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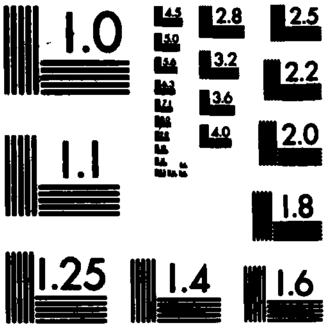

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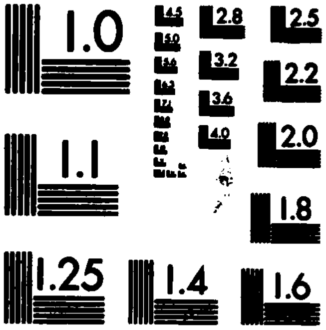

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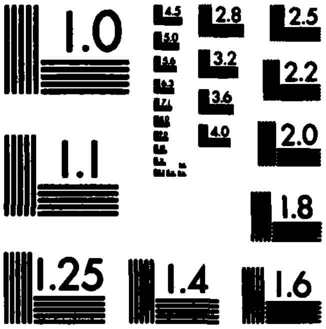

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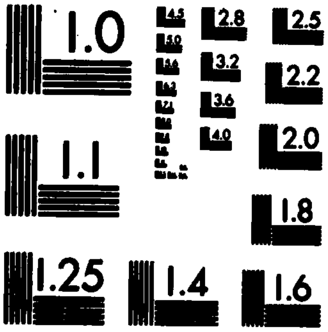

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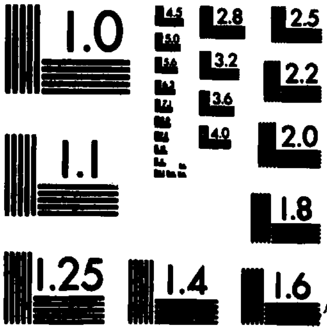

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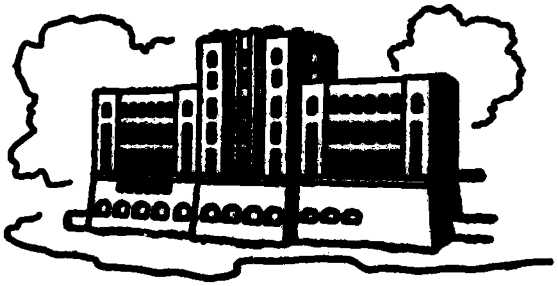
REFINEMENT AND VERIFICATION OF PREDICTIVE MODELS OF SUSPENDED SEDIMENT DISPERSION AND DESORPTION OF TOXICS FROM DREDGED SEDIMENTS

by

J. L. Schnoor, A. R. Giaquinta, C. Sato,
C. P. Robison, and D. B. McDonald

Prepared for GREAT River
Environmental Action Team

Funded by: U.S. Army Corps of Engineers
St. Louis District



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July 1982

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Field monitoring, laboratory elutriate and kinetic tests, and mathematical modeling have been performed for dredge disposal operations over a 600-mile stretch of the Mississippi River from Guttenberg, Iowa, to Cairo, Illinois, during 1979-1981.

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Results have shown that elutriation of traditional and toxic pollutants is not a significant problem in the dredging and disposal of main channel sediments. These are mostly "clean" sediments of fine-to-medium sand with very low organic contents. Mucky sediments from sloughs (and occasionally from the main channel) showed a greater potential for desorption of toxic organic pollutants and ammonia. Desorption was frequently noted for COD, NH_3, and Mn, but excursions of water quality criteria were rare.

REFINEMENT AND VERIFICATION OF PREDICTIVE MODELS OF SUSPENDED SEDIMENT DISPERSION AND DESORPTION OF TOXICS FROM DREDGED SEDIMENTS

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This project was performed in tasks and, to a large extent, the chapters of the report are based on task force studies and reports. Chapters are credited to the following individuals.

Chapter 1.	Schnoor
Chapter 2.	Robison, Giaquinta, Schnoor
Chapter 3.	Sato, Schnoor, Giaquinta, McDonald
Chapter 4.	Sato, Schnoor, Giaquinta, McDonald
Chapter 5.	Sato, Schnoor, Giaquinta, McDonald
Chapter 6.	Schnoor

Ms. Mary Beth Watson was in charge of field sampling and laboratory elutriates and kinetic studies. We thank Mr. James Goss for valuable expertise in the field and Ms. Karen Nall and Ms. Jean Fleck for final manuscript preparation. The University of Iowa Hygienic Laboratory staff performed the chemical analyses. We thank Dr. J.O. Kennedy, Mr. Lauren Johnson, and Ms. Patricia Cain of the Hygienic Laboratory.

A contract (DACW43-81-C-0126) from the U.S. Army Corps of Engineers, St. Louis District, funded this project. Mr. John Gaal was project officer, and Mr. Don Huston was our field contact. The help and direction of Mr. John Ford, Water Quality Work Group Chairman of GREAT III, was especially appreciated.

I. INTRODUCTION

The disposal of dredged material has received much attention from environmentalists. 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. There exists a need for mathematical models to predict the concentration and deposition of suspended solids and water quality constituents resulting from disposal of dredged material.

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 into open water or onto a nearby bank. This water contains suspended solids and forms a suspended-solids plume and a chemical containment plume where it enters the river.

A multidisciplinary consortium called the Great River Environmental Action Team, GREAT, was formed in 1975 to determine the environmental effects of dredging and dredge disposal on the Mississippi River. During the second phase of this study, GREAT II (from Guttenberg, Iowa, to Saverton, Missouri), two mathematical models were developed at The University of Iowa Institute of Hydraulic Research to assess water quality concentrations after dredge disposal. The three-dimensional, steady-state model of Wechsler and Cogley (the Walden Plume model) was modified for the case of side-bank disposal of dredged material in the GREAT II study reach. Also a two-dimensional, steady-state model was developed by means of an analytical solution to the depth-averaged equation. It was a recommendation of the GREAT II study that the model receive further refinement and verification.

In this research, the Wechsler-Cogley model is applied to three sites in the GREAT III study reach, from Saverton, Missouri, to Cairo, Illinois. This reach includes different environmental conditions than those encountered in GREAT II--i.e., open-water disposal of hydraulically dredged material, dustpan as well as cutterhead hydraulic dredging techniques, and conditions existing below the lock and dam and pool system of the upper Mississippi River.

Secondly, the two-dimensional analytic model is developed into a chemical contaminant plume model. It is applied to a site within the GREAT III study reach. Chemical kinetics and sorption partitioning are included in the model. In addition, sediments from seven locations along the GREAT III study reach are screened via the standard elutriate test. Elutriation kinetics are delineated.

A primary objective of this research was to refine and verify the accuracy of a mathematical model of suspended-sediment dispersion, and a model of desorption and dispersion of toxic materials from dredged sediments. These models were developed during the GREAT II study, but additional sampling of suspended-sediment plumes associated with dredge disposal is needed to test the accuracy of the model at different stream velocities and for different sediment types. The refined mathematical formulas will provide users with a quantitative method for assessing water-quality impacts under the Federal Clean Water Act for dredging. Associated scope and objectives of this research were to:

1) Measure suspended-sediment plumes (length and width at mid-depth) associated with open-water disposal channel maintenance dredging operations.

2) Refine the Wechsler-Cogley particle-dispersion model as modified by The University of Iowa Institute of Hydraulic Research.

3) Collect water and sediment samples from five designated harbor and shoreline areas on the Mississippi River, and analyze them for ammonia, phosphorus, COD, oil and grease, cadmium, chromium, copper, lead, mercury, nickel, manganese, iron, zinc, and PCB's.

4. Perform particle-size analysis and priority-chemical-pollutant analysis for the sediments.

5. Conduct standard elutriate and kinetic tests to predict the extent of release of chemical pollutants from the sediments and to determine the rate of desorption.

II. SUSPENDED SOLIDS MODEL

A. Wechsler-Cogley Model Development. The model with which this chapter is principally concerned is based on a turbidity plume computer model proposed by Wechsler and Cogley (1977). It was developed for predicting concentrations of suspended sediment downstream from a line source (e.g., a hydraulic pipeline dredge discharging into open water). These concentrations are predicted as a function of sedimentation data (from jar tests) and hydraulic parameters such as eddy diffusivity and current velocity. The initial simplifying assumptions utilized are unidirectional constant flow, infinite width, constant depth, and infinite length.

The concentration of suspended sediment downstream from a disposal site is determined by a balance among four sediment transport mechanisms: removal by downward settling and deposition, transport by vertical diffusion in the direction of decreasing concentration gradient, lateral dispersion by turbulent diffusion, and dispersion in the downstream direction by both convection and turbulent diffusion. This material balance is given by the following differential equation:

$$\frac{\partial}{\partial x}(uc) + \frac{\partial}{\partial y}\left(\int wf(w)dw\right) - \left(\frac{\partial}{\partial x}\left(E_x \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_y \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial c}{\partial z}\right)\right) = 0 \quad \text{(II-1)}$$

where x = longitudinal coordinate (m)

y = vertical coordinate (m)

z = lateral coordinate (m)

u = current velocity (m/s)

c = sediment concentration (mg/l)

w = particle settling velocity (m/s)

$f(w)$ = settling velocity frequency distribution ([sediment mass/w] vs. w)

E_x = diffusion coefficient in the x-direction (m^2/s)

E_y = diffusion coefficient in the y-direction (m^2/s)

E_z = diffusion coefficient in the z-direction (m^2/s)

The necessary assumptions for this relationship are steady, uniform, and fully turbulent flow, as well as Fickian diffusion (i.e., mass transport by diffusion is proportional to the concentration gradient).

To obtain a useful form of (II-1), further simplifying assumptions must be included:

1). Turbulent diffusion in the x-direction (downstream) is negligible when compared to the convection term, i.e.,

$$\frac{\partial}{\partial x}\left(E_x \frac{\partial c}{\partial x}\right) << \frac{\partial}{\partial x}(uc) \qquad \text{(II-2)}$$

2). For fully turbulent flow, the velocity profile will be practically flat, especially outside the near-bottom zone. Therefore, it can be assumed that the velocity is constant and equal to the mean velocity, U, and

$$\frac{\partial}{\partial c}(uc) \approx U\frac{\partial c}{\partial x} \qquad \text{(II-3)}$$

3). E_y can be assumed to be approximately equal to the diffusion coefficient for fluid momentum, E_m (the Reynolds analogy). This assumption has been found to be especially true for fine particles, which constitute the principal portion of the suspended-solids plume (Jobson and Sayre, 1970).

A relationship between E_m and y can be obtained using four equations:

a) The first equation is the definition of E_m,

$$\tau_t = \rho E_m \frac{\partial U}{\partial y} \qquad \text{(II-4)}$$

b) The second equation is obtained by differentiating the logarithmic velocity profile

$$U = \frac{u_*}{\kappa}\ln[y/H] \qquad \text{(II-5)}$$

c) The vertical distribution of shear is assumed to be given by

$$\tau_t = \tau_o[1 - y/H] \qquad \text{(II-6)}$$

d) Finally, the shear velocity and bed shear are related as follows:

$$\tau_o = \rho u_*^2 \tag{II-7}$$

Combining these three equations, the following equation is obtained:

$$E_m = \kappa u_* y[1-y/H] \tag{II-8}$$

in which

u_* = shear velocity (m/s)
κ = von Karman's constant
H = channel depth (m)
τ_t = turbulent shear stress (N/m^2)
ρ = fluid density (kg/m^3)
E_m = momentum diffusion coefficient (m^2/s)
τ_o = bed shear stress (N/m^2)

Thus it can be assumed that E_m varies parabolically from zero at the surface and bed to a maximum at mid-depth.

The bed shear stress and mean velocity are empirically related as follows:

$$\tau_o = \frac{f}{8} \rho\, U^2 \tag{II-9}$$

where f is the friction factor (approximately equal to 0.02 for natural, fully turbulent flows).

If κ is assumed to be equal to 0.4, the following relation can be obtained by combining (II-7) through (II-9):

$$E_y = E_m = 0.02Uy(1-y/H) \tag{II-10}$$

4). Based on experimental studies (Fischer, 1973), the lateral diffusion coefficient can be considered to be approximately constant and given by the expression

$$E_z = 0.2Hu_* \qquad \text{(II-11)}$$

Combining (II-9) through (II-11), E_z can be expressed as

$$E_z = 2\ (E_y)_{max} \qquad \text{(II-12)}$$

where $(E_y)_{max}$ is the maximum value of E_y (at mid-depth).

5). An assumption is made that the sediment can be divided into fractions, and that each fraction can be characterized by a representative particle size with its corresponding settling velocity. It also is assumed that no flocculation occurs (i.e., w is not a function of time).

Incorporating all of these assumptions, the material balance equation, (II-1), can be written as

$$U \frac{\partial}{\partial x} + W \frac{\partial c}{\partial y} - \frac{\partial}{\partial y} ((0.02Uy(1-y/h)) \frac{\partial c}{\partial y})$$

$$- \frac{\partial}{\partial z} (2(E_y)_{max} \frac{\partial c}{\partial z}) = 0 \qquad \text{(II-13)}$$

This equation is solved for each sediment fraction. The total concentration at each point is obtained by superimposing the weighted solutions for all fractions.

Equation (II-13) is solved numerically by a finite-difference method, using the following boundary conditions:

1). The upstream boundary condition, at $x = 0$, assumes that a vertical plane source continuously emits suspended solids at a constant given strength per unit height, $c = c_0$. The lateral limits of the source are $-b<z<b$, where b is small relative to the depth. The source is, in general, assumed to extend from the water surface to

the bottom. Variations in initial source conditions, such as a point or a depth-varying source, can also be modelled.

2). A second boundary condition for the solution of (II-13) is the physical limitation of no sediment flux across the surface, i.e., at $y = H$

$$E_y \frac{\partial c}{\partial y} + Wc = 0 \qquad \text{(II-14)}$$

3). For simplicity, it is assumed that there is no reentrainment of sediment reaching the bottom, i.e., at $y = 0$

$$E_y \frac{\partial c}{\partial y} = 0 \qquad \text{(II-15)}$$

Using these boundary conditions, the calculation proceeds downstream step by step. Over each step, Δx, a finite-difference model of the equation is used to calculate the concentrations at the end of the step from those at the beginning.

Two aspects of this process deserve special mention. First, in order for Δx to be large enough to have an efficient algorithm and to avoid instabilities of a purely numerical origin, an implicit finite-difference scheme was selected. For this implicit system, the diffusion term, $\partial/\partial x(E_x \partial c/\partial x)$, is expressed at $x + \Delta x$ rather than at x. This scheme requires the solution of a system of N equations at each step ($N = H/\Delta y$).

Second, the effect of lateral diffusion can be considered separately. Lateral diffusion could be described by

$$\frac{\partial}{\partial x}(UC) = \frac{\partial}{\partial z}\left(E_z \frac{\partial C}{\partial z}\right) \qquad \text{(II-16)}$$

where C represents the concentration obtained from the two-dimensional problem. The solution of this equation is given by

$$C(x,z) = \left[\frac{4\pi x E_z}{U}\right]^{-1/2} \int_{-b}^{b} \exp\left[-\frac{U(z-v)^2}{4xE_z}\right] dv \qquad \text{(II-17)}$$

where v is a dummy variable which represents distance within the plume. A change of variables relates this solution to the "error function" (erf).

If E_z is taken to be a constant (largely true, except near the bottom surface), and

$$\frac{U(z-v)^2}{4xE_z} = \gamma^2/2 \tag{II-18}$$

(II-17) becomes

$$C(x,z) = 1/\sqrt{2\pi} \int_{-b}^{b} \exp\,[-\gamma^2/2]d\gamma \tag{II-19}$$

which can be expressed in terms of the error function, for which an analytical solution is well known. The analytical and numerical results are computed separately and then combined to obtain an approximation of the three-dimensional concentration field.

Modifications to the Wechsler-Cogley computer program are discussed in Sections C through G. Section F includes a sample model run with its corresponding computer output. A final version of the modified program is listed in appendix A.

B. Field Trips: Procedure and Results. To gather data for refining and verifying the computer model field trips were made to Mississippi River Mile (RM) 14, RM 254.5, and RM 170. The sampling process used at each site was as follows:

1). Site Layout. It was attempted to establish a rough grid at each site to systemize the subsequent sampling. Either buoys or shore markers, located from a common reference point, were used to demarcate the different sampling transects. It was estimated that this grid would encompass the sediment plume. The general layouts of the three sites are shown in figures II-1 through II-7. Suspended-solids data for each site appear on these figures as well.

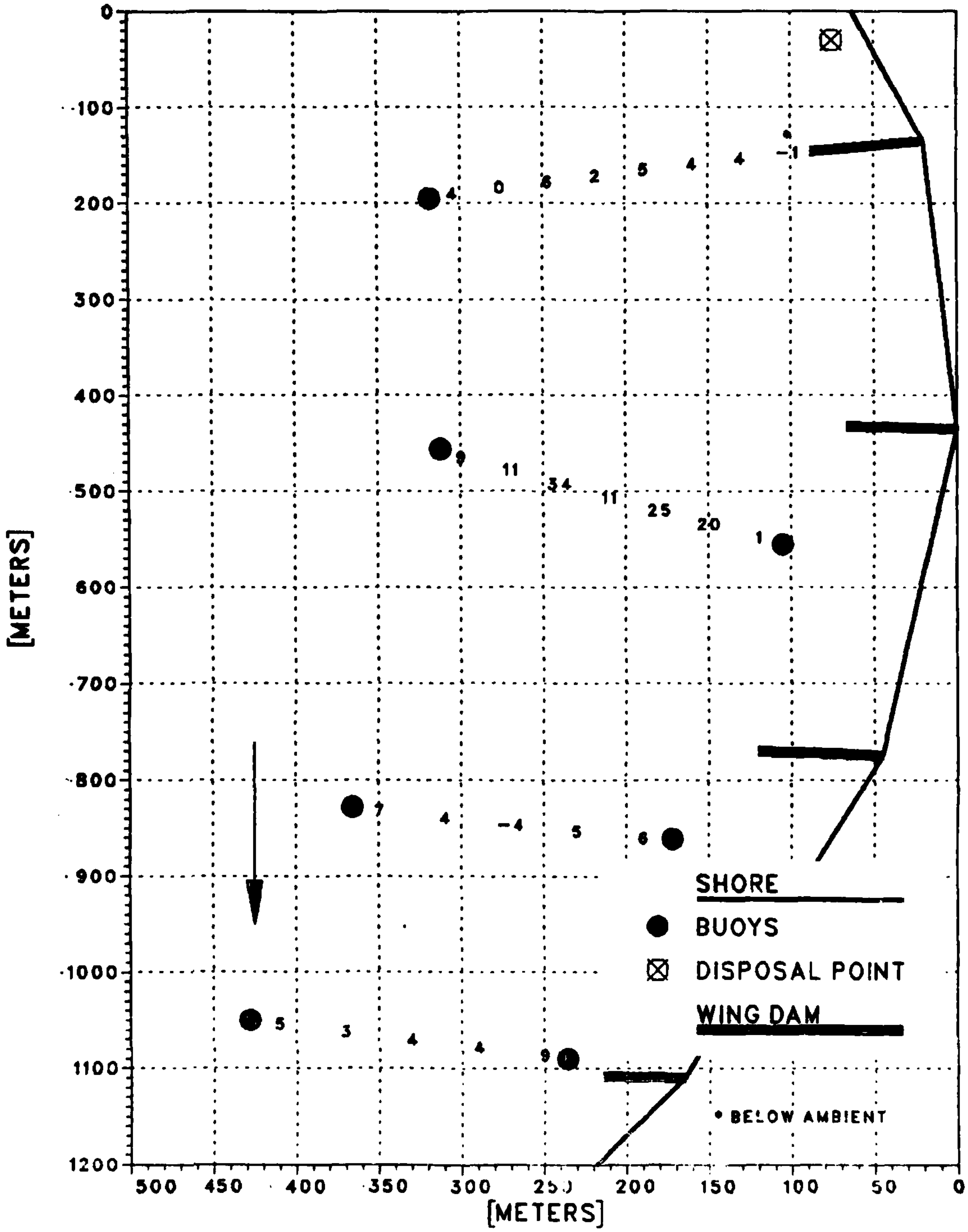

Figure II-1 RM 14: layout and above-ambient suspended-solids concentrations (mg/l) - 9-ft depth (plot 1).

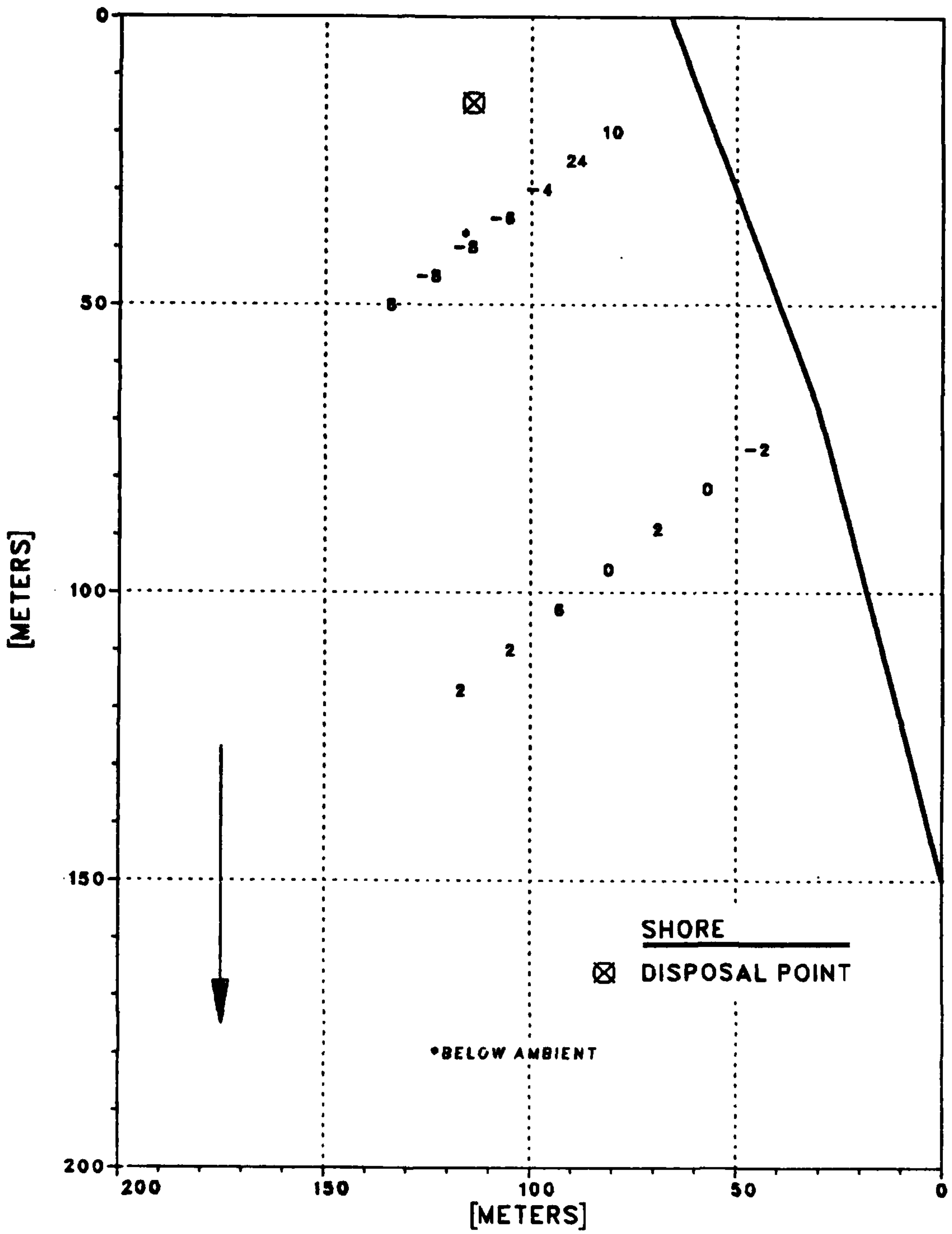

Figure II-2 RM 14: layout and above-ambient suspended-solids concentrations (mg/l) - 9-ft depth (plot 2).

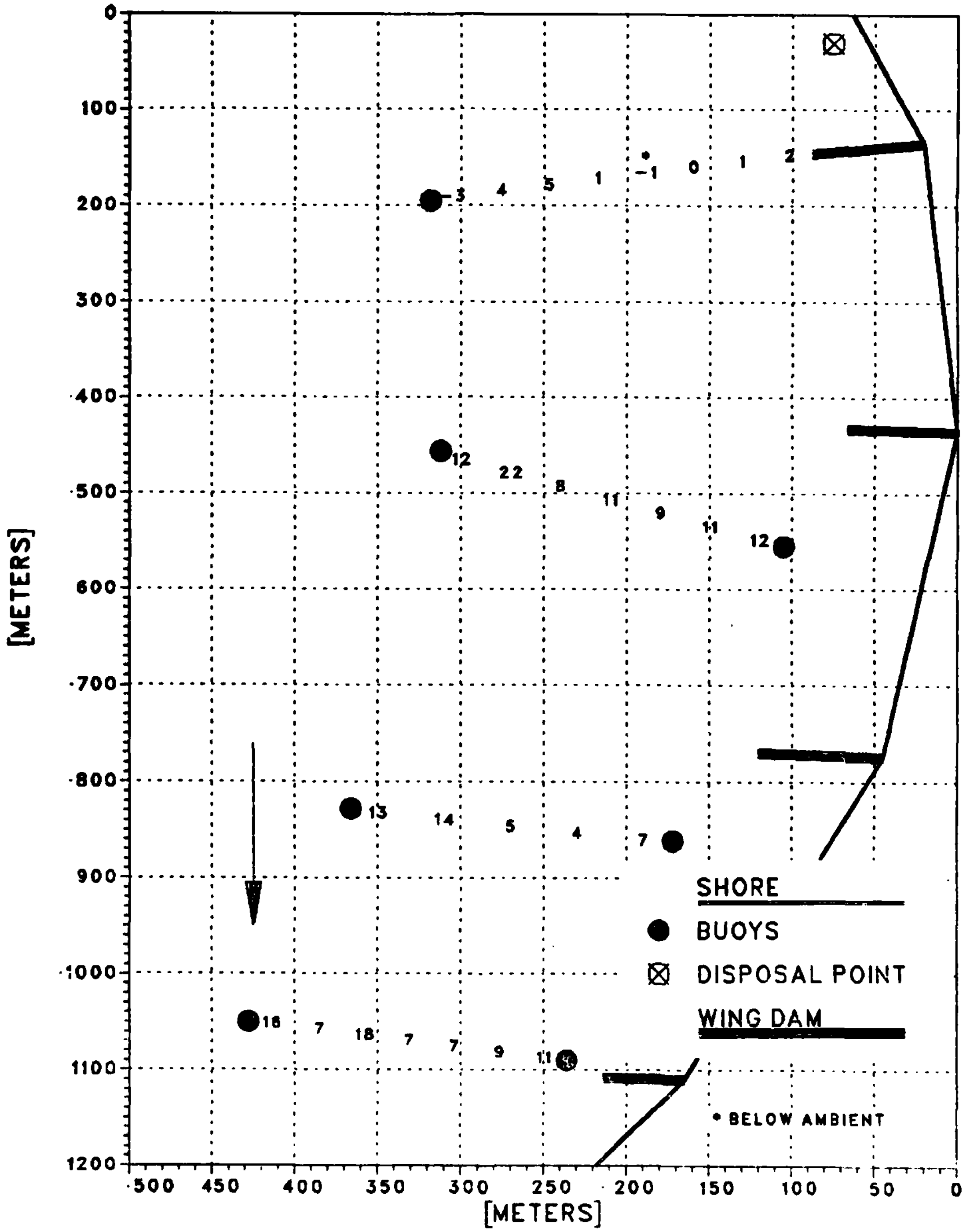

Figure II-3 RM 14: layout and above-ambient suspended-solids concentrations (mg/l) - 2-ft depth.

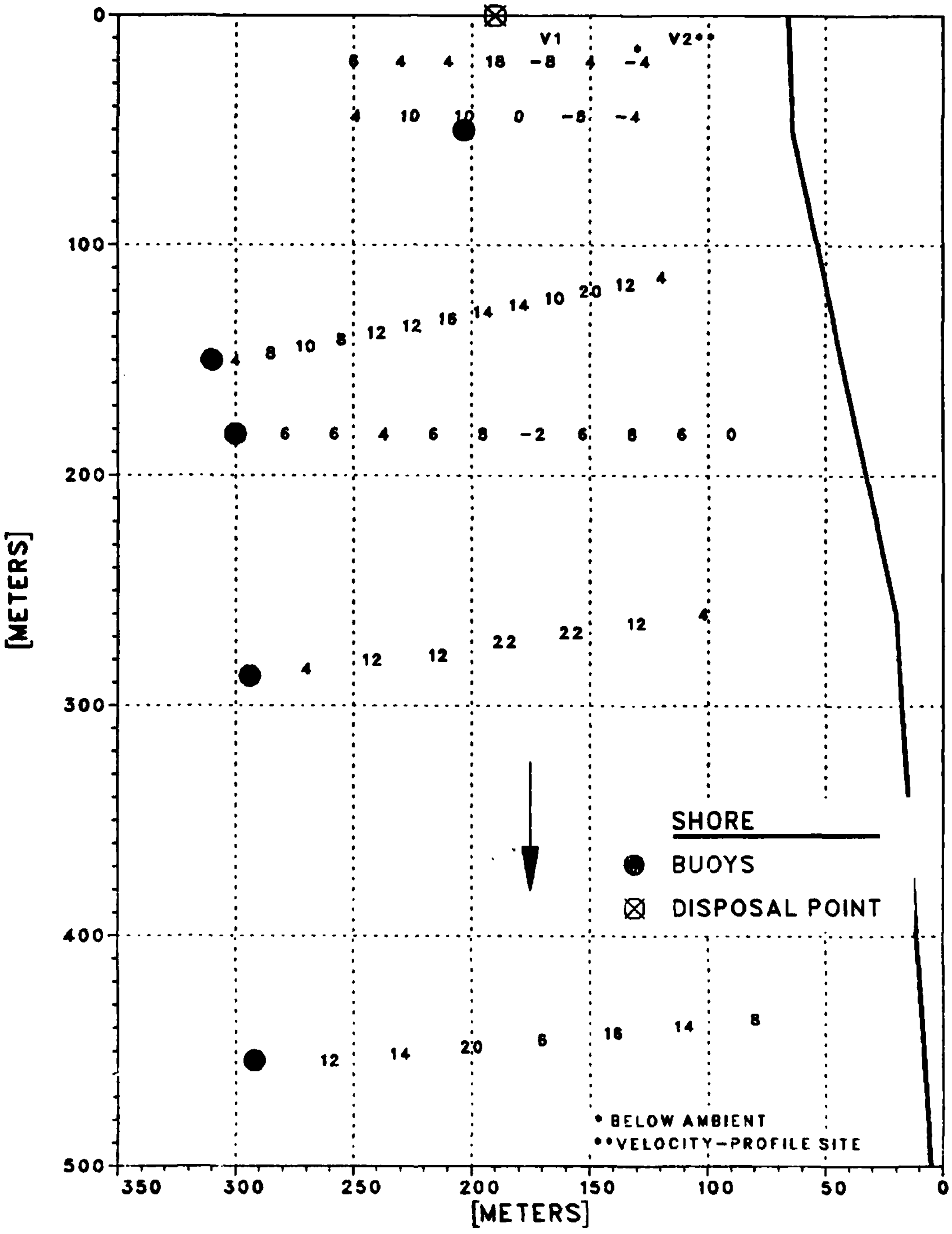

Figure II-4 RM 254.5: layout and above-ambient suspended-solids concentrations (mg/l) - 9-ft depth.

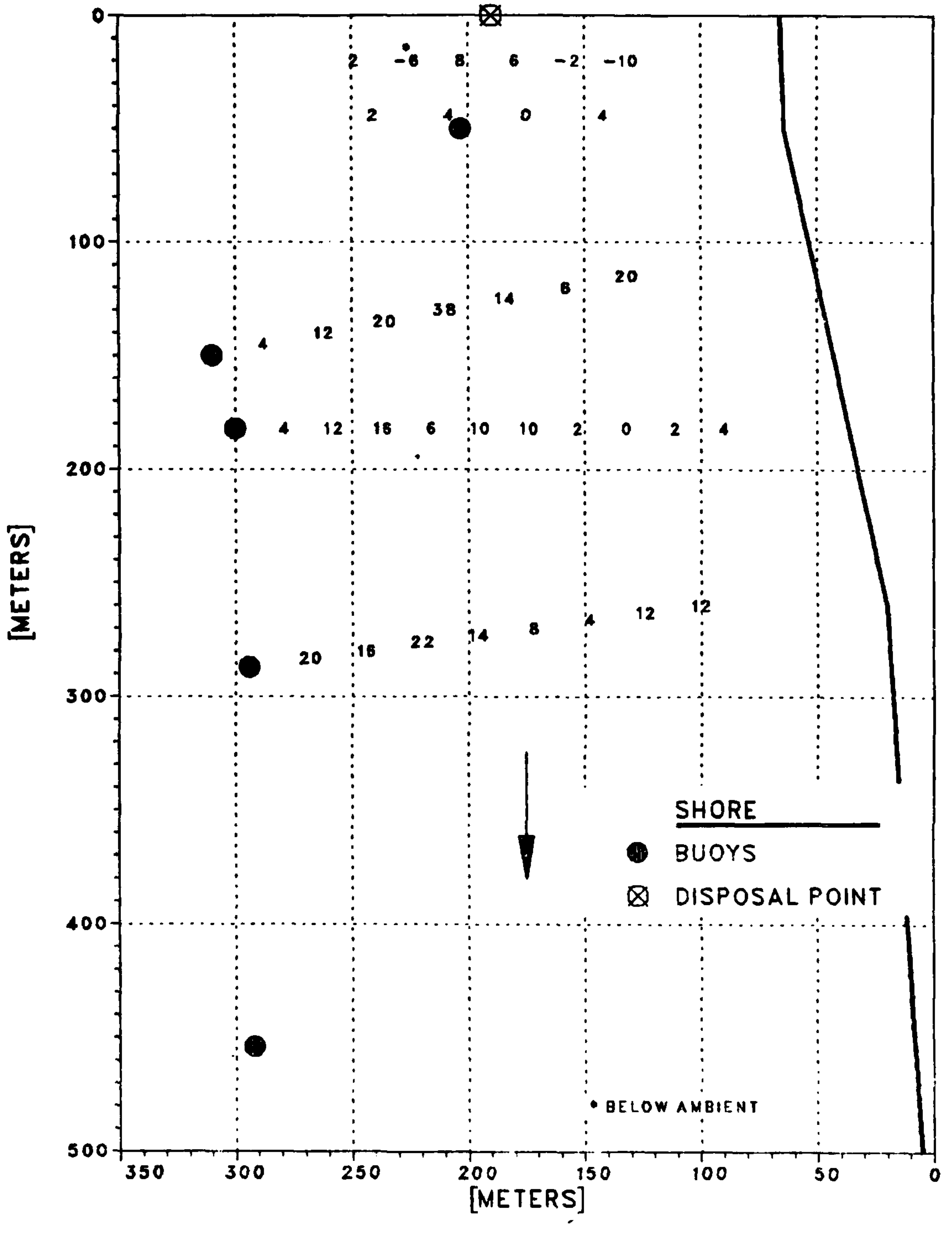

Figure II-5 RM 254.5: layout and above-ambient suspended-solids concentrations (mg/l) - 2-ft depth.

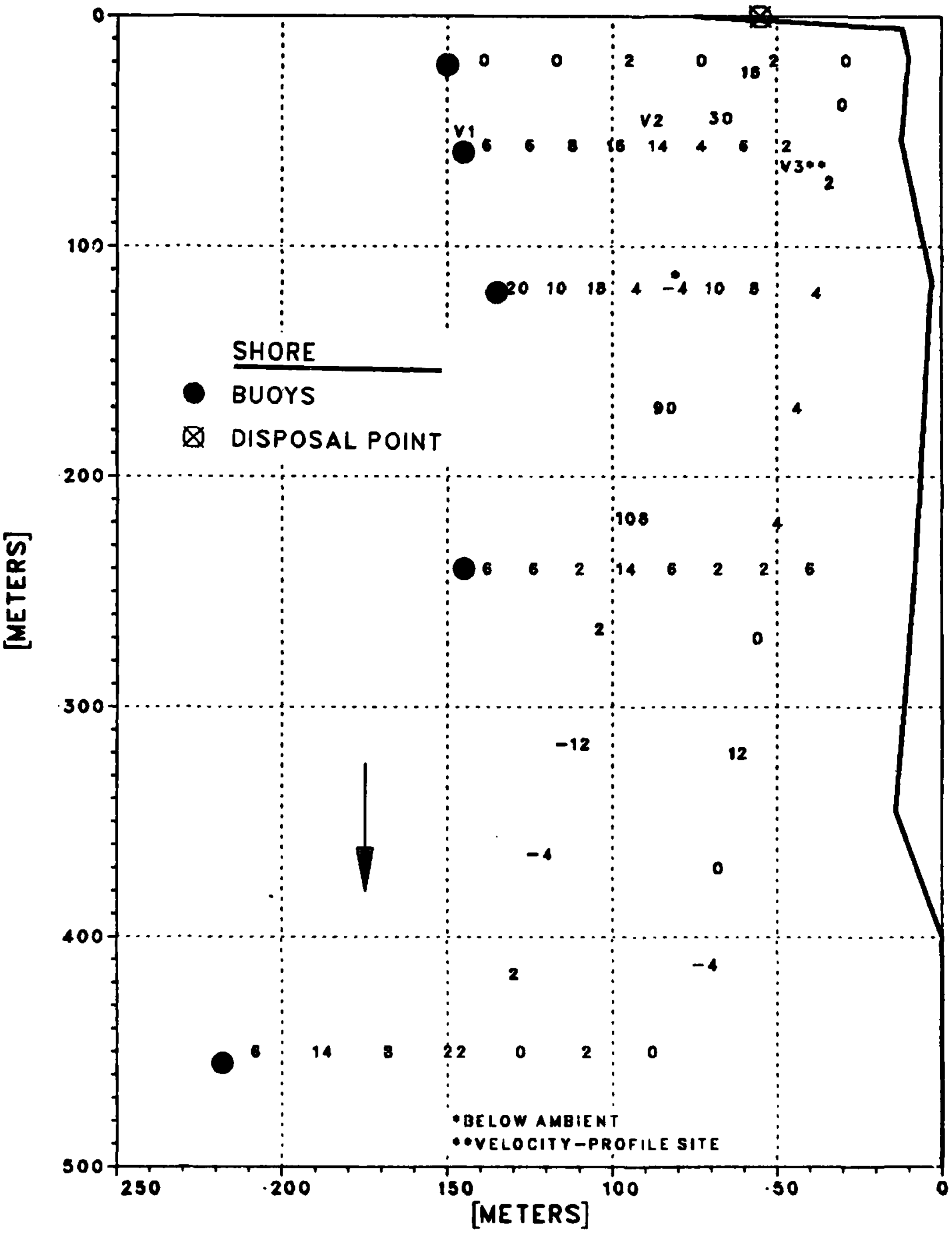

Figure II-6 RM 170: layout and above-ambient suspended-solids concentrations (mg/l) - 9-ft depth.

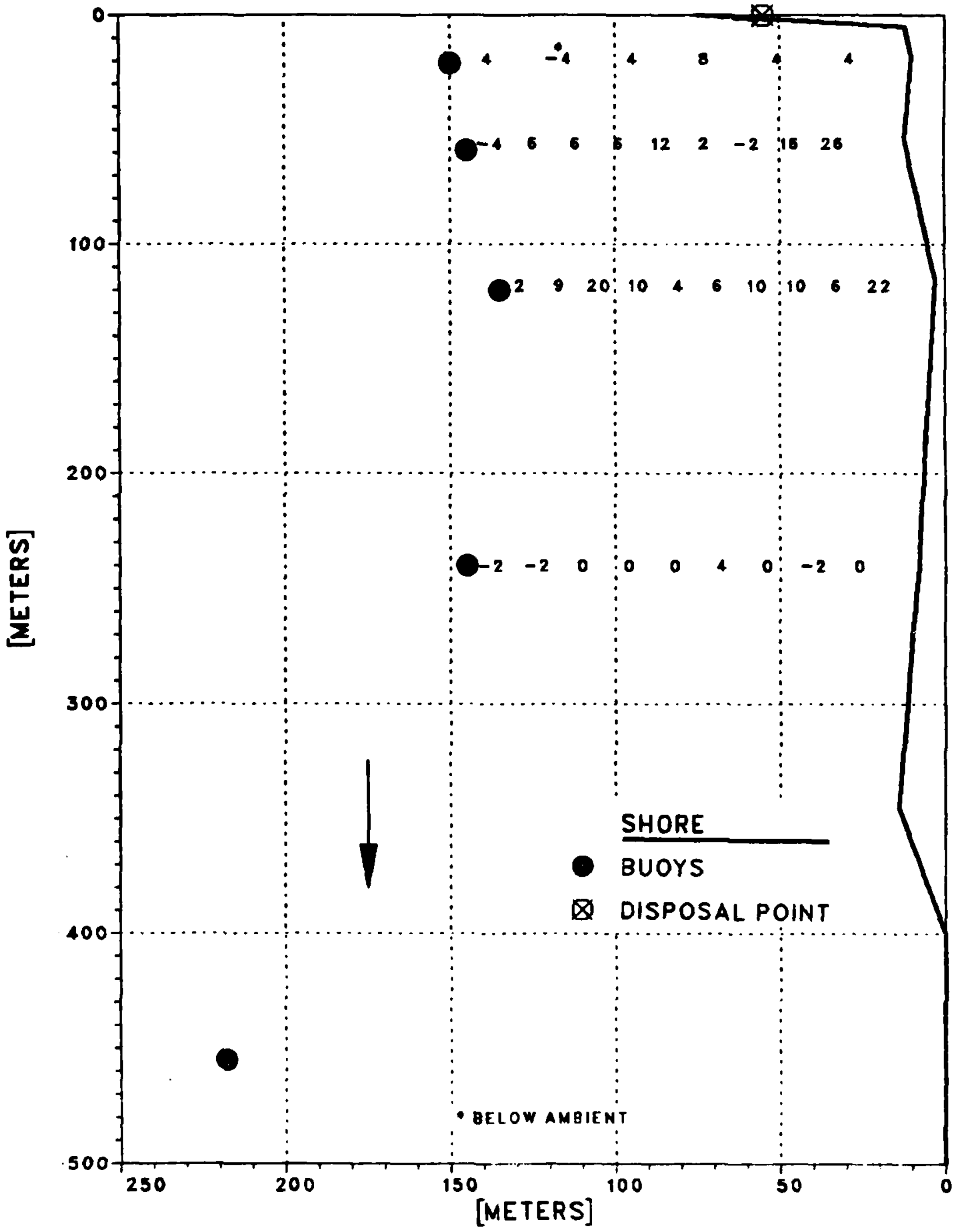

Figure II-7 RM 170: layout and above-ambient suspended-solids concentrations (mg/l) - 2-ft depth.

2). Water Samples - Suspended Solids. Water samples were taken at depths of 2 and 9 feet. Sediment-laden water was pumped continuously as the boat traversed each transect at an approximately uniform velocity. A small Cole-Darwin rotary pump was used to pump discrete samples into pint jars at intervals of approximately thirty seconds. These samples were analyzed using a standard suspended-solids analysis (Standard Methods, 1980) at the Water Plant laboratory of The University of Iowa. Figures II-1 through II-7 show the <u>above-ambient</u> suspended-solids concentrations for the three locations at 2-ft and 9-ft depths.

3). Velocity Measurements. To obtain a representative mean velocity for each site, velocity measurements were taken (with a Universal Current Meter) at ten equally spaced intervals along the depth, starting at 1 ft from the bottom, plus one measurement 0.4 ft from the surface. Thus, it was possible to construct velocity profiles for different locations at each site. These profiles are given in figures II-8 through II-10. This procedure also provided representative mean depths at each site.

4). Bed Samples. To determine a characteristic dredge material size, bed samples were taken with a Ponar dredge sampler. One sample was taken at some point which was to be dredged ("above dredge") and another was taken at the dump site.

These samples were analyzed using the U.S. Bureau of Standards sieve classification (Lambe, 1951), either by the Iowa Institute of Hydraulic Research (IIHR) or by the United States Geological Survey (USGS) in Iowa City, Iowa. The grain-size distribution curves appear in figures II-11 through II-13.

5). Water Samples - Solids Distribution. To determine the size distribution of the solids in suspension three water samples, approximately five gallons apiece, were gathered at each site; at about 20 ft (as close as possible), 40 ft, and 100 ft from the disposal point.

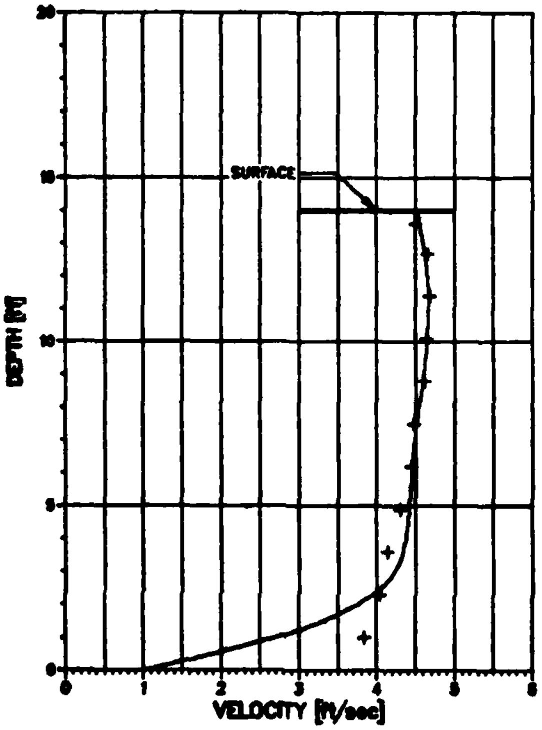

Figure II-8 Velocity profile - RM 14.

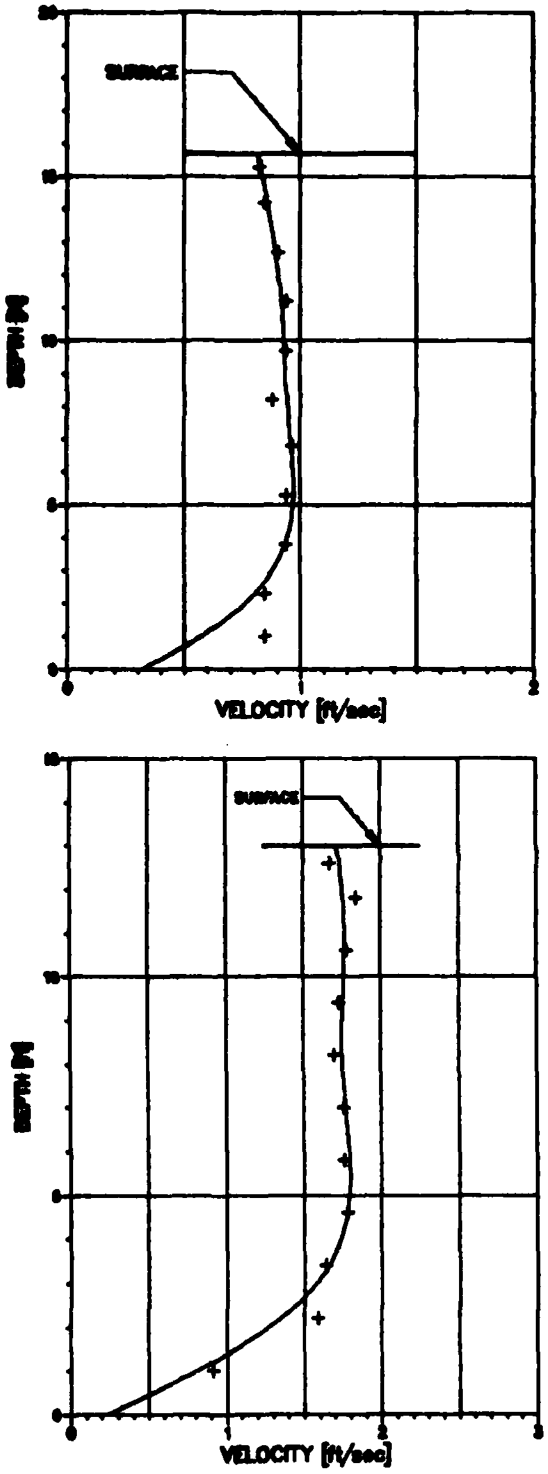

Figure II-9 Velocity profiles V1 and V2 - RM 254.5.

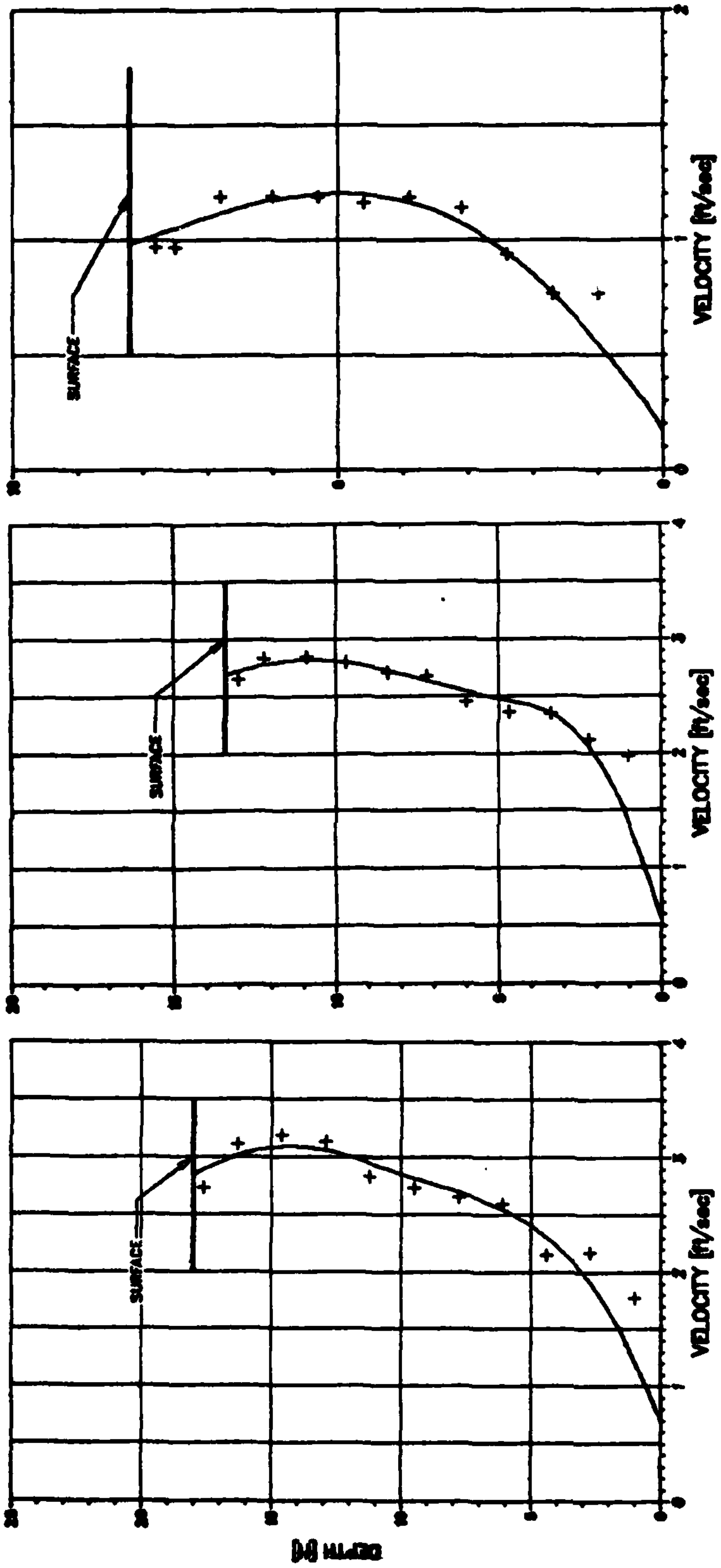

Figure II-10 Velocity profiles V1, V2, and V3 - RM 170

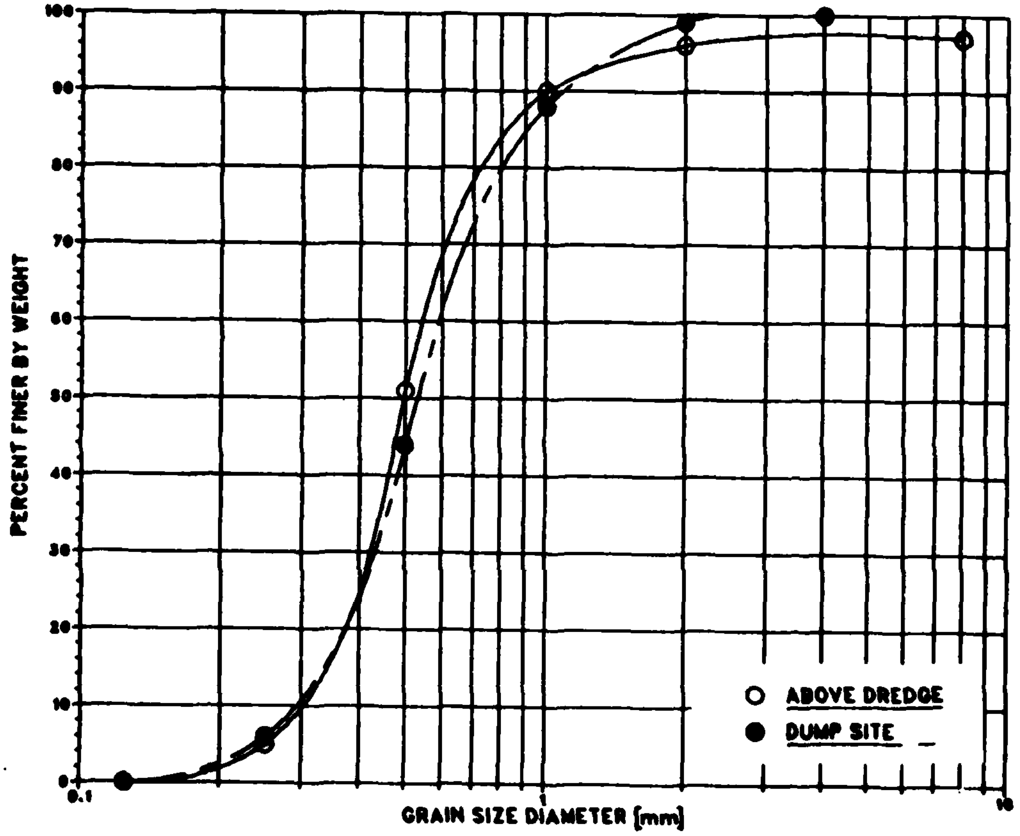

Figure II-11 Grain-size distribution of bed samples - RM 14.

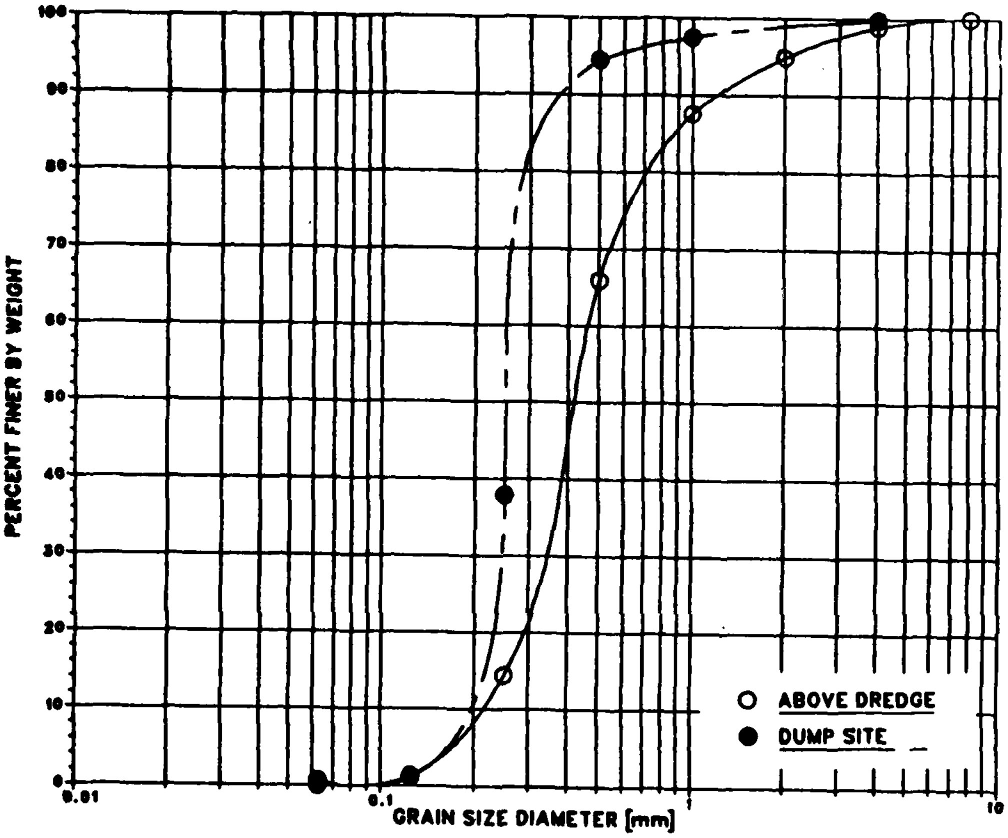

Figure II-12 Grain-size distribution of bed samples - RM 254.5.

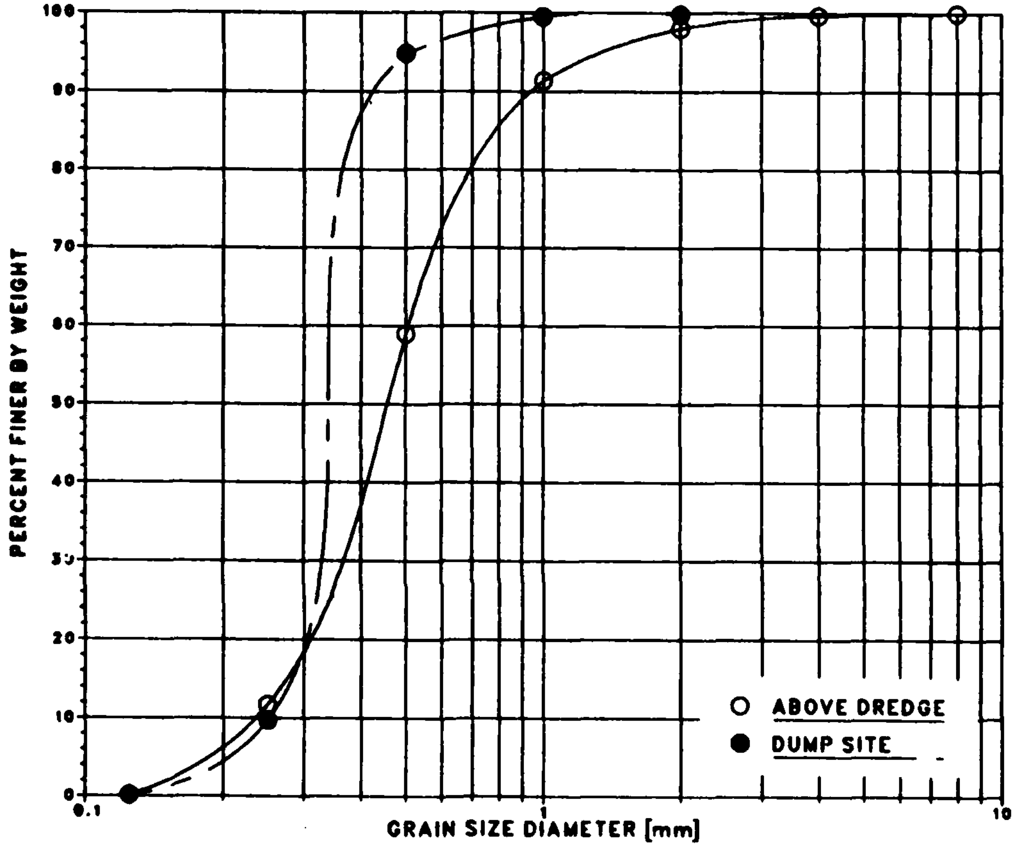

Figure II-13. Grain-size distribution of bed samples - RM 170.

These samples were analyzed by the Vsual Accumulation (VA) Tube and Pipette methods by the USGS. It should be noted that the settling velocities of the larger particles in suspension can easily be determined from the VA graph.

A brief description of each field trip follows:

1). The first field trip, to RM 14 (near Cairo, Illinois), was made between 29 September and 1 October, 1981. The general location map of the site appears in figure II-14. The COE dustpan dredge, "Potter," was operating using near-shore disposal. The layout and suspended-solids plumes appear in figures II-1 through II-3, with ambient suspended solids equal to 100 mg/l.

The plume at the 9-ft depth is presented in two parts (figures II-1 and II-2) because the dredge-disposal point was moved approximately 500 m upstream before the final two transects were sampled. Due to a lack of time and the difficulties involved in reestablishing the grid system, it was assumed that the last two transects could be incorporated with the first four for modelling purposes.

According to the MIT classification (Lambe, 1951), the dredged material at this site (see figure II-11) appears to be largely medium and coarse sand with D_{50} equal to about 0.5 mm. There was practically no silt and clay present in the samples.

Figure II-8 illustrates two of the problems encountered at RM 14: extremely high velocities and depths. Although the figure indicates a relatively high velocity of 4.5 ft/sec and a depth of 14 ft, velocities of over 8 ft/sec "gusting" around the wing dams were encountered, as well as depths of more than 50 ft. These velocities and depths made it extremely difficult to set up the original grid. The sampling itself was also difficult because the boat was rather ill-equipped to handle these conditions. The presence of a series of wing dams contributed to the general unsteadiness of the situation. All of these conditions taken together explain, to a large extent, the absence of well-

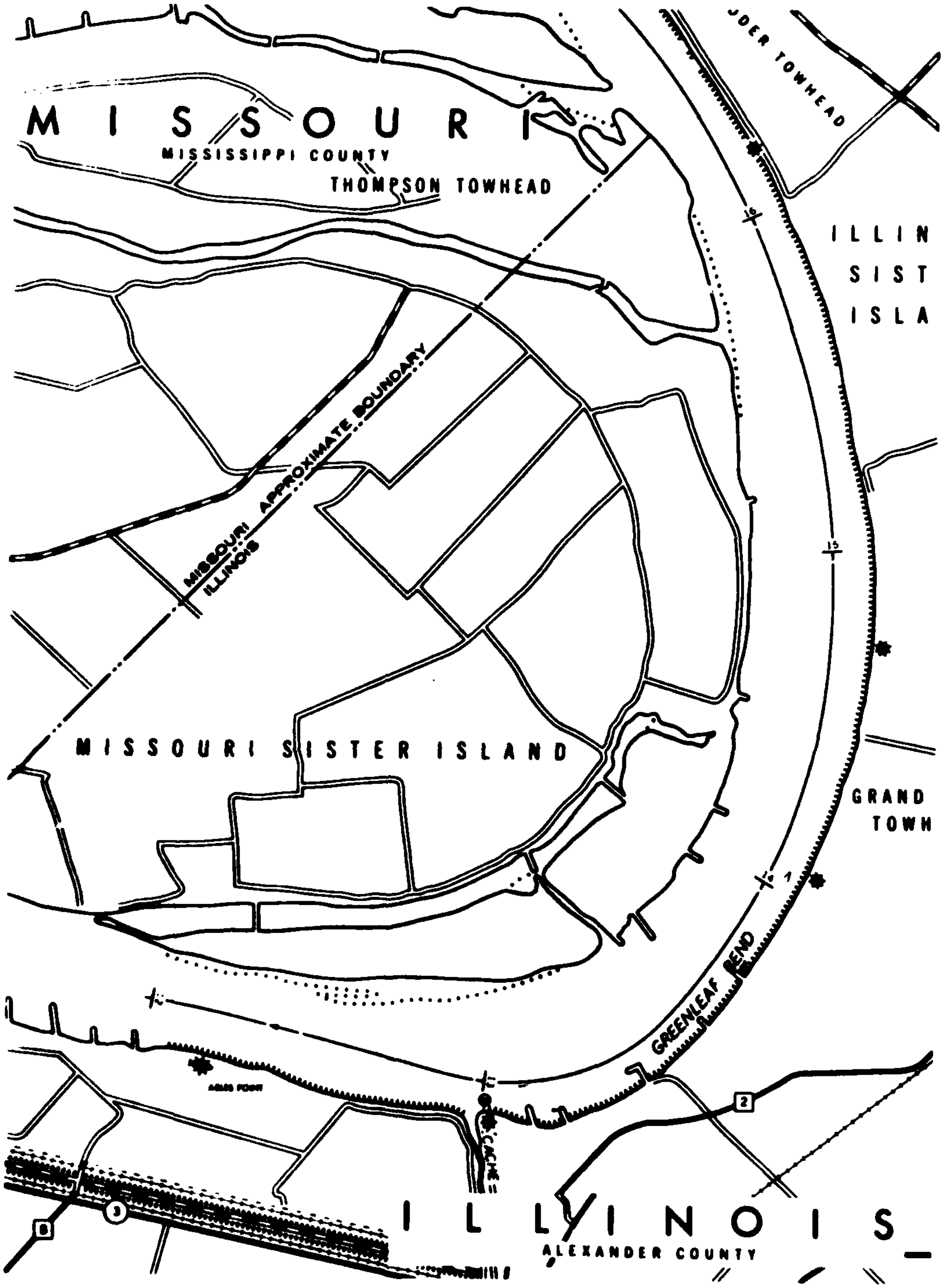

Figure II-14 Site location map - RM 14.

established plumes at this site (see figures II-1 through II-3).

2). The second field trip, to RM 254.5, was made between 20 October and 25 October, 1981. The general location map of the site appears in figure II-15. Open-water disposal of the COE cutterhead dredge, "St. Genevieve", was sampled. The general layout and suspended-solids plumes appear in figures II-4 and II-5, with ambient suspended solids equal to 156 mg/l.

The plume at the 9-ft depth (figure II-4) is fairly well established, especially on transects 3, 5, and 6 with concentration values tapering off at the edges. The plume appears to be on the order of 200 m wide. The plume at the 2-ft depth (figure II-5) is less well established.

Figure II-9 shows representative velocity profiles and depths at this site. The velocities are about 1.5 ft/sec and the depths are about 15 ft. The sites where velocities were measured appear in figure II-4 as V1 and V2.

D_{50} for the bed samples (see figure II-12) lies between 0.3 and 0.4 mm. Again, there is very little silt and clay; the dredged material appears to be medium and coarse sand. The difference between the two curves is probably due to local sorting at the discharge point.

3). The third field trip, to RM 170 (near St. Louis, Missouri), took place between 20 November and 22 November, 1981. The general location map of the site is shown in figure II-16. The dredge-disposal plume from the "St. Genevieve" was sampled. Both near-shore and on-shore disposals were used at different times. The general layout and suspended-solids plumes for this site are given in figures II-6 (ambient suspended solids = 70 mg/l) and II-7 (ambient suspended solids = 84 mg/l).

Figure II-6 (9-ft depth) shows a fairly well-established plume with the concentrations along most of the transects tapering off at the edges. The width of the plume is on the order of 100 m, but it is possible that the whole plume was not encompassed

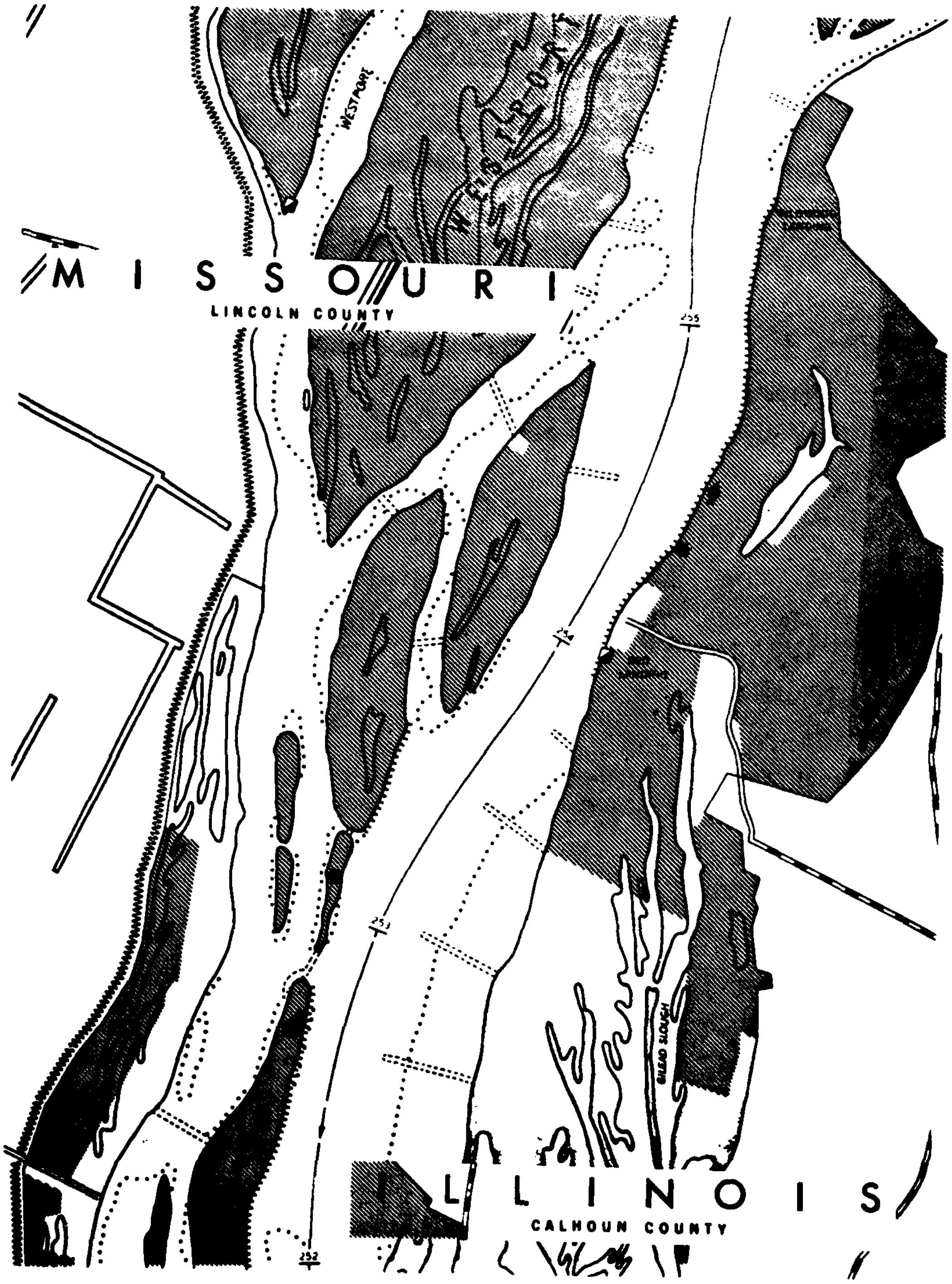

Figure II-15 Site location map - RM 254.5.

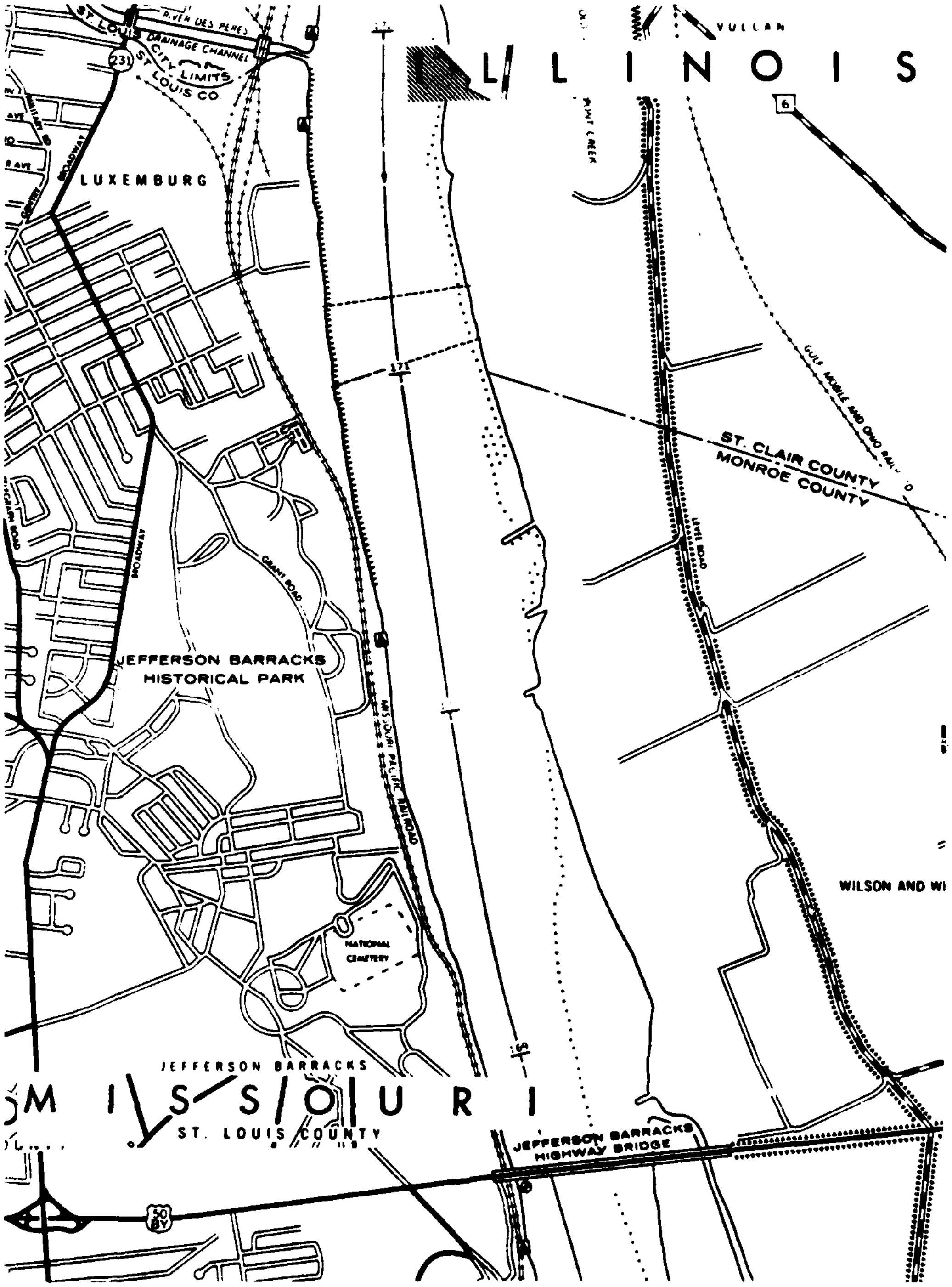

Figure II-16 Site location map - RM 170.

within the grid.

The 2-ft depth plume (figure II-7) is considerably less well established than that at the 9-ft depth. The fourth transect indicates a drop in slurry concentration.

Figure II-10 indicates representative velocities of about 2.5 ft/sec and depths ranging from about 10 to 20 ft. The measurement sites are shown as V1, V2, and V3 in figure II-6.

The grain-size distribution for this site (figure II-13) shows dredge-spoil material consisting of medium and coarse sand with a D_{50} of about 0.4 mm, with little or no silt and clay present. The difference between the two curves is probably due to sorting at the discharge point. An empirical relationship between particle diameter and settling velocity is presented in figure II-17.

One problem unique to this site was the mode of disposal. The disposal started out as near-shore in water 2 or 3 ft deep. As the sand settled out of suspension, it rapidly accumulated and the disposal became on-shore. This change naturally affected the dynamics of the whole situation and, therefore, the formation of the plume itself.

C. Model Predictions - GREAT II Data. The first modelling objective of the present project is to attempt, through manipulation of input parameters, to improve suspended-solids-concentration predictions of field data from two GREAT II sites (Schnoor et al., 1980).

Figure II-18 shows field data from the Rock Island, Illinois site. The isopleths superimposed on the data are those predicted by the model as it was in the GREAT II study, except the source half-width has been increased from 12.5 m to 15 m to improve the transverse scale on the computer output. The principal problem is too little lateral spread.

Lateral spreading can be increased by increasing either the source half-width or the lateral dispersion coefficient, E_z. Since increasing the source width essentially increases the width of the entire plume proportionately, it was decided to concentrate on increasing the plume spread by changing the

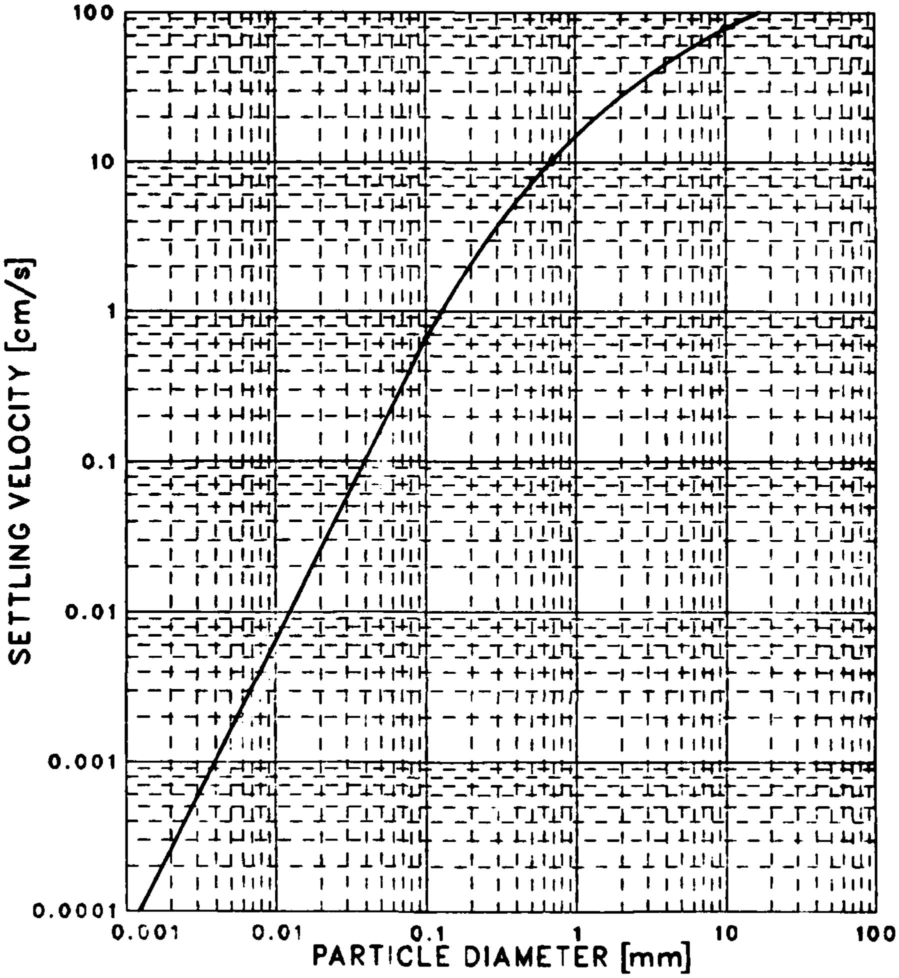

Figure II-17 Particle size vs. settling velocity for suspended sediment (Barnard, 1978).

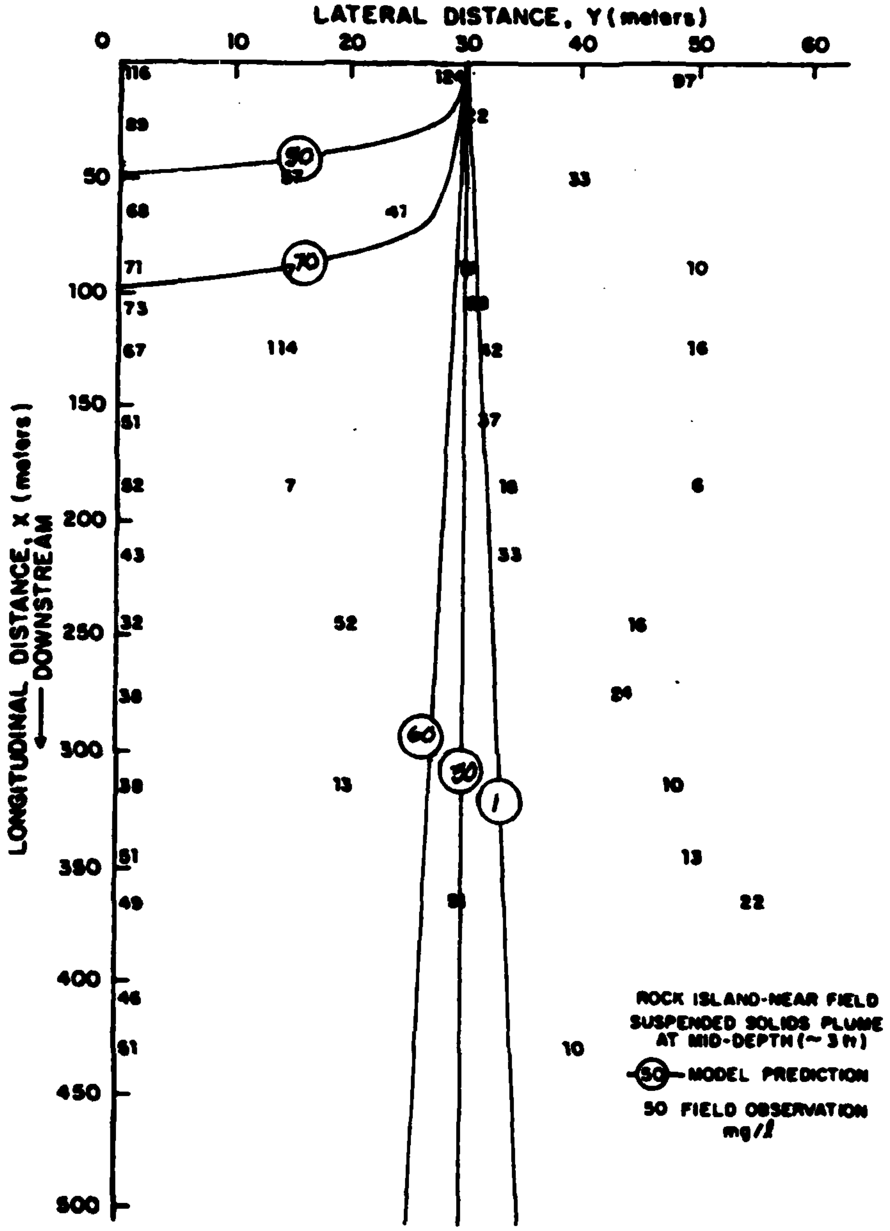

Figure II-18 Rock Island suspended-solids plume with predicted isopleths superimposed (E_z=0.0088 sq. m/s).

lateral dispersion coefficient.

The lateral dispersion coefficient for figure II-18 was calculated using the assumption that (see Section A)

$$E_z = 2.2\ (0.005UH) = 0.0088\ m^2/s \qquad \text{(II-20)}$$

A number of model simulations were made systematically increasing the lateral dispersion coefficient while keeping all other parameters the same. The most satisfactory prediction was obtained using $E_z = 2.0\ m^2/s$ (figure II-19). Because of its magnitude, this value of E_z can no longer be considered to represent only the effect of turbulent diffusion. For the remainder of this report the lateral dispersion coefficient will be referred to as the coefficient of transverse mixing, D_z. This coefficient includes effects of turbulent diffusion, transverse dispersion (Taylor, 1954) associated with secondary currents, and any transverse velocity component imparted by the disposal operation itself. This change from E_z to D_z will be discussed in more depth in Section E.

The same modelling procedure was followed for data from the Keithsburg, Illinois, site. Figure II-20 shows the model results for parameters used in the GREAT II report, except that the source width has been increased from 6 to 12 m (again, to improve the computer-output scale). This figure also shows the inability of the model to adequately predict lateral spread; near-shore and in-plume suspended-solids concentrations are also poorly predicted. It should be noted that the lateral dispersion coefficient was taken (in the GREAT II study) to be equal to $0.03\ m^2/s$, and it was not calculated by (II-20). The coefficient was increased to include effects of the sloping channel bottom.

Although the Keithsburg data were quite sketchy, $D_z = 2.0\ m^2/s$ (figure II-21) again provided the most plausible predictions for a combination of lateral spread, near-shore concentrations, and to a certain extent, the few available in-plume concentrations.

D. Model Predictions - GREAT III Data. Having obtained satisfactory results for Rock Island and Keithsburg data, the modified model was used to predict GREAT III data. The input parameters for the RM 254.5 site were

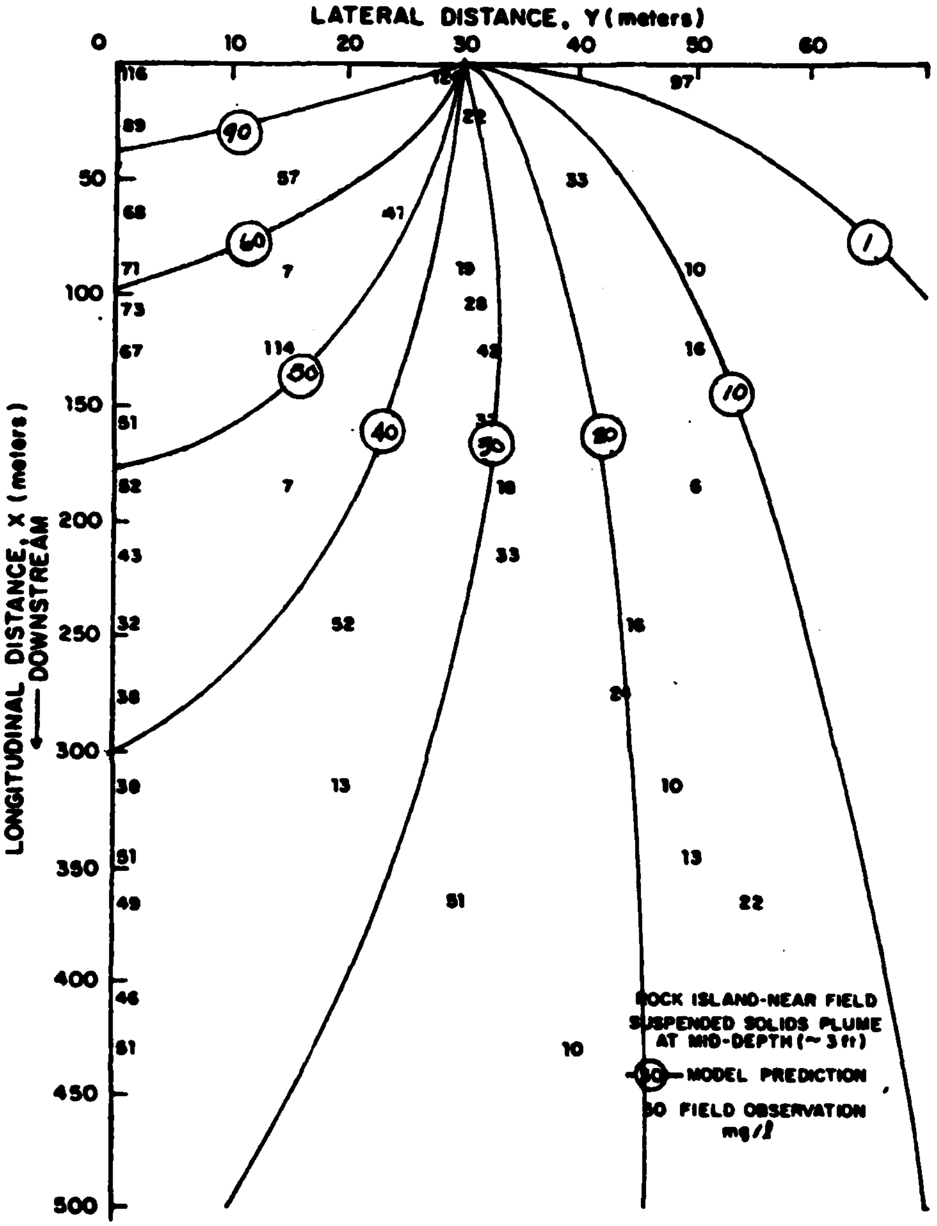

Figure II-19 Rock Island suspended-solids plume with predicted isopleths superimposed (D_z=2.0 sq. m/s).

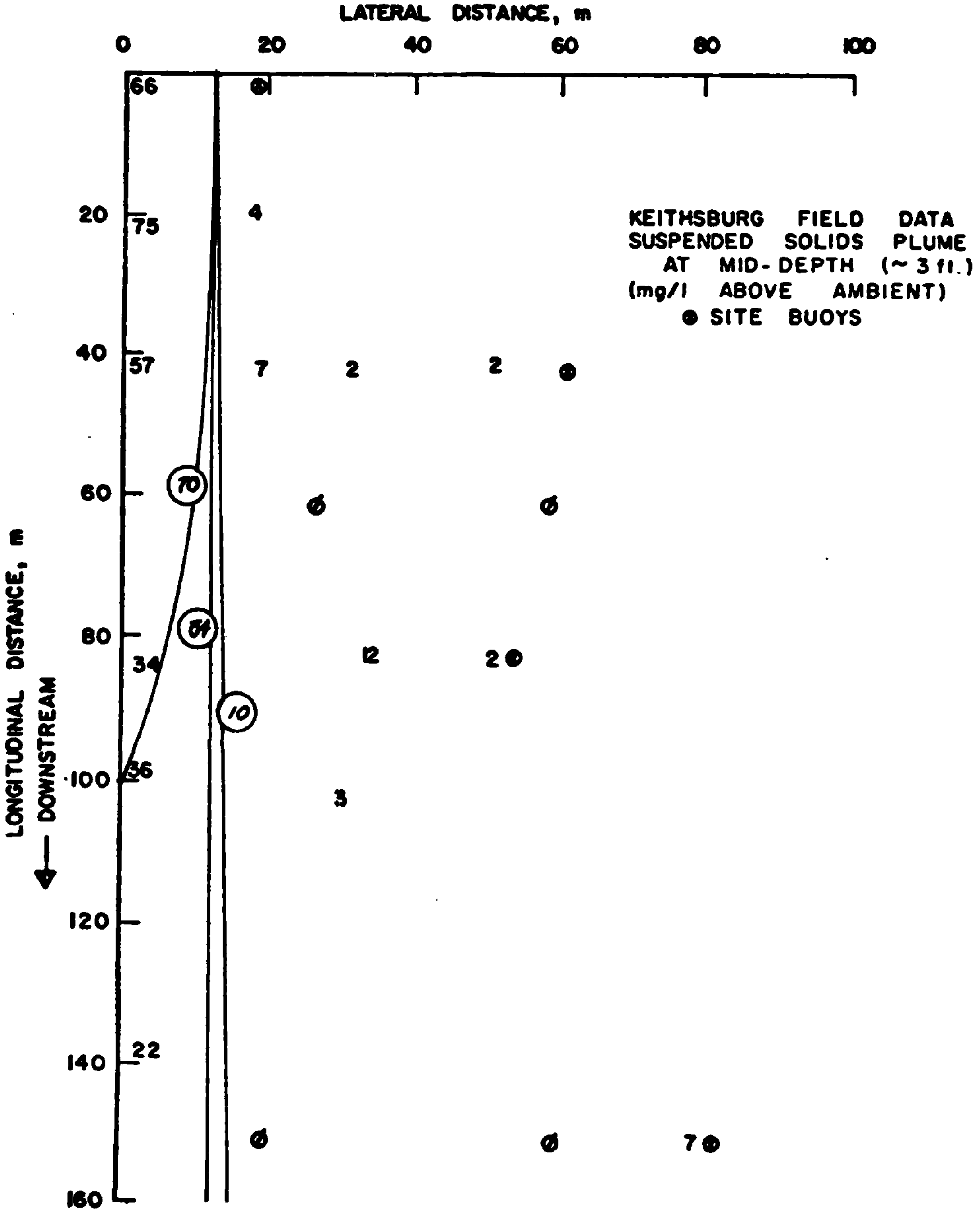

Figure II-20 Keithsburg suspended-solids plume with predicted isopleths superimposed (D_z=0.03 sq. m/s).

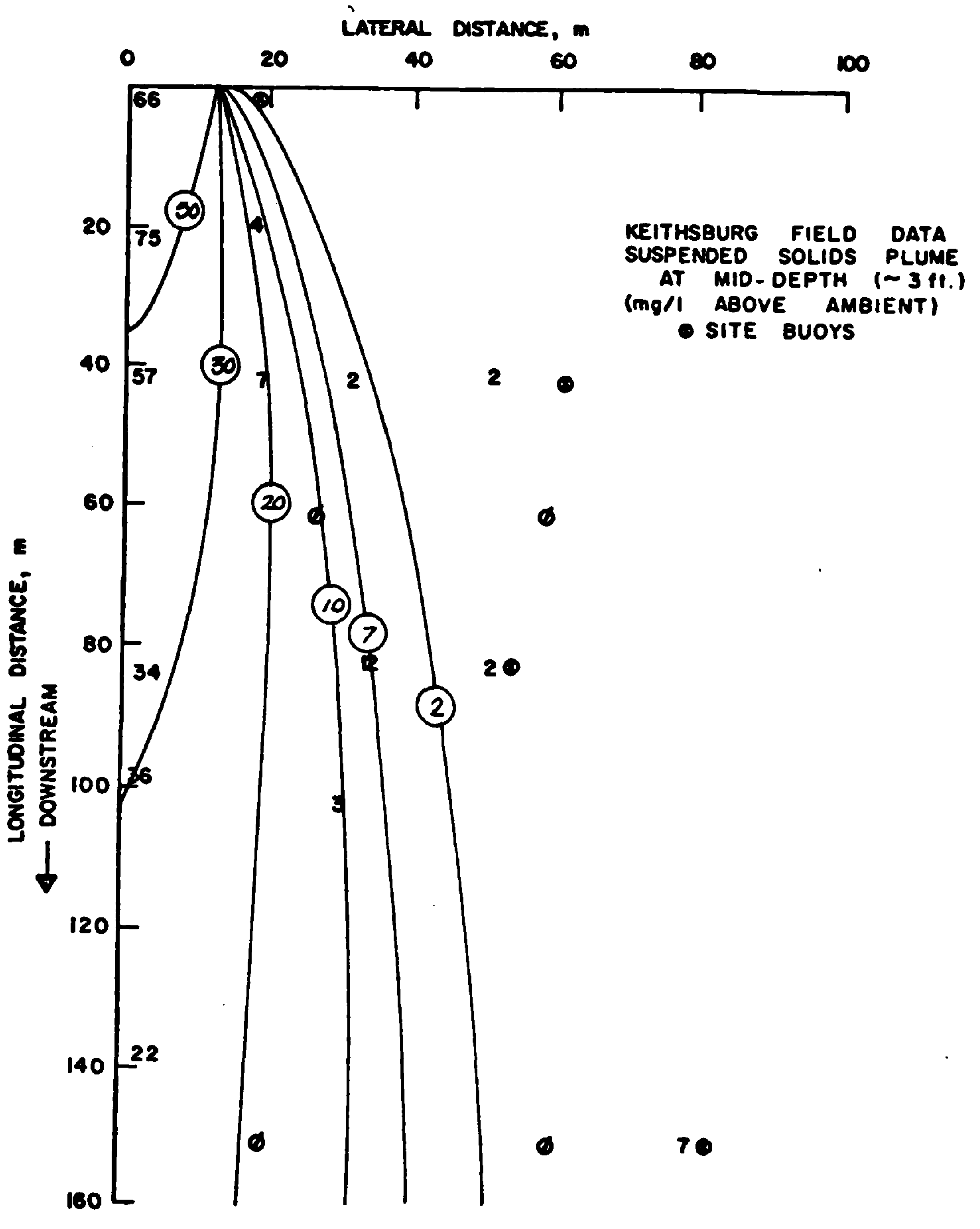

Figure II-21 Keithsburg suspended-solids plume with predicted isopleths superimposed (D_z=2.0 sq. m/s).

determined as follows:

1). The mean velocity of 0.5 m/s was determined from figure II-9.

2). The depth of 4 m was determined from figure II-9.

3). From personal observation, the source width was assumed to be equal to 20 m.

4). Above-ambient suspended-solids concentrations at RM 254.5 (see figures II-4 and II-5) were not substantial enough to provide a basis for determining the original source concentration. For this reason, a rough solids balance was used to calculate the strength of the source.

The "St. Genevieve" dredges an average of 1072 yd^3/hr of material (personal communication with Mr. Matthew Struckel, U.S. Army Corps of Engineers, St. Louis). Assuming the dredge spoil to be 85 percent solids, the mass of material discharged from the dredge is approximately 5×10^8 mg/s. Using the width, velocity, and depth calculated above, approximately 12,000 mg are discharged per liter of receiving water. Less than one percent of this material actually becomes suspended in the river upon disposal.

The next obstacle encountered was modelling the low suspended-solids concentrations at the head of the plume, precisely where the highest concentrations would normally be expected. This phenomenon is discussed in Section E. In trying a number of different source configurations, the best results were obtained when the initial plane source was assumed to cover the bottom tenth of the depth. Therefore, the initial source strength should be scaled up to 120,000 mg/l. Since 120,000 mg/l is known to be too large, the source strength was reduced considerably from the original value, because the bulk of the material (mainly sand) settles out of suspension almost immediately after discharge.

5). It was not possible to accurately determine the size division of suspended-dredged sediment from the field analyses. In light of this situation, the following procedure was followed:

a) Since the data indicated a fairly constant amount of sediment in suspension, the sediment was divided into two fractions: fines and sand.

b) Based on size analyses, the grain size of the sand in suspension was taken to be about 125 microns. From these analyses, the settling velocity for 125 microns is approximately 0.016 m/s. Because the model is unstable for a combination of this settling velocity and the current velocity at the site (see figure II-22), the settling velocity used was 0.012 m/s. Since even at the reduced velocity the sand settles out quite rapidly, this reduction has very little effect on the final result.

c) Based on the pipette analyses the representative grain size for the fines was assumed to be 0.002 mm. The corresponding settling velocity determined from figure II-17 is about 3×10^{-6} m/s.

d) Based on size analyses, the material is assumed to contain about 50 percent fines and 50 percent sand.

6). The disposal mode used was open-water discharge.

7). Since the plume spreads out very quickly at first, and then more gradually, it was decided to introduce a crude scheme (this assumption is discussed more thoroughly in Section E) for modelling the lateral mixing coefficient. It was assumed that D_z varies as follows:

$$D_z(x) = D_z^*[1+b \exp(-x/100)] \qquad \text{(II-21)}$$

where

D_z^* = eventual "steady state" lateral mixing coefficient

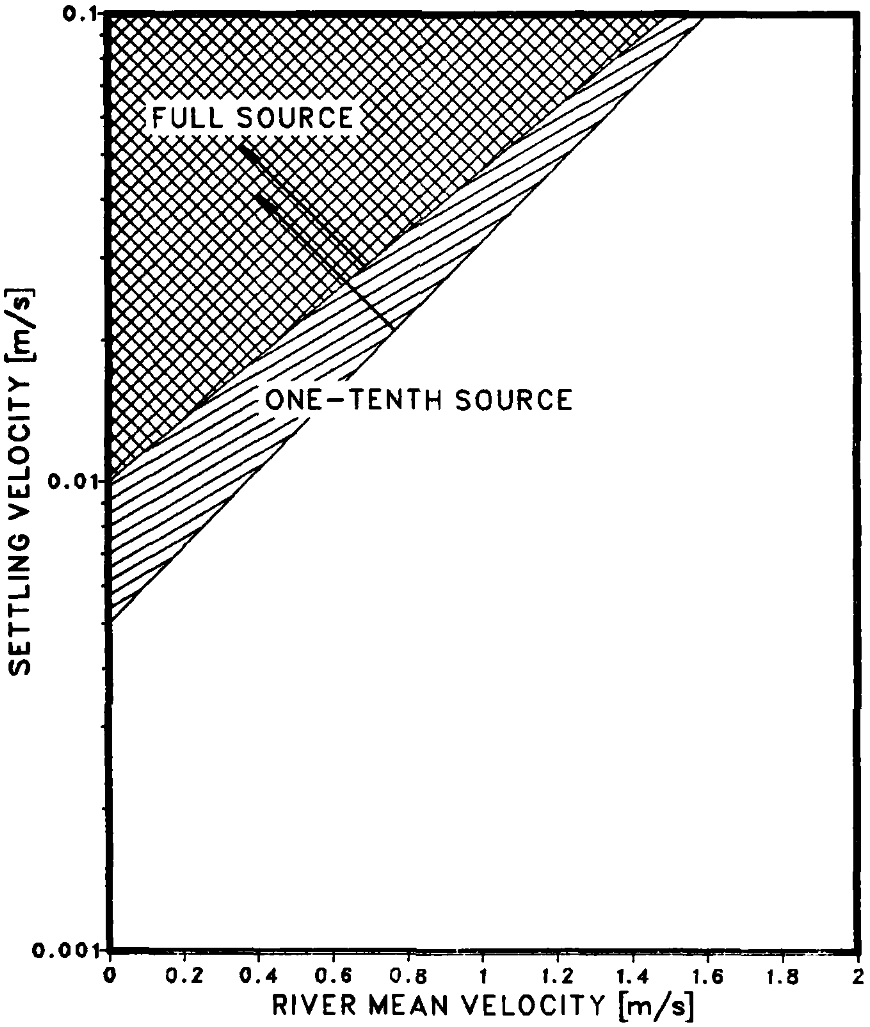

Figure II-22 Zones of model instability.

b = a constant

In other words, the lateral mixing coefficient was assumed to decrease exponentially until it reached an essentially constant value.

These parameters were modelled for different combinations of D_z^*, b, and original source concentration. The best predictions were obtained using $D_z^* = 2.0\ m^2/s$ and b = 10 for an original source strength of 2000 mg/l. The predicted isopleths appear in figures II-23 (9-ft depth) and II-24 (2-ft depth). The lateral spread is predicted well for both depths. Concentration predictions for the 9-ft depth are quite good, while those at a depth of 2 ft are too low.

The final phase of the present study consisted of verifying the modified model using data gathered at RM 170 (see figures II-6 and II-7). The parameters used for this verification were as follows:

1). Mean velocity = 0.8 m/s (from figure II-10).
2). Mean depth = 4 m (from figure II-10).
3). Source width = 20 m.
4). The source configuration and original source strength were assumed to be the same as those used at RM 254.5.
5). Even though there was a higher percentage of fines present in suspension than at RM 254.5, the distributions were quite similar. Because the grain-size distributions at the two sites (figures II-12 and II-13) were also very similar, the same sediment division and settling velocities as were used at RM 254.5 were chosen. The smaller amounts of sand in suspension at the head of the plume are probably due to the fact that the dredge spoil often traveled over land before entering the river, and therefore the sand had more opportunity to settle out. Given the similarities in distribution already mentioned and the fact that the fines predominate in the plume, the assumption that the sediment parameters were also similar is justified.
6). Since the spoil discharge alternated between near- and on-bank, the intermediate disposal mode was used.
7). Since the depths and velocities were of similar magnitudes at both

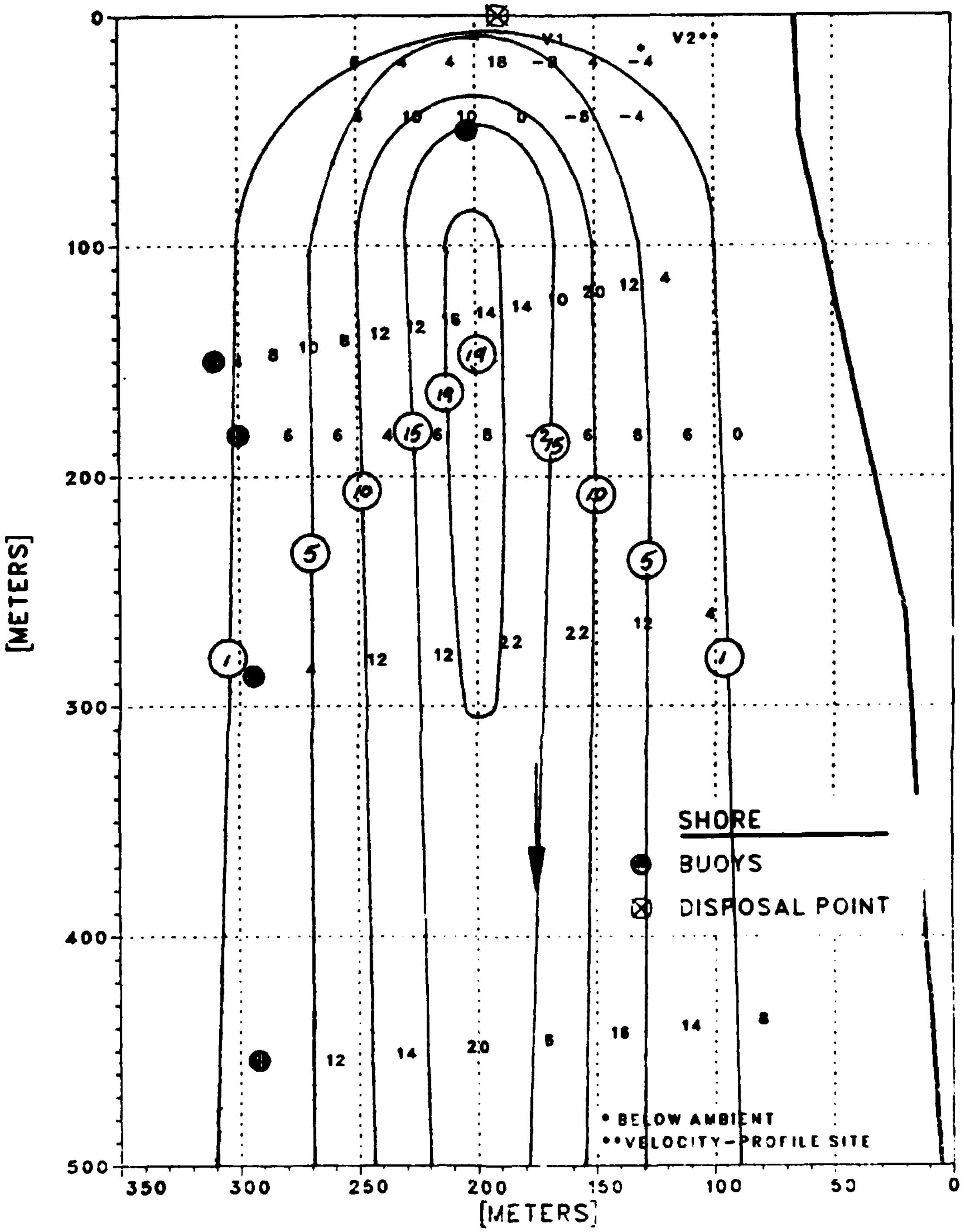

Figure II-23 RM 254.5 (9-ft depth) suspended-solids plume with predicted isopleths superimposed (mg/l above ambient).

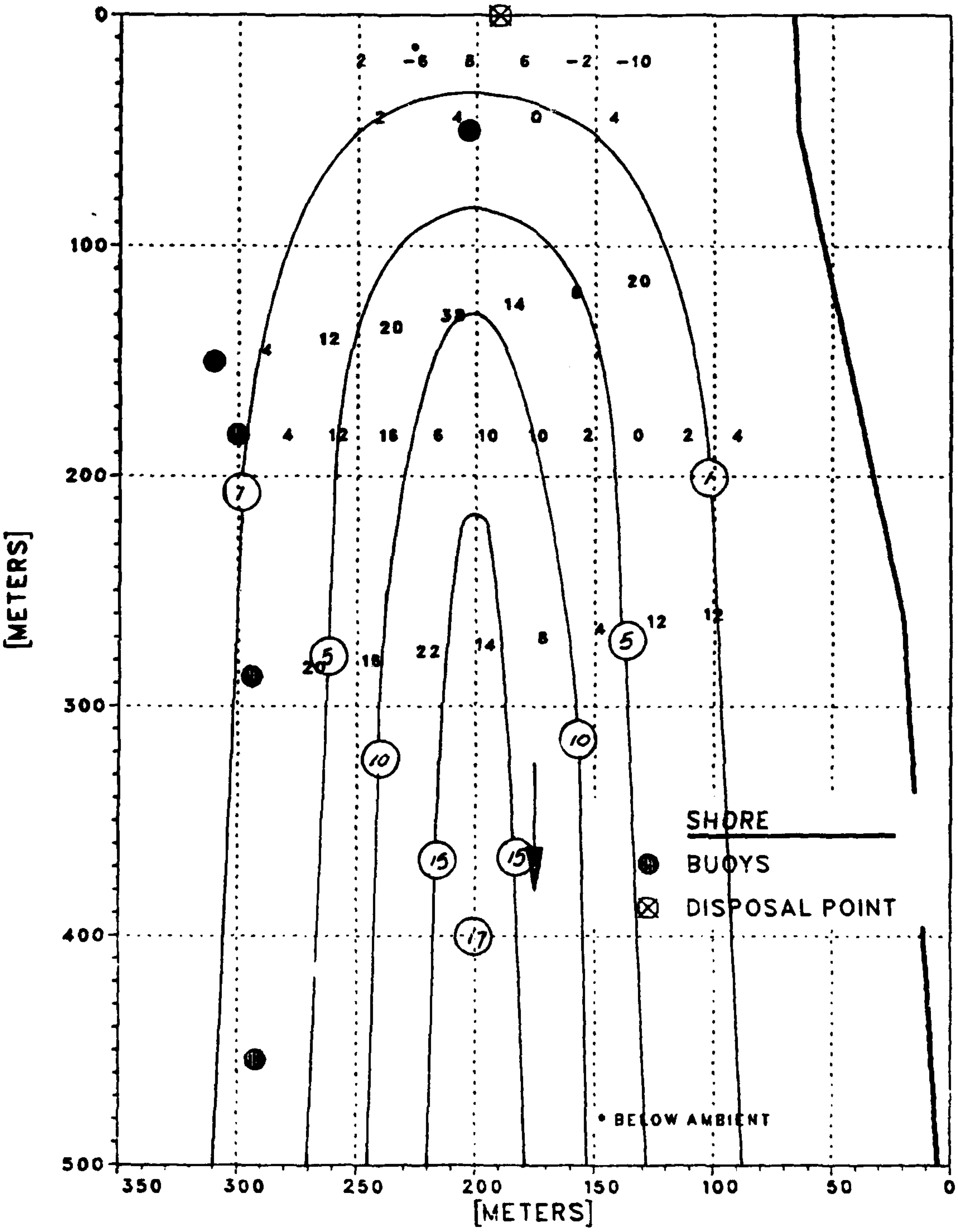

Figure II-24 RM 254.5 (2-ft depth) suspended-solids plume with predicted isopleths superimposed (mg/l above ambient).

sites, b = 10, and $D_z^* = 2.0\ m^2/s$ were used for determining the traverse mixing coefficient.

The predicted isopleths using these parameters are shown in figures II-25 (9-ft depth) and II-26 (2-ft depth). The predicted concentration values for a depth of 2 ft are extremely low. This fact may be due to the failure to obtain adequate samples for determining ambient suspended-solids concentrations, which also explains the difference in ambient values used at the two depths.

At a depth of 9 ft the magnitudes of the predicted values are much closer to those of the data. In fact, if the whole distribution were rotated away from the bank, the predicted values would agree quite well with the data. This fact indicates an abrupt increase in the depth at about 50 m from the bank. This ledge would prevent spreading and would virtually constitute a bank from which suspended solids below a certain depth would "reflect". This possibility is borne out by the inability of the boat to approach closer than 50 m from the river bank when sampling at a depth of 9 ft.

It should be noted here that it was impossible to model the data from RM 14, due principally to the fluctuating depths, fluctuating velocities, the presence of wing dams, and the moving dredge disposal.

E. Discussion. The purpose of this section is to justify the major modifications made to the model by explaining why they were successful in improving the model's predictions.

1. Transverse Mixing Coefficient. The amount of transverse mixing in an open channel can be represented by the dimensionless quantity $\theta = D_z/u_*H$, where u_* = shear velocity and H = river depth. D_z is the coefficient of transverse mixing which includes turbulent diffusion as well as transverse dispersion (Taylor type) associated with any secondary currents present (Taylor, 1954; Elder, 1959; and Brooks, 1972).

   The Wechsler-Cogley model was based on the assumption that $\theta = 0.2$, as reported by Fischer (1973). This value was obtained in flume experiments. Yotsukura and Cobb (1972) report

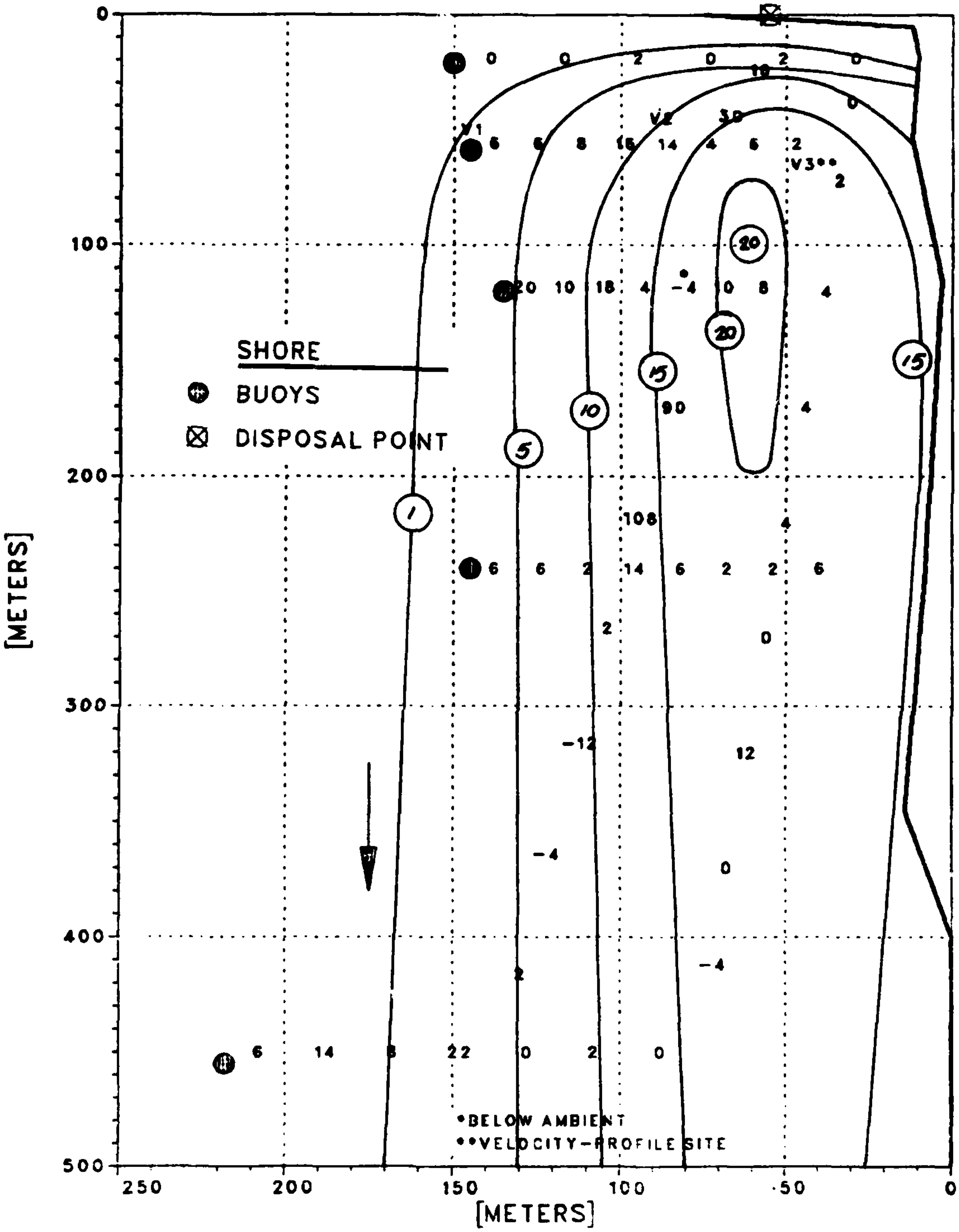

Figure II-25 RM 170 (9-ft depth) suspended-solids plume with predicted isopleths superimposed (mg/l above ambient).

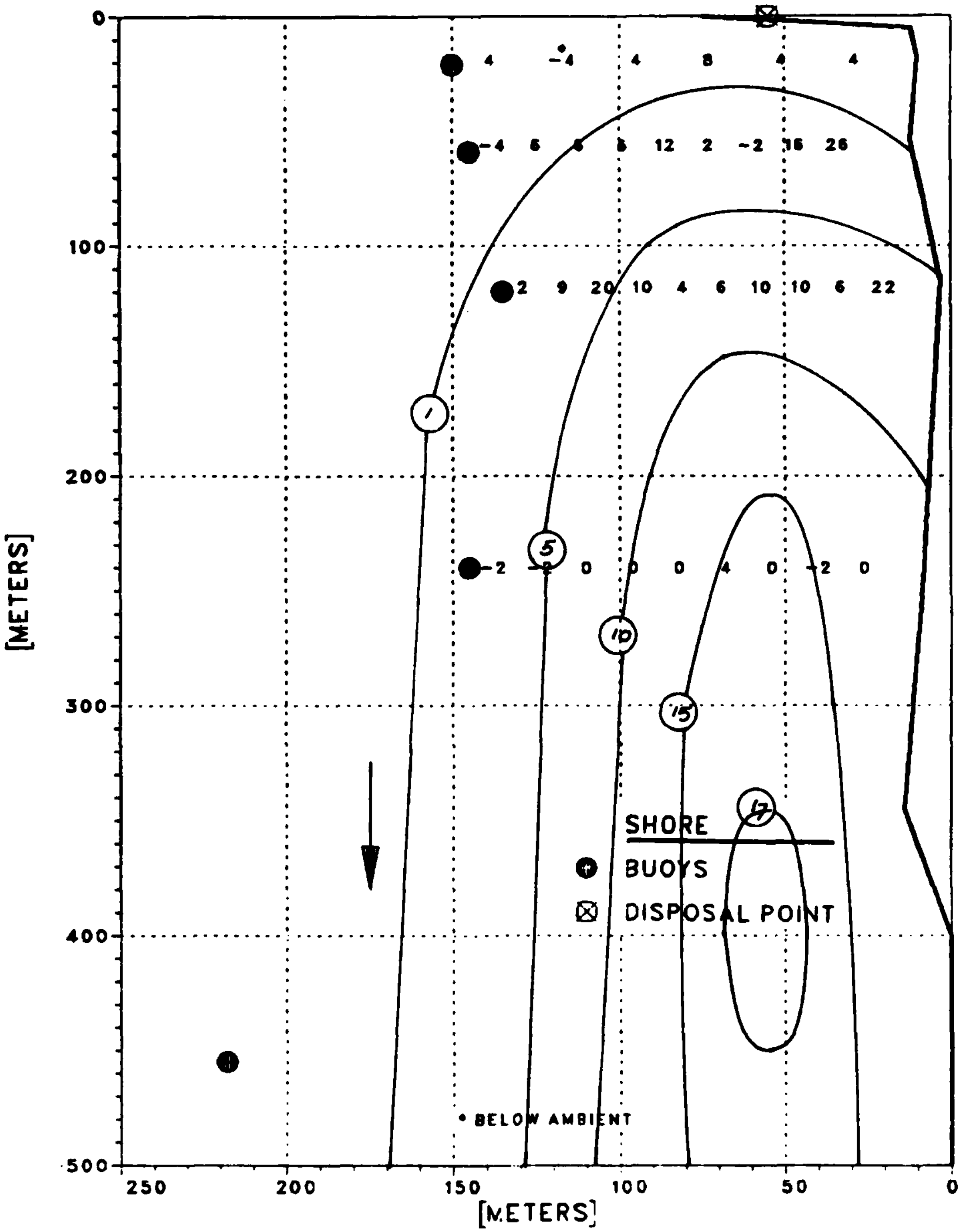

Figure II-26 RM 170 (2-ft depth) suspended-solids plume with predicted isopleths superimposed (mg/l above ambient).

values of θ for natural streams and irrigation canals varying from 0.22 to 0.65.

Okoye (1970) showed that θ is a function of the aspect ratio $\lambda = H/W$, where W is the river width. Figure II-27 shows this relationship and indicates values of θ measured in the field of up to 0.72. If a depth of 15 ft and a width of half a mile are assumed at sites sampled for the present study, the aspect ratio would be equal to about 0.005. A rough extrapolation in figure II-27 would indicate a value of θ equal to nearly 2.

Okoye also reported a variation with depth of the transverse mixing coefficient due to bed shear and the nonuniform distribution of the vertical diffusivity with depth. A typical example of this phenomenon is illustrated in figure II-28, where $\xi = x/H$ and θ_a = average value of θ. Okoye reported a maximum variation of 35 percent for $\theta(\eta)$ from its mean value. Since the sampling for the present study was done at what appears (from figure II-27) to be a depth of above-average θ, a further increase of θ by 20 percent is reasonable.

Another assumption made for the Wechsler-Cogley model is a friction factor, f, equal to 0.02. This value does not take into consideration the effect of bed-form drag on the friction factor. Using the Alam-Kennedy friction factor method (Vanoni, 1977), a rough estimate of f = 0.1 is obtained for RM 254.5. A five-fold increase in f would translate into an increase in shear velocity by a factor of 2.2.

Taking all of these factors into consideration, a transverse mixing coefficient of between 0.6 and 0.8 m^2/s could be expected at RM 254.5 and RM 170. Though these values are considerably lower than the 2.0 m^2/s used in obtaining the best model predictions, the relative magnitude is quite reasonable.

The effect of secondary currents (caused by bottom shear and channel irregularities) on transverse mixing is significant. Yotsukura and Sayre (1976) report values of θ up to 10 for sharp bends on the Missouri River. Fischer (1968) reports that higher

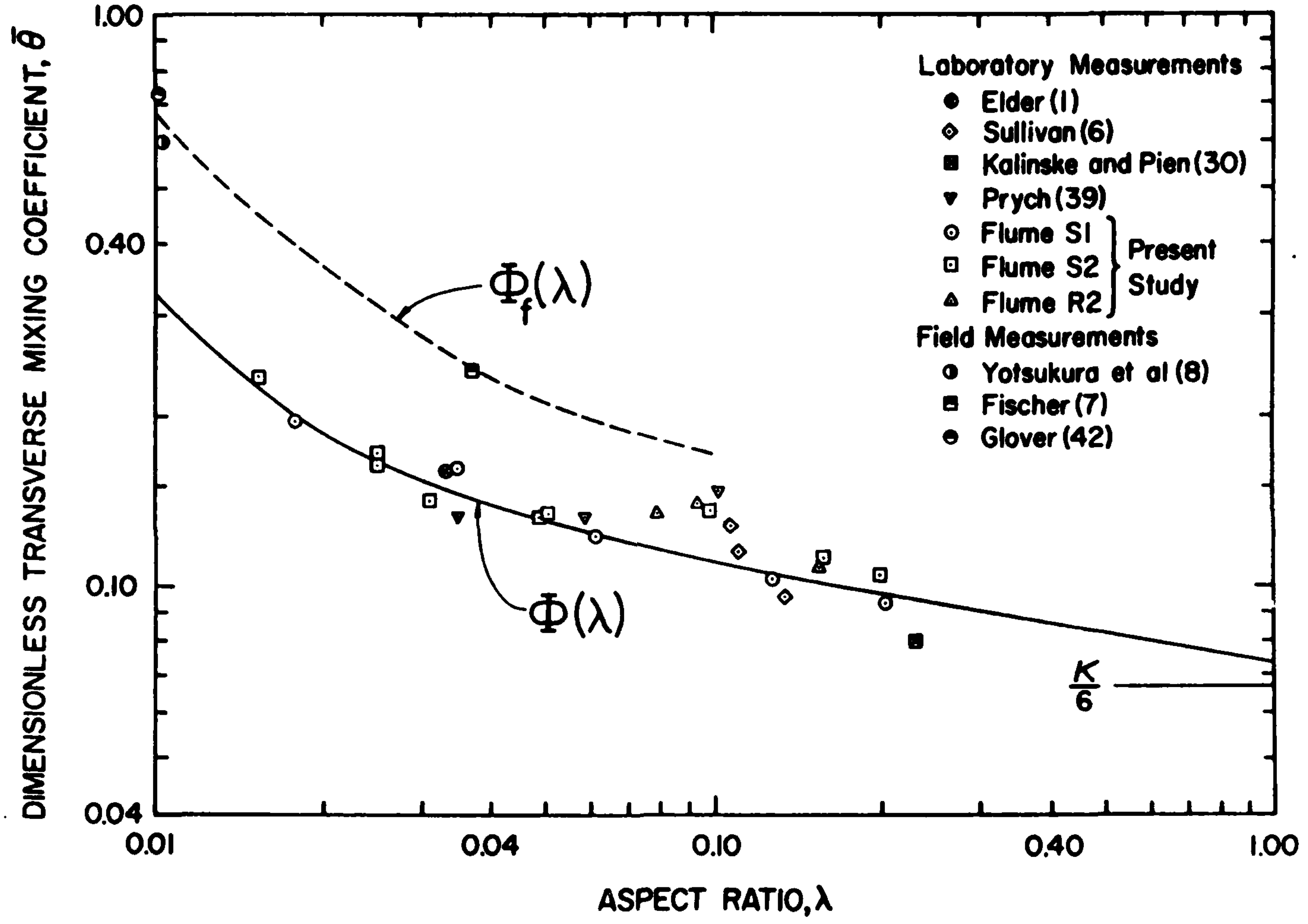

Figure II-27 Variation of the dimensionless mixing coefficient with aspect ratio (after Okoye, 1970).

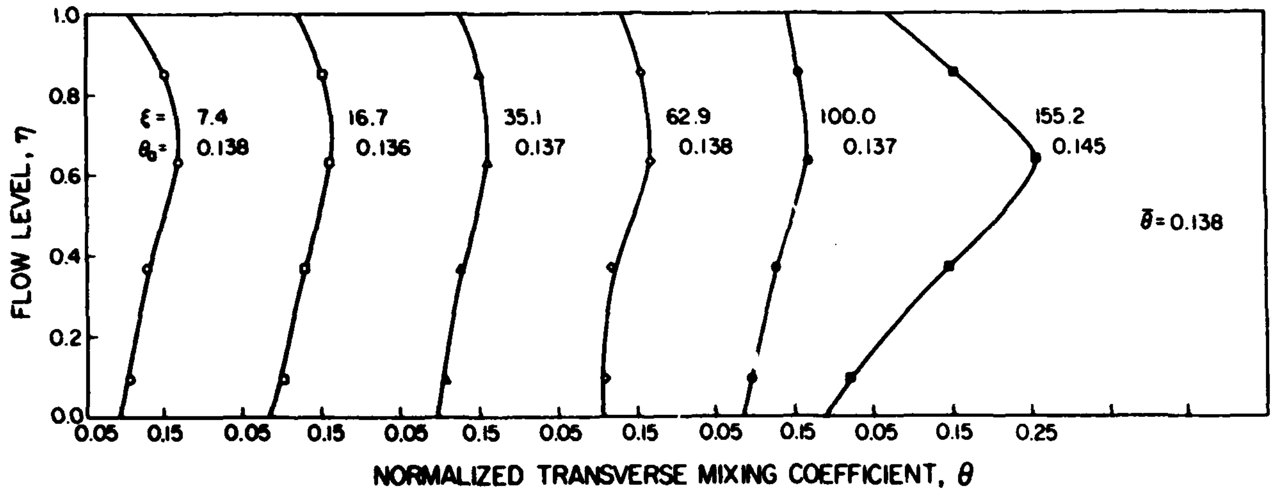

Figure II-28 Depth variation of the dimensionless mixing coefficient (after Okoye, 1970).

values of θ are also found near the banks of rivers. Therefore, even though the field values of figures II-27 already include effects of secondary currents present in all natural rivers, the fact that the dredge spoil is discharged near the bank might increase θ even further.

Any channel irregularities present would also increase θ. Irregularities caused by the dredge operation itself (in adding large amounts of material to the river bed) might be enough to cause substantial cross-currents. Therefore, when these two additional factors are taken into account a lateral mixing coefficient of 2.0 m^2/s would not be unexpected.

2. Decreasing Transverse Mixing Coefficient. Although it would be impossible to rigourously justify the decreasing-coefficient scheme used, two factors do help to justify it qualitatively.

The method of disposal (ejection of the material against a deflector plate) tends to give the dredged material a transverse velocity component which is not accounted for in the usual mixing coefficient. The transverse velocity component is even more substantial for bank disposal, where the discharge runs off the bank into the river.

Various investigators (Brooks, 1972; Bradsma and Divoky, 1976; and Prych, 1970) indicate that density differences enhance lateral spreading. Since the effluent is more dense than the receiving water, it will sink, inducing secondary currents. This sinking, of course, is especially true near the discharge point, where the density difference is especially pronounced. Both of these factors decrease as mixing progresses. Therefore, the model scheme for calculating the transverse mixing coefficient is qualitatively consistent.

3. Submerged Source. As stated in section D the source was assumed to be at the bottom of the river to account for the low suspended-solids concentrations at the head of the plume, where the heaviest concentrations would normally be expected. The effluent falls

very quickly to the bottom of the river and particles which have not settled out of suspension are distributed over the full depth as the turbulent diffusivity of the river takes over.

Bradsma and Divoky (1976) refer to the first part of this phenomenon as "convective descent", during which the material tends to fall as a cloud (or a series of minute clouds) under the influence of gravity. The slurry acts as a relatively dense liquid, and as such is affected by negative buoyancy.

This convective descent is further enhanced by the method of disposal. On both the "Potter" and the "St. Genevieve", the spoil slurry, upon emerging from the pipe, hits a deflector plate. So for much of the material, the momentum is directed downward. Material which is deflected horizontally also attains downward momentum as it falls into the river because the discharge point is ten or fifteen feet above the water surface.

F. Computer Program Modifications and Sample Model Run. The principal modification of the original Wechsler-Cogley model included as part of the GREAT II study (Schnoor et al., 1980) was to convert open-water disposal (one of the Wechsler-Cogley assumptions) to bank disposal. A "reflection principle" was introduced to simulate the effect of the river bank. This principle is illustrated in figures II-29 and II-30.

Figure II-29 shows a typical computer output of concentration values predicted at a given depth, using open-water disposal. The edge of the original source is considered to represent the bank which becomes a reflection axis. All concentration values above this "folding" axis are added to the corresponding values below it. Concentrations along the folding axis are doubled, except for the value at the source which remains the same. These concentrations are doubled because the open-water values of the lateral spreading coefficient along the original source edge are averaged with zero, thus halving them. The folded distribution corresponding to figure II-29 is shown in figure II-30.

Although this principle was used in the GREAT II study, it was not incorporated into the computer program. The first modification included as part of the present study, therefore, was to include the folding operation as

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DISTRIBUTION OF SEDIMENT IN HORIZONTAL PLANE AT DEPTH  1.20 M   (MG/L)
               0.   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.

 -100.0        0.    0.    0.    0.    0.    0.    0.    0.    0.    1.    1.
  -95.0        0.    0.    0.    0.    0.    0.    0.    0.    1.    1.    1.
  -90.0        0.    0.    0.    0.    0.    0.    0.    1.    1.    2.    2.
  -85.0        0.    0.    0.    0.    0.    0.    1.    1.    2.    2.    2.
  -80.0        0.    0.    0.    0.    0.    1.    1.    2.    2.    3.    3.
  -75.0        0.    0.    0.    0.    1.    1.    2.    3.    3.    3.    4.
  -70.0        0.    0.    0.    0.    1.    2.    3.    3.    4.    4.    5.
  -65.0        0.    0.    0.    1.    2.    3.    4.    4.    5.    5.    6.
  -60.0        0.    0.    0.    2.    3.    4.    5.    6.    6.    6.    7.
  -55.0        0.    0.    1.    3.    4.    5.    6.    7.    7.    7.    8.
  -50.0        0.    0.    2.    4.    6.    7.    8.    8.    8.    9.    9.
  -45.0        0.    1.    4.    6.    8.    9.    9.   10.   10.   10.   10.
  -40.0        0.    3.    7.    9.   10.   11.   11.   11.   11.   11.   11.
  -35.0        0.    6.   10.   12.   13.   13.   13.   13.   13.   12.   12.
  -30.0        0.   12.   14.   16.   16.   15.   15.   14.   14.   13.   13.
  -25.0        0.   21.   19.   19.   18.   18.   17.   16.   15.   15.   14.
  -20.0        0.   31.   24.   23.   21.   20.   18.   17.   16.   15.   15.
  -15.0      125.   42.   29.   26.   23.   21.   20.   18.   17.   16.   15.   *
  -10.0      125.   53.   33.   28.   25.   23.   21.   19.   18.   17.   16.
   -5.0      125.   60.   36.   30.   26.   23.   21.   20.   18.   17.   16.
    0.0      125.   63.   37.   31.   27.   24.   22.   20.   18.   17.   16.
    5.0      125.   60.   36.   30.   26.   23.   21.   20.   18.   17.   16.
   10.0      125.   53.   33.   28.   25.   23.   21.   19.   18.   17.   16.
   15.0      125.   42.   29.   26.   23.   21.   20.   18.   17.   16.   15.
   20.0        0.   31.   24.   23.   21.   20.   18.   17.   16.   15.   15.
   25.0        0.   21.   19.   19.   18.   18.   17.   16.   15.   15.   14.
   30.0        0.   12.   14.   16.   16.   15.   15.   14.   14.   13.   13.
   35.0        0.    6.   10.   12.   13.   13.   13.   13.   13.   12.   12.
   40.0        0.    3.    7.    9.   10.   11.   11.   11.   11.   11.   11.
   45.0        0.    1.    4.    6.    8.    9.    9.   10.   10.   10.   10.
   50.0        0.    0.    2.    4.    6.    7.    8.    8.    8.    9.    9.
   55.0        0.    0.    1.    3.    4.    5.    6.    7.    7.    7.    8.
   60.0        0.    0.    0.    2.    3.    4.    5.    6.    6.    6.    7.
   65.0        0.    0.    0.    1.    2.    3.    4.    4.    5.    5.    6.
   70.0        0.    0.    0.    0.    1.    2.    3.    3.    4.    4.    5.
   75.0        0.    0.    0.    0.    1.    1.    2.    3.    3.    3.    4.
   80.0        0.    0.    0.    0.    0.    1.    1.    2.    2.    3.    3.
   85.0        0.    0.    0.    0.    0.    0.    1.    1.    2.    2.    2.
   90.0        0.    0.    0.    0.    0.    0.    0.    1.    1.    2.    2.
   95.0        0.    0.    0.    0.    0.    0.    0.    0.    1.    1.    1.
  100.0        0.    0.    0.    0.    0.    0.    0.    0.    0.    1.    1.
```

* folding axis

Figure II-29 Folding axis on open-water concentration distribution (transverse distance (m) vs. downstream distance (m)).

```
        'FOLDED' DISTRIBUTION AT  1.20 M   (MG/L)

               0.    50.   100.   150.   200.   250.   300.   350.   400.   450.   500.

    0.0      125.    84.    58.    52.    46.    42.    40.    36.    34.    32.    30.
    5.0      125.    84.    57.    51.    46.    43.    39.    36.    34.    32.    31.
   10.0      125.    81.    55.    49.    44.    41.    38.    36.    33.    32.    30.
   15.0      125.    75.    51.    47.    43.    39.    37.    34.    32.    30.    29.
   20.0      125.    66.    46.    42.    39.    36.    34.    33.    31.    29.    28.
   25.0      125.    56.    40.    37.    35.    34.    32.    30.    29.    28.    27.
   30.0      125.    43.    33.    32.    31.    30.    29.    28.    27.    26.    25.
   35.0        0.    31.    26.    27.    27.    27.    26.    25.    24.    24.    24.
   40.0        0.    21.    20.    22.    22.    23.    23.    23.    22.    22.    22.
   45.0        0.    12.    14.    18.    19.    19.    20.    20.    20.    19.    20.
   50.0        0.     6.    10.    13.    15.    16.    17.    17.    18.    17.    18.
   55.0        0.     3.     7.     9.    11.    13.    14.    14.    15.    15.    16.
   60.0        0.     1.     4.     6.     9.    10.    11.    13.    13.    13.    14.
   65.0        0.     0.     2.     4.     6.     8.     9.    10.    10.    12.    12.
   70.0        0.     0.     1.     3.     4.     5.     7.     8.     9.     9.    10.
   75.0        0.     0.     0.     2.     3.     4.     5.     7.     7.     8.     9.
   80.0        0.     0.     0.     1.     2.     3.     4.     4.     6.     6.     7.
   85.0        0.     0.     0.     0.     1.     2.     3.     3.     4.     5.     6.
   90.0        0.     0.     0.     0.     1.     1.     2.     3.     3.     3.     4.
   95.0        0.     0.     0.     0.     0.     1.     1.     2.     2.     3.     3.
  100.0        0.     0.     0.     0.     0.     0.     1.     1.     2.     2.     2.
  105.0        0.     0.     0.     0.     0.     0.     0.     1.     1.     2.     2.
  110.0        0.     0.     0.     0.     0.     0.     0.     0.     1.     1.     1.
  115.0        0.     0.     0.     0.     0.     0.     0.     0.     0.     1.     1.
  120.0        0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  125.0        0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  130.0        0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  135.0        0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  140.0        0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  145.0        0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
```

Figure II-30 Folded concentration distribution corresponding to figure 7-1 (transverse distance (m) vs. downstream distance (m)).

part of the program.

The second modification made for the present study was to make available the option of different types of disposal. The program now accommodates three disposal modes:

1). The open-water disposal mode essentially uses the original version of the model.
2). The bank-disposal mode makes use of the reflection principle, as described above.
3). The near-shore or intermediate disposal mode also makes use of the reflection principle. The only difference from bank disposal is that the program operator is asked for a folding parameter, NBANK, which is the number of units of DELZ (lateral distance unit) which should be put between the bank and the nearer limit of the source plane.

The program provides two sediment-division options: fines/sand and silt/clay/sand. These divisions affect output headings and computer prompts, and can be overridden simply by entering (on prompt) a number of sediment fractions (NSEDF) larger than 3.

The fourth modification included in the final version of the program is to provide the following options for source configuration:

1). The first option is a rectangular source of constant concentration reaching from the water surface to the river bottom.
2). The second option is a rectangular source covering any given portion of the river depth.
3). The third option is a triangular source reaching from the water surface to the river bottom. The original concentration varies from zero at the water surface to a maximum at the river bottom.

Finally, the transverse mixing coefficient can be assumed to be constant (EXPCO = 0) or to decrease exponentially to an essentially constant value. This second option was discussed previously.

The computer program is written in FORTRAN and appears in appendix A. As listed, it is for use on an interactive terminal and a PRIME 750 computer.

Figure II-31 shows an example of the prompts and entered parameters which constitute a model run; RM 254.5 parameters and data are used (see Section D). Figures II-32 through II-40 show the output resulting from the example of figure II-31. The vertical concentration distributions for fines and sand are shown in figures II-32 and II-33; the total distribution is shown in figure II-34. These three tables are basicaly the results of the numerical solution discussed in Section A.

The results of the analytical solution, the lateral spreading coefficients, are shown in figure II-35. It should be noted that the values appearing in figure II-35 correspnd to the decaying mixing coefficient discussed in Section D.

The final concentration predictions are given in figures II-36 through II-40. Essentially, these tables constitute horizontal "slices" of the suspended-sediment plume taken at five different depths, from the water surface (0.00 m) to a plane 0.80 m above the bottom. These concentration values are obtained by successively multiplying the original concentration (2000 mg/l, in this case) by the corresponding coefficients from figures II-34 and II-35. It should be remembered that the coefficients from figure II-34 are percentages; they should be divided by 100 before using them to obtain the final concentrations.

The graphical representation of figure II-37 appears in figure II-24, and that of figure II-39 in figure II-23. It should be noted that the depths of 2 ft and 9 ft are rounded off to 0.80 and 2.40 m respectively.

G. Model Sensitivity Analysis. The objectives of this section are (1) to give an idea of how the model behaves by performing a sensitivity analysis, and (2) to provide a method of quickly and easily estimating the spread and concentrations of a dredge-disposal plume.

1). Instability. In its present form, the model is numerically unstable for a combination of low river velocities and high settling velocities. Since only high settling velocities are affected, this problem is of no consequence for finer material, which constitutes most of the above-ambient suspended load. The

```
  ENTER SOURCE TYPE
  1=RECT -SURF TO BOT
  2=RECT -FRAC OF DEPTH
  3=TRIANG
2
  ENTER UPPER LIMIT OF SOURCE IN TENTHS FROM BOTTOM UP
1
  ENTER LOWER LIMIT OF SOURCE IN TENTHS FROM BOTTOM UP
0
  ENTER DISPOSAL TYPE
  1=BANK
  2=OPEN WATER
  3=INTERMEDIATE
2
  ENTER ORIGINAL CONCENTRATION (MG/L)
2000
  ENTER E-SUB-Z (LATERAL EDDY DIFFUSIVITY)
2
  ENTER NSEDF
2
  ENTER VALUES OF U,H,NSTEP,XL,DELZ,EXPCO
.5
4
50
10
5
10
  FINE
  ENTER VALUES OF
  W,CO
3E-6
50
  SAND
  ENTER VALUES OF
  W,CO
.012
50


***** STOP
```

Figure II-31 Sample interactive session.

```
VERTICAL CONCENTRATION DISTRIBUTION OF FINE (%)
FALL VELOCITY (M/SEC): W=0.90E-07
ORIGINAL CONCENTRATION (%): CC =  50.

              0.    50.   100.   150.   200.   250.   300.   350.   400.   450.   500.

 0.00       0.00   0.16   1.04   2.14   3.10   3.77   4.21   4.50   4.68   4.79   4.87
 0.20       0.00   0.24   1.19   2.31   3.22   3.85   4.27   4.53   4.70   4.81   4.88
 0.40       0.00   0.33   1.39   2.51   3.37   3.95   4.33   4.58   4.73   4.83   4.89
 0.60       0.00   0.44   1.63   2.73   3.53   4.06   4.40   4.62   4.76   4.84   4.90
 0.80       0.00   0.59   1.89   2.97   3.71   4.18   4.48   4.67   4.79   4.86   4.91
 1.00       0.00   0.77   2.19   3.23   3.89   4.30   4.56   4.72   4.82   4.88   4.92
 1.20       0.00   1.00   2.52   3.52   4.08   4.43   4.64   4.77   4.85   4.90   4.94
 1.40       0.00   1.28   2.88   3.79   4.28   4.56   4.72   4.82   4.89   4.93   4.95
 1.60       0.00   1.62   3.28   4.10   4.49   4.69   4.81   4.88   4.92   4.95   4.96
 1.80       0.00   2.05   3.73   4.42   4.70   4.83   4.90   4.93   4.96   4.97   4.98
 2.00       0.00   2.57   4.22   4.76   4.92   4.97   4.99   4.99   4.99   4.99   4.99
 2.20       0.00   3.22   4.76   5.12   5.15   5.12   5.08   5.05   5.03   5.01   5.01
 2.40       0.00   4.03   5.37   5.51   5.39   5.27   5.17   5.11   5.07   5.04   5.02
 2.60       0.00   5.03   6.04   5.91   5.65   5.42   5.27   5.17   5.10   5.06   5.04
 2.80       0.00   6.29   6.79   6.35   5.91   5.59   5.37   5.23   5.14   5.09   5.05
 3.00       0.00   7.88   7.63   6.82   6.18   5.75   5.47   5.30   5.18   5.11   5.07
 3.20       0.00   9.91   8.60   7.34   6.48   5.93   5.58   5.36   5.23   5.14   5.08
 3.40       0.00  12.59   9.75   7.92   6.81   6.13   5.70   5.44   5.27   5.17   5.10
 3.60      50.00  16.34  11.20   8.62   7.19   6.35   5.84   5.52   5.32   5.20   5.12
 3.80      50.00  23.56  13.82   9.81   7.82   6.71   6.06   5.66   5.41   5.25   5.16
 AVG       50.00   5.00   5.00   4.99   4.99   4.99   4.99   4.99   4.99   4.99   4.99
```

Figure II-32 Vertical distribution of fines (depth (m) vs. downstream distance (m)).

```
VERTICAL CONCENTRATION DISTRIBUTION OF SAND (%)
FALL VELOCITY (M/SEC): W=0.012000
ORIGINAL CONCENTRATION (%): CO =  50.

               0.     50.    100.    150.    200.    250.    300.    350.    400.    450.    500.

  0.00       0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  0.20       0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  0.40       0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  0.60       0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  0.80       0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  1.00       0.00    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  1.20       0.00    0.01    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  1.40       0.00    0.01    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  1.60       0.00    0.01    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  1.80       0.00    0.02    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  2.00       0.00    0.02    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  2.20       0.00    0.03    0.01    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  2.40       0.00    0.03    0.01    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  2.60       0.00    0.04    0.01    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  2.80       0.00    0.04    0.02    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  3.00       0.00    0.05    0.02    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  3.20       0.00    0.06    0.02    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  3.40       0.00    0.08    0.02    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00
  3.60      50.00    0.09    0.03    0.01    0.01    0.00    0.00    0.00    0.00    0.00    0.00
  3.80      50.00    0.11    0.03    0.01    0.01    0.00    0.00    0.00    0.00    0.00    0.00
  AVG       50.00    0.03    0.01    0.01    0.00    0.00    0.00    0.00    0.00    0.00    0.00
```

Figure II-33 Vertical distribution of sand (depth (m) vs. downstream distance (m)).

```
                         SUMMATION OF SUSPENDED SEDIMENT (%)

             0.    50.   100.   150.   200.   250.   300.   350.   400.   450.   500.

0.00        0.00   0.18   1.04   2.16   3.10   3.77   4.21   4.50   4.68   4.79   4.87
0.20        0.00   0.24   1.19   2.32   3.22   3.85   4.27   4.53   4.70   4.81   4.88
0.40        0.00   0.33   1.39   2.51   3.37   3.95   4.33   4.58   4.73   4.83   4.89
0.60        0.00   0.45   1.63   2.73   3.53   4.06   4.40   4.62   4.76   4.84   4.90
0.80        0.00   0.59   1.89   2.97   3.71   4.18   4.48   4.67   4.79   4.86   4.91
1.00        0.00   0.79   2.19   3.23   3.89   4.30   4.56   4.72   4.82   4.88   4.92
1.20        0.00   1.00   2.52   3.50   4.08   4.43   4.64   4.77   4.85   4.90   4.94
1.40        0.00   1.29   2.89   3.79   4.28   4.56   4.72   4.83   4.89   4.93   4.95
1.60        0.00   1.63   3.29   4.10   4.49   4.69   4.81   4.88   4.92   4.95   4.96
1.80        0.00   2.06   3.74   4.42   4.70   4.83   4.90   4.93   4.96   4.97   4.98
2.00        0.00   2.59   4.23   4.77   4.93   4.97   4.99   4.99   4.99   4.99   4.99
2.20        0.00   3.25   4.78   5.13   5.16   5.12   5.08   5.05   5.03   5.01   5.01
2.40        0.00   4.06   5.38   5.51   5.40   5.27   5.17   5.11   5.07   5.04   5.02
2.60        0.00   5.07   6.05   5.92   5.65   5.43   5.27   5.17   5.10   5.06   5.04
2.80        0.00   6.34   6.80   6.36   5.91   5.59   5.37   5.23   5.14   5.09   5.05
3.00        0.00   7.93   7.65   6.83   6.19   5.76   5.47   5.30   5.18   5.11   5.07
3.20        0.00   9.97   8.62   7.35   6.49   5.93   5.58   5.36   5.23   5.14   5.08
3.40        0.00  12.66   9.77   7.93   6.81   6.13   5.70   5.44   5.27   5.17   5.10
3.60      100.00  16.43  11.23   8.63   7.20   6.35   5.84   5.52   5.32   5.20   5.12
3.80      100.00  23.70  13.84   9.82   7.83   6.72   6.06   5.66   5.41   5.25   5.16
AVG       100.00   5.03   5.01   5.00   5.00   4.99   4.99   4.99   4.99   4.99   4.99
```

Figure II-34 Total vertical distribution (depth (m) vs. downstream distance (m)).

```
                        LATERAL SPREADING COEFFICIENTS

            0.     50.    100.    150.    200.    250.    300.    350.    400.    450.    500.

   0.0   1.000  0.210  0.183  0.180  0.182  0.185  0.186  0.185  0.182  0.177  0.171
   5.0   1.000  0.208  0.182  0.179  0.181  0.184  0.185  0.184  0.181  0.176  0.170
  10.0   1.000  0.203  0.178  0.175  0.178  0.180  0.181  0.180  0.177  0.173  0.167
  15.0   0.000  0.194  0.172  0.170  0.172  0.174  0.175  0.174  0.171  0.167  0.163
  20.0   0.000  0.183  0.165  0.162  0.164  0.166  0.167  0.166  0.164  0.160  0.156
  25.0   0.000  0.169  0.155  0.153  0.155  0.157  0.157  0.156  0.155  0.152  0.148
  30.0   0.000  0.154  0.144  0.143  0.144  0.145  0.146  0.145  0.144  0.142  0.139
  35.0   0.000  0.137  0.133  0.132  0.132  0.133  0.133  0.133  0.132  0.131  0.129
  40.0   0.000  0.121  0.120  0.120  0.120  0.120  0.120  0.120  0.120  0.119  0.118
  45.0   0.000  0.104  0.107  0.108  0.107  0.107  0.107  0.107  0.107  0.108  0.107
  50.0   0.000  0.088  0.095  0.095  0.095  0.094  0.094  0.094  0.095  0.096  0.096
  55.0   0.000  0.074  0.083  0.083  0.083  0.082  0.082  0.082  0.083  0.084  0.085
  60.0   0.000  0.060  0.071  0.072  0.071  0.070  0.070  0.070  0.071  0.073  0.075
  65.0   0.000  0.049  0.060  0.062  0.061  0.059  0.059  0.059  0.061  0.063  0.065
  70.0   0.000  0.039  0.051  0.052  0.051  0.049  0.049  0.049  0.051  0.053  0.055
  75.0   0.000  0.030  0.042  0.043  0.042  0.041  0.040  0.041  0.042  0.044  0.047
  80.0   0.000  0.023  0.034  0.035  0.034  0.033  0.032  0.033  0.035  0.037  0.039
  85.0   0.000  0.017  0.027  0.029  0.028  0.026  0.026  0.026  0.028  0.030  0.032
  90.0   0.000  0.013  0.022  0.023  0.022  0.021  0.020  0.021  0.022  0.024  0.026
  95.0   0.000  0.009  0.017  0.018  0.017  0.016  0.016  0.016  0.017  0.019  0.021
 100.0   0.000  0.007  0.013  0.014  0.013  0.012  0.012  0.013  0.014  0.015  0.017
```

Figure II-35 Lateral spreading coefficients (transverse distance (m) vs. downstream distance (m)).

```
             0.   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.

  -100.0     0.    0.    0.    0.    0.    0.    1.    1.    1.    1.    1.
   -95.0     0.    0.    0.    0.    1.    1.    1.    1.    1.    1.    2.
   -90.0     0.    0.    0.    1.    1.    1.    1.    1.    2.    2.    2.
   -85.0     0.    0.    0.    1.    1.    2.    2.    2.    2.    2.    3.
   -80.0     0.    0.    0.    1.    2.    2.    2.    2.    3.    3.    3.
   -75.0     0.    0.    0.    1.    2.    3.    3.    3.    3.    4.    4.
   -70.0     0.    0.    1.    2.    3.    3.    4.    4.    4.    5.    5.
   -65.0     0.    0.    1.    2.    3.    4.    4.    5.    5.    6.    6.
   -60.0     0.    0.    1.    3.    4.    5.    5.    6.    6.    7.    7.
   -55.0     0.    0.    1.    3.    5.    6.    6.    7.    7.    8.    8.
   -50.0     0.    0.    1.    4.    5.    7.    7.    8.    8.    9.    9.
   -45.0     0.    0.    2.    4.    6.    8.    9.    9.   10.   10.   10.
   -40.0     0.    0.    2.    5.    7.    9.   10.   10.   11.   11.   11.
   -35.0     0.    0.    2.    5.    8.   10.   11.   11.   12.   12.   12.
   -30.0     0.    0.    3.    6.    8.   10.   12.   13.   13.   13.   13.
   -25.0     0.    0.    3.    6.    9.   11.   13.   14.   14.   14.   14.
   -20.0     0.    0.    3.    7.   10.   12.   14.   14.   15.   15.   15.
   -15.0     0.    0.    3.    7.   10.   13.   14.   15.   16.   16.   15.
   -10.0     0.    0.    3.    7.   11.   13.   15.   16.   16.   16.   16.
    -5.0     0.    0.    3.    7.   11.   13.   15.   16.   16.   16.   16.
     0.0     0.    0.    3.    7.   11.   13.   15.   16.   17.   16.   16.
     5.0     0.    0.    3.    7.   11.   13.   15.   16.   16.   16.   16.
    10.0     0.    0.    3.    7.   11.   13.   15.   16.   16.   16.   16.
    15.0     0.    0.    3.    7.   10.   13.   14.   15.   16.   16.   15.
    20.0     0.    0.    3.    7.   10.   12.   14.   14.   15.   15.   15.
    25.0     0.    0.    3.    6.    9.   11.   13.   14.   14.   14.   14.
    30.0     0.    0.    3.    6.    8.   10.   12.   13.   13.   13.   13.
    35.0     0.    0.    2.    5.    8.   10.   11.   11.   12.   12.   12.
    40.0     0.    0.    2.    5.    7.    9.   10.   10.   11.   11.   11.
    45.0     0.    0.    2.    4.    6.    8.    9.    9.   10.   10.   10.
    50.0     0.    0.    1.    4.    5.    7.    7.    8.    9.    9.    9.
    55.0     0.    0.    1.    3.    5.    6.    6.    7.    7.    8.    8.
    60.0     0.    0.    1.    3.    4.    5.    5.    6.    6.    7.    7.
    65.0     0.    0.    1.    2.    3.    4.    4.    5.    5.    6.    6.
    70.0     0.    0.    1.    2.    3.    3.    4.    4.    4.    5.    5.
    75.0     0.    0.    0.    1.    2.    3.    3.    3.    3.    4.    4.
    80.0     0.    0.    0.    1.    2.    2.    2.    2.    3.    3.    3.
    85.0     0.    0.    0.    1.    1.    2.    2.    2.    2.    2.    3.
    90.0     0.    0.    0.    1.    1.    1.    1.    1.    2.    2.    2.
    95.0     0.    0.    0.    0.    1.    1.    1.    1.    1.    1.    2.
   100.0     0.    0.    0.    0.    0.    0.    1.    1.    1.    1.    1.
```

Figure II-36 Suspended-solids distribution (mg/l) in the horizontal plane at a depth of 0.00 m (transverse distance (m) vs. downstream distance (m)).

```
             0.    50.   100.   150.   200.   250.   300.   350.   400.   450.   500.

 -100.0      0.     0.     0.     0.     1.     1.     1.     1.     1.     1.     1.
  -95.0      0.     0.     0.     1.     1.     1.     1.     1.     1.     1.     2.
  -90.0      0.     0.     0.     1.     1.     1.     1.     1.     2.     2.     2.
  -85.0      0.     0.     1.     1.     2.     2.     2.     2.     2.     2.     3.
  -80.0      0.     0.     1.     2.     2.     2.     2.     3.     3.     3.     3.
  -75.0      0.     0.     1.     2.     3.     3.     3.     3.     4.     4.     4.
  -70.0      0.     0.     1.     3.     3.     4.     4.     4.     4.     5.     5.
  -65.0      0.     0.     2.     3.     4.     4.     5.     5.     5.     6.     6.
  -60.0      0.     0.     2.     4.     5.     5.     6.     6.     6.     7.     7.
  -55.0      0.     0.     3.     4.     6.     6.     7.     7.     7.     8.     8.
  -50.0      0.     1.     3.     5.     7.     7.     8.     8.     9.     9.     9.
  -45.0      0.     1.     4.     6.     7.     8.     9.    10.    10.    10.    10.
  -40.0      0.     1.     4.     7.     8.    10.    10.    11.    11.    11.    11.
  -35.0      0.     1.     5.     7.     9.    11.    11.    12.    12.    12.    12.
  -30.0      0.     1.     5.     8.    10.    12.    13.    13.    13.    13.    13.
  -25.0      0.     2.     5.     9.    11.    13.    14.    14.    14.    14.    14.
  -20.0      0.     2.     6.     9.    12.    13.    14.    15.    15.    15.    15.
  -15.0      0.     2.     6.    10.    12.    14.    15.    16.    16.    16.    15.
  -10.0      0.     2.     6.    10.    13.    15.    16.    16.    16.    16.    16.
   -5.0      0.     2.     6.    10.    13.    15.    16.    17.    17.    17.    16.
    0.0      0.     2.     6.    10.    13.    15.    16.    17.    17.    17.    16.
    5.0      0.     2.     6.    10.    13.    15.    16.    17.    17.    17.    16.
   10.0      0.     2.     6.    10.    13.    15.    16.    16.    16.    16.    16.
   15.0      0.     2.     6.    10.    12.    14.    15.    16.    16.    16.    15.
   20.0      0.     2.     6.     9.    12.    13.    14.    15.    15.    15.    15.
   25.0      0.     2.     5.     9.    11.    13.    14.    14.    14.    14.    14.
   30.0      0.     1.     5.     8.    10.    12.    13.    13.    13.    13.    13.
   35.0      0.     1.     5.     7.     9.    11.    11.    12.    12.    12.    12.
   40.0      0.     1.     4.     7.     8.    10.    10.    11.    11.    11.    11.
   45.0      0.     1.     4.     6.     7.     8.     9.    10.    10.    10.    10.
   50.0      0.     1.     3.     5.     7.     7.     8.     8.     9.     9.     9.
   55.0      0.     0.     3.     4.     6.     6.     7.     7.     7.     8.     8.
   60.0      0.     0.     2.     4.     5.     5.     6.     6.     6.     7.     7.
   65.0      0.     0.     2.     3.     4.     4.     5.     5.     5.     6.     6.
   70.0      0.     0.     1.     3.     3.     4.     4.     4.     4.     5.     5.
   75.0      0.     0.     1.     2.     3.     3.     3.     3.     4.     4.     4.
   80.0      0.     0.     1.     2.     2.     2.     2.     3.     3.     3.     3.
   85.0      0.     0.     1.     1.     2.     2.     2.     2.     2.     2.     3.
   90.0      0.     0.     0.     1.     1.     1.     1.     1.     2.     2.     2.
   95.0      0.     0.     0.     1.     1.     1.     1.     1.     1.     1.     2.
  100.0      0.     0.     0.     0.     1.     1.     1.     1.     1.     1.     1.
```

Figure II-37 Suspended-solids distribution (mg/l) in the horizontal plane at a depth of 0.80 m (transverse distance (m) vs. downstream distance (m)).

```
                0.    50.   100.   150.   200.   250.   300.   350.   400.   450.   500.

 -100.0         0.     0.     0.     1.     1.     1.     1.     1.     1.     1.     1.
  -95.0         0.     0.     1.     1.     1.     1.     1.     1.     1.     1.     2.
  -90.0         0.     0.     1.     1.     1.     1.     1.     2.     2.     2.     2.
  -85.0         0.     0.     1.     2.     2.     2.     2.     2.     2.     2.     3.
  -80.0         0.     0.     2.     2.     3.     3.     3.     3.     3.     3.     3.
  -75.0         0.     0.     2.     3.     3.     3.     3.     3.     4.     4.     4.
  -70.0         0.     1.     3.     4.     4.     4.     4.     4.     5.     5.     5.
  -65.0         0.     1.     3.     5.     5.     5.     5.     5.     5.     6.     6.
  -60.0         0.     1.     4.     5.     6.     6.     6.     6.     7.     7.     7.
  -55.0         0.     2.     5.     6.     7.     7.     7.     8.     8.     8.     8.
  -50.0         0.     2.     6.     7.     8.     8.     9.     9.     9.     9.     9.
  -45.0         0.     3.     7.     8.     9.    10.    10.    10.    10.    10.    10.
  -40.0         0.     3.     7.     9.    10.    11.    11.    11.    11.    11.    11.
  -35.0         0.     4.     8.    10.    11.    12.    12.    13.    13.    12.    12.
  -30.0         0.     5.     9.    11.    12.    13.    14.    14.    14.    14.    13.
  -25.0         0.     5.    10.    12.    13.    14.    15.    15.    15.    15.    14.
  -20.0         0.     5.    10.    13.    14.    15.    16.    16.    16.    15.    15.
  -15.0         0.     6.    11.    13.    15.    16.    16.    17.    16.    16.    16.
  -10.0         0.     6.    11.    14.    15.    16.    17.    17.    17.    17.    16.
   -5.0         0.     6.    11.    14.    16.    17.    17.    17.    17.    17.    16.
    0.0         0.     6.    12.    14.    16.    17.    17.    18.    17.    17.    17.
    5.0         0.     6.    11.    14.    16.    17.    17.    17.    17.    17.    16.
   10.0         0.     6.    11.    14.    15.    16.    17.    17.    17.    17.    16.
   15.0         0.     6.    11.    13.    15.    16.    16.    17.    16.    16.    16.
   20.0         0.     5.    10.    13.    14.    15.    16.    16.    16.    15.    15.
   25.0         0.     5.    10.    12.    13.    14.    15.    15.    15.    15.    14.
   30.0         0.     5.     9.    11.    12.    13.    14.    14.    14.    14.    13.
   35.0         0.     4.     8.    10.    11.    12.    12.    13.    13.    12.    12.
   40.0         0.     3.     7.     9.    10.    11.    11.    11.    11.    11.    11.
   45.0         0.     3.     7.     8.     9.    10.    10.    10.    10.    10.    10.
   50.0         0.     2.     6.     7.     8.     8.     9.     9.     9.     9.     9.
   55.0         0.     2.     5.     6.     7.     7.     7.     8.     8.     8.     8.
   60.0         0.     1.     4.     5.     6.     6.     6.     6.     7.     7.     7.
   65.0         0.     1.     3.     5.     5.     5.     5.     5.     5.     6.     6.
   70.0         0.     1.     3.     4.     4.     4.     4.     4.     5.     5.     5.
   75.0         0.     0.     2.     3.     3.     3.     3.     3.     4.     4.     4.
   80.0         0.     0.     2.     2.     3.     3.     3.     3.     3.     3.     3.
   85.0         0.     0.     1.     2.     2.     2.     2.     2.     2.     2.     3.
   90.0         0.     0.     1.     1.     1.     1.     1.     2.     2.     2.     2.
   95.0         0.     0.     1.     1.     1.     1.     1.     1.     1.     1.     2.
  100.0         0.     0.     0.     1.     1.     1.     1.     1.     1.     1.     1.
```

Figure II-38 Suspended-solids distribution (mg/l) in the horizontal plane at a depth of 1.60 m (transverse distance (m) vs. downstream distance (m)).

	0.	50.	100.	150.	200.	250.	300.	350.	400.	450.	500.
-100.0	0.	0.	1.	1.	1.	1.	1.	1.	1.	1.	1.
-95.0	0.	0.	1.	2.	1.	1.	1.	1.	1.	1.	2.
-90.0	0.	1.	2.	2.	2.	2.	2.	2.	2.	2.	2.
-85.0	0.	1.	2.	3.	2.	2.	2.	2.	2.	3.	3.
-80.0	0.	1.	3.	3.	3.	3.	3.	3.	3.	3.	3.
-75.0	0.	2.	4.	4.	4.	4.	4.	4.	4.	4.	4.
-70.0	0.	3.	5.	5.	5.	5.	5.	5.	5.	5.	5.
-65.0	0.	3.	6.	6.	6.	6.	6.	6.	6.	6.	6.
-60.0	0.	4.	7.	7.	7.	7.	7.	7.	7.	7.	7.
-55.0	0.	6.	8.	9.	8.	8.	8.	9.	8.	8.	8.
-50.0	0.	7.	10.	10.	10.	9.	9.	9.	9.	9.	9.
-45.0	0.	8.	11.	11.	11.	11.	11.	10.	10.	10.	10.
-40.0	0.	9.	12.	13.	12.	12.	12.	12.	12.	12.	11.
-35.0	0.	11.	14.	14.	14.	14.	13.	13.	13.	13.	12.
-30.0	0.	12.	15.	15.	15.	15.	15.	14.	14.	14.	13.
-25.0	0.	13.	16.	16.	16.	16.	16.	15.	15.	15.	14.
-20.0	0.	14.	17.	17.	17.	17.	17.	16.	16.	16.	15.
-15.0	0.	15.	18.	18.	18.	18.	18.	17.	17.	16.	16.
-10.0	0.	16.	19.	19.	19.	19.	18.	18.	17.	17.	16.
-5.0	0.	16.	19.	19.	19.	19.	19.	18.	18.	17.	17.
0.0	0.	17.	19.	19.	19.	19.	19.	18.	18.	17.	17.
5.0	0.	16.	19.	19.	19.	19.	19.	18.	18.	17.	17.
10.0	0.	16.	19.	19.	19.	19.	18.	18.	17.	17.	16.
15.0	0.	15.	18.	18.	18.	18.	18.	17.	17.	16.	16.
20.0	0.	14.	17.	17.	17.	17.	17.	16.	16.	16.	15.
25.0	0.	13.	16.	16.	16.	16.	16.	15.	15.	15.	14.
30.0	0.	12.	15.	15.	15.	15.	15.	14.	14.	14.	13.
35.0	0.	11.	14.	14.	14.	14.	13.	13.	13.	13.	12.
40.0	0.	9.	12.	13.	12.	12.	12.	12.	12.	12.	11.
45.0	0.	8.	11.	11.	11.	11.	11.	10.	10.	10.	10.
50.0	0.	7.	10.	10.	10.	9.	9.	9.	9.	9.	9.
55.0	0.	6.	8.	9.	8.	8.	8.	8.	8.	8.	8.
60.0	0.	4.	7.	7.	7.	7.	7.	7.	7.	7.	7.
65.0	0.	3.	6.	6.	6.	6.	6.	6.	6.	6.	6.
70.0	0.	3.	5.	5.	5.	5.	5.	5.	5.	5.	5.
75.0	0.	2.	4.	4.	4.	4.	4.	4.	4.	4.	4.
80.0	0.	1.	3.	3.	3.	3.	3.	3.	3.	3.	3.
85.0	0.	1.	2.	3.	2.	2.	2.	2.	2.	3.	3.
90.0	0.	1.	2.	2.	2.	2.	2.	2.	2.	2.	2.
95.0	0.	0.	1.	2.	1.	1.	1.	1.	1.	1.	2.
100.0	0.	0.	1.	1.	1.	1.	1.	1.	1.	1.	1.

Figure II-39 Suspended-solids distribution (mg/l) in the horizontal plane at a depth of 2.40 m (transverse distance (m) vs. downstream distance (m)).

	0.	50.	100.	150.	200.	250.	300.	350.	400.	450.	500.
-100.0	0.	1.	2.	2.	1.	1.	1.	1.	1.	1.	1.
-95.0	0.	1.	2.	2.	2.	1.	1.	1.	1.	1.	2.
-90.0	0.	2.	3.	3.	2.	2.	2.	2.	2.	2.	2.
-85.0	0.	3.	4.	4.	3.	3.	2.	2.	2.	3.	3.
-80.0	0.	4.	5.	5.	4.	3.	3.	3.	3.	3.	3.
-75.0	0.	5.	7.	6.	5.	4.	4.	4.	4.	4.	4.
-70.0	0.	7.	8.	7.	6.	5.	5.	5.	5.	5.	5.
-65.0	0.	9.	10.	9.	7.	7.	6.	6.	6.	6.	6.
-60.0	0.	12.	12.	10.	9.	8.	7.	7.	7.	7.	7.
-55.0	0.	14.	14.	12.	10.	9.	9.	8.	8.	8.	8.
-50.0	0.	17.	16.	14.	12.	11.	10.	10.	9.	9.	9.
-45.0	0.	20.	18.	15.	13.	12.	11.	11.	11.	11.	10.
-40.0	0.	24.	20.	17.	15.	14.	13.	12.	12.	12.	12.
-35.0	0.	27.	22.	19.	17.	15.	14.	14.	13.	13.	13.
-30.0	0.	30.	24.	21.	18.	17.	16.	15.	15.	14.	14.
-25.0	0.	33.	26.	22.	20.	18.	17.	16.	16.	15.	15.
-20.0	0.	36.	28.	23.	21.	19.	18.	17.	17.	16.	15.
-15.0	0.	38.	29.	24.	22.	20.	19.	18.	17.	17.	16.
-10.0	0.	40.	30.	25.	23.	21.	20.	19.	18.	17.	17.
-5.0	0.	41.	31.	26.	23.	21.	20.	19.	18.	18.	17.
0.0	0.	41.	31.	26.	23.	21.	20.	19.	19.	18.	17.
5.0	0.	41.	31.	26.	23.	21.	20.	19.	18.	18.	17.
10.0	0.	40.	30.	25.	23.	21.	20.	19.	18.	17.	17.
15.0	0.	38.	29.	24.	22.	20.	19.	18.	17.	17.	16.
20.0	0.	36.	28.	23.	21.	19.	18.	17.	17.	16.	15.
25.0	0.	33.	26.	22.	20.	18.	17.	16.	16.	15.	15.
30.0	0.	30.	24.	21.	18.	17.	16.	15.	15.	14.	14.
35.0	0.	27.	22.	19.	17.	15.	14.	14.	13.	13.	13.
40.0	0.	24.	20.	17.	15.	14.	13.	12.	12.	12.	12.
45.0	0.	20.	18.	15.	13.	12.	11.	11.	11.	11.	10.
50.0	0.	17.	16.	14.	12.	11.	10.	10.	9.	9.	9.
55.0	0.	14.	14.	12.	10.	9.	9.	8.	8.	8.	8.
60.0	0.	12.	12.	10.	9.	8.	7.	7.	7.	7.	7.
65.0	0.	9.	10.	9.	7.	7.	6.	6.	6.	6.	6.
70.0	0.	7.	8.	7.	6.	5.	5.	5.	5.	5.	5.
75.0	0.	5.	7.	6.	5.	4.	4.	4.	4.	4.	4.
80.0	0.	4.	5.	5.	4.	3.	3.	3.	3.	3.	3.
85.0	0.	3.	4.	4.	3.	3.	2.	2.	2.	3.	3.
90.0	0.	2.	3.	3.	2.	2.	2.	2.	2.	2.	2.
95.0	0.	1.	2.	2.	2.	1.	1.	1.	1.	1.	2.
100.0	0.	1.	2.	2.	1.	1.	1.	1.	1.	1.	1.

Figure II-40 Suspended-solids distribution (mg/l) in the horizontal plane at a depth of 3.20 m (transverse distance (m) vs. downstream distance (m)).

area of instability is depicted in figure II-22; instability for a source covering the bottom tenth of the depth is somewhat more extensive than that for the full-source configuration.

2). Vertical and Longitudinal Concentration Distribution. The numerical part of the program solution (see section A, as well as figures II-32 and II-33) can be represented by the following equation:

$$P(y,x) = P'(y) \exp[-mX^*] \qquad \text{(II-22)}$$

in which

$P(y,x)$ = percentage of the original concentration of a certain grain size still in suspension

$P'(y)$ = a boundary condition percentage

X^* = dimensionless distance = x/100 m

m = a constant.

The slope m, which is a function of mean depth and U/W (mean river velocity/particle settling velocity), can be determined from figure II-41. P'(y) is calculated using figure II-42. Although (II-22) does not strictly hold for the first 50 or 100 m, the values calculated in this range using this method are generally within 5 percent of the model-generated values.

Figures II-41 and II-42 provide a good method of estimating how much of a certain size of sediment remains in suspension downstream from the dredge disposal. Figures II-41 and II-42 also give a good estimate of concentrations for the case of a fractional source, especially after the first 200 m. Care should be taken in this case to scale down the percentages calculated because a less-extensive source would be used.

3). Lateral Plume Spread. As calculated by the model, the lateral spread of the dredge-disposal plume is a function only of the transverse mixing coefficient. The amount of lateral spread can

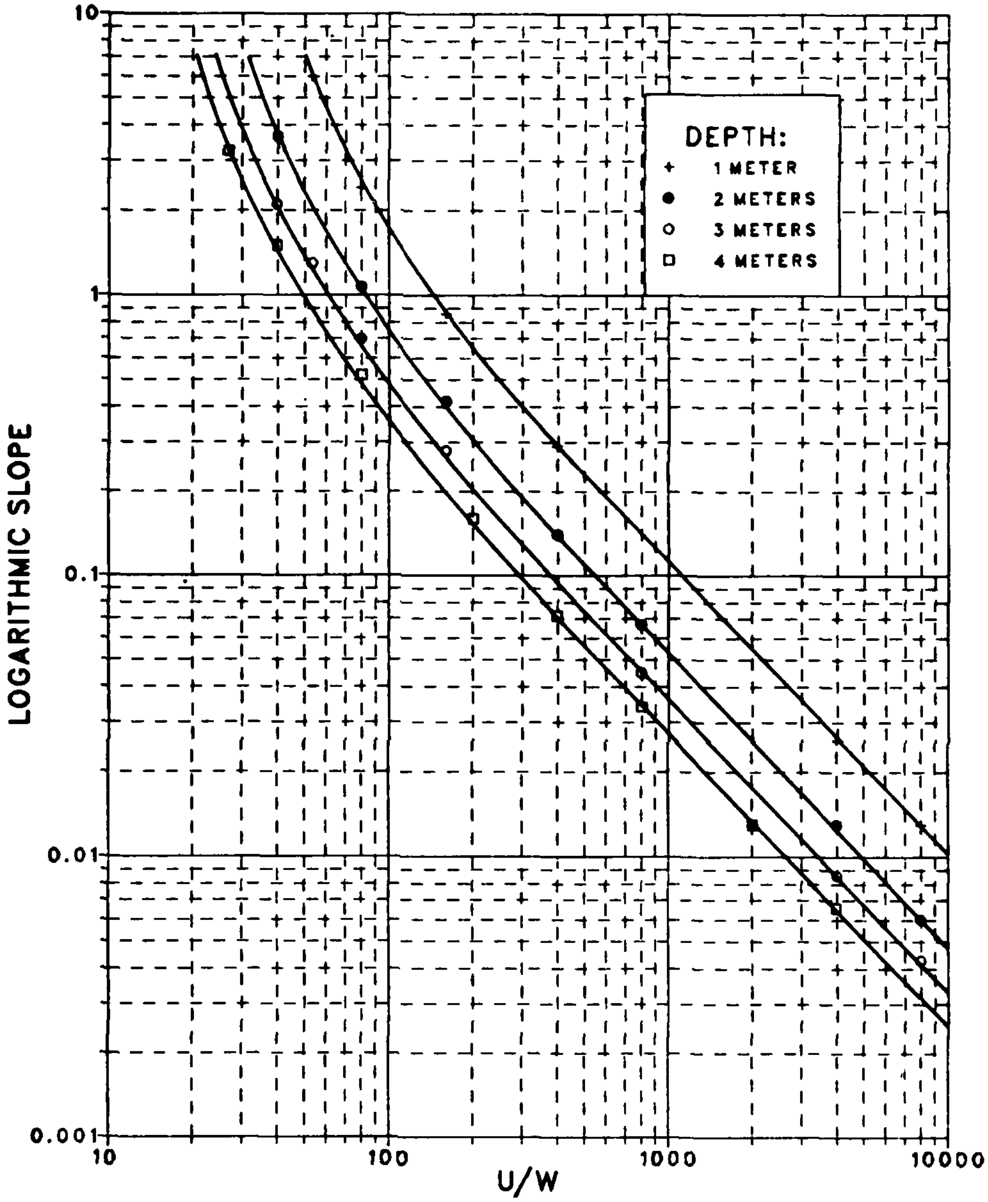

Figure II-41 Determination of logarithmic slope, m.

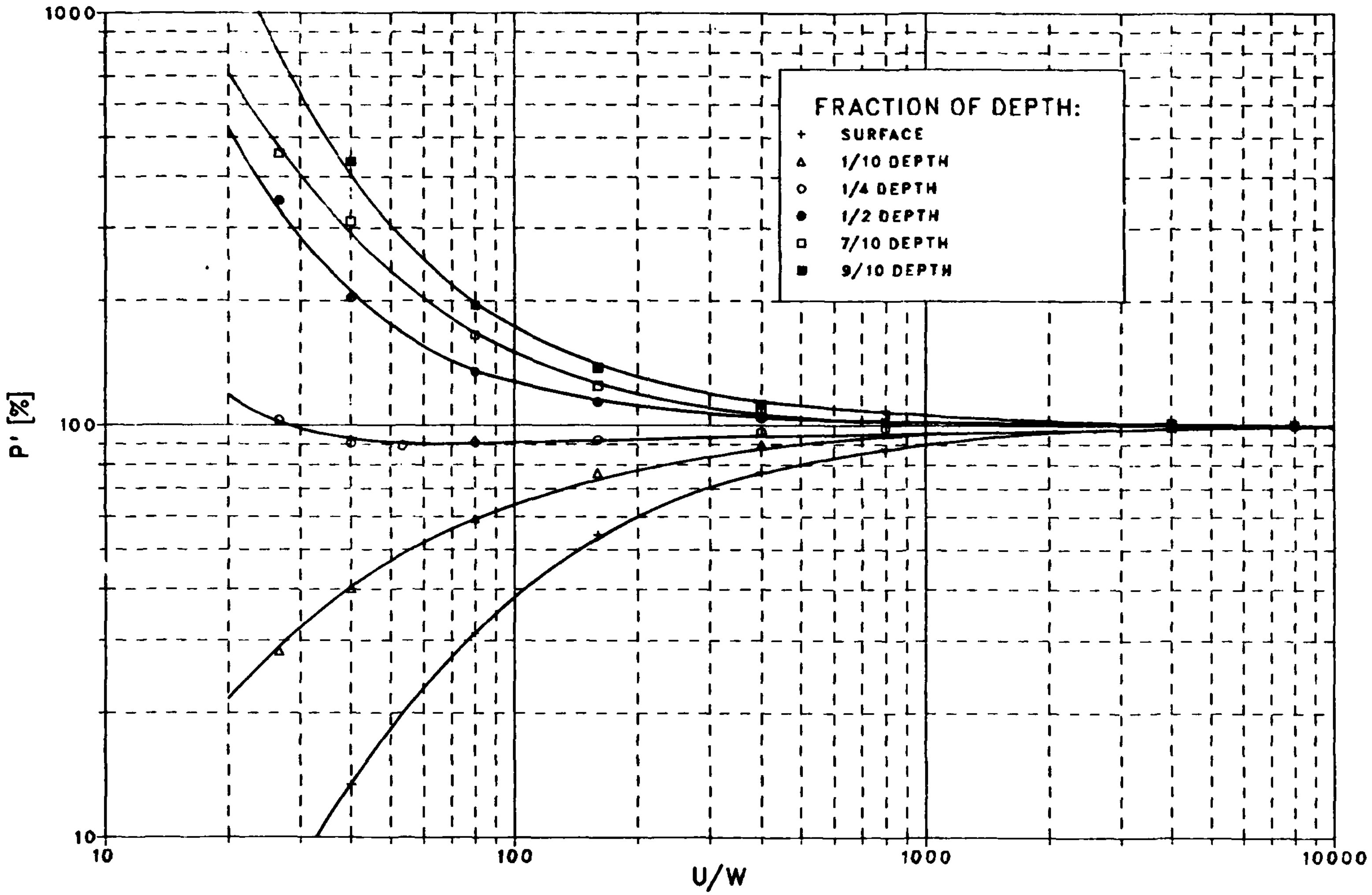

Figure II-42 Determination of P' for calculating residual suspended solids.

be represented by the following expression:

$$S^*(x) = a(D_z)\sqrt{X^*} \quad \text{(II-23)}$$

in which

S^* = dimensionless spread = S/500 m.
$a(D_z)$ = spread coefficient (a constant)
X^* = dimensionless downstream distance = x/500 m
S = spreading distance

Equation (II-23) can be used to estimate how far the effect of the dredge-disposal operation will extend. The spread coefficient, $a(D_z)$, is determined from figure II-43. S is the distance which the plume will spread (as defined by a lateral spreading coefficient = 0.001) beyond the original source width on one side of the plume. Therefore, if open-water disposal is used, S should be doubled.

4). As mentioned in Sections D and F, the model provides the option of a decreasing rate of lateral spread, which can be represented as follows:

$$D_z(x) = D_z^*(1+b \exp[-X^*]) \quad \text{(II-24)}$$

in which
X^* = dimensionless downstream distance = x/100 m
D_z^* = "steady state" value of the transverse mixing coefficient
b = a constant

Figure II-44 shows the variation of the factor $(1+b \exp[-X^*])$ with longitudinal distance. As can be seen from the figure, this particular spreading scheme has little effect past 500 m.

H. Summary. The Wechsler-Cogley (1977) model code has been modified to include three source options and two options on the lateral (transverse)

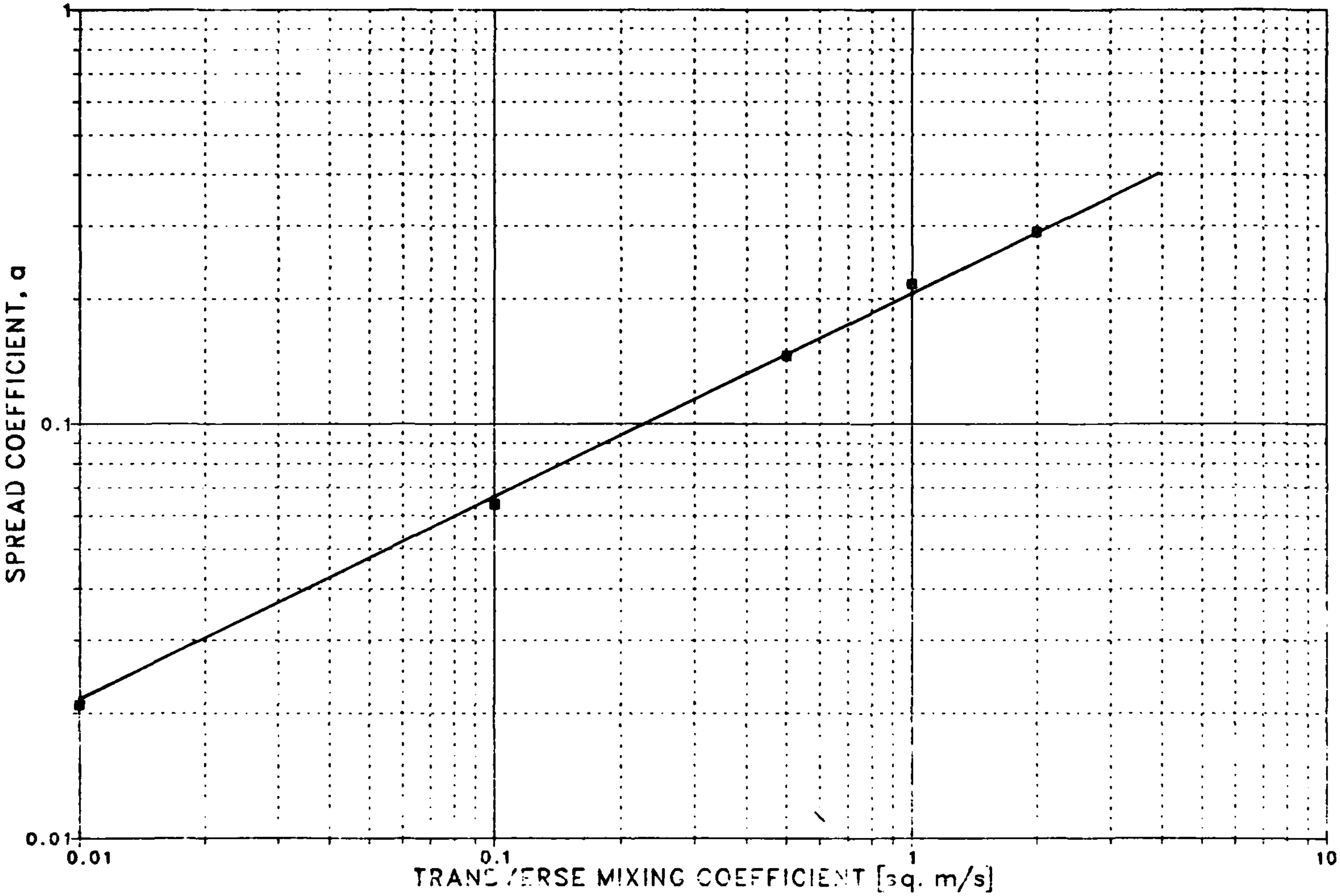

Figure II-43 Determination of spread coefficient, a.

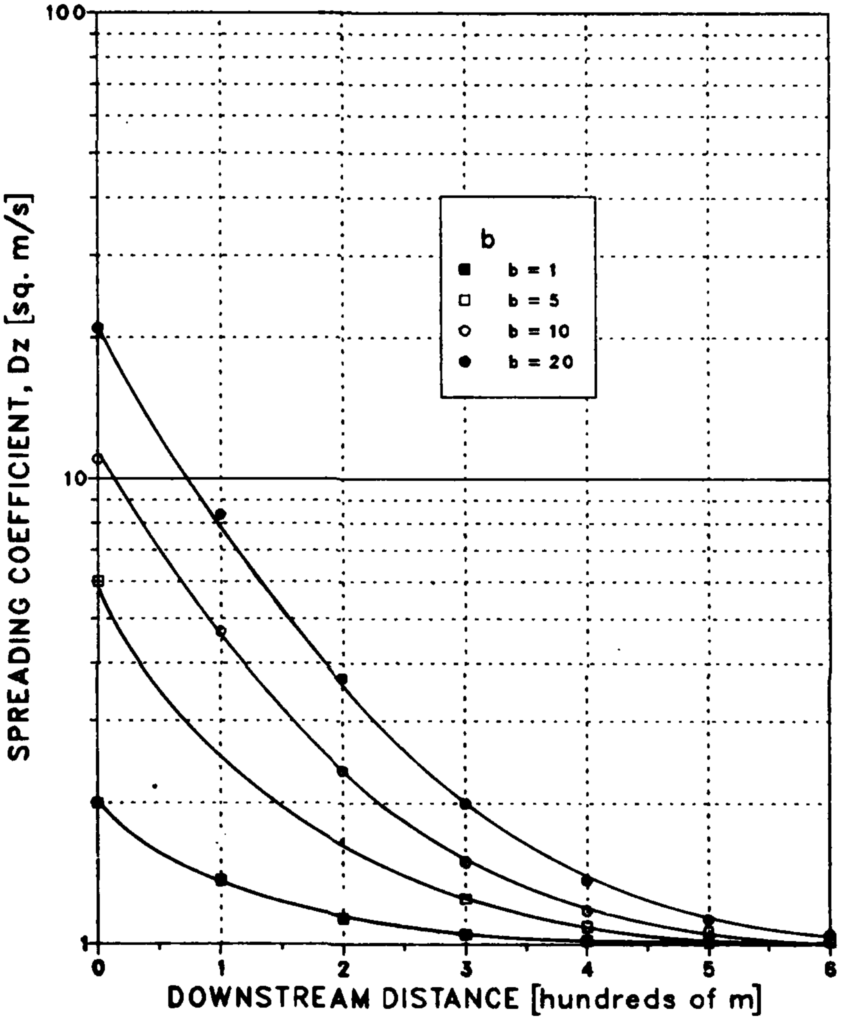

Figure II-44 Sensitivity of the spreading factor, b.

mixing coefficient. These options were consistent with observations of dredging disposal operations in the GREAT II and III reaches of the upper Mississippi River. The model was applied to two sites from GREAT II and three sites in GREAT III. Summary plots of how to estimate model coefficients and suspended-solids concentrations were given in figures II-27, II-28, II-41, II-42, II-43, and equation II-22.

Suspended-solids concentrations were quite small in the GREAT III reach which prevented further refinement and verification of the model. Better monitoring of background concentrations in the field would have been helpful. Furthermore the assumption of steady state did not always hold true in the field due to the variable dredging operation and river dynamics. lateral spreading of the plume was greater than expected due to lateral velocities of the discharge and channel morphology.

I. References

Bradsma, M.G., and Divoky, D.J., 1976, "Development of Models for Prediction of Short-Term Fate of Dredged Material Discharged in the Estuarine Environment", Contract Report D-76-5, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

Brooks, N.H., 1972, "Dispersion in Hydrologic and Coastal Environments", Report No. KH-R-29, W.M. Keck Laboratory, California Institute of Technology, Pasadena, California.

Elder, J.W., 1959, "The Dispersion of Marked Fluid in Turbulent Shear Flow", Journal of Fluid Mechanics, Vol. 5, No. 4, pp. 544-560.

Fischer, H.B., 1973, "Longitudinal Dispersion and Turbulent Mixing in Open Channel Flow", Annual Review of Fluid Mechanics, Vol. 5, pp. 59-78.

Fischer, H.B., 1968, "Methods for Predicting Dispersion Coefficients in Natural Streams, with Applications to Lower Reaches of the Green and Duwamish Rivers, Washington", U.S. Geological Survey Professional Paper 582-A.

Jobson, H.E. and Sayre, W.W., 1970, "Vertical Transfer in Open Channel Flow", Journal of Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 96, No. HY3, pp. 703-724.

Lambe, T.W., 1951, Soil Testing for Engineers, Jonn Wiley and Sons.

Okoye, J.K., 1970, "Characteristics of Transverse Mixing in Open-Channel Flows", Report No. KH-R-23, W.M. Keck Laboratory, California Institute of Technology, Pasadena, California.

Prych, E.A., 1970, "Effects of Density Differences on Lateral Mixing in Open Channel Flows", Report No. KH-R-21, W.M. Keck Laboratory, California Institute of Technology, Pasadena, California.

Schnoor, J.L., Giaquinta, A.R., Mustrove, D.D., and Sayre, W.W., 1980, "Suspended Sediment Modelling of Dredge-Disposal Effluent in the GREAT II Study Reach", Iowa Institute of Hydraulic Research Report No. 228.

Standard Methods for the Examination of Waste Water, 1980, Fourteenth Edition, American Public Health Association.

Vanoni, VA., 1977, editor, *Sedimentation Engineering*, ASCE-Manuals and Reports on Engineering Practice - No. 54, New York.

Wechsler, B.A., and Cogley, D.R., 1977, "A Laboratory Study of Turbidity Generation Potential of Sediments to be Dredged", Technical Report D-77-14, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi.

Yotsukura, N. and Cobb, E.D., 1972, "Transverse Diffusion of Solutes in Natural Streams", U.S. Geological Survey Professional Paper 582-C.

Yotsukura, N. and Sayre, W.W., 1976, "Transverse Mixing in Natural Channels", *Water Resources Research*, Vol. 12, No. 4, pp. 695-704.

III. STANDARD ELUTRIATE TEST

A number of hazardous chemicals are often associated with suspended and sediment particles, and as a result the sediments are generally considered to be sinks for a variety of chemical pollutants. These chemical pollutants may be released when the sediments are resuspended by dredging and dredge-disposal operations. The standard elutriate test attempts to simulate the open-water disposal of dredge material in the laboratory. The purpose of this test is to predict the extent of release of chemical pollutants from the sediments to be dredged.

A. Description of Sampling Sites and Sampling Procedures. Five sites were sampled along the GREAT III reach of the Missippi River (figures III-1, III-2, III-3, and III-4). The first attempt to collect water and sediment samples for the elutriate test was made on 14 August 1981. Sampling was done from an 18-foot flatbottom Jon boat with a 55 horsepower Mercury motor. The boat was equipped with a winch capable of handling over 100 pounds. The boat and motor were supplied by the Iowa Institute of Hydraulic Research of the University of Iowa. In the first sampling attempt, samples were collected from three of five recommended sites at river mile (RM) 170, 172 and 177. Sediment samples were collected from three different locations at each site and labeled as -1, -2 and -3 from the northern most location. Sediment samples were collected with a ponar dredge in 11 to 17 feet of water, at 100 to 300 feet from the shoreline. The sediment was immediately mixed in a plastic tub, and a homogeneous portion was stored in glass jars. Water samples were collected in 5-gallon Nalgene containers from the surface at the northern most location of each site. All containers had previously been acid washed and rinsed with deionized-distilled water. The samples were cooled during transit and stored in the laboratory at $4^{O}C$.

Site RM 170 is located near the National Lead Industries on the Illinois shore. Sample RM 170-3 was collected at the southern-most wing dam which was located by shore debris. Two other dams were not apparent. Sediment samples were taken at approximately 700-foot intervals upstream.

Site RM 172 is located below the Des Peres River on the Missouri shore. The first sediment sample at this site was collected approximately 100

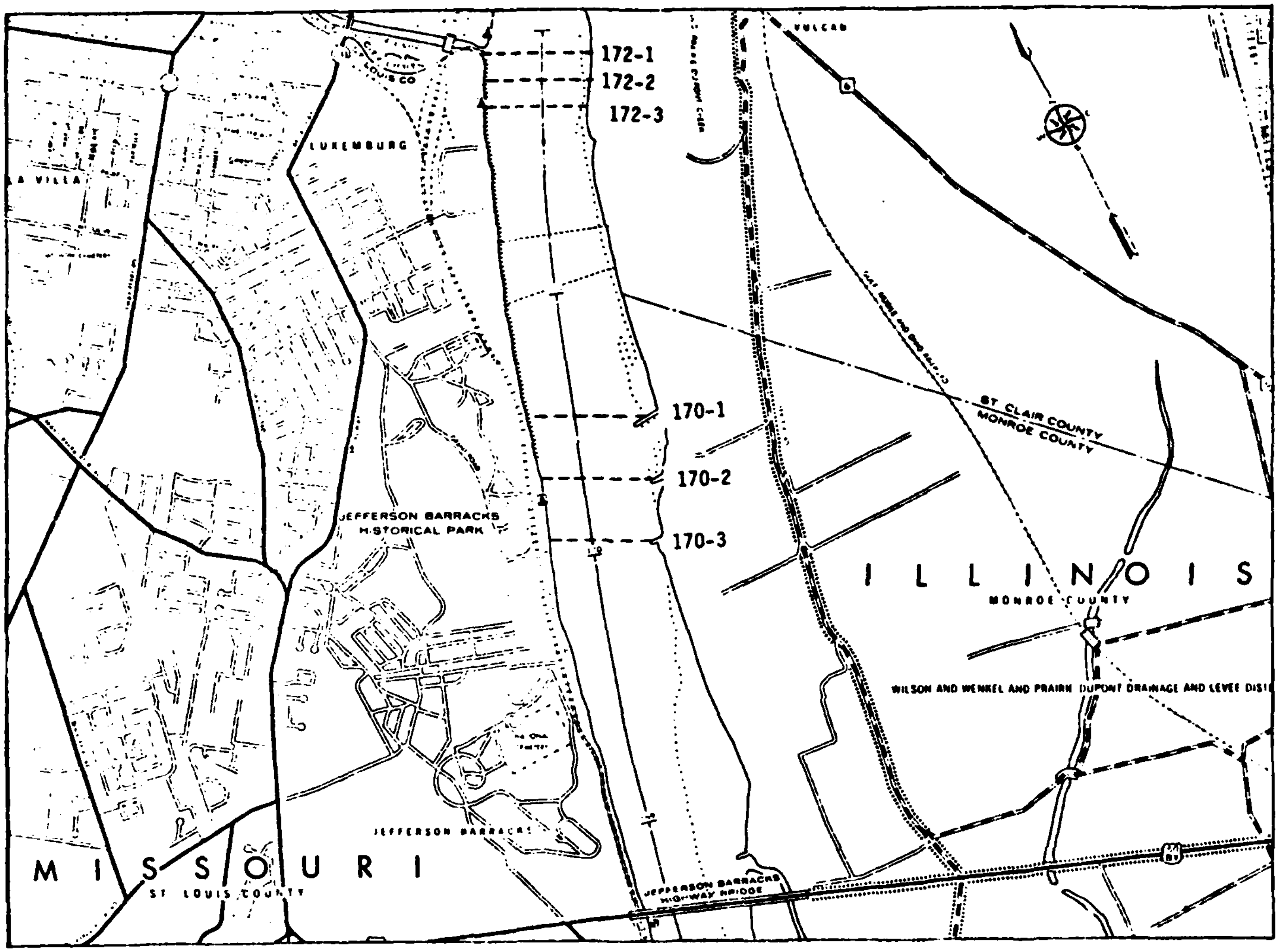

Figure III-1. Sampling Sites at River Mile 170 and 172 below St. Louis, Mo.

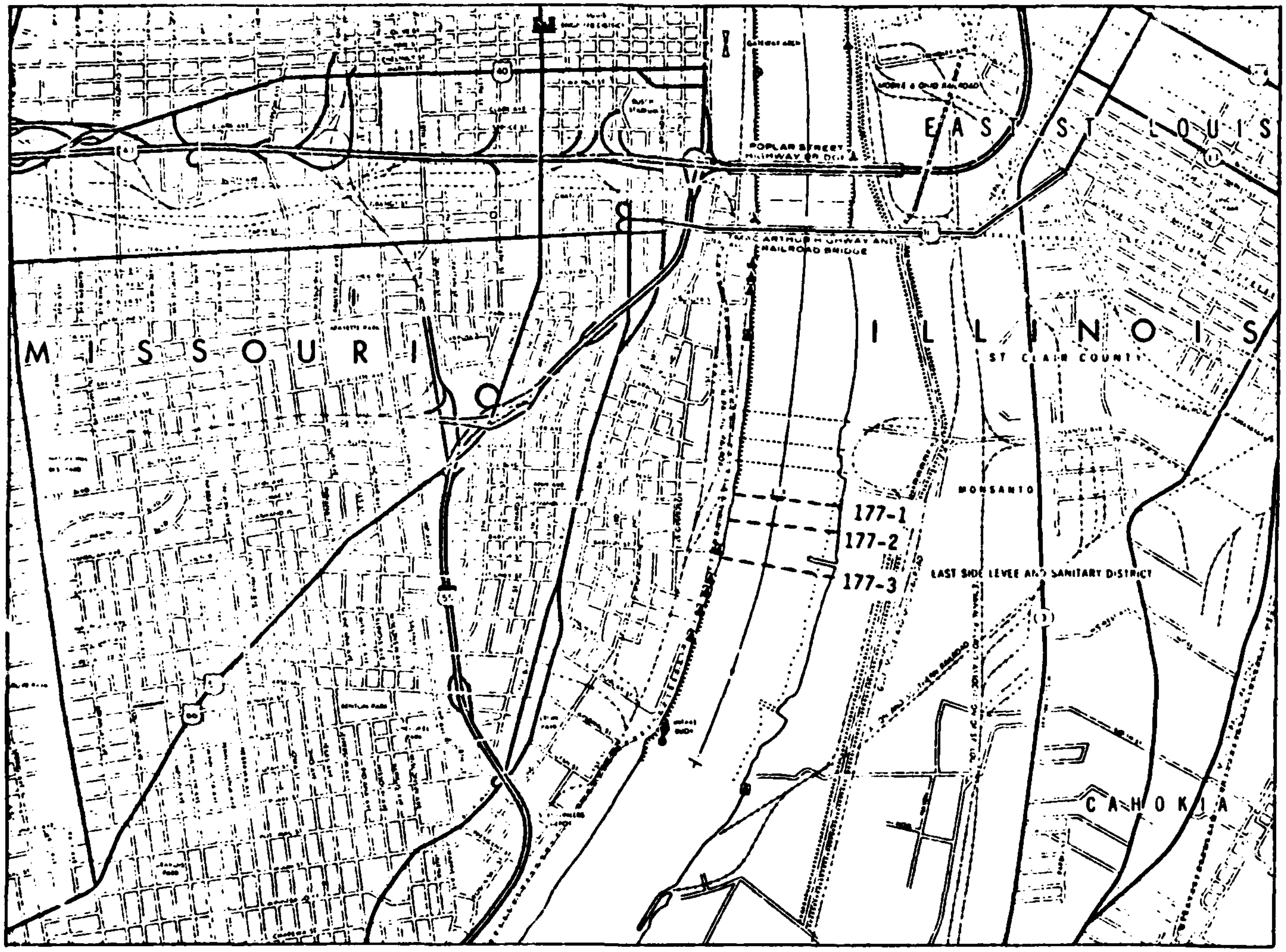

Figure III-2. Sampling Site at River Mile 177 near St. Louis, Mo.

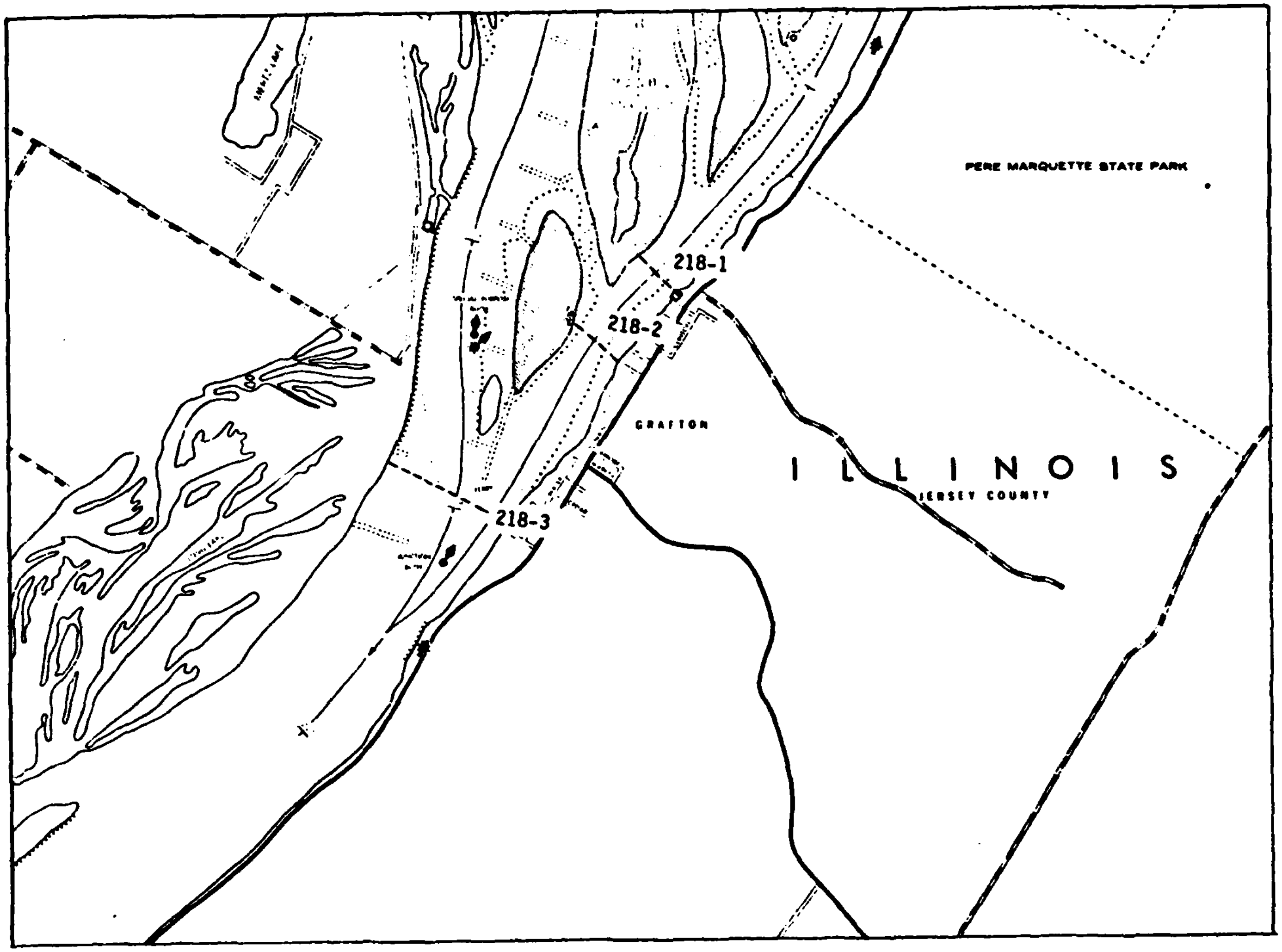

Figure III-3. Sampling Site at River Mile 218 near Grafton, IL.

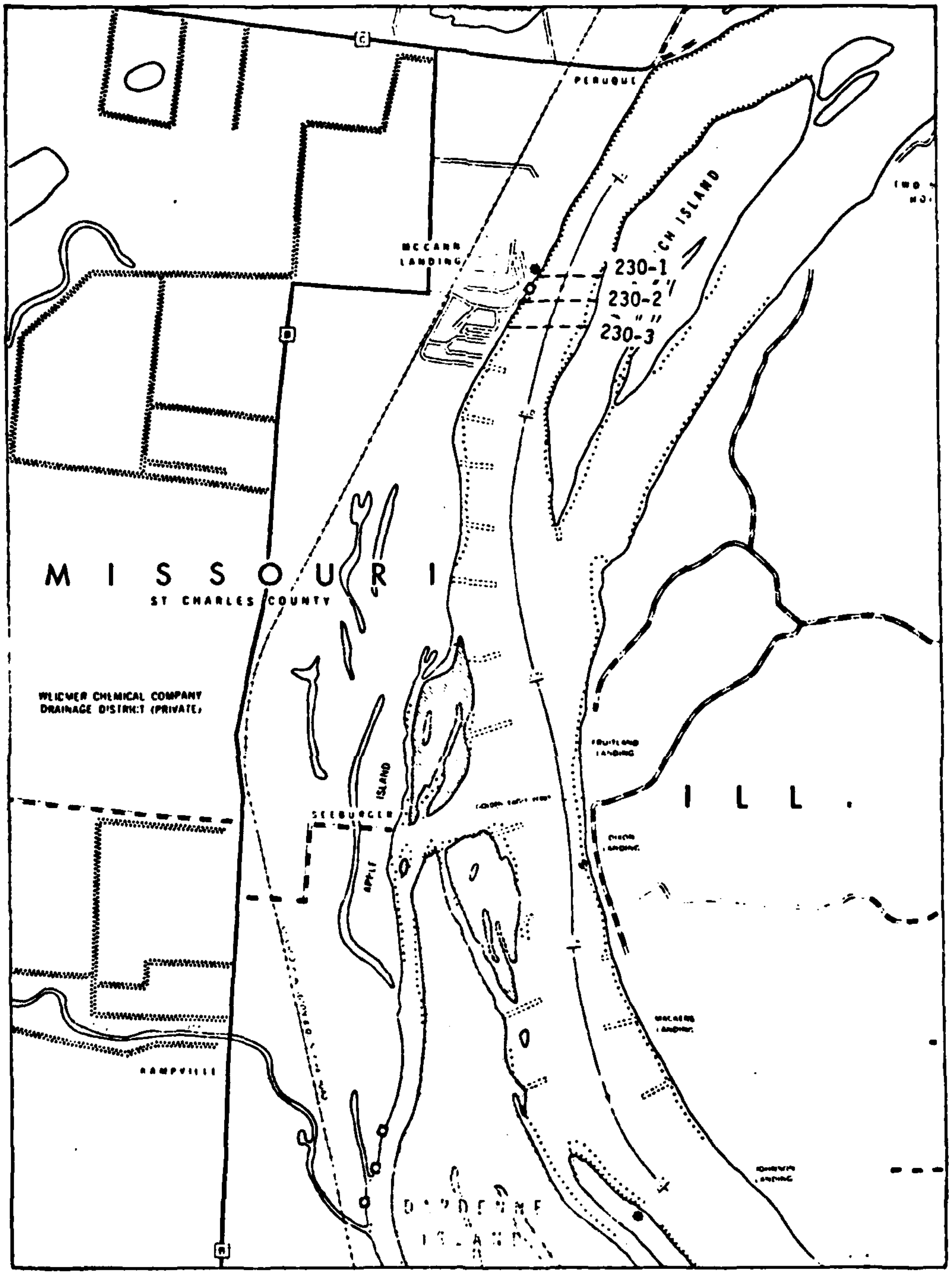

Figure III-4. Sampling Site at River Mile 230 near McCann Landing, Mo.

feet out from the shoreline of the southern bank of the Des Peres River. Two other samples were taken at approximately 600 foot intervals downstream from the barge loading areas.

Site RM 177 is located below the Monsanto terminal on the Illinois shore. The first sediment sample at this site was collected at RM 178 on the eastern bank (Illinois shore). Two other samples were taken at approximately 600 foot intervals downstream from the barge loading areas.

A second sampling attempt was made on 26 August 1981. Sediment and water samples were collected from the remaining two of five designated sampling sites. The sites were sampled at RM 218 on the Illinois shore, corresponding to the Illinois River miles 0 to 1, and at RM 230 near the Missouri shore. As in the previous sampling event, sediment samples were collected form three different locations at each site, and water samples for use in the elutriate test were collected from three different locations at each site, and water samples for use in the elutriate test were collected from the surface at the northern most location of each site. All sediment samples were uniformly mixed before distribution to the glass jars. Sediment samples for the priority pollutants analysis were taken at the northern most location (-1).

Site RM 218 is located near Venetian Harbor, approximately Illinois river mile 1. The first sample (RM 218-1) actually was collected from the Illinois River 150 feet from shore. The water depth was only 4 to 5 feet. The water was slow moving and ap##le 0.7, approximately 450 feet offshore from Grafton, Illinois. The water depth was about 30 feet. The sediment was composed of fine sand and silt. Sample RM 218-3 was obtained at 150 feet from the Illinois shore in 22 feet of water depth, downstream from the Riverway Shipping company commercial dock at the confluence of the Mississippi and Illinois Rivers on the Illinois shore. The dissolved oxygen level was 8.0 ppm.

Site RM 230 is located near Kirmill Wood Boat club on the Missouri shore. All three locations at river mile 230 were sampled at 125 feet from the Missouri shore in 23 to 25 feet of water. The three samples were collected at approximately 100 foot intervals near boat ramps. All sediment samples were composed of coarse sand.

An additional sampling atempt was made on November 20, 1981. Water and sediment samples were taken at RM 170, several hundred feet upstream from a series of wing dams and a barge docking area on the Illinois shore. Sample RM 170*-1 was taken from a dredge cut area, 100 feet upstream from the dredge in the open channel. Samples designated by * represent repetitions of samples at the same site. Sample RM 170*-2 was collected from a disposal area, 50 feet downstream from the dredge in the open channel. These samples were collected approximately 100 feet west of the dredge and well out of the plume area.

B. Procedure of the Elutriate Preparation. The procedure used to prepare elutriates is outlined in the Federal Register (1975) and was detailed by the Environmental Effects Laboratory, WES (1976). The following is a summary of the elutriate test procedure used during the study.

Step 1: One liter of wet sediment was placed in a 5-gallon Nalgene container. Four liters of unfiltered dredge site water were added to the container to give a final sediment to water volumetric ratio of 1:4. This mixture was then referred to as the elutriate slurry.

Step 2: A large coarse bubble stone diffuser was placed at the bottom of the container. Compressed air was passed through a deionized water trap before going to the diffuser. The air flow rate was sufficiently high to assure good mixing and oxic conditions.

Step 3: Every ten minutes the tanks were mechanically mixed by hand (vigorous swirling) to assure complete mixing.

Step 4: After 30 minutes the air flow was shut off and the elutriate slurry was allowed to settle for one hour.

Step 5: After settling, the supernatant was decanted and centrifuged to reduce the suspended-solids concentration and to reduce the time needed for subsequent filtering.

Step 6: After 5 minutes of centrifugation the sample centrate was pressure-filtered through an acid-rinsed 0.45 micron filter using an all glass filter apparatus.

Step 7: the filtrate is the "standard elutriate". It was stored in a plastic container at $4^{o}C$ in the dark. All analyses were completed within two weeks of sample collection.

C. Analytical Procedure.

1. Heavy Metals Analyses

a. Digestion Procedure. For the determination of total metals in raw river water the sample was acidified with 1:1 HNO_3 to a pH of 2 at the time of collection. The sample was not filtered before processing. A representative aliquot of 100 ml of the well-mixed sample was transferred to a 250 ml beaker and 3 ml of concentrated HNO_3 was added. The beaker was covered with a watch glass and returned to the hot plate. The temperature of the hot plate was increased so that a gentle reflux action occurred. Heating continued, with additional acid added as necessary, until the digestion was complete (generally indicated by a light colored residue). Sufficient 1:1 HCL was added and the beaker warmed again to dissolve the residue. Beaker walls and watch glass were washed down with distilled water and the sample filtered to remove silicates and other insoluble material that could clog the atomizer. The volume was adjusted to approximately 50 ml. Filtered and nonfiltered standard elutriate samples were digested in the same manner. Sediment samples were dried overnight at 105°C and weighed. The dried sample was ground with a mortar and pestle, and a representative aliquot of 1 gram was mixed with approximately 50 ml of distilled water. This sediment slurry was digested in the same manner described above.

b. Extraction Procedure. Digested samples were extracted prior to analysis. The pH of the samples was adjusted to pH 2.5 using 30 percent NH_4OH and 2.5 percent HCl. The samples were transferred to a 100 ml volumetric flask, and 2.5 ml fresh APDC (ammonium pyrrolidine dithiocarbonate) solution was added. A 10.0 ml MIBK (methyl isobutyl ketone) was added, and the samples were shaken vigorously for one minute. The layers were allowed to separate, and deionized distilled water was added until the MIBK layer was completely in the neck of the flask. Sample blanks, standard blanks, and prepared standards were subjected to identical extraction procedures. The MIBK layer was sampled for analysis via atomic absorption spectroscopy.

c. Atomic Absorption. Extracted samples were analyzed on a Jarrell-Ash Atomic Absorption Unit model No. 280 using a Fisher Micro Thermal Atomizer (Model 2). A 20 microliter sample was transferred to the tantulum ribbon of the MTA. Maximization of dry, ash, and atomize cycles was accomplished. Following wavelength maximization from suggested values, 20 microliter samples were analyzed until reproducibility of 0.1 unit was achieved on at least two runs of the sample. Standards and blanks also were analyzed in this same manner.

2. Traditional Pollutants Analyses. The analytical procedures for ammonia, phosphorus, chemical oxygen demand, and oil and grease followed "Standard Methods for the Examination of Water and Wastewater" (1980).

3. Priority Pollutants Analyses. The concentrations of toxic chemicals known as priority pollutants were determined in accordance with Federal Register 3 December 1979.

4. Other Measured Parameters. Dissolved oxygen measurements of raw river water and sediment-water interface water were performed in the field with a YSI Oxygen Meter Model No. 57. Oxidation-reduction potential measurements were accomplished on raw river water and sediment samples in the field using an Orion Research Model 399A/F analog pH meter. In the laboratory, pH was determined using an Orion research grade pH electrode. Redox potential measurements were accomplished using a combination platinum thimble type electrode. Redox potential and pH measurements of the elutriate samples were made using the same analog pH meter. Total suspended solids and volatile suspended solids concentrations were determined in accordance with Standard Methods (1980) at the water plant laboratory of the University of Iowa. Other

chemical analyses were performed at the University Hygienic Laboratory of the University of Iowa.

D. Results and Discussion. Chemical analyses of site water, sediments and elutriates were performed for five sites and fifteen samples in the GREAT III study reach. The concentrations of traditional pollutants, heavy metals, and PCBs (polychlorinated biphenyls) in unfiltered site water and sediments are given in table III-1. Concentrations of pollutants in filtered elutriates as compared with unfiltered site water, are presented in table III-2. The heavy metal parameters included cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), manganese (Mn), iron (Fe), and zinc (Zn). Associated statistical analyses were performed. Sediment samples were also tested for the 129 priority pollutants (U.S.EPA, 1979).

1. Comparison of Elutriate with Site Water. Results of a statistical analysis on the water quality data are given in table III-2. T is t-statistic for the null hypothesis: $u_2-u_1=0$, u_1 and u_2 are the mean concentrations of a pollutant in the unfiltered site water and the filtered elutriate, respectively. Manganese, ammonia, and COD were consistently desorbed (at the 0.05 significance level in a paired t-test). Zinc, iron and phosphate showed strong tendencies for adsorption. The results are in good agreement with those of the GREAT II study (Schnoor et al., 1979)

According to chemical equilibrium theory, manganese exists predominantly as Mn^{+2} in the reduced environment of the sediments. Intersticial waters (rich in Mn^{+2}) of the sediment are mixed with river water in the elutriate test, and consequently the filtered elutriate water contains increased dissolved manganese. Precipitation of Mn^{+2} to MnO_2 or MNOOH is not favored thermodynamically, or else kinetics limit the nucleation, crystal-growth, and sedimentation processes. Ammonia and COD are rich in sediment intersticial waters and tend to increase in the standard elutriate test. Iron exists in reduced sediments as Fe^{+2}, but is rapidly precipitated and adsorbed as Fe^{+3}, when the electrode potential increases to > + 0.2mv in oxygenated

Table III-1. Concentration of Heavy Metals, Traditional Pollutants and PCBs in Unfiltered River Water (W) and Sediment (S)

	170-1		170-2		170-3		172-1		172-2		172-3	
	W	S	W	S	W	S	W	S	W	S	W	S
Heavy Metals	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Cadmium, Cd	<0.001	<1.0	<0.001	3.4	--	1.0	<0.001	2.0	<0.001	< 1.0	--	1.0
Chromium, Cr	<0.001	11	0.03	20	--	4.3	0.04	29	0.04	7.1	--	27
Copper, Cu	<0.001	5	<0.01	15	--	3.4	<0.01	22	<0.01	7.1	--	37
Lead, Pb	<0.001	4	<0.01	17	--	4.3	0.02	54	0.02	17	--	46
Mercury, Hg	<0.001	< 1.0	<0.01	<1.0	--	< 1.0	<0.001	<1.0	<0.001	<1.0	--	<1.0
Nickel, Ni	<0.1	20	<0.1	23	--	8.7	<0.1	30	<0.01	20	--	9.6
Manganese, Mn	0.23	170	0.23	420	--	8.1	0.79	420	0.72	160	--	330
Iron, FE	4.7	8700	4.5	19000	--	3000	17	18000	17	8000	--	22000
Zinc, Zn	0.17	28	0.08	78	--	16	0.13	100	0.12	42	--	94
Traditional Pollutants												
Ammonia, NH_3-N	0.15	29	0.19	33	--	30	0.21	100	0.22	6.7	--	8.5
Phosphate, PO_4-P	0.25	--	0.22	--	--	--	0.50	--	0.46	--	--	--
COD	30	3800	45	24200	--	9300	85	34000	54	211	--	32250
Oil and Grease	1.3	<1	1.3	100	--	<1	<0.1	680	<1	<1	--	43
PCBs	μg/l	μg/kg	μg/l	μg/kg	μg/l	μg/kg	μg/l	μg/kg	μg/l	μg/kg	μg/l	μg/kg
aroclor 1260	<0.1	<20	<0.1	70	--	<20	<0.1	90	0.1	<20	--	165
aroclor 1254	<0.1	<20	<0.1	N.D.	--	<20	<0.1	N.D.	Trace	<20	--	277
Nature of Sediment		Sand		Organic		Sand		Organic		Sand		Organic
(% moisture)		(16.3)		(30.8)		(17.7)		(32.4)		(21.0)		(27.0)

W = Site Water
S = Sediment
N.D. = Not detected
-- = Chemical analysis not performed

Table III-1. (Continued)

	177-1		177-2		177-3		218-1		218-2		218-3	
	W	S	W	S	W	S	W	S	W	S	W	S
Heavy Metals	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Cd	<0.001	<1.0	<0.001	<1.0	--	2.0	<0.001	2	<0.001	3	--	1.0
Cr	0.02	2.0	0.01	2.0	--	21	0.02	28	<0.01	29	--	22
Cu	<0.01	3.0	<0.01	2.0	--	15	<0.01	16	<0.01	21	--	13
Pb	<0.01	3.0	0.01	9.0	--	22	<0.01	31	<0.01	37	--	28
Hg	<0.01	<1.0	<0.001	<1.0	--	<1.0	<0.001	<1.0	<0.01	<1.0	--	<1.0
Ni	<0.1	10	<0.1	10	--	30	<0.10	37	<0.1	40	--	30
Mn	0.19	70	0.20	68	--	370	0.15	480	0.16	610	--	460
Fe	3.9	3800	3.9	4000	--	18000	2.8	20000	2.9	22000	--	16000
Zn	0.13	11	0.03	12	--	83	0.03	66	0.03	100	--	66
Traditional Pollutants												
NH_3-N	*	18	0.15	4.5	--	55	0.06	71	0.06	270	--	91
PO_4-P	0.27	--	0.28	--	--	--	0.42	--	0.38	--	--	--
COD	43	630	10	926	--	25000	11	28900	21	36000	--	25600
Oil and Grease	<0.1	<1	<0.1	<1	--	47	1.5	<1	1.3	<1	--	<1
PCBs	μg/l	μg/kg	μg/l	μg/kg	μg/l	μg/kg	μg/l	μg/kg	μg/l	μg/kg	μg/l	μg/kg
aroclor 1260	<0.1	<20	<0.1	90	--	<20	<0.1	<20	<0.1	<20	--	<20
aroclor 1254	<0.1	<20	<0.1	Trace	--	<20	<0.1	<20	<0.1	<20	--	<20
Nature of Sediment		Sand		Sand		Organic/ Many rocks		Organic		Organic		Fine Sand/ Silt
(% moisture)		(13.3)		(16.6)		(28.3)		(35.1)		(40.8)		(29.1)

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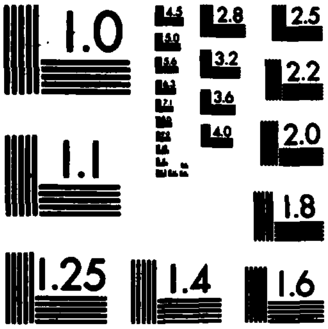

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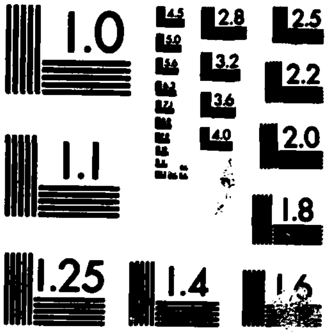

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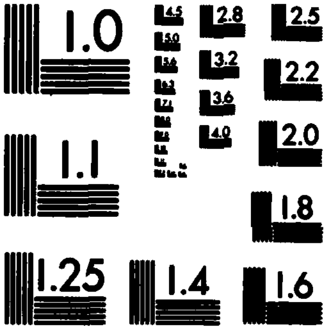

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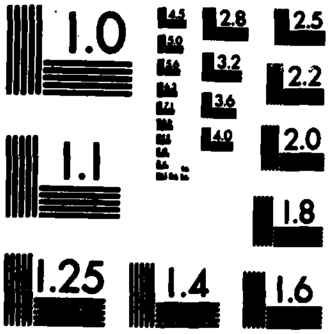

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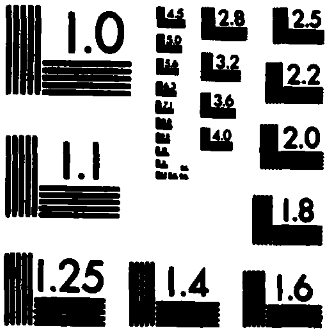

MICROCOPY RESOLUTION TEST CHART
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Table III-1. (Continued)

	230-1		230-2		230-3		170-1*		170-2*	
	W	S	W	S	W	S	W	S	W	S
Heavy Metals	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Cd	<0.001	<1.0	<0.001	<1.0	--	<1.0	--	--		--
Cr	<0.01	5	<0.01	3	--	8.9	<0.01	1.9	<0.01	2.6
Cu	<0.01	3	<0.01	5	--	15	<0.01	<1	<0.01	<1.0
Pb	<0.01	3	0.01	3	--	15	<0.01	3.8	<0.01	3.5
Hg	<0.001	<1.0	<0.001	<1.0	--	<1.0	--	--	--	--
Ni	<0.1	20	<0.1	20	--	4.0	<0.1	<9.6	<0.1	<8.9
Mn	0.08	210	0.07	220	--	240	0.16	46	0.16	70
Fe	0.69	8200	0.81	8200	--	7800	--	--		--
Zn	<0.01	17	<0.01	16	--	20	0.05	6.7	<0.01	11
Traditional Pollutants										
NH_3-N	0.05	4.2	0.09	5.3	--	61	0.03	15	0.01	9
PO_4-P	0.30	--	0.31	--	--	--	0.10	--	0.14	--
COD	25	1100	19	1200	--	1050	31	618000	35	790000
Oil and Grease	<0.1	<1	0.2	<1	--	4.4	--	--		--
PCBs	µg/l	µg/kg	µg/l	µg/kg	µg/l	µg/kg	µg/l	µg/kg	µg/kg	µg/kg
aroclor 1260	<0.1	<20	<0.1	<20	--	<20	--	--		--
aroclor 1254	--	--	--	--	--	--	--	--		--
Nature of Sediment		coarse sand		coarse sand		coarse sand		sand		sand
(% moisture)		(15.6)		(17.1)		(12.1)		(7.0)		(15.0)

Resampled on 20 November 1981

Table III-2. Concentration of Pollutants in Filtered Elutriates and Unfiltered Site Water

	Site Water 170-1	170-1	Elutriate 170-2	170-3	Site Water 172-1	172-1	Elutriate 172-2	172-3	Site Water 177-1	177-1	Elutriate 177-2	177-3
Heavy Metals	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Cadmium, Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001
Chromium, Cr	<0.01	*	*	*	0.04	*	*	*	0.02	*	<0.01	*
Copper, Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	*0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Lead, Pb	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	*0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury, Hg	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Nickel, Ni	<0.1	*	*	*	<0.1	*	*	*	0.1	*	<0.1	*
Manganese, Mn	0.23	1.0	1.4	0.35	0.79	1.50	0.19	0.68	0.19	0.06	0.05	0.63
Iron,Fe	4.7	4.4	9.1	0.16	17	4.2	1.1	3.60	3.9	0.46	0.29	0.73
Zinc, Zn	0.17	0.05	0.10	0.03	0.13	0.10	0.02	0.06	0.13	<0.01	0.02	0.04
Traditional Pollutants												
Ammonia, NH_3-N	0.15	0.46	0.90	0.06	0.21	5.7	0.20	1.8	1.8	0.06	0.66	1.7
Phosphate, PO_4-P	0.25	0.03	0.06	0.03	0.50	0.44	0.13	0.11	0.27	0.12	0.12	0.07
COD	30	74	86	73	85	115	73	63	43	22	30	63
Oil and Grease	1.3	<0.1	<0.1	<0.1	<0.1	--	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
PCBs	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
aroclor 1260	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	*0.1	<0.1	<0.1	<0.1	<0.1	<0.1
aroclor 1254	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	*0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Table III-2. (continued)

	Site Water 218-1	218-1	Elutriate 218-2	218-3	Site Water 230-1	230-1	Elutriate 230-2	230-3	Site Water 170*-1	Elutriate 170*-1	Site Water 170*-2	Elutriate 170*-2	Summary Statistics: Difference between the Means $\mu_2\mu_1$	St. Dev.	T t-test is significant	
Heavy Metals	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l				
Cd	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	--	--	--	--	<0.001	0.0003	0.33	
Cr	0.02	*	*	*	0.01	*	*	*	<0.01	<0.01	<0.01	<0.01	**	**	**	
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0000	0.0000	**	
Pb	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-0.0007	0.0070	0.72	
Hg	<0.001	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	--		--		0.0000	0.0000	**	
Ni	<0.10	*	*	*	<0.1	*	*	<0.1	<0.1	<0.1	<0.1	<0.1	**	**	**	
Mn	0.15	3.8	1.9	21	0.08	0.23	0.19	0.18	0.16	<0.01	0.16	<0.01	0.66	1.09	0.03	D
Fe	2.8	1.7	5.8	4.2	0.69	0.49	0.39	0.35	--			--	-3.36	0.06	0.05	A
Zn	0.03	0.08	0.04	0.05	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	<0.01	<0.01	-0.05	0.06	0.006	A
Traditional Pollutants																
NH_3-N	0.06	1.3	5.9	1.4	0.05	0.09	0.07	0.10	0.03	0.08	0.01	0.01	1.38	2.09	0.04	D
PO_4-P	0.42	0.10	0.22	0.24	0.30	0.14	0.36	0.20	0.10	0.06	0.14	0.11	-0.19	0.114	0.000	A
COD	11	76	78	82	25	43	36	52	31	39	35	42	25.6	32.2	0.008	D
Oil and Grease	1.5	1.7	1.4	2.3	<0.1	<0.1	0.2	1.4					-0.09	0.712	0.63	
PCBs	μg/l	μg/l	μg/l		μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l				
aroclor 1260	<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	<0.1	--	--	--	--	**	**	**	
aroclor 1254	<0.1	<0.1	<0.1	1	<0.1	<0.1	<0.1	<0.1	--	--	--	--	**	**	**	

*contaminated by stainless steel and brass filter apparatus
**computation impossible
D desorption
A adsorption
--chemical analysis not performed
Data on Samples 170*-1 and 170*-2 were not used for the statistical analysis

elutriate water. Zinc and phosphate either adsorb to particulate matter or precipitate or both. Phosphate is known to adsorb to silts and clays, but it could also precipitate with iron (III) or form Ca-hydroxyapatite.

The ammonia desorbed during the elutriate test occasionally exceeded the water quality criterion of 0.02 mg/l un-ionized ammonia. The heavy metals concentrations at the study sites were below the criteria for freshwater aquatic life (U.S.EPA, 1976). These low heavy metal concentrations are most likely due to association with suspended solids, promoted by the relatively high pH of the river water.

2. Correlations between Traditional Pollutants. The statistical analysis used here was a simple linear regression which gives a slope, intercept, and correlation coefficient. A high correlation coefficient in association with a significant slope was considered to indicate the possibility of association between two parameters.

   a. Site Water. The concentration of total suspended solids (TSS), volatile suspended solids (VSS, ammonia-nitrogen (NH_3-N), ortho-phosphorus (PO_4-P), oil and grease, chemical oxygen demand (COD), and redox potential are given in table III-3, and the associated statistical analysis is in table III-4. Unfiltered COD showed an increase with increasing TSS (figure III-5), and with increasing VSS (figure III-6). The high correlation coefficients and significant slopes indicate a strong tendency for unfiltered COD to increase as TSS or VSS increases. Statistically significant correlations were not found for other parameters.

   b. Sediment. Bed sediment consists primarily of sand, silt, clay, and organic materials. Generally the "dirty" sediment samples are darker in color and contained finer-grained sediment. These sediments are high in organic matter and are more likely to adsorb pollutants and to create a reduced (lower redox potential) environment.

Table III-3. Traditional Pollutant Concentrations of the Unfiltered Site Water

Site RM	Depth (ft)	Temp (°C)	pH	Redox (mv)	TSS (mg/l)	VSS (mg/l)	COD (mg/l)	NH_3-N (mg/l)	PO_4-P (mg/l)	Oil & Grease mg/l)
170-1	13.5	26.0	7.85	+110	180	167	30	0.15	0.25	1.3
-2	15.0	25.5	7.87	+125	--	--	45	0.19	0.22	1.3
-3	20.0	25.5	7.93	+ 80	--	--	--	--	--	--
172-1	17.0	26.5	7.73	+ 80	510	470	85	0.21	0.50	<0.1
-2	13.0	26.5	7.85	+ 80	--	--	54	0.22	0.40	<1
-3	13.0	26.5	7.83	+ 90	--	--	--	--	--	--
177-1	14.5	25.5	8.00	+ 60	130	123	43	--	0.27	<0.1
-2	15.5	25.5	7.97	+140	--	--	10	0.15	0.28	<0.1
-3	11.0	25.5	7.96	+ 95	--	--	--	--	--	--
218-1	5	23.0	7.90	+ 70	70	63	11	0.06	0.42	1.5
-2	30	23.5	8.20	+100	--	--	21	0.06	0.38	1.3
-3	22	23.5	8.00	+ 60	--	--	--	--	--	--
230-1	23	25.0	8.05	--	67	63	25	0.05	0.30	<0.1
-2	25.5	25.0	8.06	--	--	--	0.19	0.09	0.31	0.2
-3	23.5	25.0	8.05	--	--	--	--	--	--	--
*170-1	--	--	8.27	+220	98	16	31	0.03	0.10	--
-2	--	--	8.42	+210	80	12	35	0.01	0.14	--

* Sampled during dredging operation on 20 November 1981
-- Chemical analysis not performed

Table III-4. Correlations between Traditional Pollutants in the Unfiltered Site Water

Parameters			Intercept	Slope	Correlation Coefficient
NH_3-N (mg/l)	vs.	TSS (mg/l)	0.047	0.00034	0.93
	vs.	VSS (mg/l)	0.047	0.00037	0.93
	vs.	COD (mg/l)	0.072	0.002	0.74
	vs.	PO_4-P (mg/l)	0.113	0.060	0.08
	vs.	Oil & Grease (mg/l)	0.136	-0.024	0.24
	vs.	Redox (mV)	0.114	0.0003	0.13
COD (mg/l)	vs.	TSS (mg/l)	11.063	0.1449	0.94
		VSS (mg/l)	10.813	15.79	0.95
		PO_4-P (mg/l)	-7.956	134.36	0.51
		Oil & Grease (mg/l)	35.478	-4.37	0.11
		Redox (mV)	67.029	-0.310	0.35
PO_4-P (mg/l)	vs.	TSS (mg/l)	0.275	0.00038	0.65
		VSS (mg/l)	0.276	0.00041	0.64
		Oil & Grease (mg/l)	0.332	0.00029	0.002
		Redox (mV)	0.343	-0.00016	0.09
Oil & Grease (mg/l)	vs.	TSS (mg/l)	0.879	-0.0014	0.35
		VSS (mg/l)	0.886	-0.0015	0.35
TSS (mg/l)	vs.	Redox (mV)	102.5	1.50	0.17
VSS (mg/l)	vs.	Redox (mV)	96.04	1.37	0.16

Data on Samples 170*-1 and 170*-2 were not used for the statistical analysis

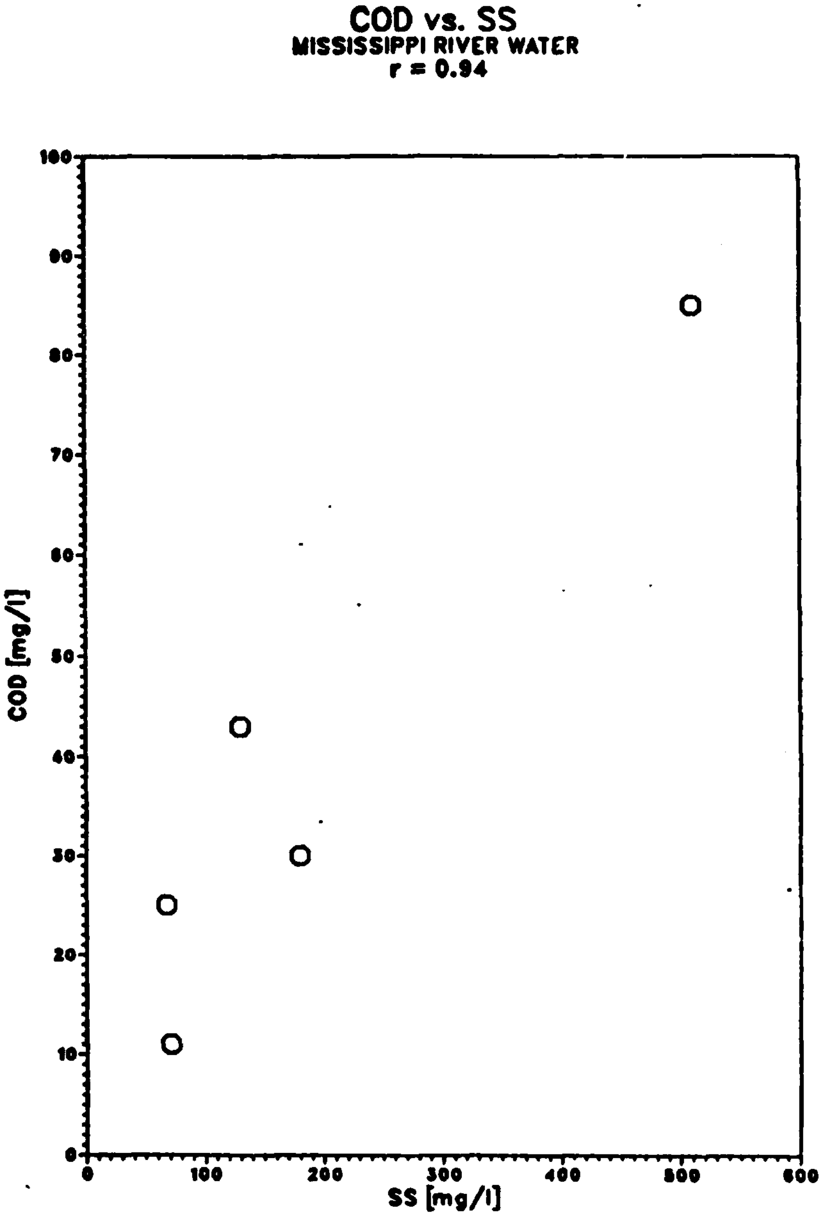


Figure III-5. Chemical Oxygen Demand in Unfiltered Samples vs. Total Suspended Solids of Site Water.

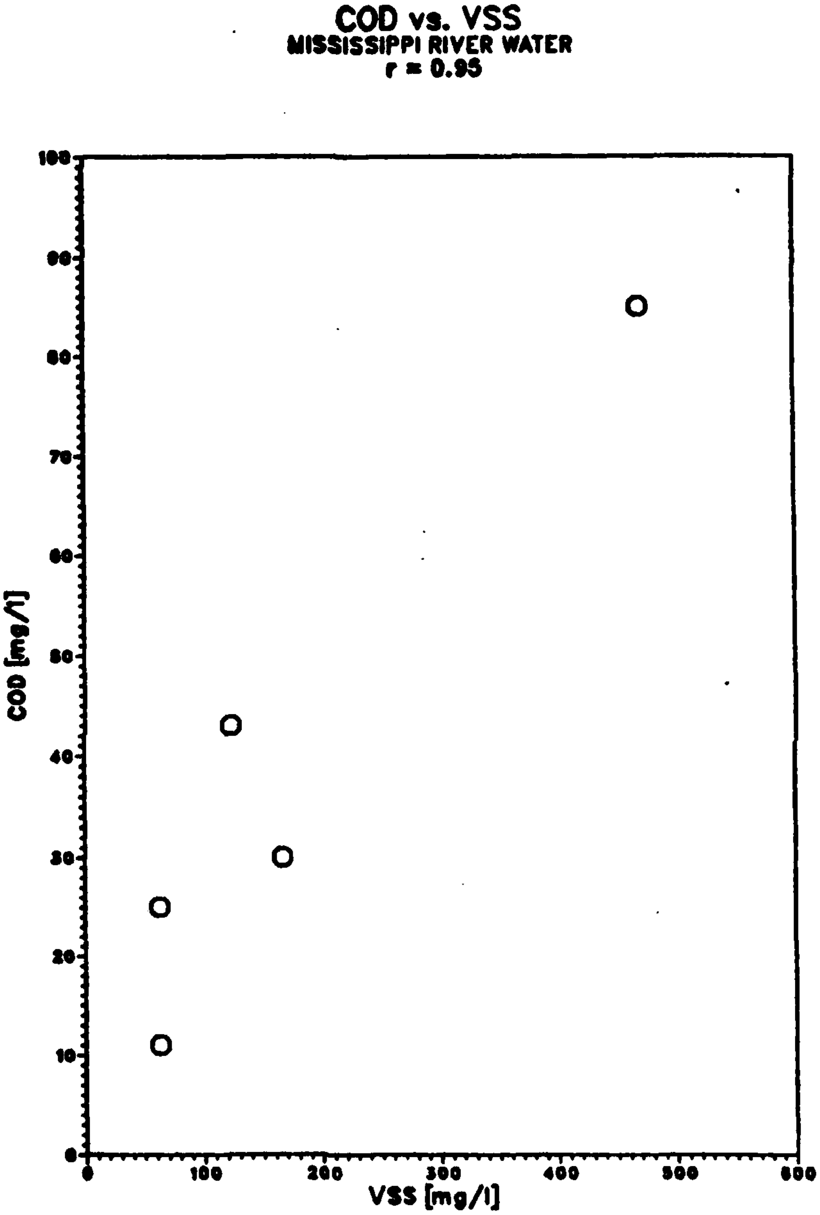


Figure III-6. Chemical Oxygen Demand in Unfiltered Smples vs. Volatile Suspended Solids of Site Water.

The concentration of ammonia, oil and grease, COD, redox potential, and moisture content (percent) of the sediment samples are given in table III-5, and the associated statistical analysis in table III-6. COD in the bulk sediment showed an increasing tendency with increases in moisture content of the sediment (figure III-7), and a decreasing tendency with increases in redox potential (figure III-8). The higher the moisture content generally the more "organic" the sediment. The high correlation coefficients and significant slope indicate strong association among COD, redox potential, and moisture (and organic) content.

Note the that organic sediments were obtained at sites RM 170-2, 172-1, 172-3, 218-1, 218-2, and 218-3. These sediments were characterized by high moisture content, COD, oil and grease, ammonia, and phosphorus. Sample RM 170-2 was collected behind the wing dam where water was moving slowly. The site RM 172 was located below the Des Peres River in an area of stagnant water. Site RM 177-3 was located below the Monsanto Terminal on the Illinois shore, in the barge loading area. A large number of rocks and twigs were sampled with the sediment. Site RM 218 was located near Venetian Harbor. The water was slow moving. Sample RM 218-3 was collected downstream from the Riverway Shipping Company commercial dock at the confluence of the Mississippi and Illinois Rivers on the Illinois shore. The sediment was composed of fine sand and silt.

The organic sediments sampled from various locations consisted of large portion of silt, clay-size particles, and colloidal organic particles. The silt and clay-size particles are transported mainly in suspension, and suspended colloidal particles behave much like the ambient fluid. Once these particles reach slow moving water, the lower current velocities allow these particles to settle. These particles are eventually deposited on the bed where they behave as bed-material particles until they are re-

Table III-5. Sediment Pollutant Concentrations

Site	Location	Nature of Sediment	COD (mg/kg dry weight)	NH_3-N (mg/kg dry weight)	Oil & Grease (mg/kg dry weight)	Redox (mV)	Moisture Content
170-1	Near National	Sand	3,800	29	<1	+25	16.3
2	Lead Industries	Organic	24,200	33	100	-120	30.8
3	Illinois shore	Sand	9.300	30	<1	210	17.9
172-1	Below Des Peres	Organic	34,000	100	630	-140	32.4
2	River	Sand	211	6.7	<1	-165	21.0
3	Missouri Shore	Organic	32,250	8.5	43	-160	27.0
177-1	Below Monsanto	Coarse Sand	630	18	<1	+220	13.3
2	Terminal	Coarse Sand	926	4.5	<1	+220	16.6
3	Illinois Shore	Organic/Many Rocks	25,000	55	47	-80	28.3
218-1	Near Venetian Harbor	Organic	28,900	71	<1	-150	35.1
2	Grafton, Illinois	Organic	36,000	270	<1	-180	40.8
3	Illinois shore	Fine Sand/Silt	25,000	91	<1	-140	29.1
230-1	Kirmill Wood Boat	Coarse Sand	1,100	4.2	<1	+170*	15.6
2	Club	Coarse Sand	1,200	5.3	<1	+100*	17.1
3	Missouri Shore	Coarse Sand	1,050	61	4.4	+185*	12.1
170*-1	Near National Lead Industries	Sand	618,000	15	--	+240	7.0
2	Illinois Shore	Sand	790,000	9	--	+245	15.0

*measured in the lab.

Table III-6. Correlations between Sediment Pollutants, Moisture Content, and Redox Potential

Parameters			Intercept	Slope	Correlation Coefficient
NH_3-N (mg/kg)	vs.	COD (mg/kg)	0.772	0.003	0.66
		Redox (mV)	57.511	-0.232	0.56
		Moisture (%)	75.405	5.428	0.71
		Oil & Grease (mg/kg)	48.473	0.072	0.17
COD (mg/kg)	vs.	Redox (mV)	16697.3	-82.744	0.94
		Moisture (%)	-20745.6	1513.16	0.93
		Oil & Grease(mg/kg)	12756.6	38.613	0.43
Redox (mV)	vs.	Moisture (%)	411.987	-16.567	0.90
Oil & Grease(mg/kg)	vs.	Redox (mV)	62.985	-0.340	0.34

Data from Sample 170*-1 and 170*-2 were not used for the statistical analysis

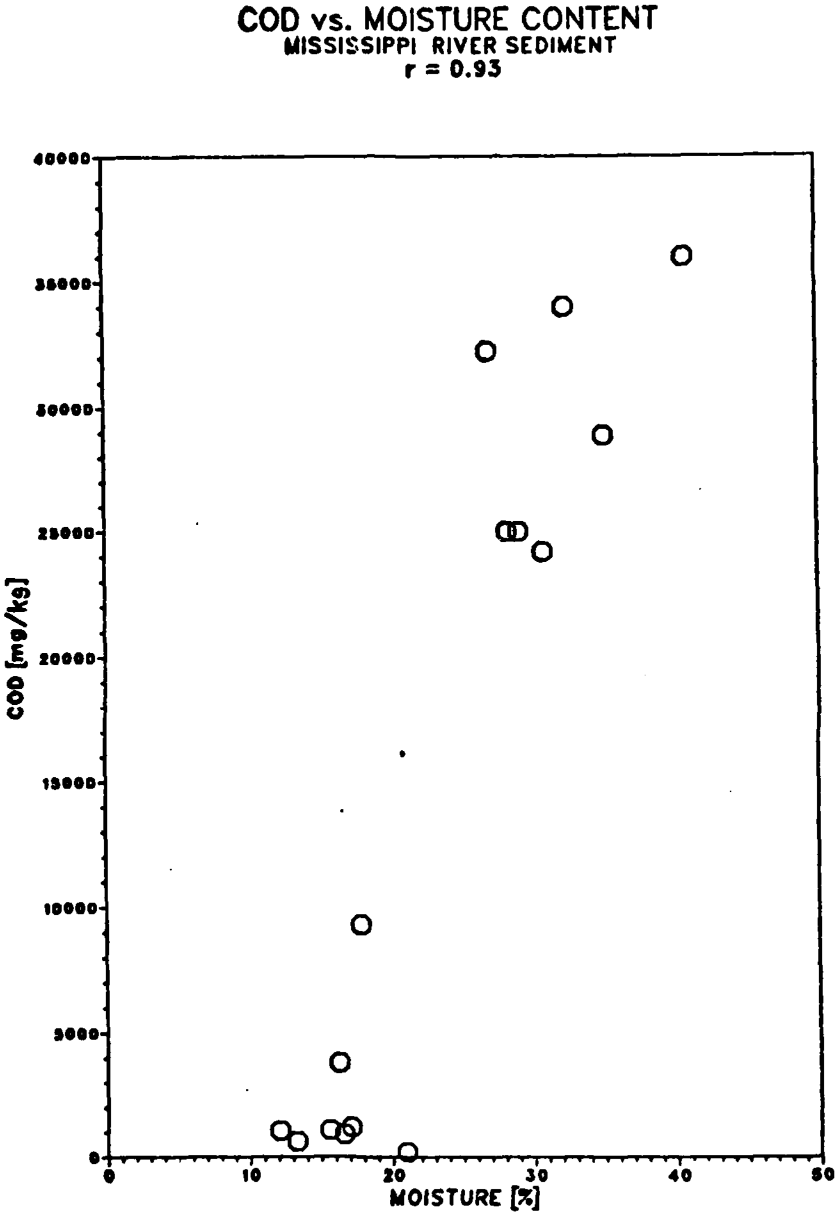


Figure III-7. Sediment Chemical Oxygen Demand vs. Moisture Content.

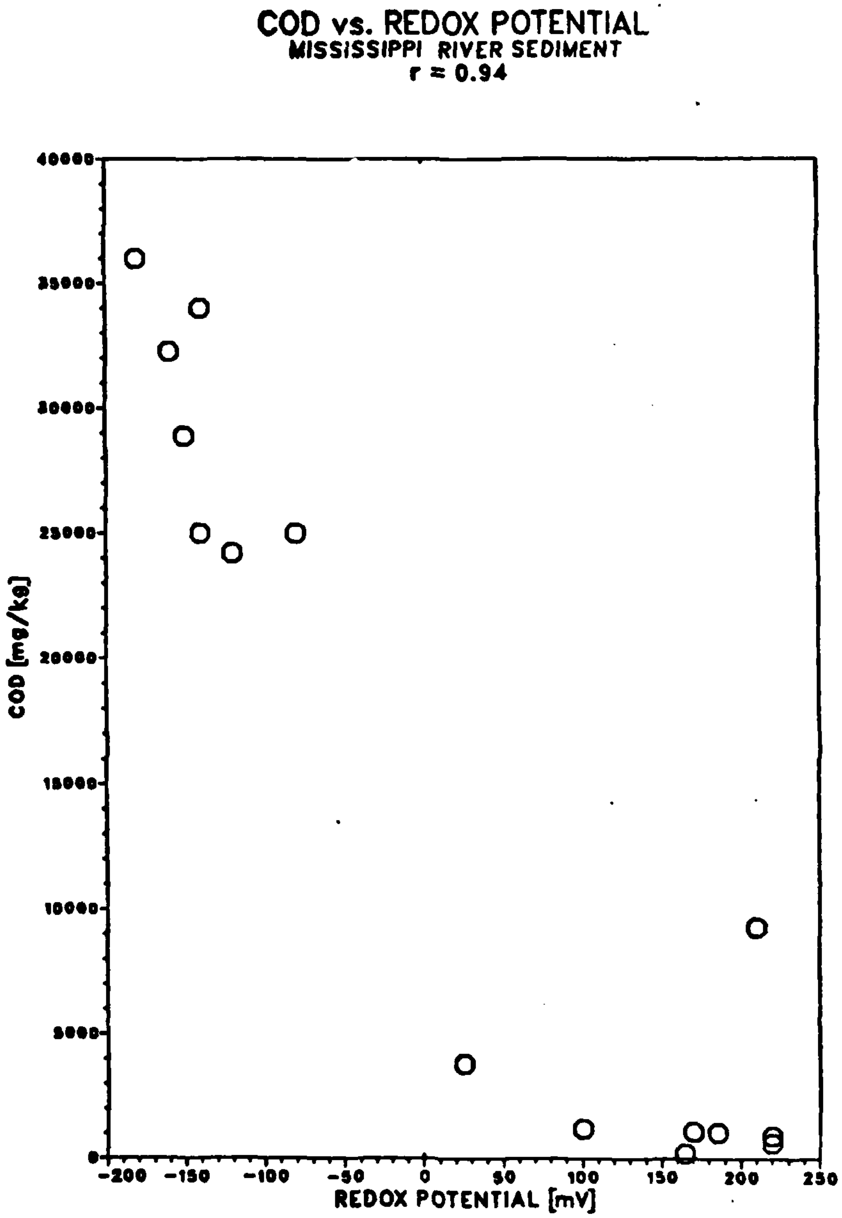


Figure III-8. Sediment Chemical Oxygen Demand vs. Sediment Redox Potential.

entrained in the flow. The sedimentation of the suspended colloidal particles involves the process of coagulation which is strongly a function of pH, temperature, and other physical-chemical factors. Since the sedimentation characteristics are constantly changing, it is difficult to predict the fate of these particles. However, it is clear that the organic sediment will be found in slow-moving or stagnant water areas.

c. Elutriate. The concentration of ammonia and COD of the elutriate samples and the statistical analyses are given in tables III-7 and III-8, respectively. No significant correlation was found between ammonia, phosphorus, and COD.

3. Priority Pollutants in Sediments. The EPA has been directed to regulate discharges of 129 priority toxic compounds into the nation's waterways to protect both aquatic and human life (Federal Register, Dec., 1979). Sediment characterization by a "gas chromatograph-mass spectrometer" scan was performed for the organic parameters at the University Hygenic Laboratory. Table III-9 shows the concentration of the organic priority pollutants at the five sampling sites. All pollutants were below the detectable level, except diethyl phthalate and di-n-butyl phthalate which were found to be 25.3 μg/l and 11.1 μg/l, respectively, at site 172. Detection limits are the limits given for each compound as less than (<).

E. Summary. A summary of all desorbed pollutants at each site is presented in table III-10. Manganese, ammonia, and COD were consistantly desorbed while zinc, iron, and phosphate showed strong tendencies for adsorption. The "dirty"sediments were found in slow-moving or stagnant water areas, and were characterized by high organic and moisture contents, high COD, oil and grease, ammonia, and phosphorus, and low redox potentials.

Table III-7. Traditional Pollutant Concentrations in Filtered Elutriates

Site	COD (mg/l)	NH_3-N mg/l)	PO_4-P (mg/l)
170-1	74	0.46	0.03
170-2	86	0.90	0.06
170-3	73	0.06	0.03
172-1	115	5.7	0.44
172-2	73	0.20	0.13
172-3	63	1.8	0.11
177-1	22	0.06	0.12
177-2	30	0.66	0.12
177-3	63	1.70	0.07
218-1	74	1.3	0.10
218-2	78	5.9	0.22
218-3	82	1.4	0.24
230-1	43	0.09	0.14
230-2	36	0.07	0.36
230-3	52	0.10	0.20
170*-1	39	0.08	0.06
-2	42	0.01	0.11

Table III-8. Correlations between Traditional Pollutants in the Elutriate

	Intercept	Slope	Correlation Coefficient
NH_3-N (mg/l) vs. COD (mg/l)	-1.619	0.047	0.60
NH_3-N (mg/l) vs. PO_4-P (mg/l)	0.042	8.343	0.51
PO_4-P (mg/l) vs. COD (mg/l)	53.590	7.850	0.62

Data from Sample 170*-1 and 170*-2 were not used for the statistical analysis.

Table III-9. Concentrations of the Organic Priority Pollutants in Sediments

	RM 170-1	RM 172-1	RM 177-1	RM 218-1	RM 230-1
Compounds (Acidic)	Concentration (µg/l)				
		concentrations at these sites are all the same as at RM 170-1			
2-chlorophenol	<25				
2,4-dichlorophenol	<25				
2,4-dimethylphenol	<25				
4,6-dinitro-o-cresol (1)	<250				
2,4-dinitrophenol	<250				
2-nitrophenol	<25				
4-nitrophenol	<100				
p-chlor-m-cresol (2)	<25				
pentachlorophenol	<25				
phenol	<25				
2,4,6-trichlorophenol	<25				
Compounds (Basic/Neutral)					
acenaphthene	<10				
acenaphthylene	<10				
anthracene	<10				
benzidine	<10				
benzo(a)anthracene	<10				
benzo(a)pyrene	<10				
3,4-benzofluoranthene	<10				
benzo(g,h,i)perylene	<25				
benzo(k)fluoranthene	<10				
bis-(2)chloroethoxy)methane	<10				
bis-(2-chloroethyl)ether	<10				
bis-(2-chloroisopropyl-ether	<10				
bis-(2-ethylhexyl)phthalate	<10				
4-bromophenyl phenyl ether	<10				
butyl benzyl phthalate	<10				
2-chloronaphthalene	<10				
4-chlorophenyl phenyl ether	<10				
chrysene	<10				
dibenzo(a,h)anthracene	<25				
1,2-dichlorobenzene	<10				
1,3-dichlorobenzene	<10				

Table III-9. (Continued)

	RM 170-I	RM 172-I	RM 177-I	RM 218-I	RM 230-I
Compounds (Acidic)	Concentration (µg/l)				
		concentrations at these sites are all the same as at RM 170-I except as noted			
1,4-dichlorobenzene	<10				
3,3'-dichlorobenzidine	<10				
diethyl phthalate	<10	25.3			
dimethyl phthalate	<10				
di-n-butyl phthalate	<10	11.1			
2,4-dinitrotoluene	<10				
di-n-octyl phthalate (3)	<10				
1,2-diphenylhydrazine	<10				
fluoranthene	<10				
fluorene	<10				
hexachlorobenzene	<10				
hexachlorobutadiene	<10				
hexachlorocyclopentadiene	<10				
hexachloroethane	<10				
indeno(1,2,3-cd)pyrene	<25				
isophorone	<10				
naphthalene	<10				
nitrobenzene	<10				
N-nitrosodimethylamine	<500				
N-nitrosodi-n-propylamine	<10				
N-nitrosodiphenylamine	<10				
phenanthrene	<10				
pyrene	<10				
1,2,4-trichlorobenzene	<10				

(1) 2 - methyl -4,6 - dinitrophenol

(2) 4 - chloro - 3 - methylphenol

(3) dioctylphthalate

Table III-10. Desorbed Chemicals in the Standard Elutriate Test

Date Sampled	Site Location	RM	Nature of Sediment	Desorbed Chemicals
08-14-81	Near National Lead Industries, Illinois Shore	170 (1)	Sand (16.3%)	Mn, COD, NH_3
		170 (2)	Organic (30.8%)	Mn, Fe, COD, NH_3
		170 (3)	Sand (17.7%)	COD
	Below Des Peres River, Missouri Shore	172 (1)	Organic (32.4%)	Mn, COD, NH_3
		172 (2)	Sand (21.0%)	
		172 (3)	Organic (27.0%)	Cd, NH_3
	Below Monsanto Terminal, Ilinois Shore	177 (1)	Coarse Sand (13.3%)	
		177 (2)	Coarse Sand (16.6%)	
		177 (3)	Organic/many rocks (28.3%)	Mn,COD
08-26-81	Illinois Shore, Grafton, Ill.	218 (1)	Organic (35.1%)	Mn, COD, NH_3
		218 (2)	Organic (40.8%)	Mn, Fe, COD, NH_3
		218 (3)	Fine Sand/Silt (29.1%)	Mn, Fe, COD, O & G, NH_3
	Kirmill Wood Boat Club, Missouri Shore	230 (1)	Coarse Sand (15.6%)	Pb, Mn, COD, NH_3
		230 (2)	Coarse Sand (17.1%)	Mn, COD, O & G, NH_3
		230 (3)	Coarse Sand (12.1%)	Mn, COD, O & G, NH_3
11-20-81	Near National Lead Industries, Illinois Shore	170*(1)	Sand (7.0%)	COD
		170*(2)	Sand (15.0%)	COD

* Sampled during dredging operation on November 20, 1981

( ) moisture content

F. References

Schnoor, J.L., Musterman, J.L., Fisher, R.A., Birks, D.W., Geadelman, C.O., and Gopinath, V.S., 1979, "Desorption of Pollutants in the GREAT II Study Reach Lab. Simulation Study, "IIHR report No. 234, Iowa Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa.

Standard Methods for the Examination of Water and Wastewater, 1980, 15th Ed., APHA-AWWA-WPCF.

U.S. Environmental Protection Agency, 1975, Federal Register 40, No. 173, 41292-41298 (Sept. 5).

U.S. Environmental Protection Agency, 1976, "Quality Criteria for Water", Washington, D.C. 20460.

U.S. Environmental Protection Agency, 1979, Federal Register 4, No. 128, 38746-38776 (July 2).

Waterways Experiment Station (WES), Environmental Effects Laboratory, 1976, "Ecological Evaluation of Proposed Discharge of Dredged or Fill Material into Navigable Waters," Interim Guidance for Implementation of PL92-500, Misc. Paper D-76-17, Vicksburg, Mississippi.

IV. DESORPTION KINETICS

The kinetics study attempts to explain the mechanisms of sorption during the process of elutriation. While the standard elutriate test is a physical model to simulate the effect of dredge disposal on water quality in the laboratory, the kinetic model presented in this report is a mathematical model to describe the sorption rates for various chemicals.

A. Description of Sampling Sites and Sampling Procedures. Based on the results obtained from previous elutriate tests, it was decided that the chemical pollutants of interest were ammonia, chemical oxygen demand, chromium, and nickel. Sampling sites selected were as follows:

170-2	Silty sediment behind old wing dam on Illinois shore.
172-1	Silty sediment at the mouth of the Des Peres River on the Missouri shore.
172-2	Silt and sand mixture approximately 150 meters downstream from 172-1.

The first sampling trip was made on September 22, 1981. The water level was approximately 10 feet lower than when the site was originally located on August 14, 1981. It took several attempts before the pocket of organic sediment could be located at RM 170-2. The pocket was located in approximately 4 feet of water, 8 feet from the shore. Site RM 172-1 was easily located at the mouth of the Des Peres River. The sample obtained was similar in nature to that previously collected. Site RM 172-2 was beneath the barge loading area where a fine sand sample, similar in nature to that previously collected, was again found.

The sediment was collected with a ponar dredge, mixed in a plastic tub, and stored in glass jars. Water samples for use in the kinetic study were collected from the surface in 5-gallon Nalgene containers. The redox potential, temperature, pH, and dissolved oxygen were measured in the field.

An additional sampling trip was made on November 20, 1981. This trip is designated by *. Water and sediment samples were taken at RM 170, several hundred meters upstream from a series of wing dams and a barge docking area on the Illinois shore. Sediment sample (RM 170^*-2) was taken from the dredge cut area, 100 feet upstream from the dredge in the open channel. Water sample (RM 170^*-3) was collected 200 feet downstream from the dredge. These samples were taken at approximately 100 feet west of the dredge and well out of the plume area.

B. Experimental Procedure of the Kinetics Study The method of the kinetic study was basically the same as that of the elutriate test. A seven liter graduated jar was equipped with a mechanical stirrer, air stone, and pH and dissolved oxygen probes. One liter of homogeneous sediment was measured into four liters of site river water by displacement. When the addition was complete, a 500 ml sample of the well-mixed slurry was immediately extracted from the surface (the time zero sample). Additional samples were taken at the following intervals: 0.1, 0.2, 0.3, 0.5, 1, 2, 6, and 12 hours. The samples were immediately centrifuged, filtered through a glass fiber filter, and finally filtered through a 0.45 micron membrane filter. The sediment was retrieved from the centrifuge tubes, diluted to 500 ml with site water, and returned to the original jar. An elutriate blank was prepared. The blank was a sample of site water run through the filtration process and preserved with nitric or sulfuric acid in the same fashion that the samples were preserved. The samples were analyzed for ammonia, COD, pH, redox potential, chromium, and nickel.

C. Development of the Kinetic Model The kinetic tests were performed in a jar reactor. The system was assumed to be a completely mixed batch reactor and to be homogeneous throughout. In this reactor, an initial limited number of factors may be involved in the reactions. The relevant reactions which remove or transform pollutants include adsorption, desorption, hydrolysis, oxidation, biodegradation, photolysis, and volatilization. The equation governing dissolved pollutant concentration in the reactor may be written as

$$dC/dt = - K_1CM + K_2rM - (K_p + H_h + K_o + K_b + K_v)C \qquad \text{(IV-1)}$$

where

C = dissolved pollutant concentration at time t, μg/l,

r = adsorbed pollutant concentration, mass of pollutant adsorbed per mass of solid, μg/kg,
t = time, hours,
M = suspended solids concentration, kg/l,
K_1= adsorption rate constant, $(\mu g/l)^{-1}$ $(\text{hour})^{-1}$,
K_2= desorption rate constant, hour^{-1},
K_p= photolysis rate constant, hour^{-1},
K_h= hydrolysis rate constant, hour^{-1},
K_o= oxidation rate constant, hour^{-1},
K_v= volatilization rate constant, hour^{-1},
K_b= biodegradation rate constant, hour^{-1}.

It was assumed that the rates of photolysis, hydrolysis, oxidation, volatilization, and biodegradation are either first order or pseudo-first order.

The equation for pollutant concentration adsorbed by the sediment may be expressed as

$$dr/dt = K_1C - K_2r \tag{IV-2}$$

where r = adsorbed pollutant concentration, μg/kg .

It was assumed that no reactions occur in the particulate phase. Since the sorptive equilibrium is generally rapid compared to the other reaction mechanisms, it may be assumed that the pollutant concentration (at small times) is only governed by adsorption and desorption rates. If these assumptions hold true, (IV-1) and (IV-2) reduce to the following adsorption-desorption kinetics:

$$dC/dt = -\ K_1CM + K_2rM \tag{IV-3}$$

$$dr/dt = K_1C - K_2r \tag{IV-4}$$

The temporal conditions for the above equations are given by

$$C = C^* \text{ at } t = t^* \tag{IV-5}$$

$$C = C_e \text{ at } t = \infty \qquad \text{(IV-6)}$$

where

$t^* =$ initial mixing time, hours,

$C^* =$ initial concentration of dissolved pollutant at t^*, μg/l,

$C_e =$ concentration of dissolved pollutant at equilibrium, μg/l.

The analytical solution of (IV-3) and (IV-4) under the foregoing conditions, is given by

$$C = C_e + (C^*-C_e) \exp - [(K_1M + K_2)(t-t^*)] \qquad \text{(IV-7)}$$

D. Evaluation of the Model Parameters. The parameters necessary to evaluate the model are: the initial concentration of dissolved pollutant (C^*), the initial mixing time (t^*), dissolved pollutant concentration at equilibrium (C_e), the suspended-solids concentration (M), the adsorption-rate constant (K_1), and the desorption-rate constant (K_2).

An attempt was made to correlate initial filtered ammonia concentration with sediment ammonia and/or redox potential. The initial concentrations of the filtered ammonia and filtered COD appear to be correlated with the initial redox potential (redox potential at t = 0) of the sample. Figure IV-1 presents a plot of the initial ammonia concentration versus the corresponding initial redox potential. Figure IV-2 shows a similar plot of the initial filtered COD versus the initial redox potential. Only three experiments were performed, so the relationships in figures IV-1 through IV-4 are preliminary and somewhat speculative.

The initial concentrations of ammonia and COD also appear to be a function of their concentrations in the bulk sediments, which is not always the case for other pollutants. Plots of the initial ammonia concentrations versus sediment ammonia concentrations are presented in figure IV-3. Similar plots for COD are shown in figure IV-4. Although C^* is seen to be a complex function of the redox potential of the solution, the expression of C^* is assumed to be linear and of the form

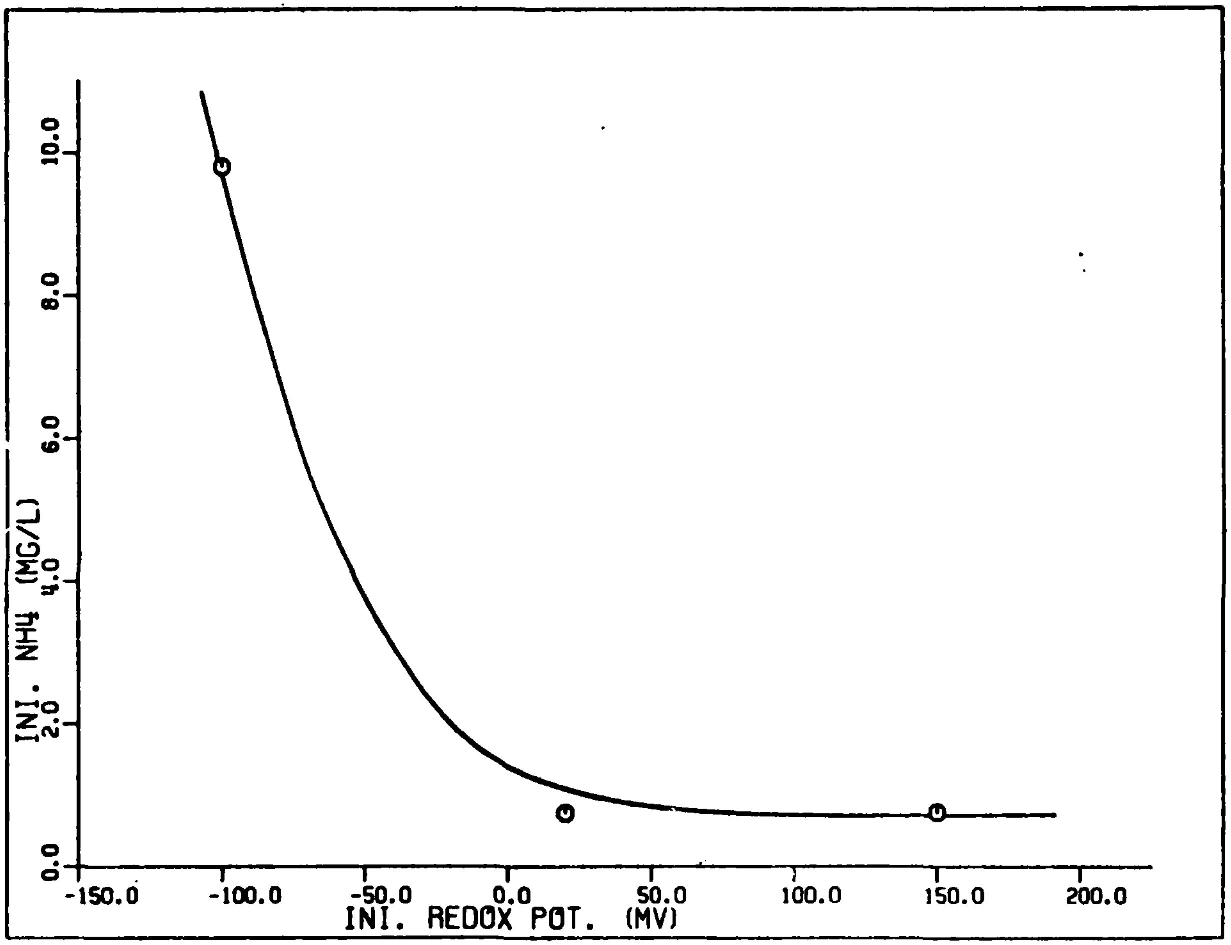


Figure IV-1 Initial Ammonia Concentration ($t^* = 0.1$ hrs) versus Initial Redox Potential ($t = 0$)

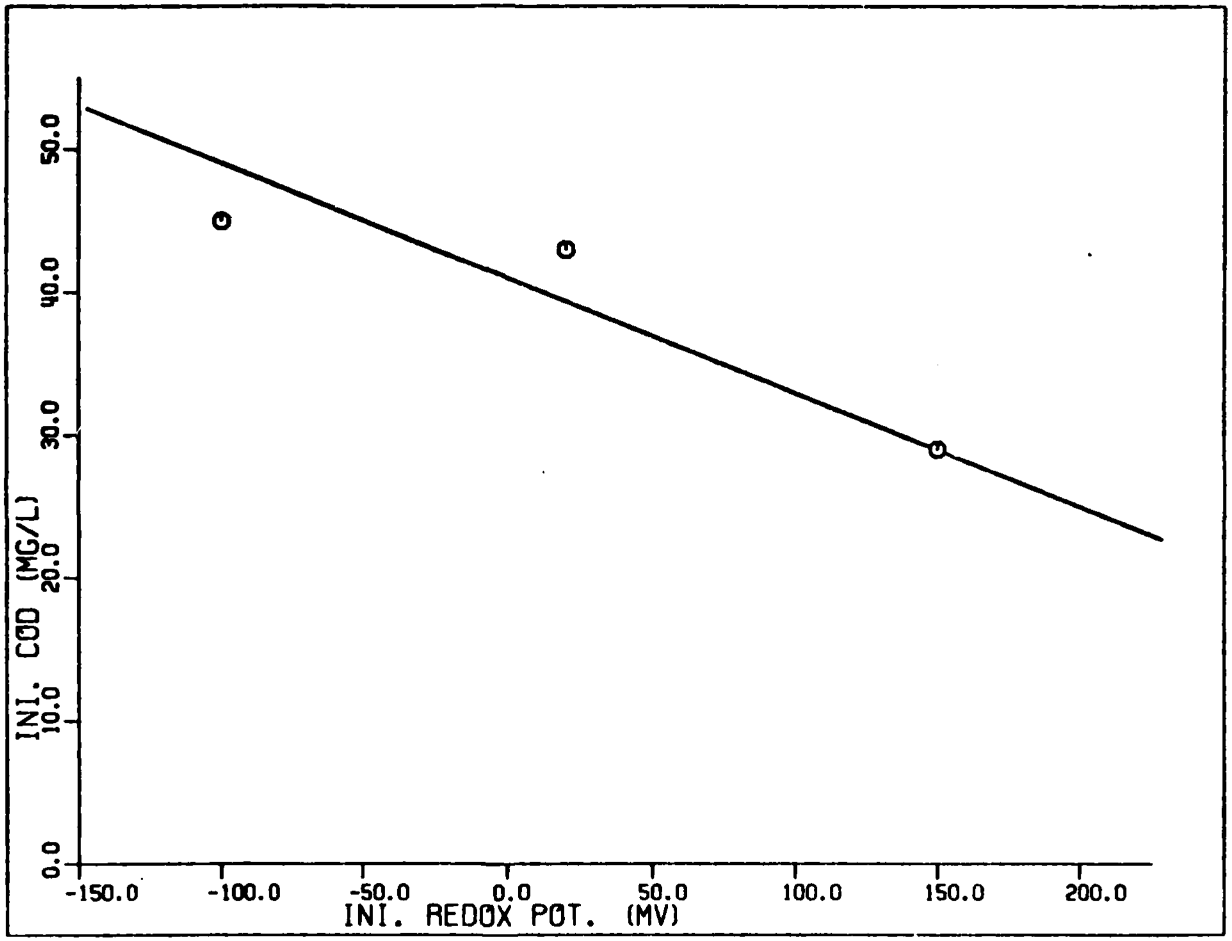


Figure IV-2 Initial COD (t^* = 0.1 hrs) versus Initial Redox Potential (t = 0)

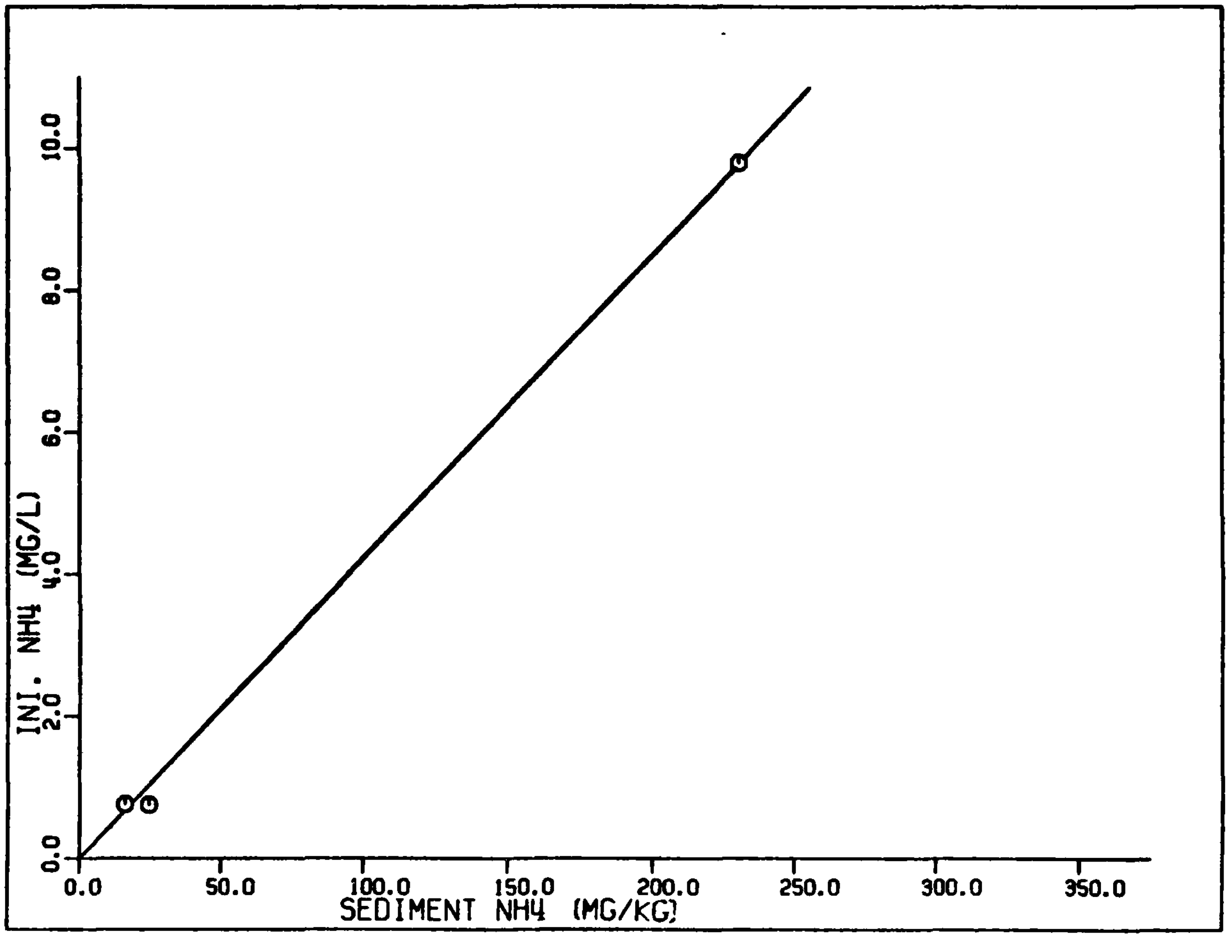


Figure IV-3 Initial Ammonia Concentration (t^* = 0.1 hrs) versus Sediment Ammonia Concentration

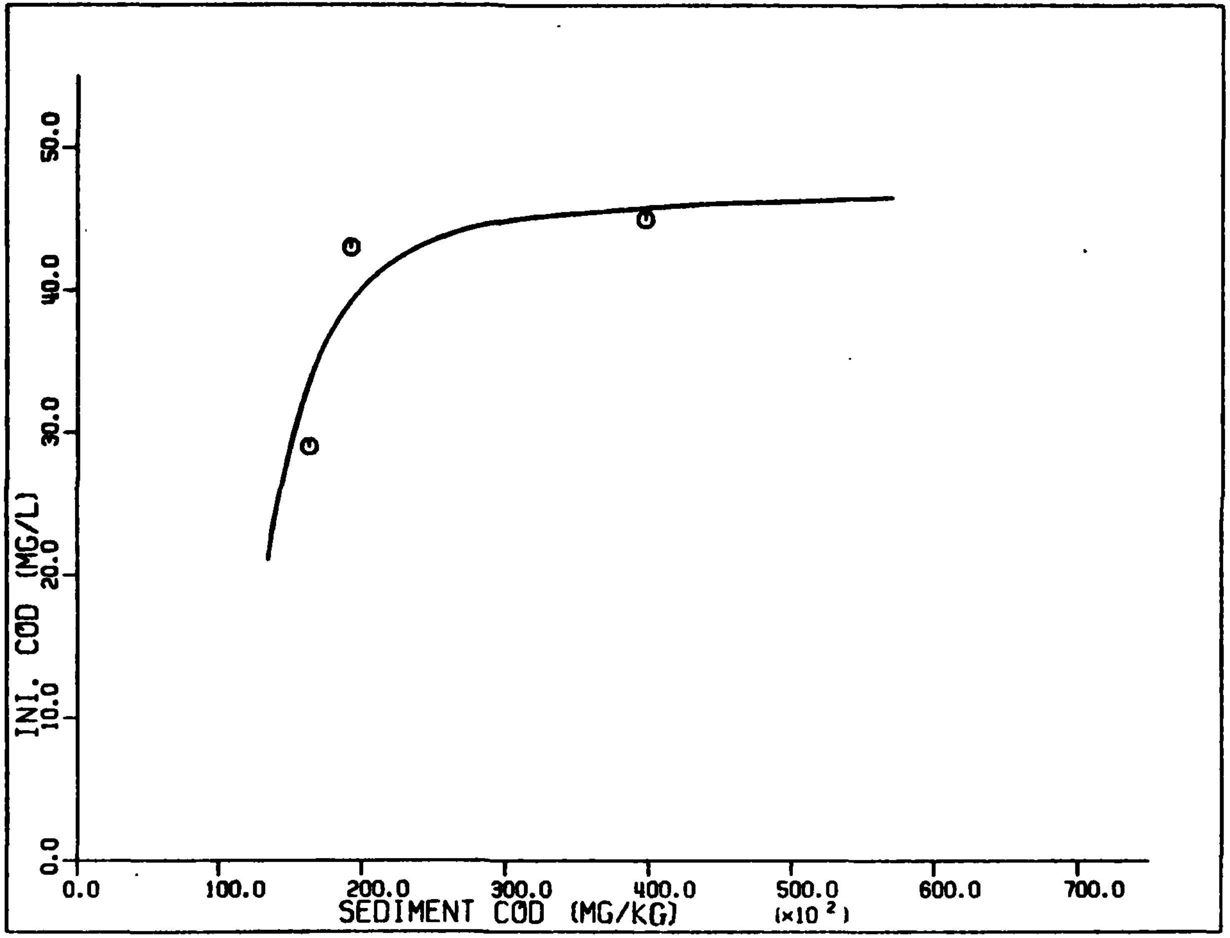


Figure IV-4 Initial COD (t^* = 0.1 hrs) versus Sediment COD

$$C^* = aZ + b \qquad \text{(IV-8)}$$

where C^* is the dependent variable (i.e., initial concentration of pollutant), Z is an independent variable, and a and b are constants. An attempt was made to correlate initial ammonia concentration with sediment ammonia and/or redox potential. Several chemical parameters were tried for z in (IV-8) including redox potential. The initial concentration of ammonia (C^*) possessed a high degree of linear correlation ($r > 0.99$) with $(NH_3)_s$, $(R')^{-1}$, $(R')^{-2}$, $(NH_3)_s (R')^{-1}$, and $(NH_3)_s (R')^{-2}$. A similar attempt was made for COD, where $R' = 101 + R$, R = redox potential (mV), and $(NH_3)_s$ = sediment ammonia concentration. A null value of 101 was added to the original data of redox potential to avoid negative values of redox potential. $(R')^2$ had the greatest linear correlation ($r = 0.99$) with the initial COD. The final expressions for C^* selected are:

$C^* = 9045. (R')^{-2} + 755.$ for ammonia, and
$C^* = 0.263 (R')^2 + 45803.$ for COD.

Note that these relations possess log power correlations, and the use of these equations may be limited in the redox potential range from -100 to 150 mV, and to the sediments and experimental conditions used in this study.

Approximations of the values of K_1, K_2, and C_e were initially performed using the nonlinear regression method (SAS, 1979). The calibration of the model was then accomplished by running a simulation and comparing the result to the corresponding experimental data. Determined values of K_1 and K_2 are 20.0 $(\mu g/l)^{-1}$ $(hour)^{-1}$ and 2.0 $(hour)^{-1}$ for ammonia, and 20.0 $(\mu g/l)^{-1}$ $(hour)^{-1}$ and 5.0 $(hour)^{-1}$ for COD, respectively. A summary of the values for the kinetic model parameters is shown in table IV-1.

E. Results and Discussion. Tables IV-2, 3, and 4 summarize the results of the chemical analyses of each experiment. Since the sample collected on November 20, 1981, showed little sorption of the chemical pollutants during elutriation (table IV-5), the data were not used for the model simulation.

Figures IV-5 through IV-7 are plots of ammonia concentrations versus time which show both the experimental and computed results for the three samples,

Table IV-1. A Summary of the Values for the Kinetic Model Parameters

Sample	Pollutants	M (kg/l)	t^* (hour)	C^* (μg/l)	C_e (μg/l)	k_1 $(kg/l)^{-1}(hour)^{-1}$	k_2 $(hour)^{-1}$
RM 170-2	NH_3-N	0.003	0.1	750	933	10	2
	COD	0.003	0.1	43000	33000	10	5
RM 172-1	NH_3-N	0.003	0.1	9800	7600	10	2
	COD	0.003	0.1	45000	31000	10	5
RM 172-2	NH_3-N	0.0004	0.1	760	600	10	2
	COD	0.0004	0.1	29000	22000	10	5

Table IV-2. Results of the Kinetic Study (Site 170-2)

	NH_3(mg/l)	COD(mg/l)	Redox Potential (mV)	pH
sediment *	24.5	19200	-40	7.89
raw water	.24	18	+220	
elutriate blank	.24	10		
Time (hours				
0	.82	48	+20	7.68
0.1	.75	43	+10	7.75
0.2	.82	28	+90	7.74
0.3	.85	29	+130	7.84
0.5	.88	42	+180	7.93
1	.94	35	+190	8.05
2	.92	37	+220	8.16
4	.88	34	+180	8.23
6	1.0	31	+205	8.23
12	.92	33	+220	8.23

*mg/kg dry weight
suspended solids 3000 mg/l

Table IV-3. Results of the Kinetic Study (Site 172-1)

	NH_3(mg/l)	COD(mg/l)	Redox Potential (mV)	pH
sediment*	230	39700	-130	
raw water	.19	18	+180	8.02
elutriate blank	.22	12		
time (hours)				
0	8.3	71	-100	7.18
0.1	9.8	45	+30	7.20
0.2	9.3	43	+140	7.19
0.3	8.8	33	+190	7.33
0.5	8.7	29	+210	7.69
1	8.0	38	+210	7.70
2	8.0	34	+215	7.84
4	7.5	34	+220	7.86
6	7.1	29	+240	7.94
12	7.9	29	+240	7.94

*mg/kg dry weight

suspended solids 3000 mg/l

Table IV-4. Results of the Kinetic Study (Site 172-2)

	NH_3(mg/l)	COD(mg/l)	Redox Potential (mV)	pH
sediment*	16	16300	+175	
raw water	.21	29	+210	8.25
elutriate blank	.10	29		
time (hours)				
0	0.70	26	+150	7.98
0.1	0.76	29	+190	8.10
0.2	0.70	24	+200	8.21
0.3	0.73	27	+205	8.30
0.5	0.68	26	+210	8.37
1	0.65	22	+210	8.36
2	0.64	22	+210	8.50
4	0.66	21	+210	8.64
6	--	--	+210	8.48
12	0.56	23	+210	8.47

*mg/kg dry weight
suspended solids 400 mg/l

Table IV-5. Results of the Kinetic Study (Site 170*)

	NH_3-N	COD	Chromium	Nickel	Manganese	Redox Potential	pH
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mV)	
Sediment*	5	540,000	2.0	<9.8	52		
Raw Water	0.02	33	<0.01	<0.1	0.21		
Elutriate Blank			<0.01	<0.1	<0.01		
Time (hours)							
0	0.03	38	<0.01	<0.1	0.02	+275	8.08
0.1	0.01	32	<0.01	<0.1	<0.01	+275	8.08
0.2	0.01	36	<0.01	<0.1	<0.01	+275	8.08
0.3	0.01	51	<0.01	<0.1	0.02	+275	8.08
0.5	0.01	50	<0.01	<0.1	0.01	+265	8.05
1	0.03	45	<0.01	<0.1	0.01	+255	8.05
2	0.05	51	<0.01	<0.1	0.01	+250	8.05
4	0.13	51	<0.01	<0.1	0.01	+250	8.26
6	<0.01	59	<0.01	<0.1	0.01	+245	8.28
12	0.02	42	<0.01	<0.1	0.02	+240	8.38

*mg/kg dry weight
suspended solids 400 mg/l

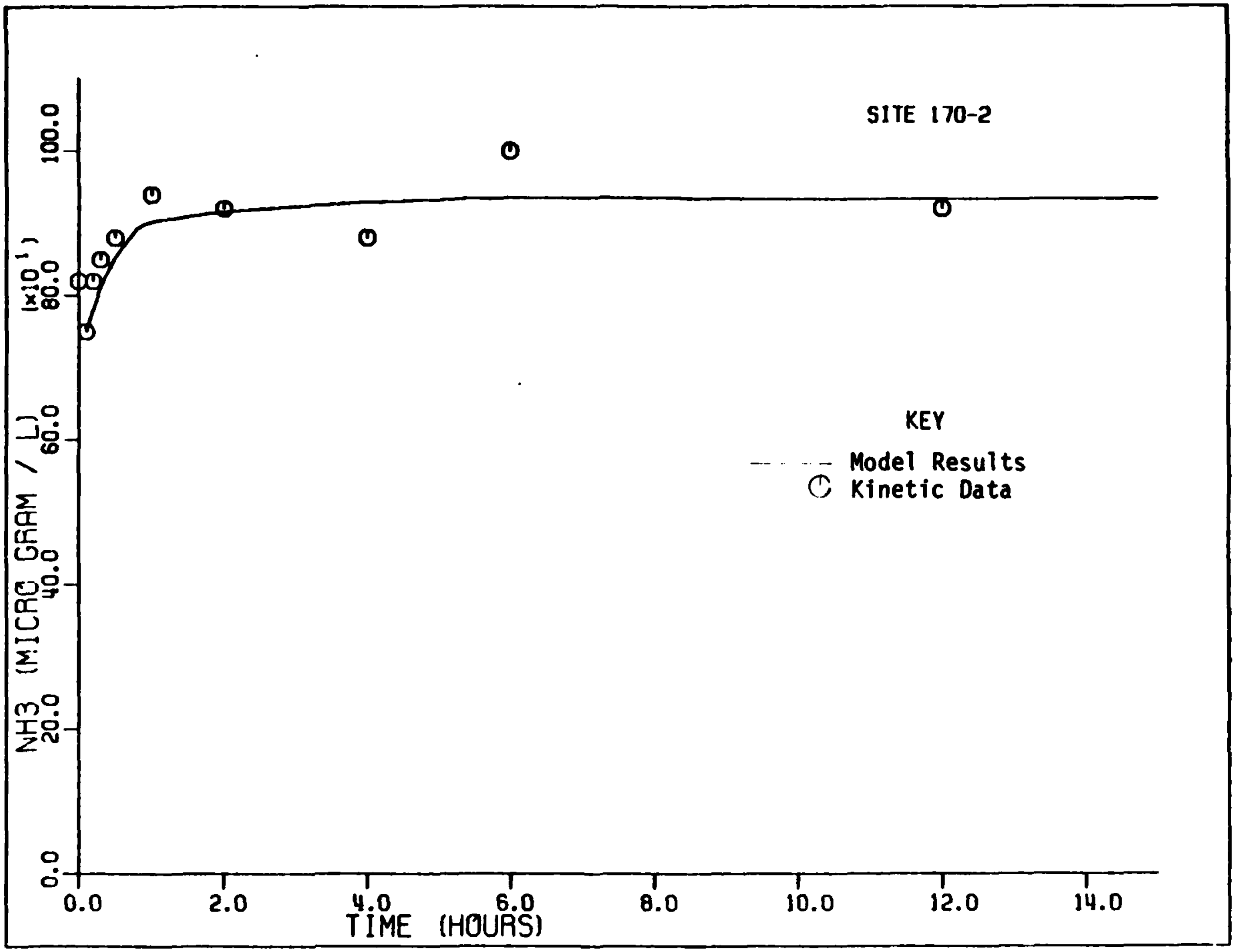


Figure IV-5 Dissolved Ammonia Concentration versus Time (Site 170-2)

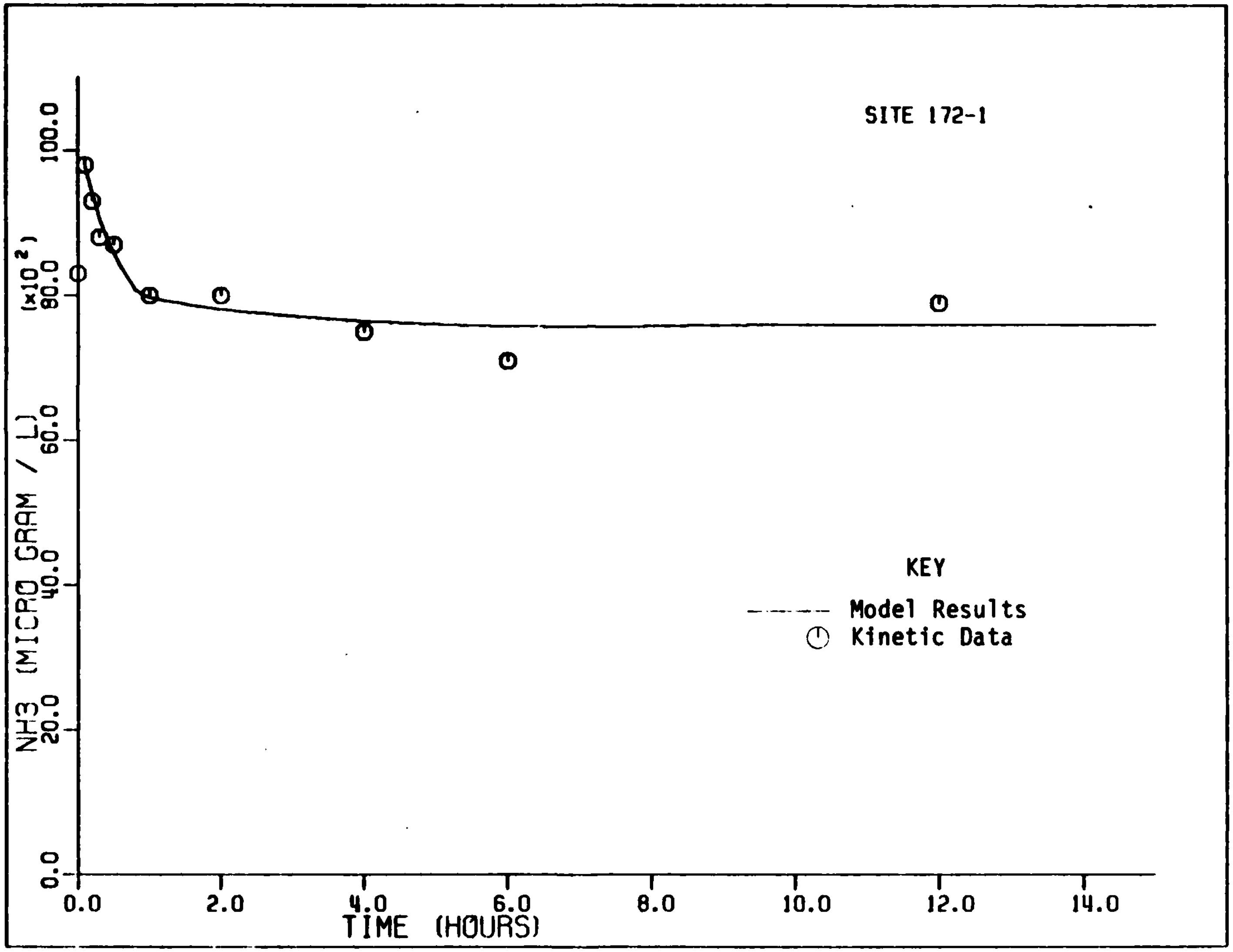


Figure IV-6 Dissolved Ammonia Concentration versus Time (Site 172-1)

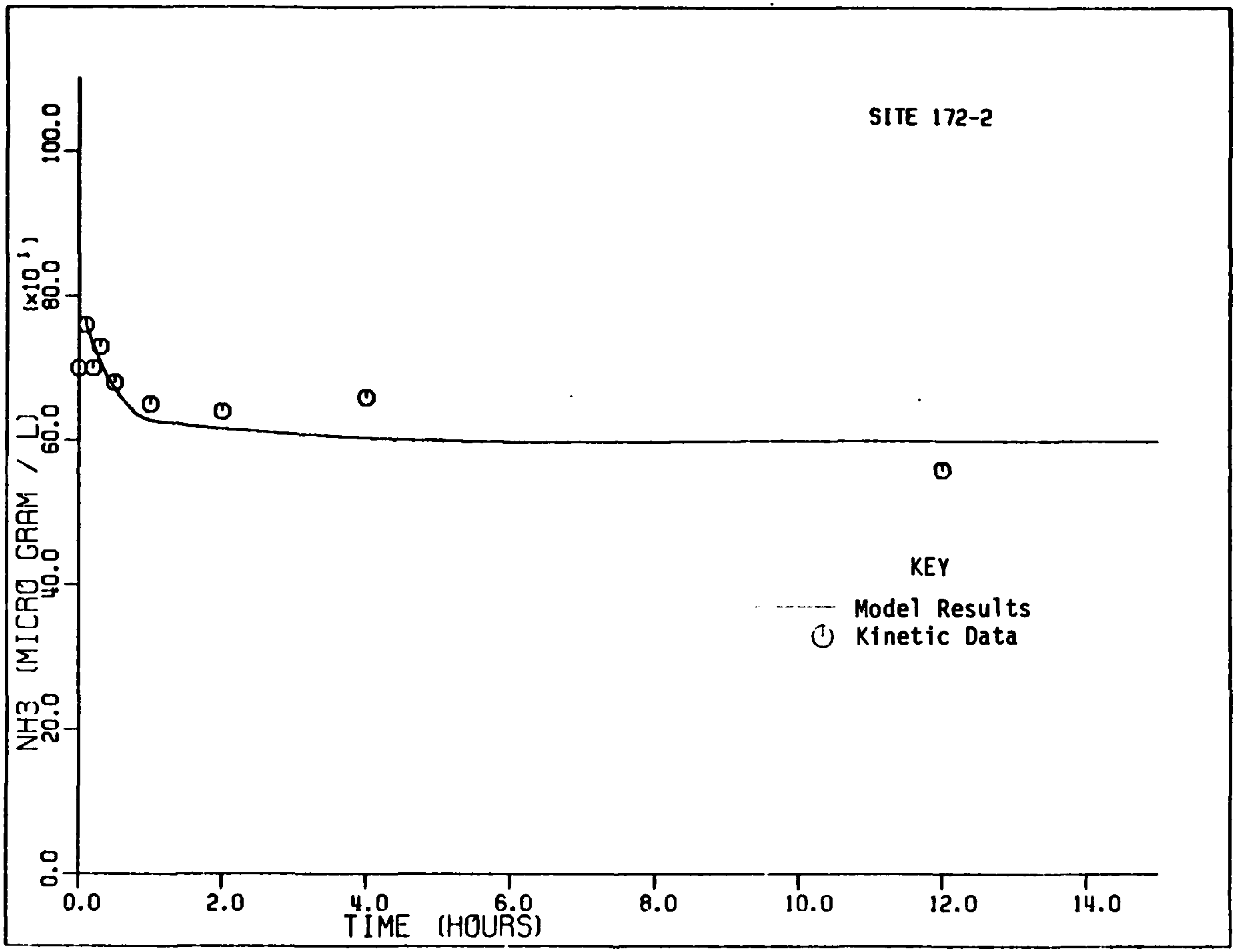


Figure IV-7 Dissolved Ammonia Concentration versus Time (Site 172-2)

170-2, 172-1, and 172-2, respectively. Plots of COD are shown in figures IV-8 through IV-10. As can be seen, the model closely approximates the experimental data obtained in the kinetic experiments. An immediate increase in ammonia and COD occurred within the first six minutes of mixing time. The concentrations of the pollutants at the time of six minutes was defined as the initial concentration of pollutants. The concentrations of pollutants were not constant, but generally decreased as the experiment progressed (an exception was the ammonia of sample 170-2). The reduction of the concentrations of the pollutants was presumably due to re-adsorption which may be explained by the increasing redox potential with time. The change in redox potential can be expressed simply as a function of time.

$$R = R_o + R_u \; (1.0 - \exp\; (-K_r t))$$

where

R = redox potential at time t, mV,
R_o = redox potential at t = 0, mV,
R_u = redox potential at equilibrium, mV,
k_r = rate constant, hour^{-1},

For example, in the study using sample RM 172-1, R_o was found to be -100 mV. R_u and K_r were determined using a nonlinear regression method (SAS, 1979) and found to be 326.6 mV and 6.18 hour^{-1}, respectively. The plots of the variation of redox potential with time obtained from the experiment are presented, along with the computed values, in figure IV-11. As can be seen from the results, a rapid increase in redox potential occurred within 30 minutes, and thus the results are in accord with the adsorption and desorption trends of the pollutants. It should be noted that according to the kinetic models about 86 percent of the concentration change was complete within 30 minutes and 99.9 percent within 90 minutes, while about 55 percent of the ammonia concentration change is complete within [illegible] minutes and 94 percent within 90 minutes.

F. Summary. The kinetic studies were very helpful in understanding the standard elutriate test. Basically the following stages occur:

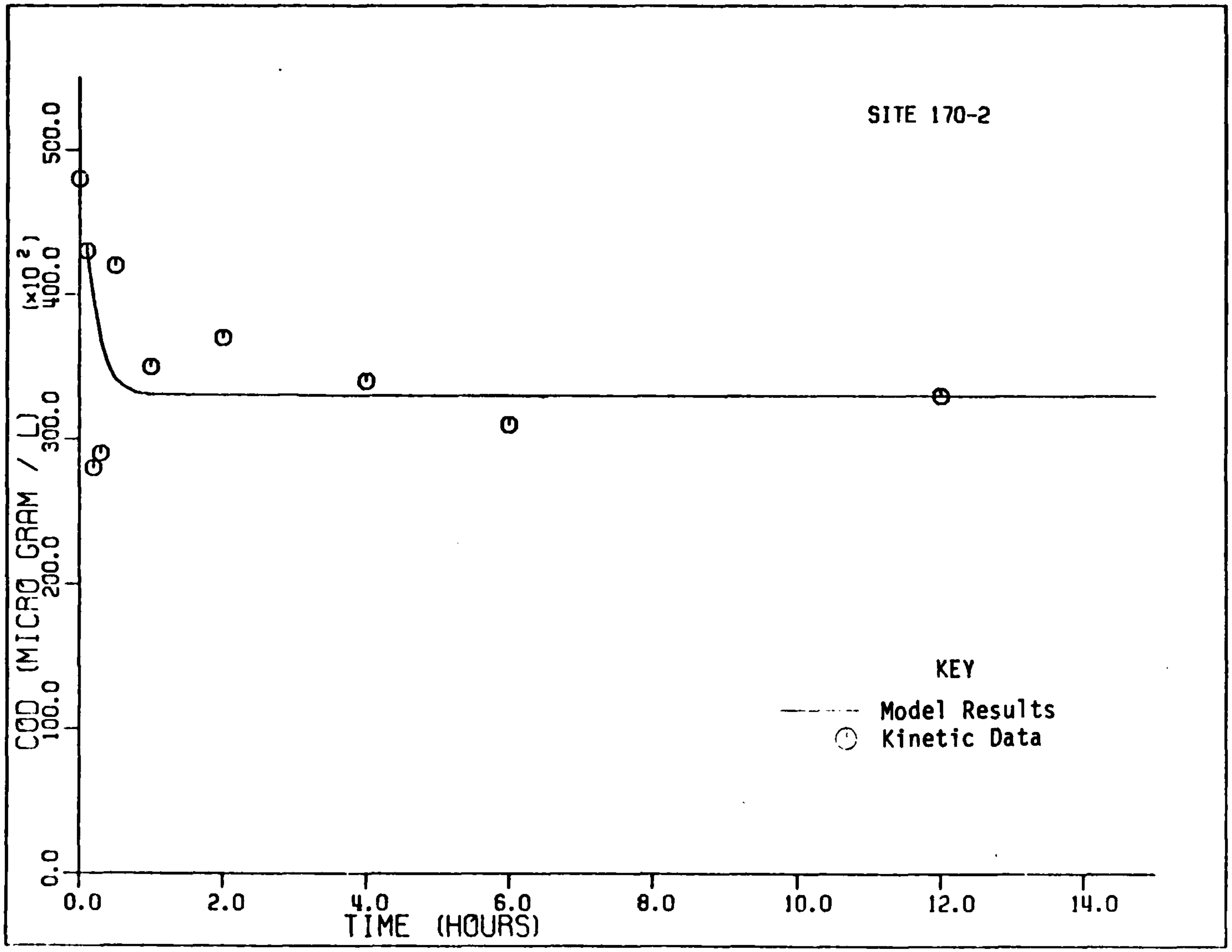


Figure IV-8 Dissolved COD versus Time (Site 170-2)

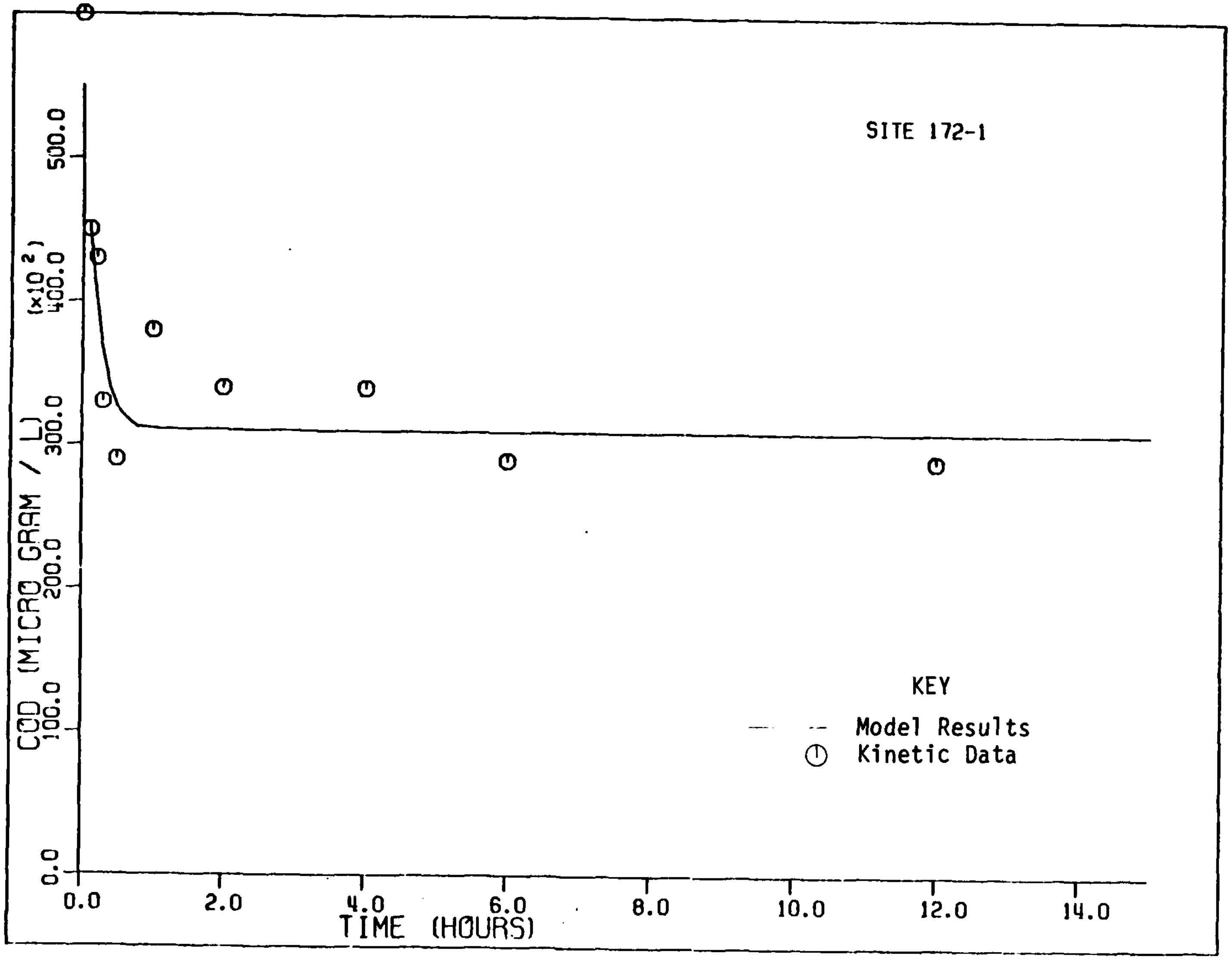


Figure IV-9 Dissolved COD versus Time (Site 172-1)

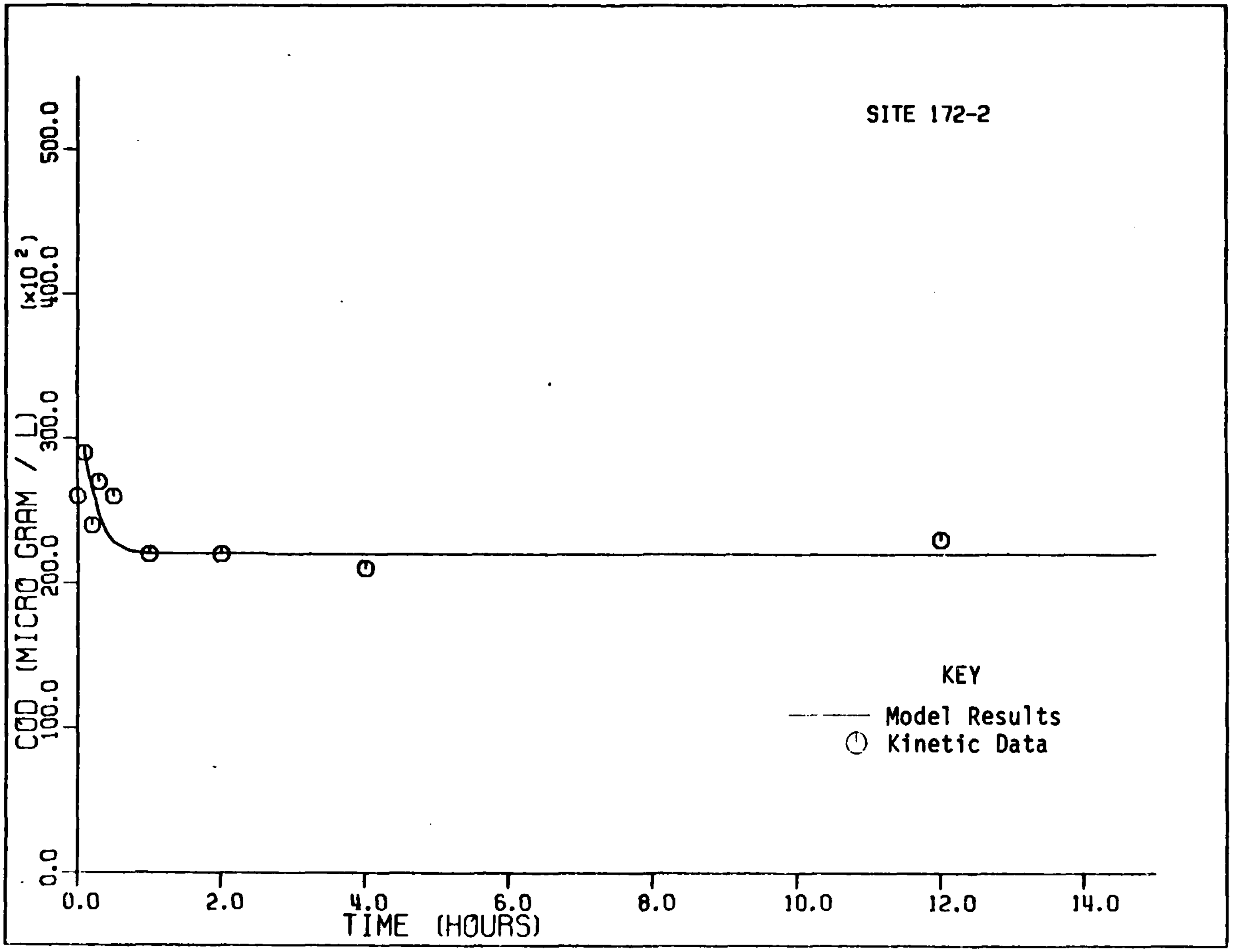


Figure IV-10 Dissolved COD versus Time (Site 172-2)

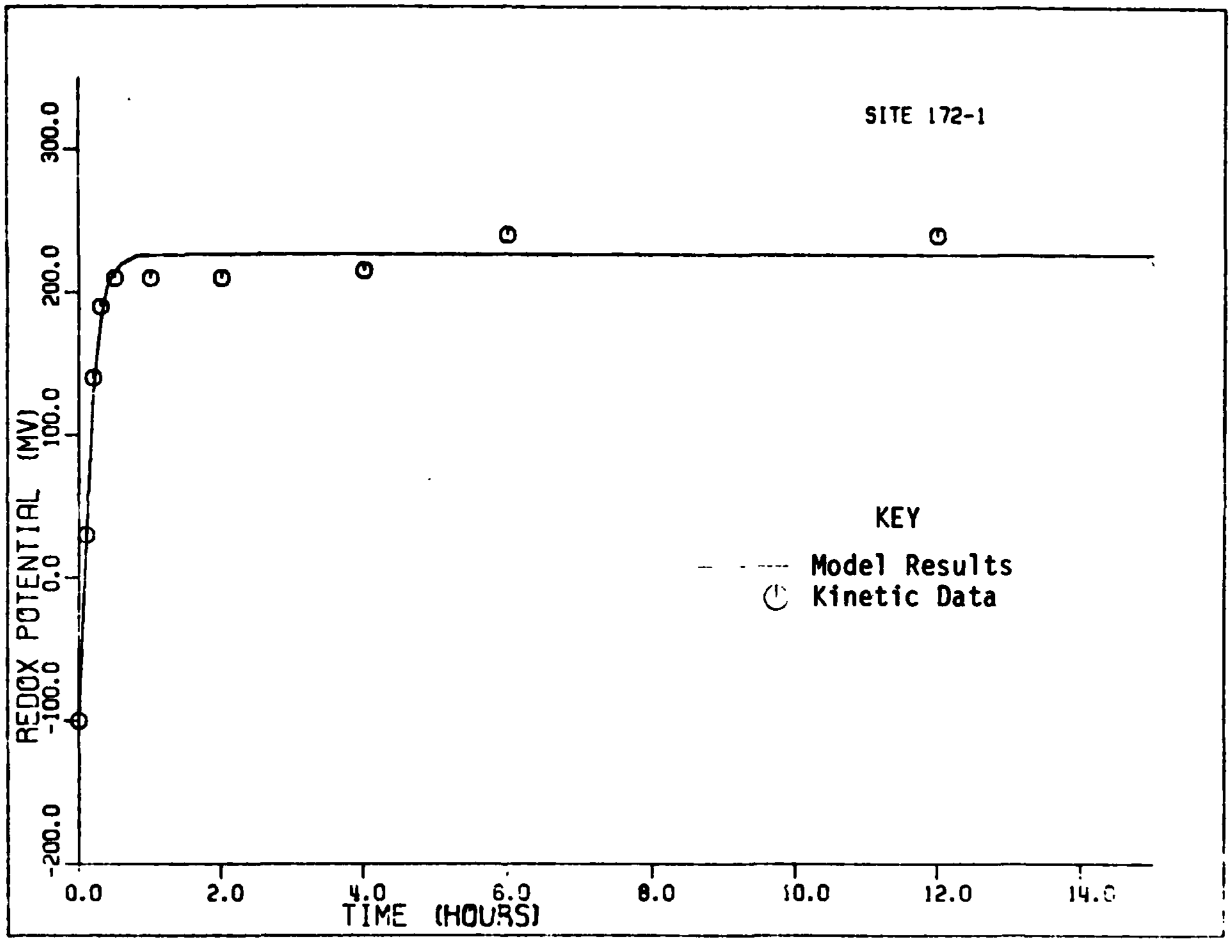


Figure IV-11 Change in Redox Potential with Time (Site 172-1)

INITIAL CONDITION

1). Reduced chemicals such as dissolved manganese (Mn^{+2}) and ammonium ion (NH_4+) and organics (measured partly as COD) are rich in the intersticial waters of the sediment sample.

INITIAL MIXING

2). Within the first few minutes of mixing (six minutes according to the mathematical model) the intersticial waters are diluted by the river water in the elutriate test. Further desorption from the mixed sediments occurs during this stage. The redox potential of the elutriate mixture increases from negative to positive.

ADSORPTION/DESORPTION

3). If the kinetics of desorption and mixing are fast enough, the eluted chemicals may "overshoot" their final equilibrium value and subsequently readsorb during the period from six minutes to 30-90 minutes in the elutriate test. After 90 minutes, sorptive equilibrium is essentially complete.

EQUILIBRIUM

4). Sorptive equilibrium is established after two hours. Any further changes would likely be caused by other mechanisms. In the Mississippi River, gas transfer or biodegradation could ultimately reduce the concentration in the water.

Mathematical modelling of the desorption kinetics aided in the interpretation of the results. However, it is still not possible to predict _a priori_ the initial elutriate concentration, C^*, or the final elutriate concentration, C_e. While the elutriate test does not exactly reflect the many environmental variables of the dredging operation and disposal (e.g., mixing intensity, sediment: water ratio, temperature, redox potential), it is a useful laboratory procedure to screen for potential problem areas. We know that organic sediments will have the following characteristics: a high moisture content (>25%), a low percent total solids, a high volatile solids content, a fine median grain size, and a dark color. These bed sediments generally occur in areas of slowly moving water, and the redox potential is perhaps the best indicator of the NH_3, Mn, and COD that will adsorb in the standard elutriate test.

G. References

SAS Institute, SAS User's Guide, 1979, SAS Institute Inc., P.O. Box 10066, Raleigh, North Carolina 27605.

V. CHEMICAL PLUME MODEL

Channel maintenance dredging operations in conjunction with the large-scale disposal of dredged material can promote a release of associated contaminants. A goal of this chapter is to develop a chemical plume model and to examine the extent and intensity of the plume of dissolved and particle-associated chemical contaminants.

A. Description of Sampling Site and Sampling Procedures. A sampling trip was made on 20 November 1981. The dredge disposal site was located at RM 170, several hundred meters upstream from a series of wing dams and a barge docking area on the Illinois shore of the Mississippi River. The sampling effort involved gathering sediment-laden water samples for analysis of suspended solids and the chemical pollutants of interest. The water samples were also used for the fall velocity analysis, and bed-sediment samples for grain-size distribution analysis. These data all serve as input parameters for the proposed computer model.

The site layout and sampling procedures were described in chapter II. Analytical procedures were described in chapter III.

B. Model Development. The concentration of pollutant in the water column may be expressed by the following differential equation.

$$\frac{\partial C_T}{\partial t} = -u_i \frac{\partial C_T}{\partial x_i} + \frac{\partial}{\partial x_i}\left(E_i \frac{\partial C_T}{\partial x_i}\right) \pm R \tag{V-1}$$

$$\begin{array}{l} \text{Rate of Change} \\ \text{in Chemical} \\ \text{Concentration} \end{array} = \begin{array}{l} \text{Rate of Change} \\ \text{in Chemical} \\ \text{Concentration} \\ \text{due to} \\ \text{Convection} \end{array} + \begin{array}{l} \text{Rate of Change} \\ \text{in Chemical} \\ \text{Concentration} \\ \text{due to} \\ \text{Diffusion} \end{array} \pm \begin{array}{l} \text{Rate of Change} \\ \text{of Chemical} \\ \text{Concentration} \\ \text{due to Reactions} \end{array} \tag{V-2}$$

where C_T refers to the total concentration (mass per unit volume) of pollutant present in both solid and liquid phases; u_i refers to the fluid velocity in a rectangular coordinate system, x_i; E_i refers to the eddy diffusion coefficient in the i'th direction; and R refers to the sum of the relevent reaction rates of the pollutant. The reactions may include photolysis, hydrolysis, oxidation, volatilization, and biodegradation. The rates of the above reactions were assumed to be either first order or pseudo-first order. Considering the above reaction rates, (V-1) can be written as:

$$\frac{\partial C_T}{\partial t} = -u_x \frac{\partial C_T}{\partial x} - u_y \frac{\partial C_T}{\partial y} - u_z \frac{\partial C_T}{\partial z} + \frac{\partial}{\partial x}\left(E_x \frac{\partial C_T}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_y \frac{\partial C_T}{\partial y}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial C_T}{\partial z}\right) - KC_T \qquad \text{(V-3)}$$

where K refers to the sum of the reaction rates of the above reactions, and x, y, and z refer to the longitudinal, vertical, and lateral directions, respectively. The initial assumptions are:

1). The chemical pollutant concentration, C_T, can be described by a vertically averaged pollutant concentration,

$$C_T = \frac{1}{D} \int_0^D C_i dy$$

where D refers to the depth of the water column and y is vertical distance in the Cartesian coordinate system, x, y, z;

2). The eddy diffusivities in the x and z directions, E_x and E_z, are independent of depth;

3). The fluid velocity in the x and z directions, u_x and u_z, are depth independent; and

4). The pollutant transport rates due to vertical diffusion and vertical fluid velocity currents are much slower than the rates of sorption.

The resulting equation is:

$$\frac{\partial C_T}{\partial t} = -u_x \frac{\partial C_T}{\partial x} - u_z \frac{\partial C_T}{\partial z} + \frac{\partial}{\partial x}\left(E_x \frac{\partial C_T}{\partial x}\right) + \frac{\partial}{\partial z}\left(E_z \frac{\partial C_T}{\partial z}\right) - KC_T \qquad (V\text{-}4)$$

The total concentration of chemical pollutant in the bulk water, C_T, is the sum of the concentrations in the particulate and dissolved phases.

$$C_T = C + C_p \qquad (V\text{-}5)$$

where C refers to the dissolved pollutant concentration, and C_p refers to the adsorbed pollutant concentration. C_p is related to the concentration of suspended solids, M, and is defined as

$$C_p = rM \qquad (V\text{-}6)$$

where r refers to the amount of pollutant adsorbed per unit mass of dry sediment. At a low pollutant level in the dissolved phase, linearity of the Langmuir isotherm may be assumed, and C may be given by

$$C = r/K_p \qquad (V\text{-}7)$$

where K_p refers to the linear adsorption partitioning coefficient. Adsorption and desorption rates are orders of magnitude greater than the rates of the decay and transport processes considered, and instantaneous sorptive equilibrium is achieved between the two phases very rapidly in comparison with sedimentation, volatilization, photolysis, hydrolysis, oxidation, and biological degradation. Therefore, C and C_p may be replaced by their equivalents in terms of C_T. Incorporating (V-6) and (V-7) into (V-5) and expressing C and C_p in terms of C_T under the conditions of sorptive equilibrium in which the concentration of suspended solids, M, is known,

$$C = \frac{C_T}{1 + K_p M} \qquad (V\text{-}8)$$

$$C_p = \frac{K_p M C_T}{1 + K_p M} \qquad (V\text{-}9)$$

It is surmised that the reactions of photolysis, volatilization, oxidation, and biodegradation occur in the dissolved phase, and that the removal of adsorbed chemical pollutants is controlled by sedimentation of suspended solids. Thus, KC_T can be described by

$$KC_T = K_s C_p + kC \tag{V-10}$$

where K_s is the chemical pollutant removal rate due to sedimentation of suspended solids, and k refers to the sum of all decay-reaction rates of dissolved chemicals. Substitution of (V-8) and (V-9) into (V-10) gives

$$KC_T = \left(\frac{K_{sj} K_{pj} M_j + k}{1 + K_{pj} M_j}\right) C_T \tag{V-11}$$

where M_j refers to the concentration of the j-size fractions of suspended solids; K_{sj} and K_{pj} are the constants corresponding to M_j. The concentrations of the suspended sediment may fall into three size fractions; M_1, M_2, and M_3 which refer to sand, silt, and clay, respectively. Substituting (V-11) for KC_T into (V-4) gives the differential equation:

$$\frac{\partial C_T}{\partial t} = -u_x \frac{\partial C_T}{\partial x} - u_z \frac{\partial C_T}{\partial z} + \frac{\partial}{\partial x}\left(E_z \frac{\partial C_T}{\partial z}\right) - \left(\frac{K_{s1}K_{p1}M_1 + K_{s2}K_{p2}M_2 + K_{s3}K_{p3}M_3 + k}{1 + K_{p1}M_1 + K_{p2}M_2 + K_{p3}M_3}\right) C_T \tag{V-12}$$

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

u_x = constant,
$u_z = 0.$,
D = constant,
E_z = constant,
$E_x \ll E_z$, so $\frac{\partial}{\partial x}\left(E_x \frac{\partial C_t}{\partial x}\right) = 0$

Incorporating these assumptions and assuming steady state, $DC_T/Dt = 0$, Equation (V-12) can be written in the form

$$\frac{\partial C_T}{\partial x} = \frac{E_z}{u_x} \frac{\partial^2 C_T}{\partial z^2} - \left(\frac{K_{s1}K_{p1}M_1 + K_{s2}K_{p2}M_2 + K_{s3}K_{p3}M_3 + k}{1 + K_{p1}M_1 + K_{p2}M_2 + K_{p3}M_3}\right)\left(\frac{C_T}{u_x}\right) \tag{V-13}$$

The solution to (V-13) at a given constant M_j can be written (Sayre, 1979) as:

$$C_T(z,x) =$$

$$C_T^{'}(z,x) \exp -\left(\frac{k_{s1}k_{p1}M1 + K_{s2}K_{p2}M_2 + K_{s3}K_{p3}M_3 + k}{1 + K_{p1}M_1 + K_{p2}M_2 + K_{p3}M_3}\right) \frac{x}{u_x} \qquad \text{(V-14)}$$

where C'(z,x) is the solution of the diffusion equation:

$$\frac{\partial C_T}{\partial x} = \frac{E_z}{u_x} \frac{\partial^2 C_T}{\partial y^2} \qquad \text{(V-15)}$$

For the case of a continuous point source of flow, Q_0, and chemical concentration, C_0, the solution of (V-15) is (Sayre, 1973):

$$C_T^{'}(z,x) = \frac{Q_oC_o}{u_xD} \frac{1}{2\sqrt{\pi E_z \frac{x}{u_x}}} \exp \left[\frac{-z^2u_x}{4E_zx}\right] \qquad \text{(V-16)}$$

This equation has the form of a normal probability function with variance, $\sigma_z^2 = 2E_z \frac{x}{u_x}$.

Substituting this relationship into (V-16) gives:

$$C_T^{'}\,(z,x) = \frac{Q_oC_o}{u_xD} \frac{1}{\sqrt{2\pi}\,\sigma_z} \exp \left[- \frac{z^2}{2\sigma_z^2}\right] \qquad \text{(V-17)}$$

Equation (V-17) describes the plume resulting from a continuous point source. The mode of dredge disposal which will be discussed later, can be better described by a line souce of width, b, perpendicular to the streamline. Equation (V-17) can be modified to describe a line source by the method used by Sayre (1973, 1979). The resulting expression is:

$$C_T^{'}(z,x) = \int_0^B C'(z',0) \frac{1}{\sqrt{2\pi}\,\sigma_z} \exp \left[- \frac{(z-z')^2}{2\sigma_z^2}\right] dz' \qquad \text{(V-18)}$$

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

$$C'(z',0) = \frac{Q_oC_o}{Q_b} \qquad 0 < z' < b$$

$$C'(z',0) = 0 \qquad b < z' < B \tag{V-19}$$

where $Q_b = u_xD_b$ is the portion of the river flow passing through the source width, b. Incorporating these into (V-18) and substituting the standard normalized variable $s = z - z'/\sigma_z$ gives

$$C'(z,x) = \frac{Q_0C_0}{Q_b} \frac{1}{\sqrt{2\pi}} \int_{\frac{z-b}{\sigma_z}}^{\frac{z}{\sigma_z}} \exp-(\frac{s^2}{2} ds) \tag{V-20}$$

which is in the form of the cumulative normal distribution function. The solution of (V-20) is

$$C_T'(z,x) = \frac{Q_oC_o}{Q_b} (F(\frac{z}{\sigma_z}) - F(\frac{z-b}{\sigma_z})) \tag{V-21}$$

where the value of F(*) can be obtained from a cumulative normal distribution table or computed by the following equations (Kennedy and Gentle, 1980).

$$F(*) = \begin{cases} 1 + \mathrm{erf}(\frac{*}{2^{1/2}}) & , \quad * > 0 \\ \frac{\mathrm{erfc}\ (\frac{*}{2^{1/2}})}{2} & , \quad * < 0 \end{cases}$$

The suspended-solids plume described by (V-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;

$$C_T'(z,x) = (\frac{Q_oC_o}{Q_b} \quad F(\frac{z + b}{\sigma_z}) - F(\frac{z - b}{\sigma_z})) \tag{V-22}$$

This equation is not applicable if the suspended solids plume disperses in the lateral direction enough to reflect from the far shoreline. Substituting (V-22) into (V-14) gives the final solution,

$$C_T(z,x) = \frac{Q_o C_o}{Q_b} \left(F\left(\frac{z + b}{\sigma_z}\right) - F\left(\frac{z - b}{\sigma_z}\right)\right)$$

$$\exp -\left(\frac{K_{s1}K_{p1}M_1 + K_{s2}K_{p2}M_2 + K_{s3}K_{p3}M_3 + k}{1 + K_{p1}M_1 + K_{p2}M_2 + K_{p3}M_3}\right)\frac{x}{u_x} \qquad \text{(V-23)}$$

Equation (V-23) can be solved simultaneously with the suspended-solids-plume equation proposed by Schnoor et al. (1980).

C. Results and Discussions. The plumes of dissolved and particulate-associated chemical pollutant are described by the simultaneous computation of two fields at a grid point of the system under consideration: a field where the suspended-solids concentration is described by a processes of convection, dispersion, and settling, and a field where the concentration of a chemical pollutant is described by processes of adsorption-desorption equilibrium and pollutant reactions. The process of the first field is translated into a change in the distribution of suspended solids, which is related to the chemical concentrations in the second field.

1. Evaluation of the Model Parameters. The behavior of the river is the result of interaction between the flow, the quantity and characters of the sediment discharge, the local topography, and local soil and geological conditions (Shen,1979). Because of the extremely complicated behavior of the river, techniques for modeling invariably involve some averaging processes. Some of the parameter values are directly determined in the field measurements, while others are estimated by calibrations of the model. The model simulate a chemical plume developed during the dredging operation at site RM 170 on 20 Nov. 1981.

   a). Mean Depth of the Plume, D. The plumes resulting from dredging operations are gererally developed in a near-shore area where the depth varies considerably. Since the model assumes a constant depth, depths were measured at several locations in the area of the plume. An average depth of 4 meters was used in the model.

b). Mean Stream Velocity, u_x. The stream velocity varies not only with location but also with depth. Therefore, the velocity profiles in the immediate vicinity of the plume are very useful to determine the mean velocity. A representative velocity of 0.08 m/sec was used for the model simulation.

c). Dispersion Coefficient, E_z. The dispersive term includes molecular diffusion, turbulent diffusion, and mixing. The dispersion coefficient lumps together all these effects. A velocity of greater than 3.0 ft/sec at the disposal site at the surface created a great deal of turbulence and large eddies. These factors are contained in the overall dispersion coefficient. Allowing for all these effects, a value $E_z = 25\ m^2/sec$ was chosen.

d). Width of the Plume Source, b. The width of the plume source is a function of the discharge, velocity, flow direction, and momentum of the dredge effluent. The mode of discharge of dredged material is so designed that the spoil slurry, carried through the discharge pipe, hits a deflector plate, splashes, and falls through several meters before it hits the water surface. The plume resulting from this mode of disposal operation would be expected to have a wider plume source than a plume resulting from side bank disposal. Considering the high-velocity discharge in the lateral direction, a plume width of 130 meters was chosen.

e). Background Suspended Solids and Chemical Concentrations. The ambient suspended-solids concentration at the site was 84 mg/l. The ambient concentrations of chemicals were: 0.03 mg/l for ammonia-nitrogen, 31 mg/l for COD, and 0.16 mg/l for manganese. Variations between ambient site-water concentrations were ± 0.002 mg/l for NH_3-N, ±4 mg/l for COD, and ± 0.04 mg/l for PO_4- P. Since the phosphorus concentration was measured as filtrable phosphorus, a total phosphorus concentration of 0.6 mg/l was assumed based on the partitioning coefficients of 13.0 for sand, 130.0 for silt, and 1300.0 $(\mu g/kg)(\mu g/l)^{-1}$ for clay. The concentrations of zinc, copper, chromium, and lead were reported as less than (<) 0.001 mg/l and the concentration of nickel as < 0.1 mg/l. An assumed concentration of 0.005 mg/l was used for all these trace metals.

The model involves three size fractions; sand, silt, and clay. The proportion of each fraction was determined from the size-analysis results. The composition of the background suspended solids was approximately 0 percent sand, 50 percent silt, and 50 percent clay. It was assumed that no background suspended solids are subject to settling within the plume, a relatively short period.

f). Initial Suspended Solids and Chemical Concentrations above Ambient. The initial concentration above ambient can be calculated by

$$C_{in} = Q_o(C_o - C_a)/(Q_o + Q)$$

where Q_o = flow discharge,

Q = receiving water flow rate,

C_o = discharge concentration of suspended solids or chemical pollutant,

C_a = ambient concentration of suspended solids or chemical pollutant.

Because of the high velocity and turbulent river conditions, it is difficult to correlate the elutriate test results with the initial chemical concentration, C_o. Therefore, it was decided to estimate a value for each chemical pollutant through the calibrations of the model. The initial suspended-solids concentration above ambient was estimated to be 5 mg/l. The composition of the suspended solids was approximately 70 percent sand, 15 percent silt, and 15 percent clay. The proportion of each fraction was determined from the size analysis of the bed sediments. The initial concentrations estimated for each chemical contaminant were: 0.15 mg/l for ammonia-nitrogen, 0.1 mg/l for total phosphorus, 3.0 mg/l for COD, 0.005 mg/l for manganese, and 0.001 mg/l for zinc, copper, chromium, lead, and nickel.

g). Settling Velocity of the Suspended Solids, W

The terminal settling velocity of a suspended particle is determined by its specific gravity and size. The particle size can be estimated by a fall velocity analysis. Knowing the particle size and assuming a specific gravity, a modification of Stoke's law can be used to determine the terminal velocity. The settling velocities of the sand, silt, and clay were respectively determined as 0.02, 0.003, and 0.000001 m/sec. The settling rate constant, Ks, was calculated as W/D, where W is the settling velocity of the suspended solids and D is the mean depth of the plume.

h). Partitioning Coefficient, Kp

It was assumed that when a dissolved chemical pollutant is released in water which contains particulates, the pollutant rapidly reaches equilibrium. Partitioning coefficients were estimated based on the results presented in the GREAT II report (Schnoor et al., 1980). The estimated values for the chemicals of interest are: 13.0 for sand, 130.0 for silt, and 1300.0 $(\mu g/kg)(\mu g/l)^{-1}$ for clay particles.

i). total Decay-Reaction Rate Constant, k

The reactions by which chemicals are removed or transformed are hydrolysis, biodegradation, oxidation, photolysis, and volatilization. These reactions were summed to yield the total chemical decay rates in the liquid phase. All the reactions were assumed to be first order in chemical concentrations. Since the previous kinetics study showed that the rates of these reactions are insignificant as compared to the rates of sorption, diffusion, and convective transport, a null value of 10^{-10}/s was used for k.

2. Calibrations of the Chemical Plume Model. As discussed in Chapter II, grain-size distribution of the bed sediment sample showed that there was very little silt and clay present. Since the dredge spoil was primarily sand, which has the least sorption capacity, it settled out quickly at the disposal site. Only a small portion of chemicals were removed by the settling of sand. The quantities of silt and clay, which have larger adsorption capacities, were small and were not subject to rapid settling. As a result the decay of the chemical pollutants associated with particle sedimentation was not very substantial, and a large portion remained in the dissolved and suspended phases. The dissolved and small-particulate associated chemicals behaved like a fluid, and thus dispersed and were transported a considerable distance prior to settling.

Calibration of the proposed chemical plume model was performed using the data obtained from site RM 170*. Based on the model, three parameters were investigated. An increase of the dispersion coefficient, E_z, was investigated first. Increasing E_z caused a wider plume, but it would decrease chemical concentration rapidly downstream. Using $E_z = 25\ m^2/sec$, the partitioning coefficients, K_{p1}, K_{p2}, and K_{p3}, were investigated next. The partitioning coefficients were not a sensitive parameter in the model because sedimentation of silt and clay particles was not substantial. Finally, increasing the width of the line source, b, was investigated. By increasing b up to 130 m, reasonable results were obtained. Since a factor of the initial mixing force to develop the initial plume width and depth is not incorporated in the model, increasing b may be a fair adjustment to the model.

The field data for suspended solids, ammonia, phosphorus, COD, manganese, chromium, lead, copper, zinc, and nickel are presented in table V-1. The simulated chemical plumes for ammonia nitrogen are shown in table V-2 and for chemical parameters are shown in appendix C. Figures V-1, V-2, and V-3 show, respectively, the simulated plumes for ammonia, phosphorus, and COD superimposed on the field data. Manganese, zinc, copper, chromium, lead, and nickel did not develop plumes and were not plotted. From figures V-1 through V-3 and table V-1, it is seen that lower chemical concentrations were detected from the first transect than those from other transects. Reasons for the low concentrations immediately downstream from the discharge point were explained for the suspended-solids plume in chapter II. Since chemicals behave similarly to suspended solids, the same discussion could be applied to the chemical plume.

As can be seen from the computer simulation results, the model concentrations correspond reasonably well with the chemical analyses. However, only in the case of ammonia nitrogen, was there a clearly discernible input to the water column from dredge disposal. This disposal operation did not result in the formation of significant chemical plumes, except in the case of ammonia.

With the given river conditions, the extent and intensity of the chemical plume was preceeded by the computation of the suspended-solids plume. In this way, the transport and fate of dissolved and particulate-associated chemicals in the river were satisfactorily described, even though the model coefficients might need further confirmation.

3. Dilution Model. The diultion model proposed by Schnoor et al. (1980) was used to examine the dilution effect of the receiving water, and to predict the concentration of dissolved chemicals in the plume. This approach provided insight into the dilution mechanisms of the river. The major assumption involved in this method is that: chemical pollutants previously adsorbed to sediment particles desorb and dissolve in the discharge pipe during the dredging operation. Once these dissolved substances return to the river, they are subject to neither settling nor

Table V-1. Field chemical plume data for suspended solids, ammonia, phosphorus, COD, Manganese, Zinc, Copper, Chromium, Lead, and Nickel

Location No.	X (m)	Z (m)	SS (mg/l)				NH_3-N (mg/l)				PO_4-P (filtrable) (mg/l)			
			Y				Y				Y			
			0.61m	2.74m	AVG	Above Ambient	0.61m	2.74m	AVG	Above Ambient	0.61m	2.74m	AVG	Above Ambient
1-1	19	29	74	84	81	0	0.17	0.15	0.16	0.13	0.14	0.14	0.14	0.04
2		51	74	86	80	0	0.15	0.15	0.15	0.12	0.14	0.14	0.14	0.04
3		73	78	84	81	0	0.14	0.14	0.14	0.10	0.14	0.14	0.14	0.04
4		95	74	86	80	0	0.15	0.12	0.14	0.10	0.14	0.14	0.14	0.04
5		117	66	84	75	0	0.13	0.12	0.13	0.10	0.14	0.14	0.14	0.04
6		139	74	84	79	0	0.14	0.12	0.13	0.10	0.14	0.14	0.14	0.04
2-1	56	73	72	88	80	0	0.15	0.16	0.16	0.13	0.14	0.15	0.15	0.05
2		86	82	98	90	6	0.14	0.15	0.15	0.12	0.15	0.16	0.16	0.06
3		99	76	100	88	4	0.17	0.14	0.16	0.13	0.14	0.15	0.15	0.05
4		112	76	94	85	1	0.14	0.13	0.14	0.11	0.14	0.15	0.15	0.05
5		125	76	90	83	0	0.14	0.14	0.14	0.11	0.14	0.15	0.15	0.05
6		138	66	90	78	0	0.12	0.13	0.13	0.10	0.15	0.15	0.15	0.05
3-1	118	69	76	94	85	1	0.20	0.19	0.20	0.17	0.15	0.16	0.16	0.06
2		81	74	80	77	0	0.14	0.16	0.15	0.12	0.15	0.15	0.15	0.05
3		92	80	88	84	0	0.12	0.14	0.13	0.10	0.14	0.15	0.15	0.05
4		105	90	102	96	12	0.12	0.14	0.13	0.10	0.14	0.15	0.15	0.05
5		117	79	94	87	3	0.11	0.14	0.13	0.10	0.14	0.15	0.15	0.05
6		129	72	104	88	4	0.14	0.13	0.14	0.11	0.14	0.15	0.15	0.05
4-1	240	68	68	86	77	0	0.16	0.12	0.14	0.11	0.15	0.14	0.15	0.05
2		82	68	90	79	0	0.16	-	-	-	0.15	-	-	-
3		96	70	98	84	0	0.15	0.13	0.14	0.11	0.15	0.16	0.16	0.06
4		110	70	86	78	0	0.13	0.14	0.14	0.11	0.15	0.15	0.15	0.05
5		124	70	90	80	0	0.09	0.11	0.10	0.07	0.14	0.15	0.15	0.05
6		138	74	90	82	0	0.09	0.08	0.09	0.06	0.14	0.15	0.15	0.05
			Ambient Conc. = 84				Ambient Conc. = 0.03				Ambient Conc. = 0.10			

X	Longitudinal (Downstream) distance
Y	Vertical distance
Z	Lateral distance
AVG	Average depth
-	Not measured

Table V-1. (Continued)

COD (mg/l)				Mn (mg/l)				Zn (mg/l)				Cu (mg/l)			
Y				Y				Y				Y			
0.61	2.74	AVG	Above Ambient	0.61	2.74	AVG	Above Ambient	0.61	2.74	AVG	Above Ambient	0.61	2.74	AVG	Above Ambient
29	29	29	0	0.16	0.15	0.16	0.00	<0.01	0.02	<0.02	0.00	<0.01	<0.01	<0.01	0.00
28	39	34	3	0.16	0.16	0.16	0.00	<0.01	0.02	<0.02	0.00	<0.01	<0.01	<0.01	0.00
28	31	30	0	0.16	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
27	29	28	0	0.16	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
31	28	30	0	0.16	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
29	28	29	0	0.16	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
33	30	32	1	0.16	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
32	32	32	1	0.16	-	-	-	0.02	0.01	0.02	0.00	<0.01	0.01	<0.01	0.00
31	33	32	1	0.16	0.15	0.15	0.00	<0.01	0.04	<0.04	0.00	<0.01	0.01	<0.01	0.00
35	34	35	4	0.16	0.15	0.16	0.00	0.01	0.01	0.01	0.00	<0.01	0.01	<0.01	0.00
33	36	35	4	0.16	0.16	0.16	0.00	0.01	0.02	0.02	0.00	<0.01	<0.01	<0.01	0.00
30	33	32	1	0.15	0.16	0.16	0.00	0.02	<0.01	<0.02	0.00	<0.01	<0.01	<0.01	0.00
35	37	36	5	0.16	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
33	38	36	5	0.15	0.15	0.15	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
30	34	32	1	0.15	0.15	0.15	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
35	32	34	3	0.15	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	0.01	<0.01	<0.01	0.00
34	33	34	3	0.15	0.15	0.15	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
34	32	33	2	0.15	0.15	0.15	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
32	37	35	4	0.16	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
33	-	-	-	0.17	0.16	0.17	0.01	0.02	-	-	0.00	<0.01	-	-	0.00
28	36	32	1	0.16	0.17	0.17	0.01	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
28	38	33	2	0.16	0.17	0.17	0.01	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
33	35	34	3	0.16	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
33	31	32	1	0.16	0.16	0.16	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00
Ambient Conc. = 31				Ambient Conc. = 0.16				Ambient Conc. = 0.05				Ambient Conc. = <0.01			

Table V-1. (Continued)

Cr (mg/l)				Pb (mg/l)				Ni (mg/l)			
Y				Y				Y			
0.61 (m)	2.74 (m)	AVG (m)	Above Ambient (mg/l)	0.61 (m)	2.74 (m)	AVG (m)	Above Ambient (mg/l)	0.61 (m)	2.74 (m)	AVG (m)	Above Ambient (mg/l)
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	-	-	-	<0.01	-	-	-	<0.1	-	-	-
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1
Ambient Conc. < 0.01				Ambient Conc. < 0.01				Ambient Conc. < 0.1			

Table V-2. Simulated Ammonia Plume - CPLUME

(1) DISTANCE X (M)	(2) WIDTH Z (M)	(3) SAND (MG/L)	(4) SILT (MG/L)	(5) CLAY (MG/L)	(6) TOTAL SS. (MG/L)	(7) TSS ABOVE AMBI. (MG/L)	(8) POLL. ON SAND (MG/L)	(9) POLL. ON SILT (MG/L)	(10) POLL. ON CLAY (MG/L)	(11) DISSOLVED POLL. (MG/L)	(12) TOTAL POLL. (MG/L)	(13) POLL. ABOVE AMBI. (MG/L)
20	0.0	3.09	41.75	41.75	86.59	4.59	0.00	0.01	0.13	0.04	0.18	0.15
20	7.1	3.09	41.75	41.75	86.59	4.59	0.00	0.01	0.13	0.04	0.18	0.15
20	14.1	3.09	41.75	41.75	86.58	4.58	0.00	0.01	0.13	0.04	0.18	0.15
20	21.2	3.09	41.75	41.75	86.58	4.58	0.00	0.01	0.13	0.04	0.18	0.15
20	28.3	3.08	41.75	41.75	86.58	4.58	0.00	0.01	0.13	0.04	0.18	0.15
20	35.4	3.08	41.75	41.75	86.57	4.57	0.00	0.01	0.13	0.04	0.18	0.15
20	38.9	3.07	41.74	41.75	86.56	4.56	0.00	0.01	0.13	0.04	0.18	0.15
20	42.4	3.07	41.74	41.75	86.56	4.56	0.00	0.01	0.13	0.04	0.18	0.15
20	46.0	3.06	41.74	41.74	86.55	4.55	0.00	0.01	0.13	0.04	0.18	0.15
20	49.5	3.05	41.74	41.74	86.54	4.54	0.00	0.01	0.13	0.04	0.18	0.15
20	56.6	3.03	41.73	41.74	86.50	4.50	0.00	0.01	0.13	0.04	0.18	0.15
20	63.6	3.00	41.73	41.73	86.45	4.45	0.00	0.01	0.12	0.04	0.18	0.15
20	70.7	2.94	41.71	41.71	86.37	4.37	0.00	0.01	0.12	0.04	0.17	0.14
20	88.4	2.72	41.66	41.66	86.04	4.04	0.00	0.01	0.11	0.04	0.16	0.13
20	106.1	2.32	41.56	41.56	85.44	3.44	0.00	0.01	0.10	0.03	0.14	0.11
20	123.7	1.76	41.43	41.43	84.62	2.62	0.00	0.01	0.08	0.03	0.12	0.09
20	141.4	1.15	41.28	41.28	83.71	1.71	0.00	0.01	0.06	0.02	0.09	0.06
20	176.8	0.29	41.07	41.07	82.43	0.43	0.00	0.00	0.03	0.01	0.04	0.01
50	0.0	2.51	41.73	41.73	85.98	3.98	0.00	0.01	0.13	0.04	0.18	0.15
50	11.2	2.50	41.73	41.73	85.97	3.97	0.00	0.01	0.12	0.04	0.18	0.15
50	22.4	2.48	41.72	41.73	85.93	3.93	0.00	0.01	0.12	0.04	0.18	0.15
50	33.5	2.45	41.71	41.72	85.88	3.88	0.00	0.01	0.12	0.04	0.17	0.14
50	44.7	2.40	41.70	41.70	85.80	3.80	0.00	0.01	0.12	0.04	0.17	0.14
50	55.9	2.32	41.68	41.68	85.68	3.68	0.00	0.01	0.12	0.04	0.17	0.14
50	61.5	2.28	41.66	41.67	85.61	3.61	0.00	0.01	0.12	0.04	0.16	0.13
50	67.1	2.23	41.65	41.65	85.53	3.53	0.00	0.01	0.11	0.04	0.16	0.13
50	72.7	2.17	41.63	41.64	85.44	3.44	0.00	0.01	0.11	0.03	0.16	0.13
50	78.3	2.11	41.61	41.62	85.34	3.34	0.00	0.01	0.11	0.03	0.15	0.12
50	89.4	1.96	41.57	41.57	85.11	3.11	0.00	0.01	0.10	0.03	0.14	0.11
50	100.6	1.79	41.52	41.53	84.84	2.84	0.00	0.01	0.10	0.03	0.14	0.11
50	111.8	1.61	41.47	41.47	84.55	2.55	0.00	0.01	0.09	0.03	0.12	0.09
50	139.8	1.10	41.32	41.32	83.75	1.75	0.00	0.01	0.07	0.02	0.09	0.06
50	167.7	0.64	41.19	41.19	83.01	1.01	0.00	0.00	0.05	0.02	0.07	0.04
50	195.7	0.31	41.09	41.09	82.49	0.49	0.00	0.00	0.03	0.01	0.05	0.02
50	223.6	0.12	41.04	41.04	82.19	0.19	0.00	0.00	0.03	0.01	0.04	0.01
50	279.5	0.01	41.00	41.00	82.02	0.02	0.00	0.00	0.02	0.01	0.03	0.00

Table V-2. (Continued)

100	0.0	1.69	41.67	41.67	85.03	3.03	0.00	0.01	0.12	0.04	0.16	0.13
100	15.8	1.67	41.66	41.67	85.01	3.01	0.00	0.01	0.12	0.04	0.16	0.13
100	31.6	1.64	41.65	41.65	84.94	2.94	0.00	0.01	0.11	0.04	0.16	0.13
100	47.4	1.57	41.62	41.63	84.83	2.83	0.00	0.01	0.11	0.03	0.16	0.13
100	63.2	1.49	41.59	41.60	84.67	2.67	0.00	0.01	0.11	0.03	0.15	0.12
100	79.1	1.38	41.55	41.55	84.48	2.48	0.00	0.01	0.10	0.03	0.14	0.11
100	87.0	1.32	41.52	41.53	84.37	2.37	0.00	0.01	0.10	0.03	0.14	0.11
100	94.9	1.25	41.50	41.50	84.25	2.25	0.00	0.01	0.09	0.03	0.13	0.10
100	102.8	1.19	41.47	41.47	84.13	2.13	0.00	0.01	0.09	0.03	0.12	0.09
100	110.7	1.12	41.44	41.45	84.00	2.00	0.00	0.01	0.08	0.03	0.12	0.09
100	126.5	0.97	41.38	41.39	83.74	1.74	0.00	0.01	0.08	0.02	0.11	0.08
100	142.3	0.82	41.33	41.33	83.47	1.47	0.00	0.01	0.07	0.02	0.10	0.07
100	158.1	0.68	41.27	41.27	83.22	1.22	0.00	0.01	0.06	0.02	0.08	0.05
100	197.6	0.37	41.15	41.15	82.66	0.66	0.00	0.00	0.04	0.01	0.06	0.03
100	237.2	0.16	41.07	41.07	82.29	0.29	0.00	0.00	0.03	0.01	0.04	0.01
100	276.7	0.06	41.02	41.02	82.11	0.11	0.00	0.00	0.02	0.01	0.03	0.00
100	316.2	0.02	41.01	41.01	82.03	0.03	0.00	0.00	0.02	0.01	0.03	0.00
100	395.3	0.00	41.00	41.00	82.00	0.00	0.00	0.00	0.02	0.01	0.03	0.00
250	0.0	0.51	41.51	41.53	83.56	1.56	0.00	0.01	0.10	0.03	0.14	0.11
250	25.0	0.51	41.51	41.52	83.53	1.53	0.00	0.01	0.09	0.03	0.13	0.10
250	50.0	0.49	41.49	41.50	83.47	1.47	0.00	0.01	0.09	0.03	0.13	0.10
250	75.0	0.45	41.45	41.46	83.37	1.37	0.00	0.01	0.09	0.03	0.12	0.09
250	100.0	0.41	41.41	41.42	83.25	1.25	0.00	0.01	0.08	0.03	0.11	0.08
250	125.0	0.36	41.36	41.37	83.10	1.10	0.00	0.01	0.07	0.02	0.10	0.07
250	137.5	0.34	41.34	41.34	83.02	1.02	0.00	0.01	0.07	0.02	0.10	0.07
250	150.0	0.31	41.31	41.32	82.94	0.94	0.00	0.01	0.07	0.02	0.09	0.06
250	162.5	0.28	41.28	41.29	82.86	0.86	0.00	0.01	0.06	0.02	0.09	0.06
250	175.0	0.26	41.26	41.26	82.78	0.78	0.00	0.01	0.06	0.02	0.08	0.05
250	200.0	0.21	41.21	41.21	82.63	0.63	0.00	0.01	0.05	0.02	0.07	0.04
250	225.0	0.16	41.16	41.17	82.49	0.49	0.00	0.00	0.04	0.01	0.06	0.03
250	250.0	0.12	41.12	41.13	82.37	0.37	0.00	0.00	0.04	0.01	0.06	0.03
250	312.5	0.05	41.05	41.05	82.16	0.16	0.00	0.00	0.03	0.01	0.04	0.01
250	375.0	0.02	41.02	41.02	82.06	0.06	0.00	0.00	0.02	0.01	0.03	0.00
250	437.5	0.01	41.01	41.01	82.02	0.02	0.00	0.00	0.02	0.01	0.03	0.00
250	500.0	0.00	41.00	41.00	82.00	0.00	0.00	0.00	0.02	0.01	0.03	0.00
250	625.0	0.00	41.00	41.00	82.00	0.00	0.00	0.00	0.02	0.01	0.03	0.00

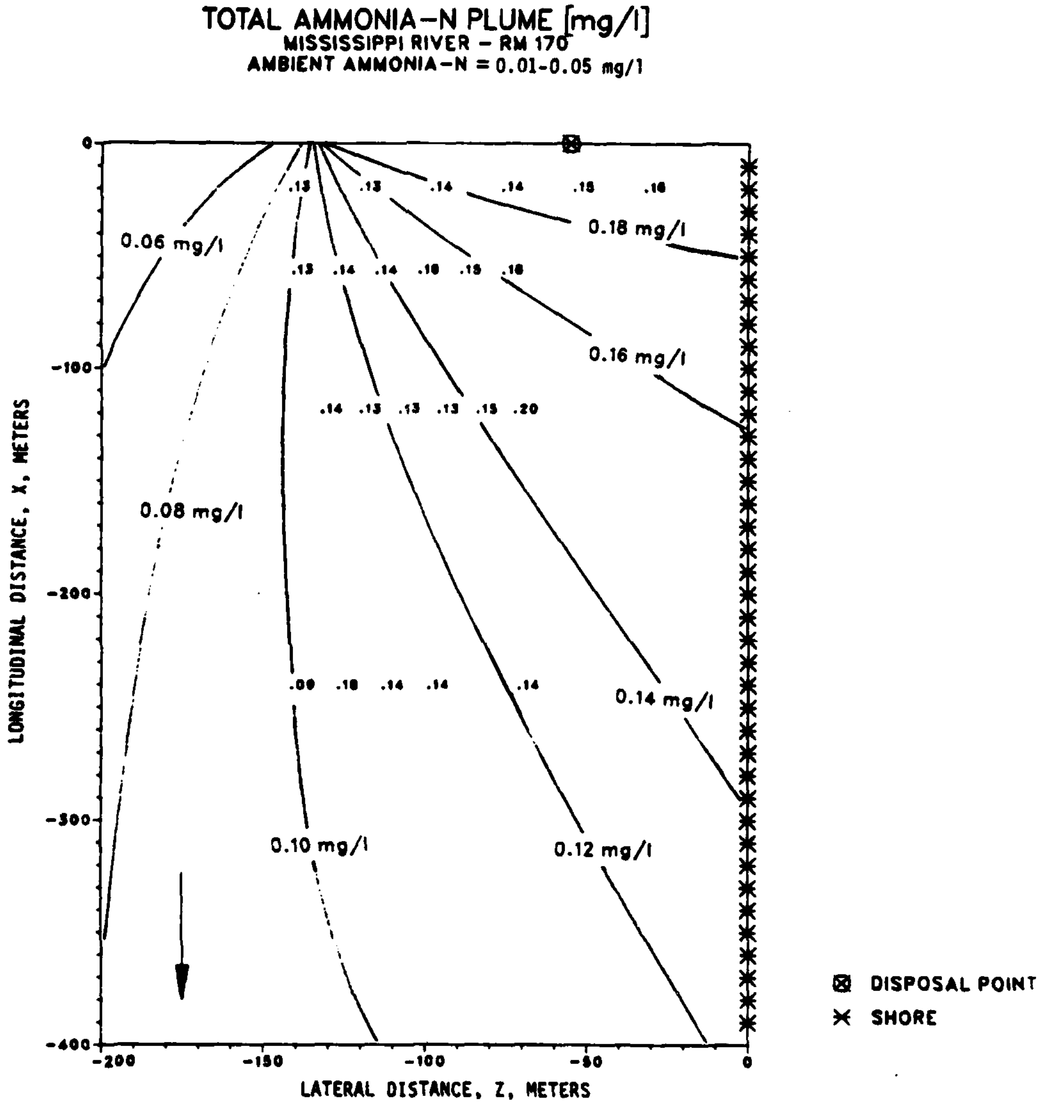


Figure V-1. Simulated Ammonia Plume Superimposed on Field Data

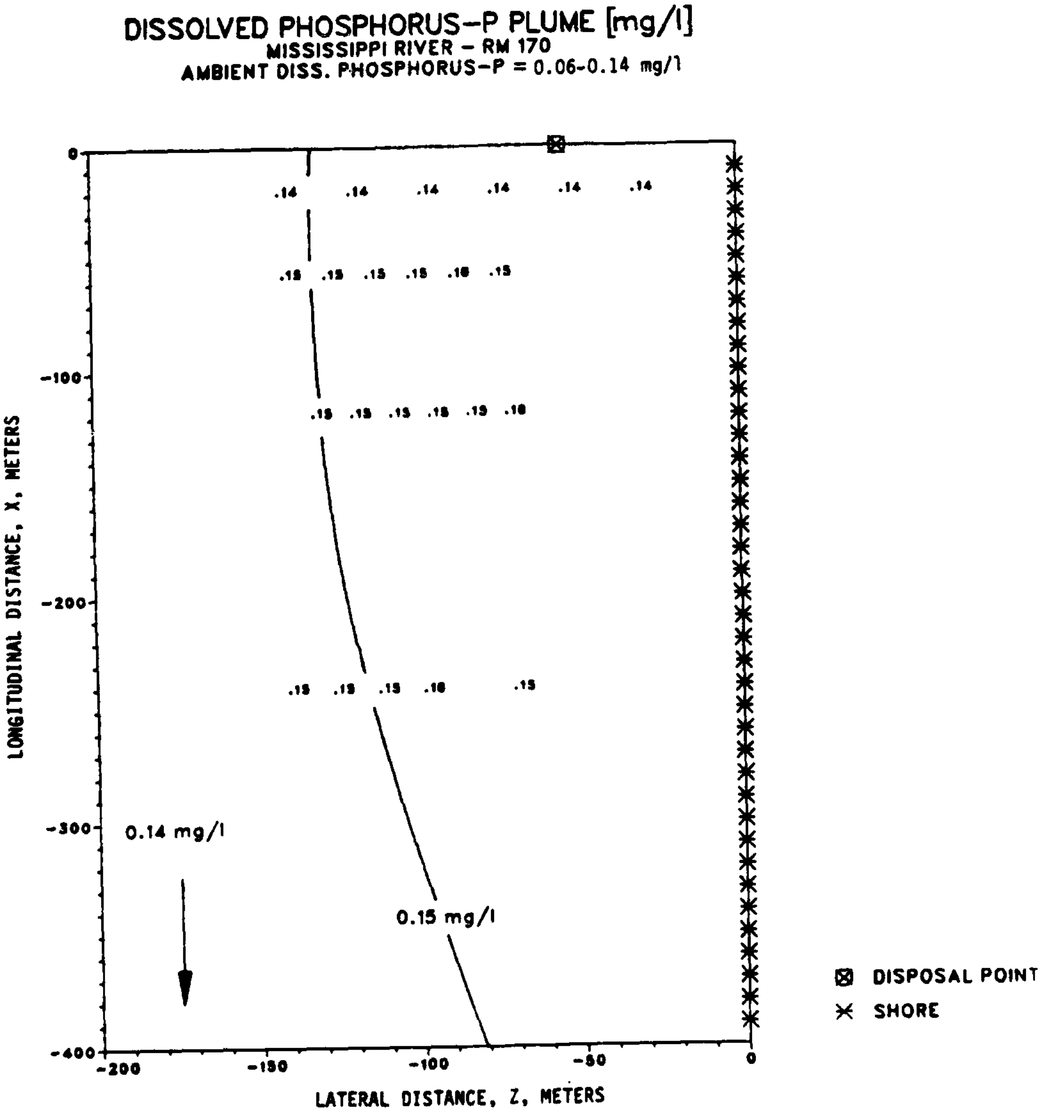


Figure V-2. Simulated Dissolved Phosphorus Plume Superimposed on Field Data

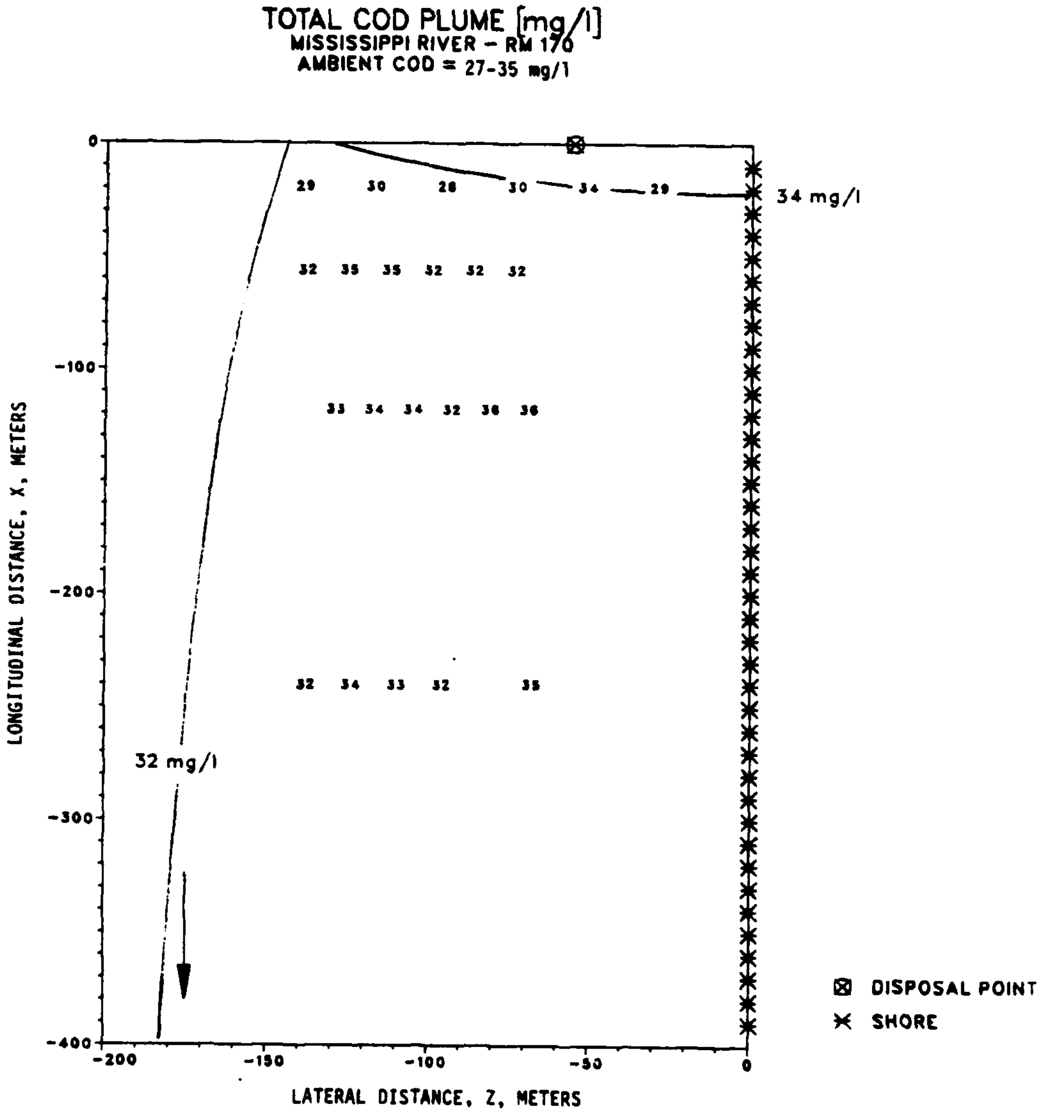


Figure V-3. Simulated COD Plume Superimposed on Field Data decay in the near field, but they are affected only by dilution with the receiving water.

The dilution ratio is defined as the number of volumes of river water added to one volume of water at the head of the plume which yields the concentration in the plume. The dilution ratio can be calculated by

$$DR = C_b/C' \tag{V-24}$$

where C_b is the concentration at the head of the plume given by

$$C_b = Q_o C_o/Q_b \tag{V-25}$$

where Q_b is the river flow rate;, C_o is the dissolved pollutant concentration discharged to the river; C' is the concentration of the dissolved pollutant in the plume, given by (V-22). Thus, the dilution ratio (DR) can be rewritten as

$$DR = \frac{1}{F(\frac{z+b}{\sigma_z}) - F(\frac{z-b}{\sigma_z})} \tag{V-26}$$

The concentration of the dissolved substance, C', is then calculated by

$$C' = C_b/DR \tag{V-27}$$

Table V-3 shows the results of calculation of the dilution factors and predicted chemical concentrations. It can be seen from the tables that the concentration of a dissolved substance calculated by the Dilution Model is almost identical to the concentrations calculated by the Chemical Plume Model. This agreement indicates that dilution is the prime mechanism operating to control the extent and intensity of the chemical plume, and that sedimentation played only a small part at site RM 170*.

D. Summary. Table V-3 comprises a summary of the chemical plume modeling effort and its relationship to the standard elutriate test. The following observations can be made from table V-3.

Table V-3. Simulated Ammonia Plume - DILUTION

(1) X (M)	(2) Z (M)	(3) F(+*)	(4) F(-*)	(5) DILUTION RATIO	(6) POLL. CONC. (MG/L)
20.	0.0	0.9999	0.0001	1.0	0.15
20.	7.1	0.9999	0.0003	1.0	0.15
20.	14.1	1.0000	0.0005	1.0	0.15
20.	21.2	1.0000	0.0010	1.0	0.15
20.	28.3	1.0000	0.0020	1.0	0.15
20.	35.4	1.0000	0.0037	1.0	0.15
20.	38.9	1.0000	0.0050	1.0	0.15
20.	42.4	1.0000	0.0066	1.0	0.15
20.	46.0	1.0000	0.0087	1.0	0.15
20.	49.5	1.0000	0.0114	1.0	0.15
20.	56.6	1.0000	0.0189	1.0	0.15
20.	63.6	1.0000	0.0303	1.0	0.15
20.	70.7	1.0000	0.0468	1.0	0.14
20.	88.4	1.0000	0.1196	1.1	0.13
20.	106.1	1.0000	0.2492	1.3	0.11
20.	123.7	1.0000	0.4298	1.8	0.09
20.	141.4	1.0000	0.6267	2.7	0.06
20.	176.8	1.0000	0.9071	10.8	0.01
50.	0.0	0.9900	0.0100	1.0	0.15
50.	11.2	0.9942	0.0168	1.0	0.15
50.	22.4	0.9968	0.0271	1.0	0.15
50.	33.5	0.9983	0.0422	1.0	0.14
50.	44.7	0.9991	0.0636	1.1	0.14
50.	55.9	0.9996	0.0925	1.1	0.14
50.	61.5	0.9997	0.1102	1.1	0.13
50.	67.1	0.9998	0.1302	1.1	0.13
50.	72.7	0.9999	0.1526	1.2	0.13
50.	78.3	0.9999	0.1774	1.2	0.12
50.	89.4	1.0000	0.2341	1.3	0.11
50.	100.6	1.0000	0.2996	1.4	0.11
50.	111.8	1.0000	0.3724	1.6	0.09
50.	139.8	1.0000	0.5693	2.3	0.06
50.	167.7	1.0000	0.7500	4.0	0.04
50.	195.7	1.0000	0.8799	8.3	0.02
50.	223.6	1.0000	0.9530	21.3	0.01
50.	279.5	1.0000	0.9963	267.2	0.00

Table V-3. (Continued)

100.	0.0	0.9500	0.0500	1.1	0.13
100.	15.8	0.9674	0.0743	1.1	0.13
100.	31.6	0.9795	0.1067	1.1	0.13
100.	47.4	0.9876	0.1482	1.2	0.13
100.	63.2	0.9927	0.1992	1.3	0.12
100.	79.1	0.9959	0.2597	1.4	0.11
100.	87.0	0.9970	0.2931	1.4	0.11
100.	94.9	0.9978	0.3284	1.5	0.10
100.	102.8	0.9984	0.3653	1.6	0.09
100.	110.7	0.9988	0.4035	1.7	0.09
100.	126.5	0.9994	0.4823	1.9	0.08
100.	142.3	0.9997	0.5618	2.3	0.07
100.	158.1	0.9999	0.6389	2.8	0.05
100.	197.6	1.0000	0.8039	5.1	0.03
100.	237.2	1.0000	0.9124	11.4	0.01
100.	276.7	1.0000	0.9682	31.5	0.00
100.	316.2	1.0000	0.9908	108.2	0.00
100.	395.3	1.0000	0.9996	2525.9	0.00
250.	0.0	0.8508	0.1492	1.4	0.11
250.	25.0	0.8925	0.2005	1.4	0.10
250.	50.0	0.9251	0.2611	1.5	0.10
250.	75.0	0.9495	0.3300	1.6	0.09
250.	100.0	0.9671	0.4052	1.8	0.08
250.	125.0	0.9793	0.4840	2.0	0.07
250.	137.5	0.9838	0.5239	2.2	0.07
250.	150.0	0.9875	0.5636	2.4	0.06
250.	162.5	0.9904	0.6026	2.6	0.06
250.	175.0	0.9927	0.6406	2.8	0.05
250.	200.0	0.9959	0.7123	3.5	0.04
250.	225.0	0.9977	0.7764	4.5	0.03
250.	250.0	0.9988	0.8315	6.0	0.03
250.	312.5	0.9998	0.9279	13.9	0.01
250.	375.0	1.0000	0.9750	40.0	0.00
250.	437.5	1.0000	0.9931	144.0	0.00
250.	500.0	1.0000	0.9985	650.2	0.00
250.	625.0	1.0000	1.0000	26715.3	0.00

1) Sediments change with season. As shown in table V-4, the 14 August 1981, elutriates showed considerably higher release of ammonia and COD then the 20 November 1981, samples. This is likely due to a lower redox potential of the sediments collected during the summer months. Summer-time dredging during low flow would represent worst-case conditions in terms of NH_3-N and COD desorption.
2) Ammonia - nitrogen was the only chemical to clearly form a plume in the field sampling of 20 November. The standard elutriate test "under-predicted" the magnitude of the NH_3 plume source concentration.
3) There was considerable variability among sediments. Results on a single sediment sample were quite reproducible, but different sediment samples from a given vicinity can give significantly different results.

Source concentrations of the plume are difficult to predict a priori. Also the source width is difficult to estimate without field work. Once the source width and strength are known, the model developed in this chapter is sufficiently detailed to simulate the contaminant plume.

The relationship between the 3-D suspended-solids model of chapter II and the 2-D chemical plume model is readily apparent. Both models, are based on steady-flow onditions and continuity of mass. Because the 3-D suspended-solids model entered the source input below the surface, the mixing parameters in the two model simulations were not identical. Greater lateral mixing and source width were required in the chemical plume model. It does not represent explicitly the lateral mixing due to density differences of the plunging and subsequently rising plume.

Table V-4. A Comparison of Site and elutriate concentrations at RM 170 on two different dates and with the model source concentrations

	NH_3-N mg/l	PO_4-P mg/l	COD mg/l	Sediment Character
Site Water 170-1 8-14-81	0.15	0.25	30	--
Elutriate 170-1 8-14-81	0.46	0.03	74	Sand
Elutriate 170-2 8-14-81	0.90	0.06	86	Organic
Elutriate 170-3 8-14-81	0.06	0.03	73	Sand
Site Water 170-1* 11-20-81	0.03	0.10	31	--
Elutriate 170-1* 11-20-81	0.08	0.06	39	Sand
Site Water 170-2* 11-20-81	0.01	0.14	35	--
Elutriate 170-2* 11-20-81	0.01	0.11	42	Sand
Model Source Concentrations for 11-20	0.18	0.2	34	

E. References

Kennedy, W.J. and Gentle, J.E., 1980, "Statistical Computing", Marcel Dekker, Inc., N.Y.

Sayre, W.W., 1973, "Natural Mixing Processes in Rivers: environmental Impact on rivers, edited and published by H.S. Shen. Fort collins, Colorado.

Sayre, W.W., 1979, "Shore-Attached Thermal Plumes in Rivers", in Modeling of Rivers, edited by H.S. Shen, John Wiley and Sons, Inc., New York.

Schnoor, J.L., Giaquinta, A.R., Musgrove, D.D., and Sayre, W.W., 1980, "Suspended Sediment Modeling of Dredge-Disposal Effluent in the GREAT II Study Reach" IIHR report No. 228, Iowa Institute of Hydraulic Research, The University of Iowa, Iowa city, Iowa.

Shen, H.W., 1979, "Modeling of Rivers:, John Wiley and Sons, N.Y.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1) Maintenance dredging and disposal of main channel sediments, as practiced by the Corps of Engineers, was not a significant water quality problem in the GREAT III study.

2) A 3-D suspended-solids model and a 2-D chemical contaminant plume model have been applied to assess water quality in the Great III reach of the Mississippi River. Refinements were made to the models. A variable-depth source option was included in the suspended-solids model to reflect conditions observed in the GREAT III study area. Sorption partitioning and chemical kinetics of contaminant transformations were incorporated into the chemical plume model. Model reaction and transport formulations were sufficient to describe the predominant processes at work in the Mississippi River.

3) Limitations of the models include:

   a) The steady-state assumption. Due to river dynamics and time-variable discharges of dredged material, the assumption of steady state was not always applicable. Dredge disposal was halted periodically to allow barge traffic to pass. Also solids concentrations changed abruptly as the cutterhead moved.

   b) The open-field assumption. Wing dams and variable velocities and depths caused spatial structure in the field data which is not accounted for by the models.

   c) The source configuration. It is not presently possible to predict _a priori_ the dredge disposal discharge characteristics, i.e., the source width, the source depth, and the source strength (concentration). These parameters can be estimated from elutriate tests and historical field studies to within an order-of-magnitude, but it is necessary to perform studies at the site to make more accurate simulations.

d) The lateral (transverse) mixing coefficient. Lateral mixing in the GREAT III field study was considerably greater than lateral dispersion coefficients reported in the literature. Increased lateral mixing was caused by the lateral velocity of the discharge jet, the density-driven sinking and rise of the plume, and by the irregular bed geometry. An apparent lateral mixing coefficient of 2.0 m^2/sec was determined by simulations of the suspended-solids field data.

4) Model verification was complicated by the low suspended solids and contaminant concentrations which were measured in this study. In-situ concentrations were several times lower than in the GREAT II study reach, from Guttenberg, Iowa, to Saverton, Missouri. Lower concentrations were caused by greater depth and flow-per-unit-width, as well as coarser and "cleaner" sand than in the GREAT II reach.

5) Water-quality criteria were not exceeded in the field study and were only rarely exceeded in the standard elutriate test. Ammonia-nitrogen, chemical oxygen demand, and manganese were the most frequently desorbed chemicals. Dissolved iron, phosphate, and zinc were the most frequently adsorbed. Heavy metals were not significantly desorbed.

6) Sediments were relatively free of contaminants with the possible exception at RM 172 below the Des Peres River at St. Louis, Missouri. (Sediment sample 172-3 contained ~ 0.4 mg/kg (dry basis) of PCBs. Sample 172-1 contained 25.3 µg/l of the plasticizer diethyl phthalate and 11.1 µg/l of the plasticizer dilrityl phthalate.)

7) The standard elutriate test was useful as a screening test. It likely provides an order-of-magnitude estimate of dredge-disposal discharge concentrations. It varies from the discharge principally due to differences in redox potential, sediment-to-water ratio, and mixing time/intensity.

8) The kinetics of the elutriate test could be described by an initial condition and three stages. The initial condition depends on the redox of the sediment sample and the related parameters: volatile solids content, percent moisture, and nature of the sediment (grain size, color, organic content). The first stage is described by an initial mixing and desorption which takes place over a few minutes. The second stage involves adsorption/desorption, ion exchange, and nucleation/precipitation processes which takes from 30-90 minutes. The final stage is sorptive equilibria. Biotransformations, volatilization, and some chemical oxidations may occur over a longer time scale. A mathematical model was developed to account for the kinetics of the standard elutriate test.

B. Recommendations

1) Further verification of the 3-D suspended-solids model and the 2-D chemical plume model is not necessary for the reasons stated in conclusions 1,3, and 4. The models can be used to estimate in-situ concentrations within an order-of-magnitude (or better if field measurements are taken near the dredge-disposal discharge).

2) However, if further verification studies of the model were to be undertaken, a better knowledge of ambient variations in suspended solids and chemical concentrations should be obtained, in both the vertical and lateral dimensions.

3) If care is taken in the collection of sediments and preparation, the standard ellutriate test can be a useful screening tool to determine potential problem cases, especially for chemical oxygen

demand and ammonia which are the oxygen demanding pollutants. To be more representative of disposal conditions, it is recommended that the ratio of sediment-to-water be changed from 1:4 to 1:9 in the elutriate test.

4) The chemical plume model can be used to roughly estimate contaminant concentrations before dredging by the following methodology. See also the GREAT II report, "Suspended Sediment Modelling of Dredge Disposal Effluent in the GREAT II Study Reach", by Schnoor et al (1980).

   a) Measure or estimate the stream velocity. Range 0.4-1.5 m/sec during late summer.

   b) Measure the size distribution of the sediment to be dredged and the weight fraction of the sand, silt, and clay particle classification. This can be performed by visual accumulation (VA) tube and micropipette analyses. Sand fall velocities normally range from 0.007 - 0.015 m/sec. For medium grade sand sediment (D_{50} = 370 μ), a direct runoff composition of 45% sand, 25% silt, and 30% clay is suggested. If the dredge discharge water is expected to run across an island before entering the river, a composition of 2% sand, 67% silt, and 30% clay is suggested. See fall velocities in chapter II.

   c) Estimate the source concentration of suspended solids at the point where the discharge water reenters the river. The range is from 20 - 200 mg/l suspended solids with a suggested rule of thumb: TSS (mg/l) = 50./u(m/sec).

   d) Estimate the source concentration of chemical contaminant from the standard elutriate test or from the relationships found in chapter III. Determine the partition coefficient between sand, silt, clay, and dissolved fractions by wet sieving and measurement of the particulate and dissolved phases.

e) Estimate the width f the discharge based on the method of disposal (i.e., side bank, near shore, or open water). A suggested average width is 20 m with a range of 10-120 m.

f) Assume a lateral (transverse) dispersion coefficient of 2.0 m^2/sec. Range: 0.1 - 20 m^2/sec.

g) From the literature determine if there are any rapid transformations (e.g., biodegradation, volatilization, photodegradation) which could occur in the near field. Most chemicals do not react sufficiently fast to require the specification of k, the first-order degradation rate constant.

h) Use the chemical plume model as described in Chapter 5.

APPENDIX A
SUSPENDED-SOLIDS COMPUTER PROGRAM
USER'S MANUAL

A. INTRODUCTION

The suspended-solids computer program is basically the WALDEN PLUME MODEL (WP) presented by Wechsler and Cogley (1977) with revisions.

The original model, WP, was used to investigate the turbidity generated by dredging and open-water disposal operations. The study was conducted to determine the nature and amount of turbidity that may be produced by a given sediment when it is suspended by dredging operations and to evaluate the effects of sediment and water compositional factors which influence particle settling rates.

Though WP was developed for estuarine conditions, Schnoor et al. (1980), modified it and used it to obtain predictions of GREAT II field data.

The present study modified the Wechsler-Cogley model further, taking the GREAT II version of it as a starting point. Once relatively satisfactory results were obtained for two GREAT II and two GREAT III sites, the refined model was used to predict suspended-solids distributions for a third GREAT III site. The suspended-solids computer model is fully discussed in Chapter II.

The model revisions include:

1). the ability to model three modes of disposal--open water, intermediate or near-shore, and on-shore disposal;

2). the folding or reflection principle needed for near-shore and on-shore disposal has been included in the program;

3). two sediment division options are possible--fines/sand or silt/clay/sand;

4). three plume-source options are now possible--constant concentration from the surface to the bottom, constant concentration over a fraction of the depth, or triangular concentration from the surface to the bottom;

5). two lateral spreading options are possible--constant diffusion coefficient, E_z= Constant or decreasing diffusion coefficient, E_z= f (spreading factor).

B. ASSUMPTIONS The assumptions made in the derivation of WP which also apply to the present model include:

1. unidirectional, steady flow of water,
2. infinite width compared to depth,
3. constant depth,
4. infinite length compared to depth,
5. eddy diffusion in downstream direction is negligible compared to other diffusion and transport terms,
6. eddy diffution in vertical direction can be related to vertical position in the flow by $E_y = 0.02\ Uy\ (1-\frac{y}{H})$,
7. eddy diffusion in lateral direction in $E_y \sim 2.2\ (E_y)_{max}$

Any other assumptions which apply to the present model are listed and discussed in chapter II.

C. SUSPENDED SOLIDS MODEL INPUT VARIABLES

All input data are entered as format-free variables.

Variable	Definition
ISCE	type (configuration) of sediment source
IUP	upper limit of suspended-solids source
IBT	lower limit of suspended-solids source
ITYPE	disposal type
NBANK	distance between river bank and source location
CONOR	original concentration (mg/l)
EZ	lateral eddy diffusivity (m^2/sec)
NSEDF	number of sediment fractions
U	average stream velocity (m/sec)
H	average stream depth (m)
NSTEP	number of downstream steps
XL	initial source half-width (m)
DELZ	lateral step size (m)
EXPCO	spreading factor
W	particle settling velocity (m/sec)
CO	sediment fraction (%)

D. SUSPENDED-SOLIDS MODEL OUTPUT

1. Instructions describing input variables
2. input values of concentration distributions and fall velocities
3. vertical distribution of sediment downstream for each sediment fraction (without lateral spreading)
4. the summation of the vertical distributions for all size fractions
5. the lateral spreading coefficients
6. horizontal slices through the 3-dimensional plume at five preselected depths showing the concentration distribution at each depth
7. folded distributions of (6.) if reflection is needed for disposal type

The interpretation and application of this model are fully explained in chapter II.

SUSPENDED SOLIDS COMPUTER PROGRAM LISTING

```
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,
C     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
C     LIBRARY, A PROPRIETARY PACKAGE FROM THE INTERNATIONAL
C     MATHEMATICAL & STATISTICAL LIBRARIES, INC., HOUSTON,
C     TEXAS.  THIS ROUTINE MAY NOT BE REDISTRIBUTED OR
C     REMOVED FROM THIS SOFTWARE FOR USE IN OTHER
C     SOFTWARE DEVELOPMENT.  THE IMSL ROUTINE INCLUDED IS
C     "ERF."
C     ******************************************************
C
C     THE PRESENT VERSION OF THE PROGRAM IS BASED ON A
C     MODIFICATION OF THE ORIGINAL WECHSLER-COGLEY MODEL
C     FROM "SUSPENDED SEDIMENT MODELING OF DREDGE-DISPOSAL
C     EFFLUENT IN THE GREAT II STUDY REACH," BY J.L.
C     SCHNOOR ET AL., IIHR REPORT NO. 228, MARCH 1980.
C
C     ******************************************************
C
C     AS PART OF THE PRESENT PROJECT, "REFINEMENT AND
C     VERIFICATION OF PREDICTIVE MODELS OF SUSPENDED
C     SEDIMENT DISPERSION AND DESORPTION OF TOXICS FROM
C     DREDGED SEDIMENTS," DONE FOR THE CORPS OF ENGINEERS -
C     GREAT III, A NUMBER OF MODIFICATIONS HAVE BEEN
C     INCORPORATED:
C
C     1. THREE MODES OF DISPOSAL:
```

```
C          A. OPEN WATER
C          B. INTERMEDIATE OR NEAR-SHORE
C          C. ON-SHORE
C
C       2. "FOLDING" FOR INTERMEDIATE AND BANK DISPOSAL
C          HAS BEEN INCLUDED AS A PART OF THE PROGRAM.
C
C       3. TWO SEDIMENT-DIVISION OPTIONS ARE INCLUDED:
C          A. FINES/SAND
C          B. SILT/CLAY/SAND
C
C       4. THREE PLANE-SOURCE OPTIONS ARE INCLUDED:
C          A. CONSTANT CONCENTRATION, SURFACE TO BOTTOM
C          B. CONSTANT CONCENTRATION, FRACTION OF DEPTH
C          C. TRIANGULAR CONCENTRATION, SURFACE (C=0.) TO
C             BOTTOM (C=CONOR)
C
C       5. TWO LATERAL SPREADING OPTIONS ARE INCLUDED:
C          A. CONSTANT EZ (EXPCO=0)
C          B. DECREASING EZ = F(EXPCO)
C
C       ******************************************************
C
        REAL IA,MA,ML,IIA
        DIMENSION WM(21,21)
        DIMENSION FOLD1(30,51),FOLD2(30,51),FOLD3(30,51)
        DIMENSION C(20,51),D(20,20),IA(20,20),MA(20,20)
        DIMENSION RA(20,20),CJ(20),IIA(20,20),B(20)
        DIMENSION ADELX(51),ADELY(20),Z(21,51),AVG(51)
        DIMENSION AVGSUM(51),B8(20),IOUT(51),CSUM(20,51)
        DATA SILT,CLAY,SAND,FINE/'SILT','CLAY','SAND','FINE'/
        DATA BD1,OWD1,OWD2,OWD3/'BANK','OPEN',' WAT','ER'/
        DATA BD2,BD3,BD4/'INTE','RMED','IATE'/
        DATA GD1,GD2,GD3/' DIS','POSA','L'/
        E(Y)=0.02*U*Y*(1-Y/H)
        CALL OPENSA(ASWRIT,'STODAT',6,4)
        REWIND 8
C
C       ENTER THE SOURCE TYPE:
C
C       1 = RECTANGULAR, SURFACE TO BOTTOM
C       2 = RECTANGULAR, FRACTION OF DEPTH
C       3 = TRIANGULAR, SURFACE (C=0) TO BOTTOM (C=CONOR)
C
        WRITE(1,18)
     18 FORMAT(2X,'ENTER SOURCE TYPE'/2X,
       +'1=RECT - SURF TO BOT'/2X,'2=RECT - FRAC OF DEPTH'/
       +2X,'3=TRIANG')
        READ(1,*)ISCE
        IF(ISCE.EQ.1)GO TO 22
        IF(ISCE.EQ.2)GO TO 24
```

```
      IF(ISCE.EQ.3)GO TO 23
   22 IUP=1
      IBT=20
      GO TO 23
   24 WRITE(1,17)
C
C     ENTER THE UPPER LIMIT OF THE SUSPENDED SOLIDS SOURCE
C     (IUP) IN TENTHS (OF DEPTH) FROM THE BOTTOM UP
C
   17 FORMAT(2X,'ENTER THE UPPER LIMIT OF SOURCE, IUP,',
     +' IN TENTHS (OF DEPTH) FROM THE BOTTOM UP')
      READ(1,*)IUP
      IUP=20-2*IUP+1
C
C     ENTER THE LOWER LIMIT OF THE SUSPENDED SOLIDS SOURCE
C     (IBT) IN TENTHS (OF DEPTH) FROM THE BOTTOM UP
C
      WRITE(1,19)
   19 FORMAT(2X,'ENTER THE LOWER LIMIT OF SOURCE,IUP,',
     +' IN TENTHS (OF DEPTH) FROM THE BOTTOM UP')
      READ(1,*)IBT
      IBT=20-2*IBT
C
C     ENTER THE TYPE OF DREDGE SPOIL DISPOSAL:
C     1 = BANK DISPOSAL
C     2 = OPEN WATER DISPOSAL
C     3 = INTERMEDIATE DISPOSAL
C     NBANK = NUMBER OF UNITS OF DELZ WHICH YOU WANT TO
C     PUT IN BETWEEN THE BANK AND THE START OF THE ORIGINAL
C     CONCENTRATION ("FOLDING" IS DONE AT THE BANK)
C     DELZ=LATERAL STEP SIZE
C
   23 WRITE(1,15)
   15 FORMAT(2X,'ENTER DISPOSAL TYPE'/2X,'1=BANK'/2X,
     +'2=OPEN WATER'/2X,'3=INTERMEDIATE')
      READ(1,*)ITYPE
      IF(ITYPE.EQ.3)GO TO 20
      GO TO 21
   20 WRITE(1,16)
   16 FORMAT(2X,'ENTER THE UNITS OF DELZ YOU WANT TO PUT',
     +' BETWEEN THE BANK ("FOLDING" LINE) AND THE START',
     +' OF THE ORIGINAL CONCENTRATION')
      READ(1,*)NBANK
   21 IF(ITYPE.EQ.1)NBANK=0
      IF(ITYPE.EQ.1)WRITE(8,30)BD1,GD1,GD2,GD3
   30 FORMAT(////2X,6A4)
      IF(ITYPE.EQ.2)WRITE(8,30)OWD1,OWD2,OWD3,GD1,GD2,GD3
      IF(ITYPE.EQ.3)WRITE(8,30)BD2,BD3,BD4,GD1,GD2,GD3
C
C     INITIALIZE ARRAYS
C
```

```
      CALL MCON (D,20,20,0.)
      CALL MCON(CSUM,20,51,0.)
      CALL MCON (Z,21,51,0.)
      CALL MCON (FOLD1,30,51,0.)
      CALL MCON (FOLD2,30,51,0.)
      CALL MCON (FOLD3,30,51,0.)
      CALL MCON (AVGSUM,51,1,0.)
      CALL MIDN (IA,20)
      CALL MIDN (IIA,20)
      CALL MSCL (IIA,IIA,20,20,-1.)
      DO 10 I=1,20
      IF(I.GT.1)IIA(I,I-1)=1.
   10 CONTINUE
C
C     ENTER MODEL PARAMETERS:
C
C     CONOR=ORIGINAL CONCENTRATION (MG/L)
C     EZ=LATERAL EDDY DIFFUSIVITY (M**2/SEC)
C     NSEDF=NUMBER OF SEDIMENT FRACTIONS
C     U=AVERAGE STREAM VELOCITY (M/SEC)
C     H=    "       "    DEPTH (M)
C     NSTEP=NUMBER OF DOWNSTREAM STEPS FOR F.D. SOLUTION
C     XL=INITIAL SOURCE HALF-WIDTH (M)
C     DELZ=LATERAL STEP SIZE (M)
C     EXPCO=SPREADING FACTOR
C
      WRITE(1,13)
   13 FORMAT( 2X,'ENTER ORIGINAL CONCENTRATION (MG/L)')
      READ(1,*)CONOR
      NSED=1
      WRITE(1,14)
      READ(1,*)EZ
   14 FORMAT(2X,'ENTER E-SUB-Z (LATERAL EDDY DIFFUSIVITY)')
      WRITE(1,9)
    9 FORMAT(2X,'ENTER NSEDF')
      READ(1,*)NSEDF
      WRITE(1,1000)
 1000 FORMAT(2X,'ENTER VALUES OF U,H,NSTEP,XL,DELZ,EXPCO')
      READ(1,*) U,H,NSTEP,XL,DELZ,EXPCO
      WRITE(8,1010)U,H,XL,CONOR,EZ
 1010 FORMAT(//2X,'INPUT PARAMETERS:'//2X,
     +'STREAM VELOCITY (M/SEC): U =',F6.2/2X,
     +'STREAM DEPTH (M): H =',F5.1,/2X,
     +'SOURCE HALF-WIDTH (M): XL =',F5.1,/2X,'ORIGINAL',
     +' TOTAL SEDIMENT CONCENTRATION (MG/L): CONOR =',
     +F5.0,/2X,'LATERAL EDDY DIFFUSIVITY (M**2/SEC): EZ =',
     +F8.6,////)
C
C     PROGRAM CONTROL 1S TRANSFERRED HERE FOR EACH
C     SEDIMENT FRACTION
C
```

```
   11 IF(NSED .GT. NSEDF)GO TO  99
   12 FORMAT(2X,A4)
      IF(NSEDF.EQ.3.AND.NSED.EQ.1)WRITE(1,12)SILT
      IF(NSEDF.EQ.3.AND.NSED.EQ.2)WRITE(1,12)CLAY
      IF(NSEDF.EQ.3.AND.NSED.EQ.3)WRITE(1,12)SAND
      IF(NSEDF.EQ.2.AND.NSED.EQ.1)WRITE(1,12)FINE
      IF(NSEDF.EQ.2.AND.NSED.EQ.2)WRITE(1,12)SAND
C
C     ENTER INDIVIDUAL SEDIMENT-FRACTION PARAMETERS:
C     CO=SEDIMENT FRACTION (%)
C         (SUM OF ALL CO=100%)
C     W=PARTICLE SETTLING VELOCITY (M/SEC)
C
      WRITE(1,101)
  101 FORMAT(2X,'ENTER VALUES OF')
      WRITE(1,102)
  102 FORMAT(2X,'W,CO')
      READ(1,*)W,CO
      IF(NSEDF.EQ.3.AND.NSED.EQ.1)WRITE(8,1011)SILT,W,CO
      IF(NSEDF.EQ.3.AND.NSED.EQ.2)WRITE(8,1011)CLAY,W,CO
      IF(NSEDF.EQ.3.AND.NSED.EQ.3)WRITE(8,1011)SAND,W,CO
      IF(NSEDF.EQ.2.AND.NSED.EQ.1)WRITE(8,1011)FINE,W,CO
      IF(NSEDF.EQ.2.AND.NSED.EQ.2)WRITE(8,1011)SAND,W,CO
 1011 FORMAT(////2X,'VERTICAL CONCENTRATION DISTRIBUTION',
     +' OF',A4,' (%)'/2X,'FALL VELOCITY (M/SEC): W=',F8.6,
     +/2X,'ORIGINAL CONCENTRATION (%): CO =',F5.0//)
      N=20
      THETA=1.0
      IF (NSTEP.GT.50) NSTEP=50
      NSTEP1=NSTEP+1
      DELX=10.
      DELY=H/FLOAT(N)
      DELI2=1./(DELY*DELY)
      AVGSUM(1)=AVGSUM(1)+CO
      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
C     CALCULATE CONCENTRATION DUE TO LATERAL DISPERSION
C
      DO 680 J=1,NSTEP
      FOREX=SQRT(ADELX(J+1)*4.*(EZ*(1+EXPCO*EXP(-(
     +ADELX(J+1)/100.)))))
      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
C     START FINITE DIFFERENCE SOLUTION
C
      IF(ISCE.EQ.3)GO TO 25
      DO 100 I=IUP,20
      C(I,1)=CO
  100 CONTINUE
      GO TO 26
   25 TRI=0.
      DO 103 I=1,20
      C(I,1)=CO*TRI
      TRI=TRI+.05
  103 CONTINUE
   26 AVG(1)=CO
      D(1,1)=-E(1.5*DELY)
      D(1,2)=E(1.5*DELY)
      N1=N-1
C
C     CALCULATE EDDY DIFFUSIVITY AT VARIOUS DEPTHS
C
      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((FLOAT(N)-.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
C     CALCULATE COEFFICIENTS OF SYSTEM OF EQUATIONS
C     RESULTING FROM FINITE DIFFERENCE SOLUTION
C
      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
      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
```

```
C     FINAL SOLUTION BY COMBINATION OF ANALYTIC AND
C     NUMERICAL SOLUTIONS
C
      CALL MMLT(B,RA,CJ,N,N,1)
      CALL LINEQ(B8,B,MA,WM,20,21,IER)
      IF (IER.GT.0) WRITE(1,4747)
      IF (IER.GT.0) WRITE(8,4747)
4747  FORMAT('NO SOLUTION FOUND')
C
C     OUTPUT OF FINAL RESULTS, FOLDING
C
      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) /FLOAT(N)
      AVGSUM(J+1)=AVGSUM(J+1)+AVG(J+1)
 400  CONTINUE
      WRITE(8,5001)(ADELX(I),I=1,NSTEP1,5)
      WRITE(8,5010)
5010  FORMAT(/)
5001  FORMAT(10X,20F6.0)
      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(KK),KK=1,NSTEP1,5)
5003  FORMAT(4X,'AVG',3X,20F6.2)
      NSED=NSED+1
      GO TO 11
  99  CONTINUE
      WRITE(8,5005)
5005  FORMAT (1H1,//T25,'SUMMATION OF SUSPENDED SEDIMENT',
     +' (%)'//)
      WRITE(8,5001)(ADELX(I),I=1,NSTEP1,5)
      WRITE(8,5010)
      DO 412 I=1,N
      WRITE(8,5000) ADELY(I),(CSUM(I,J),J=1,NSTEP1,5)
 412  CONTINUE
      WRITE(8,5003)   (AVGSUM(KK),KK=1,NSTEP1,5)
      WRITE(8,6668)
6668  FORMAT(1H1,//T25,'LATERAL SPREADING COEFFICIENTS'//)
      WRITE(8,5006)(ADELX(KK),KK=1,NSTEP1,5)
5006  FORMAT(11X,20F6.0)
      WRITE(8,5010)
      DO 411 I=1,21
      AZ=(I-1)*DELZ
      WRITE(8,5002) AZ,(Z(I,J),J=1,NSTEP1,5)
5002  FORMAT(4X,F5.1,2X,20F6.3)
 411  CONTINUE
```

```
      DO 800 IY=1,20,4
      YVAL=(IY-1)*DELY
      IF(ITYPE.EQ.1.OR.ITYPE.EQ.3)GO TO 27
      WRITE(8,5555) YVAL
 5555 FORMAT(1H1,////,T7,'DISTRIBUTION OF SEDIMENT IN',
     +' HORIZONTAL PLANE AT DEPTH',F6.2,' M   (MG/L)',//)
      WRITE(8,5001)(ADELX(KK),KK=1,NSTEP1,5)
      WRITE(8,5010)
   27 IF1=0
      IF2=0
      DO 810 IZ=1,21
      IAZ=22-IZ
      AZ=(-DELZ*(IAZ-1))
      IF1=IF1+1
      DO 801 IX=1,NSTEP1
      IOUT(IX)=((CSUM(IY,IX)*Z(IAZ,IX)*1000.+0.5)/800.)
     +*(CONOR/125.)
  801 CONTINUE
      IF(ITYPE.EQ.1.OR.ITYPE.EQ.3)GO TO 28
      WRITE(8,6666) AZ,(IOUT(KK),KK=1,NSTEP1,5)
 6666 FORMAT(2X,F6.1,2X,20F6.0)
   28 IF(ITYPE.EQ.2)GO TO 810
      IXLDZ=21-INT(XL/DELZ)-NBANK
      IF(IF1.GE.IXLDZ)GO TO 860
      DO 850 IFL1=1,NSTEP1,5
      FOLD1(IF1,IFL1)=IOUT(IFL1)
  850 CONTINUE
      GO TO 810
  860 IF2=IF2+1
      DO 852 IFL2=1,NSTEP1,5
      FOLD2(IF2,IFL2)=IOUT(IFL2)
  852 CONTINUE
  810 CONTINUE
      DO 802 IZ=2,21
      AZ=DELZ*(IZ-1)
      IF2=IF2+1
      DO 803 IX=1,NSTEP1
      IOUT(IX)=((CSUM(IY,IX)*Z(IZ,IX)*1000.+0.5)/800.)
     +*(CONOR/125.)
  803 CONTINUE
      IF(ITYPE.EQ.1.OR.ITYPE.EQ.3)GO TO 29
      WRITE(8,6666) AZ,(IOUT(KK),KK=1,NSTEP1,5)
   29 IF(ITYPE.EQ.2)GO TO 802
      DO 851 IFL2=1,NSTEP1,5
      FOLD2(IF2,IFL2)=IOUT(IFL2)
  851 CONTINUE
  802 CONTINUE
      IF(ITYPE.EQ.2)GO TO 800
      DO 853 I=2,IXLDZ
      IT=IXLDZ+1-I
      DO 853 J=1,NSTEP1,5
```

```
      FOLD3(I,J)=FOLD1(IT,J)
  853 CONTINUE
      DO 855 I=1,NSTEP1,5
      FOLD3(1,I)=0.
  855 CONTINUE
      DO 857 I=2,NSTEP1
      FOLD2(1,I)=2.*FOLD2(1,I)
  857 CONTINUE
      CALL MADD (FOLD1,FOLD2,FOLD3,30,51)
      AZ=0.
 5777 FORMAT(1H1,////,T7,'"FOLDED" DISTRIBUTION AT',F6.2,
     +' M   (MG/L)'//)
      WRITE(8,5777)YVAL
      WRITE(8,5001)(ADELX(KK),KK=1,NSTEP1,5)
      WRITE(8,5010)
      DO 854 I=1,30
      WRITE(8,6666)AZ,(FOLD1(I,K),K=1,NSTEP1,5)
      AZ=AZ+DELZ
  854 CONTINUE
  800 CONTINUE
      CALL CLOA(4)
      STOP
      END
C     ***********************************************************
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,
```

```
    +                   RES,XSQ,XNUM,XDEN,XI,X
C                       COEFFICIENTS  FOR 0.0 .LE.   Y .LT.
.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 B

GLOSSARY OF SELECTED VARIABLES
SUSPENDED SOLIDS PROGRAM

1. CO = percentage of individual size fraction.

2. CONOR = original source concentration (mg/l).

3. DELX = longitudinal step size (m).

4. DELY = vertical step size (m).

5. DELZ = transverse step size (m).

6. EXPCO = spreading factor (decreasing EZ).

7. EZ = transverse mixing coefficient (m2/21//s).

8. E(y) = function for determining vertical dispersion coefficient.

9. H = river depth (m).

10. NSEDF = number of sediment fractions.

11. NSTEP = number of longitudinal steps (usually 50).

12. THETA = model stability factor (set equal to 1.0).

13. U = river velocity (m/s).

14. W = particle settling velocity (m/s).

15. X = downstream coordinate.

16. XL = source half-width (m).

17. Y = vertical coordinate.

18. Z = transverse coordinate.

APPENDIX C

CHEMICAL PLUME AND DILUTION COMPUTER MODEL
USER'S MANUAL

The User's Guide provides information that should help users to run the Chemical Plume and Dilution computer models.

Introduction

The program 'CPLUME' refers to Chemical plume model and 'DILUTION' to the Dilution model. These two programs were written to simulate a chemical plume resulting from a dredging operation in a river system. They use a subroutine MDNORD (Normal probability distribution function of a double precision argument) to calculate the normal distribution function in the models. The subroutine MDNORD is available from IMSL (International Mathematical and Statistical Library) at the Weeg Computing Center (WCC) on the IBM 370, the Vax, and Prime 750 systems. The models were programmed in the FORTRAN language on a Prime 750 computer at The University of Iowa, Iowa City, Iowa.

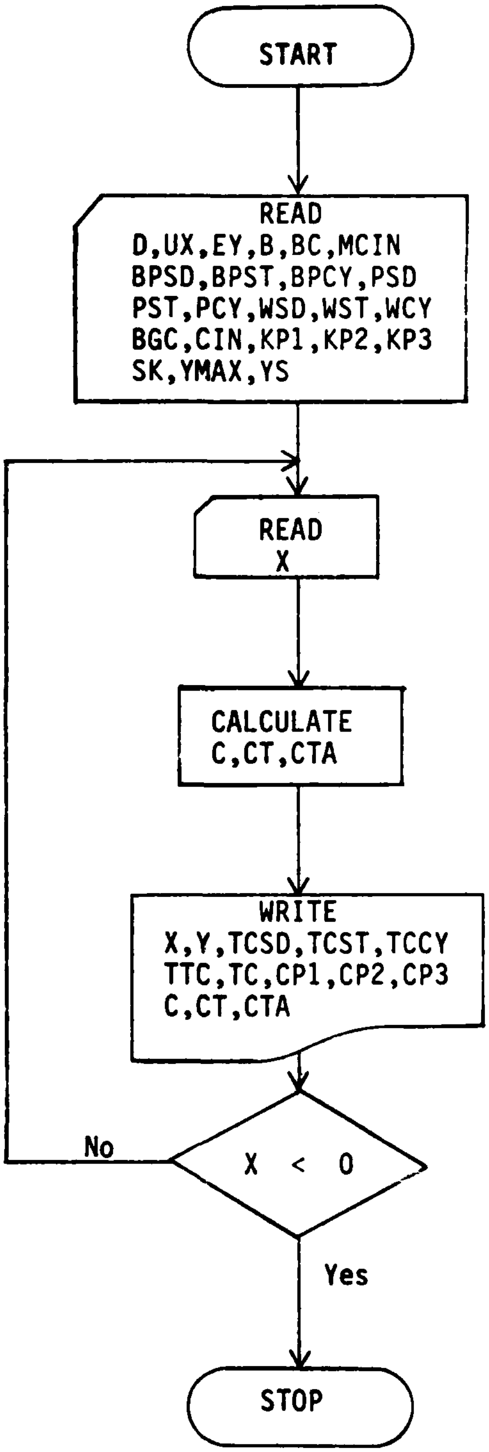
Algorithms

The computer programs were set up in the following manner.

CPLUME

First, the program reads in all the data from the data file needed to solve the equation. Next, the computer calculates the suspended-solids concentration at a given point (z,x). Using the suspended-solids concentration, it calculates the chemical concentrations in the plume and writes out the result. A flow chart and a program listing follow as well as example input and output files, and an input and output variable dictionary.

Flow Chart of CPLUME



Listing of the Computer Program "CPLUME"

```
          CPLUME
C
C   'CPLUME'
C   THE PROGRAM 'CPLUME' WAS WRITTEN TO CALCULATE
C   THE CHEMICAL CONCENTRATION IN PLUME RESULTED
C   FROM A DREDGING OPERATION
C   THE MODEL SIMULATES THE GREAT III REACH IN
C   THE MISSISSIPPI RIVER (RM 170)
C
C
      DIMENSION YS(20),Y1(20),Y2(20),Y(20),P1(20),P2(20),DPSD(20),
     *C(20),CT(20),CTA(20),DP(20),CP1(20),CP2(20),CP3(20),CSD(20),
     *CST(20),DPSY(20),CCY(20),TC(20),DPCY(20),M1(20),M2(20),M3(20),
     *XKPM1(20),XKPM2(20),XKPM3(20),XX1(20),XKPM(20),A1(20)
      DIMENSION WKM(20),WKM1(20),WKM2(20),WKM3(20),E(20),DPST(20),
     *TCSD(20),TCST(20),TCCY(20),TTC(20),TM1(20),TM2(20),TM3(20),
     *XKPTM1(20),XKPTM2(20),XKPTM3(20),X11(20),X21(20),X31(20)
C
C
      REAL*8 X,EY,SK1,SK2,SK3,M1,M2,M3,KP1,KP2,KP3
      REAL*8 P1I,P2I,Y1I,Y2I
      REAL*8 BCSD,BCST,BCCY,BPSD,BPST,BPCY,BC,BGC,MCIN
      INTEGER YMAX,XMAX,CF
C
C   SET DATA
C
      DATA CF/1000000.0/
      DATA IN,IOUT/11,10/
C
      READ(IN,*) D,UX,EY
      READ(IN,*) B
      READ(IN,*) BC,MCIN
      READ(IN,*) BPSD,BPST,BPCY
      READ(IN,*) PSD,PST,PCY
      READ(IN,*) WSD,WST,WCY
      READ(IN,*) BGC,CIN
      READ(IN,*) KP1,KP2,KP3
      READ(IN,*) SK
```

```
C   COMPUTE BACKGROUND CONCENTRATIONS OF SAND (BCSD),
C   SILT (BCST) AND CLAY (BCCY).   BC IS THE BACKGROUND
C   CONCENTRATION OF SUSPENDED SOLIDS, BPSD, BPST, AND
C   BPCY ARE FRACTION OF SAND, SILT AND CLAY, RESPECTIVERY.
C
      BCSD=BC*BPSD
      BCST=BC*BPST
      BCCY=BC*BPCY
C
C   READ NUMBER OF INPUT DATA, YMAX
C
      READ(IN,*) YMAX
C
C   READ YS, Z/SIGMA Z
C
      READ(IN,*) (YS(I),I=1,YMAX)
      WRITE(IOUT,6001) (I,I=1,YMAX)
 6001 FORMAT(//'INPUT YS'//20(I2,2X))
      WRITE(IOUT,6000) (YS(I),I=1,YMAX)
 6000 FORMAT(20F4.1)
C
C   SET TABLE FORMAT FOR THE FINAL RESULT
C
      WRITE(IOUT,207)
  207 FORMAT(1X,///)
      WRITE(IOUT,204)
  204 FORMAT(1X,T3,'(1)',T12,'(2)',T19,'(3)',T27,'(4)',T35,'(5)',
     *T43,'(6)',T50,'(7)',T58,'(8)',T66,'(9)',T74,'(10)',T83,'(11)',
     *T92,'(12)',T100,'(13)'//)
      WRITE(IOUT,202)
  202 FORMAT(1X,'DISTANCE',T11,'WIDTH',T19,'SAND',T27,
     *'SILT',T35,'CLAY',T42,'TOTAL',T50,'TSS',T58,'POLL.',T66,'POLL.',
     *T74,'POLL.',T81,'DISSOLVED',T92,'TOTAL',T100,'POLL.')
      WRITE(IOUT,203)
  203 FORMAT(1X,T50,'ABOVE',T59,'ON',T67,'ON',T75,'ON',T100,'ABOVE')
      WRITE(IOUT,201)
  201 FORMAT(1X,T5,'X',T12,'Z',T16,'   ',T24,'   ',T32,'   ',T42,'SS.',
     *T50,'AMBI.',
     *T58,'SAND',T66,'SILT',T74,'CLAY',T83,'POLL.',T92,'POLL.',
     *T100,'AMBI.')
      WRITE(IOUT,205)
  205 FORMAT(1X,T4,'(M)',T11,'(M)',T19,'(MG/L)',T27,'(MG/L)',
     *T35,'(MG/L)',T42,'(MG/L)',T50,'(MG/L)',T58,'(MG/L)',T66,'(MG/L)',
     *T74,'(MG/L)',T82,'(MG/L)',T92,'(MG/L)',T100,'(MG/L)'
     *///)
C
```

```
C
C   1. CALCULATION OF SAND, SILT AND CLAY CONCENTRATIONS ABOVE AMBIENT
C   AT GIVEN LOCATION (Z,X). SEE GREAT II REPORT (SCHNOOR ET AL. 1980)
C
C   PRELIMINARY CALCULATION
C
  210 READ(IN,*)X
      IF(X .LT. .0) GO TO 999
C
      A=X/(D*UX)
      ESD=EXP(-WSD*A)
      EST=EXP(-WST*A)
      ECY=EXP(-WCY*A)
      S=(2.*EY*X/UX)**(.5)
      DO 400 I=1,YMAX
      Y(I)=YS(I)*S
      Y1(I)=(Y(I)+B)/S
      Y2(I)=(Y(I)-B)/S
      Y1I=Y1(I)
      Y2I=Y2(I)
C
C   CALL SUBROUTINE 'MDNORD' FROM THE IMSL LIBRARY TO CALCULATE
C   NORMAL DISTRIBUTION FUNCTION
C
      CALL MDNORD (Y1I,P1I)
      CALL MDNORD (Y2I,P2I)
      P1(I)=P1I
      P2(I)=P2I
      DP(I)=P1(I)-P2(I)
      DPSD(I)=DP(I)*ESD
      DPST(I)=DP(I)*EST
      DPCY(I)=DP(I)*ECY
C
C   COMPUTE SUSPENDED SOLIDS CONCENTRATION ABOVE AMBIENT
C
      CSD(I)=DPSD(I)*PSD*MCIN
      CST(I)=DPST(I)*PST*MCIN
      CCY(I)=DPCY(I)*PCY*MCIN
      TC(I)=CSD(I)+CST(I)+CCY(I)
C
C   COMPUTE TOTAL SAND, SILT AND CLAY CONCENTRATION (AMBIENT PLUS PLUME)
C
      TCSD(I)=CSD(I)+BCSD
      TCST(I)=CST(I)+BCST
      TCCY(I)=CCY(I)+BCCY
C
C   COMPUTE TOTAL SUSPENDED SOLIDS CONCENTRATION (AMBIENT PLUS PLUME)
C
      TTC(I)=TCSD(I)+TCST(I)+TCCY(I)
```

AD-A120 725 REFINEMENT AND VERIFICATION OF PREDICTIVE MODELS OF 3/3
SUSPENDED SEDIMENT DI..(U) IOWA INST OF HYDRAULIC
RESEARCH IOWA CIYY J L SCHNOOR ET AL. JUL 82 IIHR-249
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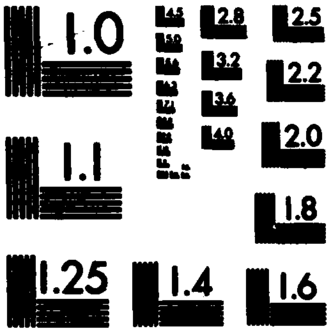
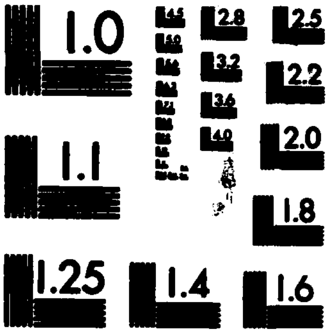


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



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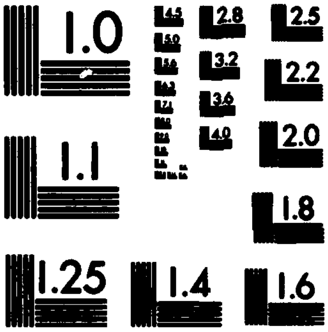

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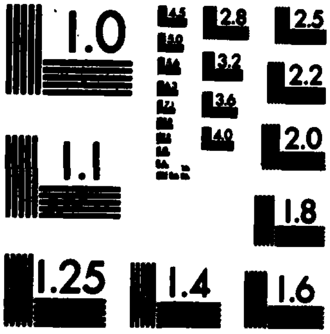
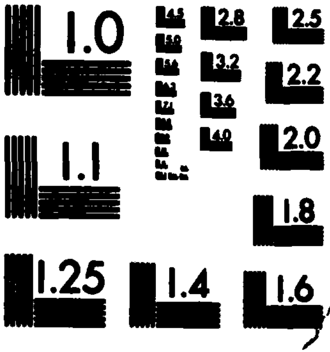


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
C
C   2. CALCULATION OF CHEMICAL CONCENTRATION AT GIVEN (Z,X) POINT
C
C
C   COMPUTE SAND, SILT AND CLAY CONCENTRATION IN KG/L (ABOVE AMBIENT)
C   CF=CONVERSION FACTOR TO CHANGE M FROM MG TO KG
C
      M1(I)=CSD(I)/CF
      M2(I)=CST(I)/CF
      M3(I)=CCY(I)/CF
C
C
C   CONVERT TOTAL SAND, SILT AND CLAY CONCENTRATION FROM MG/L TO KG/L
C
      TM1(I)=TCSD(I)/CF
      TM2(I)=TCST(I)/CF
      TM3(I)=TCCY(I)/CF
C
      XKPM1(I)=KP1*M1(I)
      XKPM2(I)=KP2*M2(I)
      XKPM3(I)=KP3*M3(I)
C
      XKPM(I)=1. +XKPM1(I)+XKPM2(I)+XKPM3(I)
C
      WKM1(I)=(WSD/4.)*XKPM1(I)
      WKM2(I)=(WST/4.)*XKPM2(I)
      WKM3(I)=(WCY/4.)*XKPM3(I)
      WKM(I)=WKM1(I)+WKM2(I)+WKM3(I)+SK
      A1(I)=WKM(I)/XKPM(I)
      E(I)=EXP(-A1(I)*X/UX)
C
C   COMPUTE CHEMICAL CONCENTRATION ABOVE AMBIENT (CTA)
C
      CTA(I)=CIN*DP(I)*E(I)
C
C   COMPUTE TOTAL CHEMICAL CONCENTRATION (AMBIENT + PLUME)
C
      CT(I)=CTA(I)+BGC
C
      XKPTM1(I)=KP1*TM1(I)
      XKPTM2(I)=KP2*TM2(I)
      XKPTM3(I)=KP3*TM3(I)
C
      XX1(I)=1. +XKPTM1(I)+XKPTM2(I)+XKPTM3(I)
C
      X11(I)=XKPTM1(I)*CT(I)
      X21(I)=XKPTM2(I)*CT(I)
      X31(I)=XKPTM3(I)*CT(I)
```

```
C   COMPUTE CP1, CP2, CP3, AND C
C
      CP1(I)=X11(I)/XX1(I)
      CP2(I)=X21(I)/XX1(I)
      CP3(I)=X31(I)/XX1(I)
      C(I)=CT(I)-(CP1(I)+CP2(I)+CP3(I))
C
  400 CONTINUE
C
C   WRITE OUT RRESULT
C
      DO 300 I=1,YMAX
      WRITE(IOUT,301)X,Y(I),TCSD(I),TCST(I),TCCY(I),TTC(I),TC(I),
     *CP1(I),CP2(I),CP3(I),C(I),CT(I),CTA(I)
  301 FORMAT(1X,F7.0,T8,F7.1,T16,F7.2,T24,F7.2,T32,F7.2,
     *T40,F7.2,T48,F7.2,T56,F7.2,T64,F7.2,T72,F7.2,T81,F7.2,
     *T90,F7.2,T98,F7.2)
  300 CONTINUE
      WRITE(IOUT,109)
  109 FORMAT(1X,//)
C
C   END OF COMPUTATION AT A GIVEN DOWNSTREAM DISTANCE X
C   READ NEW X
C
      GO TO 210
  999 STOP
      END
```

Example of Input and Output Files - CPLUME

a. Input Data

```
4.0 0.8 25.0
130.0
82.0 5.0
0.0 0.50 0.50
0.70 0.15 0.15
0.02 0.0003 0.000001
0.03 0.15
13.0 130.0 1300.0
0.0000000001
18
0.0 0.2 0.4 0.6 0.8 1.0 1.1 1.2 1.3 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 5.0
20.0
50.0
100.0
250.0
-9
```

b. Output File

```
INPUT YS

 1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18
0.0 0.2 0.4 0.6 0.8 1.0 1.1 1.2 1.3 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 5.0


  (1)      (2)    (3)     (4)     (5)     (6)     (7)     (8)     (9)     (10)     (11)      (12)    (13)

DISTANCE WIDTH   SAND    SILT    CLAY    TOTAL   TSS     POLL.   POLL.   POLL.  DISSOLVED  TOTAL   POLL.
                                                 ABOVE    ON      ON      ON                      ABOVE
   X       Z                             SS.     AMBI.   SAND    SILT    CLAY              POLL.  AMBI.
  (M)     (M)    (MG/L)  (MG/L)  (MG/L)  (MG/L)  (MG/L)  (MG/L)  (MG/L)  (MG/L)            (MG/L) (MG/L)


   20      0.0    3.09   41.75   41.75   86.59   4.59    0.00    0.01    0.13     0.04     0.18    0.15
   20      7.1    3.09   41.75   41.75   86.59   4.59    0.00    0.01    0.13     0.04     0.18    0.15
   20     14.1    3.09   41.75   41.75   86.58   4.58    0.00    0.01    0.13     0.04     0.18    0.15
   20     21.2    3.09   41.75   41.75   86.58   4.58    0.00    0.01    0.13     0.04     0.18    0.15
   20     28.3    3.08   41.75   41.75   86.58   4.58    0.00    0.01    0.13     0.04     0.18    0.15
   20     35.4    3.08   41.75   41.75   86.57   4.57    0.00    0.01    0.13     0.04     0.18    0.15
   20     38.9    3.07   41.74   41.75   86.56   4.56    0.00    0.01    0.13     0.04     0.18    0.15
   20     42.4    3.07   41.74   41.75   86.56   4.56    0.00    0.01    0.13     0.04     0.18    0.15
   20     46.0    3.06   41.74   41.74   86.55   4.55    0.00    0.01    0.13     0.04     0.18    0.15
   20     49.5    3.05   41.74   41.74   86.54   4.54    0.00    0.01    0.13     0.04     0.18    0.15
   20     56.6    3.03   41.73   41.74   86.50   4.50    0.00    0.01    0.13     0.04     0.18    0.15
   20     63.6    3.00   41.73   41.73   86.45   4.45    0.00    0.01    0.12     0.04     0.18    0.15
   20     70.7    2.94   41.71   41.71   86.37   4.37    0.00    0.01    0.12     0.04     0.17    0.14
   20     88.4    2.72   41.66   41.66   86.04   4.04    0.00    0.01    0.11     0.04     0.16    0.13
   20    106.1    2.32   41.56   41.56   85.44   3.44    0.00    0.01    0.10     0.03     0.14    0.11
   20    123.7    1.76   41.43   41.43   84.62   2.62    0.00    0.01    0.08     0.03     0.12    0.09
   20    141.4    1.15   41.28   41.28   83.71   1.71    0.00    0.01    0.06     0.02     0.09    0.06
   20    176.8    0.29   41.07   41.07   82.43   0.43    0.00    0.00    0.03     0.01     0.04    0.01
```

Chemical Plume Model Input Variables and Format

Variable	Format	Units	Definition
B	*	m	Width of the plume source, b
D	*	m	Mean stream depth in plume, D
UX	*	m/sec	Mean stream velocity, U_x
EY	*	m^2/sec	Dispersion coefficient, E_z
WSD	*	m/sec	Mean settling velocity for sand
WST	*	m/sec	Mean settling velocity for silt
WCY	*	m/sec	Mean settling velocity for clay
PSD	*	None	Fraction of sand
PST	*	None	Fraction of silt
PCY	*	None	Fraction of clay
BC	*	mg/l	Ambient suspended-solids concentration
MIN	*	mg/l	Initial suspended-solids concentration above ambient
BSPD	*	None	Fraction of ambient sand
BPST	*	None	Fraction of ambient silt
BPCY	*	None	Fraction of ambient clay
BGC	*	mg/l	Ambient chemical concentration
CIN	*	mg/l	Initial chemical concentration above ambient
KP1	*	$(\mu g/l)(\mu g/kg)^{-1}$	Partitioning coefficient for sand
KP2	*	$(\mu g/l)(\mu g/kg)^{-1}$	Partitioning coefficient for silt
KP3	*	$(\mu g/l)(\mu g/kg)^{-1}$	Partitioning coefficient for clay
SK	*	$(sec)^{-1}$	Total decay rate of the chemicals
YMAX	*	None	Number of input data, $y/\Sigma z$
YS	*	m	Distance coordinate in the lateral direction/σ_z
X	*	m	Distance coordinate in the longitudinal direction

* Free format

Chemical Plume Model Output Variables and Format

Variable	Format	Unit	Definition
X	F7.0	m	Distance coordinate in the longitudinal direction, x
Y	F7.1	m	Distance coordinate in the lateral direction, z
TCSD	F7.2	mg/l	Total sand concentration in bulk water
TCST	F7.2	mg/l	Total silt concentration in bulk water
TCCY	F7.2	mg/l	Total clay concentration in bulk water
TC	F7.2	mg/l	Total suspended-solids concentration
CP1	F7.2	mg/l	Chemical concentration adsorbed onto sand particulates in bulk water
CP2	F7.2	mg/l	Chemical concentration adsorbed onto silt particulates in bulk water
CP3	F7.2	mg/l	Chemical concentration adsorbed onto clay particulates in bulk water
C	F7.2	mg/l	Dissolved chemical concentration
CT	F7.2	mg/l	Total chemical concentration in bulk water
CTA	F7.2	mg/l	Total chemical concentration above ambient

Procedure

The following procedure and an example show how to run the program 'CPLUME'. In this manual user inputs are underlined, and computer prompts and responses are capitalized (see example run).

The PRIME 750 computer responds with OK when login is accepted.

Step 1. Open a file 'DATA' to read in data needed for computation.
Step 2. Open a file 'REST' to store the result after computation.
Step 3. Run the program 'CPLUME'.
Step 4. Close all files.
Step 5. List the computed result from the file 'REST'.

Chemical Plume Model Output

(1) Distance coordinate in the longitudinal direction.
(2) Distance coordinate in the lateral direction.
(3) Concentration of sand at a given point (z,x).
(4) Concentration of silt at a given point (z,x).
(5) Concentration of clay at a given point (z,x).
(6) Total suspended-solids concentration at (z,x).
(7) Suspended-solids concentration above ambient at (z,x).
(8) Concentration of chemical pollutant adsorbed into sand.
(9) Concentration of chemical pollutant adsorbed into silt.
(10) Concentration of chemical pollutant adsorbed into clay.
(11) Concentration of dissolved chemicals.
(12) Total concentration of chemical pollutant.
(13) Total chemical concentration above ambient.

Example Run

```
OK, O DATA 7 1
OK, O REST 6 2
OK, SEG #CPLUME

**** STOP
OK, C ALL
OK, SLIST REST

INPUT YS

 1   2   3   4   5   6   7   8   9   10  11  12  13  14  15  16  17  18
0.0 0.2 0.4 0.6 0.8 1.0 1.1 1.2 1.3 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 5.0


  (1)     (2)     (3)     (4)     (5)     (6)     (7)     (8)     (9)    (10)     (11)    (12)    (13)

DISTANCE WIDTH    SAND    SILT    CLAY   TOTAL    TSS     POLL.   POLL.   POLL.  DISSOLVED TOTAL   POLL.
                                                  ABOVE   ON      ON      ON                      ABOVE
   X       Z                              SS.     AMBI.   SAND    SILT    CLAY    POLL.    POLL.   AMBI.
  (M)     (M)    (MG/L)  (MG/L)  (MG/L)  (MG/L)  (MG/L)  (MG/L)  (MG/L)  (MG/L)  (MG/L)   (MG/L)  (MG/L)

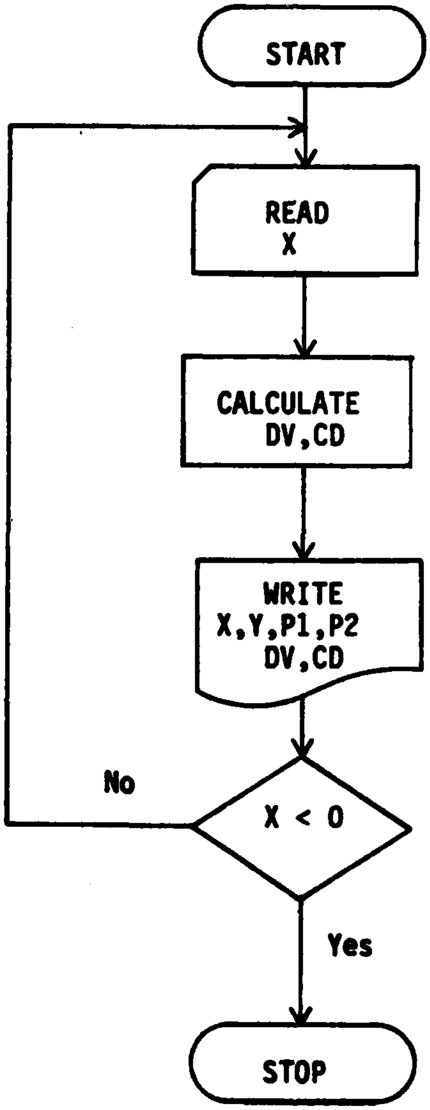

   20      0.0    3.09   41.75   41.75   86.59    4.59    0.00    0.01    0.13    0.04     0.18    0.15
   20      7.1    3.09   41.75   41.75   86.59    4.59    0.00    0.01    0.13    0.04     0.18    0.15
   20     14.1    3.09   41.75   41.75   86.58    4.58    0.00    0.01    0.13    0.04     0.18    0.15
   20     21.2    3.09   41.75   41.75   86.58    4.58    0.00    0.01    0.13    0.04     0.18    0.15
   20     28.3    3.08   41.75   41.75   86.58    4.58    0.00    0.01    0.13    0.04     0.18    0.15
   20     35.4    3.08   41.75   41.75   86.57    4.57    0.00    0.01    0.13    0.04     0.18    0.15
   20     38.9    3.07   41.74   41.75   86.56    4.56    0.00    0.01    0.13    0.04     0.18    0.15
   20     42.4    3.07   41.74   41.75   86.56    4.56    0.00    0.01    0.13    0.04     0.18    0.15
   20     46.0    3.06   41.74   41.74   86.55    4.55    0.00    0.01    0.13    0.04     0.18    0.15
   20     49.5    3.05   41.74   41.74   86.54    4.54    0.00    0.01    0.13    0.04     0.18    0.15
   20     56.6    3.03   41.73   41.74   86.50    4.50    0.00    0.01    0.13    0.04     0.18    0.15
   20     63.6    3.00   41.73   41.73   86.45    4.45    0.00    0.01    0.12    0.04     0.18    0.15
   20     70.7    2.94   41.71   41.71   86.37    4.37    0.00    0.01    0.12    0.04     0.17    0.14
   20     88.4    2.72   41.66   41.66   86.04    4.04    0.00    0.01    0.11    0.04     0.16    0.13
   20    106.1    2.32   41.56   41.56   85.44    3.44    0.00    0.01    0.10    0.03     0.14    0.11
   20    123.7    1.76   41.43   41.43   84.62    2.62    0.00    0.01    0.08    0.03     0.12    0.09
   20    141.4    1.15   41.28   41.28   83.71    1.71    0.00    0.01    0.06    0.02     0.09    0.06
   20    176.8    0.29   41.07   41.07   82.43    0.43    0.00    0.00    0.03    0.01     0.04    0.01
```

DILUTION

First, the program reads in all the data from the data file needed to solve the equation. Next, the computer calculates the dilution ratio at a given point (z,x). Using the given initial concentration of a chemical pollutant, it calculates the dissolved chemical concentration in the plume, and writes out the result.

A flow chart and a listing of the program follow as well as example input and output data files, and an input and output variable dictionary.

Flow Chart of DILUTION



Listing of the Computer Program "DILUTION"

```
         DILUTION
C
C
C   THE PROGRAM 'DILUTION' WAS WRITTEN TO COMPUTE
C   THE DILUTION RATIO AND A DISSSOLVED POLLUTANT
C   CONCENTRATION IN A PLUME
C   THE MODEL SIMULATES THE GREAT III REACH IN THE
C   MISSISSIPPI RIVER (RM 170)
C
      DIMENSION YS(20),Y1(20),Y2(20),Y(20),P1(20),P2(20),
     *DP(20),CD(20),DV(20)
      REAL*8 P1I,P2I,Y1I,Y2I,X,EY
      INTEGER YMAX
C
      DATA IN,IOUT/11,10/
C
C   READ DATA
C
      READ(IN,*) D,UX,EY
      READ(IN,*) B
      READ(IN,*)CIN
C
C   READ NUMBER OF INPUT DATA, YMAX
C
      READ(IN,*) YMAX
C
C   READ YS, Z/SIGMA Z
C
      READ(IN,*) (YS(I),I=1,YMAX)
      WRITE(IOUT,6001) (I,I=1,YMAX)
 6001 FORMAT(///'INPUT YS '//20(I2,2X))
      WRITE(IOUT,6000) (YS(I),I=1,YMAX)
 6000 FORMAT(20F4.1)
C
      WRITE(IOUT,207)
  207 FORMAT(1X,///)
C
```

```
C
C    SET TABLE FORMAT FOR THE FINAL RESULT
C
      WRITE(IOUT,204)
  204 FORMAT(1X,T3,'(1)',T13,'(2)',T27,'(3)',T42,'(4)',
     *T57,'(5)',T71,'(6)'//)
C
      WRITE(IOUT,201)
  201 FORMAT(1X,T4,'X',T14,'Z',T26,'F(+*)',T41,'F(-*)',
     *T55,'DILUTION',T68,'          ')
      WRITE(IOUT,202)
  202 FORMAT(1X,T55,'RATIO',T68,'POLL. CONC.')
C
      WRITE(IOUT,203)
  203 FORMAT(1X,T3,'(M)',T13,'(M)',T70,'(MG/L)',//)
C
C
C   READ DOWNSTREAM DISTANCE, X
C
C
    1 READ(IN,*)X
      IF(X .LT. .0) GO TO 999
      S=(2.*EY*X/UX)**(.5)
      DO 200 I=1,YMAX
      Y(I)=YS(I)*S
      Y1(I)=(Y(I)+B)/S
      Y2(I)=(Y(I)-B)/S
      Y1I=Y1(I)
      Y2I=Y2(I)
C
C   CALL SABROUTINE MDNORD FROM LIBRARY IMSL
C   TO COMPUTE THE NORMAL DISTRIBUTION FUNCTION
C
      CALL MDNORD (Y1I,P1I)
      CALL MDNORD (Y2I,P2I)
C
      P1(I)=P1I
      P2(I)=P2I
      DP(I)=P1(I)-P2(I)
C
C   COMPUTE THE DILUTION RATIO
C
      DV(I)=1./DP(I)
C
C   COMPUTE DISSOLVED POLLUTANT CONCENTRATION
C
      CD(I)=CIN/DV(I)
C
  200 CONTINUE
C
```

```
C
C   WRITE OUT COMPUTED RESULT
C
      DO 300 I=1,YMAX
      WRITE(IOUT,301)X,Y(I),P1(I),P2(I),DV(I),CD(I)
  301 FORMAT(1X,F5.0,T10,F7.1,T20,F10.4,T35,F10.4,T50,F10.1,
     *T65,F10.2)
  300 CONTINUE
      WRITE(IOUT,109)
  109 FORMAT(1X,//)
C
C   END OF COMPUTATIOPN OF DISSOLVED POLLUTANT
C   CONCENTRATIONS AT THE CROSS SECTION OF THE
C   STREAM AT GIVEN DOWNSTREAM DISTANCE, X.
C
C   READ NEXT DOWNSTREAM DISTANCE, X
C
      GO TO 1
C
  999 STOP
      END
OK,
```

Example of Input and Output Files - DILUTION

a. Input Data File

```
4.0 0.8 25.0
130.0
0.15
18
0.0 0.2 0.4 0.6 0.8 1.0 1.1 1.2 1.3 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 5.0
20.0
50.0
100.0
250.0
-9
```

b. Output File

```
INPUT YS

1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16  17  18
 0.0 0.2 0.4 0.6 0.8 1.0 1.1 1.2 1.3 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 5.0


 (1)       (2)         (3)           (4)           (5)          (6)

  X         Z         F(+$)         F(-$)        DILUTION
                                                  RATIO      POLL. CONC.
 (M)       (M)                                                 (MG/L)

  20.       0.0       0.9999        0.0001         1.0          0.15
  20.       7.1       0.9999        0.0003         1.0          0.15
  20.      14.1       1.0000        0.0005         1.0          0.15
  20.      21.2       1.0000        0.0010         1.0          0.15
  20.      28.3       1.0000        0.0020         1.0          0.15
  20.      35.4       1.0000        0.0037         1.0          0.15
  20.      38.9       1.0000        0.0050         1.0          0.15
  20.      42.4       1.0000        0.0066         1.0          0.15
  20.      46.0       1.0000        0.0087         1.0          0.15
  20.      49.5       1.0000        0.0114         1.0          0.15
  20.      56.6       1.0000        0.0189         1.0          0.15
  20.      63.6       1.0000        0.0303         1.0          0.15
  20.      70.7       1.0000        0.0468         1.0          0.14
  20.      88.4       1.0000        0.1196         1.1          0.13
  20.     106.1       1.0000        0.2492         1.3          0.11
  20.     123.7       1.0000        0.4298         1.8          0.09
  20.     141.4       1.0000        0.6267         2.7          0.06
  20.     176.8       1.0000        0.9071        10.8          0.01
```

Dilution Model

Input Variables and Format

Variable	Format	Unit	Definition
B	*	m	Width of the plume source, b
D	*	m	Mean stream depth in plume, D
UX	*	m/sec	Mean river velocity, u_x
EY	*	m^2/sec	Dispersion coefficient, E_z
CIN	*	mg/l	Initial chemical concentration above ambient

Output Variables and Format

Variable	Format	Unit	Definition
X	F7.0	m	Distance coordinate in the longitudinal direction
Y	F7.1	m	Distance coordinate in the lateral direction
P1	F7.2	None	Normal distribution function: F(*), $* \geq 0$
P2	F7.2	None	Normal distribution function: F(*), $* < 0$
DV	F7.2	None	Dilution ratio
CD	F7.2	mg/l	Dissolved chemical concentration

*Free format

Dilution Model Output

(1) Distance coordinate in the longitudinal direction

(2) Distance coordinate in the lateral direction

(3) Normal distribution function: $F(*)$, $* \geq 0$

(4) Normal distribution function: $F(*)$, $* < 0$

(5) Dilution ratio

(6) Dissolved chemical concentration

APPENDIX D

REFERENCED PROCEDURES FOR CHEMICAL ANALYSES

Analyte	Referenced Procedure
Cadmium	Atomic Absorption, Direct Aspiration - Method 213.1, Atomic Absorption, Heated Graphite Furnace - Method 213.2-1, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Chromium	Atomic Absorption, Direct Aspiration - Method 218.1, Atomic Absorption, Heated Graphite Furnace - Method 218.2, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Copper	Atomic Absorption, Direct Aspiration - Method 220.1, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Iron	Atomic Absorption, Direct Aspiration - Method 236.1, Atomic Absorption, Heated Graphite Furnace - Method 236.2, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Lead	Atomic Absorption, Direct Aspiration - Method 239.1, Atomic Absorption, Heated Graphite Furnace - Method 239.2, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Manganese	Atomic Absorption, Direct Aspiration - Method 243.1, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Mercury	Cold Vapor Method with Preliminary Digestion - Method 245.1, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Nickel	Atomic Absorption, Direct Aspiration - Method 249.2, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Zinc	Atomic Absorption, Direct Aspiration - Method 289.2, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Total Solids	Gravimetric, Dried at 103-105°C - Method 160.3, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Volatile Solids	Gravimetric, Ignition at 550°C - Method 160.4, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)

Analyte	Referenced Procedure
Oil and Grease	Gravimetric, Separatory Funnel Extraction - Method 413.1, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Ammonia Nitrogen	Automated, Phenate Method - Method 417F, Standard Methods, 14th Edition, p. 363
Orthophosphate	Automated Ascorbic Acid Reduction Method - Method 424G, Standard Methods, 14th Edition, p. 422
Chemical Oxygen Demand	Titrimetic, Mid-Level - Method 410.1, Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 (March 1979)
Polychlorinated Biphenyls (PCBs)	"Methods for Benzidine Chlorinated Organic Compounds, Pentachlorophenol and Pesticides in Water and Wastewater," U.S. EPA Environmental Monitoring and Support Laboratory, September 1978, p. 43
Priority Pollutants	EPA Method 625, Federal Register Vol. 44, No. 233 (3 December 1979), p. 69540