Attachment A

Hudson River Water Column Concentration Analysis

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Attachment A

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1.0 Introduction

An analysis of the existing total suspended solids (TSS) and PCB concentrations in the water column of the Hudson River was conducted to determine baseline concentrations of TSS and PCBs in the river. These baseline concentrations will be used as a comparison to TSS and PCB concentrations measured during dredging to evaluate the impact o dredging on the water column. However, it should be noted that the baseline and sensitivity calculations provided here will be revised based on the results of the Baseline Monitoring Program. To estimate the baseline concentrations of TSS and total PCBs in the water column, the following tasks were performed:

- Evaluation of the monthly flow rate over the dredging season.
- Review and analysis of existing TSS and PCB data collected by General Electric (GE) since 1996 were.
- Estimation of the baseline PCB and TSS concentrations.

Limitations of the Existing Data

Much of the data analysis planned for the development of the resuspension performance standard focuses on determining the pre-construction variability of contaminant concentrations, or loads, in the water column. Previous studies, notably the *Data Evaluation and Interpretation Report* (DEIR, USEPA, 1997), have shown that the variability of contaminants in the water column changes throughout the year. The variability of contaminants in the water column is greatest during the spring, and it gradually decreases through the summer and into the fall.

For PCBs, the amount of available data is much greater, since nearly weekly sampling was conducted from the early 1990s to the present. But only limited locations were monitored, with the southernmost station located at Lock 5 in Schuylerville. Because the amount of data from stations close to the Mid-Hudson portion of the river is limited, the variability of contaminants in the water column at Waterford (sampled at the Troy Dam) will be inferred from the Upper River stations. This approach is reasonable, but not perfect. The contaminant concentrations at the TI Dam are much more variable than those at the downstream stations because the dam is closer to the contaminant sources. As the contaminant load travels downstream, the “signal” is dampened by dilution from tributary inputs, homogenization, and settling of the contaminants. Thus, if the TI Dam variability is assumed to apply to the Waterford area, the variability will be too high, leading to a performance standard that is less conservative than it should be. Direct measurements of the water column, expected to be provided by future GE sampling, will give a more accurate representation of conditions at the Troy Dam.

Although the dataset for PCBs encompasses most of the 1990s through the present, the data sampled prior to 1996 may not be useable for performance standard development due to the lack of source control at the GE facilities prior to that year. This leaves approximately five years of data at the TI Dam, and less at the other water column stations, for use in the planned evaluation. While this dataset would seem to be sufficient to examine the variability of contaminant concentrations, there are concerns regarding the location of the monitoring stations within the river at the TI Dam and Schuylerville.

- At Schuylerville, the station is located near the Battenkill, but not at a point where contaminant concentrations would be influenced by this tributary's input (the station was not situated where complete mixing would be expected to occur). Because of this, the Schuylerville (Lock 5) station may not fully represent the Hudson River water column concentrations under all conditions. It is hoped that future Schuylerville (Lock 5) samples will be collected from locations in the river where the flows from the Hudson River and the Battenkill are sufficiently homogenized, adopting a standard USGS sampling approach.

- At the TI Dam, both a west wing station and a central channel station are frequently sampled. Both stations have limitations. An analysis performed for the *Responsiveness Summary for the Data Evaluation and Interpretation Report* (USEPA, 1998) on the results in the west wing indicated that the concentrations from this station may be strongly influenced by the nearby sediments, particularly during times of low flow. The center channel station is north (upstream) of the west wing station, and thus does not measure the impact from the side channel sediments near the dam. Also, the center channel is inaccessible during the winter months due to ice cover, so the dataset is limited to the warmer months. Subsequent analysis indicated that the downstream concentrations (Schuylerville) are unlike either station taken separately, but resemble a mix of the concentrations measured at the two stations.

These concerns regarding the existing water column dataset have an impact on the evaluation of water column contaminant variability. It is unclear whether the estimated variability derived only from historic data will be more or less conservative than the actual conditions in the river. If GE adjusts the locations of the monitoring stations during future sampling events, a better measure of variability will be obtained.

2.0 Estimation of Hudson River Flow Rates at Stations Within the Upper Hudson River

Monitoring of resuspension in the water column of the Hudson River during dredging will include the measurement of PCBs at the far-field monitoring locations and measurement of turbidity and TSS at locations near the dredging operation, to ensure that the loss of PCBs from dredging is not occurring at a level greater than the baseline variability of PCBs already present in the water column.

Based on this need, it has been concluded that the far-field monitoring stations will be situated at the downstream limit of each of the three pools during dredging. Of these locations, only three have a long history of water column measurements: the TI Dam, Schuylerville (Lock 5), and Waterford (Troy Dam). For each of these locations, the baseline variability of TSS and PCB loading to the water column must be computed to establish a baseline for monitoring during implementation of the remedy. To determine the baseline variability of PCBs and TSS concentrations at the monitoring locations, the flow rates at these locations are needed.

The USGS monitors the flow rate of the Hudson River at gauges in the following locations:

- At Ft. Edward, along the Hoosic River
- On the Batten Kill before it converges with the Hudson River at Schuylerville,
- On the Hudson River just north of Waterford,
- Within the drainage areas surrounding the Hudson River.

In addition, the flow rate at Stillwater is estimated by the USGS. The flow rates at TI Dam and Schuylerville are not readily available.

Flow rates at the TI Dam and Schuylerville were computed using the drainage-area ratio method and known flow rates from existing USGS gauge stations. Flows were determined for the period 1977 to 2001 to incorporate all flow rate data available at the gauged stations.

Schuylerville Flow Rate Calculation

As shown in Figure 1, the flow rate of the Hudson River as it passes through Schuylerville is equal to the sum of the following:

- The flow rate of the Hudson River measured at the USGS gauge station at Ft. Edward.

- The flow rate measured by USGS at the gauge station along the Batten Kill.

- The flow contribution from this gauged station along the Batten Kill westward to its confluence with the Hudson River.

- The flow rate between Ft. Edward and Schuylerville.

This relationship is described by the following equation:

$$\text{Flow rate at Schuylerville} \equiv F_{schuy} = F_{Ft.Ed} + F_{BKg} + F_{BKung} + \Delta f_{ung\text{-}schuy} \quad ...\textit{Equation 1}$$

where $F_{Ft.Ed}$ = Flow at Ft. Edward
F_{BKg} = Flow at the Batten Kill gauge station
F_{Bkung} = Flow within the ungauged section of the Batten Kill
$\Delta f_{ung\text{-}schuy}$ = Change in flow rate of the ungauged section of the Hudson River between Ft Edward and Schuylerville

Using the drainage-area ratio method, the relationship of watershed yield times the drainage area of the watershed was used to compute the corresponding flow rate of the watershed. In the foregoing equation, the flow rate within the ungauged section of the Batten Kill (F_{BKung}) was computed by multiplying the yield of the Batten Kill by the change in watershed area over the ungauged section of the Batten Kill (the difference of the total area of the Batten Kill minus the gauged area along the Batten Kill) before it has its confluence with the Hudson River. This relationship is expressed in Equations 2 and 3, shown below.

$$F_{BKg} = y_{BKg} * A_{BKg} \quad ....\textit{Equation 2}$$

where F_{BKg} = Flow rate at the Batten Kill USGS gauge station
y_{BKg} = Yield for the Batten Kill gauged section of the River
A_{BKg} = Drainage area for the Batten Kill gauged section of the river

$$F_{BKung} = y_{BKg} * A_{BKung} = (F_{BKg}/A_{BKg})*A_{BKung} \quad ....\textit{Equation 3}$$

where F_{BKung} = Flow rate for the ungauged section of the Batten Kill
A_{BKung} = Drainage area for the ungauged section of the Batten Kill
$=A_{BK} - A_{BKg}$
A_{BK} = Total drainage area of the Batten Kill

The flow rate contributed by the section of the Hudson River between Ft. Edward and Schuylerville was computed as the change in flow rate between the flow rates measured at Ft. Edward and Stillwater by USGS and both the gauged and ungauged sections of the Batten Kill.

$$\Delta f_{ung\text{-}schuy} = \Delta a_{ung\text{-}schuy} * y_{ung} \quad ....\textit{Equation 4}$$

where

$$y_{ung} = (F_{stwtr} - F_{Ft.Ed} - F_{BKg} - F_{BKung})/(A_{stwtr} - A_{Ft.Ed} - A_{BKg} - A_{BKung}) \quad ....\textit{Equation 5}$$

and

$\Delta a_{ung\text{-}schuy} = A_{schuy} - A_{Ft.Ed} - A_{BKg} - A_{Bkung}$ .... *Equation 6*

and

$\Delta f_{ung\text{-}schuy}$ = Change in flow rate of the ungauged section of the Hudson River between Ft. Edward and Schuylerville
$\Delta a_{ung\text{-}schuy}$ = Change in the drainage area of the ungauged section of the Hudson River between Ft. Edward and Schuylerville
y_{ung} = Yield for the ungauged section of the Hudson River between Ft. Edward and Stillwater
F_{stwtr} = USGS estimated flow rate of the Hudson River at Stillwater
A_{stwt} = Drainage Area that enters the Hudson River at Stillwater
$A_{Ft.Ed}$ = Drainage area that enters the Hudson River at Ft. Edward
A_{schuy} = Drainage area that enters the Hudson River at Schuylerville

For select days over the period 1977 through 2001, the estimated flow rates at Stillwater were less than that of Fort Edward. In these instances, the following relationship was used to estimate the flow rate at Schuylerville:

$F_{schuy} = F_{Ft.Ed} + F_{Bkg} + F_{Bkung} + \Delta a_{ung\text{-}schuy} * y_{BKg}$ .... *Equation 7*

Thompson Island Dam Flow Rate Calculation

The flow rate at the TI Dam was computed similarly to the flow rate at Schuylerville; the drainage-area ratio method and the measured flow at the Ft. Edward gauge were used to estimate the flow at the dam. The following equations, Equations 8, 9, and 10, depict the relationships used to predict the flow rate at the TI Dam (F_{TID}):

$F_{TID} = F_{Ft.Ed} + \Delta f_{TID}$ .... *Equation 8*

where

$\Delta f_{TID} = \Delta a_{TID} * y_{ung}$ .... *Equation 9*

and

$\Delta a_{TID} = A_{TID} - A_{Ft.Ed}$ .... *Equation 10*

and

F_{TID} = Flow rate of the Hudson River at the Thompson Island Dam
Δf_{TID} = Change in flow rate along the Hudson River between Ft. Edward and the Thompson Island Dam
Δa_{TID} = Change in the drainage area into the Hudson River between Ft. Edward and the Thompson Island Dam
A_{TID} = Drainage area into the Hudson River at the Thompson Island Dam

For days where data gaps existed at the Ft. Edward USGS gauge station, the flow at Ft. Edward was estimated from the regression equation generated from the plot of the daily runoff yield at Stillwater versus the daily runoff yield at Ft. Edward (Figure 2). This plot generated the following equation that was used to estimate the flow rate at Ft. Edward:

$$F_{Ft.Ed} = 1.05 * y_{stwtr} * A_{Ft.Ed} \quad \text{...} \textit{Equation 11}$$

where y_{stwtr} = Yield for the Hudson River drainage area at Stillwater
and other parameters as defined above

3.0 Baseline TSS and Total PCB Analysis

The major concern associated with the dredging operation is the resuspension of sediment particles that may introduce additional PCB contamination into the water column. The water column PCB concentration will be monitored during dredging operations, and actions will be taken to minimize the impact of resuspension on the river system when the PCB concentration exceeds a certain level/threshold. Previous sampling results indicate that the variability of water column contaminant concentrations in the Hudson River can, to some extent, be attributed to the uncertainty of laboratory analyses. However, the variability in contaminant concentration in the water column is actually primarily the result of variability of the river system. In order to measure the "net" effect of the dredging operation, it is necessary to distinguish the dredging-related contribution of PCB contamination to the water column from the flux of PCBs currently present in the water column. If the new measurements collected during dredging are within the variability determined by the samples collected prior to the onset of dredging activities, it will be assumed that there is no impact from dredging. This poses the question of whether each new observation/sample collected belongs to the populations created from the baseline data and if the new observations generate the same central tendency as the baseline data. To evaluate this question, a statistical analysis was performed over the multiple-year baseline water column data set to investigate the typical condition of the river and to estimate the upper bound and typical PCB contaminant levels representative of the river system.

3.1 Methodology

Samples collected by GE during their ongoing weekly sampling program were used to estimate the current PCB water column contamination conditions in the Hudson River. The GE sample results were used because they provide a long record of PCB and TSS concentrations in the Hudson River, have measured PCB concentrations using a congener method, represent the most comprehensive dataset of water column PCB results, and probably best reflect the current situation in the Hudson River. There are some problems with the data collection method that make this data less than representative; the samples were collected from a single centroid sample to represent the cross-section, and the detection limits are not low enough to detect concentrations at all stations throughout the year. Only post-1996 water column samples were used in this analysis (due to the lack of source control at the GE facilities prior to that year) to estimate the baseline conditions in the Hudson River prior to any impact that may result from the dredging operation.

GE has been monitoring the water column situation in the Upper Hudson River at four stations since the early 1990s. These four stations are located at Fort Edward, at the west side of the TI Dam near the shore (TID-West), in the channel section above the TI Dam (TID-PRW2), and at Schuylerville (Lock 5). Data collected at the above-listed stations were investigated in this study to estimate the natural variability of TSS and PCB concentration in the river system at different locations. Daily average flow measured and reported by the USGS was used for PCB and TSS analysis at the Fort Edward station. The flow rate at the other three stations was estimated based on the flow rate at Fort Edward, as described in detail in Section 2.0 of this attachment.

Since the proposed dredging season spans the months of May through November, only data associated with these seven months were examined for distribution and variability herein. As stated in the *Hudson River Feasibility Study Report* (USEPA, 2000), dredging is not expected to be performed during high flow conditions. Therefore, samples with flows greater than 10,000 cfs were excluded from this analysis in order to provide the best estimate of what conditions will be during dredging activities. Field duplicate samples were collected for 1 percent of the total samples taken, and an average concentration was calculated to represent the results of all duplicates. In addition, for cases where multiple samples were collected at different times in the same day, a daily average concentration was calculated and used in this analysis in order to evenly weight each sampling day.

Non-detected values for both TSS and PCBs exist in the GE data set. Typically, when these results are used in a calculation, a value is substituted for the detection limit to estimate the concentration in the sample. Usually, either zero or one-half the detection limit is used in the substitution. In the data reviewed, GE did not provide a detection limit for TSS, and, in some instances, for PCBs. To determine the best estimate of the concentration in the non-detect TSS samples, a concentration of 0.5 mg/L TSS, one-half of the lowest detected TSS concentration, was assigned to the non-detect samples. To determine the best estimate of the concentration in the non-detect PCB samples, half of the reported detection limit for PCBs (5.5 ng/L) was assigned to PCB samples reported as non-detect from the laboratory.

The impact of resuspension on water column PCB concentrations is the focus of concern during the dredging operation. Some PCBs stored in the sediment will be introduced into the water column via resuspended particles. As a result, a change in the TSS concentration can be used as an indicator of a possible increase in the PCB concentration in the water column. There are currently no instruments capable of making reliable measurements of PCBs in-situ. Measurements of PCB concentration must be performed through laboratory analysis and measurement, which can take hours to perform. Due to the inability to obtain real-time PCB concentrations in the water column during dredging, TSS will be used as a surrogate indicator of dreging related releases and thereby PCB release also. Therefore, baseline conditions for both PCB and TSS concentrations were analyzed herein.

Review of the PCB and TSS data collected by GE since 1996 at the Ft. Edward, TID-West, TID-PRW2, and Schuylerville monitoring stations indicated the following:

- Variation exists among different months' data, and
- A single concentration could not be computed for TSS or PCB to represent the background concentration over the seven-month dredging period.

Based on the above, PCB and TSS data were analyzed starting on a monthly basis at each of the four monitoring stations. This monthly variation can be seen in Figures 3 and 4 for the Ft. Edward station; Figures 5 and 6 for the TID-West station; Figures 7 and 8 for the TID-PRW2 station; and in Figures 9 and 10 for the Schuylerville monitoring station.

An example of the data analysis performed for the monthly TSS and PCB data at the above-listed stations follows, using the results from the Schuylerville station.

Figure 11 depicts results from the weekly PCB and TSS water column samples collected at the Schuylerville monitoring station from 1996 through 2001, grouped by month (May through November). The mean TSS and PCB concentrations for each month were calculated and plotted to show the trend of the monthly concentrations. The data indicate that relatively high TSS and PCB concentrations were detected more frequently in May and June as compared to the rest of the study period. PCB data in May and June are distributed over a broader range than the data in the other dredging months. The mean TSS concentration fluctuates for the period of July through September, while the mean PCB concentration declines over that same period. In addition, October's mean PCB concentration is greater than the mean PCB concentration for September and November.

The data strongly suggests that a single uniform TSS or PCB baseline value cannot be applied to every month. Similar analyses were performed for each of the data sets representative of the other three monitoring stations, and the same conclusion was drawn: that significant difference exists between the data collected at different times of the year, (for example, data collected during a spring month differ significantly from data collected during a summer month), and a uniform baseline value would not be representative of the range of conditions expected to be encountered during the dredging period. The baseline variability of the Hudson River should be addressed by a set of time-specific groupings of the available data in a reasonable way.

There are approximately 20 to 25 data points available for each month. A data group of a smaller size will not permit a reliable statistic analysis result, so one month is the smallest unit to group the data into for this analysis. In addition, it is physically meaningful to generate a baseline number for each month. Statistical analysis was conducted on each of the monthly datasets to determine whether or not it would be appropriate to group data for some months together. JMP (SAS, 1997), a statistical program, was used to perform the statistical analysis. This study included the following:

- Calculation of the minimum, mean, and maximum concentrations for each month

- Calculation of the 10 percent, 25 percent, 75 percent, and 90 percent quantiles

- Use of the Tukey-Kramer Honestly Significant Difference (HSD) to determine whether or not two sets of data are significantly different.

A sample plot for this study of TSS and PCB concentrations measured at the Schuylerville Station over the seven months of interest is shown in Figure 12. Generally speaking, this statistical study allowed months exhibiting insignificantly different means to be grouped. Circles for means that are significantly different either do not intersect or intersect slightly so that the outside angle of intersection is less than 90 degrees. If the circles intersect by an angle of more than 90 degrees, or if they are nested, the means are not significantly different. Figure 12 shows that TSS data for the period of July through November at the Schuylerville station are similar. Thus, data for these “similar” months can be consolidated into one dataset for further analysis to determine a baseline TSS concentration. Figure 12 also indicates that PCB data for the months of May and June are similar and can be consolidated into one dataset.

The studies performed on TSS and PCB data for the Ft. Edward, TID-West, and TID-PRW2 stations allowed the consolidation of several months of data into one dataset in the following cases:

- At the Ft. Edward station: consolidation of TSS data for September through November, and PCB data for July through September and October and November.

- At the TID-West station: consolidation of TSS data for July through October and PCB data for October and November.

- For the TID-PRW2 station: consolidation of TSS data for July through November and PCB data for the months of July and August.

The variability of monthly and consolidated monthly TSS and PCB data was analyzed based on interval estimates. Interval estimates are intervals that have a stated probability of containing the true population value. The intervals are wider for datasets having greater variability. There are two types of interval estimates: the prediction interval (PI) and the confidence interval. The prediction interval indicates the likelihood that a single data point with a specific magnitude comes from the population under study, while the confidence interval indicates the probability or likelihood that the interval contains the true population value. For each of the four monitoring stations, the prediction interval and the 95 percent confidence interval were estimated for each month and consolidated month dataset over the dredging period, since previous analysis of the data indicated that PCB and TSS concentration data varied.

Prediction intervals are computed for a different purpose than confidence intervals. The prediction interval deals with the individual data values as compared to a summary statistic such as the mean. A prediction interval is wider than the corresponding confidence interval because an individual observation is more variable than a summary statistic computed from several observations. Unlike a confidence interval, a prediction interval takes into account the variability of single data points around the median and mean, in addition to the error in estimating the center of the distribution.

In order to judge whether a new observation is likely to have come from the same distribution as previously collected data or, alternatively, from a different distribution, the prediction interval needs to be computed from the existing data and compared to the new observation. Prediction intervals contain 100*(1-a) percent of the data distribution, while 100*a percent are outside of the interval. If a new observation comes from the same distribution as previously collected data, there is a 100*a percent chance that it will lie outside the prediction level. Therefore, being outside of the interval does not "prove" that the new observation is different, just that it is likely to be so. Prediction intervals are used in this study as the upper bound limit for a single incident, and will be used as a baseline for comparison for a single sample result collected during the dredging operation. Sample results obtained during dredging falling above this upper bound limit (the prediction interval) will be assumed to represent some dredging-related release.

In addition to providing the prediction limit which provides an upper bound limit for individual samples, the confidence limit on the average was used as the second layer criterion to control the average of new observations. Therefore, if a group of samples are each below the prediction limit, but the average is above the upper confidence limit, it is likely that the group of samples belong to a different population than the baseline (*i.e.* indicative of dredging related releases).

Considering the possible impact of flow rate on PCB and TSS concentrations, correlations between PCB concentration and flow and between TSS concentration and flow were examined for the dredge season, either monthly or per consolidated set of dredging months, at each station. For each monitoring station, flow was plotted against PCB and TSS water column concentrations. Overall, no correlation was observed between TSS and flow at any of the four monitoring stations.

No correlation between PCB and flow was observed at the Ft. Edward monitoring station, but data indicated that correlations existed between PCB concentration and flow rate during the months of May and June at the TID-West and TID-PRW2 stations. Data for the Schuylerville station also indicated a correlation between PCB and flow for the months of May and June. Statistical data were indicative of these correlations based on a high r-squared value and an observed significant probability that was less than 0.05. The above-described correlations are presented in the following figures: TID-west station (Figure 13), TID-PRW2 station (Figure 14), and Schuylerville station (Figure 15).

For months where PCB data appeared to be correlated with the flow rate, JMP was used to estimate the center confidence and individual confidence of the data corresponding to different flows. The center confidence puts a confidence limit on the predicted central tendency, and the individual confidence interval includes both the variability of the estimates and the variability of the observation itself and is thus appropriate for a prediction interval. The JMP program was able to compute these values while performing a regression analysis between two correlated variables. The lower 95 percent confidence interval is not presented in these plots, since only the upper bound estimates were of interest in this study.

Fit curves estimating the center confidence and individual confidence of the data were generated for the PCB monthly data at the TID-West, TID-PRW2, and Schuylerville monitoring stations for months in which the data indicated a correlation between PCB concentration and flow rate. These fit curves are shown in Table 1. For stations with a defined timeframe where PCBs are correlated with flow, the flow rate was applied to the listed formulas and fit curves to determine the baseline PCB concentration, the prediction interval, and the UCL at different flows. Velocities of 2000 cfs, 4000 cfs, and 8000 cfs were used to calculate the baseline levels, representing the lower bound flow, the average flow, and the upper bound flow, respectively, during dredging operations.

For the monthly and consolidated monthly datasets where a correlation between flow and concentration was not observed, the prediction interval and UCL were estimated solely based on the concentration data.

The upper bound prediction interval was estimated using methods provided by Helsel and Hirsch (Helsel and Hirsch, 2002). Three methods were used to calculate the upper 95th prediction interval on each of the datasets. These methods were the parametric symmetric prediction interval, the parametric asymmetric prediction interval, and the nonparametric prediction interval. Because the goal of this study was to determine the upper bound level of existing data, a one-side prediction interval was applied in all three methods. The nonparametric prediction interval does not require the data to follow any particular distribution shape, while the symmetric prediction interval is calculated based on the assumption that the data follow a normal distribution. The following formula, Equation 12, is used to compute the symmetric prediction interval:

$$PI = \overline{X} + t(0.05, n-1) \cdot \sqrt{s^2 + (s^2 / n)} \text{ ....} \textit{Equation 12}$$

where PI = the upper bound of the prediction interval

$\overline{X}$ = the mean value of the data set (mean concentration for the TSS and PCB data sets)

t = the student's t for alpha equal to 0.05 and n-1 degrees of freedom

s^2 = the variance of the data set

n = number of data points

The parametric asymmetric prediction interval assumes that the data follows a lognormal distribution, and the prediction interval is computed using the formula shown in Equation 13.

$$PI = \exp(\overline{y} + t(0.05, n-1) \cdot \sqrt{s_y^2 + s_y^2 / n} \text{ ....} \textit{Equation 13}$$

where y = ln(x), $\overline{y}$ is the mean and s_y^2 is the variance of the logarithms

$\overline{y}$ = the mean logarithm

s^2_y =the variance of the logarithms

n = number of data points

t = the student’s t for alpha equal to 0.05 and n-1 degrees of freedom

The non-parametric prediction interval is computed from statistical analysis of the data and is representative of the 95th percentile of the dataset.

Similarly, three methods were used to estimate the upper bound confidence interval for each dataset based on the distribution of the data. The following formula, Equation 14, was used to compute the 95 percent UCL on datasets exhibiting a normal distribution:

$$UCL = \bar{X} + t\ (s/\sqrt{n}) \quad \ldots\ldots \text{Equation 14}$$

where $\bar{X}$ = arithmetic mean of the sample data set for the compound of concern,
s = sample standard deviation of the sample data set for the compound of concern,
t = the student’s t statistic for the 95 percent confidence interval for a one tailed distribution. The t-statistic is a function of the number of samples collected, and;
n = number of samples in the data set

For data sets that exhibited a lognormal distribution, the 95 percent UCL was computed using Equation 15, shown below.

$$UCL = EXP\ [\ \bar{X} + 0.50s2 + Hs/\sqrt{n-1}\ ] \quad \ldots\ldots \text{Equation 15}$$

where X = arithmetic average of the natural log-transformed data;
s^2 = variance of the log-transformed data;
s = sample standard deviation of the log-transformed data;
H = H statistic. The H value differs from the t-values because the formula is designed to estimate the UCL on the basis of the log-transformed data. H is a function of the standard deviation of the log-transformed data and the number of samples in the data set. H was taken from a standard table of calculated values (Gilbert, 1987) or linearly interpolated between values given in the table where necessary; and
n = the number of samples in the data set.

For non-parametric data sets, the 95 percent UCL was calculated using ProUCL (USEPA, 2001). ProUCL does provide several types of non-parametric UCLs. As recommended in the User’s Guide for ProUCL, the 95 percent Chebyshev UCL was selected for this analysis since all of the datasets that were neither normally distributed nor lognormally distributed had a standard deviation (σ) less than 1.

The Shapiro-Wilk test (W-test) and D'Agostino's test were used to determine the best data relationship among each of the monthly data sets for all four stations so the prediction interval and the 95 percent UCL could be calculated, based on the determined distribution of the data, using one of the above-listed equations. For months in which the number of samples was less than 50 (n<50), the W-test was used to evaluate the distribution of the dataset. For months in which the number of samples was greater than 50 (n>50), D'Agostino's Test was used to evaluate the distribution of the dataset.

The W-test generates a W-value and an ln-W value, which are then compared to the 5 percent W critical value. If the calculated W-value is greater than this critical value, the distribution is determined to be normal at the 5 percent confidence level. Similarly, if the computed ln-W value is greater than the critical value, then the data distribution is determined to be lognormal. In the event that the computed W-value and ln-W value are both greater than the critical value, the larger computed value (i.e., the W-value or the ln-W value) will determine the data distribution. If both of the computed values (i.e., the W-value and the ln-W value) are less than the critical W value, then the distribution is determined to be non-parametric.

For monthly and consolidated monthly datasets with more than 50 samples, D'Agostino's test was used to compute a Y-value and an ln-Y value, which are then compared to a range of set critical values. The distribution is considered to be normal when the calculated Y-value is within the range of critical Y-values. The data set is determined to be lognormal when the ln-Y value is within the range of critical ln-Y values. If the computed Y-value and ln-Y value satisfy both the normal distribution and lognormal distribution requirement, then the value representing the smallest absolute value of Y dictates the data distribution. Lastly, if the Y-value and ln-Y-value do not meet the criteria that are indicative of normal or lognormal distribution, then the data set is determined to be non-parametric.

For monthly and consolidated monthly datasets determined to have a normal distribution of data, the prediction interval and the 95 percent UCL were computed from Equations 12 and 14, respectively, to determine the baseline concentrations for TSS and PCB at each station. Similarly, for monthly and consolidated monthly datasets determined to have a lognormal distribution of data, the prediction interval and the 95 percent UCL were computed from Equations 13 and 15, respectively, to determine the baseline concentrations for TSS and PCB at each station. Lastly, as described above, the 95th percentile of the dataset was computed to determine the prediction interval baseline, and ProUCL was used to determine the 95 percent UCL baseline for months and consolidated months where the data were distributed in a non-parametric relationship.

These statistical tests were performed for each of the seven dredging months and consolidated dredging months at each of the four monitoring stations. The results are presented in Table 2, and were indicative of the following at each of the monitoring stations:

- A prediction interval baseline for PCB and TSS per month and consolidated months

- A 95 percent UCL baseline for PCB and TSS per month and consolidated months

The results for each monitoring station are included below, along with a discussion of the estimated baseline concentrations for the dredging season. Ultimately, these baselines will be compared against PCB and TSS measurements made during dredging operations to assess potential dredging-related impacts.

Note that only the samples associated with high flow events were excluded during the data analysis procedure. No data were excluded as outliers. Some elevated values found in the dataset are representative of values that could occur during the remediation, thereby making it inappropriate to treat them as outliers, although in a strict mathematical sense the values might fall into that category. This analysis is also intended to show the approach used to estimate the baseline. The final baseline values will be calculated using Baseline Monitoring Program data, which is scheduled for collection between 2004 and 2005. When the baseline data is available, some outlier analysis methods, such as Dicson analysis and Mahanalobis Distance, may be used to identify the outliers based on engineering judgment in order to provide a baseline level for addressing the Hudson River condition prior to dredging.

For the datasets in which PCBs were determined to be correlated with flow, the prediction interval and UCL of the PCB concentration were estimated using the same method that was used for datasets where concentration is not correlated with flow. The prediction interval and UCL values generated by this method are similar to the results obtained assuming a flow of 4000 cfs and using the equations listed in Table 1. A flow rate of 4000 cfs is assumed to be the average velocity that will be observed during the dredging period. Therefore, the values generated by this simple (no flow involvement) method adequately reflect the PCB concentration under the average river flow conditions.

It was also found that the estimated prediction interval and UCL values calculated for velocities of 2000 cfs and 8000 cfs were approximately within 20 percent of the values calculated for a velocity of 4000 cfs. The 20 percent variance is not a pronounced difference when considering other uncertainties involved in the analysis.

Lastly, it was thought that the measurement of the flow rate and application of the above formulas may be impractical tasks for the dredging operator to perform in the field in order to determine the PCB concentration. A developed baseline with PCB concentrations defined for each month and set of months over the dredging season would be the easiest and the most practical method for field application. It was concluded that the baseline levels (prediction interval and UCL) are all estimated based on the assumption that there is no correlation between flow and concentrations. The flow-independent prediction interval and UCL values are calculated and summarized in Table 2 for each month and consolidated months at each station.

It should be noted that all the analyses listed above are intended to demonstrate the approach used to estimate the baseline. When the new baseline data is available, the same type of analyses will be conducted, and the results may suggest some ways to simplify the process. The baseline level will be finalized based on both the new baseline level data and historic data.

3.2 Results and Discussion

Ft. Edward Monitoring Station

Water quality data for TSS were analyzed individually for May, June, July, and August, and jointly over the period of September through November. PCB data were analyzed individually for May and June, jointly over the period of July through September, and jointly over the period of October and November. These results are shown on Table 2.

As shown in Table 2, data collected for TSS during the months of May, July, and September through November have a normal distribution. In contrast, the data collected for TSS during the month of June has a non-parametric distribution and that collected for August has a lognormal distribution.

Figure 16 indicates that the prediction interval baseline generally tends to correspond to the maximum measured TSS concentration for a particular month, with the exception of months where elevated TSS data points exist. June and August each have one TSS data point that contains one TSS sample result that is more than twice the concentration of all other TSS results obtained for these months. For these two instances, the prediction interval baseline and the 95 percent UCL are representative of the majority of the data. It should also be noted that the 95 percent UCL is greater than the prediction interval for the month of June. However, for all other months, the prediction interval represents the upper limit TSS baseline concentration.

The prediction interval baseline is highest in August, with a concentration of 5.5 mg/L. In the months prior to August, the prediction interval is approximately 4.0 mg/L, on average, while for the remainder of the dredging season, in the months of September through November, the prediction interval decreases to 3.0 mg/L and levels out. The 95 percent UCL baseline follows the same seasonal distribution as the prediction interval, but reaches a maximum concentration of 5.7 mg/L in June. This baseline then decreases by 3 mg/L and fluctuates through July and August, eventually leveling out at 1.8 mg/L during the period of September through November.

The estimated 95 percent UCL baseline for TSS appears to be consistent with the mean TSS data concentration for each month, and the estimated prediction interval appears to be consistent with the upper bound measured TSS concentration for each month, with the exception of June and August where two outlying TSS concentrations exist (as previously discussed). It can be concluded that if a single TSS measurement made during dredging is greater than the prediction interval concentrations, or if the average of a set quantity of measured samples are greater than the 95 percent UCL baseline, the measured TSS concentration is most likely a result of the dredging operation.

An analysis of total PCB data collected during the proposed dredging season at the Ft. Edward monitoring station indicated that all data were representative of a non-parametric distribution. The results are presented in Table 2. The estimated baselines were plotted against the total PCB monthly datasets. These relationships are presented in Figure 17.

Figure 17 indicates that total PCB concentrations measured for this station were greatest in the months of July through August, and that the lowest concentrations were measured during the month of May. Data indicate that the estimated prediction interval baseline corresponds to the upper bound total PCB concentrations measured each month. The prediction interval baseline is the highest for total PCBs during the months of July through September, and lowest total PCB concentration during the month of May. The prediction interval baseline decreases by 15 ng/L from September to October and levels out at 19 ng/L for the period of October through November. It can be concluded that any PCB measurements with a concentration greater than the prediction interval can most likely be attributed to dredging.

The 95 percent UCL baseline result per month is always less than the prediction interval baseline result, and tends to correspond to the mean total PCB concentration per month, as shown in Figure 17. This lowest baseline concentration on the curve occurs during the month of May and the maximum concentration occurs during the month of June. Baseline values occur during the months of July through September, and are lower in concentration than the maximum estimated concentration by approximately 0.4 ng/L. The 95 percent UCL baseline concentration decreases to 10.4 ng/L in October, a result that is 8 ng/L less than the September level. This concentration remains constant during the months of October and November. It can be concluded that if the average of the PCB measurements reported during dredging activities exceeds the 95 percent UCL, it is most likely attributable to the dredging operation.

Thompson Island Dam (TID) Monitoring Stations

There are two GE monitoring stations located at the TI Dam: TID–West, located on the west side of the TI Dam near the shore, and TID-PRW2, located in the channel section of the river near the dam. TSS and total PCB monthly data and consolidated monthly data were analyzed for each of these stations. Subsequently, the prediction interval and the 95 percent UCL baseline were determined for each station's monthly and monthly consolidated TSS and total PCB data.

TID-West Monitoring Station

As shown in Table 2, TSS data analyzed at the TID-West station exhibited a non-parametric relationship for May and June. A lognormal relationship was determined for consolidated monthly data representing the period July through October and also for the month of November. The estimated prediction interval and 95 percent UCL are shown in Figures 18 and 19.

Figure 18 compares the monthly TSS data at the TID-West station with the estimated prediction interval baseline and the estimated 95 percent UCL baseline. This figure depicts that the prediction interval baseline is always greater than the 95 percent UCL baseline and tends to follow the maximum measured TSS concentration reported for each dredging month. Exceptions to this conclusion exist during months where elevated TSS concentrations exist, in this case May, June, July, and August. In these instances, the prediction interval baseline tends to correspond to a data point midway between the majority of the sample results and the elevated data point (i.e., the prediction interval tends to fall at a data point consistent with the maximum concentration of samples, excluding the outlier for these months). The maximum TSS prediction interval baseline value occurs during the month of May. This baseline decreases through June to approximately 5 mg/L during the month of July. The baseline remains level until October, and then increases slightly to 6.4 mg/L during the month of November.

The 95 percent UCL baseline shown in Figure 18 tends to follow the mean TSS concentration in each dredging month, with a maximum estimated concentration occurring in May and June and a minimum concentration occurring during the months of July through October.

The total PCB data reported for this station follow a lognormal distribution for May, June, August, and September. Total PCB data reported for July were determined to follow a normal distribution, and total PCB data for the period of October through November were determined to represent a non-parametric relationship.

As shown in Figure 19, the estimated prediction interval baseline consists of total PCB concentrations greater than those estimated for the 95 percent UCL baseline. The prediction interval maximum total PCB result occurs during the months of May and June, with a total PCB concentration of approximately 370 ng/L. The prediction interval baseline then decreases through July (211 ng/L) and August (150 ng/L), and reaches a minimum value of 120 ng/L during the month of September. During the months of October and November, the prediction interval baseline total PCB concentration increases to 300 ng/L. It was also noted that the prediction interval tends to be consistent with the maximum total PCB data concentration reported for each dredging month, on average.

The estimated 95 percent UCL baseline for total PCBs at the TID-West station tends to correspond with the mean total PCB concentration for most dredging months, on average. This can be seen in Figure 19. This baseline concentration is approximately 200 ng/L from May to June, and decreases through July (150 ng/L) and August (106 ng/L). The baseline reaches a minimum concentration of 83 ng/L in September, and then increases to a maximum concentration of 241 ng/L during the period of October and November. It is noted that the 95 percent UCL baseline follows the same seasonal variation as the estimated prediction interval baseline.

TID-PRW2 Monitoring Station

TSS data collected at this station exhibited a lognormal distribution for the month of May and for the period of July through November. Data indicated a non-parametric distribution for the month of June.

Figure 20 shows that the estimated prediction interval baseline tends to generally correspond with the maximum monthly TSS concentration for all months, with the exception of May, June, July, and August, where elevated TSS data exist. In these instances, the estimated prediction interval tends to represent the maximum TSS concentration associated with the majority of the data points. The prediction interval baseline concentration reaches a maximum during the month of June (15 mg/L) and decreases to 5 mg/L for the months of July through November.

The estimated 95 percent UCL baseline for TSS, shown in Figure 20, tends to correspond with the monthly mean TSS concentration for all months, with the exception of May and June. The baseline reaches a maximum during June (14 mg/L TSS), and decreases to a concentration of 2 mg/L for the months of July through November.

The total PCB data indicated that the months of May, June, October, and November all exhibited a normal data distribution, and that the datasets for the consolidated months of July and August and the month of September each exhibited a lognormal data distribution.

Figure 21 indicates that the estimated prediction interval fluctuates throughout the proposed dredge season, with a minimum concentration in May and June and a maximum concentration through the period of July and August. The estimated total PCB concentration in September and November are just above the minimum estimated concentration in May and June, but less than the estimated baseline value for the month of October. For most months, with the exception of May and June, the estimated prediction interval baseline tends to correspond with the maximum monthly total PCB concentration. This relationship is not observed during May and June because the total PCB concentration tends to vary with the flow rate. The prediction interval was estimated for a low flow condition of less than 5,000cfs and for a high flow condition greater than 5,000cfs. A greater range of PCB concentrations is evident during May and June. Additionally, Figure 21 indicates that the prediction interval baseline varies during May and June, and that low flow conditions result in a 100-ng/L PCB increase in the water column. It was noted that while the estimated prediction interval value for May and June shown is representative of a flow rate greater than 5,000 cfs, the prediction interval baseline data point is representative for a flow rate less than 5,000 cfs. This is also indicated in Table 2.

The estimated total PCB 95 percent UCL baseline follows the same seasonal trend as the estimated prediction interval baseline. This relationship is presented in Figure 21. The minimum estimated 95 percent UCL baseline concentration of approximately 45 ng/L occurs during May and June. However, under low flow conditions, this value could increase by almost 60 ng/L. This data point is shown on Figure 21. The maximum total PCB 95 percent UCL baseline value of 70 ng/L occurs during July and August. The 95 percent UCL baseline for total PCBs then decreases to 50 ng/L in September, increases to 65 ng/L in October, and decreases during the month of November to a total PCB concentration of 45 ng/L. Generally, the total PCB 95 percent estimated UCL baseline tends to correspond with the mean total PCB concentration for each month.

Schuylerville Monitoring Station

Monthly TSS data for the Schuylerville monitoring station was determined to have a lognormal distribution for May and for the period July through November. As indicated in Figure 22, the prediction interval TSS baseline concentration in May is approximately 7 mg/L, and increases to its maximum value of 11 mg/L during the month of June. The estimated prediction interval baseline then decreases to a TSS concentration of approximately 5 mg/L, where it remains for the period of July through November.

The estimated TSS 95 percent UCL baseline for Schuylerville follows the same seasonal trend as the estimated prediction interval, as shown in Figure 22. The estimated 95 percent UCL baseline reaches a maximum TSS concentration of approximately 10 mg/L during the month of June, and then decreases to a constant TSS concentration of 2 mg/L for the period July through November, representative of the minimum estimated 95 percent UCL baseline TSS concentration.

Total PCB results indicate that data collected for May, June, August, September, and November exhibit a lognormal distribution, and that the total PCBs dataset for the month of July exhibits a non-parametric distribution. Data for the month of October exhibit a normal data distribution.

As shown in Figure 23, both the estimated prediction interval and the 95 percent UCL baseline for total PCBs have a maximum concentration during the months of May and June. Both estimated total PCB baselines then fluctuate through the remainder of the proposed dredge season, with a minimum baseline value for both baseline curves occurring during the month of September and corresponding to a total PCB concentration of 85 ng/ L total PCBs (prediction interval) and 60 ng/L total PCBs (95% UCL baseline). As noted previously at other monitoring stations, the prediction interval baseline tends to be consistent with the maximum monthly total PCB concentration. Except for the months of May and June, the 95 percent UCL baseline tends to be consistent with the mean monthly total PCB concentration.

4.0 References

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Tables

Table 1. PCB versus Flow Correlation Analysis Based on the Fit Curve Generated from Plot

	May and June at TID W	May and June Low Flow (<5000 cfs) at TID PRW2	May and June at Schuylerville
Fit curve	Y = 283.23 - 0.026946x	Y = 186.82 - 0.030192x	Y = 176.19 - 0.012506x
Lower 95% Confidence Limit	Y = 246.5 - 0.015*x - 1.51E-6*x^2	Y = 144 - 8.73E-3*x - 3.56E-6*x^2	Y = 151.16 - 6.97E-3*x - 4.93E-7*x^2
Upper 95% Confidence Limit	Y = 386.95 - 0.0474*x + 1.51E-6*x^2	Y = 229.64 - 5.17E-2*x + 3.56E-6*x^2	Y = 201.22 - 1.80E-2*x +4.93E-7*x^2
Upper 95% Individual Limit	Y = 522.19 - 0.0342*x + 2.85E-7*x^2	Y = 242.14 - 3.72E-2*x + 1.18E-6*x^2	Y = 234 - 0.0138*x + 1.16E-7*x^2

Notes:
Y = PCB concentration
X = Flow (cfs)

Table 2
Statistics Results and Baseline Level of TSS and PCB Concentration at Upper Hudson River Monitoring Stations

	Fort Edward								
	TSS (mg/L)					PCB (ng/L)			
Parameter	May	June	July	August	Sept thru Nov	May	June	July thru Sept.	Oct. & Nov.
n	17	22	21	20	60	25	30	79	48
Minimum Detected	0.5	0.5	0.5	0.5	0.5	5.50	5.50	5.50	5.50
Maximum Detected	4.1	16	4.1	9.3	3.3	18.31	31.41	55.51	21.88
Arithmetic Mean	2	3	2	2	2	9	13	13	8
Standard Deviation	1	3	1	2	1	5	8	11	4
Median	1.9	2.2	2.2	1.95	1.6	5.5	14	12	6
W-Test (n<=50)									
W	0.920	0.429	0.936	0.648		0.657	0.862		0.531
W-LN	0.872	0.783	0.825	0.927		0.641	0.829		0.535
Critical W	0.892	0.911	0.908	0.905		0.918	0.927		0.947
D'Agostino's Test (n>50)									
Y	-1.79	-19.20	-0.20	-10.67	-0.25	-7.33	-1.49	-12.20	-19.66
Yln	-2.19	-8.70	-2.69	-3.16	-1.91	-7.33	-1.15	-3.82	-18.28
UCL 95%	2.2	5.7	2.4	3.1	1.8	12.7	19.7	18.6	10.4
UCL 95% Lognormal	2.6	3.6	3.0	3.1	1.9	10.3	17.3	15.5	8.3
UCL 95% Normal	2.2	4.0	2.4	3.1	1.8	10.2	15.8	15.4	8.6
LCL 95%	1.4	2.2	1.7	1.9	1.4	6.9	10.9	11.6	6.7
LCL 95% Lognormal	1.4	2.2	1.7	1.9	1.4	7.2	11.2	11.6	6.7
LCL 95% Normal	1.4	1.8	1.7	1.7	1.4	6.9	10.9	11.5	6.5
Data Distribution (Normal, Lognormal or non-parametric)	Normal	non-parametric	Normal	Lognormal	Normal	non-parametric	non-parametric	non-parametric	non-parametric
95th percentile	0.5	1.6	3.2	3.7	3.1	16.9	27.7	34.3	19.1
Prediction Interval (Normal)	3.4	8.2	3.9	5.6	3.0	16.8	27.1	31.1	15.1
Prediction Interval (LogNormal)	4.6	6.5	5.8	5.6	3.9	17.5	33.1	32.9	14.0
Prediction interval	3.4	4.2	3.9	5.6	3.0	16.9	27.7	34.3	19.1

Table 2 (cont'd)
Statistics Results and Baseline Level of TSS and PCB Concentration at Upper Hudson River Monitoring Stations

	TID West									
	TSS (mg/L)				PCB (ng/L)					
Parameter	May	June	July thru Oct.	Nov.	May	June	July	August	Sept.	Oct. & Nov.
n	17	24	90	22	24	32	30	29	27	54
Minimum Detected	1.20	1.40	0.50	0.50	24.5	60.1	65.52	49.02	40.00	25.82
Maximum Detected	26.00	36.00	6.50	6.70	813.6	413.4	219.45	164.00	126.25	1424.00
Arithmetic Mean	4	5	2	2	127.6	169.1	138	96	75	127
Standard Deviation	7	7	1	1	160.3	85.8	43	27	22	193
Median	2	3	1	2	81.0	156.5	135	92	73	88
W-Test (n<=50)										
W	0.514	0.454		0.892	0.6	0.9	0.961	0.931	0.962	
W-LN	0.780	0.823		0.930	1.0	0.9	0.943	0.973	0.980	
Critical W	0.892	0.916		0.911			0.927	0.926	0.923	
D'Agostino's Test (n>50)										
Y	-13.07	-18.63	-11.94	-2.89	-14.2	-0.8	0.76	-2.38	-0.42	-34.51
Yln	-4.84	-5.48	-2.12	-1.37	-0.7	0.8	0.10	-1.35	0.18	-8.09
UCL 95%	11.5	11.5	1.9	3.3	181.3	205.3	150.9	105.8	83.1	241.4
UCL 95% Lognormal	6.6	6.2	1.9	3.3	181.3	205.3	154.9	105.8	83.1	134.8
UCL 95% Normal	7.2	7.5	1.8	2.9	183.6	194.8	150.9	104.9	81.9	170.9
LCL 95%	2.6	3.4	1.5	1.9			124.3	88.8	68.2	97.7
LCL 95% Lognormal	2.6	3.4	1.5	1.9	90.5	146.0	124.9	88.8	68.2	97.7
LCL 95% Normal	1.6	2.4	1.4	1.8	71.5	143.4	124.3	88.0	67.6	82.8
Data Distribution (Normal, Lognormal or non-parametric)	non-parametric	non-parametric	Lognormal	Lognormal			Normal	Lognormal	Lognormal	non-parametric
95th percentile	18.8	15.5	3.6	4.3	264.1	280.6	202.2	151.1	113.7	297.4
Prediction Interval (Normal)	16.4	17.8	3.5	4.9	407.9	316.8	211.6	142.7	112.3	453.4
Prediction Interval (LogNormal)	12.6	12.2	3.9	6.4	367.8	368.3	233.3	148.7	119.2	272.1
Prediction interval	18.8	15.5	3.9	6.4	367.8	368.3	211.6	148.7	119.2	297.4

Table 2 (cont'd)
Statistics Results and Baseline Level of TSS and PCB Concentration at Upper Hudson River Monitoring Stations

	TID PRW								
	TSS (mg/L)			PCB (ng/L)					
Parameter	May	June	July thru Nov.	May&June Low Flow (<5000 cfs)	May&June High Flow (>5000 cfs)	July and August	Sept.	Oct.	Nov.
n	14	13	75	19.0	21	40	19	23	20
Minimum Detected	0.50	1.80	0.50	32.0	15.58	28.30	26.20	23.24	20.00
Maximum Detected	24.80	29.50	6.60	166.4	67.05	141.76	65.44	93.26	64.28
Arithmetic Mean	4	5	2	96.8	42	65	44	57	40
Standard Deviation	6	7	1	35.8	15	21	13	20	14
Median	2	3	2	107.1	41	62	44	55	39
W-Test (n<=50)					3.707150762				
W	0.468	0.434		1.0	0.968	0.936	0.929	0.970	0.943
W-LN	0.896	0.729		0.9	0.914	0.992	0.934	0.937	0.924
Critical W	0.874	0.866			0.908	0.940	0.901	0.914	0.905
D'Agostino's Test (n>50)									
Y	-13.66	-13.99	-10.21	0.2	0.14	-2.85	0.43	0.32	0.50
Yln	-3.26	-6.17	-1.73	-0.9	-1.50	-0.41	0.58	-0.79	0.12
UCL 95%	6.5	14.0	2.2	111.1	47.1	70.9	50.1	64.2	45.4
UCL 95% Lognormal	6.5	7.4	2.2	118.9	50.2	70.9	50.1	67.3	47.5
UCL 95% Normal	6.7	8.7	2.1	111.1	47.1	70.3	48.9	64.2	45.4
LCL 95%	2.2	3.2	1.6		36.0	59.4	39.1	50.2	34.4
LCL 95% Lognormal	2.2	3.2	1.6	83.5	36.2	59.4	39.1	50.6	34.9
LCL 95% Normal	0.9	1.4	1.6	82.6	36.0	58.8	38.6	50.2	34.4
Data Distribution (Normal, Lognormal or non-parametric)	Lognormal	non-parametric	Lognormal		Normal	Lognormal	Lognormal	Normal	Normal
95th percentile	12.0	15.0	4.5	148.1	64.0	93.5	64.0	86.3	61.4
Prediction Interval (Normal)	15.1	18.8	4.1	160.5	67.6	101.2	66.7	91.6	65.0
Prediction Interval (LogNormal)	11.7	13.1	4.6	189.6	80.2	106.4	71.8	104.9	73.5
Prediction interval	11.7	15.0	4.6	160.5	67.6	106.4	71.8	91.6	65.0

Table 2 (cont'd)
Statistics Results and Baseline Level of TSS and PCB Concentration at Upper Hudson River Monitoring Stations

	Schuylerville								
	TSS (mg/L)			PCB (ng/L)					
Parameter	May	June	July thru Nov.	May and June	July	August	Sept.	Oct.	Nov.
n	10	12	74	34.0	19	21	17	23	22
Minimum Detected	1.60	2.00	0.50	43.0	61.00	50.18	26.30	34.94	38.94
Maximum Detected	8.00	17.50	7.80	211.3	157.18	107.00	78.22	111.64	105.25
Arithmetic Mean	3	5	2	106.5	82	74	52	75	67
Standard Deviation	2	4	1	41.7	20	17	15	24	20
Median	3	3	2	94.9	81	71	49	75	63
W-Test (n<=50)									
W	0.739	0.548		0.9	0.694	0.953	0.948	0.936	0.933
W-LN	0.909	0.813		1.0	0.830	0.971	0.955	0.881	0.965
Critical W	0.842	0.859			0.901	0.908	0.892	0.914	0.911
D'Agostino's Test (n>50)									
Y	-5.08	-10.41	-12.01	-0.5	-9.00	0.04	0.10	0.13	-0.56
Yln	-1.63	-4.31	-1.52	0.6	-5.09	0.59	-0.10	-1.48	0.24
UCL 95%	4.4	9.9	2.2	121.3	102.7	80.6	60.1	83.8	75.2
UCL 95% Lognormal	4.4	6.5	2.2	121.3	89.5	80.6	60.1	88.0	75.2
UCL 95% Normal	4.3	6.8	2.1	118.6	90.3	79.9	58.5	83.8	74.1
LCL 95%	2.5	3.4	1.6		75.8	67.9	46.4	66.5	60.4
LCL 95% Lognormal	2.5	3.4	1.6	95.5	75.8	67.9	46.4	66.8	60.4
LCL 95% Normal	2.1	2.5	1.6	94.4	74.0	67.4	45.8	66.5	59.6
Data Distribution (Normal, Lognormal or non-parametric)	Lognormal	non-parametric	Lognormal	Lognormal	non-parametric	Lognormal	Lognormal	Normal	Lognormal
95th percentile	6.1	10.8	4.4	175.9	98.7	105.0	73.7	108.2	40.0
Prediction Interval (Normal)	6.7	12.4	4.2	178.1	118.7	103.1	79.1	117.6	101.6
Prediction Interval (LogNormal)	7.0	10.8	4.7	194.6	115.9	106.7	85.5	135.7	107.2
Prediction interval	7.0	10.8	4.7	194.6	98.7	106.7	85.5	117.6	107.2

Figures

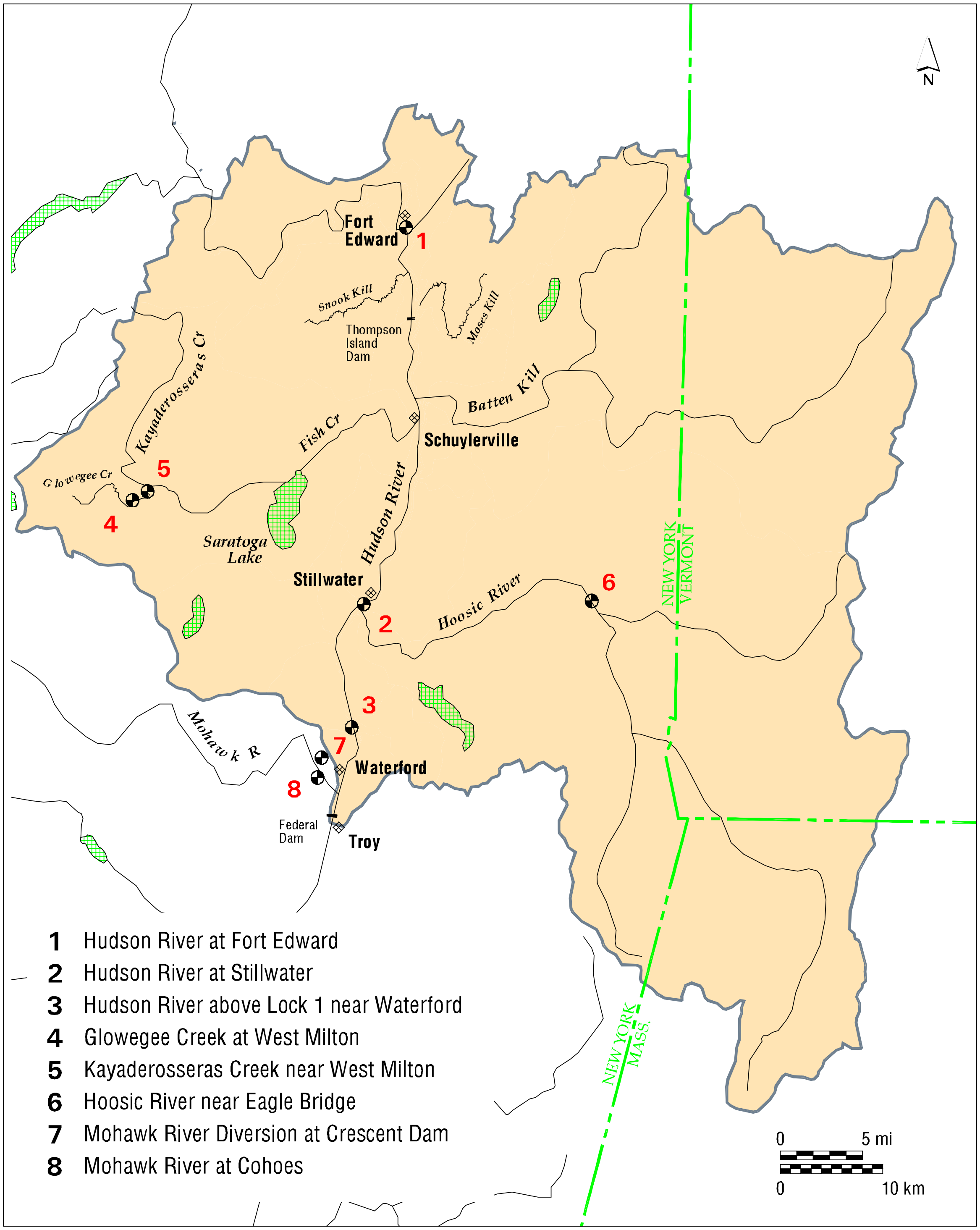

Figure 1. Upper Hudson River Basin USGS Flow Gage Stations Used in HUDTOX Modeling.

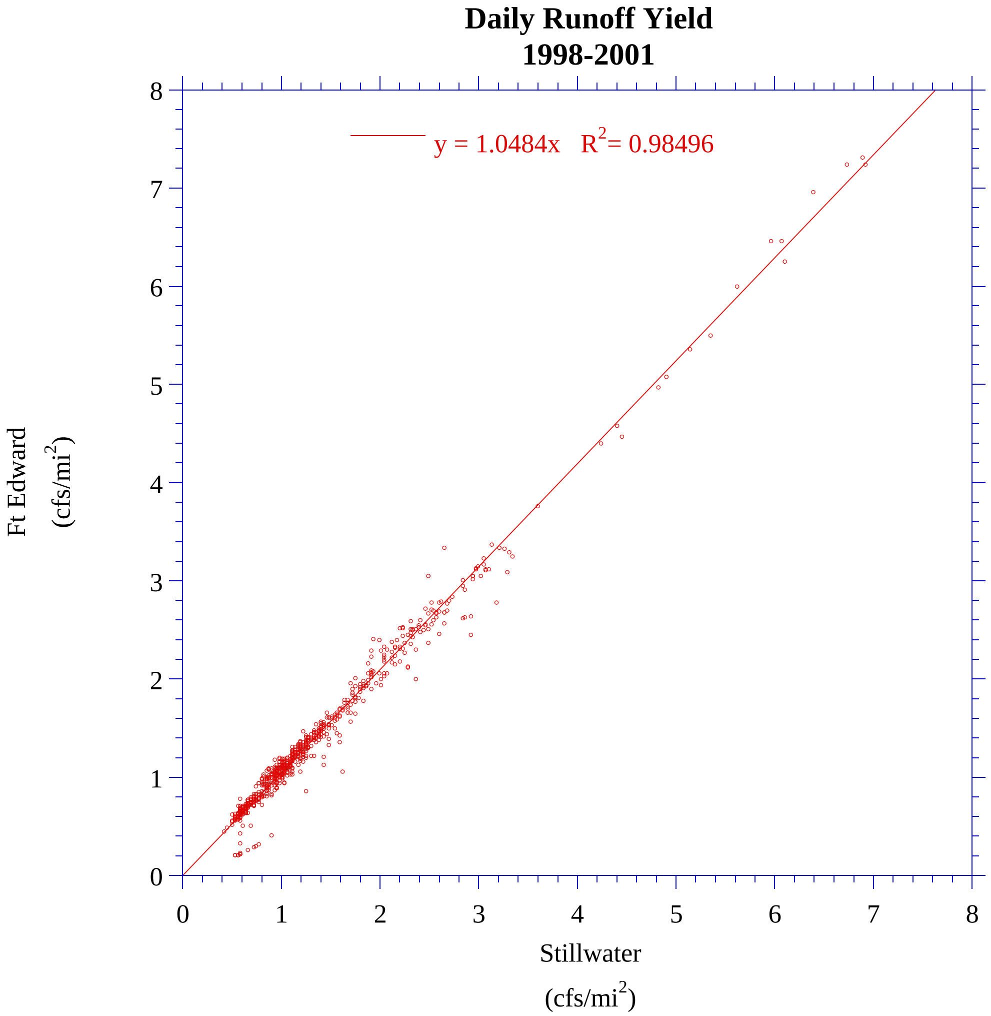

Figure 2. Stillwater versus Ft. Edward Daily Runoff Yield 1998-2001

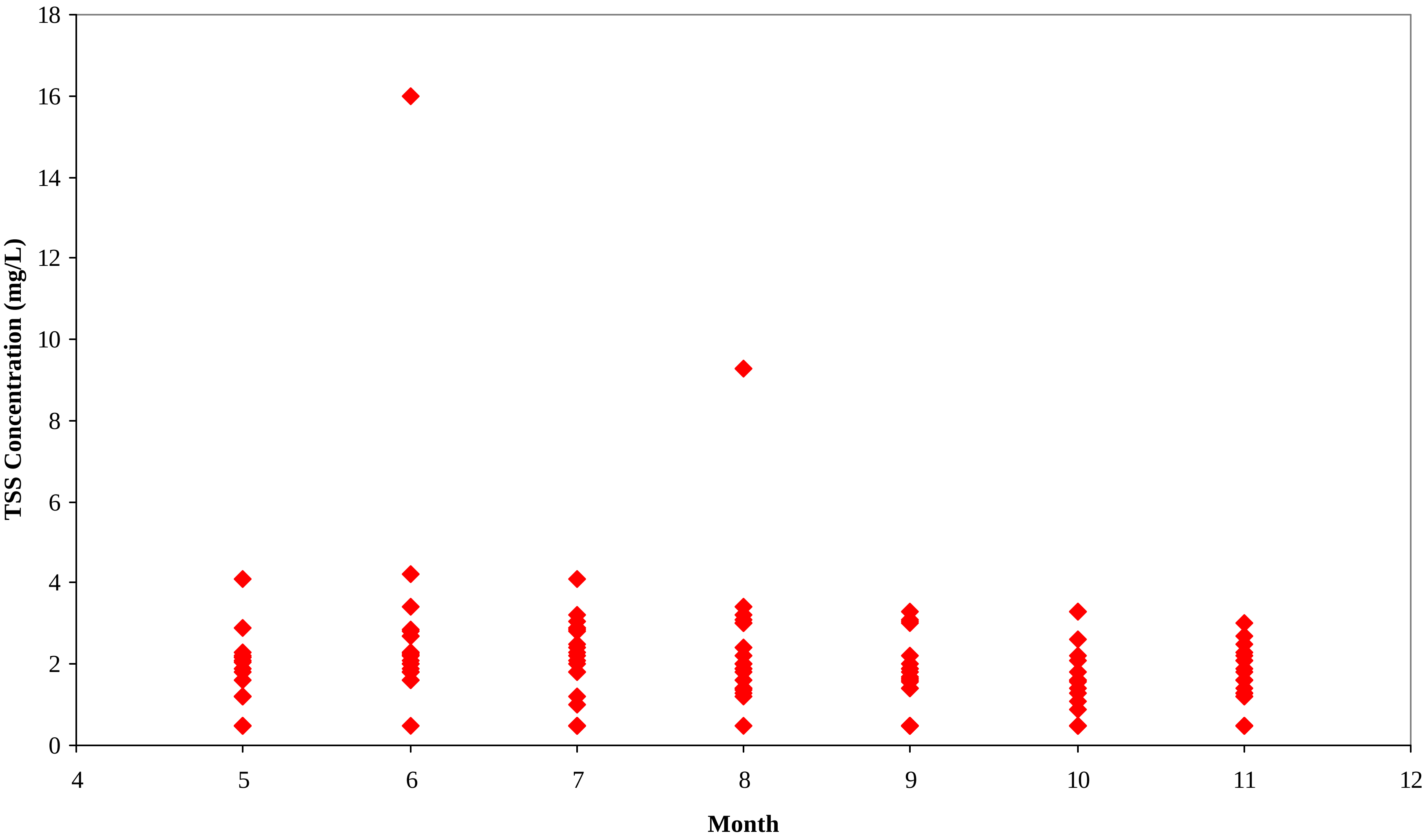

Figure 3. Fort Edward Station Monthly TSS Concentration Variation

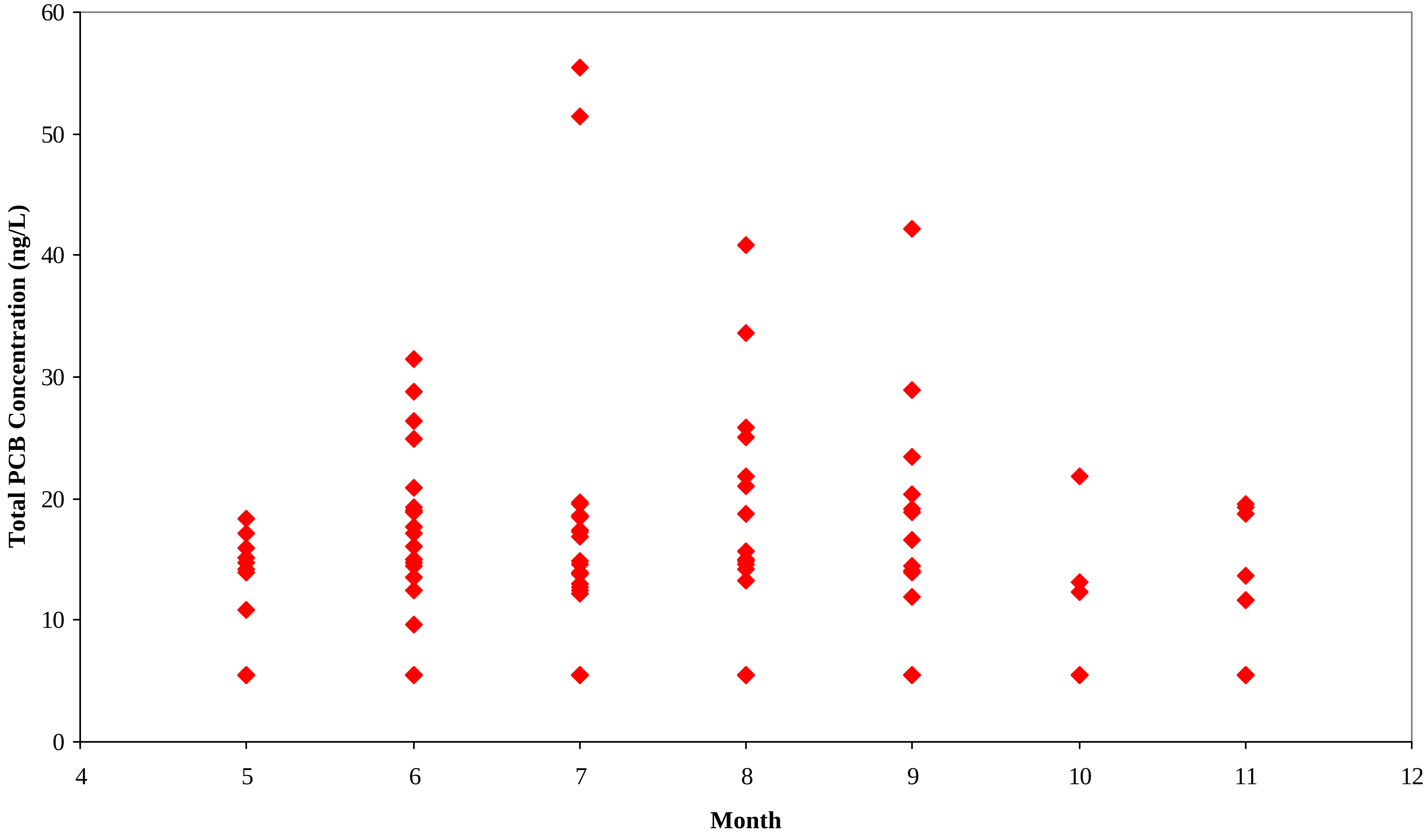

Figure 4. Fort Edward Station Monthly PCB Concentration Variation

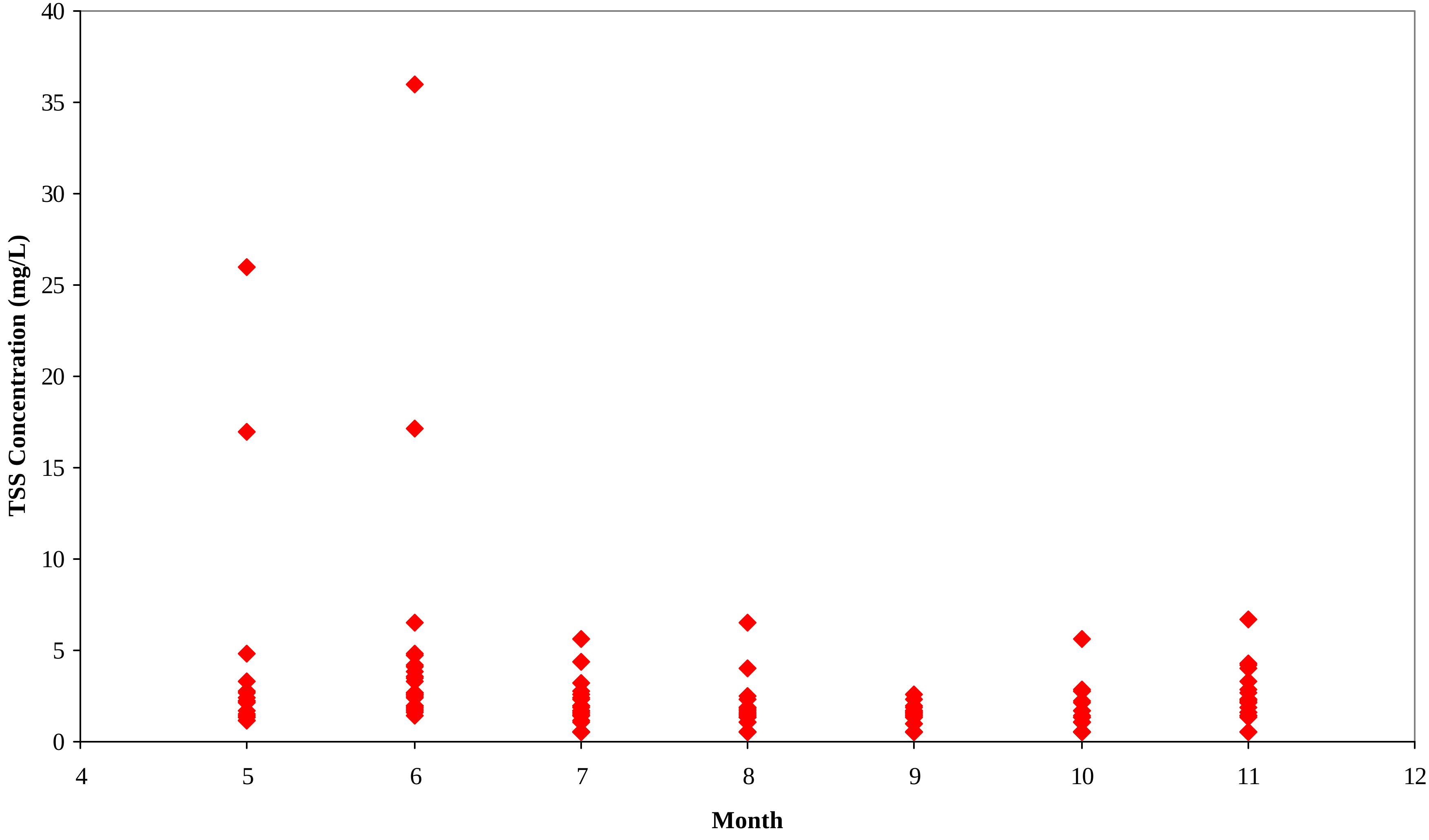

Figure 5. TID-West Station Monthly TSS Concentration Variation

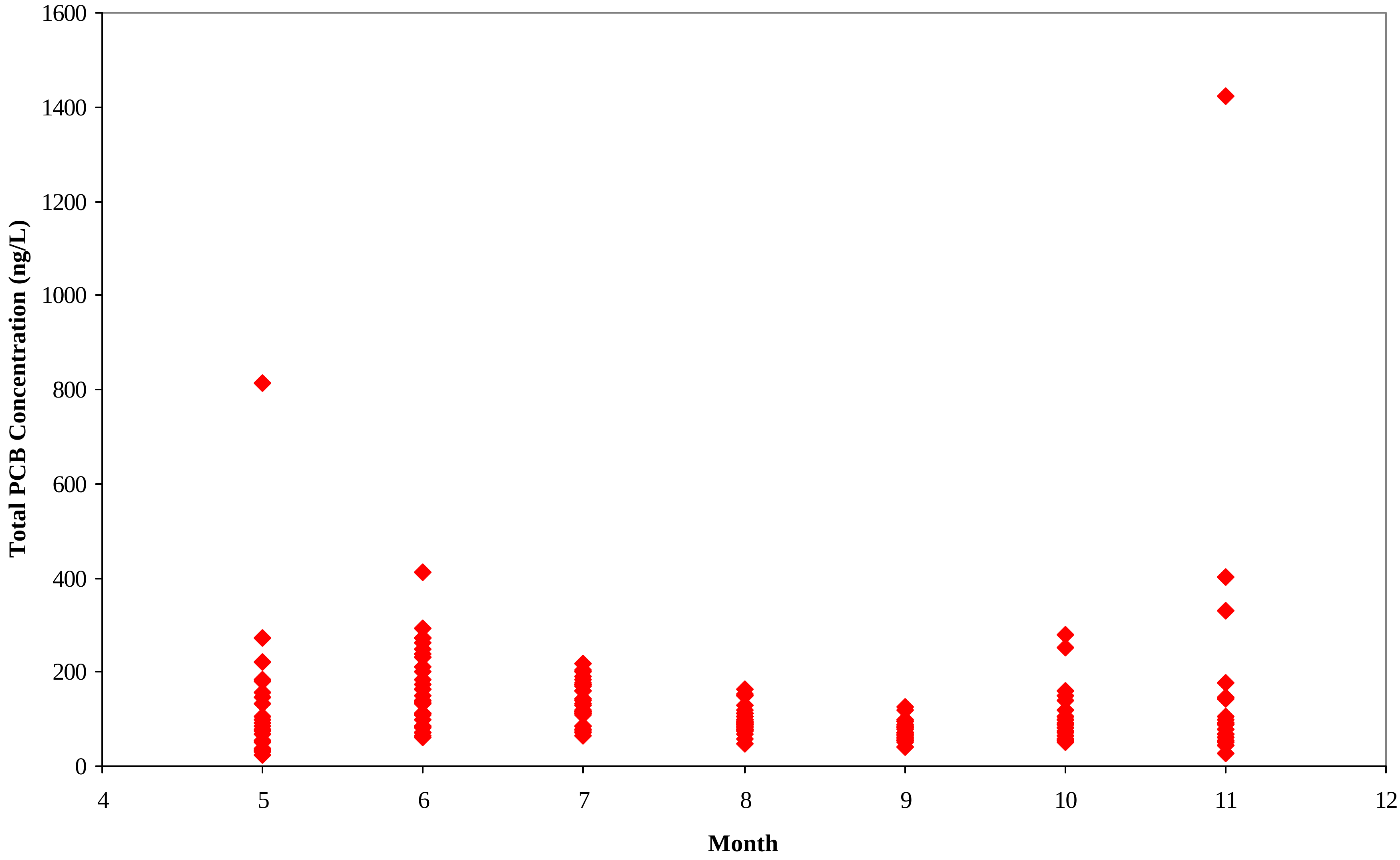

Figure 6. TID-West Station Monthly Total PCB Concentration Variation

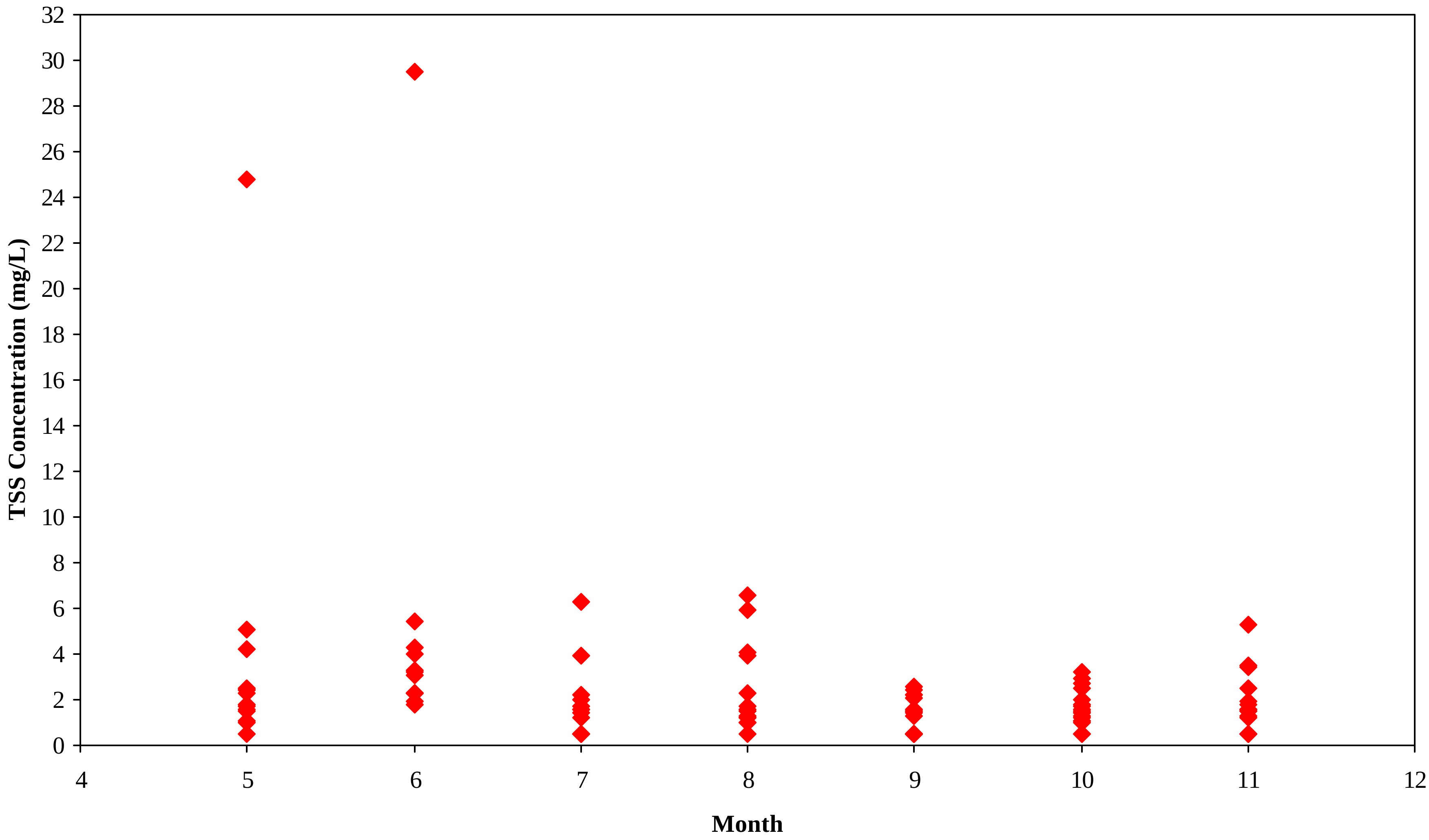

Figure 7. TID-PRW Station Monthly TSS Concentration Variation

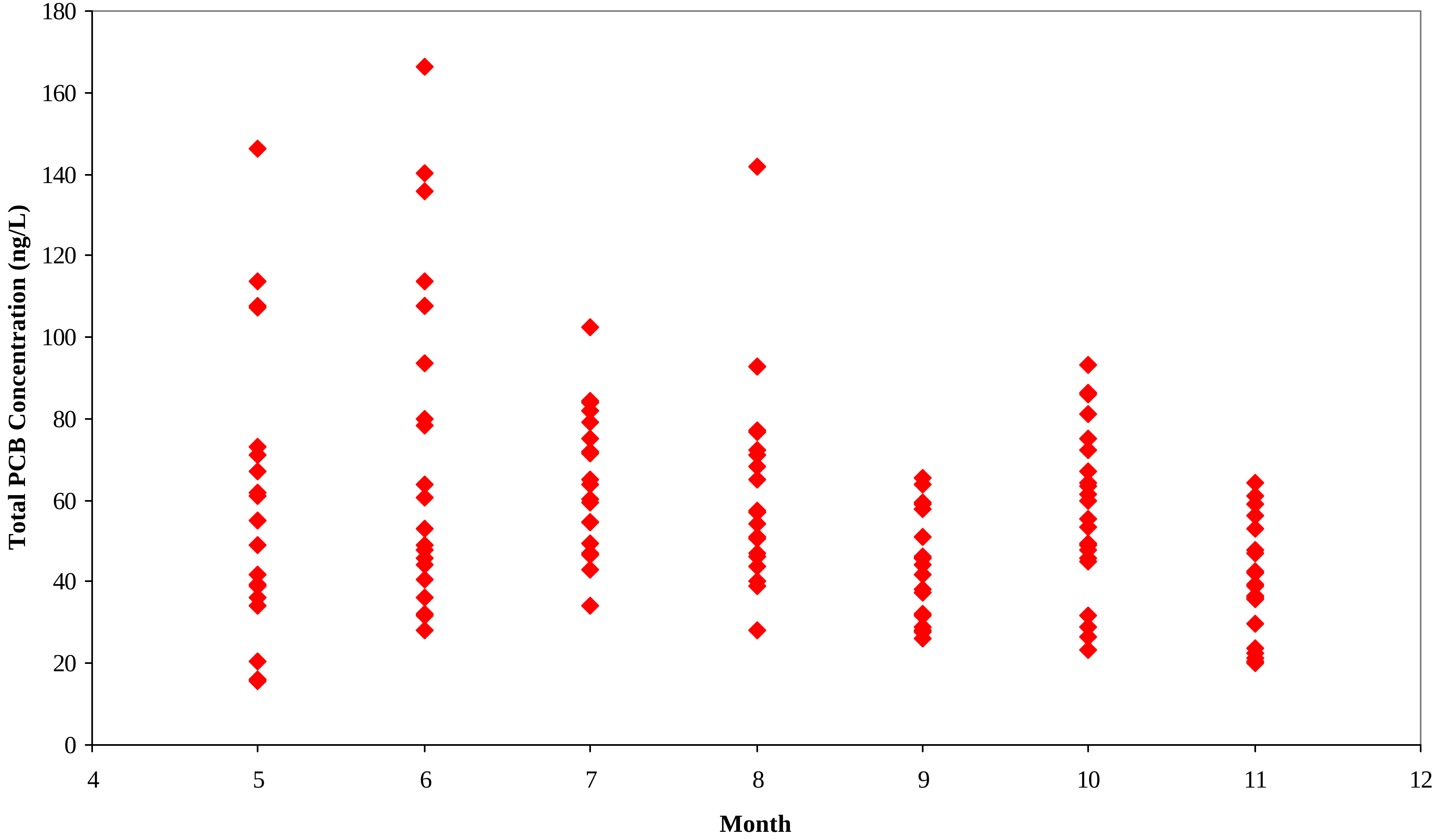

Figure 8. TID-PRW Station Monthly Total PCB Concentration Variation

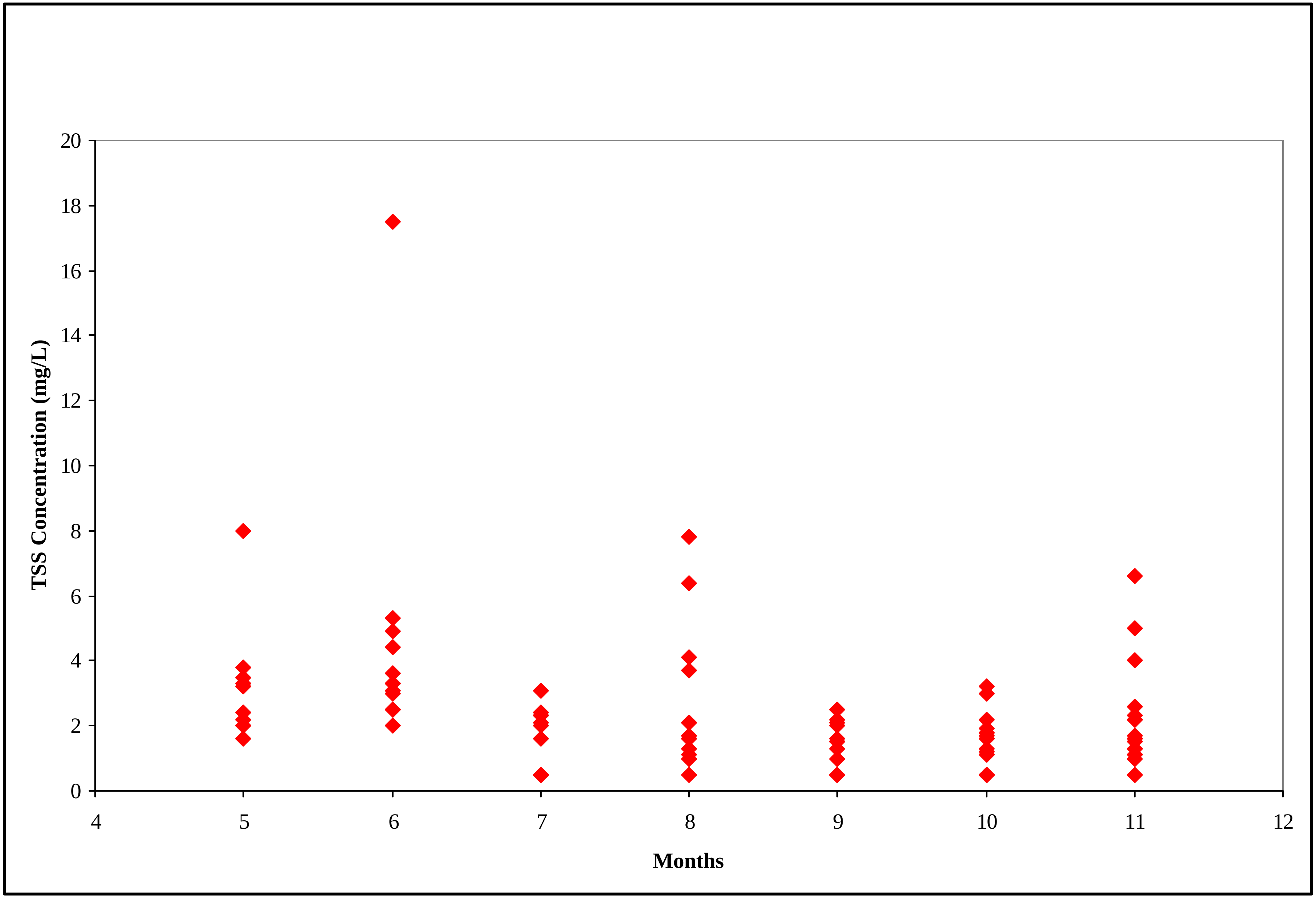

Figure 9. Schuylerville Station Monthly TSS Concentration Variation

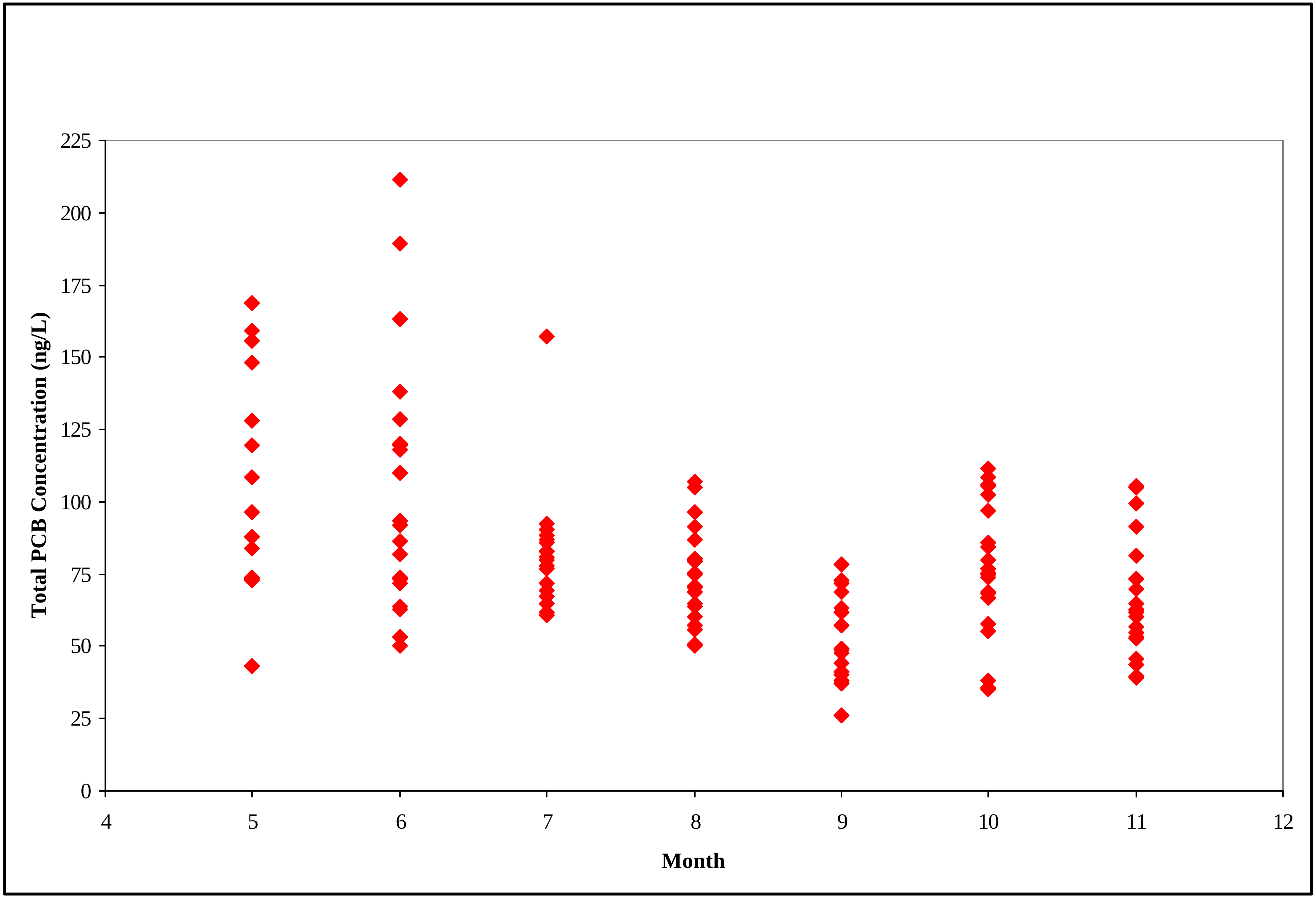

Figure 10. Schuylerville Station Monthly Total PCB Concentration Variation

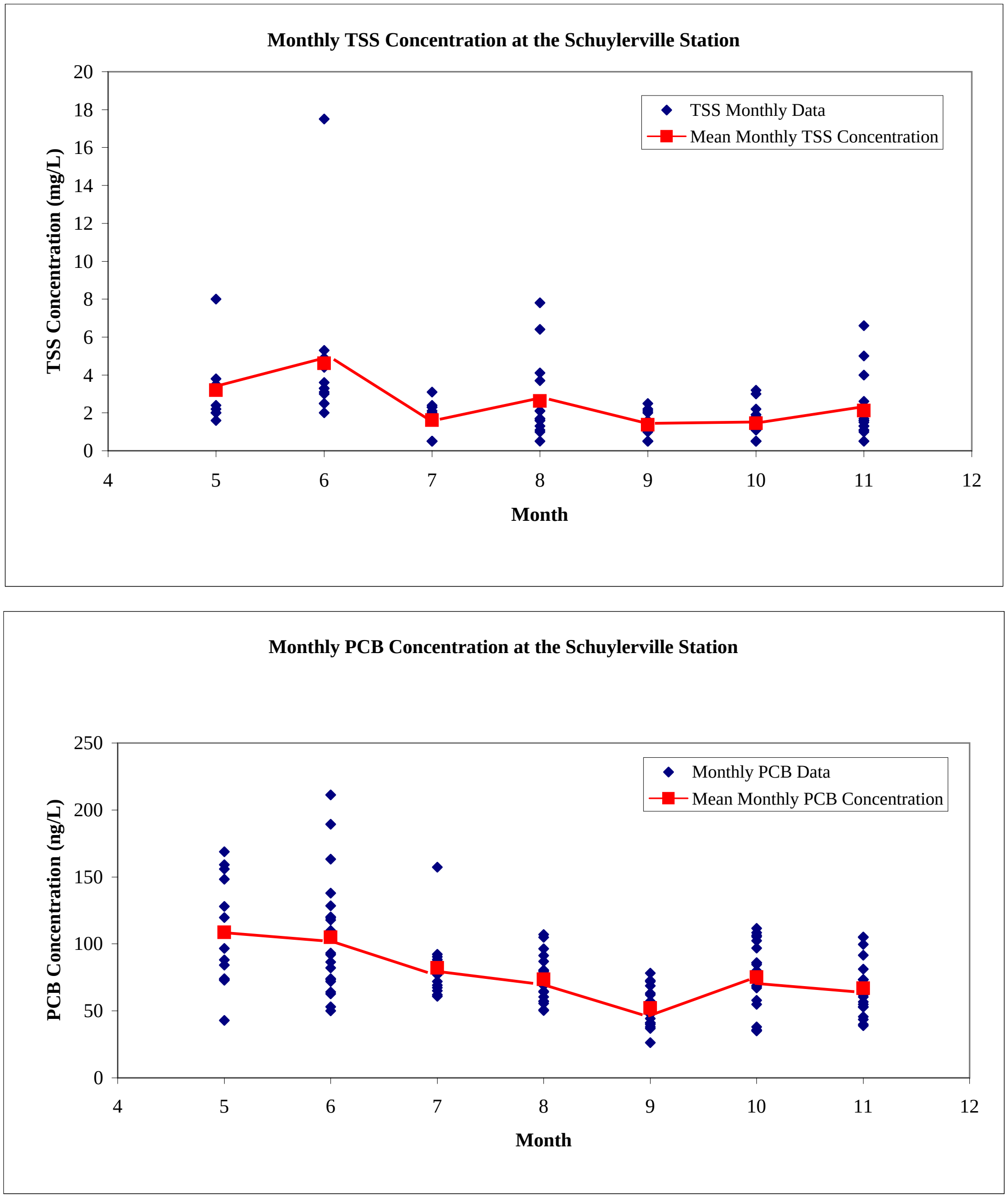

Figure 11. Schuylerville Monitoring Station Monthly TSS and PCB Concentrations Plotted Against the Monthly Mean

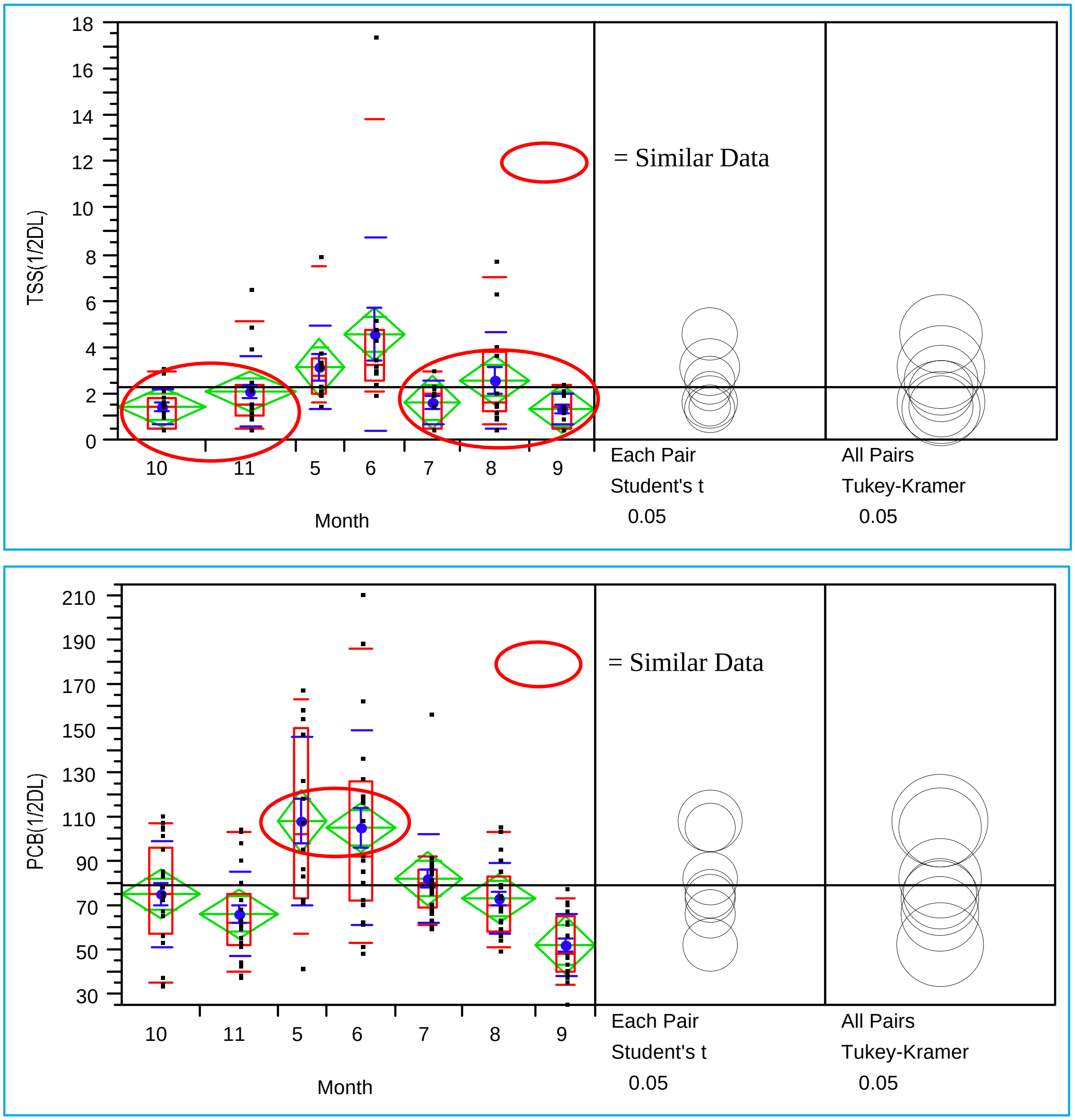

Figure 12. Schuylerville Station Box Plots
TSS Concentration vs. Month (Top Diagram)
Total PCB Concentration vs. Month (Bottom Diagram)

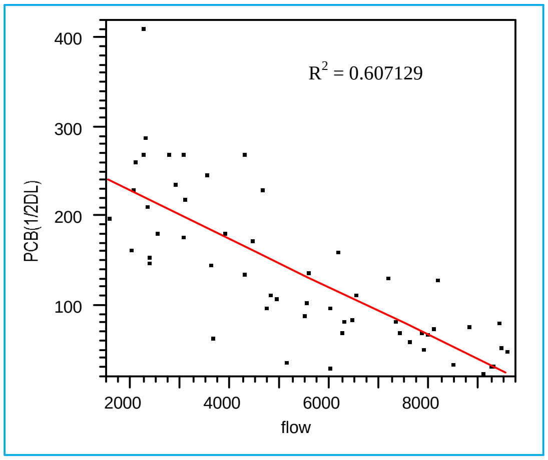

Figure 13: TID-West Monitoring Station
Flow verus Total PCB Concentration
Months of May and June

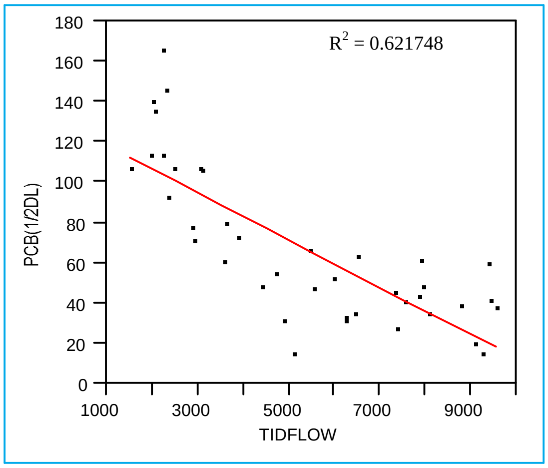

Figure 14: TID-PRW Monitoring Station
Flow versus Total PCB Concentration
Months of May and June

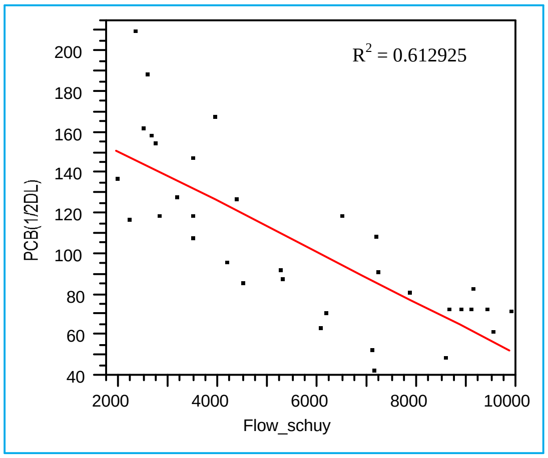

Figure 15. Schuylerville Monitoring Station
Flow versus Total PCB Concentration
Months of May and June

Units: Flow-cfs, PCB-ng.L

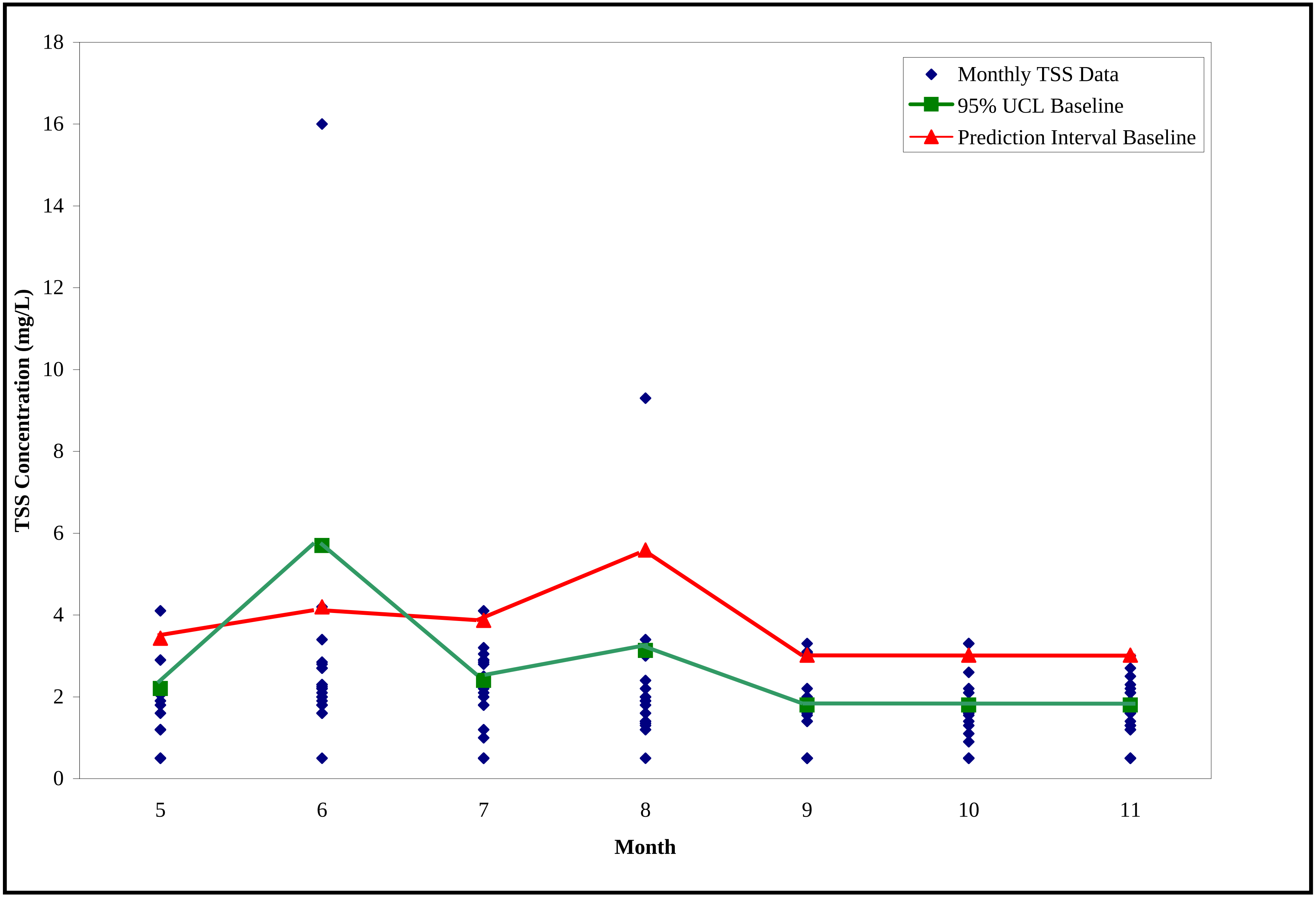

Figure 16. Fort Edward Monitoring Station Monthly TSS Data versus Estimated TSS Baselines

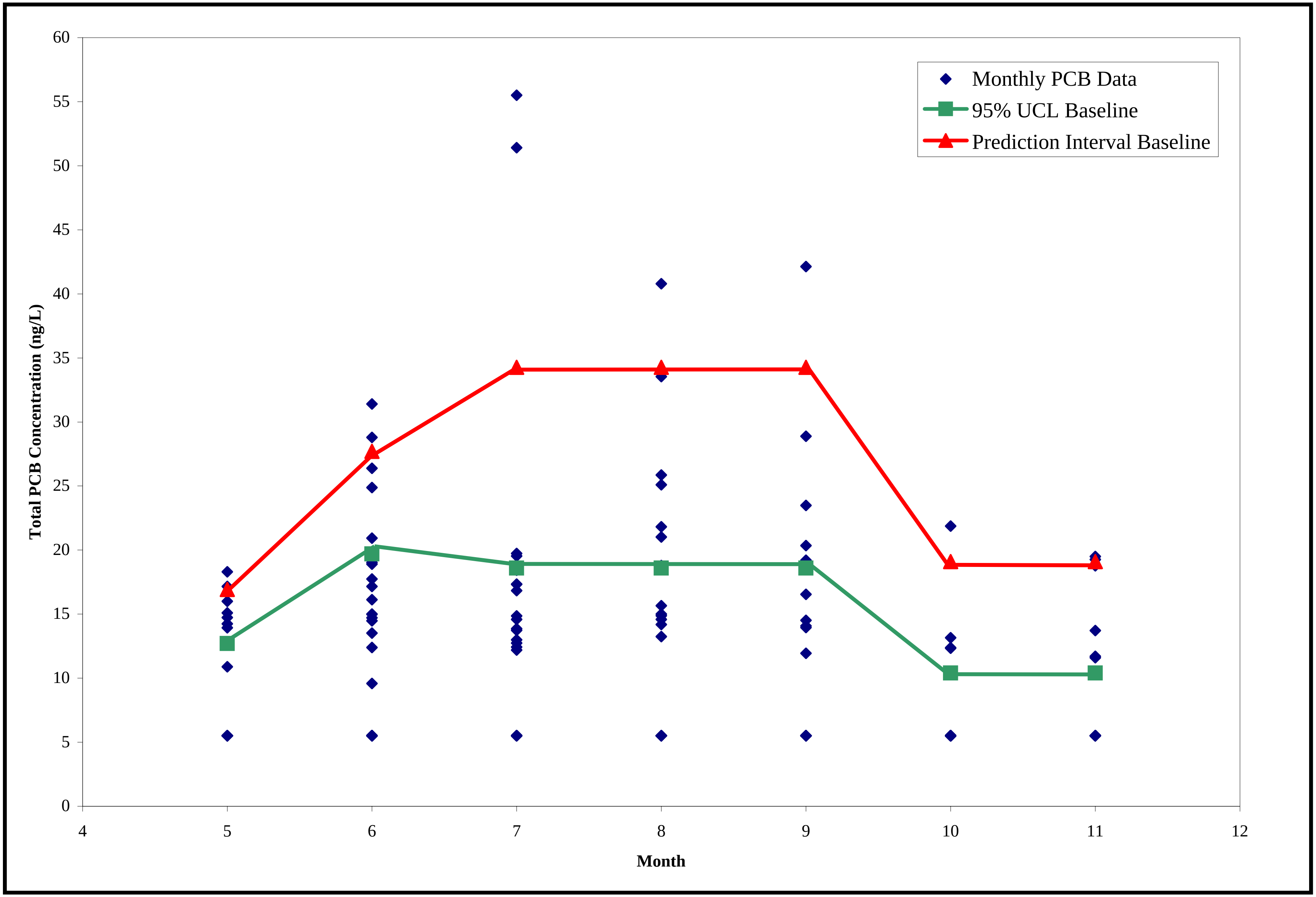

Figure 17. Fort Edward Monitoring Station Monthly Total PCB Data versus Estimated Total PCB Baselines

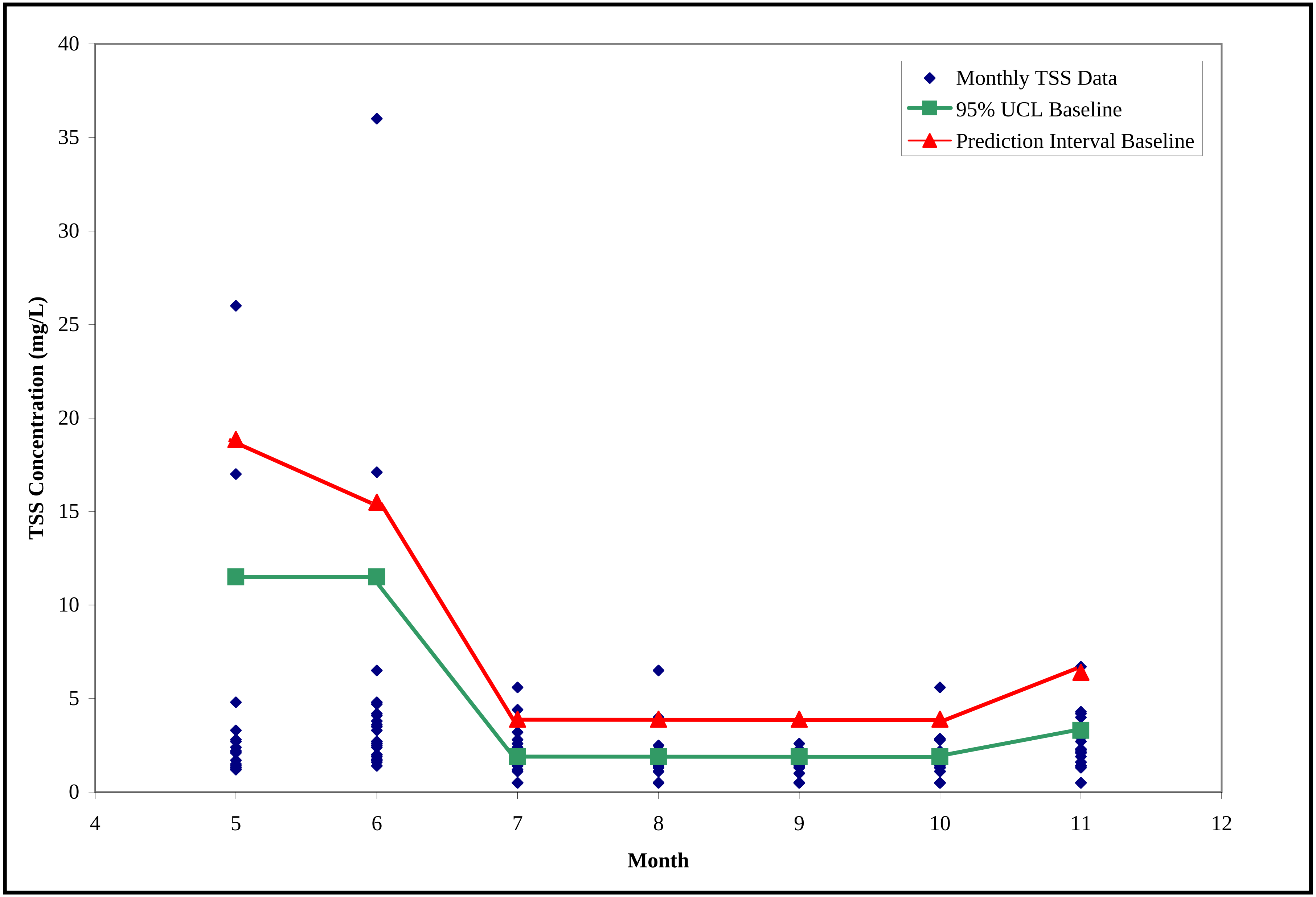

Figure 18. TID-West Monitoring Station Monthly TSS Data versus Estimated TSS Baselines

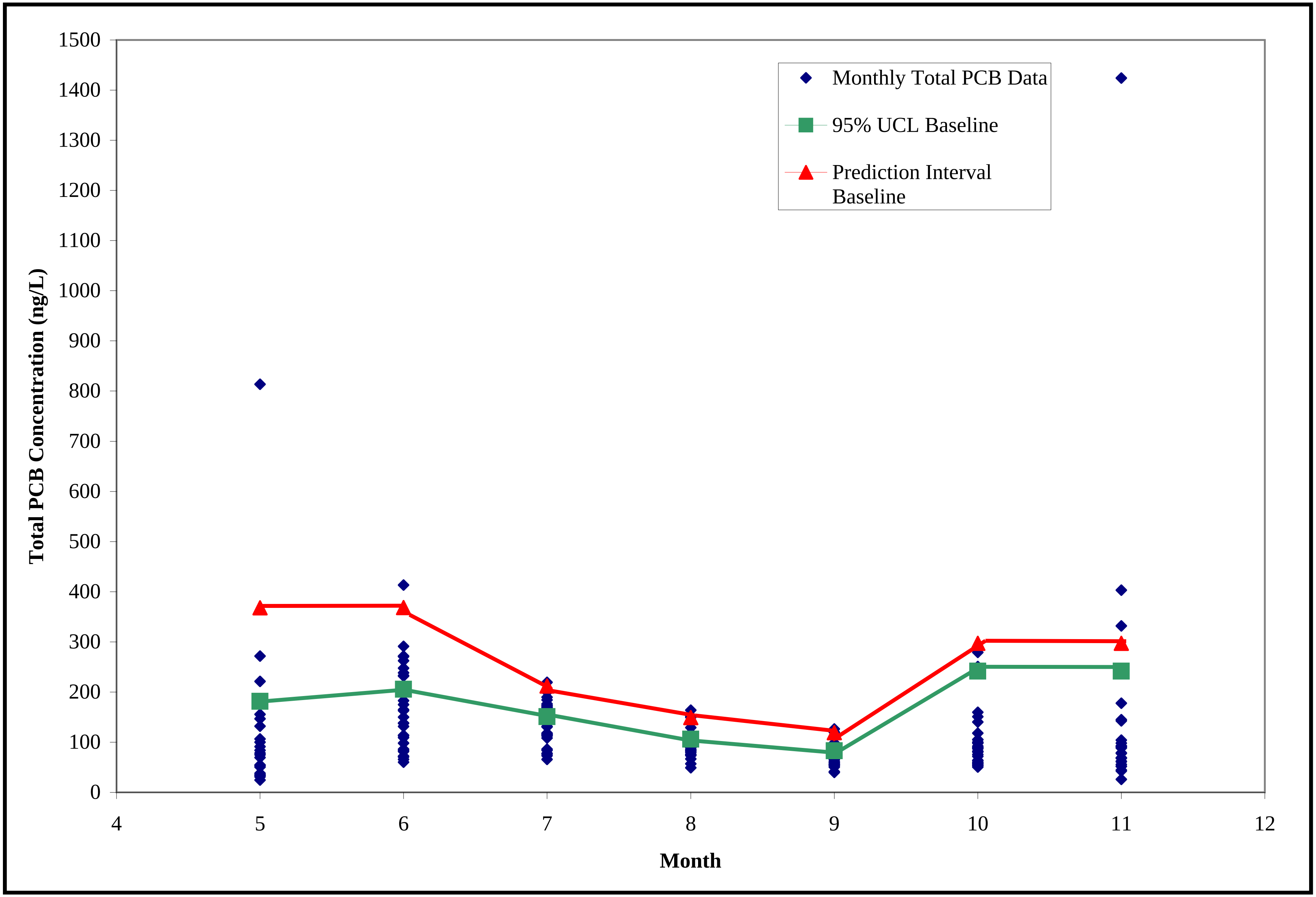

Figure 19. TID-West Monitoring Station Monthly Total PCB Data versus Estimated Total PCB Baselines

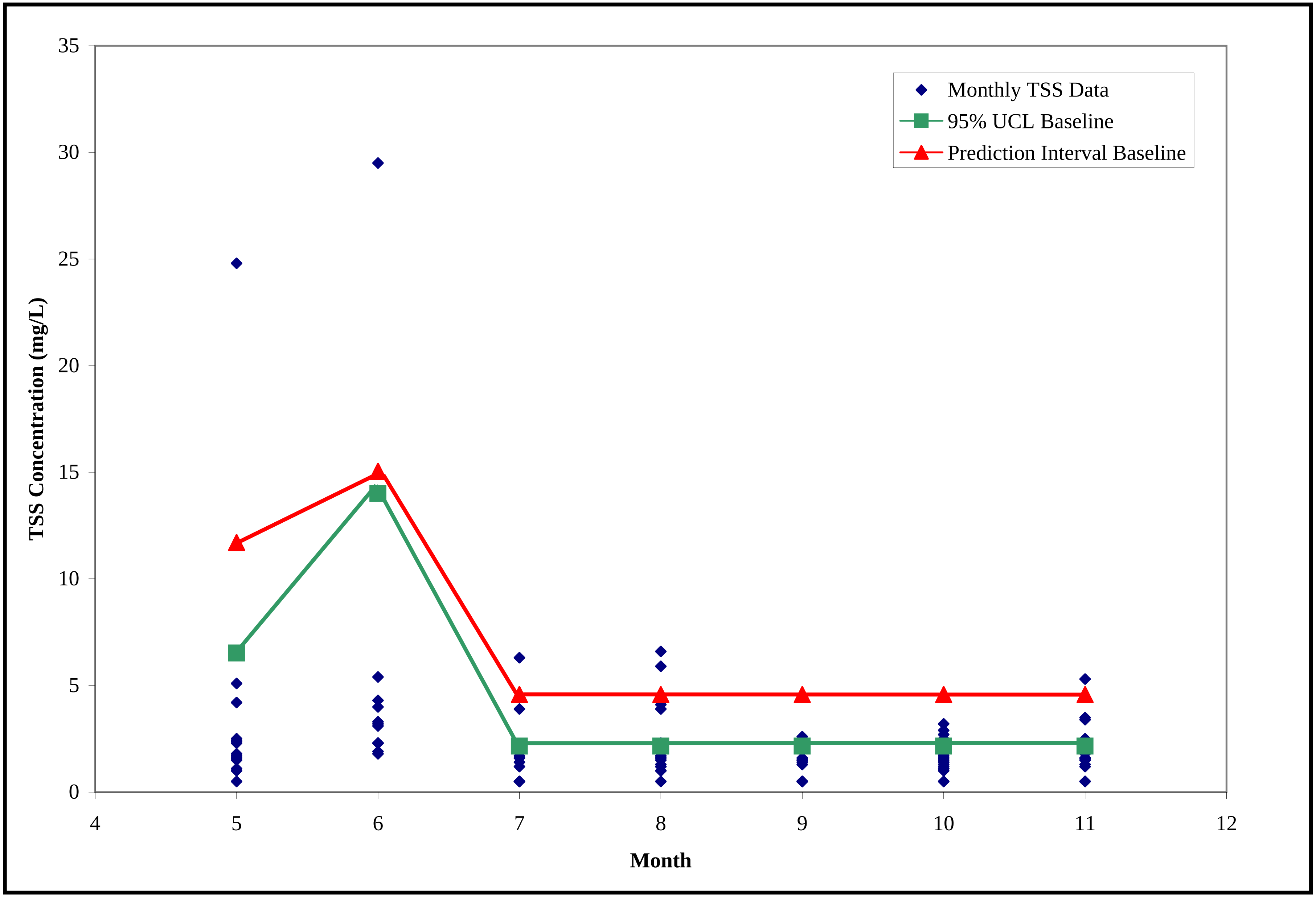

Figure 20. TID-PRW Monitoring Station Monthly TSS Data versus Estimated TSS Baselines

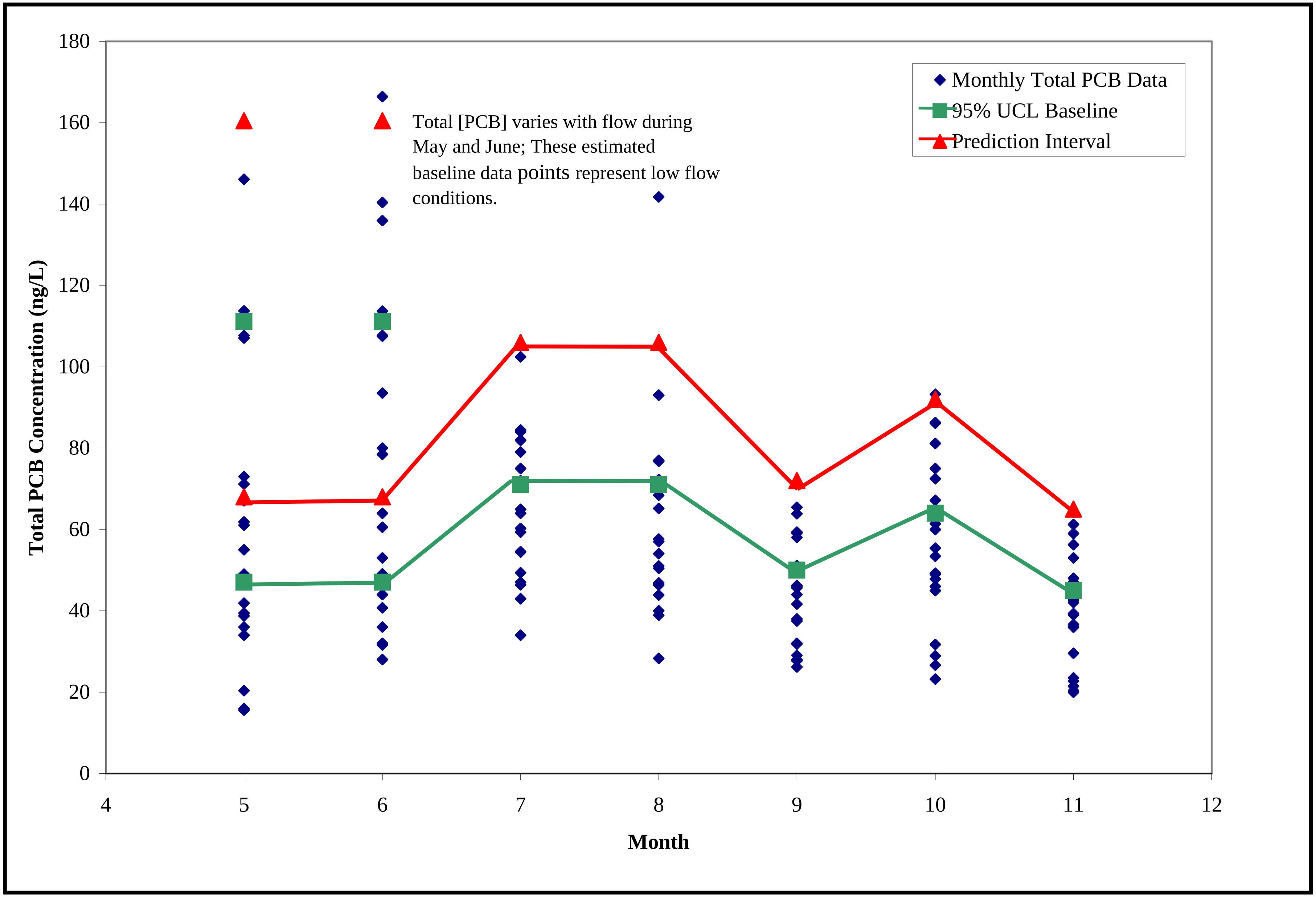

Figure 21. TID-PRW Monitoring Station Monthly Total PCB Data versus Estimated Total PCB Baselines

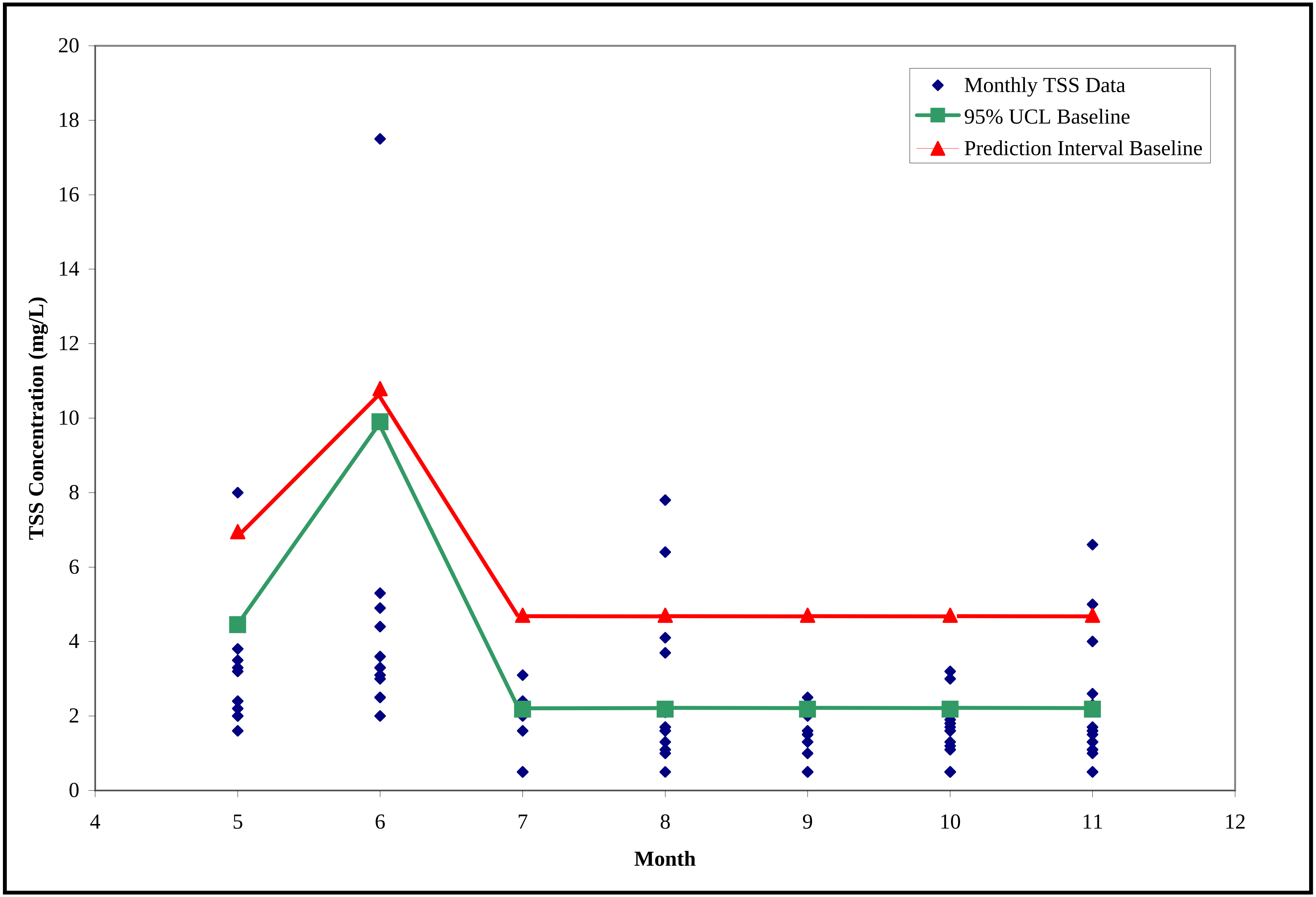

Figure 22. Schuylerville Monitoring Station Monthly TSS Data versus Estimated TSS Baselines

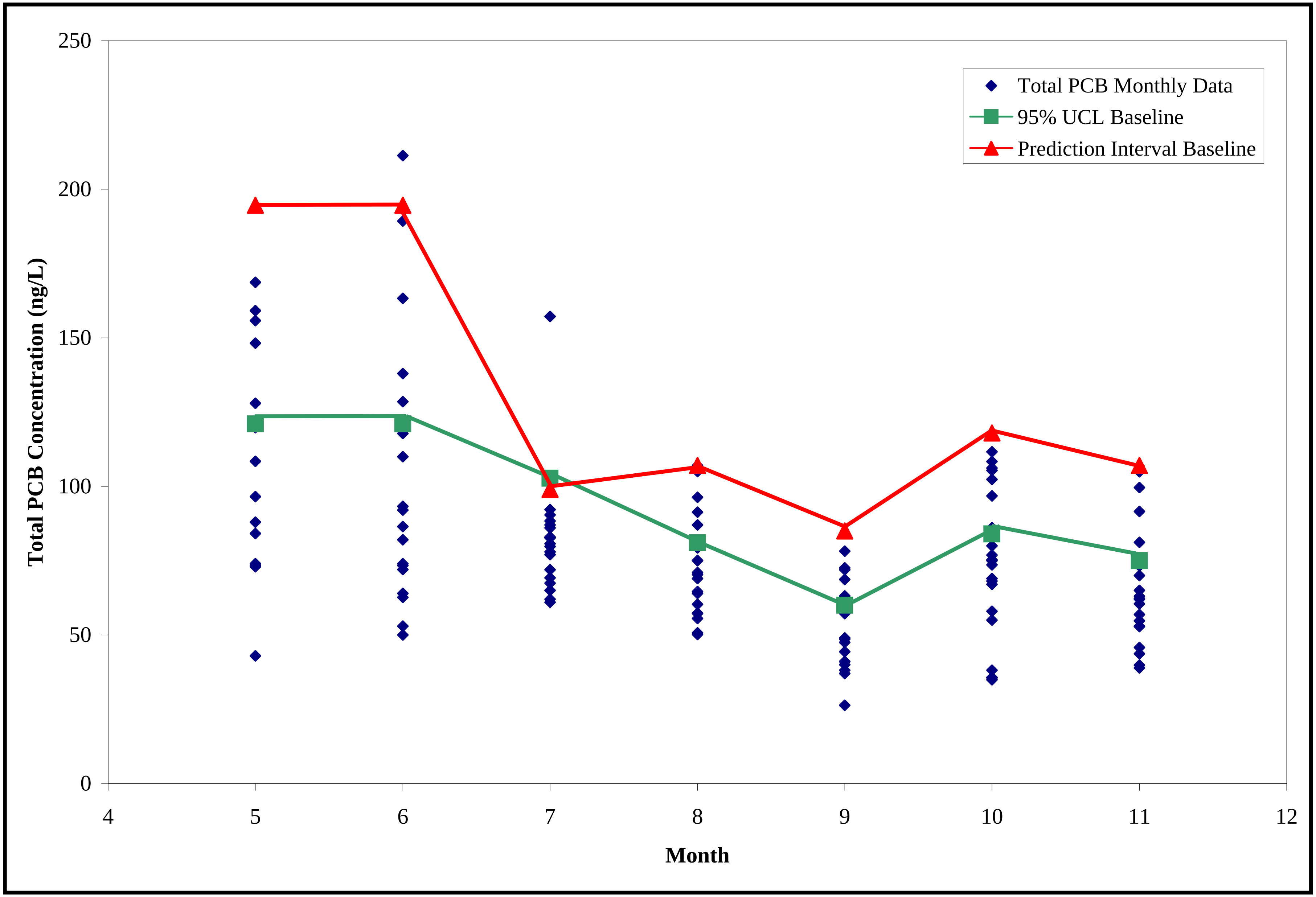

Figure 23. Schuylerville Monitoring Station Monthly Total PCB Data versus Estimated Total PCB Baselines

Attachment B

Resuspension Sensitivity

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Resuspension Sensitivity

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Attachment B

Resuspension Sensitivity

1.0 Objective

Baseline levels of PCBs in the water column fluctuate due to seasonal variables and heterogeneous sources. Therefore it is essential determine the dredging-related PCB releases as a function of time and flow that are detectable above the baseline variations. Furthermore, if data from water samples collected during dredge operations indicate that the PCB concentration transported downstream is within the baseline variation, then it is unlikely that the downstream concentrations will be noticeably impacted from dredging. Furthermore, the resuspension criteria must be set above the baseline variation in order to avoid false exceedances and unnecessary encumbrances to the dredging operations. This monitoring analysis involves the statistical range of baseline variations in total PCB water column concentrations (formulated in Attachment A) and the ability to identify a "significant increase" in the running averages that would signal an unacceptable dredging-related release (*i.e.,* exceedance of resuspension criterion) and require engineering contingencies. Historic data from the Thompson Island Dam (TID) and Schuylerville were used in this analysis, however the baseline and sensitivity calculations should be revised based on the results of the Baseline Monitoring Program. The 95 percent UCL calculations were analyzed for the all the resuspension criteria since they are based on running averages. The prediction limits are also provided, however, the prediction limit analyses indicate the likelihood that any given sample may exceed the criteria and does not apply to running averages. Assuming operations continued at the various criteria, the overall increases in loads within a dredging season were also examined.

2.0 Methodology

During remediation, water column monitoring will be implemented at far-field stations down-gradient of the work areas. Since the river system has baseline PCB levels, it is necessary to confirm that exceedances of the resuspension criteria are recognizable above the inherent variations around the baseline. If exceedances of the criteria were not discernible from the baseline variations, then either PCB levels of concern would not be detected or false exceedances could occur. To this end, an analysis was performed over a wide range of river flow rates (2,000 through 10,000 cfs) and dredging-induced resuspension PCB release rates (300 and 600 g/day), taking into account the variations in the baseline water column concentration (discussed in Attachment A of this report).

The total PCB increases due to dredging activities are based on the volume of sediment removed during each dredging season, the percent solids loss to the water column due to dredging activities, and the river discharge rate. These components are described as follows:

$$\Delta \mathrm{SS} = \frac{V_{sed} \times r \times \mathrm{loss}}{Q \times t_d} \times 9.07 \times 10^8 \qquad (1)$$

where: ΔSS = SS increase in water column (mg/L)
V_{sed} = volume of sediment to be removed (cy)
r = density of the sediment (tons/cy)
loss = dredging-induced resuspension loss rate (%)
Q = flow rate (L/s)
t_d = length of dredging season (s)
$9.07\text{x}10^8$ = conversion factor from tons to mg

The estimated volume of sediment to be removed with overcut, as estimated in the Feasibility Study (USEPA, 2000), is 2.6×10^6 cy. The dredging season is scheduled to occur from May 1 through November 30. Table 1 summarizes the estimated volume of sediment removal for each dredging season and the density of the sediment for each river section.

The total PCB increase in the water column due to dredging was calculated as follows:

$$\Delta \mathrm{TPCB} = \frac{M_{TPCB} \times \mathrm{loss}}{Q \times t_d} \times 10^{12} \qquad (2)$$

where: ΔTPCB = TPCB increase in water column (ng/L)
M_{TPCB} = mass of total PCB remediated (kg)
10^{12} = factor to convert kilograms to nanograms

and other parameters are defined above.

The estimated mass of Tri+ and total PCBs to be remediated are summarized in Table 2. The total PCB concentrations calculated for velocities of 2,000 cfs and 8,000 cfs, assuming 300 g/day and 600 g/day release rates and the 95 percent UCL and prediction interval baseline conditions, are presented in this analysis. These flow rates were selected based on historical flow data recorded during months in which dredging is antivipaed to occur (*i.e*. the dredging season months). Thus, at these two flow rates, the range of SS and total PCB conditions that will exist in the Hudson River during dredging operations were estimated. It should be noted that dredging activities are not expected to occur at Fort Edward flow rates as high as 8,000 cfs.

3.0 Discussion

As shown in the relationships demonstrated by Equations 1 and 2, the estimated total PCB concentration increase in the water column is a function of two things: the river flow rate and the solids loss rate from dredging. The estimated SS and total PCB increases as a result of 0.5 percent and 1 percent solids releases are shown in Tables 3 and 4. The 0.5 and 1 percent solids releases are equivalent to loss rates of 0.21 and 0.42 kg/s of solids, and correspond to 300 and 600 g/day total PCB releases, respectively. Data indicate that the increase in SS and PCB concentrations for a given loss rate is greatest under low flow conditions.

In order to ensure that the resuspension criteria are discernible from the baseline variations, a sensitivity analysis was performed. The sensitivity analysis was performed for the following:

- The baseline total PCB concentrations were compared with the estimated increases from dredging for total PCB release rates of 300 and 600 g/day and varying flow rates.
- The estimated total PCB water column concentrations during dredging operations associated with these release rates were computed by adding the estimated concentration increases (shown in Table 4) to the 95 percent upper confidence limit (UCL) baseline concentrations and the 95th percentile prediction interval baseline concentrations.
- The dredging related releases were superimposed onto the 95th percent UCL baseline to provide a table of conditions (dependent on flow and season), which can be compared to the running averages in order to discern if an exceedance is due to dredging operations.

The 95 percent UCL baseline data approximates the baseline variability of the total PCBs, and can be compared with resuspension criteria based on running averages. The prediction interval baseline data approximates the upper bound baseline concentration for one sampling incident, and can be compared with total PCB data collected from a single sample or incident during dredging activities to allow for the detection of a sudden increase or a change in river conditions. This method is only applicable to criteria that do not involve multiple samples, so it is not directly relevant to the current resuspension criteria.

This analysis was completed for three far field monitoring stations (Thompson Island Dam-West (TID-West), TID-PRW2, and Schuylerville) over the proposed dredging period (May through November) using historic data. New data collected during the Baseline Monitoring Program will provide a better estimate of the baseline level at the far-field monitoring stations.

The total PCB release rate of 300 g/day represents the lowest significantly detectable PCB concentration increase when added to the monthly baseline conditions. An analysis (based on the GE dataset for 1996-2000) of the annual PCB loading and 600 g/day total PCB release rate in the water column indicated the following:

- That a 600 g/day total PCB release rate due to dredging corresponds to approximately two standard deviations of the annual PCB loading of the river.
- That a 600 g/day total PCB release rate due to dredging corresponds to a dredging-induced PCB loading of approximately 130 kg per year.

It was also determined that the standard deviation for the annual PCB loading, based on existing GE water column data for the period 1996 to 2000, is approximately 70 kg total PCBs per year. Thus, a total PCB release rate greater than 600 g/day is likely to exceed the river system's annual baseline PCB loading, supporting the use of the 600 g/day release rate as an upper bound for PCB loading.

As a result, it was recommended that engineering evaluations and solutions be implemented when dredging releases approach 300 g/day total PCBs and it is mandatory that engineering evaluations and solutions be implemented for instances when dredging releases are greater than the river's baseline variation (*i.e.* 600 g/day total PCB). Ultimately, PCB loading corresponding to 300 and 600 g/day, combined with the results of this sensitivity analysis (described herein) were utilized to design a tiered, resuspension monitoring plan comprised of different action levels and monitoring requirements. These levels of monitoring will be implemented based on measured PCB concentrations and corresponding PCB loading estimates.

Additional criteria are based on SS, but the goal of the SS-based criteria is determine net dredging contributions, rendering baseline sensitivity analyses unnecessary. The monitoring programs for SS are described in Chapter 3 and Attachment F of this report.

4.0 Results

The following sections present the results of the sensitivity analysis and a discussion of estimated total PCB concentrations. The results presented assume the following:

- Variable flow rates
- Estimated baseline concentrations
- Total PCB release rates of 300 and 600 g/day.

The baseline conditions are examined at three monitoring stations, two at the TID (TID-West and TID-PRW2) and one at Schuylerville.

4.1 TID Monitoring Locations

Both TID-West and TID-PRW2 are located at the TID. As explained in Attachment A of this report, both of these stations have limitations associated with their data. The total PCB concentrations for TID-West were examined in the *Responsiveness Summary for the Data Evaluation and Interpretation Report* (DEIR) (USEPA, 1998). This analysis concluded that samples collected at the TID-West station are influenced by nearby sediment during low flows. It was also noted in the DEIR that samples collected at TID-PRW2 tend to be limited to the warmer months due to inaccessibility in the winter. Thus, it is thought that the results presented herein may not represent actual water column background conditions, and that adjustments to the location of the sampling station and sample collection in the years prior to dredging will provide a new baseline that is more appropriate. The following data, therefore, are representative of the best data that exist to date, though limitations and concerns with the data are apparent.

4.2 Increases in Total PCBs Average Concentrations Due to Dredging

As stated above, the PCB increases from dredging were estimated for PCB release rates of 300 and 600 g/day for flow rates ranging from 2,000 to 10,000 cfs. The 95 percent UCL baseline results for a total PCB release rate of 300 g/day are shown in Tables 5 through 7, and the results for a release rate of 600 g/day in Tables 8 through 10. Data for both release rates at all three monitoring stations are included. The estimated PCB concentration increases at 2,000 cfs and 8,000 cfs were added to the 95 percent UCL baseline conditions and shown in Figures 1 to 3 for TID-West, TID-PRW2 and Schuylerville respectively.

As depicted in Figures 1 through 3, the PCB concentrations are generally highest during the months of May and June, except for TID-PRW2, which also has high concentrations in October and November. The increases from dredging are more difficult to discern from baseline levels at higher flows, since the concentration increases are less than those at lower flows. In general the concentrations for these release rates are sufficiently above baseline to be discernable (at 8,000 cfs a release rate of 300 g/day increases the baseline concentration by more than 20 ng/L). In particular, TID-PRW2 and Schuylerville have fairly consistent total PCB concentrations from these releases at any given flow. However concentrations associated with these total PCB loads will have large variations with flow, making accurate flow rate measurements a necessity.

Due to the dependence of the load criteria on flow rate measurements, a second criterion for total PCBs of 350 ng/L is applied to same action level as the 600 g/day (the Control level). For TID-PRW2 and Schuylerville, this concentration is slightly higher than the 600 g/day PCB release rate and 95 percent UCL baseline concentration estimates. For TID-West, the concentrations for the 600 g/day release rates in May, June, October, and November and the 300 g/day release rate for October and November are estimated to be above the 350 ng/L criteria, assuming the 95 percent UCL baseline. This indicates that at low flows during these months, dredging in areas with high concentrations may require additional precautions to prevent dredging-related PCB releases from causing exceedances of the 350 ng/L criterion.

None of the concentrations estimated using the 300 g/day or 600 g/day loads at the 95th percentile UCL baselines are greater than the Resuspension Standard of 500 ng/L. However, since an exceedance of the Resuspension Standard only requires a confirmed occurrence, it is useful to compare the standard to the 95th prediction limits for the baseline with the 300 g/day and 600 g/day total PCB loads superimposed.

4.3 Increases in Total PCBs Single Sample Concentrations Due to Dredging

In order to examine the sensitivity of a single sampling incident, the prediction interval baseline results were applied for total PCB release rates of 300 g/day (Tables 11 to 13) and 600 g/day (Tables 14 through 16) for TID-West, TID-PRW2 and Schuylerville respectively. The estimated PCB concentration increases at 2,000 cfs and 8,000 cfs were added to the prediction interval baseline conditions and shown in Figures 4 through 6 for TID-West, TID-PRW2 and Schuylerville, respectively.

The PCB increases and prediction level baseline conditions for the 600 g/day total PCB release rate at 2,000 cfs shown in Figures 5 and 6 are below the USEPA Safe Drinking Water Act Maximum Contaminant Level (MCL) of 500 ng/L for TID-PRW2 and Schuylerville. However, for the analysis at TID-West, this 600 g/day total PCB release rate at 2,000 cfs exceeds 500 ng/L when added to the prediction level baseline for May, June, October, and November. However, the final monitoring station at the TID is expected have baseline conditions that are similar to a combination of those at TID-West and TID-PRW2. Therefore, the results from TID-West station alone are not expected to be truly representative of the PCB concentrations at the TID. Furthermore, an exceedance of the Resuspension Standard threshold requires the collection of four additional samples (in one day) to be analyzed with expedited turn-around times. Therefore, the final decision to cease operations will be based on at least 5 samples. Since the prediction limit shown represents a 5 percent chance of having one sample exceed the 500 ng/L criterion, the likelihood of 5 samples exceeding the 500 ng/L criterion will be lower. However, these results imply that in order to be conservative, dredging operations during these months at low flows may require additional precautions to prevent dredging-related PCBs from causing exceedances of the Resuspension Standard.

5.0 Comparison of the Annual Dredging Induced PCB Load to the Baseline PCB Load

Further analyses were performed to compare the annual baseline total PCB loads with the average annual total PCB loads resulting from solids releases of 0.21 kg/s and 0.42 kg/s, which are associated with the resuspension release criteria of 300 g/day and 600 g/day. The analysis assumed that these solids releases were consistently maintained throughout the dredging period. In addition, the annual loads associated with the Resuspension Standard of 500 ng/L were also examined.

Results and Discussion

The annual load, assuming that dredging operations continued with a far-field concentration of 500 ng/L throughout the dredging season (though it should be noted operations would not continue at this level), was calculated using the United States Geological Survey (USGS) daily discharge rates averaged by month at Fort Edward. The estimated loads are shown in Table 17. For these loads, it was assumed that the work will occur six days per week and that the increase in concentration occurs only during the 14–hour-a-day working period. The 0.5 and 1 percent solids releases are equivalent to loss rates of 0.21 and 0.42 kg/s of solids, and correspond to the 300 and 600 g/day total PCB release rates, respectively. The annual total PCB loads associated with these release rates were calculated, taking into account the dredging schedule proposed in the FS (USEPA, 2000) and the average concentration in each river section. The estimated loads are shown in Table 18.

The annual total PCB loads for 1992 through 2000 were calculated using the GE water column monitoring data and the USGS daily discharge estimates. The TID total PCB concentrations were adjusted for the TID-West bias according to the method described in the Responsiveness Summary to the DEIR (USEPA, 1998). At each station the daily load was calculated and the values were averaged within their respective months to get a monthly average. This average, along with the number of days within the each month, provided the monthly load. The monthly loads were then summed to determine the annual loads at each station. The average annual total PCB loads from 1992 to 2000 are shown in Table 19.

The annual loads from 1992-2000 from above Rogers Island, the TI Pool, and the stretch of river between the TID and the Schuylerville station are presented in Figure 7. The high concentrations detected in 1992 (which gradually declined) were the result of the Allen Mills failure. Controls put in place by the end of 1996 have reduced the seepage of dense non-aqueous phase liquid (DNAPL) into the Hudson River at the GE Hudson River Falls site. The DNAPL leakage is shown as the load at Fort Edward. The load for the Thompson Island (TI) Pool (Rogers Island to the TID) also decreased from the levels detected in 1992 – 1994, with the loads varying year to year between 1995 and 2000. The loads at Schuylerville are substantially less than the upstream loads, though data were available only for the years spanning 1998 – 2000.

Calculations presented in Attachment D of this Report, indicate that the best engineering estimate of the TSS fraction released from dredging would not exceed 0.13 percent. This loss rate represents approximately 110 kg of Total PCBs released throughout the entire dredging project. Assuming the same schedule presented in the FS, this amounts to an average of approximately 105 g/day (ranging from 78 to 209 g/day for the various river sections). This loss rate is less than half of that estimated using the lower resuspension criteria of 300 g/day total PCBs (*i.e.* the 300 g/day total PCB loss rate is over twice what is anticipated under normal dredging conditions), allowing for additional resuspension and mass loss resulting from the other components of the remediation, such as vehicle traffic, without exceeding the criteria. A well-controlled remediation of the Hudson River should not result in a mass loss in excess of the lower resuspension PCB load criteria; specifically, that less than 65 kg per year will be released to the river as a result of the remediation. The 65 kg/year of total PCBs is a small fraction of the baseline load to the river in most years, as shown in Table 19. A loss of 65 kg/yr represents less that 20 percent of the annual load for six of the nine years with load estimates.

A continued solids release of 0.42 kg/s would represent a release of approximately 130 kg/year total PCBs to the river. This rate of loss is approximately two standard deviations of the baseline annual loads from 1996-2000. A total PCB load of 130 kg/year within a dredging season with full production is similar to a load of 65 kg/year within a dredging season with half production (e.g., the Phase 1 resuspension criteria). Since this annual load represents continual releases that are considerably greater than the best engineer estimate resuspension rates in the FS, the dredging operations should not exceed these criteria unless excess resuspension is occurring. Continued operation at the 500 ng/L MCL would result in 500 kg/year of total PCBs being released to the river, a load similar to those found in the early 1990s. This loss is above the current baseline conditions and therefore operations cannot be maintained at this level and will be temporarily halted.

The baseline annual loads are highly variable and unpredictable. In earlier years, the annual loading was dominated by DNAPL releases from the GE Hudson Falls Plants. Since the controls have been installed, DNAPL releases have been greatly reduced and the annual loads are dominated by the release of PCBs from the sediments of the TI Pool. The annual loadings remain highly variable and significant. These calculations show that if the remediation is controlled such that the rate of mass loss is below the action levels, the increase in the annual loading will not be detectable.

6.0 References

USEPA. 1998. Hudson River PCBs Reassessment RI/FS; Responsiveness Summary for Volume 2A: Database Report; Volume 2B: Preliminary Model Calibration Report; Volume 2C: Data Evaluation and Interpretation Report. Prepared for USEPA Region 2 and USACE, Kansas City District by TAMS Consultants, Limno-Tech, Inc, Menzie-Cura & Associates, Inc., and TetraTech, Inc. December 1998.

USEPA, 2000. Hudson River PCBs Reassessment RI/FS; Feasibility Study. Prepared for USEPA Region 2 and USACE, Kansas City District by TAMS Consultants, Inc. December 2000.

USEPA, 2002. Hudson River Reassessment Record of Decision (ROD). Prepared for USEPA Region 2 and USACE, Kansas City District by TAMS Consultants, Inc. January 2002.

Tables

Table 1
Volume of Sediment Removed by Dredging Season

Sediment Removal Season, t_d	Dredging Location	Dredging speed	Volume of sediment removed [1], V_{sed}, (cy)	Sediment density, ρ, (tons/cy)
May 1 - Nov. 30, 2006	Sec. 1	half	260,000	0.94 [2]
May 1 - Nov. 30, 2007	Sec. 1	full	520,000	0.94 [2]
May 1 - Nov. 30, 2008	Sec. 1	full	520,000	0.94 [2]
May 1 - Aug. 15, 2009	Sec. 1 &	full	260,000	0.94 [2]
Aug. 16 - Nov. 30, 2009	Sec. 2	full	290,000	0.74 [3]
May 1 - Aug. 15, 2010	Sec. 2 &	full	290,000	0.74 [3]
Aug. 16 - Nov. 30, 2010	Sec. 3	full	255,000	0.71 [4]
May 1 - Aug. 15, 2011	Sec. 3	full	255,000	0.71 [4]

Notes:

1. Calculations of volume sediment removed were presented in the FS, Table 8-9.
2. Based on the calculations in the FS, sediment removed consists of 50% cohesive ($\rho = 0.71$ tons/cy) and 50% non-cohesive ($\rho = 1.16$ tons/cy).
3. Based on the calculations in the FS, sediment removed consists of 93% cohesive ($\rho = 0.71$ tons/cy) and 7% non-cohesive ($\rho = 1.16$ tons/cy).
4. Based on the calculations in the FS, sediment removed consists of cohesive sediment only ($\rho = 0.71$ tons/cy).

Table 2
Estimated Tri+ and Total PCB Mass to be Remediated

River Section	Length of time for remediation, t_d, (year)	Mass of Tri+ PCB remediated[2], M_{Tri+}, (kg)	Mass of TPCB remediated[2], M_{TPCB}, (kg)
River Section 1 (> 3 g/m^2)	3.5	11,100	36,000
River Section 2 (> 10 g/m^2)	1	7,100	24,300
River Section 3 (Select)	1	3,500	9,500
Total	5.5 [1]	21,700	69,800

Notes:

1. Dredging is scheduled to finish half way through the sixth year.
2. Mass of Tri+ and TPCB removed were calculated in the *Responsiveness Summary, Sediment PCB Inventory Estimates White Paper* (USEPA, 2002).

Table 3
Suspended Solids Estimated Increase to the Water Column

Sediment Removal Season	SS Increase @ 2,000 cfs (mg/L)	SS Increase @ 5,000 cfs (mg/L)	SS Increase @ 8,000 cfs (mg/L)
Assuming a 0.21 kg/s Solids Loss Rate from Dredging			
May 1 - Nov. 30, 2006	1.8	0.7	0.5
May 1 - Nov. 30, 2007	3.7	1.5	0.9
May 1 - Nov. 30, 2008	3.7	1.5	0.9
May 1 - Aug. 15, 2009	3.7	1.5	0.9
Aug. 16 - Nov. 30, 2009	3.2	1.3	0.8
May 1 - Aug. 15, 2010	3.2	1.3	0.8
Aug. 16 - Nov. 30, 2010	2.8	1.1	0.7
May 1 - Aug. 15, 2011	2.8	1.1	0.7
Assuming a 0.42 kg/s Solids Loss Rate from Dredging			
May 1 - Nov. 30, 2006	3.7	1.5	0.9
May 1 - Nov. 30, 2007	7.3	2.9	1.8
May 1 - Nov. 30, 2008	7.3	2.9	1.8
May 1 - Aug. 15, 2009	7.3	2.9	1.8
Aug. 16 - Nov. 30, 2009	6.5	2.6	1.6
May 1 - Aug. 15, 2010	6.5	2.6	1.6
Aug. 16 - Nov. 30, 2010	5.6	2.2	1.4
May 1 - Aug. 15, 2011	5.6	2.2	1.4

Table 4
Total PCBs Estimated Increase to the Water Column

Sediment Removal Season	Total PCB Increase @ 2,000 cfs (mg/L)	Total PCB Increase @ 5,000 cfs (mg/L)	Total PCB Increase @ 8,000 cfs (mg/L)
Assuming a 300 g/day total PCB Loss Rate from Dredging			
May 1 - Nov. 30, 2006	49	20	12
May 1 - Nov. 30, 2007	101	41	25
May 1 - Nov. 30, 2008	101	41	25
May 1 - Aug. 15, 2009	101	41	25
Aug. 16 - Nov. 30, 2009	202	81	51
May 1 - Aug. 15, 2010	202	81	51
Aug. 16 - Nov. 30, 2010	80	32	20
May 1 - Aug. 15, 2011	80	32	20
Assuming a 600 g/day total PCB Loss Rate from Dredging			
May 1 - Nov. 30, 2006	101	41	25
May 1 - Nov. 30, 2007	198	80	50
May 1 - Nov. 30, 2008	198	80	50
May 1 - Aug. 15, 2009	198	80	50
Aug. 16 - Nov. 30, 2009	418	168	105
May 1 - Aug. 15, 2010	418	168	105
Aug. 16 - Nov. 30, 2010	157	63	39
May 1 - Aug. 15, 2011	157	63	39

Table 5
Estimated Total PCB Concentrations Compared to the 95 Percent UCL Baseline Data at the TID-West Monitoring Station Assuming a 300 g/day Total PCB Release Rate

Total PCB Release Rate of 300 g/day			Total PCB – TID-West Station					
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May	June	July	August	Sept.	Oct. & Nov.
95% UCL Baseline TPCB Concentration			**181**	**205**	**151**	**106**	**83**	**241**
2,000	57	105	286	310	256	211	188	346
2,500	71	84	265	289	235	190	167	325
3,000	85	70	251	275	221	176	153	311
3,500	99	60	241	265	211	166	143	301
4,000	113	53	234	258	203	158	136	294
4,500	127	47	228	252	198	153	130	288
5,000	142	42	223	247	193	148	125	283
5,500	156	38	220	244	189	144	121	280
6,000	170	35	216	240	186	141	118	276
6,500	184	32	214	238	183	138	115	274
7,000	198	30	211	235	181	136	113	271
7,500	212	28	209	233	179	134	111	269
8,000	227	26	208	232	177	132	109	268
8,500	241	25	206	230	176	131	108	266
9,000	255	23	205	229	174	129	106	265
9,500	269	22	203	227	173	128	105	264
10,000	283	21	202	226	172	127	104	262

Table 6
Estimated Total PCB Concentrations Compared to the 95 Percent UCL Baseline Data at the TID-PRW2 Monitoring Station Assuming a 300 g/day Total PCB Release Rate

Total PCB Release Rate of 300 g/day			Total PCB - TID-PRW2 Station				
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May & June (1)	July and August	Sept.	Oct.	Nov.
95% UCL Baseline TPCB Concentration (Data representative of flow Rates>5,000 cfs)			**47**	**71**	**50**	**64**	**45**
2,000	57	105	216	176	155	169	150
2,500	71	84	195	155	134	148	129
3,000	85	70	181	141	120	134	115
3,500	99	60	171	131	110	124	105
4,000	113	53	164	123	103	117	98
4,500	127	47	158	118	97	111	92
5,000	142	42	153	113	92	106	87
5,500	156	38	85	109	88	102	84
6,000	170	35	82	106	85	99	80
6,500	184	32	79	103	82	97	78
7,000	198	30	77	101	80	94	75
7,500	212	28	75	99	78	92	73
8,000	227	26	73	97	76	91	72
8,500	241	25	72	96	75	89	70
9,000	255	23	70	94	73	88	69
9,500	269	22	69	93	72	86	68
10,000	283	21	68	92	71	85	66

Notes: (1) The 95% UCL baseline varies as a function of flow rate for the months of May and June. It was estimated that the 95% UCL baseline concentration is approximately 111 ng/L for flow rates less than 5,000 cfs. This value was applied when estimating the total PCB concentration shown in the above table for all flow rates less than 5,000 cfs.

Table 7
Estimated Total PCB Concentrations Compared to the 95 Percent UCL Baseline Data at the Schuylerville Monitoring Station Assuming a 300 g/day Total PCB Release Rate

Total PCB Release Rate of 300g/day			Total PCB (ng/L)- Schuylerville Station					
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May & June	July	August	Sept.	Oct.	Nov.
95% UCL Baseline Total PCB Concentration			**121**	**103**	**81**	**60**	**84**	**75**
2,000	57	105	226	207	185	165	189	180
2,500	71	84	205	186	164	144	168	159
3,000	85	70	191	172	150	130	154	145
3,500	99	60	181	162	140	120	144	135
4,000	113	53	174	155	133	113	136	128
4,500	127	47	168	149	127	107	131	122
5,000	142	42	163	144	122	102	126	117
5,500	156	38	160	140	118	98	122	113
6,000	170	35	156	137	115	95	119	110
6,500	184	32	154	134	112	92	116	107
7,000	198	30	151	132	110	90	114	105
7,500	212	28	149	130	108	88	112	103
8,000	227	26	148	128	106	86	110	101
8,500	241	25	146	127	105	85	109	100
9,000	255	23	145	125	103	83	107	98
9,500	269	22	143	124	102	82	106	97
10,000	283	21	142	123	101	81	105	96

Table 8
Estimated Total PCB Concentrations Compared to the 95 Percent UCL Baseline Data at the TID-West Monitoring Station Assuming a 600 g/day Total PCB Release Rate

Total PCB Release Rate of 600 g/day			Total PCB – TID-West Station					
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May	June	July	August	Sept.	Oct. & Nov.
95% UCL Baseline TPCB Concentration			**181**	**205**	**151**	**106**	**83**	**241**
2,000	57	210	391	415	361	316	293	452
2,500	71	168	349	373	319	274	251	410
3,000	85	140	321	345	291	246	223	382
3,500	99	120	301	325	271	226	203	361
4,000	113	105	286	310	256	211	188	346
4,500	127	93	275	299	244	199	176	335
5,000	142	84	265	289	235	190	167	325
5,500	156	76	258	282	227	182	159	318
6,000	170	70	251	275	221	176	153	311
6,500	184	65	246	270	216	170	148	306
7,000	198	60	241	265	211	166	143	301
7,500	212	56	237	261	207	162	139	297
8,000	227	53	234	258	203	158	136	294
8,500	241	49	231	255	200	155	133	291
9,000	255	47	228	252	198	153	130	288
9,500	269	44	226	250	195	150	127	286
10,000	283	42	223	247	193	148	125	283

Table 9
Estimated Total PCB Concentrations Compared to the 95 Percent UCL Baseline Data at the TID-PRW2 Monitoring Station Assuming a 600 g/day Total PCB Release Rate

Total PCB Release Rate of 600 g/day			Total PCB - TID-PRW2 Station				
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May & June (1)	July and August	Sept.	Oct.	Nov.
95% UCL Baseline TPCB Concentration (Data representative of flow Rates>5,000 cfs)			**47**	**71**	**50**	**64**	**45**
2,000	57	210	321	281	260	274	256
2,500	71	168	279	239	218	232	214
3,000	85	140	251	211	190	204	186
3,500	99	120	231	191	170	184	165
4,000	113	105	216	176	155	169	150
4,500	127	93	204	164	143	158	139
5,000	142	84	195	155	134	148	129
5,500	156	76	124	147	126	141	122
6,000	170	70	117	141	120	134	115
6,500	184	65	112	136	115	129	110
7,000	198	60	107	131	110	124	105
7,500	212	56	103	127	106	120	101
8,000	227	53	100	123	103	117	98
8,500	241	49	97	120	100	114	95
9,000	255	47	94	118	97	111	92
9,500	269	44	91	115	94	108	90
10,000	283	42	89	113	92	106	87

Notes: (1) The 95% UCL baseline varies as a function of flow rate for the months of May and June. It was estimated that the 95% UCL baseline concentration is approximately 111 ng/L for flow rates less than 5,000 cfs. This value was applied when estimating the total PCB concentration shown in the above table for all flow rates less than 5,000 cfs.

Table 10
Estimated Total PCB Concentrations Compared to the 95 Percent UCL Baseline Data at the Schuylerville Monitoring Station Assuming 600 g/day Total PCB Release Rate

Total PCB Release Rate of 600 g/day			Total PCB (ng/L)- Schuylerville Station					
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May & June	July	August	Sept.	Oct.	Nov.
95% UCL Baseline Total PCB Concentration			**121**	**103**	**81**	**60**	**84**	**75**
2,000	57	210	331	313	291	270	294	285
2,500	71	168	289	271	249	228	252	243
3,000	85	140	261	243	221	200	224	215
3,500	99	120	241	223	201	180	204	195
4,000	113	105	226	208	186	165	189	180
4,500	127	93	215	196	174	154	177	169
5,000	142	84	205	187	165	144	168	159
5,500	156	76	198	179	157	137	160	152
6,000	170	70	191	173	151	130	154	145
6,500	184	65	186	167	145	125	149	140
7,000	198	60	181	163	141	120	144	135
7,500	212	56	177	159	137	116	140	131
8,000	227	53	174	155	133	113	136	128
8,500	241	49	171	152	130	110	133	125
9,000	255	47	168	149	127	107	131	122
9,500	269	44	166	147	125	104	128	119
10,000	283	42	163	145	123	102	126	117

Table 11

Estimated Total PCB Concentrations Compared to the Prediction Interval Baseline Data at the TID-West Monitoring Station Assuming 300 g/day Total PCB Release Rate

Total PCB Release Rate of 300 g/day			Total PCB- TID-West Station					
Prediction Interval Baseline Total PCB Concentrations			May	June	July	August	Sept.	Oct. & Nov.
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	**368**	**368**	**212**	**149**	**119**	**297**
2,000	57	105	473	473	317	254	224	402
2,500	71	84	452	452	296	233	203	381
3,000	85	70	438	438	282	219	189	367
3,500	99	60	428	428	272	209	179	357
4,000	113	53	420	421	264	201	172	350
4,500	127	47	415	415	258	195	166	344
5,000	142	42	410	410	254	191	161	339
5,500	156	38	406	406	250	187	157	336
6,000	170	35	403	403	247	184	154	332
6,500	184	32	400	401	244	181	151	330
7,000	198	30	398	398	242	179	149	327
7,500	212	28	396	396	240	177	147	325
8,000	227	26	394	395	238	175	145	324
8,500	241	25	393	393	236	173	144	322
9,000	255	23	391	392	235	172	143	321
9,500	269	22	390	390	234	171	141	319
10,000	283	21	389	389	233	170	140	318

Table 12
Estimated Total PCB Concentrations Compared to the Prediction Interval Baseline Data at the TID-PRW2 Monitoring Station Assuming a 300 g/day Total PCB Release Rate

Total PCB Release Rate of 300 g/day			Total PCB- TID-PRW2 Station				
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May & June (1)	July and August	Sept.	Oct.	Nov.
Prediction Limit Baseline TPCB Concentration (Data representative of flow Rates>5,000 cfs)			**68**	**106**	**72**	**92**	**65**
2,000	57	105	266	211	177	197	170
2,500	71	84	245	190	156	176	149
3,000	85	70	231	176	142	162	135
3,500	99	60	221	166	132	152	125
4,000	113	53	213	159	124	144	118
4,500	127	47	207	153	118	138	112
5,000	142	42	203	148	114	134	107
5,500	156	38	106	145	110	130	103
6,000	170	35	103	141	107	127	100
6,500	184	32	100	139	104	124	97
7,000	198	30	98	136	102	122	95
7,500	212	28	96	134	100	120	93
8,000	227	26	94	133	98	118	91
8,500	241	25	92	131	97	116	90
9,000	255	23	91	130	95	115	88
9,500	269	22	90	128	94	114	87
10,000	283	21	89	127	93	113	86

Notes: (1) The 95percent UCL baseline varies as a function of flow rate for the months of May and June. It was estimated that prediction interval baseline concentration is approximately 160 ng/L for flow rates less than 5,000 cfs. This value was applied when estimating the total PCB concentration shown in the above table for all flow rates less than 5,000 cfs.

Table 13
Estimated Total PCB Concentrations Compared to the Prediction Interval Baseline Data at the Schuylerville Monitoring Station Assuming a 300 g/day Total PCB Release Rate

Total PCB Release Rate of 300 g/day			Total PCB (ng/L) - Schuylerville Station					
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May & June	July	August	Sept.	Oct.	Nov.
Prediction Interval Baseline Total PCB Concentrations			**195**	**99**	**107**	**85**	**118**	**107**
2,000	57	105	300	204	212	191	223	212
2,500	71	84	279	183	191	170	202	191
3,000	85	70	265	169	177	156	188	177
3,500	99	60	255	159	167	146	178	167
4,000	113	53	247	151	159	138	170	160
4,500	127	47	241	145	153	132	164	154
5,000	142	42	237	141	149	127	160	149
5,500	156	38	233	137	145	124	156	145
6,000	170	35	230	134	142	120	153	142
6,500	184	32	227	131	139	118	150	139
7,000	198	30	225	129	137	115	148	137
7,500	212	28	223	127	135	113	146	135
8,000	227	26	221	125	133	112	144	133
8,500	241	25	219	123	131	110	142	132
9,000	255	23	218	122	130	109	141	131
9,500	269	22	217	121	129	108	140	129
10,000	283	21	216	120	128	106	139	128

Table 14
Estimated Total PCB Concentrations Compared to the Prediction Interval Baseline Data at the TID-West Monitoring Station Assuming 600 g/day Total PCB Release Rate

Total PCB Release Rate of 600 g/day			Total PCB- TID-West Station					
Prediction Interval Baseline Total PCB Concentrations			May	June	July	August	Sept.	Oct. & Nov.
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	**368**	**368**	**212**	**149**	**119**	**297**
2,000	57	210	578	578	422	359	329	508
2,500	71	168	536	536	380	317	287	466
3,000	85	140	508	508	352	289	259	437
3,500	99	120	488	488	332	269	239	417
4,000	113	105	473	473	317	254	224	402
4,500	127	93	461	462	305	242	213	391
5,000	142	84	452	452	296	233	203	381
5,500	156	76	444	445	288	225	196	374
6,000	170	70	438	438	282	219	189	367
6,500	184	65	432	433	276	213	184	362
7,000	198	60	428	428	272	209	179	357
7,500	212	56	424	424	268	205	175	353
8,000	227	53	420	421	264	201	172	350
8,500	241	49	417	418	261	198	169	347
9,000	255	47	415	415	258	195	166	344
9,500	269	44	412	413	256	193	163	342
10,000	283	42	410	410	254	191	161	339

Table 15
Estimated Total PCB Concentrations Compared to the Prediction Interval Baseline Data at the TID-PRW2 Monitoring Station Assuming a 600 g/day Total PCB Release Rate

Total PCB Release Rate of 600 g/day			Total PCB- TID-PRW2 Station				
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May & June (1)	July and August	Sept.	Oct.	Nov.
Prediction Limit Baseline TPCB Concentration (Data representative of flow Rates>5,000 cfs)			**68**	**106**	**72**	**92**	**65**
2,000	57	210	371	317	282	302	275
2,500	71	168	329	275	240	260	233
3,000	85	140	301	246	212	232	205
3,500	99	120	281	226	192	212	185
4,000	113	105	266	211	177	197	170
4,500	127	93	254	200	165	185	158
5,000	142	84	245	190	156	176	149
5,500	156	76	144	183	148	168	141
6,000	170	70	138	176	142	162	135
6,500	184	65	132	171	136	156	130
7,000	198	60	128	166	132	152	125
7,500	212	56	124	162	128	148	121
8,000	227	53	120	159	124	144	118
8,500	241	49	117	156	121	141	114
9,000	255	47	114	153	118	138	112
9,500	269	44	112	151	116	136	109
10,000	283	42	110	148	114	134	107

Notes: (1) The 95percent UCL baseline varies as a function of flow rate for the months of May and June. It was estimated that prediction interval baseline concentration is approximately 160 ng/L for flow rates less than 5,000 cfs. This value was applied when estimating the total PCB concentration shown in the above table for all flow rates less than 5,000 cfs.

Table 16
Estimated Total PCB Concentrations Compared to the Prediction Interval Baseline Data at the Schuylerville Monitoring Station Assuming a 600 g/day Total PCB Release Rate

Total PCB Release Rate of 600 g/day			Total PCB (ng/L) - Schuylerville Station					
Flow (cfs)	Flow (m^3/s)	TPCB increase (ng/L)	May & June	July	August	Sept.	Oct.	Nov.
Prediction Interval Baseline Total PCB Concentrations			**195**	**99**	**107**	**85**	**118**	**107**
2,000	57	210	405	309	317	296	328	317
2,500	71	168	363	267	275	254	286	275
3,000	85	140	335	239	247	226	258	247
3,500	99	120	315	219	227	206	238	227
4,000	113	105	300	204	212	191	223	212
4,500	127	93	288	192	200	179	211	201
5,000	142	84	279	183	191	170	202	191
5,500	156	76	271	175	183	162	194	184
6,000	170	70	265	169	177	156	188	177
6,500	184	65	259	163	171	150	182	172
7,000	198	60	255	159	167	146	178	167
7,500	212	56	251	155	163	142	174	163
8,000	227	53	247	151	159	138	170	160
8,500	241	49	244	148	156	135	167	157
9,000	255	47	241	145	153	132	164	154
9,500	269	44	239	143	151	130	162	151
10,000	283	42	237	141	149	127	160	149

Table 17
Calculation of the Annual Dredging Induced PCB Load for the Fully Exhausted Standard (500 ng/L)

Month	Average Fort Edward Flow from 1976-1999	No. of Work Days/Mo.	**Mass Loss @ 500 ng/L**	
			Daily Mass Loss (kg)	Monthly Mass Loss (kg)
5	7,300	26	5	135
6	3,800	26	3	71
7	2,800	26	2	52
8	2,800	27	2	54
9	3,100	26	2	58
10	4,300	26	3	80
11	5,600	26	4	104

Table 18
Calculation of the Annual Dredging Induced PCB Load for the 300 and 600 g/day Total PCB Mass Loss Control Limits

0.5% loss rate (Average of 300 g/day Total PCB Mass Loss)

Sediment Removal Season	Dredging Location	speed	Cubic yards of sediment removed	Total PCB conc. on solids (mg/kg)	Total PCB flux (g/day)	Total PCB flux (kg/day)	Total PCB flux (kg/wk)	Total PCB flux (kg/year)
May 1 - Nov. 30, 2004	Sec. 1	half	260,000	27	140	0.14	0.84	25
May 1 - Nov. 30, 2005	Sec. 1	full	520,000	27	290	0.29	1.74	52
May 1 - Nov. 30, 2006	Sec. 1	full	520,000	27	290	0.29	1.74	52
May 1 - Aug. 15, 2007	Sec. 1 &	full	260,000	27	290	0.29	1.74	26
Aug. 16 - Nov. 30, 2007	Sec. 2	full	290,000	62	580	0.58	3.48	52
May 1 - Aug. 15, 2008	Sec. 2 &	full	290,000	62	580	0.58	3.48	52
Aug. 16 - Nov. 30, 2008	Sec. 3	full	255,000	28	230	0.23	1.38	21
May 1 - Aug. 15, 2009	Sec. 3	full	255,000	28	230	0.23	1.38	21
Total PCB flux (kg/project)								**302**

1% loss rate (Average of 600 g/day Total PCB Mass Loss)

Sediment Removal Season	Dredging Location	speed	Cubic yards of sediment removed	Total PCB conc. on solids (mg/kg)	Total PCB flux (g/day)	Total PCB flux (kg/day)	Total PCB flux (kg/wk)	Total PCB flux (kg/year)
May 1 - Nov. 30, 2004	Sec. 1	half	260,000	27	290	0.29	1.74	52
May 1 - Nov. 30, 2005	Sec. 1	full	520,000	27	600	0.57	3.42	103
May 1 - Nov. 30, 2006	Sec. 1	full	520,000	27	600	0.57	3.42	103
May 1 - Aug. 15, 2007	Sec. 1 &	full	260,000	27	600	0.57	3.42	51
Aug. 16 - Nov. 30, 2007	Sec. 2	full	290,000	62	1200	1.2	7.2	108
May 1 - Aug. 15, 2008	Sec. 2 &	full	290,000	62	1200	1.2	7.2	108
Aug. 16 - Nov. 30, 2008	Sec. 3	full	255,000	28	450	0.45	2.7	41
May 1 - Aug. 15, 2009	Sec. 3	full	255,000	28	450	0.45	2.7	41
Total PCB flux (kg/project)								**606**

Table 19
Dredging Induced Loss - Percent of the Baseline Annual Load

Year	Annual Load to the Water Column	300 g/day Loss (65 kg)	600 g/day Loss (130 kg)	Fully Exhausted Standard (500 kg)
1992	1,017	6%	13%	49%
1993	610	11%	21%	82%
1994	499	13%	26%	100%
1995	302	22%	43%	166%
1996	391	17%	33%	128%
1997	258	25%	50%	194%
1998	410	16%	32%	122%
1999	293	22%	44%	171%
2000	384	17%	34%	130%
Standard Deviation	70 kg/yr for the years 1996-2000 220 kg/yr for the years 1992-2000			

Figures

Figure 1
TID-West Monitoring Station - 95% UCL - Total PCB

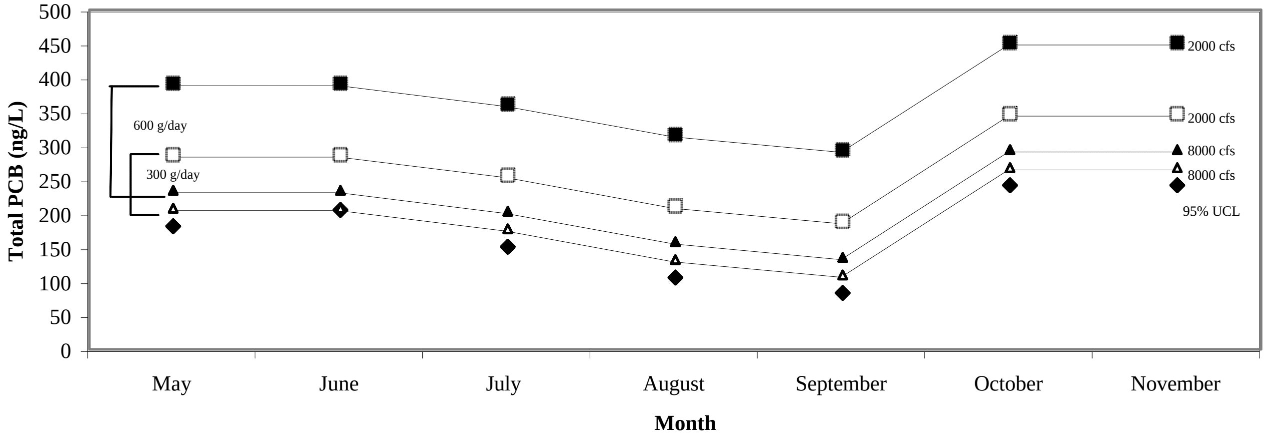


Figure 2
TID-PRW2 Monitoring Station - 95% UCL - Total PCB

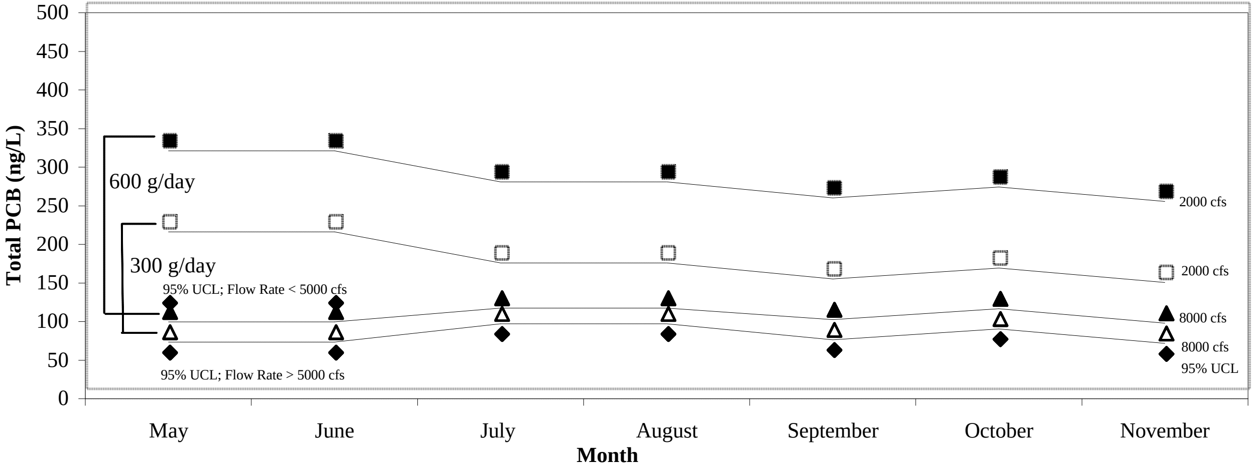


Figure 3
Schuylerville Monitoring Station - 95% UCL - Total PCB

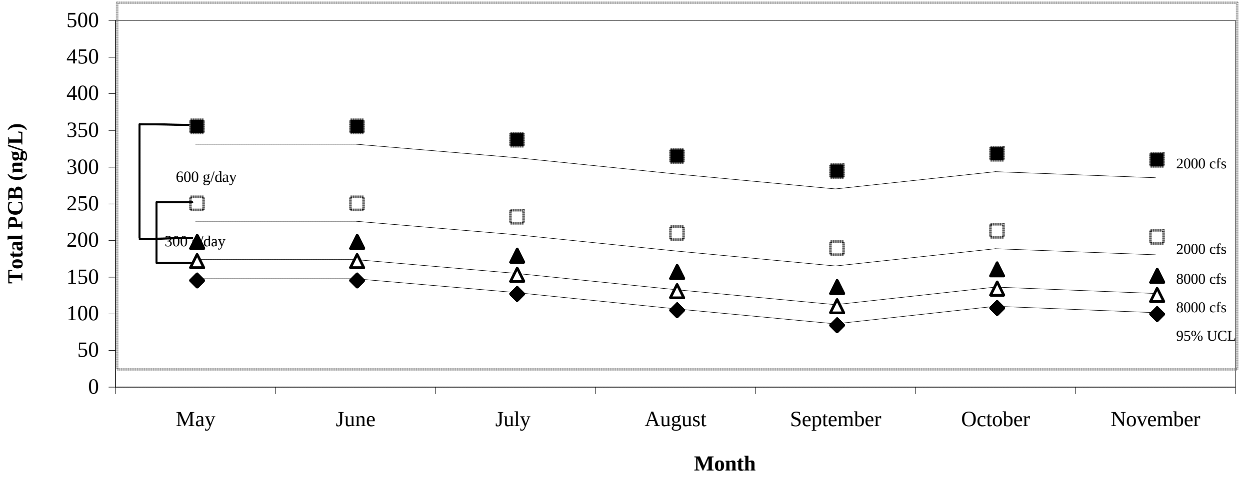


Figure 4

TID-West Monitoring Station - Single Incident - Total PCB

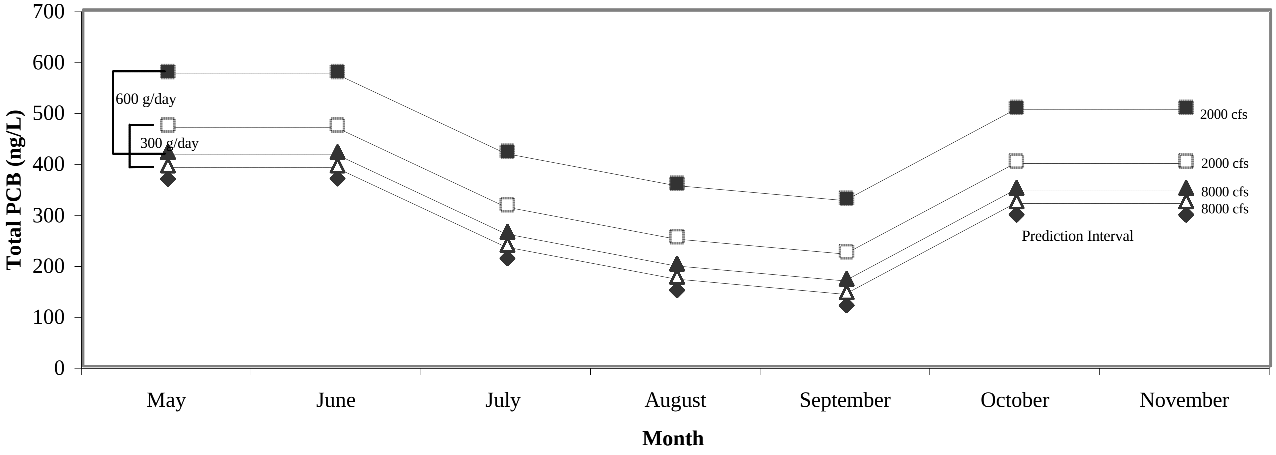


Figure 5

TID-PRW2 Monitoring Station - Single Incident - Total PCB

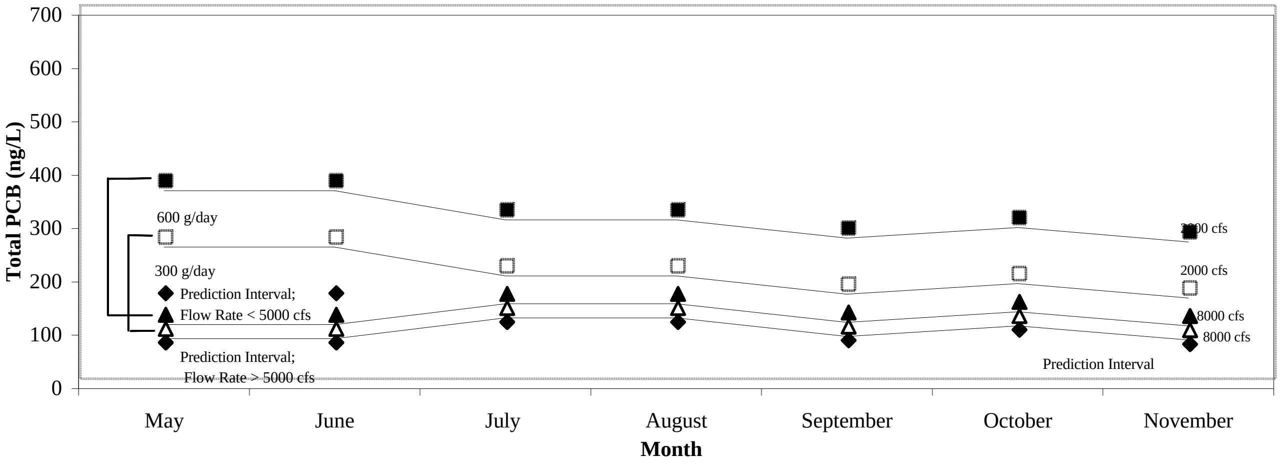
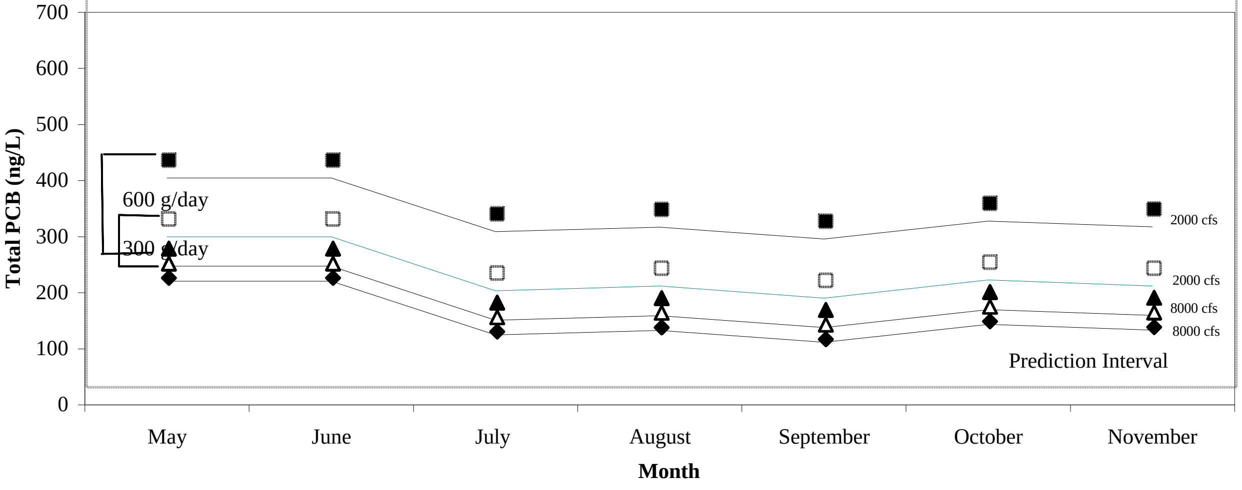


Figure 6

Schuylerville Monitoring Station - Single Incident - Total PCB



Attachment C

Examination of Mechanisms For High Dissolved Phase PCB Concentrations

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Examination of Mechanisms
For High Dissolved Phase PCB Concentrations

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APPENDIX

Attachment C

Examination of Mechanisms for High Dissolved Phase PCB Concentrations

1.0 Introduction

A United States Geological Survey (USGS) study of the Fox River SMU 56/57 demonstration projects (USGS, 2000) concluded that a large dissolved phase release of PCBs had occurred in the absence of any apparent increase in the water column load of suspended solids. Although there are some aspects of this study that suggest the conclusions regarding dissolved phase release may be incorrect, the United States Environmental Protection Agency (USEPA) has conducted several theoretical assessments of possible mechanisms to determine if, in fact, such a release is a realistic possibility. In order to address the issue of dissolved phase release, the proposed monitoring program specifies the collection of whole water PCB data under normal operating conditions (where water column concentrations are below a control limit that varies by month and flow rate outlined in Attachment B). If the water column concentrations are above a control limit, separate dissolved and particulate phase PCB concentration analyses will be required. Other indicators of the total PCB concentration in the water column will be measured, including total suspended solids, dissolved organic carbon, and a qualitative measurement of dissolved phase PCB concentrations using semipermeable membrane devices (SPMDs).

The Fox River dredging demonstration studies were examined in the *White Paper – Resuspension of PCBs During Dredging* (USEPA, 2002). However, several significant concerns were raised regarding the occurrence of a dissolved phase release during the review of this study. To summarize the white paper: although a substantial amount of data were collected from the Fox River dredging demonstration projects, the sampling approach and compositing strategy mask the results. A close review shows that the study results can only be considered inconclusive and should not be used as the basis for estimating resuspension from any future dredging operations. The limitations in the Fox River studies were discussed at length in the white paper, and are repeated here for the convenience of the reader:

- The load-gain estimate is based on a cross-section that is located too close to the dredging area. The cross-section is also located in an area that is a likely backwater (it is in a turning basin, with a nearby coal boat canal). It should be noted that sampling activities during boat activity showed higher PCB concentrations and were included in estimates of releases. Thus, flows through the cross-section are unlikely to be consistent and the estimation of load from concentration using these flows is suspect. The proximity of the cross-section to the dredging area also increases the likelihood that the sampling will not be representative of the total load, since the input from dredging will be poorly mixed.

- The sample compositing strategy, designed to reduce the number and cost of PCB analyses, was not appropriate to support the mass flux analysis that was attempted. The equal volume composites do not allow consideration of flow variation across the cross-section. USGS (2000) states that stagnant areas and even reversed flows were observed during sampling operations, confirming the errors associated with the composite PCB samples. The TSS sample composites induce less error and provide a more accurate estimate of downstream TSS flux, yet they showed an unexplained decrease in suspended sediment across the dredging operation. The decrease is almost certainly an artifact associated with compositing equal volume samples from 20 percent and 80 percent depth. Even though it has long been established that velocity measurements from these depths represent the average velocity in an open channel, there is no justification for suggesting that a composite sample from these depths represents the average concentration along the profile. This is particularly true in deeper water where the two samples represent 25 feet or more of water depth.

- The method of PCB collection was not documented, but it appears that the method represents the dissolved and suspended matter fractions inaccurately, based on the lack of change in PCB pattern across the dredging area. The load gain is attributed to a large gain in dissolved PCBs, but this is inconsistent with the PCB congener pattern. A large dissolved phase PCB contribution from the sediments, either by porewater displacement or sediment-water exchange, should yield a gain whose pattern is similar to the filter supernatant (see Figure 336740-6 in the Responsiveness Summary to the ROD [USEPA, 2002]). The fact that the congener pattern is unchanged across the study area would suggest a direct sediment addition, yet the suspended solids data document no increase in suspended sediments.

- Similarly, the total PCB concentration of the suspended matter doubles, yet there is no change in the suspended matter loading. Given the proximity of the downstream sampling cross-section to the source area, it is unlikely that the majority of the TSS in the river could be directly affected by dredging induced resuspension.

- A review of the PCB loading over the dredging period shows that PCB loads were relatively low for the first 2.5 months of operation, when dredging took place at the more upstream end of the targeted area. During this period, the estimated release was only 3 kg, or about 1.2 kg/month. This changed dramatically during the last month of operation, when the loading rate increased to about 13.5 kg/month. During this latter period, the dredging took place at the downstream end of the targeted area, very close (the closest station less than 80 feet) to the sampling cross-section, near areas with higher PCB concentrations. As discussed in the USGS paper, another significant factor that may have caused elevated PCB concentrations in the downstream profile was increased water flow velocities. Proximity of dredging operations to the deposit or water flow could have been significant contributing factors to the increased PCB concentrations observed in the downstream profile. To conclude that observed increases are only related to dredging fails to consider these and other potential influences. Additionally, a lack of comparable transect data for PCB water column concentrations pre-dredging (i.e., baseline) and during dredging also contributes to the uncertainty in evaluating dredging surface water contributions.

- The fact that significant loss of PCBs only occurred when the dredging area was close to the sampling cross-section suggests that the settling of any resuspended matter occurs within a short distance of the dredging operation. Only when the monitoring location was close to the dredging could this signal be found. This suggests that the loads obtained by this study do not represent PCBs released for long-distance transport. Rather, the PCBs appear to be quickly removed from the water column a short distance downstream. As such, it is inappropriate to use these results to estimate downstream transport from a dredging site.

There is much debate over the possibility of a dissolved phase PCB release during dredging. In the following discussion, theoretical arguments are presented as to mechanisms of release and a quantitative analysis of the magnitude of these releases. The results of the New Bedford Harbor Pre-Design Test, where both dissolved and particulate phase PCB concentrations were measured during dredging, are examined and compared to the results of the theoretical analyses. A literature review of this issue is appended to this Attachment (Attachment C-1).

2.0 Possible Release Mechanisms

In order to monitor PCBs correctly and minimize the impacts of dredging activities on water quality, the nature of PCB releases due to dredging must be understood. Specifically, the possibility that dredging will release dissolved phase PCBs must be considered. There are two basic pathways through which dredging activities may cause significant releases of dissolved phase PCBs:

- The first mechanism requires a direct release of water containing dissolved phase PCBs. Such water would most likely originate as porewater, since porewater is in direct contact with the contaminated sediments and typically contains high dissolved organic carbon concentrations, which can enhance the apparent dissolved phase PCB concentration. The possibility of such a release mechanism and the required water volumes are examined extensively from a theoretical approach in Section 2.1. The analysis presented suggests that this pathway is highly unlikely to result in significant releases.

- The second mechanism of dissolved phase releases into the water column from dredging is by desorption of PCBs from resuspended sediments. If the suspended solids added are of sufficient mass and contamination level, the dissolved phase concentration could rise markedly. It is worthy to note that the process of equilibration will not be undone by adsorption if, as a result of downstream transport, a large fraction of the suspended sediments are lost to settling. Since equilibrium between solid and dissolved phase is concentration-driven and not mass-driven, if a large mass of sediments is added to the water column, allowed to equilibrate, and lost via settling, the water column will be left with a large dissolved phase burden. This scenario is addressed in Section 2.2.

Although dissolved phase releases have historically been noted (USEPA, 1997; 2000) under baseline conditions in the TI Pool, these releases occurred during summer low flow periods without any significant resuspension of sediments. The conditions of these releases suggest that a significant portion of the dissolved phase flux may be biologically mediated. Due to the nature of dredging, it is unlikely that the same mechanism underlying these releases will cause dredging-related dissolved phase releases.

2.1 Estimates of the Effects of Dredging on the Dissolved phase PCB Concentration Using a Three-Phase Partitioning Model

2.1.1 Theoretical Estimation of the Mass of PCBs Available in the Dissolved Phase

During the Fox River PCB dredging project demonstration studies, the Water Resources Institute of the University of Wisconsin reported that 25 percent of the PCB load released from the Deposit N dredging demonstration project was in the dissolved phase (FRRAT, 2000). The United States Geological Survey (USGS) concluded in the paper *A mass-balance approach for assessing PCB movement during remediation of a PCB-contaminated deposit on the Fox River, Wisconsin*, "if chemical transport is to be quantified during a PCB remediation, then monitoring of TSS and turbidity alone is not adequate" (USGS, 2000). The study appeared to indicate that approximately 35 percent of the PCB load from dredging Sediment Management Unit 56/57 was in the dissolved phase (USGS, 2000). Due to this seemly high dissolved phase release it was concluded that a concentration-based approach to assessing remediation could be misleading unless the concentrations are converted into masses. Based on this, the PCB load into the water column mass represented less than 2.5 percent of what was dredged from the deposit. Since 35 percent of the PCB water column concentration increase was in the dissolved phase, the fraction of total mass lost as dissolved phase PCBs during dredging was 0.9 percent (2.5 percent total loss x 35 percent as dissolved) or nearly one percent of the total mass removed. Three phase partitioning models were used to estimate the volume of Hudson River porewater required for a 1 percent release of dissolved phase PCBs into the water column.

To evaluate the plausibility of the dissolved phase-based release mechanism, the estimation of dissolved and DOC-bound PCB concentrations using a three-phase equilibrium partitioning model was explored. Partitioning of organic chemicals between sediment and porewater can be approached on either a mass concentration basis (*i.e.*, mass of contaminant per dry weight of sediment), or a volumetric concentration basis (*i.e.*, mass of contaminant per volume of sediment). In this discussion, partitioning in the sediments will be analyzed on a volumetric basis. The equilibrium partitioning model assumes that the contaminant reaches equilibration among the different phases. On a volumetric basis, one volume of sediment contains PCBs sorbed to the particulate phase (solids) fraction, PCBs in the dissolved phase, and PCBs sorbed to the dissolved organic carbon. The derivation of the following equations is based on the *Data Evaluation and Interpretation Report* (DEIR) and Karickhoff (USEPA, 1997; Karickhoff, 1981). The mass of PCBs in particulate phase is described as:

$$M_P = C_{solid} \times M_{solid} \times 10^{-6} \qquad \text{(EQ 1)}$$

where: M_P = mass of PCBs in particulate phase (mg)
C_{solid} = concentration of PCBs on the suspended matter (mg/kg)
M_{solid} = mass of sediments contained in the example volume (mg)
10^{-6} = factor to convert milligrams to kilograms

The mass of PCBs in the truly dissolved phase is described as:

$$M_d = \frac{C_{solid}}{K_{OC} \cdot foc} \times \frac{M_w}{r_w} \times 10^{-6} \qquad \text{(EQ 2)}$$

where: M_d = mass of PCBs in the truly dissolved phase (mg)
C_{solid} = concentration of PCBs on the suspended matter (mg/kg)

K_{OC} = partition coefficient between water and organic carbon (L/kg)
foc = fraction of organic carbon in the solid phase (unitless)
M_w = mass of water in example volume (mg)
ρ_w = density of water (g/cc)
10^{-6} = factor to convert liters to cubic centimeters and grams to milligrams

The mass of PCBs in the DOC-bound phase is described as:

$$M_{dc} = \frac{C_{solid}}{K_{OC} \cdot foc} \times K_{DOC} \times M_{DOC} \times 10^{-6} \qquad \text{(EQ 3)}$$

where:
M_{dc} = mass of PCBs in DOC-bound phase (mg)
K_{DOC} = partition coefficient between water and dissolved organic carbon (L/kg)
10^{-6} = factor to convert kilograms to milligrams
M_{DOC} = Mass of dissolved organic carbon (mg), defined as $DOC \times V_{water}$, where:
V_{water} = Volume of water in example (L)
DOC = Dissolved organic carbon concentration (mg/L)

and other parameters are defined above.

The total concentration in the sample is given as the total mass of PCBs over the total sample mass:

$$C_T = \frac{C_{solid} M_{solid} + \frac{C_{solid}}{K_{OC} \cdot foc} \times M_w + \frac{C_{solid}}{K_{OC} \cdot foc} \times K_{DOC} \times M_{DOC}}{M_{solid} + M_w + M_{DOC}} \qquad \text{(EQ 4)}$$

where: C_T = *total concentration of PCBs*

and other parameters are defined above.

The United States Army Corp of Engineers (USACE) Waterways Experiment Station (WES) studied the partitioning of PCBs to organic carbon for differing degrees of aromaticity (USACE, 1997). WES reported studies showing that the partitioning of nonpolar organic compounds is strongly related to the octanol-water partitioning coefficient of the compound (Karickhoff, 1981). The K_{OC} values for a particular compound have been reported to vary widely between sediments (Schrap and Opperhuizen, 1989; Brannon et al., 1993, 1995a). Similarly, wide variations in K_{DOC} for sediment porewater from different sediments have been observed (Chin and Gschwend, 1992, Brannon et al., 1995b). During their study, WES found that the measured values of

K_{DOC} were consistently lower than the estimated K_{DOC} calculated using the method of DiToro and others (1991) or Karickhoff (1981).

The USEPA estimated PCB partitioning coefficients using water column transect data and the two-phase and three-phase sediment-water partition models during the Phase 2 reassessment. The results are summarized in the DEIR, Table 3-10a (USEPA, 1997). For the purpose of evaluating the DOC-bound PCB fraction for the Hudson River, BZ#4 was used to represent the mono- and di-chlorinated homologues fraction and BZ#28 and BZ#31 to represent Tri+ PCBs. The partitioning coefficient for these congeners can be found in Table 1.

The estimate of porewater DOC was obtained from the sediment sampling program conducted by the General Electric Company (GE) in 1991 (O'Brien and Gere, 1993). The median of composited porewater DOC was 37 mg/L (range of 10 to 212 mg/L), (USEPA, 1997).

The concentration of PCBs sorbed to solids in the sediment, C_{solid}, was obtained from the length-weighted average PCB concentrations reported in the *White Paper – Sediment PCB Inventory Estimates*. The average PCB concentration for River Section 1 was calculated using data from the 1984 New York State Department of Environmental Conservation (NYSDEC) survey, while concentrations in River Sections 2 and 3 were computed using the 1994 low resolution coring data. Table 2 presents the *in situ* remediated, non-remediated, and reach-wide length-weighted averages of Tri+ and Total PCBs (without any overcut). In the calculations, the average concentration of 50 mg/kg for the remediated sediment of Tri+ PCBs was used in the three-phase equilibrium calculations. This average concentration serves as an upper bound value since the remediated sediment average Tri+ concentrations for all three river sections are less than 50 mg/kg (Table 2).

To simplify the calculation, the entire Tri+ mass was assumed to act as BZ#28, which is among the more soluble of the Tri+ congeners and thereby provides an upper bound on the mass of Tri+ dissolved. Using this concentration, the mass of BZ#28 in the particulate phase was 5×10^{-2} mg, while the mass of BZ#28 in the truly dissolved and DOC-bound dissolved phases was estimated at 8.2×10^{-7} and 4.4×10^{-7} mg, respectively. The calculation was repeated for BZ#31, another common constituent of the Tri+ congeners. The BZ#31 partitioning coefficients resulted in slightly higher truly dissolved and DOC-bound phases; the values were 9.0×10^{-7} and 8.4×10^{-7} mg for the truly dissolved and DOC-bound dissolved phases, respectively. Table 3 summarizes the results of the three-phase equilibrium partitioning for BZ#4, BZ#28, and BZ#31.

To simulate the mono- and di-homologue fraction, BZ#4, the principal di-homologue found in the sediment was used in the calculation. The concentration on the solid phase for this calculation was obtained from River Section 2 (see Table 2). The Total PCB average concentration of *in situ* sediment (without any overcut) targeted for remediation in the FS for River Section 2 was 147 mg/kg, while the Tri+ average concentration for this section of the river was only 44 mg/kg. This indicates that the mono- and di-chlorinated homologues represent the majority of PCB mass in the sediments that may be selected for remediated in River Section 2. Based on this information, an average concentration of approximately 100 mg/kg was selected for the combined mono- and di-chlorinated homologue concentration. Using BZ#4 as a surrogate for this group, the mass of BZ#4 in the particulate phase is 1.0×10^{-1} mg and the mass of BZ#4 in the truly dissolved and DOC-bound dissolved phases is 3.5×10^{-7} and 3.5×10^{-6} mg, respectively.

Assuming equilibrium conditions, it is clear that the sediment porewater contains very little of the *in situ* sediment PCB mass. For the Tri+ fraction, the ratio of combined dissolved and DOC-sorbed phases to the sediment-bound PCB fraction is given by:

$$\frac{(8.2\times10^{-7} + 4.4\times10^{-7})}{5.2\times10^{-2}} = 2.4\times10^{-5}$$

$$or\, 0.002\, percent$$

Similarly for the mono- and di-homologue fractions:

$$\frac{(3.5\times10^{-7} + 3.5\times10^{-6})}{1\times10^{-1}} = 3.9\times10^{-5}$$

$$or\ 0.004\ percent$$

A simple calculation can be used to estimate the number of porewater volumes that would have to be displaced to achieve the roughly 1 percent of mass reportedly lost for the Fox River study. This calculation assumes that each porewater volume would be mixed with the sediments and brought to equilibrium before being released to the river. Thus, to remove 1 percent of the mass via a dissolved phase displacement (without resuspension), the proportion of water to sediment volume is given by the ratio of the desired mass to be lost (1 percent) over the mass available in a single porewater volume (0.0024 for Tri+ and 0.004 for mono- and di-homologues). Using the higher fraction to yield the minimum number of volumes gives:

$$\frac{1}{0.004} = 250$$

or 250 porewater volumes. Since the sediments are roughly half water by volume, to achieve the 1 percent loss without resuspension would require that each cubic yard of sediment be washed with 250 porewater volumes, or about 125 cubic yards of water. For the Tri+ fraction, with a lower percentage in the dissolved phase, this proportion would nearly double to 420 volumes, or 210 cubic yards of water. It is important to note that this mixing volume would have to be achieved for each yard of sediment removed and not for the much smaller fraction of sediment that is lost or spilled.

In conclusion, assuming an equilibrium-based porewater concentration, a direct loss of dissolved phase PCBs to the water column from porewater is highly unlikely. The required mixing volumes of sediment to water are unlikely to be attained under any reasonably well-operated dredging program. In fact, the mixing ratios suggested are much more akin to a resuspension flux where the volume of water to the mass of solids can easily achieve this, or even a much higher[1], proportion. Thus, if a large mass of dissolved PCBs is present in the water column downstream of the dredging operation, it is more likely to be the result of the resuspension of sediment accompanied by PCB equilibration between dissolved and suspended matter.

2.2 Analysis of Dissolved Phase PCB Increase as a Result of Solids Resuspension Using a Two-Phase Partitioning Model

Section 2.1 demonstrates that it is highly unlikely that the increases in dissolved phase concentration reported for the Fox River resulted from a direct release of dissolved or "apparently dissolved" DOC-bound PCBs from the sediments. An alternative explanation for the increase in reported dissolved concentrations is that it is due to desorption from temporarily resuspended contaminated sediments. This section examines the mechanisms for dissolved phase increase as a result of solids resuspension. The analysis also examines the related question of whether the dissolved fraction of PCBs present in the water column can be used as an indicator of dredging-related PCB releases.

A primary objective of the resuspension monitoring is to distinguish the dredging-related contribution of PCB contamination to the water column from the baseline flux of PCBs from the contaminated sediments. To meet this objective, it is important to determine whether or not measurement of the whole-water PCB concentration is sufficient to characterize an increase in the water column PCB concentration resulting from dredging, or if the measurement of the dissolved phase PCB concentration is also necessary.

One way to distinguish a dredging-related PCB release from the baseline PCB concentration is to compare the concentration of PCBs in the dissolved phase to the total concentration of PCBs in the water column due to dredging activities. The next step would be to compare these values to those of the baseline PCB concentrations in the TI Pool. If the ratio of the concentrations detected during dredging operations differs from the baseline ratio, then it is possible to distinguish dredging-induced inputs from the baseline.

As evidenced by the GE float survey, USEPA Phase 2 inventory assessment, and GE water column monitoring program data, Hudson River sediments continue to release PCBs to the water column throughout the year. The data analyzed during the Phase 2 reassessment and subsequent data collected by GE show that PCBs are released to the water column during low flow periods without resuspension of sediment, particularly from May through November. During low flow periods, the observed suspended phase concentration in the water column was low.

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[1] The addition of solids to achieve a concentration of 10 mg/L (a nominal value from Section 3 of this attachment) represents a liquid to solids ratio of roughly a million to one.

Recognizing the fact that there is PCB release to the water column without any corresponding increase in total suspended solids (TSS), a scenario where dredging operations cause the TSS levels to increase temporarily is considered. The affect of the TSS increase to the water column is examined using a two-phase partitioning model. This model provides a preliminary evaluation as to whether the effects of dredging activities could be distinguished from baseline river conditions by examining the relative magnitude of dissolved phase to total PCB releases to the water column.

As in the sediments, PCBs in the water column behave as a three-phase system, with components of a dissolved phase, a phase sorbed to sediment, and a phase sorbed to DOC. However, as discussed in the DEIR, the DOC-sorbed phase is of relatively minor importance in the water column of the Hudson River. In addition, because DOC concentrations are relatively constant, the system can be analyzed as an equivalent two-phase system consisting of a sediment-sorbed fraction and an “apparent” (or unfilterable) dissolved fraction that consists of truly dissolved and DOC-sorbed PCBs. Therefore, the analysis that follows is presented in terms of a two-phase partitioning model.

The two-phase partitioning model assumes that the water column and the sediments are in equilibrium. In a two-phase system, the PCB concentration in the water column is equal to the sum of the dissolved phase fraction and the suspended solids fraction, such that:

$$C_{Total} = C_{dissolved} + C_{suspended} = C_{dissolved} + \mathrm{TSS} \times C_{dissolved} \times K_D \times 10^{-6} \qquad \text{(EQ 5)}$$

where:
C_{Total} = total water column PCB concentration (ng/L)
$C_{dissolved}$ = PCB concentration of apparent (non-filterable) dissolved fraction (ng/L)
$C_{suspended}$ = PCB concentration of suspended solids fraction (ng/L)

K_d = soil-water partition coefficient (L/kg)
TSS = total suspended solids concentration (ng/L)

The whole water background concentration of the water column in the northern portion of the TI Pool is nominally 50 ng/L. The background TSS value of 1 mg/L is assumed. The concentration of the PCBs on the suspended matter, obtained from the instantaneous total PCB water column loading for Transect 6 (USEPA, 1999), is approximately 5 mg/kg. Using these values and the equation above, the suspended solids concentration of PCBs is estimated as:

$$C_{\mathrm{PCB\text{-}susp}} \times C_{\mathrm{TSS}} = C_{\mathrm{PCB\ as\ susp}} \qquad \text{(EQ 6)}$$

$$(5\ \mathrm{ng/mg}) \times (1\ \mathrm{mg/L}) = 5\ \mathrm{ng/L}$$

where:

$C_{\mathrm{PCB\text{-}susp}}$ = concentration of PCBs on the suspended solids in ng/mg (same as mg/kg)

C_{TSS} = concentration of suspended solids in the water (mg/L)

$C_{\mathrm{PCB\ as\ susp}}$ = concentration of PCBs on suspended solids per unit volume of water (ng/L)

and the dissolved phase concentrations is estimated at:

$$(50\ \mathrm{ng/L}) - (5\ \mathrm{ng/L}) = 45\ \mathrm{ng/L}$$

The sediment-water partition coefficient for this example can be checked against the values determined in the DEIR (nominally 10^5) by dividing the concentration in the sediment by the concentration in the dissolved phase. The estimated K_d value is:

$$(5\ \mathrm{mg/kg}) / (45\times10^{-6}\ \mathrm{mg/L}) = 1.1\times10^{5}$$

which agrees well with the more rigorous calculation done in the DEIR. For this calculation, the dredging operation is assumed to take place midway through the TI Pool. For dredging scenarios with 1 percent loss rate at full production and flow between 2000 to 5000 cfs (57 to 142 m^3/s), the additional TSS value to the water column due to dredging is approximately 7 to 3 mg/L. Assuming the sediment concentration of 50 mg/kg (which is an upper bound for remediated sediment average concentrations for all three river sections, USEPA, 2002), and the median TSS concentration (5 mg/L), the additional PCB concentration associated with the suspended solids becomes:

$$(50\ \mathrm{ng/mg}) \times (5\ \mathrm{mg/L}) = 250\ \mathrm{ng/L}$$

Therefore, the total concentration of PCBs in the water column accounting for the additional TSS releases from dredging becomes:

$$(250\ \mathrm{ng/L}) + (45\ \mathrm{ng/L}) + (5\ \mathrm{ng/L}) = 300\ \mathrm{ng/L}$$

The dissolved phase fraction of PCBs added due to the TSS increase in the water column can be calculated using equation 5 as:

$$(300\ \mathrm{ng/L}) = C_{dissolved} + [(5\ \mathrm{mg/L} + 1\ \mathrm{mg/L}) \times C_{dissolved} \times 1.1\times10^{5}\ \mathrm{L/kg} \times 10^{-6}\ \mathrm{kg/mg}],$$

which gives: $C_{dissolved}$ = 180 ng/L.

The sediment concentration (C_{sed}) becomes:

$$C_{sed} = C_{dissolved} \times K_D \times 10^{-6} \qquad \text{(EQ 7)}$$

$$C_{sed} = (180 \text{ ng/L}) \times (1.1 \times 10^{5} \text{ L/kg}) \times (1 \text{ kg}/10^{6} \text{ mg}) = 20 \text{ ng/mg}$$
or 20 mg/kg.

Assuming, at the subsequent monitoring station, that all the dredging-related TSS has resettled and equilibrium is achieved before the sediment settles, the TSS inventory goes from:

(6 mg/L) × (20 mg/kg) = 120 ng/L

to

(1 mg/L) × (20 mg/kg) = 20 ng/L.

The loss in the inventory is approximately 100 ng/L, which means the total water column concentration decreases from 300 ng/L to 200 ng/L during transport from the dredging location to the downstream monitoring station.

The fraction of the dissolved phase to the total concentration of PCBs in the water column due to dredging is:

(180 ng/L)/(200 ng/L) = 0.9.

Thus, resuspension of contaminated sediment and re-equilibration in the water column provides a plausible explanation for the observation of an increased dissolved phase concentration downstream of a dredging site.

As shown in the DEIR and FS, the sediments in the TI Pool continue to release PCBs to the water column. Additionally, the seasonal variability of the last three to four years of monitoring data collected by GE is strongly indicative of the absence of flow dependence in the TI Pool's PCB loads. The absence of flow dependence would suggest that resuspension resulting from flow is unlikely to be the cause of the PCB loading from the TI Pool.

PCB loadings in the TI Pool were extensively quantified during the Phase 2 reassessment. The Phase 2 water column monitoring program presents estimates of water column fluxes for the period January to September 1993 (USEPA, 1997). Based on both instantaneous and 15-day mean measurements, the TI Pool sediment was shown to be the dominant source of PCBs to the water column in eight out of nine months of monitoring. This source released less chlorinated PCB congeners that were predominantly found in the dissolved phase in the water column (USEPA, 1997). In addition, GE and USGS water column monitoring data support the findings based on Phase 2 data. In particular, the GE data show the importance of the TI Pool sediment source for the period of 1991 to 1995.

These observations can be seen in Transects 5 and 6 during low flow conditions (Figure C-3 and Figure 3-47 [corrected] of Appendix C of the *Low Resolution Coring [LRC] Responsiveness Summary*, respectively [USEPA, 1999]). The values of whole (total) water column, dissolved phase, and suspended solids concentrations at TI Dam and Schuylerville are summarized in Table 4. These data showed that the baseline flux of PCBs to the water column have a relative magnitude of dissolved phase to total concentration on the order of 0.9.

Since the fraction of the dissolved phase to the total water column PCB concentration for both background and after dredging is similar (on the order of 0.9), it is not possible to distinguish the effect of dredging by examining the fraction of the dissolved phase increase in the water column.

3.0 Estimate of the Rate of PCB Desorption

3.1 Literature Review

The theoretical assessments presented above are based on the three-phase and two-phase partitioning models. Both theoretical arguments assume that the solid and dissolved phase PCBs reach equilibrium. Recent studies have demonstrated that desorption of hydrophobic chemicals from sediments can be quite slow, and that chemical equilibrium may not be a good approximation in many real situations. In a dredging scenario, the residence time (contact time) of the resuspended sediment in the water column is relatively short, on the order of hours. It is unlikely that PCBs reach equilibrium in this period of time. Desorption rates and the relative fractional amounts of hydrophobic organic chemicals, including PCBs, released from sediment have been studied (Carroll *et al*., 1994, Borglin *et al*., 1996; Cornelissen *et al*., 1997; ten Hulscher *et al*., 1999, 2002; and Ghosh *et al*., 2000). Such kinetic rates could be used as an alternative to provide estimates of the dissolved phase PCBs resulting from dredging activities. Literature on the desorption rates of PCBs was reviewed to obtain desorption equilibrium and kinetics rates for PCBs.

Many researchers showed evidence that desorption of contaminants takes place in at least two steps: a fast and slow step. The desorption of PCBs from Hudson River sediments was studied by Brown (1981) and Carroll and associates (Carroll *et al*., 1994). Brown developed and tested a method for the analysis of rates of PCB desorption from sediment suspended by dredging activities. The data used were taken from dredging operations in the Hudson River at the town of Fort Edward in 1977. The monitoring stations were placed in the east channel of Rogers Island. Brown used the Freundlich isotherms model to obtain the sinking and sorption-desorption rate constants of Aroclor 1016. In the report, the author used the term "sinking" to refer to the rate constant for the first order settling coefficient. The sinking and sorption-desorption rates were chosen using trial and error methodology to fit the measured concentration of Aroclor 1016 under low and high flow conditions. For low flow conditions, it was found that a sinking rate of –0.08 hr^{-1} and desorption rate constants ranging from 0.025 hr^{-1} to 0.05 hr^{-1} fit the measured data well. Under high flow conditions, a reasonable fit was obtained using a sinking rate of –0.4 hr^{-1} and desorption rate constants on the order of 1.0 hr^{-1}. Brown concluded that 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.

Carroll and associates studied the desorption of PCBs from Hudson River sediment using XAD-4 resin as a PCB adsorbent. They used sediments contaminated with high, medium, and low levels of PCBs from the Hudson River near Moreau, New York. The three Hudson River sediments used in their study contained 25, 64, and 205 mg/kg (dry weight) PCBs with total organic carbon contents of 0.96, 3.43, and 4.59 percent, respectively. They reported that the PCBs present in the sediments consisted primarily of mono- and di-chlorinated biphenyls (60-70 percent of total). Both a rapidly desorbing labile component and a more slowly desorbing resistant component were observed. Rate constants for the labile (fast) and resistant (slow) fractions were obtained using a model developed by Berens and Huvard (1981). For the purpose of this study, the desorption rate constant of the untreated moderately (64 mg/kg dry weight PCB) PCB-contaminated Hudson River sediment is considered. The desorption rate constant obtained from the Carroll and associates study was approximately 0.018 hr^{-1} (Table 5).

Borglin and associates studied parameters affecting the desorption of hydrophobic organic chemicals from suspended sediments (Borglin *et al.*, 1996). In their paper, Borglin and associates presented the results from long-term experiments performed for three hydrophobic organic chemicals (hexachlorobenzenes and two polychlorinated biphenyls). They concluded that the desorption times are on the order of a month to several years, and observed that the desorption rates are dependent on the:

- Particle/floc size and density distributions.
- Type of water.
- Amount of organic carbon in the sediments.
- Time of adsorption before desorption.
- Chemical partition coefficient.

Borglin and associates presented results describing the amount of PCBs (monochlorobiphenyl and hexachlorobiphenyl) desorbed over time. The rate constants calculated are on the order of 0.0049 hr^{-1} and 0.00042 hr^{-1} for monochlorobiphenyl and hexachlorobiphenyl, respectively.

Cornelissen and associates studied desorption kinetics for chlorobenzenes, PAH, and PCBs for different contact times and solute hydrophobicity (Cornelissen *et al.*, 1997). They used a technique employing Tenax TA® beads as a "sink" for desorbed solute to measure the kinetics of desorption of the compounds mentioned above. For PCBs, they studied PCB-65 (2,3,5,6-tetrachlorobiphenyl) and PCB-118 (2,3',4,4',5-pentachlorobiphenyl). The sediment used was taken from Lake Oostvaardersplassen, located in the Netherlands. They observed two stages of desorption rates: the rapid release of the "labile" sorbed fraction, and slow release of the "non-labile" fraction. Two different contact times were considered in this study: 2 days and 34 days. The desorption rate constants were varied for the different contact times for both the rapid and slow release. The values are summarized in Table 5.

In 1999, ten Hulscher and associates studied desorption kinetics and partitioning of chlorobenzenes, PCBs, and PAHs in long-term field contaminated sediment cores and top layer sediment (ten Hulscher *et al.*, 1999). They concluded that the desorption from sediment was triphasic: fast, slow, and very slow. In this study, they used the sediment from Lake Ketelmeer, located in The Netherlands. Only core results were presented for PCB-28. They reported desorption rate constants with values of 0.21×10^{-3} hr^{-1} and 0.19×10^{-3} hr^{-1} for a very slow fraction.

Ghosh and associates studied the relationship between PCB desorption equilibrium, kinetics, and availability during land biotreatment (Ghosh *et al*., 2000). For this purpose, they conducted a study of the equilibrium partitioning and desorption kinetics using industrial lagoon sediments containing 0.91 percent oil and grease as a function of biotreatment duration. A two compartment model was used to model the desorption of PCBs from sediment. Desorption rate constants were reported for tri-, tetra-, penta-, and hexa-chlorobiphenyls. Values for the untreated sediment are summarized in Table 5.

Recently, ten Hulschler and associates studied the desorption kinetics of *in-situ* chlorobenzenes and 2,4,4'-trichlorobiphenyl (PCB-28) from River Rhine suspended matter in Lobith, located in The Netherlands (ten Huschler *et al*., 2002). They observed fast, slow, and very slow desorption rates for PCB-28. Rate constants observed were on an average of 0.2 hr^{-1} for fast, 0.0004 hr^{-1} for slow, and 0.00022 hr^{-1} for very slow desorption rates.

Table 5 summarizes the PCB desorption rate constants from different literature. From this table it can be seen that there is a high degree of variation in the magnitude of PCB desorption rate constants.

3.2 Dissolved Phase, Suspended Solids, and Whole Water PCB Concentration Estimates using Desorption Rate Constants

Most of the reported values of desorption rate constants for PCBs are homologue-based, except for Carroll, *et al*. who used an untreated PCB consisting of 60-70 percent mono- and di-chlorinated biphenyls. The desorption rate constants from literature vary from 4.2×10^{-4} to 0.2 hr^{-1} (Table 6). The highest desorption rate constant reported is within the range of those reported by Brown in 1981 for the Hudson River sediment (0.025 to 1.0 hr^{-1}). The reported rate constants correspond to a half-life range of approximately 3 to 1,700 hours and equilibrium range of 26 hours to 980 days (Table 6).

Given the length of time required for PCBs to reach equilibrium for desorption, it is unlikely that there will be large release of dissolved phase PCBs as a result of dredging activities. To demonstrate this hypothesis, the amount of dissolved phase PCBs within one hour of dredging was estimated using the two-phase partitioning model, as was described in Section 2 of this attachment. The desorption rate constants were used to estimate what level of equilibrium was achieved in one hour. Due to lack of knowledge on the amount of "labile" (fast) and "non-labile" (slow) fractions in the dredged material, only fast desorption rate constants (ranging from 4.2×10^{-4} to 0.2 hr^{-1}) are considered in this study in order to be conservative. Since the reported desorption rate constants were homologue-based, the ratios of the homologue to total PCBs are needed. The ratio of the homologue to total PCBs for the sediment was taken from the low resolution coring data (USEPA, 1998), while the ratio for the suspended solids and dissolved phase were taken from Transect 6 water column PCB homologue composition for the TI Pool reported in the DEIR (USEPA, 1997).

The background and additional concentrations and TSS values used in this analysis were the same as the values used in Section 2 of this attachment. The whole water background concentration is 50 ng/L and the corresponding TSS value is 1 mg/L (Table 7). The additional TSS value is 5 mg/L and sediment concentration is 50 mg/kg (Table 7). Assuming a residence time of 1 hour, the dissolved phase PCB released due to dredging ranges from 7.6×10^{-5} ng/L to 3.23 ng/L (Table 8). The percentage of the dissolved phase to the total concentration of PCB in the water column due to dredging ranges from 0.042 to 11 percent. From this analysis, it appears that the amount of dissolved phase in the water column as a result of dredging is relatively small.

4.0 Results from Field Studies with Dissolved and Suspended Phase PCB Measurements

4.1 New Bedford Harbor

The analyses presented in Sections 2 and 3 of this attachment conclude that a significant release of dissolved phase PCBs is unlikely to occur as a result of dredging activities. It is possible to assess these results using case study field measurements of dissolved and suspended PCB concentrations data in the water column during dredging. Measurements of dissolved and particulate phase PCBs were collected during the pre-design field test conducted at the New Bedford Harbor during August 2000.

A hybrid environmental mechanical/hydraulic excavator dredge was delivered and demonstrated by Bean Environmental LLC. The system included a portable, shallow draft barge platform, a horizontal profiling grab bucket (HPG), a crane monitoring system (CM), the Bean-patented slurry processing unit (SPU), and a water recirculation system. The average production rate for the dredge was 80 cubic yards per hour. An estimated optimal rate for the system is 95 cubic yards per hour.

A summary of field samples and analytical data is presented in Table 9. TSS and turbidity were measured along with dissolved and suspended phase PCBs. 18 National Oceanic and Atmospheric Administration (NOAA) congeners were measured and an equation developed during a previous study was used to calculate the total PCB concentration. The following information was available:

- Two pre-dredging measurements
- Data from upstream and downstream monitoring points during dredging activities
- Two measurements at the point of dredging.

The pre-dredging samples were collected 1000 feet to the north and south of the dredging location. The harbor is tidal, so the upstream/downstream locations reverse periodically. That is, the stations are located either north or south of the dredge, depending on the tide. Sampling locations were placed as follows:

Location	Initially	Adjusted in Field
Upstream	1000’	1000’
Downstream	50’	50’
Downstream	100’	300’
Downstream	500’	700’
Downstream	NA	1000’

Graphs of PCBs, TSS, and turbidity vs. distance from the dredge are shown in Figure 1. The results for the pre-dredging samples are shown at +/–1500 feet on Figure 1 for comparison. The particulate PCB and TSS measurement give similar patterns of concentrations as would be expected. At the point of dredging, the particulate PCB concentrations are elevated about ten times over the upstream conditions, but 1000 feet downstream the concentrations are just above the highest measured upstream concentration. Turbidity measurements drop off quickly with distance to a level similar to the upstream monitoring point conditions.

The dissolved phase PCB concentrations at the dredge are about ten times larger than the upstream concentrations, but these concentrations drop off quickly into the range of the upstream samples. Looking at the fraction of dissolved phase PCBs in the water column, the upstream PCBs are about 60 percent dissolved. At the dredge, this percentage drops to below 20 percent. Downstream of the dredge, the percent of dissolved phase is more variable but still less than the 60 percent fraction detected at the upstream location. This variability in the downstream samples is mirrored in the particulate PCB and TSS measurements.

These results are consistent with a mechanism of PCB release through the suspension of contaminated solids, not a significant dissolved phase release mechanism. This conclusion is more convincing in light of the high concentrations at this location (857 ppm on average in the top 0- to 1-foot segment) relative to the Hudson River (approximately 50 ppm on average in the TI Pool) and the nearly full production rate.

4.2 PCB Load Calculation

Dissolved and particulate phase PCB loads can be calculated using PCB concentrations and estimates of the flow rate. Linear velocity was measured at one location 1500 feet downstream of the dredging area. The estimate is quite crude because the volumetric flow rate is not known, but can only be calculated by using a rough estimate of the cross-sectional area at the point of the linear velocity measurement and by making the assumption that the linear velocity measurement represents the entire cross-section. This calculation further assumes that the PCB concentrations are a measure of concentration in the entire cross-section, not a portion of the harbor that has been influenced by the plume.

The linear velocity was measured at a reference station 1500 feet south of the dredge area. This section of the harbor is approximately 800 feet wide and varies from 7 to 10.5 feet in depth, depending on the tide. The velocity was measured every 10 minutes. The northern velocities peaked at 14 cm/s. A velocity 10 cm/s will be used as an average flow rate for the calculation. A limited southern component of flow was detected, indicating a stratified system.

Several measurements of the PCB concentrations were made at locations from 50 to 1000 feet downstream from the dredge area. For this estimate of load, the maximum concentration detected at the 100- to 1000-foot stations was selected to represent the mass that would remain in the water column outside of the influence of the dredge. Both the maximum dissolved and particulate concentrations were measured on the same day at

700’ from the dredge. A maximum dissolved phase PCB concentration of 0.95 ug/L was detected. A maximum particulate phase PCB concentration of 2.6 ug/L was detected. Two background measurements were made. The dissolved and particulate phase background concentrations will be subtracted. The duration of the dredging operation in hours was estimated from the time of the turbidity measurements.

Using these measurements of flow, concentration, and dredging operation duration, the maximum likely PCB loads are 1.8 kg in the dissolved phase and 7.0 kg in the particulate phase. The calculation is shown in Table 10. Twenty percent of the load is in the dissolved phase, and 80 percent in the particulate phase. It was estimated that 1,495 kg of PCBs were removed from the evaluation area. The dissolved phase load translates into 0.1 percent of the total mass removed, and the particulate phase load translates into 0.5 percent of the total mass removed.

5.0 Conclusions

The release of a significant amount of dissolved phase PCBs as a result of dredging but independent of the process of sediment resuspension would appear highly unlikely in light of the discussion presented above. There is not a sufficient reservoir of dissolved phase PCBs available to be the sole cause of a large increase in water column concentrations. That noted, the process of suspended sediment-water contact could result in a large inventory of dissolved phase PCBs if sufficient time is available to permit exchange between suspended sediments and water. It is this latter process that may be of concern during the Hudson River remediation.

Two important issues arise from this process, however. If the equilibration of dissolved and suspended matter PCBs occurred sufficiently fast, the original nature of the source (*i.e.,* the suspended solids-borne PCBs) could be masked by the changes that occur. For this reason, whole water PCB concentrations will be the main measure of PCB transport, capturing all forms of PCBs present. Measurement of suspended matter PCBs alone may under-represent the total level of PCB release.

The second issue relates to the usefulness of suspended solids as a surrogate and real-time monitoring parameter. Near-field monitoring of suspended solids can probably be relied upon to provide a useful indication of the amount of resuspension, although it will not be quantitative for several reasons, including the issue discussed above. The monitoring of suspended solids at the main downstream stations will be less sensitive to resuspension inputs, but will still provide a useful measure of conditions in general. Given the typically low suspended solids load of the Hudson during the dredging season, it is likely that major suspended solids releases will still be discernable at these stations. To account for this, whole water PCB samples will suffice when both suspended solids and PCB concentrations fall below the lowest control limit. In the event that concentrations of either parameter exceed this control limit, a second level of sampling will be required, with more frequent sampling and separate analysis of both dissolved phase and suspended matter PCBs. In addition, SPMDs will be deployed on a continuous basis to give an indication of the dissolved phase concentrations between the water column sampling events.

6.0 References

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Attachment C-1

Literature Review

Attachment C-1
Literature Reviews

1.0 Literature Search For the Impact of Dissolved Phase Contaminants During Sediment Removal Operations

Evidence has been reported that suggests that a significant dissolved phase release of PCBs is possible without any apparent increase in the suspended solids load in the water column. Because of this, several theoretical assessments of the possible mechanisms behind such an increase have been performed by the USEPA.

Two basic pathways exist that can result in high dissolved phase PCB concentrations due to dredging. The first is the direct release of water with a high dissolved phase PCB concentration. This water would most likely originate as contaminated porewater within the sediment. Porewater can be highly contaminated for two primary reasons: it is in direct contact with contaminated sediments, and it typically contains a high concentration of dissolved organic carbon, a medium that can enhance the apparent dissolved phase concentration. In addition to porewater, water that comes in contact with the sediments during the dredging process may also contain relatively high concentrations.

The second mechanism with the potential to create a high dissolved phase concentration is an event that suspends a large mass of contaminated sediments in the water column. PCBs will tend to equilibrate between solid and dissolved phases, effectively removing PCBs from the suspended sediments to the water column. If the suspended solids added are of sufficient mass and contamination level, the dissolved phase concentration can rise markedly. It can be noted that the process of equilibration will not be undone if a large fraction of the suspended sediments is lost to settling as the plume is transported downstream. Because the equilibrium between the solid and dissolved phases is concentration-driven and not mass-driven, the water column will be left with a large dissolved phase burden if a significant mass of sediments is added to the water column, allowed to equilibrate, and lost via settling.

To try to predict the changes in the water column dissolved PCB concentration during an intrusive activity like dredging, it is important to have a basic understanding of the possible mechanisms that could result in the dissolution of sorbed PCBs. The scientific papers below were reviewed towards that end.

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1. Rapidly Desorbing Fractions of PAHs in Contaminated Sediments as a Predictor of the Extent of Bioremediation (Cornelissen et al., 1998)

Desorption kinetics of PAHs from contaminated sediments before and after bioremediation are discussed in this study. The rapid desorption rate constant was approximately 100-3000 times larger than the slow desorption rate constant. It is concluded that the rapidly desorbing PAHs are primarily degraded during bioremediation and the slowly desorbing amounts remain unchanged.

Reference:
Cornelissen, G.; Rigterink, H.; Ferdinandy, M. M. A.; Van Noort, P. C. M. "Rapidly Desorbing Fractions of PAHs in Contaminated Sediments as a Predictor of the Extent of Bioremediation," *Environmental Science and. Technology,* Vol. 32, pp. 966-970, 1998.

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2. A Simple Tenax Extraction Method to Determine the Availability of Sediment-Sorbed Organic Compounds (Cornelissen et al., 2001)

Fractions of PAHs, PCBs and chlorobenzenes that can be removed from contaminated sediments by means of a single Tenax extraction are evaluated in this study. Two extraction times (6 and 30 hours) in six different contaminated sediments collected from various locations in The Netherlands were used to determine the fractions of PAHs, PCBs, and chlorobenzenes that could be removed using the Tenax Extraction Method.

Results of the experiment indicated that extraction by Tenax for 30 hours completely removed the rapidly desorbing fractions, plus some part of the slowly desorbing fraction, whereas the fraction extracted by Tenax for 6 hours removed about half of the rapidly desorbing fraction for chlorobenzenes, PCBs, and PAHs.

This study concluded that the concentration in sediment of rapidly desorbing, linearly sorbed fractions can be determined by the amount desorbed to Tenax. For PCBs, the amount linearly sorbed is about two times the amount desorbed to Tenax after a six-hour contact time.

Reference:
Cornelissen, G.; Rigterink, H.; Ten Hulscher, D. E. M.; Vrind, B. A.; Van Noort, P. C. M. "A Simple Tenax Extraction Method to Determine the Availability of Sediment-Sorbed Organic Compounds;" *Environmental Toxicology and Chemistry,* Vol. 4, pp. 706-711, 2001.

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3. Fate and Transport of PCBs at the New Bedford Harbor Superfund Site (Garton, et al., 1996)

This study presents a modeling approach, combining the theoretical, deterministic, and empirical elements that were used to predict the fate and transport of PCBs at the estuarine New Bedford Harbor Superfund Site. The theoretical approach was used to characterize volatilization and sorption. Sediment processes including settling, flocculation, resuspension, advection, and dispersion were characterized empirically and sediment settling velocity deterministically from experimental data. The following observations were reported from the model:

- Sorption to sediments was reported to be the preferred state of PCBs in water environments, with sorption coefficients ranging from 10^{-23} to $10^{-0.4}$ m^3/g for Aroclor 1242 and Aroclor 1260. Affinity to sediments reportedly increased with an increase in the percent chlorine.

- Sediments in the harbor were undergoing continuous resuspension to the water column and corresponding deposition. Resuspension and deposition were driven by the change in the suspended solids concentration and tides. Deposition was found to be greater during flood, while resuspension was greater during ebb.

- Fluid shear was the most significant flocculation mass removal mechanism contributing to the settling velocity calculation. It was observed by means of visual observation that differential settling accounted for 30 percent of the mass removal and fluid shear for 90 percent of the mass removal. Both these mechanisms accounted for 100 percent mass removal and particle removal via fluid shear occurred before differential settling.

It was concluded that the PCBs at the New Bedford Harbor are not very soluble and that they volatilize or sorb to sediment rather than staying in solution. This allows PCB transport from the harbor, either sorbed to sediments, transferred to mobile sediments during resuspension activity, or by volatilization, thus leading to PCB contamination of the water column, downstream areas, or atmosphere.

Reference:
Garton, L.S.; Bonner, J. S.; Ernest, A.N.; Autenrieth, R. L. “Fate and Transport of PCBs at the New Bedford Harbor Superfund Site,” *Environmental Toxicology and Chemistry,* Vol. 15, pp. 736-745, 1996.

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4. PCB Availability Assessment of River Dredging Using Caged Clams and Fish (Rice et al., 1987)

The effects of dredging to remove PCB-contaminated sediments in the South Branch of the Shiawassee River in south-central Michigan are presented in this study. The bioavailability of PCBs was monitored using caged fingernail clams and fathead minnows. Changes in water column concentrations of PCBs before dredging, during dredging, and up to six months after dredging was completed were monitored and compared to PCB bioavailabity data.

Monitoring of water, clams, and fish during dredging indicated that significant amounts of PCBs were released from the sediments during dredging, which declined quickly farther downstream. There were increases in the availability of PCBs for at least six months at all locations downstream and in the area of dredging. However, there was no noticeable change in the total PCB concentration in the water column after dredging. Post-dredge uptake was also higher downstream. Overall, clams showed less uptake than fish. It was concluded that dredging worsened the problem of bioavailability, at least over the short term.

The researchers noted several important site-specific features of the south branch of the Shiawassee River:

- Large PCB deposits were found to occur along with fine, erodable, and distinctly organic silt.

- The sediment of the river was essentially lacking in clay.

The researchers stated that these factors might tend to make PCBs more available than would be the case in the well mixed, sand-silt-clay type typically found on larger rivers.

Overall, it was concluded that among water, clams, and fish, there was no one ideal monitor for the true bioavailability of PCBs in the South Branch of the Shiawassee River. The fish were sensitive indicators of changes in PCB availability more than six miles downstream of the dredging site. Uptake by fingernail clams appeared to reflect local conditions at the sediment-water interface, but was not a sensitive indicator more than one mile downstream.

Reference:
Rice, C. P.; White, D. S. "PCB Availability Assessment of River Dredging Using Caged Clams and Fish," *Environmental Toxicology and Chemistry,* Vol. 6, pp. 259-274, 1987.

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5. PCB Removal from the Duwamish River Estuary: Implications to the Management Alternative for the Hudson River PCB Cleanup (Pavlou et al., 1979)

This study presents the cleanup of the Duwamish River, Washington, and uses it as a test case to compare it to the Hudson River problem. A transformer handling accident resulted in a spill of transformer fluid, containing PCBs, into the river.

The initial cleanup was staged by divers using a hand dredge to recover submerged pools of the liquid. This dredging ended within 20 days of the spill occurrence. The second, more extensive cleanup that took place approximately 17 months later used a hydraulic dredge and lasted approximately 24 days. Suspended particulate matter (SPM) and water column concentrations were monitored during this second cleanup phase. The results of monitoring reportedly revealed the following:

- No change in the SPM concentration was observed throughout the dredging operation.

- Water column PCB concentrations were observed to be constant throughout the dredging operation.

- Greater than 90 percent of PCBs were recovered in 44 days of dredging.

This study concluded that the dredging operations did not significantly alter the PCB characteristics of the river.

Using the performance results of dredging in the Duwamish River as the basis, four management alternatives for cleanup of the Hudson River were proposed. The management alternatives included:

- No Management Action Further Study
- Stabilization and / or Removal of Remnant Deposits
- Removal of Remnant Deposits and Sediments > 50 ppm
- Removal of all River Sediments > 1 ppm.

The researchers stated that the best alternative for cleanup of the Hudson River would be “Removal of Remnant Deposits and Sediments > 50 ppm,” as this alternative was similar to what was done in the Duwamish River, where no changes in the PCB levels of SPM and water were observed. The paper also concluded that this alternative would also remove 90 percent of the toxicant load, as was done in the Duwamish River, within reasonable economic limits.

Reference:
Pavlou, S.P; Hom, W. “PCB Removal from the Duwamish River Estuary: Implications to the Management Alternative for the Hudson River PCB Cleanup,” ANNALS N.Y. ACAD. SCI., Vol. 320, pp. 651-672, 1979.

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6. Predicting Effluent PCBs from Superfund Site Dredged Material (Thackston et al., 1992)

This paper discusses a feasibility study of dredge use to remove PCBs from sediments in New Bedford Harbor, Massachusetts. Part of the study evaluated the usage of an onshore confined disposal facility (CDF) to contain dredged material. A CDF is commonly used in the disposal of dredged material that contains a wide range of contaminants.

The researchers also evaluate the validity of results generated by the modified elutriate test to determine dissolved contaminant concentration and the concentrations associated with suspended solids in the effluent generated from a CDF.

The modified elutriate test simulates the expected chemical and physical conditions present in the CDF, and is based on both the dissolved and total concentrations of each contaminant in the elutriate. The test is used to predict the contaminant concentrations in the dissolved phase and also the concentrations associated with suspended solids present in the elutriate.

The paper concludes that the elutriate test is a useful, accurate, and conservative predictor of the concentrations of contaminants in the effluent from a CDF receiving highly contaminated sediments.

Reference:
Thackston, Edward L; Palermo, Michael R. "Predicting Effluent PCBs from Superfund Site Dredged Material," *Journal of Environmental Engineering*, Vol. 118, no. 5, 657-665, 1992.

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7. Predicting Release of PCBs at Point of Dredging (DiGiano et al., 1993)

A dredging elutriate test (DRET) was used to predict the concentration of contaminants (dissolved and suspended PCBs) as a function of initial concentration of sediment, aeration time, and settling time in the water column at the point of dredging. Results from the DRET were compared to field data from a pilot dredging operation at New Bedford Harbor, Massachusetts.

The total PCB concentrations were proportional to the final TSS, while the soluble PCB concentrations are nearly independent of the final TSS. The DRET tests also found that aeration time had little effect on final TSS concentration. Settling times greater than six hours produced little further removal of TSS, regardless of the initial TSS concentrations or aeration time.

This study found that while small particles dominate the particle distribution with increasing settling time, the PCB concentration per unit mass is not any greater than for larger particles, thus the fraction of organic carbon, which determines the extent of partitioning in the sediment, is not a function of particle size.

The New Bedford Harbor Field Data used three different dredge heads (cutter head, horizontal auger, and matchbox), and samples taken directly from the ports of the dredge head and from within 30m of the dredging area (plume samples). Sorbed and dissolved PCB concentrations for the field plume samples were similar to the DRET data. The data indicate that the horizontal auger causes the largest concentration of PCBs in the water column of the three methods used.

All results suggest TSS is the most important factor in determining the PCB released into the water at the point of dredging. The relationship between aqueous TSS concentration and aqueous Total PCB concentration is directly proportional. The researchers proved that the DRET could describe partitioning. The flocculent nature of particle settling implies that far less efficient settling and thus higher total PCB concentrations may be expected in freshwater dredging operations where destabilization of particles is less effective.

Reference:
DiGiano, F. A.; Miller, C. T.; Yoon, J. "Predicting Release of PCBs at Point of Dredging," *Journal of Environmental Engineering*, Vol. 119, No. 1, pp. 72-89, January/February, 1993

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8. The Effect of Sediment Dredging on the Distribution of Organochlorine Residues in a Lake Ecosystem (Sodergren et al., 1984)

Redistribution and deeper penetration of remaining residues of DDT compounds and PCBs were observed in a Swedish lake after dredging. Water, sediment, and fish samples were analyzed. Dredging was carried out in the summers of 1970 and 1971, and removed 300,000m^3 of contaminated sediment.

Ten years after dredging, the level of PCBs in the upper 5 cm of sediment was about twice as high as it had been immediately after the operations. The researchers believe that the dredging operations apparently caused mixing and internal circulation of sediment particles.

Levels of PCBs in sediment from an area of the lake that were not dredged were about ten times higher than those in the central part of the lake before dredging.. Relatively high PCB concentrations in this undredged area may be due to the historic contamination of the area as an industrial dump for drainage water.

Reference:
Sodergren, Anders. "The Effect of Sediment Dredging on the Distribution of Organochlorine Residues in a Lake Ecosystem," Ambio. Stockholm [AMBIO.], Vol. 13, no.3, pp. 206-210, 1984.

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9. Slowly Reversible Sorption of Aliphatic Halocarbons in Soils I. Formation of Residual Fractions (Pignatello et al., 1990)

This study describes the formation (thermodynamics and kinetics) of slowly reversible sorbed fractions of various halogenated aliphatic hydrocarbons (HHCs) (halogenated solvents CT, TCA, TCE, TeCE, and soil fumigants 1,3-D, 1,2-DCP, EDB, and DBCP) in two surface soils (Cheshire fine sandy loam, and an Agawam fine sandy loam). Soils were allowed to sorb the compounds under two conditions: unsaturated soil (10 percent moisture by weight), and soil suspended in an aqueous solution of HHC.

Desorption experiments using batch extraction of the HHCs from the soils with water showed that the apparent soil-water distribution coefficients increased progressively to as much as 200 times greater than equilibrium sorption coefficients K_d, obtained separately from sorption isotherms. In each desorption case, the apparent distribution coefficient ($K_{d,app}$) increased with each extraction from a value after the first extraction that was comparable to K_d, to a value after the 16th extraction that was 1 to 2 orders of magnitude greater than K_d. Thus, after repeated extraction, the soil retained significant quantities of HHC, releasing it only slowly to the aqueous phase. Desorption experiments of HHCs on soil using a continuous removal of Tenax CC polymeric absorbent beads yielded slowly reversible residual fractions in the soil.

Desorption experiments using Tenax in an aqueous suspension showed that desorption from the soil was rate-limiting. The researchers note that it is possible that uptake by Tenax actually occurred from the vapor phase, although distribution of the HHCs from the aqueous phase into Tenax is highly favorable; because Tenax is poorly wetted by water and is known from extensive use in GC applications to be an efficient absorbent of organic vapors.

The results of these experiments show that even compounds normally regarded as labile in the environment by their volatility and weak equilibrium sorption tendencies can generate kinetically slow sorbed residues.

Reference:
Pignatello, J.J. “Slowly Reversible Sorption of Aliphatic Halocarbons in Soils. I. Formation of Residual Fractions,” *Environmental Toxicology and Chemistry,* Vol. 9, pp. 1107-1115, 1990.

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10. Why biota still accumulate high levels of PCB after removal of PCB ontaminated sediments in a Norwegian fjord (Voie et al., 2002)

This study focused on a marine fjord located outside of Haakonsvern, a naval base in Norway. Sediments contained in the fjord were found to be highly contaminated with PCBs, and were removed via dredging in 1998. The objective of this study was to determine which of the following hypotheses best corresponds to the reality of bioavailability:

- That contaminated food is the most important source accumulation due to the low concentration of PCBs in water (estimated using the octanol-water partition coefficient).
- That the PCBs in the dissolved phase are the most important source of exposure.

Accumulation of low chlorinated PCB congeners with a low K_{ow} in blue mussels and SPMDs was higher than for the highly chlorinated congeners with a high K_{ow}. Bioaccumulation concentrations of PCBs before, during, and after dredging did not change. Suspended matter/solids concentrations were not addressed. Water column concentrations were not reported.

Related experiments indicated that PCBs are accumulated from the water column, and that bioaccumulation in blue mussels and SPMDs occurs mostly from PCBs dissolved in the water column. After dredging, more coarse materials were exposed to the seabed. The coarse material has less ability to bind PCBs. Also, fine contaminated particles might settle after dredging, leaving a thin contaminated layer of material.

Lower chlorinated PCBs are transported a longer distance than the higher chlorinated congeners, thus accumulation of low chlorinated PCBs was higher in less contaminated areas (4 km away).

If PCBs accumulate in blue mussel and SPMDs due to presence in the water column, the bioaccumulation amounts in the biota may not have varied as significantly, as the water concentrations of PCBs remained unchanged after dredging due to the low solubility of PCBs.

Reference:
Voie, O. A.; Johnsen, A.; Rossland, H. K. "Why biota still accumulate high levels of PCB after removal of PCB contaminated sediments in a Norwegian fjord," *Chemosphere,* Vol. 46, pp. 1367-1372, 2002.

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11. Desorption Kinetics of Chlorobenzenes, Polycyclic Aromatic Hydrocarbons, and Polychlorinated Biphenyls: Sediment Extraction with Tenax® and Effects of Contact time and Solute Hydrophobicity (Cornelissen et al., 1997)

The kinetics of desorption of chlorobenzenes, polychlorinated biphenyls, and polyaromatic hydrocarbons using Tenax beads from contaminated sediment (Lake Oostvaardersplassen, Netherlands) was studied.

The sediment was dried to remove remaining organic contaminants as well as a number of non-identified components that disturb chromatographic analyses. Contaminated lake sediments and contaminated water spiked with concentrations ranging from 1 to 100 μg/l were allowed to equilibrate for 2 days and 34 days. After the equilibration time, sediment and supernatant were separated by centrifugation, extracted with hexane, and analyzed for contaminants and dissolved organic carbon.
Kinetics of desorption were determined by the Tenax extraction method. Rates of extraction from the aqueous phase were also measured separately without any sediment. The added amount of Tenax in this experiment was rendered insufficient due to the amount of organic carbon present in the samples.

DOC data indicate that DOC is slowly released from the sediment during equilibration. The fractions of contaminant present in the slowly desorbing sediment compartment, F_{slow}, are observed to increase with increasing test compound hydrophobicity. The rate constants of slow desorption, k_{slow}, are observed to decrease with increasing equilibration time, while F_{slow} slightly increased with equilibration time. This phenomenon can be explained by proceeding diffusion into the slowly exchanging sediment part (higher F_{slow}) and by the presence of the solute at more remote locations from which desorption is slower (lower k_{slow}).

First order rate constants of rapid desorption were in the order of 10^{-1}/h. First order rate constants of slow desorption were in the order of 10^{-3}/h. These correlate well with the molecular volumes of the compounds used and decrease between 2 and 34 days of equilibration. Slowly desorbing fractions increase with both increasing solute hydrophobicity and increasing equilibration time.

Reference:
Cornelissen, G.; Van Noort, P. C. M.; Govers, H. "Desorption Kinetics of Chlorobenzenes, Polycyclic Aromatic Hydrocarbons, and Polychlorinated Biphenyls: Sediment Extraction with Tenax® and Effects of Contact time and Solute Hydrophobicity," *Environmental Toxicology and Chemistry*, Vol. 16, No. 7, pp. 1351-1357, 1997.

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12. Comparing Polychlorinated Biphenyl Concentrations and Patterns in the Saginaw River Using Sediment, Caged Fish, and Semipermeable Membrane Devices (Echols et al., 2000)

This experiment compared three possible techniques to assess the amount of bioavailable polychlorinated biphenyls (PCBs) in the Saginaw River, Michigan:

- Measurement of PCB concentrations in sediments.
- Measurement of PCB concentrations in caged channel catfish.
- Measurement of PCB concentrations in SPMDs.

The caged fish and SPMDs were placed in the river for 28 days at five sites where sediments were sampled. Rates of PCB accumulation by SPMDs that have been reported previously were used to estimate the aqueous concentrations from the PCB concentrations found in the SPMDs, sediment-water partition coefficients were used to estimate the dissolved PCB concentration from the sediment, and steady-state bioaccumulation factors and depuration rate constants were used to estimate the aqueous PCB concentration from the caged fish. The relative PCB patterns from the three techniques were compared using principal components analysis.

The study found that SPMD and sediment results were complementary; the sediment concentrations represent long-term accumulation and weathered components, while the SPMDs show accumulations only from the sampling period. The lower chlorinated PCBs predominate in the SPMDs as compared with the distribution in the fish and the sediments, likely due to the higher solubilities of the lower chlorinated PCBs. The distribution differences between the fish and the SPMDs are likely the result of metabolism and depuration of certain congeners by the fish.

Results from the water pattern modeling did not cluster on the principal component analysis plot, co-varying positively and negatively on different axes. The sediment and SPMD modeled data had similar patterns in the principal component analysis, but the water concentrations derived from the sediment model were three to nine times higher than those calculated from the SPMD model. The fish model results were closer to those obtained from the SPMD model, but the patterns were different, likely due to the use of alternate fish constraints (due to the lack of species-specific constraints available on then model) or congener metabolism and depuration.

Reference:

Echols, K. R.; Gale, R.W.; Schwartz, T. R.; Huckins, J. N.; Williams, L. L.; Meadows, J. C.; Morse, D.; Petty, J. D.; Orazio, C. E.; Tillitt, D. E. "Comparing Polychlorinated Biphenyl Concentrations and Patterns in the Saginaw River Using Sediment, Caged Fish, and Semipermeable Membrane Devices," *Environmental Science and Technology,* Vol. 34, pp. 4095-4102, 2000.

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13. Mobilization of PAHs and PCBs from In-Place Contaminated Marine Sediments During Simulated Resuspension Events (Latimer et al., 1999)

This study used a particle entrainment simulator (PES) to investigate the resuspension transport of hydrophobic organic compounds, specifically PCBs and polycyclic aromatic hydrocarbons (PAHs), to the overlying water column through the experimental production of representative estuarine resuspension events. During the experiment, the contaminants were evaluated in bulk sediments, size-fractioned sediments, resuspended particulate material, and, in some cases, dissolved phases. Two types of sediment, dredged material and bedded estuarine sediment, were used in this study, and they represented gradients in contaminant loadings and textual characteristics. The sediments were collected from Black Rock Harbor, Connecticut, and Narragansett Bay, Rhode Island. The objectives of the study were to evaluate the chemistry and dynamics of the contaminants as a function of the magnitude of resuspension.

Several conclusions regarding the resuspension chemistry and dynamics of hydrophobic organic compounds were drawn:

- The size of the particles entrained from the bedded sediments changed as the resuspension magnitude increased. This can be attributed to the non-uniform characteristics of the sediment with depth in the resuspension zone (up to 1 mm). In a case of more highly contaminated sediments, the mean particle size was relatively constant under varying conditions of resuspension. The mean particle size was also similar to that of the bulk sediment characteristics. In contrast, for the less contaminated bedded sediment, the particle sizes decreased over the same applied shear range. Also, the particle size distribution exhibited by the bedded sediments during resuspension was more skewed toward smaller particles than the bulk sediments.

- On the basis of mass loading and an organic carbon loading weight, the amount of PCBs and PAHs with a log $K_{ow} < 6$ in the entrained particulate material was somewhat depleted as the applied shear increased and the amount of material resuspended in the water column was increased. Alternately, some higher molecular weight PAH (log $K_{ow} < 6$) showed slightly enriched loadings under the same conditions. On a volume-weighted basis, the concentration of organic contaminants increased in the water column as more material was resuspended.

- In the case of the bedded sediments, accurate predictions of the entrained PAH and PCB loadings on resuspended material were made using the resuspended particle sizes and the concentration of the PAHs and PCBs in the particle size pools of the bulk sediment. This prediction could not be made for the dredged material, possibly due to contributions from the colloidal particles not specifically measured in the study.

- During the resuspension events, the distribution of PAHs between the dissolved and particulate phases (K_ds) showed relatively minor decreases with increased applied shear and TSS levels. It was possible to calculate within a factor of 2 the fraction with which the PAHs were associated based on the amount of organic carbon in each of the resuspended samples. In order to obtain more accurate predictions, however, kinetic factors and the role of other unmeasured substrates would need to be taken into consideration.

The research suggests that resuspension, while periodic in nature, is likely an important process affecting the fate and effects of contaminants in the coastal and marine environment. Further study is needed to address the roles played by different sized particles in this contamination contribution to shallower water systems and the conditions under which theses contributions occur.

Reference:
Latimer, J.S.; Davis, W.R.; Keith, D.J. “Mobilization of PAHs and PCBs from In-Place Contaminated Marine Sediments During Simulated Resuspension Events.” *Estuarine, Coastal, and Shelf Science*, Vol. 49, pp. 577-595, 1999.

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14. Distribution of Organic Carbon and Organic Xenobiotics Among Different Particle-Sized Fractions in Sediments (Kukkonen et al., 1996)

The distributions of benzo[a]pyrene, hexachlorobiphenyl, and total organic carbon in sediment samples taken from Lake Michigan and Florissant, Missouri, were determined and compared to the known bioavailability of the compounds. The goals of the study were to demonstrate that the settling velocity method can be used for measuring the xenobiotic distribution among sediment particles; to measure the effect of water quality (lake water vs. distilled water) on the distribution of particles, organic carbon, and xenobiotics in two different sediments; and to examine the sorption behavior of two different xenobiotics (one PAH and one PCB) of similar hydrophobicity to try to account for previously observed differences in bioavailability.

The distribution of the organic compounds among particles < 63 μm in diameter differed from that of the total organic carbon;, however, the organic matter remained the major sorbent for most of these compounds. Altering the fractionation conditions by performing the procedure in distilled water rather than natural lake water changed the particle distributions for both the organic carbon and the xenobiotics.

In addition, the contaminant distribution relative to the organic carbon content differed between particle-size fractions and between contaminants of different compound classes, e.g., PAHs and PCBs. The different distributions of the contaminants in the particle fractions likely contributed to the observed differences in the bioavailability of the organic contaminants to benthic organisms and may be exacerbated by selective feeding.

Reference:
Kukkonen, J.; Landrum, P.F.; "Distribution of Organic Carbon Xenobiotics Among Different Particle-Size Fractions in Sediments," *Chemospehere,* Vol. 32, no. 6, pp.1063-1076, 1996.

2.0 Literature Review for PCB Desorption Rates

Resistant Sorption of *In Situ* Chlorobenzenes and a Polychlorinated Biphenyl in River Rhine Suspended Matter

In this study, desorption kinetics of *in situ* chlorobenzenes (dichlorobenzenes, pentachlorobenzene and hexachlorobenzene) and 2,4,4'-trichlorobiphenyl (PCB-28) were measured for River Rhine suspended matter in Lobith, The Netherlands. The desorption behavior of these pollutants (chlorobenzenes and PCB-28) in the suspended matter was compared to their desorption behavior in the top layer (5-10 cm) of sediment in Lake Ketelmeer, as this suspended matter was reported to be the main source of sediment accumulation in Lake Ketelmeer.

Results of this study showed similarity of desorption profiles between River Rhine suspended matter and the top layer of sediment from Lake Ketelmeer. Rate constants observed were on an average 0.2 h^{-1} for fast desorption, 0.004 h^{-1} for slow desorption and 0.00022 h^{-1} for very slow desorption, which were in agreement to the values reported in the literature. Fast desorbing fractions were not detected for any of the compounds other than PCB-28 (1.6 percent of fast desorbing fractions were detected). The results of this study concluded the following:

- Slow and very slow desorbing fractions were already present in the material forming the top layer of Lake Ketelmeer and were not formed after deposition of this material in the lake.

- The absence of recent pollution of the suspended matter could have caused the absence of detectable fast fractions for most compounds in the suspended matter.

- Rapid disappearance of compounds from the fast fraction could also be due to a combination of a high affinity of very slow sites for these compounds and their relatively high volatility.

- The presumed differences in desorption patterns between a sediment top layer (5-10 cm) and the deepest layers (> 10 cm) did not always exist.

Reference:
ten Hulscher, T. E. M.; Vrind, B. A.; van Noort, P. C. M.; Govers, H. A. J. "Resistant Sorption of In Situ Chlorobenzenes and a Polychlorinated Biphenyl in River Rhine Suspended Matter," *Chemosphere*, Vol. 49, pp. 1231-1238, 2002.

Desorption Rates of Two PCB Congeners from Suspended Sediments – I. Experimental Results

Desorption of 2,5,2’, 5’-tetrachlorobiphenyl (PCB-52) and 2,4,5,2’, 4’, 5’-hexachlorobiphenyl (PCB-153) from suspended particles in a gas stripping reactor were studied in this paper and experimental results reported. The objectives of the research were to study the effects of particle size, congener properties, and equilibration time on PCB desorption rates during resuspension events, and to develop a kinetic model to simulate such a desorption process.

The experimental results indicated that PCB desorption was characterized by a two-stage behavior - an initial rapid desorption followed by a prolonged slower desorption. PCB desorption was found to be dependent on octanol-water partition coefficient (K_{oc}), independent of particle size during the initial rapid desorption stage and dependent on particle size during the second desorption stage. Inverse relationship (decrease in overall desorption as the equilibration time increased from 20 days to 3 years) between desorption rate and equilibration time (aging effect) was observed and was reported to be consistent with previous results reported in the literature.

The aging effect observed reportedly suggested that the release rates of PCBs in natural systems were likely much lower than those observed in short-term laboratory experiments, indicating that not only a kinetic model should be used in many aquatic system models, but also that kinetic constants obtained in short-term laboratory experiments may not be directly applicable to the desorption process in natural systems.

Reference:
Gong, Y.; Depinto, J. V.; Rhee, G. Y.; Liu, X. “Desorption Rates of Two PCB Congeners from Suspended Sediments – I. Experimental Results,” *Water Resources,* Vol. 32, No. 8, pp. 2507-2517, 1998.

Desorption Rates of Two PCB Congeners from Suspended Sediments – II. Model Simulation

Development of a two-compartment diffusion model and its application to simulate the desorption kinetics of two PCB congeners 2,5,2’, 5’-tetrachlorobiphenyl (PCB-52) and 2,4,5,2’, 4’, 5’-hexachlorobiphenyl (PCB-153) from suspended aquatic sediments are discussed in this paper. The primary objectives of this paper were:

- To explore other potential mechanisms (in addition to the retarded pore diffusion) that may contribute to the two-distinct-rate behavior of PCB desorption.

- To develop a sorption kinetics submodel that was consistent with the majority of mechanistic models and was practicable for system-level modeling of PCB transport and fate.

- To apply the developed model to simulate the experimental results presented in the preceding paper (Paper 2 above).

The simulation results of this model concluded the following:

- Both non-equilibrium sorption and non-uniform particle size distribution of the natural sediments may contribute to the two-distinct-rate desorption behavior of the PCBs that has been observed.

- Compared to the single retarded pore diffusion model, the two-compartment diffusion model, which assumed that one fraction of PCBs in solid phase reached an instantaneous equilibrium with the surrounding aqueous phase while the other fraction followed intra-particle diffusion, fit the data far better than the single retarded pore diffusion model.

- Increased adsorption time (aging) would in general decrease the instantaneous equilibrium fraction and the effective pore diffusion coefficient.

Reference:
Gong, Y.; Depinto, J. V. "Desorption Rates of Two PCB Congeners from Suspended Sediments – II. Model Simulation," *Water Resources,* Vol. 32, No. 8, pp. 2518-2532, 1998.

Polychlorinated Biphenyl Desorption from Low Organic Carbon Soils: Measurement of Rates in Soil-Water Suspensions

Desorption-release rates of 13 individual PCB congeners from four contaminated soils suspended in water were investigated using the gas purge technique. The soil samples used for this investigation were obtained from PCB spill sites and had been in contact with Aroclor 1242/1254 mixtures for 3 or more years, therefore it was assumed that sorption equilibrium was obtained in these soil samples. Soils analyzed were "engineered" ground cover materials used at utility industry substations and consisted of fine rock chips and sand-silt-clay fractions with organic carbon < 0.2 percent. The PCB congeners in the soils contained three to five chlorine atoms. Proper functioning of the gas purge technique for measurement of congener release rates was confirmed by measuring the Henry's law constants for ^{14}C-labeled congeners 24', 22'55' and 22'44'55' and comparing the results obtained with the values reported in the literature.

For all 13 congeners and all soil samples analyzed the following results were reported:

- The labile fraction was found to be 80 to 90 percent of the total congener concentration.

- Majority of the labile fraction was desorbed or released within 48 hours of contact with water.

- Release of the remaining non-labile fraction persisted for over six months with complete release estimated to be one to two years.

- Release rate constants, Kd were found to decrease with increase in the number of chlorines. The typical Kd values for labile and non-labile fractions were found to range from 1.4 to 0.5 d^{-1} and 0.008 to 0.0006 d^{-1}, respectively.

Reference:
Girvin, D. C.; Sklarew, D. S.; Scott, A. J; Zipperer, J. P. "Polychlorinated Biphenyl Desorption from Low Organic Carbon Soils: Measurement of Rates in Soil-Water Suspensions," *Chemosphere*, Vol. 35, No. 9, pp. 1987-2005, 1997.

A Simple Tenax Extraction Method to Determine the Availability of Sediment-Sorbed Organic Compounds

Fractions of PAHs, PCBs and chlorobenzenes that can be removed from contaminated sediments by means of a single Tenax extraction are evaluated in this study. Two extraction times (6 and 30 hours) in six different contaminated sediments from various locations in the Netherlands were used to determine the fractions of PAHs, PCBs, and chlorobenzenes that could be removed using the Tenax Extraction Method. Results of the experiment indicated that extraction by Tenax for 30 hours completely removed the rapidly desorbing fractions plus some part of the slowly desorbing fraction, whereas the fraction extracted by Tenax after 6 hours was about 0.5 times the rapidly desorbing fraction for chlorobenzenes, PCBs an PAHs.

Reference:
Cornelissen, G.; Rigterink, H.; Ten Hulscher, D. E. M.; Vrind, B. A.; Van Noort, P. C. M. "A Simple Tenax Extraction Method to Determine the Availability of Sediment-Sorbed Organic Compounds;" *Environmental Toxicology and Chemistry*, Vol. 4, pp. 706-711, 2001.

PCB in the Upper Hudson River: Sediment Distributions, Water Interactions, and Dredging

This paper is a summary of a number of studies performed by the DEC and various consultants dealing with the PCB sediment distribution, water interaction, and dredging for the Upper Hudson River. The studies were grouped by type and presented together. The following conclusions were reached in the area of sediment distributions:

- Over the course of mapping the sediment distributions in the Upper Hudson, it was found that sampling on transects across the river and obtaining precise locations for those samples was essential. The variation of PCB concentrations across the river was extreme, while the concentration variation was more gradual down the river.

- The distribution of PCBs in the sediments can be classified as lognormal.

- The PCB concentration was generally highest in silty sediments, next highest in coarse sands containing wood chips, and lowest in the sands and gravels that do not contain any woodchips or organics. The same trend held in sieved samples composed of sand, wood chips, and silt.

- PCB hot spots that contained concentrations above 50 μg/g were typically found in low velocity and near bank areas. In the Upper Hudson, about 68 percent of the total mass of PCBs is contained in hot spots that cover only 8 percent of the river area.

- PCB concentration was positively correlated with Cs-137, specific heavy metals, and volatile solids. PCB concentration was negatively correlated with total solids.

- Sediment cores indicated that the maximum PCB concentrations were normally found 8-30 cm below the top of the core. Dating using Cs-137 techniques placed the peak discharge of PCBs in the 1960s. PCB contamination was rarely found below 90 cm in the first 10 km from the contamination source, and rarely below 60 cm for the rest of the Upper Hudson.

The following conclusions were drawn from the water interaction studies:

- The bulk of PCBs were adsorbed on solids in a concentrated sediment-water mixture. When moving from a 10/1 elutriate test to a more dilute river system, the sediment-water coefficient increased, and a higher percentage of the PCBs in the mixture became soluble in the water. Given that Aroclor 1221 has a lower sediment-water partition coefficient than Aroclor 1254, this finding is significant to groundwater attenuation, river transport, and dredging systems.

- Cationic polymers and chitosan were helpful in rapidly removing the suspended solids in a sediment-water mixtures and reducing the concentration of PCBs in the water.

- High PCB concentrations occurred at low flow in the river, a phenomenon possibly explained by desorption of PCBs from bottom sediments. The highest concentrations of PCBs occurred during very high flows that eroded and suspended bed material. The water PCB concentrations were lowest under intermediate flow conditions.

- The projected loss of PCBs to the Lower Hudson river over 20 years averaged 3,630 kg/yr, and modeled results indicated that this would occur for decades if no action was taken.

- The rate of PCB volatilization from the Upper Hudson varies with temperature, wind speed, and turbulence conditions. The volatilization rate is projected to be 0.45-4.5 kg/day. This is in the range of the total river water transport of PCBs under low flow conditions of 3-5 kg/day.

The examination of dredging projects yielded the following conclusions:

- 20 mg/l of cationic polymer was found to be effective in boosting PCB and suspended solids removals in spoils lagoons for three full-scale hydraulic dredging projects on the Hudson. The best results were achieved when the polymer was fed at an intermediate box between the two lagoons.

- A minimum of one-hour retention time is recommended in the spoils lagoon system for a hydraulic dredging project in the Hudson.

- Scum removal in the hydraulic spoils lagoons and in the river downstream of a dragline dredge was found to be essential in the Hudson due to the high concentration of PCBs in the scum.

- Hydraulic and mechanical dredging losses to the water column for the hot spot dredging were projected to be about 2 percent of the PCB and 1 percent of the solids, based on the monitoring data. The contaminated solids not picked up by the dredge were projected to be 5 percent or greater. If the dredge operation is not precisely controlled, the loss could potentially be greater than 5 percent.

- Over 60 percent of the total mass of 200,000 kg of PCBs in the upper river is expected to be removed via dredging of the hot spots and routine maintenance dredging in 8 percent of the Upper Hudson.

Reference:

Toffelmire, T. J.; Hetling, L. J., Quinn, S.O. “PCB in the Upper Hudson River: Sediment Distributions, Water Interactions, and Dredging,” *DEC Technical Paper No. 55,* January 1979.

Volatilization of PCB from Sediment and Water: Experimental and Field Data

Studies done on the Hudson River PCB issue have suggested that the loss of PCBs through the process of volatilization is substantial despite the fact that the contaminant has a low vapor pressure. This report summarizes initial data and studies done to examine PCB loss from the Hudson River through volatilization at the water-air and solid-air interfaces.

Experimental data suggested that the volatilization of PCBs can be an important source of air pollution under certain environmental conditions. The results of field monitoring have shown that that PCB concentrations are fairly high in the ambient air and in vegetation growing near PCB dump sites or certain contaminated dredge sites.

PCBs volatilized from contaminated water and sediment at substantial rates. For a number of open PCB disposal and dredge spoil sites along the Upper Hudson River it was observed that volatilization of PCBs was a worse problem than groundwater contamination, although traditional control programs have been aimed at preventing groundwater pollution.

Improved methods to prevent and control losses due to volatilization are needed, and their long-term costs and consequences need to be considered. The comparison of some exposure routes for PCBs indicate that intake from air exposure is greater than intake from drinking water.

Reference:
Toffelmire, T. J.; Shen, T. T.; Buckley, E. H. "Volatilization of PCB from Sediment and Water: Experimental and Field Data." *Technical Paper # 63, December* 1981.

Parameters Affecting Desorption of Hydrophobic Organic Chemicals from Suspended Sediments

This study used long-term batch experiments to address the issue of chemical equilibrium and its applicability as an approximation of the adsorption and desorption of hydrophobic organic chemicals to soils and sediments. The experiments examined the behavior of three hydrophobic organics: hexachlorobenzene, a monochlorobiphenyl, and a hexachlorobiphenyl in Detroit River sediments suspended in pure water and/or filtered tap water.

The experiments performed using hexachlorobenzene were extensive and demonstrated the dependence of desorption rates on the particle/floc size and density distributions, the type of water, and the organic content of the sediments. It was also demonstrated that desorption was more rapid for sediments that were only partially equilibrated with the chemical after a short-term adsorption period.

The studies done on HCB also indicated that the rate of desorption was greatest initially and decreased as the compound was desorbed, suggesting that the rates are also dependent on the sediment concentration.

The experiments performed using PCBs demonstrated that desorption rates were also dependent on the equilibrium coefficient partition coefficient of the chemical. For example, the larger the partition coefficient, the slower desorption occurred. For more highly chlorinated PCBs and other hydrophobic chemicals with high partition coefficients, the desorption process is relatively slow, with desorption times on the order of years. For areas where the effective particle sizes are or can potentially be much larger (for example, bottom sediments and soils), the desorption times would be proportionately greater.

It was also demonstrated that a chemical diffusion model with a diffusion coefficient that is dependent on the porosity of the particle/floc, the organic content of the sediments, the chemical partition coefficient, and also the distribution of the particle/floc size and density distributions, was sufficient to explain the experimental results.

Reference:
Borglin, S.; Wilke, A.; Jepsen, R.; Lick, W. "Parameters Affecting the Desorption of Hydrophobic Organic Chemicals from Suspended Sediments," *Environmental Toxicology and Chemistry,* Vol. 15, No. 10, pp. 2254-2262, 1996.

PCB Desorption from River Sediments Suspended During Dredging: An Analytical Framework

The purpose of this paper was to develop and test a method to analyze the rates of PCB desorption from sediment that has been suspended by dredging activity. The data used were taken from the monitoring of a dredging operation in the Hudson River at Fort Edward in 1977. The monitoring activities took place in the east channel of Roger's Island.

A system of PCB sorption-desorption kinetics that was developed to describe food chain sorbents was used in the framework of a one-dimensional advective transport model and solved at steady state conditions. The partition coefficient for Aroclor 1016 was chosen for use in the model due to the prevalence of that particular PCB in the system. Due to this, only Aroclor 1016 data will be included in the study. The sinking rate coefficient was calculated using data from one of the monitoring stations, and the boundary conditions were estimated using the partition coefficient and the total water column PCB concentration.

The application of a sinking rate of –0.08 $^{hr-1}$ and sorption-desorption rate constants ranging from 0.025 $^{hr-1}$ to 0.05 $^{hr-1}$ fitted the low flow average water column concentration of Aroclor 1016 (C_T) reasonably well. However, applying a significantly slower rate indicates that if no PCBs moved from the sorbed phase to the dissolved phase, the model results would not differ significantly from what was observed. A mechanistic fit of the data using a higher sinking rate requires the utilization of a higher desorption rate constant.

In the natural system, the results indicate that if the sinking rates are very large compared to the rate of desorption, then a very low concentration of PCBs would be lost during suspension. Conversely, if the desorption rates were high relative to the sinking rates, then a substantially higher concentration of PCBs would be lost during suspension.

The best fits during model runs attempting to simulate high flow average monitoring results for suspended solids were produced sinking rates between –0.4 and –0.5 $^{\text{hr-1}}$ and desorption rate constants on the order of 1.0 $^{\text{hr-1}}$. Rate constants that produced reasonable fits for either high or low flow data ranged from 0.025 to 1.0 $^{\text{hr-1}}$.

Reference:

Brown, M. “PCB Desorption from River Sediments Suspended During Dredging: An Analytical Framework,” *DEC Technical Paper No. 65,* April 1981.

Tables

Table 1
Three-Phase Partition Coefficient Estimates for PCBs in Sediments of the Freshwater Portion of the Hudson River

PCB Congener (BZ#)	Water Column Partition Coefficient Estimates[a]	
	log K_{OC}	log K_{DOC}
4	5.19	5.43
28	5.84	4.16
31	5.80	4.40

Note:
a. Averages by homologue reported by Burgess et al. (1996) for the 4-8 cm depth layer
Source: DEIR, Table 3-10a (USEPA, 1997)

Table 2
Mean Length Weighted Average Concentration Estimate using 1984 Thiessen Polygons, 1994 LRC and GE 1991 Composite Samples (from Table 363334-2 of White Paper - Sediment PCB Inventory Estimates)

Total PCB	Remediated			Not Remediated			Reach Wide		
Contaminant (PCB) Average Concentration	Fine	Coarse	All	Fine	Coarse	All	Fine	Coarse	All
River Section 1 (> 3 g/m^2) (2)	164.5	35.2	92.1 (3)	39.4	23.8	25.4 (3)	145.3	28.9	63.0 (3)
River Section 2 (> 10 g/m^2) (2)	146.5	-	146.5 (4)	-	14.8	14.8 (5)	59.3	12.1	40.4 (7)
River Section 3 (Select) (2)	-	-	31.7 (4)	-	-	9.6 (6)	-	-	9.8 (7)

Tri+	Remediated			Not Remediated			Reach Wide		
Contaminant (PCB) Average Concentration	Fine	Coarse	All	Fine	Coarse	All	Fine	Coarse	All
River Section 1 (> 3 g/m^2) (2)	46.2	12.4	27.2 (8)	12.7	8.9	9.3 (8)	41.1	10.4	19.4 (8)
River Section 2 (> 10 g/m^2) (2)	43.1	-	43.1 (9)	-	7	6.9 (5)	-	-	17.3 (7)
River Section 3 (Select) (2)	-	-	11.7 (10)	-	-	5.1 (6)	-	-	5.4 (7)

Notes

1. Average concentrations were constructed using Thiessen polygons and Length Weighted Average values for the individual sampling locations. Note that the Total PCB values for section 1 represent the Sum of Aroclors 1242, 1254, and 1260.
2. Includes channel area to be dredged.
3. LWA concentration estimate based on 1984 Thiessen Polygons. (Concentrations based on the Sum of Aroclors 1242, 1254, and 1260).
4. Mean MVUE values estimated from 1994 coring data from Hot Spots 25, 28, 31, 34, 35 for Section 2 and from Hot Spots 37 and 39 for Section 3 (Table 4-7 Low Resolution Coring Report).
5. LWA concentration estimate based on GE 1991 Composite samples falling outside the remediation boundaries (exclusion for Rocky Areas). (Estimated from a single composite sample)
6. LWA concentration estimate based on GE 1991 composite samples falling outside the remediation boundaries (no exclusion for Rocky Areas). (Estimated from 45 composite samples)
7. LWA concentration estimate based on all GE 1991 Composite samples in the section.
8. LWA concentration estimate based on 1984 Thiessen Polygons. A factor of 0.944 is applied to the sum of Aroclors values to obtain estimates of Tri+ PCB values.
9. Tri+ values based on Total PCB estimates from 1994 coring data. A divider of 3.4 is applied to the Total PCB value.
10. Tri+ values based on Total PCB estimates from 1994 coring data. A divider of 2.7 is applied to the Total PCB value.

Table 3
Three-Phase Equilibrium Partitioning Model Results

PCB Congener (BZ#)	Mass in particulate phase, M_P (mg)	Log K_{OC}	Mass in truly dissolved phase, M_d (mg)	Log K_{DOC}	Mass in DOC-bound phase, M_{dc} (mg)	Total Mass (mg)	Dissolved Mass (mg)	Percent of dissolved mass (%)
4	1.0E-01	5.19	3.5E-07	5.43	3.5E-06	1.0E-01	3.9E-06	0.0038%
28	5.0E-02	5.84	8.2E-07	4.40	4.4E-07	5.0E-02	1.3E-06	0.0025%
31	5.0E-02	5.80	9.0E-07	4.16	8.4E-07	5.0E-02	1.7E-06	0.0035%

Table 4
Water-Column Instantaneous PCB Loading at TI Dam

TI Dam	Flow (m^3/s)	Whole (total) water PCBs (ng/L)	Dissolved phase PCB (ng/L)	Suspended solids PCBs (ng/L)	Ratio of dissolved to total concentration
TI DAM					
Transect 5	76	192	184	11.2	0.96
Transect 6	69	92	88	2.9	0.96
Schuylerville					
Transect 5	85	160	150	15	0.94
Transect 6	74	89	84	4.8	0.94

Table 5
Desorption Rate Constants from Literature

Compounds	Rate Constants (k)										
	Borglin *et al*., 1996	ten Hulscher *et al*., 1999; 2002			Cornelissen *et al*., 1997				Ghosh *et al*., 2000		Carrol *et al*., 1994
		Lobith susp. Matter		Ketelmeer	k_{rapid} (hr^{-1})		k_{slow} (hr^{-1})		k_{fast} (day^{-1})	k_{slow} (day^{-1})	k (hr^{-1})
	day^{-1}	k_{fast} (hr^{-1})	k_{vslow} (hr^{-1})	k_{vslow} (hr^{-1})	2 day	34 day	2 day	34 day			
Monochlorobiphenyls	0.1174										
Trichlorobiphenyls									0.83	0.011	
PCB-28 (trichloro)		0.2	2.25E-04	2.00E-04							
PCB 65 (tetra)					0.058	0.117	2.54E-03	1.74E-03			
Tetrachlorobiphenyls									0.38	0.011	
PCB 118 (penta)					0.045	0.112	2.01E-03	9.80E-04			
Pentachlorobiphenyls									0.15	0.004	
Hexachlorobiphenyl	0.0101								0.07	0.005	
Moderately PCB contaminated Hudson River Sediment[a]											0.018

Note:

[a] As reported by Carrol *et al*., 1994. Moderately PCB contaminated sediment contained 64 mg/kg (dry weight) PCBs, with total organic carbon of 3.43%. The PCB presents in the sediments consisted of primarily mono- and di-chlorinated biphenyls (60-70% or total).

Table 6

PCBs Desorption Rate Constants and Partitioning Coefficients

Compound	Rate constant (k)		Half-life		Estimated equilibrium time		Log Koc [h]	Log Kd [i]
	hr^{-1}	hr^{-1}	hr	hr				
PCB in equilibrium								5.05
Monochlorobiphenyls	0.0049 [a]		142 [a]		84 days [a]		5.65	4.38
Trichlorobiphenyls	0.035 [b]		20 [b]		9 days [b]		5.84	4.57
PCB-28 (trichloro)	0.2 [c]		3 [c]		26 hr [c]		5.84	4.57
PCB 65 (tetra)	0.058 [d,e]	0.117 [d,f]	12 [d,e]	6 [d,f]	5.5 days [d,e]	2.7 days [d,f]	6.27	5.00
Tetrachlorobiphenyls	0.016 [b]		44 [b]		14 days [b]		6.27	5.00
PCB 118 (penta)	0.045 [d,e]	0.112 [d,f]	15 [d,e]	6 [d,f]	7 days [d,e]	2.8 days [d,f]	6.41	5.14
Pentachlorobiphenyls	0.0063 [b]		111 [b]		50.7 days [b]		6.41	5.14
Hexachlorobiphenyl	0.00042 [a]	0.0029 [b]	1664 [a]	238 [b]	980 days [a]	108 days [b]	6.55	5.28
Moderately PCB contaminated[g]	0.0181 [g]		38 [g]		422 days [g]			5.05

Notes:

[a] Borglin *et al*. (1996)

[b] Ghosh *et al*. (2000)

[c] ten Hulscher *et al*. (1999; 2002)

[d] Cornelissen *et al*. (1997)

[e] k is for 2 day contact time

[f] k is for 34 day contact time

[g] Carroll et al. (1994).Moderately PCB contaminated sediment contained 64 mg/kg (dry weight) PCBs, with total organic carbon of 3.43%. The PCB presents in the sediments consisted of primarily mono- and di-chlorinated biphenyls (60-70% or total).

[h] Partitioning coefficients were taken from DEIR Table 3-8 (USEPA, 1997)

[i] foc of sediment is 5.38%

Table 7
Background and Dredging Induced PCB Concentrations

Compound	Ratio to Total PCB (sediment)[a]	Ratio to Total PCB (suspended phase)[b]	Ratio to Total PCB (dissolved phase)[b]	Background Concentrations					Dredging Induced			
				Csed_b mg/kg	TSS_b mg/L	Ctotal_b ng/L	Csusp_b ng/L	Cdiss_b ng/L	Csed_d mg/kg	TSS_d mg/L	Csusp_d ng/L	Ctotal_b+d ng/L
PCB in equilibrium	1	1	1	5	1	50	5	45	50	5	250	300
Monochlorobiphenyls	0.14	0.0013	0.16	0.70	0.00131	8	9.11E-04	8.2	7	0.0065	0.0455	8
Trichlorobiphenyls	0.30	0.0103	0.27	1.51	0.01034	13	0.02	13.2	15	0.0517	0.78	14
PCB-28 (trichloro)	0.30	0.0103	0.27	1.51	0.01034	13	0.02	13.2	15	0.0517	0.78	14
PCB 65 (tetra)	0.13	0.0072	0.13	0.63	0.00722	7	0.005	6.51	6.3	0.0361	0.23	6.7
Tetrachlorobiphenyls	0.13	0.0072	0.13	0.63	0.00722	7	0.005	6.51	6.3	0.0361	0.23	6.7
PCB 118 (penta)	0.044	0.0032	0.026	0.22	0.00317	1	0.0007	1.28	2.2	0.0158	0.035	1.3
Pentachlorobiphenyls	0.044	0.0032	0.026	0.22	0.00317	1	0.0007	1.28	2.2	0.0158	0.035	1.3
Hexachlorobiphenyl	0.016	0.0021	0.0035	0.08	0.00208	0.17	0.00016	0.17	0.79	0.0104	0.0082	0.18
Moderately PCB contaminated[g]	1	1	1	5	1	50	5	45	50	5	250	300

Notes:

[a] Ratio of homologue to Total PCB in the sediment was taken from the low resolution coring data (USEPA, 1998)

[b] Ratio of homologue to Total PCB were taken from transect 6 water column data reported in DEIR (USEPA, 1997)

Table 8
Dissolved Phase PCB Concentration Estimates

Compound	Time (hour)	In 1 hour					
		% equilibrium		Cdiss due to dredge ng/L		Cdiss/Ctotal %	
PCB in equilibrium	equil	100%		180 [h]		60.0% [h]	
Monochlorobiphenyls	1	0.49% [a]		4.03E-02		0.5%	
Trichlorobiphenyls	1	3.4% [b]		4.76E-01		3.4%	
PCB-28 (trichloro)	1	18% [c]		2.54		18.1%	
PCB 65 (tetra)	1	5.6% [d,e]	11% [d,f]	3.78E-01	7.42E-01	5.6%	11.0%
Tetrachlorobiphenyls	1	1.6% [b]		1.06E-01		1.6%	
PCB 118 (penta)	1	4.4% [d,e]	11% [d,f]	5.79E-02	1.39E-01	4.4%	10.6%
Pentachlorobiphenyls	1	0.6% [b]		8.20E-03		0.6%	
Hexachlorobiphenyl	1	0.042% [a]	0.29% [b]	7.60E-05	5.31E-04	0.0%	0.29%
Moderately PCB contaminated[g]	1	1.8% [g]		3.23		1.1%	

Note:

[a] Borglin *et al*. (1996)

[b] Ghosh *et al*. (2000)

[c] ten Hulscher *et al*. (1999; 2002)

[d] Cornelissen *et al*. (1997)

[e] k is for 2 day contact time

[f] k is for 34 day contact time

[g] Carroll et al. (1994).Moderately PCB contaminated sediment contained 64 mg/kg (dry weight) PCBs, with total organic carbon of 3.43%. The PCB presents in the sediments consisted of primarily mono- and di-chlorinated biphenyls (60-70% or total).

[h] Assumed equilibrium was achieved

Table 9

Summary of Field Samples and Analytical Data from the Pre-Design Field Test - Dredge Technology Evaluation Report (8/6/2001)

							Turbidity (NTU)				Total PCBs (ug/L) 18 Congeners				
Date	Type	Northing	Easting	Hour	Min		Max	Min	Avg	TSS (mg/L)	Particulate	Dissolved	Particulate+ Dissolved	Fraction Particulate	Fraction Dissolved
8/7/00	Grab	2704955	815354	16	26	Background Value - Acushnet Estuary 1000ft N				10	0.89	0.52	1.41	0.63	0.37
8/7/00	Grab	2703124	815820	16	36	Background Value - Acushnet Estuary 1000ft S				4	0.25	0.18	0.43	0.58	0.42
8/15/00	Grab	2704040	815356	17	52	Turbidity/TSS - Acushnet Estuary	26	26	26	53					
8/15/00	Grab			18	5	Turbidity/TSS - Acushnet Estuary	12	12	12	22					
8/15/00	Grab			18	8	Turbidity/TSS - Acushnet Estuary	3	5	4	5					
8/16/00	Grab	2703129	815608	9	20	Up-Current reference sample	3	6	4.5	6	0.11	0.21	0.32	0.34	0.66
8/16/00	EBB			11	56	Sampling HR1 - Station 1 (50ft)	7	10	8.5	20					
8/16/00	EBB	2703959	815530	12	2	Sampling HR1 - Station 2 (100ft)	16	21	18.5	24					
8/16/00	EBB	2703621	815717	12	11	Sampling HR1 - Station 3 (500ft)	5	12	8.5	17					
8/16/00	EBB	2704948	815379	12	22	Sampling HR1 - REF (1000ft up-current)	3	12	7.5	9					
8/16/00	EBB			13	16	Sampling HR2 - Station 1 (50ft)				11					
8/16/00	EBB	2703833	815506	14	6	Sampling HR2 - Station 2 (100ft)				43					
8/16/00	EBB	2703647	815675	14	15	Sampling HR2 - Station 3 (500ft)				11					
8/16/00	EBB	2704948	815379	14	22	Sampling HR2 - REF (1000ft up-current)				12					
8/16/00	Composite					Composite Station 1				16	1.3	0.77	2.07	0.63	0.37
8/16/00	Composite					Composite Station 2				27	2.1	0.79	2.89	0.73	0.27
8/16/00	Composite					Composite Station 3	23	27	25	12	0.85	0.75	1.6	0.53	0.47
8/16/00	Composite					Composite -REF	10	17	13.5	9	0.89	0.9	1.79	0.50	0.50
8/16/00	FLOOD	2703995	815351	16	59	Sampling HR1 - Station 1 (50ft)				20					
8/16/00	FLOOD	2704110	815393	17	17	Sampling HR1 - Station 2 (100ft)	20	20	20	17					
8/16/00	FLOOD	2704375	815410	17	23	Sampling HR1 - Station 3 (500ft)	40	40	40	25					
8/16/00	FLOOD	2702780	815578	17	44	Sampling HR1 - REF (1000ft up-current)	6	15	10.5	6					
8/16/00	FLOOD	2704028	815329	17	56	Sampling HR2 - Station 1 (50ft)	21	27	24	12					
8/16/00	Grab			17	56	Surface oil slick observed at HR1 - Station 1 (50ft)									
8/16/00	FLOOD	2704140	815363	17	58	Sampling HR2 - Station 2 (100ft)	10	15	12.5	13		1.5			
8/16/00	FLOOD	2704375	815410	18	19	Sampling HR2 - Station 3 (500ft)	39	42	40.5	9					
8/16/00	FLOOD	2702780	815578	18	40	Sampling HR2 - REF (1000ft up-current)	38	42	40	7					
8/16/00	Composite					Composite Station 1				27	2.6	0.66	3.26	0.80	0.20
8/16/00	Composite					Composite Station 2				10	0.99	0.58	1.57	0.63	0.37
8/16/00	Composite					Composite Station 3				16	1.1	0.52	1.62	0.68	0.32
8/16/00	Composite					Composite -REF				5	0.25	0.36	0.61	0.41	0.59
8/17/00	EBB			10	58	Sampling - Up-Current reference sample	23	27	25	5	0.29	0.46	0.75	0.39	0.61

Table 10
Dissolved and Particulate Percent PCB Mass Loss

Dissolved Phase Maximum						
Max >=100', no flood	0.95	ug/L				
minus background	0.52	ug/L				
	0.43	ug/L				
Maximum Flow Rate	10	cm/s	3.9	in/s	0.3	ft/s
wide	800	ft				
deep	8.75	ft				
Maximum Flow Rate	2297	cfs	2.8E-02	m^3/cf	65.0	m^3/s
	65	m3/s	1000	L/m3	65032	L/s
	65032	L/s				
x	0.43	ug/L				
	27964	ug/s				
Mass loss/second	2.8E-05	kg/s				
time worked	17.5	hrs	3600	s/hr	63000	s
	2.8E-05	kg/s				
x	63000	s				
PCB mass loss	1.8	kg				
PCBs removed	1495	kg				
Dissolved Phase Percentage	0.1%					
Particulate Phase Maximum						
Max >=100', no flood	2.6	ug/L				
minus background	0.89	ug/L				
	1.71	ug/L				
Maximum Flow Rate	10	cm/s	3.9	in/s	0.3	ft/s
wide	800	ft				
deep	8.75	ft				
Maximum Flow Rate	2297	cfs	2.83E-02	m^3/cf	65.0	m^3/s
	65	m3/s	1000	L/m3	65032	L/s
	65032	L/s				
x	1.71	ug/L				
	111205	ug/s				
Mass loss/second	1.1E-04	kg/s				
time worked	17.5	hrs	3600	s/hr	63000	s
	1.1E-04	kg/s				
x	63000	s				
PCB mass loss	7.0	kg				
PCBs removed	1495	kg				
Particulate Phase Percentage	0.5%					
Percent Dissolved	20%					
Percent Particulate	80%					

Table 9 Cont'd

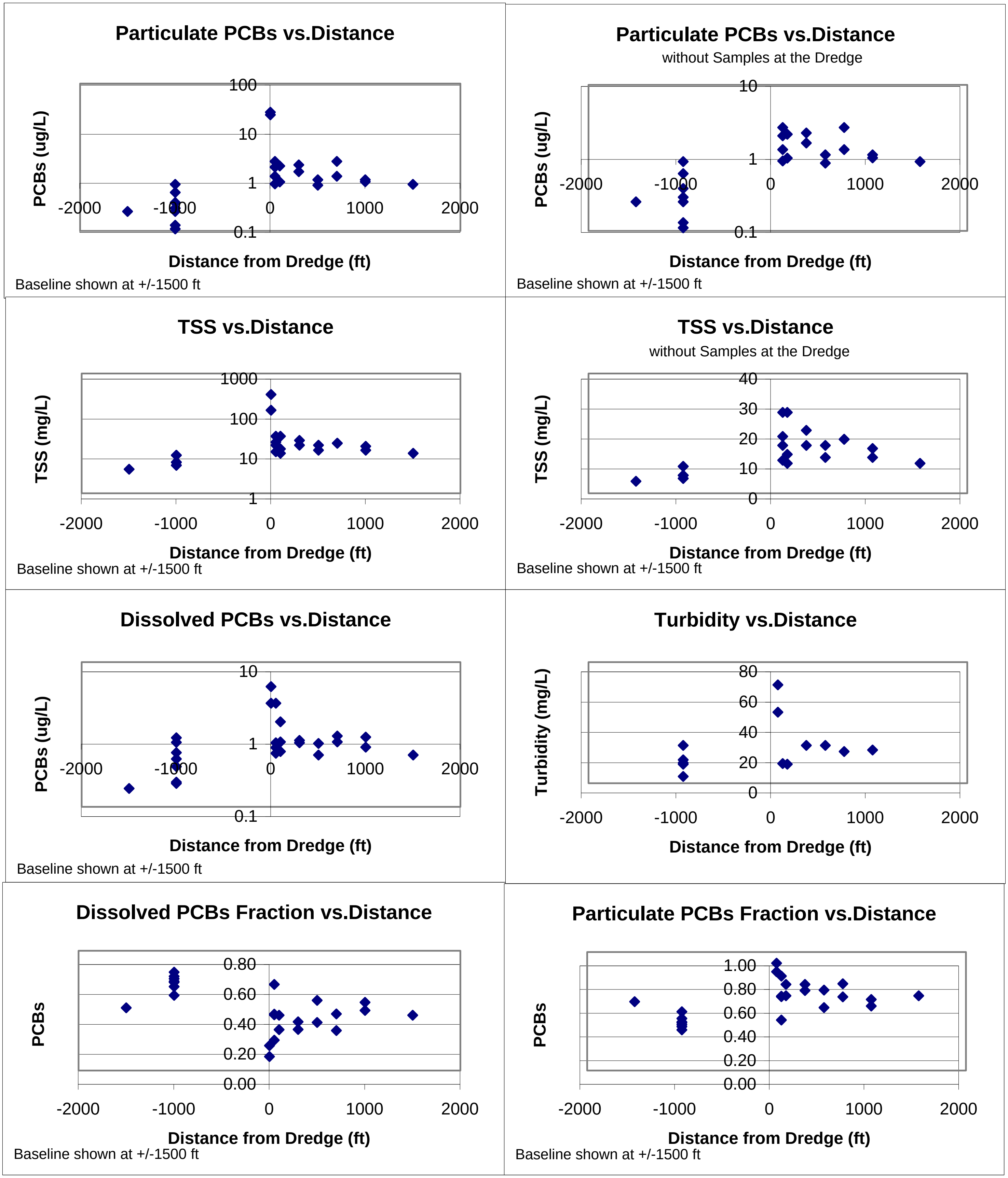
							Turbidity (NTU)				Total PCBs (ug/L) 18 Congeners				
Date	Type	Northing	Easting	Hour	Min		Max	Min	Avg	TSS (mg/L)	Particulate	Dissolved	Particulate+ Dissolved	Fraction Particulate	Fraction Dissolved
8/17/00	EBB	2703878	815379	11	7	Sampling HR1 - Station 1 (50ft)	11	18	14.5	6					
8/17/00	EBB	2702964	815758	11	42	Sampling HR1 - Station 4 (1000ft)	10	17	13.5	12					
8/17/00	EBB	2703218	815599	11	46	Sampling HR1 - Station 3 (700ft)	10	17	13.5	17					
8/17/00	EBB	2703625	815534	11	50	Sampling HR1 - Station 2 (300ft)	11	18	14.5	12					
8/17/00	EBB	2704948	815379	11	59	Sampling HR1 - REF (1000ft up-current)	9	18	13.5	9					
8/17/00	EBB	2702964	815758	12	32	Sampling HR2 - Station 4 (1000ft)	6	10	8	8					
8/17/00	EBB	2703218	815599	12	38	Sampling HR2 - Station 3 (700ft)	12	17	14.5	11					
8/17/00	EBB	2703625	815534	12	45	Sampling HR2 - Station 2 (300ft)	11	17	14	15					
8/17/00	EBB	2703878	815379	12	52	Sampling HR2 - Station 1 (50ft)	9	15	12	11					
8/17/00	EBB	2704948	815379	13	1	Sampling HR2 - REF (1000ft up-current)	5	12	8.5	7					
8/17/00	Grab			13	45	MIAMI II Plume (peak field turbidity)	60	70	65	300	26	2.7	28.7	0.91	0.09
8/17/00	EBB	2703878	815379	13	48	Sampling HR3 - Station 1 (50ft)	28	34	31	62					
8/17/00	EBB	2703625	815534	13	58	Sampling HR3 - Station 2 (300ft)	19	23	21	29					
8/17/00	EBB	2703218	815599	14	3	Sampling HR3 - Station 3 (700ft)	13	18	15.5	18					
8/17/00	EBB	2702964	815758	14	8	Sampling HR3 - Station 4 (1000ft)	13	21	17	21					
8/17/00	EBB	2704948	815379	14	38	Sampling HR3 - REF (1000ft up-current)	9	12	10.5	10					
8/17/00	EBB	2703878	815379	14	47	Sampling HR4 - Station 1 (50ft)	26	29	27.5	39					
8/17/00	EBB	2703625	815534	14	53	Sampling HR4 - Station 2 (300ft)	19	26	22.5	31					
8/17/00	EBB	2703218	815599	14	57	Sampling HR4 - Station 3 (700ft)	27	29	28	37					
8/17/00	EBB	2702964	815758	15	3	Sampling HR4 - Station 4 (1000ft)	13	18	15.5	22					
8/17/00	Composite					Composite Station 1	10	16	13	19	2	2.7	4.7	0.43	0.57
8/17/00	Composite					Composite Station 2	21	29	25	21	2.2	0.83	3.03	0.73	0.27
8/17/00	Composite					Composite Station 3	18	24	21	18	1.3	0.79	2.09	0.62	0.38
8/17/00	Composite					Composite Station 4	20	24	22	15	1	0.67	1.67	0.60	0.40
8/17/00	Composite					Composite -REF	13	18	15.5	9	0.61	0.78	1.39	0.44	0.56
8/17/00	FLOOD	2704000	815324	16	49	Sampling HR1 - Station 1 (50ft)	13	16	14.5	17					
8/17/00	FLOOD	2704266	815441	17	6	Sampling HR1 - Station 2 (300ft)	14	19	16.5	20					
8/17/00	FLOOD	2704727	815455	17	12	Sampling HR1 - Station 3 (700ft)	60	70	65	210					
8/17/00	FLOOD	2705097	815357	17	18	Sampling HR1 - Station 4 (1000ft)	10	13	11.5	10					
8/17/00	FLOOD	2702805	815548	17	33	Sampling HR1 - Station 5 (1000ft up-current)	6	13	9.5	9					
8/17/00	FLOOD	2704000	815321	18	0	Sampling HR2 - Station 1 (50ft)	6	13	9.5	8					
8/17/00	FLOOD	2704266	815441	18	6	Sampling HR2 - Station 2 (300ft)	15	18	16.5	15					
8/17/00	FLOOD	2704727	815455	18	12	Sampling HR2 - Station 3 (700ft)	11	19	15	16					
8/17/00	FLOOD	2705097	815357	18	15	Sampling HR2 - Station 4 (1000ft)	12	17	14.5	14					
8/17/00	FLOOD	2702805	815548	18	30	Sampling HR2 - REF (1000ft up-current)	11	13	12	6					

Table 9 Cont'd

Date	Type	Northing	Easting	Hour	Min		Turbidity (NTU) Max	Min	Avg	TSS (mg/L)	Total PCBs (ug/L) 18 Congeners Particulate	Dissolved	Particulate+ Dissolved	Fraction Particulate	Fraction Dissolved
8/17/00	FLOOD	2704000	815321	19	4	Sampling HR3 - Station 1 (50ft)	12	15	13.5	13					
8/17/00	FLOOD	2704266	815441	19	8	Sampling HR3 - Station 2 (300ft)	11	16	13.5	20					
8/17/00	FLOOD	2704727	815455	19	12	Sampling HR3 - Station 3 (700ft)	8	13	10.5	11					
8/17/00	FLOOD	2705097	815357	19	16	Sampling HR3 - Station 4 (1000ft)	12	19	15.5	19					
8/17/00	FLOOD	2072805	815548	19	33	Sampling HR3 - REF (1000ft up-current)	4	9	6.5	3					
8/17/00	Composite					Composite Station 1				11	0.91	0.55	1.46	0.62	0.38
8/17/00	Composite					Composite Station 2				16	1.6	0.77	2.37	0.68	0.32
8/17/00	Composite					Composite Station 3				18	2.6	0.95	3.55	0.73	0.27
8/17/00	Composite					Composite Station 4				12	1.1	0.92	2.02	0.54	0.46
8/17/00	Composite					Composite -REF				6	0.38	0.56	0.94	0.40	0.60
8/18/00	Grab			10	48	Sample Up-current-reference (Event scrubbed)	10	15	12.5	6	0.13	0.22	0.35	0.37	0.63
8/18/00	Grab			17	44	Sample inside moonpool during active dredging	44	50	47	120	23	4.6	27.6	0.83	0.17

Figures

Figure 1
PCB, TSS and Turbidity vs. Distance from the Dredge



Attachment D

Modeling Analysis

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Attachment D

Modeling Analysis

1.0 Introduction

Modeling of conditions expected during dredging operations was undertaken to evaluate the short and long-term effects of remedial activities. Far-field models - consisting of fate, transport and bioaccumulation models - were utilized to measure the long-term effects of dredging and to determine the percent PCB mass loss that will result in unacceptable river recovery and adverse impacts to downstream water supply intakes. In addition to far-field modeling, near-field modeling was conducted to simulate dredging and resulting river conditions near the dredge bucket/head and up to a mile downstream. One near-field model (TSS-Chem) was used to estimate PCB water column conditions in a lateral direction from the dredge (across the width of the river) up to one mile downstream. The modeling results were used to aid in the determination of the best location for monitoring points, the water column concentration near sensitive locations, settling effects and rates of PCB flux for use in the long-term models. A second near-field model (CSTR-Chem) was developed assuming that the conditions near the dredge are similar to a continuous stirred tank reactor (CSTR). The model provided a basis for assumptions regarding the dissolved phase PCB concentrations in the immediate vicinity of the dredge.

2.0 Objectives

2.1 Near-Field Modeling

Near-field modeling was completed to simulate water column suspended solids and total PCB concentrations in the vicinity of the dredge. The downstream models were applied to determine the following:

- Estimate monitoring locations for suspended solids and turbidity;
- Estimate plume geometry of the resuspended sediment (sediment transport and flux in close proximity to the dredge);
- Estimate depositional patterns of the settled resuspended sediment, thickness of the deposited material, and its impact on surficial sediments that are deposited downstream;
- Evaluate the potential PCB dissolved phase release downstream of the dredge.

2.2 Far-Field Modeling

Far-field modeling was completed to simulate water column, sediment and fish total PCB concentrations in the Upper and Lower Hudson River as a result of the dredging operation. The far-field model was applied to determine the following:

- Estimate the impact of contaminant mass loss from resuspension during remediation and its effect on water column concentrations at public water intakes;
- Determine the acceptable mass loss for protection on downstream water resources and public water intakes;
- Evaluate the impact of accidental release scenario on resulting water column concentrations at public water intakes and on the recovery of the river.

3.0 Selection of the Transport Models

Dredging operations are expected to release suspended sediment and PCBs into the water column. As a result, modeling was needed to estimate the duration and intensity of these impacts at sensitive downstream locations. Sensitive locations include the immediate dredging area and downstream water supply intakes. Modeling at multiple scales was conducted to estimate these impacts at all locations in the river system.

A far-field model was necessary to predict PCB concentrations over the extent of the remediated area and downstream into the Lower Hudson River. The far-field model was capable of estimating PCB concentrations during the years of dredging activities as well as several years following the completion of dredging. In contrast, a near-field model capable of estimating PCB water column concentrations over a short period of time (weeks or months) was required to simulate river conditions in the vicinity of the dredge.

During preparation of the Hudson River Feasibility Study (FS) report (USEPA, 2000a) and the Hudson River Responsiveness Summary (RS) report (USEPA, 2002), the USEPA water quality model, HUDTOX, was developed to project current river conditions into the future for comparison against model runs where active remediation such as capping and dredging were simulated. This model forecasts future water column and sediment PCB concentrations for various scenarios so the benefit of active remediation versus monitored natural attenuation (MNA) could be compared and evaluated. The results of the HUDTOX model were then utilized as input for the FISHRAND model to evaluate fish bioaccumulation PCB levels as a result of the various scenarios. This model, HUDTOX, was used to estimate far-field river and sediment concentrations for various scenarios to allow for the development of a protective resuspension performance standard.

An evaluation was conducted to determine if HUDTOX could be applied to simulate dredging conditions near the dredge (near-field modeling) since HUDTOX already reflects the conditions of the Hudson River. However, HUDTOX could not be readily modified to obtain adequate resolution for estimating near-field river conditions, therefore other models have been developed specifically for the near-field modeling.

A USACE model, SED2D, was evaluated for use as the near-field model since it has been proven to simulate near-field dredging conditions with similar accuracy as the HUDTOX model only in a much shorter time frame. SED2D is part of the TABS-MD (multi-dimensional) modeling system that was used in the development of HUDTOX. It is a two-dimensional model that can be used for depth-averaged transport of cohesive or a representative grain size of non-cohesive sediments and the deposition, erosion, and formation of bed deposits. Until 1995, this model was distributed under the name of STUDH. Sediment loading and bed elevation changes can be calculated when supplied with a hydrodynamic solution computed by the model RMA2. RMA2 is a hydrodynamic model that supports sub-critical flow analysis. The SED2D and STUDH models were not selected for use, because of the limitations of the model, including modeling a single type of solids. RMA2 was used to estimate the linear water velocities and depths at various flowrates.

The near-field model used previously in the FS and ROD was DREDGE. DREDGE is a module of the Automated Dredging and Disposal Alternatives Modeling System (ADDAMS) distributed by the USACE through the Environmental Laboratory, USAE Research and Development Center Waterways Experiment Station. DREDGE estimates the rate at which bottom sediments become suspended into the water column as the result of dredging operations and the resulting suspended sediment concentrations. TSS-Chem was developed to model the downstream transport of solids and PCBs through the near-field in the Hudson River. TSS-Chem is similar to the DREDGE model described in Appendix E of the FS. It applies the same Gaussian plume for solids transport as DREDGE but is able to model both coarse and fine solids and includes two phase partitioning of PCBs from the solids into the dissolved phase. However, unlike the DREDGE model, TSS-Chem is only applicable for dredging activities with 4-cy dredge buckets. The TSS-Chem model provides estimates of PCB and solids concentrations and fluxes across the river width from 10 meters downstream to approximately one mile downstream.

Since TSS-Chem is unable to estimate conditions directly around the dredge bucket, a second near-field model was necessary. CSTR-Chem models the area directly around the dredge bucket as a continuous stirred tank reactor. The conditions in this area are essential to the loading of TSS-Chem. By estimating the surroundings of the dredge bucket, a basis for assumptions regarding the solids source of TSS-Chem was obtained.

3.1 Interaction Among the Transport Models

The main goal of the modeling effort is to study the long-term impacts of dredging operations in the Upper and Lower Hudson River. As part of this, fish tissue recovery can provide a threshold or limit to define an unacceptable impact due to dredging releases and thereby a limit on the export rate is needed. The modeling efforts were focused on examining the impact of running the dredging operation at the specified action levels in the Resuspension Standard. The resuspension scenarios for the Resuspension Standards are specified as the PCB export rate at the far-field monitoring stations. The HUDTOX/FISHRAND model cannot be used for this purpose strictly since HUDTOX is not designed to simulate the process of dredging releases. Due to the nature of the HUDTOX model structure, PCB loads cannot be readily specified at far-field locations (i.e., specifying the resuspension export rate). Rather, the input of PCBs is specified as an input load at a location within the river, equivalent to a resuspension release rate. In order to create a correctly loaded HUDTOX run, it is first necessary to estimate the local resuspension release rate from the dredging operation; that is, the rate of Tri+ PCB, Total PCB and solids transport at the downstream end of the dredge plume. At this location most of the solids that are going to settle out, will have settled out and the suspended solids will more closely resemble those simulated by HUDTOX. To estimate the input loading term for HUDTOX, the two models designed to address the dredging release process and near-field transport, CSTR-Chem and TSS-Chem, were used.

The three models were used to represent and link the three different scales of resuspension. The immediate vicinity of the dredge (10 m radius) is simulated by the CSTR-Chem. The region from the dredge to a distance of one mile (10 to 1610 m) is represented by TSS-Chem with its solids transport and geochemical model. Finally, the region beyond one mile is represented by HUDTOX. The choice of the TSS-Chem model to represent a one-mile interval is related to the size of the individual HUDTOX cell, which is approximately 2/3 of a mile long. Figure 1 shows the links among the transport models and the different scales of resuspension they represent.

4.0 Near-Field Modeling

The near-field models are useful in determining the appropriate locations for monitoring stations and provide a practical basis for defining criteria by estimating resuspension rates that correspond to various action level scenarios. The resuspension rates were compared to production rates and the ability to realistically resuspend solids at such rates from dredge bucket operations were examined.

4.1 Parameters

The parameters required for HUDTOX and other long-term models are not directly applicable to the near-field models. Many of the HUDTOX parameters were developed empirically for long-term conditions. The near-field models only apply to periods of dredge activities. Therefore, the parameters applied for use in the near-field models were chosen based on extensive literature research, consideration of the unique conditions found in the Upper Hudson River and a tendency towards conservative (greater release) estimates.

For the near-field model simulations, the concentration of PCBs on the suspended particles was estimated as the average sediment concentrations of the removed material for each river section including the overcut. While in the water column the PCBs undergo two-phase partitioning from the suspended to dissolved phase. The partitioning of the PCBs between the two phases is based on the partition coefficient which dictates the equilibrium fractions of the phases and the desorption rate which will determine how quickly equilibrium is approached. The selection of the partition coefficient and the desorption rate is discussed in Attachment C since they are not exclusively used for these models.

With a given partition coefficient and desorption rate the time available for partitioning will control the amount of desorption that occurs. The time that the particles remain suspended is primarily a function of the sediment type. Generally the silt particles will remain suspended longer than the coarse particles. In the model, the rate at which particles fall through the water column is determined by the particle settling velocity. The model includes different settling velocities for fine and coarse particles. In addition to the time constraint, the concentration of suspended PCBs within the plume will also affect the equilibrium conditions. In the TSS-Chem model dispersion of the solids within the plume and thereby the concentration is dictated by the lateral dispersion coefficient. The selection of both the settling velocities and lateral dispersion coefficient is discussed below.

4.1.1 Settling Velocities

To accurately represent the solids concentrations and the time available for partitioning in the CSTR-CHEM and TSS-CHEM models, settling velocities for both fine and coarse resuspended sediments were researched. Eight references were examined and considered in the selection of the settling velocities for the two models. The selection process took into account the applicability of the studies to the Hudson River sediments and the inclusion of significant dynamic aspects of settling solids (*i.e.*, flocculation) in the studies. Previous data analyses have been completed to define and characterize the Hudson River sediments and the typical properties of the sediments are summarized in Table 1.

4.1.1.1 Literature Search

As part of a literature search the following references that reported or used settling velocities were examined:

(1) ***Estimating the Size-Dependent Settling Velocity of Suspended Particles Using the LISST-ST.*** (Sequoia Scientific, Inc.)
The LISST-ST is a particle counter manufactured by Sequoia Scientific, which is employed in the water column of rivers and used to count particle sizes and measure the time it takes for the particle to settle out in the chamber of the instrument. This data is then used to estimate the particle settling velocity. Data generated from field studies is indicative of:

- For particle of size 50 microns, V_s = 0.01 cm/s
- For a particle of size 100 microns, V_s = 0.10 cm/s
- For a particle of size 400 microns, V_s = 0.005 cm/s

(2) ***Transport and Transformation of Contaminants Near the Sediment-Water Interface.*** (DePinto *et al*., 1994)
This reference examined both freshwater and saltwater sediment particles for slightly flocculent New Bedford Harbor sediment and highly flocculent Passaic Valley Sewage Sludge. Data generated from this study indicated:

- New Bedford Harbor Freshwater sediment with a particle size of 21 μm: V_s = 0.0124 cm/s
- Passaic Valley Freshwater sewage sludge with a particle size of 22 μm: V_s = 0.0057 cm/s

(3) ***Filtration and Separation.com***.
This web site has an interactive program that allows the user to enter in a sediment particle size and density and then use the properties of water (density and viscosity) to compute the particle settling rate. This program computes the settling velocity using Stokes' Law, the Heywood Tables (valid for Reynolds Numbers up to 100,000) and Archimedes correlation, which bases the estimated

settling velocity on the Reynolds number computed for the specific information in the program. All results are provided as output with a recommendation of which value is most applicable.

(4) ***Measurement Suspended Sediment Characteristics in an Embanked Flood Plain Environment of the River Rhine.*** (Thonon and Van Der Perk, 2002)
This paper describes the study conducted on the River Rhine located in The Netherlands. The study was conducted to help quantify the amount of sediment-transported pollution that is occurring in the flood plains of the River Rhine. This data is being used to calibrate flood plain sedimentation models and to assist in the assessment of the fate and transport of sediment-associated pollutants in riverine environments. Field studies were completed by deploying a LISST-ST Type C portable particle counter manufactured by Sequoia Scientific at the main distributary of the Rhine River.

Generally, this instrument measures particle sizes and settling velocities for particles ranging from 2.5 to 500 um using laser diffraction principles. At the beginning of each study, the settling tube is opened for four seconds and allowed to fill with river water and suspended matter. It is then closed and the test is run for a duration of 12 hours. The suspended matter size is then measured in the tube 71 times over the 12-hour period. Finally, the settling velocity is computed from the decrease of the volume of concentration of the different particle fractions over time. Results of this study were as follows:

- For a particle of size 10 microns: V_s = 0.001 cm/s
- For a particle of size 50 microns: V_s = 0.005 cm/s
- For a particle of size 100 microns: V_s = 0.01 cm/s
- For a particle of size 400 microns: V_s = 0.01 to 0.001 cm/s

(5) ***Model for Turbidity Plume Induced by Bucket Dredge*** (Kuo and Hayes, 1991)
This study employed a model to evaluate the plume created in a river by a mechanically operated dredge. This study was completed for three river systems. Sediment characteristics were provided for each of these river systems and the settling velocity was computed using Stokes' Law.

- St. John's River: Particle size of 39.6 microns (98% of sediment finer than 62 microns) and sediment density of 2.40 g/cc; Vs = 0.12 cm/s
- Black River Harbor: Particle size of 36.3 microns and sediment density of 2.39 g/cc; V_s = 0.10 cm/s
- Thames River: Particle size of 150 microns and sediment density of 2.50 g/cc; V_s = 1.84 cm/s
- Thames River: Particle size of 160 microns and sediment density of 2.50 g/cc; V_s = 2.10 cm/s

(6) ***Dredge Induced Turbidity Plume Model***. (Kuo *et al*, 1985)

This paper examined a model to help describe the turbidity plume resulting from dredging in a ship channel with a hydraulic dredge. The model was developed to predict the sediment concentration within the plume and the resulting sedimentation alongside the dredged channel. Results of the model are compared with actual field measurements. It was concluded that the model calibrated parameters agreed with field observations and measurements. The settling velocity was computed for model input using the following equation:

$$\mathbf{Vs = w = 1/18v * ((\rho_{sp} / \rho w) - 1)) * g * a\hat{}2}$$

Where:

v = viscosity of water = 1.08 X 10^{-5} ft/s = 0.01 cc/s
ρ_{sp} = density of particle (g/cc)
ρ_w = density of water = 1 g/cc
g = acceleration due to gravity = 32.2 ft/s = 980 cm/s^2
a = particle size (cm)
In the referenced paper, a = 20 microns = 20 X 10^{-4} cm and ρ_{sp} = 2.65 g/cc and V_s = 0.0359 cm/s

Applying this equation to the Hudson River Sediment Characteristics:

- Silt assuming a particle size of 20 microns and range of particle densities from 2.2 –2.6 g/cc: V_S = 0.026 –0.035 cm/s
- Fine Sand assuming a particle size of 100 microns and range of particle densities from 2.2 –2.6 g/cc: V_S = 0.653 –0. 871 cm/s
- Medium-Coarse sand assuming a particle size of 400 microns and a range of particle densities from 2.2 – 2.6 g/cc: V_S = 4.0 – 8.5 cm/s

(7) ***New Bedford Harbor Water Quality Monitoring Pre-Design Field Test Dredge Technology Evaluation Report, Appendix K.*** (USACE, 2001)
An estimate of V_s using Stokes' Law and particle size for silts and clay was provided as follows:

- Silt with particle size of 0.02 mm; V_s = 3.21 X 10^{-6} cm/s
- Clay with particle size of 0.002 mm; V_s = 3.21 X 10^{-8} cm/s

(8) ***1999. PCBs in the Upper Hudson River Volume 2. A Model of PCB Fate, Transport, and Bioaccumulation.*** (QEA, 1999)
For application of a model to predict PCB concentrations in the Hudson River, a fate and transport model was applied. One of the parameters required for input into this model was the specific Hudson River sediment characteristics including the particle size, particle density, and the particle settling velocity. Settling velocities for cohesive and non-cohesive sediments were estimated using different

methods. The settling velocity for cohesive sediment was computed utilizing the following formula:

$$V_s = 3.3 * (C_1G)^{\wedge}0.12 \qquad \text{(EQ 1)}$$

Where:
C_1 = particle concentration (mg/l)
G = water column bottom shear stress = C_f * q^2 (dynes/cm^2)

This formula was developed for the fine particles when flocculation occurs among particles during the settling procedure. Therefore, settling velocities may be applied to silt particles since coarse/sand particles will not aggregate. Measured settling velocities were plotted as a function of C_1G and have a range from 4 to 9 m/day while the value of C_1G ranges from 10 to 2000 (mg/L*dynes/cm^2). However, the study did not show a trend with particle density (within the silt range used). In this study the non-cohesive settling velocity was estimated based on particles size and particle density using Stokes' Law.

4.1.1.2 Selection of Settling Velocity

A summary of the settling velocities from the studies above is provided in Table 2. For most of studies Stokes' Law is the theoretical basis for estimating the settling velocity of sand particles. This approach is appropriate for discrete particles that do not aggregate. For the fine sand sediments of the Hudson River, the settling velocity would be 0.6 – 0.8 cm/s assuming that the range of particle density is 2.2 to 2.6 g/cc and the particle size of fine sand is 100 microns. Using the same range of particle density, the settling velocity of medium-coarse sand in Hudson River sediments is 4.0 to 8.5 cm/s assuming that the typical particle size is 400 microns. For the CSTR-Chem and TSS-Chem models 6 cm/s was used as a conservative estimate of the typical settling velocity for the sand fraction of Hudson River sediments.

Stokes' Law only applies to discrete particles settling and does not account for the flocculation during settling. Flocculation increases the rate at which silts settle from the water column, but the rate of flocculation depends on site specific conditions and sediment properties. The silt settling velocities presented in QEA's report (1999) for Hudson River sediments were used in the near-field models since these values were directly applicable to Hudson River sediments and included the effects of flocculation. Even though the settling velocity was presented as a function of C_1*G (particle concentration * shear stress), the settling velocity varied in a very narrow range (4-9 m/day) while the value of C_1*G varied in 3 orders of magnitude (from single digit number to a couple thousands). Therefore, 7 m/day, equivalent to 8.1×10^{-3} cm/sec, was chosen as the typical settling velocity for Hudson River silt/clay. The range of 4 m/day and 9 m/day were applied to the sensitivity analyses of the models. It should be noted that 8.1×10^{-3} cm/sec is one order of magnitude less than the velocity estimated by Stokes'

Law (0.026 – 0.035 cm/s) when assuming that the particle size is 20 microns and the density is 2.2-2.6 g/cc.

Concern has been raised that a probability factor of settling should be applied to account for the effects of near-bed turbulence on particle deposition. However, sediment particles in the near-bed zone have effectively been removed from the water column. They are not available for downstream transport within the water column and no longer contribute significantly to water column exposure. Thus, the water quality models applied here do not attempt to deal with complex near-bottom sediment erosion and deposition. It would be reasonable to develop and apply models capable of considering a wider range of processes, e.g. near-bed erosion and deposition, during the design phase when more detailed analyses of the fate and transport of sediments and associated constituents are appropriate.

4.1.2 Lateral Dispersion Coefficient

The lateral dispersion coefficient impacts the width of the solids plume and therefore the concentration within the plume, as the solids are transported downstream. In order to use TSS-Chem to model the movement of the solids plume downstream, a lateral dispersion coefficient must be specified. Since the coefficient is dependent on the velocity of the river water, more than one lateral dispersion coefficient value was required.

A time-of-travel study conducted by USGS in Upper Hudson River (USGS, 1969) examined dye concentrations vs. time at both center and side channel stations located near Schuylerville. The peak concentration at the center channel station occurred 0.5 to 1 hour earlier than the peak concentration at the side channel station, demonstrating the lateral dispersion of the dye. Theoretically, the lateral dispersion coefficient can be estimated based on the conservation of dye mass, but the locations of the center and side channel stations and the raw data for the dye concentrations are not provided in the report. Due to the limitation of available data and the difficulty of finding data from an old report, the numerical solution was not pursued based on this report. Due to the limitation of available data and the complexity of natural river systems, the results presented below are considered to provide an order of magnitude estimate of the lateral dispersion coefficient.

Fischer (1979) provides the practical rule that the lateral dispersion in a bounded channel can be approximated as:

$$e_t = 0.6du^* \qquad \text{(EQ 2)}$$

Where:

e_t = lateral dispersion coefficient (m^2/s)

d = average depth of flow (m)

u^* = shear velocity (m/s), $\sqrt{gdS}$

g = gravitational acceleration, 9.81 m/s^2

S = slope of the channel (unit less)

Since surface water elevation is the energy grade indicator of the river, surface water elevation slope can also be used to calculate the shear velocity. USGS monitors the daily water elevation at gauged stations throughout the year. Gauge 119 is located near Lock 7 and gauge 118 is located near TI Pool. The distance between these two gauges is about 6 miles. The surface water elevation slope between these two gauges represents the energy slope within the TI Pool. The average water elevation difference was calculated on a monthly basis for several years of data. Negative water elevation differences were observed and treated as 0 in the averaging, which does not significantly change the monthly average values. As summarized in Table 3, the maximum monthly average elevation difference occurred in March due to high flows during spring run-off. For the dredging season (May through November), the monthly elevation difference is relatively consistent. Using these months a dredging-period slope of 8×10^{-6} was obtained.

The hydrodynamic model RMA2 (described below in Section 4.2) was used to obtain applicable depths and linear velocities for various river flowrates (2000-8000 cfs) and locations (RM 190 and 193) along the Upper Hudson River. Equation 2 was used with the applicable depths, velocities and average dredge-season slope to calculate the lateral dispersion coefficients under different conditions. The results are presented in Table 4. Dispersion coefficients calculated for the eastern segment at RM 190 were used as the typical condition. The dispersion coefficients for the other conditions were investigated in the sensitivity analysis.

4.2 RMA2

RMA2 is a hydrodynamic model created by the USACE that can be used to simulate ambient water conditions such as velocity magnitude and direction at potential dredging sites. Initially, LTI used the RMA2 model to simulate the flow patterns in the Thompson Island Pool to develop the hydrodynamic portion of the HUDTOX model. These results were presented in the Revised Baseline Model Report (USEPA, 2000b). The focus of the LTI study was to derive the spatial distribution of the shear stresses, which in turn was used to determine the depth of scouring and aggregate amount of re-suspension. The amount of re-suspension was then partitioned to PCB loads and incorporated into a long-term transport model (*i.e.*, HUDTOX).

The LTI RMA2 model considered a wide range of flows, from an average flow of about 4,000 cfs to the 100-year flow of about 47,000 cfs. While the low to moderate flows were confined within the Hudson River banks, the higher flows required the inclusion of the Hudson River flood plains into the model. Therefore, the computational domain had to be extended to include the flood plains even under low flow conditions.

Since the dredging activities are more likely to take place during normal summer flow conditions, it is logical to reconfigure the computational model and allocate all available computing resources, *(i.e.*, memory, speed, and total number of elements) to normal flow conditions only (excluding the flood plains). As a result, the narrowed flow range allows the model to incorporate a refined resolution in the river and near the dredging sites. The refined grid can also be used to incorporate more detailed bathymetric variations and to reproduce higher accuracy flow patterns.

4.2.1 Methodology

The new computation grid for RMA2 reflected the following considerations:

(1) It essentially confined to the deep channel of the river and focused on the wet boundary at low flow conditions;
(2) It uses highly refined spatial resolution (a typical resolution is about 15 feet in the transverse direction of the flow);
(3) It represents the river bathymetry more realistically by incorporating the 1990 bathymetric survey data on the refined grids. Additionally, the new grid has adopted quadratic elements to reduce numerical dispersion and enhance numerical convergence at internal wet-dry boundaries.

The new configuration of the RMA2 model to depict dredging conditions was validated by comparison to the LTI RMA2 model. To maintain continuity and consistency between the two studies for comparison, the refined model and the previous model were both set up to simulate the flow patterns and surface profiles with the same boundary conditions and physical parameters. Comparable results from both models would indicate that the refined model has inherited the characteristics of the previous model, and more importantly the credentials that the previous model has built from a thorough calibration process.

The is cross-model validation process was conducted for two flow conditions:

(1) The 100-year flow condition which was presented in the Revised Baseline Modeling Report (USEPA, 2000b);
(2) A 4,000 cfs flow condition which approximates the average flow conditions.

For the previous LTI RMA2 model, the geometry file and boundary condition file were obtained from LTI. The geometry file included both mesh and bathymetry information, and the boundary condition files included physical and model control parameters. For the refined model the boundary conditions and physical parameters were kept the same as the previous model.

The refined model and the LTI RMA2 model were compared for flow patterns for 100-year flow condition. The upstream flow is 47,330 cfs, and the downstream elevation is at 126 feet. Two Manning's n values were used in the previous model, 0.20 in the channel and 0.60 in the flood plain. The refined model is mostly confined to the river channel, therefore the Manning's n was kept at 0.20. Turbulent dispersion coefficient was 100 lb-sec/ft^2 and homogenous for both models. The previous and the refine models show similar flow patterns and velocity magnitudes. The notable differences can be attributed to the omission of flood plain in the refined model. Due to the relatively higher flow depth, the more accurate representation of the bathymetry in the refined model does not seem to contribute significantly to changes in flow pattern or the velocity magnitude.

In addition, the two models were compared for the flow patterns for 4,000 cfs. At this flow rate, the downstream water surface elevation is at 119.2 feet. Because the flows are confined mainly to the river channel, the omission of the flood plain is immaterial. However, at this lower elevation, the effects of the more detailed representation of bathymetry on the flow depth and velocities with the refined model became noticeable.

4.2.2 Results of RMA2

Once the model was validated with the previous model, it was used to simulate the flow patterns at the normal summer flow range. Three representative flows were selected based on the actual flow records - 2,000, 5,000 and 8,000 cfs. In all of these runs the Manning's n value was kept at 0.2 and the turbulent dispersion coefficients was at 100 lb-sec/ft^2. The downstream elevations were at 118.6, 119.2 and the 120.6 feet respectively. It can be seen that the magnitude of the velocity increases with flow and results an increased water surface elevation upstream.

In addition to providing more detailed velocity magnitude and direction at potential dredging sites, the RMA2 simulation results would provide a more accurate shear stress representation and scouring analysis. Potentially the simulated flow field can be used directly in contaminant and sediment transport models such as RMA4 and SED2D. As dredging operations progress, the bathymetry in the model can be easily updated to reflect the post-dredging bathymetry. The flow patterns can then be revised with the updated geometry. The impact of the post-dredging bathymetry can become particularly important when the dredged depth is comparable to the water depth and when the dredging area is relatively large.

4.3 CSTR-Chem

4.3.1 Methodology

The objective of this analysis is to estimate the net contribution of solids, and dissolved and suspended phase PCB to the water column in the immediate vicinity of the dredging operations. This analysis describes the approximation of water quality impacts in the immediate vicinity of a dredging operation using a mathematical model based upon the CSTR concept. It assumes that the waters are completely mixed by ambient and induced currents.

Ideal reactor configurations are used to simplify mathematical modeling of constituent concentrations in surface waters. Two primary ideal reactor configurations are used – continuous flow stirred tank reactors (CSTRs) and plug-flow reactors (PFRs). CSTRs assume that a constant concentration and flow influent is instantaneously mixed as it enters a confined, well-mixed tank. Physical and chemical reactions occur while the water is within the ideal tank and the tank effluent is at the same flow as the influent and at the uniform concentration within the tank. PFRs assume that constituent laden waters travel downstream in a perfectly uniform pattern without lateral and vertical mixing; physical and chemical reactions occur during downstream movement.

Real surface water systems do not have mixed flow conditions; *i.e.*, the waters are never completely mixed or travel downstream without lateral or vertical mixing. However, representing sections of water bodies as one of these ideal reactors can provide useful approximate results, often within errors associated with data available to support the models. The CSTR concept is most appropriate to the analysis of dredging operations because turbulence in the area of the dredge, coupled with ambient flows, may be assumed to produce mixed conditions.

Water Column Mass Balance for Suspended Sediments[1]

Suspended sediment concentrations in the well-mixed water volume that can be approximated as a CSTR can be approximated by:

$$V_{nf}\frac{dm}{dt} = qm_{in} - qm - v_s A_h m + \dot{M}_R \qquad \text{(EQ 3)}$$

where:

V_{nf} = volume of the near-field area (m^3)

m = Suspended solids concentration in the near-field volume approximated as a CSTR (mg/L)

t = elapsed time (sec)

q = flow through the near-field volume (m^3/sec)

m_{in} = Suspended solids concentration of flow entering the near-field volume (mg/L)

?$_s$ = settling velocity of suspended particles in near-field volume (m/sec)

A_h = cross sectional area perpendicular to the height (m^2), and

$\dot{M}_R$ = rate of mass resuspension into the near-field area due to dredging (g/sec).

Steady-state Conditions

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[1] This analysis consists of a mass balance for suspended sediments in the water column only.

If q, $\dot{M}_R$, and v_s are constant for a relatively long period of time, steady-state conditions will be reached, *i.e.*, dm/dt = 0. Steady state suspended solids concentration can then be estimated as:

$$m = \frac{m_{in} q + \dot{M}_R}{l_m V_{nf}} \tag{EQ 4}$$

and

$$l_m = \frac{1}{q_{nf}} + \frac{v_s}{H} \tag{EQ 5}$$

where:

V_{nf} = volume of the near-field area (m^3)

T = hydraulic retention time within CSTR (sec)

H = water depth (m).

If the near-field area is assumed to be a square box over a water depth H, than the volume can be expressed as:

$$V_{nf} = w^2 H$$

where:

w = width of the near-field area (m)

Hydraulic retention time is the volume divided by the flow rate

$$q_{nf} = \frac{V_{nf}}{Q_{nf}} \tag{EQ 6}$$

It should be noted that the hydraulic retention time is only a function of the width and linear velocity of the near-field. This is illustrated in the following equation.

$$q_{nf} = \frac{w^2 H}{uHw} = \frac{w}{u} \tag{EQ 7}$$

where:

u = linear velocity of water (m/s)

The solids concentration inside the CSTR before settling can be expressed as:

$$m_{added} = m_{in} + \frac{\dot{M}_R}{q} \tag{EQ 8}$$

and the solids concentration lost to settling is:

.... $m_{settled} = m_{added} - m_{out}$ (EQ 9)

Note that the concentration exiting the CSTR (m_{out}) is equivalent to that in the CSTR (m). In cases where the sediment type (*i.e.*, silt, sand) is of importance, the suspended solids mass balance can be applied to each sediment component, using the respective settling velocities.

Toxic Constituents[2]

The transport, fate and impact of toxicants are intimately connected with how they partition or associate with solid matter in or below the water body. This implies that the two forms of the toxicant - the dissolved and suspended forms must be distinguished in any analysis. This distinction has an impact on transport and fate because certain mechanisms differently impact the two forms. In the analysis that follows, volatilization and transformation of the contaminant are assumed to be negligible.

Recent studies have demonstrated that desorption of hydrophobic chemicals from sediments can be quite slow and that chemical equilibrium may not be a good approximation in many real situations. To be consistent with the literature on PCB desorption, transient partitioning is assumed in the model, and the rate of PCB desorption from solids is proportional to the difference between the PCB concentration of the suspended sediments and the concentration that would be in equilibrium with the existing soluble concentration. Therefore, a complete formulation of a mass balance under the transient partitioning first requires the concentrations of PCB under equilibrium conditions.

Contaminant Equilibrium Partitioning

It is assumed that equilibrium conditions exist in the near-field CSTR. A mass balance for the concentration of total PCB under this condition can be expressed as:

.... $V_{nf}\dfrac{dc_{Total}}{dt} = qc_{Total,in} - qc_{Total} - v_s A_h F_{s,eq} c_{Total} + \dot{M}_R c_{sed}$ (EQ 10)

where:

V_{nf} = volume of the near-field area (m^3)

C_{Total} = total concentration of the contaminant (ng/L), which is the sum of the dissolved and suspended concentrations in the near-field volume

$c_{d,eq}$ = equilibrium contaminant concentration in dissolved form in the near-field volume approximated as a CSTR (ng/L)

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[2] Porewater contributions are assumed to be negligible and are not considered in this analysis.

$c_{s,eq}$ = equilibrium contaminant concentration in suspended form in the near-field volume approximated as a CSTR (ng/L)
t = elapsed time (sec)
q = flow through the near-field volume (m^3/sec)
$c_{Total,in}$ = total concentration of the contaminant in the flow entering the near-field volume (ng/L)
$?_s$ = settling velocity of suspended particles in near-field volume (m/sec)
A_h = cross sectional area perpendicular to the height (m^2)
$\dot{M}_R$ = rate of mass resuspension into the near-field area due to dredging (g/sec)
c_{sed} = contaminant concentration on bottom sediments (mg/kg).
$F_{s,eq}$ = fraction of contaminant mass in suspended form in equilibrium (unitless)

This fraction of contaminant in suspended form under equilibrium partitioning can be estimated:

$$F_{s,eq} = \frac{K_d m \times 10^{-6}}{1 + K_d \times m \times 10^{-6}} \qquad \text{(EQ 11)}$$

where:

K_d = two-phase contaminant partition coefficient (L/kg)
m = suspended solids concentration in the near-field

Under steady state conditions:

$$c_{Total} = \frac{q c_{Total,in} + \dot{M}_R c_{sed}}{q + n_s A_h F_{p,eq}} \qquad \text{(EQ 12)}$$

The equilibrium concentrations in the dissolved phase and suspended phase along with the concentration on the particles can then be computed as:

$$c_{d,eq} = \frac{c_{Total}}{1 + K_d \times m \times 10^{-6}} \qquad \text{(EQ 13)}$$

$$C_{p,eq} = C_{d,eq} \times K_d \times 10^{-6} \quad \text{and} \quad C_{s,eq} = C_{p,eq} \times m \qquad \text{(EQ 14)}$$

where:

$C_{p,eq}$ = contaminant equilibrium concentration on the particles (mg/kg)

If the background concentration is assumed to be in equilibrium and the suspended solids and fraction of dissolved PCB are known then K_d may be computed as:

$$K_d = \frac{1 - F_{d,in}}{F_{d,in} \times m_{in} \times 10^{-6}} \text{ ....(EQ 15)}$$

where:

$F_{d,in}$ = fraction of contaminant mass in dissolved form in the background (unitless).

For lipophilic contaminants such as PCBs, three-phase partitioning (adding partitioning to dissolved organic carbon) may be important in determining the phase distribution of contaminants. The equations presented above, however, remain valid if $c_{d,eq}$ is interpreted as the "apparent" dissolved concentration or the non-filterable portion that may include both truly dissolved and DOC-sorbed PCBs.

Transient C*ontaminant Partitioning*

Assuming that desorption from the suspended particles to the waster column occurs during the residence time in the CSTR, mass balance expressions for both the dissolved and suspended phases are:

$$V_{nf} \frac{dc_d}{dt} = qc_{d,in} - qc_d + kV_{nf}\left(c_{d,eq} - c_d\right) \text{ ....(EQ 16)}$$

$$V_{nf} \frac{dc_s}{dt} = qc_{s,in} - qc_s - kV_{nf}\left(c_{s,eq} - c_s\right) - v_s A_h c_s + \dot{M}_R c_{sed} \text{ ....(EQ 17)}$$

where:

c_d = contaminant concentration in dissolved form in the near-field volume approximated as a CSTR (ng/L)

c_s = contaminant concentration in suspended form in the near-field volume approximated as a CSTR (ng/L)

$c_{d,eq}$ = equilibrium contaminant concentration in dissolved form in the near-field volume approximated as a CSTR (ng/L). Obtained from equation 13.

$c_{s,eq}$ = equilibrium contaminant concentration in suspended form in the near-field volume approximated as a CSTR (ng/L). Obtained from equation 14

$c_{d,in}$ = dissolved contaminant concentration of flow entering the near-field volume (ng/L)

$c_{s,in}$ = suspended contaminant concentration of flow entering the near-field volume (ng/L)

k = rate of desorption of contaminant concentration from suspended form, also defined as the rate at which equilibrium is reached (1/sec).

If steady-state conditions exist in the near-field area, the dissolved and suspended concentrations along with the concentration on the particles, under transient partitioning can be estimated from equations 16 and 17 as follows:

$$c_d = \frac{qc_{d,in} + kV_{nf}c_{d,eq}}{q + kV_{nf}} \quad \text{..(EQ 18)}$$

$$c_s = \frac{qc_{s,in} + \dot{M}_R c_{sed} + kV_{nf}c_{p,eq}}{q + kV_{nf} + n_s A_h} \quad \text{..(EQ 19)}$$

$$c_p = \frac{c_s}{m} \quad \text{..(EQ 20)}$$

The net contribution of dredging activities can be calculated as:

$$c_{Total,net} = (c_d + c_s) - (c_{d,in} + c_{s,in}) \quad \text{..(EQ 21)}$$

$$c_{d,net} = c_d - F_{d,in}c_{Total,in} \quad \text{..(EQ 22)}$$

and

$$c_{s,net} = c_s - (1 - F_{d,in})c_{Total,in} \quad \text{..(EQ 23)}$$

4.3.2 Results

The analysis below describes the results of CSTR-Chem model application to three different sections of the Hudson River. The following describes the model parameterization:

- Applicability of the CSTR model depends upon the presence of near-field conditions that can reasonably be represented as well-mixed. In this context, well-mixed means suspended solids and toxic constituent concentrations are identical throughout the reactor. Mixing induced by the vertical movement of a bucket dredge suggests that well-mixed conditions will exist in the immediate vicinity of the dredging position. The size of the well-mixed zone depends upon the size of the bucket, both open and closed, and the speed at which it is raised and lowered.

Mixing is less obvious with a hydraulic dredge, but should be a reasonable assumption in relatively shallow water.

- The diameter of the cylindrical area approximated as a CSTR should reflect the extent to which well-mixed conditions exist. For the purposes of this analysis, a CSTR width of 10 meters is used. Buckets expected to be used in the Hudson River project are generally 2 to 3 m in diameter closed and somewhat more open. It is reasonable to assume that velocities induced by bucket movement could extend across most of a 10 m width used in this analysis.

- The FS assumed that a 4-cy environmental bucket would be used to dredge the Hudson River with a two-minute cycle time. Appendix E-6 estimated a sediment resuspension rate of about 1 kg/sec.

- This application also considered two sediment types – silt and coarse materials. Appendix E of the FS contains information cohesive and non-cohesive fraction of sediments, as well as the silt and coarse fraction. Tables 1 and 5 summarize this information for the three sections of the river considered.

- Newly suspended bed sediments are the primary source of new toxic constituents to the water column during a dredging operation. Based upon the research of Warren, Bopp, and Simpson (1997) equilibrium is reached at a rate of 0.20/hr or less; a conservative estimate of 0.2/hr is used as the rate of PCB desorption in this analysis. The selection of the desorption rate is discussed in more detail in Attachment C.

- The partitioning coefficients used for each river section were obtained by assuming that background concentrations of dissolved and suspended PCB are in equilibrium.

- It is assumed that the inflow to the near-field consists only of silt particles. The appropriate settling velocities for silt and sand particle were obtained from review of literature on particle settling in similar systems. Sediments resuspended due to dredging operation are assumed to have uniform particulate PCB content, regardless of type.

- Transient partitioning is assumed for desorption from resuspended sediments. All other partitioning behavior is assumed to be adequately described by equilibrium assumptions.

Table 6 presents the model inputs for the three sections along with model simulation results. The results suggest that under transient partitioning conditions, which are expected within the CSTR, over 98% of the resuspended PCBs are simulated to remain in particle form.

4.3.3 Sensitivity Analysis

The CSTR-Chem model was used to simulate the net suspended solids, net fraction dissolved PCB and net total PCB flux in the near-field as a result of dredging operations. Because models typically contain parameters, the simulation results can be highly sensitive to small changes in the parameter values. Therefore, a sensitivity analysis was performed to quantify the sensitivity of model outputs of greatest interest in the CSTR-Chem model to uncertainty and variability in input parameters. This analysis is important for checking the quality of the CSTR-Chem model, as well as the robustness and reliability of CSTR-Chem modeling analysis.

The CSTR-Chem model parameters on which the sensitivity analysis was performed include:

- River Volumetric flow (thereby linear flow and depth),
- Resuspension rate,
- Silt fraction in the sediment,
- PCB sediment concentration,
- Near-field width,
- Background conditions (suspended solids and PCB concentrations, and dissolved PCB fraction),
- Partition coefficient
- Desorption rate
- Silt and Coarse Settling Velocity

Four model output values were selected to assess the sensitivity of the above parameters. These outputs of concern were:

- The net fraction of dissolved PCBs from dredging, which is estimated as fraction of the net total PCB that is dissolved. The net total PCB is the output total PCB less the background total PCB.
- Net fraction of silts, which is the fraction of net suspended solids (output suspended solids less background suspended solids) that is silt.
- Net total PCB flux exiting the near-field.
- Net suspended solids flux exiting the near-field.

A deterministic approach, which assesses sensitivity of a model output to the range of variation of a parameter, was used in this sensitivity analysis. This method involves calculating the output for a few values of an input parameter. This analysis evaluates the effect on model outputs exerted by individually varying only one of the model input parameters across its entire range of plausible values, while holding all other inputs at their nominal or base case values.

Results and Discussion

The results of the sensitivity analysis were presented using two techniques as follows:

- A dimensionless sensitivity coefficient $S_{\text{Parameter,output}}$ for each parameter was calculated as follows:

$$S_{Paramater,output} = \frac{\Delta Output / Output}{\Delta Parameter / Parameter}$$

where,

Parameter = parameter value for the base case, which is the model default value.
? *Parameter* = the absolute change in input parameter value.
Output = model simulated output for the base case input value.
? *Output* = the absolute change in model simulated output

The average of the $S_{\text{Parameter,Output}}$ values was calculated for each output of concern and the results are presented in Table 7. The higher the sensitivity coefficient for a particular input parameter, the more sensitive the model output is to perturbation of that parameter.

- A graphical method, which gave a visual indication of how each output is affected by variations in inputs, was also used to represent the results (Figures 2 through 15). These graphical representations depict the linearity or non-linearity of the relationships between parameter values and model-simulated outputs.

The results of the parameter sensitivity analysis can be summarized as follows:

- There were no significant differences between the River Sectons in the sensitivity to most of the parameters (e.g. River wide flow and sediment PCB concentration). Therefore, the sensitivity analysis is mainly focused on River Section 1.

- The net fraction dissolved is most sensitive to changes in the width of the near-field CSTR. The CSTR width directly affects the contaminant residence in the near-field, and the residence time is important to the kinetics of particulate PCB desorption. The net fraction dissolved is relatively less sensitive to changes in width at lower CSTR widths (Figure 6). However the width becomes highly sensitive at higher values, as indicated by the slope of the graph between the net fraction dissolved and the CSTR width.

- The net fraction of dissolved PCB is also sensitive to changes in the PCB partitioning coefficient and the rate of PCB desorption. The partitioning coefficient controls the equilibrium concentrations of dissolved and suspended phases, while the rate of desorption control the PCB desorption kinetics. Both parameters had no effect on the other outputs simulated.

- The net total PCB concentration is only sensitive to changes in the concentration of PCB in sediment, and rate of resuspension. Note that the net fraction dissolved is sensitive to changes in resuspension rates and sediment PCB concentrations under conditions of very low resuspension rates (Figure 7) and very low sediment PCB concentrations (Figure 9), respectively.

- The settling velocities of suspended particles were not sensitive parameters especially for silt particles. However, all the outputs of concern are moderately sensitive to the specification of the sediment silt fraction.

The sensitivity analysis suggests that the CSTR width, the PCB partitioning coefficient and the PCB desorption rate are the three most important parameters controlling the release of suspended PCB to the dissolve phase. The width of the CSTR depends on the dimensions of the dredge bucket, and a conservative input of 10 m is used as the base value in the model. The Hudson river FS presented detailed values of the partitioning coefficient of PCB for several congeners suggesting that values of this parameter are well constrained. Therefore, the rate of the PCB desorption is the only parameter that can significantly affect the reliability of the CSTR-Chem model simulations.

Recent studies have demonstrated that desorption of hydrophobic chemicals from sediments can be quite slow and that chemical equilibrium may not be a good approximation in many real situations. In the CSTR-Chem model the rate of PCB desorption from solids is proportional to the difference between the PCB concentration of the suspended sediments and the concentration that would be in equilibrium with the existing soluble concentration. Several studies (Carroll *et al.*, 1994, Borglin *et al.*, 1996; Cornelissen *et al.*, 1997; ten Hulscher *et al.*, 1999, 2002; and Ghosh *et al.*, 2000) have characterized the kinetics of PCB desorption as a two stage process: 1) the desorption of a fast desorbing labile fraction and 2) a slow desorption of a non-labile fraction. A representative value for desorption rate of the fast fraction of PCB from these studies is 0.2 hr^{-1}. The rate of desorption of the slow fraction is over an order of magnitude lower that that given for the fast fraction. In order to be conservative, the CSTR-Chem model simulation for the base case were performed using a constant desorption rate of 0.2 hr^{-1}.

Conclusions

The sensitivity analysis indicates that model simulations using conservative values of PCB desorption and CSTR width should not affect the reliability of model conclusions. Given the small residence time within the CSTR, most of the silt particles are expected to exit the CSTR. However, no significant release dissolved phase release of PCBs is expected.

4.4 TSS-Chem

4.4.1 Methodology

TSS-Chem is intended to provide a model of the downstream transport of solids and PCBs through the near-field (approximately 1 mile). TSS-Chem contains both a solids component and a PCB component. The solids considered are from the silt and coarse resuspended sediments and PCB concentrations modeled are both suspended and dissolved.

TSS-Chem uses the solids source strength of dredging activities to model downstream transport of suspended solids. The source strength differs from the resuspension rate since resuspended sediments settle around the dredgehead, and only a fraction of the suspended solids will be available for downstream transport. As was shown in the CSTR model, the solids that settle within this area are primarily coarse material. Due to the high settling velocity of coarse solids, they do not supply a significant amount of solids or PCB transport. In order to show that the coarse material will not supply a significant amount of solids or PCBs, the solids downstream transport model in Appendix E and Resuspension White Paper of the RS, was modified in TSS-Chem to include the contribution of coarse solids as well as fine solids.

During the downstream transport PCBs adsorbed to the solids will partition into the water-column. In this model two-phase partitioning from the suspended phase into the dissolved phase is estimated. As shown in the CSTR the initial dissolved phase available for downstream transport is not significant and the initial PCB concentration on the solids available for transport downstream (known as the source strength) is not significantly different from the sediment concentration.

Suspended Solids – Kuo and Hayes Model (General Equation)

The current suspended solids plume model utilizes the Kuo and Hayes (1991) Gaussian equation (Equation 24) for modeling the downstream transport of resuspended sediments with clamshell bucket dredges. This equation assumes no lateral or downstream barriers, uniform and unidirectional flow, and constant water depth.

$$c(x,y) = \frac{g}{uh\sqrt{4\pi k_Y x/u}}\, e^{-\left[\frac{uy^2}{4k_Y x} + \frac{wx}{hu}\right]} \qquad \text{(EQ 24)}$$

Where:

x = distance downstream of source (m)
y = distance across stream from the source (m)
g = sediment loss rate (kg/s)
u = ambient linear velocity in the x- direction (m/s)
h = depth (m)

k_y = lateral (y-direction) dispersion coefficient
w = settling velocity

The model presented in Equation 24 is a continuous mathematical function/model that models transport in the x-direction by advection only. Dispersion in the x direction is not considered a significant factor. It computes a concentration for a given x, y location. That value is valid at that x,y point only. However, it is not unreasonable to assume that concentration represents an approximate average of the concentration between some x-distance before the point and a similar x-distance beyond the point. Simple averaging in the lateral direction yields a less correct answer. In fact, over the centerline, it can yield an extremely incorrect answer. Equation 26 computes concentrations out to infinity, as discussed below, a cut-off concentration is necessary to limit the width of the plume to within the river. However, with a cut-off concentration the mass outside the designated plume width will not be accounted for and the model will not conserve mass. Therefore to conserve mass the integration of this function should be used obtain an average concentration of a transect (x=constant).

Suspended solids – Kuo and Hayes Model (Integrated Equation)

In order to conserve mass the average concentration along a transect is calculated using the integrated version of Equation 24. The following known integral (*CRC Handbook of Chemistry and Physics*) can be applied to Equation 24 to obtain the product of the average concentration and width of the plume with total reflection of solids along the shorelines (no mass lost past the shorelines).

$$\int_0^\infty e^{a^2y^2}\,dy = \frac{\sqrt{p}}{2a} \qquad \text{(EQ 25)}$$

Applying Equation (25) to Equation (24) and multiplying by two for both sides of the plume yields:

$$c_{avg}\,y_{plume} = 2 * \frac{g}{uh\sqrt{4pk_Y x/u}}\,e^{-\frac{wx}{hu}} * \frac{\sqrt{p}}{2\sqrt{u/(4pk_Y x)}} = \frac{g}{uh}\,e^{-\frac{wx}{hu}} \qquad \text{(EQ 26)}$$

Where: y_{plume} = width of the plume (lateral extent of the plume) (m)

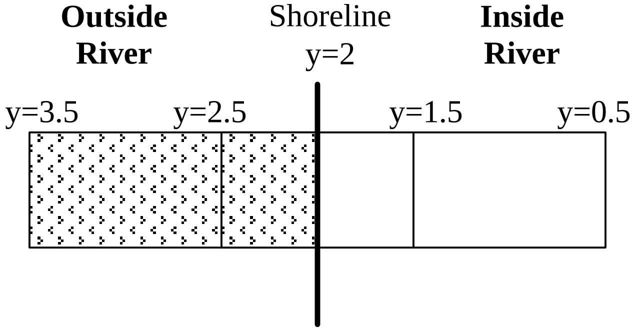
Suspended solids – Kuo and Hayes Model – Determining y_{plume} (General Equation)

To determine the width of the plume Equation 24 can be modified. The width can then be bound by a cut-off concentration or a percentage of the concentration at x=0. Equation 24 may be used to calculate the suspended concentrations for various locations along a river transect (x=constant). If the width of the river is given than a y-increment can be chosen to estimate the average concentration along the transect. The width is separated into discreet boxes each with a width equal to the y-increment, except for the outer two boxes.

For instance, if the source is located 2 meters from the shoreline and a y-increment of 1 is chosen the boxes are:

y = 2 to 1.5 (represented by y=2, width=0.5),
y = 1.5 to 0.5 (represented by y=1, width=1),
y = 0.5 to -0.5 (represented by y=0, width=1),
y = -0.5 to -1.5 (represented by y=-1, width=1), etc.

Since the model will be used to calculate the solid concentrations for a source close to one shoreline Equation 24 must be modified to include shoreline reflection. In this model it was assumed that there is total reflection. Therefore the solids that would be 1 meter outside the shoreline were added to the solids 1 meter within the shoreline. For instance in the example above:



y = 2 to 1.5 would also include the solid concentration from y=2.5 to 2,
y = 1.5 to 0.5 would also include the solid concentration from y=3.5 to 2.5, etc.

Equation 24 then becomes:

$$c(x,y) = \frac{g}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{uy^2}{4k_Y x} + \frac{wx}{hu}\right]} + \frac{g}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{uy_{out}^{\ 2}}{4k_Y x} + \frac{wx}{hu}\right]}$$

or

$$c(x,y) = \frac{g}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{wx}{hu}\right]} \left(e^{-\left[\frac{uy^2}{4k_Y x}\right]} + e^{-\left[\frac{uy_{out}^{\ 2}}{4k_Y x}\right]} \right)$$

(EQ 27)

Where:

y_{out} = the lateral distance the reflected solids would have traveled without reflection (m)

The y_{out} can be expressed in terms of y as:

$$y_{out} = \left(y_{shore} - y\right) \times 2 + y \qquad \text{(EQ 28)}$$

Where:

y_{shore} = the distance to the shoreline from the source (m)

When the cut-off to determine the width of the plume (y_{plume}) is expressed as a percentage of the solids concentration at x=0, y_{plume} is calculated as the sum of the box widths that contain solid concentrations above the cut-off or:

$$y_{plume} = \sum_{-n}^{n} width_{(box,y=i)} \qquad \text{(EQ 29)}$$

Where:

n and –*n* = furthest y distance that has a concentration greater than the cutoff

$width_{box,y=I}$ = width of the box represented by solids concentration at y=*i* (m)

For this model the plume was confined to solid concentrations greater or equal to 1% of the concentration at x = 0.

Suspended solids – Kuo and Hayes Model (Two Settling Velocities)

If the source is assumed to contain both silts and coarse grain materials Equations 24 and 26 need to be modified to include a second settling term. It the two sediment types are assumed to have the same lateral dispersion coefficient than Equation 24 may be modified to:

$$c(x,y) = \frac{g_{silt}}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{uy^2}{4k_Y x} + \frac{w_{silt}x}{hu}\right]} + \frac{g_{coarse}}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{uy^2}{4k_Y x} + \frac{w_{coarse}x}{hu}\right]}$$

or

$$c(x,y) = \frac{g_{total}}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{uy^2}{4k_Y x}\right]} \left(f_{silt} e^{-\left[\frac{w_{silt}x}{hu}\right]} + (1 - f_{silt}) e^{-\left[\frac{w_{coarse}x}{hu}\right]} \right) \qquad \text{(EQ 30)}$$

and

$$f_{silt} = \frac{g_{silt}}{g_{total}} = 1 - \frac{g_{coarse}}{g_{total}}$$

Where:

f_{silt} = fraction of silt in released sediment (unitless)

g_{total} = total sediment loss rate (kg/s)

To account for both reflection from one shoreline and two settling velocities Equation 24 becomes:

$$c(x,y) = \frac{g_{silt}}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{uy^2}{4k_Y x} + \frac{w_{silt} x}{hu}\right]} + \frac{g_{silt}}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{uy_{out}{}^2}{4k_Y x} + \frac{w_{silt} x}{hu}\right]} +$$

$$\frac{g_{coarse}}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{uy^2}{4k_Y x} + \frac{w_{coarse} x}{hu}\right]} + \frac{g_{coarse}}{uh\sqrt{4pk_Y x/u}} e^{-\left[\frac{uy_{out}{}^2}{4k_Y x} + \frac{w_{coarse} x}{hu}\right]}$$

or

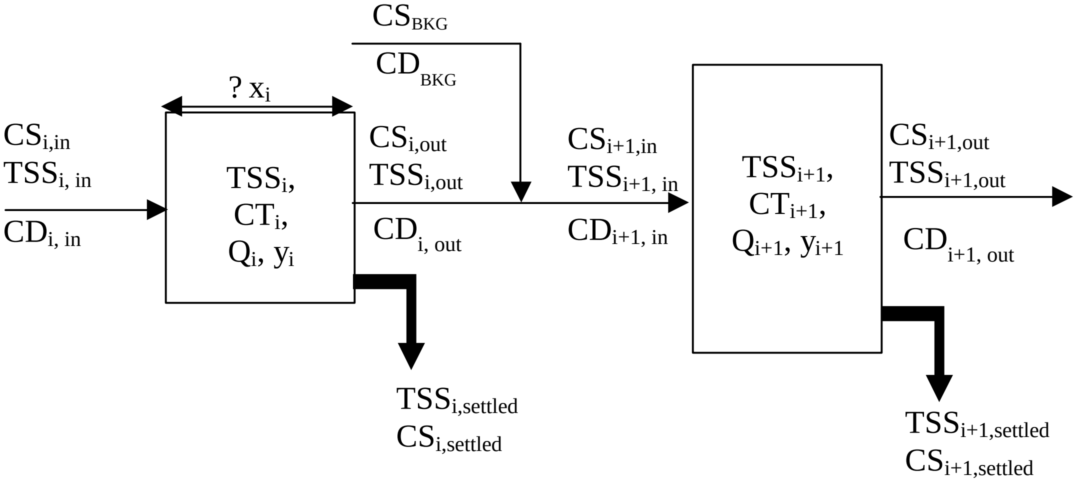
$$c(x,y) = \frac{g_{total}}{uh\sqrt{4pk_Y x/u}} \left(f_{silt} e^{-\left[\frac{w_{silt} x}{hu}\right]} + (1 - f_{silt}) e^{-\left[\frac{w_{coarse} x}{hu}\right]} \right) \left(e^{-\left[\frac{uy^2}{4k_Y x}\right]} + e^{-\left[\frac{uy_{out}{}^2}{4k_Y x}\right]} \right) \qquad \text{(EQ 31)}$$

The integral already accounts for total reflection therefore Equation 26 only needs to be modified to account for two settling velocities. Equation 26 is modified as:

$$c_{avg} y_{plume} = \frac{g_{silt}}{uh} e^{-\frac{w_{silt} x}{hu}} + \frac{g_{coarse}}{uh} e^{-\frac{w_{\cos rse} x}{hu}} = \frac{g_{total}}{uh} \left(f_{silt} e^{-\left[\frac{w_{silt} x}{hu}\right]} + (1 - f_{silt}) e^{-\left[\frac{w_{coarse} x}{hu}\right]} \right) \qquad \text{(EQ 32)}$$

Two-Phase Partition Model for PCBs

The two-phase partition model is used to estimate PCB concentrations in the water column based on the sediment releases from dredging, the PCB concentrations of the suspended sediments and the background conditions. Both the dissolved and suspended (particulate) PCB concentrations are modeled using equilibrium partitioning. As shown from the CSTR model runs, the initial fraction of the dissolved PCBs is not significant and may be assumed to be zero. For the initial conditions of the two-phase partitioning model, partitioning between dissolved and suspended has not reached equilibrium and PCBs will continue to be transferred from the particles to the dissolved phase as they are carried downstream. To estimate the progression towards equilibrium the two-phase partitioning model factors in the residence time of the sediment in the water column (time available to reach equilibrium). A conceptual depiction of the model is shown below.



Where:

TSS_i = Concentrations of TSS (mg/l)
CS_i = PCB concentration on the suspended particles (mg/kg)
CD_i = Dissolved PCB concentration in the water column (ng/l)
CT_i = Total PCB concentration in the water column (ng/l)
Q_i = Volumetric flowrate of box *i* (m^3/s)
x = Distance traveled by the water and solids within each box (m)
y_i = width of the plume (m)

in, out and *BKG* apply to the entering, exiting and background conditions respectively

The path of PCBs being transported downstream of the dredge head is divided into segments. Each segment is addressed as a box. The width of the box equals to the width of the suspended solids plume at the location of the box (its distance downstream of the dredge head). It is assumed that the width of the plume does not change within a box and therefore the volume and flowrate of the box remains constant. The incremental distances downstream (x-increments) used in the model determine the residence time of suspended solids within the boxes, since the residence time is equal to the length of the box divided by the linear velocity. The suspended solids concentration entering each box is assumed to be the average concentration inside the plume. The following assumptions are made in the calculations:

(1) The solids entering the box remain suspended. Settling only occurs after the particles exit. Therefore the PCB concentration on the settled solids equals the PCB concentration on the particles exiting the box.
(2) The change in plume width occurs between boxes. Therefore both the dissolved phase and the suspended PCBs are diluted before entering a subsequent larger box. Additional background PCBs would be included at this point since the larger plume width spreads into areas with a baseline concentration.
(3) Besides the partitioning between dissolved phase and suspended solids and loss through settling, no other mechanism or reaction exists to affect the fate of PCB

in the water column (*i.e.* volatilization, transformation, and reactions are not being considered in this model).

The equations for the two-phase partitioning model based on the conceptual model and assumptions above are listed below.

Equations for Entering Conditions

The volumetric flowrate (Q) must be calculated for each box (since it is dependent on the width of the plume). The volumetric flowrate is calculated using:

$$Q_i = u * h * y_i \qquad \text{(EQ 33)}$$

Where:

u = ambient water velocity (m/s)
h = water depth (m)

The concentration of suspended solids within the plume must also be calculated for each box. The suspended solids concentration given by the Kuo and Hayes Model above is without background; therefore, the background concentration must be added for each segment.

$$TSS_{i,in} = TSS_{KuoHayes,i} + TSS_{BKG} \qquad \text{(EQ 34)}$$

The flux into the first segment

The total PCB concentration and the dissolved fraction for the background are known. In addition, the dissolved fraction of PCBs from dredging activities is given either by the CSTR model or by assuming it is zero. The concentration of PCBs from dredging activities may also be given from the CSTR model or calculated by using:

$$CT_{Dredging} = \frac{g * CS_{SED} * 10^3}{Q_1} \qquad \text{(EQ 35)}$$

Where:

g = sediment loss rate (kg/s)
CS_{SED} = concentration of the suspended sediment (mg/kg)

The total, dissolved and suspended PCB fluxes into the first segment are:

$$\begin{aligned} F_{CT,BKG,1} &= Q_1 CT_{BKG} \\ F_{CT,Dredge,1} &= Q_1 CT_{Dredging} \\ F_{CT,1,in} &= F_{CT,Dredge,1} + F_{CT,BKG,1} \end{aligned}$$

(EQ 36)

$$\begin{aligned} F_{CD,BKG,1} &= f_{BKG} F_{CT,BKG,1} \\ F_{CD,Dredge,1} &= f_{Dredge,1} F_{CT,Dredge,1} \\ F_{CD,1,in} &= F_{CD,Dredge,1} + F_{CD,BKG,1} \end{aligned}$$

(EQ 37)

$$\begin{aligned} F_{CS,BKG,1} &= (1 - f_{BKG}) F_{CT,BKG,1} \\ F_{CS,Dredge,1} &= (1 - f_{Dredge,1}) F_{CT,Dredge,1} \\ F_{CS,1,in} &= F_{CS,Dredge,1} + F_{CS,BKG,1} \end{aligned}$$

(EQ 38)

Where:

F = Flux (g/s)
f = PCB fraction dissolved (unitless)

Subsequent segments:

For subsequent segments an additional flux from background will be added if the plume width has increased. The additional background contribution and total flux into box *i+1* may be calculated as follows:

$$F_{CT,BKG,i+1} = (Q_{i+1} - Q_i) CT_{BKG} * 10^{-6} \tag{EQ 39}$$

$$F_{CT,i+1,in} = F_{CT,i,out} + F_{CT,BKG,i+1} \tag{EQ 40}$$

$$F_{CD,i+1,in} = F_{CD,i,out} + f_{BKG} F_{CT,BKG,i+1} \tag{EQ 41}$$

$$F_{CS,i+1,in} = F_{CS,i,out} + (1 - f_{BKG}) F_{CT,BKG,i+1} \tag{EQ 42}$$

The average total and dissolved concentrations in the plume are calculated by dividing the flux by the volumetric flowrate as:

$$CT_{i,in} = \frac{F_{CT,i,in}}{Q_i} * 10^6 \qquad CD_{i,in} = \frac{F_{CD,i,in}}{Q_i} * 10^6 \tag{EQ 43, 44}$$

The average concentration on the particles is calculated by dividing the flux by the volumetric flowrate and suspended solids concentration.

$$CS_{i,in} = \frac{F_{CS,i,in}}{Q_i * TSS_{i,in}} * 10^6 \tag{EQ 45}$$

Equations for Inside Conditions (Approaching Equilibrium)

Inside the box Q, suspended solids, and the fluxes remain the same as the entering conditions. The concentrations change as the PCBs begin to partition off of the particles and into the dissolved phase. The retention time within the box is determined by:

$$q_i = \frac{\Delta x_i * y_i * h_i}{Q_i} * 3600 \tag{EQ 46}$$

Where:

$?_i$ = retention time/suspended solids contact time (hr)

If the retention time were long enough equilibrium would be achieved and the dissolved and suspended concentrations would be:

$$CD_{eq_i} = \frac{CT_i}{\left(1 + K_d \times TSS_i \times 10^{-6}\right)} \qquad CS_{eq_i} = CD_{eq_i} \times K_d \times 10^{-6} \qquad \text{(EQ 47, 48)}$$

Where:

K_d = partitioning coefficient (L/Kg)

Before equilibrium is reached the dissolved and suspended concentrations must be calculated using the following equations for net desorption:

$$CD_i = CD_{i,in} + (CD_{eq_i} - CD_{i,in}) \times (1 - e^{-l t_i}) \qquad \text{(EQ 49)}$$

$$CS_i = CS_{i,in} - \left(CS_{i,in} - CS_{eq_1}\right) \times (1 - e^{-l t_i}) \qquad \text{(EQ 50)}$$

Where:

? = desorption rate constant (hr^{-1})

Equations for Exiting Conditions

The exiting dissolved and suspended (concentration on the particles mg/kg) are equal to the concentrations inside the box or:

$$CD_{i,out} = CD_i \quad \text{and} \quad CS_{i,out} = CS_i \qquad \text{(EQ 51, 52)}$$

To calculate the total concentration, the suspended solids lost to settling must be calculated. The suspended solids loss must be calculated using the suspended solids flux since the plume volume increases in the next segment and the suspended solids concentration is being diluted, therefore the suspended solids concentration in the *i+1* box will not equal the suspended solids out of *i*. Suspended solids loss to settling can be calculated as:

$$TSS_{Settled,i} = \frac{(TSS_i * Q_i - TSS_{i+1} * Q_{i+1})}{Q_i} \qquad \text{(EQ 53)}$$

and

$$TSS_{i,out} = TSS_i - TSS_{Settled,i} \qquad \text{(EQ 54)}$$

The total PCB concentration may be calculated as:

$$CT_{i,out} = CD_{i,out} + CS_{i,out} * TSS_{i,out} \qquad \text{(EQ 55)}$$

The total, dissolved, and suspended fluxes are:

$$F_{CT,i,out} = CT_{i,out} * Q_i * 10^{-6} \tag{EQ 56}$$

$$F_{CD,i,out} = CD_{i,out} * Q_i * 10^{-6} \tag{EQ 57}$$

$$F_{CS,i,out} = CS_{i,out} * Q_i * TSS_{i,out} * 10^{-6} \tag{EQ 58}$$

Equations for Net Conditions

To get the effects from dredging alone, the contributions from background must be subtracted. The equations for the concentrations are as follows:

$$CT(net)_{i,out} = CT_{i,out} - CT_{BKG} \tag{EQ 59}$$

$$CD(net)_{i,out} = CD_{i,out} - CD_{BKG} \tag{EQ 60}$$

$$CS(net)_{i,out} = \frac{CS_{i,out} * TSS_{i,out} - CS_{BKG} * TSS_{BKG}}{TSS_{i,out} - TSS_{BKG}} \tag{EQ 61}$$

Equation for the K_d value

From previous studies the background conditions are well defined. It is assumed that the conditions of the background represent equilibrium. When the fraction of dissolved and suspended concentrations is given and a background suspended solids value the K_d value can be calculated by:

$$\frac{CD_{BKG}}{CT_{BKG}} = f_{BKG} = \frac{1}{\left(1 + K_d \times TSS_{BKG} \times 10^{-6}\right)} \tag{EQ 62}$$

4.4.2 Relationship between CSTR-Chem and TSS-Chem

The objective of the models was to determine the relationship between suspended solids and PCB (dissolved and particulate) fluxes downstream and resuspension rates. TSS-Chem is useful for the near-field downstream transport of solids and PCBs but is inadequate for modeling the resuspension from dredging activities. Therefore the CSTR-Chem model must be used to translate the resuspension rate, and sediment characteristics to the source strength and suspended solid characteristics used in the TSS-Chem model. The source strength and suspended solid characteristics will in turn determine the suspended solids and PCB fluxes downstream. The resuspension rate of sediments (input to CSTR-Chem) and source strength of suspended solids (output of CSTR-Chem, input to TSS-Chem) are not directly related since the CSTR-Chem model will provide a source strength which has a width dependent on the dredge used and the TSS-Chem models a point source. However, the CSTR-Chem can provide estimations of the initial conditions of the TSS-Chem, specifically the silt and coarse fractions within the sediment and source strength and the initial dissolved fraction of PCBs in the source strength.

Dissolved PCBs from Dredging Activities

The results of the CSTR-Chem model showed that the suspension time of the solids around the dredge head was not long enough to achieve equilibrium conditions. Though some partitioning occurred between the PCBs on the resuspended sediments and the water column, the results indicated that the amount of partitioning was negligible and the dissolved PCB fraction exiting was insignificant. However, it was necessary to determine the impact of an initial dissolved PCB source (other than background) on the PCB and suspended solids fluxes downstream. Therefore, the TSS-Chem model was run for the 350 ng/l far-field criteria scenario in River Sections 1 (2007) and 2 (2009) with and without the dredging dissolved PCB concentrations obtained from the corresponding CSTR-Chem runs. The results are shown in Table 8. The source strengths for the scenario runs did not require adjustments since the PCB flux at one mile experienced a negligible change. The suspended solids flux did not change given that it is not dependent on the dissolved PCB concentration and the source strength was not adjusted. Therefore the dissolved concentration directly around the dredgehead from the partitioning of resuspended material has a negligible effect on the downstream PCB concentration and could be assumed to be zero for the TSS-Chem model runs.

Silt and Coarse Fractions

When the fractions of silt and coarse material in the sediments were applied to the CSTR-Chem model the residence time of the solids within the model was long enough to allow a significant amount of coarse material to settle. For instance, the silt fraction in River Section 1 sediments is approximately 0.37. When the resuspension of this material is modeled using CSTR-Chem, the solids exiting the area around the dredge have a silt fraction of 0.66. To determine the impact of the silt and coarse fractions on the source strengths and fluxes, the TSS-Chem model was run for the 350 ng/l far-field criteria scenarios in sections 1 (2007) and 2 (2009) with and without coarse solids. The results for these runs are shown in Table 9. As the table shows the effect of adding coarse solids does not significantly affect the suspended solids or PCB flux. The total source strength without coarse materials, however, must change to equal the silt source strength when coarse solids are present. This illustrates that while the coarse materials will not have a significant contribution on the relationship between PCB and suspended solids fluxes downstream, they will affect the resuspension rates required to obtain those fluxes. Therefore in calculating the different resuspension rate requirements it is necessary to consider the coarse material.

4.4.3 Results

The results of the TSS-Chem analysis indicated that a significant amount of PCBs released would partition off of the solids and become dissolved by a distance of one mile.

The dissolved fraction at one mile is greater when the source strength is decreased. The majority of the PCB load at one mile was contributed by the silt fraction, since the coarse material generally fell to less than 0.1 percent of the total solids within the plume within 30 meters downstream. The results for the average source strength analyses and near-field suspended solids criteria are discussed below.

4.4.3.1 Average Source Strength Estimations

The resuspension rate is the rate at which sediments directly around the dredge will be suspended into the water column. Before the sediments are available for transport downstream resettling in the dredge area occurs. The resettled material is predominately coarse sediment. The particles that do not resettle around the dredge move downstream. The rate at which the particles are transported downstream out of the immediate dredge area is the source strength.

As outlined in Appendix E.6 of the FS and White Paper: Resuspension of PCBs During Dredging (336740) of the RS, the average resuspension rate is based on a combination of field data from other sites and a resuspension model. The downstream transport rates (source strengths) only apply to silts and finer particles (65 percent of cohesive and 20 percent of non-cohesive sediments for the Hudson River) within the sediment. The use of only silts does not significantly affect the PCB flux estimates since the silt resuspension rate (which is essentially equal to the silt source strength) is the driving source term for the PCB flux downstream. This aspect of the models is discussed in Section 4.4.2 of this attachment.

The average source strength in the FS was originally based on the cohesive sediments. An estimate of 0.3 percent of cohesive sediments was expected to be available for transport downstream. Since this only applies to silt, the percentage can be normalized to the silt fraction in cohesive sediments as 0.003)0.65 to yield 0.5 percent of silts and finer particles. The contribution to the average source strength from non-cohesive sediments must also be added to the average source strength since they are 20 percent silts. The overall fraction of non-cohesive sediments is 0.005×0.2 or 0.1 percent of cohesive sediments. Since silt fractions can be estimated for each section based on the percentages of silts in cohesive and non-cohesive sediments (given above) the source strengths can be calculated as 0.5 percent of the production rates of silty sediments.

The production rates were based on a total of five dredging seasons (two half and four full seasons). Given the amount of sediment removal necessary and the time limitations involved, the average production rates for each river section were calculated. The silt fractions in each river section were applied to yield an average source strength. Each source strength was run through TSS-Chem to estimate the resulting flux and concentration increases at one mile. The production rates, source strengths, and results are shown in Table 10.

Model Revisions from FS Appendix E.6 and RS White Paper Semi-Quantitative Estimates

As part of the FS and RS semi-quantitative assessments of water quality impacts associated with dredging activities were performed. The assessments utilized the DREDGE model (discussed in section 3.0 of this attachment) which is similar to TSS-Chem, however the assessments were not as extensive as those performed for the resuspension performance standard modeling. The semi-quantitative assessments had several assumptions that were modified by the new models. In the analysis of the FS and RS, a model similar to the TSS-Chem model was used to estimate the solids plume within 10 meters of the source term. The estimates of the plume in this model and the TSS-Chem model use the same modeling equations for solids but differ in the modeling of PCB concentrations. The modeling of solids for the TSS-Chem calculations does not use the same parameters as the solids modeling in Appendix E.6. The parameters were revised as part of an extensive literature search since the publication of the FS. The various parameters (*i.e.* dispersion coefficient and settling velocity) and the rationale for their current values are discussed in Section 4.4.1 of this attachment. The differences between the analyses and the individual effects of the differences (overall effects will vary) are discussed below.

The three differences that had the greatest effects on the estimates were:

- Mass was conserved – The suspended solids plume equations will predict concentrations to infinity. In the previous analyses the solids concentration was cut-off at 1 mg/L (or 0.5 mg/L if no values were greater than 1). Therefore the mass outside the cut-off concentration was not accounted for in the suspended solids or PCB flux. In order to preserve mass the TSS-Chem model uses the integrated form of the suspended solids plume equation. The new method increases the suspended solids and PCB concentration and flux estimates for any given resuspension rate. Even if all the other parameters had remained the same the suspended solids Flux estimates at 10 meters with mass conserved in River Section 1 increases from 11.5 to 40 g/sec and in River Sections 2 and 3 from 30.1 to 52 g/sec.

- PCB phase partitioning was included – The TSS-Chem model estimates the phase partitioning of PCBs from suspended to dissolved phases. When partitioning is taken into account the PCB flux and water column concentrations increase relative to the approach used in the FS and RS since the particles settling have a lower concentration and more PCBs remain in the water column. For the average source strengths, the TSS-Chem model estimates net PCB fluxes that contain more than one third dissolved PCBs.

- Settling velocity of silts was decreased – A decrease in the settling velocity of the silts, causes an increase in PCB concentration and flux estimates. After an extensive literature search the settling velocity was estimated to be an order of magnitude lower than was previously predicted. The revised settling velocity greatly increased the amount of solids and PCBs lost to downstream transport.

Other differences that affected the solids and PCB estimates are:

- Plume width concentration was decreased – The former models defined the plume width as described above (greater than 1 mg/L or greater than 0.5 mg/L if no values were above 1 mg/L). TSS-Chem defines the width of the plume by concentrations greater than 1% of the center concentration. The plume width is greater using the current method, however, the volumetric flow rate of the plume varies accordingly and width will not directly affect flux. The concentration in the plume is dependent on the width (concentration will decrease with increasing width), however due to the difference in plume concentration estimated (see "mass was conserved" above) the new method did not decrease the plume concentrations. This increase in the plume width is a model constraint and is not directly related to the change in the lateral dispersion coefficient discussed below.

- Dispersion coefficient was decreased – A decrease in dispersion coefficient increases the PCB concentration within the plume by decreasing the width, but does not change the average river-wide concentration or the flux.

- Linear velocity was increased – An increase in velocity results in an increase in the PCB concentration and flux estimates.

- Depth was decreased – A decrease in depth results in a decrease in the PCB concentration and flux estimates.

- River-wide volumetric flow was increased – The flow examined was changed from 3,000 cfs to 4,000 cfs, since 4,000 cfs is approximately the average flow of the summer months across the three river sections. An increase in flow decreases the PCB concentration but increases the PCB flux.

- Distance downstream was increased – The suspended solids plume concentrations in Appendix E.6 were taken for a distance downstream of 10 meters from the source term. No further removal by settling was permitted. For the revised PCB flux, the TSS-Chem model was extended to one mile downstream allowing for further settling between 10 meters and one mile. An increase in distance, and thereby in settling, will decrease estimates of PCB concentration and flux.

- PCB basis changed from Tri+ to Total – The Tri+ PCB concentrations were used in the former analysis while the new estimates are based on Total PCB concentrations. This would not change the Total PCB flux unless the PCB sediment concentrations and Tri+ to Total PCB ratio were revised. Both the sediment concentrations and the Tri+ to Total PCB ratios were revised from the FS values as part of the RS. The values from the RS were used in this analysis.

4.4.3.2 Particle Settling Results

Some fraction of the sediment resuspended from the dredge will settle downstream. If the material is contaminated, this will add to the PCB mass and concentration in the surrounding downstream areas. Using the modeled suspended solids concentrations in the water column downstream of the dredge with the associated PCB concentration on the suspended solids, it is possible to estimate the increase in PCB mass in these areas. The increase in mass per unit area and the length-weighted average concentration of the top six inch bioavailable layer will be used to measure the effect of the settled material.

The amount of settled material is estimated by calculating the mass of suspended solids in the water column at each modeled location. The mass at each cross section is summed. The difference in mass between each cross section is the amount of solids that has settled downstream. The loss for each section is distributed in the cross section in the same proportion as the amount of mass in the water column along the cross section. The rate of deposition is calculated considering the flow rate. Using the PCB concentration estimated for the suspended sediment, the rate of PCB deposition is estimated at each modeled location.

The spatial distribution of the settled contamination will vary according to the shape of the target area and the rate of dredging. For this estimate, the target area is assumed to be 5 acres, 200 ft across and approximately 1,100 ft long, because the areas of contamination are typically located in the shoals of the river and are narrow. From the FS, a time needed to dredge a 5-acre area with 1 m depth of contamination would take 15 days operating 14 hours per day. It is assumed that the dredge will move in 50 ft increments across and down the target area. With this assumption, the dredge will relocate approximately every two hours. To simulate the deposition of settled material, the amount of PCB mass per unit area, the mass of the settled material and the thickness of the settled material that is deposited in two hours downstream at each modeled location is added on a grid as the dredge moves across and down the area.

The TSS-Chem results for each river section and action levels were used to estimate the additional mass per unit area and length weighted average concentration in the target area, 100 feet to the side of the target area and approximately 2 acres downstream. The remediation could operate continuously at Evaluation Level of 300 g/day or the Control Level of 600 g/day but not Control Level of 350 ng/L. The results are shown in Table 11.

The increase in mass per unit area can be compared to the mass per unit areas values used to select the target areas in River Sections 1 and 2. Areas in River Section 3 are not selected on the basis of a single mass per unit area value. The Tri+ PCB mass per unit area values for River Sections 1 and 2 are 3 g/m^2 and 10 g/m^2. Using the conversion factors for Tri+ PCBs to total PCBs (USEPA, 2002), the total PCB mass per unit area for River Sections 1 and 2 are 6.6 g/m^2 and 34 g/m^2. It is estimated that only a small amount of PCBs will be deposited in the area to the side of the target area with the greatest increase in mass per unit area being only 0.004 g/m^2 in River Section 3.

In the target area, the increase in mass per unit area is more substantial. The mass per unit area increases by 1.8 g/m^2 in River Section 1 for the Control Level of 600g/day, which is nearly a third of the value used to select the areas. In River Section 2, the increase in mass per unit area is nearly the same as in River Section 1, but this increase is only 4 percent of the value used to select the areas. For Control Level of 350 ng/L, the increase in mass per unit area is 3.9 g/m^2 in River Section 1 (65 percent of the value used to select the areas), 4.7 g/m^2 in River Section 2 and 5.6 g/m^2 in River Section 3.

In the area immediately downstream of the target area, in River Sections 1, 2 and 3 for Evaluation Level, the increase in mass per unit area is 0.2, 0.1 and 0.2 g/m^2, respectively. The mass per unit area increases another 2 to 3 times for the 600 g/day Total PCB scenario over the Evaluation Level and increases another two to four times between the 600 g/day and 350 ng/L Total PCB scenarios. These increases in mass per unit area are only significant for Control Level Total PCB criterion of 350 ng/L in River Section 1, which is 17 percent of the value used to select the areas.

The length weighted area concentrations were calculated assuming that the PCB concentration in the sediment underlying the settled material is 1 mg/kg. The ROD defines 1 mg/kg as the acceptable residual concentration. In the area to the side of the target area, no increase in concentration was found. In the target area, the concentrations range from 5 to 29 mg/kg. In the 2 acres below the target area, the concentrations range from 2 to 9 mg/kg. These increases suggest that dredging should proceed from upstream to downstream if no silt barriers are in place so that settled material can be captured by the dredge. Also, silt barriers may be needed to prevent the spread of contamination to areas downstream of the target areas have already been dredged or are not selected for remediation. This settled material is likely to be unconsolidated and easily resuspended under higher flow conditions.

4.4.3.3 Suspended Solids Near-field Criteria and Monitoring Locations

Introduction

PCB criteria for resuspension are set in terms of concentration or load at the far-field monitoring stations. Achieving these criteria requires controlling the PCB concentration and flux from the dredging operation. Paired with the far-field PCB monitoring, suspended solids will be measured at the near-field locations in order to provide the real-time or near real-time monitoring for the potential contaminant flux from the dredging operation. High levels of suspended solids in the near-field may result in exceedances of the PCB criteria at the far-field stations, and therefore should trigger some level of concern. The near-field suspended solids criteria have been developed corresponding to the far-field PCB action levels. HUDTOX and TSS-Chem models were utilized to simulate the connection between the far-field PCB concentrations and loads and the near-field suspended solids concentrations.

Approach

The HUDTOX model was used to predict the PCB levels at the far-field stations. Therefore, for the Control Level, the regulated PCB load of 600 g/day is the output flux simulated by HUDTOX. Similarly for the total PCB concentration criterion of this action level, (350 ng/L), the PCB loads were calculated (at different flows) and were the output fluxes of the HUDTOX model (H_{out}).

HUDTOX simulates an effective rate of PCB loss during transport, due to volatilization and settling. The percentage reduction (1 – output flux/input flux) during transit through a river section varies by section and by year of operation. The percentage reduction obtained from previous HUDTOX runs was used to estimate the input of HUDTOX runs (H_{in}) which will result in the PCB level at the far-field stations corresponding to the action levels. When performing the near-field and far-field model simulation, it is assumed that PCB flux 1 mile downstream of the dredge head estimated by the TSS-CHEM model (T_{1mile}) is the input flux for the HUDTOX model (H_{in}). The input flux for TSS-Chem (T_{in}) was determined by trial and error, until the simulated plume at one mile (T_{1mile}) matched the targeted input to the HUDTOX model. The resulting suspended solids concentrations in these simulations was used as the basis to develop the near-field criteria.

Since some of the TSS-Chem input parameters, such as lateral dispersion coefficient and flow velocity, are flow-dependent, the resulting suspended solids and PCB concentrations and loads are also flow-dependent. As mentioned above, when the output concentration is set as the target value at the far-field stations, the associated load will be calculated and used as the controlling value in the whole process of estimation. Load varies with flow when the concentration is constant. Therefore, it is expected that different flows will generate different plumes at the near-field locations, which means that at the same location, the estimated suspended solids concentration can be significantly different when the flow varies. Suspended solids concentrations at different flows were fully investigated and the most reasonable value, which provides the best representation of the near-field conditions, was chosen as the basis to develop the near-field suspended solids standard.

Since the model simulation determines the values and no actual data is available, other uncertainty factors were taken into account while finalizing the criteria. Criteria were only formulated for the Evaluation Level and Control Level to avoid unnecessary shutdowns.

Results

Multiple TSS-Chem runs were used to simulate the suspended solids plume in the near-field using the one mile downstream PCB flux as the controlling factor. The estimated suspended solids concentrations downstream of the dredge head for River Section 1 at 4,000 cfs and a far-field PCB concentration of 500 ng/L is shown in Figure 16. The profile shown in Figure 16 is a good representation of the estimated suspended solids plumes under all scenarios. The suspended solids concentration decreases and the width of plume increases as the solids area transported downstream. The suspended solids concentration at 300 m downstream is about ¼ to 1/3 of the concentration at 50 m downstream. Assuming that the boundary of the plume is the location where the suspended solids concentration is 5 mg/L higher than the background level (2.3 mg/L in River Sections1 and 2, 1.7 mg/L in River Section3), the width of the plume at 50 m, 100 m, 300 m and 600 m downstream is 21 m, 29 m, 47 m and 61 m, respectively, for the scenario shown in Figure 16. The plume widths at these locations for other scenarios are within the same scale. Since the plume is wider further downstream there is more assurance that a sample collected at 300 m is within the plume than a sample collected a 50 m. At 50 m downstream, due to the narrow width, it is possible to miss the plume when collecting a sample. This could potentially cause a large exceedance at the far-field stations without any indication in the near-field. In addition, the curved shape of the river channel at some points will make it more difficult to predict the direction and the location of the center of the plume when going further downstream. However, further downstream the plume is more diluted and less visible. Therefore it is possible to miss the plume when collecting a sample. In order to counter balance the requirements, ease of sampling within the plume and ease of identifying the plume, two near-field locations are necessary. From the results of this analysis 100 m and 300 m were chosen as the near-field monitoring locations downstream of the dredge.

As mentioned in the approach section, flow will change the current velocity and the lateral dispersion coefficient, which result in different suspended solids concentrations corresponding to the same PCB level at the far-field station. Figure 17 presents the suspended solids concentration at 300 m downstream when only flow varies. Consistent with intuition considering the dilution caused by the flow, a 2,000 cfs flow results in the highest concentration and the lowest concentration occurs with the 8,000 cfs flow. But the difference in concentration is not directly proportional to the flow mainly due to the changes in the lateral dispersion coefficient. Since the flow will vary during dredging a conservative criteria was selected. Therefore the criteria were based on the lowest suspended solids level at 8,000 cfs flow.

Estimated suspended solids concentrations within the plume are used to set the criteria. As mentioned above, the boundary of the plume is determined by the location where the suspended solids concentration is 5 mg/L above the background level. The average flow during the dredging period is assumed to be 4,000 cfs. To provide a common basis for comparing the concentration at different flows, the width of the plume determined by the 4,000 cfs flow is applied to other flow conditions. That is, if the width of plume at 300 m downstream is 47 m when the flow is 4,000 cfs, the widths of plume at the same location under other flows are 47 m as well. As noted above, suspended solids concentration under the high flow is lower than the suspended solids under the low flow. Since the width of the plume is determined by the concentration at the 4,000 cfs flow and the plume at 8,000 cfs is actually not as wide, the average concentration calculated at 8,000 cfs is underestimated. This results in lower values and thereby conservative criteria.

Mean suspended solids concentrations within the plume at 300 m downstream at 8,000 cfs are summarized in Table 12 for each section, corresponding to each far-field action level. The suspended solids levels are similar in River Sections 1 and 3, while the concentrations in River Section 2 are approximately half of the values for River Sections 1 and 3. This is due to the higher average PCB sediment concentration in River Section 2. The average PCB concentration on the dredged sediment is 27, 62 and 29 ppm for Section 1, 2 and 3 respectively. Since the PCB far-field criteria are the same for all three river sections, and dredging in River Section 2 is expected to suspended solids with higher PCB concentrations, section specific SS criteria are necessary. The same criteria may be applied to River Sections 1 and 3 since the average PCB sediment concentrations in these sections are similar.

Suspended solids concentrations reported for the water column monitoring samples collected during the dredging operations in the Lower Fox River SMU 56/57 and New Bedford Harbor pre-design field test were reviewed and compared to the numbers simulated by the models. During the SMU 56/57 work, the downstream suspended solids samples were collected at fixed locations within 800 ft downstream of the dredge head. Most suspended solids numbers fall between 20 and 40 mg/L, with one greater than 100 mg/L and two around 80 mg/L. During New Bedford Harbor pre-design field test, suspended solids samples were collected at different locations within 1000 ft down current of the dredge head. These data were in the range of 10 –30 mg/L. Assuming that the suspended solids concentrations in the Hudson River during dredging are similar to these two projects, the action level corresponding to the 600 g/day of total PCBs at the far-field stations exceed too frequently and possibly cause unnecessary contingencies. Therefore, the SS action level criteria are not based on the numbers determined by 600 g/day of total PCBs, but are based on the numbers corresponding to 350 ng/L at the far-field stations

The near-field suspended solids standard assuming hourly samples is finalized and summarized below.

River Sections 1 and 3 (100 mg/L) and River Section 2 (60 mg/L)

Evaluation Level	6 hrs continuously or 9 hrs in a 24 hour period
Control Level	daily dredging period or 24 hour period

Monitoring of suspended solids at near-field stations is intended to provide timely feedback and allow prompt adjustments to be implemented in order to avoid any significant impact on the far-field stations. Decisions to shutdown operations will be made based on the PCB levels at the far-field station.

The concentration limits (100 mg/L and 60 mg/L) are based on model predictions of a total PCB concentration of 350 ng/L at the far-field station as listed in Table 12. Evaluation Level and Control Level use the same concentration limit but different durations. The duration is chosen based on engineering judgment with an emphasis on the cumulative impact of resuspension on the water quality due to dredging. The impact of a long period with a relatively low concentration is more significant than one sample with a high concentration. It should be noted that the suspended solids concentration regulated herein is the net suspended solids concentration increase, which is the suspended solids concentration 300 m downstream of the dredge head minus the suspended solids concentration upstream of the dredge head, in order to control the suspended solids increase from resuspension and thereby maintain consistent correlation between the PCB concentrations and loads and sediment concentrations.

According to the monitoring plan, the near-field suspended solids sample will be collected at 5 stations, one upstream, one close to the side channel, and three downstream. The upstream sample will provide the background suspended solids level necessary to calculate the net suspended solids increase caused by dredging. The sample for the side channel is intended to provide information on the suspended solids caused by river traffic. For the three samples collected downstream, one will be located at 100 m downstream of the dredge operation and two will be located at 300 m downstream. Even though the criteria are based on the suspended solids level at 300 m downstream, a sample collected 100 m downstream will provide information on how the suspended solids are being transported downstream, and may be useful for Phase 2 work if modifications based on Phase 1 results are necessary. The higher concentration between the two samples collected 300 m downstream will be used for determining compliance with performance standards.

In addition to the performance standards above, a second Evaluation Level criteria is set at 700 mg/L for over three hours at 100 m downstream. This concentration limit is estimated based on the maximum concentration within the plume at 100 m downstream corresponding to a total PCB concentration of 500 ng/L at the far-field station and a flow of 8000 cfs. Collection of PCB samples at the nearest far-field station should be designed to sample the suspended solids release of concern based on the travel of time and any necessary engineering contingencies will be based on the PCB results.

In the formulation of the criteria above no assumptions were made for solid control measures. At any location where a solid control measure such as a silt curtain is used, as described in the monitoring section, the near-field downstream location should be 150 m downstream of the most exterior silt control barrier. Under these conditions the single-level concentration standard (700 mg/L) is not applicable.

4.4.4 Sensitivity Analyses

Two sensitivity analyses were performed. The first analysis examines the distribution of PCBs on the fine and coarse-grained sediments, to determine if they should be modeled with different concentrations. The second sensitivity analysis varies all the inputs one at a time to determine which parameters have the greatest impact on the model outputs.

4.4.4.1 Fine and Coarse-grained PCB Distributions

The analysis presented below uses published data from River Section 1 sediment to examine the
relationships between grain size, organic content and Total PCB concentration. The limited data set was used to provide a ratio of Total PCBs for the fine and coarse-grained sediments. Using these ratios dredging-related PCB resuspension (assuming the average source strength) was modeled for different fine-grained Total PCB sediment concentrations.

The original analysis of the source strength, modeled at 4000 cfs with an average Total PCB sediment concentration of 27 mg/kg, yielded a Total PCB flux of 78 g/day. Published grain-size, organic content and PCB data indicated that the Total PCB concentration on the fine-grained sediments may range from 30 to 36 Total PCB mg/kg. The TSS-Chem transport model indicated that these concentrations on the fine-grained sediments for flows ranging from 2000 to 5000 cfs have PCB fluxes at one mile of 44 to 115 g (Total PCB) /day. Therefore, the model indicated that the Total PCB concentrations investigated do not represent a significant change in the flux or the water column concentration increase, particularly when the uncertainties in sediment homogeneity and river-wide flowrates are considered.

Although the results suggest that the original estimate may not be as conservative as possible, there are many other conservative assumptions in the model. Due to limitations of modeling, the resuspension criteria and action levels were based on the MCL and fish body burdens in the Lower Hudson. The modeling was used as an aid in estimating the resuspension rates each of the criteria may represent. During Phase 1 the model will be reevaluated and possibly modified.

Discussion

While USEPA recognizes that PCB concentrations are generally higher in fine-grained sediments relative to coarse-grained sediments when classified as a whole sample, it is not clear that the organic carbon content within a sample can approximate this relationship. That is, it is not clear that within a given sample, the PCB content of each grain-size fraction is well approximated by the organic carbon content for the sample.

The lack of a direct correlation between organic carbon content and PCB concentration can be seen in Figure 3-21 of the Low Resolution Sediment Coring Report (USEPA, 1998), included in this attachment as Figure 18. This figure shows that PCB concentration does not increase linearly with TOC and that significant variation can be found at any organic carbon concentration. The USEPA agrees that there may be some enhancement of PCB concentration with smaller particles but it is not clear that the response is linear.

According to a study of contaminated Hudson River sediments conducted by General Electric Corporate Research and Development and MIT published in Environmental

Science and Technology (Carroll et al, 1994) the Hudson River sediments greater than 0.069 µm (sand) had % TOC values from 3.2 to 7.3 while the sediments less than 0.069 µm (silt/clay) had a %TOC value of 3.9, indicating little if any difference. These data suggest that the organic carbon content is relatively homogeneous in fine-grained sediments. The data set presented in the paper represents a limited number of samples so it is unclear how far this data can be extrapolated. Nonetheless, it indicates that organic carbon content may not vary with grain size fraction in fine-grained sediments. Furthermore the PCB concentrations for these sediment fractions did not substantively differ. The sand fraction PCB concentrations ranged from 203-284 ppm and the silt/clay concentration was 338 ppm. The data are shown in Figure 19. If the ratio of these samples (which were all taken from Moreau NY, and therefore only represent River Section 1) were assumed to be applicable to the average sediment concentration in River Section 1 (27 ppm), the silt Total PCB concentration would range from 30 to 36 ppm. The equations used to estimate this range are shown below (River Section 1 has an estimated silt fraction of 37%).

$$C_{silt}\, f_{silt} + C_{coarse}\, f_{coarse} = C_{Total}$$

$$C_{silt}\, f_{silt} + Ratio_{coarse-to-silt}\, C_{silt}\, f_{coarse} = C_{Total}$$

or,

$$C_{silt} = \frac{C_{Total}}{f_{silt} + Ratio_{coarse-to-silt}(1 - f_{silt})} \qquad \text{(EQ 63)}$$

Where:

C= PCB concentration (mg/kg)
f = fraction (kg sediment type/kg total)
$Ratio_{coarse-to-silt}$ = Ratio of PCB concentrations on coarse-grained and silty sediments

Further TSS-Chem model runs were performed using River Section 1 Total PCB silt concentrations of 27, 30 and 36 mg/kg and river-wide flows of 2000, 4000, and 5000 cfs. The results are shown in Table 13.

Results

The PCB flux using the values from the previous source strength modeling (27 Total PCB mg/kg and 4000 cfs) was 78 g (Total PCB) /day at one mile. With the different concentrations and flows the PCB fluxes ranged from 44 to 115 g (Total PCB) /day. The Total PCB water-column concentration modeled in the original analysis was 14 ng/L at one mile. With the different flows and sediment concentrations the water-column concentration was modeled to range from 13-19 ng/L. Given the dependency of Total PCB flux on flow, the uncertainty introduced by using the average sediment concentrations instead of the silt concentrations (exhibited by the data from Carroll et al, 1994) is not significant.

Conclusions

Although these results suggest that the estimates originally presented may not be as conservative as possible, they are still quite conservative based on other assumptions made in the development of the standard. In particular, the model transport mechanisms themselves are quite conservative. For example, the source strength term is derived from an upper-bound estimate of the releases due to dredging. Secondly, the transport mechanisms have been idealized and further settling of particles is expected relative to the model predictions.

4.4.4.2 TSS-Chem Model Sensitivity Analysis

The sensitivity of four modeled outputs were examined for the TSS-Chem model. The four output values selected to assess the sensitivity of the above parameters are defined as:

- The net fraction of dissolved PCBs from dredging is equal to the dissolved PCB concentration minus the dissolved background concentration, divided by the total PCB concentration minus the background PCB concentration.
- The distance downstream from the dredge at which the coarse material is less than 0.1 percent of the net suspended solids from dredging.
- The net total PCB flux at one mile, which is the flux at one mile minus the contribution from background.
- The net suspended solids flux at one mile, which is estimated as the flux at one mile minus the contribution from background.

Two of the outputs, the net suspended solids and PCB fluxes, are inputs in HUDTOX. The other two outputs examined are the net dissolved PCB fraction and the distance downstream at which the coarse material is less than 0.1 percent of the net suspended solids. To test the sensitivity of these outputs, each input parameter was varied within reasonable ranges while the others were held constant and the effect on each output was examined. The ranges used for each input parameter are shown in Table 14.

The model parameters on which the sensitivity analysis was performed include:

- Volumetric flow (thereby linear flow, depth, and lateral dispersion),
- Source strength,
- Silt fraction of the entering solids (from dredging),
- PCB sediment concentration,
- Background conditions (suspended solids and PCB concentrations, and dissolved PCB fraction),
- Partition coefficient,
- Desorption rate,

- Lateral dispersion coefficient, and
- Settling velocities of silt and coarse solids being transported downstream

Along with the general effects on modeled outputs, the relative change caused by varying each input was examined. The relative change of an input parameter on the output (X) was calculated by the sensitivity of the parameter $S_{\text{Parameter},X}$ as defined by Gbondo-Tugbawa *et al.*, 2001:

$$S_{Paramater,Output} = \frac{(Output_i - Output_{default}) / Output_{default}}{(Paramter_i - Parameter_{default}) / Parameter_{default}} \qquad \text{(EQ 64)}$$

The higher the value of the average $S_{Parameter,Output}$, the more sensitive the model output is to that parameter. The relative sensitivities of the parameters were ranked by the magnitude of their average $S_{Parameter,Output}$. If the parameter was among the top 30 percent in the ranking the relative sensitivity was labeled as “high”, within 60 percent was “moderate” and below that was “low”. If the output was not sensitive to the parameter it was labeled as “none”.

Results

The input ranges are presented in Table 14. Direct and indirect relationships between the various inputs and outputs are indicated in Table 15. The relative sensitivities are qualitatively given in Table 13. The average of the absolute $S_{Parameter,Output}$ values are presented in Table 16.

Flow

The first parameter examined was the river-wide volumetric flow since this is an environmental parameter and is likely to vary continuously. The river-wide volumetric flow was varied from 2000 to 8000 cfs which is consistent with the natural variation between low and high flow in the Hudson River. However, it should be noted that dredging activities are not expected to occur at such high flow rates (8000 cfs). The default value is 4000 cfs since this is the average flow for the summer months. By changing the river-wide volumetric flows, three model parameters (linear velocity, depth and lateral dispersion) were varied. Using the RMA2 model (at RM 190 and RM 193) the linear velocities and depths for these river flows were acquired as input for the TSS-Chem model. River-wide flows have specific linear velocity-depth pairs, however since the width of the river is not constant there is more than one depth-velocity pair for each river-wide flow. In addition, the lateral dispersion is a function of linear velocity since it is dependent on the shear forces. The results for various river-wide flows are shown in Figure 20. Due to the variations in the other input parameters there is no consistent effect of varying the river-wide flow. In order to provide a clear representation of the effects each input parameter (velocity, depth and dispersion coefficient) was examined separately.

Velocity

The velocity was varied separately in the range of linear velocities that apply to the river-wide flow rates discussed above. The results of varying the velocity are shown in Figure 21. By varying the velocity, the solids will reach one mile downstream in less time. Therefore, the PCBs on the solids will have less time to partition into the water column and the net dissolved PCB fraction will decrease. Likewise, the solids will have less time to settle and the distance at which the coarse solids are less than 0.1 percent of the net solids and the net suspended solids flux will increase. The net PCB flux increases as well since a large fraction of the PCBs are associated with the solids flux. As shown in Figure 21 the net suspended solids flux and net PCB flux are closely correlated to each other.

Depth

The depth was varied separately using the depths that apply to the river-wide flow rates discussed above. The results are shown in Figure 22. For this model the depth affects the amount of settling that will take place and the volumetric flow inside the plume. With increasing depth the amount of solids lost to settling decreases therefore the solids remain suspended in the water column for a longer period of time and have more time to partition, increasing the dissolved fraction. The decrease in settling also increases the fluxes and the distance at which coarse materials are less than 0.1 percent of the net solids. As shown in Figure 22 there is still a strong correlation between PCBs and suspended solids with varying depths.

Source Strength

The source strength was varied from 0.01 kg/s to 40 kg/s. This upper limit was chosen since the production rates in the various river sections are expected be around 40 kg solids/s. It should be noted that this upper bound is unrealistic as a source strength since at this rate the dredge would be resuspending all of the material it is collecting, furthermore the reduction of suspended solids in the near-field due to settling (as exhibited by the CSTR-Chem model) is not being taken into account. For the TSS-Chem runs used to obtain HUDTOX inputs this parameter is set by the standard being examined. For instance if the HUDTOX output of 600 g/day was being examined the source term in the TSS-Chem model was increased until the PCB flux out of HUDTOX equaled 600 g/day. Therefore there is no clear default value and 1 kg/s was chosen.

The results of varying the source strength are shown in Figure 23. As the source strength is increased the net dissolved concentration increases. The net dissolved fraction however decreases since the system is being overwhelmed by solids and the PCBs associated with them. The distance that the coarse material becomes less than 0.1 percent of the net solids remains constant since it is only a function of the flow, settling rates and initial silt fraction. Both the net total PCB flux and the net suspended solids flux have a direct linear relationship to the source strength.

Silt Fraction Entering

The silt fraction entering was varied from 0 to 1. It is anticipated that the fraction will be closer to unity since the coarse materials are less prone to resuspension and have a greater settling velocity. However due to the heterogeneous nature of sediments within a river the full range including all coarse material was applied. The default value of 0.66 was obtained by entering the fractions of silt and coarse in the sediments of Section 1 into the CSTR-Chem model with the same parameter values used in the TSS-Chem model runs. The net silt fraction exiting the CSTR-Chem model (0.66) was then used as the input of the TSS-Chem model.

The results with varying silt fractions are shown in Figure 24. Since silt has a lower settling rate than coarse solids, an increase in the silt fraction entering the system will cause more solids to remain in the water column longer. With increasing silt fractions, the solids are available for partitioning longer and the dissolved PCB concentration increases. However by increasing the initial silt fraction, the suspended PCB fraction at one mile also increases. The overall effect tends to drive the dissolved PCB fraction down, as is shown in Figure 24.

The distance to 0.1 percent coarse material decreases as less coarse material is added into the system. The relationship is not linear and the distance is noticeably less sensitive between initial silt fractions of 0.1 to 0.9 in which the distance only changes by 18 meters.

As shown in Figure 24, both the net PCB flux and the net suspended solids flux linearly increase with increasing silt fraction entering. As was discussed above the increases are due to the lower settling velocity (less settling) and the greater time period available for partitioning.

PCB Sediment Concentration

Due to the heterogeneous nature of the sediments the PCB concentration may have large variations and therefore the range used for the sensitivity analysis is also large (1 to 1000 mg/kg). The default value of 27 mg/kg is the average concentration of the sediments that will be removed in River Section 1. The results for the varying sediment concentrations are shown in Figure 25.

Neither the distance at which the coarse material is less than 0.1 percent of the net solids nor the net TSS flux are dependent on PCB sediment concentrations. The net dissolved fraction increases with increasing sediment concentration, however the sensitivity of the parameter is greatest between 1 and 20 mg/kg. As shown in Figure 25, above 20 mg/kg the fraction begins to plateau. The reason this occurs can be shown by examining the calculations for the net dissolved fraction. Equation 65 below is the equation for the net dissolved fraction (for a small ? x):

$$\frac{CD_{out}-CD_{BKG}}{CT_{out}-CT_{BKG}}=\frac{CD_{in}+\left(\frac{CT_{in}}{\left(1+K_{d}\times TSS_{in}\times 10^{-6}\right)}-CD_{in}\right)\times(1-e^{-l\,t})-CD_{BKG}}{CT_{in}-CT_{settled}-CT_{BKG}} \qquad \text{(EQ 65)}$$

Where:

TSS = Concentrations of suspended solids (mg/l)

CD = Dissolved PCB concentration in the water column (ng/l)

CT = Total PCB concentration in the water column (ng/l)

x = Distance downstream (m)

K_d = partitioning coefficient (L/Kg)

? = desorption rate constant (hr^{-1})

BKG = Background, and

In, *out* and *settled* apply to the concentrations in, out and settling for *?x*.

The equation can be simplified by grouping some of the parameters that are not dependent on the sediment concentration such as K_d, TSS_{in}, $e^{-?t}$.

$$f_{net,dissolved}=\frac{CD_{in}+\left(\frac{CT_{in}}{K}-CD_{in}\right)\times E-CD_{BKG}}{CT_{in}-CT_{settled}-CT_{BKG}} \qquad \text{(EQ 66)}$$

As the sediment concentration increases $CT_{in}>>CD_{in}>CD_{BKG}$, and $CT_{in}>>CT_{settled}$ and the fraction begins to approach CT_{in}/CT_{in}*constants.

The net PCB flux is highly sensitive to the PCB sediment concentration as is exhibited in Figure 25. Since the relationship is a linear one and deviations from the average value are equally likely in either direction (though lower values will probably be more common due to over cutting), the fluctuations within a day would most likely balance out the daily loads to those anticipated with the average sediment concentration.

Dissolved PCB Fraction in the Background

The dissolved PCB fraction in the background, the background suspended solids concentration and the partition coefficient are interrelated by the following equation:

$$\frac{CD_{BKG}}{CT_{BKG}}=f_{BKG}=\frac{1}{\left(1+K_{d}\times TSS_{BKG}\times 10^{-6}\right)} \qquad \text{(EQ 67)}$$

Therefore in order to vary the dissolved fraction in the background the partition coefficient was held constant at the literature value of 5,500 L/kg and the suspended solids concentration in the background was varied from 0.5 to 40 mg/L. These values determined background PCB dissolved fraction between 0.31 and 0.97.

The results for the various PCB dissolved fractions are shown in Figure 26. Neither of the net solid outputs (distance to 0.1 percent net coarse and net suspended solids flux) are dependent on the background PCB dissolved fraction or the suspended solids concentration. The net dissolved fraction increases with an increasing background fraction since a higher background fraction will limit the partitioning and therefore the particles that settle will have a higher concentration. By the time the solids have reached one mile so many solids with higher concentrations have settled out of the water column that the conditions have moved further away from equilibrium. Therefore the dissolved concentration and net dissolved fraction at one mile increases with an increasing dissolved background fraction. However, by removing more concentrated solids through settling, the overall PCB concentration (and thereby the flux) decreases.

Partition Coefficient

As noted above, the partition coefficient, dissolved PCB fraction in the background and the background suspended solids concentration are interrelated. In order to test the model sensitivity to the partition coefficient, the coefficient was varied from 5×10^3 to 5×10^5 and the suspended solids background concentration was held constant (therefore the dissolved PCB fraction in the background varied from 0.99 to 0.47). This range was used since it is not uncommon to find partition coefficients given as log values, and therefore likely to vary by an order of magnitude. The default value is given by the measured dissolved PCB fractions and suspended solids concentrations in the background.

As is shown in Figure 27 neither the distance at which the coarse material becomes less than 0.1% of the net, nor the net suspended solids flux is effected by the varying partition coefficient (and background PCB dissolved fraction). It should be noted that a log scale is used in Figure 27 for the partition coefficient. The net dissolved fraction is highly sensitive to the partition coefficient since it indicates the equilibrium fractions. However, the net PCB flux is not highly sensitive to the magnitude changes in the partition coefficient, since most of the total PCB concentration is dominated by the suspended concentration and the suspended solids concentration is not being affected. Given that most of the criteria are determined by the total PCB value and the confidence in the default partition coefficient is fairly high, variations in the partition coefficient are not expected to limit the usefulness of the TSS-Chem model.

Desorption Rate

The range of desorption rates was obtained through a literature search which is described in attachment C in this attachment. The default value was set at the maximum of the range since this is a conservative assumption and will allow the partitioning to approach equilibrium conditions more quickly. The results for the various desorption rates are shown in Figure 28. As with many of the other parameters there is no effect on the two solids outputs.

The net dissolved fraction increases with increasing desorption rate since the system approaches equilibrium conditions more quickly. The net PCB flux increases with increasing desorption rate since both the dissolved concentration is increasing and the concentration on the settled solids is decreasing.

Lateral Dispersion

The range and default value of the lateral dispersion coefficient was obtained through a literature search, which is described Section 4.4.1 in this attachment. The results for the various coefficients are shown in Figure 29. It should be noted that a log scale is used in Figure 29.

With an increase in lateral dispersion the net dissolved fraction increases since the ratio of the volume of water to the solids becomes larger. The slope of the increase in the net dissolved fraction decreases as the solids begin to disperse so quickly that the width of the plume becomes the width of the river well before it is a mile downstream. The net PCB flux increases due to the increase in dissolved PCBs and decrease in the PCB content of settled solids. As is shown in Figure 29, the net PCB flux is less sensitive than the net dissolved fraction to changes in the lateral dispersion coefficient, due to the significance of the suspended PCB concentrations.

PCB Background Concentration

The range of background PCB water column concentrations is based on the variations experienced throughout the years. The default value is based on the average background value for June to November. The results for the various PCB Background concentrations are shown in Figure 30.

The PCB background concentration has a linearly indirect effect on both the net dissolved fraction and the net PCB flux. The high PCB background values introduce more dissolved PCBs into the system and limit the partitioning of the solids in the water column. Therefore there is a decrease in the net dissolved PCBs and the net fraction decreases. Similarly, the net total PCB flux decreases due to low dissolved concentrations, and high PCB concentrations on settled particles.

Settling Velocity of Silts

The range and default value of the settling velocity of silts was obtained through a literature search, which is described in Section 4.4.1 in this attachment. The results for the various coefficients are shown in Figure 31.

The settling velocity of the silt determines the residence time of silty solids in the water column, thereby affecting the time available for partitioning. As the silt settling velocity increases, the net dissolved concentration will decrease. However, the suspended PCB concentration is also decreasing as particles settle more quickly with higher concentrations. As shown in Figure 31, the decrease in the net dissolved concentration is smaller than the decrease in the net total PCB concentration and the net fraction thereby increases. The decrease in the total PCB concentration and flux is a result of less partitioning and therefore lower dissolved PCB concentrations and greater PCB concentrations on settled particles.

The settling velocity of the silt also affects the two solid outputs, by determining how long the silty solids will remain in the water column. Since the silt settling velocity is much greater than the coarse settling velocity and the distance at which the coarse fraction becomes 0.1 percent is limited by the incremental nature of the model (the value is only given to the nearest meter), the effect of increasing the silt settling velocity is negligible and not exhibited in Figure 31. The net suspended solids flux decreases with increasing settling velocities since the silt particles are settling from the water column at a faster rate.

Settling Velocity of Coarse Particles (Sand)

The range and default value of the settling velocity of sand was obtained through a literature search, which is described in Section 4.4.1 in this attachment. The results for the various coefficients at one mile are shown in Figure 32.

The distance at which the coarse material is less than 0.1 percent decreases as the coarse particles settle more quickly. The settling velocity of the coarse particles does not have a significant effect on the net dissolved PCB fraction, net PCB flux, or net suspended solids flux at one mile, since the coarse material settles out of the water column within 60 meters. Therefore the contributions of the coarse materials at one mile, to both PCB partitioning and solids presence are minimal.

5.0 Far-Field Modeling

5.1 HUDTOX and FISRAND: Fate, Transport, and Bioaccumulation Modeling to Simulate the Effect of the Remedial Alternative

HUDTOX models suspended sediment and PCB transport from Fort Edward through the Thompson Island Pool and downstream to the Federal Dam at Troy, New York. HUDTOX consists of a 2-dimensional vertically-averaged hydrodynamic mathematical model (the USACE RMA-2V model) and a 2-dimensional water quality model with sediment resuspension and scour submodels.

The RMA-2V half of the model simulates water movement by applying conservation of mass and momentum to a finite element mesh overlaying the water surface. It computes water depth and the depth-averaged velocity, both magnitude and direction, in each cell under a specific set of conditions. The finite element mesh used for the Thompson Island Pool consisted of about 6,000 cells connected at approximately 3,000 nodes. Nodes were spaced about 92 m apart in the downstream direction and 15 m apart laterally (see Figure 3-2 from Revised Baseline Modeling Report (BMR) (USEPA, 2000b). RMA-V2 was calibrated by adjusting Manning's n (flow resistance) values to match available water level and velocity data for steady flow conditions at 30,000 cfs. This flow represents the highest values associated with both the upstream and downstream rating curves. The model was validated using data from a 29,800 cfs event that occurred in April 1993.

HUDTOX's submodel is used to estimate sediment deposition and erosion based upon the results of the hydrodynamic model. Variations in bottom velocities within Thompson Island Pool and bottom sediment characteristics - both laterally and vertically - dictated careful consideration of sediment dynamics to accurately estimate changes in water column concentrations due to bottom sediments scour or suspended sediment deposition. PCB concentrations in some areas of the river are higher at depth than at the surface. Thus the exposure of these buried deposits is of particular concern. The Depth of Scour Model (DOSM) with a 2 cm vertical discretization was used to assess bottom sediment dynamics and changes in bottom sediment PCB concentrations due to river flows.

Fate and transport modeling within HUDTOX is based upon EPA's WASP4/TOXI4 models. One-dimensional, transient water quality models considering advection, diffusion, external loadings (e.g., sediment releases) and transformation (e.g., settling) were applied to both suspended solids and PCBs assuming vertical (z-domain) and lateral (y-domain) homogeneity. A finite difference solution was used to predict average water column concentrations in adjoining segments over time. The finite-difference derivation of the general WASP mass balance equations and the specific solution technique implemented to solve these equations are described in Ambrose *et al*. (1993).

Details on all components of the HUDTOX model along with calibration and validation procedures can be found in the Revised Baseline Modeling Report (USEPA, 2000b).

To examine the PCB transport and fish body burdens of PCB, fate, transport, and bioaccumulation models were used. The FISHRAND model requires surface sediment and dissolved water Tri+ PCB concentrations corresponding to the three river sections as described in the FS. FISHRAND is a time-varying mechanistic model based on the modeling approach presented in Gobas (1993 and 1995). The model relies on solutions of differential equations to describe the uptake of PCBs over time, and incorporates both sediment and water sources to predict the uptake of PCBs based on prey consumption and food web dynamics.

5.1.1 HUDTOX Input Values

The resuspension performance standard consists of a Resuspension Standard threshold and action levels. This action level covers operations in the immediate vicinity of dredging operations (near-field) and at the main fixed monitoring locations (far-field) so that water quality responses to the dredge operation, site conditions, engineering controls and other management efforts can be quickly identified. The action levels include both mass and concentration criteria, and apply to suspended solids and Total PCBs. The action levels for Total PCBs are:

Load Criterion of Evaluation Level	The net increase in Total PCB mass transport due to dredging-related activities at any downstream far-field monitoring station exceeds 300 g/day.
Load Criterion of Control Level	The net increase in Total PCB mass transport due to dredging-related activities at any downstream far-field monitoring station exceeds 600 g/day.
Concentration Criterion of Control Level	The total PCB concentration at any downstream far-field monitoring station exceeds 350 ng/L.

Because of the different scale of resuspension (near-field vs. far-field), the following terms have been defined in the preliminary draft of the resuspension performance standard:

- *Resuspension production rate.* Dredging-related disturbances suspend PCB-bearing sediments in the water column. The rate at which this occurs is the *resuspension production rate.*

- *Resuspension release rate.* Since most of the sediments to be remediated in the Upper Hudson are fine sands, a significant fraction and often the majority of this material will settle in the immediate vicinity of the dredge. Materials that remain in the water column are then transported away by river currents. The rate of sediment transport from the immediate vicinity of the dredge is defined as the *resuspension release rate.*

- *Resuspension export rate.* Beyond roughly 1,000 yards, further PCB removal from the water column by particle settling becomes small and most of the PCB in the water column is likely to travel long distances before it is removed or captured by natural geochemical processes. The rate at which PCBs are transported beyond 1,000 yards is defined as the *resuspension export rate.*

The Evaluation Level and the load criterion of the Control Level specify the Total PCB load at the far-field monitoring stations and the concentration criterion of the Control Level specifies the Total PCB concentration at the far-field monitoring stations. These resuspension criteria are the targeted export rates. During dredging operations, it is necessary to specify the load to the water column in the near-field that yields the targeted export rate at the far-field stations. However, there is no prior knowledge of the relationship among the resuspension production, release and export rates. For this reason, computer models will be utilized to estimate the relationship between the far-field and the near-field dredging-induced PCB transport and loss. These computer models are CSTR-Chem, a Gaussian plume model with its associated geochemical component (TSS-Chem), and HUDTOX. The three models will be used to represent and link the three different scales of resuspension. The resuspension production rate in the immediate vicinity of the dredge (30 m) is simulated by the CSTR-Chem. The resuspension release rate in the region from the dredge to a distance of one mile (30 to 1600 m) is represented by TSS-Chem model. Finally, the resuspension export rate in the region beyond one mile is represented by HUDTOX. The choice of the TSS-Chem model to represent a one-mile interval is related to the size of the individual HUDTOX cell, which is approximately 2/3 of a mile long. In addition to the fate and transport models, a series of model simulations is also needed to assess the impacts of dredging to the fish tissue concentrations in the Upper and Lower River. For this purpose, FISHRAND will be used to predict the fish trajectory in the Upper and Lower River and the Farley model will be used to predict the water column and sediment concentrations in the Lower River.

This series of computer models was used to simulate all action levels at the far-field monitoring stations. For the purpose of the modeling effort, all the far-field monitoring for River Section 1 will be done at Thompson Island Dam (TID) and all monitoring for River Sections 2 and 3 will be done at Schuylerville and Waterford, respectively. The one-mile exclusion for the monitoring purposes as stated in the performance standard is not considered in the model runs.

Since the Total PCB action levels are specified as the export rate, HUDTOX is expected to simulate the upper river dredging conditions that caused the conditions at the far-field monitoring stations as specified in the action levels (*i.e.*, 300 g/day, 600 g/day and 350 ng/L). Due to the inherent nature of the HUDTOX model structures, PCB loads cannot be readily specified at far-field locations. Rather, the input of PCBs is specified as an input load at a location within the river, equivalent to a resuspension release rate. For the initial supporting model runs completed for the performance standard, the resuspension release rate was set equal to the desired export rate, recognizing that this yields export rates less than the desired test value. In order to create a correctly loaded HUDTOX run, it is first necessary to estimate the resuspension release rate from the dredging operation, that is, the rate of PCB and solids transport at the downstream end of the dredge plume. At this location most of the solids that are going to settle out, will have settled out and the suspended solids will more closely resemble those simulated by HUDTOX. Therefore, to estimate the input loading term for HUDTOX, the CSTR-Chem and TSS-Chem models were used.

From the initial model runs, it was observed that the HUDTOX model yields an approximately 25 percent reduction (75 percent throughput) of the resuspension release rate to the export rate at the far-field monitoring stations. Therefore, based on these initial runs, the input loading of the HUDTOX model was corrected.

The model formulations for each action level will be discussed in the next sections. The Control Level Total PCB criterion of 350 ng/L will be discussed first since in the preliminary draft of the performance standard at this level, engineering solutions were mandatory and they were only suggested for the other two levels.

Control Level - 350 ng/L at the Far-Field Monitoring Stations

The Control Level of the performance standard specifies that the Total PCB concentration at any downstream far-field monitoring station (compliance point) should not exceed 350 ng/L. The 350 ng/L action level will include both mass flux and concentration criteria, and apply to total suspended solids (suspended solids) and Total PCBs.

To calculate the total flux based on the maximum concentration of 350 ng/L, the following formula is used:

$$F_T = 350\,\frac{ng}{L} \times q \times \frac{1000\ L}{m^3} \times \frac{10^{-9}\ g}{ng}$$

where:

F_T = total Total PCB flux (g/sec)
350 ng/L = Maximum Total PCB concentration (ng/L)
q = flow rate (m^3/sec)
1000 L/m^3 = conversion factor from m^3 to L
10^{-9} g/ng = conversion factor from ng to g

The 350 ng/L resuspension criterion includes ambient PCB loads as well as loads from all sources upstream of the monitoring location. To obtain the load as a result of dredging only, the ambient Total PCB loads (mean baseline loads) should be subtracted from the total flux of Total PCB. Mean baseline load is calculated as follows:

$$F_{MB} = CS_{MB} \times q \times \frac{1000\ L}{m^3} \times \frac{10^{-9}\ g}{ng}$$

where:

F_{MB} = Mean baseline Total PCB flux (g/sec)
CS_{MB} = Mean baseline Total PCB concentration (ng/L)

and other parameters as described above.

The mean baseline Total PCB concentrations were analyzed for TID and Schuylerville based on the water column samplings collected by GE in their on-going weekly sampling program. The methodology and results of the baseline concentrations analysis can be found in Attachment A of the Resuspension Performance Standard. The mean baseline Total PCB concentration for TID and Schuylerville stations can be found in Tables 17 and 18, respectively. Due to limited data available for Waterford, the mean baseline concentrations at this station were estimated by applying a dilution factor of 0.75 to the Schuylerville data. The dilution factor was based on the drainage area ratio of Schuylerville (3440 ft^2) to that of the Waterford (4611 ft^2). The drainage areas for Schuylerville and Waterford were obtained from USGS. The mean baseline Total PCB concentration for Waterford can be found in Table 19.

The net dredging export flux at the monitoring station is then:

$$F_{ND} = F_T - F_{MB}$$

where:

F_{ND} = Net dredging Total PCB flux (g/sec)
and other parameters as described above

The net dredging flux in a day depends on the length of the production or the working hours and is described as follows:

$$F_{NDdaily} = F_{ND} \times t_w \times 3600\ \frac{\sec}{hr}$$

where:

$F_{NDdaily}$ = Daily net dredging Total PCB flux (g/day)
t_w = production/working hours in one day (hr/day)
3600 sec/hr = conversion factor from seconds to hour

The daily net dredging Total PCB flux was calculated for all river sections using the above equations for both 14-hour and 24-hour workdays. Table 20 summarizes the daily net dredging flux for River Sections 1, 2, and 3. For the modeling purposes, a 14-hour workday was used to be consistent with the productivity standard.

Dredging operations are scheduled from 2006 to 2011 with a dredging season from May 1 to November 30 each year, except for the last year of dredging which ends on August

15, 2011. For the purpose of the modeling effort, May conditions are excluded in the daily average of the net dredging Total PCB flux since flow conditions in May are not representative of the remainder of the dredging season (*i.e.*, May has high flow rates compared to other months). The average is only from June to November. In the model simulation, using this average Total PCB flux will also be protective for May conditions.

As mentioned above, the resuspension criterion of 350 ng/L is specified at the far-field monitoring stations. This means the export rate at the monitoring stations should not exceed 350 ng/L. In order to simulate the 350 ng/L Total PCB concentration at the far-field monitoring stations, the Total PCB flux at the near-field location or station that causes the 350 ng/L at the far-field monitoring station is needed. Once the Total PCB flux that represents the 350 ng/L at the far-field monitoring station was obtained using the above equations, the value was increased based on the fraction remaining of the HUDTOX input to the Total PCB flux at the monitoring stations. For the first attempt, a 75 percent fraction remaining at the monitoring station was used based on the previous HUDTOX model runs (Table 21). The input to HUDTOX is calculated by applying the average daily flux for the specific river section for the whole dredging period (May to November) divided by the fraction remaining at the monitoring stations and is described as follows:

$$F_{NDinput} = \frac{F_{NDave}}{g}$$

where

$F_{NDinput}$ = Daily net dredging Total PCB flux input to HUDTOX (g/day)
F_{NDave} = June to November average of daily net dredging Total PCB flux (g/day)
γ = fraction remaining at the far-field monitoring station (%)

Table 21 summarizes the Total PCB flux input to the HUDTOX segments. For the first year of dredging, the resuspension release is applied to June 1 to September 15, 2006 only to account for the half-speed production during that period.

In order to conduct forecast simulations with the HUDTOX model, it was necessary to specify suspended solids and Tri+ PCB flux instead of Total PCB flux. To obtain the Tri+ PCB flux, the Total PCB values were divided by the sediment Total to Tri+ PCB ratio estimated in the Responsiveness Summary to the Record of Decision (USEPA, 2002). The ratio of Total to Tri+ PCB in the sediment for River Section 1 is 3.2, River Section 2 is 3.4 and River Section 3 is 2.7 (USEPA, 2002).

There is no existing data on how to load the suspended solids flux associated with the Total PCB flux for the HUDTOX input. One way to obtain the suspended solids flux is to assume instantaneous equilibrium for PCBs in the water column and use the sediment PCB concentrations in each section of the river to come up with the suspended solids flux (Table 22). However, in dredging scenario, the residence time (contact time) of the sediment in the water column is relatively short, on the order of hours. For this period of time, it is unlikely that PCB reaches equilibrium. Therefore, the suspended solids flux was estimated using TSS-Chem model that accounts for the non-equilibrium partitioning for the desorption of the Total PCBs. The suspended solids flux one mile downstream of the dredge-head was first chosen based on the size of the HUDTOX cells. The suspended solids flux at one mile downstream of the dredge-head was about 3 to 6 percent lower than that of the full equilibrium scenario, depending on the river section (Table 22).

From the Total PCB concentrations downstream of dredge-head plot, it was shown that at three miles downstream, both particulate and dissolved Total PCBs are closer to the equilibrium conditions (Figure 33). Since the HUDTOX far-field model assumes equilibrium partitioning of PCBs, the second attempt of simulating the 350 ng/L resuspension criterion is to take the suspended solids flux from TSS-Chem at three miles downstream of the dredge-head. The suspended solids flux values are slightly smaller than those at the one-mile downstream location (Table 22). To bound the model estimate, a scenario of 350 ng/L without suspended solids flux added to the model was also simulated.

Based on initial HUDTOX runs, the fraction of PCBs remaining at the monitoring station differs by reach of the river, and the fraction remaining is higher closer to the monitoring stations (Table 23). Discussions on the HUDTOX results for the first attempt of 350 ng/L can be found in the Section 5.1.4 of this attachment. Based on the first attempt results, the fraction remaining at the monitoring station was adjusted accordingly (Table 23). The final 350 ng/L scenario was simulated based on the corrected fraction remaining of total PCBs at the monitoring stations and the suspended solids flux at one mile downstream of the dredge-head. The input to the HUDTOX model for the 350 ng/L can be found in Table 23.

Evaluation Level – 300 g/day Total PCB Flux Export Rate

In Evaluation Level, the Total PCB flux at the downstream monitoring stations should not exceed 300 g/day. To examine the effect of running the dredging operation at this action level for the entire dredging period, the Total PCB flux at the downstream monitoring stations was set to be 300 g/day. The input loading for the HUDTOX model was then calculated using the corrected fraction remaining at the monitoring stations. The suspended solids flux associated with the Total PCB flux was calculated using the TSS-Chem model at one mile downstream of the dredge-head. The schedule and the input functions of the 300 g/day resuspension criterion can be found in Table 24.

Control Level – 600g/day Total PCB Flux Export Rate.

Similar to Evaluation Level , the load criterion of the Control Level specified that the Total PCB flux at the downstream monitoring stations should not exceed 600 g/day. Therefore, to study the effect of running the dredging operation at 600 g/day for the entire dredging period, the Total PCB flux at the downstream monitoring stations was set at 600 g/day. Just like the Evaluation Level scenario, the 600 g/day scenario was based on the corrected fraction remaining at the monitoring stations with suspended solids flux at 1 mile downstream of the dredge-head obtained from TSS-Chem. Table 25 summarizes the schedule and input functions of the 600 g/day resuspension criterion.

Accidental Release Scenario

HUDTOX was used to model an accidental release scenario. The purpose of modeling this scenario is to demonstrate the short-term and long-term impact to the public water intakes. The following accidental release scenarios were proposed:

1. A hopper barge containing 870 tons of silty sand (barge capacity is 1000 tons, with 87 percent sediment and 13 percent water) from River Section 2 is damaged and releases the entire load in the area just above Lock 1. The contents fall in a mound and no effort is made to remove or contain the material. Over a period of one week, the entire load is swept downstream. The sediment had been removed by mechanical dredging. The background concentrations are at the 600 g/day Total PCB flux at the River Section 3 monitoring location. For this scenario, there will be additional release of 113,000 kg/day suspended solids, with a baseline condition of 20,000 kg/day for a one week period from July 1 through 7, 2011.

2. A hydraulic pipe bursts. The dimension is 3-mile long and 16 inch diameter. The pipe consists of 20 percent solids (USEPA, 2002; Herbich and Brahme, 1991). For this scenario, the additional suspended solids flux will be approximately 125,000 kg/day for a one-day period.

Case 1 is more severe than case 2. In addition, the case 1 scenario is quite conservative in that the average concentration from River Section 2 is higher than in the TI Pool because areas with mass per unit area greater than 10 g/m^2 are targeted whereas, in the TI Pool, areas greater than 3 g/m^2 are targeted. The hopper barge was used because it has a larger capacity than the deck barge (200 tons), which was also proposed in the FS. The location of the accident is just above the public water intakes at Halfmoon and Waterford, minimizing any reductions that may occur in the water column concentration resulting from settling and dilution. Because the sediment was removed by a mechanical dredge, the entire weight is attributed to sediment with no dilution with water. The already elevated water column concentrations result in water column concentrations at the public water intakes greater than the MCL.

5.1.2 Methodology

The resuspension criteria are defined as Resuspension Standard threshold and action levels. The standard threshold is the maximum total PCB concentration of 500 ng/L at the far-field monitoring stations and represents the acute component of the criteria. The secondary action levels represent a chronic component (*i.e.*, control of long-term impacts to fish and related receptors). For the chronic component, a modeling effort was performed to define a basis for a Total PCB flux standard in terms of Total PCB mass export per year as well as a total mass exported due to dredging for the entire remedial period.

Long term impacts of dredging focus largely on annual rates of PCB transport and changes in fish body burdens of PCBs. For an unacceptable rate of release of resuspended sediments the model would forecast impacts that deviate from the selected alternative. That is, fish at downstream locations exhibit a slower recovery as a result of PCB resuspension losses relative to the original no-resuspension scenario.

To study the long-term impacts of dredging, far-field modeling was completed to simulate water column, sediment and fish Tri+ PCB concentrations in the Upper and Lower Hudson River. The modeling efforts were focused on examining the impact of running the dredging operation at the specified action levels in the resuspension performance standard. The water column, sediment and fish total PCB concentrations were forecast using USEPA's coupled, quantitative models for PCB fate, transport and bioaccumulation in the Upper Hudson River, called HUDTOX and FISHRAND, which were developed for the Reassessment RI/FS. HUDTOX was developed to simulate PCB transport and fate for 40 miles of the Upper Hudson River from Fort Edward to Troy, New York. HUDTOX is a fate and transport model, which is based on the principle of conservation of mass. The fate and transport model simulates PCBs in the water column and sediment bed, but not in fish. For the prediction of the future fish PCB body burdens, the FISHRAND model will be used. FISHRAND is a mechanistic time-varying model incorporating probability distributions and based on a Gobas approach and it predicts probability distributions of expected concentrations in fish based on mechanistic mass-balance principles, an understanding of PCB uptake and elimination, and information on the feeding preferences of the fish species of interest. Detailed descriptions of HUDTOX and FISHRAND models can be found in the Revised Baseline Modeling Report (USEPA, 2000b).

For the Lower Hudson River, the Farley *et al*. (1999) fate and transport model was used. The water and sediment concentrations from the Farley fate and transport model are used as input for FISHRAND to generate the PCB body burdens for fish species examined in the Lower Hudson.

5.1.3 HUDTOX Input Study and Relationship Between Resuspension Release and Export Rates

HUDTOX Total PCB and Suspended Solids Flux Input Study

As part of the long term impacts study, a measure of fish tissue recovery that can provide a threshold or limit to define an unacceptable impact due to dredging releases and thereby a limit on the export rate needs to be determined. The lower bound will be the ideal conditions of dredging, where there is no sediments being spilled (no resuspension) and the upper bound will be the MNA scenario. The HUDTOX/FISHRAND model runs that exist cannot be used for this purpose strictly since HUDTOX is not designed to simulate the process of dredging releases. From the previous HUDTOX model runs for the RI/FS and the Responsiveness Summary of the FS, the model runs appear to be correctly executed but it is clear from the HUDTOX's handling of the solids that the application of the model is not entirely correct. Essentially HUDTOX is exporting too many suspended solids from dredging operation. This happens because the boundary conditions formulations were not done properly. Therefore, the specification of dredging releases to HUDTOX needs to be refined.

During dredging operations, it is necessary to specify the load to the water column in the near-field that yields the targeted export rate at the far-field stations. However, there is no prior knowledge of the relationship between the near-field load and export rates at the far-field stations. Due to the inherent nature of the HUDTOX model structure, PCB loads cannot be readily specified at far-field locations (*i.e.*, specifying the resuspension export rate). Rather, the input of PCBs is specified as an input load at a location within the river, equivalent to a resuspension release rate. In order to create a correctly loaded HUDTOX run, it is first necessary to estimate the local export rate from the dredging operation, that is, the rate of Total PCB and solids transport at the downstream end of the dredge plume. At this location most of the solids that are going to settle out, will have settled out and the suspended solids will more closely resemble those simulated by HUDTOX. Unfortunately, there is no prior knowledge on the relationship between the resuspension release and export rates. In addition to the lack of knowledge on the relationship between the resuspension release and export rates, there is no existing data on how to load the suspended solids flux associated with the Total PCB flux for the HUDTOX input. To estimate the suspended solids flux input loading term for HUDTOX, the TSS-Chem model was used. The total PCB input loading term for HUDTOX (the resuspension release rate) was derived iteratively. The resuspension release rate was obtained by checking the resuspension export rate (output from HUDTOX) until the model output gives the desired total PCB export rate. Once the resuspension release rate that creates the desired resuspension export rate was obtained, the corresponding suspended solids flux associated with the total PCB release rate is estimated using TSS-Chem model. These iterations also took into account the different river sections, with their corresponding target sediment properties (*i.e.*, silt fraction), PCB concentrations and hydrodynamics. The simulations also accounted for the changes in dredging location as the remediation progresses.

To study the effect of different formulations of suspended solids flux input to the HUDTOX model, the Control Level (350 ng/L at the far-field monitoring stations) was modeled and examined in detail. The following scenarios were considered for the 350 ng/L export rate HUDTOX input:

- Suspended solids and Total PCB flux at one mile downstream of the dredge-head from TSS-Chem model (HUDTOX run number d006). The choice of the TSS-Chem model to represent a one-mile interval is related to the size of the individual HUDTOX cell, which is approximately 2/3 of a mile long.

- Suspended solids and Total PCB flux at three miles downstream of the dredge-head from TSS-Chem model (HUDTOX run number d007). This scenario was chosen based on TSS-Chem model results where the Total PCB concentrations (both particulate and dissolved phase) at 3 miles downstream of dredge-head are closer to the equilibrium conditions (Figure 33). Since the HUDTOX model assumes equilibrium partitioning of PCBs, the second attempt of simulating the 350 ng/L resuspension criterion is to take the suspended solids flux from TSS-Chem at 3 miles downstream of the dredge-head. The suspended solids flux values for the 3-mile scenario are slightly lower than those of the 1-mile location (Table 10).

- No suspended solids associated with Total PCB flux (HUDTOX run number sr03). This scenario is essentially the pure dissolved phase Total PCB release during dredging and was chosen to serve as an upper bound for the 350 ng/L simulation. The model simulation for this scenario is carried out to the year 2020 only.

- Suspended solids and Total PCB flux at one mile downstream of the dredge-head from TSS-Chem model with a corrected of the fraction remaining at the far-field monitoring stations (HUDTOX run number sr04). This scenario was simulated based on the first three runs of the 350 ng/L (d006, d007, and sr03).

From the previous HUDTOX runs, it was estimated that there is an approximately 25 percent reduction (75 percent throughput) of the resuspension release rate to the export rate. For the first attempt of simulating the export rate represented by the 350 ng/L, the input to HUDTOX model was obtained by taking the suspended solids and Total PCB flux at 1 mile downstream of the dredge-head from TSS-Chem model (d006). The suspended solids and PCB flux input to the HUDTOX model segments can be found in Table 20. The Tri+ PCB input flux was calculated based on the maximum Total PCB concentration of 350 ng/L at the monitoring locations. Detailed calculations can be found in the Sections 5.1.1 and 5.1.2 of this attachment.

The HUDTOX results are in the form of Tri+ PCB at the monitoring stations and they are:

- Tri+ PCB daily flux.
- Integrated daily flow.
- Suspended solids daily flux.

- Dissolved phase Tri+ PCB daily flux.

The Tri+ PCB HUDTOX output includes both the ambient Tri+ PCB loads, as well as loads from all sources upstream of the monitoring location, and the load resulted from dredging operations. The baseline (background) Tri+ PCB flux can be obtained from the no-resuspension scenario (d004) model run. Since the output of HUDTOX model is in Tri+ PCB, conversions are needed to get the Total PCB concentrations. Baseline Tri+ PCB concentrations are on a 24-hour basis. The Total PCB baseline concentrations can be calculated as follows:

$$\text{Baseline Tri+ PCB} = \frac{F_{\text{Tri+}}\ \text{no-resusp}}{q} \times \frac{1\ \text{hour}}{3600\ \text{sec}} \times \frac{1\ \text{day}}{24\ \text{hour}} \times \frac{1\ \text{ft}^3}{0.02832\ \text{m}^3} \times \frac{1\ \text{m}^3}{1000\ \text{L}} \times \frac{10^{12}\ \text{ng}}{1\ \text{kg}}$$

where

Baseline Tri+ PCB = Tri+ PCB concentration in the water column (ng/L)
$F_{\text{Tri+}}$ no - resusp = HUDTOX Tri+ PCB flux output for no-resuspension scenario (kg/day)
q = Flow rate (ft^3/sec)
1 hour/3600 sec = Conversion factor from seconds to hours
1 day/24 hour = Conversion factor from hours to days
1 ft^3/0.02832 m^3 = Conversion factor from ft^3 to m^3
1 m^3/1000 L = Conversion factor from m^3 to Liters
10^{12} ng/1 kg = Conversion factor from kg to ng

To estimate the Total PCB baseline concentrations, the ratios of Total PCB to Tri+ PCB in the water column are used. The Total PCB to Tri+ PCB ratios in the water column are presented in the Responsiveness Summary (RS) to the FS, Table 424694-1 (USEPA, 2002). Using the water column Total PCB to Tri+ PCB ratios, the Total PCB baseline concentrations can be calculated as follows:

Baseline Total PCB = Baseline Tri+ PCB × water column ratio

Where:

Baseline total PCB = Total PCB concentration in the water column (ng/L)
water column ratio = Water column ratio of Total PCB to Tri+ PCB.

The value is

2 for River Sections 1 and 2;
1.4 for River Section 3

and other parameters as defined above.

The net addition of Tri+ PCB concentration due to dredging is based on the 14-hour work period since the dredging operations are assumed to be 14 hours in one day, and it is estimated as follows:

$$\text{Net Tri} + \text{PCB} = \frac{(\Delta F_{Tri+})}{q} \times \frac{1\text{ hour}}{3600\text{ sec}} \times \frac{1\text{ day}}{14\text{ hour}} \times \frac{1\text{ ft}^3}{0.02832\text{ m}^3} \times \frac{1\text{ m}^3}{1000\text{ L}} \times \frac{10^{12}\text{ ng}}{1\text{ kg}}$$

where:

Net Tri+ PCB = Net additional Tri+ PCB concentration from the model run output (ng/L)

$\Delta F_{\text{Tri+}}$ = F_{Tri+}dredge scenario – F_{Tri+}no resuspension = Net Tri+ PCB flux output from dredging scenario (kg/day)

q = Flow rate (ft^3/sec)

1 hour/3600 sec = Conversion factor from hours to seconds

1 day/14 hour = Conversion factor from hours to days, taking into account 14-hour work period.

1 ft^3/0.02832 m^3 = Conversion factor from ft^3 to m^3

1 m^3/1000 L = Conversion factor from m^3 to Liter

10^{12} ng/1 kg = Conversion factor from ng to kg

To calculate the net additional Total PCB in the water column due to dredging, the sediment ratios of Total PCB to Tri+ PCB are used. The net addition of Total PCB due to dredging is calculated using the following formulas:

$$\text{Net Total PCB} = \text{Net Tri+ PCB} \times \text{sediment ratio}$$

Where:

Net total PC = Net additional Total PCB concentration in the water column (ng/L)

sediment ratio = Sediment ratio of Total PCB to Tri+ PCB.

The value is

3.2 for River Section 1;
3.4 for River Section 2;
2.7 for River Section 3;
and other parameters as defined above

The whole water Total PCB concentration is then:

$$\text{Total PCB concentration} = \text{Baseline Total PCB} + \text{Net total PCB}$$

Where:

Total PCB concentration = Whole water Total PCB concentration (ng/L)

and all other parameters as defined above.

From the first attempt of the 350 ng/L scenario (d006), it was found that the fraction remaining at the monitoring station was different for different section of the river. The fraction remaining is higher closer to the monitoring stations (Table 25). This happens because in the model simulations, the monitoring station for all River Section 1 dredging was assumed to be at Thompson Island (TID). And all the monitoring for River Sections 2 and 3 dredging were assumed to be at Schuylerville and Waterford, respectively. The one-mile monitoring exclusion from the dredging operations location was not considered in the modeling effort. Therefore, as the dredging operations moved downstream (closer to the monitoring location), the amount of Total PCB flux transported downstream were getting higher. In other words, there is less settling taking place due to the distance from the dredge-head to the monitoring station.

The model results showed that the HUDTOX model is not sensitive to the suspended solids flux input. Three different suspended solids flux inputs were modeled (Table 26). The suspended solids flux input for the 350 ng/L for the 3-mile downstream of the dredge-head scenario is about 6 to 23 percent lower than that of the 1-mile scenario. However, HUDTOX predicted that the Total PCB flux and concentrations at the far-field monitoring stations are almost the same. Figure 34 shows the Total PCB concentration in the water column for TID, Schuylerville, and Waterford, respectively for different 350 ng/L Total PCB concentration scenarios. The scenario with the suspended solids flux at three miles downstream of the dredge-head resulted in a slightly lower Total PCB flux at the monitoring stations than that of the 1-mile scenario. However, the difference is less than 2 percent (Table 26). The upper bound estimate is the model scenario with pure dissolved phase total PCB release (sr03). The model estimated a higher Total PCB flux for this scenario. However, the difference is less than 15 percent.

The effect of different suspended solids flux input to the model can also be seen from the predicted annual Tri+ PCB loads. The predicted annual Tri+ PCB loads over the TID, Schuylerville, and Waterford for each of the HUDTOX forecast scenarios are shown in Tables 28through 30. The annual loads for the 1- and 3-mile scenarios (d006 and d007) are practically the same. The predicted Tri+ PCB cumulative loads for the no suspended solids flux scenario (sr03) are higher compared to the 1- and 3-mile scenarios. However, the predicted increase in loads is less than 3 percent. Figure 35 shows the predicted Tri+ PCB cumulative loads over the TID, Northumberland Dam, and Waterford, respectively.

Due to the model's insensitivity to the amount of suspended solids flux input and to be consistent with the scale of the HUDTOX and TSS-Chem models, the 350 ng/L (sr04) scenario was simulated based on the suspended solids flux at 1 mile of the dredge-head and the fraction remaining at the far-field monitoring stations was adjusted based on the 1-mile (d006) model run results.

Similarly, the Total PCB load criterion for the Evaluation Level and Contorl Level were simulated based on the 1-mile suspended solids flux and the fraction remaining at the far-field monitoring stations was based on d006 run.

Relationship Among the Resuspension Production, Release, and Export Rates

As mentioned before, there is no prior knowledge of the relationship on the amount of sediment being suspended to the water column to the suspended solids and PCB fluxes downstream of the dredge-head. For this reason, computer models were utilized to estimate the relationship between the far-field and the near-field dredging-induced PCB transport and loss. The TSS-Chem and HUDTOX models were used to represent and link the resuspension production (at the dredge-head), release, and export rates. The resuspension production rate is represented by the source strength of the TSS-Chem model. The resuspension release rate in the region from the dredge to a distance of one mile is represented by TSS-Chem model and the resuspension export rate in the region beyond one mile is represented by HUDTOX.

The TSS-Chem and HUDTOX models were used to examine the amount of sediment being suspended to the water colum at the dredge-head, the suspended solids and Total PCB flux at one mile downstream of the dredge-head and the Total PCB flux at the far-field monitoring stations for all three action levels. Table 31shows the resuspension production, release, and export rates for the simulated action levels. Because HUDTOX predicted that the fraction remaining at the monitoring station was different for different reach of the river, the TSS-Chem model was run to simulate the Total PCB flux at 1 mile for each year of dredging. From the results it was predicted that to create an export rate of 300 g/day of Total PCB at the TID, the amount of sediments need to be suspended is approximately 1 to 1.3 kg/s depending on the location of the dredge-head to the monitoring stations. The farther away the dredge-head from the monitoring location, the larger the amount of solids may be suspended to the water column (Table 31). In order to get the same result, the resupension production rates that create an export rate of 300 g/day are on the order of 2 to 3 percent of the solids production rate, which is 42 kg/s. In River Section 2, the solids production rate is lower than that of the River Section 1, with a value of approximately 37 kg/s. For this river section, the amount of solids suspended to the water column to create the 300 g/day Total PCB flux is approximately 0.3 kg/s, which is on the order of one percent of the solids production rate. River Section 3 has the lowest solids production rate, with a value approximately 31 kg/s. The resuspension production rate that creates the 300 g/day of Total PCB flux is approximately 0.9 kg/s when the dredge-head is farther away from the monitoring location and it is around 0.7 kg/s when the dredge-head moves downstream closer to the monitoring station.

For the Control Level load criterion (600 g/day Total PCB flux), the required amount of solids suspended into the water column in River Section 1 ranges from 2 to 2.7 kg/s (on the order 5 to 6 percent of the solids production rate). In River Section 2, to obtain an export rate of 600 g/day, approximately 0.6 to 0.7 kg/s of solids need to be suspended to the water column (approximately 2 percent of the solids production rate). For River Section 3, approximately 1.4 to 1.9 kg/s of solids need to be suspended to the water column to create an export rate of 600 g/day Total PCB flux (on the order of 2 percent).

Finally, the Control Level criterion of 350 ng/L Total PCBs was also simulated. The Total PCB flux at the TID, Schuylerville, and Waterford that represents the 350 ng/L is 1200, 2000, and 2300 g/day, respectively. The resuspension production rates correspond to the 350 ng/L Total PCB concentration at TID are approximately 4 to 5.6 kg/s, which is approximately 10 to 13 percent of the solids production rate. For River Section 2, the resuspension production rates are approximately 0.6 to 0.75 kg/s (approximately 6 to 7 percent of the solids production rate). In River Section 3, approximately 6 to 7.5 kg/s of solids need to be suspended to the water column to create an export rate of 350 ng/L Total PCB concentrations. These resuspension production rates are approximately 19 to 24 percent of the solids production rate.

As for the resuspension release rates, under the 300 g/day (sr02) and 600 g/day (sr01) scenarios, HUDTOX predicted that the values are approximately 1 to 1.3 times the resuspension export rate (Table 31). For example, during the second year of dredging in River Section 1 (2007), a 400 g/day Total PCB flux resuspension release creates an export rate of 300 g/day. For the 350 ng/L scenario, HUDTOX predicted that the resuspension release rates are approximately 1 to 1.4 times the resuspension export rates.

Example of CSTR-Chem, TSS-Chem and HUDTOX Application

As an example of the use of CSTR-Chem, TSS-Chem and HUDTOX to simulate the fate and transport of PCBs during dredging operations, the development of the 350 ng/L (i.e., the Control Level) dredging scenario is discussed in this section. To simulate the Control Level, the water column at the far-field monitoring stations was specified to be 350 ng/L. The models were used in a backward sense, first determining the desired conditions to be simulated (in this case 350 ng/L at the far-field stations) and then iterating through the use of the models to determine the fluxes and dredging resuspension terms that would yield the desired condition. The far-field monitoring stations for River Sections 1, 2, and 3 were assumed to be the Thompson Island Dam (TID), Schuylerville, and Waterford, respectively. The PCB fate and transport model analysis was done in the following sequence:

1. The expected Total PCB fluxes based on the 350 ng/L scenario at these three monitoring stations are 1,200 g/day, 2,000 g/day, and 2,300 g/day, respectively based on mean flow at these stations and the desired water column concentration (Table 31)[3]. These are the resuspension export rates to be produced by HUDTOX model when driven by input conditions derived from the near-field models. HUDTOX input is the suspended solids and Total PCB flux at the upstream of the far-field monitoring stations plus the resuspension loading terms derived from TSS-Chem.
2. For HUDTOX to give the most reliable results, the Total PCB flux and the corresponding suspended solids to the water column in the near-field need to be determined. The Total PCB flux input was estimated based on previous HUDOX runs. The near-field suspended solids load derived from the TSS-Chem model run at the desired Total PCB output flux. Based on the previous HUDTOX runs, the Total PCB flux at the near-field (i.e., the resuspension release rate) is approximately 5 to 30 percent higher than the flux at the far-field monitoring stations (i.e., the resuspension export rate), depending on the river section and the dredging season (Table 31). For example, in River Section 1 during May 1 to November 30, 2007 dredging season, the input Total PCB flux was predicted to

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[3] Note that the target loads and concentrations for HUDTOX were estimated for mean flow conditions and the desired concentrations. The model was not run attempting to attain exactly 350 ng/L on each day of the period of simulation. This approach is consistent with the long-term framework of HUDTOX, *i.e.*, the model was designed to address annual scales and longer.

be approximately 27 percent higher than the output (Table 31). Therefore, for an expected Total PCB flux of 1,200 g/day, the input Total PCB flux (i.e., the resuspension release rate) has to be approximately 1,600 g/day. The 1,600 g/day Total PCB flux is the value to be attained as the output of the TSS-Chem model. The TSS-Chem output of 1,600 g/day was taken at approximately 1 mile downstream of the dredge-head to be consistent with the size of the HUDTOX model grid size. As mentioned above, the corresponding suspended solids load for the 1,600 g/day Total PCB flux was obtained from TSS-Chem model.

3. Since the target for the TSS-Chem model is to produce as output the Total PCB flux needed as input to HUDTOX, the TSS-Chem model was run iteratively to determine the corresponding suspended solids and Total PCB input to TSS-Chem. Once the suspended solids input rate to TSS-Chem yielded the desired Total PCB flux (i.e., approximating the resuspension release rate), the flux of suspended solids at 1 mile downstream of the dredge-head was taken as the suspended solids load input to HUDTOX model. For example, in River Section 1 during the May 1 to November 30, 2007 dredging season, the corresponding suspended solids input flux to TSS-Chem that creates the 1,600 g/day Total PCB output flux was approximately 60,000 kg/day.
4. To determine the resuspension production rate at the dredge-head, the CSTR-Chem model was used. The suspended solids input flux to the CSTR-Chem model the resuspension production rate. The TSS-Chem suspended solids input flux is the output of the CSTR-Chem model. Knowing the desired suspended solids output flux for CSTR-Chem, the input to the CSTR-Chem was obtained iteratively. For example, in River Section 1 during the May 1 to November 30, 2007 dredging season, the suspended solids input flux to the CSTR-Chem model that creates a 60,000 kg/day suspended solids flux was approximately 280,000 kg/day.

5.1.4 HUDTOX Results

HUDTOX was used to simulate the following scenarios:

- Control Level – 350 ng/L Total PCB concentrations at the monitoring stations (HUDTOX run number sr04).
- Contorl Level – 600 g/day Total PCB flux at the monitoring stations (HUDTOX run number sr01).
- Evaluation Level 1 – 300 g/day Total PCB flux at the monitoring stations (HUDTOX run number sr02).
- Accidental release (HUDTOX run number srA1).

The following sections summarize the results from the HUDTOX model simulations.

Control Level – 350 ng/L HUDTOX Simulation Results

The Total PCB concentration criterion of the Control Level specificies that the Total PCB concentration at any downstream far-field monitoring station (compliance point) should not exceed 350 ng/L. The suspended solids and PCB flux input to the model can be found in Sections 5.1.1 and 5.1.2 of this attachment . The 350 ng/L (sr04) scenario simulation showed that the predicted Total PCB flux at the far-field monitoring stations is within 5 percent of the expected values (Table 20). The Tri+ PCB loads for this scenario are lower than the previous two 350 ng/L model runs (d006 and d007). The HUDTOX model predicted that the Tri+ PCB loads over the TID for the 350 ng/L scenario is lower than the monitored natural attenuation (MNA) scenario by 2034 (Table 2827). The loads are higher during dredging period (2006 to 2011) and 20 years beyond the completion of dredging (Figure 35). However, by approximately 2033, the Tri+ PCB loads are the same. Similarly, the amount of Tri+ PCB loads over the Schuylerville station is higher than that of the MNA until approximately 2034 (Figure 35), where they become lower than the MNA beyond that year. The Tri+ PCB loads over the Waterford (transported to the Lower River) are predicted to be slightly higher than that of the MNA (Figure 35). However, the predicted increase is minimal, less than 4 percent.

In terms of total PCB, the loads in the water column for the 350 ng/L scenario (sr04) are predicted to be much higher than that of the MNA for all the monitoring stations (TID, Schuylerville, and Waterford). The Total PCB loads over TID, Schuylerville, and Waterford can be found in Figure 36. The Total PCB loads are higher because in order to obtain the Total PCB loads for the MNA scenario, the multiplier is the water column ratio of Total to Tri+ PCB while the multiplier for the 350 ng/L scenario is the ratio of the Total to Tri+ PCB ratio for the sediment. The ratio or Total to Tri+ PCB for the sediment is much higher than that of the water column ratio. Even though the Total PCB loads are much higher, the impact to the fish tissue is expected to be minimal. Only Tri+ PCBs include the PCB congeners that bioaccumulate in fish and hence are key to the risk assessment (USEPA, 2000b).

Figure 37 shows the whole water, particulate, and dissolved Total PCB concentrations at TID for the 350 ng/L (sr04) scenario during the dredging period (2006 through 2011). The HUDTOX model predicted that the average whole water Total PCB concentrations during dredging period in the first three years of River Section 1 is less than 350 ng/L. By the end of the River Section 1 dredging, the whole water column Total PCB concentrations are very low (Figure 37). The amount of dissolved phase Total PCB in the water column is about 40 to 50 percent of the whole water total PCB. The amount of particulate phase Total PCB increase in the reach closer to the monitoring stations (Figure 37).

During River Section 2 dredging, the predicted Total PCB concentrations in the water column are high. This is because the flow during that dredging period (August 16 to November 30, 2009), on average is about 15 percent lower than the historical flow based on the USGS data. Therefore, the high concentrations are expected. However, the average concentrations during the whole dredging period for River Section 2 (August 16 to November 30, 2009 and May 1 to August 15, 2010) is around 380 ng/L (Figure 37). HUDTOX predicted that the amount of dissolved phase Total PCB during the first period of River Section 2 dredging is about the same as the particulate phase (approximately 50 percent). During the next period of dredging (May 1 to August 15, 2010) the model predicted a slightly higher dissolved phase than the particulate phase Total PCB (Figure 37). This is probably due to the model prediction of flows that is low for that particular year and section of the river.

In River Section 3, there are some high whole water Total PCB concentrations during the last year of the dredging period. However, the average Total PCB concentration in the water column during the whole dredging period is less than 350 ng/L (Figure 37). Again, the amount of dissolved phase Total PCB is about the same as the particulate phase in the dredging period of August 16 to November 30, 2010. The next period of the dredging operations, the dissolved phase is less than the particulate because the location of the dredging operations is closer to the monitoring station (Waterford) and hence there is less settling.

Control Level – 600 g/day HUDTOX Simulation Results

The PCB load criterion of the Control Level, specifies that the Total PCB flux at any downstream monitoring station should not exceed 600 g/day. To examine the effect of running the dredging operation at this action level for the entire dredging period, the Total PCB flux at the downstream monitoring stations was set to be 600 g/day. Based on the first attempt of the 350 ng/L scenario and to be consistent with the scale of HUDTOX and TSS-Chem models, the suspended solids flux for this model simulation was based on the 1-mile TSS-Chem model results. The input suspended solids and PCB flux can be found in Sections 5.1.1 and 5.1.2 of this attachment.

The HUDTOX model predicted that the Total PCB flux at the far-field monitoring stations are within 10 percent of the expected Total PCB flux values (Table 33). The whole water Total PCB concentrations at TID during the dredging period (2006 to 2011) are predicted to be less than 250 ng/L except for few days in June 2008 (Figure 38). The whole water Total PCB concentrations at the Schuylerville and Waterford monitoring stations are predicted to be lower than 200 and 150 ng/L, respectively (Figure 38). For this scenario, HUDTOX predicted a higher fraction of dissolved phase Total PCB in the water column compared to the particulate phase total PCB. At TID, the amount of dissolved phase is slightly higher than the particulate phase Total PCB during the first and second year dredging period (May 1 to November 30, 2006 and May 1 to November 30, 2007). As the dredging operations moved downstream in the subsequent years (May 1 to November 30, 2008 and May 1 to August 15, 2009), the particulate phase Total PCB increases and the amount of dissolved and particulate phase Total PCB are almost the same (Figure 38). The fraction of dissolved phase in the water column is even higher in River Section 2 (Schuylerville monitoring station). The amount of dissolved phase in the water column is about 70 percent of the whole water Total PCB concentrations (Figure 38). The dissolved phase Total PCB in the water column at Waterford is approximately 50 percent of the whole water Total PCB concentrations (Figure 38).

The predicted annual Tri+ PCB loads over the TID, Schuylerville, and Waterford monitoring stations for the 600 g/day (sr01) scenario are shown in Figure 39. The predicted Tri+ PCB cumulative loads over TID and Schuylerville for 600 g/day scenario are below the MNA by the year 2014 (Figure 39). The predicted Tri+ PCB cumulative load over Waterford is slightly above the MNA for another year, to approximately 2015. Tables 28 through 30 summarize the predicted annual Tri+ PCB loads over TID, Schuylerville, and Waterford. In terms of total PCB, the annual loads for the 600 g/day (sr01) scenario stays higher than that of the MNA for a longer period of time (Figure 39). Similar to the 350 ng/L scenario, this is due to the sediment ratios used in converting the Tri+ PCB to total PCB.

The Total PCB Load criterion of the Control Level requires that the net increase in Total PCB mass transport due to dredging-related activities at any downstream far-field monitoring station cannot exceed 600 g/day. Look-up tables of PCB concentrations that correspond to the 600 g/day Total PCB flux as a function of river flow and month are provided in the resuspension performance standard. The concentrations that correspond to the 600 g/day Total PCB flux in these look-up tables were calculated based on the GE water column samples data at TID and Schuylerville. Since the concentrations were calculated based on the historical data, the reduction of the baseline concentrations at the subsequent section of the river due to the completion of the previous section of the river was not accounted. The HUDTOX simulation for the 600 g/day takes into account the reduction of the baseline concentrations in River Section 2 after dredging River Section 1. After completion of River Section 1 dredging, the baseline water column Total PCB concentrations in River Section 2 are lower since the source upstream at the Thompson Island Pool (TI Pool) has been removed. Control Level 1 as it is currently written assumed the baseline of whole water Total PCB concentrations at Schuylerville as if the TI Pool has not been dredged. In other words, the action level as specified in the resuspension performance standard is too high. The mean baseline Total PCB concentrations were analyzed for TID and Schuylerville based on the water column samples collected by GE in their on-going weekly sampling program. The methodology and results of the baseline concentrations analysis can be found in Attachment A of the Resuspension Performance Standard.

To examine the additional loading that might be added due to this discrepancy, the HUDTOX results for the 600 g/day are adjusted as follows. Assuming the baseline water column monitoring will be performed from 2003 through 2005, the average monthly Total PCB concentrations were estimated based on the MNA scenario results.

The difference of the average monthly Total PCB concentrations between the MNA and the 600g/day (sr01) scenarios are calculated using the following formula:

$$\Delta TPCB_i = MNA_{base_i} - sr01_{base_i}$$

where:

$\Delta TPCB_i$ = Average difference in Total PCB concentrations in month *i* (ng/L).

MNA_{base_i} = Average baseline Total PCB concentration from MNA scenario for month *i* (ng/L).

$sr01_{base_i}$ = average baseline Total PCB concentration from 600 g/day (sr01) scenario for month *i* (ng/L)

For River Section 2, the difference in Total PCB concentrations was calculated for September through November 2009 and May through August 2010. Once the average monthly difference in Total PCB was obtained, the Total PCB flux was calculated using the following formula:

$$\Delta\text{TPCBflux}_i = \Delta\text{TPCB}_i \times q_{\text{ave}_i} \times 0.02832\ \text{ft}^3/\text{m}^3 \times 3600\ \text{sec/hour} \times 14\ \text{hour/day} \times 1000\ \text{m}^3/\text{L} \times 10^{-9}\ \text{g/ng}$$

where:

$\Delta\text{TPCBflux}_i$ = Average difference in Total PCB flux for month *i* (g/day).
q_{ave_i} = Average flow rate for month *i* (ft3/sec).
$0.02832\ \text{ft}^3/\text{m}^3$ = Conversion factor from ft^3 to m^3.
3600 sec/hour = Conversion factor from second to hour
14 hour/day = Conversion factor from hour to day
$1000\ \text{m}^3/\text{L}$ = Conversion factor from m^3 to liter
10^{-9} g/ng = Conversion factor from gram to nanogram

From the average Total PCB flux difference, the average Total PCB flux difference for the whole dredging period (August 16 – November 30, 2009 and May 1 – August 15, 2010) in River Section 2 was calculated. May conditions are excluded in the average of the difference in Total PCB flux since flow conditions in May are not representative of the remainder of the dredging period. From the calculations above, the average difference in Total PCB flux for River Section 2 is approximately 200 g/day. The 200 g/day Total PCB flux was then added to the Total PCB flux of River Section 2 from HUDTOX results (sr01).

Similarly, to account for the reduction in the baseline whole water column Total PCB concentrations at Schuylerville during dredging River Section 3, the difference in Total PCB flux was calculated using the above formulas. For River Section 3, the Total PCB concentrations difference was calculated for September through November 2010 and May through August 2011. The estimated Total PCB flux that needs to be added to the Waterford Total PCB loads is approximately 300 g/day. During River Section 2 dredging, the sediments from Schuylerville are being transported downstream to River Section 3. HUDTOX predicted that 45 percent of the sediment from Schuylerville is transported to River Section 3. Therefore, during River Section 2 dredging period, 45 percent of the additional flux to the Schuylerville (95 g/day) will be transported to River Section 3. Overall, the adjustment for Total PCB loads at Waterford is an additional 95 g/day Total PCB flux from September through November 2009 and May through August 2010 and an additional of 300 g/day Total PCB flux from September through November 2010 and May through August 2011.

By adding this difference, the Total PCB loads over Schuylerville and Waterford stations are predicted to increase by approximately 2 and 3 percent, respectively. However, the 70-year forecast Total PCB loads for this scenario are still lower than that of the MNA

(Figure 39). The adjusted Tri+ PCB loads over Schuylerville and Waterford are also plotted.

Evaluation Level – 300 g/day HUDTOX Simulation Results

Similar to the Control Level, the Evaluation Level specified that the Total PCB flux at the downstream monitoring stations should not exceed 300 g/day. Therefore, to study the effect of running the dredging operation at 300 g/day for the entire dredging period, the Total PCB flux at the downstream monitoring stations was set at 300 g/day. The suspended solids flux for this model simulation was based on the 1-mile TSS-Chem model results. The input suspended solids and PCB flux can be found in Sections 5.1.1 and 5.1.2 of this attachment.

The HUDTOX model predicted that the Total PCB flux at the far-field monitoring stations is within 13 percent of the expected Total PCB flux values of 300 g/day (Table 34). Figure 40 shows the whole water Total PCB concentrations in the water column at TID, Schuylerville, and Waterford. The HUDTOX model predicted that by running the dredging operations at the load criterion of the Control Level (total PCB flux of 300 g/day), the whole water column Total PCB concentrations at TID are less than 160 ng/L. At Schuylerville and Waterford, the HUDTOX model predicted that the whole water column concentrations are less than 120 and 80 ng/L, respectively (Figure 40). The model predicted that the fraction of dissolved phase in the water column is approximately 60 to 70 percent depending on the location of the dredging operations relative to the monitoring stations for River Sections 1 and 2 (Figure 40). At Waterford, the fraction of dissolved phase Total PCB in the water column is estimated to be approximately 50 percent of the whole water column Total PCB (Figure 40).

Tables 28 through 30 summarize the predicted annual Tri+ PCB loads over the TID, Schuylerville, and Waterford stations. HUDTOX predicted that the 300 g/day (sr02) scenario has the lowest annual Tri+ PCB loads for all stations (Figure 41). Similar to the 600 g/day (sr01) scenario, the annual Total PCB loads for the 300 g/day (sr02) scenario remain higher than that of the MNA for a longer period (Figure 41). Again, this is due to the ratios of Tri+ PCB to Total PCB used in converting the Total PCB loads.

Similar to the Control Level, the 300 g/day Total PCB flux is the net increase in Total PCB mass transport due to dredging-related activities. To be consistent with the performance standard, in which it does not take into account the reduction of the mean baseline Total PCB concentrations after completion of River Sections 1 and 2 dredging operations, the Tri+ PCB and Total PCB loads for the 300 g/day Total PCB flux results from HUDTOX need to be adjusted. Based on the 600 g/day Total PCB flux (sr01) scenario results, the adjustment is expected to be small (on the order of 2 to 3 percent).

Comparison of the Water Column PCB Concentrations for Different Resuspension Criteria

Figure 41 presents comparisons over 70-year forecast period of predicted HUDTOX Tri+ PCB concentrations in the water column at various locations throughout the Upper Hudson River for the MNA, no resuspension and three action levels scenarios.

The effect of running the dredging operations at the Total PCB load criteria of the Evaluation Level and Control Level on predicted water column Tri+ PCB concentrations is largely confined to the six-year active dredging period (2006 through 2011). Outside of the period of scheduled dredging, impacts on water column Tri+ PCB concentrations are minimal. However, running the dredging operations at the PCB concentration criterion of the Control Level results in significantly higher water-column concentrations during the dredging period and slightly elevated water-column concentrations for approximately 10 years in River Section 3 (Figure 43).

The fraction of dissolved phase Total PCB in the water column is higher for dredging scenario with lower suspended solids flux introduced to the water column (compare Figures 37, 38, and 40). For example, the dissolved phase Total PCB for the 600 g/day (sr01) scenario is higher than that of the 350 ng/L (sr04) dredging scenario. This is because the amount of suspended solids flux to the water column for the 600 g/day scenario is relatively lower than that of the 350 ng/L scenario. Compared to the 600 g/day and 350 ng/L dredging scenarios Total PCB flux, the predicted Total PCB flux for the 300 g/day scenario is higher because the amount of solids introduced to the water column is less than both 600 g/day and 350 ng/L scenarios. The smaller the amount of solids introduced to the water column due to dredging, the higher the fraction of dissolved phase Total PCB in the water column.

HUDTOX Results for Accidental Release Scenario

An accidental release scenario was simulated based on a hopper barge running aground just above Lock 1 during dredging Section 3 of the river. The barge carried dredged sediment from River Section 2. The accidental release scenario was assumed to happen when dredging operations were operated under the Control Level criterion of 600 g/day Total PCB flux. The Tri+ PCB loads over TID and Schuylerville remain the same as the 600 g/day (sr01) scenario (Figure 39). The Tri+ PCB load over Waterford was predicted to increase due to the accidental release. The Tri+ PCB load increase is minimal, less than 1 percent. Due to this small increase, the impact to the fish body burdens is expected to be minimal and FISHRAND was not used to model the long-term impact of this release to the fish concentrations.

HUDTOX provided the whole water, particulate bound, and dissolved phase PCB concentrations in the water column. The model predicted that the accidental release scenario results in a short-term increase of the whole water Total PCB above the MCL in the water column at Waterford (Figure 42). However, the highest dissolved phase Total PCB concentration was less than 350 ng/L (Figure 42). These concentrations can be examined against minimal treatment such as filtration and activated carbon to give an indication if the public water supply will be adversely affected, even in the short term. The impact of the elevated solids in the water column during the one-week period can be examined versus the capacity of the Waterford treatment plant to cope with solids.

5.1.5 FISHRAND Results for the Upper and Lower River

FISHRAND model was used to simulate the dredging operations at the Control Level only. FISHRAND modeling results for the Upper River show, similar to the HUDTOX modeling, that the impact of running the dredging operations at load based criterion of the Control Level to the fish tissue concentrations are largely confined to the dredging period in River Sections 1 and 2 (Figure 43). In River Section 3, the impact to the fish tissue concentrations lasts about three years beyond the dredging period to approximately 2014. Table 35 shows the years where FISHRAND model forecasted that the fish tissue concentrations difference to the no resuspension dredging scenario is approximately 0.5 mg/kg. By 2009, the predicted fish tissue concentrations in River Section 1 are within 0.5 mg/kg of the no-resuspension scenario fish tissue concentrations. For River Section 2, the fish tissue concentrations are within less than 0.5 mg/kg of the no-resuspension scenario in 2008. The fish tissue concentrations difference in River Section 3 are predicted to be always less than 0.5 mg/kg. The 0.5 mg/kg difference in fish tissue concentrations was used because this number is within the measurement variability.

The impact of dredging operations at the Control Level criterion of 350 ng/L Total PCBs is larger than running the dredging operations at the 600 g/day scenario (Figure 43). Predicted fish tissue concentrations for the 350 ng/L scenario are within less than 0. 5 mg/kg to the no-resuspension scenario by approximately 2010 in River Section 1 (Table 37). The impact of the 350 ng/L scenario is slightly longer lasting in River Section 2 compared to that for River Section 1. The predicted fish tissue concentrations in River Section 2 are greater than 0. 5 mg/kg of the no-resuspension scenario until approximately 2010. However, in River Section 3, the predicted fish tissue concentration under the 350 ng/L scenario is within 0.05 mg/kg of the no-resuspension scenario in approximately 2011.

The Evaluation Level was not simulated since the Tri+ PCB loads to the Lower River are lower than the load and concentration based criteria of the Control Level (Figure 32 and Table 30). The results for the load based criterion of the Control Level show that the fish tissue concentrations are only slightly impacted and there is only about four years delay for the fish tissue concentrations to be the same as the no-resuspension scenario. In addition, the annual average Tri+ PCB concentrations in the water column for the Evaluation Level scenario are almost the same as that of the no-resuspension scenario by the end of dredging period. Therefore, the Evaluation Level was not simulated and the impact of running the dredging operations at this level is expected to have no adverse impact.

For the Lower Hudson River, the FISHRAND model predicted that the fish recovery is slightly longer further downstream (Figure 44). Note that the fish tissue concentrations in the Lower River are lower than those of the Upper River. The predicted fish tissue concentrations for the 600 g/day (Control Level) scenario are within less than 0.05 mg/kg relative to the no-resuspension scenario between 2013 and 2014 for all river miles (Figure 44 and Table 36). As for the 350 ng/L (Control Level) scenario, the fish tissue concentrations are within less than 0.05 mg/kg relative to the no-resuspension scenario between 2016 and 2017 at RMs 152 and 113. Further downstream, at RMs 90 and 50, the predicted fish tissue concentrations are within 0.05 mg/kg of the no-resuspension scenario in 2018 (Table 36).

5.2 Relative Reduction In Human Health And Ecological Risks In The Upper And Lower Hudson River

Human health hazards and risks and ecological risks in the Upper and Lower Hudson River were calculated for the no resuspension, 350 ng/L Total PCB, 600 g/day Total PCB, and monitored natural attenuation (MNA) scenarios. All active remediation scenarios showed reductions in human and ecological risks, as compared to the MNA scenario, with minimal differences generally seen between most active remediation scenarios.

5.2.1 Introduction

PCB body burdens in fish under various resuspension scenarios were used to calculate long term long-term risks (i.e., after completion of dredging) to anglers and ecological receptors (as represented by the river otter [Lutra canadensis]). The following four scenarios and their run designations (e.g., d004) were modeled:

- ? No resuspension (d004).
- ? 350 ng/L Total PCB (sr04).
- ? 600 g/day Total PCB (sr01).
- ? Monitored natural attenuation.

Risks were calculated with the same exposure durations used as those used the for the Hudson River PCBs Reassessment RI/FS reports (e.g., 40 years for evaluating cancer risks to the reasonably maximally exposed [RME] adult angler, 7 years for evaluating non-cancer health hazards to the RME adult angler). Start years for calculating risks were set to begin one year after the year in which dredging will be completed in the each section of the river and the average of the upper river. All other risk assumptions, locations, toxicity values, receptors, and fate, transport, and bioaccumulation models (i.e., HUDTOX, FISHRAND, and Farley) used to evaluate risks under various resuspension scenarios are the same as those used for baseline conditions in the Revised Human Health

Risk Assessment, the Revised Baseline Ecological Risk Assessment, the Feasibility Study, and the Responsiveness Summary for the Record of Decision, except where noted.

5.2.2 Human Health Risk Reduction

5.2.2.1 Upper Hudson River

Table 37 presents annual species-weighted fish fillet PCB concentrations in the Upper Hudson River, as compared to the risk-based remediation goal (RG) for the protection of human health of 0.05 mg/kg PCBs in fish fillet. The RG is based on non-cancer hazard indices for the RME adult fish consumption rate of one half-pound meal per week, but this level is protective of cancer risks as well. Other target concentrations are 0.2 mg/kg PCBs in fish fillet, which is protective of human health at a fish consumption rate of one half-pound meal per month and 0.4 mg/kg PCBs in fish fillet, which is protective of the CT or average angler, who consumes one half-pound meal every two months.

FISHRAND, the model used to calculate fish body burdens, models fish tissue PCBs on a Tri+ basis. PCB contamination in fish tissue has been shown to contain almost exclusively Tri + PCB homologues (USEPA, 2002). Therefore EPA's fish forecasts and modeling analyses, based on Tri+ PCB, require no revision for comparison to total PCB toxicity values.

The time to reach human health fish target concentrations of 0.2 mg/kg Tri+ PCB and 0.4 mg/kg Tri+ PCB in the Upper Hudson River was shorter for all resuspension scenarios as compared to monitored natural attenuation in the upper river as a whole, and in each individual river section (Table 38). The remediation goal of 0.05 mg/kg Tri+ PCB was only reached in Section 3. The greatest differences seen in the time to achieve fish target concentrations between the active remediation scenarios and MNA were seen in River Sections 1 and 2, where the MNA scenarios took up to 17 years longer to achieve some target concentrations. Smaller differences were seen between scenarios in River Section 3.

Using fish fillet concentrations based upon the three resuspension scenarios (i.e., no resuspension, 350 ng/L, and 600 g/day) human health fish consumption cancer risks and noncancer hazards show at least a 50 percent reduction in the upper river as a whole, Section 1 (River Mile 189), and Section 2 (River Mile 184) compared to monitored natural attenuation for both RME and average exposures (Tables 39 and 40). Risk reductions in Section 3 were seen for the no resuspension and 600 g/day scenarios as compared to monitored natural attenuation, but not for the 350 ng/L Total PCB scenario.

5.2.2.2 Mid-Hudson River

Based on site-specific angler surveys, the Human Health Risk Assessment determined that Mid-Hudson River anglers have a different diet than anglers in the upper river, consisting of 53 percent brown bullhead, 15 percent largemouth bass, 1.4 percent yellow perch, 7.6 percent white perch, and 23 percent striped bass (USEPA, 2000). Striped bass concentrations were modeled using the Farley model for the Hudson River RI/FS reports. However, the Farley model was not run for fish tissue concentrations for resuspension scenarios and therefore precise estimated of human health cancer risks and noncancer hazards for Mid-Hudson River anglers could not be calculated.

To provide an estimate of relative risks amongst the resuspension scenarios, angler intake was calculated using fish concentrations from the FISHRAND model. Striped bass intake was proportionally divided between the remaining fish species (i.e., 69 percent brown bullhead, 19 percent largemouth bass, 2.0 percent yellow perch, and 10 percent white perch) and white perch concentrations from the FISHRAND model were used in the absence of Farley model data. Calculated fish exposure concentrations were used only for comparison between alternatives and do not represent predicted intake concentrations based on mid-river angler consumption patterns. As expected, fewer differences were seen between the resuspension scenarios in the lower river than in the upper river, with long-term cancer risks and non-cancer hazards differing by a maximum of 32 percent. The no resuspension and 600 g/day Total PCB scenarios showed the greatest risk reductions as compared to monitored natural attenuation scenario. The 350 ng/L Total PCB showed lower and sometimes no reductions in risk, owing to elevated concentrations of PCBs predicted in fish tissues for several years following dredging operations under the 350 ng/L scenario (Table 41).

5.2.3 Ecological Risk Reduction

5.2.3.1 Upper Hudson River

Risks to ecological receptors, as represented by the river otter, were evaluated by examining largemouth bass whole fish PCB concentrations and comparing them to toxicity reference value (TRV) based target levels using lowest-observed-adverse-effect-level (LOAEL) and no- observed-adverse-effect-level (NOAEL) concentrations. In the Upper Hudson River the LOAEL target levels were reached within the modeling timeframe for the upper river as a whole and in Section 3 for all scenarios (Table 42). All resuspension scenarios, reached the LOAEL target level of 0.3 PCBs mg/kg 17 years prior to the MNA scenario for the upper river as a whole (Table 43). Ecological target levels were not reached within the modeling timeframe for Sections 1 and 2 of the river. In Section 3, all scenarios reached the LOAEL target level within five years of one another.

5.2.3.2 Lower Hudson River

Largemouth bass PCB concentrations in the Lower Hudson River were lower under all resuspension scenarios than under the MNA scenario (Table 44). The LOAEL PCB target concentration in largemouth bass was reached 4 to 11 years sooner under the various resuspension scenarios than under MNA (Table 45).

5.2.4 Conclusions

Resuspension may temporarily increase PCB concentrations locally, resulting in slight increases in fish PCB concentrations. However, human health noncancer hazards and cancer risks and ecological risks under active remediation scenario were calculated to be well below those under the monitored natural attenuation scenario. Minor differences were seen between the various resuspension scenarios indicating the human health and environmental impacts from dredging are predicted to be minimal, particularly since levels of resuspension approaching the performance criteria are expected to occur on an intermittent, rather than continuing basis. In general, human health and ecological target concentrations are achieved within similar time frames under active remediation. Non-cancer hazards, cancer risks, and ecological toxicity quotients showed minimal differences between scenarios. Increased resuspension results in a maximum delay of five years to achieve human health target concentrations under active remediation, as compared to up to 17 year delays under monitored natural attenuation.

5.3 Suspended solids Far-Field Criteria

The far-field suspended solids criteria are based on the PCB far-field criteria. The suspended solids concentration was calculated based on the PCB increase of the criteria, assuming the solids concentrations were equal to the dredged material. For a total concentration of 500 ng/L, and a background concentration of 100 ng/L, the net increase would be 400 ng/L. As stated in the FS, the average PCB concentration on the dredged sediment across all three River Sections is approximately 34 ppm. Therefore, the suspended solids concentration for 500 ng/L was calculated to be about 12 mg/L. Considering the uncertainty associated with some of the calculation assumptions, the TSS criterion for Control Level was set at twice the estimated concentration or 24 mg/L, and the TSS criterion for the Evaluation Level was set at 12 mg/L. Two-tiered far-field suspended solids criteria, applicable to all the far-field stations, are established and summarized below. It should be noted that the concentration of PCBs at the far-field station with a suspended solids concentration of 12 mg/L is modeled by TSS-Chem to be greater than 500 ng/L Total PCBs since the PCB dissolved phase would also contribute to the concentration. The far-field suspended solids criteria are specified in Chapter 2 of Volume 1.

No standard was formulated for Resuspension Standard to avoid unnecessary shutdown of operations. Exceedance of the far-field suspended solids criteria will not cause any engineering contingency except for additional monitoring of PCBs.

6.0 Modeling Studies Used

6.1 New Bedford Harbor Pre-Design Field Test Dredge Technology Evaluation Report

A numerical model of Upper New Bedford Harbor was used to predict concentrations of suspended sediments in the water column resulting from dredging activities. The model was based on previous hydrodynamic modeling of New Bedford Harbor performed by the US Army Corps of Engineers (USACE 1998; USACE 2001). The computer models RMA2 and SED2D were used to simulate hydrodynamics and sediment transport, respectively.

Methods

Hydrodynamic Model (RMA2)

RMA2 is a two-dimensional depth averaged finite element model that simulates free surface flow. The mesh size for this model ranged from 30 meters (98 feet) over most of the domain (from Cogeshall Bridge at the south to Wood Bridge at the north) to 5 meters (16 feet) in the vicinity of the dredging area (refer to Appendix K of the Pre-Design Field Test Report, Figure K-3). This model, used at the New Bedford Harbor in 1988, was calibrated to two sets of conditions: a spring high tide (March 1986), and a tide between mean high tide and mean spring tide (April 1986). The model was rerun in 2000 to study the potential impact of confined disposal facility construction on the hydrodynamics of New Bedford Harbor. The predicted water surface elevation at the Cogeshall Bridge was used to drive the new Upper New Bedford Harbor hydrodynamic model at the southern boundary, while the same freshwater inflow used in the initial model was used at the northern boundary.

Sediment Transport Model (SED2D)

The SED2D model was used to simulate sediment transport resulting from dredging activities. The model calculates suspended sediment concentration and change in bed elevation. For the application of the model to dredging it was assumed that the only sediment source was due to dredging operations, and the bed surface was assumed to be non-erodible due to waves, tidal currents, precipitation run-off etc.

Sediment source was defined as a constant input mass rate of sediment released in the water column at four mesh elements. The resolution of the model mesh in the dredging area is roughly 5 m (16 feet) square. The source was assumed to cover an area of four mesh elements at any time, an area approximately equal to that of the dredge moon pool (10 meters × 10 meters or 33 feet × 33 feet). The source strength was estimated from the expected production rate of 69 m^3/hr (90 yd^3/hr), and the fraction of sediment lost to the water column by the environmental bucket used (estimated 1 percent). Combining the production rate and the percent lost, the total sediment release rate to the water column was calculated to be about 482 kg/hr (1063 lb/hr).

The sediments were assumed to be composed of three main sediment fractions which were assumed to be non-cohesive with fall velocities calculated using Stokes' Equation, as shown in Table 466. Since the SED2D model can only simulate one sediment type at a time, each fraction was run independently, and the results were combined to obtain the total suspended solids concentration.

Model Parameters and Variables

In the absence of field measurements to calibrate the present model, a series of simulations were performed with dispersion coefficient values of 0.1, 1.0, 10 and 100 m^2/s (1, 11, 108, 1076 ft^2/s). It was confirmed that the dispersion coefficient had a major impact on the extent of the suspended sediment plume and predicted concentrations.

Results

The model was run with a constant sediment source at the point of dredging for two tide cycles, and the results for each sediment fraction were combined to predict the total suspended sediment concentration throughout Upper New Bedford Harbor at half-hour intervals. Modeled suspended sediment concentrations for flood tide and ebb tide are shown in the Pre-Design Field Test Report, Figures K-4 and K-5, respectively. Figure K-6 of the Pre-Design Field Test Report presents a time series of predicted suspended sediment concentration at specified distances north and south of the dredge, along with water surface elevations at the Cogeshall Street Bridge.

Numerous scenarios were considered with different combinations of dredge location within the test area, mass release rate, and dispersion coefficients. Predicted local suspended solids concentrations were greatest when the dredge was in the shallower waters (at the eastern end of the dredge area). However, far-field suspended solids levels were similar to those levels predicted to be present when dredging in deep waters. The peak concentration predicted (immediately adjacent to the sediment release/dredge location) decreased with increasing dispersion coefficients and varied from a maximum of about 390 mg/L for dispersion coefficient of 0.1 m^2/s (1 ft^2/s), to less than 5 mg/L for a coefficient of 100 m^2/s (1076 ft^2/s). The later value was within the variability of background measurements; therefore it was difficult to detect above ambient conditions. Table 47 presents the peak suspended sediment concentration predicted for different dispersion coefficient values. In all cases, the results predicted no re-suspended sediment transport under the Cogeshall Street Bridge to the Lower Harbor while the dredged operation within the designated Pre-Design Field Test area.

Comparison of Predictive Modeling and Field Measurements

The predictive transport of suspended solids using a dispersion coefficient of 10 m^2/s (108 ft^2/s) provided a reasonable match with the results of field monitoring. The model predicted a maximum elevation of suspended solids over background of 13 mg/L, and an elevation of 5 mg/L extending approximately 400 feet (122 m) down current. The suspended solids levels measured in the samples collected during the field test displayed some elevations above background that were slightly higher and extended further downstream than the predictions. In addition, the turbidity measurements and suspended solids data revealed much greater variability in the distribution of elevations than the model predictions of suspended solids. These differences between predictions and measured values are understandable given the following:

- Dredging source term differences – The model assumed a constant, steady source of sediment introduced to the water column while actual dredging proceeds at a highly variable pace. The model also assumes release of the sediment over the entire water column of the designated source cells. The actual release of material during the dredging process can be much more focused at a particular location (both x-y space in the depth).

- Additional source terms – The model did not include additional source terms from support activities in the area. In particular, the operation and grounding of the support vessel (shallow draft tender tug) Miami II during the monitoring period are thought to have contributed to some of the elevations noted in the suspended solids data.

Comparison of the model predictions with field measurements provided two additional insights that are important in planning additional modeling and monitoring efforts in the Upper Harbor:

- Three-dimensional flow field – Despite the shallowness of the Upper Harbor *(i.e.,* generally 1 to 4 feet), the field measurements revealed distinct variations in the flow field over depth. Although a two-dimensional simulation provides a reasonable approximation for overall circulation, consideration must be given to the vertical variation in flow when addressing transport issues.

- Environmental factors – Even the moderate winds that occurred during the field test had a measurable impact on the current regime. This highlights the importance of the use of field measurements to assess model predictions and sample collection locations on a daily basis.

6.2 Manistique River and Harbor, Michigan

The USACE RECOVERY model is employed to predict the temporal responses of surface water to contaminated sediment. This model is generally employed to simulate natural recovery of the river system. Input data to the RECOVERY model consists of sediment contaminant concentration data from the sediment mixed-layer and corresponding surface water concentrations. Output data consist of contaminant and water concentration concentrations over a projected period of time. For the Manistique River system, A second USACE model employed is the TGU (turbidity generating unit) model. This model projects the amount of suspended mass per unit volume that will result from dredging operations (*i.e.* resuspension). Typically, values of TGU range from 2 to 50 kg/m3 based various dredges and a variety of sediment bed types. This model assumes that the dredge operates within a volume of water (m3) and using a solid mass balance once can estimate the solids concentration in the water column surrounding the dredge assuming the use of permeable vertical barriers both upstream and downstream of the dredge. This set-up bases its analysis on the theory that the turbidity barriers will retain all solids while allowing water to pass through the area. This assumes that the solids must eventually settle out onto the stream body when the system reaches a steady state.

Once output is generated from the TGU model, the Equilibrium Model (EQUIL) is utilized. EQUIL is a chemical release model that determines chemical equilibrium between the particle bound solid and within the water column or aqueous phase. An end result of this model is an estimate of the soluble fraction partitioning from the resuspended solid and the constituent concentration in the dredged suspended sediment on the river bottom.

The combination of these three models was used to simulate the dredging operation at Manistique harbor. The RECOVERY model was used to simulate natural recovery following dredging (the pre-dredge condition) and the TGU/EQUIL models were used to predict the water concentration increase and the dredge suspended sediment deposit increase (*i.e.* residual from dredging). Lastly, the results from the TGU/EQUIL models were set as the starting or boundary condition into the RECOVERY model to simulate the post-dredge sediment and water quality conditions projected into the future or for a set period following the completion of dredging.

Results of the TGU/EQUIL model predicted a PCB water concentration during dredging of 460ng/L. In comparison, actual water quality samples collected during dredging in 1997 resulted in an average PCB concentration in the water column of 230ng/L and 81ng/L in 1998 or an overall average for these two dredge seasons of 170ng/L. With regard to sediment concentrations within the sediment mixed-layer following dredging, the model predicted sediment PCB concentrations would increase to 30 ppm immediately following dredging but assuming a natural depositional rate of 1 inch per year, the PCB concentration in the sediment reduced to 10 ppm in the year 2000 (two years after dredging), and to 0.012 ppm by the year 2020 (22 years after dredging). As indicated previously, the average PCB concentrations measured in the sediment following dredging in 1997 was 18.1 ppm while the average sediment PCB concentrations measured in the year 2000 by the FIELDS team following the completion of all dredging activities was 7.06 ppm. Thus, it can be concluded that the TGU/EQUIL model overestimated dredging resuspension and sediment residual concentrations following dredging activities.

7.0 Response to GE's Comments on Hudson River FS

7.1 Summary of GE's Conceptual Model and Results

In Appendix A (Assessment of Sediment Resuspension and PCB Release During Dredging Activities) of GE's comments on the FS (GE, 2001) Section 3.1, GE's consultants presented a conceptual model of the near-field dredging area. Their analysis assumed the following:

- The near-field area can be approximated as a CSTR
- Steady state condition exist in the near-field area
- Equilibrium partitioning between the suspended phase and dissolved phase PCB.

Using these assumptions GE concluded that significant losses of resuspended PCBs are expected. While the first two assumptions are reasonable, the third assumption does not accurately represent the PCB desorption kinetics of this system.

7.2 Kinetics of PCB Desorption: Literature Review

Recent studies have demonstrated that desorption of hydrophobic chemicals from sediments can be quite slow and that chemical equilibrium may not be a good approximation in many real situations. In a dredging scenario, the residence time (contact time) of the resuspended sediment in the water column is relatively short, on the order of hours. For this period of time, it is unlikely that PCB reaches equilibrium.

Many researchers showed evidence that desorption of contaminants takes place in at least two steps, a fast step and a slow step as discussed in Attachment C of this document. The desorption of PCBs from Hudson River sediments was studied by Brown (1981) and Carroll and co-workers (Carroll *et al.*, 1994). Brown developed and tested a method for the analysis of rates of PCB desorption from sediment suspended by dredging activities. The data used were taken from dredging operations in the Hudson River at the town of Fort Edward during 1977. The monitoring stations were placed in the east channel of Rogers Island. Brown used the Freundlich isotherms model to obtain the sinking and sorption-desorption rate constants of Aroclor 1016. In the report, the author used a term sinking rate constant for the first order decay settling coefficient. In this study, the sinking and sorption-desorption rates were chosen by trial and error method to fit the measured concentration of Aroclor 1016 during the low and high flow conditions. For low flow conditions, it was found that a sinking rate of -0.08 hr^{-1} and desorption rate constants ranging from 0.025 hr^{-1} to 0.05 hr^{-1} fitted the measured data well. Under the high flow conditions, a reasonable fit was obtained using a sinking rate of -0.4 hr^{-1} and desorption rate constants on the order of 1.0 hr^{-1}. Brown concluded that 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.

Carroll and co-workers studied desorption of PCBs from Hudson River sediment using XAD-4 resin as a PCB adsorbent. They used sediments contaminated with high, medium, and low levels of PCBs from the Hudson River near Moreau, NY. The three Hudson River sediment used in their study contained 25, 64, and 205 mg/kg (dry weight) PCBs with total organic carbon contents of 0.96, 3.43, and 4.59 percent, respectively. They reported that the PCBs present in the sediments consisted primarily mono- and di-chlorinated biphenyls (60-70 percent of total). Both a rapidly desorbing labile component and a more slowly desorbing resistant component were observed. Rate constants for the labile (fast) and resistant (slow) fractions were obtained using a model developed by Berens and Huvard (1981). For the purpose of our study, the desorption rate constant of the untreated moderately (64 mg/kg dry weight PCB) PCB-contaminated Hudson River sediment is considered. The desorption rate constant obtained from Carrol and co-workers study was approximately 0.018 hr^{-1} (refer to Table 5 in Attachment C).

Borglin and co-workers studied parameters affecting the desorption of hydrophobic organic chemicals from suspended sediments (Borglin *et al*., 1996). In their paper, Borglin and co-workers presented the results from the long-term experiments performed for three hydrophobic organic chemicals (hexachlorobenzene and two polychlorinated biphenyls). They concluded that the desorption times are on the order of a month to several years and they observed that the desorption rates are dependent on the particle/floc size and density distributions, the type of water, the amount of organic carbon in the sediments, the time of adsorption before desorption, and the chemical partition coefficient. Borglin and co-workers presented the results of the amount of PCBs (monochlorobiphenyl and hexachlorobiphenyl) desorbed over time. From these results, the rate constants obtain are on the order of 0.0049 hr^{-1} and 0.00042 hr^{-1} for monochlorobiphenyl and hexachlorobiphenyl, respectively.

Cornelissen and co-workers studied the desorption kinetics of chlorobenzenes, PAH, and PCBs for different contact times and solute hydrophobicity (Cornelissen *et al*., 1997). They used a technique employing Tenax TA® beads as “sink” for desorbed solute to measure the kinetics of desorption of the compounds mentioned above. For PCBs, they studied PCB-65 (2,3,5,6-tetrachlorobiphenyl) and PCB-118 (2,3’,4,4’,5-pentachlorobiphenyl). The sediment used was taken from Lake Oostvaardersplassen, The Netherlands. They observed two stages of desorption rates, the rapid release of the “labile” sorbed fraction and slow release of the “nonlabile” fraction. Two different contact times were considered in this study, 2 and 34 days. The desorption rate constants were varied for the different contact times for both the rapid and slow release. The values are summarized in Attachment C.

In 1999, ten Hulscher and co-workers studied desorption kinetics and partitioning of chlorobenzenes, PCBs, and PAHs in long term field contaminated sediment cores and top layer sediment (ten Hulscher *et al*., 1999). They concluded that the desorption from sediment was triphasic: fast, slow, and very slow. In this study, they used the sediment from Lake Ketelmeer, The Netherlands. Only core results were presented for PCB-28.

They reported the desorption rate constant for very slow fraction with values of 0.21×10^{-3} hr^{-1} and 0.19×10^{-3} hr^{-1}.

Ghosh and co-workers studied the relationship between PCB desorption equilibrium, kinetics, and availability during land biotreatment (Ghosh *et al*., 2000). For this purpose, they conducted a study of the equilibrium partitioning and desorption kinetics using industrial lagoon sediments containing 0.91 percent oil and grease as a function of biotreatment duration. A two compartment model was used to model the desorption of PCBs from sediment. Tri-, tetra-, penta-, and hexa-chlorobiphenyls desorption rate constants were reported. The values for the untreated sediment are summarized in Attachment C.

Recently, ten Hulschler and co-workers studied desorption kinetics of in-situ chlorobenzenes and 2,4,4'-trichlorobiphenyl (PCB-28) from River Rhine suspended matter in Lobith, The Netherlands (ten Huschler *et al*., 2002). They observed fast, slow and very slow desorption rates for PCB-28. Rate constants observed were on an average of 0.2 hr^{-1} for fast, 0.0004 hr^{-1} for slow, and 0.00022 hr^{-1} for very slow desorption rates.

7.3 CSTR-Chem Model

A near-field CSTR model (CSTR-Chem) was developed to understand the net effect of dredging on solids, fraction of dissolved PCB and total PCB flux. The model description, its application and sensitivity are presented in section 4.3 of this attachment. CSTR-Chem used a conservative rate of desorption of 0.2 hr^{-1}. This desorption rate was applied to the difference between the PCB concentration of the suspended sediments and the concentration that would be in equilibrium with the existing soluble PCB concentration. This formulation is consistent with the theory presented above.

Model simulations using CSTR-Chem suggest that the net fraction of dissolved PCB from dredging operations under river flows of 4,000 cfs, is approximately 0.03 percent. This net fraction of dissolved PCB of 0.03 percent was consistent for all near-field velocity and river depth values simulated in the sensitivity analysis. Therefore, negligible losses of PCBs are expected in the near-field dredging area.

8.0 Case Studies – Dissolve Phase Releases and Export Rates

Every Superfund site represents a unique setting, with different hydrologic and geological conditions, different discharge histories, and different contaminants. However, a study of other dredging sites can provide information on the conditions that may be encountered during this dredging project. In particular these other sites provide a basis to determine what distances are reasonable for monitoring, what export rates are achievable and what type of releases will occur. As the Hudson River PCBs Site is one of the largest Superfund sites, identical or near-identical conditions would not be expected at other sites. However, taken together, data from these other sites demonstrate the feasibility of achieving the individual components of the Hudson River remedy.

The previous examination of the export rates for the case studies in the Responsiveness Summary to the ROD (RS, USEPA, 2002) indicated:

- The range of resuspension rates modeled as the average source strengths (best engineering estimates) was reasonable. Furthermore, the data from the case studies indicated that the export rates estimated are likely to overestimate the anticipated export rate under routine conditions in the Hudson River.
- The releases observed at other sites have been predominately associated with the solids. As the solids are transported downstream dissolution will occur. The magnitude of the dissolution is dependent on the sediments concentrations, distance downstream and flow. The case studies with reliable split phase concentrations support the conclusion that dredging-related PCB releases are predominately solids.

Given the limitations of these case studies they are not used directly to infer the conditions that will occur during dredging in the Hudson River. Therefore, the Remedial Design should provide contingencies and dredging techniques to deal with site-specific factors.

8.1 Introduction

None of the case studies examined provide specific estimates for the conditions in the Hudson River. Rather, the studies presented evidence for:

- The range of export rates achieved and how the export rates can be accurately determined;
- The type of releases (i.e. solid or dissolved phase) that generally occur.

In the case studies reviewed, the monitoring plans, sediment concentrations/classifications, the nominal flows and weather conditions were different than those anticipated in the Hudson River. It is acknowledged that the case studies do not provide perfect templates, and therefore they were not used as such.

The three case studies examined in depth were New Bedford Harbor, Fox River, and Hudson Falls. Since these sites were examined previously for the Feasibility Study (USEPA, 2000a) and RS (USEPA, 2002), only new analyses or further clarification for each of these three sites is provided below. Other case studies were also examined, but either there was not enough information concerning resuspension or the conditions were too dissimilar to be relevant to the Hudson River PCBs Site; these are discussed briefly.

8.2 New Bedford Harbor, Massachusetts

The New Bedford Harbor Pre-Design Field Test dissolved phase releases were also discussed in Attachment C. The discussion provided here is specific to the modeling results presented in this attachment. The New Bedford Harbor Superfund Site is located in Bedford, Massachusetts, about 55 miles south of Boston. The site is contaminated with PCBs, heavy metals, and other organic chemicals from industrial discharges. Removal of PCB-contaminated sediments in hot spots located on the west side of the Acushnet River estuary was completed between April 1994 and September 1995. Dredging of the hot spots was performed using a hydraulic dredge, and the slurry was subsequently pumped into a confined disposal facility (CDF). Following the hot spot dredging, a pre-design field test using mechanical dredging equipment was performed in August 2000 and documented in the Pre-Design Field Test Final Report (USACE, 2001). During the Pre-Design Field Test the area directly around the dredge was referred to as the moonpool. At times oily sheens and oily slick releases were noticed. The report contains detailed information regarding the dredging operation, water quality monitoring for turbidity, particulate PCBs, dissolved PCBs, threshold water column levels, and contingency plans to be put in effect in the event that the action level was detected at one of the monitoring stations. Since the hot spot removal has been previously discussed in depth in the RS (USEPA, 2002), only the pre-design study is considered in this analysis.

Export Rate

A rough estimate of the PCB loading was provided in Attachment C. However due the lack of flow data, the results are not discussed any further in this attachment.

Dissolved Phase Release

In the Pre-design Field Report it was noted that New Bedford Harbor contains free oil phase PCBs as well as sediment-bound PCBs. For this analysis (and the analysis in the Performance Standard Report), the data from the oil releases and moonpool were not included since these samples represent a multiphase system, and multi-phase systems are not applicable to the lower PCB concentrations typical of the Hudson. Essentially, samples labeled as “oily sheen” or “oil slick” do not apply to the sediment resuspension processes anticipated for the Hudson. Exclusion of these oil-bearing samples provides a more consistent picture of the PCB release process at New Bedford Harbor.

In Figure 45, the total, suspended, and dissolved phase PCB concentrations are presented as a function of distance upstream and downstream of the dredging operations. For each

PCB form (total, suspended and dissolved), two plots are presented – one showing all data, and a second showing an expanded scale. In each case, samples within the "moonpool" around the dredging operation (0 distance from the dredge) show very high levels relative to baseline (i.e., upstream) conditions. These samples represent conditions in the immediate vicinity of the dredge. Examining the expanded scale graphs allows a comparison of the upstream and downstream conditions. In this comparison, it is clear that all three forms of PCB (total, dissolved, and suspended) increased downstream of the dredge, indicative of resuspension release. These conditions represent the near-field conditions referred to in the standard. However, it is also clear that the suspended matter concentration has increased substantially more than the dissolved phase, indicating that the primary form of the net PCB increase took place in suspended matter form, consistent with the analysis provided in the standard. The suspended matter concentration increased by more than 100 percent from approximately 500 ng/L to 1000-1500 ng/L. The dissolved phase increased form about 500 ng/L to about 750 ng/L or about 50 percent. The impact of the dredging related release can also be seen in Figure 46, which presents the fraction of the dissolved phase as a function of total PCB concentration and distance from the dredge. In the diagram comparing dissolved fraction to total PCB, there is a clear trend toward lower dissolved fractions as the total PCB concentration increases [i.e., the fraction of the Total PCB load in the dissolved fraction decreases as the Total PCB load (sum of dissolved and suspended) increases]. This trend correlates with the decrease in dissolved fraction PCB that occurs from upstream to downstream, as also shown in the figure. These data all support the assertion that PCB releases due to dredging occur primarily as a suspended matter release and thus can be tracked in the near field by suspended matter or possibly turbidity measurements. This also shows that PCBs enter the water column as suspended matter, a process that is independent of the baseline dissolved phase PCB concentration.

Subsequent to the resuspension, greater dissolution of PCBs takes place but the elevated PCB suspended matter fraction remains, indicating that it is possible to track PCB releases by suspended matter or turbidity. Additionally, as shown in Figure 45, the total PCB concentrations increased by roughly 1,000 ng/L or about 100 percent. Of the 1000 ng/L increase, roughly 750 ng/L is particle-borne and 250 ng/L is dissolved phase-borne. This corresponds to an increase in TSS of roughly 100 percent, consistent with the PCB gain. This TSS signal would be readily detected by the monitoring scheme required for the standard. Notably, the dissolved baseline PCB concentrations, while elevated at 500 ng/L, are not so far above those typically found in the Hudson during peak summer time conditions (150 to 200 ng/L). Thus, similar behavior of PCBs is expected in the Hudson with respect to the downstream distribution on dissolved and suspended matter fractions.

Results

As noted, the Pre-Design Field Test was not used to estimate the magnitude of dredging related PCB releases. Only the nature of the releases was examined. Nonetheless the data clearly show elevated mean concentrations of PCBs downstream of the dredge, regardless of the downstream distance. Additionally, the data show increased mean PCB concentrations on the suspended matter, as well as an increase in suspended solids at all points downstream (see Figure 47). The examination of these data shows that the suspended solids would be clear indicators of the PCB releases and that the dredging-related PCB releases are predominately from solids.

8.3 Fox River SMU 56/57 1999 And 2000 Dredging Projects, Wisconsin

The Fox River sediment management unit (SMU) 56/57 is located along the Fox River adjacent to the Fort James Plant. This river system is part of the Great Lakes Area of Concern. Approximately 80,000 cy of PCB-contaminated sediment were targeted for removal using a hydraulic cutter head dredge. After one week of dredging activities, the dredge was switched to an IMS 5012 Versi dredge in attempt to increase the solids content of the dredge slurry. The dredge was upgraded two more times during the first month of dredging in an attempt to meet an optimum production rate of 200 cy/hr. The Fox River SMU 56/57 was divided into 100 x 100 foot subunits. Dredging was conducted from August 1999 to December 1999. It was determined at the end of Phase I (December 1999) that unacceptably high residuals were left in the area dredged due to mounds of sediment left behind between dredge passes. As a result, the dredging equipment was switched to a horizontal auger dredge for Phase II, which was carried out from late August 2000 to the end of November 2000. Phase I subunits were re-dredged to meet a 1 ppm PCB residual concentration. The activities were documented in the Final Summary Report for Sediment Management Unit 56/57 (September 2000) and the Environmental Monitoring Report (July 2000). The reports contain information regarding water quality monitoring, PCB water column levels and loading, turbidity measurements, and post-dredge sampling. Since, the export rate was estimated in the Responsiveness Summary (RS, USEPA 2002) the discussion below only discusses why the export estimation is likely an overestimate of the conditions anticipated during dredging in the Hudson.

Export Rate

The export rate determined for the Fox River site is not directly applicable to the export rates anticipated in the Hudson due to difference in the monitoring locations, dredge type used, and sampling technique. However, the Fox River export estimate obtained is within the range considered in the performance standard criteria.

As noted in the Resuspension White Paper in the RS (USEPA, 2002), the Fox River studies were complicated by the location of the monitoring stations. The fact that significant loss of PCBs only occurred when the dredging area was close to the sampling cross-section suggests that settling of any resuspended matter occurs within a short distance of the dredging operation. Only when the monitoring location was close to the dredging could this signal be detected. This suggests that the loads obtained by this study do not represent PCB released for long-distance transport. Rather, the PCBs appear to be quickly removed from (settle out of) the water column a short distance downstream. As such, it is inappropriate to use these results to estimate downstream transport from a dredging site.

Furthermore, as discussed in the white paper, the higher resuspension rates may also be a result of the dredge used in these operations. In fact, the New Bedford pilot study compared the sediment resuspension characteristics of a horizontal auger dredge (used in Fox River) with a conventional hydraulic cutterhead suction dredge and found a disparity similar to that observed between the Fox River and average source strength estimates.

The sample compositing may not have been performed in such a manner as to account for flow. As noted it the Resuspension White Paper in the RS:

The sample compositing strategy [of the Fox River Studies], designed to reduce the number and cost of PCB analyses, was contrary to the mass flux analysis attempted. The equal volume composites do not allow consideration of flow variation across the cross-section. USGS (2000) states that stagnant areas and even reversed flows were observed during sampling operations, confirming the errors associated with the composite PCB samples. The TSS sample composites induce less error and provide a more accurate estimate of downstream TSS flux, yet they showed an unexplained decrease in suspended sediment across the dredging operation. The decrease is almost certainly an artifact associated with compositing equal volume samples from 20 percent and 80 percent depth. Even though it has long been established that velocity measurements from these depths represent the average velocity in an open channel, there is no justification for suggesting that a composite sample from these depths represents the average concentration along the profile. This is particularly true in deeper water where the two samples represent 25 feet or more of water depth. (USEPA, 2002)

As discussed previously in the Responsiveness Summary for the ROD (USEPA, 2002), Attachment C, there were several reasons why the field estimates for Fox River were considered overestimations. The most significant of these is that the proximity of the monitoring locations to the dredging operations did not allow for export to be reliably calculated. The sampling locations were located too close to the operations, and therefore export estimates from these samples did not account for settling. In addition, the samples taken in the cross-sections were not composited in a manner representative of the entire load. Despite these reservations, a rate of loss equivalent to 2.2 percent was obtained from the previous analysis. It should be noted that a short-term (days to weeks) export rate of 2.2 percent would not cause exceedances of the Resuspension Standard (i.e., 500 ng/L) in any of the river sections. Furthermore, the models indicate that a release of 2.2 percent would only represent a concern for the 350 ng/L Total PCB criterion in River Section 2 due to the higher sediment concentrations. However, according to the modeling this resuspension rate would represent loads greater than 600 g/day Total PCB, thus prompting additional sampling and possibly additional engineering controls if these levels are sustained. Ultimately, the Resuspension Standard has been designed to allow for occasional large loads without prompting immediate cessation of the operation.

Dissolved Phase Release

It is unclear how much time elapsed between sample collection and separation of the sample into dissolved and particulate fractions, confounding conclusions with regard to dissolved and suspended loads. The data provide evidence of this lag in separations. As noted in the RS, the data are not consistent with a large dissolved phase release based on the lack of change in PCB congener pattern across the dredging area. A large dissolved-phase PCB contribution from the sediments, either by porewater displacement or sediment-water exchange, should yield a gain whose PCB congener pattern is similar to that of the filter supernatant. The fact that the congener pattern is unchanged across the study area suggests a direct sediment addition. Yet the TSS data do not document an increase in suspended sediment concentrations. Please refer to the Resuspension White Paper in the RS (USEPA, 2002) for further details.

Results

The measurements provided in the Fox River report are not applicable or appropriate for use directly in the Resuspension Performance Standard for a variety of reasons. As noted in the Resuspension White Paper in the RS, the Fox River study was complicated by the location of the monitoring stations. In this case study there was a paper mill close by that significantly affected the monitoring results. Furthermore,

The fact that significant loss of PCBs only occurred when the dredging area was close to the sampling cross-section suggests that settling of any resuspended matter occurs within a short distance of the dredging operation. Only when the monitoring location was close to the dredging could this signal be found. This suggests that the loads obtained by this study do not represent PCB released for long-distance transport. Rather, the PCBs appear to be quickly removed from the water column a short distance downstream. As such, it is inappropriate to use these results to estimate downstream transport from a dredging site. (USEPA, 2002)

The data are not particularly useful for analysis of the PCB release mechanisms during dredging either, since the times lag prior to phase separation of the split samples may have allowed for further dissolution between the phases. Despite the analysis performed in the Resuspension Standard Report as well as previous reports suggesting no significant dissolved release will exist at the dredge, the resuspension criteria do not rely on this (i.e., assuming that the dissolved phase releases are small relative to the suspended phase). The criteria downstream are for total PCBs, both dissolved and particulate, and therefore releases in either phase (dissolved or suspended) will be detected.

8.4 Hudson Falls

Hudson River sediments were removed from the vicinity of the GE pump house near Hudson Falls. Sediments in this area contained high levels of PCBs, as well as pure PCB oil. Dredging was accomplished by diver-directed suction hoses over a total period of about seven months (October through December, 1977, and August through November, 1998). During this period, GE conducted its regular monitoring at Bakers Falls and Rogers Island, which can be used to estimate the effects of dredging to the downstream. Since the original analysis of the export rate was provided in the previous analysis (USEPA, 2002), the following discussion is only provided to further clarify the conservative assumptions incorporated in that analysis.

Export Rate

In the Hudson Falls dredging project, PCBs were present in the non-aqueous phase liquid (NAPL) form as well as on sediments. The presence of this NAPL PCB has the potential to escape on its own or to supersaturate the water column. As a result, the anticipated release and export rates should be higher than that expected from sediment resuspension alone. The mass of sediment removed from Hudson Falls was provided by the NYSDEC and the average PCB concentrations were taken from cores in the dredged area. Even if the calculations of the mass were off by a factor of two, the export rate would still be less than 1 percent. PCB export at this rate would not exceed the Resuspension Standard in any river section, based on the modeling analysis Furthermore the export rates estimated for the Hudson Falls site represent upper bounds on the losses due to dredging because of the historical sources between Bakers Falls and Rogers Island, (i.e., the Hudson Falls and Fort Edward facilities). While the baseline is considered relatively well constrained as a result of controls implemented by GE at Hudson Falls, the addition of PCBs by the GE facilities was still occurring at the time, thus potentially adding to the total load and yielding an overestimate of the export from the Hudson Falls site. Overall, the conditions noted for the Hudson Falls dredging project suggest that the conditions experienced were likely to have been much worse than those to be anticipated for this dredging project. The means of estimating loads represents a conservative approach and thus provides a useful upper bound on the actual PCB export. For these reasons it was a useful site for inclusion in the analysis for the resuspension standard.

Dissolved Phase Release

Split phase data were not available for this site.

Results

Since the export rate estimations for the Hudson Falls dredging operations were based on conservative assumptions, it is likely that the export rate has been overestimated.

8.5 Other Sites

Data from Fox River Area N and Manistique Harbor were not used for comparison to the modeled dissolved phase release and export rates based on the project size as well as the application of a dredging technology that was deemed inappropriate for the Hudson and unlikely to be used (based on its apparent loss rate). For the Fox River Area N study only slightly more than 100 lbs of PCBs were removed, suggesting that operations were too small to become routine. Much of the loss may have been associated with start-up. It is likely that the larger project on the Fox River (Areas 56/57 with nearly 1,500 lbs of PCBs removed) is more reflective of the dredging related losses even though these are probably overestimated as well. The data for Manistique are not available, however it is known that dredging at Manistique was primarily accomplished with a cable arm bucket dredge (although other dredges were used as well). In the dredged locations, extensive areas of dense, coarse sediments and debris inhibited the effectiveness of the dredge bucket. The cable arm bucket is designed to dredge soft sediments and does not perform as well where either consolidated materials or debris are present. Thereby, the Remedial Design will have to consider the type of dredge as well as the other engineering contingencies, particularly in areas identified as likely to resuspend.

8.6 Conclusions

The export rates obtained from the case studies are not directly applicable for comparison to the resuspension criteria since these represent daily averages and the criteria pertain to running averages. The long-term effects on the river will be dependent on the export rates downstream. The case studies exhibit that the monitoring stations should be sufficiently downstream to correctly measure the release rate (i.e., the load to the Lower Hudson River). As the near-field transport model of the Performance Standard Report and the Fox River case study indicated much of the TSS settle close to the dredging operations. It is likely that these solids will be removed as the dredge moves downstream.

Ultimately, these studies are not expected to be comprehensive templates for dredging on the Hudson since the conditions of dredging (operations, engineering contingencies, etc.) may have been different from those to be used on the Hudson River PCBs Site. The case studies are used to show that dredging operations at other sites (even in the Hudson) have had success with minimizing export through various techniques and engineering contingencies.

When taken together, these sites demonstrate a consistent level of site clean-up and resuspension release when viewed on a relative basis. The Resuspension Standard as developed for the Hudson River PCBs Site does not require greater degree of control for resuspension than that achieved by other remedial efforts at other sites.

9.0 References

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Tables

Table 1
Properties of Hudson River Sediments

	Non-cohesive sediments	**Cohesive sediments**
Typical location	Deeper areas and channel	Shallower areas
Fine sand or coarser (%)	80	35
Silt or finer (%)	20	65
Solids (%)	76	58
In-situ Density (gm/cc)	1.74	1.45
Organic content (%)	1 to 2	3 to 4
Average Particle Size	62 µm – 250 µm	< 1 µm to 62 µm
Particle Density	2.2- 2.6	2.2 –2.6

Table 2
Summary of Settling Velocities

Reference	Particle Density	Particle Size	V_s or w (cm/s)
Sequoia Scientific, Inc	Not Indicated	50 microns	0.01
		100 microns	0.1
		400 microns	0.005
DePinto *et al*, 1994	DePinto et al, 1994	20.7 microns	0.0124
	Passaic Valley Freshwater Sewage Sludge	22 microns	0.0022
Filtration & Separation.com, 2003	2.2 g/cc	100 microns	0.603
	2.6 g/cc	100 microns	0.789
	2.2 g/cc	400 microns	4.7
	2.6 g/cc	400 microns	5.8
Thonon and Van Der Perk, 2002	Not Indicated	10 microns	0.001
		50 microns	0.005
		100 microns	0.01
		400 microns	0.001-0.1
Kuo and Hayes, 1991	St. John's River 2.40 g/cc	39.6 microns	0.12
	Black Rock Harbor 2.39 g/cc	36.3 microns	0.1
	Thames River 2.50 g/cc	150 microns	1.84
		160 microns	2.1
Kuo *et al*, 1985	From paper: 2.65 g/cc	20 microns	3.59×10^{-2}
	HR: 2.2 g/cc	20 microns	0.026
	HR: 2.6 g/cc	20 microns	0.035
	HR: 2.2	100 microns	0.653
	HR: 2.6 g/cc	100 microns	0.871
	HR: 2.2 g/cc	400 microns	10.453
	HR: 2.6 g/cc	400 microns	13.938
USACE, 2001	Silt	20 microns	3.21×10^{-6}
	Clay	2 microns	3.21×10^{-8}
QEA, 1999	Silt	Based on cohesive Hudson River	0.005 to 0.01 (4-9m/day)

Table 3
Surface Water Elevation Slope in TI Pool based on USGS Gauge Data

Month	Monthly Average Elevation Difference (ft) including negative values	negative values treated as 0	Slope (6 mile distance)
3	1.05	1.05	3.00E-05
4	0.676	0.694	2.00E-05
5	0.416	0.436	1.00E-05
6	0.223	0.244	8.00E-06
7	0.151	0.169	5.00E-06
8	0.147	0.168	5.00E-06
9	0.166	0.185	6.00E-06
10	0.234	0.254	8.00E-06
11	0.336	0.349	1.00E-05
12	0.577	0.582	2.00E-05
Dredging period Average	0.239	0.258	8.00E-06

Table 4
Estimated Shear Velocity and Lateral Dispersion Coefficient for Upper Hudson River

RM	Flow (cfs)	Location	Depth (m)	Based on Water Elevation Slope		
				Slope	Shear Velocity (m/s)	Lateral Dispersion Coefficient (cm^2/s)
RM 193	2000	overall	2.4	8.00E-06	0.01	190
		west	0.9	8.00E-06	0.01	40
		center	3.5	8.00E-06	0.02	350
		east	2.4	8.00E-06	0.01	190
	4000	overall	2.6	8.00E-06	0.01	200
		west	1.1	8.00E-06	0.01	100
		center	3.7	8.00E-06	0.02	400
		east	2.6	8.00E-06	0.01	200
	5000	overall	2.7	8.00E-06	0.01	240
		west	1.2	8.00E-06	0.01	70
		center	3.9	8.00E-06	0.02	410
		east	2.7	8.00E-06	0.01	240
	8000	overall	3	8.00E-06	0.02	280
		west	1.6	8.00E-06	0.01	110
		center	4.2	8.00E-06	0.02	460
		east	3.1	8.00E-06	0.02	280
RM 190	2000	overall	2.9	8.00E-06	0.02	260
		west	3	8.00E-06	0.02	280
		center	4	8.00E-06	0.02	420
		east	1.7	8.00E-06	0.01	120
	4000	overall	3.1	8.00E-06	0.02	290
		west	3.2	8.00E-06	0.02	310
		center	4.2	8.00E-06	0.02	450
		east	1.9	8.00E-06	0.01	140
	5000	overall	3.2	8.00E-06	0.02	300
		west	3.3	8.00E-06	0.02	320
		center	4.3	8.00E-06	0.02	470
		east	2	8.00E-06	0.01	150
	8000	overall	3.5	8.00E-06	0.02	350
		west	3.6	8.00E-06	0.02	370
		center	4.6	8.00E-06	0.02	520
		east	2.3	8.00E-06	0.01	190

Table 5
Silt Fractions in Hudson River Sections

Section	Cohesive Sediment Fraction [1]	Non-Cohesive Sediment Fraction[1]	Silt Fraction[2]
1	0.37	0.63	0.37
2	0.62	0.38	0.48
3	0.62	0.38	0.48

Note:

1. Sediment in each river section is consisted of cohesive sediment and non-cohesive sediment.
   The sum of cohesive sediment fraction and non-cohesive sediment fraction is equal to 1.
2. It is assumed that the percentage of silt is 65% in the cohesive sediment and 20% in the non-cohesive sediment.
   Therefore, the silt fraction in Section 1 is 0.37*0.65+0.63*0.2 = 0.37 and in Section 2 and 3 is 0.65*0.62+0.2*0.38 = 0.48.

Table 6
Summary of CSTR-Chem Model simulation results for dredging operations in Section 1-3 of the Hudson River

		River Sections		
		Section 1	Section 2	Section 3
Ambient River Characteristics				
m_{in}	Ambient TSS - Silt (mg/L)	2.3	2.3	1.7
$c_{Total,in}$	Ambient PCB (ng/L)	122	76	57
$F_{d,in}$	Fraction Dissolved in BKG	0.9	0.9	0.92
Q	River flow (cfs)	4000	4000	4000
H	Water Depth (m)	1.88	1.88	1.88
u	Upstream velocity (m/s)	0.131	0.131	0.131
Dredging and Sediment Characteristics				
ν_1	Settling Velocity Silt (m/s)	0.00008	0.00008	0.00008
ν_2	Settling Velocity Sand (m/s)	0.06	0.06	0.06
F_{silt}	Fraction Sediment Silt	0.3665	0.479	0.479
c_{sed}	Sediment PCB (mg/Kg)	27	62	29
M dot R	Resuspension rate (kg/sec)	1	1	1
CSTR Conditions				
w_{nf}	width of the near field (m)	10	10	10
q_{nf}	CSTR flow (m^3/s)	2.4623	2.4623	2.4623
A_{nf}	Horizontal Area (m^2)	100	100	100
V_{nf}	CSTR Volume (m^3)	188.4	188.4	188.4
θ_{nf}	Retention time (s)	77	77	77
PCB Geochemistry				
K_d	Partition Coefficient (L/kg)	48309	48309	51151
k	Desorption Rate (1/hr)	0.2	0.2	0.2
Model Simulation Results				
Total TSS (Combined silt and coarse materials)				
m(dredge)	TSS from dredge	406	406	406
m(loss)	TSS lost to settling (mg/L)	183	151	151
m(out)	TSSout (mg/L)	226	258	257
Sediment Type 1 - Silt				
m(dredge)	TSS from dredge	149	195	195
m(loss)	TSS lost to settling (mg/L)	0	1	1
m(out)	TSSout (mg/L)	151	196	196

Table 6
Summary of CSTR-Chem Model simulation results for dredging operations in Section 1-3 of the Hudson River

Model Simulation Results (cont.)				
Sediment Type 2 – Coarse materials				
m(dredge)	TSS from dredge	257	212	212
m(loss)	TSS lost to settling (mg/L)	182	150	150
m(out)	TSSout (mg/L)	75	62	62
Equilibrium Conditions				
$C_{d,eq}$	Equilibrium Dissolved Conc (ng/L)	535	1218	541
$C_{s,eq}$	Equilibrium Suspended Conc (ng/L)	10552	24037	11293
$C_{p,eq}$	Equilibrium Particle conc (mg/kg)	25.8	58.9	27.7
$F_{d,eq}$	Equilibrium Dissolved Fraction	0.048	0.048	0.046
$F_{s,eq}$	Equilibrium Particulate Fraction	0.952	0.952	0.954
Transient Partitioning Conditions				
C_{Total}	Exiting Total Conc (ng/L)	6172	15966	7483
C_d	Exiting Dissolved Conc (ng/L)	111.6	73.3	54.5
C_s	Exiting Suspended Conc (ng/L)	6060	15893	7428
C_p	Exiting Particle Conc (mg/kg)	26.9	61.7	28.9
F_d	Exiting Fraction Dissolved	0.01808	0.00459	0.00729
F_p	Exiting Fraction Particulate	0.982	0.995	0.993
NET DREDGING Contribution				
$C_{Total,net}$	Net Total Conc (ng/L)	6050	15890	7426
$C_{d,net}$	Net Dissolved Conc (ng/L)	1.8	4.88	2.07
$C_{s,net}$	Net Suspended Conc (ng/L)	6048	15885	7424
$C_{p,net}$	Net Particle Conc (mg/kg)	27.1	62.2	29.1
TSS_{net}	Net TSS Conc (mg/L)	223	255	255
$F_{d,net}$	Net Fraction Dissolved	2.98E-04	3.07E-04	2.79E-04
$F_{p,net}$	Net Fraction Particulate	0.9997	0.9997	0.9997
$F_{silt,net}$	Net Fraction Silt Exiting	0.66	0.76	0.76

Table 7
Summary of Sensitivity of Model Outputs to Model Parameter Inputs

			Sensitivity Coefficient (S)			
Input Parameter	Range of Values	Model Default Value	Net Fraction Dissolved PCBs	Net Fraction Silt	Net PCB Flux	Net TSS Flux
River-wide Volumetric Flow (Velocity & Depth)	2000 - 8000 cfs	4000 cfs	0.14	0.16	0.16	0.16
			0.11	0.11	0.11	0.11
			0.1	0.11	0.11	0.11
Velocity (alone)	0.08 - 0.25 m/s	0.131 m/s	0.27	0.22	0.23	0.23
Depth (alone)	0.9 - 2.3 m	1.88 m	0.73	0.26	0.25	0.25
Near-Field Width	1 - 100 meters	10 meters	5.34	0.15	0.17	0.17
Resuspension Rate	0.5 - 40 kg/s	1 kg/s	0.25	<0.01	1	1
Sediment Silt Fraction	0 - 1	0.37 (Section 1)	0.46	0.52	0.47	0.47
		0.48 (Sections 2 & 3)				
Sediment PCB Concentration	1 - 1000 mg/kg	27 mg/kg (Section 1)	0.62	<0.01	1	<0.01
		62 mg/kg (Section 2)	0.33	<0.01	1	<0.01
		29 mg/kg (Section 3)	0.28	<0.01	1	<0.01
Dissolved Fraction in Background (& TSS Concentration in Background)[1]	0.15 - 1	0.9 (Sections 1 & 2)	0.16	<0.01	0.11	<0.01
		0.92 (Section 3)				
Partition Coefficient (& PCB Dissolved Fraction in Background)[2]	5E3 - 5E5 L/kg	4.8E4 (Sections 1 & 2)	2.95	<0.01	<0.01	<0.01
		5.1E4 (Section 3)				
Desorption Rate	1.6E-4 - 0.2 hr^{-1}	0.2 hr^{-1}	1	<0.01	<0.01	<0.01
Total PCB Concentration in Background	0 - 500 ng/L	122 ng/L (Section 1)	0.24	<0.01	<0.01	<0.01
		76 ng/L (Section 2)				
		57 ng/L (Section 3)				
Silt Settling Velocity	4.1 - 9 m/day	6.9 m/day (8E-5 m/s)	0	<0.01	<0.01	<0.01
Coarse Settling Velocity	0.03 - 0.08 m/s	0.06 m/s	0.25	0.26	0.27	0.27

Table 8
TSS-Chem Model Runs for the PCB 350 ng/L far-field Criterion with and without Dissolved PCBs from Dredging as Modeled by CSTR-Chem

River Section	Year	Dissolved PCBs from dredging (ng/L)	g (source strength) (kg/s)	SS Flux (1 mile) (kg/day)	TPCB Flux (1 mile) (g/day)	Fraction Dissolved (unitless)
Section 1	2007	0	3.052	60,593	1,684	0.09
Section 1	2007	1.89	3.052	60,593	1,684	0.09
Section 2	2009	0	1.669	37,841	2,466	0.14
Section 2	2009	5.06	1.669	37,841	2,466	0.14

Table 9
TSS-Chem Model Runs for the PCB 350 ng/L far-field Criterion with and without Coarse solids from Dredging as Modeled by CSTR-Chem

River Sectio	Year	Sediment Silt Fraction (unitless)	CSTR-Chem Resuspension Rate (kg/s)	Silt Fraction from dredging (unitless)	TSS-Chem source strength (kg/s)	Silt source strength (kg/s)	SS Flux (1 mile) (kg/day)	TPCB Flux (1 mile) (g/day)	Fraction Dissolved (unitless)
Section 1	2007	0.37	5.6	0.66	3.1	2.0	60,593	1,684	0.09
Section 1	2007	1	2.0	1	2.0	2.0	60,609	1,684	0.09
Section 2	2009	0.48	2.7	0.76	1.7	1.3	37,841	2,466	0.14
Section 2	2009	1	1.3	1	1.3	1.3	37,847	2,466	0.14

Table 10
Results for Average Source Strength Estimated Fluxes

	INPUT				TSS-Chem RESULTS				PERCENT LOSS	
	PCB Production rate kg PCB/day	Sediment production rate kg solids/day	Silt Fraction	SS Silt Source Strength (1,2) (kg/s)	Net TSS Flux at 1 mile (2) (kg/day)	Net Total PCB Flux at 1 mile (2) (g/day)	Net Fraction Dissolved PCBs at 1 mile unitless	Concentration increase at 1 mile (ng/l)	SS Loss at 1 mile %	PCB Loss at 1 mile %
River Section										
Section 1	57	2,099,921	0.37	0.077	2,303	78	0.35	14	0.11	0.14
Section 2	116	1,857,493	0.48	0.088	2,642	209	0.39	37	0.14	0.18
Section 3	45	1,563,927	0.48	0.074	2,225	81	0.40	14	0.14	0.18

Notes:

1. Source strengths apply to silt and finer particles only
2. Production rates are based on 7 days/week, 14 hours per day, 630 days in Section 1 and 210 days each in River Sections 2 & 3.
3. Values are based on river-wide volumetric flow of 4000 cfs.

Table 11
Increase in PCB Mass from Settled Material Estimated Using the TSS-Chem Model Results

			Increase in PCB Mass from Settled Material (g/sq. m)			Length Weighted Average Concentration (ppm)		
Management Level	Condition at Far Field Station	River Section	Target Area	Sides of Target Area	2-Acres Below the Target Area	Target Area	Sides of Target Area	2-Acres Below the Target Area
Evaluation	300 g/day PCB Mass Loss	1	0.9	6E-04	0.2	7.0	1.0	2.6
Control	600 g/day PCB Mass Loss	1	1.8	1E-03	0.5	12	1.0	4.2
Control	350 ng/L	1	3.9	3E-03	1.0	14	1.0	6.6
Evaluation	300 g/day PCB Mass Loss	2	0.6	4E-04	0.1	5.0	1.0	2.0
Control	600 g/day PCB Mass Loss	2	1.2	8E-04	0.3	10	1.0	3.3
Control	350 ng/L	2	4.7	3E-03	1.2	29	1.0	9.1
Evaluation	300 g/day PCB Mass Loss	3	0.6	4E-04	0.2	5.5	1.0	2.2
Control	600 g/day PCB Mass Loss	3	1.4	9E-04	0.4	10	1.0	3.5
Control	350 ng/L	3	5.6	4E-03	1.5	15	1.0	8.6

1. Mass/Area used to define the lateral extent of dredging in River Sections 1 and 2 is approximately 6.6 g/sq. m and 34 g/sq. m, respectively. In River Section 3, a mass/area was not used to select the areas in this way.

2. The length weighted average concentration was calculated assuming the concentration below the deposited PCBs is 1 ppm.

Table 12
TSS Average Concentration within the Plume at 300 m Downstream and under 8000 cfs Flow

Management Levels	River Section 1	River Section 2	River Section 3
350 ng/L	94	54	110
600 g/day	23	11	22

Table 13
Average Source Strength Estimated Fluxes and Concentrations for River Section 1 with Various Flows and Total PCB Sediment Concentrations

INPUT			TSS-Chem RESULTS				PERCENT LOSS	
Silt Sediment PCB Concentration (mg/kg)	Silt Fraction unitless	TSS Silt Source Strength (1,2) (kg/s)	Net TSS Flux at 1 mile (2) (kg/day)	Net Total PCB Flux at 1 mile (2) (g/day)	Net Fraction Dissolved PCBs at 1 mile unitless	Concentration increase at 1 mile (ng/l)	TSS Loss at 1 mile %	PCB Loss at 1 mile %
4000 cfs								
27	0.37	0.077	2,303	78	0.35	14	0.11	0.14
30	0.37	0.077	2,303	87	0.36	15	0.11	0.15
36	0.37	0.077	2,303	105	0.37	18	0.11	0.18
2000 cfs								
27	0.37	0.077	671	39	0.55	14	0.03	0.07
30	0.37	0.077	671	44	0.56	15	0.03	0.08
36	0.37	0.077	671	53	0.57	19	0.03	0.09
5000 cfs								
27	0.37	0.077	2,721	86	0.27	12	0.13	0.15
30	0.37	0.077	2,721	95	0.28	13	0.13	0.17
36	0.37	0.077	2,721	115	0.28	16	0.13	0.20

Table 14
Range of Values and Relative Sensitivities of Each Parameter

Input parameter		Range of Values	Default Value	Relative Model Sensitivity			
				Net Fraction Dissolved PCBs at 1 mile	Distance where coarse < 0.1%	Net PCB Flux at 1 mile	Net TSS Flux at 1 mile
River-wide Volumetric Flow (Velocity & Depth)	Q	2000-8000 cfs	4000 cfs	moderate	low	moderate	low
Velocity (alone)	u	0.08-0.25 m/s	0.131 m/s	moderate	moderate	moderate	low
Depth (alone)	h	0.9-2.3 m	1.88 m	low	moderate	moderate	moderate
Source Strength	g	0.01-40 kg/s	1 kg/s	moderate (high at low values of source strength)	none	high	high
Silt Fraction Entering	fsilt,sed	0-1	0.66 (Section 1)	moderate	low	high	high
Sediment PCB Concentration	Csed	1-1000 mg/kg	27 mg/kg (Section 1)	high (low at high concentrations)	none	high	none
Dissolved Fraction in Background (& TSS Concentration in Background)[1]	fd,bkg	0.31-0.97	0.9 (Sections 1)	low	none	low	none
Partition Coefficient (& PCB Dissolved Fraction in Background)[2]	Kd	5E3-5E5 L/kg	4.8E4 (Sections 1)	high	none	low	none
Desorption Rate	λ	1.6E-4 to 0.2 hr^{-1}	0.2 hr^{-1}	high	none	low	none
Lateral Dispersion (alone)	k(y)	1E-4 to 1E2	0.014 m^2/s	low (high at low coefficients)	none	low	low
Total PCB Concentration in Background	PCB(bkg)	0-500 ng/L	122 ng/L (Section 1)	low	none	low	none
Silt Settling Velocity	w(silt)	4.1-9 m/day	6.9 m/day (8E-5 m/s)	low	none	moderate	moderate
Coarse Settling Velocity	w(coarse)	0.03-0.08 m/s	0.06 m/s	low	high	low	none

Notes:

1. The dissolved PCB fraction in the background and the TSS concentration were varied, with Kd held constant at 5,500 L/kg.
2. The partition coefficient (Kd) and PCB dissolved fraction in the background was varied with TSS background concentration held constant at 2.3 mg/L.

Table 15
Effect on Model Output Values from Increase in Input Paramters

Input parameter		Effect on Net Fraction Dissolved PCBs at 1 mile	Effect on distance where coarse < 0.1%	Effect on Net PCB Flux at 1 mile	Effect on Net TSS Flux at 1 mile
River-wide Volumetric Flow (Velocity, Depth and Lateral Dispersion)	Q	Varies	Varies	Varies	Varies
Velocity (alone)	u	Decrease	Increase (linear)	Increase	Increase
Depth (alone)	h	Increase	Increase (linear)	Increase	Increase
Source Strength	g	Decrease	No Effect	Increase (linear)	Increase (linear)
Silt Fraction Entering	fsilt,sed	Decrease	Decrease	Increase (linear)	Increase (linear)
Sediment PCB Concentration	Csed	Increase	No Effect	Increase (linear)	No Effect
Dissolved Fraction in Background (& TSS Concentration in Background)[1]	fd,bkg	Increase	No Effect	Decrease	No Effect
Partition Coefficient (& PCB Dissolved Fraction in Background)[2]	Kd	Decrease	No Effect	Decrease	No Effect
Desorption Rate	λ	Increase	No Effect	Increase	No Effect
Lateral Dispersion (alone)	k(y)	Increase	No Effect	Increase	No Effect
Total PCB Concentration in Background	PCB(bkg)	Decrease (linear)	No Effect	Decrease (linear)	No Effect
Silt Settling Velocity	w(silt)	Increase (linear)	Increase	Decrease	Decrease
Coarse Settling Velocity	w(coarse)	No Effect	Decrease	No Effect	No Effect

Notes:

1. The dissolved PCB fraction in the background and the TSS concentration were varied, with Kd held constant at 5,500 L/kg.
2. The partiton coefficient (Kd) and PCB dissolved fraction in the background was varied with TSS background concentration held constant a
3. Due to the stepwise characteristic of the model (particularly with the distance to 0.1% coarse material), linearity was defined as an r-square greater than 99%.

Table 16
Average Sensitivity Values and Individual magnitudes

		Average $S_{parameter,output}$			
Input parameter		Net Fraction Dissolved PCBs at 1 mile	Distance where coarse < 0.1%	Net PCB Flux at 1 mile	Net TSS Flux at 1 mile
River-wide Volumetric Flow (Velocity & Depth)	Q	-0.51 (-)	0.69 (+/-)	0.32 (+/-)	0.37 (+/-)
Velocity (alone)	u	-0.71 (-)	0.97 (+)	0.43 (+)	0.52 (+)
Depth (alone)	h	0.17 (+)	1.07 (+)	0.57 (+)	0.61 (+)
Source Strength	g	-0.49 (-)	0	0.96 (+)	1 (+)
Silt Fraction Entering	fsilt,sed	-0.71 (-)	-0.72 (-)	0.96 (+)	1 (+)
Sediment PCB Concentration	Csed	0.9 (+)	0	1.02 (+)	0
Dissolved Fraction in Background (& TSS Concentration in Background)[1]	fd,bkg	0.27 (+)	0	-0.09 (+/-)	0
Partition Coefficient (& PCB Dissolved Fraction in Background)[2]	Kd	-0.93 (-)	0	-0.05 (-)	0
Desorption Rate	λ	0.87 (+)	0	0.03 (+)	0
Lateral Dispersion (alone)	k(y)	0.2 (+)	0	0.02 (+)	-5.44E-17 (+/-)
Total PCB Concentration in Background	PCB(bkg)	-0.23 (-)	0	-0.02 (-)	0
Silt Settling Velocity	w(silt)	0.33 (+)	0	-0.45 (-)	-0.53 (-)
Coarse Settling Velocity	w(coarse)	-0.0002 (-)	-1.25 (-)	-0.0009 (-)	0

Notes:

1. The dissolved PCB fraction in the background and the TSS concentration were varied, with Kd held constant at 5,500 L/kg.
2. The partition coefficient (Kd) and PCB dissolved fraction in the background was varied with TSS background concentration held constant at 2.3 mg/L.
3. The sign (+/-) indicates that the individual Sensitivity values were both positive and negative.

Table 17
Average Baseline Conditions at Thompson Island Dam

Month	Mean flow, q[1]	Mean baseline concentrations[2]		Mean baseline Load
	(cfs)	TSS (mg/L)	TPCB (ng/L)	(g/sec)
May	7,800	4	128	0.028
June	4,200	5	169	0.020
July	3,000	2	138	0.012
August	3,000	2	96	0.008
September	3,100	2	75	0.007
October	4,300	2	127	0.015
November	5,500	2	127	0.020
June - Nov Average[3]	3,900	2.3	122	0.014

Notes:

[1] Mean flow was estimated based on USGS flow data from 1977 to 2002 at Thompson Island Dam.

[2] TSS and TPCB values are arithmetic means obtained from the baseline analysis study. See Attachment A for detail analysis.

[3] Only June to November mean baseline concentrations were used. May was excluded since flow is not typical.

Table 18
Average Baseline Conditions at Schuylerville

Month	Mean flow, q[1]	Mean baseline concentrations[2]		Mean baseline load
	(cfs)	TSS (mg/L)	TPCB (ng/L)	(g/sec)
May	8,800	3	106	0.026
June	4,900	5	106	0.015
July	3,400	2	82	0.008
August	3,400	2	74	0.007
September	3,600	2	52	0.005
October	4,800	2	75	0.010
November	6,200	2	67	0.012
June - Nov Average[3]	4,400	2.3	76	0.009

Notes:

[1] Mean flow was estimated based on USGS flow data from 1977 to 2002 at Schuylerville

[2] TSS and TPCB values are arithmetic means obtained from the baseline analysis study. See Attachment A for detail analysis.

[3] Only June to November mean baseline concentrations were used. May was excluded since flow is not typical.

Table 19
Average Baseline Conditions at Waterford

Month	Mean flow, q[1]	Mean baseline concentrations[2]		Mean baseline load
	(cfs)	TSS (mg/L)	TPCB (ng/L)	(g/sec)
May	11,300	2	79	0.025
June	6,400	3	79	0.014
July	4,200	1	61	0.007
August	4,000	1	55	0.006
September	4,200	1	39	0.005
October	6,500	1	56	0.010
November	8,300	1	50	0.012
June - Nov Average[3]	5,600	1.7	57	0.009

Notes:

[1] Mean flow was estimated based on USGS flow data from 1977 to 2002 at Waterford

[2] TSS and TPCB values were obtained by multiplying a dilution factor based on drainage area ratio.
Drainage areas were obtained from USGS data. Drainage area for Schuylerville and Waterford is 4611 and 3440 ft^2, respectively.

[3] Only June to November mean baseline concentrations were used. May was excluded since flow is not typical.

Table 20
Daily Net Dredging Total PCB Flux for River Sections 1, 2, and 3 at the Monitoring Stations

Month	River Section 1 (TID)		River Section 2 (Schuylerville)		River Section 3 (Waterford)	
	Net Dredge TPCB Flux (14-hr basis) g/day	Net Dredge TPCB Flux (24-hr basis) g/day	Net Dredge TPCB Flux (14-hr basis) g/day	Net Dredge TPCB Flux (24-hr basis) g/day	Net Dredge TPCB Flux (14-hr basis) g/day	Net Dredge TPCB Flux (24-hr basis) g/day
May	2,500	4,200	3,000	5,200	4,400	7,500
June	1,100	1,900	1,700	2,900	2,500	4,200
July	900	1,600	1,300	2,300	1,700	3,000
August	1,100	1,800	1,300	2,300	1,700	2,900
September	1,200	2,100	1,500	2,600	1,900	3,200
October	1,400	2,300	1,900	3,200	2,700	4,700
November	1,700	3,000	2,500	4,300	3,600	6,100
June - Nov Average	***1,200***	2,100	***1,700***	2,900	***2,300***	4,000

Note:

Numbers are rounded to 2 significant digits

Bold italic numbers - values were used as the TPCB flux representing the 350 ng/L at the monitoring stations.

Table 21
HUDTOX Input for 350 ng/L with TSS Flux at 1 Mile Downstream of the Dredge-Head

Sediment removal season	Dredging Location	speed	Cubic yards of sediment removed[1]	Monitoring Location (Compliance Point)[2]	Sediment Total PCB concentration[3] (mg/kg)	Expected Total PCB export rate at compliance point[4] (g/day)	Percent remaining at the monitoring location[5]	TPCB input flux to HUDTOX (g/day)	Ratio of Total to Tri+ PCB[6]	Tri+ PCB Flux input to HUDTOX[7] (g/day)	TSS Flux input to HUDTOX[8] (kg/day)	HUDTOX Segment(s)
Jun. 1 - Sep. 15, 2006[9]	Sec. 1	half	260,000	TID	27	1,237	75%	1,649	3.2	520	58,800	5 & 7
May 1 - Nov. 30, 2007	Sec. 1	full	520,000	TID	27	1,237	75%	1,649	3.2	520	58,800	11 & 13
May 1 - Nov. 30, 2008	Sec. 1	full	520,000	TID	27	1,237	75%	1,649	3.2	520	58,800	20 & 22
May 1 - Aug. 15, 2009	Sec. 1 &	full	260,000	TID	27	1,237	75%	1,649	3.2	520	58,800	26 & 28
Aug. 16 - Nov. 30, 200	Sec. 2		290,000	Schuylerville	62	2,034	75%	2,712	3.4	670	34,300	30
May 1 - Aug. 15, 2010	Sec. 2 &	full	290,000	Schuylerville	62	2,034	75%	2,712	3.4	670	34,300	31
Aug. 16 - Nov. 30, 201	Sec. 3		255,000	Waterford	29	2,334	75%	3,112	2.7	1,150	104,500	38
May 1 - Aug. 15, 2011	Sec. 3	full	255,000	Waterford	29	2,334	75%	3,112	2.7	1,150	104,500	45

Notes:

[1] Volume of sediment removed is taken from Table 8-9 of the Feasibility Study.

[2] All TIP monitoring is done at TID, all River Section 2 monitoring is done at Schuylerville, and all River Section 3 monitoring is done at Waterford. 1 mile exclusion is not considered.

[3] Total PCB concentration in the sediment is for the dredge material and was taken from Table 363334-6 of the Sediment Inventory White Paper of the Resp. Summ.

[4] Total PCB Flux is the average net flux for June to Nov at the compliance point (TID, Schuylerville, & Waterford). PCB flux in May was excluded since flow is not typical.

[5] Percent reduction at the monitoring location was obtained from the initial HUDTOX runs performed for the preliminary draft of the resuspension performance standard

[6] Ratio of Total to Tri+ PCB is based on the amount of Total PCB and Tri+ PCB removed for each river section (USEPA 2002).

[7] Tri+ PCB flux is calculated based on the Total PCB flux 1 mile downstream of the dredgehead divided by the ratio of Total to Tri+ PCB for each section.

[8] TSS flux from TSS-Chem model, 1 mile downstream of the dredge-head

[9] Actual dredging period is from May 1 - Nov. 30, 2006. The PCB and TSS flux is loaded only from June 1 to Sep. 15, 2006 to account for half speed operation.

Table 22
TSS Flux Comparisons for Different Scenarios

Sediment removal season	Dredging Location	speed	Cubic yards of sediment removed	Monitoring Location (Compliance Point)[1]	Full TSS Flux[2] (kg/day)	TSS Flux[3] @ 1 mile (kg/day)	TSS Flux[3] @ 3 mile (kg/day)	TSS Flux[4] @ 1 mile with corrected percent reduction (kg/day)
Jun. 1 - Sep. 15, 2006[5]	Sec. 1	half	260,000	TID	60,602	58,800	51,200	61,030
May 1 - Nov. 30, 2007	Sec. 1	full	520,000	TID	60,602	58,800	51,200	60,575
May 1 - Nov. 30, 2008	Sec. 1	full	520,000	TID	60,602	58,800	51,200	53,423
May 1 - Aug. 15, 2009	Sec. 1 &	full	260,000	TID	60,602	58,800	51,200	45,599
Aug. 16 - Nov. 30, 2009	Sec. 2		290,000	Schuylerville	36,595	34,300	26,500	37,814
May 1 - Aug. 15, 2010	Sec. 2 &	full	290,000	Schuylerville	36,595	34,300	26,500	32,242
Aug. 16 - Nov. 30, 2010	Sec. 3		255,000	Waterford	107,575	104,500	98,400	106,675
May 1 - Aug. 15, 2011	Sec. 3	full	255,000	Waterford	107,575	104,500	98,400	82,308

Notes:

[1] All TIP monitoring is done at TID, all River Section 2 monitoring is done at Schuylerville, and all River Section 3 monitoring is done at Waterford. 1 mile exclusion is not considered.

[2] TSS flux using the concentrations of the dredged sediment in each section of the river

[3] TSS flux is obtained from TSS-Chem model output.

[4] TSS flux is obtained from TSS-Chem model output at 1 mile with corrected percent reduction at the monitoring stations.

[5] Actual dredging period is from May 1 - Nov. 30, 2006. The PCB and TSS flux is loaded only from June 1 to Sep. 15, 2006 to account for half speed operation.

Table 23
HUDTOX Input for 350 ng/L with TSS Flux at 1 Mile Downstream of the Dredge-Head and Corrected Percent Reduction at the Monitoring Stations

Sediment removal season	Dredging Location	speed	Cubic yards of sediment removed[1]	Monitoring Location (Compliance Point)[2]	Sediment Total PCB concentration[3] (mg/kg)	Expected Total PCB export rate at compliance point[4] (g/day)	Percent remaining at the monitoring location[5]	TPCB input flux to HUDTOX (g/day)	Ratio of Total to Tri+ PCB[6]	Tri+ PCB Flux input to HUDTOX[7] (g/day)	TSS Flux input to HUDTOX[8] (kg/day)	HUDTOX Segment(s)
Jun. 1 - Sep. 15, 2006[9]	Sec. 1	half	260,000	TID	27	1,237	73%	1,697	3.2	530	61,030	5 & 7
May 1 - Nov. 30, 2007	Sec. 1	full	520,000	TID	27	1,237	73%	1,684	3.2	526	60,575	11 & 13
May 1 - Nov. 30, 2008	Sec. 1	full	520,000	TID	27	1,237	83%	1,490	3.2	466	53,423	20 & 22
May 1 - Aug. 15, 2009	Sec. 1 &	full	260,000	TID	27	1,237	97%	1,278	3.2	399	45,599	26 & 28
Aug. 16 - Nov. 30, 200	Sec. 2		290,000	Schuylerville	62	2,034	82%	2,466	3.4	725	37,814	30
May 1 - Aug. 15, 2010	Sec. 2 &	full	290,000	Schuylerville	62	2,034	96%	2,117	3.4	623	32,242	31
Aug. 16 - Nov. 30, 201	Sec. 3		255,000	Waterford	29	2,334	74%	3,150	2.7	1,167	106,675	38
May 1 - Aug. 15, 2011	Sec. 3	full	255,000	Waterford	29	2,334	96%	2,441	2.7	904	82,308	45

Notes:

[1] Volume of sediment removed is taken from Table 8-9 of the Feasibility Study.

[2] All TIP monitoring is done at TID, all River Section 2 monitoring is done at Schuylerville, and all River Section 3 monitoring is done at Waterford. 1 mile exclusion is not considered.

[3] Total PCB concentration in the sediment is for the dredge material and was taken from Table 363334-6 of the Sediment Inventory White Paper of the Resp. Summ.

[4] Total PCB Flux is the average net flux for June to Nov at the compliance point (TID, Schuylerville, & Waterford). PCB flux in May was excluded since flow is not typical.

[5] Percent remaining at the monitoring location was obtained from the initial HUDTOX runs performed for the preliminary draft of the resuspension performance standard

[6] Ratio of Total to Tri+ PCB is based on the amount of Total PCB and Tri+ PCB removed for each river section (USEPA 2002).

[7] Tri+ PCB flux is calculated based on the Total PCB flux 1 mile downstream of the dredgehead divided by the ratio of Total to Tri+ PCB for each section.

[8] TSS flux from TSS-Chem model, 1 mile downstream of the dredge-head

[9] Actual dredging period is from May 1 - Nov. 30, 2006. The PCB and TSS flux is loaded only from June 1 to Sep. 15, 2006 to account for half speed operation.

Table 24
HUDTOX Schedule and Input Loading for 300 g/day Export Rate Scenario

River Section	Dredging Season	Monitoring Station	Tri+ PCB Flux input to HUDTOX[1] (g/day)	TSS Flux input to HUDTOX[2] (kg/day)	TPCB input flux to HUDTOX[3] (g/day)	Percent remaining at the monitoring location[4]	Expected Total PCB at monitoring station[5] (g/day)
Section 1 dredging	May 1-Nov 30, 2006	TID	129	13,948	411	73%	300
	May 1-Nov 30, 2007	TID	128	13,828	408	73%	300
	May 1-Nov 30, 2008	TID	113	12,130	361	83%	300
	May 1-Aug 15, 2009	TID	97	10,311	310	97%	300
Section 2 dredging	Aug 16 - Nov 30, 2009	Schuylerville	107	4,873	364	82%	300
	May 1 - Aug 15, 2010	Schuylerville	92	4,118	312	96%	300
Section 3 dredging	Aug 16 - Nov 30, 2010[3]	Waterford	150	12,725	405	74%	300
	May 1 - Aug 15, 2011	Waterford	116	9,702	314	96%	300

Notes:

[1] Tri+ PCB flux is calculated by dividing the TPCB flux with the Total to Tri+ PCB ratio estimated in the RS. The ratio is 3.2 for Section 1, 3.4 for Section 2, and 2.7 for Section 3

[2] TSS flux from TSS-Chem model, 1 mile downstream of the dredge-head

[3] Total PCB input is based on the expected flux at monitoring locations divide by the percent reduction. Same as Gaussian plume output at 1 mile.

[4] Percent remaining at the monitoring location was obtained from the initial HUDTOX runs performed for the preliminary draft of the resuspension performance standard

[5] Expected net export rate of TPCB flux at monitoring station (300 g/day).

Table 25
HUDTOX Schedule and Input Loading for 600 g/day Export Rate Scenario

River Section	Dredging Season	Monitoring Station	Tri+ PCB Flux input to HUDTOX[1] (g/day)	TSS Flux input to HUDTOX[2] (kg/day)	TPCB input flux to HUDTOX[3] (g/day)	Percent reduction at the monitoring location[4]	Expected Total PCB at monitoring station[5] (g/day)
Section 1 dredging	May 1-Nov 30, 2006	TID	257	28,975	823	73%	600
	May 1-Nov 30, 2007	TID	255	28,676	817	73%	600
	May 1-Nov 30, 2008	TID	226	25,179	723	83%	600
	May 1-Aug 15, 2009	TID	194	21,582	620	97%	600
Section 2 dredging	Aug 16 - Nov 30, 2009	Schuylerville	214	10,379	728	82%	600
	May 1 - Aug 15, 2010	Schuylerville	184	8,799	625	96%	600
Section 3 dredging	Aug 16 - Nov 30, 2010	Waterford	300	26,398	810	74%	600
	May 1 - Aug 15, 2011	Waterford	232	20,193	627	96%	600

Notes:

[1] Tri+ PCB flux is calculated by dividing the TPCB flux with the Total to Tri+ PCB ratio estimated in the RS. The ratio is 3.2 for Section 1, 3.4 for Section 2, and 2.7 for Section 3

[2] TSS flux from TSS-Chem model, 1 mile downstream of the dredge-head

[3] Total PCB input is based on the expected flux at monitoring locations divide by the percent reduction. Same as Gaussian plume output at 1 mile.

[4] Percent reduction at the monitoring location was obtained from the initial HUDTOX runs performed for the preliminary draft of the resuspension performance standard

[5] Expected net export rate of TPCB flux at monitoring station (600 g/day).

Table 26
Percent Reduction at the Monitoring Locations Comparison for the 350 ng/L Scenario

River Section	Dredging Season	Monitoring Station[1]	d006 percent remaining[2]	d007 percent remaining[3]	sr03 percent remaining[4]	sr04 percent remaining[5]
Section 1 dredging	May 1-Nov 30, 2006	TID	73%	74%	82%	73%
	May 1-Nov 30, 2007	TID	73%	74%	85%	73%
	May 1-Nov 30, 2008	TID	83%	83%	91%	83%
	May 1-Aug 15, 2009	TID	97%	97%	99%	97%
Section 2 dredging	Aug 16 - Nov 30, 2009	Schuylerville	82%	84%	92%	83%
	May 1 - Aug 15, 2010	Schuylerville	96%	97%	99%	96%
Section 3 dredging	Aug 16 - Nov 30, 2010	Waterford	74%	75%	85%	71%
	May 1 - Aug 15, 2011	Waterford	96%	96%	99%	95%

Notes:

[1] All TIP monitoring is done at TID, all River Section 2 monitoring is done at Schuylerville, and all River Section 3 monitoring is done at Waterford. 1 mile exclusion is not considered.

[2] d006 is the 350 ng/L model run with TSS and TPCB flux at 1 mile downstream of the dredge-head obtained from TSS-Chem.

[3] d007 is the 350 ng/L model run with TSS and TPCB flux at 3 mile downstream of the dredge-head obtained from TSS-Chem.

[4] sr03 is the 350 ng/L model run without any TSS flux associated with the TPCB flux.

[5] sr04 is the 350 ng/L model with TSS and TPCB flux at 1 mile downstream of the dredge-head and corrected percent reduction.

Table 27
Expected versus Model Prediction of PCB Flux for Control Level 3 - 350 ng/L Scenario

River Section	Dredging Season	Monitoring Station	Total PCB @ monitoring station				
			Expected (g/day)[2]	d006 - model estimate[3] (g/day)	d007 - model estimate[4] (g/day)	sr03 - model estimate[5] (g/day)	sr04 - model estimate[6] (g/day)
Section 1 dredging	May 1-Nov 30, 2006	TID	1237	1213	1224	1360	1234
	May 1-Nov 30, 2007	TID	1237	1222	1233	1410	1244
	May 1-Nov 30, 2008	TID	1237	1381	1389	1519	1252
	May 1-Aug 15, 2009	TID	1237	1611	1615	1653	1245
Section 2 dredging	Aug 16 - Nov 30, 2009	Schuylerville	2034	1879	1909	2097	2049
	May 1 - Aug 15, 2010	Schuylerville	2034	2189	2200	2261	2029
Section 3 dredging	Aug 16 - Nov 30, 2010	Waterford	2334	2276	2290	2619	2223
	May 1 - Aug 15, 2011	Waterford	2334	2969	2974	3083	2302

Notes:

[1] Output loading from HUDTOX d006 run at the assigned monitoring station.

[2] Total PCB flux at the monitoring station based on max concentration of 350 ng/L minus baseline concentrations.

[3] d006 is the 350 ng/L model run with TSS and TPCB flux at 1 mile downstream of the dredge-head obtained from TSS-Chem.

[4] d007 is the 350 ng/L model run with TSS and TPCB flux at 3 mile downstream of the dredge-head obtained from TSS-Chem.

[5] sr03 is the 350 ng/L model run without any TSS flux associated with the TPCB flux.

[6] sr04 is the 350 ng/L model with TSS and TPCB flux at 1 mile downstream of the dredge-head and corrected percent reduction.

Table 28
Annual Tri+ PCB Load Over TID

Year	MNA (p3nas2)	No Resuspension (d004)	Total PCB 350 ng/L @ 1 mile (d006)	Total PCB 350 ng/L @ 3 mile (d007)	Total PCB 350 ng/L fraction remaining adjusted (sr04)	Total PCB 350 ng/L with no Solids (sr03)	Total PCB 600g/day (sr01)	Total PCB 300 g/day (sr02)	Accidental Release (srA1)
	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load
2005	0	0	0	0	0	0	0	0	0
2006	57	56	97	97	98	102	77	67	77
2007	114	106	228	230	231	246	169	138	169
2008	152	133	348	349	341	374	237	185	237
2009	190	154	423	425	405	452	279	217	279
2010	241	180	450	452	431	478	305	244	305
2011	284	203	474	475	455	501	328	266	328
2012	325	224	495	497	477	523	350	288	350
2013	365	246	517	519	498	545	371	309	371
2014	398	264	536	538	517	564	390	328	390
2015	429	282	554	556	535	582	408	346	408
2016	454	297	569	571	550	597	423	361	423
2017	476	311	583	586	564	612	437	375	437
2018	503	327	599	601	580	627	453	391	453
2019	524	340	612	614	593	641	466	404	466
2020	546	354	626	629	607	655	480	418	480
2021	567	368	640	642	621		494		494
2022	584	380	652	655	633		506		506
2023	601	392	664	666	644		518		518
2024	622	405	677	680	658		531		531
2025	639	417	689	692	670		543		543
2026	656	429	701	704	682		555		555
2027	671	440	712	715	693		566		566
2028	686	452	724	727	705		578		578
2029	702	463	735	738	716		589		589
2030	716	475	747	750	728		601		601
2031	732	486	758	761	739		612		
2032	747	497	769	772	750		623		
2033	760	508	780	783	761		634		
2034	774	519	791	794	771		645		
2035	787	529	801	804	782		656		
2036	801	540	812	815	793		666		
2037	814	551	823	826	803		677		
2038	826	561	832	836	813		687		
2039	841	571	843	846	824		698		
2040	852	581	853	856	834		707		

Table 28
Annual Tri+ PCB Load Over TID

Year	MNA (p3nas2)	No Resuspension (d004)	Total PCB 350 ng/L @ 1 mile (d006)	Total PCB 350 ng/L @ 3 mile (d007)	Total PCB 350 ng/L fraction remaining adjusted (sr04)	Total PCB 350 ng/L with no Solids (sr03)	Total PCB 600g/day (sr01)	Total PCB 300 g/day (sr02)	Accidental Release (srA1)
	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load
2041	864	591	863	866	844		717		
2042	874	600	872	875	853		726		
2043	887	611	882	886	863		737		
2044	899	621	893	896	873		747		
2045	911	631	902	906	883		757		
2046	921	640	912	915	893		766		
2047	932	649	921	924	902		776		
2048	944	659	930	934	911		785		
2049	955	668	939	943	920		794		
2050	967	677	949	952	930		804		
2051	979	687	959	962	940		813		
2052	989	696	968	971	949		822		
2053	999	705	976	980	957		831		
2054	1009	714	985	988	966		840		
2055	1019	723	995	998	975		849		
2056	1028	731	1003	1006	984		858		
2057	1038	740	1012	1015	993		867		
2058	1047	749	1021	1024	1002		876		
2059	1057	758	1030	1033	1010		884		
2060	1067	767	1039	1042	1020		894		
2061	1078	777	1049	1052	1030		904		
2062	1087	786	1057	1061	1038		912		
2063	1096	794	1066	1069	1047		921		
2064	1105	803	1075	1078	1056		930		
2065	1114	812	1084	1087	1065		939		
2066	1123	821	1092	1096	1073		947		
2067	1132	829	1101	1104	1081		956		

Table 29
Tri+ PCB Load Over Schuylerville

Year	MNA (p3nas2) Cumulative Load	No Resuspension (d004) Cumulative Load	Total PCB 350 ng/L @ 1 mile (d006) Cumulative Load	Total PCB 350 ng/L @ 3 mile (d007) Cumulative Load	Total PCB 350 ng/L fraction remaining adjusted (sr04) Cumulative Load	Total PCB 350 ng/L with no Solids (sr03) Cumulative Load	Total PCB 600g/day (sr01) Cumulative Load	Total PCB 300 g/day (sr02) Cumulative Load	Accidental Release (srA1) Cumulative Load	Total PCB 600 g/day corrected to MNA (sr01) Cumulative Load
2005	0	0	0	0	0	0	0	0	0	0
2006	78	77	110	111	111	117	94	86	94	94
2007	162	155	256	258	258	280	208	183	208	208
2008	207	190	362	365	357	404	276	234	276	276
2009	253	221	496	501	488	551	344	285	344	359
2010	327	263	610	615	596	667	405	337	405	442
2011	390	291	640	645	626	697	434	365	434	471
2012	444	316	668	673	654	723	460	390	460	496
2013	499	341	695	701	681	750	485	416	485	522
2014	540	361	717	723	703	772	507	437	507	543
2015	578	381	738	744	723	793	527	457	527	564
2016	607	397	755	761	740	809	543	473	543	580
2017	632	412	770	776	755	825	558	488	558	595
2018	666	429	788	794	773	843	575	505	575	612
2019	690	443	802	808	787	857	589	519	589	626
2020	717	458	818	824	803	873	604	534	604	641
2021	742	472	832	839	817		619		619	655
2022	761	485	845	851	830		631		631	668
2023	779	496	857	863	842		643		643	679
2024	804	511	872	878	857		658		658	694
2025	824	523	884	891	869		670		670	707
2026	843	536	897	904	882		682		682	719
2027	859	547	908	915	893		693		693	730
2028	877	559	920	927	905		705		705	742
2029	894	570	932	938	917		717		717	754
2030	910	582	943	950	928		728		728	765
2031	929	594	955	962	940		741			777
2032	945	605	967	974	952		752			789
2033	959	616	977	984	962		762			799
2034	974	627	988	995	973		773			810
2035	988	638	999	1006	984		784			821
2036	1003	649	1010	1017	995		795			832
2037	1018	659	1021	1028	1006		806			843
2038	1030	669	1031	1038	1016		816			853
2039	1046	680	1042	1049	1027		827			864
2040	1058	690	1052	1059	1037		837			873
2041	1070	700	1062	1069	1047		846			883
2042	1079	708	1070	1077	1055		855			891
2043	1093	719	1081	1088	1066		866			902
2044	1106	730	1091	1099	1076		876			913
2045	1119	739	1101	1108	1086		886			923

Table 29
Tri+ PCB Load Over Schuylerville

Year	MNA (p3nas2)	No Resuspension (d004)	Total PCB 350 ng/L @ 1 mile (d006)	Total PCB 350 ng/L @ 3 mile (d007)	Total PCB 350 ng/L fraction remaining adjusted (sr04)	Total PCB 350 ng/L with no Solids (sr03)	Total PCB 600g/day (sr01)	Total PCB 300 g/day (sr02)	Accidental Release (srA1)	Total PCB 600 g/day corrected to MNA (sr01)
	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load
2046	1130	749	1111	1118	1096		896			932
2047	1140	758	1120	1127	1105		905			942
2048	1152	767	1129	1136	1114		914			951
2049	1163	776	1138	1145	1123		923			960
2050	1175	786	1147	1155	1132		932			969
2051	1188	795	1157	1164	1142		942			979
2052	1198	804	1166	1173	1151		951			988
2053	1208	812	1174	1181	1159		959			996
2054	1217	821	1183	1190	1168		968			1005
2055	1228	830	1192	1199	1177		978			1014
2056	1237	838	1200	1207	1185		985			1022
2057	1247	847	1209	1216	1194		994			1031
2058	1256	855	1217	1224	1202		1003			1039
2059	1265	864	1226	1233	1211		1011			1048
2060	1275	873	1235	1242	1220		1021			1057
2061	1286	883	1245	1252	1230		1031			1067
2062	1295	892	1253	1261	1238		1039			1076
2063	1304	900	1262	1269	1247		1047			1084
2064	1313	908	1270	1277	1255		1056			1092
2065	1322	917	1279	1286	1264		1064			1101
2066	1331	925	1287	1294	1272		1073			1109
2067	1339	933	1295	1302	1280		1081			1117

Table 30
Tri+ PCB Load Over Waterford

Year	MNA (p3nas2)	No Resuspension (d004)	Total PCB 350 ng/L @ 1 mile (d006)	Total PCB 350 ng/L @ 3 mile (d007)	Total PCB 350 ng/L fraction remaining adjusted (sr04)	Total PCB 350 ng/L with no Solids (sr03)	Total PCB 600g/day (sr01)	Total PCB 300 g/day (sr02)	Accidental Release (srA1)	Total PCB 600 g/day corrected to MNA (sr01)
	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load
2005	0	0	0	0	0	0	0	0	0	0
2006	102	102	116	117	117	122	110	106	110	110
2007	205	201	250	251	251	266	227	214	227	227
2008	254	245	325	327	324	352	287	267	287	287
2009	301	285	404	408	401	445	342	315	342	349
2010	393	353	607	612	601	664	451	404	451	484
2011	464	397	782	788	754	843	524	463	535	580
2012	528	437	848	854	818	908	572	508	584	628
2013	595	478	906	912	875	967	618	551	631	674
2014	643	508	949	955	917	1010	652	583	665	708
2015	687	536	987	993	954	1047	683	612	696	738
2016	714	553	1010	1017	977	1069	702	631	715	757
2017	738	569	1032	1038	998	1090	719	648	733	775
2018	771	588	1055	1061	1021	1113	739	667	753	795
2019	793	602	1072	1079	1039	1130	754	681	768	810
2020	821	620	1094	1100	1059	1151	772	699	786	828
2021	847	636	1112	1119	1078		789		803	845
2022	865	648	1127	1133	1092		802		816	858
2023	882	659	1140	1146	1105		813		827	869
2024	911	677	1160	1166	1125		832		846	888
2025	930	689	1174	1180	1139		845		859	901
2026	949	702	1188	1194	1153		858		872	913
2027	964	712	1199	1205	1164		868		882	924
2028	982	724	1211	1218	1177		880		894	936
2029	999	736	1224	1230	1189		892		906	948
2030	1015	747	1236	1242	1201		903		917	959
2031	1033	759	1248	1255	1213		916			972
2032	1048	769	1259	1266	1224		926			982
2033	1061	779	1269	1276	1234		936			992
2034	1077	790	1281	1287	1246		947			1003
2035	1100	809	1292	1298	1257		958			1014
2036	1134	839	1303	1310	1268		970			1026
2037	1164	864	1316	1324	1281		1001			1057
2038	1185	882	1341	1349	1307		1023			1079
2039	1212	905	1372	1380	1338		1050			1106
2040	1228	919	1391	1399	1357		1067			1123
2041	1243	932	1408	1416	1374		1082			1138
2042	1253	941	1420	1428	1385		1093			1149
2043	1272	958	1440	1447	1405		1111			1166
2044	1292	974	1457	1465	1423		1128			1184
2045	1308	987	1471	1479	1437		1141			1197

Table 30
Tri+ PCB Load Over Waterford

Year	MNA (p3nas2)	No Resuspension (d004)	Total PCB 350 ng/L @ 1 mile (d006)	Total PCB 350 ng/L @ 3 mile (d007)	Total PCB 350 ng/L fraction remaining adjusted (sr04)	Total PCB 350 ng/L with no Solids (sr03)	Total PCB 600g/day (sr01)	Total PCB 300 g/day (sr02)	Accidental Release (srA1)	Total PCB 600 g/day corrected to MNA (sr01)
	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load	Cumulative Load
2046	1322	1000	1484	1492	1450		1154			1210
2047	1334	1010	1496	1503	1461		1165			1221
2048	1346	1020	1507	1514	1472		1176			1232
2049	1356	1028	1516	1523	1481		1185			1241
2050	1369	1039	1527	1535	1492		1195			1251
2051	1382	1049	1539	1546	1504		1207			1262
2052	1392	1057	1547	1555	1513		1215			1271
2053	1400	1065	1555	1562	1520		1222			1278
2054	1409	1072	1563	1570	1528		1230			1286
2055	1419	1081	1572	1579	1537		1239			1295
2056	1426	1087	1579	1586	1544		1245			1301
2057	1435	1095	1587	1594	1552		1254			1310
2058	1443	1103	1595	1602	1560		1261			1317
2059	1451	1110	1602	1609	1567		1269			1325
2060	1462	1120	1612	1619	1577		1278			1334
2061	1473	1130	1622	1629	1587		1289			1345
2062	1481	1137	1629	1636	1594		1296			1352
2063	1488	1144	1636	1643	1601		1303			1359
2064	1495	1151	1643	1650	1608		1310			1366
2065	1503	1158	1650	1658	1616		1317			1373
2066	1510	1165	1658	1665	1623		1324			1380
2067	1517	1172	1664	1671	1629		1331			1387

Table 31
Resuspension Production, Release, and Export Rates from TSS-Chem and HUDTOX Models

Scenario	Sediment Removal Period	Dredging Location and Monitoring Station	Resuspension Production Rate of Sediment[1] (kg/s)	Resuspension Production Rate of Total PCB[2] (g/day)	Net TSS Flux at 1 mile from TSS-Chem (kg/s)	TPCB flux at 1 mile[3] (Resuspension Release Rate) (g/day)	TPCB Flux at Monitoring Stations from HUDTOX[4] (Resuspension Export Rate) (g/day)	TPCB Production Rate[6] (g/day)	Solids Production Rate[7] (kg/s)	Source Strength as Percentage of TPCB Removed[8] (%)	Resuspension Export Rate as Percentage of TPCB Removed[9] (%)
Evaluation Level - 300 g/day TPCB Flux at Monitoring Stations	May 1 - November 30, 2006	Section 1, TID	1.3	1,700	0.28	410	320	5.7.E+04	42	3%	0.56%
	May 1 - November 30, 2007	Section 1, TID	1.3	1,700	0.27	410	320	5.7.E+04	42	3%	0.56%
	May 1 - November 30, 2008	Section 1, TID	1.1	1,500	0.24	360	300	5.7.E+04	42	3%	0.53%
	May 1 - August 15, 2009	Section 1, TID	0.9	1,300	0.20	310	310	5.7.E+04	42	2%	0.54%
	August 16 - November 30, 2009	Section 2, Schuylerville	0.3	1,100	0.10	360	330	1.2.E+05	37	1%	0.29%
	May 1 - August 15, 2010	Section 2, Schuylerville	0.3	900	0.08	310	300	1.2.E+05	37	1%	0.26%
	August 16 - November 30, 2010	Section 3, Waterford	0.9	1,300	0.25	400	340	4.5.E+04	31	3%	0.75%
	May 1 - August 15, 2011	Section 3, Waterford	0.7	1,000	0.19	310	340	4.5.E+04	31	2%	0.75%
Control Level - 600 g/day TPCB Flux at Monitoring Stations	May 1 - November 30, 2006	Section 1, TID	2.6	3,600	0.57	820	620	5.7.E+04	42	6%	1.1%
	May 1 - November 30, 2007	Section 1, TID	2.6	3,600	0.57	820	630	5.7.E+04	42	6%	1.1%
	May 1 - November 30, 2008	Section 1, TID	2.3	3,100	0.50	720	620	5.7.E+04	42	6%	1.1%
	May 1 - August 15, 2009	Section 1, TID	2.0	2,700	0.43	620	590	5.7.E+04	42	5%	1.0%
	August 16 - November 30, 2009	Section 2, Schuylerville	0.7	2,300	0.21	730	620	1.2.E+05	37	2%	0.5%
	May 1 - August 15, 2010	Section 2, Schuylerville	0.6	1,900	0.17	630	590	1.2.E+05	37	2%	0.5%
	August 16 - November 30, 2010	Section 3, Waterford	1.9	2,700	0.52	810	660	4.5.E+04	31	6%	1.5%
	May 1 - August 15, 2011	Section 3, Waterford	1.4	2,100	0.40	630	650	4.5.E+04	31	5%	1.4%
Control Level - 350 ng/L TPCB Concentrations at Monitoring Stations	May 1 - November 30, 2006	Section 1, TID	5.6	7,600	1.2	1,700	1,200	5.7.E+04	42	13%	2.1%
	May 1 - November 30, 2007	Section 1, TID	5.6	7,600	1.2	1,700	1,200	5.7.E+04	42	13%	2.1%
	May 1 - November 30, 2008	Section 1, TID	4.9	6,700	1.1	1,500	1,300	5.7.E+04	42	12%	2.3%
	May 1 - August 15, 2009	Section 1, TID	4.2	5,700	0.91	1,300	1,200	5.7.E+04	42	10%	2.1%
	August 16 - November 30, 2009	Section 2, Schuylerville	2.7	8,300	0.75	2,500	2,000	1.2.E+05	37	7%	1.7%
	May 1 - August 15, 2010	Section 2, Schuylerville	2.3	7,100	0.64	2,100	2,000	1.2.E+05	37	6%	1.7%
	August 16 - November 30, 2010	Section 3, Waterford	7.5	10,900	2.1	3,100	2,200	4.5.E+04	31	24%	4.9%
	May 1 - August 15, 2011	Section 3, Waterford	5.8	8,400	1.6	2,400	2,300	4.5.E+04	31	19%	5.1%

Table 31
Resuspension Production, Release, and Export Rates from TSS-Chem and HUDTOX Models

Scenario	Sediment Removal Period	Dredging Location and Monitoring Station	Resuspension Production Rate of Sediment[1] (kg/s)	Resuspension Production Rate of Total PCB[2] (g/day)	Net TSS Flux at 1 mile from TSS-Chem (kg/s)	TPCB flux at 1 mile[3] (Resuspension Release Rate) (g/day)	TPCB Flux at Monitoring Stations[10] (Resuspension Export Rate) (g/day)	TPCB Production Rate[6] (g/day)	Solids Production Rate[7] (kg/s)	Source Strength as Percentage of TPCB Removed[8] (%)	Resuspension Export Rate as Percentage of TPCB Removed[9] (%)
Resuspension Standard - 500 ng/L TPCB Concentrations at Monitoring Stations	May 1 - November 30, 2006	Section 1, TID	9.4	12,800	2.0	2,800	2,100	5.7.E+04	42	23%	3.7%
	May 1 - November 30, 2007	Section 1, TID	9.3	12,700	2.0	2,800	2,100	5.7.E+04	42	22%	3.7%
	May 1 - November 30, 2008	Section 1, TID	8.2	11,200	1.8	2,500	2,100	5.7.E+04	42	20%	3.7%
	May 1 - August 15, 2009	Section 1, TID	7.1	9,600	1.53	2,100	2,100	5.7.E+04	42	17%	3.7%
	August 16 - November 30, 2009	Section 2, Schuylerville	3.5	10,900	0.99	3,200	2,700	1.2.E+05	37	9%	2.3%
	May 1 - August 15, 2010	Section 2, Schuylerville	3.0	9,300	0.84	2,800	2,700	1.2.E+05	37	8%	2.3%
	August 16 - November 30, 2010	Section 3, Waterford	11	16,600	3.2	4,800	3,500	4.5.E+04	31	37%	7.7%
	May 1 - August 15, 2011	Section 3, Waterford	8.8	12,800	2.5	3,700	3,500	4.5.E+04	31	28%	7.7%

Notes:

Numbers are rounded to 2 significant digits.

[1] Source strength represents the amount of solids being suspended to the water column at the dredge-head in kg/s. The value is obtained from the TSS-Chem model.

[2] TPCB flux for source strength is obtained by multiplying the solids source strength with the TPCB concentration in the sediment. The TPCB concentration for River Sections 1, 2, and 3 is 27, 62, and 29 mg/kg, respectively.

[3] Net TSS flux is the TSS-Chem model result at a distance 1 mile downstream of the dredge-head.This number is also the TSS flux input to the HUDTOX model.

[4] Values represent the amount of TPCB flux at the monitoring stations as predicted by HUDTOX.

[5] TPCB flux is obtained from TSS-Chem model. It is the TPCB flux at 1 mile downstream of the dredge-head. This is also the input TPCB flux to the HUDTOX model.

[6] TPCB production rate based on the total TPCB being removed in each river section (36,000 kg, 24,300 kg, and 9,500 kg of TPCB for River Sections 1, 2, and 3, respectively);
assuming 7days/week, 14 hours/day, 630 days in River Section 1 and 210 days each in River Sections 2 and 3.

[7] Solids production rate based on the total sediment being removed including overcut (1.5x10^6 cy, 5.8x10^5 cy, and 5.1x10^5 cy of solids in River Sections 1, 2, and 3, respectively);
assuming 7days/week and 14 hours/day, 630 days in River Section 1 and 210 days each in River Sections 2 and 3.

[8] Percentage is calculated as TPCB source strength divide by the TPCB production rate.

[9] Percentage is calculated as TPCB flux at the monitoring station divide by the TPCB production rate.

[10] TPCB flux is calculated based on the 500 ng/L at the far-field monitoring stations minus the mean baseline TPCB concentrations based on the GE water column samples data.

Table 32
Example of CSTR-Chem, TSS-Chem, and HUDTOX Application

Sediment removal season	Dredging Location	speed	Cubic yards of sediment removed[1]	Monitoring Location (Compliance Point)[2]	Expected Total PCB export rate at compliance point[3] (g/day)	Percent remaining at the monitoring location[4]	Total PCB input flux to HUDTOX (g/day)	TSS-Chem Output at 1 Mile of Dredgehead[5] (kg/day)	CSTR-Chem Input[6] (kg/day)
Jun. 1 - Sep. 15, 2006[7]	Sec. 1	half	260,000	TID	1,237	73%	1,697	61,030	281,965
May 1 - Nov. 30, 2007	Sec. 1	full	520,000	TID	1,237	73%	1,684	60,575	279,856
May 1 - Nov. 30, 2008	Sec. 1	full	520,000	TID	1,237	83%	1,490	53,423	246,754
May 1 - Aug. 15, 2009	Sec. 1 &	full	260,000	TID	1,237	97%	1,278	45,599	210,718
Aug. 16 - Nov. 30, 200	Sec. 2		290,000	Schuylerville	2,034	82%	2,466	37,814	133,724
May 1 - Aug. 15, 2010	Sec. 2 &	full	290,000	Schuylerville	2,034	96%	2,117	32,242	114,014
Aug. 16 - Nov. 30, 201	Sec. 3		255,000	Waterford	2,334	74%	3,150	106,675	377,052
May 1 - Aug. 15, 2011	Sec. 3	full	255,000	Waterford	2,334	96%	2,441	82,308	290,921

Notes:

[1] Volume of sediment removed is taken from Table 8-9 of the Feasibility Study.

[2] All TIP monitoring is done at TID, all River Section 2 monitoring is done at Schuylerville, and all River Section 3 monitoring is done at Waterford. 1 mile exclusion is not considered.

[3] Total PCB Flux is the average net flux for June to Nov at the compliance point (TID, Schuylerville, & Waterford). PCB flux in May was excluded since flow is not typical.

[4] Percent remaining at the monitoring location was obtained from the initial HUDTOX runs performed for the preliminary draft of the resuspension performance standard

[5] Input to HUDTOX

[6] CSTR-Chem suspended solids flux is the resuspension production rate.

[7] Actual dredging period is from May 1 - Nov. 30, 2006. The PCB and TSS flux is loaded only from June 1 to Sep. 15, 2006 to account for half speed operation.

Table 33
Expected versus Model Prediction of PCB Flux for Control Level - 600 g/day Scenario

River Section	Dredging Season	Loading period		Monitoring Station	Tri+ PCB Input		Tri+ PCB Output		Total PCB @ monitoring station	
		From	To		(g/day)	(g/period)	(g/day)	(g/period)[1]	Expected (g/day)[2]	Model estimate (g/day)
Section 1 dredging	May 1-Nov 30, 2006	1-Jun-06	15-Sep-06	TID	260	27,820	195	20,853	600	624
	May 1-Nov 30, 2007	1-May-07	30-Nov-07	TID	260	55,640	197	42,114	600	630
	May 1-Nov 30, 2008	1-May-08	30-Nov-08	TID	230	49,220	195	41,740	600	624
	May 1-Aug 15, 2009	1-May-09	15-Aug-09	TID	190	20,330	186	19,865	600	594
Section 2 dredging	Aug 16 - Nov 30, 2009	16-Aug-09	30-Nov-09	Schuylerville	210	22,470	183	19,573	600	622
	May 1 - Aug 15, 2010	1-May-10	15-Aug-10	Schuylerville	180	19,260	174	18,609	600	591
Section 3 dredging	Aug 16 - Nov 30, 2010[3]	16-Aug-10	30-Nov-10	Waterford	300	27,300	243	22,373	600	657
	May 1 - Aug 15, 2011	1-May-11	15-Aug-11	Waterford	230	24,610	240	25,680	600	648

Notes:

[1] Output loading from HUDTOX

[2] Total PCB flux at the monitoring station based on 1% export rate at the monitoring stations

[3] September output from HUDTOX appears to have incorrect loading, 15 days instead of 30 days. Input loading was adjusted to reflect this.

Table 34
Expected versus Model Prediction of PCB Flux for Evaluation Level - 300 g/day Scenario

River Section	Dredging Season	Loading period		Monitoring Station	Tri+ PCB Input		Tri+ PCB Output		Total PCB @ monitoring station	
		From	To		(g/day)	(g/period)	(g/day)	(g/period)[1]	Expected (g/day)[2]	Model estimate (g/day)
Section 1 dredging	May 1-Nov 30, 2006	1-Jun-06	15-Sep-06	TID	130	13,910	100	10,664	300	319
	May 1-Nov 30, 2007	1-May-07	30-Nov-07	TID	130	27,820	101	21,667	300	324
	May 1-Nov 30, 2008	1-May-08	30-Nov-08	TID	110	23,540	95	20,287	300	303
	May 1-Aug 15, 2009	1-May-09	15-Aug-09	TID	100	10,700	98	10,492	300	314
Section 2 dredging	Aug 16 - Nov 30, 2009	16-Aug-09	30-Nov-09	Schuylerville	110	11,770	98	10,456	300	332
	May 1 - Aug 15, 2010	1-May-10	15-Aug-10	Schuylerville	90	9,630	89	9,565	300	304
Section 3 dredging	Aug 16 - Nov 30, 2010[3]	16-Aug-10	30-Nov-10	Waterford	150	13,650	125	11,464	300	336
	May 1 - Aug 15, 2011	1-May-11	15-Aug-11	Waterford	120	12,840	125	13,421	300	339

Notes:

[1] Output loading from HUDTOX

[2] Total PCB flux at the monitoring station based on 0.5% export rate at the monitoring stations

[3] September output from HUDTOX appears to have incorrect loading, 15 days instead of 30 days. Input loading was adjusted to reflect this.

Table 35

FISHRAND Forecast for Year to Reach Fish Tissue Concentration Difference of 0.5 mg/kg Relative to the No Resuspension - Upper River

River Section	Total PCB 600 g/day (sr01)	Total PCB 350 ng/L (sr04)
Section 1 (RM 189)	2008-2009	2009-2010
Section 2 (RM 184)	2008	2010
Section 3 (RM 154)	Always < 0.5 mg/kg	2011

Table 36

FISHRAND Forecast for Year to Reach Fish Tissue Concentration Difference of 0.05 mg/kg Relative to the No Resuspension - Lower River

River Section	Total PCB 600 g/day (sr01)	Total PCB 350 ng/L (sr04)
RM 152	2013-2014	2016-2017
RM 113	2014	2016-2017
RM 90	2014	2018
RM 50	Always < 0.05 mg/kg	2018

Table 37
Upper Hudson Species-Weighted Fish Fillet Average PCB Concentration (in mg/kg)

	No Resuspension (d004)				350 ng/L (sr04)			
Year	Upper River Average	River Section 1 (RM 189)	River Section 2 (RM 184)	River Section 3 (RM 154)	Upper River Average	River Section 1 (RM 189)	River Section 2 (RM 184)	River Section 3 (RM 154)
1998	3.317	6.813	9.271	1.537	3.316	6.807	9.276	1.537
1999	3.328	6.908	9.406	1.510	3.328	6.909	9.410	1.509
2000	2.866	5.747	8.346	1.300	2.865	5.751	8.338	1.300
2001	2.582	5.098	7.588	1.177	2.583	5.104	7.585	1.177
2002	2.370	4.841	6.925	1.053	2.372	4.848	6.924	1.054
2003	2.182	4.340	6.471	0.978	2.182	4.338	6.474	0.978
2004	2.290	5.285	6.356	0.946	2.290	5.286	6.354	0.946
2005	1.905	3.912	5.712	0.816	1.911	3.910	5.740	0.821
2006	1.617	2.996	5.119	0.716	1.703	3.111	5.350	0.770
2007	1.487	2.838	4.669	0.647	1.709	3.461	5.141	0.739
2008	1.297	2.318	4.226	0.571	1.673	3.762	4.743	0.694
2009	0.964	1.573	2.949	0.489	1.323	2.317	3.769	0.687
2010	0.595	0.899	1.355	***0.398***	0.928	1.012	1.835	0.753
2011	0.447	0.661	0.847	0.332	0.817	0.736	1.122	0.781
2012	0.404	0.723	0.786	0.269	0.631	0.774	0.999	0.537
2013	***0.342***	0.568	0.717	0.229	0.515	0.600	0.883	0.433
2014	0.318	0.593	0.669	***0.199***	0.453	0.602	0.803	***0.361***
2015	0.289	0.520	0.638	0.178	***0.400***	0.524	0.751	0.312
2016	0.294	0.586	0.651	0.170	0.391	0.589	0.750	0.287
2017	0.296	0.671	0.612	0.161	0.379	0.672	0.704	0.260
2018	0.272	0.606	0.574	0.149	0.344	0.605	0.665	0.233
2019	0.281	0.710	0.567	0.140	0.341	0.702	0.656	0.210
2020	0.243	0.584	0.502	0.125	0.292	0.579	0.584	***0.180***
2021	0.217	0.471	0.482	0.117	0.260	0.468	0.557	0.164
2022	0.215	0.476	0.477	0.114	0.253	0.473	0.548	0.155
2023	0.216	0.529	0.454	0.108	0.247	0.524	0.514	0.142
2024	***0.195***	0.484	0.417	0.094	0.219	0.480	0.463	0.122
2025	0.176	0.415	***0.391***	0.088	***0.196***	0.413	0.426	0.110
2026	0.163	***0.357***	0.377	0.084	0.180	0.355	0.405	0.103
2027	0.183	0.490	0.380	0.083	0.197	0.488	0.403	0.100
2028	0.177	0.509	0.353	0.076	0.189	0.508	***0.371***	0.090
2029	0.158	0.414	0.337	0.072	0.168	0.412	0.351	0.084
2030	0.143	0.326	0.326	0.072	0.152	***0.325***	0.342	0.082
2031	0.151	0.422	0.303	0.067	0.159	0.421	0.320	0.075
2032	0.138	0.362	0.288	0.064	0.145	0.362	0.305	0.071
2033	0.133	0.349	0.277	0.061	0.138	0.349	0.295	0.066
2034	0.132	0.368	0.259	0.060	0.134	0.368	0.276	0.060
2035	0.123	0.279	0.249	0.068	0.116	0.279	0.266	0.056
2036	0.148	0.356	0.242	0.087	0.124	0.356	0.258	0.051
2037	0.137	0.297	0.234	0.086	0.115	0.298	0.250	0.053
2038	0.140	0.337	0.221	0.083	0.130	0.337	0.235	0.068
2039	0.128	0.270	0.214	0.083	0.132	0.271	0.227	0.087
2040	0.124	0.262	0.214	0.079	0.132	0.262	0.225	0.087
2041	0.140	0.359	0.219	0.079	0.150	0.360	0.228	0.091
2042	0.143	0.400	0.223	0.074	0.153	0.401	0.229	0.087
2043	0.123	0.318	0.202	0.068	0.132	0.318	0.206	0.080
2044	0.108	0.245	***0.191***	0.064	0.114	0.246	***0.193***	0.073
2045	0.112	0.282	0.190	0.063	0.118	0.283	0.191	0.070

BOLD-ITALICIZED - First occurrence of species-weighted fish fillet average PCB concentration below risk-based remediation goal of 0.05 mg/kg. Target concentrations of 0.2 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/month) and 0.4 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/ 2 months) are also italicized.

Upper Hudson River average is weighted by river section length:

River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 37
Upper Hudson Species-Weighted Fish Fillet Average PCB Concentration (in mg/kg)

Year	No Resuspension (d004)				350 ng/L (sr04)			
	Upper River Average	River Section 1 (RM 189)	River Section 2 (RM 184)	River Section 3 (RM 154)	Upper River Average	River Section 1 (RM 189)	River Section 2 (RM 184)	River Section 3 (RM 154)
2046	0.105	0.258	0.184	0.058	0.109	0.256	0.184	0.064
2047	0.109	0.284	0.187	0.058	0.112	0.271	0.187	0.065
2048	0.115	0.329	0.188	0.057	0.118	0.318	0.187	0.064
2049	0.116	0.339	0.190	0.055	0.120	0.340	0.189	0.062
2050	0.105	0.289	0.183	0.052	0.109	0.290	0.182	0.057
2051	0.101	0.286	0.180	***0.047***	0.104	0.287	0.178	0.052
2052	0.094	0.244	0.181	0.047	0.097	0.246	0.180	0.051
2053	0.113	0.359	0.187	0.048	0.116	0.359	0.185	0.052
2054	0.105	0.311	0.185	0.047	0.107	0.311	0.184	0.050
2055	0.098	0.274	0.182	0.045	0.100	0.274	0.180	***0.048***
2056	0.105	0.307	0.195	0.046	0.106	0.307	0.193	0.048
2057	0.105	0.323	0.185	0.045	0.107	0.324	0.183	0.047
2058	0.095	0.253	0.188	0.045	0.096	0.253	0.186	0.047
2059	0.109	0.356	0.181	0.043	0.110	0.356	0.181	0.045
2060	0.091	0.256	0.175	0.040	0.092	0.256	0.175	0.042
2061	0.086	0.234	0.169	0.040	0.087	0.233	0.169	0.042
2062	0.091	0.261	0.171	0.040	0.091	0.261	0.170	0.042
2063	0.091	0.261	0.172	0.041	0.091	0.260	0.171	0.041
2064	0.093	0.268	0.175	0.041	0.093	0.268	0.174	0.042
2065	0.092	0.255	0.178	0.043	0.093	0.255	0.177	0.043
2066	0.105	0.353	0.172	0.041	0.105	0.353	0.171	0.041
2067	0.095	0.275	0.180	0.042	0.095	0.275	0.179	0.042

BOLD-ITALICIZED - First occurrence of species-weighted fish fillet average PCB concentration below risk-based remediation goal of 0.05 mg/kg. Target concentrations of 0.2 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/month) and 0.4 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/ 2 months) are also italicized.

Upper Hudson River average is weighted by river section length:

River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 37
Upper Hudson Species-Weighted Fish Fillet Average PCB Concentration (in mg/kg)

Year	600 g/day (sr01)				Monitored Natural Attenuation			
	Upper River Average	River Section 1 (RM 189)	River Section 2 (RM 184)	River Section 3 (RM 154)	Upper River Average	River Section 1 (RM 189)	River Section 2 (RM 184)	River Section 3 (RM 154)
1998	3.316	6.807	9.276	1.537	3.353	6.774	9.659	1.529
1999	3.328	6.909	9.410	1.509	3.212	6.621	8.877	1.501
2000	2.865	5.751	8.338	1.300	2.791	5.563	8.028	1.292
2001	2.583	5.104	7.585	1.177	2.504	4.924	7.210	1.171
2002	2.372	4.848	6.924	1.054	2.301	4.705	6.571	1.047
2003	2.182	4.338	6.474	0.978	2.129	4.290	6.090	0.980
2004	2.290	5.286	6.354	0.946	2.204	5.084	5.934	0.942
2005	1.908	3.909	5.726	0.819	1.852	3.739	5.523	0.812
2006	1.666	3.076	5.237	0.746	1.574	2.890	4.904	0.716
2007	1.614	3.225	4.920	0.697	1.474	2.862	4.489	0.654
2008	1.525	3.216	4.582	0.634	1.371	2.774	4.168	0.586
2009	1.106	1.907	3.140	0.583	1.262	2.616	3.877	0.519
2010	0.707	0.943	1.411	0.535	1.116	2.321	3.533	0.440
2011	0.568	0.697	0.901	0.483	0.971	1.921	3.164	***0.388***
2012	0.469	0.747	0.818	***0.350***	0.878	1.851	2.879	0.324
2013	***0.389***	0.572	0.734	0.291	0.791	1.682	2.601	0.287
2014	0.353	0.582	0.675	0.248	0.742	1.666	2.396	0.258
2015	0.316	0.506	0.638	0.219	0.686	1.535	2.229	0.237
2016	0.317	0.573	0.648	0.205	0.680	1.610	2.126	0.231
2017	0.315	0.660	0.610	***0.190***	0.649	1.573	1.978	0.221
2018	0.289	0.595	0.577	0.173	0.593	1.437	1.765	0.210
2019	0.295	0.694	0.572	0.161	0.577	1.497	1.619	***0.200***
2020	0.253	0.571	0.507	0.142	0.512	1.270	1.480	0.182
2021	0.226	0.459	0.486	0.131	0.460	1.080	1.365	0.171
2022	0.222	0.464	0.482	0.126	0.450	1.093	1.296	0.166
2023	0.222	0.517	0.461	0.118	0.435	1.088	1.225	0.158
2024	***0.200***	0.474	0.427	0.102	***0.385***	0.939	1.123	0.139
2025	0.181	0.406	0.402	0.094	0.350	0.842	1.019	0.129
2026	0.166	***0.347***	***0.388***	0.089	0.325	0.757	0.952	0.124
2027	0.186	0.483	0.387	0.088	0.339	0.888	0.920	0.121
2028	0.179	0.504	0.353	0.080	0.322	0.863	0.875	0.111
2029	0.159	0.407	0.332	0.076	0.287	0.720	0.801	0.105
2030	0.143	0.320	0.322	0.075	0.261	0.620	0.735	0.103
2031	0.152	0.418	0.302	0.069	0.257	0.679	0.675	0.095
2032	0.139	0.357	0.289	0.066	0.234	0.602	0.610	0.091
2033	0.133	0.343	0.279	0.063	0.219	0.560	0.564	0.086
2034	0.132	0.366	0.261	0.059	0.208	0.545	0.521	0.082
2035	0.114	0.275	0.251	0.055	***0.191***	0.443	0.475	0.089
2036	0.125	0.352	0.244	0.055	0.209	0.504	0.446	0.104
2037	0.125	0.295	0.237	0.070	0.190	0.427	0.410	0.101
2038	0.140	0.335	0.224	0.083	0.189	0.456	***0.386***	0.098
2039	0.131	0.268	0.218	0.087	0.173	0.382	0.363	0.096
2040	0.128	0.260	0.217	0.085	0.164	0.352	0.346	0.092
2041	0.146	0.358	0.222	0.087	0.180	0.461	0.347	0.092
2042	0.148	0.399	0.225	0.081	0.178	0.486	0.337	0.084
2043	0.129	0.320	0.205	0.075	0.155	***0.386***	0.316	0.078
2044	0.114	0.256	***0.195***	0.069	0.136	0.301	0.289	0.074
2045	0.118	0.301	0.194	0.066	0.137	0.329	0.278	0.071

BOLD-ITALICIZED - First occurrence of species-weighted fish fillet average PCB concentration below risk-based remediation goal of 0.05 mg/kg. Target concentrations of 0.2 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/month) and 0.4 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/ 2 months) are also italicized.

Upper Hudson River average is weighted by river section length:

River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 37
Upper Hudson Species-Weighted Fish Fillet Average PCB Concentration (in mg/kg)

	600 g/day (sr01)				Monitored Natural Attenuation			
Year	Upper River Average	River Section 1 (RM 189)	River Section 2 (RM 184)	River Section 3 (RM 154)	Upper River Average	River Section 1 (RM 189)	River Section 2 (RM 184)	River Section 3 (RM 154)
2046	0.110	0.273	0.187	0.062	0.131	0.319	0.269	0.067
2047	0.112	0.285	0.190	0.062	0.153	0.474	0.261	0.066
2048	0.116	0.316	0.190	0.061	0.175	0.612	0.263	0.066
2049	0.117	0.328	0.192	0.059	0.166	0.574	0.259	0.063
2050	0.106	0.283	0.185	0.055	0.151	0.498	0.251	0.060
2051	0.104	0.294	0.182	***0.050***	0.140	0.457	0.242	0.055
2052	0.099	0.263	0.184	0.049	0.130	0.402	0.236	0.054
2053	0.118	0.379	0.189	0.050	0.146	0.494	0.244	0.055
2054	0.109	0.327	0.187	0.049	0.134	0.430	0.235	0.053
2055	0.101	0.287	0.183	0.047	0.125	0.383	0.231	0.052
2056	0.108	0.322	0.195	0.047	0.129	0.407	0.233	0.051
2057	0.108	0.337	0.186	0.046	0.126	0.397	0.231	0.050
2058	0.097	0.264	0.188	0.046	0.116	0.337	0.226	0.050
2059	0.111	0.366	0.182	0.044	0.127	0.422	0.228	***0.047***
2060	0.093	0.266	0.175	0.041	0.106	0.316	0.209	0.044
2061	0.087	0.241	0.169	0.041	0.100	0.286	***0.200***	0.043
2062	0.092	0.268	0.170	0.041	0.102	0.297	0.197	0.043
2063	0.092	0.266	0.171	0.041	0.101	0.296	0.196	0.043
2064	0.094	0.273	0.175	0.042	0.103	0.306	0.196	0.044
2065	0.093	0.260	0.177	0.043	0.100	0.283	0.195	0.045
2066	0.106	0.358	0.171	0.041	0.113	0.377	0.195	0.043
2067	0.096	0.279	0.179	0.043	0.101	0.301	0.183	0.044

BOLD-ITALICIZED - First occurrence of species-weighted fish fillet average PCB concentration below risk-based remediation goal of 0.05 mg/kg. Target concentrations of 0.2 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/month) and 0.4 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/ 2 months) are also italicized.

Upper Hudson River average is weighted by river section length:

River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 38

Upper Hudson River Modeled Times (Years) of Compliance with Human Health Risk-Based Concentrations Resuspension Scenarios

	No Resuspension (d004)	350 ng/L (sr04)	600 g/day (sr01)	MNA
Upper River Average				
Human Health risk-based RG 0.05 mg/kg	>2067	>2067	>2067	>2067
Fish Target Concentration 0.2 mg/kg	2024	2025	2024	2035
Fish Target Concentration 0.4 mg/kg	2013	2015	2013	2024
River Section 1- RM 189				
Human Health risk-based RG 0.05 mg/kg	>2067	>2067	>2067	>2067
Fish Target Concentration 0.2 mg/kg	>2067	>2067	>2067	>2067
Fish Target Concentration 0.4 mg/kg	2026	2030	2026	2043
River Section 2- RM 184				
Human Health risk-based RG 0.05 mg/kg	>2067	>2067	>2067	>2067
Fish Target Concentration 0.2 mg/kg	2044	2044	2044	2061
Fish Target Concentration 0.4 mg/kg	2025	2028	2026	2038
River Section 3- RM 154				
Human Health RG 0.05 mg/kg	2051	2055	2051	2059
Fish Target Concentration 0.2 mg/kg	2014	2020	2017	2019
Fish Target Concentration 0.4 mg/kg	2010	2014	2012	2011

Note: RG = risk-based remediation goal

Upper Hudson River average is weighted by river section length. River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 39
Resuspension Scenarios - Long-Term Fish Ingestion
Reasonable Maximum Exposure and Central Tendency PCB Non-Cancer Hazard Indices
Upper Hudson River Fish - Adult Angler

Remedial Alternative	PCB Conc. in Fish (mg/kg ww)	Intake (Non-Cancer) (mg/kg-day)	Reference Dose (mg/kg-day)	Hazard Index
Reasonable Maximum Exposure				
Upper Hudson Average				
No Resuspension d004	0.30	1.4E-04	2.0E-05	6.9
350 ng/L sr04	0.58	2.6E-04	2.0E-05	13
600 g/day sr01	0.50	2.3E-04	2.0E-05	11
MNA	1.4	6.4E-04	2.0E-05	32
River Section 1 (RM 189)				
No Resuspension d004	0.62	2.8E-04	2.0E-05	14
350 ng/L sr04	0.64	2.9E-04	2.0E-05	15
600 g/day sr01	0.62	2.8E-04	2.0E-05	14
MNA	1.7	7.7E-04	2.0E-05	39
River Section 2 (RM 184)				
No Resuspension d004	0.66	3.0E-04	2.0E-05	15
350 ng/L sr04	0.79	3.6E-04	2.0E-05	18
600 g/day sr01	0.67	3.1E-04	2.0E-05	15
MNA	2.3	1.0E-03	2.0E-05	52
River Section 3 (RM 154)				
No Resuspension d004	0.18	8.0E-05	2.0E-05	4.0
350 ng/L sr04	0.30	1.4E-04	2.0E-05	6.8
600 g/day sr01	0.21	9.7E-05	2.0E-05	4.8
MNA	0.23	1.1E-04	2.0E-05	5.4
Central Tendency				
Upper Hudson Average				
No Resuspension d004	0.27	1.2E-05	2.0E-05	0.6
350 ng/L sr04	0.52	2.4E-05	2.0E-05	1.2
600 g/day sr01	0.46	2.1E-05	2.0E-05	1.0
MNA	1.2	5.5E-05	2.0E-05	2.8
River Section 1 (RM 189)				
No Resuspension d004	0.60	2.7E-05	2.0E-05	1.4
350 ng/L sr04	0.61	2.8E-05	2.0E-05	1.4
600 g/day sr01	0.59	2.7E-05	2.0E-05	1.4
MNA	1.50	6.9E-05	2.0E-05	3.5
River Section 2 (RM 184)				
No Resuspension d004	0.59	2.7E-05	2.0E-05	1.4
350 ng/L sr04	0.70	3.2E-05	2.0E-05	1.6
600 g/day sr01	0.60	2.7E-05	2.0E-05	1.4
MNA	1.9	8.7E-05	2.0E-05	4.4
River Section 3 (RM 154)				
No Resuspension d004	0.15	6.8E-06	2.0E-05	0.3
350 ng/L sr04	0.24	1.1E-05	2.0E-05	0.5
600 g/day sr01	0.18	8.0E-06	2.0E-05	0.4
MNA	0.21	9.4E-06	2.0E-05	0.5

Notes: The RME non-cancer exposure time frame is seven years, while the CT time frame is 12 years.
Upper Hudson River average is weighted by river section length. River Section 1: 6.3 miles = 15.4%;
River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 40
Resuspension Standard Scenarios - Long-Term Fish Ingestion
Reasonable Maximum Exposure and Central Tendency Cancer Risks
Upper Hudson River Fish - Adult Angler

Remedial Alternative	PCB Conc. in Fish (mg/kg ww)	Intake (Cancer) (mg/kg-day)	Cancer Slope Factor (mg/kg-day)	Cancer Risk
Reasonable Maximum Exposure				
Upper Hudson Average				
No Resuspension d004	0.18	4.6E-05	2	9.3E-05
350 ng/L sr04	0.32	8.3E-05	2	1.7E-04
600 g/day sr01	0.30	7.7E-05	2	1.5E-04
MNA	0.60	1.7E-04	2	3.3E-04
River Section 1 (RM 189)				
No Resuspension d004	0.43	1.1E-04	2	2.2E-04
350 ng/L sr04	0.43	1.1E-04	2	2.2E-04
600 g/day sr01	0.42	1.1E-04	2	2.2E-04
MNA	0.86	2.2E-04	2	4.5E-04
River Section 2 (RM 184)				
No Resuspension d004	0.36	9.3E-05	2	1.9E-04
350 ng/L sr04	0.40	1.0E-04	2	2.1E-04
600 g/day sr01	0.36	9.4E-05	2	1.9E-04
MNA	0.90	2.4E-04	2	4.9E-04
River Section 3 (RM 154)				
No Resuspension d004	0.09	2.4E-05	2	4.8E-05
350 ng/L sr04	0.12	3.2E-05	2	6.4E-05
600 g/day sr01	0.10	2.7E-05	2	5.3E-05
MNA	0.12	3.2E-05	2	6.4E-05
Central Tendency				
Upper Hudson Average				
No Resuspension d004	0.27	2.1E-06	1	2.1E-06
350 ng/L sr04	0.52	4.0E-06	1	4.0E-06
600 g/day sr01	0.46	3.6E-06	1	3.6E-06
MNA	1.2	9.5E-06	1	9.5E-06
River Section 1 (RM 189)				
No Resuspension d004	0.60	4.7E-06	1	4.7E-06
350 ng/L sr04	0.61	4.8E-06	1	4.8E-06
600 g/day sr01	0.59	4.7E-06	1	4.7E-06
MNA	1.5	1.2E-05	1	1.2E-05
River Section 2 (RM 184)				
No Resuspension d004	0.59	4.7E-06	1	4.7E-06
350 ng/L sr04	0.70	5.5E-06	1	5.5E-06
600 g/day sr01	0.60	4.7E-06	1	4.7E-06
MNA	1.9	1.5E-05	1	1.5E-05
River Section 3 (RM 154)				
No Resuspension d004	0.15	1.2E-06	1	1.2E-06
350 ng/L sr04	0.24	1.9E-06	1	1.9E-06
600 g/day sr01	0.18	1.4E-06	1	1.4E-06
MNA	0.21	1.6E-06	1	1.6E-06

Notes: The RME cancer exposure time frame is 40 years, while the CT time frame is 12 years.
Upper Hudson River average is weighted by river section length. River Section 1: 6.3 miles = 15.4%;
River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 41
Mid-Hudson River
Species-Weighted Fish Fillet Average PCB Concentration (in mg/kg)

	No Resuspension (d004)			350 ng/L (sr04)		
Year	River Section 1 (RM 152)	River Section 2 (RM 113)	River Section 3 (RM 90)	River Section 1 (RM 152)	River Section 2 (RM 113)	River Section 3 (RM 90)
1999	1.150	0.963	0.792	1.150	0.963	0.792
2000	1.080	0.851	0.712	1.080	0.851	0.712
2001	1.154	0.821	0.656	1.154	0.821	0.656
2002	0.972	0.745	0.611	0.972	0.745	0.611
2003	0.837	0.658	0.553	0.837	0.658	0.553
2004	0.622	0.537	0.485	0.622	0.537	0.485
2005	0.592	0.462	0.420	0.598	0.463	0.420
2006	0.605	0.435	***0.373***	0.661	0.453	***0.375***
2007	0.522	***0.398***	0.337	0.641	0.441	0.349
2008	***0.386***	0.335	0.301	0.560	0.407	0.326
2009	0.316	0.278	0.263	0.537	0.370	0.296
2010	0.308	0.250	0.231	0.734	0.420	0.294
2011	0.307	0.234	0.208	1.119	0.558	0.325
2012	0.247	0.205	***0.187***	0.570	0.464	0.329
2013	0.253	***0.192***	0.170	0.443	***0.381***	0.308
2014	0.217	0.172	0.155	***0.330***	0.305	0.274
2015	***0.181***	0.152	0.140	0.259	0.245	0.238
2016	0.136	0.127	0.125	***0.186***	***0.190***	0.201
2017	0.118	0.110	0.111	0.138	0.149	***0.168***
2018	0.110	0.098	0.099	0.118	0.123	0.139
2019	0.093	0.086	0.088	0.095	0.099	0.115
2020	0.108	0.084	0.080	0.109	0.090	0.098
2021	0.101	0.081	0.075	0.101	0.084	0.086
2022	0.087	0.075	0.071	0.087	0.077	0.078
2023	0.080	0.070	0.066	0.080	0.071	0.071
2024	0.085	0.069	0.064	0.085	0.070	0.066
2025	0.088	0.070	0.063	0.088	0.071	0.064
2026	0.083	0.068	0.061	0.083	0.068	0.062
2027	0.069	0.063	0.059	0.069	0.063	0.060
2028	0.068	0.060	0.056	0.068	0.060	0.057
2029	0.076	0.060	0.055	0.076	0.060	0.055
2030	0.074	0.060	0.054	0.074	0.060	0.054
2031	0.068	0.058	0.054	0.068	0.058	0.054
2032	0.067	0.058	0.053	0.067	0.058	0.053
2033	0.063	0.056	0.052	0.063	0.056	0.052
2034	0.064	0.055	0.051	0.064	0.055	0.051
2035	0.095	0.063	0.052	0.095	0.063	0.052
2036	0.126	0.078	0.056	0.126	0.078	0.056
2037	0.141	0.091	0.063	0.141	0.091	0.063
2038	0.138	0.093	0.068	0.138	0.094	0.068
2039	0.122	0.091	0.070	0.122	0.091	0.070
2040	0.106	0.086	0.070	0.106	0.086	0.070
2041	0.081	0.075	0.067	0.081	0.075	0.067
2042	0.069	0.066	0.063	0.069	0.066	0.063
2043	0.079	0.064	0.059	0.079	0.064	0.059
2044	0.091	0.067	0.058	0.091	0.067	0.058
2045	0.085	0.067	0.057	0.085	0.067	0.057
2046	0.076	0.063	0.056	0.076	0.063	0.056

BOLD-ITALICIZED - First occurrence of species-weighted fish fillet average PCB concentration below risk-based remediation goal of 0.05 mg/kg. Target concentrations of 0.2 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/month) and 0.4 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/ 2 months) are also italicized.

Note: Fish concentrations were not available for all species used to model Mid-Hudson River angler consumption. Therefore, the concentrations here provide only an estimate of fish concentrations.

Table 41
Mid-Hudson River
Species-Weighted Fish Fillet Average PCB Concentration (in mg/kg)

	600 g/day (sr01)			Monitored Natural Attenuation		
Year	River Section 1 (RM 152)	River Section 2 (RM 113)	River Section 3 (RM 90)	River Section 1 (RM 152)	River Section 2 (RM 113)	River Section 3 (RM 90)
1999	1.150	0.963	0.792	1.126	0.952	0.788
2000	1.080	0.851	0.712	1.093	0.848	0.708
2001	1.154	0.821	0.656	1.138	0.822	0.654
2002	0.972	0.745	0.611	0.959	0.742	0.607
2003	0.837	0.658	0.553	0.826	0.655	0.549
2004	0.622	0.537	0.485	0.611	0.532	0.482
2005	0.595	0.463	0.420	0.580	0.459	0.417
2006	0.633	0.444	***0.374***	0.598	0.432	***0.370***
2007	0.589	0.420	0.343	0.500	***0.394***	0.334
2008	0.478	***0.374***	0.314	***0.388***	0.333	0.299
2009	0.420	0.321	0.280	0.333	0.279	0.261
2010	0.467	0.316	0.259	0.367	0.272	0.236
2011	0.549	0.335	0.251	0.391	0.276	0.222
2012	***0.343***	0.284	0.235	0.338	0.256	0.210
2013	0.313	0.252	0.215	0.352	0.252	***0.199***
2014	0.253	0.216	***0.193***	0.303	0.230	0.188
2015	0.205	***0.182***	0.171	0.246	0.202	0.173
2016	***0.152***	0.147	0.149	***0.185***	***0.167***	0.155
2017	0.130	0.124	0.130	0.171	0.145	0.138
2018	0.120	0.109	0.113	0.165	0.136	0.125
2019	0.100	0.094	0.098	0.143	0.120	0.112
2020	0.115	0.090	0.088	0.168	0.120	0.104
2021	0.106	0.085	0.081	0.153	0.115	0.098
2022	0.091	0.079	0.075	0.127	0.106	0.093
2023	0.084	0.073	0.070	0.119	0.097	0.087
2024	0.088	0.072	0.066	0.127	0.097	0.084
2025	0.091	0.073	0.065	0.131	0.100	0.083
2026	0.085	0.070	0.063	0.119	0.095	0.081
2027	0.070	0.065	0.061	0.098	0.087	0.078
2028	0.070	0.061	0.058	0.098	0.081	0.073
2029	0.078	0.061	0.056	0.106	0.081	0.070
2030	0.075	0.061	0.055	0.102	0.079	0.068
2031	0.069	0.059	0.054	0.094	0.077	0.067
2032	0.068	0.058	0.054	0.092	0.077	0.068
2033	0.064	0.056	0.052	0.084	0.073	0.066
2034	0.062	0.055	0.051	0.086	0.071	0.063
2035	0.069	0.056	0.050	0.118	0.079	0.064
2036	0.068	0.055	***0.050***	0.145	0.093	0.067
2037	0.111	0.070	0.053	0.166	0.107	0.074
2038	0.152	0.088	0.060	0.156	0.107	0.079
2039	0.141	0.094	0.066	0.139	0.105	0.080
2040	0.123	0.093	0.070	0.120	0.098	0.080
2041	0.094	0.083	0.069	0.092	0.085	0.076
2042	0.078	0.072	0.066	0.078	0.073	0.070
2043	0.088	0.071	0.063	0.093	0.073	0.066
2044	0.097	0.073	0.062	0.107	0.077	0.064
2045	0.087	0.070	0.060	0.098	0.076	0.064
2046	0.078	0.066	0.058	0.086	0.072	0.062

BOLD-ITALICIZED - First occurrence of species-weighted fish fillet average PCB concentration below risk-based remediation goal of 0.05 mg/kg. Target concentrations of 0.2 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/month) and 0.4 mg/kg PCBs (protective at a fish consumption rate of 0.5 lbs/ 2 months) are also italicized.

Note: Fish concentrations were not available for all species used to model Mid-Hudson River angler consumption. Therefore, the concentrations here provide only an estimate of fish concentrations.

Table 42
Upper Hudson River Average Largemouth Bass (Whole Fish) PCB Concentration (in mg/kg)

Year	**No Resuspension (d004)**				**Total PCB 350 ng/L (sr04)**			
	Upper River Average	**Section 1 (RM 189)**	**Section 2 (RM 184)**	**Section 3 (RM 154)**	**Upper River Average**	**Section 1 (RM 189)**	**Section 2 (RM 184)**	**Section 3 (RM 154)**
1998	7.13	16.73	17.22	3.33	7.13	16.70	17.24	3.33
1999	7.04	17.11	16.80	3.20	7.04	17.12	16.83	3.20
2000	5.84	13.71	14.51	2.66	5.84	13.74	14.47	2.66
2001	5.29	12.01	13.33	2.47	5.30	12.04	13.32	2.47
2002	4.91	11.63	12.30	2.20	4.92	11.66	12.29	2.20
2003	4.43	10.12	11.39	2.01	4.43	10.11	11.40	2.01
2004	5.12	14.37	11.49	2.04	5.12	14.38	11.48	2.04
2005	3.94	9.68	9.91	1.67	3.95	9.67	9.97	1.68
2006	3.14	6.44	8.80	1.45	3.38	6.61	9.48	1.63
2007	2.96	6.45	8.04	1.33	3.63	8.59	9.25	1.59
2008	2.59	5.37	7.38	1.17	3.88	11.02	8.77	1.51
2009	2.00	4.08	5.15	1.02	3.06	6.90	7.31	1.50
2010	1.35	2.88	2.56	0.81	2.14	3.17	3.68	1.66
2011	1.00	2.02	1.57	0.68	1.94	2.18	2.05	1.86
2012	0.94	2.35	1.48	0.55	1.38	2.45	1.85	1.07
2013	0.76	1.69	1.30	0.47	1.08	1.75	1.59	0.85
2014	0.72	1.80	1.22	0.41	0.97	1.81	1.44	0.71
2015	0.64	1.52	1.16	0.37	0.85	1.53	1.35	0.62
2016	0.68	1.72	1.26	0.36	0.87	1.72	1.43	0.59
2017	0.73	2.17	1.18	0.35	0.89	2.16	1.34	0.54
2018	0.66	1.93	1.09	0.32	0.79	1.91	1.24	0.48
2019	0.72	2.34	1.13	***0.30***	0.83	2.32	1.28	0.43
2020	0.59	1.89	0.92	0.26	0.68	1.86	1.06	0.36
2021	0.51	1.44	0.90	0.25	0.59	1.43	1.03	0.33
2022	0.51	1.43	0.92	0.24	0.58	1.43	1.04	0.33
2023	0.54	1.69	0.88	0.24	0.60	1.67	0.98	0.30
2024	0.49	1.58	0.79	0.20	0.53	1.57	0.87	***0.25***
2025	0.43	1.29	0.74	0.19	0.46	1.29	0.80	0.23
2026	0.38	1.08	0.71	0.18	0.41	1.07	0.75	0.21
2027	0.47	1.60	0.74	0.18	0.50	1.59	0.78	0.21
2028	0.46	1.69	0.65	0.16	0.48	1.69	0.68	0.18
2029	0.39	1.34	0.63	0.15	0.41	1.33	0.65	0.17
2030	0.35	0.99	0.63	0.16	0.36	0.98	0.65	0.18
2031	0.40	1.42	0.58	0.15	0.41	1.41	0.61	0.16
2032	0.35	1.18	0.55	0.14	0.36	1.18	0.58	0.15
2033	0.34	1.14	0.53	0.13	0.35	1.13	0.56	0.14
2034	0.34	1.23	0.49	0.13	0.35	1.23	0.52	0.13
2035	***0.29***	0.88	0.47	0.14	***0.28***	0.87	0.50	0.12
2036	0.40	1.21	0.48	0.22	0.33	1.21	0.50	0.11
2037	0.36	0.98	0.46	0.21	0.29	0.98	0.49	0.11
2038	0.36	1.13	0.43	0.19	0.33	1.13	0.45	0.14
2039	0.33	0.89	0.42	0.19	0.34	0.89	0.44	0.21
2040	0.31	0.86	0.42	0.17	0.33	0.86	0.44	0.20

Notes:

1. Fish fillets multiplied by 2.5 to obtain whole fish concentrations.
2. All whole fish PCB concentrations are above target fish concentration of 0.3 mg/kg and/or 0.03 mg/kg based on the river otter lowest-observed-adverse-effects-level (LOAEL) and no-observed-adverse-effects-level (NOAEL), respectively.

Upper Hudson River average is weighted by river section length:
River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 42
Upper Hudson River Average Largemouth Bass (Whole Fish)
PCB Concentration (in mg/kg)

	No Resuspension (d004)				**Total PCB 350 ng/L (sr04)**			
Year	**Upper River Average**	**Section 1 (RM 189)**	**Section 2 (RM 184)**	**Section 3 (RM 154)**	**Upper River Average**	**Section 1 (RM 189)**	**Section 2 (RM 184)**	**Section 3 (RM 154)**
2041	0.37	1.23	0.44	0.18	0.40	1.23	0.45	0.22
2042	0.39	1.40	0.46	0.16	0.42	1.40	0.47	0.20
2043	0.33	1.10	0.39	0.15	0.35	1.10	0.40	0.18
2044	0.28	0.82	0.37	0.14	0.29	0.82	0.37	0.16
2045	0.30	0.97	0.38	0.14	0.31	0.97	0.38	0.16
2046	0.27	0.86	0.36	0.13	0.28	0.86	0.36	0.14
2047	0.28	0.93	0.37	0.13	0.29	0.91	0.37	0.14
2048	0.30	1.08	0.37	0.13	0.31	1.07	0.37	0.14
2049	0.31	1.14	0.39	0.12	0.33	1.15	0.39	0.14
2050	0.28	0.96	0.36	0.12	0.29	0.96	0.36	0.13
2051	0.27	0.96	0.36	0.10	0.28	0.96	0.36	0.11
2052	0.24	0.80	0.36	0.10	0.25	0.80	0.36	0.11
2053	0.32	1.26	0.38	0.11	0.32	1.26	0.38	0.12
2054	0.29	1.08	0.38	0.11	0.29	1.08	0.38	0.11
2055	0.26	0.93	0.36	0.10	0.26	0.93	0.36	0.11
2056	0.28	1.03	0.41	0.10	0.29	1.02	0.40	0.11
2057	0.29	1.14	0.37	0.10	0.30	1.14	0.37	0.10
2058	0.25	0.85	0.37	0.10	0.25	0.85	0.37	0.10
2059	0.31	1.27	0.36	0.10	0.31	1.26	0.36	0.10
2060	0.24	0.88	0.35	0.09	0.25	0.87	0.35	0.09
2061	0.23	0.79	0.33	0.09	0.23	0.79	0.33	0.09
2062	0.25	0.89	0.34	0.09	0.25	0.89	0.34	0.09
2063	0.24	0.89	0.35	0.09	0.25	0.89	0.34	0.09
2064	0.25	0.92	0.36	0.09	0.25	0.92	0.36	0.09
2065	0.25	0.88	0.36	0.10	0.25	0.87	0.36	0.10
2066	0.30	1.25	0.34	0.09	0.30	1.25	0.34	0.09
2067	0.26	0.95	0.37	0.09	0.26	0.95	0.37	0.09

Notes:
1. Fish fillets multiplied by 2.5 to obtain whole fish concentrations.
2. All whole fish PCB concentrations are above target fish concentration of 0.3 mg/kg and/or 0.03 mg/kg based on the river otter lowest-observed-adverse-effects-level (LOAEL) and no-observed-adverse-effects-level (NOAEL), respectively.

Upper Hudson River average is weighted by river section length:
River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 42
Upper Hudson River Average Largemouth Bass (Whole Fish) PCB Concentration (in mg/kg)

Year	**Total PCB 600 g/day (sr01)**				**Monitored Natural Attenuation**			
	Upper River Average	**Section 1 (RM 189)**	**Section 2 (RM 184)**	**Section 3 (RM 154)**	**Upper River Average**	**Section 1 (RM 189)**	**Section 2 (RM 184)**	**Section 3 (RM 154)**
1998	7.13	16.70	17.24	3.33	7.19	16.61	18.04	3.29
1999	7.04	17.12	16.83	3.20	6.76	16.16	15.91	3.17
2000	5.84	13.74	14.47	2.66	5.74	13.09	14.57	2.64
2001	5.30	12.04	13.32	2.47	5.13	11.34	12.94	2.45
2002	4.92	11.66	12.29	2.20	4.76	11.11	11.84	2.18
2003	4.43	10.11	11.40	2.01	4.33	9.92	10.73	2.03
2004	5.12	14.38	11.48	2.04	4.88	13.63	10.57	2.02
2005	3.94	9.67	9.95	1.68	3.85	9.04	10.09	1.66
2006	3.28	6.57	9.17	1.55	3.06	5.97	8.70	1.46
2007	3.35	7.78	8.73	1.47	2.96	6.39	7.95	1.36
2008	3.40	9.02	8.30	1.36	2.78	6.45	7.30	1.21
2009	2.49	5.39	5.93	1.27	2.60	6.16	6.88	1.10
2010	1.65	3.00	2.76	1.17	2.31	5.51	6.40	0.92
2011	1.34	2.12	1.67	1.11	1.95	4.24	5.61	0.83
2012	1.07	2.41	1.54	0.70	1.78	4.21	5.16	0.68
2013	0.85	1.71	1.34	0.59	1.55	3.47	4.60	0.61
2014	0.79	1.80	1.23	0.50	1.46	3.49	4.23	0.55
2015	0.70	1.51	1.16	0.44	1.33	3.13	3.87	0.50
2016	0.73	1.71	1.26	0.43	1.36	3.53	3.65	0.50
2017	0.77	2.16	1.18	0.40	1.38	3.73	3.60	0.49
2018	0.70	1.92	1.10	0.37	1.24	3.29	3.21	0.46
2019	0.75	2.33	1.14	0.34	1.25	3.68	2.94	0.43
2020	0.61	1.87	0.93	***0.29***	1.08	3.02	2.71	0.38
2021	0.53	1.42	0.91	0.27	0.93	2.43	2.40	0.36
2022	0.53	1.42	0.93	0.27	0.93	2.51	2.26	0.36
2023	0.55	1.68	0.89	0.25	0.94	2.67	2.21	0.35
2024	0.50	1.57	0.81	0.21	0.82	2.26	2.05	***0.29***
2025	0.44	1.28	0.76	0.20	0.73	1.98	1.82	0.28
2026	0.39	1.06	0.72	0.19	0.66	1.69	1.68	0.26
2027	0.48	1.59	0.75	0.19	0.75	2.29	1.66	0.27
2028	0.46	1.69	0.66	0.17	0.73	2.33	1.61	0.23
2029	0.40	1.33	0.62	0.16	0.62	1.83	1.44	0.22
2030	0.35	0.98	0.62	0.17	0.55	1.45	1.33	0.23
2031	0.40	1.41	0.58	0.15	0.59	1.86	1.27	0.21
2032	0.35	1.18	0.55	0.14	0.53	1.59	1.13	0.20
2033	0.34	1.13	0.53	0.13	0.49	1.47	1.04	0.18
2034	0.34	1.23	0.49	0.13	0.48	1.50	0.98	0.17
2035	***0.28***	0.87	0.48	0.12	0.41	1.12	0.87	0.18
2036	0.33	1.20	0.48	0.12	0.51	1.43	0.85	0.26
2037	0.32	0.98	0.47	0.15	0.45	1.19	0.75	0.24
2038	0.37	1.13	0.43	0.20	0.45	1.32	0.72	0.22
2039	0.34	0.89	0.42	0.21	0.41	1.09	0.68	0.22
2040	0.32	0.86	0.42	0.19	0.38	0.98	0.63	0.20

Notes:

1. Fish fillets multiplied by 2.5 to obtain whole fish concentrations.
2. All whole fish PCB concentrations are above target fish concentration of 0.3 mg/kg and/or 0.03 mg/kg based on the river otter lowest-observed-adverse-effects-level (LOAEL) and no-observed-adverse-effects-level (NOAEL), respectively.

Upper Hudson River average is weighted by river section length:
River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 42
Upper Hudson River Average Largemouth Bass (Whole Fish) PCB Concentration (in mg/kg)

	Total PCB 600 g/day (sr01)				**Monitored Natural Attenuation**			
Year	**Upper River Average**	**Section 1 (RM 189)**	**Section 2 (RM 184)**	**Section 3 (RM 154)**	**Upper River Average**	**Section 1 (RM 189)**	**Section 2 (RM 184)**	**Section 3 (RM 154)**
2041	0.39	1.23	0.44	0.20	0.45	1.42	0.66	0.21
2042	0.41	1.40	0.46	0.18	0.46	1.56	0.65	0.19
2043	0.34	1.10	0.40	0.16	0.39	1.22	0.62	0.17
2044	0.28	0.83	0.37	0.15	0.32	0.88	0.55	0.16
2045	0.31	1.00	0.38	0.15	0.34	1.04	0.52	0.16
2046	0.28	0.88	0.36	0.14	0.32	0.95	0.51	0.15
2047	0.29	0.93	0.37	0.14	0.35	1.17	0.49	0.15
2048	0.31	1.07	0.37	0.13	0.39	1.42	0.50	0.15
2049	0.32	1.13	0.39	0.13	0.38	1.39	0.50	0.14
2050	0.28	0.95	0.37	0.12	0.34	1.21	0.49	0.13
2051	0.27	0.96	0.37	0.11	0.32	1.12	0.47	0.12
2052	0.25	0.82	0.36	0.11	***0.29***	0.98	0.44	0.12
2053	0.33	1.28	0.38	0.11	0.37	1.41	0.49	0.12
2054	0.30	1.10	0.38	0.11	0.32	1.18	0.46	0.12
2055	0.27	0.95	0.36	0.10	0.30	1.06	0.44	0.11
2056	0.29	1.04	0.41	0.10	0.32	1.16	0.45	0.11
2057	0.30	1.15	0.37	0.10	0.32	1.17	0.46	0.11
2058	0.25	0.87	0.38	0.10	0.27	0.91	0.43	0.11
2059	0.31	1.28	0.36	0.10	0.33	1.31	0.46	0.10
2060	0.25	0.89	0.35	0.09	0.26	0.93	0.40	0.10
2061	0.23	0.80	0.33	0.09	0.25	0.84	0.38	0.09
2062	0.25	0.90	0.34	0.09	0.26	0.91	0.38	0.10
2063	0.25	0.89	0.35	0.09	0.26	0.91	0.37	0.10
2064	0.25	0.92	0.36	0.09	0.27	0.97	0.38	0.10
2065	0.25	0.88	0.36	0.10	0.25	0.87	0.38	0.10
2066	0.30	1.25	0.34	0.09	0.31	1.26	0.40	0.09
2067	0.26	0.95	0.37	0.09	0.27	0.97	0.37	0.10

Notes:
1. Fish fillets multiplied by 2.5 to obtain whole fish concentrations.
2. All whole fish PCB concentrations are above target fish concentration of 0.3 mg/kg and/or 0.03 mg/kg based on the river otter lowest-observed-adverse-effects-level (LOAEL) and no-observed-adverse-effects-level (NOAEL), respectively.

Upper Hudson River average is weighted by river section length:
River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 43
Modeled Times of Compliance with River Otter Risk-Based Fish Concentrations Upper Hudson River

	River Otter - RI/FS TRVs (whole fish tissue)	
	LOAEL 0.3 PCBs mg/kg	NOAEL 0.03 PCBs mg/kg
Upper Hudson River Average		
No Resuspension (d004)	2035	> 2067
Total PCB 350 ng/L (sr04)	2035	> 2067
Total PCB 600 g/day (sr01)	2035	> 2067
Monitored Natural Attenuation	2052	> 2067
Upper Hudson River Section 1		
No Resuspension (d004)	> 2067	> 2067
Total PCB 350 ng/L (sr04)	> 2067	> 2067
Total PCB 600 g/day (sr01)	> 2067	> 2067
Monitored Natural Attenuation	> 2067	> 2067
Upper Hudson River Section 2		
No Resuspension (d004)	> 2067	> 2067
Total PCB 350 ng/L (sr04)	> 2067	> 2067
Total PCB 600 g/day (sr01)	> 2067	> 2067
Monitored Natural Attenuation	> 2067	> 2067
Upper Hudson River Section 3		
No Resuspension (d004)	2019	> 2067
Total PCB 350 ng/L (sr04)	2024	> 2067
Total PCB 600 g/day (sr01)	2020	> 2067
Monitored Natural Attenuation	2024	> 2067

Notes:
First year in which fish target concentrations are achieved are provided.
Upper Hudson River average is weighted by river section length. River Section 1: 6.3 miles = 15.4%; River Section 2: 5.1 miles = 12.5%; and River Section 3: 29.5 miles = 72.1%.

Table 44
Lower Hudson River Average Largemouth Bass (Whole Fish)
PCB Concentration (in mg/kg)

Year	No Resuspension (d004)				Total PCB 350 ng/L (sr04)			
	River Mile 152	River Mile 113	River Mile 90	River Mile 50	River Mile 152	River Mile 113	River Mile 90	River Mile 50
1998	7.15	5.21	3.55	3.26	7.15	5.21	3.55	3.26
1999	4.53	4.12	3.30	3.01	4.53	4.12	3.30	3.01
2000	3.81	3.56	2.93	2.73	3.81	3.56	2.93	2.73
2001	4.50	3.54	2.66	2.49	4.50	3.54	2.66	2.49
2002	3.97	3.19	2.49	2.31	3.97	3.19	2.49	2.31
2003	3.42	2.82	2.26	2.10	3.42	2.82	2.26	2.10
2004	2.42	2.26	1.97	1.89	2.42	2.26	1.97	1.89
2005	2.27	1.95	1.69	1.67	2.27	1.95	1.69	1.67
2006	2.37	1.85	1.49	1.48	2.53	1.89	1.49	1.49
2007	1.93	1.71	1.35	1.34	2.37	1.86	1.40	1.36
2008	1.54	1.41	1.22	1.20	2.33	1.77	1.33	1.25
2009	1.21	1.15	1.06	1.05	2.03	1.53	1.18	1.12
2010	1.10	1.02	0.92	0.94	2.55	1.71	1.16	1.06
2011	1.25	1.01	0.84	0.86	5.16	2.57	1.35	1.10
2012	0.92	0.86	0.75	0.77	2.17	2.06	1.38	1.13
2013	1.02	0.82	0.68	0.71	1.78	1.63	1.28	1.11
2014	0.86	0.74	0.62	0.64	1.33	1.29	1.12	1.04
2015	0.72	0.65	0.56	0.59	1.04	1.04	0.96	0.94
2016	0.55	0.53	0.50	0.53	0.76	0.78	0.79	0.83
2017	0.46	0.45	0.44	0.48	0.54	0.60	0.65	0.73
2018	0.43	0.41	0.39	0.44	0.45	0.50	0.54	0.63
2019	0.34	0.35	0.35	0.40	0.35	0.39	0.44	0.54
2020	0.42	0.35	0.32	0.36	0.42	0.37	0.38	0.46
2021	0.41	0.34	***0.30***	0.34	0.41	0.36	0.34	0.41
2022	0.35	0.32	0.29	0.32	0.35	0.33	0.31	0.37
2023	0.30	***0.29***	0.27	***0.30***	0.30	***0.29***	***0.28***	0.33
2024	0.32	0.28	0.25	0.28	0.32	0.28	0.26	0.31
2025	0.35	0.30	0.25	0.27	0.35	0.30	0.26	***0.29***
2026	0.33	0.29	0.25	0.27	0.33	0.29	0.25	0.28
2027	***0.26***	0.26	0.24	0.26	***0.26***	0.26	0.24	0.27
2028	0.24	0.24	0.23	0.25	0.24	0.25	0.23	0.26
2029	0.29	0.25	0.22	0.24	0.29	0.25	0.22	0.25
2030	0.29	0.25	0.22	0.24	0.29	0.25	0.22	0.24
2031	0.25	0.24	0.21	0.23	0.25	0.24	0.21	0.23
2032	0.25	0.24	0.21	0.23	0.25	0.24	0.21	0.23
2033	0.23	0.23	0.21	0.23	0.23	0.23	0.21	0.23
2034	0.22	0.22	0.20	0.22	0.22	0.22	0.20	0.22
2035	0.35	0.25	0.21	0.22	0.35	0.25	0.21	0.22
2036	0.48	0.32	0.23	0.23	0.48	0.32	0.23	0.23
2037	0.57	0.39	0.26	0.24	0.57	0.39	0.26	0.24
2038	0.58	0.40	0.28	0.26	0.58	0.40	0.28	0.26
2039	0.48	0.39	0.29	0.27	0.48	0.39	0.29	0.27
2040	0.43	0.37	0.29	0.27	0.43	0.37	0.29	0.27
2041	0.30	0.32	0.28	0.27	0.30	0.32	0.28	0.27
2042	0.25	0.27	0.26	0.26	0.25	0.27	0.26	0.26
2043	0.29	0.26	0.24	0.25	0.29	0.26	0.24	0.25
2044	0.35	0.28	0.23	0.24	0.35	0.28	0.23	0.25
2045	0.33	0.28	0.23	0.24	0.33	0.28	0.23	0.24
2046	0.29	0.26	0.22	0.24	0.29	0.26	0.22	0.24

Notes:
Fish fillets multiplied by 2.5 to obtain whole fish concentrations.
All whole fish PCB concentrations are above target fish concentration of 0.3 mg/kg and/or 0.03 mg/kg based on the river otter lowest-observed-adverse-effects-level (LOAEL) and no-observed-adverse-effects-level (NOAEL), respectively.

Table 44
Lower Hudson River Average Largemouth Bass (Whole Fish)
PCB Concentration (in mg/kg)

Year	Total PCB 600 g/day (sr01)				Monitored Natural Attenuation			
	River Mile 152	River Mile 113	River Mile 90	River Mile 50	River Mile 152	River Mile 113	River Mile 90	River Mile 50
1998	7.15	5.21	3.55	3.26	7.54	5.30	3.55	3.24
1999	4.53	4.12	3.30	3.01	4.37	4.06	3.28	2.99
2000	3.81	3.56	2.93	2.73	4.01	3.56	2.91	2.71
2001	4.50	3.54	2.66	2.49	4.51	3.54	2.65	2.47
2002	3.97	3.19	2.49	2.31	3.91	3.17	2.47	2.28
2003	3.42	2.82	2.26	2.10	3.39	2.82	2.25	2.08
2004	2.42	2.26	1.97	1.89	2.39	2.23	1.96	1.88
2005	2.27	1.95	1.69	1.67	2.25	1.94	1.68	1.66
2006	2.49	1.86	1.49	1.49	2.34	1.86	1.49	1.47
2007	2.20	1.79	1.38	1.34	1.89	1.70	1.35	1.32
2008	1.97	1.60	1.27	1.23	1.57	1.42	1.21	1.20
2009	1.62	1.34	1.12	1.08	1.27	1.16	1.06	1.05
2010	1.73	1.30	1.02	1.00	1.36	1.13	0.94	0.95
2011	2.43	1.49	1.01	0.96	1.63	1.22	0.91	0.89
2012	1.32	1.20	0.96	0.90	1.30	1.11	0.86	0.83
2013	1.27	1.08	0.88	0.84	1.48	1.13	0.83	0.79
2014	1.01	0.92	0.78	0.77	1.27	1.03	0.79	0.74
2015	0.82	0.78	0.69	0.70	1.00	0.90	0.73	0.70
2016	0.61	0.61	0.60	0.63	0.76	0.72	0.65	0.64
2017	0.51	0.51	0.51	0.56	0.68	0.62	0.57	0.59
2018	0.47	0.45	0.45	0.50	0.65	0.58	0.51	0.53
2019	0.37	0.38	0.39	0.45	0.52	0.50	0.46	0.49
2020	0.45	0.37	0.35	0.40	0.68	0.51	0.42	0.44
2021	0.44	0.36	0.32	0.36	0.63	0.49	0.40	0.41
2022	0.37	0.34	0.30	0.34	0.51	0.45	0.38	0.39
2023	0.32	0.30	***0.28***	0.32	0.46	0.41	0.35	0.37
2024	0.33	***0.29***	0.26	***0.30***	0.48	0.40	0.34	0.35
2025	0.37	0.31	0.26	0.29	0.53	0.43	0.34	0.34
2026	0.34	0.29	0.25	0.28	0.48	0.40	0.33	0.33
2027	***0.26***	0.27	0.24	0.27	0.37	0.36	0.32	0.32
2028	0.25	0.25	0.23	0.26	0.35	0.34	***0.30***	0.31
2029	0.30	0.25	0.22	0.25	0.42	0.34	0.28	***0.30***
2030	0.30	0.25	0.22	0.24	0.40	0.34	0.28	0.29
2031	0.25	0.24	0.22	0.24	0.34	0.32	0.27	0.28
2032	0.26	0.24	0.22	0.24	0.35	0.32	0.27	0.28
2033	0.23	0.23	0.21	0.23	0.31	0.30	0.26	0.28
2034	0.22	0.22	0.20	0.23	***0.29***	***0.29***	0.25	0.27
2035	0.27	0.23	0.20	0.22	0.42	0.33	0.25	0.26
2036	0.23	0.22	0.20	0.22	0.54	0.38	0.27	0.26
2037	0.40	0.28	0.21	0.22	0.69	0.46	0.30	0.28
2038	0.65	0.38	0.24	0.23	0.65	0.47	0.32	0.29
2039	0.56	0.41	0.27	0.25	0.55	0.44	0.33	0.30
2040	0.51	0.40	0.29	0.26	0.48	0.42	0.33	0.31
2041	0.35	0.35	0.28	0.27	0.35	0.36	0.31	0.30
2042	0.29	0.30	0.27	0.27	0.28	0.30	0.28	0.29
2043	0.33	0.29	0.25	0.26	0.35	0.30	0.26	0.28
2044	0.38	0.31	0.25	0.25	0.42	0.32	0.26	0.27
2045	0.34	0.30	0.24	0.25	0.38	0.32	0.26	0.26
2046	0.30	0.27	0.23	0.24	0.33	0.30	0.25	0.26

Notes:

Fish fillets multiplied by 2.5 to obtain whole fish concentrations.

All whole fish PCB concentrations are above target fish concentration of 0.3 mg/kg and/or 0.03 mg/kg based on the river otter lowest-observed-adverse-effects-level (LOAEL) and no-observed-adverse-effects-level (NOAEL), respectively.

Table 45
Modeled Times of Compliance with River Otter Risk-Based Fish Concentrations Lower Hudson River

	River Otter - RI/FS TRVs (whole fish tissue)	
	LOAEL 0.3 PCBs mg/kg	**NOAEL 0.03 PCBs mg/kg**
Lower Hudson River RM 152		
No Resuspension (d004)	2027	> 2067
Total PCB 350 ng/L (sr04)	2027	> 2067
Total PCB 600 g/day (sr01)	2027	> 2067
Monitored Natural Attenuation	2034	> 2067
Lower Hudson River RM 113		
No Resuspension (d004)	2023	> 2067
Total PCB 350 ng/L (sr04)	2023	> 2067
Total PCB 600 g/day (sr01)	2024	> 2067
Monitored Natural Attenuation	2034	> 2067
Lower Hudson River RM 90		
No Resuspension (d004)	2021	> 2067
Total PCB 350 ng/L (sr04)	2023	> 2067
Total PCB 600 g/day (sr01)	2023	> 2067
Monitored Natural Attenuation	2028	> 2067
Lower Hudson River RM 50		
No Resuspension (d004)	2023	> 2067
Total PCB 350 ng/L (sr04)	2025	> 2067
Total PCB 600 g/day (sr01)	2024	> 2067
Monitored Natural Attenuation	2029	> 2067

Notes:
First year in which fish target concentrations are achieved are provided.

Table 46
Sediment Characteristics

Fraction Name	Fraction by Weight (%)	Mass Release Rate (kg/hr)	Representative Grain Diameter (mm)	Fall velocity from Stokes equation[1](m/s)	Comments
Sand	0.19	91.5	2	3.21	Middle of ASTM 1990 “fine sand”
Silt	0.53	255.2	0.02	3.21 x 10-4	Middle of ASTM 1990 “silt”
Clay	0.28	134.8	0.002	3.21 x 10-6	Middle of ASTM 1990 “clay”

1. Stokes equation: Fall velocity (w) = gd2/rs-r)/18m, where g is 9.81 m/s2, d is the diameter of a spherical grain (m), rs is the density of sediment particles (kg/m3), r is the water density (999 kg/m3), and m is the dynamic viscosity of water (1.12 x 10-3 N-s/m2 at 15.6oC). A dry density of 700 kg/m3 was assumed for all sediments.

Table 47
Impact of Dispersion Coefficient on Predicted Peak Concentration and Length of Suspended Sediment Plume

Dispersion Coefficient (m2/s)	Peak suspended sediment concentration in immediate vicinity of dredge (mg/L) – above ambient conditions	Approximate length of plume at 5 mg/L contour (m)
0.1	390	900
1	72	800
10	13	120
100	2	0

Figures

CSTR-Chem
(0-10 m)

TSS-Chem
(10-1600 m)

HUDTOX
(Greater than 1 mile)

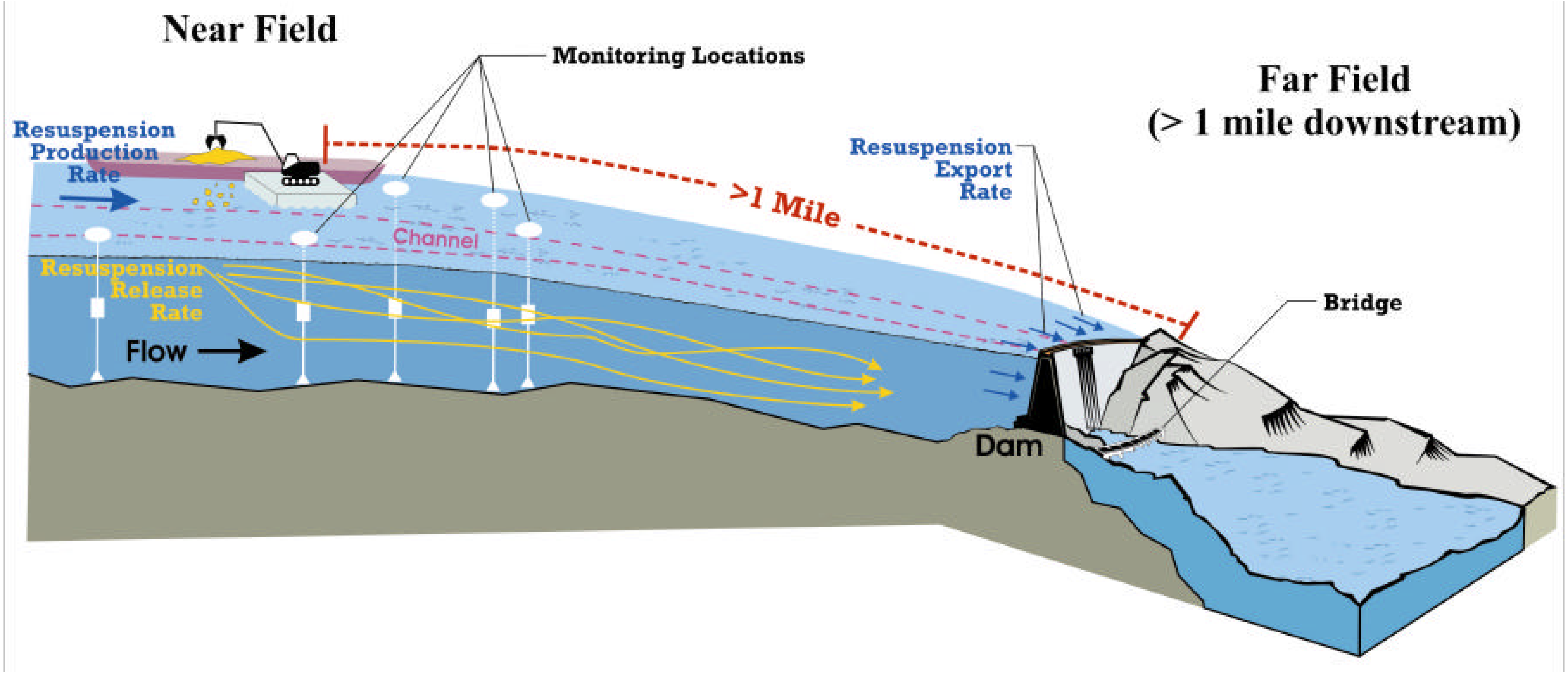
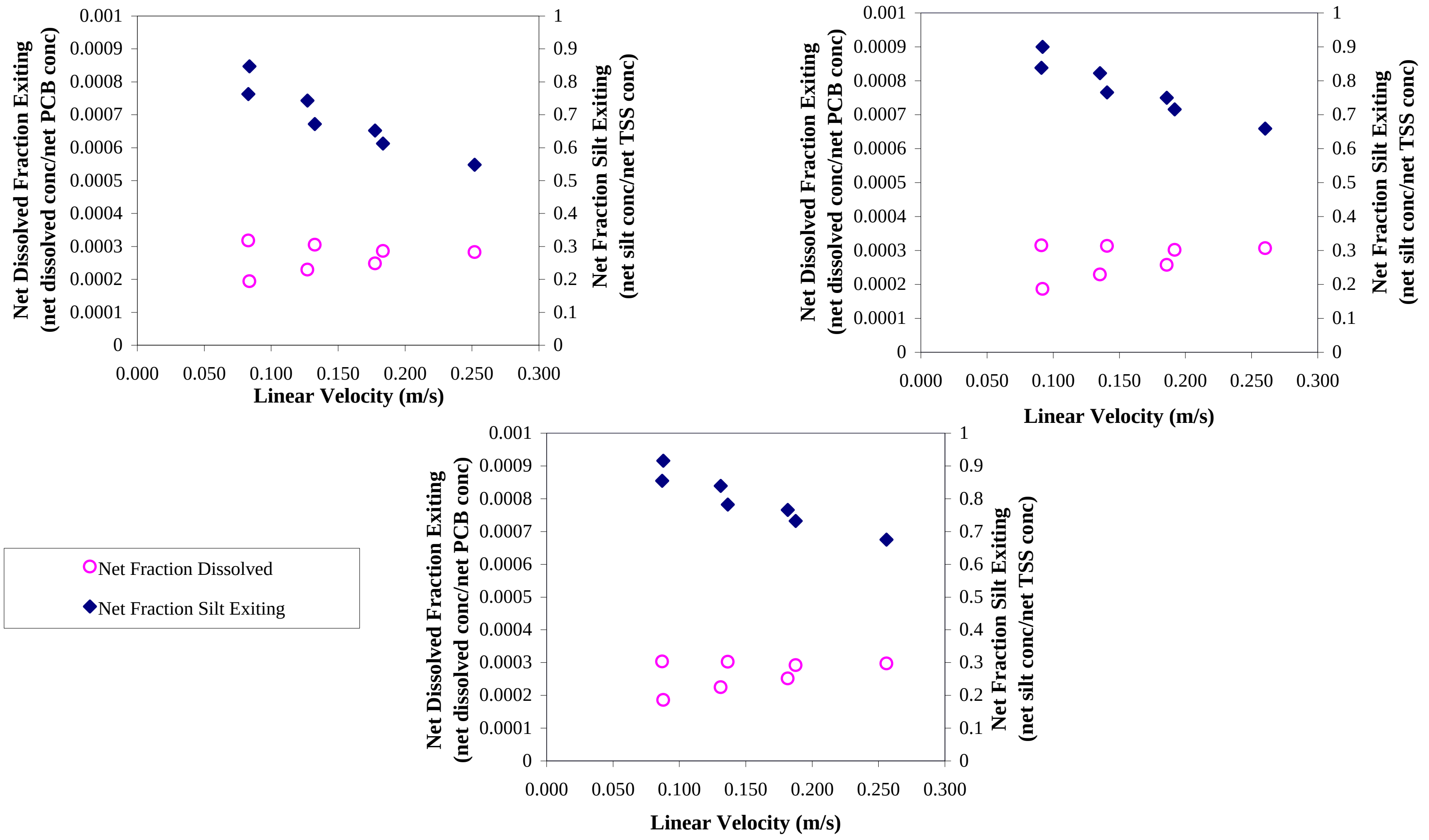


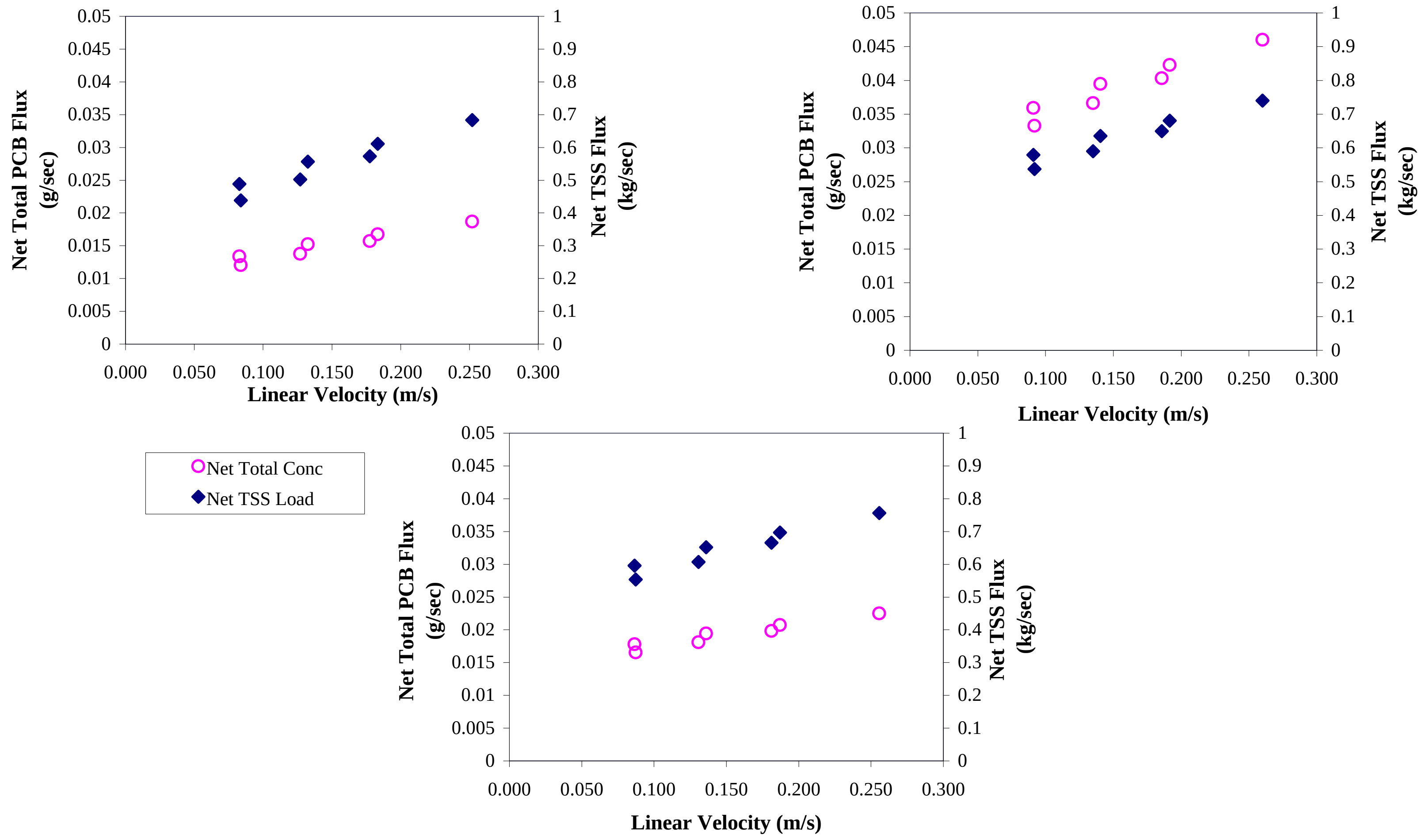
Figure 1. Interaction Among the Transport Models



Note: Net concentrations exclude background.

Figure 2

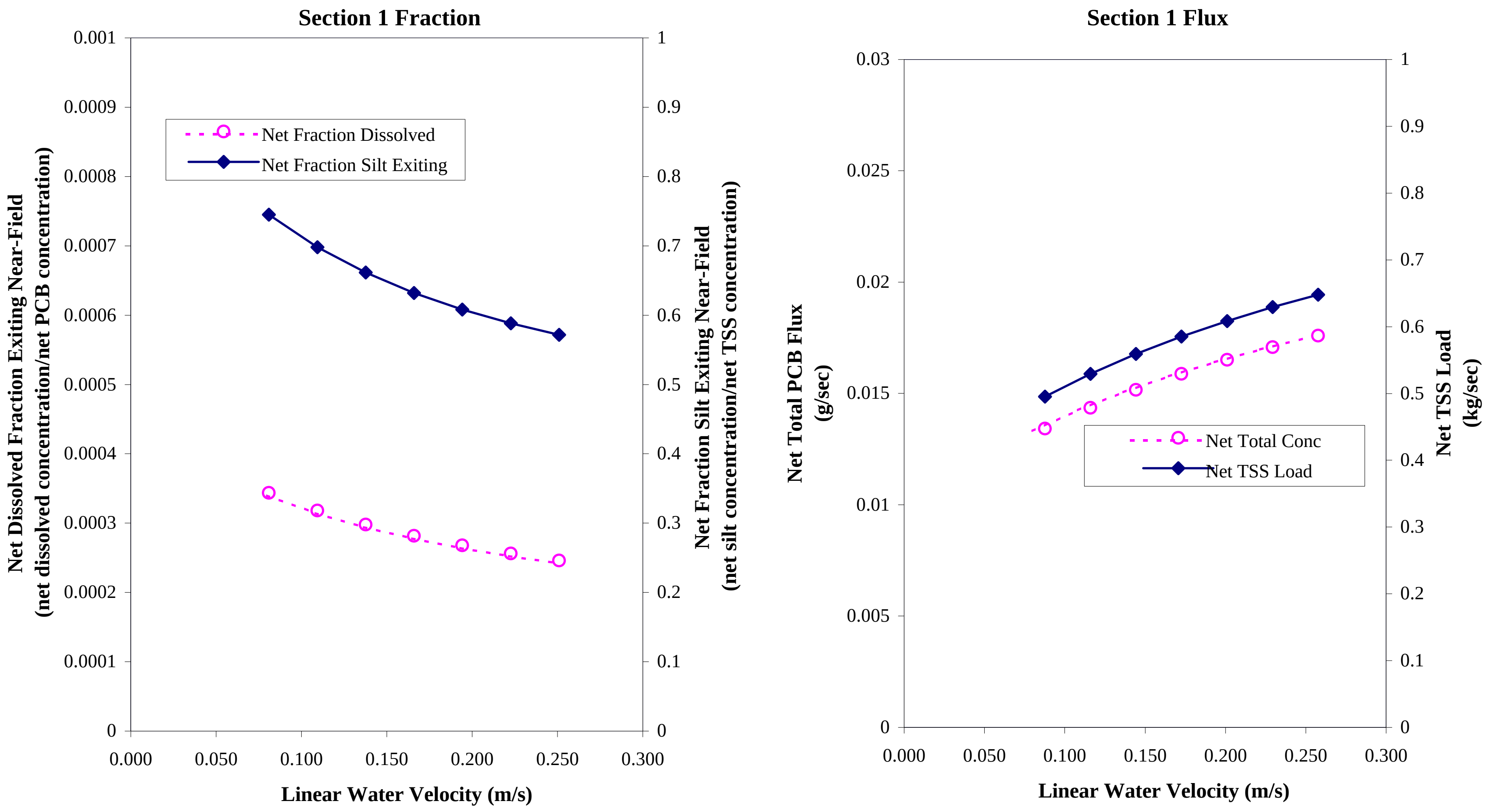
Sensitivity of Net Dissolved and Silt Fractions Exiting Near-Field with Variations in Linear Velocity and Depth for CSTR-Chem



Note: Net concentrations exclude background.

Figure 3

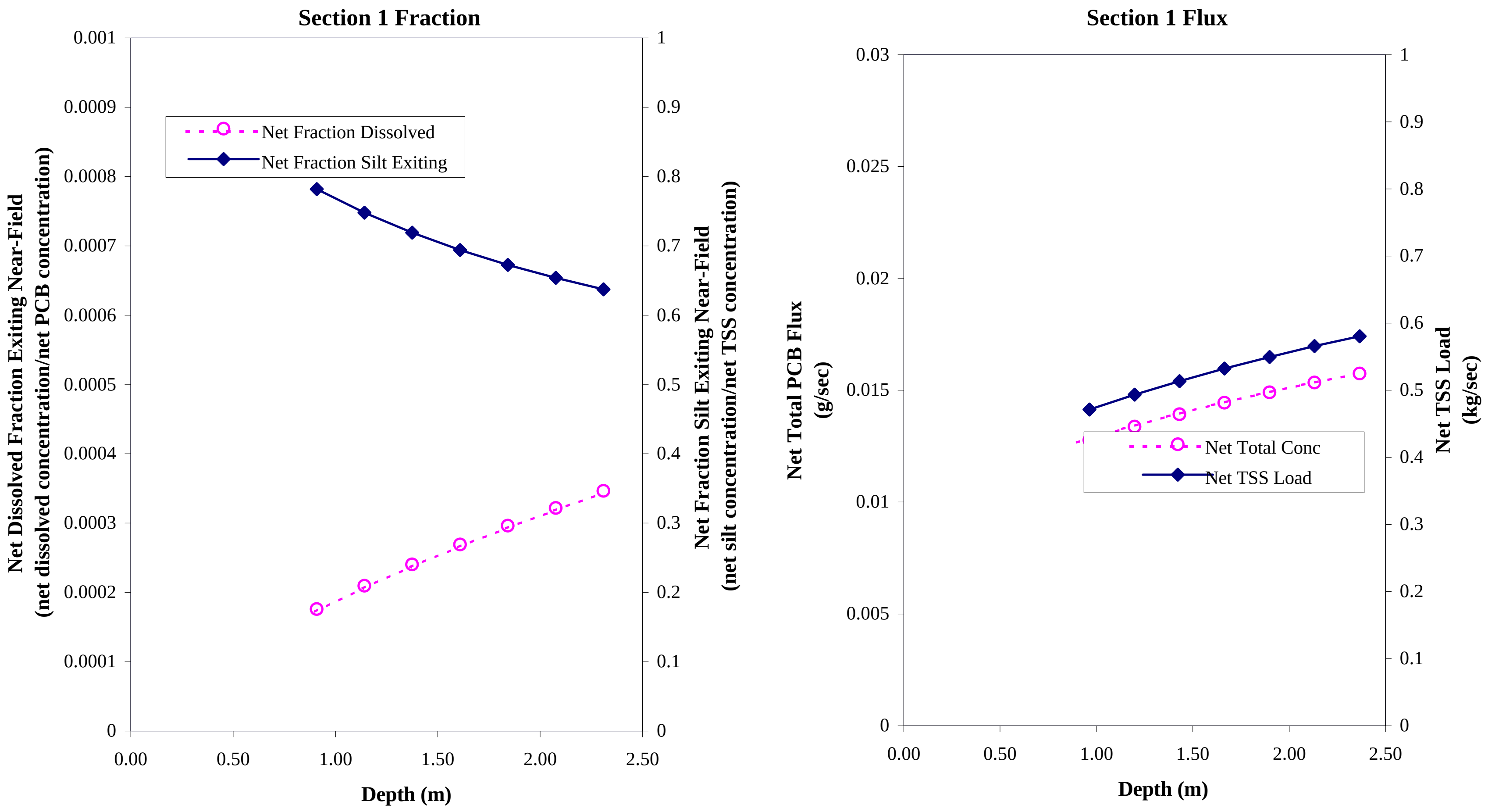
Sensitivity of Net Total PCB Flux and Net TSS Flux Exiting Near-Field with Variations in Linear Velocity and Depth for CSTR-Chem



Note: Net concentrations exclude background.

Figure 4

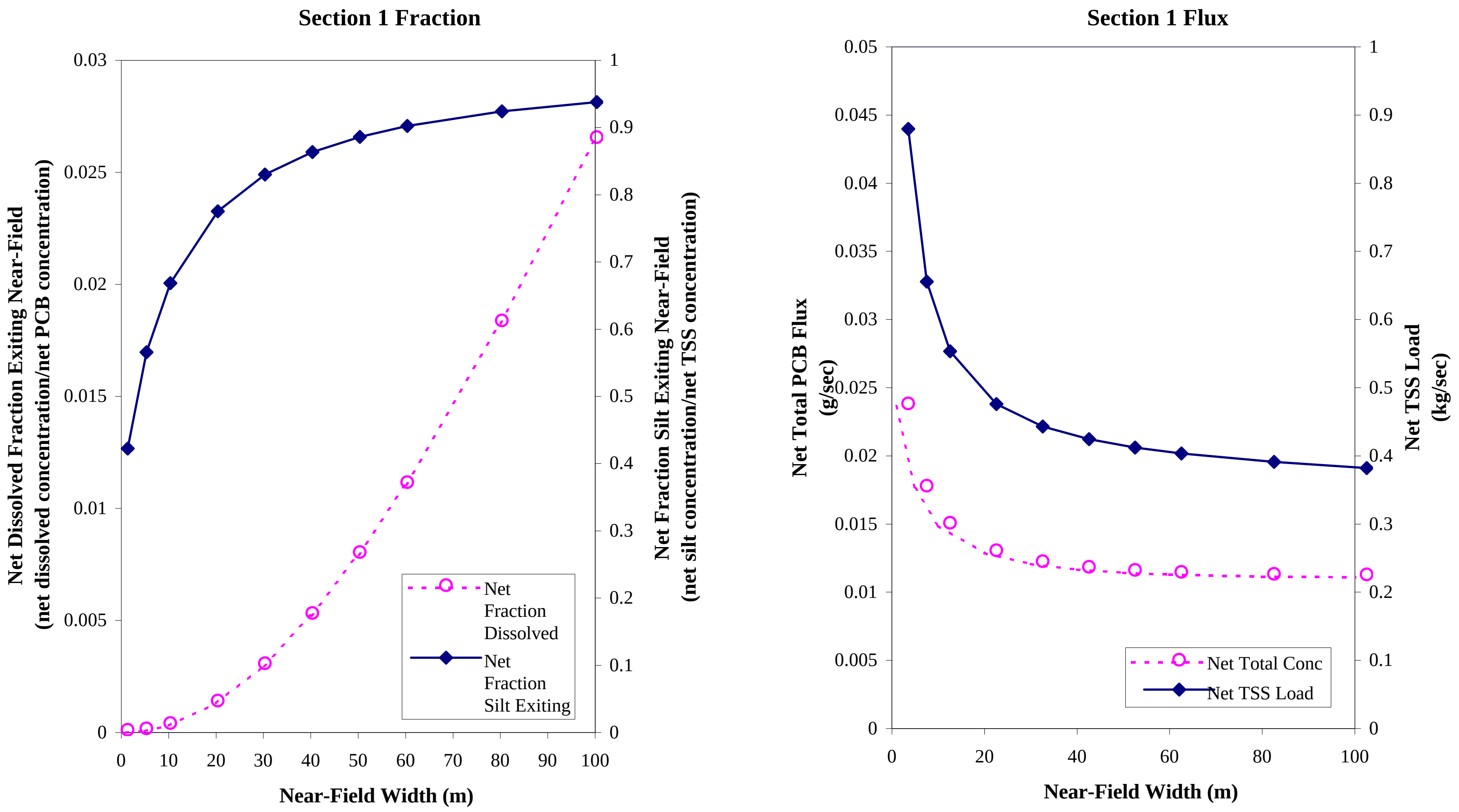
Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Velocity for CSTR-Chem



Note: Net concentrations exclude background.

Figure 5

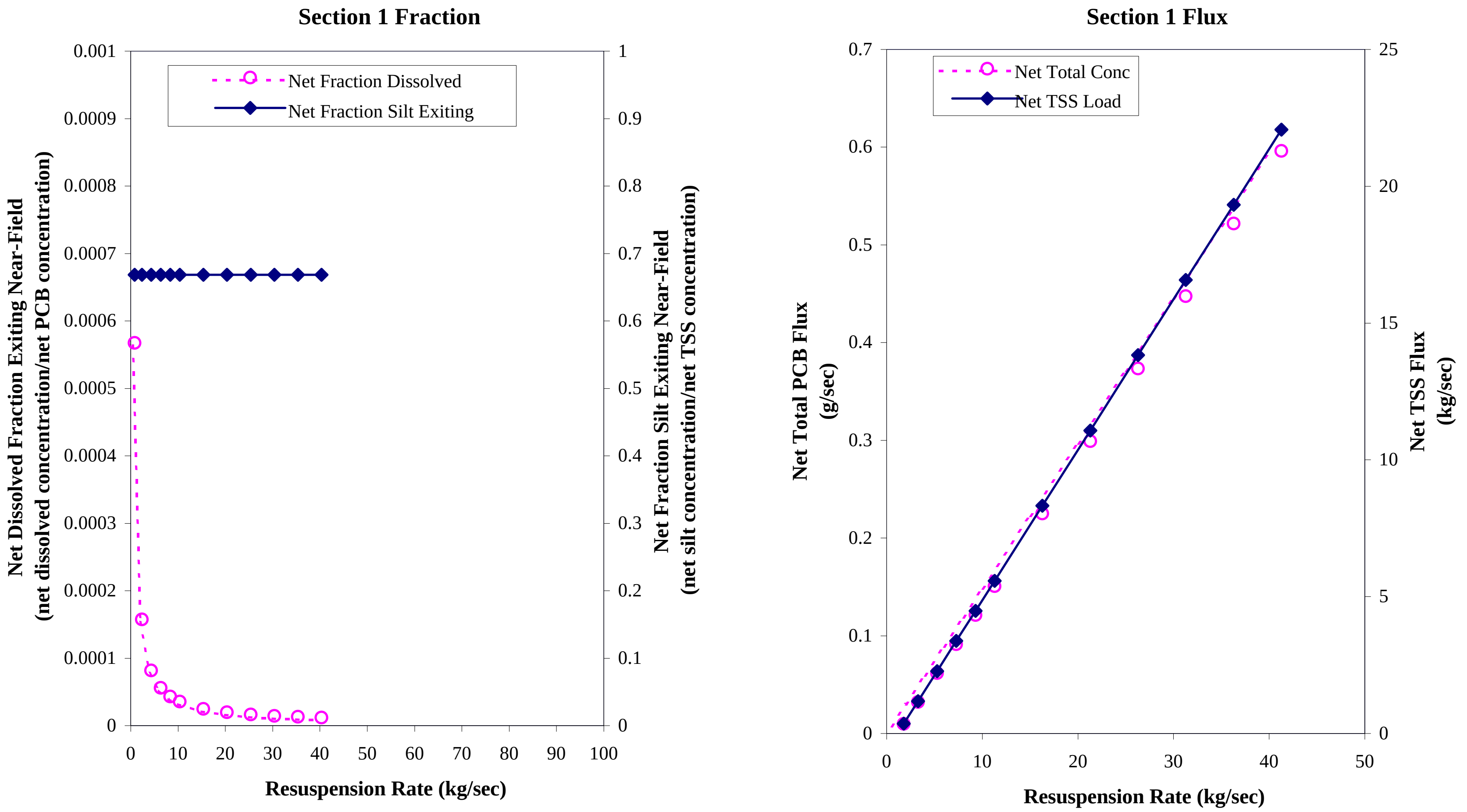
Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Depth for CSTR-Chem



Note: Net concentrations exclude background.

Figure 6

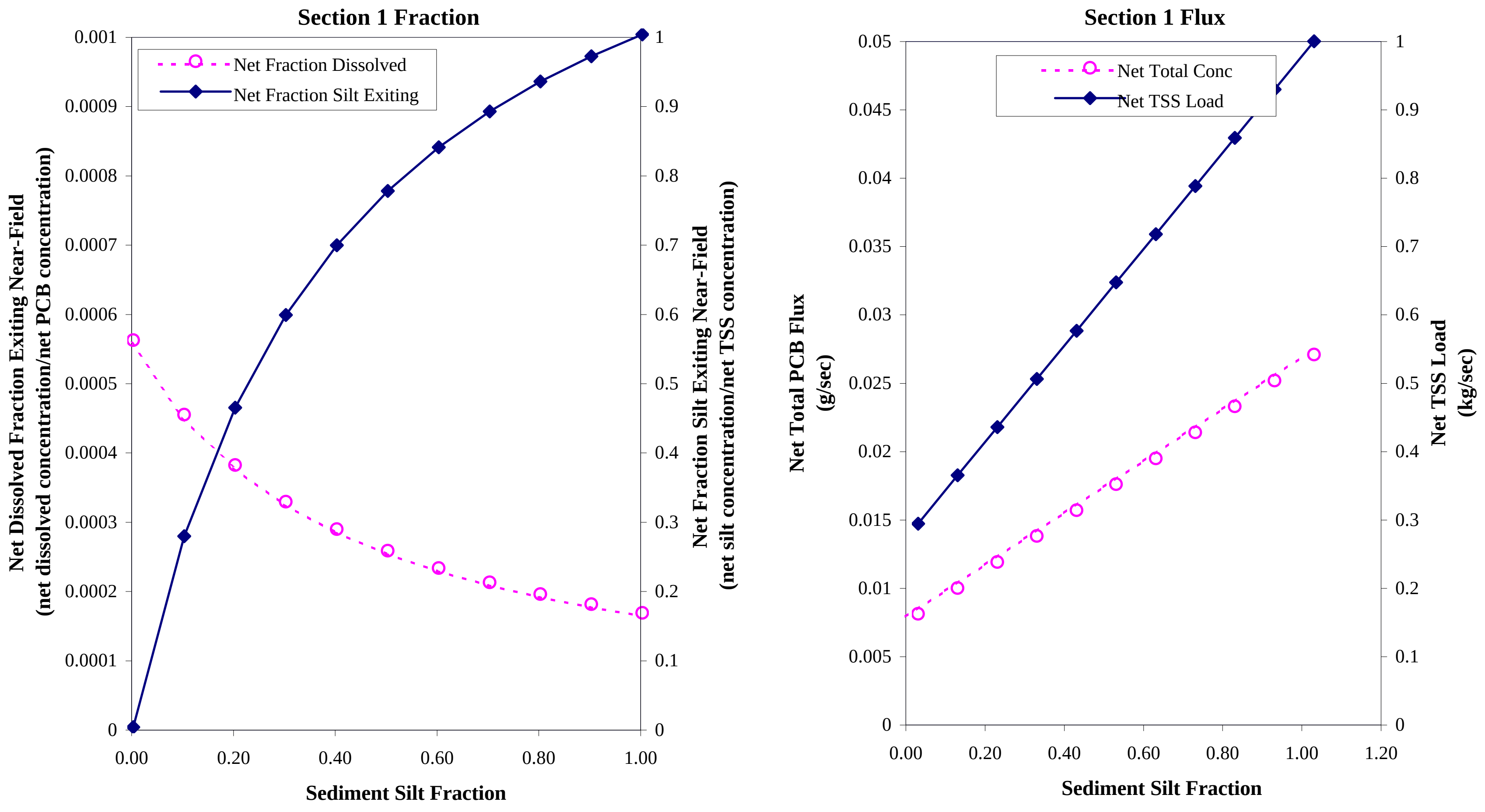
Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Near-Field Width for CSTR-Chem



Note: Net concentrations exclude background.

Figure 7

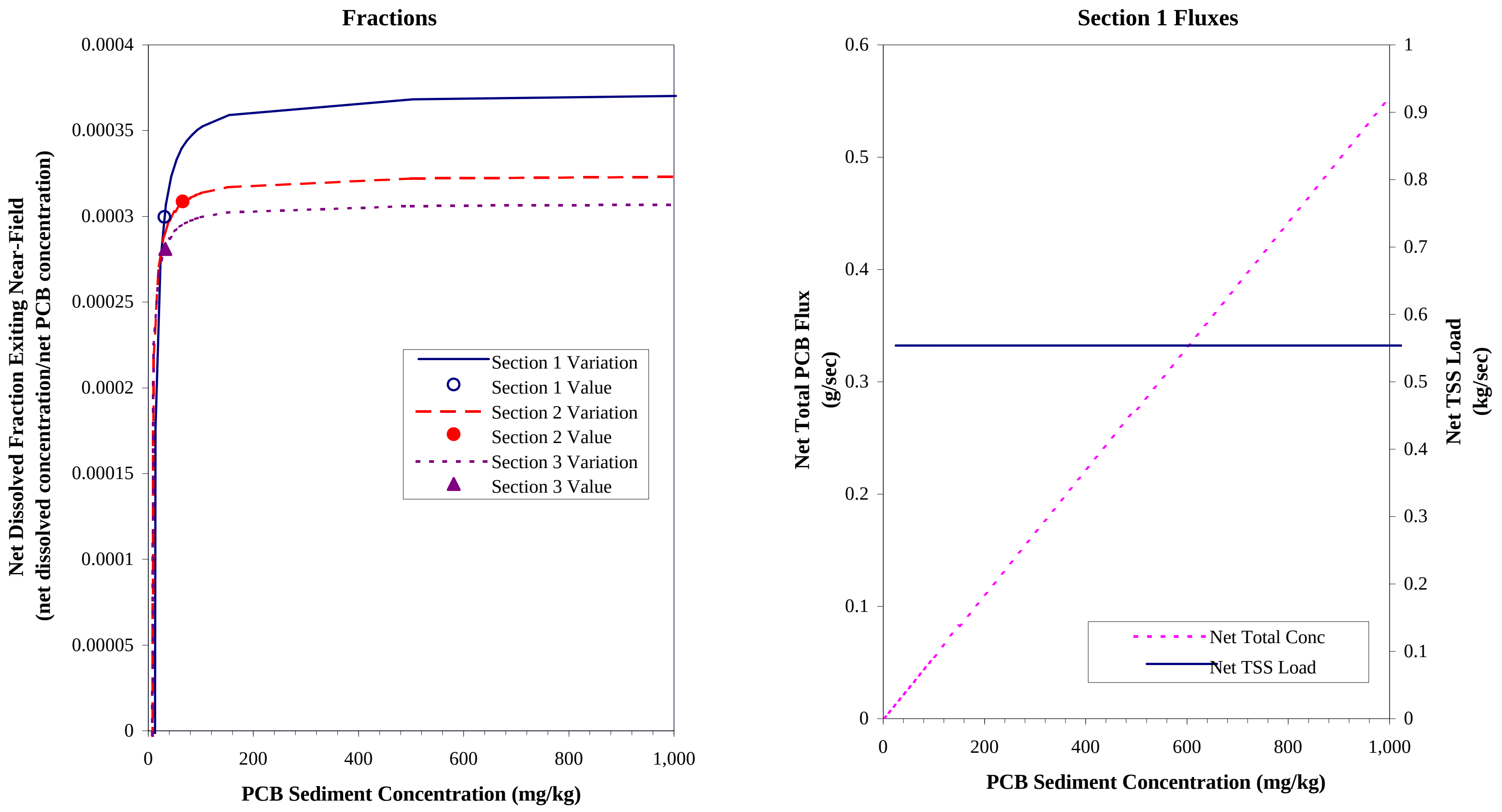
Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Resuspension Rate for CSTR-Chem



Note: Net concentrations exclude background.

Figure 8

Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Sediment Silt Fraction for CSTR-Chem



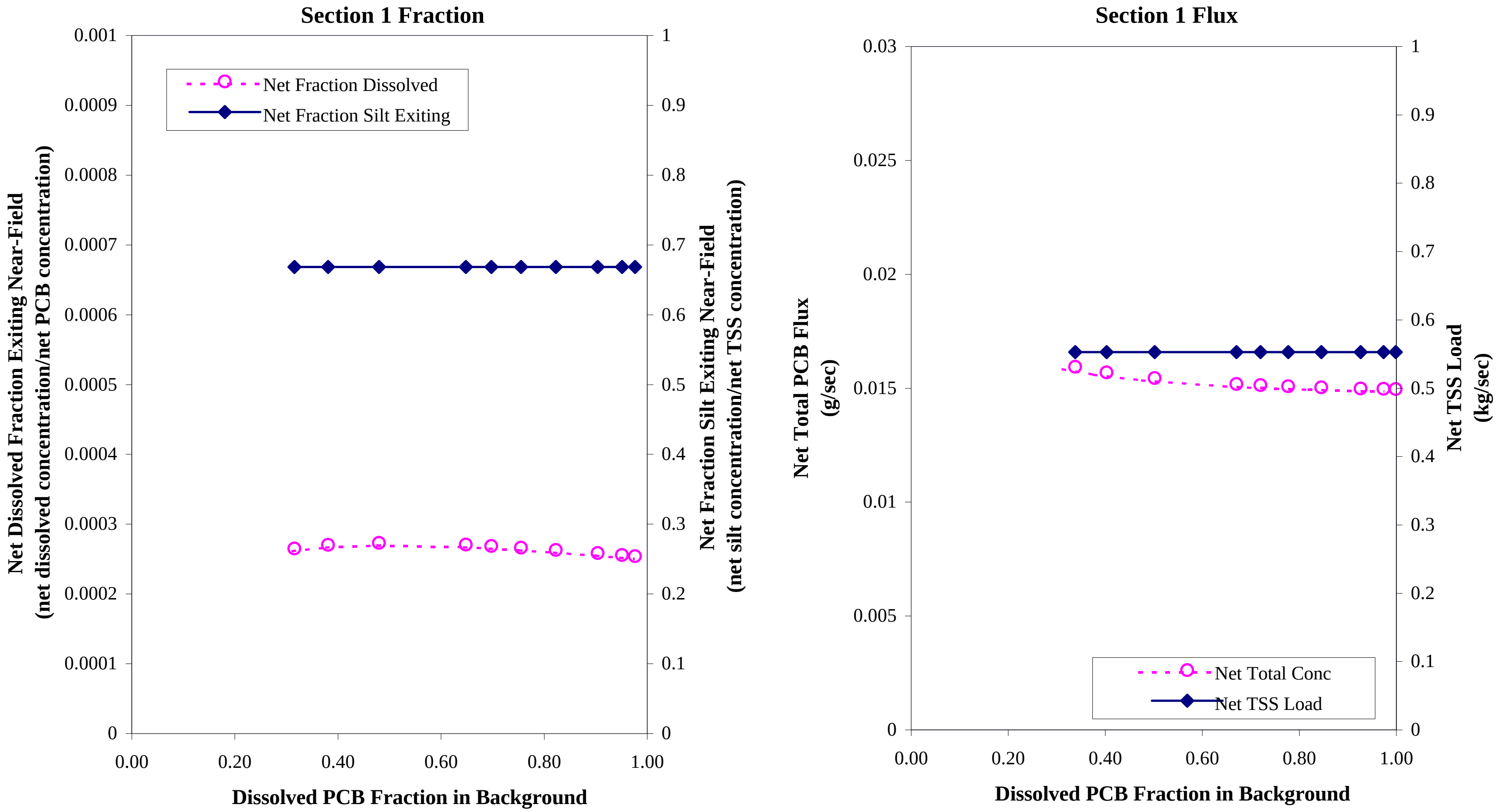
Fractions

Section 1 Fluxes

Note: Net concentrations exclude background.

Figure 9

Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of PCB Sediment Concentration for CSTR-Chem

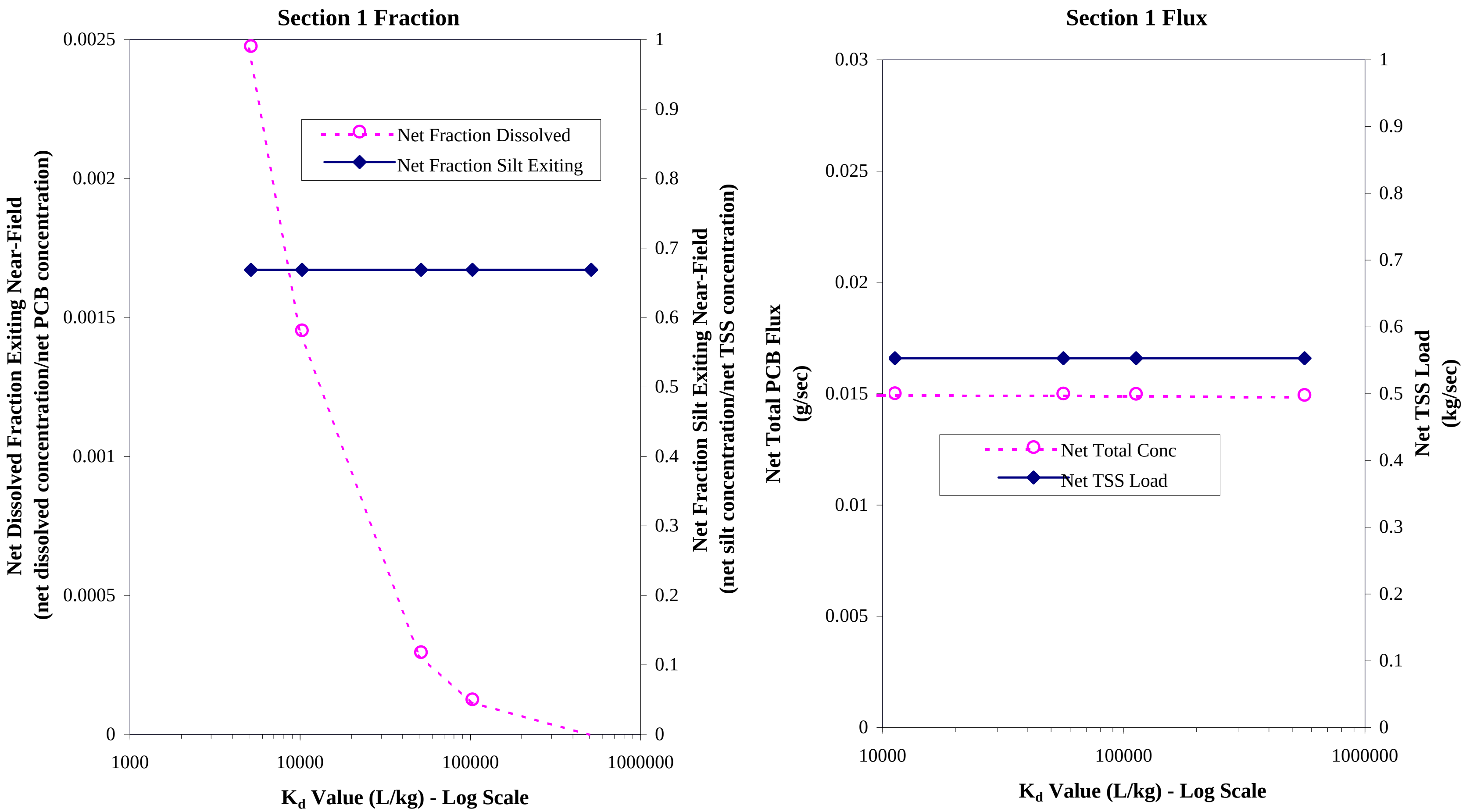


Note: Net concentrations exclude background.

Kd was held constant at 5,500 L/kg and Background TSS was varied from 0.5 to 40 mg/L.

Figure 10

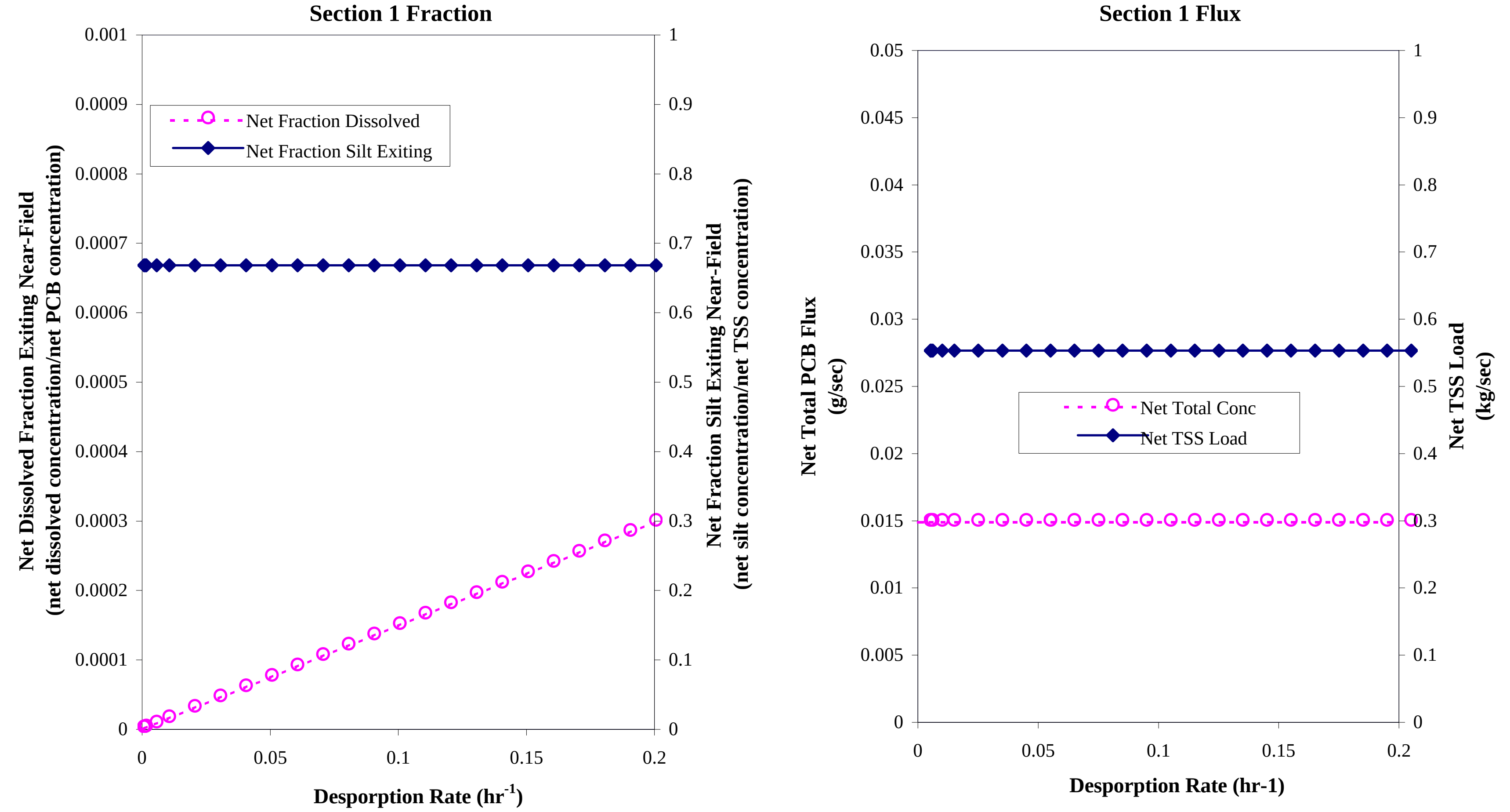
Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Dissolved PCB Fraction in the Background and TSS Background Concentrations for CSTR-Chem



Note: Net concentrations exclude background.
Background TSS was held constant at 2.3 mg/L

Figure 11

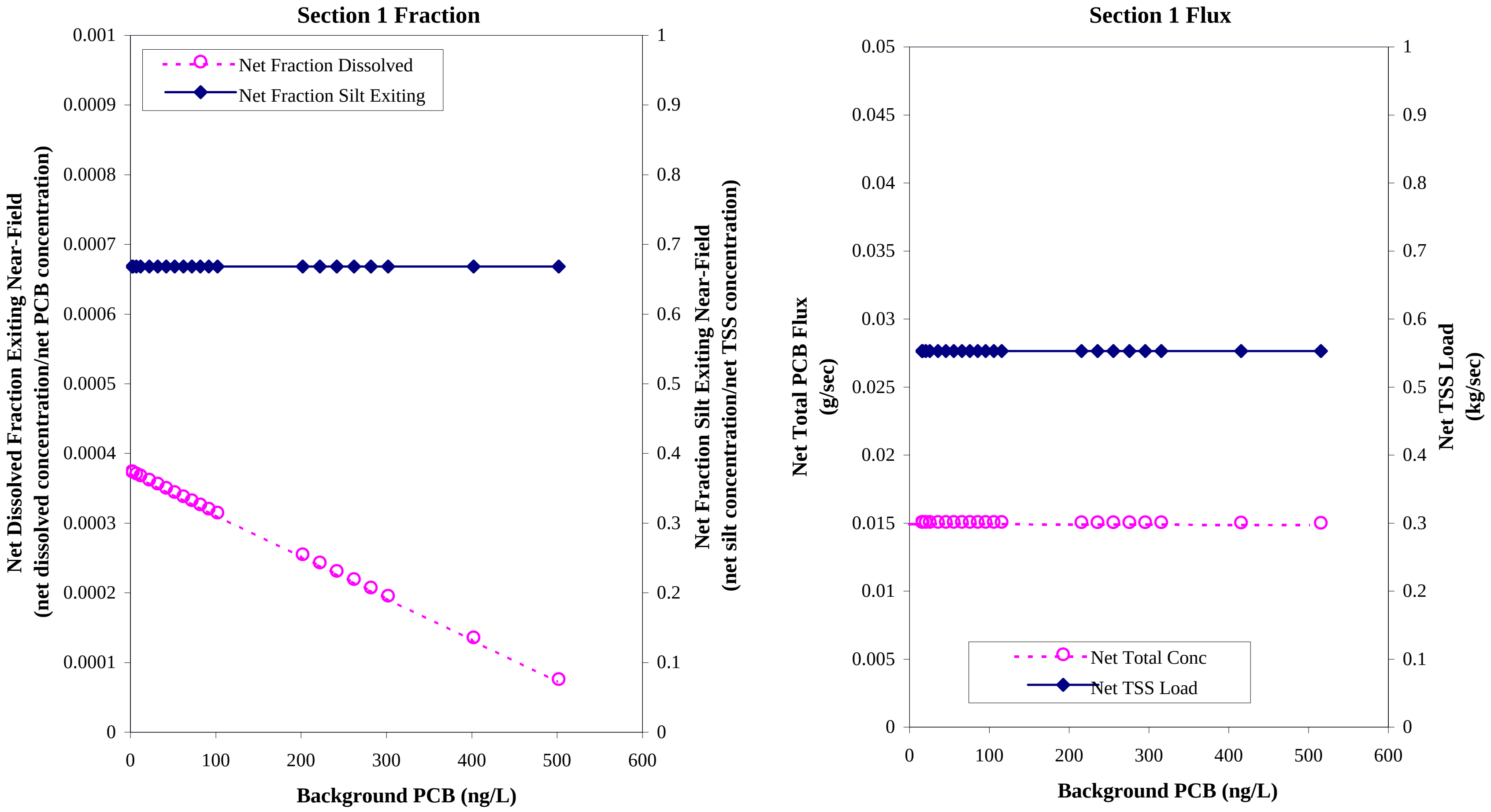
Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Dissolved PCB Fraction in the Background and Kd Value for CSTR-Chem



Note: Net concentrations exclude background.

Figure 12

Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Desorption Rate for CSTR-Chem



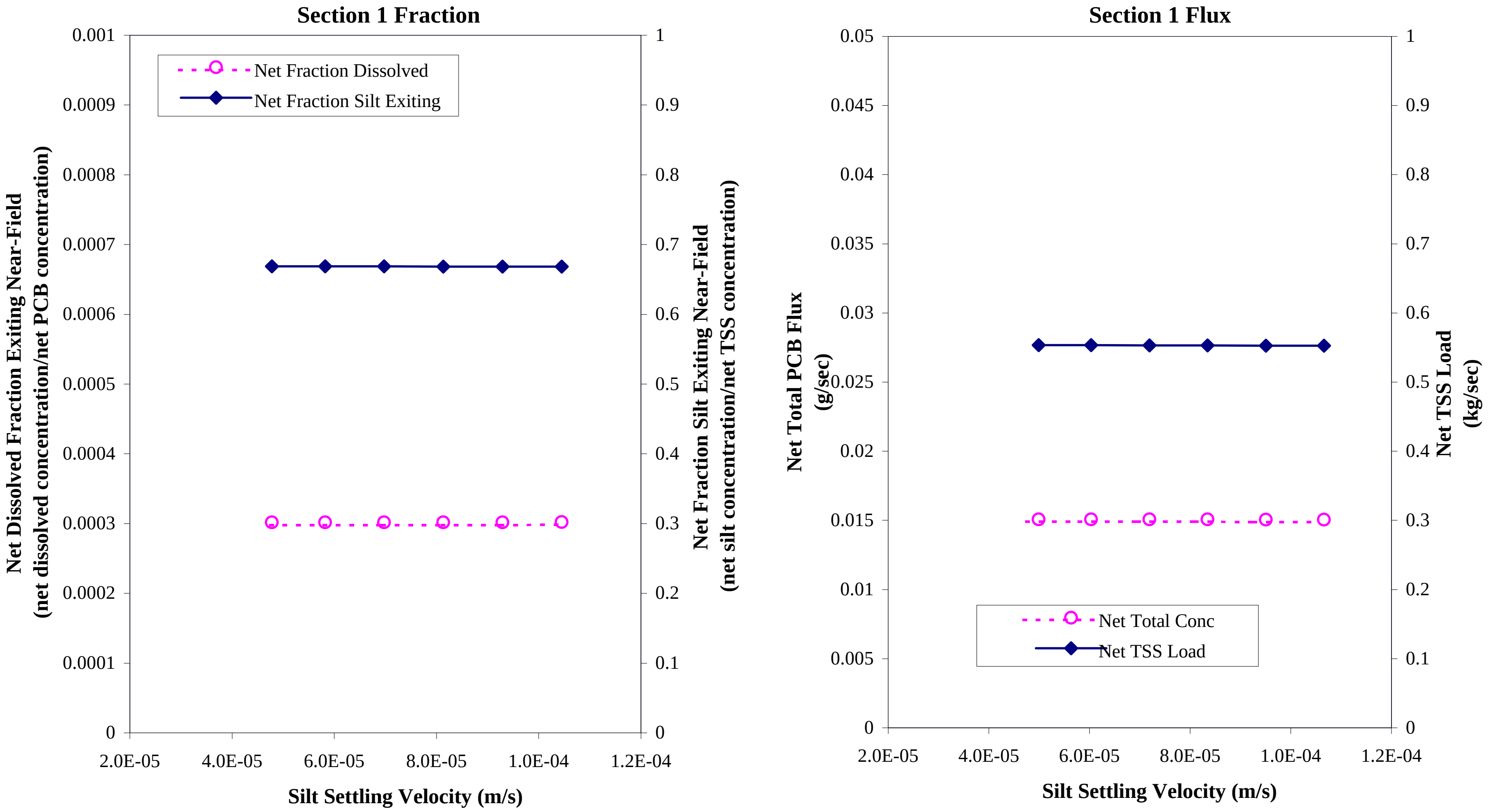
Section 1 Fraction

Section 1 Flux

Note: Net concentrations exclude background.

Figure 13

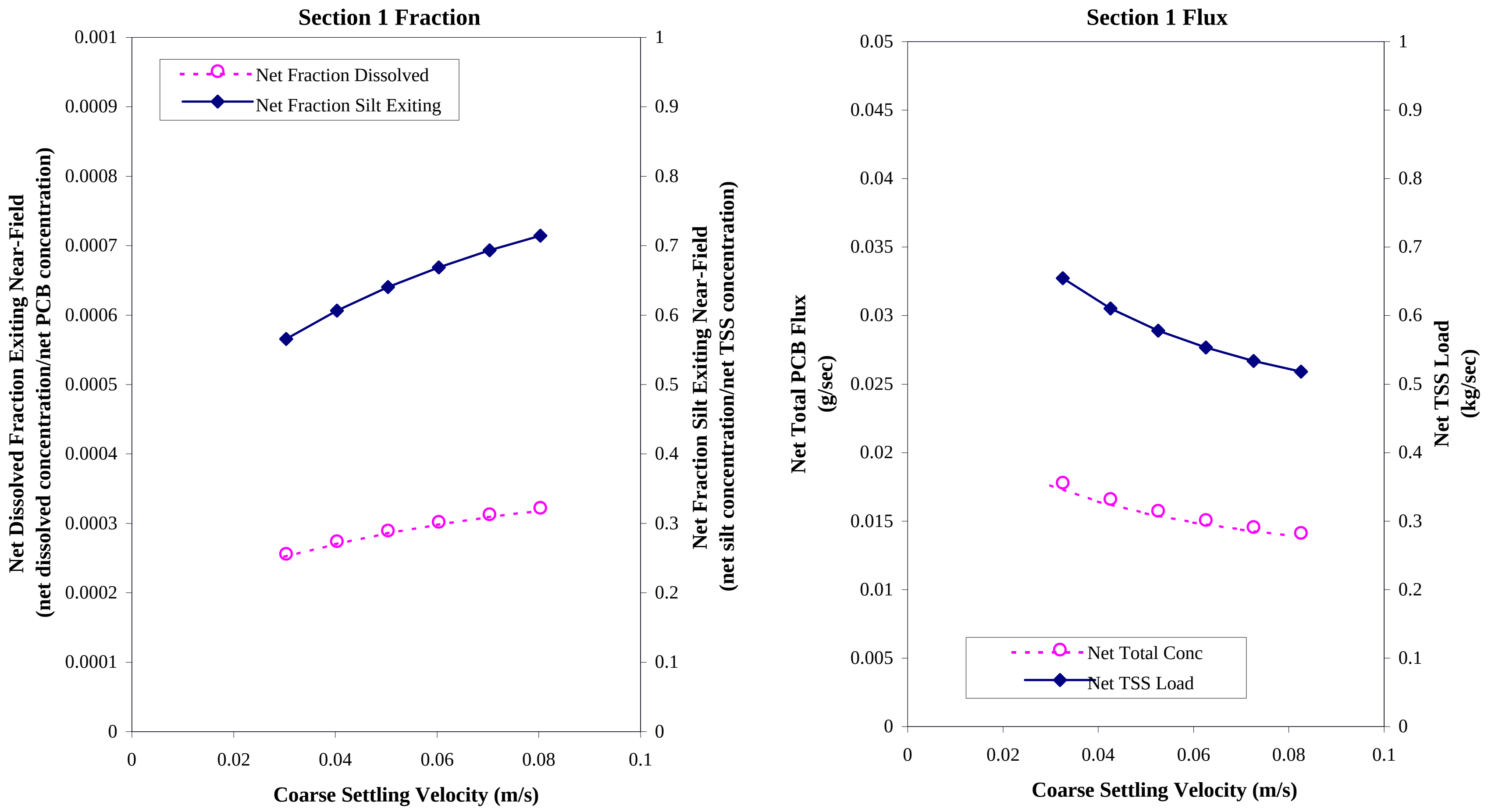
Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Background PCB Concentration for CSTR-Chem



Note: Net concentrations exclude background.

Figure 14

Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Silt Settling Velocity for CSTR-Chem



Note: Net concentrations exclude background.

Figure 15

Net Dissolved PCB Fraction, Net Silt Fraction, Net Total PCB Flux and Net TSS Flux Exiting Near-Field as Functions of Coarse Settling Velocity for CSTR-Chem

Figure 16
Estimated TSS Concentration Downstream of the Dredge Head in Section 1 (Flow is 4000 cfs and PCB concentration is 500 ng/L at the far field station)

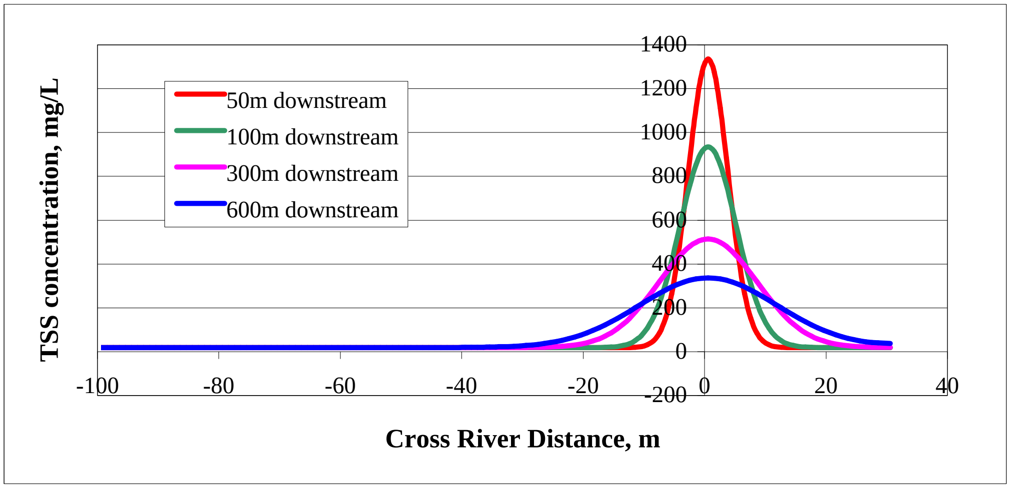
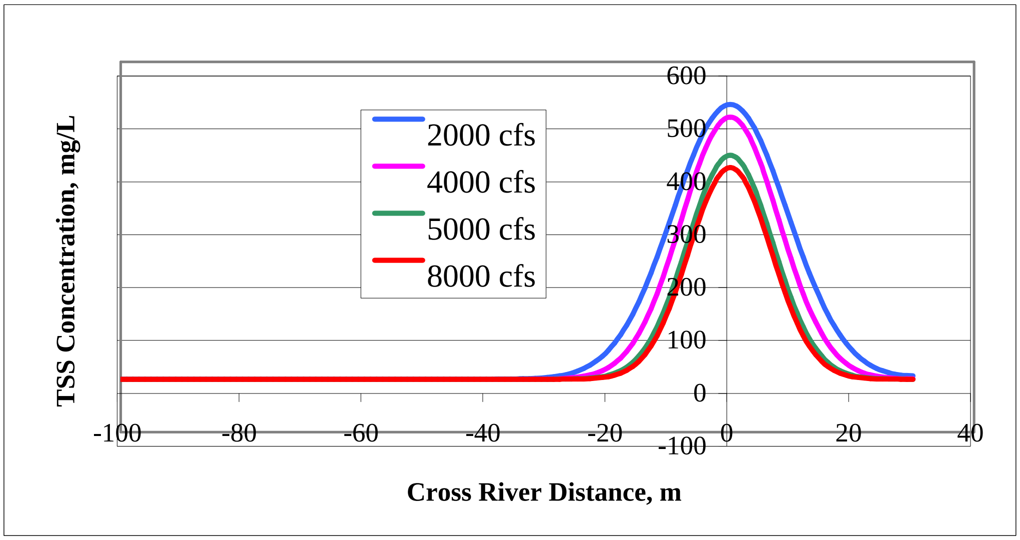
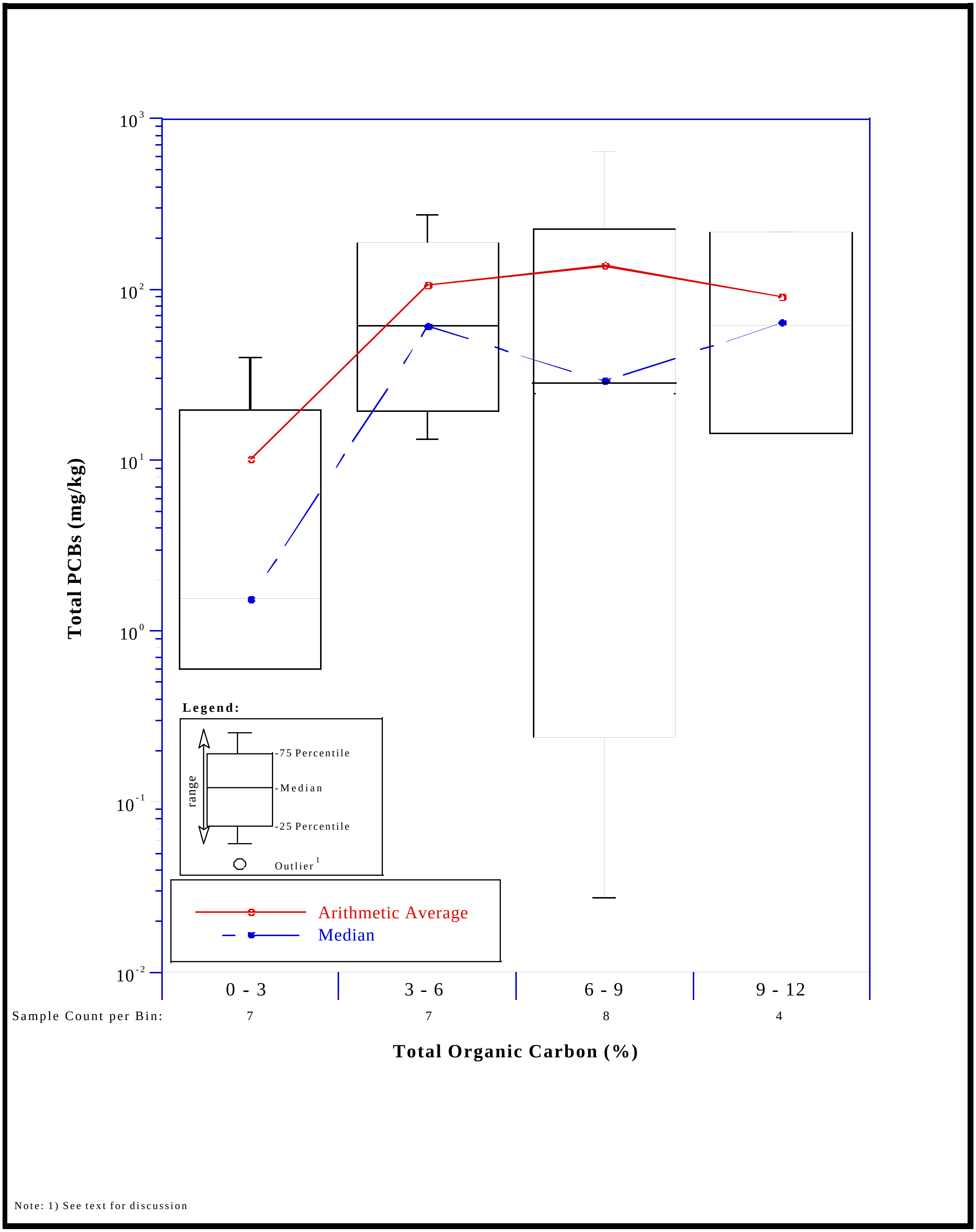


Figure 17
Estimated TSS Concentration at 300 m Downstream of the Dredge Head in Section 1 (PCB concentration at the far-field station is 500 ng/L)





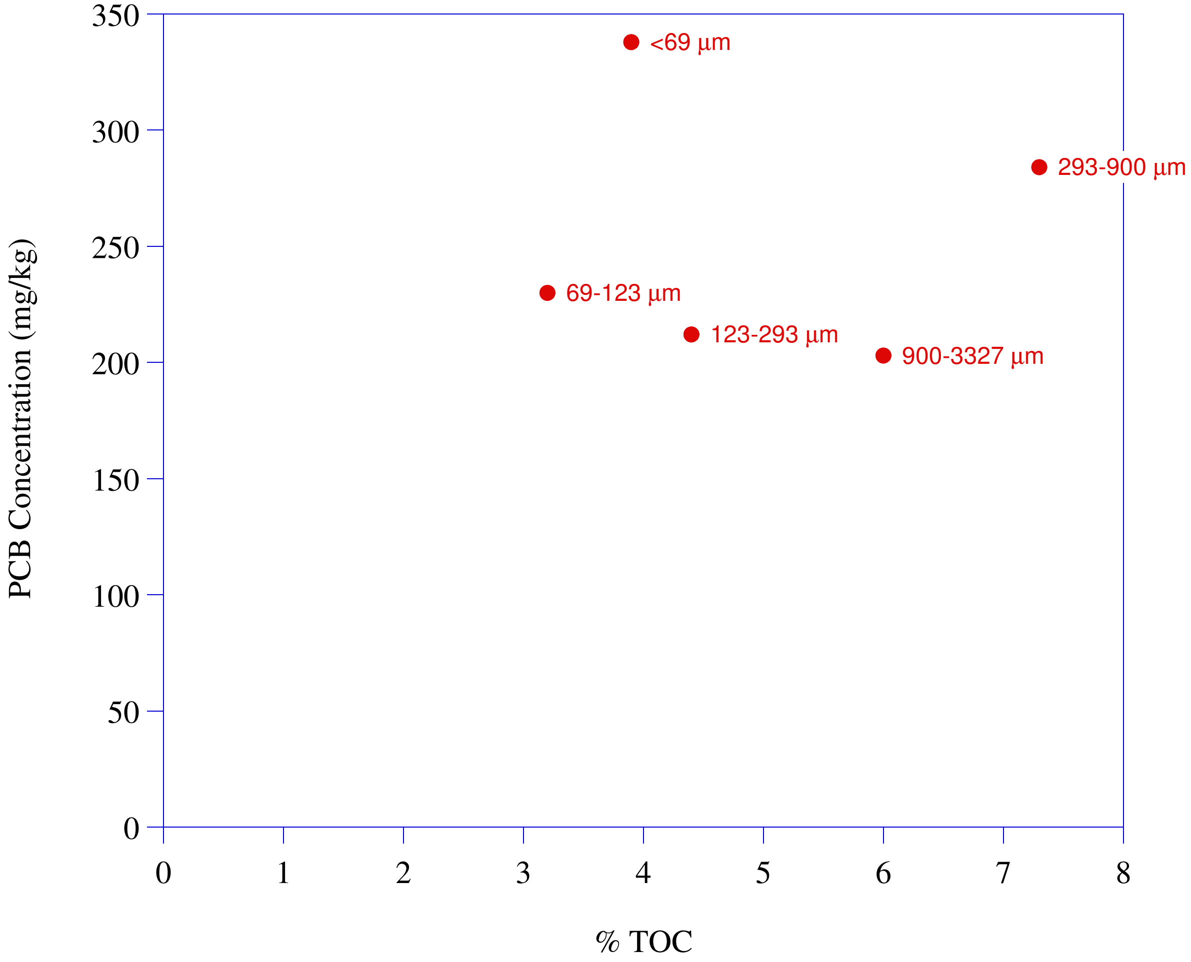
Note: 1) See text for discussion

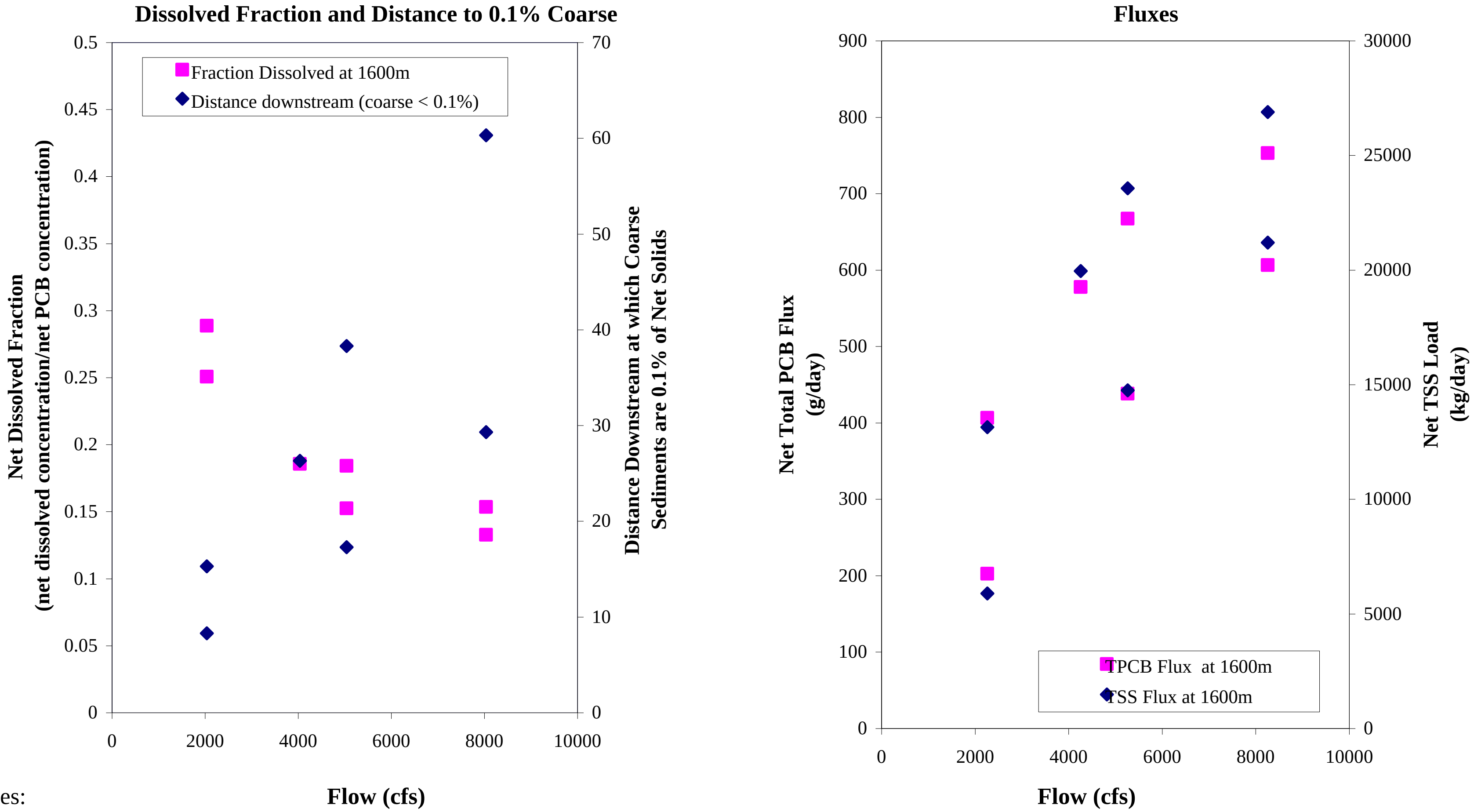
Source: TAMS/Gradient Database, Release 3.5

TAMS

Figure 18 (Figure 3-21 of LRC Report)
Total PCBs Grouped by Total Organic Carbon

Figure 19
Grain Size, Organic Content and PCB Concentrations in Hudson River Sediment collected near Moreau



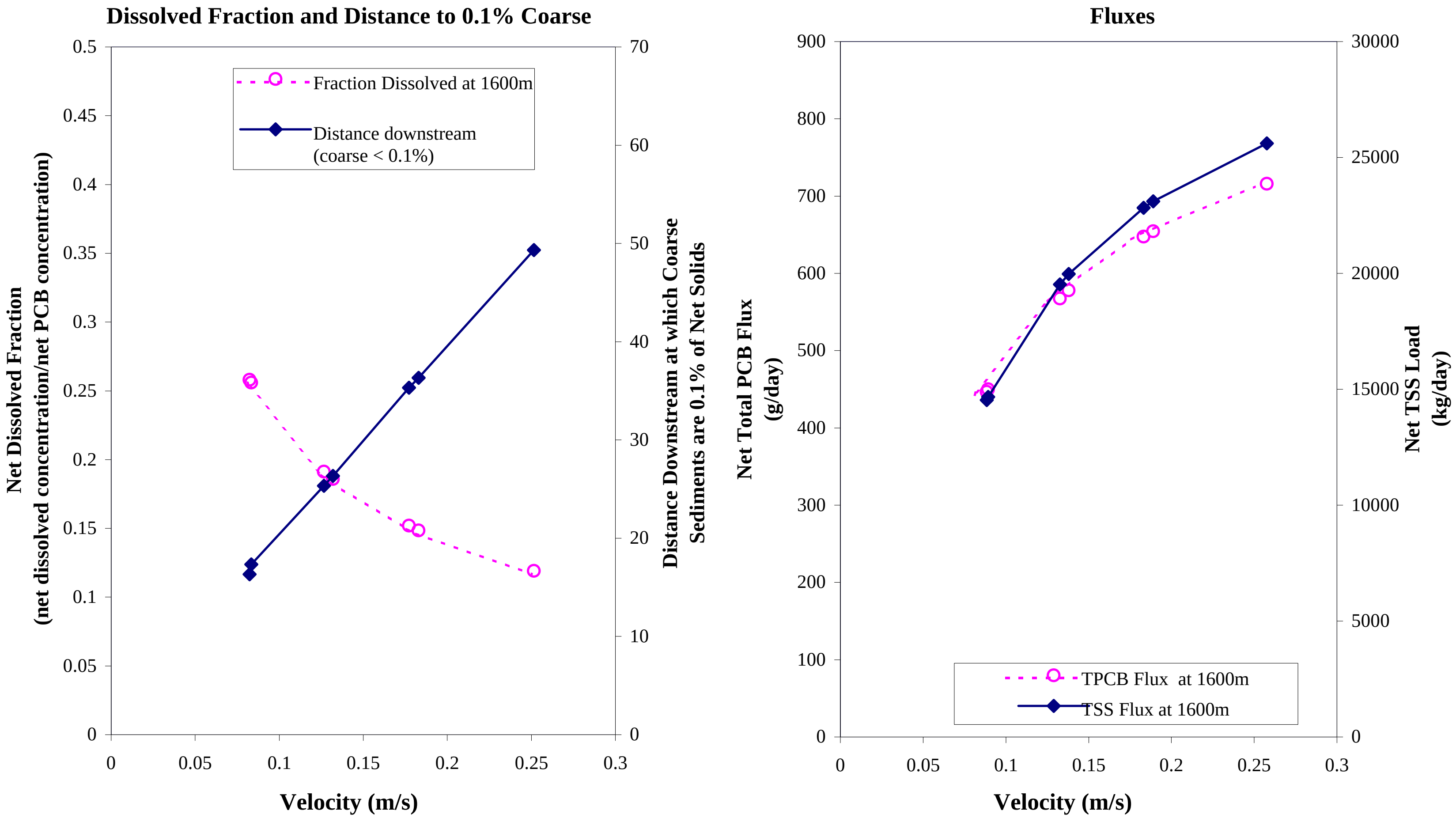


Notes:

1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 20

Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Riverwide Volumetric Flow (Velocity-Depth Pairs) for the TSS-Chem

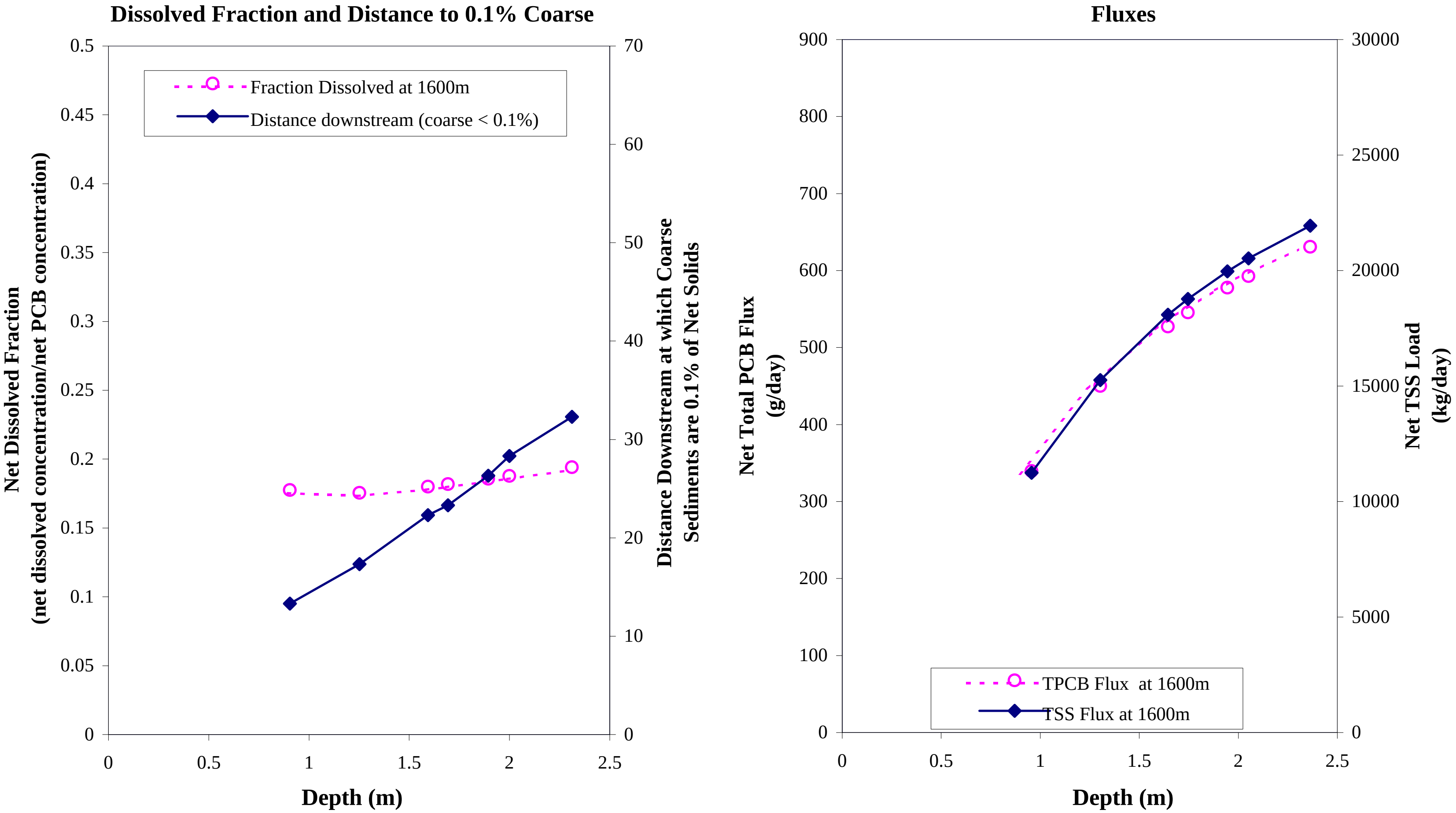


Notes:

1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 21

Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Velocity for the TSS-Chem

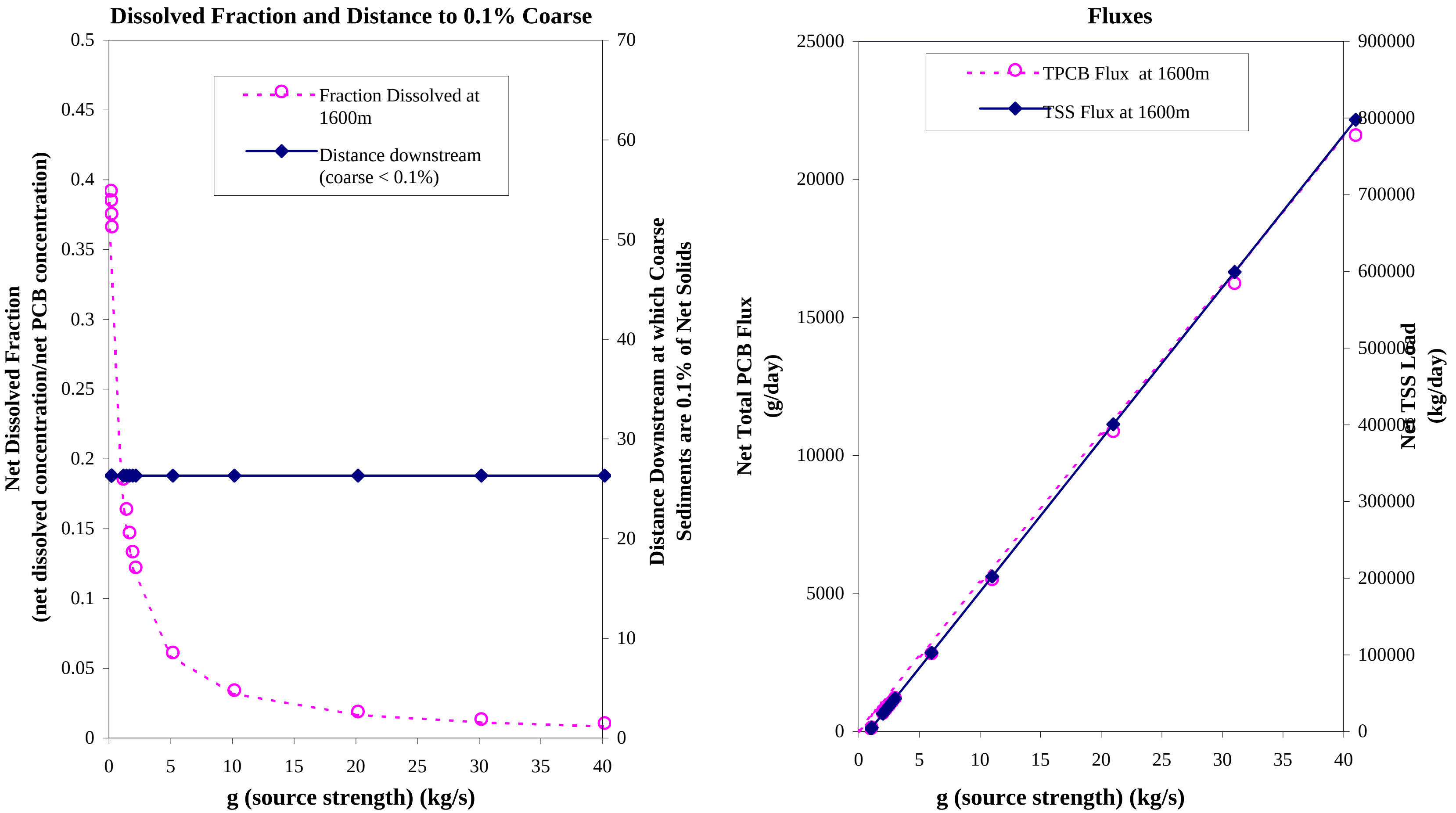


Notes:

1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 22

Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Depth for the TSS-Chem

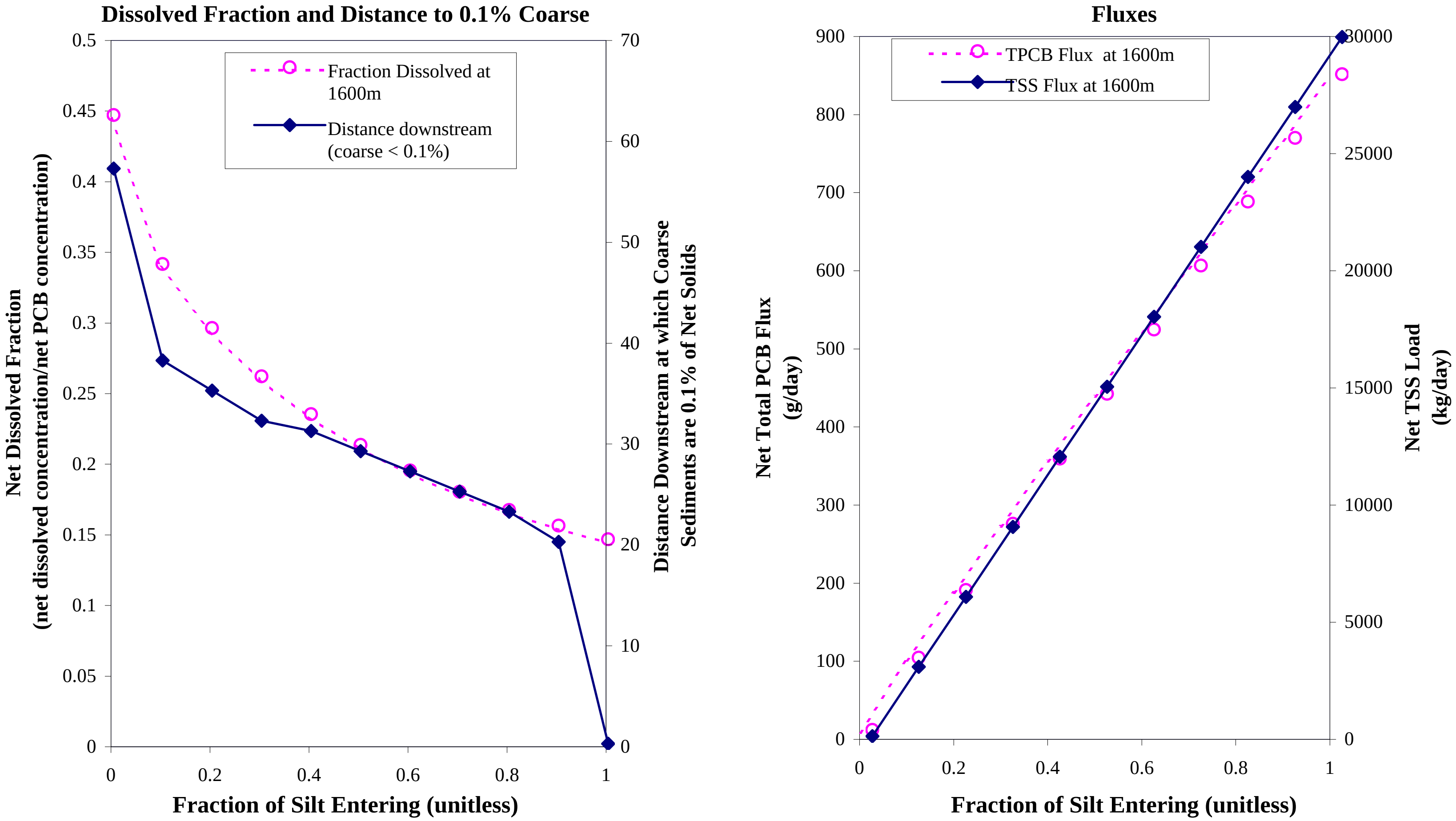


Notes:

1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 23

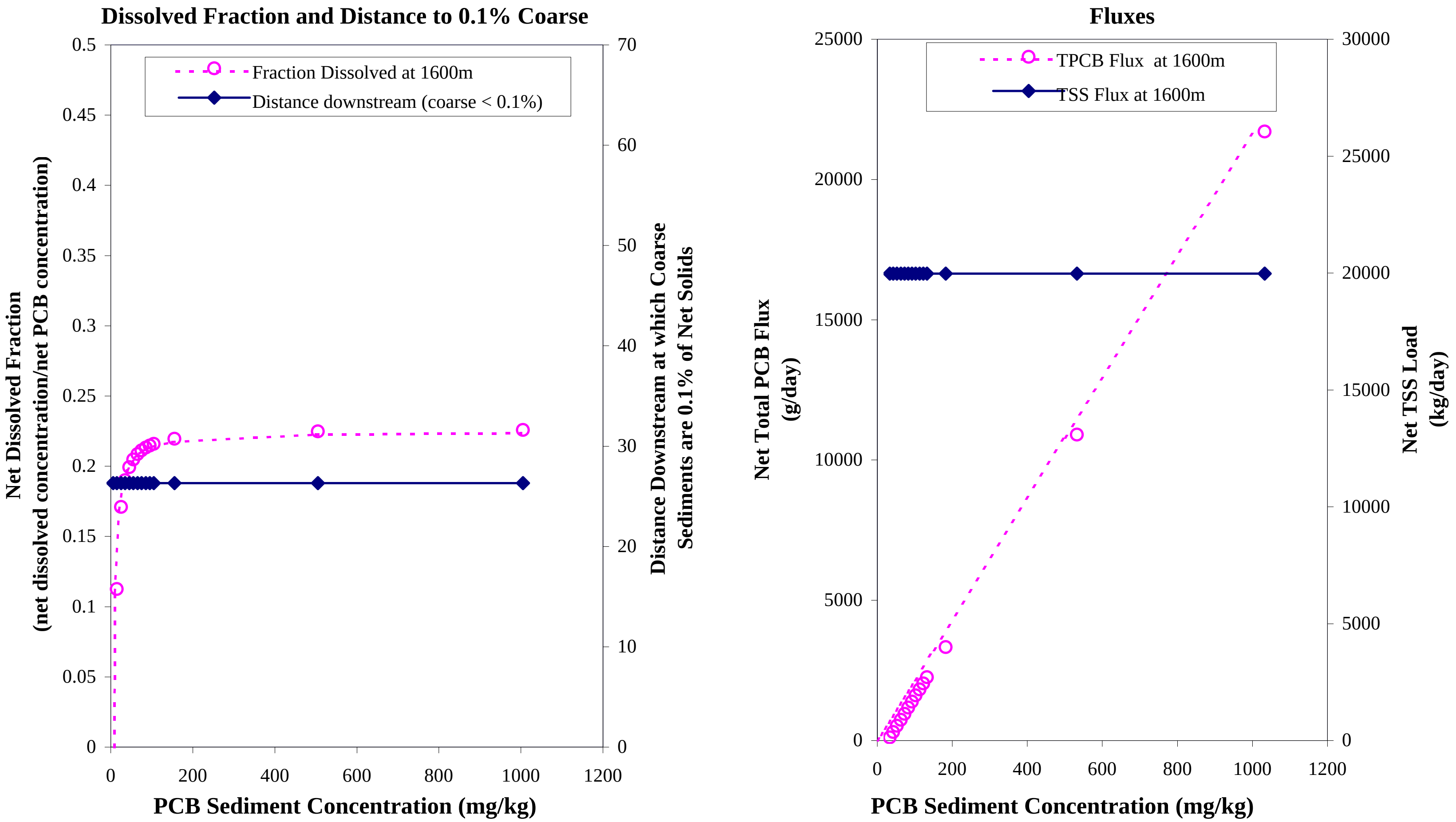
Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Source Strength for the TSS-Chem



Notes:
1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 24

Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Silt Fraction Entering for the TSS-Chem

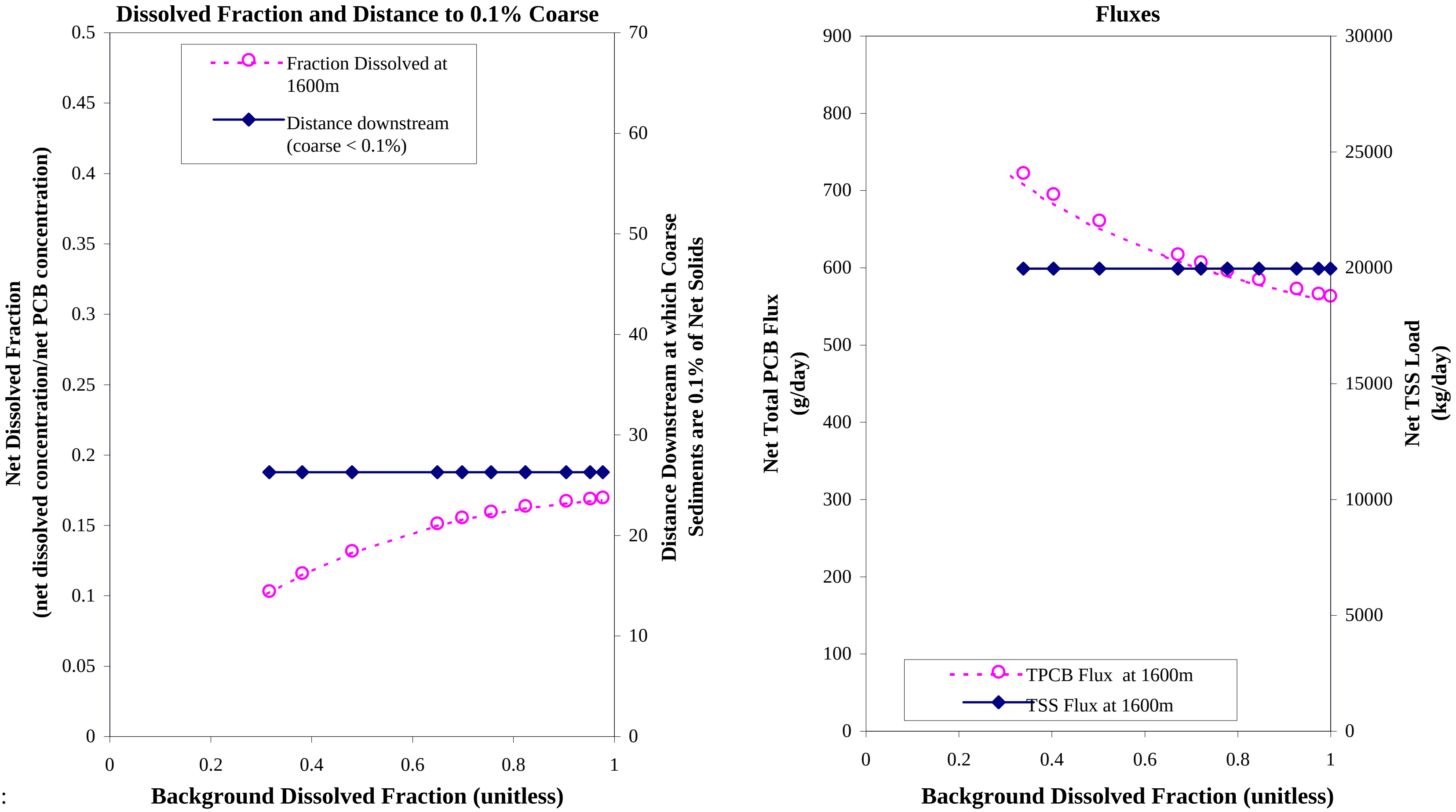


Notes:

1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 25

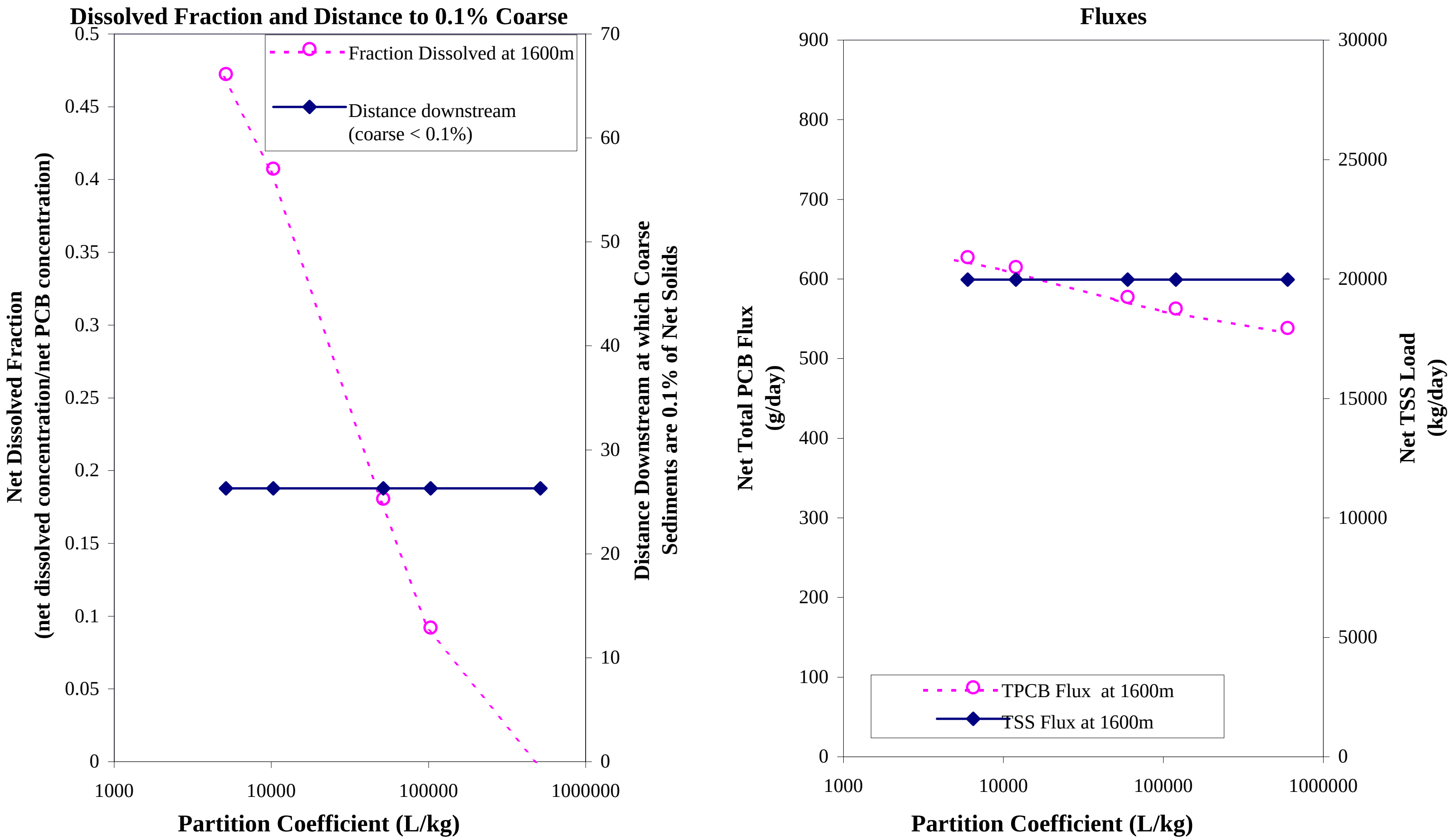
Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Sediment PCB Concentration for the TSS-Chem



Notes:
1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 26

Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of TSS Background and PCB Dissolved Fraction (Kd = 55,000) for the TSS-Chem

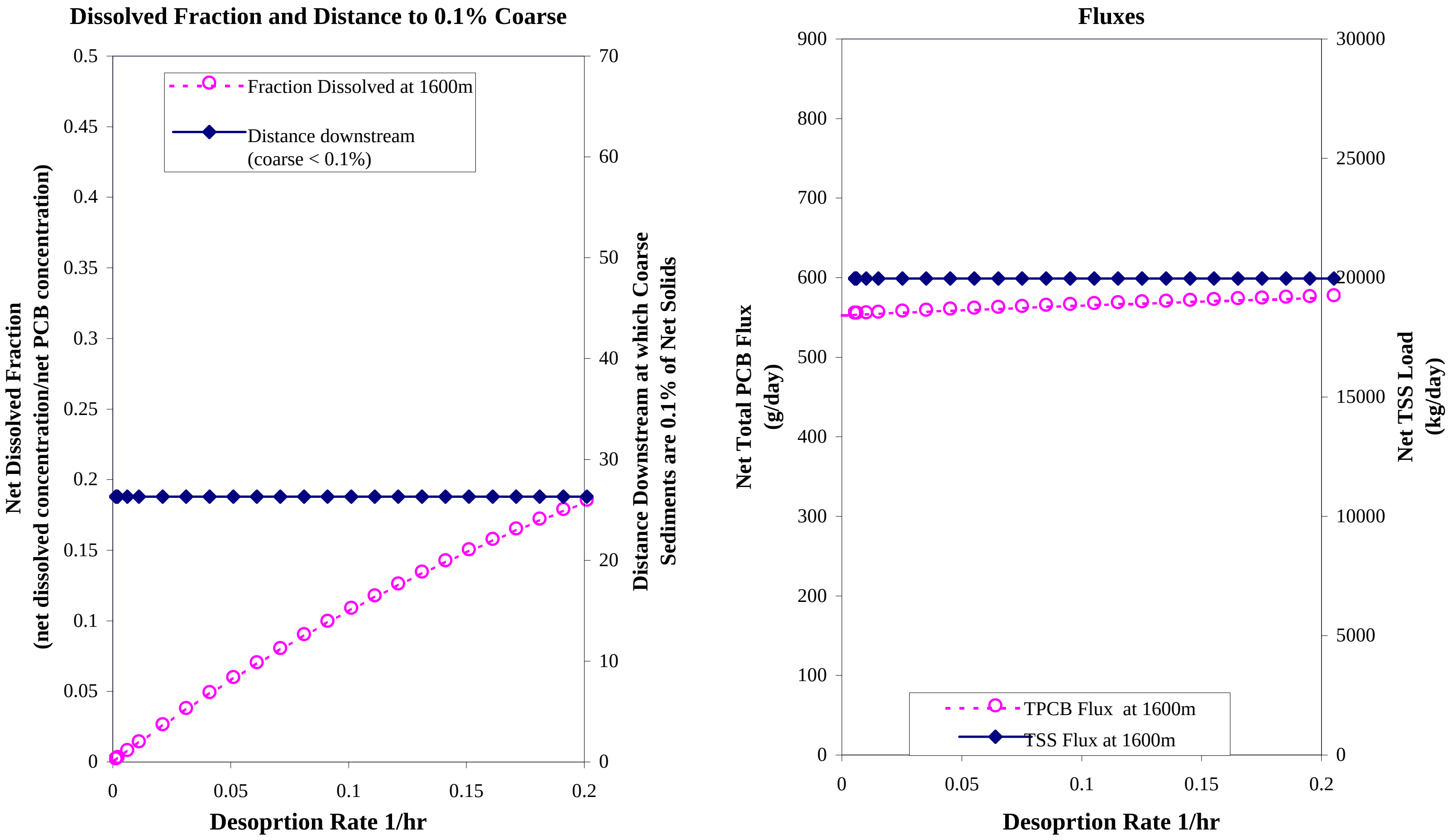


Notes:

1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 27

Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Kd for the TSS-Chem



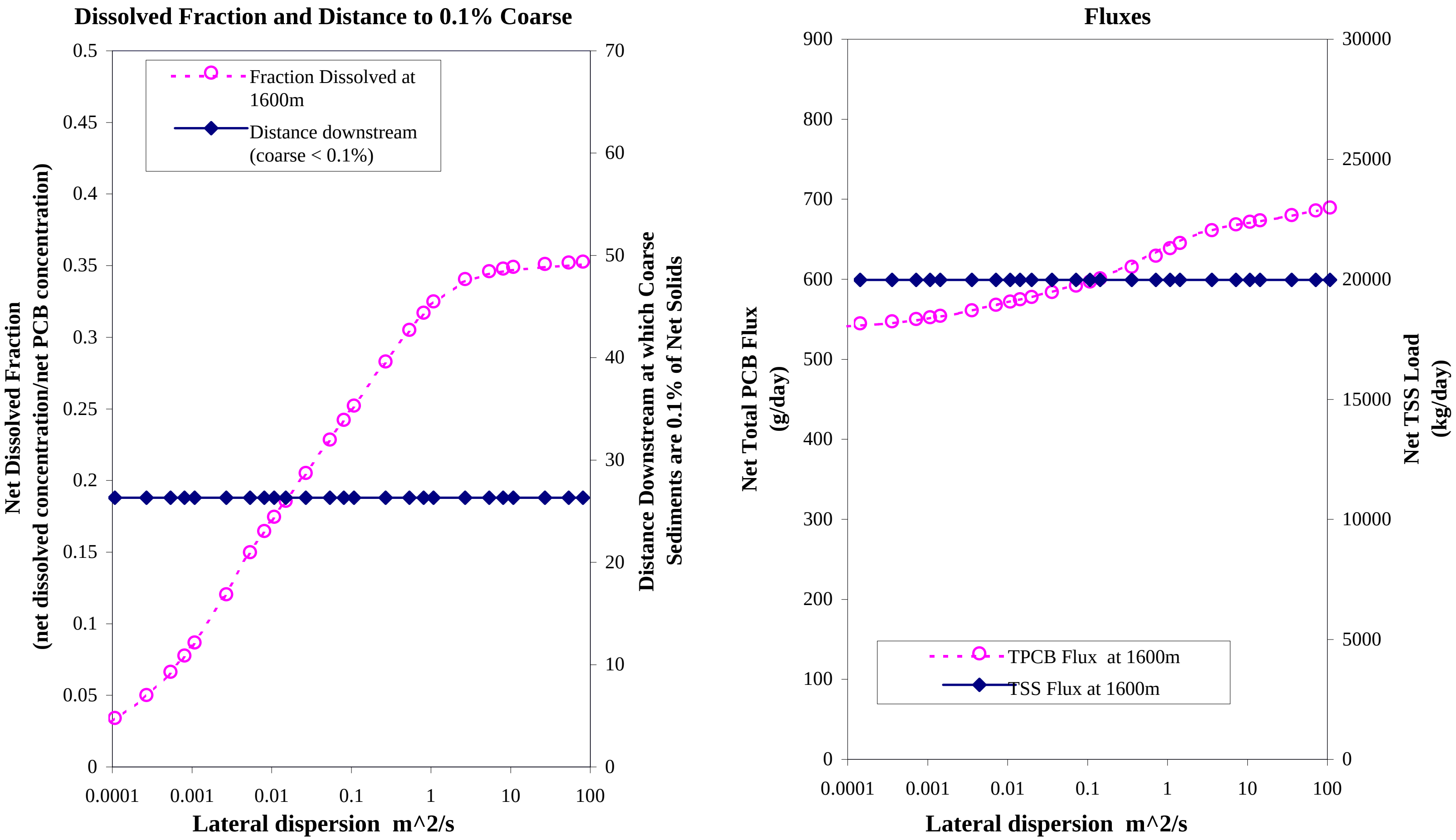
Notes:

1. Net concentrations exclude background.

2. Fluxes are based on 14 hours per day.

Figure 28

Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Desorption Rate for the TSS-Chem

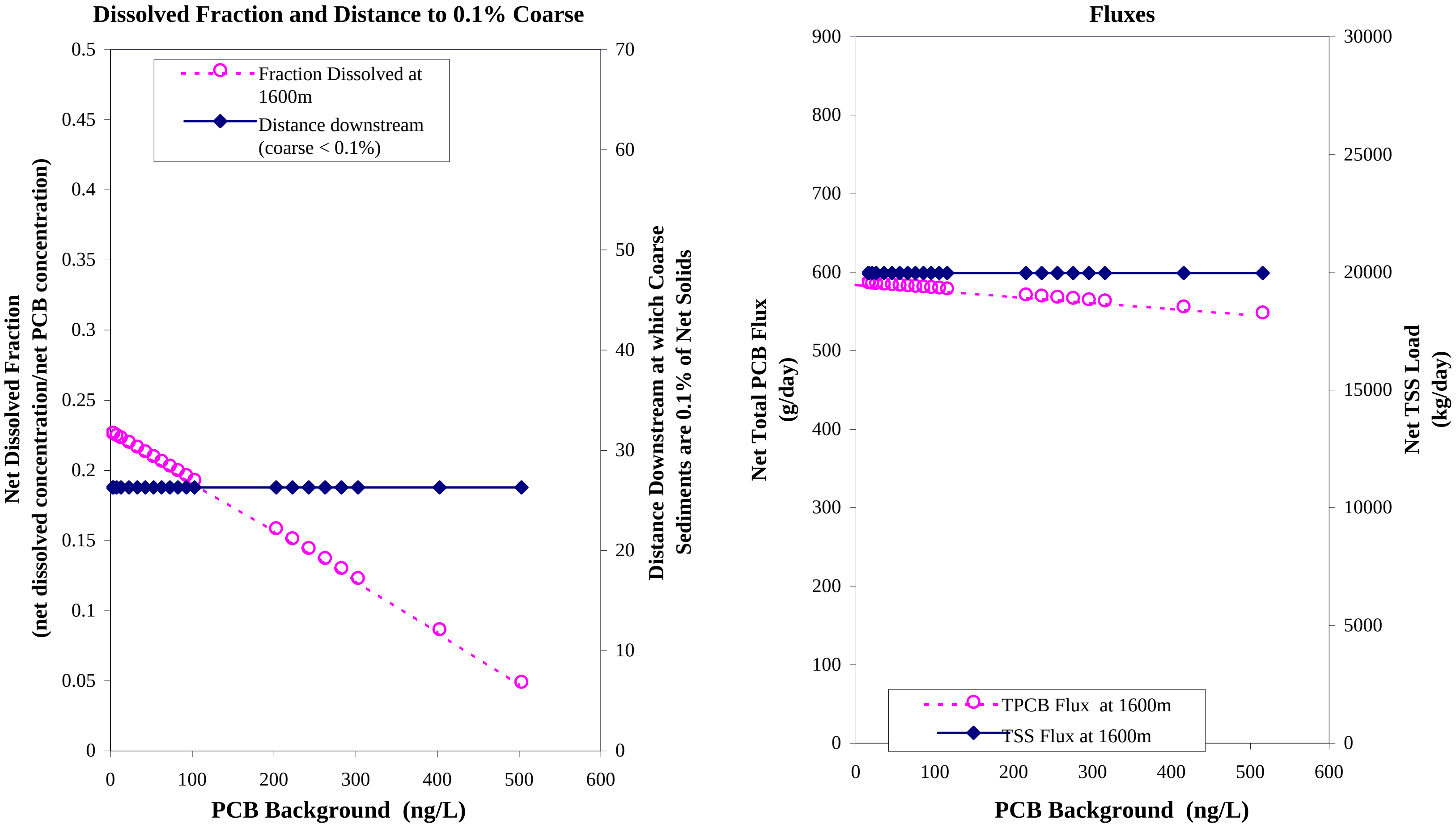


Notes:

1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 29

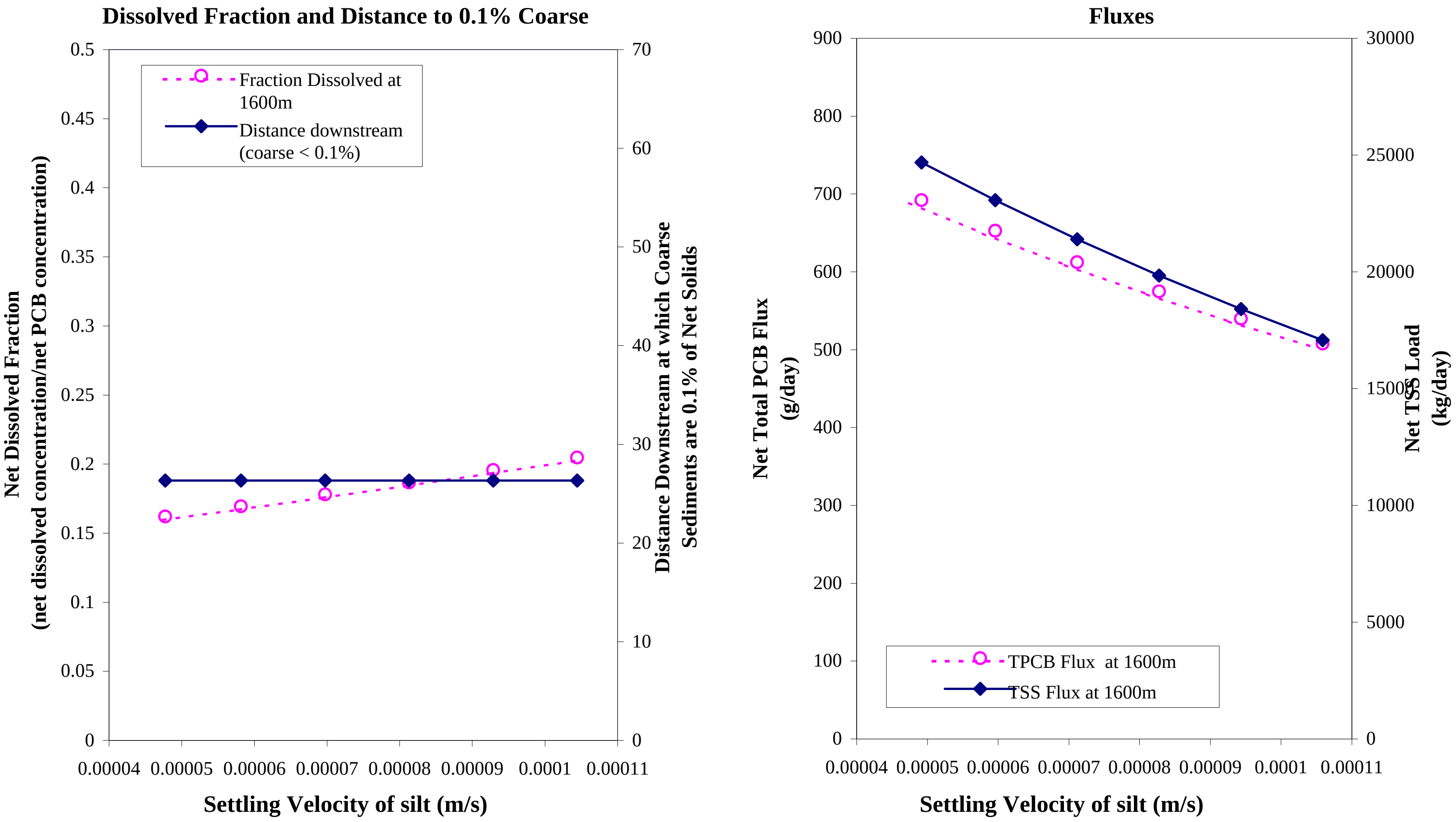
Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Lateral Dispersion for the TSS-Chem



Notes:
1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 30

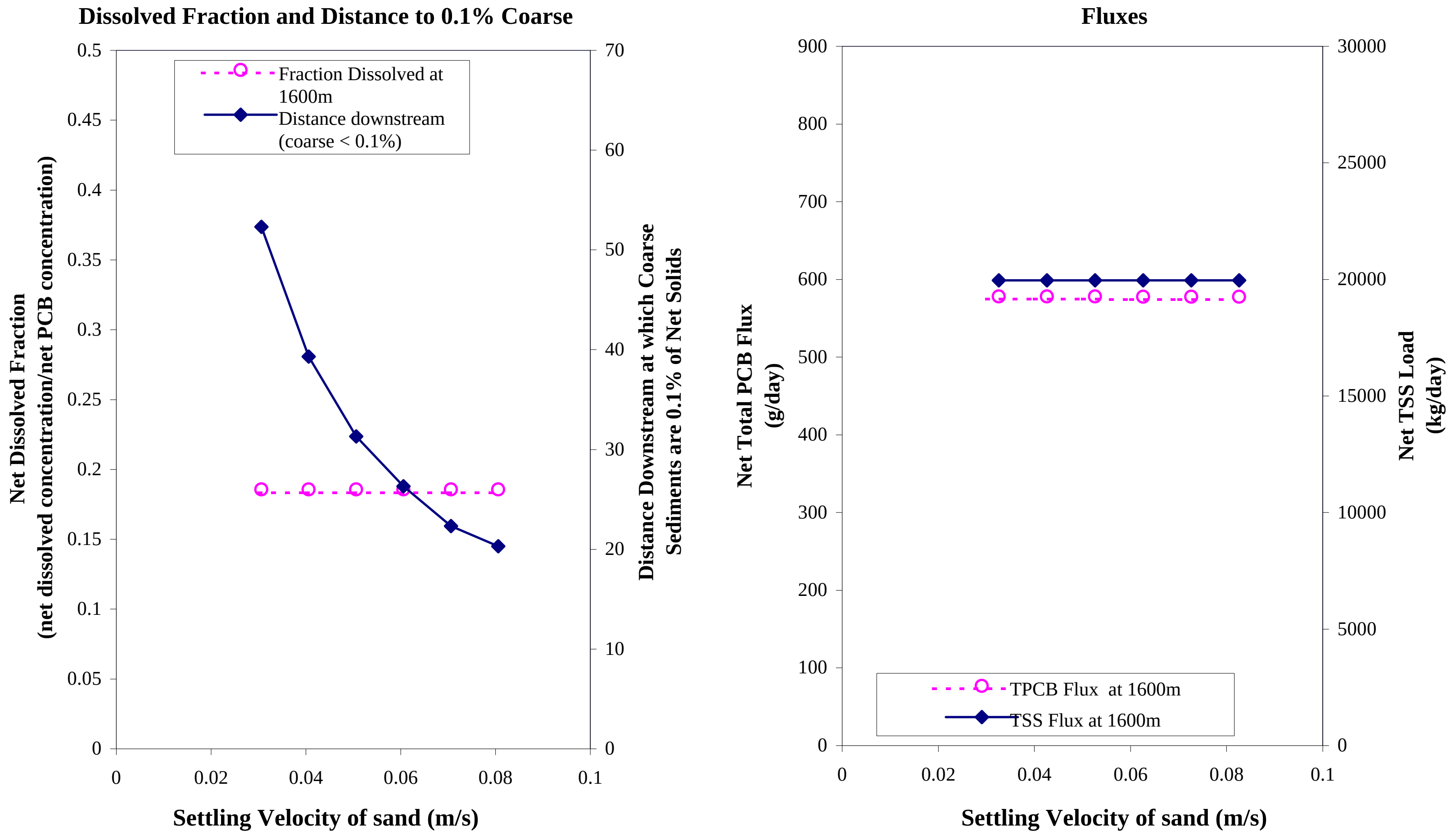
Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of PCB Background Concentration for the TSS-Chem



Notes:
1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 31

Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Silt Settling Velocity for the TSS-Chem



Notes:

1. Net concentrations exclude background.
2. Fluxes are based on 14 hours per day.

Figure 32

Net Dissolved PCB Fraction, Distance to Coarse < 0.1%, Net Total PCB Flux and Net TSS Flux at 1600 meters as Functions of Sand Settling Velocity for the TSS-Chem

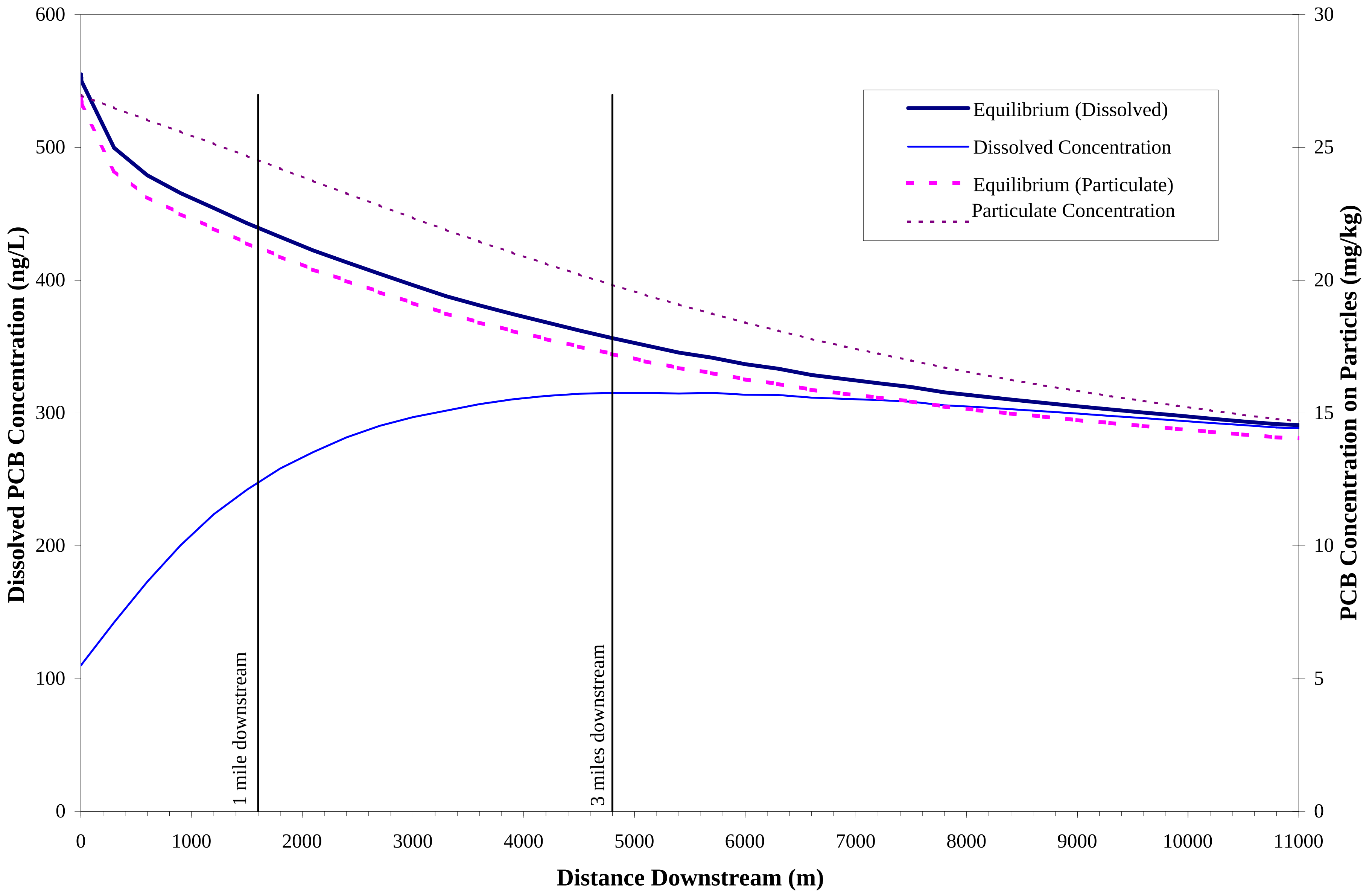


Figure 33
PCB Concentrations Downstream of Dredge for 350 ng/L scenario
Section 1 at 1 mile and 3 miles

Figure 34

Whole Water Total PCB Concentration for Different 350 ng/L Input Formulations

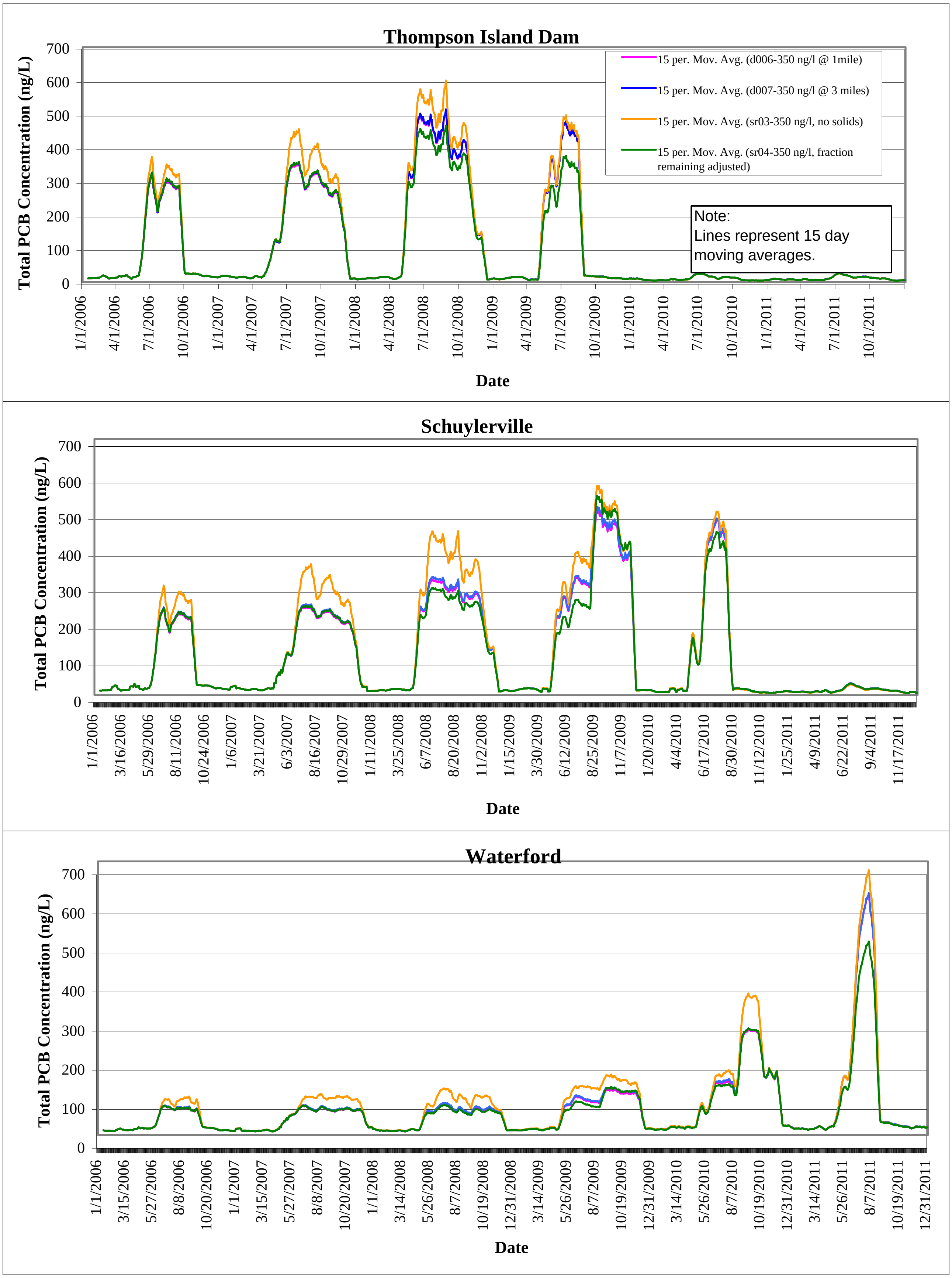


Figure 35
Tri+ PCB Cumulative Load for Different Dredging Scenarios

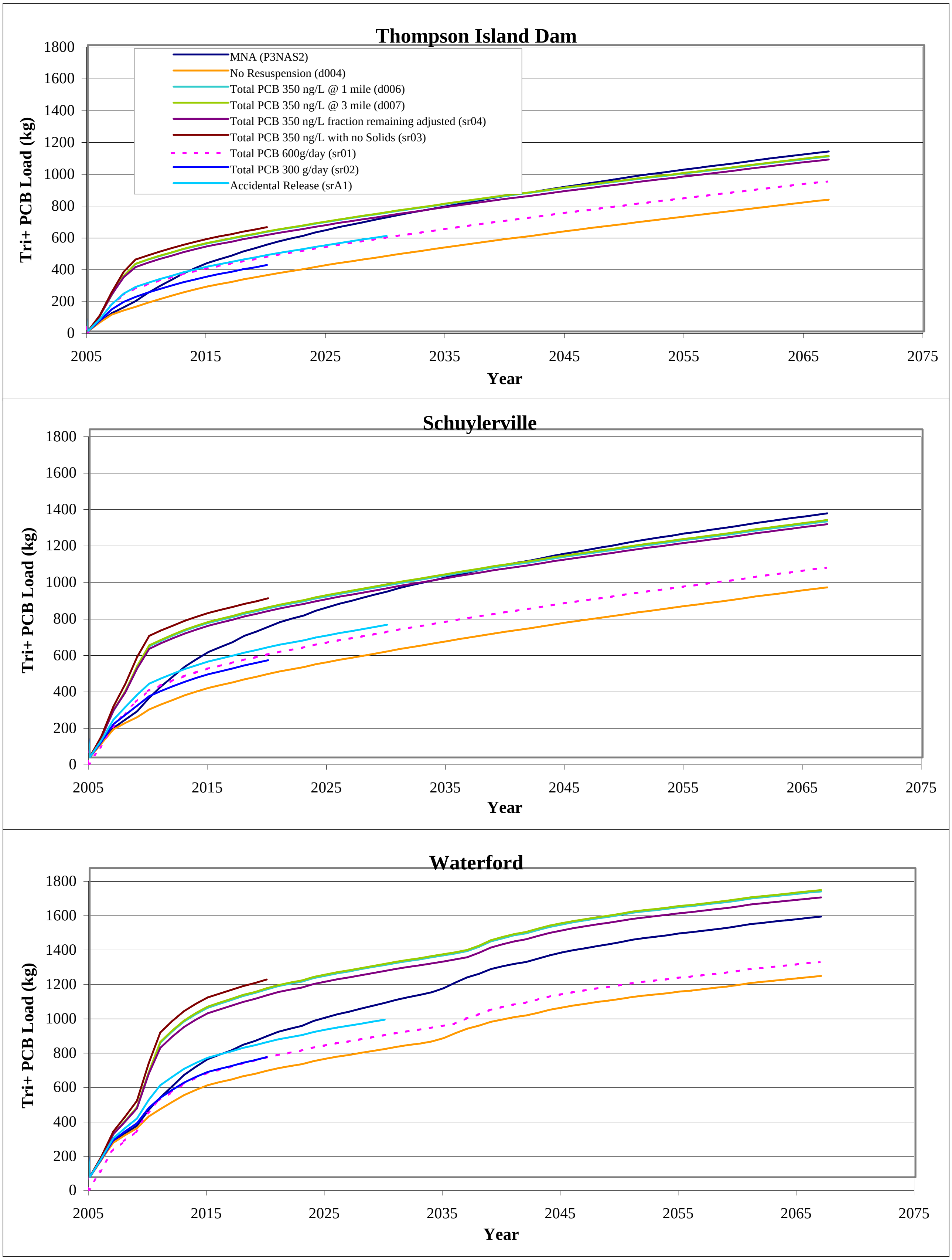


Figure 36

Total PCB Cumulative Load for Different Dredging Scenarios

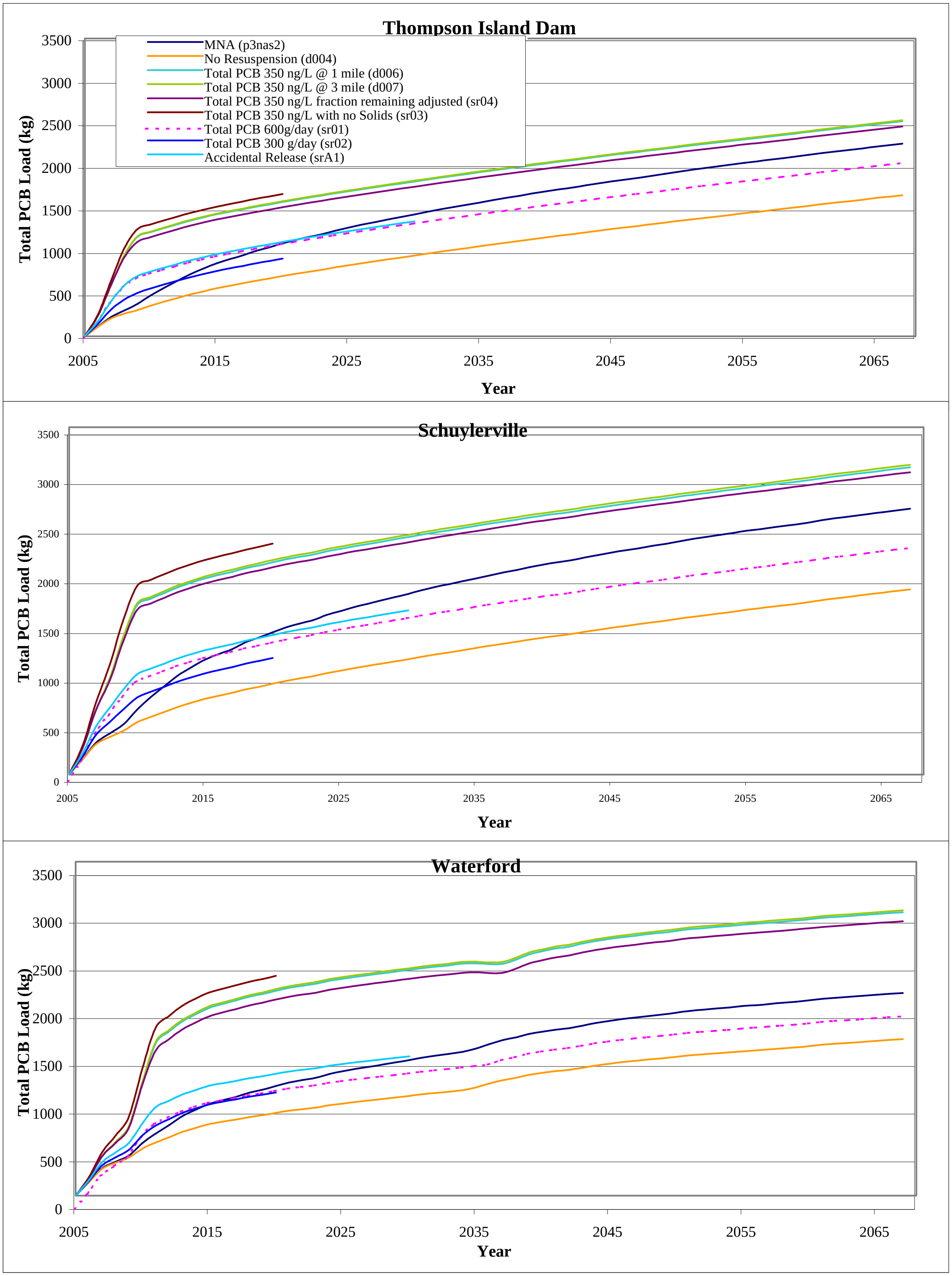


Figure 37

Whole Water, Particulate, and Dissolved Total PCB Concentrations for the 350 ng/L Dredging Scenario (sr04)

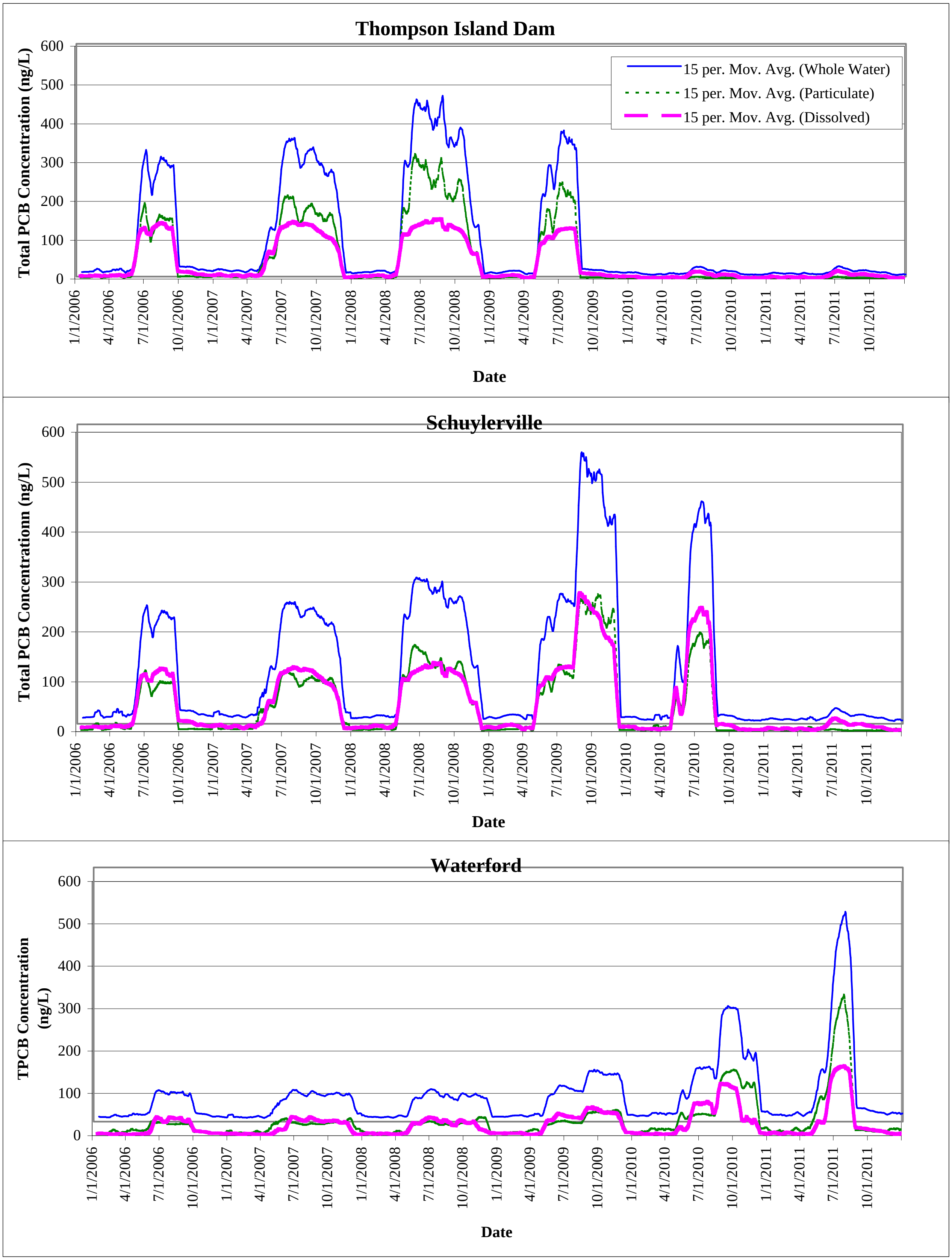


Figure 38
Whole Water, Particulate and Dissolved Total PCB Concentration for Control Level - 600 g/day Total PCB Flux Dredging Scenario (sr01)

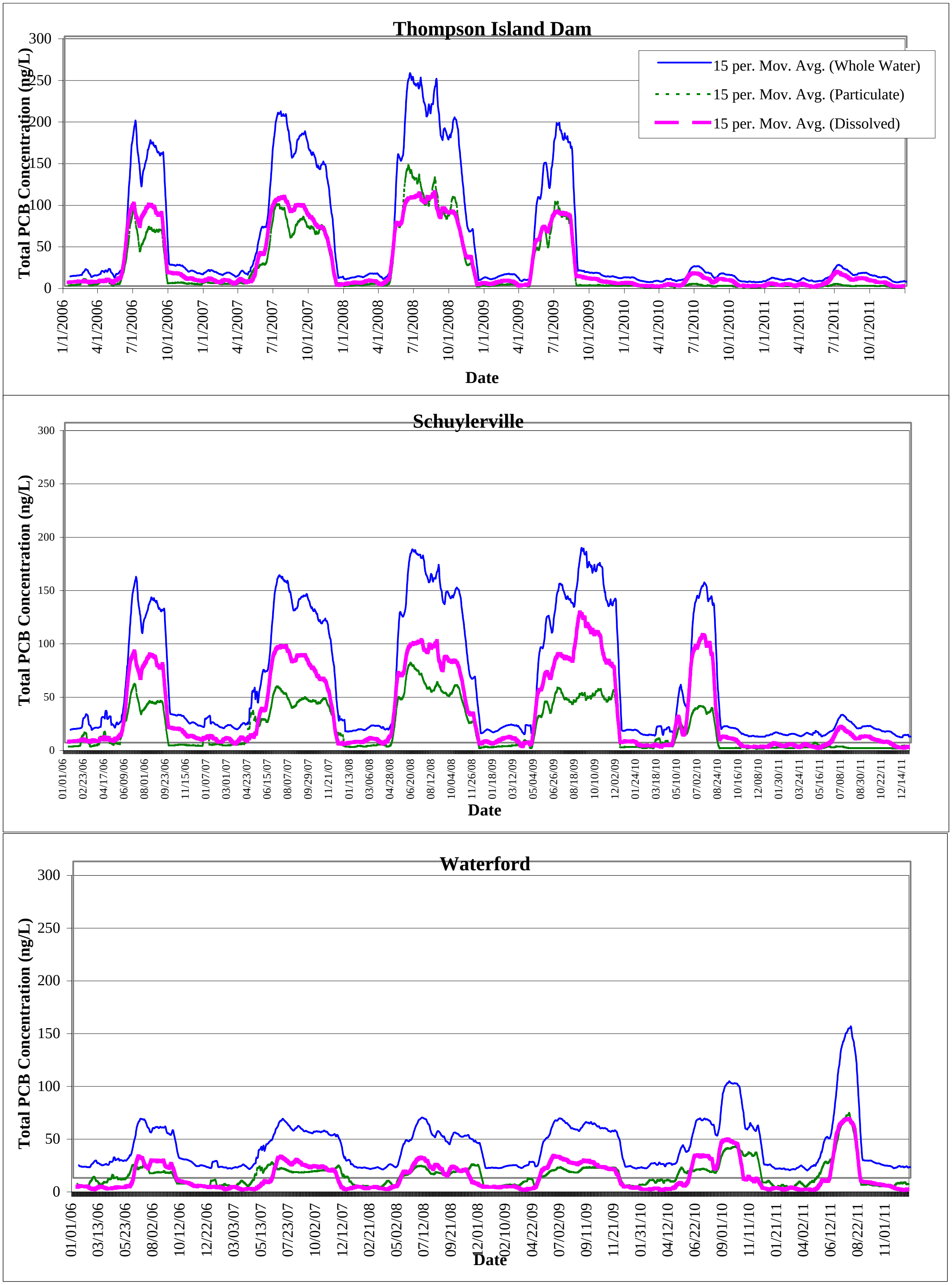
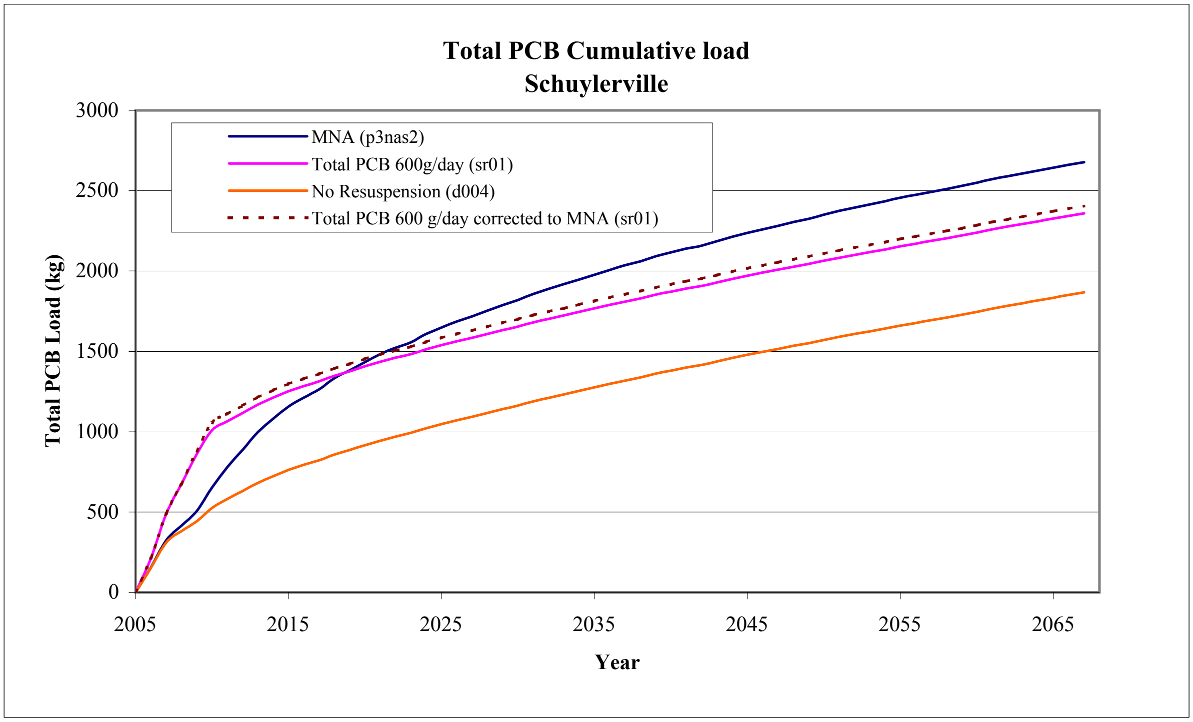


Figure 39. Tri+ PCB and Total PCB Cumulative Load for 600 g/day (sr01) Scenario



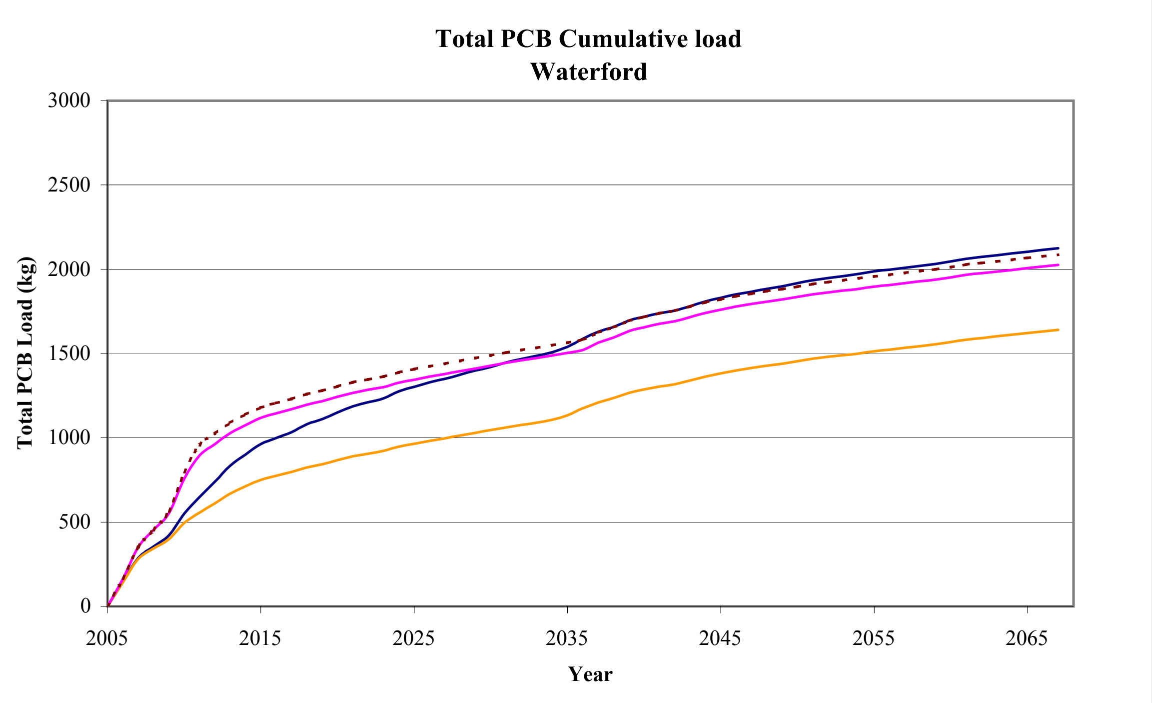
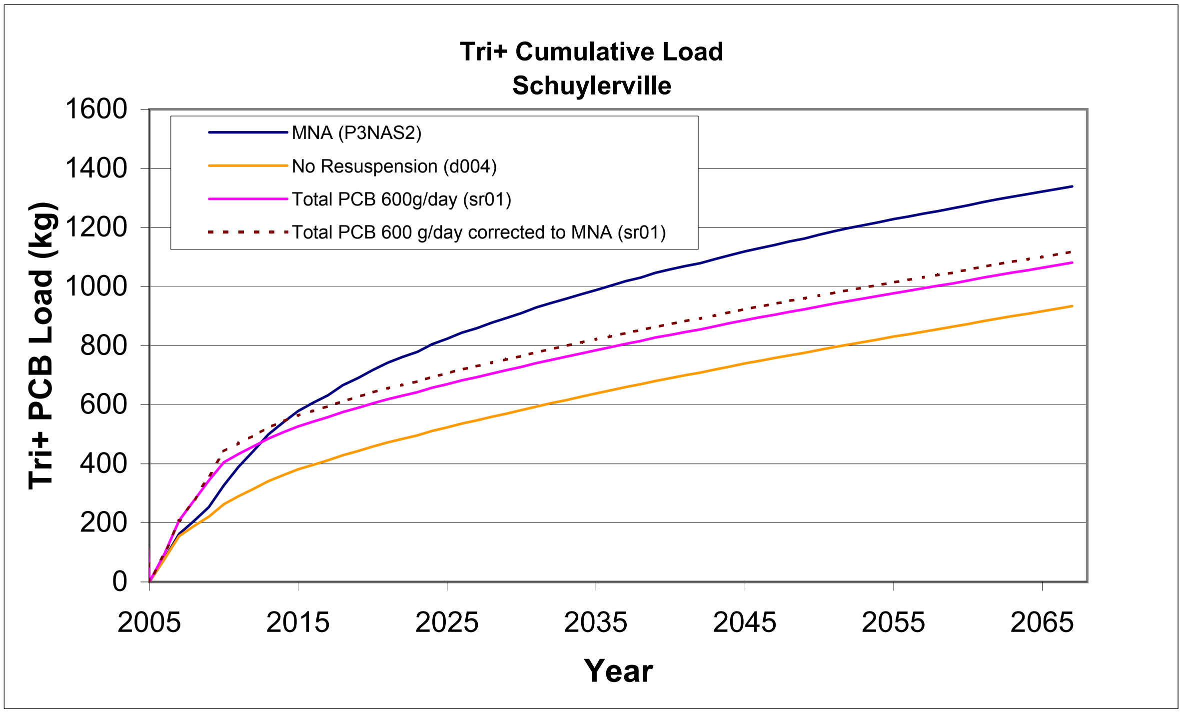


Figure 39 (Cont'd). Tri+ PCB and Total PCB Cumulative Load for 600 g/day (sr01) Scenario



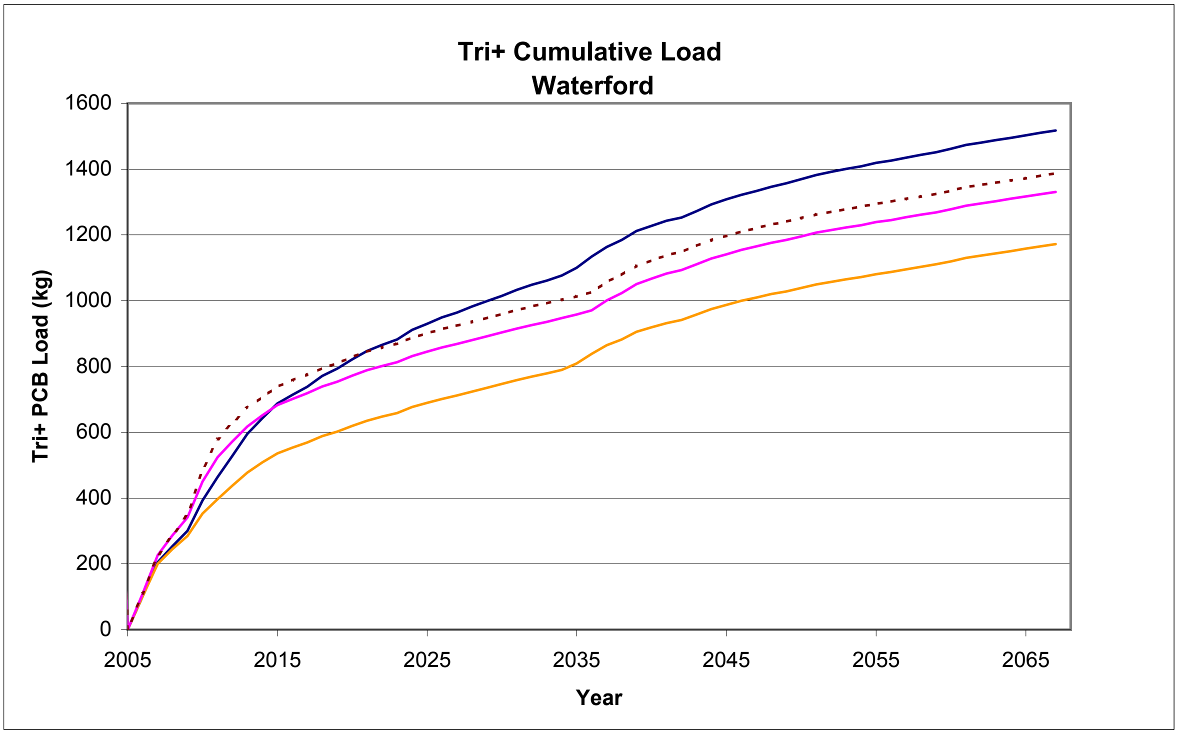


Figure 40
HUDTOX Forecast of Whole Water, Particulate, and Dissolved Total PCB Concentrations for Evaluation Level - 300 g/day Scenario

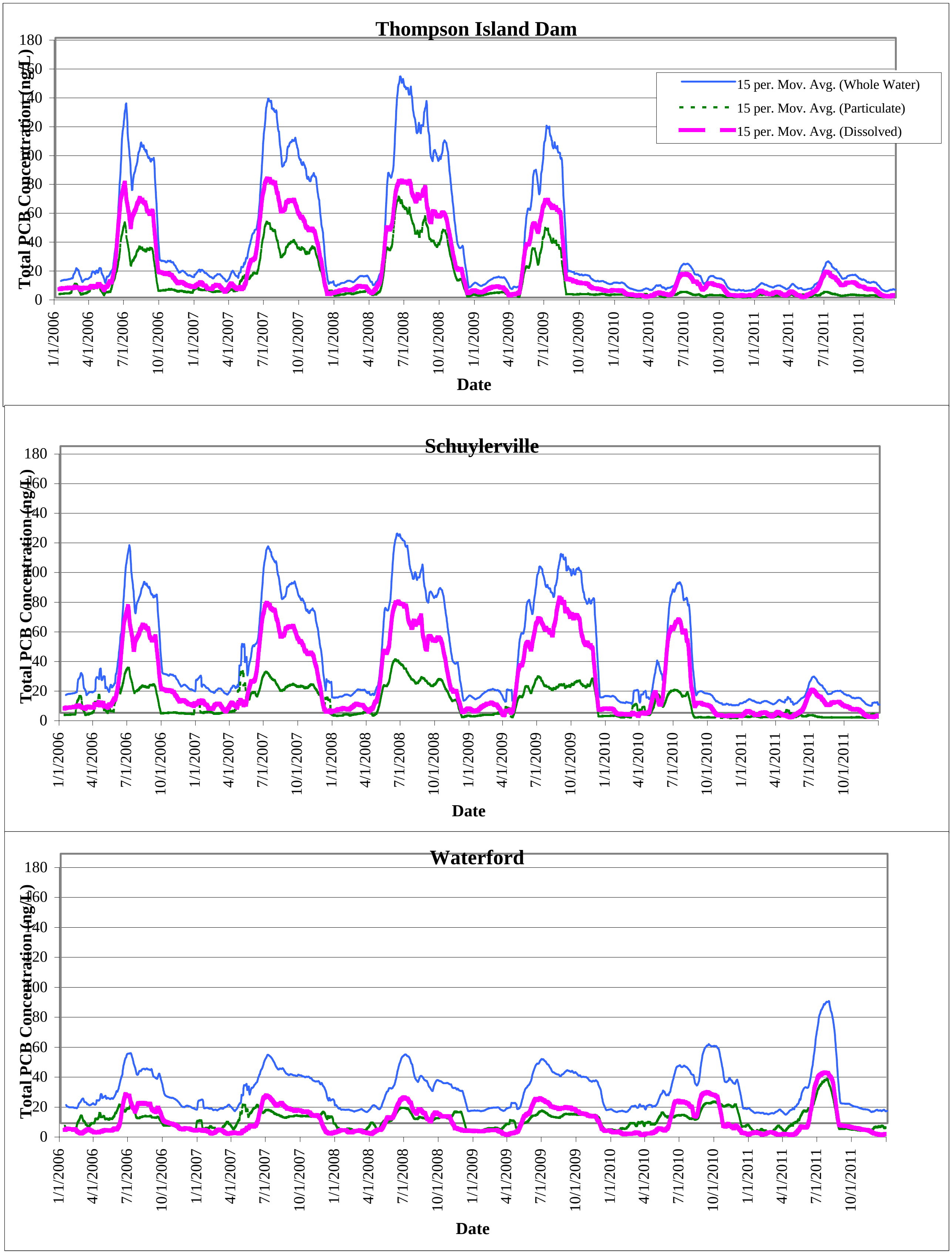


Figure 41

Comparison Between Upper Hudson River Remediation Scenario (Various Export Rates) and Monitored Natural Attenuation (MNA) Forecast for Thompson Island Dam, Schuylerville, and Waterford

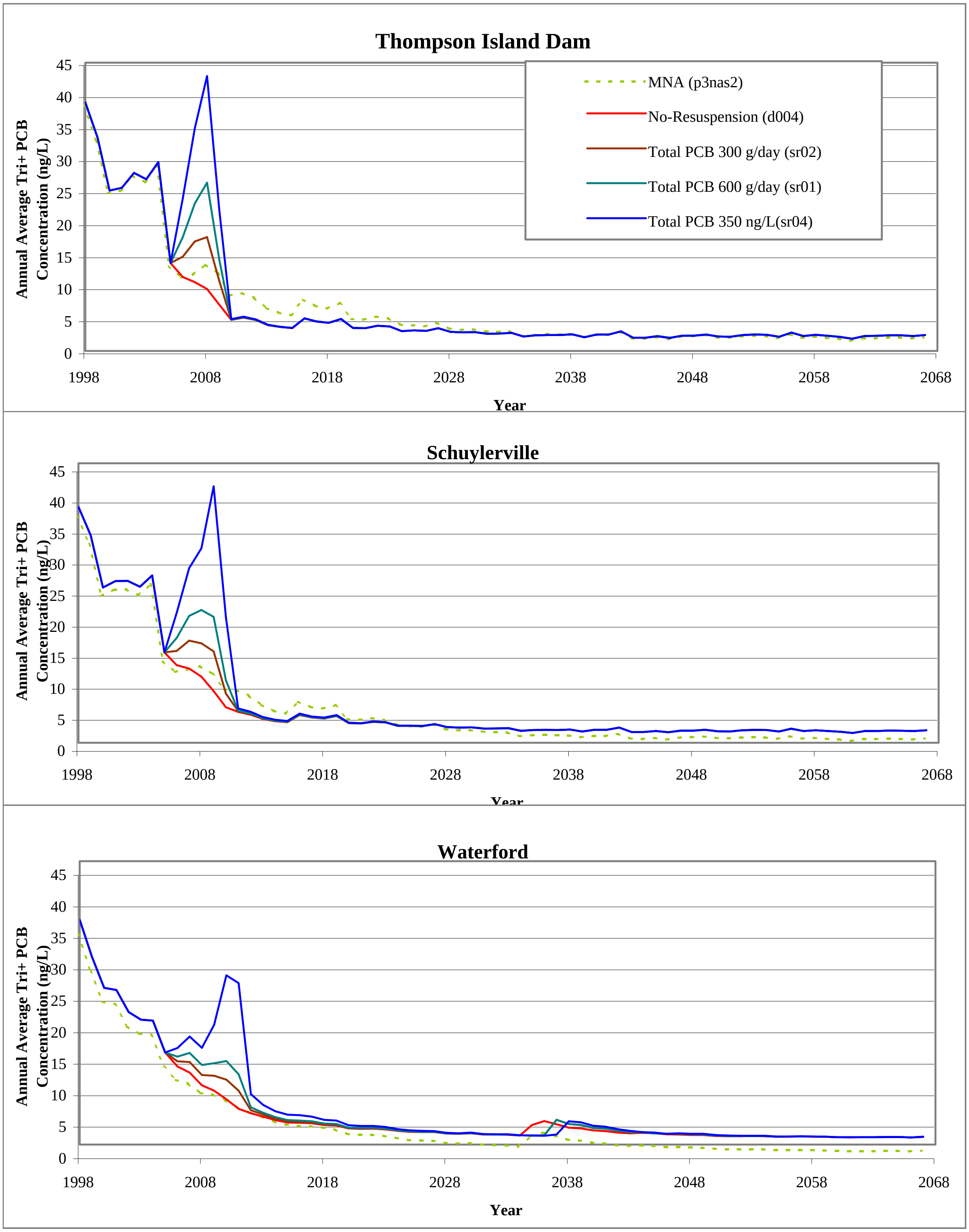


Figure 42
Total PCB Concentrations at Waterford for the Accidental Release Scenario

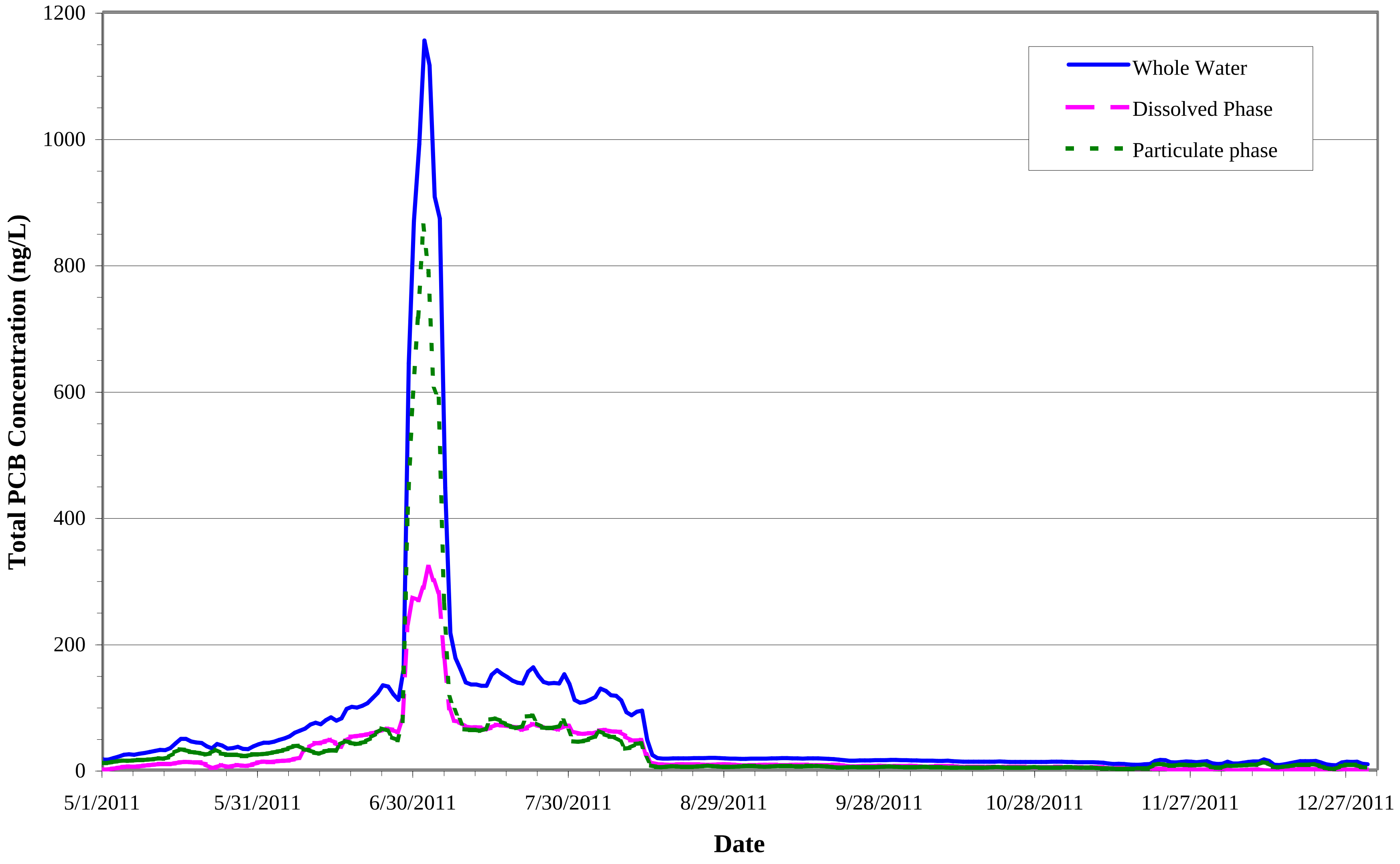
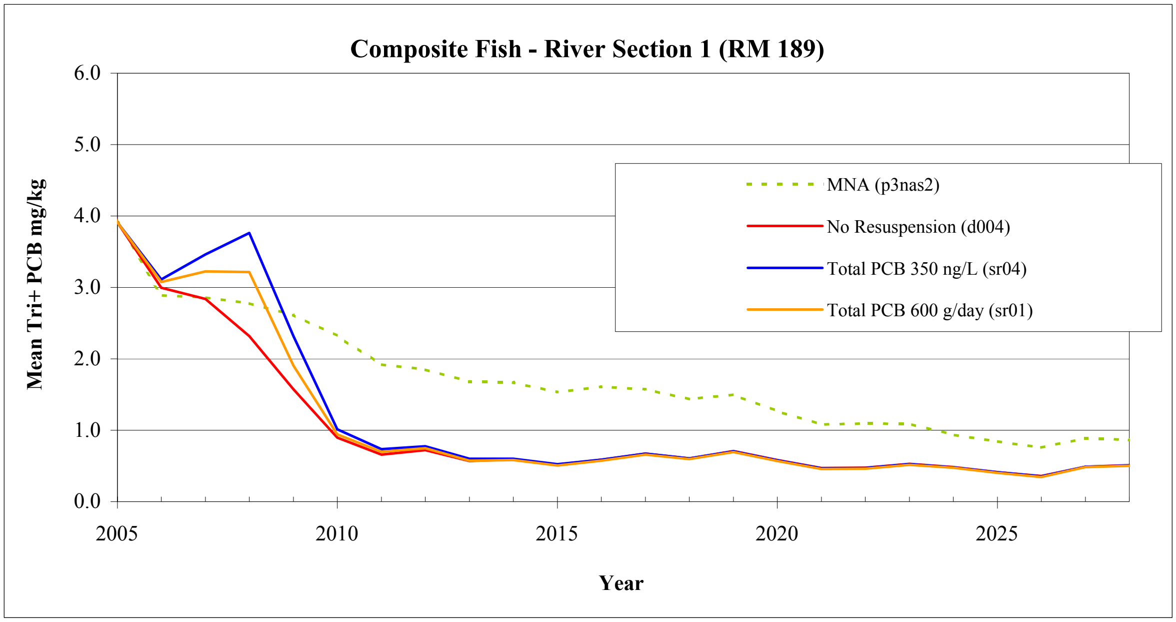


Figure 43

Composite Fish Tissue Concentrations for the Upper Hudson River



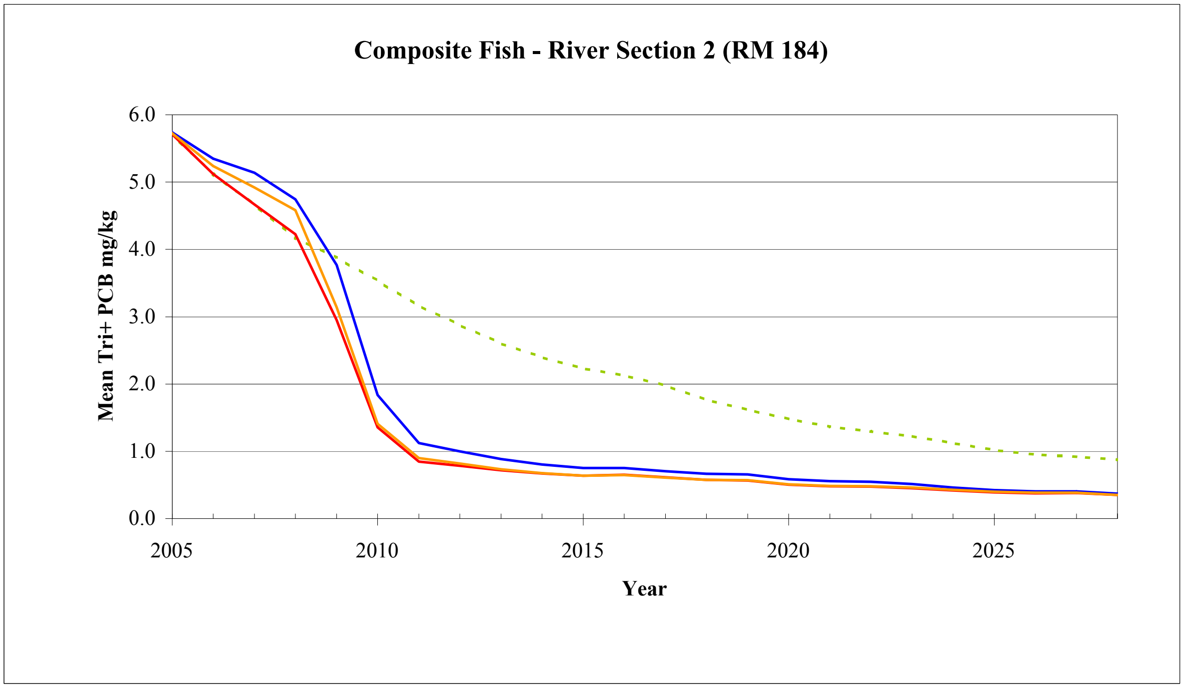
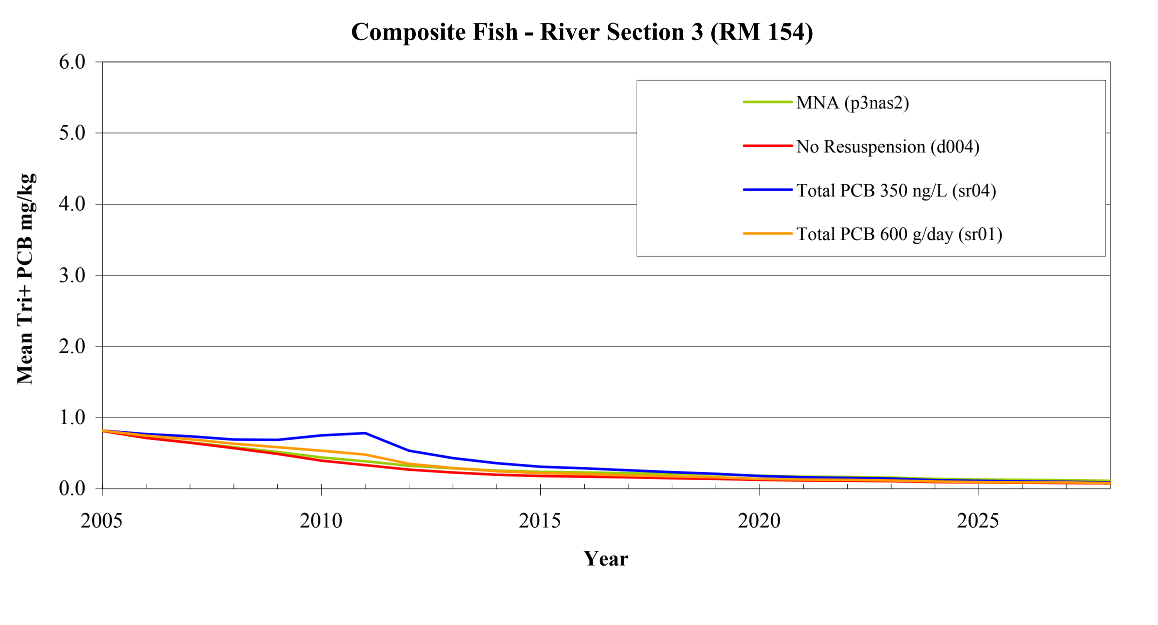
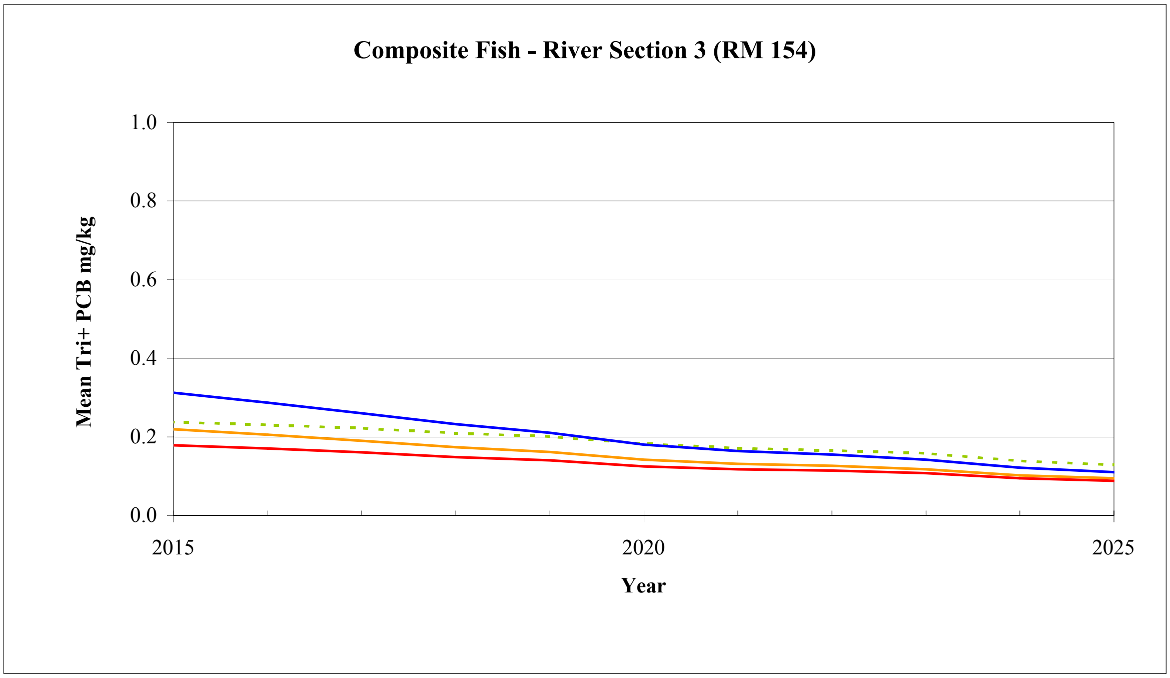


Figure 43 (Cont.)

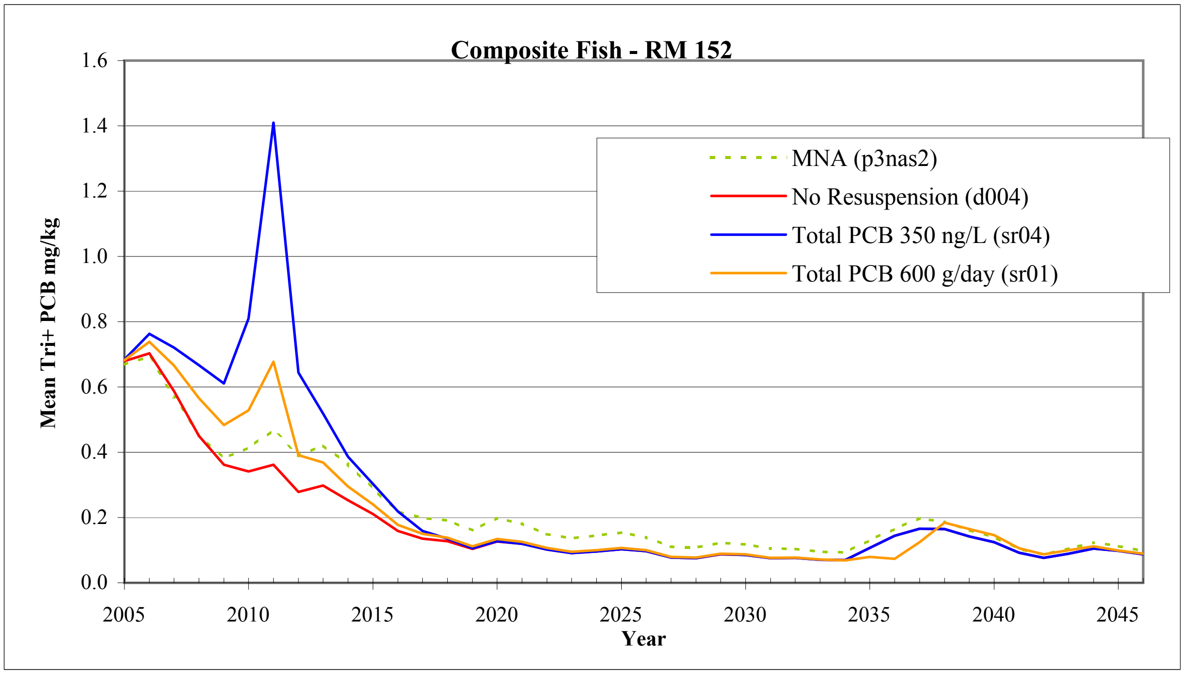
Composite Fish Tissue Concentrations for the Upper Hudson River

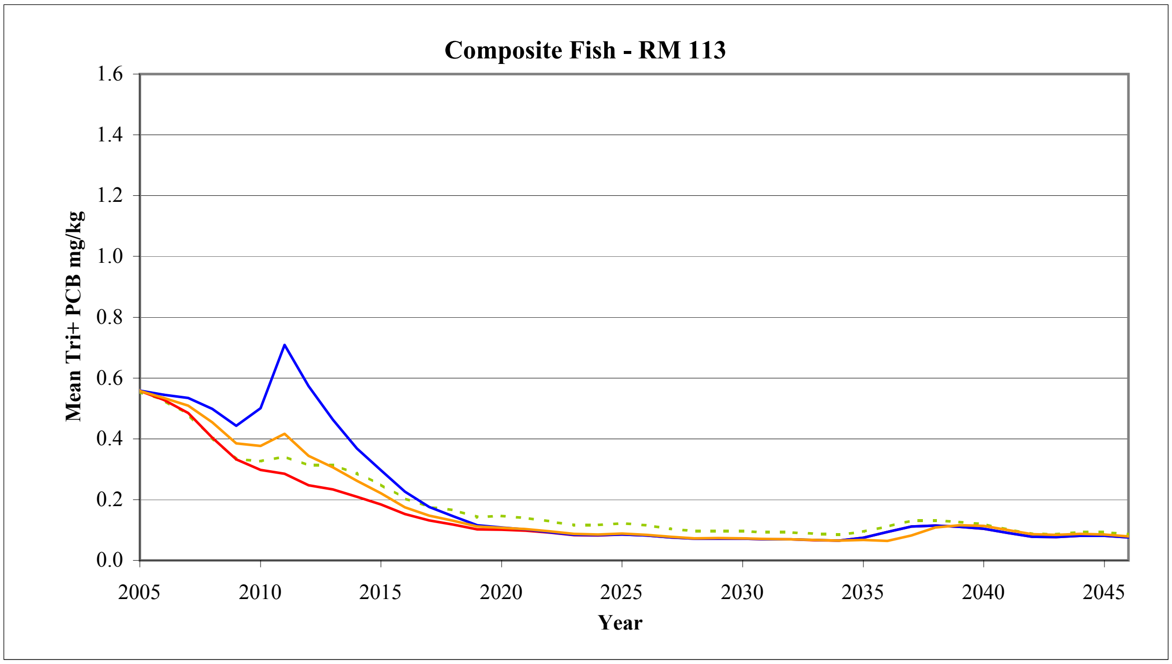




Notes:
Fish composite is 47% largemouthbass + 44% brown bullhead + 9% yellow perch
The bottom figure is portion of the top figure.

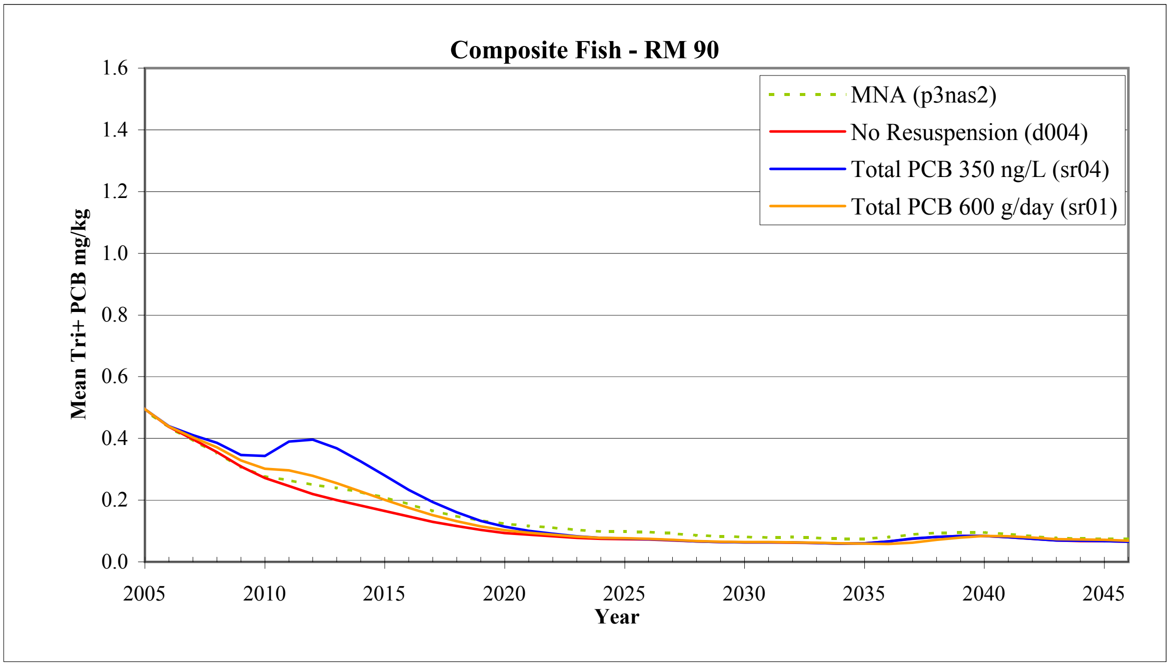
Figure 44
Composite Fish Tissue Concentrations for the Lower Hudson River

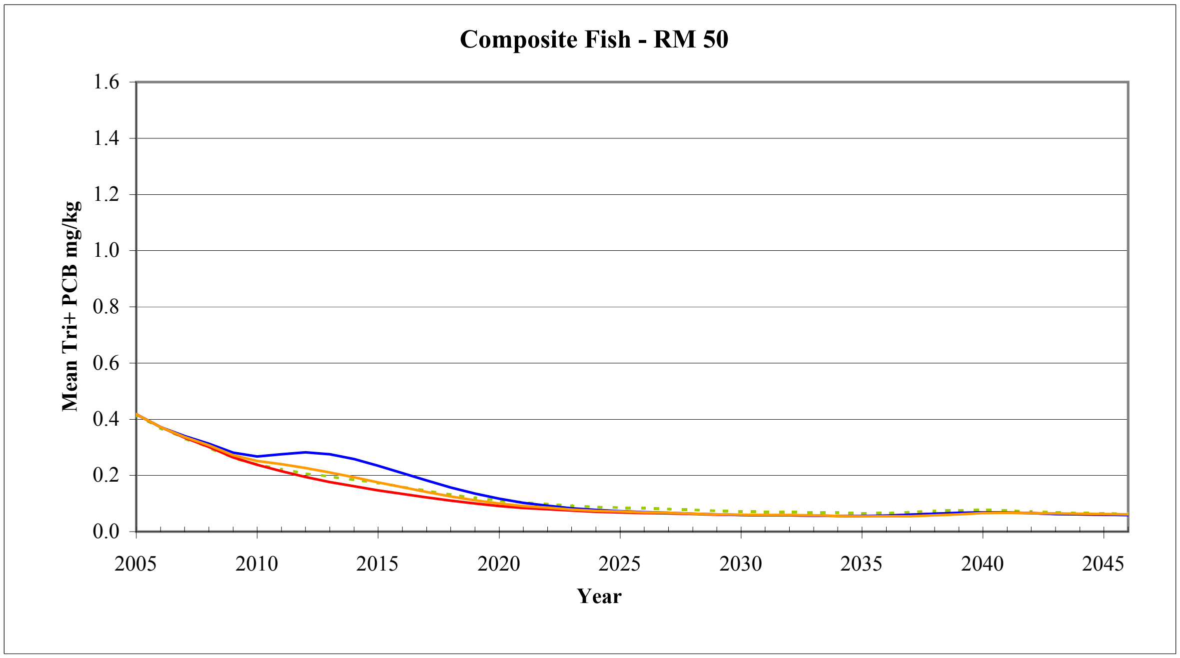




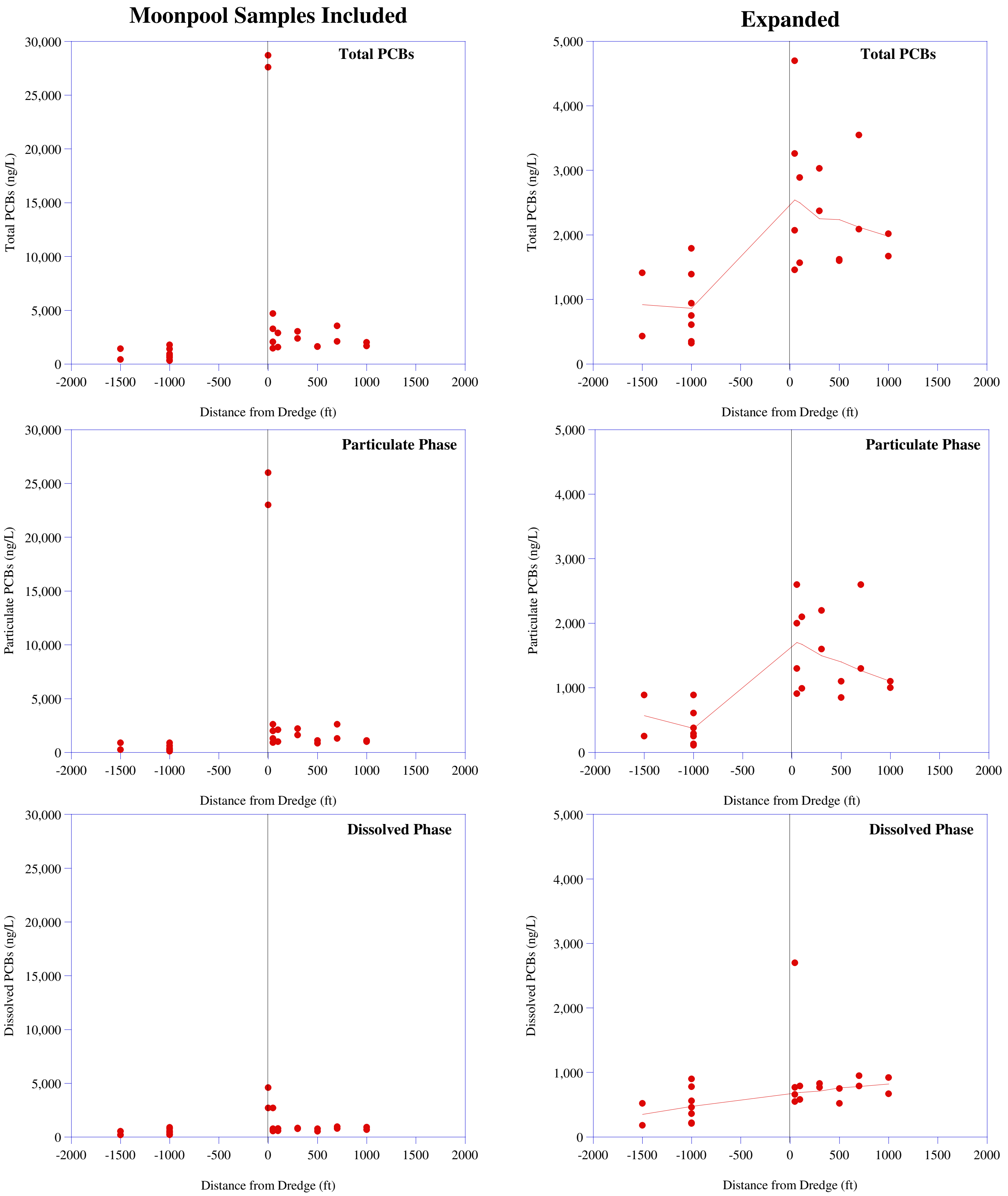
Note:
Fish composite is 47% largemouthbass + 44% brown bullhead + 9% yellow perch

Figure 44 (Cont.)
Composite Fish Tissue Concentrations for the Lower Hudson River



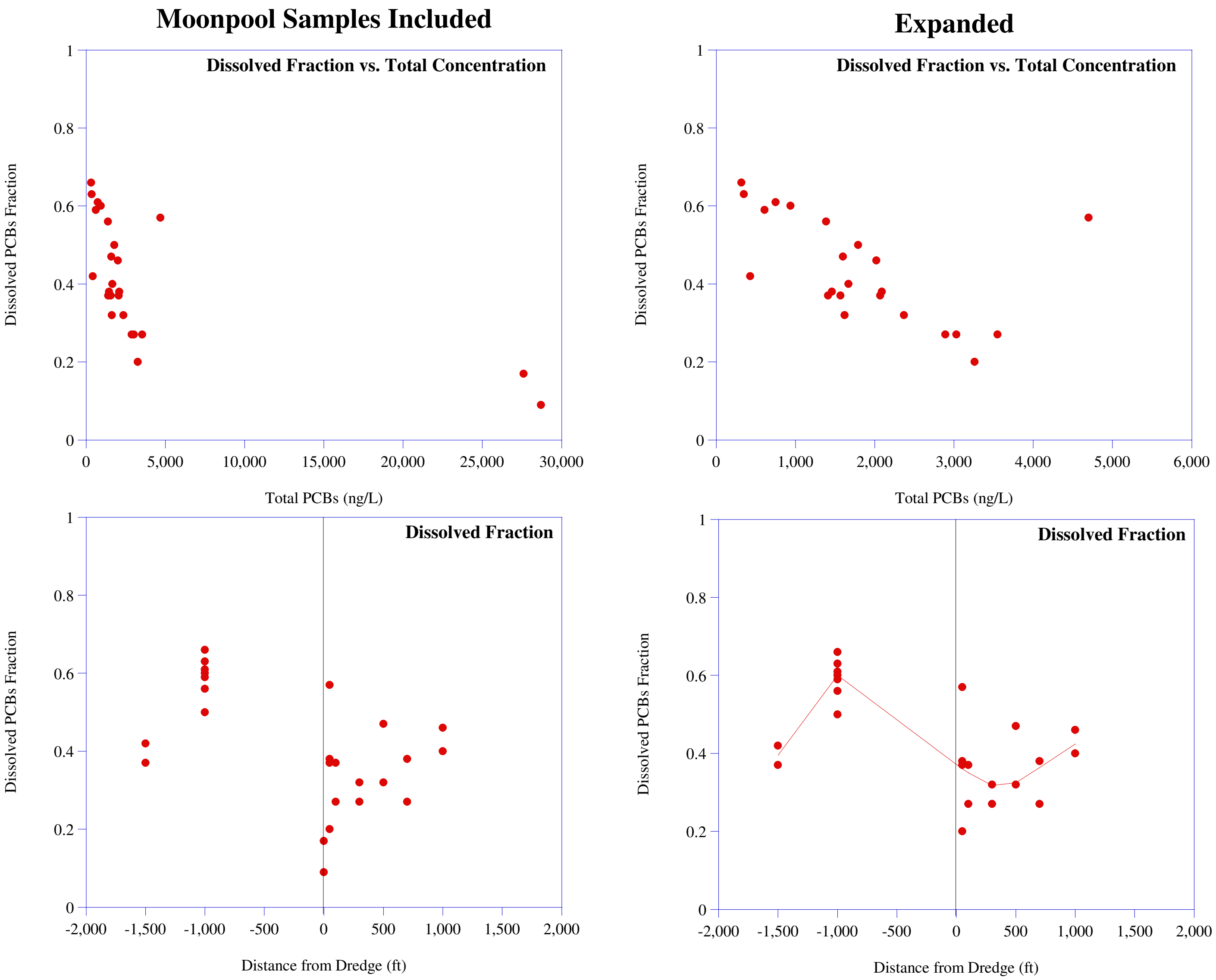


Note:
Fish composite is 47% largemouthbass + 44% brown bullhead + 9% yellow perch



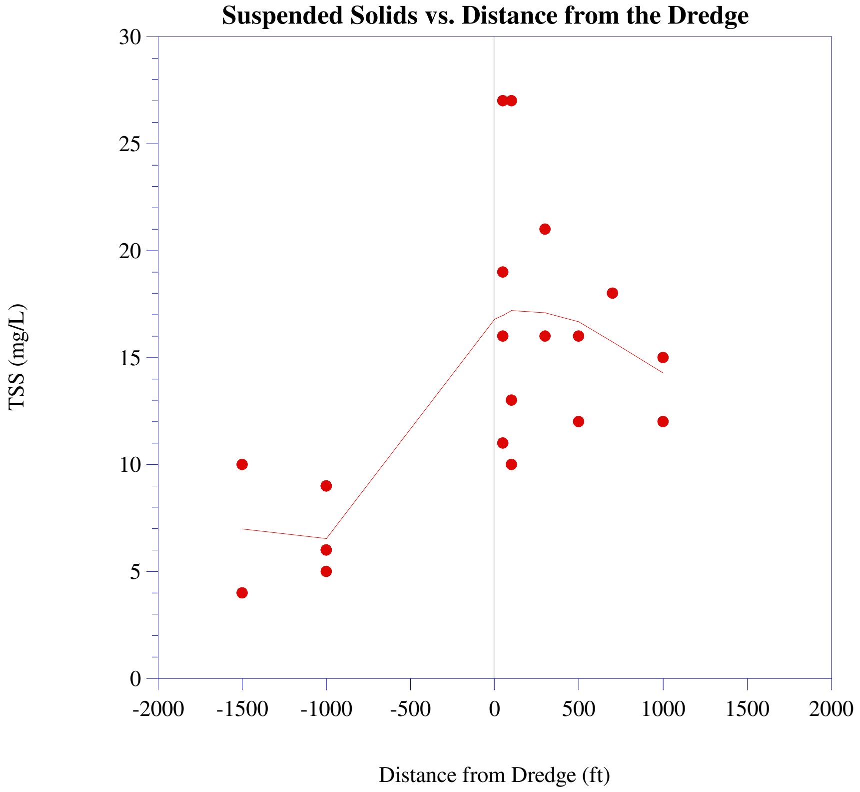
Notes
1.The points at a distance of 0 ft are in the moonpool. The plots with the expanded scales do not include the moonpool samples.
2. Baseline is shown at -1,500 ft.
3. The expanded plots have weighted curves as visual aids to show the approximate mean conditions.

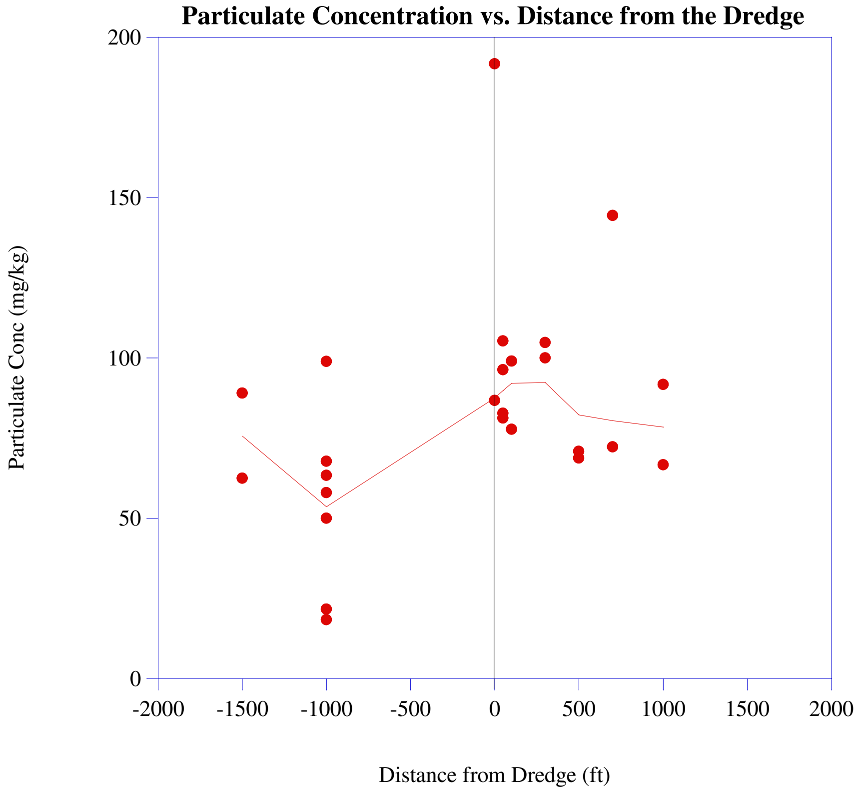
Figure 45
PCB Concentrations for New Bedford Harbor
Pilot Dredging Study



Notes
1.The points at a distance of 0 ft are in the moonpool. The plots with the expanded scales do not include the moonpool samples.
2. Baseline is shown at -1,500 ft.
3. The expanded plot has a weighted curves as a visual aid to show the approximate mean conditions.

Figure 46
Dissolved Fraction of PCB for
New Bedford Harbor Pilot Dredging Study


Suspended Solids vs. Distance from the Dredge


Particulate Concentration vs. Distance from the Dredge

Notes
1.The points at a distance of 0 ft are in the moonpool.
2. Baseline is shown at -1,500 ft.
3. The plots have weighted curves as visual aids to show the approximate mean conditions.

Figure 47
TSS and PCB Concentrations for New Bedford Harbor
Pilot Dredging Study