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**PCB Desorption
from
River Sediments Suspended
During Dredging**

An Analytical Framework

April 1981

New York State/Department of Environmental Conservation

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PCB DESORPTION FROM RIVER SEDIMENTS SUSPENDED DURING DREDGING:
AN ANALYTICAL FRAMEWORK

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Introduction

In assessing the environmental impact of dredging PCB-laden sediment from the upper Hudson River, the downstream PCB transport from the dredge site during dredging should be addressed. The draft Environmental Impact Statement for the hot spot dredging program prepared by Malcolm Pirnie (1980) addresses this topic but does not explicitly consider the mechanisms which accommodate losses of PCB from the site. Depending upon the acceptability of the dredging proposal to the public and federal and state regulatory bodies, a more detailed analysis of the various mechanisms producing PCB losses from a dredging site may be sought in the future.

Studies of dredging operations in the Hudson River and Stamford Harbor indicate that sediment, suspended by dredging, tends to settle rather quickly. However, Tofflemire (Pers. Comm.) observed that water column PCB concentration elevated by the dredging of the Hudson River near Fort Edward during 1977, decreased downstream at a slower rate than suspended sediment. The monitoring report prepared by Miner (1978) presents ratios of water column PCB to suspended solids concentration for mean high flow and mean low flow conditions for a series of sampling stations downstream of the dredge. This ratio increased downstream to the second station while decreasing to the third station at low flow.

Three mechanisms that would result in a proportionately greater export of PCB than sediment from a dredge site are: 1.) The retention in the water column of particles having a greater affinity for PCB and lesser density than other particles which would sink more rapidly; 2.) The mixing of sediment interstitial water with the overlaying water column; and 3.) The transformation of PCB from a sorbed to soluble state. It is likely that all three processes would be ongoing.

The greater affinity of organic particles than inorganic particles for PCB has been demonstrated (Nau-Ritter, 1980; Steen *et al.*, 1978). Organic particles in river sediments would generally be less dense than the inorganic fraction and consequently sink at a slower rate. Such a process might be reflected in measurements of suspended and volatile suspended solids downstream from a river dredging operation. In addition, particles with varying affinities for PCB within the inorganic fraction might also be selected by density.

Interstitial water in contaminated bed sediments, such as those proposed to be dredged, is likely to have a much higher PCB concentration than the water column. Interstitial water may represent more than half of the total volume of sediment material removed and is quite exchangeable with process water used during hydraulic dredging. However, since PCB's have relatively high sediment-water partition coefficients ($\sim 10^4$), this mechanism is of less concern for PCB's than other compounds or metals having lower partition coefficients. In any event, the importance of this mechanism can be evaluated for a hydraulic dredging project design in a very straightforward manner, employing a mixing model developed by Adams

and Darby (1980). Their model can be used to indicate whether desorption of a contaminant is occurring in the process water, but does not provide a direct means for predicting soluble contaminant concentrations where partitioning equilibrium is not rapidly approached. Adams and Darby (1980) have limited their analysis to contaminant losses to hydraulic dredging process water and not to disturbances and exchange in the river resulting from the dredgehead.

PCB desorption from both inorganic (illite) and organic (phytoplankton) particles has been demonstrated experimentally (Nau-Ritter, 1980; Kleppel, unpublished). The results of these experiments at equilibrium conform with partitioning relationships developed from sorption experiments. Assuming a linear partitioning relationship between particulate-sorbed and soluble PCB, the following may be considered in relation to PCB desorption from suspended sediment. The general $10^3 - 10^5$ range for PCB sediment partition coefficients (Tofflemire et al., 1979.) indicates "soluble"¹ PCB concentrations ranging 0.2 - 20 ppb required to maintain equilibrium with suspended "hot spot" sediment having a typical concentration of 20 ppm. It is unlikely that water entering a hot spot dredging area would be PCB-saturated or in equilibrium with suspended hot spot sediment. If conditions in the water column favor the desorption of PCB from sediment, the rate of desorption is of critical interest. While partitioning relationships can be employed to calculate the mass of PCB that would be lost from suspended sediment prior to equilibrium under experimental conditions (e.g., batch experiments, elutriate tests), equilibrium expressions are of limited use to calculate PCB loss from suspended sediments in a system where suspended sediments are non-conservative (dredging operations). Only if the PCB desorption rate is much smaller than suspended sediment sinking rates could equilibrium partitioning expressions be reasonably employed. Conversely, if PCB desorption rates are much slower than suspended sediment sinking rates, PCB export from a dredge site via desorption from suspended sediments would be a moot topic.

As an avenue for PCB export from a dredging site, PCB desorption from sediment suspended by dredging is particularly important since the newly soluble PCB would be readily available for accumulation on/in relatively cleaner biological sorbents spanning the food web from phytoplankton to fish.

The purpose of this technical note is to develop and test a method for the analysis of rates of PCB desorption from sediment suspended by dredging. The data available for such an exercise are from monitoring a dredging operation in the Hudson River at the town of Fort Edward during 1977.

¹ Considering the experimental methods used to determine some PCB-sediment partition coefficients, the term "soluble" may include aggregate in addition to truly soluble PCB. The solubility of Aroclor 1254 is probably less than 0.1 ppb in fresh water (Shoor, 1976). Lower chlorinated Aroclors are generally more soluble.

A map of the dredging site showing monitoring stations is presented in Figure 1. The data used in this exercise are from stations 3, 4, 5, and 7 in the river's east channel at Rogers Island. While stations 3, 4, and 5 were fixed positions, station 7 was a mobile station, located just below the dredge during the operation. The results of 14 sets of composite samples collected during the dredging were reported. Six of these were collected during a low flow (98 - 380 cfs, mean = 207 cfs) period while eight were collected during a period of higher flow (475 - 1480 cfs, mean=1240 cfs). Composite samples were collected during dredging at stations 3, 5, and 7 and analyzed for Aroclors 1016, 1242, 1254. River flow was gaged in both east and west channels and suspended solids determined for PCB composite samples. The complete methods and data of the dredging monitoring are presented by Miner (1978).

Methods

PCB Kinetics

A system of PCB sorption - desorption kinetics developed for food chain sorbents (Brown et al., in press) is employed in the framework of a one dimensional advective transport model and solved at steady state. Parkhomenko et al., (1980) have recently applied these kinetics to describe the results of ^{86}Rb and ^{137}Cs bioconcentration experiments using marine microorganisms. The symbols used in the model's development are summarized in Table 1.

The Freundlich isotherm can describe the relationship between the concentration of PCB in solution, C_w , and the mass of sorbed PCB per unit mass of sorbent, C_p , at equilibrium (Clayton et al., 1977; Harding and Phillips, 1978):

$$C_p = K_f C_w^{\frac{1}{n}} \quad (1)$$

where K is the unitless Freundlich partition coefficient. Typically, the constants K and n are determined from experimental or field data at equilibrium and a fitting procedure for the logarithmic transformation of Equation 1. In this exercise, the denominator of the exponent, n, is assumed equal to one.

The model describing the sorption - desorption reaction is consistent at equilibrium with the Freundlich isotherm (with $n = 1$) and assumes the rate of sorption to and desorption from a given sorbent is proportional to the difference between the mass of PCB per unit mass of sorbent, C_p , and the value, C_{psat} , that would be in equilibrium with the existing soluble PCB concentration:

$$\frac{dC_p}{dt} = k (C_{psat} - C_p) \quad (2)$$

where k is a first order reaction coefficient. Expressing C_{psat} in terms of the Freundlich isotherm, Equation 2 becomes:

$$\frac{dC_p}{dt} = k (K_f C_w - C_p) \quad (3)$$

If b is the concentration of sorbent expressed as part sorbent per part water (i.e., $\frac{g}{ml}$, $\frac{g}{g}$, $\frac{kg}{l}$ ) the corresponding rate of change in C_w is

seen as:

$$\frac{dC_w}{dt} = b k (C_p - K_f C_w) \quad (4)$$

Analytical solutions for Equations 3 and 4 for several sets of initial conditions are presented by Brown et al. (in press).

Equations 3 and 4 can be expanded to include advective transport terms. A brief review of one dimensional advective modeling might make the inclusion of these terms more reasonable. A finite volume (V) of stream with complete vertical and lateral (bank to bank) mixing, and no mixing in the horizontal (x) direction can be considered. The mass of soluble PCB entering this volume from upstream over the time interval Δt is $QC_w \Delta t$ where Q is the stream flow rate. The mass of soluble PCB leaving the volume through transport downstream is:

$$Q (C_w + \frac{dC_w}{dx} \Delta x) \Delta t.$$

The mass lost or gained through sorption or desorption is:

$$Vbk (C_p - K_f C_w) \Delta t$$

as in Equation 4. The entire mass balance for the volume can be presented as:

$$V \Delta C_w = QC_w \Delta t - Q(C_w + \frac{dC_w}{dx} \Delta x) \Delta t + Vbk (C_p - K_f C_w) \Delta t \quad (5)$$

Canceling and rearranging terms results in the following expression:

$$\frac{dC_w}{dt} = -\frac{Q}{A} \frac{dC_w}{dx} + bk(C_p - K_f C_w) \quad (6)$$

Considering that flow is equal to the product of velocity (U) and area (A) and that $C_p = \frac{B}{b}$, Equation 6 can be rewritten as:

$$\frac{dC_w}{dt} = -U \frac{dC_w}{dx} + k(B - b K_f C_w) \quad (7)$$

Similar equations can be written for B and b:

$$\frac{dB}{dt} = -U \frac{dB}{dx} + k(bK_f C_w - B) - K_s B \quad (8)$$

$$\frac{db}{dt} = -U \frac{db}{dx} - K_s b \quad (9)$$

where K_s is a first order decay coefficient representing the loss of suspended sediment and PCB associated with suspended sediment through sinking. At steady state ($\frac{dC_w}{dt} = \frac{dB}{dt} = \frac{db}{dt} = 0$), Equations 8, 9, and 10

can be reduced to the following matrix expression differentiated with respect to distance (x).

$$\begin{bmatrix} C_w \\ B \\ b \end{bmatrix}' = \begin{bmatrix} \frac{-k K_f b}{U} + \frac{k}{U} & 0 \\ \frac{k K_f b}{U} - \frac{k+K_s}{U} & 0 \\ 0 & 0 & \frac{-K_s}{U} \end{bmatrix} \begin{bmatrix} C_w \\ B \\ b \end{bmatrix} \quad x$$

If coefficients k , K_f , K_s , and U are determined and initial conditions provided in the variable vector, the system can be solved numerically using a Runge-Kutta or similar technique. If values for C_w , B and b are known over distance (x), trial and error methods may be used to determine the best fitted value for a single coefficient. Here, the sorption - desorption rate constant is found using such a method while assigning values to other coefficients.

Coefficient Selection

To calculate average velocity, U , for the east channel for a given set of results, the river flow and the average cross-sectional area of

the channel were required. Miner (1978) reported flow data corresponding to each set of composite samples in addition to high flow and low flow means for the period monitored. Average cross-sectional area in the channel was calculated by two methods: 1.) from a time of travel study reported by Tofflemire and 2.) from trapezoidal integration over distance of cross-sectional areas determined from bathymetric profiles developed by Malcolm Pirnie (see appendix A). These methods produced average cross-sectional areas of 1,566 and 1,603 ft.² respectively. Station distances were adjusted to be consistent with the use of an average cross-sectional area and spatially averaged velocity in the model, so that time of travel between stations, for a given flow, would be the same for average velocity with adjusted distances, and actual velocities with actual distances. This adjustment was made by dividing the cumulative volume of the channel to a station by the average cross-sectional area of 1,600 ft.². Adjusted station distances are presented in Table 2. The detailed calculations are presented in Appendix B. The exact location of the dredge on different days is not reported by Miner (1978). In this exercise, the location is assumed to be fixed, 825 ft. (adjusted distance) upstream of station 3.

The PCB partition coefficient, K_f , was selected in light of values reported for Aroclor 1016. Much of the data for Aroclors 1221 and 1254 from the dredging monitoring are reported as being less than a specified value (Table 3). However, Aroclor 1016, due to its high levels, was generally reported without this limitation. Therefore, only the Aroclor 1016 data will be included in this analysis. Tofflemire *et al.* (1979) have summarized sediment-water PCB partitioning coefficients for several Aroclors. For 1016, the partition coefficient from an elutriate dredging simulation, 5×10^3 , is employed here as the value of K_f .

K_s , the sinking rate coefficient, was determined by two methods. In the matrix representation of the steady-state system of simultaneous equations, the expression for $\frac{db}{dx}$ is independent of the other equations:

$$\frac{db}{dx} = \frac{-K_s b}{U} \quad (10)$$

The solution to Equation 10 for the boundary condition; b at $x=0$ is equal to b_0 is:

$$b = b_0 e^{\frac{-K_s x}{U}} \quad (11)$$

$$b = b_0 e$$

or

$$\ln \frac{b}{b_0} = \frac{-K_s x}{U} \quad (12)$$

Therefore, the value for $\frac{K_s}{U}$ can be determined as the slope of a linear regression of field measurements of b on adjusted station distances, X. Such regressions were performed using the Fort Edward dredging data for each group of composites and for a mean of high flow composites and a mean of low flow composite samples.

Regressions of the natural logarithm of suspended solids concentrations on adjusted river distances yielded six significant ($p < .1$) slopes. Sinking rates calculated from these slopes ranged from $-.06$ to $-.74 \text{ hr}^{-1}$ (Table 4). The slopes for average high flow and average low flow suspended solids were significant. The fits of the high and low flow suspended solids regressions are presented in Figure 2. Since the Aroclor 1016 data, corresponding to the other four sampling periods producing significant slopes, were incomplete or had data reported as less than a specified value, desorption rates were determined using the average low flow and average high flow data.

While the above is a good method for calculating, K_s , the use of data from Station 7, downstream of the dredge in the development of boundary conditions as described in a following section, warranted that the fitted line pass through the actual suspended solids value at $X=0$. Thus, successive approximations were also used to fit the line (Equation 12) to mean high flow and low flow suspended solids concentrations (Table 2) with the constraint of a fixed y intercept.

Boundary Condition Selection

A major weakness in the selection of boundary conditions and in the solution to the PCB sorption - desorption rate, k, is that no measurements of C_p or C_w were made during the dredging. The actual PCB measurements are total water column PCB, C_T , which represents the sum of C_w and B. However, assuming a known partition coefficient, boundary conditions for C_w and b can be estimated.

Boundary condition for C_w was selected using the following relation:

$$C_w = \frac{C_T}{K_f b + 1} \quad (13)$$

where C_T is the total water column PCB concentration in water at a station above the dredge (ug/ℓ), b is the suspended solids concentration above the dredge (kg/ℓ) and K_f is the partition coefficient assumed here to be 5×10^3 . The boundary condition for B was calculated by the difference between C_w for the station above the dredge and C_T for the station below the dredge. The boundary value for b was assigned the suspended solids concentration below the dredge. The assumption inherent to the selection of boundary conditions is that no desorption had occurred at the station immediately below the dredge.

Above the dredge during high flow, C_T is assumed to be $.01 \text{ ug}/\ell$ and b is $5.5 \times 10^{-6} \text{ kg}/\ell$. Therefore, using Equation 13, $C_w = .0097 \text{ ug}/\ell$. C_T , below the dredge is $.291 \text{ ug}/\ell$. Therefore, $B_{x=0}$ is $.281 \text{ ug}/\ell$.

$b_{x=0}$ is $18. \times 10^{-6}$ kg/l. Thus, the assumed 1016 burden of the sediments at $x=0$, is approximately 15 ppm.

Above the dredge during low flow, C_T is assumed to be .23 ug/l and b is 6.7×10^{-6} kg/l. Therefore, $C_{w_{x=0}} = 2.2$ ug/l. C_T for below the dredge is 2.41 ug/l and therefore $B_{x=0} = 2.19$ ug/l. $b_{x=0}$ is $24. \times 10^{-6}$ kg/l. The assumed 1016 burden of the sediments at $x = 0$ for the low flow run is 92 ppm.

Using the above initial conditions, values for the PCB sorption - desorption rate, k , were determined for a range of K_s values through trial and error use of the Runge Kutta solution technique. A distance step of 10 ft. was employed over a distance of 4,110 ft. for the solution.

Results

Some of the results of the low flow and high flow simulations are presented in Figures 3 - 8. The fit of the model to low flow average suspended solids, with the constraint of passing through the data used to assign boundary conditions at $x=0$, is presented in Figure 3. As indicated by this figure, the sinking coefficient determined from the linear regression method, $-.06 \text{ hr}^{-1}$, does not provide a best fit with such a constraint.

In all figures, series of curves are provided to indicate the sensitivity of model results to several values of coefficients. Employing a sinking rate of -0.08 hr^{-1} and sorption - desorption rate constants ranging from $.025 \text{ hr}^{-1}$ to 0.05 hr^{-1} fitted the low flow average water column Aroclor 1016 concentration, C_T , reasonably well (Figure 4). However, employing much slower rates as presented in Figure 4 indicates that if there was no transformation between particulate sorbed (B) and soluble (C_w) fractions, the model results would not be much different from the observed. To mechanistically fit the data, using higher sinking rates, requires use of higher desorption rate constants in the model. This can be seen in Figure 5 for the curve using a sinking rate of $-.10 \text{ hr}^{-1}$ and a sorption - desorption rate of $.075 \text{ hr}^{-1}$.

In the natural system this corresponds to the intuitively realized fact that if sinking rates are very large compared to transformation rates from the particulate-sorbed state, then very little PCB would be given up by the sediment during suspension. Conversely, if the desorption rates are high relative to sinking rates, then substantially more PCB could be lost from the sediments during suspension. The effect of the

desorption rate on the soluble PCB concentration below the dredge can be seen in Figure 4. Monitoring data for C_w and B which would provide the necessary evidence of transformations of PCB and a better means for calculating transformation rates, were not available. The model fits of C_T to monitoring data were calculated as the sum of model results for C_w and B.

The results of attempts to simulate the high flow average monitoring results for suspended solids and Aroclor 1016 concentration are presented in Figures 7 and 8 respectively. The best fits were produced using sinking rates between -0.4 and -0.5 hr^{-1} (Figure 8). The total concentration of Aroclor 1016 data was fitted reasonably well, using a sinking rate of -0.4 hr^{-1} and desorption rate constants on the order of 1.0 hr^{-1} .

The range of desorption rate constants producing reasonable fits for either high or low flow data is 0.025 to 1.0 hr^{-1} .

Discussion

This exercise employed only data from the east channel of Roger's Island which contains a relatively small portion of the total Hudson River flow at this point. Therefore, the presented water concentration of PCB's does not indicate the river-wide distribution resulting from a dredging operation. Again, it should be noted that, throughout this exercise, the sorption - desorption rate described in the model when applied to the Fort Edward dredging data probably represents at least two mechanisms: 1.) the transformation of PCB from sorbed to soluble state and 2.) the selection of less dense particles having a greater affinity for PCB. The two mechanisms cannot be treated separately in the Fort Edward data set due to the absence of data for C_w and B.

Sorption - desorption rate constants determined for Aroclor 1254 in batch experiments using organisms ranging from phytoplankton to gammarids ranged from $.03$ to 1.7 hr^{-1} and were positively correlated with organism size (Brown et al., in press). The sorption - desorption rate constants determined in this exercise for Aroclor 1016 ranged from $.025 \text{ hr}^{-1}$ for mean low flow data to 1.0 hr^{-1} for mean high flow data.

While the model was used here primarily to empirically determine the sorption - desorption rate constant, the model might better be employed for prediction of downstream effects of dredging (PCB export from dredging). In the results of the low flow simulation (Figure 4),

a sorption - desorption rate constant of 0.1 hr^{-1} resulted in a 40 percent increase in water column PCB 4,000 ft. from the dredge compared to simulations with virtually no desorption taking place.

In assessing the physical conditions for a specific application of this analytical framework, the importance of PCB volatilization from the river, here considered to be negligible, should be evaluated. The rate constants and Freundlich coefficients for the various Aroclors would be better determined from batch (elutriate type) experiments using river sediments. Replicate samples could be harvested at selected intervals prior to equilibrium, centrifuged, and PCBs measured on the supernatant and pellet fractions. If centrifugation was used experimentally, it could be argued that supernatant PCB measurements would not be truly representative of C_w as defined here and that rate constants determined would represent both desorption and non-settleable or non-centrifugeable particle selection. However, in terms of ability to predict PCB export from the dredging site, this particular coefficient would be of interest. The analytical solutions to Equations 3 and 4 could be used to fit values of k and K_f to experimental data rather than the numerical solutions employed here.

The preliminary findings of Wildish et al (1980), using Aroclor 1254 and estuarine sediments, indicate that desorption experiments (i.e. $C_T = B$ at $t = 0$) provide more relevant estimates of K_f since equilibrium relationships generated from desorption experiments produce significantly higher partition coefficients than data from adsorption experiments. Although this observation is slightly problematic for a model which assumes all sorbed PCB is exchangeable and that both types of experiments would produce results that lie on the same Freundlich isotherm plot, this effect may be compensated for in the assignment of PCB partition coefficients for solids.

New estimates of sinking rates would be necessary. Malcolm Pirnie (1980) has noted that the "hot spot" sediments are composed of finer-grained material than the relatively sandy sediment that was dredged from near Roger's Island.

Boundary conditions for the model could be made more specific to the actual dredging operation. For example, Miner (1978) indicated that the relationship between flow and suspended solids during the dredging suggested a constant source from the dredge. If it behaved in such a manner, boundary conditions for b could be expressed as $\frac{W}{Q} + b_u$, where W would be the suspended solids loading rate from the dredge, and b_u , the upstream concentration of suspended solids. Boundary conditions for B could be expressed as $\frac{W C_p}{Q} + B_u$ where C_p is the PCB concentration of the dredged sediments and B_u is the upstream PCB concentration associated with suspended solids. PCB loading to the river via process water could be included as a boundary condition in a similar manner.

Equations for three or more Aroclors could be developed using the specific partition and rate coefficients and solved simultaneously. The

model can be used to estimate rate coefficients from monitoring data as well as to estimate critical values for sinking rates or desorption rates. In the model, the rate of PCB desorption from solids is proportional to the difference between the PCB burden of the suspended sediments and the burden that would be in equilibrium with the existing soluble concentration. The following can be stated for conditions where the initial loss of PCB from sediments to the water column equals loss of PCB due to sinking:

$$\frac{k (K_f C_w - 1)}{C_p} = K_s \quad (14)$$

Similarly, PCB desorption from sediments would not be a significant mechanism for conditions where:

$$\frac{k (K_f C_w - 1)}{C_p} \ll K_s \quad (15)$$

At the dredge, the quantity $\frac{K_f C_w}{C_p}$ would likely be less than 1. If such a relationship is true for the real world, an increase in C_w above the dredge would reduce the potential for PCB loss by desorption below the dredge. Thus, process water from hydraulic dredging, if all expenses and other consequences were considered equal, would be better discharged upstream of the dredge.

To thoroughly test this model, in addition to obtaining better values for partition coefficients and sorption - desorption rate constants, a good calibration data set must be developed. To do this, vertical and laterally integrated flow proportional samples must be collected above the dredge, at the dredge and at successive stations below the dredge. Samples would be centrifuged in a large volume centrifuge and the pellet and supernatant PCB (however many Aroclors or isomer) concentrations determined. Suspended sediment and volatile solids would be determined on aliquots of the integrated samples. Suspended and volatile solids determinations would occasionally be determined on the centrifuge supernatant. Downstream channel geometry and flow would be determined as well.

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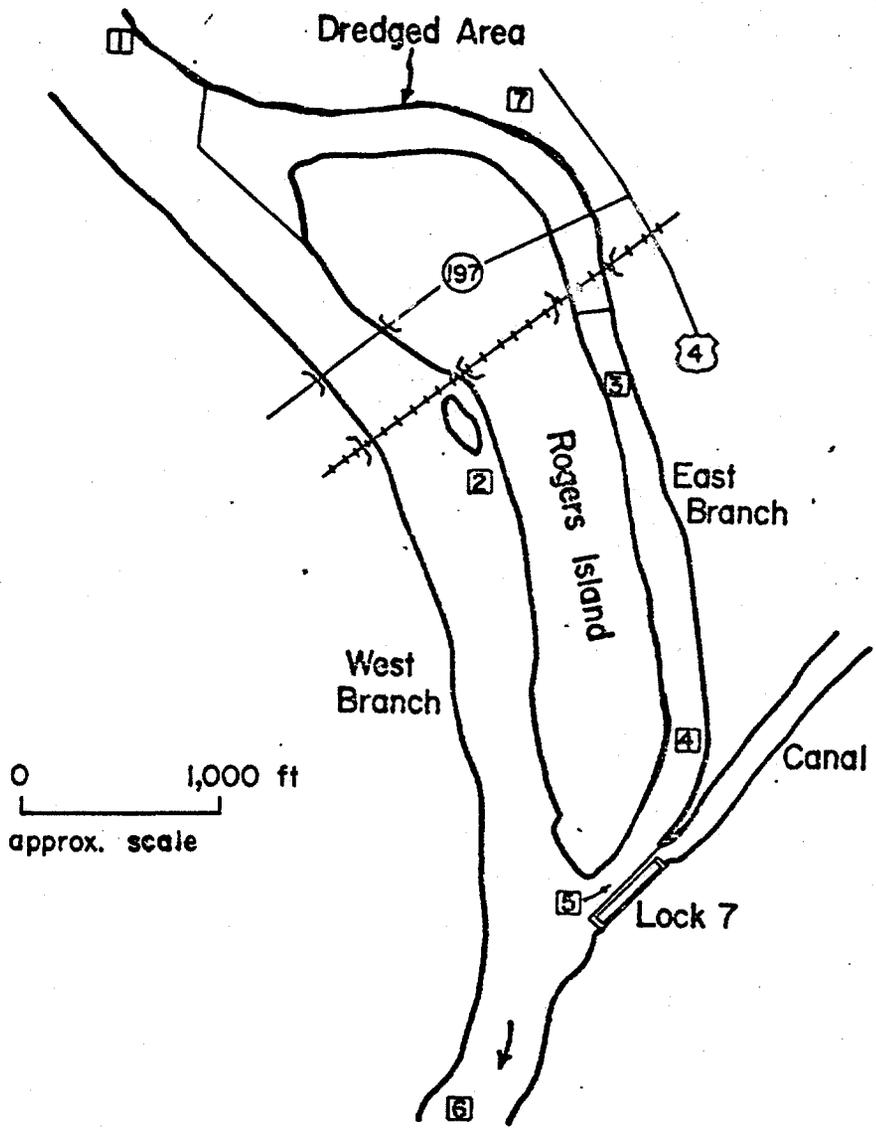


Figure 1. Fort Edward dredging monitoring sites (from Miner, 1978).

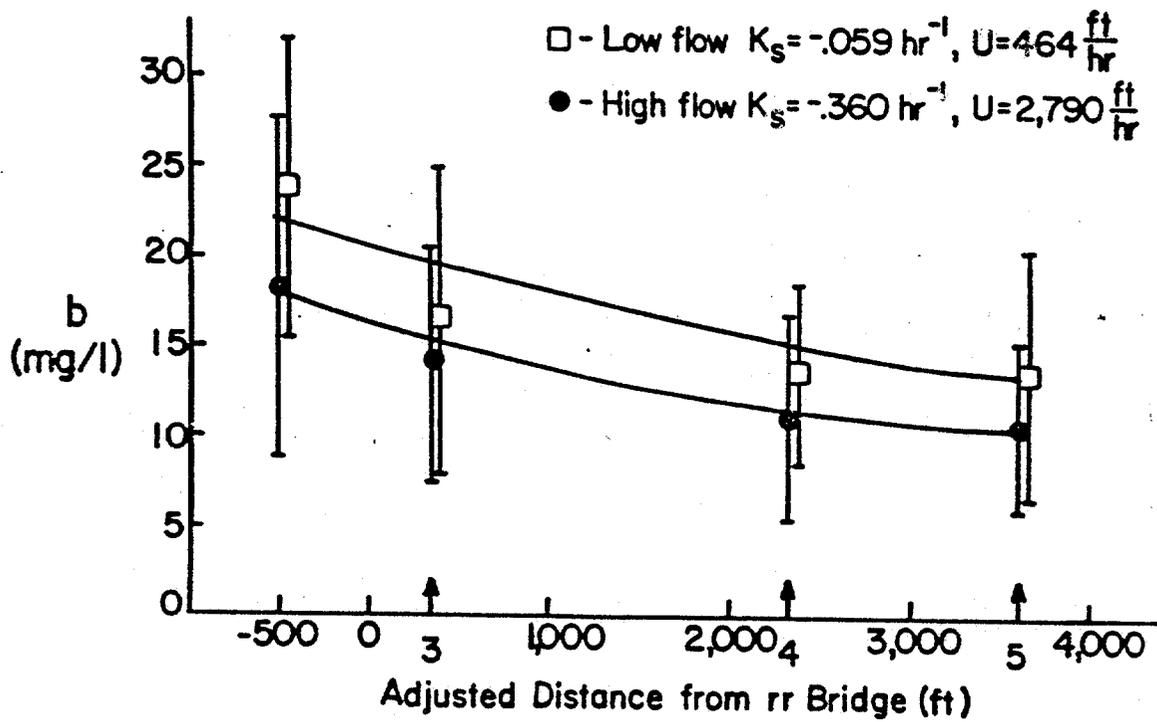


Figure 2. Regression fits for high flow and low flow mean suspended solids (b).

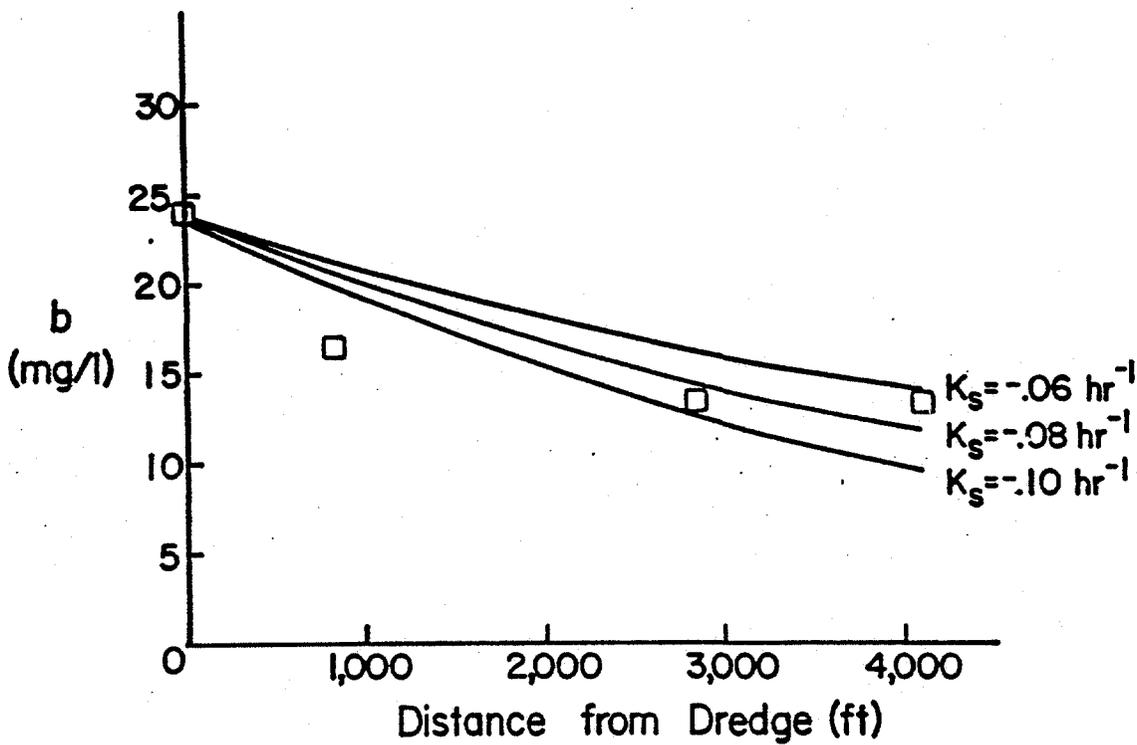


Figure 3. Low flow average suspended solids concentration (b) fitted using various sinking rates (K_s).

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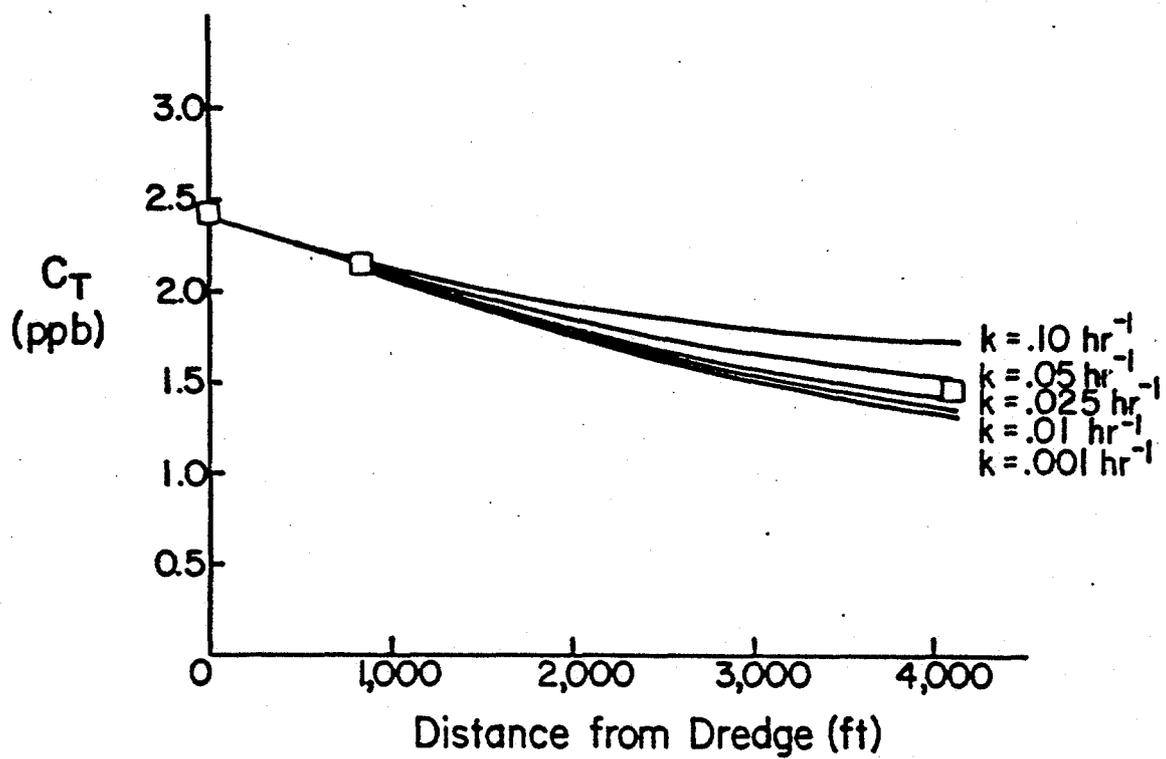


Figure 4. Low flow average Aroclor 1016 concentration (C_T) fitted using a sinking rate, $K_S = 0.08 \text{ hr}^{-1}$ and various desorption rates (k).

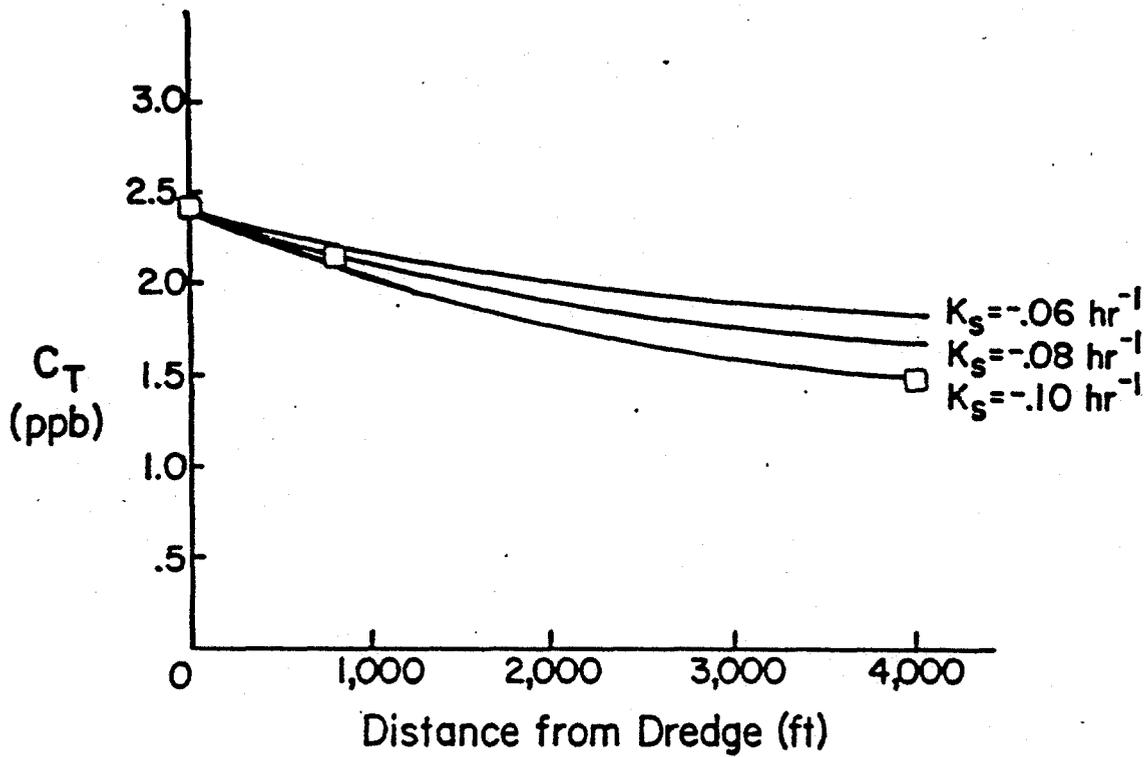


Figure 5. Low flow average Aroclor 1016 concentration (C_T) fitted using a desorption rate, $k = .075 \text{ hr}^{-1}$ and various sinking rates (K_S).

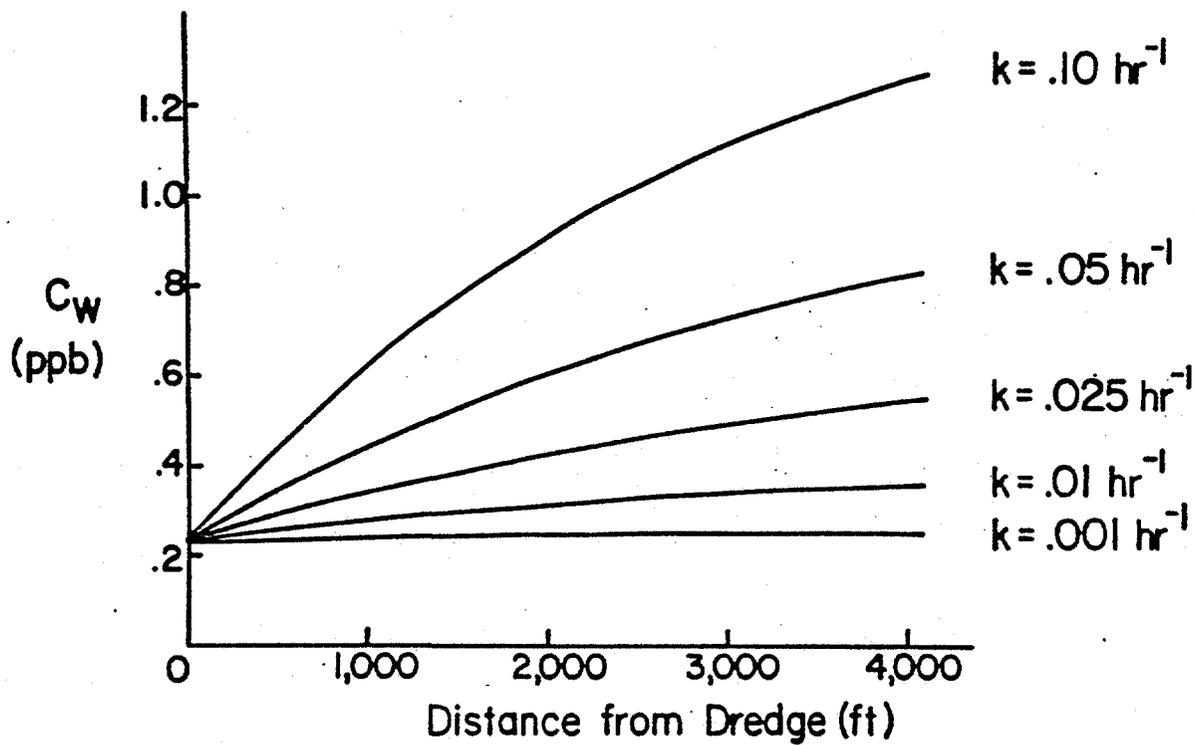


Figure 6. Soluble Aroclor 1016 concentration (C_w) resulting from low flow simulations using a sinking rate, $K_s = .08 \text{ hr}^{-1}$, and various sorption - desorption rates (k).

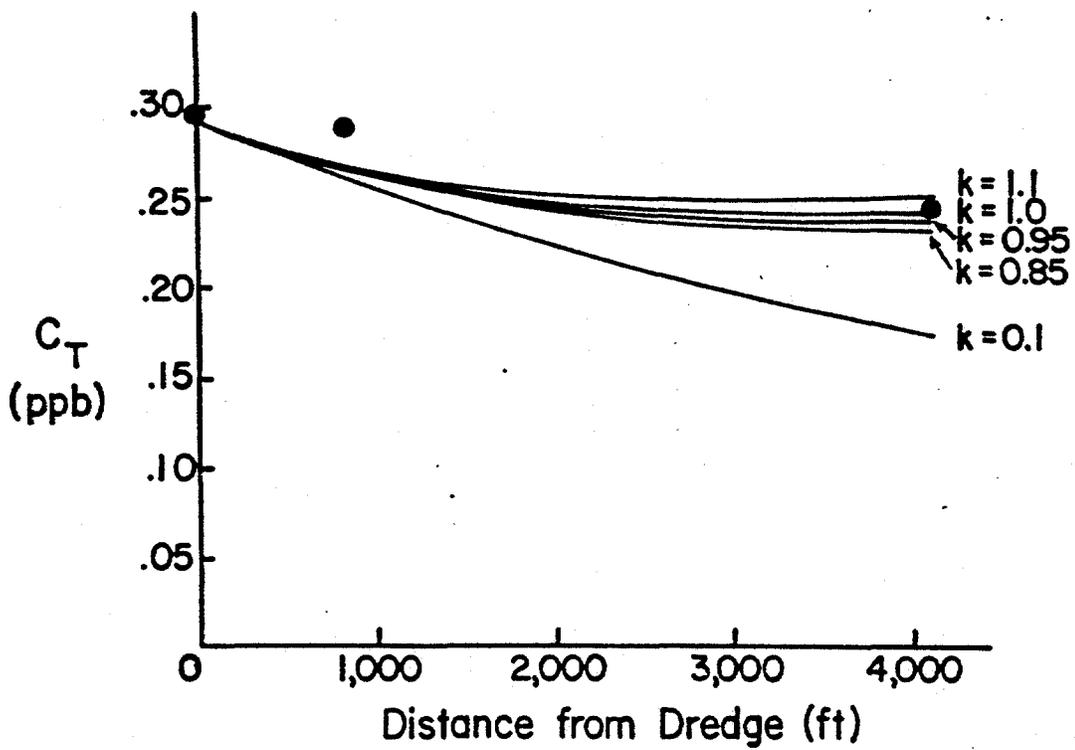


Figure 7 High flow average Aroclor 1016 concentration (C_T) fitted using a sinking rate, $K_s = 0.4 \text{ hr}^{-1}$, and various desorption rates (k).

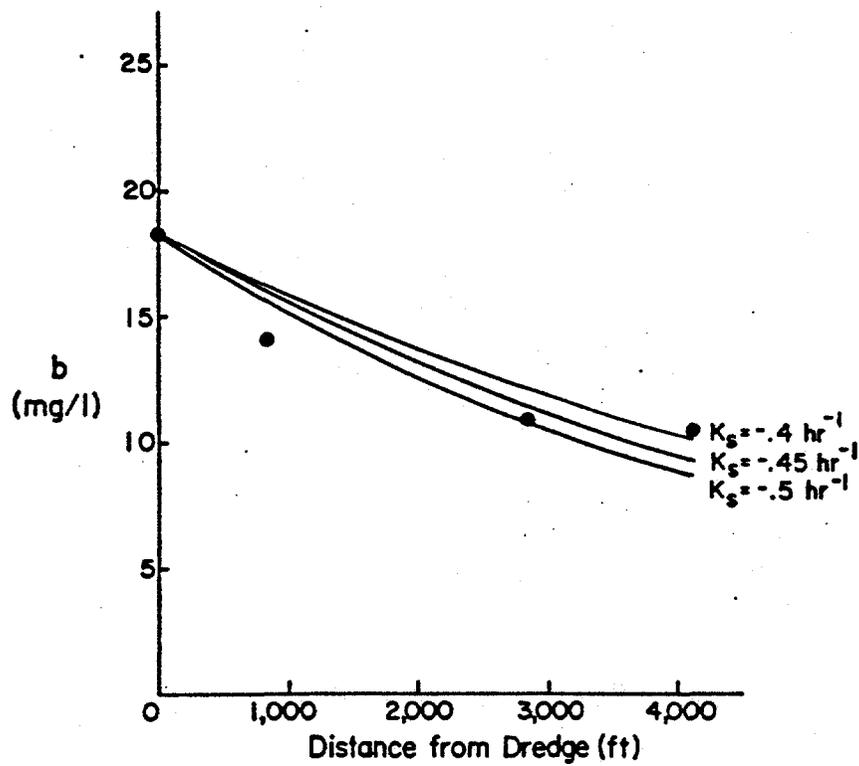


Figure 8. High flow average suspended solids (b) fitted using various sinking rates (K_s).

Table 1. Model Symbols

<u>A Symbol Definition</u>	<u>Units in Model</u>
A - cross sectional area	ft ²
b - concentration of suspended sediment	kg/l
B - concentration of PCB associated with suspended sediments	ug/l
C _p - PCB burden of suspended sediments	ug/kg (ppb)
C _w - soluble PCB concentration	ug/l (ppb)
C _T - total PCB concentration	ug/l (ppb)
k - sorption - desorption rate constant	hr ⁻¹
K _s - sinking rate (first order coefficient)	hr ⁻¹
K _f - Freundlich partition coefficient	(unitless)
n - Freundlich isotherm constant	(unitless)
Q - river flow rate	ft ³ /s
t - time	hr
U - river velocity	ft/hr
x - horizontal river distance	ft
V - volume	ft ³

Table

Suspended Solids and Aroclor 1016 Data for Average High and Low Flow Monitoring

Station	1	7	3	4	5
Adjusted distance from dredge (ft)	upstream	0	825	2827	4107
Mean high flow (1240) suspended solids(mg/l)	4.50	18.29	14.14	11.00	10.57
SD	2.88	12.54	8.29	7.68	6.21
SE	1.18	4.74	3.14	2.90	2.35
#	6	7	7	7	7
Mean high flow (1240 cfs) Aroclor 1016 (ppb)	.01	.291	.290	-	.243
SD	-	.211	.372	-	.238
SE	-	.075	.124	-	.090
#	8	8	9	-	7
Mean low flow (207 cfs) suspended solids (mg/l)	7.00	23.80	16.42	13.40	13.40
SD	2.00	9.42	10.57	5.63	7.70
SE	0.82	4.21	4.31	2.52	3.44
#	6	5	6	5	5
Mean low flow (207 cfs) Aroclor 1016 (ppb)	.235	2.41	2.15	-	1.46
SD	.512	2.96	3.26	-	2.28
SE	.181	1.12	1.15	-	0.93
#	8	7	8	-	6

SD - standard deviation
 SE - standard error
 # - number of samples

Table 3

Percent of PCB results reported as being less than a specified value in the Fort Edward dredging data set.

Aroclor	Station Number					
	1	7	3	5	6	2
1016	56	13	18	8	29	40
1221	100	93	82	92	100	93
1254	75	40	53	54	88	80

Table 4 Significant $\ln b$ on x Linear Relationships

Sample Date	N*	Slope ($\times 10^{-4}$)	Intercept	Percent ** Confidence for Slope	Velocity (ft/hr)	Sinking Rate (hr^{-1})
9/12-9/17	3	-3.511	3.932	90	290.	-.102
10/3-10/8	3	-0.2496	3.242	95	3,330.	-.083
11/7-11/12	4	-2.328	3.214	95	3,168.	-.738
8/15-8/19	4	-6.984	2.572	90	855.	-.597
High flow mean	4	-1.289	2.282	95	2,790.	-.3596
Low flow mean	4	-1.278	3.038	90	466.	-.0595

* - for N=3, data for the mobile station (7) was omitted

** - only compared against critical values for 90 and 95 confidence

Appendix A -continued (from Miner 1978)

Station:		1			7			3			5			6		
Aroclor:		1016	1221	1254	1016	1221	1254	1016	1221	1254	1016	1221	1254	1016	1221	1254
1977																
Composite Dates																
8/16-8/19	AM	.02	<.05	<.05	.32	<.05	<.05	1.1	.34	<.05	No Sample			.18	<.05	<.05
8/16-8/19	PM	.07	<.05	<.05	8.1	1.9	<.05	10.0	1.9	<.05	No Sample			.08	<.05	<.05
8/22-8/26	AM	0.1	<.05	<.05	0.3	<.05	<.05	0.8	0.9	<.05	0.6	<.05	<.05	<.02	<.05	<.05
8/22-8/26	PM	.07	<.05	<.05	4.7	<.05	0.7	2.8	<.05	0.4	1.6	<.05	0.17	.05	<.05	<.05
8/29-9/2	PM	.07	<.05	.55	2.1	<.05	0.36	0.69	<.05	0.11	0.11	<.05	<.05	.06	<.05	<.05
9/2-9/10	PM	.03	<.05	<.05	0.6	<.05	<.05	0.5	<.05	<.05	.31	<.05	<.05	.04	<.05	<.05
9/2-9/16	PM	1.5	<.05	.72	No Sample			.56	<.05	<.05	.34	.44	<.05	.12	<.05	<.05
9/21-9/24	PM	<.02	<.05	<.05	.74	<.05	.20	.78	<.05	<.05	.41	<.05	<.05	.86	<.05	.26
9/27-10/1	PM	<.02	<.05	<.05	.40	<.05	.36	1.2	<.05	.25	.35	<.05	.33	<.25	<.25	<.25
10/3-10/8	PM	<.02	<.05	<.05	<.01	<.01	<.08	0.17	<.05	<.05	.032	<.05	<.05	.11	<.05	<.05
10/10-10/15	PM	<.01	<.01	0.5	<.02	<.02	0.5	0.2	<.01	.06	<.02	<.02	0.4	<.01	<.01	.04
10/18 Grab Samples		No Sample			No Sample			<.02	<.02	0.5	No Sample			<.05	<.05	<.05
10/24-10/29	PM	<.01	<.01	<.01	0.4	<.01	0.1	0.2	<.01	0.5	0.7	<.01	<.01	<.01	<.01	<.01
10/31-11/5	PM	<.01	<.01	<.01	0.1	<.02	0.1	<.01	<.01	0.09	Sample Lost			.06	<.01	<.01
11/7-11/12	PM	<.01	<.01	.06	0.4	<.04	<.04	<.01	<.01	<.01	0.3	<.02	0.1	.03	<.01	<.01
11/14-11/19	PM	<.02	<.02	<.02	0.5	<.05	0.5	0.4	<.2	<.2	0.1	<.01	0.02	.04	<.02	<.02
11/21-11/25	PM	<.02	<.02	<.02	0.5	<.05	0.2	0.4	<.01	.05	0.2	<.01	0.07	0.10	<.08	<.08

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Appendix B

East Channel geometry and adjusted distances

Total volume and average CS area from the railroad bridge to station was determined by two methods.

1 a) using total times of travel and low flow. Low flow 207 cfs distance traveled 3,600 ft. time 454 min.

$$\text{avg. } U = \frac{3,600}{454 \text{ min} \times 60 \frac{\text{sec}}{\text{min}}} = .132159 \text{ fps}$$

$$A = \frac{Q}{U} = 1,566 \text{ ft}^2$$

1 b) using total time of travel at high flow 1,240 cfs 75.5 min

$$\text{avg. } u = .7947 \text{ fps}$$

$$1,560 \text{ ft}^2$$

2. using trapezoidal integration for volumes between Malcolm Pirnie cross sections

<u>Segment Boundaries</u>		<u>CS Areas (ft²)</u>		<u>Volume of Segment (ft³)</u>
<u>a₁</u>	<u>a₂</u>	<u>a₁</u>	<u>a₂</u>	
rr bridge	600 ft. (Sta. 3)	630	1103	519,900
600 ft. (Sta. 3)	1600	1103	1628	1,365,500
1600	2600 (Sta. 4)	1628	2048	1,838,000
2000	3600 (Sta. 5)	2048	2048	2,048,000
				5,771,400 ft ³
<u>Total Volume</u>				= 1,603 ft ²
Distance				

Appendix B (con't)

Adjusted distances for the assumption of uniform CS area (1,600 ft²)

<u>Station</u>	True Distance from RR Bridge (ft)	Volume to Station (ft)	Volume Adjusted Distance (ft)	Adjusted distance from dredge assuming dredge was 500 ft. upstream of RR Bridge (ft)
7	1600 - 0	?		0
3	600	519,900	325	825
4	2,600	3,723,400	2,327	2,827
5	3,600	5,771,400	3,607	4,107