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SAM Hydraulic Design Package for Channels

William A. Thomas, Ronald R. Copeland,
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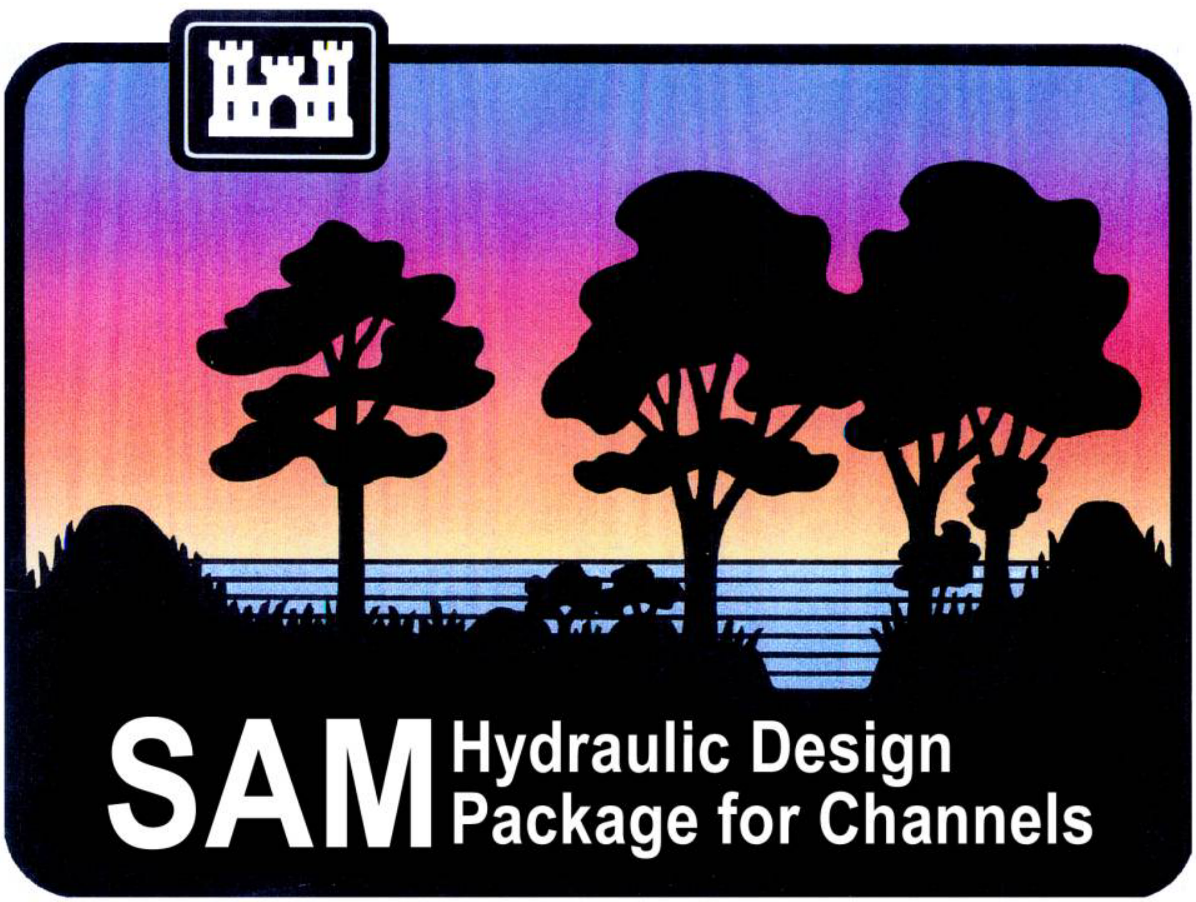

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Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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Preface

The SAM Hydraulic Design Package for Channels has been evolving since the late 1980's. The majority of algorithms are a result of research conducted in the Flood Control Channels Research Program in the 1980's and early 1990's. Mr. W.A. Thomas (retired) was one of the driving forces behind the beginnings of SAM. Mr. Thomas, Dr. Ronald Copeland (retired), Dr. Nolan Raphelt, and Mrs. Dinah McComas, all in the former Hydraulics Laboratory (now Coastal and Hydraulics Laboratory (CHL), Engineering Research and Development Center (ERDC), Vicksburg, MS), did most of the original programming for SAM. The package has been debugged, refined and added to from its inception to the present. In 2001, CHL entered into a Cooperative Research and Development Agreement (CRDA) with Owen Ayres & Associates, Inc., Ft. Collins, CO, to put the DOS-based SAM into a more user-friendly interface. Ayres developed a Windows interface which uses the same executable programs, with necessary improvements and fixes, as the earlier DOS-based SAM package. Ayres has exclusive rights to sell and support the SAM package to the private sector and all government agencies except the Corps of Engineers. The Corps of Engineers can receive the new SAM package, and support, through CHL, free with participation in the Numerical Model Maintenance Program at ERDC.

1 Introduction

Purpose and Philosophy

SAM is an integrated system of programs developed through the Flood Damage Reduction and Stream Restoration Research Program to aid engineers in analyses associated with designing, operating, and maintaining flood control channels and stream restoration projects. The package was designed primarily to satisfy the need for qualitative, easy-to-use methodology, especially for use in preliminary screening of alternatives where funds for more extensive investigations are not available.

The SAM package, designed to run on PC computers, is intended to be used primarily as an aid in the design of stable channels. In the past, the design of a stable channel has focused on the erosion process (Simons and Senturk, 1977, and ASCE, 1975). However, erosion is only one of the five fundamental processes--erosion, entrainment, transportation, deposition and compaction--in sedimentation. SAM provides the computational capability to include all these processes except the compaction of the deposited bed sediments in the design of stable channels.

The SAM package is designed to provide hydraulic engineers smooth transition from making hydraulic calculations to calculating sediment transport capacity to making sediment yield determinations. The three main modules of the package can be used in series, as described, or their separate capabilities utilized to aid in various hydraulic design situations. SAM.hyd calculates the width, depth, slope and n-values for stable channels in alluvial material. SAM.sed calculates sediment transport capacity according to a wide range of sediment transport functions, usually using the hydraulic parameters calculated in SAM.hyd. SED.yld uses the sediment transport capacity calculated in SAM.sed to calculate the sediment yield. Channel stability can then be evaluated in terms of the cost of maintaining the constructed channel.

Overview of Manual

This manual describes the fundamental concepts, numerical model capabilities and limitations, computational procedures, input requirements and output descriptions of the various modules in SAM. A brief description of model capabilities and the organization of this manual is presented below.

Theoretical Basis for SAM.hyd, SAM.sed, and SAM.yld calculations (Chapters 2, 3, 4)

These chapters describe the theoretical bases for the hydraulic computations, the sediment transport calculations, and the sediment yield calculations in the SAM.hyd, SAM.sed, and SAM.yld modules, respectively. They present the general capabilities of the modules and describe how the computations are performed.

Theoretical Basis for SAM.aid (Chapter 5)

This chapter describes the general capabilities of this module and describes how the selection of recommended sediment transport equations is made in SAM.aid.

Input Requirements and Program Output for SAM.hyd, SAM.sed, and SAM.yld (Chapters 6, 7, and 8)

These chapters describe the general input data requirements for implementation of specific module capabilities, as well as providing information on the various output tables in each module.

Appendices

The various appendices provide specific instructions on the use of the package. These appendices are:

A. References
B. List of Variables
C. Data Records for Hydraulic Calculations (SAM.hyd)
D. Data Records for Sediment Transport Functions (SAM.sed)
E. Data Records for Sediment Yield Calculations (SAM.yld)
F. SAM.aid – Guidance in Sediment Transport Function Selection

Summary of SAM Capabilities

Geometry

SAM considers only one cross section, not a reach, of a river. However, the geometry of that cross section can be prescribed in several ways. For trapezoidal channels, either a simple or compound channel can be input. Also, an irregular channel can be prescribed with station and elevation coordinates.

SAM.hyd

This module calculates normal depth and composite hydraulic parameters for a cross section with variable roughness. The calculations can be made with a variety of bed roughness predictors. It will also calculate stable channel dimensions--channel width, depth and slope-- for a prescribed discharge and sediment load. The stable channel dimensions calculated in SAM are not constrained by the external hypothesis advocated by Chang (1980) and others. Rather, the designer is able to choose from a family of solutions to meet project constraints. These calculations use analytical equations which include bed material transport and which separate total hydraulic roughness into bank and bed components.

SAM.hyd also provides the option of calculating riprap size, either by the method prescribed in EM 1110-2-1601, "Hydraulic Design of Flood Control Channels" (USACE 1991, 1994), or through testing the results of the normal depth calculations against the Shield’s Diagram for particle stability.

SAM.sed

This module calculates the bed material sediment discharge rating curve by size class using hydraulic parameters either calculated in SAM.hyd or user specified. Several sediment transport functions have been programmed into SAM.sed, covering a range of riverine conditions. SAM.sed applies the sediment transport functions at a point thus allowing for no temporal or spatial variability in the size class distribution.

SAM.yld

SAM.yld calculates sediment yield passing a cross-section during a specified period of time using the "Flow-Duration Sediment-Discharge Rating Curve method" described in EM 1110-2-4000, "Sediment Investigations in Rivers and Reservoirs" (USACE 1989). The time period considered can be a single flood event or an entire year. In SAM.yld the flow can be specified by either a flow duration curve or a hydrograph. The sediment discharge rating curve can be specified as either sediment discharge versus water discharge or sediment concentration versus water discharge.

SAM.aid

SAM.aid provides guidance in the selection of a sediment transport function(s) to use with a given project, based on five screening parameters: d_{50}, slope, velocity, width, and depth.

General

The SAM package is a product of the Flood Damage Reduction and Stream Restoration Research Program. The conception and initial development of the package were the results of the efforts of William A. Thomas, Ronald R. Copeland and Nolan Raphelt. However, many workunits and many principal investigators have contributed to the package. The US Government is not responsible for results obtained with this software. However, the office supporting the package would welcome documentation of program errors and should respond if fiscally feasible.

Files

The program operates interactively. However it saves the input data in an ASCII files and uses these files to pass data from module to module.

Theoretical Assumptions and Limitations

SAM is not a package of one-dimensional models. SAM makes calculations based on one cross section at one point in time. There are no provisions in any of the modules for simulating the effects of a hydrograph nor for looking at a reach of a river, except as it might be represented by an average. SAM is designed to be used as a tool during reconnaissance level planning studies. Broad application of SAM results must be made with caution.

Sediment transport functions in SAM must be used with care. Essentially, SAM.sed applies the sediment transport functions at a point, which allows for no variability in the size class distribution over time or space. Considering that the size class distribution of bed material in the natural river changes with discharge, reach, time of year, and other temporal factors, SAM's use of a fixed, non-varying, as-prescribed size class distribution for all calculations presents the possibility that the calculated transport rates are not truly representative of the natural river. The procedure in HEC-6, which integrates processes over several cross sections which describe a reach of the river and provides a continuity equation for sediment movement, will consequently produce a more reliable result than comes from applying a sediment transport function at a single point.

However, SAM will provide reasonable answers if the user is cognizant of the need for the careful prescribing of the bed material gradation.

2 Theoretical Basis for SAM.hyd Calculations

Purpose

The purpose of the hydraulics module, SAM.hyd, is to provide hydraulic design engineers with a systematic method, based on state-of-the-art theory, for rapidly calculating channel size in both fixed and mobile boundary streams.

General

SAM.hyd solves the steady state, normal-depth equation to transform complex geometry into composite, 1-dimensional hydraulic parameters. The program can solve for either depth, width, slope, discharge, or roughness. It allows roughness to be calculated by several different roughness equations within the same cross-section.

SAM.hyd contains an analytical procedure for calculating stable channel dimensions in either sand bed or gravel bed streams. It is based on the Brownlie equations for sediment transport and bed roughness. This calculation provides a table of channel width-depth-slope dimensions which are in equilibrium with the inflowing sediment load. Channel dimensions at minimum stream power are also calculated.

SAM.hyd provides the option of calculating riprap size as described in EM 1110-2-1601, "Hydraulic Design of Flood Control Channels" (USACE 1991, 1994) or through testing the results of the normal depth calculations against the Shield's Diagram for particle stability. The 13 standard riprap sizes from EM 1110-2-1601 are coded into SAM. The user can also specify quarry run riprap.

SAM.hyd offers two procedures for calculating riprap. When flow velocity and depth are known, the riprap size is calculated directly. When water discharge and cross section are given, riprap size is determined by a more complicated calculation since n-value becomes a function of riprap size.

SAM.hyd also has the ability to determine whether or not riprap is required. The program evaluates the calculated bed shear stress and the Shield's critical value. If the calculated bed shear stress is greater than Shield's critical value, SAM.hyd will notify the user that riprap is required. The user may then alter the data file to request riprap calculations.

Regime channel dimensions, determined using the Blench (1970) equations, can be calculated as a function of bed material gradation, bank consistency, and bed-material sediment concentration.

SAM.hyd Options

SAM.hyd can solve for any one of the variables in the uniform flow equation. Water discharge is usually the dependent variable (equation 2-1). However, SAM allows any of the variables on the right hand side to become the dependent variable, except side slope, z. SAM.hyd inspects each input record type in a data set and determines which variables have been prescribed. The variable omitted becomes the dependent variable.

$$Q = f(D, n, W, z, S) \qquad \textbf{Equation 2-1}$$

where

Q = water discharge
D = water depth
n = n-value
W = bottom width
z = side slopes of the channel
S = energy slope

Most of the major calculation options in SAM.hyd rely on the above relationship. For SAMwin, all variables can be prescribed. The user must select the variable to be calculated: normal depth, bottom depth, energy slope, hydraulic roughness (n-values and k_s values), and water discharge. Flow distribution is calculated each time the uniform flow equation is solved, and can be requested during any of the calculations.

Other parameters are also calculated when the uniform flow equation is solved. In SAM.hyd, composite hydraulic parameters can be calculated by four options: alpha method, equal velocity method, total force method and conveyance method.

Bed Form Roughness Prediction is made using Brownlie's (1983) method. It uses velocity, hydraulic radius, slope, particle specific gravity, d_{50} and the geometric standard deviation of the bed sediment mixture.

Cross Section Velocity is printed for comparison with the velocity criteria for stable channel design.

Shear Stress is printed for comparison with the boundary shear stress criteria for stable channel design.

Riprap Size can be requested. If the calculated bed shear stress is greater than Shield's critical value, the program will notify the user.

Effective Width, Depth and Velocity are calculated, printed, and written to an input file for use in sediment transport calculations, SAM.sed.

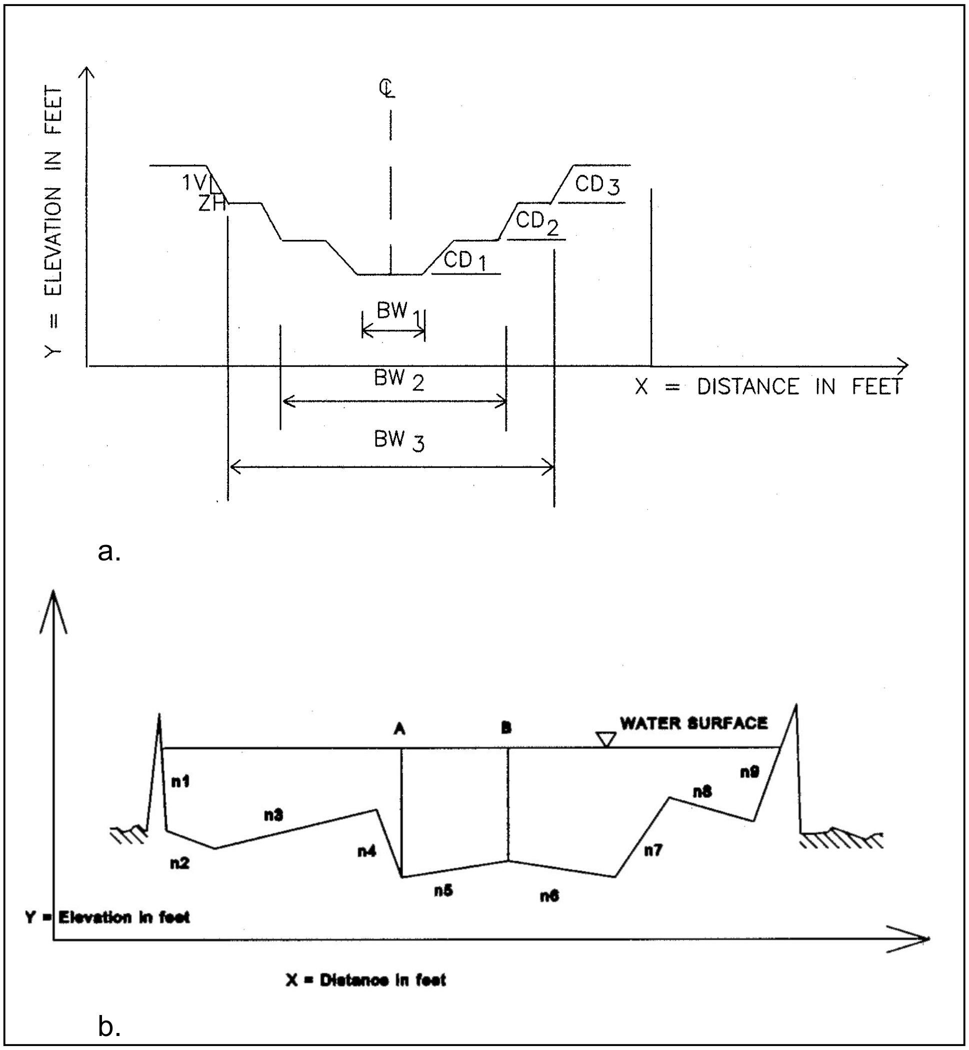
Equivalent Hydraulic Radius and n-Value are calculated and printed for each subsection in the cross section after the normal depth calculations are completed.

Also, there are two options for coding the cross section. Single or compound channels can be prescribed by defining the bottom width and side slopes for simple triangular, rectangular or trapezoidal shapes. For example, Figure 2.1A shows a low flow channel, a normal flow channel, and a high flow berm. Complex channels can be prescribed by defining the station and elevation coordinates, as on X1 and GR records in HEC-2/HEC-6. Figure 2.1B shows a typical complex cross section as an example of what could be coded in this format.

Normal Depth Calculations

Normal depth is calculated using one of five uniform flow equations, or one of five USDA Soil Conservation Service (SCS) equations for grass-lined channels. Different equations may be used in different panels. An iterative procedure is used to converge on the specified total discharge. Then a composite Manning's roughness coefficient and the effective hydraulic parameters are calculated for the cross section.

Manning Roughness Equation When the hydraulic roughness is prescribed as n-values, the Manning equation is used to determine normal depth.



NOTE: The trapezoidal element 'AB(6)(5)' in this figure is called a "panel" in this document.

1V:ZH -- definition of the side slopes, with the Z as the input parameter
CD1 -- the height of the low flow channel
CD2 -- the incremental height of the normal channel
CD3 -- the incremental height of the high flow channel
BW1 -- the width, toe to toe, of the low flow channel
BW2 -- the width, toe to toe, of the normal channel
BW3 -- the width, toe to toe, of the high flow channel
Note: therefore total depth = CD1+CD2+CD3

Figure 2.1A and 2.1B. Complex Geometry using CT records, top; using X1 and GR records.

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$ **Equation 2-2**

where

V	=	velocity, feet per second
R	=	hydraulic radius, feet
S	=	slope, feet per feet
n	=	Manning's roughness coefficient

Hydraulic Roughness Equations Hydraulic roughness can be prescribed directly with n-values (option 0) or it can be related to the physical properties of the cross section by another hydraulic roughness equation. Available roughness equations are given in Table 1.

0. Manning’s Equation
1. Keulegan equations
2. Strickler Equation
3. Limerinos Equation
4. Brownlie Bed Roughness Equations

5-9. Five Soil Conservation Service equations for grass lined channels

Table 1. Hydraulic Roughness Options in SAM.hyd.

Note that as each channel problem is unique, no one predictor should be considered as "best."

Effective Surface Roughness Height, k_s

A value for k_s is required when the Keulegan equations or Strickler equation is specified. For the design of concrete channels the suggested values for k_s are shown in EM 1110-2-1601 (USACE 1991, 1994). For the case of channels in natural materials, there are no tables of generally accepted k_s values as there are for Manning's n-values. Moreover, there is no generally accepted technique for measuring this property geometrically. Therefore, unless a specific value of k_s is known, it is recommended that the hydraulic roughness be prescribed with n-values or by another analytical method. When sufficient data are available -- discharge, area, hydraulic radius, and slope -- k_s can be calculated and then used to calculate hydraulic parameters for additional discharges.

Relative Roughness

Relative roughness refers to the ratio of the effective surface roughness height, k_s, to the hydraulic radius, R. The relative roughness parameter is R/k_s. When this parameter is less than 3, which indicates a very rough surface, the logarithmic velocity distribution theory breaks down. For this reason, SAM will not apply the Keulegan equation when relative roughness is less than 3. Instead, the Strickler equation is automatically substituted.

Keulegan equations, rigid bed

The relative roughness approach based on the Keulegan (1938) equations for velocity distribution is still the state-of-the-art for rigid boundary channel design. Keulegan classified flow types as hydraulically smooth, hydraulically rough, or transitional. His equations can be combined with the Chezy equation to obtain a Chezy roughness coefficient. The equations are written in terms of the Chezy coefficient, C, because the powers are simpler than when the Manning's equation is employed. Chezy's C may then be converted directly to a Manning's n-value.

(1) The equation for fully rough flow is

$$C = 32.6 \log_{10}\left(\frac{12.2\ R}{k_s}\right)$$ **Equation 2-3**

(2) For smooth flow the equation is

$$C = 32.6 \log_{10}\left(\frac{5.2\ R_n}{C}\right)$$ **Equation 2-4**

The smooth flow equation is a trial and error solution, best accomplished using a computer program such as SAM.

(3) The equation for transitional flow is

$$C = -\ 32.6 \log_{10}\left(\frac{C}{5.2\ R_n} + \frac{k_s}{12.2\ R}\right)$$ **Equation 2-5**

(4) The equation showing the relationship of n-value and Chezy *C* is

$$n = \frac{1.486}{C} R^{1/6}$$ **Equation 2-6**

where

R_n = Reynolds number
= 4RV/υ
v = kinematic viscosity of water

and 32.6, 12.2 and 5.2 are empirical coefficients determined from laboratory experiments. These equations, when graphed, produce the Moody-type diagram for open channel flow, Figure B-3, EM 1110-2-1601 (USACE 1991, 1994).

The Iwagaki relationship

Using experimental data obtained from many sources, Iwagaki (Chow, 1959) found that the coefficients 12.2 and 5.2 in equations 2-3, 2-4, 2-5, and 2-6 varied with Froude number. The results of his study disclosed that resistance to turbulent flow in open channels becomes obviously larger with increase in the Froude number. Iwagaki reasoned that this is due to the increased instability of the free surface at high Froude numbers. The Iwagaki relationship is shown in Figure 2.2.

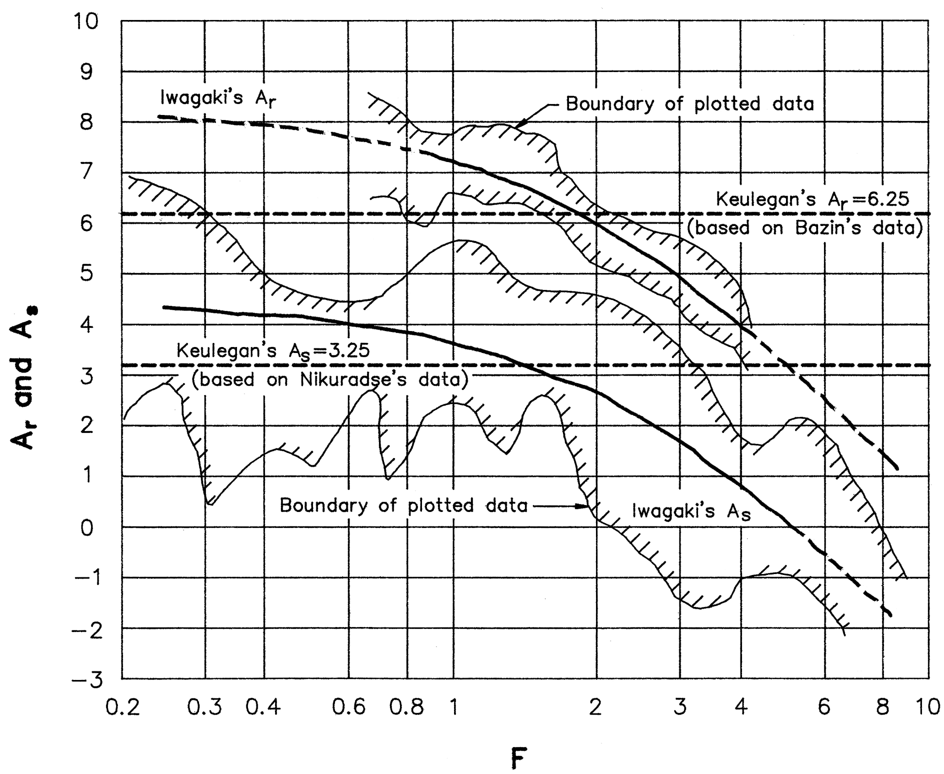


Figure 2.2. The Iwagaki relationship (Chow, 1959), used with permission from McGraw-Hill Book Company, Inc.

Keulegan's equations can be modified to incorporate Iwagaki's results.

(1) Chow (1959) presents Keulegan's equation for the average flow velocity V in the following form

$$V = U_* \left[6.25 + 5.75 \log_{10}\left(\frac{R}{k_s} \right) \right]$$ **Equation 2-7**

where

$U_* = \sqrt{gRS} =$ boundary shear velocity
g = acceleration of gravity
6.25 = empirical constant for fully rough flow

(2) The equation for rough flow may be obtained by substituting a variable, A_r, for the constant, 6.25, and $\sqrt{gRS}$ for U_*, and then combining with the Chezy equation.

$$\frac{V}{U_*} = \frac{C}{\sqrt{g}} = A_r + 5.75 \log_{10}\left(\frac{R}{k_s}\right)$$ **Equation 2-8**

$$C = \sqrt{g}\left[A_r + 5.75 \log_{10}\left(\frac{R}{k_s}\right)\right]$$ **Equation 2-9**

$$C = 32.6 \log_{10}\left[10^{\frac{A_r\sqrt{g}}{32.6}}\left(\frac{R}{k_s}\right)\right]$$ **Equation 2-10**

where A_r is the Iwagaki variable for rough flow. From Keulegan's study of Bazin's data, the value of A_r was found to have a wide range, varying from 3.23 to 16.92. Keulegan used a mean value of 6.25 for A_r.

(3) The comparable form of the equation for smooth flow is

$$C = 32.6 \log_{10}\left[10^{\frac{A_s\sqrt{g}}{32.6}}\left(\frac{\sqrt{g}\,R_n}{4C}\right)\right]$$ **Equation 2-11**

where A_s is the Iwagaki variable for smooth flow.

(4) The roughness equation in the transition zone is a combination of the equations for smooth and fully rough flow as follows:

$$C = -32.6 \log_{10}\left(\frac{4C}{\sqrt{g}\,R_n\,10^{\frac{A_s\sqrt{g}}{32.6}}} + \frac{k_s}{R\,10^{\frac{A_r\sqrt{g}}{32.6}}}\right)$$ **Equation 2-12**

A_r and A_s variables The A_r and A_s variables are shown graphically in Figure 2.2. An equation for A_r is

$$A_r = -27.058 \log_{10}(F + 9) + 34.289 \qquad \textbf{Equation 2-13}$$

where F is the Froude number. Data ranges from $0.2 < F < 8.0$.

Using an equation of the same form, the relationship for A_s is

$$A_s = -24.739 \log_{10}(F + 10) + 29.349 \qquad \textbf{Equation 2-14}$$

Equations 2-6, 2-10, 2-12, 2-13 and 2-14 are used in SAM.hyd to calculate the roughness coefficient when the Keulegan equations are specified.

Strickler Equation

The Strickler function is compared to measured data in Figure 2.3. (Chow, 1959) This figure shows that for a wide range in relative roughness, R/k_s, the variability of the Strickler function φ R/k_s is small. Strickler assumed this to be a constant, 0.0342 when k_s and R were expressed in feet. The effective surface roughness height, k_s, is the d_{50} of the bed sediment in this figure. However, k_s can be correlated with other measures of the surface roughness, depending on what is representative of the surface roughness height of the boundary materials. For example, riprap research at WES (Maynord 1991, 1992) has shown that the Strickler equation will give satisfactory n-values when k_s is taken to be the d_{90} of the stone.

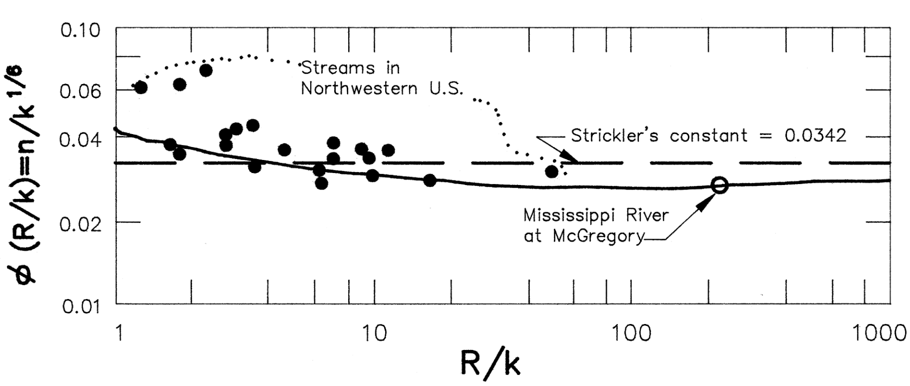


Figure 2.3. The Strickler Function (Chow, 1959), used with permission from McGraw-Hill Book Company, Inc.

$$n = \phi \frac{R}{k_s} k_s^{1/6}$$ **Equation 2-15**

where, in SAM,

k_s = effective surface roughness, ft
φ R/k_s = 0.0342 for natural channels,
where $k_s = d_{50}$
= 0.0342 for velocity and stone size calculations in riprap design,
where $k_s = d_{90}$
= 0.038 for discharge capacity calculations in riprap design,
where $k_s = d_{90}$

SAM uses different values for the Strickler function, depending on the calculations to be made. Chow (1959) recommends the use of 0.0342 for natural sediment, so that is the default value. In accordance with EM 1110-2-1601 (USACE 1991, 1994), 0.0342 is also used for velocity and stone size calculations. Thus, the same Strickler function is used in specified panels for cross-sections where some panels have riprap and others have natural sediment. Also in accordance with EM 1110-2-1601, 0.038 is used for water surface calculations after riprap has been calculated. In this case, n-values for all panels in the cross section will use this constant whether riprap was prescribed for that panel or not, possibly calculating some n-values incorrectly. Problems can be avoided by using another roughness equation in panels without riprap.

Limerinos n-value Predictor

Limerinos (1970) developed an empirical relative roughness equation for coarse, mobile bed streams using field data. He correlated n-values with hydraulic radius and bed sediment size. The resulting equation is shown below.

$$n = \frac{0.0926\, R^{1/6}}{1.16 + 2.0 \log_{10}\left(\frac{R}{d_{84}}\right)}$$ **Equation 2-16**

where

d_{84} = the particle size, ft, for which 84% of the sediment mixture is finer. Data ranged from 1.5 mm to 250 mm.
n = Manning's n value. Data ranged from .02 to 0.10.
R = Hydraulic radius, ft. Data ranged from 1 to 6 ft.

Grain sizes in Limerinos's data ranged from very course sand to large cobbles. Consequently, it follows that this equation is applicable to gravel/cobble bed streams and to bed regimes similar to those found in such streams and within the energy spectrum contained in Limerinos' field data. n-values predicted with the Limerinos equation are sufficiently larger than those predicted by the Strickler equation indicating that some loss other than grain roughness must have been present. The Limerinos equation is not applicable to lower regime flow nor does it forecast the transition between upper and lower regimes.

Burkham and Dawdy (1976) showed that the Limerinos equation could be used in sand bed streams provided the regime was plane bed. In their analysis they extended the range of the relative roughness parameter as follows.

$$600 < \frac{R}{d_{84}} < 10{,}000 \qquad \text{Equation 2-17}$$

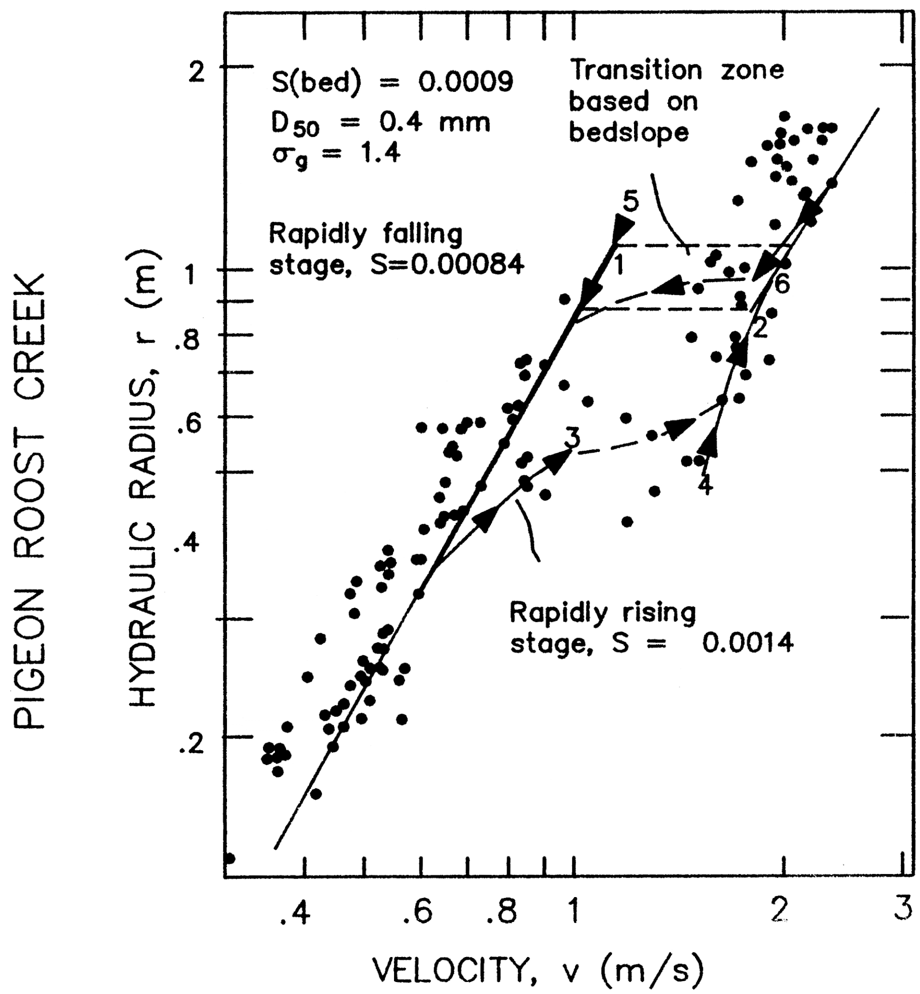


Figure 2.4. Velocity versus hydraulic radius in a mobile bed stream, used with permission of California Institute of Technology.

Brownlie (1983) Bed-roughness Predictor

In sediment transport calculations it is important to link n-values to the bed regime. This is particularly true when hydraulic conditions shift between upper regime and lower regime flow.

Brownlie sought to reconstitute the discontinuity in the graph of hydraulic radius versus velocity, Figure 2.4. (Brownlie 1983) In the process of his research, Brownlie collected the known sediment data sets, 77 in all, containing 7027 data points. Of the total, 75 percent were from flume studies and 25 percent from field tests. He used 22 of these data sets and demonstrated a significant agreement with both field and laboratory data.

Brownlie's basic equations were modified for SAM to display bed roughness as a coefficient times the grain roughness. Any consistent set of units are applicable.

n = [Bedform Roughness] * [Strickler Grain Roughness] **Equation 2-18**

The resulting form of the equations for lower and upper regime are:

LOWER REGIME FLOW:

$$n = \left(1.6940 \left(\frac{R}{d_{50}} \right)^{0.1374} S^{0.1112} \sigma^{0.1605} \right) 0.034 \left(d_{50} \right)^{0.167}$$ **Equation 2-19**

UPPER REGIME FLOW:

$$n = \left(1.0213 \left(\frac{R}{d_{50}} \right)^{0.0662} S^{0.0395} \sigma^{0.1282} \right) 0.034 \left(d_{50}{}^{0.167} \right)$$ **Equation 2-20**

where

d_{50} = the particle size for which 50% of the sediment mixture is finer.
R = hydraulic radius of the bed portion of the cross section.
S = bed slope; probably the energy slope would be more representative if flow is non-uniform.
σ = the geometric standard deviation of the sediment mixture, where

$$\sigma = 0.5\left(\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}}\right)$$ **Equation 2-21**

TRANSITION FUNCTION:

If the slope is greater than 0.006, flow is always UPPER REGIME. Otherwise, the transition is correlated with the grain Froude number as follows:

$$F_g = \frac{V}{\sqrt{(s_s - 1)\, g\ d_{50}}}$$ **Equation 2-22**

$$F_g{}' = \frac{1.74}{S^{1/3}}$$ **Equation 2-23**

if $F_g < F_g'$ Lower Regime Flow

if $0.8\ F_g' < F_g < 1.25\ F_g'$ Transition Flow

if $F_g > F_g'$ Upper Regime Flow

where

F_g = grain Froude number.
s_s = specific gravity of sediment particles.
V = velocity of flow.
S = bed slope.

The transition occurs over a range of hydraulic radii and not at a point. Over this range, then, it is a double-valued function, and the transition test will give different regimes depending on which equation is being solved for roughness at that iteration. That is realistic since one expects the rising side of a hydrograph to trigger the transition at a different discharge than does the falling side. This can cause the calculations to fail to converge in the transition zone, and the program will notify the user. **If convergence fails,** inspect the maximum and minimum values printed. Usually, the depths are the same whereas the discharges are significantly different. This signifies that the transition has been located from both the upper regime and the lower regime curves, and the results are the best that can be achieved.

Soil Conservation Service (SCS) Roughness for Grass Cover

Hydraulic roughness curves for five types of grass cover were published by SCS (US Department of Agriculture 1954), Figure 2.5. Each curve type, A through E, refers to grass conditions described in Table 4. EM 1110-2-1601 (USACE 1991, 1994) presents an example of the use of these curves.

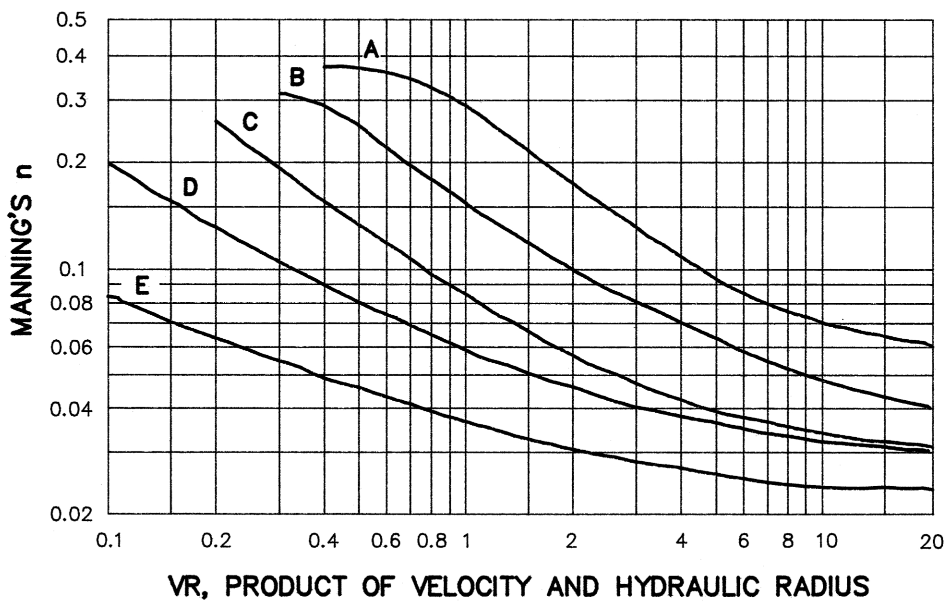


Figure 2.5. n-value relationships for grass cover.

Distribution of Hydraulic Roughness

Hydraulic roughness should be prescribed between each pair of coordinates, i.e., for each panel, as shown in Figure 2.6. It is important to establish which portion of the channel cross section is bed and which is bank because the bed roughness predictors apply only to the channel bed. That is, typically the vegetation roughness and bank angle do not permit the bed load to move along the face of the banks. Therefore, the Limerinos and Brownlie n-value equations should not be used to forecast bank roughness, i.e., should not be assigned to the channel banks.

On the other hand, the point bar is a natural source-sink zone for sediment transport. Consequently, it is a location at which Limerinos and Brownlie equations would apply.

Table 4. Characteristics of Grass Cover.

Type	Cover	Condition
A	Weeping lovegrass................	Excellent stand, tall (average 30 in.)
	Yellow bluestem Ischaemum....	Excellent stand, tall (average 36 in.)
B	Kudzu	Very dense growth, uncut
	Bermudagrass......................	Good stand, tall (average 12 in.)
	Native grass mixture (little bluestem, blue grama, other long and short midwest grasses)	Good stand, unmowed
	Weeping lovegrass................	Good stand, tall (average 24 in.)
	Lespedeza serices.................	Good stand, not woody, tall (average 19 in.)
	Alfalfa..............................	Good stand uncut (average 11 in.)
	Weeping lovegrass...............	Good stand, mowed (average 13 in.)
	Kudzu..............................	Dense growth, uncut
	Blue grama........................	Good stand, uncut (average 13 in.)
C	Crabgrass..........................	Fair stand, uncut (10 to 48 in.)
	Bermudagrass.....................	Good stand, mowed
	Common lespedeza.............	Good stand, uncut (average 11 in.)
	Grass-legume mixture--summer (orchard grass, redtop, Italian ryegrass and common lespedeza)	Good stand, uncut (6 to 8 in.)
	Centipedegrass....................	Very dense cover (average 6 in.)
	Kentucky bluegrass..............	Good stand headed (6 to 12 in.)
D	Bermudagrass......................	Good stand, cut to 2.5-inch height
	Common lespedeza..............	Excellent stand, uncut (average 4.5 in.)
	Buffalograss.......................	Good stand, uncut (3 to 6 in.)
	Grass-legume mixture--fall, spring (Orchardgrass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (4 to 5 in.)
	Lespedeza sericea................	After cutting to 2-inch height; very good stand before cutting
E	Bermudagrass......................	Good stand, cut to 1.5-inch height
	Bermudagrass......................	Burned stubble

None of the n-value equations account for momentum or bend losses. Presently, the only technique to account for bend losses is to increase the n-values by some factor. Chow (1959) presents the Cowan method for including bend losses. This method requires the user to input the n-values directly, thus this method could be applied by the user to the SAM input.

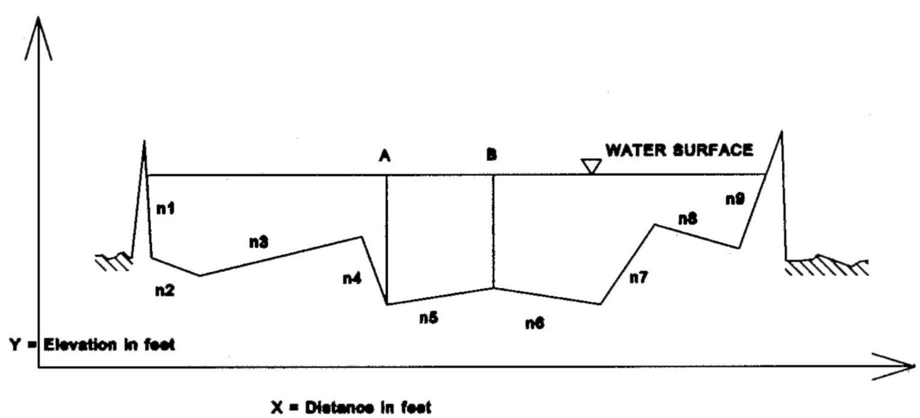


Figure 2.6. Prescribing hydraulic roughness.

Composite Hydraulic Properties

The compositing routines in SAM calculate representative hydraulic parameters for cross sections with complex geometry and variable roughness. Representative hydraulic parameters are used to calculate the same normal depth that would be calculated by a more rigorous analysis that analyzed each homogeneous cross-section subarea separately. Due to the obfuscated relationships between variables that can occur in compound and complex channels, parameter definition for a composite variable may be different than normally employed for that variable. For example, in the alpha compositing method, the composite hydraulic radius is not defined as the total area divided by the wetted perimeter; rather it includes, in addition to the usual geometric element property, the variation of both depth and n-values. There are several methods in the literature for compositing. The alpha method was selected as the default for SAM. Three other methods are provided as options: equal velocity, total force, and conveyance methods.

Alpha Method

The discussion of the derivation and use of hydraulic properties by the Alpha method appears in Appendix C, EM 1110-2-1601 (USACE 1991, 1994). A cross section is subdivided into panels between coordinate points. The divisions between panels are assumed to be vertical. The cross section is not subdivided between channel and overbanks for this calculation.

A water-surface elevation is either assigned or assumed, and calculations begin at the first wet panel in the cross section. The geometric properties of area and wetted perimeter are calculated, and the panel's hydraulic radius is calculated from them. The assigned roughness for the panel is converted to a Chezy C, and a panel conveyance is calculated. Computations move panel by panel to the end of the cross section. The composite cross-sectional area is defined as the sum of all the panel subareas and is the true area. The composite velocity is defined as the total discharge divided by the area, conserving continuity. The composite hydraulic radius is conveyance weighted as given by the following equation:

$$\overline{R} = \frac{\sum_{i=1}^{k} R_i \, C_i \, A_i \sqrt{R_i}}{\sum_{i=1}^{k} C_i \, A_i \sqrt{R_i}}$$

Equation 2-24

where:

$\overline{R}$ = the composite hydraulic radius
k = the number of panels
i = the panel number
$R_i = A_i / P_i$

C_i = the panel Chezy roughness coefficient
A_i = the panel cross-sectional area
P_i = Wetted perimeter in wet panel i

The composite roughness coefficient, $\bar{n}$, is calculated using the composite $\underline{R}$ in the Manning equation.

$$\bar{n} = \frac{1.486 \ \bar{R}^{\frac{2}{3}} \ S^{\frac{1}{2}} \sum_{i=1}^{k} A_i}{Q}$$

Equation 2-25

where:

S = energy slope
Q = total discharge

The alpha method ignores roughness on vertical walls, and renders roughness contributions negligible when there are steep side slopes. When significant roughness is contributed by vertical or steep side slopes, one of the other compositing methods should be employed.

Equal Velocity Method

A more rational compositing method for cross-sections with rough vertical walls or steep side slopes is the equal velocity method. It was proposed independently by both Horton and Einstein (Chow, 1959) and assumes that the velocity is equal in all panels. All hydraulic variables are calculated in the normal fashion except the Manning roughness coefficient, which is calculated using the following equation.

$$\bar{n} = \frac{\left(\sum_{i=1}^{k-1} P_i \, n_i^{1.5} \right)^{2/3}}{\left(\sum_{i=1}^{k-1} P_i \right)^{2/3}}$$

Equation 2-26

where

$\bar{n}$ = the composite n-value for the total section
n_i = n-value in wet panel i
k = number of panels

Since only wetted perimeter, and not hydraulic radius, appears in this equation, it is always well behaved. EM 1110-2-1601 (USACE 1991, 1994) discusses two other equal velocity methods. However, Horton's method was retained in SAM.hyd because of its simplicity. It is adequate for simple cross-section shapes, and it is programmable for complex cross-section shapes.

Total Force Method

This method was proposed by Pavlovskii, by Muhlhofer, and by Einstein and Banks (Chow, 1959). It is based on the hypothesis that the total force resisting the flow is equal to the sum of the forces resisting the flow in each panel. The resulting composite n-value is

$$\bar{n} = \frac{\left(\sum_{i=1}^{k} P_i \, n_i^2 \right)^{1/2}}{\left(\sum_{i=1}^{k} P_i \right)^{1/2}}$$

Equation 2-27

where

P_i = Wetted perimeter in wet panel i
n_i = n-value in wet panel i
P = Total wetted perimeter in cross section

Conveyance Method

With the conveyance method, a composite roughness coefficient is calculated based on weighted conveyances in three subsections. The conveyance method separates the overbanks from the channel so the calculations can be confined to strips, or subsections within the cross section, having similar hydraulic properties. The conveyance for each subsection can be calculated and the values summed to provide the conveyance for the entire cross section. The Manning equation is used to calculate conveyance instead of the Chezy equation used in the alpha method. Composite hydraulic radius is calculated as total area divided by total wetted perimeter, rather than as a conveyance weighted parameter -- thus the compositing characteristics are concentrated in the Manning's roughness coefficient. Conveyance for the overbanks and channel are calculated in English units using the following equations:

$$K_{LOB} = \frac{1.486\ A_{LOB}\left(\frac{A_{LOB}}{P_{LOB}}\right)^{2/3}}{\frac{\sum_{i=1}^{i=LCB} P_i\ n_i}{P_{LOB}}}$$

$$K_{CH} = \frac{1.486\ A_{CH}\left(\frac{A_{CH}}{P_{CH}}\right)^{2/3}}{\frac{\sum_{i=LCB}^{i=RCB} P_i\ n_i}{P_{CH}}}$$

$$K_{ROB} = \frac{1.486\ A_{ROB}\left(\frac{A_{ROB}}{P_{ROB}}\right)^{2/3}}{\frac{\sum_{i=LCB}^{k} P_i\ n_i}{P_{ROB}}}$$

Equation 2-28

$$K_{TOTAL} = K_{LOB} + K_{CH} + K_{ROB}$$

where:

K = conveyance
LOB = Left overbank
CH = channel
ROB = right overbank
LCB = left channel bank
RCB = right channel bank

The composite hydraulic radius is calculated using the following equation:

$$\overline{R} = \frac{\sum_{i=1}^{k} A_i}{\sum_{i=1}^{k} P_i}$$ **Equation 2-29**

$$\overline{n} = \frac{1.486\ A_{TOTAL}\ \overline{R}^{2/3}}{K_{TOTAL}}$$ **Equation 2-30**

The composite Manning's roughness coefficient for the total channel is calculated using the following equation:

Compositing in a narrow-deep channel

The importance of accounting for the roughness of the side slopes in the calculation of normal depth is illustrated by the following example. A proposed trapezoidal channel has a 60 ft base width, 1V:2H side slopes, a slope of 0.001, and a design discharge of 5000 cfs. Assuming that the sides slopes have a roughness coefficient of 0.08 and the bed has a roughness coefficient of 0.030, normal depth and composited hydraulic parameters, calculated using the four compositing methods in SAM, are shown in the following tabulation:

Comparison of Calculated Composite Hydraulic Parameters
Deep-Narrow Channel with High Side Slope Roughness

Method	Depth ft	Area sq ft	R ft	Velocity ft/sec	n
Alpha	10.4	839	10.0	6.0	0.037
Equal Velocity	14.7	1312	10.4	3.8	0.059
Total Force	15.0	1356	10.6	3.7	0.062
Conveyance	14.3	1262	10.2	4.0	0.056

The calculated depth is significantly lower with the alpha method because the side slope roughness is inadequately accounted for due to the assumption of vertical divisions between panels. If the side slopes had been vertical the alpha method would have completely neglected their contribution to roughness.

Compositing compound channels and overbanks

Variable roughness and depth across the cross-section introduce turbulence into the flow which results in additional energy loss due to the momentum transfer. Existing theory is currently inadequate to properly quantify the magnitude of these losses. However, it is important that these losses be recognized and considered when choosing a compositing technique.

Compositing by the equal velocity and total force methods can overemphasize the contribution to roughness of channel subareas in cases where homogeneous flow conditions do not exist, such as on irregular overbanks. The same effect can occur with the conveyance method in SAM when only a single subsection is considered. James and Brown (1977) reported that without adjustments to either the resistance coefficient or the hydraulic radius, using composite hydraulic parameters in the Manning or Chezy equations did not accurately predict the stage-discharge relation in a channel-floodplain configuration when there were shallow depths on the floodplain--1.0 < Y/D < 1.4, where Y is water depth in the channel and D is the bank height. However, the effects of geometry seemed to disappear at the higher stages, i.e., for Y/D > 1.4, when it no longer became necessary to make any correction to the basic equations. Figure 2.7 summarizes that finding, stressing that the conveyance (separate-channels) method is the best choice if Y/D falls within the 1.0 to 1.4 range and that another method should be used if Y/D > 1.4.

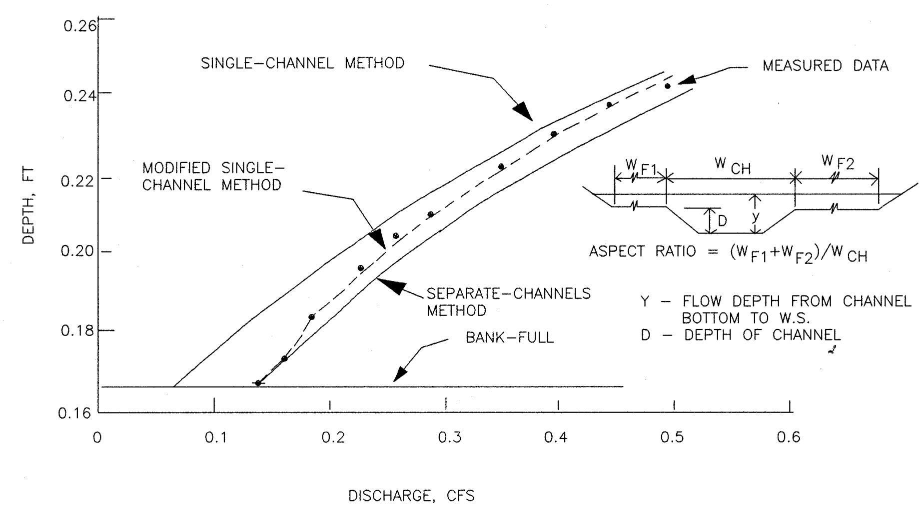


Figure 2.7. Comparison of measured data and theoretical methods.

Effective Hydraulic Parameters for Sediment Transport

The problem of obtaining representative hydraulic parameters is critical when making sediment transport calculations involving complex cross sections. The velocity, depth, width and slope are needed for subsections having similar hydraulic properties. This requirement leads to a compositing technique that produces an EFFECTIVE WIDTH and an EFFECTIVE DEPTH. Variables in the following equations are illustrated in Figure 2.8.

$$EFD = \frac{\Sigma D_i \; A_i D_i^{\;2/3}}{\Sigma A_i \; D_i^{\;2/3}}$$ **Equation 2-31**

$$EFW = \frac{\Sigma \; A_i D_i^{\;2/3}}{EFD^{5/3}}$$ **Equation 2-32**

where

A_i = Area of panel i, $\Delta X \, D_i$
D_i = Average depth of panel i, 1/2 (A+B)
EFD = Effective Depth of the cross section
EFW = Effective Width of the cross section

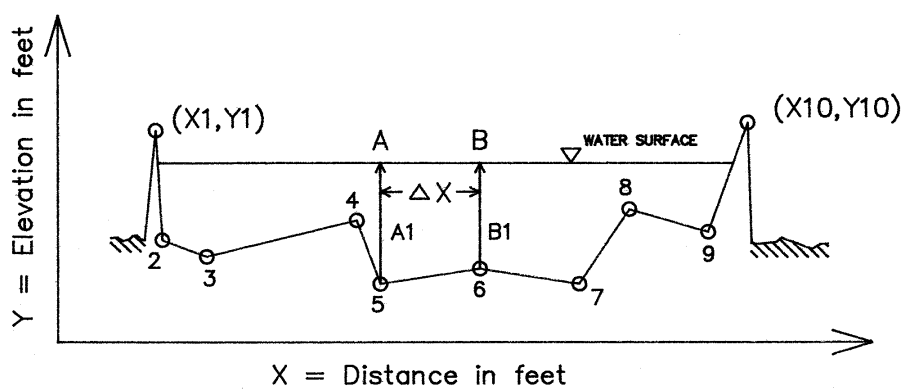


Figure 2.8. Calculating effective depths and widths.

In SAM the slope can be either the bed slope, water surface slope, or energy slope since all are parallel in normal depth computations. Effective values are calculated in SAM after the normal depth has been determined. Although effective values are calculated for both overbanks and the channel, only the channel values are written into the sediment transport input file for sediment transport calculations.

Flow Distribution Across the Cross Section

Flow distribution across the cross section will be calculated when all the variables in the uniform flow equation are prescribed. In addition, flow distribution will be calculated after the uniform flow equation is solved for an unknown variable. A conveyance weighted discharge, Q_i, is calculated for each panel using the following equation:

$$Q_i = Q\left(\frac{C_i\, A_i \sqrt{R_i}}{\Sigma\, C_i\, A_i \sqrt{R_i}}\right)$$ **Equation 2-33**

where

Q = total discharge
C = Chezy coefficient
A = area
R = hydraulic radius
i = panel number

Bottom Width Calculation-Fixed Bed

This option allows bottom width to become the dependent variable in the uniform flow equation:

$$W = f\ (Q, n, D, z, S)$$ **Equation 2-34**

where

Q = water discharge
D = water depth
z = side slopes of the channel
n = n-value
S = energy slope

This bottom width calculation is strictly a solution of the uniform flow equation for a fixed bed and does not consider sediment transport requirements. This option can only be used when a trapezoidal channel is specified on a CT-record. The compound channel may have up to 3 trapezoidal-shaped templates. The solution technique begins by sizing the low flow channel first, then solving for the main channel and then the overbank channel.

Energy Slope Calculation

This option allows the energy slope to become the dependent variable in the uniform flow equation:

$$S = f \ (Q, n, W, D, z) \qquad \textbf{Equation 2-35}$$

The calculations are trial and error and convergence may be difficult. The Brownlie n-value relationships may result in convergence failure due to the discontinuity at the transition between lower and upper regime flow. SAM.hyd prints a message to the output file when convergence fails.

Hydraulic Roughness Calculation

This option allows the n-value to become the dependent variable in the uniform flow equation.

$$n = f \ (Q, W, D, z, S) \qquad \textbf{Equation 2-36}$$

It is especially useful for calculating unknown roughness for one section of the cross-section when roughness in known for other sections of the cross-section.

This calculation, like the other solutions of the uniform flow equation which involve compositing, is trial and error. A simple solution of the Manning equation for the total cross section is used to calculate the first trial roughness. Roughness can be specified in some panels and calculated for others. If a roughness in a panel is input, the program will convert it to a k_s using the Keulegan equation for fully rough flow unless the equation specified is Strickler. However, only the Keulegan or Strickler equations can be used to calculate roughness. If the program is asked to calculate roughness using the Manning's equation option then it automatically uses the Strickler equation. If the program is asked to calculate roughness using the Brownlie or Limerinos equation then there is nothing to calculate because the roughness has been implicitly determined by the bed gradation used. If the program is asked to calculate roughness using the Grass equations then there is still nothing to calculate because the roughness is again implicitly determined by the Grass equation chosen.

NOTE: Limerinos, Brownlie and the Grass equations are not to be used with negative roughness values because there is nothing to calculate — the roughness is implicitly determined by the bed gradation or the grass.

Roughness in the remaining panels will be calculated as a specified proportion of k_s for the Manning, Strickler, and Keulegan equations. The iterative solution for k_s uses the secant method for convergence as follows.

$$X_3 = X_2 - \left(\frac{f(X_2)}{f(X_2) - f(X_1)} \right) (X_2 - X_1) \qquad \textbf{Equation 2-37}$$

where

X_1 = is the first trial value of k_s
$f(X_1)$ = is the difference between Qtrue and the calculated Q for X_1
X_2 = is the second trial value of k_s
$f(X_2)$ = is the difference between Qtrue and calculated Q for X_2
X_3 = is the next trial value of k_s.

Of the several equations for hydraulic roughness, the Strickler equation is the most likely to converge. The Limerinos, Brownlie, and grass equations are independent of k_s and therefore cannot be used to solve for k_s. This algorithm is primarily intended for use with equations using k_s. Expect convergence problems with other equations.

Water Discharge Calculation

This option allows the water discharge to become the dependent variable in the uniform flow equation.

$$Q = f(Q, W, D, z, S) \qquad \textbf{Equation 2-38}$$

This calculation, like the other solutions of the uniform flow equation which involve compositing, is trial and error. It also uses the secant method for convergence. When convergence fails, assume a range of discharges and use the normal depth calculations to arrive at the correct value.

Riprap Size for a Given Velocity and Depth

When flow velocity and depth are known, the riprap size is calculated using the following equation, taken from EM 1110-2-1601(1991,1994):

$$d_{30cr} = S_f\, C_S\, C_V\, C_T\, D \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V_{AVE}\, C_B}{\sqrt{K_1\, g\, D}} \right]^{2.5}$$ **Equation 2-39**

where

- d_{30CR} = Critical d_{30} (i.e. minimum d_{30}) size for stable riprap
- S_f = Safety factor
- C_S = Coefficient of incipient failure
- C_V = vertical velocity coefficient
- C_T = coefficient for riprap thickness
- D = local water depth
- γ_w = unit weight of water
- γ_s = unit weight of riprap
- V_{AVE} = average channel velocity
- C_B = bend correction for average velocity (V_{SS}/V_{AVE})
- K_1 = Correction for side slope steepness
- g = Acceleration of gravity

Required input data for simple riprap calculations are: average channel velocity, depth at the toe of the riprap, channel width, side slope, bend radius, bend angle, riprap specific weight, and whether the cross-section is trapezoidal or natural.

Riprap Gradation Tables

Size and specific gravity of available riprap are needed for this calculation, and the 13 standard riprap sizes shown in EM 1110-2-1601 are encoded into SAM.hyd as shown in the Table 6. Calculations begin with the smallest size stone and continue until a stable size is reached.

Quarry-Run Stone

A known riprap gradation table may be specified in SAM. This input is not currently available in SAMwin This option is useful for quarry-run riprap where the gradation is known. Up to 5 sizes of quarry run riprap can be encoded. These gradations should be entered one size per record starting with the smallest and ending with the largest size. When this information is present, riprap size computations use the quarry run stone. When quarry run stone is prescribed, those stone sizes are used in lieu of the gradation tables encoded in SAM.

Table 6. Graded Riprap Sizes.

Low Turbulence zones, placed in the dry, γ_s = 165 lbs/cuft

Layer No.	DMAX[1] in	D30[1] ft	D50[1] ft	D90[1] ft	POROSITY[2] %
1	9	0.37	0.43	0.53	38
2	12	0.48	0.58	0.70	38
3	15	0.61	0.73	0.88	38
4	18	0.73	0.88	1.06	38
5	21	0.85	1.03	1.23	38
6	24	0.97	1.17	1.40	38
7	27	1.10	1.32	1.59	38
8	30	1.22	1.46	1.77	38
9	33	1.34	1.61	1.94	38
10	36	1.46	1.75	2.11	38
11	42	1.70	2.05	2.47	38
12	48	1.95	2.34	2.82	38
13	54	2.19	2.63	3.17	38

Notes:
[1] These values were taken from EM 1110-2-1601.
[2] These values are estimated from one set of field data.

Riprap Size for a Given Discharge and Cross-Section Shape

Riprap size is a more complicated calculation when water discharge and cross section are given than it is when the flow velocity and depth are given because n-value becomes a function of riprap size. The computational procedure in SAM.hyd is as follows.

The computations begin with the unprotected channel. The bed sediment size is determined as the d_{50} calculated from the given bed gradation. Input must include hydraulic roughness equations and either n-values or k_s values, as required for normal depth computations. If the Strickler equation is selected for hydraulic roughness, the Strickler coefficient is 0.034, which is the value for natural sediment where $k_s = d_{50}$ (Chow, 1959). Normal depth is calculated using the alpha method, and flow is distributed across the section. Stability of the bed sediment is then calculated at each cross section coordinate using the distributed velocity and the depth at that point. Shield's Diagram is used to test for particle stability. The calculated shear stress is compared to the critical shear stress determined from Shield's diagram.

$$\tau_c = \Theta(\gamma_s - \gamma_w) d_{50}$$ **Equation 2-40**

where:

τ_c = critical shear stress
Θ = Shield's parameter

If this test shows that the actual bed shear stress exceeds the critical value then the bed sediment is diagnosed as unstable. If the panel is designated as a panel where riprap computations are desired, SAM will solve the riprap equation to find the smallest riprap size that will be stable. If the panel is not so designated, the program prints a message to the output file concerning the instability.

Considerable care must be employed when applying the cross-section shape option because flow conditions may be outside the range of conditions used to develop the riprap equations. When this option is used, it is important that the side slope protection be defined as a single panel in the geometry input. SAM will use 0.8 times the maximum depth in the panel for the local flow depth in the riprap equation. When a bend radius is specified, SAM uses the average velocity in the cross section for V_{AVE} in the riprap equation. Therefore, it is important that the input geometry include only channel geometry and discharge. When a bend radius is not specified, SAM uses the calculated panel velocity for V_{AVE} in the riprap equation. This calculation may provide useful information for compound channels in straight river reaches, but it is an extension of the procedure outlined in EM 1110-2-1601. Careful study of the recommendations and guidelines described in EM 1110-2-1601 should be considered essential.

In SAM, riprap computations begin with the smallest rock size. The hydraulic roughness equation, in each panel designated as having riprap, is automatically changed to the Strickler equation and the Strickler coefficient, is set equal to 0.034. Normal depth is calculated for the resulting n-values. The alpha method is used to calculate normal depth and flow is distributed across the section. The riprap size equation is solved for each panel. When the resulting size is stable in each panel, riprap computations are finished. Otherwise, computations move to the next larger riprap size and the procedure is repeated.

After the stable stone size is determined, a stage discharge curve is calculated for the riprapped channel. The Strickler coefficient, which was 0.034 when determining stone size, is increased to 0.038 in this calculation for flow capacity. This calculation determines the rating curve with the selected riprap in place.

Blench Regime Equations

Stable channel dimensions may be calculated using the Blench (1970) regime equations. These regime equations are also shown in ASCE Manual 54 (ASCE 1975). The equations were intended for design of canals with sand beds. The basic three channel dimensions, width, depth and slope, are calculated as a function of bed-material grain size, channel-forming discharge, bed-material sediment concentration, and bank composition.

$$W = \left(\frac{F_B \; Q}{F_S} \right)^{0.5}$$ **Equation 2-41**

$$F_B = 1.9 \sqrt{d_{50}}$$ **Equation 2-42**

$$D = \left(\frac{F_S \; Q}{F_B^2} \right)^{\frac{1}{3}}$$ **Equation 2-43**

$$S = \frac{F_B^{0.875}}{\dfrac{3.63 \; g}{\nu^{0.25}} W^{0.25} D^{0.125} \left(1 + \dfrac{C}{2,330} \right)}$$ **Equation 2-44**

where

W = channel width - ft
F_B = bed factor
F_S = side factor
Q = water discharge -cfs
d_{50} = median grain size of bed material - mm
D = depth - ft
S = slope
C = bed-material sediment concentration - in parts per million
g = acceleration of gravity - ft/sec^2
υ = kinematic viscosity - ft^2/sec

The results are true regime values only if Q is the channel forming discharge. However, a width, depth and slope will be calculated for any discharge by these equations.

Blench suggests that the following values be used for the side factor:

F_S = 0.10 for friable banks
F_S = 0.20 for silty, clay, loam banks
F_S = 0.30 for tough clay banks

In order to calculate the Blench regime dimensions, the side factor, bed-material sediment concentration, and the bed-material gradation should be input. SAM.hyd sets default values for the Blench variables if none are specified: F_S = 0.20, C = 0.0, and d_{50} = 0.25 mm.

Stable Channel Dimensions

SAM may be used to calculate stable channel dimensions that will pass a prescribed sediment load without deposition or erosion. This analytical approach (Copeland, 1994) determines dependent design variables of width, slope, and depth from the independent variables of discharge, sediment inflow, and bed material composition. It involves the solution of flow resistance and sediment transport equations, leaving one dependent variable optional. Minimum stream power is used as a third equation for an optional unique solution. This method is based on a typical trapezoidal cross section and assumes steady uniform flow. The method is especially applicable to small streams because it accounts for transporting the bed material sediment discharge in the water above the bed, not the banks, and because it separates total hydraulic roughness into bed and bank components.

Basic Equations for Sand-bed Streams

If the sand-bed option is selected, SAM uses the sediment transport and resistance equations developed by Brownlie (1981). There are separate resistance equations for upper and lower regime flow. The equations are dimensionless and can be used with any consistent set of units.

Upper regime:

$$R_b = 0.2836\, d_{50}\, q_*^{0.6248}\, S^{-0.2877}\, \sigma^{0.0813}$$

Equation 2-45

Lower regime:

$$R_b = 0.3742\, d_{50}\, q_*^{0.6539}\, S^{-0.2542}\, \sigma^{0.1050}$$

Equation 2-46

$$q_* = \frac{V\,D}{\sqrt{g\,d_{50}^3}}$$

where:

R_b = hydraulic radius associated with the bed
d_{50} = median grain size
S = slope
σ = geometric bed material gradation coefficient

V = average velocity
D = water depth
g = acceleration of gravity

To determine if upper or lower regime flow exists for a given set of hydraulic conditions, a grain Froude number F_g and a variable F_g' were defined by Brownlie. According to Brownlie, upper regime occurs if $S > 0.006$ or if $F_g > 1.25\,F_g'$, and lower regime occurs if $F_g < 0.8\,F_g'$. Between these limits is the transition zone. In the analytical method, $F_g = F_g'$ is used to distinguish between upper and lower regime flow. The program will inform the user which regime is being assumed in the calculations and if the bed forms are in the transition zone.

$$F_g = \frac{V}{\sqrt{g\, d_{50}\left(\frac{\gamma_s - \gamma}{\gamma}\right)}}$$

Equation 2-47

$$F_g' = \frac{1.74}{S^{0.3333}}$$

where:

γ_s = specific weight of sediment
γ = specific weight of water

The hydraulic radius of the side slope is calculated using Manning's equation:

$$R_s = \left(\frac{V\, n_s}{1.486\, S^{0.5}}\right)^{1.5}$$

Equation 2-48

where:

R_s = hydraulic radius associated with the side slopes, ft
V = average velocity, fps
n_s = Manning's roughness coefficient for the bank

If the roughness height k_s of the bank is known, then it can be used instead of Manning's roughness coefficient to define bank roughness. The model uses Strickler's equation to calculate the bank roughness coefficient:

$$n_s = 0.039\, k_s^{\frac{1}{6}}$$ **Equation 2-49**

where k_s is the roughness height, in ft. For riprap, k_s should be set equal to the minimum design d_{90}.

Composite hydraulic parameters are partitioned in the manner proposed by Einstein (1950):

$$A = R_b P_b + R_s P_s$$ **Equation 2-50**

where:

A = total cross-sectional area
P_b = perimeter of the bed
P_s = perimeter of the side slopes

This method assumes that the average velocity for the total cross section is representative of the average velocity in each subsection.

Concentration, C, in ppm, is calculated using the Brownlie sediment transport equation, which is also a regression equation and is based on the same extensive set of flume and field data used to develop his resistance equations. This equation was chosen because of its compatibility with the resistance equations, which are coupled with the sediment transport equation in the numerical solution:

$$C = 9022\,(F_g - F_{go})^{1.978}\, S^{0.6601} \left(\frac{R_b}{d_{50}}\right)^{-0.3301}$$ **Equation 2-51**

$$F_{go} = \frac{4.596\, \tau_{*o}^{0.5293}}{S^{0.1405}\, \sigma^{0.1606}}$$ **Equation 2-52**

$$\tau_{*o} = 0.22\, Y + 0.06\,(10)^{-7.7\, Y}$$ **Equation 2-53**

where

$$Y = \left(\sqrt{\frac{\gamma_s - \gamma}{\gamma}} \right)^{-0.6}$$

and

$$R_g = \frac{\sqrt{g\, d_{50}^{\;3}}}{\nu}$$

Basic Equations for Gravel-bed Streams

If the gravel-bed option is selected, SAM uses equations more appropriate for coarse bed streams. Sam uses the Limerinos (1970) equation to calculate grain roughness on the bed. The Manning equation is used to calculate the roughness on the channel side slope. Additional roughness may be added in the manner suggested by Cowan (1956). Sediment transport is calculated using the Meyer-Peter and Muller (1948) equation.

The Limerinos equation accounts for the grain roughness in a uniform reach of a gravel-bed stream that is relatively free of bed forms. The Limerinos equation may be presented in dimensionless units as:

$$\frac{V}{U'_*} = 5.66 \log \left(3.80\, {R'_b}/{d_{84}} \right)$$

where:

V = average velocity
U'_* = shear velocity associated with grain roughness
R'_b = hydraulic radius associated with grain roughness
d_{84} = grain size for which 84% of the bed is finer.

Manning's roughness coefficient associated with grain roughness can be determined from the Limerinos equation:

$$n'_b = \frac{CME\; {R'_b}^{1/6}}{g\; 5.66 \log\left(3.80\, {R'_b}/{d_{84}} \right)}$$

where:

n'_b = roughness coefficient associated with bed
CME = 1.486 English units
1.0 SI units

R_b' = bed hydraulic radius associated with grain roughness (ft or m)
g = acceleration of gravity (ft/s or m/s)
d_{84} = grain size for which 84" of the bed is finer (ft or m)

Additional bed roughness may be added to the grain bed roughness using the Cowan (1956) method. Roughness may be added to account for factors such as surface irregularities, variability in channel shape, obstructions, vegetation and meandering. Meandering is accounted for with a meandering coefficient, m. In a straight channel the meandering coefficient is 1.0. Appropriate values for the meandering coefficient and additions to the grain roughness n-value can be found in Cowan (1956) and Chow (1959). Using the Cowan equation the total bed roughness coefficient is:

$$n_b = m\left(n_b'' + n_b'\right)$$

where:

n_b = total bed roughness coefficient
m = Cowan meander coefficient
n_b'' = bed roughness other than grain roughness.

Using the Manning equation the hydraulic radius associated with the bed is calculated

$$R_b = \left(\frac{V\, n_b}{S^{1/2}\, CME}\right)^{3/2}$$

where:

S = channel slope.

The hydraulic radius associated with the bank or side slope is

$$R_s = \left(\frac{V\, n_s}{S^{1/2}\, CME}\right)^{3/2}$$

where:

n_s = the roughness coefficient associated with the side slope.

Values for m, n_b'', and n_s must be selected by the user and provided as program input.

If the roughness height, k_s, of the bank is known, then it can be used instead of Manning's roughness coefficient to define bank roughness. The model uses Strickler's equation to calculate the bank roughness coefficient

$$n_s = 0.039\, k_s^{1/6}$$

where k_s is the roughness height in feet.

Composite hydraulic parameters are partitioned in the manner proposed by Einstein (1950),

$$A = R_b\, P_b + R_s\, P_s$$

where:

A = total cross-sectional area
P_b = perimeter of the bed
P_s = perimeter of the side slopes.

This method assumes that the average velocity for the total cross section is representative of the average velocity in each subsection (equal velocity method of compositing).

Sediment transport for the gravel-bed option is calculated using the Meyer-Peter Muller equation:

$$\left(\frac{k_r}{k_r'}\right)^{3/2} \gamma_w\, R_b\, S = 0.047\left(\gamma_s - \gamma_w\right) d_m + 0.25\left(\frac{\gamma_w}{g}\right)^{1/3}\left(\frac{\gamma_s - \gamma_w}{\gamma_s}\right)^{2/3} g_s^{2/3}$$

where:

k_r = total bed roughness = $1/n_b$
k_r' = particle roughness = $1/n_b'$
γ_w = specific weight of water, lbs/ft3 or N/m3
γ_s = specific weight of sediment
d_m = median sediment size, ft or m
g_s = sediment transport in lbs/sec-ft or N/sec-m
R_b = bed hydraulic radius in ft or m

and

$$\left(\frac{k_r}{k'_r}\right)^{3/2} R_b = R'_b$$

and

$$d_m = \sum_{i=1}^{n} f_i \, d_i$$

where:

f_i = fraction of size class "i" in bed
d_i = geometric mean diameter of size class "i" in bed.

Calculating sediment discharge and concentration

A typical cross section, with the critical hydraulic parameters labeled, is shown in Figure 2.9. The concentration calculated from the sediment transport equation applies only vertically above the bed. Total sediment transport in weight per unit time is calculated by the following equation:

$$Q_s = \gamma \, C \, B \, D \, V$$ **Equation 2-54**

where:

Q_s = sediment transport in weight/time
B = base width

$$\overline{C} = \frac{Q_s}{0.0027\,Q}$$ **Equation 2-55**

An average concentration for the total discharge is then calculated:

where:

$\overline{C}$ = concentration using the total discharge, in ppm
Q_s = sediment transport in tons/day
Q = discharge in cfs

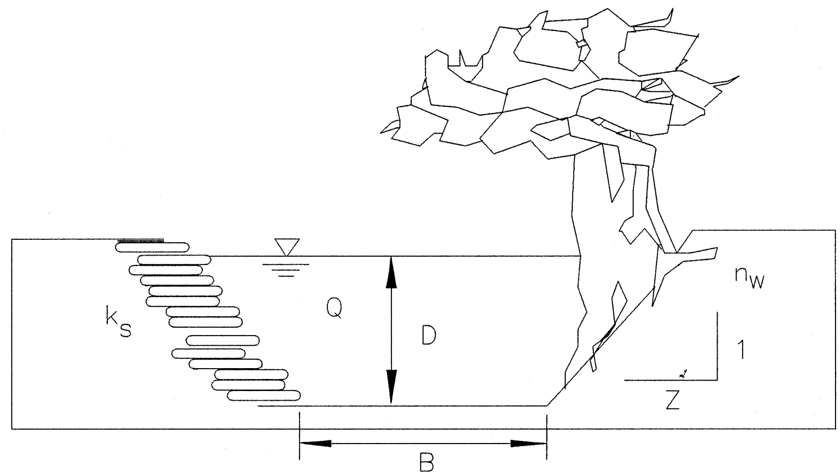


Figure 2.9. Typical cross section used in analytical method.

Input Requirements

Required input data are sediment inflow concentration, side slope, bank roughness coefficient, bed material d_{50}, bed material gradation coefficient, and water discharge. If sediment inflow is to be calculated, which is the recommended procedure, then additional data are required for the supply reach. These are: base width, side slope, bank roughness coefficient, bed-material median grain size, geometric gradation coefficient, average slope, and discharge. It is important that the base width be representative of the total movable-bed width of the channel. The bank roughness should serve as a composite of all additional roughness factors, i.e., channel irregularities, variations of channel cross-section shape, and the relative effect of obstructions, vegetation, and sinuosity. Only flow that is vertical above the bed is considered capable of transporting the bed material sediment load. If the gravel bed calculations are to be made, the user has the option of inputting the added roughness and meander multiplier for the Cowan option.

Water Discharge

The design discharge is critical in determining appropriate dimensions for the channel. Investigators have proposed different methods for estimating that design discharge. The 2-year frequency flood is sometimes used for perennial streams. For ephemeral streams the 10-year frequency is sometimes used. The “bankfull” discharge is sometimes suggested. Others prefer using the "effective" discharge, which is the discharge that transports the most bed material sediment. Currently, there is no generally accepted method for determining the channel-forming discharge. It is recommended that a range of discharges be used in the analysis to test sensitivity of the solution.

Inflowing Sediment Discharge

This is the concentration of the inflowing bed material load. It is best if SAM.hyd is allowed to calculate the sediment concentration based on hydraulic conditions in the sediment supply reach. The bed material composition is defined by the median grain size and the gradation coefficient.

Valley Slope

Valley slope is the maximum possible slope for the channel invert. This value is used in the test for sediment deposition. If the required slope exceeds the prescribed valley slope, the following message is printed:

>>>>MINIMUM SLOPE IS GREATER THAN VALLEY SLOPE - THIS IS A SEDIMENT TRAP <<<<

Bank Slopes and Roughness

The analytical method assumes that all bed material transport occurs over the bed of the cross section and that none occurs above the side slopes. Therefore, the portion of water conveyed above the side slopes expends energy but does not transport sediment, making "Flow Distribution" an extremely important calculation. The input parameters for flow distribution are bank angle and bank roughness. The recommended procedure to use for this is discussed in Chapter 5 of EM 1110-2-1601 (USACE 1991, 1994). Any roughness input for the bed will be disregarded by the calculations as bed roughness is calculated using the Brownlie equations. For maximum transport of sediment, use the steepest bank angle allowed by bank stability requirements.

Range of Solutions

Stable channel dimensions are calculated for a range of widths. For each combination of slope and base width, a unique value of depth is calculated. This can be used to evaluate stability in an existing channel or in a proposed design channel. It is important to consider river morphology when interpreting these calculated values. It is also important to be consistent in the selection of channel dimensions. That is, once a width is selected, the depth and slope are fixed. This allows the designer to select specific project constraints, such as right-of-way or bank height or minimum bed slope, and then arrive at a consistent set of channel dimensions.

If the calculations indicate that the slope of the project channel needs to be less than the natural terrain, the slopes in the table can be used to aid in spacing drop structures or in introducing sinuosity into the project alignment.

An example of a family of slope-width solutions that satisfy the resistance and sediment transport equations for the design discharge is illustrated by Figure 2.11. Any combination of slope and base width from this curve will be stable for the prescribed channel design discharge. Combinations of width and slope that plot above the stability curve will result in degradation, and combinations below the curve will result in aggradation. The greater the distance from the curve, the more severe the instability.

Constraints on this wide range of solutions may result from a maximum possible slope, or a width constraint due to right-of-way. Maximum allowable depth could also be a constraint. Depth is not plotted in Figure 2.10, but it is calculated for each slope and width combination determined. With constraints, the range of solutions is reduced.

Different water and sediment discharges will produce different stability curves. First, the stable channel solution is obtained for the channel-forming discharge. Then, stability curves are calculated for a range of discharges to determine how sensitive the channel dimensions are to variations in water and sediment inflow events.

The stable channel dimensions are calculated for a range of widths on either side of a prescribed median value. If no median value is prescribed, the program assigns a value based on the hydraulic geometry equation proposed in EM 1110-2-1418 (USACE 1994).

$$B = 2.0\,Q^{0.5}$$ **Equation 2-56**

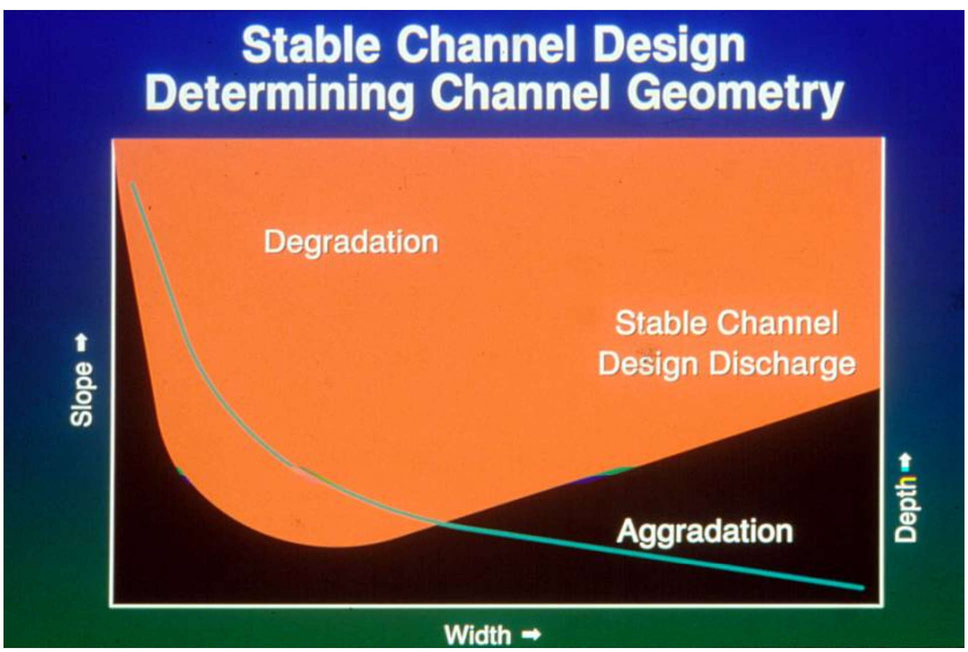


Figure 2.10. Graph of a family of slope-width solutions.

The SAM program assigns 20 base widths for the calculation, each with an increment of 0.1B. Calculations for these conditions are displayed as output. Stability curves can then be plotted from these data.

A solution for minimum stream power is also calculated by the model. This solution represents the minimum slope that will transport the incoming sediment load. Solution for minimum slope is obtained by using a second-order Lagrangian interpolation scheme. Opinions are divided regarding the use of minimum stream power to uniquely define channel stability.

An optional use of the analytical method is to assign a value for slope, thereby obtaining unique solutions for width and depth. Typically there will be two solutions for each slope.

Meander Program

Langbein and Leopold (1966) proposed the sine-generated curve as an analytical descriptor for meander planform in sand-bed rivers. Their "theory of minimum variance" is based on the hypothesis that the river will seek the most probable path between two fixed points, which is described by the following equation:

$$\phi = \omega \cos \frac{2 s \pi}{M}$$ **Equation 2-57**

where:

φ =	angle of the meander path with the mean longitudinal axis
ω =	maximum angle a path makes with the mean longitudinal axis
s =	the curvilinear coordinate along the meander path
M =	the meander arc length

These variables are shown in Figure 2.11.

Meander planform may thus be described with a shape parameter, ω, and a scale parameter, M. The sine generated curve has been shown to effectively replicate meander patterns in a wide variety of natural rivers. (Langbein and Leopold, 1966)

The purpose of the meander algorithm in SAM is to provide both curvilinear and Cartesian coordinates for a meander planform based on the sine-generated curve. Required input are the meander arc length, M, and the meander wave length, λ. The meander arc length can be determined from the valley slope, the meander wave length, and the design stable channel slope.

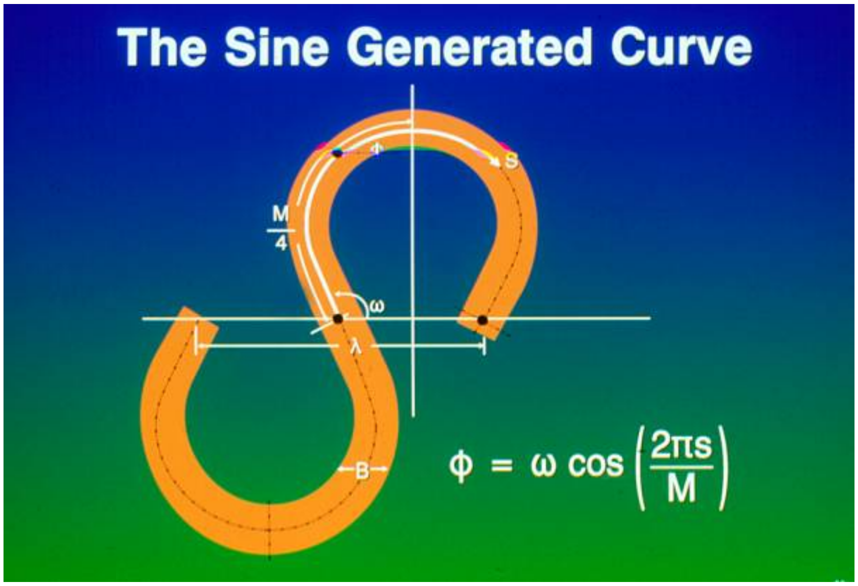


Figure 2.11. Variable definitions for the Meander Program.

$$M = \frac{\lambda \ * valley\ slope}{channel\ slope}$$ **Equation 2-58**

The meander wavelength can be determined using hydraulic geometry relationships or the analogy methodology. Generalized hydraulic geometry relationships for meander wavelength can be found in EM 1110-2-1418 and Copeland et al 2001. The analogy method is described in Chapter 5 of Copeland et al, 2001.

3 Theoretical Basis for SAM.sed Calculations

Purpose

Sediment transport functions can be used to calculate the bed material portion of the sediment discharge rating curve. This rating curve can then be used in the Flow-Duration Sediment-Discharge Rating Curve Method, programmed in SAM.yld, to calculate the bed-material sediment yield. Various sediment transport equations have been programmed into SAM.sed.

EM 1110-2-4000, "Sediment Investigations of Rivers and Reservoirs," provides a good description of the mechanics of sediment transport (USACE 1989).

General

SAM.sed will calculate a sediment discharge rating curve based on hydraulic conditions and the bed gradation. The hydraulic input data for SAM.sed can be calculated using SAM.hyd or or it can be determined external to the program and input directly (SAM.m95 can be sued only in DOS mode). SAM.sed will create a partial input data set for SAM.yld. There is also a module, SAM.aid, which provides guidance on the selection of transport functions.

Sediment transport functions in SAM must be used with care. There is no allowance for variability in the size class distribution over time or space. In natural rivers the size class distribution of bed material varies with discharge, reach, time of year, and other temporal factors. SAM's use of a fixed, average size class distribution for all calculations presents the possibility that the calculated transport rates are not truly representative of the natural river. The procedure in HEC-6, which integrates processes over several cross sections and provides a continuity equation for sediment movement, will consequently produce a more reliable result. SAM provides reasonable time-averaged results in cases where the river is in general equilibrium; that is, it is neither aggrading or degrading. It is very important that the user correctly prescribe a representative bed material gradation.

Sediment Transport Functions

The following sediment transport functions have been incorporated into SAM. Except for Brownlie, these functions are also available in HEC-6. Some are identified as "d_{50}" which means the original version was for a single grain size. That capability is provided in SAM.sed. The HEC-6 versions of the functions calculate by grain size class and that capability is also in SAM.sed.

Table 7. Sediment Transport Functions available in SAM.sed.

ACKERS-WHITE.	MPM (1948), D50
ACKERS-WHITE, D50	PARKER
BROWNLIE, D50	PROFITT (SUTHERLAND)
COLBY	SCHOKLITSCH
EINSTEIN (BED-LOAD)	TOFFALETI.
EINSTEIN (TOTAL-LOAD)	TOFFALETI-MPM
ENGELUND-HANSEN	TOFFALETI-SCHOKLITSCH
LAURSEN (COPELAND)	YANG
LAURSEN (MADDEN), 1985	YANG, D50
MEYER-PETER and MULLER (MPM) (1948)	VAN RIJN

Ackers-White is a version of Ackers-White (1973) which has been modified, at WES, for multiple grain size calculations on sand and/or gravel bed streams. Modifications made by Ackers (1993) have been incorporated.

Ackers-White, D50 is a single grain size function.

Brownlie (1981) is a single grain size function for sand transport.

Colby (1964) is a version of Colby's single grain size function which has been modified at WES for multiple grain size calculations. It is valid for sand transport in streams and small rivers.

Einstein (Bed-load) (1950) is a multiple grain size function used to calculate the bed-load discharge of sand and/or gravel bed streams. The hiding factor has been modified at WES, incorporating the work of Pemberton (1972) and Shen and Lu (1983).

Einstein (Total-load) (1950) is a function that extends the Einstein bed-load calculations to include suspended load by grain size classes and sums them to get the total load.

Engelund (Hansen) (1967) is a version of Engelund-Hansen D_{50} which has been modified at WES for multiple grain size calculations on sand bed streams.

Laursen (Copeland) (Copeland and Thomas, 1989) is a modification to Laursen's (1958) multiple grain size function, extending its range to larger gravel sizes.

Laursen (Madden) (Madden, 1993) is a multiple grain size function modified by Madden for sand bed transport. It has been used for mixtures of sand and gravel. There is a 1963 modification in HEC-6 that is not available in SAM.

MPM – Meyer-Peter and Muller (1948) is a multiple grain size function for gravel bed rivers. It is not valid when appreciable suspended load is present.

MPM, D50 -- Meyer-Peter and Muller (1948), D50 is a version of the multiple grain size function MPM which has been modified, at WES, using a single grain size function.

Parker (1990) is a version of Parker's multiple grain size function. It can be applied to poorly sorted gravel bed streams. Finer sizes, less than 2 mm, must be excluded from the specified surface size distribution and the gradation must be 100% defined, i.e., there must be a size for which 0% of the material is finer. The bed material sizes used must be representative of the coarse upper layer of the bed.

Profitt (Sutherland) (1983) is a multiple grain size function modification of the Ackers-White formula. It can be used on sand and/or gravel bed streams.

Schoklitsch (1930) is a version of the Schoklitsch single grain size function that has been modified at WES for multiple grain size calculations. It is applicable to sand and gravel bed streams which do not have considerable amounts of suspended sediment transport.

Toffaleti (1968) is a multiple grain size function for sand bed rivers. It is not valid for gravel transport.

Toffaleti-MPM is a combined function for sand and gravel bed streams. Sediment transport is calculated using both functions by size class. Calculated bed load from the Toffaleti function is compared to the total calculated by MPM and the larger is used for bed load. Suspended load is then calculated using Toffaleti.

Toffaleti-Schoklitsch is a combined function for sand and gravel bed streams. Sediment transport is calculated using both functions by size class. Calculated bed load from the Toffaleti function is compared to the total calculated by Schoklitsch and the larger is used for bed load. Suspended load is then calculated using Toffaleti.

Van Rijn is based on Van Rijn (1984 a, b). Some of the modifications made by Spasojevic and Holly (1994) for CH3D-SED are incorporated. The most significant change is the multiple-grain grain size treatment. A hiding factor is applied to the bed load transport, but not the suspended load transport. Shield's parameter is calculated using Van Rijn's equations. The suspended sediment concentration profile is calculated using equations proposed in Van Rijn's paper (1984b). Recommended use is for grain sizes between 0.1 and 0.5 mm.

Yang (1973, 1984) is a version of Yang, D50, which has been modified, at WES, for multiple grain size calculations in sand and gravel bed streams (less than 10 mm).

Yang, D50 is a single grain size function for sand and gravel transport in streams and small rivers.

This is not an exhaustive list of transport functions. These were selected based on both corporate experience and recommendations from the literature. There is no implication that those not selected are deficient. The objective in SAM.sed was to provide designers with a "few" acceptable methods whose use could be supported. The criteria for selection were

a. to cover a broad range of particle sizes;

b. to cover a broad range of hydraulic conditions;

c. to calculate sediment transport by partitioning the mixture into size classes and summing the rate of each to get the total, except when d_{50} functions are requested; and

d. to have a history of being reliable when used within the range of data for which each was calibrated.

The Brownlie function is included here because it is used in the analytical method for calculating channel width, depth and slope in SAM.hyd. It is a single grain size function.

Calculations

The functional form for sediment transport equations is

$$GS_i = \ddot{u}\,(V, D, S_e, B_e, d_e, \rho_s, G_{sf}, d_s, i_b, \rho_f, T) \qquad \textbf{Equation 3-1}$$

where

GS_i = transport rate for size class i
V = average flow velocity
D = effective depth of flow
S_e = energy slope
B_e = effective width of flow (width of portion of cross section which is transporting bed material sediment)
d_e = effective particle size for the mixture
ρ_s = density of sediment particles
G_{sf} = grain shape factor
d_s = geometric mean of particles in size class i
i_b = fraction of size class i in bed
ρ_f = density of fluid
T = temperature of fluid

Of particular interest are the groupings of terms: hydraulic parameters (V, D, S_e, B_e), sediment particle parameters (d_e, ρ_s, G_{sf}), sediment mixture parameters (d_s, i_b) and fluid properties (ρ_f, T).

Not all listed parameters are used in all sediment transport functions. In SAM.sed, the specific gravity of sediment defaults to 2.65, and the particle shape factor defaults to 0.667. However, these defaults can be over-ridden.

Procedure for Calculating Sediment-Discharge Rating Curve

The steps in calculating a sediment-discharge rating curve from the bed-material gradation are:

1. assemble field data (cross sections and bed gradations)

2. develop representative values for roughness coefficients, geometry, and bed gradation from the field measurements

3. calculate the stage-discharge rating curve accounting for possible regime shifts due to bed-form change

4. calculate the bed-material sediment-discharge rating curve using hydraulic parameters from the stage-discharge calculation.

SAM.sed can be used for step 4. The input information required by SAM.sed, from step 3, can be obtained from SAM.hyd or HEC-2.

Data Ranges used in Development of Sediment Transport Functions

The range of data used in the development of the sediment transport functions that have been included in SAM.sed are summarized in Tables 9 through 21. These summaries are based on the authors' stated ranges when presented in their original papers. Otherwise, the summaries were determined based on the author's description of his data base in combination with the data listings of Brownlie (1981) or Toffaleti (1968).

Table 9. Ackers-White Transport Function

Parameter	Flume Data
Particle Size Range, mm	0.04 - 7.0
Specific Gravity	1.0 - 2.7
Multiple Size Classes	no
Velocity, fps	0.07 - 7.1
Depth, ft	0.01 - 1.4
Slope, ft per ft	0.00006 - 0.037
Width, ft	0.23 - 4
Water Temperature, Deg F	46 - 89

Table 10. Brownlie Transport Function

Parameter	River Data	Flume Data
Particle Size Range, mm	0.086 - 1.4	0.088 - 1.4
Multiple Size Classes	no	no
Velocity, fps [calculated]	1.2 - 7.9	0.7 - 6.6
Depth, ft	0.35 - 57	0.11 - 1.9
Slope, ft per ft	0.00001 - 0.0018	0.00027 - 0.017
Width, ft	6.6 - 3640	0.83 - 8.0
Water Temperature, Deg F	32 - 95	35 - 102

Table 11. Colby Transport Function

Parameter	Data Range
Particle Size Range, mm	0.18 - 0.70
Multiple Size Classes	no
Velocity, fps	0.70 - 8.0
Depth, ft	0.20 - 57
Slope, ft per ft	0.000031 - 0.010
Width, ft	0.88 - 3000
Water Temperature, Deg F	32 - 89
Correction for Fines, ppm	yes

Table 12. Einstein Transport Function

Parameter	Flume Data
Particle Size Range, mm	0.78 - 29
Multiple Size Classes	yes
Velocity, fps	0.9 - 9.4
Depth, ft	0.03 - 3.6
Slope, ft per ft	0.00037 - 0.018
Width, ft	0.66 - 6.6
Water Temperature, Deg F	not reported

Table 13. Engelund-Hansen Transport Function

Parameter	River Data	Flume Data
Particle Size Range, mm		
Multiple Size Classes		
Velocity, fps		
Depth, ft		**DATA NOT AVAILABLE YET**
Slope, ft per ft		
Width, ft		
Water Temperature, Deg F		

Table 14. Laursen(Copeland) Transport Function

Parameter	River Data	Flume Data
Median Particle Size Range, mm	0.08 - 0.70	0.011 - 29
Multiple Size Classes	yes	yes
Velocity, fps	0.068 - 7.8	0.70 - 9.4
Depth, ft	0.67 - 54	0.03 - 3.6
Slope, ft per ft	0.0000021 - 0.0018	0.00025 - 0.025
Width, ft	63 - 3640	0.25 - 6.6
Water Temperature, Deg F	32 - 93	46 - 83

Table 15. Laursen(Madden),(1985)

Parameter	Data Range
Particle Size Range, mm	0.04 - 4.8
Multiple Size Classes	yes
Velocity, fps	0.85 - 7.7
Depth, ft	0.25 - 54
Slope, ft per ft	0.00001 - 0.1
Width, ft	3 - 3640
Water Temperature, Deg F	36 - 90

Table 16. Meyer-Peter and Muller, 1948, Transport Function

Parameter	Data Range
Particle Size Range, mm	0.4 - 29
Particle Specific gravity	1.25 - 4
Multiple Size Classes	yes
Velocity, fps	1.2 - 9.4
Depth, ft	0.03 - 3.9
Slope, ft per ft	0.0004 - 0.02
Width, ft	0.5 - 6.6
Water Temperature, Deg F	not published

Table 17. Parker Transport Function

Parameter	River Data	Flume Data
Median Particle Size Range, mm	18 - 28	
Total Particle Size Range, mm	2 - 102	
Multiple Size Classes	yes	
Velocity, fps	2.6 - 3.7	
Depth, ft	1.0 - 1.5	
Slope, ft per ft	0.0097 - 0.011	
Width, ft	16 - 20	
Water Temperature, Deg F	41 - 44	

Table 18. Profitt(Sutherland) Transport Function

Parameter	River Data
Particle Size Range, mm	2.90 - 12
Multiple Size Classes	yes
Velocity, fps	2.00 - 3.4
Depth, ft	0.35 - 0.84
Slope, ft per ft	0.003
Width, ft	2.00
Water Temperature, Deg F	59 - 63

Table 19. Schoklitsch Transport Function

Parameter	Data Range
Particle Size Range, mm	0.3 - 4.9
Multiple Size Classes	no
Velocity, fps	0.8 - 4.5
Depth, ft	0.037 - 0.74
Slope, ft per ft	0.00012 - 0.055
Width, ft	0.23 - 2.0
Water Temperature, Deg F	not published

Table 20. Toffaleti Transport Function

Parameter	River Data	Flume Data
Median Particle Size Range, mm	0.095 - 0.76	0.91 - 0.45
Total Particle Size Range, mm	0.062 - 4	0.062 - 4
Multiple Size Classes	yes	yes
Velocity, fps	0.7 - 7.8	0.7 - 6.3
Hydraulic Radius, ft	0.7 - 56.7	0.07 - 1.1
Slope, ft per ft	0.000002 - 0.0011	0.00014 - 0.019
Width, ft	63 - 3640	0.8 - 8
Water Temperature, Deg F	32 - 93	40 - 93

Table 21. Van Rijn Transport Function

Parameter	Sand Data	Gravel Data
Particle Size Range, mm		
Multiple Size Classes		
Velocity, fps		
Depth, ft	**DATA NOT AVAILABLE YET**	
Slope, ft per ft		
Width, ft		
Water Temperature, Deg F		

Table 22. Yang Transport Function

Parameter	Sand Data	Gravel Data
Particle Size Range, mm	0.15 - 1.7	2.5 - 7.0
Multiple Size Classes	no	no
Velocity, fps	0.8 - 6.4	1.4 - 5.1
Depth, ft	0.04 - 50	0.08 - 0.72
Slope, ft per ft	0.000043 - 0.028	0.0012 - 0.029
Width, ft	0.44 - 1750	0.7 - 1.3
Water Temperature, Deg F	32 - 94	not reported

Correction for Sand Transport in High Concentration of Fines

Colby (1964) showed a significant increase in the transport capacity of sands when high concentrations ($Cf > 10{,}000$ ppm) of fine sediments (wash load) were present. The correction factor ranged up to 100 times the normal transport as the water depth and fines-concentration increased. The range of parameters tested is given in the following table.

Parameter	Range of data
concentrations	up to 200,000 ppm
velocities	up to 10 fps
depths	up to 100 ft
grain sizes	up to 0.9 mm.

At present, only the Colby function contains a correction for fines in SAM. In HEC-6, the Colby correction factor is applied to all sediment transport equations except Toffaleti, when Toffaleti is not combined with other equations.

Importance of Bed-material Gradation Designation

In the calculation of sediment transport, the designated bed gradation controls the calculated sediment discharge. The rate of transport increases exponentially as the grain size decreases, as shown in Figure 3.1. Therefore, bed-material gradations must be determined carefully. Techniques for selecting a representative sample are discussed in EM 1110-2-4000 (USACE 1989). Due to the sensitivity of transport calculations to the grain size, especially the finer sizes, Einstein (1950) recommended excluding the finest 10 percent of the sampled bed gradation from calculation of the total bed-material load.

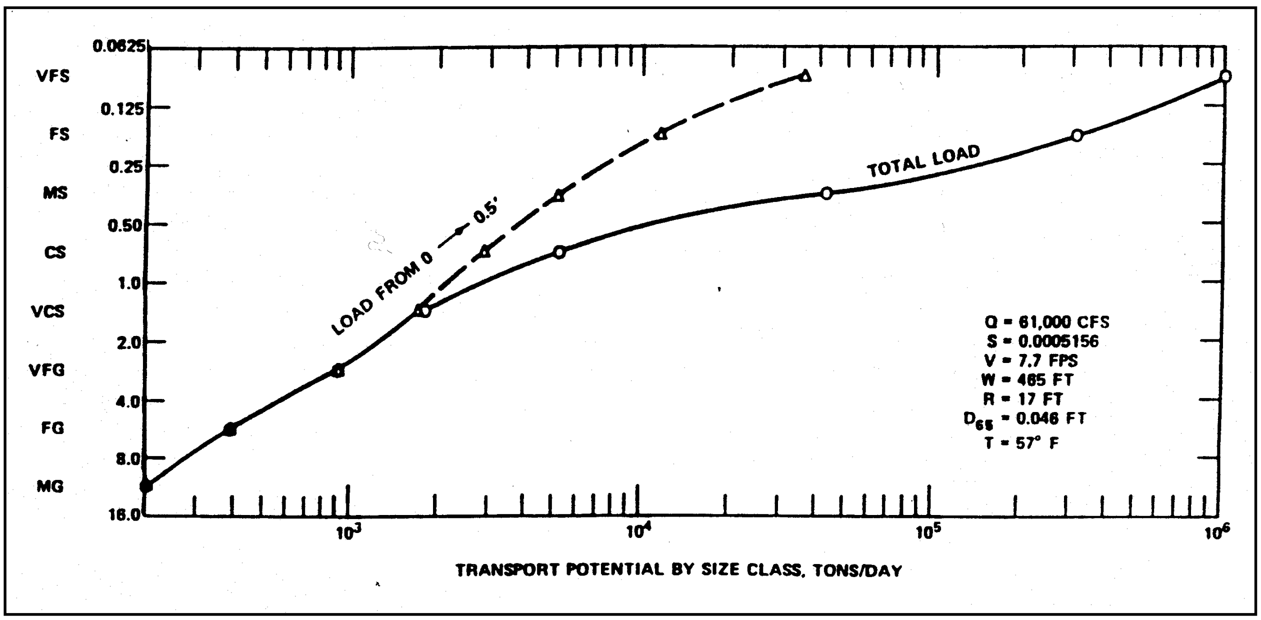


Figure 3-1. Variation of sediment transport with grain size (from EM 1110-2-4000 (USACE 1989), Figure 10-7)

4 Theoretical Basis for SAM.yld Calculations

Purpose

Sediment yield is the total sediment outflow from a watershed or drainage basin, measurable at a cross section of reference and in a specified period of time (ASCE, 1975). Sources of the total sediment yield include the watershed surface, rills and gullies, streambanks, and degrading streambeds. Sediment yield can be subdivided based on the method of transport. The finer portion of the sediment yield is continuously maintained in suspension by flow turbulence and is called the washload. The coarser fraction of the sediment yield is actively exchanged with the sediment on the bed and is called the bed-material sediment yield. SAM.yld provides hydraulic design engineers a systematic method for rapidly calculating sediment yield. If sediment transport is calculated using sediment transport *equations*, only the bed-material sediment yield is calculated. If sediment transport is determined from total load *measurements*, then the total sediment yield (washload and bed-material load) is calculated.

General

SAM.yld calculates sediment yield passing a cross-section during a specified period of time. The time period considered can be a single flood event or an entire year. In SAM.yld the flow can be specified by either a flow duration curve or a hydrograph. The sediment discharge curve can be specified as either sediment discharge versus water discharge or as sediment concentration versus water discharge. Calculations are based on the flow-duration sediment-discharge rating curve method.

Flow-Duration Sediment-Discharge Rating Curve Method

This is a simple integration of the flow duration curve with the sediment discharge rating curve at the outflow point from the drainage basin. This method is widely used in the Corps of Engineers for two reasons. First, both the flow duration curve and the sediment discharge rating curve are process-based and can be changed from the historical values needed for hindcasting to values needed for forecasting water and sediment yield in the future. Also, the curves can be defined to reflect specific components of the sediment runoff process, i.e., a sediment discharge rating curve can be calculated for sand and gravels when those are the types of sediment of most interest to project performance.

Sediment discharge rating curve

The sediment discharge rating curve is a relationship between water discharge and sediment discharge as discussed in chapter 3. SAM.sed calculates the bed-material sediment discharge rating curve needed for SAM.yld. SAM.sed will create this rating curve in terms of sediment concentration. However, the sediment discharge rating curve may be described in terms of tons/day by direct input to SAM.yld. If total sediment yield is required, the sediment discharge rating curve must be determined from measurements and directly input to SAM.yld.

Flow duration curve

The flow duration curve is a relationship between water discharge and the cumulative frequency each discharge occurs over a given time. It is a graphic description of a hydrologic event. The discharge magnitudes are plotted as the ordinates with the corresponding percents of time exceeded as the abscissas. Care should be taken in developing this curve.

Often the flow duration curve is calculated from historical databases containing the USGS mean daily records. If this data is used as the basis for a flow duration curve, efforts must be made to ensure that the peak flows are represented. This may be important in smaller streams where peak flow durations are considerably shorter than one day. Discharge durations for events larger than those in the mean daily record can be determined by one of several methods. If there are flood hydrographs on record, they can be the basis for calculating the discharge duration for the high flow events. If there is no recorded hydrograph for a flood event that has a published peak discharge, then the discharge durations can be determined assuming that the hydrograph had the same shape as a flood hydrograph of record or as a synthetic hydrograph calculated using HEC-1 or another hydrologic method. In any case, to ensure reasonable results the peak discharges of record should be incorporated into the flow duration curve, or the hydrograph, used in SAM.yld.

Calculations

Class intervals of water discharge are used in the integration of the flow-duration and sediment discharge rating curves. The percent exceedance is tabulated at each ordinate in user-defined increments that should be sufficiently small so the exceedance curve is approximated by straight line segments. The value of the discharge at the midpoint of each segment and its incremental time in percent is then calculated. The representative value of the sediment discharge is calculated as the geometric mean of the sediment discharges corresponding to the water discharges that bound the increment. The daily average discharge is calculated by multiplying the water discharge by the incremental exceedance fraction and summing all increments. The daily average sediment discharge is calculated similarly, by summing all results of multiplying the incremental sediment load by the incremental exceedance fractions. The average annual sediment yield is the product of the mean daily value times 365 days.

Points of caution

The sediment discharge rating curve is plotted as water discharge (Q) versus sediment discharge (QS) on a log-log grid. The typical scatter in such plots demonstrates that sediment discharge is not a simple function of water discharge. When the water discharge in cfs is plotted versus the sediment concentration in ppm, scatter is more apparent than when water discharge is plotted versus sediment discharge in tons/day. This is due to the spurious correlation between Q and QS resulting from the dependency of QS on Q. The engineer should investigate and evaluate any regional and watershed characteristics which might contribute to scatter. This can be accomplished by testing for homogeneity with respect to season of the year, systematic changes in land use, type of sediment load, and type of erosive mechanisms. A multiple correlation approach coupled with good engineering judgement may be employed to establish the dominant factors influencing historical concentrations. It is important to predict how these factors might change in the future and how such changes would impact sediment concentrations and particle sizes.

Additional factors contributing to scatter include washload concentration and temperature. The percent of the sediment load that is washload influences the amount of scatter in the data because the washload depends on its availability from source areas and not upon hydraulics of flow at the point of interest. Also, as the concentration of fines increases above 10,000 ppm, the transport rate of sands and gravels increases significantly. Water temperature may cause a significant variation in transport capacity of the bed material load. Thus water temperature variations, when coupled with seasonal changes in land use, may require that separate warm and cold weather sediment discharge rating curves be used to achieve acceptable accuracy in the calculated results.

It is usually necessary to extrapolate the sediment discharge rating curve to water discharges well above the range of measured data. Straight-line extrapolations typically over-estimate sediment load at high discharges. Extrapolating the relationship for total concentrations does not guarantee the proper behavior of individual size classes. Typically, the rating curves for finer size classes tend to flatten with increasing discharge.

Flow Hydrograph Method

This modification of the flow-duration--sediment discharge rating curve method substitutes water discharges from a hydrograph for the flow-duration curve. Those ordinates are integrated with the sediment discharge rating curve to produce the sediment yield for that event.

5 Theoretical Basis for SAM.aid — Guidance in Sediment Transport Function Selection

Purpose

SAM.aid is a module of the SAM package that provides guidance in the selection of the most applicable sediment transport function(s) to use for given hydraulic conditions for a specified river or stream. The traditional approach for selecting a function has involved collecting field data, including both suspended sediment measurements and bed material gradations; processing and testing that data with a number of sediment transport functions; and then selecting the function that best matched the field measurements. Because many of today's projects are on small ungaged streams and because field data are often too limited for this approach to be satisfactorily applied, SAM.aid was developed to provide an alternative in which only bed-material gradations and hydraulic parameters are required.

General

Different functions may give widely differing results for a specified channel. Therefore it is important to test the predictive capability of a sediment transport function against measured data in the project stream or in a similar stream before its adoption for use in a sediment study. Also, different functions were developed from different sets of field and laboratory data and are better suited to some applications than others.

Most sediment transport functions predict a rate of sediment transport for a given set of steady-state hydraulic and bed material conditions. Typically, hydraulic variables are laterally averaged. Some sediment transport functions were developed for calculation of bed-load only, and others were developed for calculation of total bed-material load. This distinction can be critical in sand-bed streams, where the suspended bed-material load may be orders of magnitude greater than the bed-load. Another important difference in sediment transport functions is the manner in which grain size is treated. Most sediment transport functions were developed as single-grain-size functions, usually using the median bed material size to represent the total bed. Single-grain-size functions are most appropriate in cases where equilibrium sediment transport can be assumed, i.e., when the project will not significantly change the existing hydraulic or sediment conditions. When the purpose of the sediment study is to evaluate the effect of a project on sediment transport characteristics, i.e., the project or a flood will introduce non-equilibrium conditions, then a multiple-grain-size sediment transport function should be used. Multiple-grain-size functions are very sensitive to the grain-size distribution of the bed material. Extreme care must be exercised in order to ensure that the fine component of the bed-material gradation is representative of the bed surface for the specified discharge. This is very difficult without measured data. For this reason Einstein (1950) recommended ignoring the finest 10 percent of the bed material sample for computation of bed-material load with a multiple-grain-size function. In HEC-6 and SAM, single-grain-size functions are converted to multiple-grain-size functions simply by calculating sediment transport using geometric mean diameters for each size class in the bed (sediment transport potential) and then assuming that transport of that size class (sediment transport capacity) can be obtained by multiplying the sediment transport potential by the bed fraction. This can produce unreliable results since the assumption is that each size class fraction in the bed acts independent of other size classes on the bed, thus ignoring the effects of hiding.

Description

SAM.aid is based on the premise that a sediment transport function that accurately predicts measured sediment in a gaged stream would be an appropriate predictor in an ungaged stream with similar characteristics. SAM.aid compares calculated "screening parameters" for a given river to the same screening parameters from a database of rivers (Brownlie, 1981) that have sufficient sediment data to determine an appropriate sediment transport function. The "screening parameters" are velocity, depth, slope, width, and d_{50}. It should be noted that Brownlie reduced measured bed material gradations to median grain sizes and geometric standard deviations. This means that this guidance is not applicable to rivers that have bed gradations that are not log-normally distributed.

When the user inputs velocity, depth, slope, width and d_{50} for an ungaged river, SAM.aid compares each of these screening parameters with those of each river in the Brownlie database. A "match” is identified when a parameter falls within the range of data for a database river. The d_{50} must fall within the range for a river in the database before SAM.aid will examine the other parameters. The three best sediment transport functions for each database river is then listed, along with the type of parameter(s) that matched and the name of the data set matched.

After the matches are displayed, the user can check the description of the rivers on which SAM.aid based its choices to see how close those descriptions match the user's river or stream. This is an essential step in ensuring that the sediment transport functions will actually provide the best predictive capability for the river in question. This will also narrow the choices when SAM.aid displays several data sets that "matched" a user's data, all with the same matching screening parameters.

Criteria for selecting sediment transport functions

Discrepancy ratios were calculated for each measured discharge. Raphelt (1996) describes the discrepancy ratio that Yang (1984), van Rijn (1984) and others have used as

$$\frac{q_s \ computed}{q_s \ measured}$$

For each data base, the percentage of discrepancy ratios between 0.5 and 2.0[1] was determined, and the average discrepancy ratio was calculated. The five to eight sediment transport functions with the highest percentage of discrepancy ratios within the selected range were selected first. From these, the functions were ranked by average discrepancy ratio. The function with the discrepancy ratio closest to 1.0 was ranked highest.

Only one of the Toffaleti function combinations was considered in each ranking. For instance, if both the Toffaleti and the Toffaleti-Schoklitsch functions ranked in the top three, only the function with the highest ranking would be included in the final recommendations. For some functions, sediment transport is calculated two ways: 1) assuming a median grain size and 2) making calculations by size class fractions. For these functions only the multiple grain size option was considered in the rankings. Since the Brownlie function calculates sediment transport using only the median grain size, it is included in the rankings.

In some cases, when the data is clearly outside the range for which a sediment transport function was developed, a function was excluded from the rankings.

The rankings for all the sediment transport functions in SAM.sed, for all the data sets in SAM.aid, are given in tables 5.2 through 5.21. They are also available onscreen in SAM.aid as part of the site description, allowing the user to apply personal engineering judgement and experience. This is an important feature to remember since the results of SAM.aid are meant only as suggestions, for guidance.

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[1] This range, 0.5 to 2.0 was chosen because it is the range that is used in many other researchers in this field: van Rijn (1984a), Alonso (1980), White, Milli and Crabbe (1975), among others.

Table 5.1. LIST OF BROWNLIE DATA SETS	
Data Code	River and Investigator(s)
ACP	ACOP Canal, k. Mahmood et al., 1979
AMC	American Canal, D. B. Simons, 1957
ATC	Atchafalaya River, F. B. Toffaleti, 1968
CHO	Chop Canals, Chaudhry et al., 1970
COL	Colorado River, U. S. Bureau of Reclamation, 1958
HII	Hii River, K. Shinohara and T. Tsubaki, 1959
LEO	River Data, L. B. Leopold, 1969
MID	Middle Loup River, D. Hubbell and D. Matejka, 1959
MIS	Mississippi River, F. B. Toffaleti, 1968
MOU	Mountain Creek, H. A. Einstein, 1944
NED	Rio Magdelena and Canal del Dique, NEDCO, 1973
NIO	Niobrara River, B. R. Colby and C. H. Hembree, 1955
NSR	North Saskatchewan River and Elbow River, G. W. Samide, 191
OAK	Oak Creek, Oregon, R. T. Milhous. 1973
POR	Portugal Rivers, L. V. da Cunha, 1969
RED	Red River, F. B. Toffaleti, 1968
RGC	Rio Grande Conveyance Channel, J. K. Culbertson et al., 1976
RGR	Rio Grande River, C. F. Nordin and C. P. Beverage, 1965
RIO	Rio Grande near Bernalillo, NM, F. B. Toffaleti, 1968

Table 5.2. Sediment Transport Function Rankings for ACP Data Set.

DATA SET: ACP		# DATA POINTS IN SET: 142		
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
TOFFALETI-MPM		57.04	1.343	1.2863
TOFFALETI.	3	56.34	1.222	1.2112
TOFFALETI-SCHOKLITSCH		55.63	1.305	1.2650
LAURSEN(COPELAND)		54.93	1.567	1.7284
PROFITT(SUTHERLAND)		54.23	1.716	1.6165
LAURSEN(MADDEN),1985		53.52	1.440	1.7098
ACKERS-WHITE.	2	50.70	0.830	0.7461
ACKERS-WHITE, D50		49.30	0.859	0.7996
ENGELUND-HANSEN	1	45.77	1.019	0.9600
BROWNLIE, D50		44.37	0.812	0.7816
VAN RIJN		41.55	0.731	0.8370
COLBY		40.14	1.456	1.6258
EINSTEIN(TOTAL-LOAD)		37.32	1.405	1.9642
YANG, D50		31.69	0.445	0.7005
YANG.		26.76	0.416	0.7059
EINSTEIN(BED-LOAD)		21.13	0.370	0.8619
MPM(1948),D50		5.63	0.158	0.8590
MPM(1948).		2.11	0.137	0.8759
SCHOKLITSCH		0.70	0.094	0.9140
PARKER		0.00	0.000	1.0035

Table 5.3. Sediment Transport Function Rankings for AMC Data Set.

DATA SET: AMC		# DATA POINTS	IN SET: 11	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
LAURSEN(COPELAND)	1	45.45	1.092	1.2213
PROFITT(SUTHERLAND)		45.45	0.462	0.6777
BROWNLIE, D50		27.27	0.309	0.7708
LAURSEN(MADDEN),1985	3	27.27	0.690	0.8809
ENGELUND-HANSEN		27.27	0.434	0.6877
ACKERS-WHITE, D50		27.27	0.294	0.7822
COLBY		27.27	0.370	0.7592
ACKERS-WHITE.		27.27	0.283	0.7858
EINSTEIN(TOTAL-LOAD)	2	27.27	0.741	1.2944
TOFFALETI.		18.18	0.455	0.8375
YANG.		18.18	0.270	0.8012
EINSTEIN(BED-LOAD)		18.18	0.230	0.8374
VAN RIJN		18.18	0.359	0.7513
TOFFALETI-MPM		18.18	0.579	0.7908
TOFFALETI-SCHOKLITSCH		18.18	0.490	0.8215
YANG, D50		18.18	0.265	0.8115
MPM(1948),D50		9.09	0.175	0.8835
SCHOKLITSCH		0.00	0.041	1.0068
MPM(1948).		0.00	0.150	0.9008
PARKER		0.00	0.001	1.0473

Table 5.4. Sediment Transport Function Rankings for ATC Data Set.

DATA SET: ATC	# DATA POINTS	IN SET: 63	
FUNCTION	Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
COLBY	69.84	1.285	1.0056
LAURSEN(COPELAND) **3**	69.84	1.140	1.2790
LAURSEN(MADDEN),1985 **1**	68.25	1.104	1.1584
TOFFALETI-MPM	65.08	1.169	1.3231
TOFFALETI. **2**	63.49	1.132	1.3043
TOFFALETI-SCHOKLITSCH	63.49	1.142	1.3154
PROFITT(SUTHERLAND)	57.14	1.197	1.3708
VAN RIJN	42.86	0.621	0.7357
BROWNLIE, D50	39.68	0.533	0.5941
ACKERS-WHITE.	36.51	0.657	0.8902
ENGELUND-HANSEN	34.92	0.498	0.6517
ACKERS-WHITE, D50	33.33	0.521	0.6789
EINSTEIN(TOTAL-LOAD)	20.63	4.208	5.8703
EINSTEIN(BED-LOAD)	7.94	0.182	0.8557
YANG.	3.17	0.132	0.8832
YANG, D50	1.59	0.137	0.8784
SCHOKLITSCH	0.00	0.012	0.9959
MPM(1948).	0.00	0.056	0.9522
MPM(1948),D50	0.00	0.070	0.9389
PARKER	0.00	0.000	1.0080

Table 5.5. Sediment Transport Function Rankings for CHO Data Set.

DATA SET: CHO	# DATA POINTS	IN SET: 33	
FUNCTION	Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
COLBY **1**	69.70	0.826	0.5573
PROFITT(SUTHERLAND)	54.55	2.743	5.2183
ACKERS-WHITE, D50	51.52	1.201	1.9122
ENGELUND-HANSEN **3**	48.48	0.753	0.7301
BROWNLIE, D50	45.45	0.635	0.6155
LAURSEN(COPELAND)	42.42	2.347	5.6214
ACKERS-WHITE. **2**	42.42	1.211	1.9239
VAN RIJN	33.33	0.986	1.3950
TOFFALETI-MPM	27.27	1.603	2.8109
TOFFALETI-SCHOKLITSCH	27.27	1.604	2.8167
EINSTEIN(TOTAL-LOAD)	21.21	2.372	6.9618
YANG, D50	18.18	0.467	0.7810
YANG.	18.18	0.422	0.7588
LAURSEN(MADDEN),1985	18.18	1.897	3.9564
TOFFALETI.	15.15	1.541	2.7744
SCHOKLITSCH	0.00	0.079	0.9387
MPM(1948).	0.00	0.075	0.9404
MPM(1948),D50	0.00	0.085	0.9308
PARKER	0.00	0.000	1.0155
EINSTEIN(BED-LOAD)	0.00	0.113	0.9050

Table 5.6. Sediment Transport Function Rankings for COL Data Set.

DATA SET: COL		# DATA POINTS	IN SET: 100	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
PROFITT(SUTHERLAND)		72.00	1.249	1.4127
COLBY	2	68.00	1.144	1.5363
ENGELUND-HANSEN	1	62.00	1.004	0.8986
LAURSEN(COPELAND)	3	50.00	0.851	1.1833
ACKERS-WHITE, D50		49.00	0.700	0.8543
BROWNLIE, D50		48.00	0.704	0.8256
ACKERS-WHITE.		44.00	0.672	0.8588
TOFFALETI-MPM		39.00	0.624	0.7591
TOFFALETI-SCHOKLITSCH		39.00	0.614	0.7486
YANG.		38.00	0.472	0.6868
YANG, D50		38.00	0.503	0.6802
LAURSEN(MADDEN),1985		32.00	0.595	0.7617
VAN RIJN		31.00	0.518	0.9252
TOFFALETI.		29.00	0.502	0.7606
EINSTEIN(TOTAL-LOAD)		27.00	0.587	0.8892
EINSTEIN(BED-LOAD)		14.00	0.298	0.7617
SCHOKLITSCH		2.00	0.123	0.8885
MPM(1948).		2.00	0.136	0.8771
MPM(1948),D50		2.00	0.159	0.8575
PARKER		0.00	0.000	1.0050

Table 5.7. Sediment Transport Function Rankings for HII Data Set.

DATA SET: HII		# DATA POINTS	IN SET: 38	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
YANG.		94.74	1.290	0.5404
EINSTEIN(BED-LOAD)	2	86.84	1.219	0.6851
ENGELUND-HANSEN		84.21	1.246	0.6062
PROFITT(SUTHERLAND)	3	81.58	1.225	0.6691
TOFFALETI-MPM	1	78.95	0.815	0.4836
EINSTEIN(TOTAL-LOAD)		73.68	1.586	1.0890
ACKERS-WHITE,D50		68.42	0.667	0.4901
ACKERS-WHITE.		68.42	0.623	0.4999
VAN.RIJN		65.79	0.898	0.7972
YANG,D50		63.16	1.806	1.0598
BROWNLIE,D50		52.63	0.513	0.5586
MPM(1948),D50		52.63	0.661	0.5770
MPM(1948).		50.00	0.535	0.6076
LAURSEN(COPELAND)		44.74	2.500	2.1361
TOFFALETI-SCHOKLITSC		42.11	1.512	1.4665
COLBY		42.11	0.571	0.8030
SCHOKLITSCH		42.11	1.230	1.2945
TOFFALETI.		28.95	0.338	0.7500
LAURSEN(MADDEN),1985		26.32	0.370	0.7345
PARKER		13.16	0.258	0.8996

Table 5.8. Sediment Transport Function Rankings for LEO Data Set.

DATA SET: LEO		# DATA POINTS	IN SET: 55	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
COLBY	**3**	61.82	1.351	1.0382
PROFITT(SUTHERLAND)		56.36	2.245	2.8644
BROWNLIE,D50	**2**	56.36	0.907	0.7016
ACKERS-WHITE,D50	**1**	49.09	1.013	0.8411
YANG,D50		47.27	0.699	0.6532
YANG.		47.27	0.674	0.6592
ENGELUND-HANSEN		45.45	1.393	1.2055
ACKERS-WHITE.		45.45	1.274	1.5971
LAURSEN(COPELAND)		38.18	1.290	1.5349
TOFFALETI-MPM		38.18	1.016	1.1138
TOFFALETI-SCHOKLITSC		36.36	1.024	1.1624
VAN.RIJN		36.36	0.806	0.9061
EINSTEIN(TOTAL-LOAD)		34.55	0.847	1.8083
TOFFALETI.		32.73	0.876	1.0742
LAURSEN(MADDEN),1985		29.09	1.496	2.5647
EINSTEIN(BED-LOAD)		14.55	0.303	0.7613
SCHOKLITSCH		5.45	0.167	0.8556
MPM(1948),D50		3.64	0.179	0.8404
MPM(1948).		1.82	0.155	0.8614
PARKER		0.00	0.000	1.0092

Table 5.9. Sediment Transport Function Rankings for MID Data Set.

DATA SET: MID		# DATA POINTS	IN SET: 38	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
ENGELUND-HANSEN	**1**	89.47	0.947	0.3875
TOFFALETI-SCHOKLITSCH	**2**	89.47	0.908	0.4413
COLBY		86.84	0.839	0.4599
PROFITT(SUTHERLAND)		86.84	1.349	0.8418
YANG.	**3**	84.21	0.866	0.4175
YANG, D50		84.21	0.850	0.4042
ACKERS-WHITE, D50		81.58	0.792	0.4271
ACKERS-WHITE.		81.58	0.788	0.4664
VAN RIJN		81.58	0.862	0.7021
LAURSEN(MADDEN),1985		71.05	0.785	0.7419
TOFFALETI-MPM		71.05	0.710	0.4879
EINSTEIN(TOTAL-LOAD)		65.79	0.964	1.6763
BROWNLIE, D50		60.53	0.613	0.4689
LAURSEN(COPELAND)		44.74	2.528	3.6580
SCHOKLITSCH		36.84	0.448	0.5931
TOFFALETI.		34.21	0.487	0.6241
EINSTEIN(BED-LOAD)		18.42	0.381	0.6417
MPM(1948),D50		2.63	0.286	0.7324
PARKER		0.00	0.001	1.0120
MPM(1948).		0.00	0.235	0.7798

Table 5.10. Sediment Transport Function Rankings for MIS Data Set.

DATA SET: MIS		# DATA POINTS	IN SET: 164	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
COLBY		76.22	1.547	1.0581
BROWNLIE, D50	3	73.17	0.830	0.4689
PROFITT(SUTHERLAND)		67.68	1.491	1.4003
ACKERS-WHITE, D50		65.85	0.720	0.5006
ENGELUND-HANSEN	2	65.85	1.081	0.7669
LAURSEN(COPELAND)	1	56.10	1.048	1.0764
ACKERS-WHITE.		51.83	1.093	1.2248
VAN RIJN		50.61	0.848	0.6916
TOFFALETI-MPM		48.78	0.976	0.9019
TOFFALETI-SCHOKLITSCH		46.34	0.927	0.8960
TOFFALETI.		44.51	0.882	0.8655
LAURSEN(MADDEN),1985		41.46	1.393	2.5404
YANG.		39.02	0.457	0.6310
YANG, D50		38.41	0.453	0.6288
EINSTEIN(TOTAL-LOAD)		20.12	3.611	6.4857
EINSTEIN(BED-LOAD)		3.05	0.179	0.8375
MPM(1948),D50		2.44	0.147	0.8618
SCHOKLITSCH		0.00	0.052	0.9525
MPM(1948).		0.00	0.119	0.8871
PARKER		0.00	0.004	0.9990

Table 5.11. Sediment Transport Function Rankings for MOU Data Set.

DATA SET: MOU		# DATA POINTS	IN SET: 100	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
MPM(1948).	1	89.00	1.055	0.4512
MPM(1948),D50		86.00	1.151	0.5324
BROWNLIE, D50	2	85.00	1.159	0.8983
ACKERS-WHITE.	3	80.00	1.510	1.4543
ACKERS-WHITE, D50		76.00	1.668	1.5602
TOFFALETI-MPM		72.00	1.630	1.3082
ENGELUND-HANSEN		71.00	1.938	1.5777
YANG.		68.00	2.015	1.6222
EINSTEIN(BED-LOAD)		67.00	1.764	1.2732
TOFFALETI-SCHOKLITSCH		62.00	1.463	1.4282
COLBY		61.00	1.859	1.7847
EINSTEIN(TOTAL-LOAD)		61.00	2.314	2.3943
YANG, D50		60.00	2.241	1.8333
TOFFALETI.		42.00	0.801	1.0200
VAN RIJN		39.00	2.896	2.7415
PROFITT(SUTHERLAND)		33.00	3.124	3.1845
SCHOKLITSCH		33.00	0.740	0.8733
LAURSEN(MADDEN),1985		17.00	0.587	0.8257
LAURSEN(COPELAND)		9.00	6.768	8.6024
PARKER		7.00	0.109	0.9213

Table 5.12. Sediment Transport Function Rankings for NED Data Set.

DATA SET: NED	# DATA POINTS	IN SET: 66	
FUNCTION	Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
VAN RIJN **2**	53.03	0.940	0.9852
BROWNLIE, D50	53.03	0.650	0.5866
COLBY	50.00	1.933	10.0131
PROFITT(SUTHERLAND)	50.00	1.103	1.3030
ENGELUND-HANSEN **1**	48.48	1.000	0.8293
YANG, D50	42.42	0.596	0.7126
TOFFALETI-SCHOKLITSCH **3**	42.42	1.090	1.3328
TOFFALETI-MPM	40.91	1.123	1.3662
ACKERS-WHITE.	40.91	0.761	0.8038
TOFFALETI.	37.88	1.016	1.3059
YANG.	37.88	0.507	0.6720
ACKERS-WHITE, D50	31.82	0.588	0.7186
LAURSEN(MADDEN),1985	31.82	1.163	1.4970
LAURSEN(COPELAND)	30.30	1.687	2.2986
EINSTEIN(TOTAL-LOAD)	13.64	1.587	3.6978
EINSTEIN(BED-LOAD)	9.09	0.201	0.8536
MPM(1948),D50	6.06	0.180	0.8585
MPM(1948).	3.03	0.137	0.8842
SCHOKLITSCH	1.52	0.098	0.9163
PARKER	0.00	0.029	0.9827

Table 5.13. Sediment Transport Function Rankings for NIO Data Set.

DATA SET: NIO	# DATA POINTS	IN SET: 40	
FUNCTION	Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
BROWNLIE, D50	97.50	0.804	0.3088
TOFFALETI-SCHOKLITSCH	97.50	1.166	0.4614
YANG, D50	97.50	1.158	0.3790
ACKERS-WHITE, D50	97.50	1.060	0.4113
YANG. **2**	97.50	1.170	0.3763
TOFFALETI-MPM **1**	92.50	0.954	0.4436
ENGELUND-HANSEN	92.50	1.378	0.5148
COLBY **3**	92.50	0.832	0.3227
ACKERS-WHITE.	87.50	1.242	0.6482
VAN RIJN	85.00	1.223	0.7311
TOFFALETI.	72.50	0.774	0.4962
LAURSEN(MADDEN),1985	70.00	1.328	0.8450
EINSTEIN(TOTAL-LOAD)	67.50	1.188	0.8245
PROFITT(SUTHERLAND)	60.00	1.953	1.2746
LAURSEN(COPELAND)	47.50	2.624	2.2278
SCHOKLITSCH	30.00	0.490	0.5416
EINSTEIN(BED-LOAD)	7.50	0.298	0.7168
MPM(1948),D50	0.00	0.215	0.7974
PARKER	0.00	0.000	1.0127
MPM(1948).	0.00	0.186	0.8264

Table 5.14. Sediment Transport Function Rankings for NSR Data Set.

DATA SET: NSR	# DATA POINTS	IN SET: 55	
FUNCTION	Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
LAURSEN(MADDEN),1985 **1**	58.18	1.475	1.6476
SCHOKLITSCH **3**	56.36	2.317	2.8571
TOFFALETI-SCHOKLITSCH	56.36	2.384	2.8983
BROWNLIE, D50 **2**	50.91	1.703	2.0211
VAN RIJN	47.27	0.950	0.8668
ACKERS-WHITE.	43.64	3.268	5.9799
ACKERS-WHITE, D50	34.55	3.806	7.4862
PARKER	27.27	6.603	13.3796
PROFITT(SUTHERLAND)	21.82	6.493	11.2715
YANG.	21.82	6.255	10.2682
YANG, D50	20.00	9.118	15.4717
MPM(1948),D50	14.55	6.661	12.1554
MPM(1948).	9.09	7.636	11.1704
TOFFALETI-MPM	9.09	7.712	11.2263
TOFFALETI.	7.27	0.161	0.8634
EINSTEIN(BED-LOAD)	1.82	13.757	18.6927
EINSTEIN(TOTAL-LOAD)	1.82	13.762	18.6946
LAURSEN(COPELAND)	1.82	20.655	26.6636
COLBY	0.00	0.000	1.0092
ENGELUND-HANSEN	0.00	21.050	28.2610

Table 5.15. Sediment Transport Function Rankings for OAK Data Set.

DATA SET: OAK	# DATA POINTS	IN SET: 17	
FUNCTION	Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
LAURSEN(MADDEN),1985 **1**	41.18	1.081	1.0122
ACKERS-WHITE.	29.41	0.373	0.8095
TOFFALETI.	29.41	0.850	0.9430
YANG. **2**	29.41	1.142	2.0338
BROWNLIE, D50 **3**	17.65	0.862	1.3960
MPM(1948),D50	5.88	2.651	5.7522
PROFITT(SUTHERLAND)	5.88	0.136	0.9356
PARKER	0.00	185.278	274.7783
VAN RIJN	0.00	181.225	326.1328
SCHOKLITSCH	0.00	56.861	79.6337
ENGELUND-HANSEN	0.00	89.682	119.9400
EINSTEIN(BED-LOAD)	0.00	25.277	33.3275
ACKERS-WHITE, D50	0.00	0.000	1.0308
TOFFALETI-SCHOKLITSCH	0.00	57.585	80.6903
COLBY	0.00	0.000	1.0308
EINSTEIN(TOTAL-LOAD)	0.00	25.301	33.3628
MPM(1948).	0.00	27.752	40.5980
YANG, D50	0.00	0.019	1.0141
LAURSEN(COPELAND)	0.00	108.222	160.7211
TOFFALETI-MPM	0.00	28.486	41.5653

Table 5.16. Sediment Transport Function Rankings for POR Data Set.

DATA SET: POR		# DATA POINTS	IN SET: 219	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
YANG.	1	87.21	1.009	0.4888
LAURSEN(COPELAND)	2	67.58	1.245	0.9824
ENGELUND-HANSEN	3	65.75	1.933	1.3088
BROWNLIE, D50		48.86	0.563	0.5322
PROFITT(SUTHERLAND)		44.75	0.613	0.5739
EINSTEIN(TOTAL-LOAD)		43.38	0.734	0.6747
MPM(1948),D50		42.92	0.538	0.5646
EINSTEIN(BED-LOAD)		42.92	0.722	0.6683
PARKER		41.10	1.803	1.4934
TOFFALETI-MPM		35.62	0.542	0.5668
MPM(1948).		31.51	0.485	0.5952
ACKERS-WHITE.		23.74	0.387	0.6626
VAN RIJN		19.63	0.386	0.7461
TOFFALETI-SCHOKLITSCH		17.81	0.378	0.6486
ACKERS-WHITE, D50		12.33	0.279	0.7487
SCHOKLITSCH		10.96	0.313	0.7109
YANG, D50		2.28	0.103	0.9062
COLBY		0.46	0.131	0.8756
TOFFALETI.		0.00	0.086	0.9198
LAURSEN(MADDEN),1985		0.00	0.117	0.8882

Table 5.17. Sediment Transport Function Rankings for RED Data Set.

DATA SET: RED		# DATA POINTS	IN SET: 30	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
TOFFALETI-MPM		93.33	0.968	0.3799
TOFFALETI-SCHOKLITSCH	1	90.00	1.010	0.4302
ACKERS-WHITE.	3	86.67	1.047	0.8088
LAURSEN(COPELAND)	2	83.33	0.960	0.5720
TOFFALETI.		83.33	0.895	0.3838
ENGELUND-HANSEN		66.67	1.239	1.2817
PROFITT(SUTHERLAND)		63.33	2.167	2.6062
LAURSEN(MADDEN),1985		60.00	2.348	2.0326
ACKERS-WHITE, D50		50.00	0.874	0.9478
EINSTEIN(TOTAL-LOAD)		30.00	2.176	2.9836
BROWNLIE, D50		26.67	0.462	0.5873
VAN RIJN		23.33	0.352	0.6771
COLBY		16.67	0.353	0.7126
YANG, D50		13.33	0.369	0.7336
EINSTEIN(BED-LOAD)		10.00	0.177	0.8616
YANG.		10.00	0.339	0.7302
SCHOKLITSCH		3.33	0.116	0.9108
MPM(1948).		0.00	0.073	0.9442
MPM(1948),D50		0.00	0.091	0.9269
PARKER		0.00	0.000	1.0171

Table 5.18. Sediment Transport Function Rankings for RGC Data Set.

DATA SET: RGC	# DATA POINTS	IN SET: 8	
FUNCTION	Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
TOFFALETI-MPM	87.50	0.932	0.6064
TOFFALETI-SCHOKLITSCH **1**	87.50	0.983	0.5786
LAURSEN(MADDEN),1985 **3**	87.50	0.910	0.4430
ENGELUND-HANSEN **2**	87.50	0.955	0.3160
YANG, D50	87.50	0.656	0.4267
YANG.	75.00	0.612	0.4568
LAURSEN(COPELAND)	75.00	1.407	1.2483
ACKERS-WHITE, D50	75.00	0.814	0.4445
VAN RIJN	75.00	0.834	0.5599
PROFITT(SUTHERLAND)	75.00	1.578	1.1581
BROWNLIE, D50	75.00	0.603	0.4792
COLBY	75.00	0.626	0.4480
ACKERS-WHITE.	75.00	0.912	0.6165
TOFFALETI.	62.50	0.862	0.6174
EINSTEIN(TOTAL-LOAD)	50.00	0.813	0.6449
SCHOKLITSCH	0.00	0.165	0.8947
MPM(1948).	0.00	0.072	0.9923
MPM(1948),D50	0.00	0.082	0.9821
PARKER	0.00	0.000	1.0690
EINSTEIN(BED-LOAD)	0.00	0.112	0.9505

Table 5.19. Sediment Transport Function Rankings for RGR Data Set.

DATA SET: RGR	# DATA POINTS	IN SET: 286	
FUNCTION	Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
PROFITT(SUTHERLAND)	59.79	1.448	1.9547
ENGELUND-HANSEN	58.39	2.175	7.4489
LAURSEN(COPELAND)	53.50	2.370	3.7390
YANG, D50	52.80	1.202	2.7583
TOFFALETI-SCHOKLITSCH	50.00	1.442	4.3807
YANG.	48.95	1.208	2.5535
ACKERS-WHITE.	44.06	1.279	2.7020
ACKERS-WHITE, D50	43.36	0.703	0.8658
VAN RIJN	42.66	0.929	1.3087
BROWNLIE, D50	40.56	0.675	0.8832
TOFFALETI-MPM	40.21	0.729	0.8448
EINSTEIN(TOTAL-LOAD)	38.81	1.041	1.5765
LAURSEN(MADDEN),1985	34.27	1.065	1.5503
COLBY	31.12	1.217	11.2550
TOFFALETI.	29.02	0.511	0.7592
SCHOKLITSCH	19.58	0.992	4.2301
EINSTEIN(BED-LOAD)	12.94	0.349	0.8443
MPM(1948),D50	9.79	0.274	0.8270
MPM(1948).	8.04	0.230	0.8460
PARKER	0.70	0.018	0.9877

Table 5.20. Sediment Transport Function Rankings for RIO Data Set.

DATA SET: RIO		# DATA POINTS	IN SET: 38	
FUNCTION		Percent of data points in discrepancy ratio range	Average Standard deviation of Discrepancy Ratio	Standard Deviation of Discrepancy Ratio
PROFITT(SUTHERLAND)		97.37	1.343	0.5688
ACKERS-WHITE.	2	94.74	0.861	0.3329
ACKERS-WHITE, D50		94.74	0.818	0.3245
VAN RIJN	1	89.47	1.013	0.4775
BROWNLIE, D50		86.84	0.729	0.3848
COLBY	3	86.84	0.731	0.4029
ENGELUND-HANSEN		65.79	0.706	0.4176
YANG.		63.16	0.567	0.4759
YANG, D50		63.16	0.579	0.4672
EINSTEIN(TOTAL-LOAD)		63.16	1.309	0.8508
TOFFALETI-SCHOKLITSCH		63.16	0.633	0.4708
TOFFALETI-MPM		63.16	0.622	0.4756
LAURSEN(COPELAND)		57.89	1.962	1.3509
TOFFALETI.		42.11	0.541	0.5399
LAURSEN(MADDEN),1985		39.47	0.508	0.5844
EINSTEIN(BED-LOAD)		2.63	0.177	0.8408
MPM(1948).		0.00	0.123	0.8904
SCHOKLITSCH		0.00	0.137	0.8794
PARKER		0.00	0.000	1.0134
MPM(1948),D50		0.00	0.140	0.8735

Data Ranges of the Data Sets used in SAM.aid

The data sets used in SAM.aid for comparison of user-input data each have a range of values for the five selection parameters: d_{50}, velocity, depth, width, and slope. These ranges are given in Table 5.22. However, in the SAM.aid program the upper and lower limits of the ranges for D_{50} have been extended to the next size class boundary, according to the American Geophysical Union standard size classes. This allows a somewhat wider range of choices to be offered to the user without compromising the theory behind SAM.aid.

Table 5.22. Data ranges of the data sets referenced in SAM.aid.

ACP			**AMC**		
D50	0.0830	0.3640	D50	0.0960	7.0000
SLOPE	0.0004510	0.0001358	SLOPE	0.0000580	0.0003300
VELOCITY	1.1445	4.2513	VELOCITY	1.3630	2.5167
WIDTH	112.9703	459.8822	WIDTH	10.4973	72.7812
DEPTH	2.4994	14.0965	DEPTH	2.6092	8.4978
ATC			**CHO**		
D50	0.0800	0.3033	D50	0.0900	0.3200
SLOPE	0.0000056	0.0000513	SLOPE	0.0000510	0.0002538
VELOCITY	1.0000	6.6000	VELOCITY	2.2000	5.3000
WIDTH	1000.0	1650.0	WIDTH	75.0000	400.0000
DEPTH	20.0000	50.0000	DEPTH	4.2000	12.0000
COL			**HII**		
D50	0.1550	0.6950	D50	0.210	1.440
SLOPE	0.0000370	0.0004070	SLOPE	0.0008400	0.0113000
VELOCITY	1.5561	4.1576	VELOCITY	0.47	3.05
WIDTH	303.8716	834.9249	WIDTH	1.14	26.25
DEPTH	3.7192	12.7566	DEPTH	0.06	2.4
LEO			**MID**		
D50	0.140	0.814	D50	0.2000	0.4500
SLOPE	0.0000533	0.0003460	SLOPE	0.0009000	.0016000
VELOCITY	1.19	4.14	VELOCITY	1.9000	3.7000
WIDTH	291.01	822.03	WIDTH	122.0000	153.0000
DEPTH	3.15	13.47	DEPTH	0.8000	1.4000
MIS			**MOU**		
D50	0.1629	1.1292	D50	0.2859	0.8992
SLOPE	0.0000183	0.0001336	SLOPE	.0013600	.0031500
VELOCITY	2.0000	8.0000	VELOCITY	1.2008	4.4326
WIDTH	1495.0000	3640.0000	WIDTH	10.7971	14.2165
DEPTH	15.0000	60.0000	DEPTH	0.1299	1.4366

NED			NIO		
D50	0.1000	1.0800	D50	0.2000	0.3600
SLOPE	0.0000030	0.0006200	SLOPE	.0011000	.0018000
VELOCITY	0.6507	5.3835	VELOCITY	2.0000	4.2000
WIDTH	88.5600	2771.5990	WIDTH	65.0000	75.0000
DEPTH	4.3296	43.5584	DEPTH	1.3000	2.0000
NSR			**OAK**		
D50	13.0000	76.0000	D50	8.2000	27.0000
SLOPE	.0015800	.0074500	SLOPE	.0097000	.0126000
VELOCITY	5.0000	11.0000	VELOCITY	2.6502	3.6719
WIDTH	9.0000	20.0000	WIDTH	13.8577	19.3976
DEPTH	2.0000	9.0000	DEPTH	1.0076	1.7256
POR			**RED**		
D50	2.2000	2.6000	D50	0.0900	0.2200
SLOPE	.0005400	.0009700	SLOPE	0.0000661	0.0000824
VELOCITY	2.0000	4.8000	VELOCITY	1.2000	3.8000
WIDTH	225.0000	620.0000	WIDTH	425.0000	600.0000
DEPTH	1.5000	8.0000	DEPTH	9.8000	25.0000
RGC			**RGR**		
D50	0.1800	0.2800	D50	0.1700	5.2000
SLOPE	0.0005300	0.0008000	SLOPE	0.0006900	.0024600
VELOCITY	2.6000	5.0000	VELOCITY	0.6000	8.0000
WIDTH	65.0000	75.0000	WIDTH	25.0000	400.0000
DEPTH	3.0000	5.0000	DEPTH	.5000	11.0000
RIO					
D50	0.2073	0.3676			
SLOPE	0.0007400	0.0008900			
VELOCITY	2.0481	7.8271			
WIDTH	132.9659	644.8348			
DEPTH	1.0896	4.7986			

6 Input Requirements and Program Output for SAM.hyd

Purpose

SAM.hyd has four main calculation options, with variations within each of these. While some of the input and output are consistent for all options, each calculation option also has specific input data requirements as well as varying output. This chapter will address these specific input data requirements and present an overview of associated output, option by option.

General

SAM.hyd expects an input file designated as *x*.hi, with **no embedded spaces**. SAM.hyd will write a corresponding file *x*.ho, which is the hydraulic calculations output file. All SAM.hyd options except the stable channel calculations also create an *x*.si file, which is an input file to SAM.sed.

SAM.hyd's four calculation options are briefly described below. The first option allows for determination of the unknown variable in the Manning equation, i.e., depth, bottom width in a trapezoidal channel, slope, roughness or discharge. Detailed discussions of the various input requirements follow.

<u>Normal Depth Calculations and Variations</u> offers the user the option of calculating normal depth, bottom width, discharge, energy slope, hydraulic roughness, and flow distribution. Four compositing methods are available. Riprap can be added to most of these calculations.

<u>Stable Channel Dimensions (Copeland Method)</u> will calculate the dependent design variables of width, slope and depth from the independent variables of discharge, sediment inflow and bed material composititon using the analytical approach known as the Copeland Method.

Meander Geometry Calculations will provide both curvilinear and Cartesian coordinates for a meander planform based on the sine-generated curve.

Riprap Size, Known Velocity and Depth, will calculate riprap size according to the procedure in EM 1110-2-1601 (USACE 1991, 1994) for cases when the velocity and depth are given.

Most of the above calculation options have additional options within. These are briefly described below. The input required to trigger these options will be discussed in detail in following sections.

In the uniform flow calculations hydraulic parameters can be calculated by one of four compositing methods: (1) alpha method, (2) equal velocity method, (3) total force method or (4) conveyance method.

Bed-form roughness prediction may be accounted for by using Brownlie's method, which uses velocity, hydraulic radius, slope, particle specific gravity, D_{50} and the geometric standard deviation of the bed sediment mixture.

Regime dimensions using the Blench equation can be calculated when requested with specific input, but this option is not available in SAMwin. (An editor can be used to alter an input file – see Appendix C.) Channel width, depth and slope are calculated as a function of bed-material grain size, channel-forming discharge, bed-material sediment concentration, and bank composition.

Geometry can be simple, as defined by a Channel Template (CT record), or complex, as prescribed by multiple CT records, or with station/elevation data, as in X1/GR-record data sets from HEC-2/HEC-6. In either case the geometry will be transformed into effective hydraulic parameters for sediment transport calculations.

Riprap can be added to most options.

The installation CD contains an example application, and discussion, in the LWV folder. This folder is not copied to the CD during installation, so to review the example application, see the CD.

Program execution

The hydraulic calculations can made in SAMwin by selecting a calculation type from the "Edit" dropdown menu, inputting the data, and selecting "solve," or from the "Run" dropdown menu, see Figure 6.1. This second option is useful if a ready-to-run data set exists.

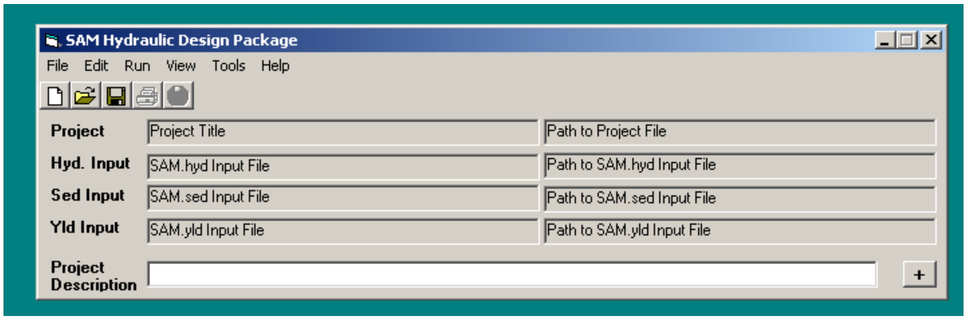


Figure 6.1. Opening window of SAMwin.

Normal Depth Calculations

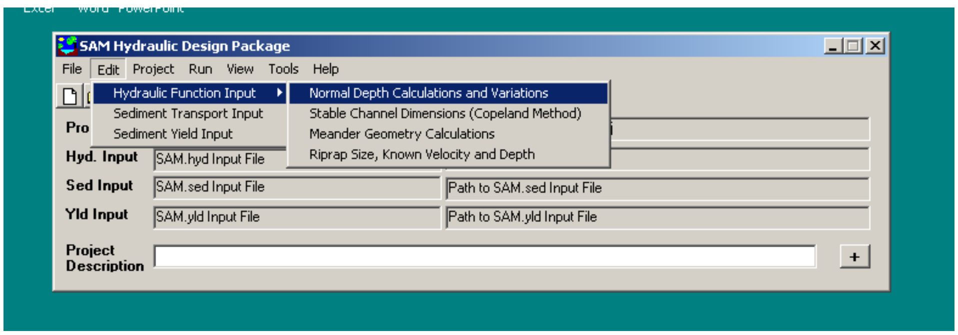


Figure 6.2. Choosing Normal Depth Calculations and Variations.

Input

"Normal Depth Calculations and Variations" selected from within the "Hydraulics Functions Input" menu of the "Edit" drop-down menu is shown in Figure 6.2. This selection will open the screen in Figure 6.3.

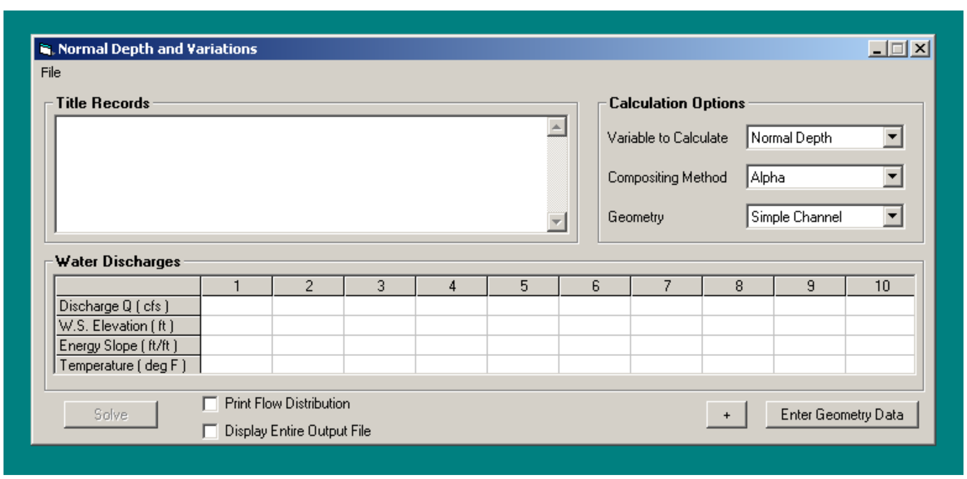


Figure 6.3. Normal Depth and Variations window of SAMwin.

Title Records.

This area allows the user to input descriptive strings, up to about 80 characters long, for use in identifying data sets. Extra characters will be truncated, not wrapped.

Calculation Options.

Variable to Calculate. The dropdown menu allows the user to choose the variable to be calculated without having to leave data blank for that particular variable. Choices are: normal depth, bottom width, energy slope, hydraulic roughness, and water discharge.

Compositing Method. SAM offers four compositing methods: alpha, equal velocity, total force, and conveyance.

Geometry. The three choices here are simple channel (single trapezoidal channel), compound channel (up to three, 'stacked,' trapezoidal channels), and station-elevation.

Flow Data

Water Discharges.

SAM data records accept a maximum of 10 data points per data type. This area allows the user to input discharge (cfs), water surface elevation (ft), energy slope (ft/ft), and temperature (F°)

Enter Geometry Data

This button opens the screen for geometry input according to the choice made in the Calculation Options box. Geometry input will be discussed later.

" + " Box.

This button toggles, opens/closes, a small window which will receive selected output. The output coming to this window cannot be selected by the user.

Print Flow Distribution

When this box is checked, SAM will add the results of the flow distribution calculations to the output file.

Display Entire Output File

When this box is checked the output file will open in its own window (using Notepad) after calculations are complete. If this button is not checked, some input will echo to the screen in an area that will drop down below this entire "Normal Depth and Variations" window. The entire output file can also be viewed by checking the View menu of the SAM main window and selecting "Hydraulic Output File."

Solve

This button causes SAM.hyd to execute. However, SAMwin often "forces" the user to check the geometry. If the Solve button is "greyed out," click on the Geometry button to check the geometry. Be sure to click OK to have the Solve button operational after the Geometry screen closes.

Geometry

The screen that opens here is determined by the Geometry type chosen in the Calculation Options of the screen in Figure 6.3.

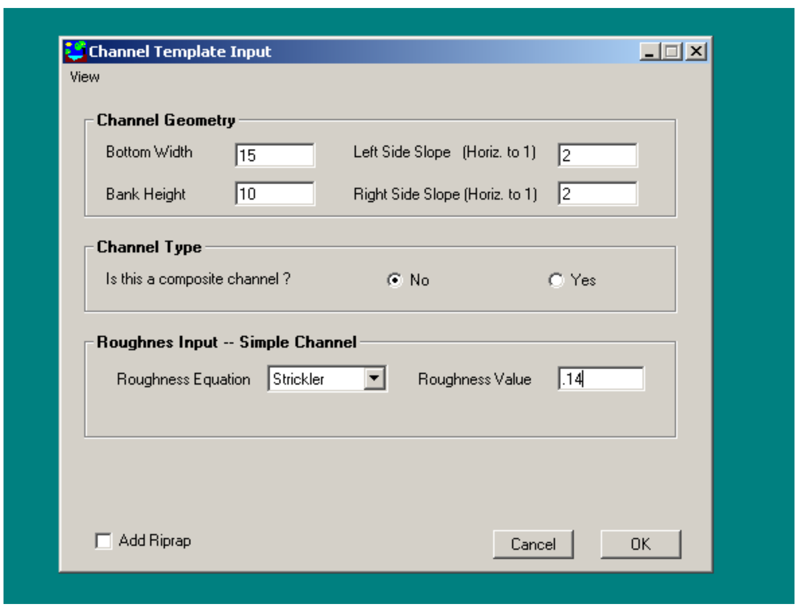


Figure 6-4. Simple Channel screen – showing data for a not composite channel

Simple and Compound Channel. A simple channel is described on either the "Channel Template Input" screen, shown in Figure 6.4, or the "Compound Channel Template" screen, shown in Figure 6.5. The Channel Geometry section of these screens prescribes bottom width, bank height and side slopes for a simple triangular, rectangular, or trapezoidal shape. A plot of the cross-section is available by clicking the View menu and selecting "Cross Section." The Compound Channel Template can describe up to three, "stacked" shapes in one channel. For example, a low flow channel can be coded on the first tab, followed by a normal flow channel and a high flow berm, as shown in Figure 1A, Chapter 2. **NOTE:** The Compound Channel option requires the discharges to be input in a specific way. See Appendix C, CT Record. Also note that if bottom width calculations are prescribed, the cross section is not sufficiently defined by the input to be plotted by the View menu.

Low Flow Channel Geometry. Bank height must be input even if water surface elevation is being calculated.

Low Flow Channel Type and Low Flow Roughness Input – Simple (or Composite) Channel. These are linked inputs. If the channel described by the geometry in this window has uniform roughness, then that channel is not a composite channel, and only one roughness equation and value are required, as shown in Figure 7.4. However, if the channel and banks either have different roughness values or require different roughness equations, then the channel is a composite channel. Clicking the "yes" button in answer to the "Type" question causes the "Low Flow Roughness" area to change to request the required input, Figure 6.5.

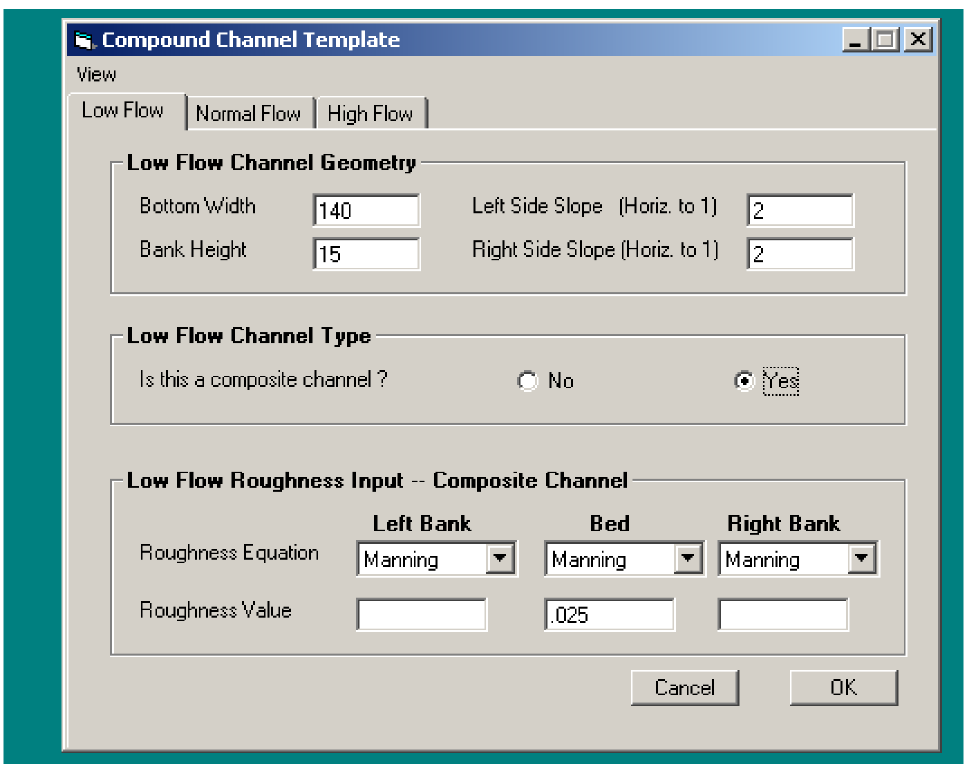


Figure 6.5. Channel template window showing composite channel input.

In addition, if the Limerinos or Brownlie equations are selected, the window further changes to request the “Bed Material Gradation,” as shown in Figure 6.6. DMAX is a required input whereas the specific gravity of sediment is optional (the value shown is the default value). The program will accept up to 18 points on the bed material gradation, and they **must** be input from largest grain size to smallest. However, a grain size for 100% finer and for 0% finer is not required.

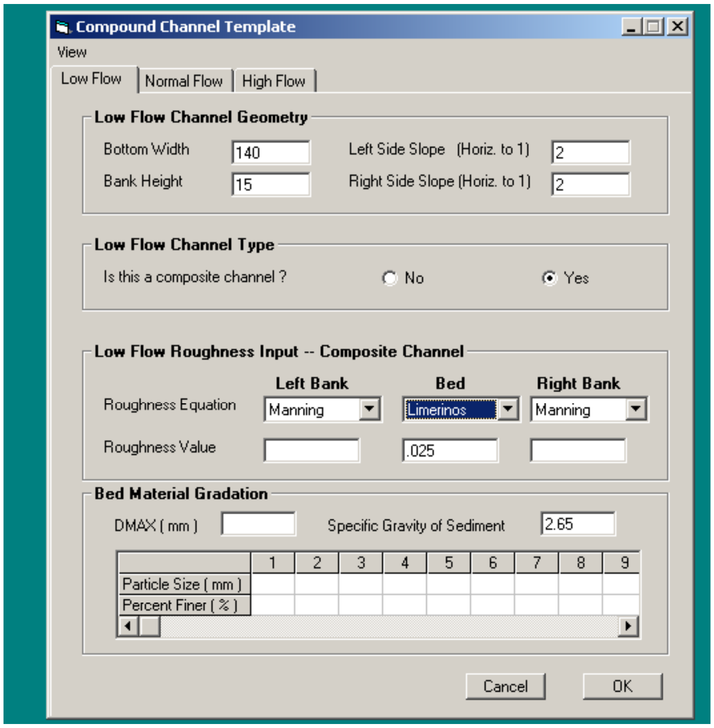


Figure 6.6. Bed Material Gradation input area of the Compound Channel Template.

Station Elevation. Complex channels can be prescribed by station and elevation coordinates. This format is the same as that in HEC-2 and HEC-6. Figure 1B in Chapter 2 shows a typical complex cross section that would be coded in this format. Figure 6.7 shows the input window for this geometry option.

Cross Section Characteristics. River mile is an optional input. The Left and Right bank stations designate the moveable bed and must be points on the cross section, but are also optional in SAM.hyd.

X-Y Coordinates of Channel Cross Section. The user can input up to 100 points. The “Edit” pull down menu offers typical editing functions, including inserting and deleting rows. These edit commands allow the user to cut to or from a columnar spreadsheet, i.e., Microsoft Excel.

Roughness Equations and Roughness Values for Panels. This area will define panels by their station/elevation endpoints and allow the user to input both the roughness equation and value to use for each panel. Roughness equation choices are listed to the right of the input area. To have hydraulic roughness calculated, put a negative number in the panels involved. Generally a "-1" is used, but the roughness can be prorated by panel. See Appendix C, KS Record, for details of this option.

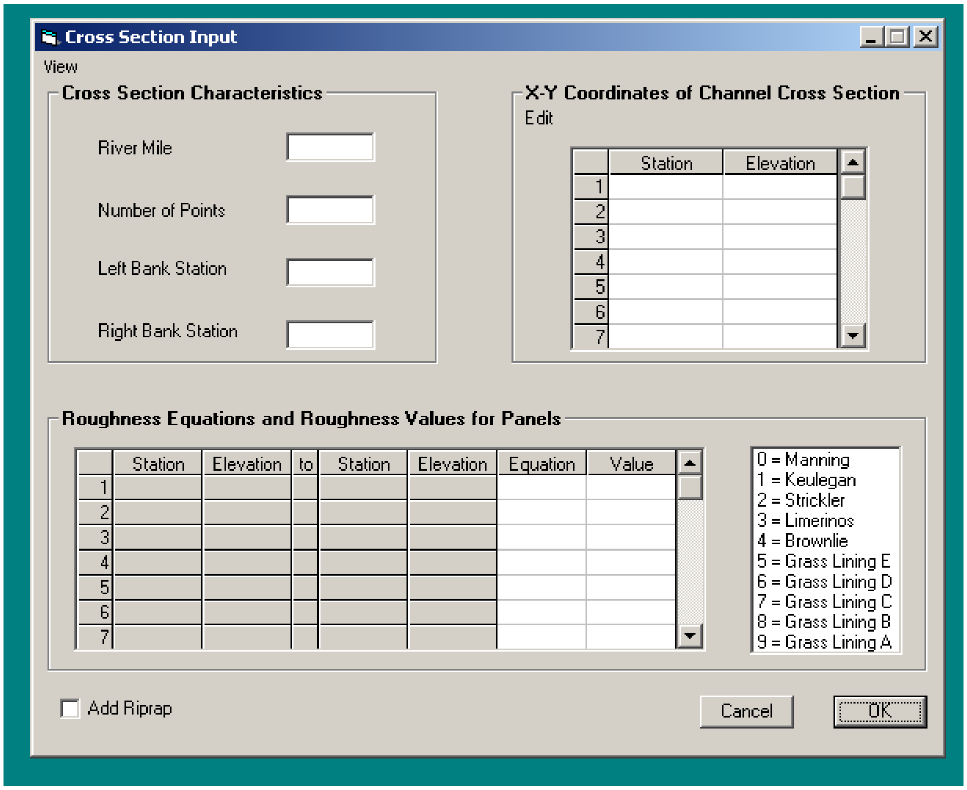


Figure 6.7. Complex geometry input window.

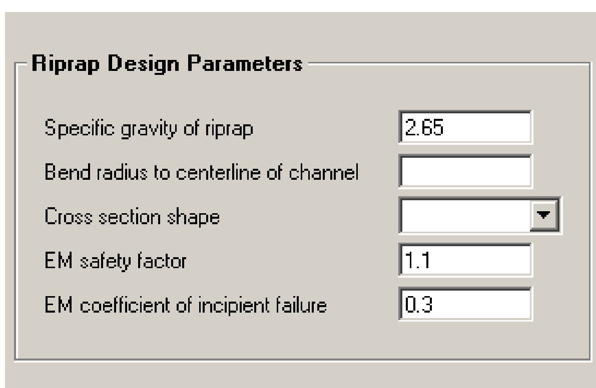


Figure 6.8. Input window added when riprap is requested.

Add Riprap. Checking this box will open the window in Figure 6.8. The numbers already in the input areas are defaults. Cross section shape offers the choice between natural and trapezoidal.

Sample Data Sets

The following examples illustrate input data for normal depth calculations.

```
T1 Test 1A  Calculate normal depth rating curve for Trapezoid
T1           100-ft bottom, 3:1 side slopes, n-value = 0.025, slope = 0.00521, t
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR     1
CT   100      10       3       3       0    .025
QW   100    1000    5000   10000   20000
ES.00521
WT    50
$$END

T1 Test 1B  same as 1A except using station-elevation geometry
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR     1
X1     1       4
GR    10     -80       0     -50       0      50      10      80
KN  .025
NE     0
QW  5000
ES.00521
WT    50
$$END


T1 Test 1C  same as 1A except using Brownlie n-value for bed & Strickler for ban
T1     requires bed gradation input;  ask for flow distribution printout
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR     1       1
CT   100      10       3       3       4               2      .5       2      .5
PF                             1      .8      98     .48      50     .25      16
QW   100    1000    5000   10000   20000
ES.00521
WT    50
SP  2.65
$$END

T1 Test 1D   Calculate normal depth in a Concrete lined, rectangular channel
T1                 Tubeworm roughness below sea level
T1                 Fish rests in center of channel
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR     2
X1     1       8
GR    12   -16.5       0   -16.5     -12   -16.5     -12      -2     -12       2
GR   -12    16.5       0    16.5      12    16.5
KN  .007     .10    .007    .035    .007     .10    .007
NE     1
QW  6900
ES.00380
WT    55
$$END
```

Sample Output Data

Selected results are printed to the drop down notebook area of the "Normal Depth and Variations" screen. The user has no control over what prints to this display. The complete output is saved in the appropriate default output file. This file will open upon program execution completion if the "Display Entire Output File" box is checked. Otherwise, the View option on the main screen can be used.

The hydraulic parameters needed for sediment transport calculations are written into the default sediment input file along with the other data needed for calculating sediment transport capacity.

The following output description is from TEST 1C, as given. Note that the Flow Distribution information was requested.

NOTE: The table numbers may change in other output files, depending on the calculation option chosen.

```
*****************************************************************************
*                                                                           *
*      SAMwin   ---   HYDRAULIC DESIGN PACKAGE FOR FLOOD CONTROL CHANNELS      *
*                                                                           *
*                            HYDRAULIC CALCULATIONS                         *
*                                                                           *
*                            version 2.0     23Jan03                        *
*                                                                           *
*           A Product of the Flood Control Channels Research Program        *
* Coastal & Hydraulics Laboratory, USAE Engineer Research & Development Center *
*                                                                           *
*                            in cooperation with                            *
*                                                                           *
*               Owen Ayres & Associates, Inc., Ft. Collins, CO              *
*                                                                           *
*****************************************************************************

 Msg 1:  HYD. READING INPUT DATA FROM FILE [  C:\Hold\hydtests.hi  ] THIS
DIRECTORY.
TABLE  1.  LIST INPUT DATA.

 T1 Test 1C  same as 1A except using Brownlie n-value for bed & Strickler for ban
 T1     requires bed gradation input;  ask for flow distribution printout
 TR     1       1
 CT   100      10       3       3       4               2      .5       2      .5
 PF                             1      .8      98     .48      50     .25      16
 QW   100    1000    5000   10000   20000
 ES.00521
 WT    50
 SP  2.65
 $$END

 INPUT IS COMPLETE.

 BED SEDIMENT GRADATION CURVE, PERCENT FINER.
 SIZE, MM=    0.250   0.500   1.000
    %,   =   16.000  53.836 100.000

 D84(mm)=    0.786  D50(mm)=    0.466  D16(mm)=    0.250  Geom Std Dev=   1.8

                        TABLE  2-1.  CROSS SECTION PROPERTIES
  #    STATION     ELEV   ROUGHNESS  N-VALUE :     GROUND     : DELTA Y   RIPRAP
         FT         FT      HEIGHT  EQUATION :SLOPE     ANGLE :    FT    Dmax*[ ]

   1     -80.0     10.00
                          0.5000      STRICKLE    -3.00    -18.4    -10.00     0.0
   2     -50.0      0.00
                          0.1529E-02  BROWNLIE     0.00      0.0      0.00     0.0
   3      50.0      0.00
                          0.5000      STRICKLE     3.00     18.4     10.00     0.0
   4      80.0     10.00

         TOP     MINIMUM     TOTAL
        WIDTH     ELEV       DEPTH
        160.0      0.00      10.00
```

```
 INEFFECTIVE FLOW ELEVATIONS BY STRIP NO.
    1       2       3
 -9999.0


    TABLE  2-2.  PHYSICAL PROPERTIES.
    ACCELERATION OF GRAVITY =  32.174


    TABLE  2-3.  PROPERTIES OF THE WATER

  #  TEMP     RHO    VISCOSITY  UNIT WT
                      *100000    WATER
    DEG F #-S2/FT4    SF/SEC    #/FT3
  1    50.    1.940      1.411   62.411
  2    50.    1.940      1.411   62.411
  3    50.    1.940      1.411   62.411
  4    50.    1.940      1.411   62.411
  5    50.    1.940      1.411   62.411


TABLE  8-1.  CALCULATE NORMAL DEPTH;  COMPOSITE PROPERTIES BY ALPHA METHOD.


 **** N     Q       WS     TOP COMPOSITE  SLOPE COMPOSITE VEL  FROUDE  SHEAR
                   ELEV   WIDTH    R             n-Value       NUMBER  STRESS
          CFS      FT     FT      FT     ft/ft            FPS             #/SF

 **** 1     100.    0.36   102.2   0.36 0.005210 0.0199   2.73   0.80   0.12

      TABLE  8-2.  FLOW DISTRIBUTION.   Q =  100.000      ALFA=  1.009
 ________________________________________________________________________________
 STATION  INC.      area    perm      r=     Ks        n       vel    taup   CMT
           %Q      sqft      ft      a/p     ft      value     fps   #/sf
    -80.0
          0.21       0.2     1.1    0.17 0.5000     0.0305  1.09  0.0188   R S
    -50.0
         99.57      36.2   100.0    0.36 0.8252E-01 0.0198  2.75  0.0710   RTB
     50.0
          0.21       0.2     1.1    0.17 0.5000     0.0305  1.09  0.0188   R S
     80.0
         _____ _________ _______  ------ ---------- ------ ----- -------
        100.00      36.6   102.3    0.36 0.8433E-01 0.0199  2.73  0.0704
________________________________________________________________________________


 **** N     Q       WS     TOP COMPOSITE  SLOPE COMPOSITE VEL  FROUDE  SHEAR
                   ELEV   WIDTH    R             n-Value       NUMBER  STRESS
          CFS      FT     FT      FT     ft/ft            FPS             #/SF


 **** 2    1000.    1.27   107.6   1.26 0.005210 0.0165   7.59   1.20   0.41

      TABLE  8-2.  FLOW DISTRIBUTION.   Q =  1000.00      ALFA=  1.040
 ________________________________________________________________________________
 STATION  INC.      area    perm      r=     Ks        n       vel    taup   CMT
           %Q      sqft      ft      a/p     ft      value     fps   #/sf
    -80.0
          0.61       2.4     4.0    0.60 0.5000     0.0305  2.51  0.0621   R S
    -50.0
         98.79     126.9   100.0    1.27 0.2412E-01 0.0161  7.79  0.3495   RUB
     50.0
          0.61       2.4     4.0    0.60 0.5000     0.0305  2.51  0.0621   R S
     80.0
         _____ _________ _______  ------ ---------- ------ ----- -------
        100.00     131.7   108.0    1.26 0.2776E-01 0.0165  7.59  0.3359
________________________________________________________________________________
```

**** N	Q CFS	WS ELEV FT	TOP WIDTH FT	COMPOSITE R FT	SLOPE ft/ft	COMPOSITE n-Value	VEL FPS	FROUDE NUMBER	SHEAR STRESS #/SF
**** 3	5000.	3.42	120.5	3.36	0.005210	0.0181	13.26	1.28	1.09

TABLE 8-2. FLOW DISTRIBUTION. Q = 5000.00 ALFA= 1.100

STATION	INC. %Q	area sqft	perm ft	r= a/p	Ks ft	n value	vel fps	taup #/sf	CMT
-80.0									
	1.71	17.5	10.8	1.62	0.5000	0.0305	4.86	0.1680	R S
-50.0									
	96.59	342.0	100.0	3.42	0.3042E-01	0.0172	14.12	0.9019	RUB
50.0									
	1.71	17.5	10.8	1.62	0.5000	0.0305	4.86	0.1680	R S
80.0									
	100.00	377.1	121.6	3.36	0.4422E-01	0.0181	13.26	0.8150	

TABLE 8-4. HYDRAULIC PARAMETERS FOR SEDIMENT TRANSPORT

Q NO	STRIP NO	STRIP Q CFS	---EFFECTIVE--- WIDTH FT	DEPTH FT	SLOPE FT/FT	n- VALUE	EFF. VEL. FPS	Froude NO	TAU Prime #/SF
1	1	100.	101.3	0.36	0.005210	0.0198	2.74	0.80	0.071
2	1	1000.	104.4	1.25	0.005210	0.0161	7.64	1.20	0.339
3	1	5000.	112.1	3.32	0.005210	0.0172	13.45	1.30	0.834
4	1	10000.	118.6	4.98	0.005210	0.0177	16.94	1.34	1.211
5	1	20000.	128.5	7.38	0.005210	0.0183	21.09	1.37	1.729

TABLE 8-5. EQUIVALENT HYDRAULIC PROPERTIES FOR OVERBANKS AND CHANNEL
DISTRIBUTED USING CONVEYANCE

N	STRIP NO	HYDRAULIC RADIUS ft	MANNING n-VALUE	.........SUBSECTION........... DISCHARGE cfs	AREA sqft	VELOCITY fps
1	1	0.36	0.0198	100.00	36.61	2.73
2	1	1.22	0.0161	1000.00	131.71	7.59
3	1	3.10	0.0172	5000.00	377.08	13.26
4	1	4.53	0.0177	10000.00	602.54	16.60
5	1	6.51	0.0183	20000.00	976.11	20.49

...END OF JOB...

General Tables The banner will reflect the version and date of the particular code being used. Table 1 simply echoes the input. Table 2-1 gives information on the cross-section properties before any calculations are made. Table 2-2 shows the acceleration of gravity. Table 2-3 shows the properties of water as calculated from the specified temperature and assuming sea level elevation.

Normal Depth Table Table 8-1 gives the normal depth calculated using the specified compositing method, which in this example is the alpha method. Also given are composite variables for the entire cross section. Since the alpha method is specified, the composite hydraulic radius, $\overline{R}$, is calculated by a conveyance weighted procedure using the panels between every point defining the cross section. For the conveyance, equal velocity, and total force methods, the composite hydraulic radius is calculated as the total area divided by the total wetted perimeter.

For the alpha method:

$$\bar{R} = \frac{\sum_{i=1}^{k} R_i C_i A_i \sqrt{R_i}}{\sum_{i=1}^{k} C_i A_i \sqrt{R_i}}$$

For the conveyance, equal velocity, and total force methods:

$$\bar{R} = \frac{\sum_{i=1}^{k} A_i}{\sum_{i=1}^{k} P_i}$$

where:

k = the number of panels
i = the panel number
$\underline{R}$ = the composite hydraulic radius
$R_i = A_i / P_i$
C_i = the panel Chezy roughness coefficient
A_i = the panel cross-sectional area
P_i = the wetted perimeter

The composite roughness coefficient, $\bar{n}$, is calculated using the composite R in the Manning equation:

$$\bar{n} = \frac{1.486\, \bar{R}^{\frac{2}{3}} S^{\frac{1}{2}} \sum_{i=1}^{k} A_i}{Q}$$

where:

S = energy slope
Q = total discharge

Other results in Table 8-1 are calculated as follows:

$$\overline{V} = \frac{Q}{\sum A_i}$$

$$Froude\ Number = \frac{\overline{V}}{\sqrt{EFD * g}}$$

$$\tau = \gamma \overline{R} S$$

where:

$\underline{V}$ = average velocity
EFD = effective depth
g = acceleration of gravity
τ = bed shear stress
γ = unit weight of water

Flow Distribution Table. Table 8-2 gives the flow distribution for each panel of the cross section. The conveyance weighted discharge percentage for each panel, Q_i , is calculated by the following equation:

$$Q_i = 100\, Q \left(\frac{C_i\, A_i \sqrt{R_i}}{\sum C_i\, A_i \sqrt{R_i}} \right)$$

Area, wetted perimeter, and hydraulic radius are reported for each panel. Panel hydraulic radius, R_i , is defined as A_i/P_i. k_s and *n* are calculated or given for each panel. Velocity, V_i , is defined as Q_i/A_i. If no bed gradation is specified:

$$\tau = \gamma\, D_i\, S$$

where:

D_i = average depth in the panel

If a bed gradation is specified, then τ in the table is the grain shear stress calculated using a combination of the Manning and Limerinos equations, where R' is the hydraulic radius associated with grain roughness and is determined from the following:

$$\frac{V_i}{\sqrt{g\ R'_i\ S}} = 3.28 + 5.75 \log \frac{R'_i}{d_{84}}$$

and the grain shear stress is calculated as:

$$\tau'_i = \gamma\ R'_i\ S$$

The **CMT column** consists of 6 columns of single letter codes. The first 3 columns define the flow type, which is considered to be rough if

$$\frac{\frac{4\ R_i V_i}{\nu} k_{si}}{C_i\ R_i} \geq 50$$

where:

v = kinematic viscosity

If the flow is rough, an R appears in the third column. Otherwise T/S, standing for transitional to smooth flow, appears in **columns 1 through 3**.

Other nomenclature in **columns 1 through 3** are "V:O", indicating that this panel has a vertical wall, and "DRY", indicating that there is no water in this panel.

The **fourth column** is used to define the flow regime, if the Brownlie equations are specified, or to identify that the SCS grass equations are being used.

U - upper bed regime
T - transitional
L - lower bed regime
G - indicates the equation flagged in column 6 is a grass equation.

The **last column** indicates the roughness equation used for the panel.

B - Brownlie
K - Keulegan
L - Limerinos
M - Strickler (Manning)
A,B,C,D,E - various grass equations if the fourth column was a “G” .

At the bottom of the table are summaries. The numbers below the solid line are totals for the column. The numbers below the dashed line are composite values for the cross-section, calculated the same as in Table 8-1.

In the output for TEST 1C, notice that for Q = 100, the panel between stations 50.0 and 80.0 has a calculated n-value of 0.0305. The comment column for this panel shows "R S", indicating rough flow and that the Strickler method was used. The input data requested Keulegan, but, **NOTE**, SAM will not apply Keulegan if $k_s/R < 3$. It automatically substitutes Strickler.

The Normal depth Table 8-1 and the Flow Distribution Table 8-2 are repeated for every discharge prescribed on the QW-record. The composite hydraulic parameters for each discharge are highlighted between the flow distribution tables, with "****". In the example output included in this chapter, the printout for discharges 4 and 5 have been omitted.

Hydraulic Parameters for Sediment Transport Table The results printed in Table 8-4 are representative hydraulic parameters for making sediment transport calculations. The effective velocity, depth, width and slope are calculated for both overbanks and the channel. EFFECTIVE WIDTH, EFW, and EFFECTIVE DEPTH, EFD are defined by the following equations:

$$EFD = \frac{\Sigma\, d_i \;\; A_i\, d_i^{\;2/3}}{\Sigma\, A_i \;\; d_i^{\;2/3}}$$

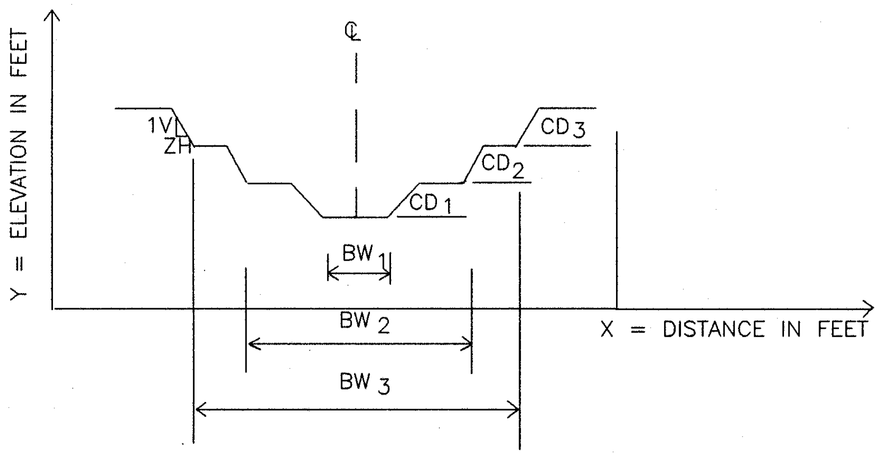
$$EFW = \frac{\Sigma\, A_i\, d_i^{\;2/3}}{EFD^{5/3}}$$

where:

Ai = flow area of each trapezoidal element
di = average water depth of each trapezoidal element

Equivalent Hydraulic Properties for overbanks and channel Flow distribution and conveyance-weighted hydraulic parameters are calculated for the overbanks and channel and listed in Table 8-5. The water-surface elevation that was calculated using the specified compositing method determines channel and overbank subareas and wetted perimeters. Conveyance for each subarea is calculated using the Chezy equation and conveyance weighted discharges determined. Using the area, wetted perimeter, discharge, and slope for the three subareas, a composite n value is calculated for the channel and both overbanks.

Plotting The following hydraulic output plots should be available: stage versus n-value; stage versus average velocity in cross section; stage versus effective velocity; stage versus discharge; stage versus width; stage versus effective width; stage versus hydraulic radius; cross section geometry; and, slope versus width.



1V:ZH -- definition of the side slopes, with the Z as the input parameter
CD1 -- the height of the low flow channel
CD2 -- the incremental height of the normal channel
CD3 -- the incremental height of the high flow channel
BW1 -- the width, toe to toe, of the low flow channel
BW2 -- the width, toe to toe, of the normal channel
BW3 -- the width, toe to toe, of the high flow channel
Note: therefore total depth = CD1+CD2+CD3

Figure 6.9. Definition of input for bottom calculations for compound channels.

Bottom Width Calculations: Input and Output

Bottom width of a simple or compound channel can be determined with this option. Roughness and compositing are handled the same as described for normal depth calculations. Bottom width becomes the dependant variable in the Manning equation:

$$W = f(Q, n, D, z, S)$$

where

W = bottom width
Q = water discharge
n = n-value
D = water depth
z = side slopes of the channel
S = energy slope

Bottom Width must be selected in the “Variable to Calculate” drop down box on the “Normal Depth and Variations” screen, Figure 6-3.

Geometry input

Either the “Simple Channel” or the “Compound Channel” method for inputting geometry is permitted in this calculation; but not the station/elevation method. Note that the water surface elevation, on the “Normal Depth and Variations” screen does not have to be given a value for the bottom width calculations. The bank height input on the “Compound Channel Template” screen sets a limiting depth on the channel.

Simple Channel. To calculate bottom width for a simple channel, put only 1 discharge in the “Flow Data” area, Figure 6-3.

Compound Channel. To calculate bottom width for a compound channel, use the “Compound ChannelTemplate” screen, Figure 6-6. The number of discharges input on the “Flow Data” area **must** match the number of “tabs” filled out. Also, the discharges must be in low-normal-high flow channel order. **NOTE:** The requirements for discharge input in this calculation are different from those for all other hydraulic calculations.

Input for Compound Channel Calculations. The ‘bank heights’ requested on the “Compound Channel Template” screen are the heights represented by CD1, CD2, and CD3 in Figure 6.9. Each of these heights is *incremental*; each is for its own section of the channel (see Figure 6.9). For example, in Test 2B, below, the maximum depth for the normal channel is 13 ft (3+10); the maximum depth in the high flow channel is 28 ft (3+10+15). The program will increase the calculated bottom width to convey the prescribed discharge rather than increase the depth beyond that 28 ft. The calculated water surface, and depth, is the distance from the low flow channel invert to the water surface. The discharge input is the *total* discharge (input on the “Flow Data” area of the “Normal Depth and Variations” screen).

Sample Input Data

The following example shows input data when calculating bottom width. The difference between this input and that required to calculate normal depth is bottom width, CT record field 1, is left blank by SAMwin. Also note no water surface is prescribed.

```
T1 Test 2A   Calculate bottom width in simple x-section
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR     1
CT             3       3       3       4               2      .3       2      .3
PF                             1      .8      98     .48      50     .25      16
QW  6000
ES .0050
WT    65
SP  2.65
$$END
```

```
T1   TEST 2B Bottom Width Calculations for Compound channel
T1                       Low Flow, Normal and High Flow channels defined
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
CT             3       3       3       4               2      .3       2      .3
CT            10       3       3       4               2      .3       2      .3
CT            15       3       3       4               2      .3       2      .3
PF                             1      .8      98     .48      50     .25      16
QW   600   12000   85000
ES .0030
WT   65.
$$END
```

Sample Output Data

The following output is taken from the output from Test 2A, above. The general output tables from these calculations are described earlier. However, note that table series "8-*x*" has become "5-*x*". The information contained in the two series of tables is the same, with the title of the "*x*-1" table flagging both the calculation performed and the compositing method used. **NOTE**: The calculated bottom width is shown in Table 5-1 as "Bottom Width" and is not flagged as having been calculated.

```
TABLE  5-1.  CALCULATE BOTTOM WIDTH;  COMPOSITE PROPERTIES BY ALPHA METHOD.


 **** N      Q       WS   BOTTOM    R      SLOPE    n      VEL  FROUDE  SHEAR
                    ELEV   WIDTH                  Value         NUMBER  STRESS
         CFS        FT     FT      FT     ft/ft           FPS             #/SF

 **** 1    6000.    3.00   153.1   2.97 0.005000 0.0175  12.34   1.27   0.92


     TABLE  5-4.  HYDRAULIC PARAMETERS FOR SEDIMENT TRANSPORT
      Q STRIP  STRIP        ---EFFECTIVE---    SLOPE    n-    EFF.  Froude
    TAU
     NO   NO      Q            WIDTH   DEPTH           VALUE   VEL.    NO
    Prime
               CFS              FT      FT     FT/FT          FPS
    #/SF
      1   1    6000.           163.6   2.95 0.005000 0.0170  12.45   1.28
    0.729


     TABLE  5-5.  EQUIVALENT HYDRAULIC PROPERTIES FOR OVERBANKS AND CHANNEL
                  DISTRIBUTED USING CONVEYANCE
       N  STRIP  HYDRAULIC   MANNING .........SUBSECTION...........
            NO     RADIUS    n-VALUE DISCHARGE     AREA    VELOCITY
                     ft                 cfs        sqft       fps

       1     1       2.83     0.0170   6000.00     486.35    12.34
```

The following output is from Test 2B, above. Note the "**** 1" lines from the example above and the example below – the bottom widths are very different, because the discharges prescribed are very different and the maximum depth is 3, as prescribed by the bank height input in both. Also note that the "WS ELEV FT" in Table 5-1 is cumulative (the distance from the low flow channel invert to the water surface), i.e., the 85,000 cfs discharge fills the 28 ft of depth prescribed by the bank heights, causing the high flow channel to gain width. Each bottom width given in Table 5-1 is the width of that channel, from toe of slope to toe of slope, as shown in Figure 6.9.

Occassionally the following warning message will appear:

ABNORMAL TERMINATION OF WIDTH CALCULATION.
SUCCESSIVE ITERATIONS ARE NOT IMPROVING THE CONVERGENCE.

The program will then print values on the "****" lines anyway. The warning indicates problems encountered when trying to converge on an appropriate width. To check the answer for reasonableness, use the calculated bottom width as input to the water surface elevation calculations. If the water surface then calculated is close to that the bottom width calculations printed, then the answer is reasonable.

TABLE 5-1. CALCULATE BOTTOM WIDTH; COMPOSITE PROPERTIES BY ALPHA METHOD.

**** N	Q CFS	WS ELEV FT	BOTTOM WIDTH FT	R FT	SLOPE ft/ft	n Value	VEL FPS	FROUDE NUMBER	SHEAR STRESS #/SF
**** 1	600.	3.00	16.5	2.74	0.003000	0.0203	7.83	0.85	0.51
**** 2	12000.	13.00	41.1	10.46	0.003000	0.0254	15.23	0.84	1.96
**** 3	85000.	28.00	145.2	20.32	0.003000	0.0258	23.34	0.91	3.80

Energy Slope Calculation: Input and Output

Energy slope can be determined with this option, where slope becomes the dependant variable in the Manning equation:

$$S = f\ (W, Q, n, D, z, S)$$

Geometry, roughness, compositing, and plotting are handled the same as described for the normal depth calculations. Choose "Energy Slope" as the "Variable to Calculate."

Sample Input Data

The following example shows input data when calculating energy slope. Notice that it is the same as shown for Normal Depth except that the WS-record is present and the ES-record is missing. The missing ES-record tells SAM to calculate the slope.

```
TI   TEST NO. 4  CALCULATE ENERGY SLOPE
TI     1       2       3       4       5       6       7       8       9      10
F#  345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
CT     100      10       3       3       2     .02       2      .2       2      .2
QW    4050
WS    3.07
WT      55
$$END
```

Sample Output Data

The general output tables from these calculations are described earlier. However, note that table series "8-*x*" has become "6-*x*". The information contained in the two series of tables is the same, with the title of the "*x*-1" table flagging both the calculation performed and the compositing method used. Also note that the calculated slope is shown in Table 6-1 as "Slope" and is not flagged as having been calculated.

```
TABLE  6-1.  CALCULATE ENERGY SLOPE;  COMPOSITE PROPERTIES BY ALPHA METHOD.


 **** N     Q       WS      TOP      R       SLOPE     n       VEL  FROUDE  SHEAR
                   ELEV   WIDTH                      Value         NUMBER  STRESS
          CFS       FT      FT      FT      ft/ft            FPS             #/SF

 **** 1    4050.    3.07   118.4   3.01 0.005203 0.0185  12.08   1.23   0.98


 TABLE  6-4.  HYDRAULIC PARAMETERS FOR SEDIMENT TRANSPORT
  Q STRIP  STRIP         ---EFFECTIVE---     SLOPE     n-    EFF.  Froude   TAU
 NO   NO     Q             WIDTH   DEPTH              VALUE   VEL.    NO    Prime
            CFS              FT      FT     FT/FT            FPS            #/SF
  1   1    4050.           110.8   2.99 0.005203 0.0177  12.24   1.25  0.969
```

Hydraulic Roughness Calculations: Input and Output

In this calculation roughness becomes the dependant variable in the Manning equation, thus calculating that variable:

$$W = f(Q, n, D, z, S)$$

Geometry, compositing and plotting are handled as described for normal depth calculations. This calculation, like the other solutions of the Manning equation which involve compositing, is trial and error. A simple solution of the Manning equation is used to calculate the first trial roughness coefficient. Of the several equations for hydraulic roughness, the Strickler (Manning) equation is the most likely to converge. The Brownlie equation may have trouble converging due to the discontinuity associated with the transition zone.

Sample Input Data

The following example shows input data when calculating k_s. Note the KN record in Test 4B, and field 6 on the CT record in Test 4A. The negative values flag the program to make the hydraulic roughness calculations. The absolute value, i.e., 0.5in Test 4B, tells the program the ratio of roughness in that element to the composite roughness. For example, if the values are -1, as on the KS-record fields 3, 4, 5, and 6, or as on the CT record in field 6 in Test 4A, then the roughness in each of these panels would be calculated as equal proportions of the composite. The program is supposed to supply "missing" values on a record by repeating the data in the previous fields; i.e., on the CT record, the data for fields 7 and 8, and 9 and 10, would be repeated from fields 5 and 6 (see Appendix C). **Note**, however, that currently this does not work *for the KN record*, and *data for all fields should be supplied by the user.*

```
T1 Test 4A  Calculate Ks from Barnes n-value        Simple trapezoidal channel
T1 fld 1    2       3       4       5       6       7       8       9      10
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR     2       1
CT   301      10       0       0       1      -1
QW 13900
WS   5.3
ES .0034
WT    50
$$END
```

```
T1 4B Calculate Ks from Barnes, p34
T1           Station-Elevation Geometry
T1 fld 1    2       3       4       5       6       7       8       9      10
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR     1
X1     1       7
GR    16       0    12.6      40    12.4      65     9.5      80     8.8     200
GR   8.8     290      16     320
KN           -.5      -1      -1      -1      -1
NE     9       2       1
QW 13900
WS  15.6
ES .0034
WT    50
$$END
```

Output Data

The information contained in the output tables is the same as that described in the normal depth calculation output.

Water Discharge Calculations: Input and Output

This option allows water discharge to become the dependant variable in the Manning equation.

$$W = f\ (Q, n, D, z, S)$$

Geometry, roughness, compositing, and plotting are all handled as in the normal depth calculations.

Note, when convergence fails, assume a range of discharges and use the normal depth calculations to arrive at the correct value.

Sample input data

The following example shows input data when calculating Q.

```
T1 Calculate Energy Slope
T1     Simple channel
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR     1
CT   100      10       3       3       2     .02       2      .2       2      .2
WS  3.07
ES.00052
WT    55
$$END
```

Sample Output

The general output tables from these calculations are described in the normal depth calculation output. However, note that table series "8-*x*" has become "9-*x*". The information contained in the two series of tables is the same, with the title of the "*x*-1" table flagging both the calculation performed and the compositing method used. Also note that the calculated water discharge is shown in Table 9-1, as "Q," and is not flagged as having been calculated.

```
TABLE  9-1.  CALCULATE WATER DISCHARGE;  COMPOSITE PROPERTIES BY ALPHA METHOD.


 **** N     Q       WS     TOP     R      SLOPE    n      VEL  FROUDE  SHEAR
                   ELEV   WIDTH                  Value         NUMBER  STRESS
          CFS       FT     FT     FT     ft/ft          FPS              #/SF


 **** 1    1281.    3.07   118.4   3.01 0.000520 0.0185   3.82   0.39   0.10

 TABLE  9-4.  HYDRAULIC PARAMETERS FOR SEDIMENT TRANSPORT
  Q STRIP  STRIP        ---EFFECTIVE---    SLOPE    n-    EFF.  Froude   TAU
 NO   NO     Q            WIDTH   DEPTH            VALUE   VEL.    NO    Prime
            CFS             FT      FT     FT/FT           FPS            #/SF
  1   1    1281.           110.8   2.99 0.000520 0.0177   3.87   0.39  0.097



 TABLE  9-5.  EQUIVALENT HYDRAULIC PROPERTIES FOR OVERBANKS AND CHANNEL
              DISTRIBUTED USING CONVEYANCE
  N  STRIP  HYDRAULIC   MANNING .........SUBSECTION...........
       NO     RADIUS    n-VALUE DISCHARGE     AREA    VELOCITY
                ft                cfs         sqft       fps

  1     1       2.81     0.0177   1281.32     335.35     3.82
```

Riprap Size for a Given Velocity and Depth (RS-Record) Calculations

Input and Output

The input window for these calculations is accessed from the SAMwin main menu – Edit – Hydraulic Function Input – Riprap size, Known Velocity and Depth, Figure 6.10.

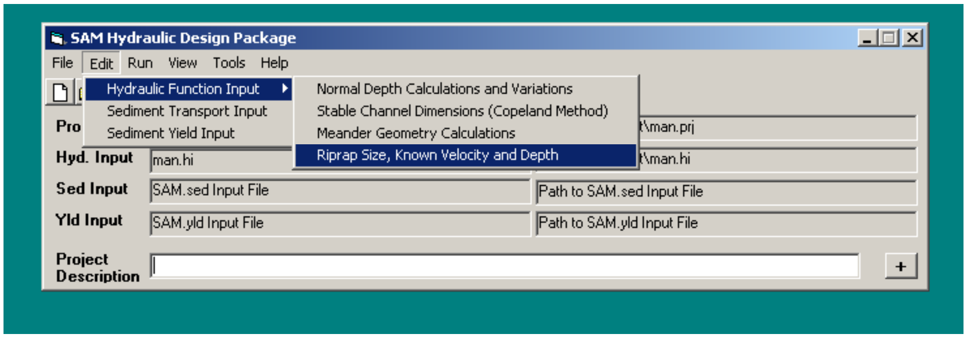


Figure 6.10. Finding the Riprap Calculations input screen.

When flow velocity and depth are known, the riprap size is calculated using the equation described in EM 1110-2-1601 (USACE 1991, 1994). Since the size and specific gravity of available riprap are needed for this calculation, the 13 standard riprap sizes (shown in EM 1110-2-1601 and in Chapter 2) are available in the program by default. The riprap design equation is:

$$d_{30} = S_f\, C_S\, C_V\, C_T\, D \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V_{AVE}\, C_B}{\sqrt{K_1\, g\, D}} \right]^{2.5}$$

where

- d_{30} = characteristic riprap size of which 30 percent is finer by weight
- S_f = Safety factor
- C_S = Coefficient of incipient failure
- C_V = vertical velocity coefficient
- C_T = coefficient for riprap thickness
- D = local water depth
- γ_w = unit weight of water
- γ_s = unit weight of riprap
- V_{AVE} = average channel velocity
- C_B = bend correction for average velocity (V_{SS}/V_{AVE})
- K_1 = Correction for side slope steepness
- g = Acceleration of gravity

Up to five sizes of quarry run riprap can be specified and will be used in the calculations instead of the default if they appear in the data set. This capability is not available in SAMwin at this time. However, the quarry run riprap data can be input on the RQ record with an editor; see Appendix C. That data set can then be run with the "Run" option of the SAMwin main menu. No plots are available from these calculations.

The safety factor, S_f, accounts for variability and uncertainty in calculated hydrodynamic and non-hydrodynamic imposed forces and/or for uncontrollable physical conditions. The minimum safety factor recommended in EM 1110-2-1601 (USACE 1991, 1994) is 1.1. This is the default value used in SAM. However, a larger value may be specified on the riprap input screen. A discussion of appropriate values for the safety factor is presented in EM 1110-2-1601 (USACE 1991, 1994).

The thickness coefficient, C_T, accounts for the increase in stability that occurs when riprap is placed thicker than the minimum thickness. Minimum thickness is the greater of $d_{100\,MAX}$ and 1.5 $d_{50\,MAX}$. If minimum thickness is desired, then $C_T = 1.0$. EM 1110-2-1601 (USACE 1991, 1994) provides three curves for determining C_T as a function of the ratio d_{85}/d_{15} and the ratio of design thickness to minimum thickness -- T_R/T_{MIN}. Currently, SAM uses the curve that results in the least reduction in design riprap size:

$$C_T = 1.44 - 0.58\,\frac{T_R}{T_{\mathrm{MIN}}} + 0.14\,\frac{T_R}{T_{\mathrm{MIN}}} \qquad 1 \le \frac{T_R}{T_{\mathrm{MIN}}} \le 2$$

where:

T_R = riprap thickness
$T_{MIN} = d_{100\,MAX}$ or 1.5 $d_{50\,MAX}$, whichever is greater.

This equation is appropriate when the gradation uniformity coefficient, d_{85}/d_{15}, = 1.7, which corresponds to the gradations recommended in EM 1110-2-1601 (USACE 1991, 1994). Larger gradation uniformity coefficients would result in a smaller value for C_T. In SAM, the default value for T_R/T_{MIN} is 1.0. A different ratio may be prescribed as variable RSEC on the RS record or a variable RT(i) of the RT record. T_R/T_{MIN} ratios usually range between 1.0 and 1.5.

NOTE: THIS DESCRIPTION AND CODING FOR C_T REFLECTS 1991 GUIDANCE.

The stability coefficient for incipient failure, C_S, has been determined to be 0.030 for angular rock, and 0.0375 for rounded stone. These values have been demonstrated for riprap gradations where $1.7<d_{85}/d_{15}<5.2$. The default in SAM is for the angular rock. The rounded stone coefficient may be used by specifying a negative thickness ratio, T_R/T_{MIN}, for the variable RSEC on the RS record or for variable RT(L) on the RT record. The stability coefficient for incipient failure may also be changed by changing the variable CIFRRS on the RR record and using negative values for T_R/T_{MIN} . C_S = 0.30 is multiplied by CIFRSS when T_R/T_{MIN} is negative -- the default for CIFRRS is 1.25 which yields C_S = 0.375.

The vertical velocity distribution coefficient, C_V , varies as a function of the ratio of bend radius, R, to channel width, W. C_V = 1.0 in straight channels, for the inside of bends, and for bends where R/W is ñ 26. The equation for C_V when R/W < 26 is:

$$C_V = 1.283 - 0.2 \log_{10}\left(\frac{R}{W}\right)$$

The maximum value allowed for C_V is 1.283. C_V is determined in SAM using either a calculated water-surface width or a water-surface width prescribed on record RS, and a bend radius prescribed as variable on the RR record.

The side slope correction factor, K_1 , is calculated by SAM from geometric input and the empirical side slope correction graph in EM 1110-2-1601. The side slope steepness angle is calculated for each panel. When the steepness is milder than 1V:3H the side slope correction factor is 1.0. The steepest side slope allowed is 1V:1.5H.

The bend correction factor, C_B , which is the same as V_{SS} / V_{AVE} in EM 1110-2-1601, is determined differently depending on whether the channel is a natural channel or a trapezoidal channel. In SAM, a trapezoidal cross section is identified by setting NTRAP on the RR record equal to 1. If no value is assigned a natural channel is assumed. C_B is calculated in SAM as a function of the R/W ratio. For trapezoidal channels:

$$C_B = 1.71 - 0.78 \log_{10}\left(\frac{R}{W}\right) \qquad 1.48 \leq C_B \leq 0.82$$

and for natural channels:

$$C_B = 1.74 - 0.52 \log_{10}\left(\frac{R}{W}\right) \qquad 1.58 \leq C_B \leq 0.90$$

NOTE: THESE DESCRIPTIONS AND CODING FOR CB REFLECT 1991 GUIDANCE.

When riprap calculations are made using known velocity and depth, care must be taken in defining the input variables. Depth is the depth of water at the toe of the riprap. SAM will adjust the depth to 0.8 D as prescribed in EM 1110-2-1601 (USACE 1991, 1994). If the local depth averaged velocity at 20 percent up-slope from the riprap toe is input, then no bend radius should be prescribed. On the other hand, if the average channel velocity upstream of the bend is input, then a bend radius should also be prescribed. The bend radius, R, is defined as the centerline radius of the bend, considering only the main channel. The water-surface width, W, is defined as the main channel water-surface width at the upstream end of the bend.

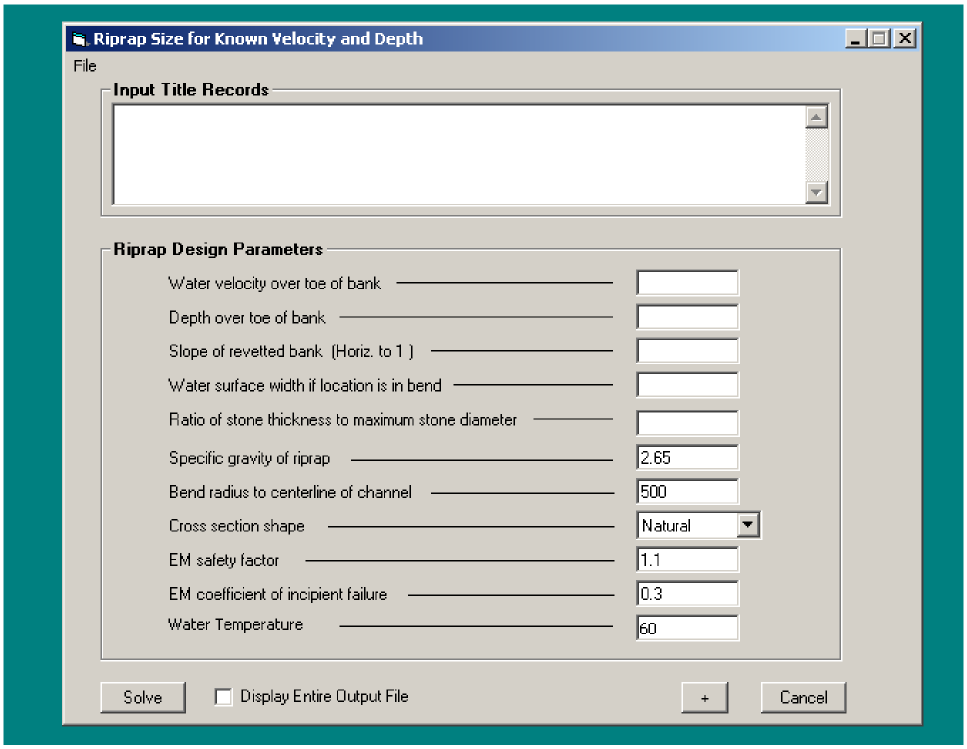


Figure 6.11. Input screen for riprap calculations for known velocity and depth.

Sample Input Data

The required input data for simple riprap calculations are shown in Figure 6.11. Again, if quarry run riprap gradations are to be specified, they must be added to the data set with and editor, and should be entered one size per record, starting with the smallest. This record is currently not available in SAMwin.

Various input data sets are given in the following examples.

```
T1 Test 6A   Simple Riprap design -- given velocity and depth
T1                Problem 1  Appendix H, EM 1110-2-1601
T1                EM 1110-2-1601 gradations
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
RS   7.1      15       2     200
RR  2.65     620                  0     1.1     0.3
WT    60
$$END
```

```
T1 Test 6B  Simple Riprap design -- given velocity and depth
T1                with 155 lb stone    Trapezoidal channel
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
RS     8      20       2     500
RR  2.48    1700              1     1.1     0.3
WT    60
$$END

T1 Test 6C Simple Riprap design -- given velocity and depth
T1                with 155 lb stone at 7 fps           Trapezoidal channel
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
RS     7      20       2     500
RR  2.48    1700              1     1.1     0.3
WT    60
$$END

T1 Test 6D Simple Riprap design -- given velocity and depth
T1                with 155 lb stone at 7 fps and 1V:1.5H side slope
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
RS     7      20     1.5     500
RR  2.48    1700              1     1.1     0.3
WT    60
$$END

T1 Test 6E Simple Riprap design -- given velocity and depth
T1        with 155 lb stone at 7 fps and 1V:1.5H side slope, 1.5*DMAX thickness
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
RS     7      20     1.5     500     1.5
RR  2.48    1700              1     1.1     0.3
WT    60
$$END
```

Sample Output Data

The following example is taken from the output from Test 6A. The general tables, Tables 1 and 0-3, are described in the normal depth calculation output. The output shown below is the additional, riprap output. The first line describes the calculation being performed. The next line states the source of the riprap sizes tested. It would have stated "USING QUARRY RUN RIPRAP" had that been prescribed. The first table shown describes the necessary riprap size as determined by the calculations. The second, longer table describes both the riprap and some of its effects as well as some of the factors used in the calculations. The cross section properties are echoed, and there is a table with the "Hydraulic properties with riprap in place." The standard tables, 8-4 and 8-5, are repeated but contain the parameters as calculated with the stated riprap size in place.

DETERMINE RIPRAP SIZE FOR A GIVEN WATER DISCHARGE

USING GRADED RIPRAP TABLES FROM EM 1110-2-1601

LAYER #	D30CR FT	DMAXRR IN	D30 FT	D50 FT	D90 FT	WIDTH FT	CY/FT	TONS/FT	$/FT
5	0.71	21.00	0.85	1.03	1.23	187.42	12.148	0.622	0.00

```
RIPRAP SIZE      = LAYER#  5            DMAX, INCHES      =      21.
  VELOCITY, FT   =       7.90           VSS/VAVG          =     1.354
  BEND RADIUS,FT =       500.           TOP WIDTH, FT     =      175.
  R/W            =      2.861           VERT VEL CORR, Cv =     1.192
  LOCAL DEPTH, FT=      10.60           DESIGN DEPTH      =      8.48
  SAFETY FAC, Sf =       1.10           STABILITY COEF, Cs =    0.300
  THICKNESS, IN  =      21.00           THICKNESS COEF, Cv =    1.750
  SIDE SLOPE     =       2.00           SIDE SLOPE CORR, K1=    1.180
  SP.GR. RIPRAP  =       2.65           POROSITY, %       =     38.00
  CHANNEL TYPE   = TRAPEZOID            COST PER FOOT,$/FT =     0.00


                    TABLE  8-1.  CROSS SECTION PROPERTIES
 #   STATION    ELEV   ROUGHNESS  N-VALUE :    GROUND     : DELTA Y   RIPRAP
       FT        FT     HEIGHT  EQUATION :SLOPE    ANGLE :   FT    Dmax*[ ]

  1   -100.0    15.00
                 1.230      STRICKLE    -2.00   -26.6    -15.00     1.0
  2    -70.0     0.00
                 1.230      STRICKLE     0.00     0.0     0.00     1.0
  3     70.0     0.00
                 1.230      STRICKLE     2.00    26.6    15.00     1.0
  4    100.0    15.00
1
HYDRAULIC PROPERTIES WITH RIPRAP IN PLACE.    STRICKLER COEFFICIENT = 0.038

**** N     Q       WS     TOP COMPOSITE  SLOPE COMPOSITE VEL  FROUDE  SHEAR
              ELEV   WIDTH    R            n-Value      NUMBER  STRESS
        CFS      FT     FT      FT     ft/ft          FPS          #/SF

**** 1   13500.   11.26   185.0  10.73 0.001700 0.0404   7.38   0.40   1.14

TABLE  8-4.  HYDRAULIC PARAMETERS FOR SEDIMENT TRANSPORT
 Q STRIP  STRIP       ---EFFECTIVE---    SLOPE    n-    EFF.  Froude   TAU
NO   NO     Q           WIDTH   DEPTH          VALUE   VEL.    NO    Prime
         CFS           FT      FT     FT/FT         FPS          #/SF
 1   1   13500.          166.8  10.74 0.001700 0.0376   7.53   0.41  1.139



TABLE  8-5.  EQUIVALENT HYDRAULIC PROPERTIES FOR OVERBANKS AND CHANNEL
           DISTRIBUTED USING CONVEYANCE
 N  STRIP  HYDRAULIC   MANNING .........SUBSECTION...........
     NO     RADIUS    n-VALUE DISCHARGE     AREA    VELOCITY
            ft               cfs       sqft       fps

 1     1       9.61     0.0376  13500.00    1830.33     7.38

...END OF JOB...
```

Riprap Size for a Given Discharge and Cross Section Shape: Input and Output

Riprap size calculations are more complicated when the water discharge and cross section are given than when the flow velocity and depth are given because n-value becomes a function of riprap size. The computational procedure is described in detail in Chapter 2.   The stone size gradation table is the default for riprap sizes, but quarry run stone can be prescribed, as noted above, although that option is currently not available in SAMwin. Riprap size is determined automatically when the RR-, RT-, and PF-records are included in a data set for normal depth, bottom width, energy slope or water discharge calculations. The

PF record is required for riprap calculations because the program tests bed particles against the Shield's diagram to determine whether or not riprap is needed.

Considerable care must be employed when applying the cross-section shape option because flow conditions may be outside the range of conditions used to develop the riprap equations. When these calculations are made, it is important that the user define the side slope protection as a single panel in the geometry input. SAM will use 0.8 times the maximum depth in the panel for the local flow depth in the riprap equation. When a bend radius is specified, SAM uses the average velocity in the cross section for V_{AVE} in the riprap equation. Therefore, it is important that the input geometry include only channel geometry and discharge. When a bend radius is not specified, SAM uses the calculated panel velocity for V_{AVE} in the riprap equation. This calculation may provide useful information for compound channels in straight river reaches, but it is an extension of the procedure outlined in EM 1110-2-1601 (USACE 1991, 1994). Careful study of the recommendations and guidelines described in that EM are considered essential.

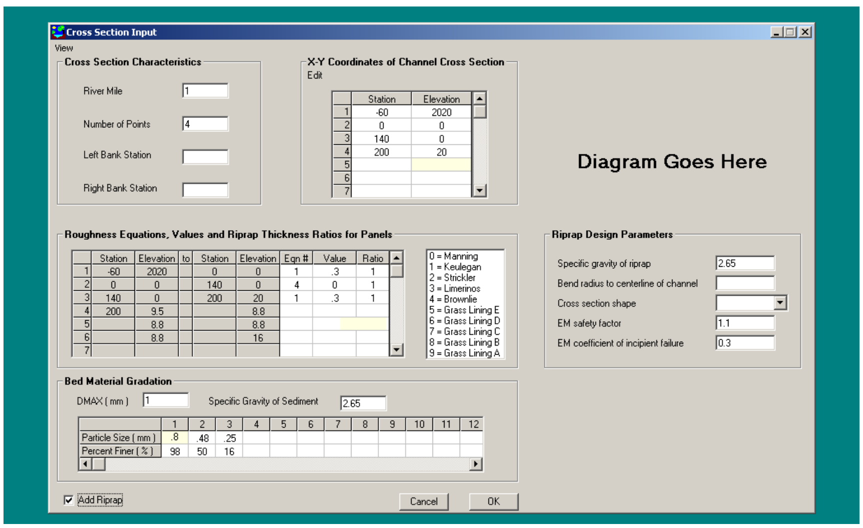


Figure 6-12. Additional input needed when riprap requested on the Station-Elevation normal depth input screen.

Sample Input Data

These calculations can be accessed through the "Normal Depth" input, as described earlier. Figure 6-12 shows some of the required input data for riprap size calculations when station elevation geometry is input. Figure 6-13 shows some of the required input data for riprap size calculations when channel template geometry is input. Other required data are particle size on the channel bed and thickness of the riprap by panel (the RT record). The RT record also tells the calculations in which panel to put riprap. This record is not available in SAMwin at this time and must be manually made and put in the input file. The other data in this calculation-type file are required to perform the normal depth calculations and produce the water velocity and depth in each panel.

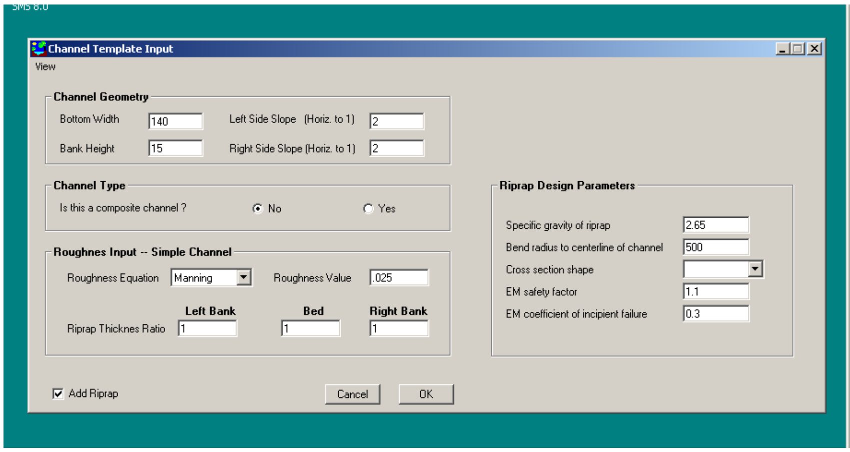


Figure 6-13. Additional input needed when riprap requested on the Channel Template Input screen.

```
T1  7A    Calculate Normal depth, with riprap
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR      1
X1      1       4
GR     20     -60       0       0       0     140      20     200
KN     .3       0      .3
NE      1       4       1
PF                              1      .8      98     .48      50     .25      16
RR   2.65                       1     1.1     0.3
QW   5000   10000   15000
ES  0.010
WT     65
SP   2.65
$$END
```

```
T1  7B    Riprap Design in a Trapezoidal Channel
T1          Problem 2,   Appendix H    EM-1110-2-1601
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR      1
CT    140      15       2       2       0    .025
RT      1       1       1
RR   2.65     500               0     1.1     0.3
QW  13500
ES  .0017
$$END
```

Geometry, roughness, compositing and plotting are handled the same as described for normal depth calculations without riprap.

Sample Output Data

The following example is taken from the output from Test 7C. The general output tables from these calculations are described in the normal depth output section. However, the output for these calculations is threefold. The first set of normal depth tables show the results of the normal depth, or other, calculations without riprap. The next set of output, starting with "DETERMINE RIPRAP SIZE FOR A GIVEN WATER DISCHARGE," describes the results of the riprap calculations using the hydraulic parameters shown in the first set of tables. The third set of output is a second set of normal depth calculations showing the hydraulic parameters calculated with the given riprap in place. The parameters written to the sediment transport, SAM.sed, input file are taken from this second set of normal depth calculations.

```
TABLE  8-1.  CALCULATE NORMAL DEPTH;  COMPOSITE PROPERTIES BY ALPHA METHOD.

 **** N     Q       WS     TOP COMPOSITE  SLOPE COMPOSITE VEL   FROUDE  SHEAR
                   ELEV   WIDTH    R             n-Value       NUMBER  STRESS
          CFS      FT     FT      FT     ft/ft           FPS             #/SF

 **** 1   13500.    8.68   174.7   8.36 0.001700 0.0255   9.88   0.60   0.89

 TABLE  8-4.  HYDRAULIC PARAMETERS FOR SEDIMENT TRANSPORT
  Q STRIP  STRIP        ---EFFECTIVE---    SLOPE    n-    EFF.  Froude   TAU
 NO   NO     Q            WIDTH   DEPTH           VALUE   VEL.   NO    Prime
            CFS            FT      FT     FT/FT           FPS            #/SF
  1   1   13500.           160.5   8.37 0.001700 0.0241  10.05   0.61  0.887


 TABLE  8-5.  EQUIVALENT HYDRAULIC PROPERTIES FOR OVERBANKS AND CHANNEL
              DISTRIBUTED USING CONVEYANCE
  N  STRIP  HYDRAULIC   MANNING .........SUBSECTION...........
      NO     RADIUS    n-VALUE DISCHARGE     AREA    VELOCITY
               ft               cfs         sqft       fps

  1     1       7.64     0.0241  13500.00    1366.50     9.88

 DETERMINE RIPRAP SIZE FOR A GIVEN WATER DISCHARGE


        USING GRADED RIPRAP TABLES FROM EM 1110-2-1601

  LAYER  D30CR  DMAXRR    D30    D50    D90    WIDTH    CY/FT  TONS/FT    $/FT
    #      FT     IN       FT     FT     FT      FT
    6    0.89   24.00   0.97   1.17   1.40   188.01   13.927    0.714    0.00


 RIPRAP SIZE      = LAYER#  6              DMAX, INCHES       =       24.
   VELOCITY, FT   =       7.79             VSS/VAVG           =     1.503
   BEND RADIUS,FT =       500.             TOP WIDTH, FT      =      175.
   R/W            =      2.861             VERT VEL CORR, Cv  =     1.192
   LOCAL DEPTH, FT=      10.74             DESIGN DEPTH       =      8.59
   SAFETY FAC, Sf =       1.10             STABILITY COEF, Cs =     0.300
   THICKNESS, IN  =      24.00             THICKNESS COEF, Cv =     2.000
   SIDE SLOPE     =       2.00             SIDE SLOPE CORR, K1=     1.180
   SP.GR. RIPRAP  =       2.65             POROSITY, %        =     38.00
   CHANNEL TYPE   =   NATURAL             COST PER FOOT,$/FT =      0.00


                        TABLE  8-1.  CROSS SECTION PROPERTIES
  #    STATION      ELEV   ROUGHNESS  N-VALUE :     GROUND      : DELTA Y   RIPRAP
         FT          FT      HEIGHT  EQUATION :SLOPE     ANGLE :    FT    Dmax*[ ]

   1    -100.0     15.00
                         1.400      STRICKLE    -2.00    -26.6    -15.00     1.0
```

```
  2     -70.0      0.00
                        1.400      STRICKLE     0.00       0.0      0.00     1.0
  3      70.0      0.00
                        1.400      STRICKLE     2.00      26.6     15.00     1.0
  4     100.0     15.00

HYDRAULIC PROPERTIES WITH RIPRAP IN PLACE.    STRICKLER COEFFICIENT = 0.038

**** N      Q       WS      TOP COMPOSITE  SLOPE COMPOSITE VEL  FROUDE  SHEAR
                   ELEV   WIDTH    R             n-Value       NUMBER  STRESS
          CFS      FT      FT      FT     ft/ft            FPS            #/SF

**** 1   13500.   11.40   185.6  10.85 0.001700 0.0413   7.27   0.39   1.15

TABLE  8-4.  HYDRAULIC PARAMETERS FOR SEDIMENT TRANSPORT
 Q STRIP  STRIP        ---EFFECTIVE---    SLOPE    n-    EFF.  Froude   TAU
NO   NO     Q            WIDTH   DEPTH            VALUE   VEL.    NO    Prime
           CFS             FT      FT     FT/FT           FPS            #/SF
 1   1   13500.           167.1  10.87 0.001700 0.0384   7.43   0.40  1.153


TABLE  8-5.  EQUIVALENT HYDRAULIC PROPERTIES FOR OVERBANKS AND CHANNEL
             DISTRIBUTED USING CONVEYANCE
 N  STRIP  HYDRAULIC   MANNING .........SUBSECTION...........
     NO     RADIUS    n-VALUE DISCHARGE     AREA    VELOCITY
              ft                 cfs        sqft       fps

 1     1       9.72     0.0384  13500.00    1856.17     7.27

...END OF JOB...
```

If there is no RT record in the data set and riprap is required, the following message appears:

```
DETERMINE RIPRAP SIZE FOR A GIVEN WATER DISCHARGE
     USING GRADED RIPRAP TABLES FROM EM 1110-2-1601

     NO LOCATIONS WERE SPECIFIED FOR RIPRAP.
    N, Q(N), AND WS(N) =    1   6000.    3.00
```

(This message was produced by adding only an RR record to Test 2A. With no RT record SAM had no idea where to put the riprap.)

Blench Regime Equations

Stable channel dimensions may be calculated using the Blench (1970) regime equations. These regime equations are also shown in ASCE Manual 54 (ASCE 1975). The equations were intended for design of canals with sand beds. The basic three channel dimensions, width, depth and slope, are calculated as a function of bed-material grain size, channel-forming discharge, bed-material sediment concentration, and bank composition.

$$W = \left(\frac{F_B \ Q}{F_S} \right)^{0.5}$$

$$F_B = 1.9 \sqrt{d_{50}}$$

$$D = \left(\frac{F_S \ Q}{F_B^2} \right)^{\frac{1}{3}}$$

$$S = \frac{F_B^{0.875}}{\frac{3.63 \ g}{\nu^{0.25}} W^{0.25} d^{0.125} \left(1 + \frac{C}{2,330} \right)}$$

where

W = channel width - ft
F_B = bed factor
F_S = side factor
Q = water discharge -cfs
d_{50} = median grain size of bed material - mm
D = depth - ft
S = slope
C = bed-material sediment concentration - in parts per million
g = acceleration of gravity - ft/sec^2
v = kinematic viscosity - ft^2/sec

The results are true regime values only if Q is the channel forming discharge. However, a width, depth and slope will be calculated for any discharge by these equations.

Blench suggests that the following values be used for the side factor:

F_S = 0.10 for friable banks
F_S = 0.20 for silty, clay, loam banks
F_S = 0.30 for tough clay banks

In order to calculate the Blench regime dimensions, the side factor, bed-material sediment concentration, and the bed-material gradation should be input. SAM.hyd sets default values for the Blench variables if none are specified: F_S = 0.20, C = 0.0, and d_{50} = 0.25 mm.

Sample input

The following example is data set 2A with a Blench record, a BL record, added. This record is not currently available in SAMwin and must be put in the input file manually. The side factor is all that has been specified in this example. The BL record can be added to the following calculations: normal depth, bottom width, hydraulic roughness, flow distribution, and the riprap calculations given discharge and depth. Since the Blench equation requires a discharge and a slope, the BL record added to a data set which will calculate discharge, slope, or riprap given velocity and depth will be ignored, usually with a message printed to the output file saying the Blench regime calculations could not be made.

```
TI      TEST BLENCH REGIME EQUATION
TI   1       2       3       4       5       6       7       8       9      10
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
CT              3       3       3       4               2      .3       2      .3
BL   .20
PF                              1      .8      98     .48      50     .25      16
QW  6000
ES .0050
WT   65.
$$END
```

Sample Output

Adding a BL record to a data set only triggers additional output, "Table 3. Blench Regime-Channel Dimensions." It does not change the calculated results for that data set. Shown below is a selection of output from above input file, including Table 3, Table 5-1 and Table 5-4. Tables 5-1 and 5-4 can be compared to the output shown in the bottom width calculations section earlier to see that there is no change in the calculated output specified by the input file without the BL record.

```
TABLE  3.  BLENCH REGIME-CHANNEL DIMENSIONS (ASCE MANUAL 54).
            FB=   0.95  FS=   0.20

     N     Q      REGIME  REGIME    R     REGIME     n      VEL  FROUDE  SHEAR
                  DEPTH   WIDTH            SLOPE   Value         NUMBER  STRESS
          CFS       FT      FT      FT     ft/ft             FPS            #/SF

     1    6000.   11.00   168.8   9.73 0.000098 0.0207   3.23   0.17   0.06


TABLE  5-1.  CALCULATE BOTTOM WIDTH;  COMPOSITE PROPERTIES BY ALPHA METHOD.


**** N     Q       WS   BOTTOM    R      SLOPE     n      VEL  FROUDE  SHEAR
                  ELEV   WIDTH                   Value         NUMBER  STRESS
         CFS       FT      FT      FT     ft/ft             FPS            #/SF

**** 1    6000.    3.00   153.1   2.97 0.005000 0.0175  12.34   1.27   0.92


TABLE  5-4.  HYDRAULIC PARAMETERS FOR SEDIMENT TRANSPORT
 Q STRIP  STRIP        ---EFFECTIVE---    SLOPE    n-    EFF.  Froude   TAU
NO   NO     Q            WIDTH   DEPTH            VALUE   VEL.    NO    Prime
           CFS             FT      FT     FT/FT           FPS            #/SF
 1   1    6000.           163.6   2.95 0.005000 0.0170  12.45   1.28  0.729
```

Stable Channel Dimensions Calculations: Input and Output

These calculations are accessed through the Edit-Hydraulic Function Input-Stable Channel Dimensions (Copeland Method) dropdown menu, as shown in Figure 6.14.

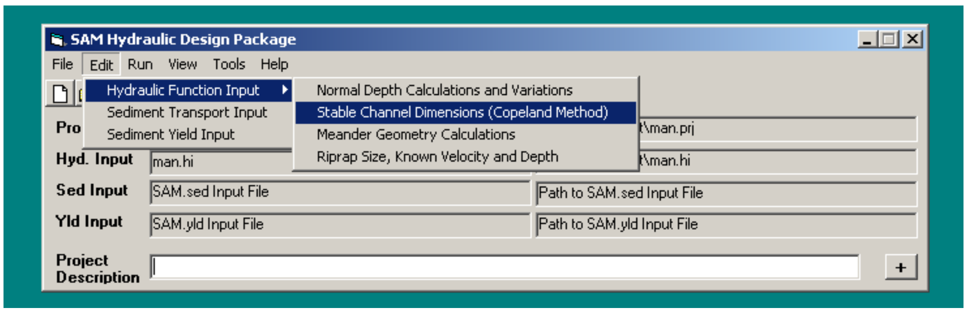


Figure 6.14. Accessing the Stable Channel Method input screens.

General Input Requirements

The input data required, sediment inflow concentration, base width, side slope, bank roughness coefficient, bed material d_{50}, bed material gradation coefficient, valley slope and water discharge, are shown in Figure 6.15.

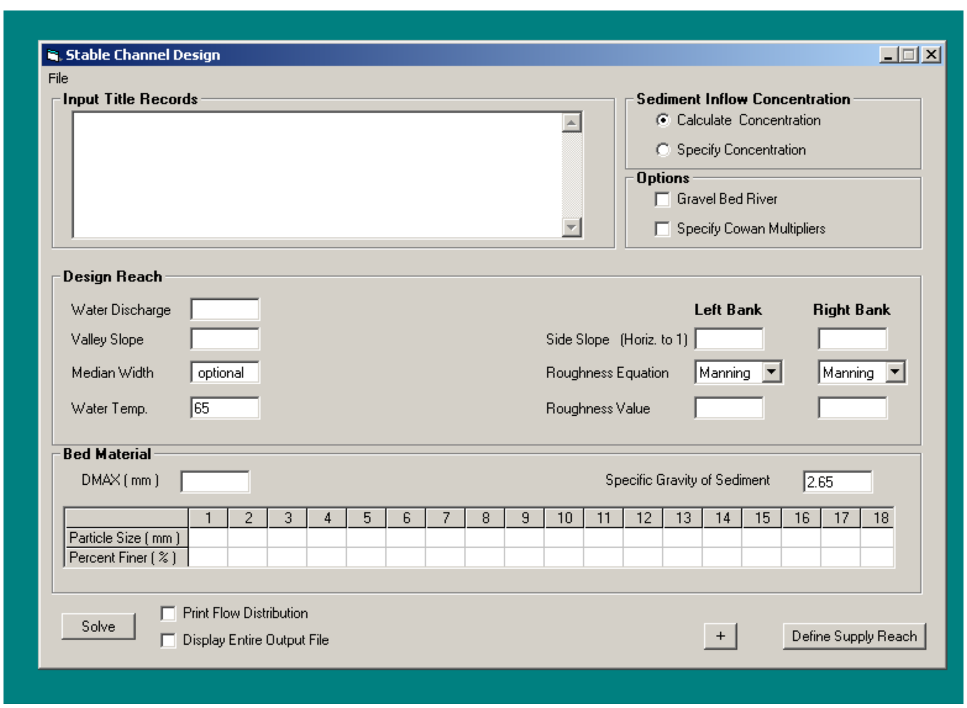


Figure 6.15. Main data input screen for the Stable Channel Dimensions Method.

If sediment inflow is to be calculated, which is the recommended procedure, additional data are required for the supply reach. This screen is accessed by clicking the "Define Supply Reach" button on the lower right, Figure 6.15. The additional input screen, asking for base width, side slope, bank roughness coefficient, bed-material median grain size geometric gradation coefficient, average slope, and discharge, is shown in Figure 6.16.

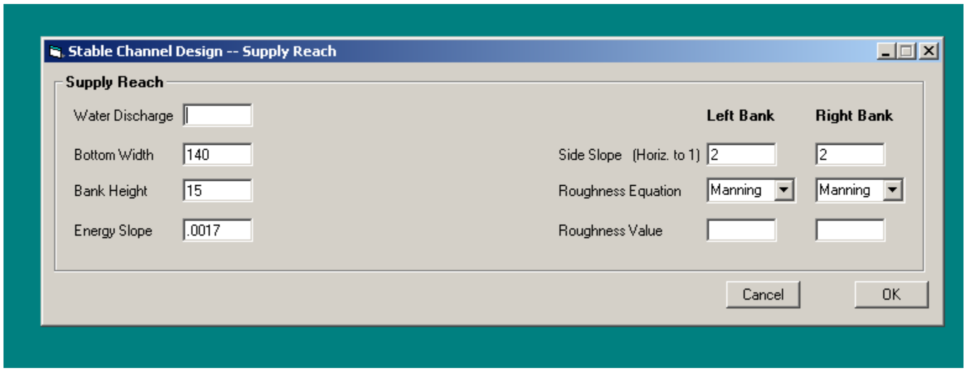


Figure 6.16. Input screen for the Supply Reach for Stable Channel Design Method Calculations.

For both these sub-data sets, it is important that the base width is representative of the total movable-bed width of the channel. The bank roughness should serve as a composite of all additional roughness factors, i.e., channel irregularities, variations of channel cross-section shape, relative effect of obstructions, vegetation, and sinuosity. Only flow that is vertical above the bed is considered capable of transporting the bed material sediment load.

Specific Input Requirements

Water Discharge The design discharge is critical in determining appropriate dimensions for the channel. Investigators have proposed different methods for estimating that design discharge. The 2-year frequency flood is sometimes used for perennial streams. For ephemeral streams the 10-year frequency is some times used. The "bankfull" discharge is sometimes suggested. Others prefer using the "effective" discharge. Currently, there is no generally accepted method for determining the channel-forming discharge. It is recommended that a range of discharges be used in the analysis to test sensitivity of the solution. However, currently SAMwin will calculate for only one discharge at a time.

Inflowing Sediment Discharge This is the concentration of the inflowing bed material load. It is best if SAM.hyd is allowed to calculate the sediment concentration based on hydraulic conditions in the sediment supply reach. The bed-material composition is defined by the median grain size and the gradation coefficient.

Valley Slope Valley slope is the maximum possible slope for the channel invert. This value is used in the test for sediment deposition. If the required slope exceeds the prescribed valley slope, the following message is printed:

```
>>>>MINIMUM SLOPE IS GREATER THAN VALLEY SLOPE - THIS IS A SEDIMENT TRAP <<<<
```

Bank Slopes and Roughness The analytical method assumes all bed material transport occurs over the bed of the cross section and that none occurs above the side slopes. Therefore, the portion of water conveyed above the side slopes expends energy but does not transport sediment, making "Flow Distribution" an extremely important calculation. The input parameters for flow distribution are bank angle and bank roughness. The recommended procedure to use for this is that discussed in Chapter 5 of EM 1110-2-1601 (USACE 1991, 1994). Any roughness input for the bed will be disregarded by the calculations as bed roughness is calculated using the Brownlie equations. Also, only the Manning and Strickler equations are available for roughness calculations in this option. For maximum transport of sediment, use the steepest bank angle allowed by bank stability requirements

Bottom Width Again, it is important that the base width is representative of the total movable-bed width of the channel.

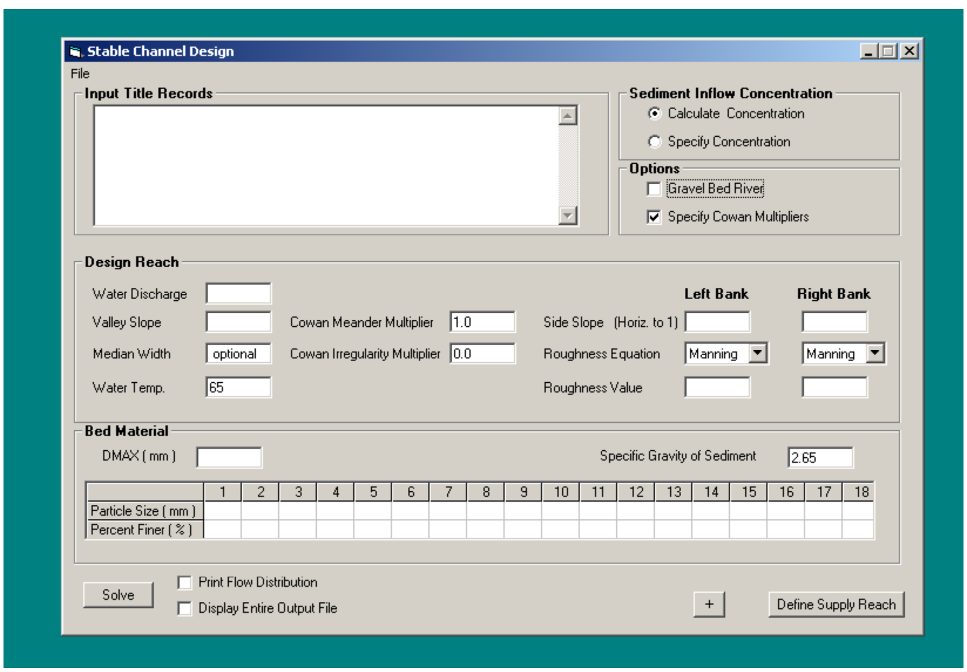


Figure 6.17. Cowan Multipliers input turned on – Stable Channel Methods screen.

Gravel Bed River Option

In this option SAM uses the Limerinos (1970) equation to calculate grain roughness on the bed, the Manning equation to calculate roughness on the channel side slope, and the Meyer-Peter and Muller (1948) equation to calculate sediment transport.

To access this option the "Gravel Bed River" box in the Options area must be checked. No extra input is required; the checkbox simply sends flag to the program to make the gravel bed calculations.

Cowan Multiplier Option

This option is currently available **only** for gravel bed streams. To access this option, the "Specify Cowan Multipliers" box in Options area of the Stable Channel Design screen must be checked see Figure 6.17. It allows the user to provide additional bed roughness that may be added to the grain bed roughness using the Cowan (1956) method. The additional roughness may be added to account for factors such as surface irregularities, variability in channel shape, obstructions, vegetation and meandering.

$$n_{total} = m\left(n_{base} + n_{additional}\right)$$

where

n_{base} = the base n-value, input for the bed and channel side slopes (input elsewhere on the screens)

$n_{additional}$ = the addition for surface irregularities +
the addition for variation in channel cross section +
the addition for obstructions +
the addition for vegetation.

Suggested values for these additions can be found in Cowan (1956) and Chow (1959).

Meandering is accounted for with a meandering coefficient, m; for a straight channel the meandering coefficient is 1.0. Appropriate values for the meandering coefficient and additions to the grain roughness n-value can be found in Cowan (1956) and Chow (1959).

The n-value additions and the meandering coefficient can be input for the design reach and/or the supply reach. See Appendix C, GB record.

Example input data

Test 8A is a data set that provides the parameters for calculating the stable channel dimension, i.e., the GC and PF records, and asks SAM.hyd to calculate the inflowing sediment concentration by providing information about the supply reach, i.e., the CT record. Note that when field 2 of the GC record is either blank, a zero or a –1, the program will calculate the design sediment concentration for the design water discharge; that is, all concentrations will be calculated from the supply reach parameters. However, if a negative value other than 1 is coded, it is interpreted as the water discharge to use for calculating the design sediment concentration, i.e., the water discharge for the approach reach. (See Appendix C, GC record.) Also note that the channel geometry, (CT record), channel slope (ES record) and bed sediment gradation (PF record) must be supplied for the approach channel when concentrations are to be calculated.

Test 8B contains two GC records which will allow SAM.hyd to calculate two sets of stable channel dimensions with the only difference between the two being the water discharge. This means of running is not currently available in SAMwin, but may be accomplished by manually editing the input file. Test 8C provides the sediment inflow concentration on the GC record, so is complete without any supply reach information records.

```
T1 Test 8A   Calculate stable channel geometry
T1 Calculate Design sediment concentration using a reference reach
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR
CT    15      10       2       2       4               1       1       1       1
PF                             1      .8      98     .48      50     .25      16
ES.00016
WT    60
GC  2680   -2680 .000162       3       3       1      .7       1      .7
SP  2.65
$$END

TI   TEST NO. 8B  CALCULATE GEOMETRY USING COPELAND'S PROCEDURE
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
CT    15      10    1.65     3.0       4               1       2       1       2
PF                             1      .8      98     .48      50     .25      16
ES162E-6
GC  3680         .000162       3       3       2      .7       2      .7
GC  6530         .000162       3       3       0     .05       0     .05
WT    60
$$END

TI   TEST NO. 8C  CALCULATE GEOMETRY USING COPELAND'S PROCEDURE
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
GC  3680     100 .000162       3       3       2      .7       2      .7
PF                             1      .8      98     .48      50     .25      16
WT    60
$$END

T1 8D    Stable Channel Design,  Gravel Bed river option
T1             Cowan multiplier used for both design and supply reach
F#345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
TR
CT   140      15       2       2       4               0               0
PF                            16       8      98       4      65       2      45
PFC    1      20      .5      10
ES0.0017
WT    50
GC  2680   -2680 .000162       3       3       1      .7       1      .7
SP  2.65
GB    10    1.15   0.025  1.0000  0.0150
$$END
```

Output description

The general output tables are the same as those generated in the normal depth calculations and are described in that section. The following output is from Test 8A. The calculations being made are stated, and then the results of the inflowing sediment concentration calculations are listed. The rest of the parameters used for the stable channel dimension calculations are listed. Table 4-1 provides the results of these calculations. Note that included in this output, at the end of the file, is a key to the regime abbreviations in the right-most column. Also notice that the line starting "Table 4-1" also lists the discharge, concentration and d_{50}. If gravel bed calculations had been made, as for Test 8D, the statement

USING MEYER-PETER-MULLER & LIMERINOS EQUATIONS

would have appeared on the line after

CALCULATE STABLE CHANNEL DIMENSIONS.

That statement in the output is the only one that flags that output file as having used the gravel bed calculations.

```
CALCULATE CHANNEL WIDTH, DEPTH AND SLOPE BY COPELAND METHOD.  GC-RECORD # 1

 CALCULATE INFLOWING SEDIMENT CONCENTRATION, PPM.

 INFLOWING WATER DISCHARGE, CFS        =   2680.000
 BASE WIDTH                            =   15.00000
 CHANNEL SLOPE, FT/FT                  = 0.00016000

                                         LEFT BANK  RIGHT BANK
 SIDE SLOPE                            =      2.000       2.000
 Ks, FT                                =  1.000       1.000
 n-VALUE                               =    0.03420     0.03420

 CALCULATE STABLE CHANNEL DIMENSIONS.

        USING  BROWNLIES RESISTANCE & TRANSPORT EQUATIONS

 MEDIAN BED SIZE ON BED, MM            =    0.46607
 GRADATION COEFFICIENT                 =      1.776
 VALLEY SLOPE                          = 0.00016200

                                         LEFT BANK  RIGHT BANK
 SIDE SLOPE                            =      3.000       3.000
 Ks, FT                                = 0.7000      0.7000
 n-VALUE                               =    0.03223     0.03223

 TABLE  4-1.  STABLE CHANNELS FOR Q=      2680.0 C,mgl=  22.69     D50=    0.466
  K: BOTTOM : DEPTH :  ENERGY :CMPOSIT:   HYD :   VEL : FROUDE:  SHEAR:   BED *
   :  WIDTH :       :   SLOPE :n-Value: RADIUS:       : NUMBER: STRESS:B-REGIME
   :    FT   :   FT  :   FT/FT :       :   FT  :   FPS :       :  #/SF:

  1      10.   16.0  0.000220  0.0317    8.38    2.86    0.13    0.22      LO
  2      21.   15.5  0.000158  0.0312    8.80    2.56    0.11    0.15      LO
  3      31.   14.7  0.000133  0.0306    8.93    2.41    0.11    0.12      LO
  4      42.   13.9  0.000120  0.0301    8.92    2.33    0.11    0.10      LO
  5      52.   13.0  0.000111  0.0295    8.81    2.27    0.11    0.09      LO
  6      62.   12.2  0.000106  0.0290    8.65    2.22    0.11    0.08      LO
  7      73.   11.5  0.000102  0.0286    8.45    2.18    0.11    0.07      LO
  8      83.   10.8  0.000100  0.0282    8.23    2.15    0.12    0.07      LO
  9      94.   10.2  0.000099  0.0278    8.00    2.12    0.12    0.06      LO
 10     104.    9.6  0.000098  0.0275    7.75    2.10    0.12    0.06      LO
```

```
11      114.    9.1  0.000098  0.0271    7.51    2.07    0.12    0.06      LO
12      125.    8.7  0.000098  0.0269    7.27    2.05    0.12    0.05      LO
13      135.    8.3  0.000098  0.0266    7.04    2.03    0.12    0.05      LO
14      146.    7.9  0.000098  0.0264    6.82    2.01    0.13    0.05      LO
15      156.    7.5  0.000099  0.0262    6.61    1.99    0.13    0.05      LO
16      166.    7.2  0.000100  0.0260    6.40    1.97    0.13    0.05      LO
17      177.    6.9  0.000101  0.0258    6.21    1.96    0.13    0.04      LO
18      187.    6.7  0.000102  0.0256    6.02    1.94    0.13    0.04      LO
19      198.    6.4  0.000103  0.0255    5.84    1.93    0.13    0.04      LO
20      208.    6.2  0.000105  0.0253    5.68    1.91    0.14    0.04      LO

          RESULTS AT MINIMUM STREAM POWER
21      118.    9.0  0.000098  0.0270    7.43    2.07    0.12    0.05      LO

* REGIMES:  LO=LOWER, TL=TRANSITIONAL-LOWER, TU=TRANSITIONAL-UPPER, UP=UPPER.

...END OF JOB...
```

Table 4-1 contains the family of widths, depths, and slopes which satisfies the sediment transport and resistance equations for the given conditions. It is important to consider river morphology when interpreting these calculated values. That is, each line in the table satisfies the governing equations, but natural rivers tend toward a regime width. Consequently, the calculations start with the regime width as determined by the following equation:

$$B = 2.0\,Q^{0.5}$$

For the water discharge in this example, the equation gives a regime width of 120 feet. This regime width is then divided by 10 to provide a starting value for the table, 12 ft in this case. The rest of the table is produced by adding the 12 ft increment to each successive width and repeating the depth, slope, n-value calculations. Note the last column in the table, "Flow Regime." Four conditions are possible:

LO = Lower regime
(i.e. ripples and dunes)
TL = Transition zone, Lower regime selected
(bed forms tend towards ripples and dunes.)
TU = Transition zone, Upper regime selected
(Bed forms tend toward plain bed.)
UP = Upper regime selected
(Plain bed and antidunes)

Channel dimensions corresponding to minimum stream power, Q*S , (which also corresponds to minimum slope), are presented at the bottom of the table. In this example the energy slope reaches a minimum value at about the regime width. However, that is not always the case. Much depends on the bank roughness.

These calculations will provide the information to plot the stable channel dimension curve,

Range of Solutions

Stable channel dimensions are calculated for a range of widths. For each combination of slope and base width, a unique value of depth is calculated. This can be used to evaluate stability in an existing channel or in a proposed design channel. It is important to consider river morphology when interpreting these calculated values. It is important to be consistent in the selection of channel dimensions. That is, once a width is selected, the depth and slope are fixed. This allows the designer to select specific project constraints, such as right-of-way, bank height or minimum bed slope, and then arrive at a consistent set of channel dimensions.

If the calculations indicate that the slope of the project channel needs to be less than the natural terrain, the slopes in the table can be used to aid in spacing drop structures or introducing sinuosity into the project alignment.

An example of a family of slope-width solutions that satisfy the resistance and sediment transport equations for the design discharge is illustrated by Figure 6.18. Any combination of slope and base width from this curve will be stable for the prescribed channel design discharge.

NOTE: Combinations of width and slope that plot above the stability curve will result in degradation, and combinations below the curve will result in aggradation. The greater the distance from the curve, the more severe the instability.

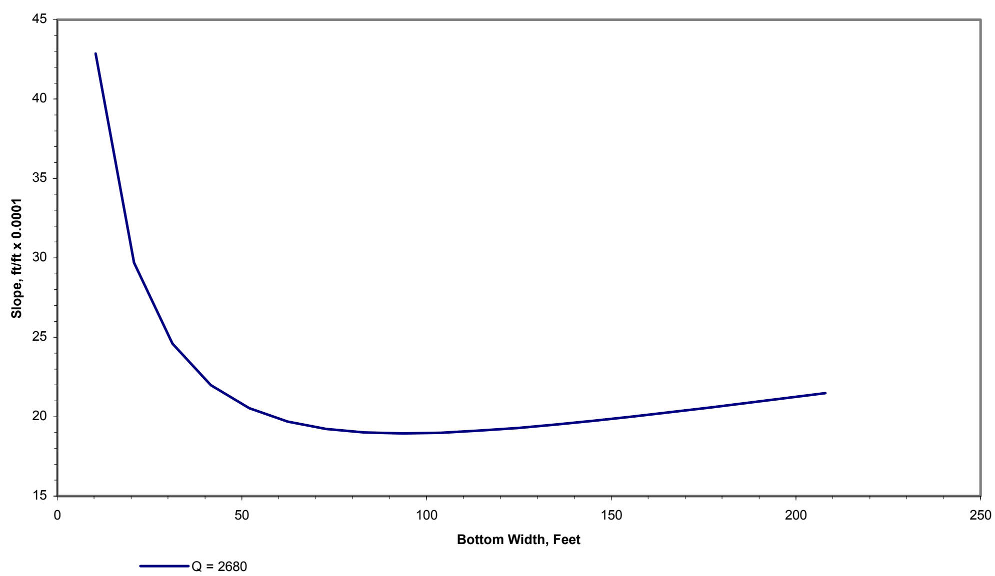


Figure 6.18. Example slope-width graph from the stable channel dimensions calculations.

Constraints on this wide range of solutions may result from a maximum possible slope, or a width constraint due to right-of-way. Maximum allowable depth could also be a constraint. Depth is not plotted in Figure 6.18, but it is calculated for each slope and width combination determined. With constraints, the range of solutions is reduced, see Figure 6.19.

Different water and sediment discharges will produce different stability curves. First, the stable channel solution is obtained for the channel-forming discharge. Then, stability curves are calculated for a range of discharges to determine how sensitive the channel dimensions are to variations in water and sediment inflow events.

The stable channel dimensions are calculated for a range of widths on either side of a prescribed median value. (A median value can be prescribed, manually, on the GC record, but not in SAMwin.) If no median value is prescribed, the program assigns a value based on the following hydraulic geometry equation, proposed in EM 1110-2-1418 (USACE 1994).

$$B = 2.0\,Q^{0.5}$$

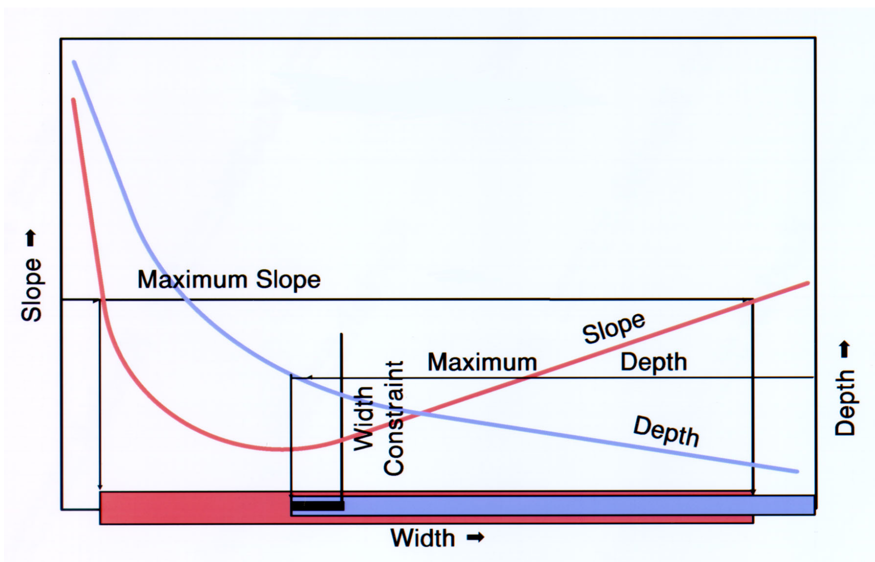


Figure 6.19. Slope-width graph showing the effect of constraints on the range of solutions.

The SAM program assigns 20 base widths for the calculation, each with an increment of 0.1B. Calculations for these conditions are displayed as output. Stability curves can then be plotted from these data.

A solution for minimum stream power is also calculated by the model. This solution represents the minimum slope that will transport the incoming sediment load. Solution for minimum slope is obtained by using a second-order Lagrangian interpolation scheme. Opinions are divided regarding the use of minimum stream power to uniquely define channel stability. An optional use of the analytical method is to assign a value for slope, thereby obtaining unique solutions for width and depth. Typically there will be two solutions for each slope.

Meander Geometry

Input

The purpose of the meander calculations is to provide both curvilinear and Cartesian coordinates for a meander planform based on the sine-generated curve. The sine-generated curve has been shown to effectively replicate meander patterns in a wide variety of natural rivers. (Langbein and Leopold, 1966)

Required input are the meander arc length and the meander wavelength, as shown in Figure 6.20. Title records are optional. The Meander arc length is the actual length of the channel, whereas the wavelength is the length, along the valley, of one full meander.

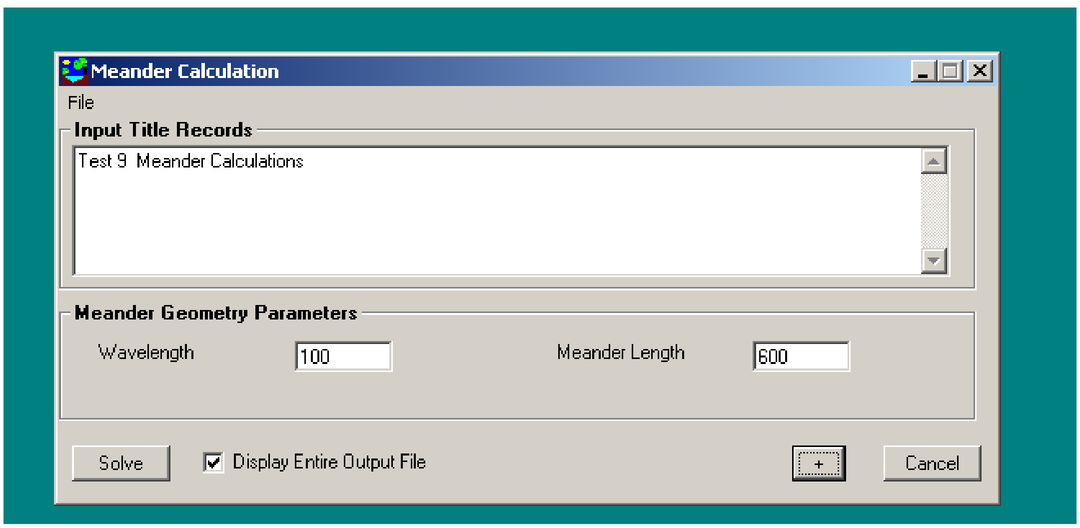


Figure 6.20. The Meander Calculation screen, with input.

Output

The output file first displays the SAM.hyd banner and echoes the input. An internal banner stresses that these calculations are appropriate for sand-be streams. The input wavelength and meander length are then printed along with the sinuosity, maximum deflection angle (in degrees), and the amplitude. Then a table of "Coordinates along one meander wavelength" is printed, giving the distance along the channel, deflection angle in degrees, the Y perpendicular to the valley slope, and the X along the valley slope.

```
*********************************************************
*                                                       *
*   PLANFORM GEOMETRY FOR A MEANDERING SAND-BED STREAM   *
*                                                       *
*********************************************************
```

WAVE LENGTH	MEANDER LENGTH	SINUOSITY	MAXIMUM DEFLECTION ANGLE-DEG	AMPLITUDE
100.00	600.00	6.00	120.371	236.90

COORDINATES ALONG ONE MEANDER WAVELENGTH

ALONG THE CHANNEL S	DEFLECTION ANGLE DEGREES THETA	PERPENDICULAR TO VALLEY SLOPE Y	ALONG THE VALLEY SLOPE X
0.00	120.37	0.00	0.00
6.00	120.13	5.20	-3.03
12.00	119.42	10.43	-6.02
18.00	118.24	15.70	-8.93
24.00	116.59	21.04	-11.70
30.00	114.48	26.47	-14.29
36.00	111.92	32.01	-16.66
42.00	108.92	37.65	-18.76
48.00	105.48	43.39	-20.54
54.00	101.63	49.24	-21.95
60.00	97.38	55.18	-22.95
66.00	92.75	61.17	-23.48
72.00	87.75	67.18	-23.50
78.00	82.40	73.17	-22.99
84.00	76.73	79.09	-21.90
90.00	70.75	84.86	-20.21
96.00	64.50	90.42	-17.93
102.00	57.99	95.69	-15.03
108.00	51.25	100.59	-11.55
114.00	44.31	105.04	-7.52
120.00	37.20	108.96	-2.96
126.00	29.94	112.28	2.04
132.00	22.56	114.94	7.43
138.00	15.09	116.87	13.12
144.00	7.56	118.05	19.01
150.00	0.00	118.45	25.00
156.00	-7.56	118.05	30.99
162.00	-15.09	116.87	36.88
168.00	-22.56	114.94	42.57
174.00	-29.94	112.28	47.96
180.00	-37.20	108.96	52.96
186.00	-44.31	105.03	57.52
192.00	-51.25	100.58	61.55
198.00	-57.99	95.68	65.03
204.00	-64.50	90.42	67.93
210.00	-70.75	84.86	70.21
216.00	-76.73	79.09	71.90
222.00	-82.40	73.17	72.99
228.00	-87.75	67.18	73.50
234.00	-92.75	61.17	73.48
240.00	-97.38	55.18	72.95
246.00	-101.63	49.24	71.95
252.00	-105.48	43.39	70.54
258.00	-108.92	37.65	68.76
264.00	-111.92	32.01	66.66
270.00	-114.48	26.47	64.29
276.00	-116.59	21.04	61.70
282.00	-118.24	15.70	58.93
288.00	-119.42	10.43	56.02

294.00	-120.13	5.20	53.03
300.00	-120.37	0.00	50.00
306.00	-120.13	-5.20	46.97
312.00	-119.42	-10.43	43.98
318.00	-118.24	-15.70	41.07
324.00	-116.59	-21.04	38.30
330.00	-114.48	-26.47	35.71
336.00	-111.92	-32.01	33.34
342.00	-108.92	-37.65	31.24
348.00	-105.48	-43.39	29.46
354.00	-101.63	-49.24	28.05
360.00	-97.38	-55.18	27.05
366.00	-92.75	-61.17	26.52
372.00	-87.75	-67.18	26.50
378.00	-82.40	-73.17	27.01
384.00	-76.73	-79.09	28.10
390.00	-70.75	-84.86	29.79
396.00	-64.50	-90.42	32.07
402.00	-57.99	-95.68	34.97
408.00	-51.25	-100.58	38.45
414.00	-44.31	-105.03	42.48
420.00	-37.20	-108.96	47.03
426.00	-29.94	-112.28	52.04
432.00	-22.56	-114.94	57.43
438.00	-15.09	-116.87	63.12
444.00	-7.56	-118.05	69.01
450.00	0.00	-118.45	75.00
456.00	7.56	-118.05	80.99
462.00	15.09	-116.87	86.88
468.00	22.55	-114.94	92.57
474.00	29.93	-112.28	97.96
480.00	37.20	-108.96	102.96
486.00	44.31	-105.04	107.52
492.00	51.25	-100.59	111.55
498.00	57.99	-95.69	115.03
504.00	64.50	-90.42	117.92
510.00	70.75	-84.86	120.21
516.00	76.73	-79.09	121.90
522.00	82.40	-73.17	122.99
528.00	87.75	-67.18	123.50
534.00	92.75	-61.17	123.48
540.00	97.38	-55.18	122.95
546.00	101.63	-49.24	121.95
552.00	105.48	-43.39	120.54
558.00	108.91	-37.65	118.76
564.00	111.92	-32.01	116.66
570.00	114.48	-26.47	114.29
576.00	116.59	-21.04	111.70
582.00	118.24	-15.70	108.93
588.00	119.42	-10.43	106.02
594.00	120.13	-5.20	103.03
600.00	120.37	0.00	100.00

This calculation has no plotting capability, but the table of coordinates could be copied into a spreadsheet for plotting.

7 Input Requirements and Program Output for SAM.sed

Purpose

SAM.sed calculates sediment discharge rating curves for the bed material load using sediment transport functions. The input and output vary only insofar as different functions are selected. This chapter will address the input data requirements and discuss the associated output. Be aware that there is an option, SAM.aid (under Tools on the SAMwin main menu) that can provide guidance in the selection of sediment transport functions.

General

The SAM.sed module expects an input file designated as *xxxxxxxx*.**si**, where *x* can be any DOS acceptable character, including a space (but no embedded spaces), i.e., acceptable file names could be *say.si* or *ITSNEVER.SI*. SAM.sed will write a corresponding file *xxxxxxxx*.**so**, which is the sediment transport calculation's output file; and a *xxxxxxxx.*.**yi** file which may be used as an input file to SAM.yld.

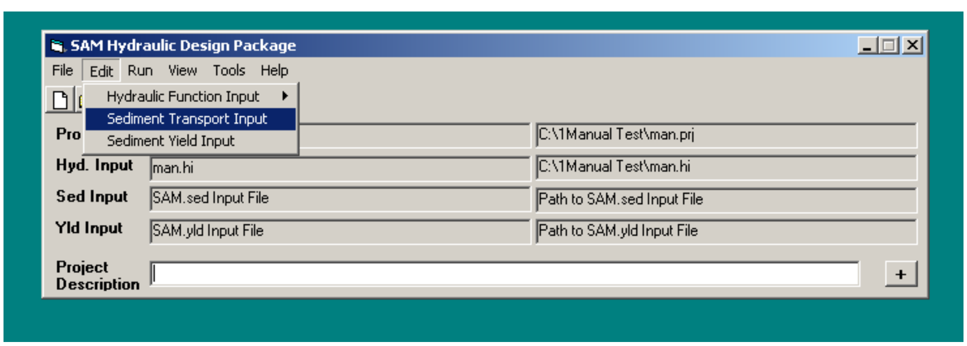


Figure 7.1. Accessing the Sediment Transport Input screens.

SAM.hyd generally creates a ".si" file. The ".si" file can be created or edited in SAMwin as shown in Figure 7.1. A sediment transport input file can also be created or edited using a system editor, or, in a DOS window only, by using SAM.m95 in combination with a TAPE95 from an HEC-2 execution (see

Appendix H). In some cases, modifications to the SAM.hyd-created ".si" file may be necessary before sediment transport calculations can be made.

The sample data sets used in the input and output discussions are those provided with the SAM package in the SEDPC.LIB files.

Program execution

The sediment transport calculations are made in SAMwin from the "Solve" button on the input screen, Figure 7.2, or from the "Run" dropdown menu on the opening screen, Figure 7.1. This second option is useful if a ready-to-run data set exists.

Selected output will scroll to the screen. The output coming to this window cannot be selected by the user. All output will be saved in the default output filename.

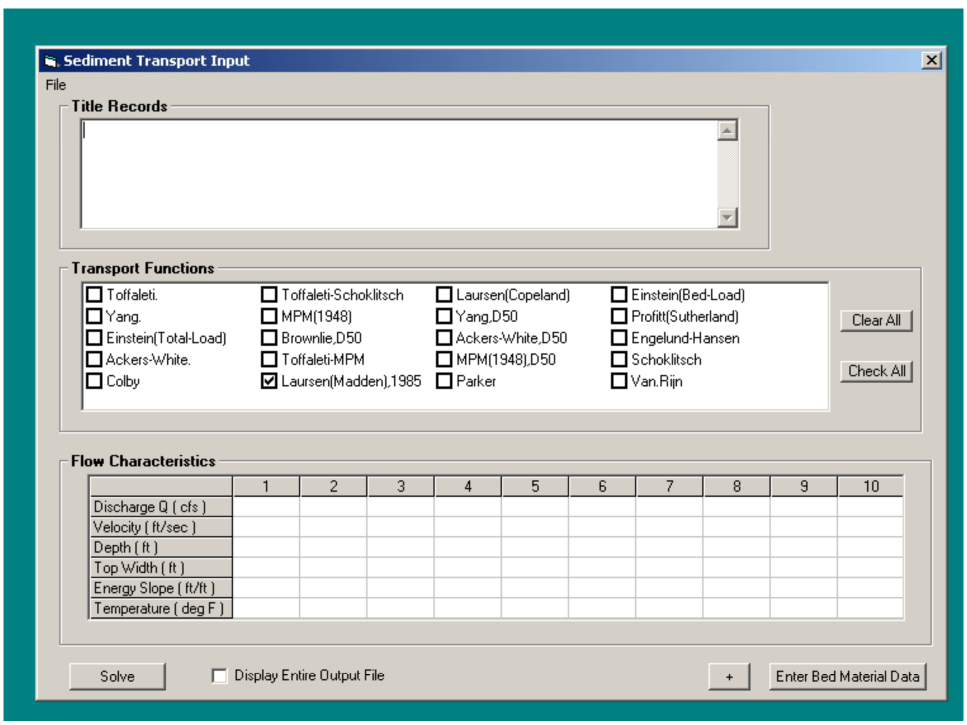


Figure 7.2. Sediment transport calculations input screen.

Title Records.

This area allows the user to input descriptive strings, up to 78 characters long, for use in identifying data sets. This input is optional.

Transport Functions. All sediment transport functions available in SAM.sed are listed here. The user can select functions to be calculated. The Laursen-Madden (1985) function is simply the one function that is on by default when the input file has been created by SAM.hyd.

Flow Characteristics. Generally, these fields would be filled with the calculated data from a SAM.hyd-generated input file. However, the user can input this information if so desired. A "column" of numbers is considered together for calculation purposes. The maximum is 10 columns.

Bed Material Gradation. This input is necessary for these calculations, Figure 8.3. DMAX is a required input whereas the specific gravity of sediment is optional (the value shown is the default value). The program will accept up to 18 points on the bed material gradation, and they **must** be input from largest grain size to smallest. However, a grain size for 100% finer and for 0% finer is not required.

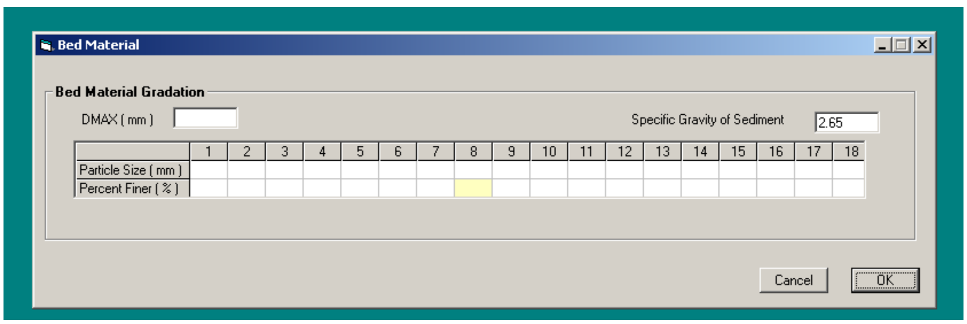


Figure 7.3. Bed Material Gradation data input screen.

" + " Box. This button toggles, opens/closes, a small window which will receive selected output. The output coming to this window cannot be selected by the user.

Display Entire Output File. When this box is checked the output file will open in its own window (using Notepad) after calculations are complete. If this button is not checked, some input will echo to the screen in the area mentioned above. The entire output file can also be viewed by checking the View menu of the SAM main window and selecting "Sediment Transport Results."

Solve. This button causes SAM.sed to execute.

Sample Input Data

In addition to the SAMwin option to create or edit a sediment transport input file, the input data file can be prepared with a system editor, or by the hydraulics calculations in SAM.hyd. (SAM.m95, which reads the HEC-2 output to create a SAM.sed input file, is not available in SAMwin). Of these, however, only

SAM.hyd provides the "effective" value for sediment transport variables. If channel and overbanks are specified in the SAM.hyd file, only the channel variables are transferred to the “.si” file. The discharge is the total discharge and is used only as an identifier and not used in the calculations.

The following example shows input data as created by running TEST 1C in SAM.hyd. Notice that only the `Laursen(Madden)` function shows "YES." Other transport functions can be “turned on” for computation with an editor or the SAMwin data entry windows.. The SAM.hyd input file from which this file was developed contained a PF-record so this required record is already in the file. If the record were not in the SAM.sed input file, it would also have to be added.

```
T1      FILE WRITTEN BY SAM.hyd
TF TOFFALETI.            NO
TF YANG.                 NO
TF EINSTEIN(TOTAL-LOAD)  NO
TF ACKERS-WHITE.         NO
TF COLBY                 NO
TF TOFFALETI-SCHOKLITSC  NO
TF MPM(1948).            NO
TF BROWNLIE,D50          NO
TF TOFFALETI-MPM         NO
TF LAURSEN(MADDEN),1985 YES
TF LAURSEN(COPELAND)     NO
TF YANG,D50              NO
TF ACKERS-WHITE,D50      NO
TF MPM(1948),D50         NO
TF PARKER                NO
TF EINSTEIN(BED-LOAD)    NO
TF PROFITT(SUTHERLAND)   NO
TF ENGELUND-HANSEN       NO
TF SCHOKLITSCH           NO
TF VAN.RIJN              NO
VE  1.29    2.77    5.41    7.41   10.14
DE  0.76    3.23    7.23    9.71   13.28
WI  103.   111.7   127.9   138.8   148.5
QW   100    1000    5000   10000   20000
ES521E-6
WT    50
PF                             1      .8      98     .48      50     .25      16
$$END
```

Sample Output Data

Selected results are printed to the screen as the program executes. The entire output is saved in the default output file. Also, the sediment transport rating curve needed for the sediment yield calculations is written to the default SAM.yld file.

Output Data Sets

The following output description refers to the output of Test 1C listed above. The Ackers-White,D50, and the Van Rijn functions have been selected in order to point out certain associated output.

```
*******************************************************************************
*                                                                             *
*      SAMwin   ---   HYDRAULIC DESIGN PACKAGE FOR FLOOD CONTROL CHANNELS      *
*                                                                             *
*                        SEDIMENT TRANSPORT CALCULATIONS                      *
*                                                                             *
*                              version 2.0     23Jan03                        *
*                                                                             *
*           A Product of the Flood Control Channels Research Program          *
* Coastal & Hydraulics Laboratory, USAE Engineer Research & Development Center *
*                                                                             *
*                           in cooperation with                               *
*                                                                             *
*               Owen Ayres & Associates, Inc., Ft. Collins, CO                *
*                                                                             *
*******************************************************************************


 Msg 1:  SED. READING INPUT DATA FROM FILE [  hydtests.si  ] THIS DIRECTORY.

 TABLE  1.  LIST INPUT DATA.

 T1
 TF LAURSEN(MADDEN),1985 YES
 TF ACKERS-WHITE,D50     YES
 TF VAN.RIJN             YES
 TR
 VE  1.29    2.77    5.41    7.41   10.14
 DE  0.76    3.23    7.23    9.71   13.28
 WI   103   111.7   127.9   138.8   148.5
 QW   100    1000    5000   10000   20000
 ES.00052
 WT    50
 PF                  1.0       1      .8      98     .48      50     .25      16
 SP  2.65
 $$END

 BED SEDIMENT FRACTIONS CALCULATED FROM PF-DATA.

   NO     PERCENT   PARTICLE   INCREMENTAL
           FINER      SIZE       FRACTION
      |      %     |    mm     |            |
 _____|____________|___________|____________|

    8 |    16.000 |    0.2500 |            |
      |           |           |  0.3783586 |
    9 |    53.836 |    0.5000 |            |
      |           |           |  0.4616414 |
   10 |   100.000 |    1.0000 |            |


   TABLE  3.  PROPERTIES OF THE WATER

                       KINEMATIC
  #  TEMP     RHO    VISCOSITY  UNIT WT
     DEG F  #-S2/FT4   SF/SEC    WATER
                      x10,000    #/FT3

  1   50.0    1.940      1.411   62.411
  2   50.0    1.940      1.411   62.411
  3   50.0    1.940      1.411   62.411
  4   50.0    1.940      1.411   62.411
  5   50.0    1.940      1.411   62.411
```

TABLE 2.1. HYDRAULIC PARAMETERS

N	TOTAL DISCHARGE CFS	EFFECTIVE DISCHARGE CFS	EFFECTIVE VELOCITY FPS	EFFECTIVE DEPTH FT	EFFECTIVE WIDTH FT	ENERGY SLOPE FT/FT
1	100.	101.	1.29	0.76	103.00	0.0005200
2	1000.	999.	2.77	3.23	111.70	0.0005200
3	5000.	5003.	5.41	7.23	127.90	0.0005200
4	10000.	9987.	7.41	9.71	138.80	0.0005200
5	20000.	19997.	10.14	13.28	148.50	0.0005200

TABLE 4.1 LAURSEN(MADDEN),1985 METHOD = NO. 13

SIZE CLASS no	GRAIN SIZE mm	PERCENT IN CLASS %	SEDIMENT TRANSPORT POTENTIAL TONS/DAY	SEDIMENT TRANSPORT CAPACITY TONS/DAY	SEDIMENT TRANSPORT CONC PPM
8	0.354	37.84	6.58286	2.49068	9.2248
9	0.707	46.16	0.100000E-06	0.461641E-07	0.17098E-06
Q, CFS = 100.000			QS, TOTAL =	2.49068	9.2248

TABLE 4.1 LAURSEN(MADDEN),1985 METHOD = NO. 13

SIZE CLASS no	GRAIN SIZE mm	PERCENT IN CLASS %	SEDIMENT TRANSPORT POTENTIAL TONS/DAY	SEDIMENT TRANSPORT CAPACITY TONS/DAY	SEDIMENT TRANSPORT CONC PPM
8	0.354	37.84	64645.7	24459.3	452.95
9	0.707	46.16	6936.62	3202.23	59.301
Q, CFS = 20000.0			QS, TOTAL =	27661.5	512.25

TABLE 4.1 ACKERS-WHITE,D50 METHOD = NO. 16

SIZE CLASS no	GRAIN SIZE mm	PERCENT IN CLASS %	SEDIMENT TRANSPORT POTENTIAL TONS/DAY	SEDIMENT TRANSPORT CAPACITY TONS/DAY	SEDIMENT TRANSPORT CONC PPM
1	0.466	100.00	6.72704	6.72704	24.915
Q, CFS = 100.000			QS, TOTAL =	6.72704	24.915

TABLE 4.1 ACKERS-WHITE,D50 METHOD = NO. 16

SIZE CLASS no	GRAIN SIZE mm	PERCENT IN CLASS %	SEDIMENT TRANSPORT POTENTIAL TONS/DAY	SEDIMENT TRANSPORT CAPACITY TONS/DAY	SEDIMENT TRANSPORT CONC PPM
1	0.466	100.00	87227.4	87227.4	1615.3
Q, CFS = 20000.0			QS, TOTAL =	87227.4	1615.3

VANRIJN -- CONCENTRATION CAPACITY PROFILE BY SIZE CLASS IN MG/L

SD(I)MM	REF CONC	Y/D=.1	Y/D=.2	Y/D=.3	Y/D=.5	Y/D=.7	Y/D=1.0
0.35367	1675.8	0.3	0.0	0.0	0.0	0.0	0.0
0.70734	694.5	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	2370.3	0.3	0.0	0.0	0.0	0.0	0.0

TABLE 4.1 VAN.RIJN METHOD = NO. 23

SIZE CLASS no	GRAIN SIZE mm	PERCENT IN CLASS %	SEDIMENT TRANSPORT POTENTIAL TONS/DAY	SEDIMENT TRANSPORT CAPACITY TONS/DAY	SEDIMENT TRANSPORT CONC PPM
8	0.354	37.84	8.77455	3.31993	12.296
9	0.707	46.16	2.75041	1.26970	4.7026
Q, CFS = 100.000			QS, TOTAL =	4.58963	16.999

VANRIJN -- CONCENTRATION CAPACITY PROFILE BY SIZE CLASS IN MG/L

SD(I)MM	REF CONC	Y/D=.1	Y/D=.2	Y/D=.3	Y/D=.5	Y/D=.7	Y/D=1.0
0.35367	42628.9	3650.2	1589.8	915.0	0.0	169.1	49.4
0.70734	42082.9	425.7	90.0	32.1	0.0	1.4	0.1
TOTAL	84711.9	4075.9	1679.8	947.0	0.0	170.5	49.6

TABLE 4.1 VAN.RIJN METHOD = NO. 23

SIZE CLASS no	GRAIN SIZE mm	PERCENT IN CLASS %	---------SEDIMENT TRANSPORT---------- POTENTIAL TONS/DAY	CAPACITY TONS/DAY	CONC PPM
8	0.354	37.84	226417.	85666.7	1586.4
9	0.707	46.16	85322.8	39388.5	729.42
Q, CFS =	20000.0		QS, TOTAL =	125055.	2315.8

TABLE 5.0 SUMMARY TABLE: BED-MATERIAL SEDIMENT DISCHARGE, TONS/DAY

Q NO	WATER DISCHARGE	TRANSPORT FUNCTIONS LAURSEN (MADDEN), 85	ACKERS-WHITE, D50	VAN.RIJN
1	100.00	2.49	6.73	4.59
2	1000.00	150.64	646.38	271.79
3	5000.00	3276.38	9240.40	8683.24
4	10000.00	9779.14	29045.88	33187.63
5	20000.00	27661.49	87227.36	125055.28

End of Job PRINTOUT SAVED IN FILE hydtests.so

Output Data Description

Table 1 echoes the input data file. An un-numbered table lists the "Bed Sediment Fractions Calculated From PF-Data." The properties of water, Table 3, are calculated from the water temperature at sea-level. The hydraulic parameters from input data are listed in Table 2.1. Effective discharge is the product of the width, depth, and velocity and represents channel discharge. Table 4.1 presents detailed results of the sediment transport calculations by discharge, in rows by sediment size class and in columns as labeled. Notice the discharges are the total discharges from the QW-record. Concentration is calculated using total discharge, not channel discharge. There will also be a separate Table 4.1 for each sediment transport function selected in the input file. Only two discharges' output for each function are shown here.

The Van Rijn function provides additional printout – for each water discharge, the sediment concentration profile by size class is calculated in mg/l. Table 5 is a summary of the calculated total bed-material sediment discharge, in rows according to water discharge and in columns by sediment transport function.

Sample of Data Written to SAM.yld Input File

SAM.sed writes the sediment concentration rating curve calculated for each sediment transport function selected to the SAM.yld input file, as shown below.

```
TI      FILE WRITTEN BY SAM.sed
TF     LAURSEN(MADDEN),1985
QW   100    1000    5000   10000   20000
SC 9.225  55.792    243.    362.    512.
$JOB
TI      FILE WRITTEN BY SAM.sed
TF     ACKERS-WHITE,D50
QW   100    1000    5000   10000   20000
SC24.915    239.    684.   1076.   1615.
$JOB
TI      FILE WRITTEN BY SAM.sed
TF     VAN.RIJN
QW   100    1000    5000   10000   20000
SC16.999    101.    643.   1229.   2316.
$$END
```

A separate sediment concentration rating curve is written for each sediment transport function selected in SAM.sed. If there is only one discharge in the SAM.sed input file, no SAM.yld input file is written, as no curve had been calculated. A warning message to that effect is written to the end of the output file and is echoed to the printout area on the input window.

8 Input Requirements and Program Output for SAM.yld

Purpose

SAM.yld provides hydraulic design engineers a systematic method for rapidly calculating bed-material sediment yield. This chapter will address the input data requirements and discuss the associated output.

SAM.yld calculates sediment yield passing a cross-section during a specified period of time. The time period considered can be a single flood event or an entire year. In SAM.yld the flow can be specified by either a hydrograph or a flow duration curve. The sediment rating curve can be specified either as sediment discharge versus water discharge or as sediment concentration versus water discharge. Calculations are based on the flow-duration sediment-discharge rating curve method (EM 1110-2-4000 USACE 1989).

General

The SAM.yld module expects an input file designated as *xxxxxxxx*.**yi**, where *x* can be any DOS acceptable character, including a space (but no embedded spaces), i.e., acceptable file names could be *say.yi* or *ITSNEVER.YI*. SAM.yld will write a corresponding file *xxxxxxxx*.**yo**, which is the output file. There is no plot output. SAM.yld input screens are accessed as shown in Figure 8.1.

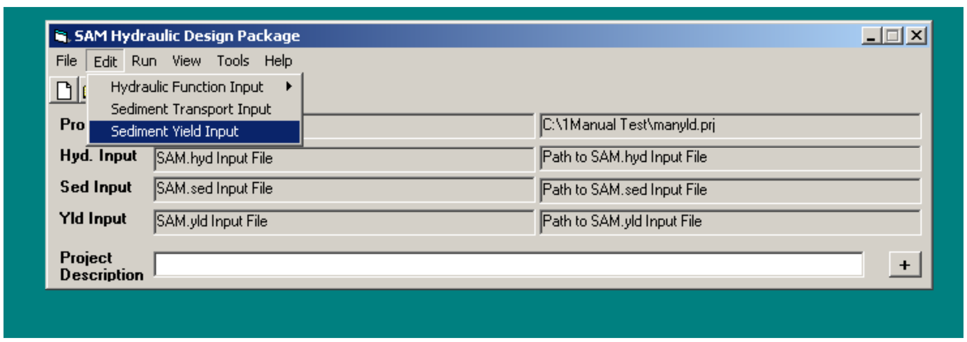


Figure 8.1. Accessing the Sediment Yield Input Screen

On the SAMwin main menu, clicking Edit/Sediment Yield Input brings up the screen in Figure 8-2. If there is an appropriate input file, a *.yi file, in the project directory, it's data will appear on the screen.

SAM.yld is designed to most easily run the data set made by SAM.sed, the *.yi file. SAM.sed writes the sediment concentration rating curve to a SAM.yld input file. If more than one sediment transport function was selected in SAM.sed, the SAM.yld input file will contain all sediment concentration rating curves, separated by a *$JOB* record. The flow duration curve or hydrograph, whichever is used, is not written into the *.yi file. This information can be added to a SAM.yld data set on the SAMwin Sediment Yield Input screen shown, Figure 8-2. Both the *.yi input file and the flow data file can be prepared with a system editor and read into the screen in Figure 8-2 using the File dropdown menu. The flow data file **MUST** be named CDFFIL and reside in the project directory.

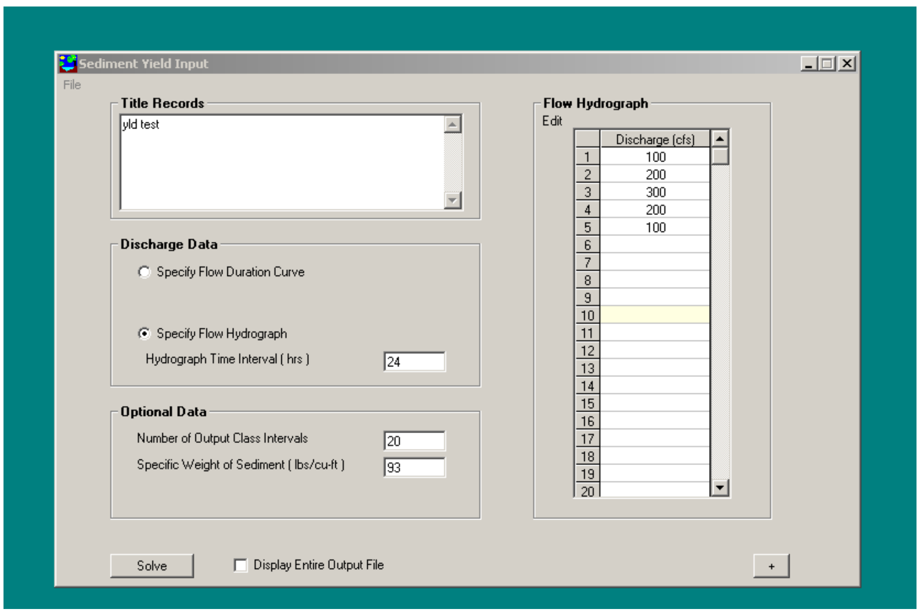


Figure 8-2. The Sediment Yield Input screen.

Title Records. This area allows the user to input descriptive strings, up to 78 characters long, for use in identifying data sets. These title records are written to the flow data file so should be used to describe the flow data, but the input is optional.

Discharge Data. The flow data may be input as a flow duration curve, the option shown in Figure 8.3, or as a flow hydrograph, Figure 8.4. Both options require the time interval to be input. Both the right hand side of the screen and the "Optional Data" area of the screen will request different data depending on the option selected here.

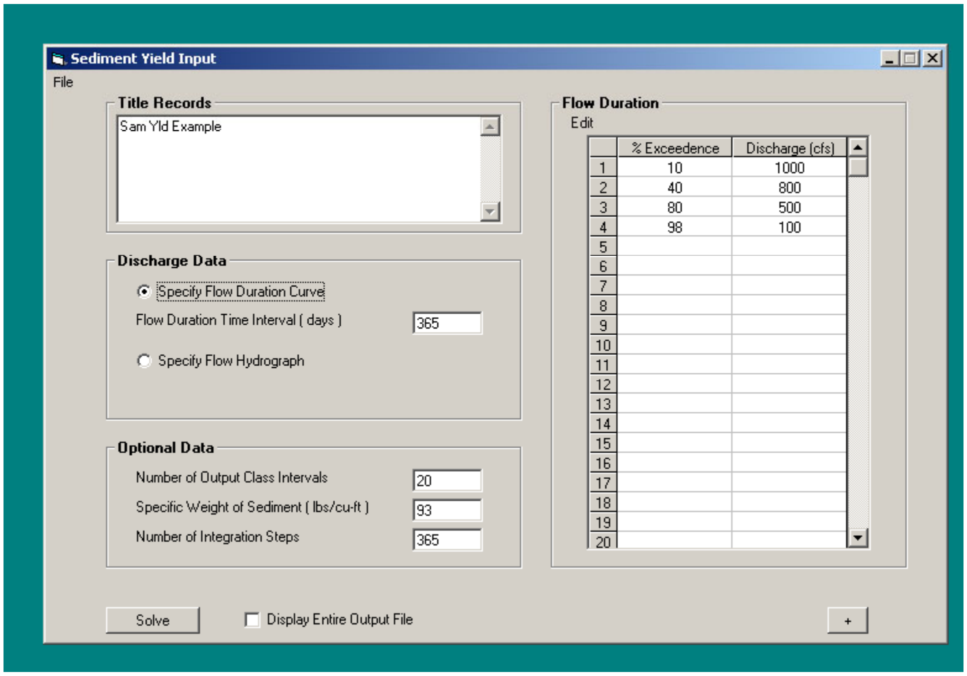


Figure 8.3. Example flow duration data input.

Flow Duration. This area allows the user to input the flow duration data. Data can be input in either increasing or decreasing percentage. **NOTE:** Do not use zero as the first or last discharge – use a very small number instead of zero, i.e., 0.0001. EM 1110-2-1415 (USACE) describes the procedure for calculating the flow duration curve. The time interval is input in days, and the default is 365. In the "Optional Data" section the "Number of Output Class Intervals" affects the Table 3.2 in the output file, a table useful for determining the effective discharge. The default for this value is 20. The "Specific Weight of Sediment (lbs/cu ft)" defaults to 93. The "Number of Integration Steps" refers to calculations internal to SAM.yld. The default is 365.

Flow Hydrograph. This area allows the user to input the flow hydrograph ordinate data. This hydrograph must have a uniform time-step. Zero can be used as a flow. The time interval is input in hours, and the default is 24. In the "Optional Data" section the "Number of Output Class Intervals" affects the Table 3.2 in the output file, a table useful for determining the effective discharge. The default for this value is 20. The "Specific Weight of Sediment (lbs/cu ft)" defaults to 93.

" + " Box. This button opens a small area below this window which will receive selected output. The output coming to this window cannot be selected by the user.

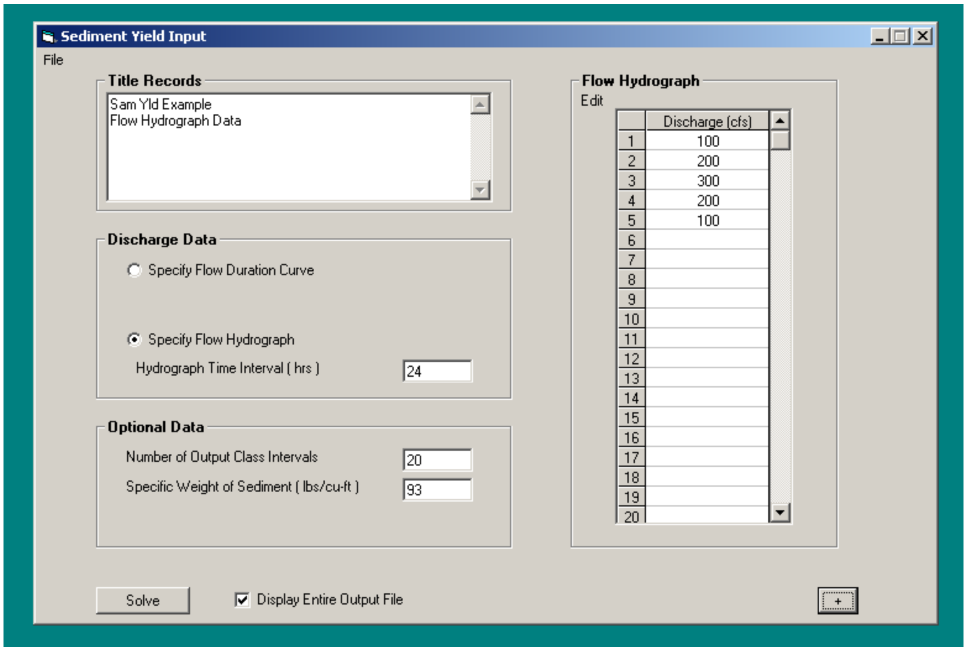


Figure 8.4. Example flow hydrograph data input.

Display Entire Output File. When this box is checked the output file will open in its own window (using Notepad) after calculations are complete. If this button is not checked, some input will echo to the screen in the area mentioned above. The entire output file can also be viewed by checking the View menu of the SAM main window and selecting "Sediment Yield Results."

Solve. This button causes SAM.yld to execute.

Program execution

The sediment yield calculations are made in SAMwin from the "Solve" button on the input screen, Figure 8.3 and 9.4, or from the "Run" dropdown menu. This second option is useful if a ready-to-run data set exists. This ready-to-run data set must contain the flow data, as described in the SAM Manual, or the flow data can be in a separate file that MUST be named "CDFFIL," no extension.

NOTE: If SAM.yld is run from the Run dropdown menu and it seems as though nothing happened, and there is no output file -- check to see if there is water data for the *.yi file being used, i.e., that there is a CDFFIL file in the directory.

Input Data Descriptions

The following example shows input data as created by running TEST 1C in SAM.sed. Notice that there is a separate input data set for each sediment transport function chosen in SAM.sed, with each data set ending with a *$JOB*, and a *$$END* record at the end. Also notice that no data set contains any flow-duration or hydrograph data.

```
TI      FILE WRITTEN BY SAM.sed
TF     LAURSEN(MADDEN),1985
QW   100    1000    5000   10000   20000
SC 9.225  55.792    243.    362.    512.
$JOB
TI      FILE WRITTEN BY SAM.sed
TF     ACKERS-WHITE,D50
QW   100    1000    5000   10000   20000
SC24.915    239.    684.   1076.   1615.
$JOB
TI      FILE WRITTEN BY SAM.sed
TF     VAN.RIJN
QW   100    1000    5000   10000   20000
SC16.999    101.    643.   1229.   2316.
$$END
```

In order to execute, the above data sets require flow information. This data is input through the “Sediment Yield Input” screen and automatically written to the *CDFFIL* file.

The flow information can also be in the “.yi” file, input using a system editor. Note that the information must be put in **each** “stacked” job, i.e., in each data set defined by a $JOB record. This format may be used to describe a flow-duration curve using discharge and percent of time exceeded, or a hydrograph, using QH records. See the Appendix E of this manual. The following examples show data sets containing the water data – the JP record, the QQ-QD record sets, and the QH records.

```
TI      FILE WRITTEN BY SAM.sed    VAN.RIJN
JP    25            500            730            89
QQ   100     140     160     180     200     250     300     350     400     450
QQ   500     550     600     650     700     750     800     850     900     950
QQ  1000    1100    1200    1300    1400    1500    1600    1700    1800    1920
QD 39.23   31.23   27.90   25.13   22.78   18.42   14.87   12.47   10.62    9.11
QD  7.89    7.05    6.44    5.69    5.19    4.69    4.16    3.90    3.55    3.30
QD  3.07    2.71    2.32    1.97    1.82    1.63    1.39    1.24    1.10    0.87
QW   100    1000    5000   10000   20000
SC20.354    107.    644.   1230.   2319.
$JOB

TI      FILE WRITTEN BY SAM.sed    LAURSEN(MADDEN),1985
F# 45678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
JP    12                                    18      85
QW   100    1000    5000   10000   20000
SC 9.239  55.940    243.    363.    513.
QH   100     100     100     500     750    1000    1050    1100    1800    2500
QH  4000    5000    8000   13000   15000   18000   19850   17000   16000   13000
QH 11000   10000    8000    7000    4000    1000     800     500     200     100
QH   100
$$END
```

Sample Output Data

Selected results are printed to a window which opens below the input area as the program executes. The output coming to this window cannot be selected by the user. The complete output is saved in the appropriate default output file.

Output Data Sets

The following output files are from TEST 1C. The first output file shows that a flow duration curve data was input on the Sediment Yield Input screen. Note that the data set originally contained only the sediment discharge rating curves as output from SAM.sed and read the water data from the *CDFFIL* file. The output from only one sediment transport function is given here. The output from all sediment transport functions in the *.yi file are written to one file, the corresponding *.yo file.

```
******************************************************************************
*                                                                            *
*      SAMwin   ---   HYDRAULIC DESIGN PACKAGE FOR FLOOD CONTROL CHANNELS      *
*                                                                            *
*                          SEDIMENT YIELD CALCULATIONS                       *
*                                                                            *
*                               version 2.0     23Jan03                      *
*                                                                            *
*           A Product of the Flood Control Channels Research Program         *
* Coastal & Hydraulics Laboratory, USAE Engineer Research & Development Center *
*                                                                            *
*                              in cooperation with                           *
*                                                                            *
*               Owen Ayres & Associates, Inc., Ft. Collins, CO               *
*                                                                            *
******************************************************************************

 Msg 1:  YLD. READING INPUT DATA FROM FILE [  C:\Hold\hydtests.yi  ] THIS DIRECTORY.


 TABLE  1.  LIST INPUT DATA.

 TI      FILE WRITTEN BY SAM.sed
 TF     LAURSEN(MADDEN),1985
 QW   100    1000    5000   10000   20000
 SC 9.225  55.792    243.    362.    512.
 $JOB

 SAM.yld IS IMPORTING FLOWS FROM FILE = CDFFIL

 T1 yld test
 T1     using a flow duration curve
 T1     10 days
 T1
 JP    20            365            10              93
 QQ   100     700    1450    5600    8800   10300   16000   21000
 QD   100      98      95      80      67      34       2       0

 INPUT IS COMPLETE.


 TABLE 2.1  SEDIMENT DISCHARGE TABLE.

 Q,CFS       =      100.0    1000.0    5000.0   10000.0   20000.0
 QS,TONS/DAY =        2.5     150.6    3280.5    9774.0   27648.0
```

```
     MINIMUM Q IN Q-QS TABLE =  100.000
     MAXIMUM Q               =  20000.0

            TABLE 2.2  FLOW-DURATION TABLE
    #     CFS        %        #     CFS        %        #     CFS        %

    1    100.00    100.00     4   5600.00     80.00     7  16000.00      2.00
    2    700.00     98.00     5   8800.00     67.00     8  21000.00      0.00
    3   1450.00     95.00     6  10300.00     34.00

TABLE 2.3  INTEGRATION PARAMETERS FOR FLOW-DURATION OPTION
           MINIMUM FLOW, CFS          =       100.00
           MAXIMUM FLOW, CFS          =     21000.00
           INTEGRATION INTERVAL, CFS  =        57.26
           NUMBER OF INTEGRATION STEPS =       365

TABLE 2.7  DENSITY OF SEDIMENT DEPOSIT.
           IN LB/CUFT   =        93.00
           IN CY/TON    =         0.80

               TABLE 3.1  CALCULATED YIELDS

   SEDIMENT TRANSPORT FUNCTION USED -- LAURSEN(MADDEN),1985

    TIME PERIOD,    DAYS =      10.000
    WATER YIELD,    ACFT =     171691.,  Mean Daily Flow, CFS =      8656.07
    SEDIMENT YIELD, TONS =      84052.,  Mean Daily Load, T/D =        8405.
                    CUYD =      66947.,  Mean Daily Conc, mg/l=      359.636

TABLE 3.2  DISTRIBUTION OF YIELD BY WATER DISCHARGE CLASS INTERVAL.
           NO. OF CLASSES =        20   ,          CLASS INTERVAL =      1045.00
           MINIMUM Q, CFS =       100.00,          MAXIMUM Q, CFS =     21000.00

CLASS DISCHARGE     SEDIMENT   INCREMENT OF         INCREMENT OF SEDIMENT
         CFS        TONS/DAY    WATER, ACFT   %     %      TONS             CU YD

          100.          2.
   1                               272.   0.16   0.01          9.          7.
         1145.        195.
   2                              1835.   1.07   0.25        212.        169.
         2190.        676.
   3                              2314.   1.35   0.51        430.        343.
         3235.       1425.
   4                              2224.   1.30   0.67        562.        447.
         4280.       2436.
   5                              2157.   1.26   0.81        677.        539.
         5325.       3623.
   6                              5172.   3.01   2.22       1868.       1488.
         6370.       4804.
   7                              6025.   3.51   2.85       2393.       1906.
         7415.       6102.
   8                              5700.   3.32   2.92       2456.       1957.
         8460.       7511.
   9                             35692.  20.79  19.65      16520.      13158.
         9505.       9023.
  10                             37756.  21.99  22.11      18583.      14801.
        10550.      10591.
  11                             29234.  17.03  18.03      15151.      12067.
        11595.      12204.
  12                             16306.   9.50  10.52       8841.       7042.
        12640.      13890.
  13                              9551.   5.56   6.42       5398.       4299.
        13685.      15648.
  14                              5830.   3.40   4.07       3423.       2727.
        14730.      17474.
  15                              3686.   2.15   2.67       2243.       1787.
        15775.      19367.
  16                              1812.   1.06   1.36       1140.        908.
        16820.      21323.
  17                              1531.   0.89   1.18        993.        791.
        17865.      23341.
  18                              1531.   0.89   1.22       1023.        815.
        18910.      25419.
  19                              1531.   0.89   1.25       1052.        838.
```

```
        19955.       27555.
  20                             1531.   0.89   1.28       1080.        860.
        21000.       29748.
                             ___________ ______ ______ ___________ ___________
                                171691. 100.00 100.00      84052.      66947.

 ...END OF JOB...     Printout is in FILE [  C:\Hold\hydtests.yo
```

The next output file shows the use of the hydrograph water data.

```
********************************************************************************
*                                                                              *
*      SAMwin   ---   HYDRAULIC DESIGN PACKAGE FOR FLOOD CONTROL CHANNELS      *
*                                                                              *
*                          SEDIMENT YIELD CALCULATIONS                         *
*                                                                              *
*                               version 2.0     23Jan03                        *
*                                                                              *
*           A Product of the Flood Control Channels Research Program           *
* Coastal & Hydraulics Laboratory, USAE Engineer Research & Development Center *
*                                                                              *
*                             in cooperation with                              *
*                                                                              *
*               Owen Ayres & Associates, Inc., Ft. Collins, CO                 *
*                                                                              *
********************************************************************************

 Msg 1:  YLD. READING INPUT DATA FROM FILE [  C:\Hold\hydtests.yi  ] THIS
DIRECTORY.

 TABLE  1.  LIST INPUT DATA.

 TI      FILE WRITTEN BY SAM.sed
 TF     LAURSEN(MADDEN),1985
 QW   100    1000    5000   10000   20000
 SC 9.225  55.792    243.    362.    512.
 $JOB

 SAM.yld IS IMPORTING FLOWS FROM FILE = CDFFIL

 T1 yld test
 T1     using a hydrograph
 T1     24-hr interval
 T1
 JP    20                                      24      93
 QH   500     950    1300    2800    4850    6600    9825   13790   15980   14760
 QH 11030    7800    3550    1870     850     590     240

 INPUT IS COMPLETE.

 TABLE 2.1  SEDIMENT DISCHARGE TABLE.

 Q,CFS       =      100.0    1000.0    5000.0   10000.0   20000.0
 QS,TONS/DAY =        2.5     150.6    3280.5    9774.0   27648.0

      MINIMUM Q IN Q-QS TABLE =  100.000
      MAXIMUM Q               =  20000.0

 TABLE 2.4  DISCHARGE HYDROGRAPH POINTS, CFS
            TIME BETWEEN POINTS, HRS =    24.0000
      500.00      950.00     1300.00     2800.00     4850.00     6600.00
     9825.00    13790.00    15980.00    14760.00    11030.00     7800.00
     3550.00     1870.00      850.00      590.00      240.00

 TABLE 2.5  FLOW-DURATION TABLE FROM HYDROGRAPH POINTS
            CLASS VARIABLE =  DISCHARGE, CFS

 CLASS        CLASS INTERVAL       DURATION    %    EXCEEDENCE
   #       LIMIT       MIDPOINT      DAYS              %

    1       240.00                                    100.00
                       633.50          4.50  28.13
```

```
   2      1027.00                                       71.88
                    1420.50          1.00   6.25
   3      1814.00                                       65.63
                    2207.50          1.00   6.25
   4      2601.00                                       59.38
                    2994.50          1.00   6.25
   5      3388.00                                       53.13
                    3781.50          1.00   6.25
   6      4175.00                                       46.88
                    4568.50          1.00   6.25
   7      4962.00                                       40.63
                    5355.50          0.00   0.00
   8      5749.00                                       40.63
                    6142.50          0.00   0.00
   9      6536.00                                       40.63
                    6929.50          1.00   6.25
  10      7323.00                                       34.38
                    7716.50          1.00   6.25
  11      8110.00                                       28.13
                    8503.50          0.00   0.00
  12      8897.00                                       28.13
                    9290.50          0.00   0.00
  13      9684.00                                       28.13
                   10077.50          1.00   6.25
  14     10471.00                                       21.88
                   10864.50          1.00   6.25
  15     11258.00                                       15.63
                   11651.50          0.00   0.00
  16     12045.00                                       15.63
                   12438.50          0.00   0.00
  17     12832.00                                       15.63
                   13225.50          0.00   0.00
  18     13619.00                                       15.63
                   14012.50          1.00   6.25
  19     14406.00                                        9.38
                   14799.50          1.00   6.25
  20     15193.00                                        3.13
                   15586.50          0.50   3.13
  21     15980.00                                        0.00
                                ____________
             TOTAL TIME    =         16.00    TOTAL EVENTS=        17
             MAXIMUM VALUE =      15980.00       EVENT NO.=         9
             MINIMUM VALUE =        240.00       EVENT NO.=        17
             % BELOW RANGE =        0.0000    ABOVE RANGE =    0.0000

TABLE 2.6  INTEGRATION PARAMETERS FOR HYDROGRAPH OPTION
           MINIMUM FLOW, CFS           =      240.00
           MAXIMUM FLOW, CFS           =    15980.00
           NUMBER OF INTEGRATION STEPS =       365

TABLE 2.7  DENSITY OF SEDIMENT DEPOSIT.
           IN LB/CUFT   =        93.00
           IN CY/TON    =         0.80

              TABLE 3.1  CALCULATED YIELDS
   SEDIMENT TRANSPORT FUNCTION USED -- LAURSEN(MADDEN),1985

    TIME PERIOD,    DAYS =      17.000
    WATER YIELD,    ACFT =     188757., Mean Daily Flow, CFS =      5597.94
    SEDIMENT YIELD, TONS =      89439., Mean Daily Load, T/D =        5261.
                    CUYD =      71237., Mean Daily Conc, mg/l=      348.084

TABLE 3.2  DISTRIBUTION OF YIELD BY WATER DISCHARGE CLASS INTERVAL.
           NO. OF CLASSES =        20   ,          CLASS INTERVAL =       787.00
           MINIMUM Q, CFS =       240.00,          MAXIMUM Q, CFS =     15980.00

CLASS DISCHARGE     SEDIMENT   INCREMENT OF         INCREMENT OF SEDIMENT
         CFS        TONS/DAY    WATER, ACFT   %     %      TONS              CU YD

          240.          12.
   1                                4728.   2.50   0.23        210.        167.
         1027.         159.
   2                                2888.   1.53   0.33        294.        234.
         1814.         471.
   3                                4597.   2.44   0.80        715.        570.
```

```
        2601.         939.
  4                                6282.   3.33   1.45       1300.       1036.
        3388.        1557.
  5                                7959.   4.22   2.29       2046.       1629.
        4175.        2323.
  6                                9632.   5.10   3.30       2947.       2347.
        4962.        3233.
  7                                   0.   0.00   0.00          0.          0.
        5749.        4087.
  8                                   0.   0.00   0.00          0.          0.
        6536.        5002.
  9                               14641.   7.76   6.58       5884.       4687.
        7323.        5983.
 10                               16308.   8.64   7.80       6974.       5555.
        8110.        7027.
 11                                   0.   0.00   0.00          0.          0.
        8897.        8131.
 12                                   0.   0.00   0.00          0.          0.
        9684.        9292.
 13                               21310.  11.29  11.86      10609.       8450.
       10471.       10473.
 14                               22976.  12.17  13.30      11892.       9472.
       11258.       11675.
 15                                   0.   0.00   0.00          0.          0.
       12045.       12921.
 16                                   0.   0.00   0.00          0.          0.
       12832.       14208.
 17                                   0.   0.00   0.00          0.          0.
       13619.       15535.
 18                               29642.  15.70  19.48      17427.      13880.
       14406.       16901.
 19                               31308.  16.59  21.15      18917.      15067.
       15193.       18305.
 20                               16487.   8.73  11.43      10223.       8143.
       15980.       19746.
                              ___________ ______ ______ ___________ ___________
                                 188757. 100.00 100.00      89439.      71237.

...END OF JOB...     Printout is in FILE [  C:\Hold\hydtests.yo]
```

Output Data Description

Since the SAM.yld input file contained a *$$JOB* record, the use here of the term "output data set" refers to output from program banner to the "END OF JOB" tag. As in SAM.hyd and SAM.sed, Table 1 in every output data set is an echo of the input data set. However, in SAM.yld this table echoes the input from both the *.yi file and the *CDFFIL* water data file. Table 2.1 is the "Sediment Discharge Table" and shows the input sediment discharge rating curve in tons per day. The next several table numbers and the information displayed differ depending on whether the calculations were based on a flow duration curve or a hydrograph. If the input data included flow-duration information, the output includes tables 2.2 and 2.3. Table 2.2 simply echoes the input flow-duration curve. Table 2.3, "Integration Parameters for Flow-Duration Option," includes the number of integration steps, an input item on the Sediment Yield Input screen, and the integration interval in cfs. If the input data included QH records, the output includes tables 2.4, 2.5, and 2.6. Table 2.4 echoes the QH records and lists the time between points. Table 2.5 shows the hydrograph converted to a flow-duration table. Table 2.6 corresponds the Table 2.3, above, but is the "Integration Parameters for Hydrograph Option." The number of integration steps, echoed on this table, is an input parameter.

At this point the output table names and information specified become the same. Table 2.7 gives the density of the sediment deposit, another possible input variable. Table 3.1, “Calculated Yields,” echoes to the screen in the drop down area of the Sediment Yield Input screen as well as printing to the output file. This table provides the “answers” for the SAM.yld option, giving the sediment yield in both tons and cubic yards, and echoing the time period, in days, as input on Figure 8.3 or 9.4. It also lists the sediment transport function used for that data set.

Table 3.2 is the “Distribution of Yield by Water Discharge Class Interval.” The first column, “Class,” is ‘20’ in the example problems, because in the “Optional Data” area on the “Sediment Yield Input” screen, the “Number of Output Class Intervals” was left at the default of 20. The number of intervals into which the range of flows is divided can be changed with this input parameter. When a flow duration curve has been input, Table 3.2 can be used to determine the effective discharge – the discharge that moves the most sediment. The effective discharge can be determined by looking for the class that has the largest “increment of sediment.” Copeland et al. (2001) has a discussion of effective discharge in chapter 3.

The end of the output for this data set is marked with “...END OF JOB...” and a note with the output filename. If the input file has stacked jobs, the next data set will begin with a new program banner.

If some discharges in the flow-duration or hydrograph information fall outside the range of discharges in the sediment discharge rating curve, the program will inform the user. These messages will print out in connection with the “Integration Parameters” table. The program will then assign a sediment discharge in tons per day to the water discharge value that is out of range, based on the existing sediment discharge table, Table 2.1. This is the “YOUT” value listed in the “INDEPENDENT VARIABLE XIN OUT OF TABLE BOUNDS” message if it appears.

Plotting

SAM.yld has no plotting capabilities at this time.