SUSPENDED SEDIMENT MODELING OF DREDGE-DISPOSAL EFFLUENT IN THE GREAT-II STUDY REACH

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LIST OF SYMBOLS

Symbols for Chapters I - V and Appendix A

Symbol	Description	Units
A	Cross-sectional area of stream	L^2
a	Radius of a pipe	L
B	Stream width	L
b	Plume source width	L
C	Mean concentration of material at a point	M/L^3
C(I)	Concentration to define plume boundary	M/L^3
C_o	Concentration of plume source, Q_o	M/L^3
c_i	Individual concentration of the i'th size fraction of particles	M/L^3
CSF	Concentration scaling factor	
D	Mean stream depth in plume	L
DSF	Distance scaling factor	
g	Acceleration of gravity	L/T^2
K_i	Dispersion coefficient in the i'th direction	L^2/T
K_s	Settling rate constant	1/T
K_x, K_y, K_z	Dispersion coefficient in the longitudinal, lateral and vertical directions, respectively	L^2/T
L	Downstream distance from plume source	L
ℓ	Characteristic cross-sectional length of a stream	L

Symbol	Description	Units
Q_o	Flow returning to the stream, forming the plume	L^3/T
Q_B	Stream flow	L^3/T
Q_b	Stream flow passing through the source width, b	L^3/T
q	Rate of suspended material added to plume	M/T
q'	Stream flow per unit width	L^2/T
r	Hydraulic radius of stream	L
S_e	Energy slope of stream	
s	Standardized variable of the normal probability density function	
t	Time	T
t'	Travel time from head of plume to downstream point	T
t^*	Dimensionless time	
U	Local mean velocity	L/T
U_*	Shear velocity	L/T
u_i	Particle velocity in the i'th direction	L/T
u_x, u_y	Convective velocities in the longitudinal and lateral directions, respectively	L/T
u_z	Particle velocity in the z direction	L/T
u'	Deviation from the local mean velocity	L/T
W	Mean settling velocity of particles	L/T
w	Convective velocity of stream in the vertical direction	L/T
w_i	Individual settling velocity of the i'th particle in quiescent water	L/T

Symbol	Description	Units
x, y, z	Distance coordinates in the longitudinal, lateral and vertical directions respectively	L
x_i	Distance coordinate in the i'th direction	L
x^*, y^*	Dimensionless distances in the longitudinal and lateral directions	
y'	Lateral displacement from the origin in the plume source width	L
α	Dimensionless dispersion coefficient, relating K_x to DU_*	
β	Dimensionless dispersion coefficient for calculating K_x	
γ	Dimensionless coefficient relating plume age to settling time	
ε_M	Coefficient of molecular diffusion	L^2/T
ε_T	Coefficient of turbulent diffusion	L^2/T
ε_i	Diffusion coefficient in the i'th direction	L^2/T
κ	von Karman coefficient	
λ	Aspect ratio - ratio of stream depth to stream width	
ρ	Fluid density	M/L^3
σ^2_y	Variance of lateral concentration distribution	L
τ_o	Shear stress at the boundary	M/LT^2
ϕ	Dimensionless dispersion coefficient for calculating K_y	
ω	Diffusion velocity	L/T

Symbols for Chapter VI and Appendix F

Symbol	Description	Units
b	Channel half width	L
C (x,z)	Two-dimensional concentration distribution by lateral diffusion	
C' (x,y)	Two-dimensional concentration distribution by vertical diffusion	
c	Sediment concentration	M/L^3
c (x,y,z)	Three-dimensional concentration distribution	
c_o	Initial sediment concentration	M/L^3
E_x, E_y, E_z	Eddy diffusivity in x, y, z directions	L^2/T
h	Channel depth	L
Ly	Vertical diffusion and sedimentation term	1/T
Lz	Lateral diffusion term	1/T
N	Number of vertical steps	
U	Average stream velocity	L/T
u	Stream velocity at any point	L/T
v	Dummy variable representing distance within plume	L
W	Particle setting velocity	L/T
W_s	Sand settling velocity	L/T
x	Longitudinal (downstream) distance	L
y	Vertical (depth) distance	L
z	Lateral (transverse) distance	L

Symbol	Description	Units
Δx	Longitudinal step size	L
Δy	Vertical step size	L
γ	Dummy variable in probability integral	

CHAPTER I

INTRODUCTION

The disposal of dredged material has recently received much attention. Section 404(b) of the Federal Water Pollution Control Act Ammendments of 1972, P.L. 92-500, prohibits discharges of dredged material to navigable waters of the United States unless permits are issued through the U.S. Army Corps of Engineers. In 1975, guidelines on the issuance of permits were published in the Federal Register. Among the ecological impacts from dredged material disposal to be examined were impairment of the water column and the covering of benthic communities. The need for mathematical models to predict the disposition of suspended solids resulting from disposal of dredged material therefore becomes apparent.

The Corps of Engineers currently dredges portions of the upper Mississippi River to maintain a nine foot deep channel for barge traffic. The hydraulically dredged material is discharged onto a nearby island or bank and the excess water flows back into the river. This water contains suspended solids, either from the dredged sediment or from the disposal site, and forms a suspended solids plume where it enters and rejoins the river.

Much of the modeling on suspended solids plumes resulting from dredge disposal has been for open sea or estuarine operations. Little work has been done on dredge disposal in the river environment. The objectives of this study were to:

1) Collect field data on suspended solids and turbidity during two dredge disposal operations on the Mississippi River,
2) Check the utility of the Schubel and Carter (1978) model for adequately describing the observed field data and modify, if possible, to reflect river conditions,
3) Examine other models available to describe the observed field data, including the numerical, computer solution of Weschler and Cogley (1977) (such models can be used to rapidly generate a number of simulations covering a spectrum of conditions expected in the Mississippi River), and
4) Develop a convenient, analytical solution for the prediction of suspended solids concentrations caused by hydraulically dredged sediment and compare the model results to field measurements.

The scope of this modeling effort includes the utilization of existing dredge disposal mathematical models, both analytical and numerical, as well as the development of a new model. The new model is specifically derived for continuous nonpoint source, sidebank disposal type of operations such as commonly practiced in the upper Mississippi River. Suspended solids concentrations are predicted.

This research grew out of a larger dredging study by a multi-departmental, multi-disciplinary consortium called the Great River Environmental Action Team, GREAT II. The GREAT II study reach of the Mississippi River stretches from Guttenberg, Iowa to Saverton, Missouri.

CHAPTER II

LITERATURE REVIEW

Review of Models

Models for predicting the distribution of suspended solids resulting from disposal of dredged material have been proposed by Schubel, Carter et al., (1978) and Wechsler and Cogley (1977). Both models begin with the Fickian diffusion equation:

$$\frac{\partial C}{\partial t} + u_i \frac{\partial C}{\partial x_i} = \frac{\partial}{\partial x_i}\left(K_i \frac{\partial C}{\partial x_i}\right) \tag{2.1}$$

Rate of change of suspended solids concentration	+	Rate of change of suspended solids concentration due to convection	=	Rate of change of suspended solids concentration due to diffusion

where C refers to the concentration (mass per unit volume) of suspended sediment; u_i refers to the fluid velocity in a rectangular coordinate system, x_i; and K_i refers to the eddy diffusion coefficient in the i'th direction. The models begin to differ at this point in the assumptions that are made.

Schubel and Carter Model

The model developed by Schubel, Carter et al., (1978) is for estuarine or shallow coastal dredge disposal operations. The initial assumptions are: 1) the individual concentrations of the various size fractions of suspended sediment, c_i, can be described by a vertically averaged suspended solids concentration, $C = \frac{1}{D} \int_0^D \Sigma c_i \, dz$, where D is the depth of the water column and z is vertical distance in the Cartesian coordinate system, x, y, z; 2) the eddy diffusivities in the x and y directions, K_x and K_y, are equal and independent of depth; 3) the fluid velocity in the x and y directions, u_x and u_y, are depth independent; and 4) the terms for vertical diffusion and convection can be combined into one term, $-\frac{WC}{D}$, where W is the mean settling velocity of the particles,

$$W = \frac{\int_0^D \Sigma w_i c_i \, dz}{\int_0^D \Sigma c_i \, dz}$$

and w_i is the settling velocity of the individual particle, c_i. This fourth assumption is based on the assumption that the suspended solids transport due to vertical diffusion and vertical fluid velocity currents is much smaller than the transport due to the settling velocity of the suspended solids. The resulting equation is:

$$\frac{\partial C}{\partial t} = - \frac{\partial}{\partial x} u_x C - \frac{\partial}{\partial y} u_y C + \frac{\partial}{\partial x} K_x \frac{\partial C}{\partial x} + \frac{\partial}{\partial y} K_x \frac{\partial C}{\partial x} - \frac{WC}{D} \qquad (2.2)$$

Okubo and Pritchard (Okubo, 1962) proposed the solution assuming an instantaneous vertical line source. This solution is then integrated over time to describe a continuous vertical line source. The resulting equation is:

$$C(x,y,t) = \frac{q}{\pi \, \omega^2 D} \int_0^t \frac{1}{t'^2} \exp\left[-\frac{x - u_x t'}{\omega t'}\right]^2 \exp\left[-\frac{y}{\omega t'}\right]^2$$

$$\exp\left[-\frac{Wt'}{D}\right] dt' \qquad (2.3)$$

where q is the rate of suspended material added to the plume (mass per time) and ω is the diffusion velocity (cm/sec). The diffusion velocity, ω, is related to the horizontal eddy diffusion coefficient by $K_x = \omega^2 t$. The first and second exponential terms in the integral refer to diffusion of suspended solids in the x and y direction, while the third exponential term in the integral represents particle settling.

The model is not used in this form, however. First, x, y, and t' are nondimensionalized to x^*, y^* and t^*, where

$x = x^* u_x t$

$y = y^* u_x t$

$t' = t^* t$

The resulting equation is:

$$C(x,y,t) = \frac{q}{\pi \omega^2 Dt} \int_0^1 \frac{1}{(t^*)^2} \exp -\left[\frac{u_x}{\omega}\right]\left[\frac{x^* - t^*}{t^*}\right] \exp -\left[\frac{u_x}{\omega}\right]\left[\frac{y^*}{t^*}\right]$$

$$\exp -\left[\gamma t^*\right] dt^* \qquad (2.4)$$

The integral term is defined as a function, G, of x^*, y^*, ω/u_x and γ, where $\gamma = Wt/D$ and relates the plume age, t, to the settling time, W/D. Normalizing Equation 2.4 by the concentration at the plume front (at distance $u_x t$), the final form of the model is obtained:

$$\frac{C(x,y,t)}{C(u_x t,y,t)} = \frac{G(x^*, y^*, \omega/u_x, \gamma)}{G(1, y^*, \omega/u_x, \gamma)} \tag{2.5}$$

For the centerline, $y^* = 0$, Equation 2.5 reduces to:

$$\frac{C(x,0,t)}{C(u_x t,o,t)} = \frac{G(x^*, \omega/u_x, \gamma)}{G(1, \omega/u_x, \gamma)}$$

The solution to the model for the plume centerline is contained in a series of graphs of $\frac{G(x^*, \omega/u_x, \gamma)}{G(1, \omega/u_x, \gamma)}$ vs. x^* with ω/u_x and γ as parameters. These graphs are contained in Schubel, Carter et al., (1978) and some are included in Chapter V of this report as examples.

The lateral dimensions of the plume are determined by taking the second moment, $\overline{y^2}$, of the concentration distribution of Equation 2.4. The second moment can also be described as a function of x^*, ω/u_x and γ and has the value:

$$\overline{y^2}\,(x,t) = \frac{\omega^2 t^2}{2}\ F\,(x^*, \omega/u_x, \gamma) \tag{2.7}$$

where

$$F(x^*, \omega/u_x, \gamma) = \frac{\int_0^1 t^* \exp - \left(\frac{u_x}{\omega}\right)\left(\frac{x^* - t^*}{t^*}\right) \exp - (\gamma t^*)\, dt^*}{\int_0^1 \frac{1}{t^*} \exp - \left(\frac{u_x}{\omega}\right)\left(\frac{x^* - t^*}{t^*}\right) \exp - (\gamma t^*)\, dt^*} \tag{2.8}$$

Again, Equation 2.7 is normalized with respect to the second moment at the plume front to obtain:

$$\frac{\overline{y^2}\,(x,t)}{\overline{y^2}\,(u_x t,t)} = \frac{F(x^*, \omega/u_x, \gamma)}{F(1, \omega/u_x, \gamma)} \tag{2.9}$$

The lateral dimensions of the plume are determined from another set of graphs in Schubel, Carter et al., (1978). A few examples are shown in the example calculation in Chapter V of this report.

This model is particulary applicable to dredge disposal in a shallow, wide estuary. The assumption of $K_x = K_y$ is only valid in an area where there is not a strong primary flow velocity, u_x. The vertically averaged suspended solids concentration is suitable for a shallow disposal area. The assumption of a vertical line source is also typical of the normal mode of dredge disposal in an estuarine environment (Barnard, 1978).

Wechsler and Cogley Model

The model developed by Wechsler and Cogley (1977) is for prediction of downstream concentration of suspended sediment in waters characterized by unidirectional, steady flow, infinite width, constant depth and infinite length. The initial differential equation for describing the suspended solids concentration at any point downstream of the dredge discharge is:

$$\frac{\partial}{\partial x}(u_x C) + \frac{\partial}{\partial z}\left(\int W f(W)\,dW\right) - \frac{\partial}{\partial x}\left(K_x \frac{\partial C}{\partial x}\right) - \frac{\partial}{\partial y}\left(K_y \frac{\partial C}{\partial y}\right) - \frac{\partial}{\partial z}\left(K_z \frac{\partial C}{\partial z}\right) = 0 \qquad (2.10)$$

where x,y and z represent the longitudinal, lateral and vertical coordinates, respectively; u_x is the mean current velocity in the x direction; C is the suspended sediment concentration; W is the settling velocity; K_x, K_y, and K_z are the eddy diffusion coefficients in the x, y, and z directions; and f(W) is the settling velocity frequency distribution. The first term in Equation 2.10 describes downstream advection, the second term describes vertical sedimentation, while the last three terms describe eddy diffusion in the x, y and z directions, respectively.

Several simplifying assumptions are made to make the model useful: 1) the eddy diffusion in the downstream direction is negligible compared to the other diffusion and transport terms, therefore, $\frac{\partial}{\partial x}\left(K_x \frac{\partial C}{\partial x}\right) = 0$; 2) the eddy diffusion in the vertical direction can be related to the vertical position in the flow by, $K_z = 0.02\ u_x z \left(1-\frac{z}{D}\right)$; 3) the eddy diffusion in the lateral direction is given by $K_y \simeq 2.2\ (K_z)_{max}$; and 4) for non-flocculant sediment, the settling term can be described by $W\ \partial C/\partial z$, and solving the model for each sediment size fraction and superimposing the results for the final solution. The resulting equation is:

$$u_x \frac{\partial C}{\partial x} + W \frac{\partial C}{\partial z} - \frac{\partial}{\partial z}\left(0.02\ u_x z\ (1-\frac{z}{D})\ \frac{\partial C}{\partial z}\right) - \frac{\partial}{\partial y}\left(2.2\ (K_z)_{max}\ \frac{\partial C}{\partial y}\right) = 0 \tag{2.11}$$

Equation 2.11 is solved using the finite difference method for the downstream and vertical directions and an analytical solution involving the "error function" for the lateral direction. It is assumed the source is a vertical line source, continuously emitting sediment at a given strength per unit height. This source strength is converted to a concentration by assuming the sediment is initially concentrated in a vertical column of width, b, which is small relative to the depth, D. The upstream boundary condition is then, $C = C_0$ at $x = 0$, $|y| \leq b$, $z \leq D$. The surface boundary condition specifies no net flux of material across the surface, or $K_z \frac{\partial C}{\partial z} + WC = 0$. The bottom boundary condition assumes all material settling to the bottom remains, with no re-entrainment, or $K_z \frac{\partial C}{\partial z} = 0$.

The model solution is contained in a computer program which is described in Wechsler and Cogley (1977). The inputs to the program are mean current velocity, mean stream depth, settling velocity distribution (given as any number of sediment fractions and their corresponding concentration and settling velocity) and three computational parameters. The output consists of 1) a section showing the vertical distribution of sediment downstream for each sediment fraction (without lateral spreading); 2) the summation of the vertical distributions for all size fractions; 3) the lateral spreading coefficients; and 4) horizontal slices through the three-dimensional plume at five pre-selected depths showing the concentration distribution at each depth.

The assumption of a vertical line source of width, b, which is less than the total depth, D, is applicable to open water discharge of dredged material. It is less applicable to a plume resulting from land runoff since the plume source tends to be wide with respect to the depth. The assumptions concerning the eddy diffusivities, K_x, K_y and K_z, are suitable for describing a plume developing in a river or an estuary with a strong current flow.

Convection - Dispersion Equation

The basic equation describing convection and dispersion of dissolved matter or suspended particles is based on the principle of conservation of mass. For a conservative substance, the principle of conservation of mass can be stated (Sayre, 1968):

$$\begin{bmatrix}\text{Rate of change}\\ \text{of mass in}\\ \text{control volume}\end{bmatrix} = \begin{bmatrix}\text{Rate of change of}\\ \text{mass in control}\\ \text{volume due to}\\ \text{convection}\end{bmatrix} + \begin{bmatrix}\text{Rate of change of}\\ \text{mass in control}\\ \text{volume due to}\\ \text{diffusion}\end{bmatrix}$$

$$\frac{\partial C}{\partial t} = -u_i \frac{\partial C}{\partial x_i} + \frac{\partial}{\partial x_i}\left(\varepsilon_i \frac{\partial C}{\partial x_i}\right) \qquad (2.12)$$

where ε_i is the diffusion coefficient in the i'th direction and all other terms are described previously. For laminar flow, $\varepsilon_i = \varepsilon_M$, the coefficient of molecular diffusion. For turbulent flow, $\varepsilon_i = \varepsilon_T + \varepsilon_M$, where ε_T is the coefficient of turbulent diffusion. In Fickian diffusion theory, it is assumed that dispersion resulting from turbulent open-channel flow is exactly analogous to dispersion from molecular diffusion. The dispersion coefficients in the x, y, and z directions are assumed to be constants, given by K_x, K_y and K_z. The resulting equation, expressed in Cartesian coordinates is:

$$\frac{\partial C}{\partial t} + u_x \frac{\partial C}{\partial x} + u_y \frac{\partial C}{\partial y} + u_z \frac{\partial C}{\partial z} = K_x \frac{\partial^2 C}{\partial x^2} + K_y \frac{\partial^2 C}{\partial y^2} + K_z \frac{\partial^2 C}{\partial z^2} \qquad (2.13)$$

The solution of Equation 2-13 depends on the values of K_x, K_y and K_z. Various authors have arrived at equations to approximate the values of the dispersion coefficients (K) in the longitudinal (x), lateral (y), and vertical (z) directions.

Longitudinal Dispersion Coefficient

The first discussion of dispersion in turbulent flow was by Taylor (1954) for dispersion in a long, straight, circular pipe. Taylor found the dispersion coefficient to be:

$$K_x = 10.06\ a\ U_* \tag{2.14}$$

where a is the pipe radius and U_* is the shear velocity. The shear velocity can be calculated by $U_* = \sqrt{\tau_0/\rho}$, where τ_0 is the shear stress at the wall of the pipe and ρ is the fluid density.

Elder (1959) obtained an expression for K_x in two-dimensional open-channel flow:

$$K_x = \alpha\ D\ U_* \tag{2.15}$$

where α = 5.93, D is the mean depth and U_* is, again, the shear velocity, calculated as $U_* = \sqrt{\tau_0/\rho} = \sqrt{g\ D\ S_e}$ where τ_0 is the shear stress at the bottom, g is the acceleration of gravity and S_e is the energy slope. Elder's expression is for infinitely wide channels, meaning no lateral velocity or concentration gradients, and a logarithmic vertical velocity distribution. Longitudinal dispersion, therefore, is a result of differential convection in the vertical direction and turbulent diffusion.

Yotsukura and Fiering (1964) applied Taylor's solution method to open channels and used a computer solution to obtain values of α varying from 9 to 13 as the ratio of u_x/U_* varied from 14.5, indicating a rough channel boundary, to 20, indicating a smooth channel boundary.

Thackston and Krenkel (1967) included the term u_x/U_* in the dispersion equation, resulting in:

$$K_x = \alpha\ D\ U_* \left(\frac{u_x}{U_*}\right)^{1/4} \tag{2.16}$$

where α has the value 5.82 or 7.25. The value u_x/U_* is a dimensionless measure of the bottom roughness; larger values meaning smoother bottoms.

Thackston and Krenkel are careful to point out, however, that Equation 2.16, as well as all of the previously mentioned equations, does not apply in areas where there is appreciable lateral velocity variation. In such a case, the authors state that K_x will be much larger than calculated by Equation 2.16, and recommend *in situ* measurement of K_x. Since natural streams have a significant lateral velocity profile, none of the preceeding equations and α coefficients are directly applicable.

Fischer (1966) showed that the dispersion of a slug of material injected into a natural stream is divided into two distinct phases; 1) the convective period, in which the material diffuses laterally and longitudinally until the material is completely distributed across the channel, and 2) the diffusive period (called the Taylor period), in which the lateral concentration gradient is small. The convective period is characterized by a highly skewed longitudinal concentration profile; the downstream face being blunt and the upstream tail being long. The above equations for K_x are not applicable to the convective period. The Taylor period is characterized by a more nearly Gaussian longitudinal concentration profile. The above equations are applicable, with the restrictions mentioned, to the Taylor period. The criterion for determining if dispersion of a material is in the convective period or the Taylor period is (Fischer, 1966):

$$L > 1.8 \frac{\ell^2}{r} \frac{u_x}{U_*} \qquad (2.17)$$

where L is the distance downstream from the source of the material; ℓ is the characteristic cross-sectional length, described as the distance from the point of maximum surface velocity to the far bank; r is the hydraulic radius and u_x/U_* is as previously defined. If L is greater than the right hand side of Equation 2.17, then the Taylor period has been reached.

Working with natural streams, Fischer (1967) found that longitudinal dispersion was a result of the combination of two effects; 1) variable lateral convective velocities and 2) concentration gradients giving rise to lateral diffusion of material. The effect of the lateral diffusion is to dampen the dispersion caused by the differential lateral convective velocities. This mechanism for dispersion in natural streams is in contrast to the mechanism proposed by Elder (1954) and used by the other authors, in that dispersion is caused by lateral velocity gradients as opposed to vertical velocity gradients.

Using this mechanism, Fischer (1967) found an equation for the longitudinal dispersion coefficient in the Taylor period:

$$K_x = -\frac{1}{A}\int_0^B q'(y)\,dy \int_0^y \frac{1}{K_y\,D(y)}\,dy \int_0^y q'(y)\,dy \qquad (2.18)$$

where

$$q'(y) = \int_0^{D(y)} u'(z,y)\,dz \qquad (2.19)$$

and q'(y) is described as the discharge per unit width; u' is the deviation of the local mean velocity, U, from the cross-sectional mean velocity, u_x,($U = u_x - u'$); B is the stream width; and K_y is the lateral dispersion coefficient, taken as $K_y = 0.23\, DU_*$ by Fischer (1967). Equation 2.18 can be solved for any stream after measuring the energy slope, S_e, the cross-sectional geometry and the cross-sectional velocity distribution of a "typical" cross-section. Fischer (1967) solved Equation 2.18 with the use of a computer for several laboratory flumes and related the resulting K_x values back to Equation 2.15 and found values of α ranging from 5 to 16. The higher values of α were for flumes with sloping sides rather than perpendicular sides. Again, the lateral velocity currents set up by the sloping sides of natural streams give problems in predicting α, so the more simple Equation 2.15 can not be used.

Liu (1977) used Equation 2.18, since it correctly describes the prime mechanism of dispersion in natural streams, to develop an expression for K_x which is much easier to calculate:

$$K_x = \beta \frac{u_x^{2}\, B^3}{U_* A} = \beta \frac{Q_B^{\,2}}{U_*\, D^3} \tag{2.20}$$

where (Liu 1978),

$$\beta = 0.5\left(\frac{U_*}{u_x}\right)^2 \tag{2.21}$$

and Q_B is the river discharge. The new coefficient, β, is an easier coefficient to use than α, since β does not depend on stream morphometry but on the dimensionless bottom roughness, a value more easily estimated. Based on existing data for K_x in streams and the value of K_x predicted by Equation 2.20, K_x can be predicted to within a factor of six by Equation 2.20. This is better than any other of the simple methods described for predicting the longitudinal dispersion coefficient.

Lateral Dispersion Coefficient

Elder (1959) proposed the equation for predicting the lateral dispersion coefficient, K_y:

$$K_y = \phi D U_* \tag{2.22}$$

where ϕ is equal to 0.23. The value of $\phi = 0.23$ was obtained by experiment in long, wide laboratory flumes.

Many authors have since investigated the value of ϕ in both laboratory flumes and natural streams. Sayre and Chang (1968) reported $\phi = 0.17$ in a straight laboratory flume. Yotsukura and Cobb (1972) report values of ϕ for natural streams and irrigation canals varying from 0.22 to 0.65, with most values being near 0.3. Other reported values of ϕ range from 0.17 to 0.72. The higher values for ϕ are all for very fast rivers. The conclusions drawn are that; 1) the form of Equation 2.22 is correct for predicting K_y, but ϕ may vary, and 2) application of Fickian theory to lateral dispersion is correct as long as there are no appreciable lateral currents in the stream.

Okoye (1970) refined the determination of ϕ somewhat by use of the aspect ratio, $\lambda = D/B$, the ratio of the stream depth to stream width. It was found that ϕ decreased from 0.24 to 0.093 as λ increased from 0.015 to 0.200.

The effect of bends in the channel on K_y is significant. Yotsukura and Sayre (1976) reported that ϕ varies from 0.1 to 0.2 for straight channels, ranging in size from laboratory flumes to medium size irrigation chanals; ϕ varies from 0.6 to 10 in the Missouri River, and ϕ varies from 0.5 to 2.5 in curved laboratory flumes. Fischer (1968) from the point of maximum surface velocity to the far bank; r is the hydraulic radius and u_x/U_* is as previously defined. If L is greater than the right hand side of Equation 2.17, then the Taylor period has been reached.

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Using this mechanism, Fischer (1967) found an equation for the longitudinal dispersion coefficient in the Taylor period:

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where

$$q'(y) = \int_0^{D(y)} u'(z,y)\,dz \qquad (2.19)$$

and q'(y) is described as the discharge per unit width; u' is the deviation of the local mean velocity, U, from the cross-sectional mean velocity, u_x, $(U = u_x - u')$; B is the stream width; and K_y is the lateral

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Many authors have since investigated the value of ϕ in both laboratory flumes and natural streams. Sayre and Chang (1968) reported ϕ = 0.17 in a straight laboratory flume. Yotsukura and Cobb (1972) report values of ϕ for natural streams and irrigation canals varying from 0.22 to 0.65, with most values being near 0.3. Other reported values of ϕ range from 0.17 to 0.72. The higher values for ϕ are all for very fast rivers. The conclusions drawn are that; 1) the form of Equation 2.22 is correct for predicting K_y, but ϕ may vary, and 2) application of Fickian theory to lateral dispersion is correct as long as there are no appreciable lateral currents in the stream.

Okoye (1970) refined the determination of ϕ somewhat by use of the aspect ratio, $\lambda = D/B$, the ratio of the stream depth to stream width. It was found that ϕ decreased from 0.24 to 0.093 as λ increased from 0.015 to 0.200.

The effect of bends in the channel on K_y is significant. Yotsukura and Sayre (1976) reported that ϕ varies from 0.1 to 0.2 for straight channels, ranging in size from laboratory flumes to medium size irrigation chanals; ϕ varies from 0.6 to 10 in the Missouri River, and ϕ varies from 0.5 to 2.5 in curved laboratory flumes. Fischer (1968) reports that higher values of ϕ are also found near the banks of rivers.

Vertical Dispersion Coefficient

Very little experimental work has been done on the vertical dispersion coefficient, K_z. Jobson and Sayre (1970) reported a value for marked fluid particles of:

$$K_z = \kappa U_* z \left(1 - \frac{z}{D}\right) \tag{2.23}$$

for a logarithmic vertical velocity distribution. κ is the von Karman coefficient, which is shown, experimentally, to be approximately = 0.4 (Tennekes and Lumley 1972). Equation 2.23 agrees with experimental data fairly closely.

Water Quality Criteria

The federal water quality criterion for turbidity and suspended solids is based on protection of freshwater fish and other aquatic life (Water Quality Criteria 1976). The criterion is stated: "settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life."

Turbidity and suspended solids have several effects on fish and other aquatic organisms. Deposited sediments can damage invertebrate populations and cover gravel spawning areas. Silt attached to eggs may inhibit oxygen transfer and so increase mortality. Suspended solids may act directly on fish by either killing them or inhibiting their growth, and by reducing the availability of food. Suspended solids reduce light penetration which causes a reduction in the depth of the photic zone. This reduced photic zone may lead to a reduction in primary production which leads to a decrease in the amount of food for fish. Turbidity also interferes with aesthetic enjoyment of waterways.

The Iowa Water Quality Standard (1977) for surface water states; "the turbidity of the receiving water shall not be increased by more than 25 Nephelometric turbidity units by any point source discharge." The criterion shall apply after an appropriate mixing zone. The mixing zone is the area of diffusion of an effluent in the receiving water. In all cases, the mixing zone should be as small as practicable and not include more than 25 percent of the cross-sectional area.

CHAPTER III

MODEL DEVELOPMENT

The distribution of sediment in the water column is governed by the equation:

$$\frac{\partial C}{\partial t} + u_i \frac{\partial C}{\partial x_i} = \frac{\partial}{\partial x_i}\left(K_i \frac{\partial C}{\partial x_i}\right) \tag{3.1}$$

where u_i refers to the fluid velocity in a rectangular coordinate system (x_i), C refers to the concentration (mass per unit volume) of sediment suspended in the water column, and K_i refers to the dispersion coefficient in the i'th direction (Sayre 1968). Equation (3.1) can be rewritten as:

$$\frac{\partial C}{\partial t} + u_x \frac{\partial C}{\partial x} + u_y \frac{\partial C}{\partial y} + u_z \frac{\partial C}{\partial z} = \frac{\partial}{\partial x}\left(K_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial C}{\partial z}\right) \tag{3.2}$$

where x, y and z refer to the longitudinal, lateral and vertical directions, respectively.

The solids in the plume are not uniform, but consist of various size particles, each with a distinct settling velocity. The vertical velocity of a particle (u_z) can be divided into two fractions, its natural settling velocity in quiescent water, w_i, and the velocity of the water in the z direction, w. Incorporating these into Equation (3.2) gives:

$$\frac{\partial}{\partial t} \Sigma c_i + u_x \frac{\partial}{\partial x} \Sigma c_i + u_y \frac{\partial}{\partial y} \Sigma c_i + (w_i + w) \frac{\partial}{\partial z} \Sigma c_i =$$

$$\frac{\partial}{\partial x} \left(K_x \frac{\partial}{\partial x} \Sigma c_i\right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial}{\partial y} \Sigma c_i\right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial}{\partial z} \Sigma c_i\right) \quad (3.3)$$

These plumes develop along a shore of the river where the water is shallow; therefore vertically averaged solids concentrations will be calculated. The necessary assumptions are that u_x, u_y, K_x and K_y are depth independent, w = 0 and there can be no flux of suspended material across the surface of the river ($- K_z \frac{dC}{dz} + u_z C = 0$ at z = 0). With these assumptions, Equation (3.3) can be integrated to obtain (Schubel, et al., 1978):

$$\frac{\partial C}{\partial t} + u_x \frac{\partial C}{\partial x} + u_y \frac{\partial C}{\partial y} = \frac{\partial}{\partial x}\left(K_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial C}{\partial y}\right) - \frac{WC}{D} \quad (3.4)$$

where $$C = \frac{1}{D} \int_0^D \Sigma c_i \, dz, \quad (3.5)$$

$$\frac{WC}{D} \approx \frac{1}{D} \left[K_z \frac{\partial}{\partial z} \Sigma c_i - \Sigma w_i c_i\right]_{z=D} \quad (3.6)$$

and $$W \approx \frac{\int_0^D \Sigma w_i c_i dz}{\int_0^D \Sigma c_i dz} \quad (3.7)$$

C is defined as the mean suspended solids concentration and W is the mean settling velocity of the particles. D is the average depth of the water containing the plume.

In a river, the following additional assumptions can be made to further simplify Equation (3.4) (Sayre, 1973).

$$u_x = \text{constant} \tag{3.8}$$

$$D = \text{depth} = \text{constant} \tag{3.9}$$

$$u_y = 0 \tag{3.10}$$

$$K_y = \text{constant} \tag{3.11}$$

$$\text{and } K_x << K_y \quad \text{so} \quad \frac{\partial}{\partial x}\left(K_x \frac{\partial C}{\partial x}\right) = 0 \tag{3.12}$$

Incorporating these assumptions into Equation (3.4) and assuming steady state ($\partial C/\partial t = 0$) gives:

$$\frac{\partial C}{\partial x} = \frac{K_y}{u_x} \frac{\partial^2 C}{\partial y^2} - \frac{WC}{u_x D} \tag{3.13}$$

The solution to this equation can be written (Sayre, 1979) as:

$$C\,(y,x) = C'(y,x) \exp\left[-\frac{Wx}{u_x D}\right] \tag{3.14}$$

where $C'(y,x)$ is the solution to the diffusion equation:

$$\frac{\partial C}{\partial x} = \frac{K_y}{u_x} \frac{\partial^2 C}{\partial y^2} \tag{3.15}$$

For the case of a continuous point source of flow, Q_o and solids concentration, C_o, the solution to Equation (3.15) is (Sayre, 1973):

$$C'(y,x) = \frac{Q_o C_o}{u_x D} \frac{1}{2\sqrt{\pi K_y x/u_x}} \exp\left[-\frac{y^2 u_x}{4 K_y x}\right] \tag{3.16}$$

This equation has the form of a normal probability function with variance, $\sigma_y^2 = 2K_y x/u_x$. Substituting this into Equation (3.16) gives:

$$C'\,(y,x) = \frac{Q_o C_o}{u_x D} \frac{1}{\sqrt{2\pi}\,\sigma_y} \exp\left[-\frac{y^2}{2\sigma_y^2}\right] \tag{3.17}$$

Equation (3.17) describes the plume resulting from a continuous point source. Water running off from a shore can better be described by a line source of width, b, perpendicular to the shoreline. Equation (3.17) can be modified to describe a line source by the method used by Sayre (1973, 1979). The resulting expression is:

$$C'(y,x) = \int_0^B C'(y',0) \frac{1}{\sqrt{2\pi}\,\sigma_y} \exp -\left[\frac{(y-y')^2}{2\,\sigma_y^2}\right] dy' \quad (3.18)$$

where B is the width of the river and y' is a dummy variable describing any point within the source width. The initial conditions for this line source are:

$$C'(y',0) = \frac{Q_o C_o}{Q_b}, \qquad 0 < y' < b$$

$$C'(y',0) = 0, \qquad b < y' < B \quad (3.19)$$

where $Q_b = \bar{u}_x Db$ and is the portion of the river flow passing through the source width, b. Incorporating these into Equation (3.18) and substituting the standard normalized variable $s = \frac{y-y'}{\sigma_y}$ gives

$$C'(y,x) = \frac{Q_o C_o}{Q_b} \left[\frac{1}{\sqrt{2\pi}} \int_{\frac{y-b}{\sigma_y}}^{y/\sigma_y} \exp -\left[\frac{s^2}{2}\right] ds \right] \quad (3.20)$$

which is in the form of the cumulative normal distribution function. The solution to Equation (3.20) is

$$C'(y,x) = \frac{Q_o C_o}{Q_b} \left[F\left(\frac{y}{\sigma_y}\right) - F\left(\frac{y-b}{\sigma_y}\right) \right] \quad (3.21)$$

where the value of F (*) can be obtained from a cumulative normal distribution table, such as the one included as Appendix C.

The suspended solids plume described by Equation (3.21) includes no effects from the side banks of the river. It is assumed that the channel banks act as reflecting barriers. Including the effects of reflection from the near side bank, the equation becomes:

$$C'\ (y,x) = \frac{Q_oC_o}{Q_b}\left[F\left(\frac{y+b}{\sigma_y}\right) - F\left(\frac{y-b}{\sigma_y}\right)\right] \tag{3.22}$$

This equation is not applicable if the suspended solids plume disperses in the lateral direction enough to reflect from the far shoreline. An exact solution is presented by Sayre (1969).

Substituting Equation (3.22) back into Equation (3.14) gives the final solution,

$$C\ (y,x) = \frac{Q_oC_o}{Q_b}\left[F\left(\frac{y+b}{\sigma_y}\right) - F\left(\frac{y-b}{\sigma_y}\right)\right] \exp\left[-\frac{Wx}{Du_x}\right] \tag{3.23}$$

$\frac{Q_oC_o}{Q_b}$ is the initial suspended solids concentration at the source. By dividing both sides of Equation (3.23) by the initial concentration, the model can be written:

$$\frac{Q_b}{Q_oC_o}\ C\ (y,x) = \left[F\left(\frac{y+b}{\sigma_y}\right) - F\left(\frac{y-b}{\sigma_y}\right)\right] \exp\left[-\frac{Wx}{Du_x}\right] \tag{3.24}$$

and the right hand side can be solved independent of the source concentration.

The parameters that are necessary to solve the model are the source width, b; the mean depth, D; the mean downstream velocity, u_x; the lateral dispersion coefficient, K_y; and the terminal settling velocity of the suspended particle, W. Values of downstream distance, x, are chosen and the lateral extent of the plume is calculated by varying the value of y/σ_y, and hence, y. An additional advantage is that the model can be solved several times for size fractions with different terminal settling velocities and the several solutions summed for the final solution, due to the principle of superposition for linear differential equations.

The model can be programmed for solution with a programmable calculator. One program for a Hewlett-Packard 29C is included as Appendix A.

CHAPTER IV

FIELD PROCEDURES AND RESULTS

Suspended Solids/Turbidity Relationships

It was intended to use a continuous flow turbidity monitoring device to sample the plume. Discrete samples were also to be taken and analyzed for suspended solids concentration. With this data, a correlation could be developed to translate the continuous flow turbidity data into suspended solids, which was necessary for input into the model. To this end, experiments were carried out in the laboratory to develop correlations for three distinct types of particles, sand, laboratory grade colloidal kaolin clay* and Iowa River mud, a mixture of silt and clay.

Turbidity was measured nephelometrically with a Turner Model 111 Fluorometer equipped with a flow-through door. A 2A secondary filter was used with no primary filter. The sample of turbid water was contained in a 1000 ml Erlenmeyer flask and was continuously mixed with a magnetic stirrer and stir bar. The sample was withdrawn from the flask, drawn through the fluorometer at approximately 1.2 l/min, and returned to the flask. When a steady turbidity reading was obtained, a sample was collected from the pump discharge and analyzed for suspended solids. Flow was downflow through the fluorometer. The material in the flask

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* Fisher Scientific Co., Fair Lawn, N.J., Laboratory Grade Colloidal Kaolin Powder.

was then diluted and the procedure repeated. Figure 4-1 shows the equipment used.

The procedure was repeated for each of the three types of materials, sand, kaolin, and river mud. The relationship between suspended solids and turbidity for each of these materials is shown in Figure 4-2. It can be seen that although there are great differences in the suspended solids concentration necessary to produce a certain turbidity, each material exhibits a distinct relationship between suspended solids and turbidity. The clay particles are smaller and more numerous per unit mass and therefore scatter light to a greater degree than Iowa River mud or sand.

It was felt the suspended solids in the plume resulting from disposal operations would exhibit this same phenomenon. It was therefore decided to measure turbidity continuously in transects across the plume and take enough discrete samples for suspended solids analysis to describe the relationship between the two parameters.

Field Sampling

Three of the four dredging operations by the U.S. Army Corps of Engineers, Rock Island District, on the Mississippi River in 1978 were monitored. Dredging operations monitored were near Hannibal, Missouri, river mile 313.5, on October 16 and 17; near Keithsburg, Illinois, river mile 425.8, on October 25; and at Rock Island, Illinois, river mile 482.0 on October 28. These three sites are shown in Figure 4-3. At the Hannibal site, 18,800 cubic yards of sediment were dredged. At

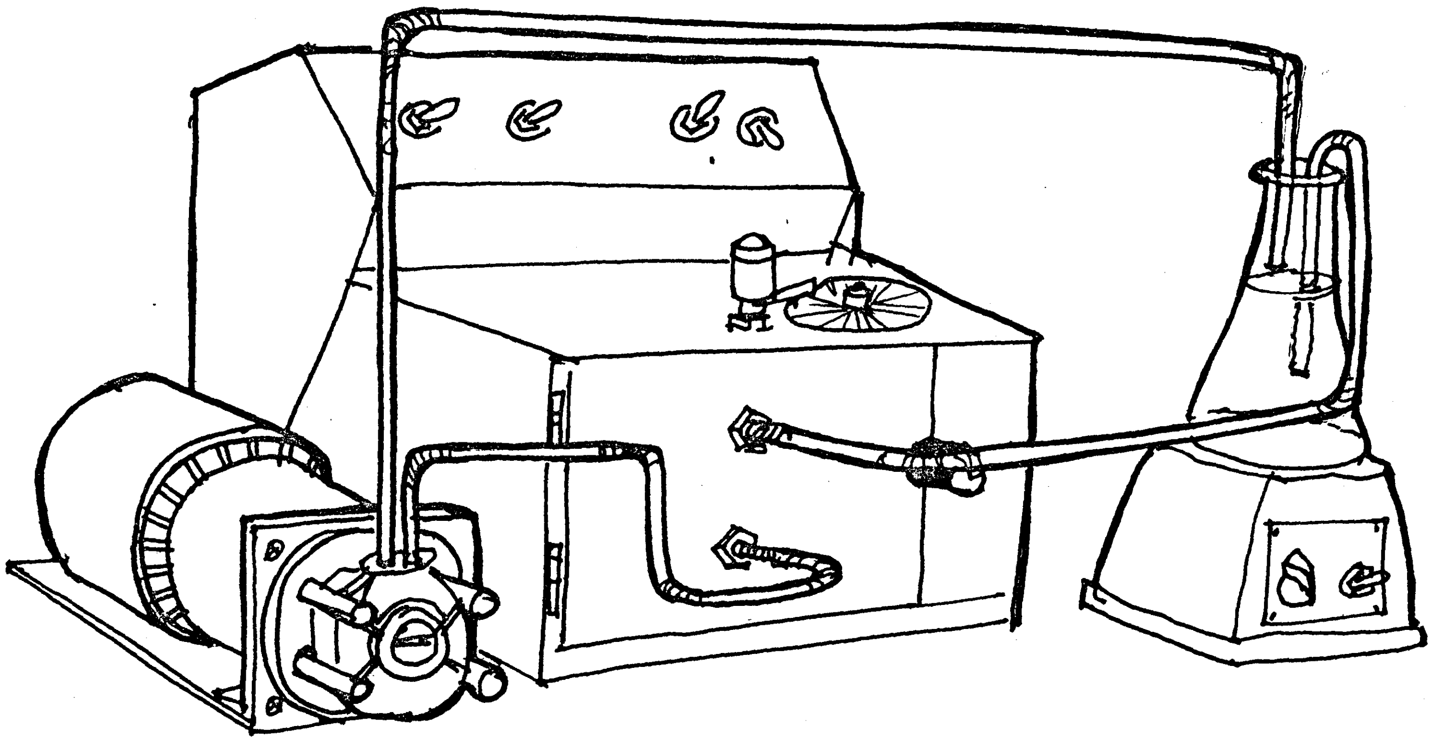


Figure 4-1. Experimental apparatus used to develop turbidity vs. suspended solids relationships.

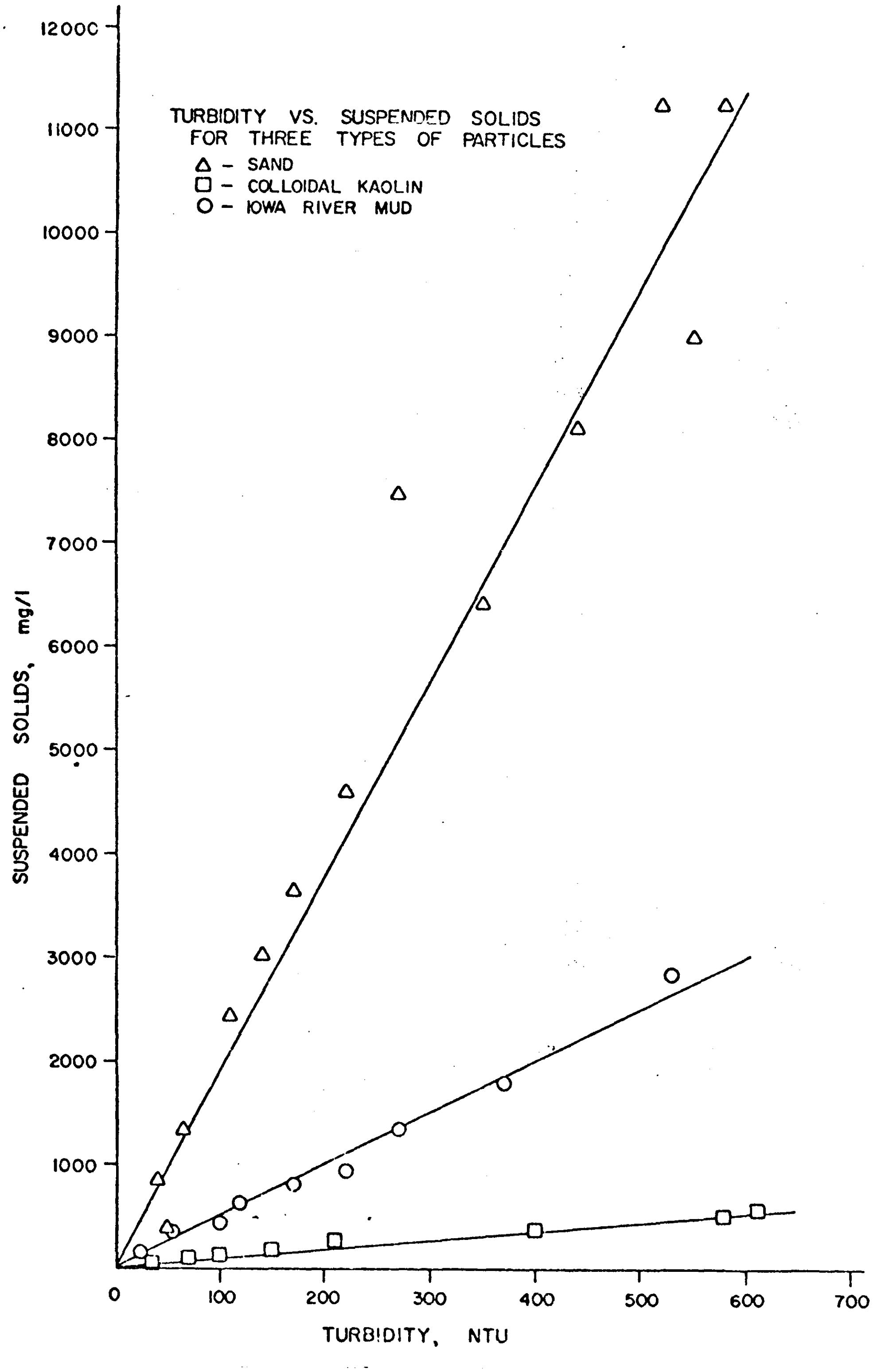


Figure 4-2. Turbidity vs. suspended solids relationships for sand, colloidal kaolin and Iowa River mud.

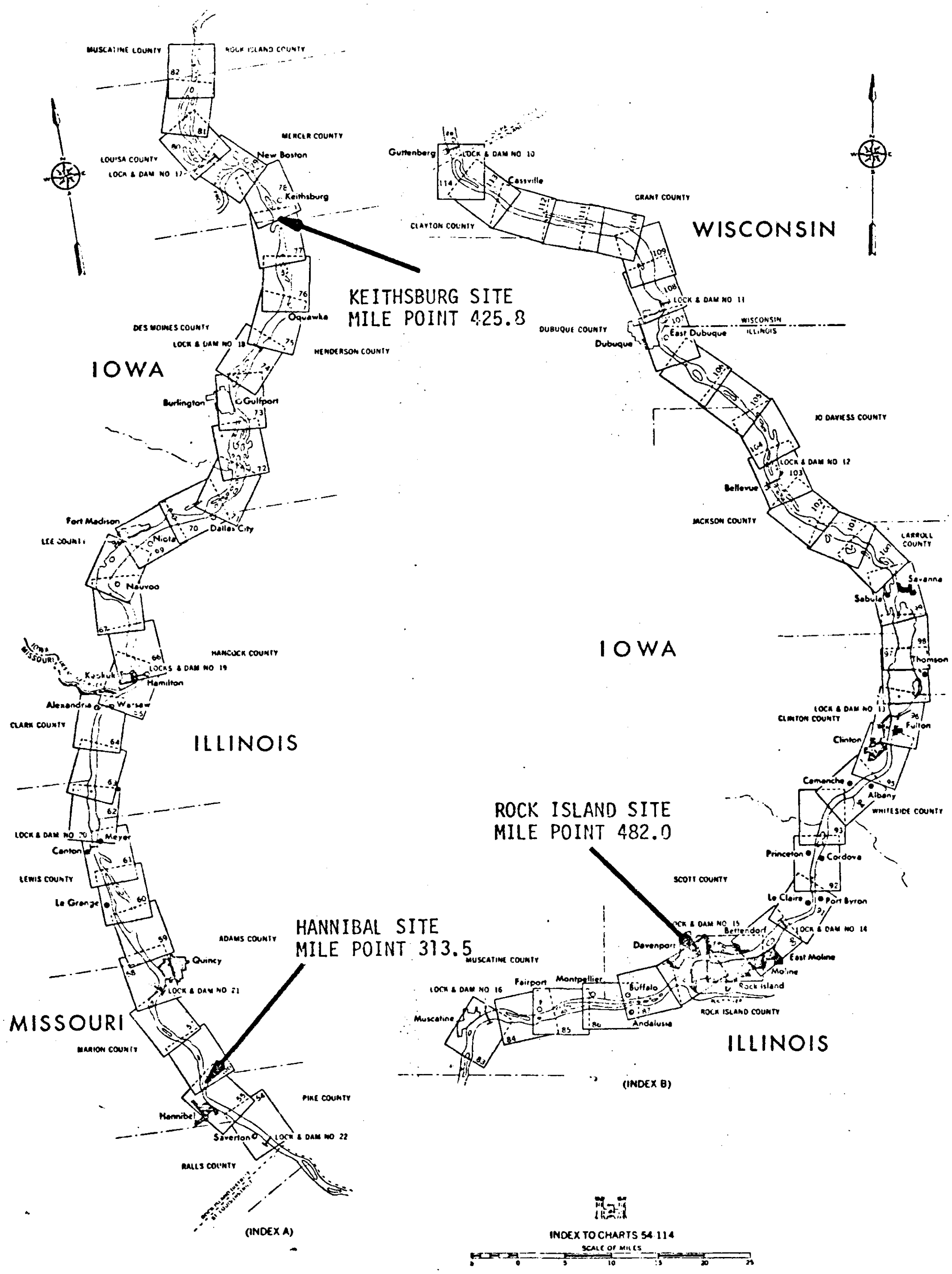


Figure 4-3. Map of GREAT II study area showing locations of dredging operations monitored.

Keithsburg, 11,166 cubic yards of sediment were dredged in 16.0 hours and at Rock Island, 11,596 cubic yards of sediment were dredged in 18.58 hours. Each dredging disposal operation was unique with respect to the resulting turbidity plume generated.

The dredge spoil at the Hannibal site was discharged to nearby Armstrong Island, shown in Figure 4-4. This island is approximately 1.7 miles long and 0.3 miles wide at its widest point. It also has a large inland depression and lake. There was no runoff from this island during the dredging. Much of the discharged water was assumed to be percolating, with the rest ponding in depressions on the island. Samples of the discharged water and of the ponded water were collected for size analysis of the suspended solids for the purposes of comparison.

The dredge spoil at the Keithsburg site was discharged to Willow Bar Island, adjacent to the dredge cut, see Figure 4-5. Willow Bar Island is approximately 2500 feet long and 400 feet wide and gently slopes away from the main channel of the river. Consequently, there was a return water flow to the back side of the island. Several points of entry were noted but only the area downstream from the major runoff point was monitored.

The possible lateral and longitudinal dimensions of the turbidity plume were estimated from surface debris washed into the river with the runoff flow. A system of shore markers and in-stream buoys was laid out to act as location markers so that the dimensions of the plume could be accurately determined. A geodimeter (distance meter), Hewlett-Packard Model 3800B, was used to measure the distance of each

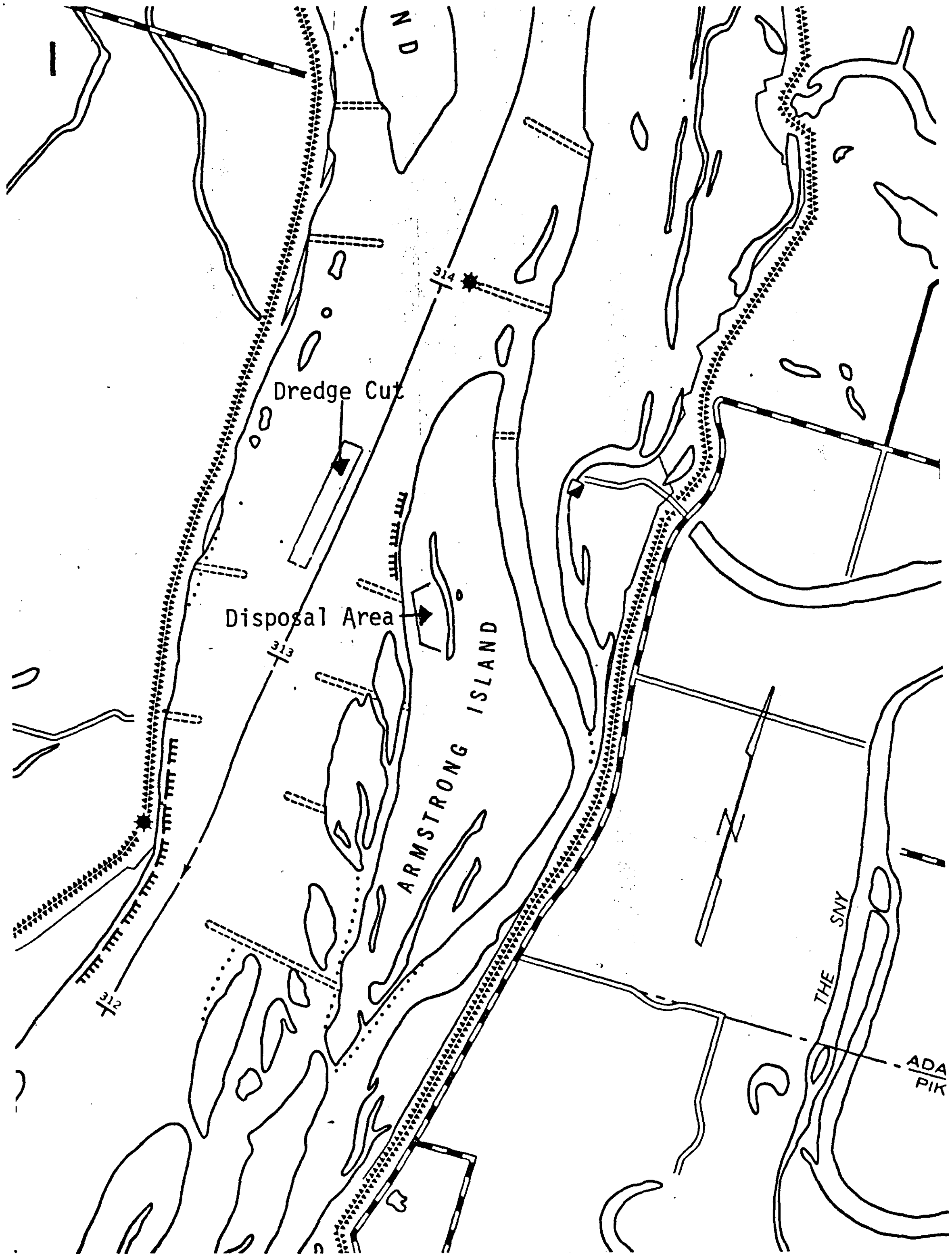


Figure 4-4. Site of dredging operation near Hannibal, Missouri showing dredge cut and disposal area.

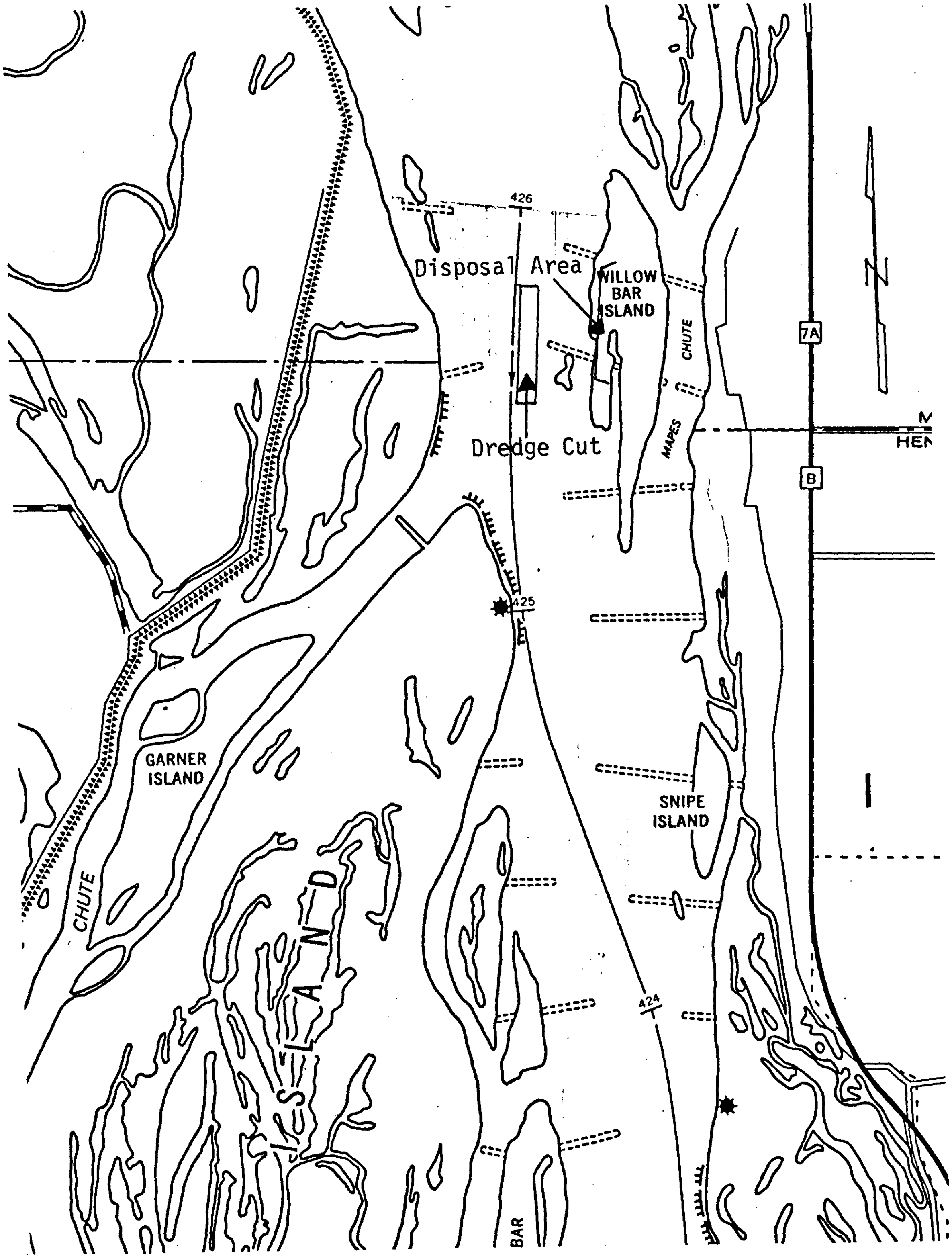


Figure 4-5. Site of dredging operation near Keithsburg, Illinois showing dredge cut and disposal area.

of the shore markers and buoys from the source of the plume. Each buoy was placed so that it was roughly perpendicular from the shore line. With this information, it was possible to calculate all of the distances in the grid system of markers and buoys. The grid system was approximately 180 m. long by 80 m. wide.

Sampling of the plume was done by traversing the grid system in a serpentine fashion in a slow moving boat. Samples were drawn through the fluorometer continuously with a Masterflex Model 7545, Variable Speed Drive pump. The pump was equipped with a number 7017 head and used 0.225 in. I.D. by 0.3900 in. O.D. Tygon tubing. Samples were drawn at a rate of approximately 0.6 l/min and had an approximate residence time of 0.4 minutes in the tubing. The boat was estimated to be moving at 1 m/sec so the boat had moved approximately 20 m. between the time the sample was removed from the water column and the time the turbidity was read and the sample collected for suspended solids analysis. A YSI Model 81A recorder with a 30 in/hr chart speed gear was attached to the fluorometer to continuously record the turbidities. 100 ml discrete samples were taken from the pump discharge for calibration of the turbidity vs. suspended solids relationship.

The plume was sampled at three depths; top, middle and bottom. During the sampling, the fluorometer became inoperable. It began showing relatively constant turbidity readings at all points in the plume. It was also giving an abnormally high reading for the turbidity, around 500 to 900 NTU. Normal turbidity readings were all less than 100 NTU. Consequently, the continuous output was not used.

Additional water samples were collected for size analysis of the suspended sediment at the head of the plume, and at the discharge point into the river. Size analysis included visual accumulation tube (VA tube) as well as micropipette measurements for coarse and fine graded materials. The velocity of the water flowing into the river was sufficient to erode the shoreline of the island. A channel was cut into the shoreline approximately three feet wide at the mouth and extending approximately fifteen feet inland. Since this material was forming the plume, a sample of this soil was collected. At the point where the flow entered the river, a sand bar was built up during the course of the sampling. This sediment was also sampled for size analysis. The final measurement taken was the current velocity at a point midway between the shore and the buoy line. The current velocity was measured with a Universal Current Meter 10.002.

Due to the location of the sediment to be dredged at this site, the discharge line from the U.S. Army Corps of Engineer's Dredge Thompson to the shore ran across the entire width of the main channel. This effectively blocked any barge traffic from either direction. For this reason, the dredging operation was frequently halted and the discharge line separated for barges to pass. This interrupted the flow from the island and sampling was halted until the flow was resumed. Sampling was not restarted for a period of time after the flow had returned to allow time for the plume to become re-established.

The dredge spoil at the Rock Island, Illinois site was discharged directly to the Illinois shore of the river in what is known as a "beach nourishment" type of operation, see Figure 4-6. This was the only operation with side bank disposal. In this type of operation, a major percentage of the discharged sediment settles on the river bank while a small portion of the sand and the majority of the silt and clay fractions are retained in the water that returns to the river. These fractions make up the plume.

Shore markers and buoys were again located in such a manner as to encompass the plume. The grid marked out was 430 m. long and approximately 100 m. wide. Distances were taken with the geodimeter and sampling of the plume was begun. The fluorometer was still inoperative, it would not hold a zero reading, so many discrete samples were taken to be analyzed for suspended solids and turbidity at the laboratory. All samples were taken at the three foot depth, which was approximately mid-depth. Water samples were taken at several points in the plume for size analysis of the suspended sediments. Samples were taken of the water flowing across the bank before entering the river, the water at the head of the plume, and water approximately 100 meters downstream from the head of the plume. A sample of the deposited sediment near the dredge discharge was also collected for size analysis.

Discharge flow at this location was also quite intermittent. Due to the morphometry of the river bed, there were times when very little sediment was being dredged and discharged. These periods of pure water discharge could last for minutes. During these times, very little suspended material was being added to the plume. The dredging

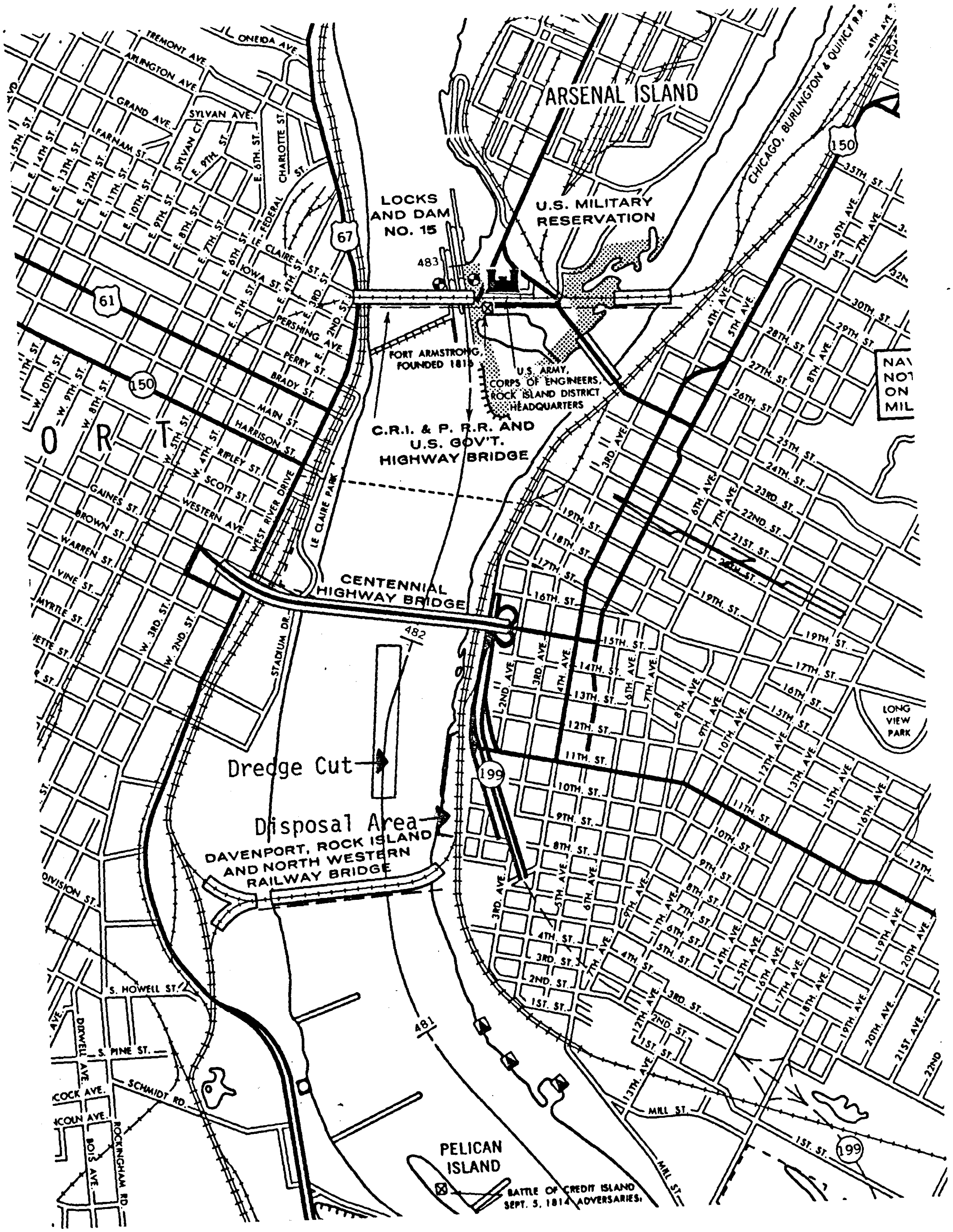


Figure 4-6. Site of dredging operations at Rock Island, Illinois showing dredge cut and disposal area.

operation was also halted several times to move the discharge pipe further upstream. This had the dual effect of stopping the sampling activity and moving the source of the plume to a new location.

Field Results

The results from the Hannibal, Missouri sampling trip were size analyses on suspended material in two samples. The first was a sample of water flowing very near to the dredge discharge. It was attempted to get a homogenous sample of material being discharged from the dredge but this was not possible. When material was discharged from the dredge discharge pipe, a large portion of the solids immediately settled. The water portion of the dredged material flowed over this mounded sand. This water was sampled for size analysis. The results of the size analysis are shown in Figure B-1, Appendix B and a summary is shown in Table 4-1. This sample contained 2100 mg/l of suspended solids.

The second sample was of water flowing overland across Armstrong Island. This sample was collected approximately one half mile from the discharge point. The water was fairly slow moving and had passed through some relatively quiescent pools. It was felt that this water was indicative of the water that would have returned to the river, had there been return flow.

The suspended solids content of this sample was 74 mg/l. It can be seen in Table 4-1 that the size of the suspended solids in the overland flow water was much smaller than the size of the suspended

DESCRIPTION:	Sand, %	Silt, %	Clay, %	D_{50}, μm	Character
Hannibal:					
Discharge Pipe	95.6	1.4	3.0	270	fine to medium sand
Overland Flow	0.3	7.2	92.5	< 2	clay
Keithsburg:					
Island Mud	0.7	89.3	10.0	5	silt
Deposited Sand	81.5	13.5	5.0	490	medium sand
Discharge Creek	5.0	66.0	29.0	17	silt and clay
Head of Plume	1.8	67.0	31.0	15	silt and clay
Rock Island					
Sediment near discharge	95.5	2.3	2.2	370	medium sand
Discharge Pipe	>99.9	---	---	455	medium to course sand
Beginning of Plume	95.0	3.7	1.3	330	fine to medium sand
Suspended Solids in Plume	0.7	25.3	74.0	< 2	silt and clay

Table 4-1. Results of size analysis of water and sediment samples.

solids in the discharged material. This is due to settling of the larger material in the quiescent pools. The results of the size analysis can be seen in Figure B-2, Appendix B.

The size analyses were performed by Mr. Wilbur Matthes, Jr., United States Geological Survey, Iowa City. The particle sizes were analyzed by the Visual Accumulation Method and the Pipet Method. The Visual Accumulation method gives an analysis in the range of 62 to 1000 micrometers (μm). The Pipet Method gives an analysis of the particles in the range of 2 to 62 μm. One sample was analyzed by the Dry Sieve Method which gives an analysis of particles in the range of 62 to 4000 μm.

The mid-depth suspended solids plume as sampled at Keithsburg is shown in Figure 4-7. It can be seen that the plume hugged the shoreline and exhibited little lateral dispersion; the plume is less than 20 meters wide.

The results from the four size analyses performed are shown summarized in Table 4-1 and in Figures B-3 through B-6, Appendix B. The samples analyzed were island mud, deposited sand, discharge creek and head of plume. The first two were sediment samples while the second two were water samples. The island mud sample was the material being eroded to form the suspended solids plume. It was mostly silt with a small amount of sand and clay. The deposited sand is material deposited as the runoff water entered the river. Of the two water samples, the first was taken in the eroded discharge creek before entering the river, and the second was taken at the head of the plume, after

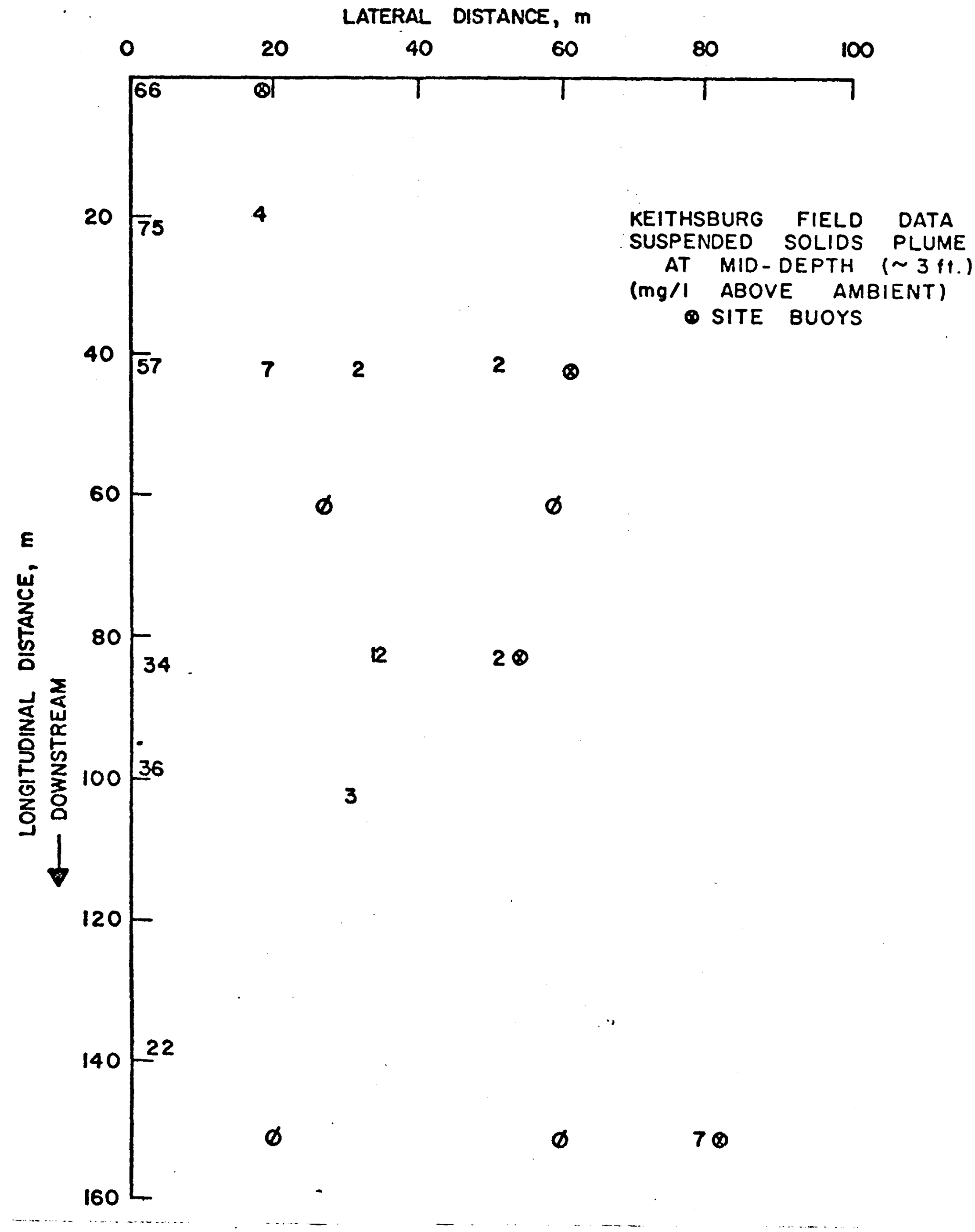


Figure 4-7. Mid-depth suspended solids plume at Keithsburg, Illinois site.

the sand had been deposited. This can be seen by comparing the two particle size frequency plots; the head of plume sample shows a lower percentage of sand than the discharge creek plot.

The mid-depth suspended solids plume as sampled at Rock Island is shown in Figure 4-8, with iso-concentration lines. It can be seen that this plume also hugged the shoreline and exhibited little lateral dispersion over 500 m. downstream distance. The drop in suspended solids concentration between 200 m. and 350 m. is assumed to be caused by a prolonged period of low solids concentration in the discharge. The sampling was discontinued at 450 m. because of a large widening and change in river morphometry at this point.

There were four samples collected at Rock Island for size analysis, one sediment sample and three water samples, see Table 4-1 and Figures B-7 through B-10, Appendix B. The sediment sample was of sediment near the dredge discharge, but away from the bank approximately 5 feet. This sediment is material that had been dredged from the channel, discharged on the bank and carried back into the river by the water. It can be seen that this was very large material. A sample was collected near the discharge pipe in the same manner as the sample collected at the Hannibal, Missouri dredge operation. It can be seen that these samples are very similar. The water samples collected at the head of the plume and 100 meters downstream in the plume show interesting results. The suspended solids in the plume at the head consist of primarily sand, while only 100 meters downstream, there is almost no sand. Another interesting observation is that the

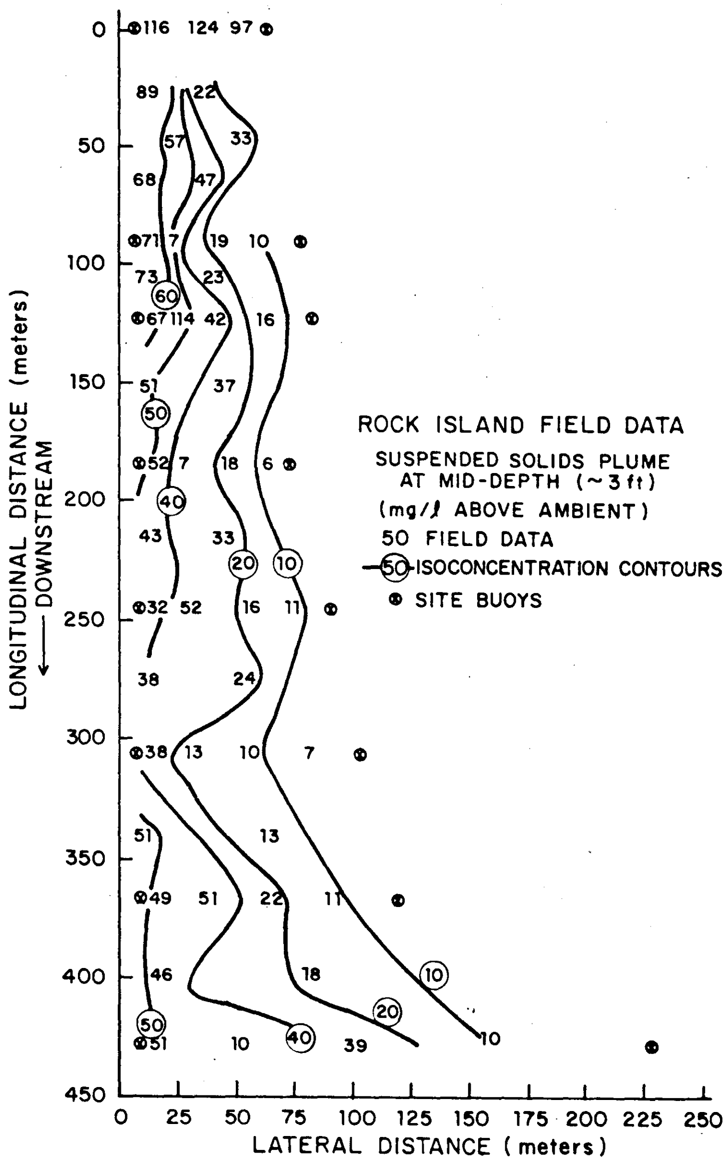


Figure 4-8. Mid-depth suspended solids plume at Rock Island, Illinois site.

silt and clay fractions have reversed, there being a much higher percentage clay in the body of the plume than at the head of the plume.

The turbidity of the samples collected for size analysis was measured in the laboratory with a Hach Model 2100 Turbidimeter. The maximum turbidity measured was 33 nephelometric turbidity units (NTU) above ambient at the plume source. The ambient turbidity was 22 NTU. The turbidity in the plume rapidly decreased with downstream distance; the turbidity had decreased to 15 NTU at 100 m. downstream. Figure D-2 in Appendix D shows the relationship between suspended solids and turbidity for the Rock Island samples. The correlation coefficient for this data is 0.87.

CHAPTER V

MODEL RESULTS AND DISCUSSION

Graphical Solution

The model development by Schubel, Carter et al., (1978) was first used to try to simulate the observed field data. It was decided to simulate the data from the Rock Island, Illinois sampling trip.

Model Input Parameters

There are six input parameters to the model; a) the rate of addition of suspended solids to the receiving water, b) the average vertical thickness of the plume, c) the mean particle settling velocity, d) the diffusion velocity, e) the time interval for the plume to reach its maximum length and f) the average current velocity of the receiving water. Each of these parameters will be discussed as pertaining to the Rock Island, Illinois site.

Rate of addition of suspended solids to the receiving water (q)

The rate of addition of suspended solids to the receiving water is a function of the size of the dredge, the type of material being dredged and the amount of time for settling before the discharged water returns to the receiving water. Since the operation at Rock Island was side bank disposal, there was essentially no time for settling before the discharged water re-entered the river. The amount of suspended material entering the river and the rate of addition can be calculated in several ways.

The fraction of the total solids discharged from the dredge that becomes incorporated into the plume has been calculated to vary from 1% to 5% (Schubel, Carter et al., 1978). The mass of material discharged from the dredge per unit time, Q_m, can be calculated. At Rock Island, 11,596 cubic yards of material were dredged in an operating time of 18.58 hours (personal communication with Mr. Dick Baker, Chief of Operations, Rock Island District, U.S. Army Corps of Engineers). Using these values and assuming the sediment to be 85% solids, $Q_m = 2.39 \times 10^8$ mg/sec. The fraction remaining suspended and becoming incorporated into the plume is assumed to be the silt and clay fraction, which from Table 4-1, is seen to be 5.0% at the beginning of the plume. Therefore, the rate of addition of suspended particulates to the plume, q, is equal to 1.20×10^7 mg/sec.

An alternate method of calculation of the rate of addition of suspended solids to the plume is to calculate the value of $q = u_x AC_b$, where A is the cross-sectional area of the head of the plume, C_b is the concentration of suspended solids at the head of the plume and u_x is the mean plume velocity in the longitudinal direction. From Figure 4-8, it is seen that the width of the plume is approximately 50 meters at the source, and the concentration is approximately 112 mg/l at that point. The average depth of the river was measured to be 6 feet and the mean current velocity was 0.40 meters/second. Using this information:

$$A = (50\ \text{m})(2\ \text{m}) = 100\ \text{m}^2 \tag{5.1}$$

$$q = (0.40\ \text{m/sec})(100\ \text{m}^2)(112\ \text{mg/l})(1000\ \text{l/m}^3) = 4.48 \times 10^6\ \text{mg/sec.} \tag{5.2}$$

It is seen that there is a large disagreement in q calculated by the two methods. Since the objective is to try to match the observed suspended solids plume, the value $q = 4.5 \times 10^6$ mg/sec is chosen. Evidently some of the silt and clay must settle-out in a dense wedge as the discharge water first enters the river. Approximately 2% of the total sediment that is dredged actually enters the River and becomes entrained in the plume.

Average vertical thickness of the plume, D

The depth of the river was measured at several locations in the suspended solids plume. The average depth was determined to be approximately 6 feet. Schubel, Carter et al., (1978) advise using a value of one half the total water depth in areas where the water depth is 8 feet or less. Therefore, the value D = 3 feet = 0.9 meters is chosen.

Mean particle settling velocity, W

The mean particle size can be determined from the size analysis on the suspended solids. Since the sand settles immediately, the material forming the plume is the silt and clay fraction. The mean particle size of the silt/clay fraction was determined to be 0.02 mm. Using Stoke's Law and a water temperature of 50° F, the mean particle settling velocity was calculated, W = 0.027 cm/sec.

Diffusion velocity, ω

Schubel, Carter et al., (1978) reported the range of the longitudinal and lateral diffusion velocity in open rivers to be 0.2 - 0.5 cm/sec. The value of 0.5 cm/sec was chosen.

Time interval for the plume to reach its maximum length, t

The maximum length of a suspended solids plume in a river is determined by the settling velocity of the suspended particle and the vertical distance the mean particle must settle (Barnard, 1978). For the Rock Island case, W = 0.027 cm/sec and D = 3 feet,

$$t = \frac{D}{W} = \frac{91 \text{ cm}}{0.027 \text{ cm/sec}} = 3370 \text{ seconds} \tag{5.3}$$

Average current velocity of the receiving water, u_x

The current velocity of the river was measured at several locations within the suspended solids plume. The average current velocity was calculated to be, u_x = 0.4 m/sec.

Non-dimensional Ratios and Scaling Factors

The suspended solids model presented by Schubel, Carter et al., (1978) is in the form of a series of graphs. The graphs were developed as functions of the following non-dimensional ratios and scaling factors.

Ratio of diffusion velocity to advective velocity, ω/u_x

$$\frac{\omega}{u_x} = \frac{0.5 \text{ cm/sec}}{40 \text{ cm/sec}} = 0.013 \tag{5.4}$$

This ratio indicates that the longitudinal dispersion is small in comparison to the mean longitudinal velocity.

Ratio of the plume age to the settling time, γ

$$\gamma = \frac{Wt}{D} = \frac{(0.027 \text{ cm/sec})(3370 \text{ sec})}{91 \text{ cm}} = 1 \qquad (5.5)$$

The value of γ will always be equal to 1 in a river since t is defined as D/W.

Distance Scaling Factor, DSF

$$DSF = u_x t = (0.4 \text{ m/sec})(3370 \text{ sec}) = 1350 \text{ m} \qquad (5.6)$$

This is the expected distance of travel for the mean particle which falls from the surface to the bottom.

Concentration Scaling Factor, CSF

$$CSF = \frac{q}{\pi \omega^2 Dt} = \frac{2.24 \times 10^6 \text{ mg/sec } (1000 \text{ cm}^3/1)}{(\pi)(0.5 \text{ cm/sec})^2 (91 \text{ cm})(3370 \text{ sec})} = 18{,}600 \text{ mg/1} \qquad (5.7)$$

Calculation of the Centerline Concentrations

The above ratios and factors are used along with the graphs of Schubel, Carter et al., (1978) to calculate the concentration of the suspended solids plume along the centerline. The centerline for a sidebank disposal operation in a river is along the near bank. The model was originally developed for estuarine open water disposal, and therefore,no effects of sidebanks were included in the solution. This is easily modified for sidebank disposal in a river by assuming the bank is a reflecting barrier. The effect of this reflecting barrier on a plume resulting from sidebank disposal can be described as folding the plume back on itself along the ceterline. The net effect is that the suspended solids concentrations calculated with this model must be doubled to describe sidebank disposal in a river.

Suspended solids concentration at distance $u_x t$

The first step in determining the suspended solids concentrations along the centerline is to determine the suspended solids concentration at distance $u_x t$. This concentration is found by using Figure 5-1, (Barnard, 1978). Enter Figure 5-1 at the calculated value of ω/u_x. Move vertically to the curve corresponding to the calculated value of γ and horizontally to determine the value of

$$\frac{\text{Concentration, mg/l at distance } u_x t}{\text{CSF}} = 0.0045$$

Therefore,the suspended solids concentration at 1350 m is calculated to be equal to 84 mg/l above the ambient river value. Doubling this value to account for reflection from the bank gives a value of 167 mg/l above ambient.

Distance, x, where centerline concentration is a specified concentration above ambient

The next step in determining the suspended solids concentrations along the centerline is to choose a centerline concentration and find the distance downstream that corresponds to this concentration. As an example, the distance where the centerline suspended solids concentration = 1000 mg/l above ambient will be calculated.

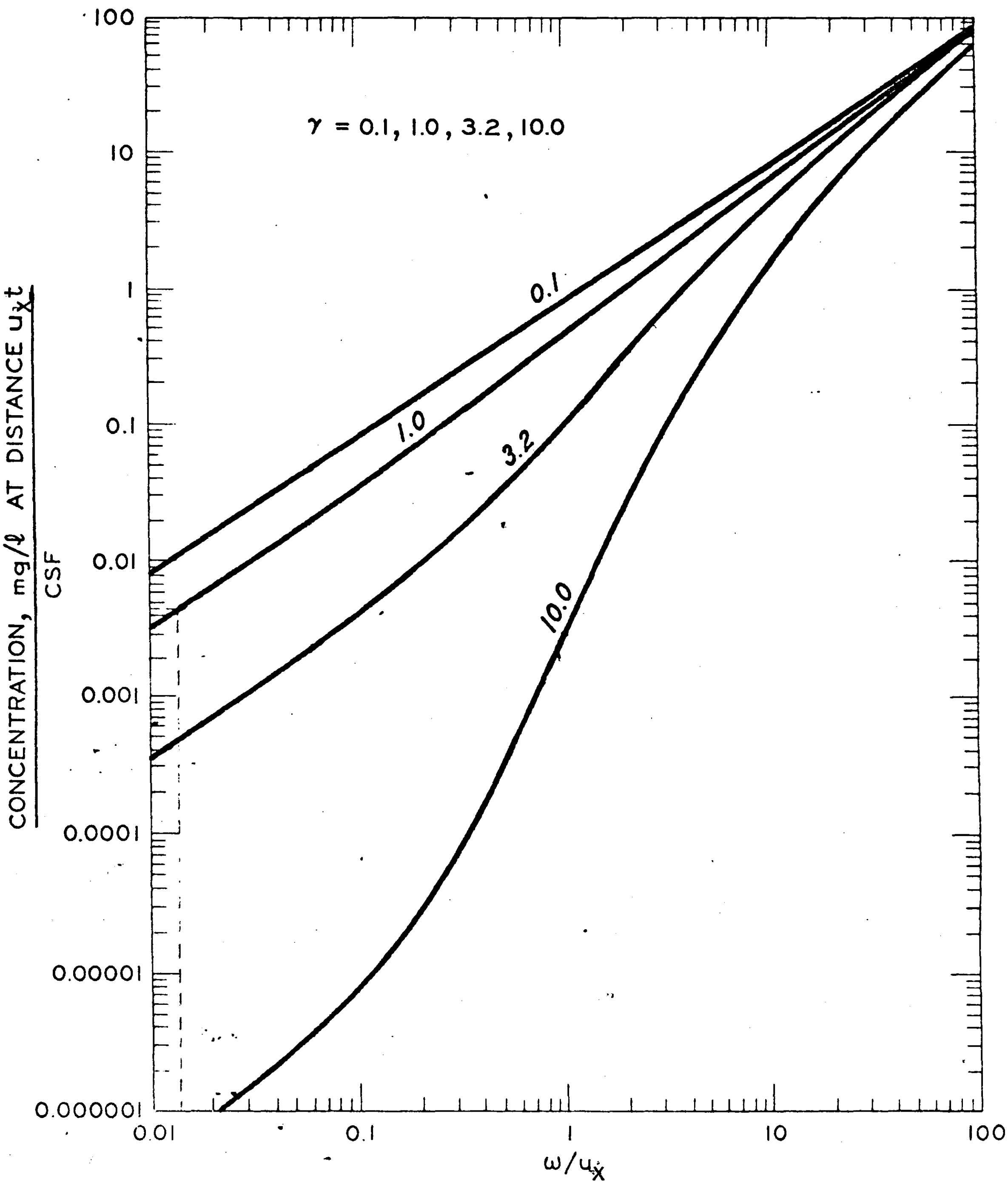


Figure 5-1. Relationship between ω/u_x and $\frac{\text{Solids concentration at distance X}}{\text{CSF}}$ for γ = 0.1, 1, 3.2 and 10.

1) Calculate: $\frac{1000 \text{ mg/l}}{\text{concentration at distance } u_x t} = \frac{1000 \text{ mg/l}}{167 \text{ mg/l}} = 6.0$ (5.8)

2) Use this ratio to enter Figure 5-2 from Barnard (1978) along the ordinate. Move horizontally to the curve corresponding to ω/u_x and then vertically to determine the value of

$$\frac{\text{Distance } x}{\text{DSF}}$$

Figure 5-2 is for $\gamma = 1$. Figures for $\gamma = 0.01$, 0.1, 10 and 100 are included in Schubel, Carter et al., (1978). Multiplying this value by DSF gives the distance at which the centerline suspended solids concentration is 1000 mg/l above ambient.

For the Rock Island site, $\omega/u_x = 0.013$ and DSF = 1350 m. Figure 5-2 shows

$$\frac{\text{Distance } x}{\text{DSF}} = 0.52 \tag{5.9}$$

Therefore, the distance where the centerline suspended solids concentration is 1000 mg/l above ambient is equal to 700 m.

3) Steps 1 and 2 are repeated for as many different suspended solids concentrations as are needed to adequately describe the centerline of the plume. Values calculated for the Rock Island site are shown in Table 5-1.

It can be seen in Figure 5-2 that the curve for ω/u_x is nearly vertical below

$$\frac{\text{Concentration at distance } x}{\text{Concentration at distance } u_x t} = 1.$$

For this reason, plume concentrations can not be calculated at distances

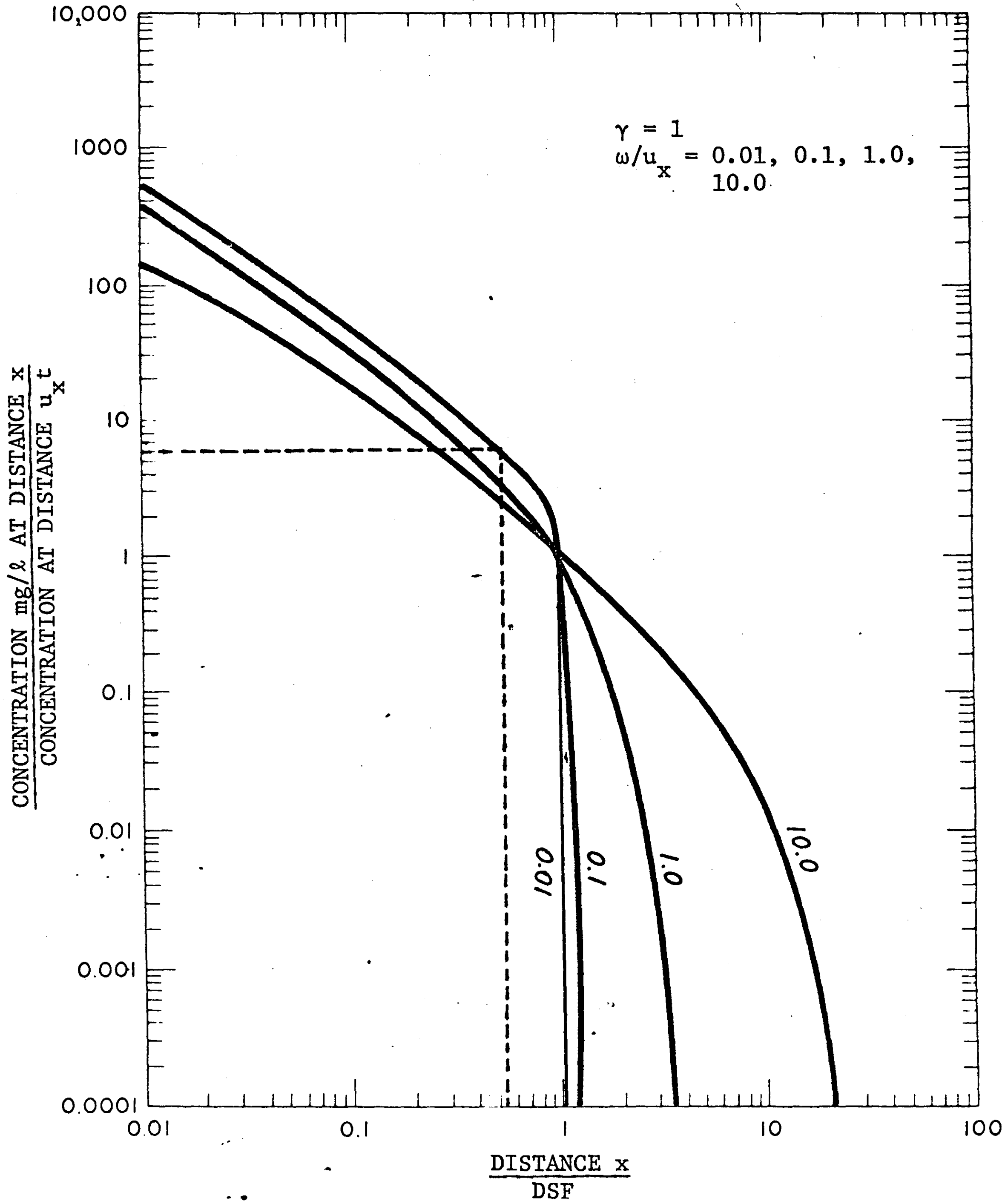


Figure 5-2. Relationship between $\frac{\text{Distance x}}{\text{DSF}}$ and $\frac{\text{Solids concentration at distance x}}{\text{Solids concentration at distance } u_x t}$ for ω/u_x equal to 0.1, 1, and 10, and γ = 1.

Concentration (mg/l)	$\frac{\text{Concentration}}{\text{Concentration at distance } u_x t}$	$\frac{\text{Distance x}}{\text{DSF}}$	Distance x (m)
25,000	150	0.032	43
10,000	60	0.085	115
5,000	30	0.14	189
2,500	15	0.23	310
1,000	6	0.52	700
500	3	0.80	1080
167	1	1.00	1350

Table 5-1. Downstream distance corresponding to various suspended solids concentrations along the centerline. Rock Island, Illinois site.

beyond $u_x t$. For the Rock Island plume, the plume can not be described at a distance beyond 1350 m. The suspended solids concentration at this point is 167 mg/l.

Lateral Dimensions of the Plume

The plume described by this model is approximately Gaussian and therefore, the lateral dimensions are directly related to x, the downstream distance. The width of the plume as determined by the C(I) isopleth and measured from the centerline, y, is determined by:

$$\frac{y}{DSF} = \sqrt{\sigma^2\left(\frac{x}{DSF}\right) \quad \sigma^2(1)\left(\frac{\omega}{u_x}\right)^2\left[-\frac{\ln C(I)/CSF}{C(x)}\right]} \tag{5.10}$$

where $\sigma^2(x/DSF)$ is determined from Figure 5-3, $\sigma^2(1)$ is determined from Figure 5-4, C(x) = suspended solids concentration on the centerline at distance x, C(I) = suspended solids concentration of the isopleth chosen to define the plume, ω/u_x, DSF, CSF and x as defined previously.

Assume the plume is defined by the 50 mg/l above ambient isopleth. For the Rock Island site, C(I) = 25 mg/l since the plume is reflected from the shoreline. The width of the plume can be calculated at each of the distances where the centerline suspended solids concentration is known. To finish the example calculation, the width of the plume is calculated at x = 700 m or where C(x) = 1000 mg/l above ambient.

(1) Calculate:

$$\frac{x}{DSF} = \frac{700\ \text{m}}{1350\ \text{m}} = 0.52 \tag{5.9}$$

This is the value that was found in Step 2, previously.

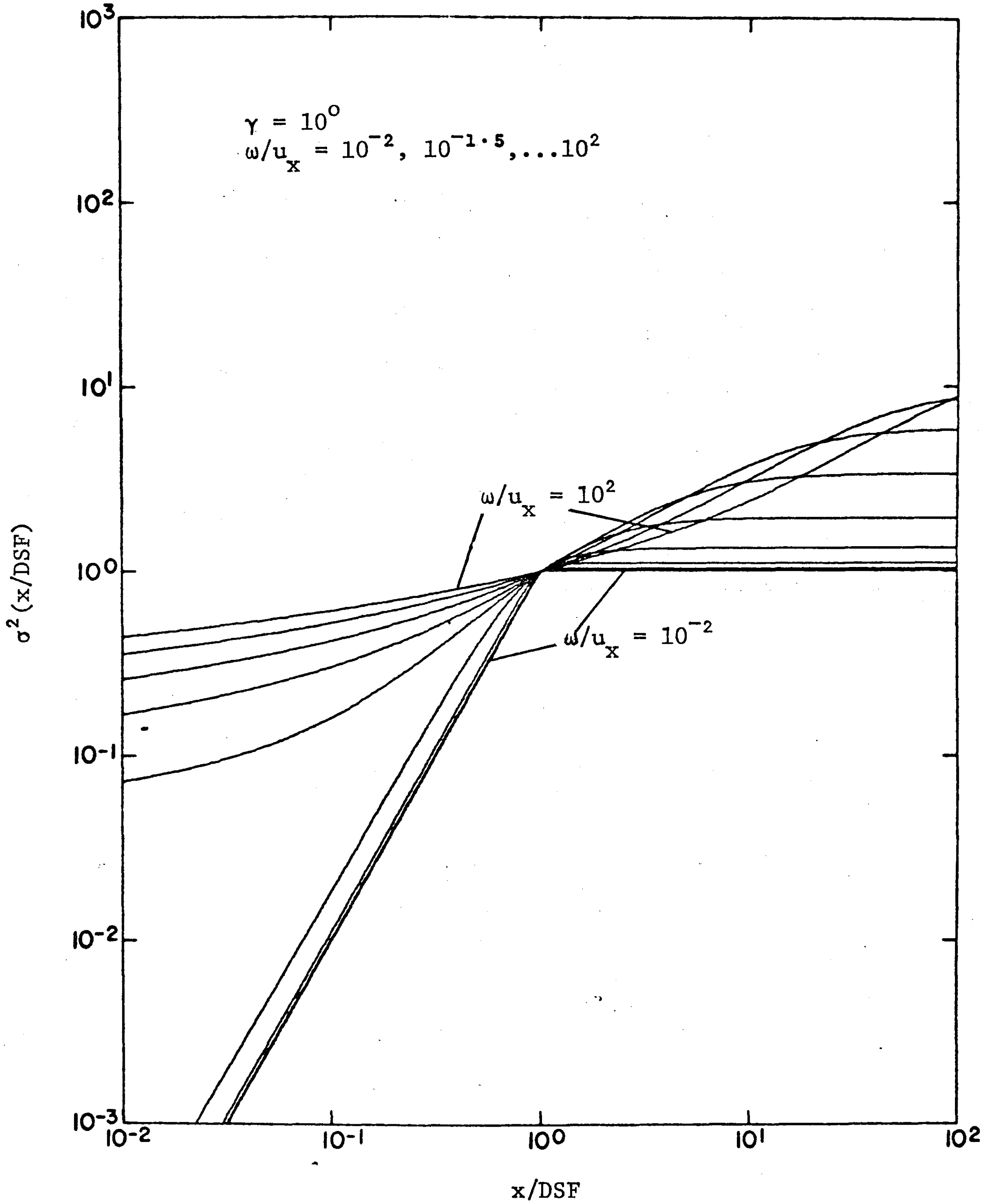


Figure 5-3. Relationship between $\sigma^2(x/DSF)$ and x/DSF with γ as a parameter, for determining the lateral dimensions of the plume.

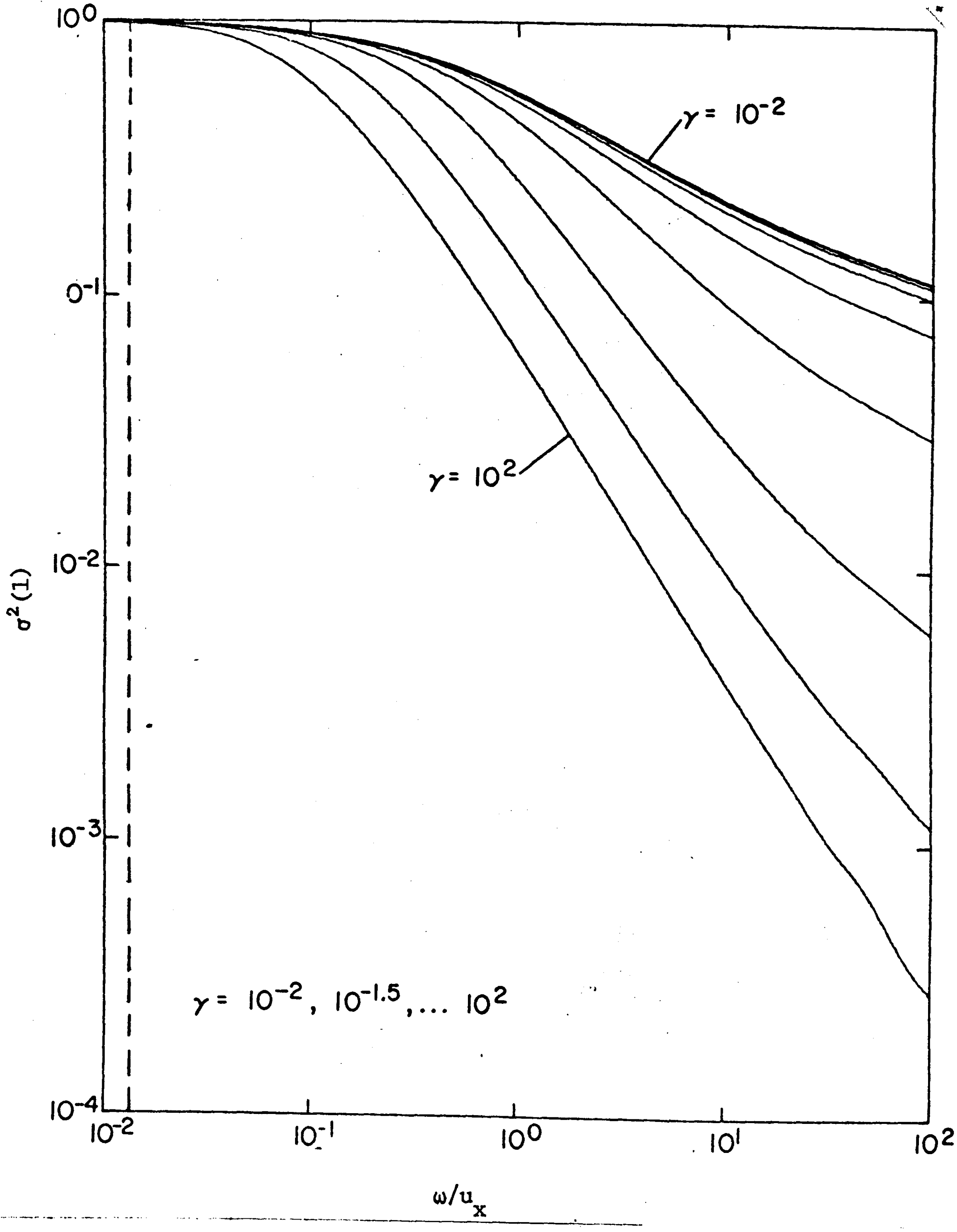


Figure 5-4. Relationship between $\sigma^2(1)$ and ω/u_x for determining the lateral dimensions of the plume.

(2) Calculate:

$$\frac{C(I)}{CSF} = \frac{25 \text{ mg/l}}{18600 \text{ mg/l}} = 0.0013 \tag{5.11}$$

(3) Use the value x/DSF to enter Figure 5-3 along the abscissa. Move vertically to the correct ω/u_x curve and then horizontally to determine the value of σ^2(x/DSF). From Figure 5-3, with x/DSF = 0.52 and ω/u_x = 0.013, σ^2(x/DSF) = 0.25.

(4) Use the value ω/u_x to enter Figure 5-4 along the abscissa. Move vertically to the correct γ curve and then horizontally to determine the value of σ^2(1). From Figure 5-4, with ω/u_x = 0.013 and γ = 1, $\sigma^2(1) = 1$.

(5) Calculate:

$$\frac{y}{DSF} = \sqrt{\sigma^2\left(\frac{x}{DSF}\right) \sigma^2(1) \left(\frac{\omega}{u_x}\right)^2 \left[- \ell n \frac{C(I)/CSF}{C(x)}\right]} \tag{5.10}$$

$$= \sqrt{(0.25)(1)(0.013)^2 \left(- \ell n \frac{0.0013}{1000}\right)} = 0.024$$

(6) Calculate:

$$y = (y/DSF)(DSF) = (0.024)(1350 \text{ m}) = 32 \text{ m} \tag{5.12}$$

(7) Steps 1-6 are repeated for other values of x and C(x) until the shape of the 50 mg/l isopleth is adequately determined. Table 5-2 shows the values calculated for the 50 mg/l isopleth for the Rock Island site. If other isopleths are desired, the procedure is repeated for a different C(I) value.

x (m)	$\frac{x}{DSF}$	C(x) (mg/l)	$\sigma^2\left(\frac{x}{DSF}\right)$	$\frac{y}{DSF}$	y (m)
43	0.032	25,000	0.0010	0.0017	2.3
115	0.085	10,000	0.0068	0.0043	5.8
189	0.14	5,000	0.020	0.0072	10
310	0.23	2,500	0.053	0.011	15
700	0.52	1,000	0.25	0.024	32
1080	0.80	500	0.62	0.037	50
1350	1.00	167	1.0	0.045	60

Table 5-2. Estimate of lateral extent of the plume at various distances x for Rock Island, Illinois.

Discussion of Model

It can be seen by comparing Table 5-1 to Figure 4-8 that the model does not predict the plume observed during the dredge disposal operation. The maximum suspended solids concentration observed was 124 mg/l above ambient with the maximum extent of the 50 mg/l isopleth being approximately 500 m. downstream. The model shows a maximum suspended solids concentration in excess of 25,000 mg/l and the maximum longitudinal extent of the 50 mg/l isopleth is greater than 1350 m.

Much of this problem can be traced to the assumptions concerning the type of source of the plume. The model assumes a point source discharge which is consistent with the mode of discharge in estuarine pipeline disposal operations, but it is not representative of the side-bank disposal operations performed on the Mississippi River, GREAT II reach.

It can be seen from Figure 4-8 that the concentration of suspended solids at x = 0 is approximately constant for a distance of 50 m. This line source means that the same amount of solids is suspended in a much greater volume of water for the observed plume, as opposed to the model calculated plume.

The solution to this problem would be to modify the model so the initial source condition would be a line instead of a point. Unfortunately, this is not an easy task.

An alternative solution would be to solve the model assuming several point sources located at several points across the observed plume source width. This type of solution may have more closely described the observed plume, but the problem of reflection from the shoreline would have made the solution very unwieldy. It was decided that this type of solution was beyond the scope of "a simple model" and so was unsatisfactory for this study.

Because the model could not be used to predict the observed plume at Rock Island, this model was not used to try to predict the Keithsburg plume.

Analytical Solution

The model discussed in Chapter III was developed as an alternative to the model developed by Schubel, Carter, et al. This analytical model was developed to describe transport and dispersion of suspended solids in a river. It was decided to simulate the suspended solids plume that was observed during the Rock Island dredging operation.

Model Input Parameters

There are six input parameters to the model, a) the width of the plume source, b) the mean depth of the portion of the river containing the plume, c) the mean velocity of the river in the area of the plume, d) the dispersion coefficient, e) the settling velocity of the suspended particle and f) the downstream distance from the plume source. Each parameter will be discussed.

Width of the plume source, b

The width of the plume source is a function of the velocity of the returning flow, the direction of that flow with respect to the direction of the receiving water flow and the velocity of the receiving water. A plume resulting from sidebank disposal would be expected to have a wider plume source than a plume resulting from disposal at a site where the water could not immediately return to the river. A plume developing in a backwater area characterized by a slow moving current would be expected to have a wider plume source than a plume developing near the main channel of a river with a fast current.

Mean depth of the plume, D

The plumes resulting from dredge disposal operations are generally shore-attached and are therefore in areas of varying depth. The model assumes constant depth. Therefore, an attempt should be made to measure the depth at several locations in the area of the plume to determine an average depth. This average depth will be used in the model, directly.

Mean river velocity, u_x

The mean velocity of the river in the immediate vicinity of the plume must be known.

Dispersion coefficient, K_y

The lateral dispersion coefficient must be either measured or calculated from empirical relationships. Assuming Elder's (1959) relationship of $K_y = 0.23\ DU_*$, K_y was calculated to be approximately 100 cm^2/sec. Allowing for some effects of the sloping channel bottom, the value of K_y was chosen to be 300 cm^2/sec.

Settling velocity of the suspended particle, W

The terminal settling velocity of a suspended particle is determined by its specific gravity and its size. The particle size can be estimated by fall velocity analysis. Knowing the particle size and assuming a specific gravity, Stoke's Law can be used to determine the terminal settling velocity. A chart is included in Barnard (1978) and is reproduced in Appendix D, relating particle size to terminal settling velocity. This chart can be used for settling velocity approximations.

Downstream distance from the plume source, x

The model equation given in Chapter III is solved at a particular distance downstream from the plume source. To determine the entire plume, the model must be solved several times with different x distances.

Solution to Rock Island, Illinois Plume

A solution was first attempted using a mean settling velocity, as with the model of Schubel, Carter, et al., (1978). It was not possible to calculate a plume that resembled the field-observed plume using this technique. Therefore it was decided to calculate the plume resulting from each of three different size fractions and sum the individual concentrations to get the overall plume.

The final solution involved three size fractions; sand, silt and clay. The proportion of each fraction was determined by knowing the size analysis at a point in the plume and the concentration of total solids in the plume at various locations. Table 4-1 shows that the silt/clay ratio was approximately 25:75 at a point in the plume.

Figure 4-8 shows a suspended solids concentration of approximately 45 mg/l at the end of the plume. Assuming no clay settled out of the plume over the short length of the measured plume, the initial clay concentration was calculated to be approximately 35 mg/l or 30% of the initial suspended solids concentration. The proportion of sand was determined from Figure 4-8. The initial suspended solids concentration was approximately 112 mg/l and the suspended solids concentration at 100 m was approximately 60 mg/l. Assuming all of the sand had settled in the first 100 m and that little of the silt and clay had been removed, gave an initial sand concentration of 52 mg/l or approximately 45% of the initial suspended solids. The remaining 25% of the initial suspended solids was assumed to be the silt fraction. Thus, the composition of the suspended solids at the plume source was approximately 45% sand, 25% silt and 30% clay.

The settling velocity for each of these fractions was estimated from Appendix D and from the size analysis of the material entering the plume, Figure B-9, Appendix B. The mean diameter of the sand fraction was determined to be 0.26 mm, corresponding to a settling velocity of 0.02 m/sec. The silt fraction mean particle size was 0.026 mm with a settling velocity of 0.003 m/sec. The settling velocity of the clay fraction was chosen as 0.000001 m/s.

The following parameters were used as input to solve the model for the Rock Island simulation:

$b = 25$ m

$D = 2$ m

$u_x = 0.4$ m/s

$K_y = 0.03$ m^2/s

$W_{sand} = 0.02$ m/s

$W_{silt} = 0.003$ m/s

$W_{clay} = 0.000001$ m/s

$\frac{Q_o C_o}{Q_b} = 112$ mg/l

where $\frac{Q_o C_o}{Q_b}$ is the concentration of suspended material at x = 0.

These values are used in Equation 3.24 to simulate the plume.

$$\frac{Q_b}{Q_o C_o} \; C\,(y,x) = \left[F \left(\frac{y + b}{\sigma_y}\right) - F\left(\frac{y - b}{\sigma_y}\right)\right] \exp\left[-\frac{Wx}{Du_x}\right] \qquad (3.24)$$

The method of solution to Equation 3.24 follows.

(1) Choose a distance, x, downstream from the source. For example, choose 50 m.

(2) Calculate the value of the exponential term.

$$\exp\left[-\frac{Wx}{Du_x}\right] = \exp\left[-\frac{(0.02 \text{ m/s})(50 \text{ m})}{(2 \text{ m})(0.4 \text{ m/s})}\right] = 0.287$$

(3) Choose value of y/σ_y. This value corresponds to the distance from the plume centerline, y. The plume centerline, y = 0, is defined as the shoreline along which the plume develops. To calculate the centerline concentration, $y/\sigma_y = 0$.

(4) Calculate the value of σ_y.

$$\sigma_y = \sqrt{2K_y \; x/u_x} = \sqrt{2\left(0.03 \; \frac{\text{m}^2}{\text{sec}}\right)\left(\frac{50 \text{ m}}{0.4 \text{ m/s}}\right)} = 2.75 \text{ m.}$$

(5) Calculate the distance from the centerline, y.

$$y = \left(\frac{y}{\sigma_y}\right)\left(\sigma_y\right) = (0)\ (2.75\ m) = 0\ m.$$

(6) Calculate the value b/σ_y.

$$\frac{b}{\sigma_y} = \frac{25\ m}{2.75\ m} = 9.09$$

(7) Calculate the value $\frac{y+b}{\sigma_y}$.

$$\frac{y+b}{\sigma_y} = \frac{y}{\sigma_y} + \frac{b}{\sigma_y} = 0 + 9.09 = 9.09.$$

(8) Calculate the value $\frac{y-b}{\sigma_y}$.

$$\frac{y-b}{\sigma_y} = \frac{y}{\sigma_y} - \frac{b}{\sigma_y} = 0 - 9.09 = -9.09.$$

(9) Determine $F\left(\frac{y+b}{\sigma_y}\right)$ and $F\left(\frac{y-b}{\sigma_y}\right)$ from a table of the cumulative normal distribution function. This table is included as Appendix C.

$$F\ (9.09) = 1.0$$

$$F\ (-9.09) = 0.0$$

(10) Insert values calculated in steps 2 and 10 into Equation 3.24 to calculate the proportion of chosen size fraction remaining in the plume at point (y,x).

$$\frac{Q_b}{Q_o C_o}\ C\ (y,x) = (1.0 - 0.0)\ (0.287) = 0.287.$$

(11) Calculate the initial concentration of the sediment fraction chosen.

$$\left[\frac{Q_o C_o}{Q_b}\right]\left[\%\text{ sediment chosen}\right] = (112\text{ mg/l})(0.45\text{ sand})$$
$$= 50.4\text{ mg/l sand}$$

(12) Calculate the concentration of the chosen sediment fraction at point (y,x).

C (y,x) = (50.4 mg/l)(0.287) = 14.5 mg/l

(13) Repeat steps 3 through 12 for a sufficient number of values of y/σ_y to determine the concentration of the chosen sediment fraction in the plume cross-section at distance x.

(14) Repeat steps 2 through 13 for the various sediment fractions.

(15) Sum the values calculated in step 12 for each point (y,x) to determine the overall suspended solids concentration at point (y,x).

(16) Repeat steps 1 through 15 for sufficient number of values of x to determine the dimensions of the plume and the concentrations in the plume.

The simulated suspended solids plume calculated for the Rock Island, Illinois site is shown in Table 5-3.

Figures 5-5, 5-6 and 5-7 all show the simulated suspended solids plume. Figure 5-5 shows the plume superimposed on the field data. Figures 5-6 and 5-7 show the simulated plume to a distance of 10,000 meters for different values of K_y. Figure 5-6 is for K_y = 300 cm^2/sec.,

x (m)	$\frac{y}{\sigma_y}$	$\frac{y+b}{\sigma_y}$	$\frac{y-b}{\sigma_y}$	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	SAND Fraction Remaining	SAND C (y,x) (mg/l)	SILT Fraction Remaining	SILT C (y,x) (mg/l)	CLAY Fraction Remaining	CLAY C (y,x) (mg/l)	Total Solids in Plume C (y,x) (mg/l)
50	0	9.086	-9.086	0.0	1.0	0.0	0.283	14.3	0.981	27.5	1.000	33.6	75.4
	6	15.086	-3.086	16.5	1.0	0.0010	0.283	14.3	0.980	27.4	0.999	33.6	75.3
	7	16.086	-2.086	19.3	1.0	0.0185	0.278	14.0	0.963	27.0	0.981	33.0	74.0
	8	17.086	-1.086	22.0	1.0	0.1388	0.244	12.3	0.845	23.7	0.861	28.9	64.9
	9	18.086	-0.086	24.8	1.0	0.4657	0.151	7.6	0.524	14.7	0.534	17.9	40.2
	10	19.086	0.914	27.5	1.0	0.8196	0.051	2.6	0.177	5.0	0.180	6.0	13.6
	11	20.086	1.914	30.3	1.0	0.9722	0.008	0.4	0.027	0.8	0.028	0.9	2.1
	12	21.086	2.914	33.0	1.0	0.9982	0.001	0.0	0.002	0.0	0.002	0.1	0.1
100	0	6.425	-6.425	0.0	1.0	0.0	0.080	4.0	0.963	27.0	1.000	33.6	64.6
	3	9.425	-3.425	11.7	1.0	0.0003	0.080	4.0	0.963	27.0	1.000	33.6	64.6
	4	10.425	-2.425	15.6	1.0	0.0076	0.080	4.0	0.956	26.8	0.992	33.3	64.1
	5	11.425	-1.425	19.4	1.0	0.0771	0.074	3.7	0.889	24.9	0.923	31.0	59.6
	6	12.425	-0.425	23.3	1.0	0.3352	0.053	2.7	0.640	17.9	0.665	22.3	42.9

Table 5-3. Simulated suspended solids plume for Rock Island, Illinois site.

x (m)	$\frac{y}{\sigma_y}$	$\frac{y+b}{\sigma_y}$	$\frac{y-b}{\sigma_y}$	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	SAND Fraction Remaining	SAND C (y,x) (mg/l)	SILT Fraction Remaining	SILT C (y,x) (mg/l)	CLAY Fraction Remaining	CLAY C (y,x) (mg/l)	Total Solids in Plume C (y,x) (mg/l)
100	7	13.425	0.575	27.2	1.0	0.7173	0.023	1.2	0.272	7.6	0.283	9.5	18.3
	8	14.425	1.575	31.1	1.0	0.9424	0.005	0.2	0.055	1.5	0.058	1.9	3.6
	9	15.425	2.575	35.0	1.0	0.9950	0.000	0.0	0.005	0.1	0.005	0.2	0.3
200	0	4.543	-4.543	0.0	1.0	0.0	0.006	0.3	0.927	26.0	1.000	33.6	59.9
	1	5.543	-3.543	5.5	1.0	0.0002	0.006	0.3	0.927	26.0	1.000	33.6	59.9
	2	6.543	-2.543	11.0	1.0	0.0055	0.006	0.3	0.922	25.8	0.994	33.4	59.5
	3	7.543	-1.543	16.5	1.0	0.0614	0.006	0.3	0.870	24.4	0.938	31.5	56.2
	4	8.543	-0.543	22.0	1.0	0.2936	0.005	0.2	0.655	18.3	0.706	23.7	42.2
	5	9.543	0.457	27.5	1.0	0.6761	0.002	0.1	0.300	8.4	0.324	10.9	19.4
	6	10.543	1.457	33.0	1.0	0.9275	0.000	0.0	0.067	1.9	0.072	2.4	4.3
	7	11.543	2.457	38.5	1.0	0.9930	0.000	0.0	0.006	0.2	0.007	0.2	0.4
300	0	3.709	-3.709	0.0	0.9999	0.0001	0.0	0.0	0.892	25.0	0.999	33.6	58.6
	1	4.709	-2.709	6.7	1.0	0.0034	0.0	0.0	0.890	24.9	0.996	33.5	58.4

Table 5-3 (continued).

x (m)	$\frac{y}{\sigma_y}$	$\frac{y+b}{\sigma_y}$	$\frac{y-b}{\sigma_y}$	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	SAND Fraction Remaining	SAND C (y,x) (mg/l)	SILT Fraction Remaining	SILT C (y,x) (mg/l)	CLAY Fraction Remaining	CLAY C (y,x) (mg/l)	Total Solids in Plume C (y,x) (mg/l)
300	2	5.709	-1.709	13.5	1.0	0.0437	0.0	0.0	0.854	23.9	0.956	32.1	56.0
	3	6.709	-0.709	20.2	1.0	0.2392	0.0	0.0	0.679	19.0	0.761	25.6	44.6
	4	7.709	0.291	27.0	1.0	0.6145	0.0	0.0	0.344	9.6	0.385	12.9	22.5
	5	8.709	1.291	33.7	1.0	0.9017	0.0	0.0	0.088	2.5	0.098	3.3	5.8
	6	9.709	2.291	40.4	1.0	0.9890	0.0	0.0	0.010	0.3	0.011	0.4	0.7
	7	10.709	3.291	47.2	1.0	0.9995	0.0	0.0	0.000	0.0	0.000	0.0	0.0
400	0	3.212	-3.212	0.0	0.9993	0.0007	0.0	0.0	0.858	24.0	0.998	33.5	57.5
	1	4.212	-2.212	7.8	1.0	0.0135	0.0	0.0	0.848	23.7	0.986	33.1	56.8
	2	5.212	-1.212	15.6	1.0	0.1127	0.0	0.0	0.763	21.4	0.887	29.8	51.2
	3	6.212	-0.212	23.3	1.0	0.4160	0.0	0.0	0.502	14.1	0.584	19.6	33.7
	4	7.212	0.788	31.1	1.0	0.7817	0.0	0.0	0.188	5.3	0.219	7.4	12.9
	5	8.212	1.788	38.9	1.0	0.9631	0.0	0.0	0.032	0.9	0.037	1.2	2.1
	6	9.212	2.788	46.7	1.0	0.9974	0.0	0.0	0.002	0.1	0.003	0.1	0.2

Table 5-3 (continued).

x (m)	$\frac{y}{\sigma_y}$	$\frac{y+b}{\sigma_y}$	$\frac{y-b}{\sigma_y}$	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	SAND Fraction Remaining	SAND C (y,x) (mg/l)	SILT Fraction Remaining	SILT C (y,x) (mg/l)	CLAY Fraction Remaining	CLAY C (y,x) (mg/l)	Total Solids in Plume C (y,x) (mg/l)
500	0	2.873	-2.873	0.0	0.9979	0.0021	0.0	0.0	0.824	23.1	0.995	33.4	56.5
	1	3.873	-1.873	8.7	0.9999	0.0305	0.0	0.0	0.802	22.5	0.969	32.6	55.1
	2	4.873	-0.873	17.4	1.0	0.1914	0.0	0.0	0.669	18.7	0.808	27.1	45.8
	3	5.873	0.127	26.1	1.0	0.5505	0.0	0.0	0.372	10.4	0.449	15.1	25.5
	4	6.873	1.127	34.8	1.0	0.8701	0.0	0.0	0.107	3.0	0.130	4.4	7.4
	5	7.873	2.127	43.5	1.0	0.9833	0.0	0.0	0.014	0.4	0.017	0.6	1.0
	6	8.873	3.127	52.2	1.0	0.9991	0.0	0.0	0.001	0.0	0.001	0.0	0.0

Table 5-3 (continued).

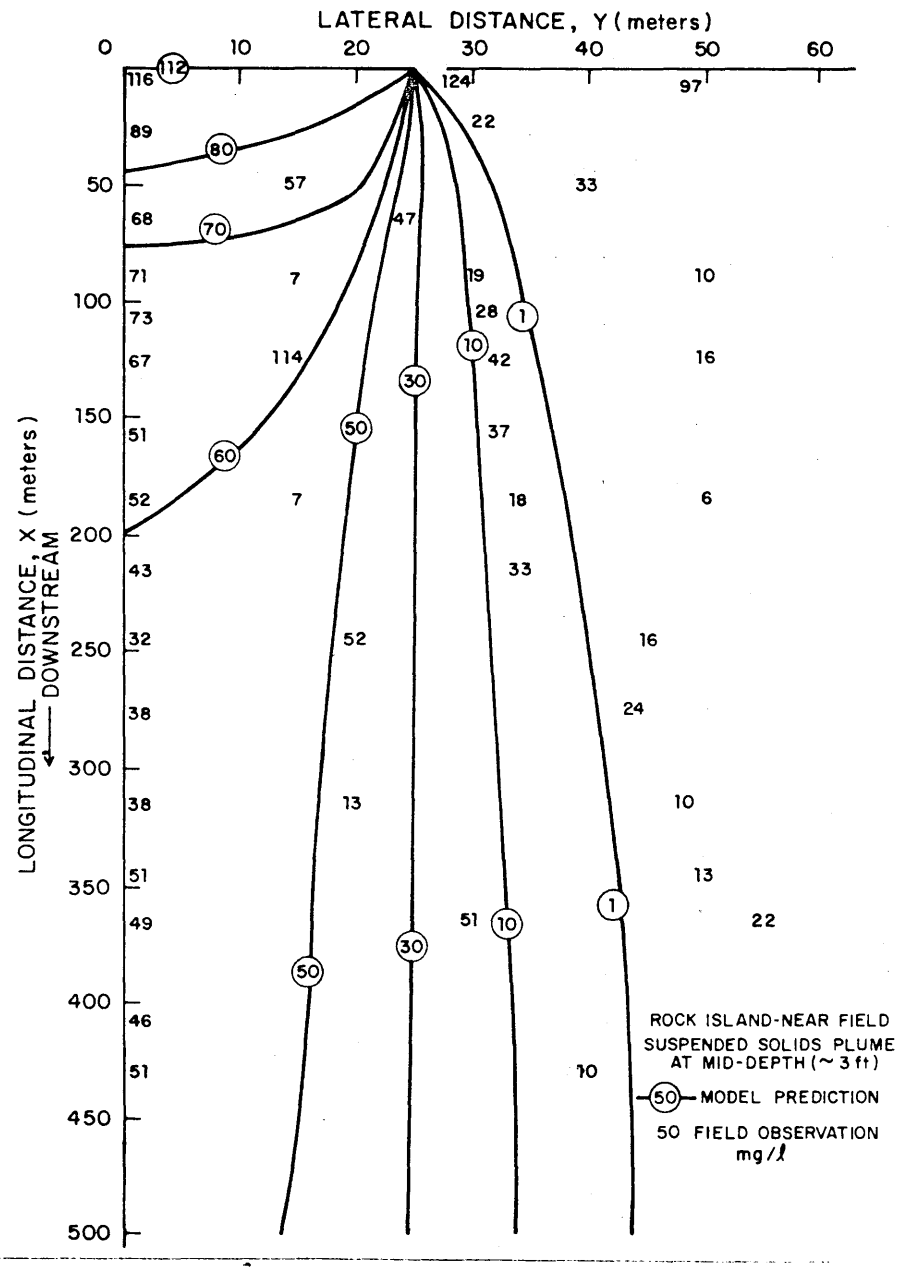


Figure 5-5. Simulated suspended solids plume for Rock Island, Illinois site superimposed on field data.

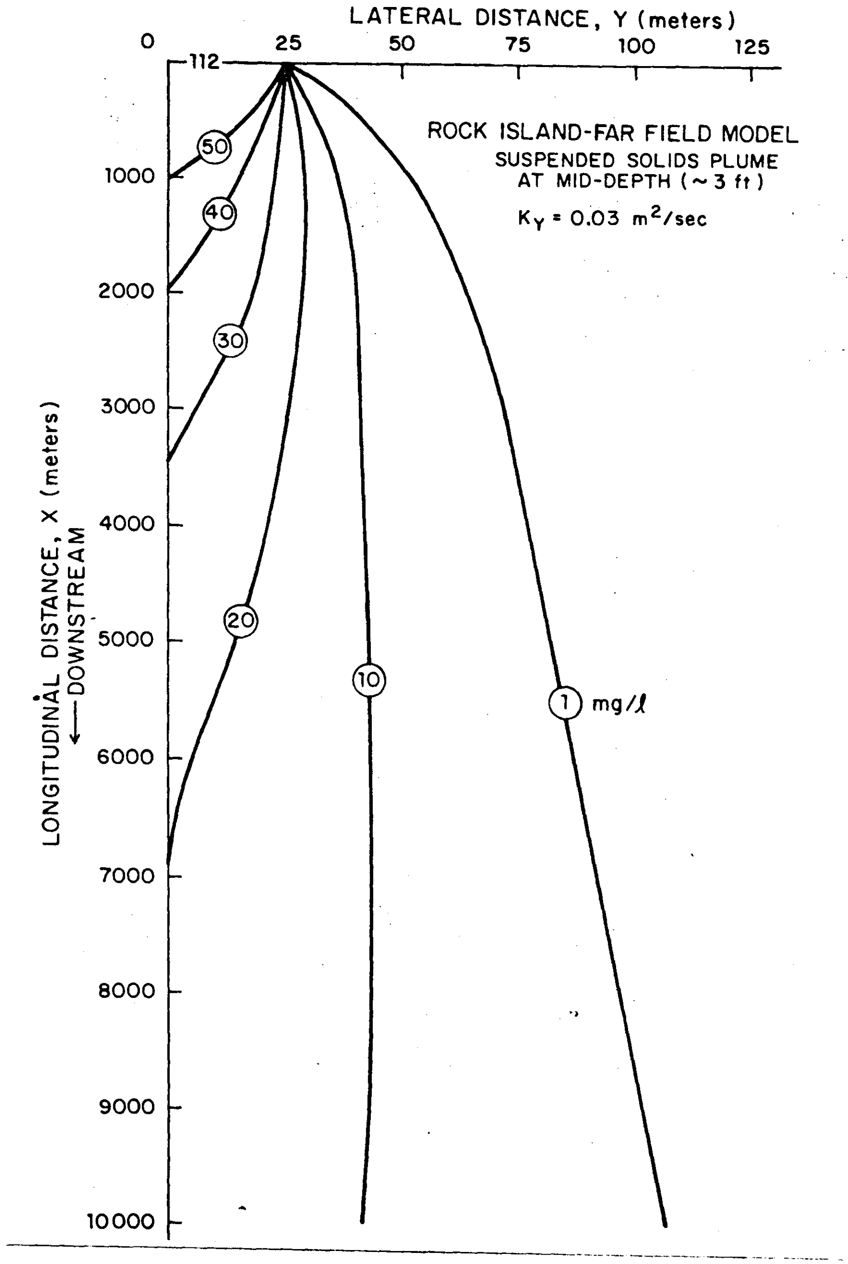


Figure 5-6. Far field suspended solids plume for Rock Island, Illinois site. K_y = 300 cm^2/sec.

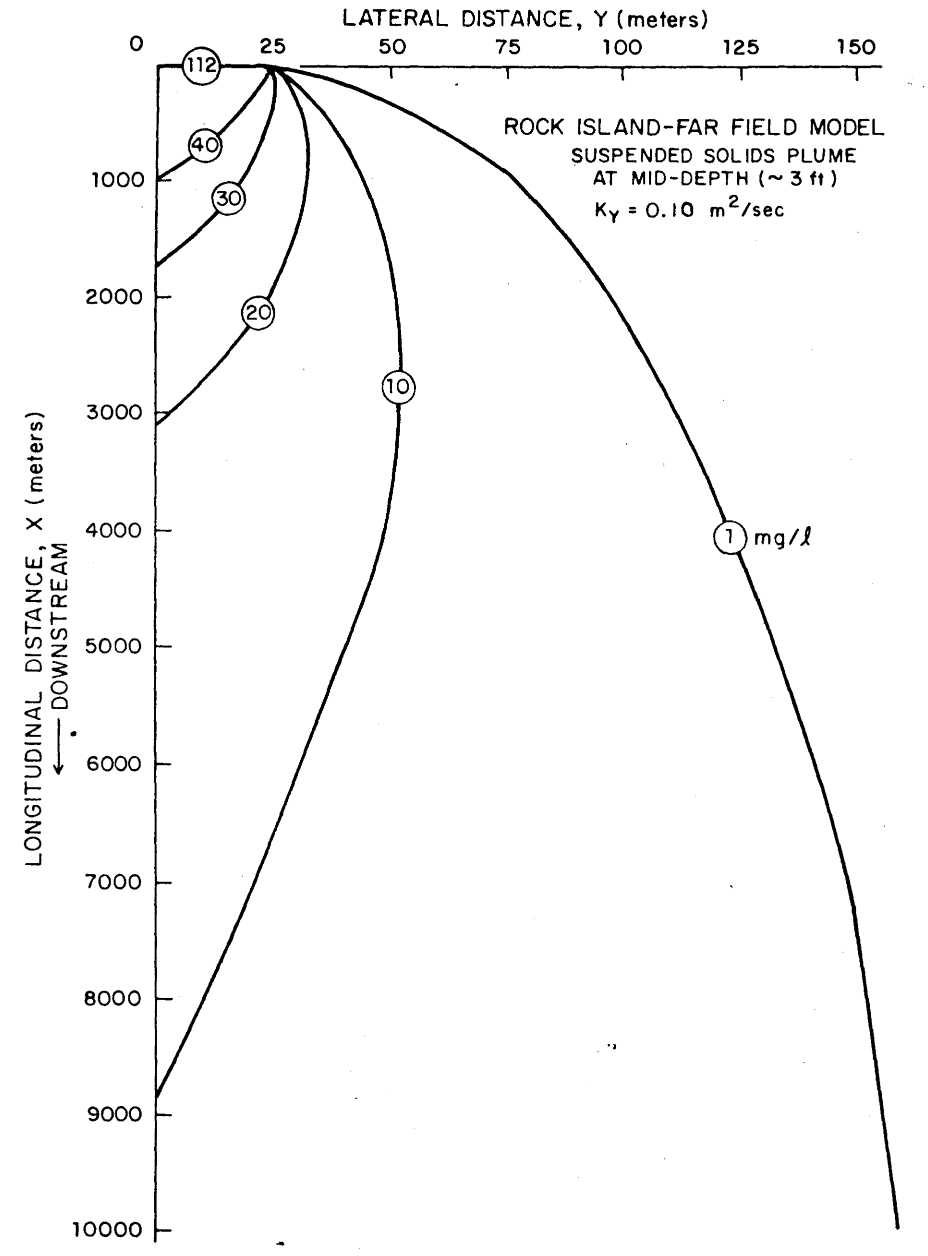


Figure 5-7. Far field suspended solids plume for Rock Island, Illinois site. K_y = 1000 cm^2/sec.

the same value used for Figure 5-5, while Figure 5-7 is for K_y = 1000 cm^2/sec. Since the far field plume was not measured during the field sampling, there is no basis for choosing either one as the correct plume. However the turbulence scale would increase as the lateral dimensions of the plume increases downstream, so one might expect an increase in K_y, the lateral dispersion coefficient.

Solution to Keithsburg, Illinois Plume

The observed suspended solids plume at Keithsburg, Illinois was quite different from the plume observed at Rock Island, Illinois. It can be seen from Figure 4-7 that the source width is much smaller; it was estimated to be 3 meters. Table 4-1 indicates that a very different sand:silt:clay ratio was measured at Keithsburg; approximately 2:67:31 at the head of the plume. Figure B-6 in Appendix B shows mean diamters for the particles to be; sand = 0.0086 cm and silt = 0.0017 cm. These correspond to settling velocities of 0.005 m/sec for sand and 0.00022 m/sec for silt. The settling velocity for clay was again chosen to be 1×10^{-6} m/sec. The stream velocity was measured to be 0.35 m/sec. The initial suspended solids concentration was estimated to be 75 mg/l from Figure 4-7. The parameters used as input to the model for the Keithsburg, Illinois simulation are summarized below.

$b = 3$ m

$D = 2$ m

$u_x = 0.35$ m/s

$K_y = 0.03\ m^2/s$

$W_{sand} = 0.005\ m/s$

$W_{silt} = 0.00022\ m/s$

$W_{clay} = 0.000001\ m/s$

$$\frac{Q_o C_o}{Q_b} = 75\ mg/l$$

The simulated suspended solids plume for Keithsburg, Illinois is shown in Table 5-4. Figure 5-8 shows this model plume superimposed on the field data while Figure 5-9 shows this same plume in the far field. Figure 5-10 shows what the far-field plume might look like if $K_y = 1000\ cm^2/sec$. Again, the far-field plume was not measured in the field so it can not be determined which plume, Figure 5-9 or Figure 5-10 is more correct.

Discussion of the Analytical Model

Inspection of the plumes generated by the model (Figures 5-5 through 5-10) yield several physical parameters that can be estimated by solving the model for a particular dredge disposal operation. Some of these parameters are, the plume centerline suspended solids concentration, the lateral suspended solids concentrations, the amount of solids being deposited at some point in the receiving river, the dilution volume for dissolved substances, and the maximum length of the plume.

The model does a good job of predicting the centerline (near bank) suspended solids concentration. Figure 5-11 and Figure 5-12 show the

x (m)	$\frac{y}{\sigma_y}$	$\frac{y+b}{\sigma_y}$	$\frac{y-b}{\sigma_y}$	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	SAND		SILT		CLAY		Total Solids in Plume C (y,x) (mg/l)
							Fraction Remaining	C (y,x) (mg/l)	Fraction Remaining	C (y,x) (mg/l)	Fraction Remaining	C (y,x) (mg/l)	
20	0.0	1.620	-1.620	0.0	0.9474	0.0526	0.776	1.2	0.889	44.7	0.895	20.8	66.7
	0.5	2.120	-1.120	0.9	0.9830	0.1314	0.738	1.1	0.846	42.5	0.852	19.8	63.4
	1.0	2.620	-0.620	1.8	0.9956	0.2676	0.631	0.9	0.723	36.3	0.728	16.9	54.1
	1.5	3.120	-0.120	2.8	0.9991	0.4522	0.474	0.7	0.543	27.3	0.547	12.7	40.7
	2.0	3.620	0.380	3.7	0.9998	0.6480	0.303	0.4	0.350	17.6	0.352	8.2	26.2
	2.5	4.120	0.880	4.6	1.0	0.8106	0.164	0.2	0.188	9.4	0.189	4.4	14.0
	3.0	4.620	1.380	5.6	1.0	0.9162	0.073	0.1	0.083	4.2	0.084	2.0	6.3
	3.5	5.120	1.880	6.5	1.0	0.9699	0.026	0.0	0.030	1.5	0.030	0.7	2.2
	4.0	5.620	2.380	7.4	1.0	0.9913	0.008	0.0	0.009	0.5	0.009	0.2	0.7
	4.5	6.120	2.880	8.3	1.0	0.9980	0.002	0.0	0.002	0.1	0.002	0.0	0.1
40	0.0	1.146	-1.146	0.0	0.8741	0.1259	0.562	0.8	0.739	37.1	0.748	17.4	55.3
	0.5	1.646	-0.646	1.3	0.9501	0.2591	0.519	0.8	0.682	34.3	0.691	16.1	51.2

Table 5-4. Simulated suspended solids plume for Keithsburg, Illinois site.

x (m)	$\frac{y}{\sigma_y}$	$\frac{y+b}{\sigma_y}$	$\frac{y-b}{\sigma_y}$	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	SAND Fraction Remaining	SAND C (y,x) (mg/l)	SILT Fraction Remaining	SILT C (y,x) (mg/l)	CLAY Fraction Remaining	CLAY C (y,x) (mg/l)	Total Solids in Plume C (y,x) (mg/l)
40	1.0	2.146	-0.146	2.6	0.9840	0.4420	0.407	0.6	0.535	26.9	0.542	12.6	40.1
	1.5	2.646	0.354	3.9	0.9960	0.6383	0.269	0.4	0.353	17.7	0.358	8.3	26.4
	2.0	3.146	0.854	5.2	0.9992	0.8034	0.142	0.2	0.186	9.3	0.189	4.4	13.9
	2.5	3.646	1.354	6.5	0.9998	0.9121	0.066	0.1	0.087	4.4	0.088	2.0	6.5
	3.0	4.146	1.854	7.8	1.0	0.9681	0.024	0.0	0.032	1.6	0.032	0.7	2.3
	3.5	4.646	2.354	9.2	1.0	0.9907	0.007	0.0	0.009	0.5	0.009	0.2	0.7
	4.0	5.146	2.854	10.5	1.0	0.9978	0.002	0.0	0.002	0.1	0.002	0.0	0.1
80	0.0	0.810	-0.810	0.0	0.7910	0.2190	0.323	0.5	0.558	28.0	0.572	13.3	41.8
	0.5	1.310	-0.310	1.8	0.9049	0.3783	0.297	0.4	0.514	25.8	0.527	12.3	38.5
	1.0	1.810	0.190	3.7	0.9649	0.5753	0.220	0.3	0.380	19.1	0.390	9.1	28.5
	1.5	2.310	0.690	5.6	0.9896	0.7549	0.133	0.2	0.229	11.5	0.235	5.5	17.2
	2.0	2.810	1.190	7.4	0.9975	0.8830	0.065	0.1	0.112	5.6	0.115	2.7	8.4

Table 5-4 (continued).

x (m)	$\frac{y}{\sigma_y}$	$\frac{y+b}{\sigma_y}$	$\frac{y-b}{\sigma_y}$	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	SAND Fraction Remaining	SAND C (y,x) (mg/l)	SILT Fraction Remaining	SILT C (y,x) (mg/l)	CLAY Fraction Remaining	CLAY C (y,x) (mg/l)	Total Solids in Plume C (y,x) (mg/l)
80	2.5	3.310	1.690	9.2	0.9995	0.9545	0.025	0.0	0.045	2.3	0.045	1.0	3.3
	3.0	3.810	2.190	11.1	0.9999	0.9857	0.008	0.0	0.014	0.7	0.014	0.3	1.0
	3.5	4.310	2.690	13.0	1.0	0.9964	0.002	0.0	0.004	0.2	0.004	0.1	0.3
120	0.0	0.661	-0.661	0.0	0.7457	0.2543	0.209	0.3	0.473	23.8	0.491	11.4	35.5
	0.5	1.161	-0.161	2.3	0.8772	0.4360	0.187	0.3	0.425	21.4	0.441	10.3	32.0
	1.0	1.661	0.339	4.5	0.9516	0.6327	0.135	0.2	0.307	15.4	0.319	7.4	23.0
	1.5	2.161	0.839	6.8	0.9846	0.7992	0.079	0.1	0.179	9.0	0.185	4.3	13.4
	2.0	2.661	1.339	9.1	0.9961	0.9097	0.037	0.0	0.083	4.2	0.086	2.0	6.2
	2.5	3.161	1.839	11.3	0.9992	0.9670	0.014	0.0	0.031	1.6	0.032	0.7	2.3
	3.0	3.661	2.339	13.6	0.9998	0.9904	0.004	0.0	0.009	0.5	0.009	0.2	0.7
	3.5	4.161	2.839	15.9	1.0	0.9977	0.001	0.0	0.002	0.1	0.002	0.0	0.1

Table 5-4 (continued).

x (m)	$\frac{y}{\sigma_y}$	$\frac{y+b}{\sigma_y}$	$\frac{y-b}{\sigma_y}$	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	SAND Fraction Remaining	SAND C (y,x) (mg/l)	SILT Fraction Remaining	SILT C (y,x) (mg/l)	CLAY Fraction Remaining	CLAY C (y,x) (mg/l)	Total Solids in Plume C (y,x) (mg/l)
160	0.0	0.573	-0.573	0.0	0.7167	0.2833	0.138	0.2	0.412	20.7	0.433	10.1	31.0
	0.5	1.073	-0.073	2.6	0.8580	0.4709	0.123	0.2	0.368	18.5	0.387	9.0	27.7
	1.0	1.573	0.427	5.2	0.9421	0.6653	0.088	0.1	0.263	13.2	0.277	6.4	19.7
	1.5	2.073	0.927	7.8	0.9809	0.8230	0.050	0.1	0.158	7.9	0.158	3.7	11.7
	2.0	2.573	1.427	10.5	0.9949	0.9232	0.023	0.0	0.068	3.4	0.072	1.7	5.1
	2.5	3.073	1.927	13.1	0.9989	0.9730	0.008	0.0	0.025	1.3	0.026	0.6	1.9
	3.0	3.573	2.427	15.7	0.9998	0.9924	0.002	0.0	0.007	0.4	0.007	0.2	0.6
	3.5	4.073	2.927	18.3	1.0	0.9983	0.001	0.0	0.002	0.1	0.002	0.0	0.1

Table 5-4 (continued).

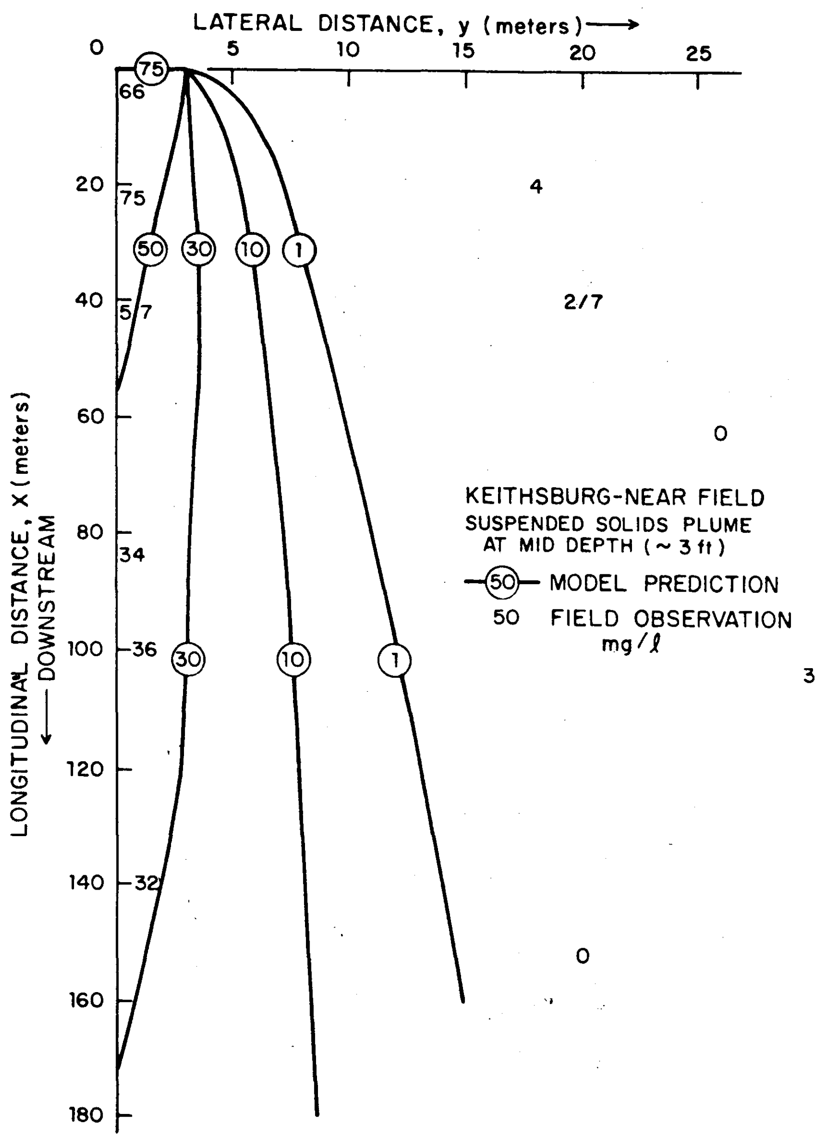


Figure 5-8. Simulated suspended solids plume for Keithsburg, Illinois site superimposed on field data.

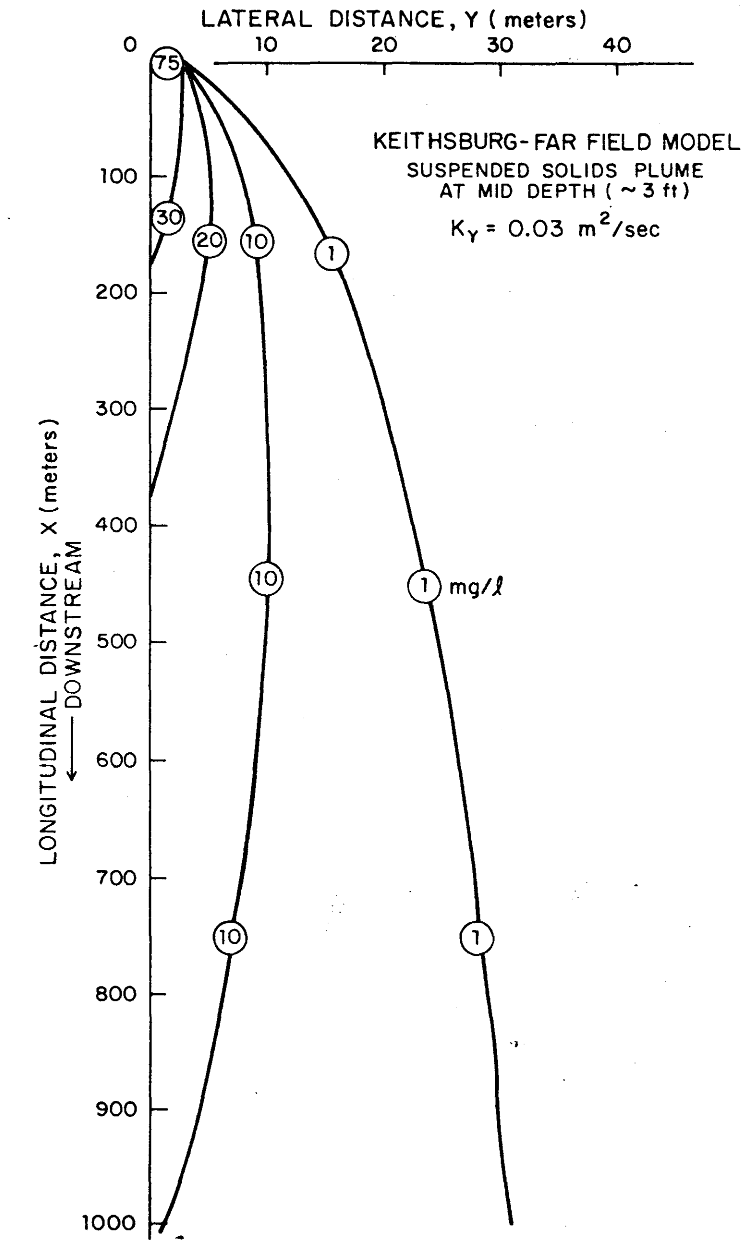


Figure 5-9. Far field suspended solids plume for Keithsburg, Illinois site. K_y = 300 cm^2/sec.

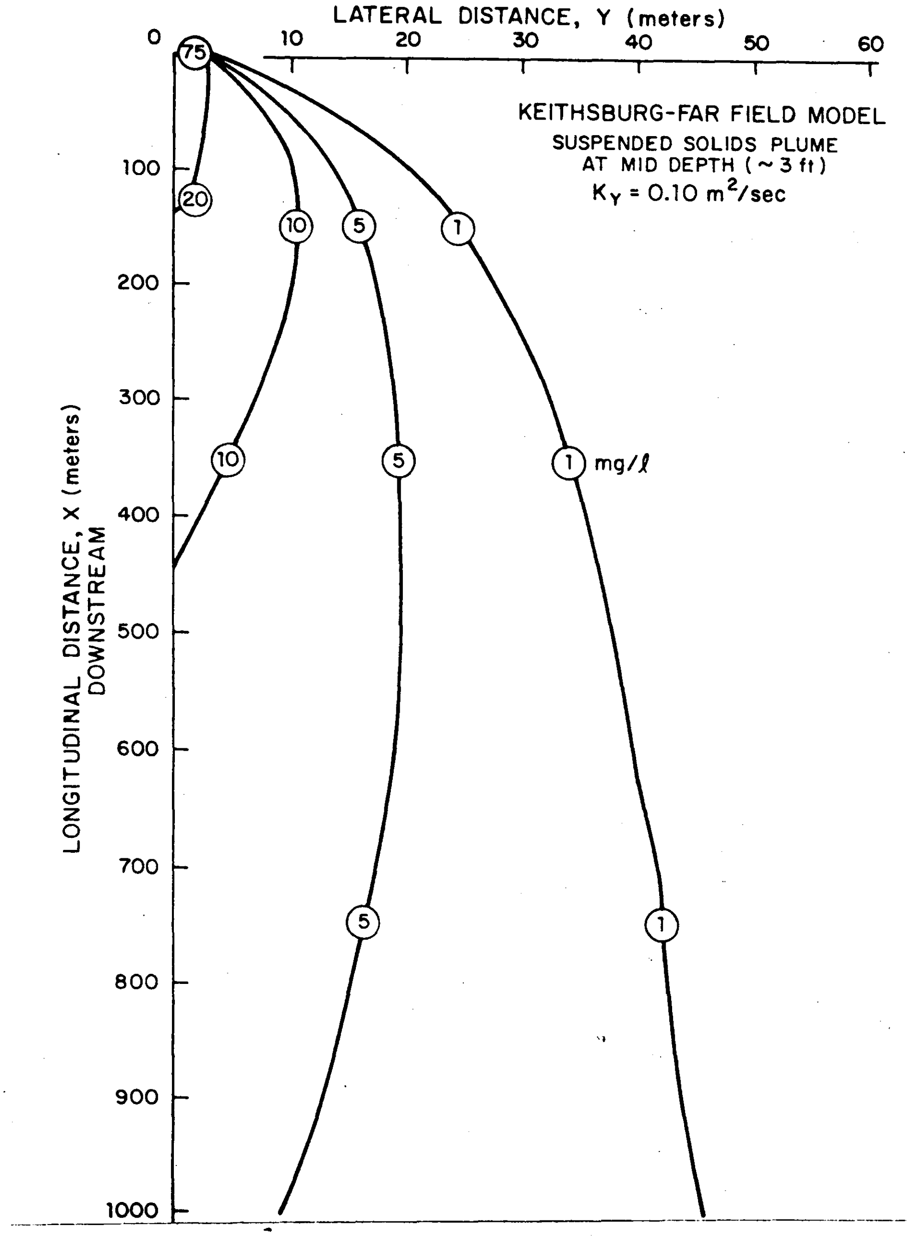


Figure 5-10. Far field suspended solids plume for Keithsburg, Illinois site. K_y = 1000 cm^2/sec.

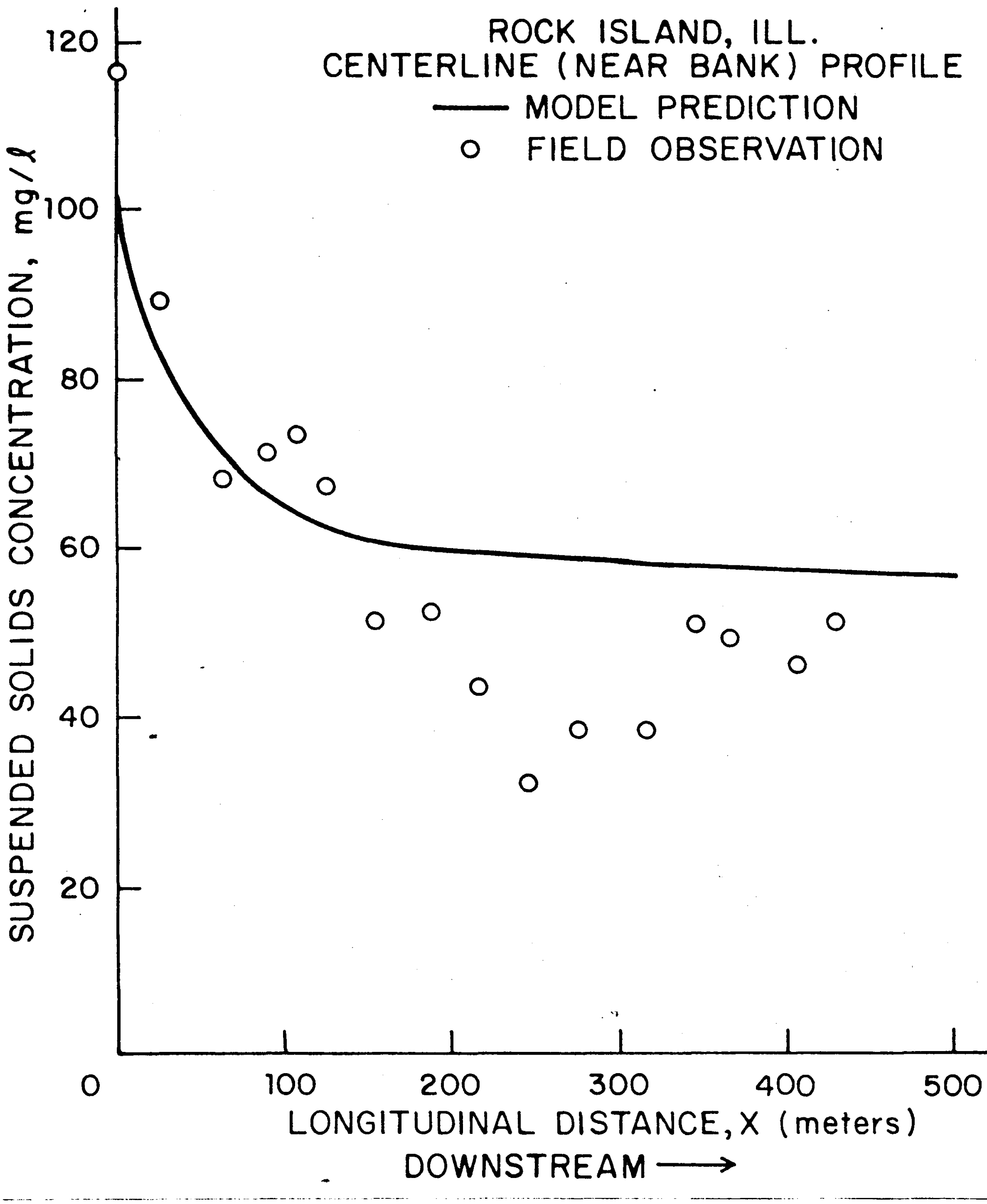


Figure 5-11. Model prediction vs. field observation for centerline Rock Island site.

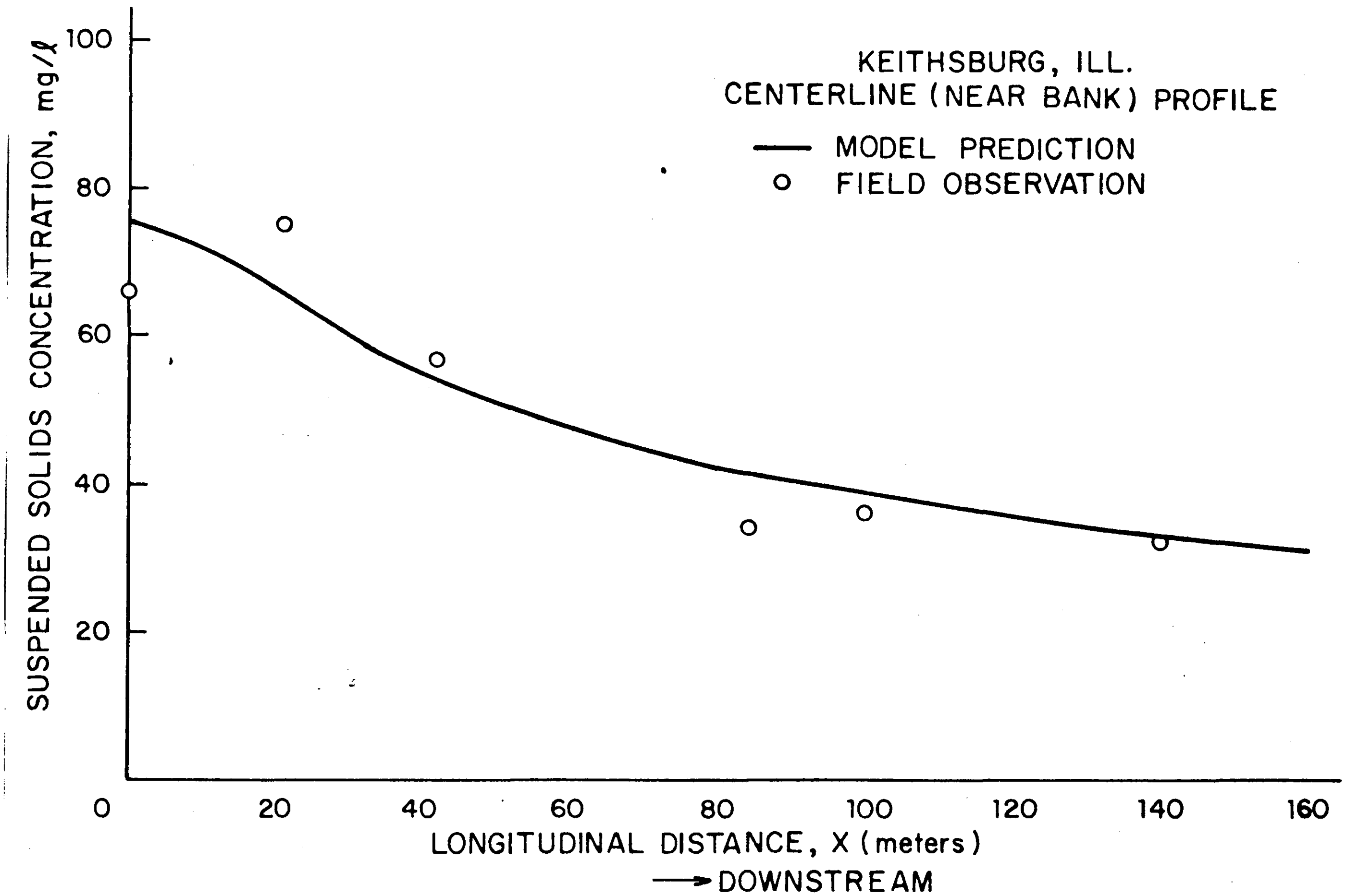


Figure 5-12. Model prediction vs. field observation for centerline Keithsburg site.

suspended solids concentration predicted and observed as a function of downstream distance for the Rock Island and Keithsburg sites, respectively. Figure 5-11 shows good agreement between the predicted and observed suspended solids concentrations for the first 150 meters downstream. The low field measurements observed between 150 and 350 meters are assumed to be due to an extended period of dredging in an area of deep water, hence, lower than normal solids concentration being discharged from the dredge. At the end of the observed plume, there is about a 5 mg/l difference between the observed concentration and the predicted concentration. Figure 5-12 shows excellent agreement between the observed and the predicted suspended solids concentration at Keithsburg.

The model is less successful in predicting the degree of lateral dispersion. It can be seen in Figure 5-5 for Rock Island that considerable suspended solids concentrations were observed beyond the 10 mg/l and 1 mg/l isopleths predicted by the model. It can also be seen that there were few samples taken inside the area bounded by the 10 mg/l predicted isopleth, and that those samples that were taken show a great deal of variability with no smooth concentration gradient.

In Figure 5-8 for Keithsburg, no samples were taken within the predicted plume at any point other than the centerline. Those samples taken beyond the predicted plume show no excess suspended solids in the stream resulting from dredge disposal.

In order to assess the effect of dredge spoils disposal on the benthic community, the amount of dredged material deposited on the bottom must be calculated. This can be readily calculated with the known parameters and the predicted suspended solids plume.

At steady state, the rate of solids deposition at any point in the plume is:

$$\text{Deposition Rate} = C\ (y,x)\ K_s D \tag{5.13}$$

where C (y,x) is the mean suspended solids concentration at the point (y,x), K_s is the settling rate constant and D is the depth. The settling rate constant can be calculated by $^W/_D$, where W is the settling velocity and D is the depth. The solids deposition rate can now be expressed:

$$\text{Deposition Rate} = C\ (y,x)\ W \tag{5.14}$$

Equation 5.14 is solved for each sediment fraction and the results are summed for the total solids deposition rate. The concentration of each sediment fraction at many points in the plume is given in Table 5-3 for Rock Island and Table 5-4 for Keithsburg. Multiplying these concentrations by their respective settling velocities gives the deposition rate for that sediment fraction. The results of this calculation are given in Table 5-5 and Figure 5-13 for Rock Island and Table 5-6 and Figure 5-14 for Keithsburg.

To determine the total mass of solids deposited at any point, multiply the deposition rate at that point by the time of operation of the dredge. The depth of solids deposited at any point can then be calculated by assuming a solids density and a percent solids. The depth of solids deposited at all points in the plume at Rock Island is

x (m)	SAND C (y,x) (mg/l)	SAND Deposition Rate (mg/m²-sec)	SILT C (y,x) (mg/l)	SILT Deposition Rate (mg/m²-sec)	CLAY C (y,x) (mg/l)	CLAY Deposition Rate (mg/m²-sec)	y (m)	Total Solids Deposition Rate (mg/m²-sec)
50	14.3	286.0	27.5	82.5	33.6	0.0	0.0	386.5
	14.3	286.0	27.4	82.2	33.6	0.0	16.5	386.3
	14.0	280.0	27.0	81.0	33.0	0.0	19.3	361.0
	12.3	246.0	23.7	71.1	28.9	0.0	22.0	317.1
	7.6	152.0	14.7	44.1	17.9	0.0	24.8	196.1
	2.6	52.0	5.0	15.0	6.0	0.0	27.5	67.0
	0.4	8.0	0.8	2.4	0.9	0.0	30.3	10.4
	0.0	0.0	0.0	0.0	0.1	0.0	33.0	0.0
100	4.0	80.0	27.0	81.0	33.6	0.0	0.0	161.0
	4.0	80.0	27.0	81.0	33.6	0.0	11.7	161.0
	4.0	80.0	26.8	80.4	33.3	0.0	15.6	160.4
	3.7	74.0	24.9	74.7	31.0	0.0	19.4	148.7

Table 5-5. Bottom sedimentation rate for Rock Island, Illinois site.

x (m)	SAND C (y,x) (mg/l)	SAND Deposition Rate (mg/m²-sec)	SILT C (y,x) (mg/l)	SILT Deposition Rate (mg/m²-sec)	CLAY C (y,x) (mg/l)	CLAY Deposition Rate (mg/m²-sec)	y (m)	Total Solids Deposition Rate (mg/m²-sec)
100	2.7	54.0	17.9	53.7	22.3	0.0	23.3	107.7
	1.2	24.0	7.6	22.8	9.5	0.0	27.2	46.8
	0.2	4.0	1.5	4.5	1.9	0.0	31.1	8.5
	0.0	0.0	0.1	0.3	0.2	0.0	35.0	0.3
200	0.3	6.0	26.0	78.0	33.6	0.0	0.0	84.0
	0.3	6.0	26.0	78.0	33.6	0.0	5.5	84.0
	0.3	6.0	25.8	77.4	33.4	0.0	11.0	83.4
	0.3	6.0	24.4	73.2	31.5	0.0	16.5	79.2
	0.2	4.0	18.3	54.9	23.7	0.0	22.0	58.9
	0.1	2.0	8.4	25.2	10.9	0.0	27.5	27.2
	0.0	0.0	1.9	5.7	2.4	0.0	33.0	5.7
	0.0	0.0	0.2	0.6	0.2	0.0	38.5	0.6

Table 5-5 (continued).

x (m)	SAND C (y,x) (mg/l)	SAND Deposition Rate (mg/m²-sec)	SILT C (y,x) (mg/l)	SILT Deposition Rate (mg/m²-sec)	CLAY C (y,x) (mg/l)	CLAY Deposition Rate (mg/m²-sec)	y (m)	Total Solids Deposition Rate (mg/m²-sec)
300	0.0	0.0	25.0	75.0	33.6	0.0	0.0	75.0
	0.0	0.0	24.9	74.7	33.5	0.0	6.7	74.7
	0.0	0.0	23.9	71.7	32.1	0.0	13.5	71.7
	0.0	0.0	19.0	57.0	25.6	0.0	20.2	57.0
	0.0	0.0	9.6	28.8	12.9	0.0	27.0	28.8
	0.0	0.0	2.5	7.5	3.3	0.0	33.7	7.5
	0.0	0.0	0.3	0.9	0.4	0.0	40.4	0.9
	0.0	0.0	0.0	0.0	0.0	0.0	47.2	0.0
400	0.0	0.0	24.0	72.0	33.5	0.0	0.0	72.0
	0.0	0.0	23.7	71.1	33.1	0.0	7.8	71.1
	0.0	0.0	21.4	64.2	29.8	0.0	15.6	64.2
	0.0	0.0	14.1	42.3	19.6	0.0	23.3	42.3

Table 5-5 (continued).

x (m)	SAND C (y,x) (mg/l)	SAND Deposition Rate (mg/m²-sec)	SILT C (y,x) (mg/l)	SILT Deposition Rate (mg/m²-sec)	CLAY C (y,x) (mg/l)	CLAY Deposition Rate (mg/m²-sec)	y (m)	Total Solids Desposition Rate (mg/m²-sec)
400	0.0	0.0	5.3	15.9	7.4	0.0	31.1	15.9
	0.0	0.0	0.9	2.7	1.2	0.0	38.9	2.7
	0.0	0.0	0.1	0.3	0.1	0.0	46.7	0.3
500	0.0	0.0	23.1	69.3	33.4	0.0	0.0	69.3
	0.0	0.0	22.5	67.5	32.6	0.0	8.7	67.5
	0.0	0.0	18.7	56.1	27.1	0.0	17.4	56.1
	0.0	0.0	10.4	31.2	15.1	0.0	26.1	31.2
	0.0	0.0	3.0	9.0	4.4	0.0	34.8	9.0
	0.0	0.0	0.4	1.2	0.6	0.0	43.5	1.2
	0.0	0.0	0.0	0.0	0.0	0.0	52.2	0.0

Table 5-5 (continued).

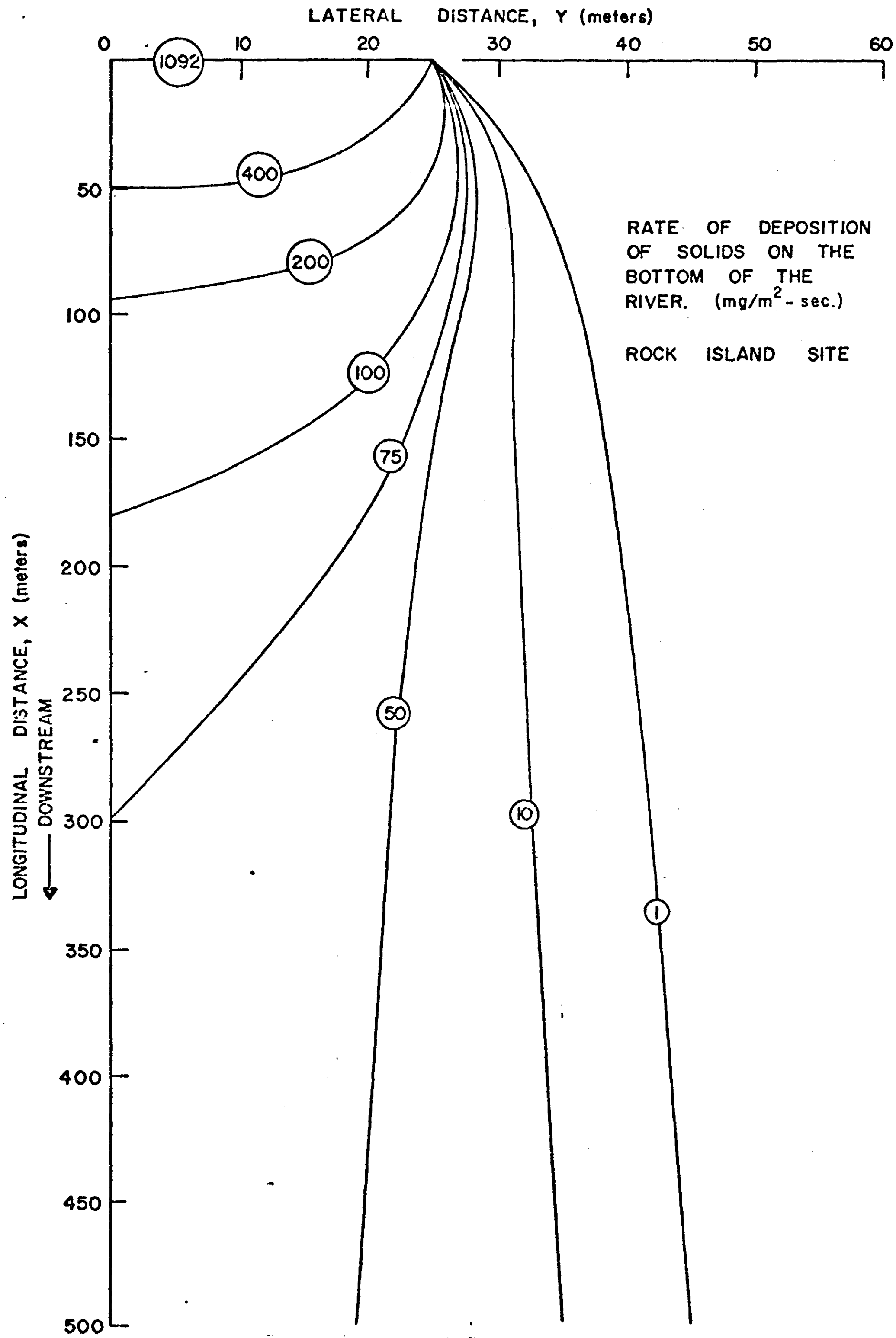


Figure 5-13. Deposition rate at all points in plume for Rock Island, Illinois.

x (m)	y (m)	SAND C (y,x) (mg/l)	SAND Deposition Rate (mg/m^2-sec)	SILT C (y,x) (mg/l)	SILT Deposition Rate (mg/m^2-sec)	Total Solids Deposition Rate (mg/m^2-sec)
20	0.0	1.2	6.0	44.7	9.8	12.0
	0.9	1.1	5.5	42.5	9.4	10.5
	1.8	0.9	4.5	36.3	8.0	8.9
	2.8	0.7	3.5	27.3	6.0	6.7
	3.7	0.4	2.0	17.6	3.9	4.3
	4.6	0.2	1.0	9.4	2.1	2.3
	5.6	0.1	0.5	4.2	0.9	1.0
	6.5	0.0	0.0	1.5	0.3	0.3
	7.4	0.0	0.0	0.5	0.1	0.1
	8.3	0.0	0.0	0.1	0.0	0.0
40	0.0	0.8	4.0	37.1	8.2	9.0
	1.3	0.8	4.0	34.3	7.5	8.3

Table 5-6. Bottom sedimentation rate for Keithsburg, Illinois site.

x (m)	y (m)	SAND C (y,x) (mg/l)	SAND Deposition Rate (mg/m^2-sec)	SILT C (y,x) (mg/l)	SILT Deposition Rate (mg/m^2-sec)	Total Solids Deposition Rate (mg/m^2-sec)
40	2.6	0.6	3.0	26.9	5.9	6.5
	3.9	0.4	2.0	17.7	3.9	4.3
	5.2	0.2	1.0	9.3	2.0	2.2
	6.5	0.1	0.5	4.4	1.0	1.1
	7.8	0.0	0.0	1.6	0.4	0.4
	9.2	0.0	0.0	0.5	0.1	0.1
	10.5	0.0	0.0	0.1	0.0	0.0
80	0.0	0.5	2.5	28.0	6.2	6.7
	1.8	0.4	2.0	25.8	5.7	6.1
	3.7	0.3	1.5	19.1	4.2	4.5
	5.6	0.2	1.0	11.5	2.5	2.7
	7.4	0.1	0.5	5.6	1.2	1.3

Table 5-6 (continued).

x (m)	y (m)	SAND C (y,x) (mg/l)	SAND Deposition Rate (mg/m²-sec)	SILT C (y,x) (mg/l)	SILT Deposition Rate (mg/m²-sec)	Total Solids Deposition Rate (mg/m²-sec)
80	9.2	0.0	0.0	2.3	0.5	0.5
	11.1	0.0	0.0	0.7	0.2	0.2
	13.0	0.0	0.0	0.2	0.0	0.0
120	0.0	0.3	1.5	23.8	5.2	6.7
	2.3	0.3	1.5	21.4	4.7	6.2
	4.5	0.2	1.0	15.4	3.4	4.4
	6.8	0.1	0.5	9.0	2.0	2.5
	9.1	0.0	0.0	4.2	0.9	0.9
	11.3	0.0	0.0	1.6	0.4	0.4
	13.6	0.0	0.0	0.5	0.1	0.1
	15.9	0.0	0.0	0.1	0.0	0.0

Table 5-6 (continued).

x (m)	y (m)	SAND C (y,x) (mg/l)	SAND Deposition Rate (mg/m^2-sec)	SILT C (y,x) (mg/l)	SILT Deposition Rate (mg/m^2-sec)	Total Solids Deposition Rate (mg/m^2-sec)
160	0.0	0.2	1.0	20.7	4.6	5.6
	2.6	0.2	1.0	18.5	4.1	5.1
	5.2	0.1	0.5	13.2	2.9	3.4
	7.8	0.1	0.5	7.9	1.7	2.2
	10.5	0.0	0.0	3.4	0.7	0.7
	13.1	0.0	0.0	1.3	0.3	0.3
	15.7	0.0	0.0	0.4	0.1	0.1
	18.3	0.0	0.0	0.1	0.0	0.0

Table 5-6 (continued).

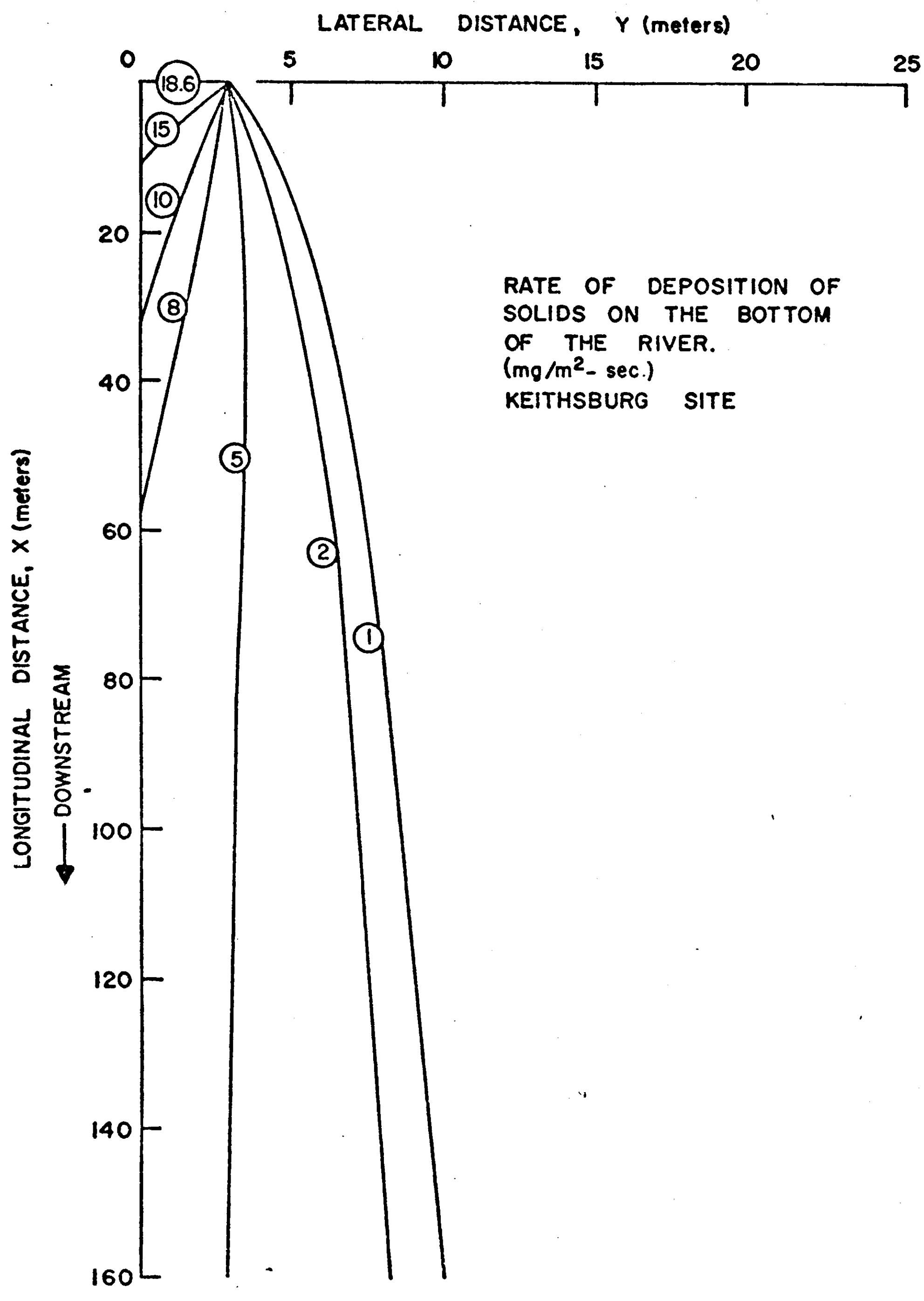


Figure 5-14. Deposition rate at all points in plume for Keithsburg, Illinois.

shown in Figure 5-15. The solids density is assumed to be 2.65 gm/cm^3 and the sediment is assumed to be 85% solids. It can be seen in Figure 5-15 that only at the head of the plume is there significant solids deposition. At a distance of approximately 50 m downstream, only 1 mm of sediment accumulates during the 18.58 hours of dredging. It should be noted that this calculation does not include sediment which immediately falls to the bottom in a dense wedge near the head of the plume.

The depth of solids deposited from the plume at Keithsburg is shown in Figure 5-16. It can be seen that there is less than 0.5 mm of sediment deposited in the 16 hours of dredging.

Another area of interest in impact assessment of dredge spoils discharge operations is desorption of substances previously adsorbed to sediment particles during dredging and disposal. After desorption, these substances are dissolved in the discharge water and thus are returned to the river in an active form with the return flow. These dissolved substances are not subject to settling. The analytical model can be used to calculate the concentration of a dissolved substance at any point in the suspended solids plume with minor modification.

Equation 3.14 is the general solution describing dispersion and settling in a river. The exponential term describes the settling while C' (y,x) describes the dispersion. The equation that describes the dispersion of a dissolved substance is then:

$$C(y,x) = C'(y,x) \tag{5.15}$$

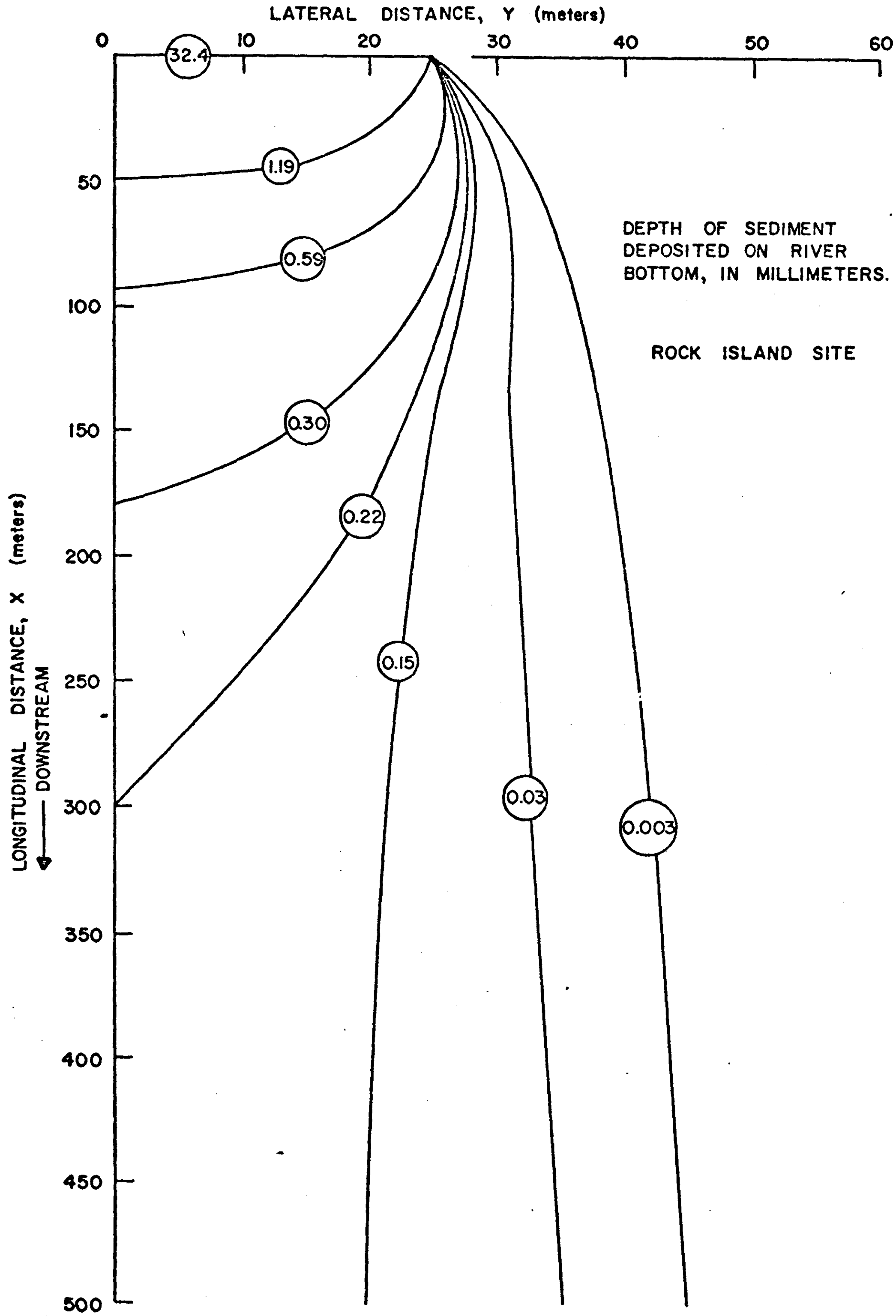


Figure 5-15. Depth of sediment deposited from plume at Rock Island, Illinois, mm.

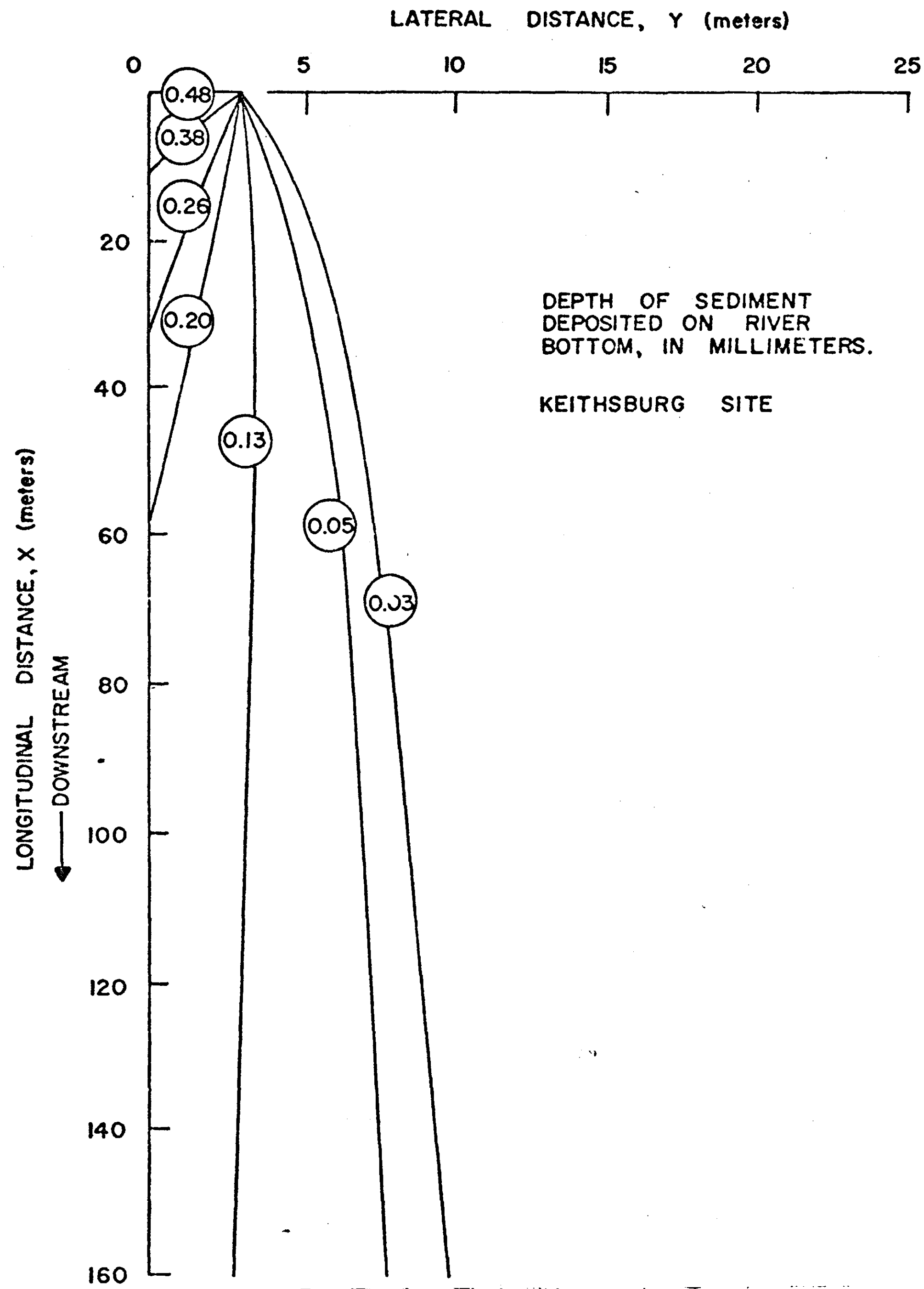


Figure 5-16. Depth of sediment deposited from plume at Keithsburg, Illinois, mm.

The particular solution to Equation 5.15 is Equation 3.22. Examination of Tables 5-3 and 5-4 shows that all of the terms of Equation 3.22 are known. It becomes an easy matter to calculate $\frac{Q_b}{Q_o C_o} C'(y,x)$ at the specific points (y,x) in the plume. Multiplying this term by the concentration of dissolved substance at the head of the plume will yield the concentration of the dissolved substance at the several points in the plume.

An alternate method of arriving at the concentration of a dissolved substance in the plume is calculation of the dilution volume. The dilution volume is defined as the number of volumes of river water added to one volume of water at the head of the plume to arrive at the concentration in the plume. The dilution volume is calculated as:

$$\text{Dilution Volume} = \frac{C_b}{C'} \tag{5.16}$$

where $C_b = \frac{-Q_o C_o}{Q_b}$, the concentration at the head of the plume. The concentration of a dissolved substance, C', is then calculated:

$$C' = \frac{C_b}{\text{Dilution Volume}} \tag{5.16a}$$

Tables 5-7 and 5-8 show the method of calculation of the dilution factor for the plumes at Rock Island and Keithsburg, respectively. It can be seen from Figure 5-17 that the concentration of a dissolved substance along the shoreline is the same as the concentration of that substance at the head of the plume, after initial mixing has taken place between the discharge water and the river. This indicates that settling is the prime mechanism operating to reduce the suspended

x (m)	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	$\frac{Q_b}{Q_o C_o} C'(y,x)$	C' (y,x) (mg/l)	Dilution Volume C_b/C'
50	0.0	1.0	0.0000	1.0000	112.0	1.0
	16.5	1.0	0.0010	0.9990	111.9	1.0
	19.3	1.0	0.0185	0.9815	109.9	1.0
	22.0	1.0	0.1388	0.8612	96.4	1.2
	24.8	1.0	0.4657	0.5343	59.8	1.9
	27.5	1.0	0.8196	0.1804	20.2	5.5
	30.3	1.0	0.9722	0.0278	3.1	36.0
	33.0	1.0	0.9982	0.0018	0.2	555.6
100	0.0	1.0	0.0000	1.0000	112.0	1.0
	11.7	1.0	0.0003	0.9997	112.0	1.0
	15.6	1.0	0.0076	0.9924	111.1	1.0
	19.4	1.0	0.0771	0.9229	103.4	1.1

Table 5-7. Calculation of dilution volume for dissolved substances, Rock Island.

x (m)	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	$\frac{Q_b}{Q_o C_o} C'(y,x)$	C' (y,x) (mg/1)	Dilution Volume C_b/C'
300	0.0	0.9999	0.0001	0.9998	112.0	1.0
	6.7	1.0	0.0034	0.9966	111.6	1.0
	13.5	1.0	0.0437	0.9563	107.1	1.0
	20.2	1.0	0.2392	0.7608	85.2	1.3
	27.0	1.0	0.6145	0.3855	43.2	2.6
	33.7	1.0	0.9017	0.0983	11.0	10.2
	40.4	1.0	0.9890	0.0110	1.2	90.9
	47.2	1.0	0.9995	0.0005	0.1	2000.0
400	0.0	0.9993	0.0007	0.9986	111.8	1.0
	7.8	1.0	0.0135	0.9865	110.5	1.0
	15.6	1.0	0.1127	0.8873	99.4	1.1
	23.3	1.0	0.4160	0.5840	65.4	1.7

Table 5-7 (continued).

x (m)	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	$\frac{Q_b}{Q_o C_o} C'(y,x)$	$C'(y,x)$ (mg/l)	Dilution Volume C_b/C'
100	23.3	1.0	0.3352	0.6648	74.5	1.5
	27.2	1.0	0.7173	0.2827	31.7	3.5
	31.1	1.0	0.9424	0.0576	6.5	17.4
	35.0	1.0	0.9950	0.0050	0.6	200.0
200	0.0	1.0	0.0000	1.0000	112.0	1.0
	5.5	1.0	0.0002	0.9998	112.0	1.0
	11.0	1.0	0.0055	0.9945	111.4	1.0
	16.5	1.0	0.0614	0.9386	105.1	1.1
	22.0	1.0	0.2936	0.7064	79.1	1.4
	27.5	1.0	0.6761	0.3239	36.3	3.1
	33.0	1.0	0.9275	0.0725	8.1	13.8
	38.5	1.0	0.9930	0.0070	0.8	142.9

Table 5-7 (continued).

x (m)	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	$\frac{Q_b}{Q_o C_o} C'(y,x)$	$C'(y,x)$ (mg/l)	Dilution Volume C_b/C'
400	31.1	1.0	0.7817	0.2183	24.4	4.6
	38.9	1.0	0.9631	0.0368	4.1	27.2
	46.7	1.0	0.9974	0.0026	0.3	384.6
500	0.0	0.9979	0.0021	0.9958	111.5	1.0
	8.7	0.9999	0.0305	0.9694	108.6	1.0
	17.4	1.0	0.1914	0.8086	90.6	1.2
	26.1	1.0	0.5505	0.4495	50.3	2.2
	34.8	1.0	0.8701	0.1298	14.5	7.7
	43.5	1.0	0.9833	0.0167	1.9	59.9
	52.2	1.0	0.9991	0.0009	0.1	1111.1

Table 5-7 (continued).

x (m)	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	$\frac{Q_b}{Q_o C_o} C'(y,x)$	C' (y,x) (mg/l)	Dilution Volume C_b/C'
20	0.0	0.9474	0.0526	0.8948	67.1	1.1
	0.9	0.9830	0.1314	0.8516	63.9	1.2
	1.8	0.9956	0.2676	0.7280	54.6	1.4
	2.8	0.9991	0.4522	0.5469	41.0	1.8
	3.7	0.9998	0.6480	0.3518	26.4	2.8
	4.6	1.0	0.8106	0.1894	14.2	5.3
	5.6	1.0	0.9162	0.0838	6.3	11.9
	6.5	1.0	0.9699	0.0301	2.2	33.2
	7.4	1.0	0.9913	0.0087	0.6	114.9
	8.3	1.0	0.9980	0.0020	0.2	500.0
40	0.0	0.8741	0.1259	0.7482	56.1	1.3
	1.3	0.9501	0.2591	0.6910	51.8	1.4

Table 5-8. Calculation of dilution volume for dissolved substances, Keithsburg.

x (m)	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	$\frac{Q_b}{Q_o C_o}$ C' (y,x)	C' (y,x) (mg/l)	Dilution Volume C_b/C'
40	2.6	0.9840	0.4420	0.5420	40.6	1.8
	3.9	0.9960	0.6383	0.3577	26.8	2.8
	5.2	0.9992	0.8034	0.1958	14.7	5.1
	6.5	0.9998	0.9121	0.0877	6.6	11.4
	7.8	1.0	0.9681	0.0319	2.4	31.3
	9.2	1.0	0.9907	0.0093	0.7	107.5
	10.5	1.0	0.9978	0.0022	0.2	454.5
80	0.0	0.7910	0.2190	0.5720	42.9	1.7
	1.8	0.9049	0.3783	0.5266	39.5	1.9
	3.7	0.9649	0.5753	0.3896	29.2	2.6
	5.6	0.9896	0.7549	0.2347	17.6	4.3
	7.4	0.9975	0.8830	0.1145	8.6	8.7

Table 5-8 (continued).

x (m)	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	$\frac{Q_b}{Q_o C_o} C'(y,x)$	C' (y,x) (mg/l)	Dilution Volume C_b/C'
80	9.2	0.9995	0.9545	0.0450	3.4	22.2
	11.1	0.9999	0.9857	0.0142	1.1	70.4
	13.0	1.0	0.9964	0.0036	0.3	227.8
120	0.0	0.7457	0.2543	0.4914	36.8	2.0
	2.3	0.8772	0.4360	0.4412	33.1	2.3
	4.5	0.9516	0.6327	0.3189	23.9	3.1
	6.8	0.9846	0.7992	0.1854	13.9	5.4
	9.1	0.9961	0.9097	0.0864	6.5	11.6
	11.3	0.9992	0.9670	0.0322	2.4	31.1
	13.6	0.9998	0.9904	0.0094	0.7	106.4
	15.9	1.0	0.9977	0.0023	0.2	434.8

Table 5-8 (continued).

x (m)	y (m)	$F\left(\frac{y+b}{\sigma_y}\right)$	$F\left(\frac{y-b}{\sigma_y}\right)$	$\frac{Q_b}{Q_o C_o} C'(y,x)$	$C'(y,x)$ (mg/l)	Dilution Volume C_b/C'
160	0.0	0.7167	0.2833	0.4334	32.5	2.3
	2.6	0.8580	0.4709	0.3871	29.0	2.6
	5.2	0.9421	0.6653	0.2768	20.8	3.6
	7.8	0.9809	0.8230	0.1579	11.8	6.4
	10.5	0.9949	0.9232	0.0717	5.4	13.9
	13.1	0.9989	0.9730	0.0259	1.9	38.6
	15.7	0.9998	0.9924	0.0074	0.6	135.1
	18.3	1.0	0.9983	0.0017	0.1	588.2

Table 5-8 (continued).

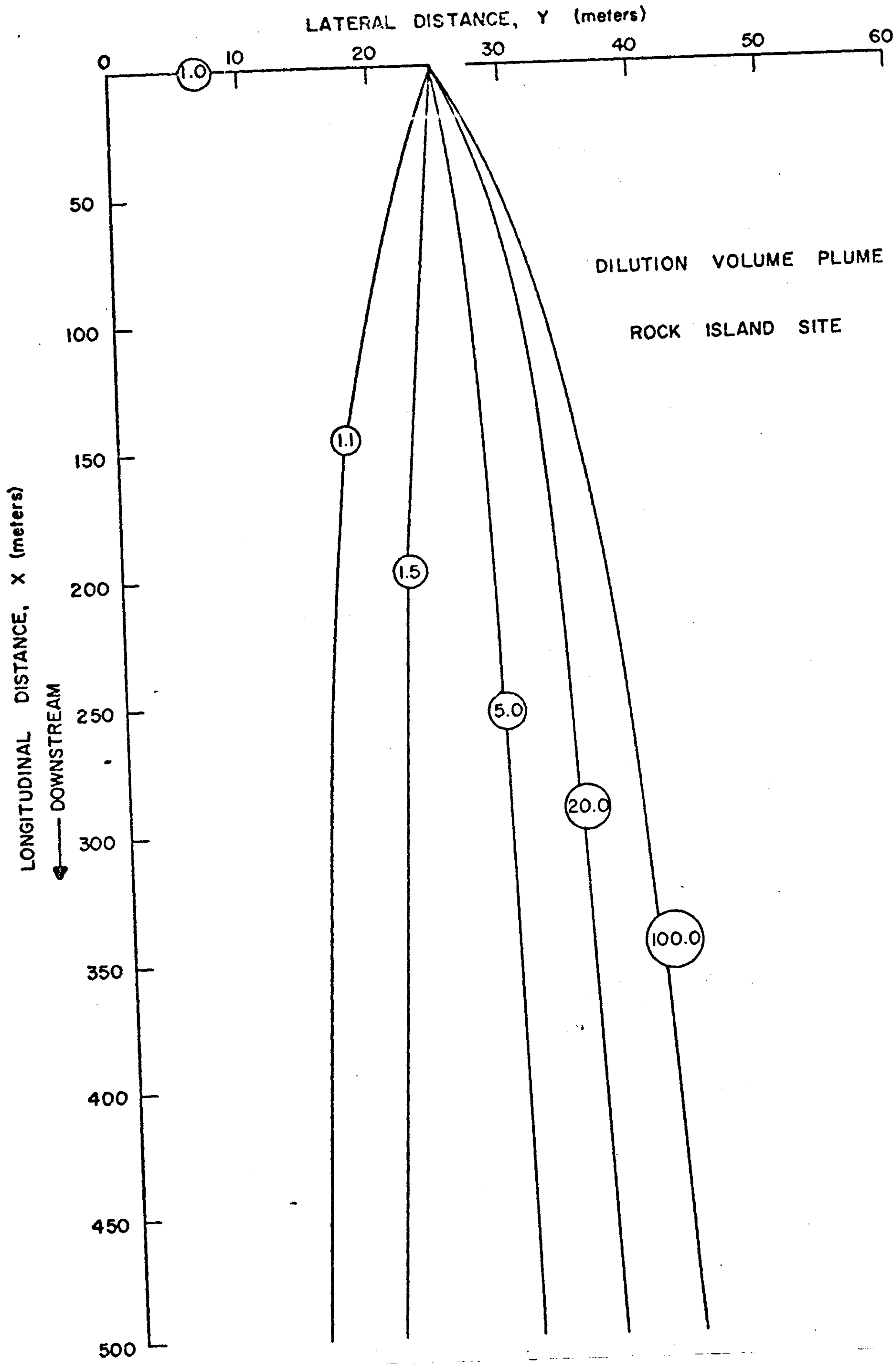


Figure 5-17. Dilution volume at points in plume, Rock Island, Illinois.

solids concentration and that dilution played only a small part at Rock Island after the initial mixing. It also indicates that a toxicant desorbing from the sediment and re-entering the river would be in its greatest concentration along the shoreline. Figure 5-18 for Keithsburg shows a much greater degree of dilution than occurs at Rock Island. This is primarily because of the much narrower plume source with lower flow and momentum after having traversed the disposal island.

The final physical parameter given by the model is the maximum length of the plume. The limits of the plume are defined as the point where the suspended solids concentration in the plume is no longer distinguishable from the ambient suspended solids concentration. A practical value for defining the limits of a suspended solids plume in the Mississippi River might be 10 mg/l above ambient. To find the maximum length of the plume, the model can be solved for the centerline concentration at various values of x until the distance where the suspended solids concentration is 10 mg/l is found.

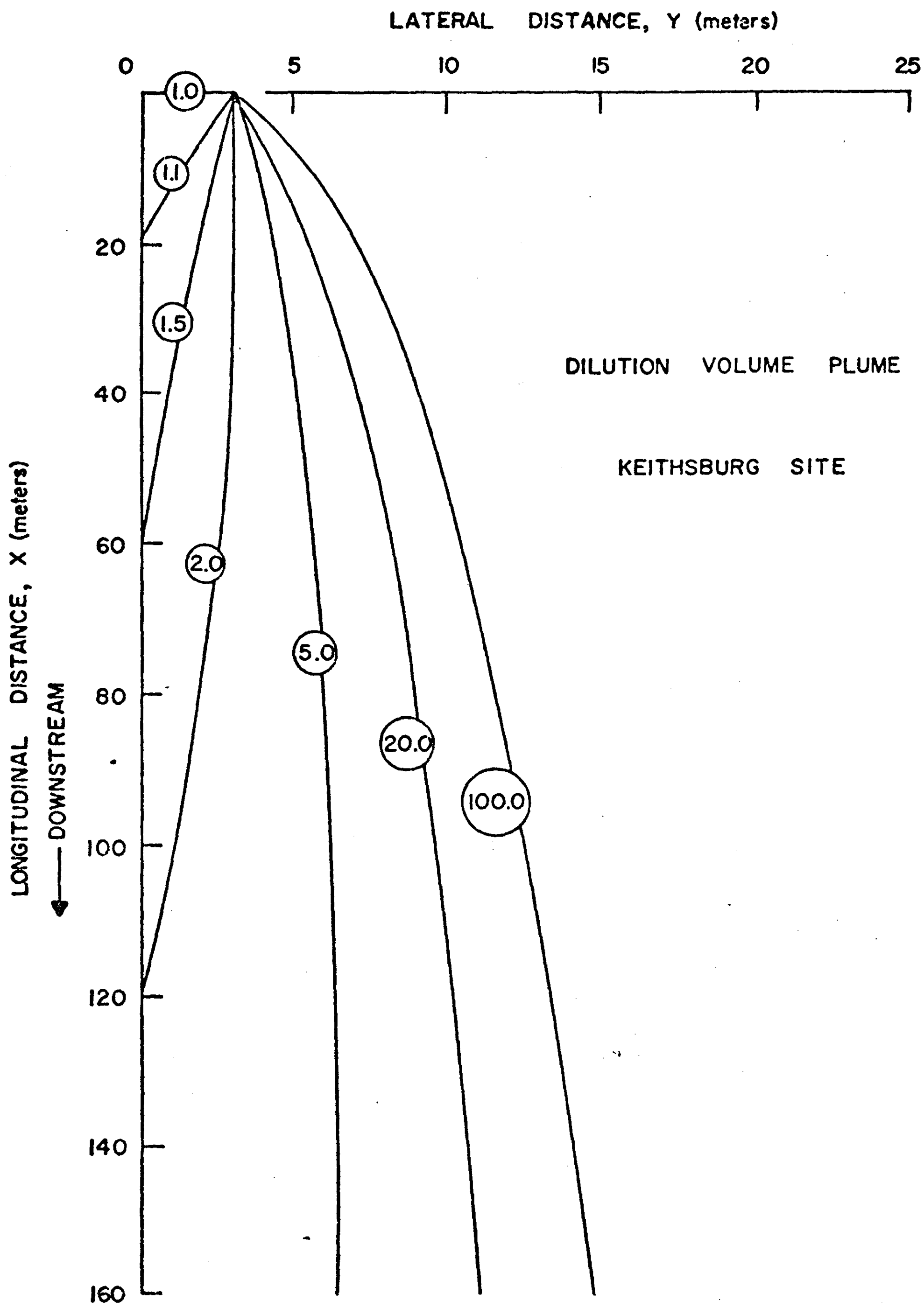


Figure 5-18. Dilution volume at points in plume, Keithsburg, Illinois.

CHAPTER VI

WALDEN PLUME MODEL

Walden Plume Model

One of the computational models utilized to investigate the turbidity plume caused by dredge disposal is the Walden Plume Model presented by Wechsler and Cogley (1977). The turbidity plume model was developed to predict the suspended sediment concentration downstream from a line source in open water. The model uses sedimentation data obtained from jar tests and hydraulic data based on simplifying assumptions of unidirectional constant flow, essentially infinite width, constant depth, and infinite length.

The mathematical model is a material balance among the sediment transport mechanisms of (1) downward transport by settling with ultimate sediment removal by deposition on the bottom, (2) upward transport by vertical eddy diffusion in the direction of decreasing concentration gradient, (3) lateral dispersion by eddy diffusion, and (4) downstream dispersion by both bulk advection and eddy diffusion.

The differential equation expressing the material balance downstream from a dredging site may be expressed as:

$$\frac{\partial}{\partial x}(uc) + \frac{\partial}{\partial y}\left\{\int W \quad f(W)dW\right\} -$$

$$\frac{\partial}{\partial x}\left(E_x \frac{\partial c}{\partial x}\right) - \frac{\partial}{\partial y}\left(E_y \frac{\partial c}{\partial y}\right) - \frac{\partial}{\partial z}\left(E_z \frac{\partial c}{\partial z}\right) = 0 \qquad (6.1)$$

in which

x = downstream distance, m

y = vertical distance, m

z = lateral distance, m

u = stream velocity at any point, m/sec

c = sediment concentration, kg/m^3

W = settling velocity, m/sec

$f(W)$ = settling velocity frequency distribution (sediment mass/W) vs. W

E_x, E_y, E_z = eddy diffusivities in x, y, and z directions, respectively, m^2/sec

In the derivation of this equation it was assumed that the flow is steady, uniform, and fully turbulent, and that eddy diffusion can be characterized by Fick's Law with eddy diffusion coefficients.

To apply the equation to the plume model other assumptions must be made which are listed below.

(1) Eddy diffusion in the downstream direction is negligible compared to the other diffusive transport terms; i.e.,

$$\frac{\partial}{\partial x}\left(E_x \frac{\partial c}{\partial x}\right) = 0 \tag{6.2}$$

(2) The fully turbulent velocity profile is flat, and it can be assumed that u is constant and equal to the mean velocity, U; i.e.,

$$\frac{\partial}{\partial x}(uc) = U\frac{\partial c}{\partial x} \tag{6.3}$$

(3) The equation relating eddy diffusivity, E_y, and vertical

position in the flow can be derived by classical sediment transport mechanisms as described by Wechsler and Cogley (1977).

$$E_y = 0.02\ Uy(1 - y/h) \tag{6.4}$$

in which h = channel depth, m.

(4) The lateral eddy diffusivity, E_z, is approximately constant and can be expressed in terms of the maximum value of E_y (at mid-depth) as

$$E_z \simeq 2.2\ (.005\ Uh) \tag{6.5}$$

Based on these assumptions, Equation (6.1) becomes

$$U \frac{\partial c}{\partial x} + \frac{\partial}{\partial y} \left\{ \int W\ f(W) dW \right\} - \frac{\partial}{\partial y} \left(E_y \frac{\partial c}{\partial y}\right) - \frac{\partial}{\partial z} \left(E_z \frac{\partial c}{\partial z}\right) = 0 \tag{6.6}$$

with E_y and E_z given by Equations (6.4) and (6.5). The first term of Equation (6.6) represents downstream advection, the second terms accounts for vertical sedimentation (or settling), and the last two terms represent eddy diffusion in the vertical and lateral directions, respectively. The integral in the settling terms accounts for the range of settling velocities of the sediment components and must be evaluated over the entire range of settling velocities. However, for nonflocculent sediment, the settling velocity of each particle is invariant in time and space. Thus, the settling term may be replaced by the simpler form W $\partial c/\partial y$, and the equation which becomes

$$U \frac{\partial c}{\partial x} + W \frac{\partial c}{\partial y} - \frac{\partial}{\partial y} \left(E_y \frac{\partial c}{\partial y}\right) - \frac{\partial}{\partial z} \left(E_z \frac{\partial c}{\partial z}\right) = 0 \tag{6.7}$$

must be solved for each sediment size present. The results are then superimposed to obtain total concentration at each point downstream from the source.

If the sediment is flocculating, the problem becomes more difficult, and some simplifying assumptions become necessary. This simplification is discussed in detail by Wechsler and Cogley (1977).

Equation (6.7) is then to be solved for each settling - velocity fraction in the sediment. The total suspended - sediment - concentration profile is obtained by adding the concentration profiles for each sediment fraction.

Numerical Solution

Equation (6.7) is solved numerically by a finite-difference method. The boundary condition at the water surface specifies that there is no sediment flux across the surface; i.e.,

$$E_y \frac{\partial c}{\partial y} + Wc = 0 \tag{6.8}$$

The bottom boundary condition states that all sediment reaching the bottom is deposited and that there is no reentrainment. Therefore, at the bottom

$$E_y \frac{\partial c}{\partial y} = 0 \tag{6.9}$$

The initial concentration at the disposal site, $x = 0$, is known; i.e., at any vertical level, y, $-b \leq z \leq b$, and $c = c_0$. The calculation proceeds stepwise downstream. Over each step, Δx, an implicit finite-difference approximation of Equation (6.7) is solved to compute the concentration at the end of the step from the concentration at the start. The boundary conditions at the top and bottom surfaces enter at each step.

It is important to note that the longitudinal diffusion terms, $\partial/\partial x\ (E_x\ \partial c/\partial x)$, is expressed at $x + \Delta x$ rather than at x giving rise to an implicit finite-difference scheme. This approximation is necessary to allow the use of large values of Δx without generating numerical instabilities. The equation is solved at N levels in the vertical direction where $N = h/\Delta y$. The implicit system requires the solution of N coupled equations at each downstream step.

The effect of lateral diffusion can be found by using the analytical solution of the diffusion equation together with the numerical solution previously described. The lateral diffusion may be described by:

$$\frac{\partial}{\partial x}(uC) = \frac{\partial}{\partial z}\left(E_z \frac{\partial C}{\partial z}\right) \tag{6.10}$$

in which C represents the concentration for the two-dimensional problem at each vertical level. The solution of Equation (6.10) is:

$$C(x,z) = \left(\frac{4\pi x E_z}{u}\right)^{-\frac{1}{2}} \int_{-b}^{b} \exp\left\{-\frac{(z-v)^2 u}{4xE_z}\right\} dv \tag{6.11}$$

in which v is a dummy variable representing distance within the plume. A transformation of variables relates this expression to the error function (erf). If E_z is taken as constant, and

$$\frac{(z-v)^2 u}{4xE_z} = \frac{\gamma^2}{2} \tag{6.12}$$

Equation (6.11) becomes

$$C(x,z) = \frac{1}{\sqrt{2\pi}} \int_{-b}^{b} e^{-\gamma^2/2}\, d\gamma \tag{6.13}$$

A transformation of the limits of integration yields the error function for which a solution is well known. Thus, an analytical solution can be attained for the lateral diffusion.

The combination of the analytical solution for the lateral diffusion problem and the finite-difference solution of the sedimentation and vertical diffusion problem, as described by Wechsler and Cogley (1977), yields a good approximation to the three-dimensional concentration field, c(x,y,z).

Computer Program

A FORTRAN IV computer program to predict the three-dimensional sediment plume was presented by Wechsler and Cogley (1977). Appropriate revisions were made by the present authors to solve the problem of interest herein using a Control Data Corporation (CDC) CYBER 71 computer system. The program is listed in Appendix E.

The use of the program is discussed next. Input data include the stream velocity, U, stream depth, H, sediment settling velocity distribution (given as the number of sediment fractions, NSEDF, and the concentration, CO, and settling velocity, W, of each), the initial discharge half-width, XL, and two computational parameters - the number of downstream steps, NSTEP, and the size of the computational steps in the lateral (z) direction, DELZ. The longitudinal step size, DELX, is taken as a constant; it is defined in a substitution statement in the program. The vertical step size, DELY, is computed from the stream depth, H, and the number of vertical steps, XN.

Each sediment factor is analyzed separately, and all fractions are combined to show the three-dimensional sediment plume. The first input value which is entered is the number of sediment parameters needed. The next data which are read in are U, W, H, CO, NSTEP, XL, DELZ. The values change for each sediment fraction, and they are entered separately as the program considers each fraction.

After calculating certain constants to be employed during the program execution and after computing the lateral eddy diffusivity from Equation (6.5), the lateral diffusion is found by solving Equation (6.13), the transformed version of Equation (6.11). The program then performs a finite-difference solution of the longitudinal diffusion equation at each level in the vertical direction.

The analytical and numerical results are combined (as described by Wechsler and Cogley, 1977) by rewriting the diffusion equation symbolically as

$$u \frac{\partial c}{\partial x} \doteq (L_y + L_z)c \tag{6.14}$$

in which L_z represents lateral diffusion and L_y represents vertical diffusion and sedimentation.

If $C(x,z)$ represents the analytical solution, and $C'(x,y)$ represents the finite-difference solution of the two-dimensional problem ignoring L_z, the required solution which satisfies Equation (6.14), after matching the initial conditions, is

$$c(x,y,z) = C(x,z)C'(x,y) \tag{6.15}$$

Since L_y and L_z affect only $C'(x,y)$ and $C(x,z)$, respectively, it is possible to compute the analytical and numerical results separately and combine them to obtain a valid numerical approximation of the three-dimensional concentration field.

Results

The program output consists of: (1) the vertical distribution of sediment, in the absence of lateral spreading, downstream from the source for each sediment fraction; (2) the summation of all the vertical slices for all sediment fractions; (3) the lateral spreading coefficients; and (4) horizontal slices through the three-dimensional plume at preselected depths.

Sample results are given for the dredge disposal plume in the Mississippi River at two sites - Rock Island, Illinois, River Mile (RM) 482, and Keithsburg, Illinois, RM 428.

Rock Island, Illinois

At Rock Island the sediment is assumed to consist of 25 percent silt, 30 percent clay, and 45 percent sand. The settling velocity of the silt is taken as 3×10^{-4} m/sec and of the clay as 3×10^{-6} m/sec which are in agreement with pipette measurements by Birks (1980). The settling velocity of the sand is 0.012 m/sec. The channel depth is approximately 2 m, and the stream velocity is 0.4 m/sec. The initial width of the sediment disposal plume is taken as 25 m, and the initial concentration is 125 mg/l. The lateral dispersion coefficient, E_z, is computed from Equation (6.5), and it has a magnitude of 0.0088 m^2/sec.

The next three figures give the vertical distribution of each sediment component, in percent of total concentration, downstream from the disposal site. Figures 6-1, 6-2, and 6-3 show (in tabular form), the hypothetical distribution in the absence of lateral spreading of

DISTANCE DOWNSTREAM, m

DEPTH, m	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
0.00	25.00	23.04	22.34	21.82	21.37	20.94	20.54	20.14	19.75	19.37	18.99
.10	25.00	23.60	22.91	22.38	21.92	21.48	21.06	20.66	20.26	19.86	19.48
.20	25.00	23.92	23.25	22.72	22.25	21.81	21.39	20.97	20.57	20.17	19.78
.30	25.00	24.14	23.49	22.97	22.50	22.05	21.62	21.21	20.80	20.39	20.00
.40	25.00	24.30	23.67	23.16	22.69	22.24	21.81	21.39	20.97	20.57	20.17
.50	25.00	24.42	23.82	23.32	22.85	22.40	21.96	21.54	21.12	20.72	20.32
.60	25.00	24.51	23.95	23.45	22.98	22.53	22.09	21.67	21.25	20.84	20.44
.70	25.00	24.59	24.06	23.56	23.10	22.65	22.21	21.78	21.36	20.95	20.54
.80	25.00	24.66	24.15	23.67	23.20	22.75	22.31	21.88	21.46	21.04	20.64
.90	25.00	24.71	24.23	23.76	23.29	22.84	22.40	21.97	21.55	21.13	20.72
1.00	25.00	24.75	24.30	23.84	23.38	22.93	22.49	22.05	21.63	21.21	20.80
1.10	25.00	24.79	24.37	23.91	23.46	23.01	22.56	22.13	21.70	21.28	20.87
1.20	25.00	24.82	24.43	23.98	23.53	23.08	22.63	22.20	21.77	21.35	20.94
1.30	25.00	24.85	24.48	24.05	23.60	23.15	22.70	22.26	21.84	21.41	21.00
1.40	25.00	24.88	24.53	24.11	23.66	23.21	22.76	22.33	21.90	21.47	21.06
1.50	25.00	24.90	24.58	24.16	23.72	23.27	22.83	22.39	21.95	21.53	21.12
1.60	25.00	24.91	24.62	24.22	23.78	23.33	22.88	22.44	22.01	21.59	21.17
1.70	25.00	24.93	24.66	24.27	23.83	23.39	22.94	22.50	22.07	21.64	21.22
1.80	25.00	24.95	24.70	24.32	23.89	23.45	23.00	22.56	22.13	21.70	21.28
1.90	25.00	24.96	24.75	24.40	23.98	23.53	23.09	22.64	22.21	21.78	21.36
AVG	25.00	24.53	24.06	23.60	23.15	22.70	22.26	21.83	21.41	21.00	20.60

Figure 6-1. Vertical concentration distribution of silt downstream from source (no lateral spreading) - Rock Island.

DISTANCE DOWNSTREAM, m

DEPTH, m	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
0.00	30.00	29.98	29.97	29.96	29.95	29.95	29.94	29.94	29.93	29.93	29.92
.10	30.00	29.98	29.97	29.97	29.96	29.96	29.95	29.94	29.94	29.93	29.93
.20	30.00	29.99	29.98	29.97	29.97	29.96	29.95	29.95	29.94	29.94	29.93
.30	30.00	29.99	29.98	29.98	29.97	29.96	29.96	29.95	29.95	29.94	29.94
.40	30.00	29.99	29.98	29.98	29.97	29.97	29.96	29.95	29.95	29.94	29.94
.50	30.00	29.99	29.99	29.98	29.97	29.97	29.96	29.96	29.95	29.95	29.94
.60	30.00	29.99	29.99	29.98	29.98	29.97	29.96	29.96	29.95	29.95	29.94
.70	30.00	30.00	29.99	29.98	29.98	29.97	29.97	29.96	29.95	29.95	29.94
.80	30.00	30.00	29.99	29.98	29.98	29.97	29.97	29.96	29.96	29.95	29.94
.90	30.00	30.00	29.99	29.99	29.98	29.97	29.97	29.96	29.96	29.95	29.95
1.00	30.00	30.00	29.99	29.99	29.98	29.97	29.97	29.96	29.96	29.95	29.95
1.10	30.00	30.00	29.99	29.99	29.98	29.98	29.97	29.96	29.96	29.95	29.95
1.20	30.00	30.00	29.99	29.99	29.98	29.98	29.97	29.97	29.96	29.95	29.95
1.30	30.00	30.00	29.99	29.99	29.98	29.98	29.97	29.97	29.96	29.96	29.95
1.40	30.00	30.00	29.99	29.99	29.98	29.98	29.97	29.97	29.96	29.96	29.95
1.50	30.00	30.00	30.00	29.99	29.98	29.98	29.97	29.97	29.96	29.96	29.95
1.60	30.00	30.00	30.00	29.99	29.99	29.98	29.97	29.97	29.96	29.96	29.95
1.70	30.00	30.00	30.00	29.99	29.99	29.98	29.98	29.97	29.96	29.96	29.95
1.80	30.00	30.00	30.00	29.99	29.99	29.98	29.98	29.97	29.97	29.96	29.95
1.90	30.00	30.00	30.00	29.99	29.99	29.98	29.98	29.97	29.97	29.96	29.95
AVG	30.00	29.99	29.99	29.98	29.98	29.97	29.97	29.96	29.96	29.95	29.94

Figure 6-2. Vertical concentration distribution of clay downstream from source (no lateral spreading) - Rock Island.

DISTANCE DOWNSTREAM, m

DEPTH, m	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
0.00	45.00	.15	.01	.00	.00	.00	.00	.00	.00	.00	.00
.10	45.00	.37	.02	.00	.00	.00	.00	.00	.00	.00	.00
.20	45.00	.75	.03	.00	.00	.00	.00	.00	.00	.00	.00
.30	45.00	1.44	.06	.00	.00	.00	.00	.00	.00	.00	.00
.40	45.00	1.97	.09	.00	.00	.00	.00	.00	.00	.00	.00
.50	45.00	2.69	.13	.01	.00	.00	.00	.00	.00	.00	.00
.60	45.00	3.80	.18	.01	.00	.00	.00	.00	.00	.00	.00
.70	45.00	5.30	.24	.01	.00	.00	.00	.00	.00	.00	.00
.80	45.00	7.12	.31	.01	.00	.00	.00	.00	.00	.00	.00
.90	45.00	9.20	.39	.02	.00	.00	.00	.00	.00	.00	.00
1.00	45.00	11.43	.49	.02	.00	.00	.00	.00	.00	.00	.00
1.10	45.00	13.76	.59	.03	.00	.00	.00	.00	.00	.00	.00
1.20	45.00	16.13	.71	.03	.00	.00	.00	.00	.00	.00	.00
1.30	45.00	18.48	.84	.04	.00	.00	.00	.00	.00	.00	.00
1.40	45.00	20.80	.98	.04	.00	.00	.00	.00	.00	.00	.00
1.50	45.00	23.05	1.14	.05	.00	.00	.00	.00	.00	.00	.00
1.60	45.00	25.22	1.31	.06	.00	.00	.00	.00	.00	.00	.00
1.70	45.00	27.30	1.49	.07	.00	.00	.00	.00	.00	.00	.00
1.80	45.00	29.33	1.70	.07	.00	.00	.00	.00	.00	.00	.00
1.90	45.00	31.66	1.97	.09	.00	.00	.00	.00	.00	.00	.00
AVG	45.00	12.50	.63	.03	.00	.00	.00	.00	.00	.00	.00

Figure 6-3. Vertical concentration distribution of sand downstream from source (no lateral spreading) - Rock Island.

silt, clay, and sand, respectively. It is interesting to note that the heavy sand particles are seen to settle out of the plume in a relatively short distance downstream from the source. The lighter silt and clay remain dispersed in the flow and are transported a much greater distance downstream. The concentration of the clay is seen to change very little downstream from the source, since it becomes a colloidal suspension. The distribution of all the sediment in the plume, i.e., the summation of the vertical distributions of each suspended sediment fraction is shown in Figure 6-4.

Lateral spreading factors are given in Figure 6-5. These factors are then applied to the vertical concentration profiles, and the three-dimensional plume is calculated as horizontal sections at specified depths. Figures 6-6 through 6-10 show the horizontal distributions of sediment at the surface and at depths of 0.4 m, 0.8 m, 1.2 m, and 1.6 m. These figures give a good picture of the three-dimensional plume in tabular form.

Because the Walden Plume Model is designed to simulate open-water disposal, its use in the bank-disposal problem considered herein requires the horizontal concentration distribution to be folded about the line taken as the river bank. In other words, a reflection principle is used to simulate the river bank. This reflection is illustrated in Figure 6-11 with the horizontal concentration distribution at the depth of 1.2 m. The open-water plume, Figure 6-9, is folded about a line at the edge of the line source, at $z = -12.50$ m, to approximate the river bank. To determine the distribution for the bank disposal

DISTANCE DOWNSTREAM, m

DEPTH, m	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
0.00	100.00	53.17	52.31	51.78	51.32	50.89	50.48	50.07	49.68	49.29	48.91
.10	100.00	53.96	52.90	52.35	51.88	51.44	51.01	50.60	50.19	49.80	49.41
.20	100.00	54.66	53.26	52.69	52.22	51.77	51.34	50.92	50.51	50.11	49.71
.30	100.00	55.57	53.53	52.94	52.47	52.02	51.58	51.16	50.74	50.34	49.94
.40	100.00	56.25	53.75	53.14	52.66	52.21	51.77	51.34	50.92	50.51	50.11
.50	100.00	57.10	53.94	53.30	52.82	52.37	51.93	51.50	51.07	50.66	50.26
.60	100.00	58.31	54.12	53.44	52.96	52.50	52.06	51.63	51.20	50.79	50.38
.70	100.00	59.88	54.29	53.56	53.08	52.62	52.17	51.74	51.31	50.90	50.49
.80	100.00	61.77	54.45	53.66	53.18	52.72	52.28	51.84	51.41	50.99	50.58
.90	100.00	63.90	54.62	53.76	53.27	52.82	52.37	51.93	51.50	51.08	50.67
1.00	100.00	66.18	54.78	53.85	53.36	52.90	52.46	52.02	51.58	51.16	50.75
1.10	100.00	68.55	54.95	53.93	53.44	52.98	52.53	52.09	51.66	51.24	50.82
1.20	100.00	70.95	55.13	54.00	53.51	53.06	52.61	52.16	51.73	51.30	50.89
1.30	100.00	73.33	55.31	54.07	53.58	53.12	52.67	52.23	51.80	51.37	50.95
1.40	100.00	75.67	55.50	54.14	53.65	53.19	52.74	52.29	51.86	51.43	51.01
1.50	100.00	77.94	55.71	54.20	53.71	53.25	52.80	52.35	51.92	51.49	51.07
1.60	100.00	80.13	55.92	54.26	53.77	53.31	52.86	52.41	51.97	51.54	51.12
1.70	100.00	82.23	56.15	54.33	53.82	53.37	52.92	52.47	52.03	51.60	51.18
1.80	100.00	84.28	56.40	54.39	53.88	53.43	52.98	52.53	52.09	51.66	51.23
1.90	100.00	86.63	56.72	54.48	53.97	53.52	53.06	52.62	52.17	51.74	51.31
AVG	100.00	67.02	54.69	53.61	53.13	52.67	52.23	51.80	51.37	50.95	50.54

Figure 6-4. Summation of two-dimensional concentration distributions for all sediment (no lateral spreading) - Rock Island.

DISTANCE DOWNSTREAM

LATERAL DISTANCE, m											
0.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2.50	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5.00	1.000	1.000	1.000	1.000	1.000	1.000	.999	.999	.998	.996	.994
7.50	1.000	1.000	1.000	.999	.996	.991	.985	.978	.970	.962	.954
10.00	1.000	.996	.970	.938	.909	.883	.862	.843	.827	.813	.800
12.50	1.000	.500	.500	.500	.500	.500	.500	.500	.500	.500	.500
15.00	0.000	.004	.030	.062	.091	.117	.138	.157	.173	.187	.200
17.50	0.000	.000	.000	.001	.004	.009	.015	.022	.030	.038	.046
20.00	0.000	.000	.000	.000	.000	.000	.001	.001	.002	.004	.006
22.50	0.000	0.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
25.00	0.000	0.000	0.000	.000	.000	.000	.000	.000	.000	.000	.000
27.50	0.000	0.000	0.000	0.000	.000	.000	.000	.000	.000	.000	.000
30.00	0.000	0.000	0.000	0.000	0.000	0.000	.000	.000	.000	.000	.000
32.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.000	.000	.000
35.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.000	.000
37.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
42.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47.50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 6-5. Table of lateral spreading coefficients - Rock Island.

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	1	1	2	2
-15.00	0	0	1	4	5	7	8	9	10	11	12
-12.50	125	33	32	32	32	31	31	31	31	30	30
-10.00	125	66	63	60	58	56	54	52	51	50	48
-7.50	125	66	65	64	63	63	62	61	60	59	58
-5.00	125	66	65	64	64	63	63	62	61	61	60
-2.50	125	66	65	64	64	63	63	62	62	61	61
0.00	125	66	65	64	64	63	63	62	62	61	61
2.50	125	66	65	64	64	63	63	62	62	61	61
5.00	125	66	65	64	64	63	63	62	61	61	60
7.50	125	66	65	64	63	63	62	61	60	59	58
10.00	125	66	63	60	58	56	54	52	51	50	48
12.50	125	33	32	32	32	31	31	31	31	30	30
15.00	0	0	1	4	5	7	8	9	10	11	12
17.50	0	0	0	0	0	0	0	1	1	2	2
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

$U = 0.4$ m/sec
$W_s = 0.012$ m/sec
$E_z = 0.0088$ m^2/sec

Sand 45%
Silt 25%
Clay 30%

Figure 6-6. Sediment concentration distribution in horizontal plane at the surface - Rock Island.

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	1	1	2	2
-15.00	0	0	1	4	6	7	8	10	11	11	12
-12.50	125	35	33	33	32	32	32	32	31	31	31
-10.00	125	70	65	62	59	57	55	54	52	51	50
-7.50	125	70	67	66	65	64	63	62	61	60	59
-5.00	125	70	67	66	65	65	64	64	63	62	62
-2.50	125	70	67	66	65	65	64	64	63	63	62
0.00	125	70	67	66	65	65	64	64	63	63	62
2.50	125	70	67	66	65	65	64	64	63	63	62
5.00	125	70	67	66	65	65	64	64	63	62	62
7.50	125	70	67	66	65	64	63	62	61	60	59
10.00	125	70	65	62	59	57	55	54	52	51	50
12.50	125	35	33	33	32	32	32	32	31	31	31
15.00	0	0	1	4	6	7	8	10	11	11	12
17.50	0	0	0	0	0	0	0	1	1	2	2
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

U = 0.4 m/sec — Sand 45%

W_s = 0.012 m/sec — Silt 25%

E_z = 0.0088 m^2/sec — Clay 30%

Figure 6-7. Sediment concentration distribution in horizontal plane at depth of 0.4 m - Rock Island.

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	1	1	2	2
-15.00	0	0	2	4	6	7	9	10	11	11	12
-12.50	125	38	34	33	33	32	32	32	32	31	31
-10.00	125	76	66	62	60	58	56	54	53	51	50
-7.50	125	77	68	67	66	65	64	63	62	61	60
-5.00	125	77	68	67	66	65	65	64	64	63	62
-2.50	125	77	68	67	66	65	65	64	64	63	63
0.00	125	77	68	67	66	65	65	64	64	63	63
2.50	125	77	68	67	66	65	65	64	64	63	63
5.00	125	77	68	67	66	65	65	64	64	63	62
7.50	125	77	68	67	66	65	64	63	62	61	60
10.00	125	76	66	62	60	58	56	54	53	51	50
12.50	125	38	34	33	33	32	32	32	32	31	31
15.00	0	0	2	4	6	7	9	10	11	11	12
17.50	0	0	0	0	0	0	0	1	1	2	2
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

$U = 0.4$ m/sec
$W_s = 0.012$ m/sec
$E_z = 0.0088\ m^2/sec$

Sand 45%
Silt 25%
Clay 30%

Figure 6-8. Sediment concentration distribution in horizontal plane at depth of 0.8 m - Rock Island.

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	1	1	2	2
-15.00	0	0	2	4	6	7	9	10	11	12	12
-12.50	125	44	34	33	33	33	32	32	32	32	31
-10.00	125	88	66	63	60	58	56	54	53	52	50
-7.50	125	88	68	67	66	65	64	63	62	61	60
-5.00	125	88	68	67	66	66	65	65	64	63	63
-2.50	125	88	68	67	66	66	65	65	64	64	63
0.00	125	88	68	67	66	66	65	65	64	64	63
2.50	125	88	68	67	66	66	65	65	64	64	63
5.00	125	88	68	67	66	66	65	65	64	63	63
7.50	125	88	68	67	66	65	64	63	62	61	60
10.00	125	88	66	63	60	58	56	54	53	52	50
12.50	125	44	34	33	33	33	32	32	32	32	31
15.00	0	0	2	4	6	7	9	10	11	12	12
17.50	0	0	0	0	0	0	0	1	1	2	2
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

$U = 0.4$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.0088\ m^2/sec$

Sand 45%

Silt 25%

Clay 30%

Figure 6-9. Sediment concentration distribution in horizontal plane at depth of 1.2 m - Rock Island.

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	1	1	2	2
-15.00	0	0	2	4	6	7	9	10	11	12	12
-12.50	125	50	34	33	33	33	33	32	32	32	31
-10.00	125	99	67	63	61	58	56	55	53	52	51
-7.50	125	100	69	67	66	66	65	64	63	61	60
-5.00	125	100	69	67	67	66	66	65	64	64	63
-2.50	125	100	69	67	67	66	66	65	64	64	63
0.00	125	100	69	67	67	66	66	65	64	64	63
2.50	125	100	69	67	67	66	66	65	64	64	63
5.00	125	100	69	67	67	66	66	65	64	64	63
7.50	125	100	69	67	66	66	65	64	63	61	60
10.00	125	99	67	63	61	58	56	55	53	52	51
12.50	125	50	34	33	33	33	33	32	32	32	31
15.00	0	0	2	4	6	7	9	10	11	12	12
17.50	0	0	0	0	0	0	0	1	1	2	2
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

$U = 0.4$ m/sec — Sand 45%

$W_s = 0.012$ m/sec — Silt 25%

$E_z = 0.0088\ m^2/sec$ — Clay 30%

Figure 6-10. Sediment concentration distribution in horizontal plane at depth of 1.6 m - Rock Island.

Open Water Disposal (see figure 6-9)

x →

z	0	50	100	150	200	250	
-17.5	0	0	0	0	0	0	
-15.0	0	0	2	4	6	7	
-12.5	125	44	34	33	33	33	folding axis
-10.0	125	88	66	63	60	58	
- 7.5	125	88	68	67	66	65	
- 5.0	125	88	68	67	66	66	
- 2.5	125	88	68	67	66	66	
0.0	125	88	68	67	66	66	

Bank Disposal (above folded)

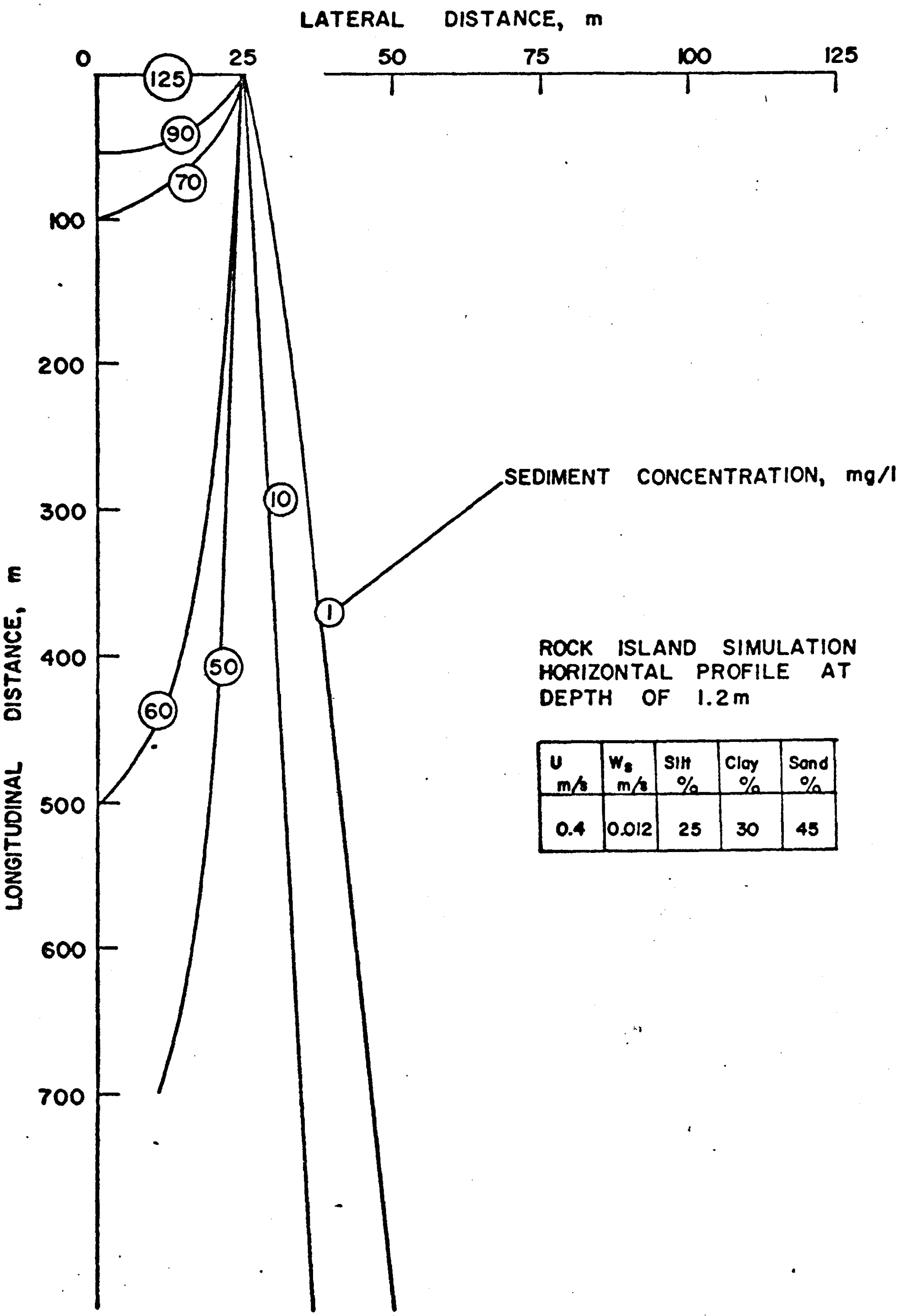
-17.5	0	0	0	0	0	0	
-15.0	0	0	0	0	0	0	bank
-12.5	125	88	68	66	66	66	
-10.0	125	88	68	67	66	65	
- 7.5	125	88	68	67	66	65	
- 5.0	125	88	68	67	66	66	
- 2.5	125	88	68	67	66	66	
0.0	125	88	68	67	66	66	

Figure 6-11. Illustration of reflection principle for bank disposal.

(lowerportion of Figure 6-11), the distribution values for the open-water disposal (upper portion of Figure 6-11) along the folding axis are doubled, and the values below the folding axis are determined by adding the corresponding values of the open-water plume above and below the folding axis.

A graphical presentation of the numerical simulation of the disposal plume at Rock Island is shown in Figure 6-12. Several sediment concentration isopleths are drawn at the depth of 1.2 m. This depth is of interest because it is the depth of the mean concentration of the suspended solids, and it is approximately equal to the depth where field measurements were taken. Although field measurement data are not shown in this figure, the results obtained from the Walden Plume Model are in close agreement with the field measurements and the results given in Chapters IV and V. The observed lateral spread was somewhat greater than that shown in Figure 6-12.

Another indication of the plume orientation is given by a plot of the line of maximum sediment concentration at the depth of 1.2 m with distance downstream from the source. This simulation is shown for Rock Island in Figure 6-13. The field data from Figure 2-8 are shown in this figure as a verification of the Walden Plume Model. The agreement of the model prediction and the data is quite good. The problem downstream from about 175-350 m was caused by the disposal operation pumping pure water while the field measurements were taken as explained earlier. Field observations indicate a larger lateral spread than calculated in Figure 6-12, so the lateral dispersion coefficient should



U m/s	W_s m/s	Silt %	Clay %	Sand %
0.4	0.012	25	30	45

Figure 6-12. Numerical simulation of disposal plume at depth of 1.2 m - Rock Island, Illinois.

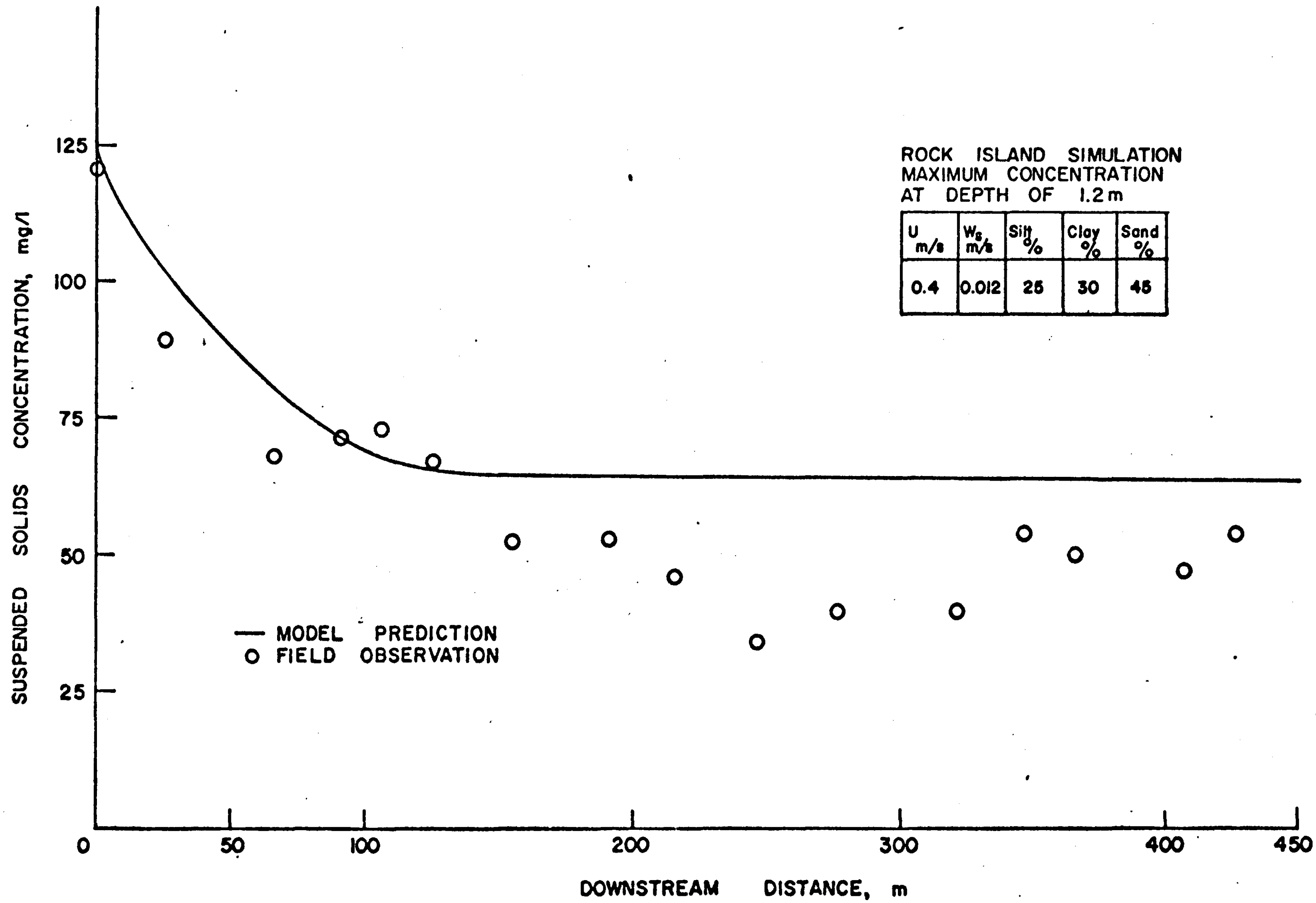


Figure 6-13. Line of maximum sediment concentration at depth of 1.2 m - Rock Island, Illinois.

have been greater than 88 cm^2/sec. It is noted that the maximum concentration levels out at about 150 m downstream from the source to approximately 66 mg/l. This trend indicates that in the first 150 m downstream from the source, the heavy sand particles settle out of the plume, and the light silt and clay particles remain suspended for a long distance. A comparison with Figures 6-1, 6-2, and 6-3 verifies this observation.

One of the important variables in a turbidity study is the settling velocity of the sediment particles. The settling velocity is related to the nominal size of the sediment particle which may be determined by a pipette and visual accumulation tube analysis. Obviously, the heavy particles have a high settling velocity and settle out of the turbidity plume first. The effect of the sand settling velocity on the maximum concentration distribution at the depth of 1.2 m is shown in Figure 6-14 in which results are given for two different settling velocities of sand. As expected the plume with the heavier sand reaches its asymptotic concentration first.

The effect of the amount of sand in the sediment on the turbidity plume is shown in Figure 6-15. The maximum solids concentration at a depth of 1.2 m downstream from the source is shown for sediments with different amounts of sand. The stream velocity and the sand settling velocity are held constant, and the amount of sand in the sediment is varied from 2 percent to 45 percent. As expected, the more sand there is in the sediment, the lower the suspended solids concentration becomes, and the sooner the concentration levels out

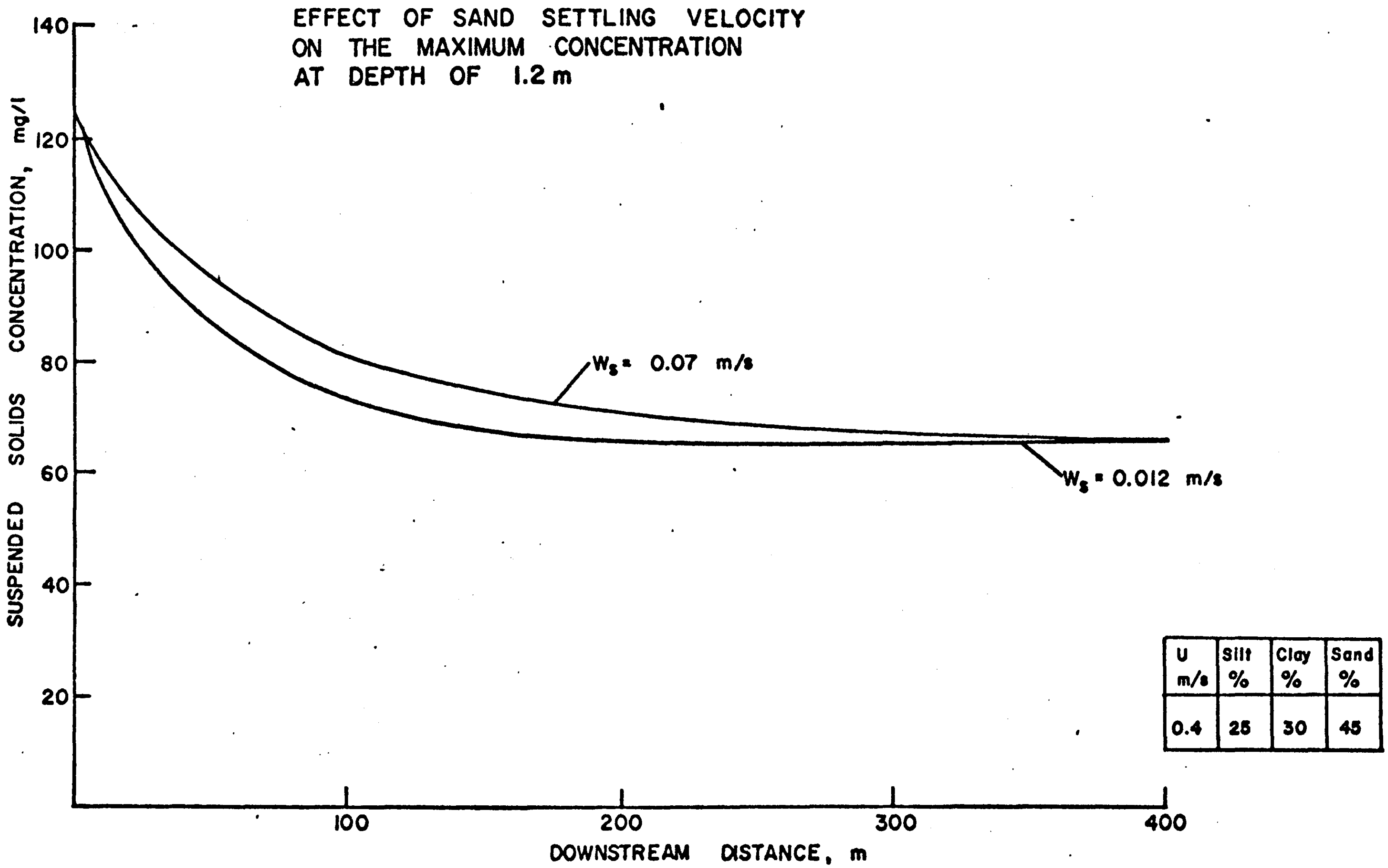


Figure 6-14. Effect of sand settling velocity on maximum concentration at depth of 1.2 m - Rock Island, Illinois.

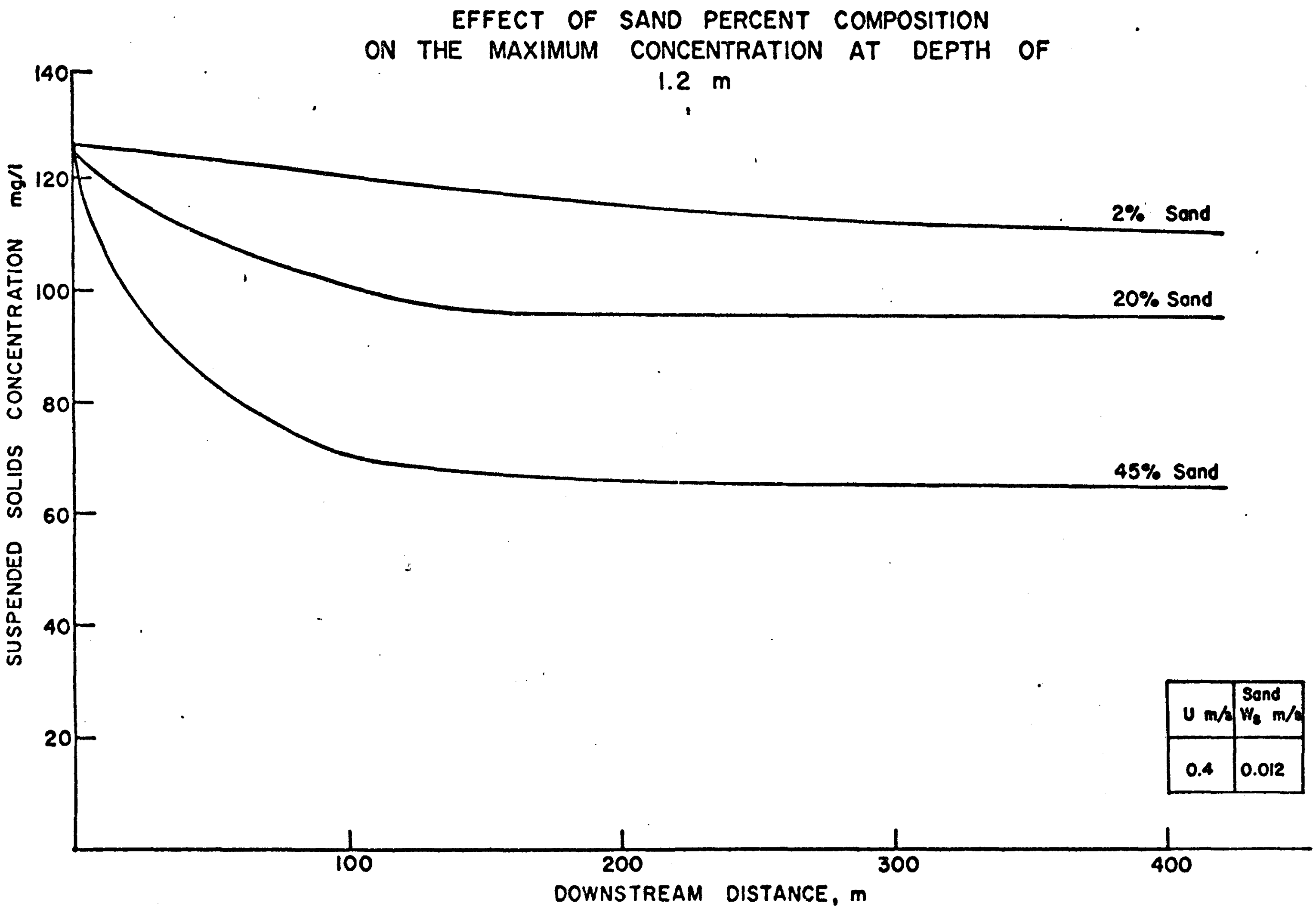


Figure 6-15. Effect of amount of sand in the sediment on maximum concentration at depth of 1.2 m - Rock Island, Illinois.

downstream from the source. After the sand is settled, first the silt and next the clay fractions can be expected to settle, but at distances on the order of $^{hu}/_{W}$.

Figure 6-16 shows the effect of river velocity on the suspended solids concentration. It is seen that higher stream velocities tend to keep more solids in suspension, since over a given distance the sediment has less time to settle out. Thus, a higher solids concentration is maintained at any distance downstream from the source by a higher river velocity.

Keithsburg, Illinois

The sediment at Keithsburg is assumed to consist of 67 percent silt, 31 percent clay, and 2 percent sand. The settling velocities of the sediment components, channel depth, and river velocity are the same as those for Rock Island. However, the initial width of the disposal plume is 3 m, the initial concentration is 75 mg/l, and the lateral dispersion coefficient is taken as E_z = 0.03 m^2/sec.

The two-dimensional (vertical) concentration distributions in the absence of lateral spreading are shown in tabular form in Figures 6-17, 6-18, and 6-19 for silt, clay, and sand, respectively. The summation of the vertical distributions of each fraction is given in Figure 6-20, and the lateral spreading factors are shown in Figure 6-21.

The horizontal distributions of sediment at the surface and at depths of 0.4 m, 0.8 m, 1.2 m, and 1.6 m are given in Figures 6-22 through 6-26. The dredge disposal at Keithsburg also was on the river bank, so the reflection principle must be applied in the interpretation

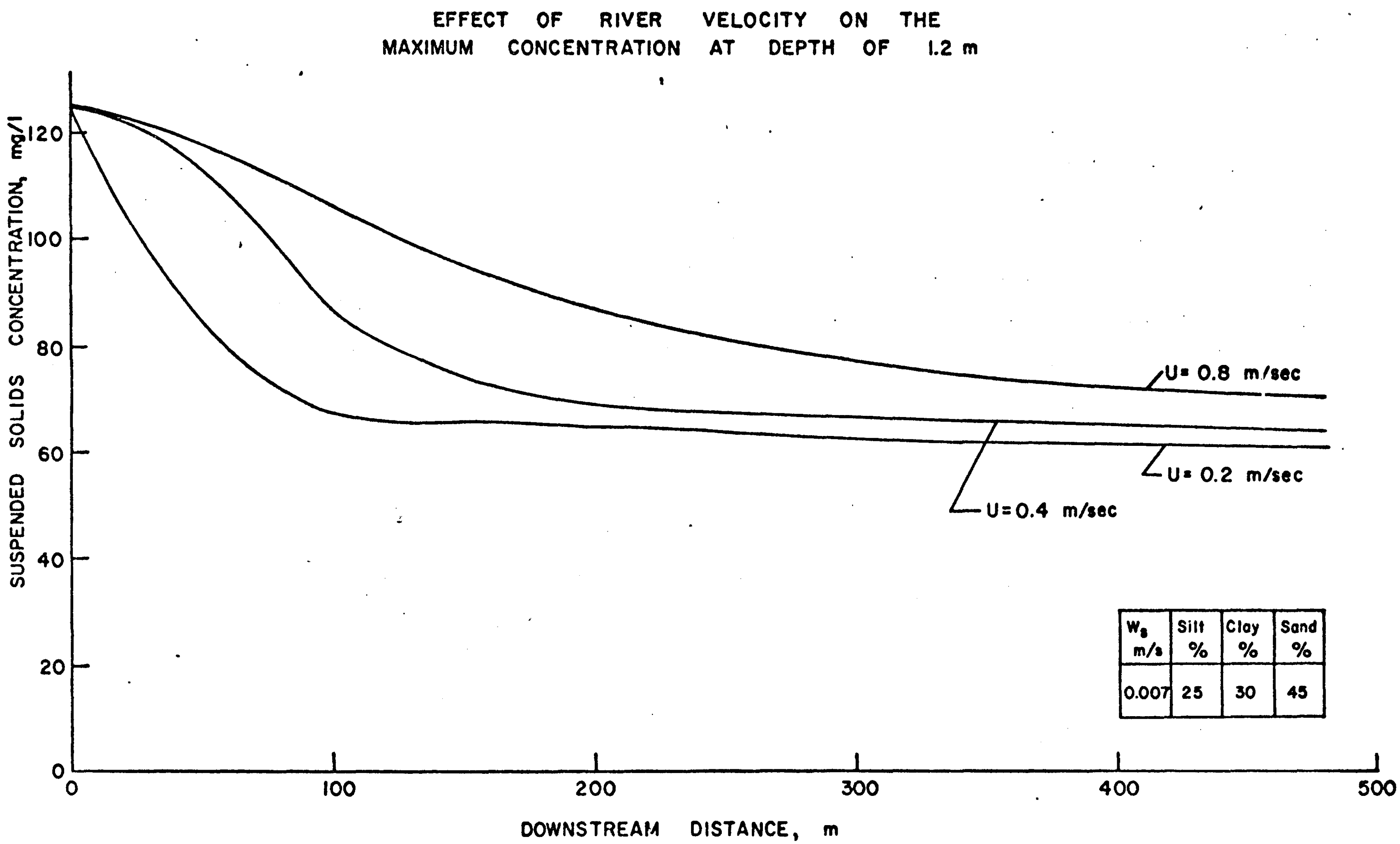


Figure 6-16. Effect of river velocity on maximum concentration at depth of 1.2 m - Rock Island, Illinois.

DISTANCE DOWNSTREAM, m

DEPTH, m	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
0.00	67.00	61.76	59.87	58.49	57.27	56.13	55.03	53.97	52.92	51.90	50.90
.10	67.00	63.25	61.39	59.98	58.74	57.57	56.45	55.36	54.29	53.24	52.21
.20	67.00	64.11	62.30	60.89	59.64	58.46	57.32	56.21	55.12	54.06	53.02
.30	67.00	64.69	62.95	61.55	60.29	59.10	57.95	56.83	55.73	54.66	53.60
.40	67.00	65.11	63.45	62.06	60.81	59.61	58.45	57.32	56.21	55.13	54.06
.50	67.00	65.44	63.85	62.49	61.23	60.03	58.86	57.72	56.61	55.52	54.45
.60	67.00	65.70	64.19	62.84	61.59	60.39	59.21	58.07	56.95	55.85	54.77
.70	67.00	65.90	64.47	63.15	61.90	60.70	59.52	58.37	57.24	56.14	55.06
.80	67.00	66.08	64.72	63.42	62.18	60.97	59.79	58.64	57.51	56.40	55.31
.90	67.00	66.22	64.94	63.67	62.43	61.22	60.04	58.88	57.74	56.63	55.54
1.00	67.00	66.34	65.14	63.89	62.66	61.45	60.26	59.10	57.96	56.84	55.74
1.10	67.00	66.44	65.31	64.09	62.87	61.66	60.47	59.30	58.16	57.04	55.94
1.20	67.00	66.53	65.47	64.27	63.06	61.85	60.66	59.49	58.34	57.22	56.11
1.30	67.00	66.60	65.61	64.44	63.24	62.03	60.84	59.67	58.52	57.39	56.28
1.40	67.00	66.67	65.74	64.60	63.41	62.20	61.01	59.84	58.68	57.55	56.44
1.50	67.00	66.72	65.86	64.76	63.57	62.37	61.17	59.99	58.84	57.70	56.59
1.60	67.00	66.77	65.98	64.90	63.72	62.52	61.33	60.15	58.99	57.85	56.74
1.70	67.00	66.81	66.09	65.04	63.88	62.68	61.48	60.30	59.14	58.00	56.88
1.80	67.00	66.85	66.20	65.19	64.03	62.84	61.64	60.46	59.30	58.15	57.03
1.90	67.00	66.90	66.34	65.39	64.26	63.07	61.87	60.68	59.52	58.37	57.24
AVG	67.00	65.74	64.49	63.26	62.04	60.84	59.67	58.52	57.39	56.28	55.20

Figure 6-17. Vertical concentration distribution of silt downstream from source (no lateral spreading) - Keithsburg.

DEPTH, m	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
0.00	31.00	30.97	30.97	30.96	30.95	30.95	30.94	30.93	30.93	30.92	30.92
.10	31.00	30.98	30.97	30.97	30.96	30.95	30.95	30.94	30.94	30.93	30.92
.20	31.00	30.99	30.98	30.97	30.96	30.96	30.95	30.95	30.94	30.94	30.93
.30	31.00	30.99	30.98	30.97	30.97	30.96	30.96	30.95	30.94	30.94	30.93
.40	31.00	30.99	30.98	30.98	30.97	30.96	30.96	30.95	30.95	30.94	30.94
.50	31.00	30.99	30.99	30.98	30.97	30.97	30.96	30.96	30.95	30.94	30.94
.60	31.00	30.99	30.99	30.98	30.97	30.97	30.96	30.96	30.95	30.95	30.94
.70	31.00	31.00	30.99	30.98	30.98	30.97	30.96	30.96	30.95	30.95	30.94
.80	31.00	31.00	30.99	30.98	30.98	30.97	30.97	30.96	30.95	30.95	30.94
.90	31.00	31.00	30.99	30.98	30.98	30.97	30.97	30.96	30.96	30.95	30.94
1.00	31.00	31.00	30.99	30.99	30.98	30.97	30.97	30.96	30.96	30.95	30.95
1.10	31.00	31.00	30.99	30.99	30.98	30.98	30.97	30.96	30.96	30.95	30.95
1.20	31.00	31.00	30.99	30.99	30.98	30.98	30.97	30.96	30.96	30.95	30.95
1.30	31.00	31.00	30.99	30.99	30.98	30.98	30.97	30.97	30.96	30.95	30.95
1.40	31.00	31.00	30.99	30.99	30.98	30.98	30.97	30.97	30.96	30.95	30.95
1.50	31.00	31.00	30.99	30.99	30.98	30.98	30.97	30.97	30.96	30.96	30.95
1.60	31.00	31.00	31.00	30.99	30.99	30.98	30.97	30.97	30.96	30.96	30.95
1.70	31.00	31.00	31.00	30.99	30.99	30.98	30.97	30.97	30.96	30.96	30.95
1.80	31.00	31.00	31.00	30.99	30.99	30.98	30.98	30.97	30.96	30.96	30.95
1.90	31.00	31.00	31.00	30.99	30.99	30.98	30.98	30.97	30.97	30.96	30.95
AVG	31.00	30.99	30.99	30.98	30.98	30.97	30.97	30.96	30.95	30.95	30.94

(Column heading: DISTANCE DOWNSTREAM, m)

Figure 6-18. Vertical concentration distribution of clay downstream from source (no lateral spreading) - Keithsburg.

DISTANCE DOWNSTREAM, m

DEPTH, m	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
0.00	2.00	.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
.10	2.00	.02	.00	.00	.00	.00	.00	.00	.00	.00	.00
.20	2.00	.03	.00	.00	.00	.00	.00	.00	.00	.00	.00
.30	2.00	.06	.00	.00	.00	.00	.00	.00	.00	.00	.00
.40	2.00	.09	.00	.00	.00	.00	.00	.00	.00	.00	.00
.50	2.00	.12	.01	.00	.00	.00	.00	.00	.00	.00	.00
.60	2.00	.17	.01	.00	.00	.00	.00	.00	.00	.00	.00
.70	2.00	.24	.01	.00	.00	.00	.00	.00	.00	.00	.00
.80	2.00	.32	.01	.00	.00	.00	.00	.00	.00	.00	.00
.90	2.00	.41	.02	.00	.00	.00	.00	.00	.00	.00	.00
1.00	2.00	.51	.02	.00	.00	.00	.00	.00	.00	.00	.00
1.10	2.00	.61	.03	.00	.00	.00	.00	.00	.00	.00	.00
1.20	2.00	.72	.03	.00	.00	.00	.00	.00	.00	.00	.00
1.30	2.00	.82	.04	.00	.00	.00	.00	.00	.00	.00	.00
1.40	2.00	.92	.04	.00	.00	.00	.00	.00	.00	.00	.00
1.50	2.00	1.02	.05	.00	.00	.00	.00	.00	.00	.00	.00
1.60	2.00	1.12	.06	.00	.00	.00	.00	.00	.00	.00	.00
1.70	2.00	1.21	.07	.00	.00	.00	.00	.00	.00	.00	.00
1.80	2.00	1.30	.08	.00	.00	.00	.00	.00	.00	.00	.00
1.90	2.00	1.41	.09	.00	.00	.00	.00	.00	.00	.00	.00
AVG	2.00	.56	.03	.00	.00	.00	.00	.00	.00	.00	.00

Figure 6-19. Vertical concentration distribution of sand downstream from source (no lateral spreading) - Keithsburg.

DISTANCE DOWNSTREAM, m

SUMMATION OF SUSPENDED SEDIMENTS

DEPTH, m	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
0.00	100.00	92.74	90.84	89.44	88.22	87.08	85.97	84.90	83.85	82.83	81.82
.10	100.00	94.25	92.36	90.95	89.70	88.53	87.40	86.30	85.22	84.17	83.14
.20	100.00	95.13	93.28	91.86	90.61	89.42	88.27	87.16	86.07	85.00	83.95
.30	100.00	95.74	93.93	92.53	91.26	90.07	88.91	87.78	86.68	85.60	84.54
.40	100.00	96.19	94.43	93.04	91.78	90.58	89.41	88.27	87.16	86.07	85.00
.50	100.00	96.55	94.84	93.47	92.20	91.00	89.82	88.68	87.56	86.46	85.38
.60	100.00	96.86	95.18	93.82	92.56	91.35	90.18	89.03	87.90	86.79	85.71
.70	100.00	97.13	95.47	94.13	92.88	91.67	90.48	89.33	88.20	87.09	86.00
.80	100.00	97.39	95.73	94.41	93.16	91.94	90.76	89.60	88.46	87.34	86.25
.90	100.00	97.62	95.95	94.65	93.41	92.19	91.01	89.84	88.70	87.58	86.48
1.00	100.00	97.84	96.15	94.87	93.64	92.42	91.23	90.06	88.92	87.79	86.69
1.10	100.00	98.05	96.33	95.08	93.85	92.63	91.44	90.27	89.12	87.99	86.88
1.20	100.00	98.24	96.49	95.26	94.04	92.83	91.63	90.46	89.30	88.17	87.06
1.30	100.00	98.42	96.64	95.43	94.22	93.01	91.81	90.63	89.48	88.34	87.23
1.40	100.00	98.59	96.78	95.60	94.39	93.18	91.98	90.80	89.64	88.50	87.39
1.50	100.00	98.74	96.91	95.75	94.55	93.34	92.14	90.96	89.80	88.66	87.54
1.60	100.00	98.89	97.03	95.89	94.71	93.50	92.30	91.12	89.95	88.81	87.69
1.70	100.00	99.03	97.15	96.04	94.86	93.66	92.46	91.27	90.10	88.96	87.83
1.80	100.00	99.16	97.27	96.18	95.02	93.82	92.62	91.43	90.26	89.11	87.98
1.90	100.00	99.31	97.43	96.38	95.24	94.05	92.85	91.66	90.48	89.33	88.20
AVG	100.00	97.29	95.51	94.24	93.02	91.81	90.63	89.48	88.34	87.23	86.14

Figure 6-20. Summation of two-dimensional concentration distributions for all sediment (no lateral spreading) - Keithsburg.

LATERAL DISTANCE, m	DISTANCE DOWNSTREAM										
0.00	1.000	.614	.460	.383	.335	.301	.276	.257	.241	.227	.216
.50	1.000	.594	.451	.378	.332	.299	.274	.255	.239	.226	.215
1.00	1.000	.539	.427	.364	.322	.292	.269	.251	.236	.223	.212
1.50	1.000	.458	.390	.341	.307	.281	.260	.244	.230	.218	.208
2.00	0.000	.365	.343	.312	.286	.266	.248	.234	.222	.211	.202
2.50	0.000	.271	.290	.278	.262	.247	.234	.222	.212	.203	.195
3.00	0.000	.189	.237	.242	.236	.227	.217	.209	.201	.193	.186
3.50	0.000	.122	.186	.205	.207	.204	.199	.194	.188	.182	.177
4.00	0.000	.074	.141	.169	.179	.182	.180	.178	.174	.170	.166
4.50	0.000	.041	.103	.136	.152	.159	.161	.161	.160	.158	.155
5.00	0.000	.022	.073	.107	.126	.136	.142	.144	.145	.145	.144
5.50	0.000	.010	.049	.081	.102	.115	.123	.128	.131	.132	.132
6.00	0.000	.005	.032	.061	.082	.096	.106	.112	.116	.119	.120
6.50	0.000	.002	.020	.044	.064	.079	.090	.097	.102	.106	.109
7.00	0.000	.001	.012	.031	.049	.064	.075	.083	.089	.094	.097
7.50	0.000	.000	.007	.021	.037	.051	.062	.070	.077	.082	.086
8.00	0.000	.000	.004	.014	.027	.040	.050	.059	.066	.072	.076
8.50	0.000	.000	.002	.009	.020	.030	.040	.049	.056	.062	.067
9.00	0.000	.000	.001	.006	.014	.023	.032	.040	.047	.053	.058
9.50	0.000	.000	.001	.004	.010	.017	.025	.032	.039	.045	.050
10.00	0.000	.000	.000	.002	.007	.013	.019	.026	.032	.037	.042

Figure 6-21. Table of lateral spreading coefficients - Keithsburg.

-10.00	0	0	0	0	0	0	1	1	2	2	2
-9.50	0	0	0	0	0	1	1	2	2	2	3
-9.00	0	0	0	0	0	1	2	2	2	3	3
-8.50	0	0	0	0	1	1	2	3	3	3	4
-8.00	0	0	0	0	1	2	3	3	4	4	4
-7.50	0	0	0	1	2	3	3	4	4	5	5
-7.00	0	0	0	2	3	4	4	5	5	5	5
-6.50	0	0	1	2	4	5	5	6	6	6	6
-6.00	0	0	2	4	5	6	6	7	7	7	7
-5.50	0	0	3	5	6	7	7	8	8	8	8
-5.00	0	1	4	7	8	8	9	9	9	8	8
-4.50	0	2	7	9	10	10	10	10	10	9	9
-4.00	0	5	9	11	11	11	11	11	10	10	10
-3.50	0	8	12	13	13	13	12	12	11	11	10
-3.00	0	13	16	16	15	14	14	13	12	12	11
-2.50	0	18	19	18	17	16	15	14	13	12	11
-2.00	0	25	23	20	18	17	16	14	13	13	12
-1.50	75	31	26	22	20	13	16	15	14	13	12
-1.00	75	37	29	24	21	19	17	15	14	13	13
-.50	75	41	30	25	21	19	17	16	15	14	13
0.00	75	42	31	25	22	19	17	16	15	14	13
.50	75	41	30	25	21	19	17	16	15	14	13
1.00	75	37	29	24	21	19	17	15	14	13	13
1.50	75	31	26	22	20	18	16	15	14	13	12
2.00	0	25	23	20	18	17	16	14	13	13	12
2.50	0	18	19	18	17	16	15	14	13	12	11
3.00	0	13	16	16	15	14	14	13	12	12	11
3.50	0	8	12	13	13	13	12	12	11	11	10
4.00	0	5	9	11	11	11	11	11	10	10	10
4.50	0	2	7	9	10	10	10	10	10	9	9
5.00	0	1	4	7	8	8	9	9	9	8	8
5.50	0	0	3	5	6	7	7	8	8	8	8
6.00	0	0	2	4	5	6	6	7	7	7	7
6.50	0	0	1	2	4	5	5	6	6	6	6
7.00	0	0	0	2	3	4	4	5	5	5	5
7.50	0	0	0	1	2	3	3	4	4	5	5
8.00	0	0	0	0	1	2	3	3	4	4	4
8.50	0	0	0	0	1	1	2	3	3	3	4
9.00	0	0	0	0	0	1	2	2	2	3	3
9.50	0	0	0	0	0	1	1	2	2	2	3
10.00	0	0	0	0	0	0	1	1	2	2	2
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

$U = 0.4$ m/sec — Sand 2%

$W_s = 0.012$ m/sec — Silt 67%

$E_z = 0.03\ m^2/sec$ — Clay 31%

Figure 6-22. Sediment concentration distribution in horizontal plane at the surface - Keithsburg.

-10.00	0	0	0	0	0	0	1	1	2	2	2
-9.50	0	0	0	0	0	1	1	2	2	2	3
-9.00	0	0	0	0	0	1	2	2	3	3	3
-8.50	0	0	0	0	1	2	2	3	3	3	4
-8.00	0	0	0	1	1	2	3	3	4	4	4
-7.50	0	0	0	1	2	3	4	4	5	5	5
-7.00	0	0	0	2	3	4	5	5	5	6	6
-6.50	0	0	1	3	4	5	6	6	6	6	6
-6.00	0	0	2	4	5	6	7	7	7	7	7
-5.50	0	0	3	5	7	7	8	8	8	8	8
-5.00	0	1	5	7	8	9	9	9	9	9	9
-4.50	0	2	7	9	10	10	10	10	10	10	9
-4.00	0	5	10	11	12	12	12	11	11	10	10
-3.50	0	8	13	14	14	13	13	12	12	11	11
-3.00	0	13	16	16	16	15	14	13	13	12	11
-2.50	0	19	20	19	18	16	15	14	13	13	12
-2.00	0	26	24	21	19	18	16	15	14	13	12
-1.50	75	33	27	23	21	19	17	16	15	14	13
-1.00	75	38	30	25	22	19	18	16	15	14	13
-.50	75	42	31	26	22	20	18	16	15	14	13
0.00	75	44	32	26	23	20	18	16	15	14	13
.50	75	42	31	26	22	20	18	16	15	14	13
1.00	75	38	30	25	22	19	18	16	15	14	13
1.50	75	33	27	23	21	19	17	16	15	14	13
2.00	0	26	24	21	19	18	16	15	14	13	12
2.50	0	19	20	19	18	16	15	14	13	13	12
3.00	0	13	16	16	16	15	14	13	13	12	11
3.50	0	8	13	14	14	13	13	12	12	11	11
4.00	0	5	10	11	12	12	12	11	11	10	10
4.50	0	2	7	9	10	10	10	10	10	10	9
5.00	0	1	5	7	8	9	9	9	9	9	9
5.50	0	0	3	5	7	7	8	8	8	8	8
6.00	0	0	2	4	5	6	7	7	7	7	7
6.50	0	0	1	3	4	5	6	6	6	6	6
7.00	0	0	0	2	3	4	5	5	5	6	6
7.50	0	0	0	1	2	3	4	4	5	5	5
8.00	0	0	0	1	1	2	3	3	4	4	4
8.50	0	0	0	0	1	2	2	3	3	3	4
9.00	0	0	0	0	0	1	2	2	3	3	3
9.50	0	0	0	0	0	1	1	2	2	2	3
10.00	0	0	0	0	0	0	1	1	2	2	2
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

U = 0.4 m/sec
W_s = 0.012 m/sec
E_z = 0.03 m^2/sec

Sand 2%
Silt 67%
Clay 31%

Figure 6-23. Sediment concentration distribution in horizontal plane at depth of 0.4 m - Keithsburg.

-10.00	0	0	0	0	0	0	1	1	2	2	2
-9.50	0	0	0	0	0	1	1	2	2	2	3
-9.00	0	0	0	0	0	1	2	2	3	3	3
-8.50	0	0	0	0	1	2	2	3	3	4	4
-8.00	0	0	0	1	1	2	3	3	4	4	4
-7.50	0	0	0	1	2	3	4	4	5	5	5
-7.00	0	0	0	2	3	4	5	5	5	6	6
-6.50	0	0	1	3	4	5	6	6	6	6	7
-6.00	0	0	2	4	5	6	7	7	7	7	7
-5.50	0	0	3	5	7	7	8	8	8	8	8
-5.00	0	1	5	7	8	9	9	9	9	9	9
-4.50	0	3	7	9	10	10	10	10	10	10	10
-4.00	0	5	10	11	12	12	12	11	11	11	10
-3.50	0	8	13	14	14	14	13	13	12	11	11
-3.00	0	13	17	17	16	15	14	14	13	12	12
-2.50	0	19	20	19	18	17	15	14	14	13	12
-2.00	0	26	24	22	20	18	16	15	14	13	13
-1.50	75	33	27	24	21	19	17	16	15	14	13
-1.00	75	39	30	25	22	20	18	16	15	14	13
-.50	75	43	32	26	23	20	18	17	15	14	13
0.00	75	44	33	27	23	20	18	17	15	14	13
.50	75	43	32	26	23	20	18	17	15	14	13
1.00	75	39	30	25	22	20	18	16	15	14	13
1.50	75	33	27	24	21	19	17	16	15	14	13
2.00	0	26	24	22	20	18	16	15	14	13	13
2.50	0	19	20	19	18	17	15	14	14	13	12
3.00	0	13	17	17	16	15	14	14	13	12	12
3.50	0	8	13	14	14	14	13	13	12	11	11
4.00	0	5	10	11	12	12	12	11	11	11	10
4.50	0	3	7	9	10	10	10	10	10	10	10
5.00	0	1	5	7	9	9	9	9	9	9	9
5.50	0	0	3	5	7	7	8	8	8	8	8
6.00	0	0	2	4	5	6	7	7	7	7	7
6.50	0	0	1	3	4	5	6	6	6	6	7
7.00	0	0	0	2	3	4	5	5	5	6	6
7.50	0	0	0	1	2	3	4	4	5	5	5
8.00	0	0	0	1	1	2	3	3	4	4	4
8.50	0	0	0	0	1	2	2	3	3	4	4
9.00	0	0	0	0	0	1	2	2	3	3	3
9.50	0	0	0	0	0	1	1	2	2	2	3
10.00	0	0	0	0	0	0	1	1	2	2	2
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

$U = 0.4$ m/sec — Sand 2%

$W_s = 0.012$ m/sec — Silt 67%

$E_z = 0.03\ m^2/sec$ — Clay 31%

Figure 6-24. Sediment concentration distribution in horizontal plane at depth of 0.8 m - Keithsburg.

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-10.00	0	0	0	0	0	0	1	1	2	2	2
-9.50	0	0	0	0	0	1	1	2	2	2	3
-9.00	0	0	0	0	0	1	2	2	3	3	3
-8.50	0	0	0	0	1	2	2	3	3	4	4
-8.00	0	0	0	1	1	2	3	3	4	4	4
-7.50	0	0	0	1	2	3	4	4	5	5	5
-7.00	0	0	0	2	3	4	5	5	5	6	6
-6.50	0	0	1	3	4	5	6	6	6	7	7
-6.00	0	0	2	4	5	6	7	7	7	7	7
-5.50	0	0	3	5	7	8	8	8	8	8	8
-5.00	0	1	5	7	8	9	9	9	9	9	9
-4.50	0	3	7	9	10	11	11	10	10	10	10
-4.00	0	5	10	12	12	12	12	12	11	11	10
-3.50	0	9	13	14	14	14	13	13	12	12	11
-3.00	0	13	17	17	16	15	14	14	13	12	12
-2.50	0	19	21	19	18	17	16	15	14	13	12
-2.00	0	26	24	22	20	18	17	15	14	13	13
-1.50	75	33	28	24	21	19	17	16	15	14	13
-1.00	75	39	30	25	22	20	18	17	15	14	13
-.50	75	43	32	27	23	20	18	17	16	14	14
0.00	75	45	33	27	23	20	18	17	16	15	14
.50	75	43	32	27	23	20	18	17	16	14	14
1.00	75	39	30	25	22	20	18	17	15	14	13
1.50	75	33	28	24	21	19	17	16	15	14	13
2.00	0	26	24	22	20	18	17	15	14	13	13
2.50	0	19	21	19	18	17	16	15	14	13	12
3.00	0	13	17	17	16	15	14	14	13	12	12
3.50	0	9	13	14	14	14	13	13	12	12	11
4.00	0	5	10	12	12	12	12	12	11	11	10
4.50	0	3	7	9	10	11	11	10	10	10	10
5.00	0	1	5	7	8	9	9	9	9	9	9
5.50	0	0	3	5	7	8	8	8	8	8	8
6.00	0	0	2	4	5	6	7	7	7	7	7
6.50	0	0	1	3	4	5	6	6	6	7	7
7.00	0	0	0	2	3	4	5	5	5	6	6
7.50	0	0	0	1	2	3	4	4	5	5	5
8.00	0	0	0	1	1	2	3	3	4	4	4
8.50	0	0	0	0	1	2	2	3	3	4	4
9.00	0	0	0	0	0	1	2	2	3	3	3
9.50	0	0	0	0	0	1	1	2	2	2	3
10.00	0	0	0	0	0	0	1	1	2	2	2

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec — Sand 2%

$W_s = 0.012$ m/sec — Silt 67%

$E_z = 0.03\ m^2/sec$ — Clay 31%

Figure 6-25. Sediment concentration distribution in horizontal plane at depth of 1.2 m.- Keithsburg.

-10.00	0	0	0	0	0	0	1	1	2	2	2
-9.50	0	0	0	0	0	1	1	2	2	2	3
-9.00	0	0	0	0	0	1	2	2	3	3	3
-8.50	0	0	0	0	1	2	2	3	3	4	4
-8.00	0	0	0	1	1	2	3	4	4	4	5
-7.50	0	0	0	1	2	3	4	4	5	5	5
-7.00	0	0	0	2	3	4	5	5	6	6	6
-6.50	0	0	1	3	4	5	6	6	6	7	7
-6.00	0	0	2	4	5	6	7	7	7	7	7
-5.50	0	0	3	5	7	8	8	8	8	8	8
-5.00	0	1	5	7	8	9	9	9	9	9	9
-4.50	0	3	7	9	10	11	11	11	10	10	10
-4.00	0	5	10	12	12	12	12	12	11	11	10
-3.50	0	9	13	14	14	14	13	13	12	12	11
-3.00	0	13	17	17	16	15	15	14	13	12	12
-2.50	0	20	21	20	18	17	16	15	14	13	12
-2.00	0	27	24	22	20	18	17	15	14	14	13
-1.50	75	33	28	24	21	19	18	16	15	14	13
-1.00	75	39	31	26	22	20	18	17	15	14	13
-.50	75	44	32	27	23	20	19	17	16	15	14
0.00	75	45	33	27	23	21	19	17	16	15	14
.50	75	44	32	27	23	20	19	17	16	15	14
1.00	75	39	31	26	22	20	18	17	15	14	13
1.50	75	33	28	24	21	19	18	16	15	14	13
2.00	0	27	24	22	20	18	17	15	14	14	13
2.50	0	20	21	20	19	17	16	15	14	13	12
3.00	0	13	17	17	16	15	15	14	13	12	12
3.50	0	9	13	14	14	14	13	13	12	12	11
4.00	0	5	10	12	12	12	12	12	11	11	10
4.50	0	3	7	9	10	11	11	11	10	10	10
5.00	0	1	5	7	8	9	9	9	9	9	9
5.50	0	0	3	5	7	8	8	8	8	8	8
6.00	0	0	2	4	5	6	7	7	7	7	7
6.50	0	0	1	3	4	5	6	6	6	7	7
7.00	0	0	0	2	3	4	5	5	6	6	6
7.50	0	0	0	1	2	3	4	4	5	5	5
8.00	0	0	0	1	1	2	3	4	4	4	5
8.50	0	0	0	0	1	2	2	3	3	4	4
9.00	0	0	0	0	0	1	2	2	3	3	3
9.50	0	0	0	0	0	1	1	2	2	2	3
10.00	0	0	0	0	0	0	1	1	2	2	2
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

$U = 0.4$ m/sec — Sand 2%

$W_s = 0.012$ m/sec — Silt 67%

$E_z = 0.03$ m^2/sec — Clay 31%

Figure 6-26. Sediment concentration distribution in horizontal plane at depth of 1.6 m - Keithsburg.

of the horizontal distributions. A graphical presentation of the horizontal distribution at the depth of 1.2 m is given in Figure 6-27. It is interesting to note that due to the low concentration of sand and the relatively high dispersion coefficient, the turbidity plume spreads very rapidly.

Figure 6-28 presents the variation of the maximum sediment concentration with distance downstream together with the field data. The agreement of the model prediction and the field measurements is quite good.

A complete set of horizontal sediment distributions at the depth of 1.2 m is given in tabular form in Appendix F. In these studies, the stream velocity, the percentages of sand, silt and clay in the sediment, and the fall velocity of the sand were varied. For some of these studies, the lateral dispersion coefficient and the initial sediment concentration also were varied. As mentioned earlier, the reflection principle must be applied to interpret these results for bank disposal.

The distributions are separated according to sediment composition. For each sediment composition, sand fall velocities of 0.007 m/sec, 0.012 m/sec, and 0.015 m/sec are studied. For each fall velocity, river velocities of 0.2 m/sec, 0.4 m/sec, and 0.8 m/sec are considered. In some cases the magnitude of the lateral dispersion factor and/or the initial sediment concentration also were varied.

It should be noted that even though an implicit finite-difference scheme was used to calculate the vertical sediment distribution, some of the numerical results are seen to be unstable. See, for example,

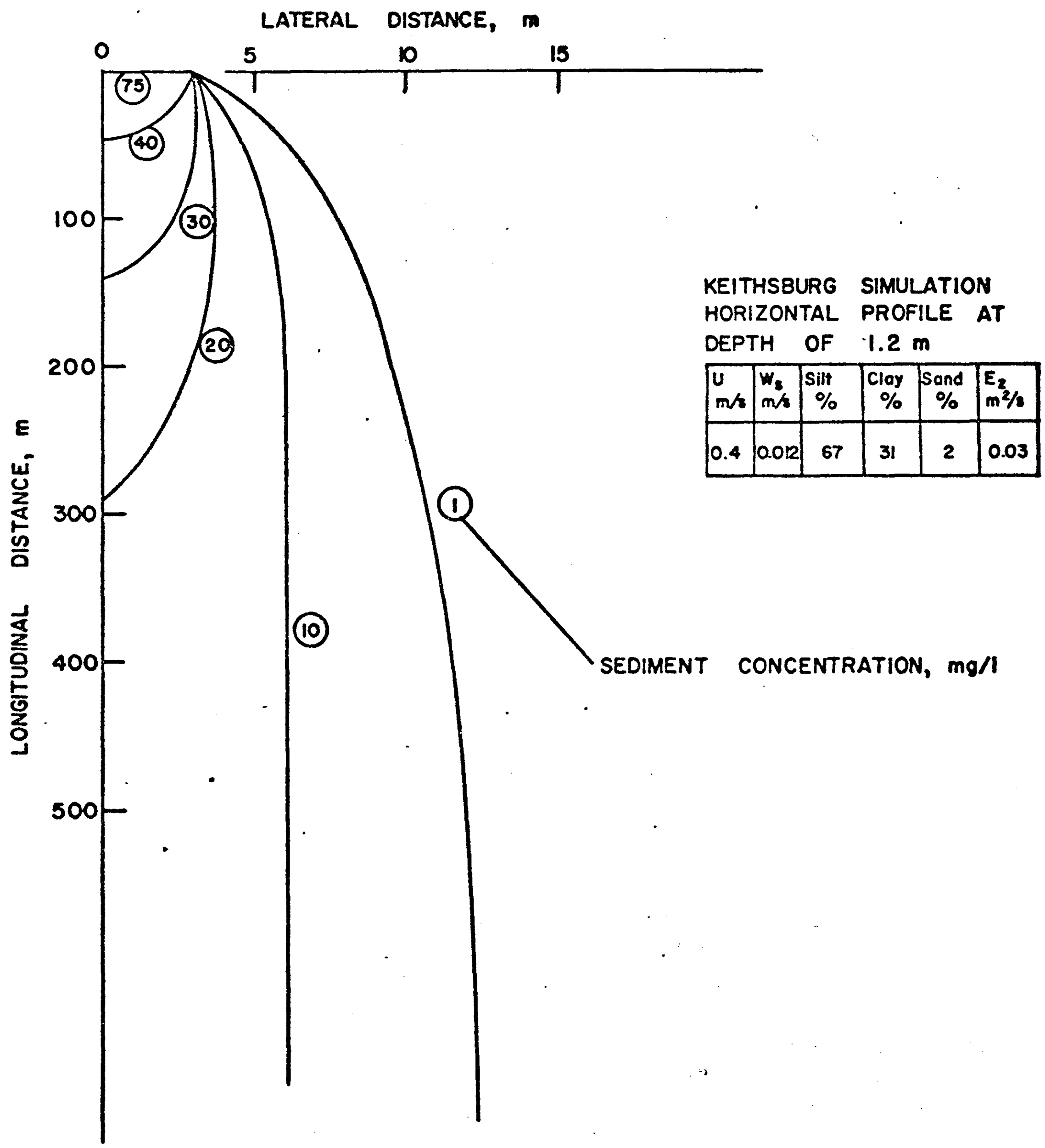


Figure 6-27. Numerical simulation of disposal plume at depth of 1.2 m - Keithsburg, Illinois.

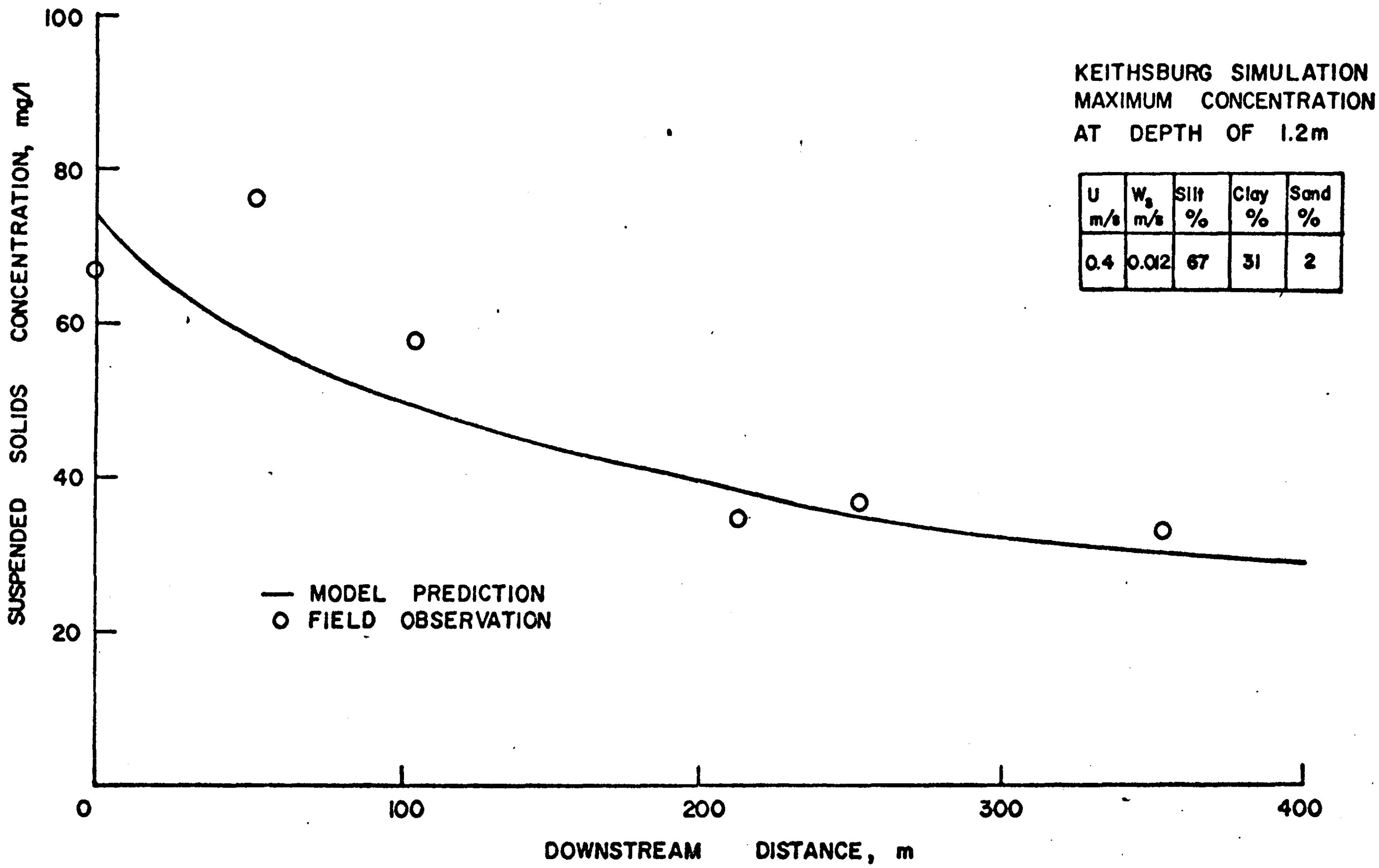


Figure 6-28. Line of maximum sediment concentration at depth of 1.2 m - Keithsburg, Illinois.

the results for a sand fall velocity of 0.015 m/sec coupled with a stream velocity of 0.2 m/sec. The combination of the relatively high settling velocity of the sand and the low stream velocity yields very high concentration gradients which lead to the instability. Another example of instability is shown on the last page of this appendix where a high sand fall velocity, W_s = 0.03 m/sec, is coupled with a sediment which is almost all sand (95 percent) and a relatively low river velocity, U = 0.4 m/sec. Results are not reliable in these instances.

This appendix can be used most effectively to compare results with different values of the governing variables. It can be seen that higher river velocities lead to higher sediment concentrations downstream from the source. It also is seen that higher sand fall velocities lead to lower sediment concentrations downstream. Increasing the magnitude of the lateral dispersion factor is seen to increase the lateral spread of the plume.

Appendix F is organized in three parts. The sediment composition of the first 11 simulations was 45% sand, 25% silt, and 30% clay. This composition was characteristic of a medium grain sand ($\sim$370 μ) which was pumped onto the beach and which immediately returns to the main channel of the river. This was typical of the beach nourishment type of disposal operation at Rock Island (Figure 4-6). At the shore line the sediment size distribution was 95% sand (Table 4-1), but by the time it entered the river, it was estimated at 45% sand, 25% silt, and 30% clay. This is the maximum percentage of sand that one would expect to measure in the River near the beginning of the plume. By measuring the dredged material size distribution and the river velocity, one could find a figure in the Appendix F of similar characteristics and thereby estimate the extent and magnitude of the suspended solids plume. A lateral dispersion coefficient, E_z, of 0.044 m^2/sec is suggested.

The second set of plots in Appendix F is for a sediment composition of 2% sand, 67% silt, and 30% clay, and was characteristic of the dredge disposal operation at Keithsburg (Figure 4-5). For this case, the discharge ran across Willow Bar Island and lost all but 1.8% of its sand (see Table 4-1). Once again if the stream velocity is known for a similar case, the suspended solids plume could be chosen from the 11 at that sediment composition in Appendix F. Also available are 10 simulations at an intermediate sediment composition of 20% sand, 25% silt, and 55% clay which might be representative of an island disposal operation which rapidly returns to the channel.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

Field studies were conducted on three dredged sites (Hannibal, Missouri; Keithsburg, Illinois and Rock Island, Illinois). Turbidity and suspended solids measurements were taken 0 - 500 m downstream from the discharge site. Excess turbidities in the plume ranged from 0 - 33 nephelometric turbidity units (NTU) while excess suspended solids were 0 - 125 mg/l. The plumes were shore-attached and near shore concentrations (centerlines) were measurable as far as 500 m (at Rock Island) and were less than 75 m wide.

Each dredging disposal operation was unique depending on whether it was a beach nourishment or island disposal type of operation. The island disposal operation at Hannibal was entirely impounded with no return water discharge whatsoever. It is felt that the "worst case" beach nourishment disposal condition was monitored at Rock Island. Only if the sediment were finer grained silt and clay would a greater suspended solids plume develop.

Channel maintenance dredging at the three sites did not violate Iowa Water Quality Standards of 25 nephelometric turbidity units (NTU). Turbidities greater than 25 NTU were measured only at the initial point of runoff into the Mississippi River for the beach nourishment type of dredge materials disposal at Rock Island. Such short term concentrations would be within an allowable mixing zone of most State Water Quality Standards.

Three mathematical models were utilized to describe the collected field data: the Schubel-Carter (1978) model, the Wechsler-Cogley (1977) Walden Plume model, and an analytical solution developed herein. Preliminary results show that the Schubel-Carter (1978) nomogram solution is cumbersome to use for riverine conditions and involves a very time consuming trial and error technique to calculate the correct initial suspended solids concentration at the point of discharge. The Wechsler-Cogley (1977) Walden Plume computer model has proven to have several advantages over the Schubel and Carter approach. First, it is possible to use a plane source discharge which is more realistic than a line source as in Schubel and Carter (1978). Secondly it can handle several size fractions easily and the computations are quickly facilitated by digital computer. The analytical solution developed herein utilizes probability density function tables and is easier to understand than the numerical solution of Wechsler and Cogley, but it does require extensive hand calculations.

The Walden Plume model and the analytical solution developed herein were successfully used to simulate the shore-attached centerline of the dredge disposal operations at Keithsburg and Rock Island. It is recommended that these 2 models be used in future modeling efforts.

Lateral concentration variations were not well described due to insufficient field data as well as a lack of knowledge of the lateral dispersion coefficients under these conditions. It is therefore recommended that further studies be undertaken to better delineate the lateral dispersion phenomena as well as the initial mixing and density-dependent settling at the head of the plume. Furthermore a worst case of beach mourishment disposal at a site with silt or clay sediment should be monitored if such a situation arises.

Each of the two models employed have relative advantages. The analytical solution was conveniently utilized to provide estimates of the *in-situ* dilution factors for dissolved constituents as well as the expected rate and depth of sedimented material in the River. The Walden Plume model was used to generate a range of solutions for dredge disposal operations provided in Appendix F. If a planner or engineer knows the grain size distribution of the material to be dredged, the approximate river velocity, and the mean depth of the discharge area, it is possible to locate a graph in Appendix F of similar conditions and to predict the extent and concentration of the suspended solids plume.

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APPENDIX A

ANALYTICAL MODEL PROGRAM FOR HEWLETT-PACKARD 29C

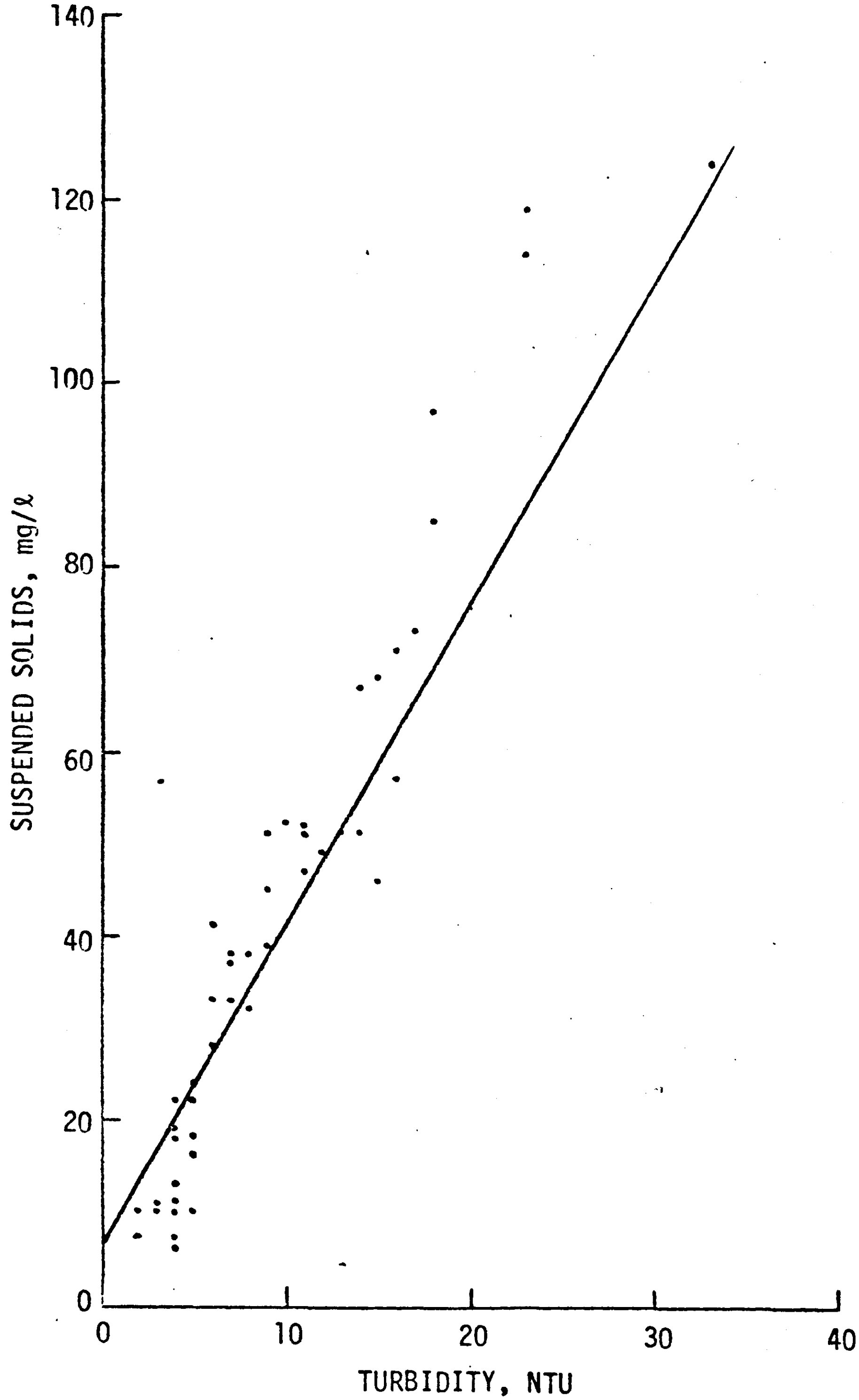

Figure D-2. Suspended solids vs. turbidity relationship for Rock Island field data. All values are expressed as mg/ℓ or NTU above ambient.

APPENDIX E

WALDEN PLUME MODEL

COMPUTER PROGRAM

```
      PROGRAM PLUME(INPUT,OUTPUT,OUTPLM,TAPE5=INPUT,TAPE6=OUTPUT,
+     TAPE8=OUTPLM)
C
C
C     PROGRAM SOURCE   A LABORATORY STUDY OF THE TURBIDITY
C     GENERATION POTENTIAL OF SEDIMENTS TO BE DREDGED,  BY
C     B.A. WECHSLER & D.R. COGLEY, TECH. REPORT D-77-14,
C     U.S. ARMY ENGINEEER WATERWAYS EXPERIMENT STATION, NOV. 1977
C
C
C     WALDEN PLUME MODEL
C     *****************************************************************
C     ASSUMPTIONS INCLUDE STEADY STATE, NO MOMENTUM EFFECTS
C     AND NO RESUSPENSION OF MATERIAL
C
C     *****************************************************************
C     THIS PROGRAM CONTAINS A SUBROUTINE FROM THE IMSL LIBRARY, A
C     PROPRIETARY PACKAGE FROM THE INTERNATIONAL MATHEMATICAL &
C     STATISTICAL LIBRARIES, INC., HOUSTON, TEXAS.  THIS ROUTINE MAY
C     NOT BE REDISTRIBUTED OR REMOVED FROM THIS SOFTWARE FOR USE IN
C     OTHER SOFTWARE DEVELOPMENT.  THE IMSL ROUTINE INCLUDED IS  ERF.
C     *****************************************************************
C
      REAL IA,MA,ML,IIA
      DOUBLE PRECISION B8,MP
      DIMENSION C(20,51),D(20,20),IA(20,20),MA(20,20),RL(400)
      DIMENSION RA(20,20),CJ(20),ML(400),B(20),MP(400),IIA(20,20)
      DIMENSION ADELX(51),ADELY(20),Z(21,51),AVG(51),CSUM(20,51)
      DIMENSION AVGSUM(51),B8(20),IOUT(51)
      DATA CSUM/1020*0./
      DATA IA/400*0./,D/400*0./,IIA/400*0./,Z/1050*0./,AVGSUM/51*0./
C     STATEMENT FUNCTION TO CALCULATE EDDY DIFFUSIVITY AT ANY DEPTH
      E(Y)=0.02*U*Y*(1.-Y/H)
      DO 10 I=1,20
      IA(I,I)=1.
      IIA(I,I)=-1.
      IF (I.GT.1) IIA(I,I-1)=1.
   10 CONTINUE
      NSED=1
C     NO. OF SED. FRACTIONS............
      READ*,NSEDF
C ***************************************************************
C     U=STREAM VELOCITY,M/SEC       W=SETTLING VELOCITY,M/SEC
C     H=STREAM DEPTH , M            CO=CONCENTRATION OF SED. FRACTION
C     NSTEP=NO.OF DOWNSTREAM STEPS XL=INITIAL DISCHARGE HALF-WIDTH,M
C     DELZ=LATERAL STEP SIZE,M.
C ***************************************************************
C     PROGRAM CONTROL IS TRANSFERRED HERE FOR EACH SED.FRACTION
   11 IF(NSED .LE. NSEDF) READ*,U,W,H,CO,NSTEP,XL,DELZ
      IF(NSED .GT. NSEDF) GO TO 99
C     XN=NUMBER OF DEPTHS
      XN=20
      THETA=1.0
      IF (NSTEP.GT.50) NSTEP=50
      NSTEP1=NSTEP+1
      WRITE(8,1001) U,W,H,CO,NSTEP,XL,DELZ
 1001 FORMAT(//2X,*INPUT-   *,*U =*,F6.2,2X,*W =*,F8.6,2X,
+     *H =*,F5.1,2X,*CO =*,F6.2,2X,*NSTEP =*,I5,2X,
+     *XL =*,F5.2/,*  DELZ =*,F6.2//)
      N=XN
```

```
C     LONGITUDINAL STEP SIZE...........
      DELX=10.
C     VERTICAL STEP SIZE..............
      DELY=H/XN
      CONZ=2.2
      DELI2=1./(DELY*DELY)
      AVGSUM(1)=AVGSUM(1)+CO
      INC=1
      DO 501 J=1,NSTEP1
      ADELX(J)=(J-1)*DELX
      AVG(J)=0.
  501 CONTINUE
      DO 500 I=1,N
      ADELY(I)=(I-1)*DELY
      IF ((I-1)*DELZ.LE.XL) Z(I,1)=1.
  500 CONTINUE
C     CALCULATE LATERAL EDDY DIFFUSIVITY,EQ.(5)
      EZ=0.005*H*U*CONZ
      FOREZ=4.*EZ
C     CALCULATE CONCENTRATION DUE TO LATERAL DISPERSION
      DO 680 J=1,NSTEP
      FOREX=SQRT(ADELX(J+1)*FOREZ)
      DO 680 IZ=1,21
      AZ=(IZ-1)*DELZ
      TOP=(AZ+XL)/FOREX
      ET=ERF(TOP)
      BOT=(AZ-XL)/FOREX
      EB=ERF(BOT)
      Z(IZ,J+1)=0.5*(ET-EB)
  680 CONTINUE
C     START FINITE DIFFERENCE SOLUTION.......
      DO 100 I=1,20
      C(I,1)=CO
  100 CONTINUE
      AVG(1)=CO
      D(1,1)=-E(1.5*DELY)
      D(1,2)=E(1.5*DELY)
      N1=N-1
C     CALCULATE EDDY DIFFUSIVITY AT VARIOUS DEPTHS
      DO 200 I=2,N1
      X1=(2*I-1)*.5*DELY
      X2=(2*I+1)*.5*DELY
      D(I,I-1)=E(X1)
      D(I,I)=-E(X1)-E(X2)
      D(I,I+1)=E(X2)
  200 CONTINUE
      D(N,N)=-E((XN-.5)*DELY)
      D(N,N-1)=-D(N,N)
      DO 300 I=1,N
      DO 300 J=1,N
      D(I,J)=DELI2*D(I,J)
C     CALCULATE COEFFICIENTS OF SYSTEM OF EQ. RESULTING FROM
C     FINITE DIFFERENCE SOLUTION
      MA(I,J)=U/DELX*IA(I,J)-THETA*D(I,J)
      RA(I,J)=U/DELX*IA(I,J)+(1.-THETA)*D(I,J)+W*IIA(I,J)/DELY
  300 CONTINUE
      CALL ARRAY(2,N,N,20,20,ML,MA)
      CALL ARRAY(2,N,N,20,20,RL,RA)
      DO 400 J=1,NSTEP
      DO 405 I=1,N
      CJ(I)=C(I,J)
```

```
          CSUM(I,J)=CSUM(I,J)+CJ(I)
     405  CONTINUE
C         FINAL SOLUTION BY COMBINATION OF ANALYTIC AND NUM. SOLUTIONS
          CALL GMPRD(RL,CJ,B,N,N,1)
          DO 406 I=1,400
          MP(I)=ML(I)
     406  CONTINUE
          DO 407 I=1,20
          B8(I)=B(I)
     407  CONTINUE
C         SOLVE SYSTEM OF EQUATIONS......
          CALL DGELG(B8,MP,N,1,.000000001,IER)
          IF (IER.GT.0) WRITE(6,4747) IER,J
    4747  FORMAT(* LOSS OF SIGNIFICANCE AT PIVOT  *,I3,* IN STEP *,I3)
          DO 399 K=1,N
          C(K,J+1)=B8(K)
          AVG(J+1)=B8(K)+AVG(J+1)
     399  CONTINUE
          AVG(J+1)=AVG(J+1)  /XN
          AVGSUM(J+1)=AVGSUM(J+1)+AVG(J+1)
     400  CONTINUE
          WRITE(8,5001) (ADELX(I),I=1,NSTEP1,5)
    5001  FORMAT(11X,20F6.1,/)
          DO 410 I=1,N
          CSUM(I,NSTEP1)=CSUM(I,NSTEP1)+C(I,NSTEP1)
          WRITE(8,5000) ADELY(I),(C(I,J),J=1,NSTEP1,5)
    5000  FORMAT(3X,F5.2,2X,20F6.2)
     410  CONTINUE
          WRITE(8,5003)    (AVG(KKK),KKK=1,NSTEP1,5)
    5003  FORMAT(4X,*AVG*,3X,20F6.2)
          WRITE(8,6667)
          NSED=NSED+1
          GO TO 11
      99  CONTINUE
C         OUTPUT....FINAL RESULTS
          WRITE(8,5005)
    5005  FORMAT(1H1,//T40,*SUMMATION OF SUSPENDED SEDIMENTS*)
          WRITE(8,5001) (ADELX(I),I=1,NSTEP1,5)
          DO 412 I=1,N
          WRITE(8,5000) ADELY(I),(CSUM(I,J),J=1,NSTEP1,5)
     412  CONTINUE
          WRITE(8,5003)    (AVGSUM(KKK),KKK=1,NSTEP1,5)
          WRITE(8,6668)
    6668  FORMAT(1H1)
          DO 411 I=1,21
          AZ=(I-1)*DELZ
          WRITE(8,5002) AZ,(Z(I,J),J=1,NSTEP1,5)
    5002  FORMAT(4X,F5.2,2X,20F6.3)
     411  CONTINUE
          DO 800 IY=1,20,4
          YVAL=(IY-1)*DELY
          WRITE(8,5555) YVAL
    5555  FORMAT(1H1,////,T7,*DISTRIBUTION OF SEDIMENT IN HORIZONTAL *,
+         *PLANE AT DEPTH*,F6.2,* M    (MG/L)*,//)
          DO 810 IZ=1,21
          IAZ=22-IZ
          AZ=(-DELZ*(IAZ-1))
          DO 801 IX=1,NSTEP1,INC
          IOUT(IX)=(CSUM(IY,IX)*Z(IAZ,IX)*1000.+0.5)/800
     801  CONTINUE
          WRITE(8,6666) AZ,(IOUT(KKK),KKK=1,NSTEP1,5)
```

```
 6666 FORMAT(2X,F6.2,2X,20I6)
  810 CONTINUE
      DO 802 IZ=2,21
      AZ=DELZ*(IZ-1)
      DO 803 IX=1,NSTEP1,INC
      IOUT(IX)=(CSUM(IY,IX)*Z(IZ,IX)*1000.+0.5)/800
  803 CONTINUE
      WRITE(8,6666) AZ,(IOUT(KKK),KKK=1,NSTEP1,5)
  802 CONTINUE
      WRITE(8,6667)
 6667 FORMAT(//)
      WRITE(8,5001) (ADELX(KKK),KKK=1,NSTEP1,5)
  800 CONTINUE
      STOP
      END
      SUBROUTINE ARRAY(MODE,I,J,N,M,S,D)
C     *****************************************************************
C     CONVERTS DATA ARRAY FROM SINGLE TO DOUBLE PRECISION OR VICE-VERSA
C     *****************************************************************
C     MODE=1 - FROM SINGLE TO DOUBLE PRECISICN
C     MODE=2 - DOUBLE PRECISION TO SINGLE
C     I= - ROWS IN DATA MATRIX
C     J= - COLUMNS IN DATA MATRIX
C     N= - ROWS SPECIFIED IN DIMENSION STATEMENT FOR MATRIX D
C     M= - COLUMNS SPECIFIED IN DIMENSION STATEMENT
C     *****************************************************************
      DIMENSION S(1),D(1)
      NI=N-I
      IF(MODE-1)100,100,120
  100 IJ=I*J+1
      NM=N*J+1
      DO 110 K=1,J
      NM=NM-NI
      DO 110 L=1,I
      IJ=IJ-1
      NM=NM-1
  110 D(NM)=S(IJ)
      GO TO 140
  120 IJ=0
      NM=0
      DO 130 K=1,J
      DO 125 L=1,I
      IJ=IJ+1
      NM=NM+1
  125 S(IJ)=D(NM)
  130 NM=NM+NI
  140 RETURN
      END
      SUBROUTINE GMPRD(A,B,R,N,M,L)
C     *****************************************************************
C     MULTIPLIES TWO MATRICES TO FORM NEW MATRIX
C     *****************************************************************
C     A= - FIRST MATRIX
C     B= - SECOND MATRIX
C     R= - OUTPUT MATRIX
C     N= - ROWS IN A
C     M= - COLUMNS IN A
C     L= - COLUMNS IN B
C     *****************************************************************
      DIMENSION A(1),B(1),R(1)
      IR=0
```

```
      IK=-M
      DO 10 K=1,L
      IK=IK+M
      DO 10 J=1,N
      IR=IR+1
      JI=J-N
      IB=IK
      R(IR)=0
      DO 10 I=1,M
      JI=JI+N
      IB=IB+1
   10 R(IR)=R(IR)+A(JI)*B(IB)
      RETURN
      END
      SUBROUTINE DGELG(R,A,M,N,EPS,IER)
C     ******************************************************************
C     TO SOLVE A GENERAL SYSTEM OF LINEAR EQUATIONS
C     R - DOUBLE PRECISION M X N RIGHT HAND SIDE MATRIX
C     A - DOUBLE PREDISION M X N COEFF MATRIX
C     M - NO OF EQUATIONS
C     N - NUMBER OF RIGHT HAND SIDE VECTORS
C     EPS - TOLERANCE FOR TEST
C     IER = 0 - NO ERROR
C           -1 - NO RESULT BECAUSE M LESS THAN 1 OR PIVOT ELEMENT =0
C           K - WARNING DUE TO POSSIBLE LOSS OF SIGNIFICANCE INDICATED
C     ******************************************************************
      DIMENSION A(1),R(1)
      DOUBLE PRECISION R,A,PIV,TB,TOL,PIVI
      IF(M) 23,23,1
C
C     SEARCH FOR GREATEST ELEMENT IN A
    1 IER=0
      PIV=0.D0
      MM=M*M
      NM=N*M
      DO 3 L=1,MM
      TB=DABS(A(L))
      IF(TB-PIV)3,3,2
    2 PIV=TB
      I=L
    3 CONTINUE
      TOL=EPS*PIV
C
C     A(I) IS PIVOT ELEMENT
C     START ELIMINATION LOOP
      LST=1
      DO 17 K=1,M
C
C     TEST ON SINGULARITY
      IF(PIV) 23,23,4
    4 IF(IER)7,5,7
    5 IF(PIV-TOL)6,6,7
    6 IER=K-1
    7 PIVI=1.D0/A(I)
      J=(I-1)/M
      I=I-J*M-K
      J=J+1-K
C
C     I+K IS ROW INDEX, J+K COLUMN INDEX OF PIVOT ELEMENT
C     PIVOT ROW REDUCTION AND ROW INTERCHANGE IN RIGHT HAND SIDE R
      DO 8 L=K,NM,M
```

```
      LL=L+I
      TB=PIVI*R(LL)
      R(LL)=R(L)
    8 R(L)=TB
C
C     IS ELIMINATION TERMINATED
      IF(K-M)9,18,18
C
C     COLUMN INTERCHANGE IN A
    9 LEND=LST+M-K
      IF(J)12,12,10
   10 II=J*M
      DO 11 L=LST,LEND
      TB=A(L)
      LL=L+II
      A(L)=A(LL)
   11 A(LL)=TB
C     ROW INTERCHANGE AND PIVOT ROW REDUCTION IN A
   12 DO 13 L=LST,MM,M
      LL=L+I
      TB=PIVI*A(LL)
      A(LL)=A(L)
   13 A(L)=TB
C
C     SAVE COLUMN INTERCHANGE INFO
      A(LST)=J
C
C     ELEMENT REDUCTION AND NEXT PIVOT SEARCH
      PIV=0.D0
      LST=LST+1
      J=0
      DO 16 II=LST,LEND
      PIVI=-A(II)
      IST=II+M
      J=J+1
      DO 15 L=IST,MM,M
      LL=L-J
      A(L)=A(L)+PIVI*A(LL)
      TB=DABS(A(L))
      IF(TB-PIV) 15,15,14
   14 PIV=TB
      I=L
   15 CONTINUE
      DO 16 L=K,NM,M
      LL=L+J
   16 R(LL)=R(LL)+PIVI*R(L)
   17 LST=LST+M
C
C     END OF ELIMINATION LOOP
C     BACK SUBSTITUTION AND INTERCHANGE
   18 IF(M-1)23,22,19
   19 IST=MM+M
      LST=M+1
      DO 21 I=2,M
      II=LST-I
      IST=IST-LST
      L=IST-M
      L=A(L)+0.5D0
      DO 21 J=II,NM,M
      TB=R(J)
      LL=J
```

```
      DO 20 K=IST,MM,M
      LL=LL+1
   20 TB=TB-A(K)*R(LL)
      K=J+L
      R(J)=R(K)
   21 R(K)=TB
   22 RETURN
C
C     ERROR RETURN
   23 IER=-1
      RETURN
      END
C
C   IMSL ROUTINE NAME   - MERF=ERF
C
C-----------------------------------------------------------------------
C
C   PURPOSE             - EVALUATE THE ERROR FUNCTION
C
C   USAGE               - RESULT = ERF(Y)
C
C   ARGUMENTS    Y      - INPUT ARGUMENT OF THE ERROR FUNCTION.
C               ERF     - OUTPUT VALUE OF THE ERROR FUNCTION.
C
C   COPYRIGHT           - 1978 BY IMSL, INC. ALL RIGHTS RESERVED.
C
C   WARRANTY            - IMSL WARRANTS ONLY THAT IMSL TESTING HAS
C                           APPLIED TO THIS CODE. NO OTHER WARRANTY
C                           EXPRESSED OR IMPLIED, IS APPLICABLE.
C
C-----------------------------------------------------------------------
C
      REAL FUNCTION ERF(Y)
C                                  SPECIFICATIONS FOR ARGUMENTS
      REAL               Y
C                                  SPECIFICATIONS FOR LOCAL VARIABL
      INTEGER            ISW,I
      DIMENSION          P(5),Q(3),P1(8),Q1(7),P2(5),Q2(4)
      REAL               P,Q,P1,Q1,P2,Q2,XMIN,XLARGE,SSQPI,X,
     +                   RES,XSQ,XNUM,XDEN,XI
C                                  COEFFICIENTS FOR 0.0 .LE. Y .LT.
C                                  .477
      DATA               P(1)/-.44422647396874/,
     +                   P(2)/10.731707253648/,
     +                   P(3)/15.915606197771/,
     +                   P(4)/374.81624081284/,
     +                   P(5)/2.5612422994823E-02/
      DATA               Q(1)/17.903143558843/,
     +                   Q(2)/124.82892031581/,
     +                   Q(3)/332.17224470532/
C                                  COEFFICIENTS FOR .477 .LE. Y
C                                  .LE. 4.0
      DATA               P1(1)/7.2117582508831/,
     +                   P1(2)/43.162227222057/,
     +                   P1(3)/152.98928504694/,
     +                   P1(4)/339.32081673434/,
     +                   P1(5)/451.91895371187/,
     +                   P1(6)/300.45926102016/,
     +                   P1(7)/-1.3686485738272E-07/,
     +                   P1(8)/.56419551747897/
      DATA               Q1(1)/77.000152935229/,
```

```
+                         Q1(2)/277.58544474399/,
+                         Q1(3)/638.98026446563/,
+                         Q1(4)/931.35409485061/,
+                         Q1(5)/790.95092532790/,
+                         Q1(6)/300.45926095698/,
+                         Q1(7)/12.782727319629/
C                                   COEFFICIENTS FOR 4.0 .LT. Y
      DATA                P2(1)/-.22695659353969/,
+                         P2(2)/-4.9473091062325E-02/,
+                         P2(3)/-2.9961070770354E-03/,
+                         P2(4)/-2.2319245973418E-02/,
+                         P2(5)/-2.7866130860965E-01/
      DATA                Q2(1)/1.0516751070679/,
+                         Q2(2)/.19130892610783/,
+                         Q2(3)/1.0620923052847E-02/,
+                         Q2(4)/1.9873320181714/
C                                   CONSTANTS
      DATA                XMIN/1.0E-8/,XLARGE/5.6875E0/
      DATA                SSQPI/.56418958354776/
C                                   FIRST EXECUTABLE STATEMENT
      X = Y
      ISW = 1
      IF (X.GE.0.0E0) GO TO 5
      ISW = -1
      X = -X
    5 IF (X.LT..477E0) GO TO 10
      IF (X.LE.4.0E0) GO TO 25
      IF (X.LT.XLARGE) GO TO 35
      RES = 1.E0
      GO TO 50
C                                   ABS(Y) .LT. .477, EVALUATE
C                                   APPROXIMATION FOR ERF
   10 IF (X.LT.XMIN) GO TO 20
      XSQ = X*X
      XNUM = P(5)
      DO 15 I=1,4
         XNUM = XNUM*XSQ+P(I)
   15 CONTINUE
      XDEN = ((Q(1)+XSQ)*XSQ+Q(2))*XSQ+Q(3)
      RES = X*XNUM/XDEN
      GO TO 50
   20 RES = X*P(4)/Q(3)
      GO TO 50
C                                   .477 .LE. ABS(Y) .LE. 4.0
C                                   EVALUATE APPROXIMATION FOR ERF
   25 XSQ = X*X
      XNUM = P1(7)*X+P1(8)
      XDEN = X+Q1(7)
      DO 30 I=1,6
         XNUM = XNUM*X+P1(I)
         XDEN = XDEN*X+Q1(I)
   30 CONTINUE
      RES = XNUM/XDEN
      GO TO 45
C                                   4.0 .LT. ABS(Y), EVALUATE
C                                   APPROXIMATION FOR ERF
   35 XSQ = X*X
      XI = 1.0E0/XSQ
      XNUM = P2(4)*XI+P2(5)
      XDEN = XI+Q2(4)
      DO 40 I=1,3
```

```
          XNUM = XNUM*XI+P2(I)
          XDEN = XDEN*XI+Q2(I)
   40 CONTINUE
      RES = (SSQPI+XI*XNUM/XDEN)/X
   45 RES = RES*EXP(-XSQ)
      RES = 1.0E0-RES
   50 IF (ISW.EQ.-1) RES = -RES
      ERF = RES
      RETURN
      END
```

APPENDIX F

HORIZONTAL SEDIMENT DISTRIBUTIONS

AT DEPTH OF 1.2 m

Sediment Composition

Sand 45%

Silt 25%

Clay 30%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	0	0	0	0
-15.00	0	0	0	0	1	2	3	4	5	6	6
-12.50	125	39	33	33	32	31	31	30	30	29	29
-10.00	125	79	66	65	63	60	58	57	55	53	52
-7.50	125	79	67	66	64	63	62	61	60	59	58
-5.00	125	79	67	66	65	63	62	61	60	59	58
-2.50	125	79	67	66	65	63	62	61	60	59	58
0.00	125	79	67	66	65	63	62	61	60	59	58
2.50	125	79	67	66	65	63	62	61	60	59	58
5.00	125	79	67	66	65	63	62	61	60	59	58
7.50	125	79	67	66	64	63	62	61	60	59	58
10.00	125	79	66	65	63	60	58	57	55	53	52
12.50	125	39	33	33	32	31	31	30	30	29	29
15.00	0	0	0	0	1	2	3	4	5	6	6
17.50	0	0	0	0	0	0	0	0	0	0	0
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.2$ m/sec

$W_s = 0.007$ m/sec

$E_z = 0.0044$ m^2/sec

Sand 45%

Silt 25%

Clay 30%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	1	1	2	2
-15.00	0	0	2	4	6	7	9	10	11	12	12
-12.50	125	54	42	37	34	33	33	32	32	32	31
-10.00	125	108	82	69	63	59	57	55	53	52	50
-7.50	125	108	85	74	69	66	65	63	62	61	60
-5.00	125	108	85	74	69	67	66	65	64	63	63
-2.50	125	108	85	74	69	67	66	65	64	64	63
0.00	125	108	85	74	69	67	66	65	64	64	63
2.50	125	108	85	74	69	67	66	65	64	64	63
5.00	125	108	85	74	69	67	66	65	64	63	63
7.50	125	108	85	74	69	66	65	63	62	61	60
10.00	125	108	82	69	63	59	57	55	53	52	50
12.50	125	54	42	37	34	33	33	32	32	32	31
15.00	0	0	2	4	6	7	9	10	11	12	12
17.50	0	0	0	0	0	0	0	1	1	2	2
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.007$ m/sec

$E_z = 0.0088\ m^2/sec$

Sand 45%

Silt 25%

Clay 30%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	1	1	2	2
-17.50	0	0	0	1	2	3	4	5	6	7	8
-15.00	0	3	9	13	15	16	17	17	18	18	19
-12.50	125	59	53	47	43	41	38	37	36	35	34
-10.00	125	115	96	82	72	65	60	56	53	51	49
-7.50	125	118	105	94	85	78	72	68	65	63	60
-5.00	125	118	106	95	87	81	76	73	70	68	66
-2.50	125	118	106	95	87	81	77	74	71	69	68
0.00	125	118	106	95	87	82	77	74	72	70	68
2.50	125	118	106	95	87	81	77	74	71	69	68
5.00	125	118	106	95	87	81	76	73	70	68	66
7.50	125	118	105	94	85	78	72	68	65	63	60
10.00	125	115	96	82	72	65	60	56	53	51	49
12.50	125	59	53	47	43	41	38	37	36	35	34
15.00	0	3	9	13	15	16	17	17	18	18	19
17.50	0	0	0	1	2	3	4	5	6	7	8
20.00	0	0	0	0	0	0	0	1	1	2	2
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.8$ m/sec — Sand 45%

$W_s = 0.007$ m/sec — Silt 25%

$E_z = 0.0176\ m^2/sec$ — Clay 30%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	0	0	0	0
-15.00	0	0	0	0	1	2	3	4	5	6	6
-12.50	125	16	25	32	32	31	31	30	30	30	27
-10.00	125	33	51	64	62	60	59	57	55	54	48
-7.50	125	33	51	65	64	63	62	61	60	60	53
-5.00	125	33	51	65	64	63	62	61	60	60	54
-2.50	125	33	51	65	64	63	62	61	60	60	54
0.00	125	33	51	65	64	63	62	61	60	60	54
2.50	125	33	51	65	64	63	62	61	60	60	54
5.00	125	33	51	65	64	63	62	61	60	60	54
7.50	125	33	51	65	64	63	62	61	60	60	53
10.00	125	33	51	64	62	60	59	57	55	54	48
12.50	125	16	25	32	32	31	31	30	30	30	27
15.00	0	0	0	0	1	2	3	4	5	6	6
17.50	0	0	0	0	0	0	0	0	0	0	0
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.2$ m/sec
$W_s = 0.012$ m/sec
$E_z = 0.0044\ m^2/sec$

Sand 45%
Silt 25%
Clay 30%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	1	1	2	2
-15.00	0	0	2	4	6	7	9	10	11	12	12
-12.50	125	44	34	33	33	33	32	32	32	32	31
-10.00	125	88	66	63	60	58	56	54	53	52	50
-7.50	125	88	68	67	66	65	64	63	62	61	60
-5.00	125	88	68	67	66	66	65	65	64	63	63
-2.50	125	88	68	67	66	66	65	65	64	64	63
0.00	125	88	68	67	66	66	65	65	64	64	63
2.50	125	88	68	67	66	66	65	65	64	64	63
5.00	125	88	68	67	66	66	65	65	64	63	63
7.50	125	88	68	67	66	65	64	63	62	61	60
10.00	125	88	66	63	60	58	56	54	53	52	50
12.50	125	44	34	33	33	33	32	32	32	32	31
15.00	0	0	2	4	6	7	9	10	11	12	12
17.50	0	0	0	0	0	0	0	1	1	2	2
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec — Sand 45%

$W_s = 0.012$ m/sec — Silt 25%

$E_z = 0.0088\ m^2/sec$ — Clay 30%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	1	1	1
-22.50	0	0	0	0	0	1	1	2	2	3	4
-20.00	0	0	0	1	2	3	4	5	6	7	8
-17.50	0	0	3	5	7	9	10	11	12	13	14
-15.00	0	9	13	16	18	19	20	21	21	22	22
-12.50	125	38	34	33	33	32	32	32	32	31	31
-10.00	125	68	54	50	48	46	44	43	42	41	40
-7.50	125	76	64	61	58	56	54	52	51	50	48
-5.00	125	77	67	65	64	62	60	59	57	56	54
-2.50	125	77	68	66	65	64	63	62	60	59	58
0.00	125	77	68	67	66	65	64	63	62	60	59
2.50	125	77	68	66	65	64	63	62	60	59	58
5.00	125	77	67	65	64	62	60	59	57	56	54
7.50	125	76	64	61	58	56	54	52	51	50	49
10.00	125	68	54	50	48	46	44	43	42	41	40
12.50	125	38	34	33	33	32	32	32	32	31	31
15.00	0	9	13	16	18	19	20	21	21	22	22
17.50	0	0	3	5	7	9	10	11	12	13	14
20.00	0	0	0	1	2	3	4	5	6	7	8
22.50	0	0	0	0	0	1	1	2	2	3	4
25.00	0	0	0	0	0	0	0	0	1	1	1
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.0440\ m^2/sec$

Sand 45%

Silt 25%

Clay 30%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	1
-30.00	0	0	0	0	0	0	0	0	1	1	1
-27.50	0	0	0	0	0	0	1	1	2	2	3
-25.00	0	0	0	0	1	1	2	3	4	5	5
-22.50	0	0	0	1	3	4	5	6	7	8	9
-20.00	0	0	2	4	6	8	9	11	12	12	13
-17.50	0	4	8	11	13	14	16	17	17	18	18
-15.00	0	17	18	21	22	23	24	24	24	24	25
-12.50	125	44	34	33	33	33	32	32	32	31	31
-10.00	125	70	49	46	44	42	41	40	39	38	37
-7.50	125	84	60	56	53	51	49	47	46	44	43
-5.00	125	88	66	62	59	57	55	53	51	49	48
-2.50	125	88	68	65	63	61	58	56	54	52	51
0.00	125	88	68	66	64	62	60	57	55	53	51
2.50	125	88	68	65	63	61	58	56	54	52	51
5.00	125	88	66	62	59	57	55	53	51	49	48
7.50	125	84	60	56	53	51	49	47	46	44	43
10.00	125	70	49	46	44	42	41	40	39	38	37
12.50	125	44	34	33	33	33	32	32	32	31	31
15.00	0	17	18	21	22	23	24	24	24	24	25
17.50	0	4	8	11	13	14	16	17	17	18	18
20.00	0	0	2	4	6	8	9	11	12	12	13
22.50	0	0	0	1	3	4	5	6	7	8	9
25.00	0	0	0	0	1	1	2	3	4	5	5
27.50	0	0	0	0	0	0	1	1	2	2	3
30.00	0	0	0	0	0	0	0	0	1	1	1
32.50	0	0	0	0	0	0	0	0	0	0	1
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.0880$ m^2/sec

Sand 45%

Silt 25%

Clay 30%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	1	1	1	2
-17.50	0	0	0	1	2	3	4	5	6	6	7
-15.00	0	3	8	10	12	14	15	16	16	17	18
-12.50	125	55	45	39	36	35	34	33	33	33	33
-10.00	125	108	82	68	60	56	53	51	50	48	47
-7.50	125	111	90	78	71	67	64	62	60	59	58
-5.00	125	111	91	79	73	69	67	66	65	64	63
-2.50	125	111	91	79	73	70	68	67	66	66	65
0.00	125	111	91	79	73	70	68	67	66	66	66
2.50	125	111	91	79	73	70	68	67	66	66	65
5.00	125	111	91	79	73	69	67	66	65	64	63
7.50	125	111	90	78	71	67	64	62	60	59	58
10.00	125	108	82	68	60	56	53	51	50	48	47
12.50	125	55	45	39	36	35	34	33	33	33	33
15.00	0	3	8	10	12	14	15	16	16	17	18
17.50	0	0	0	1	2	3	4	5	6	6	7
20.00	0	0	0	0	0	0	0	1	1	1	2
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.8$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.0176$ m^2/sec

Sand 45%

Silt 25%

Clay 30%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	-41
-20.00	0	0	0	0	0	0	0	0	-1	118	-7686
-17.50	0	0	0	0	0	0	0	2	-183	8689	******
-15.00	0	0	0	4	4	1	-23	100	-4365	151534	******
-12.50	125	13	80	153	68	18	-189	654	-23896	725018	******
-10.00	125	26	159	302	133	35	-356	1207	-43428	******	******
-7.50	125	26	160	307	137	37	-379	1305	-47609	******	******
-5.00	125	26	160	307	137	37	-379	1308	-47792	******	******
-2.50	125	26	160	307	137	37	-379	1308	-47793	******	******
0.00	125	26	160	307	137	37	-379	1308	-47793	******	******
2.50	125	26	160	307	137	37	-379	1308	-47793	******	******
5.00	125	26	160	307	137	37	-379	1308	-47792	******	******
7.50	125	26	160	307	137	37	-379	1305	-47609	******	******
10.00	125	26	159	302	133	35	-356	1207	-43428	******	******
12.50	125	13	80	153	68	18	-189	654	-23896	725018	******
15.00	0	0	0	4	4	1	-23	100	-4365	151534	******
17.50	0	0	0	0	0	0	0	2	-183	8689	******
20.00	0	0	0	0	0	0	0	0	-1	118	-7686
22.50	0	0	0	0	0	0	0	0	0	0	-41
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.2$ m/sec

$W_s = 0.015$ m/sec

$E_z = 0.0044\ m^2$/sec

Sand 45%

Silt 25%

Clay 30%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	1	1	2	2
-15.00	0	0	2	4	6	7	9	10	11	12	12
-12.50	125	37	34	33	33	33	32	32	32	32	31
-10.00	125	74	66	63	60	58	56	54	53	52	50
-7.50	125	74	68	67	66	65	64	63	62	61	60
-5.00	125	74	68	67	66	65	65	65	64	63	63
-2.50	125	74	68	67	66	65	65	65	64	64	63
0.00	125	74	68	67	66	66	65	65	64	64	63
2.50	125	74	68	67	66	66	65	65	64	64	63
5.00	125	74	68	67	66	65	65	65	64	63	63
7.50	125	74	68	67	66	65	64	63	62	61	60
10.00	125	74	66	63	60	58	56	54	53	52	50
12.50	125	37	34	33	33	33	32	32	32	32	31
15.00	0	0	2	4	6	7	9	10	11	12	12
17.50	0	0	0	0	0	0	0	1	1	2	2
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.015$ m/sec

$E_z = 0.0088$ m^2/sec

Sand 45%

Silt 25%

Clay 30%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	1	1	1	2
-17.50	0	0	0	1	2	3	4	5	6	6	7
-15.00	0	3	7	10	12	13	14	15	16	17	18
-12.50	125	53	41	36	34	34	33	33	33	33	33
-10.00	125	103	75	63	57	54	52	51	49	48	47
-7.50	125	107	82	72	67	65	63	61	60	59	58
-5.00	125	107	83	73	69	67	66	65	65	64	63
-2.50	125	107	83	73	69	63	67	66	66	66	65
0.00	125	107	83	73	69	63	67	67	66	66	65
2.50	125	107	83	73	69	63	67	66	66	66	65
5.00	125	107	83	73	69	67	66	65	65	64	63
7.50	125	107	82	72	67	65	63	61	60	59	58
10.00	125	103	75	63	57	54	52	51	49	48	47
12.50	125	53	41	36	34	34	33	33	33	33	33
15.00	0	3	7	10	12	13	14	15	16	17	18
17.50	0	0	0	1	2	3	4	5	6	6	7
20.00	0	0	0	0	0	0	0	1	1	1	2
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.8$ m/sec　　Sand 45%

$W_s = 0.015$ m/sec　　Silt 25%

$E_z = 0.0176$ m^2/sec　　Clay 30%

Sediment Composition

Sand 2%

Silt 67%

Clay 31%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	0	0	0	0
-15.00	0	0	0	1	3	5	6	8	9	10	11
-12.50	125	60	59	57	56	54	53	52	50	49	48
-10.00	125	121	118	113	109	104	100	96	92	88	85
-7.50	125	121	118	115	112	109	106	103	101	98	95
-5.00	125	121	118	115	112	109	106	104	101	98	96
-2.50	125	121	118	115	112	109	106	104	101	98	96
0.00	125	121	118	115	112	109	106	104	101	98	96
2.50	125	121	118	115	112	109	106	104	101	98	96
5.00	125	121	118	115	112	109	106	104	101	98	96
7.50	125	121	118	115	112	109	106	103	101	98	95
10.00	125	121	118	113	109	104	100	96	92	88	85
12.50	125	60	59	57	56	54	53	52	50	49	48
15.00	0	0	0	1	3	5	6	8	9	10	11
17.50	0	0	0	0	0	0	0	0	0	0	0
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.2$ m/sec

$W_s = 0.007$ m/sec

$E_z = 0.0044\ m^2/sec$

Sand 2%

Silt 67%

Clay 31%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	1	2	3	4	5
-15.00	0	0	3	7	10	13	15	17	19	20	21
-12.50	125	61	60	59	58	58	57	56	55	55	54
-10.00	125	123	117	111	106	102	98	95	92	89	87
-7.50	125	123	121	119	117	115	112	110	108	106	103
-5.00	125	123	121	119	117	116	114	112	111	109	108
-2.50	125	123	121	119	117	116	114	113	111	110	108
0.00	125	123	121	119	117	116	114	113	111	110	108
2.50	125	123	121	119	117	116	114	113	111	110	108
5.00	125	123	121	119	117	116	114	112	111	109	108
7.50	125	123	121	119	117	115	112	110	108	106	103
10.00	125	123	117	111	106	102	98	95	92	89	87
12.50	125	61	60	59	58	58	57	56	55	55	54
15.00	0	0	3	7	10	13	15	17	19	20	21
17.50	0	0	0	0	0	0	1	2	3	4	5
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.007$ m/sec

$E_z = 0.0088\ m^2/sec$

Sand 2%

Silt 67%

Clay 31%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	1	1	2	3	4
-17.50	0	0	0	1	3	5	7	9	10	12	13
-15.00	0	3	11	16	20	23	26	28	29	30	31
-12.50	125	62	61	61	60	59	59	59	58	58	57
-10.00	125	120	111	105	100	95	92	89	87	85	83
-7.50	125	124	122	120	117	114	111	108	106	104	102
-5.00	125	124	123	121	120	119	117	116	114	112	111
-2.50	125	124	123	122	120	119	118	117	116	115	114
0.00	125	124	123	122	120	119	118	118	117	116	115
2.50	125	124	123	122	120	119	118	117	116	115	114
5.00	125	124	123	121	120	119	117	116	114	112	111
7.50	125	124	122	120	117	114	111	108	106	104	102
10.00	125	120	111	105	100	95	92	89	87	85	83
12.50	125	62	61	61	60	59	59	59	58	58	57
15.00	0	3	11	16	20	23	26	28	29	30	31
17.50	0	0	0	1	3	5	7	9	10	12	13
20.00	0	0	0	0	0	0	1	1	2	3	4
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.8$ m/sec

$W_s = 0.007$ m/sec

$E_z = 0.0176\ m^2/sec$

Sand 2%

Silt 67%

Clay 31%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	0	0	0	0
-15.00	0	0	0	1	3	5	6	8	9	10	11
-12.50	125	59	58	57	56	54	53	52	50	49	48
-10.00	125	119	117	113	109	104	100	96	92	88	85
-7.50	125	119	117	115	112	109	106	103	101	98	95
-5.00	125	119	117	115	112	109	106	104	101	98	96
-2.50	125	119	117	115	112	109	106	104	101	98	96
0.00	125	119	117	115	112	109	106	104	101	98	96
2.50	125	119	117	115	112	109	106	104	101	98	96
5.00	125	119	117	115	112	109	106	104	101	98	96
7.50	125	119	117	115	112	109	106	103	101	98	95
10.00	125	119	117	113	109	104	100	96	92	88	85
12.50	125	59	58	57	56	54	53	52	50	49	48
15.00	0	0	0	1	3	5	6	8	9	10	11
17.50	0	0	0	0	0	0	0	0	0	0	0
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.2$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.0044$ m^2/sec

Sand 2%

Silt 67%

Clay 31%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	1	2	3	4	5
-15.00	0	0	3	7	10	13	15	17	19	20	21
-12.50	125	61	60	59	58	58	57	56	55	55	54
-10.00	125	122	117	111	106	102	98	95	92	89	87
-7.50	125	122	120	118	117	115	112	110	108	106	103
-5.00	125	122	120	119	117	116	114	112	111	109	108
-2.50	125	122	120	119	117	116	114	113	111	110	108
0.00	125	122	120	119	117	116	114	113	111	110	108
2.50	125	122	120	119	117	116	114	113	111	110	108
5.00	125	122	120	119	117	116	114	112	111	109	108
7.50	125	122	120	118	117	115	112	110	108	106	103
10.00	125	122	117	111	106	102	98	95	92	89	87
12.50	125	61	60	59	58	58	57	56	55	55	54
15.00	0	0	3	7	10	13	15	17	19	20	21
17.50	0	0	0	0	0	0	1	2	3	4	5
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.0088\ m^2/sec$

Sand 2%

Silt 67%

Clay 31%

-10.00	0	0	0	0	0	0	1	1	2	2	2
-9.50	0	0	0	0	0	1	1	2	2	2	3
-9.00	0	0	0	0	0	1	2	2	3	3	3
-8.50	0	0	0	0	1	2	2	3	3	4	4
-8.00	0	0	0	1	1	2	3	3	4	4	4
-7.50	0	0	0	1	2	3	4	4	5	5	5
-7.00	0	0	0	2	3	4	5	5	5	6	6
-6.50	0	0	1	3	4	5	6	6	6	7	7
-6.00	0	0	2	4	5	6	7	7	7	7	7
-5.50	0	0	3	5	7	8	8	8	8	8	8
-5.00	0	1	5	7	8	9	9	9	9	9	9
-4.50	0	3	7	9	10	11	11	10	10	10	10
-4.00	0	5	10	12	12	12	12	12	11	11	10
-3.50	0	9	13	14	14	14	13	13	12	12	11
-3.00	0	13	17	17	16	15	14	14	13	12	12
-2.50	0	19	21	19	18	17	16	15	14	13	12
-2.00	0	26	24	22	20	18	17	15	14	13	13
-1.50	75	33	28	24	21	19	17	16	15	14	13
-1.00	75	39	30	25	22	20	18	17	15	14	13
-.50	75	43	32	27	23	20	18	17	16	14	14
0.00	75	45	33	27	23	20	18	17	16	15	14
.50	75	43	32	27	23	20	18	17	16	14	14
1.00	75	39	30	25	22	20	18	17	15	14	13
1.50	75	33	28	24	21	19	17	16	15	14	13
2.00	0	26	24	22	20	18	17	15	14	13	13
2.50	0	19	21	19	18	17	16	15	14	13	12
3.00	0	13	17	17	16	15	14	14	13	12	12
3.50	0	9	13	14	14	14	13	13	12	12	11
4.00	0	5	10	12	12	12	12	12	11	11	10
4.50	0	3	7	9	10	11	11	10	10	10	10
5.00	0	1	5	7	8	9	9	9	9	9	9
5.50	0	0	3	5	7	8	8	8	8	8	8
6.00	0	0	2	4	5	6	7	7	7	7	7
6.50	0	0	1	3	4	5	6	6	6	7	7
7.00	0	0	0	2	3	4	5	5	5	6	6
7.50	0	0	0	1	2	3	4	4	5	5	5
8.00	0	0	0	1	1	2	3	3	4	4	4
8.50	0	0	0	0	1	2	2	3	3	4	4
9.00	0	0	0	0	0	1	2	2	3	3	3
9.50	0	0	0	0	0	1	1	2	2	2	3
10.00	0	0	0	0	0	0	1	1	2	2	2
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.03\ m^2/sec$

Sand 2%

Silt 67%

Clay 31%

-10.00	0	0	0	0	0	0	0	0	0	0	0
-9.50	0	0	0	0	0	0	0	0	0	0	0
-9.00	0	0	0	0	0	0	0	0	0	0	0
-8.50	0	0	0	0	0	0	0	0	0	0	0
-8.00	0	0	0	0	0	0	0	0	0	1	1
-7.50	0	0	0	0	0	0	0	0	1	1	2
-7.00	0	0	0	0	0	0	0	1	2	2	3
-6.50	0	0	0	0	0	0	1	2	3	3	4
-6.00	0	0	0	0	0	1	2	3	4	5	6
-5.50	0	0	0	0	1	3	4	5	6	7	8
-5.00	0	0	0	1	3	5	7	8	9	10	11
-4.50	0	0	1	3	6	8	10	11	13	13	14
-4.00	0	0	3	7	10	13	14	16	17	17	18
-3.50	0	2	7	12	16	18	20	21	21	22	22
-3.00	0	6	15	20	23	25	26	26	26	26	26
-2.50	0	17	27	31	32	33	33	32	32	31	30
-2.00	0	36	42	43	42	41	40	38	37	35	34
-1.50	125	61	53	55	52	49	46	43	41	39	37
-1.00	125	85	74	66	60	55	51	47	44	42	39
-.50	125	103	85	74	65	59	54	50	47	44	41
0.00	125	109	89	76	67	60	55	51	47	44	42
.50	125	103	85	74	65	59	54	50	47	44	41
1.00	125	85	74	66	60	55	51	47	44	42	39
1.50	125	61	53	55	52	49	46	43	41	39	37
2.00	0	36	42	43	42	41	40	38	37	35	34
2.50	0	17	27	31	32	33	33	32	32	31	30
3.00	0	6	15	20	23	25	26	26	26	26	26
3.50	0	2	7	12	16	18	20	21	21	22	22
4.00	0	0	3	7	10	13	14	16	17	17	18
4.50	0	0	1	3	6	8	10	11	13	13	14
5.00	0	0	0	1	3	5	7	8	9	10	11
5.50	0	0	0	0	1	3	4	5	6	7	8
6.00	0	0	0	0	0	1	2	3	4	5	6
6.50	0	0	0	0	0	0	1	2	3	3	4
7.00	0	0	0	0	0	0	0	1	2	2	3
7.50	0	0	0	0	0	0	0	0	1	1	2
8.00	0	0	0	0	0	0	0	0	0	1	1
8.50	0	0	0	0	0	0	0	0	0	0	0
9.00	0	0	0	0	0	0	0	0	0	0	0
9.50	0	0	0	0	0	0	0	0	0	0	0
10.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.03\ m^2/sec$

Sand 2%

Silt 67%

Clay 31%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	1	1	2	3	4
-17.50	0	0	0	1	3	5	7	9	10	12	13
-15.00	0	3	11	16	20	23	26	28	29	30	31
-12.50	125	62	61	60	60	59	59	58	58	58	57
-10.00	125	120	111	104	99	95	92	89	87	85	83
-7.50	125	124	122	119	116	113	111	108	106	104	102
-5.00	125	124	122	121	120	118	117	115	114	112	111
-2.50	125	124	122	121	120	119	118	117	116	115	114
0.00	125	124	122	121	120	119	118	117	116	116	115
2.50	125	124	122	121	120	119	118	117	116	115	114
5.00	125	124	122	121	120	118	117	115	114	112	111
7.50	125	124	122	119	116	113	111	108	106	104	102
10.00	125	120	111	104	99	95	92	89	87	85	83
12.50	125	62	61	60	60	59	59	58	58	58	57
15.00	0	3	11	16	20	23	26	28	29	30	31
17.50	0	0	0	1	3	5	7	9	10	12	13
20.00	0	0	0	0	0	0	1	1	2	3	4
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.8$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.0176$ m^2/sec

Sand 2%

Silt 67%

Clay 31%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	-1
-20.00	0	0	0	0	0	0	0	0	0	5	-341
-17.50	0	0	0	0	0	0	0	0	-7	386	-16751
-15.00	0	0	0	1	3	4	5	12	-185	6744	******
-12.50	125	59	61	63	57	54	43	79	-1012	32271	******
-10.00	125	119	122	124	112	103	81	147	-1840	57797	******
-7.50	125	119	122	126	115	108	87	159	-2017	64155	******
-5.00	125	119	122	126	115	108	87	159	-2025	64537	******
-2.50	125	119	122	126	115	108	87	159	-2025	64542	******
0.00	125	119	122	126	115	108	87	159	-2025	64542	******
2.50	125	119	122	126	115	108	87	159	-2025	64542	******
5.00	125	119	122	126	115	108	87	159	-2025	64537	******
7.50	125	119	122	126	115	108	87	159	-2017	64155	******
10.00	125	119	122	124	112	103	81	147	-1840	57797	******
12.50	125	59	61	63	57	54	43	79	-1012	32271	******
15.00	0	0	0	1	3	4	5	12	-185	6744	******
17.50	0	0	0	0	0	0	0	0	-7	386	-16751
20.00	0	0	0	0	0	0	0	0	0	5	-341
22.50	0	0	0	0	0	0	0	0	0	0	-1
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.2$ m/sec

$W_s = 0.015$ m/sec

$E_z = 0.0044\ m^2/sec$

Sand 2%

Silt 67%

Clay 31%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	1	2	3	4	5
-15.00	0	0	3	7	10	13	15	17	19	20	21
-12.50	125	61	60	59	58	58	57	56	55	55	54
-10.00	125	121	116	111	106	102	98	95	92	89	87
-7.50	125	122	120	118	117	115	112	110	108	106	103
-5.00	125	122	120	119	117	116	114	112	111	109	108
-2.50	125	122	120	119	117	116	114	113	111	110	108
0.00	125	122	120	119	117	116	114	113	111	110	108
2.50	125	122	120	119	117	116	114	113	111	110	108
5.00	125	122	120	119	117	116	114	112	111	109	108
7.50	125	122	120	118	117	115	112	110	108	106	103
10.00	125	121	116	111	106	102	98	95	92	89	87
12.50	125	61	60	59	58	58	57	56	55	55	54
15.00	0	0	3	7	10	13	15	17	19	20	21
17.50	0	0	0	0	0	0	1	2	3	4	5
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.015$ m/sec

$E_z = 0.0088$ m^2/sec

Sand 2%

Silt 67%

Clay 31%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	1	1	2	3	4
-17.50	0	0	0	1	3	5	7	9	10	12	13
-15.00	0	3	11	16	20	23	26	28	29	30	31
-12.50	125	61	61	60	60	59	59	58	58	58	57
-10.00	125	120	111	104	99	95	92	89	87	85	83
-7.50	125	123	121	119	116	113	111	108	106	104	102
-5.00	125	123	122	120	119	118	117	115	114	112	111
-2.50	125	123	122	121	120	119	118	117	116	115	114
0.00	125	123	122	121	120	119	118	117	116	116	115
2.50	125	123	122	121	120	119	118	117	116	115	114
5.00	125	123	122	120	119	118	117	115	114	112	111
7.50	125	123	121	119	116	113	111	108	106	104	102
10.00	125	120	111	104	99	95	92	89	87	85	83
12.50	125	61	61	60	60	59	59	58	58	58	57
15.00	0	3	11	16	20	23	26	28	29	30	31
17.50	0	0	0	1	3	5	7	9	10	12	13
20.00	0	0	0	0	0	0	1	1	2	3	4
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

U = 0.8 m/sec
W_s = 0.015 m/sec
E_z = 0.0176 m^2/sec

Sand 2%
Silt 67%
Clay 31%

Sediment Composition

Sand 20%

Silt 25%

Clay 55%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	1	2	2	3	4
-15.00	0	0	3	6	9	11	13	15	16	17	18
-12.50	125	58	53	50	49	49	48	48	47	47	47
-10.00	125	117	103	95	90	86	83	81	79	77	75
-7.50	125	117	106	101	98	97	95	94	93	91	90
-5.00	125	117	106	101	99	98	97	96	95	94	94
-2.50	125	117	106	101	99	98	97	96	95	95	94
0.00	125	117	106	101	99	98	97	96	95	95	94
2.50	125	117	106	101	99	98	97	96	95	95	94
5.00	125	117	106	101	99	98	97	96	95	94	94
7.50	125	117	106	101	98	97	95	94	93	91	90
10.00	125	117	103	95	90	86	83	81	79	77	75
12.50	125	58	53	50	49	49	48	48	47	47	47
15.00	0	0	3	6	9	11	13	15	16	17	18
17.50	0	0	0	0	0	0	1	2	2	3	4
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.007$ m/sec

$E_z = 0.0088\ m^2/sec$

Sand 20%

Silt 25%

Clay 55%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	1	1	2	2	3
-17.50	0	0	0	1	3	4	6	7	9	10	11
-15.00	0	3	10	15	18	21	22	24	25	26	27
-12.50	125	61	58	55	53	52	51	50	50	49	49
-10.00	125	118	105	96	89	84	80	77	74	73	71
-7.50	125	122	115	109	104	100	96	93	91	89	87
-5.00	125	122	116	111	107	104	102	99	98	96	94
-2.50	125	122	116	111	107	105	103	101	99	98	97
0.00	125	122	116	111	107	105	103	101	100	99	98
2.50	125	122	116	111	107	105	103	101	99	98	97
5.00	125	122	116	111	107	104	102	99	98	96	94
7.50	125	122	115	109	104	100	96	93	91	89	87
10.00	125	118	105	96	89	84	80	77	74	73	71
12.50	125	61	58	55	53	52	51	50	50	49	49
15.00	0	3	10	15	18	21	22	24	25	26	27
17.50	0	0	0	1	3	4	6	7	9	10	11
20.00	0	0	0	0	0	0	1	1	2	2	3
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.8$ m/sec

$W_s = 0.007$ m/sec

$E_z = 0.0176\ m^2/sec$

Sand 20%

Silt 25%

Clay 55%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	0	0	0	0	0
-15.00	0	0	0	1	2	4	5	7	8	9	10
-12.50	125	41	45	48	48	47	47	46	45	45	44
-10.00	125	83	91	95	93	90	88	85	83	81	77
-7.50	125	83	91	96	96	95	93	92	91	90	87
-5.00	125	83	91	96	96	95	94	93	91	91	88
-2.50	125	83	91	96	96	95	94	93	91	91	88
0.00	125	83	91	96	96	95	94	93	91	91	88
2.50	125	83	91	96	96	95	94	93	91	91	88
5.00	125	83	91	96	96	95	94	93	91	91	88
7.50	125	83	91	96	96	95	93	92	91	90	87
10.00	125	83	91	95	93	90	88	85	83	81	77
12.50	125	41	45	48	48	47	47	46	45	45	44
15.00	0	0	0	1	2	4	5	7	8	9	10
17.50	0	0	0	0	0	0	0	0	0	0	0
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.2$ m/sec
$W_s = 0.012$ m/sec
$E_z = 0.0044$ m^2/sec

Sand 20%
Silt 25%
Clay 55%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	1	2	2	3	4
-15.00	0	0	2	6	8	11	13	15	16	17	18
-12.50	125	54	49	49	49	48	48	48	47	47	47
-10.00	125	108	96	92	89	86	83	81	79	77	75
-7.50	125	108	99	98	97	96	95	94	93	91	90
-5.00	125	108	99	98	98	97	96	96	95	94	94
-2.50	125	108	99	98	98	97	96	96	95	95	94
0.00	125	108	99	98	98	97	96	96	95	95	94
2.50	125	108	99	98	98	97	96	96	95	95	94
5.00	125	108	99	98	98	97	96	96	95	94	94
7.50	125	108	99	98	97	96	95	94	93	91	90
10.00	125	108	96	92	89	86	83	81	79	77	75
12.50	125	54	49	49	49	48	48	48	47	47	47
15.00	0	0	2	6	8	11	13	15	16	17	18
17.50	0	0	0	0	0	0	1	2	2	3	4
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.012$ m/sec

$E_z = 0.0088\ m^2/sec$

Sand 20%

Silt 25%

Clay 55%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	1	1	2	2	3
-17.50	0	0	0	1	3	4	6	7	8	10	11
-15.00	0	3	10	14	17	19	21	23	24	25	26
-12.50	125	59	54	52	50	49	49	49	49	48	48
-10.00	125	115	99	89	83	80	77	75	73	71	70
-7.50	125	119	109	102	98	95	92	90	89	87	86
-5.00	125	119	109	104	101	99	98	96	95	94	93
-2.50	125	119	109	104	101	99	98	98	97	97	96
0.00	125	119	109	104	101	99	99	98	97	97	97
2.50	125	119	109	104	101	99	98	98	97	97	96
5.00	125	119	109	104	101	99	98	96	95	94	93
7.50	125	119	109	102	98	95	92	90	89	87	86
10.00	125	115	99	89	83	80	77	75	73	71	70
12.50	125	59	54	52	50	49	49	49	49	48	48
15.00	0	3	10	14	17	19	21	23	24	25	26
17.50	0	0	0	1	3	4	6	7	8	10	11
20.00	0	0	0	0	0	0	1	1	2	2	3
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.8$ m/sec | Sand 20%
$W_s = 0.012$ m/sec | Silt 25%
$E_z = 0.0176\ m^2/sec$ | Clay 55%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	-18
-20.00	0	0	0	0	0	0	0	0	0	52	-3416
-17.50	0	0	0	0	0	0	0	1	-81	3362	******
-15.00	0	0	0	3	3	3	-6	49	-1934	67355	******
-12.50	125	40	69	102	64	41	-51	323	-10583	322262	******
-10.00	125	81	139	201	124	79	-96	597	-19242	577170	******
-7.50	125	81	139	204	128	83	-102	645	-21095	640663	******
-5.00	125	81	139	204	128	83	-102	647	-21176	644472	******
-2.50	125	81	139	204	128	83	-102	647	-21176	644525	******
0.00	125	81	139	204	128	83	-102	647	-21176	644525	******
2.50	125	81	139	204	128	83	-102	647	-21176	644525	******
5.00	125	81	139	204	128	83	-102	647	-21176	644472	******
7.50	125	81	139	204	128	83	-102	645	-21095	640663	******
10.00	125	81	139	201	124	79	-96	597	-19242	577170	******
12.50	125	40	69	102	64	41	-51	323	-10588	322262	******
15.00	0	0	0	3	3	3	-6	49	-1934	67355	******
17.50	0	0	0	0	0	0	0	1	-81	3862	******
20.00	0	0	0	0	0	0	0	0	0	52	-3416
22.50	0	0	0	0	0	0	0	0	0	0	-18
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.2$ m/sec

$W_s = 0.015$ m/sec

$E_z = 0.0044\ m^2/sec$

Sand 20%

Silt 25%

Clay 55%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	1	2	2	3	4
-15.00	0	0	2	6	8	11	13	15	16	17	18
-12.50	125	51	49	49	49	48	48	48	47	47	47
-10.00	125	101	96	92	89	86	83	81	79	77	75
-7.50	125	102	99	98	97	96	95	94	93	91	90
-5.00	125	102	99	98	98	97	96	96	95	94	94
-2.50	125	102	99	98	98	97	96	96	95	95	94
0.00	125	102	99	98	98	97	96	96	95	95	94
2.50	125	102	99	98	98	97	96	96	95	95	94
5.00	125	102	99	98	98	97	96	96	95	94	94
7.50	125	102	99	98	97	96	95	94	93	91	90
10.00	125	101	96	92	89	86	83	81	79	77	75
12.50	125	51	49	49	49	48	48	48	47	47	47
15.00	0	0	2	6	8	11	13	15	16	17	18
17.50	0	0	0	0	0	0	1	2	2	3	4
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.015$ m/sec

$E_z = 0.0088$ m^2/sec

Sand 20%

Silt 25%

Clay 55%

-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	1	1	2	2	3
-17.50	0	0	0	1	2	4	6	7	8	10	11
-15.00	0	3	9	14	17	19	21	23	24	25	26
-12.50	125	58	53	50	49	49	49	49	48	48	48
-10.00	125	113	96	87	82	79	76	74	73	71	70
-7.50	125	116	105	100	96	94	92	90	88	87	85
-5.00	125	116	106	101	99	98	97	96	95	94	93
-2.50	125	116	106	101	99	99	98	98	97	97	96
0.00	125	116	106	101	99	98	98	98	97	97	97
2.50	125	116	106	101	99	99	98	98	97	97	96
5.00	125	116	106	101	99	98	97	96	95	94	93
7.50	125	116	105	100	96	94	92	90	88	87	85
10.00	125	113	96	87	82	79	76	74	73	71	70
12.50	125	58	53	50	49	49	49	49	48	48	48
15.00	0	3	9	14	17	19	21	23	24	25	26
17.50	0	0	0	1	2	4	6	7	8	10	11
20.00	0	0	0	0	0	0	1	1	2	2	3
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

U = 0.8 m/sec
W_s = 0.015 m/sec
E_z = 0.0176 m^2/sec

Sand 20%
Silt 25%
Clay 55%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	0	0	0	0	0
-17.50	0	0	0	0	0	0	1	2	2	3	4
-15.00	0	0	2	6	8	11	13	15	16	17	18
-12.50	125	45	49	49	49	48	48	48	47	47	47
-10.00	125	91	95	92	89	86	83	81	79	77	75
-7.50	125	91	98	98	97	96	95	94	93	91	90
-5.00	125	91	98	98	98	97	96	96	95	94	94
-2.50	125	91	98	98	98	97	96	96	95	95	94
0.00	125	91	98	98	98	97	96	96	95	95	94
2.50	125	91	98	98	98	97	96	96	95	95	94
5.00	125	91	98	98	98	97	96	96	95	94	94
7.50	125	91	98	98	97	96	95	94	93	91	90
10.00	125	91	95	92	89	86	83	81	79	77	75
12.50	125	45	49	49	49	48	48	48	47	47	47
15.00	0	0	2	6	8	11	13	15	16	17	18
17.50	0	0	0	0	0	0	1	2	2	3	4
20.00	0	0	0	0	0	0	0	0	0	0	0
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.02$ m/sec

$E_z = 0.0088\ m^2/sec$

Sand 20%

Silt 25%

Clay 55%

	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0
-50.00	0	0	0	0	0	0	0	0	0	0	0
-47.50	0	0	0	0	0	0	0	0	0	0	0
-45.00	0	0	0	0	0	0	0	0	0	0	0
-42.50	0	0	0	0	0	0	0	0	0	0	0
-40.00	0	0	0	0	0	0	0	0	0	0	0
-37.50	0	0	0	0	0	0	0	0	0	0	0
-35.00	0	0	0	0	0	0	0	0	0	0	0
-32.50	0	0	0	0	0	0	0	0	0	0	0
-30.00	0	0	0	0	0	0	0	0	0	0	0
-27.50	0	0	0	0	0	0	0	0	0	0	0
-25.00	0	0	0	0	0	0	0	0	0	0	0
-22.50	0	0	0	0	0	0	0	0	0	0	0
-20.00	0	0	0	0	0	0	1	1	2	2	3
-17.50	0	0	0	1	2	4	6	7	8	10	11
-15.00	0	3	9	13	17	19	21	23	24	25	26
-12.50	125	56	50	49	49	49	49	49	48	48	48
-10.00	125	109	92	85	81	79	76	74	73	71	70
-7.50	125	112	101	98	96	94	92	90	88	87	85
-5.00	125	112	101	99	98	98	97	96	95	94	93
-2.50	125	112	101	99	99	98	98	97	97	97	96
0.00	125	112	101	99	99	98	98	98	97	97	97
2.50	125	112	101	99	99	98	98	97	97	97	96
5.00	125	112	101	99	98	98	97	96	95	94	93
7.50	125	112	101	98	96	94	92	90	88	87	85
10.00	125	109	92	85	81	79	76	74	73	71	70
12.50	125	56	50	49	49	49	49	49	48	48	48
15.00	0	3	9	13	17	19	21	23	24	25	26
17.50	0	0	0	1	2	4	6	7	8	10	11
20.00	0	0	0	0	0	0	1	1	2	2	3
22.50	0	0	0	0	0	0	0	0	0	0	0
25.00	0	0	0	0	0	0	0	0	0	0	0
27.50	0	0	0	0	0	0	0	0	0	0	0
30.00	0	0	0	0	0	0	0	0	0	0	0
32.50	0	0	0	0	0	0	0	0	0	0	0
35.00	0	0	0	0	0	0	0	0	0	0	0
37.50	0	0	0	0	0	0	0	0	0	0	0
40.00	0	0	0	0	0	0	0	0	0	0	0
42.50	0	0	0	0	0	0	0	0	0	0	0
45.00	0	0	0	0	0	0	0	0	0	0	0
47.50	0	0	0	0	0	0	0	0	0	0	0
50.00	0	0	0	0	0	0	0	0	0	0	0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.8$ m/sec

$W_s = 0.02$ m/sec

$E_z = 0.0176\ m^2/sec$

Sand 20%

Silt 25%

Clay 55%

-20.00	0	0	0	0	0	0	0	0	0	0	0
-19.00	0	0	0	0	0	0	0	0	0	0	0
-18.00	0	0	0	0	0	0	0	0	0	0	0
-17.00	0	0	0	0	0	0	0	0	0	0	-3
-16.00	0	0	0	0	0	0	0	0	0	0	-19
-15.00	0	0	0	0	0	0	0	0	0	0	-106
-14.00	0	0	0	0	0	0	0	0	0	5	-525
-13.00	0	0	0	0	0	0	0	0	0	29	-2317
-12.00	0	0	0	0	0	0	0	0	-1	136	-9148
-11.00	0	0	0	0	0	0	0	0	-7	551	-32340
-10.00	0	0	0	0	0	0	0	0	-33	1975	******
-9.00	0	0	0	0	0	0	0	1	-121	6264	******
-8.00	0	0	0	0	0	0	-1	5	-385	17580	******
-7.00	0	0	0	0	0	0	-3	18	-1069	43670	******
-6.00	0	0	0	0	0	0	-12	51	-2584	96044	******
-5.00	0	0	0	3	2	-1	-33	120	-5451	187050	******
-4.00	0	0	2	16	8	-3	-75	241	-10035	322636	******
-3.00	0	-1	13	52	20	-7	-140	413	-16128	492940	******
-2.00	0	-11	43	122	38	-12	-219	607	-22631	667186	******
-1.00	125	-39	87	201	56	-15	-286	764	-27731	800027	******
0.00	125	-57	110	238	64	-18	-312	825	-29674	849940	******
1.00	125	-39	87	201	56	-16	-286	764	-27731	800027	******
2.00	0	-11	43	122	38	-12	-219	607	-22631	667136	******
3.00	0	-1	13	52	20	-7	-140	413	-16128	492940	******
4.00	0	0	2	16	8	-3	-75	241	-10035	322636	******
5.00	0	0	0	3	2	-1	-33	120	-5451	187050	******
6.00	0	0	0	0	0	0	-12	51	-2584	96044	******
7.00	0	0	0	0	0	0	-3	18	-1069	43670	******
8.00	0	0	0	0	0	0	-1	5	-385	17580	******
9.00	0	0	0	0	0	0	0	1	-121	6264	******
10.00	0	0	0	0	0	0	0	0	-33	1975	******
11.00	0	0	0	0	0	0	0	0	-7	551	-32340
12.00	0	0	0	0	0	0	0	0	-1	136	-9148
13.00	0	0	0	0	0	0	0	0	0	29	-2317
14.00	0	0	0	0	0	0	0	0	0	5	-525
15.00	0	0	0	0	0	0	0	0	0	0	-106
16.00	0	0	0	0	0	0	0	0	0	0	-19
17.00	0	0	0	0	0	0	0	0	0	0	-3
18.00	0	0	0	0	0	0	0	0	0	0	0
19.00	0	0	0	0	0	0	0	0	0	0	0
20.00	0	0	0	0	0	0	0	0	0	0	0
	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0	500.0

DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE

$U = 0.4$ m/sec

$W_s = 0.03$ m/sec

$E_z = 0.0088\ m^2/sec$

Sand 95%

Silt 5%

Clay 0%