

**USER'S GUIDE TO SAC, A COMPUTER PROGRAM FOR
COMPUTING DISCHARGE BY SLOPE-AREA METHOD**

U.S. GEOLOGICAL SURVEY

Open-File Report 94-360



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By Janice M. Fulford

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Open-File Report 94-360



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CONVERSION FACTORS

Multiply	By	To obtain
inch(in)	25.4	millimeter
foot(ft)	0.3048	meter
square foot (ft ²)	0.09290	square meter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second

USER'S GUIDE TO SAC--A COMPUTER PROGRAM
FOR COMPUTING DISCHARGE BY SLOPE-AREA METHOD

By Janice M. Fulford

ABSTRACT

This user's guide contains information on applying the slope-area computation program, SAC. SAC can be used to compute peak flood discharges from measurements of high-water marks along a stream reach. The slope-area method used by the program is based on the U.S. Geological Survey (USGS) procedure presented in Techniques of Water Resources Investigations of the U.S. Geological Survey, book 3, chapter A2, "Measurement of Peak Discharge by the Slope-Area Method". The program uses input files that have formats compatible with those used by the Water-Surface Profile (WSPRO) computer program. The guide briefly describes the slope-area method, documents the input requirements and the output produced, and demonstrates use of SAC.

INTRODUCTION

The slope-area computation program, SAC, was developed to provide a computer program to calculate discharge by the slope-area method that runs on a variety of available computers with no modifications to the program and that uses a data format that is compatible with other popular USGS hydraulic analysis programs. SAC is written in Fortran 77 and is based on an older slope-area computer program written by O.G. Lara in 1970 and modified by W. Kirby of the U.S. Geological Survey in 1987. SAC employs the basic technique presented in "Measurement of Peak Discharge by the Slope-Area Method" (Dalrymple and Benson, 1968).

SAC computes discharges from a user-prepared input file that uses WSPRO (Shearman, 1990) compatible formats. Use of WSPRO compatible data formats provides a simple and well-documented format in which to enter data that permits easy modification of SAC input files for use with the WSPRO program or easy modification of WSPRO input files for use with SAC. This user's guide describes SAC and contains information on using the program to compute peak discharges from measurements of high-water mark elevations and channel geometry. This guide does not explain in detail the proper application of the slope-area method or the computations used to determine cross-section geometric properties. The guide contains information on installing the program, general information on the slope-area method, information on program operation, and several examples that demonstrate program use. The user should be familiar with the slope-area method or refer to Dalrymple and Benson (1968) and texts on hydraulics such as French (1985, p. 182-185), Henderson (1966, p.365-381), or Petersen (1986, p.118-119) for more detailed information on properly applying the slope-area method and computing hydraulic properties.

INSTALLATION OF SLOPE-AREA COMPUTATION (SAC) PROGRAM

Depending on the computer used, the program files may be available either on tape, diskette or over a computer network. SAC files should be copied or transferred onto the computer's hard drive depending on the source of the files. The SAC files include the following:

README	File listing and update information.
SAC.EXE	Executable file (not available for all computer systems).
SAC.F	Source code. Contains the main program, and subroutines that compute the slope-area equations.
SHYDIE.F	Source code. Contains routines that compute hydraulic properties.
EXAMPLE1.DAT	Test data set, reach with level water-surface elevations in the cross sections.
EXAMPLE2.DAT	Test data set, super-elevated reach.
EXAMPLE3.DAT	Test data set, super-elevated reach with conveyance weighing of water-surface elevations.
EXAMPLE1.OUT	SAC output for EXAMPLE1.DAT.
EXAMPLE2.OUT	SAC output for EXAMPLE2.DAT.
EXAMPLE3.OUT	SAC output for EXAMPLE3.DAT.

The source-code file extension listed in the manual is commonly used by UNIX Fortran compilers and is not applicable for all Fortran F77 compilers. Many DOS Fortran compilers use .FOR for the source extension. The source file extension may vary depending on the computer system for which the program was requested. The readme file contains the latest information on the program and should be read before either installing or executing SAC. Regardless of the computer used, the steps required to install SAC are the same.

This section contains information on installing the program. Details on system requirements, transferring the program to new computer systems, and program testing are included.

System Requirements

SAC compiles, links, and runs successfully on IBM personal computers and compatibles (PC's), Macintosh personal computers, minicomputers, and mainframe computers. It does not use or require graphics capability, color monitor, or a mouse. Disk space of approximately one-quarter megabyte (Mbyte) is sufficient for the array sizes specified in this manual. Source code for the program is approximately 87 kilobytes (Kbyte). A typical executable file on an IBM compatible personal computer is 80 Kbytes. Additional disk space is needed for input, output, and temporary files.

Installing SAC on New Systems

If an executable file is available for the target computer system compiling and linking of the program files is not necessary and users can skip to the section on post-installation testing. SAC installs (compiles and links to produce an executable) with minimal effort on

most computers. The target computer should have a Fortran 77 compiler that adheres to the American National Standards Institute (ANSI) Fortran 77 standard (American National Standards Institute, 1978). Installation requires the user to compile and link the program on the target computer system. Familiarity with the compiler and linker on the computer is necessary before attempting to install the code.

Compiling the Source Code

Before attempting to compile the source, the user should review the readme file which contains the latest information on SAC. The source uses no include statements or common blocks. This should minimize the need to set compiler options. SAC installers should use the target computer's Fortran compiler to compile all the above files except for the readme and .dat and .out example files. The source filename extension (.F) is not compatible with every Fortran compiler and may require modification before compiling.

Linking

Successfully compiled files can be linked with the computer's linking facility. Compiled files should be linked in the following order: SAC, SHYDIE. The source has been compiled and linked successfully with Microsoft Fortran version 5.0 (DOS), Greenhills Fortran-88000 version 1.8.6 (UNIX), and MacFortranII (MAC OS).

Post-Installation Testing

The newly created or existing SAC executable file can be tested with one of the supplied example data sets by running SAC. The commands required to run the program (or executable file) are dependent on the computer system. For a personal computer or a workstation such as a Data General AViiON™ 300, entering the program name, SAC, will start the program. Users should enter one of the example data-set names after the query for data file. Additionally, users should enter an output file name and title header for the output after the appropriate queries. The results for each example data set are listed in the Examples section of this guide.

Program Array Sizes

SAC allows up to 30 cross-sections. Each cross-section may have up to 20 subareas and 150 coordinates. Array sizes for the number of cross-sections and subareas can be changed in the source code. Changing array sizes requires editing the source code and recompiling and linking of the source code. Resizing the arrays requires an understanding of Fortran programming.

DESCRIPTION OF THE SLOPE-AREA METHOD

The slope-area method (Dalrymple and Benson, 1967) is a common technique used to determine peak discharges from measurements of high-water marks. This technique is called an indirect measurement of discharge because direct measurement of flow velocities (usually by current meter) is not used to determine discharge. The slope-area method is based on one-dimensional gradually varied, steady flow equations. In nature, flows rarely achieve steady flow. Flood flows especially are spatially and temporally varied. However, these variations are usually considered to be small enough so that the flow can be approximated with the gradually-varied steady flow equations to sufficient accuracy for most purposes.

The slope-area method uses the conservation of energy (Bernoulli equation) and mass (continuity equation) and the normal-flow equation (Manning's equation) to determine discharge. The equation for the conservation of energy between the end sections of a simple reach as illustrated in figure 1 is

$$h_1 + \frac{\alpha_1 V_1^2}{2g} = h_2 + \frac{\alpha_2 V_2^2}{2g} + h_{f_{1-2}} + h_{e_{1-2}} \quad , \quad (1)$$

where h_1 and h_2 are water-surface elevations at sections 1 and 2; V_1 and V_2 are mean velocities at sections 1 and 2; α_1 and α_2 are the velocity-head coefficients at sections 1 and 2; g is the acceleration of gravity; h_f is the friction loss; and h_e is the energy loss due to contraction or expansion of the flow. The velocity-head coefficient, α , assumed for unsubdivided cross sections is 1.0. For subdivided cross sections, the velocity coefficient is computed as

$$\alpha = \frac{\sum_{i=1}^{nsa} \frac{K_i^3}{A_i^2}}{\frac{K^3}{A^2}} \quad , \quad (2)$$

where K_i and A_i are the conveyance and area of the i th subarea; nsa is the number of subareas; K and A are the conveyance and area for the cross section. Conveyance in cubic feet per second (ft^3/s) is computed using foot-second units from $K = \frac{1.49}{n} A R^{\frac{2}{3}}$, where n is Manning's coefficient of roughness, A is the cross section area, and R is the hydraulic radius in feet. The friction loss term is computed using Manning's equation as

$$h_{f_{1-2}} = \frac{Q^2 L}{K_1 K_2} \quad , \quad (3)$$

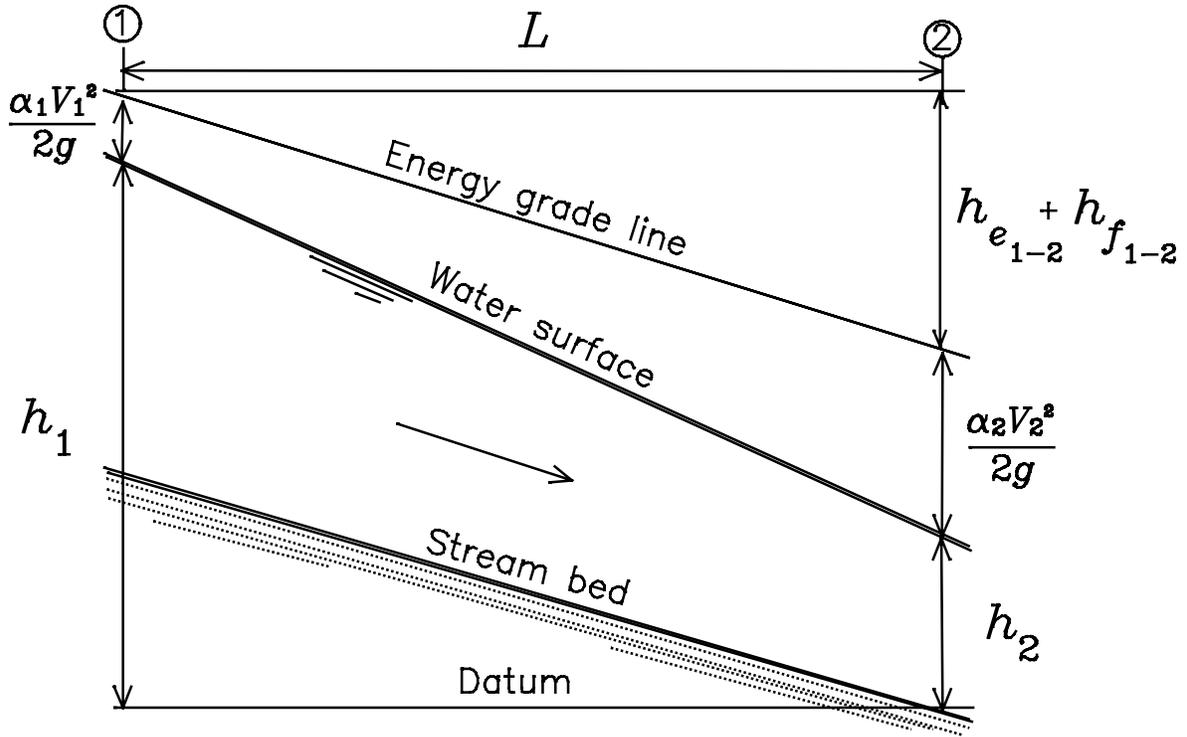


Figure 1. Definition sketch of a slope-area reach. L is the reach length; h_1 and h_2 are water-surface elevations at sections 1 and 2; V_1 and V_2 are mean velocities at sections 1 and 2; α_1 and α_2 are the velocity-head coefficients at sections 1 and 2; g is the acceleration of gravity; h_f is the friction loss; and h_e is the energy loss due to contraction or expansion of the flow.

where Q is the discharge in the reach in ft^3/s , L is the reach length in feet, and K_1 and K_2 are the conveyances in ft^3/s at sections 1 and 2. The energy loss due to contraction or expansion of the flow is computed as

$$h_{e_{1-2}} = k \left(\frac{\alpha_1 V_1^2}{2g} - \frac{\alpha_2 V_2^2}{2g} \right), \quad (4)$$

where k is the coefficient for energy losses due to expansion or contraction of the flow. The coefficient k is assumed to equal 0.5 for expanding reaches, and 0 for contracting reaches. A reach is defined as expanding if $(A_2/\sqrt{\alpha_2}) > (A_1/\sqrt{\alpha_1})$ and contracting if $(A_2/\sqrt{\alpha_2}) < (A_1/\sqrt{\alpha_1})$.

Equation (1) can be applied to multiple subreaches over the reach and solved for discharge, as is done in the program SAC. The resulting discharge equation (Dalrymple and Benson, 1967) is

$$Q = K_m \sqrt{\frac{\Delta h}{A+B}} \quad (5)$$

where

$$A = K_m^2 \frac{L_{1-2}}{K_1 K_2} + K_m^2 \frac{L_{2-3}}{K_2 K_3} + \dots + \frac{K_m^2 L_{(m-2)-(m-1)}}{K_{(m-2)} K_{(m-1)}} + \frac{K_m^2 L_{(m-1)-m}}{K_{(m-1)} K_m} \quad (6)$$

and

$$B = \frac{K_m^2}{A_m^2 2g} \left[-\alpha_1 \left(\frac{A_m}{A_1} \right)^2 (1-k_{1-2}) + \alpha_2 \left(\frac{A_m}{A_2} \right)^2 (k_{2-3} - k_{1-2}) + \alpha_3 \left(\frac{A_m}{A_3} \right)^2 (k_{3-4} - k_{2-3}) + \dots \right. \\ \left. + \alpha_{(m-1)} \left(\frac{A_m}{A_{(m-1)}} \right)^2 (k_{(m-1)-m} - k_{(m-2)-(m-1)}) + \alpha_m (1 - k_{(m-1)-m}) \right] \quad (7)$$

and where Δh , the fall, is the difference in water-surface elevation at two end sections; m is the number of cross sections in the reach, A_m is the cross-section area of cross-section m ; g is the acceleration of gravity; L is length of reach between two cross-sections indicated by the subscripts; K_m is the conveyance of cross-section m ; α_m is the velocity head coefficient; and k is the coefficient of energy loss (for expanding reach $k=0.5$, for contracting reach $k=0$).

When water-surface elevations vary in a cross section, the fall is computed from the average water-surface elevation. The average can be computed as the mean of the right and left bank water-surface elevations. It can also be computed by using conveyance weighing from

$$\bar{h} = \frac{\sum_{i=1}^{nsa} K_i h_i}{K} \quad (8)$$

where \bar{h} is the conveyance weighted water-surface elevation for a cross section, h_i and K_i are the width-weighted water-surface elevation and the conveyance for the i th subarea, and K is the total conveyance for the cross section.

Additionally SAC computes diagnostic terms that are printed in the output. These include the total friction head for multiple subreaches,

$$HF = Q^2 \sum_{j=1}^{m-1} \frac{L_{j-(j+1)}}{K_j K_{j+1}}, \quad (9)$$

where j is the index for the cross section and m is the number of cross sections in the reach; the spread in percent,

$$SPREAD = 100 \times \frac{(Q_0 - Q_1)}{Q_1}, \quad (10)$$

where Q_0 is the discharge computed with no expansion or contraction losses ($k=0$) and Q_1 is the discharge computed with full expansion losses ($k=1$); CX , the ratio of the computed discharge divided by the discharge computed with no expansion loss ($k=0$),

$$CX = \frac{Q}{Q_0}, \quad (11)$$

RC , the ratio of the velocity head change in contracting subreaches divided by the friction head,

$$RC = \frac{\sum_{j=1}^{m-1} h_{e(c)j-(j-1)}}{\sum_{j=1}^{m-1} \frac{L_{j-(j+1)}}{K_j K_{j+1}}} \quad (12)$$

where $h_{e(c)j-(j-1)}$ is computed for contracting subreaches from equation (4); and RX , the ratio of the velocity head change in the expanding sections divided by the friction head,

$$RX = \frac{\sum_{j=1}^{m-1} h_{e(x)j-(j+1)}}{\sum_{j=1}^{m-1} \frac{L_{j-(j+1)}}{K_j K_{j+1}}} \quad (13)$$

where $h_{e(x)j-(j-1)}$ is computed for expanding sections from equation (4). The terms, HF, RC, and RX, are related to the discharge by the energy equation. Solving the energy equation (equation 1) for discharge using the terms HF, RC, and RX yields,

$$Q = \left[\frac{\Delta h}{\frac{HF}{Q^2} \left(1 + \frac{1}{2gHF} \sum_{j=1}^m \left(\frac{\alpha_j}{A_j^2} - \frac{\alpha_{j-1}}{A_{j-1}^2} \right) - k_c RC + k_x RX \right)} \right]^{\frac{1}{2}} \quad (14)$$

where k_c and k_x are the contraction and expansion loss coefficients, respectively. The form of equation 14 is mathematically equivalent to equation 5. However, the form of equation 14 makes evident the effect of velocity-head changes on the computed discharges.

For a presentation of the method's hydraulic principles and computations and evaluation of results, see Dalrymple and Benson (1967). An error analysis of the slope-area method and a detailed derivation of the slope-area equations are presented by Kirby (1987).

OPERATION OF PROGRAM

The preparation of an input file containing the data necessary for slope-area computations is required before the program can be executed. The necessary data are the cross-section data that adequately describe the flow geometry of an appropriate reach. Specifically, the data include the reach length, the water-surface elevation for each measured cross section in the reach, and an estimate of the roughness of the reach. Benson and Dalrymple (1967) present data collection procedures for indirect measurements. Dalrymple and Benson (1967) discuss the selection of an appropriate reach and the measurement procedures.

The input data are formatted as WSPRO (Shearman, 1990) input records. The first 10 columns of a record are reserved for fixed-field format. Columns 11 through 80 are available for free-field format. Data items entered in free-field format are separated by either a comma, one or more blank spaces, or any combination of blanks and a comma. Null values must be specified unless they occur at the end of the list of the data items entered on the record. Null values are specified by either an asterisk or two successive commas. Any text editor that produces ASCII files may be used to create the input file.

Input File

Required input data for each cross section include, water-surface elevation(s), location of the cross section from an arbitrary horizontal reference, estimates of roughness and cross-section geometry data. Cross-section geometry data include x, y coordinate pairs that define the shape of the cross-section and the location of subarea divisions that define areas of similar roughness or geometry. Input data is required to be in foot-second units and all elevations in the input file must be referenced to a common elevation datum.

Only a few WSPRO (Shearman, 1990) records are actually used as input to SAC. These records are XS, GR, N, ND, SA, XT, GT, T1, T2, T3, and HP. Other WSPRO records in the input file are ignored by the program and do not effect SAC execution. This allows the use of existing WSPRO files with limited editing.

Geometry and roughness data for each cross section in the reach are entered in the appropriate WSPRO record format (XS, GR, N, SA, and ND). For a cross section with a constant or level water surface, the water-surface elevation is entered on the HP record. (Because SAC uses tables of hydraulic properties, the HP record is used.) For a cross section

*TT	(specify conveyance weighing of water elevations)
T1	(WSPRO title record)
T2	(WSPRO title record)
T3	(WSPRO title record)
XS	(WSPRO cross-section header record for most downstream section)
*ID	(extra section identifier)
GR	(WSPRO x, y coordinate pairs record)
N	(WSPRO roughness record)
ND	(WSPRO roughness depth record)
SA	(WSPRO subarea locations record)
HP	(WSPRO hydraulic properties table record)
XS	(WSPRO cross-section header record for next upstream section)
GR	(WSPRO x, y coordinate pairs record)
N	(WSPRO roughness record)
ND	(WSPRO roughness depth record)
SA	(WSPRO subarea locations record)
HP	(WSPRO hydraulic properties table record)

Figure 2. Typical SAC input data sequence.

with a varying water surface (left bank and right bank water-surface elevations are different) the variation of water-surface elevation is entered as pairs of station and elevation coordinates with the station and ground-elevation coordinates of the cross section on the GR record.

SAC computes water-surface fall between cross sections from the information on the HP record for cross sections with constant water-surface elevation and from the average of the right and left bank water-surface elevations for cross sections with varying water-surface elevations unless conveyance weighing is specified. When conveyance weighing is specified, SAC computes falls using the cross-section water-surface elevations that are conveyance weighted averages of subarea water-surface elevations (equation 8).

The cross-section information is placed in downstream to upstream order in the input file. Sufficient cross sections should be entered that adequately describe the geometry and roughness variations in the reach.

The general order of input records for the slope area program is an optional conveyance weighing record (*TT) followed by the WSPRO records. The WSPRO records include T1, T2, and T3 which specify output titling, XS, GR, SA, N, and ND which specify cross-section geometry and roughness, and HP records. A typical input data sequence is listed in figure 2.

As for WSPRO, cross-section information from the previous downstream section may be propagated to successive cross sections using XS, GT, and XT WSPRO records. Data propagated to subsequent sections for which little or no survey data exists can include geometry and roughness values. Normally, data for cross sections are obtained from field surveys of the cross section (Benson, Dalrymple, 1976, p.13) The use of propagated cross

sections for slope-area computations is not documented by Dalrymple and Benson (1967) or in this user's guide and is not recommended except for special circumstances. The addition of propagated cross sections to a slope-area reach will not improve the solution unless the water-surface slope or channel slope changes in the reach between the measured cross sections. Because the slope-area equations are solved assuming water-surface elevations are known at all cross sections, propagated cross sections should not be located where the water-surface elevation cannot be defined from nearby high water marks. See Shearman (1990) for examples of using these records to propagate cross sections.

The following sections describe in alphabetical order the XS, GR, N, ND, SA, T1, T2, T3, and HP WSPRO records and the *TT and *ID records used by the slope-area program. Comments may be inserted into the input file by using an * and blank in the first two columns of the comment record. Shearman (1990) presents a complete description of all WSPRO records and instructions on using those records to describe cross-section geometry.

GR Record

Purpose: Specifies the x,y coordinates that define the shape of the cross-section. This record can also be used to describe the water-surface elevations along with the shape of the cross sections for cross sections where the water-surface elevations are not level. Cross sections with level and sloping water surfaces may be mixed together in the same input file. All elevations in the input file must be referenced to a common elevation datum.

Format:

<u>Column</u>	<u>Format</u>	<u>Contents</u>
1-2	A2	GR
3-10	8X	blank
11-80	free	$X(1), Y(1), X(2), Y(2), \dots, X(N), Y(N)$

Definition of variables:

The parenthetical notation indicates the order number, i , assigned by the program to each x,y coordinate pair. For the first pair, $i=1$, and, for the last pair, $i= N$. The number of coordinate pairs, N , must be less than or equal to 150.

$X(i)$ Station, in feet, from an arbitrary origin on the left bank (facing downstream) specified for the i th station.

$Y(i)$ Ground elevation, or water-surface elevation specified at the i th station in feet above common elevation datum.

To specify a cross section with a level water surface, enter x, y coordinates that describe the ground shape of the cross section from left to right (counter-clockwise). Each successive x-coordinate must be equal to or greater than the previous x-coordinate. Edges of water are determined by the program from the elevation entered on the HP record.

To specify a cross section with a varying water surface, x, y coordinates are entered that describe the shape enclosed by the channel geometry and the water surface. The x, y coordinates of the left and right edge of water must be included in the list of x, y coordinates

entered. Enter the x, y coordinates in counterclockwise order, starting with the high-water mark coordinate pair at the water's edge that has the smallest valued x-coordinate (or station). This pair is followed by coordinate pairs that describe the channel shape and then by the coordinate pair for the high-water mark at the opposite water edge. If desired, additional coordinates can be entered next to describe any changes in water-surface elevations between the two edges of water. Close the figure by making the first and last coordinate pairs the same. In general, each successive high-water mark coordinate or x ground coordinate must be equal to or greater than the previous x-coordinate and each successive x-coordinate used to describe water-surface in the cross section must be less than or equal to the previous x-coordinate.

Any additional coordinates entered to describe the water-surface elevation between the two edges of water are always used to compute cross-section properties. However, these coordinates are used to compute fall between cross sections only when conveyance weighing is requested. The SAC program will compute the fall through the subreach using the average water-surface elevations of the two banks as the water-surface elevation for the cross section unless conveyance weighing is specified. If conveyance weighing is specified (refer to *TT record) the fall is computed using the conveyance weighted average of cross-section subarea water-surface elevations. WSPRO does not allow on GR records the inclusion of x, y coordinates that describe the water-surface elevations. Therefore, SAC input files with GR records describing enclosed sections will not be suitable for WSPRO execution without appropriate modifications.

HP Record

Purpose: Specifies the water-surface elevation at which the hydraulic properties for a cross section are computed. For cross sections with a level or constant water surface, the elevation specified is the water-surface elevation for that cross section. This record is not needed for sections with varying water-surface elevations. HP records can follow other records that describe a cross section or they can be grouped at the beginning or end of the file. If grouped at the beginning or end of the file, order HP records like the cross sections in the input file.

Format:

<u>Column</u>	<u>Format</u>	<u>Contents</u>
1-2	A2	HP
3	1X	blank
4	I1	4
5	1X	blank
6-10	A5	SECID
11-80	free	WSEL

Definition of variables:

SECID Section identification code. This code is required by the slope-area code regardless of where in the input file the record is placed.

WSEL The water surface elevation in feet at the cross section specified by the **SECID**. For cross sections with level-water surfaces, this value is the water-surface elevation that is

used in the computation of fall in the reach as well as the elevation at which the hydraulic properties are computed.

***ID Record**

Purpose: Provides input of a 16 character identifier for a cross section. Should be placed after the XS record in the input file.

Format:

<u>Column</u>	<u>Format</u>	<u>Contents</u>
1-3	A2	*ID
4-5	3X	blanks
6-21	A5	BIGID

Definition of variables:

BIGID Unique cross section identification code of up to sixteen characters. Used in addition to the *SECID* on the XS records.

N Record

Purpose: Specifies Manning's coefficient of roughness, n, for a cross section.

Format:

<u>Column</u>	<u>Format</u>	<u>Contents</u>
1-2	A2	N
3-10	8X	blank
11-80	free	either <i>NVAL(1) [, NVAL(2)... NVAL(nsa)]</i> or <i>BOTN(1), TOPN(1) [, BOTN(2), TOPN(2)... BOTN(nsa), TOPN(nsa)]</i>

Definition of variables:

The parenthetical notation indicates the subarea to which the roughness coefficient is applicable. For the left-most subarea, $i=1$, and for the right-most subarea, $i=nsa$ (number of subareas, $nsa \leq 20$). The first coding option must be used when roughness values do not vary with depth. Only one roughness coefficient value is needed for each subarea. For slope-area computations, only one roughness coefficient is usually assigned to a subarea. The roughness coefficient used should be for the depth of flow indicated by high-water marks and for flow conditions at the time of the flow.

NVAL(i) Roughness coefficient (Manning's coefficient of roughness, n) applicable to the full depth of the i th subarea.

The second coding option is used when the values vary with depth. ND records specifying the depths must be coded when this option is used. A pair of roughness coefficients is coded for each subarea.

BOTN(i) Roughness coefficient applicable to the depths equal to and less than the lower depth specified for the *i*th subarea on the ND record.

TOPN(i) Roughness coefficient applicable to the depth equal to and greater than the upper depth specified for the *i*th subarea on the ND record.

ND Record

Purpose: Specifies the depth breakpoints for vertical variation of roughness coefficients (Manning's coefficient of roughness, *n*). Used in conjunction with the N record.

Format:

<u>Column</u>	<u>Format</u>	<u>Contents</u>
1-2	A3	ND
3-10	8X	blank
11-80	free	BOTD(1), TOPD(1) [, BOTD(2), TOPD(2),... BOTD(<i>nsa</i>), TOPD(<i>nsa</i>)]

Definition of variables:

The parenthetical notation indicates the subarea to which the depths are applicable: *i*=1 for the left most subarea and *i=nsa* for the right most subarea (*nsa*≤20).

BOTD(i) Hydraulic depth (area divided by top width) in the *i*th subarea at or below which the roughness coefficient BOTN (specified for the *i*th subarea in the N record) is applicable.

TOPD(i) Hydraulic depth in the *i*th subarea at or above which the roughness coefficient of TOPN(*i*) (specified for the *i*th subarea in the N record) is applicable.

The program uses the roughness coefficient that is applicable for the water-surface elevation specified by either the HP or GR records. Values of roughness for the depths between BOTD and TOPD are determined by straight line interpolation.

SA Record

Purpose: Specifies the horizontal breakpoints for subdivision of a cross section for roughness or geometric variation.

Format:

<u>Column</u>	<u>Format</u>	<u>Contents</u>
1-2	A2	SA
3-10	8X	blank
11-80	free	XSA(1), XSA(2), ..., XSA(<i>nsa</i>-1)

Definition of variables:

The parenthetical notation indicates the subarea number, *i*, assigned by the program to each subarea of a cross section. *i*=1 for the left most subarea and *i=nsa* for the rightmost subarea (*nsa*≤20). The number of breakpoints entered is always one less than the number of subareas.

For cross sections without subdivisions no SA record is entered.

XSA(i) The horizontal coordinate, or station in feet, of the rightmost limit of the *i*th subarea.

T1, T2, T3 Record

Purpose: Specifies the title information for identification of SAC output.

Format:

<u>Column</u>	<u>Format</u>	<u>Contents</u>
1-2	A2	T1, T2, or T3
3-10	8X	blank
11-80	A69	<i>Any alphanumeric string.</i>

Discussion:

Information entered on T1, T2, or T3 records are printed on every page of output except when the input data is echoed. These records should be entered only once in the input file.

***TT Record**

Purpose: Optional; specifies the type of weighing to use to determine water-surface elevations used in computing falls.

Format:

<u>Column</u>	<u>Format</u>	<u>Contents</u>
1-3	A3	*TT
4-6	3X	blank
7	A1	<i>SLPCODE</i>

Definition of variable:

SLPCODE Specifies the type of weighing used to determine the cross-section water-surface elevations used in the computation of fall. *SLPCODE* equal to a blank specifies no weighing of cross-section water-surface elevations. The water-surface elevations used to compute falls are either the averages of the left and right bank water-surface elevations (water surface described on GR records) or the elevation specified on the HP record. *SLPCODE* equal to 1 specifies conveyance weighing of subarea water-surface elevations. The water-surface elevation, *h*, used to compute falls is computed for each cross section using equation 8.

XS Record

Purpose: Required; header record for unconstricted valley cross section.

Format:

<u>Column</u>	<u>Format</u>	<u>Contents</u>
1-2	A2	XS
3-5	3X	blank
6-10	A5	SECID
11-80	free	SRD [, SKEW , EK , CK , VSLOPE]

Definition of variables:

SECID Unique cross-section identification code.

SRD Section reference distance, in feet. Cumulative distance along the stream measured from an arbitrary zero reference point.

SKEW The acute angle through which the section must be rotated to orient it normal to the flow direction.

EK,CK Not used by SAC, but dummy values are required if **VSLOPE** is used.

VSLOPE Valley slope, in feet per foot, used for adjusting cross-section elevations when the geometry data for the section are being propagated from a template section.

EXAMPLES OF PROGRAM USE

This section contains examples that demonstrate how to use the slope-area program, SAC. Three examples using two reaches are presented. The first example uses a reach with level-water surfaces in the cross sections and computes falls from the HP record. The second and third examples use a reach with non-level water surfaces in the cross sections. The second example computes falls from the average bank water-surface elevations in the cross sections. The third example computes falls from the conveyance weighted average of the mean subarea water-surface elevations in the cross sections. The method used by the second and third example to describe water-surface elevations is recommended only when the lateral water-surface slope is large or significantly changes the distribution of area and conveyance in the cross section. The first example illustrates the more commonly encountered situation where the use of a level water surface in the cross sections gives satisfactory results.

Reach with Level Water Surfaces in the Cross Sections

The first example is based on a problem presented at an indirect measurement workshop. In each of the three cross sections the water surface is approximated by a level surface. The water-surface elevations are entered on HP records and are used by SAC to compute the water-surface fall in the reach. In figure 3 are plots of the geometry for each cross section in the reach. The input file for this example follows.

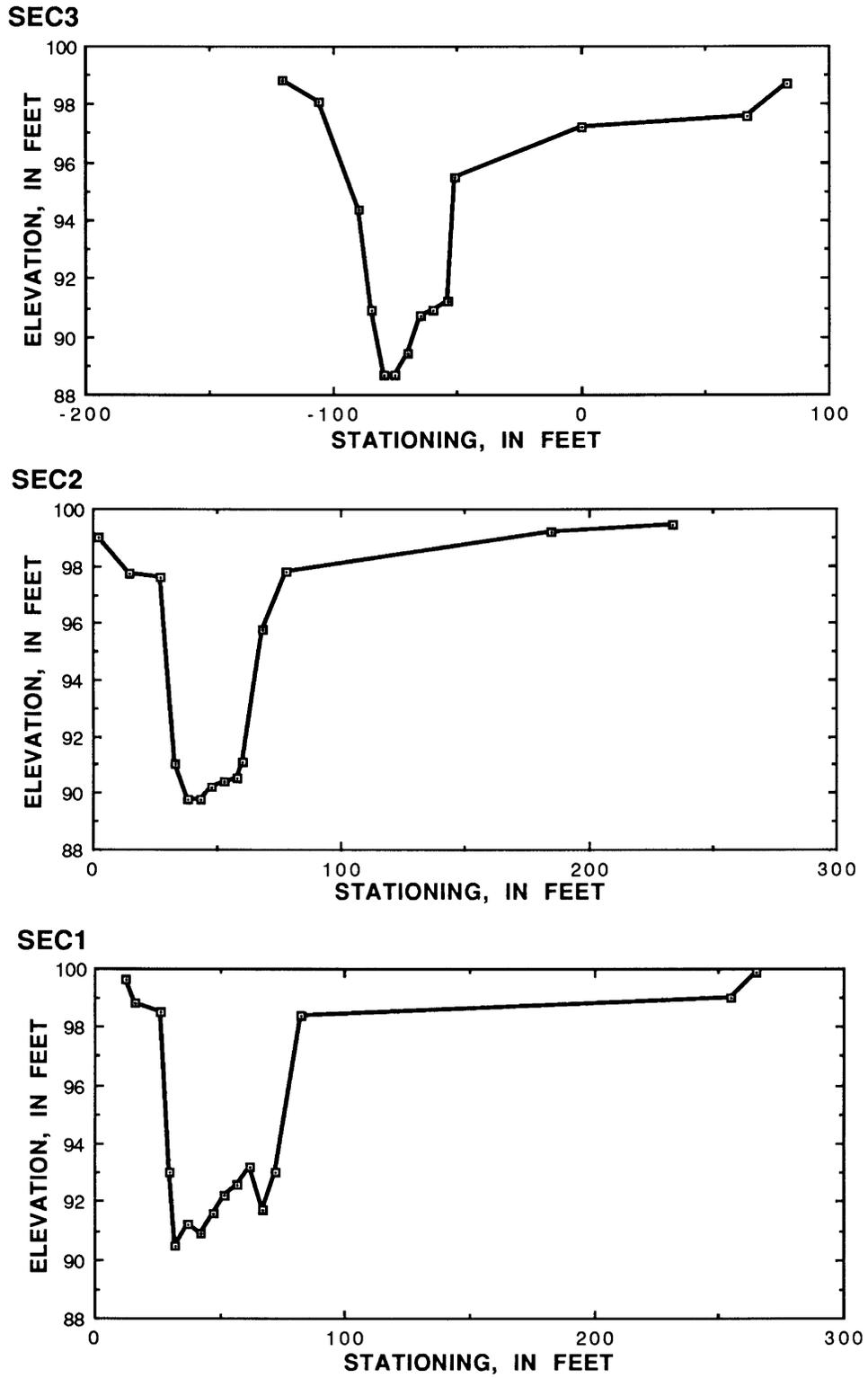


Figure 3. Cross sections for reach with level water surfaces in the cross sections.

```

*TT 4
T1  EXAMPLE1:  Simple reach data
XS  SEC3 1000
GR   -121,98.8 -106.,98.1 -90.,94.4 -85.,90.9 -80.,88.7
GR   -75.,88.7 -70.,89.4 -65.,90.7 -60.,90.9 -54.,91.2 -51.,95.5
GR   0.,97.2 67.,97.6 83.,98.7
N    0.035 0.040 0.030
SA   -106. -51.
HP 4 SEC3 98.75
XS  SEC2 1380
GR   2.,99. 15.,97.7 27.,97.6 33.,91. 38.,89.8 43.,89.8 48.,90.2
GR   53.,90.4 58.,90.5 60.,91.1 68.,95.8 78.,97.8 185.,99.2
GR   234.,99.4
N    0.030 0.037 0.030
SA   27. 78.
HP 4 SEC2 99.20
XS  SEC1 1666.
GR   12.1,99.6 16.,98.9 26.,98.5 30.,93. 32.,90.5 37.,91.2 42.,90.9
GR   47.,91.6 52.,92.2 57.,92.6 62.,93.2 67.,91.7 72.,93. 82.,98.4
GR   255.,99. 265.1,99.9
N    0.030 0.045 0.030
SA   26. 82.
HP 4 SEC1 99.75

```

Output of the slope-area program includes the input cross-section data echoed, results of the slope-area computations, hydraulic properties for the cross section and subareas of the cross sections, and definitions of the variable names used in the output. Warning codes are printed under the ER column for each slope-area computation when applicable. Error messages are printed to the screen during program execution, and with the echoed input data section of the output. Figure 4, on pages 17-19, is the output from the slope-area program for the first example. Note that the fall between the cross sections is computed from the elevations entered on the HP records.

```

Echo input data file
Slope-area reach example with level-water surface in cross sections
XS  SEC3 1000
GR   -121,98.8 -106.,98.1 -90.,94.4 -85.,90.9 -80.,88.7
GR   -75.,88.7 -70.,89.4 -65.,90.7 -60.,90.9 -54.,91.2 -51.,95.5
GR   0.,97.2 67.,97.6 83.,98.7
N    0.035 0.040 0.030
SA   -106. -51.
HP  SEC3 98.75
XS  SEC2 1380
GR   2.,99. 15.,97.7 27.,97.6 33.,91. 38.,89.8 43.,89.8 48.,90.2
GR   53.,90.4 58.,90.5 60.,91.1 68.,95.8 78.,97.8 185.,99.2
GR   234.,99.4
N    0.030 0.037 0.030
SA   27. 78.
HP  SEC2 99.20
XS  SEC1 1666.
GR   12.1,99.6 16.,98.9 26.,98.5 30.,93. 32.,90.5 37.,91.2 42.,90.9
GR   47.,91.6 52.,92.2 57.,92.6 62.,93.2 67.,91.7 72.,93. 82.,98.4
GR   255.,99. 265.1,99.9
N    0.030 0.045 0.030
SA   26. 82.
HP  SEC1 99.75

```

Figure 4. Example 1 SAC output for reach with level water surface in the cross sections.

Slope-area reach example with level-water surface in cross sections
 EXAMPLE1: Simple reach data

DISCHARGE COMPUTATIONS

	dH,fall (ft)	Reach length (ft)	Discharge (cfs)	Spread (%)	HF (ft)	CX	RC	RX	ER
SEC1 - SEC2	.55	286.	1923.	0	.392	1.000	.403	.000	
SEC2 - SEC3	.45	380.	2108.	26	.555	.876	.000	-.378	*
SEC1 - SEC3	1.00	666.	2000.	9	.924	.952	.185	-.205	

Definitions:

Spread, the percent difference between discharge computed with no expansion loss (k=0) and discharge computed with full expansion loss (k=1.0), divided by the discharge computed with full expansion loss
 HF, friction head- $HF = \text{sum of } Q^2 \cdot L / (K1 \cdot K2)$ over subreaches; Q, discharge; L, reach length; K1, upstream section conveyance;
 K2, downstream section conveyance
 CX, the computed discharge divided by the discharge computed with no expansion loss (k=0)
 RC, velocity head change in contracting section divided by friction head
 RX, velocity head change in expanding section divided by friction head
 ER, warnings, *-fall < 0.5ft, @-conveyance ratio exceeded, #-reach too short

CROSS SECTION PROPERTIES

I.D. SEC3		Velocity head		Discharge		2000.cfs				
Ref.distance	1000.ft	Q/K	.22ft	Alpha	1.200					
Sub area no.	Water surface el.(ft)	n	Area (sq.ft)	Top width (ft)	Wetted perimeter (ft)	Hydraulic radius (ft)	Conveyance x 0.001 (cfs)	Vel. % (fps)	F	
1	98.75	.035	4.5	13.9	13.9	.32	.091	0.	.7	1.05
2	98.75	.040	359.7	55.0	59.5	6.05	44.476	74.	4.1	.23
3	98.75	.030	222.5	134.0	134.1	1.66	15.481	26.	2.3	.47
Total	98.75	---	587.	203.	208.	2.83	60.048	100.	3.4	.35

I.D. SEC2		Velocity head		Discharge		2000.cfs				
Ref.distance	1380.ft	Q/K	.41ft	Alpha	1.299					
Sub area no.	Water surface el.(ft)	n	Area (sq.ft)	Top width (ft)	Wetted perimeter (ft)	Hydraulic radius (ft)	Conveyance x 0.001 (cfs)	Vel. % (fps)	F	
1	99.20	.030	29.6	25.0	25.3	1.17	1.638	3.	2.2	.73
2	99.20	.037	341.4	51.0	55.6	6.14	46.086	91.	5.3	.31
3	99.20	.030	74.9	107.0	107.0	.70	2.933	6.	1.5	.94
Total	99.20	---	446.	183.	188.	2.37	50.657	100.	4.5	.51

Definitions:

n, Manning's coefficient of roughness $Q/K = \text{discharge}/\text{conveyance}$
 F, Froude number- $F = Q / (A \cdot \text{sqrt}(g \cdot (A1/TW1)))$; Q, discharge; A, total cross-section area; g, acceleration of gravity; A1, sub-section area; TW1, sub-section top width

Figure 4. Example 1 SAC output for reach with level water surface in the cross sections-continued.

Slope-area reach example with level-water surface in cross sections
 EXAMPLE1: Simple reach data

CROSS SECTION PROPERTIES										
I.D. SEC1			Velocity head			.23ft	Discharge	2000.cfs		
Ref.distance	1666.ft		Q/K			.0014	Alpha	1.290		
Sub Water	area surface	n	Area	Top width	Wetted perimeter	Hydraulic radius	Conveyance	x 0.001	Vel.	F
no.	el.(ft)		(sq.ft)	(ft)	(ft)	(ft)	(cfs)	%	(fps)	
1	99.75	.030	12.4	13.9	14.1	.88	.569	1.	1.7	.64
2	99.75	.045	386.8	56.0	61.9	6.24	43.418	81.	4.2	.23
3	99.75	.030	184.8	181.4	181.5	1.02	9.292	17.	1.9	.60
Total	99.75	---	584.	251.	258.	2.27	53.278	100.	3.4	.40

Definitions:

n, Manning's coefficient of roughness Q/K = discharge/conveyance
 F, Froude number- $F = Q / (A \sqrt{g * (A1 / TW1)})$; Q, discharge; A, total cross-section area; g, acceleration of gravity; A1, sub-section area; TW1, sub-section top width

Figure 4. Example 1 SAC output for reach with level water surface in the cross sections-continued.

Reach with Super-Elevated Water-Surfaces in the Cross Sections

The second and third examples compute discharges for cross-sections that do not have a level-water surface. The same reach and water-surface elevations are used in both examples to demonstrate how to use either the average bank water-surface elevation or the conveyance weighted water-surface elevation in computing fall.

Reaches with super-elevated water surfaces should be avoided when using the slope-area method. The slope-area method assumes that a flow is one-dimensional or nearly so. Flows with super-elevation are not usually well approximated by one-dimensional flow equations. In practice, however, minor super elevation or variations in water-surface elevations in the cross sections are typically measured. For those cases, the user may either assume an approximate level water-surface elevation in each cross section or enter the nonlevel water surface, as is done in this example. If nonlevel water surfaces are entered, only mass conservation is ensured for the slope-area equations and no adjustments are made for any additional energy losses that occur because of variation in the cross-stream velocities.

The reach used in the second and third examples is based on one presented by Dalrymple and Benson (1967). The water-surface variation in the cross sections is small enough to allow approximation with a level-water surface. It is used only to demonstrate the structure of the inputs for super-elevated cross sections and not as an example of a typical super-elevated reach. The reach is a 340 foot section of Snake Creek near Connell, Washington. The four cross sections in the reach are shown in figure 5.

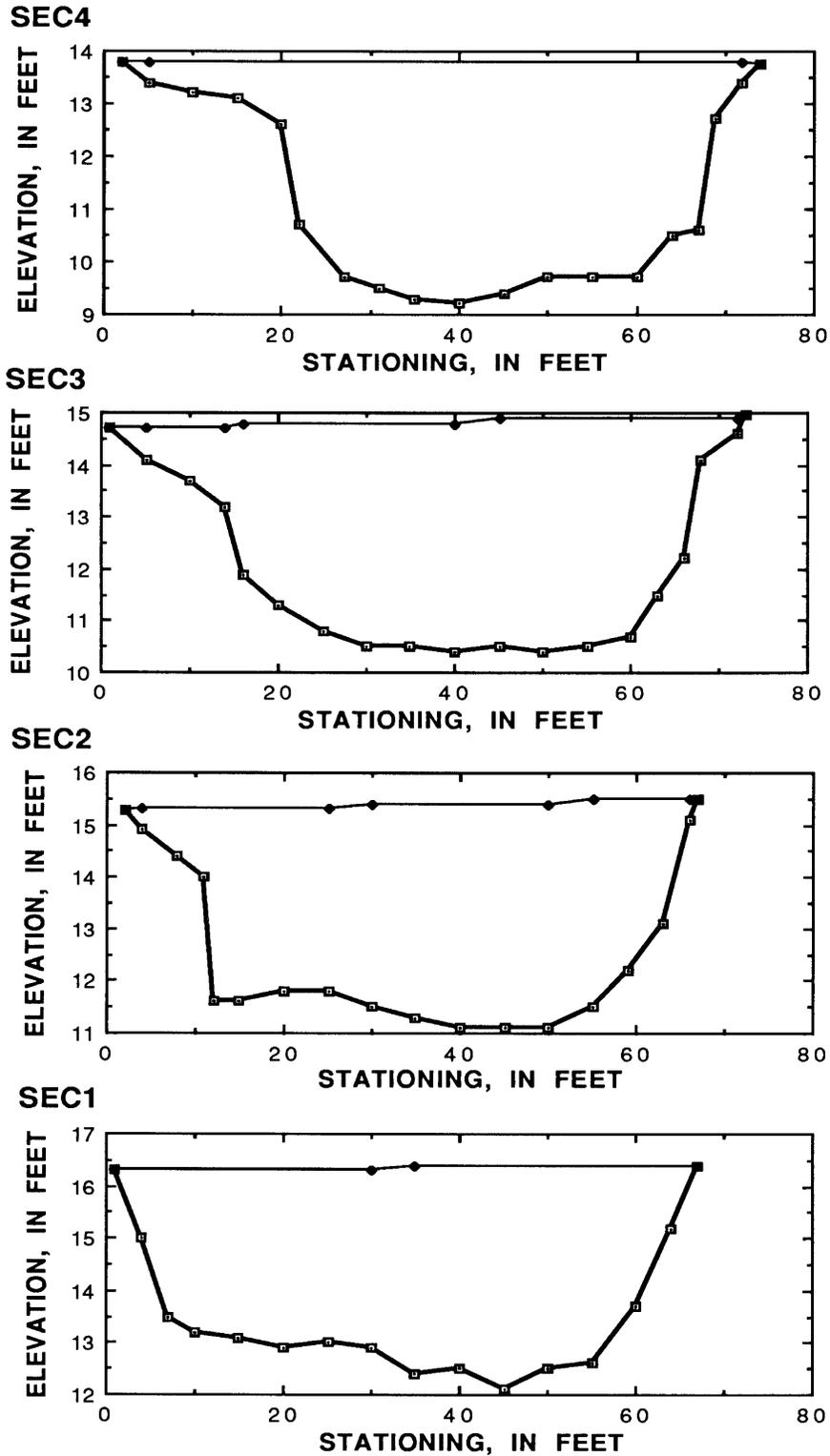


Figure 5. Cross sections and water-surface elevations for reach with super-elevated water surfaces in the cross sections; Snake Creek near Connell, Washington.

Fall Computed from Average of Bank Water-Surface Elevations

The second example computes fall from the average bank water-surface elevations in the cross sections. The input data file for the slope-area program is as follows.

```

T1  EXAMPLE 2:  Sloping water surface
XS  SEC4 1000
GR  2,13.78 5,13.4 10,13.2 15,13.1 20,12.6 22,10.7
GR  27,9.7 31,9.5 35,9.3 40,9.2 45,9.4 50,9.7
GR  55,9.7 60,9.7 64,10.5 67,10.6 69,12.7 72,13.4
GR  74,13.75 72.,13.8 5.,13.8 2.,13.78
N   0.080 0.045 0.045
SA  20. 69.
XS  SEC3 1119
GR  1,14.71 5,14.10,13.70 14,13.20 16,11.90 20,11.30
GR  25,10.80 30,10.50 35,10.50 40,10.40 45,10.50,10.40
GR  55,10.50 60,10.70 63,11.50 66,12.20 68,14.10 72,14.60
GR  73,14.95 72.,14.90 45.,14.90 40.,14.80 16.,14.80
GR  14.,14.70 5.,14.07 1.,14.71
N   0.080 0.045 0.045
SA  14. 68.
XS  SEC2 1209
GR  2,15.26 4,14.90 8,14.40 11,14.00 12,11.60 15,11.60
GR  20,11.80 25,11.80 30,11.50 35,11.30 40,11.10 45,11.10
GR  50,11.10 55,11.50 59,12.20 63,13.10 66,15.10 67,15.51
GR  66,15.50 55.,15.50.,15.40 30.,15.40 25.,15.30 4.,15.30
GR  2,15.26
N   0.080 0.045
SA  11.
XS  SEC1 1330
GR  1,16.30 4,15.00 7,13.50 10,13.20 15,13.10 20,12.90 25,13.00
GR  30,12.90 35,12.40,12.50 45,12.10 50,12.50 55,12.60,13.70
GR  64,15.20 67,16.40 35.,16.40 30.,16.30 1,16.30
N   0.045

```

Note that the super-elevated water surface and cross-section geometry shown in figure 5 are described by x, y coordinate pairs entered on the GR records. The x, y coordinates are ordered counterclockwise from the left-hand edge of the water (looking downstream) that is a high-water mark. The first and last coordinate pairs of each cross section are the same, enclosing the figure. In figure 6 is the output produced by SAC from the input file for Snake Creek. Note that the water-surface elevations used to compute fall are an average of the left and right bank water-surface elevations entered on the GR records. Water-surface elevations between banks were entered to match the "stairstepping" of elevations used to compute conveyance and area in Dalrymple and Benson(1967) and to demonstrate the ability of SAC to compute area and conveyance for varying water surfaces. In practice the water surface in this example would be specified by entering only the bank water-surface elevations. Only when high-water marks indicate that different water-surface elevations occurred in the main channel versus an overbank area is it appropriate to enter water-surface elevations between the cross-section banks. The cross-section elevation used to compute fall is computed from the average of the water-surface elevations at the edges of water. Because SAC does not round at intermediate steps and the calculations presented by Dalrymple and Benson (1967) are rounded at intermediate computation steps, the numbers listed in figure 6 are slightly different from those listed by Dalrymple and Benson.

Echo input data file

Slope-area reach: Snake Creek near Connell, WA for flood of Feb. 21, 1956

```

XS   SEC4 1000
GR   2,13.78 5,13.4 10,13.2 15,13.1 20,12.6 22,10.7
GR   27,9.7 31,9.5 35,9.3 40,9.2 45,9.4 50,9.7
GR   55,9.7 60,9.7 64,10.5 67,10.6 69,12.7 72,13.4
GR   74,13.75 72.,13.8 5.,13.8 2.,13.78
N    0.080 0.045 0.045
SA   20. 69.
XS   SEC3 1119
GR   1,14.71 5,14.1 10,13.7 14,13.2 16,11.9 20,11.3
GR   25,10.8 30,10.5 35,10.5 40,10.4 45,10.5 50,10.4
GR   55,10.5 60,10.7 63,11.5 66,12.2 68,14.1 72,14.6
GR   73,14.95 72.,14.9 45.,14.9 40.,14.8 16.,14.8
GR   14.,14.7 5.,14.7 1.,14.71
N    0.080 0.045 0.045
SA   14. 68.
XS   SEC2 1209
GR   2,15.26 4,14.9 8,14.4 11,14.0 12,11.6 15,11.6
GR   20,11.8 25,11.8 30,11.5 35,11.3 40,11.1 45,11.1
GR   50,11.1 55,11.5 59,12.2 63,13.1 66,15.1 67,15.51
GR   66,15.5 55.,15.5 50.,15.4 30.,15.4 25.,15.3 4.,15.3
GR   2,15.26
N    0.080 0.045
SA   11.
XS   SEC1 1330
GR   1,16.3 4,15.0 7,13.5 10,13.2 15,13.1 20,12.9 25,13.0
GR   30,12.9 35,12.4 40,12.5 45,12.1 50,12.5 55,12.6 60,13.7
GR   64,15.2 67,16.4 35.,16.4 30.,16.3 1,16.3
N    0.045

```

Figure 6. Example 2 SAC output for reach with nonlevel water surface in the cross sections.

Slope-area reach: Snake Creek near Connell, WA for flood of Feb. 21, 1956
 EXAMPLE 2: Sloping water surface

DISCHARGE COMPUTATIONS

	dH,fall (ft)	Reach length (ft)	Discharge (cfs)	Spread (%)	HF (ft)	CX	RC	RX	ER
SEC1 - SEC2	.96	121.	1326.	0	.949	1.000	.017	.000	#
SEC2 - SEC3	.56	90.	1325.	6	.588	.970	.000	-.113	#
SEC3 - SEC4	1.07	119.	1457.	0	.922	1.000	.155	.000	#
SEC1 - SEC3	1.52	211.	1326.	2	1.537	.989	.010	-.043	#
SEC2 - SEC4	1.62	209.	1407.	2	1.524	.988	.087	-.049	#
SEC1 - SEC4	2.58	330.	1376.	1	2.476	.993	.058	-.029	

Definitions:

Spread, the percent difference between discharge computed with no expansion loss (k=0) and discharge computed with full expansion loss (k=1.0), divided by the discharge computed with full expansion loss
 HF, friction head- $HF = \text{sum of } Q \cdot Q \cdot L / (K1 \cdot K2)$ over subreaches; Q, discharge; L, reach length; K1, upstream section conveyance; K2, downstream section conveyance
 CX, the computed discharge divided by the discharge computed with no expansion loss (k=0)
 RC, velocity head change in contracting section divided by friction head
 RX, velocity head change in expanding section divided by friction head
 ER, warnings, *-fall < 0.5ft, @-conveyance ratio exceeded, #-reach too short

CROSS SECTION PROPERTIES

I.D. SEC4		Velocity head		Discharge					
Ref.distance		Q/K		Alpha					
1000.ft		.76ft		1376.cfs					
		.0076		1.104					
Sub area no.	Water surface el.(ft)	n	Area (sq.ft)	Top width (ft)	Wetted perimeter (ft)	Hydraulic radius (ft)	Conveyance x 0.001 (cfs)	Vel. %	F
1	13.80	.080	11.1	18.0	18.1	.61	.149	1.	1.2
2	13.80	.045	193.1	49.0	50.9	3.80	15.553	99.	7.0
3	13.79	.045	2.7	5.0	5.1	.52	.057	0.	1.9
Total	13.76	---	207.	72.	74.	2.79	15.759	100.	6.7

Definitions:

n, Manning's coefficient of roughness $Q/K = \text{discharge}/\text{conveyance}$
 F, Froude number- $F = Q / (A \cdot \text{sqrt}(g \cdot (A1/TW1)))$; Q, discharge; A, total cross-section area; g, acceleration of gravity; A1, sub-section area; TW1, sub-section top width

Figure 6. Example 2 SAC output for reach with nonlevel water surface in the cross sections-continued.

Slope-area reach: Snake Creek near Connell, WA for flood of Feb. 21, 1956
 EXAMPLE 2: Sloping water surface

CROSS SECTION PROPERTIES											
I.D. SEC3				Velocity head		.63ft	Discharge		1376.cfs		
Ref.distance		1119.ft		Q/K		.0063	Alpha		1.083		
Sub Water	area surface	n	Area	Top	Wetted	Hydraulic	Conveyance				
no.	el.(ft)		(sq.ft)	width	perimeter	radius	x 0.001	Vel.	F		
				(ft)	(ft)	(ft)	(cfs)	%	(fps)		
1	14.70	.080	10.2	13.0	13.1	.78	.161	1.	1.2	1.22	
2	14.85	.045	212.0	54.0	55.4	3.83	17.170	99.	6.4	.54	
3	14.90	.045	2.3	5.0	5.1	.46	.046	0.	1.6	1.57	
Total	14.83	---	225.	72.	74.	3.05	17.378	100.	6.1	.61	

I.D. SEC2				Velocity head		.70ft	Discharge		1376.cfs		
Ref.distance		1209.ft		Q/K		.0079	Alpha		1.045		
Sub Water	area surface	n	Area	Top	Wetted	Hydraulic	Conveyance				
no.	el.(ft)		(sq.ft)	width	perimeter	radius	x 0.001	Vel.	F		
				(ft)	(ft)	(ft)	(cfs)	%	(fps)		
1	15.30	.080	6.3	9.0	9.1	.69	.092	1.	1.3	1.39	
2	15.40	.045	202.8	56.0	58.5	3.47	15.377	99.	6.7	.61	
Total	15.39	---	209.	65.	68.	3.09	15.469	100.	6.6	.65	

I.D. SEC1				Velocity head		.69ft	Discharge		1376.cfs		
Ref.distance		1330.ft		Q/K		.0090	Alpha		1.000		
Sub Water	area surface	n	Area	Top	Wetted	Hydraulic	Conveyance				
no.	el.(ft)		(sq.ft)	width	perimeter	radius	x 0.001	Vel.	F		
				(ft)	(ft)	(ft)	(cfs)	%	(fps)		
1	16.35	.045	207.1	66.0	67.3	3.08	14.498	100.	6.6	.66	
Total	16.35	---	207.	66.	67.	3.08	14.498	100.	6.6	.66	

Definitions:

n, Manning's coefficient of roughness Q/K = discharge/conveyance

F, Froude number- $F = Q / (A \sqrt{g \cdot (A_1 / TW_1)})$; Q, discharge; A, total cross-section area; g, acceleration of gravity; A₁, sub-section area; TW₁, sub-section top width

Figure 6. Example 2 SAC output for reach with nonlevel water surface in the cross sections-continued.

Fall Computed from Conveyance-Weighted Average of Water-Surface Elevations

The third example uses the same Snake Creek reach used in the second example. However, in this example falls are computed from cross-sectional water-surface elevations that are conveyance-weighted averages of the subarea water-surface elevations. The input data file is the same as the second example's except for the inclusion of slpcode equal to 1 on the *TT record. The input data file for the third example is as follows.

```
*TT      1
T1      EXAMPLE 3:  Sloping water surface with conveyance weighing
XS      SEC4 1000
GR      2,13.78 5,13.4 10,13.2 15,13.1 20,12.6 22,10.7
GR      27,9.7 31,9.5 35,9.3 40,9.2 45,9.4 50,9.7
GR      55,9.7 60,9.7 64,10.5 67,10.6 69,12.7 72,13.4
GR      74,13.75 72.,13.8 5.,13.8 2.,13.78
N      0.080 0.045 0.045
SA      20. 69.
XS      SEC3 1119
GR      1,14.71 5,14.1 10,13.7 14,13.2 16,11.9 20,11.3
GR      25,10.8 30,10.5 35,10.5 40,10.4 45,10.5 50,10.4
GR      55,10.5 60,10.7 63,11.5 66,12.2 68,14.1 72,14.6
GR      73,14.95 72.,14.9 45.,14.9 40.,14.8 16.,14.8
GR      14.,14.7 5.,14.7 1.,14.71
N      0.080 0.045 0.045
SA      14. 68.
XS      SEC2 1209
GR      2,15.26 4,14.9 8,14.4 11,14.0 12,11.6 15,11.6
GR      20,11.8 25,11.8 30,11.5 35,11.3 40,11.1 45,11.1
GR      50,11.1 55,11.5 59,12.2 63,13.1 66,15.1 67,15.51
GR      66,15.5 55.,15.5 50.,15.4 30.,15.4 25.,15.3 4.,15.3
GR      2,15.26
N      0.045 0.045
SA      11.
XS      SEC1 1330
GR      1,16.3 4,15.0 7,13.5 10,13.2 15,13.1 20,12.9 25,13.0
GR      30,12.9 35,12.4 40,12.5 45,12.1 50,12.5 55,12.6 60,13.7
GR      64,15.2 67,16.4 35.,16.4 30.,16.3 1,16.3
N      0.045
```

In figure 7 is the output for the third example. It is similar to the previous example's output. Note that conveyance weighing can make the effective water-surface elevation higher or lower, but does not affect the computation of the other hydraulic properties used in the slope-area calculations.

Echo input data file

Slope-area reach: Snake Creek near Connell, WA for flood of Feb. 21, 1956

```

XS   SEC4 1000
GR   2,13.78 5,13.4 10,13.2 15,13.1 20,12.6 22,10.7
GR   27,9.7 31,9.5 35,9.3 40,9.2 45,9.4 50,9.7
GR   55,9.7 60,9.7 64,10.5 67,10.6 69,12.7 72,13.4
GR   74,13.75 72.,13.8 5.,13.8 2.,13.78
N    0.080 0.045 0.045
SA   20. 69.
XS   SEC3 1119
GR   1,14.71 5,14.1 10,13.7 14,13.2 16,11.9 20,11.3
GR   25,10.8 30,10.5 35,10.5 40,10.4 45,10.5 50,10.4
GR   55,10.5 60,10.7 63,11.5 66,12.2 68,14.1 72,14.6
GR   73,14.95 72.,14.9 45.,14.9 40.,14.8 16.,14.8
GR   14.,14.7 5.,14.7 1.,14.71
N    0.080 0.045 0.045
SA   14. 68.
XS   SEC2 1209
GR   2,15.26 4,14.9 8,14.4 11,14.0 12,11.6 15,11.6
GR   20,11.8 25,11.8 30,11.5 35,11.3 40,11.1 45,11.1
GR   50,11.1 55,11.5 59,12.2 63,13.1 66,15.1 67,15.51
GR   66,15.5 55.,15.5 50.,15.4 30.,15.4 25.,15.3 4.,15.3
GR   2,15.26
N    0.045 0.045
SA   11.
XS   SEC1 1330
GR   1,16.3 4,15.0 7,13.5 10,13.2 15,13.1 20,12.9 25,13.0
GR   30,12.9 35,12.4 40,12.5 45,12.1 50,12.5 55,12.6 60,13.7
GR   64,15.2 67,16.4 35.,16.4 30.,16.3 1,16.3
N    0.045

```

Figure 7. Example 3 SAC output for reach with conveyance weighing of water-surface elevations.

Slope-area reach: Snake Creek near Connell, WA for flood of Feb. 21, 1956
 EXAMPLE 3: Sloping water surface with conveyance weighing

DISCHARGE COMPUTATIONS										
	K weighted	Reach	Discharge	Spread	HF	CX	RC	RX	ER	
	dH,fall	length	(cfs)	(%)	(ft)					
	(ft)	(ft)								
SEC1 - SEC2	.96	121.	1330.	0	.949	1.000	.008	.000		#
SEC2 - SEC3	.55	90.	1319.	5	.580	.974	.000	-.099		#
SEC3 - SEC4	1.04	119.	1443.	0	.904	1.000	.155	.000		#
SEC1 - SEC3	1.51	211.	1326.	1	1.530	.990	.005	-.038		#
SEC2 - SEC4	1.60	209.	1396.	2	1.496	.990	.088	-.043		#
SEC1 - SEC4	2.55	330.	1370.	1	2.449	.994	.055	-.025		

Definitions:

Spread, the percent difference between discharge computed with no expansion loss (k=0) and discharge computed with full expansion loss (k=1.0), divided by the discharge computed with full expansion loss
 HF, friction head- $HF = \text{sum of } Q*Q*L/(K1*K2)$ over subreaches; Q, discharge; L, reach length; K1, upstream section conveyance; K2, downstream section conveyance
 CX, the computed discharge divided by the discharge computed with no expansion loss (k=0)
 RC, velocity head change in contracting section divided by friction head
 RX, velocity head change in expanding section divided by friction head
 ER, warnings, *-fall < 0.5ft, @-conveyance ratio exceeded, #-reach too short

CROSS SECTION PROPERTIES

I.D.	SEC4	Velocity head		.75ft	Discharge		1370.cfs				
Ref.distance	1000.ft	Q/K		.0076	Alpha		1.104				
Sub	Water	Top		Wetted	Hydraulic	Conveyance					
area	surface	n	Area	width	perimeter	radius	x 0.001	Vel.	F		
no.	el.(ft)		(sq.ft)	(ft)	(ft)	(ft)	(cfs)	%	(fps)		
1	13.80	.080	11.1	18.0	18.1	.61	.149	1.	1.2	1.49	
2	13.80	.045	193.1	49.0	50.9	3.80	15.553	99.	7.0	.59	
3	13.79	.045	2.7	5.0	5.1	.52	.057	0.	1.9	1.60	
Total	13.80	---	207.	72.	74.	2.79	15.759	100.	6.6	.69	

Definitions:

n, Manning's coefficient of roughness $Q/K = \text{discharge}/\text{conveyance}$
 F, Froude number- $F = Q/(A \text{ sqrt}(g*(A1/TW1)))$; Q, discharge; A, total cross-section area; g, acceleration of gravity; A1, sub-section area; TW1, sub-section top width

Figure 7. Example 3 SAC output for reach with conveyance weighing of water-surface elevations-continued.

Slope-area reach: Snake Creek near Connell, WA for flood of Feb. 21, 1956
 EXAMPLE 3: Sloping water surface with conveyance weighing

CROSS SECTION PROPERTIES											
I.D. SEC3				Velocity head		.63ft	Discharge		1370.cfs		
Ref.distance		1119.ft		Q/K		.0062	Alpha		1.083		
Sub Water	area surface	n	Area	Top	Wetted	Hydraulic	Conveyance				
no.	el.(ft)		(sq.ft)	width	perimeter	radius	x 0.001	Vel.	F		
				(ft)	(ft)	(ft)	(cfs)	%	(fps)		
1	14.70	.080	10.2	13.0	13.1	.78	.161	1.	1.2	1.21	
2	14.85	.045	212.0	54.0	55.4	3.83	17.170	99.	6.4	.54	
3	14.90	.045	2.3	5.0	5.1	.46	.046	0.	1.6	1.57	
Total	14.84	---	225.	72.	74.	3.05	17.378	100.	6.1	.61	

I.D. SEC2				Velocity head		.69ft	Discharge		1370.cfs		
Ref.distance		1209.ft		Q/K		.0078	Alpha		1.031		
Sub Water	area surface	n	Area	Top	Wetted	Hydraulic	Conveyance				
no.	el.(ft)		(sq.ft)	width	perimeter	radius	x 0.001	Vel.	F		
				(ft)	(ft)	(ft)	(cfs)	%	(fps)		
1	15.30	.045	6.3	9.0	9.1	.69	.163	1.	2.3	1.38	
2	15.40	.045	202.8	56.0	58.5	3.47	15.377	99.	6.7	.61	
Total	15.40	---	209.	65.	68.	3.09	15.541	100.	6.6	.64	

I.D. SEC1				Velocity head		.68ft	Discharge		1370.cfs		
Ref.distance		1330.ft		Q/K		.0089	Alpha		1.000		
Sub Water	area surface	n	Area	Top	Wetted	Hydraulic	Conveyance				
no.	el.(ft)		(sq.ft)	width	perimeter	radius	x 0.001	Vel.	F		
				(ft)	(ft)	(ft)	(cfs)	%	(fps)		
1	16.35	.045	207.1	66.0	67.3	3.08	14.498	100.	6.6	.66	
Total	16.35	---	207.	66.	67.	3.08	14.498	100.	6.6	.66	

Definitions:

n, Manning's coefficient of roughness Q/K = discharge/conveyance

F, Froude number- $F = Q / (A \sqrt{g \cdot (A_1 / TW_1)})$; Q, discharge; A, total cross-section area; g, acceleration of gravity; A₁, sub-section area; TW₁, sub-section top width

Figure 7. Example 3 SAC output for reach with conveyance weighing of water-surface elevations-continued.

WARNING AND ERROR MESSAGES

SAC generates both warning and error messages. Depending on the type of error or warning the messages will be printed either to the screen or the output. Messages are printed on the output under the ER column in the discharge computation section as warning codes. The following is a list of the warning codes and explanations that can be printed to the output file.

Warning code	Explanation
*	The computed fall for the reach is less than the recommended minimum fall of 0.5 feet. In general the fall should be large enough that the range of error due to alternate interpretations of the high-water profile is small.
@	The ratio of upstream to downstream section conveyances is greater than 1.25 or less than 0.8. Large conveyance ratios can result when hydraulic jumps or excessive expansion or contraction occur in the reach. Large ratios may invalidate the assumption that the mean conveyance is equal to the geometric mean of the conveyances at the end sections.
#	The length of the reach should be greater than 75 times the mean depth in the reach. Generally the accuracy of slope-area computations is increased as the length of the reach is increased.

Error messages printed to the output file and to the screen during program execution are usually the result of errors in the input file. These error messages are usually generated when data have been entered incorrectly into the input file or when the sizes of data arrays exceed the default sizes set in the program code. The error messages are printed with the echoed data section of the output. Other screen messages are runtime messages generated by the compiler and are not printed to the output file. Maximum array sizes have been previously discussed in the installation section of this user's guide. The following is a list of error messages that may be generated by the CAP during execution. Runtime messages generated by the compiler are not listed here and are dependent on the compiler used to produce the executable version of SAC. In the following messages, *nn* is a number generated by the program.

**FATAL ERROR---- stage entered on HP record is
less than the water-surface elevation at a bank
Please check GR & HP records for cross section _____**

When cross sections with varying water surfaces are used, the stage (WSEL) entered on the HP record must be equal to or larger than any elevations entered on the GR record for that cross section. Omit the HP record.

***nn* allowable roughness depths, ----- EXCEEDED for ID _____**

Number of roughness values entered exceeds the array sized for the cross-section ID listed.
Reduce the number of roughness depths.

***nn* allowable roughness values, -----EXCEEDED for ID _____**

Number of roughness values entered exceeds the array size for the cross-section ID listed.
Reduce the number of roughness values.

***nn* allowable x,y coordinates, ----- EXCEEDED for ID _____**

Number of coordinates entered exceeds the array size for the cross-section ID listed. Reduce the number of coordinates.

Inconsistent no. of roughnesses & roughness depths @ ID _____

If two roughness values per subarea are entered, the number of roughness depths should equal the number of roughnesses, otherwise, no depths should be entered.

Inconsistent no. of roughnesses and subareas for ID _____

Number of roughness values and subareas do not match. Number of entered roughnesses should be equal either to the number of subareas or to twice the number of subareas.

***nn* subarea breakpoints allowed. ----- EXCEEDED for ID _____**

Number of breakpoints entered exceeds the array size for the cross-section ID listed. Reduce the number of subareas.

x,y coordinates are ordered funny ----- ID _____

Coordinates should be entered in counterclockwise order. If an enclosed section is being used, the first and last coordinate must be the same.

SUMMARY

This guide is an aid to persons using SAC, a computer program that performs slope-area computations. The slope-area program described by the guide uses WSPRO formatted data files that can be used by the WSPRO program with few or no modifications. This feature minimizes the time needed to learn a new input file format by utilizing an existing and accepted file format. The SAC program code is based on the slope-area code written by O.G. Lara and modified by W. Kirby of the U.S. Geological Survey.

SELECTED REFERENCES

- American National Standards Institute, 1978, American National Standard Programming Language FORTRAN: American National Standards Institute, New York, N.Y.
- Benson, M.A., and Dalrymple, Tate, 1967, General field and office procedures for indirect discharge measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book3, chap. A1, 30 p.
- Dalrymple, Tate, and Benson, M.A., 1967, Measurement of peak discharge by the slope-area method: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A2, 12 p.
- French, Richard H., 1985, Open-channel hydraulics: New York, N.Y., R.R. Donnelley & Sons Co., 705 p.
- Henderson, F.M., 1966, Open channel flow: New York, N.Y., Macmillan, 522 p.
- Kirby, W., 1987, Linear error analysis of slope-area discharge: Proceedings of the United States-People's Republic of China Bilateral Symposium on the Analysis of Extraordinary Flood Events, Journal of Hydrology, v. 96, p. 125-138
- Petersen, Margaret S., 1986, River engineering: Englewood Cliffs, N.J., Prentice-Hall, 580 p.
- Shearman, J.O., 1990, User's manual for WSPRO--A computer model for water surface profile computations: Federal Highway Administration Report, FHWA-IP-89-027, 187 p.