January 1982

Hydraulics and Numerical Solutions of Steady-State but Spatially Varied Debris Flow

Alfredo A. DeLeon

Roland W. Jeppson

HYDRAULICS AND NUMERICAL SOLUTIONS OF STEADY-STATE BUT SPATIALLY VARIED DEBRIS FLOW

by

Alfredo A. DeLeon and Roland W. Jeppson

The research on which this publication is based was supported in part by funds provided by the Office of Water Research and Technology, U. S. Department of the Interior, through the Annual Cooperative Program of that agency, as authorized under the Water Resources Act of 1978. Contract No. 14-34-0001-1147, A-052-UTAH.

HYDRAULICS AND HYDROLOGY SERIES
UWRL/H-82/03

Utah Water Research Laboratory
Utah State University
Logan, Utah 84322

July 1982

ABSTRACT

Debris flow is a natural phenomenon triggered by special conditions that combine: high intensity rainfall, material available for transport, slopes steep enough to induce flowage, and insufficient protection of the ground by vegetation and/or other erosion control means. These conditions are very common in semiarid and arid regions in Utah, other Western states and many other parts of the globe. Previously, the two models proposed to solve debris flow are the Bingham plastic model and the dilatant model. Both these models depend upon coefficients that are not easy to obtain. Therefore, they are not very useful in practice.

According to the field observations and data reported, most debris flows that occur in nature are laminar. The viscosity of these flows has been as large as 600,000 times that of water. Reynolds numbers are less or equal to 500 for these debris flows. Laminar debris flows are the subject of this report.

A theoretical model based on the Saint-Venant equations of continuity and motion, together with a modified Chezy equation for defining the energy loss, were found to be suitable to describe debris flow in the laminar range. These equations were solved by numerical methods implemented in a computer program. This report covers only steady but gradually varied debris flow solutions.

A formula defining the Chezy coefficient as a function of Reynolds number is proposed. A relationship between the debris flow density and its viscosity is also proposed. These relationships are of necessity based on the limited data available for debris flows.

Solutions to four examples are given. The results show that this open channel debris flow model reproduces well debris flows observed in nature. These solutions show that debris flows develop depths greater than water flows. The bed slope is the most important variable that affects the ratio of the depth of debris flow to depth of an equivalent volumetric water flow. For milder slopes this depth ratio exceeds ten. The substantially larger depth of debris flow than of equivalent water flow explains in part why debris flows have been observed to stop flowing, leaving an abrupt wave-shaped form on the landscape.

ACKNOWLEDGMENTS

The research on which this publication is based was supported in part by funds provided by the Office of Water Research and Technology, U.S. Department of the Interior, through the allotment program of that agency with Utah State University, as authorized under the Water Resources Act of 1964, as amended. Contract No. 14-34-0001-1147.

The material of the report is similar to the dissertation submitted by the first author in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Engineering from Utah State University under the title of "Hydraulics of Debris Flow." The second author is Dr. DeLeon's major professor. The title of this report has been changed in anticipation of a follow-on report covering additional work dealing with unsteady debris flows.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF SYMBOLS

Symbols	Definition
a_i	= numerical coefficient
α	= friction angle in moving grains
α	= angle for which the shear stress is a maximum or minimum
a	= exponent in the equation that expresses the relationship between the debris flow density and its viscosity
A	= cross-sectional area
A_m	= constant
b,B	= width
B_m	= constant
C_d	= grain concentration by volume in debris flow
C_*	= grain concentration by volume in stationary bed
C	= Chezy coefficient
d	= grain diameter
δ	= slope angle
D	= pipe diameter
η_b	= Bingham viscosity
η	= coefficient of rigidity
f	= Darcy resistance coefficient
F_r	= Froude number

Symbols	Definition
F_q	= inflow parameter
g	= acceleration due to gravity
$\dot{\gamma}$	= shear strain rate
γ	= unit weight
Γ	= sheer stress function
h	= depth of debris flow
h	= height k water surface above datum
H	= total energy
h_c	= distance between water surface and centroid of cross-sectional area
k	= constant in the equation that expresses the relationship between the debris flow density and its viscosity
k	= proportionality constant for a power law fluid
k	= Takahashi's resistance coefficient
k	= sheer strength or the maximum magnitude of sheer stress
m	= integer constant
m	= slope of channel side
μ	= viscosity
μ_p	= plastic viscosity

Symbols	Definition
μ_a	= apparent viscosity
n	= exponent for a power law fluid
n	= Manning's resistance coefficient
ν	= kinematic viscosity
p	= fluid pressure
P	= wetted perimeter
ϕ	= debris flow bed slope
π	= A constant (3.14159...)
q	= unit flow rate
q^*	= lateral inflow rate
Q	= flow rate
R	= hydraulics radius
R_e	= Reynolds number
ρ	= density of water
ρ_m	= density of slurry
S_a	= acceleration slope
S_e	= energy slope
S_f	= friction slope
S_o	= slope of the channel bottom
S_p	= shearing stress in a flowing material at pipe wall
S_y	= shearing stress at the yield point of a plastic material

Symbols	Definition
σ	= stress
σ	= grain density
t	= time
T	= top width
τ	= shear stress
τ_o	= shear stress at solid boundary
τ_y	= yield stress
Θ	= slope angle of debris bed
u	= velocity in the x-direction
U	= cross-sectional mean velocity
u_s	= velocity at surface
V	= mean velocity of flow in pipe or channel
$\dot{w}$	= component of the velocity in the z-direction
x, y, z	= cartesian coordinate systems
y	= depth of the flow
y_c	= critical depth
y_d	= debris flow depth
y_o	= normal depth
z	= elevation of the channel bottom

CHAPTER I

INTRODUCTION

Open channel flow theory provides the necessary tools for solving problems related to free surface flows of Newtonian fluids such as water. In this theory the differential Saint-Venant equations of continuity and motion are solved jointly with an algebraic equation such as Chezy's or Manning's equation, for defining the friction slope. Debris flows, however, are generally accepted as non-Newtonian, and little has been accomplished in extending open channel flow principles to these flows. Yet developing the means to do so would represent a fundamental step toward being able to deal with problems associated with flow that annually cause large property losses.

Debris flows historically have been associated with cloudburst runoff from steep mountain catchments located in arid and semiarid regions. Conditions that trigger debris flows develop in watersheds upstream from where the debris flows generally cause damage. Common conditions are: 1) insufficient protection of the ground by vegetation and/or stone rubble to hold the ground in place; 2) loose material available for transport; 3) slopes steep enough to induce gravity flowage; and 4) sufficient water to lubricate the material.

Methods are needed so that 1) depths and magnitudes of debris flow can be predicted and used to map areas subject to damage, and 2) hydraulic structures across and along channels and rivers can be designed to control and withstand this type of flow without damage. With such information planning agencies will be in a position to set up guidelines for regulating the development and protection of areas subjected to debris flood flow. Also flood insurance programs would have a much improved base from which to charge actuarial rates and evaluate debris flood insurance claims. Since debris flows likely exhibit some chracteristics similar to flows consisting of a mixture of water and ash, the solution of debris flow would also be important for streams located near active volcanos.

Presently, two models have been proposed for solving steady state debris flows: 1) the Bingham plastic model supported by American investigators (Johnson 1965, 1970, Leopold et al. 1964, and Hooke 1967) and 2) the dilatant model proposed by Takahashi (1978, 1980) in Japan. Both models have been tested on a small scale in laboratories. Both depend upon coefficients (yield stress at zero shear rate (τ_y) for the Bingham model and the resistant coefficient (k) for the dilatant model) that are specific for each debris flow and, furthermore, difficult to estimate even under controlled laboratory conditions. The solution is strongly effected by the magnitude of these parameters. Applications of these models to unsteady flows is further complicated since these coefficients vary with time.

Almost all the references listed agree that debris flows are laminar. Values of reported viscosities are as large as a hundred to several hundred times the viscosity of water. Densities range between 1.7 to 2.4 gr/cm^3, grain sizes from a few millimeters to meters, and velocities from several tens of centimeters per second to several tens of meters per second. A useful description of debris flow is (Takahashi 1980, p. 381): "Debris flow is a flowage of a mixture of all sizes of sediment. Boulders accumulate and tumble at the front of the debris wave and form a lobe, behind which follows the finer-grained more fluidic debris."

For laminar open channel debris flows, the concern of this research, a theoretical model is proposed and calibrated based on the few data available. This model is implemented in a computer solution to handle steady state but gradually varied open channel debris flow. The essential principles and equations upon which the model is based are: 1) The Saint-Venant equations of continuity and motion in simplified form for steady spatially varied flow. The Euler method is employed to solve the resulting first order ordinary differential equation numerically. 2) The Chezy equation, but with a modified coefficient, is used to define energy losses. Based on available data, a relationship for Chezy's C is defined, which eliminates the need to use the Takahashi resistance coefficient and represents an improvement in the practical solution of debris flows. 3) The critical slope and the normal depth are computed by Chezy's modified equation by means of the Newton iterative method. 4) The ratio of the debris flow density to its viscosity (ρ/μ) is proposed to be a linear function of the hydraulics radius as evidenced by limited available data and thus Reynolds number becomes a function of ρ/μ. 5) The critical depth is computed by means of known theory of open channel flow.

Chapter II presents a literature survey of work related to the problem. Differential equations describing open channel debris flow are derived in Chapter III. Chapter IV describes the model formation, Chapter V explains the computer model, Chapter VI shows the application of the computer model to some open channel debris flows, and Chapter VII presents conclusions and recommendations.

CHAPTER II

REVIEW OF LITERATURE

Types of Fluids

The relationship between fluid shear stress and the rate of strain (velocity gradient) as one moves away from a laminar flow boundary determines the theoretical development of a flow equation. Fluids can be classified by their characteristic relationship. An excellent description of different types of fluids is given by Hughes and Brighton (1967). The main characteristics of these fluids are summarized in Figures 1 and 2, and Equations 1, 2, 3, 4, and 5.

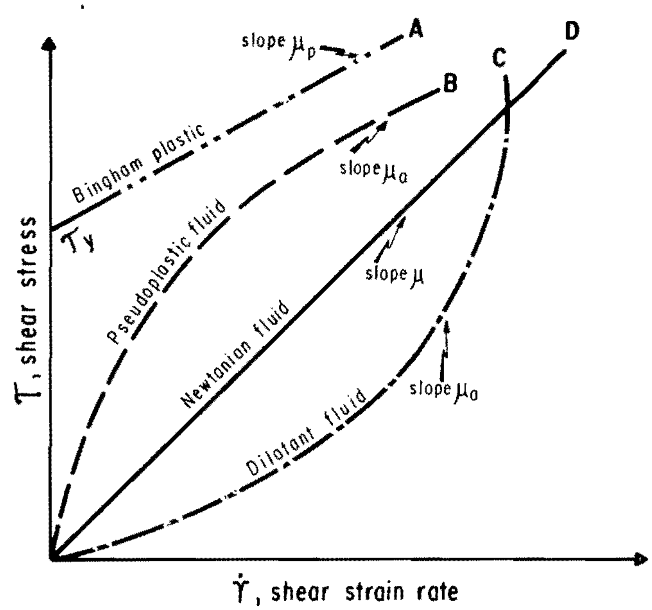


Figure 1. Typical shear stress strain rate relationships for non-Newtonian fluids.

Newtonian Fluid, Curve D

Water and other Newtonian fluids show a linearly relation of the shearing stress τ to the shear strain or velocity gradient. The slope of the straight line relationship in Figure 1 is the viscosity μ

$$\tau = \mu\dot{\gamma} = \mu \frac{\partial u}{\partial y} \quad . . . .(1)$$

where τ is the shear stress, and $\dot{\gamma}$ is the rate of shear strain.

Bingham Plastic Fluid
$\tau_y > 0$, Curve A

The definitional characteristic of a Bingham plastic fluid is that the shear stress exceeds some minimal amount (yield stress τ_y) before exhibiting a shear rate, followed by a straight line relationship between shear stress and shear rate.

$$\tau = \tau_y + \mu_p \dot{\gamma} \quad . . . .(2)$$

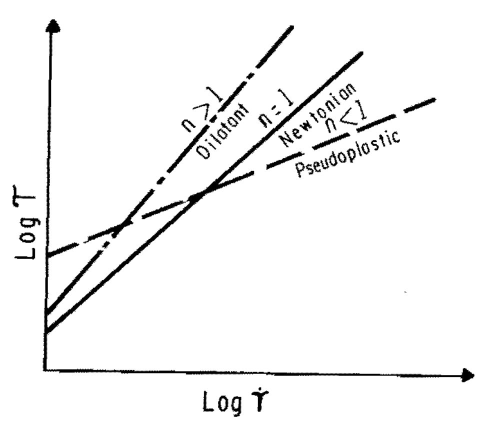


Figure 2. Log-log plot of power law fluids.

where τ_y is the yield stress and μ_p is the plastic viscosity.

Pseudoplastic and Dilatant Fluids, Curves B and C

Pseudoplastic fluids and dilatant fluids do not have a yield stress at which shear strain begins. A pseudoplastic fluid is characterized by a progressively decreasing slope of shear stress versus shear rate. A dilatant fluid exhibits an increasing slope of this relationship with increasing shear rate. The varying slope of the shear stress versus shear rate is defined in both cases as the apparent viscosity, μ_a, of the fluid or

$$\mu_a = \tau/\dot{\gamma} \quad \ldots\ldots\ldots\ldots (3)$$

A number of empirical relations have been used to describe pseudoplastic and dilatant fluids. The simplest is the power law proposed by Ostwald, cited by Hughes and Brighton (1967). This law is:

$$\tau = k\dot{\gamma}^n \quad \ldots\ldots\ldots\ldots (4)$$

where

$n < 1$ for pseudoplastic fluids

$n > 1$ for dilatant fluids

Substituting in Equation 3 gives

$$\mu_a = k\dot{\gamma}^{(n-1)} \quad \ldots\ldots\ldots (5)$$

where k and n are constants for a particular fluid; k is a measure of the consistency of the fluid and n, the exponent, is a measure of how the fluid deviates from a Newtonian fluid. A graphical representation of Equation 5 for different values of n is given in Figure 2.

Hydraulic Characteristics of Debris Flows

A concensus scientific definition of debris flow has not been reached. This hydraulic-geologic phenomenon, however, has been described by several authors. One of the earliest descriptions (McGee 1897) called it a "sheetflood." Perhaps the best definition is that quoted previously from Takahashi (1980, p. 381). Other relevant descriptions have been given by Pack (1923), Paul and Baker (1925), Blackwelder (1928), Cannon (1931), Chawner (1935), Sharp and Nobles (1953), Hooke (1967), Johnson (1965, 1970), and Takahashi (1978). Mudflow is a term used to describe debris flow that consists mainly of sand-size and finer sediments (Sharp and Nobles 1953, Leopold et al. 1964, and Bull 1968). Table 1 gives a summary of the main parameters that characterize debris flow as recorded by various authors.

Recently, debris flow has been classified in regimes. Starting from the assumption that it behaves like Bingham's fluid, based on data obtained from the literature, and defining appropriately such parameters as Reynolds, Froude, and Bingham numbers, Enos (1977) classified debris flows as laminar, turbulent, subcritical, and super critical. The behavior that debris flows show in nature, including such intrinsic characteristics as ability to climb walls, to suddenly stop, and exhibit large values of viscosity, has caused some researchers to categorize these mixtures as non-Newtonian fluids. Leopold et al. (1964), Johnson (1965, 1970) and Hooke (1967) proposed to treat debris flows as plastic or Bingham fluids. Takahashi (1978, 1980), based on experiments conducted by Bagnold (1954), claims that some debris flows, if not all of them, can be modeled as dilatant fluids. Johnson (1970) pointed out that most of the early investigators assumed that debris flows behave as viscous or Newtonian substances.

Table 1. Summary of debris flow characteristics.

Source	Reynolds number	Froude number	Velocity	Density	Viscosity	Slope	Water content	Consistency - Description
Cannon (1931)	-	-	-	-	-	-	-	The advance portion of at least the first flow in each canyon was a thick mixture barely fluid enough to flow, with no free water going before it.
Pierson (1981)	-	0.3	1.0 m/s measured at surface	1.73 gr/cm^3 (bulk density)	like motor oil	5-7°	40% (by weight)	Turbulent muddy streamflow (between surges), having the apparent viscosity of motor oil.
Pierson (1981)	30	0.01	0.2 m/s measured at surface	1.73 gr/cm^3 (bulk density)	slurry	"	"	Viscous, laminar debris flow, slurry
Pierson (1981)	500 - 3000	2.3	5.0 m/s measured at surface	2.08 gr/cm^3 (bulk density)	-	"	22%	Higher velocity viscous debris flow with renewed turbulence
Takahashi (1980)	-	-	Several tens of meters/second to several tens of cms/second	-	apparent Newtonian viscosity 10^3 to 10^4 poise	-	-	Flowage of a mixture of all sizes of sediment. Boulders accumulate and tumble at the front of the debris wave and form a lobe, behind which follows the finer-grained more fluidic debris
Pack (1923)	-	-	These gigantic masses of heterogeneous material were shot from the narrow canyons into the open valleys with a suddenness that almost challenges belief.	-	-	4-8°	near absence of water at the precise time of the greatest deposition of debris	Slightly following this first impulse were tremenous quantities of rock waste ranging in size from impalpable material to boulders of very large dimensions.
Segerstroem (1950)	-	-	0.6 m/s	-	-	25%	-	-
Leopold et al. (1964)	-	-	0.2 m/s	-	-	12-15%	-	-
Blackwelder (1928)	-	-	-	-	-	4-6°	-	The flood sweeps large quantities of washed gravel, sand, clay, and even small boulders.
Sharp and Nobles (1953)	-	-	1.20-3.00 m/sec (average velocity)	2.4 (specific gravity)	$2x10^3$-$6x10^3$ poise	6° average	25-30% (by weight)	Highly fluidic slimy cement-like mud containing abundant stones.

Sharp and Nobles (1953) inserted data coming from a specific debris flood flow into a simplified one dimensional Navier-Stokes equation and obtained values for the viscosity varying between 2000 and 6000 poise. This means that the debris flow viscosity is 200,000 to 600,000 times larger than the viscosity of water (0.01 poise).

Several investigators have suggested explanations why large particles remain suspended in debris flows. Pierson (1981) attributes the ability of debris flow to transport large boulders to the mechanisms of buoyancy, due to the large density of the mixture. Johnson (1965) also says that the density and strength of debris retards or prevents coarse particles from sinking. Pack (1923) in describing the 1923 devastating debris floods along the Wasatch Front in Utah, in which boulders weighing up to 95 ton were transported long distances, provides a number of indicators that very little mixing of the flow occurs between different depths. He notes ample visible evidence along the courses traversed by the "sliding mass of rock" of "striations and flutings impressed upon the clays and other compact soils." Also he notes "similar striations present on several large iron pipes over which the flood passed," and the "cement is scratched by a series of parallel marks" where the flow crossed highways and trees and undergrowth "were cut off at the ground almost as if a great knife had passed through them" rather than being pressed down as they would by rolling boulders. Pack's excellent description of these 1923 Utah debris flows, which occurred nearly simultaneously from several canyons, provides a mental image of a conglomerate flowing mass moving across the flatter valley floors almost as if it were an earthen slide. The lack of usual water flow characteristics, however, fits well laminar flows of all fluids. Rather than mixing between adjacent layers of depths, the movement occurs by means of a shear strain between layers, with the largest stress occurring at its bottom.

Analytical Approaches to Debris Flows

Closed form solutions for the velocity distribution under steady state uniform flow conditions with specific boundaries condition have been obtained by Johnson (1965, 1970) through a Bingham model and by Takahashi (1980) through a dilatant model. No unsteady flow solution has yet been obtained. Neither have solutions been obtained for the gradually varied flow state. These two models, based on different stress-strain rate relationships are outlined below.

Takahashi's Dilatant Model

In his derivation of the velocity distribution and its application to estimate debris flow in a rectangular section, Takahashi (1980) used the continuity equation:

$$\frac{\partial h}{\partial t} + \frac{\partial (Uh)}{\partial x} = 0 \quad \ldots\ldots(6)$$

and the equation of motion:

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} = g\sin\Theta - g\cos\Theta\frac{\partial h}{\partial x} - k\frac{U^2}{h} \quad .(7)$$

in which

x = distance along the channel

t = time

U = cross-sectional mean velocity

h = depth of debris flow

k = coefficient of resistance

Θ = slope angle of debris bed

Equation 7 is the well known Saint-Venant equation applied so that the x-axis is in the flow direction and the y-axis is normal thereto. He defined a resistance coefficient as:

$$k = \frac{25\, a_i \sin\alpha}{4[\, C_d + (1-C_d)\, \frac{\rho}{\sigma}\,]\, [(\frac{C_*}{C_d})^{1/3} - 1]^2} \left(\frac{d}{h_\infty}\right)^2 \quad \ldots\ldots\ldots\ldots (8)$$

where

a_i = numerical but flow dependent value

α = friction angle of the moving grains

C_d = grain concentration by volume in debris flow

ρ = density of water

σ = grain density

C_* = grain concentration by volume in the stationary bed

d = grain diameter

h_∞ = steady state depth of debris flow

Later in this report the writers provide a much simplier alternate for defining Takahashi's resistance coefficient as:

$$k = \frac{g}{C^2} \quad \ldots\ldots\ldots\ldots (9)$$

where

g = gravity force (L/T^2)

C = Chezy coefficient ($\frac{L^{1/2}}{T}$)

The coefficient k is dimensionless.

Takahashi also solved Equations 6 and 7 by considering the phenomenon in a system of coordinates moving with a velocity (U) with the result,

$$h_\infty = \frac{kU^2}{g\sin\Theta} \quad \ldots\ldots\ldots (10)$$

This same procedure for solution of particular cases of unsteady flow is suggested by Strelkoff (1969).

Johnson's Bingham Model

By starting from the Navier-Stokes equations and by supposing that the debris flow behaves like a Bingham substance, Johnson (1965, 1970) obtained a form of the Poisson equation that describes the fluid movement in channels, as follows:

$$\frac{\partial^2 \dot{w}}{\partial x^2} + \frac{\partial^2 \dot{w}}{\partial y^2} = \frac{1}{\eta_b}$$

$$[\, -\gamma \sin\delta + k\, (\sin\alpha \frac{\partial\alpha}{\partial x} + \cos\alpha \frac{\partial\alpha}{\partial y})\,]$$

$$\ldots\ldots\ldots\ldots\ldots (11)$$

where

$\dot{w}$ = velocity in the z direction (flow direction)

η_b = Bingham viscosity

γ = fluid unit weight

δ = slope angle of the surface of the fluid and also the slope angle of the channel

k = shear strength or the maximum magnitude of shear stress that a Bingham substance can withstand without flowing

α = angle for which the shear stress is a maximum or minimum

These quantities and the coordinate axes are defined in Figures 3a and 3b.

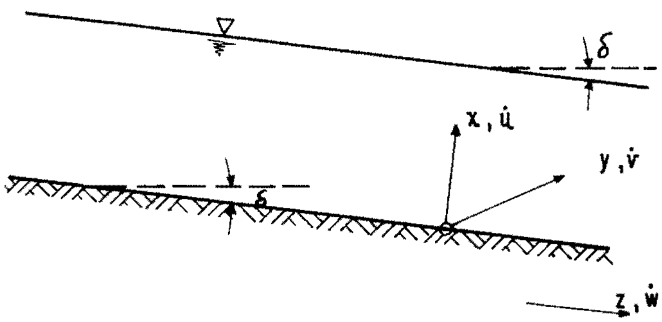


Figure 3a. Typical longitudinal section.

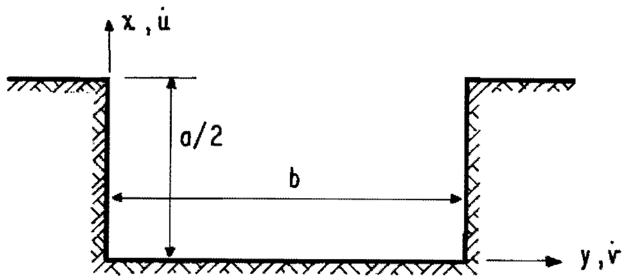


Figure 3b. Typical cross-section.

In order to solve Equation 11, Johnson defined a shear stress function, Γ, such that:

$$\sigma_{xy} = \frac{\partial \Gamma}{\partial x} + k\cos\alpha + \eta_b \frac{\partial \dot{w}}{\partial x} \quad . \ (12)$$

and

$$\sigma_{yz} = \frac{\partial \Gamma}{\partial y} - k\sin\alpha + \eta_b \frac{\partial \dot{w}}{\partial y} \quad . \ (13)$$

where σ_{xy} and σ_{yz} are shear stresses acting on faces xy and yz respectively. He concluded that the velocity distribution can be given by,

$$\dot{w} = \frac{1}{\eta_b} \{ (\frac{\gamma \sin\delta}{2} (y^2 - yb) - ky + \sum_{m=1}^{\infty} \sin (m\pi y/b) \cdot [A_m \cosh (m\pi a/2b) + B_m \sinh (m\pi a/2b)] \} \quad . \ . \ (14)$$

where

$$A_m = \frac{-2 \ \gamma \ \sin\delta b^2}{m^3 \ \pi^3} [\cos(m\pi) - 1] \quad . \ (15)$$

and

$$B_m = \frac{A_m [1 - \cosh (am\pi/b)]}{\sinh (am\pi/b)}$$

Babbit and Caldwell (1939), working with sludges in pipes in the laminar flow condition found that the sludges follow the "true plastic fluid" behavior and the velocity and viscosity of that fluid are given by:

$$V = \frac{4D}{\eta} \ (S_p - \frac{4}{3} S_y) \quad . \ . \ . \ . \ (16)$$

$$\mu = \frac{16 \ D \ S_y + \eta}{3V} \quad . \ . \ . \ . \ (17)$$

where

V = mean velocity of flow in a pipe (feet/second)

D = diameter of pipe (feet)

η = coefficient of rigidity (lbs - sec/ft^2)

S_p = shearing stress in a flowing material at the boundary or pipe wall (lbs/ft^2)

S_y = shearing stress at the yield point of a plastic material, called yield value (lbs/ft^2)

μ = coefficient of viscosity (lbs - sec/ft^2)

Summary

By applying Takahashi's model for his given volumetric debris flow rate and Manning's equation to an equal volumetric flow of water in the same cross-section and slope shows the depth of debris flow is four times greater than the depth of water flow. No comparison with the Johnson model was made due to the lack of data for his model. In summary, two models have been proposed to solve debris flow problems. One is the Bingham plastic model supported by American investigators. The other is the dilatant model supported by Takahashi in Japan. Both provide solutions only for steady state conditions and have been verified in the laboratory in small models. Furthermore, both solutions depend upon empirical coefficients that have to be determined for each specific application.

CHAPTER III

DIFFERENTIAL EQUATION DESCRIBING OPEN CHANNEL DEBRIS FLOW

Flow Regimes

For Newtonian, isotrophic and incompressible fluids like water, the Saint-Venant equations of motion and continuity, when combined with an equation defining friction losses, allow solution of unsteady open channel turbulent flows. Either the Chezy or the Manning equation may be used to estimate friction losses, but the latter is generally preferred in practice. If the flow is laminar, the Chezy equation is superior.

The kinds of debris flows of interest herein have Reynolds numbers up to 500. While quantitative data are not available for natural debris flows, description of them imply they "behave like a plastic or muddy substance," indicating that they are in the laminar range. The open channel flow equations and assumed laminar conditions will be the basis for the theory of debris flow that will be developed herein.

Applicability of Saint-Venant Equations to Laminar Flow in Open Channel

To the present time, researchers have only applied the Saint-Venant equation to flows in open channels for which the Reynolds number is large and consequently the viscous forces are not as important as gravity forces. Such examles are given by Cunge and Wegner (1964), Strelkoff (1969, 1970), Amein and Fang (1970), Yevjevich (1975a), and Jeppson (1974).

In open-channel flow, four kinds of regimes have been recognized by Rouse and Robertson (1941):

1. Tranquil-Laminar, Reynolds number < 500, Froude number < 1.

2. Rapid-Laminar, Reynolds number < 500, Froude number > 1.

3. Tranquil-Turbulent, Reynolds number > 500, Froude number < 1.

4. Rapid-Turbulent, Reynolds number > 500, Froude number > 1.

Rouse and Robertson (1941) state that laminar open channel flows can be found when rain water flows down a roof or sidewalk and also in hydraulic model testing and in the control of so-called sheet-flow erosion. We can add to this list the case of debris flow with high viscosity. Researchers who have applied the Saint-Venant equation to laminar flows include Chen (1975), Amisial (1969), Morgali (1970), Takahashi (1980).

From the original title of the Saint-Venant formulation, "theory of unsteady water flow, with application to river floods and to propagation of tides in river channels," Yevjevich (1975a) gives the impression that its applicability is more in the field of turbulent flow for relatively large Reynolds number rather than for laminar conditions. It is worthwhile to consider the commentaries of Yevjevich (1975a) in which he states that for an infinitely long wave, when the ratio of wave height h to the wave length L approaches zero, the flow is almost completely governed by channel friction. The equations of Saint-Venant can be used to describe the wave in this case.

The friction slope, S_f, in the Saint-Venant equations is expressed by the following in terms of the Chezy coefficient:

$$S_f = \frac{V^2}{C^2 R} \quad \cdots\cdots\cdots\cdots \quad (18)$$

The Chezy coefficient C is a function of Reynolds number Re for the laminar and the transition flow cases. Only in the fully rough zone, C is independent of Reynolds number. Possibly, when Saint-Venant derived his formulas, he was thinking only of turbulent flow. However, the equations describe laminar flow as well. Rouse and Robertson (1941) say that Saint-Venant derived the Navier-Stokes equations in 1843, which is two years ahead of Stokes (1845), and these formulas are valid for either laminar or turbulent flow. But in 1871, 28 years later, he derived the equation that describes the gradually varied unsteady flow. In conclusion, there is no evidence to prevent applying the Saint-Venant equations to open channel laminar flows.

Saint-Venant Equations

The two Saint-Venant equations are based on conservation of mass (continuity) and Newton's second law (motion), respectively. In presenting these equations the following notation will be used:

$q^* = \frac{dQ}{dx}$ (steady) is the lateral inflow rate (positive) in the direction of motion

Q, V, y are the dependent variables and x, t, the independent variables, so:

$Q = f(x,t)$

$V = f(x,t)$

$y = f(x,t)$

Applying mass conservation as shown in Figure 4,

$$[Q + q^* dx - (Q + \frac{\partial Q}{\partial x} dx)]\ dt = (\frac{\partial A}{\partial t} dt)\ dx$$

change in volume   change in area

$$[Q + q^* dx - Q - \frac{\partial Q}{\partial x} dx]\ dt = (\frac{\partial A}{\partial t} dt)\ dx$$

dividing through by dtdx, and rearranging the terms gives,

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q^* = 0 \quad \cdots\cdots \quad (19)$$

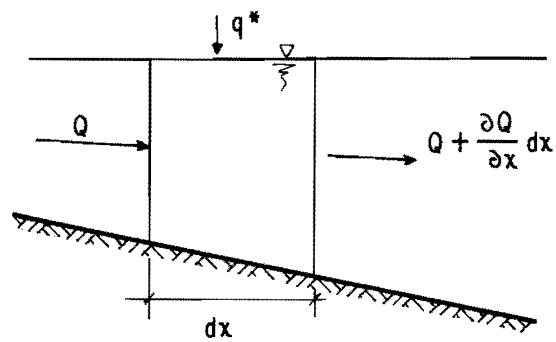


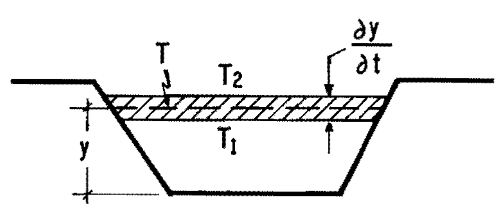
Figure 4. Definition sketch for the equation of continuity.

An alternative form of the continuity Equation 19 replaces Q by V. Since Q = VA; A = f(x,y,t); Equation 19 becomes,

$$\frac{\partial (VA)}{\partial x} + \frac{\partial A}{\partial t} - q^* = 0$$

or

$$V\frac{\partial A}{\partial x} + A\frac{\partial V}{\partial x} + \frac{\partial A}{\partial t} - q^* = 0 \quad . \quad (20)$$



The term $\partial A/\partial x$ can be expanded as follows:

$$\frac{\partial A}{\partial x} = \frac{\partial A}{\partial y} \left.\frac{\partial y}{\partial x}\right|_t + \left.\frac{\partial A}{\partial x}\right|_{y,t}$$

$$\frac{\partial A}{\partial t} = T\frac{\partial y}{\partial t} \text{ and } \frac{\partial A}{\partial y} = T;$$

so making replacement into Equation 20 gives,

$$A\frac{\partial V}{\partial x} + VT\frac{\partial y}{\partial x} + V\left.\frac{\partial A}{\partial x}\right|_{y,t} - q^* = -T\frac{\partial y}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots (21)$$

The continuity equation forms 19 and 21 are good for a channel with any cross-sectional shape, including lateral inflow or outflow.

These equations can be simplified for the case when the section is rectangular by noting that $Q = qB$. Taking $B = 1$, then $Q = q$, $A = Y$, $R \simeq y$, so Equation 19 becomes:

$$\frac{\partial q}{\partial x} + \frac{\partial y}{\partial t} - q^* = 0 \quad \ldots\ldots (22)$$

Now if we make the substitution in Equation 22, $q = Vy$; then:

$$V\frac{\partial y}{\partial x} + y\frac{\partial V}{\partial x} + \frac{\partial y}{\partial t} - q^* = 0 \ . \ (23)$$

Equation of Motion

Strelkoff (1969), gives a complete derivation of this equation and so does Jeppson (1980). Two alternate forms of this equation are used. The first considers the velocity and depth as the primary dependent variables. In this form, the equation of motion is

$$\frac{V}{g}\frac{\partial V}{\partial x} + \frac{\partial y}{\partial x} - S_o + S_f + F_q = -\frac{1}{g}\frac{\partial V}{\partial t} \quad \ldots\ldots\ldots\ldots\ldots (24)$$

In the previous equations, F_q accounts for the momentum flux per unit mass for lateral inflow or outflow. Values of F_q, are:

$F_q = 0$ (for bulk lateral outflow)

$F_q = \frac{Vq^*}{2gA}$ (for seepage outflow since outflow is from bottom with zero velocity)

$F_q = \frac{V-U_q}{gA}q^* + \frac{h_c}{A}\left.\frac{\partial A}{\partial x}\right|_{y,t}$ (for lateral inflow in which U_q is the velocity component of the inflow in the direction of the flow, and h_c is the depth from the water surface to the centroid of the area)

The second form considers the depth y and the flow rate Q, instead of velocity V, as the primary dependent variables. The result is,

$$\frac{2Q}{gA^2}\frac{\partial Q}{\partial x} + (1 - F_r^2)\frac{\partial y}{\partial x} - \frac{Q^2}{gA^3}\left.\frac{\partial A}{\partial x}\right|_{y,t} +$$

$$S_f - S_o + F_q - \frac{Qq^*}{gA^2} + \frac{1}{gA}\frac{\partial Q}{\partial t} = 0 \ . \ (25)$$

For the case of a rectangular section of unit width, the equation becomes:

$$\frac{2q}{gy^2}\frac{\partial q}{\partial x} + (1-F_r^2)\frac{\partial y}{\partial x} - \frac{q^2}{gy^3}\left.\frac{\partial y}{\partial x}\right|_{y,t}$$

$$+ S_f - S_o + F_q - \frac{Qq^*}{gy^2}$$

$$+ \frac{1}{gy}\frac{\partial Q}{\partial t} = 0$$

The term $\frac{q^2}{gy^3}\left.\frac{\partial y}{\partial x}\right|_{y,t}$ becomes zero because we evaluate $\frac{\partial y}{\partial x}$ holding y,t constant. Finally, the equation for rectangular channel becomes

$$\frac{2q}{gy^2}\frac{\partial q}{\partial x} + (1-F_r^2)\frac{\partial y}{\partial x} + S_f - S_o + F_q - \frac{Qq^*}{gy^2} + \frac{1}{gy}\frac{\partial Q}{\partial t} = 0 \quad . \; . \; (26)$$

The Saint-Venant equations (19 and 25) or (21 and 24) describe unsteady spatially varied flow in channels whose hydraulic and geometric properties vary with x, and these equations, with some modifications that will be introduced later, describe well the hydraulic characteristics of debris flow.

If the flow is steady, the continuity equation simplifies to an algebraic equation and the equation of motion to an ordinary differential equation since the derivatives with respect to t become equal to zero. Specifically Equation 19 becomes $dQ = q^*dx$. Integrating

$$\int_{Q_o}^{Q} dQ = \int_{o}^{x} q^* dx; \qquad Q\Big|_{Q_o}^{Q} = q^* x\Big|_{o}^{x}$$

therefore $Q - Q_o = q^* x$ so:

$$Q = Q_o + q^* x \quad . \; . \; . \; . \; . \; . \; . \; (27)$$

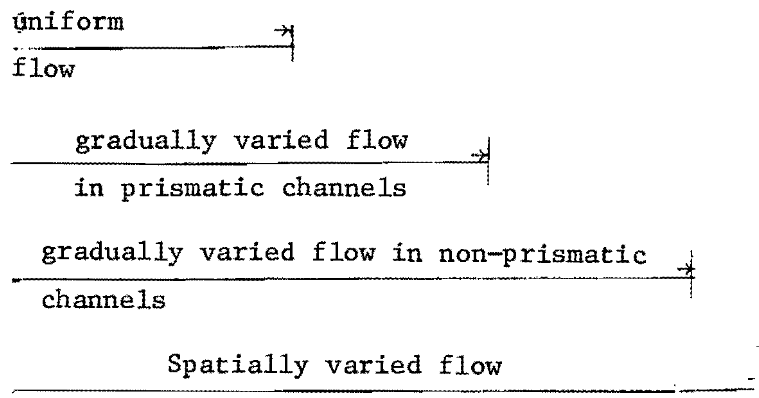
The equation of motion for steady state simplifies by noting that Q and y are now only functions of x. Consequently the partial derivatives become total derivatives, and Equation 25 reduces to:

$$\frac{dy}{dx} = \frac{S_o - S_f + \frac{Q^2}{gA^3}\left.\frac{\partial A}{\partial x}\right|_y - \frac{Qq^*}{gA^2} - F_q}{1 - F_r^2}$$

$$. \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (28)$$

In Equation 28 $F_r^2 = \frac{Q^2 T}{gA^3}$. Also, Equation 28 can be rearranged as:

$$S_f = S_o - (1-F_r^2)\frac{dy}{dx} + \frac{Q^2}{gA^3}\left.\frac{\partial A}{\partial x}\right|_y - \frac{Qq^*}{gA^2} - F_q \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; (29)$$



Friction Slope Approach for Deriving the Equation of Motion for Open Channel Debris Flow

We intend here to derive the equation of motion for open channel debris flow and then compare the result with the equation obtained by Takahashi (1980) Equation 7.

Using Figure 5, assume, 1) no lateral inflow or outflow, and 2) the pressure distribution along OP is hydrostatic. (The latter equates the cosine of the angle of the channel slope to unity.[1])

[1]Since debris flows often begin on relatively steep slopes, the validity of assumption 2 might be questioned. In consideration of the uncertainty of other flow parameters, as well as the desire to arrive at a simple practical means for solving debris flow, the authors justify this assumption.

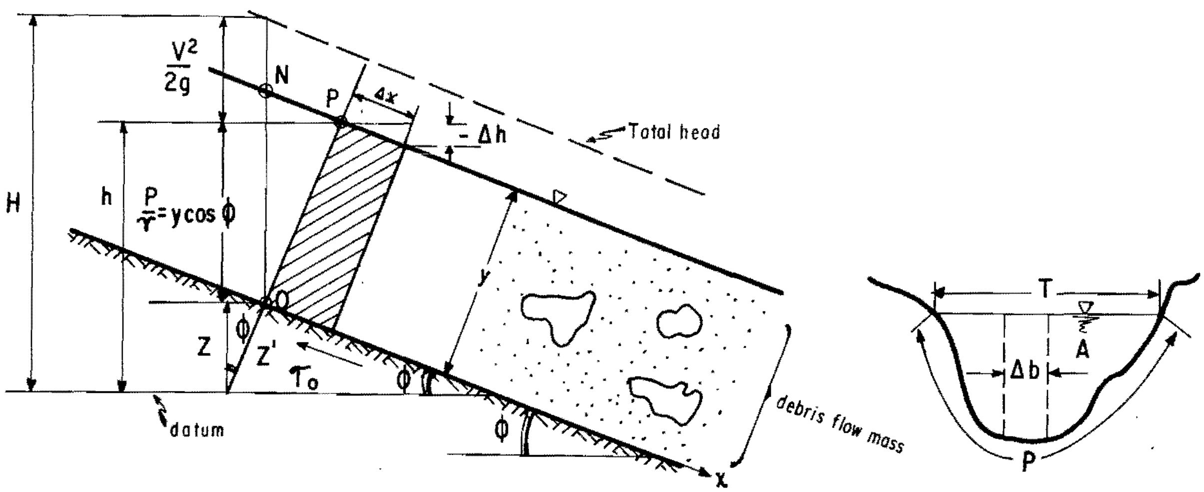


Figure 5. Definition sketch for the equation of motion.

$$S_o = -\frac{dz}{dx} = -\tan\phi = \text{bed slope and}$$

$$S_f = -\frac{dH}{dx} = \text{energy slope.}$$

The slopes have been defined as positive when the surfaces are dropping in the downstream direction. From Figure 5, note that

$-\gamma A\Delta h - \tau_o P\Delta x$ = net force acting in the flow direction, and

$$H = h + \frac{V^2}{2g} \quad \text{therefore}$$

$$\frac{\partial H}{\partial x} = \frac{\partial h}{\partial x} + \frac{V}{g}\frac{\partial V}{\partial x} \quad \ldots\ldots (30)$$

and

$$h = z + y\cos\phi \quad \text{therefore}$$

$$\frac{\partial H}{\partial x} = \frac{\partial}{\partial x}(z + y\cos\phi) + \frac{V}{g}\frac{\partial V}{\partial x}$$

or

$$\frac{\partial H}{\partial x} = \frac{\partial z}{\partial x} + \cos\phi\frac{\partial y}{\partial x} + \frac{V}{g}\frac{\partial V}{\partial x} \quad \text{since}$$

$z = z'\cos\phi$ therefore $\frac{\partial z}{\partial x} = \frac{\partial z'}{\partial x}\cos\phi = -\tan\phi\cos\phi = \sin\phi$

or

$$\frac{\partial H}{\partial x} = -\sin\phi + \cos\phi\frac{\partial y}{\partial x} + \frac{V}{g}\frac{\partial V}{\partial x} \quad . \ (31)$$

since

$$a_x = \frac{dV}{dt} = V\frac{\partial V}{\partial x} + \frac{\partial V}{\partial t}$$

= total acceleration on the x - direction

Applying Newton's second law,

$$-\gamma A\Delta h - \tau_o P\Delta x = \rho A\Delta x \left(V\frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} \right)$$

Rearranging with $R = \frac{A}{P}$ gives,

$$\tau_o = -\gamma R\left[\frac{\partial h}{\partial x} + \frac{V}{g}\frac{\partial V}{\partial x} + \frac{1}{g}\frac{\partial V}{\partial t} \right] \quad . \ (32)$$

Substituting Equation 30 into Equation 32 results in,

$$\frac{\tau_o}{\gamma R} = -\left(\frac{\partial H}{\partial x} + \frac{1}{g}\frac{\partial V}{\partial t} \right)$$

It is well known that: $S_f = \frac{\tau_o}{\gamma R} = \frac{V^2}{C^2 R}$,

so:

$$-\frac{V^2}{C^2V} = \frac{\partial H}{\partial x} + \frac{1}{g}\frac{\partial V}{\partial t}; \text{ therefore}$$

$$\frac{\partial H}{\partial x} + \frac{1}{g}\frac{\partial V}{\partial t} + \frac{V^2}{C^2R} = 0 \quad \cdots \quad (33)$$

and this equation may be rewritten:

$$S_e + S_a + S_f = 0 \quad \cdots\cdots \quad (34)$$

by naming the three terms of Equation 33, the energy slope, the acceleration slope, and the friction slope respectively. From Equation 33, we get:

$$\frac{\partial H}{\partial x} = -\frac{V^2}{C^2R} - \frac{1}{g}\frac{\partial V}{\partial t} \quad \cdots \quad (35)$$

Now equating Equations 31 and 35 gives:

$$-\frac{V^2}{C^2R} - \frac{1}{g}\frac{\partial V}{\partial t}$$

$$= -\sin\phi + \cos\phi \frac{\partial y}{\partial x} + \frac{V}{g}\frac{\partial V}{\partial x}$$

or rearranging

$$\frac{1}{g}\frac{\partial V}{\partial t} + \frac{V}{g}\frac{\partial V}{\partial x} = \sin\phi - \cos\phi \frac{\partial y}{\partial x} - \frac{V^2}{C^2R}$$

$$\cdots\cdots\cdots\cdots\cdots \quad (36)$$

For small bed angle $\sin\phi \simeq \tan\phi \simeq S_o$ and $\cos\phi \simeq 1$ and Equation 36 becomes

$$\frac{1}{g}\frac{\partial V}{\partial t} + \frac{V}{g}\frac{\partial V}{\partial x} = S_o - \frac{\partial y}{\partial x} - \frac{V^2}{C^2R} \quad \cdots \quad (37)$$

If we rearrange the previous equation and replace $\frac{V^2}{C^2R} = S_f$, we get:

$$\frac{V}{g}\frac{\partial V}{\partial x} + \frac{\partial y}{\partial x} - S_o + S_f = -\frac{1}{g}\frac{\partial V}{\partial t} \quad . \quad (38)$$

This equation is the same as Equation 24 obtained by Strelkoff except that the term F_q that accounts for the momentum flux per unit mass for lateral inflow or outflow is not included.

It is very interesting to compare Equation 36 with that obtained by Takahashi (1980) for the debris flow motion. For this purpose multiply Equation 36 by the gravity term (g),

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} = g\sin\phi - g\cos\phi \frac{\partial y}{\partial x} - \frac{g}{C^2}\frac{V^2}{R}$$

$$\cdots\cdots\cdots\cdots\cdots \quad (39)$$

Then simplifying for a very wide rectangular section (R = y) gives

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} = g\sin\phi - g\cos\phi \frac{\partial y}{\partial x} - \frac{g}{C^2}\frac{V^2}{y}$$

Finally we get the Takahashi formula 7 if $\frac{g}{C^2} = k$

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} = g\sin\phi - g\cos\phi \frac{\partial y}{\partial x} - k\frac{V^2}{y}$$

The only difference is the notation V in place of U for velocity and ϕ in place of Θ for the slope angle.

Some conclusions that can be deduced from the formulas derived above are:

1. The Saint-Venant equations of continuity and motion can be applied to describe the open channel debris flow if the Chezy coefficient C is properly defined.

2. The Takahashi resistance coefficient (k) is the same as g/C^2 with no dimension where (C) is the Chezy coefficient which is a function of Reynolds number, boundary roughness, and possibly also the shape of the cross section.

3. It is not known at this point how Chezy's coefficient behaves for debris flow.

Type Classification of the Saint-Venant Equation

The methods used to solve partial differential equations depend directly upon whether the equations are parabolic, elliptic, or hyperbolic. For determining the type of Saint-Venant equations, Equations 39 and 23 are rewritten below using a subscript to denote partial derivatives.

$$VV_x + V_t + g\cos\phi\ y_x = g\sin\phi - \frac{g}{C^2}\frac{V^2}{R} \quad \ldots\ldots\ldots\ldots\ldots (40)$$

$$yV_x + Vy_x + y_t = q^* \quad \ldots\ldots (41)$$

For any pair first order partial differential equations of the form

$$a_1 f_x + b_1 f_y + c_1 g_x + d_1 g_y = e_1 \,. \quad (42)$$

$$a_2 f_x + b_2 f_y + c_2 g_x + d_2 g_y = e_2 \,. \quad (43)$$

where a_1, b_1, c_1, d_1, e_1, a_2, b_2, c_2, d_2, e_2 may be functions of x,y,f and g, the discriminant $(a_1d_2 - a_2d_1 + b_1c_2 - b_2c_1)^2 - 4(a_1c_2-a_2c_1)(b_1d_2-b_2d_1)$ allows us to classify what type of equations they are as follows:

Sign of discriminant	Type of equation
Positive	hyperbolic equations
Zero	parabolic equations
Negative	elliptic equations

For Equations 40 and 41,

$$a_1 = V;\ b_1 = 1;\ c_1 = g\cos\phi;$$

$$d_1 = 0;\ e_1 = g\sin\phi - \frac{g}{C^2}\frac{V^2}{R}$$

$$a_2 = y;\ b_2 = 0;\ c_2 = V;$$

$$d_2 = 1;\ e_2 = q^*$$

and therefore the discriminant becomes

$$(a_1d_2 - a_2d_1 + b_1c_2 - b_2c_1)^2$$

$$- 4(a_1c_2 - a_2c_1)(b_1d_2 - b_2d_1) =$$

$$(V \times 1 - y \times 0 + 1 \times V - 0 \times g\cos\phi)^2$$

$$- 4(V \times V - y \times g\cos\phi).$$

$$(1 \times 1 - 0 \times 0) = (V + V)^2$$

$$- 4(V^2 - y\ g\cos\phi) \times 1$$

$$= 4V^2 - 4(V^2 - y\ g\cos\phi)$$

For ϕ small, $\cos\phi \simeq 1$ and the discriminant $= 4\ V^2 - 4\ V^2 + 4\ yg$; so $4yg > 0$. This positive value indicates the Saint-Venant equations are of the hyperbolic type. Other forms of the Saint-Venant equations have been classified by many researchers and their conclusions are that the equations are of the hyperbolic type.

CHAPTER IV

MODEL FORMULATION

Background

Previous chapters justified application of the Saint-Venant equations to debris flows. The well known Chezy equation will be used to calculate the friction slope, S_f, in these equations.

While debris flows in nature are known to almost always be laminar, available data in the literature for quantifying depth and velocity is very limited. The few data available are given by Sharp and Nobles (1953), Pierson (1981), Babbit and Caldwell (1939), and Takahashi (1980). Those data from Sharp and Nobles seem most reasonable. We assume that the Chezy theory when modified slightly applies for open channel debris flow in the laminar regime. In order to justify this hypothesis, the available data will be fit by the Chezy equation below.

The Chezy Equation

The Chezy equation is:

$$V = C \sqrt{RS} \quad . . . . (44)$$

in which

V = average velocity in flow direction

R = hydraulic radius

S = bed slope, if we deal with steady nonuniform flow, then S is the friction slope (S_f)

C = Chezy coefficient with dimensions of $L^{1/2}/T$

It is well known that Darcy's equation for pipe flow is equivalent to a special case of the Chezy equation, provided that:

$$C = \sqrt{8g/f} \quad . . . . (45)$$

in which

g = acceleration of gravity

f = friction factor

and for laminar flow in pipes,

$$f = \frac{64}{R_e} \quad . . . . (46)$$

in which

R_e = Reynolds number

Combining Equations 45 and 46, gives:

$$C = \sqrt{(g/8)\, R_e}^{\,1/2} \quad . . . . . . (47)$$

For SI units with g = 9.81 m/sec^2

$$C = 1.107\ R_e^{1/2} \quad . . . . (48)$$

and for ES units with

$$g = 32.2\ ft/sec^2;\ C = 2.006\ R_e^{1/2}\ .\ (49)$$

Relationship Between Takahashi Resistance Coefficient (k) and Chezy Coefficient (C)

In Chapters II and III, we found the resistance coefficient k can be written as $k = \frac{g}{C^2}$

Combining with Equation 8, and rearranging gives

$$C = \frac{2}{5}\frac{h_\infty}{d}\sqrt{\frac{g[C_d + (1-C_d)\frac{\rho}{\sigma}]\,[(\frac{C_*}{C_d})^{1/3}-1]^2}{a_i \sin\alpha}} \quad \ldots\ldots\ldots\ldots\ldots (50)$$

where

$$C_d = \frac{\rho_m \tan\Theta}{(\sigma - \rho_m)(\tan\alpha - \tan\Theta)}$$

provided its value is less than C_*, the grain concentration in the stationary bed. Otherwise

$$C_d = 0.9\, C_* \quad \ldots\ldots\ldots (51)$$

in which

ρ_m = density of the debris flow mixture

Θ = bottom slope angle of debris flow as defined earlier

Takahashi (1980) gives the velocity distribution for two-dimensional debris flow in the fully inertial range as:

$$u = \frac{2}{3d}\left\{\frac{g\sin\Theta}{a_i \sin\alpha}[C_d + (1-C_d)\frac{\rho_m}{\sigma}]\right\}^{1/2} [(\frac{C_*}{C_d})^{1/3}-1]\,[h^{3/2} - (h-y)^{3/2}] \quad \ldots\ldots\ldots\ldots\ldots (52)$$

in which

u = velocity in x direction

h = depth of debris flow

y = distance perpendicular to the bed

At the surface, where y = h, Equation 52 becomes:

$$u = \frac{2}{3d}\left\{\frac{g \sin}{a_i \sin}[C_d + (1-C_d)\frac{\rho_m}{\sigma}]\right\}^{1/2} [(\frac{C_*}{C_d})^{1/3} - 1]\,.\,h^{3/2} \quad \ldots\ldots\ldots (53)$$

Steady Laminar Flow of Viscous Liquid with a Free Surface

Since debris flows are assumed to obey laws for laminar flow, it is well to review some of these principles and the associated equations. We start with a simplified form of the Navier-Stokes equations. Assume: 1) the fluid is isotrophic and Newtonian, 2) the fluid is incompressible (ρ = density = constant), 3) viscosity is constant (this condition is more nearly satisfied in gases than in liquids), 4) the flow is only in the x-direction, constant depth and steady, then

$$\frac{Du}{Dt} = -\frac{1}{\rho}\frac{\partial}{\partial x}(p + \gamma h') + \nu\nabla^2 u \quad . (54)$$

or expanding

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} =$$

$$-\frac{1}{\rho}\left(\frac{\partial p}{\partial x} + \gamma\frac{\partial h'}{\partial x} + h\frac{\partial \gamma}{\partial x}\right) + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right)$$

However, based on the above assumptions and Figure 6,

$$0 = -\frac{1}{\rho}\ \gamma\frac{\partial h'}{\partial x} + \nu\frac{\partial^2 u}{\partial y^2}$$

Therefore,

$$\gamma\frac{\partial h'}{\partial x} = \rho\nu\frac{\partial^2 u}{\partial y^2} = \mu\frac{\partial^2 u}{\partial y^2}$$

but $\frac{\partial h'}{\partial x} = -\sin\Theta$, making the previous equation:

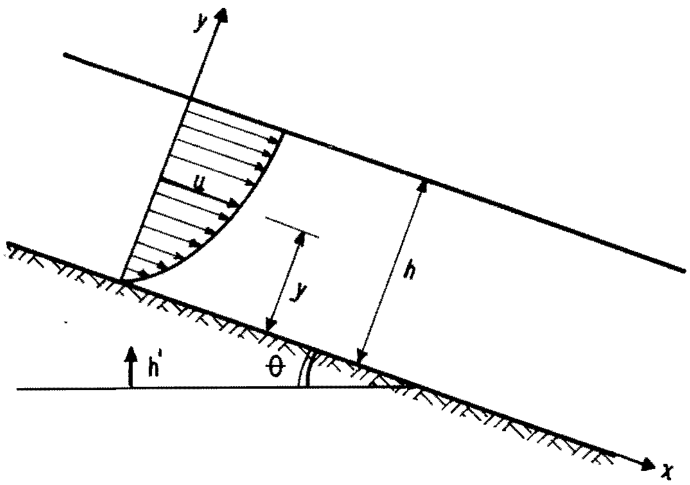


Figure 6. Definition sketch for laminar fluid flow on an inclinal surface.

$$-\gamma \sin\Theta = \mu \frac{\partial^2 u}{\partial y^2}$$

By integration,

$$\frac{\partial u}{\partial y} = -\frac{\gamma}{\mu} \sin\Theta \; y + C_1$$

and

$$u = -\frac{\gamma}{2\mu} \sin\Theta \; y^2 + C_1 y + C_2$$

Applying the first boundary condition: $y = h$, $\frac{\partial u}{\partial y} = 0$ gives

$$C_1 = \frac{\gamma}{\mu} \sin\Theta \; h$$

and then

$$u = -\frac{\gamma}{2\mu} \sin\Theta \; y^2 + \frac{\gamma}{\mu} \sin\Theta \; h \; y + C_2$$

Now applying the second boundary conditions, $y = 0$, $u = 0$, (this conditions means no slip) gives $C_2 = 0$; so:

$$u = \frac{\gamma}{\mu} y(h - \frac{y}{2}) \sin\Theta \; . \; . \; . \; . \; (55)$$

If y = h we get the velocity at the surface.

$$u_s = \frac{\gamma}{2\mu} h^2 \sin\Theta \; . \; . \; . \; . \; . \; (56)$$

The rate of flow per unit width is obtained by integrating the velocity over the area or,

$$Q = \int_0^A u dA = \int_0^A uB dy = B \int_0^A u dy$$

or

$$q = \frac{Q}{B} = \int_0^A u dy$$

or

$$q = \int_0^h u dy = \int_0^h \left[\frac{\gamma}{\mu} y \; (h - \frac{y}{2}) \sin\Theta\right] dy$$

or

$$q = \frac{\gamma}{\mu} \sin\Theta \left[\frac{h}{2} y^2 - \frac{y^3}{6}\right]_0^h = \frac{\gamma}{\mu} \sin\Theta \left(\frac{h^3}{2} - \frac{h^3}{6}\right)$$

$$q = \frac{1}{3} \frac{\gamma h^3}{\mu} \sin\Theta \; . \; . \; . \; . \; . \; . \; . \; (57)$$

The average velocity and the depth below the free surface at which the point velocity is equal to the average velocity of the flow are obtained as follows:

$$A \; V = \int_A u dA$$

$$h \; V = \int_0^h u dy = \frac{1}{3} \frac{\gamma h^3}{\mu} \sin\Theta$$

therefore

$$V = \frac{1}{3} \frac{\gamma h^2}{\mu} \sin\Theta \; . \; . \; . \; . \; . \; (58)$$

Now equating the average velocity to the point velocity, gives:

$$\frac{1}{3}\ \frac{\gamma h^2}{\mu}\ \sin\Theta = \frac{\gamma}{\mu}\ y\ (h - \frac{y}{2})\ \sin\Theta$$

Therefore, when y = 0.42 h or the depth below the surface = h - 0.42, h = 0.58 h, the point velocity equals the average velocity.

The Reynolds number represents the ratio of inertia to viscous forces acting within the fluid. The Reynolds number is:

$$R_e = \frac{V(A/P)}{\nu} \quad . . . . (59)$$

in which

P is the wetted perimeter, and

ν is the kinematic viscosity of the fluid.

Another expression for Equation 59, is the following

$$R_e = \frac{V(A/P)\ \rho}{\mu} \quad . . . . (60)$$

in which

ρ = fluid density

μ = fluid viscosity

If the channel is wide the term A/P can be replaced by the fluid depth. For debris flows R_e is almost always less than 500, indicating the flow is laminar.

The Froude number is the ratio of inertial to gravity forces acting on the fluid.

$$F_r = \frac{V}{\sqrt{gA/T}} = \sqrt{\frac{Q^2 T}{gA^3}} \quad . . . (61)$$

Evaluation of Chezy Coefficient

The best data available in the literature for debris flows is from Sharp and Nobles (1953). The following values are reported by them:

density = 2.4 gr/cm^3

flow depth = 76.2 cms

average velocity = 120 to 300 cm/sec

bed slope = 6 degrees, therefore S_o = 0.105

viscosity = 2 to 6 x 10^3 poise = 2 to 6 x 10^2 Newton• sec/m^2

Substituting this data into Equation 44 gives

$$C = \frac{1.20}{\sqrt{0.762 \times 0.105}} = 4.24$$

Using Equation 60,

$$R_e = \frac{1.20 \times 0.762 \times 2.4 \times 10^3}{2 \times 10^2} = 10.97$$

and from Equation 48,

$$C = 1.107\ (10.97)^{1/2} = 3.67$$

The following data for debris flow are taken from Pierson (1981),

Reynolds number = 500 ; velocity = 5 m/sec

Froude number = 2.3 ; density = 2.08 gr/cm^3

bed slope = 5 degrees, therefore S_o = 0.088

Applying Equation 61,

$$2.3 = \frac{5}{\sqrt{9.81\ n\ y}}$$

therefore, y = 0.4817 m,

and from Equation 44,

$$C = \frac{5}{\sqrt{0.4817 \times 0.088}} = 24.35$$

From Equation 48,

$$C = 1.107\ (500)^{1/2} = 24.75$$

and Equation 60 gives

$$\mu = \frac{5 \times 0.4817 \times 2.08 \times 10^3}{500}$$

$= 10\ N \cdot s/m^2 = 10^2$ poise.

From Takahashi (1980) Figure 3, we get the following information: For debris flow depth, h = 8 cm, velocity at surface u_s = 100 cm/sec. For debris flow depth, h = 7 cm, velocity at surface u_s = 105 cm/sec. Particles diameter, d = 5 mm, almost uniform.

a_i = 0.5, run 1, a_i = 0.35, run 2.

Slope bed, Θ = 18 degrees, tan 18° = 0.32492, sin 18° = 0.3090.

Tan α = 0.6, therefore α = 30.96°; sin 30.96° = 0.5144

Grain density, σ = 2.65 gr/cm^3

Slurry density, ρ_m = 1 gr/cm^3 (because the material contains essentially no clay component)

Grain concentration, C_* = 0.7

Substituting the above values into Equation 53 and solving for the grain concentration by volume in debris flow, C_d, gives the following values of C_d.

For: h = 0.08 m, u = 1.0 m/sec, a_i = 0.50 we get: C_d = 0.494.

For: h = 0.07 m, u = 1.05 m/sec, a_i = 0.35 we get: C_d = 0.483.

Now applying Equation 50, in order to obtain the Chezy coefficient for the two previous cases:

$$C = \frac{0.4 \times 0.08}{0.005} \left[\left(\frac{0.7}{0.494}\right)^{1/3} - 1\right]$$

$$\sqrt{\frac{9.81\ [0.494 + (1-0.494)\ \frac{1.00}{2.65}\ ]}{0.5 \times 0.5144}} = 4.03$$

$$C = \frac{0.4 \times 0.07}{0.005} \left[\left(\frac{0.7}{0.483}\right)^{1/3} - 1\right]$$

$$\sqrt{\frac{9.81\ [0.483 + (1-0.493)\ \frac{1.00}{2.65}]}{0.35 \times 0.5144}} = 4.48$$

We can also obtain the Chezy coefficient from Equation 44, as follows:

First set of data:

$$R = \frac{A}{P} = \frac{8 \times 20}{20 + 16} = 4.44 \text{ cms} = 0.044 \text{ m}$$

by Equation 44,

$$C = \frac{1.00}{\sqrt{0.044 \times 0.32492}} = 8.36$$

Second set of data:

$$R = \frac{A}{P} = \frac{7 \times 20}{20 + 14} = 4.1176 \text{ cms} = 0.041176 \text{ m}$$

by Equation 44,

$$C = \frac{1.05}{\sqrt{0.041176 \times 0.32402}} = 9.08$$

There are many uncertainties involved in estimating the terms a_i and tan α. Bagnold (1954) found values of a_i = 0.042 and tan α = 0.32 for the inertia range, and tan α = 0.75 for the viscous region without having found value of

a_i for the viscous region. Takahashi (1978), assumed $a_i = 0.042$ for $C_d \leq 0.81\ C_*$ and:

$$a_i = \{ \frac{1}{[(C_*/C_d)^{1/3}-1]} - 14 \} \times 0.066$$

$$+ 0.042 \text{ for } C_d \geq 0.81\ C_*$$

Takahashi (1980), in order to explain the velocities measured in the laboratory, adopted values of $a_i = 0.5$ and $a_i = 0.35$ without giving an explanation. He concluded that "to determine the exact value of a_i and α, however, stricter experiments are necessary." At this point in time it is very complicated to measure parameters like C_* and C_d; therefore, a simpler alternative for estimating k is needed.

Suppose smaller values of a_i are accepted as more correct in light of Bagnold's work, the fact that $a_i = 0.042$ for the inertia range, and the other evidence just given, such as $a_i = 0.1$ instead of Takahashi (1980) $a_i = 0.5$ and $a_i = 0.07$ instead of $a_i = 0.35$. Then the computed value of Chezy coefficients from Takahashi (1980) data become 9.0 and 10.0 instead of 4.03 and 4.48 as given above. In order to estimate the Chezy C from the Reynolds number using Equations 48, 56, and 60, the bulk density and viscosity are needed. Takahashi (1978, 1980) didn't give these values. For bulk density, ρ_m, Pierson (1981) gives 1.73 and 2.08 gr/cm^3, Sharp and Nobles give 2.4 gr/cm^3 respectively. An assumed bulk density equal to 2.0 gr/cm^3 seems reasonable. Taking Takahashi (1980) first set of data ($\theta = 18°$, $u = 100$ cm/sec, $h = 8$ cm) and substituting into Equation 56 gives,

$$\mu = \frac{2 \times 10^3 \times 0.3090 \times (0.08)^2 \times 9.81}{2 \times 1.0} =$$

$$19.4 \text{ N.s/m}^2 = 194 \text{ poise.}$$

and Equation 60 gives

$$R_e = \frac{1.0 \times 0.08 \times 2 \times 10^3}{19.4} = 8.25$$

and Equation 48 gives

$$C = 1.107\ (8.25)^{1/2} = 3.18$$

Based on Takahashi (1980) second set of data, Equation 56 gives

$$\mu = \frac{2 \times 10^3 \times 0.309017 \times (0.07)^2 \times 9.81}{2 \times 1.05} =$$

$$14.15 \text{ N.s/m}^2 = 141.5 \text{ poise.}$$

and Equation 60 gives

$$R_e = \frac{1.05 \times 0.07 \times 2 \times 10^3}{14.15} = 10.39$$

and finally Equation 48 gives,

$$C = 1.107\ (10.39)^{1/2} = 3.57.$$

Table 2 summarizes the Chezy coefficients obtained.

Babbit and Caldwell

Babbit and Caldwell (1939) obtained data from sludge flows in pipes and showed that sludges exhibit some characteristics, such as yield shearing stress and coefficient of rigidity that are very similar to some debris flows. Table 3 contains a summary of Chezy coefficient computed using Equations 12, 48, and 60, as well as other important parameters obtained from Babbit and Caldwell's sludge flow data.

Least Square Fit to Obtain the Best Relationship for the Chezy Coefficients C

The Chezy coefficients from Tables 2 and 3 are plotted against the Reynolds numbers on log-log paper in Figure 7.

Table 2. Chezy coefficient calculated from Sharp, Pierson and Takahashi data (open channel debris flow).

Set of data came from	Chezy Coefficient C: $C = \frac{V}{\sqrt{RS}}$	Chezy Coefficient C: $C=1.107\ R_e^{1/2}$	Chezy Coefficient C: C from Equation 50	Rey. No. R_e	Ave. Val. V (m/s)	Slope of Bot. S degrees	Visc. μ (poise)	Hyd. Radius R (m)
Sharp and Nobles (1953)	4.24	3.65	-	10.97	1.20	6	2000	0.762
Pierson (1981)	24.35	24.75	-	500	5.00	5	100	0.4817
Takahashi (1980)	8.36	3.18 to 9.96	4.03 to 9.00[1]	8.25 to 80.93[2]	1.00	18	194	0.044
Takahashi (1980	9.08	3.57 to 11.18	4.48 to 10.00[1]	10.39 to 102.08[2]	1.05	18	141	0.041

1. Value resulting from a slight modification of a_i coefficients.

2. Values assumed by comparison with the data given by Babbit.

Table 3. Chezy coefficients computed from Babbit and Caldwell data (pipe sludge flow).

Sludge type	Specific gravity	S_y lbs/ft^2	Velocity (ft/sec)	Pipe diameter (inches)	η lb-sec/ft^2	μ lbs-sec/ft^2	R_e	C
Illinois yellow clay	1.49	0.72	16.5[1]	1	0.028	0.047	84.56	10.17
#3 Indianapolis Ind.digested	1.032	0.405	27.00[1]	3/8	0.032	0.0345	48.96	7.75
Exp.Sta.Plant Primary	0.991	0.090	21.00[1]	3/8	0.019	0.01971	64.01	8.86
Illinois yellow clay	1.49	0.72	1.20	1	0.028	0.255	1.228	1.226
Exp.Sta.Plant Primary	0.991	0.090	1.80	3/8	0.019	0.02689	4.24	2.28
#4 Indianapolis Ind.digested	1.023	0.243	5.00	3/8	0.029	0.0371	8.36	3.20
#8 Springfield Ill.digested	1.026	0.315	13.00	3/8	0.030	0.034	23.78	5.40
#8 Springfield Ill.digested	1.026	0.315	20.00	3/8	0.030	0.0326	38.16	6.83
#6 Decatur,Ill digested	1.068	0.581	3.90	3/8	0.040	0.0648	61.11	8.65
Illinois yellow clay	1.49	0.72	2.30	1	0.028	0.167	3.317	2.02
Illinois yellow clay	1.49	0.72	3.50	1	0.028	0.1194	7.06	2.94
#20 Decatur,Ill Sewage,Imhoff	1.06	0.115	6.5[1]	3	0.0163	0.03988	83.77	10.13

1. This refers to the critical velocity, other velocities were obtained from Figure 1, Babbit (1939).

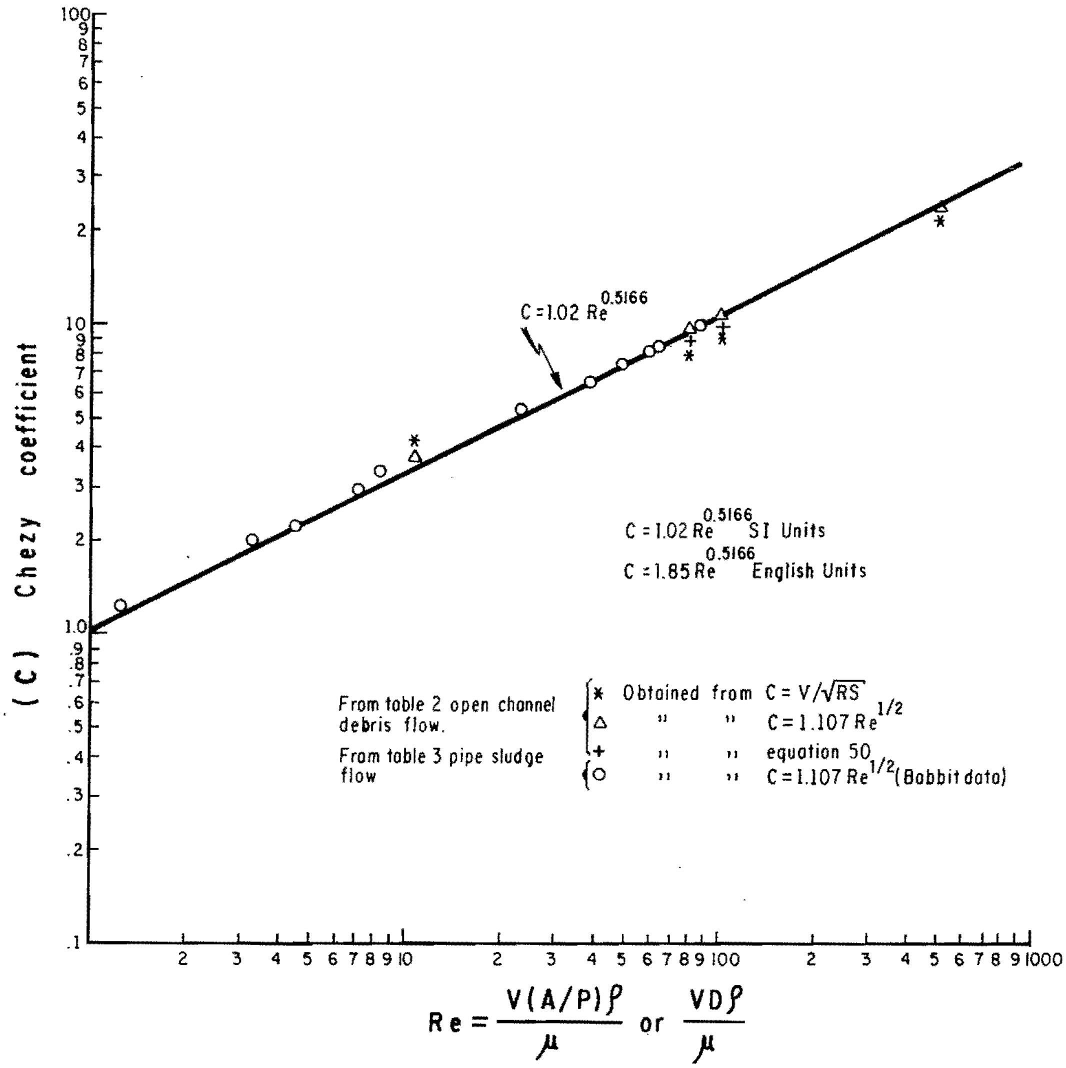


Figure 7. Chezy coefficients vs. Reynold's number.

Fitting a line through these data by the least square method gives the following results for SI units using Figure 7.

$$C = 1.02\ R_e^{0.52} \quad .\ .\ .\ .\ (62)$$

In English units this relationship is,

$$C = 1.85\ R_e^{0.52} \quad .\ .\ .\ .\ (63)$$

<u>Friction Factor f</u>

Having found the relationships between the Chezy coefficient and Reynolds number for debris flow, the friction factor can be solved by equating Equations 45 and 62, obtaining:

$$f = \frac{75.43}{R_e^{1.03}} \quad .\ .\ .\ .\ .\ .\ .\ .\ .\ (64)$$

The results are shown in Table 4 and Figure 8.

Table 4. Some friction factors and Chezy coefficients calculations, selected from Tables 2 and 3.

R_e	$f = \frac{75.43}{R_e^{1.0332}}$	$C = 1.02\ R_e^{0.52}$ (SI)	$C = 1.85\ R_e^{0.52}$ (ES)
10.97	6.35	3.52	6.37
500	0.123	25.29	45.82
80.93	0.805	9.87	17.88
102.08	0.634	11.13	20.16
84.56	0.769	10.10	18.29
48.96	1.354	7.61	13.79
64.01	1.026	8.74	15.84
1.228	61.008	1.13	2.06
4.24	16.957	2.15	3.90
8.36	8.408	3.06	5.54
23.78	2.855	5.24	9.50
38.16	1.751	6.69	12.13
61.11	1.077	8.54	15.47
3.317	21.850	1.90	3.43
7.06	10.013	2.80	5.07
83.77	0.771	9.99	18.10

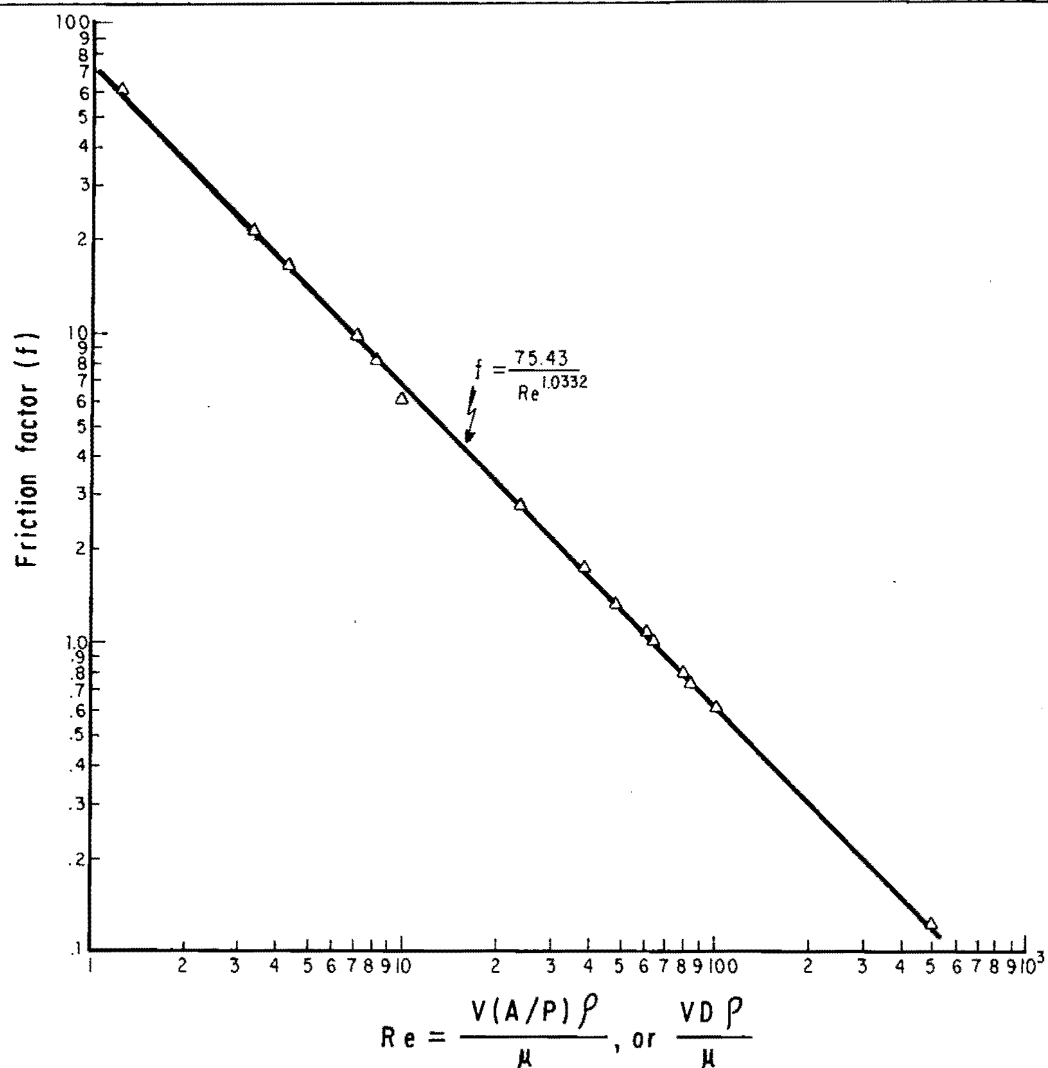


Figure 8. Friction factor vs. Reynold's number.

Relationship Between the Fluid Density (ρ) and Its Viscosity (μ)

The relationship between the density and viscosity of the debris flow is important because it determines the Reynolds number and consequently the flow properties. We hypothesize that both vary as a function of such flow characteristics as depth and velocity. The density depends on how much material is picked up and how much is deposited by the flow. The viscosity varies with the relationship between the shear stress and the shear strain and particularly with the time and spatial patterns of particle collisions. For uniform flow of a Newtonian fluid with a free surface down an inclined plane, the fluid velocity is a direct function of ρ/μ, the square of the fluid depth, and the plane slope. For debris flow under the same circumstances, the ratio ρ/μ is not constant. At present, no solution for how ρ/μ varies has been verified or proposed. Two possibilities look attractive for deriving this needed relationship. One is through experimentation, and the other is through derivation of an empirical equation from the limited available data.

We propose for debris flows, in the laminar range, the following equation:

$$\rho/\mu \frac{1}{\nu} = \frac{k}{R^a} \quad \text{. . . . . (65)}$$

in which

ρ = debris flow bulk density

μ = fluid viscosity

ν = kinematic viscosity

k = constant

R = hydraulic radius

a = an exponent greater than zero. If the value of a is taken as 1, Equation 65 becomes

$$\rho/\mu = \frac{k}{R} \quad \text{. . . . . (66)}$$

and ρ/μ varies linearly and inversely with the hydraulic radius.

The following are rationalizations assuming ρ/μ varies only with the hydraulic radius R.

1. The wetted perimeter (the surface along which the boundary shear occurs) plays an important role in determining how the particles in a debris flow arrange themselves. The hydraulic radius is the ratio of the area of the flow to the wetted perimeter or R = A/P.

2. For a given flowrate, when the hydraulic radius increases, ρ/μ decreases. If ρ remains constant, then μ must increase. Evidence for these relationships is found in the description of debris flow. For example debris flow typically have a larger depth at the wave front than at upstream position, and have been observed to suddenly stop without water leaving the mixture. Based on the available data, there is little justification to assume a nonlinear relationship.

Thus accepting Equation 66 only the constant k needs evaluation from available data. For open channel debris flow, the Sharp and Nobles (1953) data were taken as the most dependable. A computer program, described more in Chapter V, was run several times changing the k value until the computed values for fluid depth, velocity, etc., fit their data well.

A value of k = 3 results for ES units. Since the dimensions of k are T/L, k = 3/0.3048 ≃ 10, for use with SI units. Consequently the relationship proposed is,

$$\rho/\mu = \frac{3}{R} \text{ (ES)} \quad \text{. . . . . . (67)}$$

$$\rho/\mu = \frac{10}{R} \text{ (SI)} \quad \text{. . . . . (68)}$$

Equations Defining Debris Flow

In order to solve for the critical slope, and normal depth of debris flows in the laminar range, the Saint-Venant equations can be applied as Equations 63 and 67. Beginning from the Chezy equation,

$$Q^2 = \frac{A^3 S C^2}{P} \quad \ldots\ldots\ldots \quad (69)$$

For estimating C^2, use Equation 67 or 68 for obtaining the Reynolds number and then Equation 62 or 63 gives,

$$R_e = V(A/P)\rho/\mu = VR \times 3/R = 3V. \quad . \quad (70)$$

$$C^2 = [1.85\ R_e^{0.52}]^2 = 3.42\ (3V)^{1.03}$$

$$= 10.65V^{1.03} = 10.65\ \left(\frac{Q}{A}\right)^{1.03} \quad . \quad (71)$$

Substituting Equation 71 into 69 gives the following implicit equation for the depth of flow:

$$Q^2 P - 10.65\ A^{1.97}\ Q^{1.03}\ S = 0 = F(y) \quad \ldots\ldots\ldots\ldots \quad (72)$$

The Newton method, $y^{(m+1)} = y^{(m)} - \frac{F(y^{(m)})}{\frac{dF(y^{(m)})}{dy}}$, will be used to solve Equation 72. The needed derivative is

$$\frac{dF(y)}{dy} = Q^2\ \frac{dP}{dy} - 20.94\ Q^{1.03}\ A^{0.97}\ S\ \frac{dA}{dy} \quad \ldots\ldots\ldots\ldots \quad (73)$$

If the cross section is trapezoidal, then:

$$\frac{dP}{dy} = 2\ \sqrt{m^2 + 1} \quad \ldots\ldots \quad (74)$$

$$\frac{dA}{dy} = B + 2my \quad \ldots\ldots \quad (75)$$

in which

m = side slope channel

B = bed width of the trapezoidal channel

In conclusion, a pausible equation has been proposed for defining how the Chezy coefficient varies with the ratio ρ/μ. This relationship, together with the Chezy and Saint-Venant equations allows us to solve open channel debris flows. Equation 72 gives the steady-state depth for debris flows. When used in conjunction with Equation 28 (an ordinary differential equation) the gradually varied flow depths are computed.

CHAPTER V

THE DEBRIS FLOW COMPUTER MODEL

Generalities

The theoretical and empirical relationships developed in Chapter IV have been implemented in a computer program that provides a solution to steady but varied debris flow. Much of the methodology used by Jeppson (1974) in his program for steady and unsteady water inflows in channels was used. The computer program is listed in Appendix A, and examples showing and explaining the input data and output are presented in Chapter VI and Appendices B, C, D, and E.

The original computer program is documented by Jeppson (1974). Therefore, the description provided here will include only the changes made to the original program to handle debris flows. An explanation of the input variables will go along with the program listing in Appendix A.

The computer program is applicable only for debris flows with Reynolds number less than 500. No attempt was made to provide for the turbulent condition because debris flows in nature are thought to be almost always laminar. The program uses FORTRAN-77 and has been run on a VAX 11/780 computer. The program has been designed for use primarily from a time shared terminal instead of batch.

The computer program was written and modified under the assumption that at selected sections along the channel or stream the geometric and hydraulic properties can be obtained. Consequently as input, the program requires the upstream or downstream flow rate, as well as the following information at each of several designated sections: 1) the geometry, 2) the slope, S, of the channel bottom, and 3) flow accretions or losses between these sections. The variables at sections along the channel will be denoted by a subscript i = 1, 2, . . . n. Two options are available to specify the geometry at each section. The first assumes a trapezoidal shape (of which rectangular and triangular are special cases), and the second allows for any arbitrary section. Use of the trapezoidal shape is generally easier, requiring only that the following be given at each section (as defined in Figure 9a): 1) the bottom width b_i and 2) the slope of the channel side m_i. If the general option is to be used, it is necessary to give the following at each section for a number of specified depths, denoted by a j subscript, at the section (Figure 9b): 1) the cross-sectional area A_{ij}, 2) the wetted perimeter P_{ij}, and 3) the top width, T_{ij}.

Additional input specifies the total length of channel, and the number of sections into which this length is divided for flow computations. When the flow computations require data at sections where no input data are given, often the situation, then the data for three consecutive input sections are fit by a second degree polynominal by means of the Lagrange formula, and intermediate values are interpolated, or extrapolated to the ends if necessary.

The computer solution provides the following information at each section into which the channel length is divided. (Some of these 13 items are

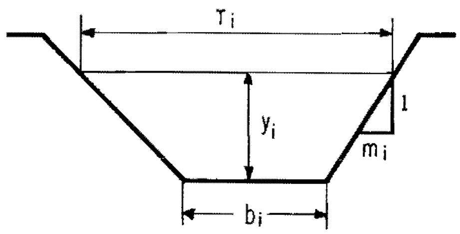


Figure 9a. Trapezoidal channel section.

$$A_i = (b_i + m_i y)\, y_i \qquad T_i = b_i + 2m_i y_i$$

$$P_i = b_i + 2y_i \sqrt{m_i^2 + 1}$$

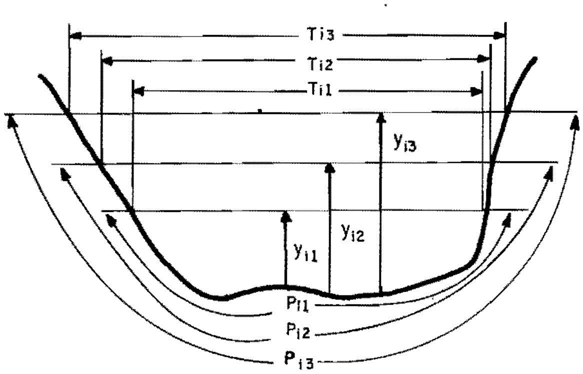


Figure 9b. Arbitrary channel section.

computed by interpolation from the input data, and some are computed by numerically solving the differential equations describing open channel debris flow.)

1. The distance or x-coordinate to each station.

2. The discharges at these stations.

3. The geometries of the channel. (If trapezoidal section is specified, these data include the bottom width and the slope of the channel side. If an arbitrary section is specified, these data include the area, wetted perimeter and the top width for several depth increments.)

4. The slopes of the channel bottom.

5. The critical depths.

6. The critical slopes.

7. The normal depths.

8. Velocities and areas corresponding to critical depths.

9. Reynolds numbers corresponding to critical and normal depths.

10. Chezy coefficients corresponding to critical and normal depths.

11. The varied flow depths from the specified boundary conditions.

12. The areas and velocities corresponding to the depths of #11.

13. The Reynolds numbers corresponding to the depths of #11.

Item #11 is the solution being sought; the other items are supporting data.

The original computer program was made up of a main program named MAIN, five subroutines name NAMELI, AREAP, VARIED, TRANST, and BAND and one subprogram FUNCTION. In this research we are concerned only with those related to the steady state, specifically: MAIN, NAMELI, AREAP, VARIED,and FUNCTION. The subroutine NAMELI was designed to replace the NAMELIST OF FORTRAN implemented by many vendors, but not by VAX or an extension of the 77 ANSI standards. The AREAP subroutine is used when quadratic interpolation is required. The VARIED subroutine and the subprogram FUNCTION calculate the steady gradually varied flow given by the first order ordinary differential Equation 28.

Modifications Made to Original Program

The changes that had to be made to the original program to handle debris flow are of two types: 1) general, and 2) particular, concerning each variable calculation.

The program had to be converted from using Manning's equation to Chezy's equation to handle the laminar debris flows. This required that in the COMMON block, the singles arrays FNI(10) and FN(40) refer to the Manning coefficients for each input and output station, were replaced by arrays REY(40) and CH(40) for Reynolds numbers and Chezy coefficients for each station. All the FORTRAN statements related to Manning equation were replaced by comparable statements based on Chezy's equation.

Particular Changes

Particular changes were needed to compute critical depth and critical slope. The computation of critical depth is determined from the implicit equation obtained by equating the Froude number, Equation 61 to unity which results in

$$F(y_c) = Q^2 T(y_c) - gA^3(y_c) = 0 \quad . \; . \; (76)$$

in which y_c is the critical depth. Equation 76 is solved by the Newton iterative formula,

$$y_c^{(m+1)} = y_c^{(m)} - \frac{F^{(m)}(y_c)}{\frac{dF^{(m)}}{dy_c}} \quad . \; . \; (77)$$

in which the superscript (m) denotes the iteration number and the derivative is,

$$\frac{dF}{dy_c} = Q^2 \frac{dT}{dy_c} - 3 \; g \; A^2 \frac{dA}{dy_c} \quad . \; . \; (78)$$

for a trapezoidal cross section:

$$T_c = b + 2my_c \text{ therefore } \frac{dT_c}{dy_c} = 2m$$

and

$$A = by_c + my_c^2$$

therefore $\frac{dA}{dy_c} = b + 2my_c$

The computation of the critical slope utilizes Equation 69. The computational procedure is outlined in Figure 10.

For the calculation of normal depths, several changes were made to the original program as follows:

1. Equation 72 was solved by Newton method for the normal depth (y_o). The function given by Equation 72 behaves erratically for some slopes so that unless the initial guess is very close to the solution, convergence will not occur. In order to overcome this difficulty, an equation was devised as follows: Starting from Equation 72, we have:

$Q^2p - 10.65A^{1.97} Q^{1.03} S_o = 0$ (for uniform flow $S = S_o$)

Making the following approximations

$A^{1.97} \simeq A^2$

$A^{1.03} \simeq Q$

and making the constant 10.65 equal to 10, in order to work with even numbers, then we get:

$$\frac{A^2}{p} = \frac{Q}{10S_o} \; , \; \frac{A}{p} \; . \; A = \frac{Q}{10S_o}$$

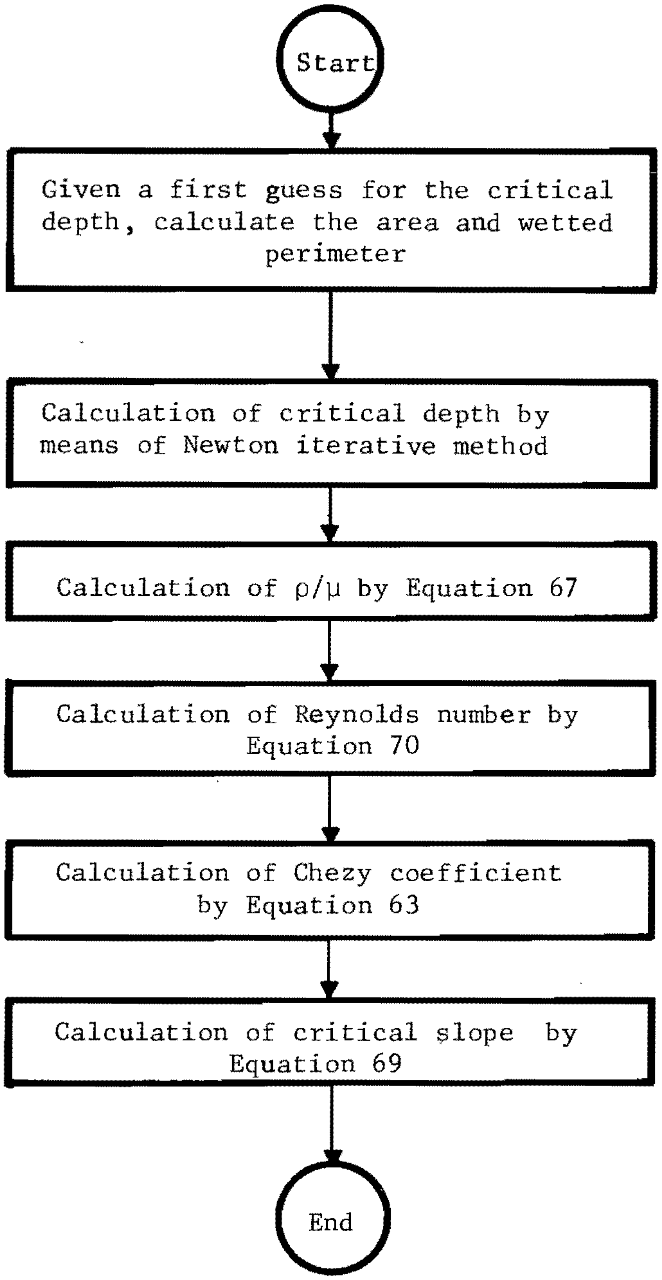


Figure 10. Flow chart for the critical slope computation.

therefore

$$R\ A = \frac{Q}{10S_o}$$

$R \simeq y_o$ for a wide rectangular channel and the area A is given by By_o where B is the bottom width, so that

$$y_o^2\ B = \frac{Q}{10S_o}, \text{ therefore } \quad y_o \simeq \sqrt{\frac{Q}{10S_oB}} \quad . . . . (79)$$

Equation 79 is used to provide the first guess for the normal depth computation by the Newton method. A simplified flow chart (see Figure 11) shows the way that this part of the program has been implemented.

Steady Gradually Varied Flow

This kind of flow is represented by the Saint-Venant equations of motion 28 and continuity 27. Since the area is a nonlinear function of y in general, and Q, q^* and S_o may be arbitrary functions of x, no closed form solution for Equation 28 can be obtained. Its solution therefore must be achieved by numerical methods. The Euler method will be used here to solve for the gradually varied flow profile.

Euler Method

The Euler method is a self-starting predictor-corrector technique. The first prediction (the first approximation at step Δx beyond where the dependent variable y is known) to y_{i+1} is given by,

$$y_{i+1} = y_i + \Delta x \frac{dy}{dx} \quad . . . . (80)$$

Subsequent predictions may be based on a second order difference equation,

$$y_{i+1} = y_{i-1} + 2\Delta x\left(\frac{dy}{dx}\right)_i \quad . (81)$$

After the prediction is completed, the value y_{i+1} is corrected by the trapezoidal formula:

$$y_{i+1} = y_i + \frac{\Delta x}{2}\left[\left(\frac{dy}{dx}\right)_{i+1} + \left(\frac{dy}{dx}\right)_i\right]$$

$$. . . . . (82)$$

Equation 82 is iteratively applied until the change between consecutive iterations becomes less than a selected

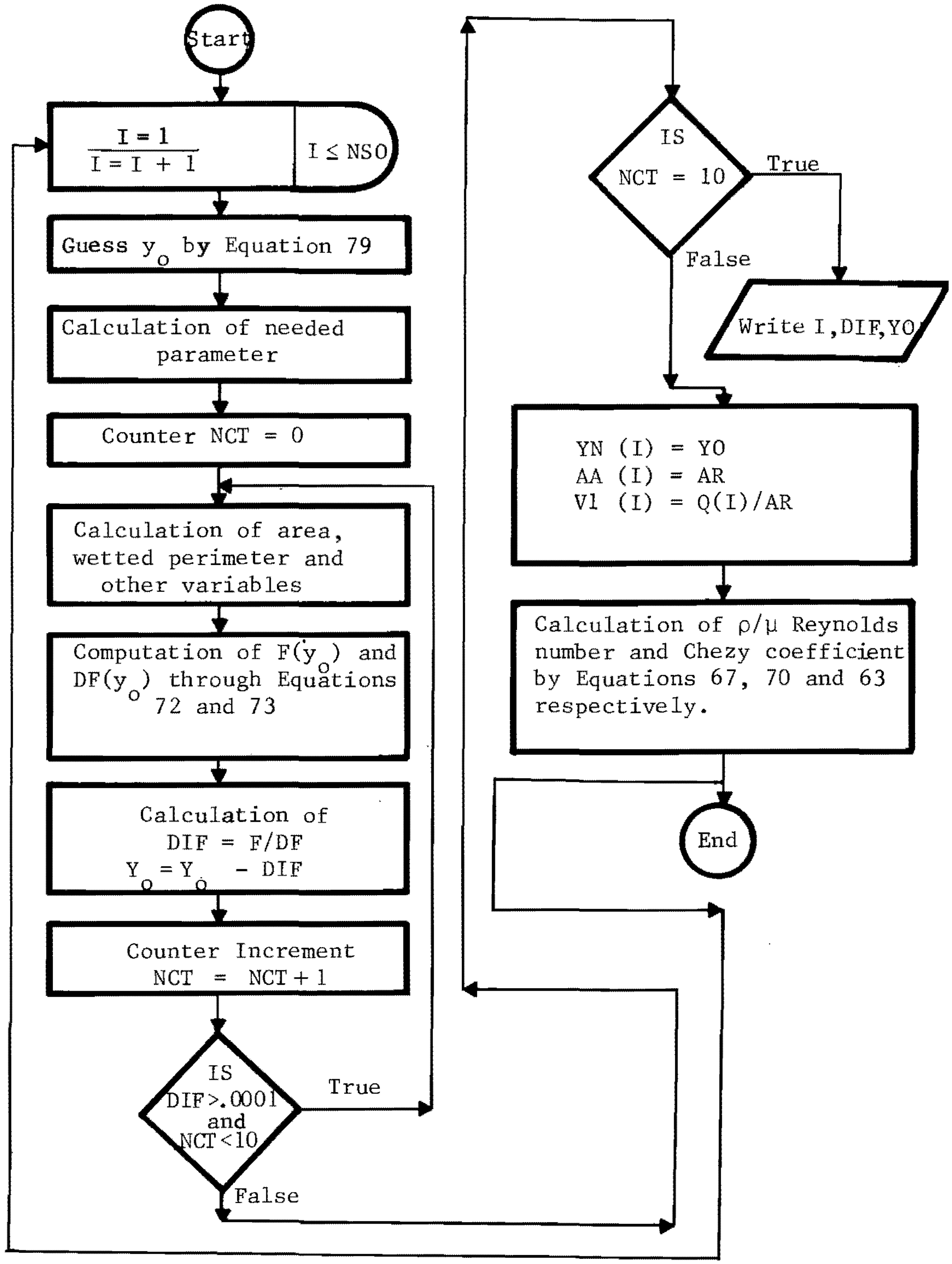


Figure 11. Flow chart for the normal depth computations.

small quantity. In Equations 80 through 82, the value of dy/dx is determined from Equation 28 with x and y evaluated at the section indicated by the subscripts.

The Euler method remains the same in both the original program and the implemented one. The changes introduced are:

1. In the subprogram FUNCTION, the calculation of dy/dx by Equation 28 was modified by 1) insertion of Equation 71 in order to compute the Chezy coefficient square and 2) the replacement of the equation that computes the friction slope (S_f) by Equation 69.

2. In the subroutine VARIED, a statement was inserted to calculate the Reynolds number at each station. Open channel debris flows are always subcritical (Pierson 1981 and Dawdy 1979); therefore the computer program has capability only to compute profiles type M1, M2 and M3.

Computer Program for Solving the Function (F) Given by Equation 72

This small computer program was written to solve for the terms Q^2P and $10.65A^{1.97}\ Q^{1.03}\ S$. A program listing is shown in Appendix A, and a flow chart in Figure 12. This program allows: 1) a better understanding of the behavior of Equation 72, and 2) a way to obtain a solution for the steady state normal depth (Y_o). Examples will be shown in Chapter VI.

The input data for this program are the following:

1. The flow rate in ft^3/sec (Q)

2. The channel bottom width in feet (B)

3. The channel slope (SO)

4. The channel side slope (FM)

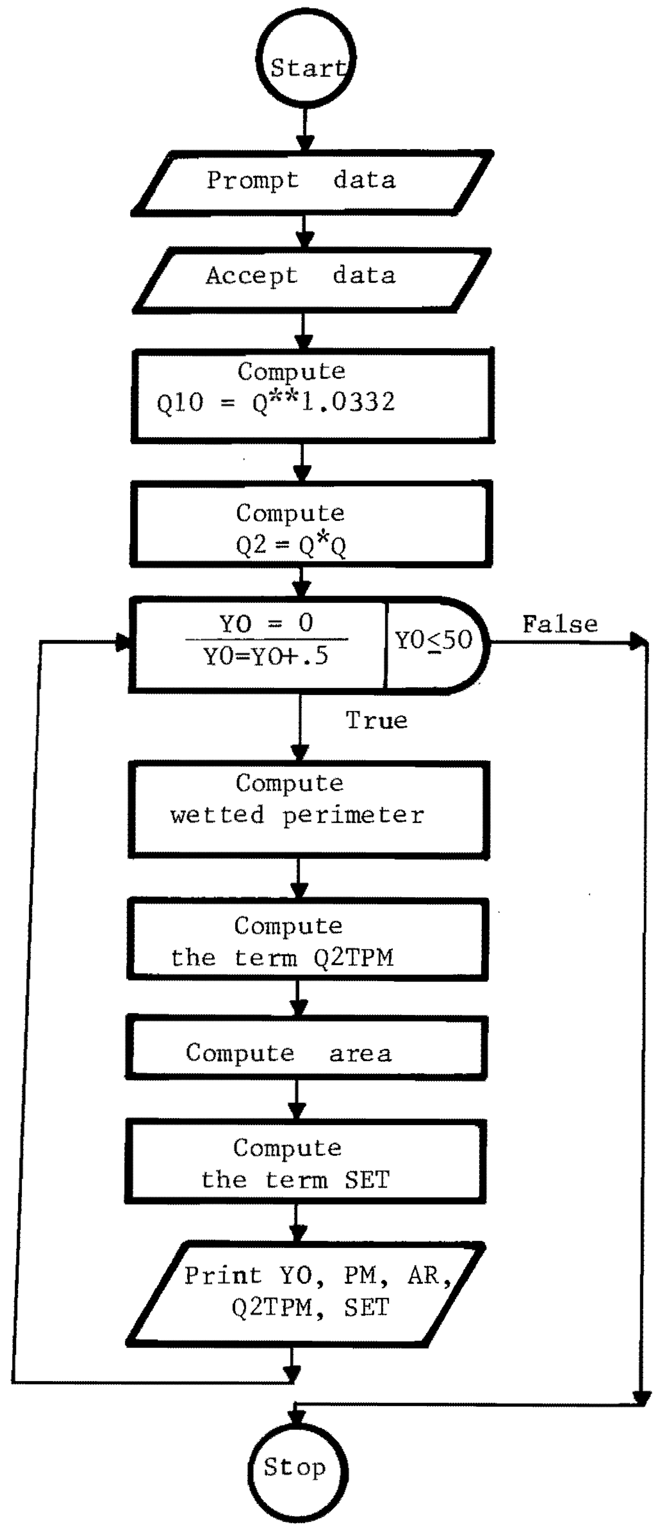


Figure 12. Flow chart for solving Equation 72.

The output gives us:

1. Depth (YO)

2. Wetted perimeter (PM)

3. Area (AR)

4. The term Q^2P called in the FORTRAN program Q2TPM

5. The term $10.65A^{1.97}\ Q^{1.03}\ S$, called in the FORTRAN program SET

CHAPTER VI

APPLICATION OF THE COMPUTER MODEL

The purpose of this chapter is to apply the equations and methods described in the previous three chapters to typical debris flows. The validity of a mathematical approach can be determined by comparing the results from the solution with available data. Unfortunately, available field data are fragmentary; and furthermore, the collection of new field data is not feasible for this project. Consequently, much of this comparison must be qualitative.

The approach used in this chapter will be to obtain solutions for examples of possible debris flows. Utilization of the computer model requires data in the order listed below.

1. The number of sections for which channel geometry data will be given (NSI).

2. The number of sections for which solution results will be computed and printed (NSO).

3. Flow rate at the upstream end (QO).

4. x distance for section 1 (XBEG).

5. x distance for the last section (XEND).

6. Depth of flow at section where the gradually varied profile solution begins (YSTART).

7. Output station number where gradually varied flow is to begin.

8. x distance for the NSI input sections.

9. Bottom slopes for the NSI input sections.

10. Lateral inflow, if there is any, for the NSI input sections.

11. Bottom width and side slopes for the NSI input sections.

12. The file name onto which the output should be written.

Relationship between Debris Flow Depth and Water Flow Depth

Damage by debris flows is related directly to the depths of such flows. Debris flows develop depths greater than water flows. Two reasons are: 1) debris flow contains both the water that must be transported from the area (which is usually considerably more than the volumetric flow rate that the stream transported before the debris flows occurred from high intensity rainfall and other flood conditions), and the debris it transports, and 2) the hydraulics of transporting debris flow requires depths in excess of those required to transport an equivalent volumetric flow rate of water. Flow rates can be computed from the hydrology of the event and debris movement by knowing the fraction of solids in the fluid mixture. The hydraulics of debris flow versus the hydraulics of water flow are presented in this section. For comparing debris flow depths versus water flow depths to transport the same volumetric flow rate, the debris flow equations of Chapter IV will be assumed to represent the hydraulics of debris flows.

The Manning formula for water flowing in a wide rectangular channel in ES unit simplifies to:

$$\frac{Q}{B} = q = 1.49 \frac{y_o^{5/3} S_o^{1/2}}{n} \quad . . . (83)$$

or

$$y_o = \left(\frac{nq}{1.49\ S_o^{1/2}}\right)^{3/5} \quad . . . (84)$$

in which

q = unit flow rate in cfs/foot

y_o = normal depth in feet

s_o = bed slope

n = Manning coefficient

For an open channel debris flow, starting from Equation 72

$$Q^2P - 10.65\ A^{1.97}\ Q^{1.03}\ S_o = 0$$

If the channel is rectangular and wide then the wetted perimeter, P, can be approximated by the bed width, B. Under these circumstances Equation 72 becomes:

$$Q^2B - 10.65\ (By_d)^{1.97}\ Q^{1.03}\ S_o = 0$$

Therefore

$$y_d^{1.97} = \frac{Q^{0.97}}{10.65\ B^{0.97}\ S_o}$$

$$y_d = \left(\frac{Q^{0.97}}{10.65\ B^{0.97}\ S_o}\right)^{0.51} \quad . . . . (85)$$

but Q = qB. Therefore Equation 85 becomes:

$$y_d = \left(\frac{q^{0.97}}{10.65\ S_o}\right)^{0.51} \quad . . . . . . (86)$$

in which

y_d = normal depth in feet for the debris flow.

Combining Equations 84 and 86, we get:

$$\frac{y_d}{y_o} = \frac{0.38}{S_o^{0.2084}\ n^{0.6}\ q^{0.1085}} \quad . (87)$$

In Figure 13, for a Manning coefficient of n = 0.035, the solution to Equation 87 is plotted against bed slope for several unit flow rates. Figure 13 shows the importance of the slope process. Figure 13 and Equation 87 represent an analytical approach to the depth ratio. Later this ratio will be given for specific cases for which gradually varied flows will be involved.

It is worthwhile to note some results from Figure 13. For a relatively small flow rate per unit width such as 2 cfs/ft the debris flow depth will be more than 16 times the water flow depth if the slope is as mild as 0.0001. As the slope becomes as large as 10 percent (0.1) this ratio decreases to about 4.0. As the flow rate per unit width increases the ratio decreases modestly, but not near as much as it decreases as the slope increases. The substantial increases of the ratio of debris flow depth to water flow depth for the same volumetric flow rate explains in part why debris flows have been observed to stop flowing, leaving an abrupt wave-shaped form on the landscape. As the depths increase as the slope of the land decreases, the velocity of the flow decreases until the flow comes to rest.

Illustrative Examples

Four examples were chosen to demonstrate how the computer program

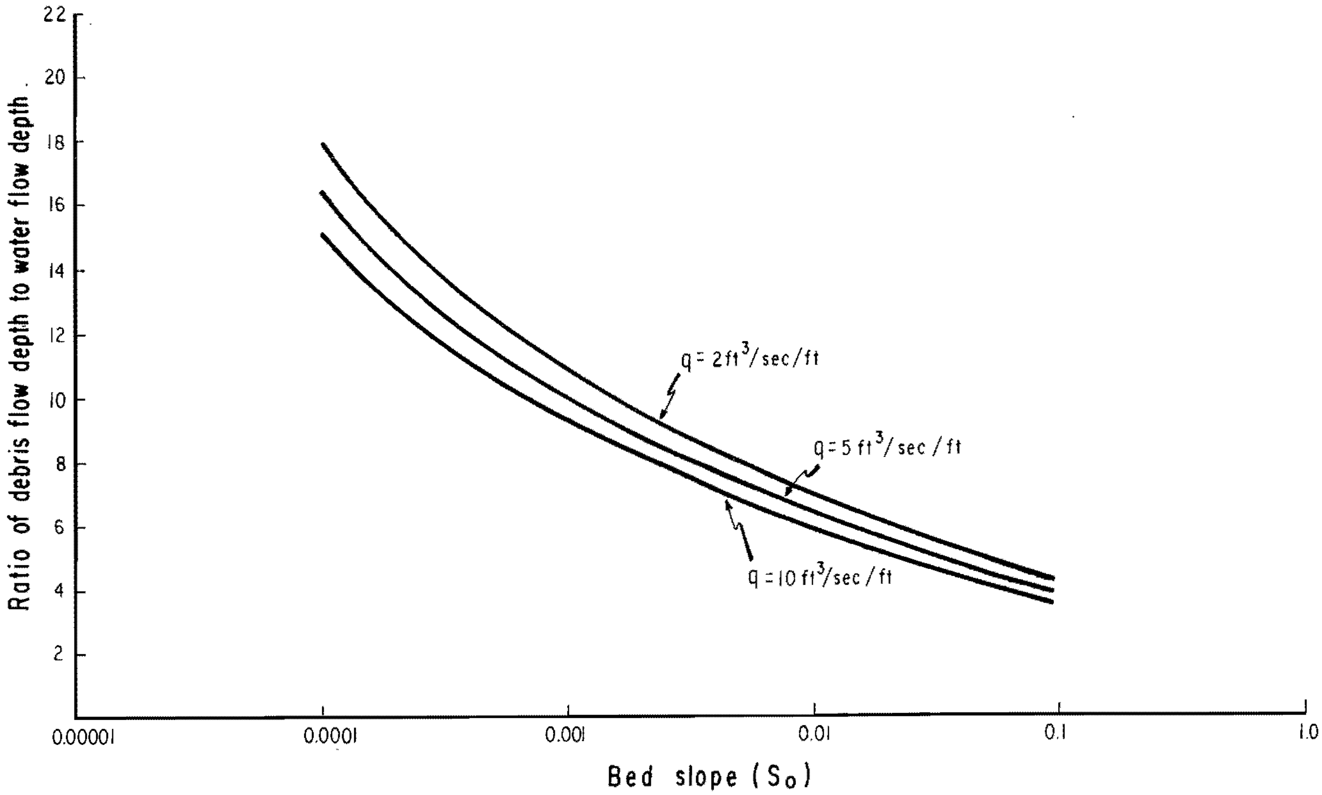


Figure 13. Debris flow depth/water flow depth vs. bed slope for n = .035 and variable unit flow rate.

performs. The first example is based on hypothetical data believed to represent a typical debris flow in Utah. The second is the typical debris flow described by Sharp and Nobles (1953), with a hypothetical downstream control. The third is a hypothetical example taken from the report by Jeppson (1974) for a water flow in a stream with rapidly varying cross sections. The fourth repeats the first example with a dramatic increase in the bed width which is likely to occur as the debris flow spreads laterally. This last example is also solved for the case of adverse slope. In all examples, comparison is made to equivalent water flows.

Example 1

A debris flow of 100 cfs comes down a canyon of rectangular section with a bed width of 100 feet and a slope of 0.1. When the debris flow passes the mouth of the canyon, it spreads over areas with decreasing slopes of 0.1, 0.05, 0.005, 0.001 and 0.0005 in a total reach of 4000 feet. The rectangular section widens from 100 feet to 500 feet. Flow onto this flood plain was solved for debris flow and water flow with Manning coefficients of 0.035, 0.07, 0.1 and 0.2. To illustrate this problem the profile and top view are shown in Figure 14. In Table 5 and Figure 15, the ratios of debris flow depth to water flow depth for different slopes and Manning coefficients are shown. In Appendix B the input data and the output solutions are given. Data for computation in Table 5 were obtained from the computer solution, Appendix B. In Table 6, some values are shown in order to illustrate a typical output.

Going into detail in Figures 14 and 15, it is clear how the slope controls

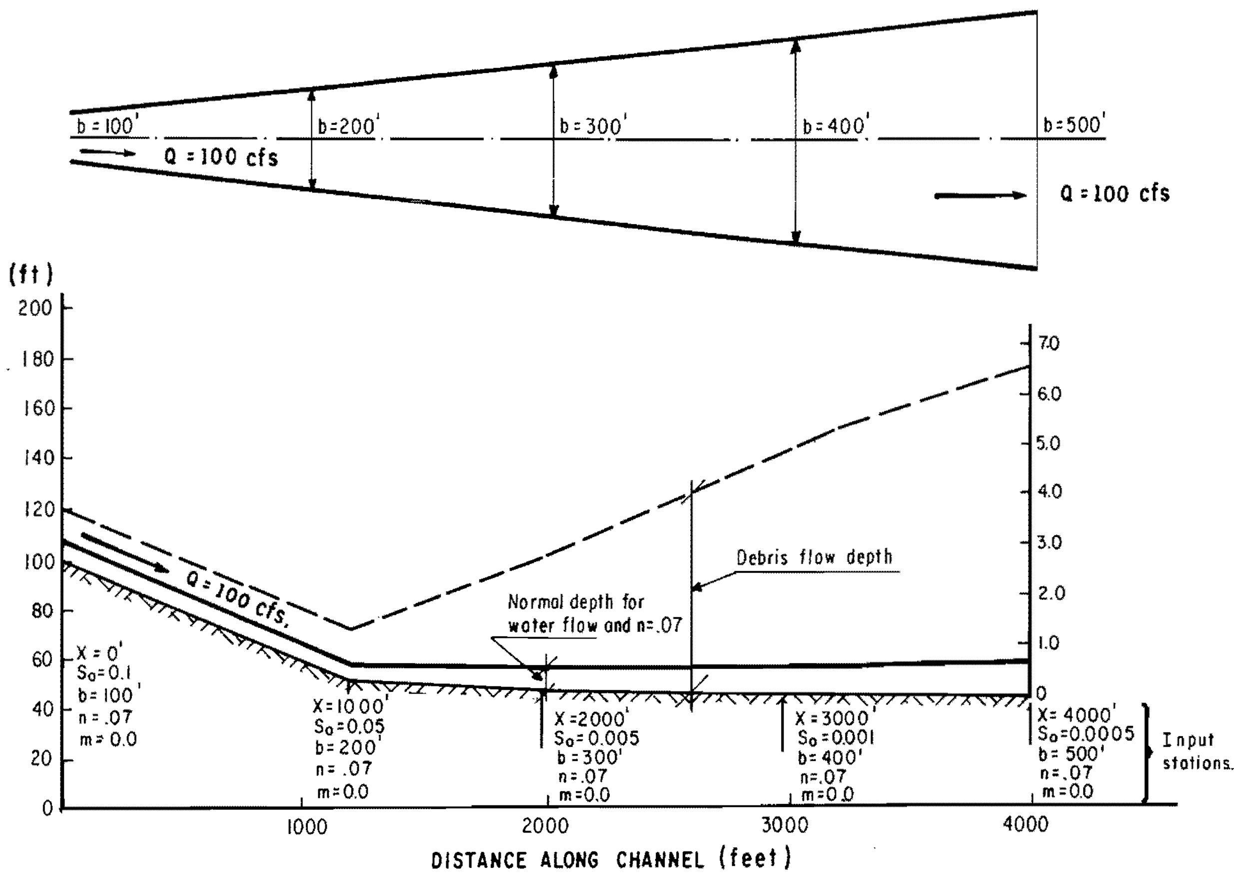


Figure 14. Profile and top view for problem 3.

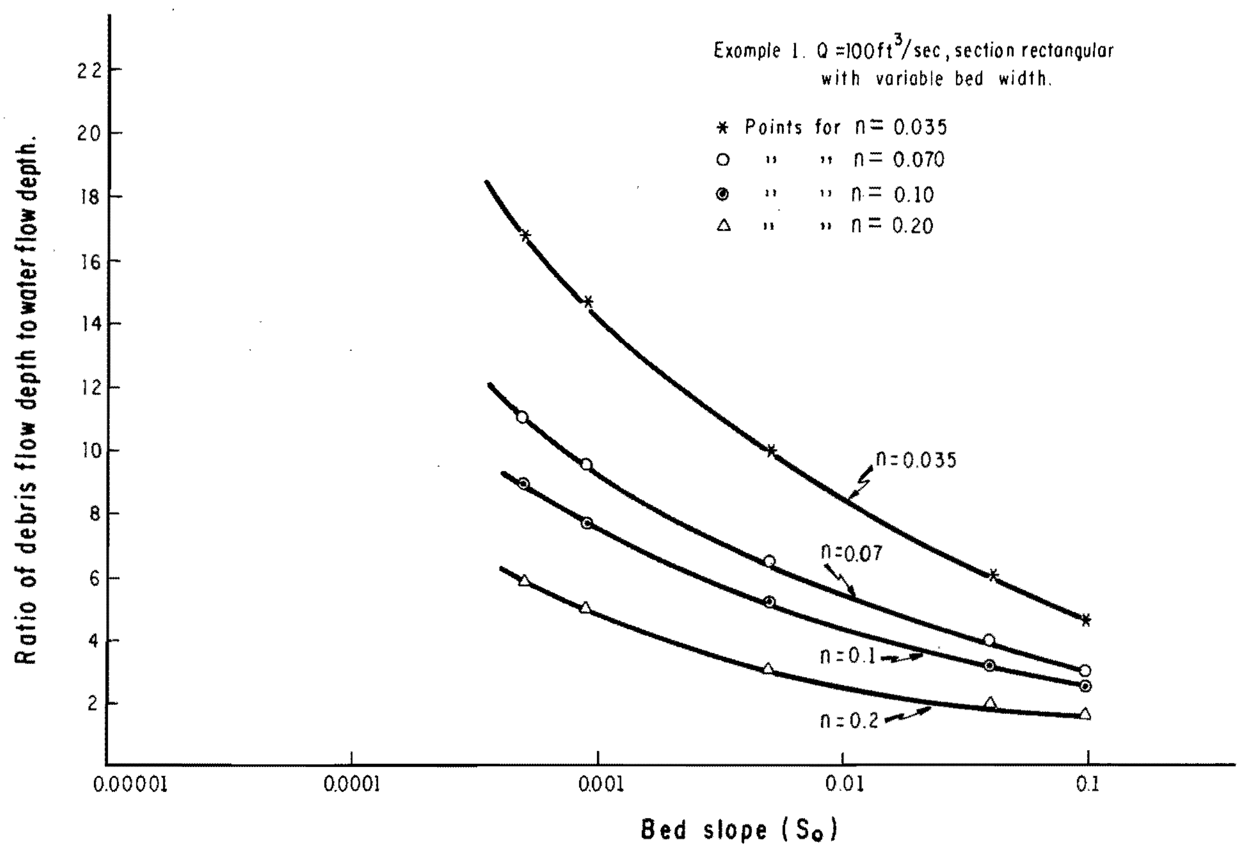


Figure 15. Debris flow depth/water flow depth vs. bed slope.

the relationship between the debris and water flow depths. The smaller the slope the larger this difference is. Also, when the Manning coefficient increases, the difference between the debris flow depth and the water flow depth becomes smaller. It can be observed that as the channel slope becomes very large the debris and water flow depths become nearly equal. Furthermore, under some conditions, the debris flow depth becomes so large, or the sediment content and viscosity so large, that the debris flow will likely stop. The mathematical model does not accommodate such stoppage, but this phenomenon has been observed in many debris flows in nature. As the slope becomes small and the debris flow contains sufficient solid material, then the viscosity becomes large, as given by Equation 66, as the depth or hydraulic radius increases, the resulting decrease in velocity reduces Chezy's coefficient, as given by Equation 63 which starts the cycle over. In practice the large material accumulates at the wave front, and the entire mass stops.

Table 5. Variation of debris flow depth/water flow depth vs. slopes for different Manning coefficients for Example 1.

Output Station	1	2	3	4	5
distance (feet)	0	1200	2000	32000	4000
slope	0.1	0.041	0.005	0.0009	0.0005
Normal depth debris flow y_d (feet)	0.978	1.039	2.612	5.314	6.58
Normal depth water flow for n=.035 y_{35} (feet)	0.211	0.171	0.267	0.365	0.392
Normal depth water flow for n=.07 y_{70} (feet)	0.319	0.260	0.405	0.554	0.595
Normal depth water flow for n=.1 y_{100} (feet)	0.396	0.322	0.502	0.686	0.737
Normal depth water flow for n=.2 y_{200} (feet)	0.601	0.488	0.761	1.041	1.118
y_d/y_{35}	4.64	6.08	9.78	14.56	16.79
y_d/y_{70}	3.07	3.99	6.45	9.59	11.06
y_d/y_{100}	2.47	3.23	5.20	7.75	8.93
y_d/y_{200}	1.63	2.13	3.43	5.10	5.89

Table 6. Typical output values. Example 1.

Sections along channel (feet)	Discharge along channel ft^3/sec	Bottom widths (feet)	Slope of channel bottom at sections	Critical depths at sections (feet)	Critical slopes at sections	Normal depths at sections (feet)	Velocities corresponding to normal depth (ft/sec)	Reynold's number corresponding to normal depth	Chezy's numbers corresponding to normal depth	Depth of flow at sections (feet)	Top width (feet)
0.0	100.00	100.000	0.10000	0.3143	0.920379	0.978	1.022	3.07	3.30	2.746	100.00
400.0	100.00	140.000	0.08000	0.2512	1.030679	0.926	0.772	2.31	2.85	35.033	140.00
800.0	100.00	180.000	0.06000	0.2124	1.122495	0.946	0.587	1.76	2.48	60.904	180.00
1200.0	100.00	220.000	0.04100	0.1858	1.201330	1.039	0.437	1.31	2.13	79.559	220.00
1600.0	100.00	260.000	0.02300	0.1662	1.272320	1.285	0.299	0.90*	1.75	91.358	260.00
2000.0	100.00	300.000	0.00500	0.1511	1.336402	2.612	0.128	0.38	1.13	96.483	300.00
2400.0	100.00	340.000	0.00340	0.1390	1.395091	2.988	0.098	0.30	0.99	98.032	340.00
2800.0	100.00	380.000	0.00180	0.1291	1.449416	3.915	0.067	0.20	0.81	98.989	380.00
3200.0	100.00	420.000	0.00090	0.1207	1.500119	5.314	0.045	0.13	0.66	99.485	420.00
3600.0	100.00	460.000	0.00070	0.1136	1.547756	5.774	0.038	0.11	0.60	99.779	460.00
4000.0	100.00	500.000	0.00050	0.1075	1.592756	6.580	0.030	0.09	0.54	100.000	500.00

* Reynold's numbers so low that it is physically impossible and the flow would stop.

Example 2

The debris flow presented by Sharp and Nobles (1953) is described in Table 1. In addition, they pointed out that the flow "was largely confined by pre-existing channels to a path 20-150 feet wide." No information about the discharge has been reported, but if we assume an average channel width of 70 feet and a rate of debris flow of 500 ft^3/sec, the velocity and debris flow depth resulting from the computer program coincide remarkably well with those given by Sharp and Nobles (1953). With this background, we can describe Example 2 as a 500 ft^3/sec debris flow discharging into a rectangular channel with bottom width of 70 feet and a slope of 0.105. The channel is 1000 feet long starting at section 0 and ending at section 1000. The section is the same throughout the whole length. At the end a control backs up the debris flow initially to a depth of 10 feet. There is no lateral inflow. The steady state uniform and varied flow solution is desired to be obtained at 21 output nodes or stations.

In solving this problem the input data and the output are shown in Appendix C. In order to see how debris flow behaves in comparison with water flow, the same data were utilized for solving the water flow problem except one more item was added; the Manning coefficient was taken as 0.2 for this specific location. For solving the water flow problem, the original program was used. (See Jeppson 1974.) The output result is shown in Appendix C.

Based on Sharp and Nobles (1953) data, it is also possible to apply Takahashi (1980) dilatant model. In order to use his Equation 8, coefficients now needed, but not given by Sharp and Nobles, must be generated. Without any other means for getting the values for these coefficients, the values reported by Takahashi in his experiment were used. The values adopted for doing the computation are:

$a_i = 0.5$, $\tan\alpha = 0.6$ therefore $\alpha = 30.96$ (from Takahashi 1980)

$\sin\alpha = 0.5144$ (from Takahashi 1980)

$C_* = 0.7$ (from Takahashi 1980)

$C_d = 0.9 \times 0.7 = 0.63$ (from Takahashi 1980)

$\sigma = 2.7$ gr/cm^3 (assumed)

$\rho = 2.4$ gr/cm^3 (from Sharp and Nobles 1953)

$h_\infty = 0.76$ m $= 2.5$ feet (from Sharp and Nobles 1953)

$d = 0.001$ m (from Sharp and Nobles 1953)

by Equation 8,

$$k = \frac{25 \times 0.5 \times 0.5144}{4[0.63 + (1-0.63) \times \frac{2.4}{2.7}] \, [(\frac{0.7}{0.9\times0.7})^{1/3} - 1]^2} \times \frac{0.001}{0.76}$$

by Equation 10,

$$U^2 = \frac{h_\infty g \sin\Theta}{k}$$

Therefore

$$U^2 = \frac{2.5 \times 32.2 \times 0.1045}{1.73} = 4.86$$

Therefore

$$U = 2.2 \text{ ft/sec}$$

Results are summarized in Table 7.

The normal depth of 2.575 in Table 7 obtained for the debris flow computer model matches well the value reported by Sharp and Nobles (1953) of 2.50 feet. Comparing the depth with that for the

Table 7. Debris flow and water flow results of Example 2.

Parameters	Data reported by Sharp and Nobles (1953) for debris flow	Results obtained from debris flow computer model	Takahashi (1980) dilatant model for debris flow	Water flow result using Jeppson model (1974)
Critical depth	-	1.166 ft	-	1.116 ft.
Critical slope	-	0.480	-	0.576
Normal depth	2.50 ft	2.575 ft.	2.50 ft.	1.959 ft.
Velocity corresponding to normal depth	3.94 ft/sec[1]	2.774 ft/sec	2.20 ft/sec	3.645 ft/sec

1. If the discharge is 500 ft^3/sec and the average width 70 feet, then the velocity should be 2.86 ft/sec instead of 3.94 ft/sec as reported.

water flow, only a modest increase (30%) is observed. The explanation for this modest increment is that for this large slope of 0.105 and the same flow rate, the depth ratio increase is not too different from unit as shown by the theoretical results of Figure 13. When the velocity increases, the fluid viscosity decreases, so this behavior tends toward a Newtonian fluid and then both depths, debris flow and water flow depth tend to be the same. In Examples 1 and 2 it is clear that smaller slopes result in a larger ratio of debris flow depth to water flow depth. A representative Reynolds number from Example 2 is 18.38 (see Appendix C). This value is between those ranges given in Tables 2, 3, and 4 in Chapter IV.

The gradually varied M_1 profile for both debris and water flow is shown in Figure 16. Figure 17 shows the solution of the function given by Equation 72 for three different slopes and a debris flow rate of 500 ft^3/sec. Notice, for the slope equal to 0.105, a solution of normal depth equal to 2.57 feet is obtained. This solution corresponds to that of Example 2. Figure 17 is helpful in understanding how the implicit function given by Equation 72 behaves. When using the Newton method the first guess is very important for convergence to occur. The slope of the function (or its derivative) decreases as the solution is approached.

Example 3

In this hypothetical example, 80 ft^3/sec is flowing into a channel where size and slope changes rapidly with position. The downstream depth is controlled. The downstream control backs up the water initially to a depth of 100 ft (30.48 m). The reach is 4180 feet long. The first portion of the reach has a steeply sloping bottom, with a maximum slope of 0.019. The next portion of the reach is flat with a slope of 0.00002; and before the end of

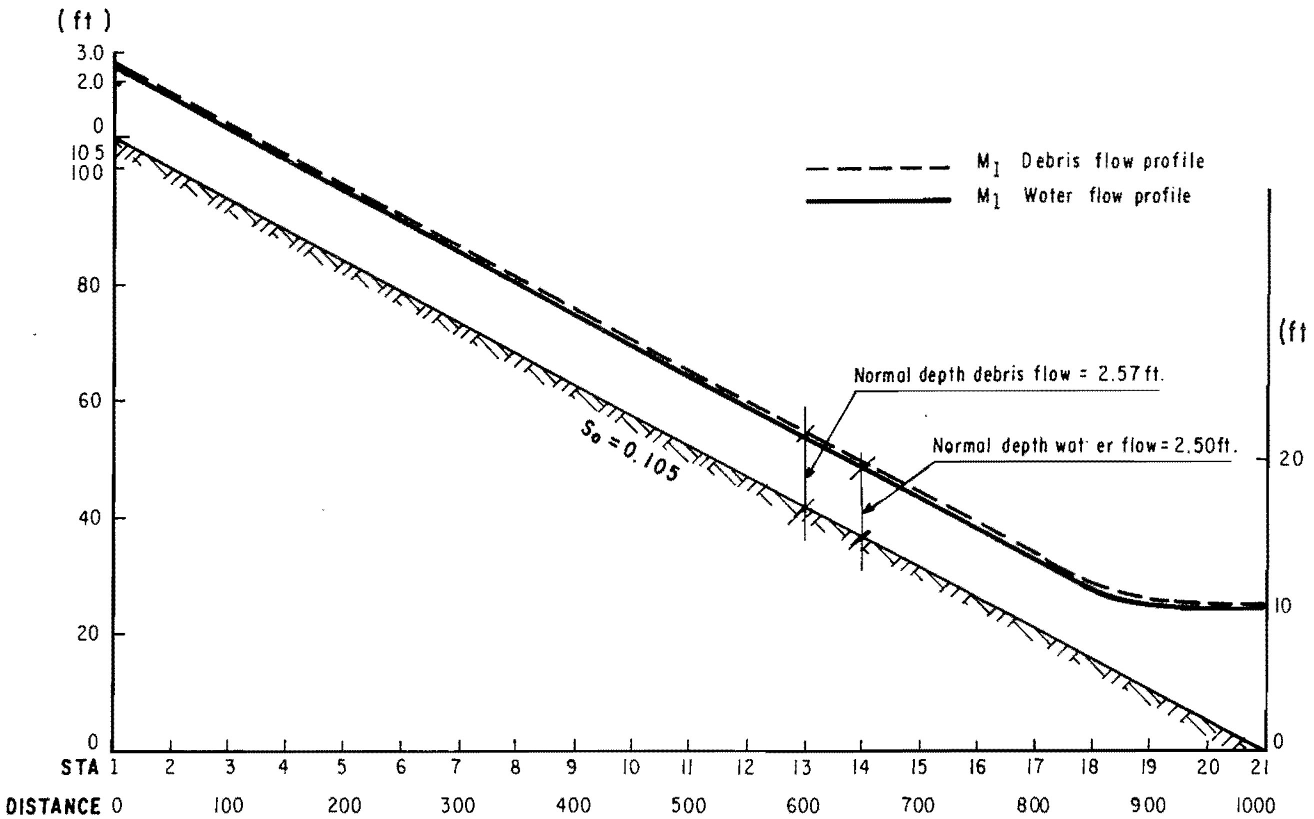


Figure 16. M_1 profiles for debris and water flow of Example 2.

the reach the slope increases sharply, but just upstream from the downstream end the slope again diminishes to 0.00005. Over the flat center portion of the channel the bottom width increases substantially. Also over this central portion lateral inflow contributes 10 cfs of water to the channel. The profile view of the channel on Figure 18 shows its geometry and the specifications used to describe the channel. The top width of the channel shown on the plan view of Figure 19 represents the steady flow obtained from solving the gradually varied flow equation with the boundary condition at the downstream and specifying a depth of 100 feet.

The solution to the gradually varied profile was obtained using 39 nodes. Thus the space increment ΔX used in the solution equals 110 feet.

This same problem was solved assuming debris flow instead of water flow under the same conditions. In Appendix D the input data and output lists are shown for both cases. In Figures 18 and 19 the solutions are shown. In this example, the Manning coefficient varies at each section. In order to examine the influence of the Manning coefficient, it was decided to run this example several times for different Manning coefficients, but holding each of them constant through the reach. These results are shown in Appendix D and in Table 8 and Figure 20.

Example 4

In this example we have tried to simulate a debris flow of 100 cfs coming down a canyon of rectangular section with a bed width of 100 feet and a slope

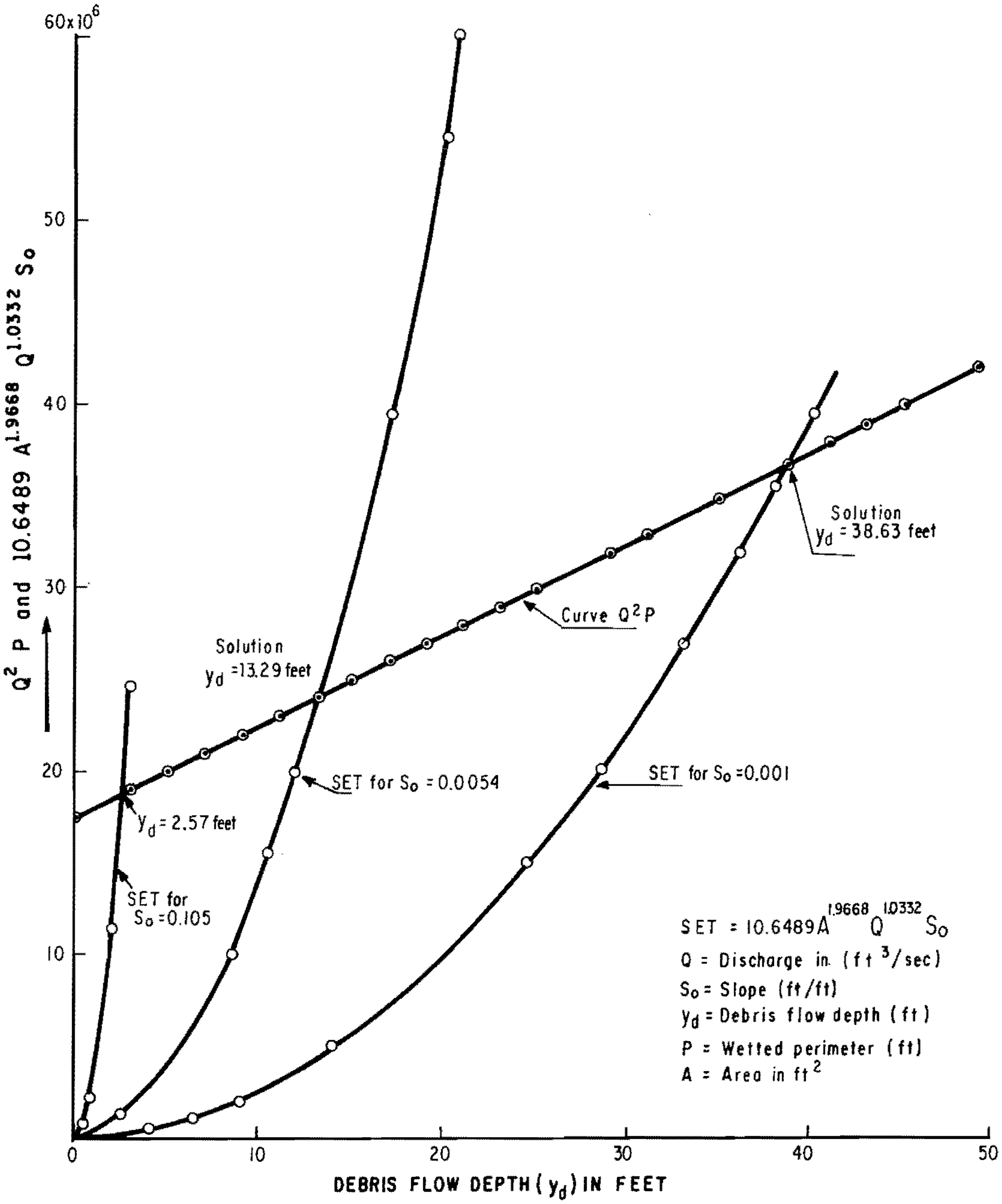


Figure 17. Q^2P and SET vs. y for Q = 500 ft^3/sec and B = 70 ft.

of 0.1. When the debris flow passes the mouth of the canyon, it spreads over areas with decreasing and sometimes with short adverse slopes (Figure 21). The rectangular section widens from 100 feet to 5000 feet. This spreading takes place in nature. Flow onto this floodplain was solved for debris flow and water flow with Manning coefficient of 0.035. In Tables 9 and 10 and Figure 22, the ratios of debris flow depth to water flow depth for different slopes is shown. In Appendix E the input data and the output lists are shown.

Two basic debris flow characteristics are clearly illustrated. When the debris flow spreads out over a

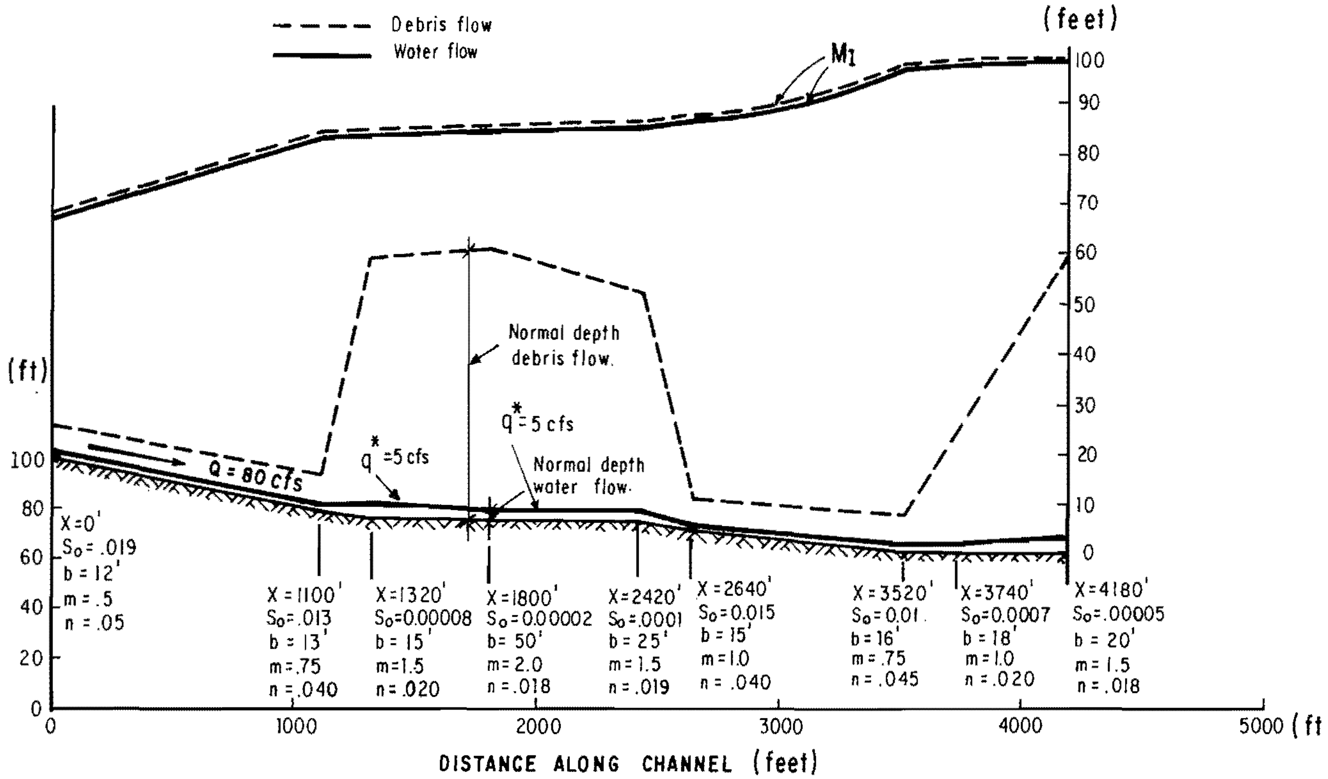


Figure 18. Profile view for problem 3.

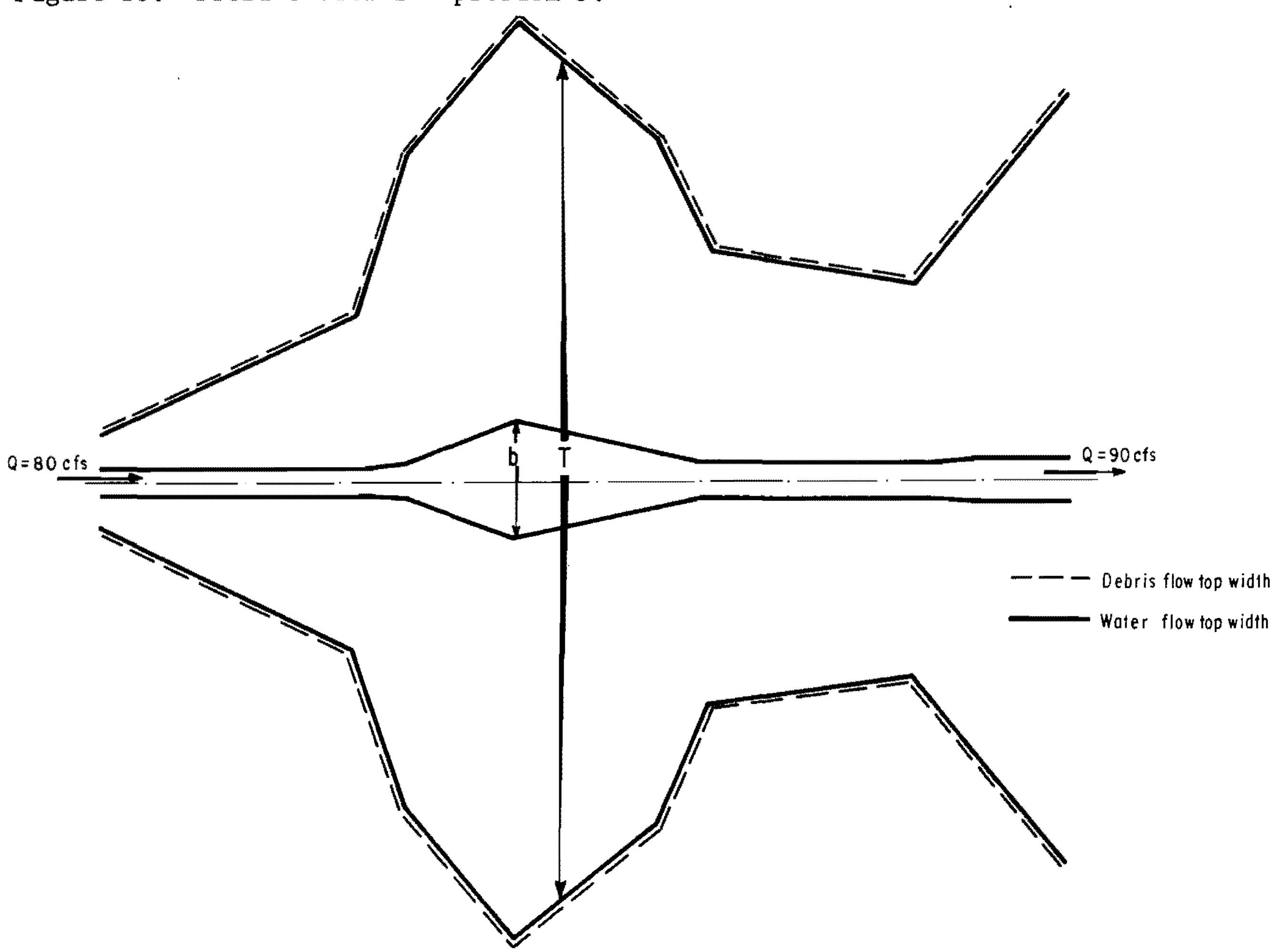


Figure 19. Plane view for problem 3.

Table 8. Variation of debris flow depth/water flow depth vs. slopes for different Manning coefficients for Example 3.

Station	1	2	3	4	5	6	7	8	9	10	11
Distance (feet)	0	1100	1320	2090	2420	2640	3520	3630	3740	3960	4180
Slopes	0.019	0.013	0.00008	0.00006	0.0001	0.015	0.01	0.0053	0.0007	0.00037	0.00005
Normal depth debris flow y_d (feet)	6.762	7.338	51.765	48.648	45.655	6.426	8.018	10.363	25.069	29.937	61.276
Normal depth water flow for n=.035 y_{35} (feet)	1.12	1.171	4.656	3.223	3.503	1.093	1.199	1.388	2.452	2.814	4.782
Normal depth water flow for n=.05 y_{50} (feet)	1.386	1.454	5.639	3.966	4.299	1.354	1.488	1.721	3.030	3.462	5.821
Normal depth water flow for n=.08 y_{80} (feet)	1.853	1.933	-	5.197	5.607	1.793	1.978	2.283	3.994	4.532	7.498
y_d/y_{35}	6.08	6.27	11.12	15.09	13.033	5.88	6.69	7.47	10.22	10.64	12.81
y_d/y_{50}	4.88	5.05	9.18	12.27	10.62	4.75	5.39	6.02	8.27	8.65	10.53
y_d/y_{80}	3.65	3.80	-	9.36	8.14	3.58	4.05	4.54	6.28	6.61	8.17

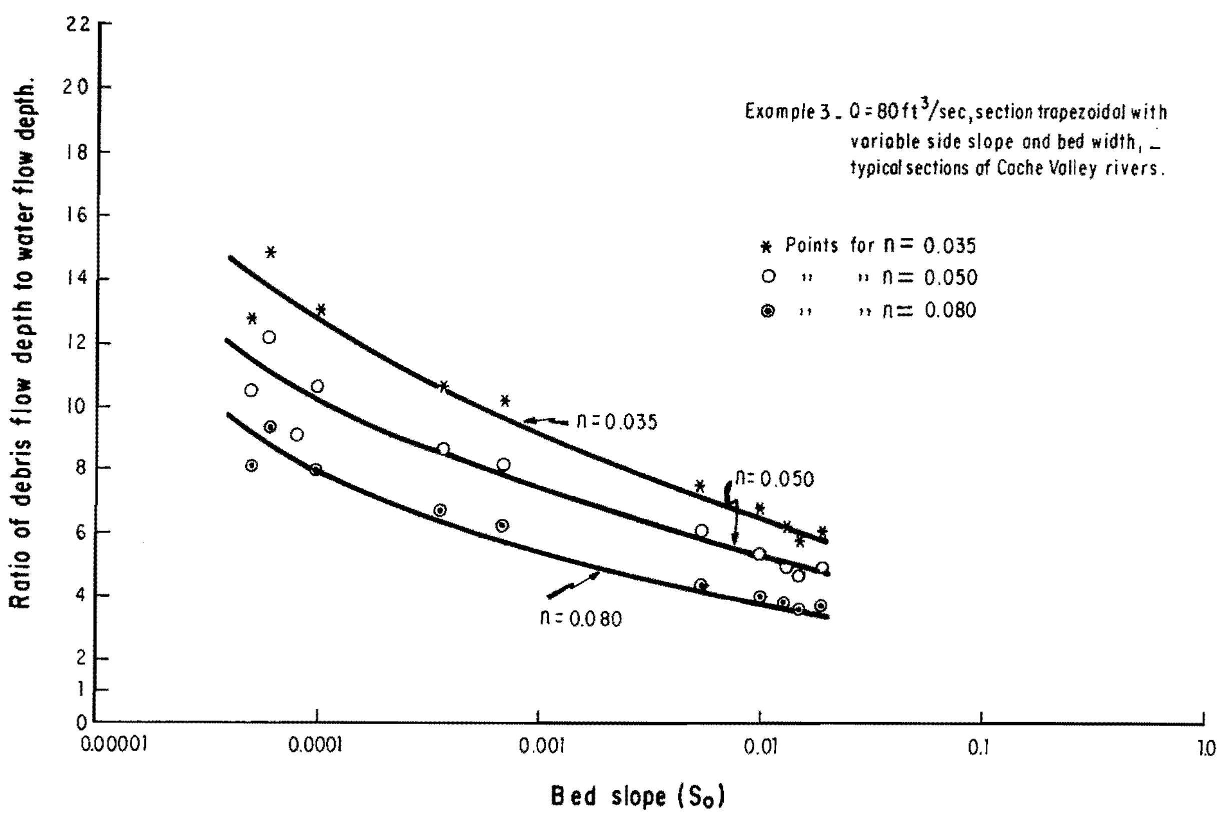


Figure 20. Debris flow depth/water flow depth vs. slope.

Table 9. Variation of debris flow depth/water flow depth vs. slopes for a given Manning coefficient and large lateral spreading for Example 4.

Output Station	1	2	3	4	5
Distance (feet)	0	1200	2000	3200	4000
Slope	0.1	0.041	0.005	0.0009	0.0005
Normal depth debris flow Y_d (feet)	0.978	0.837	1.511	1.778	2.095
Normal depth water flow for n=0.035 Y_{35} (feet)	0.211	0.132	0.138	0.097	0.099
Y_d/Y_{35}	4.64	6.34	10.95	18.33	21.16

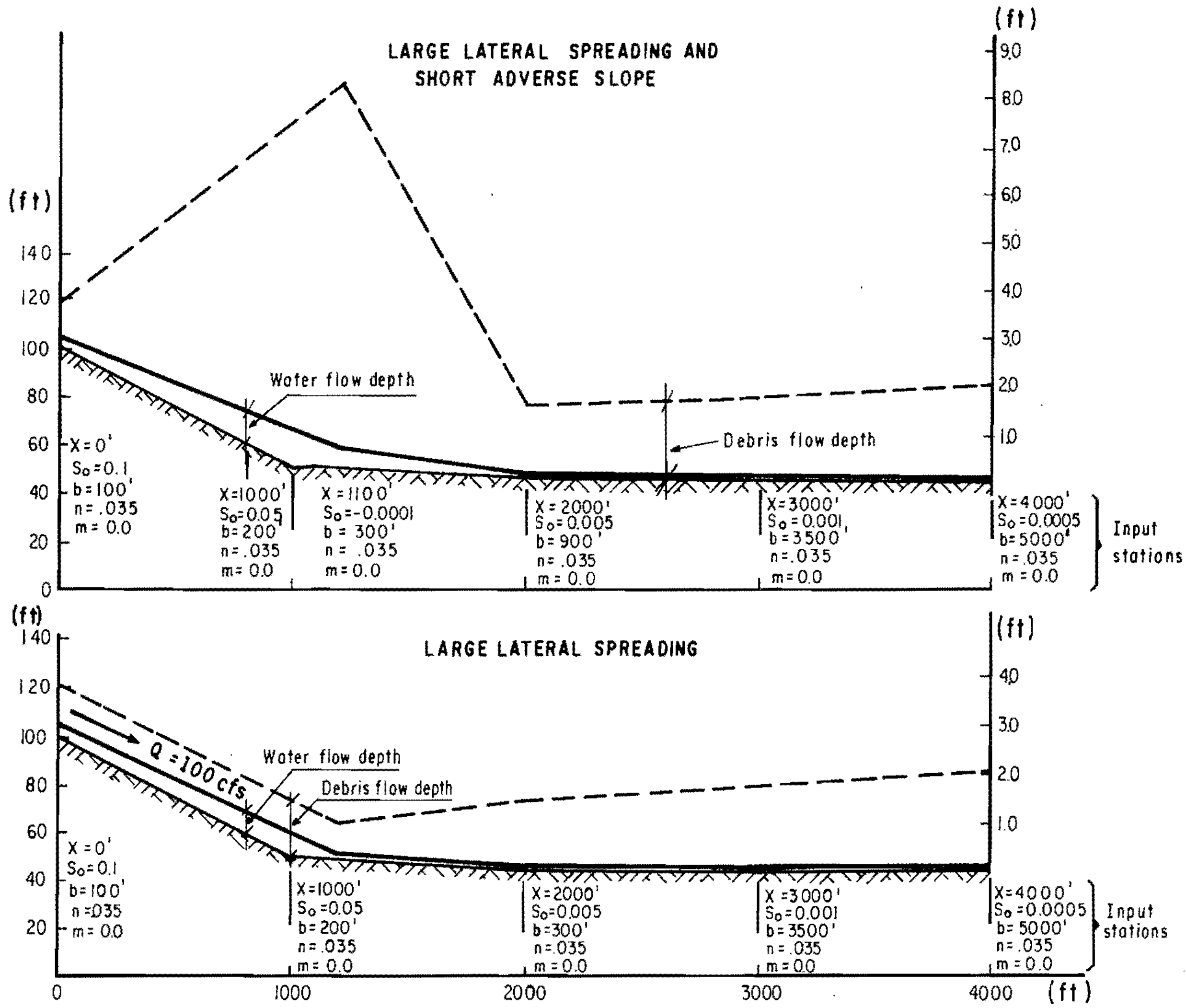


Figure 21. Profiles views for problem 4.

Table 10. Variation of debris flow depth/water flow depth vs. slopes for a given Manning coefficient, large lateral spreading and a short adverse slope for Example 4.

Output Station	1	2	3	4	5
Distance (feet)	0	1200	2000	3200	4000
Slope	0.1	0.00047	0.005	0.0009	0.0005
Normal depth debris flow Y_d (feet)	0.978	8.005	1.511	1.778	2.095
Normal depth water flow for n = 0.035 Y_{35} (feet)	0.211	0.483	0.138	0.097	0.099
Y_d / Y_{35}	4.64	16.57	10.95	18.33	21.16

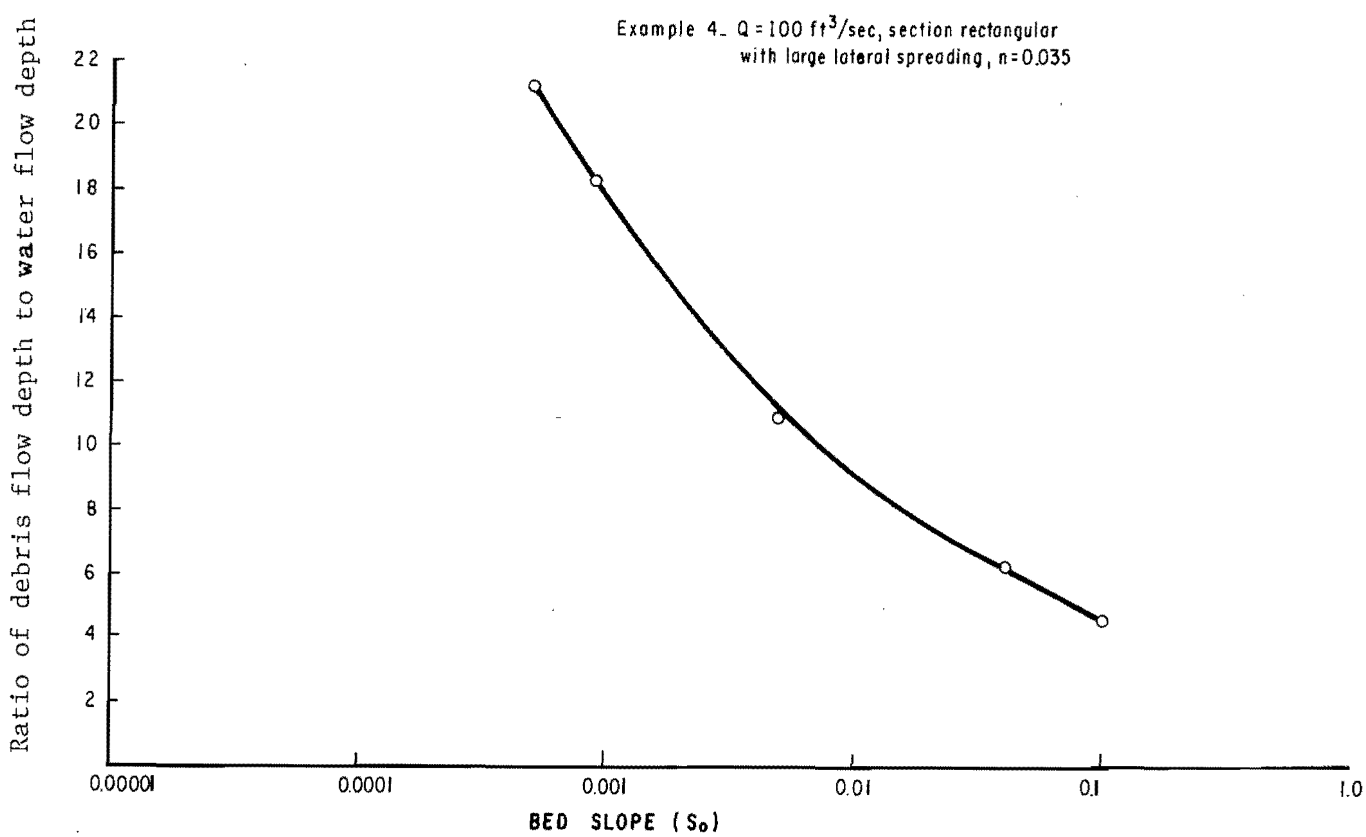


Figure 22. Debris flow depth/water flow depth vs. bed slope.

wider area as it moves downstream, as in this case, then the debris flow depth remains almost constant. Secondly, when a short adverse slope takes place, a sharp increase in the depth of debris flow occurs (Figure 21).

General Discussion

The equation used to represent the relationship between the Chezy coefficient and Reynolds number for debris flow, Equation 62 or 63 has a significant impact on the solution results. This equation was based on the few data obtainable by searching the literature. Those data were fitted by the Chezy equation which was developed for Newtonian fluid, and the results were taken to indicate that the equation applies for debris flow in the laminar range. Collection of more data by experiments, or by quantitatively observing debris flow in the field, may assist in validating or improving this relationship, or showing that it is not acceptable for certain classes of debris flows.

Equation 65, that describes the relationship between open channel debris flow density, ρ, viscosity, μ, and the hydraulic radius of the resulting flow is also important. It was evaluated from limited data provided by Sharp and Nobles (1953). Also, additional data would assist in validating this relationship.

Despite the very limited data available to, and the simplicity of the equations used in fitting the data, the solutions describe the phenomenon of debris flow well, both from the basis of qualitative observations as they can be gleaned from the literature as well as in duplicating the few quantitative data available. The Takahashi dilatant debris model result and the Sharp and Nobles (1953) data, for the uniform debris flow depth and velocity compare closely to our results as shown by Table 7. Takahashi coefficients such as a_i, tan α, C_d, C_*, and d are not easily obtained. From this point of view the model proposed herein is far superior. It also appears to produce results as good as Takahashi does.

The greater debris flow depth than water flow depth is something to be expected, not only based on descriptions given by several authors but also because of its much larger viscosity in comparison with water. The friction slope, defined by Equations 69 and 63, constitutes the basis for future application of this debris flow model to the routing of any hydrograph in channels or streams and the nonsteady debris flow solution. The bed slope plays a very important role in the debris flow process.

CHAPTER VII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A theoretical model based on one dimensional Saint-Venant equations of continuity and motion, together with the modified Chezy equation for defining the friction slope, have been found suitable for describing open channel debris flow in the laminar range with Reynolds number less than or equal to 500. This research included only steady state flows.

A computer program with the capability for solving steady state open channel debris flows by numerical methods has been developed.

Equations 63 and 65 constitute the foundation for the theoretical model. The former equation expresses the relationship between the Chezy coefficient and the Reynolds number for laminar debris flows. The latter equation provides the relationship between the debris flow density, viscosity, and the hydraulic radius of the flow. These relationships are of necessity based on the limited data available for debris flow. Solutions to four examples were obtained to verify the theoretical model and test the computer program. The result shows that this open channel debris flow model reproduces very well debris flows observed in nature like that described by Sharp and Nobles (1953). The advantage of this model over those proposed by Johnson (1965, 1970) and Takahashi (1980) is that it does not depend upon coefficients that are difficult to obtain and vary with flow conditions. Furthermore, the model is easily applied.

Debris flows develop depths greater than water flows do. The bed slope is the most important variable that affects the ratio of the depth of debris flow to depth of an equivalent volumetric water flow. The substantial increase of the ratio of debris flow depth to water flow depth for the same volumetric flow rate at low slopes, explain in part why debris flows have been observed to stop flowing, leaving a wave-shaped form on the landscape. As the depths increase as the slopes of the land decreases, the velocity of the flow decreases until the mixture can no longer flow.

The following are recommendations for future research related to debris flows:

1. Extend this theoretical model to the solution of unsteady debris flows. In order to do this, approximate boundaries conditions are required. A critical component of the unsteady model will be the methodologies used in handling the wave front.

2. Collection of more data by experiments or by quantitative observation of debris flow in the field are needed to provide greater assurance regarding the range of acceptability of Equation 63.

3. Equation 65, that describes the relationship between the debris flow density, viscosity, and hydraulic radius needs verification. Verification of Equations 65 and 63 means that field data, as well as possibly laboratory

data need to provide values of ρ, μ, R_e, and R along the flow in the x-direction as the bed slope varies.

4. Application of this debris flow model to field situations that are likely candidates for future debris flow.

REFERENCES

Amein, M., and C. S. Fang. 1970. Implicit flood routing in natural channels. Journal of the Hydraulics Division, ASCE 96(HY12): 2489-2500.

Amisial, R. A. 1969. Analog computer solution of the unsteady flow equations and its use in modeling the surface runoff process. PhD dissertation, Utah State University, Logan, Utah. 189 p.

Babbit, H. E., and D. H. Caldwell. 1939. Laminar flow of sludges in pipes with special reference to sewage sludge. University of Illinois. Engineering Experiment Station, Bulletin Series No. 319, 59 p.

Bagnold, R. A. 1954. Experiments on a gravity-free dispersion of large solid spheres in a Newtonian fluid under shear. Proc. Roy. Soc. London, Ser. A., 225:49-63.

Blackwelder, E. 1928. Mudflow as a geologic agent in semi-arid mountains. Bulletin of the Geological Society of America, 39: 465-583.

Bull, W. B. 1968. Alluvial fans. Journal of Geological Education, 16:101-106.

Cannon, S. Q. 1931. Torrential floods in northern Utah, 1930. Agricultural Experiment Station, Utah State Agricultural College, Logan, Utah, Circular 92.

Chawner, W. D. 1935. Alluvial fan flooding, the Montrose, California flood of 1934. Georgr. Review 25:255-263.

Chen, Cheng-lung. 1975. Urban storm runoff inlet hydrograph study. Volume 1, Computer analysis of runoff from urban highway watersheds under time- and space-varying rainstorms. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Cunge, J. A., and M. Wegner. 1964. Integration numerique des equations de ecoulement de Barre de Saint-Venant par un schema implicite de differences finies. La Houille Blanche, pp. 33-30.

Dawdy, D. R. 1979. Flood frequency estimates on alluvial fans. Journal of the Hydraulics Division, ASCE 105(HY11):1407-1413.

Enos, P. 1977. Flow regimes in debris flow. Sedimentology, 24:133-142.

Henderson, F. M. 1966. Open channel flow. Macmillan Publishing Co., Inc. New York, 522 p.

Hooke, R. Leb. 1967. Processes on arid-region alluvial fans. Journal of Geology, 75:438-460.

Hughes, W. F., and J. A. Brighton. 1967. Fluid dynamics, Shaum's outline series. McGraw-Hill Book Co., New York.

Jeppson, R. W. 1974. Simulation of steady and unsteady flows in channels and rivers. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Jeppson, R. W. 1980. Lecture notes from "open channel flow." Course No. CE 655, taught at Utah State University, Logan, Utah.

Jeppson, R. W. 1981. Lecture notes from "numerical methods." Course No. CE 753, taught at Utah State University, Logan, Utah.

Johnson, A. M. 1965. A model for debris flow. Thesis presented to Pennsylvania State University, University Park, Pennsylvania, in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Geology. 232 p.

Johnson, A. M. 1970. Physical processes in geology. Freeman, Cooper and Company, San Francisco, 577 p.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. Freeman, Cooper and Company, San Francisco.

McGee, W. J. 1897. Sheetflood erosion. Bulletin of the Geological Society of America, 8:87-112.

Morgali, J. R. 1970. Laminar and turbulent overland flow hydrographs. Journal of the Hydraulics Division, ASCE 96(HY2):441-459.

Pack, F. J. 1923. Torrential potential of desert waters. Pan-American Geologist 40:349-356.

Paul, J. H., and F. S. Baker. 1925. The floods of 1923 in northern Utah. Bulletin of the University of Utah, V. XV(3).

Pierson, T. C. 1981. Dominant particle support mechanisms in debris flows at Mt. Thomas, New Zealand, and implications for flow mobility. Sedimentology 28:49-60.

Rouse, H., and J. M. Robertson. 1941. On the four regimes of open-channel flow. Civil Eng. 11(3):169-171.

Segerstroem, K. 1960. Erosion studies at Paricutin, State of Michoacan, Mexico: U.S. Geological Survey Bulletin 965-A, 164 p.

Sharp, R. P. and L. H. Nobles. 1953. Mudflow of 1941 at Wrightwood, Southern California. Geological Society of America Bulletin, 64:547-560.

Strelkoff, T. 1969. One-dimensional equations of open-channel flow. Journal of the Hydraulics Division, ASCE 95(HY3):861-876.

Strelkoff, T. 1970. Numerical solution of Saint-Venant equations. Journal of the Hydraulics Division, ASCE 96(HY1):223-252.

Takahashi, T. 1978. Mechanical characteristics of debris flow. Journal of the Hydraulics Division, ASCE 104(HY8):1153-1169.

Takahashi, T. 1980. Debris flow on prismatic channel. Journal of the Hydraulics Division, ASCE 106(HY3):381-396.

Yevjevich, V. 1975a. Introduction, p. 1. In K. Mahmood and V. Yevjevich (Eds.). Unsteady flow in open channels, Vol. 1. Water Resources Publication, Fort Collins, Colorado.

Yevjevich, V. 1975b. Storm-drain networks. In K. Mahmood and V. Yevjevich (Eds.). Unsteady flow in open channels, Vol. II. Water Resources Publication, Fort Collins, Colorado.

APPENDICES

Appendix A. Computer Program Lists

EXPLANATION OF INPUT VARIABLES

Steady State Solution

FORTRAN Variable	Description of Data
NSI	No. of section for which channel geometry data will be given.
NSO	No. of section for which solution results will be computed and printed.
ITRAPE	If 0 channel is not a trapezoidal channel and geometry at NSI sections must be given as two dimensional arrays in which the second subscript gives the area, wetted perimeter and top width as a function of depth.
IOYES	If not 0 geometry of this problem will be taken the same as previous problem.
QO	Flow at upstream end. If QO = 0, then the array Q(I), read in later, represents flows at sections.
XBEG	x distance to Section 1.
XINC	Δx distance between output sections consisting of NSO in number.
ERR	Error parameter to terminate Newton iteration.
NSTART	Section number at which gradually varied profile solution begins.
NSINC	1 if computation of gradually varied flow proceed downstream; -1 if they proceed upstream.
NEND	Ending section number for gradually varied flow computations.
INFLOW	0 if flowrates are to be given at NSO sections; 1 if at NSI sections.
YSTART	Depth of flow at NSTART section.
MYSTRT	If greater than 0 a check will be made to determine whether a control exists in channel other than at section NSTART.
IUNSTE	If equal to zero only a steady state solution will be obtained.
LINTER	If greater than zero the geometry, etc ., at the NSO sections will be obtained from the NSI sections by linear interpolation, otherwise quadratic interpolation will be employed.
Q(I)	Lateral (accretion) inflows (or actual flows - see QO).
XI(I)	x - distances for NSI sections.
SI(I)	Slope of channel bottom S_o at NSI sections.
BI(I)	Bottom widths of channel at NSI sections.
FMI(I)	Side slopes of channel at NSI sections.

```
C THIS PROGRAM IS THE RESULT OF SEVERAL CHANGES INTRODUCED INTO THE
C ORIGINAL PROGRAM CALLED STREAM AND IS GOOD IN ORDER TO GET THE STEA-
C OY STATE CDNOITION FOR OEBRIS FLOW.BUT ALSO THE OPTION FOR THE IMPLE-
C MENTATION OF THE UNSTEADY STATE CDNOITION REMAIN DPEN SD THAT IT CAN
C BE DONE LATER.THIS IS THE REASON WHEN THE PROGRAM ASK YOU ABOUT TO
.C CHANGE SOME OF THE VARIABLES,YOU HAVE TO PUT THE VARIABLE IUNSTE
C EQUAL TO ZERD(0),SO THAT THE PROGRAM CAN GIVE TO YOU THE RESULTS
C UNTIL THE GRADUALLY VARIED FLOW.
C THIS PRDGRAM IS ONLY GOOD FOR DEBRIS FLOW WITH FREE SURFACE AND LA-
C MINAR FLOW CONDITION THAT MEANS REYNDLDS NUMBER LESS OR EQUAL TO 500.
C-----------------------------------------------------------------
C-----------------------------------------------------------------
       CHARACTER*6 ANAME(6),RW1(2),AHELP(5,6),PAR
       CHARACTER*12 PAR1
      INTEGER IVAR(8)
      REAL RVAR(1)
      COMMON BI(10),FMI(10),REY(40),8(40),FM(40),CH(40),SI(10),S(40),
     *XI(10),YI(10,10),QO,TI(10,10),TT(30,10),X(40),AI(10,10),PI(10,10),
     *A(30,10),P(30,10),YC(40),SC(40),YN(40),YT(3D,10),Y(40),AA(40),Q(40
     *),PP(40),TOP(40),V1(40),FAC1,FAC2,FAC3,XINC,XBEG,ERR,QC2,QG2,DELX,
     *DEL2,DEL32,RDX4,RDX3,DXG,N5O,ITRAPE,NP,NSTART,NSINC,NEND,MCURVE,
     *I1,I2,I3,MCT,MYSTRT,IVARR,ELEVB(10),NSII,LINTER,NCONTT,ELB(40),NPR
     *,INPUT,1OUT
      COMMON CGC(80,6),VCG(80)
      REAL FMTI(7),FMT2(7),AIARY(6)
      LOGICAL SUBC,SUBCI
C      NAMELIST/SPECIF/1RAPE,IOYES,ERR,INFLDW,MYSTRT,IUNSTE,LINTER,NCON
C     *,NPR
      CHARACTER*6 NAMES(9)/'ITRAPE','IOES','INFLOW','MYSTRT','1UNSTE',
     *'LINTER','NCDNT','NPR','ERR'/
      CHARACTER*6 SPECIF/'SPECIF'/
      EQUIVALENCE (IOYES,IVAR(2)),(INFLOW,IVAR(3))
     *,(IUNSTE,IVAR(5))
      DATA ANAME/'NSI','NSO','QO','XBEG','XEND','YSTART'/
      DATA ITRAPE,IOYES,ERR,INFLOW,MYSTRT,IUNSTE,LINTER,NCOTT,NPR/1,0,
     *.001,1,0,1,1,0,0/
      DATA INPUT,IOUT/5,6/
      DATA AHELP/'NO. OF',' SEC. ','FOR IN','PUT DA','TA
     *'NO. OF',' SEC. ','FOR OU','TPUT D','ATA   ',
     *'FLDWRA','TE AT ','8EG. O','F CHAN','NELL  ',
     *'X-DIST',' AT BE','G. OF ','GVF-PR','OFILE ',
     *'X=DIST',' AT EN','D  OF ','GVF-PR','OFILE ',
     *'DEPTH ','Y AT  ','XBEGIN','      ','      '/
      IVAR(1)=ITRAPE
      IVAR(4)=MYSTRT
      IVAR(8)=NPR
      IVAR(7)=NCONT
      IVAR(6)=LINTER
      RVAR(I)=ERR
C  98 READ(INPUT,100,END=99) NSII,NSO,ITRAPE,IOYES,QO,XBEG,XINC,ERR
      WRITE(IOUT,10)
10    FORMAT(' DO YOU WANT A DEFINITION OF NAMELIST OPTIONS IN SPECIF?
     *Y  OR  N',/)
      READ(INPUT,I20) PAR
      IF(PAR .EQ. 'Y     ') WRITE(IOUT,20)
20    FORMAT(' ITRAPE=1   IF O CHANNEL IS NOT TRAPEZOIOAL ANO GOEMETRY
     *AT NSI SECTIONS MUST BE GIVEN',/,' IOYES=0  IF NOT O GEOMETRY OF
     *THIS PROBLEM WILL BE TAKEN THE SAME AS PREVIOUS PROBLEM.',/,
     *' ERR=.001     ERROR PARAMETER',/,' INFLOW=1   IF GREATER THAN O A
     *CHECK WILL BE MADE TO DETERMINE WHETHER A CONTRDL EXISTS IN CHANNE
     *L OTHER THAN AT SECTION MYSTART',/,' IUNSTE=1  IF EQUAL TO O ONLY
     *A STEAOY STATE SOLUTION WILL BE OBTAINED',/,' LINTER=1  IF I GEOME
     *TRY,ETC. AT NSO SECTIONS IS DETERMINED BY LINEAR INTERPOLATION;
     *IF O BY QUATRATIC INTERPOLATION',/)
25    WRITE(IOUT,30)
30    FORMAT(' OEFAULT OPTIONS ARE;')
C      WRITE(IOUT,SPECIF)
      WRITE(IOUT,31)ITRAPE,IOYES,ERR,INFLOW,MYSTRT,IUNSTE,LINTER,NCONT,
     * NPR
31    FORMAT(' ITRAPE=',I4,' IOYES=',I3,' ERR=',F10.5,' INFLOW=',I3,
     *' MYSTRT=',I3,'1UNSTE=',I3,' LINTER=',I3,' NCONT=',I3,' NPR=',I3)
      WRITE(IOUT,40)
40    FORMAT(' DO YOU WANT ANY OF THESE CHANGEO? Y OR N',/)
      READ(INPUT,120) PAR
      IF(PAR .EQ. 'N     ') GO TO 60
      WRITE(IOUT,50)
50    FORMAT(' GIVE CHANGED OPTIONS IN &SPECIF LIST',/)
C      READ(INPUT,SPECIF)
      CALL NAMEL1(SPECIF,NAMES,IVAR,RVAR,8,I,9)
      1TRAPE=IVAR(1)
      MYSTRT=IVAR(4)
      NPR=IVAR(8)
      LINTER=IVAR(6)
      NCONT=IVAR(7)
60    WRITE(IOUT,70)
70    FORMAT(' GIVE THE INPUT DATA AFTER THE NAME.  IF YOU DONOT UNDERST
     *AND NAME WRITE; HELP')
      DO 90 I=1,6
80    WRITE(IOUT,85) ANAME(I)
85    FORMAT(1H ,A6,'- ')
      READ(INPUT,I20) RWI
      IF(RWI(1) .EQ. HELP') GO TO 82
      GO TO 90
82    WRITE(IDUT,100)ANAME(I),(AHELP(J,I),J=I,5)
      GO TO 80
90    READ(RWI,91,ERR=80) AIARY(1)
91    FORMAT(BN,FI2.0)
100   FORMAT(' THE VARIABLE ',A6,' IS ',5A6)
      NSII=AIARY(I)
      NSO=AIARY(2)
      QO=AIARY(3)
      XBEG=AIARY(4)
      XEND=AIARY(5)
      YSTART=AIARY(6)
C IF NSII IS NEG. THEN ELEV OF BOTTOM INSTEAD OF SLOP IS GIVEN
110   FORMAT(4I5,6FI0.5)
      DELX=(XEND-XBEG)/FLOAT(NSO-1)
      NSI=IABS(NSII)
120   FORMAT(7A6)
      IVARR=0
      XINC=DELX
      OEL2=2.*DELX
      DEL32=1.5/DELX
      RDX4=4./OELX
      RDX3=3./DELX
      DXG=32.2*DELX
      XINC2=XINC/2.
      WRITE(IDUT,122) NSO
122    FORMAT(' PROVIDE OUTPUT STA. NO. WHERE GVF SOL. IS TO BEG.,I.E.'
     *,' 1 OR',I5,/)
      READ(INPUT,*) NSTART
      IF(NSTART .EQ. NSO) GO TO 124
      NSINC=1
      NEND=NSO
       GO TO 128
124   NSINC=-1
       NEND=1
C NSTART -- SECTION WHERE GRADUALLY VARIED PROFILE COMPUTATION IS TO BE
C NSINC  -- +I  IF COMPUTATION PROCEDES FOREARD, -1 IF COMPUTAION PRC.
C  NEND -- FINAL SEC. OF GRAD. VARIED FLOW COMP.
C INFLOW  --  O IF Q(I) IS GIVEN AT NSO SECTIONS,  1 IF Q(I) IS GIVEN A
C  IF QO =0, THEN Q(I) ARE ACTUAL FLOWS AT SECTIONS, IF QO GREATER THAN
C   Q(I) ARE INFLOWS.
C  IF MYSTRT IS GREATER THAN  O  CHECK WILL NOT BE MADE TO DETERMINE IF
C IUNSTE = 0  IF NOT UNSTEADY SOL.  IS SOUGHT.
C  IF  LINTER  IS GREATER THAN  O  LINEAR INTERPOLATION IS USED BETWEEN
C      READ(INPUT,102) NSTART,NSINC,NEND,INFLOW,YSTART
C 102 FORMAT(4I5,6F10.5)
C      READ(INPUT,502) MYSTRT,IUNSTE,LINTER,NCONTT,NPR
C 502 FORMAT(IDI5)
I28   WRITE(IOUT,130) NSI,NSO,ITRAPE,IOYES,QD,XBEG,XINC,ERR,NSTART,
     *NSINC,NEND,INFLOW,YSTART,MYSTRT,IUNSTE,LINTER
130   FORMAT(' NSI=',I3,' NSO=',I3,' ITRAPE=',I2,' IOYES=',I2,' QO=',F8.
     *2,' XBEG=',F8.2,' XINC=',F8.2,' ERR=',F8.5,/' NSTART=',I2,' NSINC=
     *',I2,' NEND=',I2,' 1NFLOW=',I2,' YSTART=',F8.3,' MYSTRT=',I2,' IUN
     *STE=',I2,' LIN. INT. =',I2)
      SUBC=.TRUE.
C     READ(INPUT,101) FMT2
135   WRITE(IOUT,I40) NSI,NSI
140   FORMAT(' PROVIDE',I5,' X-DIST. FOR',I5,' INPUT STATIONS',/)
      READ(INPUT,*) (XI(1),I=1,NS1)
      IF(NSII .GT. 0) GO TO 200
       WRITE(IOUT,150) NSI
150   FORMAT(' PROVIDE BDTTOM ELEVATIONS FOR',I5,' INPUT STATIONS',/)
      READ(INPUT,*) (ELEVB(I),I=1,NSI)
      WRITE(IOUT,160) (ELEVB(I),I=1,NS1)
160   FORMAT(' ELEV. OF BOTTOM',/,(1H ,12F10.2))
      DO 170 I=2,NSI
170   SI(I)=    ((ELEVB(I-1)-ELEVB(1))/(XI(I)-XI(I-1)))
      SIAV1=SI(2)
      DO 180 I=2,NSI
      SIAV=.5*(SI(I-1)+SI(I))
      SI(I-I)=SIAV1
180   SIAV1=SIAV
      SI(NSI)=SIAV1
      GO TO 210
20D   WRITE(IOUT,190) NSI
190   FORMAT(' PROVIDE BOTTOM SLOPES FOR',I5,' INPUT STATIONS',/)
      READ(INPUT,*) (SI(I),I=1,NSI)
210   WRITE(IOUT,220) (XI(1),I=1,NSI)
220   FORMAT('OPROBLEM SPECIFICATIDNS',/,' X',(12F10.I,F9.1))
      WRITE(IOUT,230) (SI(1),I=I,NSI)
230   FORMAT(' S',(12FI0.5,F9.5))
      MSO=NSI
      IF(INFLOW .EQ. O) MSO=NSO
      WRITE(IOUT,240)
240   FORMAT(' IS THERE LATERAL INFLOW?  Y OR N',/)
      READ(INPUT,120) PAR
      IF(PAR .EQ. 'Y     ') GO TO 260
      DO 250 I=I,MSO
250   Q(I)=0.
      GO TO 265
260   WRITE(IOUT,262) MSO
262   FORMAT(' PROVIOE',I5,' VALUES OF LATERAL INFLOW.  IF QO=0 THESE
     *ARE ACTUAL FLOWS.',/)
      READ(INPUT,*) (Q(I),I=1,MSO)
265   WRITE(IOUT,270) (Q(I),I=1,MSO)
270   FORMAT(' SQ',(11F10.3,2F9.3))
      IF(QO .LT. 1.E-5) GO TO 290
      Q(1)=QO
      DO 280 I=2,MSO
280   Q(I)=Q(I-1)+Q(1)
C 25 READ(INPUT,101)     FMT1
290   IF(ITRAPE .EQ. O) GO TO 340
      WRITE(IOUT,300)NSI,NSI
300   FORMAT(' PROVIOE',I5,' BOTTOM WIDTHS, THEN',I5,' SIOE SLOPES',/)
      READ(INPUT,*) (BI(I),I=1,NSI),(FMI(I),I=1,NSI)
      WRITE(IOUT,310) (BI(1),I=1,NSI)
310   FORMAT(' B',(I2F10.3,F9.3))
      WRITE(IOUT,320) (FMI(I),I=1,NSI)
320   FORMAT(' M',(12F10.3 ,F9.3))
C     WRITE(IOUT,330) (FNI(I),I=1,NSI)
C 330 FORMAT('N',(I2F10.3,F9.3))
      WRITE(IOUT,334)
334   FORMAT(' HAVE YOU MADE ANY MISTAKES?  Y OR N',/)
      READ(INPUT,120) PAR
      IF(PAR .EQ.'N     ') GO TO 450
      WRITE(IOUT,336)
336   FORMAT(' DO YOU WANT TO START AGAIN AT THE BEGINNING OR
     *JUST WITH CHANNEL DATA? TYPE BEGIN.  DR   CHANNEL',/)
      READ(INPUT,I20) PAR
      IF(PAR .EQ. 'CHANNE') GO TO 135
      GO TO 25
340   IF(NSII .LT. 0) GD TO 360
      WRITE(IDUT,350)
350   FORMAT(' PROVIDE FORMAT AND THEN CROSS-SECTION DATA',/)
      READ(INPUT,I20) FMT1
      READ(INPUT,FMTI) NP,((Y1(I,J),J=1,NP),I=1,NSI),
     *((AI(I,J),J=1,NP),I=I,NSI),((PI(I,J),J=I,NP),I=I,NSI),((TI(I,J),J=
```

```
     *1,NP),I=I,NSI)
      GO TO 380
C 360 READ(INPUT,FMT1) (FN1(I),I=1,NSI)
 360  READ(INPUT,*) NP
      OO 370 I=1,NSI
      REAO(INPUT,FMT1) (YI(I,J),J=I,NP)
      READ(INPUT,FMTI) (AI(I,J),J=1,NP)
      READ(INPUT,FMTI) (PI(I,J),J=1,NP)
370   READ(INPUT,FMTI) (T1(I,J),J=I,NP)
380   DO 430 I=1,NSI
      WRITE(IOUT,390) X1(I),Q(I)
390   FORMAT(' X=',FIO.I,' SQ=',FIO.3)
      WRITE(IOUT,400) (YI(1,J),J=I,NP)
400   FORMAT(' Y',(I2FIO.3,F9.3))
      WRITE(1OUT,410) (AI(I,J),J=I,NP)
410   FORMAT(' A',(I2F10.2,F9.2))
      WRITE(IOUT,420) (PI(I,J),J=1,NP)
420   FORMAT(' P',(I2F10.2,F9.2))
430   WRITE(IOUT,440) (TI(I,J),J=I,NP)
440   FORMAT(' T',(12FIO.2,F9.2))
450   WRITE(6,*) 'WHERE SHOULD THE OUTPUT GO? GIVE 1) TTY IF TERM ONLY;
     * 2) FILE NAME'
      READ(5,452) PARI
452   FORMAT(A12)
      IF(PAR1.EQ.'TTY') GO TO 455
      IF(PARI.NE.'TTY') GO TO 453
453   IOUT=3
454   OPEN(UNIT=1OUT,FILE=PARI,STATUS='NEW')
455   IF(IOYES) 460,460,610
460   II=1
      I2=2
      I3=3
      IF(LINTER .EQ. O) GO TO 530
      DNI=XI(I2)-XI(II)
      DO 520 I=1,NSO
      X(I)=XBEG+XINC*FLOAT(I-1)
470   IF(X(I) .LT. XI(I2) .OR. I2 .EQ. NSI)  GO TO 480
      I1=I1+I
      I2=I2+1
      DNI=XI(I2)-XI(II)
      GO TO 470
480   FACI=(X(I)-XI(I1))/DNI
      IF(ITRAPE .EQ. O) GO TO 490
      B(I)=BI(I1)+FAC1*(BI(I2)-BI(II))
      FM(I)=FMI(I1)+FACI*(FMI(I2)-FMI(I1))
      GO TO 510
490   DO 500 J=I,NP
      A(I,J)=AI(II,J)+FACI*(AI(I2,J)-AI(I1,J))
      TT(I,J)=TI(II,J)+FACI*(TI(I2,J)-TI(II,J))
      YT(I,J)=YI(II,J)+FACI*(YI(I2,J)-YI(II,J))
500   P(I,J)=PI(II,J)+FACI*(PI(I2,J)-PI(I1,J))
510   S(1)=SI(II)+FAC1*(SI(I2)-SI(II))
      IF(INFLOW .GT. O) AA(I)=Q(II)+FACI*(Q(I2)-Q(II))
      IF(NSII.LT.O)ELB(I)=ELEVB(I1)+FACI*(ELEVB(I2)-ELEVB(I1))
C 520 FN(I)=FNI(I1)+FAC1*(FNI(I2)-FNI(I1))
520   CONTINUE
      GO TO 660
530   OO 600 I=1,NSO
      X(I)=XBEG+XINC*FLOAT(I-1)
      IF(I .EQ. I) GO TO 550
540   IF(X(I) .LT. .5*(XI(I2)+XI(I3)) .OR. I3 .EQ. NSI) GO TO 560
      II=II+1
      I2=I2+I
      I3=I3+1
550   DN1=(XI(I1)-XI(I2))*(XI(I1)-XI(I3))
      DN2=(XI(I2)-XI(I1))*(XI(I2)-XI(I3))
      DN3=(XI(I3)-XI(I1))*(XI(I3)-X1(I2))
      GO TO 540
560   FACI=(X(I)-XI(I2))*(X(1)-XI(I3))/DNI
      FAC2=(X(I)-XI(II))*(X(I)-X1(I3))/DN2
      FAC3=(X(1)-XI(I1))*(X(I)-XI(I2))/DN3
      IF(ITRAPE .EQ. O) GO TO 570
      B(I)=FACI*BI(II)+FAC2*BI(I2)+FAC3*BI(I3)
      FM(I)=FACI*FMI(II)+FAC2*FMI(I2)+FAC3*FMI(13)
      GO TO 590
570   DO 580 J=I,NP
      A(I,J)=FAC1*AI(1I,J)+FAC2*AI(I2,J)+FAC3*AI(I3,J)
      TT(I,J)=FACI*TI(I1,J)+FAC2*TI(12,J)+FAC3*TI(I3,J)
      YT(I,J)=FACI*YI(II,J)+FAC2*YI(12,J)+FAC3*YI(I3,J)
580   P(I,J)=FAC1*P1(I1,J)+FAC2*PI(I2,J)+FAC3*PI(I3,J)
590   S(I)=FAC1*S1(II)+FAC2*SI(I2)+FAC3*SI(I3)
      IF(NSII.LT.O)ELB(I)=FACI*ELEVB(I1)+FAC2*ELEVB(12)+FAC3*ELEVB(I3)
      IF(INFLOW .GT. O) AA(I)=FACI*Q(I1)+FAC2*Q(I2)+FAC3*Q(I3)
C600   FN(I)=FACI*FNI(I1)+FAC2*FNI(I2)+FAC3*FNI(I3)
600   CONTINUE
      GO TO 660
610   DO 650 I=1,NSO
      X(I)=XBEG+XINC*FLOAT(I-I)
      IF(ITRAPE .EQ. O) GO TO 620
      B(I)=BI(1)
      FM(I)=FMI(I)
C     GO TO 640
620   DO 630 J=1,NP
      A(I,J)=AI(I,J)
      TT(I,J)=TI(I,J)
      YT(I,J)=YI(I,J)
630   P(1,J)=PI(I,J)
C640   FN(I)=FN1(I)
650   S(I)=SI(I)
660   WRITE(IOUT,700) (X(I),I=1,NSO)
      IF(INFLOW .EQ. O) GO TO 680
      DO 670 I=1,NSO
570   Q(I)=AA(I)
680   WRITE(IOUT,690) (Q(I),I=I,NSO)
690   FORMAT('O OISCHARGE ALONG CHANNEL',/,(1H ,I3F10.2))
700   FORMAT('OSECTIONS ALONG CHANNEL',/,(1H ,13F10.1))
      IF(ITRAPE .EQ. O) GO TO 730
      WRITE(IOUT,710) (B(I),I=1,NSO)
710   FORMAT('O BOTTOM WIDTHS',/,( 1H ,13F1D.3))
      WRITE(IOUT,720) (FM(I),I=1,NSO)
720   FORMAT('O SLOPES OF SIDE OF CHANNEL',/,(IH ,13F10.3))
C     GO TO 770
      GO TO 785
730   WRITE(IOUT,740)
740   FORMAT('O CROSS-SECTIONAL AREAS AND WETTED PERIMETERS OF CHANNEL')
      OO 750 I=I,NSO
750   WRITE(IOUT,760) (YT(I,J),A(1,J),P(I,J),J=1,NP)
760   FORMAT(IH ,5(3F8.3,1X))
C770   WRITE(IOUT,780) (FN(I),I=1,NSO)
C780   FORMAT('O MANNINGS N   FOR SECTIONS OF CHANNEL',/,(IH,13F10.3))
785   WRITE(IOUT,790) (S(I),I=I,NSO)


790   FORMAT('O SLOPE OF CHANNEL BOTTOM AT SECTIONS',/,(IH ,I3FIO.5))
C  SOLUTION OF CRITICAL DEPTH AND CRITICAL SLOPE
      IF(NSI1.LT.O)WRITE(IOUT,800)(ELB(I),I=1,NSO)
800   FORMAT(' ELEV. OF CHANNEL BOTTOM',/,(1H ,13FIO.2))
      IF(ITRAPE .EQ. O) GO TO 840
      YO=((Q(1)/B(1))**2/32.2)**.3333333
      DO 830 I=1,NSO
      QG2=Q(I)**2
C     QC2=QG2/2.22
      QG2=QG2/32.2
      FM2=2.*FM(1)
      NCT=0
810   AR=(B(I)+FM(1)*YO)*YO
      WPR=B(I)+2.*YO*SQRT(FM(I)**2+1.)
      A2=AR*AR
      TR=B(I)+FM2*YO
      F=QG2*TR-AR*A2
      DF=QG2*FM2-3.*TR*A2
      DIF=F/DF
      YO=YO-OIF
      NCT=NCT+I
      IF(ABS(DIF) .GT. .0001 .AND. NCT .LT. IO) GO TO 810
      IF(NCT .EQ. IO) WRITE(IOUT,820) NCT,I,DIF,YO
820   FORMAT(' DID NOT CONVERGE IN',I3,' ITERATIONS, I=',13,' DIF=',E10.
     *3,' Y(I)=',FIO.3)
      YC(1)=YO
      AA(I)=AR
      VI(I)=Q(1)/AR
      DEVI=3.*WPR/AR
      REY(I)=Q(I)*DEVI/WPR
      CH(I)=1.85*REY(I)**.5166
      QC2=QG2*32.2/(CH(I)*CH(I))
C830   SC(I)=QC2*FN(I)**2*(B(I)+2.*YO*SQRT(FM(I)**2+1.))**1.3333333/((
C    *B(I)+FM(I)*YO)*YO)**3.3333333
830   SC(I)=QC2*WPR/(A2*AR)
      GO TO 910
840   II=I
      I2=2
      I3=3
      YO=((Q(1)/(.7*P(1,I)))**2/32.2)**.33333
      DO 900 I=1,NSO
      QG2=Q(I)**2
C     QC2=QG2/2.22
      QG2=QG2/32.2
      NCT=0
      MCT=1
850   IF(LINTER .EQ. 0) GO TO 880
      DO 860 JJ=2,NP
      J=JJ
      IF(YT(I,J) .GE. YO) GO TO 870
860   CONTINUE
870   FACT=(YO-YT(I,J-1))/(YT(I,J)-YT(I,J-1))
      AA(I)=A(I,J-1)+FACT*(A(I,J)-A(I,J-I))
      TR=TT(I,J-I)+FACT*(TT(I,J)-TT(I,J-1))
      I2=J
      II=J-1
      GO TO 890
880   CALL AREAP(I,YO)
      TR=FACI*TT(I,I1)+FAC2*TT(I,I2)+FAC3*TT(1,I3)
890   AR=AA(I)
      A2=AR*AR
      F=QG2*TR-AR*A2
      DF=(QG2*(TT(I,I2)-TT(I,I1))-3.*A2*(A(I,I2)-A(I,I1)))/(YT(I,I2)-YT(
     *I,II))
      DIF=F/DF
      YO=YO-DIF
      IF(YO .LT. O.) YO=.3*(Q(1)**.4)
      NCT=NCT+I
      IF(ABS(DIF) .GT. .001 .AND. NCT .LT. 10) GO TO 850
      IF(NCT .EQ. 10) WRITE(IOUT,820) NCT,I,DIF,YO
      YC(I)=YO
      PR=FAC1*P(I,II)+FAC2*P(I,I2)+FAC3*P(I,I3)
      VI(1)=Q(I)/AR
      DEV1=3.*PR/AR
      REY(1)=Q(I)*DEVI/PR
      CH(I)=1.85*REY(1)**.5166
      QC2=QG2*32.2/(CH(I)*CH(I))
C900   SC(1)=QC2*FN(I)**2/A2*(PR/AR)**1.333333
900   SC(I)=QC2*PR/(A2*AR)
910   WRITE(IOUT,920) (YC(I),I=1,NSO)
920   FORMAT( 'O CRITICAL OEPTHS AT SECTIONS',/,(1H ,13F10.4))
      WRITE(IOUT,930) (SC(1),I=1,NSO)
930   FORMAT('O CRITICAL SLOPES AT SECTIONS',/,(1H ,13F10.6))
      WRITE(IOUT,940) (AA(I),I=1,NSO)
940   FORMAT('O AREAS CORRESPONDING TO CRITICAL DEPTH',/,(1H ,13F10.2))
      WRITE(IOUT,950) (VI(I),I=1,NSO)
950   FORMAT('O VELOCITIES CORRESPONDING TO CRITICAL OEPTH',/,(1H ,13F10
     *.3))
      WRITE(IOUT,955) (REY(I),I=I,NSO)
955   FORMAT('O REYNOLD''S NUMBERS CORRESPONDING TO CRITICAL DEPTH',/,(1
     *H,I3F10.2))
      WRITE(IOUT,956) (CH(I),I=1,NSO)
956   FORMAT('O CHEZY''S NUMBERS CORRESPONDING TO CRITICAL DEPTH',/,(1H,
     *13F10.2))
C  SOLUTION OF NORMAL DEPTH BASED ON CHEZY EQUATION
```

```
      IF(ITRAPE .EQ. 0) GO TO 1010
      DO 1000 I=1,NSD
      YO=SQRT(Q(1)/(10.*S(I)*B(1)))
      IF(S(1) .GT. 1.E-12)  GO TO 960
      YN(I)=0.
      GO TO 1000
960   IF(Q(I) .GT. .01) GO TO 970
      YN(I)=0.
      AA(I)=.001
      GO TD  1000
970   FM2=2.*FM(1)
      QG2=Q(I)**2
C     QCN=FN(1)*Q(1)/1.49
      CTS=10.6489*S(I)
C     SQS=SQRT(S(I))
C     S53=1.6666667*SQS
      S1DS=2.*SQRT(FM(I)**2+1.)
C      QCN2=.6666667*QCN
      CTSQ=CTS*Q(I)**1.0332
      NCT=0
980   PR=B(1)+SIDS*YO
      AR=(B(1)+FM(I)*YO)*YO
      A19=AR**1.9668
      A09=AR**.9668
C     P23=PR**.66666667
C     A23=AR**.66666667
C     F=QCN*P23-AR*A23*SQS
      F=QG2*PR-CTSQ*A19
C     DF=QCN2*SIDS*P23/PR-S53*A23*(B(I)+FM2*YO)
      QU1=1.9668*CTSQ*A09
      DF=QG2*S1DS-QU1*(B(I)+FM2*YO)
      DIF=F/DF
      YO=YO-DIF
      NCT=NCT+1
      IF(ABS(DIF) .GT. .0001 .AND. NCT .LT. 10) GO TO 980
      IF(NCT .EQ. 10) WRITE(1OUT,990) I,D1F,YO
990   FORMAT(' FAILED TO CONVERGE FDR SECTION,',I5,' DIF=',E10.4,'  YO='
     *,F10.3)
      YN(I)=YO
      AA(1)=AR
      V1(I)=Q(I)/AR
      OEVI=3.*PR/AR
      REY(I)=Q(I)*DEVI/PR
      CH(1)=1.85*REY(I)**.5166
1000  CONTINUE
      GO TO 1120
1010  I1=1
      12=2
      13=3
      OO 1110 I=1,NSO
      YO=SQRT(Q(1)/(10.*S(I)*B(I)))
      IF(S(1) .GT. 1.E-12)  GO TO 1020
      YN(I)=0.
      GO TO 1I10
1020  IF(Q(I) .GT. .01) GO TO 1030
      YN(1)=0.
       GO TO 1110
C1030 QCN=FN(I)*Q(I)/1.49
1030  QG2=Q(1)**2
      IF(S(I) .GT. 0.) GO TO I040
      YN(I)=.00I
      GO TO 1110
C1040 SQS=SQRT(S(1))
1040  CTS=10.6489*S(I)
:C    S53=1.66666667*SQS
|C    QCN2=.66666667*QCN
      CTSQ=CTS*Q(I)**1.0332
      NCT=0
      MCT=1
1050  IF(L1NTER .EQ. 0) GO TO 1080
      OO 1060 KJ=2,NP
      J=KJ
      IF(YT(I,J) .GE. YO) GO TO 1070
1060  CONTINUE
1070  FACT=(YO-YT(I,J-1))/(YT(I,J)-YT(I,J-1))
      AR=A(1,J-1)+FACT*(A(I,J)-A(I,J-1))
      AA(I)=AR
      PR=P(1,J-1)+FACT*(P(I,J)-P(I,J-1))
      12=J
      I1=J-1
      GO TO 1090
1080  CALL AREAP(I,YO)
      AR=AA(1)
      PR=FAC1*P(I,I1)+FAC2*P(I,12)+FAC3*P(I,I3)
C1090 P23=ABS(PR)**.6666667
1090  A19=AR**1.968
      A09=AR**.9668
C     A23=ABS(AR)**.6666667
C     F=QCN*P23-AR*A23*SQS
      F=QG2*PR-CTSQ*A19
      QU1=1.9668*CTSQ*A09
      DF=QG2*(P(I,12)-P(I,11))/(YT(I,I2)-YT(I,11))-QU1*(A(I,I2)-A(I,11)
     */(YT(1,I2)-YT(I,I1))
C     DF=(QCN2*P23*(P(1,I2)-P(I,11))/PP-S53*A23*(A(I I2)-A(I,I1)))/(YT(
C    *I,I2)-YT(I,I1))
      DIF=F/DF
      YO=YO-D1F
      NCT=NCT+1
      IF(ABS(DIF) .GT. .001 .AND. NCT .LT. 10) GO TO 1050
      IF(NCT .EQ. I0) WRITE(IOUT,990) 1,DIF,YO
1100  YN(I)=YO
      V1(I)=Q(1)/AA(1)
      DEVI=3.*PR/AR
      REY(I)=Q(I)*DEV1/PR
      CH(I)=1.85*REY(I)**.5166
1110  CONTINUE
1120  WRITE(IOUT,1130) (YN(I),I=1,NSO)
1130  FORMAT('O NORMAL OEPTHS AT SECTIONS',/,(1H ,13F10.3))
      WRITE(IOUT,1140) (AA(I),I=1,NSO)
1140  FORMAT('O AREAS CORRESPONOING TO NORMAL DEPTHS',/,(IH ,13F10.3)
      WRITE(IOUT,1150) (V1(I),I=1,NSO)
1150  FORMAT('OVELOCITIES CORRESPONDING TO NORMAL OEPTHS',/,(1H ,13F10.3
     *))
      WRITE(1OUT,1155) (REY(I),1=1,NSO)
1155  FORMAT('O REYNOLO''S NUMBERS CORRESPONDING TO NORMAL DEPTHS',/,(1H
     *,13F10.2))
      WRITE(IOUT,1157) (CH(I),I=1,NSO)
1157  FORMAT('O CHEZY''S NUMBERS CORRESPONDING TO NORMAL DEPTH',/,(1H,13
     *F10.2))

      DO 1170 I=1,NSO
      SUBCI=SUBC
      IF(SC(I) .LT. S(1)) SUBC1=.FALSE.
      IF(SUBC1 ) GO TO 1170
      WRITE(1OUT,1160) I
1160  FORMAT('THIS PROGRAM ASSUMES DEBRIS FLOW IN NATURAL CHANNELS IN
     *WHICH FLOW MUST BE SUB OR CRITICAL CHECK SECTION',I2)
1170  CONTINUF
      IF(MYSTRT .EQ. 0) GO TO 1270
      ELEV=0.
      EL1=YN(1)+V1(1)**2/64.4
      I1=0
      DO 1180 I=2,NSO
      1M=I-1
      ELEV=ELEV-XINC2*(S(I)-S(IM))
      EL=ELEV+Y(I)+V1(1)**2/64.4
      IF(EL .LT. EL1) GO TO 1180
      11=I
      ELM=EL
1180  EL1=EL
      IF(1TRAPE) 1200,1200,1190
1190  AR=(B(NSTART)+YSTART*FM(NSTART))*YSTART
      GO TO 1240
1200  IF(LINTER .EQ. 0) GOT O 1230
      K=NSTART
      DO 1210 KJ=2,NP
      J=KJ
      IF(YT(K,J) .GE. YSTART) GO TO 1220
1210  CONTINUE
1220  FACT=(YSTART-YT(K,J-1))/(YT(K,J)-YT(K,J-1))
      AR=A(K,J-1)+FACT*(A(K,J)-A(K,J-1))
      AA(K)=AR
      GOTO 1240
1230  CALL AREAP(NSTART,YSTART)
      AR=AA(NSTART)
1240  ELE1=0.
      IF(NSTART .EQ. NSD) ELE1=ELEV
      EL1=ELE1+YSTART+(Q(NSTART)/AR)**2/64.4
      IF(EL1 .GT. ELM) GO TO 1270
      YNMAX=YN(II)+.005
      WRITE(IOUT,1250) II,YNMAX,YSTART,ELM
1250  FORMAT(' YSTART IS NOT LARGE ENOUGH TO ACT AS A CONTROL -- CONTROL
     * IS AT SECTION',I3,3F10.3)
1260  IF(II .LT. 2 .OR. II .GT. NSO-2) GO TO 1270
      IVARR=I
      YSTART=YNMAX
      Y(II)=YNMAX
      NSTART=1I
      NSINC=-1
      MCURVE=1
      NEND=1
      Y(NSTART)=YSTART
      CALL VARIED
      NSTART=I1
      NS1NC=1
      NENO=1
      MCURVE=2
      IVARR=0
      Y(NSTART)=YSTART
      CALL VARIED
1270    IF(YSTART .LT. 1.E-4) YSTART=YN(NSTART)+1.E-3
      Y(NSTART)=YSTART
      IF(YSTART .GT. YC(NSTART)) GO TO I280
      MCURVE=3
      GO TO 1300
1280  IF(YSTART .GT. YN(NSTART)) GO TO 1290
      MCURVE=2
      GO TO 1300
1290  MCURVE=1
1300  CALL VARIED
      IF(IUNSTE .EQ. 0) GO TO 1350
      IF(1TRAPE .GT. 0) GO TO  1320
      WRITE(IOUT,1310)
1310  FORMAT(' UNSTEADY SOLUTION SUBROUTINE HAS BEEN WRITTEN TO ACCOMMOD
     *ATE ONLY TRAPEZOIOAL CHANNELS - NO UNSTEAOY SOL. IS THEREFORE POSS
     *IBLE')
      GO TO 1350
1320  WRITE(IOUT,1330)
1330  FORMAT('D UNSTEADY SOLUTION BEGINS')
      CALL TRANST
      GO TO 1350
1340  STOP
1350  WRITE(1OUT,1360)
1360  FORMAT('OOO YOU WANT TO SOLVE ANOTHER PROBLEM? Y OR N',/)
      READ(INPUT,120) PAR
      IF(PAR .EQ.'N       ') STOP
      GO TO 25
      END
      SUBROUTINE NAMEL1(NAME,NAMES,IVAR,RVAR,NINT,NREAL,NTOT)
      COMMON BI(10),FMI(10),REY(40),B(40),FM(40),CH(40),SI(10),S(40),
     *XI(10),YI(10,10),QO,TI(10,10),TT(30,10),X(40),AI(10,10),PI(10,10),
     *A(30,10),P(30,10),YC(40),SC(40),YN(40),YT(30,10),Y(40),AA(40),Q(40
     *),PP(40),TOP(40),VI(40),FAC1,FAC2,FAC3,XINC,XBEG,ERR,QC2,QG2,DELX,
     *DEL2,OEL32,ROX4,RDX3,OXG,NSO,1TRAPE,NP,NSTART,NSINC,NEND,MCURVE,
     *I1,I2,I3,MCT,MYSTRT,IVARR,ELEVB(10),NSII,LINTER,NCONTT,ELB(40),NPR
     *,1NPUT,IOUT
```

```
C  This subroutine is designed to replace the NAMELIST of FORTRAN.
C
C  THE ARGUMENTS IN THE SUBROUTINE HAVE THE FOLLOWING MEANINGS:
C      1.  NAME is the name of the NAMELIST.
C      2.  NAMES is an array NTOT long that contains the names of the
C      NAMELIST variables.  These variables must  be arranged with INTEGERS
C      first and REALS thereafter.  The number of integer variables = NINT.
C      The number of real variables = NREAL.
C      3. IVAR is an integer array that will contain the integer
C      variables in the NAMELIST in the order in which they are given in NAI
C      4. RVAR  is a real array that will contain the real variables in the
C      order in which they are given in NAMES after the last integer variab
C      the first real variable will be placed in RVAR(1) and the last in
C      RVAR(NTOT-NINT).
C      5. NINT = number of integer variables in NAMELIST.
C       6. NREAL = number of real variables in NAMELIST (listed after the i
C      7. NTOT= total number of variables in NAMELIST, i.e. NTOT=NINT+NREAL
C
C  IN THE CALLING PROGRAM THE FOLLWOING NEEOS TO BE OONE:
C      1.  Replace the NAMELIST declaration (NAMELIST/SPECIF/ list ) with
C      a  CHARACTER declaration statement that places the NAMELIST variable
C      in the array NAMES.  For example:
C      CHARACTER*6 NAMES(4)/'NUNIT','NFLOW','PEAKF','VISC'/
C      2.Include the NAMELIST NAME in a CHARACTER declaracter and give it
C      the names of the NAMELIST  variables, i.e.
C      CHARACTER*6 NAME/'SPECIF'/
C      3   Add an EQUIVALENCE statement that equivalences each integer vari
C      in the NAMELIST to the postions in the integer array IVAR in the
C      same order as they appear in the NAMES list.  Also equivalence each
C      variable to the real array RVAR in the same order as they appear
C      in NAMES after the  integer variables.
C      4.  Provide values to NINT,NREAL and NTOT, i.e.
C       DATA NINT,NREAL,NTOT/2,2,4/
C      5.  Replace the NAMELIST READ i.e. READ(5,SPECIF)  with
C      a call to SUBROUTINE NAMELI (this subroutine), i.e.
C       CALL NAMELI(NAME,NAMES,IVAR,RVAR,NINT,NREAL,NTOT)
C    ************************************************************
      REAL RVAR(NREAL)
      INTEGER IVAR(NINT)
      CHARACTER*6 NAMES(NTOT),NAME,PAR
      CHARACTER*12 FMT
      CHARACTER*1 CARD1
      CHARACTER*80 CARO
      IIA=0
5     READ(1NPUT,10,END=99) CARO
10    FORMAT(A8D)
      I=1
      J=0
      IF(IIA .GT. 0) GD TO 40
15    IF(CARO(1:I) .NE. ' ') GO TO 20
      I=1+1
      IF(I .LT. 81) GO TO 15
      GO TO 5
20    IF(CARD(I:I) .EQ. '$' .OR. CARD(I:1) .EQ. '&') GO TO 30
      WRITE(IOUT,22)
22    FORMAT(' LOOKING FOR $ OR &')
       STOP
30    I=I+1
      J=1
      JJ=I+6
32    J=J+1
      IF(CARD(J:J) .EQ. ' ') GO TO 34
      IF(J .LT. JJ) GO TO 32
      WRITE(IOUT,33) CARD
33    FORMAT(' YOU MUST LEAVE A BLANK AFTER NAMELIST NAME. YOU GAVE'
     *,/,A80)
34    J=J-1
      IF(CARD(I:J) .EQ. NAME) GO TO 40
      WRITE(1OUT,35) NAME, CARD(1:J)
35    FORMAT(' YOU SPELLED ',A6,' AS ',A6)
      STOP
40    J=J+1
      CARD1=CARD(J:J)
      IF(J .GT. 79) GO TO 5
      IF(CARD1 .NE.'$' .AND. CARD1 .NE.'&') GO TO 42
      1=J
      GO TO 310
42    IF(CARD1 .EQ.' ' .OR. CARD1 .EQ.',') GO TO 40
45    I=J-1
      JJ=1+7
50    I=I+1
      IF(I .GT. JJ) GO TO 410
      IF(I .GT.79) GO TO 5
      CARD1=CARD(I:1)
      IF(CARD1 .EQ. '$' .OR. CARD1 .EQ. '&') GO TO 310
      IF(CARD1 .NE. '=' .AND. CARD1 .NE. ' ') GO TO 50
      I=I-1
      PAR=CARD(J:I)
      DD 60 K=1,NTOT
      IF(NAMES(K) .EQ. PAR) GO TO 80
60    CONTINUE
      WRITE(1OUT,70) PAR
70    FORMAT(1H ,A6,' IS AN INVALIO OPTION NAME')
      STOP
80    KK=K
85     I=I+2
82    IF(CARD(I.I) .NE. ' ' .AND. CARD(I:I) .NE. '=') GO TO 86
      I=1+I
      GD TO 82
86    J=I
      IF(J .GT. 79) GO TO 5
90    J=J+1
      IF(J .GT. 80) GO TO 100
      CARD1=CARD(J:J)
      IF(CARD1 .EQ. ' ' .OR. CARD1 .EQ.',') GO TO 100
      GO TO 90
100   IJ=J-I
      ENCOOE(12,110,FMT) 1,1J
110   FORMAT('(T',I2,',F',I2,'.0) ')
      DECODE(J,FMT,CARD) FVALUE
      IF(KK .GT. NINT) GO TO 120
      IVAR(KK)=FVALUE
      GO TO 300
120   I1=KK-NINT
      RVAR(I1)=FVALUE
300   IIA=1
      IF(J .GT. 79) GO TO 5
      GO TO 40
310   IF(CARD(I:I+3).EQ.'$END' .OR. CARD(I:I+3) .EQ.'&END') RETURN
      WRITE(IOUT,320) NAME,CARO(I:I+3)
320   FORMAT(1X,A6,' LIST MUST END WITH A $END OR &END.  YOU ENDED WITH
     * ',A4,/'  ONLY PREVIOUSLY GIVEN OPTIONS WILL BE CHANGED FROM DEFAULT
     * VALUES')
      RETURN
99    WRITE(IOUT,330)
330   FORMAT(' NO $END OR &END  FOUND  -- STOP')
      STOP
410   WRITE(IOUT,420) CARD(J:J),CARD
420   FORMAT(' VARIABLE ',A7, ' MORE THAN 6 CHAR. ',/,A80)
      STOP
      END
      SUBROUTINE AREAP(I,YO)
      COMMON BI(10),FMI(10),REY(40),B(4 ),FM(40),CH(40),SI(10),S(40),
     *XI(10),YI(10,10),QO,TI(10,10),TT(30,10),X(40),AI(10,10),PI(10,10),
     *A(30,10),P(30,10),YC(40),SC(4D),YN(40),YT(30,10),Y(40),AA(40),Q(40
     *),PP(40),TOP(40),V1(40),FAC1,FAC2,FAC3,XINC,XBEG,ERR,QC2,QG2,DELX,
     *DEL2,DEL32,RDX4,RDX3,DXG,NSO,1TRAPE,NP,NSTART,NSINC,NEND,MCURVE,
     *I1,I2,I3,MCT,MYSTRT,IVARR,ELEVB(10),NSI1,LINTER,NCONTT,ELB(40),NPR
     *,INPUT,IOUT
      IF(YO .GT. 1.E-6) GO TO 10
      AA(I)=.001
      GO TO 50
10    IF(YO .LE. .5*(YT(I,I2)+YT(I,I3))  .OR. I3 .EQ. NP) GO TO 20
      I1=I1+1
      I2=I1+1
      I3=I2+1
      MCT=1
      GO TO 10
20    IF(YO .GE. .5*(YT(I,I1)+YT(I,I2)) .OR. I1 .EQ. 1) GO TO 30
      I1=I1-1
      I2=I1+1
      I3=I2+1
      MCT=1
      GO TD 20
30    IF(MCT .EQ. 0) GO TO 40
      DN1=(YT(I,I1)-YT(I,I2))*(YT(I,I1)-YT(I,I3))
      ON2=(YT(I,I2)-YT(I,I1))*(YT(I,I2)-YT(I,I3))
      DN3=(YT(I,I3)-YT(I,I1))*(YT(I,I3)-YT(I,I2))
      MCT=0
40    FAC1=(YO-YT(I,I2))*(YO-YT(I,I3))/DN1
      FAC2=(YO-YT(I,I1))*(YO-YT(I,I3))/ON2
      FAC3=(YO-YT(I,I1))*(YO-YT(I,I2))/DN3
      AA(I)=FAC1*A(I,I1)+FAC2*A(I,I2)+FAC3*A(I,I3)
50    RETURN
      END
      SUBROUTINE BAND(N,MI1)
      COMMON BI(10),FMI(10),REY(40),B(40),FM(40),CH(40),SI(10),S(40),
     *XI(10),YI(10,10),QO,TI(10,10),TT(30,10),X(40),AI(10,10),PI(10,10),
     *A(30,10),P(30,10),YC(40),SC(40),YN(40),YT(30,10),Y(40),AA(40),Q(40
     *),PP(40),TOP(40),V1(40),FAC1,FAC2,FAC3,XINC,XBEG,ERR,QC2,QG2,DELX,
     *OEL2,DEL32,RDX4,RDX3,DXG,NSO,ITRAPE,NP,NSTART,NSINC,NEND,MCURVE,
     *I1,I2,I3,MCT,MYSTRT,IVARR,ELEVB(10),NSII,LINTER,NCONTT,ELB(40),NPR
     *,INPUT,IOUT
      COMMON C(80,6),V(80)
      GO TO (10,10,20,20,10,10,20,20),MI1
10    K4=4
      GO TO 30
20    K4=5
30    DO 100 K=1,2
      KP=K+1
      K1=K4-K
40    DO 90 I=K1,N
      IM=I-1
      FAC=C(I,K)/C(IM,KP)
      IF(MOD(I,2)) 50,50,60
50    M=5
      GO TO 70
60    M=4
70    DO 80 J=KP,M
80    C(I,J)=C(I,J)-FAC*C(IM,J+1)
90    V(I)=V(I)-FAC*V(IM)
100   CONTINUE
      M1=I
      I=N-1
      V(N)=V(N)/C(N,3)
      GO TO(110,110,120,140,130,130,120,140),MI1
110   II=NSO-1
      Q(NSO)=V(N)
      V(I)=(V(I)-V(N)*C(I,4))/C(I,3)
      Q(II)=V(I)
      IM=I-1
      V(IM)=(V(IM)-C(IM,4)*V(I)-C(IM,5)*V(N))/C(IM,3)
      Y(II)=V(IM)
      GO TO 150
120   II=NSO-1
      Q(II)=V(N)
      V(I)=(V(1)-V(N)*C(I,4))/C(I,3)
      Y(II)=V(1)
      I=N
      MI=3
      GO TO 150
130   Y(NSO)=V(N)
      V(I)=(V(I)-V(N)*C(I,4))/C(I,3)
      II=NSO-1
      Q(II)=V(1)
      IM=I-1
      V(IM)=(V(IM)-C(IM,4)*V(I)-C(IM,5)*V(N))/C(IM,3)
      Y(II)=V(IM)
      GO TO 150
140   Y(NSO)=V(N)
      V(I)=(V(I)-V(N)*C(I,4))/C(I,3)
      O(NSO)=V(I)
```

```
      II=NSO
      I=N
      MI=3
150   IE=I
      IP=IE-1
      I=IP-1
      IM=I-1
      II=II-1
      V(I)=(V(I)-C(I,4)*V(IP)-C(I,5)*V(IE))/C(I,3)
      V(IM)=(V(IM)-C(IM,4)*V(I)-C(IM,5)*V(IP)-C(IM,6)*V(IE))/C(IM,3)
      Q(II)=V(I)
      Y(II)=V(IM)
      IF(IM .GT. MI) GO TO 150
      IF(MI .EQ. 1) RETURN
      V(2)=(V(2)-C(2,4)*V(3)-C(2,5)*V(4))/C(2,3)
      IF(MII .GT. 6) GO TO 160
      Q(1)=V(2)
      RETURN
160   Y(1)=V(2)
      RETURN
      END
      FUNCTION DYX(I)
      COMMON BI(10),FMI(10),REY(40),B(40),FM(40),CH(40),SI(10),S(40),
     *XI(10),YI(10,10),QO,TI(10,10),TT(30,10),X(40),AI(10,10),PI(10,10),
     *A(30,10),P(30,10),YC(40),SC(40),YN(40),YT(30,10),Y(40),AA(40),Q(40
     *),PP(40),TOP(40),VI(40),FAC1,FAC2,FAC3,XINC,XBEG,ERR,QC2,QG2,DELX,
     *DEL2,DEL32,RDX4,ROX3,DXG,NSO,ITRAPE,NP,NSTART,NSINC,NEND MCURVE,
     *I1,I2,I3,MCT,MYSTRT,IVARR,ELEVB(10),NSII,LINTER,NCONTT,ELB(40),NPR
     *,INPUT,IOUT
      QG2=Q(I)**2
C     QC2=QG2/2.22
      QG2=QG2/32.2
      Q103=Q(I)**1.0332
      IF(ITRAPE .EQ. 0) GO TO 50
      AR=(B(I)+FM(I)*Y(I))*Y(I)
      A2=AR*AR
      TR=B(I)+2.*FM(I)*Y(I)
      PR=B(I)+2.*Y(I)*SQRT(FM(I)**2+1.)
      IF(I .EQ. 1) GO TO 10
      IF(I .EQ. NSO) GO TO 20
      DEL2=2.*XINC
      IP=I+1
      IM=I-1
      DAX=(B(IP)-B(IM)+Y(I)*(FM(IP)-FM(IM)))*Y(I)/DEL2
      DQX=(Q(IP)-Q(IM))/DEL2
      GO TO 30
10    DAX=(B(2)-B(1)+Y(1)*(FM(2)-FM(1)))*Y(1)/XINC
      DQX=(Q(2)-Q(1))/XINC
      DQXF=(Q(2)+Q(1))*DQX/(64.4*A2)
      GO TO 40
20    DAX=(B(NSO)-B(NSO-1)+Y(NSO)*(FM(NSO)-FM(NSO-1)))*Y(NSO)/XINC
      DQX=(Q(NSO)-Q(NSO-1))/XINC
30    DQXF=(Q(I)+Q(IM))*DQX/(64.4*A2)
40    A3=AR*A2
      A103=AR**1.0332
      CH2=10.6489*Q103/A103
      IF(DQX .GT. 0.0) DQXF=2.*DQXF
C     SF=QC2*FN(I)**2(PR/AR)**1.3333333333/A2
      SF=(32.2*QG2*PR)/(A3*CH2)
      DYX=(S(I)-SF+QG2/A3*DAX-DQXF)/(1.-QG2*TR/A3)
      RETURN
50    IF(LINTER .EQ.0) GO TO 90
      DO 60 J=2,NP
      IF(YT(I J)-Y(I)) 60,70,70
60    CONTINUE
70    FACT=(Y(I)-YT(I,J-1))/(YT(I,J)-YT(I,J-1))
      AR = A(I,J-1)+FACT*( A(I,J)- A(I,J-1))
      TR =TT(I,J-1)+FACT*(TT(I,J)-TT(I,J-1))
      PR = P(I,J-1)+FACT*( P(I,J)- P(I,J-1))
      A2=AR*AR
      IF(I .EQ. 1) GO TO 80
      IM=I-1
      ARM=A(IM,J-1)+FACT*(A(IM,J)-A(IM,J-1))
      DAX=(AR-ARM)/(X(I)-X(IM))
      DQX=(Q(I)-Q(IM)) /(X(I)-X(IM))
      DQXF=(Q(I)+Q(IM))*DQX/(64.4*A2)
      GOTO 40
80    ARP=A(2,J-1)+FACT*(A(2,J)-A(1,J-1))
      DAX=(ARP-AR)/(X(2)-X(1))
      DQX=(Q(2)-Q(1))/(X(2)-X(1))
      DQXF=(Q(2)+Q(1))*DQX/(64.4*A2)
      GO TO 40
90    IF(Y(I) .LE. .5*(YT(I,I2)+YT(I,I3)) .OR. I3 .EQ. NP) GO TO 100
      I1=I1+1
      I2=I2+1
      I3=I3+1
      MCT=1
      GO TO 50
100   IF(Y(I) .GE. .5*(YT(1,I1)+YT(I,I2)) .OR. I1 .EQ. 1) GO TO 110
      I1=I1-1
      I2=I2-1
      I3=I3-1
      MCT=1
      GO TO 100
110   IF(MCT .EQ. 0) GO TO 120
      DN1=(YT(I,I1)-YT(I,I2))*(YT(I,I1)-YT(I,I3))
      DN2=(YT(I,I2)-YT(I,I1))*(YT(I,I2)-YT(I,I3))
      DN3=(YT(I,I3)-YT(I,I1))*(YT(I,I3)-YT(I,I2))
120   FAC1=(Y(I)-YT(I,I2))*(Y(I)-YT(I,I3))/DN1
      FAC2=(Y(I)-YT(I,I1))*(Y(I)-YT(I,I3))/DN2
      FAC3=(Y(I)-YT(I,I1))*(Y(I)-YT(I,I2))/DN3
      AR=FAC1*A(I,I1)+FAC2*A(I,I2)+FAC3*A(I,I3)
      A2=AR*AR
      TR=FAC1*TT(I,I1)+FAC2*TT(I,I2)+FAC3*TT(I,I3)
      PR=FAC1* P(I,I1)+FAC2* P(I,I2)+FAC3* P(I,I3)
      DAX=(AR-FAC1*A(IM,I1)-FAC2*A(IM,I2)-FAC3*A(IM,I3))/(X(I)-X(IM))
      GO TO 30
      END
      SUBROUTINE VARIED
      COMMON BI(10),FMI(10),REY(40),B(40),FM(40),CH(40),SI(10),S(40),
     *XI(10),YI(10,10),QO,TI(10,10),TT(30,10),X(40),AI(10,10),PI(10,10),
     *A(30,10),P(30,10),YC(40),SC(40),YN(40),YT(30,10),Y(40),AA(40),Q(40
     *),PP(40),TOP(40),VI(40),FAC1,FAC2,FAC3,XINX,XBEG,ERR,QC2,QG2,DELX,
     *DEL2,DEL32,RDX4,ROX3,DXG,NSO,ITRAPE,NP,NSTART,NSINC,NEND,MCURVE,
     *I1,I2,I3,MCT,MYSTRT,IVARR,ELEVB(10),NSII,LINTER,NCONTT,ELB(40),NPR
     *,INPUT,IOUT
      COMMON CGC(80,6),DY(80)
      JIJI=0
      J=NSTART
      CFAC=.2
      XINC=X(NSTART+NSINC)-X(NSTART)
      DIFFA=100.*(ELB(1)-ELB(NSO))/(XINC*FLOAT(NSO-1))
      IF(YN(J) .GT. 1.E-4) GO TO 10
      DY(J)=0.
      GO TO 20
10    DY(J)=DYX(J)
20    IF(ITRAPE .EQ. 0) GO TO 30
      AA(J)=(B(J)+FM(J)*Y(J))*Y(J)
      PP(J)=B(J)+2.*Y(J)*SQRT(FM(J)*FM(J)+1.)
      TOP(J)=B(J)+2.*Y(J)*FM(J)
      GO TO 70
30    IF(LINTER .EQ. 0) GOTO 60
      DO 40 KK=2,NP
      K=KK
      IF(YT(J,K) .GE. Y(J)) GO TO 50
40    CONTINUE
50    FACT=(Y(J)-YT(J,K-1))/(YT(J,K)-YT(J,K-1))
      AA(J)=A(J,K-1)+FACT*(A(J,K)-A(J,K-1))
      PP(J)=P(J,K-1)+FACT*(P(J,K)-P(J,K-1))
      TOP(J)=TT(J,K-1)+FACT*(TT(J,K)-TT(J,K-1))
      GO TO 70
60    CALL AREAP(J,Y(J))
      PP(J)=FAC1*P(J,I1)+FAC2*P(J,I2)+FAC3*P(J,I3)
70    JM=J
      J=J+NSINC
      NCT=0
      Y(J)=Y(JM)+XINC*DY(JM)*CFAC
      ZC1=Y(J)
      MCT=1
80    IF(YN(J) .GT. 1.E-4) GO TO 90
      DY(J)=0.
      GO TO 100
90    DY(J)=DYX(J)
100   DY1=.5*(DY(JM)+DY(J))
      NCT=NCT+1
      ZC=Y(JM)+XINC*DY1
      ZC1=ZC1+ZC
      IF(NCT .NE. 1) GO TO 110
      IF(ABS(ZC-Y(J)) .GT. DIFFA) ZC=ZC1/FLOAT(NCT+1)
      Y(J)=ZC
      GO TO 80
110   DIF=ZC-Y(J)
      IF(ABS(DIF)      .GT. DIFFA) ZC=ZC1/FLOAT(NCT+1)
      Y(J)=ZC
      IF(ABS(DIF) .GT. ERR .AND. NCT .LT. 10) GO TO 80
      CFAC=2./FLOAT(NCT)
      IF(MCURVE-2) 120,220,240
120   IF(Y(J) .GT. 1.02*YN(J)) GO TO 290
      IF(MCURVE.EQ.1 .AND.JIJI.EQ.0)WRITE(IOUT,130)NSTART,J,Y(J)
130   FORMAT(' M1 - CURVE BEGAN AT SECTION',I5,' AND ENDED AT SECTION',
     *I5,' WITH Y =',F10.3)
      JIJI=JIJI+1
      IF(NCONTT .EQ. 0) GO TO 290
      J=J-NSINC
140   J=J+NSINC
      Y(J)=YN(J)
      IF(ITRAPE .EQ. 0) GO TO 150
      AA(J)=(B(J)+FM(J)*Y(J))*Y(J)
      PP(J)=B(J)+2.*Y(J)*SQRT(FM(J)*FM(J)+1.)
      TOP(J)=B(J)+2.*Y(J)*FM(J)
      GO TO 190
150   IF(LINTER .EQ. 0) GO TO 180
      DO 160 KK=2,NP
      K=KK
      IF(YT(J,K) .GE. Y(J)) GO TO 170
160   CONTINUE
170   FACT=(Y(J)-YT(J,K-1))/(YT(J,K)-YT(J,K-1))
      AA(J)=A(J,K-1)+FACT*(A(J,K)-A(J,K-1))
      PP(J)=P(J,K-1)+FACT*(P(J,K)-P(J,K-1))
      TOP(J)=TT(J,K-1)+FACT*(TT(J,K)-TT(J,K-1))
      GO TO 190
180   CALL AREAP(J,Y(J))
      PP(J)=FAC1*P(J,I1)+FAC2*P(J,I2)+FAC3*P(J,I3)
      TOP(J)=FAC1*TT(J,I1)+FAC2*TT(J,I2)+FAC3*TT(J,I3)
190   IF(NSINC) 200,590,210
200   IF(J .GT. NEND) GO TO 140
      GO TO 370
210   IF(J .LT. NEND) GO TO 140
      GO TO 370
220   IF(Y(J) .GT. YC(J)+.05*(YN(J)-YC(J))) GO TO 290
      WRITE(IOUT,230) J,Y(J)
230   FORMAT(' CONTROL AT SECTION',I5,' CAUSING CRITICAL DEPTH',F10.3,
     *'.  EXAMINE RESULTS TO DETERMINE ITS NATURE.')
      WRITE(IOUT,380)(Y(I),I=NSTART,J)
      GO TO 590
240   AR=(B(J)+FM(J)*YN(J))*YN(J)
      VEL=Q(J)/AR
      YCONJ=.5*YN(J)*(SQRT(1.+.24845*VEL*VEL/YN(J))-1.)
      QG2=Q(J)**2/32.2
      FFM=QG2/AR+(.5*B(J)+FM(J)*YN(J)/3.)*YN(J)**2
      NCT=0
250   Y2=YCONJ*YCONJ
      AR=B(J)*YCONJ+FM(J)*Y2
      FAC=.5*B(J)+FM(J)*YCONJ/3.
      F=QG2/AR+FAC*Y2-FFM
      DF=2.*YCONJ*FAC+Y2*FM(J)/3.-QG2*(B(J)+2.*FM(J)*YCONJ)/(AR*AR)
      DIF=F/DF
      YCONJ=YCONJ-DIF
      NCT=NCT+1
```

```
      IF(ABS(DIF) .GT. .0001 .AND. NCT .LT. 7) GO TO 250
      IF(NCT .EQ. 7) WRITE(IOUT,260) J,DIF,YCONJ
260   FORMAT(' OID NOT CONVERGE IN DETERMINING CONJUGATE DEPTH AT SECTIO
     *N',I5,2E12.5)
      YT(J,3)=YCONJ
      IF(Y(J) .LT. YCONJ) GO TO 290
      WRITE(IOUT,270) (YT(I,3),I=NSTART,J)
270   FORMAT(' CONJUGATE DEPTHS TO NORMAL DEPTHS' ,(1H ,13F10.3))
      WRITE(IOUT,280) J,YCONJ ,YN(J)
280   FORMAT(' A HYDRAULIC JUMP OCCURS BEFORE SECTION',I5,'  TAKING DEPT
     *H FROM',F10.3,' TO NORMAL DEPTH',F10.3)
      MCURVE=0
      DY(J)=0.
      Y(J)=YN(J)
290   IF(ITRAPE .EQ. 0) GO TO 300
      AA(J)=(B(J)+FM(J)*Y(J))*Y(J)
      PP(J)=B(J)+2.*Y(J)*SQRT(FM(J)*FM(J)+1.)
      TOP(J)=B(J)+2.*Y(J)*FM(J)
      GO TO 340
300   IF(LINTER .EQ. 0) GO TO 330
      DO 310 KK=2,NP
      K=KK
      IF(YT(J,K) .GE. Y(J)) GO TO 320
310   CONTINUE
320   FACT=(Y(J)-YT(J,K-1))/(YT(J,K)-YT(J,K-1))
      AA(J)=A(J,K-1)+FACT*(A(J,K)-A(J,K-1))
      PP(J)=P(J,K-1)+FACT*(P(J,K)-P(J,K-1))
      TOP(J)=TT(J,K-1)+FACT*(TT(J,K)-TT(J,K-1))
      GOTO 340
330   CALL AREAP(J,Y(J))
      PP(J)=FAC1*P(J,I1)+FAC2*P(J,I2)+FAC3*P(J,I3)
      TOP(J)=FAC1*TT(J,I1)+FAC2*TT(J,I2)+FAC3*TT(J,I3)
340   IF(NSINC) 350,590,360
350   IF(J .GT. NEND) GO TO 70
      GO TO 370
360   IF(J .LT. NEND) GO TO 70
370   IF(IVARR .GT. 0) RETURN
C     WRITE(IOUT,100) (Y(I),I=1,NSO)
      IF(NPR.GT.0.OR.NSI1.GT.0)WRITE(IOUT,380) (Y(I),I=1,NSO)
380   FORMAT(' DEPTHS OF FLOW AT SECTIONS',/,(1H ,13F10.3))
C     WRITE(IOUT,300) (AA(I),I=1,NSO)
      IF(NPR.GT.0.OR.NSI1.GT.0)WRITE(IOUT,390) (AA(I),I=I,NSO)
390   FORMAT(' CROSS-SECTIONAL AREAS',/,(1H ,13F10.1))
      DO 400 I=I,NSO
      VI(I)=Q(I)/AA(I)
400   REY(I)=3.*VI(I)
C     WRITE(IOUT,303) (V1(I),I=I,NSO)
      IF(NPR.GT.0.OR.NSI1.GT.0)WRITE(IOUT,410) (V1(I),I=I,NSO)
410   FORMAT(' VELOCITY',/,(1H ,13F10.3))
C     WRITE(IOUT,301) (PP(I),I=1,NSO)
      IF(NPR.GT.0.OR.NSI1.GT.0) WRITE(IOUT,415) (REY(I),I=1,NSO)
415   FORMAT(' REYNOLDS NUMBERS FOR GVF',/,(1H,13F10.3))
      IF(NPR.GT.0.OR.NSI1.GT.0)WRITE(IOUT,420) (PP(I),I=1,NSO)
420   FORMAT(' WETTED PERIMETERS',/,(1H ,13F10.1))
C     WRITE(IOUT,302) (TOP(I),I=1,NSO)
      IF(NPR.GT.0.OR.NSI1.GT.0)WRITE(IOUT,430) (TOP(I),I=1,NSO)
430   FORMAT(' TOP WIDTH',/,(1H ,13F10.2))
      IF(NSI1 .GT. 0) RETURN
      DO 440 I=1,NSO
      I1=I+1
      IF(I .EQ. NSO) I1=I-1
440   DY(I)=ELB(I)+Y(I)
C     WRITE(IOUT,308) (DY(I),I=I,NSO)
      IF(NPR.GT.0) WRITE(IOUT,450) (DY(I),I=1,NSO)
450   FORMAT(' ELEV. OF HGL',/,(1H ,13F10.2))
      DO 460 I=1,NSO
460   DY(I)=DY(I)+V1(I)**2/64.4
C     WRITE(IOUT,309) (DY(I),I=1,NSO)
      IF(NPR.GT.0) WRITE(IOUT,470) (DY(I),I=I,NSO)
470   FORMAT(' ELEV. OF E.L.',/,(1H ,13F10.2))
      IREP=0
      I=NSO
480   J=I-1
      IF(DY(I) .LT. OY(J)) GO TO 520
      IREP=IREP+1
      K=J
490   K=K-1
      IF(K .EQ. 0) GO TO 500
      VHA=V1(I)**2
      VHA=VHA+VI(J)**2
      IF(DY(K) .GT. DY(I)) GO TO    500
      VHA=VHA+VI(K)**2
      GO TO 490
500   VHA=VHA/FLOAT(I-K+1)
      DHAV=(DY(K)-OY(K))/(FLOAT(I-K)*ABS(XINC))
      II=K+1
      DO 510 KK=II,J
510   DY(KK)=DY(KK-1)-DHAV*VI(KK)**2/VHA
      J=K
520   I=J
      IF(I .GT. 1) GO TO 480
      IF(IREP .EQ. 0) RETURN
      WRITE(IOUT,470) (DY(I),I=1,NSO)
      DO 530 I=I,NSO
      OY(I)=OY(I)-V1(I)**2/64.4
530   Y(I)=OY(I)-ELB(I)
      WRITE(IOUT,450) (DY(I),I=I,NSO)
      WRITE(IOUT,380) (Y(I),I=I,NSO)
      DO 570 I=I,NSO
      IF(LINTER .EQ. 0) GO TO 560
      DO 540 KK=2,NP
      K=KK
      IF(YT(I,K) .GT. Y(I)) GO TO 550
540   CONTINUE
550   FAC=(Y(I)-YT(I,K-1))/(YT(I,K)-YT(I,K-1))
      AA(I)=A(I,K-1)+FACT*(A(I,K)-A(I,K-1))
      PP(I)=P (I,K-1)+FACT*(P(I,K)-P(I,K-1))
      TOP(I)=TT(I,K-1)+FACT*(TT(I,K)-TT(I,K-1))
      GO TO 570
560   CALL AREAP(I,Y(I))
      PP(I)=FAC1*P(I,I1)+FAC2*P(I,I2)+FAC3*P(I,I3)
      TOP(I)=FAC1*TT(I,I1)+FAC2*TT(I,I2)+FAC3*TT(I,I3)
570   V1(I)=Q(I)/AA(I)
580   WRITE(IOUT,390)(AA(I),I=1,NSO)
      WRITE(IOUT,410)(V1(I),I=1,NSO)
      WRITE(IOUT,420)(PP(I),I=1,NSO)
      WRITE(IOUT,430)( TOP(I),I=1,NSO)
590   RETURN
      END
      SUBROUTINE YDET(I,W,W2)
C THIS SUBROUTINE IS IN THE ORIGINAL PROGRAM JEPPSON 1974
C  BUT FOR THE DEBRIS PROGRAM IT HAS NOTHING TO DO,SO YOU
C HAVE THE OPTION TO LEAVE IT IN OR OUT IT DOES NOT MAKE ANY
C DIFFERENCE.
      REAL W(30,15),W2(40)
      COMMON BI(10),FMI(10),REY(40),B(40),FM(40),CH(40),SI(10),S(40),
     *XI(10),YI(10,10),QO,TI(10,10),TT(30,10),X(40),AI(10,10),PI(10,10),
     *A(30,10),P(30,10),YC(40),SC(40),YN(40),YT(30,10),Y(40),AA(40),Q(40
     *),PP(40),TOP(40),V1(40),FACI,FAC2,FAC3,XINC,XBEG,ERR,QC2,QG2,DELX,
     *DEL2,DEL32,RDX4,RDX3,DXG,NSO,ITRAPE,NP,NSTART,NSINC,NEND,MCURVE,
     *I1,I2,I3,MCT,MYSTRT,IVARR,ELEVB(10),NSI1,LINTER,NCONTT,ELB(40),NPR
     *,INPUT,IOUT
      MCT=I
10    IF(W2(I) .LE. .5*(W(I,I2)+W(I,I3)) .OR. I3 .EQ. NY) GO TO 20
      I1=I1+1
      I2=I1+1
      I3=I2+1
      MCT=1
      GO TO 10
20    IF(W2(I) .GE. .5*(W(I,I1)+W(I,I2)) .OR. I1 .EQ. 1) GO TO 30
      I1=I1-1
      I2=I1+1
      I3=I2+1
      MCT=1
      GO TO 20
30    IF(MCT .EQ. 0) GO TO 40
      ON1=(W(I,I1)-W(I,I2))*(W(I,I1)-W(I,I3))
      ON2=(W(I,I2)-W(I,I1))*(W(I,I2)-W(I,I3))
      ON3=(W(I,I3)-W(I,I1))*(W(I,I3)-W(I,I2))
      MCT=0
40    FACI=(W2(I)-W(I,I2))*(W2(I)-W(I,I3))/ON1
      FAC2=(W2(I)-W(I,I1))*(W2(I)-W(I,I3))/DN2
      FAC3=(W2(I)-W(I,I1))*(W2(I)-W(I,I2))/DN3
      RETURN
      END
      SUBROUTINE TRANST
C  THIS SUBROUTINE HAS NOT BEEN WRITTEN YET.   IT IS INTENDED TO
C  OBTAIN THE SOLUTION OF DEBRIS FLOWS FOR UNSTEADY CONDITIONS.
      RETURN
      END
C THIS PROGRAM MAKE THE CALCULATION OF THE PARAMETERS Q2TPM AND SET
C Q IS THE DISCHARGE IN CUBICS FEET/SECOND, B IS THE CHANNEL BASE IN
C FEET,SO IS THE CHANNEL SLOPE,YO IS THE DEPTH AND C IS A CONSTANT
C EQUAL TO 10.6489 FOR THIS SPECIFIC KIND OF FLUID.
C-------------------------------------------------------------------
C-------------------------------------------------------------------
      REAL Q,B,SO,FM,YO,Q2TPM,SET,PM,AR
      DATA C/10.6489/
      TYPE*,'Q,B,SO,FM'
      ACCEPT*,Q,B,SO,FM
      Q10=Q**1.0332
      Q2=Q*Q
      DO YO=0,50.,.5
      PM=B+2.*YO*SQRT(FM**2+1.)
      Q2TPM=Q2*PM
      AR=B*YO+FM*YO**2
      AI9=AR**1.9668
      SET=C*AI9*Q10*SO
      PRINT*,YO,PM,AR,Q2TPM,SET
      TYPE*,YO,PM,AR,Q2TPM,SET
      END DO
      END
```

Appendix B. Example 1

Input Data for Example 1. Debris Flow

```
$ RUN MAIN
DO YOU WANT A DEFINITION OF NAMELIST IN SPECIF? Y OR N
N
DEFAULT OPTIONS ARE:
ITRAPE = 1 IOYES = 0 ERR = 0.00100 INFLOW = 1  MYSTRT = 0
IUNSTE = 1  LINTER = 1  NCONT = 0  NPR = 0
DO YOU WANT ANY OF THESE CHANGED? Y OR N
Y
GIVE CHANGED OPTIONS IN & SPECIFIC LIST
& SPECIF IUNSTE = 0  &  END
GIVE THE INPUT DATA AFTER THE NAME.  IF YOU DO NOT UNDERSTAND NAME WRITE,HELP
NSI
5
NSO
11
QO
100
XBEG
0
XEND
4000
YSTART
100
PROVIDE OUTPUT STA. NO. WHERE GVF IS TO BEG; I.E. 1 OR 11
11
```

Input Data for Example 1. Debris Flow (Continued)

```
PROVIDE 5 X-DIST. FOR 5 INPUT SECTIONS
0,1000, 2000, 3000, 4000
PROVIDE BOTTOM SLOPES FOR 5 INPUT SECTIONS
0.1, 0.05, 0.005, 0.001, 0.0005
PROBLEM SPECIFICATIONS
X  0.0  1000.0  2000.0  3000.0  4000.0
S  0.1000  0.00500  0.00500  0.00100  0.00050
IS THERE LATERAL INFLOW Y OR N
N
SQ  0.000  0.000  0.000  0.000  0.000
PROVIDE 5 BOTTOM WIDTHS, THEN 5 SIDE SLOPES
100, 200, 300, 400, 500, 0, 0, 0, 0, 0
B  100.000  200.000  300.000  400.000  500.000
M  0.000  0.000  0.000  0.000  0.000
HAVE YOU MADE ANY MISTAKES  Y OR N
N
WHERE SHOULD THE OUTPUT GO? 1) TTY IF TERM ONLY; 2) FILE NAME
```

```
SECTIONS ALONG CHANNEL
      0.0       400.0      800.0     1200.0     1600.0     2000.0     2400.0     2800.0
   3200.0      3600.0     4000.0

 DISCHARGE ALONG CHANNEL
   100.00      100.00     100.00     100.00     100.00     100.00     100.00     100.00
   100.00      100.00     100.00

 BOTTOM WIDTHS
  100.000     140.000    180.000    220.000    260.000    300.000    340.000    380.000
  420.000     460.000    500.000

 SLOPES OF SIDE OF CHANNEL
    0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000       0.000      0.000

 SLOPE OF CHANNEL BOTTOM AT SECTIONS
  0.10000     0.08000    0.06000    0.04100    0.02300    0.00500    0.00340    0.00180
  0.00090     0.00070    0.00050

 CRITICAL DEPTHS AT SECTIONS
   0.3143      0.2512     0.2124     0.1858     0.1662     0.1511     0.1390     0.1291
   0.1207      0.1136     0.1075

 CRITICAL SLOPES AT SECTIONS
 0.920379    1.030679   1.122495   1.201330   1.272320   1.336402   1.395091   1.449416
 1.500119    1.547756   1.592756

 AREAS CORRESP~NDING TO CRITICAL DEPTH
    31.43       35.16      38.24      40.89      43.23      45.34      47.27      49.05
    50.72       52.28      53.75

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
    3.181       2.844      2.615      2.445      2.313      2.206      2.116      2.039
    1.972       1.913      1.860

 REYNOLD'S NUMBERS CORRESPONDING TO CRITICAL DEPTH
     9.54        8.53       7.85       7.34       6.94       6.62       6.35       6.12
     5.92        5.74       5.58

 CHEZY'S NUMBERS CORRESPONDING TO CRITICAL DEPTH
     5.93        5.60       5.36       5.18       5.03       4.91       4.81       4.71
     4.63        4.56       4.50

 NORMAL DEPTHS AT SECTIONS
    0.978       0.926      0.946      1.039      1.285      2.612      2.988      3.915
    5.314       5.774      6.580

 AREAS CORRESPONDING TO NORMAL DEPTHS
   97.813     129.595    170.221    228.669    334.049    783.451   1015.885   1487.631
 2231.852    2655.847   3289.836

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
    1.022       0.772      0.587      0.437      0.299      0.128      0.098      0.067
    0.045       0.038      0.030

 REYNOLD'S NUMBERS CORRESPONDING TO NORMAL DEPTHS
     3.07        2.31       1.76       1.31       0.90       0.38       0.30       0.20
     0.13        0.11       0.09

 CHEZY'S NUMBERS CORRESPONDING TO NORMAL DEPTH
     3.30        2.85       2.48       2.13       1.75       1.13       0.99       0.81
     0.66        0.60       0.54
DEPTHS OF FLOW AT SECTIONS
    2.746      35.033     60.904     79.559     91.358     96.483     98.032     98.989
   99.485      99.779    100.000
CROSS-SECTIONAL AREAS
    274.6      4904.6    10962.7    17502.9    23753.1    28944.8    33331.0    37615.8
  41783.6     45898.5    50000.0
VELOCITY
    0.364       0.020      0.009      0.006      0.004      0.003      0.003      0.003
    0.002       0.002      0.002
REYNOLDS NUMBERS FOR GVF
    1.092       0.061      0.027      0.017      0.013      0.010      0.009      0.008
    0.007       0.007      0.006
WETTED PERIMETERS
    105.5       210.1      301.8      379.1      442.7      493.0      536.1      578.0
    619.0       659.6      700.0
TOP WIDTH
   100.00      140.00     180.00     220.00     260.00     300.00     340.00     380.00
   420.00      460.00     500.00
```

```
       0.0       400.0       800.0      1200.0      1600.0      2000.0      2400.0      2800.0
    3200.0      3600.0      4000.0

 DISCHARGE ALONG CHANNEL
    100.00      100.00      100.00      100.00      100.00      100.00      100.00      100.00
    100.00      100.00      100.00

 BOTTOM WIDTHS
   100.000     140.000     180.000     220.000     260.000     300.000     340.000     380.000
   420.000     460.000     500.000

 SLOPES OF SIDE OF CHANNEL
     0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
     0.000       0.000       0.000

 MANNINGS  N  FOR SECTIONS OF CHANNEL
     0.200       0.200       0.200       0.200       0.200       0.200       0.200       0.200
     0.200       0.200       0.200

 SLOPE OF CHANNEL BOTTOM AT SECTIONS
   0.10000     0.08000     0.06000     0.04100     0.02300     0.00500     0.00340     0.00180
   0.00090     0.00070     0.00050

 CRITICAL DEPTHS AT SECTIONS
    0.3143      0.2512      0.2124      0.1858      0.1662      0.1511      0.1390      0.1291
    0.1207      0.1136      0.1075

 CRITICAL SLOPES AT SECTIONS
  0.860462    0.923952    0.975427    1.019000    1.056960    1.090718    1.121197    1.149043
  1.174721    1.198583    1.220895

 AREAS CORRESPONDING TO CRITICAL DEPTH
     31.43       35.16       38.24       40.89       43.23       45.34       47.27       49.05
     50.72       52.28       53.75

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
     3.181       2.844       2.615       2.445       2.313       2.206       2.116       2.039
     1.972       1.913       1.860

 NORMAL DEPTHS AT SECTIONS
     0.601       0.524       0.491       0.488       0.525       0.761       0.793       0.898
     1.041       1.062       1.118

 AREAS CORRESPONDING TO NORMAL DEPTHS
    60.087      73.372      88.372     107.304     136.420     228.425     269.564     341.083
   437.119     488.743     538.957

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
     1.664       1.363       1.132       0.932       0.733       0.438       0.371       0.293
     0.229       0.205       0.179
DEPTHS OF FLOW AT SECTIONS
     1.746      34.991      60.881      79.543      91.347      96.474      98.026      98.985
    99.482      99.778     100.000
CROSS-SECTIONAL AREAS
     174.6      4898.7     10958.7     17499.5     23750.2     28942.3     33328.9     37614.2
   41782.5     45898.0     50000.0
VELOCITY
     0.573       0.020       0.009       0.006       0.004       0.003       0.003       0.003
     0.002       0.002       0.002
WETTED PERIMETERS
     103.5       210.0       301.8       379.1       442.7       492.9       536.1       578.0
     619.0       659.6       700.0
TOP WIDTH
    100.00      140.00      180.00      220.00      260.00      300.00      340.00      380.00
    420.00      460.00      500.00
```

```
SECTIONS ALONG CHANNEL
     0.0       400.0      800.0     1200.0     1600.0     2000.0     2400.0     2800.0
  3200.0      3600.0     4000.0

 DISCHARGE ALONG CHANNEL
  100.00      100.00     100.00     100.00     100.00     100.00     100.00     100.00
  100.00      100.00     100.00

 BOTTOM WIDTHS
 100.000     140.000    180.000    220.000    260.000    300.000    340.000    380.000
 420.000     460.000    500.000

 SLOPES OF SIDE OF CHANNEL
   0.000       0.000      0.000      0.000      0.000      0.000      0.000      0.000
   0.000       0.000      0.000

 MANNINGS  N  FOR SECTIONS OF CHANNEL
   0.035       0.035      0.035      0.035      0.035      0.035      0.035      0.035
   0.035       0.035      0.035

 SLOPE OF CHANNEL BOTTOM AT SECTIONS
 0.10000     0.08000    0.06000    0.04100    0.02300    0.00500    0.00340    0.00180
 0.00090     0.00070    0.00050

 CRITICAL DEPTHS AT SECTIONS
  0.3143      0.2512     0.2124     0.1858     0.1662     0.1511     0.1390     0.1291
  0.1207      0.1136     0.1075

 CRITICAL SLOPES AT SECTIONS
 0.026352  0.028296  0.029872  0.031207  0.032369  0.033403  0.034337  0.035189
 0.035976  0.036707  0.037390

 AREAS CORRESPONDING TO CRITICAL DEPTH
   31.43       35.16      38.24      40.89      43.23      45.34      47.27      49.05
   50.72       52.28      53.75

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
   3.181       2.844      2.615      2.445      2.313      2.206      2.116      2.039
   1.972       1.913      1.860

 NORMAL DEPTHS AT SECTIONS
   0.211       0.184      0.172      0.171      0.184      0.267      0.278      0.315
   0.365       0.373      0.392

 AREAS CORRESPONDING TO NORMAL DEPTHS
  21.054      25.734     31.012     37.665     47.890     80.167     94.615    119.716
 153.414     171.572    196.200

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
   4.750       3.886      3.225      2.655      2.088      1.247      1.057      0.835
   0.652       0.583      0.510
THIS PROGRAM ASSUMES NATURAL CHANNELS IN WHICH FLOW MUST BE SUBCRITICAL--ROUGHNE
SS MUST BE INCREASED AT SECTION
THIS PROGRAM ASSUMES NATURAL CHANNELS IN WHICH FLOW MUST BE SUBCRITICAL--ROUGHNE
SS MUST BE INCREASED AT SECTION
THIS PROGRAM ASSUMES NATURAL CHANNELS IN WHICH FLOW MUST BE SUBCRITICAL--ROUGHNE
SS MUST BE INCREASED AT SECTION
DEPTHS OF FLOW AT SECTIONS
   1.665      34.991     60.881     79.543     91.347     96.474     98.026     98.985
  99.482      99.778    100.000
CROSS-SECTIONAL AREAS
   166.5      4898.7    10958.7    17499.5    23750.2    28942.3    33328.9    37614.2
 41782.5     45898.0    50000.0
VELOCITY
   0.601       0.020      0.009      0.006      0.004      0.003      0.003      0.003
   0.002       0.002      0.002
WETTED PERIMETERS
   103.3       210.0      301.8      379.1      442.7      492.9      536.1      578.0
   619.0       659.6      700.0
TOP WIDTH
  100.00      140.00     180.00     220.00     260.00     300.00     340.00     380.00
  420.00      460.00     500.00
```

```
SECTIONS ALONG CHANNEL
       0.0     400.0     800.0    1200.0    1600.0    2000.0    2400.0    2800.0
    3200.0    3600.0    4000.0

 DISCHARGE ALONG CHANNEL
    100.00    100.00    100.00    100.00    100.00    100.00    100.00    100.00
    100.00    100.00    100.00

 BOTTOM WIDTHS
   100.000   140.000   180.000   220.000   260.000   300.000   340.000   380.000
   420.000   460.000   500.000

 SLOPES OF SIDE OF CHANNEL
     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
     0.000     0.000     0.000

 MANNINGS  N  FOR SECTIONS OF CHANNEL
     0.070     0.070     0.070     0.070     0.070     0.070     0.070     0.070
     0.070     0.070     0.070

 SLOPE OF CHANNEL BOTTOM AT SECTIONS
   0.10000   0.08000   0.06000   0.04100   0.02300   0.00500   0.00340   0.00180
   0.00090   0.00070   0.00050

 CRITICAL DEPTHS AT SECTIONS
    0.3143    0.2512    0.2124    0.1858    0.1662    0.1511    0.1390    0.1291
    0.1207    0.1136    0.1075

 CRITICAL SLOPES AT SECTIONS
  0.105407  0.113184  0.119490  0.124827  0.129478  0.133613  0.137347  0.140758
  0.143903  0.146826  0.149560

 AREAS CORRESPONDING TO CRITICAL DEPTH
     31.43     35.16     38.24     40.89     43.23     45.34     47.27     49.05
     50.72     52.28     53.75

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
     3.181     2.844     2.615     2.445     2.313     2.206     2.116     2.039
     1.972     1.913     1.860

 NORMAL DEPTHS AT SECTIONS
     0.319     0.279     0.261     0.260     0.279     0.405     0.422     0.478
     0.554     0.565     0.595

 AREAS CORRESPONDING TO NORMAL DEPTHS
    31.934    39.027    47.023    57.108    72.609   121.555   143.458   181.518
   232.616   260.141   297.480

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
     3.131     2.562     2.127     1.751     1.377     0.823     0.697     0.551
     0.430     0.384     0.336
DEPTHS OF FLOW AT SECTIONS
     1.673    34.991    60.881    79.543    91.347    96.474    98.026    98.985
    99.482    99.778   100.000
CROSS-SECTIONAL AREAS
     167.3    4898.7   10958.7   17499.5   23750.2   28942.3   33328.9   37614.2
   41782.5   45898.0   50000.0
VELOCITY
     0.598     0.020     0.009     0.006     0.004     0.003     0.003     0.003
     0.002     0.002     0.002
WETTED PERIMETERS
     103.3     210.0     301.8     379.1     442.7     492.9     536.1     578.0
     619.0     659.6     700.0
TOP WIDTH
    100.00    140.00    180.00    220.00    260.00    300.00    340.00    380.00
    420.00    460.00    500.00
```

```
SECTIONS ALONG CHANNEL
      0.0      400.0      800.0     1200.0     1600.0     2000.0     2400.0     2800.0
   3200.0     3600.0     4000.0

 DISCHARGE ALONG CHANNEL
   100.00     100.00     100.00     100.00     100.00     100.00     100.00     100.00
   100.00     100.00     100.00

 BOTTOM WIDTHS
  100.000    140.000    180.000    220.000    260.000    300.000    340.000    380.000
  420.000    460.000    500.000

 SLOPES OF SIDE OF CHANNEL
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000      0.000      0.000

 MANNINGS  N  FOR SECTIONS OF CHANNEL
    0.100      0.100      0.100      0.100      0.100      0.100      0.100      0.100
    0.100      0.100      0.100

 SLOPE OF CHANNEL BOTTOM AT SECTIONS
  0.10000    0.08000    0.06000    0.04100    0.02300    0.00500    0.00340    0.00180
  0.00090    0.00070    0.00050

 CRITICAL DEPTHS AT SECTIONS
   0.3143     0.2512     0.2124     0.1858     0.1662     0.1511     0.1390     0.1291
   0.1207     0.1136     0.1075

 CRITICAL SLOPES AT SECTIONS
 0.215115   0.230988   0.243857   0.254750   0.264240   0.272680   0.280299   0.287261
 0.293680   0.299646   0.305224

 AREAS CORRESPONDING TO CRITICAL DEPTH
    31.43      35.16      38.24      40.89      43.23      45.34      47.27      49.05
    50.72      52.28      53.75

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
    3.181      2.844      2.615      2.445      2.313      2.206      2.116      2.039
    1.972      1.913      1.860

 NORMAL DEPTHS AT SECTIONS
    0.396      0.345      0.324      0.322      0.346      0.502      0.523      0.592
    0.686      0.701      0.737

 AREAS CORRESPONDING TO NORMAL DEPTHS
   39.583     48.359     58.261     70.751     89.954    150.600    177.734    224.887
  288.197    322.248    368.550

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
    2.526      2.068      1.716      1.413      1.112      0.664      0.563      0.445
    0.347      0.310      0.271
DEPTHS OF FLOW AT SECTIONS
    1.684     34.991     60.881     79.543     91.347     96.474     98.026     98.985
   99.482     99.778    100.000
CROSS-SECTIONAL AREAS
    168.4     4898.7    10958.7    17499.5    23750.2    28942.3    33328.9    37614.2
  41782.5    45898.0    50000.0
VELOCITY
    0.594      0.020      0.009      0.006      0.004      0.003      0.003      0.003
    0.002      0.002      0.002
WETTED PERIMETERS
    103.4      210.0      301.8      379.1      442.7      492.9      536.1      578.0
    619.0      659.6      700.0
TOP WIDTH
   100.00     140.00     180.00     220.00     260.00     300.00     340.00     380.00
   420.00     460.00     500.00
```

Appendix C. Example 2

Input data for Example 2. Debris flow

```
$ RUN MAIN
DO YOU WANT A DEFINITION OF NAMELIST IN SPECIF?  Y OR N
N
DEFAULT OPTIONS ARE:
ITRAPE = 1 IOYES = 0 ERR = 0.00100 INFLOW = 1 MYSTRT = 0
IUNSTE = 1 LINTER = 1 NCONT = 0 NPR = 0
DO YOU WANT ANY OF THESE CHANGED? Y OR NO
Y
GIVE CHANGED OPTIONS IN & SPECIF LIST
&SPECIF IUNSTE = 0 &END
GIVE THE INPUT DATA AFTER THE NAME.  IF YOU DO NOT UNDERSTAND NAME WRITE,HELP
NSI
2
NSO
21
Q0
500
XBEG
0
XEND
1000
YSTART
10
PROVIDE OUTPUT STA.NO. WHERE GVG. IS TO BEG., I.E. 1 or 21
21
```

Input data for Example 2 (cont.)

```
PROVIDE 2-X DIST. FOR 2 INPUT SECTIONS
0,1000
PROVIDE BOTTOM SLOPES FOR 2 INPUT STATIONS
0.105, 0.105
PROBLEM SPECIFICATIONS
X 0.0  1000.0
S 0.10500  0.10500
IS THERE LATERAL INFLOW Y OR N
N
SQ  0.000  0.000
PROVIDE 2 BOTTOM WIDTHS, THEN 2 SIDE SLOPES
70, 70, 0, 0
B  70.000  70.000
M  0.000  0.000
HAVE YOU MADE ANY MISTAKES Y OR N
N
WHERE SHOULD THE OUTPUT GO? GIVE 1) TTY IF TERM ONLY; 2) FILE NAME
```

SECTIONS ALONG CHANNEL

0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0
400.0	450.0	500.0	550.0	600.0			
650.0	700.0	750.0	800.0	850.0	900.0	950.0	1000.0

DISCHARGE ALONG CHANNEL

500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00
500.00	500.00	500.00	500.00	500.00			
500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00

BOTTOM WIDTHS

70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000
70.000	70.000	70.000	70.000	70.000			
70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000

SLOPES OF SIDE OF CHANNEL

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000			
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

SLOPE OF CHANNEL BOTTOM AT SECTIONS

0.10500	0.10500	0.10500	0.10500	0.10500	0.10500	0.10500	0.10500
0.10500	0.10500	0.10500	0.10500	0.10500			
0.10500	0.10500	0.10500	0.10500	0.10500	0.10500	0.10500	0.10500

CRITICAL DEPTHS AT SECTIONS

1.1658	1.1658	1.1658	1.1658	1.1658	1.1658	1.1658	1.1658
1.1658	1.1658	1.1658	1.1658	1.1658			
1.1658	1.1658	1.1658	1.1658	1.1658	1.1658	1.1658	1.1658

CRITICAL SLOPES AT SECTIONS

0.480177	0.480177	0.480177	0.480177	0.480177	0.480177	0.480177	0.480177
0.480177	0.480177	0.480177	0.480177	0.480177			
0.480177	0.480177	0.480177	0.480177	0.480177	0.480177	0.480177	0.480177

AREAS CORRESPONDING TO CRITICAL DEPTH

81.61	81.61	81.61	81.61	81.61	81.61	81.61	81.61
81.61	81.61	81.61	81.61	81.61			
81.61	81.61	81.61	81.61	81.61	81.61	81.61	81.61

VELOCITIES CORRESPONDING TO CRITICAL DEPTH

6.127	6.127	6.127	6.127	6.127	6.127	6.127	6.127
6.127	6.127	6.127	6.127	6.127			
6.127	6.127	6.127	6.127	6.127	6.127	6.127	6.127

REYNOLD'S NUMBERS CORRESPONDING TO CRITICAL DEPTH

18.38	18.38	18.38	18.38	18.33	18.38	18.38	18.38
18.38	18.38	18.38	18.38	18.38			
18.38	18.38	18.38	18.38	18.38	18.38	18.38	18.38

CHEZY'S NUMBERS CORRESPONDING TO CRITICAL DEPTH

8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32
8.32	8.32	8.32	8.32	8.32			
8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32

NORMAL DEPTHS AT SECTIONS

2.575	2.575	2.575	2.575	2.575	2.575	2.575	2.575
2.575	2.575	2.575	2.575	2.575			
2.575	2.575	2.575	2.575	2.575	2.575	2.575	2.575

AREAS CORRESPONDING TO NORMAL DEPTHS

180.238	180.238	180.238	180.238	180.238	180.238	180.238	180.238
180.238	180.238	180.238	180.238	180.238			
180.238	180.238	180.238	180.238	180.238	180.238	180.238	180.238

VELOCITIES CORRESPONDING TO NORMAL DEPTHS

2.774	2.774	2.774	2.774	2.774	2.774	2.774	2.774
2.774	2.774	2.774	2.774	2.774			
2.774	2.774	2.774	2.774	2.774	2.774	2.774	2.774

REYNOLD'S NUMBERS CORRESPONDING TO NORMAL DEPTHS

8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32
8.32	8.32	8.32	8.32	8.32			
8.32	8.32	8.32	8.32	8.32	8.32	8.32	8.32

CHEZY'S NUMBERS CORRESPONDING TO NORMAL DEPTH

5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53
5.53	5.53	5.53	5.53	5.53			
5.53	5.53	5.53	5.53	5.53	5.53	5.53	5.53

M1 - CURVE BEGAN AT SECTION 21 AND ENDED AT SECTION 18 WITH Y = 2.490

DEPTHS OF FLOW AT SECTIONS

2.575	2.575	2.575	2.575	2.575	2.575	2.575	2.575
2.575	2.575	2.575	2.574	2.576			
2.573	2.579	2.563	2.610	2.490	3.008	5.773	10.000

CROSS-SECTIONAL AREAS

180.2	180.2	180.2	180.2	180.2	180.2	180.2	180.2
180.2	180.2	180.2	180.2	180.3			
180.1	180.6	179.4	182.7	174.3	210.6	404.1	700.0

VELOCITY

2.774	2.774	2.774	2.774	2.774	2.774	2.774	2.774
2.774	2.774	2.774	2.774	2.773			
2.776	2.769	2.787	2.737	2.869	2.375	1.237	0.714

REYNOLDS NUMBERS FOR GVF

8.323	8.322	8.322	8.322	8.322	8.323	8.323	8.323
8.323	8.322	8.322	8.323	8.320			
8.328	8.307	8.362	8.211	8.608	7.124	3.712	2.143

WETTED PERIMETERS

75.1	75.1	75.1	75.1	75.1	75.1	75.1	75.1
75.1	75.1	75.1	75.1	75.2			
75.1	75.2	75.1	75.2	75.0	76.0	81.5	90.0

TOP WIDTH

70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00
70.00	70.00	70.00	70.00	70.00			
70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00

```
SECTIONS ALONG CHANNEL
     0.0        50.0       100.0       150.0       200.0       250.0       300.0       350.0
   400.0       450.0       500.0       550.0       600.0
   650.0       700.0       750.0       800.0       850.0       900.0       950.0      1000.0

 DISCHARGE ALONG CHANNEL
   500.00      500.00      500.00      500.00      500.00      500.00      500.00      500.00
   500.00      500.00      500.00      500.00      500.00
   500.00      500.00      500.00      500.00      500.00      500.00      500.00      500.00

 BOTTOM WIDTHS
   70.000      70.000      70.000      70.000      70.000      70.000      70.000      70.000
   70.000      70.000      70.000      70.000      70.000
   70.000      70.000      70.000      70.000      70.000      70.000      70.000      70.000

 SLOPES OF SIDE OF CHANNEL
    0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
    0.000       0.000       0.000       0.000       0.000
    0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000

 MANNINGS  N  FOR SECTIONS OF CHANNEL
    0.200       0.200       0.200       0.200       0.200       0.200       0.200       0.200
    0.200       0.200       0.200       0.200       0.200
    0.200       0.200       0.200       0.200       0.200       0.200       0.200       0.200

 SLOPE OF CHANNEL BOTTOM AT SECTIONS
  0.10500     0.10500     0.10500     0.10500     0.10500     0.10500     0.10500     0.10500
  0.10500     0.10500     0.10500     0.10500     0.10500
  0.10500     0.10500     0.10500     0.10500     0.10500     0.10500     0.10500     0.10500

 CRITICAL DEPTHS AT SECTIONS
   1.1658      1.1658      1.1658      1.1658      1.1658      1.1658      1.1658      1.1658
   1.1658      1.1658      1.1658      1.1658      1.1658
   1.1658      1.1658      1.1658      1.1658      1.1658      1.1658      1.1658      1.1658

 CRITICAL SLOPES AT SECTIONS
 0.575873    0.575873    0.575873    0.575873    0.575873    0.575873    0.575873    0.575873
 0.575873    0.575873    0.575873    0.575873    0.575873
 0.575873    0.575873    0.575873    0.575873    0.575873    0.575873    0.575873    0.575873

 AREAS CORRESPONDING TO CRITICAL DEPTH
    81.61       81.61       81.61       81.61       81.61       81.61       81.61       81.61
    81.61       81.61       81.61       81.61       81.61
    81.61       81.61       81.61       81.61       81.61       81.61       81.61       81.61

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
    6.127       6.127       6.127       6.127       6.127       6.127       6.127       6.127
    6.127       6.127       6.127       6.127       6.127
    6.127       6.127       6.127       6.127       6.127       6.127       6.127       6.127

 NORMAL DEPTHS AT SECTIONS
    1.959       1.959       1.959       1.959       1.959       1.959       1.959       1.959
    1.959       1.959       1.959       1.959       1.959
    1.959       1.959       1.959       1.959       1.959       1.959       1.959       1.959

 AREAS CORRESPONDING TO NORMAL DEPTHS
  137.163     137.162     137.162     137.162     137.162     137.162     137.162     137.162
  137.162     137.162     137.162     137.162     137.162
  137.162     137.162     137.162     137.162     137.162     137.162     137.162     137.162

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
    3.645       3.645       3.645       3.645       3.645       3.645       3.645       3.645
    3.645       3.645       3.645       3.645       3.645
    3.645       3.645       3.645       3.645       3.645       3.645       3.645       3.645
M1 - CURVE BEGAN AT SECTION   21 AND ENDED AT SECTION   18 WITH Y =      1.896
DEPTHS OF FLOW AT SECTIONS
    1.960       1.959       1.960       1.959       1.960       1.959       1.961       1.958
    1.962       1.956       1.965       1.952       1.971
    1.944       1.984       1.927       2.012       1.896       2.083       5.198      10.000
CROSS-SECTIONAL AREAS
    137.2       137.2       137.2       137.1       137.2       137.1       137.2       137.0
    137.3       136.9       137.5       136.6       138.0
    136.1       138.9       134.9       140.9       132.7       145.8       363.8       700.0
VELOCITY
    3.645       3.645       3.645       3.646       3.644       3.647       3.643       3.648
    3.641       3.652       3.635       3.659       3.624
    3.675       3.600       3.706       3.549       3.767       3.430       1.374       0.714
WETTED PERIMETERS
     73.9        73.9        73.9        73.9        73.9        73.9        73.9        73.9
     73.9        73.9        73.9        73.9        73.9
     73.9        74.0        73.9        74.0        73.8        74.2        80.4        90.0
TOP WIDTH
    70.00       70.00       70.00       70.00       70.00       70.00       70.00       70.00
    70.00       70.00       70.00       70.00       70.00
    70.00       70.00       70.00       70.00       70.00       70.00       70.00       70.00
```

Appendix D. Example 3

Input data for Example 3. Debris flow.

```
$ RUN MAIN
DO YOU WANT A DEFINITION OF NAMELIST IN SPECIF? Y OR N
N
DEFAULT OPTIONS ARE:
ITRAPE = 1 IOYES = 0 ERR = 0.00100 INFLOW = 1 MYSTRT = 0
IUNSTE = 1 LINTER = 1 NCONT = 0 NPR = 0
DO YOU WANT ANY OF THESE CHANGED? Y OR N
Y
GIVE CHANGED OPTIONS IN & SPECIF LIST
& SPECIF IUNSTE = 0 & END
GIVE THE INPUT DATA AFTER THE NAME.  IF YOU DO NOT UNDERSTAND NAME
WRITE, HELP
NSI
9
NSO
39
QO
80
XBEG
0
XEND
4180
YSTART
100
PROVIDE OUTPUT STA. NO. WHERE GVG. IS TO BEG., I.E. 1 OR 39
39
```

Input data for Example 3.

```
PROVIDE 9 X-DIST. FOR 9 INPUT SECTIONS
0,1100, 1320, 1800, 2420, 2640, 3520, 3740, 4180
PROVIDE BOTTOM SLOPES FOR 9 INPUT SECTIONS
.019, .013, .00008, .00002,.0001, .015, .01, .0007, .00005
PROBLEM SPECIFICATIONS
X 0.0  1100.0  1320.0  1800.0  2420.0  2640.0  3520.0  3740.0  4180.0
S 0.0190  0.01300  0.00008  0.00002  0.00010  0.01500  0.01000  0.00070
0.00005
IS THERE LATERAL INFLOW? Y OR N
Y
PROVIDE 9 VALUES OF LATERAL INFLOW.  IF QO=0 THESE ARE ACTUAL FLOWS
0, 0, 5, 5, 0, 0, 0, 0, 0
SQ 0.000  0.000  5.000  5.000  0.000  0.000  0.000  0.000  0.000
PROVIDE 9 BOTTOM WIDTHS, THEN 9 SIDE SLOPES
12, 13, 15, 50, 25, 15, 16, 18, 20,
.5, .75, 1.5, 2., 1.5, 1., .75, 1., 1.5
B  12.000  13.000  15.000  50.000  25.000  15.000  16.000  18.000  20.000
M  0.500  0.750  1.500 2.000  1.500  1.000  0.750  1.000  1.500
HAVE YOU MADE ANY MISTAKES Y OR N
N
WHERE SHOULD THE OUTPUT GO?  GIVE 1) TTY IF TERM ONLY; 2) FILE NAME
```

SECTIONS ALONG CHANNEL

0.0	110.0	220.0	330.0	440.0	550.0	660.0	770.0
880.0	990.0	1100.0	1210.0	1320.0			
1430.0	1540.0	1650.0	1760.0	1870.0	1980.0	2090.0	2200.0
2310.0	2420.0	2530.0	2640.0	2750.0			
2860.0	2970.0	3080.0	3190.0	3300.0	3410.0	3520.0	3630.0
3740.0	3850.0	3960.0	4070.0	4180.0			

DISCHARGE ALONG CHANNEL

80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
80.00	80.00	80.00	82.50	85.00			
86.15	87.29	88.44	89.58	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			
90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			

BOTTOM WIDTHS

12.000	12.100	12.200	12.300	12.400	12.500	12.600	12.700
12.800	12.900	13.000	14.000	15.000			
23.021	31.042	39.063	47.083	47.177	42.742	38.306	33.871
29.435	25.000	20.000	15.000	15.125			
15.250	15.375	15.500	15.625	15.750	15.875	16.000	17.000
18.000	18.500	19.000	19.500	20.000			

SLOPES OF SIDE OF CHANNEL

0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675
0.700	0.725	0.750	1.125	1.500			
1.615	1.729	1.844	1.958	1.944	1.855	1.766	1.677
1.589	1.500	1.250	1.000	0.969			
0.938	0.906	0.875	0.844	0.813	0.781	0.750	0.875
1.000	1.125	1.250	1.375	1.500			

SLOPE OF CHANNEL BOTTOM AT SECTIONS

0.01900	0.01840	0.01780	0.01720	0.01660	0.01600	0.01540	0.01480
0.01420	0.01360	0.01300	0.00654	0.00008			
0.00007	0.00006	0.00005	0.00003	0.00004	0.00005	0.00006	0.00008
0.00009	0.00010	0.00755	0.01500	0.01437			
0.01375	0.01312	0.01250	0.01187	0.01125	0.01063	0.01000	0.00535
0.00070	0.00054	0.00037	0.00021	0.00005			

CRITICAL DEPTHS AT SECTIONS

1.0963	1.0896	1.0831	1.0766	1.0703	1.0640	1.0579	1.0519
1.0459	1.0400	1.0343	0.9976	0.9663			
0.7443	0.6190	0.5373	0.4794	0.4803	0.5125	0.5508	0.5970
0.6543	0.7275	0.8415	1.0141	1.0096			
1.0051	1.0006	0.9961	0.9918	0.9874	0.9831	0.9788	0.9392
0.9035	0.8860	0.8694	0.8536	0.8385			

CRITICAL SLOPES AT SECTIONS

0.541161	0.541239	0.541420	0.541658	0.541950	0.542291	0.542680	0.543112
0.543586	0.544099	0.544648	0.547024	0.552327			
0.610759	0.662062	0.706809	0.746055	0.745581	0.722555	0.698206	0.672335
0.644734	0.615396	0.579010	0.540916	0.541850			
0.542825	0.543822	0.544841	0.545883	0.546948	0.548039	0.549154	0.556143
0.563554	0.567510	0.571665	0.575959	0.580343			

AREAS CORRESPONDING TO CRITICAL DEPTH

13.76	13.81	13.86	13.91	13.96	14.01	14.06	14.11
14.15	14.20	14.25	15.09	15.90			
18.03	19.88	21.52	23.03	23.11	22.39	21.63	20.82
19.94	18.98	17.72	16.24	16.26			
16.27	16.29	16.31	16.33	16.34	16.36	16.38	16.74
17.08	17.27	17.46	17.65	17.83			

VELOCITIES CORRESPONDING TO CRITICAL DEPTH

5.816	5.794	5.772	5.751	5.731	5.711	5.691	5.671
5.652	5.633	5.615	5.468	5.347			
4.778	4.392	4.109	3.890	3.895	4.019	4.160	4.323
4.513	4.742	5.080	5.542	5.536			
5.530	5.524	5.518	5.513	5.507	5.501	5.495	5.377
5.269	5.210	5.153	5.100	5.049			

REYNOLD'S NUMBERS CORRESPONDING TO CRITICAL DEPTH

17.45	17.38	17.32	17.25	17.19	17.13	17.07	17.01
16.96	16.90	16.84	16.41	16.04			
14.33	13.18	12.33	11.67	11.68	12.06	12.48	12.97
13.54	14.23	15.24	16.62	16.61			
16.59	16.57	16.56	16.54	16.52	16.50	16.48	16.13
15.81	15.63	15.46	15.30	15.15			

CHEZY'S NUMBERS CORRESPONDING TO CRITICAL DEPTH

8.10	8.09	8.07	8.06	8.04	8.03	8.01	8.00
7.98	7.97	7.96	7.85	7.76			
7.32	7.01	6.77	6.58	6.59	6.69	6.82	6.95
7.11	7.29	7.56	7.90	7.90			
7.89	7.89	7.89	7.88	7.88	7.87	7.87	7.78
7.70	7.66	7.61	7.57	7.53			

NORMAL DEPTHS AT SECTIONS

6.762	6.789	6.822	6.861	6.907	6.959	7.019	7.086
7.161	7.245	7.338	9.274	51.765			
51.315	51.979	53.993	57.990	55.839	51.394	48.648	46.953
46.007	45.655	7.665	6.426	6.572			
6.729	6.899	7.084	7.285	7.506	7.749	8.018	10.363
25.069	26.828	29.937	36.302	61.276			

AREAS CORRESPONDING TO NORMAL DEPTHS

104.005	106.337	108.816	111.452	114.261	117.256	120.456	123.882
127.558	131.510	135.773	226.611	4795.986			
5432.809	6285.459	7484.182	9315.880	3694.245	7095.897	6043.200	5288.446
4716.957	4267.990	226.742	137.690	141.237			
145.062	149.203	153.702	158.611	163.994	169.924	176.500	270.144
1079.681	1306.050	1689.068	2519.940	6857.591			

VELOCITIES CORRESPONDING TO NORMAL DEPTHS

0.769	0.752	0.735	0.718	0.700	0.682	0.664	0.646
0.627	0.608	0.589	0.364	0.018			
0.016	0.014	0.012	0.010	0.010	0.013	0.015	0.017
0.019	0.021	0.397	0.654	0.637			
0.620	0.603	0.586	0.567	0.549	0.530	0.510	0.333
0.083	0.069	0.053	0.036	0.013			

REYNOLD'S NUMBERS CORRESPONDING TO NORMAL DEPTHS

2.31	2.26	2.21	2.15	2.10	2.05	1.99	1.94
1.88	1.82	1.77	1.09	0.05			
0.05	0.04	0.04	0.03	0.03	0.04	0.04	0.05
0.06	0.06	1.19	1.96	1.91			
1.86	1.81	1.76	1.70	1.65	1.59	1.53	1.00
0.25	0.21	0.16	0.11	0.04			

CHEZY'S NUMBERS CORRESPONDING TO NORMAL DEPTH

2.85	2.82	2.78	2.75	2.71	2.68	2.64	2.60
2.56	2.52	2.48	1.94	0.41			
0.38	0.36	0.33	0.30	0.31	0.34	0.37	0.40
0.42	0.44	2.02	2.62	2.59			
2.55	2.51	2.48	2.44	2.39	2.35	2.30	1.85
0.90	0.82	0.72	0.58	0.35			

DEPTHS OF FLOW AT SECTIONS

69.461	71.355	73.189	74.964	76.678	78.332	79.926	81.459

82.932	84.344	85.695	86.682	87.011			
87.017	87.022	87.026	87.029	87.031	87.035	87.039	87.044
87.050	87.058	87.453	88.608	90.103			
91.533	92.900	94.203	95.442	96.618	97.730	98.778	99.553
99.854	99.915	99.960	99.988	100.000			

CROSS-SECTIONAL AREAS

3245.9	3536.5	3839.1	4153.3	4478.5	4814.1	5159.4	5513.6
5875.9	6245.6	6621.8	9666.5	12661.5			
14228.7	15796.0	17363.1	18930.0	18827.2	17770.5	16713.9	15657.5
14601.3	13545.1	11309.2	9180.5	9227.6			
9250.6	9249.7	9225.1	9177.2	9106.5	9013.3	8898.2	10364.4
11768.3	13079.4	14389.2	15696.5	17000.0			

VELOCITY

0.025	0.023	0.021	0.019	0.018	0.017	0.016	0.015
0.014	0.013	0.012	0.009	0.007			
0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.006
0.006	0.007	0.008	0.010	0.010			
0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.009
0.008	0.007	0.006	0.006	0.005			

REYNOLDS NUMBERS FOR GVF

0.074	0.068	0.063	0.058	0.054	0.050	0.047	0.044
0.041	0.038	0.036	0.026	0.020			
0.018	0.017	0.015	0.014	0.014	0.015	0.016	0.017
0.018	0.020	0.024	0.029	0.029			
0.029	0.029	0.029	0.029	0.030	0.030	0.030	0.026
0.023	0.021	0.019	0.017	0.016			

WETTED PERIMETERS

167.3	173.3	179.3	185.2	191.2	197.2	203.3	209.3
215.3	221.3	227.2	274.9	328.7			
353.5	378.7	404.1	429.8	427.6	409.5	391.6	373.8
356.3	338.9	300.0	265.6	266.0			
266.2	266.1	265.8	265.4	264.7	263.9	262.9	281.6
300.4	319.3	339.0	359.5	380.6			

TOP WIDTH

81.46	87.02	92.71	98.51	104.41	110.42	116.50	122.67
128.90	135.20	141.54	209.03	276.03			
304.01	331.99	359.97	387.95	385.48	365.61	345.75	325.89
306.03	286.17	238.63	192.22	189.70			
186.87	183.76	180.36	176.68	172.75	168.58	164.17	191.22
217.71	243.31	268.90	294.47	320.00			

SECTIONS ALONG CHANNEL

0.0	110.0	220.0	330.0	440.0	550.0	660.0	770.0
880.0	990.0	1100.0	1210.0	1320.0			
1430.0	1540.0	1650.0	1760.0	1870.0	1980.0	2090.0	2200.0
2310.0	2420.0	2530.0	2640.0	2750.0			
2860.0	2970.0	3080.0	3190.0	3300.0	3410.0	3520.0	3630.0
3740.0	3850.0	3960.0	4070.0	4180.0			

DISCHARGE ALONG CHANNEL

80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
80.00	80.00	80.00	82.50	85.00			
86.15	87.29	88.44	89.58	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			
90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			

BOTTOM WIDTHS

12.000	12.100	12.200	12.300	12.400	12.500	12.600	12.700
12.800	12.900	13.000	14.000	15.000			
23.021	31.042	39.063	47.083	47.177	42.742	38.306	33.871
29.435	25.000	20.000	15.000	15.125			
15.250	15.375	15.500	15.625	15.750	15.875	16.000	17.000
18.000	18.500	19.000	19.500	20.000			

SLOPES OF SIDE OF CHANNEL

0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675
0.700	0.725	0.750	1.125	1.500			
1.615	1.729	1.844	1.958	1.944	1.855	1.766	1.677
1.589	1.500	1.250	1.000	0.969			
0.938	0.906	0.875	0.844	0.813	0.781	0.750	0.875
1.000	1.125	1.250	1.375	1.500			

MANNINGS N FOR SECTIONS OF CHANNEL

0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
0.035	0.035	0.035	0.035	0.035			
0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
0.035	0.035	0.035	0.035	0.035			
0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
0.035	0.035	0.035	0.035	0.035			

SLOPE OF CHANNEL BOTTOM AT SECTIONS

0.01900	0.01840	0.01780	0.01720	0.01660	0.01600	0.01540	0.01480
0.01420	0.01360	0.01300	0.00654	0.00008			
0.00007	0.00005	0.00004	0.00002	0.00003	0.00004	0.00006	0.00007
0.00009	0.00010	0.00755	0.01500	0.01437			
0.01375	0.01312	0.01250	0.01187	0.01125	0.01063	0.01000	0.00535
0.00070	0.00054	0.00037	0.00021	0.00005			

CRITICAL DEPTHS AT SECTIONS

1.0963	1.0896	1.0831	1.0766	1.0703	1.0640	1.0579	1.0519
1.0459	1.0400	1.0343	0.9976	0.9663			
0.7443	0.6190	0.5373	0.4794	0.4803	0.5125	0.5508	0.5970
0.6543	0.7275	0.8415	1.0141	1.0096			
1.0051	1.0006	0.9961	0.9918	0.9874	0.9831	0.9788	0.9392
0.9035	0.8860	0.8694	0.8536	0.8385			

CRITICAL SLOPES AT SECTIONS

0.019931	0.019884	0.019841	0.019802	0.019765	0.019732	0.019702	0.019675
0.019651	0.019629	0.019609	0.019354	0.019295			
0.020369	0.021360	0.022229	0.022993	0.022979	0.022535	0.022064	0.021562
0.021028	0.020462	0.019812	0.019248	0.019279			
0.019311	0.019344	0.019377	0.019412	0.019448	0.019484	0.019522	0.019549
0.019614	0.019638	0.019677	0.019728	0.019786			

AREAS CORRESPONDING TO CRITICAL DEPTH

13.76	13.81	13.86	13.91	13.96	14.01	14.06	14.11
14.15	14.20	14.25	15.09	15.90			
18.03	19.88	21.52	23.03	23.11	22.39	21.63	20.82
19.94	18.98	17.72	16.24	16.26			
16.27	16.29	16.31	16.33	16.34	16.36	16.38	16.74
17.08	17.27	17.46	17.65	17.83			

VELOCITIES CORRESPONDING TO CRITICAL DEPTH

5.816	5.794	5.772	5.751	5.731	5.711	5.691	5.671
5.652	5.633	5.615	5.468	5.347			
4.778	4.392	4.109	3.890	3.895	4.019	4.160	4.323
4.513	4.742	5.080	5.542	5.536			
5.530	5.524	5.518	5.513	5.507	5.501	5.495	5.377
5.269	5.210	5.153	5.100	5.049			

NORMAL DEPTHS AT SECTIONS

1.112	1.116	1.120	1.124	1.129	1.134	1.140	1.147
1.154	1.163	1.171	1.379	4.656			
3.988	3.651	3.531	3.634	3.486	3.286	3.223	3.245
3.337	3.503	1.123	1.093	1.103			
1.113	1.125	1.137	1.150	1.165	1.181	1.199	1.388
2.452	2.590	2.814	3.245	4.782			

AREAS CORRESPONDING TO NORMAL DEPTHS

13.969	14.155	14.350	14.552	14.763	14.983	15.214	15.455
15.709	15.977	16.259	21.443	102.368			
117.489	136.384	160.910	196.970	188.074	160.492	141.810	127.566
115.924	105.998	24.034	17.589	17.856			
18.138	18.437	18.754	19.092	19.453	19.640	20.256	25.286
50.150	55.452	63.355	77.766	129.958			

VELOCITIES CORRESPONDING TO NORMAL DEPTHS

5.727	5.652	5.575	5.498	5.419	5.339	5.258	5.176
5.093	5.007	4.920	3.847	0.830			
0.733	0.640	0.550	0.455	0.479	0.561	0.635	0.706
0.776	0.849	3.745	5.117	5.040			
4.962	4.881	4.799	4.714	4.627	4.536	4.443	3.559
1.795	1.623	1.421	1.157	0.693			

DEPTHS OF FLOW AT SECTIONS

69.323	71.230	73.075	74.860	76.583	78.245	79.846	81.385
82.864	84.281	85.637	86.627	86.959			
86.966	86.973	86.977	86.981	86.984	86.987	86.992	86.998
87.006	87.016	87.413	88.571	90.068			
91.502	92.872	94.178	95.421	96.599	97.714	98.766	99.544
99.848	99.911	99.957	99.987	100.000			

CROSS-SECTIONAL AREAS

3234.7	3525.5	3828.5	4143.0	4468.6	4804.5	5150.0	5504.5
5867.1	6237.1	6613.5	9655.0	12647.1			
14213.4	15779.6	17345.6	18911.4	18808.9	17753.1	16697.7	15642.6
14587.7	13532.9	11299.6	9173.3	9221.0			
9244.7	9244.5	9220.6	9173.4	9103.2	9010.7	8896.2	10362.6
11766.8	13078.2	14388.4	15696.1	17000.0			

VELOCITY

0.025	0.023	0.021	0.019	0.018	0.017	0.016	0.015
0.014	0.013	0.012	0.009	0.007			
0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.006
0.006	0.007	0.008	0.010	0.010			
0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.009
0.008	0.007	0.006	0.006	0.005			

WETTED PERIMETERS

167.0	173.0	179.0	185.0	191.0	197.0	203.1	209.1
215.1	221.1	227.1	274.8	328.5			
353.4	378.5	403.9	429.6	427.4	409.3	391.4	373.7
356.1	330.7	299.9	265.5	265.9			
266.1	266.0	265.8	265.3	264.7	263.9	262.9	281.5
300.4	319.3	339.0	359.5	380.6			

TOP WIDTH

81.32	86.89	92.58	98.39	104.30	110.31	116.40	122.57
128.81	135.11	141.46	208.91	275.88			
303.85	331.82	359.79	387.76	385.29	365.44	345.58	325.74
305.89	286.05	238.53	192.14	189.63			
186.82	183.71	180.31	176.65	172.72	168.55	164.15	191.20
217.70	243.30	268.89	294.46	320.00			

SECTIONS ALONG CHANNEL

0.0	110.0	220.0	330.0	440.0	550.0	660.0	770.0
880.0	990.0	1100.0	1210.0	1320.0			
1430.0	1540.0	1650.0	1760.0	1870.0	1980.0	2090.0	2200.0
2310.0	2420.0	2530.0	2640.0	2750.0			
2860.0	2970.0	3080.0	3190.0	3300.0	3410.0	3520.0	3630.0
3740.0	3850.0	3960.0	4070.0	4180.0			

DISCHARGE ALONG CHANNEL

80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
80.00	80.00	80.00	82.50	85.00			
86.15	87.29	88.44	89.58	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			
90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			

BOTTOM WIDTHS

12.000	12.100	12.200	12.300	12.400	12.500	12.600	12.700
12.800	12.900	13.000	14.000	15.000			
23.021	31.042	39.063	47.083	47.177	42.742	38.306	33.871
29.435	25.000	20.000	15.000	15.125			
15.250	15.375	15.500	15.625	15.750	15.875	16.000	17.000
18.000	18.500	19.000	19.500	20.000			

SLOPES OF SIDE OF CHANNEL

0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675
0.700	0.725	0.750	1.125	1.500			
1.615	1.729	1.844	1.958	1.944	1.855	1.766	1.677
1.589	1.500	1.250	1.000	0.969			
0.938	0.906	0.875	0.844	0.813	0.781	0.750	0.875
1.000	1.125	1.250	1.375	1.500			

MANNINGS N FOR SECTIONS OF CHANNEL

0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
0.050	0.050	0.050	0.050	0.050			
0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
0.050	0.050	0.050	0.050	0.050			
0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
0.050	0.050	0.050	0.050	0.050			

SLOPE OF CHANNEL BOTTOM AT SECTIONS

0.01900	0.01840	0.01780	0.01720	0.01660	0.01600	0.01540	0.01480
0.01420	0.01360	0.01300	0.00654	0.00008			
0.00007	0.00005	0.00004	0.00002	0.00003	0.00004	0.00006	0.00007
0.00009	0.00010	0.00755	0.01500	0.01437			
0.01375	0.01312	0.01250	0.01187	0.01125	0.01063	0.01000	0.00535
0.00070	0.00054	0.00037	0.00021	0.00005			

CRITICAL DEPTHS AT SECTIONS

1.0963	1.0896	1.0831	1.0766	1.0703	1.0640	1.0579	1.0519
1.0459	1.0400	1.0343	0.9976	0.9663			
0.7443	0.6190	0.5373	0.4794	0.4803	0.5125	0.5508	0.5970
0.6543	0.7275	0.8415	1.0141	1.0096			
1.0051	1.0006	0.9961	0.9918	0.9874	0.9831	0.9788	0.9392
0.9035	0.8860	0.8694	0.8536	0.8385			

CRITICAL SLOPES AT SECTIONS

0.040676	0.040580	0.040492	0.040411	0.040337	0.040270	0.040209	0.040153
0.040103	0.040058	0.040018	0.039498	0.039378			
0.041570	0.043592	0.045366	0.046924	0.046896	0.045990	0.045028	0.044005
0.042915	0.041759	0.040433	0.039281	0.039345			
0.039410	0.039477	0.039546	0.039617	0.039689	0.039764	0.039841	0.039896
0.040028	0.040078	0.040158	0.040261	0.040381			

AREAS CORRESPONDING TO CRITICAL DEPTH

13.76	13.81	13.86	13.91	13.96	14.01	14.06	14.11
14.15	14.20	14.25	15.09	15.90			
18.03	19.88	21.52	23.03	23.11	22.39	21.63	20.82
19.94	18.98	17.72	16.24	16.26			
16.27	16.29	16.31	16.33	16.34	16.36	16.38	16.74
17.08	17.27	17.46	17.65	17.83			

VELOCITIES CORRESPONDING TO CRITICAL DEPTH

5.816	5.794	5.772	5.751	5.731	5.711	5.691	5.671
5.652	5.633	5.615	5.468	5.347			
4.778	4.392	4.109	3.890	3.895	4.019	4.160	4.323
4.513	4.742	5.080	5.542	5.536			
5.530	5.524	5.518	5.513	5.507	5.501	5.495	5.377
5.269	5.210	5.153	5.100	5.049			

FAILED TO CONVERGE FOR SECTION, 13 DIF=0.7807E-05 YO= 5.639

NORMAL DEPTHS AT SECTIONS

1.386	1.389	1.394	1.399	1.404	1.410	1.417	1.425
1.434	1.444	1.454	1.704	5.639			
4.873	4.479	4.340	4.470	4.289	4.044	3.966	3.991
4.101	4.299	1.389	1.354	1.366			
1.379	1.394	1.410	1.427	1.445	1.466	1.488	1.721
3.030	3.193	3.462	3.980	5.821			

AREAS CORRESPONDING TO NORMAL DEPTHS

17.591	17.826	18.072	18.327	18.594	18.873	19.165	19.472
19.794	20.133	20.491	27.124	132.267			
150.523	173.725	204.236	249.561	238.110	203.206	179.702	161.892
147.434	135.209	30.196	22.137	22.470			
22.821	23.193	23.589	24.011	24.460	24.944	25.467	31.849
63.715	70.545	80.749	99.402	167.260			

VELOCITIES CORRESPONDING TO NORMAL DEPTHS

4.548	4.488	4.427	4.365	4.302	4.239	4.174	4.109
4.042	3.974	3.904	3.042	0.643			
0.572	0.502	0.433	0.359	0.378	0.443	0.501	0.556
0.610	0.666	2.981	4.066	4.005			
3.944	3.880	3.815	3.748	3.679	3.608	3.534	2.826
1.413	1.276	1.115	0.905	0.538			

DEPTHS OF FLOW AT SECTIONS

69.323	71.230	73.075	74.860	76.583	78.245	79.846	81.385
82.864	84.281	85.637	86.627	86.959			
86.966	86.973	86.977	86.981	86.984	86.987	86.992	86.998
87.006	87.016	87.413	88.571	90.068			
91.502	92.872	94.178	95.421	96.599	97.714	98.766	99.544
99.848	99.911	99.957	99.987	100.000			

CROSS-SECTIONAL AREAS

3234.7	3525.5	3828.5	4143.0	4468.6	4804.5	5150.0	5504.5
5867.1	6237.1	6613.5	9655.0	12647.1			
14213.4	15779.6	17345.6	18911.4	18808.9	17753.1	16697.7	15642.6
14587.7	13532.9	11299.6	9173.3	9221.0			
9244.7	9244.5	9220.6	9173.4	9103.2	9010.7	8896.2	10362.6
11766.8	13078.2	14388.4	15696.1	17000.0			

VELOCITY

0.025	0.023	0.021	0.019	0.018	0.017	0.016	0.015
0.014	0.013	0.012	0.009	0.007			
0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.006
0.006	0.007	0.008	0.010	0.010			
0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.009
0.008	0.007	0.006	0.006	0.005			

WETTED PERIMETERS

167.0	173.0	179.0	185.0	191.0	197.0	203.1	209.1
215.1	221.1	227.1	274.8	328.5			
353.4	378.5	403.9	429.6	427.4	409.3	391.4	373.7
356.1	338.7	299.9	265.5	265.9			
266.1	266.0	265.8	265.3	264.7	263.9	262.9	281.5
300.4	319.3	339.0	359.5	380.6			

TOP WIDTH

81.32	86.89	92.58	98.39	104.30	110.31	116.40	122.57
128.81	135.11	141.46	208.91	275.88			
303.85	331.82	359.79	387.76	385.29	365.44	345.58	325.74
305.89	286.05	238.53	192.14	189.63			
186.82	183.71	180.31	176.65	172.72	168.55	164.15	191.20
217.70	243.30	268.89	294.46	320.00			

SECTIONS ALONG CHANNEL

0.0	110.0	220.0	330.0	440.0	550.0	660.0	770.0
880.0	990.0	1100.0	1210.0	1320.0			
1430.0	1540.0	1650.0	1760.0	1870.0	1980.0	2090.0	2200.0
2310.0	2420.0	2530.0	2640.0	2750.0			
2860.0	2970.0	3080.0	3190.0	3300.0	3410.0	3520.0	3630.0
3740.0	3850.0	3960.0	4070.0	4180.0			

DISCHARGE ALONG CHANNEL

80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
80.00	80.00	80.00	82.50	85.00			
86.15	87.29	88.44	89.58	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			
90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			

BOTTOM WIDTHS

12.000	12.100	12.200	12.300	12.400	12.500	12.600	12.700
12.800	12.900	13.000	14.000	15.000			
23.021	31.042	39.063	47.083	47.177	42.742	38.306	33.871
29.435	25.000	20.000	15.000	15.125			
15.250	15.375	15.500	15.625	15.750	15.875	16.000	17.000
18.000	18.500	19.000	19.500	20.000			

SLOPES OF SIDE OF CHANNEL

0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675
0.700	0.725	0.750	1.125	1.500			
1.615	1.729	1.844	1.958	1.944	1.855	1.766	1.677
1.589	1.500	1.250	1.000	0.969			
0.938	0.906	0.875	0.844	0.813	0.781	0.750	0.875
1.000	1.125	1.250	1.375	1.500			

MANNINGS N FOR SECTIONS OF CHANNEL

0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
0.080	0.080	0.080	0.080	0.080			
0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
0.080	0.080	0.080	0.080	0.080			
0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
0.080	0.080	0.080	0.080	0.080			

SLOPE OF CHANNEL BOTTOM AT SECTIONS

0.01900	0.01840	0.01780	0.01720	0.01660	0.01600	0.01540	0.01480
0.01420	0.01360	0.01300	0.00654	0.00008			
0.00007	0.00005	0.00004	0.00002	0.00003	0.00004	0.00006	0.00007
0.00009	0.00010	0.00755	0.01500	0.01437			
0.01375	0.01312	0.01250	0.01187	0.01125	0.01063	0.01000	0.00535
0.00070	0.00054	0.00037	0.00021	0.00005			

CRITICAL DEPTHS AT SECTIONS

1.0963	1.0896	1.0831	1.0766	1.0703	1.0640	1.0579	1.0519
1.0459	1.0400	1.0343	0.9976	0.9663			
0.7443	0.6190	0.5373	0.4794	0.4803	0.5125	0.5508	0.5970
0.6543	0.7275	0.8415	1.0141	1.0096			
1.0051	1.0006	0.9961	0.9918	0.9874	0.9831	0.9788	0.9392
0.9035	0.8860	0.8694	0.8536	0.8385			

CRITICAL SLOPES AT SECTIONS

0.104131	0.103886	0.103660	0.103453	0.103264	0.103091	0.102934	0.102792
0.102664	0.102549	0.102446	0.101116	0.100808			
0.106418	0.111594	0.116137	0.120126	0.120053	0.117735	0.115272	0.112652
0.109861	0.106902	0.103510	0.100560	0.100723			
0.100890	0.101061	0.101237	0.101419	0.101605	0.101796	0.101993	0.102135
0.102473	0.102600	0.102805	0.103067	0.103374			

```
 AREAS CORRESPONDING TO CRITICAL DEPTH
     13.76      13.81      13.86      13.91      13.96      14.01      14.06      14.11
     14.15      14.20      14.25      15.09      15.90
     18.03      19.88      21.52      23.03      23.11      22.39      21.63      20.82
     19.94      18.98      17.72      16.24      16.26
     16.27      16.29      16.31      16.33      16.34      16.36      16.38      16.74
     17.08      17.27      17.46      17.65      17.83

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
     5.816      5.794      5.772      5.751      5.731      5.711      5.691      5.671
     5.652      5.633      5.615      5.468      5.347
     4.778      4.392      4.109      3.890      3.895      4.019      4.160      4.323
     4.513      4.742      5.080      5.542      5.536
     5.530      5.524      5.518      5.513      5.507      5.501      5.495      5.377
     5.269      5.210      5.153      5.100      5.049
FAILED TO CONVERGE FOR SECTION,   13 DIF=0.2576E+02  YO=     55.673

 NORMAL DEPTHS AT SECTIONS
     1.853      1.857      1.861      1.866      1.873      1.880      1.888      1.898
     1.908      1.920      1.933      2.248     55.673
     6.313      5.839      5.675      5.852      5.620      5.301      5.197      5.225
     5.361      5.607      1.837      1.793      1.810
     1.829      1.849      1.870      1.894      1.920      1.948      1.978      2.283
     3.994      4.196      4.532      5.186      7.498

 AREAS CORRESPONDING TO NORMAL DEPTHS
    23.954     24.275     24.610     24.960     25.325     25.708     26.109     26.529
    26.972     27.439     27.933     37.162  11167.237
   209.685    240.231    281.073    342.607    326.545    278.712    246.768    222.766
   203.468    187.329     40.954     30.109     30.554
    31.025     31.522     32.053     32.620     33.228     33.882     34.588     43.369
    87.838     97.420    111.776    138.097    234.296

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
     3.340      3.296      3.251      3.205      3.159      3.112      3.064      3.016
     2.966      2.916      2.864      2.220      0.008
     0.411      0.363      0.315      0.261      0.276      0.323      0.365      0.404
     0.442      0.480      2.198      2.989      2.946
     2.901      2.855      2.808      2.759      2.709      2.656      2.602      2.075
     1.025      0.924      0.805      0.652      0.384
DEPTHS OF FLOW AT SECTIONS
    69.323     71.230     73.075     74.860     76.583     78.245     79.846     81.385
    82.864     84.281     85.637     86.627     86.959
    86.966     86.973     86.977     86.981     86.984     86.987     86.992     86.998
    87.006     87.016     87.413     88.571     90.068
    91.502     92.872     94.178     95.421     96.599     97.714     98.766     99.544
    99.848     99.911     99.957     99.987    100.000
CROSS-SECTIONAL AREAS
    3234.7     3525.5     3828.5     4143.0     4468.6     4804.5     5150.0     5504.5
    5867.1     6237.1     6613.5     9655.0    12647.1
   14213.4    15779.6    17345.6    18911.4    18808.7    17753.1    16697.7    15642.6
   14587.7    13532.9    11299.6     9173.3     9221.0
    9244.7     9244.5     9220.6     9173.4     9103.2     9010.7     8896.2    10362.6
   11766.8    13078.2    14388.4    15696.1    17000.0
VELOCITY
     0.025      0.023      0.021      0.019      0.018      0.017      0.016      0.015
     0.014      0.013      0.012      0.009      0.007
     0.006      0.006      0.005      0.005      0.005      0.005      0.005      0.006
     0.006      0.007      0.008      0.010      0.010
     0.010      0.010      0.010      0.010      0.010      0.010      0.010      0.009
     0.008      0.007      0.006      0.006      0.005
WETTED PERIMETERS
     167.0      173.0      179.0      185.0      191.0      197.0      203.1      209.1
     215.1      221.1      227.1      274.8      328.5
     353.4      378.5      403.9      429.6      427.4      409.3      391.4      373.7
     356.1      338.7      299.9      265.5      265.9
     266.1      266.0      265.8      265.3      264.7      263.9      262.9      281.5
     300.4      319.3      339.0      359.5      380.6
TOP WIDTH
     81.32      86.89      92.58      98.39     104.30     110.31     116.40     122.57
    128.81     135.11     141.46     208.91     275.88
    303.85     331.82     359.79     387.76     385.29     365.44     345.58     325.74
    305.89     286.05     238.53     192.14     189.63
    186.82     183.71     180.31     176.65     172.72     168.55     164.15     191.20
    217.70     243.30     268.89     294.46     320.00
```

SECTIONS ALONG CHANNEL

0.0	110.0	220.0	330.0	440.0	550.0	660.0	770.0
880.0	990.0	1100.0	1210.0	1320.0			
1430.0	1540.0	1650.0	1760.0	1870.0	1980.0	2090.0	2200.0
2310.0	2420.0	2530.0	2640.0	2750.0			
2860.0	2970.0	3080.0	3190.0	3300.0	3410.0	3520.0	3630.0
3740.0	3850.0	3960.0	4070.0	4180.0			

DISCHARGE ALONG CHANNEL

80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
80.00	80.00	80.00	82.50	85.00			
86.15	87.29	88.44	89.58	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			
90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
90.00	90.00	90.00	90.00	90.00			

BOTTOM WIDTHS

12.000	12.100	12.200	12.300	12.400	12.500	12.600	12.700
12.800	12.900	13.000	14.000	15.000			
23.021	31.042	39.063	47.083	47.177	42.742	38.306	33.871
29.435	25.000	20.000	15.000	15.125			
15.250	15.375	15.500	15.625	15.750	15.875	16.000	17.000
18.000	18.500	19.000	19.500	20.000			

SLOPES OF SIDE OF CHANNEL

0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675
0.700	0.725	0.750	1.125	1.500			
1.615	1.729	1.844	1.958	1.944	1.855	1.766	1.677
1.589	1.500	1.250	1.000	0.969			
0.938	0.906	0.875	0.844	0.813	0.781	0.750	0.875
1.000	1.125	1.250	1.375	1.500			

MANNINGS N FOR SECTIONS OF CHANNEL

0.050	0.049	0.048	0.047	0.046	0.045	0.044	0.043
0.042	0.041	0.040	0.030	0.020			
0.020	0.019	0.019	0.018	0.018	0.018	0.018	0.019
0.019	0.019	0.030	0.040	0.041			
0.041	0.042	0.043	0.043	0.044	0.044	0.045	0.033
0.020	0.020	0.019	0.019	0.018			

SLOPE OF CHANNEL BOTTOM AT SECTIONS

0.01900	0.01840	0.01780	0.01720	0.01660	0.01600	0.01540	0.01480
0.01420	0.01360	0.01300	0.00654	0.00008			
0.00007	0.00006	0.00005	0.00003	0.00004	0.00005	0.00006	0.00008
0.00009	0.00010	0.00755	0.01500	0.01437			
0.01375	0.01312	0.01250	0.01187	0.01125	0.01063	0.01000	0.00535
0.00070	0.00054	0.00037	0.00021	0.00005			

CRITICAL DEPTHS AT SECTIONS

1.0963	1.0896	1.0831	1.0766	1.0703	1.0640	1.0579	1.0519
1.0459	1.0400	1.0343	0.9976	0.9663			
0.7443	0.6190	0.5373	0.4794	0.4803	0.5125	0.5508	0.5970
0.6543	0.7275	0.8415	1.0141	1.0096			
1.0051	1.0006	0.9961	0.9918	0.9874	0.9831	0.9788	0.9392
0.9035	0.8860	0.8694	0.8536	0.8385			

CRITICAL SLOPES AT SECTIONS

0.040676	0.038973	0.037318	0.035707	0.034142	0.032619	0.031138	0.029697
0.028297	0.026935	0.025612	0.014219	0.006301			
0.006350	0.006350	0.006295	0.006195	0.006154	0.006154	0.006143	0.006119
0.006082	0.006030	0.014075	0.025140	0.025974			
0.026823	0.027689	0.028572	0.029471	0.030387	0.031320	0.032271	0.016856

0.006405	0.006096	0.005799	0.005512	0.005233

AREAS CORRESPONDING TO CRITICAL DEPTH

13.76	13.81	13.86	13.91	13.96	14.01	14.06	14.11
14.15	14.20	14.25	15.09	15.90			
18.03	19.88	21.52	23.03	23.11	22.39	21.63	20.82
19.94	18.98	17.72	16.24	16.26			
16.27	16.29	16.31	16.33	16.34	16.36	16.38	16.74
17.08	17.27	17.46	17.65	17.83			

VELOCITIES CORRESPONDING TO CRITICAL DEPTH

5.816	5.794	5.772	5.751	5.731	5.711	5.691	5.671
5.652	5.633	5.615	5.468	5.347			
4.778	4.392	4.109	3.890	3.895	4.019	4.160	4.323
4.513	4.742	5.080	5.542	5.536			
5.530	5.524	5.518	5.513	5.507	5.501	5.495	5.377
5.269	5.210	5.153	5.100	5.049			

NORMAL DEPTHS AT SECTIONS

1.386	1.372	1.359	1.347	1.334	1.322	1.311	1.300
1.290	1.280	1.270	1.258	3.422			
2.829	2.505	2.327	2.257	2.189	2.146	2.157	2.211
2.308	2.455	1.014	1.184	1.206			
1.229	1.253	1.278	1.305	1.333	1.363	1.396	1.328
1.756	1.831	1.965	2.240	3.286			

AREAS CORRESPONDING TO NORMAL DEPTHS

17.591	17.594	17.599	17.605	17.614	17.624	17.637	17.654
17.673	17.696	17.724	19.392	68.888			
78.058	88.602	100.884	116.220	112.563	100.258	90.842	83.092
76.400	70.425	21.562	19.165	19.649			
20.155	20.684	21.240	21.824	22.442	23.097	23.795	24.110
34.686	37.646	42.156	50.586	81.912			

VELOCITIES CORRESPONDING TO NORMAL DEPTHS

4.548	4.547	4.546	4.544	4.542	4.539	4.536	4.532
4.527	4.521	4.514	4.254	1.234			
1.104	0.985	0.877	0.771	0.800	0.898	0.991	1.083
1.178	1.278	4.174	4.696	4.580			
4.465	4.351	4.237	4.124	4.010	3.897	3.782	3.733
2.595	2.391	2.135	1.779	1.099			

DEPTHS OF FLOW AT SECTIONS

69.318	71.224	73.070	74.854	76.578	78.240	79.840	81.380
82.858	84.276	85.632	86.622	86.954			
86.961	86.968	86.974	86.978	86.981	86.986	86.991	86.998
87.006	87.016	87.413	88.571	90.068			
91.502	92.872	94.178	95.421	96.599	97.714	98.766	99.544
99.848	99.911	99.957	99.987	100.000			

CROSS-SECTIONAL AREAS

3234.3	3525.1	3828.0	4142.5	4468.0	4803.9	5149.4	5503.9
5866.5	6236.4	6612.8	9653.9	12645.7			
14211.9	15778.1	17344.3	18910.3	18808.0	17752.6	16697.4	15642.5
14587.7	13532.9	11299.6	9173.3	9221.0			
9244.7	9244.5	9220.6	9173.4	9103.2	9010.7	8896.2	10362.6
11766.8	13078.2	14388.4	15696.1	17000.0			

VELOCITY

0.025	0.023	0.021	0.019	0.018	0.017	0.016	0.015
0.014	0.013	0.012	0.009	0.007			
0.006	0.006	0.005	0.005	0.005	0.005	0.005	0.006
0.006	0.007	0.008	0.010	0.010			
0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.009
0.008	0.007	0.006	0.006	0.005			

WETTED PERIMETERS

167.0	173.0	179.0	185.0	191.0	197.0	203.0	209.1
215.1	221.1	227.1	274.8	328.5			
353.3	378.5	403.9	429.6	427.4	409.3	391.4	373.7
356.1	338.7	299.9	265.5	265.9			
266.1	266.0	265.8	265.3	264.7	263.9	262.9	281.5
300.4	319.3	339.0	359.5	380.6			

TOP WIDTH

81.32	86.89	92.58	98.38	104.29	110.30	116.39	122.56
128.80	135.10	141.45	208.90	275.86			
303.83	331.81	359.78	387.75	385.28	365.43	345.58	325.74
305.89	286.05	238.53	192.14	189.63			
186.82	183.71	180.31	176.65	172.72	168.55	164.15	191.20
217.70	243.30	268.89	294.46	320.00			

Appendix E. Example 4

Input data for Example 4. Debris Flow

```
$ RUN MAIN
DO YOU WANT A DEFINITION OF NAMELIST IN SPECIF?  Y OR N
N
DEFAULT OPTIONS ARE
ITRAPE = 1  IOYES = 0  ERR = 0.00100  INFLOW = 1  MYSTRT = 0
IUNSTE = 1  LINTER = 1  NCONT = 0  NPR = 0
DO YOU WANT ANY OF THESE CHANGED?  Y OR N
Y
GIVE CHANGED OPTIONS IN & SPECIF LIST
& SPECIF IUNSTE = 0  & END
GIVE THE INPUT DATA AFTER THE NAME.  IF YOU DO NOT UNDERSTAND NAME
   WRITE, HELP
NSI
5
NSO
11
QO
100
XBEG
0
XEND
4000
YSTART
```

Input data for Example 4. Debris Flow (continued)

```
100
PROVIDE OUTPUT STA. NO. WHERE GVF IS TO BEG: I.E. 1 or 11
11
PROVIDE 5 X- DIST. FOR 5 INPUT SECTIONS
0, 1000, 2000, 3000, 4000
PROVIDE BOTTOM SLOPES FOR 5 INPUT SECTIONS
0.1, 0.05, 0.005, 0.001, 0.0005
PROBLEM SPECIFICATIONS
X 0.0  100.0  2000.0  3000.0  4000.0
X  0.10000  0.0500  0.00500  0.00100  0.00050
IS THERE LATERAL INFLOW Y OR N
N
SQ  0.000  0.000  0.000  0.000  0.000
PROVIDE 5 BOTTOM WIDTHS, THEN 5 SIDE SLOPES
100, 200, 900, 3500, 5000, 0, 0, 0, 0, 0
B  100.000  200.000  900.000  3500.000  5000.000
M    0.000     0.000     0.000     0.000     0.000
HAVE YOU MADE ANY MISTAKES Y OR NO
N
WHERE SHOULD THE OUTPUT GO?  1)ITTY IF TERM ONLY; 2)FILE NAME
```

```
SECTIONS ALONG CHANNEL
      0.0      400.0      800.0     1200.0     1600.0     2000.0     2400.0     2800.0
   3200.0     3600.0     4000.0

 DISCHARGE ALONG CHANNEL
   100.00     100.00     100.00     100.00     100.00     100.00     100.00     100.00
   100.00     100.00     100.00

 BOTTOM WIDTHS
  100.000    140.000    180.000    340.000    620.000    900.000   1940.000   2980.000
 3800.000   4400.000   5000.000

 SLOPES OF SIDE OF CHANNEL
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000      0.000      0.000

 MANNINGS  N  FOR SECTIONS OF CHANNEL
    0.035      0.035      0.035      0.035      0.035      0.035      0.035      0.035
    0.035      0.035      0.035

 SLOPE OF CHANNEL BOTTOM AT SECTIONS
  0.10000    0.08000    0.06000    0.04100    0.02300    0.00500    0.00340    0.00180
  0.00090    0.00070    0.00050

 CRITICAL DEPTHS AT SECTIONS
   0.3143     0.2512     0.2124     0.1390     0.0931     0.0726     0.0435     0.0327
   0.0278     0.0252     0.0232

 CRITICAL SLOPES AT SECTIONS
 0.026352   0.028296   0.029872   0.034337   0.039214   0.042592   0.050510   0.055564
 0.058648   0.060589   0.062335

 AREAS CORRESPONDING TO CRITICAL DEPTH
    31.43      35.16      38.24      47.29      57.76      65.38      84.59      97.45
   105.74     110.98     115.80

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
    3.181      2.844      2.615      2.115      1.731      1.529      1.182      1.026
    0.946      0.901      0.864

 NORMAL DEPTHS AT SECTIONS
    0.211      0.184      0.172      0.132      0.109      0.138      0.098      0.092
    0.097      0.096      0.099

 AREAS CORRESPONDING TO NORMAL DEPTHS
   21.051     25.734     31.012     44.824     67.772    124.347    189.874    272.675
  369.980    423.069    492.627

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
    4.750      3.886      3.225      2.231      1.476      0.804      0.527      0.367
    0.270      0.236      0.203
THIS PROGRAM ASSUMES NATURAL CHANNELS IN WHICH FLOW MUST BE SUBCRITICAL--ROUGHNE
SS MUST BE INCREASED AT SECTION
THIS PROGRAM ASSUMES NATURAL CHANNELS IN WHICH FLOW MUST BE SUBCRITICAL--ROUGHNE
SS MUST BE INCREASED AT SECTION
THIS PROGRAM ASSUMES NATURAL CHANNELS IN WHICH FLOW MUST BE SUBCRITICAL--ROUGHNE
SS MUST BE INCREASED AT SECTION
DEPTHS OF FLOW AT SECTIONS
    1.665     34.991     60.881     79.543     91.347     96.474     98.026     98.985
   99.482     99.778    100.000
CROSS-SECTIONAL AREAS
    166.5     4898.7    10958.7    27044.7    56635.1    86826.8   190170.9   294974.6
 378032.4   439024.0   500000.0
VELOCITY
    0.601      0.020      0.009      0.004      0.002      0.001      0.001      0.000
    0.000      0.000      0.000
WETTED PERIMETERS
    103.3      210.0      301.8      499.1      802.7     1092.9     2136.1     3178.0
   3999.0     4599.6     5200.0
TOP WIDTH
   100.00     140.00     180.00     340.00     620.00     900.00    1940.00    2980.00
  3800.00    4400.00    5000.00
```

```
SECTIONS ALONG CHANNEL
      0.0       400.0      800.0     1200.0     1600.0     2000.0     2400.0     2800.0
   3200.0      3600.0     4000.0

 DISCHARGE ALONG CHANNEL
    100.00     100.00     100.00     100.00     100.00     100.00     100.00     100.00
    100.00     100.00     100.00

 BOTTOM WIDTHS
   100.000    140.000    180.000    366.667    633.333    900.000   1940.000   2980.000
  3800.000   4400.000   5000.000

 SLOPES OF SIDE OF CHANNEL
     0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
     0.000      0.000      0.000

 MANNINGS  N  FOR SECTIONS OF CHANNEL
     0.035      0.035      0.035      0.035      0.035      0.035      0.035      0.035
     0.035      0.035      0.035

 SLOPE OF CHANNEL BOTTOM AT SECTIONS
   0.10000    0.08000    0.06000    0.00047    0.00273    0.00500    0.00340    0.00180
   0.00090    0.00070    0.00050

 CRITICAL DEPTHS AT SECTIONS
    0.3143     0.2512     0.2124     0.1322     0.0918     0.0726     0.0435     0.0327
    0.0278     0.0252     0.0232

 CRITICAL SLOPES AT SECTIONS
  0.026352   0.028296   0.029872   0.034913   0.039399   0.042592   0.050510   0.055564
  0.058648   0.060589   0.062335

 AREAS CORRESPONDING TO CRITICAL DEPTH
     31.43      35.16      38.24      48.47      58.16      65.38      84.59      97.45
    105.74     110.98     115.80

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
     3.181      2.844      2.615      2.063      1.719      1.529      1.182      1.026
     0.946      0.901      0.864

 NORMAL DEPTHS AT SECTIONS
     0.211      0.184      0.172      0.483      0.204      0.138      0.098      0.092
     0.097      0.096      0.099

 AREAS CORRESPONDING TO NORMAL DEPTHS
    21.051     25.734     31.012    177.008    129.524    124.334    189.874    272.675
   369.980    423.069    492.627

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
     4.750      3.886      3.225      0.565      0.772      0.804      0.527      0.367
     0.270      0.236      0.203
THIS PROGRAM ASSUMES NATURAL CHANNELS IN WHICH FLOW MUST BE SUBCRITICAL--ROUGHNE
SS MUST BE INCREASED AT SECTION
THIS PROGRAM ASSUMES NATURAL CHANNELS IN WHICH FLOW MUST BE SUBCRITICAL--ROUGHNE
SS MUST BE INCREASED AT SECTION
DEPTHS OF FLOW AT SECTIONS
    24.233     57.542     83.433     94.430     95.032     96.474     98.026     98.985
    99.482     99.778    100.000
CROSS-SECTIONAL AREAS
    2423.3     8055.9    15017.9    34624.4    60186.8    86826.8   190170.9   294974.6
  378032.4   439024.0   500000.0
VELOCITY
     0.041      0.012      0.007      0.003      0.002      0.001      0.001      0.000
     0.000      0.000      0.000
 WETTED PERIMETERS
     148.5      255.1      346.9      555.5      823.4     1092.9     2136.1     3178.0
    3999.0     4599.6     5200.0
 TOP WIDTH
    100.00     140.00     180.00     366.67     633.33     900.00    1940.00    2980.00
   3800.00    4400.00    5000.00
```

```
SECTIONS ALONG CHANNEL
      0.0      400.0      800.0     1200.0     1600.0     2000.0     2400.0     2800.0
   3200.0     3600.0     4000.0

 DISCHARGE ALONG CHANNEL
   100.00     100.00     100.00     100.00     100.00     100.00     100.00     100.00
   100.00     100.00     100.00

 BOTTOM WIDTHS
  100.000    140.000    180.000    366.667    633.333    900.000   1940.000   2980.000
 3800.000   4400.000   5000.000

 SLOPES OF SIDE OF CHANNEL
    0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
    0.000      0.000      0.000

 SLOPE OF CHANNEL BOTTOM AT SECTIONS
  0.10000    0.08000    0.06000    0.00047    0.00273    0.00500    0.00340    0.00180
  0.00090    0.00070    0.00050

 CRITICAL DEPTHS AT SECTIONS
   0.3143     0.2512     0.2124     0.1322     0.0918     0.0726     0.0435     0.0327
   0.0278     0.0252     0.0232

 CRITICAL SLOPES AT SECTIONS
 0.920379   1.030679   1.122495   1.431833   1.727117   1.949626   2.531766   2.944095
 3.197512   3.366533   3.518294

 AREAS CORRESPONDING TO CRITICAL DEPTH
    31.43      35.16      38.24      48.47      58.16      65.38      84.59      97.45
   105.74     110.98     115.80

 VELOCITIES CORRESPONDING TO CRITICAL DEPTH
    3.181      2.844      2.615      2.063      1.719      1.529      1.182      1.026
    0.946      0.901      0.864

 REYNOLD'S NUMBERS CORRESPONDING TO CRITICAL DEPTH
     9.54       8.53       7.85       6.19       5.16       4.59       3.55       3.08
     2.84       2.70       2.59

 CHEZY'S NUMBERS CORRESPONDING TO CRITICAL DEPTH
     5.93       5.60       5.36       4.74       4.32       4.06       3.56       3.31
     3.17       3.09       3.03

 NORMAL DEPTHS AT SECTIONS
    0.978      0.926      0.946      8.005      2.447      1.511      1.259      1.408
    1.778      1.880      2.095

 AREAS CORRESPONDING TO NORMAL DEPTHS
   97.813    129.595    170.221   2935.100   1549.698   1359.968   2442.467   4197.257
 6756.075   8270.690  10472.803

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
    1.022      0.772      0.587      0.034      0.065      0.074      0.041      0.024
    0.015      0.012      0.010

 REYNOLD'S NUMBERS CORRESPONDING TO NORMAL DEPTHS
     3.07       2.31       1.76       0.10       0.19       0.22       0.12       0.07
     0.04       0.04       0.03

 CHEZY'S NUMBERS CORRESPONDING TO NORMAL DEPTH
     3.30       2.85       2.48       0.57       0.79       0.85       0.63       0.47
     0.37       0.33       0.30
DEPTHS OF FLOW AT SECTIONS
   24.295     57.559     83.440     94.433     95.034     96.475     98.027     98.985
   99.482     99.778    100.000
CROSS-SECTIONAL AREAS
   2429.5     8058.3    15019.2    34625.6    60188.0    86827.7   190172.0   294975.7
 378033.2   439024.5   500000.0
VELOCITY
    0.041      0.012      0.007      0.003      0.002      0.001      0.001      0.000
    0.000      0.000      0.000
REYNOLDS NUMBERS FOR GVF
    0.123      0.037      0.020      0.009      0.005      0.003      0.002      0.001
    0.001      0.001      0.001
WETTED PERIMETERS
    148.6      255.1      346.9      555.5      823.4     1093.0     2136.1     3178.0
   3999.0     4599.6     5200.0
TOP WIDTH
   100.00     140.00     180.00     366.67     633.33     900.00    1940.00    2980.00
  3800.00    4400.00    5000.00
```

```
SECTIONS ALONG CHANNEL
      0.0       400.0       800.0      1200.0      1600.0      2000.0      2400.0      2800.0
   3200.0      3600.0      4000.0

DISCHARGE ALONG CHANNEL
   100.00      100.00      100.00      100.00      100.00      100.00      100.00      100.00
   100.00      100.00      100.00

BOTTOM WIDTHS
  100.000     140.000     180.000     340.000     620.000     900.000    1940.000    2980.000
 3800.000    4400.000    5000.000

SLOPES OF SIDE OF CHANNEL
    0.000       0.000       0.000       0.000       0.000       0.000       0.000       0.000
    0.000       0.000       0.000

SLOPE OF CHANNEL BOTTOM AT SECTIONS
  0.10000     0.08000     0.06000     0.04100     0.02300     0.00500     0.00340     0.00180
  0.00090     0.00070     0.00050

CRITICAL DEPTHS AT SECTIONS
   0.3143      0.2512      0.2124      0.1390      0.0931      0.0726      0.0435      0.0327
   0.0278      0.0252      0.0232

CRITICAL SLOPES AT SECTIONS
 0.920379    1.030679    1.122495    1.393996    1.714033    1.949613    2.531766    2.944095
 3.197512    3.366533    3.518294

AREAS CORRESPONDING TO CRITICAL DEPTH
    31.43       35.16       38.24       47.29       57.76       65.38       84.59       97.45
   105.74      110.98      115.80

VELOCITIES CORRESPONDING TO CRITICAL DEPTH
    3.181       2.844       2.615       2.115       1.731       1.529       1.182       1.026
    0.946       0.901       0.864

REYNOLD'S NUMBERS CORRESPONDING TO CRITICAL DEPTH
     9.54        8.53        7.85        6.34        5.19        4.59        3.55        3.08
     2.84        2.70        2.59

CHEZY'S NUMBERS CORRESPONDING TO CRITICAL DEPTH
     5.93        5.60        5.36        4.80        4.33        4.06        3.56        3.31
     3.17        3.09        3.03

NORMAL DEPTHS AT SECTIONS
    0.978       0.926       0.946       0.837       0.835       1.511       1.259       1.408
    1.778       1.880       2.095

AREAS CORRESPONDING TO NORMAL DEPTHS
   97.813     129.595     170.221     284.664     517.750    1359.968    2442.467    4197.257
 6756.075    8270.690   10472.803

VELOCITIES CORRESPONDING TO NORMAL DEPTHS
    1.022       0.772       0.587       0.351       0.193       0.074       0.041       0.024
    0.015       0.012       0.010

REYNOLD'S NUMBERS CORRESPONDING TO NORMAL DEPTHS
     3.07        2.31        1.76        1.05        0.58        0.22        0.12        0.07
     0.04        0.04        0.03

CHEZY'S NUMBERS CORRESPONDING TO NORMAL DEPTH
     3.30        2.85        2.48        1.90        1.40        0.85        0.63        0.47
 [illegible] [illegible] [illegible]
DEPTHS OF FLOW AT SECTIONS
    2.739      35.020      60.891      79.547      91.349      96.475      98.027      98.985
   99.482      99.778     100.000
CROSS-SECTIONAL AREAS
    273.9      4902.8     10960.4     27046.0     56636.3     86827.7    190172.0    294975.7
 378033.2    439024.5    500000.0
VELOCITY
    0.365       0.020       0.009       0.004       0.002       0.001       0.001       0.000
    0.000       0.000       0.000
REYNOLDS NUMBERS FOR GVF
    1.095       0.061       0.027       0.011       0.005       0.003       0.002       0.001
    0.001       0.001       0.001
WETTED PERIMETERS
    105.5       210.0       301.8       499.1       802.7      1093.0      2136.1      3178.0
   3999.0      4599.6      5200.0
TOP WIDTH
   100.00      140.00      180.00      340.00      620.00      900.00     1940.00     2980.00
  3800.00     4400.00     5000.00
```