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William H. Hollings III for the degree of Master of Science

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Title: FIELD VERIFICATION OF A MATHEMATICAL MODEL FOR THE PHYSICAL FATE PREDICTION OF DREDGED MATERIAL INSTANTANEOUSLY DISPOSED AT SEA

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Abstract approved: ______________________
Dr. Charles K. Sollitt

Dredged spoil plumes are monitored during nine hopper dredge disposal events in 186 foot water depths offshore near Coos Bay, Oregon. Position and solids volume concentration characteristics of the plumes are established.

Computer simulations of the monitored events are executed using the WES modified version of the Koh-Chang instantaneous disposal program. Field data, including ambient currents and density profiles, dredge volumes, and sediment characteristics, are used as model input.

Field observations are compared directly with model predictions of cloud position, component sediment concentrations, and accumulated depth and position of material settled out of suspension. Significant differences are noted between predicted and observed cloud position and concentration.

FIELD VERIFICATION OF A MATHEMATICAL MODEL FOR THE PHYSICAL FATE PREDICTION OF DREDGED MATERIAL INSTANTANEOUSLY DISPOSED AT SEA

by

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1. INTRODUCTION

1.1 Motivation

Historically, one of the primary civil works functions of the U.S. Army Corps of Engineers has been the maintenance of navigable waterways. In this context the Corps annually performs dredging in excess of 300 million cubic yards, of which a substantial portion is accomplished using seagoing hopper dredges.

The hopper dredge is a self-propelled, self-contained dredging plant. It is typically used where the project area is far removed from the disposal site; in such circumstances the speed and mobility of the hopper dredge makes it the most efficient plant available.

Dredged sediment is stored in hoppers. Once at the disposal site, the spoil material is released through bottom opening doors. Other means of disposal include continuous, pumped discharge from a stationary barge or vessel, and a similar discharge into the wake of a moving vessel. This investigation is limited to instantaneous (within practical limits) bottom disposal from a stationary hopper dredge.

In order to assess the impact of the repeated disposal of large quantities of dredged material at a given spoil location, one must be able to evaluate the fate of the material following release. Material could be transported to an environmentally unacceptable area outside the selected disposal site; or, currents could cause material to be redeposited in the project area. Such movement was observed by Joyce (1979). For these reasons, a predictive determination of the spatial and temporal distribution of the dredged material subsequent to a disposal event is required.

In some instances, it may be desirable to maintain the material in a compact location, while in other circumstances a wide dispersal may be required to reduce the concentration of some undesirable component of the spoils. In either case, the mechanics of the dispersion of the discharged material must be examined in order to predict its fate.

Johnson (1974) identified the Koh-Chang mathematical model as the most suitable modeling instrument available. The Koh-Chang numerical model was subsequently modified on several different occasions in order to make it more readily usable as well as to provide improved flexibility and accuracy of prediction. See Section 1.3 for a discussion of the various modifications implemented.

Given the Koh-Chang model in its present modified form, the question arises as to how much confidence may be placed in the resulting predictions. The model has been laboratory tested and calibrated (see Koh and Chang, 1973; Bowers and Goldenblatt, 1978); it has also been field tested (see Johnson and Holliday, 1978) under certain conditions. While these field experiments included estuarine, Great Lakes, and open sea disposals, no conclusive results were available for the at sea events. No ocean disposal events were monitored in depths comparable to those under consideration--around 200 feet.

While the Koh-Chang model in its present form may be used to predict the short-term fate of dredged material instantaneously released from a hopper dredge at sea in 200 foot water depths, the accuracy of the model prediction has never been verified under these circumstances. It is the purpose of this study to investigate the reliability of the model through comparison of field data with model predictions.

1.2 Dispersive behavior of sediments disposed at sea.

1.2.1 General Considerations.

Various factors affect the short-term fate of dredged material disposed at sea. These factors may be divided into three groups for convenience:

1) ambient conditions

2) dredged material properties

3) disposal parameters

Ambient conditions include currents, ocean density profile, and turbulence. Currents may be a function of the three orthogonal coordinates x, y, z, and of time; the ocean density is determined by temperature and salinity profiles. Turbulence is caused by many factors, including surface wave conditions, shear between currents of varying velocity, and shear between currents and the ocean bottom.

Dredged material properties are those parameters required to completely describe the material released. The sediment may be described by the grain size distribution, cohesive properties, flocculation tendencies, and specific gravity of solids. The aggregate dredged material may be characterized by solids volume concentration and resulting density, and the density distribution within the hopper.

Disposal parameters include the total volume of material released, the insertion speed or initial downward velocity, and the water depth.

The dredged material consists of a fluid portion (specific gravity approximately equal to one) and a solid portion (s.g.>1). As noted, the solid portion may be characterized by a grain size distribution. If the volume concentration of solids is low and the individual particles are small, the slurry will behave as a dense liquid according to Clark, et al (1971). The material under consideration satisfies these criteria, having a median grain size < 20 microns and solids volume concentrations of approximately 0.2.

Investigators have generally divided dispersion following an instantaneous dump into four phases (see Figure 1-1):

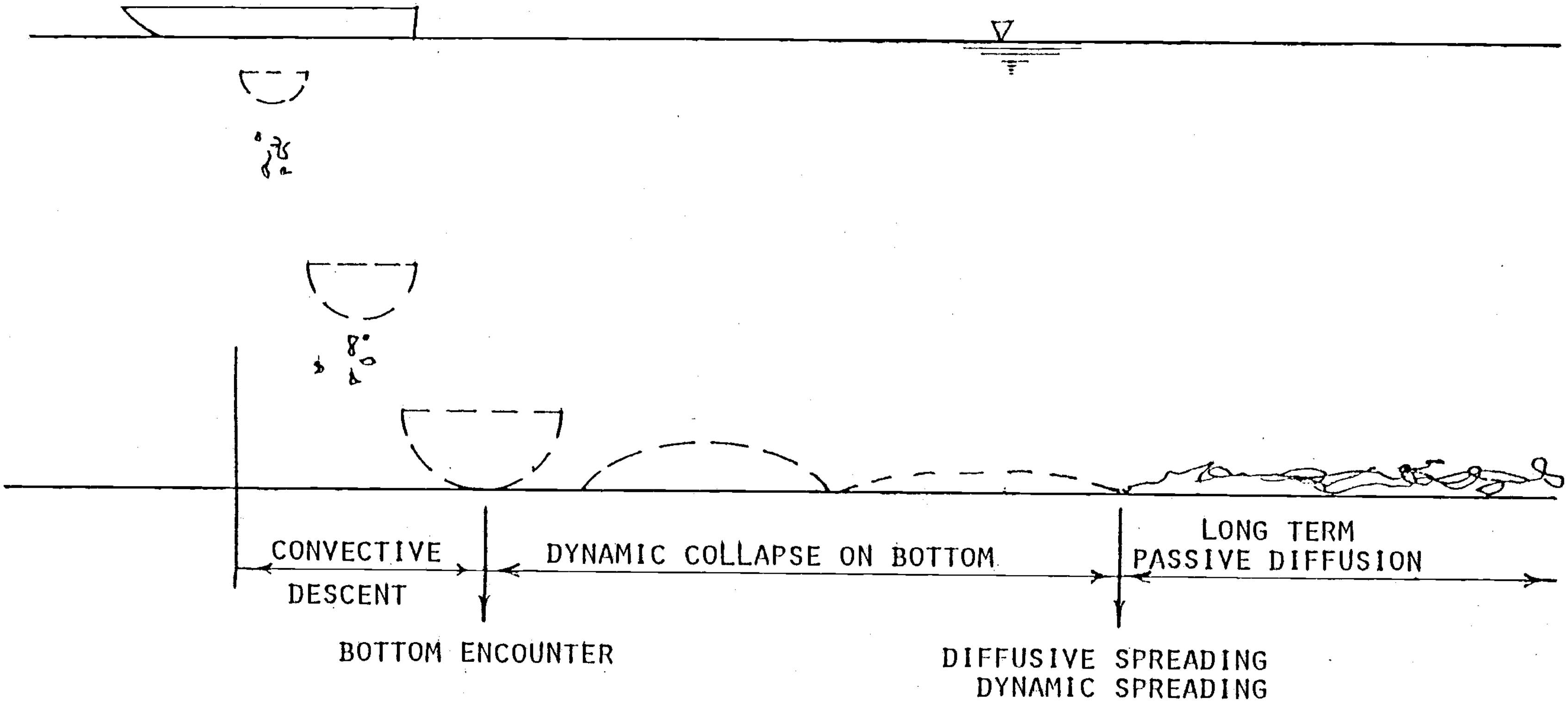


Figure 1-1 Phases of instantaneously dumped material dispersion.
(from Brandsma and Divoky, 1976)

1) convective descent

2) collapse

3) long-term diffusion

4) bottom transport or resuspension.

1) Convective Descent.

The material will have a mean density greater than ambient and may possess initial downward momentum due to the insertion speed caused by the hydraulic head in the hopper.

The slurry descends under the influence of negtive buoyancy and initial downward momentum; drag and inertia forces act to slow the acceleration of the slug of dense fluid. Entrainment of ambient will tend to impart momentum to the mass in the direction of ambient flow.

Shear stresses will develop at the cloud-ambient interface, resulting in entrainment of ambient and dissipation of momentum from turbulent eddies. Larger solid particles with settling velocities greater than the velocity of the descending plume will settle out, reducing the plume density. Entrainment of ambient will also decrease density.

2) Dynamic Collapse.

The convective descent phase is over when either of two eventualities occurs: 1) the plume density becomes equal to ambient density at some intermediate depth, where the plume comes to rest or oscillates with a decaying motion about that depth, or, 2) the bottom is encountered. Result 1) is possible if the ocean is density stratified, however, all referenced investigators have observed a bottom encounter of the dumped material.

Upon bottom impact, the material will undergo a dynamic spreading or collapse phase. In this phase the material spreads horizontally in the form of a turbidity current while the vertical dimension decreases. At the same time, further ambient entrainment occurs; this entrainment, along with bottom friction and drag, dissipates the remaining momentum, and may result in an increase in the cloud thickness.

3) Long-term Diffision.

This phase begins when the much diluted cloud, having dissipated all momentum, becomes dynamically passive. Further mixing is caused by ambient turbulence and currents. Molecular diffusion is considered to be insignificant. Larger solids remaining in suspension at this time will tend to settle out while vertical turbulence will keep a portion of the fine particles in suspension.

4) Bottom transport or resuspension.

When all solids have come to rest on the bottom, further movement is possible through bed load (bottom) transport or resuspension of material. This last phase is not included in the short-term model under consideration. The reader is referred to Graf (1971) for a complete discussion of the mechanisms involved in this phase.

1.2.2 Previous investigations.

Gordon (1974) monitored dredged material disposal in Long Island Sound. The material was characterized as "marine silt of high water content." Water depth at the spoil site was 20 meters. Bottom dump scows of 1200 and 2000 m^3 capacity were used. Currents at the site ranged from 6 cm/sec to 30 cm/sec. Sediment concentrations were quantified using 10 cm pathlength transmissometers.

Following a disposal event, Gordon observed an upper turbid cloud and a bottom density flow. Downward velocities of the descending cloud were calculated, from timed transmissometer data, to be approximately 2 m/sec. This descent speed was observed to decline with increasing depth. Gordon postulated that this was due to entrainment and increased drag caused by additional frontal area.

Gordon also observed the bottom collapse phenomena, with initial horizontal spreading speeds of around 12 m/min. This horizontal motion was dissipated after around 15 minutes, indicating the end of the collapse phase. Gordon's observations also corroborated the decreasing vertical scale of the bottom turbid cloud as it spread horizontally.

Gordon estimated the size of the upper turbid cloud as 10 m thick and 60 m in diameter. From measured sediment concentrations he determined that approximately 19 m^3 of solids were contained in this cloud, or less than one percent of the total released.

Joyce (1979) observed a two phase behavior in dredge spoils dumped in 15 meters of water at Lowestoft, England. He hypothesized that the dredged mud divided into a "solid fraction and a semi-fluid fraction." Joyce used an echo sounder set at maximum sensitivity in a research vessel 50 m downstream of the dredge, to track spoils following release. He observed a turbid cloud passing beneath the vessel three to four minutes after the dump, extending from six meters beneath the sea surface to the bottom. No attempt was made to quantify cloud size, solids concentrations, or total amount of solids in this upper cloud.

Nittrouer and Sternberg (1975) observed a "minor surface plume" on aerial photographs taken after barged dredged material disposal events in Dana Passage, Puget Sound, Washington. Water depths were 30 meters. Again, no attempt was made to establish the amount of material in this surface plume.

The main conclusion drawn by Nittrouer and Sternberg was that 84 percent of the material dumped was lost from the disposal site within four months of termination of the disposal operations.

It has been noted that clods of cohesive material may have fall velocities such that they may fall out of a descending cloud. Bokuniewicz, et al., (1978) determined that no clods were present in a hopper dredge release, due, presumably, to the extensive reworking of sediment during the dredging operation, and the large amount of water released with the soil. Bokuniewicz, et al., observed that material released from a hopper dredge "behaves like a dense, viscous fluid." Bokuniewicz' experiments were carried out under a variety of conditions; he found that conditions favorable to clod formation included bucket dredging, cohesive soils, and low insertion speeds.

Bokuniewicz found mean cloud descent speeds of .5 to 2.8 m/sec for insertion speeds of .4 to 6.5 m/sec, with higher descent speeds resulting from higher insertion speeds. In all events studied, the cloud was traveling at about one m/sec when it reached the sea floor. Following the bottom encounter, an initial spreading velocity of one m/sec was calculated. Thickness of the collapsed cloud was found to be approximately four meters, with solids concentrations on the order of eight g/l.

Bokuniewicz, et al., also observed decreasing cloud speed and thickness with increasing radius.

1.3 Historical model development.

Koh and Fan (1969) developed a mathematical model to predict the radioactive debris distribution subsequent to a deep underwater nuclear explosion. Koh (1971) noted that this model could be adapted to predict the short term fate of sludge disposed at sea.

Koh and Chang (1973) working under contract with the U. S. Environmental Protection Agency, carried out the adaptation, resulting in a general model designed to predict the short term fate of ocean disposed materials. This model treated three disposal methods:

1) instantaneous dump from a bottom opening hopper dredge or scow

2) pumped jet discharge

3) pumped discharge into the wake of a moving vessel

Koh and Chang wrote a computer program incorporating the mathematical model; it was designed to allow analysis of the dispersal of disposed material after a proposed dump.

Johnson (1974) in a study of available models for physical fate prediction of dredged materials conducted for the U. S. Army Engineer Waterways Experiment Station (WES), identified the Koh-Chang model as the most suitable then available and recommended modifications to be made to it.

Brandsma and Divoky (1976), working for Tetra Tech, Inc. under contract to the WES, undertook the task of modifying the original Koh-Chang model to better meet the Corps requirements. These improvements allowed the original Koh-Chang model to accomodate:

1) unsteady currents (in time)

2) horizontal and vertical current variation

3) variable depth

4) terrestrial boundaries.

In addition, the long term diffusion phase of the model was rewritten to employ a scheme developed by Fischer (1972) better suited to efficiently handle the newly imposed conditions (1-4, above) rather than the method-of-moments approach used by Koh and Chang.

Brandsma and Divoky's efforts resulted in two programs; one for instantaneous discharge and one for continuous (jet) discharge.

Johnson and Holliday (1978) accomplished a preliminary calibration of these two models using field data collected by Bokuniewicz, et al., (1978). Instantaneous dumps monitored occurred at Duwamish Waterway, Puget Sound, Washington, in 200 feet of water, and in the New York Bight area in 85 feet of water.

Johnson and Holliday concluded that the models can accurately simulate events occurring in the water column following release, however, the model's description of bottom impact and surge was not found to be realistic. By adjusting coefficients, the model could be made to predict the lateral spread of the collapsing cloud and the rate of change in total cloud volume.

Given adequate characterization of the sediment properties of the dredged material, a "reasonable description of the concentrations within the surge and long-term phase" was noted.

The program was further modified by Johnson and Holliday to allow tracing of a conservative chemical element in the disposed material. In addition, a modification was introduced to calculate settling velocities of cohesive fractions as a function only of their concentrations, in the collapse and passive diffusion phases. Other modifications are discussed in Johnson and Holliday (1978).

Bowers and Goldenblatt (1978) working for JBF Scientific Corporation under contract to the U. S. Environmental Protection Agency, modified, simplified, and calibrated the instantaneous dump dredged material model. The calibration method adopted by Bowers and Goldenblatt involved a series of model tests conducted in a laboratory tank. Entrainment, drag, and apparent mass coefficients were then adjusted to provide a best fit to measured data describing cloud radius versus depth.

A parameter referred to as the MLL, (or multiple of the liquid limit), equal to the percent moisture divided by the liquid limit of the sediment, was introduced. The above mentioned coefficients are then calculated as functions of the MLL.

Other modifications to the WES model allowed the user to select a simplified input/output version of the program. A users' manual was also prepared. This is the program version used in the present study.

1.4 Scope of this research project.

It was proposed to accomplish a full scale field verification of the Koh-Chang instantaneous dump model in its present form. The model may be used without modification to simulate a hopper dredge dump at an unbounded deep water disposal site. The predictive accuracy of the model has never been tested under conditions of currents, deep water, open ocean, and dissimilar sediments.

Disposal events were monitored at the selected site. The sediment concentrations and the size and position of the spoil cloud were monitored following the dump; simultaneously a record of ambient currents was assembled. Data describing the dump were then be input to the computer model forming a basis of comparison to measured data.

Before each monitored disposal event, recording current meters and transmissometers were deployed in the area downstream from the buoy designating the disposal site location. Subsequent to the event, the plume was tracked from a research vessel while concentration profiles were taken, using 5 and 25 cm path length transmissometers attached to a cable, to quantify sediment concentrations. The depth of each reading was determined using a pressure transducer fixed to the cable with the transmissometers.

A computer simulation of each event was then executed using the most recent version of the Koh-Chang computer model available; concentration profiles measured in the field were then compared directly to the predicted values.

2. MODEL DEVELOPMENT, APPLICATION, AND BEHAVIOR

2.1 Mathematical model development.

The mathematical model in its present form is briefly described here. A more complete development is found in Koh and Chang (1973), Brandsma and Divoky (1976), Johnson and Holliday (1978), and Bowers and Goldenblatt (1978). The following assumptions are essential to the model development:

1) The dredged material is composed of two phases: a liquid portion that is miscible with the ambient, and a solid portion. The solids consist of several components that may be characterized by a fall velocity (V_{fi}) a solid density (S_{gi}) and an initial concentration (C_{si}).

2) Material fate may be modeled as four separate transport phases; the initial conditions required for each subsequent phase are obtained from the output of the previous phase. The phases are convective descent, dynamic collapse, and long term diffusion. Phase four, bottom transport and and resuspension, is not considered in the present model.

3) The cloud will rapidly assume the form of a hemisphere following the instantaneous dump and thus may be initially characterized by a radius, a, and volume, V_c,

$$V_c = \frac{2}{3} \Pi \ a^3$$

where V_c is the volume of material disposed.

2.1.1. Convective descent phase.

A list of equations governing the convective descent phase follows. Symbols are defined as they occur.

The equations are expressions of mass, momentum, buoyancy, and vorticity conservation. The cloud is assumed to possess a mean radius, a(t) and velocity, U(t), where t is the elapsed time from release.

Equation (1) is an expression of mass conservation; the difference between rate of ambient mass entrainment and rate of mass loss (resulting from particles settling out of the cloud) is set equal to the time rate of change of cloud mass. The ambient entrainment rate (E) as defined in equation (2) is a function of the plume's frontal area, the vector difference between cloud and ambient velocities ($\Delta\vec{V}$) and an entrainment coefficient, α.

Equation (4) is used to calculate the rate at which the i^{th} particle group settles out ahead of the cloud. The settling coefficient, β_i, is assumed to be zero. Conservation of momentum is expressed in equation (5); the vector sum of the negative buoyant force, drag force, rate of ambient momentum entrainment, and momentum lost when particles settle out of the cloud is set equal to the time rate of change of momentum.

The drag force defined by equation (7) has x and z components caused by shearing ambient currents and a component due to shear at the cloud ambient interface.

Equations governing convective descent phase.

$$\frac{d}{dt}(V_c \rho) = E\rho_a - \sum_i a\, S_i\, \rho_i \qquad (1)$$

V_c = cloud volume

E = (ambient) entrainment rate

S_i = settling rate of i^{th} particle group

ρ_i = density of i^{th} particle group

$\rho_a(y)$ = ambient density at depth y

$\rho(t)$ = mean cloud density

$$E = 2\Pi a^2 \left|\Delta\vec{V}\right| \alpha \qquad (2)$$

a = hemisphere radius

α = entrainment coefficient

$$\left|\Delta\vec{V}\right| = \left|\vec{U} - \vec{U}_a\right| \qquad (3)$$

$\vec{U}$ = cloud vector velocity

$\vec{U}_a$ = ambient vector velocity

$$S_i = \Pi a^2\, V_{fi}\, C_{si}\, (1-\beta_i) \qquad (4)$$

V_{fi} = fall velocity of i^{th} particle group

C_{si} = volume concentration of ith particle group

β_i = settling coefficient assumed = 0

$$\frac{d}{dt}\vec{M} = \vec{F}_j - \vec{D} + E\,\rho_a\,\vec{U}_a - \sum_i \rho_i\, S_i\, \vec{U} \qquad (5)$$

$\vec{M}$ = momentum

$\vec{F}_j$ = negative buoyant force

$\vec{D}$ = drag force on descending cloud

$$\vec{F}_j = \frac{2}{3} \Pi a^3 g (\rho - \rho_a) \tag{6}$$

$$\vec{D} = \frac{1}{2} \rho_a \Pi a^2 \left|\Delta\vec{V}\right| \Delta\vec{V} Cd \tag{7}$$

C_D = drag coefficient

$$\vec{M} = C_m \rho \frac{2}{3} \Pi a^3 \vec{U} \tag{8}$$

C_m = apparent mass coefficient

$$\alpha = .285 + .00493 (MLL - 2.9) \tag{9}$$

$$C_m = 1.075 + 0.675 \tanh [3.2(MLL - 1.875)] \tag{10}$$

$$C_d = 0.7 - 0.5 \tanh [3.2 (MLL - 1.875)] \tag{11}$$

MLL = multiple of the liquid limit of the dredged material

$$MLL = \frac{\text{moisture content}}{\text{liquid limit}}$$

$$\frac{dK}{dt} = -A\varepsilon \tag{12}$$

K = vorticity

A = a dissipation parameter

ε = the ambient density gradient

$$A = \frac{C a^2 g}{\rho_a(0)} \tag{13}$$

C = a vorticity dissipation coefficient

$\rho_a(0)$ = the density at the free surface

$$\varepsilon = \frac{d\rho_a}{dy} \tag{14}$$

Momentum Eq. (8) is the product of cloud mass, velocity, and an apparent mass coefficient.

Equations (9) - (11) are empirical expressions for the calculation of entrainment, apparent mass, and drag coefficients. Bowers and Goldenblatt (1978) derived the expressions for these coefficients as functions of the multiple of the liquid limit (MLL) using experimental laboratory data.

Conservation of vorticity is written as equation (12). The reader is referred to Brandsma and Divoky (1976) for further information.

Equations (1) to (14) (Brandsma and Divoky, 1976) form an initial value problem that may be solved numerically, given the required initial conditions. A standard fourth order Runge-Kutta scheme is employed.

2.1.2 Collapse phase.

The convective descent phase is terminated when either of two eventualities occur:

(1) the descending cloud impacts the bottom or,

(2) in case of density statified ambient, sufficient entrainment occurs that the cloud becomes neutrally buoyant and oscillates about some intermediate depth.

In either case, the cloud's vertical dimension will decrease and the horizontal scale will increase as the cloud collapses. In order to account for this collapse, the cloud is assumed to be an oblate spheroid (or one half of an oblate spheroid in case of bottom collapse) having major and minor axes, a, and b, respectively. The same equations used in the convective descent phase are employed, with the exception of vorticity, which is assumed dissipated and is therefore neglected.

A net pressure due to density differences between the cloud and the ambient provides the force causing the cloud's collapse and radial spreading. Form drag, skin friction drag, and, in case of bottom impact, bottom friction drag, resist the collapse.

Summing forces on an elemental cloud slice (see Fig. 2-1)

$$I = F_D - D_D - F_f - F_{bf} \qquad (15)$$

where I = horizontal inertia force
F_D = net pressure force
D_D = form drag
F_f = skin friction drag
F_{bf} = bottom friction force

The horizontal inertia force may be set equal to the time rate of change of the product of slice mass and centroidal velocity, V_1:

$$I = \frac{d}{dt} \left(\rho \frac{\Pi\, ab^2}{16} V_1\right) d\theta \qquad (16)$$

In solving for the value of V_1 at the next time step, equation (15) and the current value of V_1 are used to calculate $\int I dt$. Equation (16) is then solved for the subsequent value of V_1.

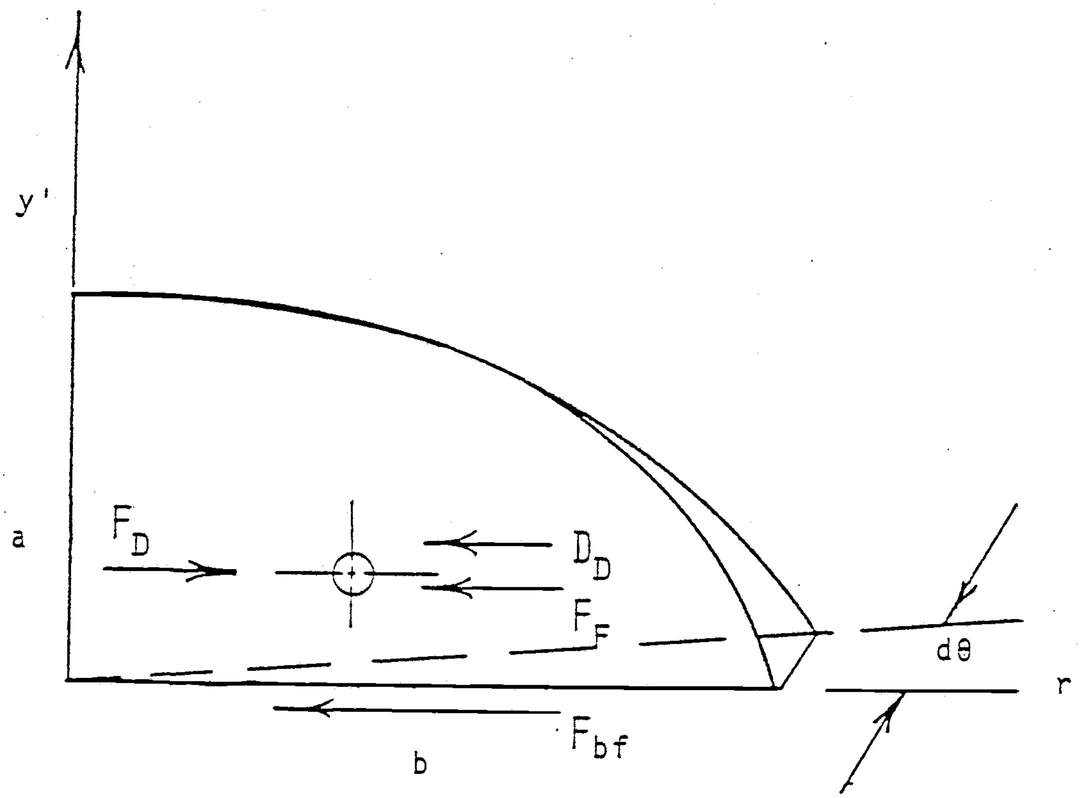


Figure 2-1 Summation of forces on an elemental cloud slice. (After Brandsma and Divoky, 1976)

Given a set of initial conditions (obtained from the output of the convective descent phase) the equations may be solved using numerical integration techniques.

2.1.3 Passive diffusion phase

The present model employs an adaptation of the convolution integral method developed by Fischer (1972) to calculate the concentration of a dispersing material as a function of time and location. The passive diffusion phase begins when the cloud's momentum has decayed due to friction losses to the point where additional mixing is due primarily to ambient turbulence and currents.

The disposal location is subdivided into a grid (see Fig. 2-2); each grid square measures DX by DX. The material remaining in suspension at the end of the collapse phase is stored for bookkeeping purposes in a group of small clouds. These small clouds are then tracked through each time step until the cloud size approaches the scale of the grid square; at this time it is inserted into the grid.

The approximate form of Fischers' convolution integral appears in the model as follows:

$$C_1' = C_1 - \frac{E\Delta t}{\Delta X^2}(4C_1 - C_2 - C_3 - C_4 - C_5)$$

where C_2, C_3, C_4, and C_5 are the concentrations in neighboring grid squares, (see Fig. 2-3), C_1 and C_1' are the concentrations at the beginning and end of a time step, Δt is the length of a time step,

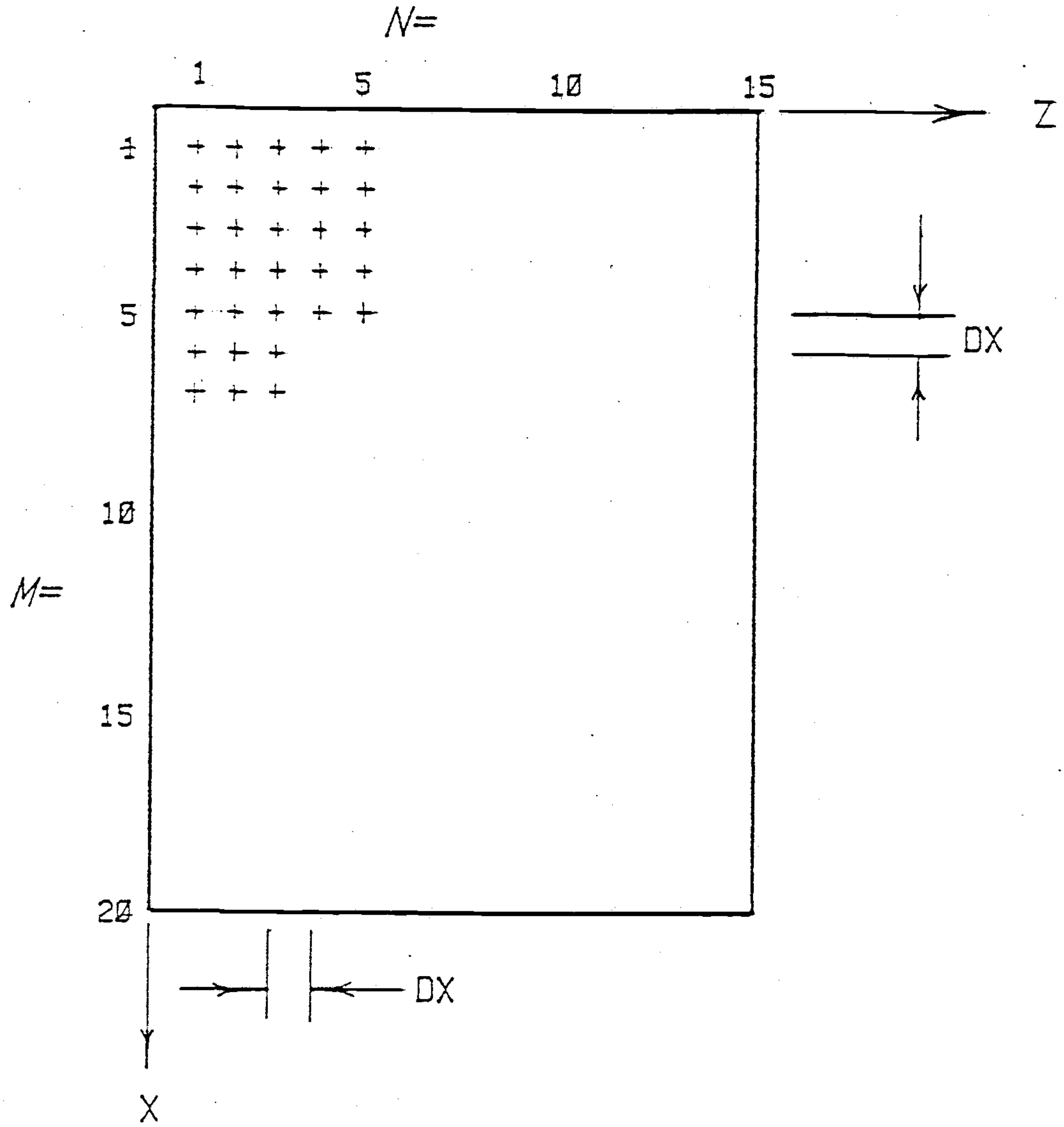


Figure 2-2 Long term diffusion grid. (example)

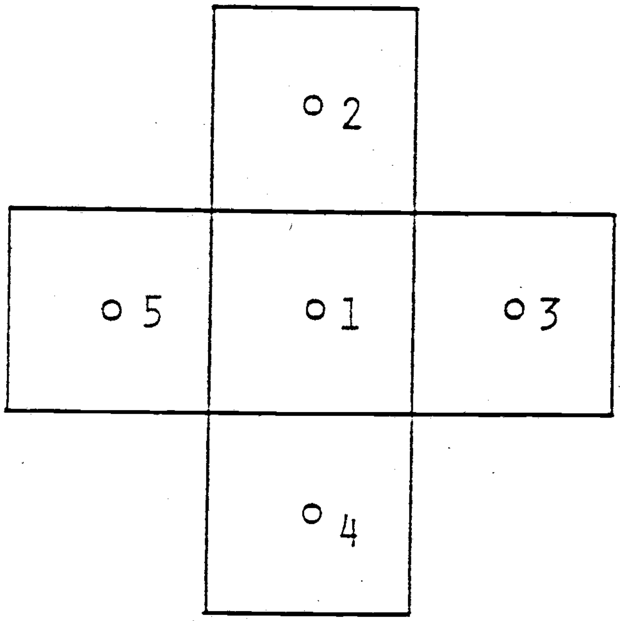


Figure 2-3 Adjacent grid points used in long term diffusion calculations.

and Δx is the grid spacing. E is a diffusion coefficient assumed equal to

$$E = A_\lambda \, (\Delta x)^{4/3}$$

where A_λ is a dissipation parameter empirically determined.

A "top hat" profile of uniform concentration is assumed for each grid square and material component (see Fig. 2-4). Output information for each grid square includes plume thickness, depth to top of plume, and concentration, for each solid component.

Material is allowed to settle out at velocity V_f for the time step; vertical growth (due to vertical turbulent diffusion) is approximated by the expression:

$$\Delta\xi = 2(2 \, K_y \, \Delta t)^{1/2}$$

where $\Delta\xi$ = the vertical growth experienced by the upper and lower cloud boundaries during time Δt (see Fig. 2-5). K_y is a vertical diffusion coefficient determined empirically. When material encounters the bottom, it is assumed to remain and accumulated there.

2.2 Required model input

Davis and Bowers (1980) have prepared a comprehensive users' manual describing the operation of the computer model under consideration. These instructions were followed in making the analyses for the present study. Program users are referred to that document for

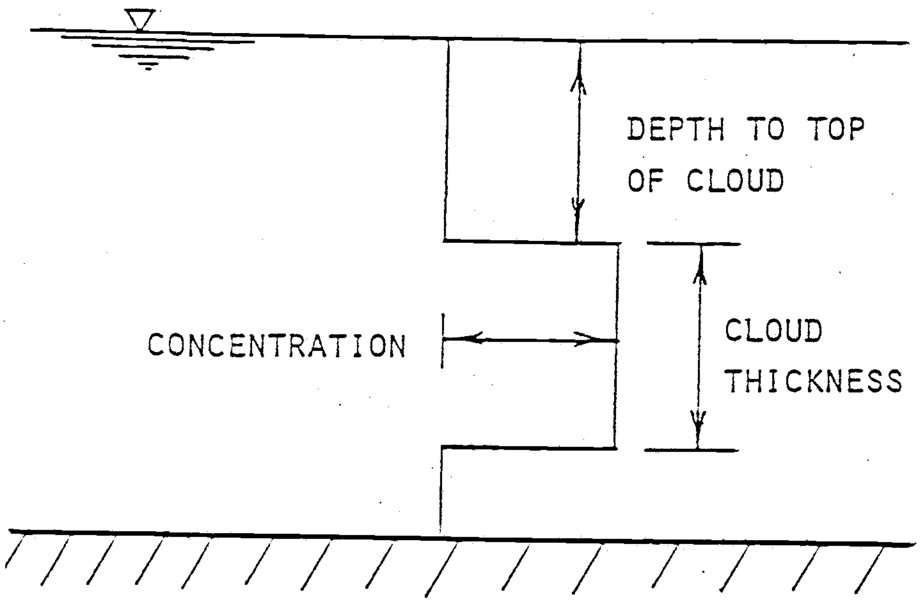


Figure 2-4 Assumed "top hat" concentration profile of a solids component in the long term diffusion phase as specified at a grid point.

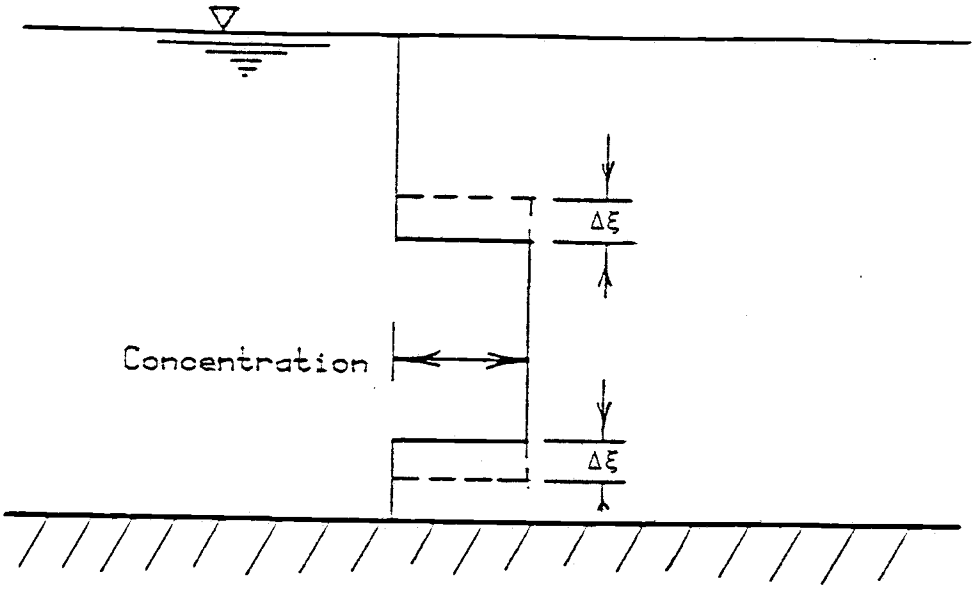


Figure 2-5 Vertical growth of cloud at a grid point.

more specific information regarding input format and operational options; a brief description of the required input data is presented for the readers' information.

Input data is divided into four groups for discussion purposes:

(1) sediment characteristics

(2) ambient conditions

(3) disposal parameters

(4) operational parameters

2.2.1 Sediment characteristics.

The solid material in the dredge spoil is divided into components (three in the present study). Each component is assigned a density (gm/cc), volume concentration (ft^3/ft^3), fall velocity (ft/sec) and "void ratio." Up to twelve components are permitted. In addition, the liquid limit of the aggregate sediment is required.

2.2.2 Ambient conditons

2.1.2.1 Ambient density profile

Ambient density at specified depths is input; the final value must be at the extreme water depth.

2.2.2.2 Ambient currents

A two level velocity profile was used for the present study (see Fig. 2-6). X and Z velocity components are specified at two depths. Velocities were assumed constant in horizontal space and time, although the program is capable of handling time variant velocities, as well as other velocity profile options. (i.e., a logarithmic velocity profile.)

2.2.3 Disposal parameters

The disposal site is subdivided into an N by M grid, with grid spacing, DX, specified. Barge coordinates are input as XBARGE and ZBARGE (in feet), where the upper left-hand corner is 0,0. Depth for the entire disposal area was input as a single value; a varying depth field is permitted, requiring depth specification at each grid point.

Time parameters required are time of dump (in seconds after the beginning of a tidal cycle), duration of simulation (seconds), and the long term time step (seconds).

Discharge parameters include initial cloud radius (ft) depth of centroid (ft) and velocity (fps). The material disposed is grossly characterized by its density, aggregate voids ratio, liquid limit, and average specific gravity.

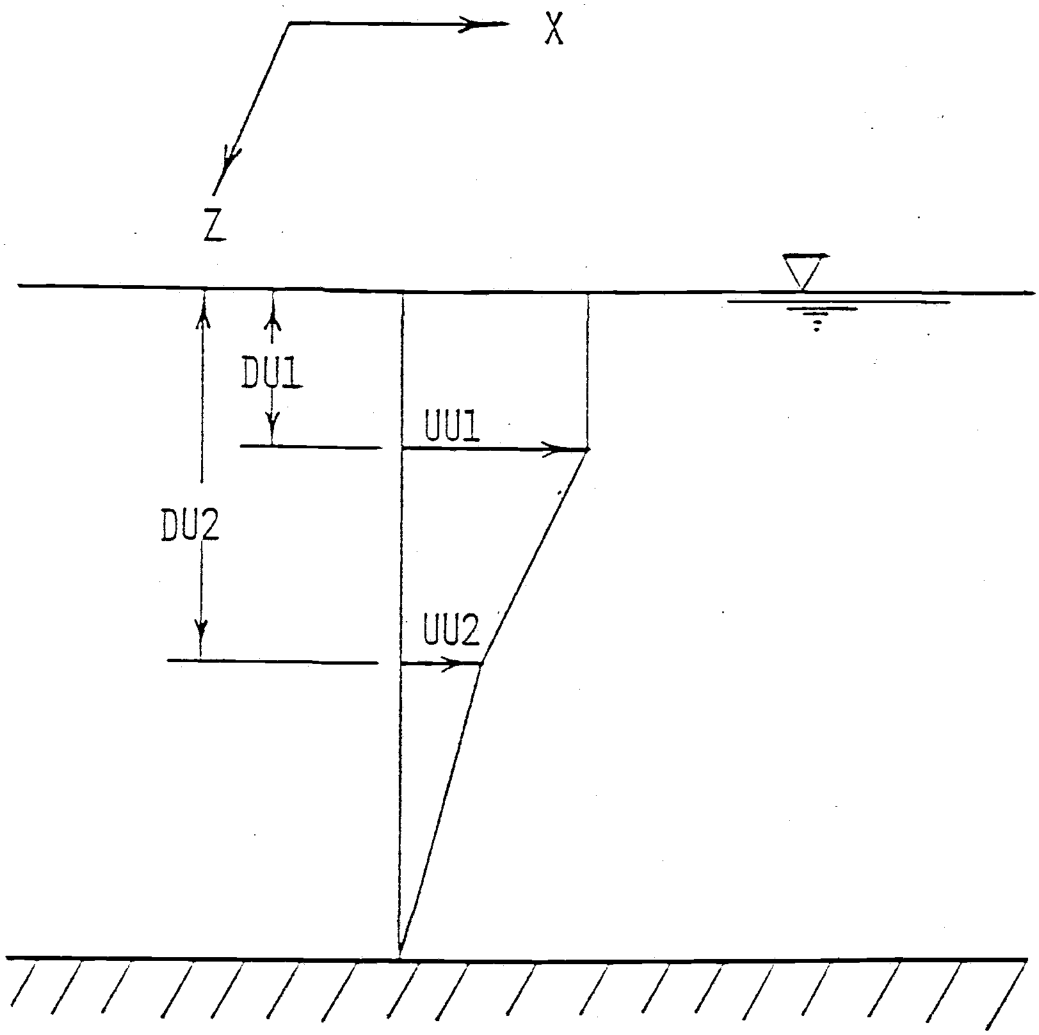


Figure 2-6 Ambient velocity profile as input; Z direction similar. (After Davis and Bowers, 1980)

2.2.4 Operational parameters

Operational parameters include output format options, and options to specify a simplified input. Figure 2-7 shows the computer generated input data summary for a typical run.

2.3 Explanation of Output.

Results are divided into three parts corresponding to the phases of dispersion: convective descent, dynamic collapse, and long-term diffusion.

2.3.1 Convective descent output.

An example of output describing the convective descent phase is presented in Figure 2-8. Computational parameters used in arriving at the results are first listed. NTRIAL is the trial number; DT is the time step, initially selected according to the clouds' characteristics as input at the time of dump, and subsequently modified until the cloud either reaches bottom or a neutrally buoyant state in between 100 and 200 time steps. ISTEP is the number of time steps required.

The variable IPLUNG is an indicator of bottom impact. Initially set to equal zero, IPLUNG will change to a positive value in case of bottom impact. A value of one indicates bottom impact during the convective descent phase; two means the event occurred during the

```
BARGE COORDINATES...
XBARGE (FT) =    5000.        ZBARGE (FT) =    3750.

              ---AMBIENT CONDITIONS---

        DEPTH (FT)        5.600      35.00      66.00      100.0      186.0
AMBIENT
DENSITY (GM/CC)          1.026      1.026      1.027      1.027      1.028

 INTERPOLATED DEPTH AT DUMP COORDINATES, H =    186.0    FT.

TWO VELOCITY PROFILES SPECIFIED IN X AND Z DIRECTIONS FOR --QUICK LOOKS--
DEPTH ASSUMED CONSTANT AND VELOCITIES CONSIDERED STEADY IN TIME
VELOCITY PROFILE PARAMETERS FOLLOW...
DU1 =    80.0     DU2 =    83.0     UU1 =     .230     UU2 =     .230
DW1 =    80.0     DW2 =    83.0     WW1 =   -.500E-01 WW2 =   -.500E-01

TIME PARAMETERS FOLLOW...
TIME OF DUMP =          0.00 SECONDS AFTER START OF TIDAL CYCLE
DURATION OF SIMULATION =     5500.00 SECONDS AFTER DUMP
LONG TERM TIME STEP (DTL) =     250.00 SECONDS

DISCHARGE PARAMETERS...
INITIAL RADIUS OF CLOUD, RB =      24.60000
INITIAL DEPTH OF CLOUD CENTROID, DREL =    15.00
INITIAL CLOUD VELOCITIES...CU(1) =   0.          CV(1) =    1.000       CW(1) =   0.

BULK PARAMETERS...
DENSITY, ROO =    1.330000
AGGREGATE VOIDS RATIO, BVOID =    .8000
LIQUID LIMIT =    90.00
AVERAGE SPECIFIC GRAVITY =     2.650

THERE ARE  3 SOLIDS,  PARAMETERS FOLLOW.......

DESCRIPTION  DENSITY(GM/CC)  CONCENTRATION(CUFT/CUFT)  FALL VELOCITY(FT/SEC)   VOIDS RATIO

 SAND           2.650            .6700E-01                 .1100E-01          .8000
 SILT           2.650            .6700E-01                 .1400E-02          .8000
 CLAY           2.650            .6600E-01                 .1200E-04          .8000
 FLUID          1.000            .8000                     0.

PERCENT MOISTURE CONTENT =   150.9434,    1.6771     TIMES LIQUID LIMIT
CALCULATED ENTRAINMENT COEFFICIENT =    .180771
```

Figure 2-7 Computer generated input data summary. (typical)

CONVECTIVE DESCENT

COMPUTATIONAL INDICATORS FOLLOW...

NTRIAL	DT	IPLUNG	NUTRL	ISTEP
1	.44584651E-01	1	0	425
2	.12745651	1	0	151

X AND Z ARE MEASURED W/R TO BARGE POSITION

TIME	X	Y	Z	U	V	W	DEN-DIF	RADIUS	DIA	VORT.	FLUID CONC.	SOLID-VOL.	CONCENTRATION
0.00	0.00	15.00	0.00	0.00	1.000	0.00	.3039E+00	24.60	49.20	24.6000	.8000E+00	.2089E+04	.6700E-01
												.2089E+04	.6700E-01
												.2058E+04	.6600E-01
.25	.00	15.42	-.00	.00	2.263	-.00	.3011E+00	24.68	49.35	24.5505	.7926E+00	.2089E+04	.6638E-01
												.2089E+04	.6638E-01
												.2058E+04	.6539E-01
.51	.00	16.15	-.00	.01	3.467	-.00	.2962E+00	24.81	49.62	24.5005	.7800E+00	.2089E+04	.6532E-01
												.2089E+04	.6532E-01
												.2058E+04	.6435E-01
.76	.00	17.18	-.00	.01	4.585	-.00	.2897E+00	24.99	49.99	24.4499	.7627E+00	.2089E+04	.6387E-01
												.2089E+04	.6387E-01
												.2058E+04	.6292E-01
1.02	.01	18.48	-.00	.02	5.598	-.00	.2816E+00	25.23	50.46	24.3985	.7415E+00	.2089E+04	.6210E-01
												.2089E+04	.6210E-01
												.2058E+04	.6118E-01
1.27	.01	20.02	-.00	.02	6.494	-.00	.2725E+00	25.51	51.02	24.3459	.7174E+00	.2089E+04	.6009E-01
												.2089E+04	.6009E-01
												.2058E+04	.5919E-01
1.53	.02	21.78	-.00	.03	7.269	-.01	.2625E+00	25.83	51.65	24.2922	.6913E+00	.2089E+04	.5790E-01
												.2089E+04	.5790E-01
												.2058E+04	.5703E-01
1.78	.02	23.72	-.01	.04	7.926	-.01	.2521E+00	26.18	52.36	24.2370	.6639E+00	.2089E+04	.5560E-01
												.2089E+04	.5560E-01
												.2058E+04	.5477E-01
2.04	.03	25.81	-.01	.04	8.471	-.01	.2415E+00	26.56	53.11	24.1802	.6359E+00	.2089E+04	.5326E-01
												.2089E+04	.5326E-01
												.2058E+04	.5246E-01
2.29	.05	28.03	-.01	.05	8.913	-.01	.2309E+00	26.96	53.91	24.1218	.6080E+00	.2089E+04	.5092E-01
												.2089E+04	.5092E-01
												.2058E+04	.5016E-01
2.55	.06	30.35	-.01	.06	9.264	-.01	.2204E+00	27.38	54.75	24.0616	.5804E+00	.2089E+04	.4861E-01
												.2089E+04	.4861E-01

Figure 2-8 Typical output describing the convective descent phase.

collapse phase, and four indicates that the cloud will rise from the bottom following impact.

Similarly, NUTRL indicates whether or not the cloud has reached a state of neutral buoyancy. Initially assigned a zero value, NUTRL is set to one if the cloud becomes neutrally buoyant. A value of three indicates that diffusive spreading is greater than dynamic spreading at this time.

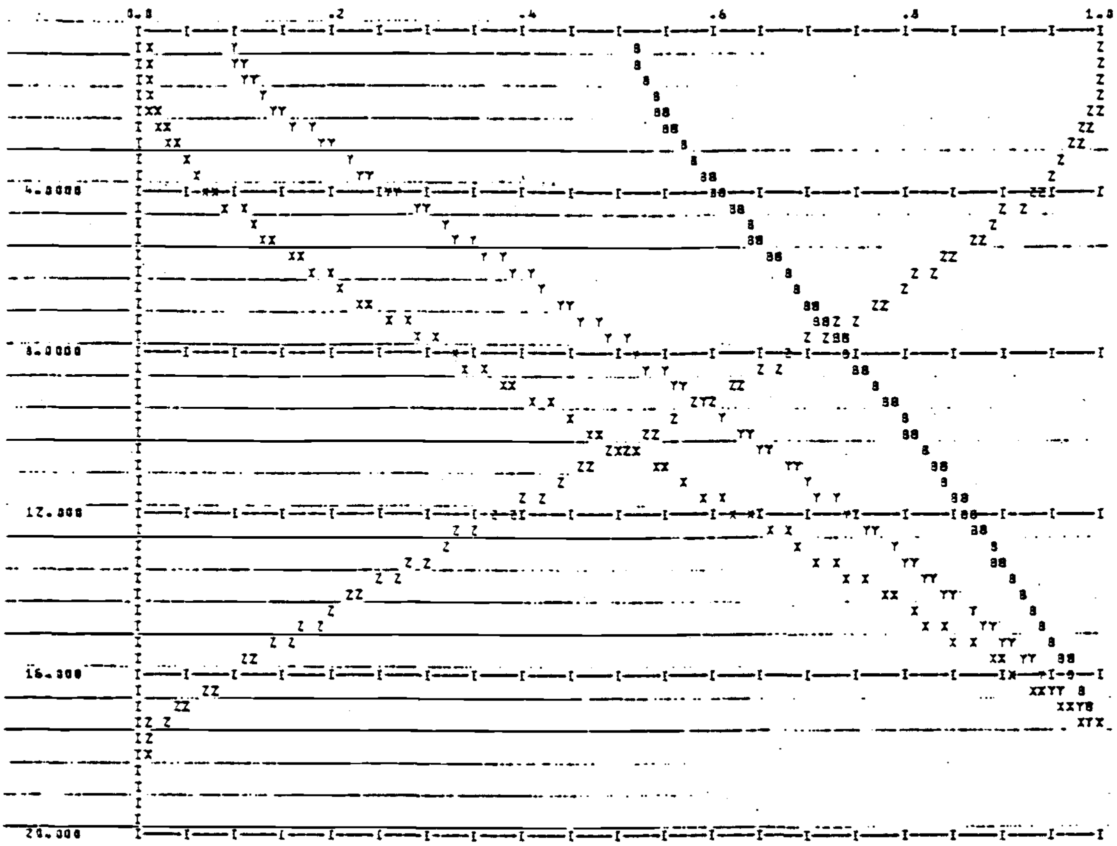
Following the computational indicators, a list of parameters describing the descending cloud as a function of time is printed. This list includes the time, (in seconds from dump time), X, Y, and Z, (position of cloud centroid with respect to dump site), and U, V, and W, (cloud velocity in X, Y and Z directions respectively.)

The density difference between the cloud and the ambient water is listed along with cloud radius and diameter (feet), vorticity (feet^2/sec), and fluid volume concentration. Solid material volume (cubic feet) and volume concentration are tabulated for each solid component.

Also included is a plot of normalized X, Y, Z, and B (cloud radius) as functions of time, and one of solids concentration as a function of time. Examples are presented in Figures 2-9 and 2-10.

2.3.2 Collapse phase output

Similar data is presented for the collapse phase. Vorticity, assumed to be zero at this stage, is eliminated from the output; a



PLOT OF CLOUD PATH AND RADIUS AS SEEN FROM POINT OF RELEASE

INDEPENDENT VARIABLE IS TIME (SEC) OVER RANGE 0. 17.295

DEPENDENT VARIABLES, ALL NORMALIZED FOR PLOTTING ON UNIT AXIS

SYMBOL	Y	8	X	Z
MAX PLOTTED	165.73	55.228	1.0279	0.
MIN PLOTTED	0.	0.	0.	-.47440
REMARKS	DEPTH	RADIUS	HOR DIST(CX)	HOR DIST(CZ)

MAX.MIN.INC. OF IND.VAR.
20.000000 0. .4000000

MAX.MIN.INC. OF DEP. VAR.
1.0000000 0. .10000000E-01

Figure 2-9 Cloud position and radius as a function of time

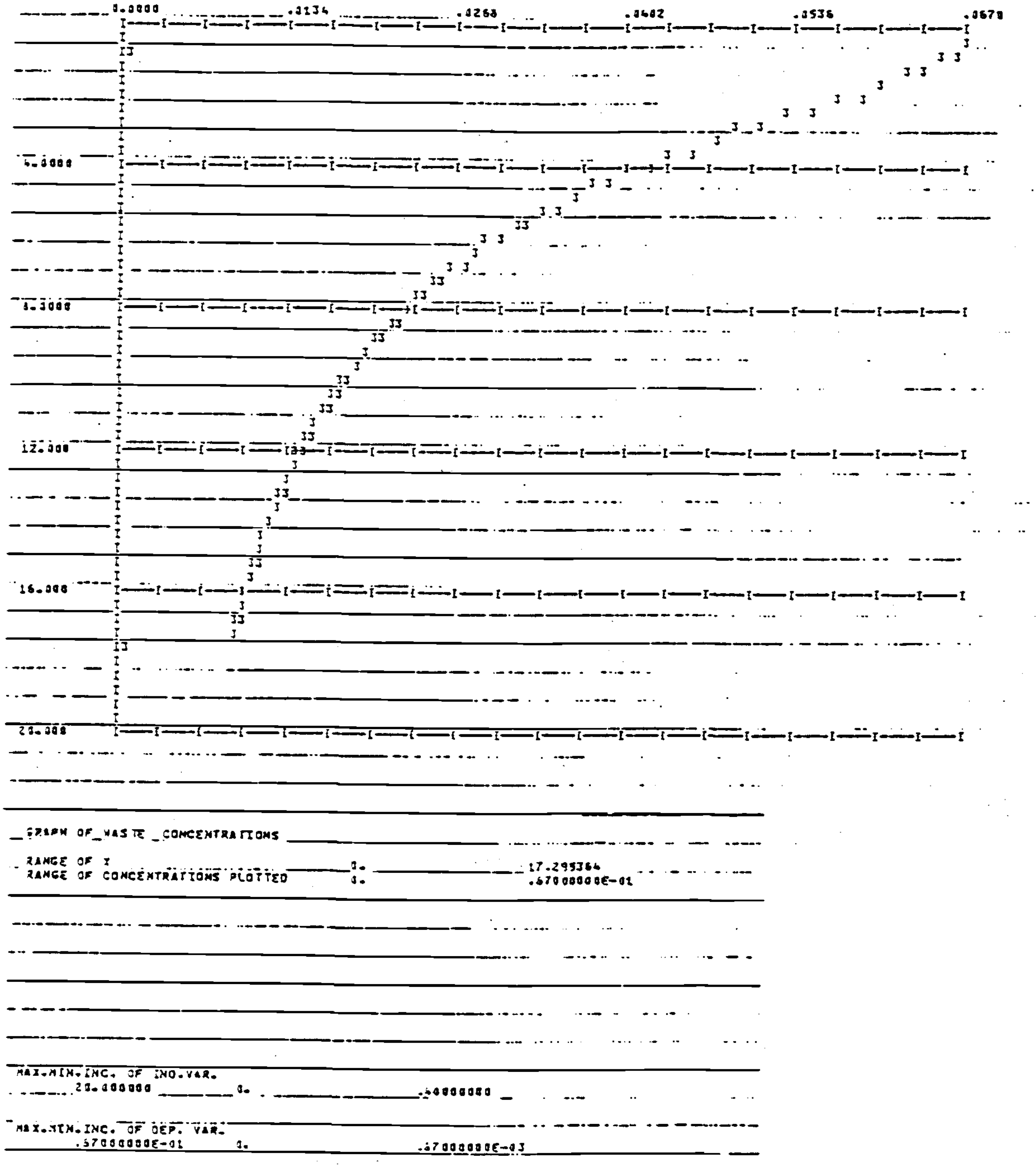


Figure 2-10 Solid volume concentration as a function of time

vertical (AA) and a horizontal (BC) radius are listed to describe the assumed oblate spheroid form of the collapsing cloud. Figure 2-11 is an example of collapse phase data.

A plot of collapsing cloud characteristics (Figure 2-12) follows the data tabulation.

2.3.3 Long-term diffusion phase.

At each time step, a summary of solid material component distribution is listed (see Figure 2-13). In addition, at approximately 1/4, 1/2, 3/4, and 4/4 of the simulation duration period (TSTOP) a graphic presentation of several cloud parameters is output. For each component a printout of solid material concentration, depth to the top of the cloud (ft), cloud thickness (ft) and bottom accumulation (ft), is printed as a function of grid position. See Figures 2-14 to 2-17 for examples of these plots.

The solid component concentration is assumed constant throughout the cloud thickness, forming the "top hat" profile as illustrated in Figure 2-4.

2.4 Sensitivity Analysis.

There is considerable uncertainty associated with some input parameters. In particular, it is difficult to assign a precise value to such initial conditions as void ratio, depth of cloud centroid,

COLLAPSE PHASE OF CLOUD

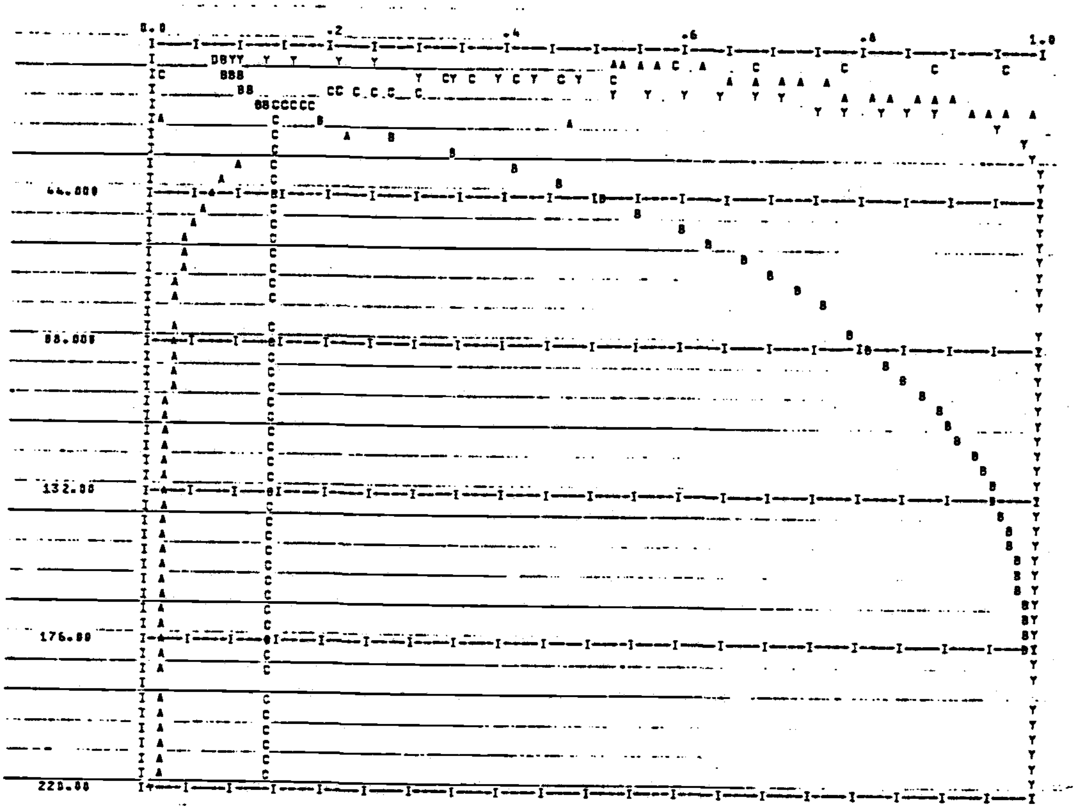
COMPUTATIONAL INDICATORS...

NTRIAL	DT	IPLUNG	NUTRL	ISTEP	IBED	ILEAVE
1	.1275	1	0	598	151	999
2	.2279	1	0	598	151	999
3	.4075	1	0	598	151	999
4	.7286	1	3	430	151	999

X AND Z MEASURED FROM BARGE POSITION

TIME	X	Y	Z	U	V	W	DEN-DIF	AA	BC	FLUID CONC.	SOLID-VOL.	CONCENTRATION
19.12	2.15	166.81	-.4668	.11	6.428	-.02	.3158E-01	52.05	104.1	.8448E-01	.2089E+04	.7075E-02
											.2089E+04	.7075E-02
											.2058E+04	.6969E-02
22.03	2.28	177.04	-.4962	.01	1.887	-.00	.3156E-01	23.89	153.6	.8448E-01	.2086E+04	.7065E-02
											.2089E+04	.7074E-02
											.2058E+04	.6969E-02
24.95	2.29	180.59	-.4988	.00	.774	-.00	.3153E-01	14.42	197.8	.8448E-01	.2080E+04	.7046E-02
											.2088E+04	.7072E-02
											.2058E+04	.6970E-02
27.86	2.30	182.22	-.4994	.00	.402	-.00	.3148E-01	10.07	236.6	.8448E-01	.2072E+04	.7018E-02
											.2087E+04	.7068E-02
											.2058E+04	.6970E-02
30.78	2.30	183.13	-.5000	.00	.241	-.00	.3141E-01	7.65	271.6	.8449E-01	.2061E+04	.6980E-02
											.2085E+04	.7063E-02
											.2058E+04	.6970E-02
33.69	2.30	183.70	-.5005	.00	.159	-.00	.3132E-01	6.12	303.5	.8449E-01	.2046E+04	.6931E-02
											.2083E+04	.7058E-02
											.2058E+04	.6970E-02
36.60	2.30	184.09	-.5011	.00	.112	-.00	.3121E-01	5.09	332.9	.8450E-01	.2028E+04	.6872E-02
											.2081E+04	.7050E-02
											.2058E+04	.6971E-02
39.52	2.31	184.37	-.5016	.00	.083	-.00	.3109E-01	4.34	360.4	.8450E-01	.2008E+04	.6802E-02
											.2078E+04	.7042E-02
											.2058E+04	.6971E-02
42.43	2.31	184.58	-.5022	.00	.063	-.00	.3094E-01	3.78	386.2	.8451E-01	.1984E+04	.6722E-02
											.2075E+04	.7032E-02
											.2058E+04	.6972E-02
45.35	2.31	184.75	-.5027	.00	.050	-.00	.3078E-01	3.34	410.5	.8452E-01	.1957E+04	.6632E-02
											.2072E+04	.7020E-02
											.2058E+04	.6972E-02
48.26	2.32	184.88	-.5033	.00	.040	-.00	.3060E-01	3.00	433.6	.8453E-01	.1928E+04	.6533E-02
											.2068E+04	.7007E-02

Figure 2-11 Typical Listing of collapse phase data



PLOT OF COLLAPSING CLOUD CHARACTERISTICS

INDEPENDENT VARIABLE IS TIME OVER RANGE 0. 216.87

DEPENDENT VARIABLE, ALL NORMALIZED FOR PLOTTING ON UNIT AXIS

SYMBOL	A	B	C	Y
MAX PLOTTED	54.768	895.67	.79900	185.69
MIN PLOTTED	0.	0.	0.	0.
REMARKS	VERT SIZE	HOR SIZE	CONCENTRATION	DEPTH

MAX,MIN,INC. OF IND.VAR.
220.00000 0. 4.4000000

MAX,MIN,INC. OF DEP. VAR.
1.0000000 0. .10000000E-01

Figure 2-12 Plot of collapsing cloud characteristics

```
TOTAL SUSPENDED MATERIAL (CUFT) =      2016.4
SUSPENDED MATERIAL IN LONG TERM GRID (CUFT) =      2016.4
SUSPENDED MATERIAL IN SMALL CLOUDS (CUFT) =    0.
TOTAL MATERIAL SETTLED TO BOTTOM (CUFT) =     41.428

OUTPUT SUPPRESSED IN LOCATIONS WITH NO MATERIAL PRESENT


SUMMARY OF CLAY       DISTRIBUTIONS AFTER    2000.00 SEC.

TOTAL SUSPENDED MATERIAL (CUFT) =      2010.0
SUSPENDED MATERIAL IN LONG TERM GRID (CUFT) =      2010.0
SUSPENDED MATERIAL IN SMALL CLOUDS (CUFT) =    0.
TOTAL MATERIAL SETTLED TO BOTTOM (CUFT) =     47.811

OUTPUT SUPPRESSED IN LOCATIONS WITH NO MATERIAL PRESENT


SUMMARY OF CLAY       DISTRIBUTIONS AFTER    2250.00 SEC.

TOTAL SUSPENDED MATERIAL (CUFT) =      2003.7
SUSPENDED MATERIAL IN LONG TERM GRID (CUFT) =      2003.7
SUSPENDED MATERIAL IN SMALL CLOUDS (CUFT) =    0.
TOTAL MATERIAL SETTLED TO BOTTOM (CUFT) =     54.119

OUTPUT SUPPRESSED IN LOCATIONS WITH NO MATERIAL PRESENT


SUMMARY OF CLAY       DISTRIBUTIONS AFTER    2500.00 SEC.

TOTAL SUSPENDED MATERIAL (CUFT) =      1997.4
SUSPENDED MATERIAL IN LONG TERM GRID (CUFT) =      1997.4
SUSPENDED MATERIAL IN SMALL CLOUDS (CUFT) =    0.
TOTAL MATERIAL SETTLED TO BOTTOM (CUFT) =     60.354

OUTPUT SUPPRESSED IN LOCATIONS WITH NO MATERIAL PRESENT
```

Figure 2-13 Solid material component data summary

```
CONCENTRATIONS OF CLAY        (VOLUME RATIO) IN THE CLOUD    2500.00 SECONDS AFTER DUMP
...MULTIPLY DISPLAYED VALUES BY   .1000E-02      (LEGEND... + = .LT. .01    . = .LT. .0001    0 = .LT. .000001)
 M N=  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15

 1 000000000000000000000000000000000000000000000000000000000000

 2 0000    0    0    0    0    0    0    0    0    0    0    0   00000

 3 0000    0    0    0    0    0    0    0    0    0    0    0   00000

 4 0000    0    0    0    0    0    0    0    0    0    0    0   00000

 5 0000    0    0    0    0    0    0    0    0    0    0    0   00000

 6 0000    0    0    0    0    0    0    0    0    0    0    0   00000

 7 0000    0    0    0    0    0    0    0    0    0    0    0   00000

 8 0000    0    0    0    0    0    .    .    0    0    0    0   00000

 9 0000    0    0    0    0    .  .01  .01    .    0    0    0   00000

10 0000    0    0    0    .  .02  4.0  4.0  .01    .    0    0   00000

11 0000    0    0    0    0    .  .05  .05    .    0    0    0   00000

12 0000    0    0    0    0    0    .    .    0    0    0    0   00000

13 0000    0    0    0    0    0    0    0    0    0    0    0   00000

14 0000    0    0    0    0    0    0    0    0    0    0    0   00000

15 0000    0    0    0    0    0    0    0    0    0    0    0   00000

16 0000    0    0    0    0    0    0    0    0    0    0    0   00000

17 0000    0    0    0    0    0    0    0    0    0    0    0   00000

18 0000    0    0    0    0    0    0    0    0    0    0    0   00000

19 0000    0    0    0    0    0    0    0    0    0    0    0   00000

20 000000000000000000000000000000000000000000000000000000000000
```

Figure 2-14 Example of component concentration plot during passive diffusion phase

```
POSITION OF TOP OF CLAY        CLOUD (FEET BELOW SURFACE)    2500.00 SECONDS AFTER DUMP
...MULTIPLY DISPLAYED VALUES BY    1.000           (LEGEND... + = .LT. .01   . = .LT. .0001   0 = .LT. .000001)
 M N=  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15

 1 000000000000000000000000000000000000000000000000000000000000

 2 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

 3 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

 4 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

 5 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

 6 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

 7 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

 8 0000    0    0    0    0  185  185  185    0    0    0    0    0 00000

 9 0000    0    0    0  185  185  185  185  185    0    0    0    0 00000

10 0000    0    0  185  185  185  185  185  185  185    0    0    0 00000

11 0000    0    0  185  185  185  185  185  185  185    0    0    0 00000

12 0000    0    0    0  185  185  185  185  185    0    0    0    0 00000

13 0000    0    0    0    0  185  185  185    0    0    0    0    0 00000

14 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

15 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

16 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

17 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

18 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

19 0000    0    0    0    0    0    0    0    0    0    0    0    0 00000

20 000000000000000000000000000000000000000000000000000000000000
```

Figure 2-15 Sample plot of depth to top of component cloud as a function of position

```
THICKNESS OF CLAY        CLOUD (FEET)     2500.00 SECONOS AFTER OUMP
...MULTIPLY DISPLAYEO VALUES BY    1.000          (LEGENO... + = .LT. .01    . = .LT. .0001    0 = .LT. .000001)
 M N=  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15

  1 000000000000000000000000000000000000000000000000000000000000000000000000000
  2 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
  3 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
  4 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
  5 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
  6 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
  7 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
  8 0000    0    0    0    0  .97  .97  .97    0    0    0    0    0    00000
  9 0000    0    0    0  .97  .97  .97  .97  .97    0    0    0    0    00000
 10 0000    0    0  .97  .97  .97  .97  .97  .97  .97    0    0    0    00000
 11 0000    0    0  .97  .97  .97  .97  .97  .97  .97    0    0    0    00000
 12 0000    0    0    0  .97  .97  .97  .97  .97    0    0    0    0    00000
 13 0000    0    0    0    0  .97  .97  .97    0    0    0    0    0    00000
 14 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
 15 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
 16 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
 17 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
 18 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
 19 0000    0    0    0    0    0    0    0    0    0    0    0    0    00000
 20 000000000000000000000000000000000000000000000000000000000000000000000000000
```

Figure 2-16 Sample plot of component cloud thickness as a function of position

```
BOTTOM ACCUMULATION OF CLAY       (CUFT/GRID SQUARE)    2500.00 SECONDS AFTER DUMP
...MULTIPLY DISPLAYED VALUES BY    1.000          (LEGEND... + = .LT. .01    . = .LT. .0001    0 = .LT. .000001)
 M N=  1    2    3    4    5    6    7    8    9   10   11   12   13   14   15

  1 000000000000000000000000000000000000000000000000000000000000000000000000

  2 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

  3 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

  4 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

  5 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

  6 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

  7 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

  8 0000    0    0    0    0    0    .    .    0    0    0    0    0   00000

  9 0000    0    0    0    0    .  .31  .31    .    0    0    0    0   00000

 10 0000    0    0    0    .  .08   29   29  .06    .    0    0    0   00000

 11 0000    0    0    0    0    +  .53  .52    +    0    0    0    0   00000

 12 0000    0    0    0    0    0    +    +    0    0    0    0    0   00000

 13 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

 14 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

 15 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

 16 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

 17 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

 18 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

 19 0000    0    0    0    0    0    0    0    0    0    0    0    0   00000

 20 000000000000000000000000000000000000000000000000000000000000000000000000
```

Figure 2-17 Sample position plot of component bottom accumulation velocity, and plume radius. In practice, the ambient density profile and liquid limit of solid material may not be known precisely.

In light of this, a simple sensitivity analysis was performed under conditions similar to those of the monitored dumps, with the objective of determining the model's response to variation of these parameters. A standard set of input data (see Table 2-1) was established; individual parameters were then varied while all others were held constant. Data of interest was tabulated to determine the model's degree of sensitivity to each parameter. Results are found in Tables 2-2 through 2-8, and are graphically presented in Figures 2-18 through 2-23.

The model is insensitive to variations in initial depth of cloud centroid and initial cloud velocity. Changes in plume radius, void ratio, and liquid limit do have considerable effect on maximum solids concentrations, while not significantly affecting the quantity of material settled out at various elapsed times.

When the initial plume radius is increased from 18.6 feet to 34 feet, the predicted maximum volume concentration after 45 minutes increases from .07 ppt to .21 ppt. (See Table 2-5). Similar increases are noted at other times. Results are presented graphically in Figure 2-21.

Increasing the void ratio (or decreasing the solids content) has a pronounced effect on predicted solids concentrations. A void ratio increase from .75 to .95 causes the predicted concentration after 45

Table 2-1 Standard input parameters: for sensitivity analysis.

Grid: 15(z) x 20(x) @ 500' spacing

Barge Coordinates: XBARGE = 5000' ZBARGE = 3750'

Ambient Density Profile: 1.026 gm/cc @ D = 10'
1.028 gm/cc @ D = 186'

Ambient Velocity Profile:

Depth	u(fps)	w(fps)
76'	.5	-.5
179'	-.1	-.2

Time Parameters: Duration of simulation: 1 hr = 3600s
Long term time step: .25 hr = 900s

Discharge parameters:
Initial - cloud radius = 34'
depth centroid = 15'
cloud velocity = 1.0 fps

Bulk Parameters: Density = 1.32 g/cc
"Voids ratio" = .80
LL = 90%
avg. S.G. = 2.65

Solids component parameters:

component	density	volume conc.	V_f(fps)	"voids ratio"
sand	2.65	.033	.11E-01	.8
silt	2.65	.033	.14E-02	.8
clay	2.65	.034	.12E-04	.8

Table 2-2

Sensitivity analysis results. Parameter: Initial void ratio.

SA# (ID)	void ratio	time to bottom (sec)	conc. @ impact (ppt)	time to collapse (sec)	conc. @ end collapse (ppt)	max. conc. @ 30 (minutes) (ppt)	max. conc. @ 45 (minutes) (ppt)	max. conc. @ 60 (minutes) (ppt)	% total mat'l settled @ 15 (minutes)	% total mat'l settled @ 30 (minutes)	% total mat'l settled @ 45 (minutes)	% total mat'l settled @ 60 (minutes)
17	.75	10.7	186.4	66.6	138.1	1.10	.79	.50	38	39	40	41
*1	.80	15.3	34.8	213.6	20.7	.30	.21	.19	37	37	38	39
18	.90	13.2	9.2	343.1	5.3	.10	.10	.09	34	37	38	39
19	.95	22.1	4.1	473.4	2.3	.03	.03	.03	32	37	38	38

* standard input values

Table 2-3

Sensitivity analysis results. Parameter: Initial depth of cloud centroid.

SA# (ID)	initial depth (ft)	time to bottom (sec)	conc. @ impact (ppt)	time to collapse (sec)	conc. @ end collapse (ppt)	max. conc. @ 30 (minutes) (ppt)	45 (minutes) (ppt)	60 (minutes) (ppt)	% total mat'l settled @ 15 (minutes)	30	45	60
13	0	17.4	30.8	245.5	18.3	.28	.21	.18	36	38	38	39
14	5	16.1	32.1	227.2	19.0	.28	.21	.17	37	38	38	39
15	10	15.8	33.4	221.0	19.7	.30	.23	.20	37	38	39	40
*1	15	15.3	34.8	213.6	20.7	.30	.21	.19	37	38	38	39
16	20	14.8	36.3	209.0	21.6	.30	.22	.19	37	38	38	39

* standard input values

Table 2-4

Sensitivity analysis results. Parameter: Initial velocity.

SA# (ID)	initial velocity (fps)	time to bottom (sec)	conc. @ impact (ppt)	time to collapse (sec)	conc. @ end collapse (ppt)	max. conc. @ 30 (minutes) (ppt)	45 (ppt)	60 (ppt)	% total mat'l settled @ 15 (minutes)	30	45	60
11	0	15.4	35.1	215.7	20.6	.30	.21	.19	37	38	38	39
10	.5	15.3	35.1	212.6	20.7	.30	.21	.19	37	38	38	39
*1	1.0	15.3	34.8	213.6	20.7	.30	.21	.19	37	38	38	39
12	2.0	15.1	34.8	213.8	20.7	.30	.21	.19	37	38	38	39

* standard input values

Table 2-5

Sensitivity analysis results. Parameter: Plume radius.

SA# (ID)	plume radius (ft)	time to bottom (sec)	conc. @ impact (ppt)	time to collapse (sec)	conc. @ end collapse (ppt)	max. conc. @ 30 (minutes) (ppt)	max. conc. @ 45 (minutes) (ppt)	max. conc. @ 60 (minutes) (ppt)	% total mat'l settled @ 15 (minutes)	% total mat'l settled @ 30 (minutes)	% total mat'l settled @ 45 (minutes)	% total mat'l settled @ 60 (minutes)
*1	34'	15.3	34.8	214	20.7	.30	.21	.19	37	38	38	39
7	28'	17.6	26.0	219	15.4	.21	.16	.13	37	38	39	39
8	24'	19.9	20.2	226	11.9	.17	.12	.10	37	38	39	40
9	18.6'	24.7	12.8	236	7.6	.11	.07	.05	37	39	40	41

* standard input values

Table 2-6

Sensitivity analysis results. Parameter: Density profile.

SA# (ID)	density profile	time to bottom (sec)	conc. @ impact (ppt)	time to collapse (sec)	conc. @ end collapse (ppt)	max. conc. @ 30 (ppt)	max. conc. @ 45 (minutes) (ppt)	max. conc. @ 60 (ppt)	% total mat'l settled @ 15 (minutes)	30	45	60
*1	10'/1.026 186'/1.028	15.3	34.8	214	20.7	.30	.21	.19	37	38	38	39
4	10'/1.026 186'/1.030	15.3	34.8	214	20.7	.30	.22	.19	37	38	39	40
5	50'/1.0268 100'/1.0273 186'/1.0277	19.3	34.9	208	21.2	.35	.19	.13	15	19	21	23
6	10'/1.0265 186'/1.0275	15.3	34.7	214	20.7	.28	.20	.17	36	38	38	38

* standard input values

Table 2-7

Sensitivity analysis results. Parameter: Liquid limit.

SA# (ID)	L.L. %	time to bottom (sec)	conc. @ impact (ppt)	time to collapse (sec)	conc. @ end collapse (ppt)	max. conc. @ 30 (minutes) (ppt)	max. conc. @ 45 (minutes) (ppt)	max. conc. @ 60 (minutes) (ppt)	% total mat'l settled @ 15 (minutes)	% total mat'l settled @ 30 (minutes)	% total mat'l settled @ 45 (minutes)	% total mat'l settled @ 60 (minutes)
3	60	9.2	19.8	161	13.8	.25	.25	.24	37	39	40	40
*1	90	15.3	34.8	214	20.7	.30	.21	.19	37	38	38	39
2	120	11.9	149.8	77	107	.92	.65	.42	38	40	41	42

* standard input values

Table 2-8

Sensitivity analysis results. Parameter: Long-term time step, DTL

SA# (ID)	DTL, (sec)	time to bottom (sec)	conc. @ impact (ppt)	time to collapse (sec)	conc. @ end collapse (ppt)	max. conc. @ 30 (minutes) (ppt)	max. conc. @ 45 (minutes) (ppt)	max. conc. @ 60 (minutes) (ppt)	% total mat'l settled @ 15 (minutes)	% total mat'l settled @ 30 (minutes)	% total mat'l settled @ 45 (minutes)	% total mat'l settled @ 60 (minutes)
20	300	15.3	34.8	213.6	20.7	.35	.26	.18	12	15.7	19.4	23.2
*1	900	15.3	34.8	213.6	20.7	.30	.21	.19	37	37	38	39
21	1800	15.3	34.8	213.6	20.7	-	-	.18	-	40	-	42

* standard input values

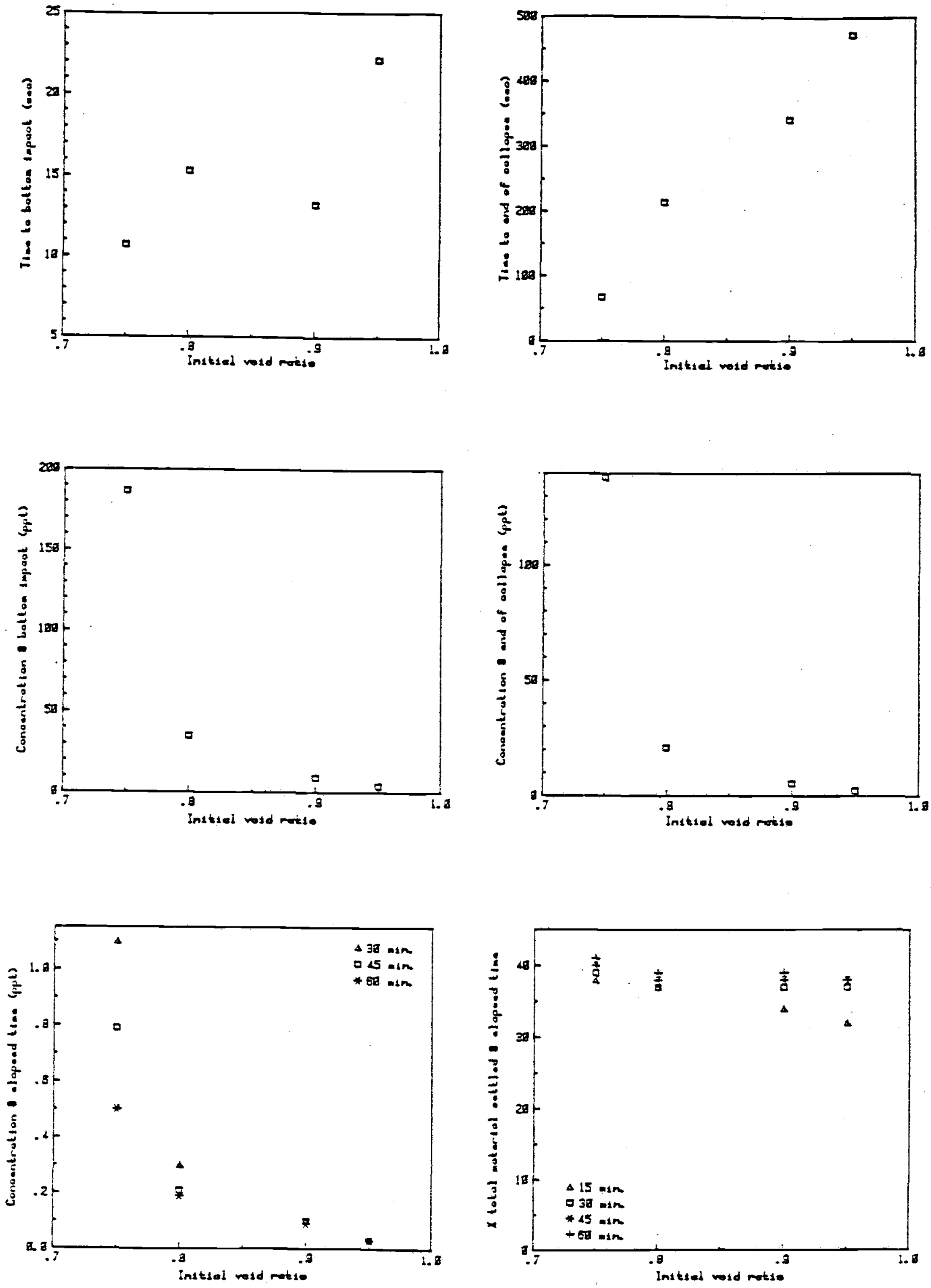


Figure 2-18 Sensitivity analysis results for condition of Table 2-2.

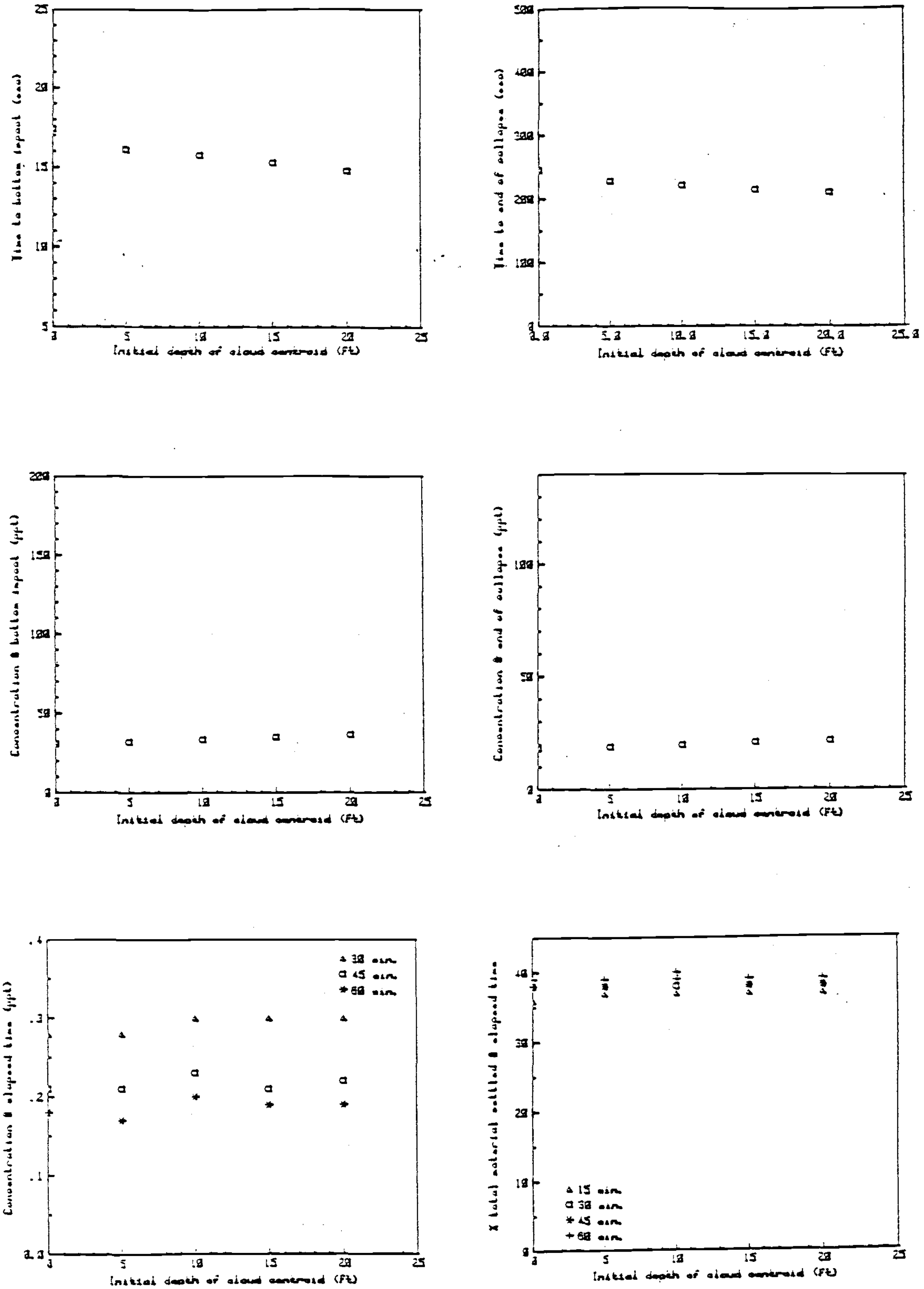


Figure 2-19 Sensitivity analysis results for condition of Table 2-3

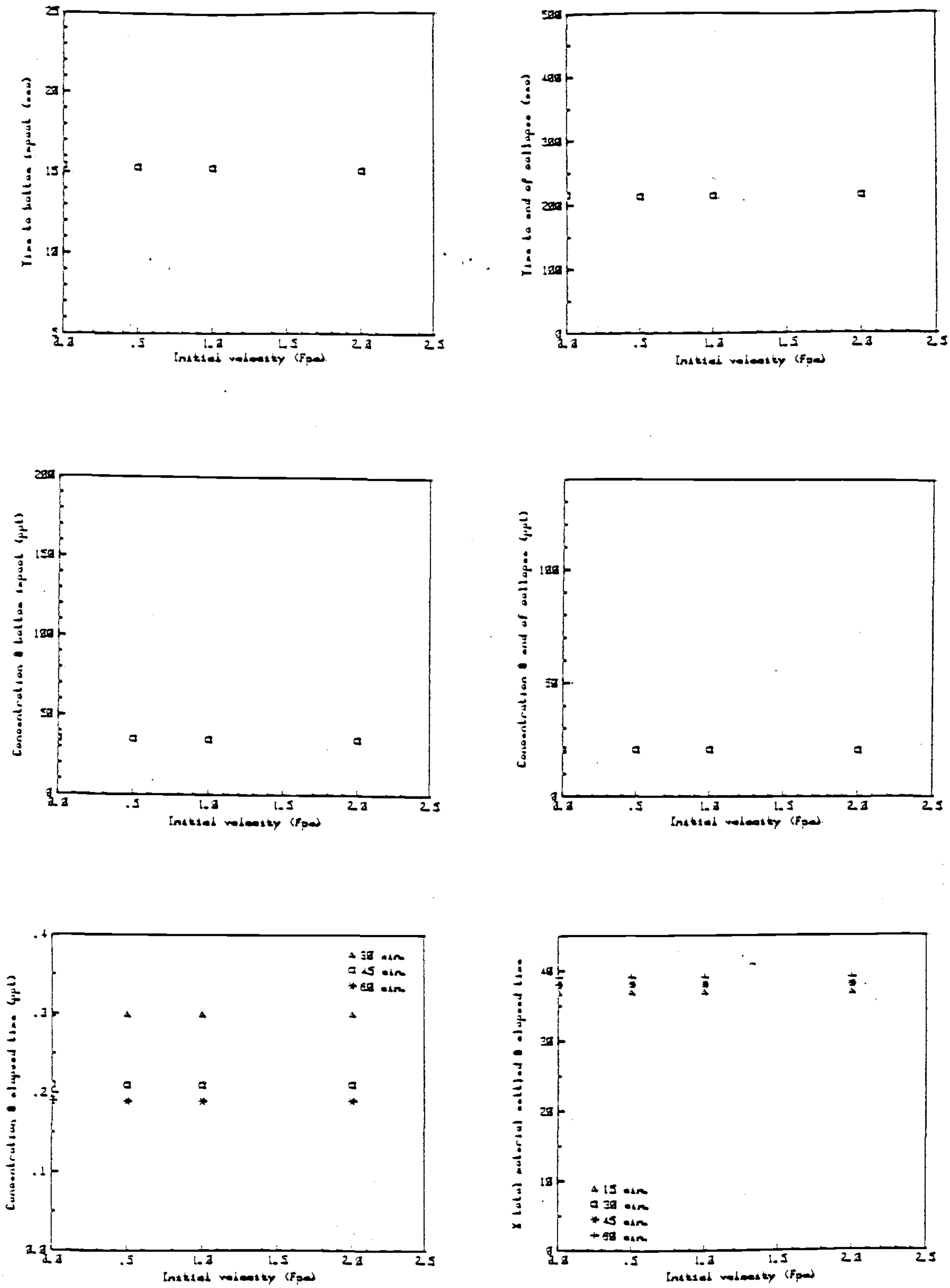


Figure 2-20 Sensitivity analysis results for condition of Table 2-4

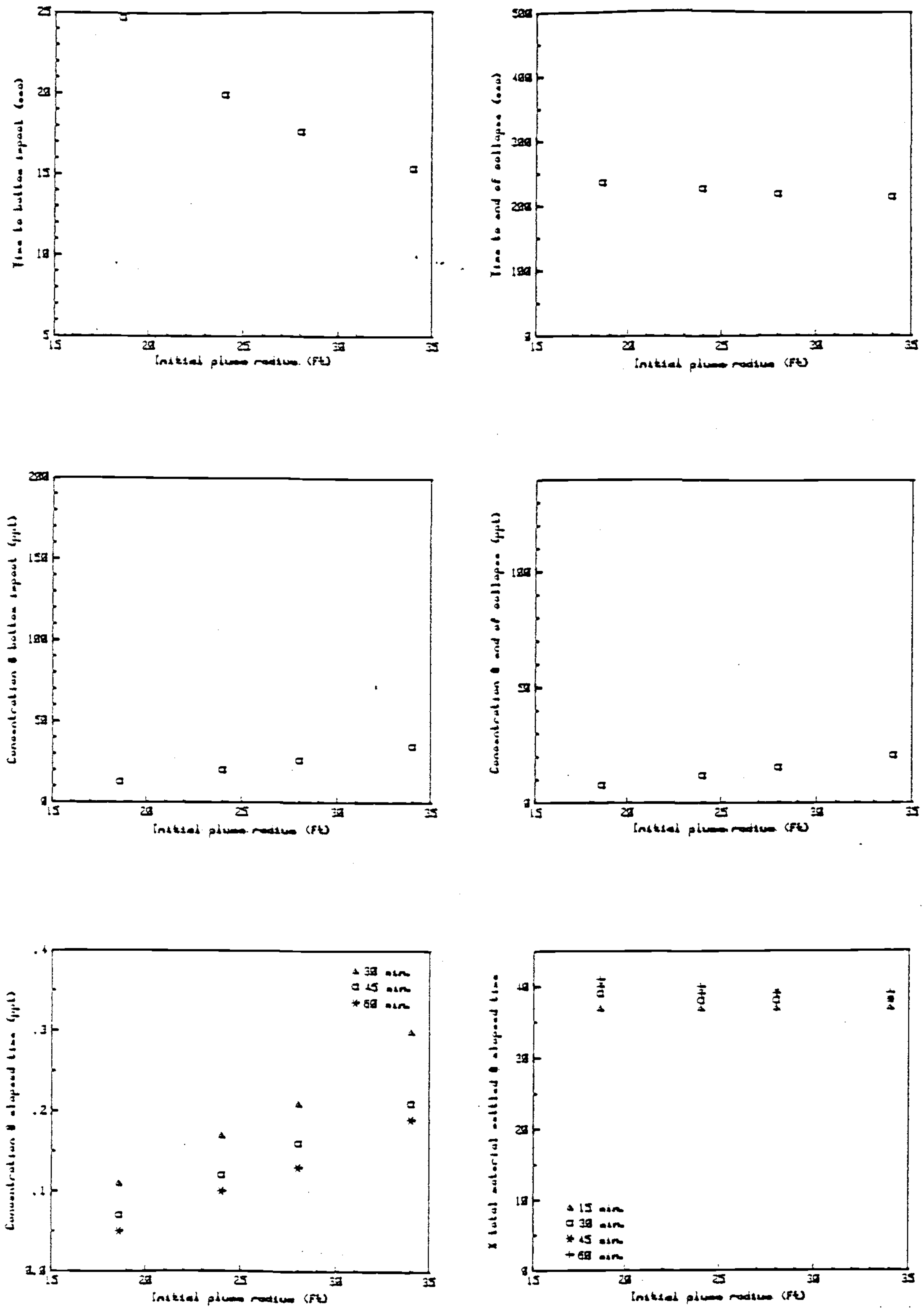


Figure 2-21 Sensitivity analysis results for condition of Table 2-5

minutes to decrease from .79 ppt to .03 ppt. Similar changes are noted at other time increments. See Table 2-2 and Figure 2-18.

Variation of the liquid limit (LL) causes inconsistent changes in predicted solids concentrations. At the 45 minute mark, for LL of 60 and 90%, predicted concentration is .25 and .21 ppt, respectively. A further increase (LL=120%) caused a prediction of .65 ppt at this time (45 minutes). See Table 2-7 and Fig. 2-22 for complete results.

Variation of the long term time step (DTL) is demonstrated to have a significant effect on the predicted amount of settled material. (See Figure 2-23). Increasing DTL from 300 to 900 seconds causes the percentage of material settled out to more than double after 30 minutes, from 16% to 37%. Further increasing DTL to 1800 seconds has a much less pronounced effect; at this value (DTL=1800 sec) 40% of the material has accumulated on the bottom after 30 minutes. Note that the lowest numerical value that may be assigned to DTL is the time required to complete the collapse phase.

The long term model results can be highly sensitive to the specific ambient density profile used. (See Table 2-6) For identical events modeled with slightly varying density profiles, significant differences in the amount of settled material are noted. Specifically, the three point density profile used in run five caused settled material predictions of approximately half the values predicted for all other runs. Use of a similar desnity gradient (run 6) input as a two point profile caused settled material predictions to increase by a factor of two.

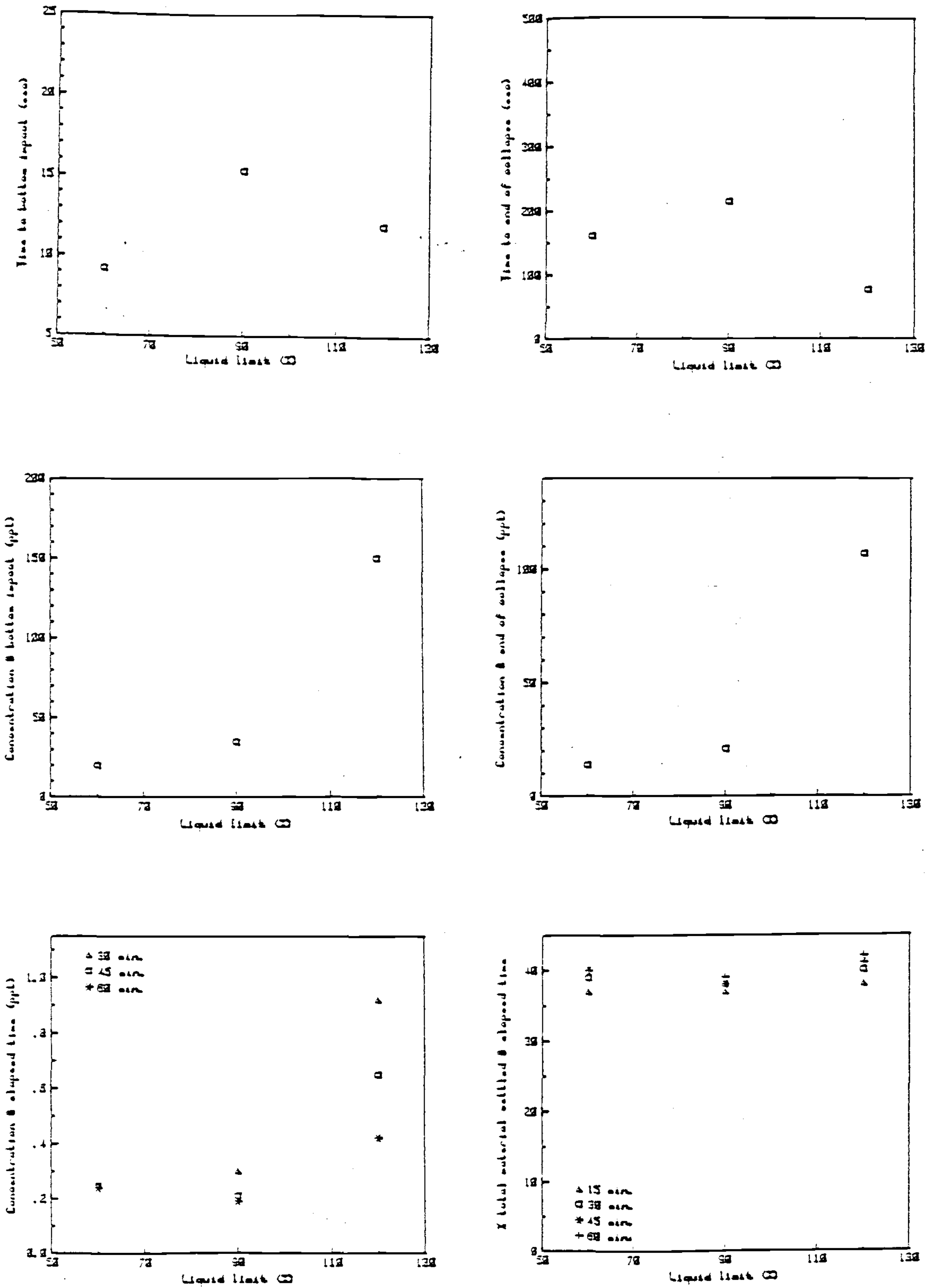


Figure 2-22 Sensitivity analysis results for condition of Table 2-7

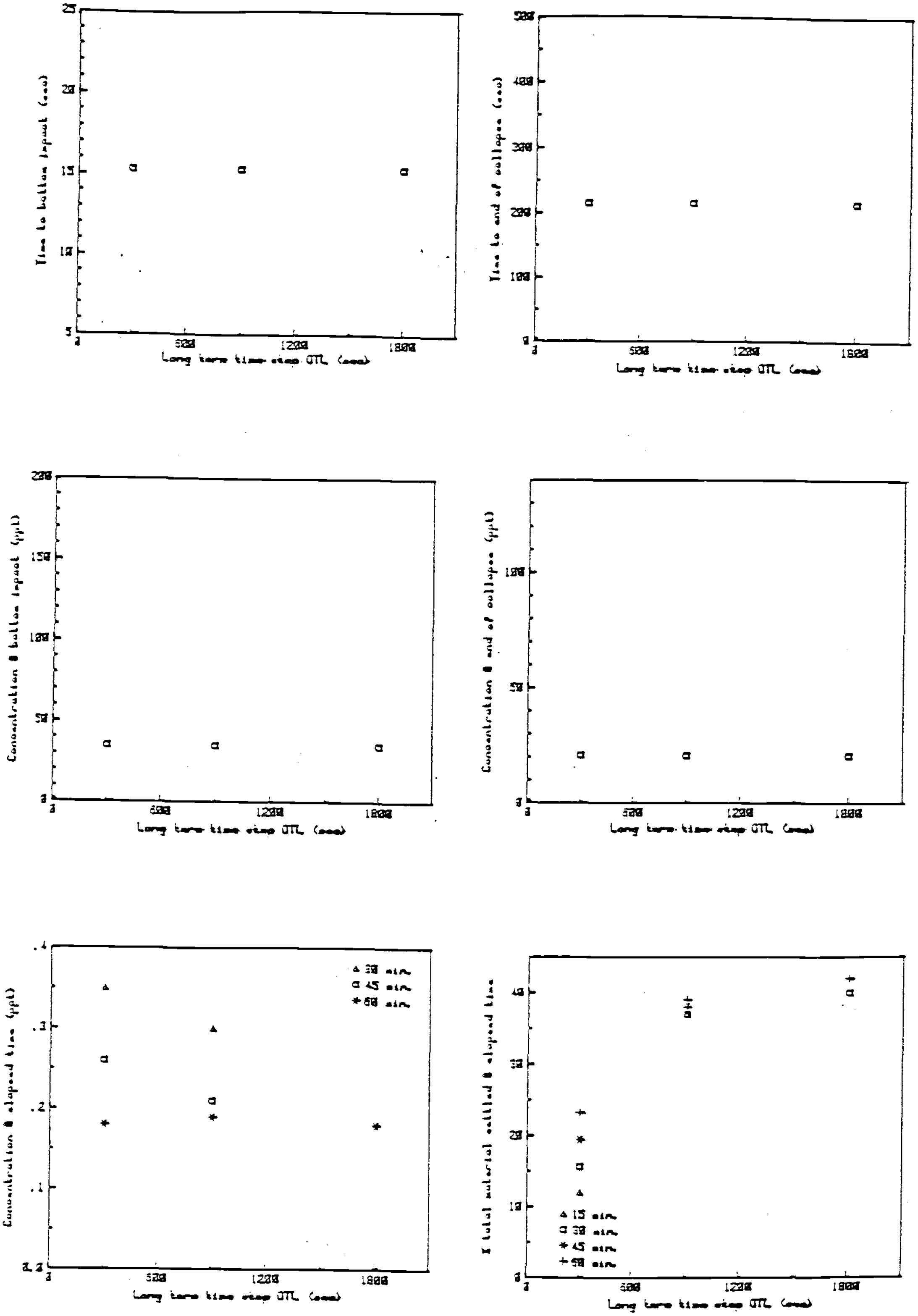


Figure 2-23 Sensitivity analysis results for condition of Table 2-8

3. DATA ACQUISITION

3.1 Background: verification experiments.

Coos Bay, Oregon was selected as the location for the studies described herein. Four million cubic meters of sediment are dredged in four year maintenance cycles to provide a 35 foot deep navigation channel 15 miles upriver to the industrial areas bordering Isthmus Slough.

Sediments disposed of in the events monitored were dredged from Isthmus Slough (see Fig. 3-1). The sediment may be characterized as a silty, organic clay. Previously, this material had been removed by hydraulic pipeline dredge to upland disposal sites; as these neared capacity, offshore spoil sites were sought.

Two Corps of Engineers seagoing hopper dredges participated in the study: the Yaquina and the Biddle, of 500 and 3060 cubic years capacity, respectively. These are self-contained suction-head hydraulic dredges; sediment is stored in hoppers equipped with bottom-opening doors for at-sea disposal.

A total of nine disposal events were monitored in the present study, extending over a period of time from August 12 to August 19, 1981. Data for each event monitored is listed in Table 3-1, including date and time of release, dredge involved and volume released, ambient currents, and the number of concentration profiles recorded. "Volume disposed" is a figure supplied by the Corps of

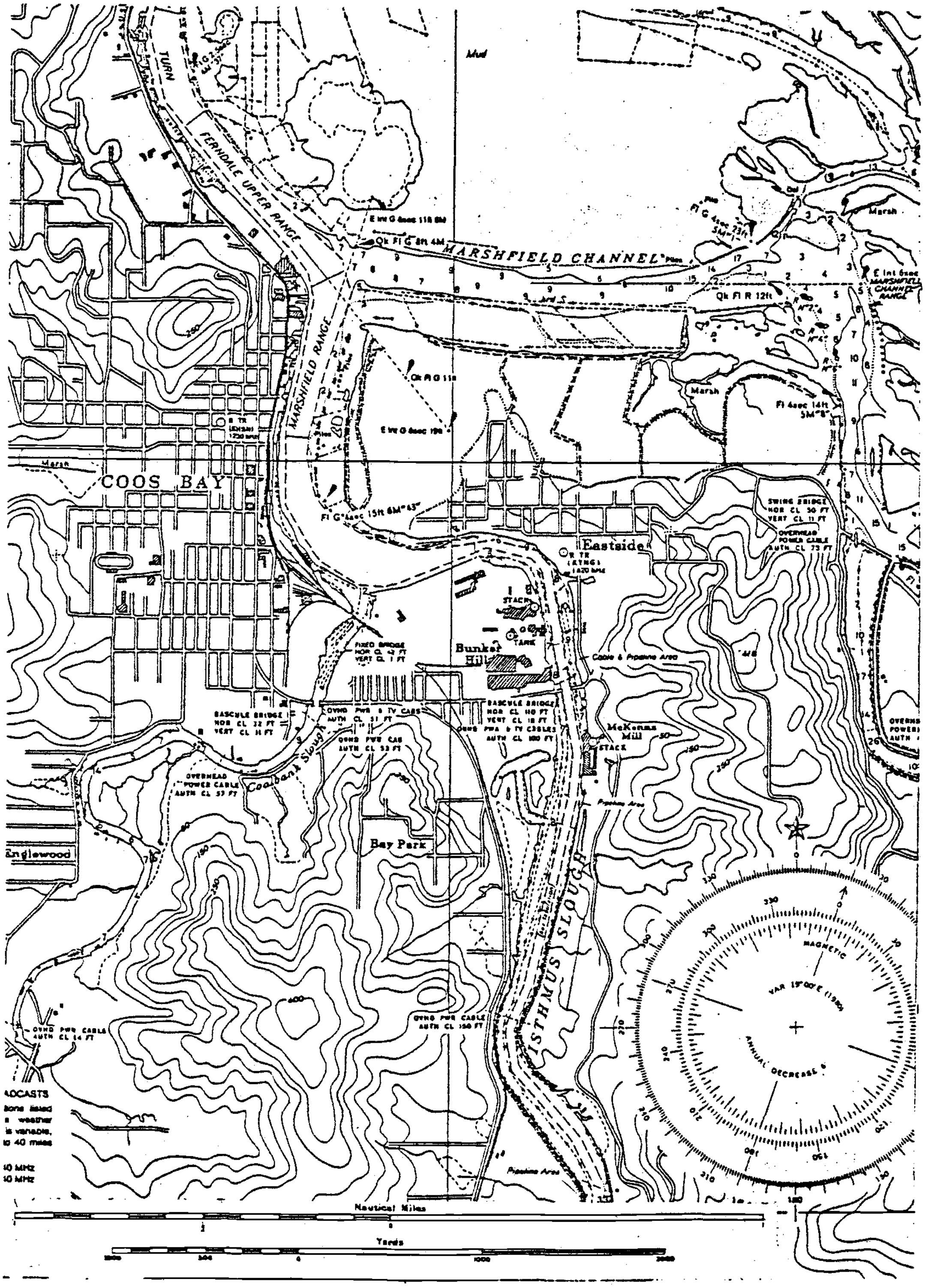


Figure 3-1 Dredging location.

Engineers, Portland District, and represents the total quantity of materials at 20% solids volume concentration released; it was calculated by the Corps using recorded draft measurements.

Ambient current data listed were obtained by averaging current meter recorded values over the time period monitored. Depth measured is the depth of the current meter. South and east component velocities listed have been corrected for declination to represent true (not magnetic) direction.

In operation, the hopper dredge will pump to hopper capacity; pumping will then continue, as excess material overflows, until a so-called "economic load" is achieved. See Mauriello and Caccese (1963) for a discussion of economic load determination. At this point, dredging is terminated and the vessel steams to the offshore disposal site. Approximately two hours were required to traverse the 20 miles from Isthmus Slough to the spoil site. During this time the dredged material may be expected to consolidate in the hopper.

The selected disposal site was located about three NM north-north west of the Coos River entrance. Water depth at this location is 186 feet. A marker buoy was placed at the location (referred to as CP, center of project); dredge masters were instructed to approach the buoy, come to a stop, and open the hopper doors. The CP location is shown in Figure 3-2.

Six minutes were required to completely empty the *Biddle's* hoppers. The material occupies 12 hoppers (six per side); these are

Table 3-1

Disposal event record

Dump ID#	Date	Time	Dredge	Volume Disposed (yd^3)	Ambient currents (fps) dpth meas. (ft)	south (fps)	east (fps)	# conc. profiles
1	8/12/81	15:37	Biddle	1270	-	-	-	0
2	8/13/81	15:34	Biddle	1670	79	.71	-.16	4
					182	.05	-.13	
3	8/13/81	17:25	Yaquina	350	79	.71	-.25	4
					182	.04	-.20	
4	8/15/81	11:10	Yaquina	375	97	-.1	.14	2
					176	-.29	.42	
5	8/15/81	13:25	Biddle	1580	97	.13	.0	4
6	8/17/81	13:25	Biddle	1360	76	.47	.08	3
					179	.02	.42	
7	8/17/81	17:30	Biddle	1300	76	.52	-.56	7
					179	.31	-.20	
8	8/19/81	9:22	Biddle	1750	80	.07	.04	10
9	8/19/81	14:05	Biddle	1150	80	.23	-.05	6

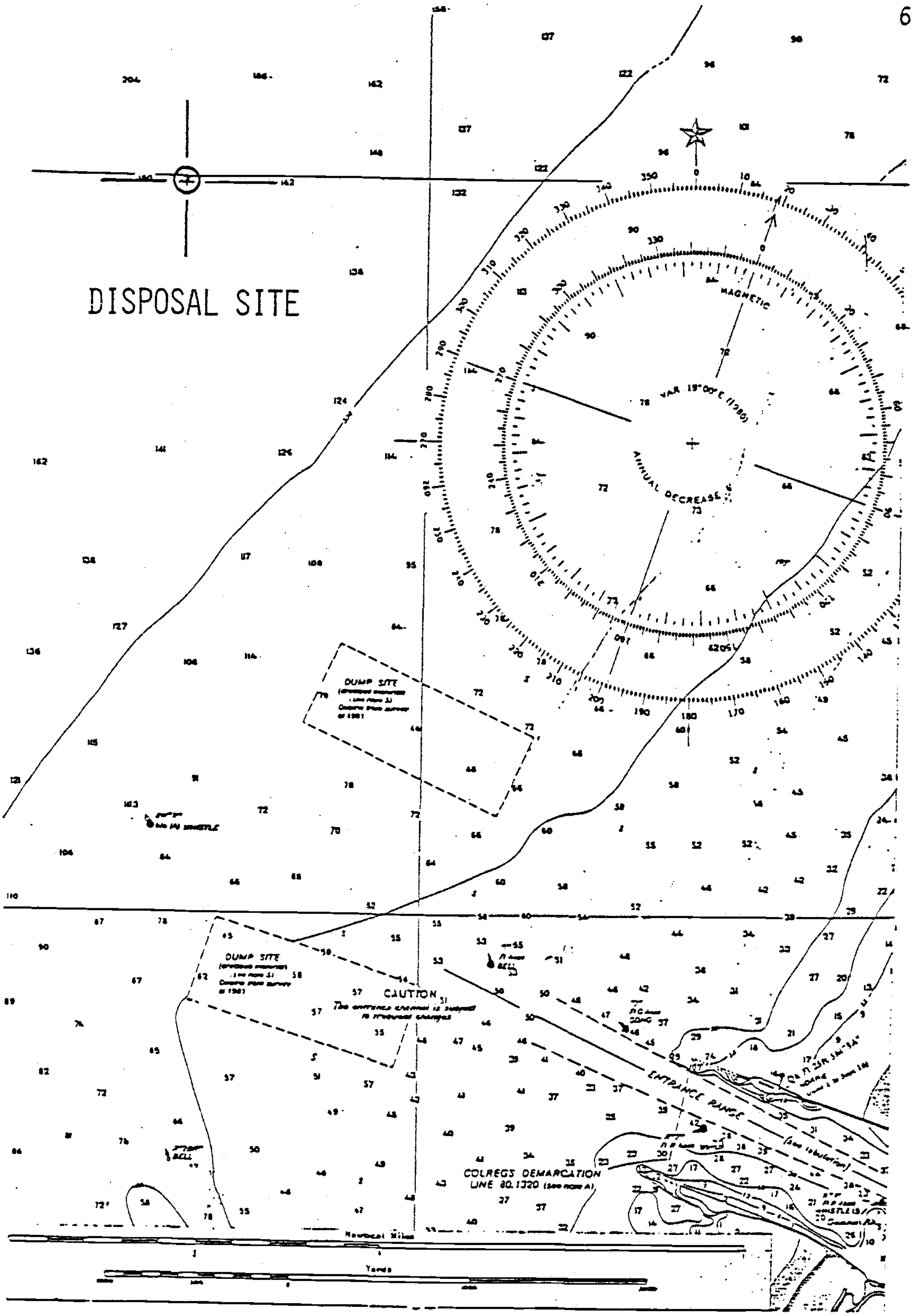


Figure 3-2 CP: disposal site location offshore near Coos Bay, Oregon

emptied one pair at a time, alternating fore and aft to maintain vessel trim. At the beginning of the dump there is approximately 20 feet of head (distance from free surface to vessel waterline) in the hoppers. The hydraulically operated hopper doors open in seconds. No hopper washdown was performed following a dump.

3.2 Methods and Procedures

3.2.1 Currents

Currents were continuously monitored during the period of study. Current meters were deployed in the vicinity of the CP on taut moorings at depths as indicated in Table 3-2. Also listed are meter type (burst or vector average), burst length and frequency if a burst meter, water depth and LORAN C coordinates at the meter location, and transmissometer type (5 or 25 cm), if attached. Figures 3-3 through 3-6 show corresponding current meter locations.

Neil Brown, Inc. burst and vector averaging current meters were deployed. The deployment procedure and mooring configuration are described by Hancock, et al. (1980). The meters are digital recording acoustic current meters expressing currents in terms of two orthogonal vectors, a magnetic north and east component. A burst meter measures and records the time and instantaneous velocity vectors each second at preset time intervals for a specified record duration. In the present study, burst meters were set to various intervals, as

Table 3-2

Current meters in place

Date	Mooring ID	Meter #	Burst or Vector Avg.	Burst length/freq (sec/min)	Water dpth (ft)	Meter dpth (ft)	LORAN C coord. 9940 W	LORAN C coord. 9940X	Trans. ?
8/13/81	P	42			186	182	13,511.8	27,783.9	NO
	T1	47			144	140	518.0	782.9	NO
	T1	26	B	64/5	144	41	518.0	782.9	5cm
	T2	46			186	182	520.5	779.8	NO
	T2	25	B	64/5	186	83	520.5	779.8	5cm
	T3	22			186	182	524.8	777.5	NO
	T4	43	B	*	186	83	524.8	777.5	5cm
	T4	41			240	236	519.3	778.6	NO
	T4	24	B	64/5	240	137	519.3	778.6	25cm

* meter 43 malfunctioned: no data.

Table 3-2 (Continued)

Current meters in place

Date	Mooring ID	Meter #	Burst or Vector Avg.	Burst length/freq (sec/min)	Water dpth (ft)	Meter dpth (ft)	LORAN C coord. 9940 W	9940X	Trans. ?
8/15/81	P	42			186	182	13,511.8	27,783.9	NO
	T1	47			150	146	517.8	782.7	NO
	T1	26	B	64/5	150	47	517.8	782.7	5cm
	T2	46			204	200	516.9	780.8	NO
	T2	25	B	64/5	204	101	516.9	780.8	5cm
	T3	22			180	176	521.1	780.1	NO
	T3	43	B	*	180	77	521.1	780.1	5cm
	T4	41			186	182	517.2	781.5	NO
	T4	24	B	64/5	186	83	517.2	781.5	25cm

Table 3-2 (Continued)

Current meters in place

Date	Mooring ID	Meter #	Burst or Vector Avg.	Burst length/freq (sec/min)	Water dpth (ft)	Meter dpth (ft)	LORAN C coord. 9940 W	LORAN C coord. 9940X	Trans. ?
8/17/81	CP	43	B	*	186	182	13,514.8	27,782.2	5cm
	CP	25	B	64/5	186	103	514.8	782.2	25cm
	T1	47			165	161	517.4	7,82.6	NO
	T1	26	B	64/5	165	62	517.4	782.6	NO
	T4	41			183	179	517.3	781.6	NO
	T4	24	B	64/5	183	80	517.3	781.6	25cm
	P	42			186	182	511.8	783.9	NO
8/19/81	P	42			192	188	511.8	783.9	NO
	P	41			192	89	511.8	783.9	NO
	CP	43	B	*	186	182	514.8	782.2	25cm
	CP	25	B	20/5	186	83	514.8	782.2	25cm

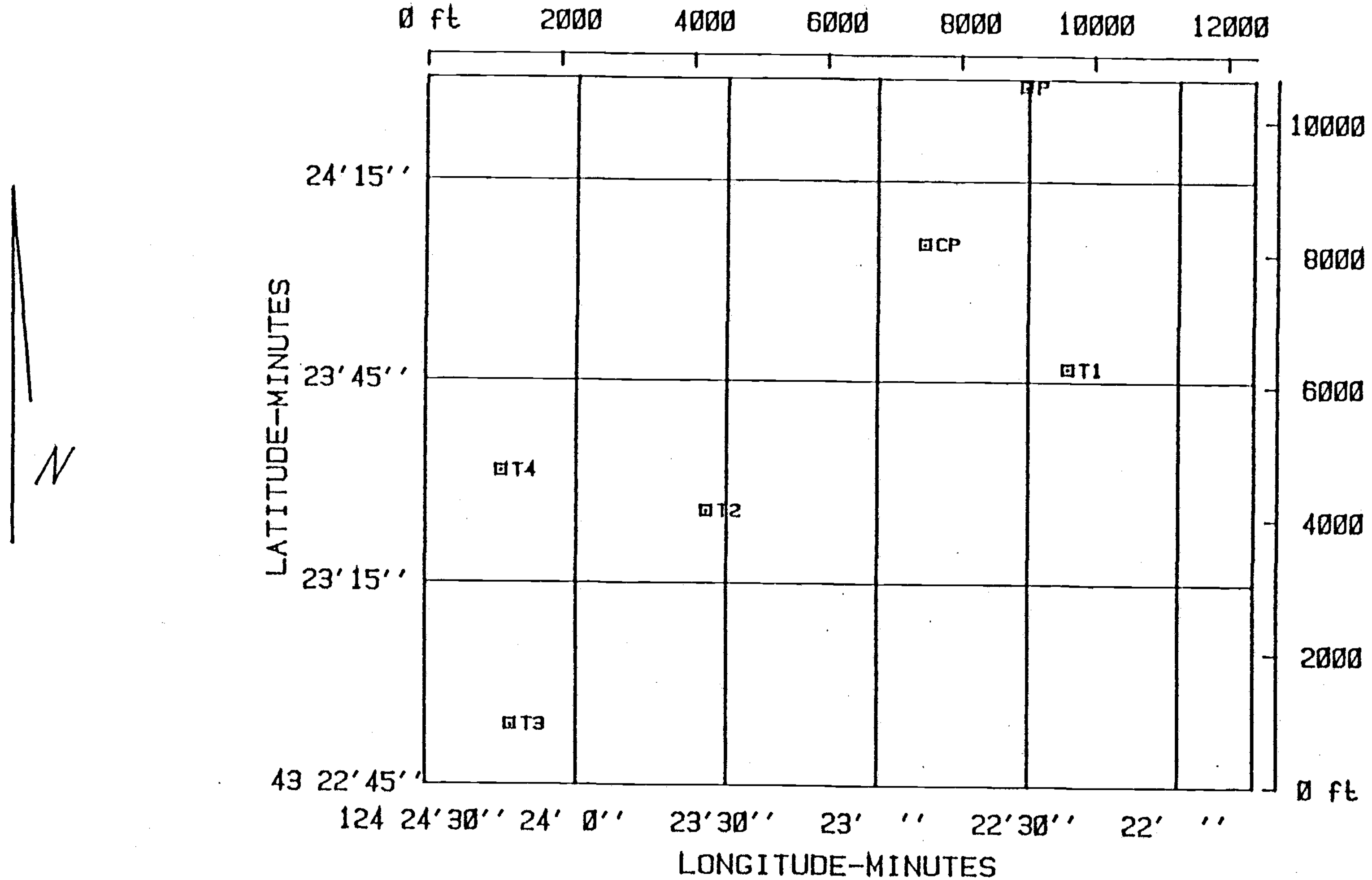


Figure 3-3 Current meters in place on 8/13/81.

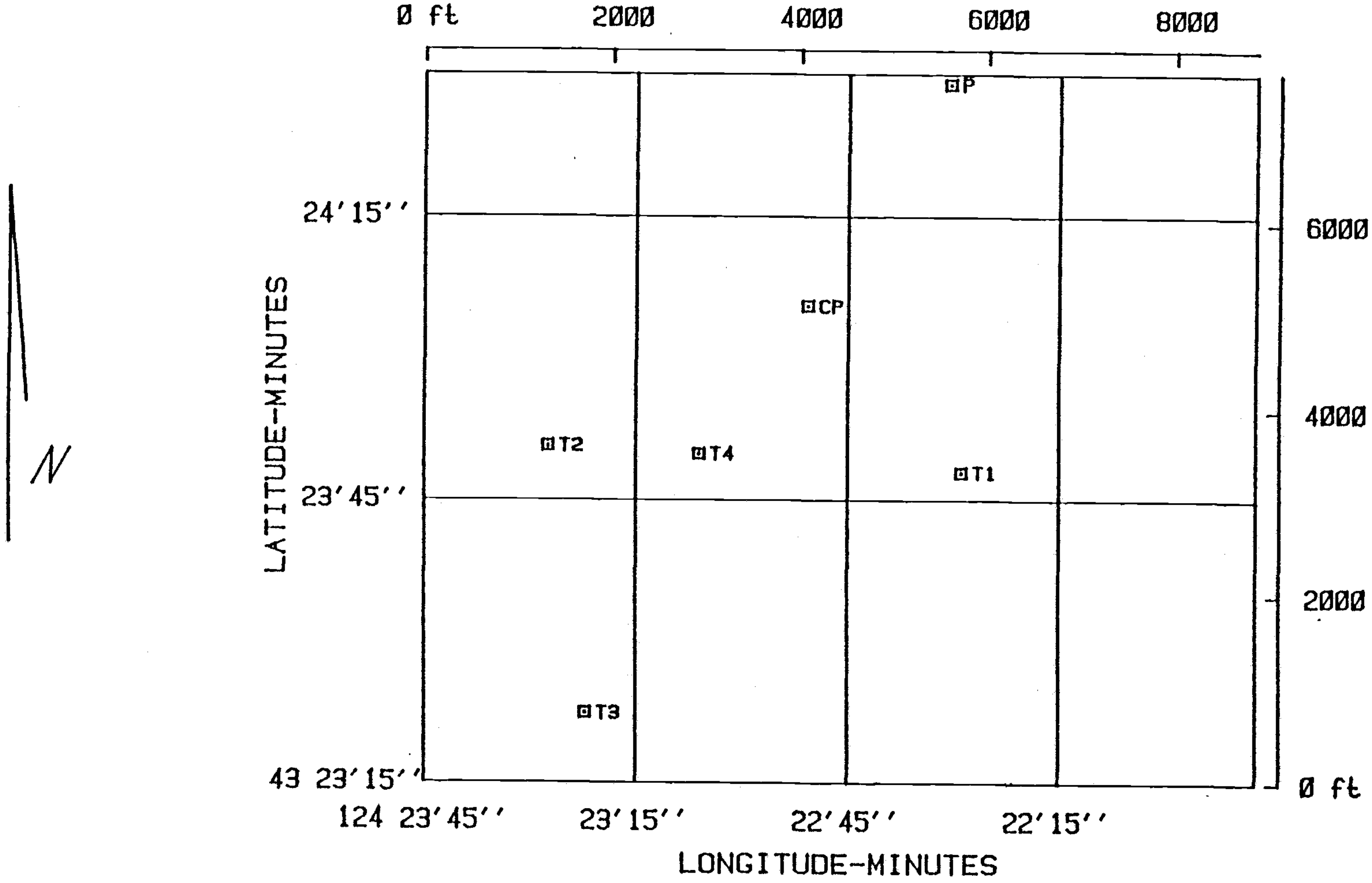


Figure 3-4 Current meters in place on 8/15/81

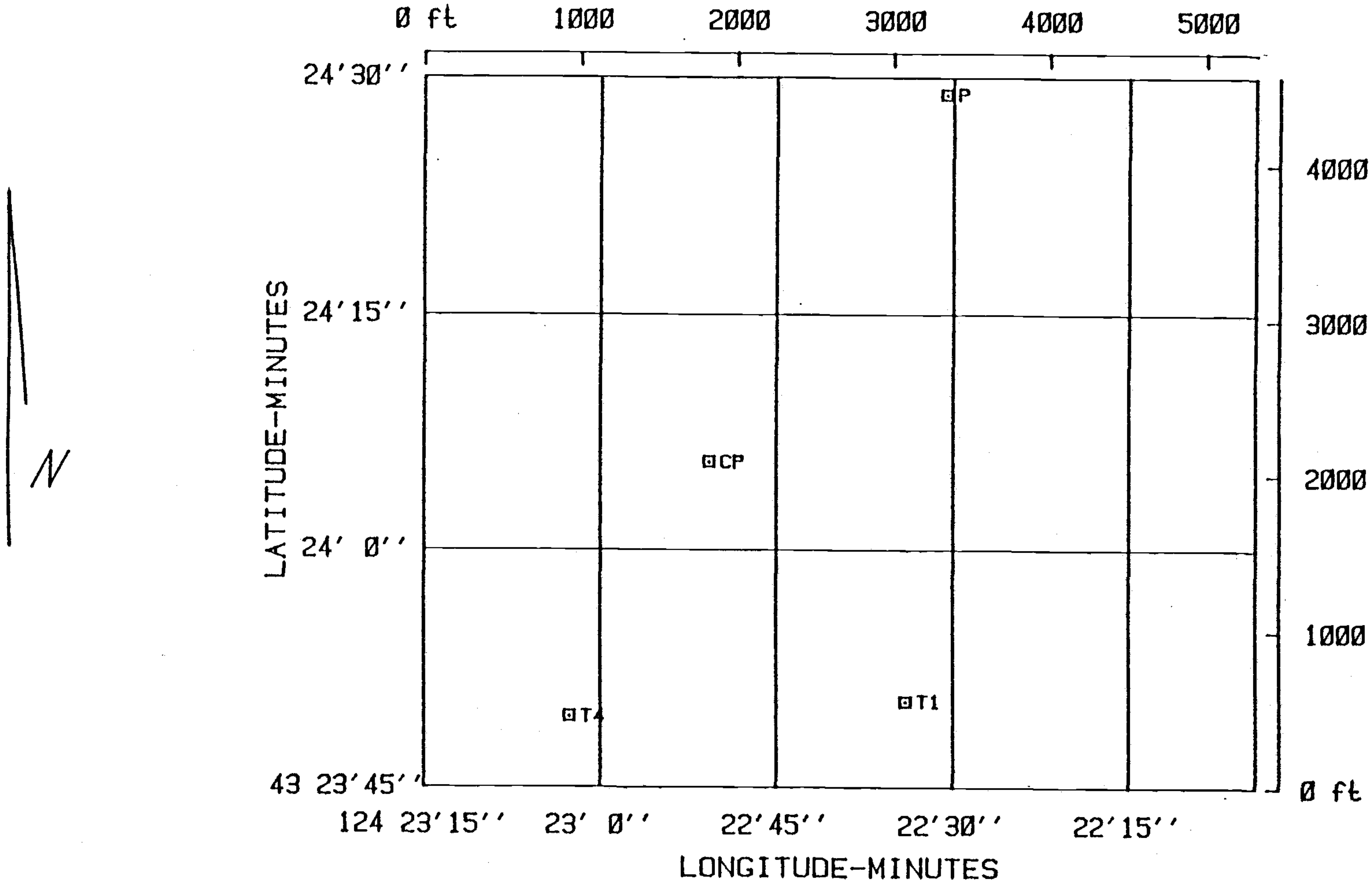


Figure 3-5 Current meters in place on 8/17/81.

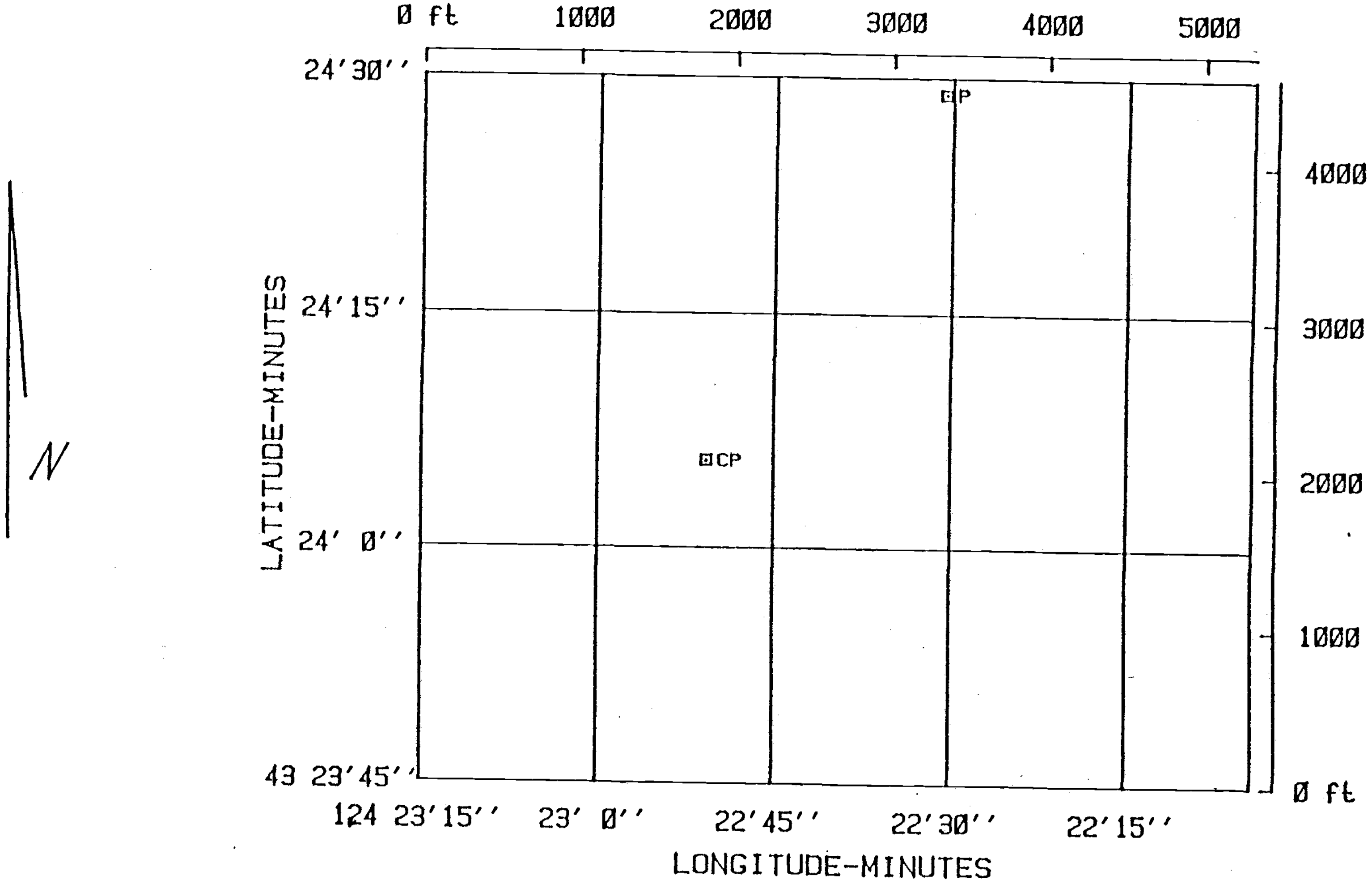


Figure 3-6 Current meters in place on 8/19/81.

indicated in Table 3-2. A vector averaging meter averages current vectors over time for a specified time period and stores the time and average velocity data for that period. One minute periods were recorded, and subsequently summed to produce five minute averaged velocity components; this period was determined to be sufficient to remove unsteady components due to waves and mooring motion. All information is stored on magnetic tape cartridges and is later interpreted at the Oregon State University Wave Research Laboratory.

3.2.2 Sediment Concentrations

Burst current meters are equipped to record data from an attached transmissometer. At locations noted in Table 3-2, burst meters were so equipped. Five and 25 cm path length optical transmissometers manufactured by Sea Tech Inc. were used. These were positioned down current from the disposal site to record any passing turbidity.

The transmissometer measures the attenuation of a transmitted light beam across the five or 25 cm path. This attenuation is caused by the water and the suspended particulate matter. Particles absorb and scatter a portion of the light beam, as does the water itself. Output (in volts) indicates the amount of light crossing the path, and, indirectly, the suspended sediment volume concentration. A more detailed explanation of transmissometer theory, and of methods of calibration used, is found in Appendix C.

The R/V "Mar Rae", a 40 foot fishing craft modified for research purposes, was used to follow the disposal plume in an effort to quantify sediment lost from the immediate spoil site. Although several investigators (see, for example, Gordon (1974) and Bokuniewicz et al. (1978) have calculated from observations of disposal events that less than one percent of the solid material is lost from the spoil site in this manner, it was felt that these observations were not conclusive for the sea conditions under investigation.

Attempts to track the plume visually, from the R/V and with an air spotter, proved fruitless until a drogue, consisting of a sea anchor attached to a surface float with a 60 foot long line (see Fig. 3-7) was deployed immediately following the disposal event. The drogue then gave observers a good indication of the plume location.

On board the R/V Mar Rae, two transmissometers were attached to a Hydro-Lab water quality monitor. In addition to the 5 cm and 25 cm transmissometers, the monitor was equipped with probes to quantify temperature, depth (via a pressure transducer), conductivity, and pH. Readings were recorded on board; the time and LORAN-C time delays were noted for each reading.

Limits of the sediment plume were established as the depth where transmissometer readings decreased to ambient. Continuous profiles of the plume were taken. Horizontal transects were made in an attempt to establish the horizontal scale of the plume.

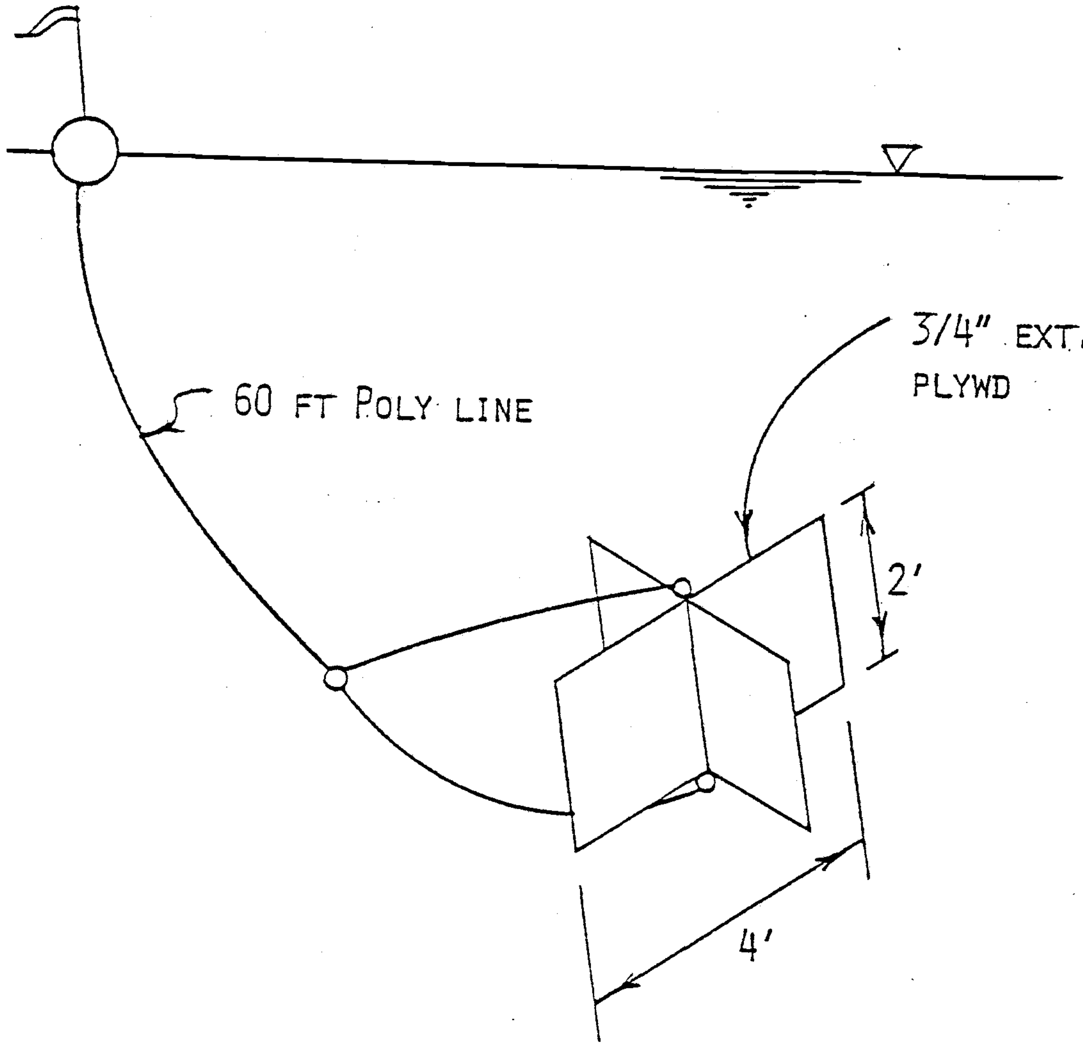


Figure 3-7 Drogue used in tracking plume.

Water bottle samples were periodically taken with an XRB 135 at-depth messenger-activated sampler manufactured by Hydro Products. Samples were secured at the cloud depth as indicated by transmissometer readings. These samples were later analyzed for suspended solids content, the results being used to check transmissometer obtained values.

Prior to each disposal event, background profiles were conducted at the disposal site. In this manner, the information necessary to later establish ambient density profiles and background sediment volume concentrations was accumulated.

3.2.3 Disposal parameters

The time of disposal was noted so that elapsed time could be calculated for all plume monitor data. The Corp of Engineers, Portland District, provided records of dredge volumes and solids contents. These were calculated from draft measurements recorded on board the dredge.

Periodically, samples were taken from the drag head, drag arm, and from the dredge hopper. Samples were analyzed to determine dredged material properties including liquid and plastic limits, grain size distribution, and water content. Results are summarized in Table 4-3.

3.3 Position determination

At all data stations noted during monitoring studies LORAN-C time delay readings were observed to establish horizontal positons. An LCA 3450 "Master Cycle" LORAN-C receiver manufactured by Morrow Electronics Inc. was used. This receiver is reported by the manufacturer to have a repeatable accuracy of ±50 feet and an absolute accuracy of 250 feet or less. This precision was adequate for the purpose of the present study; repeatable (relative) accuracy was of primary importance, since the information required was position relative to the disposal site.

3.4 Sea Conditions

Generally, conditions throughout the observation period were quite calm, with a four foot swell the only sea surface disturbance of any magnitude. Currents, noted in Table 3-1 for each disposal event, are summarized with the current roses of Figures 3-8 thru 3-10. The current roses are oriented to magnetic, not true, north. Overall, the plots show a relatively even distribution of current direction, with no clear trend exhibited except for meter 41 on mooring T4 at a depth of 89 feet. During the period from 8/18 to 8/20, 1981, currents at this location were almost exclusively in the southerly quadrant, at speeds in the 10 to 20 cm/sec range. (See Fig. 3-8).

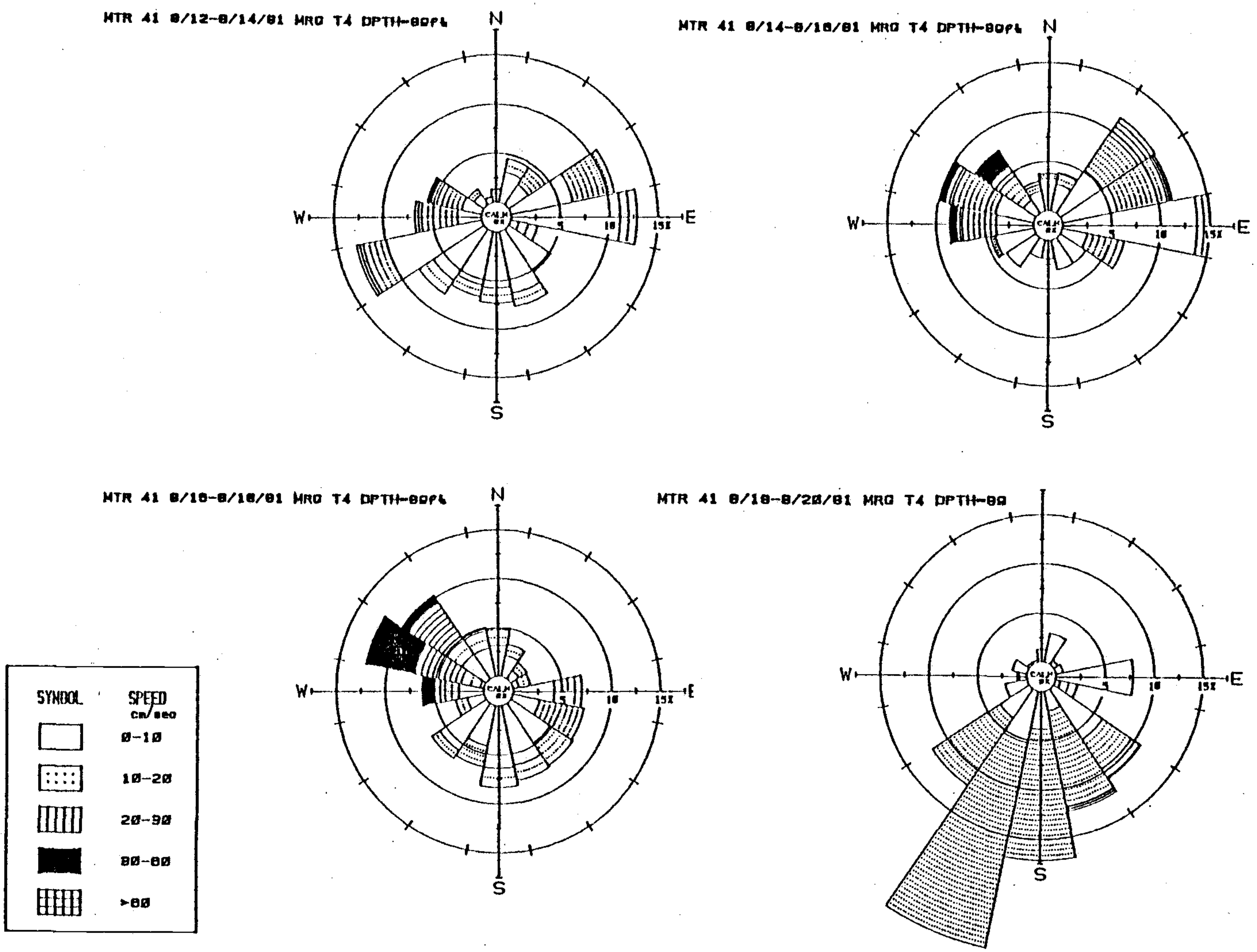


Figure 3-8 Vector average currents at mooring T4.

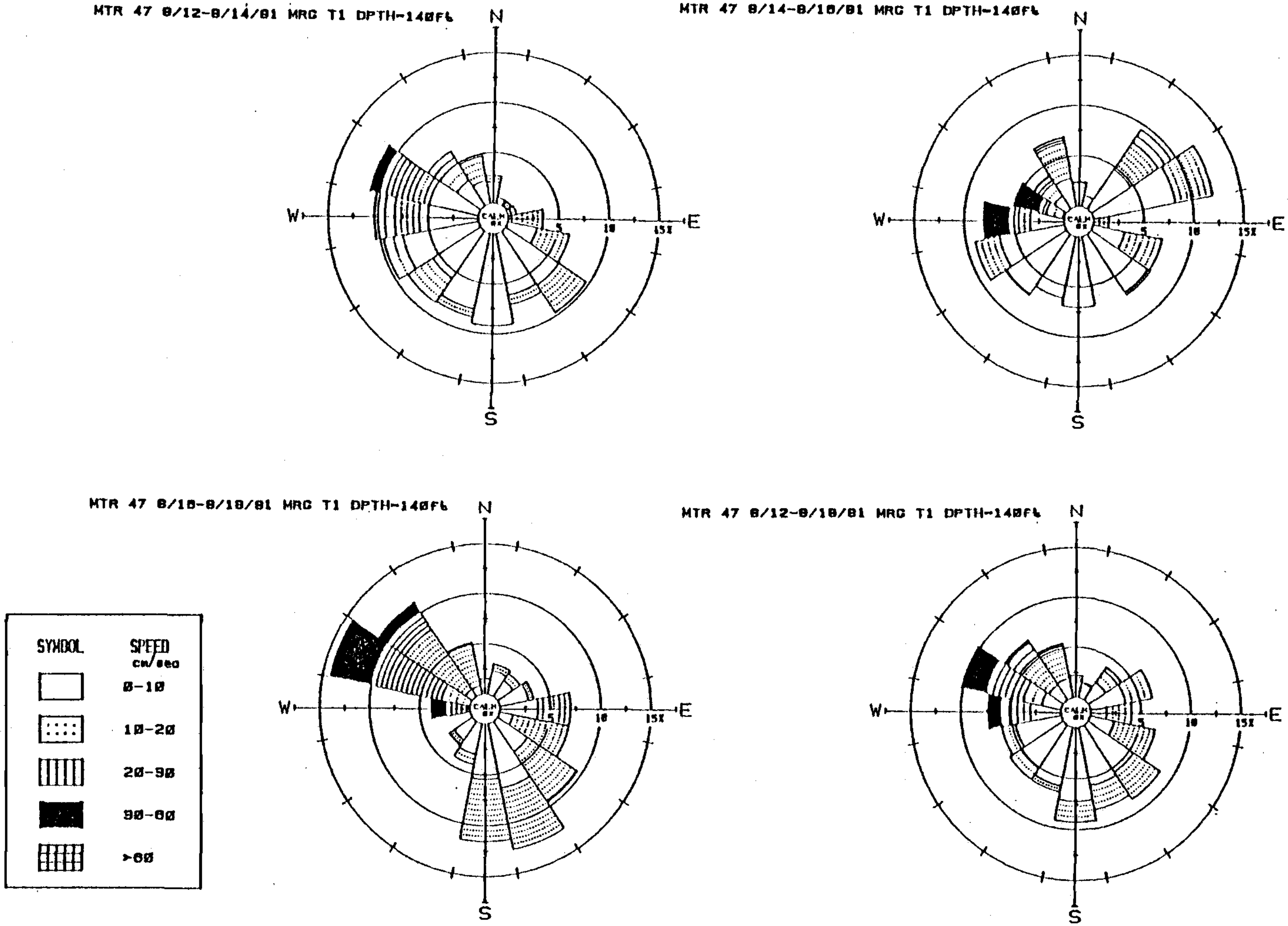


Figure 3-9 Vector average currents at mooring T1.

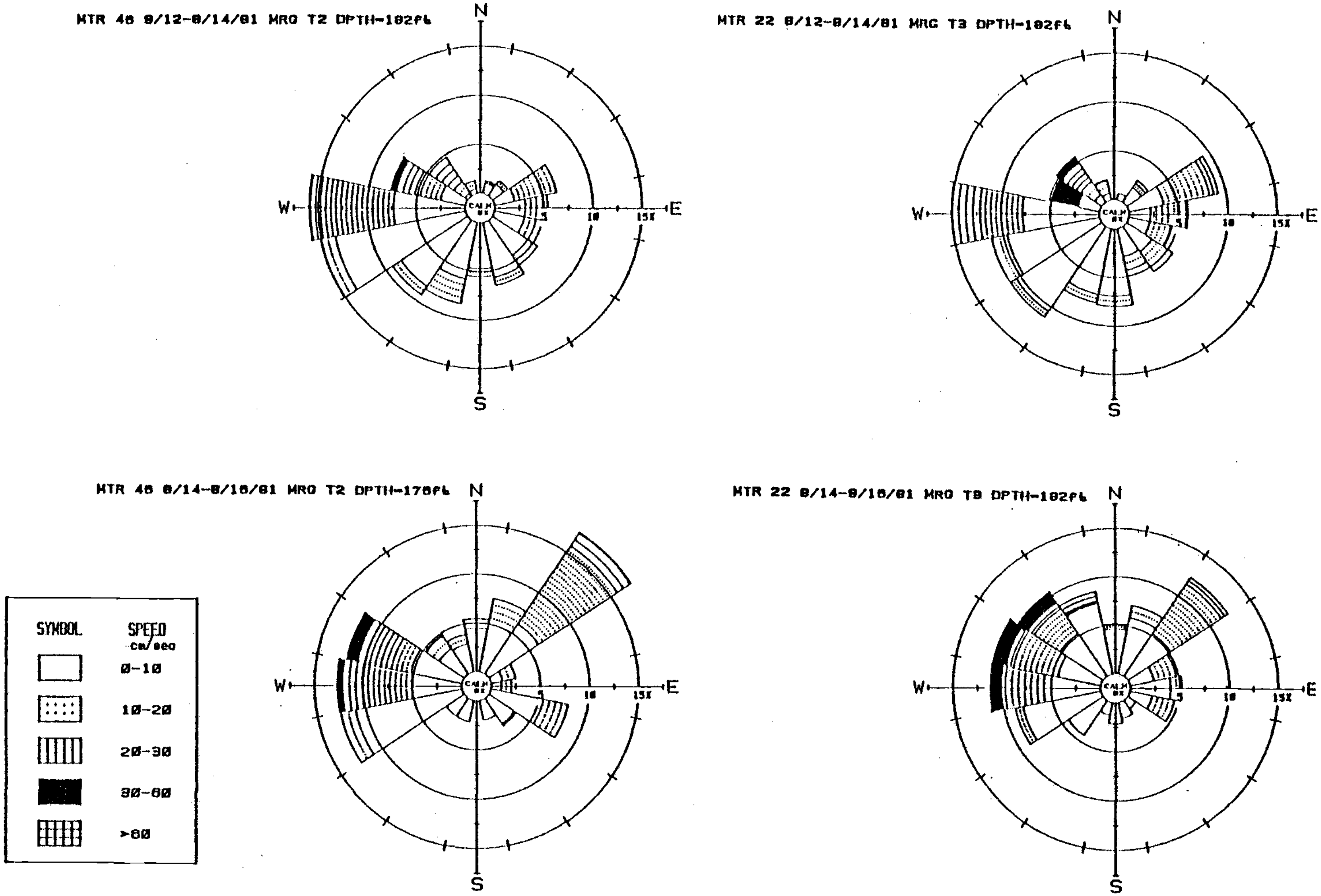


Figure 3-10 Vector average currents at moorings T2 and T3.

The variability shown in the short period current rose summaries (Figs. 3-8 to 3-10) illustrates why actual current measurements were used rather than seasonal average currents as model input. Actual instantaneous currents may be 90 to 180 degrees out of alignment with long-term mean trends. For this reason, all current inputs to the Koh-Chang model were obtained from the closest current meter location during the time period of the observed disposal event.

4. DATA ANALYSIS

4.1 Averaging the Field Data.

The plume data collected during disposal monitoring studies was processed to facilitate comparison with model predictions and to allow calculation of sediment volumes in suspension. The weighted averaging technique described below was devised. Averaged data is listed in Table 4-1 and 4-2. Complete plume profile data is compiled in Appendix A.

In Tables 4-1 and 4-2, the ID# is a consecutive identification code assigned to that particular profile through the plume; A or B designates the first or second disposal event of that day. "Average depth" is the average of all depth readings within the profile, assumed to be the depth of the center of the plume. "Delta time" is time elapsed from the release of the spoil. Average volume concentrations listed in units of parts per thousand are weighted averaged values calculated using the procedure described below for 5 cm and 25 cm transmissometer data. The calibration procedure used to convert transmissometer output (voltage) to concentration is described in Appendix C.

Delta X and Delta Z are distances (measured in feet) from the disposal site to the profile position. South (X) and east (Z) are considered positive for ease of comparison with computer model output.

Table 4-1

Average plume profile data; 8/13/81 and 8/15/81

Date	ID#	AVG DEPTH (ft)	DELTA TIME (min)	AVG CONC (ppt) x 10^3 (5cm)	(25cm)	DELTA X (ft)	DELTA Z (ft)
8/13/81	1A	31	18.5	5.6	5.5	366	-627
A	2A	43	29.7	7.6	6.2	707	-547
	3A	64	55.2	2.3	2.6	1787	-1046
	4A	40	69.0	1.9	2.3	2952	-1163
8/13/81	1B	26	11.7	10.4	10.6	165	-54
B	2B	21	17.0	11.6	12.5	120	-138
	3B	49	27.0	4.1	4.2	1025	-192
	4B	148	71.0	1.9	2.6	2754	-1004
8/15/81	1A	27	5.0	33.5	28.3	4	-431
A	2A	34	17.0	12.9	9.6	218	-507
8/15/81	1B	146	10.7	37.0	26.0	614	622
B	2B	131	16.4	18.0	15.8	614	622
	3B	91	36.5	1.6	2.4	993	220
	4B	182	44.0	2.4	2.9	795	90

Table 4-2

Average plume profile data; 8/17/81 and 8/19/81.

Date	ID#	AVG DEPTH (ft)	DELTA TIME (min)	AVG CONC (ppt) x 10^3 (5cm)	AVG CONC (ppt) x 10^3 (25cm)	DELTA X (ft)	DELTA Z (ft)
8/17/81	1A	28	17.5	5.8	5.5	699	-444
A	2A	173	24.0	1.1	1.5	1042	-398
	3A	66	41.0	2.1	2.5	1404	-593
8/17/81	1B	52	10.2	36.9	22.2	86	-594
B	2B	72	15.5	10.0	9.1	86	-594
	3B	136	22.5	12.1	7.1	646	-659
	4B	62	37.5	6.0	4.9	761	-1235
	5B	59	44.5	5.4	5.7	1272	-1549
	6B	56	57.5	2.3	2.7	1560	-2119
	7B	84	71.5	1.6	2.2	1897	-2439
8/19/81	1A	27	11.2	14.8	4.4	-61	394
A	2A	133	16.0	1.6	1.7	-406	673
	3A	70	24.3	23.1	5.6	-97	262
	4A	126	34.7	4.5	3.0	129	627
	5A	135	38.4	12.7	4.6	591	420
	6A	132	42.2	20.6	5.1	987	289
	7A	86	51.2	10.0	4.2	608	48
	8A	98	61.0	2.7	3.4	288	525
	9A	137	82.2	2.3	3.1	-326	1557
	10A	139	86.4	2.8	3.2	65	1344
8/19/81	1B	117	15.5	16.9	11.9	5	3
B	2B	88	22.1	31.6	28.9	-65	-206
	3B	94	31.1	2.5	3.2	-123	-135
	4B	96	42.5	8.6	11.0	902	-382
	5B	118	46.8	2.0	2.5	814	-6
	6B	93	55.5	3.6	5.0	1624	-159

In examining the plume data as collected, a group of data points spanning the plume in the vertical direction was selected as a representative profile. Limits of the plume (top and bottom extremes) were established as those depths where measured sediment concentrations returned to ambient. Average depth, time, concentration, and position for this profile were then calculated using the program "WTDAVG" (Appendix B). Profile locations were subsequently plotted using the plotter program "PLOT" (Appendix B). These plots appear as Figures 4-1 through 4-4.

The program "WTDAVG" weights concentration readings according to depth, and then computes an average for the transect. A weight equal to that percentage of plume thickness spanned by a reading is assigned to that reading. A concentration value is assumed to apply to a vertical distance from the midpoints between the reading above and the reading below. (See Figure 4-5)

4.2 Input for the computer model.

As noted in Section 2.3, computer model input may be divided into three groups of data applicable to a specific disposal event:

1) sediment characteristics

2) ambient conditions

3) disposal parameters

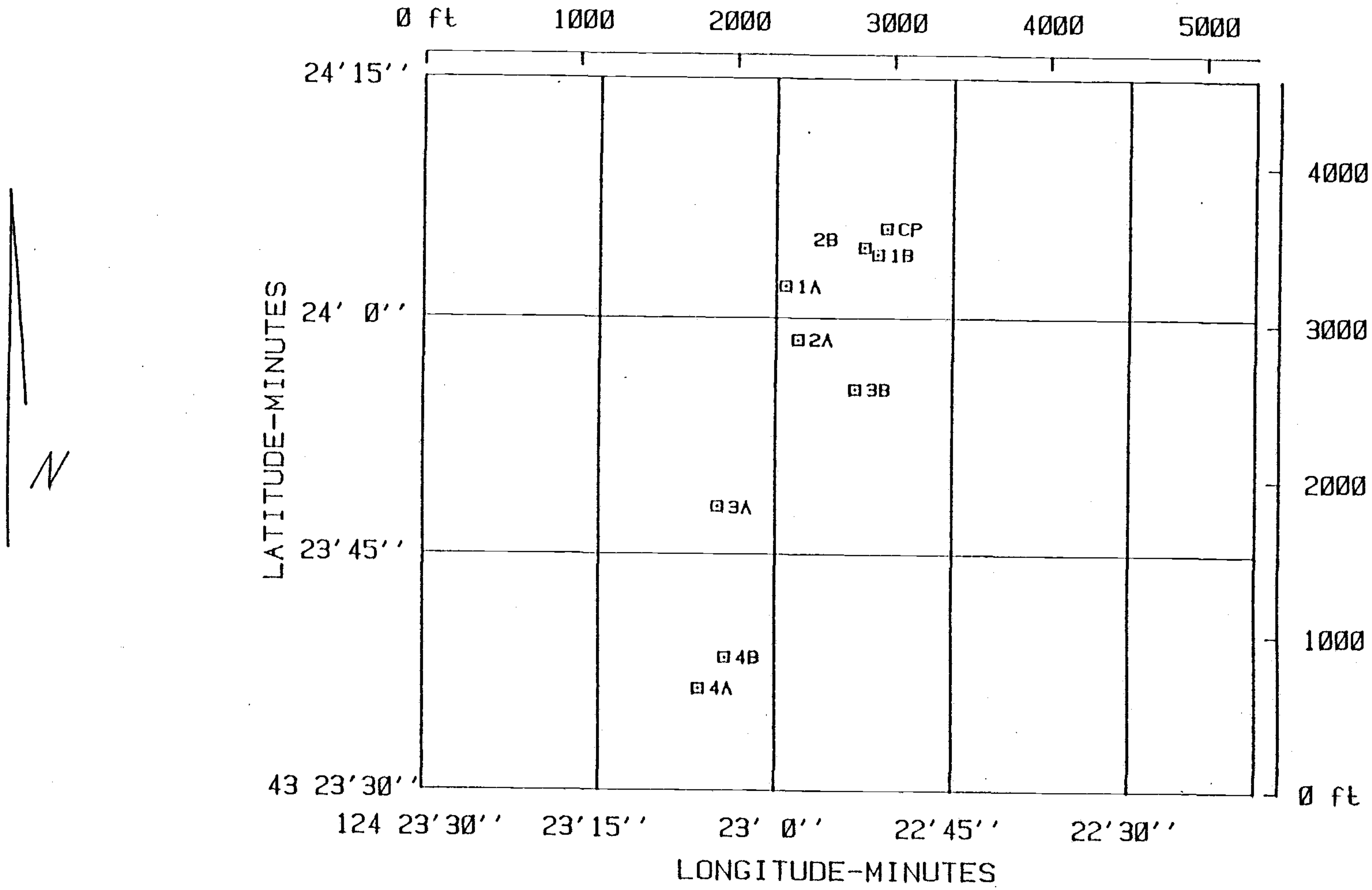


Figure 4-1 Profile locations: 8/13/81.

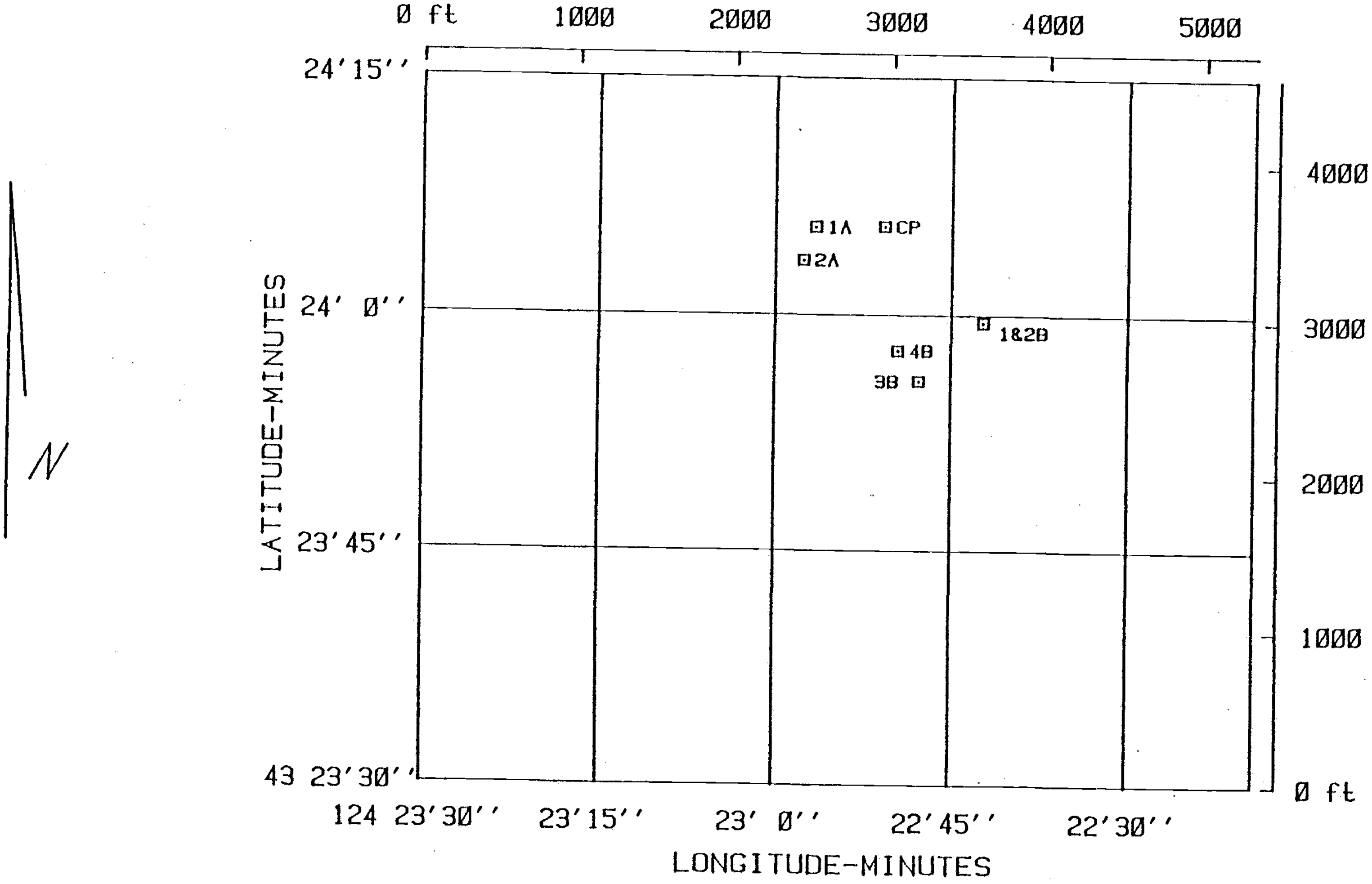


Figure 4-2 Profile locations: 8/15/81.

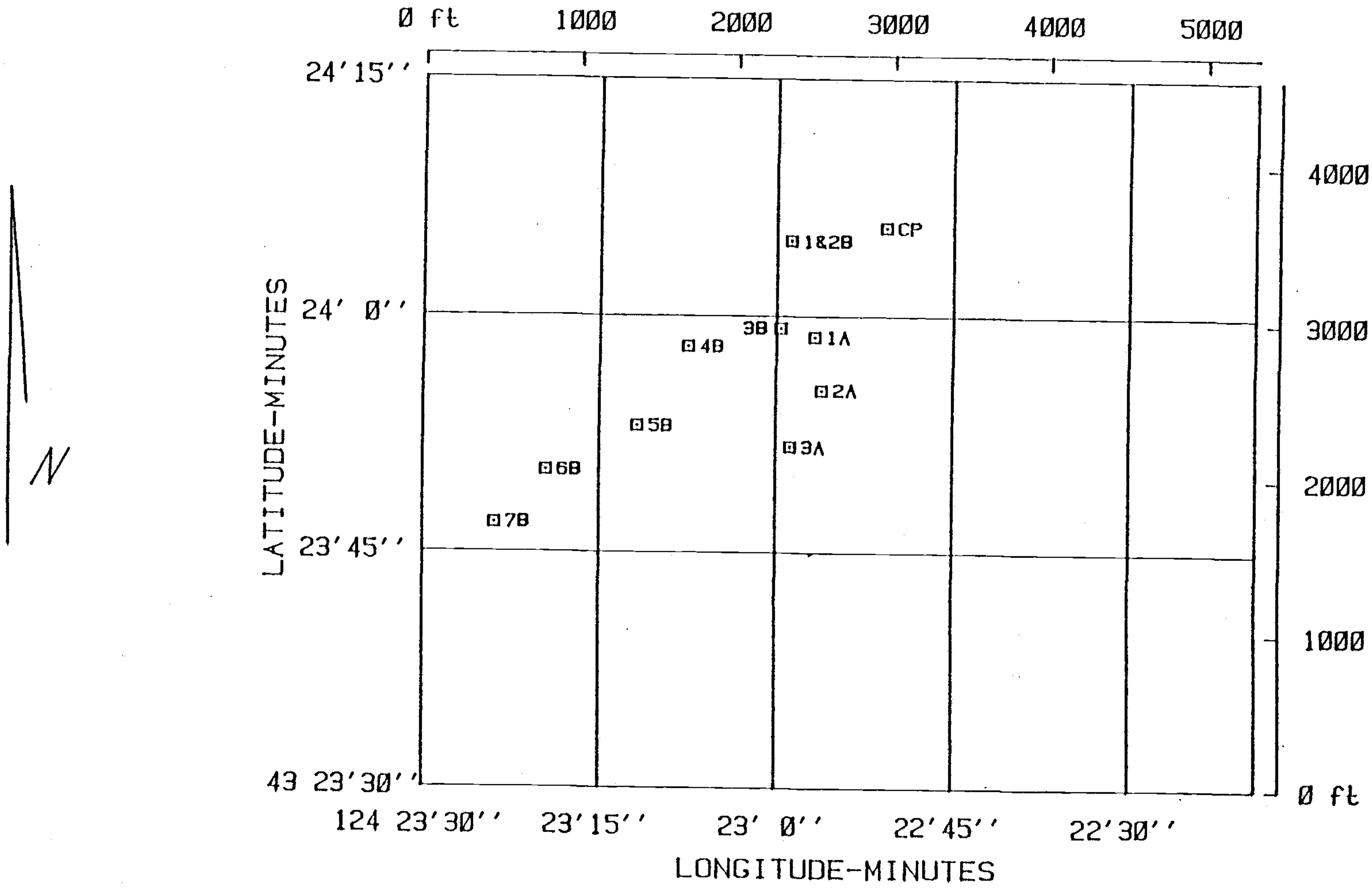


Figure 4-3 Profile locations: 8/17/81.

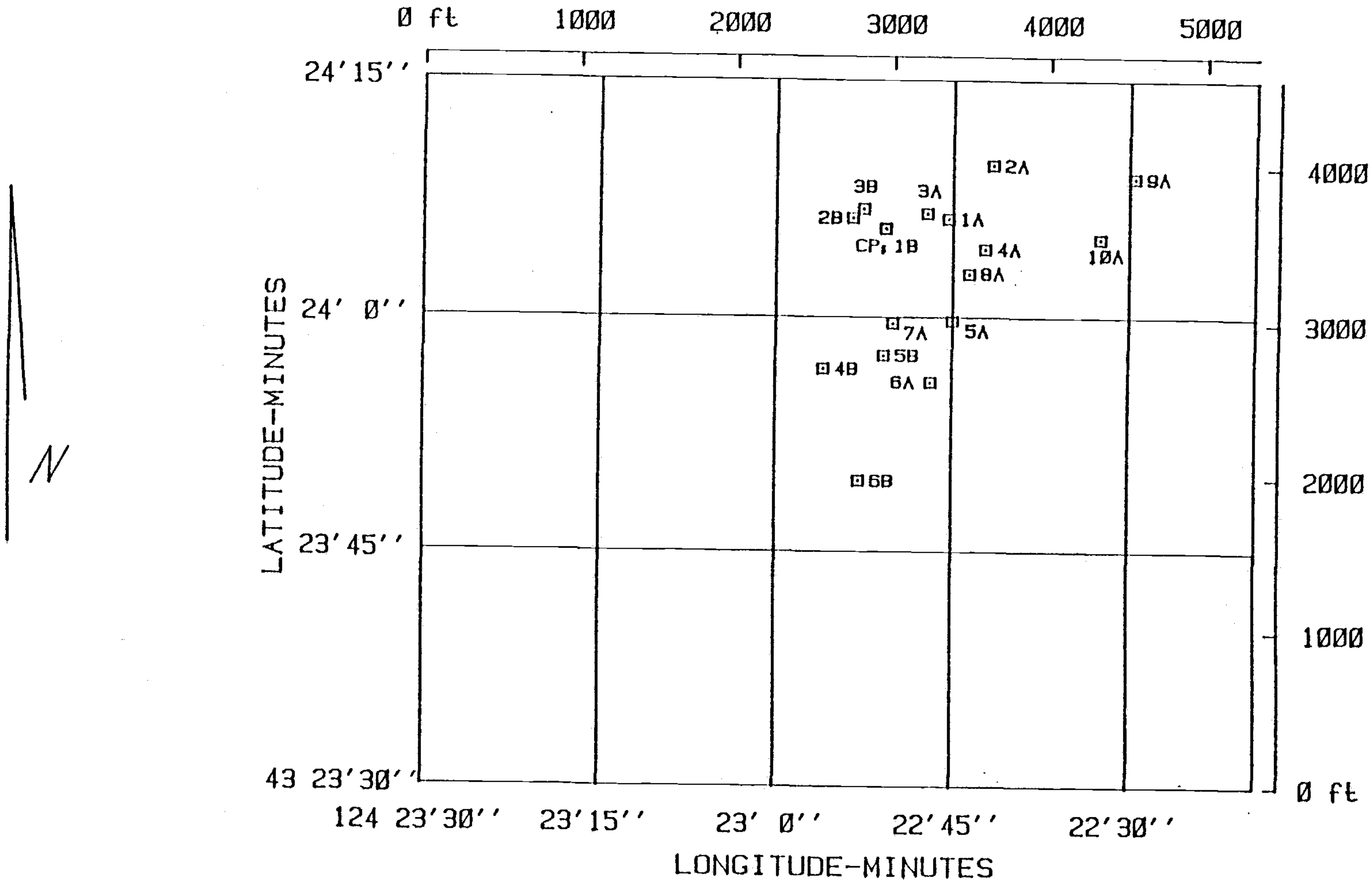


Figure 4-4 Profile locations: 8/19/81.

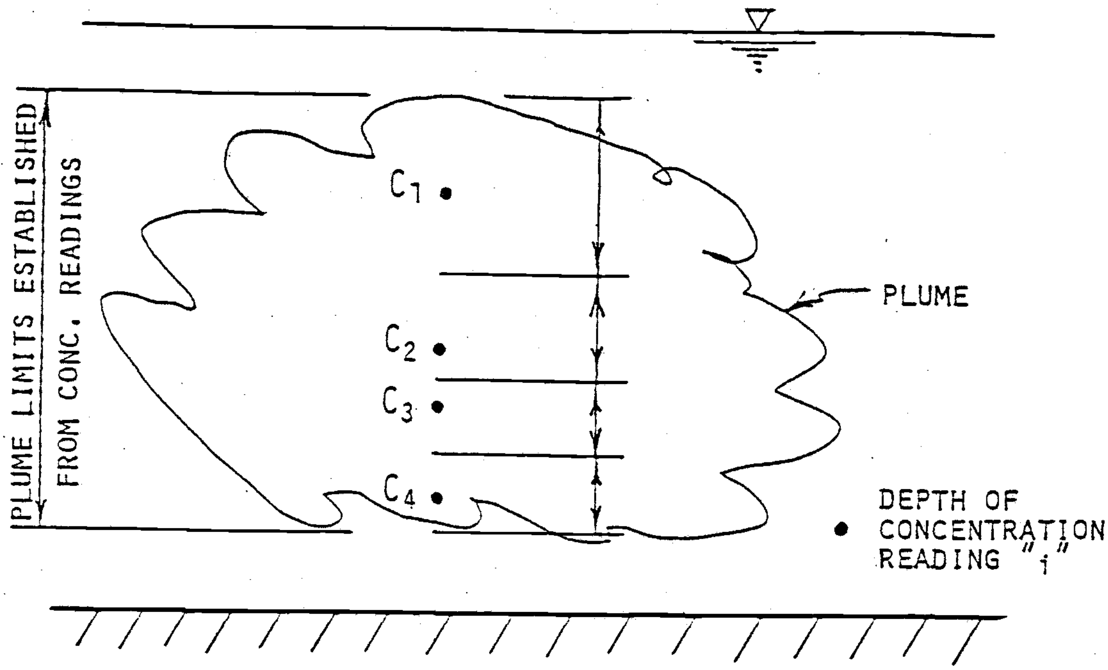


Figure 4-5 Weighted averaging procedure.

Discussion of the input parameters for the computer model will follow this organization. A list of input data for each event is listed as Table 4-3.

4.2.1 Sediment characteristics.

Dredged sediment samples were collected variously from the hoppers, drag head and drag arm (see Section 3.2). This material was then tested at the OSU Ocean Engineering soils laboratory according to standard ASTM procedures. Properties determined included specific gravity of solids, grain size distribution, volatile solids content, liquid limit, and plastic limit. These properties are listed in Table 4-4. A typical grain size distribution is shown in Figure 4-6.

The model is capable of tracking up to 12 solid components. Bowers and Goldenblatt (1978) conducted a sensitivity analysis using various numbers of solids components, and found three to be adequate. Hence three are used in the present study.

The grain size distribution curve is divided into three equal parts as suggested by Davis and Bowers (1980) (the division points being at 66.7% finer and 33.3% finer), and a median grain size is determined graphically for each sub-component. This median grain size is then used to represent that component. A fall velocity, V_f is calculated using Stoke's law (Graf, 1971). Each component is assigned one third of the total sediment concentration.

Table 4-3

Model Input Values

A. Input parameters common to all events:

Grid: 15(z) x 20(x) @ 500' spacing

Barge Coordinates: XBARGE = 5000' ZBARGE = 3750'

Bulk Parameters: Density = 1.32 g/cc
"Voids ratio" = .80
Liquid Limit = 90%
avg. S.G. = 2.65

Solids component parameters:

component	density	volume conc.	V_f(fps)	"voids ratio"
sand	2.65	.066	.11E-01	.8
silt	2.65	.066	.14E-02	.8
clay	2.65	.067	.12E-04	.8

Depth: 186' Initial Cloud Velocity: 1 fps

Table 4-3 (Continued)

B. Variable input parameters:

Event	Initial Radius	Initial Dpth.	Duration (sec)	Time Step (sec)	Dpth 1 ft	Velocity Profile X vel fps	Z vel fps	Dpth 2 ft	X vel fps	Z vel fps
8/13 A	27.8'	15'	5865	345	79'	.65	-.15	182'	.09	-.07
8/13 B	16.5'	7.5'	4725	525	79'	.71	-.25	182'	.04	-.2
8/15 A	16.9'	7.5'	2700	540	97'	-.1	.14	176'	-.29	.42
8/15 B	27.3'	15'	2970	330	97'	.13	0	176'	-.22	.03
8/17 A	27.3'	15'	2700	300	76'	.47	.08	179'	-.17	.42
8/17 B	25.6'	15'	4590	270	76'	.52	-.56	179'	.32	-.2
8/19 A	28.3'	15'	5500	750	80'	.7	-.4	83'	.7	-.4
8/19 B	24.6'	15'	3500	250	80'	.23	-.05	83'	.23	-.05

Table 4-4

Soil analysis results

Sample ID	Plastic Limit	Liquid Limit	Volatile Solids (%)	Mean (mm)	Median (mm)	Mode (mm)	Std.Dev. (mm)	Skewness	Kurtosis
1	41	65	6.98	.0356	.0238	.054	.0363	.89	2.51
3	53	97	10.03	.0226	.0141	.052	.0217	.74	2.03
4	41	89	9.27	.0340	.0210	.052	.0369	1.24	3.40
13	61	83	2.34	.0217	.0148	.053	.0222	.89	2.42
19	39	60	5.23	.0471	.0177	.052	.0749	1.78	4.94
21	62	114	13.41	.0480	.0150	.052	.0859	2.04	5.84
22C	64	87	8.24	.0420	.0132	.052	.0733	1.99	5.65
22D	74	116	11.78	.0303	.0102	.052	.0481	1.82	5.09

#1 8/12/81 1100: Centerline channel; sample taken 13:00. Sample not available from hopper. Sample from chute: heavy materials.
#3 8/13/81 13:00 taken from top drag head.
#4 8/13/81 17:00 from drag head.
#13 8/15/81 11:50 drag head.
#19 8/16/81 from hopper w/core sample.
#21 8/17/81 from drag arm.
#22D 8/17/81 from drag head.
#22C 8/17/81 from core sample.

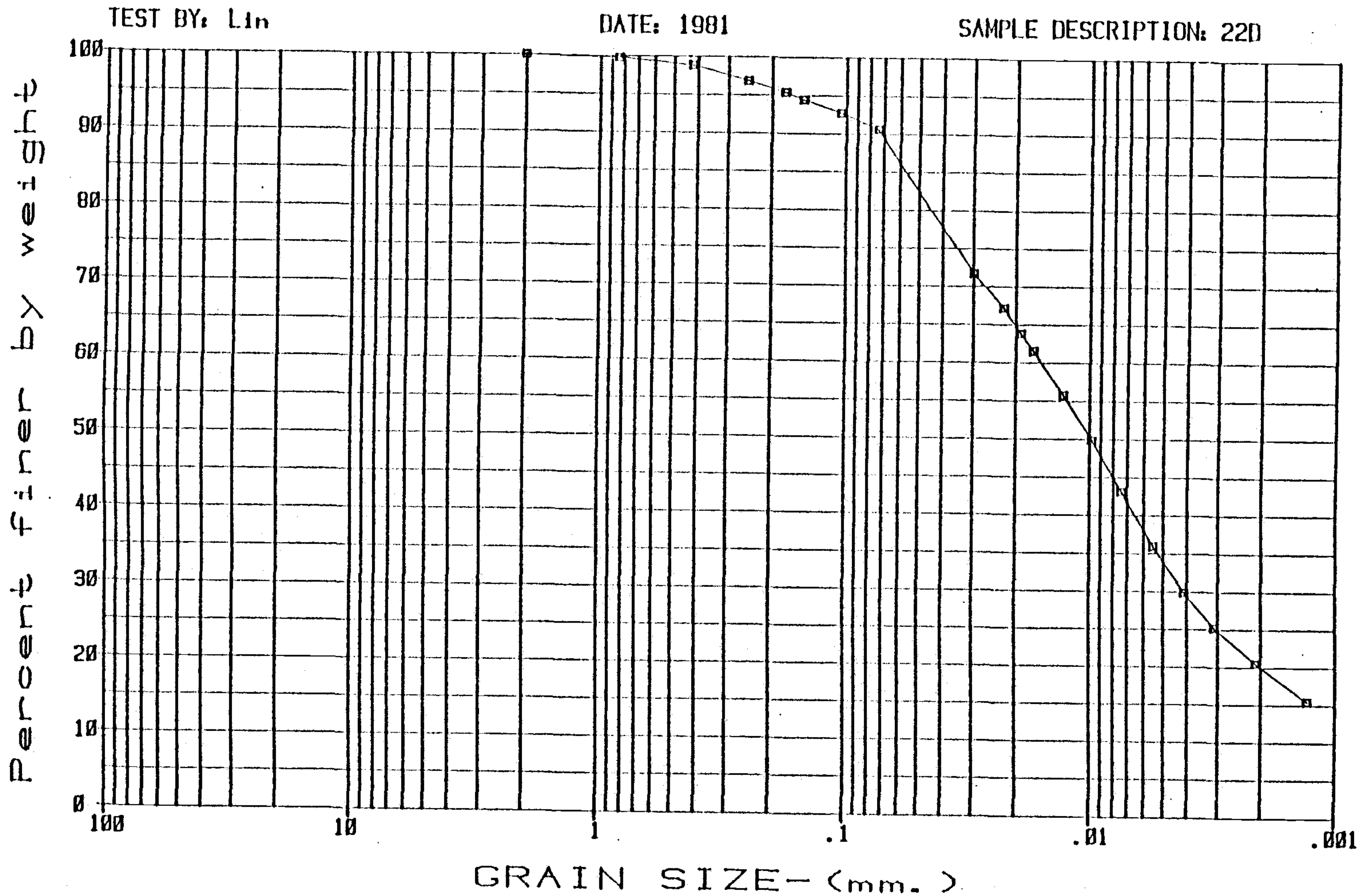


Figure 4-6 Typical spoil material grain size distribution curve.

For the grain sizes under consideration, Stoke's law is deemed accurate enough for the present application. It should be noted that for cohesive elements in the collapse and long-term diffusion phases, V_f is an internally calculated parameter dependent solely on sediment concentration (Johnson and Holliday, 1978). Considering the particle sizes encountered in this study, no material would be expected to settle out of the descending cloud, so the specific V_f assigned in this case is not important. Existence of larger clumps was not observed, nor was it expected, after observations of Bokuniewicz, et al. (1978) regarding the total lack of clods in hopper dredge releases. Nevertheless, golfball sized clumps were subsequently found on the sea floor at the disposal site.

4.2.2 Ambient conditions.

4.2.2.1 Currents

Measured current data was interpreted and tabulated at the OSU Wave Research Laboratory. Resulting data is in the form of (magnetic) north and east vectors, averaged over consecutive five minute periods. The model allows input of a two layer velocity profile, velocity input being specified at two depths in the form of x and z vectors. Hence, data from the upper and lower meters of a two meter string could be used to define the ambient velocity profile.

Current velocity vector data for the period of interest (approximately 45 minutes after release time) was converted to a new coordinate system; for clarity and to be consistent with model output, true north was used as the x-axis, with south designated positive x and east as positive z. (An easterly current is defined as one moving toward the east.) This data was then averaged to obtain the input current values.

The model does permit the input of a time dependent current; this was not found to be necessary for the periods of time for which the plume was monitored.

4.2.2.2 Density profiles.

Density profiles were generated using pre-release conductivity and temperature profiles taken at the CP. Salinity (obtained directly from a calibration curve supplied with the Hydro Lab instrument) and temperature were combined to determine density directly from a temperature-salinity diagram (Sverdrup, 1954). Pressure effects were not considered in regard to the moderate depth and degree of precision required. A stable density gradient was observed in all cases, as might be expected in light of the calm conditions and consequent lack of mixing effects. Density data is tabulated in Table 4-5.

The depth was considered to be a constant 186 feet in the area of interest. This area was modeled as a 15 by 20 grid, grid spacing being 500 feet. (See Figure 4-7)

Table 4-5

Pre-dump in situ temperature, salinity, and density profiles.

Date (time) of profile	Depth (ft)	Temp. (°C)	Conductivity (mmho/cm)	Salinity (ppt)	Density (g/cc)
8/12/81 (15:26- 15:37)	50	9.6	53.3	35.1	1.0271
	82	9.0	53.5	35.2	1.0272
	114	8.6	53.6	35.3	1.0274
	138	8.6	53.6	35.3	1.0274
	168	8.3	53.8	35.5	1.0275
	179	8.2	53.8	35.5	1.0276
	181	8.2	53.9	35.5	1.0276
8/13/81 (14:55- 14:59)	51	9.9	53.0	34.9	1.0269
	111	8.8	53.5	35.2	1.0273
	189	8.1	53.9	35.5	1.0276
8/15/81 (11:00- 11:04)	17	14.3	52.1	34.3	1.0256
	50	12.7	52.5	34.5	1.0261
	83	9.9	53.1	35.0	1.0270
	113	9.2	53.5	35.2	1.0272
	147	8.5	53.7	35.4	1.0275
	182	8.3	53.8	35.5	1.0275
	195	8.3	53.8	35.5	1.0275
8/17/81 (13:11- 13:15)	15	13.5	52.4	34.5	1.0259
	53	11.1	52.6	34.6	1.0264
	84	9.8	53.0	34.9	1.0269
	115	9.7	53.2	35.0	1.0270
	147	9.8	53.3	35.1	1.0271
	176	8.7	53.7	35.4	1.0275
9/17/81 (17:10- 17:17)	32	11.7	52.8	34.8	1.0264
	108	9.1	53.6	35.3	1.0273
	166	8.1	53.7	35.4	1.0275
8/19/81 (9:06- 9:12)	6	12.8	52.6	34.6	1.0261
	17	12.8	52.6	34.6	1.0261
	35	12.6	52.7	34.7	1.0262
	66	9.7	53.1	35.0	1.0270
	100	8.8	53.5	35.2	1.0273
	132	8.2	53.9	35.5	1.0277
	161	8.2	53.9	35.5	1.0277

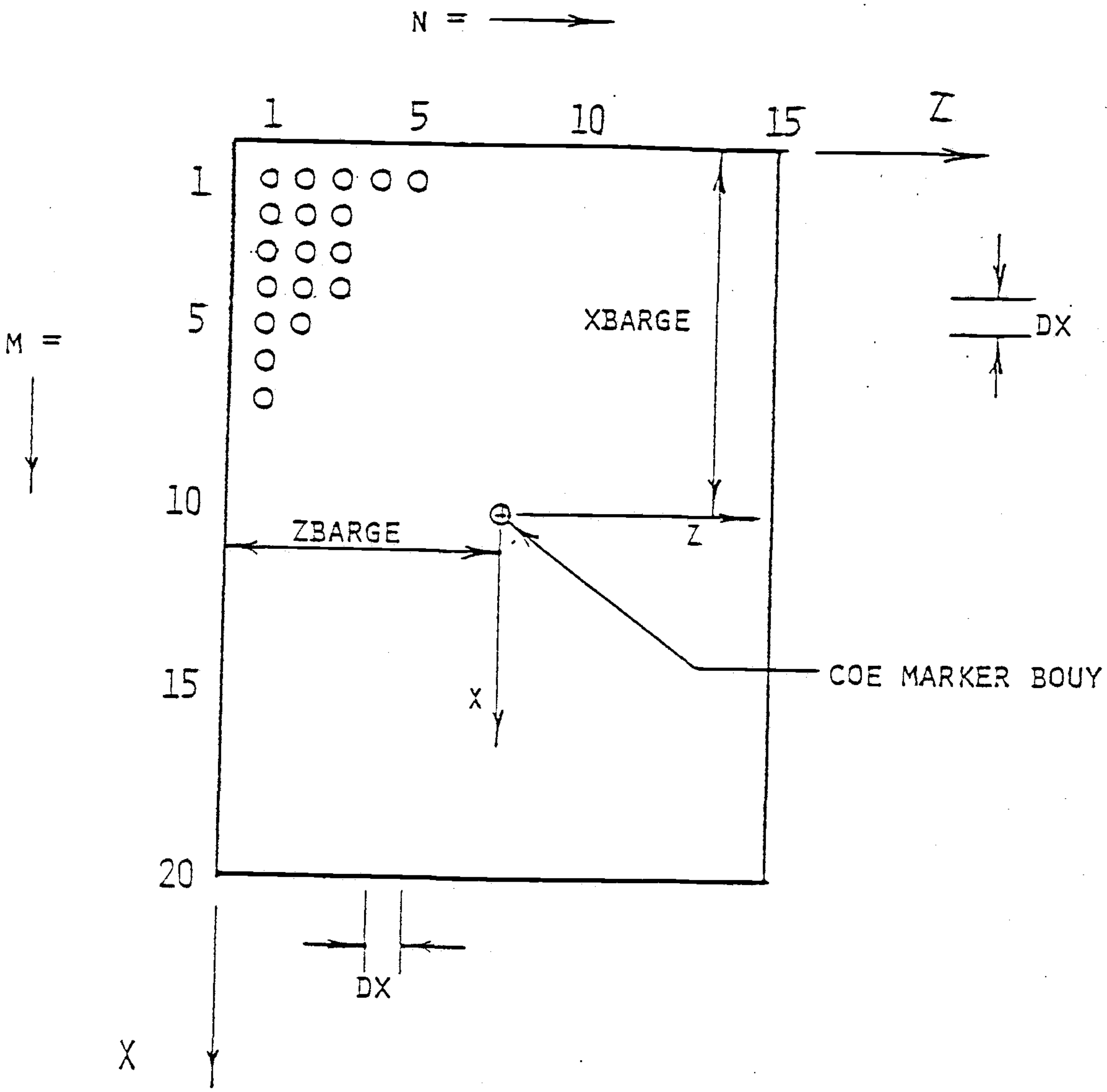


Figure 4-7 Definition sketch of disposal area as input to computer model.

4.2.3 Disposal parameters.

4.2.3.1 Barge coordinates.

The dredge coordinates (XBARGE and ZBARGE) are somewhat arbitrary, as the point of release in fact becomes the reference point by which model output may be compared with monitor data. A location is specified so that the drifting cloud will not encounter the model boundaries during the time duration of the modeled event.

4.2.3.2 Initial cloud radius, velocity, and depth.

Initial cloud radius, RB, is calculated by equating the volume of a hemisphere, $\frac{\Pi D^3}{12}$, to the known volume of material released. hence, $RB = (\frac{3V}{2\Pi})^{1/3}$, where V is the known volume.

Depth of the cloud centroid at discharge was somewhat arbitrarily set at 15 feet, or 7.5 feet in case of the smaller Yaquina dumps. A sensitivity test (Section 2.4) showed minimal model sensitivity to this parameter.

The initial downward velocity of the cloud was estimated from the time required to empty the hoppers (six minutes), the quantity of material released, and the total cross-sectional area of the hopper doors. Again, sensitivity tests showed the model to be insensitive to variations of this parameter (Section 2.4).

4.2.3.3 Aggregate material properties.

Bulk density and voids ratio of the aggregate dredge material were calculated from Corps supplied volume and density figures.

4.3 Model predictions.

Generally one might expect model predictions for similar sized events to be largely the same. However, the ambient density profile used apparently has a considerable effect, particularly on the long term results. (See Section 2.4, Sensitivity Analysis, for a discussion of the effects of an altered ambient density profile.) A summary of some predicted data for modeled events is presented in Table 4-6.

4.3.1 Convective descent phase predictions

In most cases the model predicts that the cloud will impact the bottom approximately 20 seconds after release; however the model predicts double this time (40 seconds) for event 8/13 A. In the case of the smaller Yaquina dump of 8/15 A, the predicted time to bottom impact was 32.2 seconds.

Predicted concentrations on impact range from 10.1 ppt in case of the 8/15 A event up to 27.0 ppt for 8/19 A. Although the cloud has acquired a horizontal velocity from the ambient by the time of impact, horizontal translation is negligible due to the brief travel time.

4.3.2 Collapse phase predictions.

Following bottom impact, the model cloud spreads and flattens

Table 4-6

Comparison of disposal event predicted values.

ID	Initial cloud radius (ft)	Time to bottom impact (sec)	Conc.@ impact (ppt)	Cloud dimensions @ end collapse (ft) vert.	horiz.	Time to collapse (sec.)	Conc.@ end of collapse (ppt)	max conc @ 30 min (ppt)	45 min	% total mat'l settled @ 15 min	30 min	45 min
2	27.8	40.1	26.3	2.57	529.7	345	22.6	.23	.10	9	12	20
3	16.5	33.0	9.4	4.00	618.5	272	5.6	.03	.01	19	24	27
4	16.9	32.2	10.1	.97	720.7	533	3.6	.03	.03	23	27	32
5	27.3	17.6	25.5	.83	872.2	216	15.1	17	.10	27	31	35
6	27.3	17.9	25.6	.84	869.9	217	15.2	.20	.11	10	13	16
7	25.6	20.2	23.0	.92	794.4	233	13.8	.11	.07	35	38	38
8	28.3	17.2	27.0	.83	895.9	214	16.1	5.6	5.2	67	67	68
9	24.6	19.0	21.6	.84	810.9	219	12.8	4.4	4.2	67	67	68

erally, the model predicts that collapse will terminate approximately four minutes after disposal time. Event 8/13 A is predicted to have a collapse phase lasting nearly six minutes; the smaller dump of 8/15 A is predicted to collapse for nearly nine minutes.

At termination of the collapse phase, cloud thickness has decreased to less than one foot (except in case of 8/13 A) while the cloud has spread to a horizontal dimension varying between 500 feet and 900 feet (See Table 4-6). Solids concentrations at this point range from 3.6 to 22.6 ppt.

4.3.3 Long term diffusion predictions.

Significant differences are noted in model predictions for the long term diffusion phase. As can be seen in Table 4-6, predicted concentrations vary by two orders of magnitude, or by one order of magnitude if the smaller dump is not included. This can only be attributed to variations in ambient density profiles and initial radius, in view of the results of the sensitivity analysis. Solids concentrations (predicted) are seen to range from .03 ppt to 4.7 ppt.

Plots of predicted maximum concentrations as a function of time have been prepared and are included in Appendix F. An example is found in Figure 4-8.

Large variation is also noted in the predicted amount of material settled out at various times. For the events of 8/19, the sand and silt components are predicted to quickly settle out of suspen-

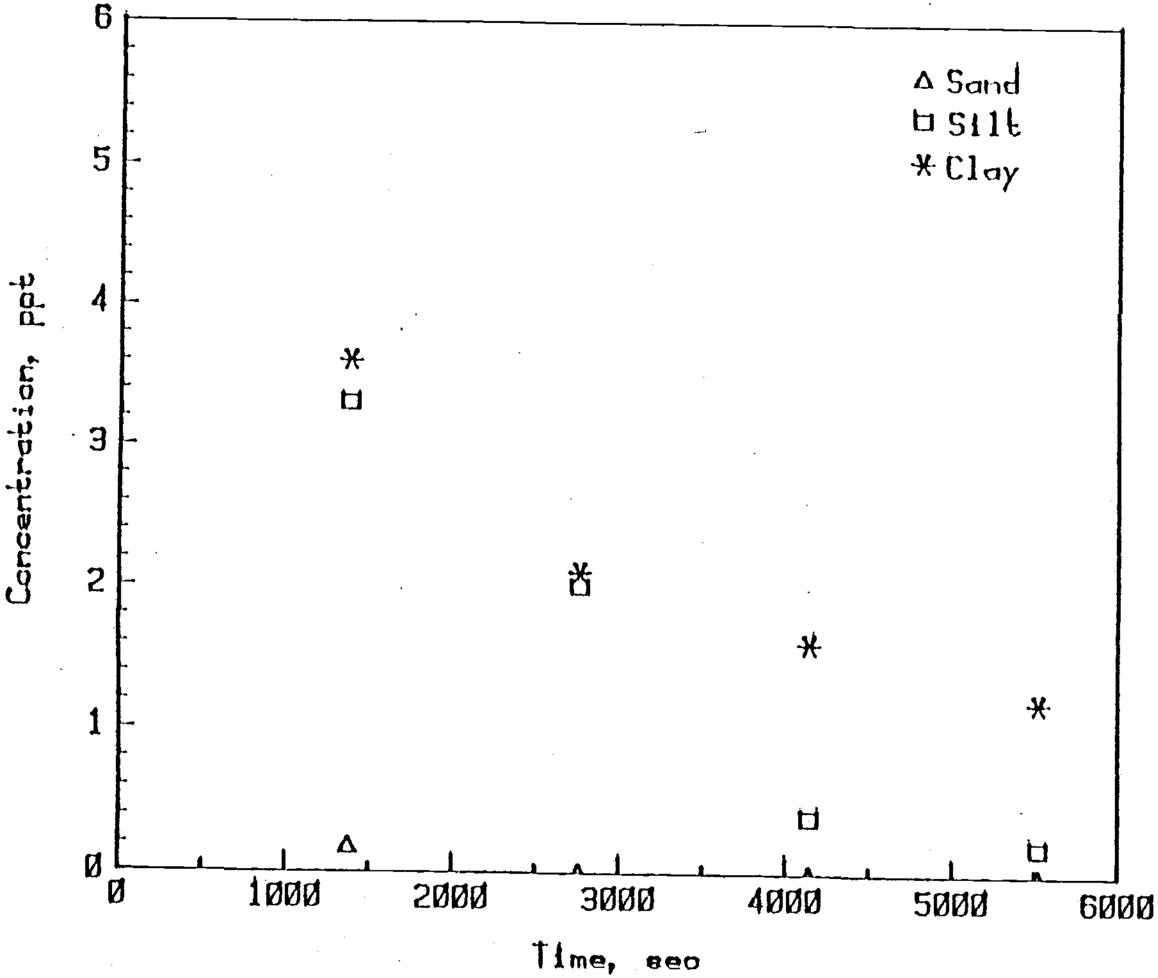


Figure 4-8 8/13/81A: Maximum predicted concentration.

sion; in contrast, for 8/17 A only 16% of the solid material is predicted to settle out after 45 minutes.

4.4 Comparison: model predictions vs. field observations.

4.4.1 Convective descent phase.

No data is available to permit direct comparisons for this phase. The model predicts that the cloud will impact the bottom in less than a minute; no observations were made during this period.

4.4.2 Collapse phase.

Similarly, no data is available from field observations to allow direct comparisons with the model predictions for the collapse phase, with the exception of the first profile of 8/15 A. See Figure 4-9 for a graph of the measured concentration profile compared with model predicted profiles.

At this time (+5 minutes) observations indicate a plume in the upper 60 feet of the water column having solids concentrations of approximately .01 ppt. In contrast the model predicts that at this time the plume will have become a layer less than one foot thick on the ocean floor with a lower concentration (5 ppt.) of solids.

4.4.3 Long term diffusion phase.

Model output for the long term diffusion phase includes position plots which indicate, for each component solid, concentration and plume thickness as a function of grid position. This information is given at 1/4, 1/2, 3/4, and 4/4 of the simulation time (to the nearest even time step).

Concentration data for the points of interest (profile locations) were plotted vs. time so that concentrations at the time of the profile could be obtained graphically. Plume thickness data was obtained in a similar manner. This data was used to construct plots of predicted and measured (weighted average) concentration profiles. These are included as Appendix D; an example plot is found in Figure 4-10.

For many profiles, the measured position was completely out of, or on the fringe of, the predicted cloud location. Due to buoy movement and varying wind and current conditions at dump times, there is some uncertainty associated with the dump position. Figure 4-11 is a plot of the various buoy locations noted during the study; movement is due to mooring line scope and variations in currents and winds. In view of these uncertainties as well as those associated with profile position fixing, a comparison was made assuming that the profile was taken at the point of maximum concentration. A similar procedure was followed, where graphs of maximum predicted concentration as a function of time were prepared (included in Appendix F). Concentration data from these graphs was then used to plot maximum predicted,

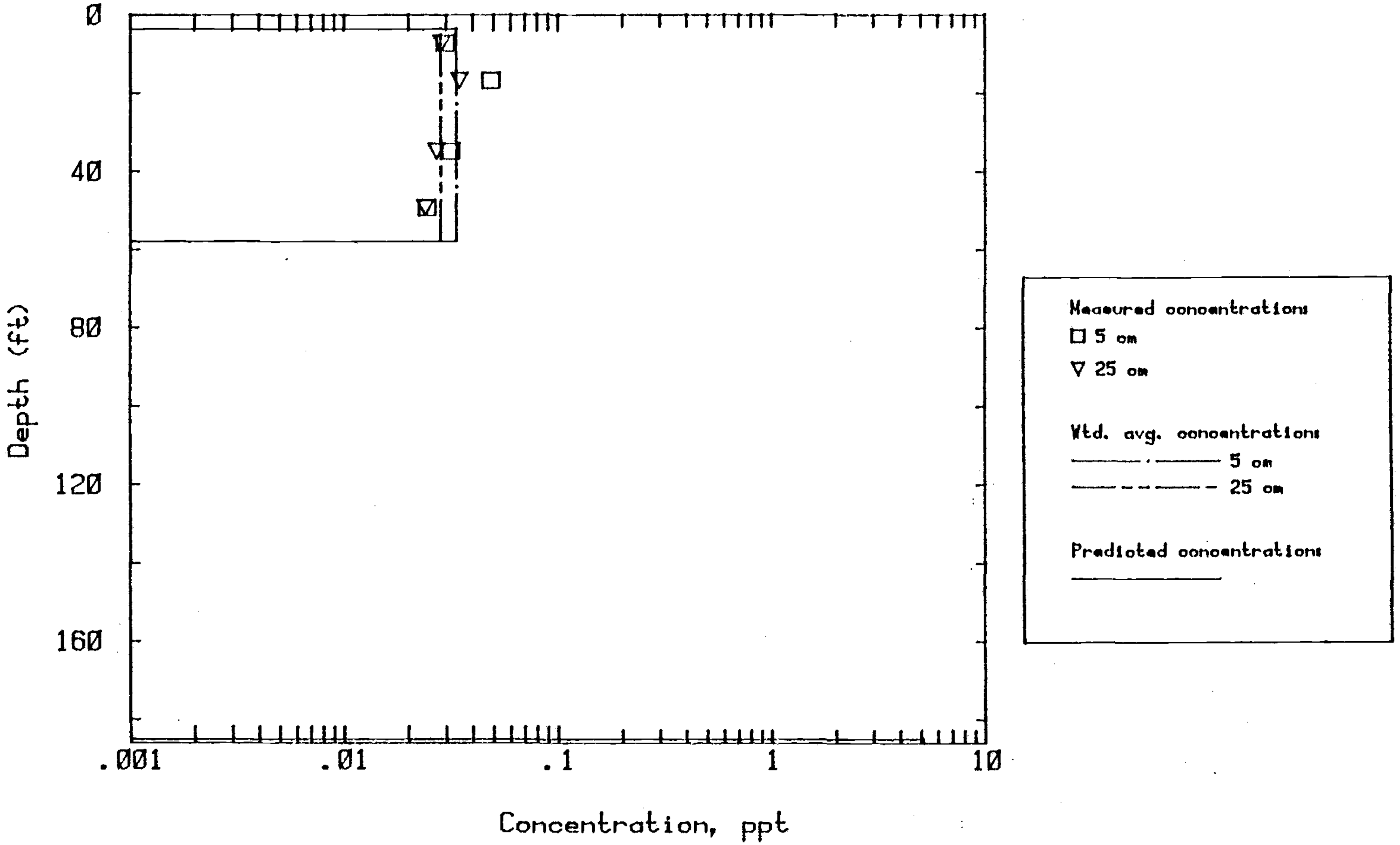
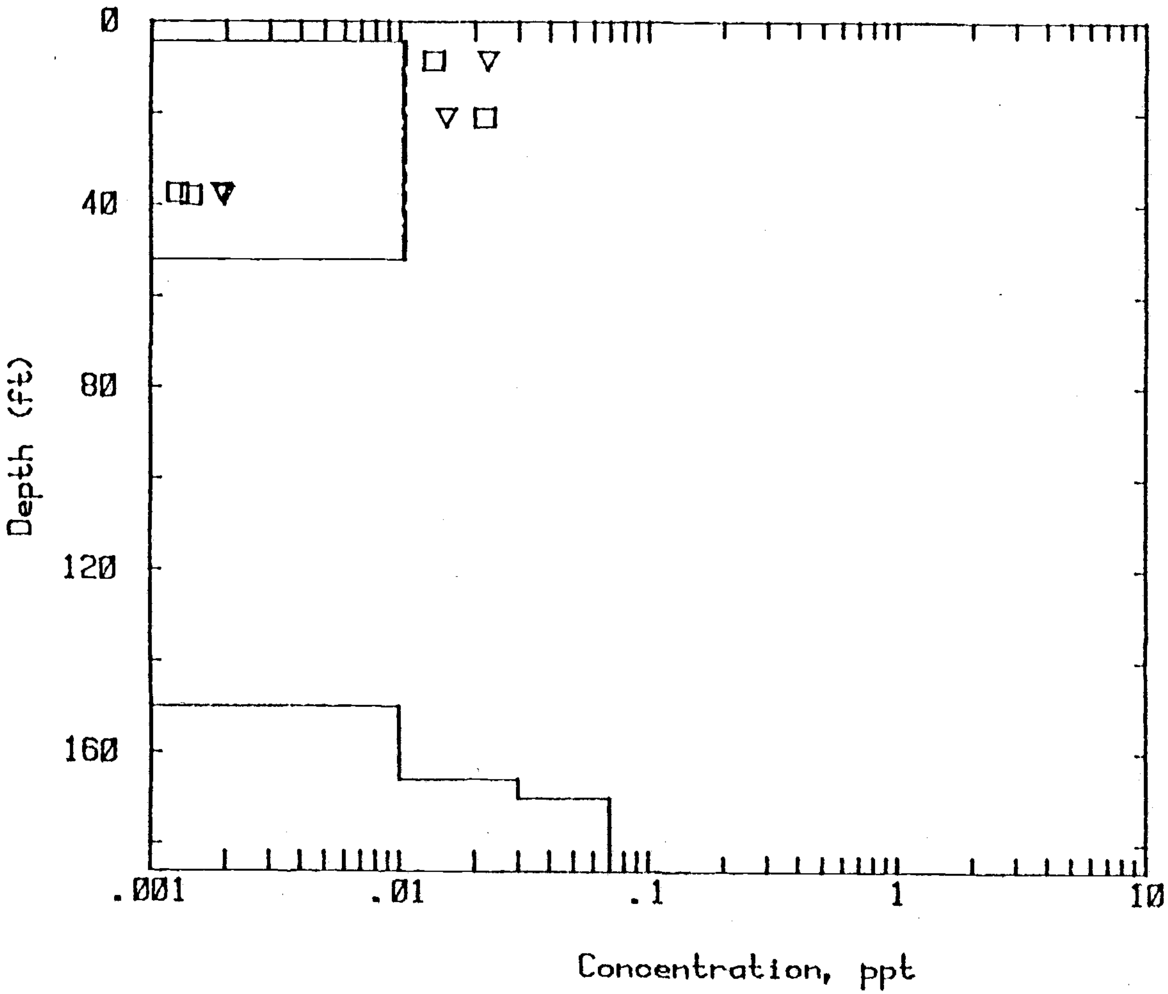


Figure 4-9 Predicted vs. measured concentration profiles for 8/15/81A @ +5 minutes.



8/13/81B: Predicted vs. measured concentration profiles: profile 1.

Figure 4-10 Predicted vs. measured concentration profiles (example).

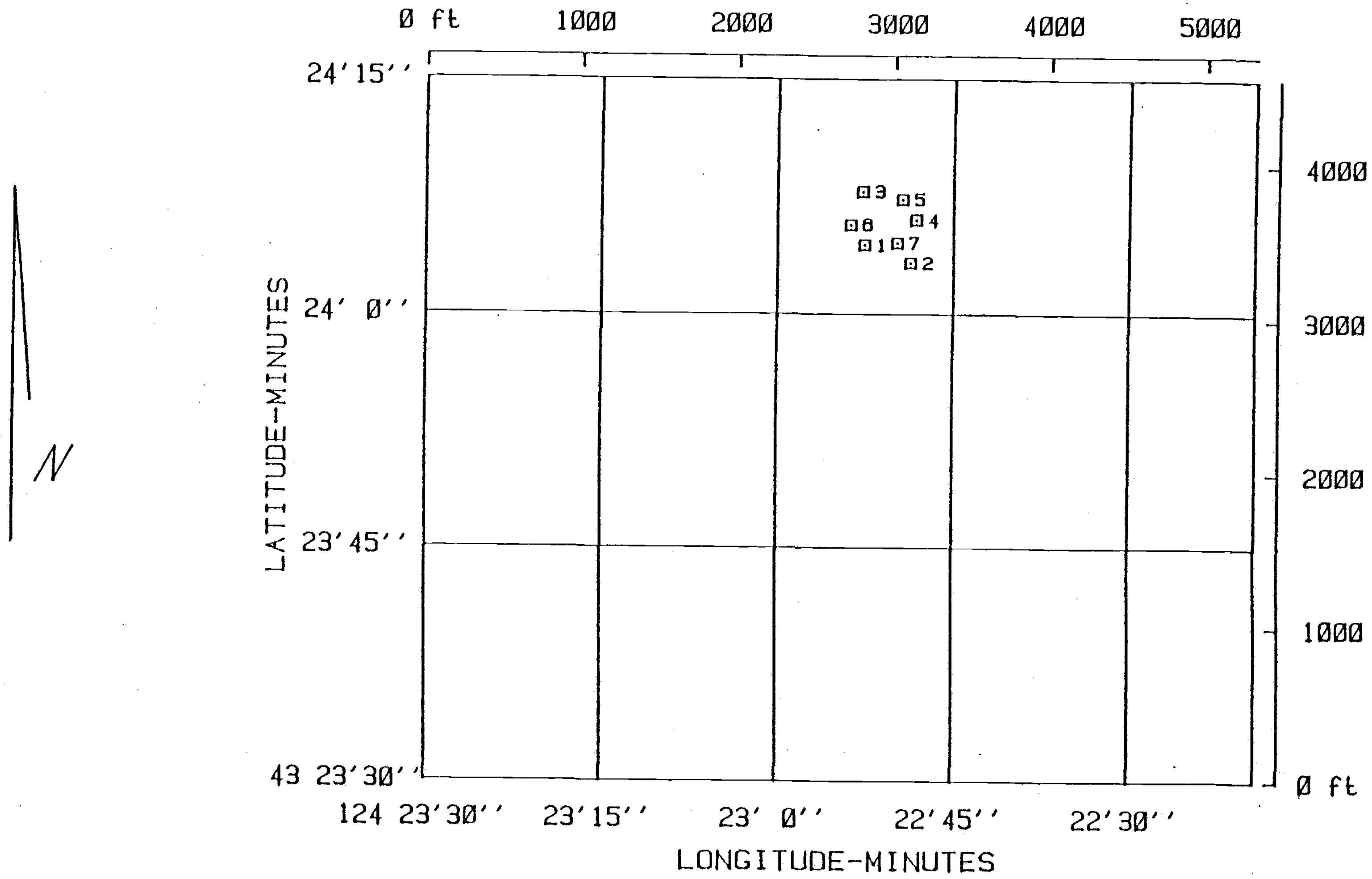


Figure 4-11 Excursion of the CP buoy.

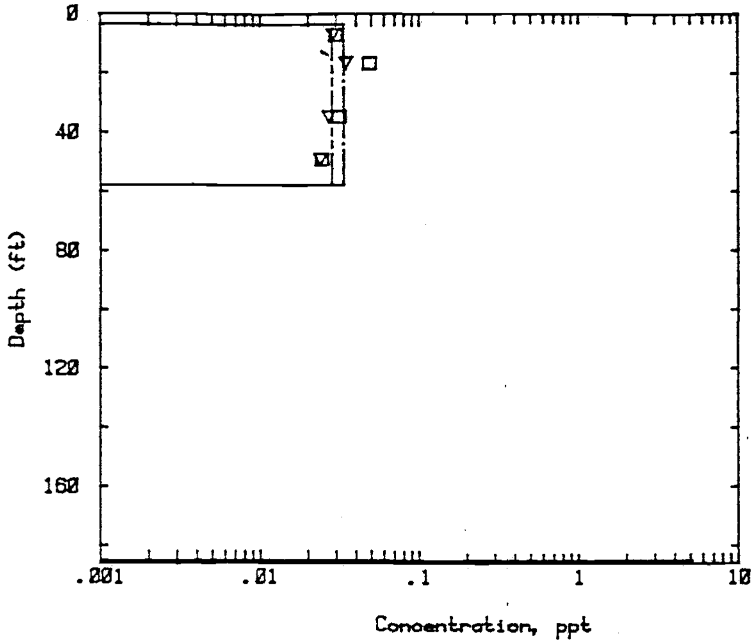
and measured (weighted average) concentration profiles. An example is found in Figure 4-12.

Typically, the model overpredicted concentrations by one or more orders of magnitude when compared with profiles obtained using measured data and the weighted average technique. The model invariably showed the plume on the ocean floor, while field measurements indicated that the plume was at an intermediate depth.

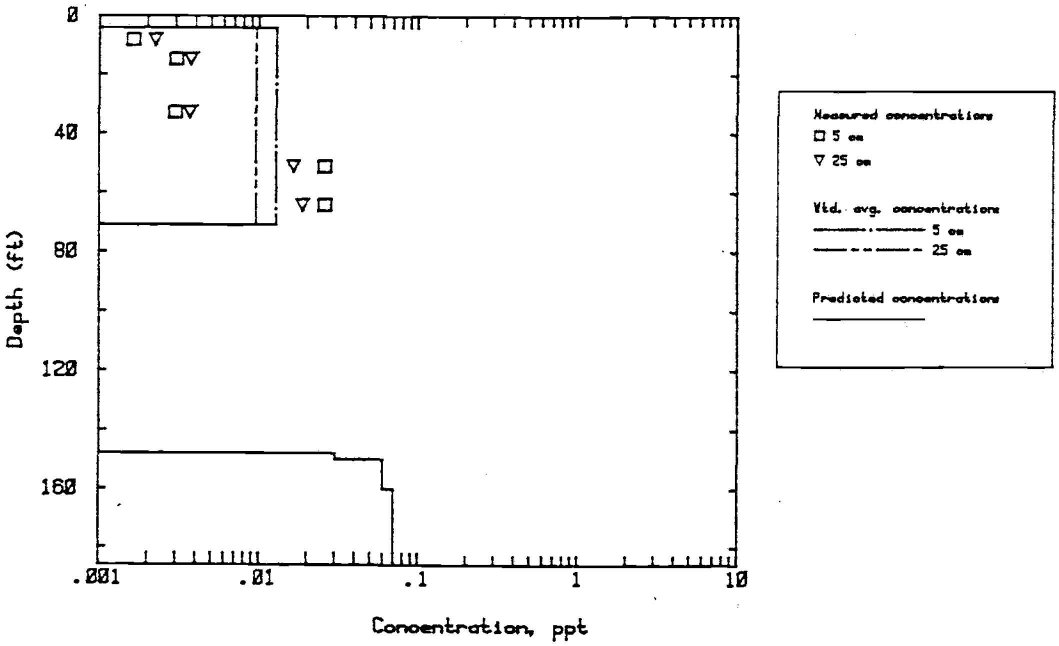
Generally, observed plume concentrations exceeded .01 ppt for the first 20 minutes following material release. Between 40 and 80 minutes were required to disperse the material to instrument threshold levels (< .001 ppt.) Model predictions indicate detectable sediment concentrations persisting up in the water column for well over one hour in all cases except the events of 8/19/81; here the material is predicted to be in a thin (approximately one foot thick) layer on the ocean floor with solids concentrations of between four and six ppt, after 45 minutes have elapsed. (See Figure 4-15)

A wide range of cloud thicknesses was observed, with the average being 56 feet. On most occasions the plume was found up in the water column. The model predicts that the cloud will extend to the bottom, frequently consisting of a thin layer one foot thick or less, but sometimes, as in the case of event 8/17 A, extending more than 100 feet up into the water column. (See Figure 4-16)

A scatter diagram (Figure 4-17) summarizes the differences between model predictions and field observations. Model observed

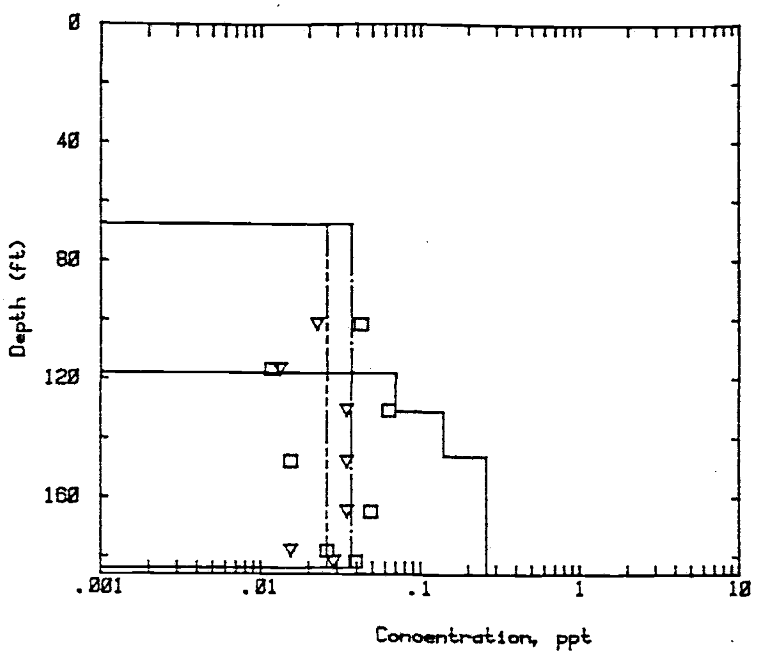


8/15/81A: Maximum predicted, and measured, concentration profiles: transect 1

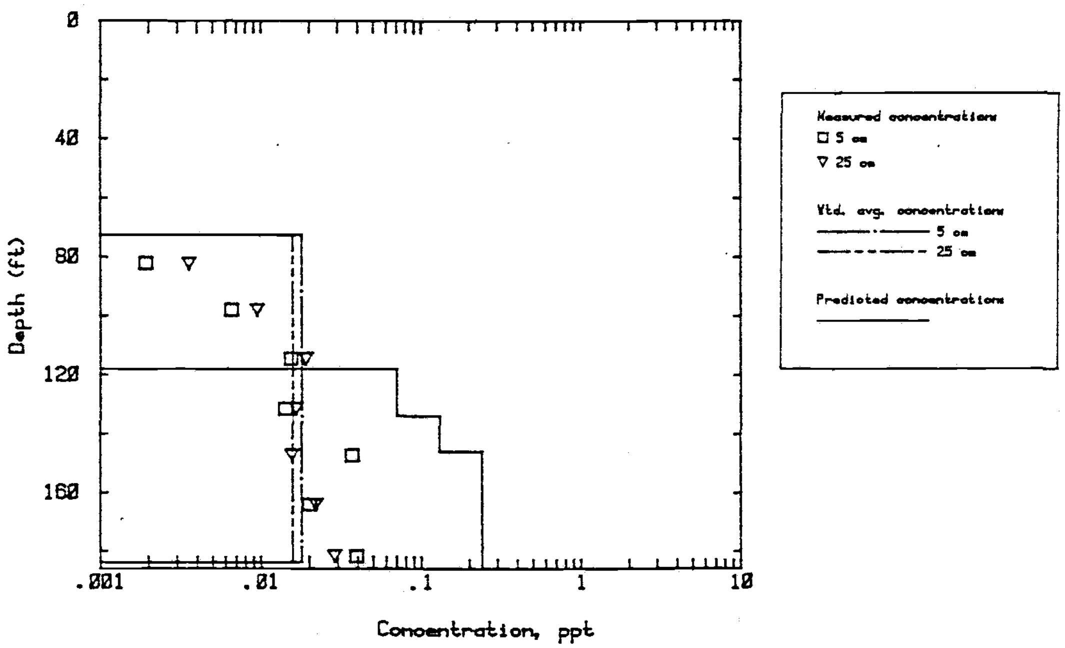


8/15/81A: Maximum predicted, and measured, concentration profiles: transect 2.

Figure 4-12 Maximum predicted vs. measured concentration profiles. (example)

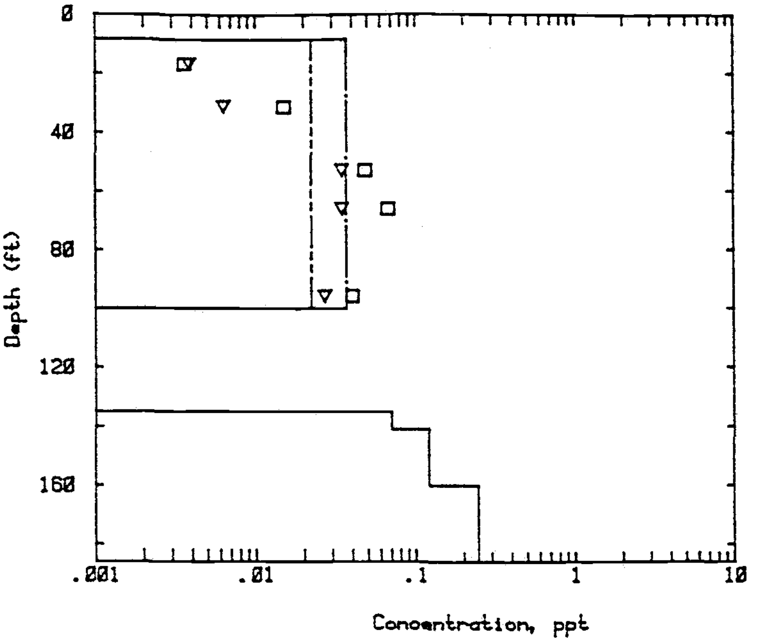


8/15/81B; Maximum predicted, and measured, concentration profiles; transect 1.

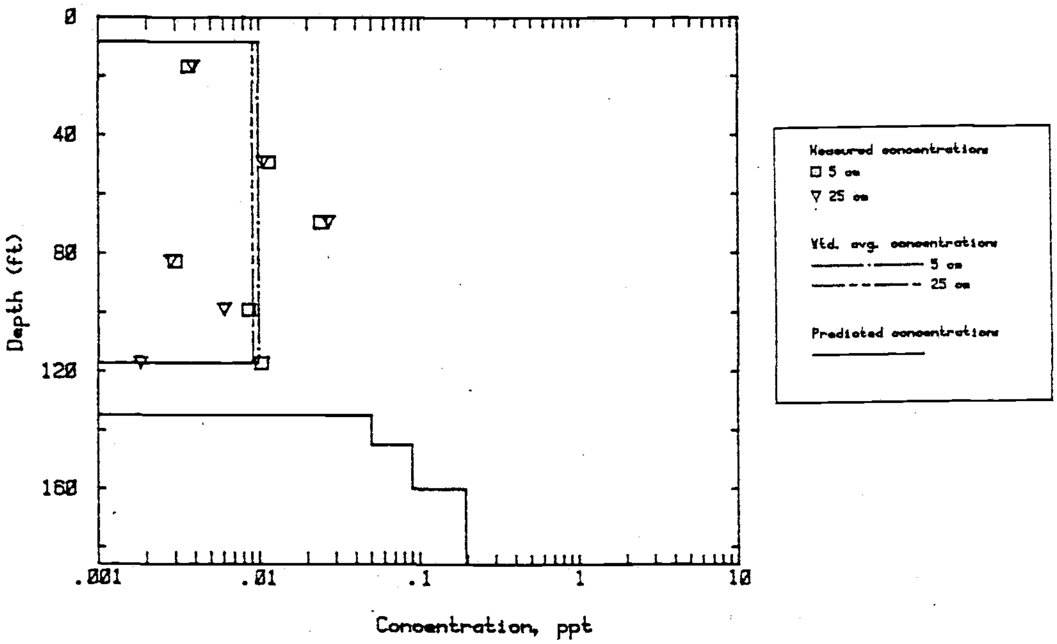


8/15/81B; Maximum predicted, and measured, concentration profiles; transect 2

Figure 4-13 Maximum predicted vs. measured concentration profiles. (example)

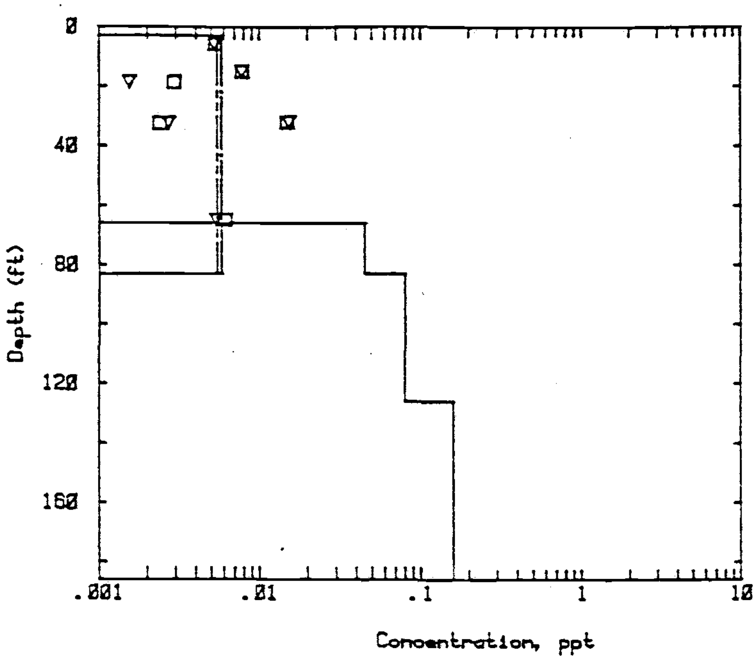


8/17/81B: Maximum predicted, and measured, concentration profiles: transect 1.

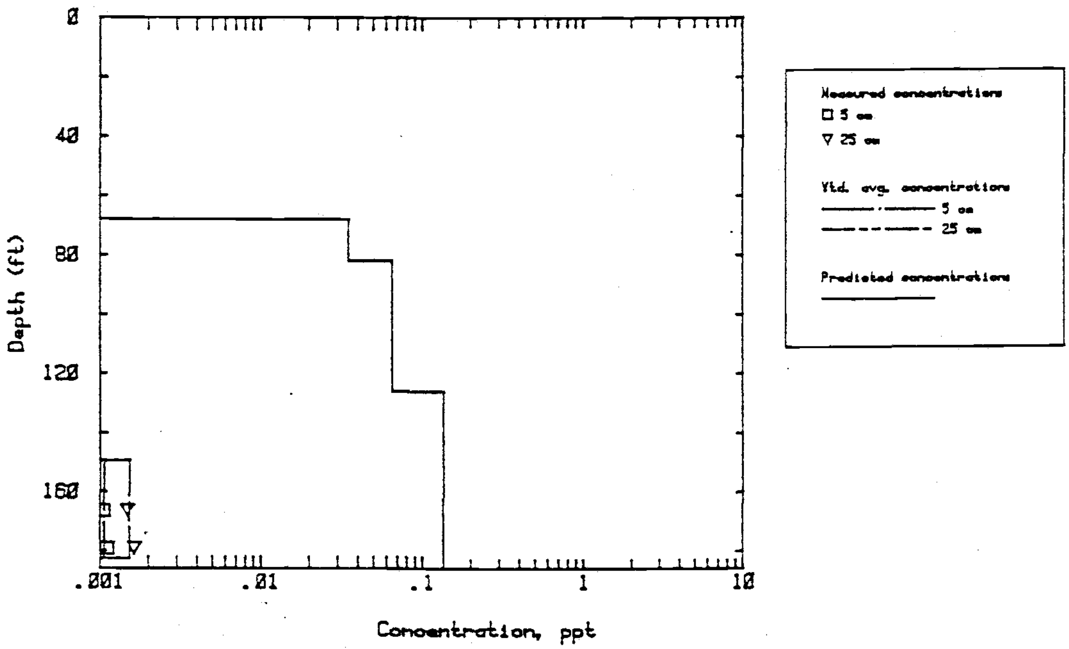


8/17/81B: Maximum predicted, and measured, concentration profiles: transect 2.

Figure 4-14 Maximum predicted vs. measured concentration profiles. (example)

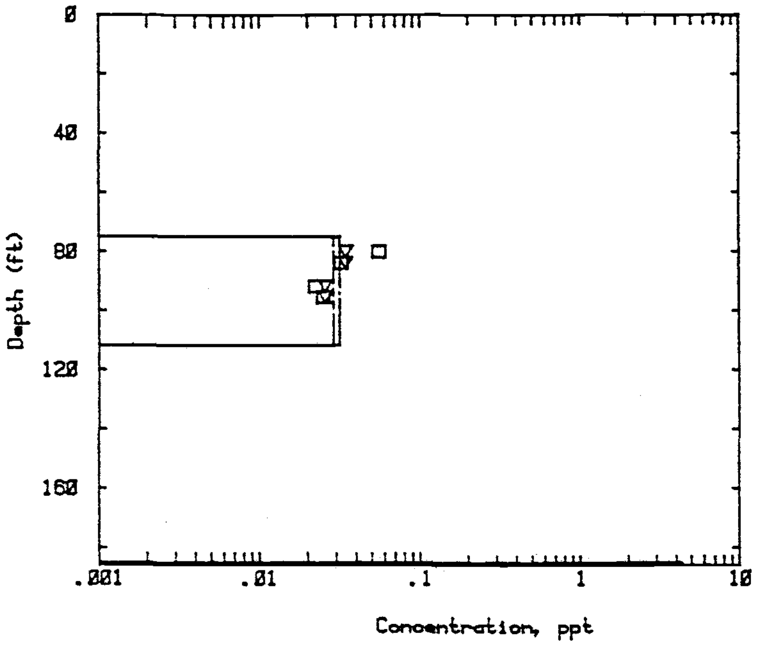


8/17/81A: Maximum predicted, and measured, concentration profiles: transect 1.

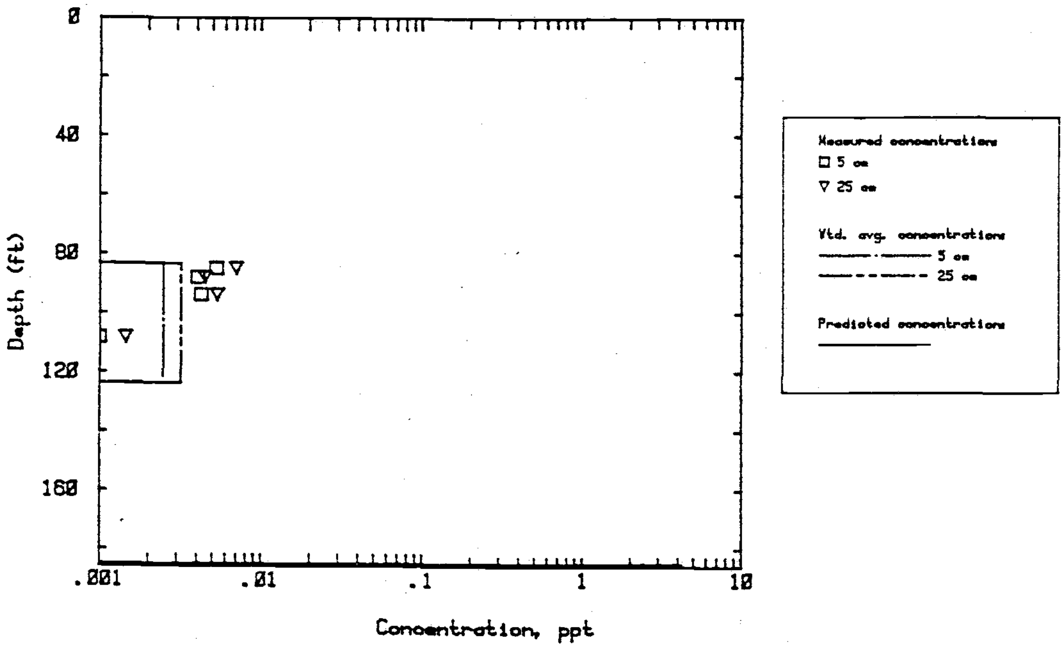


8/17/81A: Maximum predicted, and measured, concentration profiles: transect 2.

Figure 4-15 Maximum predicted vs. measured concentration profiles. (example)



8/18/81B: Maximum predicted, and measured, concentration profiles: profile 2.



8/18/81B: Maximum predicted, and measured, concentration profiles: profile 3.

Figure 4-16 Maximum predicted, and measured, concentrations. First two profiles of 8/17/81A.

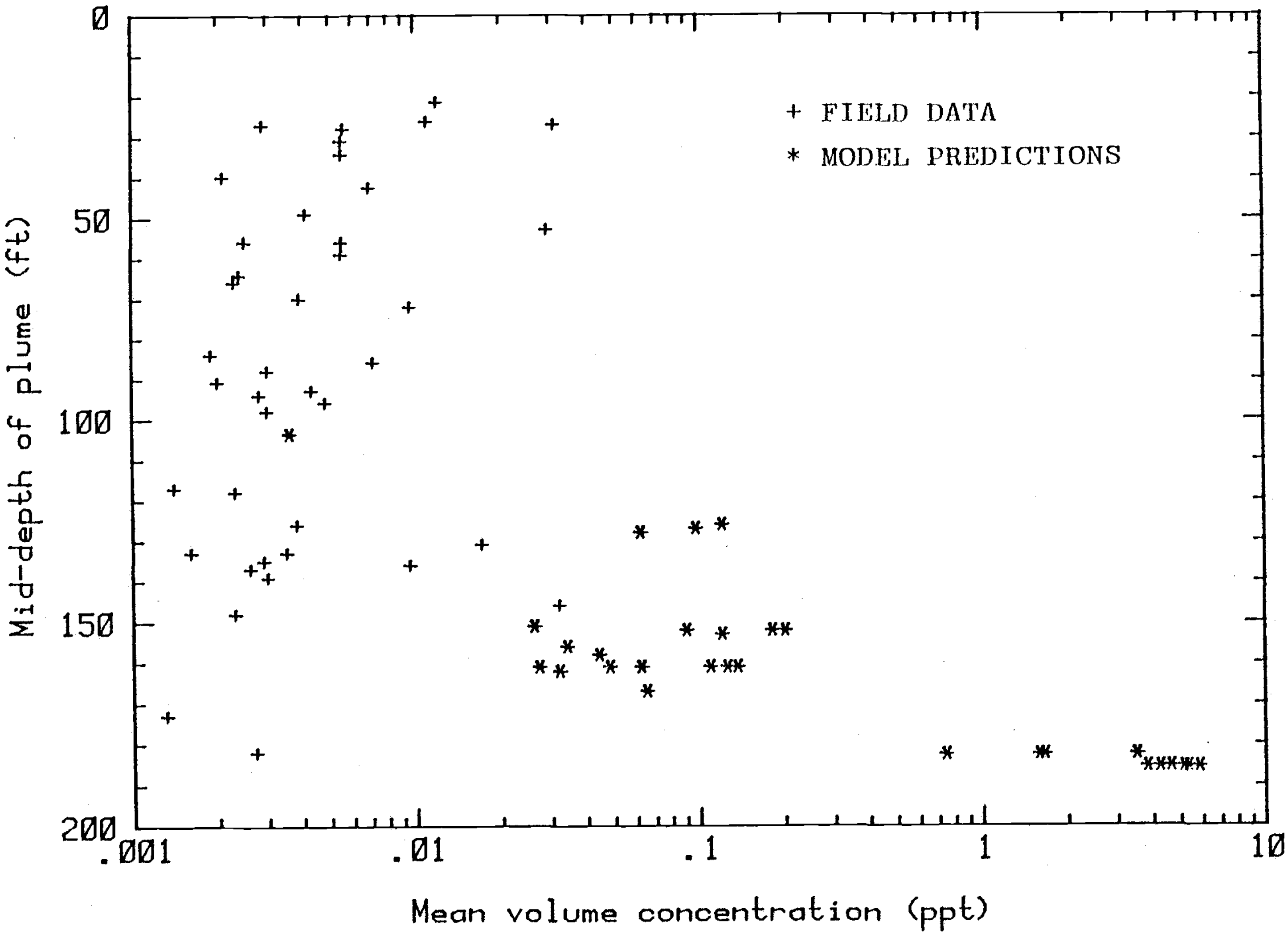


Figure 4-17 Scatter diagram of model and field data.

concentrations are generally lower than predicted by one or more orders of magnitude. Predicted plume depths are almost invariably deeper than those indicated by observation.

The reason for the disparity between model and field results is revealed by Figs. 4-12, 14, 16, and 17. The model is predicting the immediate fate of the dense solid mass released from the bottom of the hopper. This material reaches the bottom in less than a minute. It takes ten minutes, or more, for the dredge to close the hopped doors and leave the area above the cloud and for the research vessel to initiate its water column meausrements. By this time, the dense material has impacted on the sea floor and only the water fraction of the hopper spoils remains in the upper portion of the water column. The suspended material lfrom this fraction of the hopper has a much lower concentration of solids and a mass density which is much closer to that of the ambient. It settles more slowly and disperses more readily because ambient turbulence and shear can mix the cloud over a greater time period. Several methods have been employed to force the model to predict the behavior of this residual cloud of the hopper "dirty water" phase. These are discussed in Section 4.5.

4.4.4 Bottom Accumulation

4.4.4.1 Predicted bottom accumulation.

A model prediction of the total thickness of new material on the bottom at the conclusion of all disposal operations was obtained in the following manner. For each of the eight events simulated, the predicted thickness of new material on the bottom after 90 minutes was noted for 20 grid points near the center of project (CP). This figure was normalized with respect to the quantity of material disposed (yd^3) in that event. Normalized thickness figures for each grid point were then averaged, resulting in an average predicted thickness, t_p, per cubic yard of material disposed. Total volume disposed (V_t) was obtained from Corps dredge logs. The total predicted thickness, t_{pt}, is then determined simply as

$$t_{pt} = V_t \times t_p$$

for each grid point of interest. Total predicted bottom accumulations at grid points, and depth contours, are presented in Figure 4-18 b.

4.4.4.2 Observed bottom accumulation.

After completion of disposal operations at the project site, bottom samples were obtained using a one square foot box core sampler. Sub-samples taken with 7.5 cm diameter clear plastic tubes permitted evaluation of sediment layers. Layers were tested separately for physical properties including grain size distribution and volatile solids content. A volatile solids content exceeding two per cent identifies spoil materials. The position of samples containing layers of spoil material are plotted in Figures 4-18 a and d, for August 1981 and August 1982 respectively; the observed depth of the material is noted. Approximate depth contours are plotted.

4.4.4.3 Comparison: predicted and observed bottom accumulations.

Fig. 4-18c is a plot of predicted depth contours superimposed on those resulting from observations of August, 1981. Predicted contours are also superimposed on the plot of August, 1982 samples (Figure 4-18d.) Observations made at the conclusion of disposal operations (August, 1981) indicate a deeper sediment layer than predicted, (four inch maximum, measured, versus two inch maximum, predicted) while the area covered is approximately the same. After one year, the maximum mound thickness has reduced to two inches.

The accumulation prediction is for 90 minutes after material release. Depending on the event modeled, between 30 and 70 percent of the material disposed has settled to the bottom at this time. Modeling for a longer time period may increase the predicted depth of accumulated sediments on the sea floor. However, ambient currents could disperse this suspended material over a greater area, causing only a slight increase in local accumulated spoils. The model assumed that material deposited on the bottom will return to its original 20% solids content. Disturbing the dredged material in the pump and hopper is likely to dilate the sediment, producing a higher water content, and conversely, a lower solids content. A lower solids content would result in a greater observed depth of material, as indicated from the core samples.

4.5 Alternate modeling procedures.

Because of differences between model predictions and observed conditions, several alternate modeling techniques were devised and executed, as described below. Predicted values for the various procedures are listed in Table 4-7.

The first event listed (8/17A @ 80%) is modeled, according to the standard procedure followed in this study, as a single event with an 80% void ratio. The same quantity of solid material was then diluted to full hopper volume (3060 yd^3), and released as one event (8/17A @ 91%). The initial ratio was 91%.

The next approach was to model the event as six smaller dumps. Since the Biddle's 12 hoppers are released in pairs in a total time of six minutes, six smaller events were linearly superimposed at one minute intervals. (Event 8/15A x 6.) For this method no modifications to the ambient density profile were made.

Finally, the ambient density profile was modified to account for predicted material in suspension one minute after a smaller dump. At this time the model predicts a cloud five feet thick at rest on the bottom, with a maximum concentration of ten ppt. Thus, predicted ambient density near the bottom at the time of the next dump (8/15 A1 + 60 sec) is 1.054 gm/cc.

The above methods are approximations. The Biddle is 352 feet long, hence subsequent events would not be at exactly the same location. Predicted concentrations should actually be somewhat lower than those listed in Table 4-7. None of these techniques gives a prediction comparable closer to observations; however, the increased dilution of 8/17 A @ 91% decreases the predicted concentrations to levels closer to those observed.

A second approximation of the dirty water condition was accomplished by analyzing only the fraction of solids remaining in suspension after the two-hour transit time from the dredge site to the disposal site. This fraction was determined by first computing the fall velocity, V_f, for a sediment particle to settle from the hopper survace to the hopper bottom, h, during the ransit time, t (V_f=h/t). Then the particle diameter, D, associated with this fall velocity was calculated using Stokes equation for laminar settling (Graf, 1971):

$$D = \frac{18 \nu \; V}{g(SG-1)}$$

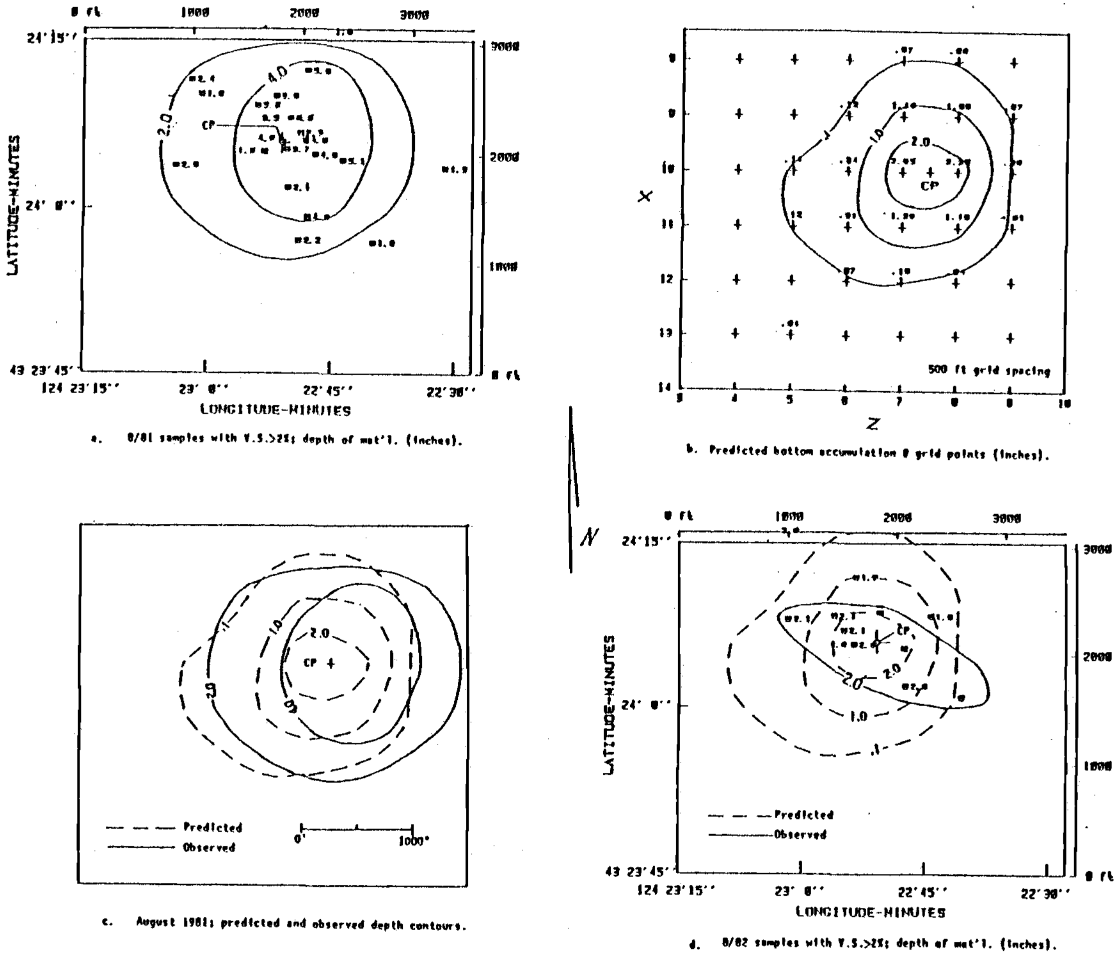


Figure 4-18 Predicted and measured bottom accumulation.

Table 4-7

Comparison of disposal event predicted values for alternate modeling procedures.

ID	Initial cloud radius (ft)	Time to bottom impact (sec)	Conc.@ impact (ppt)	Cloud dimensions @ end collapse (ft) vert.	horiz.	Time to collapse (sec.)	Conc.@ end of collapse (ppt)	max conc @ 30 min (ppt)	max conc @ 45 min (ppt)	% total mat'l settled @ 15 min	30 min	45 min
8/17A @ 80%	27.3	17.9	25.6	.84	869.9	217	15.0	.20	.11	10	13	16
8/17A @ 91%	34.0	14.3	7.9	1.23	1206.0	365	4.7	.10	.10	36	36	37
8/15A x 6	16.9	32.2	10.1	.97	720.7	833	20.5	.18	.18	23	27	32
8/15A1 (+ 60 sec)	16.9	35.3	9.8	1.07	785.4	401	3.1	1	1	63	67	68

modified density profile

where v = kinematic viscosity of estuary water = $1.05 \cdot 10^{-5}$ ft^2/sec; g = acceleration due to gravity = 32.2 ft/sec^2; SG = specific gravity of geologic solids = 2.68.

A hopper depth of 14.4 feet computed from dredge log soundings and transit time of 113 minutes, also from the log, yields a particle diameter of 0.026 mm. It is assumed that all particles with diameters exceeding 0.026 mm have settled to the bottom of the hopper during transit. All particles with diameters less than 0.026 mm remain in suspension in the hopper. Given the grain size distribution curve for the dredge spoils, one can determiine the fraction of material remaining in suspension. A representative curve is presented in Fig., 4-6, the sample being obtained from the dredge Biddle suction head during the field study period. The curve reveals that 70% by weight of the material is finer than 0.026 mm and remains in suspension. The weight averaged size of the material is found at 35% (70/2) finer diameter of 0.0052 mm; this may be interpreted as the mean diameter of the material in suspension. The average volume of dredged material, obtained from the log of the Biddle, is 1474 cubic yards at an assumed (Portland District) porosity of 80%. This solids volume is determined from the draft, hence weight, of the dredge and therefore includes material in suspension as well as material settled to the bottom of the hopper. The settled material is 30% of 1474, or 442 cubic yards. This reduces the water volume of the hopper from a total volume of 3060 cubic yards to a net volume of

2618 cubic yards. Now 70% of 1474 or 1032 cubic yards, at 80% porosity, is diluted by an additional (2618-1032) cubic yards of water. This yields a porosity of material in suspension of 92%, i.e.,

$$[0.8(1032) + 1.0(2618-1032)] \quad 2618 = 0.92.$$

In summary, the characteristics of the "dirty water" or suspended material in the hopper are: mean diameter equal to 0.0052 mm, porosity equal to 92%, hopper volume equal to 2618 cubic yards. The effect of the coarse solids has been shown to persist for only a few minutes and is ignored. This information is input to the Koh-Chang model along with the undisturbed liquid-limit to obtain the response summarized in row one of Table 4-8. The time to collapse is still less than seven minutes and the cloud is predicted to be only 1.23 feet thick. However, predicted concentrations at 30 and 45 minutes past disposal approach the high end of the range of measured values. The effect of further dilutions to 94%, 96%, and 98% is revealed in rows 2, 3 and 4 of Table 4-8. The time to the end of collapse increases to 16 minutes, still less than the observed values of one hour. Concentrations continue to decline 30 and 45 minutes after disposal operations have ceased. It is interesting to note, however, that higher cloud concentrations occur at 30 and 45 minutes for porosities ("void ratio") of 94% and 98% than at 92% and 96%. The reason for this is revealed by the cloud thickness in columns 2 and 3 of Table 4-8. The cloud thicknesses at 94% and 98% are 59 feet and 86 feet, respectively, as compared to 103 feet and 104 feet at 92% and 96%. Thus, greater dilution occurs at the latter, yielding lower sediment concentrations. The 98% cloud found a depth of neutral buoyancy 34 feet above the bottom and then collapsed to a relatively thin layer. All other clouds impacted with the sea floor. Of greatest interest is the 96% cloud. It extends 104 feet above the sea floor and has a stable mean concentration of 0.01 ppt at 30 and 45 minutes after disposal operations have ceased. Comparison with Fig. 4-13 reveals that this result is very close to observed plume concentrations at disposal event 8/15/81 B. Unfortunately, we do not know if a porosity of 96% is a reasonable approximation of conditions existing in the water phase of the hopper at the instant of release.

These extreme perturbations on the model input indicate that dilution of the water phase to 96% porosity and using a single component of fines in suspension tends to reproduce some observed conditions from the field experiments. All other perturbations did not significantly improve the correlation between predicted and observed plume thickness and/or solids concentration in suspension.

Table 4-8

Comparison of disposal event predicted values for alternate modeling procedures

ID	Initial cloud radius (ft)	Time to bottom impact (sec)	Conc. @ impact (ppt)	Cloud dimensions @ end collapse (ft) vert.	horiz.	Time to collapse (sec)	Conc. @ end of collapse (ppt)	Max conc @ (ppt) 30 min	45 min	Cloud thickness @ (ft) 30 min	45 min	% Total mat'l settled @ 15 min	30 min	45 min
8/17A @ 92%	32.2	16.0	6.4	1.23	1161.0	403	6.3	.02	.02	103	103	.2	.2	.3
8/17A @ 94%	32.2	19.6	4.6	1.34	1136.0	454	4.5	.03	.03	59	59	.5	.7	.8
8/17A @96	32.2	27.4	2.8	1.57	1097.0	565	2.7	.01	.01	104	104	.4	.5	.5
8/17A @ 98%	32.2	79.3	1.1	7.23	629.7	975	.9	.45	.33	8.6	8.6	0	0	0

5. SUMMARY AND CONCLUSIONS

5.1 Summary

In the present study, position and concentration characteristics of a dredged sediment plume were established subsequent to hopper dredge disposal events in 186 feet of water offshore near Coos Bay, Oregon. Individual disposal volumes of 500 and 3060 cubic yards were observed until dispersion reduced concentrations to ambient levels.

Computer simulations of the events were then executed using the latest available version of the Koh-Chang instantaneous disposal program. Field data including currents, ambient density, dredge volumes, and sediment characteristics were used as input. Computer output included cloud position, component sediment concentrations, and depth and position of material settled out of suspension. A direct comparison between field data and model prediction was therefore possible.

5.2 Applicability to open water disposal problems.

The model allows only for the convective descent of a hemispherical cloud as a unit. No provision is made for separation into two or more clouds. In dredge hoppers during the two hour trip to the disposal site, larger sediment particles will settle out due to higher settling velocities. On disposal, this settled material may descend rapidly to the bottom leaving behind a turbidity cloud consisting of the fine material in suspension.

This would account for the cloud in the water column that was tracked during the field studies. Horizontal transects (event 8/19A, transects 4 through 10) taken to establish the scale of this upper turbidity plume indicate that it is approximately 400 feet across and 15 feet thick, with solids concentrations of around .003 ppt. Assuming a disk shape, this would contain 5.6 ft^3 of solid materials, or one cubic yard of material at the assumed 20% solids content. This is less than one-tenth of one percent of the quantity disposed (1750 cy).

The existing model assumes no resuspension. A particle once settled to the bottom is assumed to remain at rest. According to Graf (1971), velocities as low as one fps can cause resuspension of grains of the size discussed here, while much lower velocities can cause bed transport. Even if the collapsing plume does not cause 3 fps velocities as predicted by the model, ambient velocities of sufficient magnitude to cause movement and possibly resuspension do exist. This would cause higher sediment concentrations and more movement as previously disposed material is resuspended.

According to model predictions corresponding to all measured events, plume concentrations remain above instrument threshold levels for more than one hour after release. In contrast, measurements show dispersion to below detectable solids concentrations 30 to 60 minutes after the disposal events.

The model indicates that all material is in a cloud that goes to the bottom in a matter of seconds and remains there, either in a thin (one foot thick) layer spread across the sea floor, or in a cloud resting on the bottom. In contrast, field measurements typically indicate a plume up in the water column. Measurement techniques did not permit taking data as close as one foot away from the bottom.

The model generally overpredicts concentration values, although in some cases (such as 8/15 B), predicted concentration values are within one order of magnitude of those measured.

5.3 Suggestions for future research.

5.3.1 Model modifications.

A multi phase model is suggested that would account for separation of the spoil material into two or more distinct clouds. As noted above, the present model transports the material in a single cloud during the convective descent phase. While larger particles may fall out ahead of the cloud, no material can be left behind as presently modeled. Experimental observations indicate that a small quantity of material does in fact remain behind in the water column.

A more accurate description of the material in the dredge hopper would be required. At present, a homogeneous mixture is assumed.

The hopper contents are grossly characterized by input specifying the quantity of material, the aggregate density, the specific gravity of the solids, and the void ratio.

In practice, a homogeneous mixture does not exist in the hopper at the time of release. During the transport period (two hours in this case) larger solids particles will consolidate on the bottom, resulting in a density gradient within the hopper. The density profile could be quantified by taking samples from the hopper at various depths just before release.

Further experimental studies are required to verify the coefficients as calculated or specified by the model. Some laboratory and field calibration has been done; see, for example, Bowers and Goldenblatt (1978), Johnson and Holliday (1978), and Koh and Chang (1973). However, entrainment, drag, settling, apparent mass, friction and diffusion coefficients have not been verified for all disposal conditions.

5.3.2 Experimental procedure modifications.

A means of tracking the plume and quantifying solids concentrations during the convective descent and collapse phases is required. One or more strings of timed, continuously recording transmissometers deployed at the disposal site (see Figure 5-1) would provide information permitting calculation of descent speed, cloud size and rate of entrainment, and sediment concentrations.

The transmissometer arrangement used in the present study did not permit measurements to be taken within seven feet of the ocean bottom. As the model often predicts a cloud forming a thin (approximately one foot thick) layer on the sea floor, sediment concentrations in this zone are of interest. A modified arrangment to permit measurement as close to the bottom as possible should be devised.

The point transmissometer readings are believed to be representative of the portion of the water column assigned that concentration value as shown in Figure 4-5. To verify this assumption, a continuously recording transmissometer plotting (or recording onto a magnetic tape) voltage vs. depth should be developed.

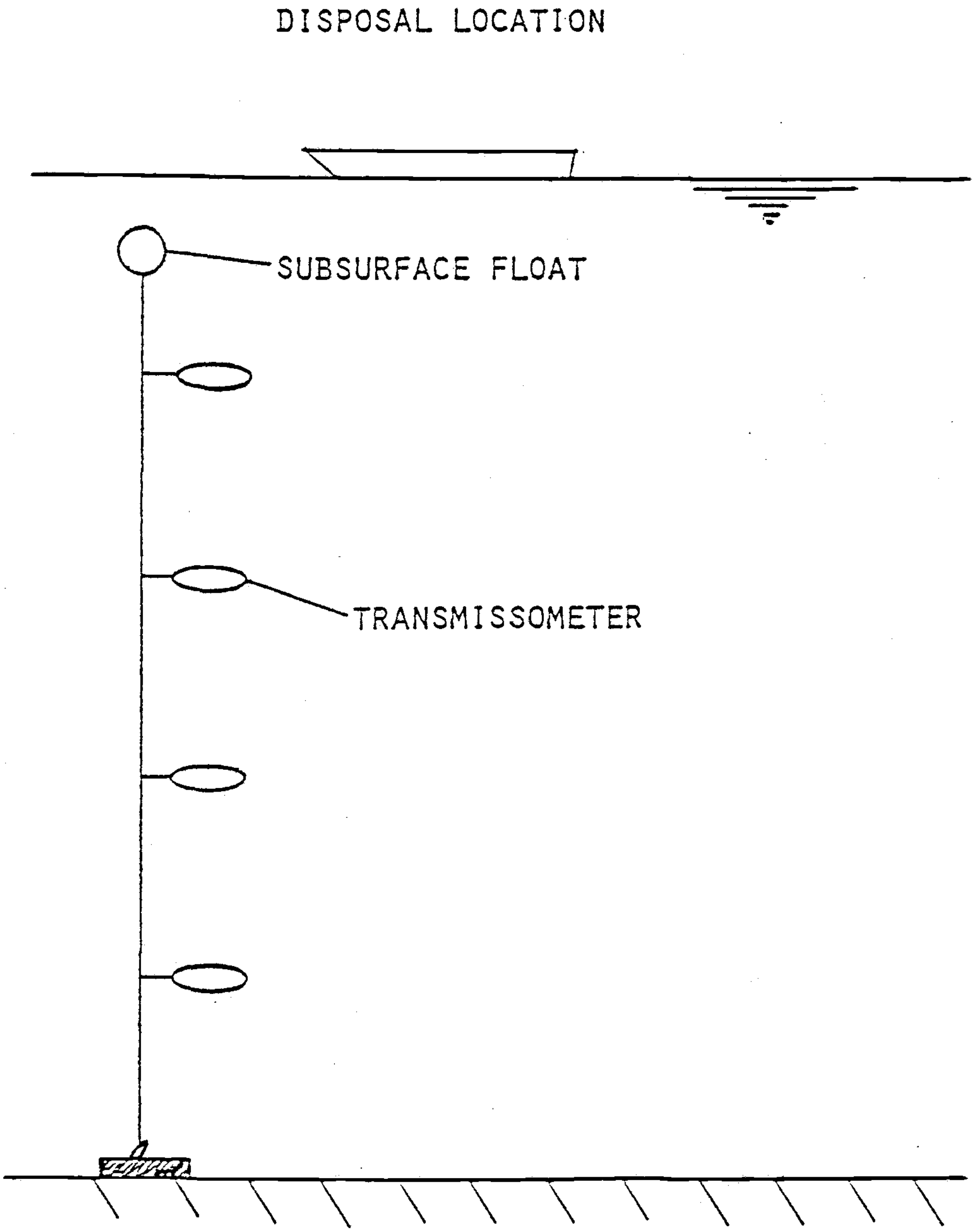


Figure 5-1 Suggested transmissometer string placement at disposal site.

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APPENDICES

APPENDIX A: PLUME MONITOR DATA

As recorded on August 12,13,15,17,19, 1981.

Plume monitor data from 8/12/81.

ID#	TIME	LATITUDE	LONGITUDE	DEPTH (ft)	V1	V2	C1 (E-03)	C2 (E-03)	COMMENTS
1	1526	43.4000498893	124.3785751590	107.0	4.91	4.50	.6	1.2	BACKGROUND
2	1527	43.4000498893	124.3785751590	138.1	4.90	4.47	.7	1.2	
3	1528	43.4000498893	124.3785751590	168.3	4.80	3.98	1.2	1.8	
4	1529	43.4000498893	124.3785751590	179.1	4.81	4.19	1.2	1.6	BOTTOM
5	1530	43.4000498893	124.3785751590	181.1	4.83	4.10	1.1	1.7	
6	1533	43.4000498893	124.3785751590	144.7	4.89	4.39	.7	1.3	
7	1535	43.4000498893	124.3785751590	114.2	4.92	4.52	.5	1.1	
8	1536	43.4000498893	124.3785751590	81.7	4.91	4.49	.6	1.2	
9	1537	43.4000498893	124.3785751590	47.9	4.88	3.35	.8	2.8	DUMP; INITIAL SPOIL
10	1538	43.4000498893	124.3785751590	15.7	4.85	4.24	.9	1.5	
11	1545	43.4000498893	124.3785751590	14.4	4.85	4.22	.9	1.5	
12	1546	43.4000498893	124.3785751590	51.8	4.90	4.45	.7	1.2	
13	1547	43.4000498893	124.3785751590	87.9	4.92	4.51	.5	1.2	
14	1549	43.4000498893	124.3785751590	121.7	4.92	4.53	.5	1.1	
15	1554	43.4000498893	124.3785751590	81.7	4.91	4.47	.6	1.2	
16	1558	43.3981996051	124.3809916950	85.6	0.00	0.00	0.0	0.0	
17	1602	43.3972511640	124.3809498950	156.2	4.90	4.42	.7	1.3	

Plume monitor data from 8/13/81.

ID#	TIME	LATITUDE	LONGITUDE	DEPTH (ft)	V1	V2	C1 (E-03)	C2 (E-03)	COMMENTS
1	1455	43.4050641451	124.3806630430	188.6	4.86	4.40	.9	1.3	NORTH SITE BUOY
2	1457	43.4048833288	124.3804991660	110.9	4.90	4.47	.7	1.2	
3	1459	43.4047025177	124.3803352950	51.2	4.82	4.08	1.1	1.7	BACKGROUND
4	1534	43.4005027090	124.3806239300	17.1	4.83	4.11	1.1	1.7	BIDDLE DUMP
5	1536	43.4000965147	124.3810746710	52.2	4.00	4.25	6.2	1.5	
6	1538	43.4000518023	124.3818534270	86.0	4.89	4.41	.7	1.3	
7	1539	43.4000965147	124.3810746710	115.2	4.91	4.50	.6	1.2	CLEAR WATER
8	1552	43.4005494268	124.3831245820	13.1	4.10	2.07	5.6	5.4	DR PLACED IN PLUME:
9	1553	43.4005494268	124.3831245820	48.9	4.10	2.00	5.6	5.6	APPROX CTR
10	1555	43.4003686399	124.3829604760	82.0	4.89	4.42	.7	1.3	PLUME ABSENT APPROX 30 M
11	1556	43.4003686399	124.3829604760	115.5	4.92	4.50	.5	1.2	
12	1557	43.4003686399	124.3829604760	150.6	4.92	4.53	.5	1.1	
13	1559	43.3998263107	124.3824681970	111.9	4.91	4.50	.6	1.2	
14	1600	43.3998263107	124.3824681970	84.3	4.89	4.38	.7	1.3	
15	1601	43.3998263107	124.3824681970	49.9	3.44	1.90	10.4	5.9	
16	1602	43.3998263107	124.3824681970	37.7	3.98	1.30	6.4	8.0	MAX TURB. DPTH 200' NW DR
17	1608	43.3991944725	124.3835336190	40.0	4.81	4.09	1.2	1.7	
18	1609	43.3991944725	124.3835336190	103.0	4.91	4.48	.6	1.2	
19	1614	43.4002792201	124.3845186830	100.4	4.90	4.46	.7	1.2	400'NW DR
20	1615	43.4002792201	124.3845186830	63.0	4.78	3.93	1.3	1.9	
21	1619	43.4002792201	124.3845186830	34.8	4.86	4.31	.9	1.4	
22	1620	43.4002792201	124.3845186830	16.7	4.89	3.17	.7	3.1	
23	1626	43.3968457894	124.3846784470	16.4	4.85	4.20	.9	1.5	BACK AT DR
24	1627	43.3968457894	124.3846784470	51.5	4.40	2.85	3.6	3.7	
25	1628	43.3968457894	124.3846784470	33.8	4.86	4.30	.9	1.4	
26	1629	43.3968457894	124.3846784470	70.9	4.63	3.64	2.2	2.3	
27	1633	43.3960777948	124.3848000560	100.7	4.60	3.35	2.4	2.8	
28	1634	43.3960777948	124.3848000560	134.5	4.91	4.50	.6	1.2	
29	1640	43.3939995957	124.3845497870	128.6	4.88	4.31	.8	1.4	500' SE DR
30	1641	43.3939995957	124.3845497870	104.3	4.91	4.52	.6	1.1	
31	1642	43.3939995957	124.3845497870	65.6	4.54	3.24	2.8	3.0	
32	1643	43.3931863788	124.3854491630	35.4	4.85	4.22	.9	1.5	
33	1644	43.3931863788	124.3854491630	19.0	4.77	3.87	1.4	2.0	
34	1730	43.4007281242	124.3800092050	20.0	4.82	4.13	1.1	1.6	YAGUINA DUMP @ 1725
35	1731	43.4007281242	124.3800092050	8.5	3.05	.09	13.7	22.6	
36	1737	43.4012257518	124.3812798320	21.0	2.25	.33	22.1	15.5	
37	1738	43.4012257518	124.3812798320	37.4	4.79	3.92	1.3	1.9	PROFILE @ DISP SITE BUOY
38	1741	43.4012257518	124.3812798320	38.1	4.76	3.88	1.5	2.0	CTR OF PL FR AIR RE REESE
39	1742	43.4012257518	124.3812798320	18.0	2.08	.05	24.3	25.8	
40	1743	43.4012257518	124.3812798320	8.2	2.66	.19	17.5	18.5	
41	1744	43.4012257518	124.3812798320	65.9	4.89	4.43	.7	1.3	
42	1751	43.3987417934	124.3814838050	62.0	4.38	2.50	3.7	4.4	AT DR:
43	1752	43.3987417934	124.3814838050	49.9	3.53	1.20	9.7	8.4	APPEAR SW MAJOR SURF PLUME;
44	1753	43.3987417934	124.3814838050	35.1	4.81	4.00	1.2	1.8	
45	1754	43.3981547633	124.3817701880	18.7	4.86	4.28	.9	1.4	APPEAR TO BE 2 LAYERS
46	1755	43.3981547633	124.3817701880	101.7	3.21	.54	12.3	12.8	
47	1758	43.3976125880	124.3812779930	132.9	4.82	4.33	1.1	1.4	STILL @ DR
48	1759	43.3976125880	124.3812779930	163.7	4.87	4.41	.8	1.3	
49	1802	43.3972062575	124.3817282570	98.1	3.70	1.10	8.4	8.9	
50	1803	43.3972062575	124.3817282570	71.2	4.90	4.45	.7	1.2	
51	1804	43.3972062575	124.3817282570	34.1	4.80	4.06	1.2	1.7	

52	1805	43.3972062575	124.3817282570	16.1	4.77	3.83	1.4	2.0	
53	1812	43.3979740330	124.3816061160	98.1	0.00	4.49	0.0	1.2	CRUISE FR DR TO CTR SP SITE:
54	1816	43.3991480553	124.3810332860	56.8	0.00	3.53	0.0	2.5	@ 20 M LOOKING FOR MAX TURB DP
55	1819	43.3989673216	124.3808692770	59.1	0.00	4.00	0.0	1.8	@ SP SITE CTR; NO SIG TRENDS
56	1827	43.3989673216	124.3808692770	70.5	0.00	4.17	0.0	1.6	BACK TOWARDS DR; 800' FR CTR S
57	1835	43.3939995957	124.3845497870	159.4	4.77	3.50	1.4	2.5	PROFILE @ DR
58	1836	43.3939995957	124.3845497870	151.6	4.65	3.40	2.1	2.7	
59	1837	43.3939995957	124.3845497870	133.9	4.60	3.40	2.4	2.7	
60	1838	43.3939995957	124.3845497870	117.5	4.89	4.36	.7	1.3	
61	1842	43.3929154070	124.3835640070	104.3	4.74	3.80	1.6	2.1	
62	1843	43.3929154070	124.3835640070	82.0	4.75	4.13	1.5	1.6	
63	1844	43.3929154070	124.3835640070	68.9	4.84	4.21	1.0	1.5	
64	1845	43.3929154070	124.3835640070	51.2	4.84	4.22	1.0	1.5	
65	1846	43.3929154070	124.3835640070	35.1	4.88	4.35	.8	1.4	
66	1847	43.3929154070	124.3835640070	15.1	4.89	4.39	.7	1.3	
67	1848	43.3929154070	124.3835640070	.7	4.88	4.92	.8	.7	AIR CALIBRATION

Plume monitor data from 8/15/81.

ID#	TIME	LATITUDE	LONGITUDE	DEPTH (ft)	V1	V2	C1 (E-03)	C2 (E-03)	COMMENTS
1	1030	43.4009088709	124.3801731300	.7	4.65	4.40	2.1	1.3	AIR CALIBRATION
2	1100	43.4009088709	124.3801731300	17.4	4.88	4.38	.8	1.3	BACKGROUND: CTR SP SITE
3	1101	43.4009088709	124.3801731300	49.9	4.89	4.39	.7	1.3	
4	1102	43.4009088709	124.3801731300	83.0	4.86	4.28	.9	1.4	
5	1104	43.4009088709	124.3801731300	113.2	4.90	4.45	.7	1.2	
6	1105	43.4009088709	124.3801731300	146.7	4.84	4.15	1.0	1.6	
7	1106	43.4009088709	124.3801731300	183.4	4.73	3.79	1.6	2.1	
8	1107	43.4009088709	124.3801731300	194.9	4.52	2.90	2.9	3.6	
9	1110	43.4015426908	124.3823868470	0.0	0.00	0.00	0.0	0.0	YAQUINA DUMP
10	1113	43.4015426908	124.3823868470	16.7	.86	.01	48.6	34.6	
11	1114	43.4015426908	124.3823868470	7.2	1.70	.03	29.8	28.6	FOLLOWING DR
12	1115	43.4015426908	124.3823868470	34.8	1.60	.04	31.5	27.0	
13	1118	43.4015426908	124.3823868470	49.2	2.07	.07	24.4	24.0	
14	1119	43.4015426908	124.3823868470	66.6	4.89	4.34	.7	1.4	CONSTANT TURB
15	1120	43.4015426908	124.3823868470	157.5	4.86	4.20	.9	1.5	
16	1123	43.4009556799	124.3826737220	81.4	4.87	4.25	.8	1.5	
17	1124	43.4009556799	124.3826737220	77.8	4.95	2.83	.4	3.7	
18	1125	43.4009556799	124.3826737220	64.3	1.95	.18	26.1	18.8	
19	1126	43.4009556799	124.3826737220	51.2	1.95	.27	26.1	16.6	
20	1127	43.4009556799	124.3826737220	32.8	4.50	2.83	3.0	3.7	
21	1128	43.4009556799	124.3826737220	14.8	4.50	2.80	3.0	3.8	
22	1129	43.4009556799	124.3826737220	8.2	4.73	3.70	1.6	2.2	
23	1132	43.4005941131	124.3823455850	15.1	4.89	4.40	.7	1.3	FOLLOWING DR
24	1133	43.4005941131	124.3823455850	33.8	4.63	4.28	2.2	1.4	100' W DR
25	1134	43.4005941131	124.3823455850	47.2	4.85	4.35	.9	1.4	
26	1135	43.4005941131	124.3823455850	66.3	4.88	4.34	.8	1.4	
27	1136	43.4005941131	124.3823455850	82.0	4.86	4.27	.9	1.5	
28	1137	43.4005941131	124.3823455850	100.7	4.90	4.47	.7	1.2	
29	1139	43.4005941131	124.3823455850	115.2	4.90	4.43	.7	1.3	LOST PLUME;TRANS FOR MAX TURB
30	1204	43.4000984158	124.3843544900	91.9	0.00	4.00	0.0	1.8	TRANS 200' SW DR
31	1205	43.4000984158	124.3843544900	91.9	0.00	3.00	0.0	3.4	MIN @ DR
32	1206	43.4000984158	124.3843544900	82.0	0.00	3.70	0.0	2.2	100' SW DR
33	1207	43.4000984158	124.3843544900	7.2	0.00	3.24	0.0	3.0	40' SW DR
34	1208	43.4000984158	124.3843544900	82.0	0.00	4.30	0.0	1.4	20' SW DR
35	1209	43.4000984158	124.3843544900	96.5	0.00	4.00	0.0	1.8	150' NE DR
36	1210	43.4000984158	124.3843544900	109.9	0.00	4.48	0.0	1.2	NW-SE TRANS; 400' NW
37	1211	43.4000984158	124.3843544900	97.1	0.00	4.43	0.0	1.3	250' NW
38	1212	43.4000984158	124.3843544900	94.2	0.00	4.39	0.0	1.3	120' NW DR
39	1213	43.4000984158	124.3843544900	94.2	0.00	4.30	0.0	1.4	50' W DR
40	1214	43.4000984158	124.3843544900	105.0	0.00	4.50	0.0	1.2	50' E DR
41	1215	43.4000984158	124.3843544900	114.8	0.00	4.50	0.0	1.2	
42	1216	43.4000984158	124.3843544900	88.6	0.00	3.90	0.0	2.0	
43	1217	43.4000984158	124.3843544900	68.9	0.00	4.25	0.0	1.5	100' E DR
44	1235	43.4000984158	124.3843544900	133.2	4.90	4.42	.7	1.3	50' S DR
45	1236	43.4000984158	124.3843544900	115.2	4.91	4.50	.6	1.2	
46	1237	43.4000984158	124.3843544900	99.1	4.90	4.42	.7	1.3	
47	1238	43.4000984158	124.3843544900	66.3	4.82	4.30	1.1	1.4	
48	1242	43.4000984158	124.3843544900	31.2	4.87	4.36	.8	1.3	
49	1243	43.4000984158	124.3843544900	15.1	4.89	4.40	.7	1.3	
50	1244	43.4000984158	124.3843544900	134.2	4.91	4.47	.6	1.2	
51	1245	43.4000984158	124.3843544900	165.4	4.89	4.40	.7	1.3	

52	1246	43.4000984158	124.3843544900	198.2	4.82	4.05	1.1	1.7	
53	1325	43.3998691799	124.3784113120	18.7	4.87	4.36	.8	1.3	BIDDLE DUMP
54	1326	43.3998691799	124.3784113120	6.9	4.89	4.41	.7	1.3	
55	1327	43.3998691799	124.3784113120	33.5	4.89	4.37	.7	1.3	
56	1333	43.3998691799	124.3784113120	101.4	1.07	.09	42.6	22.6	
57	1334	43.3998691799	124.3784113120	116.8	3.29	.50	11.6	13.2	
58	1335	43.3998691799	124.3784113120	130.6	.50	.01	63.6	34.6	
59	1336	43.3998691799	124.3784113120	148.0	2.86	.01	15.5	34.6	
60	1337	43.3998691799	124.3784113120	164.7	.86	.01	48.6	34.6	TRANS. 100' NE DR
61	1337	43.3998691799	124.3784113120	178.1	1.95	.33	26.1	15.5	BOAT STATIONARY
62	1338	43.3998691799	124.3784113120	181.8	1.21	.03	39.2	28.6	
63	1339	43.3998691799	124.3784113120	164.0	2.42	.10	20.1	22.0	
64	1340	43.3998691799	124.3784113120	147.3	1.31	.32	37.0	15.6	
65	1341	43.3998691799	124.3784113120	131.6	3.00	.27	14.2	16.6	
66	1343	43.3998691799	124.3784113120	114.5	2.87	.17	15.4	19.1	
67	1344	43.3998691799	124.3784113120	98.1	3.96	.99	6.5	9.5	
68	1345	43.3998691799	124.3784113120	82.3	4.68	2.90	1.9	3.6	
69	1346	43.3998691799	124.3784113120	62.7	4.86	4.22	.9	1.5	
70	1347	43.3998691799	124.3784113120	31.5	4.89	4.36	.7	1.3	
71	1359	43.3988313848	124.3799268450	31.8	4.87	4.33	.8	1.4	PROF @ DR; 200 YDS SE SP SITE
72	1400	43.3988313848	124.3799268450	51.2	4.85	4.13	.9	1.6	
73	1401	43.3988313848	124.3799268450	81.4	4.79	3.62	1.3	2.4	
74	1402	43.3988313848	124.3799268450	100.4	4.65	3.56	2.1	2.4	
75	1403	43.3988313848	124.3799268450	117.5	4.90	4.30	.7	1.4	
76	1404	43.3988313848	124.3799268450	180.8	4.55	3.10	2.7	3.2	
77	1414	43.3999157662	124.3809106770	182.4	4.80	3.97	1.2	1.9	MIDWAY BET DR & CTR SP SI
78	1415	43.3999157662	124.3809106770	163.4	4.89	4.37	.7	1.3	30 FATH
79	1416	43.3999157662	124.3809106770	131.9	4.72	3.46	1.7	2.6	
80	1417	43.3999157662	124.3809106770	101.4	4.91	4.47	.6	1.2	
81	1418	43.3999157662	124.3809106770	117.1	4.74	4.25	1.6	1.5	
82	1422	43.3995542849	124.3805827080	83.0	4.88	4.35	.8	1.4	
83	1423	43.3995542849	124.3805827080	45.3	4.86	4.26	.9	1.5	
84	1424	43.3995542849	124.3805827080	16.1	4.88	4.36	.8	1.3	
85	1445	43.3979291717	124.3823846650	7.9	0.00	4.20	0.0	1.5	MIN @ 24M; SP SITE TO DR
86	1500	43.3979291717	124.3823846650	.1	4.69	4.73	1.9	.9	AIR READINGS

Plume monitor data from 8/17/81.

ID#	TIME	LATITUDE	LONGITUDE	DEPTH (ft)	V1	V2	C1 (E-03)	C2 (E-03)	COMMENTS
1	1211	43.3999157662	124.3809106770	0.0	4.75	4.82	1.5	.8	AIR CALIBRATION
2	1311	43.3999157662	124.3809106770	15.1	4.87	4.33	.8	1.4	BACKGRROUND PROFILE
3	1312	43.3999157662	124.3809106770	53.5	4.86	4.27	.9	1.5	
4	1313	43.3999157662	124.3809106770	83.7	4.82	4.10	1.1	1.7	
5	1314	43.3999157662	124.3809106770	114.8	4.86	4.29	.9	1.4	
6	1315	43.3999157662	124.3809106770	147.0	4.86	4.29	.9	1.4	
7	1316	43.3999157662	124.3809106770	175.9	4.83	4.17	1.1	1.6	
8	1325	43.3998263107	124.3824681970	32.2	2.92	.34	14.9	15.3	BIDDLE DUMP
9	1340	43.3998263107	124.3824681970	32.2	2.92	.34	14.9	15.3	PROFILE DELAYED 15 MIN
10	1341	43.3998263107	124.3824681970	15.1	3.78	1.35	7.8	7.8	
11	1342	43.3998263107	124.3824681970	5.9	4.14	2.13	5.3	5.3	
12	1343	43.3998263107	124.3824681970	18.7	4.51	4.20	2.9	1.5	
13	1344	43.3998263107	124.3824681970	32.5	4.60	3.39	2.4	2.7	
14	1345	43.3986969854	124.3822624380	65.0	4.02	2.09	6.1	5.4	
15	1346	43.3986969854	124.3822624380	101.4	4.87	4.36	.8	1.3	
16	1347	43.3986969854	124.3822624380	132.5	4.86	4.28	.9	1.4	
17	1348	43.3986969854	124.3822624380	166.3	4.83	4.25	1.1	1.5	
18	1350	43.3986969854	124.3822624380	179.1	4.82	4.13	1.1	1.6	
19	1351	43.3986969854	124.3822624380	46.3	4.87	4.30	.8	1.4	
20	1404	43.3977035545	124.3829991560	139.8	4.86	4.26	.9	1.5	
21	1405	43.3977035545	124.3829991560	81.4	4.82	3.86	1.1	2.0	100 YDS FR DR:
22	1406	43.3977035545	124.3829991560	66.9	4.58	3.63	2.5	2.3	TOWARDS CTR SP SITE
23	1407	43.3977035545	124.3829991560	48.6	4.38	2.86	3.7	3.6	S OF SP SITE
24	1408	43.3977035545	124.3829991560	32.2	4.86	4.35	.9	1.4	APPRROX 1500' FROM SP SITE
25	1409	43.3977035545	124.3829991560	52.2	4.49	2.93	3.1	3.5	
26	1407	43.3963485227	124.3834070850	75.8	4.82	3.80	1.1	2.1	100' FR DR; 300' NE T4; 0 TO 5
27	1429	43.4000965147	124.3810746710	144.0	4.85	4.25	.9	1.5	100' FR CT SP SITE TO SW
28	1430	43.4000965147	124.3810746710	181.1	4.82	4.07	1.1	1.7	
29	1431	43.4000965147	124.3810746710	119.1	4.88	4.37	.8	1.3	
30	1432	43.4000965147	124.3810746710	66.3	4.87	4.31	.8	1.4	
31	1443	43.4000070818	124.3826322830	83.3	4.89	4.43	.7	1.3	
32	1444	43.4000070818	124.3826322830	48.2	4.87	4.26	.8	1.5	
33	1445	43.4000070818	124.3826322830	16.1	4.88	4.36	.8	1.3	
34	1710	43.4004580274	124.3814026770	32.2	4.84	4.21	1.0	1.5	BACKGROUND
35	1711	43.4004580274	124.3814026770	107.6	4.90	4.42	.7	1.3	
36	1717	43.4004580274	124.3814026770	166.3	4.85	4.23	.9	1.5	
37	1730	43.4013172675	124.3830018850	50.2	4.85	4.23	.9	1.5	BIDDLE DUMP;
38	1731	43.4013172675	124.3830018850	17.4	4.86	4.30	.9	1.4	N OF :
39	1732	43.4013172675	124.3830018850	68.6	4.86	4.23	.9	1.5	
40	1738	43.4013172675	124.3830018850	95.8	1.17	.04	40.1	27.0	CTR PLUME
41	1739	43.4013172675	124.3830018850	65.9	.44	.01	67.1	34.6	
42	1740	43.4013172675	124.3830018850	52.8	.86	.01	48.6	34.6	
43	1741	43.4013172675	124.3830018850	31.2	2.91	1.76	15.0	6.3	
44	1743	43.4013172675	124.3830018850	16.7	4.40	2.74	3.6	3.9	
45	1744	43.4013172675	124.3830018850	49.2	3.30	.80	11.6	10.6	
46	1745	43.4013172675	124.3830018850	69.6	2.09	.04	24.1	27.0	
47	1746	43.4013172675	124.3830018850	99.1	3.67	1.84	8.6	6.1	
48	1747	43.4013172675	124.3830018850	82.7	4.50	3.33	3.0	2.8	
49	1748	43.4013172675	124.3830018850	117.1	3.44	3.98	10.4	1.8	PEAK TURB AT 32M
50	1749	43.4013172675	124.3830018850	95.8	4.90	4.44	.7	1.2	
51	1752	43.3997815707	124.3832471090	135.5	3.32	1.96	11.4	5.7	PEAK TURB

52	1753	43.3997815707	124.3832471090	136.5	3.12	1.04	13.1	9.2	
53	1754	43.3997815707	124.3832471090	163.7	4.90	4.02	.7	1.8	
54	1755	43.3993752507	124.3836977810	181.8	4.77	4.01	1.4	1.8	
55	1756	43.3993752507	124.3836977810	154.5	4.84	4.09	1.0	1.7	
56	1757	43.3987881192	124.3839841980	136.2	4.87	4.15	.8	1.6	
57	1758	43.3987881192	124.3839841980	98.4	0.00	4.33	0.0	1.4	
58	1805	43.3994664914	124.3854201890	121.4	3.62	1.50	9.0	7.2	100' NW OF DR
59	1806	43.3994664914	124.3854201890	95.1	4.03	1.95	6.0	5.7	
60	1807	43.3994664914	124.3854201890	63.0	3.74	2.50	8.1	4.4	
61	1808	43.3994664914	124.3854201890	47.2	3.91	1.90	6.9	5.9	
62	1809	43.3994664914	124.3854201890	29.5	4.72	3.78	1.7	2.1	
63	1810	43.3994664914	124.3854201890	15.1	4.79	3.97	1.3	1.9	
64	1813	43.3980663455	124.3866076380	5.2	4.82	4.07	1.1	1.7	100' E OF DR
65	1814	43.3980663455	124.3866076380	50.9	3.93	1.63	6.7	6.7	1ST MAX TURB W/ DPTH
66	1815	43.3980663455	124.3866076380	67.3	4.52	2.83	2.9	3.7	
67	1816	43.3980663455	124.3866076380	85.0	4.84	4.11	1.0	1.7	
68	1817	43.3980663455	124.3866076380	103.3	4.90	4.41	.7	1.3	NEAR MOORING T4
69	1820	43.3970275245	124.3881232780	182.7	4.74	3.78	1.6	2.1	100' NW DR
70	1824	43.3976149158	124.3878373490	177.8	4.83	4.11	1.1	1.7	CLEAR TO 32M
71	1825	43.3976149158	124.3878373490	94.2	4.48	3.11	3.1	3.2	
72	1826	43.3971633841	124.3890671210	60.0	4.66	3.50	2.0	2.5	
73	1829	43.3971633841	124.3890671210	24.9	4.77	3.87	1.4	2.0	
74	1830	43.3971633841	124.3890671210	44.9	4.56	3.07	2.6	3.3	
75	1831	43.3971633841	124.3890671210	112.5	4.86	4.39	.9	1.3	
76	1836	43.3957625412	124.3902533670	173.2	4.86	4.30	.9	1.4	CONST TURB BET THIS & PREV DPT
77	1840	43.3963500751	124.3899677580	172.9	4.87	3.97	.8	1.9	MOVE BACK TO 100' NW DR
78	1841	43.3963500751	124.3899677580	93.8	4.81	3.99	1.2	1.8	MAX TURB
79	1842	43.3963500751	124.3899677580	52.2	4.40	2.98	3.6	3.4	MAX TURB
80	1843	43.3963500751	124.3899677580	16.7	4.81	3.97	1.2	1.9	DR NOW 3000' S DISP SITE
81	1856	43.3963500751	124.3899677580	-.1	4.55	4.91	2.7	.7	AIR CALIBRATION

Plume monitor data from 8/19/81; AM.

ID#	TIME	LATITUDE	LONGITUDE	DEPTH (ft)	V1	V2	C1 (E-03)	C2 (E-03)	COMMENTS
1	849	43.4021742441	124.3813207850	-1.3	4.70	0.00	1.8	0.0	AIR CALIBRATION
2	906	43.4021742441	124.3813207850	5.6	4.82	4.15	1.1	1.6	100' TO CP
3	907	43.4021742441	124.3813207850	17.4	4.83	4.17	1.1	1.6	
4	908	43.4021742441	124.3813207850	35.4	4.83	4.17	1.1	1.6	
5	909	43.4021742441	124.3813207850	65.6	4.88	4.36	.8	1.3	
6	910	43.4021742441	124.3813207850	100.1	4.90	4.40	.7	1.3	
7	911	43.4021742441	124.3813207850	132.2	4.86	4.32	.9	1.4	
8	912	43.4021742441	124.3813207850	161.1	4.68	3.57	1.9	2.4	100' TO CP
9	922	43.4021742441	124.3813207850	0.0	0.00	0.00	0.0	0.0	BIDDLE FINISHED DUMPING
10	929	43.4017210971	124.3792713510	48.9	3.85	3.72	7.3	2.2	DUMPING; DR. IN
11	932	43.4017210971	124.3792713510	32.5	2.22	2.07	22.5	5.4	
12	934	43.4017210971	124.3792713510	15.1	2.07	2.07	24.4	5.4	
13	935	43.4017210971	124.3792713510	4.6	3.14	3.43	12.9	2.7	
14	936	43.4017210971	124.3792713510	34.4	4.03	1.46	6.0	7.3	
15	936	43.4017210971	124.3792713510	66.6	4.89	4.39	.7	1.3	DR. 100' TO LEFT
16	936	43.4025331932	124.3783693330	98.4	4.70	4.50	1.8	1.2	
17	938	43.4025331932	124.3783693330	133.9	4.84	4.22	1.0	1.5	
18	940	43.4029391924	124.3779182350	166.0	4.66	3.45	2.0	2.6	
19	942	43.4030754537	124.3788607390	125.3	4.90	4.57	.7	1.1	
20	943	43.4030754537	124.3788607390	89.6	4.88	4.55	.8	1.1	
21	944	43.4030754537	124.3788607390	64.6	4.87	4.25	.8	1.5	
22	946	43.4011342544	124.3795583790	86.6	2.46	2.07	19.6	5.4	
23	946	43.4011342544	124.3795583790	76.8	1.14	1.01	40.8	9.4	
24	947	43.4018572690	124.3802139830	65.0	3.15	3.67	12.8	2.3	
25	947	43.4018572690	124.3802139830	61.7	4.83	4.25	1.1	1.5	
26	948	43.4018572690	124.3802139830	63.0	4.82	4.42	1.1	1.3	DR. 300' N OF CP
27	949	43.4018572690	124.3802139830	76.1	4.89	4.42	.7	1.3	
28	950	43.4028056763	124.3802546280	79.4	4.88	4.43	.8	1.3	
29	953	43.4024441289	124.3799268440	80.7	4.89	4.39	.7	1.3	
30	953	43.4024441289	124.3799268440	96.5	4.91	4.49	.6	1.2	
31	955	43.4016295299	124.3775504480	103.7	4.91	4.49	.6	1.2	
32	956	43.4016295299	124.3775504480	127.0	4.38	2.63	3.7	4.1	
33	957	43.4011788780	124.3787797960	128.6	4.65	3.26	2.1	2.9	
34	957	43.4009981488	124.3786159590	124.3	3.82	1.49	7.5	7.2	
35	958	43.4009981488	124.3786159590	122.7	4.26	3.89	4.5	2.0	
36	958	43.4009981488	124.3786159590	123.4	4.88	4.12	.8	1.6	
37	958	43.4004113234	124.3789028750	130.6	4.36	2.32	3.9	4.8	
38	960	43.4004113234	124.3789028750	134.8	4.22	2.50	4.8	4.4	200 YDS TO CP
39	1000	43.4000051895	124.3793535640	133.5	2.27	2.53	21.9	4.3	
40	1000	43.4000051895	124.3793535640	133.2	3.17	3.28	12.7	2.9	
41	1001	43.3998244690	124.3791896690	134.2	2.69	2.08	17.2	5.4	
42	1002	43.3996437536	124.3790257810	138.5	2.76	2.14	16.5	5.2	
43	1003	43.3992375855	124.3794763430	141.4	2.38	2.39	20.6	4.6	
44	1004	43.3992375855	124.3794763430	133.5	2.06	2.09	24.5	5.4	
45	1004	43.3988313848	124.3799268450	129.6	2.55	2.03	18.7	5.5	
46	1005	43.3988313848	124.3799268450	131.2	2.77	2.18	16.4	5.1	
47	1005	43.3984699661	124.3795989510	129.3	2.75	2.10	16.6	5.3	
48	1006	43.3984699661	124.3795989510	129.9	2.36	2.02	20.8	5.6	
49	1007	43.3980188862	124.3808276700	133.2	4.85	4.23	.9	1.5	
50	1009	43.3978830289	124.3798853530	124.7	4.86	4.38	.9	1.3	
51	1011	43.3992375855	124.3794763430	94.8	2.44	2.03	19.9	5.5	MIDDLE OF PLUME HEADING W

52	1012	43.3994183018	124.3796402660	86.9	2.32	2.38	21.3	4.7	
53	1013	43.3997797500	124.3799681290	82.0	3.35	3.22	11.1	3.0	
54	1013	43.3999157662	124.3809106770	82.7	3.56	3.43	9.5	2.7	
55	1014	43.3999157662	124.3809106770	85.3	4.46	2.79	3.2	3.8	
56	1014	43.4002772684	124.3812386710	89.9	4.52	2.42	2.9	4.6	
57	1015	43.4002772684	124.3812386710	74.1	4.48	2.25	3.1	5.0	
58	1015	43.4002772684	124.3812386710	93.2	4.56	2.92	2.6	3.5	
59	1016	43.4006387916	124.3815666900	102.4	4.88	4.35	.8	1.4	
60	1017	43.4006387916	124.3815666900	115.2	4.89	4.39	.7	1.3	APPARENT W BOUND.
61	1017	43.4005941131	124.3823455850	128.6	4.91	4.47	.6	1.2	OF PLUME
62	1018	43.4005941131	124.3823455850	150.9	4.90	4.49	.7	1.2	
63	1019	43.4012257518	124.3812798320	89.9	4.89	4.40	.7	1.3	HEADING EAST
64	1020	43.4010449832	124.3811158470	81.4	4.85	4.16	.9	1.6	
65	1020	43.4010449832	124.3811158470	78.4	4.87	4.28	.8	1.4	
66	1021	43.4009088709	124.3801731300	84.6	4.86	3.83	.9	2.0	
67	1021	43.4009088709	124.3801731300	89.6	4.49	3.03	3.1	3.3	
68	1022	43.4009088709	124.3801731300	93.2	4.16	2.89	5.2	3.6	
69	1022	43.4007727785	124.3792306140	95.1	4.39	1.74	3.7	6.4	
70	1023	43.4007727785	124.3792306140	99.1	4.22	2.58	4.8	4.2	
71	1023	43.4008174248	124.3784521250	101.0	4.53	3.18	2.8	3.1	
72	1024	43.4006367059	124.3782882980	102.0	4.66	3.74	2.0	2.2	
73	1024	43.4006367059	124.3782882980	104.7	4.61	3.23	2.3	3.0	
74	1025	43.4006813555	124.3775099580	104.7	4.64	3.01	2.2	3.4	
75	1025	43.4006813555	124.3775099580	103.7	4.77	3.70	1.4	2.2	
76	1026	43.4006813555	124.3775099580	103.0	4.81	4.01	1.2	1.8	
77	1026	43.4005453061	124.3765679910	99.7	4.89	4.33	.7	1.4	APPARENT E BOUND.
78	1027	43.4005453061	124.3765679910	99.4	4.89	4.33	.7	1.4	
79	1027	43.4005899509	124.3757899000	100.7	4.89	4.39	.7	1.3	
80	1030	43.4015825534	124.3750520220	93.2	4.89	4.12	.7	1.6	SOUTH,NORTH TRAVERSE
81	1031	43.4019884660	124.3746011530	81.4	4.89	4.40	.7	1.3	
82	1032	43.4025305279	124.3750919250	79.4	4.89	4.40	.7	1.3	
83	1033	43.4031171022	124.3748044650	81.0	4.87	4.40	.8	1.3	
84	1034	43.4037036472	124.3745168820	83.0	4.88	4.39	.8	1.3	
85	1035	43.4041538426	124.3732874450	82.0	4.86	4.40	.9	1.3	
86	1036	43.4045152359	124.3736143870	91.5	4.88	4.33	.8	1.4	
87	1038	43.4044708739	124.3743926990	136.5	4.90	4.40	.7	1.3	
88	1038	43.4042901632	124.3742291790	139.4	4.90	4.45	.7	1.2	
89	1039	43.4042457818	124.3750075440	131.9	4.90	4.44	.7	1.2	
90	1039	43.4040650652	124.3748439840	124.7	4.89	4.42	.7	1.3	
91	1040	43.4037036472	124.3745168820	111.5	4.89	4.38	.7	1.3	
92	1041	43.4033422502	124.3741898050	120.7	4.90	4.46	.7	1.2	
93	1043	43.4027112255	124.3752555300	133.2	4.85	4.18	.9	1.6	
94	1044	43.4027557138	124.3744773330	132.2	4.73	3.42	1.6	2.7	
95	1044	43.4025750275	124.3743137750	135.8	4.49	2.96	3.1	3.5	
96	1045	43.4025305279	124.3750919250	138.5	4.49	2.71	3.1	3.9	
97	1045	43.4021691481	124.3747647380	140.7	4.48	2.76	3.1	3.8	
98	1046	43.4019439245	124.3753792660	142.4	4.48	2.88	3.1	3.6	
99	1046	43.4019439245	124.3753792660	142.1	4.32	2.44	4.1	4.5	
100	1047	43.4017632363	124.3752156410	138.5	4.56	3.01	2.6	3.4	
101	1048	43.4015825534	124.3750520220	136.8	4.26	2.33	4.5	4.8	
102	1049	43.4013572921	124.3756664840	136.5	4.13	2.99	5.4	3.4	
103	1050	43.4011320053	124.3762809610	135.2	4.61	3.32	2.3	2.8	
104	1050	43.4011320053	124.3762809610	138.1	4.60	3.32	2.4	2.8	
105	1051	43.4007706306	124.3759535810	137.8	4.52	3.13	2.9	3.2	
106	1051	43.4007706306	124.3759535810	141.4	4.56	3.06	2.6	3.3	APPARENT N BOUND.
107	1053	43.4003646203	124.3764042700	142.7	4.89	4.30	.7	1.4	OF TURBIDITY PLUME
108	1054	43.4001839399	124.3762405560	128.6	4.94	4.42	.4	1.3	
109	1059	43.4016765075	124.3800500720	170.6	4.68	3.76	1.9	2.2	CENTER OF SPOIL SITE-
110	1100	43.4016765075	124.3800500720	132.9	4.85	4.13	.9	1.6	VERTICAL PROFILE
111	1101	43.4016765075	124.3800500720	98.8	4.90	4.44	.7	1.2	
112	1102	43.4016765075	124.3800500720	67.3	4.84	4.24	1.0	1.5	
113	1104	43.4016765075	124.3800500720	34.8	4.84	4.32	1.0	1.4	BREAK FOR LUNCH

Plume monitor data from 8/19/81; PM.

ID#	TIME	LATITUDE	LONGITUDE	DEPTH (ft)	V1	V2	C1 (E-03)	C2 (E-03)	COMMENTS
1	1349	43.4016765075	124.3800500720	165.0	4.82	4.09	1.1	1.7	CP
2	1351	43.4016765075	124.3800500720	131.2	4.87	4.37	.8	1.3	CP
3	1351	43.4016765075	124.3800500720	98.1	4.82	4.25	1.1	1.5	CP
4	1352	43.4016765075	124.3800500720	65.9	4.85	4.36	.9	1.3	CP
5	1353	43.4016765075	124.3800500720	32.5	4.87	4.35	.8	1.4	CP
6	1405	43.4016765075	124.3800500720	0.0	0.00	0.00	0.0	0.0	BIDDLE DUMPING
7	1419	43.4023995848	124.3807057520	105.0	4.87	4.34	.8	1.4	RUNNING SOUTH
8	1420	43.4019934609	124.3811568160	118.4	4.85	4.03	.9	1.8	
9	1420	43.4016319099	124.3808288960	117.5	3.56	.78	9.5	10.8	
10	1421	43.4014511424	124.3806649450	116.1	2.27	.56	21.9	12.6	
11	1422	43.4011811154	124.3820587650	113.8	4.88	4.36	.8	1.3	
12	1422	43.4012257518	124.3812798320	113.5	4.88	4.39	.8	1.3	
13	1424	43.4006387916	124.3815666900	128.0	4.86	4.38	.9	1.3	
14	1427	43.4014065254	124.3814438230	95.5	2.02	.05	25.1	25.8	
15	1427	43.4014065254	124.3814438230	91.9	2.22	.05	22.5	25.8	
16	1427	43.4019488779	124.3819358340	84.0	1.55	.01	32.4	34.6	
17	1428	43.4021742441	124.3813207850	80.1	.67	.01	55.5	34.6	
18	1429	43.4023550326	124.3814847620	0.0	4.45	1.82	3.3	6.1	
19	1430	43.4027166253	124.3818127310	81.7	4.88	4.42	.8	1.3	
20	1433	43.4028529035	124.3827559770	117.1	4.88	4.35	.8	1.4	
21	1434	43.4024467208	124.3832071600	139.1	4.88	4.37	.8	1.3	
22	1435	43.4021296726	124.3820998500	108.3	4.84	4.27	1.0	1.5	
23	1436	43.4019934609	124.3811568160	85.0	4.14	1.54	5.3	7.0	
24	1437	43.4018126828	124.3809928530	87.9	4.33	2.45	4.1	4.5	
25	1437	43.4016319099	124.3808288960	93.8	4.30	2.09	4.3	5.4	
26	1438	43.4016765075	124.3800500720	94.8	4.85	3.99	.9	1.8	
27	1438	43.4014957513	124.3798861680	93.8	4.86	4.42	.9	1.3	
28	1440	43.4009535138	124.3793944930	97.1	4.88	4.37	.8	1.3	
29	1441	43.4005473827	124.3798452850	109.6	4.88	4.42	.8	1.3	
30	1441	43.4003666464	124.3796813720	124.3	4.88	4.36	.8	1.3	
31	1442	43.4001859154	124.3795174640	113.2	4.88	4.36	.8	1.3	
32	1443	43.3997797500	124.3799681290	108.6	4.84	4.35	1.0	1.4	
33	1443	43.3995990234	124.3798041940	113.5	4.87	4.36	.8	1.3	
34	1444	43.3994183018	124.3796402660	116.5	4.88	4.39	.8	1.3	
35	1444	43.3993735520	124.3804187320	115.5	4.88	4.37	.8	1.3	
36	1445	43.3989673216	124.3808692770	107.0	4.88	4.28	.8	1.4	
37	1447	43.3989225331	124.3816478550	102.4	3.65	1.03	8.8	9.2	
38	1448	43.3992392546	124.3827547460	88.9	3.68	.60	8.5	12.2	
39	1449	43.3994647839	124.3821400410	74.5	4.88	4.21	.8	1.5	
40	1450	43.4000518023	124.3818534270	109.6	4.72	3.91	1.7	1.9	
41	1451	43.3995095384	124.3813613240	135.5	4.77	4.16	1.4	1.6	
42	1452	43.3993287944	124.3811973020	117.8	4.22	1.47	4.8	7.3	
43	1453	43.3991928245	124.3802547650	116.8	4.50	2.73	3.0	3.9	
44	1453	43.3990121021	124.3800908010	115.8	4.67	3.45	2.0	2.6	
45	1454	43.3988313848	124.3799268450	111.5	4.77	3.98	1.4	1.8	
46	1454	43.3988313848	124.3799268450	108.3	4.89	4.39	.7	1.3	
47	1500	43.3970255419	124.3815641710	101.4	4.43	2.12	3.4	5.3	
48	1501	43.3970255419	124.3815641710	92.2	4.09	1.41	5.6	7.5	
49	1501	43.3972511640	124.3809498950	85.6	4.76	4.15	1.5	1.6	DROGUE
50	1502	43.3976574638	124.3804996390	79.4	4.88	4.39	.8	1.3	
51	1508	43.4001859154	124.3795174640	151.9	4.76	3.86	1.5	2.0	
52	1509	43.4001859154	124.3795174640	131.9	4.84	4.27	1.0	1.5	
53	1510	43.4001859154	124.3795174640	99.1	4.88	4.36	.8	1.3	
54	1511	43.4001859154	124.3795174640	67.9	4.88	4.36	.8	1.3	
55	1512	43.4003219614	124.3804599700	42.3	4.88	4.32	.8	1.4	
56	1512	43.4003219614	124.3804599700	0.0	4.54	4.70	2.8	.9	FINISH

APPENDIX B: PROGRAMS USED IN DATA ANALYSIS.

(Programs in Hewlett-Packard enhanced BASIC for the HP 85 computer)

```
1000 ! W.H.Hollings for COE DMRP.
1010 ! Position plot; input via data file or manually.*************
1020 DEG @ OPTION BASE 1
1030 DIM T1$[50],L$[50]
1040 PLOTTER IS 705 @ PRINTER IS 705 @ PRINT "IN" @ PRINT "VS10"
1050 GOSUB 1170
1060 GOSUB 1320
1070 GOSUB 1370
1080 GOSUB 1540
1090 GOSUB 1120
1100 DISP "PLOT COMPLETED" @ DISP "END"
1110 PRINT "IN" @ END
1120 ! ****SUB- OPTIONS ***********************************************
1130 DISP "TITLE DESIRED? (Y/N)" @ INPUT A$@ IF A$="Y" THEN GOSUB 2090
1140 DISP "DATA FILE OR MANUAL INPUT? (D/M)" @ INPUT D1$
1150 IF D1$="D" THEN GOSUB 1790 ELSE GOSUB 1940
1160 RETURN
1170 ! ****SUB-EST. PLOT LIMITS ***************************************
1180 DISP "DEFAULT PLOT LIMITS? (Y/N)" @ INPUT Y$@ IF Y$="N" THEN GOTO 1210
1190 L1=43 @ L2=23 @ L3=30 @ U1=43 @ U2=24 @ U3=15 @ Z1=124 @ Z2=23 @ Z3=30
1200 Y1=43+23/60+30/3600 @ Y2=43+24/60+15/3600 @ X2=124+23/60+30/3600 @ GOTO 1270
1210 DISP "ENTER MINIMUM LATITUDE:DEGREES,MINUTES,SECONDS" @ BEEP @ INPUT L1,L2,L3
1220 Y1=L1+L2/60+L3/3600
1230 DISP "ENTER MAXIMUM LATITUDE:DEGREES,MINUTES,SECONDS" @ BEEP @ INPUT U1,U2,U3
1240 Y2=U1+U2/60+U3/3600
1250 DISP "ENTER MAXIMUM LONGITUDE:DEGREES,MINUTES,SECONDS" @ BEEP @ INPUT Z1,Z2,Z3
1260 X2=Z1+Z2/60+Z3/3600
1270 Y8=Y2-Y1 ! Y8 IS THE LENGTH OF THE Y AXIS.
1280 C=COS((Y1+Y2)/2) ! C=COSINE OF THE AVERAGE LATITUDE.
1290 X1=X2-Y8*8/(7*C)
1300 X8=X2-X1 ! X8 IS THE LENGTH OF THE X AXIS
1310 RETURN
1320 ! ****SUB-COMPASS ARROW ******************************************
1330 MOVE 10,50 @ IDRAW 0,30
1340 IDRAW 1.5,-18 @ MOVE 12,55
1350 CSIZE 6,.5,29 @ LABEL "N"
1360 RETURN
1370 ! ****SUB-ft AXES ************************************************
1380 M1=60/(Y8*60*6.0761) ! MI=LENGTH OF 1000 ft IN GU's
1390 MOVE 115,92 @ IDRAW -70,0
1400 IDRAW 0,-1 @ IMOVE 0,3 @ CSIZE 3
1410 LORG 4 @ LABEL "0 ft"
1420 FOR I=1 TO 70/M1
1430 IMOVE 0,1 @ IMOVE M1,0 @ IDRAW 0,-1
1440 LORG 4 @ IMOVE 0,3
1450 LABEL USING "4D" ; 1000*I @ NEXT I
1460 MOVE 117,90 @ IDRAW 0,-60
1470 IDRAW -1,0 @ IMOVE 3,0 @ LORG 2
1480 LABEL "0 ft" @ IMOVE -2,3
1490 FOR I=1 TO 60/M1+.1
1500 IMOVE 0,M1 @ IDRAW -1,0 @ IMOVE 2,0
1510 LABEL USING "5D" ; 1000*I
1520 IMOVE -1,3 @ NEXT I
1530 RETURN
1540 ! ****SUB-DRAW & LABEL AXES **************************************
1550 LOCATE 45,115,30,90 @ FRAME ! PLOT AREA IS 80(X) BY 70(Y) GU'S****************************
1560 ! DRAW AND LABEL LAT AND LONG AT 15 SEC INTERVALS ************
1570 SCALE X2,X1,Y1,Y2
1580 FOR Y=Y1+15/3600 TO Y2+1/3600 STEP 15/3600
1590 XAXIS Y @ MOVE X2,Y @ LORG 8
1600 T1=(Y-IP(Y))*60 @ T2=(T1-IP(T1))*60
```

```
1610 IF T2>59.9 THEN 1620 ELSE 1630
1620 T1=T1+1 @ T2=0
1630 LABEL USING "DD,A,DD,AAA" ; IP(T1),"'",T2,"'' " @ NEXT Y
1640 FOR X=X2-15/3600 TO X1 STEP -(15/3600)
1650 YAXIS X @ MOVE X,Y1-.04*Y8 @ LORG 6
1660 Q1=(X-IP(X))*60 @ Q2=(Q1-IP(Q1))*60
1670 IF Q2>59.9 THEN 1680 ELSE 1690
1680 Q1=Q1+1 @ Q2=0
1690 LABEL USING "DD,A,DD,AA" ; IP(Q1),"'",Q2,"''" @ NEXT X
1700 ! LABEL DEGREEES ***********************************************
1710 MOVE X2,Y1-.04*Y8 @ LORG 6
1720 LABEL USING "3D,A,2D,A,2D,2A" ; Z1," ",Z2,"'",Z3,"''"
1730 MOVE X2,Y1 @ LORG 8
1740 LABEL USING "2D,A,2D,A,2D,2A" ; L1," ",L2,"'",L3,"''"
1750 MOVE (X1+X2)/2,Y1-.1*Y8
1760 LORG 6 @ CSIZE 3 @ LABEL "LONGITUDE-MINUTES"
1770 MOVE X2+.19*X8,(Y1+Y2)/2 @ LDIR 90 @ LABEL "LATITUDE-MINUTES"
1780 RETURN
1790 ! ****SUB-DATA FILE PLOT*****************************************
1800 DISP "INPUT DATA FILE NAME" @ INPUT N1$
1810 DISP "INPUT N1,N2" @ INPUT N1,N2
1820 ASSIGN# 1 TO N1$
1830 FOR I=N1 TO N2
1840 READ# 1,I ; I$,P,X
1850 GOSUB 2140
1860 PENUP @ PLOT X,P
1870 PENUP @ LORG 2 @ CSIZE 2
1880 LDIR 0 @ LABEL USING 1890 ; I$
1890 IMAGE " ",2A
1900 NEXT I
1910 ASSIGN# 1 TO *
1920 DISP "ANY MORE?" @ INPUT Y$@ IF Y$="Y" THEN GOTO 1800
1930 RETURN
1940 ! ****SUB-MANUAL INPUT *****************************************
1950 DISP "INPUT # DATA PTS" @ INPUT N2
1960 FOR I=1 TO N2
1970 DISP "DEC OR DMS?" @ INPUT Z6$
1980 IF Z6$="DEC" THEN 2030
1990 DISP "INPUT LAT.LONG"
2000 INPUT A1,B1,C1,D1,E1,F1
2010 P=A1+B1/60+C1/3600 @ X=D1+E1/60+F1/3600
2020 GOTO 2040
2030 DISP "INPUT DEC LAT,LONG" @ INPUT P,X
2040 GOSUB 2140
2050 DISP "LABEL?" @ INPUT L$@ MOVE X,P @ LORG 2
2060 CSIZE 2 @ LABEL " ",L$
2070 PLOT X,P @ NEXT I
2080 RETURN
2090 REM *SUB-TITLE*
2100 DISP "TITLE? (50 CHAR MAX)" @ INPUT T1$
2110 LDIR 0 @ CSIZE 3
2120 MOVE (X1+X2)/2+.1*X8,Y1-.2*Y8 @ LABEL T1$
2130 RETURN
2140 ! ****SUB- PLOT SQUARE*******************************************
2150 MOVE X,P
2160 ! D8,D9,DEFINE SIZE OF SQUARE PLOTTED
2170 D8=.02*Y8 @ D9=.02*Y8*C
2180 IMOVE -(D8/2),D9/2
2190 IDRAW D8,0 @ IDRAW 0,-D9
2200 IDRAW -D8,0 @ IDRAW 0,D9 @ PENUP
2210 RETURN
```

```
1000 ! W.H.Hollings for COE DMRP.
1010 ! PROGRAM "WTDAVG"*used to create data files "PM___"************
1020 ! CALCULATE DEPTH WEIGHTED AVERAGE CONCENTRATIONS ***************
1030 ! CALCULATE AVERAGE TIME, POSITION, DEPTH, C1, C2*****************
1040 ! CALCULATE DELTA T,X,Z FROM DUMP TIME AND POSITION (T0,X0,Z0)***
1050 ! INPUT DATA FILE NAME, I1, I2(FIRST AND LAST DATA POINTS)*******
1060 DIM K(130),A1(130),A2(130),D(130),V1(130),V2(130),T(130),D1(130),C1(130),C2(130)
1070 DEG
1080 PRINTER IS 701,909
1090 PRINT ""
1100 DISP "INPUT DATA FILE NAME DESIRED?" @ INPUT D1$
1110 DISP "INPUT # RECORDS REQUIRED?" @ INPUT R1@ R1=R1+1
1120 CREATE D1$,R1,120
1130 ASSIGN# 2 TO D1$
1140 J=1
1150 DISP "INPUT DATA FILE NAME"
1160 INPUT D$
1170 DISP "INPUT TZERO=TIME OF DUMP"
1180 INPUT T9
1190 T0=IP(T9/100)+RMD(T9,100)/60 ! DECIMALIZED T9=T0
1200 DISP "INPUT I1,I2"
1210 INPUT I1,I2
1220 DISP "INPUT EST. OF UPPER & LOWER LIMITS OF PLUME, FEET"
1230 INPUT D0,D9
1240 ! X0 AND Z0 ARE LAT AND LONG COORDINATES OF CP DUMP SITE*********
1250 X0=43.401554442
1260 Z0=124.380758649
1270 ! B0(1) AND B1(1) ARE CALIBRATION CONSTANTS FOR 5cm TRANS.*******
1280 ! B0(2) AND B1(2) ARE CALIBRATION CONSTANTS FOR 25cm TRANS*******
1290 B0(1)=1.613 @ B0(2)=1.717 @ B1(1)=-.0137 @ B1(2)=-.0689
1300 PRINT @ PRINT @ PRINT
1310 PRINT USING 1320 ; D$,I1,I2,T9
1320 IMAGE "DATA FILE ",7A,";",3X,"DATA POINTS ",3D,X,"THRU ",3D,";",3X,"T(DUMP)=",5D
1330 PRINT USING 1340 ; D0,D9
1340 IMAGE "ESTIMATED UPPER AND LOWER BOUNDS OF PLUME: ",3D.D,"ft",3X,3D.D,"ft"
1350 PRINT USING 1390 @ PRINT
1360 A1$="LATITUDE" @ A2$="LONGITUDE" @ A3$="C(25cm)"
1370 PRINT USING 1400 ; A1$,A2$,A3$
1380 PRINT USING 1410
1390 IMAGE "***************************************************************************"
1400 IMAGE "ID#",3X,"TIME",7X,8A,8X,9A,5X,"DEPTH",3X,"V(5cm)",3X,"V(25cm)",3X,"C(5cm)",3X,7A
1410 IMAGE 48X,"(ft)",23X,"(ml/l)",3X,"(ml/l)"
1420 ASSIGN# 1 TO D$
1430 FOR I=I1 TO I2
1440 READ# 1,I ; K(I),T(I),A1(I),A2(I),D(I),V1(I),V2(I)
1450 C1(I)=(LOG(V1(I))-B0(1))/(B1(1)*2.65)
1460 C2(I)=(LOG(V2(I))-B0(2))/(B1(2)*2.65)
1470 D(I)=D(I)/.3048 ! CHANGE m TO ft
1480 PRINT USING 1500 ; K(I),T(I),A1(I),A2(I),D(I),V1(I),V2(I),C1(I),C2(I)
1490 T(I)=IP(T(I)/100)+RMD(T(I),100)/60 ! DECIMALIZE TIME
1500 IMAGE 3D,3X,4D,3X,3D.10D,3X,3D.10D,3X,3D.D,3X,2D.2D,3X,2D.2D,5X,3D.D,4X,3D.D
1510 NEXT I
1520 T1=0 @ A8=0 @ A9=0
```

```
1530 D1=0 @ V8=0 @ V9=0
1540 FOR I=I1 TO I2
1550 T1=T1+T(I) @ D1=D1+D(I)
1560 A8=A8+A1(I) @ A9=A9+A2(I)
1570 NEXT I
1580 N=I2-I1+1
1590 T1=T1/N @ D1=D1/N @ A8=A8/N @ A9=A9/N
1600 T2=T1-T0 ! CALCULATE DELTA TIME
1610 T1=RMD(T1,1)*60+IP(T1)*100 ! CONVERT TIME BACK TO hrs, min
1620 GOSUB 1960
1630 D1(I1)=(D(I1)+D(I1+1))/2-D0
1640 FOR M=I1+1 TO I2-1
1650 D1(M)=(D(M+1)-D(M-1))/2
1660 NEXT M
1670 D1(I2)=D9-(D(I2)+D(I2-1))/2
1680 S3=0 @ S4=0
1690 FOR I=I1 TO I2
1700 S3=S3+C1(I)*D1(I)
1710 S4=S4+C2(I)*D1(I)
1720 NEXT I
1730 C8=S3/(D9-D0) @ C9=S4/(D9-D0)
1740 PRINT @ PRINT
1750 PRINT "COMPUTED AVERAGE DATA FOR THIS TRANSECT"
1760 PRINT "****************************************"
1770 PRINT USING 1830 ; T1,D1,A8,A9
1780 PRINT USING 1840 ; C8,C9
1790 T8=RMD(T2,1)*60+IP(T2)*60
1800 PRINT USING 1850 ; T8
1810 X8=(X0-A8)*6076.1*60 @ Z8=-((A9-Z0)*6076.1*60*COS(A8))
1820 PRINT USING 1860 ; X8,Z8
1830 IMAGE "TIME=",4D.D,2X,"DEPTH=",3D.D,"ft",2X,"LAT=",3D.8D,2X,"LONG=",3D.8D
1840 IMAGE "WTD AVG CONCENTRATIONS: 5cm=",D.3DE,3X,"25cm=",D.3DE," ml/l"
1850 IMAGE "DELTA T=",3D.D," min"
1860 IMAGE "DELTA X=",5D,3X,"DELTA Z=",5D," FEET, SOUTH AND EAST POSITIVE"
1870 DISP "INPUT ID FOR THIS TRANSECT?" @ INPUT I$
1880 PRINT# 2,J ; I$,A8,A9,D0,D9,D1,T1,C8,C9,I1,I2,T8,X8,Z8
1890 PRINT "**********************************************************************************"
1900 PRINT @ PRINT @ PRINT @ J=J+1
1910 DISP "ANY MORE? (Y,N)"
1920 INPUT Y$@ IF Y$="Y" THEN GOTO 1200
1930 PRINT# 2,J ; "CP",X0,Z0,186,186,186,T9,0,0,0,0,0
1940 DISP "END"
1950 END
1960 ! SUB: PUT D(I)'S IN ASCENDING ORDER; REORDER V1'S, V2'S********
1970 FOR K=I1 TO I2-1
1980 FOR M=K+1 TO I2
1990 IF D(K)<=D(M) THEN 2030
2000 R=D(K) @ Q=C1(K) @ P=C2(K)
2010 D(K)=D(M) @ C1(K)=C1(M) @ C2(K)=C2(M)
2020 D(M)=R @ C1(M)=Q @ C2(M)=P
2030 NEXT M @ NEXT K
2040 RETURN
2050 END
```

APPENDIX C: TRANSMISSOMETER CALIBRATION

Transmissometer Calibration

Transmissometers used to measure suspended sediment concentrations for this project were manufactured by Sea Tech, Inc. Five cm and 25 cm path length instruments were used. Calibration was accomplished using the following experimental procedure.

A 275 gallon cylindrical plastic container was filled with filtered sea water. An electric propellor mixer was affixed to the container. Following air and clean water calibrations, a known quantity of spoil material, (obtained from the dredge hopper), was introduced into the container and allowed to mix completely. Voltage readings were then recorded for each of the six instruments undergoing calibration. This procedure was repeated until the voltage range of the instrument was covered. Results are plotted on a semilog graph, voltage being the logarithmic axis. Figure C-1 is a typical plot, with a least squares fitted straight line superimposed over data points.

Loss of light from a monochromatic beam is due to scattering and absorption caused by the water and the suspended solids. It can be shown* that the loss of light may be predicted by

$$\frac{I(z)}{I(0)} = \exp-(c_w + Vc_p^*)\ z$$

---

* Sea Tech, Inc. Transmissometer owners' manual, Corvallis, OR.

$I(z)$ = transmitted voltage @ radius = z

z = path length

$I(0)$ = transmitted voltage in air

C_w = beam attenuation coefficient of water

C_p^* = beam attenuation coefficient of particulate matter under consideration

V = volume concentration of suspended material

taking the log of both sides,

$$\ln I(z) - \ln I(o) = (-C_w - Vc_p^*)\, z.$$

or

$$\ln I(z) = \ln I(o) - C_w z - Vc_p^*\, z.$$

Since $I(o)$ and z are constant characteristics of the transmissometer, C_w is a constant, and C_p^* is constant for a given homogeneous material, let

$$\ln I(0) - C_w a = B0 \text{ and } c_p^* z = B1 \text{ leaving}$$

$$\ln I(z) = B0 - B1V.$$

Hence the logarithm of the transmitted voltage is a linear function of the volume concentration. Typical calibration curves are shown in

Figures C-1 and C-2 where B0 and B1 are caluclated from a least squares fit to the experimental data. Table C-1 is a compilation of the various constants for all transmissometers calibrated.

Table C-1

Summary of transmissometer of calibration constants:

	ID #	BO	B1 $x10^2$	z cm	I(o) (air) volts	Cw $x10^2$	Cp* $x10^2$
SN	82	1.602	1.378	5	4.67	-1.22	.276
	83	1.606	1.367	5	4.71	-1.13	.273
	84	1.720	6.872	25	4.56	-.81	.275
	85	1.638	1.364	5	4.76	1.56	.273
	88	1.605	1.365	5	4.62	-1.49	.273
	98	1.714	6.905	25	4.63	-.73	.276
$\bar{x}$	25cm	1.717	6.889		4.60	.77	.276
$\bar{x}$	5cm	1.613	1.369		4.69	1.35	.274
s	25cm	.004	$2.3x10^{-2}$		.05	.06	.0007
s	5cm	.017	$6.4x10^{-3}$		.06	.21	.0015

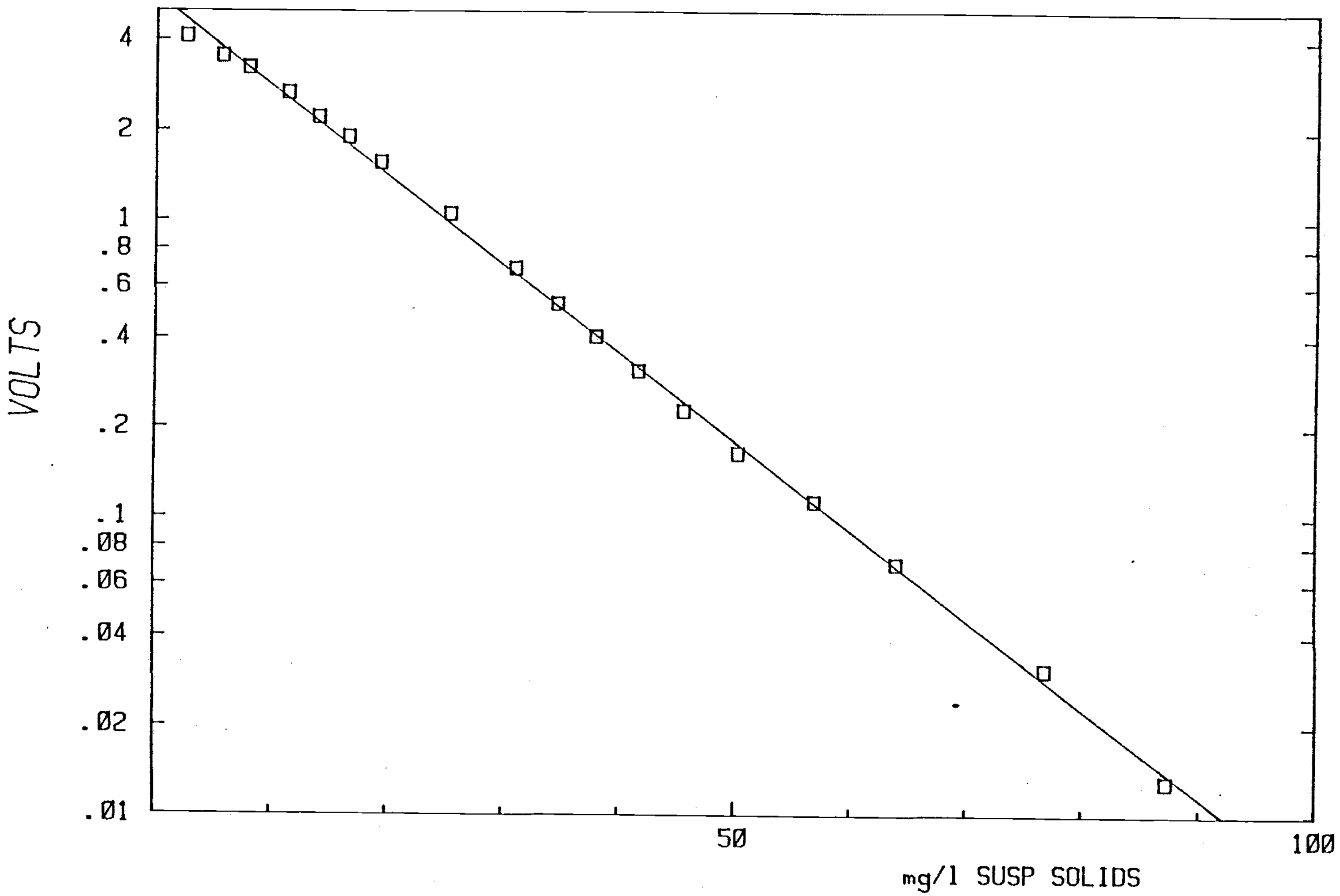


Figure C-1 Calibration curve for #SN-84

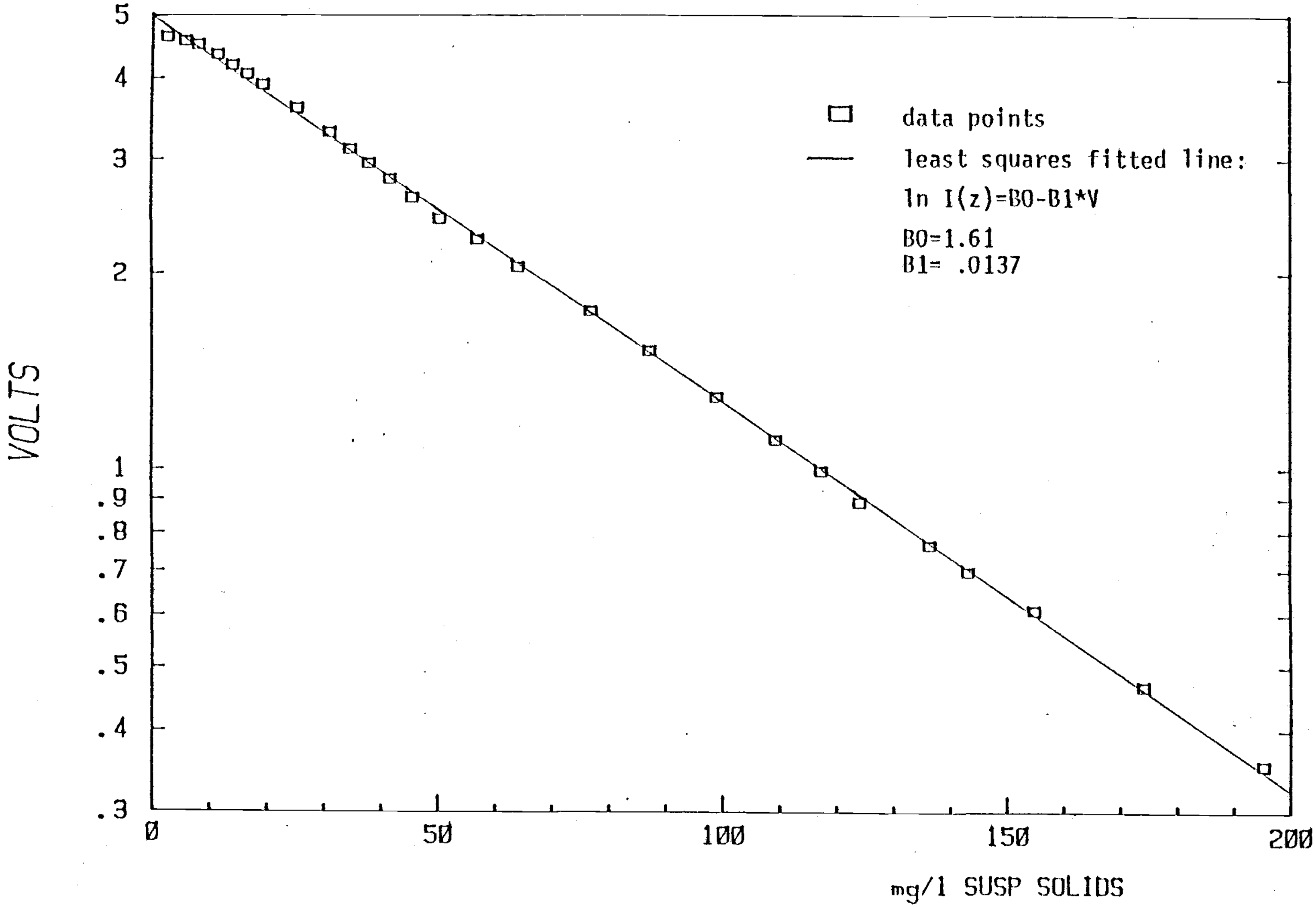
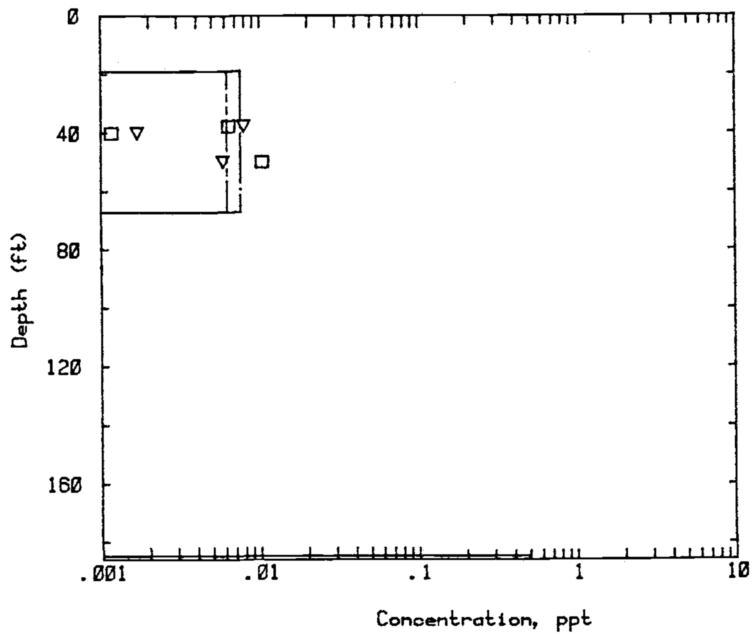


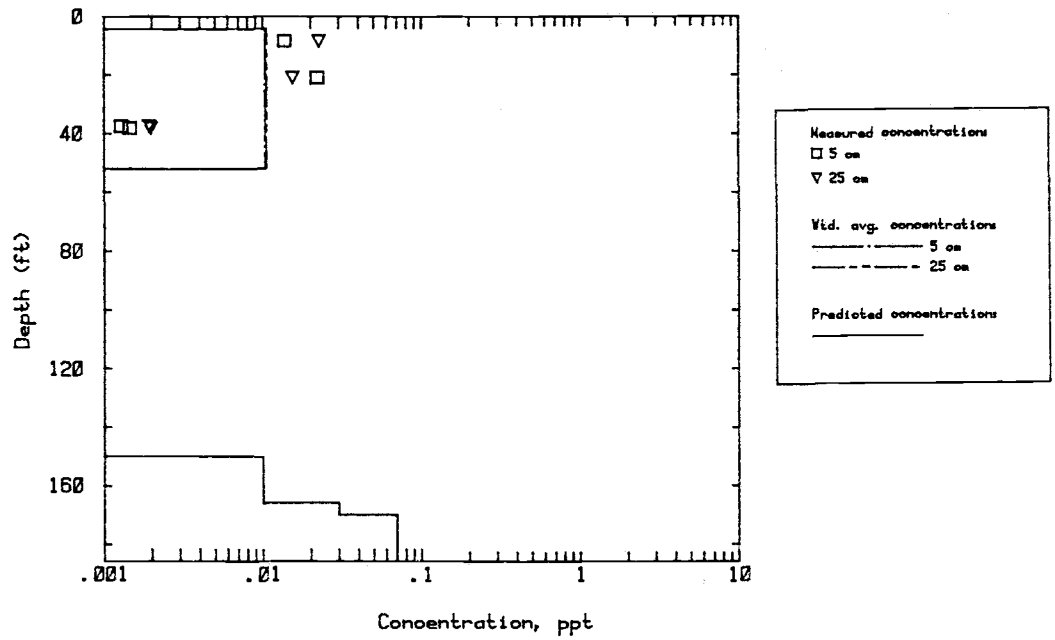
Figure C-2 Calibration Curve for #SN-88

APPENDIX D

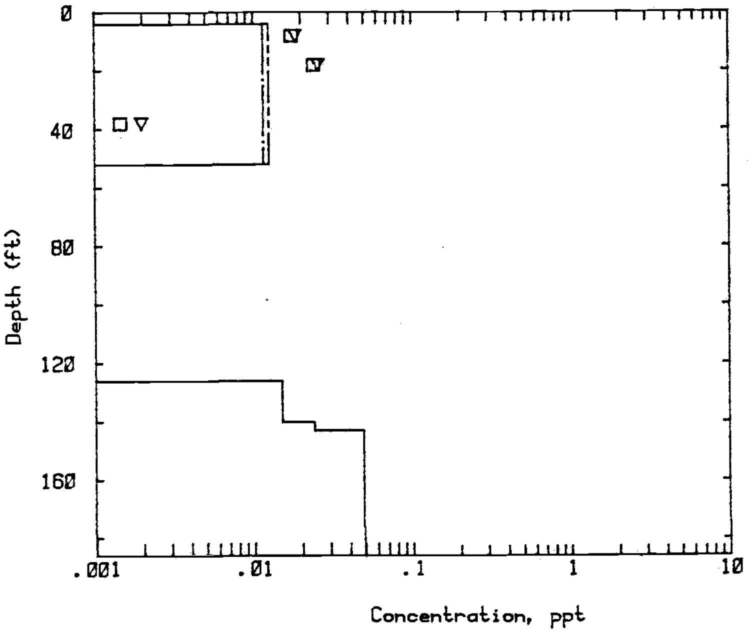
PREDICTED CONCENTRATION PROFILES AT TRANSECT LOCATIONS PLOTTED WITH MEASURED TRANSECT DATA AND WEIGHTED AVERAGE PROFILES



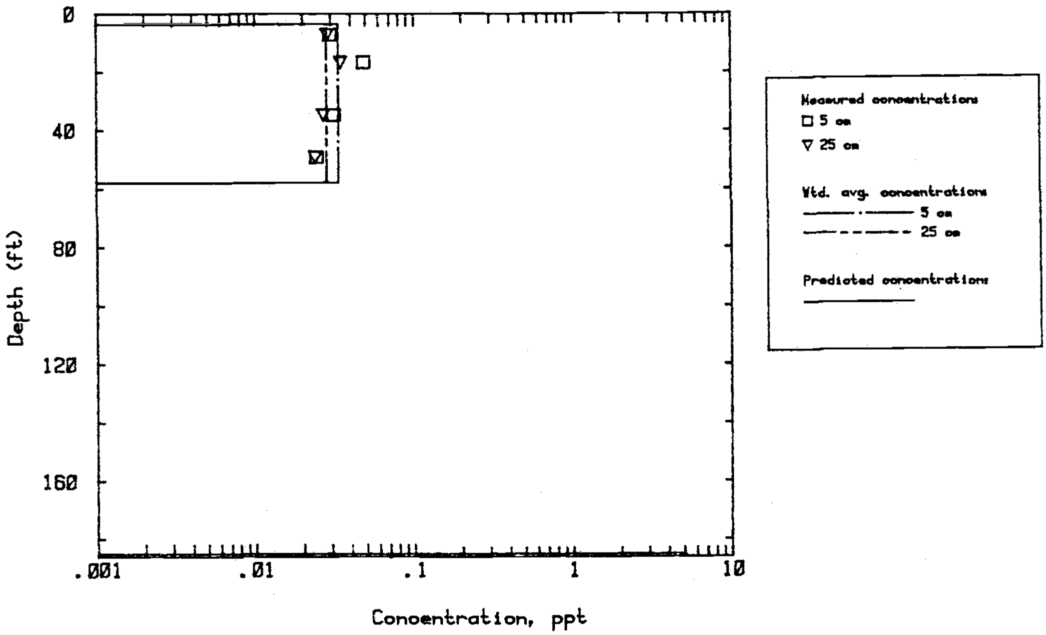
8/13/81A: Predicted vs. measured concentration profiles: profile 2.



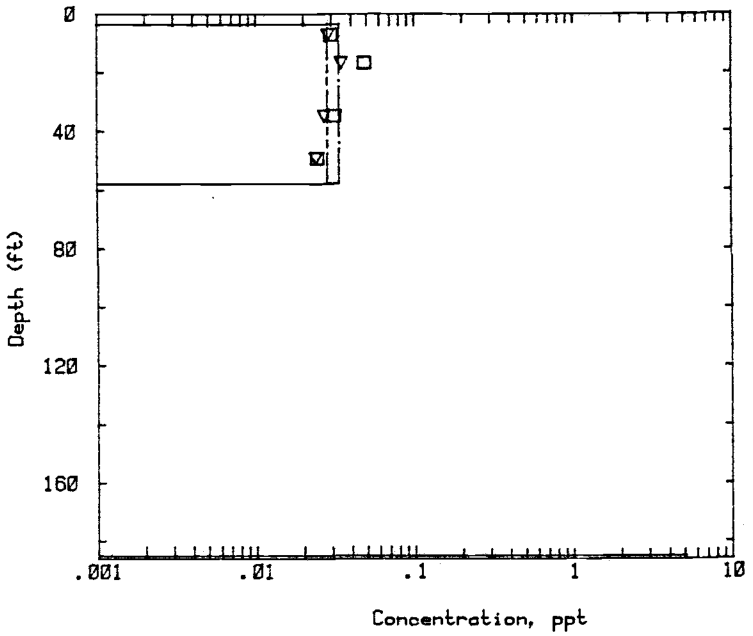
8/13/81B: Predicted vs. measured concentration profiles: profile 1.



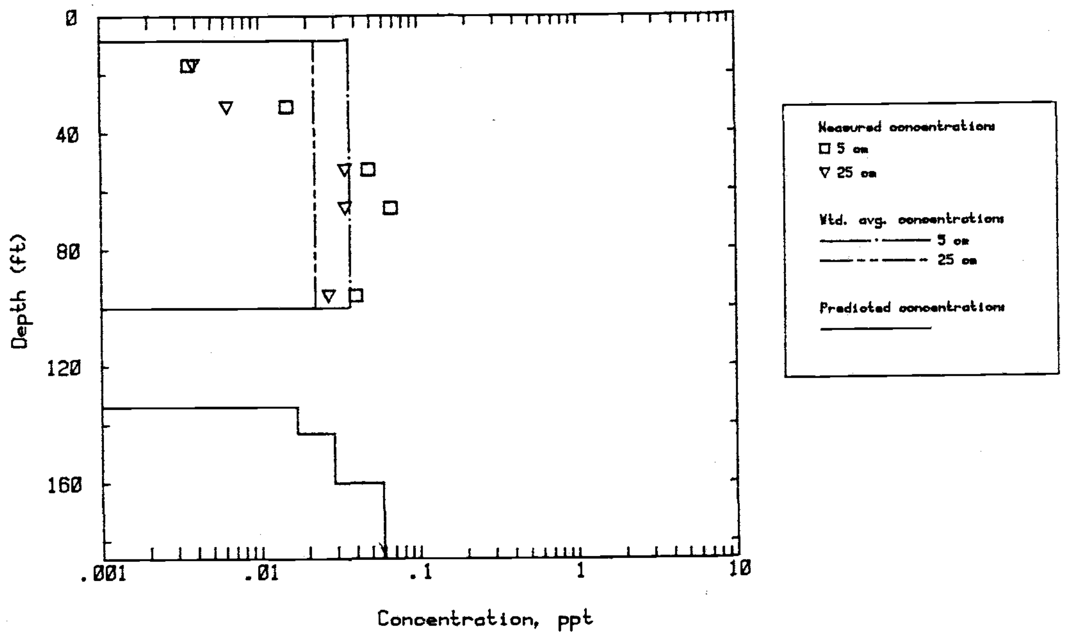
8/13/81B: Predicted vs. measured concentration profiles: profile 2.



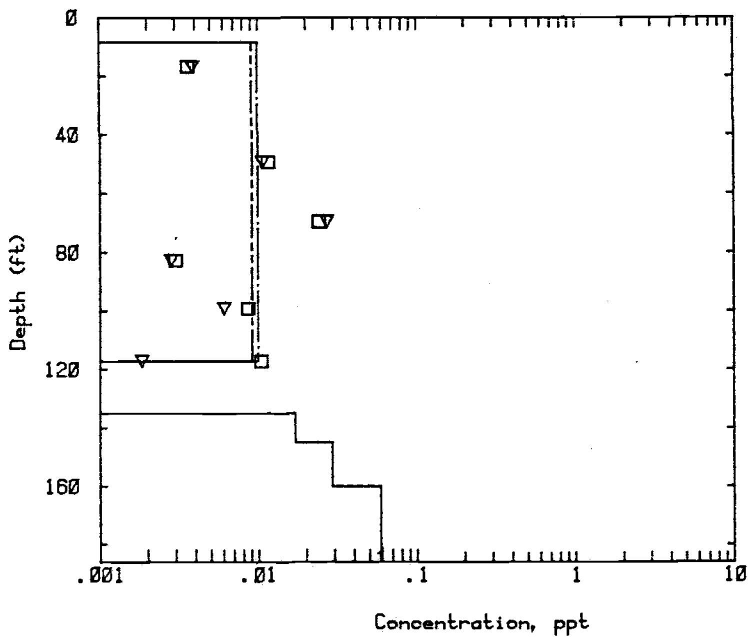
8/15/81A: Predicted vs. measured concentration profiles: profile 1.



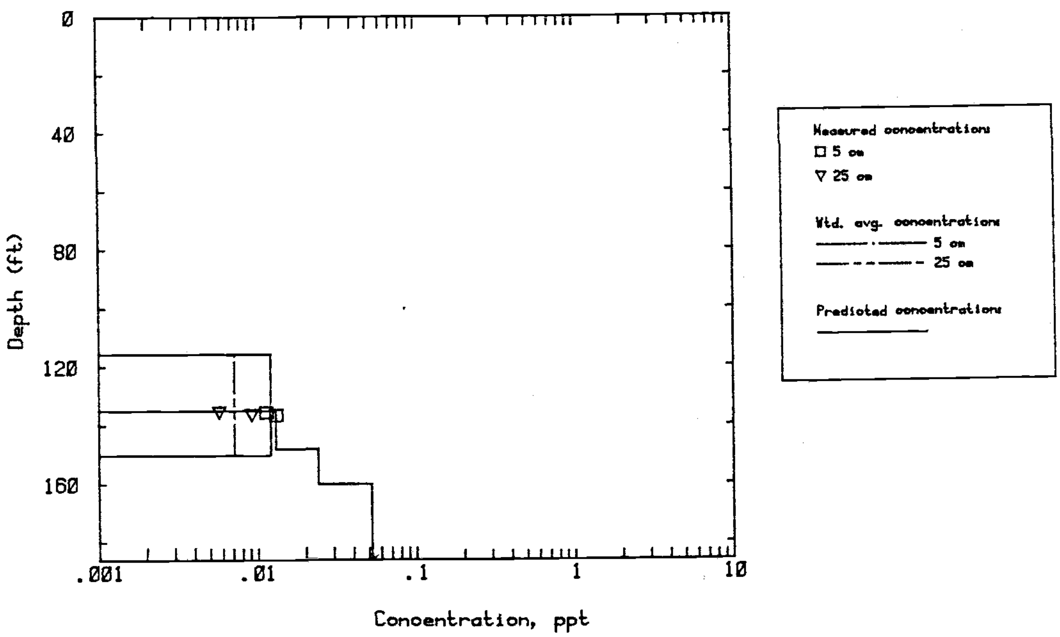
8/15/81A: Predicted vs. measured concentration profiles: profile 1.



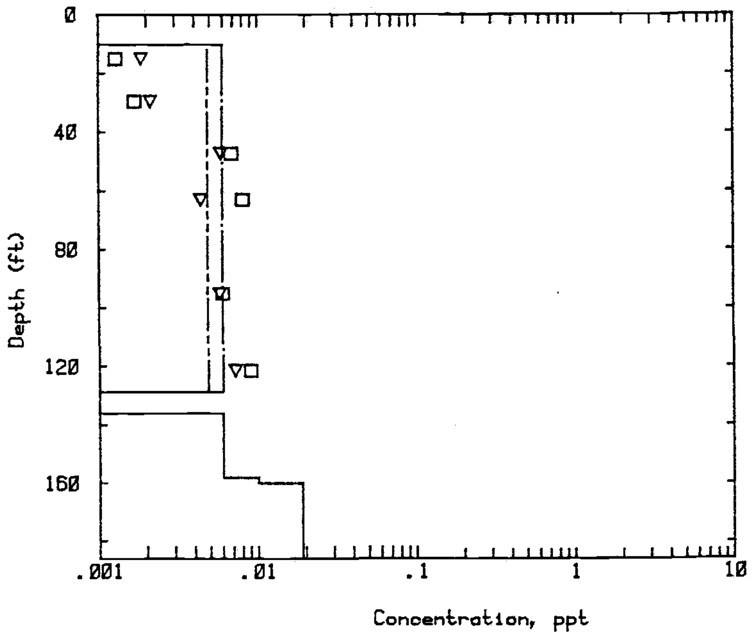
8/17/81B: Predicted vs. measured concentration profiles: profile 1.



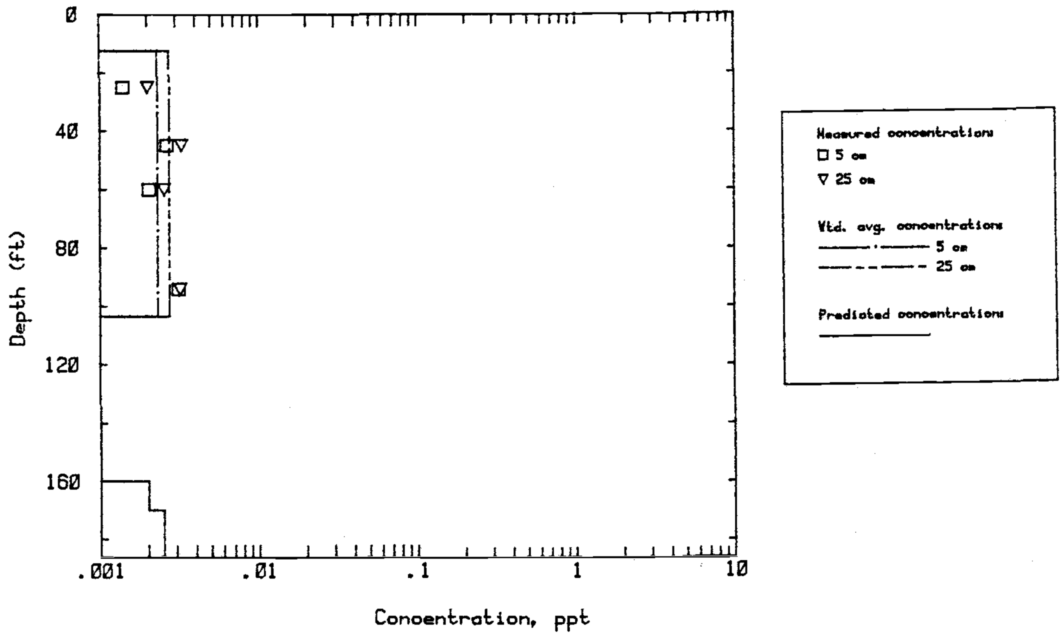
8/17/81B: Predicted vs. measured concentration profiles: profile 2.



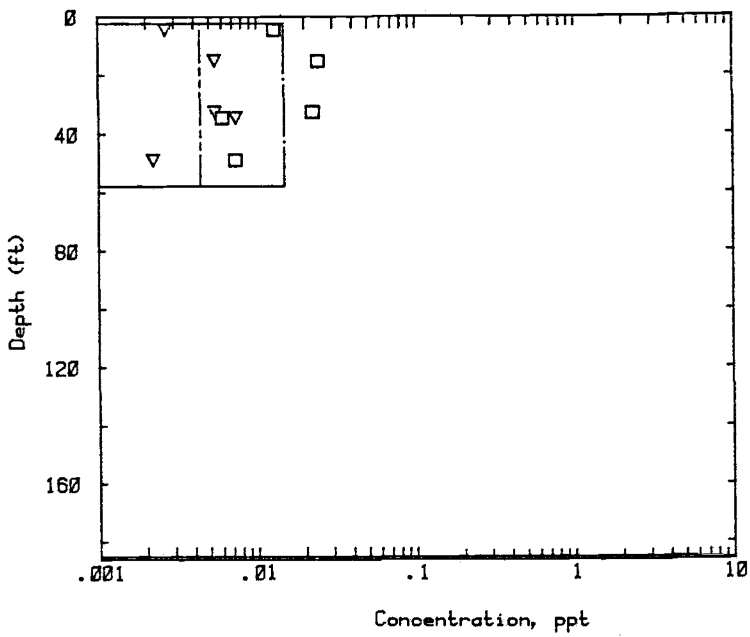
8/17/81B; Predicted vs. measured concentration profiles: profile 3.



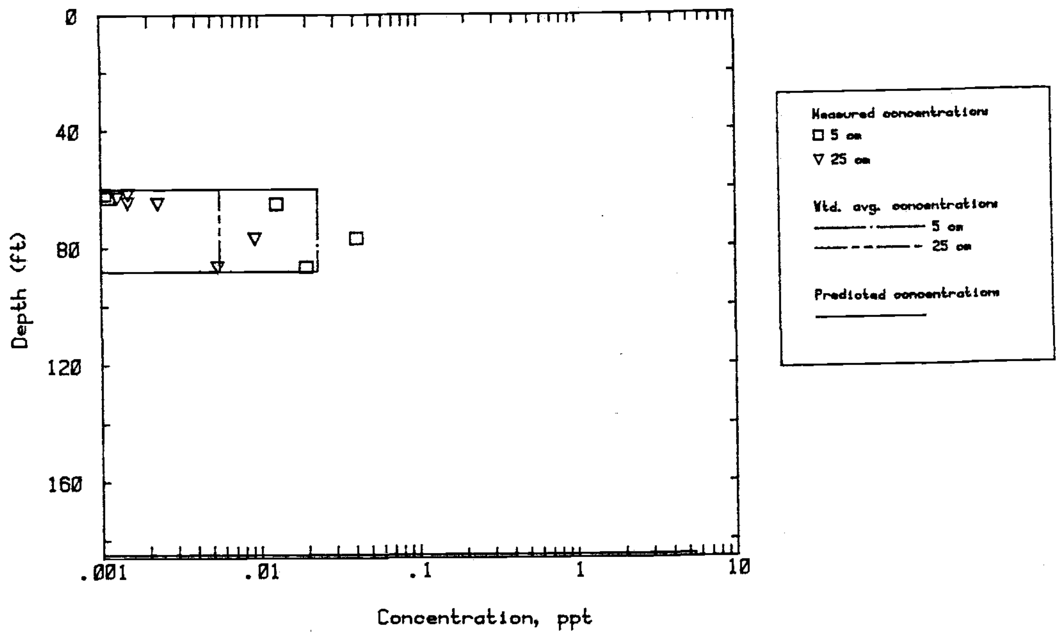
8/17/81B: Predicted vs. measured concentration profiles: profile 4.



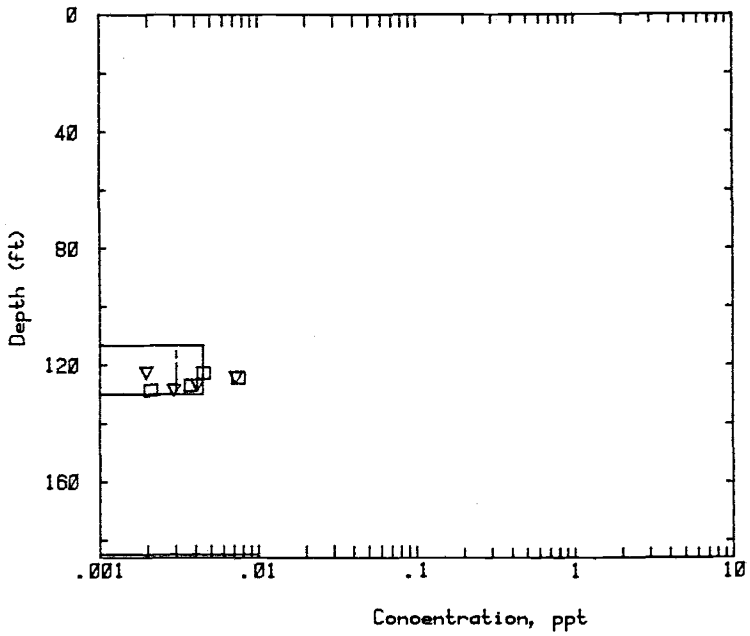
8/17/81B: Predicted vs. measured concentration profiles: profile 6.



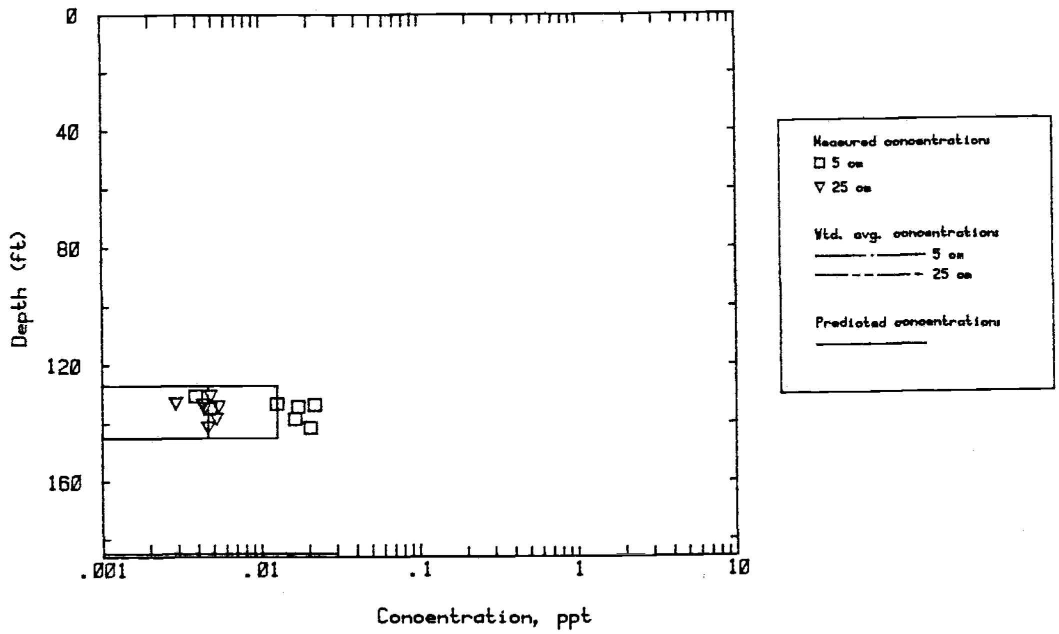
8/19/81A: Predicted vs. measured concentration profiles; profile 1.



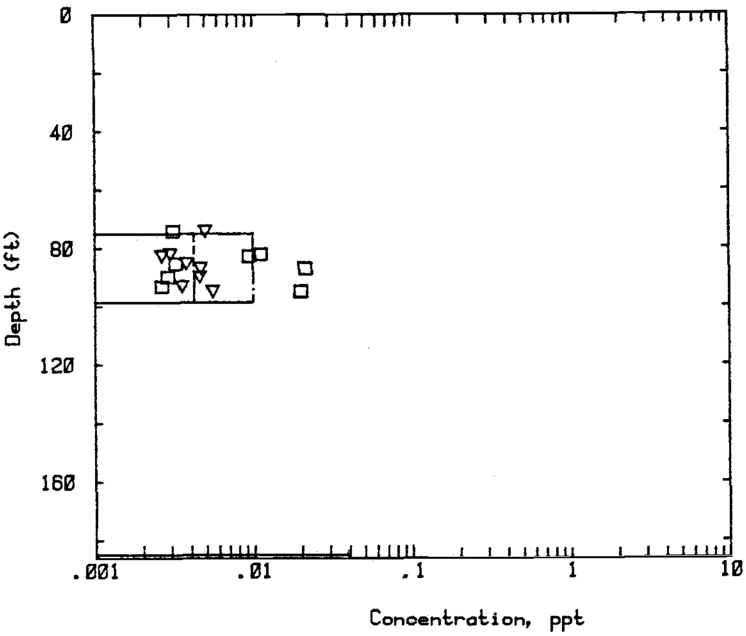
8/19/81A: Predicted vs. measured concentration profiles; profile 3.



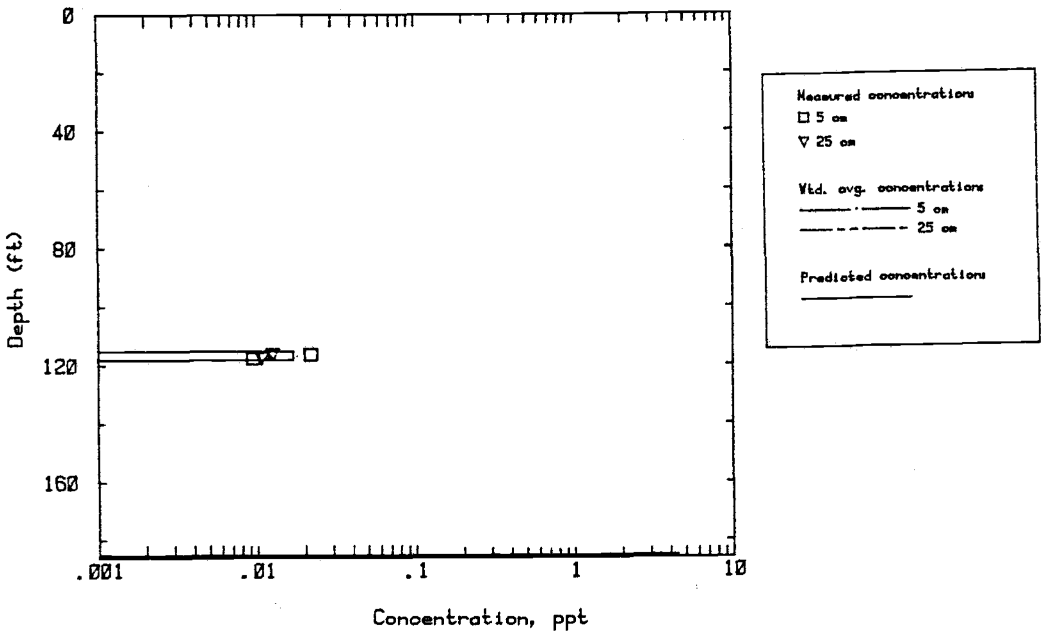
8/19/81A: Predicted vs. measured concentration profiles: profile 4.



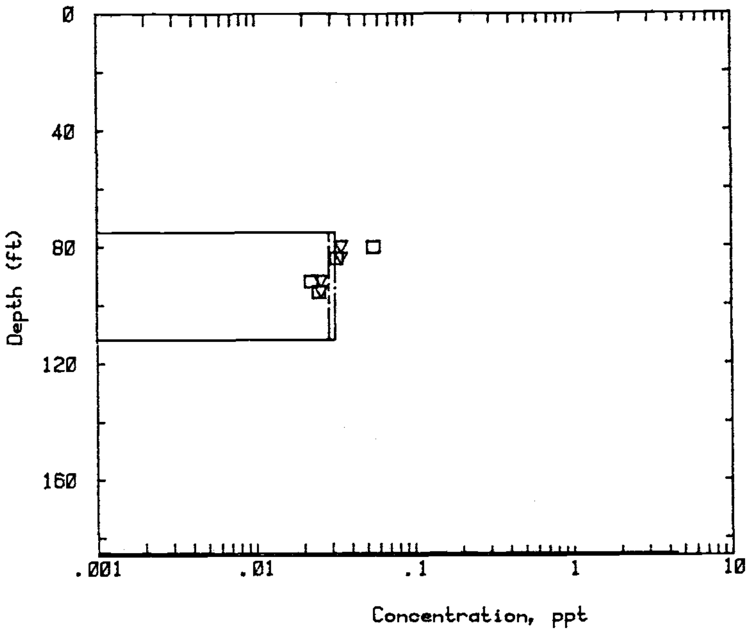
8/19/81A: Predicted vs. measured concentration profiles: profile 5.



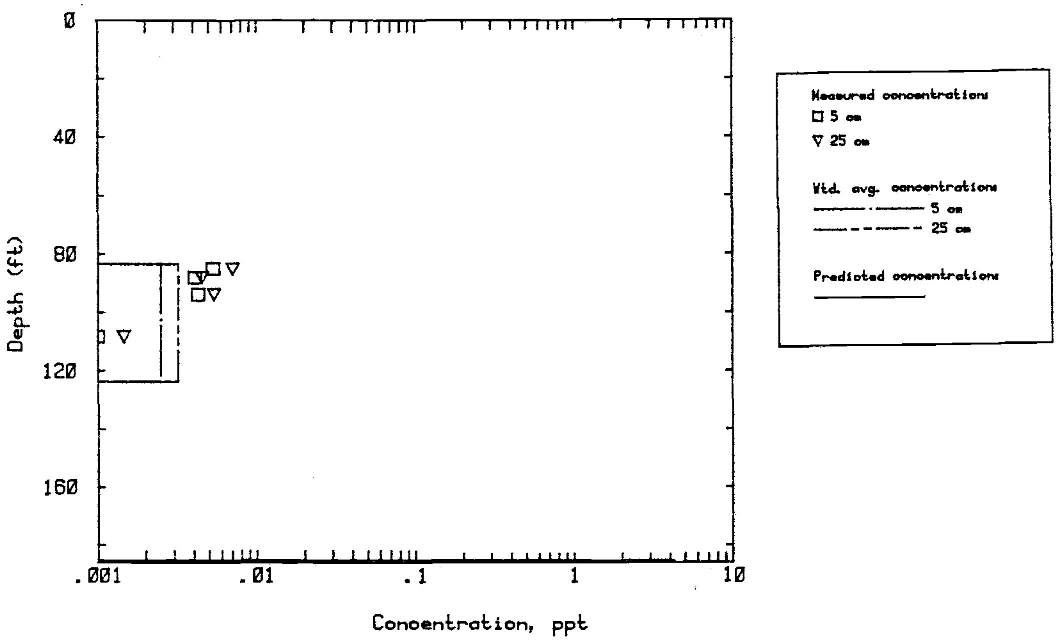
8/19/81A; Predicted vs. measured concentration profiles; profile 7.



8/19/81B; Predicted vs. measured concentration profiles; profile 1.



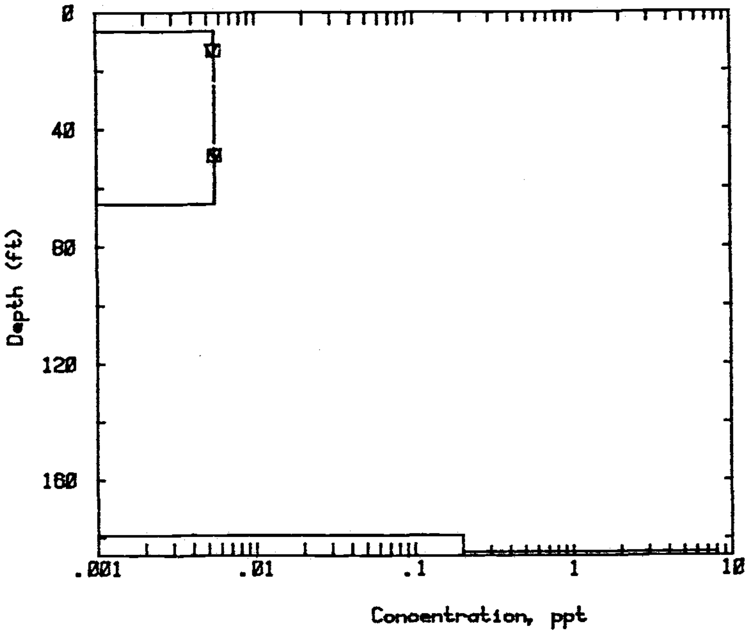
8/19/81B: Predicted vs. measured concentration profiles: profile 2.



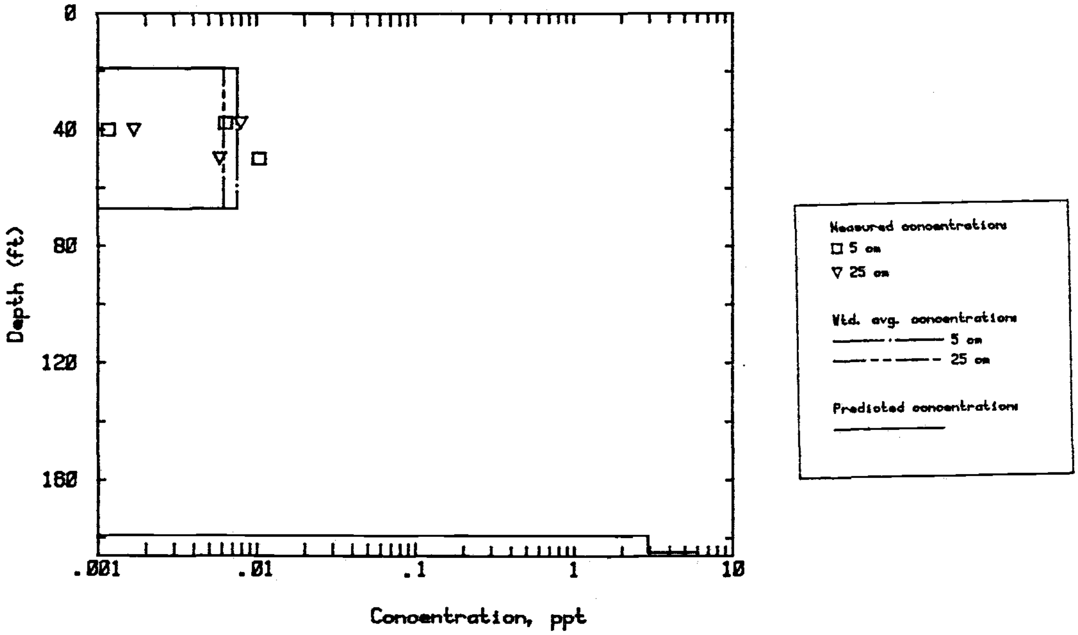
8/19/81B: Predicted vs. measured concentration profiles: profile 3.

APPENDIX E

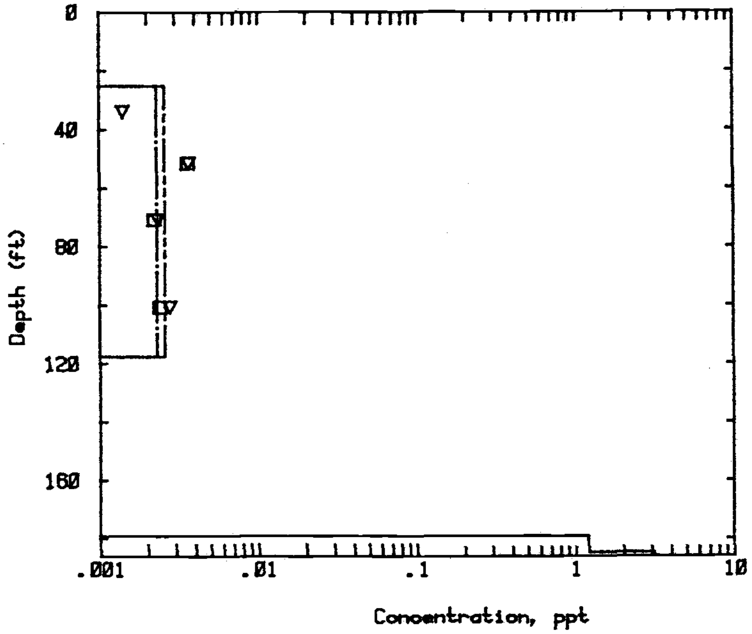
PREDICTED MAXIMUM CONCENTRATION PROFILES PLOTTED WITH MEASURED CONCENTRATION DATA AND WEIGHTED AVERAGE PROFILES



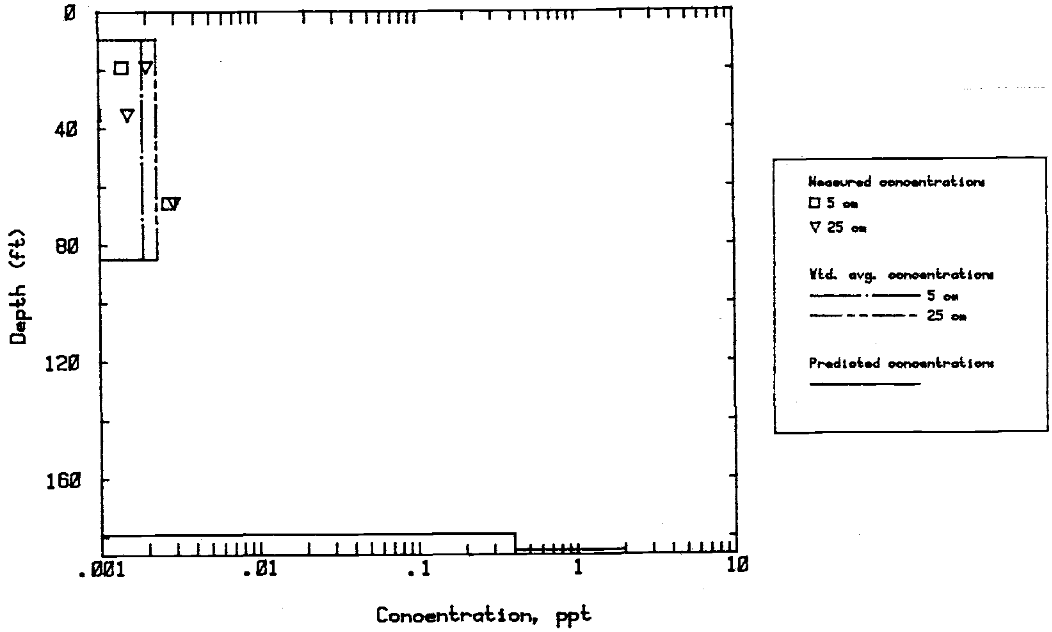
8/13/81A; Maximum predicted, and measured, concentration profiles; transect 1



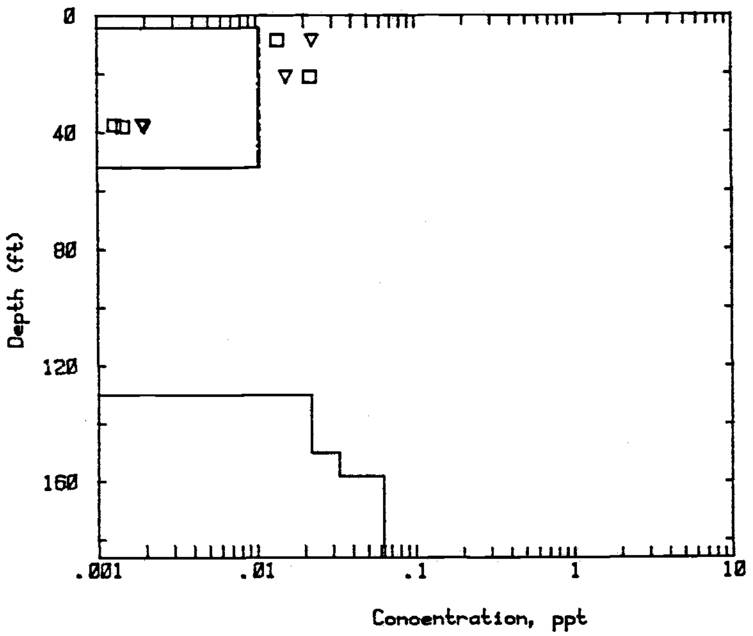
8/13/81A; Maximum predicted, and measured, concentration profiles; transect 2.



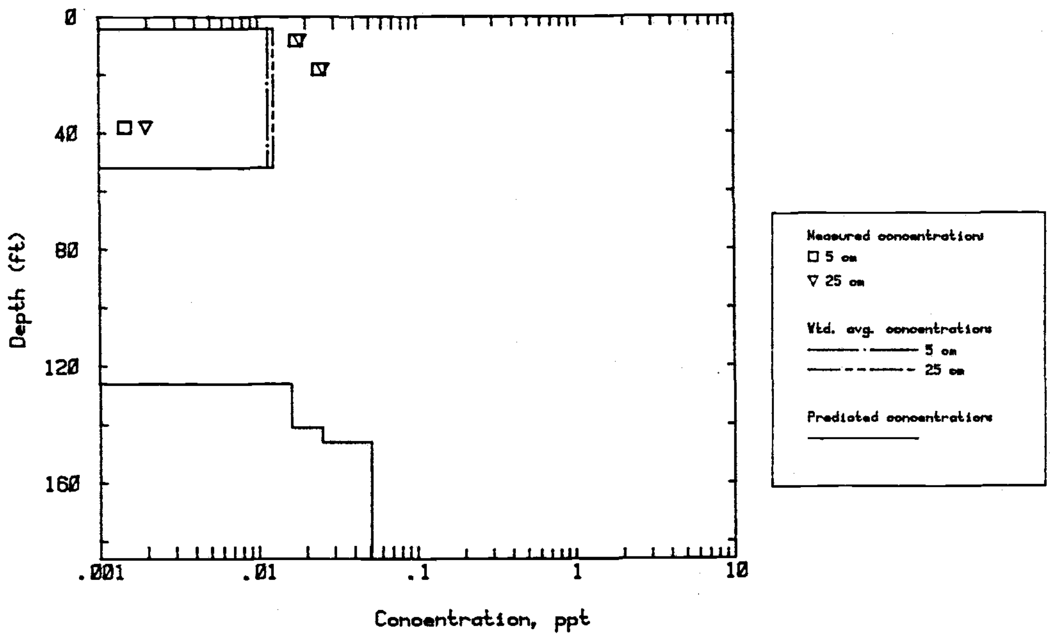
8/13/81A: Maximum predicted, and measured, concentration profiles: transect 3.



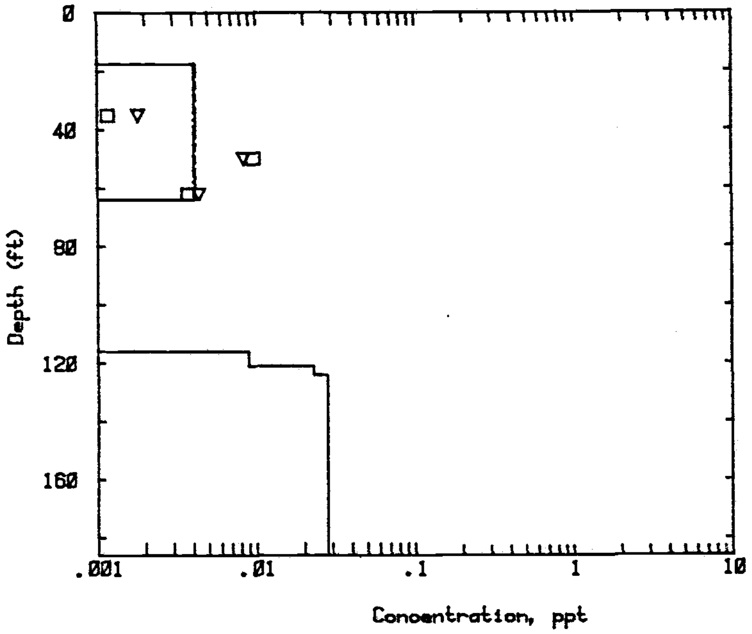
8/13/81A: Maximum predicted, and measured, concentration profiles: transect 4.



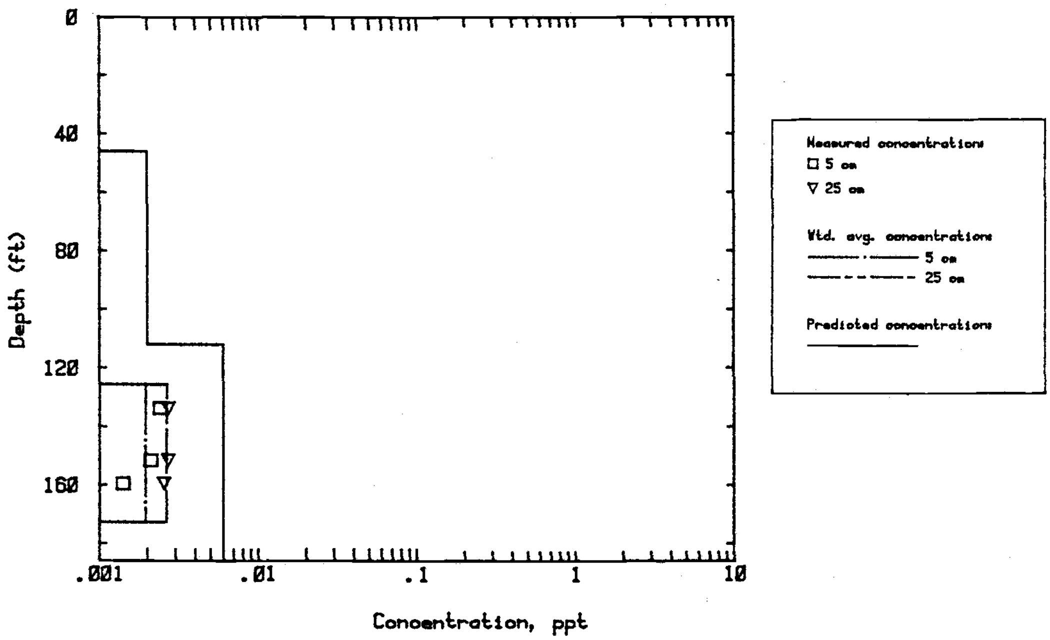
8/13/81B: Maximum predicted, and measured, concentration profiles: transect 1.



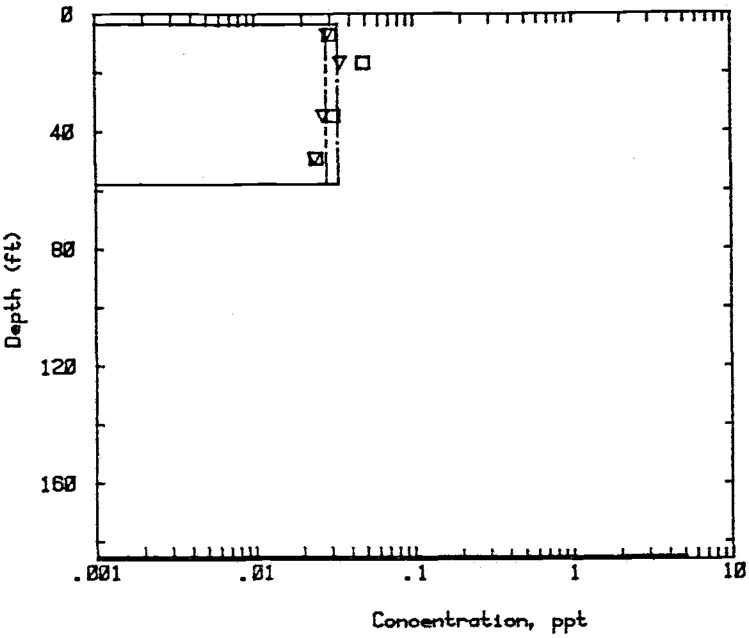
8/13/81B: Maximum predicted, and measured, concentration profiles: transect 2.



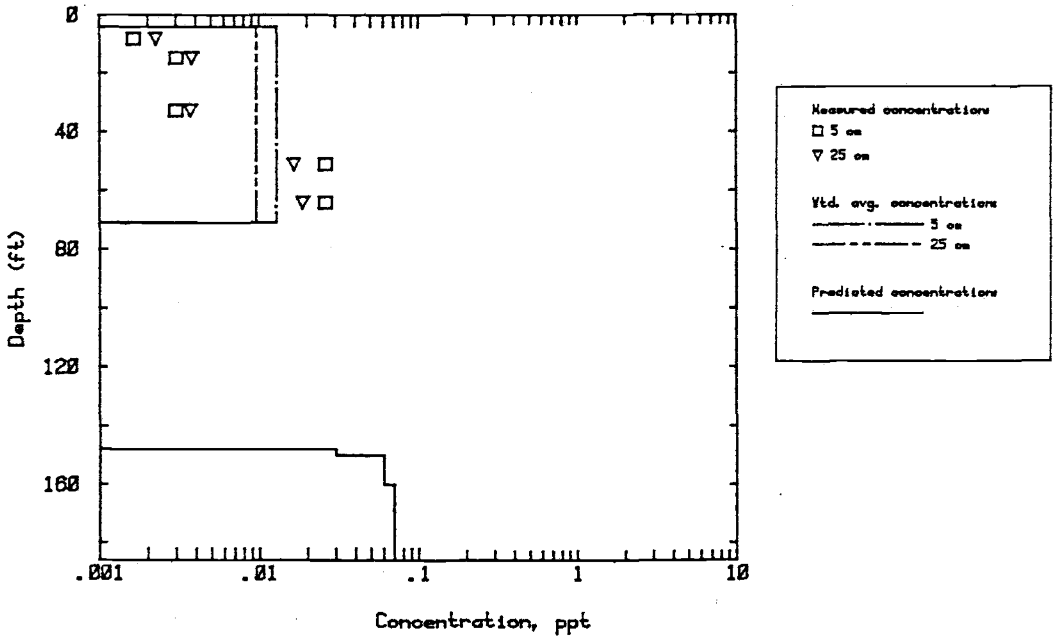
8/13/81B; Maximum predicted, and measured, concentration profiles; transect 3.



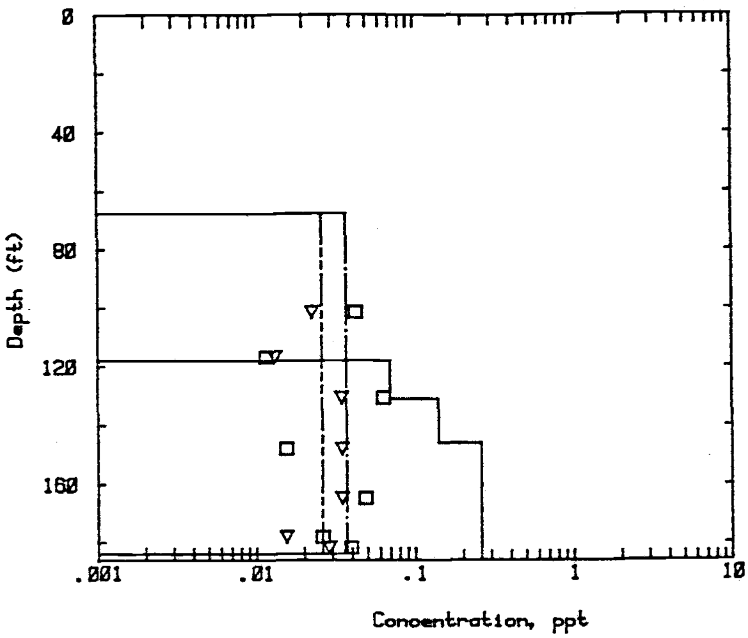
8/13/81B; Maximum predicted, and measured, concentration profiles; transect 4.



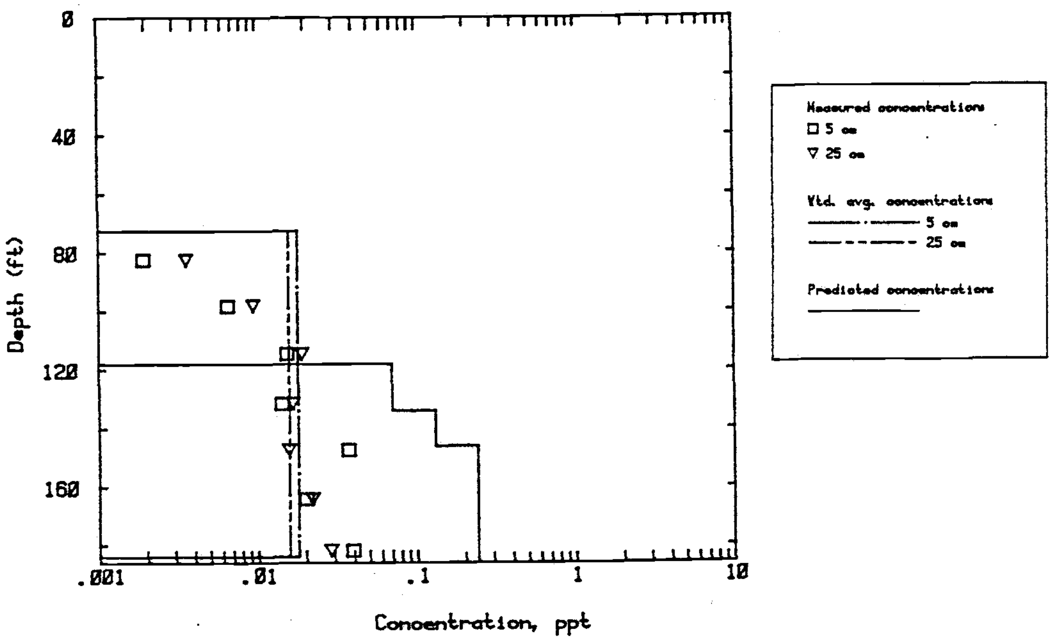
8/15/81A: Maximum predicted, and measured, concentration profiles: transect 1



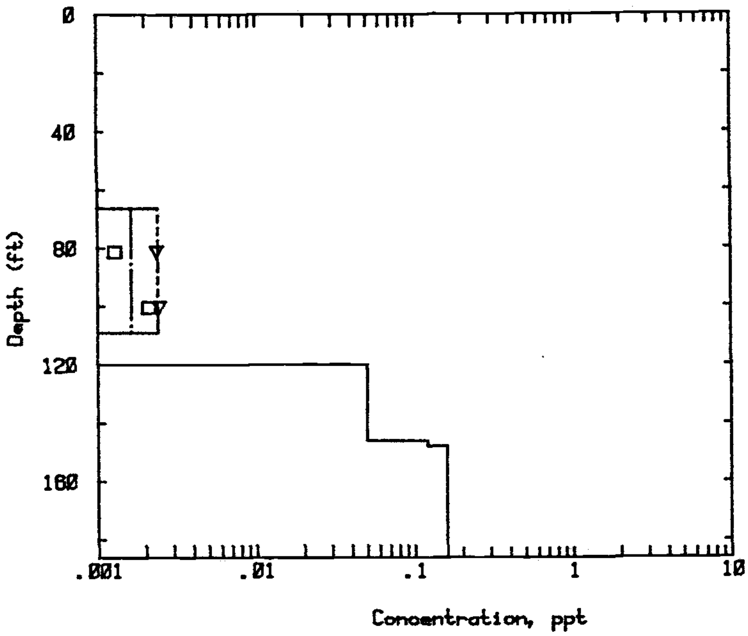
8/15/81A: Maximum predicted, and measured, concentration profiles: transect 2.



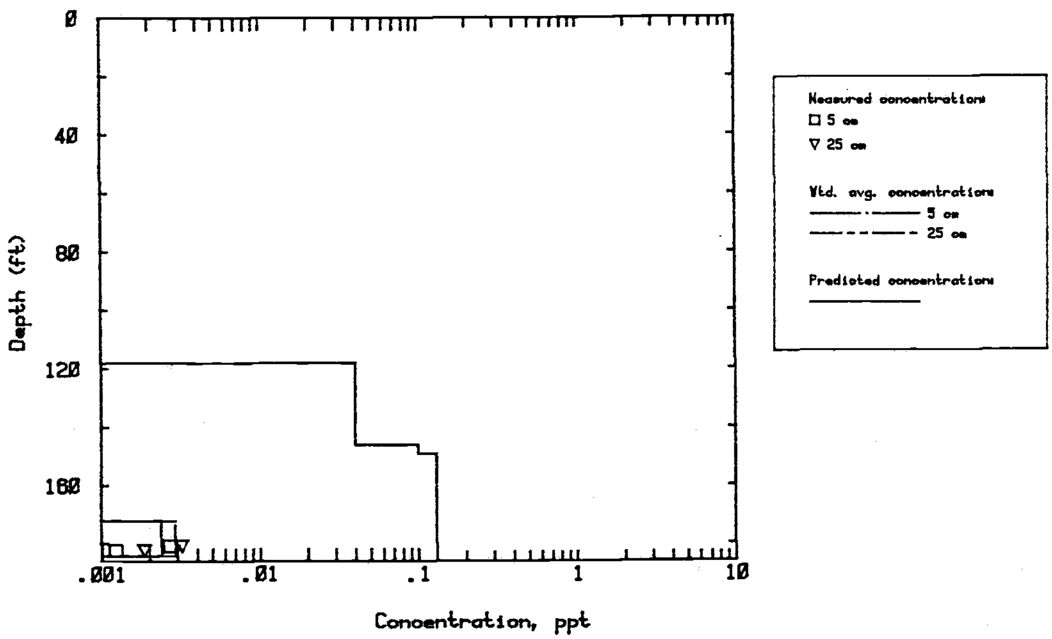
8/15/81B; Maximum predicted, and measured, concentration profiles; transect 1.



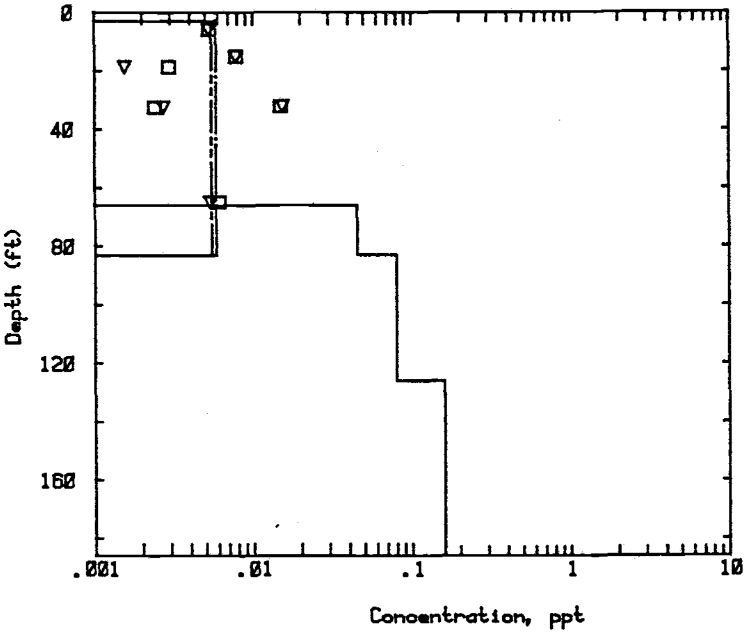
8/15/81B; Maximum predicted, and measured, concentration profiles; transect 2



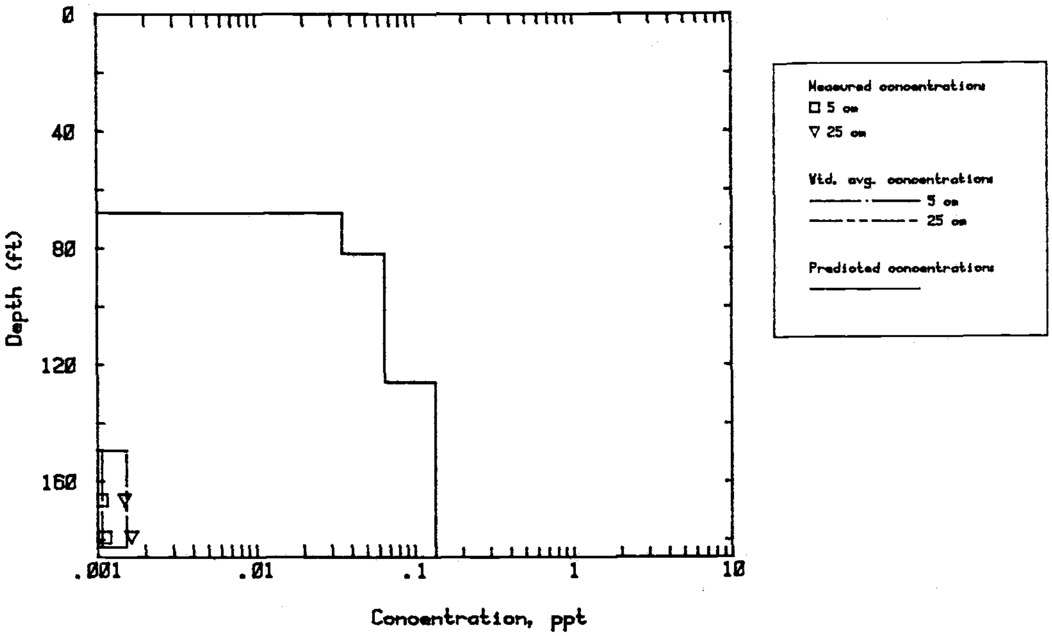
8/15/81B; Maximum predicted, and measured, concentration profiles; transect 3



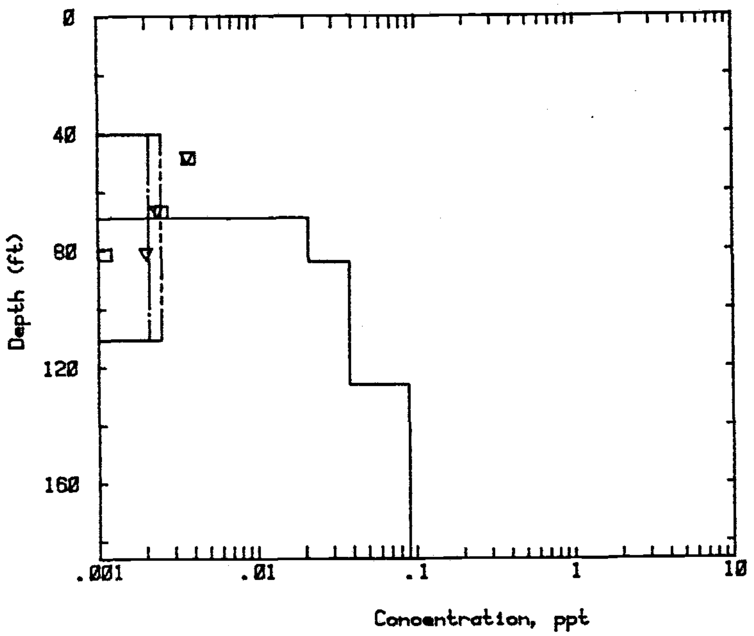
8/15/81B; Maximum predicted, and measured, concentration profiles; transect 4.



8/17/81A: Maximum predicted, and measured, concentration profiles: transect 1.



8/17/81A: Maximum predicted, and measured, concentration profiles: transect 2.



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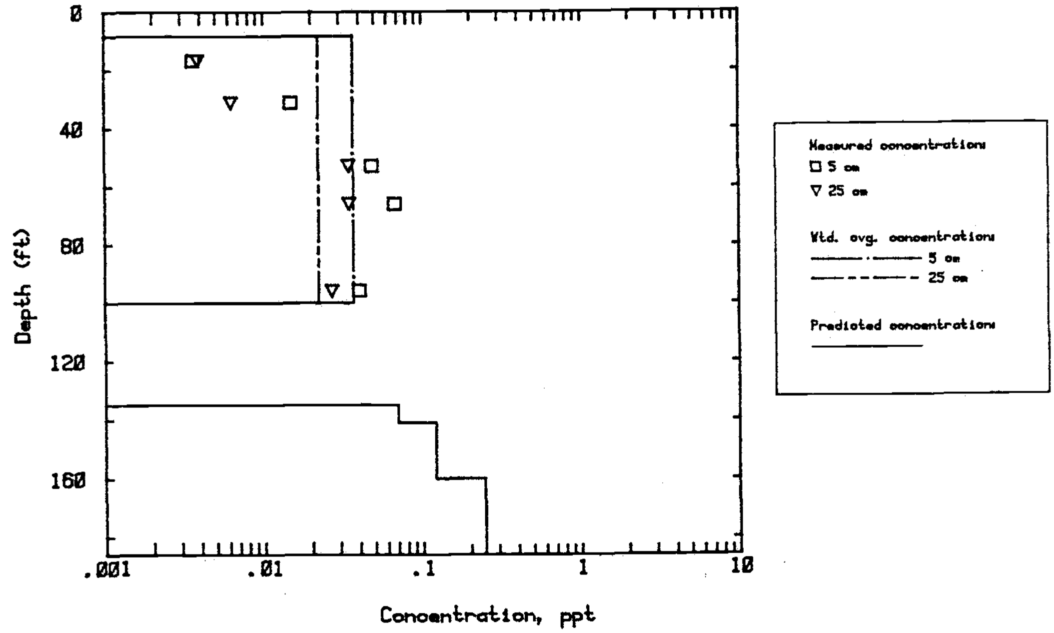
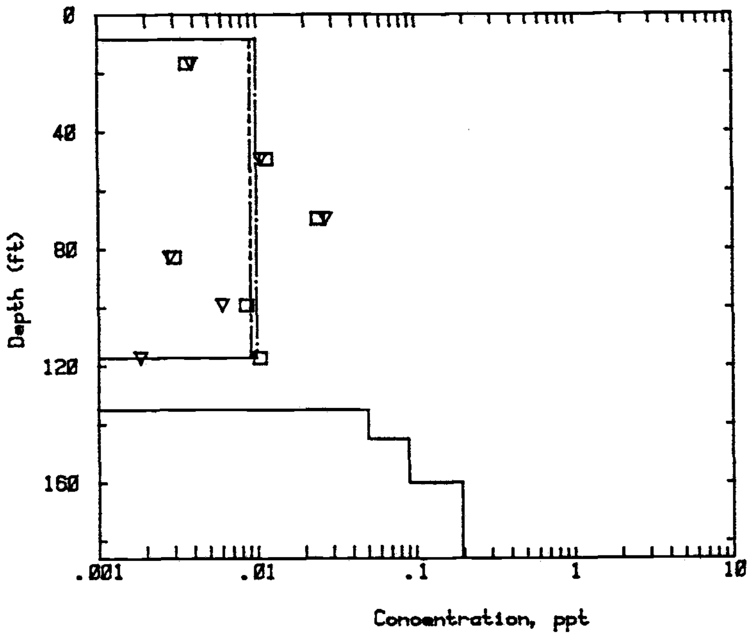
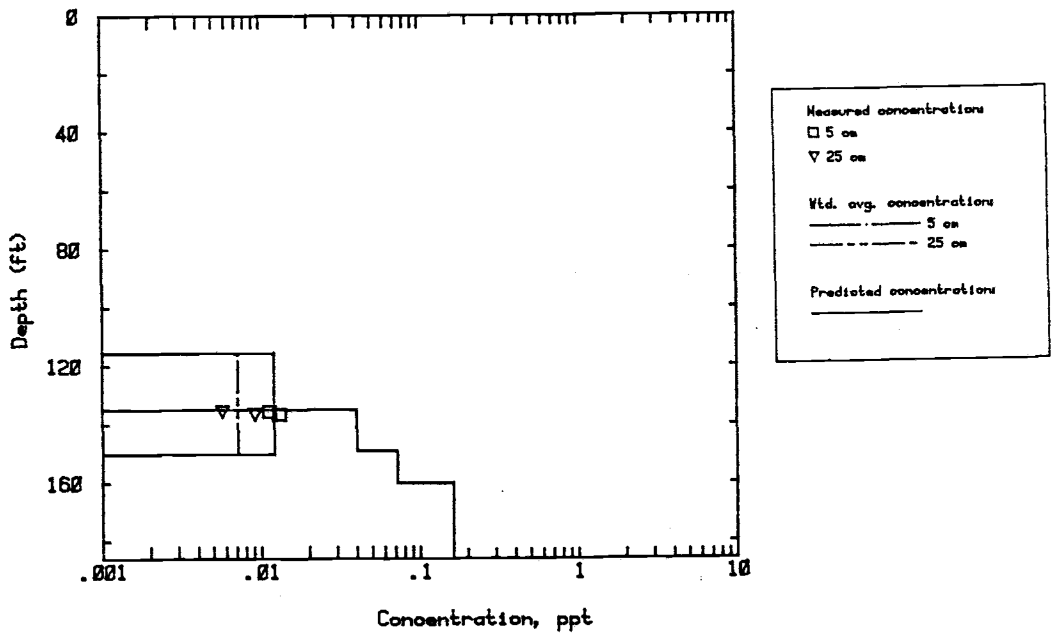


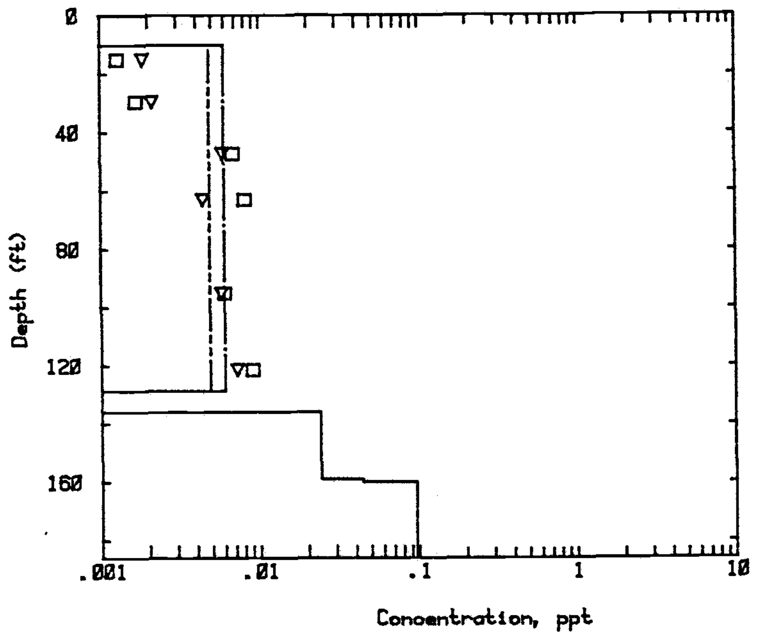
8/17/81B; Maximum predicted, and measured, concentration profiles; transect 1.



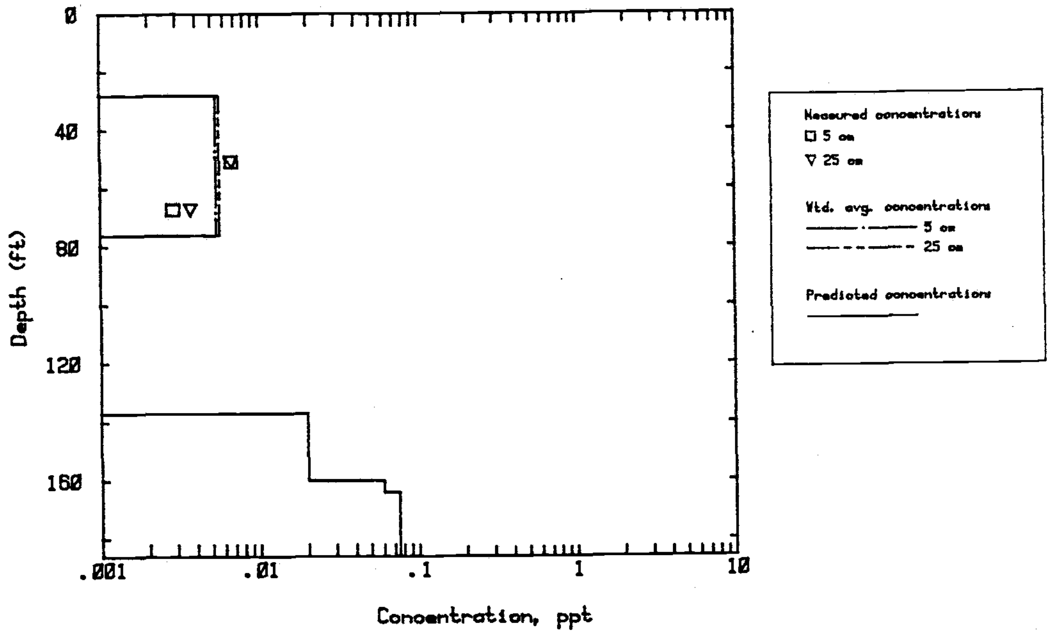
8/17/81B: Maximum predicted, and measured, concentration profiles: transect 2.



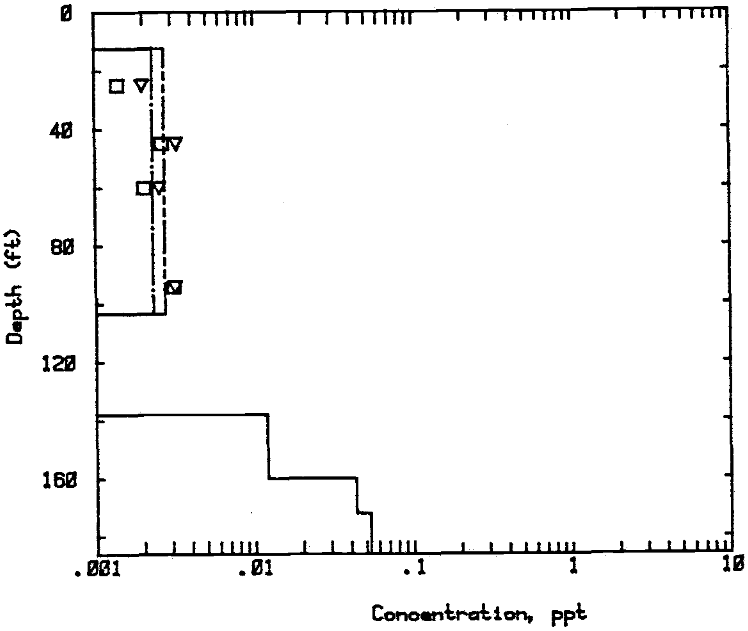
8/17/81B: Maximum predicted, and measured, concentration profiles: transect 3.



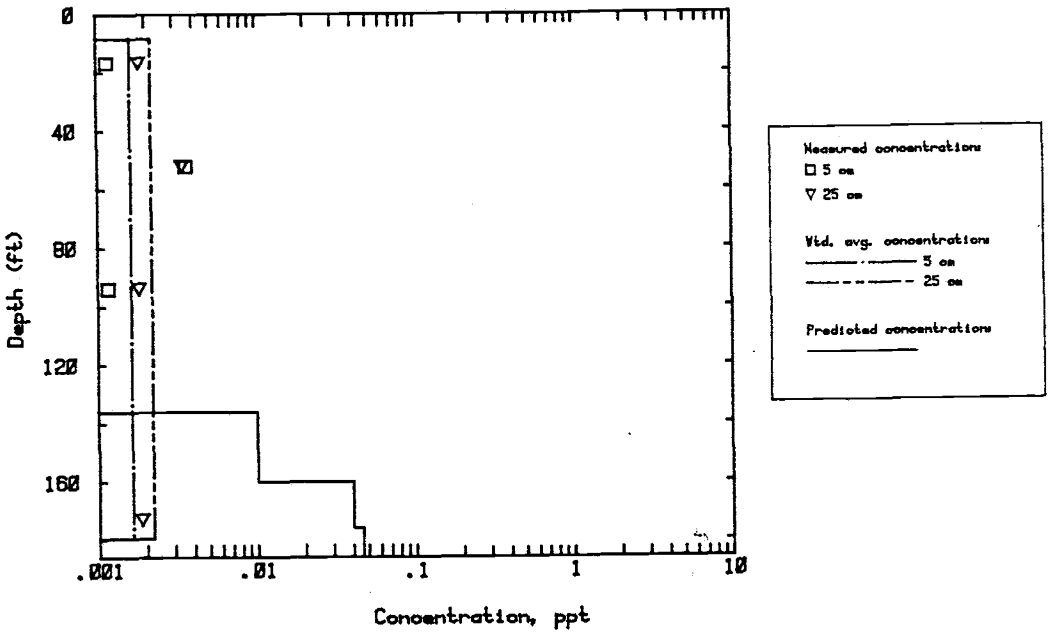
8/17/81B: Maximum predicted, and measured, concentration profiles: transect 4.



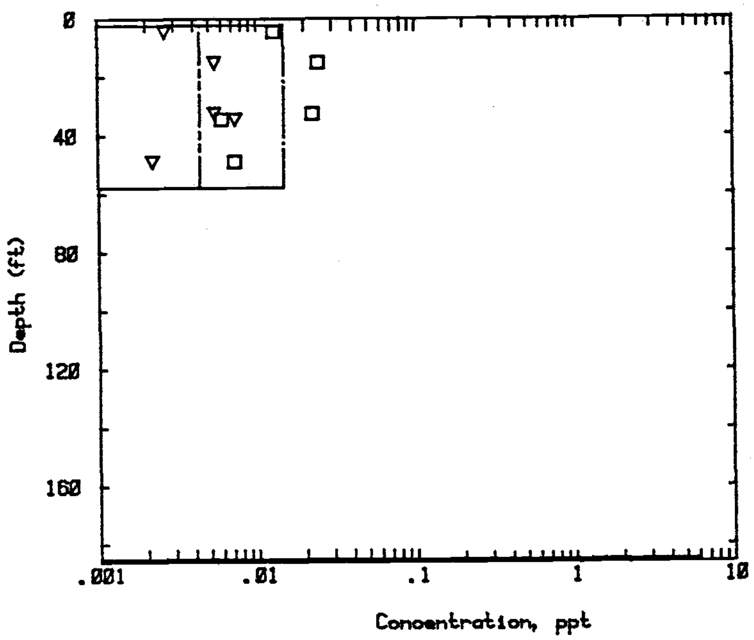
8/17/81B: Maximum predicted, and measured, concentration profiles: transect 5.



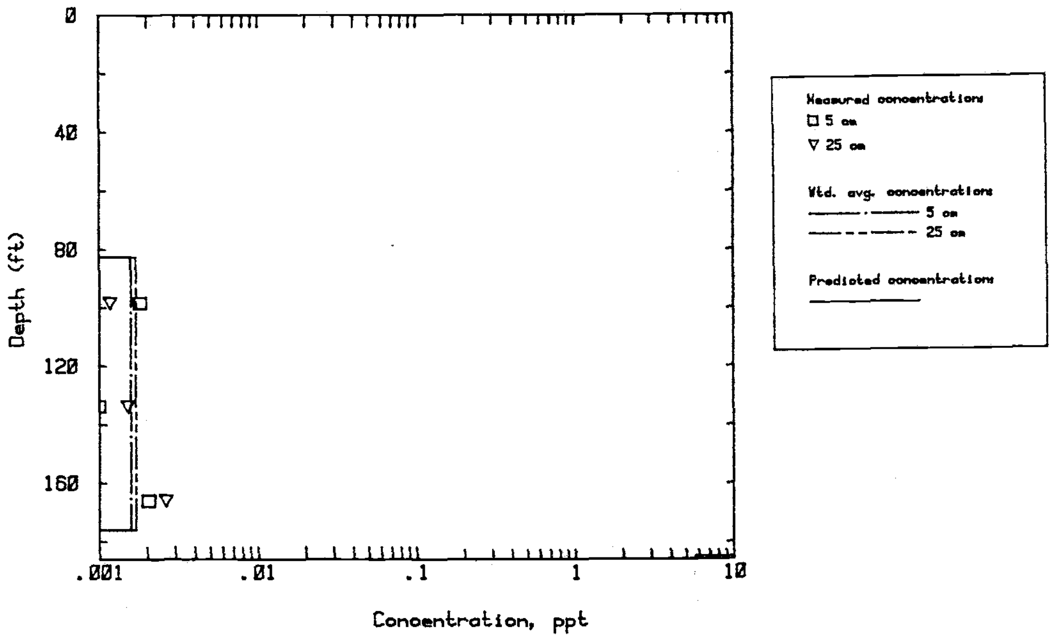
8/17/81B: Maximum predicted, and measured, concentration profiles: transect 6.



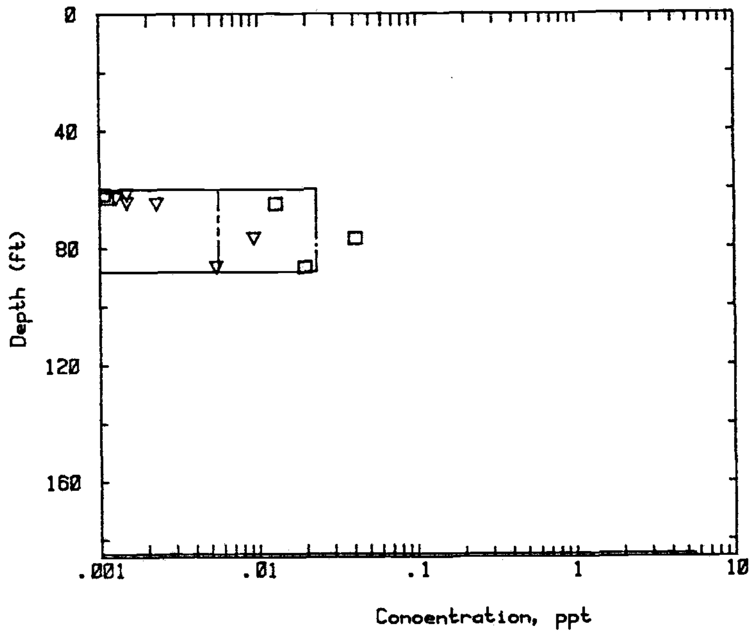
8/17/81B: Maximum predicted, and measured, concentration profiles: transect 7.



8/19/81A: Maximum predicted, and measured, concentration profiles: profile 1.



8/19/81A: Maximum predicted, and measured, concentration profiles: profile 2.



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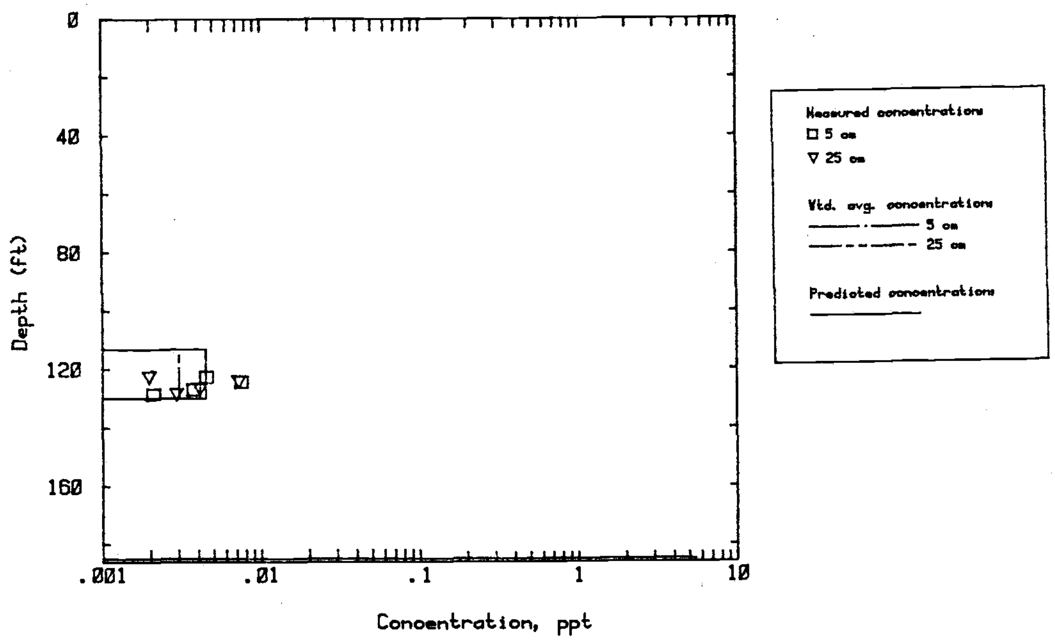
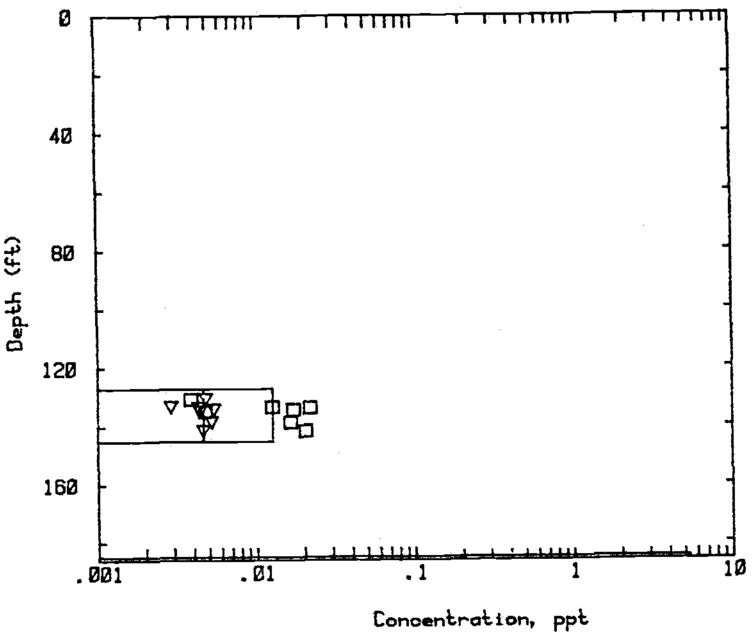
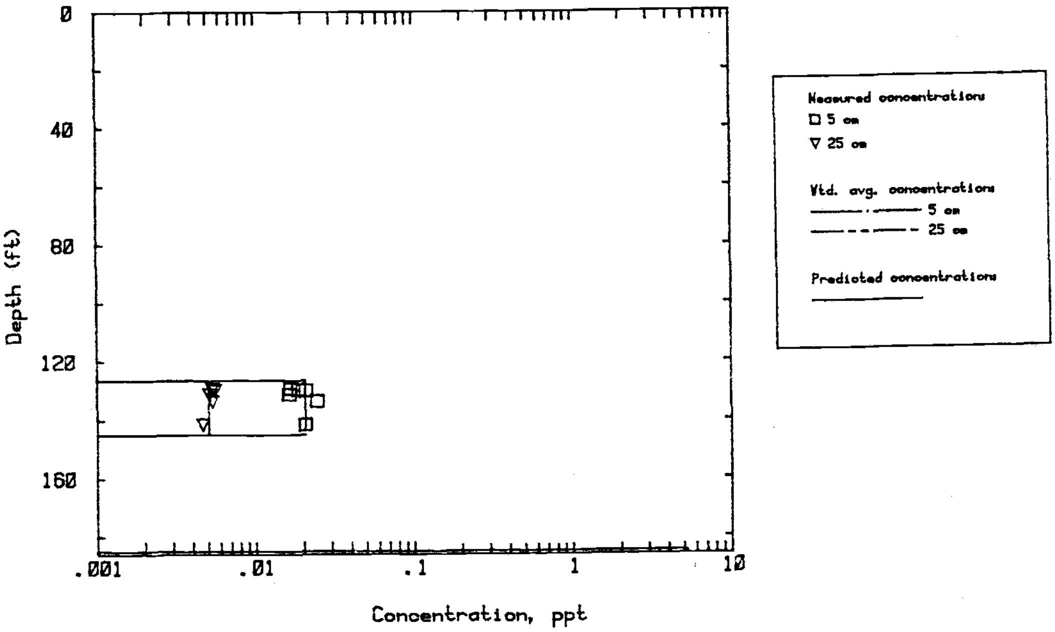


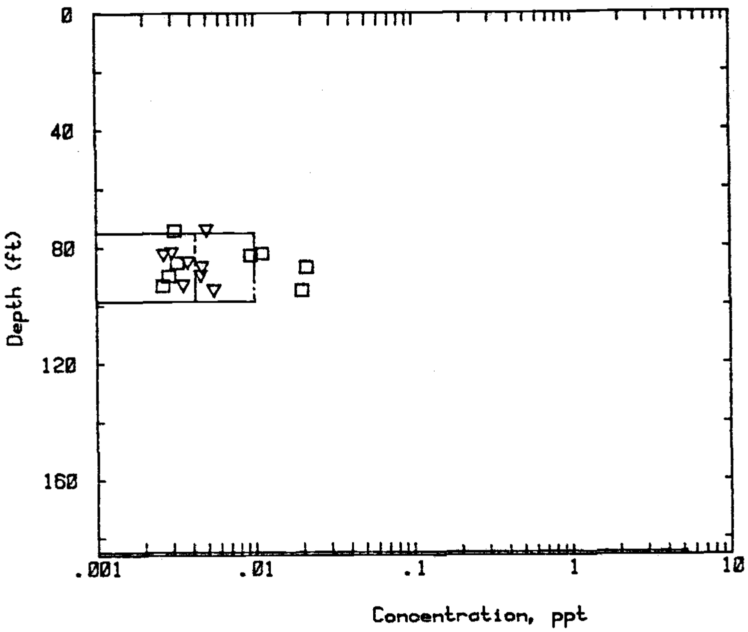
8/19/81A: Maximum predicted, and measured, concentration profiles: profile 4.



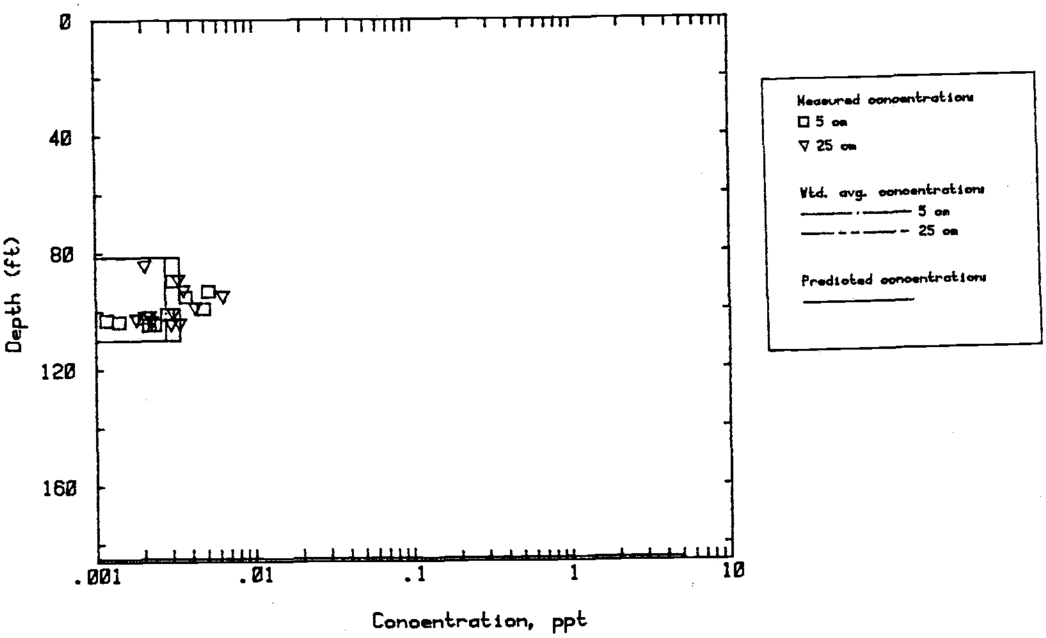
8/19/81A: Maximum predicted, and measured, concentration profiles: profile 5.



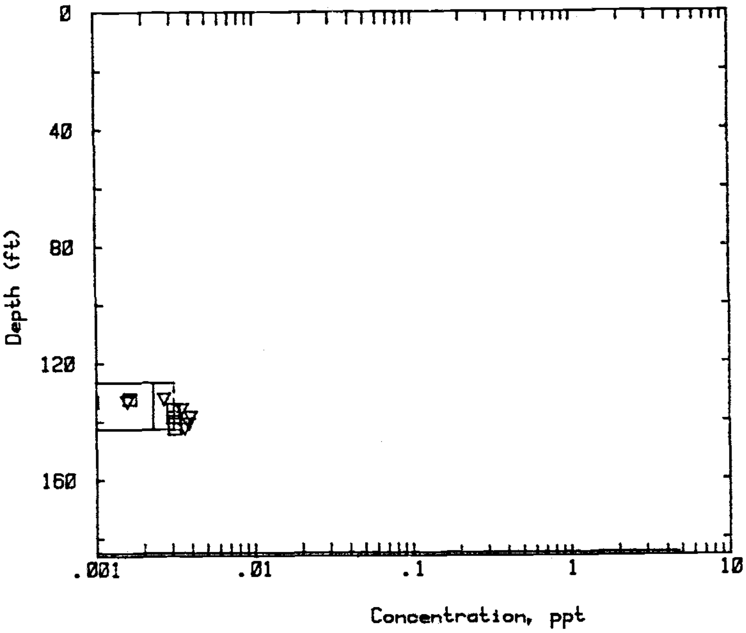
8/19/81A: Maximum predicted, and measured, concentration profiles: profile 6.



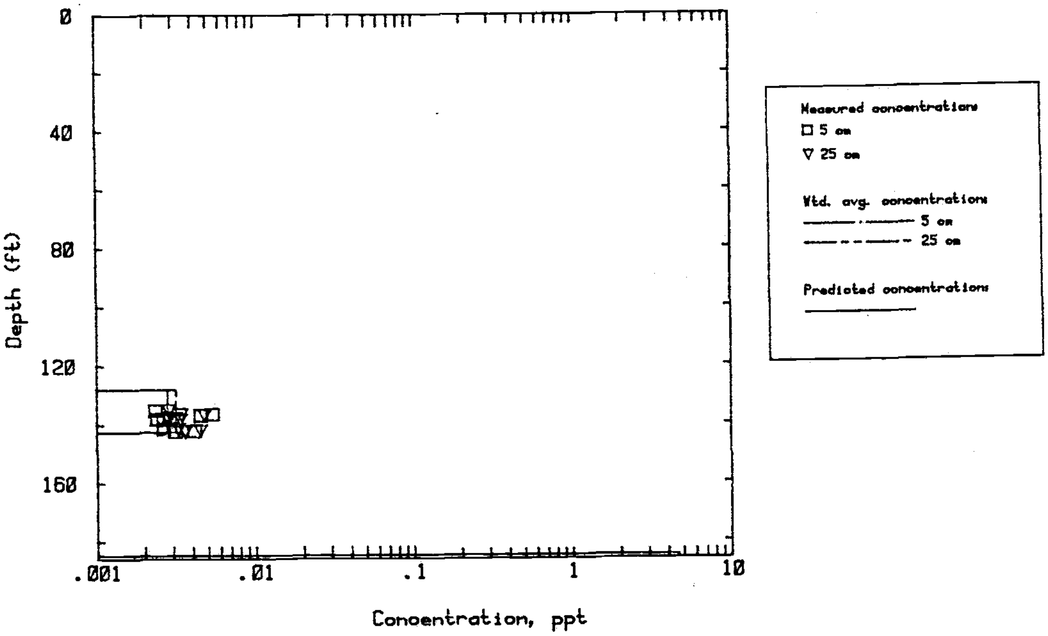
8/19/81A: Maximum predicted, and measured, concentration profiles: profile 7.



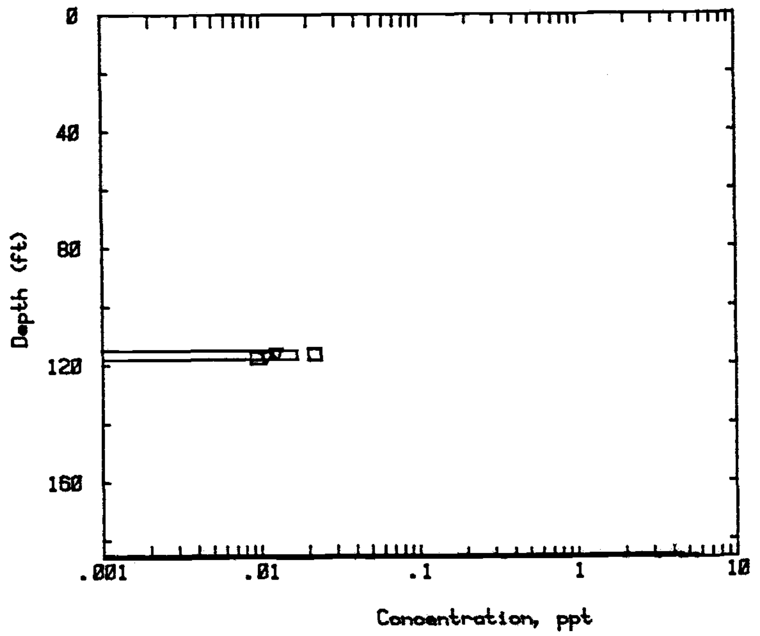
8/19/81A: Maximum predicted, and measured, concentration profiles: profile 8.



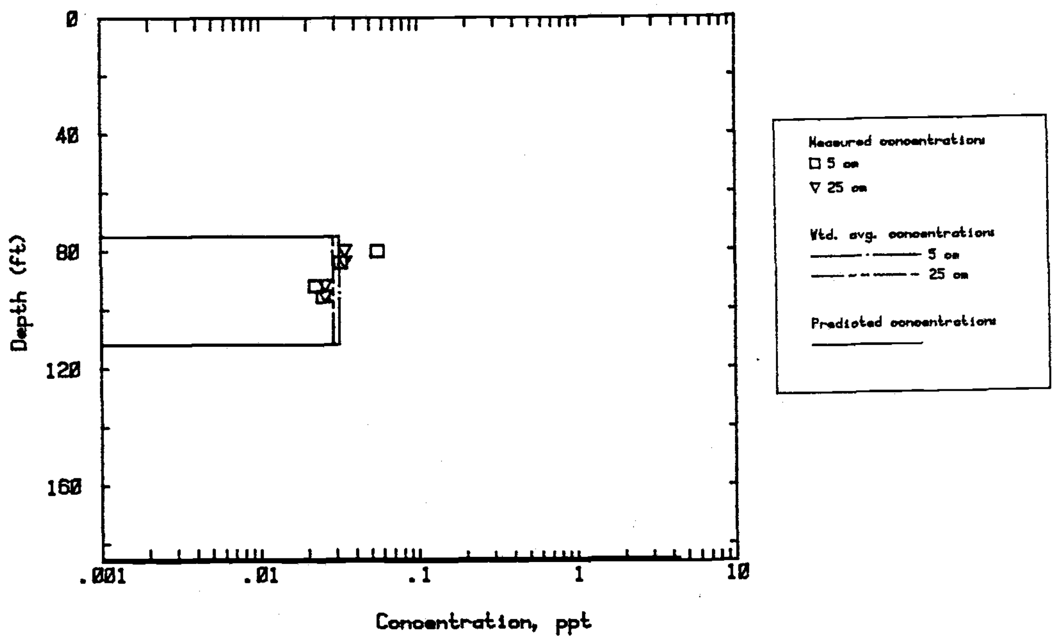
8/19/81A: Maximum predicted, and measured, concentration profiles: profile 9.



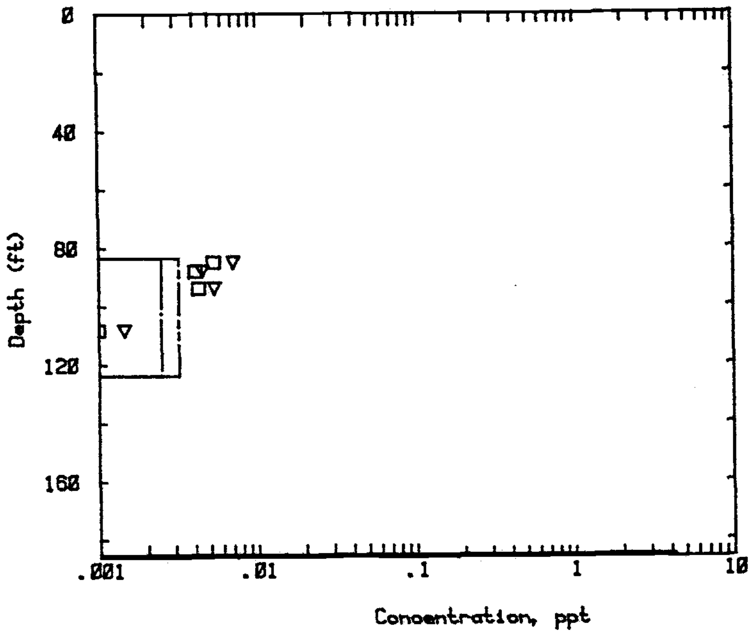
8/19/81A: Maximum predicted, and measured, concentration profiles: profile 10



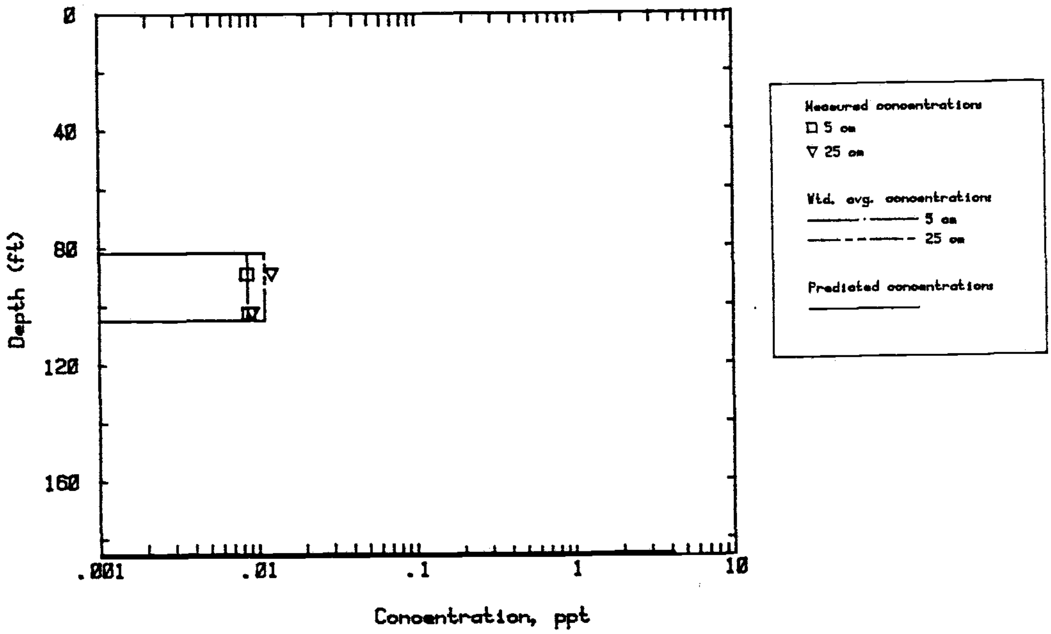
8/19/81B: Maximum predicted, and measured, concentration profiles: profile 1.



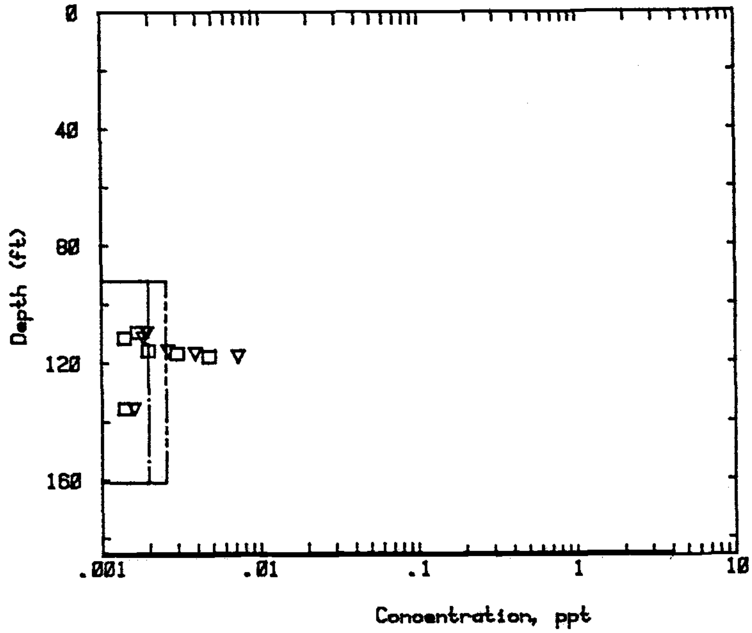
8/19/81B: Maximum predicted, and measured, concentration profiles: profile 2.



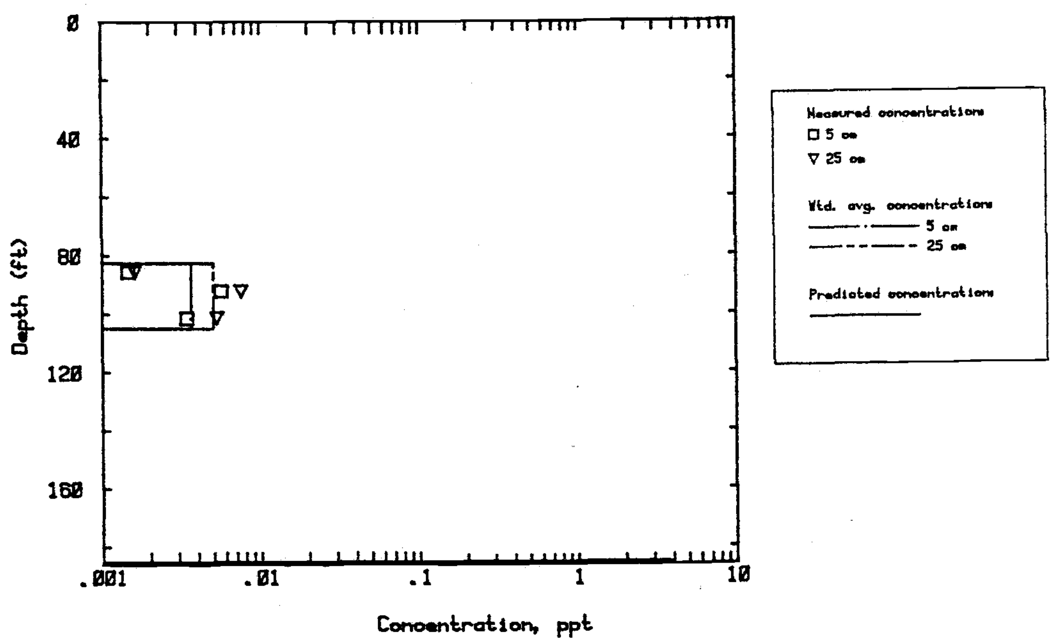
8/18/81B: Maximum predicted, and measured, concentration profiles: profile 3.



8/18/81B: Maximum predicted, and measured, concentration profiles: profile 4.



8/19/81B: Maximum predicted, and measured, concentration profiles: profile 5.

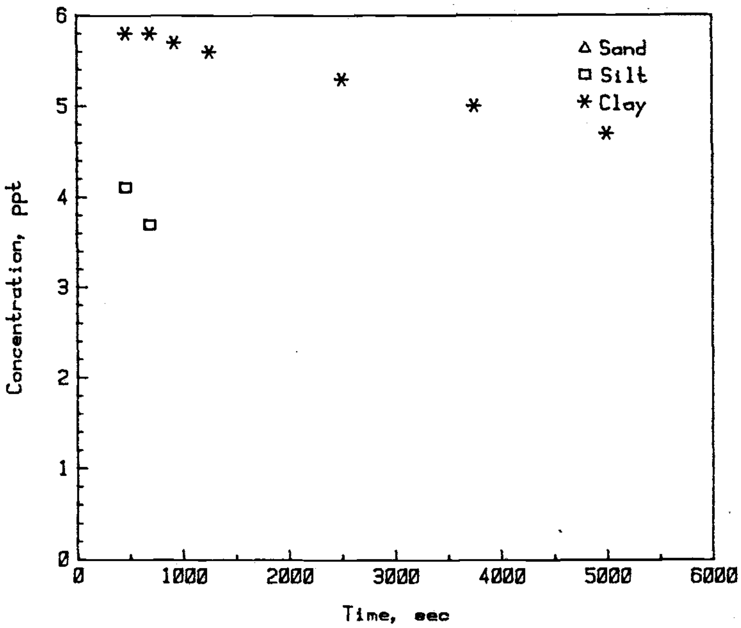


8/19/81B: Maximum predicted, and measured, concentration profiles: profile 6.

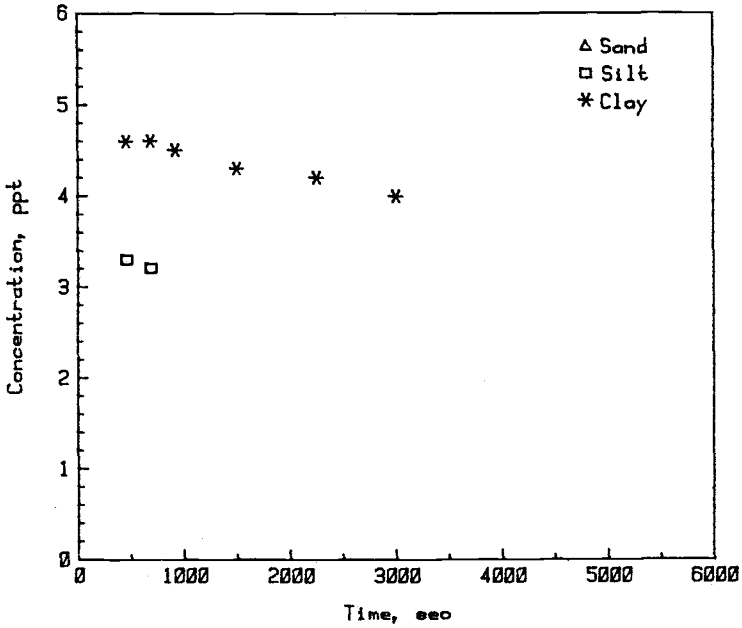
APPENDIX F

MAXIMUM PREDICTED CONCENTRATIONS VS. TIME

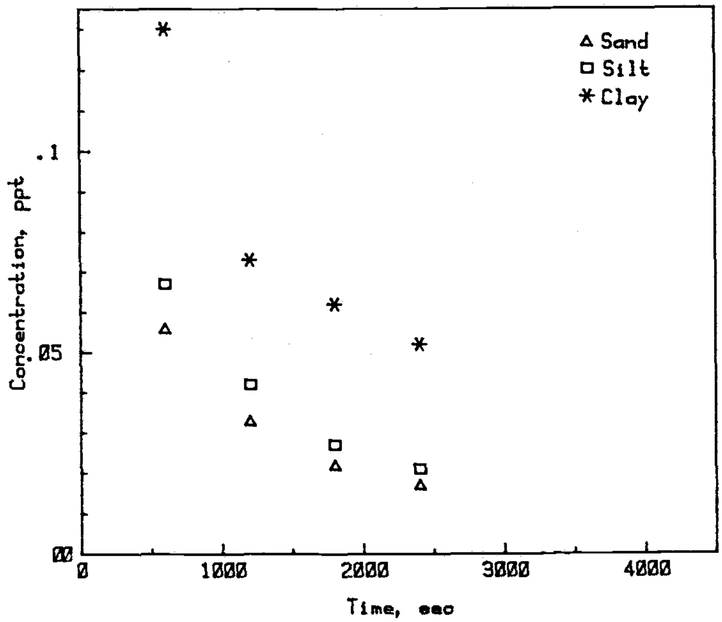
FOR EACH DISPOSAL EVENT



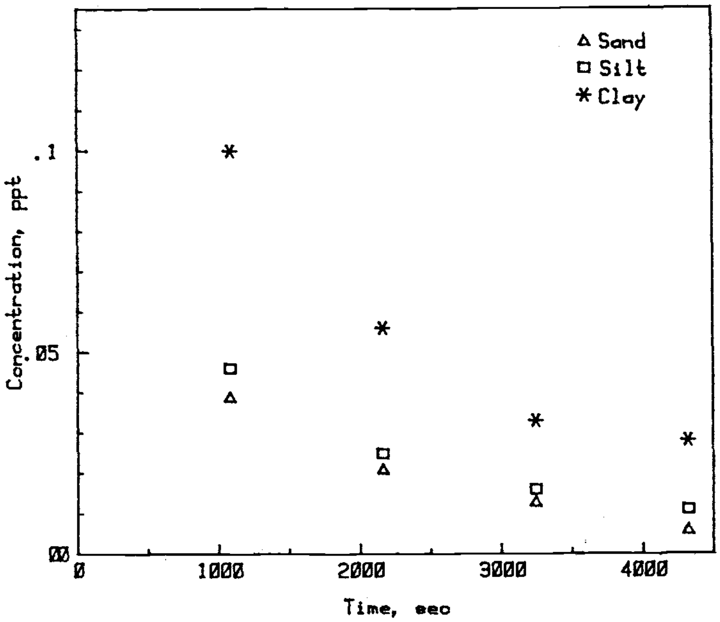
8/19/81A: Maximum predicted concentration.



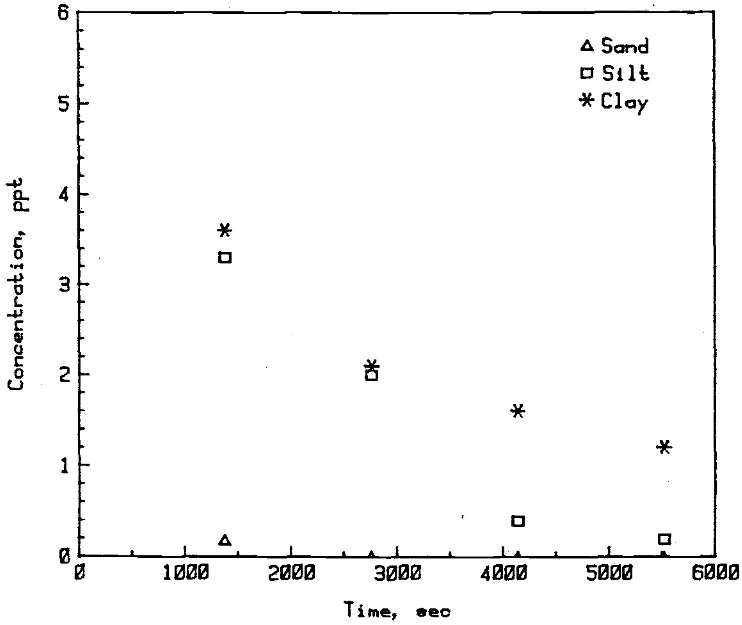
8/19/81B: Maximum predicted concentration.



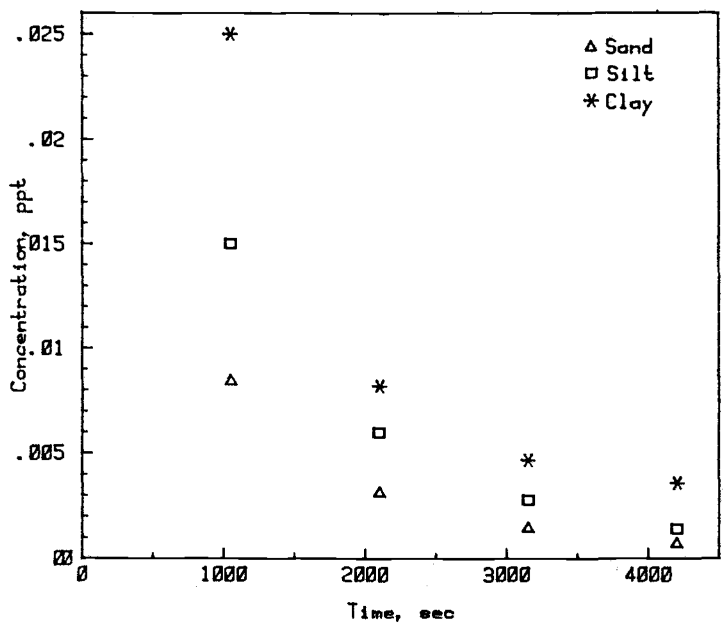
8/17/81A: Maximum predicted concentration.



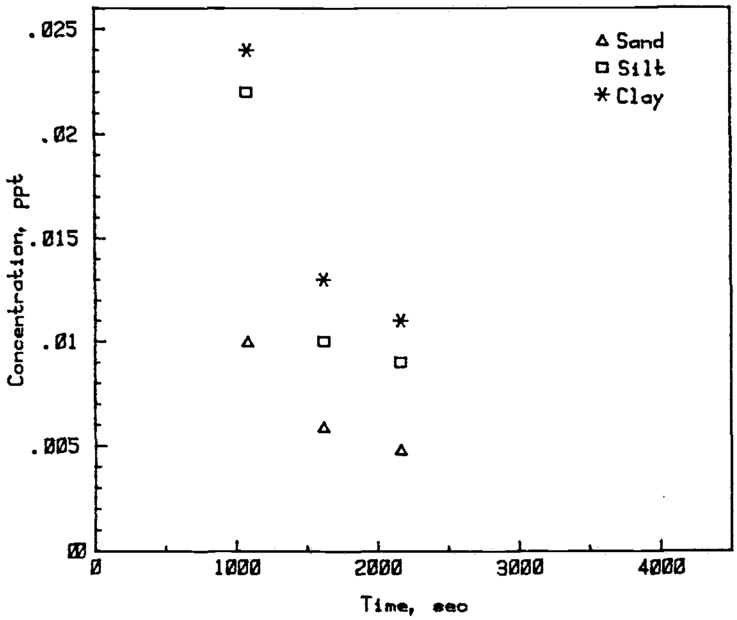
8/17/81B: Maximum predicted concentration.



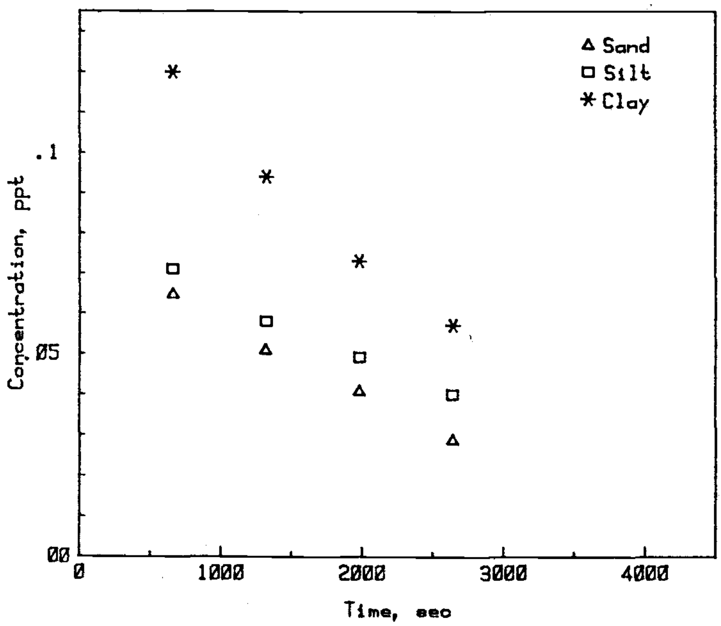
8/13/81A: Maximum predicted concentration.



8/13/81B: Maximum predicted concentration.



8/15/81A: Maximum predicted concentration.



8/15/81B: Maximum predicted concentration.