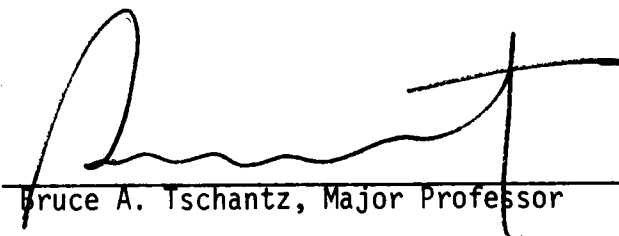


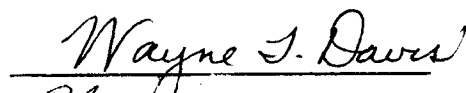
To the Graduate Council:

I am submitting herewith a thesis written by Kenneth D. Hiltgen entitled "Computer Modeling of DDT Contaminated Sediment Movement In Huntsville Spring Branch Near Huntsville, Alabama." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Environmental Engineering.

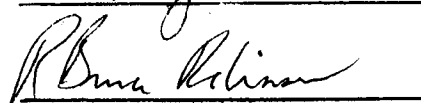


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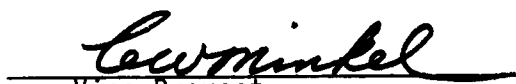


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COMPUTER MODELING OF DDT CONTAMINATED SEDIMENT MOVEMENT
IN HUNTSVILLE SPRING BRANCH
NEAR HUNTSVILLE, ALABAMA

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Kenneth D. Hiltgen
December 1985

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This thesis could not be possible without the assistance of Wanda Raper. Without her help in the past years in correcting my grammar and putting my writing in proper report format, I would not have been able to turn out several well written reports of which this thesis is an example. I am very much in her debt.

ABSTRACT

A small stream near Huntsville, Alabama contains considerable amounts of DDT contaminated sediments.(1)(2)(3) This stream, called Huntsville Spring Branch, flows into the Indian Creek which in turn flows into the Tennessee River. Ten miles of stream is contaminated with varying degrees of DDT. The erosion of these contaminated soils cause higher than normal concentrations of DDT in the water column of the stream. This has caused elevated concentrations of DDT in the local fish population.

In order to reduce the DDT content of the fish, the stream morphology was studied so that methods to reduce erosion of the contaminated soils could be examined. A literature search was conducted and only a few studies involving contaminated sediment were found. However, some computer programs for calculating sediment erosion were found to be applicable to the project and were investigated.

A computer program called HEC-6 (4) was used to identify potential scour and depositional areas of the stream. The potential amount of sediment erosion from the areas of potential scour was quantified with the respective DDT content at each site. In this way, a relative ranking of potential sources of DDT to the water column was made. The modeling results showed that a small section of the stream was identified as being the major source of DDT due to a combination of stream morphology causing high degree scouring and the high DDT concentrations in these soils. Rerouting the stream around this mile long reach should substantially reduce DDT in water concentrations.

Other remedial measures were evaluated for their effectiveness in reducing DDT water concentrations. A difference in DDT erosion between high pool and low pool conditions was predicted by the model and confirmed with field data. Although current sediment transport theory cannot accurately predict the amounts of sediment that can erode from a stream, computer modeling was found useful in studying and understanding stream morphology, and in ranking the relative effectiveness of possible remedial measures.

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INTRODUCTION

In 1947, the Calabama Chemical Company began production of DDT on the Redstone Arsenal near Huntsville, Alabama. Calabama operated this plant, leased from the Arsenal, for seven years with capacity at approximately 1.13×10^7 kilograms (kg) of DDT [1,1,1-trichloro-2,2-bis (p-chlorophenyl)ethane] per year.(21) The plant was located so that wastewater was discharged directly into Huntsville Spring Branch (HSB). The effluent contained calcium chloride, hydrochloric acid, monochlorobenzene, hypochlorides, chloral, sulfuric and sulfonic acid, and DDT. DDT levels ranged up to 0.8 ppm, mainly in particulates. Olin Matheson Chemical Company bought Calabama Chemical Company in 1954 and continued the manufacture of DDT. In 1969, the Federal Water Pollution Control Act (FWPCA) set new standards for DDT in wastewater at 0.02 ppb. Olin installed a carbon filter at the outlet to the settling pond, but, unable to meet FWPCA standards, stopped production of DDT at the plant on June 30, 1970.

During the 23 years of DDT production, the continuous DDT discharge collected in the bottom sediments of the adjoining stream. Fish surveys of 1979-80, indicated that fish in the Huntsville Spring Branch/Indian Creek streams (HSB-IC) contained high concentrations of DDT. In general, DDT values in fish were much greater than the 5 ppm FDA limit. This lead to a study to determine by what means the DDT in fish could be reduced.

As part of that study, the transport of DDT through the bottom sediment was studied. In all, there are approximately 5 miles of Huntsville Spring Branch and 5 miles of Indian Creek in which sediments

are contaminated with DDT residues. These bottom sediments have been slowly moving or eroding at a rate of 5 to 10 lb/day through the water column.

Olin has conducted biological uptake studies and field measurements in Huntsville Spring Branch from 1983 to 1985.(8)(9) The uptake studies addressed the manner of how fish in the river were accumulating the majority of the DDT in their bodies. Conventional thought is that DDT accumulation in fish proceeds along the same mechanism as that for mammals, i.e., bioaccumulation through the food chain. But after years of study, the mechanism of uptake was conclusively shown to be through direct uptake from the water column. This was shown from the results of cage studies where the contaminated food source was removed, but the exposure to the water column remained. Resultant DDT concentrations in the fish were the same as those in the stream. This and many other similar supporting studies conclude that the main route of uptake is from the water column and not from the food source. This could best be explained by comparing relative exposures of DDT to the fish. The amount of DDT in the water passing the gill membranes was calculated to be 1,000 times greater than what would be taken in by a fish in an average food diet of contaminated invertebrates.

Concurrent with biological uptake studies, there was extensive water quality and sediment sampling along Huntsville Spring Branch, Indian Creek, and their tributaries.(8) Water quality samples for DDT and suspended solids were taken as far upstream as five (5) miles above where the "old DDT ditch" entered into Huntsville Spring Branch and as

far downstream as the Tennessee River. Background concentrations of DDT in the water ranged from 0 to 1 ppb. As water passes by HSB mile 5.4 downstream to mile 2.4 DDT increases in the water column by an increase of 10 ppb, but with considerable variation and with no correlation with flow. This section of the stream is termed "Reach A". Continuing downstream, HSB mile 2.4 to the confluence with Indian Creek (IC) at HSB mile 0.0, is defined as "Reach B". In this reach, DDT concentrations generally tend to neither increase or decrease. From IC mile 5.4 to mile 0.0 where the system empties into the Tennessee River, "Reach C", DDT concentrations generally decrease to 2 ppb. This decrease could be due to settling or dilution from fresh water or both. No continuing discharge of DDT into the stream was identified in any of the reaches.

Water quality analysis on HSB water samples included filtering the samples and analyzing the filtrate and filter residues for DDT. The results indicate that the DDT is associated with fine sediments. DDT is slightly soluble in water with lab tests indicating up to 5 ppm solubility, but in a dynamic system like a stream, it is thought that dissolution is not a major factor. The filtering tests have borne this out with soluble DDT always less than 1 ppb. The analysis of DDT movement need not consider dissolution.

This initiated a study of sediment erosion in HSB-IC, its aspects and causes. To facilitate this, a computer model was used to study the system. Areas of potential erosion and deposition could then be identified. Once these areas were identified, remedial measures could be selected and designed.

CHAPTER I

SCOPE AND OBJECTIVES

The purpose of this study is to review current sediment transport theory and determine if there is any applicable method to analyze the erosion of contaminated sediments in the Huntsville stream. It is not possible to accurately predict the exact contaminant transport rates of DDT within current limits of sediment transport theory, which provide only order of magnitude estimates of sediment load. Use of a computer model that utilizes current methods will provide insight into the erosion and depositional mechanisms occurring in the stream.

Currently, there are several computer models in use for predicting sediment transport. These models were developed generally for analysis of dredging operations and analysis in areas where river navigation is of a main concern. There have been only a few instances of using these computer models to determine fate of environmental contaminants in stream beds.

The objective of this project is to use or adapt these sediment transport models to evaluate the hydraulic factors of Huntsville Spring Branch, such as flow, channel dimensions, and soil sieve analysis as they apply to erosion and deposition in the channel. In so doing, areas of the stream that have the greatest potential for causing high DDT suspension into the water column can be highlighted. Sections of the stream can be compared and relative effects of possible remedial

measures can be evaluated. Modeling the stream also provides a better understanding of the stream morphology and stimulates ideas on alternative remedial measures. The following tasks are addressed:

- 1) Determine from study of sediment transport theory and previous studies what factors are important in erosion of the DDT contaminated sediments.
- 2) Complete a literature search to assess what computer models are available and applicable to the Huntsville Spring Branch - Indian Creek (HSB-IC) system. Other studies may provide insight on how to handle the field data. Choose the most appropriate model.
- 3) Collect and coalesce field data pertinent to the sediment transport modeling.
- 4) Apply the computer model to address sediment erosion in the HSB-IC system. The following items need to be answered:
 - a) Define what areas (sub-reaches) are erosional or depositional and determine what factors are most important in erosion of the stream bed (sensitivity analysis).
 - b) Identify the areas that have the highest potential of suspending DDT in the water column. This is to be done by comparing relative quantities of erosion of DDT contaminated soils for various sections of the stream.
 - c) Use the model to study stream morphology, which will aid in explanation of the field data. This will generate

items for possible remediation of the site. The model is then to be used for comparing and choosing the most appropriate remedial measure.

By doing the above, this project provides insight into comparative effects of remedial measure. This creates a more educated atmosphere in which to decide where vital resources can best be applied. The computer model is to be used as a guidance in making such decisions, and not to be applied as an exact predictive tool.

CHAPTER II

SITE DESCRIPTION

The DDT plant was located on Redstone Arsenal near Huntsville in northern Alabama, see Figure 1. The site was located approximately 1/2 mile from Huntsville Spring Branch (HSB) and the plant's liquid effluent was discharged via NPDES outfall directly into HSB through a drainage ditch at HSB Mile 5.4.(21)

Huntsville Spring Branch drains an area of 46.9 square miles, primarily that adjoining the Redstone Arsenal.(18) The major tributary is McDonald Creek. HSB flows into the Indian Creek (IC) five miles before it empties into the Tennessee River above Wheeler Reservoir. Flowrates in HSB vary from a normal 50 to 100 cfs to approximately 1,000 cfs during typical storm events, a peak discharge usually occurring in the spring. Depths range from 2 to 10 feet depending upon location and time of year. The stream is affected by backwater of the Tennessee River from the Wheeler Reservoir up into the stream as far as HSB Mile 6.0. The major tributary of HSB, McDonald Creek, collects substantial urban runoff and contains the discharge of the local Publicly Owned Treatment Works (POTW) (which may be rerouted in the future). The stream receives most of the urban runoff from the city of Huntsville.

As part of an ongoing assessment, the HSB-IC system has been monitored for approximately three years with stream gaging stations at selected sites and periodic water quality samplings. Sample locations are shown on the site map, Figure 2. The samples were analyzed for total DDT, total organic carbon, total suspended solids, and alkalinity.

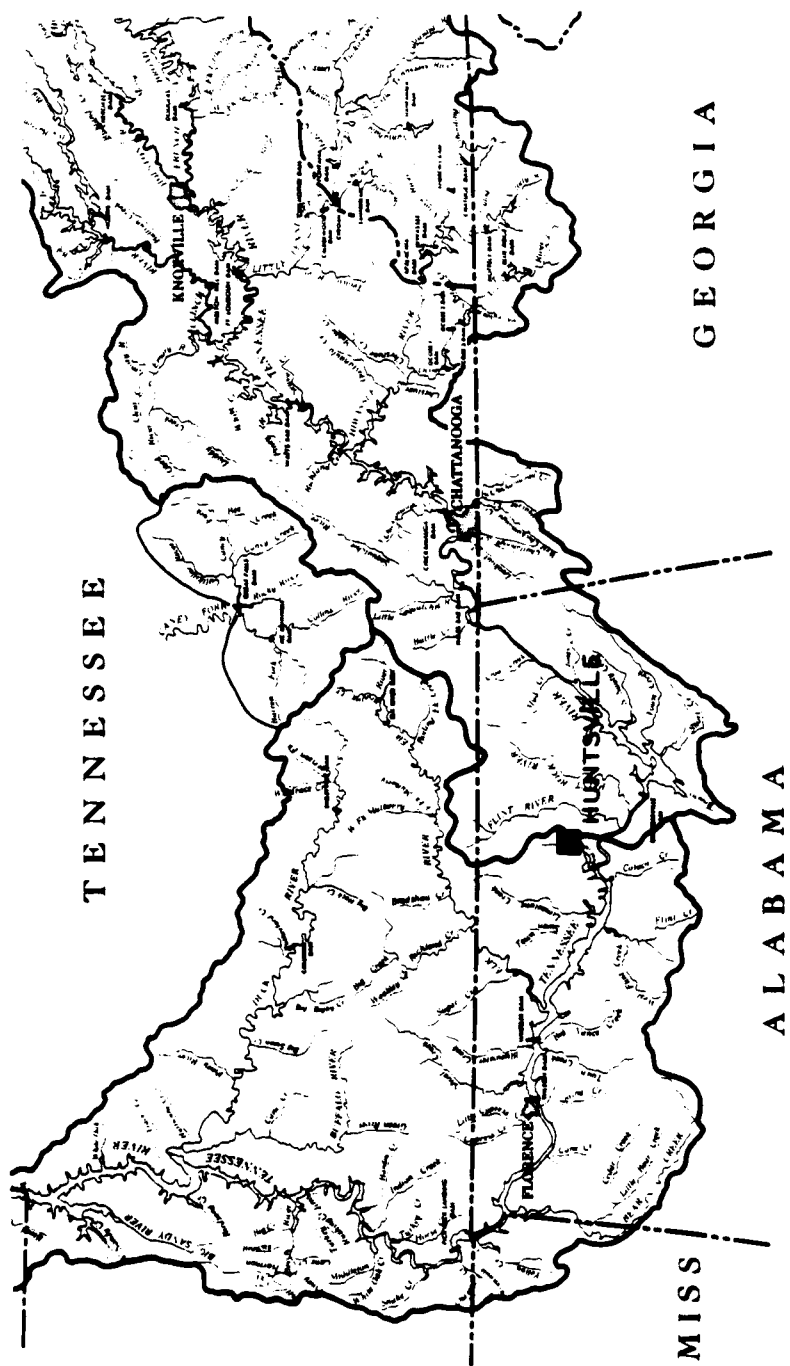


Figure 1. Site Location In Northern Alabama

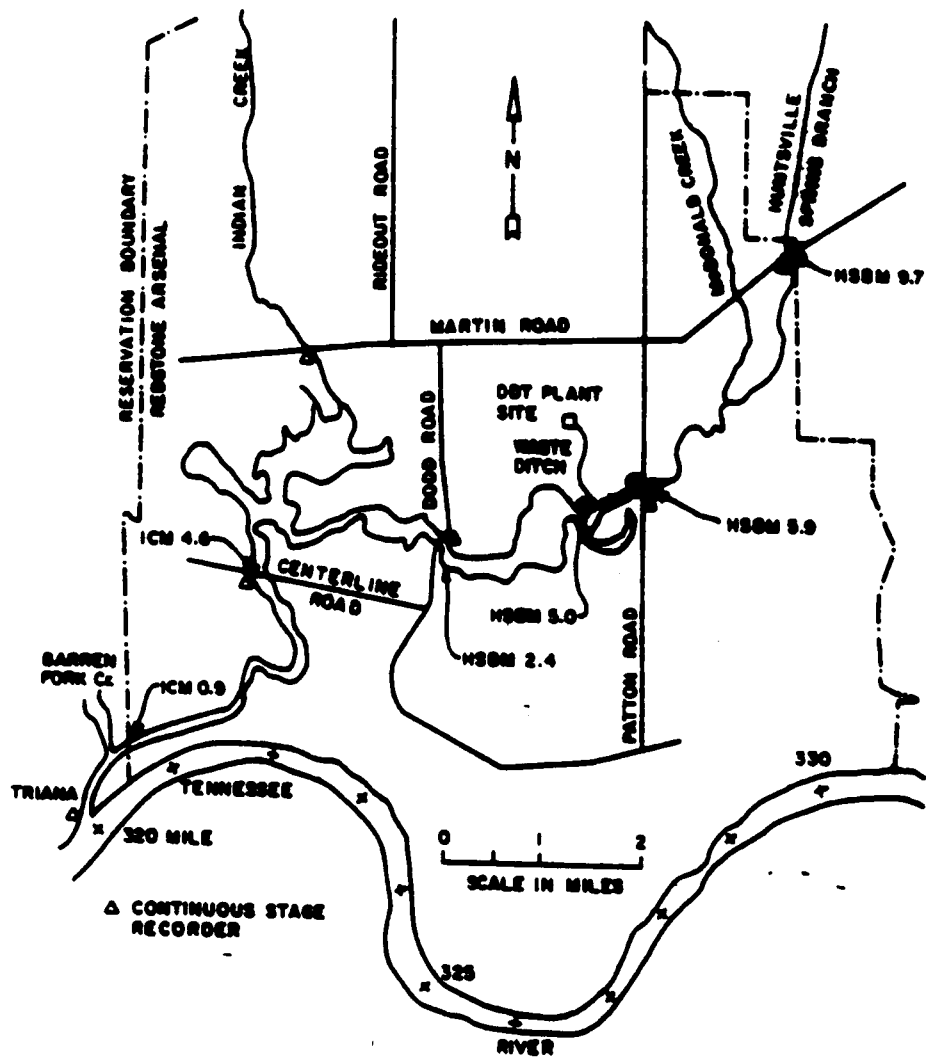


Figure 2. General Area Map With Gage Locations

At each sample point, stage height, depth of water, stream velocity along the centerline at the 60% level, pH, and temperature were taken. Stream velocity was determined to vary from -0.5 (backwater conditions) to 2.8 fps, dependent upon the location of sampling and time of year. Temperatures varied from 15° to 28°C, also dependent upon the season of the year. Stream depth varied up to five feet, dependent upon the seasonal variation.

There is a well defined channel throughout the entire stream length except for a small reach between HSB Mile 5.2 to 5.6. In this section, the area is completely wooded and a single channel is hard to define. In some places, brush from the flood fringe extends into the center of the channel, typical cross-section shown in Figure 3. This is true particularly between HSB Mile 4.0 to HSB Mile 2.7. The floodway in this area extends 100 feet on both sides of the channel. The floodway in other areas is heavily wooded and not as evident. The 100 year floodway encompasses the entire location, and portions of Redstone Arsenal. Therefore the entire site can be classified as floodplain.

As part of this study plan and site-wide sampling program, sediment samples were taken along cross-sectional transects every 0.2 miles. The river bottom elevations were noted when using a steel probe and sediment samples were taken from the 0-6 inch depth, 6-12 inch depth and >12 inch depth. These samples were analyzed for total residual DDT on selected samples. A sieve analysis was performed. The soil was found to be predominately silt and clay loam (termed Huntington, Lindside or Melvin silty clay loam).(23) However, there is a considerable sand fraction in the lower reaches of HSB-IC.

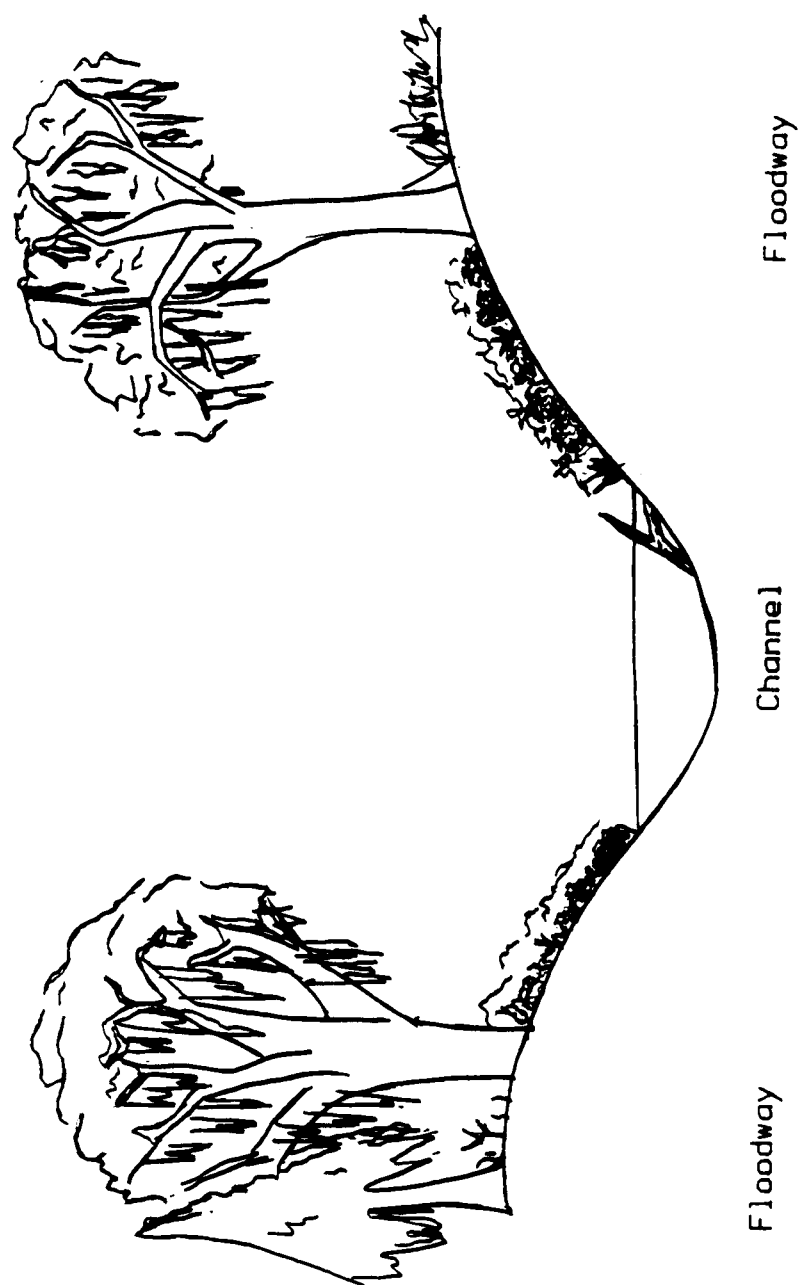


Figure 3. Typical Cross Section of Stream and Floodway

The DDT prevalent in the soil in the area is confined almost entirely to the stream channel bottom with less than 1% occurring in the overbank (8)(9). The DDT is prevalent mainly upstream of HSB Mile 4.0 and downstream of HSB Mile 5.4. This section of the stream has sediments containing up to 90,000 ppm DDT, and comprises 77% of the total DDT in the system. In the lower reaches of HSB, from HSB Mile 0.0 to HSB Mile 2.4, concentrations vary from 30 to 1,000 ppm. DDT concentrations in sediment reduce significantly in Indian Creek, where concentrations generally vary from 0 to 300 ppm.

This DDT in sediment data illustrates the low rate of movement of DDT contaminated soils. Since the cessation of DDT production in 1970, there has not been a great loss of DDT out of the system. Most of the DDT is still within 1.4 miles of its origin. This low rate of soil erosion is typical of a slow moving stream with water velocities normally $< .1$ fps and inherently due to the nature of the clay soils. Clay and silts tend to be cohesive sediment making them harder to erode.

The shape of the channel changes throughout the stream length. Channel depths in HSB rarely exceed 10 feet, but the channel is deep and narrow between HSB Mile 4.0 to 5.2. At HSB Mile 4.0, there is a tributary entering the system known as the "embayment." This embayment encompasses a low-lying area south of the site which collects drainage from the surrounding wooded area. It remains filled with water throughout the year.

Downstream of HSB Mile 4.0, the stream becomes wider and shallower with small islands and brush interspersed throughout the stream until HSB Mile 2.72 is reached, where for 100 feet, it narrows to a small

throat section. This was cut to bypass the original stream section so that a levee to protect the test firing range for Redstone Arsenal could be built. The stream meanders on through heavily wooded areas until it meets with Indian Creek (IC) where it empties into a large embayment.

All of Reach C (Indian Creek) and 6 miles of Huntsville Spring Branch is affected by backwater from Wheeler Dam. During the summer months, April through October, the water is allowed to rise to 556 feet MSL at Wheeler Dam. During the remaining months, the elevation is reduced to 550 feet MSL(18). By using the model, this variation in water depth was tested for its effect on erosion and deposition of soil.

CHAPTER III

THEORY OF SEDIMENT TRANSPORT MODELING

Sediment particles in the bottom of the river are subject to several different forces, as shown in Figure 4. There is the force of gravity on the particles which pulls the particles down to the bottom and is dependent upon the particle density. Counteracting this force is the buoyancy force of water upward which is dependent upon the volume of the particle. Horizontal movement of particles is dependent upon the drag force of the river water imparted on it, versus the drag force in the opposite direction by the adhesion of other particles surrounding it. These drag forces are dependent upon the shape of the particles, density, water velocity, depth of water, and several other factors that may or may not be quantifiable. When sediment particles are at rest all of these forces cancel each other out, but if there is an imbalance in forces, this causes incipient motion. A detailed discussion on the forces upon a particle at rest is provided by Graf: (5) referring again to Figure 4.

The condition of incipient movement for an assembly of cohesionless, loose, and solid particles is described in terms of the forces acting on the particle by

$$\tan \phi = \frac{F_t}{F_n}$$

where F_t and F_n are the forces parallel and normal to the angle of repose ϕ . In our study F_t and F_n are resultants of the hydrodynamic drag F_D , the lift force F_L , and the submerged weight W . The condition of incipient movement under the action of these three forces becomes,

$$\tan \phi = \frac{W \sin \alpha + F_D}{W \cos \alpha - F_L}$$

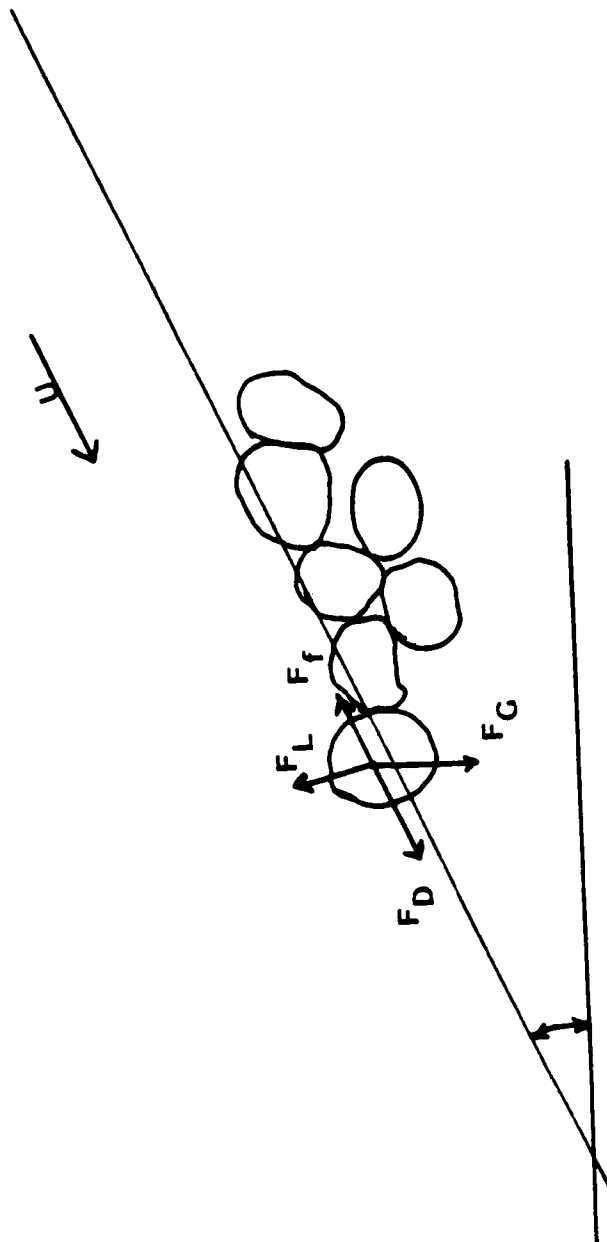


Figure 4 Force balance on a sediment particle. With water flowing at a velocity U imparts a drag force F_D on a sediment particle with frictional force F_f counter imposing it. The lift force of water F_L moving the particle up into the water column while the force of gravity F_g counteracts this hydraulic force.

where angle α is the inclination of the bed from the horizontal at which incipient sediment movement takes place.
In the usual way, drag and lift forces are expressed by

$$F_D = C_D k_1 d^2 \frac{\rho U_b^2}{2}$$

and

$$F_L = C_L k_2 d^2 \frac{\rho U_b^2}{2}$$

where U_b = fluid velocity at the bottom of the channel
 C_D, C_L = drag and lift coefficient, respectively
 d = particle diameter
 k_1, k_2 = particle shape factors
 ρ = liquid density

The submerged weight of the particle is expressed as

$$W = k_3 (\rho_s - \rho) g d^3$$

with k_3 being another shape factor and ρ_s being the solid-particle density.

There are generally two types of sediment transport bedload and suspended load. Bedload is the quantity of particles moving along the bottom of the stream bed. They can be rolling, sliding or bouncing along the bottom. Suspended load deals with particles that have jumped up into the water column and move with the column. The following general discussion deals with bedload movement but treatment of suspended load or total load (bedload plus suspended load) is analagous.

The first attempt to quantify these forces was done by DuBuat (5) (1743-1809). His book "Principals of Hydraulics" laid the ground work for a shear resistance concept, which is considered to be a force which a stream exhibits with respect to the motion toward its bed. The formula given for this "friction force" is :

$$\tau = \frac{S-r}{b}$$

r = average radius

S = bed area

b = 1/Slope

τ = Tractive force on bed

Approximately a century later, DuBoys as presented by Vanoni (19) derived a useful expression for transport rate of sediment:

$$g_s = \psi \cdot \tau (\tau - \tau_c)$$

g_s = transport rate, lb/s.ft

ψ = proportionality constant characteristic of sediment, ft³/lb.s

τ = force of entrainment, lb/ft²

τ_c = critical force at the beginning of sand motion, lb/ft²

He arrived at this expression, which was the first of its type to quantify bedload transport, by imagining that the transport occurs in a series of layers. Because of its simplicity and its ease of use, the DuBoy's expression is often used by engineers today. The estimates are based on the concept that there is a certain critical shear which must be overcome before there is movement of sediment particles. Figure 5 is a graph giving these critical shear strengths as a function of particle diameter along with the values for the proportionality constant, also varying with particle diameter. The DuBoy's Method, as well as all current methods, are a blend of theory and empirical data. The empirical data is introduced from field or lab tests in the form of those plotted in Figure 5.

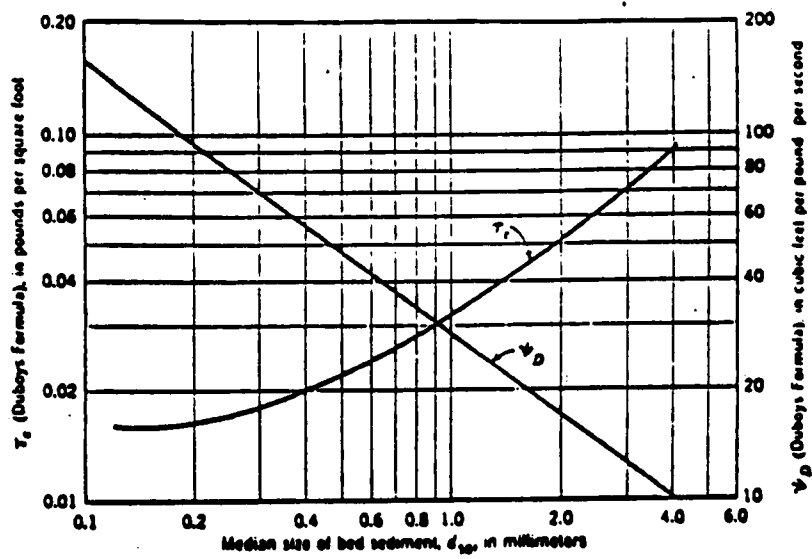


Figure 5. Relationship Between The Two Transport Parameters in DuBoy's Equation versus Particle Size.

Taken from Vanoni (19)

In 1935, Schoklitsh (5) modified the DuBoy's approach to relate more toward the stream hydraulics. Instead of a difference between bed shears, he expressed it as a difference between flows (flow of the stream versus critical flow required to move a particle). The Schotlitsh equation for a single particle size is:

$$g_s = x \cdot S^{1.5} (q - q_c)$$

x = proportionality constant characteristic dependent upon
particle size

S = channel slope

q = volumetric flow of stream per unit width ft^2/s

q_c = critical volumetric flow of stream per unit width ft^2/s

g_s = sediment transport rate per unit width $\text{lb}/\text{s}\cdot\text{ft}$

The Schoklitsh equation was similar to Duboy's equation in form, i.e., sediment erosion is calculated as a function of some critical property flow or shear. The critical flowrate, or more correctly critical velocity was found to be proportional to the diameter of the particle to approximately $1/2$ the power. Strictly speaking, the critical velocity should only be related to the bottom velocity, not the average velocity, but for convenience of calculation most empirical relationships are based on stream average velocity. Figure 6 shows a range of critical tractive force evaluation as a function of mean particle diameter. Note the range of data from the various researchers spans almost an order of magnitude. This illustrates the grossness of estimating quantities of sediment transport, but the curves do follow

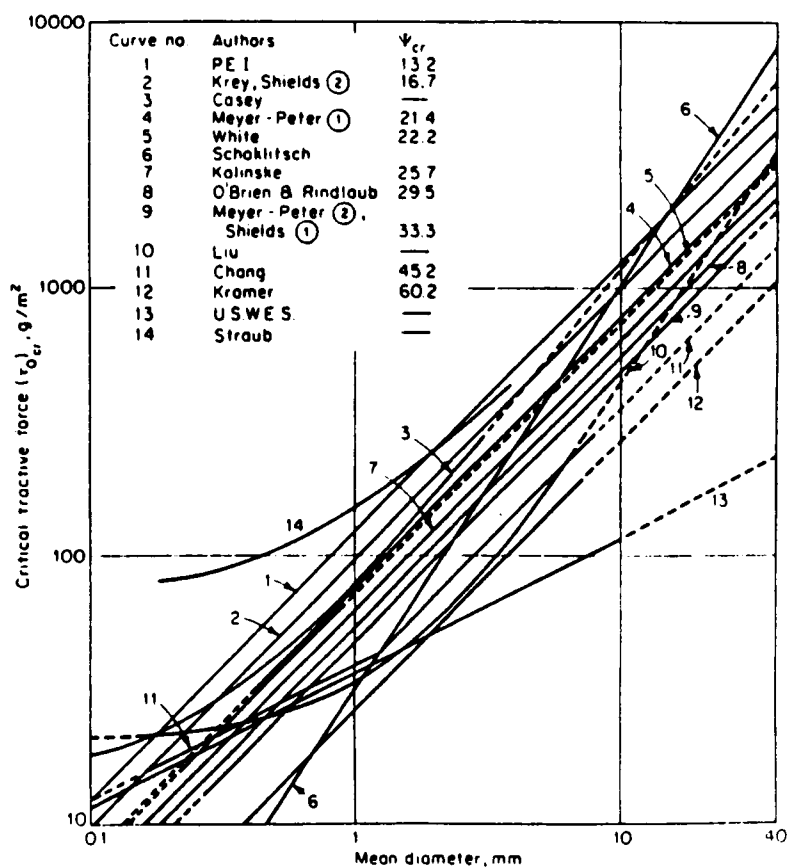


Figure 6. Critical Tractive Force versus Mean Particle Diameter
Taken from Graf (5)

the same general trend illustrating the consistency between the functionality between particle diameter, a critical shear.

As further developments were made, terms were added to the basic equations to more correctly fit the data. A more rigorous approach was developed by Hans Einstein in 1950 as presented by Shen (14). His method was based upon probability theory. The probability of a sediment particle eroding was equated to the probability of a particle depositing and found to be a function of a stream potential term. An empirical curve was developed to relate stream function to the probability of erosion parameters. Figure 7 shows the relationship. The variability of data is not great as previous plots, but considerable variation is left. The two expressions for Einstein's functions are:

$$\phi = \frac{g_s}{\gamma_s} \sqrt{\frac{\rho}{\rho_s - \rho} \cdot \frac{1}{gd_3}}$$

$$\psi = \frac{\rho_s - \rho}{\rho} \cdot \frac{d}{sR_h}$$

ϕ = intensity of bedload transport

ψ = flow intensity

s = energy slope of stream

ρ_s = particle density lb/ft³

ρ = water or fluid density lb/ft³

g_s = sediment transport lb/s.ft

γ_s = specific weight of particles lb/ft³

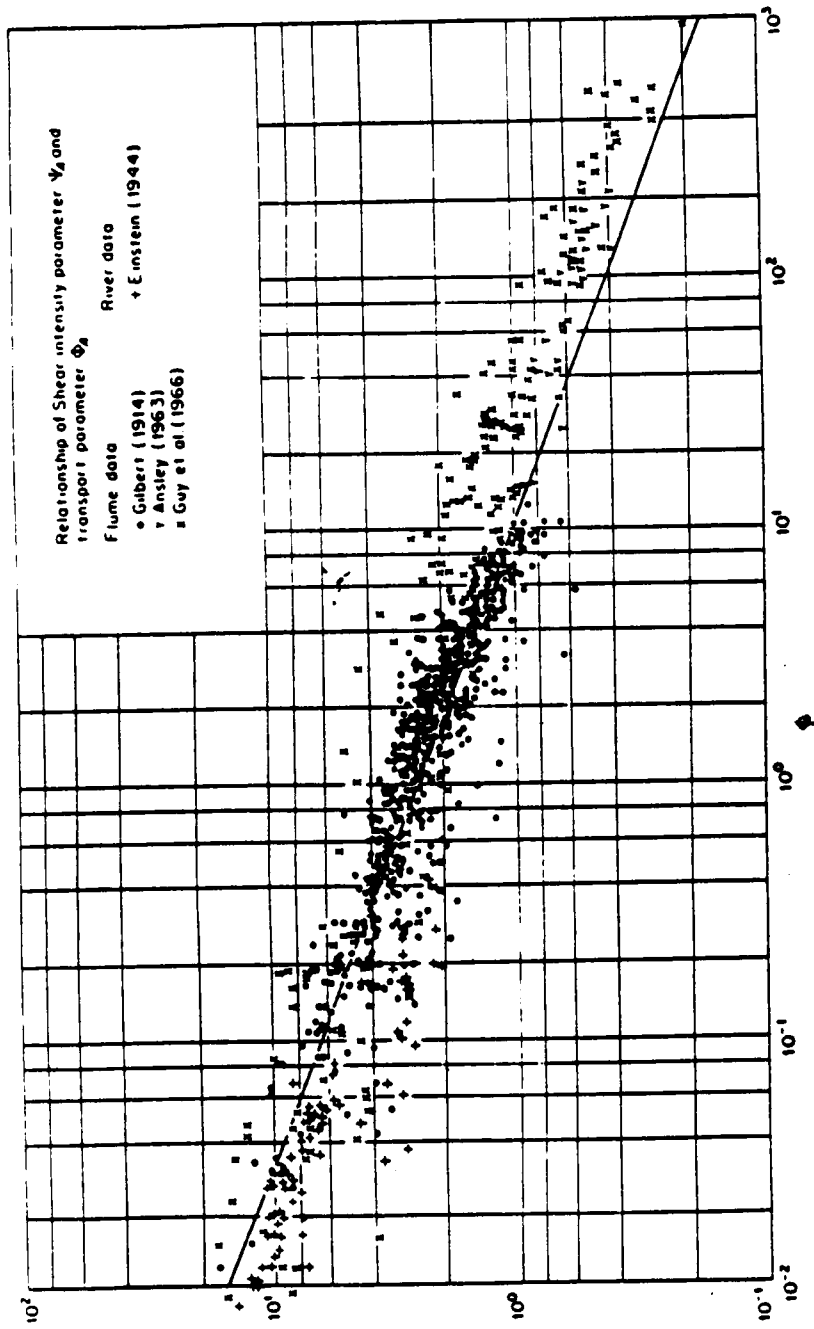


Figure 7. Relationship Between Einstein's Sediment Discharge Parameters
Taken From Graf (5)

d = particle diameter ft.

g = gravitational constant

32 ft/sec²

This last method is considered state-of-the-art and there have only been minor modifications in how the parameters are calculated by such researchers as Meyer-Peter (1948) and Chien (1954) as presented by Yalin (24).

A similar approach to Einstein was made by Laursen (1958) presented by Graf (5), who defined two parameters regarding sediment transport, and developed an empirical relationship between them. One parameter is the shear velocity and settling velocity ratio, or

$$\frac{\sqrt{\tau/\rho}}{V_{ss}}$$

V_{ss} = settling velocity ft/s

ρ = density of liquid lb/ft³

τ = unit tractive force lb/ft²

which expresses the effectiveness of the mixing action of the turbulence. The other parameter is the ratio of the concentration of moving sediment to the available or effective tractive force obtained by use of Manning's and Stricklers relation (in consistent units):

$$\left(\frac{d}{D}\right)^{7/6} \cdot \frac{C}{\left[\begin{array}{cc} \tau & -1 \\ \tau & cr \end{array} \right]}$$

D = depth of flow

$$C = \frac{q}{q_s} \cdot 256$$

q = Volume rate of liquid per unit width

q_s = volume bedload rate per unit width

τ = available tractive force

$(\tau)_{cr}$ = critical tractive force

These two parameters are equated in an empirical relationship "for reasons more intuitive than rational."

Toffaletti modified the Einstein procedures as presented by Shen (14) in an attempt to match field data for rivers, and eliminate the graphical solution. The depth of water flow is divided into three zones. These three zones are the lower zone where the depth of flow is less than $R/11.24$ (R is the hydraulic radius), the middle zone for depth between $R/2.5$ to $R/11.25$ and the upper zone where the depth is above $R/2.5$. The distribution of sediment in the water column is assumed to be a power function of depth.

$$C_y = C_a \left(\frac{R_H}{y} \right)^Z$$

$$Z = \frac{VW}{C_z} S R_H$$

C_y = sediment concentration at depth y

V = velocity of water ft/s

W = Fall velocity of particle ft/s

$$C_z = 260.7 - 0.669 F$$

F = temperature in Fahrenheit

R_H = hydraulic radius ft.

y = depth ft.

S = water level slope

C_a = known sediment concentration

Once a sediment concentration is determined in the lower zone, it can be calculated in the upper zones. Integrating over the entire depth yields total sediment load. Einstein's ψ vs ϕ relationship is expressed analytically as

$$\psi = \frac{TA}{V^2} \cdot 10^4 d$$

d = particle diameter ft

V = velocity of water

TA = field parameter ft/s²

The sediment load transport is then expressed as:

$$G_s = \frac{1.905}{\frac{(TA)}{V}^{5/3}}$$

where G_s is the sediment load per unit width.

The TA field parameters were determined from field data from over 600 cases laboratory and field data. The calculation procedure is to first determine sediment load in the lower zone and then work up to the other two zones. Because of the elimination of the curve, this procedure is well suited for computer programming.

One of the underlying assumptions upon which all the above theory is based, is no interactive forces between particles. This is true for larger grain sizes, sand and gravel, but not true of smaller grained sizes, clays and silts. The electrostatic potential between particles and other possible forces (such as chemical attraction) causes clays and silts to be cohesive. This cohesive nature makes it hard to determine the erosion potential of soils. Some researchers, one by the name of Partheniades (12), have had some success in predicting silt movement near estuaries. However, the nature of different soils make it hard to generalize about the cohesion forces of all soils. For this reason, to quantitatively predict erosion of clays, a flume study is required on the soil in question.

To summarize the above, there are several different methods of quantifying sediment transport load, but only a few have been presented. Table 1 lists the most commonly used equations. The methods yield different predictions of sediment load but tend to be within an order of magnitude of each other, see Figure 8. The important factors that all these methods require are particle diameter and density, water velocity along the bottom, depth of the water (therefore shear) and developed empirical relationships. These must be well defined before sediment transport predictions can be made.

TABLE 1
SUMMARY OF AVAILABLE SEDIMENT TRANSPORT FORMULAS (1)

TYPE	PREDICTED LOAD	AUTHOR(S) AND REFERENCE	DATE
Deterministic-----Bed		DuBoys	1879
Deterministic-----Bed		Schoklitsh	1934
Deterministic-----Bed		Meyer-Peter	1934
Deterministic-----Bed		Waterways Experiment Station	1935
Deterministic-----Bed		Shields	1936
Deterministic-----Bed		Schoklitsh	1943
Deterministic-----Bed		Kalinske	1947
Empirical-----Total		Inglis	1947
Deterministic-----Bed		Meyer-Peter and Muller	1948
Stochastic-----Bed		Einstein	1950
Stochastic-----Total		Einstein	1950
Stochastic-----Bed		Einstein and Brown	1950
Stochastic-----Total		Colby and Hembree	1955
Deterministic-----Bed		Bagnold	1956
Deterministic-----Total		Egiazoroff	1957
Deterministic-----Total		Bogardi	1958
Deterministic-----Total		Laursen	1958
Deterministic-----Bed		Rottner	1959
Deterministic-----Bed		Yalin	1963

Table 1 (continued)

TYPE	PREDICTED LOAD	AUTHOR(S) AND REFERENCE	DATE
Empirical-----Total		Blench	1964
Stochastic-----Total		Colby	1964
Stochastic-----Total		Bishop, Simons and Richardson	1965
Deterministic-----Total		Bagnold	1966
Stochastic-----Total		Wilson	1966
Deterministic-----Total		Chang, Simons and Richardson	1967
Deterministic-----Total		Engelund and Hansen	1967
Deterministic-----Total		Graf	1968
Deterministic-----Total		Toffaletti	1968
Deterministic-----Total		Akers and White	1973
Deterministic-----Total		Yang	1973

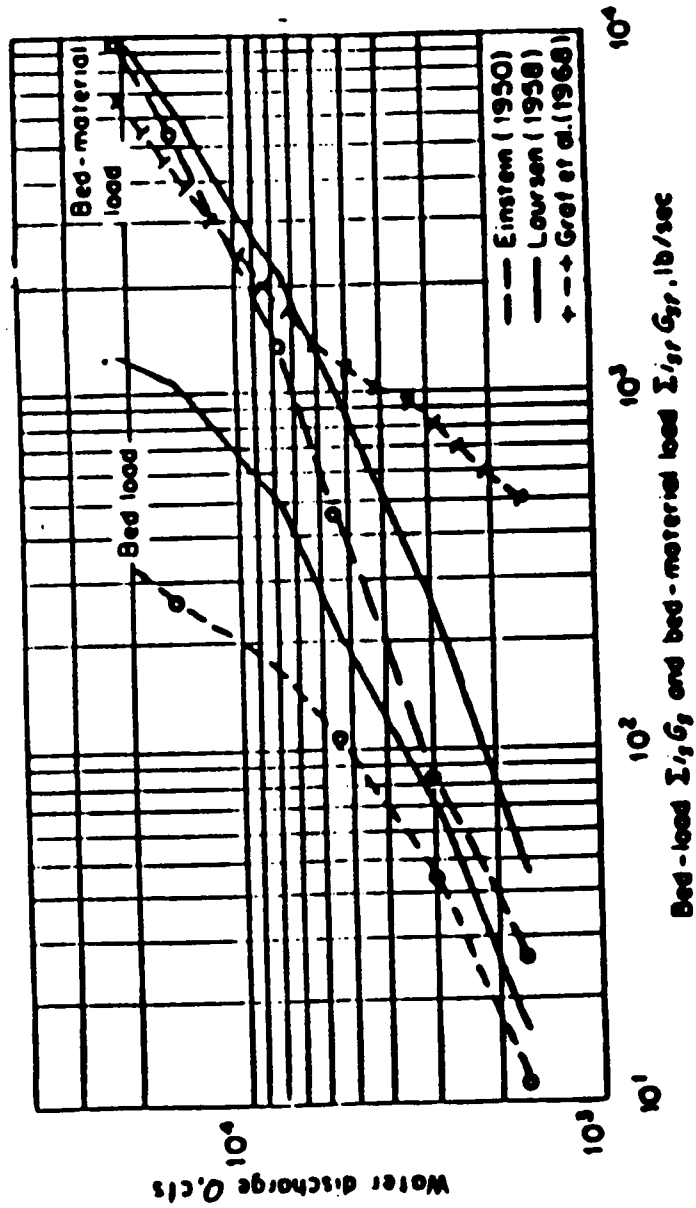


Figure 8. Comparison of Three Different Models of Sediment Transport Prediction versus Flow

CHAPTER IV

MODEL SELECTION

A literature search was conducted to determine availability of computer models to provide the transport analysis necessary for the HSB-IC system. Many references were made to ocean estuaries and deposition of sediment. Considerable data were found on water quality measurements of suspended sediment in streams. Many studies involved formation of sand dunes along the coastline and dredging from rivers, but there were few studies relating to contaminated sediment transport. The studies that have been reported dealing with contaminated sediments were generally limited to sedimentation in lakes and bays.

There were two studies cited which involved contaminated sediments in streams. One was the Hudson River dealing with PCB contaminated soils.(2) The computer model used in this study was one developed by the Army Corps of Engineers, developed by the Hydraulic Engineering Center, Davis, California (HEC-6). This model was originally developed for applications towards design of reservoir systems, but was successfully used to analyze the PCB contaminated soils along the Hudson River.

The HEC-6 model is a one-dimensional routing model that has no provision for lateral distribution of sediment across a section. The geometry of the physical system is represented by specifying cross sections with coordinates of stations (up to 150 can be handled), elevations and distance between each transect. The Manning's n-values may be varied for each transect. The hydraulics needed to be specified

are flows and duration along with downstream elevation. In-flowing sediment load (washload) must be specified as a function of water discharge.

Grain sizes in the model are separated in fifteen (15) divisions, one (1) clay, four (4) silt, five (5) sand fractions, and five (5) fractions of gravel. The water surface profile is calculated in the model using a method called "Standard Step," which determines depth by means of an energy balance. Friction loss is calculated as a function of Manning's sediment transport. The user is required to define the limits of the moveable bed layer, i.e., what areas of the channel are erodible sediments. This also allows definition of the overbank areas. Though the computer program was written with deposition at reservoirs in mind, the program is flexible enough to be adaptable to many other physical systems (16). There are four options for calculating sediment transport. They are: 1) Toffaleti's modification of Einstein's Method; 2) Einstein's Method; 3) Larsen's Method, or 4) DuBoy's Method. Toffaleti's method was chosen for this work because of its calibration to actual field data and its specific application to wide rivers. The limits of the moveable bed were taken at the edges of the channel to a maximum depth of 1 foot. This is a conservative assumption in the model since the entire bed is not likely to be in an eroding environment.

The other study found in the literature review dealing with contaminated sediments in rivers was conducted by Battelle Laboratories, Pacific Northwest on the James River in Virginia with Kepone contaminated soils (10,11). The model they developed for the work is called FETRA. It is an unsteady state, two-dimensional finite

element model. The model handles three (3) separate sediment sizes, cohesive sediments (with associated flume studies), and dissolution of the contaminant. The model predicts erosional and depositional areas similar to HEC-6 with the additional capability of handling clays and silts using formulas developed by Partheniades and Krone (1962). Battelle Laboratories have not made this model commercially available.

Other computer models were investigated. It was quite apparent there are few models available for this work. The only other models available are from independent consultants. A more appropriate model for modeling clay is Sed IV (Resource Management Associates) (3). This model was developed by Ranjan Arithiaurian to describe cohesive sediment movement in coastal estuaries, and uses an expression developed by Partheniades and Krone. Though the model is more equipped to handle clays, a more rigorous analysis is called for which would include laboratory flume tests to develop model parameters.

In light of the availability of the HEC-6 model and its capabilities, it was selected to complete the study. It is a time honored model capable of evaluating the scour and depositional potential of various areas. The choice of HEC-6 is coherent with the scope of this project. Although an exact predictive model is always desirable, the current state-of-art sediment transport theory is not adequate to support such a model. An empirical model for this individual site could be developed by means of flume studies and laboratory experiments, and using other models as a basis, such as SED IV. Such an intensive study is unnecessary considering the objectives of this project which are to identify erosional or depositional areas,

determine what portions of the stream bed provide the greatest percentage of DDT into the water column and evaluate impacts of alternative remedial measures. If an empirical model were developed, its accurate application after a change in hydraulic conditions (e.g., rerouting of a stream) is questionable since these conditions would be outside the range of its development. The objectives may change, requiring further analysis, after completion of this project. At that time, other approaches would be evaluated.

CHAPTER V

MODEL DEVELOPMENT

Stream bed profiles were measured along transects (i.e. cross sections) located every 0.2 miles. These data were collected in the field by using a modified range probe. The profile data was collected and plotted by Recra Research (13). The transects used in the modeling are shown in Figure 9. Transects could only be used if there was a sediment analysis at that transect. The data was coded into the computer using the extreme South bank as the (0) coordinate. There were at least ten (10) stations used for each transect. For those transects in which there was an island, the data input into the computer was the extreme south and north banks of the island. In all, there were twenty-three (23) transects input into the computer from HSB Mile 0.0 to 5.6, and IC 0.28 to 5.4. This encompassed essentially all of affected reaches of the stream. Transect selection was based on whether there was sufficient sediment grain size analysis and stream profiles. The Indian Creek mile transects were 0.7, 1.3, 2.4, 3.6 and 4.4. The HSB mile transects were 0.0, 0.4, 1.4, 2.0, 2.2, 2.5, 2.7, 3.4, 3.7, 3.8, 4.0, 4.4, 5.2, 5.4, 5.8, and 6.0.

The model was tested for sensitivity to Manning's n-value. Manning's n- value is a measure of resistance of water flow in a stream. Manning's n-values for the stream vary from 0.02 to 0.04, and for the overbank 0.06 to 1.0 throughout the length of the channel. These values were determined from visual inspection of the stream compared to publish standards (a standard means of determination) (4).

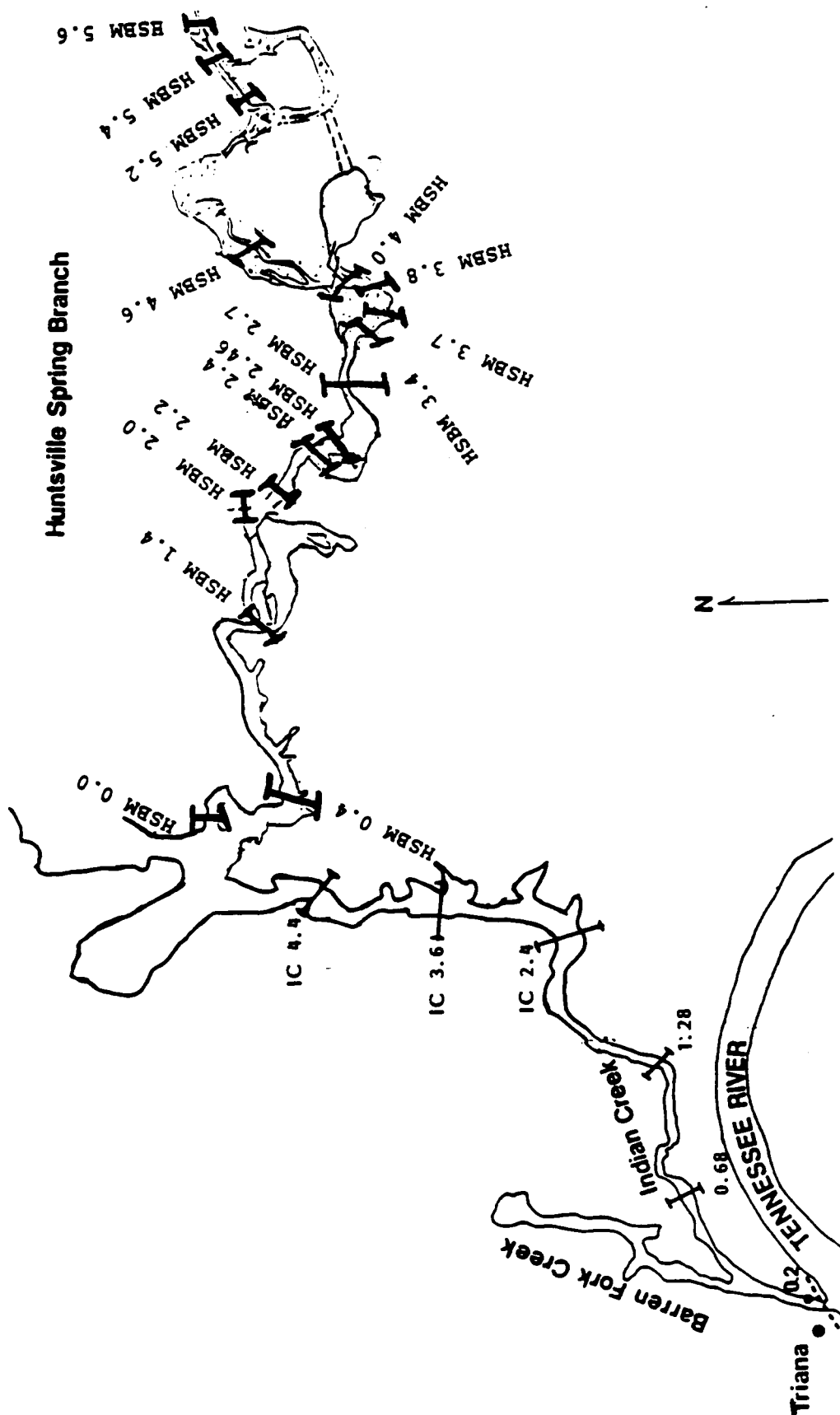


Figure 9. Location of Transects Used In The Modeling

A preliminary sensitivity analysis using the model and varying Manning's n-values throughout the expected range demonstrated that sediment transport rates did not vary substantially with this value, so mean values were chosen for the work of 0.03 for the entire stream length, 0.08 for all of the overbank.

Sediment samples were taken along each transect and a particle size analysis performed. Only those samples which represented soil from 0 to 6 inches in the stream bed were considered because these were the soils potentially available for scouring. All of the various samples for each transect which varied from 1 to 6 in number were averaged for each particle size fraction and this average was then used as representative of the soil along that cross section. Table 2 presents the averages for each section. The overall average soil grain size was reduced to 27% clay, 20% silt, and 53% sand. The most sandy areas are between HSB Mile 4.0 and 5.6 and also between HSB Mile 2.2 and 2.5.

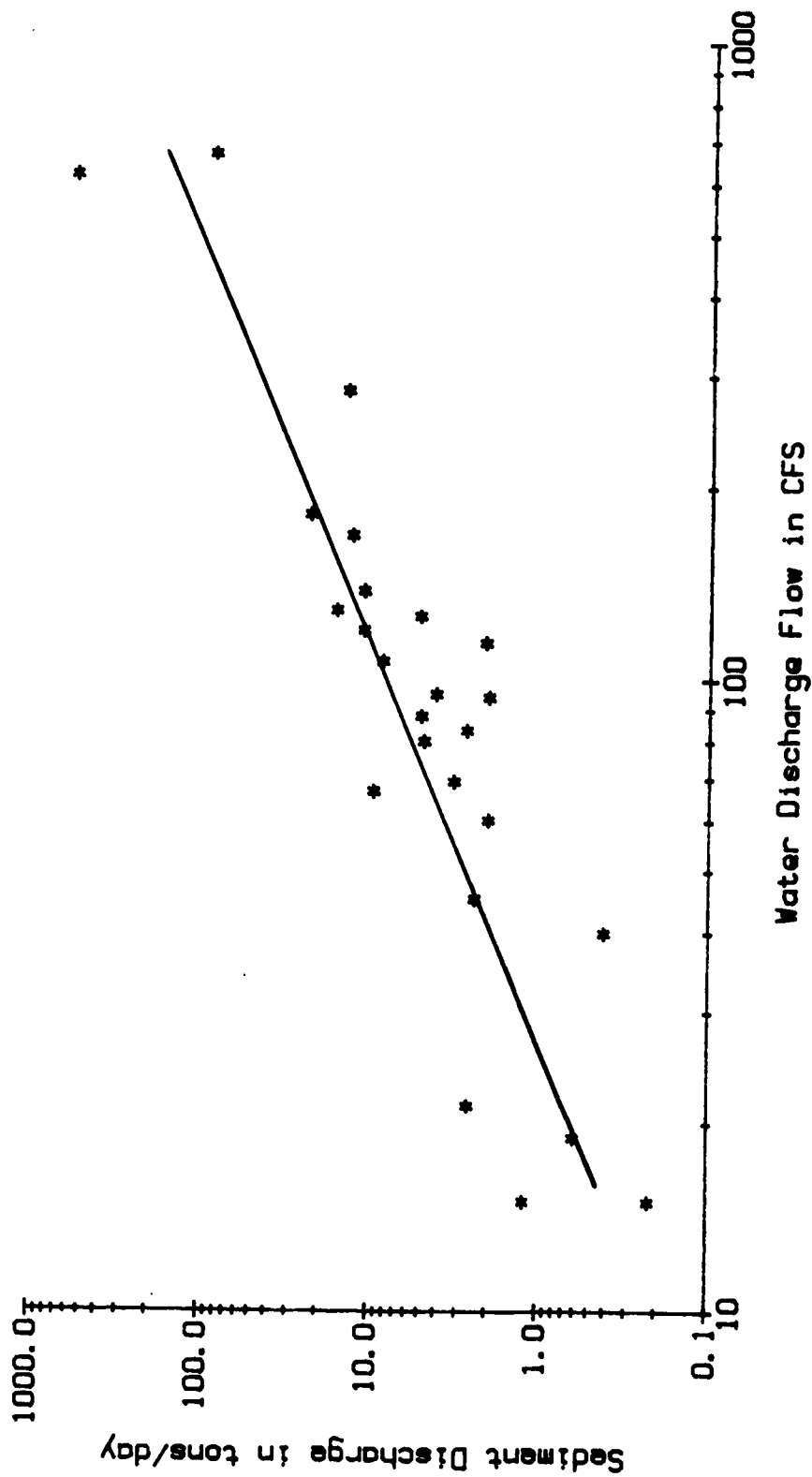
Inflowing sediment load or wash load is required by the model in order to maintain sediment load balance. Figure 10 is a plot of total suspended solids versus flow calculated from suspended solids analysis of water sample taken at sample site # 1 (HSB Mile 9.75), upstream of the study area. A sieve analysis of solids was not completed, so it is unknown exactly what size fractions these solids comprise. Since the topsoil in the Huntsville urban area consists mostly of clays and silts in equal proportions, the total suspended load was assumed to be divided equally between the silt and clay fractions. Four (4) different flow

TABLE 2
 PARTICLE SIZE DISTRIBUTION FOR EACH TRANSECT BY MAJOR SOIL GROUPING
 RECRA RESEARCH (13)

Transect Location HSB Mile	Clay	Percentage Silt	Sand
5.6	5.3	9.3	85.4
5.4	19.1	24.2	56.7
5.2	6.1	7.8	86.1
4.6	14.3	20.6	65.1
4.0	37.5	25.3	37.2
3.8	29.9	9.9	60.2
3.7	30.1	22.7	47.2
3.4	26.9	22.0	51.1
2.7	43.3	15.0	41.7
2.6	40.9	44.3	14.8
2.5	18.5	7.3	74.2
2.4	15.2	6.4	78.4
2.2	12.8	7.5	79.7
2.0	26.0	20.4	53.6
1.4	46.6	35.4	18.0
0.4	55.6	38.9	5.5
0.0	31.5	31.8	36.7
0.68	51.6	40.2	8.2
1.28	60.5	32.0	7.5
2.22	43.6	45.4	11.0

Table 2 (continued)

Transect Location Indian Creek	Clay	Percentage Silt	Sand
3.56	46.5	45.0	8.5
4.4	48.2	34.7	17.1
AVG.	50.1	39.5	10.5
Size	<.004 mm	>.004 mm	>.0625 mm
Fraction		<.0625 mm	



regimes (100, 300, 600, and 800 cfs) were read from the curve and the data points used as input. The computer interpolated the data for flows between these points.

The data sets were run with various flow regimes ranging from 200 cfs, which is the median flow, to 1,000 cfs, which occurs only 0.2% of the time. These flows were chosen from an analysis of the field data. In Figure 11, a log normal probability plot of flow frequency for the transect at HSB Mile 2.4 is presented. Three different curves are shown. Two curves, one for winter and one for summer were derived from TVA regional runoff equations knowing the drainage area of 83.9 sq. mi. The third curve is the result of 27 monthly measurements of flow at the transect. The expected range of flows is illustrated by the plot.

Uptake studies have shown that the rate of DDT uptake by fish is slow process. For this reason, major storm events were not modeled because of their short duration. It is thought that their impact on the fish population is negligible because maximum exposure is only a few days. Rather, steady normal events were evaluated for potential scouring and deposition which would represent the average conditions that the fish are exposed.

The HSB-IC system is within the influence of Wheeler Dam on the Tennessee River. This dam causes backwater up into the stream. This backwater effect is seasonal because TVA lowers the reservoir level in the winter months. The model was used to consider erosion potential both normal summer and winter Tennessee River elevations. By using average controlled elevations for the two seasons (stated earlier), the entire range of backwater effects on the sediment potentials was tested.

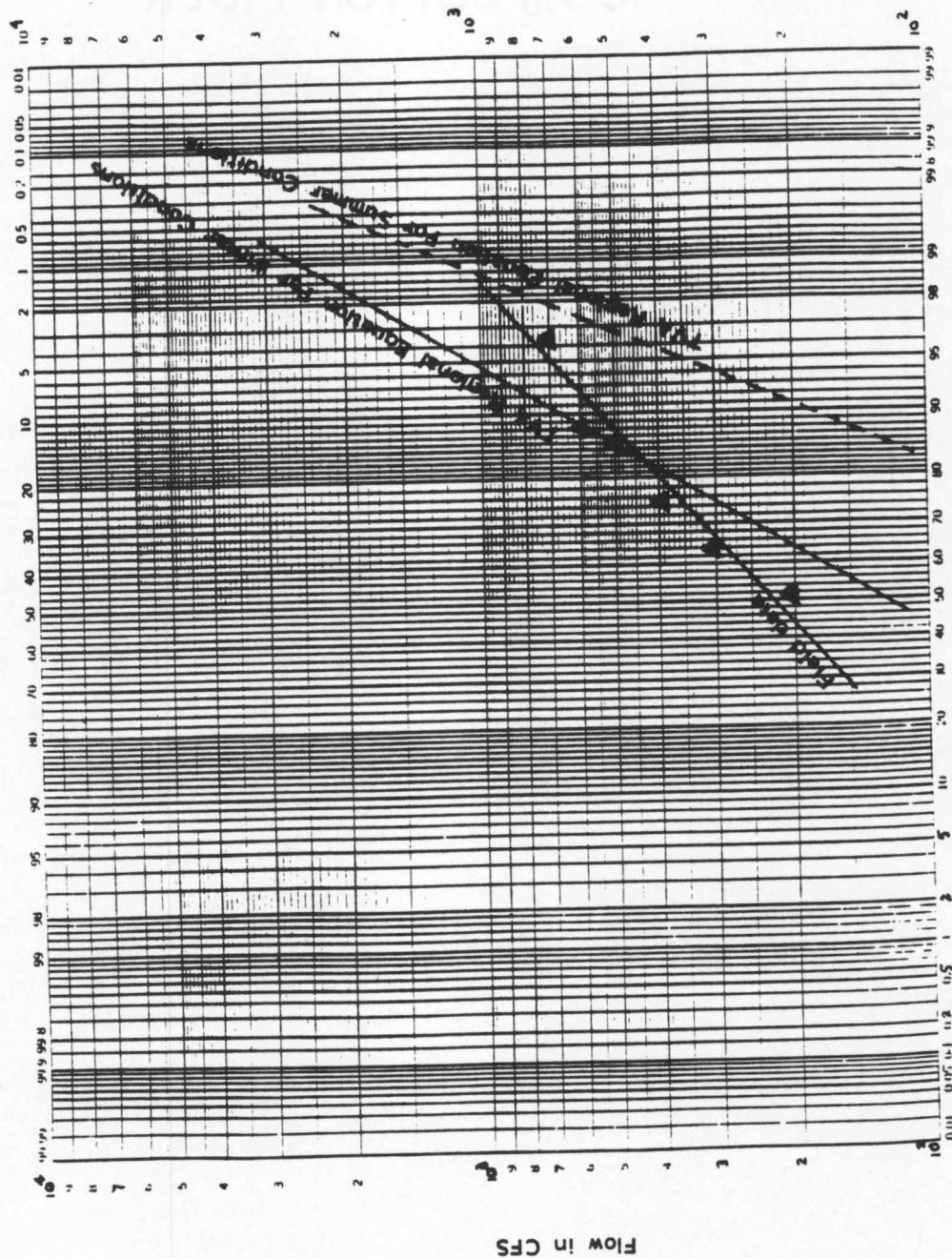


Figure 11. Flow Frequency Plot for Site No. 4

CHAPTER VI

MODEL RESULTS

The model was run with several different flows corresponding to the range observed in field measurements. An example run at a typical flow (400 CFS at IC) is attached as an Appendix. Figure 12 is a plot of tractive force on the stream bed calculated by the model at this flow. Literature values for tractive force to cause incipient scour of clays and silts vary from 0.02 to 0.04 lbs/ft² (12)(7)(20). Using this criteria, the areas of scour identified in the model are from HSB Mile 4.0 to 5.4 and marginally between HSB Mile 2.0 to 2.7. The sieve analysis in the HSB Mile 4.0 to 5.4 reaches is predominately sand fraction, demonstrating that the clay silt fraction has eroded away. Also, in these areas, DDT decreases with depth, further demonstrating that the DDT has been eroded away. Sediment probes were used to semi-quantitatively evaluate the transportable amount of sediment at each transect. The probe was pushed into the bottom as far as possible by hand. This depth was recorded for each transect. Sediment probes show little to no accumulation of loose sediment along the bottom at HSB Mile 4.0 to 5.4, and the only sediment present was along the sides of the channel attesting to the scouring nature along this reach predicted by the model.

Probing the stream bottom between HSB Mile 2.4 to 2.72 showed loose sediment. DDT values for this sediment tapered off quickly with depth, (again, this is an indication of scouring). Between HSB Mile 2.7 and 4.0, the stream widens, becoming shallower with sediment settling out

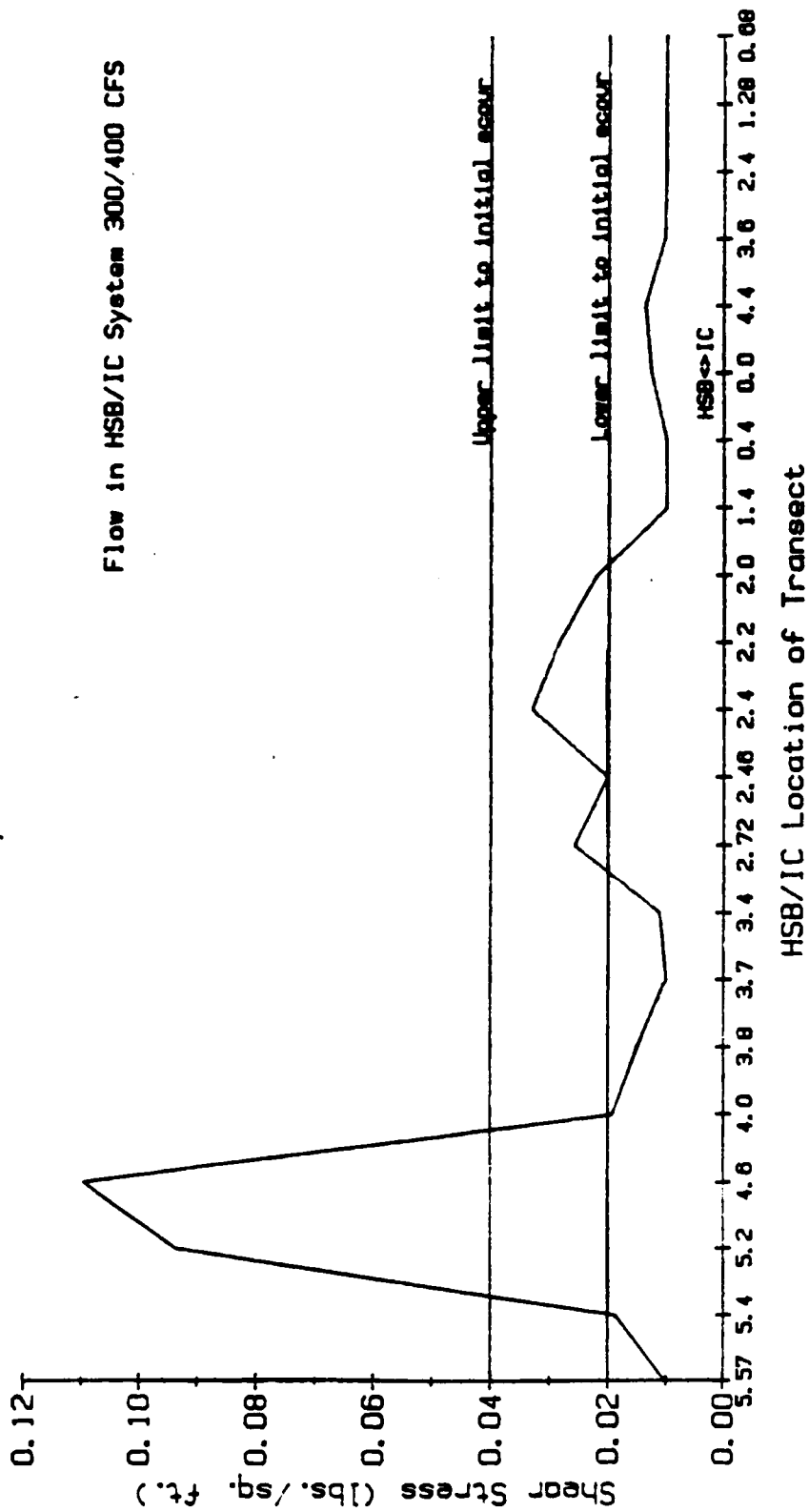


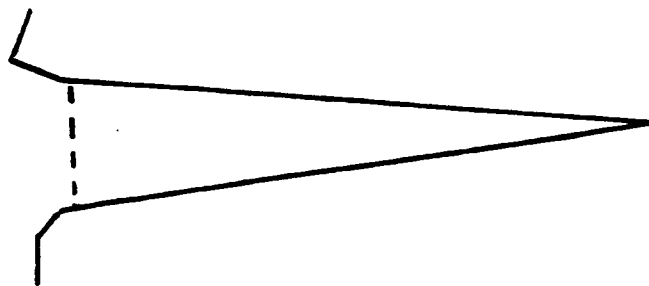
Figure 12. Tractive Force Along Stream Bed

forming channel bars or islands, typical of a depositional environment. DDT is evident in most portions of the channel, but concentrated in the center.

Downstream of HSB Mile 2.4 to 2.0 is an area that the model predicts to be erosional at flows greater than 300 CFS which occurs 30 to 40% of the time. This is somewhat borne out by field observations in that consistent concentrations of DDT and a small amount of sediment in the center of the channel. The remainder of HSB was predicted to be depositional downstream of HSB Mile 2.0. This is observed in the channel by measurements of several feet of sediment with considerable clay content, broad flat stream profiles and DDT concentrations less than 23 ppm.

Indian Creek was found to be a depositional environment for all events modeled. The shape of the channel and depth of flows create little shear on the stream bed bottom, explaining the existence of a high proportion of clay in the sediments along this reach. This explains why DDT in this reach becomes progressively less concentrated with depth rather than abruptly dropping as in Reach A, because clean sediment from IC is being deposited with HSB sediment diluting the sediment mixture.

Figure 13 shows the bed cross sections for two different transects HSB Mile 4.6 and 3.4. Note the contrast between the two. The cross section at 4.6 is in the shape of a sharp "V". The shear stress on a stream bed is a function of stream velocity and depth of water. This transect with such a small cross sectional area causes a high velocity



Stream bed profile at
HSBM 4.6 erosional
area



Stream bed profile at HSBM 3.4 depositional area

Figure 13. Comparison of Stream Bed Cross Sections In A
Scouring and A Deposition Area

with a large depth. Additionally, the stream bed slopes upward along this reach, potential conditions for scouring. On the other hand, the transect at mile 3.4 is flat and long, with mean low velocity and shallow depth, which are potential conditions for deposition. All model runs, regardless of flow, show the highest erosion occurring from mile 4.6 upstream.

Table 3 is a summary table of model runs using various flows. The range of flows was from 200 cfs to 1,000 cfs, which represent average flows to that which occurs only 0.5% of the time. (See flow frequency plot, Figure 11 on page 41). The relative sediment yield listed includes all fractions of sand, but none of clay and silt, so the clay and silt portion is minimal. The average concentration of DDT in the soil is listed beside each transect. It has been shown that the majority of the DDT is in the silt fraction so this is the fraction that the mass rate movement of DDT is calculated for each transect flow combination. These rates must be considered as only relative rate of DDT movement. Actual rates cannot be accurately predicted with this model. (The highest rate of movement is at transect 4.6, which varies from 30 to 4,000 lb/day of DDT movement for the range of assumed flows). Totaling all DDT loss for each flow, the proportion of that coming from upstream of HSB Mile 4.0 is 93%, 99%, 98% and 96% for 200, 400, 600, and 1000 cfs flows respectively.

This analysis highlights this section of stream (upstream of 4.0) as the primary source of erodible DDT. One alternate remedial action will eliminate this source by rerouting the stream. This rerouting would involve bypassing the stream from HSB Mile 5.4 to 4.0 by cutting

TABLE 3

SUMMARY TABLE OF MODEL RESULTS WITH VARIOUS FLOWS DDT IN
SEDIMENT BEING ERODED FROM HSB DDT IN LBS/DAY
AND SEDIMENT IN TONS/DAY
(HSB MILE 0.0)
ELEV.=552 FT

Sec. HSB No.	DDT Conc.	Q = 200		Q = 400		Q = 600		Q = 1000	
		Sed. Load	DDT Loss	Sed. Load	DDT Loss	Sed. Load	DDT Loss	Sed. Load	DDT Loss
5.6	0	.1	0	.75	0	4.1	0	6.6	0
5.4	4860	.1	1.0	.75	7.3	4.1	40	7.1	69
5.2	4800	1.3	12.5	1.9	18.2	5.3	50.9	19.1	183
4.6	5015	3.3	33	88.0	882.6	220	2206	389	3902
			(95%)		(99%)		(98%)		(99%)
4.0	1038		A R E A O F D E P O S I T I O N						
3.8	1350		A R E A O F D E P O S I T I O N						
3.7	939		A R E A O F D E P O S I T I O N						
3.4	2315		A R E A O F D E P O S I T I O N						
2.7	410	0.9	0.7	.8	0.7	15.8	13.0	15.8	13
2.5	131		A R E A O F D E P O S I T I O N						
2.4	68	1.7	0.2	2	0.3	33.3	4.5	40.5	5.5
2.2	116	1.7	0.4	2.9	0.7	35.4	8.2	43.1	10.0
2.0	116	3.3	0.8	4.5	1.0	47.1	10.9	54.6	12.6
1.4	67		A R E A O F D E P O S I T I O N						
0.4	126	0.6	.2	1.5	0.4	2.0	0.5	3.9	1.0
0.0	8.6	0.1	.002	1.8	0.03	3.4	0.1	98.5	1.7
Total*		13.1	48.8	104.9	911.2	370.5	2334.1	678.2	4198
Movement									

* Not necessarily leaving the system

a channel from HSB Mile 6.0 down into the embayment, which flows into HSB Mile 4.0. A large reduction in DDT erosion and expected DDT concentrations in the water column should become quickly evident if this is done. To further analyze this case, the model was run to evaluate the impact of hydraulic changes due to the rerouting of the stream. Plotted in Figure 14 is a plot of tractive force or shear stress of the water along the river bottom at various transects. All of Indian Creek is depositional and in fact the only scour potential left in the entire system is HSB Mile 2.2 through 2.0. This section of the river is less wide and has a gentle sloping bottom which provides for increased velocities of water. The only way to change this condition would be to widen the river or create a restriction downstream that effectively slows velocities and essentially has the same effect.

Cohesive sediments such as clays and silts erode at shear stresses ranging from 0.02 to 0.04 lb/ft². After rerouting, and at normal flows (less than 200 cfs in the system), there would be no erosion because these critical values are generally not exceeded. However, at flows greater than 300 cfs, HSB Mile 6.0 to 5.8 and portions of HSB Mile 2.72 to 2.0 become erosional with bottom shear stresses greater than 0.04 lb/ft². This is great enough to erode the clays, silts and fine sands. Water quality sampling between HSB Mile 4.0 to 2.4 has shown the section between 4.0 and 2.7 to be consistently depositional, but at flows greater than 200 cfs, DDT increases in the water column past HSB Mile 2.72. (Which is confirmation of this subsections' scouring potential).

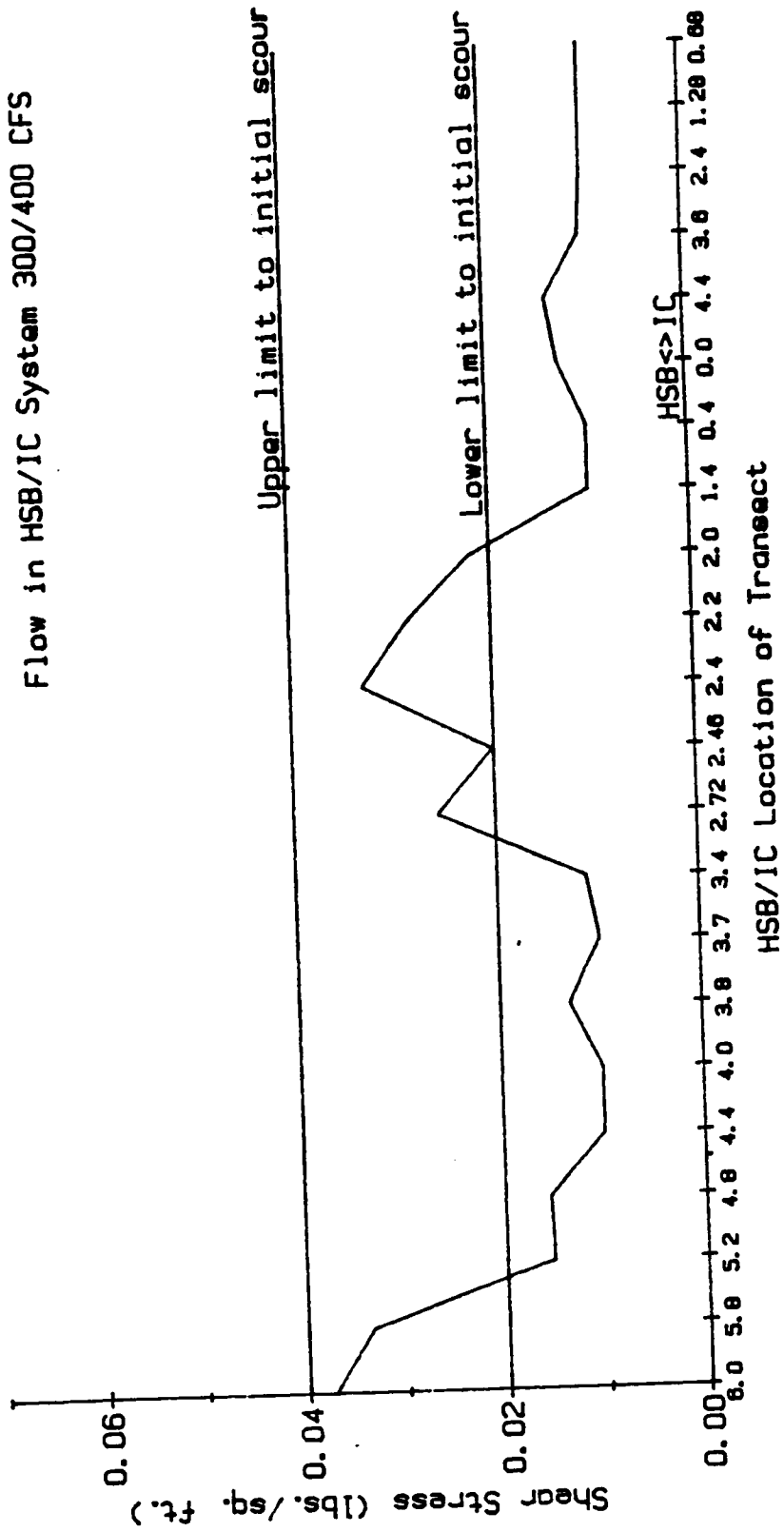


Figure 14. Tractive Force Along New Stream Bottom

Generally, areas of scour versus deposition can be measured by the width of the stream. Looking more closely at the potential erosion between HSB Mile 2.0 to 2.7, Figure 2 on page 9 which shows a layout of the HSB-IC system, the throat area at HSB Mile 2.72 is a narrow section in the river that causes backwater upstream, creating a depositional environment. This also causes scouring inside the throat and immediately downstream of it. The stream remains relatively narrow up to HSB Mile 2.0 where it widens noticeably. Downstream remains wide enough to maintain a depositional environment during most flow regimes.

One method to reduce the amount of erosion along this section of stream would be to widen the throat section at mile HSB 2.72. This cut throat measure will trade-off some of the backwater condition above 2.72 for reducing erosion through the throat and immediately downstream of it. The model was run widening the throat by approximately 100 feet to the south with a flat bottom at an elevation of 551 feet MSL. Figure 15 includes shear stress plots for the three base flows and the throat widened. Two changes are evident. First, the desired effect erosion potential at 2.72 and 2.5 is reduced by almost half. However, downstream of this, there is no change in erosion or deposition potential. The second effect is the increased erosion potential at HSB Mile 3.8, 5.8 and 6.0. The increased erosion at 5.8 and 6.0 inconsequential because this area is uncontaminated.

The increase in bottom shear stress at 3.8 would be a problem if it was significant, but since the force is still below the critical shear of $.02 \text{ lb/ft}^2$ the the model did not predict any increased erosion of sediment in this area. The reduced sediment load caused by this

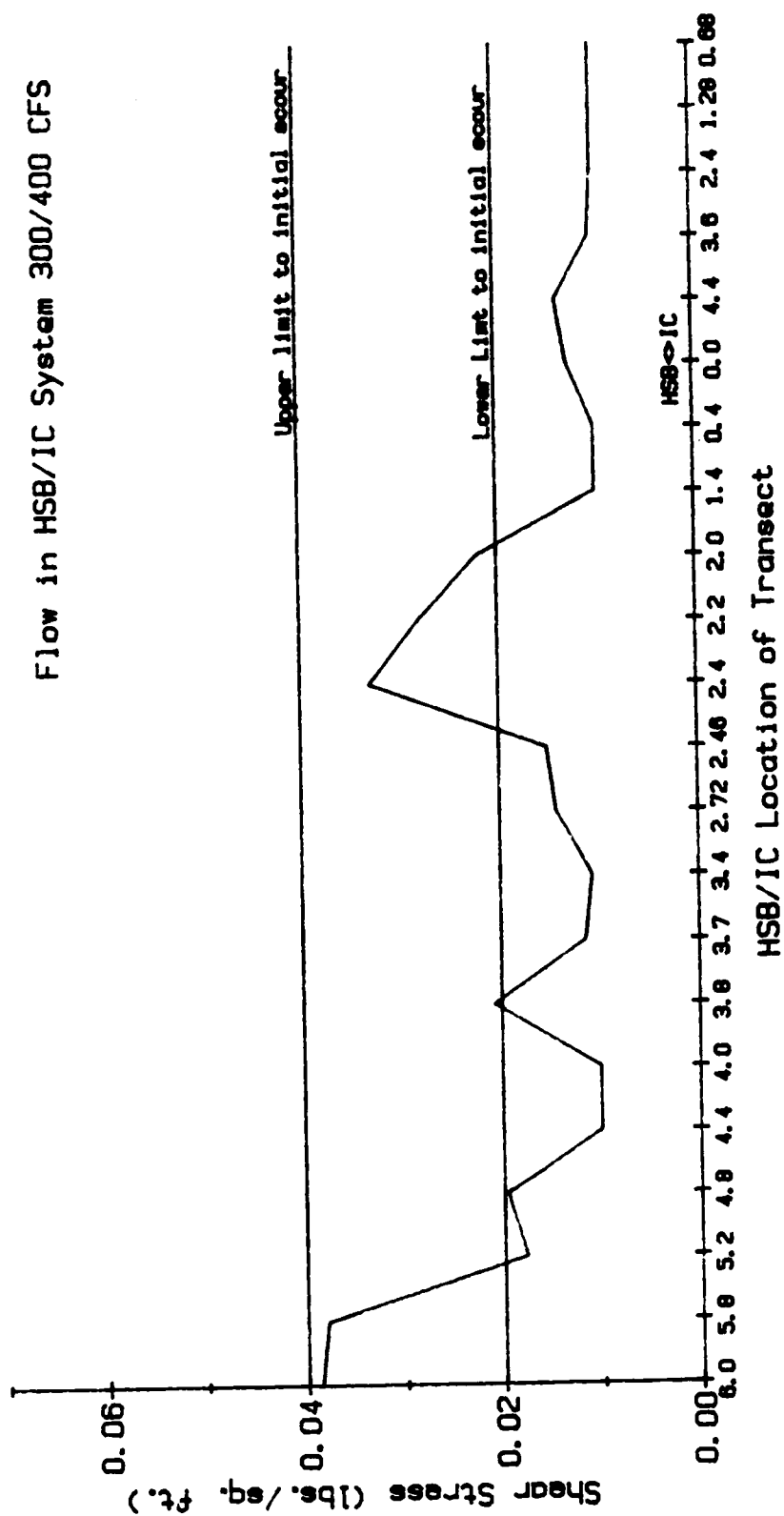


Figure 15. Tractive Force Along Stream Bottom With A Widened Throat Area At HSB Mile 2.72

measure compared to the base case, shows erosion at HSB Mile 2.72 and 2.5 is eliminated and is reflected in a 30% reduced sediment load at HSB Mile 2.0.

The model was run this time varying downstream elevation with constant flow. Downstream elevations were chosen to correspond to that which occur during summer (high pool) and during winter (low pool). As expected, erosion at low pool is at a higher rate than at high pool. The greater depth caused by backwater causes lower water velocities and less potential for erosion. The comparison was made by assuming total sediment eroded for the two runs for a typical flow. Erosion of sediment during summer pool is two thirds that of what occurs during the winter. Generally, water quality sampling has shown this to be the case. This information indicates that a dam would have some utility as a remedial measure, but is not expected to have an overwhelming effect.

As an illustration of the predictive capabilities of HEC-6, an attempt was made to compare field data to computed values of sediment erosion. Since the model calculates total load (bedload plus suspended load), and the field data is only measuring suspended load, several new modeling assumptions had to be made to make a fair comparison (22). To make a comparison, the bed was assumed to be comprised of 100% very fine grained sand, necessary because HEC-6 cannot accurately predict movement of silts and clays. The model was run for various flows and the predicted sediment load at HSB Mile 2.4 (water sampling site no. 4) was plotted on a log scale as a straight line, Figure 16. The suspended sediment load calculated from field data is also plotted on the Figure.

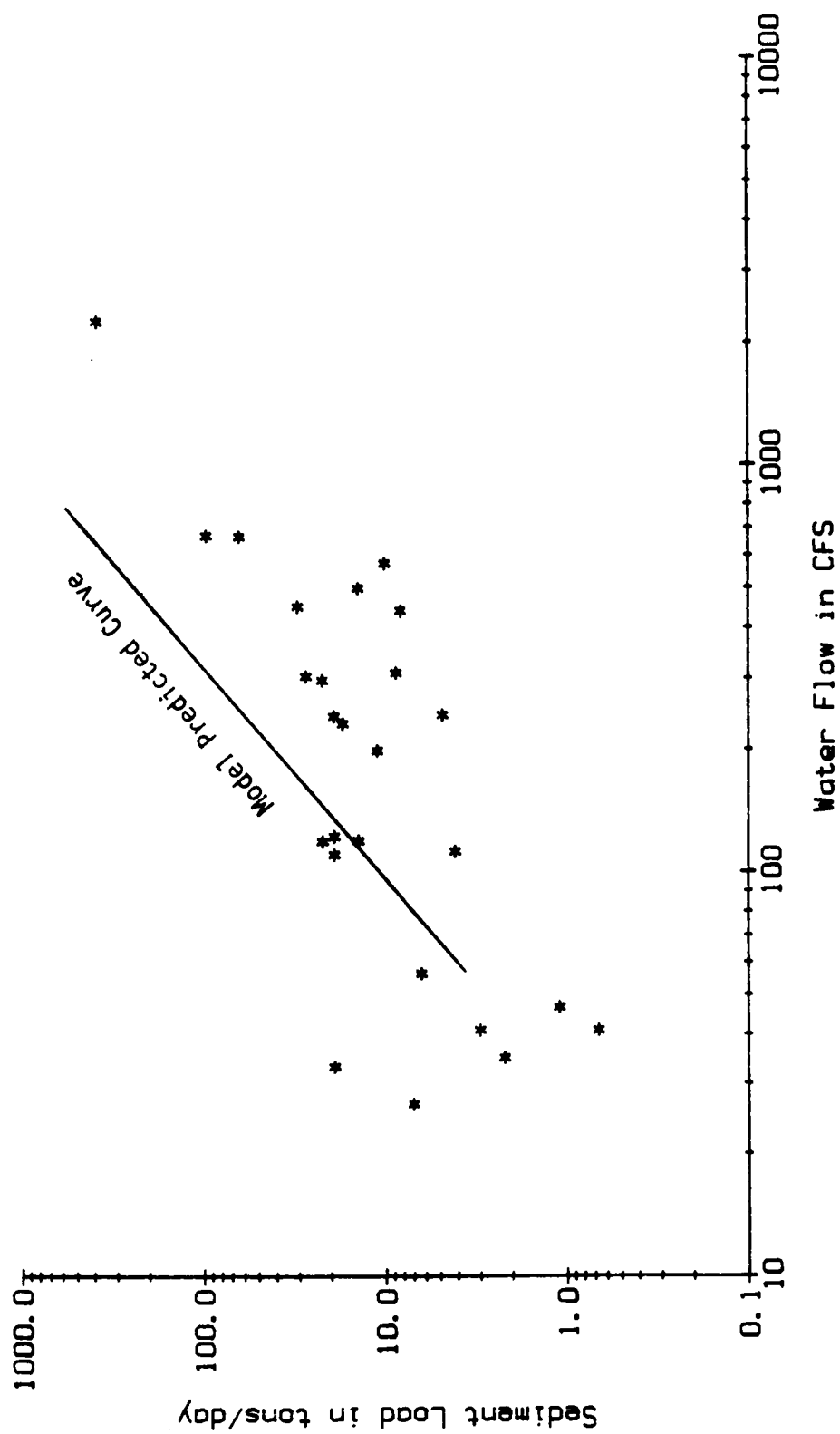


Figure 16. Predicted versus Actual Sediment Load at Site No. 4

Generally, the model overpredicts suspended load at high flows, but is always within an order of magnitude of field data. This illustrates again that sediment transport modeling should not be used as an exact predictive tool, but as a means of understanding the general scour and deposition properties of the stream.

CHAPTER VII

CONCLUSIONS

The transport characteristics of bottom sediment of Huntsville Spring Branch and Indian Creek were studied using a computer model called HEC-6. This model was useful in defining areas of deposition and scour. Model calculations of shear stress along the stream bottom were instrumental in making this determination. The model provided an understanding of the link between the stream morphology and sediment erosion/deposition characteristics. Field observations supported the model analysis and supported the predictions.

The model was used to determine what remedial measures might be instrumental in reducing erosion of sediments contaminated with DDT. A section of the stream was highlighted with the model as being the source of greater than 95% of the erodible DDT. Bypassing, or otherwise eliminating this section (HSB Mile 4.0 to 5.4), should greatly reduce the DDT concentration in the water column. Another possible remedial action was identified using the model to reduce erosion of sediments between HSB Mile 2.4 to 2.7. This involved a narrow section in the stream which could be widened, reducing scour potential downstream of this section by 30%. Computer modeling sediment was useful in this study, not in predicting exact rates of sediment movement, but in identifying areas of erosion and deposition, understanding stream morphology, and developing remedial alternatives by comparing relative rates of contaminant transport.

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APPENDIX

T1 SEDIMENT TRANSPORT PROBLEM ON HUNTSVILLE SPRING BRANCH AND
 T2 INDIAN CREEK TO DETERMINE EROSION RATES OF SEDIMENT
 T3 SO IN TURN DDT TRANSPORT COULD BE ESTIMATED

NC	.08	.08	.03						
X1	.68	16	0	181					
GR	559.2	0	558.7	9	556.2	14	552.4	16	550.9
GR	547.6	30	544.3	50	541.7	70	540.2	90	542.9
GR	547.7	130	550.6	140	553.4	150	556.0	152	557.1
GR	558.6	181							
H	0.68	535.0	20	150					
X1	11.28	14	0	230	3168	3168	3168		
GR	560.0	0	553.3	20	550.6	30	547.6	50	545.7
GR	544.3	90	544.0	110	544.2	130	545.6	150	549.2
GR	550.8	190	554.7	210	559.4	220	560.9	230	
H	1.28	540	30	210					
X1	2.4	18	0	232	6072	6072	6072		
GR	559.4	0	558.9	16	556.0	20	552.7	21	549.6
GR	548.2	52	546.2	72	546.2	92	546.5	112	546.7
GR	547.4	152	548.3	172	550.0	192	552.2	212	554.3
GR	556.0	224	557.0	225	558.0	232			
H	2.43	545	20	220					
X1	3.6	19	0	318	6178	6178	6178		
GR	558.3	0	557.3	12	552.8	15	549.6	28	547.8
GR	547.2	68	547.6	88	548.4	108	548.9	128	548.9
GR	549.5	168	550.6	188	551.2	208	551.5	228	551.9
GR	552.5	268	554.5	288	556.0	298	558.1	318	
H	3.6	540	20	300					
X1	4.4	19	0	279	4224	4224	4224		
GR	559.4	0	559.3	10	555.5	23	553.2	35	551.9
GR	551.5	75	551.5	95	551.3	115	550.8	135	549.8
GR	548.3	175	546.7	195	547.5	215	550.9	225	555.7
GR	555.3	255	557.7	259	559.1	269	560.1	279	
H	3.6	545	20	260					
QT									
X1	0.0	17	0	547	5808	5808	5808		
GR	558.9	0	556.0	25	547.6	51	548.8	111	550.6
GR	552.3	166	557.9	195	555.9	196	555.6	221	552.7
GR	551.9	301	551.7	361	551.5	401	551.4	441	552.2
GR	553.5	521	556.5	547					
H	0.0	545	20	520					
X1	0.4	13	0	470	2112	2112	2112		
GR	557.5	0	553.6	30	549.0	60	551.7	120	551.8
GR	551.4	200	551.8	240	552.4	280	552.7	320	553.0
GR	553.7	400	554.9	440	556.9	470			
H	0.4	547	30	440					
X1	1.4	17	0	1319	5280	5280	5280		
GR	557.1	0	554.6	40	552.0	80	551.0	160	551.6
GR	556.1	330	555.7	427	554.4	527	553.4	627	553.0
GR	552.6	827	552.4	927	552.2	1027	552.4	1127	553.1
GR	557.8	1294	560.0	1319					
H	1.4	548	40	1227					
X1	2.0	11	0	231	3168	3168	3168		
X5	1.9	555.0	1.0						
GR	556.7	0	555.1	30	551.6	60	551.5	90	551.2
GR	552.6	150	555.8	180	556.1	200	556.3	210	556.5

Listing of a Data Input File

X1	5.2	10	0	340	2112	2112	2112			
GR	556.5	0	555.5	40	555	80	553.9	120	554.4	160
GR	555.0	200	554.5	240	554.8	280	555.8	320	556.5	340
H	5.2	553.0	10	320						
X1	5.8	11	0	125	3168	3168	3168			
GR	555.1	0	555.2	22	554.5	35	554.0	55	551.8	65
GR	552.5	75	554.8	85	555.2	95	555.9	105	555.9	112
GR	555.8	125								
H	5.8	551	35	110						
X1	6.0	13	0	111	898	898	898			
GR	555.4	0	555.8	10	556.5	16	555.8	23	553.9	31
GR	550.7	41	552.6	51	551.8	61	553.5	71	554.9	81
GR	555.1	91	554.9	101	555.8	111				
H	6.0	550	10	90						

EJ
 *1 SEDIMENT MODEL INCLUDES CLAY, SILT, AND SAND. TOTAL SAND LOAD IS DIVIDED
 *2 INTO 4 CLASSES-VERY FINE, FINE, MEDIUM, AND COARSE.
 *3 BED MATERIAL GRADATION = DM 6-4, P. 16, REACH A, B
 *4 B TRANSPORT CAPACITY TOFFALETTI EQUATION
 *5 MODEL VERIFIED FOR STORM EVENT
 11 50
 12 0.01 0.01
 13 0.01 0.01
 14
 L Q 100 300 600 800
 L CLAY 0.6 2.4 6.4 9.8
 L VFS 0.6 2.4 6.4 9.8
 L FS 0.6 2.4 6.4 9.8
 L MS 0.6 2.4 6.4 9.8
 L CS 0.6 2.4 6.4 9.8
 L VFS 0.4 1.6 4.2 6.4
 L FS
 L MS
 L CS
 L VCS
 N 0.68 .516 .143 .126 .090 .043
 N .006 .002
 N 1.28 .605 .147 .094 .059 .020
 N .006 .003
 N 2.22 .436 .166 .158 .098 .032
 N .011 .001
 N 3.56 .465 .128 .132 .128 .062
 N .005 .004
 N 4.4 .482 .116 .111 .081 .039
 N .006 .004
 N 0.0 .315 .107 .118 .092
 N .017
 N 0.4 .556 .104 .104 .179
 N .001
 N 1.4 .466 .074 .099 .165
 N .044 .005 .003 .001
 N 2.0 .26 .059 .069 .076 .377
 N .089 .030 .024
 N 2.2 .128 .035 .020 .02
 N .482 .238 .049 .021 .006

Listing of a Data Input File (contd.)

N 2.4					.152	.027	.022	.014
N	.5455	.141	.083					
N 2.5					.185	.025	.028	.020
N	.069	.592	.047	.019	.015			
N 2.7					.433	.058	.044	.048
N	.265	.066	.033	.028				
N 3.4					.269	.079	.064	.077
N	.384	.036	.032	.022	.005			
N 3.7					.301	.092	.078	.056
N	.233	.100	.053	.056	.034			
N 3.8					.299	.048	.033	.018
N	.38	.161	.034	.019	.010			
N 4.0					.375	.088	.077	.087
N	.274	.058	.022	.017	.006			
N 4.4					.299	.048	.033	.018
N	.38	.161	.034	.019	.010			
N 4.8					.299	.048	.033	.018
N	.38	.161	.034	.019	.010			
N 5.4					.299	.048	.033	.018
N	.38	.161	.034	.019	.010			
N 5.8					.191	.045	.155	.041
N	.340	.114	.040	.033	.044			
N 6.0					.053	.033	.033	.027
N	.706	.053	.022	.021	.052			
STRIB								
L Q	100	300	600	800				
L CLAY	0.6	2.4	6.4	9.8				
L VFS	0.6	2.4	6.4	9.8				
L FS	0.6	2.4	6.4	9.8				
L MS	0.6	2.4	6.4	9.8				
L CS	0.6	2.4	6.4	9.8				
L VFS	0.4	1.6	4.2	6.4				
L FS								
L MS								
L CS								
L VCS								
\$HYD								
* C								
Q 400								
R 552.0								
T 77								
W 100								
\$SEND								

RUN 1 137 CFS

100

Listing of a Data Input File (contd.)

```
*****
* U.S. ARMY CORPS OF ENGINEERS
* THE HYDROLOGIC ENGINEERING CENTER
* 609 SECOND STREET, SUITE D
* DAVIS, CALIFORNIA 95616
*****
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*****
* SCOUR AND DEPOSITION IN RIVERS AND RESERVOIRS
* VERSION 2.9 UPDATED JUNE 1981
* MODIFICATION - 50,51 ERROR CORRECTION - 01.02.03
* RUN DATE
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X X XXXXXXXX XXXX X
X X X X X X
X X X X X X
XXXXXX X X XXXXX
X X X X X X
X X XXXXXXXX XXXX
X X X X X X

```

Sample Computer Output File

T1 SEDIMENT TRANSPORT PROBLEM ON HUNTSVILLE SPRING BRANCH AND
T2 INDIAN CREEK TO DETERMINE EROSION RATES OF SEDIMENT
T3 SO IN TURN DDT TRANSPORT COULD BE ESTIMATED

ALR	ASEL	CE	CC	LFA	NR	TAN	CRL
P 0.050000	0.0	1.000000	1.000000	1			
ALR	ASEL	CE	CC	LFA	NR	TAN	CRL
		1.000000	1.000000				

SEC NO. 0.680

SEC NO. 1.280

SEC NO. 2.400

SEC NO. 3.600

SEC NO. 4.400

TRIBUTARY ENTRY POINT 0. OCCURS AT X-SECTION NO. 6

SEC NO. 0.0

SEC NO. 0.400

SEC NO. 1.400

SEC NO. 2.000

SEC NO. 2.200

SEC NO. 2.400

SEC NO. 2.460

SEC NO. 2.720

SEC NO. 3.400

SEC NO. 3.700

SEC NO. 3.800

SEC NO.	4.000
SEC NO.	4.400
SEC NO.	4.800
SEC NO.	5.200
SEC NO.	5.800
SEC NO.	6.000

NO. OF CROSS SECTIONS READ IN = 22
NO. OF INPUT DATA MESSAGES= 0
END OF GEOMETRIC DATA

- *1 SEDIMENT MODEL INCLUDES CLAY SILT, AND SAND, TOTAL SAND LOAD IS DIVIDED
 *2 INTO 4 CLASSES-VERY FINE, FINE, MEDIUM, AND COARSE.
 *3 BED MATERIAL GRADATION = DM 6-4, P.16, REACH A, B
 *4 B TRANSPORT CAPACITY TOFFALETTI EQUATION
 *5 MODEL VERIFIED FOR STORM EVENT

BASIC BACKWATER TAPE
 SEDIMENT TRANSPORT PROBLEM ON HUNTSVILLE SPRING BRANCH AND

INDIAN CREEK TO DETERMINE EROSION RATES OF SEDIMENT
 SO IN TURN DDT TRANSPORT COULD BE ESTIMATED

SEDIMENT PARAMETER DATA									
	SPI	IBG	MNQ	SPGF	ACGR				
11	50.	0	1	1.000	32.174				
	MTCL			SPGC	DTCL	STCD	PUCD	UMCL	CCCD
12	1			2.650	0.040	0.040	78.000	30.000	16.000
	MTCL	IASL	LASL	SGSL	DTSL	STSD	PUSD	UMSD	CCSD
13	1	1	4	2.650	0.040	0.040	82.000	65.000	5.700
	MTC	IASA	LASA	SPGS	GSF	BSAE	PSI	UMD	
14	1	1	5	2.650	0.667	0.500	30.000	93.000	

FOLLOWING GRAIN SIZES UTILIZED

CLAY SIZE= 0.000013
 SILT SIZE= 0.000026 0.000052 0.000101 0.000205
 SAND SIZE UP= 0.000288 0.000580 0.001160 0.002319 0.004639

Q-QS RATING TABLE

	Q	100.000	300.000	600.000	800.000
L Q					
L CLAY	0.600	2.400	6.000	6.400	9.800
L VFS	0.600	2.400	6.400	6.400	9.800
L FS	0.600	2.400	6.400	6.400	9.800
L MS	0.600	2.400	6.400	6.400	9.800
L CS	0.600	2.400	6.400	6.400	9.800
L VFS	0.400	1.600	4.200	6.400	6.400
L FS	0.0	0.0	0.0	0.0	0.0
L MS	0.0	0.0	0.0	0.0	0.0
L CS	0.0	0.0	0.0	0.0	0.0
L VCS	0.0	0.0	0.0	0.0	0.0

VOLUME VS DEPTH OF DEPOSITS

SEC NO.	SHAPE FACTOR	VOLUME	MOVEABLE BED WIDTH	%	LEFT SIDE	ELEVATIONS	RIGHT SIDE	THALWEG
0.68			132.5		550.90	553.40	540.20	
1.28			190.0		550.60	554.70	544.00	
2.40			199.5		556.00	552.20	546.20	
3.60			286.5		549.60	556.00	547.20	
4.40			247.5		555.50	557.70	546.70	
0.0			498.5		556.00	552.20	547.60	
0.40			440.0		553.60	554.90	549.00	
1.40			1240.5		554.60	553.10	551.00	
2.00			210.5		555.10	556.50	551.20	
2.20			424.0		556.20	555.00	551.30	

NONE SPECIFIED, ASSUMED ZERO

TRIBUTARY INFLOW DATA

Q-QS RATING TABLE

Q	100.000	300.000	600.000	800.000
L CLAY	0.600	2.400	6.400	9.800
L VFS	0.600	2.400	6.400	9.800
L FS	0.600	2.400	6.400	9.800
L MS	0.600	2.400	6.400	9.800
L CS	0.600	2.400	6.400	9.800
L VCS	0.400	1.600	4.200	6.400
L FS	0.0	0.0	0.0	0.0
L MS	0.0	0.0	0.0	0.0
L CS	0.0	0.0	0.0	0.0
L VCS	0.0	0.0	0.0	0.0

PROGRAM TRANSLATED INPUT DATA INTO FOLLOWING INFORMATION

UNIT WEIGHT OF WATER= 62.450 ACCELERATION OF GRAVITY= 32.174

PROPERTIES OF THE SEDIMENT MATERIAL AND DEPOSITS
 GRAIN SHAPE UNIT WEIGHT
 SPECIFIC GRAIN SHAPE OF DEPOSITS
 FACTOR LB/CU. FT.
 2.65 0.67
 83.85

Q-QS RATING TABLE

GRAIN SIZE WATER DISCHARGE FOLLOWED BY SEDIMENT DISCHARGES BY GRAIN SIZE, EXPRESSED AS NATURAL LOG VALUES

0.46051702E+01 0.57037821E+01 0.63969297E+01 0.66846123E+01
 0.28800010E-03-0.51082557E+00 0.67546867E+00 0.18562975E+01 0.22823820E+01
 0.51999999E-03-0.51082557E+00 0.67546867E+00 0.18562975E+01 0.22823820E+01
 0.11600000E-02-0.51082557E+00 0.67546867E+00 0.18562975E+01 0.22823820E+01
 0.23190000E-02-0.51082557E+00 0.67546867E+00 0.18562975E+01 0.22823820E+01
 0.46389997E-02-0.51082557E+00 0.67546867E+00 0.18562975E+01 0.22823820E+01
 0.0 0.91629088E+00 0.47000384E+00 0.16350843E+01 0.18562975E+01
 0.0 -0.92103405E+01-0.92103405E+01-0.92103405E+01-0.92103405E+01
 0.0 -0.92103405E+01-0.92103405E+01-0.92103405E+01-0.92103405E+01
 0.0 -0.92103405E+01-0.92103405E+01-0.92103405E+01-0.92103405E+01
 0.0 -0.92103405E+01-0.92103405E+01-0.92103405E+01-0.92103405E+01

VOLUME VS DEPTH OF DEPOSITS

VOLUME (X-SECTION AREA,DEPTH) COEFFICIENTS
 SHAPE FACTOR IN FEET

0.50000000E+00 0.13249997E+03
 0.50000000E+00 0.19000000E+03
 0.50000000E+00 0.19949989E+03
 0.50000000E+00 0.28449878E+03
 0.50000000E+00 0.24750006E+03
 0.50000000E+00 0.49849976E+03
 0.50000000E+00 0.43999609E+03
 0.50000000E+00 0.12404985E+04
 0.50000000E+00 0.21049989E+03
 0.50000000E+00 0.42399976E+03
 0.50000000E+00 0.17664680E+03
 0.50000000E+00 0.32749951E+03
 0.50000000E+00 0.14423975E+03
 0.50000000E+00 0.48349927E+03
 0.50000000E+00 0.10890000E+04
 0.50000000E+00 0.12752869E+03
 0.50000000E+00 0.27056421E+03
 0.50000000E+00 0.17999961E+04
 0.50000000E+00 0.74999878E+02
 0.50000000E+00 0.31000000E+03
 0.50000000E+00 0.79999847E+02
 0.50000000E+00 0.80999649E+02

ACTIVE AND INACTIVE SEDIMENT DEPOSITS BY CROSS SECTION

AVG. SECTION NO.= 0.680
 INITIAL DEPTH OF SEDIMENT IN BED OF MODEL= 5.200
 SAE, DMAX, DXPI, XPI = 0.10000000E+01 0.46389997E-02 0.46389997E-02 0.0
 TOTAL VOLUME AND VOLUME BY GRAIN SIZE, ACTIVE FOLLOWED BY INACTIVE STORAGE, TONS

LOAD PASSING SECTION IN TONS/DAY=									
CLAY=									
SILT=									
SAND AND LARGER=									
1.19	*			1.03		0.32		0.00	0.00
1.35				1.76		0.07		0.04	
1.91									0.00
SEC. NO= 4.800									
ACTIVE PLUS INACTIVE DEPOSITS									
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
CLAY									
FALL, XPT, DECAY, GP(LCS)				0.449474		0.120374		0.886588	1.05
SILT									
FALL, XPT, DECAY, GP(LCS)				0.541793		0.145099		0.864936	0.89
FALL, XPT, DECAY, GP(LCS)				1.286445		0.344525		0.708555	0.23
FALL, XPT, DECAY, GP(LCS)				4.641629		1.243083		0.288491	0.00
FALL, XPT, DECAY, GP(LCS)				12.284291		3.289879		0.037258	0.00
SAND									
DEQ, DAL, DED1, DED2, D2				0.37415018E+01		0.37339640E+01		0.35921211E+01	0.43788433E+01
IMDS, IMD, LGS, SAE, SAA, SA1				1.000000		85.545029		0.0	0.41002943E-03
SAE, SGC, GAL				1.00000000		0.0		0.00071108	
ACTIVE LAYER									
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
CLAY									
FALL, XPT, DECAY, GP(LCS)				0.71875066		0.15178579		0.08482146	0.04464290
SILT									
FALL, XPT, DECAY, GP(LCS)				0.71875066		0.87053645		0.95535791	1.00000000
SAND									
DEQ, DAL, DED1, DED2, D2				0.11153917E+01		0.37339640E+01		0.70609253E+02	0.22474688E-03
IMDS, IMD, LGS, SAE, SAA, SA1				0.10348463E+02		0.11136818E+01		0.82572645E+00	0.54966324E-04
SAE, SGC, GAL									0.29681349E+00
ACTIVE LAYER									
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
CLAY									
FALL, XPT, DECAY, GP(LCS)				0.04800006		0.03300004		0.01800002	0.0
SILT									
FALL, XPT, DECAY, GP(LCS)				0.16100019		0.03400005		0.01900003	0.0
FALL, XPT, DECAY, GP(LCS)				0.04800006		0.08100009		0.09900010	0.0
FALL, XPT, DECAY, GP(LCS)				0.64000082		0.67400086		0.69300085	0.70300084
SAND									
DEQ, DAL, DED1, DED2, D2				0.04800006		0.03300004		0.01800002	0.0
IMDS, IMD, LGS, SAE, SAA, SA1				0.16100019		0.03400005		0.01900003	0.0
SAE, SGC, GAL				0.04800006		0.08100009		0.09900010	0.0
ACTIVE LAYER				0.64000082		0.67400086		0.69300085	0.70300084
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
CLAY									
FALL, XPT, DECAY, GP(LCS)				7.048969		2.910934		0.054424	0.06
SILT									
FALL, XPT, DECAY, GP(LCS)				8.496785		3.508823		0.029931	0.03
FALL, XPT, DECAY, GP(LCS)				20.174942		8.331424		0.000241	0.00
FALL, XPT, DECAY, GP(LCS)				72.793320		30.060654		0.000000	0.00
FALL, XPT, DECAY, GP(LCS)				192.650940		50.000000		0.000000	0.00
SAND									
DEQ, DAL, DED1, DED2, D2				0.35202163E+00		0.24215479E+01		0.28877586E+00	0.35202163E+00
IMDS, IMD, LGS, SAE, SAA, SA1				1.000000		0.0		0.0	0.20501472E-03
SAE, SGC, GAL				1.00000000		0.0		0.00028800	

ACTIVE LAYER
BED MATERIAL BY GRAIN SIZE FRACTION

* BY PERCENT FINER/100

TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO

IHO2081 IBCOM - PROGRAM INTERRUPT (P) - UNDERFLOW OLD PSM IS FFF5000D82031914 . REGISTER CONTAINED FD342A05DCFF7CFC

TRACEBACK ROUTINE CALLED FROM ISN	REG. 14	REG. 15	REG. 0	REG. 1
TFMOD6	42027D92	00030110	00000001	00022740
SRMOD5	6201A2EE	00022000	0000000A	00017318
BWMOD4	42030104	00016ED0	00000000	00000000
STMOD2	420167B4	00029880	00000000	00000000
HEC6	60D48E40	00012000	00000000	00000200

ENTRY POINT= 00012000

STANDARD FIXUP TAKEN , EXECUTION CONTINUING

TRANSPORT CAPACITY(FINE TO COARSE)

LOAD PASSING SECTION IN TONS/DAY=	0.06	0.03	0.00	0.00	0.00	0.00	0.00
CLAY=	0.06	0.03	0.00	0.00	0.00	0.00	0.00
SILT=	0.03	0.00	0.00	0.00	0.00	0.00	0.00
SAND AND LARGER=	0.00	0.00	0.00	0.00	0.00	0.00	0.00

SEC. NO= 4.000

ACTIVE PLUS INACTIVE DEPOSITS

BED MATERIAL BY GRAIN SIZE FRACTION

* BY PERCENT FINER/100

CLAY

FALL, XPT, DECAY, GP(LCS)

SILT

FALL, XPT, DECAY, GP(LCS)

FALL, XPT, DECAY, GP(LCS)

FALL, XPT, DECAY, GP(LCS)

FALL, XPT, DECAY, GP(LCS)

SAND

DEQ, DAL, DED1, DED2, D2

IMDS, IMD, LGS, SAE, SAA, SA1

SAE, SGC, GAL

ACTIVE LAYER

BED MATERIAL BY GRAIN SIZE FRACTION

* BY PERCENT FINER/100

TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO

TRANSPORT CAPACITY(FINE TO COARSE)

LOAD PASSING SECTION IN TONS/DAY=	0.04	0.06	0.10	0.20	0.40	0.80	1.00
CLAY=	0.04	0.06	0.10	0.20	0.40	0.80	1.00
SILT=	0.06	0.10	0.20	0.40	0.80	1.00	0.00
SAND AND LARGER=	0.10	0.20	0.40	0.80	1.00	0.00	0.00

SAND		8	8	10	0.34868126E+04	0.34798346E+01	0.34521446E+01	0.42082062E+01	0.82005886E-03
DEQ, DAL, DED1, DED2, D2									
IMDS, IMD, LGS, SAE, SAA, SA1									
SAE, SGC, GAL					1.00000000	104.380127	0.0	0.0158376	
ACTIVE LAYER									
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
					0.51968509	0.25984263	0.22047251	0.0	0.0
					0.51968509	0.77952772	1.00000000	1.00000000	1.00000000
TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO					0.14243135E+01	0.34798346E+01	0.58702621E+02	0.24253239E-03	0.58712583E-04
TRANSPORT CAPACITY(FINE TO COARSE)					0.35108582E+02	0.63137131E+01	0.50088024E+01	0.32414999E+01	0.17873125E+01
LOAD PASSING SECTION IN TONS/DAY=									
CLAY=					0.01	0.00	0.00	0.00	0.00
SILT=					0.00	0.28	0.14	0.12	0.00
SAND AND LARGER=					0.54				0.00
SEC. NO= 2.460									
ACTIVE PLUS INACTIVE DEPOSITS									
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
					0.02500001	0.02800000	0.02000000	0.0	0.06900001
					0.59200037	0.04700002	0.01900000	0.01500001	0.0
					0.02500001	0.05100001	0.07300001	0.07300001	0.14200002
					0.73400038	0.78100038	0.80000037	0.81500036	0.81500036
CLAY					1.111712	0.414155	0.660897	0.01	
FALL, XPT, DECAY, GP(LGS)									
SILT					1.340053	0.499220	0.607002	0.00	
FALL, XPT, DECAY, GP(LGS)					3.181849	1.185359	0.305634	0.00	
FALL, XPT, DECAY, GP(LGS)					11.480445	4.276901	0.013885	0.00	
FALL, XPT, DECAY, GP(LGS)					30.383530	11.319019	0.000012	0.00	
SAND					0.19017744E+01	0.26842899E+01	0.15600939E+01	0.19017744E+01	0.20501472E-03
DEQ, DAL, DED1, DED2, D2									
IMDS, IMD, LGS, SAE, SAA, SA1									
SAE, SGC, GAL					1.00000000	0.0	0.0028800		
ACTIVE LAYER									
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
					0.03204988	0.06454486	0.12908971	0.25806820	0.51624763
					0.03204988	0.09659469	0.22568440	0.48375261	1.00000000
TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO					0.46217138E+00	0.26842899E+01	0.23538158E+03	0.24279673E-02	0.52625997E-04
TRANSPORT CAPACITY(FINE TO COARSE)					0.15234333E+00	0.12756031E-01	0.43005198E-02	0.28194282E-02	0.15679325E-02
LOAD PASSING SECTION IN TONS/DAY=									
CLAY=					0.01	0.00	0.00	0.00	0.00
SILT=					0.00	0.07	0.00	0.00	0.00
SAND AND LARGER=					0.07				
SEC. NO= 2.400									
ACTIVE PLUS INACTIVE DEPOSITS									
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
					0.02699999	0.02200000	0.01400000	0.0	0.54550010
					0.14099997	0.08300000	0.0	0.0	0.0
					0.02699999	0.04899999	0.06299996	0.06299996	0.60850006
					0.74950004	0.83250004	0.83250004	0.83250004	0.83250004
CLAY					0.183456	0.058023	0.943628	0.01	
FALL, XPT, DECAY, GP(LGS)									

SILT FALL, XPT, DECAY, GP(LCS) FALL, XPT, DECAY, GP(LCS) FALL, XPT, DECAY, GP(LCS) FALL, XPT, DECAY, GP(LCS)	0.221137 0.525073 1.894518 5.013931	0.069941 0.166069 0.599196 1.585800	0.932449 0.846986 0.549251 0.204782	0.00 0.00 0.00 0.00
SAND DEQ, DAL, DED1, DED2, D2 IMDS, IMD, LGS, SAE, SAA, SA1 SAE, SGC, GAL ACTIVE LAYER BED MATERIAL BY GRAIN SIZE FRACTION * BY PERCENT FINER/100	8 8 10 0.31837215E+01 1.0000000 0.0 0.62946421 0.62946421	0.31617670E+01 4.546174 0.0 0.37053573 0.99999994	0.26755915E+01 0.0 0.0089243 0.0 0.99999994	0.82005886E-03 0.0 0.0 0.0 0.99999994
TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO TRANSPORT CAPACITY(FINE TO COARSE)	0.11612883E+01 0.11114367E+02	0.31617670E+01 0.19616547E+01	0.79026291E+02 0.15538263E+01	0.21047219E-03 0.10057192E+01
LOAD PASSING SECTION IN TONS/DAY= CLAY= SILT= SAND AND LARGER=	0.01 0.00 1.33	0.00 0.86	0.00 0.00	0.00 0.00 0.00
SEC. NO= 2.000 ACTIVE PLUS INACTIVE DEPOSITS BED MATERIAL BY GRAIN SIZE FRACTION * BY PERCENT FINER/100	0.03500002 0.23800009 0.03500002 0.79500020	0.02000000 0.04900002 0.05500002 0.84400022	0.02000000 0.02100001 0.07499999 0.86500019	0.0 0.00600000 0.07499999 0.87100017
CLAY FALL, XPT, DECAY, GP(LCS)	0.563583	0.207412	0.812684	0.00
SILT FALL, XPT, DECAY, GP(LCS) FALL, XPT, DECAY, GP(LCS) FALL, XPT, DECAY, GP(LCS) FALL, XPT, DECAY, GP(LCS)	0.679340 1.613038 5.820011 15.402935	0.250013 0.593636 2.141901 5.668644	0.778789 0.592313 0.117430 0.003452	0.00 0.00 0.00 0.00
SAND DEQ, DAL, DED1, DED2, D2 IMDS, IMD, LGS, SAE, SAA, SA1 SAE, SGC, GAL ACTIVE LAYER BED MATERIAL BY GRAIN SIZE FRACTION * BY PERCENT FINER/100	0 6 10 0.18849974E+01 1.0000000 0.03204988 0.03204988	0.27172165E+01 0.0 0.06454486 0.09659469	0.15463295E+01 0.0 0.12908971 0.22568440	0.18849974E+01 0.0 0.25806820 0.48375261
TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO TRANSPORT CAPACITY(FINE TO COARSE)	0.44477922E+00 0.97881556E-01	0.27172165E+01 0.80443993E-02	0.23782771E+03 0.30522083E-02	0.56373700E-03 0.20036693E-02
LOAD PASSING SECTION IN TONS/DAY= CLAY= SILT= SAND AND LARGER=	0.00 0.00 0.06	0.00 0.06	0.00 0.00	0.00 0.00 0.00

SEC. NO= 2.000
ACTIVE PLUS INACTIVE DEPOSITS

SAND AND LARGER= SILT= 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

SEC. NO= 0.400
ACTIVE PLUS INACTIVE DEPOSITS
BED MATERIAL BY GRAIN SIZE FRACTION
* BY PERCENT FINER/100

CLAY FALL, XPT, DECAY, GP(LCS) 3.604069 1.003289 0.17900014 0.0 0.04400003
SILT FALL, XPT, DECAY, GP(LCS) 4.344323 1.209359 0.00300000 0.00100000 0.0
FALL, XPT, DECAY, GP(LCS) 10.315251 2.871528 0.00300000 0.00100000 0.0
FALL, XPT, DECAY, GP(LCS) 37.218506 10.360773 0.00000000 0.00000000 0.0
FALL, XPT, DECAY, GP(LCS) 98.500549 27.420273 0.00000000 0.00000000 0.0

SAND DEQ, DAL, DED1, DED2, D2 0 6 10 0.14382153E+01 0.35922518E+01 0.11798191E+01 0.14382153E+01 0.20501472E-03
IMDS, IND, LGS, SAE, SAA, SA1 1.00000000 0.0 0.0 0.00028800 0.0
SAE, SGC, GAL 1.00000000 0.0 0.0 0.00028800 0.0
ACTIVE LAYER 0.03204988 0.06454486 0.12908971 0.25806820 0.51624763
BED MATERIAL BY GRAIN SIZE FRACTION 0.03204988 0.06454486 0.12908971 0.25806820 0.51624763
* BY PERCENT FINER/100 0.03204988 0.06454486 0.12908971 0.25806820 0.51624763

TRANSPORT VAR9 VEL, EFD, EFM, D65, SLO 0.24343157E+00 0.35922518E+01 0.32608447E+03 0.11299658E-02 0.31557956E-05

IH02621 DEXP ARG= 0.2247205004834580D+03, GT 174.673

TRACEBACK ROUTINE CALLED FROM ISN REG. 14 REG. 15 REG. 0 REG. 1
DEXP 42037822 0003B1A0 000000FC 000378A0
FDXPD# 0149 42031706 000377C8 00000009 00030308
TFMOD6 0668 42027D92 00030110 00000001 00022740
SRMOD5 0478 6201A2EE 00022000 0000000A 00017318
BIMOD4 0884 42030104 00016ED0 00000000 00000000
STMOD2 0761 42016784 00029880 00000000 00000000
HEC6 60D48E40 00012000 00000000 00000200

ENTRY POINT= 00012000

STANDARD FIXUP TAKEN , EXECUTION CONTINUING
TRANSPORT CAPACITY(FINE TO COARSE) 0.18863428E-03 0.19589266E-03 0.15185322E-03 0.97086668E-04 0.53266151E-04

LOAD PASSING SECTION IN TONS/DAY= 0.00 0.00 0.00 0.00 0.00
CLAY= 0.00 0.00 0.00 0.00 0.00
SILT= 0.00 0.00 0.00 0.00 0.00
SAND AND LARGER= 0.00 0.00 0.00 0.00 0.00

SEC. NO= 0.0

ACTIVE PLUS INACTIVE DEPOSITS
BED MATERIAL BY GRAIN SIZE FRACTION
* BY PERCENT FINER/100

CLAY
FALL, XPT, DECAY, GP(LCS)

SILT
FALL, XPT, DECAY, GP(LCS)
FALL, XPT, DECAY, GP(LCS)
FALL, XPT, DECAY, GP(LCS)
FALL, XPT, DECAY, GP(LCS)

SAND
DEQ, DAL, DED1, DED2, D2
IMDS, IMD, LGS, SAE, SAA, SA1
SAE, SGC, GAL
ACTIVE LAYER
BED MATERIAL BY GRAIN SIZE FRACTION
* BY PERCENT FINER/100

TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO
TRANSPORT CAPACITY(FINE TO COARSE)

LOAD PASSING SECTION IN TONS/DAY=
CLAY=
SILT=
SAND AND LARGER=

TRIBUTARY INFLOW POINT NO. 1 Q=
CLAY=
SILT=
SAND AND LARGER=

SEC. NO= 4, 400
ACTIVE PLUS INACTIVE DEPOSITS
BED MATERIAL BY GRAIN SIZE FRACTION
* BY PERCENT FINER/100

CLAY
FALL, XPT, DECAY, GP(LCS)

SILT
FALL, XPT, DECAY, GP(LCS)
FALL, XPT, DECAY, GP(LCS)
FALL, XPT, DECAY, GP(LCS)
FALL, XPT, DECAY, GP(LCS)

SAND
DEQ, DAL, DED1, DED2, D2
IMDS, IMD, LGS, SAE, SAA, SA1
SAE, SGC, GAL
ACTIVE LAYER
BED MATERIAL BY GRAIN SIZE FRACTION

0.10700005
0.06300002
0.10700005
0.58000028

0.11800003
0.04800003
0.22500008
0.62800026

0.09200007
0.03200001
0.31700015
0.66000026

0.10700005
0.06300002
0.10700005
0.58000028

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0.99605377E-05

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0.99605377E-05

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* BY PERCENT FINER/100									
TRANSPORT VAR9	VEL, EFD, EFM, D65, SLO	0.03204988	0.09659469	0.22568440	0.48375261	1.00000000			
TRANSPORT CAPACITY(FINE TO COARSE)		0.4128228E+00	0.5854626E+01	0.15366779E+03	0.12647130E-02	0.45082779E-05			
		0.29705830E-02	0.28185309E-02	0.21985616E-02	0.14086764E-02	0.77355257E-03			
LOAD PASSING SECTION IN TONS/DAY=									
	CLAY=	0.37	0.33	0.15	0.00	0.00			
	SILT=	0.48	0.00	0.00	0.00	0.00			
	SAND AND LARGER=	0.00	0.00	0.00	0.00	0.00			
SEC. NO= 3.600									
ACTIVE PLUS INACTIVE DEPOSITS									
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
CLAY		4.323630	0.710275	0.491507	0.18				
FALL, XPT, DECAY, GP(LCS)									
SILT		5.211679	0.856161	0.424787	0.14				
FALL, XPT, DECAY, GP(LCS)		12.374716	2.032887	0.130955	0.02				
FALL, XPT, DECAY, GP(LCS)		44.649277	7.334868	0.000452	0.00				
FALL, XPT, DECAY, GP(LCS)		118.166412	19.412064	0.000000	0.00				
SAND									
DEQ, DAL, DED1, DED2, D2		0.25814457E+01	0.60872631E+01	0.21176519E+01	0.25814457E+01	0.20501472E-03			
INDS, IND, LGS, SAE, SAA, SA1		1.00000000	0.0	0.0					
SAE, SGC, GAL		1.00000000	0.0	0.00028800					
ACTIVE LAYER									
BED MATERIAL BY GRAIN SIZE FRACTION		0.03204988	0.06454486	0.12908971	0.25806820	0.51624763			
* BY PERCENT FINER/100									
TRANSPORT VAR9	VEL, EFD, EFM, D65, SLO	0.03204988	0.09659469	0.22568440	0.48375261	1.00000000			
TRANSPORT CAPACITY(FINE TO COARSE)		0.28554624E+00	0.60872631E+01	0.21973024E+03	0.99517661E-03	0.45299093E-05			
		0.44127530E-03	0.21127149E-03	0.16676346E-03	0.10728434E-03	0.59011829E-04			
LOAD PASSING SECTION IN TONS/DAY=									
	CLAY=	0.18	0.14	0.02	0.00	0.00			
	SILT=	0.16	0.00	0.00	0.00	0.00			
	SAND AND LARGER=	0.00	0.00	0.00	0.00	0.00			
SEC. NO= 2.800									
ACTIVE PLUS INACTIVE DEPOSITS									
BED MATERIAL BY GRAIN SIZE FRACTION									
* BY PERCENT FINER/100									
CLAY		4.936178	0.651966	0.521018	0.09				
FALL, XPT, DECAY, GP(LCS)									
SILT		5.950039	0.785876	0.455718	0.06				
FALL, XPT, DECAY, GP(LCS)		14.127896	1.865999	0.154740	0.00				
FALL, XPT, DECAY, GP(LCS)		50.974930	6.732721	0.001191	0.00				
FALL, XPT, DECAY, GP(LCS)		134.907562	17.818466	0.000000	0.00				

SAND
 DEQ, DAL, DED1, DED2, D2
 IMDS, IMD, LGS, SAE, SAA, SAI
 SAE, SGC, GAL
 ACTIVE LAYER
 BED MATERIAL BY GRAIN SIZE FRACTION

	0	6	10	0.31503344E+01	0.75712214E+01	0.25843315E+01	0.31503344E+01	0.20501472E-03
				0.0	0.0	0.00028800		
				0.03204988	0.06454486	0.12908971	0.25806820	0.51624763
* BY PERCENT FINER/100				0.03204988	0.09659469	0.22568440	0.48375261	1.00000000
TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO				0.29454631E+00	0.75712214E+01	0.17417282E+03	0.94575528E-03	0.28663198E-05
TRANSPORT CAPACITY(FINE TO COARSE)				0.28080423E-03	0.23034847E-03	0.18030872E-03	0.11566703E-03	0.63348141E-04
LOAD PASSING SECTION IN TONS/DAY=	0.09							
CLAY=	0.07	0.06		0.00	0.00	0.00	0.00	0.00
SILT=	0.00	0.00		0.00	0.00	0.00	0.00	0.00
SAND AND LARGER=								

SEC. NO= 1.280
 ACTIVE PLUS INACTIVE DEPOSITS
 BED MATERIAL BY GRAIN SIZE FRACTION

	0	6	10	0.14700013	0.09400004	0.05900005	0.02000002	0.01300001
				0.02300002	0.01500002	0.01200001	0.00600000	0.00300000
				0.14700013	0.24100018	0.30000019	0.32000017	0.33300018
* BY PERCENT FINER/100				0.35600019	0.37100017	0.38300014	0.38900012	0.39200008

CLAY
 FALL, XPT, DECAY, GP(LCS)

	0	6	10	0.35739622E+01	0.92296734E+01	0.29318514E+01	0.35739622E+01	0.20501472E-03
				0.0	0.0	0.0	0.0	
				0.03204988	0.06454486	0.12908971	0.25806820	0.51624763
* BY PERCENT FINER/100				0.03204988	0.09659469	0.22568440	0.48375261	1.00000000
TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO				0.27513874E+00	0.92296734E+01	0.15033301E+03	0.15701030E-02	0.21511078E-05
TRANSPORT CAPACITY(FINE TO COARSE)				0.13427014E-03	0.11414681E-03	0.89300913E-04	0.57275203E-04	0.31464879E-04
LOAD PASSING SECTION IN TONS/DAY=	0.06							
CLAY=	0.04	0.04		0.00	0.00	0.00	0.00	0.00
SILT=	0.00	0.00		0.00	0.00	0.00	0.00	0.00
SAND AND LARGER=								

SAND
 DEQ, DAL, DED1, DED2, D2
 IMDS, IMD, LGS, SAE, SAA, SAI
 SAE, SGC, GAL
 ACTIVE LAYER
 BED MATERIAL BY GRAIN SIZE FRACTION

	0	6	10	0.35739622E+01	0.92296734E+01	0.29318514E+01	0.35739622E+01	0.20501472E-03
				0.0	0.0	0.0	0.0	
				0.03204988	0.06454486	0.12908971	0.25806820	0.51624763
* BY PERCENT FINER/100				0.03204988	0.09659469	0.22568440	0.48375261	1.00000000
TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO				0.27513874E+00	0.92296734E+01	0.15033301E+03	0.15701030E-02	0.21511078E-05
TRANSPORT CAPACITY(FINE TO COARSE)				0.13427014E-03	0.11414681E-03	0.89300913E-04	0.57275203E-04	0.31464879E-04
LOAD PASSING SECTION IN TONS/DAY=	0.06							
CLAY=	0.04	0.04		0.00	0.00	0.00	0.00	0.00
SILT=	0.00	0.00		0.00	0.00	0.00	0.00	0.00
SAND AND LARGER=								

SEC. NO= 0.680
 ACTIVE PLUS INACTIVE DEPOSITS
 BED MATERIAL BY GRAIN SIZE FRACTION

	0	6	10	0.14299995	0.12599999	0.08999991	0.04300001	0.01900000
				0.02700000	0.00800000	0.00500000	0.00600000	0.00200000
				0.14299995	0.26899993	0.35899985	0.40199983	0.42099983
* BY PERCENT FINER/100				0.44799978	0.45599973	0.46099973	0.46699971	0.46899968

CLAY
 FALL, XPT, DECAY, GP(LCS)

	0	6	10	1.245296	0.106365	0.899096	0.05

SILT									
FALL, XPT, DECAY, GP(LCS)									0.03
FALL, XPT, DECAY, GP(LCS)									0.00
FALL, XPT, DECAY, GP(LCS)									0.00
FALL, XPT, DECAY, GP(LCS)									0.00
SAND									
DEQ, DAL, DED1, DED2, D2	0	6	10	0.47308044E+01	0.11707726E+02	0.38808470E+01	0.47308044E+01	0.20501472E-03	
IMDS, IMD, LGS, SAE, SAA, SA1				1.0000000	0.0	0.0			
SAE, SGC, GAL				1.00000000	0.0	0.00028800			
ACTIVE LAYER				0.03204988	0.06454486	0.12908971	0.25806820	0.51624763	
BED MATERIAL BY GRAIN SIZE FRACTION				0.03204988	0.09659469	0.22568440	0.48375261	1.00000000	
* BY PERCENT FINER/100									
TRANSPORT VAR9 VEL, EFD, EFW, D65, SLO				0.30194002E+00	0.11707726E+02	0.10838577E+03	0.11748921E-02	0.18884766E-05	
TRANSPORT CAPACITY(FINE TO COARSE)				0.17438189E-03	0.14649106E-03	0.11464933E-03	0.73542775E-04	0.40403867E-04	
LOAD PASSING SECTION IN TONS/DAY=									
				CLAY=					
				SILT=					
				SAND AND LARGER=					
				0.05	0.03	0.00	0.00	0.00	0.00
				0.03	0.00				
				0.00					
ACCUMULATED AC-FT BY ENTRY *									
DAYS				CLAY	INFLOW	OUTFLOW	TRAP EFF*	SILT	SAND
								OUTFLOW	TRAP EFF*
100.00					0.37		*		*
					0.09		*		*
					0.46		*		*
TOTAL=							0.98*		1.00*
							*		*
								0.08	
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VITA

Kenneth D. Hiltgen was born in Pittsburgh, Pennsylvania on April 9, 1952. received a Bachelor of Science degree in Chemical Engineering in 1974 from the University of Wisconsin, Madison, Wisconsin. Ken joined Olin Corporation at their Charleston, Tennessee facility in 1974 as a Development Engineer. In 1979 he was promoted into Olin's Environmental Department where he served as an Environmental Engineering Associate. In 1984 Ken was promoted to Supervisor of Environmental Technology. He is responsible for designing and overseeing the installation of groundwater monitoring systems. He has experience in computer modeling of groundwater movement, stream hydraulics (HEC) and air dispersion of pollutants (UNAMAP). Mr. Hiltgen is a registered Professional Engineer in the State of Tennessee, and an active member of the Air Pollution Control Association and the National Water Well Association.