Attachment A

Hudson River Water Column Concentration Analysis

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Hudson River Water Column Concentration Analysis

1.0 Introduction

An analysis of existing total suspended solids (TSS) and PCB concentrations in the water column of the Hudson River was conducted to provide background concentrations and a baseline to which TSS and PCB concentrations measured while dredging can be compared and the subsequent dredging impact evaluated. To estimate the baseline concentrations of TSS and total PCBs in the water column:

- The monthly flow rate was evaluated over the dredging season.
- Existing TSS and PCB data collected by General Electric (GE) since 1996 were reviewed and analyzed.
- The baseline PCB and TSS concentrations were estimated.

Limitations of the Existing Data

Much of the data analysis planned for the resuspension performance standard development 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; during spring the variability is greatest, 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 being 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 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 at the downstream stations because the dam is closer to the sources. As the contaminant load travels downstream, the "signal" is damped out 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 data set for PCBs encompasses most of the 1990s through the present, the data sampled prior to 1996 may not be useable for performance standard development because of 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 station may not fully represent the Hudson River water column concentrations under all conditions. It is hoped that future Schuylerville 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, a west wing and central channel station are frequently sampled. Both stations have limitations. The concentrations at the west wing were examined in the *Responsiveness Summary for the Data Evaluation and Interpretation Report* (USEPA, 1998). This analysis showed 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 data set is limited to the warmer months. Subsequent analysis showed that the downstream concentrations (Schuylerville) are similar to neither station, but resemble a mix of the concentrations measured at the two stations.

These concerns regarding the existing water column data set have an impact on the evaluation of water column contaminant variability. It is unclear whether the estimated variability derived from historic data only 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 made.

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 in the far field monitoring locations, as well as 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 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: Thompson Island Dam, Schuylerville (Lock 5), and Waterford. 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.

USGS monitors the flow rate of the Hudson River at gauges located 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, and within the drainage areas surrounding the Hudson

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

Flow rates at the TI Dam and Schuylerville were computed based on 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:

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

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.

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

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

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

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 from 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.

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

where

$y_{ung} = (F_{stwtr} - F_{Ft.Ed} - F_{BKg} - F_{BKung})/(A_{stwtr} - A_{Ft.Ed} - A_{BKg} - A_{BKung})$ .... *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, where in the drainage area ratio method and the measured flow at the Ft. Edward gauge was used to estimate the flow at the dam. The following equations, Equation 8, 9, and 10, depict the relationships used to predict the flow rate at the TI Dam (F_{TID}):

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

where

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

and

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

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:

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

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 caused by 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 the dredging operation and actions will be taken when the water column PCB concentration exceeds a certain level/threshold to minimize the impact of resuspension on the river system. 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; that 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 in their on-going weekly sampling program were used to estimate the current PCB water column contamination conditions in the Hudson River, because it provides a long record of PCB and TSS concentrations in the Hudson River and has measured PCB concentrations using a congener method. represent the most comprehensive water column dataset 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, such as the samples are 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 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 Thompson Island Dam near the shore (TID-West), in the channel section above the TI Dam (TID-PRW2), and at Schuylerville (Lock 5). Data collected at these four stations were investigated in this study to estimate the natural variability of TSS and PCB concentration in the river system at different locations/reaches of the river. Daily average flow measured and reported by the USGS was used for PCB and TSS analysis at the Fort Edward station and 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.

Since the proposed dredging season is during the period 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 a best estimate of conditions during dredging. Field duplicated samples were collected for a percent of collected samples. An average concentration was calculated to represent these field duplicate samples. 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 weight every sampling day evenly.

There are non-detected values for both TSS and PCBs in the GE data set. When using these values in a calculation, a value will be substituted for the detection limit to estimate the concentration in the sample. Typically, either zero or one-half the detection limit is used in the substitution. A detection limit was not provided by GE for TSS and in some instances, for PCBs in the data reviewed. To make a 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-detected samples. To make a 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 the resuspended particles. As a result, the change in the TSS concentration will act as an indicator of a possible increase in the PCB concentration in the water column. There are no instruments currently capable of making reliable measurements of PCBs in situ. Measurements of PCBs must be done through a laboratory 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 surrogate indicator of a PCB release. Therefore, the TSS level under baseline conditions are analyzed herein in addition to the total PCB baseline concentrations.

Review of PCB and TSS data collected by GE since 1996 at the Ft. Edward, TID-West, TID-PRW2, and Schuylerville monitoring stations indicated that variation exists among different months' data, and that one TSS and PCB concentration could not be computed to represent the background concentration over the seven-month dredging period. As a result, 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 these stations follows, using the Schuylerville station. Figure 11 depicts weekly PCB and TSS water column samples collected at the Schuylerville monitoring station from 1996 through 2001, grouping by month (May through November). The mean TSS and PCB concentration for each month was calculated and connected to show the trend of the monthly concentrations. It is clear from the data 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 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.

It is evident, therefore, that a single uniform TSS or PCB baseline value is not applicable to every month. Similar analyses were performed for each of the data sets representative of the other three monitoring stations. The same conclusion was drawn: that significant difference exists among some months' data, such as a spring month and a later summer month, and a uniform baseline value will not represent the dredging period condition appropriately and efficiently. The natural variability of the Hudson River should be addressed by a set of time-specific baseline values by grouping the available data in a reasonable way.

There are about 20 - 25 data points available for each month. A smaller size data group will not permit a reliable statistic analysis result. Therefore, one month is the smallest unit to group the data in this analysis. In addition, it is physically meaningful to generate a baseline number for each month. A statistic analysis was conducted on each of the monthly data sets to determine whether to group data for some months together. JMP (SAS, 1997), a statistical program, was used to perform the statistic analysis. This study included: calculation of the minimum, mean, and maximum concentrations per month, along with the 10 percent, 25 percent, 75 percent, and 90 percent quantiles, and, most important, the Tukey-Kramer Honestly Significant Difference (HSD) used to determine whether two sets of data are really different.

A sample plot for this study at the Schuylerville station for TSS and PCB concentrations measured 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 data set 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 data set.

Study on TSS and PCB data for the Ft. Edward, TID-West, and TID-PRW2 allowed consolidation of several months data into one data set in the following cases:

- At the Ft. Edward station: TSS data for September through November and PCB data for July through September and October and November.
- At the TID-West station: TSS data for July through October and PCB data for October and November.
- For the TID-PRW2 station: TSS data for July through November and PCB data for the months of July and August.

The monthly/consolidated monthly variability of the 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 data sets having greater variability. There are two types of interval estimates, prediction interval (PI) and 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/consolidated months 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 the 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 one 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 to single sample results collected during the dredging operation. Sample results obtained during dredging lying above this upper bound limit (the prediction interval) will be assumed to represent some dredging-related releases.

In addition to providing an upper bound limit for individual sample, it is also true that if all the new sample results are greater than the average level determined by previously collected data, the new population is different from the old population even though every single new value is less than the limit on individual sample. Therefore, the confidence limit on the average was used as the second layer criterion to control the average of new observations.

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.

With regard to PCB and flow, no correlation was observed between PCB and flow at the Ft. Edward monitoring station. At the TID-West station, a correlation between PCBs and flow was observed during the months of May and June. Analysis of data versus flow at the TID-PRW2 station indicated that a correlation existed with PCBs versus flow during the months of May and June. Data for the Schuylerville station indicated a correlation between PCB and flow for the months of May and June as well. Statistical data were indicative of these correlations based on a high r-squared value and an observed significant probability less than 0.05. These 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. This program was able to compute these values while performing a regression analysis between two correlated variables. The center confidence provides the confidence limit on the predicted central tendency. 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 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 PCB data was determined to be correlated with the flow rate. These fit curves are shown in Table 1. Since PCBs are correlated with flow in the stated months per station, the flow rate was applied to the listed formulas/fit curves to determine the baseline PCB concentration, the PI and UCL, at different flows. 2000 cfs, 4000 cfs and 8000 cfs were used to calculate the baseline levels, representing the lower bound flow, average flow and upper bound flow, respectively, during dredging.

For the monthly/consolidated monthly data sets where correlation between flow and concentration is not observed, PI and UCL are estimated solely based on the concentration data itself.

The upper bound prediction interval was estimated using the methods provided by Helsel and Hirsch (Helsel and Hirsch, 2002). Three methods were used to calculate the upper 95th PI on each of the data sets. These methods were the parametric symmetric prediction interval, the parametric asymmetric prediction interval, and the nonparametric prediction interval. Since the interest 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; however, 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:

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

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 the data follows a lognormal distribution and the prediction interval is computed using the formula shown in Equation 13.

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

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 data set.

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

$$UCL = \overline{X} + t\ (s/\sqrt{n}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{Equation 14}$$

where $\overline{X}$ = 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.

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

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, 95 percent Chebyshev UCL was selected for this analysis since all the data sets 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 PI and the 95 percent UCL could be computed from one of the above listed equations based on the determined distribution of the data. For months in which the number of samples was less than 50 (n<50), the W-test was used. 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 data set.

The W-test was applied to each month's/consolidated months' data set when there were 50 or less data points. This test generates a W-value and ln-W value. These values were 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 greater than the critical value for both cases, the larger computed value (W versus ln-W) determines the data distribution. If both the computed W-value and ln-W-value are less than the critical W value, then the distribution is determined to be non-parametric.

For monthly/consolidated monthly data sets with more than 50 samples, D'Agostino's test was used to compute a Y and ln-Y value. These Y-value and ln-Y values were 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 in the event that the ln-Y value is within the range of critical ln-Y values. If the computed Y and ln-Y values 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 Y and ln-Y do not meet the criteria indicative of normal or lognormal distribution, then the data set is determined to be non-parametric.

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

These statistical tests were performed for each of the seven dredging months/consolidated dredging months at each of the four monitoring stations. Table 2 depicts these results. The results were indicative of a prediction interval baseline for PCB and TSS per month/consolidated month and a 95 percent UCL baseline for PCB and TSS per month/consolidated months at each of the monitoring stations. The results for each monitoring station follow, 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 while dredging to assess potential dredging-related impacts.

Note that during the data analysis procedure, only the samples associated with high flow event were excluded. No data were excluded as outliers. Some elevated values found in the data set are representative of values that could occur during the remediation. Therefore, it is inappropriate to treat them as outliers although in a strict mathematical sense, these values might be outliers. In addition, this analysis is intended to show the approach to estimating the baseline. The final baseline values will be calculated from the Baseline Monitoring Program data, which is planned to be collected between 2003 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 where PCB concentration was determined to be correlated with flow, the PI and UCL of PCB concentration were also estimated using the method listed above for the datasets where concentration is not correlated with flow. Values of PI and UCL, generated by this method, are quite similar to the values associated with a flow of 4000 cfs using the equations listed in Table 1. 4000 cfs flow is assumed to be the average flow during the dredging period. Therefore, the values generated by this simple (no flow involvement) method reflect the level of PCB under the average river flow well. It is also found that the estimated PI and UCL values at 2000 cfs and 8000 cfs are approximately within ± 20 percent of the values at 4000 cfs. And the 20 percent is not a pronounced difference considering other uncertainties involved in the analysis. Lastly, it was thought that it may be impractical for the dredging operator to measure the flow rate and apply to these formulas in the field to determine the PCB concentration. A developed baseline with a set PCB concentration for each month/set of months over the dredge season would be easiest and most practical for field application. It is concluded that the baseline levels (PI and UCL) are all estimated based on the assumption that there is no correlation between flow and concentrations. The flow-independent PI and UCL values are calculated and summarized in Table 2 for each month/consolidated months at each station.

It should be noted that all the analysis listed above is intended to show the approach to estimating the baseline. When the new baseline data is available, same type of analysis will be conducted and the result may be able to suggest some simplification on estimating the baseline. 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 September through November, while PCB data were analyzed individually for May and June and jointly over the period 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 for May through November have a normal distribution of data for the months of May and July and for the period September through November, while data for June has a non-parametric relationship and data for August has a lognormal distribution,

Figure 16 indicates that the prediction interval baseline generally tends to correspond with 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 concentration more than double all other TSS samples collected 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. Prior to August, the prediction interval is approximately 4.0 mg/L, on average. Following August, the prediction interval decreases to 3.0 mg/L, where it levels out for the remainder of the dredging season (September through November). The 95 percent UCL baseline follows the same seasonal distribution as the prediction interval; however, it achieves a maximum concentration in June of 5.7 mg/L. 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. These results are shown in Table 2. These estimated baselines were plotted against the total PCB monthly data sets. These relationships are presented in Figure 17.

Figure 17 indicates that total PCBs measured for this station were greatest in concentration during the months of July through August and that the smallest concentrations were measured during the month of May. The estimated prediction interval baseline can be seen to correspond with the upper bound total PCB measured concentrations per month, with the prediction interval baseline being highest in total PCB concentration during the months of July through September and lowest during the month of May. The prediction interval baseline decreases by 15 ng/L from September to October where it 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 data per month is always less than the prediction interval baseline and tends to correspond to the mean total PCB concentration per month, as shown in Figure 17. This curve has its lowest baseline concentration during May and its maximum concentration during the month of June, with the baseline values in the months of July through September being slightly less, approximately 0.4 ng/L less, than the maximum estimated concentration for the month of June. The 95 percent UCL baseline decreases by 8 ng/L from September to a constant concentration of 10.4 ng/L during the months of October and November. It can be concluded that if the average of the PCB measurements reported during dredging 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 exist at the TI Dam TID–West. on the west side of the TI Dam near the shore and TID-PRW2 in the channel section of the river near the dam. TSS and total PCB monthly data/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/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 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, with the exception of months where elevated TSS concentrations exist, which are May, June, July and August. In these instances, the prediction interval baseline tends to correspond to a data point mid-way between the majority of samples 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, levels out until October, and then slightly increases 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 per dredging month with a maximum estimated 95 percent UCL baseline TSS concentration occurring in May and June with a minimum estimated 95 percent UCL TSS baseline concentration occurring during the months of July through October.

For total PCB data reported for this station, data 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 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 has its largest total PCB concentration during May and June and represents 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 its minimum value of 120 ng/L during September. The prediction interval baseline then increases through October and November to a total PCB concentration of 300 ng/L. It was also noted that the prediction interval tends to be consistent with the maximum total PCB data point 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 represents approximately 200 ng/L from May to June, decreases through July (150 ng/L) and August (106 ng/L), reaches its minimum concentration in September (83 ng/L), and then increases greatly to reach its maximum concentration during the period of October and November (241 ng/L). It is noted that the 95 percent UCL baseline follows the same seasonal variation as the estimated prediction interval baseline.

TID-PRW2 Monitoring Station

For TSS data, it was determined that data represented a lognormal distribution for May and the period July through November that data for the month of June represented a non-parametric distribution

Figure 20 shows that the estimated prediction interval baseline tends to generally correspond with the maximum monthly TSS concentration, 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 data points. The prediction interval baseline is highest in (15 mg/L), then 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, with the exception of May and June. This baseline is greatest during June (14 mg/L TSS), and then decreases to a concentration of 2 mg/L through the months of July through November.

For the total PCB data, it was concluded that May, June, October, and November all represented a normal data distribution, and that the data sets for the consolidated months of July and August and the month of September each represented a lognormal data distribution.

Figure 21 indicates that the estimated prediction interval fluctuates throughout the 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 seen during May and June since the total PCB concentration tends to vary with the flow rate. The PI 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 concentration 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 the plotted estimated prediction interval value for May and June is representative of a flow rate greater than 5,000 cfs; however, the prediction interval baseline data point is presented for a flow rate less than 5,000cfs. 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 depicted 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 per 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 then increases to its maximum value of 11 mg/L during 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 has a maximum TSS concentration of approximately 10 mg/L during 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.

For total PCB data, it was concluded that May and June, represent a lognormal distribution and that the total PCBs data set for the month of July represents a non-parametric distribution. August, September, and November also have a lognormal distribution and the month of October data set exhibits 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 May and June. Both estimated total PCB baselines then fluctuate through the remainder of the dredge season, with a minimum baseline value for both baseline curves occurring during 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 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)

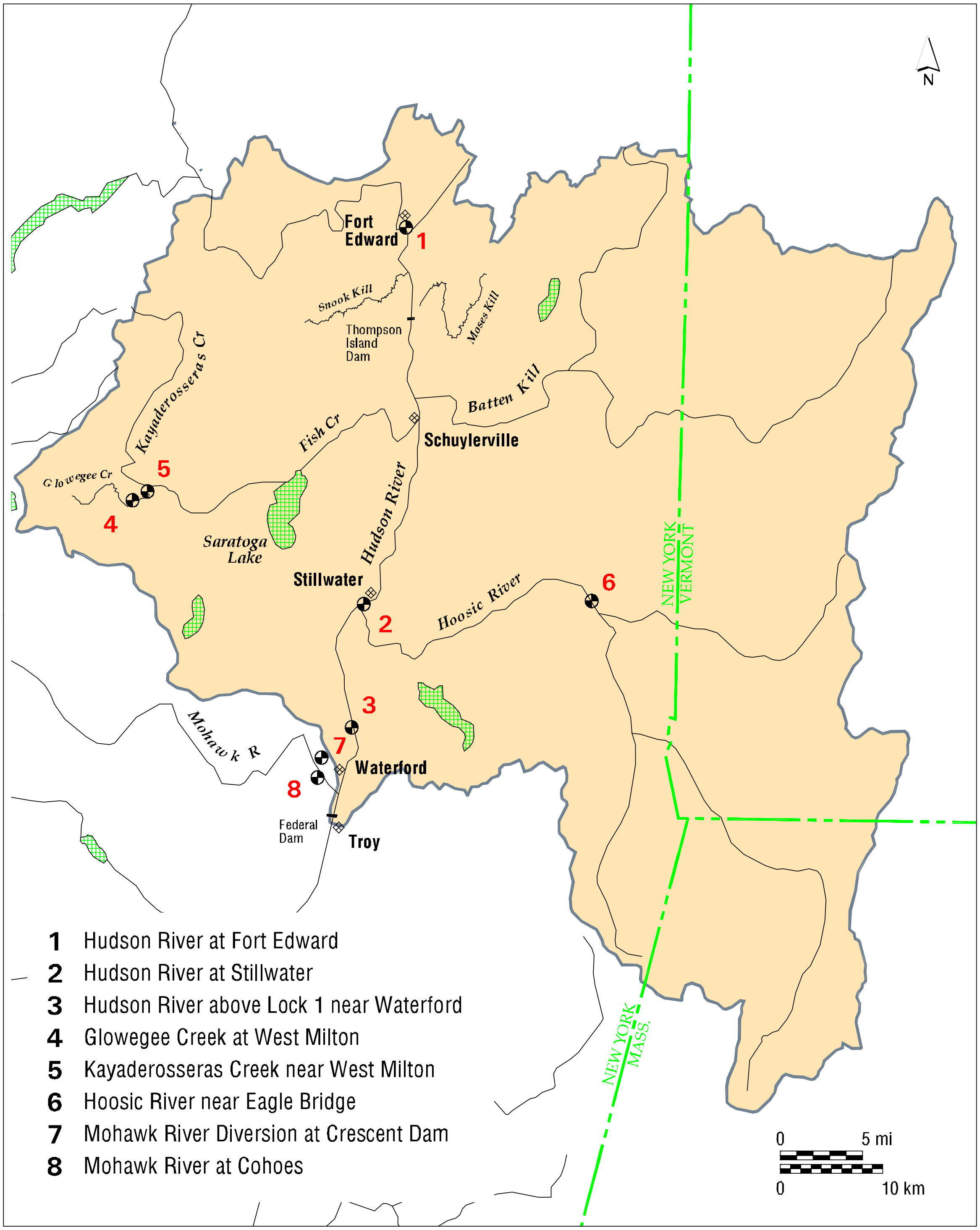
Table 2
Statistics Results and Baseline Level of TSS and PCB Concentration at Upper Hudson River Monitoring Stations

	Fort Edward									TID West									
	TSS (mg/L)					PCB (ng/L)				TSS (mg/L)				PCB (ng/L)					
Parameter	May	June	July	August	Sept thru Nov	May	June	July thru Sept.	Oct. & Nov.	May	June	July thru Oct.	Nov.	May	June	July	August	Sept.	Oct. & Nov.
n	17	22	21	20	60	25	30	79	48	17	24	90	22	24	32	30	29	27	54
Minimum Detected	0.5	0.5	0.5	0.5	0.5	5.50	5.50	5.50	5.50	1.20	1.40	0.50	0.50	24.5	60.1	65.52	49.02	40.00	25.82
Maximum Detected	4.1	16	4.1	9.3	3.3	18.31	31.41	55.51	21.88	26.00	36.00	6.50	6.70	813.6	413.4	219.45	164.00	126.25	1424.00
Arithmetic Mean	2	3	2	2	2	9	13	13	8	4	5	2	2	127.6	169.1	138	96	75	127
Standard Deviation	1	3	1	2	1	5	8	11	4	7	7	1	1	160.3	85.8	43	27	22	193
Median	1.9	2.2	2.2	1.95	1.6	5.5	14	12	6	2	3	1	2	81.0	156.5	135	92	73	88
W-Test (n<=50)																			
W	0.920	0.429	0.936	0.648		0.657	0.862		0.531	0.514	0.454		0.892	0.6	0.9	0.961	0.931	0.962	
W-LN	0.872	0.783	0.825	0.927		0.641	0.829		0.535	0.780	0.823		0.930	1.0	0.9	0.943	0.973	0.980	
Critical W	0.892	0.911	0.908	0.905		0.918	0.927		0.947	0.892	0.916		0.911			0.927	0.926	0.923	
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	-13.07	-18.63	-11.94	-2.89	-14.2	-0.8	0.76	-2.38	-0.42	-34.51
Yln	-2.19	-8.70	-2.69	-3.16	-1.91	-7.33	-1.15	-3.82	-18.28	-4.84	-5.48	-2.12	-1.37	-0.7	0.8	0.10	-1.35	0.18	-8.09
UCL 95%	2.2	5.7	2.4	3.1	1.8	12.7	19.7	18.6	10.4	11.5	11.5	1.9	3.3	181.3	205.3	150.9	105.8	83.1	241.4
UCL 95% Lognormal	2.6	3.6	3.0	3.1	1.9	10.3	17.3	15.5	8.3	6.6	6.2	1.9	3.3	181.3	205.3	154.9	105.8	83.1	134.8
UCL 95% Normal	2.2	4.0	2.4	3.1	1.8	10.2	15.8	15.4	8.6	7.2	7.5	1.8	2.9	183.6	194.8	150.9	104.9	81.9	170.9
LCL 95%	1.4	2.2	1.7	1.9	1.4	6.9	10.9	11.6	6.7	2.6	3.4	1.5	1.9			124.3	88.8	68.2	97.7
LCL 95% Lognormal	1.4	2.2	1.7	1.9	1.4	7.2	11.2	11.6	6.7	2.6	3.4	1.5	1.9	90.5	146.0	124.9	88.8	68.2	97.7
LCL 95% Normal	1.4	1.8	1.7	1.7	1.4	6.9	10.9	11.5	6.5	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)	Normal	non-parametric	Normal	Lognormal	Normal	non-parametric	non-parametric	non-parametric	non-parametric	non-parametric	non-parametric	Lognormal	Lognormal			Normal	Lognormal	Lognormal	non-parametric
95th percentile	0.5	1.6	3.2	3.7	3.1	16.9	27.7	34.3	19.1	18.8	15.5	3.6	4.3	264.1	280.6	202.2	151.1	113.7	297.4
Prediction Interval (Normal)	3.4	8.2	3.9	5.6	3.0	16.8	27.1	31.1	15.1	16.4	17.8	3.5	4.9	407.9	316.8	211.6	142.7	112.3	453.4
Prediction Interval (LogNormal)	4.6	6.5	5.8	5.6	3.9	17.5	33.1	32.9	14.0	12.6	12.2	3.9	6.4	367.8	368.3	233.3	148.7	119.2	272.1
Prediction interval	3.4	4.2	3.9	5.6	3.0	16.9	27.7	34.3	19.1	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									Schuylerville								
	TSS (mg/L)			PCB (ng/L)						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.	May	June	July thru Nov.	May and June	July	August	Sept.	Oct.	Nov.
n	14	13	75	19.0	21	40	19	23	20	10	12	74	34.0	19	21	17	23	22
Minimum Detected	0.50	1.80	0.50	32.0	15.58	28.30	26.20	23.24	20.00	1.60	2.00	0.50	43.0	61.00	50.18	26.30	34.94	38.94
Maximum Detected	24.80	29.50	6.60	166.4	67.05	141.76	65.44	93.26	64.28	8.00	17.50	7.80	211.3	157.18	107.00	78.22	111.64	105.25
Arithmetic Mean	4	5	2	96.8	42	65	44	57	40	3	5	2	106.5	82	74	52	75	67
Standard Deviation	6	7	1	35.8	15	21	13	20	14	2	4	1	41.7	20	17	15	24	20
Median	2	3	2	107.1	41	62	44	55	39	3	3	2	94.9	81	71	49	75	63
W-Test (n<=50)					3.707150762													
W	0.468	0.434		1.0	0.968	0.936	0.929	0.970	0.943	0.739	0.548		0.9	0.694	0.953	0.948	0.936	0.933
W-LN	0.896	0.729		0.9	0.914	0.992	0.934	0.937	0.924	0.909	0.813		1.0	0.830	0.971	0.955	0.881	0.965
Critical W	0.874	0.866			0.908	0.940	0.901	0.914	0.905	0.842	0.859			0.901	0.908	0.892	0.914	0.911
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	-5.08	-10.41	-12.01	-0.5	-9.00	0.04	0.10	0.13	-0.56
Yln	-3.26	-6.17	-1.73	-0.9	-1.50	-0.41	0.58	-0.79	0.12	-1.63	-4.31	-1.52	0.6	-5.09	0.59	-0.10	-1.48	0.24
UCL 95%	6.5	14.0	2.2	111.1	47.1	70.9	50.1	64.2	45.4	4.4	9.9	2.2	121.3	102.7	80.6	60.1	83.8	75.2
UCL 95% Lognormal	6.5	7.4	2.2	118.9	50.2	70.9	50.1	67.3	47.5	4.4	6.5	2.2	121.3	89.5	80.6	60.1	88.0	75.2
UCL 95% Normal	6.7	8.7	2.1	111.1	47.1	70.3	48.9	64.2	45.4	4.3	6.8	2.1	118.6	90.3	79.9	58.5	83.8	74.1
LCL 95%	2.2	3.2	1.6		36.0	59.4	39.1	50.2	34.4	2.5	3.4	1.6		75.8	67.9	46.4	66.5	60.4
LCL 95% Lognormal	2.2	3.2	1.6	83.5	36.2	59.4	39.1	50.6	34.9	2.5	3.4	1.6	95.5	75.8	67.9	46.4	66.8	60.4
LCL 95% Normal	0.9	1.4	1.6	82.6	36.0	58.8	38.6	50.2	34.4	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		Normal	Lognormal	Lognormal	Normal	Normal	Lognormal	non-parametric	Lognormal	Lognormal	non-parametric	Lognormal	Lognormal	Normal	Lognormal
95th percentile	12.0	15.0	4.5	148.1	64.0	93.5	64.0	86.3	61.4	6.1	10.8	4.4	175.9	98.7	105.0	73.7	108.2	40.0
Prediction Interval (Normal)	15.1	18.8	4.1	160.5	67.6	101.2	66.7	91.6	65.0	6.7	12.4	4.2	178.1	118.7	103.1	79.1	117.6	101.6
Prediction Interval (LogNormal)	11.7	13.1	4.6	189.6	80.2	106.4	71.8	104.9	73.5	7.0	10.8	4.7	194.6	115.9	106.7	85.5	135.7	107.2
Prediction interval	11.7	15.0	4.6	160.5	67.6	106.4	71.8	91.6	65.0	7.0	10.8	4.7	194.6	98.7	106.7	85.5	117.6	107.2

Figures



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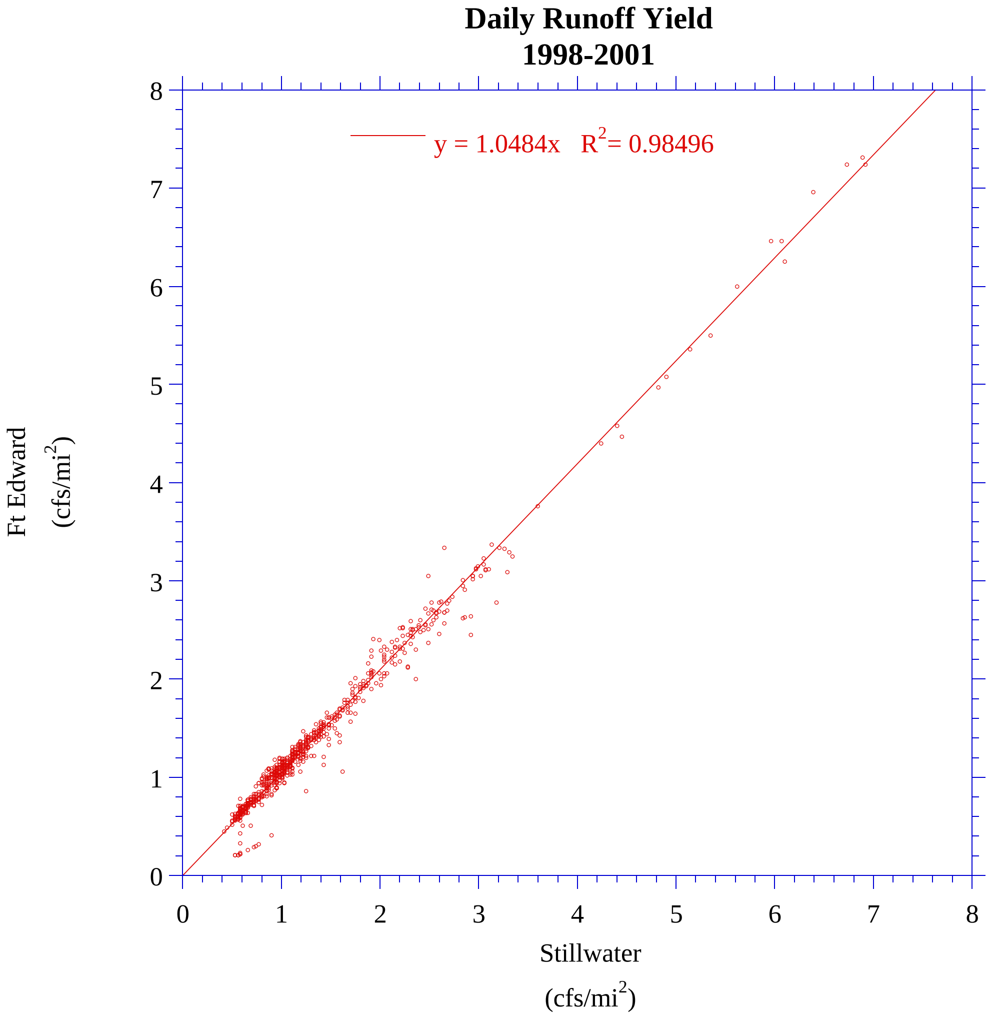

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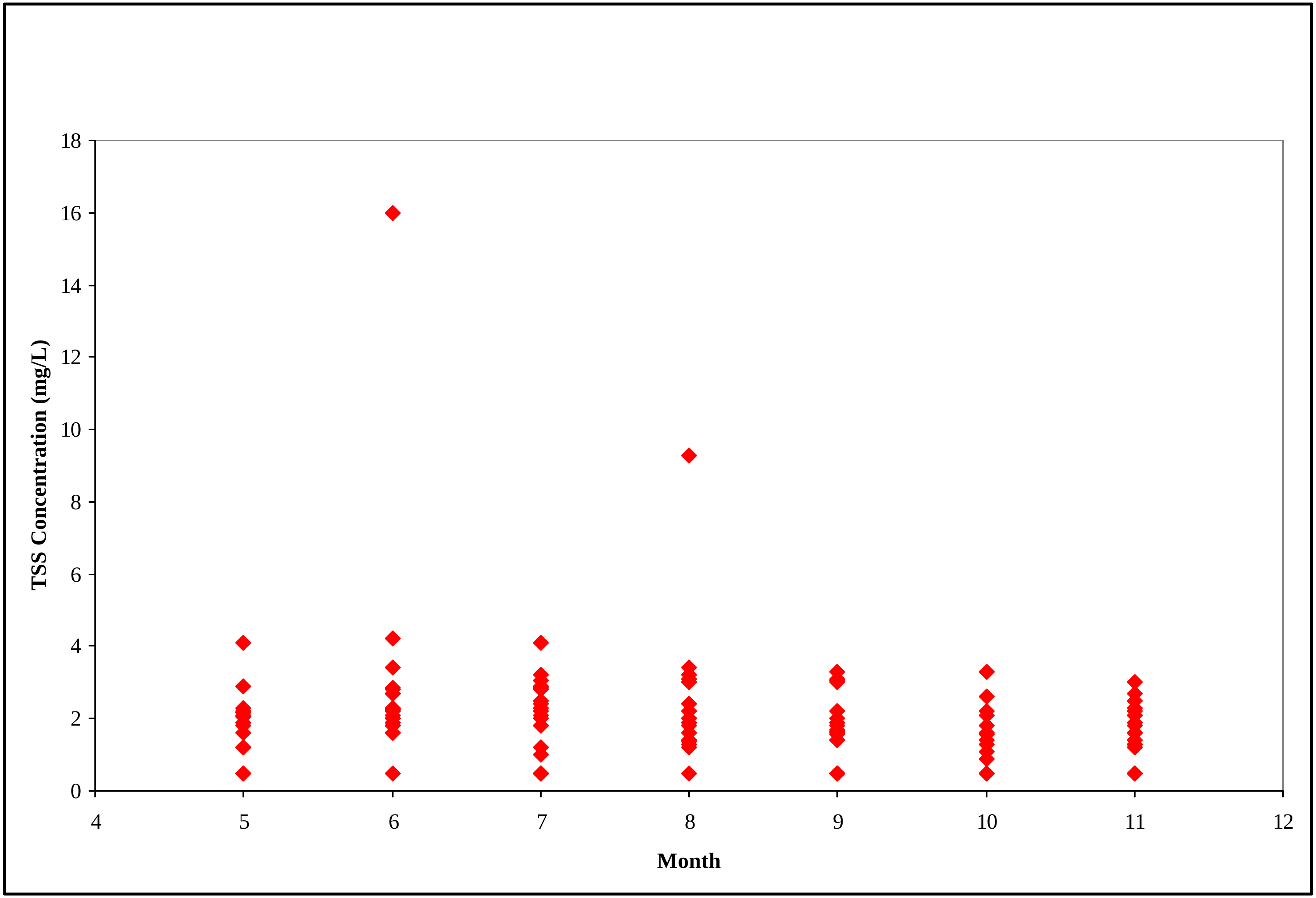
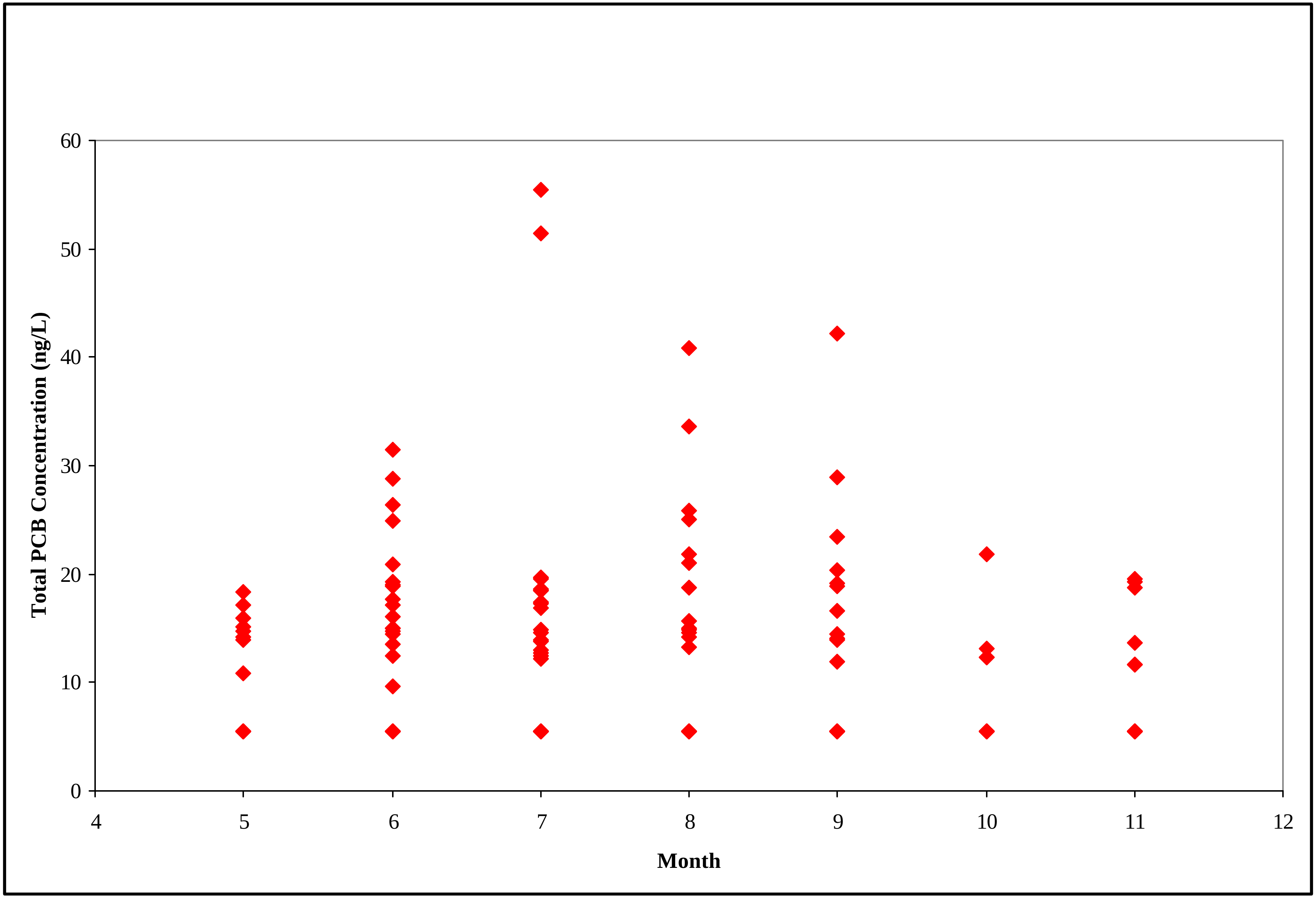


Figure 3. Fort Edward Station Monthly TSS Concentration Variation



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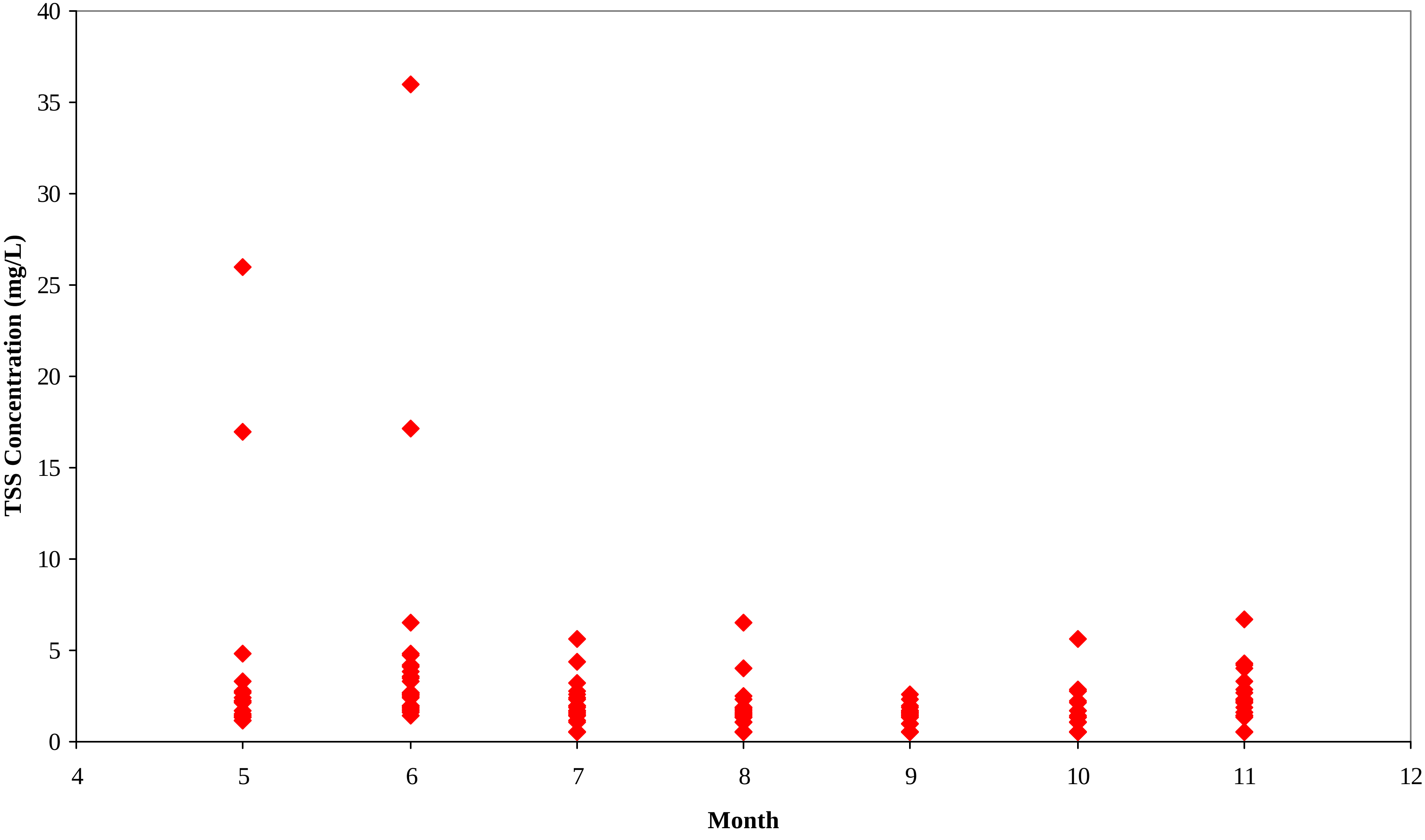


Figure 5. TID-West Station Monthly TSS Concentration Variation

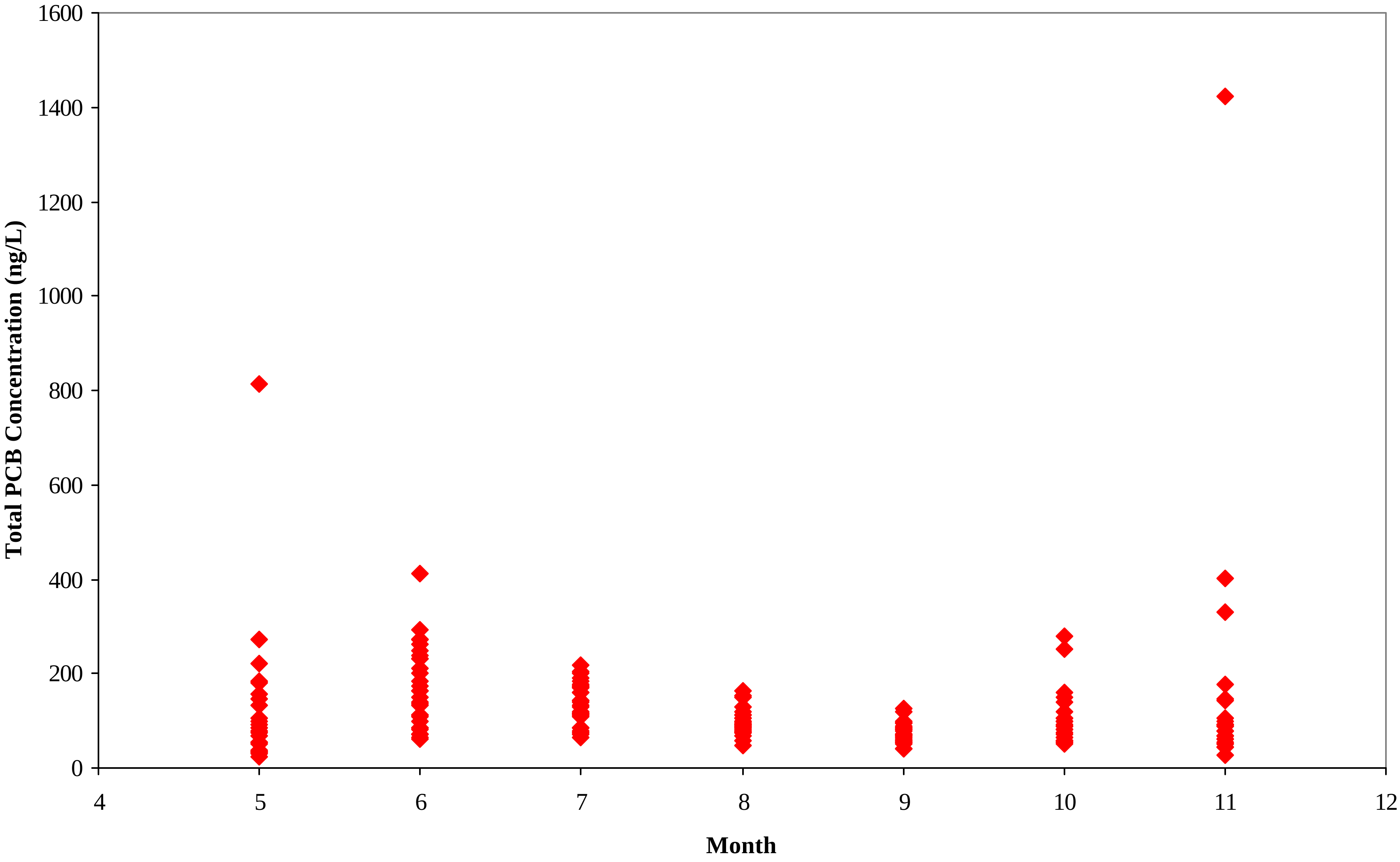
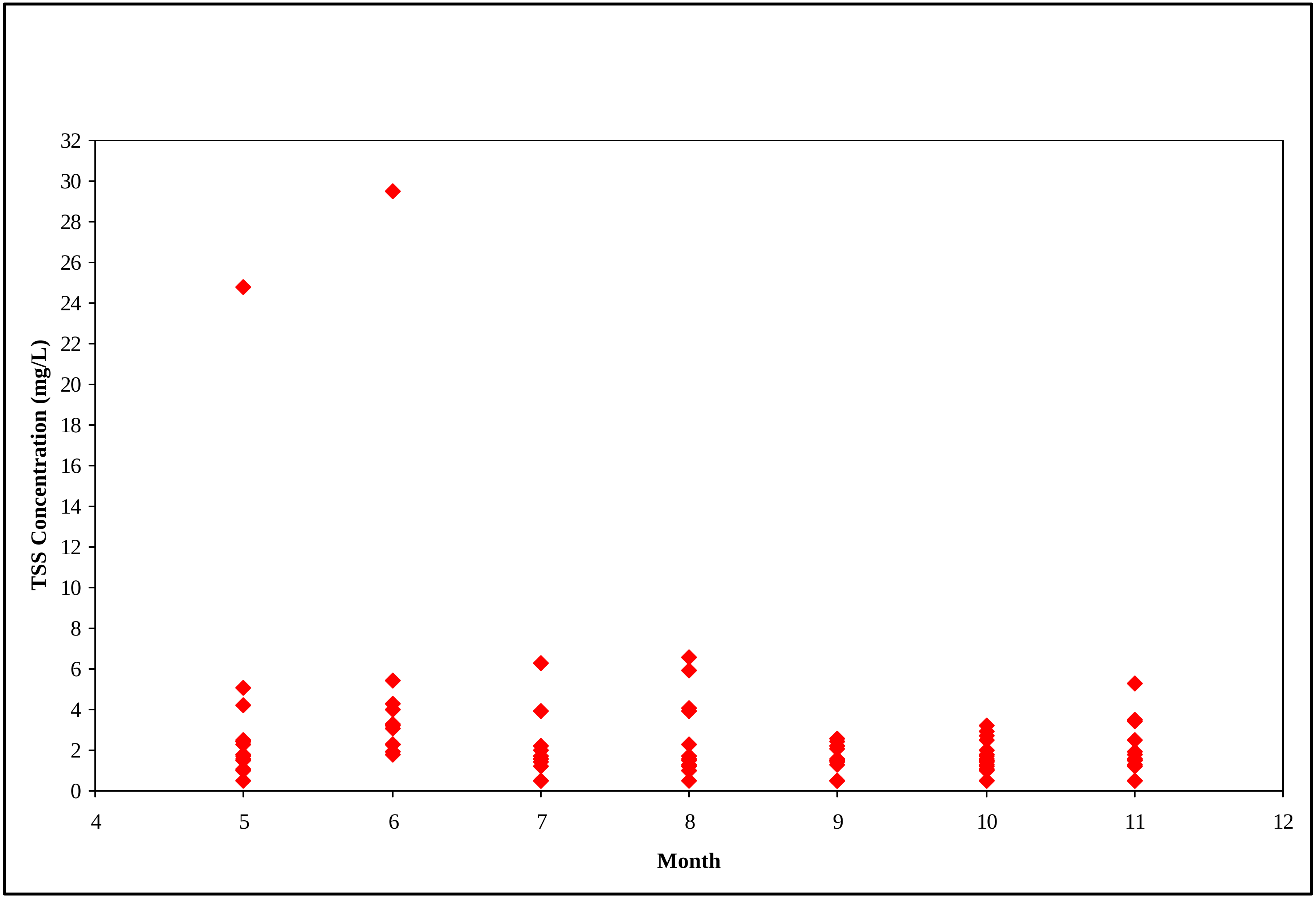


Figure 6. TID-West Station Monthly Total PCB Concentration Variation



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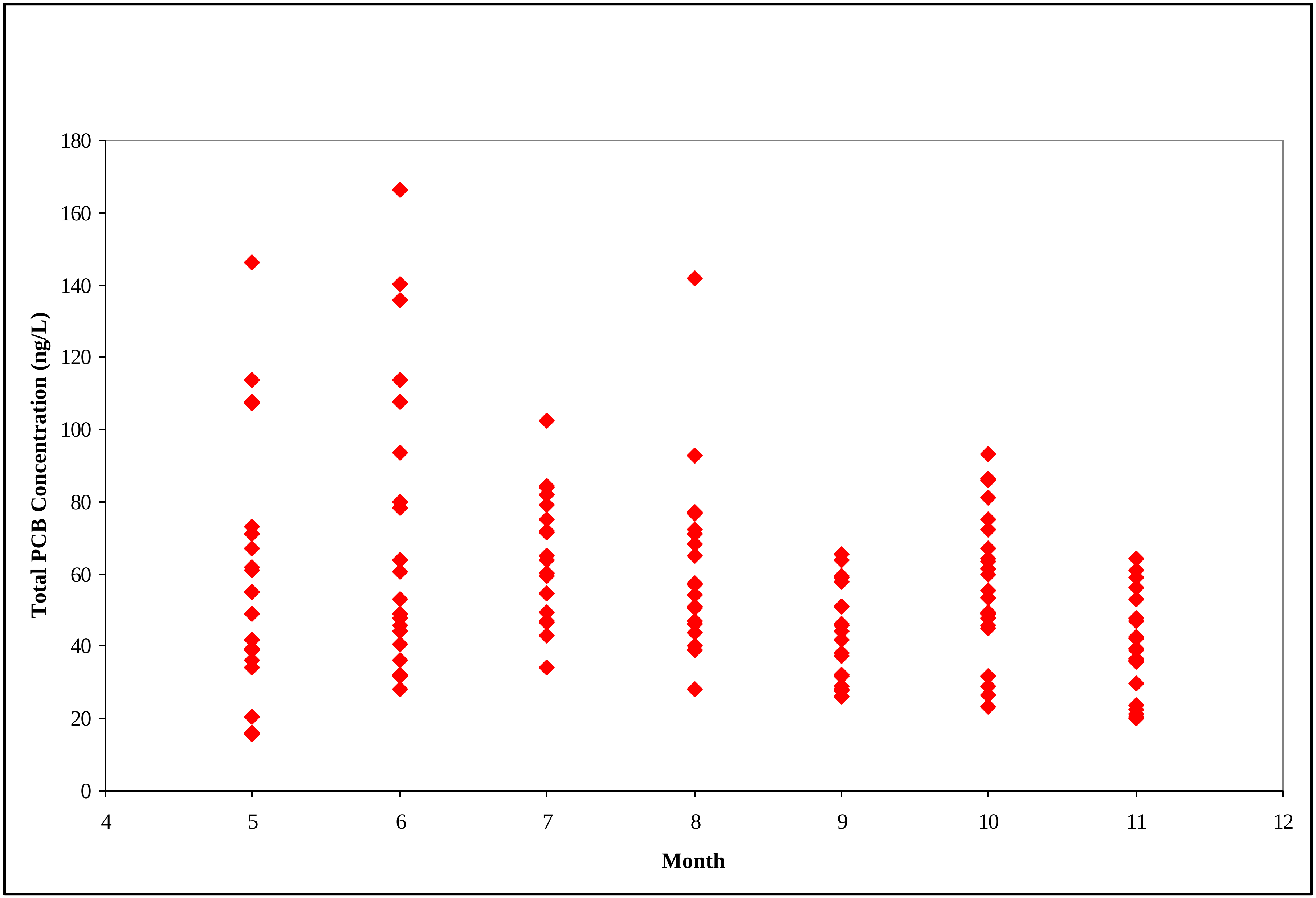

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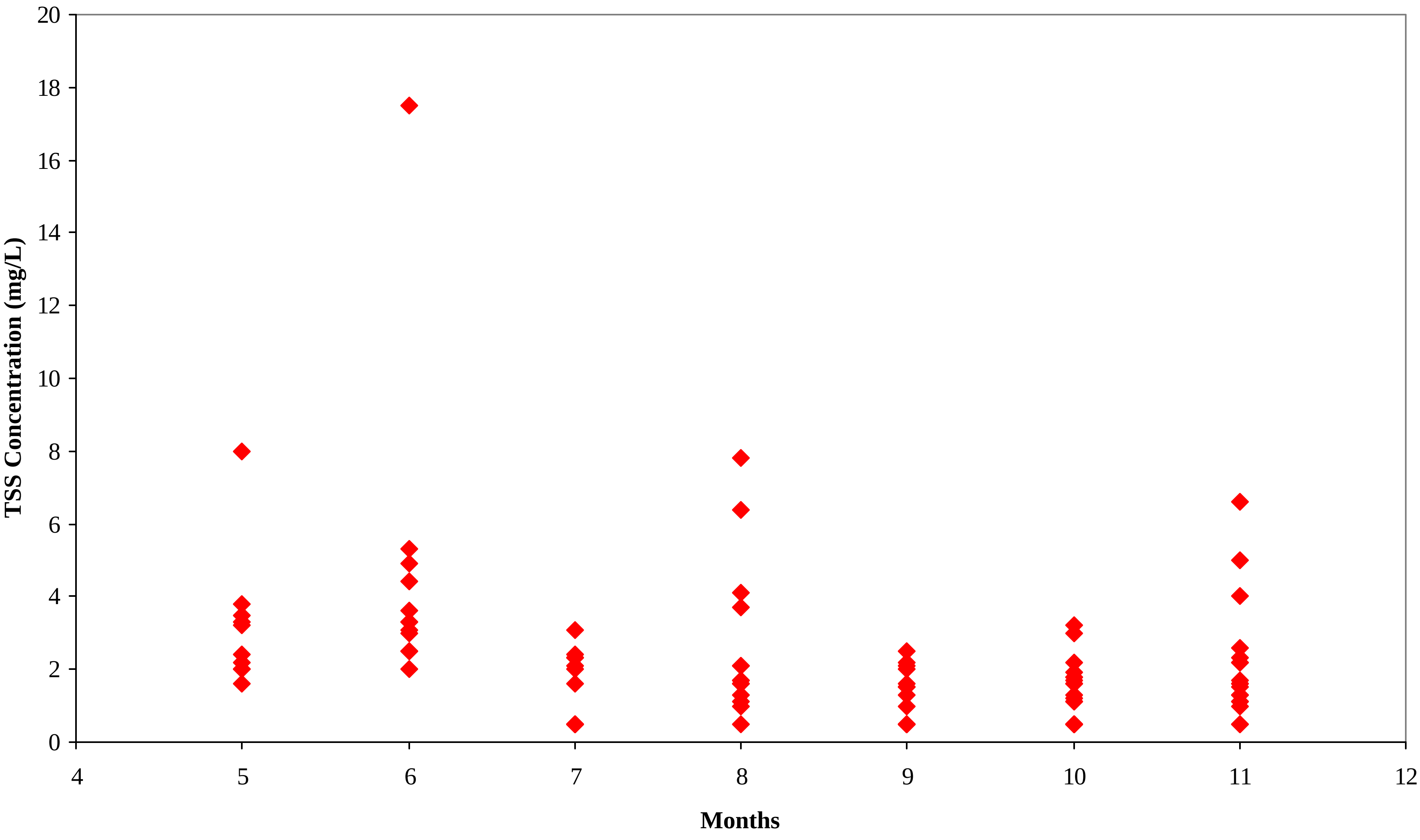

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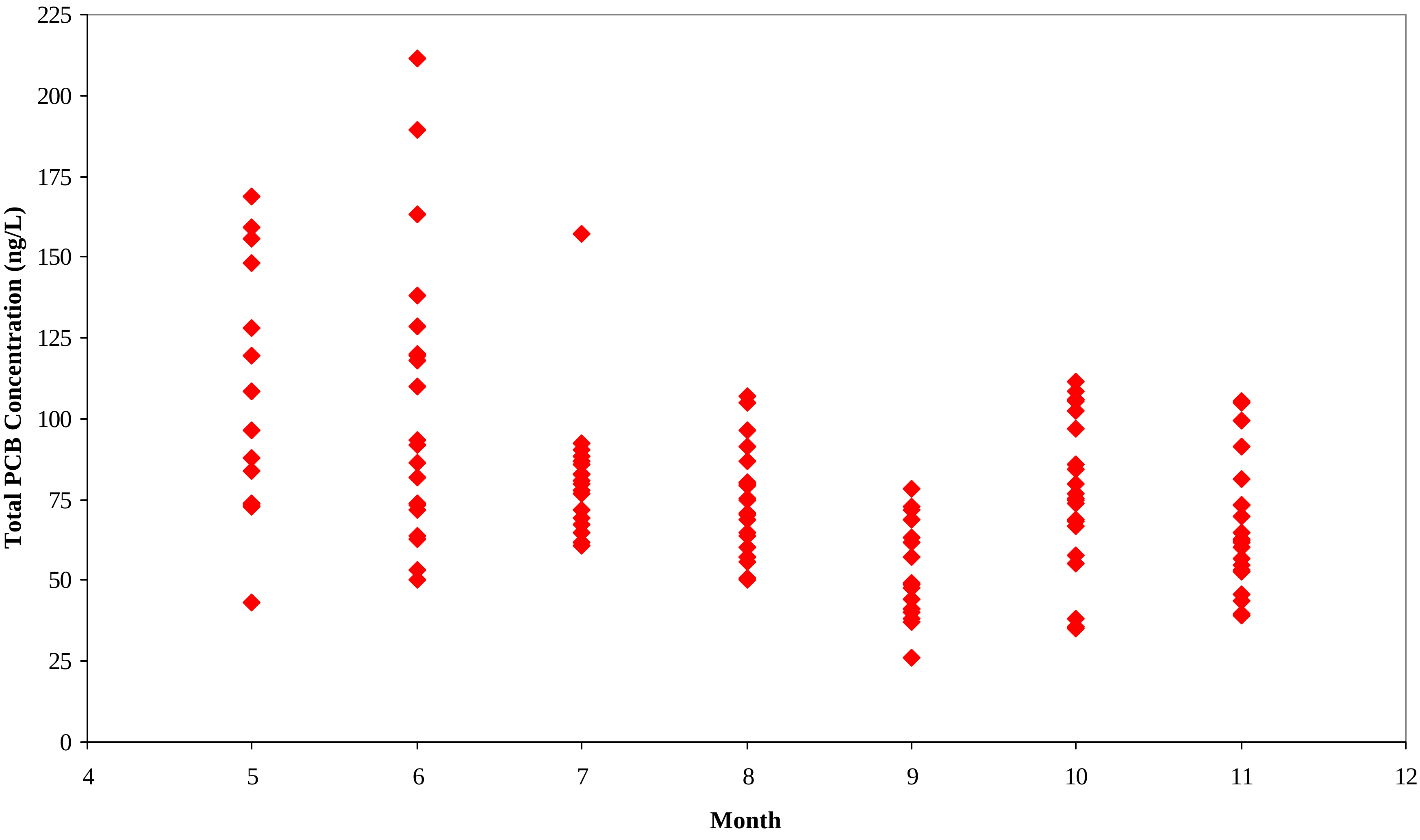

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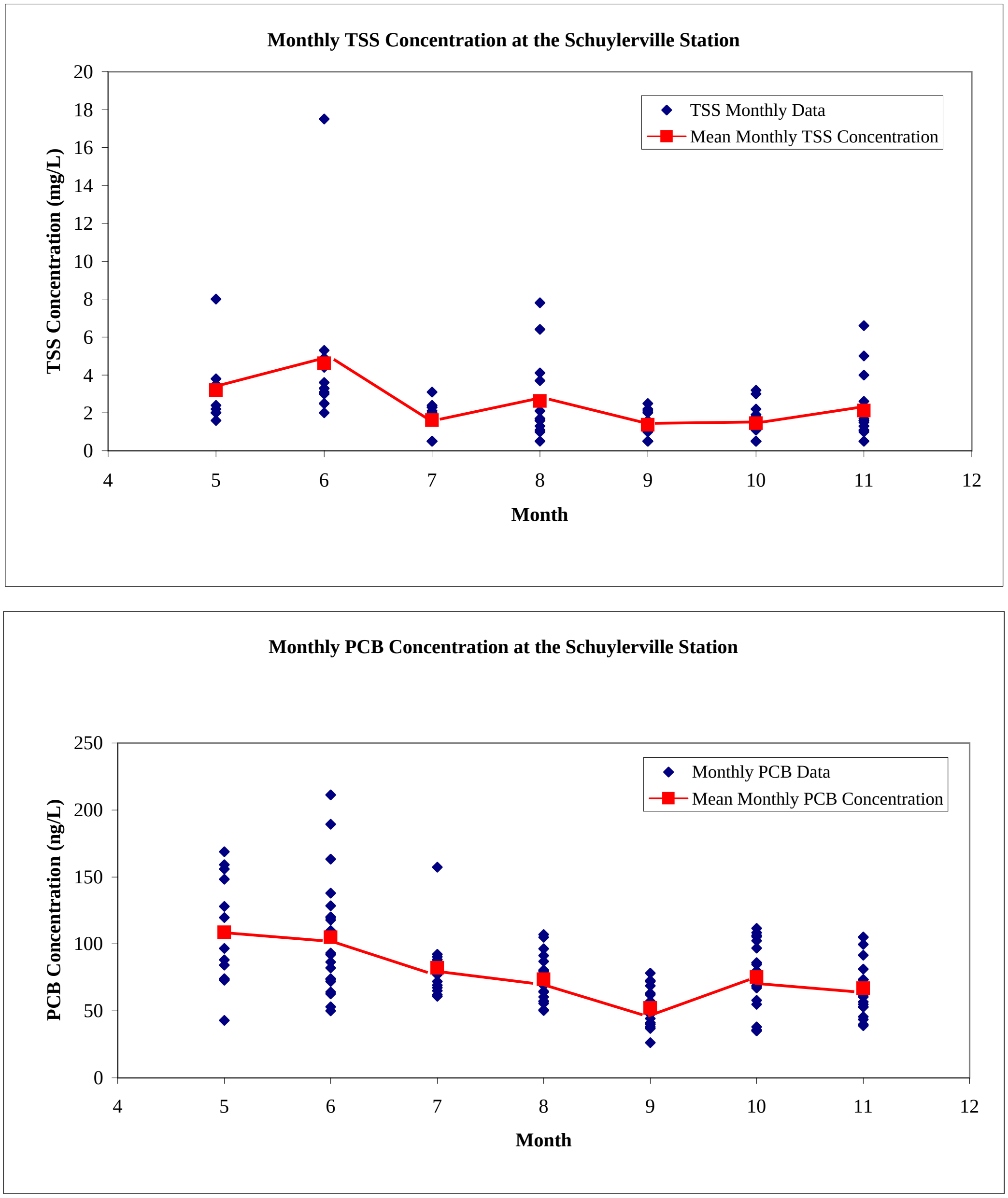

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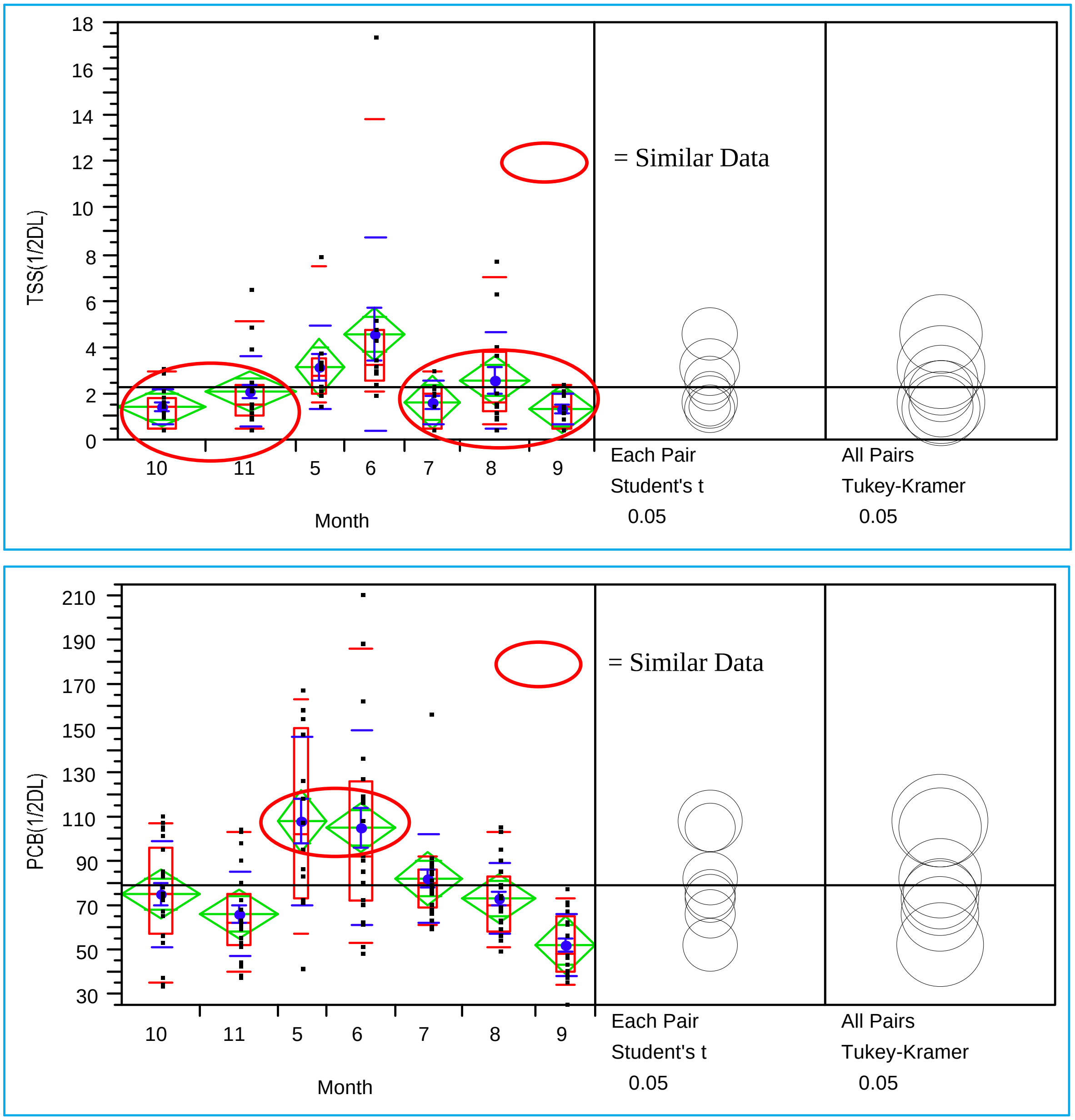

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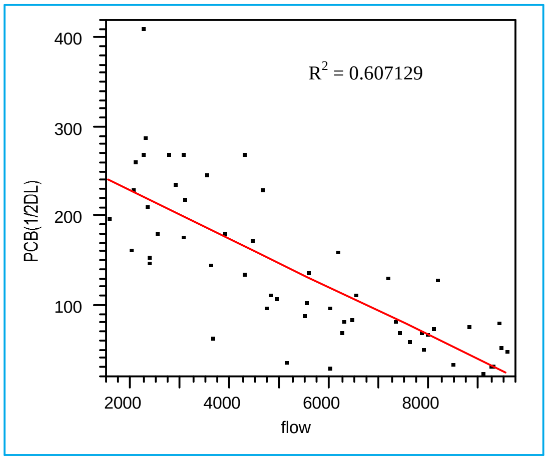

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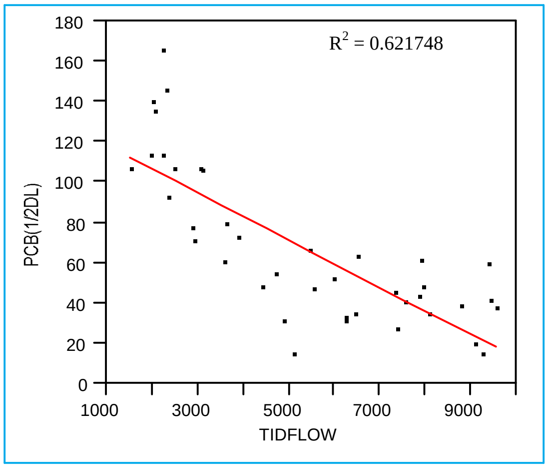

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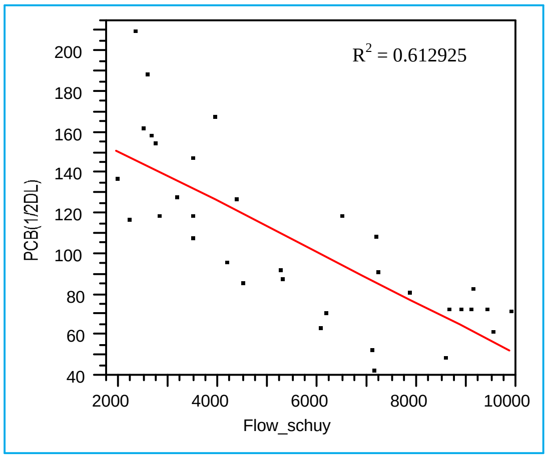

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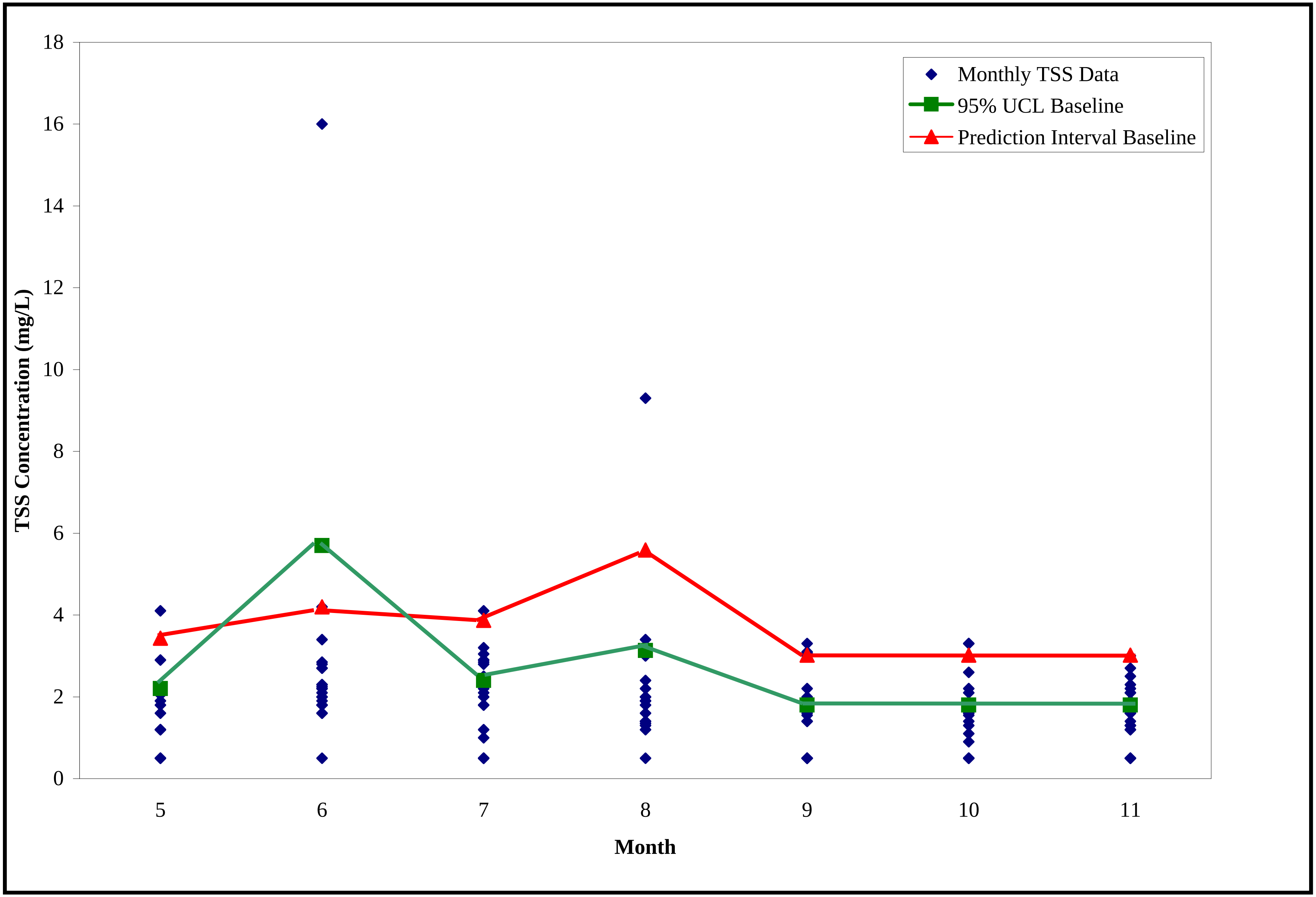

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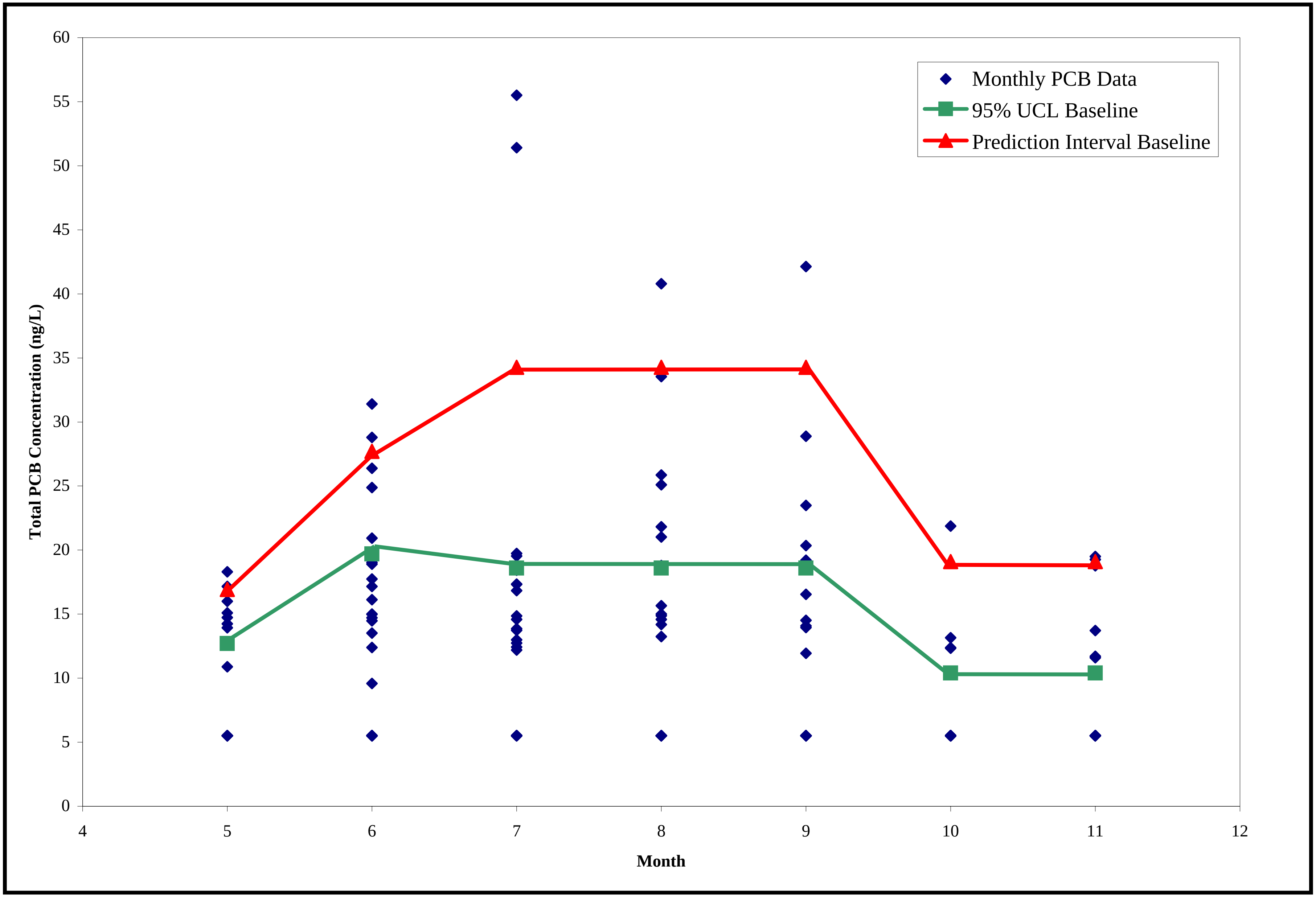

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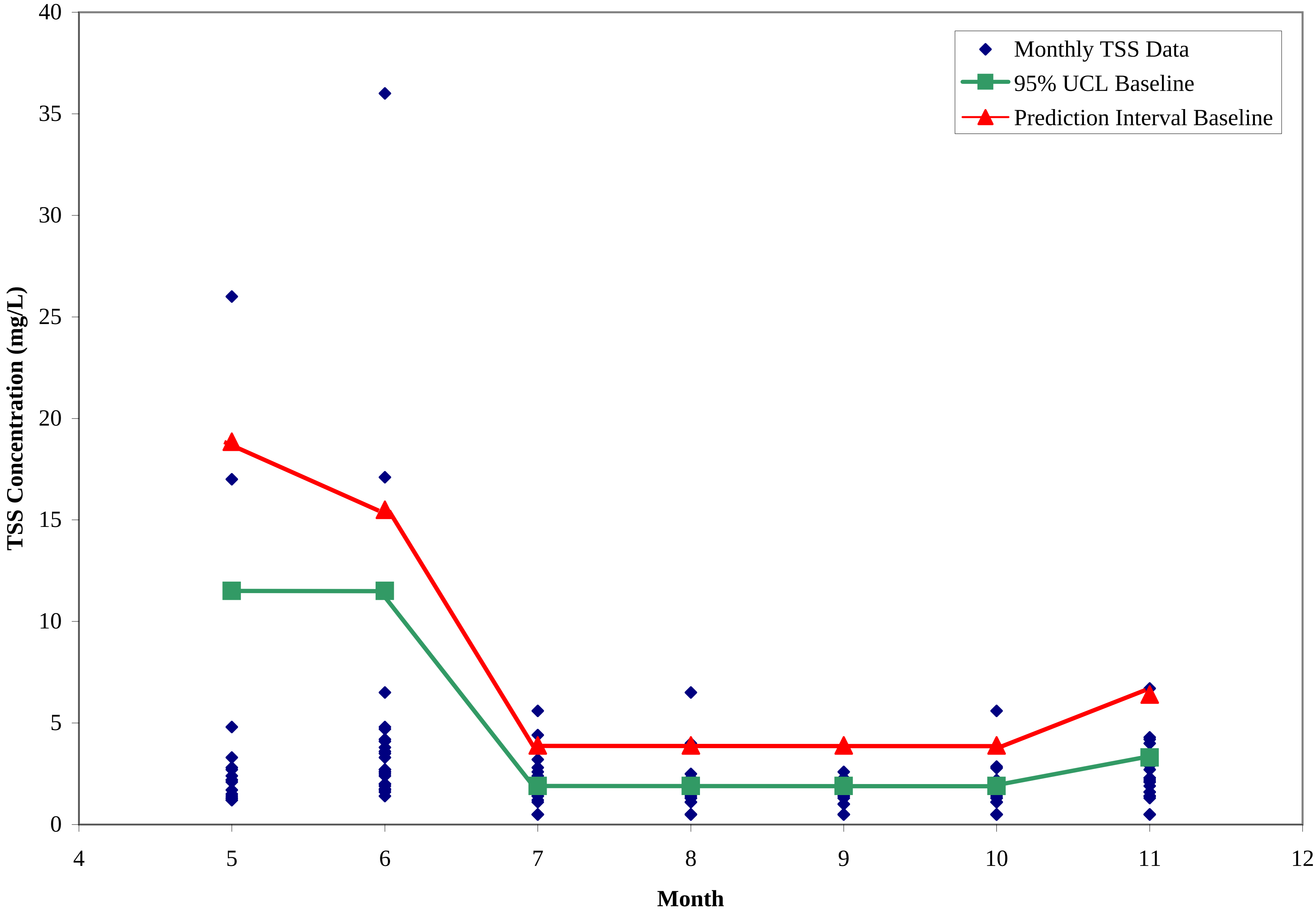

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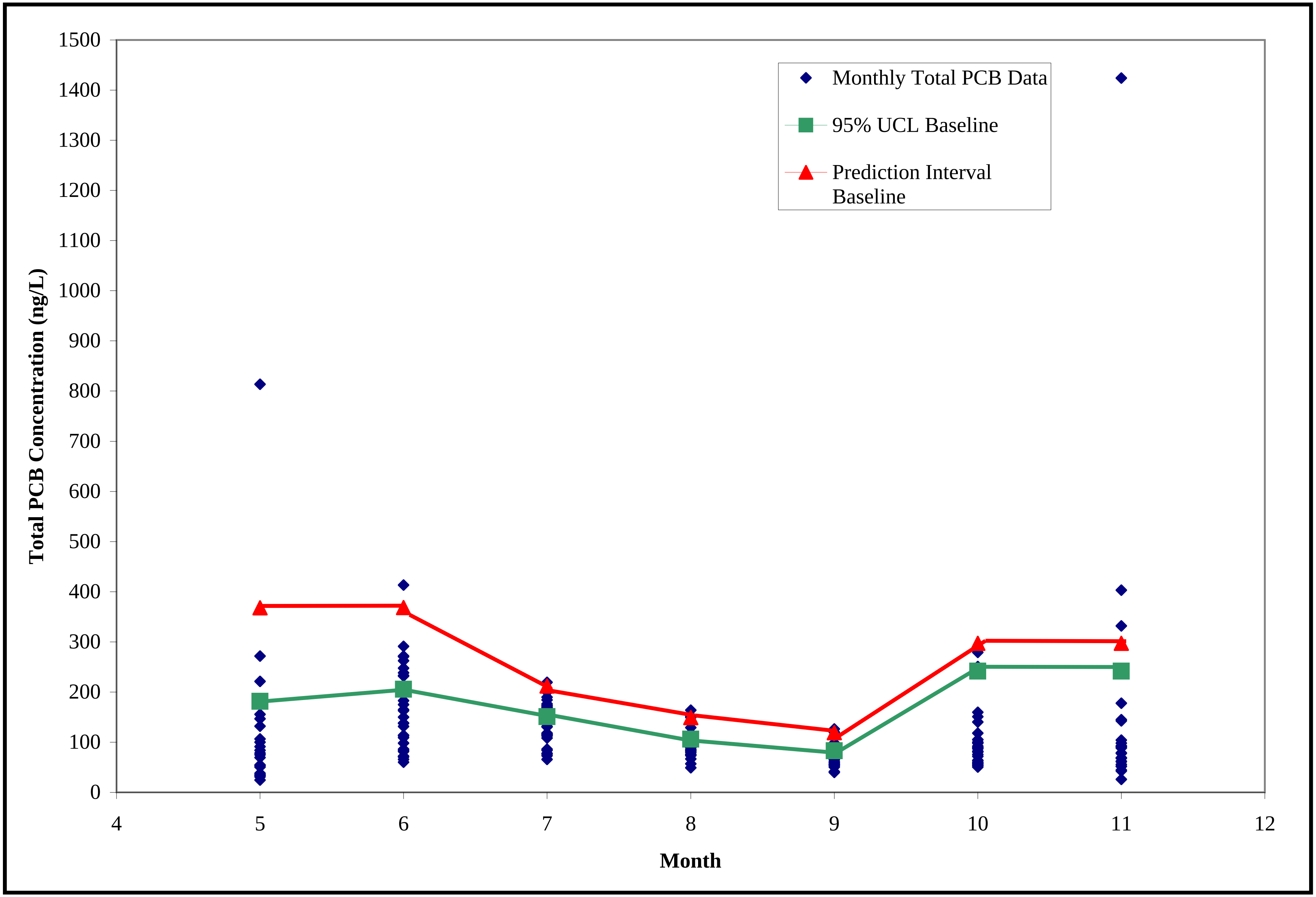

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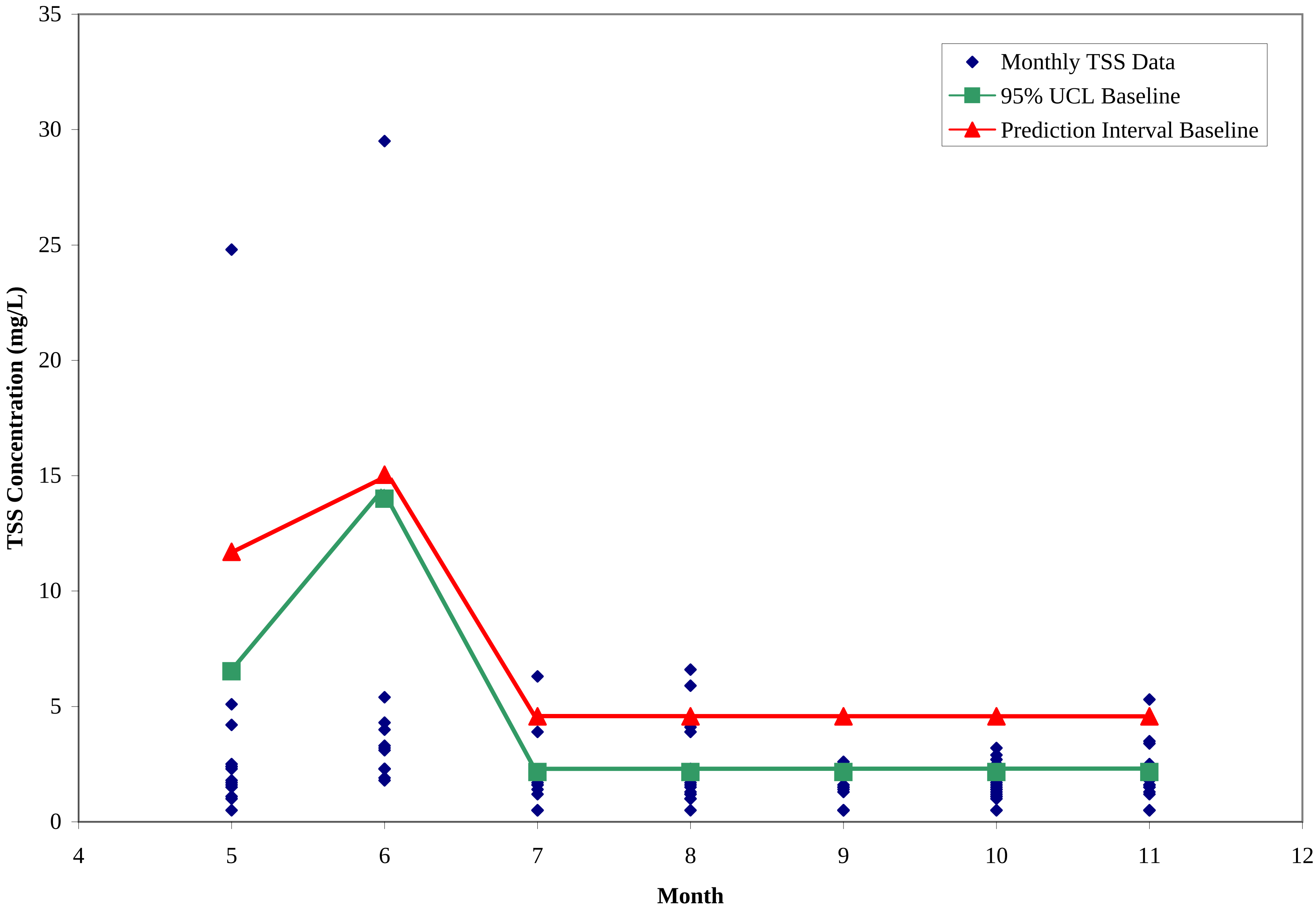

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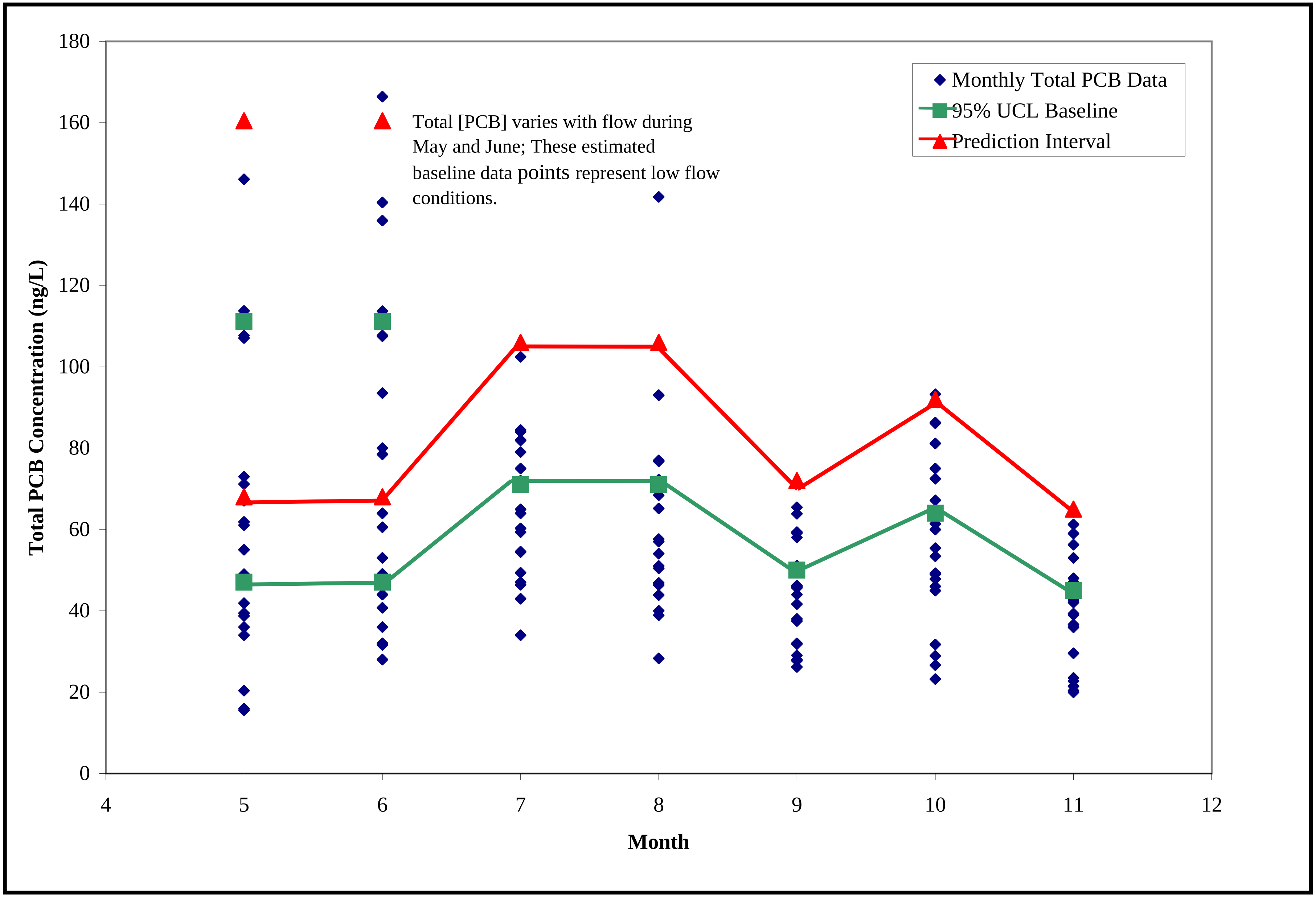

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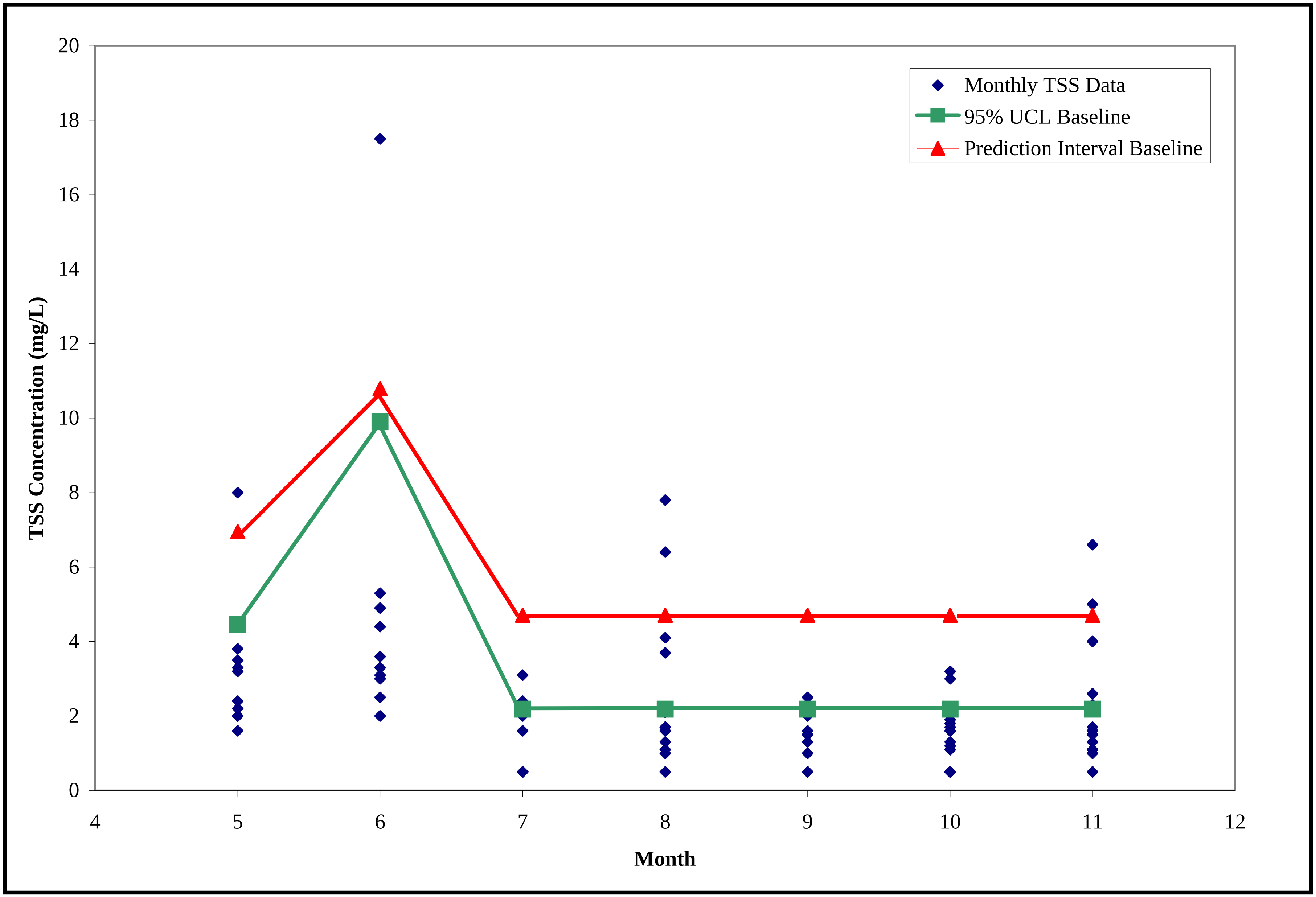

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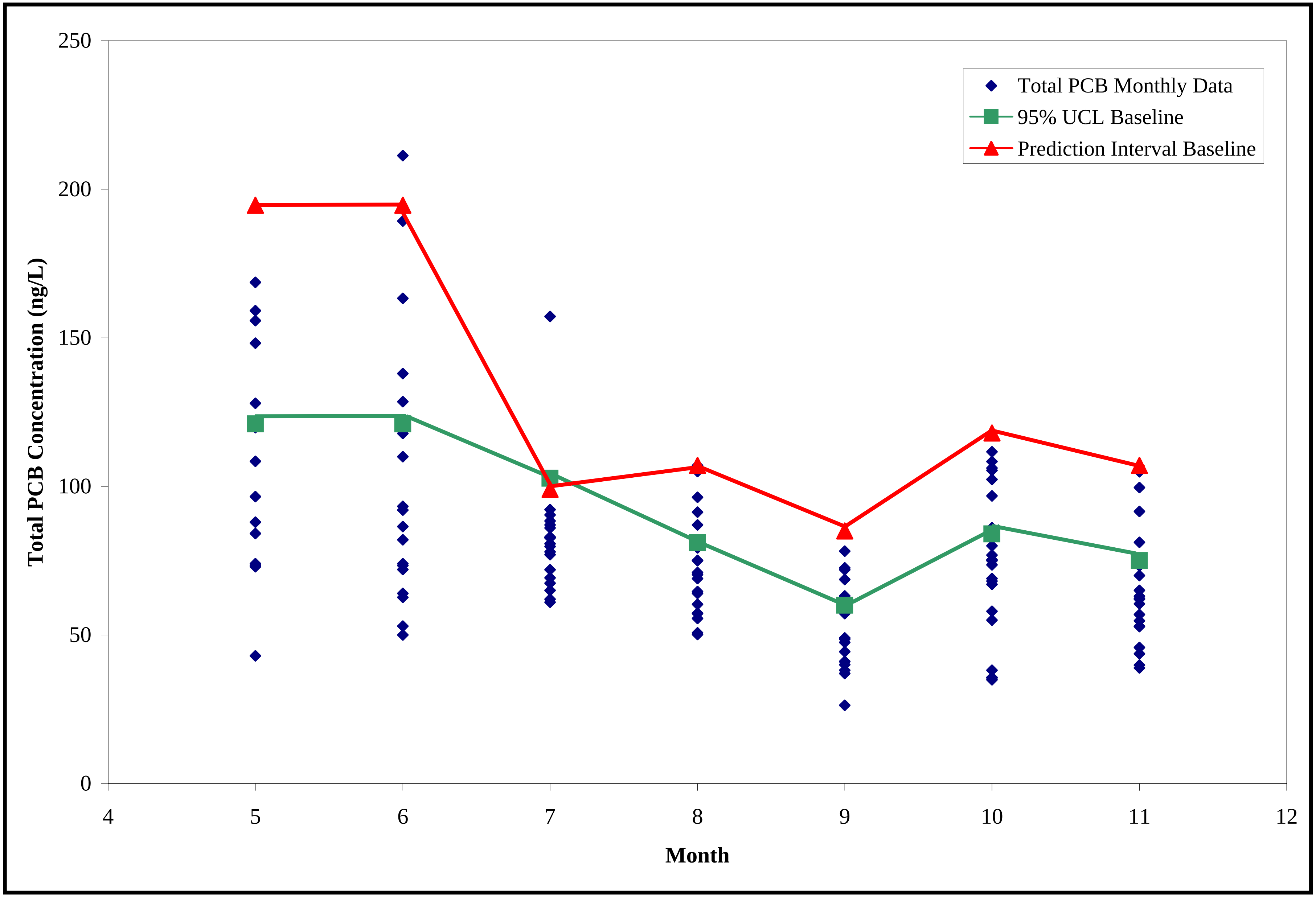

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Attachment B

Resuspension Sensitivity

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Attachment B

Resuspension Sensitivity

1.0 Objective

Accurate and reliable monitoring during dredge operations is necessary to minimize any potential impacts in the immediate area of the dredge as well as for areas downstream. Since the sample results may alter operational procedures, monitoring is essential to ensure a high level of operational success. Monitoring of the water column during dredge operations is important to demonstrate that the performance criteria are adhered to and that minimal downstream transport of PCBs occurs. Since PCB levels naturally fluctuate within the water column due to seasonal variables and heterogeneous sources, it is essential to estimate the ability to resolve dredging-related releases as a function of time and flow. If the water samples during dredge operations indicate that the downstream PCB transport is within the natural variation, then it is unlikely that the downstream will be noticeably impacted from dredging. On the other hand, if sampling indicates levels of PCBs are above the natural baseline variations further preventative measures will be necessary to minimize the downstream impact. 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 of a "significant increase" in the running averages that would signal an unacceptable dredge-related impact 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 may be revised based on the results of the Baseline Monitoring Program. The 95 percent UCL calculations were analyzed for the resuspension criteria that are based on running averages, while the prediction limits were used for the Resuspension Standard threshold of 500 ng/L (federal drinking water standard, maximum concentration limit) since this criteria requires only one exceedance to change the monitoring regime. 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 the criteria were not recognizable either PCB levels of concern would note be noticed 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 baseline variations in water column concentrations (discussed in Attachment A of this report).

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

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

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

The estimated volume of sediment to be removed with over-cut as estimated in the Feasibility Study (USEPA, 2000) is 2.6×10^6 cy. The dredging season is scheduled 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:

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

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.

As shown in the above relationships, equations (1) and (2), the estimated total PCB concentration increase in the water column is a function of the river flow rate and the solids loss rate from the dredging. The estimated SS and total PCB increases as a result of 0.5 percent and 1 percent solids release from dredging are shown in Table 3 and Table 4. The 0.5 and 1 percent solids releases are equivalent to 0.21 and 0.42 kg/s of solids release, respectively and correspond to 300 and 600 g/day total PCB release, respectively.

As shown in Tables 3 and 4, dredging operations conducted during lower flow conditions will result in a greater increase of SS and total PCB concentrations in the water column than at high flow conditions. It can also be seen that a 0.5 percent increase in the solid loss rate from dredging doubles the SS and Total PCB concentration released into the water column.

To test the appropriateness of the resuspension criteria, a sensitivity analysis was performed which compared the baseline total PCB concentrations with the estimated increases from dredging, assuming PCB release rates of 300 and 600 g/day at varying flow rates. The estimated total PCB water column concentrations during dredging operations (with these release rates) were computed by adding the estimated concentration increases (shown in Table 4) to the 95 percent upper confidence limit (95 percent UCL) baseline concentrations and the 95th percentile prediction interval baseline concentrations.

The 95 percent UCL baseline data approximates the average natural variability of the total PCBs and can be compared with running averages for total PCB concentration measurements taken during the dredging operations. Therefore the 95 percent UCL analyses were useful for analyzing resuspension criteria that are based on running averages (*i.e.* the Evaluation, Concern and Control Levels). The prediction interval baseline data approximates the upper bound existing/natural concentration for one sampling incident and can be compared with total PCB data collected during dredging from a single sample/incident to allow for the detection of sudden increase or change in river conditions. This method was only applicable to resuspension criteria that do not involve multiple samples (*i.e.* the Resuspension Standard threshold, 500 ng/L). 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 results from this analysis will be useful in determining PCB concentrations that are indicative of dredging releases. The total PCB monitoring results at each of the stations can be compared to the results presented herein to determine whether a group of measurements is within the normal variability of the total PCB range given the time of year sampling occurred.

The calculated total PCB concentrations for 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 during the dredging period months. Thus at these two flow rates a reasonable range for SS and total PCB conditions that will exist in the Hudson River during dredging operations can be calculated. Though it should be noted that dredging activities are not expected to occur at flow rates as high as 8,000 cfs.

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 1996 to 2000 GE data set) of the annual PCB natural loading in the water column indicated that a 600 g/day total PCB release rate from dredging corresponds to approximately two standard deviations of the annual natural PCB loading of the river. More specifically, it was determined that a 600 g/day total PCB release from dredging corresponds to a dredging induced PCB loading of approximately 130 kg per year; and it was also determined that the standard deviation for the annual natural 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 natural PCB loading and therefore 600 g/day could be used as an upper bound loading.

As a result, it was concluded that engineering contingencies need to be implemented when dredging releases approach 300 g/day total PCB and more stringent controls need to be implemented for instances when dredging releases are greater than the river's natural variation (*i.e.* 600 g/day total PCB). Ultimately, PCB loading corresponding of 300 and 600 g/day, combined with the results of this sensitivity analysis (described herein) were utilized to design a stepped, or 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 since they are for net dredging contributions baseline sensitivity analysis is not necessary (The resuspension criteria are discussed in more detail in Section 2 and Attachment D of this report). The final criterion in the tiered plan is the Resuspension Standard threshold, which is based on the federal drinking water standard, maximum contaminant limit (MCL) for total PCBs of 500 ng/L. The monitoring programs are described in Chapter 3 and Attachment F of this report.

The total PCB concentration based on the 95 percent UCL baseline and releases from dredging is an indicator of the average measured concentrations, as previously described. The dredge induced total PCB concentration with the prediction interval baseline indicates measured concentrations for single samples and how they relate to criteria that are not based on averages.

3.0 Results and Discussion

The following sections present the results of the sensitivity analysis and a discussion of estimated total PCB concentrations, assuming variable flow rates, estimated baseline concentrations and 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.

3.1 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 those data are apparent.

3.2 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 5-7 and a release rate of 600 g/day in Tables 8-10 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 95 percent UCL baseline conditions and shown in Figures 1-3 for TID-West, TID-PRW2 and Schuylerville respectively.

As depicted in Figures 1-3, 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 (the measured parameter) does not increase as much as it does 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 will have large variations with flow rate and therefore accurate flow rate measurements are necessary. Due to the dependence of the criteria on flow rate measurements a second criteria for total PCBs of 350 ng/L is applied to same action levels as the 600 g/day (the Concern and Control levels). These criteria are also based on running averages. 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 this months dredging in areas with high concentrations of PCBs in should be avoided or additional engineering contingencies may be necessary, since lower release rates will exceed the resuspension criteria than in other months.

3.3 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 11-13) and 600 g/day (Tables 14-16) 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 4-6 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 MCL of 500 ng/L for TID-West and TID-PRW2. However, for the analysis at TID-West this release rate at 2,000 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 similar to a combination of TID-West and TID-PRW2. Therefore the results from TID-West alone are not expected to be truly representative of the PCB concentrations at the TID. Furthermore, when an exceedance of the Resuspension Standard threshold occurs four additional samples (in one day) with expedited turn-around times will be taken. 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 getting one sample above 500 ng/L, it is not directly applicable to 5 samples since the likelihood of 5 samples over 500 ng/L will be lower. However, these results imply that in order to be conservative, dredging operations during these months at low flow rates may require additional engineering contingencies and dredging in areas with high PCB sediment concentrations should be avoided when possible.

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

The previous sections have presented the means of calculating the control limits for the performance standard by determining the water column concentrations that are equivalent to a 300 and 600 g/day total PCB mass loss during the remediation. It is possible to compare the dredging induced load to the baseline loads. This will show whether or not the remediation will have a measurable impact on the annual loads.

Method

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 then these 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 for the annual loads at each station.

The annual load for the assuming dredging operations continue at 500 ng/L throughout the dredging season (though it should be noted operations would not continue at this level) was calculated using the USGS daily discharge rates at Fort Edward averaged by month. The calculations are shown in Table 17. For these loads is 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 added total PCB load for the 300 g/day and 600 g/day total PCB release rates was calculated, taking into account the dredging schedule proposed in the FS (USEPA, 2000) and the average concentration in each River Section. The calculations are shown in Table 18.

Results and Discussion

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 in 1992 that gradually declined were the result of the Allen Mills failure. Controls, in place by the end of 1996 have reduced the seepage of 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 Pool (Rogers Island to TID) also decreased from their previous levels 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 1998 – 2000.

The dredging induced loads from the action levels and Resuspension Standard threshold (at TID) are presented. From calculations presented in Appendix E of the FS (USEPA 2000), the average Tri+ PCB Mass loss from dredging should not exceed 0.13 percent. Converting the Tri+ PCB mass loss total PCBs using a factor of two (as defined in the *Responsiveness Summary* to the ROD [USEPA, 2002]), the total PCB mass loss from the dredging operation should not exceed

0.26 percent. This loss rate is nearly half of the lower action level of 300 g/day total PCB, allowing additional resuspension and mass loss resulting from the other components of the remediation, such as vehicle traffic and still have loads below the criteria. A well-controlled remediation of the Hudson River should not have a mass loss in excess of the lower resuspension PCB load criteria (300 g/day), meaning 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. This represents less that 20 percent of the annual load for six of the nine years with load estimates.

A continued total PCB release rate of 600 g/day would represent approximately 130 kg/year total PCB released to the river. This rate of loss is approximately two standard deviations of the baseline annual loads from 1996-2000. Since this annual load represents continual releases that are considerably greater than the estimated resuspension rates (0.26 percent) from the FS, a 130 kg/year load within a dredging season is also a resuspension criterion; with a 65 kg/year load allowed in Phase 1. Continued operation at 500 ng/L MCL would result in 500 kg/year total PCB being released to the river. This load is similar to those found in the early 1990s.

The baseline annual loads are highly variable and unpredictable. In earlier years, the annual loading was dominated by the DNAPL releases from the GE Hudson Falls Plants. Since the controls have been installed, the 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.

5.0 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 (ρ = 0.71 tons/cy) and 50% non-cohesive (ρ = 1.16 tons/cy).
3. Based on the calculations in the FS, sediment removed consists of 93% cohesive (ρ = 0.71 tons/cy) and 7% non-cohesive (ρ = 1.16 tons/cy).
4. Based on the calculations in the FS, sediment removed consists of cohesive sediment only (ρ = 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

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**

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

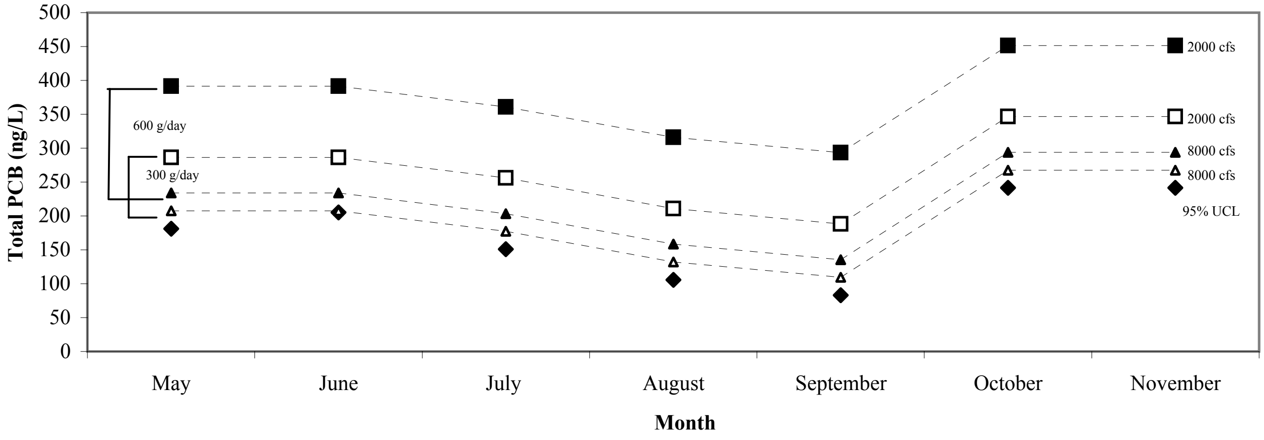


Figure 2
TID-PRW Monitoring Station - 95% UCL - Total PCB

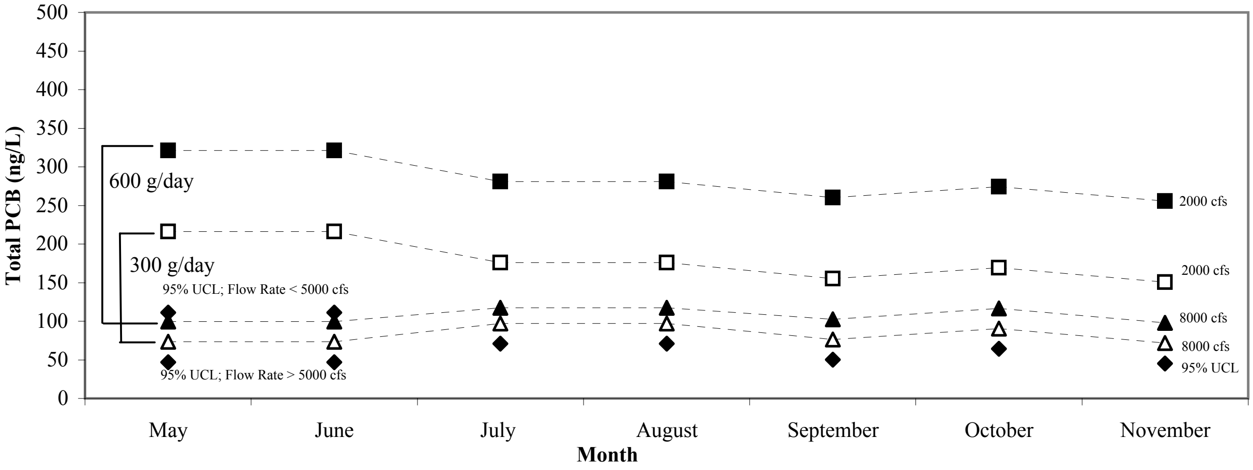


Figure 3
Schuylerville Monitoring Station - 95% UCL - Total PCB

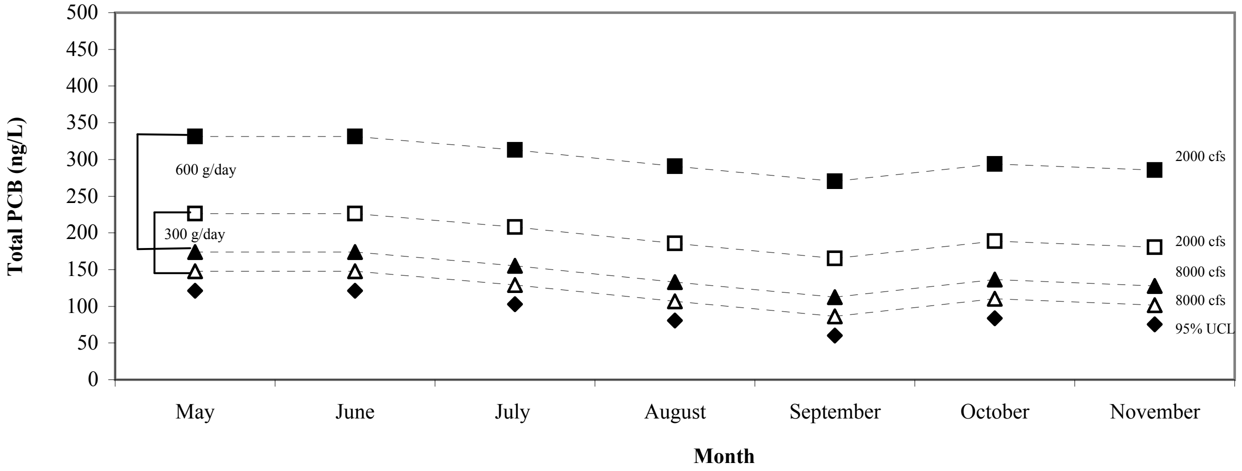


Figure 4

TID-West Monitoring Station - Single Incident - Total PCB

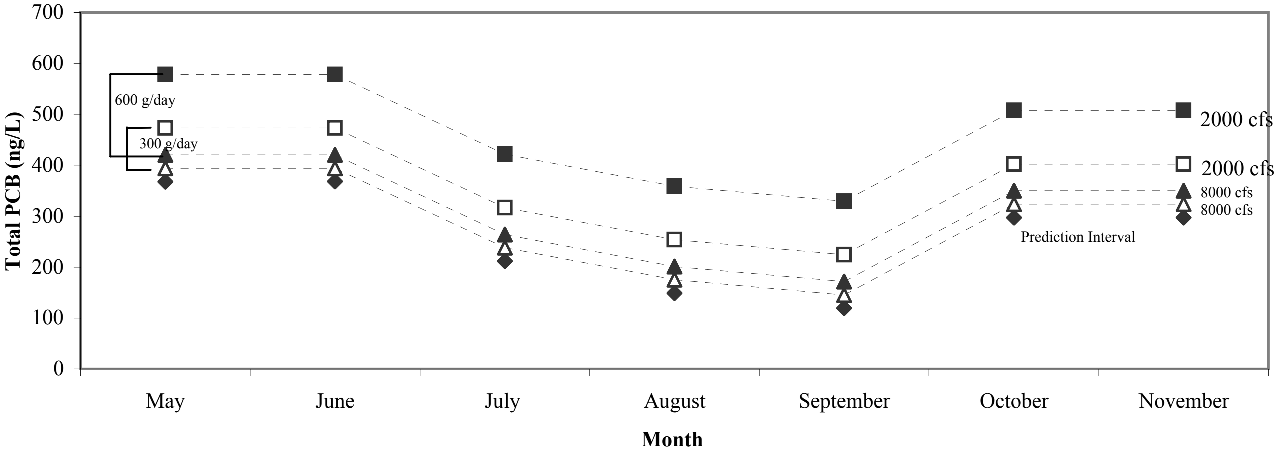


Figure 5

TID-PRW2 Monitoring Station - Single Incident - Total PCB

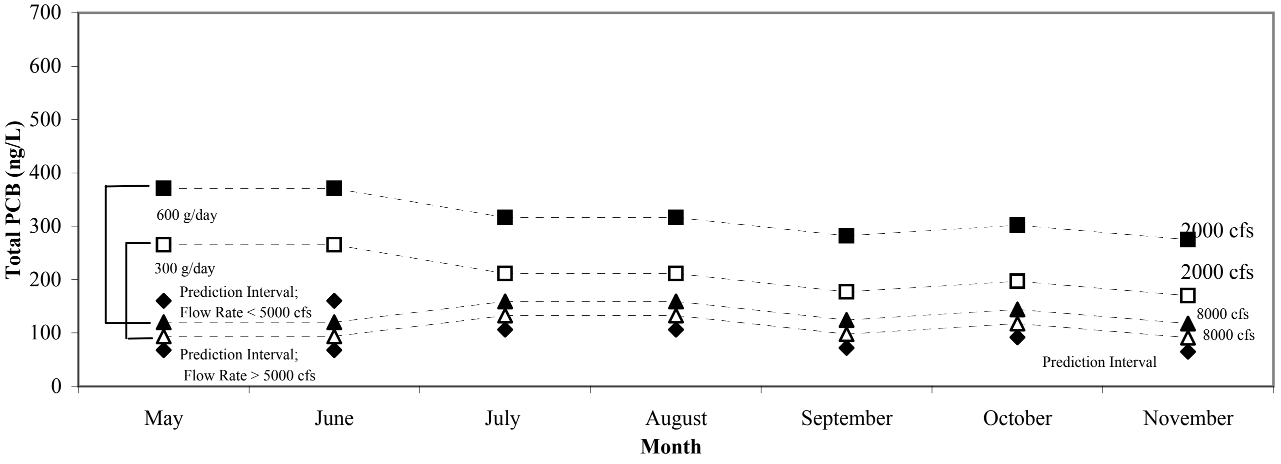


Figure 6

Schuylerville Monitoring Station - Single Incident - Total PCB

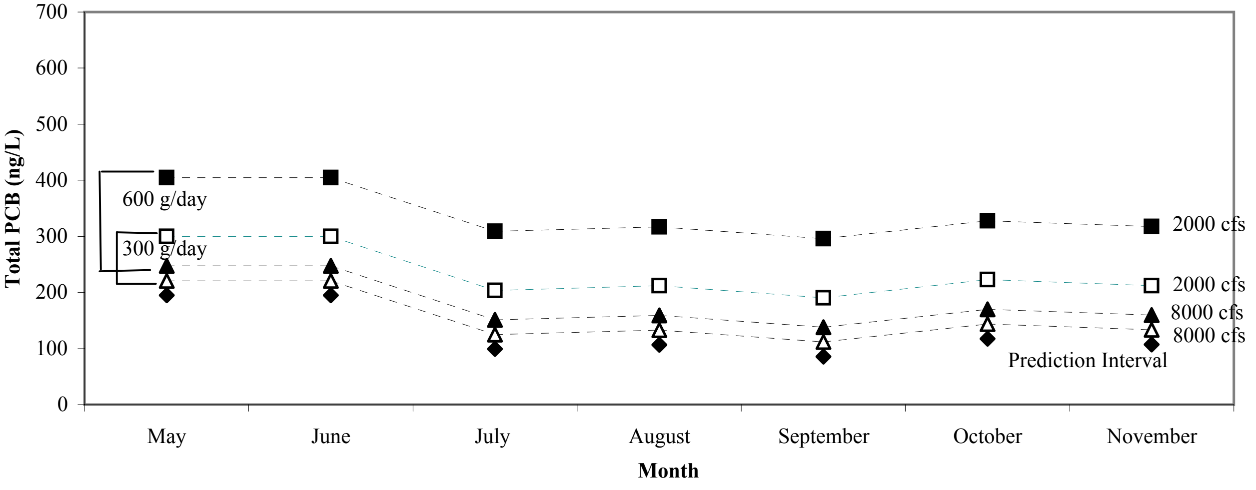
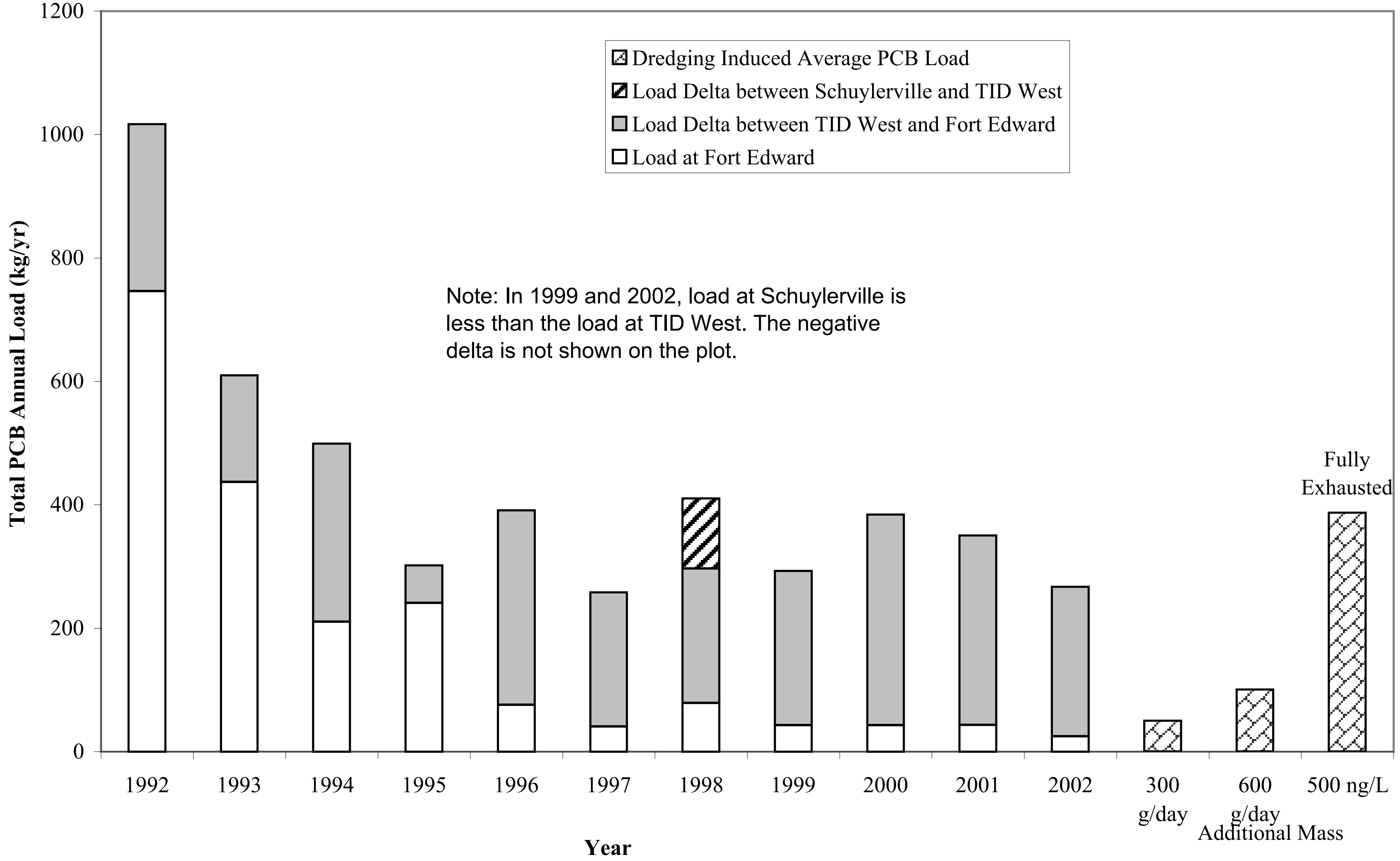


Figure 7
Water Column Total PCB Load at Fort Edward, TID West and Schuylerville Compared to Estimated Dredging Induced Total PCB Load



Attachment C

Examination of Mechanisms For High Dissolved Phase PCB Concentrations

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Examination of Mechanisms for High Dissolved Phase PCB Concentrations

1.0 Introduction

A 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 are likely incorrect, the USEPA has conducted several theoretical assessments of possible mechanisms to determine if, in fact, such a release is a realistic possibility. This concern has been reflected in the proposed monitoring program that will collect data on whole water PCBs under normal operating conditions (where water column concentrations are below a control limit that varies by month and flow rate). 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 concentrations 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 concerning the occurrence of a dissolved phase release during the review of this work. 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 to the deposit or water flow could have been significant contributing factors for 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., “natural”) 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 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 presented at the end of this document.

2.0 Possible Release Mechanisms

There are two basic pathways by which high dissolved-phase PCB concentrations can occur as a result of dredging. The first is the direct release of water with a high dissolved-phase concentration of PCBs. This water would be likely to originate as porewater, since this water is in direct contact with the contaminated sediments and 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 as well. 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.

A second means to create a high dissolved phase concentration is simply to suspend 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. In the event that the suspended solids added are of sufficient mass and contamination level, the dissolved phase concentration will rise markedly. It is worthy to note as well that the process of equilibration will not be undone if, as a result of downstream transport, a large fraction of the suspended sediments are lost to settling. Because 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.

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

2.1.1 Overview

There is a concern regarding the potential impact of contaminated sediment resuspension that may occur during dredging. Specifically of concern is the impact of dredging operations on the flux of dissolved and dissolved organic compound-bound (DOC-bound) PCBs from porewater. The concern is that by looking only at suspended sediment, PCBs in the dissolved phase that may be released by dredging will not be accounted for. There is evidence that appears to suggest that such releases may be significant. During the Fox River PCB dredging projects demonstrations 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) reported in their paper "if chemical transport is to be quantified during a PCB remediation, then monitoring of TSS and turbidity alone is not adequate" (USGS, 2000). They reported that approximately 35 percent of the PCB load from dredging Sediment Management Unit 56/57 was in the dissolved phase (USGS, 2000). The USGS concluded that the results of their study illustrated that concentration-based approach to assessing remediation can be misleading until this concentration is converted to a mass basis. 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 this water column mass increase was in the dissolved phase, the fraction of total mass lost as dissolved phase 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.

The Hudson River RRI/FS (USEPA, 1997; 2000) demonstrated that, under current conditions, a significant flux of PCBs from contaminated sediments of the TI Pool occurs during summer low flow periods without resuspension of sediment. A significant portion of this flux may be biologically mediated. Dredging operations could conceivably alter both the physical and biological conditions controlling this non-resuspension flux.

2.1.2 Theoretical Estimation of the Mass of PCBs Available as Dissolved Phase

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, the 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 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:

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

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:

$$C_T = \frac{C_{solid} M_{solid} + \frac{C_{solid}}{K_{OC} \cdot foc} \times M_w + \frac{C_{solid}}{K_{OC} \cdot foc} \times K_{DOC} \times M_{DOC}}{M_{solid} + M_w + M_{DOC}}$$

(EQ 4)

where: C_T = *total concentration of PCBs*

and other parameters are defined above.

The US 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 partitioning of nonpolar organic compounds are 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).

USEPA estimated PCB partitioning coefficients using the two-phase and three-phase sediment-water partition during the Phase 2 water using the column transect data. The results are summarized in the *Data Evaluation and Interpretation Report* (DEIR), Table 3-10a (USEPA, 1997). For the purpose of evaluating the DOC-bound PCB 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 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 NYSDEC survey, while concentrations in River Sections 2 and 3 were computed using the 1994 low resolution coring data. Table 2 presents the remediated, non-remediated, and reach-wide length-weighted averages of Tri+ and Total PCBs. 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 an upper bound value since the remediated sediment average Tri+ concentrations for all river sections (1, 2, and 3) 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 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. 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 dihomologue 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 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 to be 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 dihomologue 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 equilibrium-based porewater concentration, a direct loss of PCBs to the water column as a dissolved phase would appear 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 proportion or even much higher[1]. Thus, if a large mass of dissolved PCBs is present in the water column downstream of the dredging operation, it is likely that this is the result of the resuspension of sediment accompanied by PCB equilibration between dissolved and suspended matter.

---

[1] The addition of solids to achieve a concentration of 10 mg/L (a nominal value from Section 3.2) represents a liquid to solids ratio of roughly a million to one.

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.

One of the objectives of resuspension monitoring is to distinguish the dredging-related contribution of PCB contaminations to the water column from the 'natural' flux of PCBs from the contaminated sediments. To meet this objective, there is a question as to whether measurement of whole water PCB concentration is sufficient to characterize the dredging-related water column concentrations increase, or measurement of the dissolved phase PCB is also needed. In order to answer this question, the water column PCB increase will be estimated under the dredging scenario. One way to distinguish the dredging-related PCB release from the 'natural' flux is to look at the distribution of the dissolved phase to the total concentration of PCBs in the water column due to dredging, and compare it to that of the 'natural' flux of PCB in the TI Pool. If the ratio is different, it is possible to distinguish them.

As evidenced by the General Electric 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.

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 could be distinguished from 'natural' 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:

$$C_{Total} = C_{dissolved} + C_{suspended} = C_{dissolved} + \text{TSS} \times C_{dissolved} \times K_D \times 10^{-6}$$

(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:

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

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

where:

$C_{\text{PCB-susp}}$ = 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)

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

and the dissolved phase concentrations is estimated at:

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

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:

$$(5 \text{ mg/kg}) / (45 \times 10^{-6} \text{ mg/L}) = 1.1 \times 10^5$$

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 river sections 1, 2, and 3 (USEPA, 2002), the suspended solids concentration becomes:

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

Therefore, the total concentration of the water column due to the additional TSS from dredging becomes:

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

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

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

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

The sediment concentration (C_{sed}) becomes:

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

$$C_{sed} = (180 \text{ ng/L}) \times (1.1\times10^{5} \text{ L/kg}) \times (1 \text{ kg}/10^{6} \text{ mg}) = 20 \text{ ng/mg}$$

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:

$$(6 \text{ mg/L}) \times (20 \text{ mg/kg}) = 120 \text{ ng/L}$$

to

$$(1 \text{ mg/L}) \times (20 \text{ mg/kg}) = 20 \text{ ng/L}.$$

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:

$$(180 \text{ ng/L})/(200 \text{ ng/L}) = 0.9.$$

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

Quantification of PCB loadings in the TI Pool was done extensively during Phase 2 reassessment. 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 source was shown to be the dominant PCB source 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 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 'natural' flux of PCBs to the water column have the 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. For this period of time, it is unlikely that PCBs reach equilibrium. 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 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 the term "sinking" to refer to the rate constant for the first order settling coefficient. 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} 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 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, New York. 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 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 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 the Carrol and co-workers study was approximately 0.018 hr^{-1} (Table 5).

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 (hexachlorobenzenes 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.
- Type of water.
- Amount of organic carbon in the sediments.
- Time of adsorption before desorption.
- 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 Table 5.

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. Values for the untreated sediment are summarized in Table 5.

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.

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 Carrol, *et al.* who used an untreated PCB consisted 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 of approximately 3 to 1,700 hours and equilibrium time of 26 hours to 980 days (Table 6).

Given the length of time that it takes for PCBs to reach equilibrium for desorption, it is unlikely that there will be large amount dissolved phase PCBs released as a result of dredging. 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 3. The desorption rate constants were used to estimate how much 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 3. 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 Harbors

The analyses presented in Sections 2, 3, and 5 conclude that the release of a large amount of dissolved phase PCBs is unlikely to occur as a result of dredging. It is possible to assess these results using field measurements of dissolved and suspended PCB concentrations in the water column during dredging, using the case study data. 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.

The summary of field samples and analytical data is presented in Table 9. TSS and turbidity were measured as well as dissolved and suspended phase PCBs. The 18 NOAA congeners were measured and an equation developed during a previous study used to calculate total PCBs. Two pre-dredging measurements were taken. There were upstream and downstream monitoring points during dredging and 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 by 1000 feet the concentrations are just above the highest measured upstream concentration. Turbidity measurements drop off quickly with distance to upstream monitoring point conditions. The dissolved phase PCB concentrations at the dredge are again 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 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 the 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. 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 dredging area. For this estimate of load, the maximum concentration from the 100- to 1000-foot stations was selected to represent the mass that would remain in the water column and is 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 duration of the dredging operation, the PCB loads are at most 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, 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. 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 arguments presented above. There is simply not a sufficient reservoir of dissolved phase PCBs available to cause a large increase in water column concentrations by themselves. 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. The equilibration of dissolved and suspended matter PCBs may occur sufficiently fast that the original nature of the source (*i.e.,* the suspended solids-borne PCBs) may 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 underrepresent 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 are low, that is, 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.

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USEPA, 2000. Phase 3 Report: Feasibility Study, Hudson River PCBs Reassessment RI/FS. Prepared for EPA Region 2 and the US Army Corps of Engineers (USACE), Kansas City District by TAMS Consultants, Inc. December 2000.

USEPA. 1999. Responsiveness Summary for Volume 2C-A Low Resolution Sediment Coring Report, Addendum to the Data Evaluation and Interpretation Report. Prepared for USEPA Region 2 and the USACE, Kansas City District by TAMS and TetraTech, Inc. February 1999.

USEPA, 2002. Responsiveness Summary Hudson River PCBs Site Record Of Decision. Prepared for USEPA Region 2 and USACE by TAMS Consultants, Inc. January 2002.

U.S. Geological Survey (USGS). 2000. A mass-balance approach for assessing PCB movement during remediation of a PCB-contaminated deposit on the Fox River, Wisconsin. USGS Water Resources Investigations Report 00-4245. December 2000.

Attachment C-1

Literature Reviews

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.

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.

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 contaminated 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 $^{\text{hr}^{-1}}$ and sorption-desorption rate constants ranging from 0.025 $^{\text{hr}^{-1}}$ to 0.05 $^{\text{hr}^{-1}}$ 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 **Contaminant (PCB) Average Concentration**	Remediated			Not Remediated			Reach Wide		
	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+ **Contaminant (PCB) Average Concentration**	Remediated			Not Remediated			Reach Wide		
	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 Csed_b mg/kg	TSS_b mg/L	Ctotal_b ng/L	Csusp_b ng/L	Cdiss_b ng/L	Dredging Induced 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 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

							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	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

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%					

Figures

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