

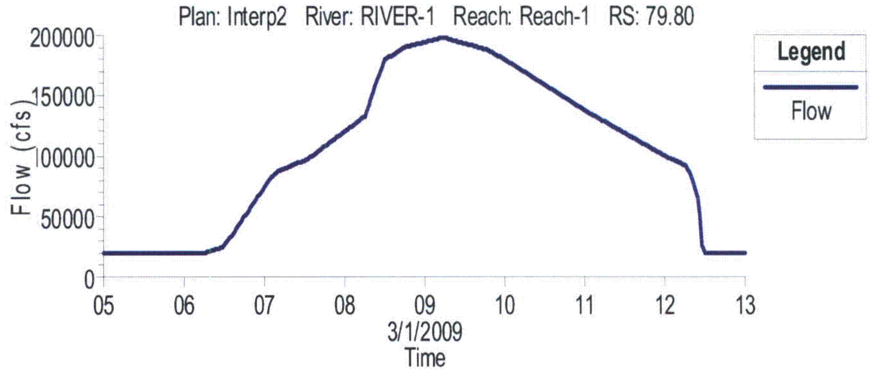


Figure 38. Upstream hydrograph used in Test Problem 28.

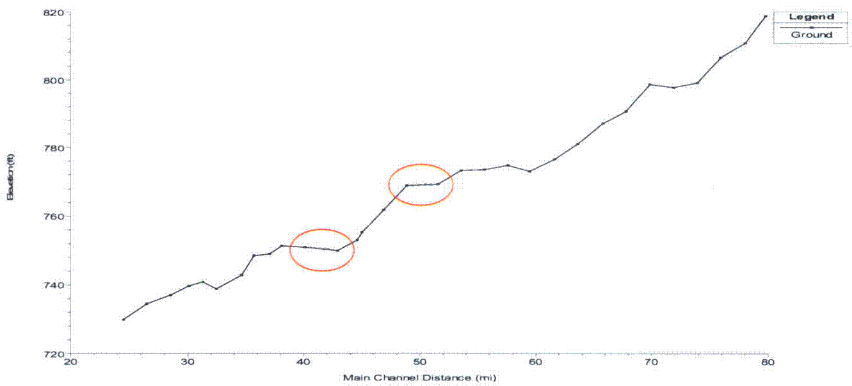


Figure 39. Location of the interpolated cross sections in Test Problem 28.

4.3 Results of the SOCH Test Plans

The detailed results of the implementation of the SOCH test plan must be presented in the SOCH Software Verification and Validation Report (SVVR).

5. REFERENCES

1. Chaudhry, M. H. (1993) "Open-Channel Flow", Prentice-Hall, Englewood Cliffs, NJ
2. Chow, V. T. (1959) "Open Channel Hydraulics", McGraw-Hill Book Company Inc., New York.
3. Gee, M.D. and G. Brunner, 2005: Dam Break routing using HEC-RAS and NWS-FLDWAV, presented at the ASCE/EWRI World Water & Environmental Resources Congress, Anchorage, Alaska, May 15-19, 2005.
4. Gee, M.D. and G. Brunner, 2005: Dam Break routing using HEC-RAS and NWS-FLDWAV, presented at the ASCE/EWRI World Water & Environmental Resources Congress, Anchorage, Alaska, May 15-19, 2005.
5. Hirsch, C. (1988) "Numerical Computation of Internal and External Flows", Vol. 1, Fundamentals of Numerical Discretization, J. Wiley and Sons, Chirchester
6. Hirsch, C. (1988) "Numerical Computation of Internal and External Flows", Vol. 1, Fundamentals of Numerical Discretization, J. Wiley and Sons, Chirchester
7. Hydrologic Engineering Center, HEC-RAS Application Guide Manual, Version 3.1, November 2002, U.S. Army Corps of Engineers, Davis, CA.
8. Hydrologic Engineering Center, HEC-RAS User's Manual, Version 3.1, November 2002, U.S. Army Corps of Engineers, Davis, CA.
9. Hydrologic Engineering Center; HEC-RAS Hydraulic Reference Manual, Version 3.1, November 2002; U.S. Army Corps of Engineers, Davis, CA.
10. Jain, S. C. (2001) "Open Channel Flow", J. Wiley and Sons, Inc., New York
11. Liggett, J. A. (1975) "Basic Equations of Unsteady Flow", Chapter 2 in Vol. 1, Unsteady Flow in Open Channels, Mahmood, K., and Yevjevich, V., Water Resources Publications, Ft. Collins, CO.
12. Liggett, J. A., and Cunge, J. A. (1975) "Numerical Methods of Solution of Unsteady Flow Equations," Chapter 4 in Vol. 1, Unsteady Flow in Open Channels, Mahmood, K., and Yevjevich, V., Water Resources Publications, Ft. Collins, CO.
13. Perkins, F. E. (1968) "The Role of Damping in the Stability of Finite Difference Techniques,", Meeting Preprint 689, ASCE National Meeting on Environmental Engineering, Chattanooga, TN, May 13-17.
14. Price, R. K. (1974) "Comparison of Four Numerical Methods for Flood Routing", J. Hyd. Div., ASCE, Vol. 100, No. HY7, July, pp. 879-899
15. Steven E. Yochum;Larry A. Goertz and Philip H. Jones, 2008: Case study of the Big Bay Dam Failure: Accuracy and Comparison of Breach Predictions, .
16. Sturm, T. W. (2001) "Open Channel Hydraulics", McGraw-Hill Book Co., Boston
17. TVA, 2008: SPP-2.6, Computer Software Control, Revision 12
18. TVA, 2009: Response to RFI 25447-000-GRI-GEX-00070, dated April 6, 2009 transmitting the required data for the dambreak analysis of a typical TVA dam (EDMS No. L58 090406 800).
19. TVA, 2009: User's Manual for DBREACH (EDMS No. L58090213002)

20. TVA, 2009: User's Manual for UNITGRAPH, FLDHYDRO, TRBROUT and CHANROUT (EDMS No. L58090325001)

21. TVA, 2009: User's User's Manual for CONVEYANCE and WTDWIDTH (EDMS No. L580903213001)

22. U.S. Corps of Engineers, HEC-RAS Download website http://www.hec.usace.army.mil/software/hec-ras/hecras-download.html accessed on March 20, 2009