Hudson River PCBs Site
EPA Phase 1 Evaluation Report
Addendum

Prepared for:
US Environmental Protection Agency, Region 2

and
US Army Corps of Engineers, Kansas City District

Prepared by:
The Louis Berger Group, Inc.

April 2010

Table of Contents

INTRODUCTION

INTRODUCTION

This Addendum to the EPA Phase 1 Evaluation Report presents information compiled in response to requests and questions submitted by the Peer Review Panel after its introductory meeting in February 2010. This Addendum also includes several evaluations referenced in EPA's Phase 1 Evaluation Report but not yet completed at the time of its release. The contents of this Addendum corroborate and supplement the conclusions presented in the report, support EPA's proposed changes to the Engineering Performance Standards (with certain adjustments which are discussed below or which will be explained at the Peer Review Deliberation Meeting), and help demonstrate that the dredging operation can be modified in a number of respects to obtain significant improvements over the Phase 1 performance.

The Addendum is a series of independent discussions organized under six Topics to provide a logical sequence of information. The findings are summarized below:

1. **Water Column PCB Loads During and After Dredging -** The release of PCB non-aqueous phase liquid (NAPL) from the dredging areas is influencing the resuspension monitoring results; however, it is difficult to accurately quantify its impact. The presence of NAPL is consistent with the high dissolved PCB concentrations detected in combination with low TSS concentrations. Changes observed in homolog patterns between near and far-field samples can be attributed to gas exchange of lighter, more volatile PCBs with the atmosphere during transport downstream. TSS data do not support attribution of resuspension monitoring results to releases and subsequent transport of suspended sediments. GE's resuspension data interpretation and analysis do not incorporate these findings.

2. **Causes of Resuspension -** The most significant factors affecting resuspension are not simply the mass removed and river velocity. A group of six factors comprises the key "resuspension drivers": mass and volume removal, vessel traffic, exposure of recently disturbed dredging residuals to flow, backfilling processes, and bucket closure.

3. **Redistribution of Contaminants -** Resuspension impacts are not exclusively tied to the creation and transport of suspended solids releases from the dredging area. As discussed in Topic 1, TSS data do not support the conclusion that significant amounts of sediment were redistributed beyond the dredging areas. Sediment trap data analyses advanced in the GE Phase 1 report lack a robust baseline data set, and were also impacted by tug traffic; they are therefore not reliable and the co-located cores used by GE as surrogates for this analysis are not adequate to support their assertions.

4. **Forecasts of Dredging-Related Impacts and Related Risk –** EPA has revised the analysis set forth in Appendix I-G of EPA's Phase 1 Evaluation Report to improve the predictions of PCB loads at Waterford. The reanalysis used PCB concentration instead of loads, since a better correlation could be developed for concentrations to evaluate the recovery. The analysis indicates that a dredging release of approximately 500 kg of Tri+ PCB, as measured

at the Waterford far-field station, provides net benefit to the river compared to MNA. While the load standard will continue to be based on a 1 percent net loss of PCB mass removed (approximately 2000 kg Total PCBs or 667 kg Tri + PCBs), the goal will be to minimize the dredging-related release of Tri+ PCB to 500 kg (as measured at Waterford) over the life of the project (including both Phase 1 and Phase 2). Support for the adoption of control levels derived from the 1 percent net loss figure is provided by consideration of the impact on fish tissue concentrations and project risks in both the Upper and Lower Hudson River. Analysis was performed to estimate the impact of dredging-related PCB release on fish tissue concentrations in the Lower Hudson River for the expected duration of dredging and the brief period immediately beyond. The Farley-FISHRAND models were run for Upper Hudson loads that correspond to the upper end of the proposed revisions to the Resuspension Standard. The impacts predicted here are similar to those noted in the supporting documentation for the Record of Decision. This analysis indicates that the proposed range of revisions to the allowable load standard for the Lower Hudson would not have any measurable long term impacts to the recovery of fish tissue concentrations and therefore would not pose any additional long term risks to Hudson River fish-consuming populations in the Lower Hudson.

5. **Scow Unavailability and Its Impact on Meeting Performance Standards** - Dredging project implementation can and should be enhanced during Phase 2. The lack of availability of empty scows (due to only partial filling and limited unloading capacity) created a greater adverse impact on dredging productivity than did resuspension concerns. It also increased boat traffic and the length of time CUs were left open, both of which contribute to resuspension. The addition of a second unloading station and the addition of a minimum of another 0.5 foot of dredged material to each scow will be necessary to facilitate achievement of the Phase 2 dredging productivity targets.

6. **Underestimated Depth of Contamination: the Need for Multiple Dredging Passes –** EPA shows that GE's use of SSAP cores is incorrect and causes an underestimate of PCB mass removed during Phase 1 dredging. Most of the additional dredging was required to address underestimation of the depth of contamination (DoC). Since the additional dredging was generally not conducted to capture dredging residuals but rather inventory, the addition of a designed overcut to the first dredging pass during Phase 2 will reduce the number of dredging passes required and increase efficiency. An overcut is needed to address uncertainty in coring data and the dynamic nature of the sediment bed.

These findings corroborate EPA's belief that Phase 2 of the dredging remediation can be accomplished in a way that achieves the benefits ascribed in the ROD, with some modifications to the EPS and the dredging project design, and that it can consistently meet EPA's proposed engineering performance standards for Phase 2.

Below is a summary of each of the Topics presented in the Addendum. Also discussed below is a recent decision by EPA relating to the Halfmoon and Waterford public water supplies, and the implications of that decision for the use of the 500 ng/L water column standard.

Topic 1 is an examination of the water column loads observed during and after the 2009 Phase 1 dredging and an analysis of various studies regarding water column PCB and TSS loads that were conducted by GE.

The low detected TSS concentrations, combined with high dissolved concentrations in the near-field studies, indicate that release of PCB NAPL is influencing the resuspension monitoring results (although the impact cannot be accurately quantified). EPA's evaluations of GE's water column studies found that near-field releases were dominated by PCBs in the dissolved phase, and that the data do not support GE's conclusions that the oil phase observed near the dredging operations represented only small, ephemeral amounts of PCBs. A 2-phase partitioning model as used by GE is not applicable in the presence of NAPL and will incorrectly identify the PCB partitioning as being in equilibrium. Since the NAPL was not explicitly characterized and is not appropriately represented in GE's model, its overall impact on the dissolved phase concentrations cannot be quantified. If the NAPL is as concentrated as oil found at the Fort Edward Plant Site former 004 Outfall #5-58-004 (GE, 2008), even a small droplet can significantly alter the PCB concentration of a water sample. At the Fort Edward outfall, PCB concentrations of 255 to 1,240 ppm (more than six orders of magnitude – a million times - greater than concentrations in typical baseline river water samples) were detected in oil that is similar to the oil which is the source of the NAPL in the river.

The dynamics of TSS and PCB loads in the near-field are highly variable due to the impacts of dredging and related activities being conducted in the river. For this reason, samples collected by GE along near-field transects can only be used to represent conditions during a relatively short duration immediately preceding sample collection. It follows that load estimations based on transect samples represent only conditions that occurred during a narrow time interval (*i.e.*, a snapshot), and cannot be used to create a long-term mass balance to draw conclusions about transport of PCBs from dredging. The variability of the near-field was recognized when the Resuspension Standard was developed and, at that time, it was determined that the only substantive, reliable measure of load is data from far-field stations. GE's observations from Phase 1 confirm that the near-field is highly variable.

The PCBs detected in the far-field samples at Thompson Island contained a greater percentage of Tri+ homologs (45 percent) than the near-field PCB transect study samples (31 percent) and the near-field release mechanism study samples (18 percent). It is most likely that, during transport from the near-field, the lighter, more-volatile PCB homologs were lost by gas exchange, causing the shift towards higher Tri+ PCB fraction at Thompson Island. Loss of PCBs to the air was documented on a number of occasions during Phase 1, particularly when an oil phase was visible and concentrated, such as at CU-3 or in the sheet pile area at CU-18. While gas exchange losses were most apparent in these focused areas, the elevated local concentrations near the dredge operations likely create similar opportunities for gas exchange. EPA's hypothesis and analysis showing a loss of the lighter homologs is consistent with the entire set of available data. GE's hypothesis that a gain in Tri+ PCBs between the near-field and the far-field TID station is due to transport of resuspended sediments is not supported by the observed TSS concentrations in the near-field. TSS concentrations detected at monitoring buoys downstream of the East Griffin Island Area (EGIA) were higher and more variable than TSS concentrations at Thompson Island. If additional solids were re-suspended downstream of EGIA, the observed TSS concentrations at Thompson Island would have been significantly higher than values at EGIA.

Five years of baseline monitoring established a fairly predictable relationship among PCB loads at the far-field monitoring stations, with both TSS and PCB loads increasing steadily downstream. During dredging, however, a consistent decline in all PCB homolog loads between Thompson Island and Waterford was observed, despite an increasing TSS load downstream, consistent in direction and magnitude with the observations of TSS under baseline.

EPA analyzed the loss of PCBs between Thompson Island and Schuylerville (Lock 5) during dredging. EPA's findings suggest that recycling of particles at the sediment bed is resulting in dilution of the Tri+ PCB concentration and a decline in Tri+ load, as well as the loss of lighter fractions via gas exchange. It should be noted that the Total PCB/Tri+PCB ratio for the three far-field stations consistently decreases with increasing flow. Because sediment scour and resuspension are more likely under higher flow conditions, particle recycling with less contaminated sediments in the far-field would maintain the high Tri+ component of TPCB, while loss of monochlorobiphenyl and dichlorobiphenyl would ensure that the ratio increases downstream. GE's hypothesis that the loss of PCBs is due to setting of particulate matter is not consistent with the increases in the observed TSS loads between the two stations.   While none of these hypotheses can be unequivocally confirmed from the available data, any settling of contaminated particles during transport from Thompson Island will not significantly change the downstream contaminant exposure in surface sediment, as these materials will primarily settle in the areas slated for dredging, since they are the primary areas for deposition and hence have identified for removal..

Comparison of post-dredging water quality PCB data to baseline concentrations is hampered by the fact that the TI station auto-sampler was significantly fouled sometime after November 2009 and at least 4 of the 5 sample ports were compromised under a load of debris and vegetation.[1] All of the data from this sampler after November 2009 are suspect due to this condition. The other auto-sampler stations have consistent Total PCB to Tri+ PCB ratios through time

---

[1] The last time the ports were inspected prior to retrieval in mid-April 2010 was November 2009, and it cannot be known precisely when the fouling occurred after that time. Freeze-thaw cycles which release vegetation to the river, or accumulation of debris during high flows in January or March are possible explanations for the fouling. It is believed that this fouling was sufficient to pull these intakes to the river bottom, especially under high flows.

regardless of absolute concentrations; but at TID, the ratios (not just the concentrations) fluctuate significantly over short periods of time, indicating there were problems with the sampler. At Waterford, with the exception of one questionable data point, there are no indications of post-dredging impacts after November 2009. At Schuylerville, there are possible indications of post-dredging impacts during high flow conditions; however, data from some samples are suspect and three of the five auto-sampler intakes at Schuylerville were compromised as well. . It appears that GE's assertion of a significant post-dredging increase is tied to use of a "correction factor" to the post-2009 analytical data, without applying the same correction factor to the baseline data. This one-sided correction increases the post-dredging data without a corresponding increase in the baseline, hence artificially indicating a post-dredging impact. Moreover, EPA has not approved this correction factor because there is insufficient explanation for its basis and differences from earlier evaluations.

Topic 2 is an evaluation of the factors that contributed to resuspension.

EPA's careful analysis of factors associated with water column PCB concentrations has found that the primary "resuspension drivers" are associated with 6 process variables. The most likely factors contributing PCBs to the water column are not unexpected—mass and volume removal, vessel traffic, exposure of freshly disturbed residual sediments to active flows, processes associated with backfilling, and bucket closure. A multiple variable factor analysis and corresponding regression has led to development of a factor-based predictive model and shows that it is the combination of these variables that causes the resuspension to be increased. By controlling process variables such as vessel traffic, bucket closure, and the time CUs are open, Phase 2 resuspension and productivity will be improved relative to 2009 performance. This analysis also indicates that Phase 2 dredging can be conducted with reasonable resuspension rates while meeting productivity goals.

Statements in GE's Phase 1 Evaluation Report that exclusively predict resuspension in direct proportion to PCB mass removed and flow are not a reasonable response to the extensive information that is available to further refine and optimize the dredging operation. Recent statistical analysis by EPA has shown that this view is over-simplified; the many and varied mechanisms associated with increased water column PCB concentrations should not be reduced to a mere proportionality to mass or volume removed. Mass or volume removed is a surrogate for the net effect of all of the processes involved in dredging, and therefore correlates well with water column PCB concentrations; however, the manner in which dredging and other related activities were conducted during Phase 1 is very important and its examination provides a good source of information on how dredging and other activities could be modified to reduce resuspension of PCBs in Phase 2.

Topic 3 is an examination of the re-distribution of PCBs as a result of dredging.

EPA's examination of the impacts of re-distributing sediment downstream is in disagreement with GE's argument that resuspension is evidence of the distribution of large amounts of residuals to the sediment bed beyond the dredge prisms. GE claims that, in the near-field, 35 percent of the dredged PCB mass is lost. Although the EPA does not dispute that some amount of resuspended sediment will be deposited outside of the dredge prism, this assertion is difficult to explain in light of GE's denial of the presence of a significant oil fraction, and the fact that there is no associated TSS increase. Part of GE's argument relies on the use of sediment traps near the dredging during Phase 1. Apparently GE used sediment traps to collect baseline sediments before the start of dredging but no analytical results are available. The lack of baseline sediment trap data seriously affects the conclusion that can be drawn from the study because there is no comparable baseline for sediment trap data. To compensate for the lack of a baseline for the sediment trap data, GE collected post-dredging cores co-located with pre-dredging SSAP cores for comparison to serve as surrogates. Comparison of pre-dredging surface concentrations to post-dredging concentrations in the co-located cores showed no statistical difference from comparisons among co-located core pairs where both cores were collected before dredging started, as discussed in EPA's Phase 1 Evaluation Report. Thus, the co-located cores simply cannot be used for this purpose. EPA's evaluation found that the sediment trap deployment was significantly affected by tug traffic, and therefore is not reliable, as it is not representative of general conditions.

Topic 4 examines the potential impacts on fish tissue concentrations in the Lower Hudson River as a result of dredging as a measure of the general impacts of the remedy down-river.

The goal of the remedy as stated in the Record of Decision (ROD, p. 50) is to "reduce the cancer risks and non-cancer health hazards for people eating fish from the Hudson River by reducing the concentration of PCBs in fish." This goal is focused on the improvement of conditions in the Upper Hudson since this is where the greatest risks were estimated and the greatest concentrations of PCB are found. It was anticipated by the ROD that remediation conducted in the Upper Hudson would also yield improvements in the Lower Hudson but this improvement was not the primary goal of the remediation. EPA evaluated the potential effects of the loads anticipated for Phase 2 by estimating the impacts to fish tissue concentrations in the Lower Hudson.

The analysis presented in Topic 4-A of this Addendum revises the analysis set forth in Appendix I-G of EPA's Phase 1 Evaluation Report, which stated that estimates of Total PCB loads at Waterford based on USGS and GE data for the period 1995 to 2008 show no statistically significant decline, with a "half life" of 99 years. The reanalysis uses PCB concentration instead of loads to improve the original calculation, since a better correlation could be developed for concentrations to evaluate the recovery. Flows were simulated via a Monte Carlo analysis rather than forecast as a single set of values. Additionally, further analysis of the historical data suggested that the records for the years 1999 and 2000 were inconsistent with the general trend observed in the data. Although no specific reason could be identified for the inconsistency, these data were considered unusable and were excluded from the best estimate calculation of the rate of concentration decline with time.

Predictions were made of Monitored Natural Attenuation (MNA) of Tri+ PCB load at Waterford, generated from historical data from the United States United States Geological Survey (USGS; 1995-2001) and baseline monitoring data collected by General Electric Company (GE; 2004-2009) using an empirical approach. The results of this analysis indicate a dredging release limited to approximately 500 kg of Tri+ PCB, as measured at the Waterford far-field station, provides a net benefit to the river based on an overlap in the band of forecasted uncertainty between this dredging release scenario and MNA. While the load standard will continue to be based on a 1 percent net loss of PCB inventory removed (approximately 2000 kg Total PCB or 667 kg Tri + PCBs), the goal will be to minimize the dredging-related release of Tri+ PCB to 500 kg (as measured at Waterford) over the life of the project (including both Phase 1 and Phase 2). Support for the adoption of control levels derived from the 1 percent net loss figure is provided by consideration of the impact on fish tissue concentrations and project risks in both the Upper and Lower Hudson River.

An analysis was performed to estimate the impact of dredging-related PCB release on fish tissue concentrations in the Lower Hudson River for the expected duration of dredging (2009 and 2011 to 2015) and the brief (*i.e.*, 5-8 year) period immediately beyond. The intention was to examine potential incremental increases in projected fish tissue PCB concentrations. Additional risks (above current risk levels) to human health via fish consumption would be identified if such incremental increases in fish tissue concentrations remain elevated above the forecasted MNA recovery curve for the remedy selected in the ROD for many years after completion of the dredging. The water column and sediment concentrations in the Lower Hudson River were estimated from the same model of chemical fate and transport that was used in the Performance Standard (Farley *et al.* (1999)), referred to herein as the Farley model. The Farley model was run for two dredging-related PCB release scenarios that correspond to the upper end of the proposed revisions to the Resuspension Standard, to estimate sediment and water column concentrations of the Lower Hudson out to 2046. The fish tissue concentration was predicted by interpolating previous results from a bioaccumulation model developed for the Hudson River remedial investigation and used in both the ROD and the Performance Standards (FISHRAND, USEPA, 2000).

Scenarios were run for dredging-related loads of 600 kg and 800 kg of Tri+ PCBs (approximately 1800 and 2400 kg Total PCBs) at Waterford. The impacts of these loads were contrasted with the MNA recovery curve, used here as a surrogate for the remedy curve response in the Lower Hudson. This approach provided an upper bound on the likely time to rejoin the ideal recovery curve (representing no resuspension load due to dredging). The results show only minimal increases in the time to rejoin the ideal recovery curve relative to scenarios representing less PCB loss to the Lower Hudson. The potential impacts due to dredging resuspension were recognized as part of the preparation of the ROD and were included in the Responsiveness Summary. The impacts predicted here are similar to those noted in the supporting ROD documentation. Taken together, the observations and calculations from this analysis indicate that the proposed range of revisions to the allowable load standard for the Lower Hudson would not have any measurable long term impacts to the recovery of fish tissue concentrations and therefore would not pose any additional long term risks to Hudson River fish-consuming populations in the Lower Hudson.

Topic 5 examines the limitations to productivity caused by system factors such as scow load thickness and using a single unloading station.

The ability to meet productivity targets was severely limited during Phase 1 by the unavailability of scows. The reason for the lack of scows is not due to the number of scows that were on hand, but rather the way the scows were used and how they were unloaded, which resulted in long queues of partially full scows waiting to be unloaded. Although there is significant discussion on GE's part about how resuspension limited productivity, the reality is that the unloading system was under-designed for the Phase 1 sediment volume targets and *scow unavailability is the most important factor that limited productivity*. Analyses by EPA show that productivity was decreasing due to scow queues before resuspension-related shut-down events occurred (indicating other causes, as discussed below) and that, given the optimum unloading rates recorded during Phase 1, the unloading facility could not have sustained the target productivity.

EPA's evaluation shows that as GE attempted to meet the Phase 1 productivity target in late July and early August 2009, productivity became limited by scow unavailability (as seen by the number of scows in the unloading dock queue reaching a maximum) which caused the daily volume dredged to start its decline two weeks before the early August resuspension event. This contrasts sharply with GE's assertion that resuspension is the limiting factor for productivity. It was found that in the days leading up to the shutdown as few as 4 scows were available for loading by the 11 active dredges in 10 open CUs. Further, it was found that after the 4-day Labor Day weekend, during which no dredging occurred, most of the scows had been unloaded and were available to the dredgers (*i.e.*, there were no scows waiting to be unloaded at the unloading dock), and the two greatest productivity days of Phase 1 occurred. However, the queue quickly returned to previous levels and productivity declined. In addition, scow queues also increased the length of time CUs were left open, which contributed to resuspension, as did GE's frequent practice of transporting under-filled scows (resulting in more vessel traffic than would otherwise have occurred, as well as lengthening the queue).

A probabilistic queuing model was developed using the Phase 1 data to evaluate productivity based on load thickness and to make predictions of productivity that may be attained in Phase 2 using one and using two unloading stations. The model shows that, even with increased load thickness, scow queues will limit productivity to less than the Phase 2 targets if there is only one unloading station. However, by adding a second unloading station and loading scows with an additional 0.5 foot of material (well within the load constraints of the scows) the productivity of targets for Phase 2 can be met.

Topic 6 evaluates the implications of the underestimation of the depth of contamination (DoC) during Phase 1.

The uncertainty in DoC is acknowledged as one of the largest impediments encountered during Phase 1. GE asserts that much of the dredging was spent attempting to remove residuals; however, while additional dredging may have been dictated by requirements included in the Residuals Standard, the fact is that the sampling required by the standard identified additional inventory to be removed as a result of consistent underestimation of the DoC. In the 10 CUs encompassing approximately 48 acres that were dredged during Phase 1, 445 locations were targeted for post-dredging sampling. Notably, less than 35 percent of the post-dredging coring sites had a residuals layer requiring removal. By inference, less than 35 percent of the Phase 1 dredging area was re-dredged to address a residuals layer. The purpose of this tracking and analysis performed by EPA was to measure the success of the Standard in avoiding one or more residuals passes, and to demonstrate that, contrary to what GE has asserted in its Phase 1 Evaluation Report (GE, 2010), over 60 percent of the remediation area went directly from inventory removal to compliant, whereas only 8 percent of the Phase 1 area required 2 dredging passes. Moreover, since 6 inches of remaining inventory could not be discerned from a true residual layer based on the Performance Standard sampling requirements, the estimate of 35 percent is an upper bound on the actual extent of residuals. Ultimately this analysis shows that the underestimated DoC was the primary cause of additional dredging passes. Specifically, 42 percent of the 445 locations were shown to have inventory present after the first dredging pass based on identification of deeper contaminated sediments during one of the subsequent sampling surveys and 20 percent of all locations actually required three inventory passes.

The tracking and analysis of each post-dredging coring location yielded several important results pertaining to the implementation of the Residuals Performance Standard:

- It identified areas where the DoC was poorly characterized and inventory remained below the first dredging pass (volume removed by inventory dredging was more than double of that removed by residuals dredging).
- It provided evidence that the standard was successfully implemented, without undue difficulty or schedule impacts, and that dredging-generated residuals (i.e., residuals due to spillage and bucket movements) were not a pervasive issue.

- It provided further support of EPA's proposal for an overcut addition to each dredging pass in Phase 2 to address uncertainty. Adding an overcut to the first pass will serve to reduce the number of dredging passes and increase dredging efficiency, and will not simply produce more residuals.

The findings presented in the Addendum corroborate EPA's belief that Phase 2 can be accomplished in a way that achieves the benefits ascribed in the ROD, with some modifications to the Engineering Performance Standards and with modifications to the dredging design. The Addendum studies show that assertions of the inevitability of conflicts among the three engineering standards are superficial and depend on over-generalization of the data. When the details are more closely examined, the generalizations are not borne out. As an example, contrary to GE's assertion that productivity in general is inextricably linked to resuspension, there are several periods during Phase 1 where productivity was increased but resuspension was not above critical thresholds. As shown in the Addendum, the severity of water quality impacts due to resuspension (as measured at Thompson Island) is better explained by where dredging was occurring, the volume of ship traffic, dredging bucket efficiencies, and river flow, than simply by how much sediment (or PCB mass) was being dredged. The same dismantling of generalizations occurs when examining assertions about residuals (*e.g.,* distribution of residuals outside of the dredge prisms, and the effects of uncertainty in depth of contamination), resuspension (*e.g.,* the use of near-field data to characterize loads attributable to dredging, and attributing the TPCB to Tri+PCB ratio change with distance from dredging to settling alone), and productivity (*e.g.,* peak productivity was actually limited by scow unavailability due to inefficiencies in unloading causing long scow queues, and not due to resuspension).

Water Supplies and the Resuspension Standard

EPA has informed the Towns of Halfmoon and Waterford, NY that it will agree to reimburse them for their incremental costs in obtaining drinking water from the City of Troy until November 2012, and throughout each of the Phase 2 dredging seasons, until the Hudson River dredging is complete. This decision ensures that those towns, which are the only ones that have a public water intake in the Upper Hudson, will not be using the river as their source of potable water during the Phase 2 dredging. Before the end of the 2012 dredging season, EPA will make a decision about whether to continue to pay for water full-time during the remaining off-seasons, or to pay for water on a more limited basis during those off-seasons. EPA will make that decision after additional data is gathered about the impact (if any) of the dredging activities on off-season PCB levels in the Upper Hudson.

As a result of this decision, EPA is proposing to change the way it uses the 500 parts per trillion (ppt) standard during Phase 2. Rather than treat the 500 ppt standard as the maximum allowable Total PCB concentration in the water column (as measured at the far-field monitoring stations), such that a confirmed exceedance of the standard would require a temporary halt of dredging activities, EPA is proposing to use 500 ppt as a control level that will allow EPA to require GE to propose and implement operational changes to reduce the PCB levels in the water column. Additionally, EPA would also be able to require operational changes to reduce the level of resuspension in the event of a seven-day running average of more than 350 ppt at one of those monitoring stations. Such operational changes might include such measures as relocation of dredge operations to lower concentration areas, reduction of the number of dredges working at the same time, or temporarily moving dredges to lower velocity areas of the river. EPA would also retain the discretion to require a temporary halt to dredging activities.

The primary reason for the inclusion of the 500 ppt standard in the Phase 1 Resuspension Standard was to protect the water supply intakes at Waterford and Halfmoon (Statement of the Engineering Performance Standards for Dredging (EPA, April 2004), Vol. 1, pp. 37, 93; Vol. 2, p. 47). This reason no longer applies because the two towns are not going to use the Hudson River as their source of potable water during the Phase 2 dredging.

Along with the daily PCB load standard, the 500 ppt and 350 ppt control levels would be used to help monitor the amount of resuspension that is occurring and help signal whether operational changes need to be made.

The conclusions of this Addendum support EPA's proposed changes to the Engineering Performance Standards, and help demonstrate that the dredging operation can be modified in a number of respects to obtain significant improvements over the Phase 1 performance in Phase 2. EPA will closely review the data from the first year of the Phase 2 dredging and in light of that data, as appropriate, consider further changes to the performance standards and/or operational details for the second year of Phase 2. The Agency anticipates a similar adaptive management approach to be followed during the remaining years of the project.

TOPIC 1

WATER COLUMN LOADS DURING AND AFTER DREDGING

TOPIC 1-A

PCB CONCENTRATIONS AT THE FAR-FIELD STATIONS:

POST-DREDGING VS BASELINE

Topic 1-A - PCB Concentration at the Far-Field Stations: Post-Dredging *vs.* Baseline

The purpose of this analysis is to compare Total PCB (TPCB) concentrations at the far-field monitoring stations at Thompson Island Dam, Schuylerville (Lock 5), and Waterford during the post-dredging period from December 1, 2009 through April 6, 2010 versus the baseline period between 2004 and 2008. The goal is to discern whether dredging-related PCB release is evident after completion of the Phase 1 activities or whether conditions related to PCB transport have returned to baseline.

1-A.1. Post-Dredging Monitoring

Monitoring data collected by GE for the post-dredging period shows that the TPCB concentrations measured at the far-field stations are comparable to TPCB concentrations observed at these stations during the baseline period. Figures 1-A-1a, 1-A-1b and 1-A-1c show the water column concentrations for the post-dredging period, beginning December 1, 2009, for the three far field stations, Thompson Island, Lock 5 (Schuylerville) and Waterford, respectively. The plots also show the available baseline data for the period prior to dredging (2004 to 2008). The range of baseline concentrations during the December to April period is denoted by the region colored in gray on each plot. Figure 1-A-1a shows the TPCB concentrations at the Thompson Island station for all flows between the dates identified above, including two high flow events from March 23 to 28, 2010 and April 1 to 4, 2010. Note that the amount of baseline data for the Thompson Island station is limited to early December and late March. Additionally, largely due to access limitations, there is very little high flow data for this station. Nonetheless, the data shows that TPCB concentrations dropped to within baseline ranges soon after the remedial activities stopped on December 4, 2009 and remained within the low-flow baseline range except during the January, March and April 2010 high flow events. (While dredging and capping/backfilling within the 10 Certification Units [CU] was completed on December 4, 2009, demobilization of dock structures and related floats continued through December 23, 2009 and one tug boat remained in the water after December 11, 2009). A similar observation can be made for the Lock 5 and Waterford stations, as shown in Figures 1-A-1b and 1-A-1c, respectively. Once again, the data shows that TPCB concentrations have fallen to within baseline ranges except during high flows at Lock 5. At the Thompson Island and Lock 5 monitoring stations, high flows are defined as flows greater than or equal to 10,000 cfs whereas at the Waterford monitoring station high flows are defined as flows greater than or equal to 14,000 cfs due to contributions from major tributaries (Hoosic River and the Batten Kill).

1-A.2. High Flow Monitoring

While it is clear that the water column concentrations returned to baseline concentrations under low flow soon after all remedial activities ended, conditions under high flows are not as easily characterized. In particular, post-dredging high flow monitoring data collected at the Thompson Island monitoring station has yielded some of the highest observed concentrations in the Upper Hudson. Notably, the values observed during the March and April 2010 high flow events were, in some cases, more than an order of magnitude higher than the highest TPCB values observed during dredging (*e.g.,* 13,400 ng/L on March 25, 2010, *vs.* 686 ng/L on October 14, 2009[1]). The cause of these post-dredging observations was unclear at first but the likely explanation became clear when all five of the intakes were shown to be badly fouled with plant debris and perhaps damaged. This was discovered during an April, 2010 maintenance inspection. It is believed that the plant debris clogged the intakes as well as forced them into the river bottom during high flows. One of the intakes was so badly fouled that it could not be found with an underwater camera and had to be snagged with a grappling hook. All five intake screens were clogged with plant matter and mud. Since the last routine maintenance visit was conducted in November 2009, it is unclear when the intakes became fouled, but all data obtained since November 2009 must be viewed with caution. Figure 1-A-2a is a photograph showing an example of the fouling at three of the Thompson Island intakes.

Similar but less extensive fouling was observed for the Lock 5 as shown in Figure 1-A-2b. In this instance, the debris screen for one intake was lost entirely and the intake itself was clogged with plant matter and mud. For two other intakes, the routine backflush revealed that visible quantities of mud had lodged in the tubes. The reported poorly operating pumps at Thompson Island and pump failure at Waterford suggest that intake fouling impacted the ability of the sampling systems to draw water in addition to compromising the properties of the water drawn. Related sampling evidence is discussed below.

1-A.2.1. High Flow Monitoring: Comparison of Post-Dredging Period to Baseline Period

In Figure 1-A-3a, the TPCB concentrations at the Lock 5 station measured during the two post-dredging high flow events from March 23 to 28, 2010 and April 1 to 4, 2010 are compared with similar high flow data collected during all months in the baseline period. Post-dredging TPCB concentrations at high flows at Lock 5 are close to, but still exceed similar measurements for the pre-dredge period. In light of the discovery of the fouled intake and mud collection within the intake lines, the results are considered suspect. As shown in this figure, the TPCB concentrations measured in many of the samples from the March 23 to 28, 2010 high flow event are between 100 ng/L and 500 ng/L. Notably, the highest measured value during the March 2010 sampling appears to be equivalent to the highest TPCB concentration observed at this station during active dredging in 2009. Because of its similarity to the suspect samples at Thompson Island (discussed further below), this sample is suspect as well. In direct contradiction of the March observations, samples collected during the April 1 to 4, 2010 post-dredging high flow event appear to show TPCB concentrations that are within the range observed during the baseline period (10 ng/L to 50 ng/L).

Figure 1-A-3b presents the TPCB concentrations at the Waterford station measured during three post-dredging high flow events from January 26 to 28, 2010, from March 16 to 29, 2010 and from April 1 to 4, 2010 as compared with similar high flow data collected during all months in the baseline period. (Note that three high flow events were observed at Waterford during the post-dredging period, as opposed to only two such events at the two upstream stations.) Unlike

---

[1] This value was obtained along with a split sample that yielded a concentration of 306 mg/L. The factor of 2 variation between these samples was typical of the poor sample replicate precision noted at Thompson Island during dredging.

the data from samples at the Lock 5 monitoring station, the TPCB concentrations in nearly all post-dredging samples at Waterford station fall well within the pre-dredging baseline range for high flow conditions (6 ng/L to 200 ng/L). Values for TPCB concentrations in three samples from the March 16 to 29, 2010 high flow event are greater than or equal to the highest TPCB concentration observed at Waterford after June 1, 2009 during active dredging in the Upper Hudson River. Also, the highest value obtained during the March high flow event (1,900 ng/L) is nearly an order of magnitude greater than the highest value observed post-June 1, 2009 (201 ng/L). As will be further discussed below, these data are suspect and most likely indicative of fouling of the water intakes at the Waterford monitoring station. Other than these three samples, water column concentrations at Waterford appear to have returned to baseline conditions under both low and high flow. There is no evidence of dredging-related PCB loads after the remedial activities were concluded.

1-A.2.2. Impact of Intake Fouling

The next set of three figures provides indirect chemical evidence of the impact of intake fouling. The figures depict the TPCB concentrations normalized to TSS (i.e., ng TPCB/mg solids) versus flow (Fort Edwards flow for the Thompson Island and Lock 5 stations and Waterford flow at the Waterford station) measured at the three far-field monitoring stations during the post-dredging period between January and March 2010. Since PCB transport during the high flow events is generally considered the result of sediment resuspension due to higher water velocities, it is reasonable to expect that this normalization should yield a consistent relationship between TSS and water column concentration. In particular, given the broad integrating nature of resuspension during high flow events (*i.e.*, increased water velocities occur throughout the river during high flows, increasing the rate of resuspension from sediments across much of the river bottom), it is reasonable to expect that the levels of PCBs on suspended matter should not be highly variable during these events.

Figure 1-A-4a shows that at Thompson Island, the normalized TPCB concentration ranges from less than 1 to more than 1,000 ppm during higher flows (*i.e.*, greater than 10,000 cfs). Also the normalized concentration is notably higher during high flows as opposed to low flow conditions, suggesting that the nature of the solids transported during high flow are different from those transported at low flow. This is distinctly different behavior from what is observed at the downstream stations. As noted previously, it is likely that the high concentration, high normalized concentration samples are due to the plant fouling observed at all five intakes for the station.

In contrast, Figure 1-A-4b shows that at Lock 5, for all but one sample, the normalized TPCB concentration is less than 20 ppm regardless of flow. Additionally, there is no substantive change in the normalized concentration with flow, although the trend suggests there may be some reduction in variability at higher flows. This relationship is much more consistent with the expectation described above. It also contrasts sharply with the data from the Thompson Island station, located only 6 miles upstream. However, as described previously, the Lock 5 station are still suspect. One sample yielded a normalized PCB concentration that was more than 3 times greater than the any other value. This result occurred in the sample with the highest reported concentration at this station post dredging (560 ng/L), very close to the highest reported for the station during dredging (643 ng/L). As described below, the occurrence of this sample did not coincide with any flow-related change that might have suggested a mechanism to cause it, adding to its uncertainty. The other high flow samples fall outside the range of baseline high flow data, which might suggest dredging-related PCB transport (*i.e.*, PCB redistribution) on top of the normal baseline loads. However, this observation is not borne out by similar above baseline transport at Waterford and so is considered suspect in light of the compromised intakes.

The normalized TPCB results for the Waterford station show a similar relationship to that at Lock 5. The results presented in Figure 1-A-4c indicate that, except for three samples, the measured normalized TPCB concentration is less than 5 ppm during higher flows.[2] Like the samples at Lock 5, the results show a fairly consistent relationship across the range of flows, again with the suggestion of reduced variability in normalized TPCB at the highest flows. Also similar to the Lock 5 results, the three samples with unusually high normalized TPCB concentrations are also the three with highest absolute TPCB concentrations. The normalized TPCB levels in these samples are nearly an order of magnitude higher than any other sample obtained under similar high flow conditions (high flows at Waterford are defined here as greater than 14,000 cfs). These samples are also without corresponding hydrologic changes and appear unrelated to conditions at Lock 5 based on time-of-travel considerations, described further below.

Given the direct evidence for the intake fouling at Thompson Island and Lock 5, neither the March nor April 2010 high flow results for these stations can be considered accurate measurements of load in the water column during this period. The observation that the fouling was less extensive at Lock 5 than at Thompson Island suggests that the Lock 5 reported values are perhaps less compromised than those at Thompson Island. Thus the Thompson Island samples show no consistency in their normalized TPCB levels whereas the Lock 5 samples generally have consistent results. Notably, nearly all Waterford high flow samples fall within the range of baseline results (described below). These observations suggest that the extensive fouling at Thompson Island caused the intakes to incorporate muds directly from the river bottom, thereby changing the normalized TPCB levels during high flow. The less compromised Lock 5 station simply accumulated water borne sediments that were later incorporated in samples. The results for Lock 5 suggest that there may be some evidence for dredging-related PCB transport (*i.e.*, PCB redistribution) at this station but the actual amount of transport cannot be quantified. The high flow samples in March 2010 are at best upper bound estimates and are not considered reliable. Taken together, these observations indicate that there is no direct evidence of dredging related PCB transport to the Lower Hudson after completion of the dredging activities in December 2009, and some suggestive Upper Hudson transport was seen during only one event (March 23-28, 2010) at only one station.

---

[2] The lower average normalized TPCB value is consistent with a conceptual model of load originating primarily in the Thompson Island Pool. Transit downstream adds water and additional, less contaminated sediments, while transporting the PCBs fairly conservatively. This behavior is probably best exhibited during high flow events where loads remain the same or increase and downstream transport occurs rapidly. Constant or increasing loads downstream were also observed during baseline monitoring.

1-A.2.3. PCB Concentrations during March 2010 High Flow Event

During the period of high flows in March and April 2010, the time of travel between Thompson Island and Lock 5 (Schuylerville) was on the order of 4 to 6 hours. There are no major tributaries entering the river between the stations but the TSS load increases from Thompson Island to Lock 5, suggesting resuspension of sediments in the intervening 6 miles. (The Batten Kill enters the Hudson just below the Lock 5 station.) Despite the increasing TSS load and short travel time, overall PCB concentrations and PCB load declined markedly during this high flow period. This is shown in Figure 1-A-5a, which compares flow and concentrations over time at Thompson Island and Lock 5.

Evident in the figure is the rapid variation in concentration at the Thompson Island station, in contrast to the much more gradually varying concentrations at Lock 5. Other than the second sample obtained at Thompson Island, the higher concentration samples occur erratically during declining flows. Additionally, the concentrations observed during the first 48 hours of the sampling period are as much as 20 times greater than the highest concentrations observed during the dredging operation itself, despite the lack of dredge plumes, oil sheens and other factors that were present during dredging but absent during this post-dredging study period.

Note that through most of this period, the samples represent 6-hour composites collected continuously one after the other. Given the relatively smooth hydrologic record observed during this period, sequential samples are expected to be similar to each other. This was, in fact, observed fairly consistently at Lock 5 but clearly not at Thompson Island.

Note as well the lack of correlation between the samples at the 2 stations. None of the high concentration samples at Thompson Island result in a similar response downstream, save one sample collected at 1800 hours on March 25, 2010. Even in this instance, the single high value at Lock 5 actually predates by 4 to 6 hours the arrival of the putative 13,600 ng/L water from the Thompson Island station. Both the lack of correlation between the stations and the rapid apparent rate of TPCB concentration decline between stations indicate that the results of the two stations are inconsistent. Given the particularly unusual TPCB behavior at the Thompson Island station and the documented intake fouling at both stations, the lack of correlation between station results is not surprising. Of the two, the Thompson Island data are considered to be the least related to actual in-river conditions but data from both stations are subject to considerable uncertainty.

As noted previously, the one high concentration sample at Lock 5 obtained at 1800 hours on March 25, 2010 is inconsistent with all of the other samples obtained at this station during the January to March 2010 post-dredging period, based on the normalized TPCB concentration. When viewed as part of the sample collection sequence, it is also inconsistent with the observed trend. Neither adjacent sample gives any suggestion of the short-term change in absolute or normalized concentration shown by this sample. As a result, this sample is considered unrelated to the true river conditions during this time.

Figure 1-A-5b presents a similarly constructed comparison for the Lock 5 and Waterford stations, with the flow at Waterford shown instead of the flow at Ft Edward. The majority of the sample results at both stations appear to vary smoothly and similarly over time. The suspect sample at Lock 5 is noted on this diagram with a magenta circle. Three Waterford samples are also noted in this manner, representing the three samples discussed earlier, with high normalized

TPCB levels. The highest of the samples appears to be an outlier relative to its adjacent samples, much as the one sample at Lock 5. However, the other two identified samples at Waterford occur sequentially, suggesting they may be related, although they are clearly unlike the majority of Waterford samples. As it turns out, the two samples follow a 24 hour period marked by a pump failure, in which no samples were obtained at the station. While the complete details have not been provided to EPA as of this writing, it is suspected that sediment accumulation in the lines or simply fouling of the intake at Waterford is the likely cause of the suspect sample results. For the reasons given above, the three identified samples at Waterford are not considered representative of in-river conditions at the time of their collection.

While the lack of correlation as well as the chemical properties clearly identify the Thompson Island station samples as well as a few downstream samples as suspect, it is useful to examine PCB loads during the post-dredging period to form a further basis for their dismissal. EPA compared the TPCB loads at the three far-field monitoring stations during Phase 1 dredging (May 15 to November 30, 2009) as well as for the main post-dredging high flow event (March 23 to 28, 2010). These TPCB loads are shown in Figure 1-A-6. The left panel shows the TPCB loads during active dredging and the right panel shows the corresponding loads during the March 23 to 28, 2010 post-dredging high flow event.

For the left panel, the cumulative total load is shown for each station, broken down into the estimated baseline contribution, shown in blue, and that due to dredging, shown in green. Each bar is also annotated to show the overall level that corresponded to 117 kg over baseline as well as the level corresponding to 1 percent of the mass removed. Note that the load at Waterford did not exceed this threshold.

A decline in the TPCB transport from Thompson Island to Lock 5 is evident in both panels. While the decline during dredging may be questionable (see the EPA Phase 1 Evaluation Report, Chapter 2)[3], it is clear that the rate of decline during dredging is significantly less than during the post-dredging high flow event. The loads at each station for Phase 1 were obtained from the simple product of daily data and flow for the May to November 2009 period. The loads for the high flow event were also obtained as the simple product of flow and concentration for the period. Loads during the high flow event at Lock 5 and Waterford are calculated with and without the suspect data. The suspect data have only a small effect at Lock 5 but serve to more than double the estimated total load at Waterford.

In both panels, the load decline from Thompson Island to Lock 5 is noted. In particular, the load decline during dredging is quite substantial, at 30 percent of the total transport. This decline occurs largely during low flow conditions. While there are concerns over the Thompson Island data, some of this decline may be the result of settling or gas exchange losses during transit to

---

[3] The results obtained at the Thompson Island station were also problematic during dredging. In particular, when higher concentrations were obtained at this station, they were not consistently observed downstream at Lock 5, as might be expected. Additionally, replicate samples at the Thompson Island station typically exhibited poor reproducibility when concentrations approached or exceeded 500 ng/L. The presence of oil sheens were frequently observed during Phase 1 and had the potential to confound sample results at this station. These observations have potentially compromised the use of this station data for Phase 1 calculations. As a result, the data from Thompson Island during Phase 1 are undergoing thorough review at the time of this writing.

the Lock 5 station. Flows are generally low during this period, so as to provide 12 to 18 hours of time for these losses to occur. This decline is dwarfed, however, in comparison to the loss that occurs during the five day high flow event. Nearly 90 percent of the apparent load is lost during a period of rapid transit (4 to 6 hours) while gaining TSS load between the stations (not shown here). It is this observation that finalizes EPA's perspective on the Thompson Island data. This loss is simply too unlikely and without a probable mechanism to be an actual representation of in-river conditions. For all of these reasons, the Thompson Island post-dredging high flow data are considered suspect. As mentioned previously, given the extent of fouling observed, all Thompson Island post-dredging samples must be viewed with caution.

The load data at Lock 5 and Waterford are also telling here. While the following analysis does not provide the same strength of evidence as Thompson Island, it can be seen that by eliminating the 4 suspect values at Lock 5 and Waterford based on their normalized TPCB levels, the loads can be shown to match fairly closely, with about a 5 to 10 percent increase in load between the stations. However, the scale of this load gain is lower than historical observations between the stations during baseline high flow events. This observation suggests that some component of the load at Lock 5 may be the result of dredging-related PCB transport. Given the uncertainty of the sample results at Lock 5, it is not clear what the actual flux of dredging-related PCB would be. However, the load as calculated is quite small relative to the active Phase 1 period and includes the baseline load as well. (The cumulative load at Lock 5 was about 350 kg including baseline, see Figure 1-A-6) Perhaps, more importantly, the high flow event that followed in early April showed concentrations consistent with baseline, suggesting no further dredging-related PCB transport.

To complete its review of the post dredging monitoring, EPA examined the "fingerprint" of the PCBs being transported by the river before, during and after Phase 1. This was accomplished by examining the Tri+ fraction of the PCBs in the water column. This ratio is a fairly sensitive indicator of the extent of dechlorination on the PCB mixture and has served well in the past as a diagnostic tool (*e.g.*, EPA, 1997. Hudson River PCBs Phase 2 RI/FS - *Data Evaluation and Interpretation Report*). In Figure 1-A-7, EPA has plotted the Tri+ to TPCB ratio versus the TPCB concentrations observed at the Waterford station during three periods: baseline (2004 to 2008); active dredging (May 15 to November 30, 2009) and post-dredging (December 1, 2009 to March 29, 2010). A careful examination of this figure shows that the patterns in the upper panel (baseline) and the lower panel (post-dredging) are similar to each other and different from the pattern observed in the middle panel (active dredging). Specifically, high concentrations are marked by a high fraction of Tri+ PCB. This is attributed to scouring of relatively low concentration, less dechlorinated PCB mixtures present at the sediment surface. In contrast, the relatively high concentrations and high loads observed during dredging were driven by the resuspension of the more concentrated, more dechlorinated sediments that were associated with the sediment removed by dredging.[4]

---

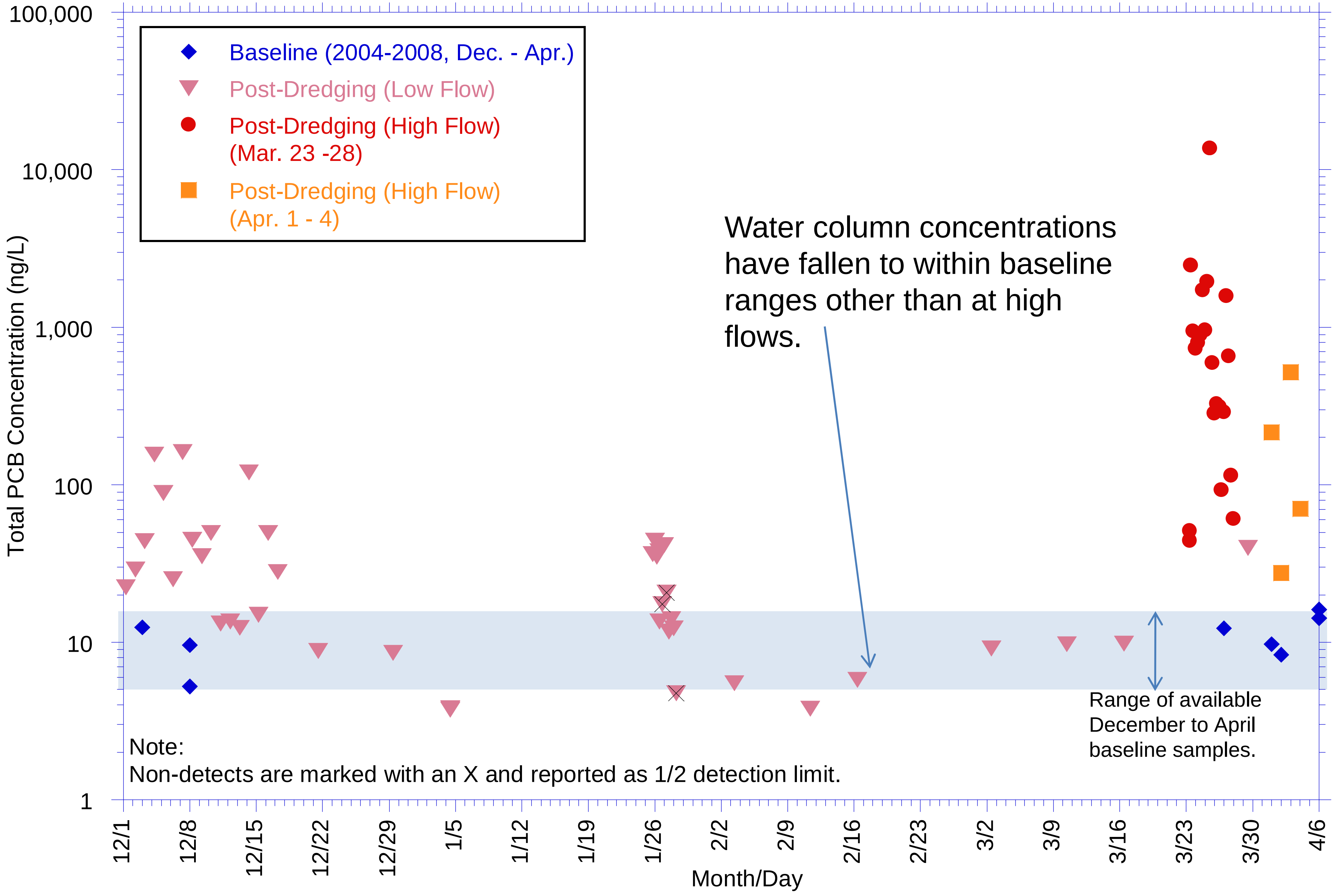
[4] As extensively documented in the Hudson River PCBs Phase 2 RI/FS - *Data Evaluation and Interpretation Report* (EPA, 1997), the extent of dechlorination increases with PCB concentration, thus marking the most highly contaminated sediments as most dechlorinated.

This demonstrates that the PCB mixture in the water column of the Upper Hudson River during the post-dredging period has returned to the pattern observed prior to the Phase 1 dredging event in 2009. Since one of the remedial goals of the ROD was to reduce PCB mass in the Upper Hudson, the remedy targeted the concentrated deposits of PCB mass. Thus the Tri+ fraction in PCBs released by dredging is characteristically lower than that observed during baseline conditions. It is clear from the evidence presented in the third panel in Figure 1-A-7 that the concentrations and Tri+ fraction have returned to the baseline relationship. Contrary to what GE has asserted in its Phase 1 Evaluation Report, EPA believes that the data collected by GE actually shows no significant short-term impacts to the water column of the Upper or Lower Hudson River due to the redistribution of PCBs from dredging.

1-A.3. Summary

This analysis has identified the following concerns:

- PCB concentrations at the Thompson Island station post-dredging must all be considered suspect, particularly those collected during recent high flow events. Documented intake fouling as well as a geochemical analysis of the nature of the PCB concentrations and patterns indicate that these results are not indicative of in-river conditions.
- Samples from Lock 5 and a limited number of samples at Waterford stations obtained during the post-dredging period are also clearly suspect, based on based on evidence of fouling at Lock 5 as well as geochemical lines of evidence at both stations.
- The inability to maintain the automated sampling apparatus over the winter from the physical limitations due to ice cover and safety is likely to have compromised much of the post-dredging data to date.
- Changes in PCB "fingerprint" that might indicate the presence of dredging related PCBs are only shown to occur in samples that appear suspect based on the ratio of PCBs to suspended matter. The inconsistent and random occurrence of these samples during the post-dredging monitoring period as well as the evidence of fouling and pump problems suggest these data are unreliable measures of in-river conditions.
- Nonetheless, a large number of the samples obtained at the Lock 5 and Waterford stations, and even some of the Thompson Island samples are consistent with the PCB concentrations and patterns observed prior to Phase 1. These samples occur fairly consistently over the post-dredging period, lending credence to their interpretation and suggesting the absence of dredging-related PCB transport during these sampling periods.
- A limited number of samples at Lock 5 suggest a single, short term transport event of dredging-related PCBs, but do not provide an acceptable basis to quantify this transport. Taken at face value, the results indicate only a small transport event.
- Estimates of load to the Lower Hudson as measured at Waterford during high and low flow conditions in the post dredging period show no increase over baseline loads. That is, the relationship between flow and concentration observed during the post dredging period at Waterford is the same as that observed prior to Phase 1.
- The post-dredging evidence collected to date shows no significant short-term impacts to the Upper or Lower Hudson River due to the redistribution of PCBs from dredging.

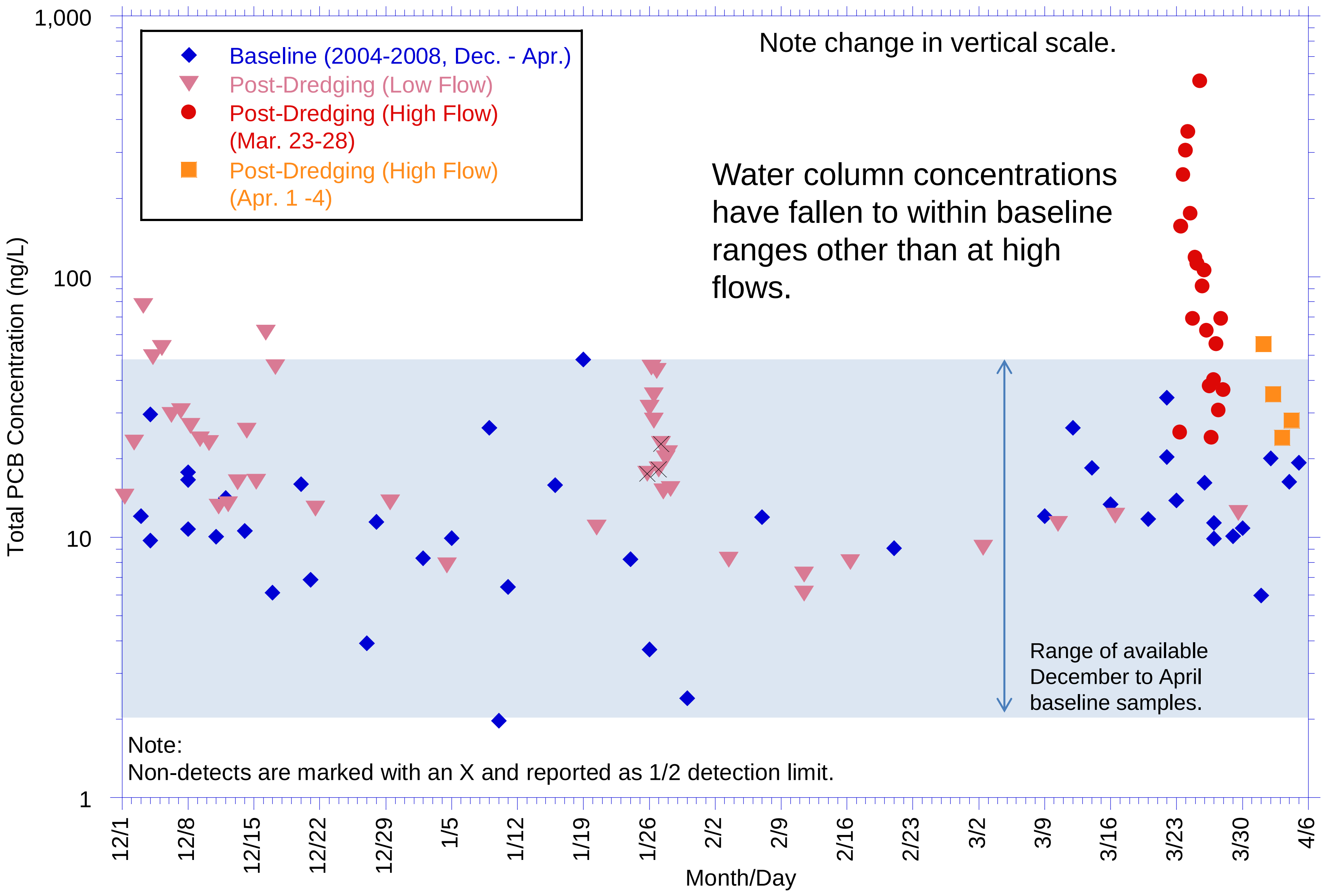


Post-Dredging Monitoring at Thompson Island
Total PCB Concentration vs. Date

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-1a

April 2010

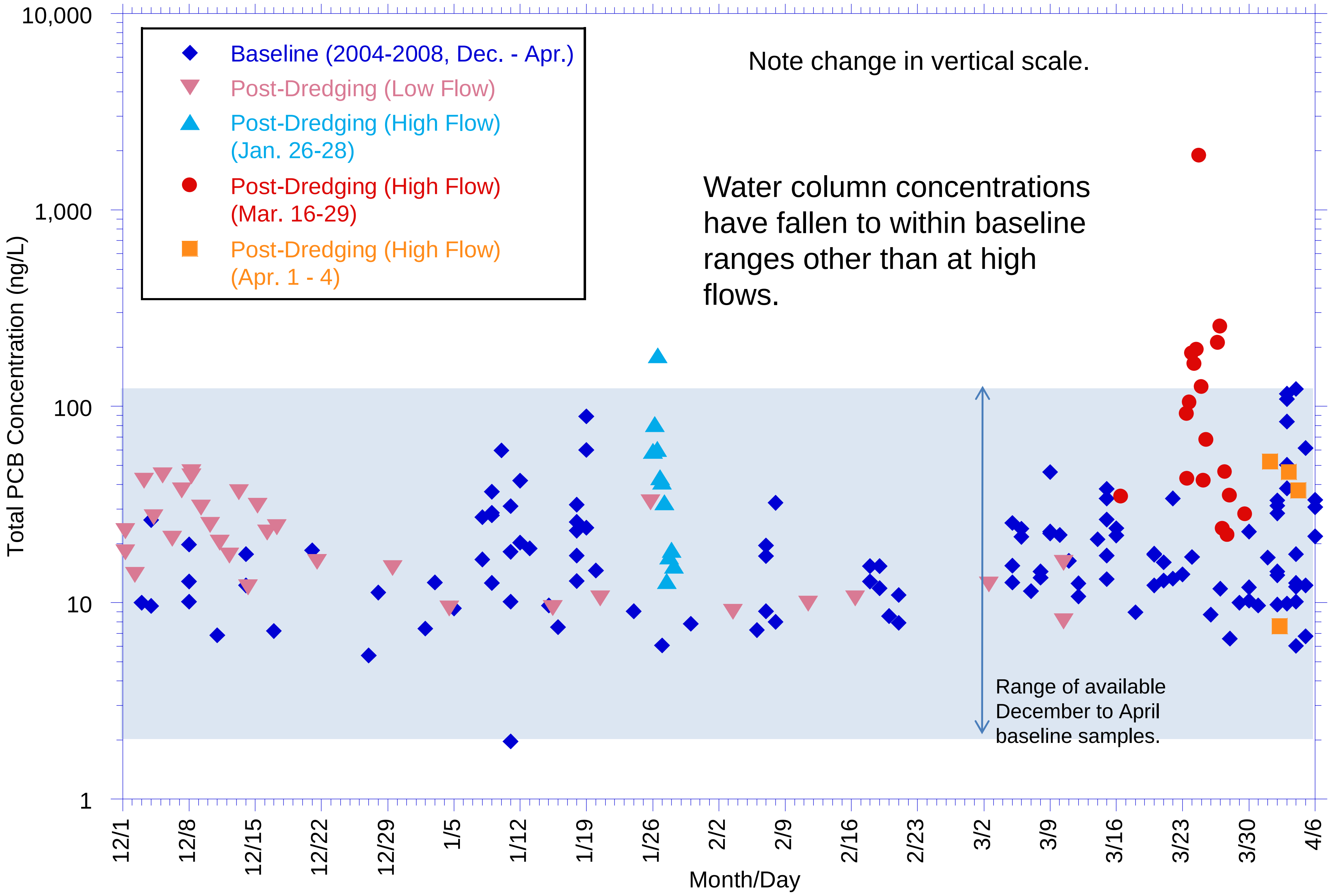


Post-Dredging Monitoring at Lock 5 (Schuylerville)
Total PCB Concentration vs. Date

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-1b

April 2010



Post-Dredging Monitoring at Waterford
Total PCB Concentration vs. Date

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-1c

April 2010

TID Intake Screen #3 being pulled from river and covered with weeds and mud

TID Intake Screen #4 being pulled to surface and covered with weeds and mud.

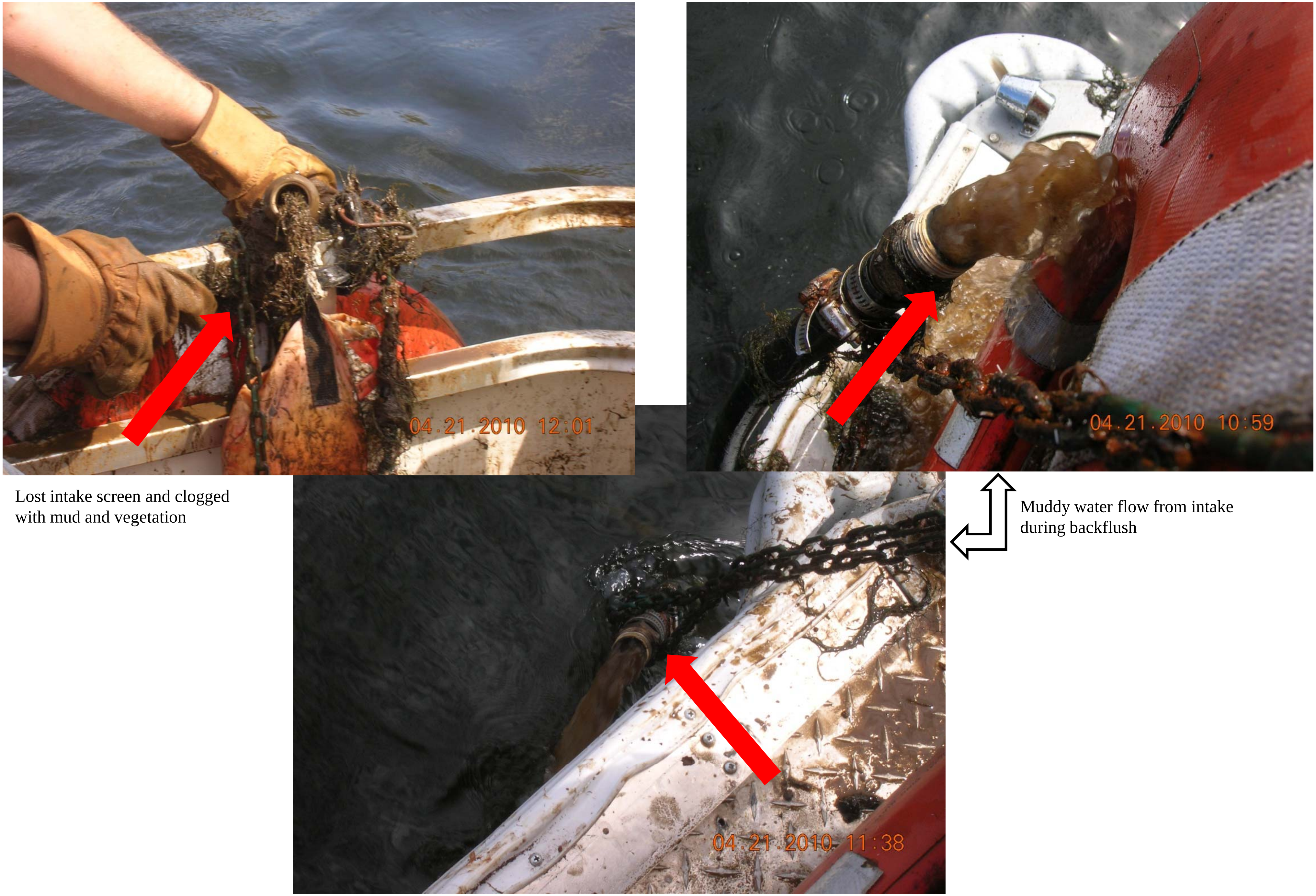
TID Intake #1 covered with weeds and mud

Thompson Island Intake Photos

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-2a

April 2010



Lost intake screen and clogged
with mud and vegetation

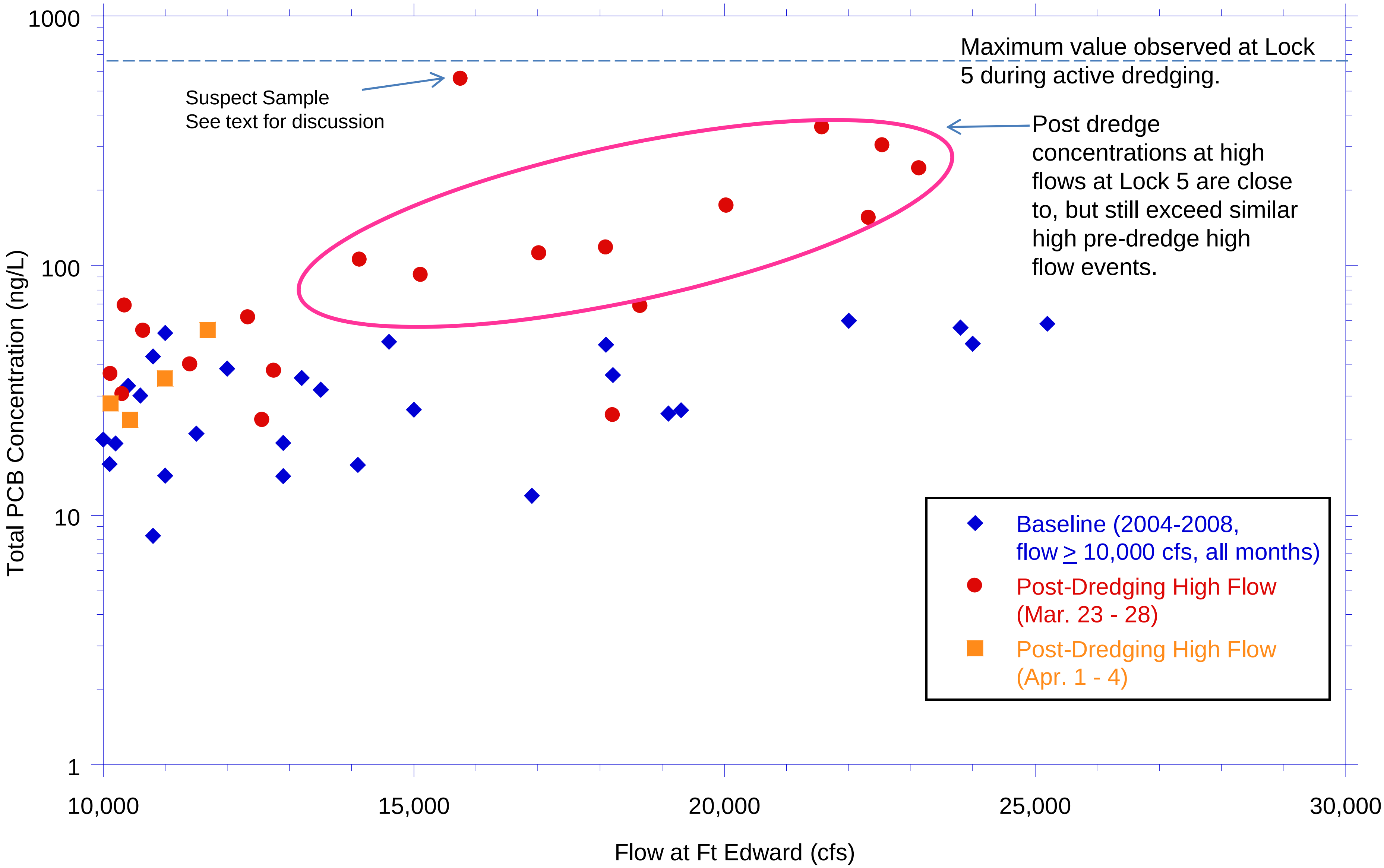
Muddy water flow from intake
during backflush

Lock 5 Intake Photos

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-2b

April 2010

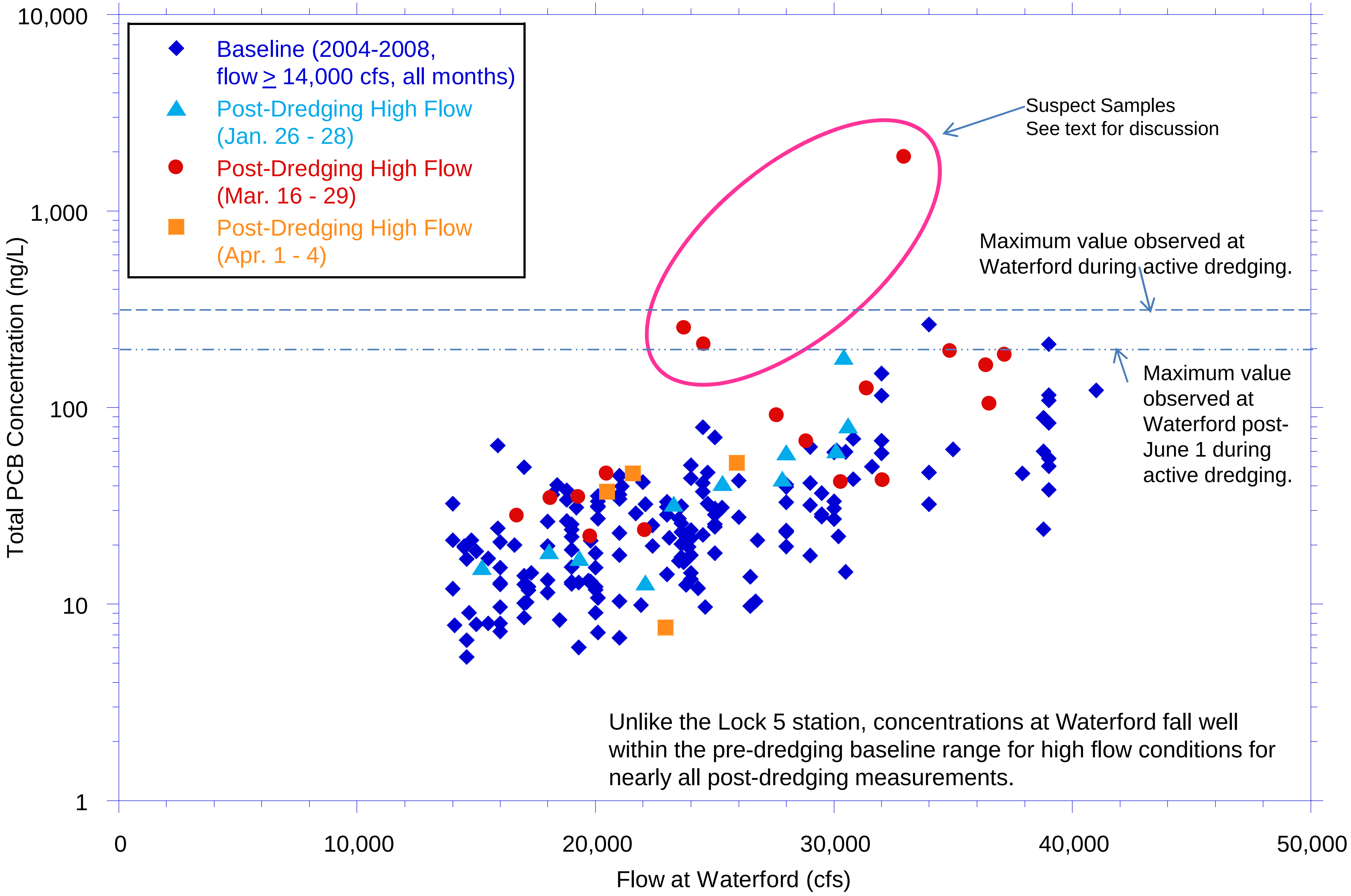


High Flow Monitoring at Lock 5 (Schuylerville)
Total PCB Concentration vs. Fort Edward Flow

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-3a

April 2010



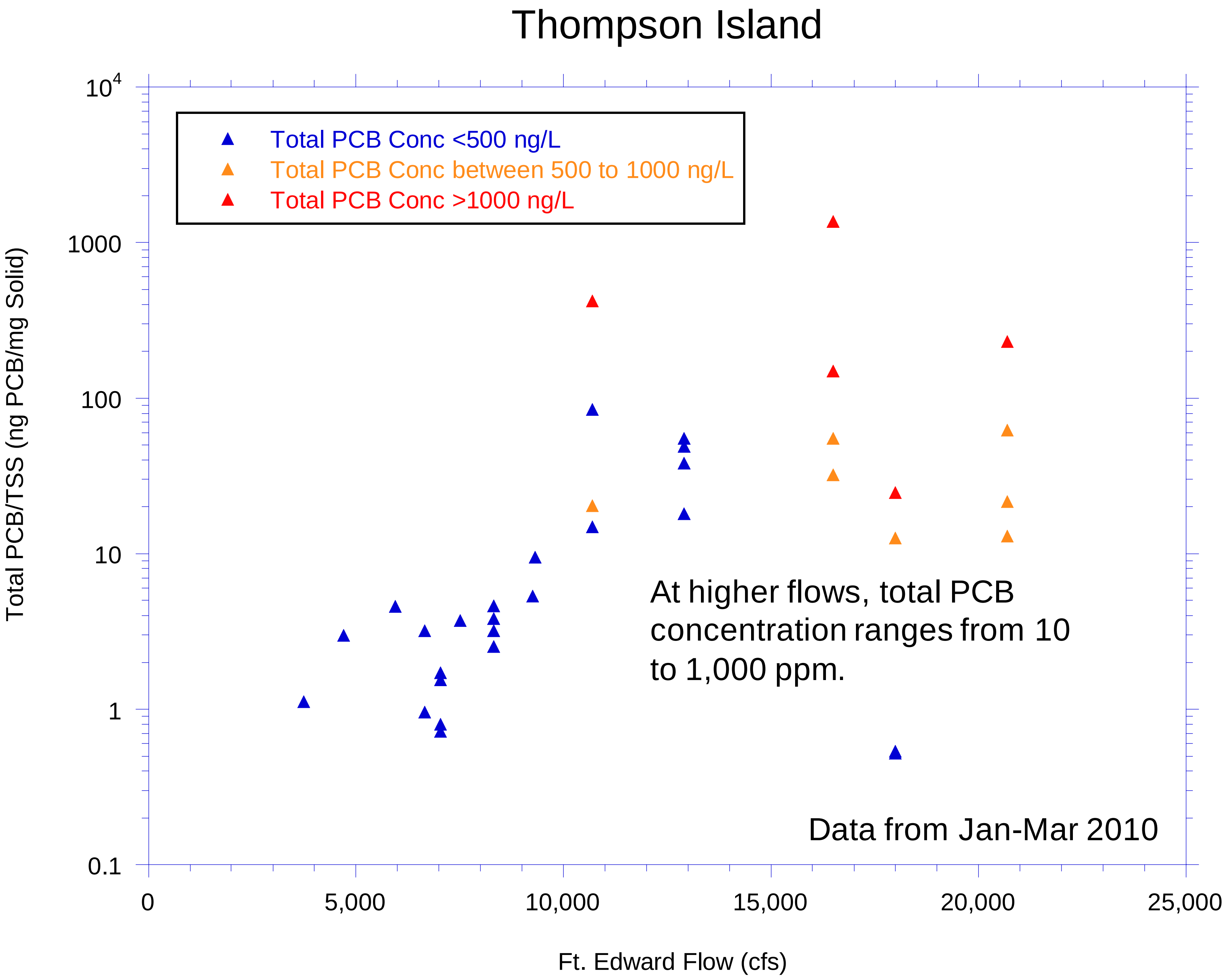
Unlike the Lock 5 station, concentrations at Waterford fall well within the pre-dredging baseline range for high flow conditions for nearly all post-dredging measurements.

High Flow Monitoring at Waterford
Total PCB Concentration vs. Waterford Flow

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-3b

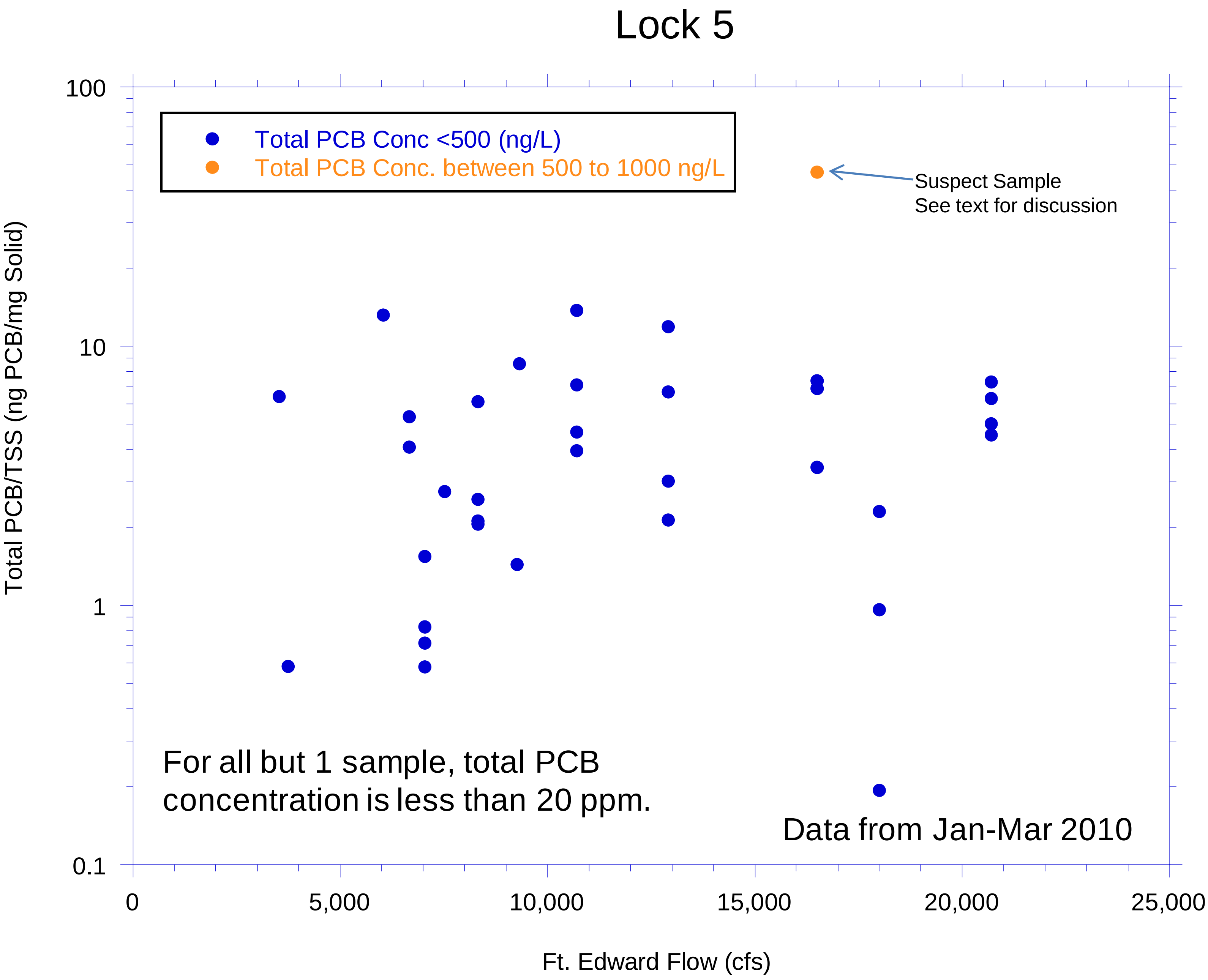
April 2010



Total PCB Concentrations Normalized to TSS Thompson Island

Figure 1-A-4a

April 2010

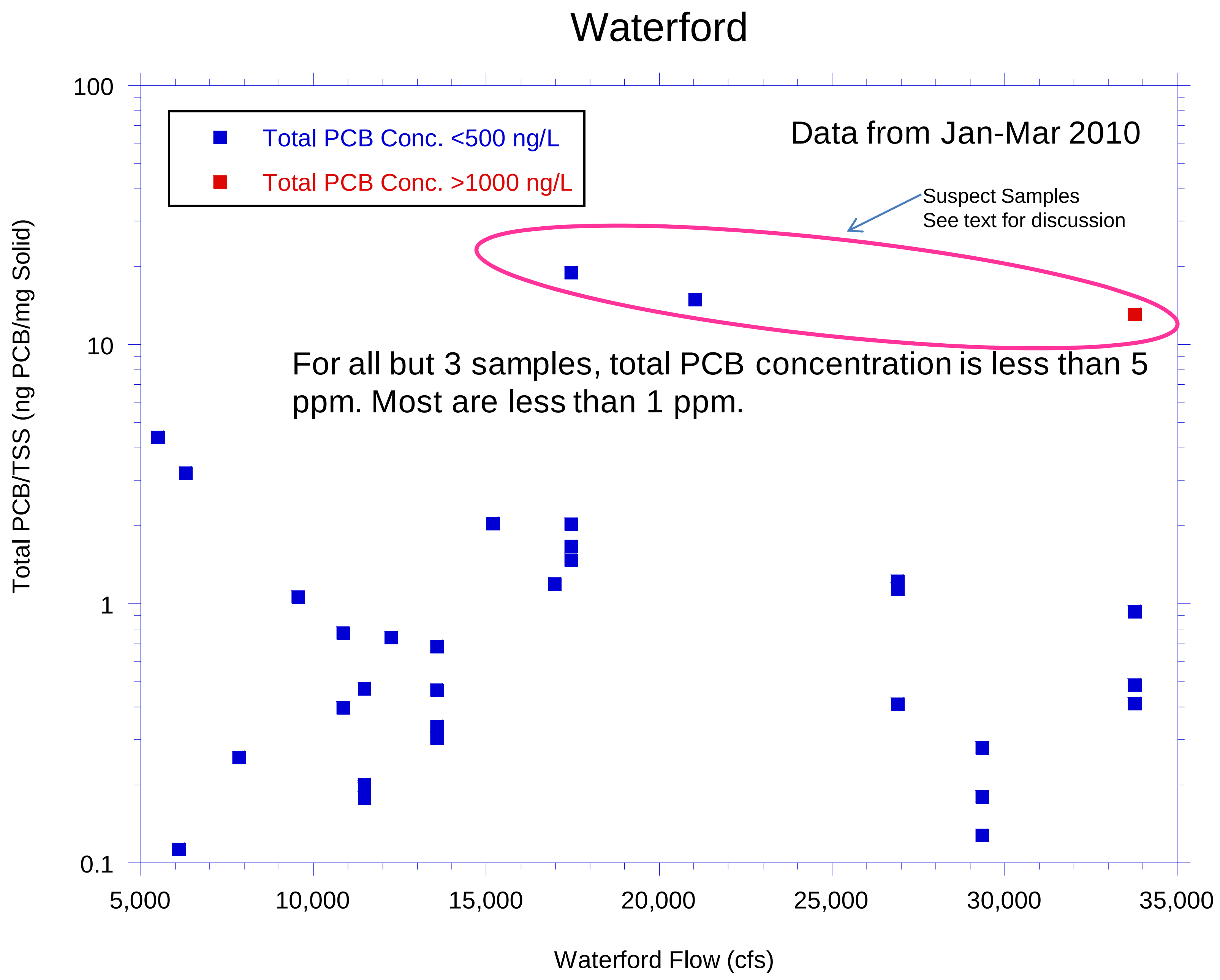


Total PCB Concentrations Normalized to TSS Lock 5

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-4b

April 2010



Data from Jan-Mar 2010

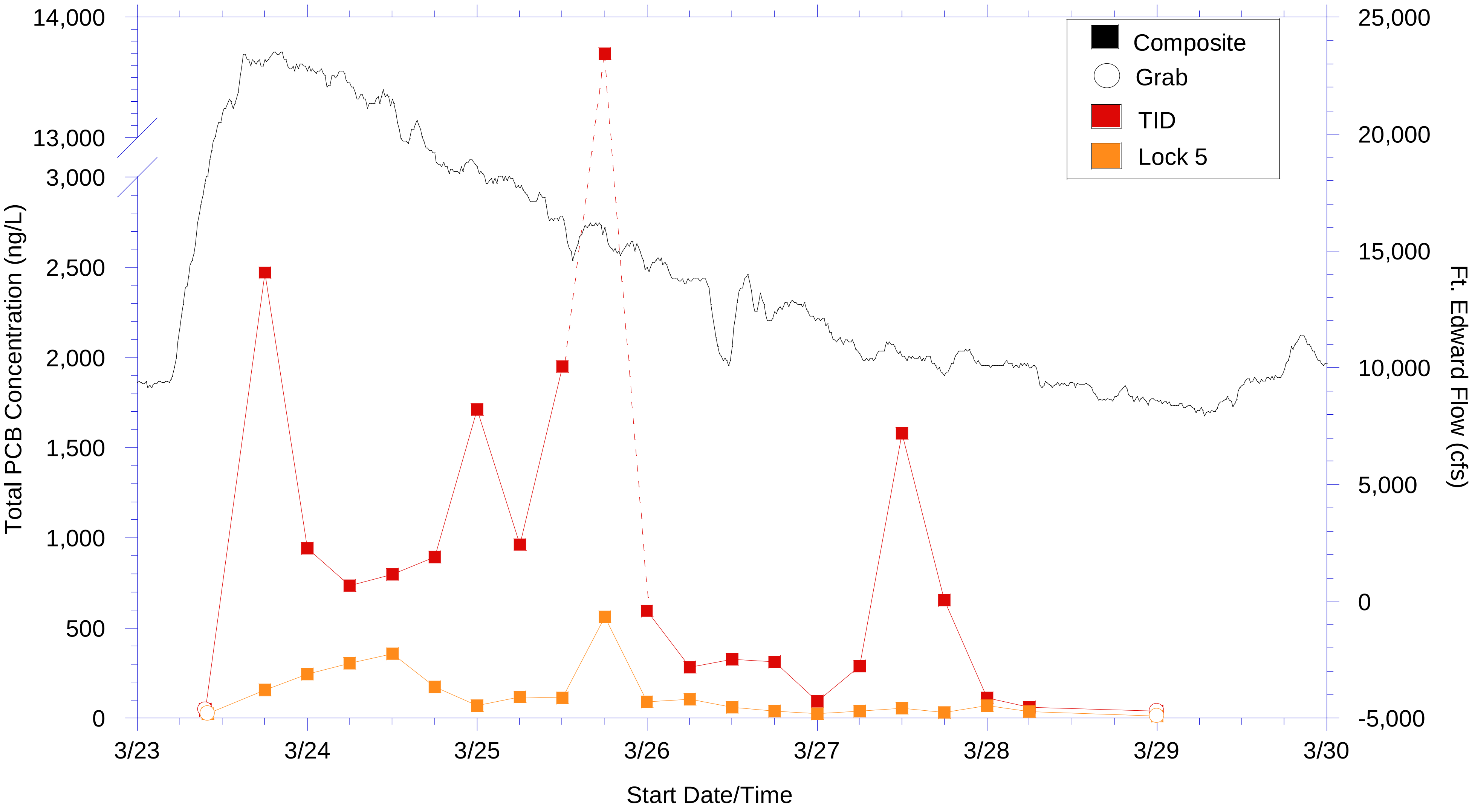
Suspect Samples
See text for discussion

For all but 3 samples, total PCB concentration is less than 5 ppm. Most are less than 1 ppm.

Total PCB Concentrations Normalized to TSS Waterford

Figure 1-A-4c

April 2010

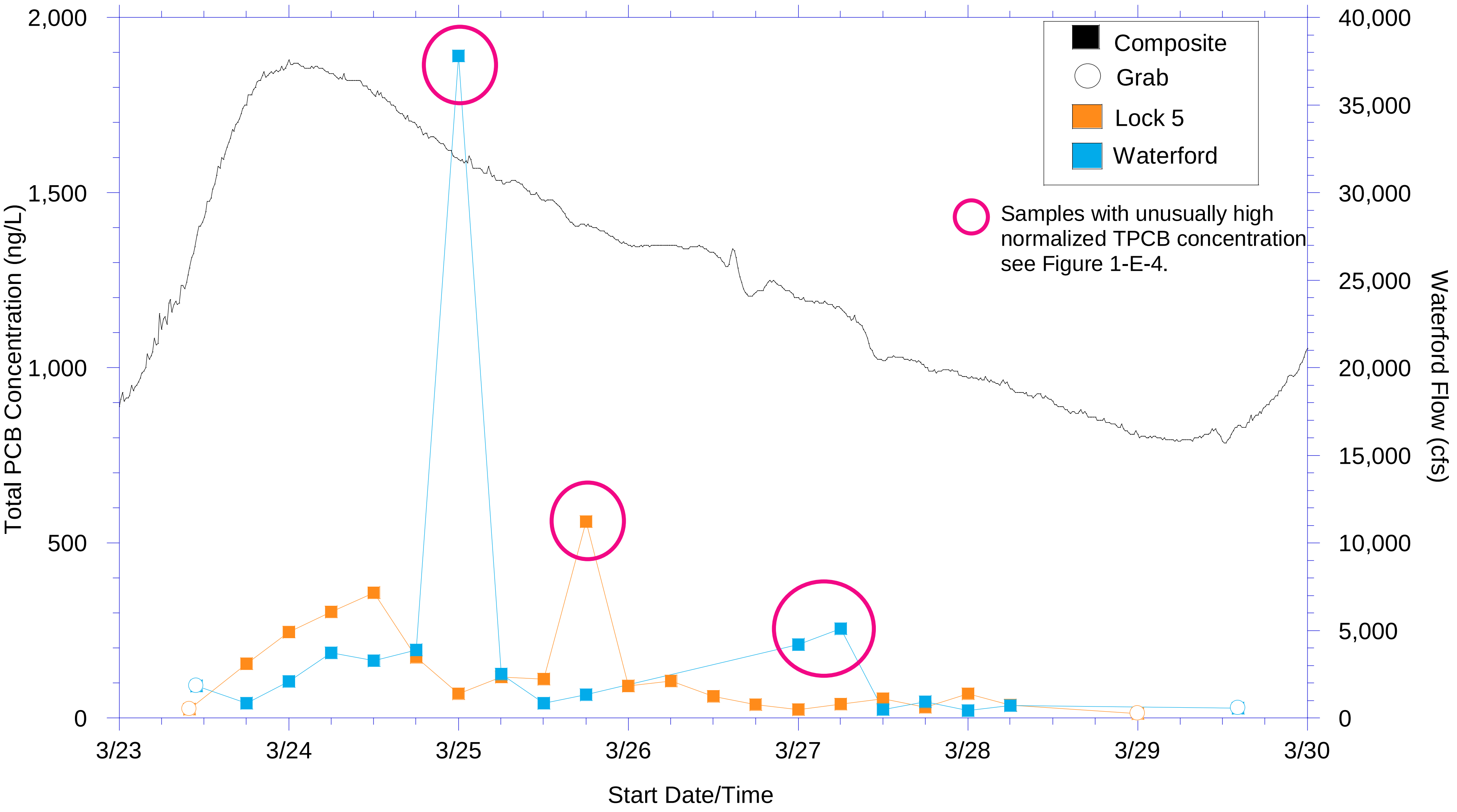


Thompson Island and Lock 5 Total PCB Concentration and Fort Edward Flow vs. Date

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-5a

April 2010

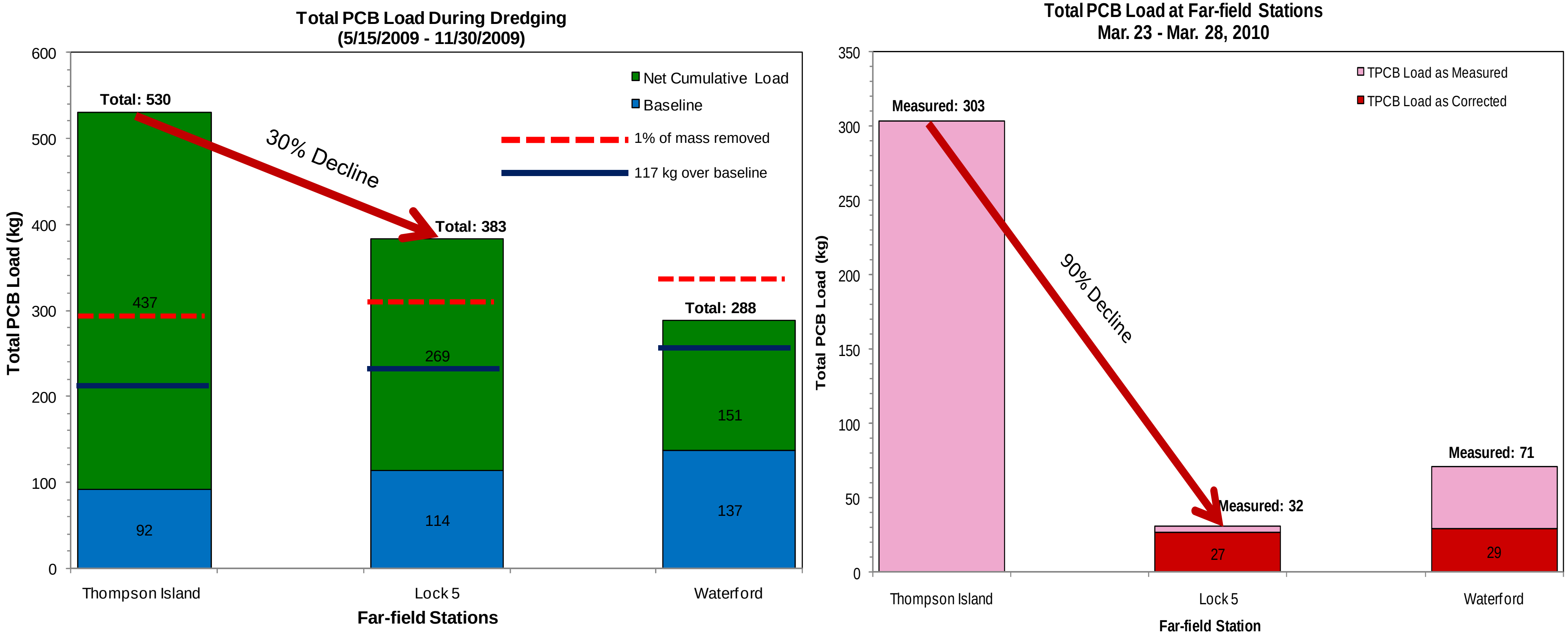


Lock 5 and Waterford Total PCB Concentration and Fort Edward Flow vs. Date

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-5b

April 2010

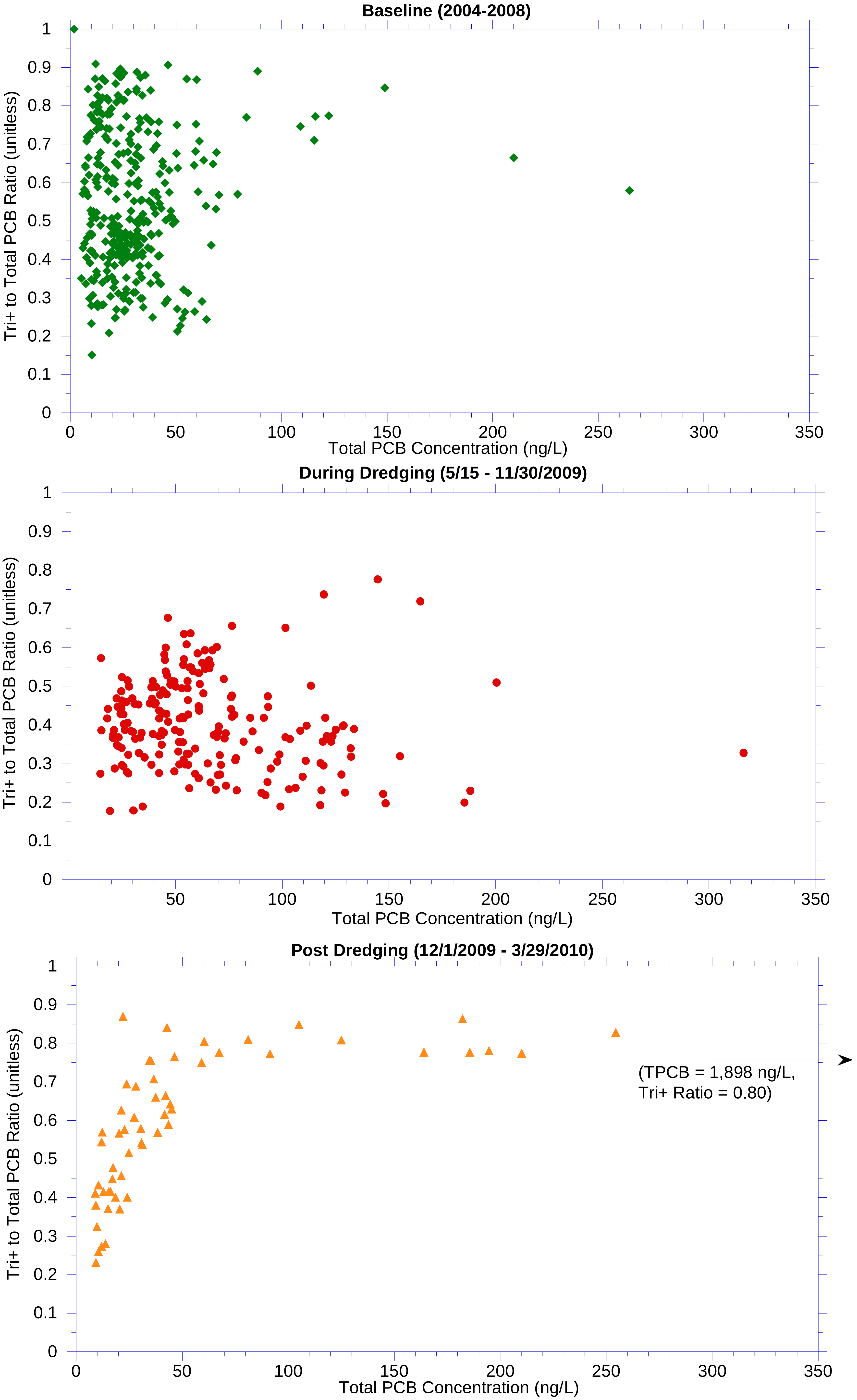


Comparison of Total PCB Load During Dredging vs. Post Dredging

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-A-6

April 2010



Tri+ to Total PCB Ratio vs. Total PCB Concentration
at Waterford Station

EPA Phase 1 Evaluation Report - Addendum - Hudson River PCBs Site

Figure 1-A-7

April 2010

TOPIC 1-B

NEAR-FIELD PCB RELEASE MECHANISM STUDY

Topic 1-B - Near-Field PCB Release Mechanism Study

1-B.1. Objectives and Field Implementation

The Near-Field PCB Release Mechanism Study was conducted by GE to assess the nature of the primary release mechanism in the vicinity of dredging operations. The Data Quality Objectives (DQOs) of this study were to evaluate the extent to which the PCBs released by remedial operations are dissolved or associated with suspended matter and to determine whether near-field TSS concentrations can be a reliable indicator of PCB releases. This study is described in the Remedial Action Monitoring Plan Quality Assurance Project Plan (RAM QAPP; GE, 2009). The RAM QAPP specified that the near-field PCB release mechanism study was to be conducted in five areas so that a range of dredging conditions could be evaluated, including: different sediment types (cohesive and non-cohesive), sediment PCB concentration ranges, and the range of anticipated dredge types). However, due to project logistics, dredging was not performed in four of the five areas designated in the RAM QAPP for this study. As a result, the study was conducted only in the East Griffin Island Area (EGIA).

Dissolved and particulate samples were collected in the following locations in the vicinity of EGIA dredging activities.

- EGIA100M-UP (point; 100 m upstream of the dredging operation)
- EGIA30M-DN (transect; 30 m downstream of the dredging operation)
- EGIA100M-DN (transect; 100 m downstream of the dredging operation)
- EGIA300M-DN (transect; 300 m downstream of the dredging operation)

Monitoring locations are shown on Figure 1-B-1.

Water samples were filtered in the field at the time of collection, and the filters and the filtered water submitted for analysis (GE, 2010).

1-B.2. Nature of PCB Release

Based on the results obtained from study, both EPA and GE in their March 2010 reports observed that PCBs in the water column were predominantly in the dissolved form, averaging over 90% of the total PCBs (Table 1-B-1). Furthermore, the dissolved PCB fraction was dominated by mono- and di- chlorinated congeners, while the particulate fraction is dominated by tri- and tetra-chlorinated congeners (EPA, 2010 and GE, 2010).

In addition, PCB-bearing oils were also released during dredging. This NAPL was observed as small droplets of oil in the river downstream of the dredging operation and sheens occurred frequently in the ERI and EGIA. Sheens were sampled on several occasions to assess PCB concentrations. Duplicate samples showed large disparities probably due to variability in sheen thickness and surface coverage and the amount of underlying water in the sample. However, the oils were not isolated for analysis such that a specific congener pattern could be identified. EPA believes that the presence of oil was partially responsible for the high degree of variability observed in sample replicates when concentrations of PCBs in river water approached the 500 ng/L threshold. GE has argued that the filters would have removed the oils and that they did not see much oily sediment in the processing facility.

GE has assumed that the oil droplets would be trapped on the filter when samples are filtered for dissolved and particulate PCB analysis and that they would primarily influence the measurement of particulate PCBs. Based on this assumption GE has concluded that an oil phase can at most account for a minority of the PCBs measured at the far-field stations. However, this assumption is not valid because such filters are not designed to retain liquids and the size (longest dimension) of a typical PCB molecule with at least two chlorine atoms in meta- or ortho-substitution positions is approximately 1.1 nanometers whereas the nominal pore size (diameter of opening) for such filters is approximately 700 nm. The PCB-bearing oils will pass through the filter and will become part of the dissolved PCBs sample and may in fact account for a significant portion of the PCBs measured at far-field stations.

1-B.3. Use of TSS as an Indicator of PCB Releases

As stated above, one of the DQOs of this study was to determine whether or not near-field TSS concentrations are a reliable indicator of PCB releases in the vicinity of remedial operations. For the impact of dredging on a particular parameter to be assessed, it must first be shown that variation in the parameter can be attributed to dredging. Evaluation of the PCB and TSS data collected by GE on July 14, 15, and 17, 2009 at EGIA near-field stations indicates that the release due to dredging at the time of sample collection cannot be accurately quantified.

In order to show that variation in PCB and TSS concentration is due to dredging, the same parcel of water must be sampled at each near-field location, beginning with the upstream station (*i.e.*, EGIA100M-UP) and ending with the southernmost transect (*i.e.*, EGIA300M-DN). Using daily velocities obtained from GE for the study area, approximate travel times were estimated between each station on July 14, 2009 as follows:

- EGIA100M-UP to EGIA30M-DN: 36 min
- EGIA30M-DN to EGIA100M-DN: 9 min
- EGIA100M-DN to EGIA300M-DN: 12 min

The travel times on July 15 and July 17, 2009 were similar to those calculated for July 14, 2009. All calculated average velocities and travel times are shown on Table 1-B-2.

Examination of GE sample times on these dates showed that water samples were not collected on the above schedule. The approximate time between GE sample collection events on July 14, 2009 were as follows:

- EGIA100M-UP and EGIA30M-DN: 4 hrs
- EGIA30M-DN and EGIA100M-DN: 2 hrs
- EGIA100M-DN and EGIA300M-DN: 1 hr

All GE sample collection times and differences are shown on Table 1-B-1. The lag in sample collection times between the EGIA100M-UP and EGIA30M-DN and EGIA30M-DN and EGIA100M-DN did reduce on July 15 and 17, 2009, but only to approximately 1 hour between samples – a value still nearly double the calculated travel time between the EGIA100M-UP and EGIA30M-DN stations and 5-6 times greater than the travel times between the other stations. This information is summarized below. As the GE samples do not represent values obtained from the same parcel of water as it moves downstream, the total and dissolved phase concentrations obtained at each station cannot be compared to evaluate PCB releases due to dredging. Dissolved phase concentrations and total PCB concentrations change rapidly in the near-field because of the dynamic nature of the dredging operation and related activities. Therefore, the importance of collecting a sample from the same parcel of water as it travels downstream cannot be overemphasized.

Comparison of Travel Time and Sampling Interval for Near-field Release Mechanism Study

Station	July 14, 2009		July 15, 2009		July 17, 2009	
	Travel Time (minutes)	Interval between samples (minutes)	Travel Time (minutes)	Interval between samples (minutes)	Travel Time (minutes)	Interval between samples (minutes)
EGIA100M-UP to EGIA30M-DN	36	226	36	62	46	80
EGIA30M-DN to EGIA100M-DN	9	123	9	62	11	70
EGIA100M-DN to EGIA300M-DN	12	65	12	62	15	72

Further, the samples were collected slowly, over a one-hour period of time, further compounding the discrepancy between the actual travel time between stations and the time of GE sample collection. For example, in order to capture the same parcel of water at both the EGIA100M-UP and EGIA30M-DN stations, the timing of sample collection at both stations would need to overlap, with collection EGIA30M-DN starting approximately 36 minutes after initiation of collection at the EGIA100M-UP sample. Addition of the single hour between sample collection events achieved on July 15 and 17, 2009 places the initiation of collection at the EGIA30M-DN station approximately 30 minutes after the last of the 1-hour parcel of water sampled at EGIA100M-UP has already passed.

This conclusion is further supported by the actual TSS and dissolved and particulate phase PCB concentrations measured on July 14, 15, and 17, 2009. Neither TSS nor dissolved or particulate PCB concentrations collected downstream of the dredging operation show trends of consistency between sampling locations. TSS concentrations measured on July 14, 2009 fluctuated between stations, increasing from 1.1 mg/L at the EGIA100M-UP station to 5 mg/L at the EGIA30M-DN station and then declining to 1.4 mg/L at the EGIA100M-DN station, a value similar to that observed upstream of dredging. TSS concentrations then increased again, reaching 2.4 mg/L at the EGIA300M-DN station.

On July 15 and 17, 2009, TSS levels did increase in the downstream direction. However, on July 15, 2009 the total gain in TSS between the EGIA100M-UP and EGIA300M-DN stations was 1 mg/L. On July 17, 2009, the total gain between those locations was 5.6 mg/L. It would be expected that other factors (such as river flows, effectiveness of resuspension controls, dredging cycle times, presence of debris, proper bucket closure, boat traffic, and release of bucket decant water) being the same, the largest increase in TSS above upstream levels would correspond to the date with the greatest removal volume of sediments. This was not the case for this subset of days. Approximately 890 CY of sediment was removed from CU-17 on July 14, 2009, 456 CY on July 15, 2009, and approximately 370 CY on July 17, 2009.

Dissolved phase PCB concentrations also fluctuated between stations on July 14, 2009, increasing from 248 ng/L at the EGIA100M-UP station to 1,568 ng/L at the EGIA30M-DN station, and then declining to 253 ng/L at the EGIA100M-DN station, a value similar to that observed upstream of dredging. Dissolved phase PCB concentrations then increased again, reaching 813 ng/L at the EGIA300M-DN station. PCB concentrations observed on July 15, 2009 displayed a similar pattern with concentrations of 448 ng/L, 1070 ng/L, 964 ng/L, and 1355 ng/L measured from the northernmost to southernmost monitoring locations.

Dissolved phase PCB concentrations measured on July 17, 2009 increased from upstream of dredging to downstream of dredging, with values of 839 ng/L, 973 ng/L, 3970 ng/L, and 8,220 ng/L from the northernmost to southernmost stations, respectively. Dissolved phase PCB concentrations change rapidly in the near-field because of the dynamic nature of the dredging operation and related activities. Therefore, the importance of collecting a sample from the same parcel of water as it travels downstream cannot be overemphasized. Further, results of some of the downstream dissolved phase samples may have been affected by the oil sheens that were observed near CU-18.

Particulate phase PCB concentration patterns observed on July 14, 15, and 17, 2009 were similar to those displayed by the dissolved phase. Particulate phase results from July 14 and 15, 2009 fluctuated in the downstream direction, with respective station PCB concentrations of 10.9 ng/L, 182 ng/L, 58 ng/L, and 95 ng/L observed on July 14, 2009 and 17 ng/L, 81 ng/L, 53 ng/L, and 98 ng/L measured on July 15, 2009. PCB concentrations generally increased in the downstream direction on July 17, 2009, with respective station values of 14 ng/L, 33 ng/L, 275 ng/L, and 220 ng/L.

It should be noted that the EGIA100M-UP station is a single node whereas all other stations are transects, with collection nodes spaced across the width of the river. Data obtained from transects at the top and bottom of the EGIA during the near-field transect study (described in GE Phase 1 Evaluation Report Section 5.1.1) indicate that constituent concentrations varied across the channel, both when the water entered the pool and when it left. This suggests that the river may not be mixed enough for a sample collected from a single node from EGIA100M-UP to be representative of baseline to the EGIA area.

1-B.4. Kinetics of PCB Release

GE has applied a two –phase equilibrium partitioning to the near-field release mechanism data and concluded that the partitioning behavior was similar to that observed under baseline conditions, indicating that there was no evidence of oil in the river. However this analysis cannot be supported because: 1) a two phase partitioning is not valid in the presence of NAPLs, and 2) the initial total mass of PCBs that released the PCBs to the dissolved phase is not known. The total amount of dissolved phase PCBs added to the water column due to dredging is equal to the sum of the following:

1. The resuspension and release from sediments at the dredged head

2. Release of pore water due to impact of the dredge bucket on the sediment surface (bottom disturbance), and
3. Any releases resulting from bucket decanting.

The presence of NAPL strongly suggests that the two phase partitioning model cannot be used to discern the dynamics of PCB release in the near-field. In general, PCB release to the dissolved phase is kinetically controlled because it takes longer for equilibrium partitioning to be achieved. It has been reported that PCB congeners containing up to four chlorines approach equilibrium within 6 weeks and congeners with greater than 6 chlorines may require months or years to reach equilibrium (Coates and Elzerman 1986).

1-B.5. Conclusion

The near-field observations indicate that PCBs were dominated by the dissolved phase component. Because the majority of the resuspended particles are deposited closer to the dredge head, the dissolved PCBs they release is a small component of the dissolved phase concentrations observed in the near-field water column. It is likely that the high dissolved phase concentrations observed are due to the presence of NAPLs, which were constantly reported in the EGIA area where the near-field release mechanism study was conducted.

References

Coates, J. T., and Elzerrnan, A. W. (1986). “Desorption kinetics for selected PCB congeners from river sediments,” Journal of Contaminant Hydrology 1, 191-210.

GE, 2009. Remedial Action Monitoring Quality Assurance Project Plan. Prepared for General Electric Company, Albany, NY by Anchor QEA, Environmental Standards, Inc, and Arcadis. May 2009.

GE, 2010. Phase 1 Evaluation Report. Prepared for General Electric Company, Albany, NY by Anchor QEA, LLC and Arcadis. March 2010.

EPA, 2010. Phase 1 Evaluation Report. Prepared for EPA Region 2 and USACE Kansas City District by The Louis Berger Group, Inc. March 2010.

Table 1-B-1
GE Sample Time Differences

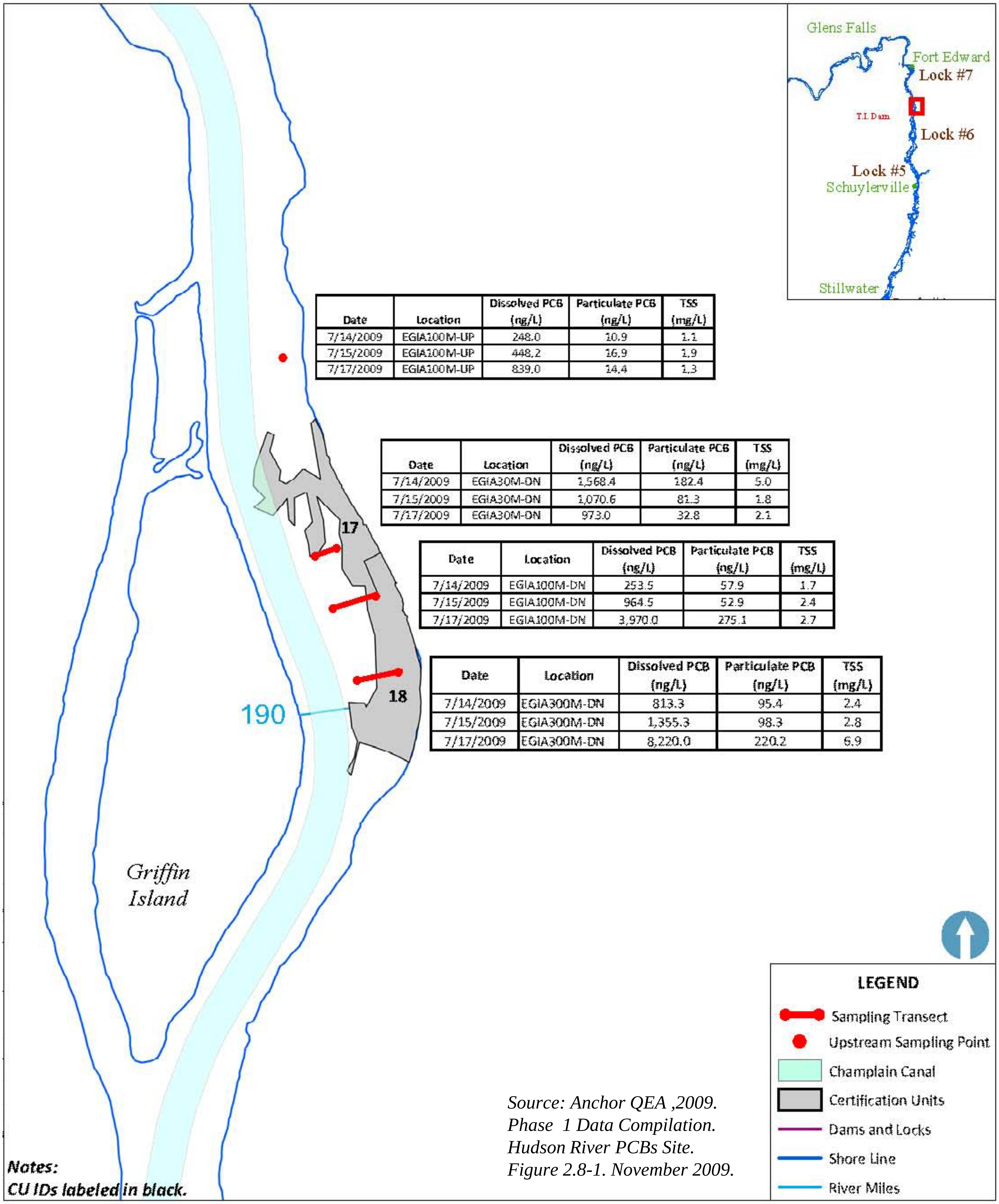
Station	Sample Collection Time 7/14/2009	Sample Collection Time 7/15/2009	Sample Collection Time 7/17/2009	Collection Time Difference 7/14/09	Collection Time Difference 7/15/09	Collection Time Difference 7/17/09
EGIA100M-UP	10:41	9:41	12:00			
EGIA30M-DN	14:27	10:43	13:20	3:46	1:02	1:20
EGIA100M-DN	16:30	11:45	14:30	2:03	1:02	1:10
EGIA300M-DN[1]	15:25	12:47	15:42	1:05	1:02	1:12

Notes:

1 - On July 14, the sample from EGIA300M-DN was collected before that obtained from EGIA100M-DN.

Table 1-B-2
Time of Travel for Near-Field PCB Release Mechanism
East Griffin Island Area

Location	Distance (m)	Average of Velocity (m/s) 7/14	Average of Velocity (m/s) 7/15	Average of Velocity (m/s) 7/17	Time of Travel (min)7/14	Time of Travel (min)7/15	Time of Travel (min)7/17
100 m up		0.164	0.163	0.126			
30 m down	350	0.194	0.193	0.151	35.57	35.79	46.30
100 m down	100	0.187	0.186	0.145	8.59	8.64	11.04
300 m down	133	0.148	0.147	0.114	11.86	11.93	15.26



Date	Location	Dissolved PCB (ng/L)	Particulate PCB (ng/L)	TSS (mg/L)
7/14/2009	EGIA100M-UP	248.0	10.9	1.1
7/15/2009	EGIA100M-UP	448.2	16.9	1.9
7/17/2009	EGIA100M-UP	839.0	14.4	1.3

Date	Location	Dissolved PCB (ng/L)	Particulate PCB (ng/L)	TSS (mg/L)
7/14/2009	EGIA30M-DN	1,568.4	182.4	5.0
7/15/2009	EGIA30M-DN	1,070.6	81.3	1.8
7/17/2009	EGIA30M-DN	973.0	32.8	2.1

Date	Location	Dissolved PCB (ng/L)	Particulate PCB (ng/L)	TSS (mg/L)
7/14/2009	EGIA100M-DN	253.5	57.9	1.7
7/15/2009	EGIA100M-DN	964.5	52.9	2.4
7/17/2009	EGIA100M-DN	3,970.0	275.1	2.7

Date	Location	Dissolved PCB (ng/L)	Particulate PCB (ng/L)	TSS (mg/L)
7/14/2009	EGIA300M-DN	813.3	95.4	2.4
7/15/2009	EGIA300M-DN	1,355.3	98.3	2.8
7/17/2009	EGIA300M-DN	8,220.0	220.2	6.9

LEGEND

- Sampling Transect
- ● Upstream Sampling Point
- 🟩 Champlain Canal
- ▨ Certification Units
- Dams and Locks
- Shore Line
- River Miles

Source: Anchor QEA ,2009.
Phase 1 Data Compilation.
Hudson River PCBs Site.
Figure 2.8-1. November 2009.

Notes:
CU IDs labeled in black.

Near- Field PCB Release Mechanism Study Results

EPA Phase 1 Evaluation Report –Addendum - Hudson River PCBs Site

Figure 1-B-1

April 2010

TOPIC 1-C

NEAR-FIELD PCB TRANSECT STUDY

Topic 1-C - Near-Field PCB Transect Study

During Phase 1 dredging, GE collected samples along transects in the near-field. Two types of near-field transects were collected. The first, which was associated with the near-field daily monitoring program, is turbidity/TSS transect studies, in which turbidity was monitored along transects located upstream, adjacent to, and downstream of dredging operations. TSS was measured at the point of maximum turbidity within each transect. The second type of transect studies, called PCB transect studies, consisted of PCB monitoring along transects perpendicular to river flow during May, July, August, and September 2009 as described in the Phase 1 Data Compilation report (GE 2009). While these transects represent instantaneous observations in a very dynamic near-field area, and mostly did not follow a time of travel sampling approach, GE has used the PCB transects results to determine load gains and losses, compared them to 24-hour composite loads calculated in the far-field, and made inferences about the redistribution of PCBs downstream of dredging. Based on GE's analysis (GE, 2010) they concluded that:

- PCBs were lost between the Rogers Island and EGIA dredging areas and the Thompson Island Dam far-field station, with average declines in concentration of 0.5 kg/day between Rogers Island and the Thompson Island Dam and 1.4 kg/day between the EGIA and the Thompson Island Dam, for a total of 1.9 kg of PCBs lost per day.
- The decline lessened between Lock 7 and just upstream of CU-17 over the course of the transect studies, possibly reflecting a growing contribution to the river from re-suspended sediments which had deposited in the Thompson Island Pool. The impact of re-distributed sediments is also demonstrated in the increase in PCB loads through the Thompson Island Pool measured during the August 10, 2009 sampling event, conducted while there was no dredging. The percentage of PCBs released by dredging operations that did not reach the Thompson Island station could actually be higher because losses may have been partially masked by PCB releases from re-distributed sediments (GE, 2010).

Because the data collected and used to develop the above conclusions regarding load was collected in the near field and is thus highly dependent on several different factors at any time during the day, it is viewed by the EPA as instantaneous. Collection of an instantaneous sample within a plume is dependent of conditions upstream at the dredge head, including time of travel, bucket decant, presence of NAPL, and the closure or non-closure of the dredge bucket due to debris. These conditions vary in the near field suggesting that the transect results are subject to high variability and uncertainty. The objective of this section is to present evidence that supports the instantaneous and highly variable nature of these transects and while useful, they should be used with considerable caution when generalized over the dredging period.

1-C.1. Comparison of Transect and Buoy TSS Measurements

In order to determine if instantaneous data could be used to give a reasonable picture of daily load, TSS concentrations obtained from samples collected in the morning were compared to those measured in samples collected during the afternoon during the twice daily turbidity transect observations in the near-field. Samples obtained from the Lock 7 and West Rogers Island transects identified below were used in the analysis:

- 100 m upstream
- 10m side channel
- 100 m downstream
- 300m downstream

One set of paired data from each transect was analyzed from Lock 7, and four sets from each transect were analyzed from the West Channel of Rogers Island. The comparison, shown on Figures 1-C-1a through 1-C-1e, shows that the morning and afternoon concentrations are not consistent, indicating that there is too much variability inherent in these measurements in order for them to be used to represent load for an entire day.

This conclusion is further supported by comparison of transect and buoy data from Lock 7 (100 m upstream and 300 m downstream), the West Channel of Rogers Island (100 m upstream and 300 m downstream), and the East Channel of Rogers Island (downstream). The TSS concentrations measured in the transect samples and buoy samples were also dissimilar; in most cases, the transect TSS values exceeded those observed in the buoy samples, indicating that the transect values may overestimate the amount of suspended solids in the water column. Comparison of transect and buoy results is shown on Figures 1-C-2a through 1-C-2f.

1-C.2. TSS Loading

Examination of TSS loads calculated using transect and buoy results for both the Rogers Island area and the EGIA further support the conclusion that the near-field transects data in the water column are highly variable. Comparisons of these loads are presented on Figures 1-C-3 and 1-C-4, respectively. In the Rogers Island area, the TSS loads yielded by the transect data and buoy data are similar during the time period of May 2009 through the beginning of October 2009, with the exception of several instances of elevated load in the middle to the end of August 2009 based on the buoy TSS results. In approximately the middle of October 2009, the TSS loads diverge, with the transect loads exceeding the buoy loads in the majority of instances (Figure 1-C-3).

In the EGIA, TSS loads were calculated for transect and buoy data on the following dates:

- July 23, 2009
- August 12, 2009
- August 14, 2009
- August 17, 2009
- August 22, 2009

Comparison of transect and buoy TSS loads for these dates indicates that for all dates but August 14 and August 22, 2009, the loads obtained using transect data exceeded those developed with the buoy data. In the cases of July 23 and August 17, 2009, the discrepancy was more significant for either the upstream or downstream load comparison, or for both.

On July 23, 2009, the upstream transect loads were approximately 40 tons/day, a value 5 times greater than the upstream buoy load of approximately 8 tons/day. The downstream transect load, approximately 40 tons/day, was 5 times greater than the downstream east and west buoys loads, also approximately 8 tons/day, and approximately 3 times greater than that (approximately 12 tons/day) calculated based on the 100 m downstream buoy data. On August 17, 2009, the TSS load obtained from the upstream transect data was approximately 100 tons/day, a value approximately 7 times greater than the 15 tons/day calculated based on the upstream buoy. The discrepancies between the loads based on the downstream transect data and those developed using the downstream east and downstream west buoys were less pronounced, exceeding by only 1 to 2 times. The TSS load calculated using data from the 100 m downstream buoy was of a similar magnitude. Comparisons of loads for all dates are shown on Figure 1-C-4. During these transect studies, the propeller wash of the sampling boat induced resuspension may have compromised the evaluation of TSS load changes between Rogers Island and East Griffin Island. In Section 5.1.1.2 of the GE Phase 1 Evaluation Report (GE, 2010), GE also attributes the increases in TSS to sediment resuspension caused by operation of the sampling vessel in very shallow water.

1-C.3. Instantaneous PCB Loading

Analysis of PCB load data developed using transect study data indicated that loads were not uniform across transects. For example, the loads calculated for each node sampled along the WRI transect on May 26, 2009 ranged from 14 to 651 g/day, with the smallest load observed at Node # 8 (see Figure I-4-2 in EPA's Phase 1 Evaluation Report [EPA, 2010] and Figure 2.8-15 in GE's Phase 1 Data Compilation Report [GE, 2009]), closest to the west bank of Rogers Island (also the eastern most node). The loads calculated along the ERI transect on that date ranged from 6 to 17 g/day, with the smallest load observed at Node #4, one node west of that closest to the east bank of the river. While there was no pattern of consistent increase or decline in either direction along the WRI and ERI transects, in both instances, the highest loads were present at the westernmost and central nodes. The loads calculated along the NTIP transect on that date ranged from 24 to 149 g/day, with the smallest load observed at Node # 1, located closest to the east bank of the river. In this case, the highest loads were present at the central nodes and eastern nodes. The variability in concentrations between transect nodes suggests that equal volume compositing, done at some stations during the May 2009 transect studies, are likely biased. In Section 5.1.1.2 of the GE Phase 1 Evaluation Report (GE, 2010), GE has also acknowledged that the transect results may be biased high due to the sampling technique, which included using equal volumes from five nodes across the river to form a single composite sample when the hydrologic data collected in May 2009 from this area showed that the westernmost node represents only one percent of the total flow of the river. This uncertainty strongly indicates that the transect data must be interpreted with due caution as the lack of mixing along the cross section might be obscured if equal aliquots are taken to form a sample as was done for the NTIP transect.

Loads calculated along the EGIA-Down transect on July 23, 2009 ranged from 214 to 2406 g/day, with the smallest load observed at Node # 1, closest to the west bank of the river. In this instance, the highest loads were observed in the central nodes. During the July 2009 transect studies, because of variability in flow, and uncertainties related to differences in time of travel, sample compositing, the analytical measurements and presence of NAPL, instantaneous load differences of about 12 mg/second cannot be discerned as being significant (see Section I-4.2.1 in EPA's Phase 1 Evaluation Report (EPA, 2010).

Transect loads are presented in Table 1-C-1.

1-C.4. Daily PCB Loading

Daily PCB loads were calculated based on instantaneous transect PCB data for the following stations:

- North WRI
- WRI
- North ERI
- ERI
- NTIP
- EGIA-Up
- EGIA-Curtain
- EGIA-Down

Analysis of the loads observed at these stations (not including the EGIA-Curtain, as it is located inside the silt curtain and may not be representative of river conditions) indicated a general increase in PCB loading in the downstream direction. Examination of daily loads on the dates where transect sampling was performed in both the Rogers Island Area and EGIA (shown on Figure 1-C-5) indicated that maximum daily PCB loads were generally observed at the NTIP transect, with approximate values of 1500 g/day on 8/10/09, 4000 g/day on 8/14/09, and 2600 g/day at 8/17/09, and at the EGIA-Down transect, with approximate values of 1300 g/day on 8/12/09, 3000 g/day on 8/22/09, and 2800 g/day on 10/21/09. During the August 2009 transect studies, the propeller wash of the sampling boat induced resuspension which may have compromised the evaluation of PCB load changes between Rogers Island and East Griffin Island since this may be a factor even when TSS differences do not appear to be large. In Section 5.1.1.2 of the GE Phase 1 Evaluation Report (GE, 2010), GE also attributes the increases in TSS to sediment resuspension caused by operation of the sampling vessel in very shallow water. In the 8/14/09 sampling event, a load loss occurred between the EGI-Up and EGI-Down transects, suggesting that uncertainties in these data and the daily variability in near-field concentrations preclude an assessment of whether the concentration and load differences are statistically significant. On 7/23/09, the maximum load of approximately 9,000 g/day was observed at the EGIA-Up transect. The corresponding load at the EGIA-Down transect for that date was approximately 7,500 g/day. Another point worth noting is that for the July 2009 transect studies, the sampling event conducted by GE started at the EGIA-Down transect and proceeded towards the EGIA-Up transect. The time of travel approach was not followed.

Though there are no calculations of PCB load based on buoy results to compare to those obtained using the transect results, the conclusion stated above for TSS loads applies here, as well. The inherent variability in the near-field precludes the use of instantaneous measurements to evaluate PCB load added to the water column due to dredging.

1-C.5. Summary

The above analysis strongly suggests that the near-field area is highly dynamic and instantaneous measurements should be treated as such because they represent a snap shot at the time of collection. While the PCB transects do shed light on the nature of the near-field PCBs, in terms of dissolved and particulate phases, uncertainties related to this data indicate caution in generalizing their meaning. GE relies on instantaneous measurements that are representative of a snapshot to calculate daily PCB and TSS loads and then bases further analysis for the entire dredging period on such calculations. Such conclusions are not valid for the intended purpose of the data.

References

GE, 2009. Phase 1 Data Compilation Report. Prepared for General Electric Company, Albany, NY, by Anchor QEA, LLC. November 2009.

GE, 2010. Phase 1 Evaluation Report. Prepared for General Electric Company, Albany, NY by Anchor QEA, LLC and Arcadis. March 2010.

Table 1-C-1
PCB Transect Study Loading Analysis

Location [1]	Date	Total PCB (ng/L)[2]	Diss. PCB (ng/L)[2]	% Diss. PCB [3]	Part. PCB (mg/kg)	TSS (mg/L)	Mean USGS Flow at Fort Edward During Sampling (cfs)	% Flow per Transect Node	Flow Factor	Node or Transect Flow (cfs)	PCB Loading (g/day)
WRI-1	5/22/2009	853.0	487.0	57.1	26.0	14.1	8993	3.9	0.96	334	696
WRI-2	5/22/2009	1284.0	310.9	24.2	31.4	31.0	8993	8.1	0.96	704	2212
WRI-3	5/22/2009	541.9	121.7	22.5	30.7	13.7	8993	9.8	0.96	850	1126
WRI-4	5/22/2009	47.0	25.5	54.3	3.4	6.4	8993	17.5	0.96	1516	174
WRI-5	5/22/2009	32.4	11.1	34.3	5.1	4.2	8993	21.6	0.96	1871	148
WRI-6	5/22/2009	6.9	19.1	100.0	--[4]	4.2	8993	15.6	0.96	1348	23
WRI-7	5/22/2009	11.8	15.8	100.0	--[4]	4.9	8993	15.5	0.96	1338	39
WRI-8	5/22/2009	3.2	20.9	100.0	--[4]	3.8	8993	8.0	0.96	696	5
ERI-1	5/22/2009	189.6	154.0	81.2	9.5	3.7	9340	28.0	0.04	98	45
ERI-2	5/22/2009	202.4	151.0	74.6	18.9	2.7	9340	22.1	0.04	77	38
ERI-3	5/22/2009	199.8	146.0	73.1	17.2	3.1	9340	26.5	0.04	93	45
ERI-4	5/22/2009	192.0	167.2	87.1	8.1	3.1	9340	9.8	0.04	34	16
ERI-5	5/22/2009	242.5	161.0	66.4	19.6	4.2	9340	13.6	0.04	48	28
NTIP-1	5/22/2009	177.2	161.0	90.9	3.9	4.1	8890	1.1	1.0	97	42
NTIP-2	5/22/2009	160.9	87.8	54.6	21.2	3.5	8890	6.4	1.0	572	225
NTIP-3	5/22/2009	79.9	74.1	92.7	1.4	4.1	8890	22.6	1.0	2010	393
NTIP-4	5/22/2009	35.0	45.7	100.0	--[4]	3.6	8890	40.3	1.0	3579	306
NTIP-5	5/22/2009	54.2	24.2	44.6	8.0	3.8	8890	29.6	1.0	2631	348
WRI-1	5/25/2009	92.2	NA	--	--	1.3	6900	3.9	0.96	256	58
WRI-2	5/25/2009	54.9	NA	--	--	1.4	6900	8.1	0.96	540	73
WRI-3	5/25/2009	3.0	NA	--	--	1.2	6900	9.8	0.96	652	5
WRI-4	5/25/2009	19.0	NA	--	--	1.2	6900	17.5	0.96	1163	54
WRI-5	5/25/2009	14.7	NA	--	--	1.2	6900	21.6	0.96	1435	52
WRI-6	5/25/2009	3.0	NA	--	--	1.4	6900	15.6	0.96	1035	8
WRI-7	5/25/2009	3.2	NA	--	--	1.2	6900	15.5	0.96	1026	8
WRI-8	5/25/2009	15.8	NA	--	--	1.7	6900	8.0	0.96	534	21
ERI-1	5/25/2009	53.3	NA	--	--	1.1	7647	28.0	0.04	80	10
ERI-2	5/25/2009	71.3	NA	--	--	1.2	7647	22.1	0.04	63	11
ERI-3	5/25/2009	79.0	NA	--	--	1.4	7647	26.5	0.04	76	15
ERI-4	5/25/2009	74.9	NA	--	--	2.7	7647	9.8	0.04	28	5
ERI-5	5/25/2009	66.8	NA	--	--	1.5	7647	13.6	0.04	39	6
NTIP-1	5/25/2009	57.4	NA	--	--	2.0	6750	1.1	1.0	74	10
NTIP-2	5/25/2009	44.6	NA	--	--	1.3	6750	6.4	1.0	434	47
NTIP-3	5/25/2009	35.1	NA	--	--	1.4	6750	22.6	1.0	1526	131
NTIP-4	5/25/2009	16.8	NA	--	--	1.6	6750	40.3	1.0	2718	112
NTIP-5	5/25/2009	8.2	NA	--	--	1.5	6750	29.6	1.0	1998	40
WRI-1	5/26/2009	429.7	NA	--	--	7.2	8276	3.9	0.96	307	322
WRI-2	5/26/2009	410.4	NA	--	--	8.9	8276	8.1	0.96	648	651
WRI-3	5/26/2009	221.4	NA	--	--	5.8	8276	9.8	0.96	782	423
WRI-4	5/26/2009	155.6	NA	--	--	4.1	8276	17.5	0.96	1395	531
WRI-5	5/26/2009	36.5	NA	--	--	3.0	8276	21.6	0.96	1721	154
WRI-6	5/26/2009	69.1	NA	--	--	4.1	8276	15.6	0.96	1241	210
WRI-7	5/26/2009	18.8	NA	--	--	3.2	8276	15.5	0.96	1231	57
WRI-8	5/26/2009	9.1	NA	--	--	3.6	8276	8.0	0.96	641	14
ERI-1	5/26/2009	94.7	NA	--	--	1.2	6849	28.0	0.04	72	17
ERI-2	5/26/2009	94.1	NA	--	--	1.2	6849	22.1	0.04	57	13
ERI-3	5/26/2009	88.8	NA	--	--	1.3	6849	26.5	0.04	68	15
ERI-4	5/26/2009	100.3	NA	--	--	1.5	6849	9.8	0.04	25	6
ERI-5	5/26/2009	96.0	NA	--	--	1.2	6849	13.6	0.04	35	8
NTIP-1	5/26/2009	133.8	NA	--	--	2.2	6753	1.1	1.0	74	24
NTIP-2	5/26/2009	75.2	NA	--	--	2.0	6753	6.4	1.0	435	80
NTIP-3	5/26/2009	39.8	NA	--	--	1.6	6753	22.6	1.0	1527	149
NTIP-4	5/26/2009	16.0	NA	--	--	1.7	6753	40.3	1.0	2719	106
NTIP-5	5/26/2009	29.4	NA	--	--	1.9	6753	29.6	1.0	1999	144
WRI-1	5/28/2009	1620.0	NA	--	--	7.3	5975	3.9	0.96	222	878
WRI-2	5/28/2009	1542.8	NA	--	--	7.9	5975	8.1	0.96	468	1766
WRI-3	5/28/2009	494.5	NA	--	--	4.0	5975	9.8	0.96	565	683
WRI-4	5/28/2009	192.4	NA	--	--	2.3	5975	17.5	0.96	1007	474
WRI-5	5/28/2009	83.9	NA	--	--	1.8	5975	21.6	0.96	1243	255

Table 1-C-1
PCB Transect Study Loading Analysis

Location (1)	Date	Total PCB (ng/L)(2)	Diss. PCB (ng/L)(2)	% Diss. PCB (3)	Part. PCB (mg/kg)	TSS (mg/L)	Mean USGS Flow at Fort Edward During Sampling (cfs)	% Flow per Transect Node	Flow Factor	Node or Transect Flow (cfs)	PCB Loading (g/day)
WRI-6	5/28/2009	11.8	NA	--	--	1.6	5975	15.6	0.96	896	26
WRI-7	5/28/2009	3.0	NA	--	--	1.8	5975	15.5	0.96	889	7
WRI-8	5/28/2009	9.1	NA	--	--	1.8	5975	8.0	0.96	462	10
ERI-1	5/28/2009	3000.0	NA	--	--	9.6	3860	28.0	0.04	40	296
ERI-2	5/28/2009	3070.0	NA	--	--	8.2	3860	22.1	0.04	32	240
ERI-3	5/28/2009	5098.0	NA	--	--	8.5	3860	26.5	0.04	38	477
ERI-4	5/28/2009	4127.0	NA	--	--	7.8	3860	9.8	0.04	14	143
ERI-5	5/28/2009	4920.0	NA	--	--	7.9	3860	13.6	0.04	20	237
NTIP-1	5/28/2009	360.0	NA	--	--	2.1	7478	1.1	1.0	82	72
NTIP-2	5/28/2009	361.0	NA	--	--	2.5	7478	6.4	1.0	481	425
NTIP-3	5/28/2009	431.9	NA	--	--	2.9	7478	22.6	1.0	1691	1785
NTIP-4	5/28/2009	204.8	NA	--	--	2.1	7478	40.3	1.0	3011	1508
NTIP-5	5/28/2009	230.9	NA	--	--	2.5	7478	29.6	1.0	2213	1250
WRI-1	7/23/2009	1208.1	777.2	64.3	93.1	4.6	6085	20	0.96	1171	3460
WRI-2	7/23/2009	229.0	214.5	93.6	7.4	2.0	6085	20	0.96	1171	656
WRI-3	7/23/2009	127.2	55.4	43.5	21.3	3.4	6085	20	0.96	1171	364
WRI-4	7/23/2009	384.5	238.5	62.0	60.6	2.4	6085	20	0.96	1171	1101
WRI-5	7/23/2009	369.6	317.7	86.0	38.1	1.4	6085	20	0.96	1171	1059
ERI-Comp.	7/23/2009	6678.2	5141.7	77.0	113.0	13.6	6070	100	0.04	227	3707
NTIP-Comp.	7/23/2009	590.9	548.0	92.7	16.3	2.6	5930	100	1.0	5930	8568
EGIA-Up	7/23/2009	623.1	523.9	84.1	31.3	3.2	5930	100	1.0	5930	9034
EGIA - Inside Sheeting	7/23/2009	21687.5	9464.7	43.6	745.3	16.4	--	--	--	--	--
EGIA-DS of Sheeting - 1	7/23/2009	611.1	545.8	89.3	18.3	3.6	5953	20	1.0	1191	1779
EGIA-DS of Sheeting - 2	7/23/2009	623.7	481.8	77.2	44.9	3.2	5953	20	1.0	1191	1816
EGIA-DS of Sheeting - 3	7/23/2009	682.1	551.4	80.8	55.1	2.4	5953	20	1.0	1191	1986
EGIA-DS of Sheeting - 4	7/23/2009	672.7	587.4	87.3	50.2	1.7	5953	20	1.0	1191	1958
EGIA-DS of Sheeting - 5	7/23/2009	928.7	651.9	70.2	63.8	4.3	5953	20	1.0	1191	2703
EGIA-Down-1	7/23/2009	564.2	518.6	91.9	14.2	3.2	5176	3	1.0	155	214
EGIA-Down-2	7/23/2009	592.3	459.0	77.5	41.8	3.2	5176	26	1.0	1346	1949
EGIA-Down-3	7/23/2009	528.1	461.8	87.4	19.1	3.5	5176	36	1.0	1863	2406
EGIA-Down-4	7/23/2009	648.7	535.1	82.5	31.5	3.6	5176	27	1.0	1398	2217
EGIA-Down-5	7/23/2009	752.7	705.2	93.7	25.6	1.9	5176	8	1.0	414	762
TI Stilling Well Grab	7/23/2009	366.2	320.4	87.5	17.6	2.6	--	--	--	--	--
WRI-North	8/10/2009	5.6	4.6	81.3	0.8	1.4	7269.0	100	0.96	6997	96
WRI-Comp.	8/10/2009	33.0	28.4	86.1	2.6	1.8	7269.0	100	0.96	6997	564
ERI-North	8/11/2009	48.7	24.6	50.4	9.4	2.6	7269.0	100	0.04	272	32
ERI-Comp.	8/10/2009	186.9	127.0	68.0	3.1	19.2	7269.0	100	0.04	272	124
NTIP-Comp.	8/10/2009	82.0	25.6	31.3	9.8	5.7	7269.0	100	1.0	7269	1457
EGIA-Up	8/10/2009	48.4	31.6	65.3	6.0	2.8	7269.0	100	1.0	7269	860
EGIA - Inside Sheeting	8/10/2009	21692.1	14773.2	68.1	1438.4	4.8	7269.0	--	--	--	--
EGIA-DS of Sheeting	8/10/2009	71.5	56.2	78.6	6.0	2.6	7269.0	--	--	--	--
EGIA - Inside Silt Curtain	8/10/2009	86.8	58.2	67.0	14.5	2.0	7269.0	--	--	--	--
EGIA-Down-1	8/10/2009	44.0	38.4	87.4	2.9	1.9	7269.0	3	1.0	218	23
EGIA-Down-2	8/10/2009	43.1	31.0	72.0	5.2	2.3	7269.0	26	1.0	1890	199
EGIA-Down-3	8/10/2009	57.2	33.9	59.3	8.8	2.6	7269.0	36	1.0	2617	366
EGIA-Down-4	8/10/2009	62.7	41.5	66.2	8.7	2.4	7269.0	27	1.0	1963	301
EGIA-Down-5	8/10/2009	112.5	78.9	70.2	18.6	1.8	7269.0	8	1.0	582	160
WRI-North	8/12/2009	18.9	8.8	46.4	3.9	2.6	6767.0	100	0.96	6514	300
WRI-Comp.	8/12/2009	64.7	73.5	100.0	--(4)	3.1	6767.0	100	0.96	6514	1031
ERI-North	8/12/2009	234.3	85.1	36.3	14.9	10.0	6767.0	100	0.04	253	145
ERI-Comp.	8/12/2009	817.8	533.3	65.2	54.9	5.2	6767.0	100	0.04	253	506
NTIP-Comp.	8/12/2009	59.8	49.1	82.0	2.5	4.3	6767.0	100	1.0	6767	990
EGIA-Up	8/12/2009	74.9	73.9	98.6	0.5	2.3	6767.0	100	1.0	6767	1240
EGIA - Inside Sheeting	8/12/2009	26254.2	17210.0	65.6	611.1	14.8	6767.0	--	--	--	--
EGIA-Down-1	8/12/2009	77.1	64.0	83.1	5.0	2.6	6767.0	3	1.0	203	38
EGIA-Down-2	8/12/2009	71.3	45.4	63.7	9.6	2.7	6767.0	26	1.0	1759	307
EGIA-Down-3	8/12/2009	66.8	53.8	80.6	4.8	2.7	6767.0	36	1.0	2436	398
EGIA-Down-4	8/12/2009	85.3	79.6	93.4	2.7	2.1	6767.0	27	1.0	1827	381
EGIA-Down-5	8/12/2009	150.0	132.7	88.5	8.2	2.1	6767.0	8	1.0	541	199

Table 1-C-1
PCB Transect Study Loading Analysis

Location [1]	Date	Total PCB (ng/L)[2]	Diss. PCB (ng/L)[2]	% Diss. PCB [3]	Part. PCB (mg/kg)	TSS (mg/L)	Mean USGS Flow at Fort Edward During Sampling (cfs)	% Flow per Transect Node	Flow Factor	Node or Transect Flow (cfs)	PCB Loading (g/day)
WRI-North	8/14/2009	14.8	10.3	70.0	2.7	1.6	4044.0	100	0.96	3893	141
WRI-Comp.	8/14/2009	223.5	161.1	72.1	15.8	4.0	4044.0	100	0.96	3893	2127
ERI-North	8/14/2009	93.3	35.7	38.3	8.0	7.2	4044.0	100	0.04	151	35
ERI-Comp.	8/14/2009	3993.5	2277.1	57.0	195.9	8.8	4044.0	100	0.04	151	1477
NTIP-Comp.	8/14/2009	415.8	248.6	59.8	4.3	38.8	4044.0	100	1.0	4044	4112
EGIA-Up	8/14/2009	206.8	126.9	61.3	28.6	2.8	4044.0	100	1.0	4044	2045
EGIA - Inside Sheeting	8/14/2009	32038.6	16592.8	51.8	141.7	109.0	4044.0	--	--	--	--
EGIA-Down-1	8/14/2009	137.1	105.9	77.3	14.4	2.2	4044.0	3	1.0	121	41
EGIA-Down-2	8/14/2009	163.0	123.1	75.5	20.1	2.0	4044.0	26	1.0	1051	419
EGIA-Down-3	8/14/2009	173.0	117.6	68.0	22.9	2.4	4044.0	36	1.0	1456	616
EGIA-Down-4	8/14/2009	168.0	122.6	73.0	20.9	2.2	4044.0	27	1.0	1092	448
EGIA-Down-5	8/14/2009	197.6	137.1	69.4	21.2	2.9	4044.0	8	1.0	324	156
WRI-North	8/17/2009	140.6	67.8	48.2	25.8	2.8	3711.0	100	0.96	3572	1228
WRI-Comp.	8/17/2009	155.8	97.6	62.6	21.3	2.7	3711.0	100	0.96	3572	1361
ERI-North	8/17/2009	272.8	68.5	25.1	10.2	20.1	3711.0	100	0.04	139	93
ERI-Comp.	8/17/2009	1568.6	869.5	55.4	116.3	6.0	3711.0	100	0.04	139	532
NTIP-Comp.	8/17/2009	288.6	133.6	46.3	1.3	117.0	3711.0	100	1.0	3711	2618
EGIA-Up	8/17/2009	192.1	88.7	46.2	9.2	11.3	3711.0	100	1.0	3711	1743
EGIA - Inside Sheeting	8/17/2009	25444.1	25420.1	99.9	0.7	32.6	3711.0	--	--	--	--
EGIA-Down-1	8/17/2009	188.2	100.5	53.4	26.5	3.3	3711.0	3	1.0	111	51
EGIA-Down-2	8/17/2009	193.7	96.1	49.6	49.8	2.0	3711.0	26	1.0	965	457
EGIA-Down-3	8/17/2009	227.2	102.5	45.1	77.0	1.6	3711.0	36	1.0	1336	742
EGIA-Down-4	8/17/2009	237.2	119.7	50.5	65.3	1.8	3711.0	27	1.0	1002	581
EGIA-Down-5	8/17/2009	434.7	290.0	66.7	51.2	2.8	3711.0	8	1.0	297	316
WRI-North	8/22/2009	43.9	27.0	61.6	5.3	3.2	2381.0	100	0.96	2292	246
WRI-Comp.	8/22/2009	105.8	55.4	52.4	25.1	2.0	2381.0	100	0.96	2292	593
ERI-North	8/22/2009	288.5	37.1	12.9	4.4	57.7	2381.0	100	0.04	89	63
ERI-Comp.	8/22/2009	2480.5	1457.8	58.8	103.4	9.9	2381.0	100	0.04	89	540
NTIP-Comp.	8/22/2009	235.0	188.8	80.4	1.5	30.8	2381.0	100	1.0	2381	1368
EGIA-Up	8/22/2009	187.0	138.9	74.3	28.8	1.7	2381.0	100	1.0	2381	1088
EGIA - Inside Sheeting	8/22/2009	3473.0	2609.0	75.1	326.0	2.7	2381.0	--	--	--	--
EGIA - Inside Silt Curtain	8/22/2009	3102.6	2375.3	76.6	60.6	12.0	2381.0	--	--	--	--
EGIA-Down-1	8/22/2009	191.1	115.2	60.3	11.6	6.6	2381.0	3	1.0	71	33
EGIA-Down-2	8/22/2009	157.3	109.8	69.8	29.2	1.6	2381.0	26	1.0	619	238
EGIA-Down-3	8/22/2009	598.7	415.6	69.4	130.8	1.4	2381.0	36	1.0	857	1255
EGIA-Down-4	8/22/2009	623.7	477.9	76.6	92.9	1.6	2381.0	27	1.0	643	980
EGIA-Down-5	8/22/2009	1220.1	894.6	73.3	125.2	2.6	2381.0	8	1.0	190	568
WRI-Comp.	10/21/2009	41.0	NA	--	--	NA	4039.0	100	0.96	3888	390
ERI-Comp.	10/21/2009	688.3	NA	--	--	NA	4039.0	100	0.04	151	254
NTIP-Comp.	10/21/2009	70.9	NA	--	--	NA	4039.0	100	1.0	4039	700
EGIA-Up	10/21/2009	142.5	NA	--	--	NA	4039.0	100	1.0	4039	1407
EGIA-Down	10/21/2009	272.2	NA	--	--	NA	4039.0	100	1.0	4039	2688

Notes:

(1). Sample locations illustrated in Figure 5.1-2.

(2) Revised correction factor developed during RAMP has been applied to PCB data.

(3) For paired samples where dissolved fraction exceeds total fraction, % dissolved is assumed to be 100%.

(4) For paired samples where dissolved fraction exceeds total fraction particulate fraction not calculated

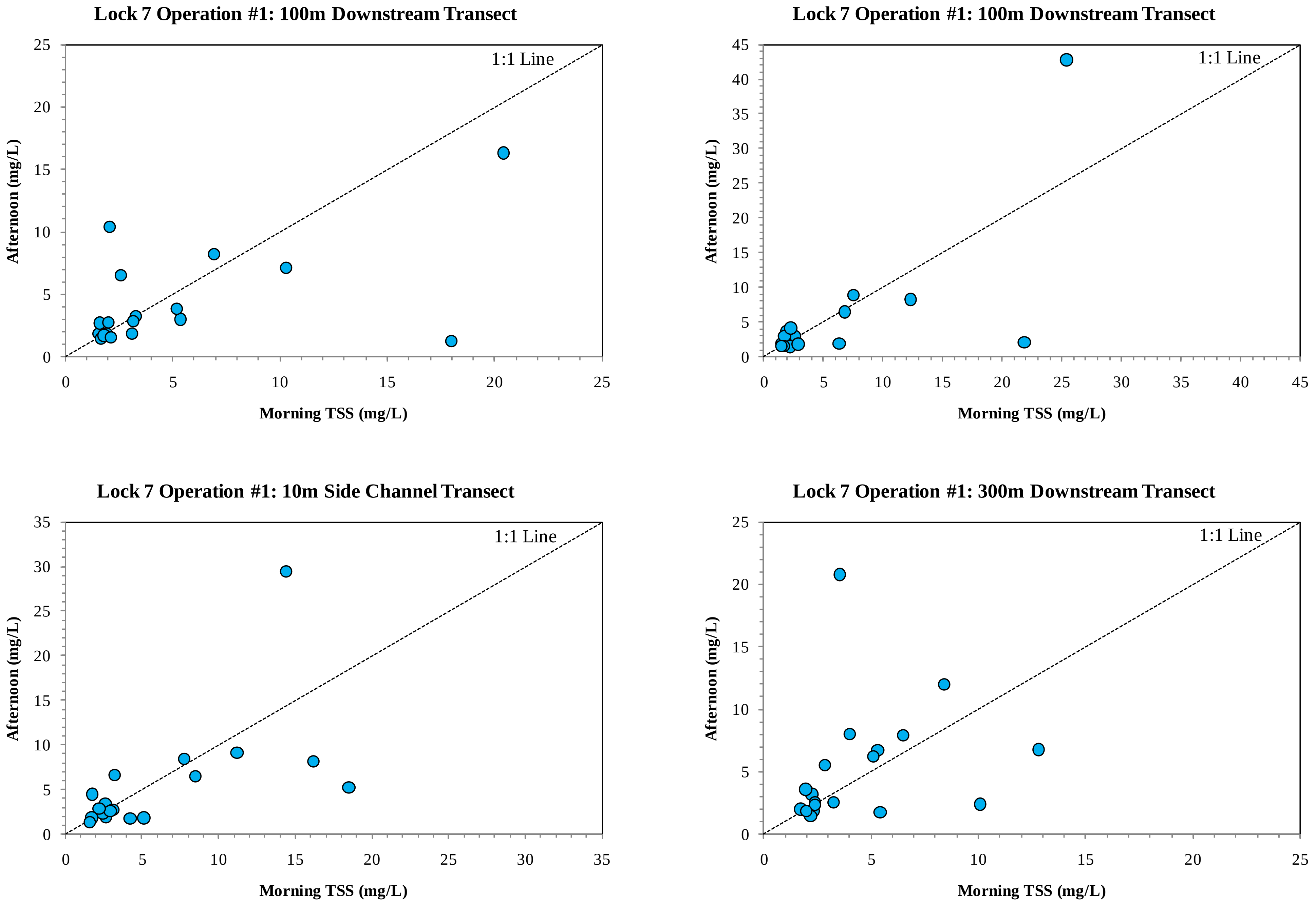
WRI = West Rogers Island

ERI = East Rogers Island

NTIP = Northern Thompson Island Pool

EGIA = East Griffin Island Area

Source: Anchor QEA and ARCADIS,2010. Phase 1 Evaluation Report. Hudson River PCBs Site. Table 5.1-1. March 2010.

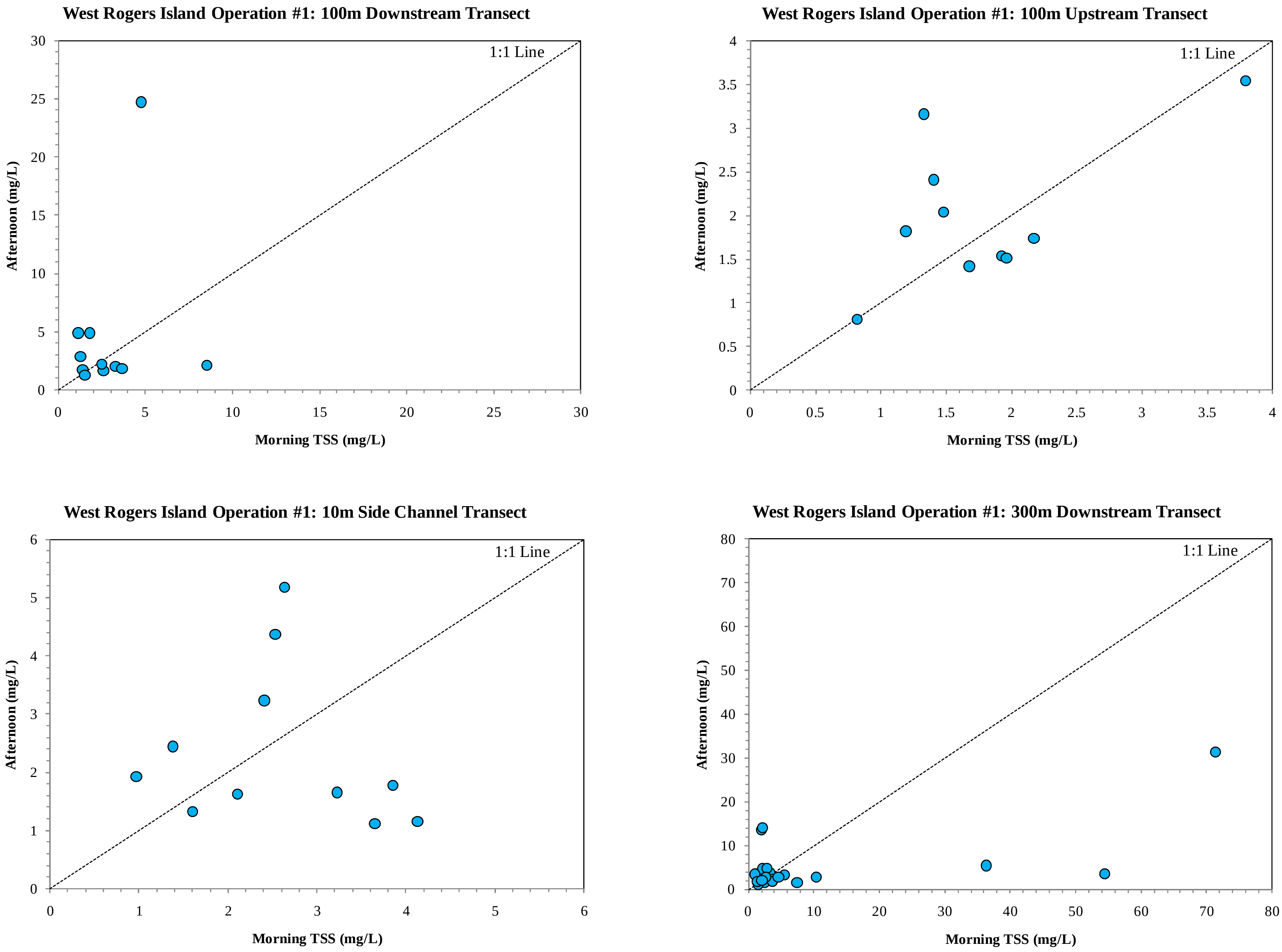


Near-field TSS Transect AM versus PM

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-C-1a

April 2010

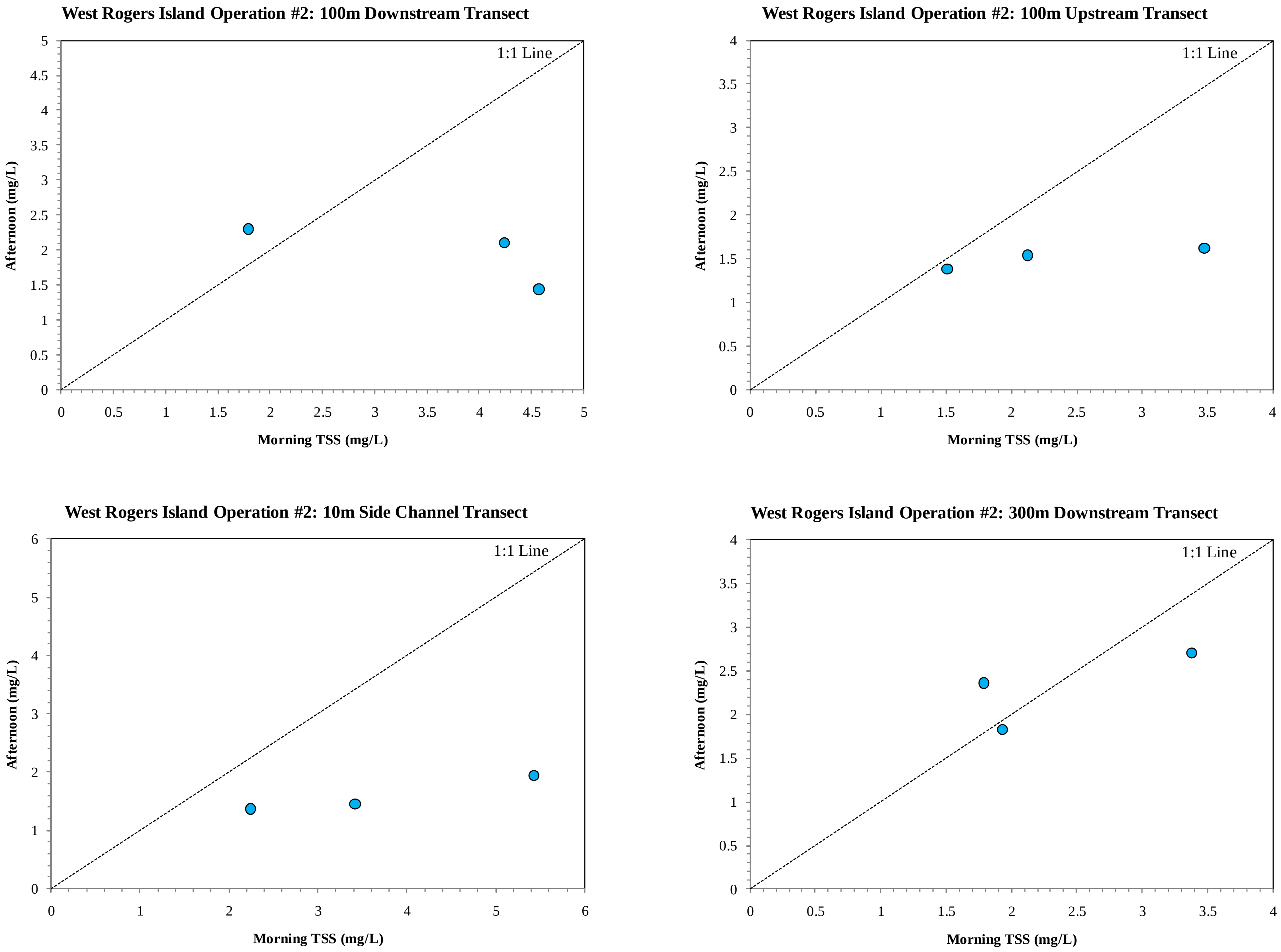


Near-field TSS Transect AM versus PM

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-C-1b

April 2010



West Rogers Island Operation #2: 100m Downstream Transect

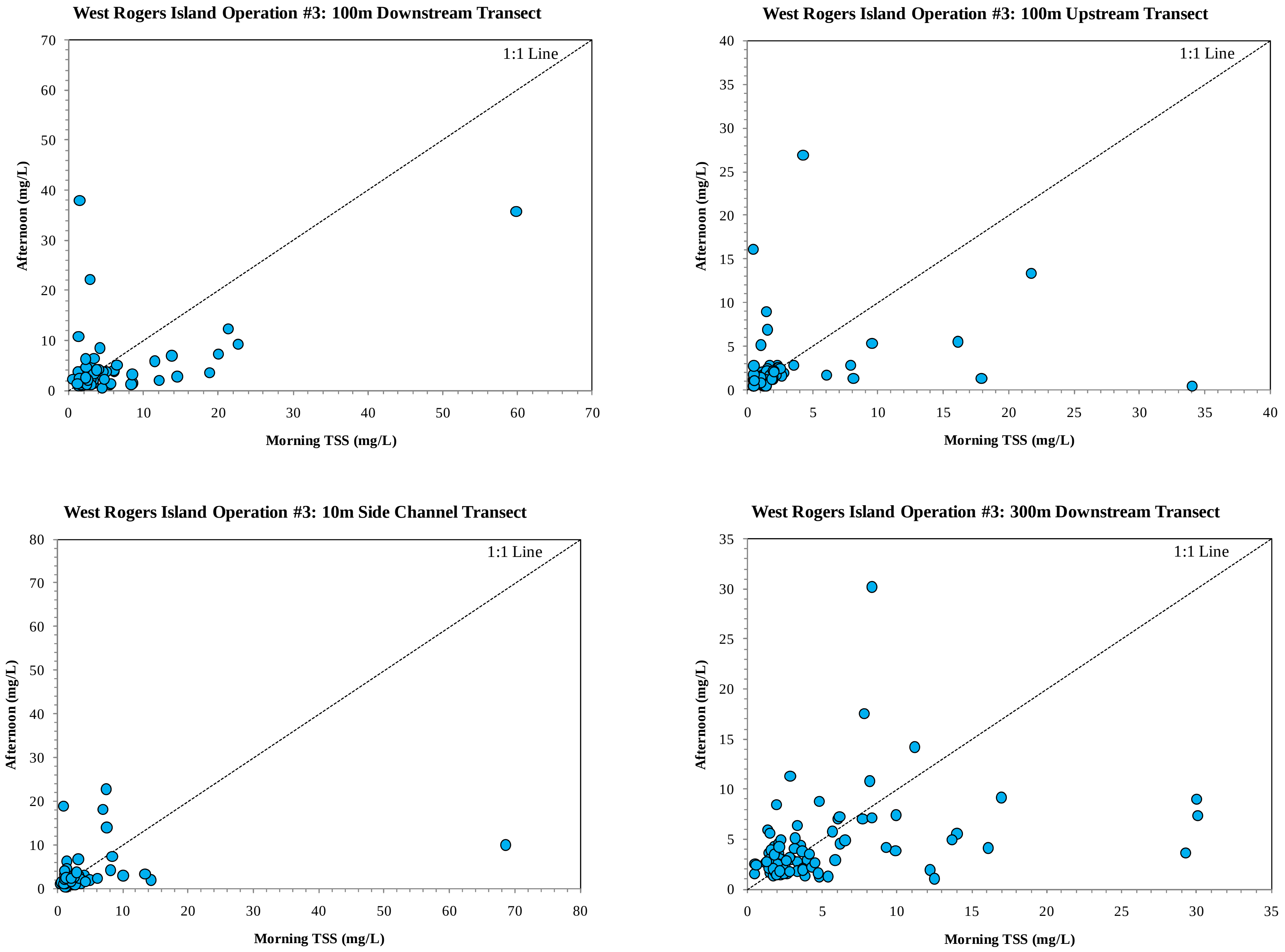
West Rogers Island Operation #2: 100m Upstream Transect

West Rogers Island Operation #2: 10m Side Channel Transect

West Rogers Island Operation #2: 300m Downstream Transect

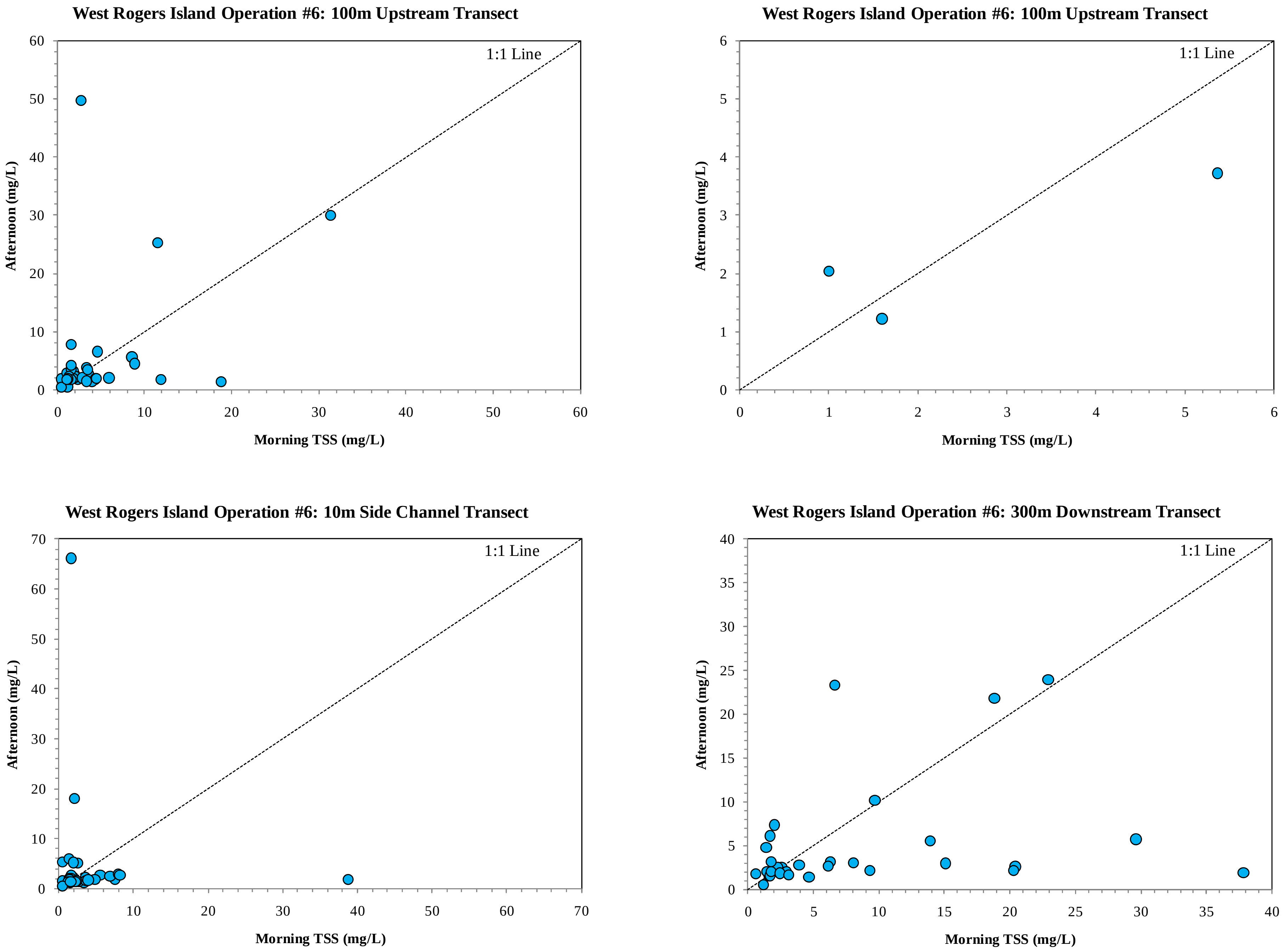
Near-field TSS Transect AM versus PM

Figure 1-C-1c



Near-field TSS Transect AM versus PM

Figure 1-C-1d


West Rogers Island Operation #6: 100m Upstream Transect

West Rogers Island Operation #6: 100m Upstream Transect

West Rogers Island Operation #6: 10m Side Channel Transect

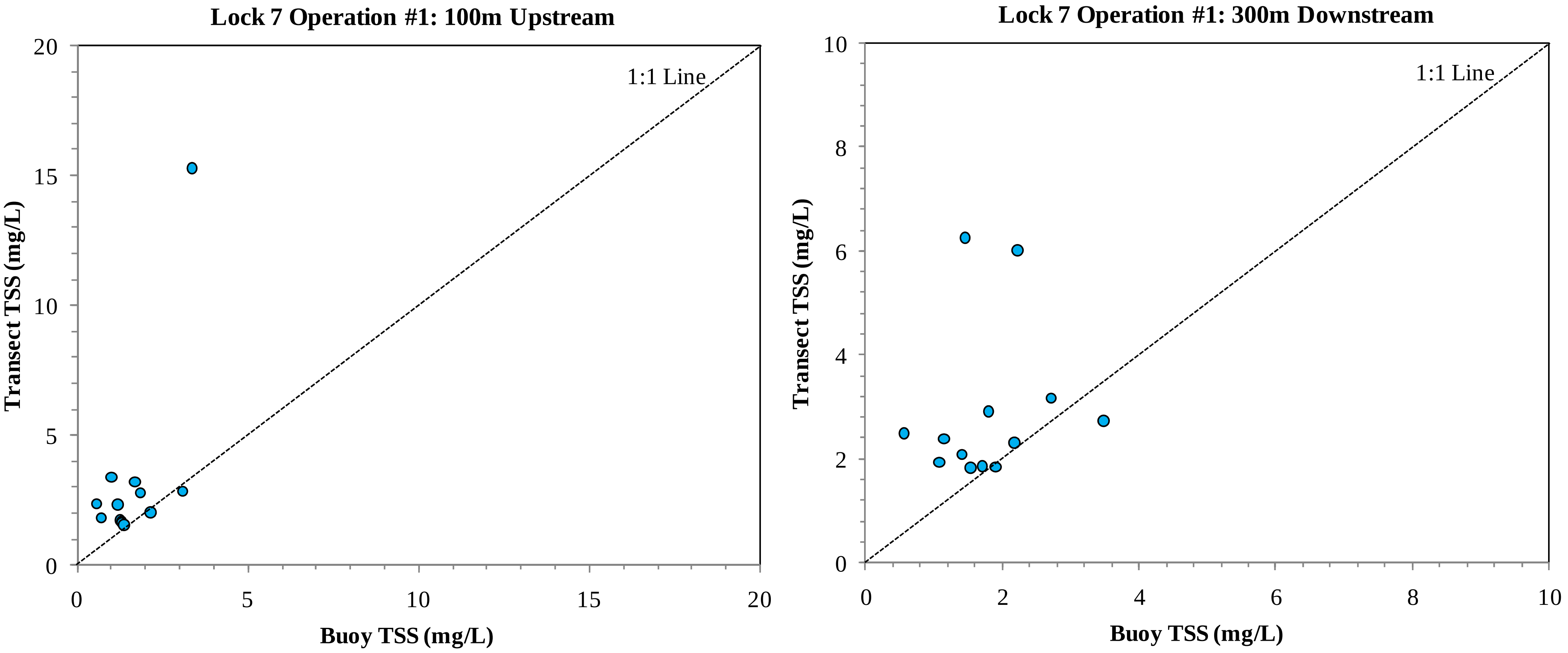
West Rogers Island Operation #6: 300m Downstream Transect

Near-field TSS Transect AM versus PM

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-C-1e

April 2010

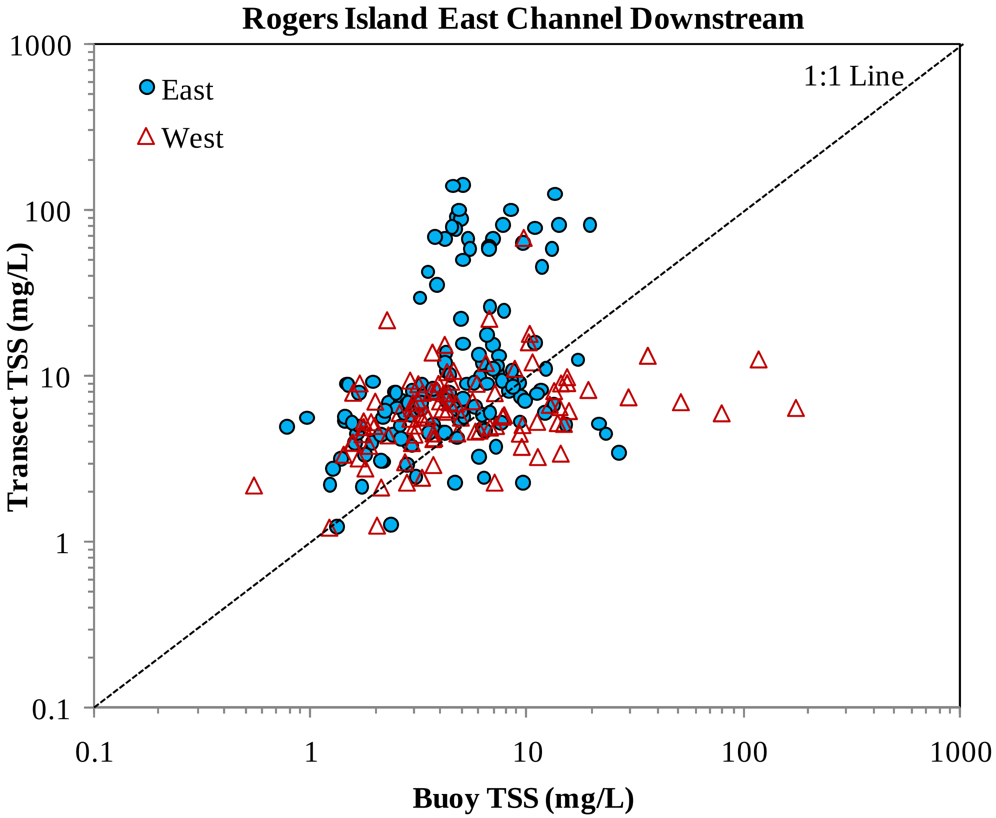

Lock 7 Operation #1: 100m Upstream

Lock 7 Operation #1: 300m Downstream

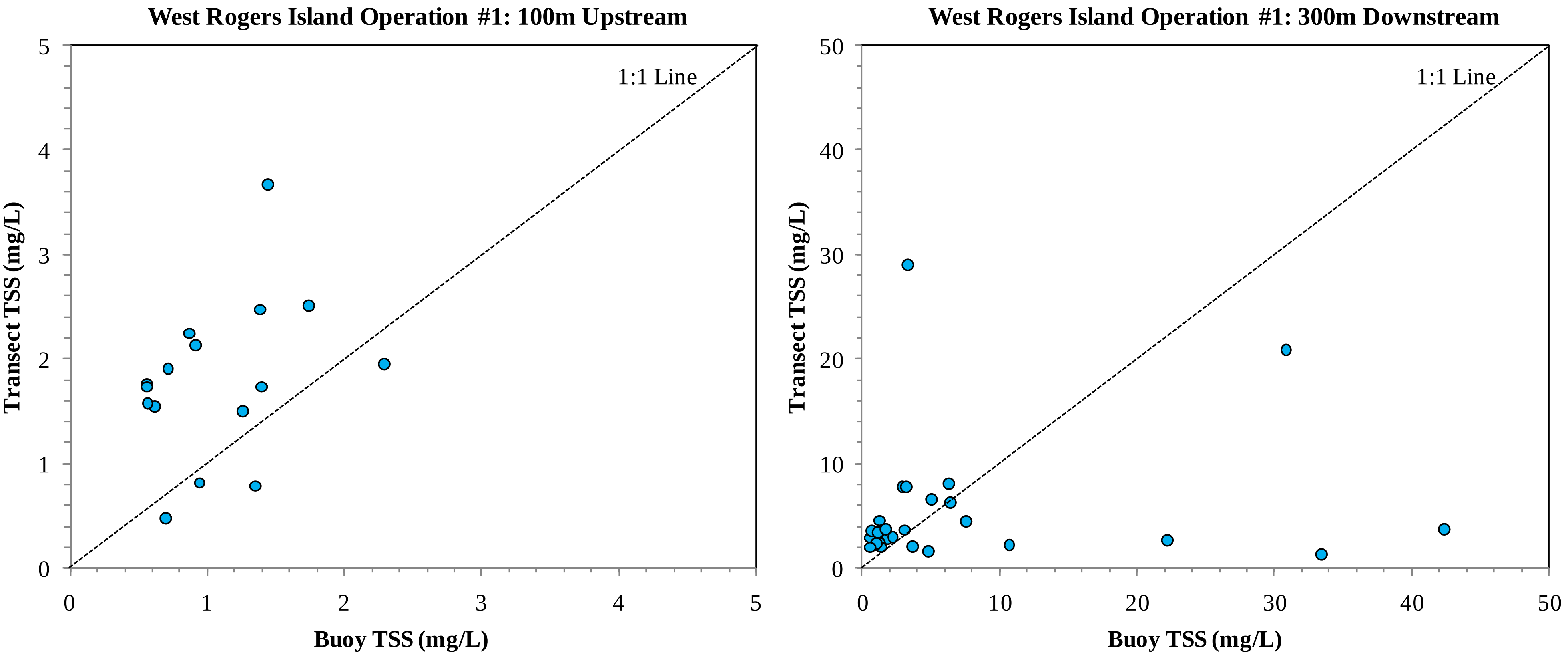
Near-field TSS Buoy versus Transect

Figure 1-C-2a

April 2010



Near-field TSS Buoy versus Transect

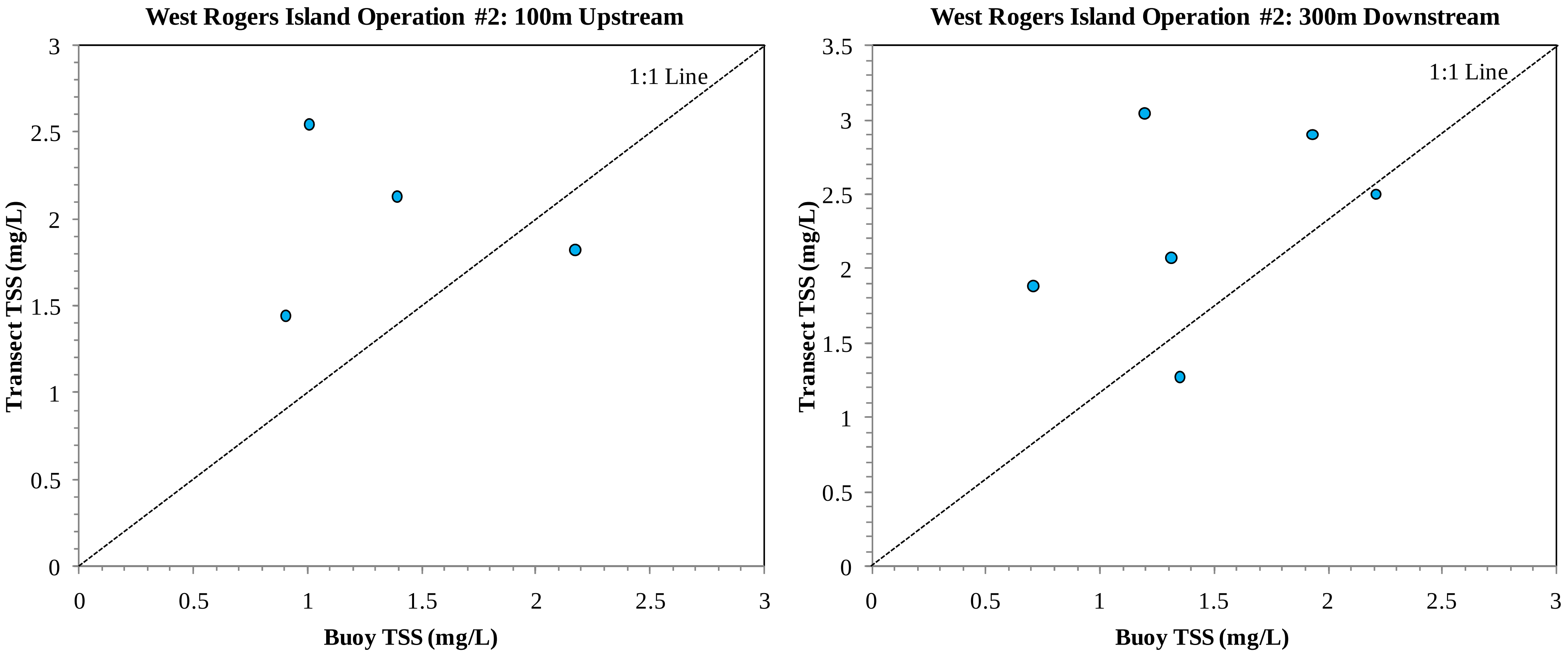


Near-field TSS Buoy versus Transect

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-C-2c

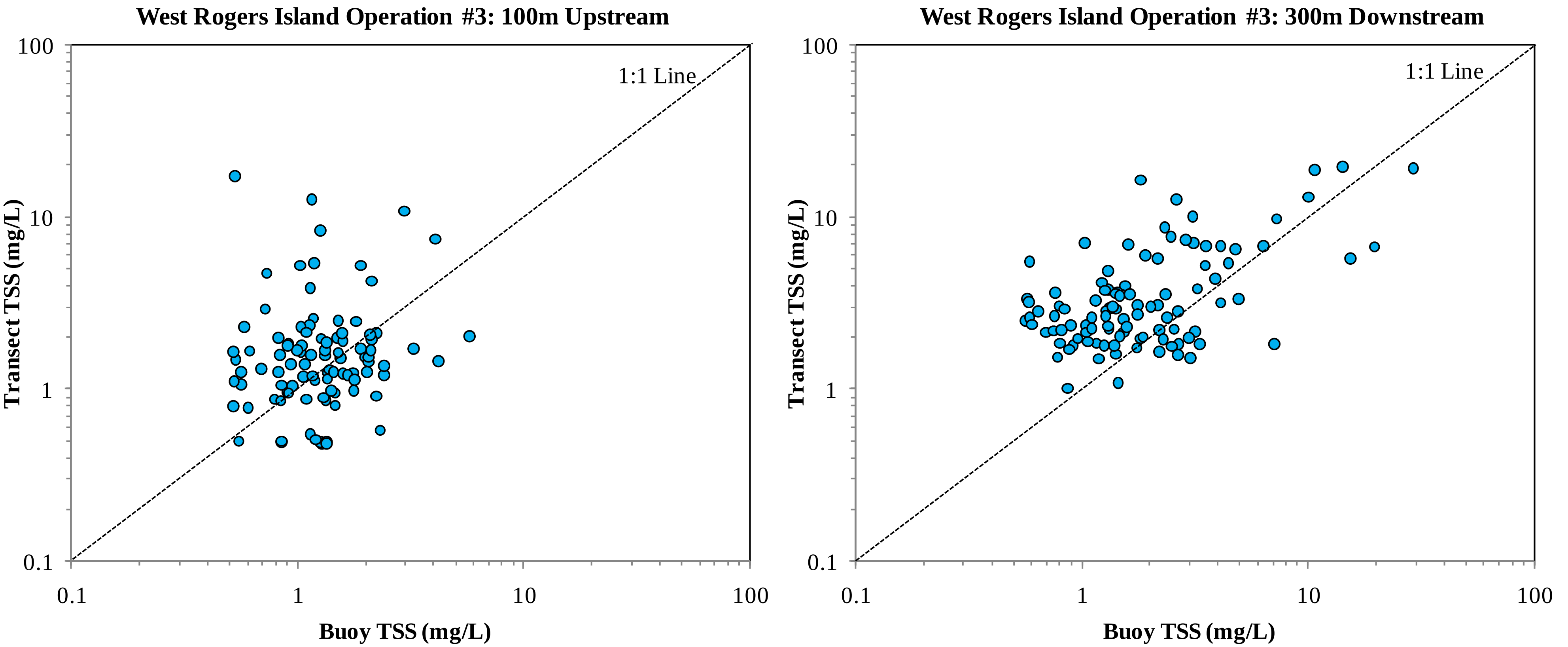
April 2010



Near-field TSS Buoy versus Transect

Figure 1-C-2d

April 2010

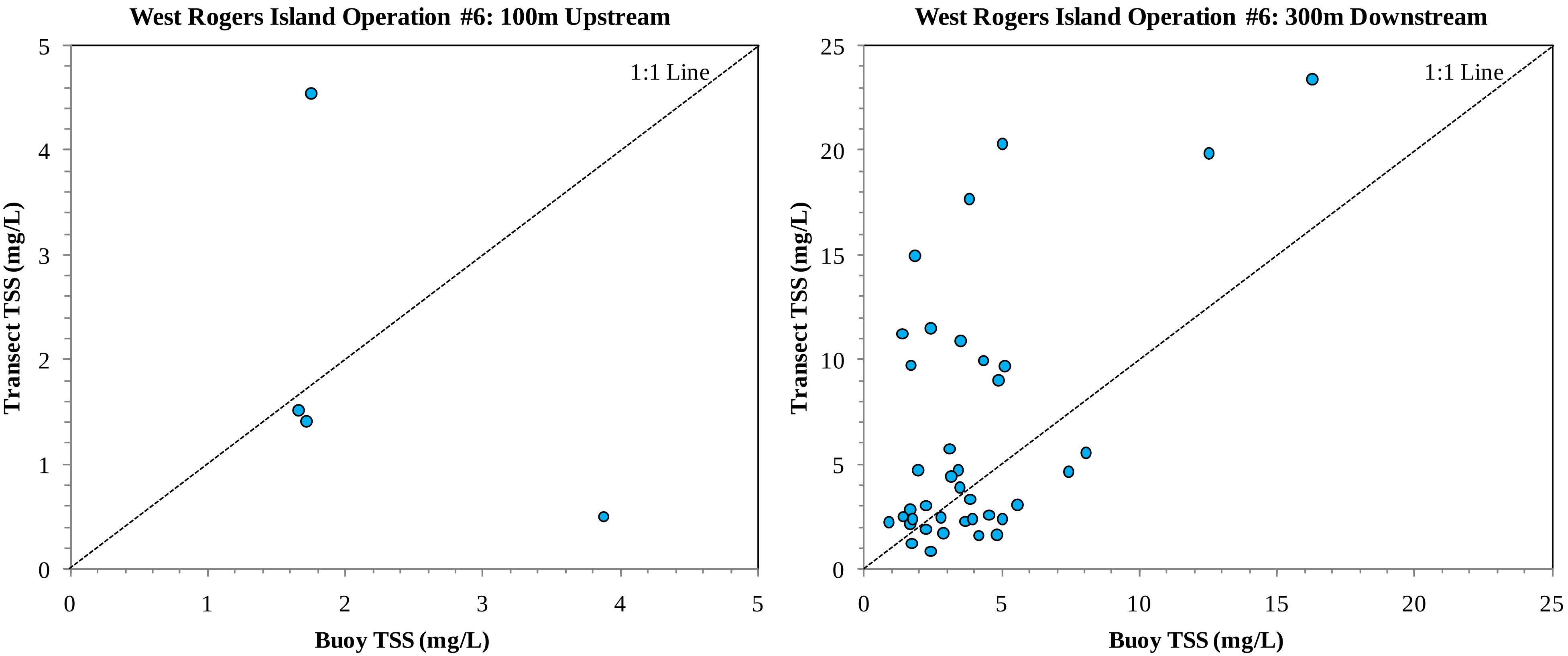


Near-field TSS Buoy versus Transect

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-C-2e

April 2010

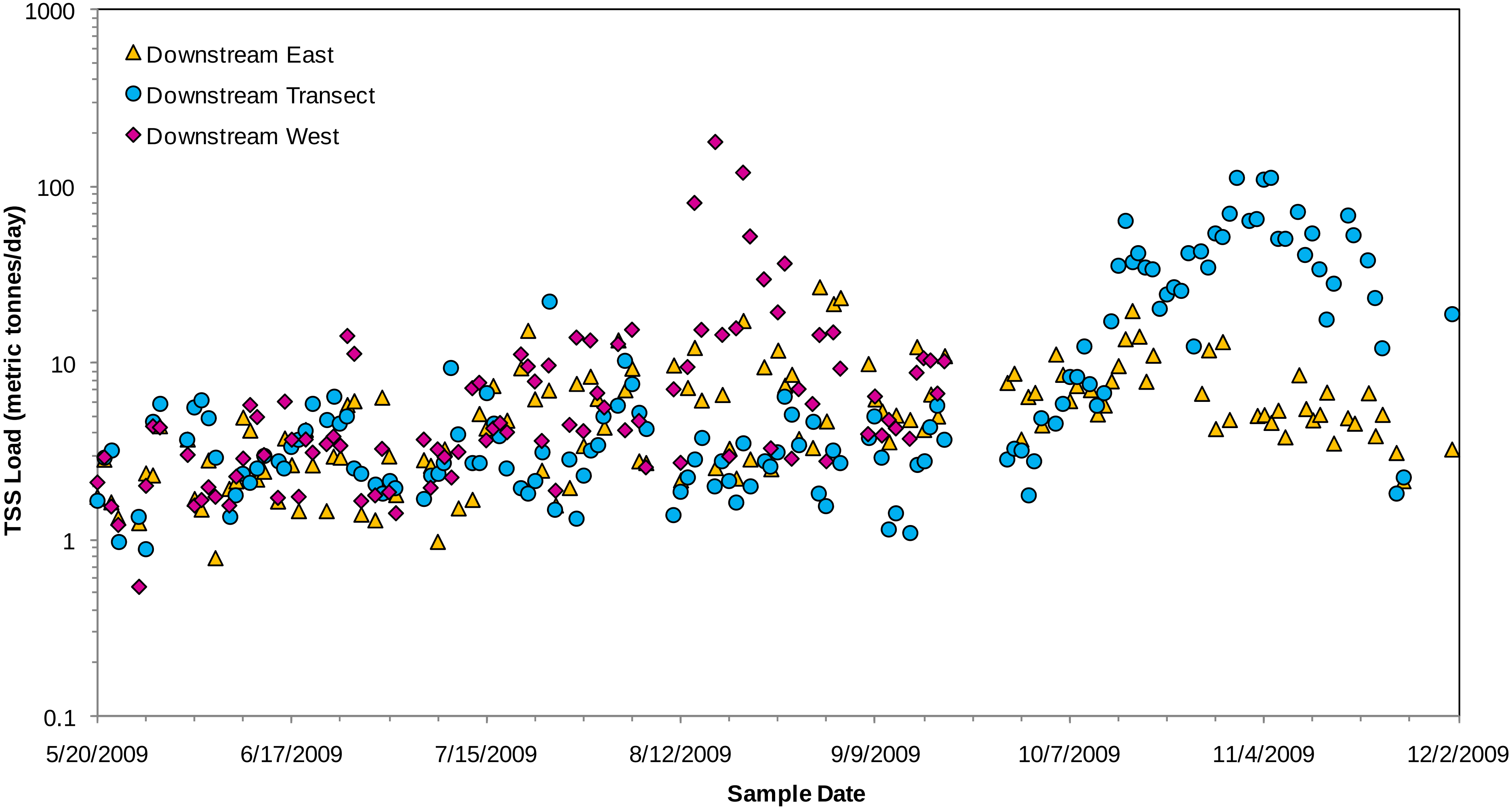


Near-field TSS Buoy versus Transect

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-C-2f

April 2010

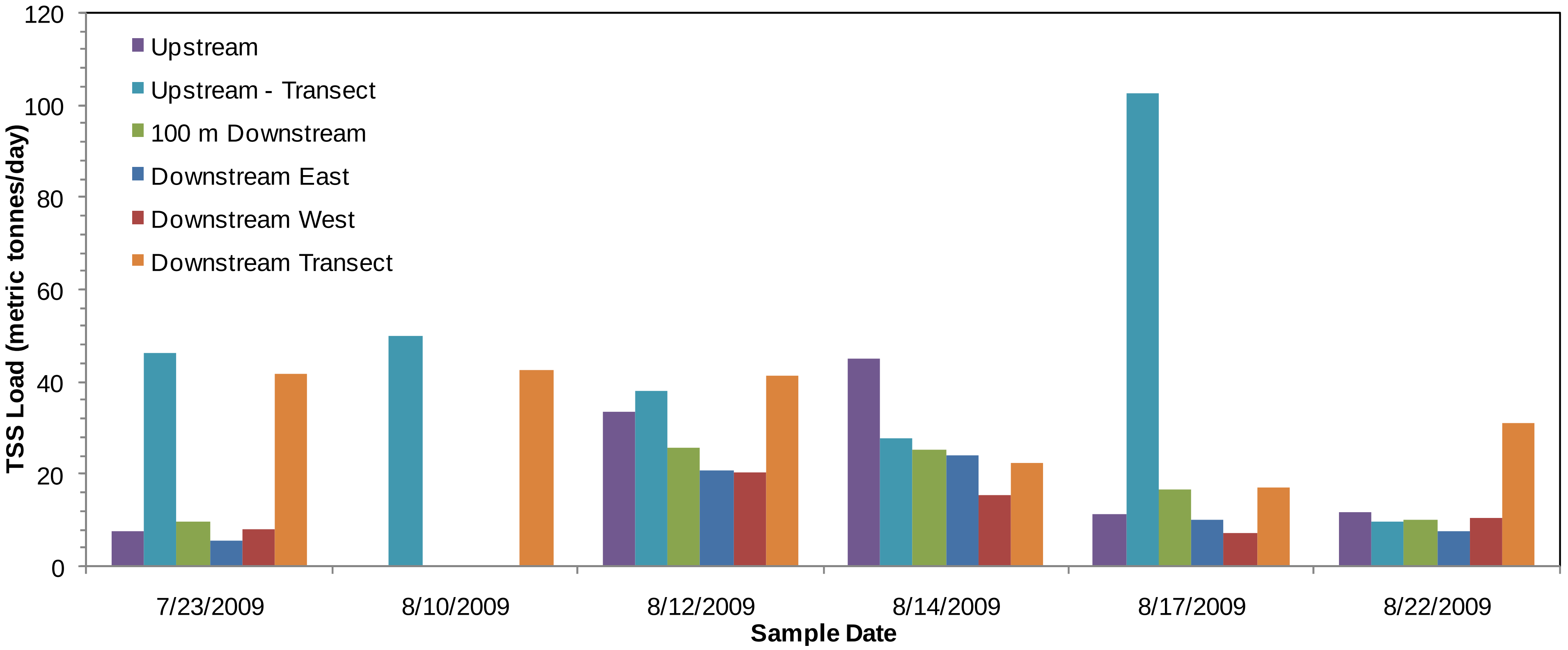


Near-field East Rogers Island: 25m Downstream Transect TSS Load Analysis

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

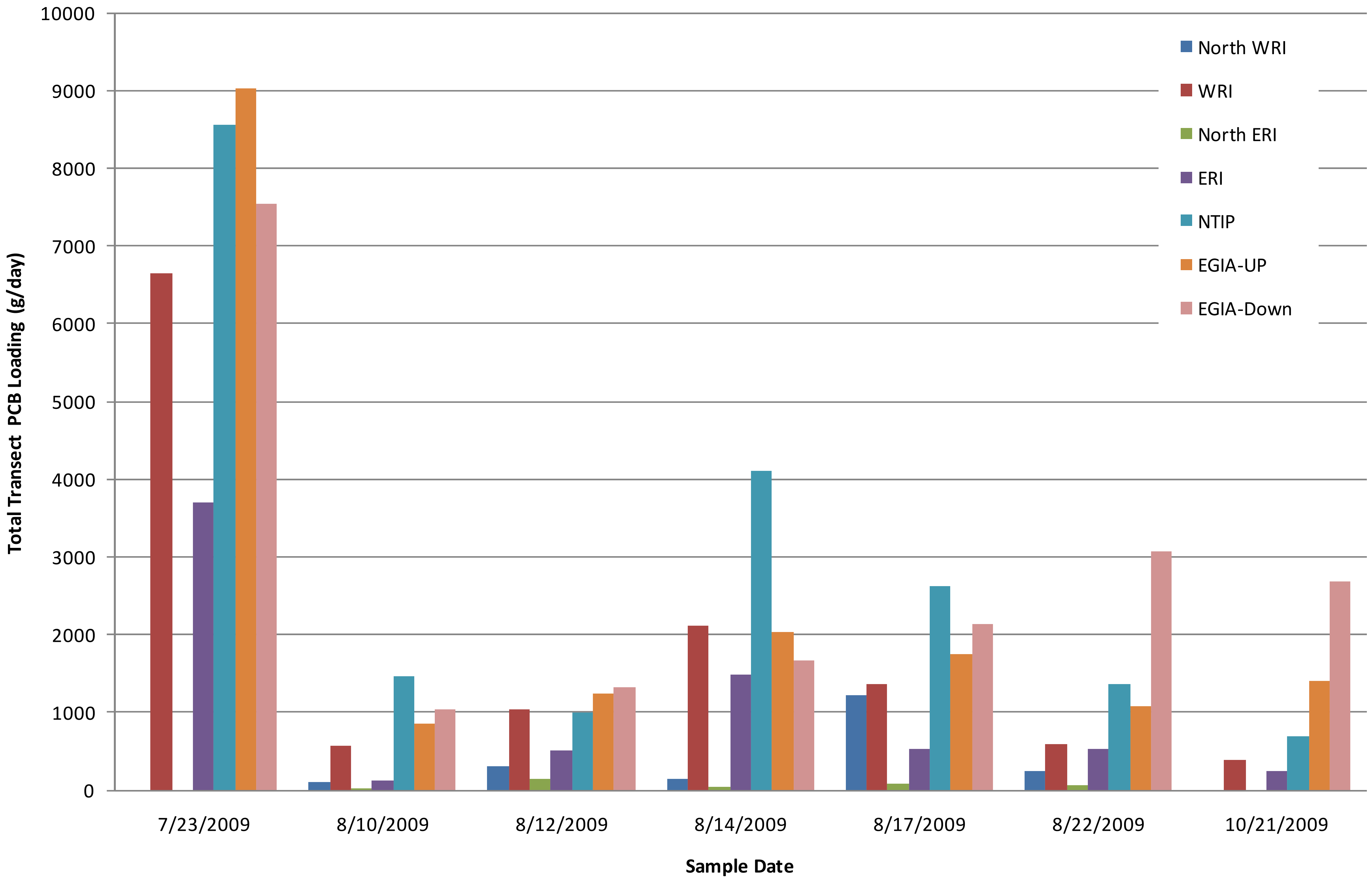
Figure 1-C-3

April 2010



East Griffin Island Area Near-field Down- and Upstream Buoy versus Transect TSS Load Analysis

Figure 1-C-4



Near-field Daily Total PCB Loading Transect Average

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-C-5

April 2010

TOPIC 1-D

PCB FATE AND TRANSPORT IN THE FAR-FIELD DURING DREDGING

Topic 1-D - PCB Fate and Transport in the Far-field during Phase 1 Dredging

1-D.1. Introduction

In order to better understand the water column PCB loads during the 2009 Phase 1 dredging event, EPA has conducted a more complete analysis of the fate and transport of PCBs and TSS within the Thompson Island Pool and within the Upper Hudson River. This analysis is based on an examination of the changes in the PCB homolog distribution and the behavior of the particulates with movement downstream from the dredging operations in the near-field to the first far-field station at Thompson Island and then to Waterford. It also makes the analyses performed by EPA in related topics (Topics 1-A through 1-C, and 3) more complete.

1-D.2. PCB Fate and Transport between the Near-field and Thompson Island

Several studies were conducted during Phase 1 that provide information on the transport of PCBs between the dredging operations (the near-field) and the first far-field station at Thompson Island. While the data obtained at Thompson Island was specifically designed to examine PCB transport and estimate PCB loads, the samples obtained in the near field were diagnostic in nature and do not provide time-integrated observations. Nonetheless, the properties of the near-field samples can provide some information on the nature of PCBs at the point of release and how the PCB mixture changes downstream.

To examine PCB transport, the mixture of PCBs (*i.e.,* the PCB homolog distribution) was compiled for near-field and far-field samples. The average mass fraction for each PCB homolog was calculated for all far-field samples collected at the Thompson Island far-field station between May 2009 and October 2009. This Phase 1 average was then compared to the average homolog mass fractions observed in the PCB near-field release mechanism study samples (collected on July 14, 15, and 17, 2009) and PCB transect study samples (collected on July 23, 2009, August 10-12, 14, 17, and 22, 2009, and October 21, 2009) to evaluate any changes in the homolog pattern between the dredging operation (the near-field) and the far-field. Mass fractions were determined based on whole water PCB values; for the near-field release mechanism data, this value was calculated as the sum of the dissolved and particulate results.

Analysis of the monochlorobiphenyl fraction indicated that the amount of this homolog in the water column declined in the downstream direction. The highest average percentage was observed in the near-field release sample (43 percent), followed by the transect samples (24 percent), and lowest amount was observed in the in the far-field samples (16 percent).

The dichlorobiphenyl fraction variation was not as pronounced; the percentage of far-field whole water PCBs composed of dichlorobiphenyl was 39 percent, a value that is consistent with what was observed in the near-field release study samples (also 39 percent). The transect study samples, however, were composed of 45 percent dichlorobiphenyl.

Unlike the monochlorobiphenyl and dichlorobiphenyl fractions, the remaining average homolog fractions (trichlorobiphenyl through decachlorobiphenyl) all increased in the downstream direction. The distribution of PCBs present in the far-field samples contained a greater percentage of Tri+ homologs than the near-field and transect study samples; average Tri+ percentages in the far-field, transect, and near-field samples are 45, 31, and 18 percent, respectively. Note that the Tri+ PCB composition of the Total PCBs (TPCB) observed at Thompson Island also increases at higher river flows.

Average homolog mass fractions for the far-field TID station, the PCB transect study, and the PCB near-field release mechanism study samples are shown in Figure 1-D-1a. Figure 1-D-1b is a ternary diagram of the mass fractions of mono, di and Tri+ homologs for the entire set of samples examined here. In this diagram, the homolog mass fractions clearly show the differences in mass fraction among the three sample groups. The gradual shift to the heavier homolog spectrum from the near-field to transect to the far-field samples is evident in both representations.

Two hypotheses may be advanced to explain the findings described above: either a loss of lower chlorinated PCBs or a gain of Tri+ PCBs between the near-field and the far-field TID station. GE has advocated the second hypothesis, *i.e.*, that a gain in Tri+ PCBs is responsible for the shift, and that re-distributed sediments are the source of the additional Tri+ PCBs observed in the far-field. To accomplish this gain in Tri+ PCBs, an increase in suspended matter would need to occur at the same time to deliver the Tri+ PCB to the water column. However, this hypothesis is not supported by the observed TSS concentrations in the near field. TSS concentrations in the buoys downstream of East Griffin Island Area (EGIA) were higher and more variable, particularly later in the program, than TSS concentrations measured at Thompson Island. If additional solids were re-suspended downstream of EGIA, the observed TSS concentrations at Thompson Island would have been significantly higher than values at EGIA. Therefore, the first hypothesis, *i.e*., a loss of lower chlorinated PCBs, is the likelier explanation for the shift in homologs. It is likely that during transport from the near-field, the lighter, more volatile PCB homologs are lost by gas exchange causing the shift towards higher Tri+ PCB fraction at Thompson Island. Notably loss of PCBs to the air was documented on a number of occasions during Phase 1, particularly when oil-phase was visible and concentrated, such as at CU-3 or in the sheet pile area at CU-18. While gas exchange losses were most apparent in these focused areas, the elevated local concentrations near the dredge operations likely create similar opportunities for gas exchange. This process is consistent with the entire set of available data.

1-D.3. PCB Fate and Transport through the Upper Hudson River

This section examines the mass of TPCB and PCB homologs transported to the Thompson Island, Schuylerville (Lock 5) and Waterford far-field stations during the active dredging period (May 15, 2009 to October 27, 2009), as well as the PCB homolog patterns at these three stations that existed under baseline conditions (*i.e.*, prior to dredging between 2004 through 2008). Associated TSS loads for the three far-field stations during dredging and under baseline conditions were also evaluated. In addition, potential causes and/or mechanisms to which the observed PCB and TSS loss/gain rates and patterns might be attributed are discussed.

1-D.4. PCB and TSS Mass Balance Calculations

The mass of PCB homologs at the three far-field stations and the PCB mass lost or gained between Thompson Island and Lock 5 and between Lock 5 and Waterford were calculated for both the baseline condition and the active dredging period. TSS loads at the three far-field stations were also calculated.

1-D.4.1. Mass Balance under Baseline Conditions

The average PCB homolog and TSS daily loads under baseline conditions for the period of May to November (which corresponds to the active Phase 1 dredging period[1]) were compiled for the years 2004 to 2008 using available BMP data and the AutoBeale Load Estimation Program (Richards, 1998). AutoBeale which is a computer implementation of the Beale Ratio Estimator, iteratively seeks out the discharge stratification and minimizes the variance of the load estimate for a given set of data. The cumulative PCB and TSS masses at the three stations were then estimated by summing the average daily loads for this time period. These results are shown in Table 1-D-1 and Figures 1-D-2a and 1-D-2b.

1-D.4.2. Mass Balance under Active Dredging

In a similar manner, the mass of TPCB and PCB homologs at the three far-field stations during active dredging were calculated for the period from July 5 to October 27, 2009. The PCB sampling results prior to July 5, 2009 were not included because congener data were not available for the Thompson Island station prior to that date, and congener data are needed to assess the PCB homolog pattern being transported downstream. Additionally, the AutoBeale Estimator was not need for this calculation since the water column was sampled daily on a 24 hour basis during this period.

For the dredging period, the mass flux of each PCB homolog was calculated using the water column concentration multiplied by the flow in the following equation:

$$M_{F_{PCB}} = C_W \times F_{ff} \times \frac{86400\ \text{seconds}}{\text{day}} \times \frac{1000\ \text{L}}{\text{m}^3} \times \frac{1\ \text{g}}{10^9\ \text{ng}} \qquad \text{(Eq. 1-D-1)}$$

Where: $M_{F_{PCB}}$ = Mass flux of PCB (gram/day)
C_w = PCB concentration in water column (ng/L)
F_{ff} = Daily flow at the far-field station (m^3/s)
Thompson Island flow = 1.03 X Ft. Edward flow[2]
Schuylerville flow = 1.07 X Ft. Edward flow[2]
Ft. Edward and Waterford flows were obtained from USGS

The cumulative PCB mass for each homolog was then calculated by adding the daily mass fluxes. For example, the cumulative PCB mass for the period of July 5 through October 27, 2009 was calculated as follows:

$$M_{PCB} = \sum_{t=July5}^{Oct27} M_{F_{PCB}} \qquad \text{(Eq. 1-D-2)}$$

---

[1] The period of May to November is used as a general baseline condition for comparison to the transport during the dredging period. The minor difference in the time periods to be compared (May 1 to November 30 *vs.* May 15 to Oct 27 should not have any bearing on the comparison of general PCB transport behavior. Note that all in-river activities related to the Phase 1 remediation actually ended on December 4, 2009. Demobilization of dock structures and related floats continued through December 23, 2009.

[2] These factors adjust for the increase in drainage area from Ft Edward to these monitoring locations. They are the ratio of the drainage area at the station to the drainage area at Ft Edward as given in USGS Open-File Report 81-1055 Wagner (1982).

Where M_{PCB} = Mass of PCB (grams)
$M_{F_{PCB}}$ = Mass flux of PCB (gram/day)

Similar calculations were used to obtain associated TSS loads. The results are shown in Table 1-D-2, and Figures 1-D-3a and 1-D-3b. This table and these figures also show PCB mass fraction, mass loss/gain between stations and percent mass loss/gain. For PCBs, the percent mass loss or gain is calculated as:

$$\%M_L = \frac{M_{ff1} - M_{ff2}}{M_{ff1}} \times 100 \qquad \text{(Eq. 1-D-3)}$$

Where: $\%M_L$ = percent mass loss/gain (unit less)
M_{ff1} = mass of PCB homolog at the 1st far-field station
M_{ff2} = mass of PCB homolog at the 2nd far-field station

1-D.5. Evaluation of PCB and TSS Loads

The results of the PCB homolog and TSS load calculations under baseline conditions and during active dredging are provided below.

1-D.5.1. PCB and TSS Loads under Baseline Conditions

Table 1-D-1 shows baseline PCB homolog and TSS at the three far-field stations for the years 2004 to 2008. Table 1-D-1 and Figure 1-D-2a show the average of the 5-year period for each homolog. The table and figure indicate a consistent mass increase from the Thompson Island Station to Schuylerville and from Schuylerville to Waterford for all homologs, with the exception of monochlorobiphenyls which increased only slightly between Thompson Island and Schuylerville and then decreased slightly from Schuylerville to Waterford. Table 1-D-1 and Figure 1-D-2b show the average TSS for the 5-year period at each station. The table and figure indicate a consistent increase in average TSS load from Thompson Island Station to Schuylerville and from Schuylerville to Waterford. Thus under baseline conditions, PCB transport increased downstream consistent with an increasing TSS load. The increase in PCB loads between TI and Schuylerville are consistent in magnitude with the increase in TSS, *i.e.*, TSS and PCB loads both increase about the same amount. However, to Waterford, the increase in TSS load is significantly greater than the increase in PCB load. The substantially greater increase in TSS load reflects the solids contributions from the Hoosic River and the Batten Kill. This relationship between TSS load and PCB load was not evident during Phase 1, as discussed below.

1-D.5.2. PCB and TSS Gross Loads under Active Dredging

Table 1-D-2 shows PCB homolog and Total PCB load at the three far-field stations for the period from July 5 through October 27, 2009. The same information is presented graphically in Figure 1-D-3a. As shown in this table and these figures, PCB homolog and Total PCB loads were

highest at Thompson Island station (TPCB of 500 kg), and progressively decreased from Thompson Island to Schuylerville (TPCB of 290 kg), and from Schuylerville to Waterford (TPCB of 190 kg). However, the percent loss for dichlorobiphenyl, trichlorobiphenyl, tetrachlorobiphenyl, and pentachlorobiphenyl are greater from Thompson Island to Schuylerville than from Schuylerville to Waterford. Conversely, the percent loss for monochlorobiphenyl and hexachlorobiphenyl is greater from Schuylerville to Waterford than from Thompson Island to Schuylerville. It should be noted that percent mass fraction and mass loss for the heptachlorobiphenyl, octachlorobiphenyl, nonachlorobiphenyl, and decachlorobiphenyl were not calculated because the contributions from these homologs are minimal. Table 1-D-2 and Figure 1-D-3b show total TSS load at the three stations for the period July 5 to October 27, 2009. As was observed for baseline conditions, the TSS table and corresponding figure show an increasing trend from Thompson Island to Schuylerville and from Schuylerville to Waterford, although the cumulative TSS loads are lower than the baseline TSS loads. However, when the TSS loads shown in Table 1-D-2 are scaled for the time difference between the periods being compared (~4 months *vs.* 7 months), the results are consistent with the cumulative baseline period average to within 20 percent or less.

Based on these data, an increasing TSS trend downriver is observed during both baseline and Phase 1. The increases in solids loads from station to station are generally consistent from baseline to Phase 1. However, the changes in PCB loads are not, with PCB concentration increasing downstream under baseline but decreasing under Phase 1.

1-D.6. Discussion of Potential Causative Mechanisms for Observed PCB and TSS Load Patterns

A summary of the various hypotheses that have been advanced to explain the observed PCB and TSS transport patterns, along with the associated mechanisms, are discussed below. Baseline conditions and the active dredging period are discussed separately.

1-D.6.1. PCB and TSS Transport

1-D.6.1.1. PCB and TSS Transport under Baseline Conditions

In the review above, PCB sampling data for years 2004 to 2008 (May to November) revealed an increasing trend for the PCB homologs between Thompson Island and Waterford. A likely explanation for the observed increasing trend of the PCB homologs with distance downstream from Thompson Island appears to be the increase in TSS load, which increases from station to station downstream, suggesting scour of river bottom sediments between stations. This is particularly true for the Thompson Island to Schuylerville increase, since there are no major tributaries in this section. Notably flow is only expected to increase 4 percent based on drainage area whereas the increases in TSS, Total PCB s and Tri+ PCBs are 27, 14 and 27 percent, respectively under baseline. This evidence is considered strongly indicative of net sediment scour in this river section. In the Schuylerville to Waterford segment, there are two major tributaries known to significantly increase the flow and solids load in this section. However, these tributaries have been shown to have orders of magnitude lower PCB concentrations in their sediments and similarly low levels in loads relative to the Upper Hudson (US EPA, 1997). Thus again, the increase in PCB loads is attributable to resuspension of PCB-bearing sediments from the river bottom in this river segment.

1-D.6.2. Potential Homolog Transport Mechanisms

Figure 1-D-4a shows that the TPCB/Tri+PCB ratio decreases moving downstream from Thompson Island to Waterford under baseline conditions. From this diagram it can be seen that the mixture leaving the Thompson Island Pool is roughly 2/3 mono plus di homologs and 1/3 Tri+ PCBs. When the mixture arrives at Waterford, this relationship has changed significantly, with Tri+ PCBs now comprising nearly 50 percent of the mixture. The drop in the TPCB/Tri+PCB ratio from Schuylerville to Waterford is greater than the drop in the TPCB/Tri+PCB ratio from Thompson Island to Schuylerville, correlates to the greater increase in PCB load that occurs between these stations (see Figure 1-D-2a). Examined on an individual homolog basis, the data on Figure 1-D-4b indicate a consistent increase in the PCB load from the Thompson Island Station to Schuylerville and from Schuylerville to Waterford for all homologs under baseline, with the exception of monochlorobiphenyls which increased only slightly between Thompson Island and Schuylerville and then dropped slightly from Schuylerville to Waterford. Figure 1-D-4b also shows that the magnitude of the increase in the PCB load from Schuylerville to Waterford for most homologs, including dichloro- through hexachlorobiphenyl is higher than the increase in the PCB load from the Thompson Island Station to Schuylerville.

1-D.6.2.1. <u>PCB and TSS Transport during Active Dredging</u>

Five years of baseline monitoring established a fairly predictable relationship among PCB loads at the monitoring stations, with both TSS and PCB loads increasing steadily downstream. During dredging, however, a consistent decline in all PCB homolog loads between Thompson Island and Waterford was observed, based on the July 5 to October 27, 2009 sampling data despite an increasing TSS load downstream, consistent in direction and magnitude with the observations of TSS under baseline. Notably, the observed homolog loss patterns under Phase 1 differed between the lighter and heavier homologs, as discussed below. The following discussion will examine possible explanations for these observations.

1-D.6.3. Potential Tri+ Homolog Loss Mechanisms

While the Tri+ homologs predominantly exhibited greater mass losses from Thompson Island to Schuylerville than from Schuylerville to Waterford, the monochlorobiphenyl and dichlorobiphenyl homolog loss patterns varied between the two river segments. A bar chart of TPCB/Tri+PCB ratios (Figure 1-D-4c) shows an increasing trend in the ratio from Thompson Island to Waterford, with a greater percentage increase in the ratio between Thompson Island and Schuylerville (20 percent) than between Schuylerville and Waterford (7 percent). This is consistent with a greater percentage loss of Tri+ PCBs from Thompson Island to Schuylerville than from Schuylerville to Waterford during dredging but differs from the increasing downriver trend in the ratio under baseline, which was attributed to sediment scour and resuspension (see Section 1-D.3.1.1 above). GE hypothesized that the loss of PCBs between Thompson Island and Lock 5 during dredging is due to setting of particulate matter. However, this hypothesis is not consistent with the increases in the observed TSS loads between the two stations. As shown in Table 1-D-2and Figure 1-D-3b, the TSS load increased by 16 percent from 4,270 kg at Thompson Island to 4,950 kg at Schuylerville, an increase well within the range observed under baseline. A more plausible hypothesis is the recycling of particles resulting in dilution of the Tri+ PCB concentration and a decline in Tri+ load, and in addition, loss of lighter fractions via gas exchange. It should be noted that plots of TPCB/Tri+PCB ratio versus flow for the three far-field stations consistently show a decreasing ratio with increasing flow. The referenced plots for the three stations are provided as Figures 1-D-5a, I-D-5b, and 1-D-5c. Because sediment scour and resuspension are more likely under higher flow conditions, particle recycling with less contaminated sediments in the far-field would maintain the high Tri+ component of TPCB, while loss of monochlorobiphenyl and dichlorobiphenyl would ensure that the ratio increases downstream.

While none of these hypotheses can be confirmed, any settling of contaminated particles during transport from Thompson Island will not significantly change the downstream contaminant exposure in surface sediment (see Topic 3).

1-D.6.4. Potential Lighter Homolog Loss Mechanisms

A 1999 study that was conducted by TAMS Consultants to examine observed PCB loss patterns titled "Examination of the Gas Exchange Flux for PCBs from the Upper Hudson Schuylerville to Waterford" (Attachment C of “Data Evaluation and Interpretation Report and Low Resolution Sediment Coring Report [DEIR LRC] for Hudson River PCBs Superfund Site Peer Review Responsiveness Summary) reported theoretical air-water gas exchange calculations on the scale of 40 percent of total PCB inventory for the lighter congeners between Thompson Island and Waterford. Table 1-D-2 shows observed losses for monochlorobiphenyl that that exceed 40 percent of starting inventory, which suggests that other mechanisms besides air-water gas exchange might be responsible for the lighter (and potentially, heavier) PCB homolog losses.

To explain the additional PCB losses, it can be hypothesized that direct mass losses of PCB Non-aqueous Phase Liquids (NAPLs) to the atmosphere through air bubbles entrained in turbulent flow at dams may account for the additional declines in the lighter PCB congeners beyond losses theoretically attributable to air-water gas exchange. Based on a review of the published literature, it was found that a void fraction of up to approximately 20 percent is possible near the plunge pool of cascading flow over a dam where the most turbulence occurs (Chanson et al., 2002; Hoque, 2002). Assuming 20 percent air entrainment, an average water flow rate of approximately 5,000 cfs equates to approximately 1,000 cfs air flow comprising PCB NAPL-coated air bubbles under turbulent flow conditions in the plunge pool downstream of each dam, potentially resulting in substantial PCB losses to the vapor phase. The following approximate calculations (based on Aroclor 1242, which is the predominant PCB mixture at the site) provide a measure of the potential loss rates that might be achievable by this mechanism if full equilibrium conditions are attained:

Given

Assumed Air flow:	1,000 cfs (28,000 liter/sec
Aroclor 1242 vapor pressure:	0.001 mmHg (source: NIOSH)
1 atm:	760 mmHg
Density of air:	1.2 kg/m^3 (0.0012 kg/liter)

Potential PCB Mass Loss Rate

28000 l/sec x 0.001mmHg/760mm Hg x 0.0012 kg/l = 0.00004421 kg/sec = 3.82 kg/day

While this calculation makes several assumptions, it does illustrate the potential for gas exchange of the PCB oils to be very important under turbulent conditions as the water is transported over the dams.

1-D.7. Conclusions

In the analyses for the fate and transport of PCBs and TSS within the Thompson Island Pool and within the Upper Hudson River described above, several hypotheses and mechanisms proposed by EPA for the changes in the PCB homolog distribution with movement downstream have been postulated, examined carefully and discussed. These include among others, the formulation of gas bubbles due to turbulence and those induced by flow over dams into the plunge pool, as well as gas exchange from the dissolved phase and NAPLs, and the increase in river flows and suspended solids due to contribution from major tributaries between the far-field stations. These hypotheses have also been compared with those advanced by GE in their Phase 1 Evaluation Report (GE, 2010). While some of these hypotheses postulated by EPA can be confirmed by well established peer-reviewed studies and others cannot, it becomes clear that any settling of contaminated particles during transport from Thompson Island will not significantly change the downstream contaminant exposure in surface sediment (see Topic 3). EPA's analysis is consistent with the entire set of available data.

References

Chanson, H., Aoki, S. and Maruyama, M. 2002. "Unsteady air bubble entrainment and detrainment at a plunging breaker: dominant time scales and similarity of water level variations," Coastal Engineering 46(2): 139-157.

EPA, 2010. Phase 1 Evaluation Report. Prepared for EPA Region 2 and USACE Kansas City District by The Louis Berger Group, Inc. March 2010.

GE, 2010. Phase 1 Evaluation Report. Prepared for General Electric Company, Albany, NY by Anchor QEA, LLC and Arcadis. March 2010.

Hoque, M.A. 2002. "Air Bubble Entrainment by Breaking Waves and Associated Energy Dissipation." Ph.D. thesis, Toyohashi University of Technology, Japan.

Richards, R.P. 1998. Estimation of Pollutant Loads in River and Streams: A guidance document for NPS Programs. Project report prepared under Grant X998397-01-0, U.S.Environmental Protection Agency, Region VIII, Denver. 108 p.

USEPA, 1997. "Data Interpretation and Evaluation Report – Hudson River PCBs Reassessment RI/FS, New York." Prepared for the US Environmental Protection Agency Region 2 and the US Army Corps of Engineers Kansas City District by TAMS Consultants, Inc., the Cadmus Group and Gradient Corp. February, 1997.

Wagner, L.A.1982. "Drainage areas of New York streams, by river basins; a stream gazetteer; Part 1, Data compiled as of October 1980." U.S. Geological Survey, Water-Resources Investigations, Open-File Report 81-1055

Table 1-D-1
PCB Homolog and TSS Loads at Far-Field Stations under Baseline Conditions

PCB LOAD (kg) and TSS (metric tons) for TID Station - May 15 to November 30

Year	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca	Total PCB	Ratio TPCB/Tri+	TSS
2004	19.7	34.8	15.8	6.7	2.9	0.2	0.0	0.0	0.0	0.0	80.2	3.1	4,700
2005	17.4	34.7	18.7	7.4	2.0	0.1	0.0	0.0	0.0	0.0	80.3	2.8	6,400
2006	30.8	60.6	34.2	13.5	5.1	0.7	0.0	0.0	0.0	0.0	144.9	2.7	16,000
2007	16.6	28.4	12.8	3.9	1.1	0.2	0.0	0.0	0.0	0.0	63.0	3.5	3,700
2008	17.6	30.3	16.4	5.2	1.4	0.1	0.0	0.0	0.0	0.0	71.0	3.1	5,100
Average	20.4	37.8	19.6	7.4	2.5	0.3	0.0	0.0	0.0	0.0	87.9	3.0	7,200

PCB LOAD (kg) for Schuylerville (Lock 5) Station - May 15 to November 30

Year	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca	Total PCB	Ratio TPCB/Tri+	TSS
2004	22.0	44.1	25.7	10.7	4.3	0.4	0.0	0.0	0.0	0.0	107.2	2.6	5,300
2005	17.6	41.5	22.7	9.7	2.8	0.3	0.0	0.0	0.0	0.0	94.7	2.7	8,300
2006	37.5	62.3	40.1	17.7	5.8	1.3	0.0	0.0	0.0	0.0	164.8	2.5	23,000
2007	15.9	29.0	13.4	4.8	1.5	0.2	0.0	0.0	0.0	0.0	64.7	3.3	2,800
2008	13.7	30.8	18.3	6.3	1.7	0.1	0.0	0.0	0.0	0.0	70.9	2.7	6,300
Average	21.3	41.5	24.0	9.8	3.2	0.5	0.0	0.0	0.0	0.0	100.4	2.7	9,100

PCB LOAD (kg) for Waterford Station - May 15 to November 30

Year	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca	Total PCB	Ratio TPCB/Tri+	TSS
2004	15.76	43.82	26.65	16.16	6.00	0.63	0.00	0.00	0.00	0.00	109.0	2.2	31,000
2005	16.56	45.95	35.29	22.24	7.81	1.87	0.04	0.02	0.00	0.00	129.8	1.9	85,000
2006	36.95	84.78	72.25	37.73	14.19	4.68	0.21	0.05	0.00	0.00	250.8	1.9	90,000
2007	12.51	31.77	15.32	6.96	2.20	0.38	0.00	0.00	0.00	0.00	69.1	2.8	83,000
2008	12.05	36.39	21.90	8.88	2.77	0.16	0.00	0.00	0.00	0.00	82.2	2.4	20,000
Average	18.8	48.5	34.3	18.4	6.6	1.5	0.1	0.0	0.0	0.0	128.2	2.1	62,000

Average PCB LOADs (kg) and TSS (metric tins) for Baseline Period May 15 to November 30

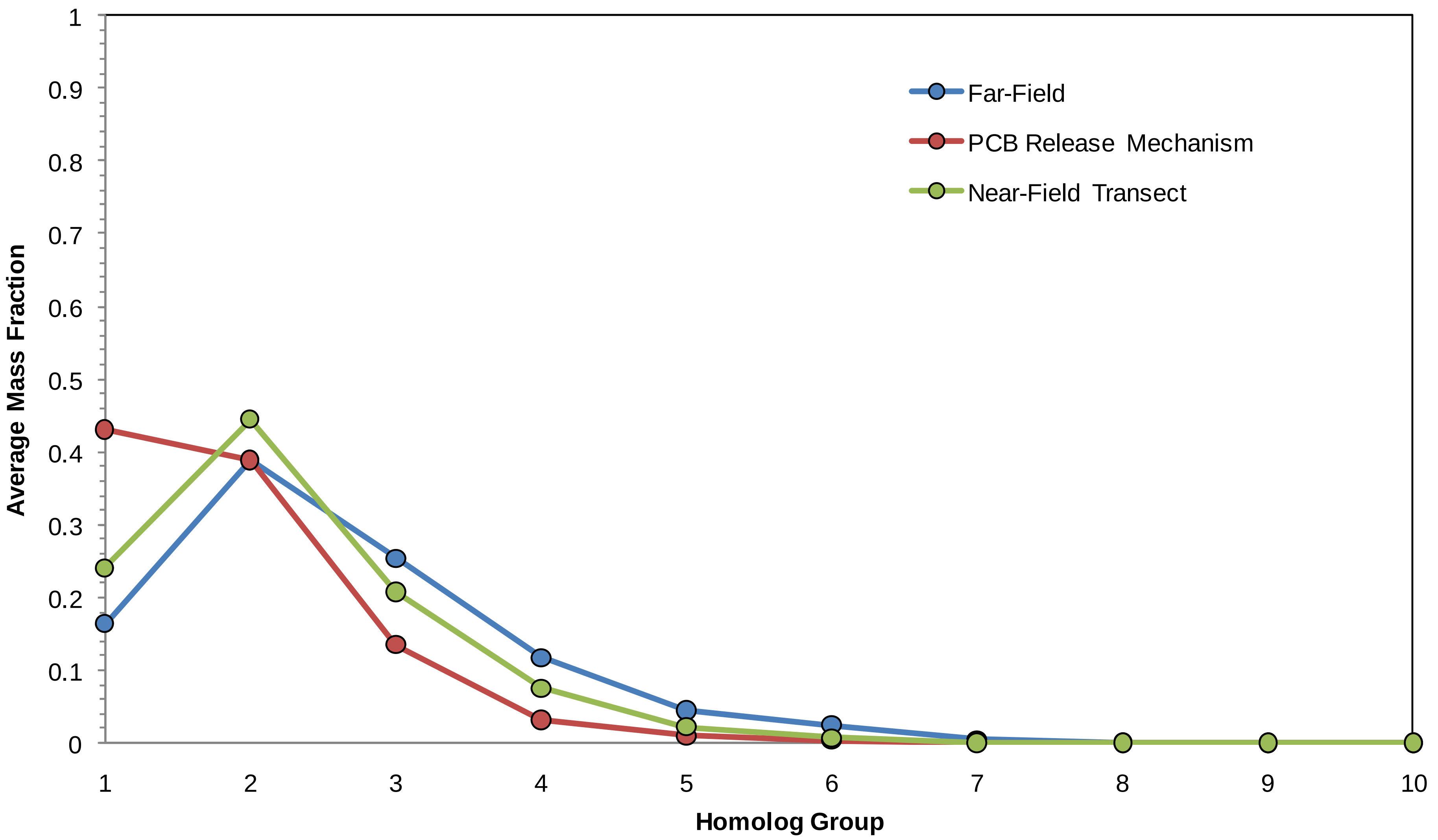
Station	Mono	Di	Tri	Tetra	Penta	Hexa	Hepta	Octa	Nona	Deca	Total PCB	Ratio TPCB/Tri+	TSS
TID	20.42	37.76	19.57	7.37	2.48	0.27	0.00	0.00	0.00	0.00	87.90	3.00	7,200
Schuylerville	21.33	41.54	24.03	9.84	3.23	0.46	0.00	0.00	0.00	0.00	100.40	2.70	9,100
Waterford	18.76	48.54	34.28	18.40	6.59	1.54	0.05	0.01	0.00	0.00	128.20	2.10	62,000

Table 1-D-2

PCB and TSS Loads From July 5 to October 27, 2009 for Different Far-Field Stations during Active Dredging

		Mass (kg)			Mass Loss (kg)		Percent Mass Loss (%)		Mass Fraction Transport		
	PCB Homologue	TID	Schuylerville	Waterford	TI to Schuylerville	Schuylerville to Waterford	TI to Schuylerville	Schuylerville to Waterford	TID	Schuylerville	Waterford
Mono	Monochlorobiphenyl	80	60	30	20	30	25%	50%	0.16	0.21	0.16
Di	Dichlorobiphenyl	180	110	80	70	30	39%	27%	0.36	0.38	0.42
Tri	Trichlorobiphenyl	130	70	40	60	30	46%	43%	0.26	0.24	0.21
Tetra	Tetrachlorobiphenyl	70	30	20	40	10	57%	33%	0.14	0.1	0.11
Penta	Pentachlorobiphenyl	30	10	8	20	2	67%	17%	0.06	0.03	0.04
Hexa	Hexachlorobiphenyl	10	7	4	3	3	31%	44%	0.02	0.02	0.02
Hepta	Heptachlorobiphenyl	3	1	0.36	2	1					
Octa	Octachlorobiphenyl	1	0.13	0.01	1	0.12					
Nona	Nonachlorobiphenyl	0.14	0.02	0	0.11	0.02					
Deca	Decachlorobiphenyl	0	0	0	0	0					
	Total PCB	500	290	190	210	100					
	Total TSS	4270	4950	38614							

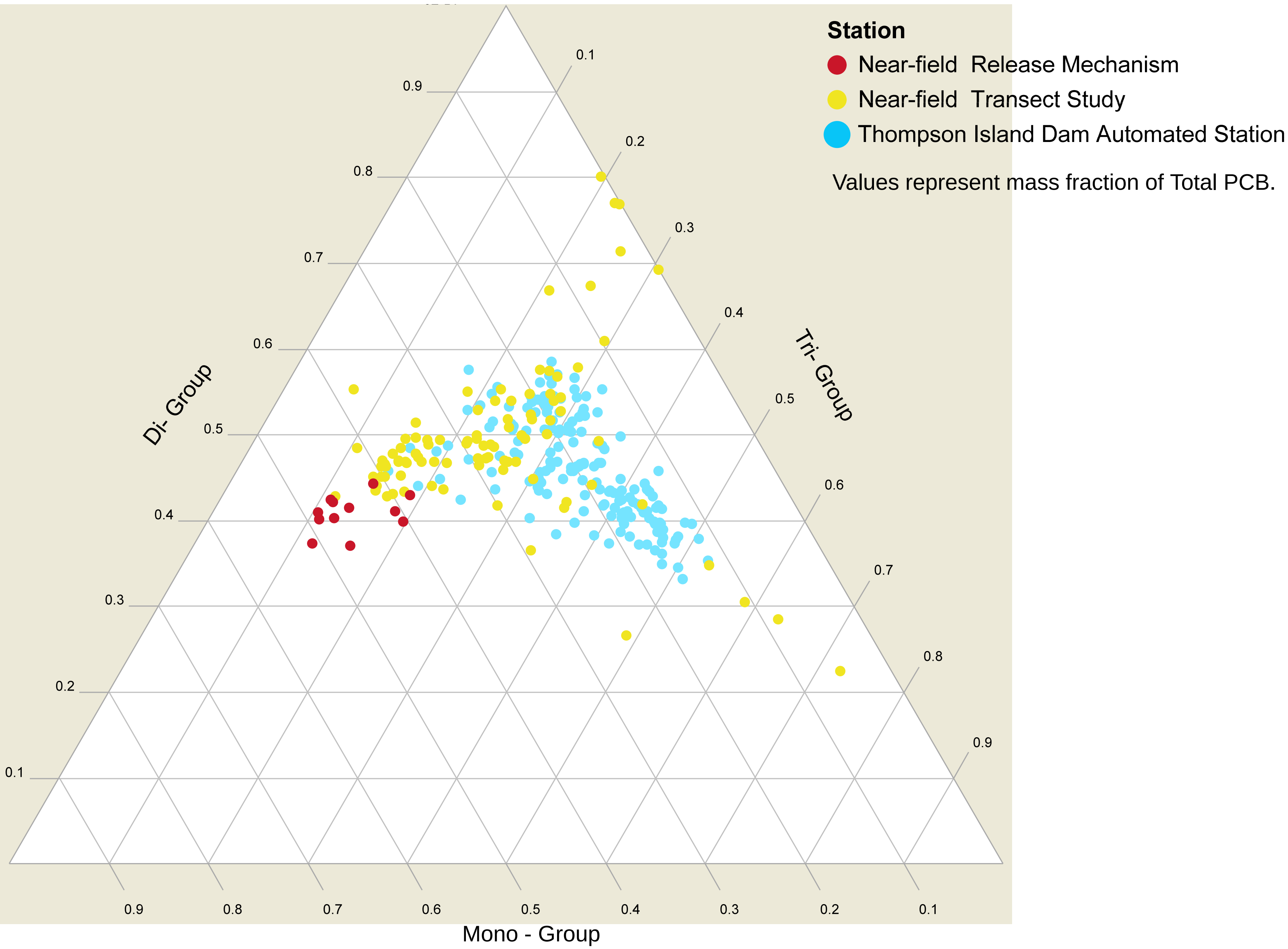
Notes: 1. Numbers are rounded to 1 or 2 significant digits; 2. Percent mass loss and mass fraction transport are not calculated for Mono- through Hexachlorobiphenyl only since the contribution from Hepta- through Decachlorobiphenyl to the Total PCB are small



Average Mass Fraction for Each Homolog Group

Figure 1-D-1a

April 2010



Values represent mass fraction of Total PCB.

PCB Homolog Patterns Observed in Near-Field and Far-Field Measurements in TIP

EPA Phase 1 Evaluation Report - Addendum- Hudson River PCBs Site

Figure 1-D-1b

April 2010

Figure 1-D-2a

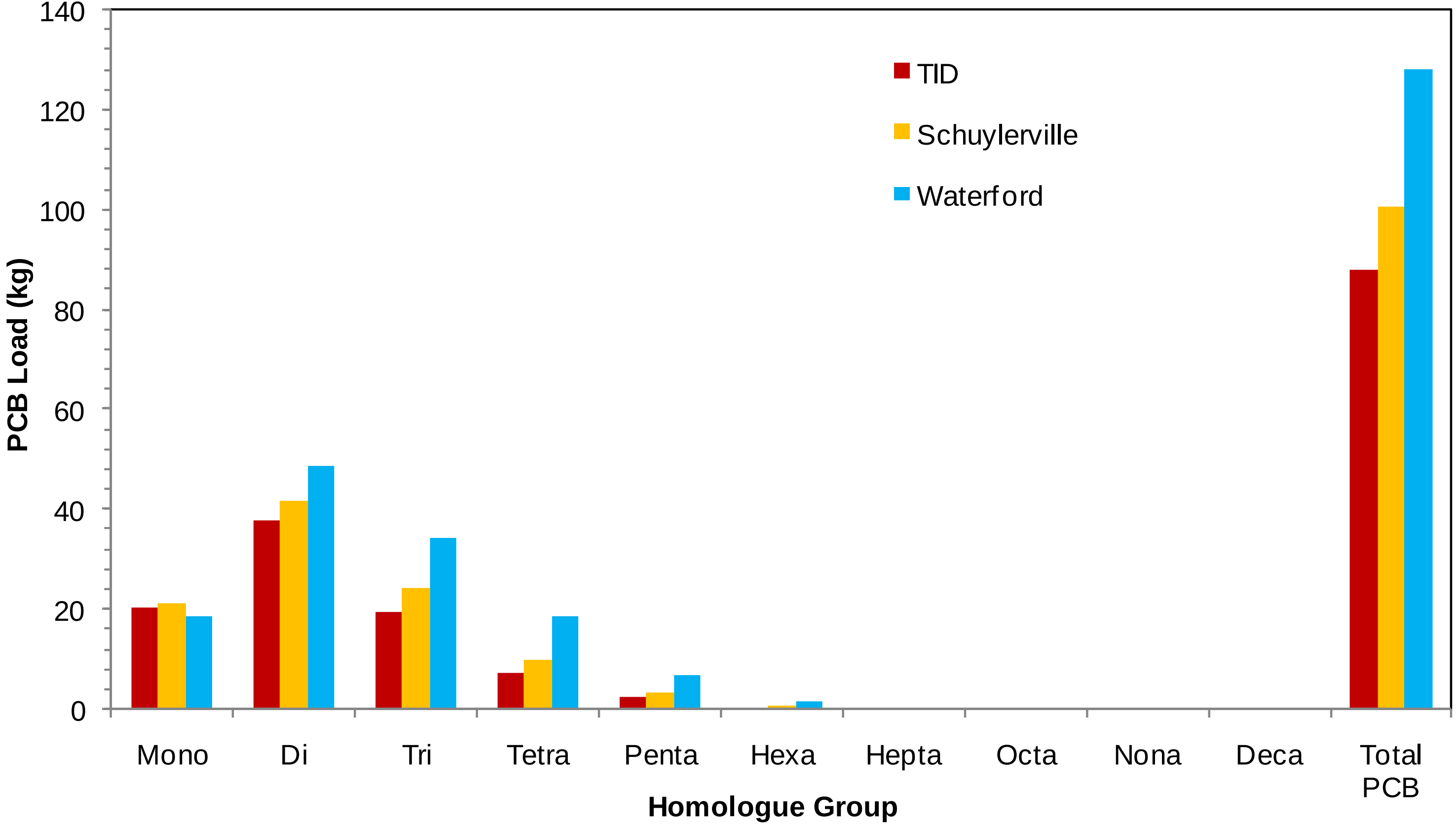
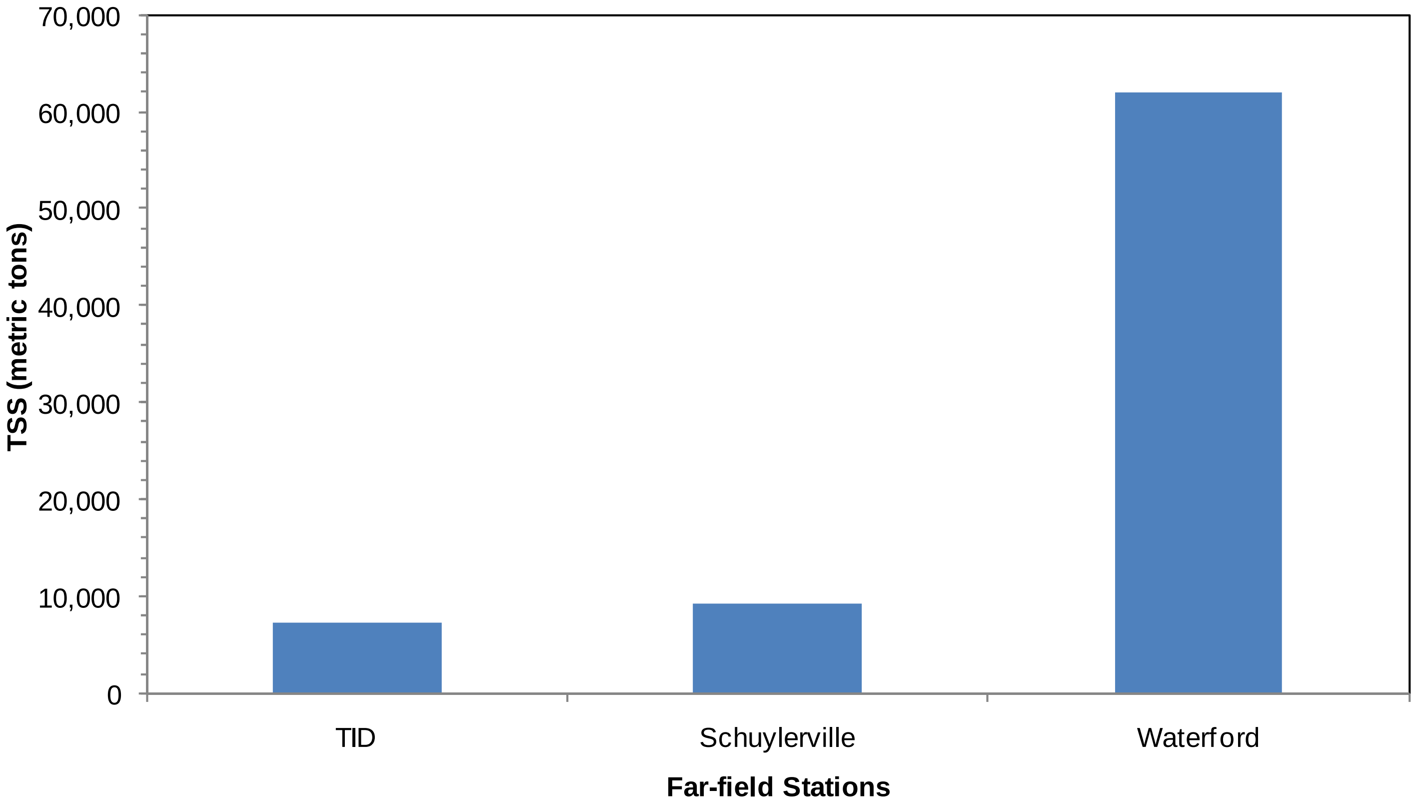


Figure 1-D-2b



Average Cumulative Homolog, Total PCB Loads and TSS at Far-Field Stations under Baseline Conditions for May to November (2004 to 2008)

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-D-2

April 2010

Figure 1-D-3a

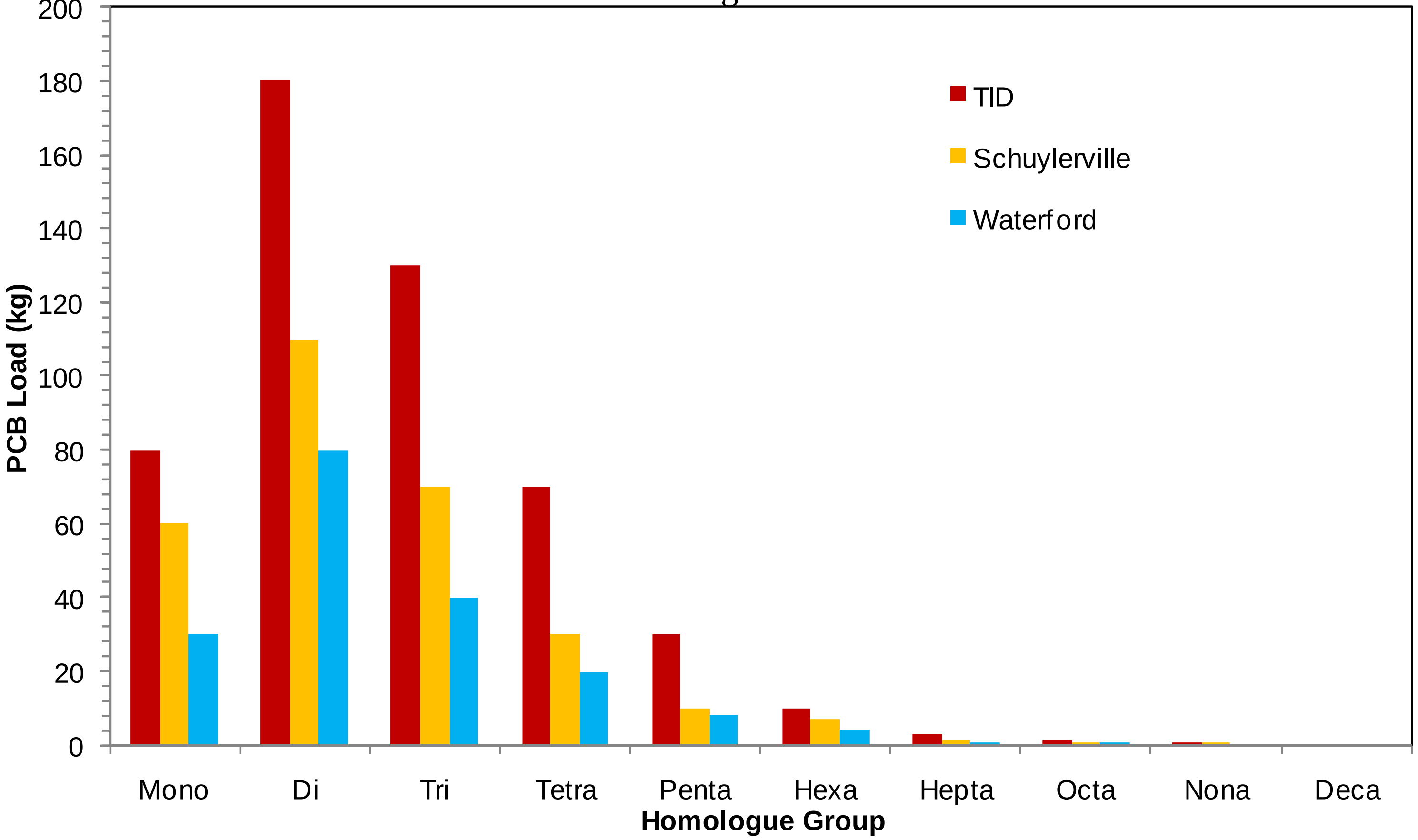
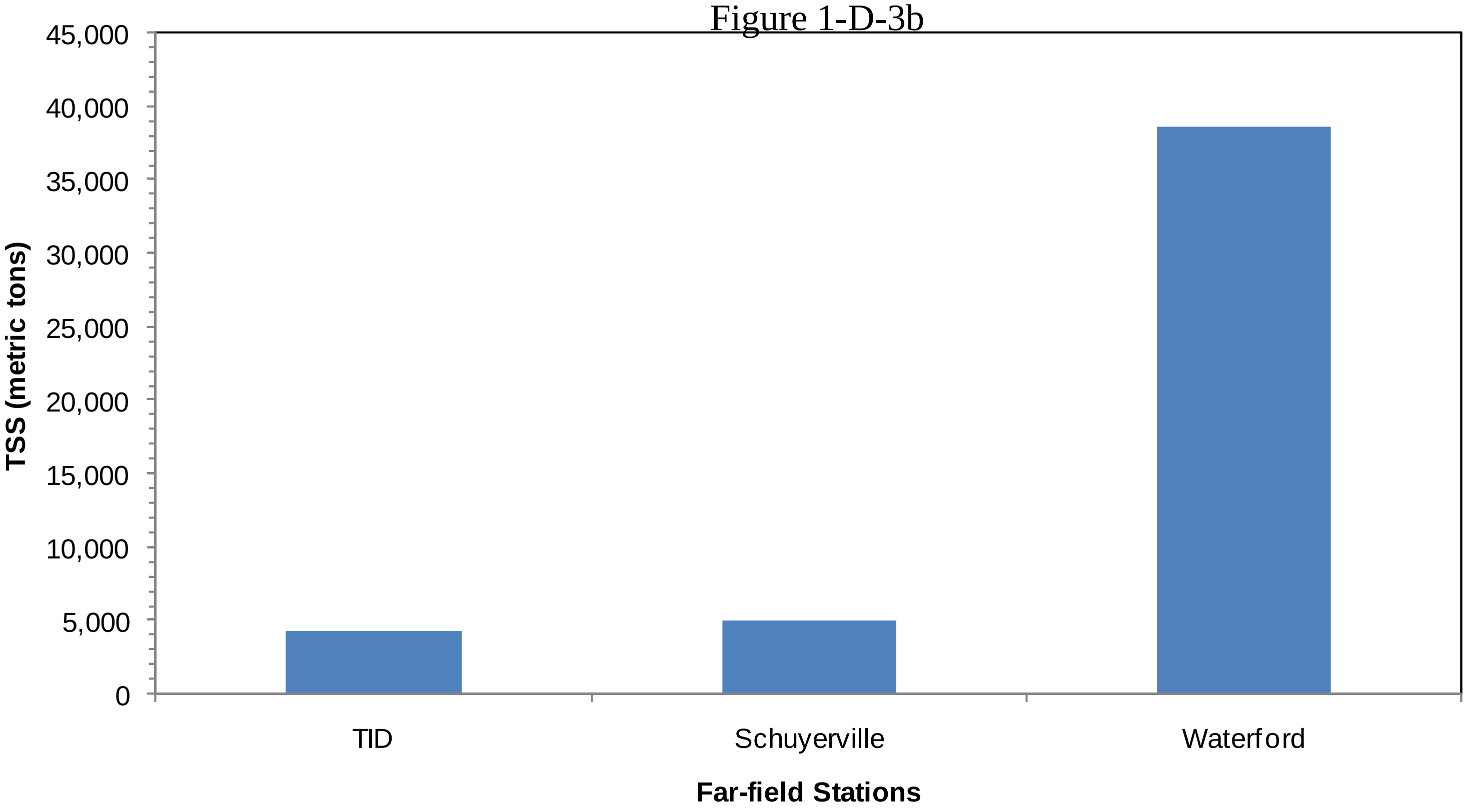


Figure 1-D-3b

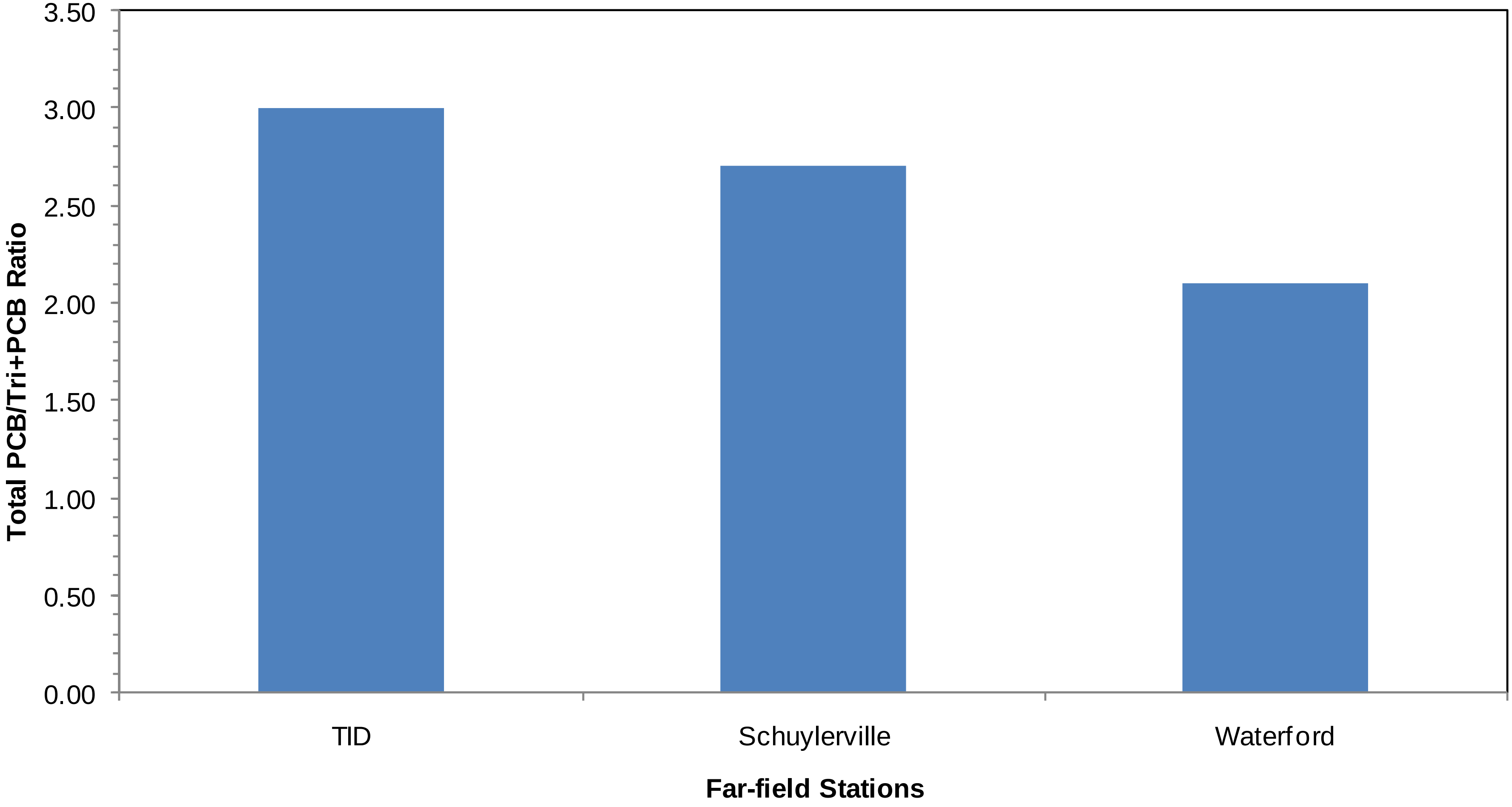


PCB Homolog Loads and TSS Load for July 5 to October 27, 2009
at Far-Field Stations during Dredging

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 1-D-3

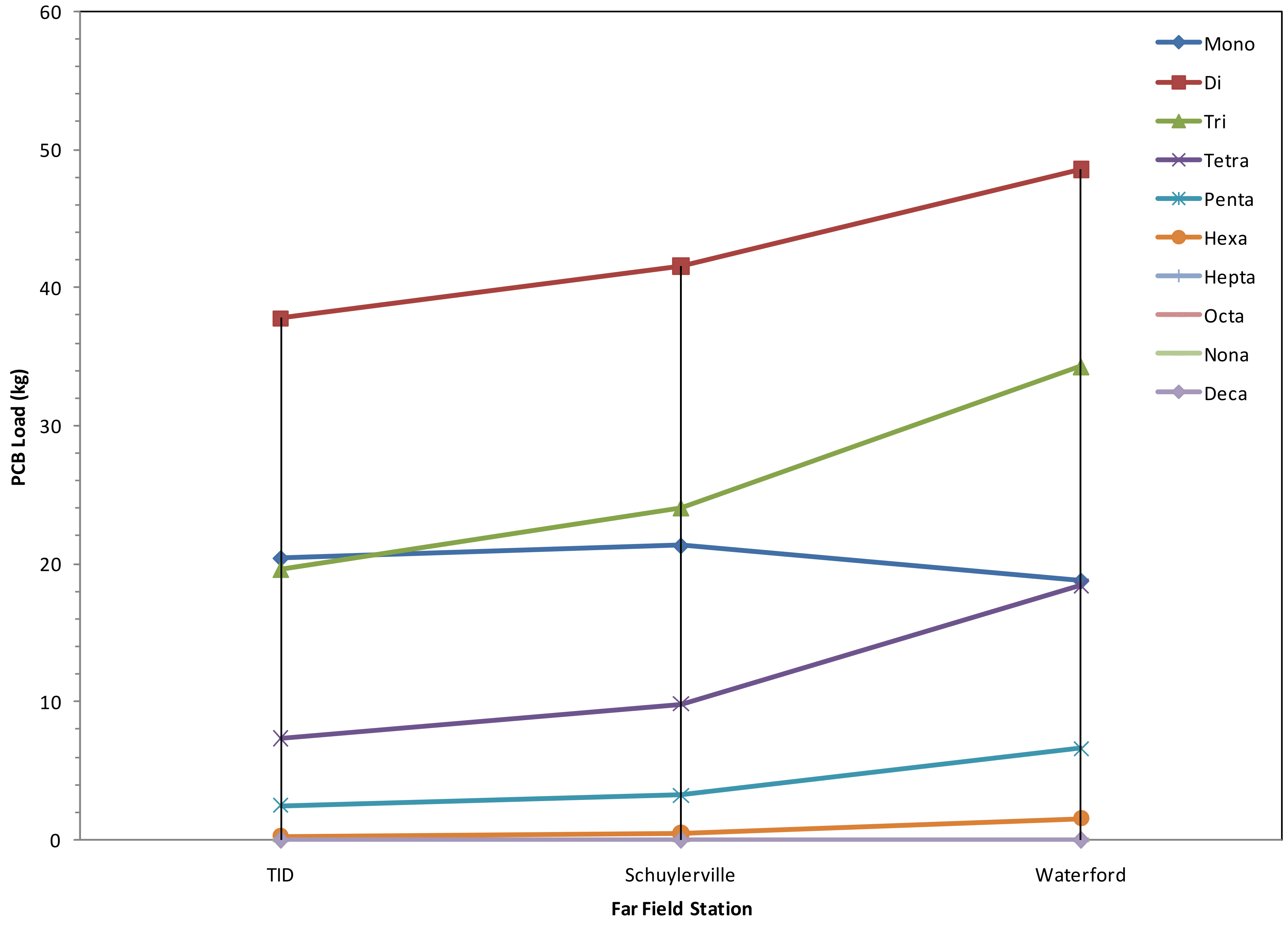
April 2010



Average Total PCB/Tri+PCB Ratio at Far-Field Stations under Baseline Conditions for May to November

Figure 1-D-4a

April 2010

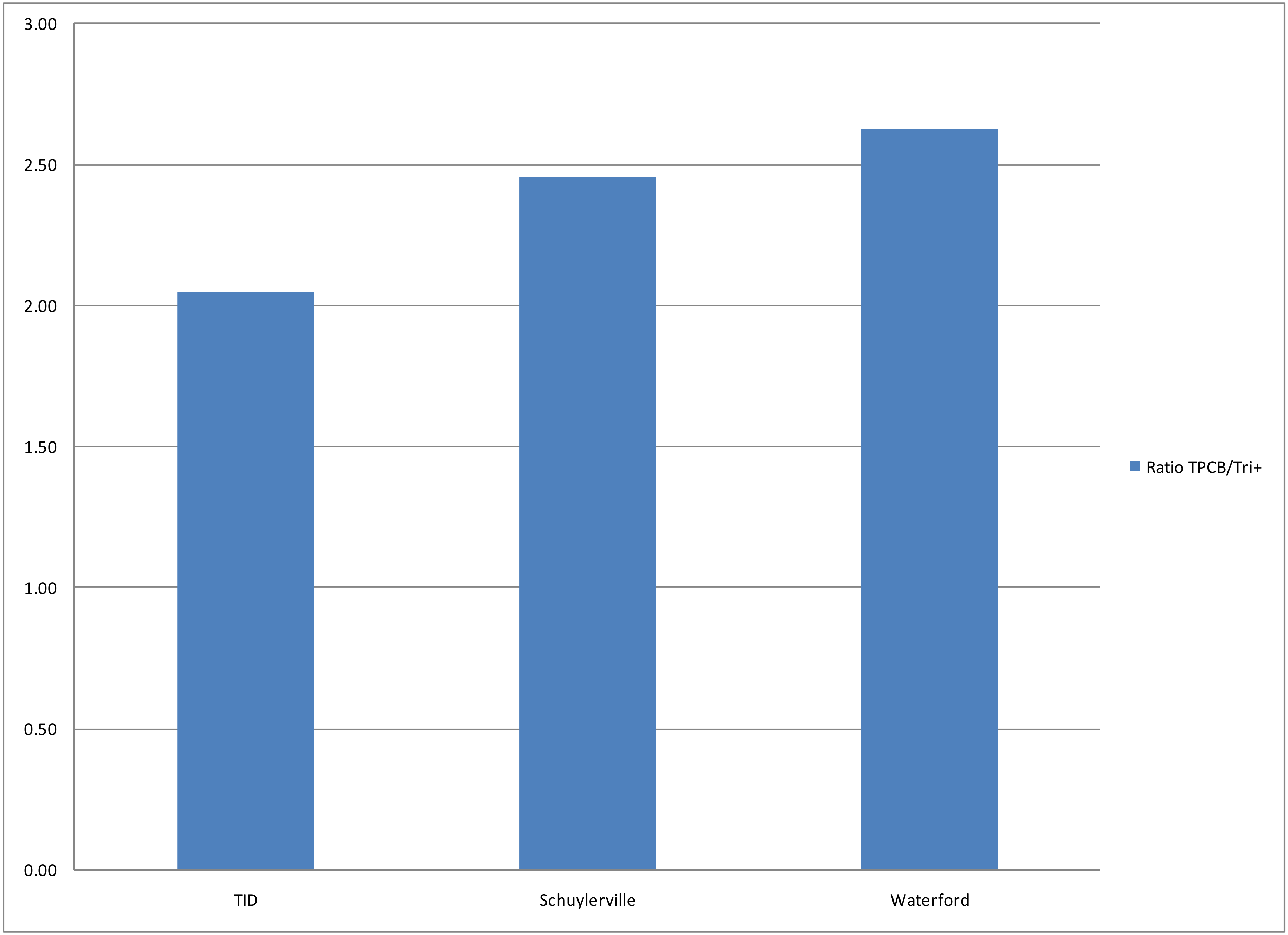


Average of PCB Loads Measured at Far-field Stations during Baseline Period (2004 - 2008)

EPA Phase 1 Evaluation Report - Addendum- Hudson River PCBs Site

Figure 1-D-4b

April 2010

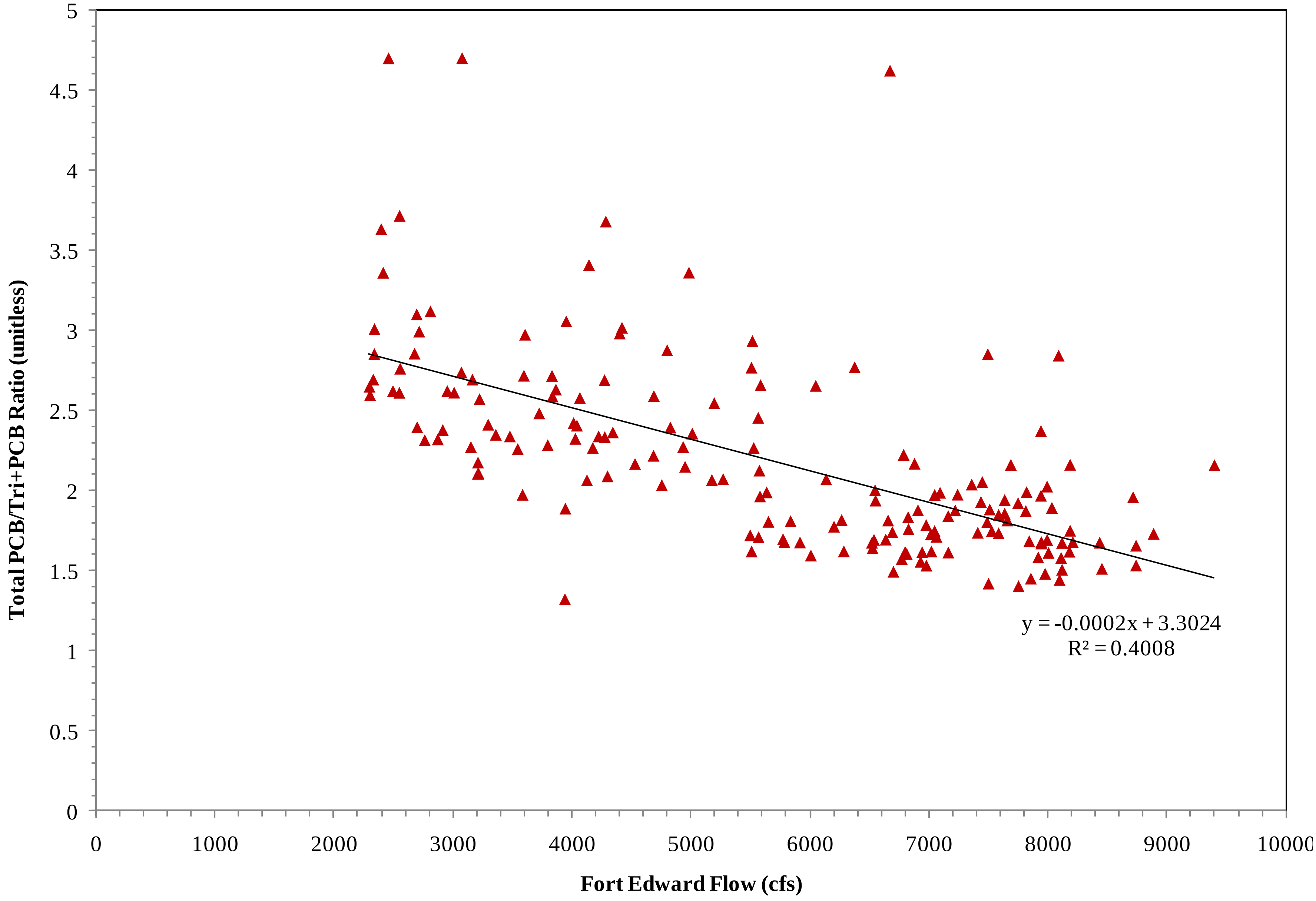


TPCB/Tri+ Ratio for July 5 to October 27, 2009 at Far-Field Stations during Dredging

EPA Phase 1 Evaluation Report - Addendum- Hudson River PCBs Site

Figure 1-D-4c

April 2010

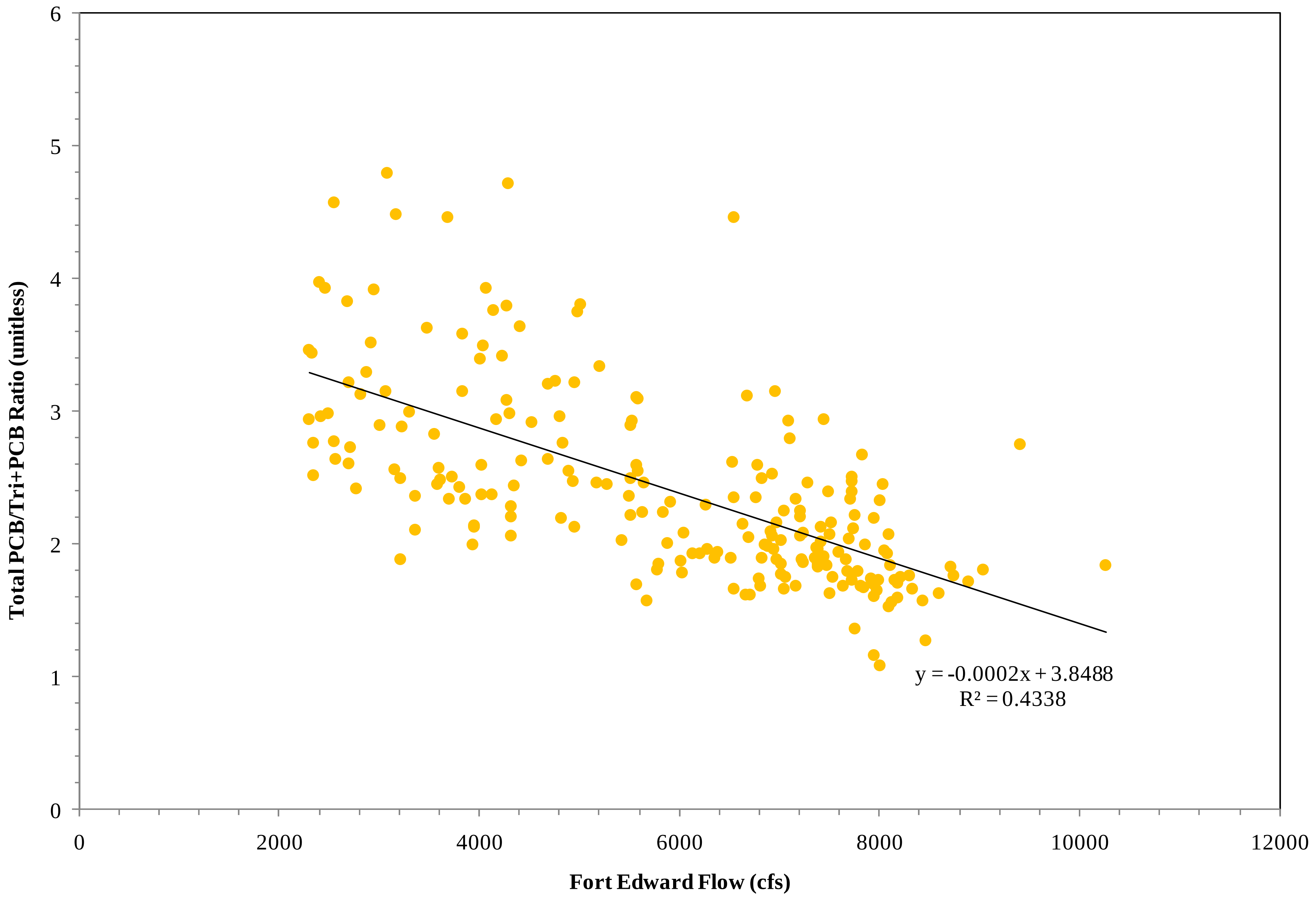


TPCB/Tri+PCB Ratio vs. Fort Edward Flow at Thompson Island During Dredging

EPA Phase 1 Evaluation Report - Addendum- Hudson River PCBs Site

Figure 1-D-5a

April 2010

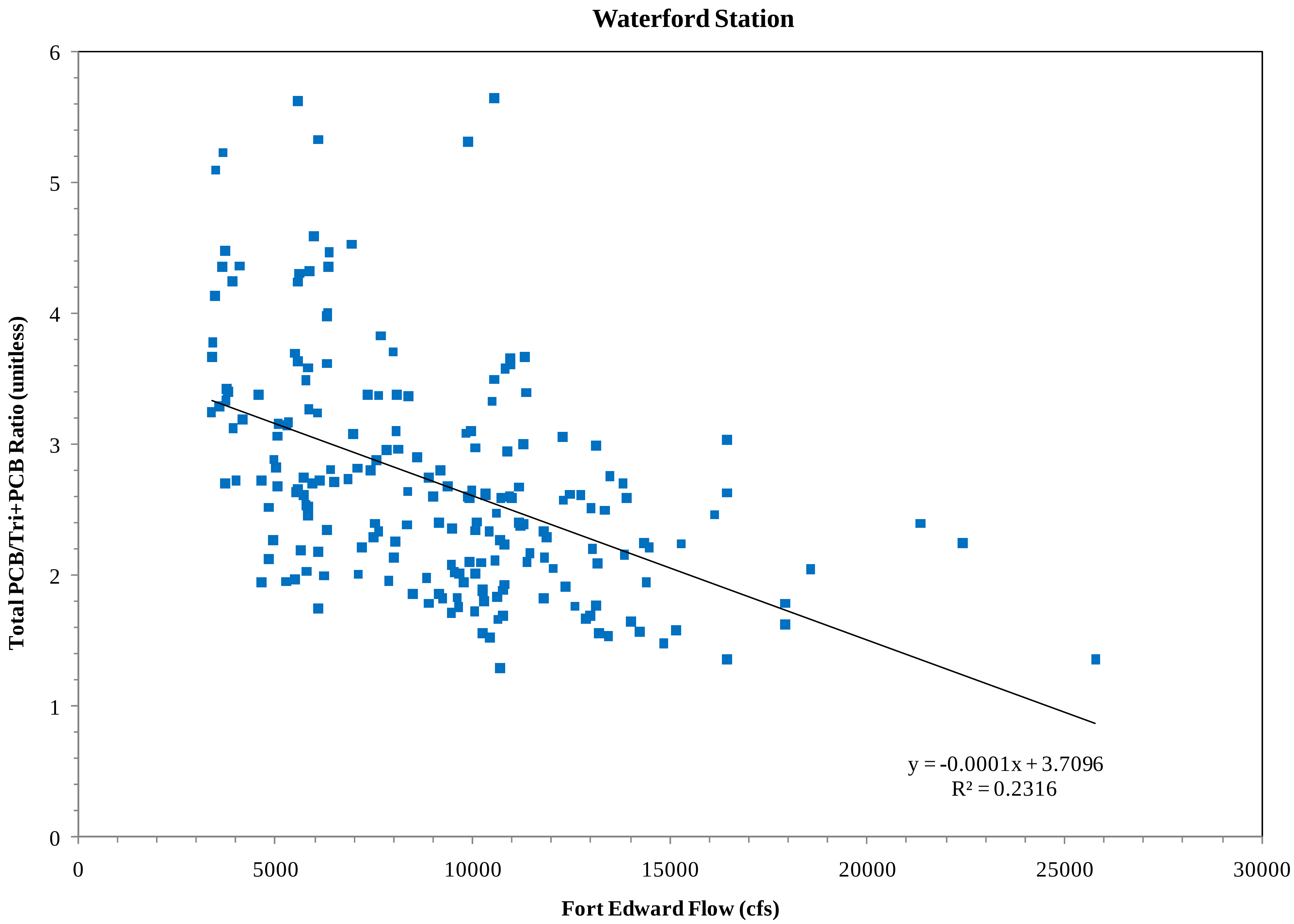


TPCB/Tri+PCB Ratio vs. Fort Edward Flow at Lock 5 During Dredging

EPA Phase 1 Evaluation Report - Addendum- Hudson River PCBs Site

Figure 1-D-5b

April 2010

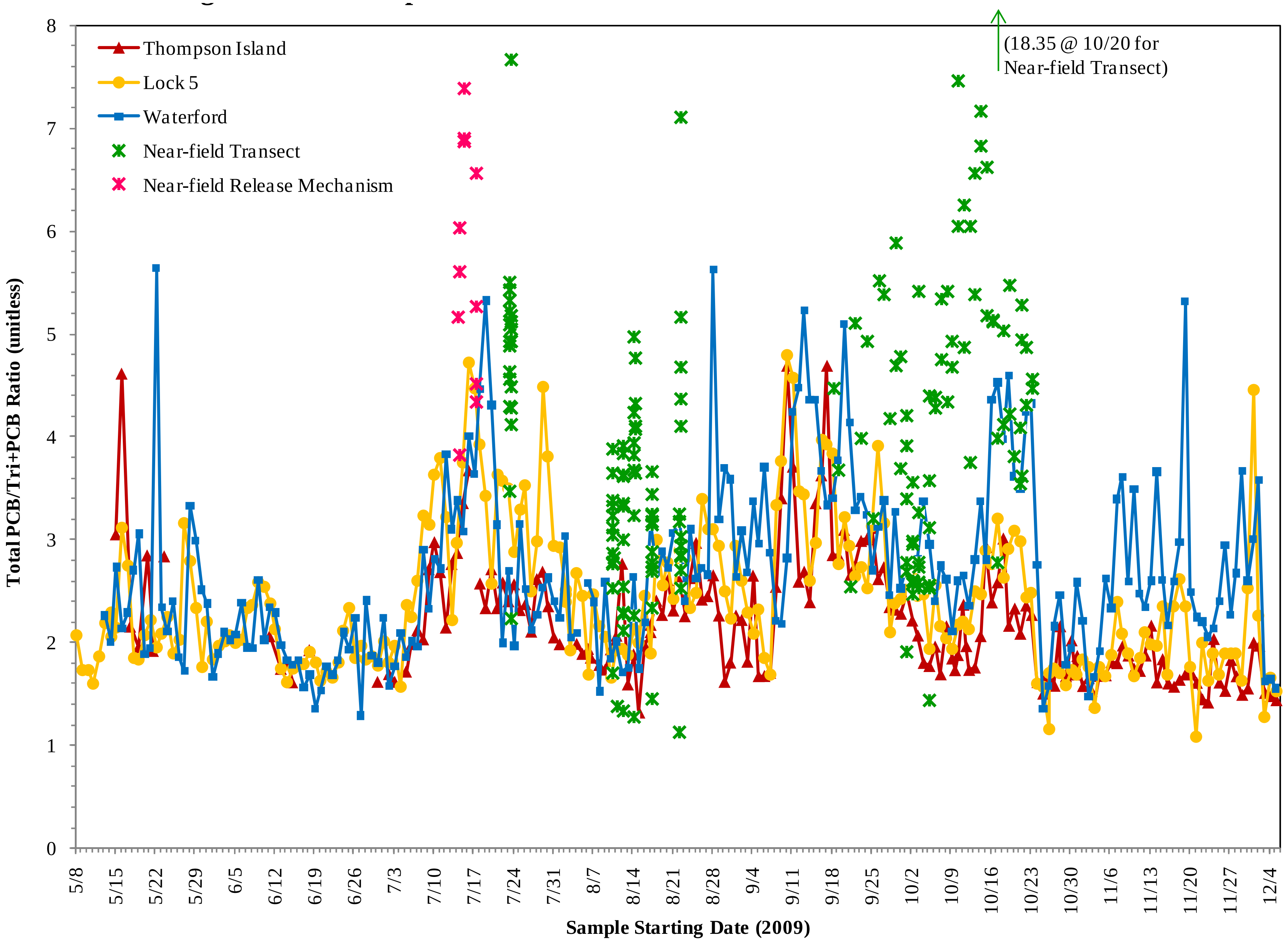


TPCB/Tri+PCB Ratio vs. Fort Edward Flow at Waterford During Dredging

EPA Phase 1 Evaluation Report - Addendum- Hudson River PCBs Site

Figure 1-D-5c

April 2010



Comparison of Near-field and Far-field Total PCB to Tri+PCB Ratio

EPA Phase 1 Evaluation Report - Addendum- Hudson River PCBs Site

Figure 1-D-6

April 2010

TOPIC 2

CAUSES OF RESUSPENSION DURING PHASE 1 DREDGING

Topic-2 -Causes of Resuspension during Phase 1 Dredging

Abstract

Water column PCB concentrations at Thompson Island Dam (TID) were compared with daily measurements of dredging and backfilling processes to develop multiple regression models (Kern Statistical Services, Inc. 2010). The analysis concludes that the mechanisms associated with increased water column PCB concentrations are varied and likely many and should not be simplified to a simple proportionality to mass or volume removed. Rather, metrics quantifying Phase 1 dredging are the most promising guide to how dredging and other activities could be modified to reduce resuspension of PCBs in Phase 2. Using a combination of Factor Analysis and Multiple Regression of the daily process and water column data, EPA has determined that process metrics are positively associated with and influence release and resuspension of PCB contamination. These metrics include:

1. Sediment removal (*i.e.*, bucket counts, volume removed, mass removed),
2. Flow rate,
3. Vessel traffic (primarily distance traveled by scows pushed by tugs),
4. The number of certification units (CUs) being backfilled in any given day,
5. The area and concentration of disturbed sediments in CUs open to the water column, and
6. Bucket fill-rate and other surrogates to PCB contaminated sediment and water spillage.

Given EPA's understanding that the primary drivers of resuspension are associated with the collective group of 6 process variables identified above, it is reasonable to expect that if these six process variables are adjusted to levels observed during periods of resuspension less than 200ng/l and productivity on the order of 3,000 to 3,500 cubic yards per day (August 9 to September 7, 2009 and September 11 to October 5, 2009), future resuspension results would be improved over the Phase 1 performance. This analysis also indicates that Phase 2 dredging can be conducted in a way that results in reasonable resuspension rates and also meets productivity goals.

2.2.Introduction

In their Phase 1 Evaluation Report, GE has indicated that:

1. Phase 1 demonstrated that the Resuspension Standard cannot be met (ES-5), and that EPA's proposed increase to the load standard would compromise the remedy (ES-7).
2. The federal drinking water standard of 500 ng/L PCBs will be exceeded frequently in Phase 2 because of higher rates of dredging and fewer resuspension control opportunities than in Phase 1.
3. Re-deposition in non-dredge areas will compromise remedy benefits.
4. There are no practical means to reduce resuspension to avoid exceeding the Resuspension Standard.

Further, GE has adopted the view that the apparent relationship between *dredged volumes of sediment and resuspension is inevitable*. Based on recent analysis (Kern Statistical Services, Inc. 2010) included as Attachment 2 to the Addendum, it can be concluded that this view is over-simplified and that the mechanisms associated with increased water column PCB concentrations are varied and, likely, many and should not be reduced to a mere proportionality to mass or volume removed, as suggested by GE. EPA agrees that mass or volume removed is a surrogate for the net effect of all of the processes involved in dredging, and therefore correlates well with water column PCB concentrations. However, this does not preclude that individual operational variables can be managed to reduce resuspension of PCBs. The manner in which dredging and other related activities were conducted during Phase 1 is very important and, therefore, provides a good source of information on how dredging and other activities could be modified to reduce resuspension of PCBs in Phase 2.

EPA's analysis of factors associated with water column PCB concentrations has found that while water column PCB concentrations are indeed positively associated with mass of PCBs removed, a more careful analysis indicates that this relationship is due to a combination of several operational factors, some of which are readily manageable in ways that would logically be expected to reduce PCB releases associated with dredging operations. EPA also observes that there were periods of time in Phase 1 when resuspension rates were low (less than 200 ng/l, and productivity was adequate to meet proposed Phase 2 productivity criteria.

Based on a multivariate analysis of the daily process and water column data, EPA finds that water column PCB concentrations are positively associated with several factors, all of which would be expected to influence release and resuspension of PCB contamination, including:

1. Sediment removal (*i.e.*, bucket counts, volume removed, mass removed),
2. Flow rate,
3. Vessel traffic (primarily distance traveled by scows),
4. The number of CUs being backfilled in any given day,
5. The area and concentration of freshly disturbed sediments in CUs open to the water column each day, and
6. Bucket fill-rate, cycle time and other surrogates to sediment spillage.

Thirteen of the 28 process variables (shown in Tables 2-1 through 2-3) considered by EPA demonstrated statistically significant positive associations with water column PCB concentrations with squared Spearman Rank correlation coefficients ranging from approximately 0.2 to 0.4. These levels of association are individually weak, indicating that no single process can be identified as "*the source*" of resuspension; but rather a complex set of interactions among processes appears most likely to be "*causative.*" The well known adage is that "association does not imply causation" but, conversely, lack of apparent association also does not eliminate causation. It is expected that multiple variable models may be necessary to adequately explain variation in water column concentrations. It is further expected that controlling PCB resuspension may be accomplished through a combination of additional or improved management practices / strategies applied to several stages in the sediment removal and backfilling process.

2.3.Objective

The primary objective of EPA's analysis is to develop an empirical data-driven model describing water column concentrations of total PCB as a function of physical and operational variables associated with remedial activities in the Phase 1 project.

2.4.Method

Data specific to individual CUs from the Phase 1 project provides the basis to develop an empirical model of water column concentration as a function of measured data collected on a daily basis specific to the operations in the Thompson Island Pool in 2009. A combination of factor analysis (Seber, 1977) and multiple regression (Neter *et al.*, 1996) is used to statistically identify groups of parameters most strongly associated with water column PCB concentrations. This empirical approach provides the opportunity to test hypotheses and assumptions that otherwise would remain untested in more typical situations where data are less rich—providing the means to evaluate the influence of various remediation processes on water column concentration.

The data include metrics quantifying potential sources of PCBs associated with:

1. Flow and temperature conditions,
2. Debris removal,
3. Volume and mass removed,
4. Vessel traffic,
5. Efficiency of removal operations,
6. Resuspension of exposed PCB deposits in open CUs, and
7. Sediment disturbance associated with backfilling.

In EPA's analysis, 28 variables were tested statistically for potential to predict water column PCB concentration at far field stations downstream of dredging operations. Data were summarized on a daily basis, so for most variables there were approximately 166 days (May 15 through October 27, 2009) on which PCB concentration could be compared with dredging process variables. Some variables such as bucket fill rates were only available on the 127 days when active dredging occurred within the 166 day time period. Therefore the analyses were repeated for variables measured on all 166 days as well as for the subset of variables measured on just 127 days, primarily after June. Data measured on the smaller subset of days are more closely associated with how dredging was conducted and are therefore the more likely source of information on how dredging and other activities could be modified to reduce resuspension of PCBs to the water column.

2.5.Modeling Overview

This factor analysis and regression approach is used to develop a model of the form

$$C_{water} = C_{baseline} + K_1 C_{Source-1} + K_2 C_{Source-2} + \cdots + K_n C_{Source-n} \quad (1)$$

Where the constants $K_1, K_2, K_3,\ldots K_n$ are loosely interpreted as "*net*" sediment-to-water partitioning coefficients for each source, and where it is understood that source terms are based on surrogates for sediment removal processes.

The Phase 1 project is unique in the richness of data available to not only estimate these coefficients, but also to identify those combinations of measured processes that are most important for predicting water column concentrations. A combination of factor analysis and multiple regression analysis is used to identify metrics contributing significantly to prediction of water column PCB concentrations. These are further described in Attachment 2.

2.6.Results – Bivariate Correlations

EPA identified thirteen variables representing 5 groups of processes that were associated with water column PCB concentrations at the Thompson Island Dam monitoring station (TID). Five variable groups (factors) were identified that collectively explained 55 and 60 percent of the variation in water column PCB concentration in the 166-day and 127-day models, respectively. These factors represented volume and mass removed and efficiency, area of recently disturbed sediments in open certification units, vessel traffic and backfilling. Following is a summary of the results of the analysis.

Squared Spearman Rank correlation coefficients for water column PCB concentration with each of the process variables are reported in Table 2-1. The analysis was repeated with process variables paired with one-day and two-day lagged PCB concentrations to evaluate the potential effects of travel time on the strength of correlation. These squared correlation coefficients represent the proportion of variation explained by the relationship between water column PCB concentration and each variable, analogous to an R^2 from a regression. The Spearman correlation coefficient is preferred because the assumption of linearity inherent in the Pearson's coefficient is relaxed. Results summarized in Table 2-1 show that:

1. Correlations between water column PCB concentrations and process variables are generally weak, ranging from 2 percent for debris removal to 42 percent for volume and mass removal, indicating that no single variable could be expected to adequately explain the fluctuations in water column PCBs observed during the Phase 1 project.
2. Correlations for water column concentrations that were lagged by one day were less than those for concurrent measurements and two-day lagged measurements produced still lower correlations.
    a. In contrast GE asserted that weekly averages were needed to counter the effects of travel time in their analysis of the water column PCB data.
    b. EPA views this as counterproductive given the lack of correlation between lagged water data and process variables.
    c. Weekly averaging would artificially reduce the power to detect subtle multiple variable relationships, thereby suppressing our ability to identify potentially important relationships between water column PCB concentration and operational variables.
3. Statistically significant positive associations were identified for most processes expected to disturb sediments

   a. Volume and mass removed (R^2=0.22 to 0.42)
   b. Dredging efficiency measures such as bucket fill rate and depth of cut (R^2=0.08 to 0.22)
   c. Sources due to area of open CUs (R^2=0.15 to 0.19)
   d. Debris removal (R^2=0.02)
   e. Boat traffic (R^2=0.11 to 0.26)
   f. Backfilling operations (Number of CUs being backfilled) (R^2=0.09)
4. Weak statistical relationships may be indicative of surrogate relationships that are markers for important, but crudely quantified, sources of PCB resuspension.
5. Water column concentrations were negatively associated with flow at the Fort Edward Station, but the relationship was not statistically significant.

2.7.Regression on Factor Scores – Factor Analysis

Because water column PCB concentrations were weakly associated with several individual operational variables, EPA developed a multivariable model that would adequately explain water column PCB concentrations. In order to understand interrelationships between process variables a factor analysis was conducted to identify a set of independent factors that would be meaningful, as well as providing inputs for a regression model predictive of water column PCB concentrations.

The factor analysis was conducted with only the predictor variables for the subset measured on all 166 days, as well as the subset measured on just 127 of the 166 days. Resulting factor scores were used as predictors in a regression analysis to identify important factors for prediction of water column PCB concentrations.

2.7.1. Factor Analysis (127-day model)

Table 2-2 shows the factor loadings for each of the 28 process variables under consideration. The factor loadings are unitless and range from plus one to minus one and are considered meaningful when they exceed approximately 0.4 in magnitude. Cells in Tables 2-2 and 2-3 are shaded green to draw attention to factor loadings that exceed this nominal level.

There were 5 factors associated with total PCB concentration in the water column describing from 2 to 37 percent of the total 60 percent variance in water column PCB concentration explained by the regression model.

Factor-1 includes loadings on bucket counts, mass removed, volume removed, residual Total PCB Concentration in Open CUs and the product of mass and removal efficiency (ME). Factor-1 summarizes potential PCB sources from variables that are directly related to sediment removal, as well as efficiency of the removal process.

Factor-6 is most heavily weighted on the amount of backfilling being conducted and the product of flow and backfill (a surrogate for load from backfilling). Factor-6 also has substantial negative loadings on bucket counts and temperature. This may reflect that bucket counts coincidentally vary inversely with temperature and backfilling operations (*i.e.*, it is coincidental that dredging started slowly when temperatures were colder, increased through the summer and then declined in the fall when temperatures also declined and backfilling commenced).

Factor-7 is most heavily weighted on concentration-weighted surface area of open CUs and the product of flow and concentration-weighted surface area of open CUs. Factor-7 has a clear signal exclusively related to the amount of open CUs at any point in time that is independent of volume and mass removal.

Factor-8 is most heavily weighted on flow, and the product of flow and total vessel traffic. Factor-8 is also independent of variables in Factor-1 describing removal metrics, indicating that there may be an independent PCB source to the water column associated with vessel traffic. This variable is a crude measure of potential sources due to vessel traffic, because it does not account for either water depth or concentration of areas over which traffic occurs. It is expected that refinement of this variable will substantively improve its relative strength as a predictor of water column concentrations.

Factor-9 is most heavily weighted on boat distance, which is a single metric that only accounts for distance traveled by vessels.

As a general observation, these results show that resuspension of PCBs to the water column is associated with a combination of removal activities, backfilling activities, vessel traffic and the surface area and duration that disturbed residuals are exposed in open CUs. This indicates that additional or improved management practices could be applied to one or several of these processes to reduce concentrations of PCBs in the water column.

2.7.2. Factor Analysis (166-Day Model)

The factor loadings for the 166-day model are summarized in Table 2-3. Results were similar to those for the 127-day model because the majority of data were common to both models. The model fit was slightly weaker with an adjusted R^2=0.55 as compared with 0.60 for the 127-day model. The five factors were qualitatively similar to those identified in the 127-day model representing variables associated with sediment removal (semi-partial R^2=0.28), backfilling (semi-partial R^2=0.06), concentration-weighted surface area of open CUs (semi-partial R^2=0.04), flow times vessel distance (semi-partial R^2=0.05), and mass removed (semi-partial R^2=0.13). Because performance data related to bucket filling rates were not included in the 166-day model, the separation of variables among factors was less obvious and general surrogates for overall activity such as mass and volume removal and boat traffic tended to group together in the first factor. This shows that further refinements in the understanding of processes controlling fluxes of PCBs to the water column should focus on variables that characterize how dredging and other supporting operations are conducted as opposed to just on how much dredging is done.

2.7.3. Regression on Mechanistic Variables

Model fit was improved through inclusion of mechanistic variables that were summarized specific to individual CUs, increasing the adjusted R^2 for the 127-day model from 0.60 to 0.68. The primary improvements in model fit were due to incorporation of the dredge efficiency term in place of the more general mass removed term proposed by GE, and also importantly by differentiating vessel traffic by water depth and sediment bed concentration, and finally by incorporation of a source term specific to activities that occurred during dredging performed inside the sheet pile wall at CU-18, particularly in late July and early August.

2.8.Primary Mechanisms Influencing Water Column PCB Concentrations

A multiple regression model for water column PCB concentration was developed using individual measured variables rather than factors as described above. The model included 6 variables and the overall proportion of variation explained by the model was 0.68 and the proportion explained by each variable was: mass removal efficiency (partial R^2=0.25); boat traffic specific to backfilling operations (partial R^2=0.11); boat traffic specific to mass removal at CU-17 and CU-18 (partial R^2=0.01); flow at the Fort Edward station (partial R^2=0.08); the number of scows on queue for unloading (partial R^2=0.01) and mass removed from inside the sheet pile wall at CU-18 (partial R^2=0.03). When predictors are inter-correlated, the sum of the variance explained by each variable independently is often less than the total variance explained (*i.e.*, adjusted R^2). This component of the total variance is the variance explained jointly by the collection of variables in the model. In this case 19 percent of the variance was explained jointly, indicating that approximately a quarter of the variance explained by the model cannot be uniquely tied to any particular factor. These results are summarized graphically in Figure 2-1.

Figure 2-2 shows the fitted model plotted against time, along with the observed water column concentrations and upper 95 percent confidence limits for predicted PCB concentrations. This model based on mechanisms provides better agreement between observed and predicted values, particularly during early August and early September when there were high excursions in the TID PCB concentrations.

The mass removal efficiency variable was the primary predictor of water column concentrations explaining 24 percent of the total variance in water column PCB concentrations. This variable is comprised of the product of mass removed and apparent bucket fill rate. This variable identifies situations where mass removal is conducted when daily bucket fill rates are calculated as greater than 100 percent (thought to represent situations where multiple bucket closures are counted as a single bite due to debris or less-well controlled operations). EPA evaluated whether this correlation between dredging efficiencies and water column concentration could be due primarily to correlation with mass removed. This hypothesis was tested by comparing model fit for a model including mass removed alone with a model including mass removal efficiency. The model including the other four variables identified above, plus mass removal efficiency, had an adjusted R^2=0.68, while the model including the same four variables and just mass removed (*i.e.*, without multiplying by efficiency) had an adjusted R^2=0.60. This indicates that mass removal efficiency was a better predictor of water column concentration than mass removed alone. This relationship indicates that, in addition to simple proportionality of mass removed, unclosed dredge buckets (and potentially other inefficiencies) also contributed to resuspension of PCBs to the water column.

Disturbance due to tug traffic in shallow areas between CUs 17 and 18 and the Lock 7 entrance was found to contribute significantly to water column concentrations (semi-partial R^2=0.11). A plot of water column PCB concentration vs. tug traffic weighted by depth and concentration is given in Figure 2-3. This term might also be thought to be a surrogate for mass removed from CUs 17 and 18; however, it was found that mass removal in CUs 17 and 18 (outside sheet pile) was poorly correlated with water column PCB concentrations. This suggests that the tug traffic associated with removal of 2600 kg of PCBs from CUs 17 and 18 (outside the sheet pile containment) caused erosion and resuspension of PCB-contaminated sediments in areas with water depths less than 11 feet.

Dredging declined through October, ending on October 27, yet water column concentrations remained elevated at TID. Disturbance due to shallow-water tug traffic primarily servicing backfilling operations was associated with water column concentration (partial R^2=0.11). Because the act of backfilling itself is unlikely to cause resuspension of PCBs on the order of dredging, this relationship represents strong evidence that tug traffic in shallow areas caused disturbance and resuspension of PCBs to the water column. Water column PCB concentrations were on the order of 300 ng/L during October when nearly all sediment disturbance was caused by backfilling and capping operations. These water column PCB concentrations are similar to those observed during June and July 2009 when most disturbance was associated with dredging-related activities, including tug traffic. Backfilling itself should be a relatively innocuous activity because clean fill was placed on sediments that generally had much lower PCB concentrations than the material removed. However, capping was performed over inventory due to schedule constraints, in some cases with elevated concentrations, but disturbance of those areas should be less than occurs with dredging. This indicates that tug traffic was the likely cause of disturbance leading to resuspension of PCBs during October 2009, as opposed to merely acting as a surrogate for mass removal.

Tug traffic was associated with water column PCB concentration during both backfilling and dredging operations. If tug traffic were merely a surrogate for mass removal as opposed to a causative agent, one would not expect to see the tug traffic signal in the water column record during backfilling. This indicates that resuspension due to tug traffic is likely to be a true causative factor of resuspension as opposed to a mere surrogate. Based on these findings, GE should consider alternative processes for distribution of cap and backfill material that minimize tug traffic.

Improvement in model fit during the late July to early August period was due to inclusion of the variable quantifying mass removed in CU-18 from within the sheet pile wall. As these activities were conducted within the confines of the sheet pile, this is counter-intuitive, but it is thought that this spike in water column concentrations, particularly during late July and early August, may be due to the release of extremely highly concentrated PCB contaminated water associated with accidental losses and bucket decanting as sediment (and water) was lifted over the sheet pile and into scows. For example, in a letter to EPA dated August 14th, 2009, GE reported water column PCB concentrations within the sheet pile of 12,800 ng/l, 116,000 ng/l and 19,800 ng/l, on July 31, August 5 and August 8, respectively. This was during the period of time when dredging activities were conducted within the sheet pile and when water column PCB concentrations spiked at TID.

Dredging in CU-18 was initiated in late July 2009 and at this point in time water column concentrations increased dramatically at TID to some of the highest levels observed during the Phase 1 removal. Although there was much less PCB mass produced in CU-18 (inside the sheet pile) (430kg) in comparison to CUs 17 and 18 (outside the sheet pile) (2600 kg), and in spite of the fact that the sheet pile wall was in place to contain resuspended PCBs, mass removal in this CU was strongly associated with water column PCB concentrations. PCB concentrations in water inside the sheet wall were on the order of 20,000 ng/L and exceeded 100,000ng/l on at least one occasion. In late August when some sheet piling was removed, and dredge equipment was moved in and out of CU-18, PCB concentrations exiting the sheet pile area were on the order of 2,000 ng/L. The response in PCB concentrations at TID was nearly immediate, particularly in late July and Early August and much greater in magnitude than would have been expected, given the small mass of PCBs removed from inside the sheet pile wall, and the fact that flow rates were apparently restricted by the sheet pile. Water column PCB concentrations at TID during these episodes were higher than at any other time during the Phase 1 removal, indicating that processes other than mere proportionality to mass removed are important to explain PCB resuspension to the water column.

Associations between dredging activities at CU-18 and water column PCBs were statistically significant, in spite of the fact that activities inside the sheet pile at CU-18 were of relatively short duration and represented a very small fraction of the mass removed in Phase 1. While this operation was relatively small, its influence was disproportionately large; the related activities represented 3 percent of the total variance explained in water column concentrations over the entire dredging and backfilling season. Conversely, nearly 6 times as much PCB mass was produced from CUs 17 and 18 (outside the sheet pile wall), and yet the response in water column PCB concentrations was minimal after adjusting for the other factors included in the model. This shows that combinations of other factors better describe water colum PCB concentrations than a simple proportionality to mass removal rates. Otherwise, general dredging activities at CU-17 and areas outside the sheet pile at CU-18 should have been more strongly correlated with water column concentrations than the much smaller mass removal from inside the CU-18 sheet pile.

Flow at the Fort Edward Gauge was also included in regression models and was found to be an important predictor of PCB concentration at TID. Because water column PCB concentrations were found to be correlated with flow it is important that any analyses attempting to explain variation in water column PCB concentrations during dredging should explicitly account for variations in flow. Regression models between loads and flow are not valid for inference to causative mechanisms, because load is a function of flow. It is not valid to “regress” a function of flow against flow, because the 1 to 1 correlation of flow with itself is sure to cause a false but apparent correlation between the functions of interest.

2.8.1. Model Predictions

The fitted model results are plotted on Figure 2-4 showing that the modeled concentrations generally track day to day fluctuations in concentration in most months, including patterns observed in October that were not well described by GE’s simpler model. This shows that GE’s assertion that concentrations are driven exclusively by the amount of dredging is not justified. Also included in the plot are upper 95 percent prediction limits which are an added benefit of the regression approach to model development. It can be seen that the prediction intervals capture the majority of observations.

2.8.2. Process Settings for Phase 2

This analysis identifies 6 parameters that collectively explain a large proportion of the variation in water column PCBs at TID. There were periods of time when dredging and backfilling produced PCB concentrations at TID below 200 ng/l (August 9 to September 7, 2009 and September 11 to October 5, 2009) and yet productivity was on the order of 2,500 to 3,500 cubic yards per day (Table 2-4). Within the August period of time active dredging occurred on 21 days, and productivity averaged 2,557 cubic yards per day, exceeding 3,378 cubic yards per day (EPAs proposed average daily productivity rate) on the three most productive days. There were also periods of time when PCB concentrations exceeded 300 ng/l on average (July 10 to August 9, 2009 and October 5 to October 27, 2009). Figure 2-5 compares the distribution of each of the 6 key process variables during these periods of time when resuspension was high with those periods when resuspension was low. The clear shift in distributions illustrates the magnitude of difference in how process variables were "set" during Phase 1. This shows that Phase 1 dredging was at times conducted in such a way that Productivity and Resuspension Standards were met simultaneously. For Phase 2 dredging, process variables should be targeted to meet the ranges identified in Figure 2-5 to achieve high productivity with the expectation of low frequency of resuspension exceedances. As noted in development of the performance standards, flow is an important predictor of concentrations and extreme flow events may precipitate higher water column levels, necessitating adaptive management actions.

2.9.Conclusions

The multiple variable factor analysis and corresponding regression is a first step in understanding the processes contributing PCBs to the water column. Several processes may be contributing to the PCB loads to TID far field station and there is potential to improve dredging processes while maintaining a high likelihood that EPA's proposed Resuspension Standard for Phase 2can be met. The most likely factors contributing PCBs to the water column are not unexpected—mass and volume removal, vessel traffic, exposure of freshly disturbed residual sediments to active flows, processes associated with backfilling, and the extent to which dredging may have encountered debris or have been less-well controlled, resulting in buckets that weren't fully closed and increasing the potential for PCB losses.

This analysis shows that a combination of processes are likely contributing measureable concentrations of PCBs to the water column, which presents an opportunity to fine tune dredging operations in Phase 2.

The factor-based model reported here supports the hypothesis that sources of PCBs to the water column are many and varied and that there are likely to be opportunities to minimize PCB resuspension during the upcoming Phase 2 dredging project. GE's statements in their Phase 1 evaluation report are not a reasonable response to the extensive information that is available to further refine and optimize the dredging operation. Regression of water column PCB concentration on mechanistic variables extends the multivariate factor analysis toward the goal of a predictive model than can be used to adjust dredging process parameters with an expectation of a commensurate response in water column PCB concentrations.

This analysis indicates that primary drivers of resuspension are associated with the collective group of 6 identified process variables. It is reasonable to expect that if these six process variables are adjusted to levels generally observed during periods of acceptable resuspension and productivity, future resuspension results would be improved relative to 2009 performance.

EPA recognizes that there are many process variables that may influence dredging performance that have either not been measured or, of those measured, did not result in discernable associations with TID water column concentrations. This analysis shows that resuspension and productivity standards were met simultaneously at times during Phase 1—therefore, it is possible to do so. It is also fully expected that a relatively wide range of combinations of process best practices could be used to achieve similarly reasonable resuspension rates at levels of production necessary to meet the Phase 2 Productivity Standard.

There may also be gross process changes in dredging and backfilling technologies that were not evaluated in Phase 1 that may achieve similar or larger reductions in resuspension than would be achieved through incremental changes in existing technologies. For example, this analysis identified tug traffic associated with both sediment removal and backfilling as being associated with water column concentrations at TID (Figure 2-3). Backfilling and capping material was transported to CUs using tugs and scows, so the majority of this tug traffic could be completely eliminated if backfill and cap material were pumped as slurry and applied hydraulically, rather than mechanically.

This analysis also supports the conclusion that Phase 2 dredging can be conducted with reasonable resuspension rates while meeting productivity goals.

References

General Electric, 2009. Letter to David King, USEPA dated August 14th, 2009. From Timothy Kruppenbacher.

Kern Statistical Services, Inc. 2010. Conditions associated with water column PCB concentrations: Thompson Island Dam 2009 multiple analysis of water column PCB and operational data.

Neter, J., Kutner, M.H., Nachtsheim, C.J., and W. Wasserman. 1996. Applied Linear Statistical Models, 4th ed., Irwin. Chicago.

Seber, G.A.F. 1977. *Multivariate Observations.* Wiley Series in Probability and Mathematical Statistics. John Wiley and Sons. New York, NY.

Table 2-1.
Squared Spearman rank correlation coefficients between water column total PCB concentrations lagged by 0, 1 and 2 days. Correlations are more often the strongest when based on concurrent measurements of water column PCBs and sediment disturbance and productivity factors.

Variable	PCB_ng/L	PCB_ng/L_Lag1	PCB_ng/L_Lag2
BargeDist	0.001	0.000	0.003
BargeV_D	0.005	0.004	0.001
BargeVel	0.003	0.002	0.001
BCntTotal	**0.217**	0.174	0.094
BoatDist	**0.338**	**0.315**	**0.189**
BoatV_D	**0.315**	**0.313**	**0.188**
BoatVel	**0.275**	**0.254**	**0.145**
Debris	**0.135**	**0.165**	**0.186**
DrdgDist	0.033	0.016	0.002
DrdgV_D	0.004	0.000	0.001
DrdgVel	0.001	0.002	0.010
Fill Rate	0.095	0.063	0.021
FlowFE	0.014	0.035	0.044
Load_Bfill	**0.091**	**0.094**	**0.094**
Load_CU_Area	0.191	0.190	0.193
Load_MassRem2	**0.379**	**0.316**	**0.191**
LoadBoats	**0.303**	**0.253**	0.136
MassRemTotal3	**0.417**	**0.323**	**0.185**
ME	**0.384**	**0.346**	**0.225**
SbDist	0.108	0.066	0.026
SbV_D	0.118	0.076	0.038
SbVel	0.022	0.007	0.000
ScowDist	**0.265**	**0.220**	**0.140**
ScowV_D	**0.257**	**0.225**	**0.144**
ScowVel	**0.178**	**0.125**	0.072
Temp_C	0.007	0.011	0.013
TotalBfill	**0.090**	**0.094**	**0.093**
tPCB_CU_AREA	**0.146**	**0.147**	**0.148**
VolRemTotal	**0.346**	**0.285**	**0.161**

Notes:

1) Gray cells indicate when water current water column concentrations correlate more strongly than lag-1 measurements or when lag-1 measurements correlated more strongly than lag-2 measurements.

2) Bold numbers indicate that correlations are significantly different from zero at the 5% level of significance.

3) Number of days represents the number of paired observations for values measured concurrently. Sample sizes associated with one and two day lags are reduced by one or two respectively.

Table 2-2.

Factor loadings for each variable for those factors found to be associated with water column Total PCB concentration in Thompson Island Pool from May to November in 2009, Hudson River. Loadings range from minus 1 to plus 1 and values greater in magnitude than 0.4 (green shaded and bold) are thought to be meaningful. Based on 127 day model.

Variable	**Factor1**	**Factor6**	**Factor7**	**Factor8**	**Factor9**
BCntTotal	**0.66**	**-0.40**	0.19	-0.07	0.13
BargeDist	-0.09	0.22	-0.10	-0.04	0.08
BargeV_D	0.02	0.06	-0.04	-0.10	0.09
BargeVel	-0.10	0.22	-0.11	0.00	0.04
DrdgDist	0.04	0.08	0.02	0.01	0.11
DrdgV_D	0.03	0.00	-0.05	-0.03	0.04
DrdgVel	-0.11	0.03	-0.12	0.01	-0.08
Load_Bfill	-0.16	**0.94**	-0.03	0.16	0.06
FlowFE	-0.35	0.12	0.00	**0.86**	-0.19
Temp_C	0.18	**-0.72**	0.16	-0.11	0.09
Load_CU_Area	0.27	-0.09	**0.87**	0.24	0.05
MassRemTotal	**0.92**	-0.11	0.10	-0.11	0.06
SbDist	0.10	0.05	0.02	0.02	0.12
SbV_D	0.09	0.13	0.02	-0.01	0.11
SbVel	-0.02	-0.03	-0.11	0.02	-0.13
ScowDist	0.34	-0.03	0.14	-0.03	0.20
ScowV_D	0.26	0.04	0.19	-0.02	0.10
ScowVel	0.28	-0.13	-0.15	0.04	-0.05
TotalBfill	-0.14	**0.93**	-0.05	0.03	0.09
VolRemTotal	**0.82**	-0.10	0.14	-0.04	0.08
tPCB_CU_ARE	**0.44**	-0.17	**0.78**	-0.18	0.13
TotalEfficiency	0.32	-0.10	0.16	0.09	0.03
ME	**0.92**	-0.11	0.10	-0.06	0.04
BoatDist	0.36	0.15	0.11	0.04	0.70
BoatVel	0.19	0.03	0.06	0.06	0.14
BoatV_D	0.36	0.09	0.14	0.03	0.68
LoadBoats	0.01	0.32	0.15	0.77	0.41
Semi-Partial R^2	37%	10%	2%	10%	2%
Factor Label	Volume/Mass Bucket Fill	Backfill and Flow Weighted Backfill	PCB/Flow Weighted CU Area	Flow Weighted Vessel Dist.	Vessel Distance/Velocity

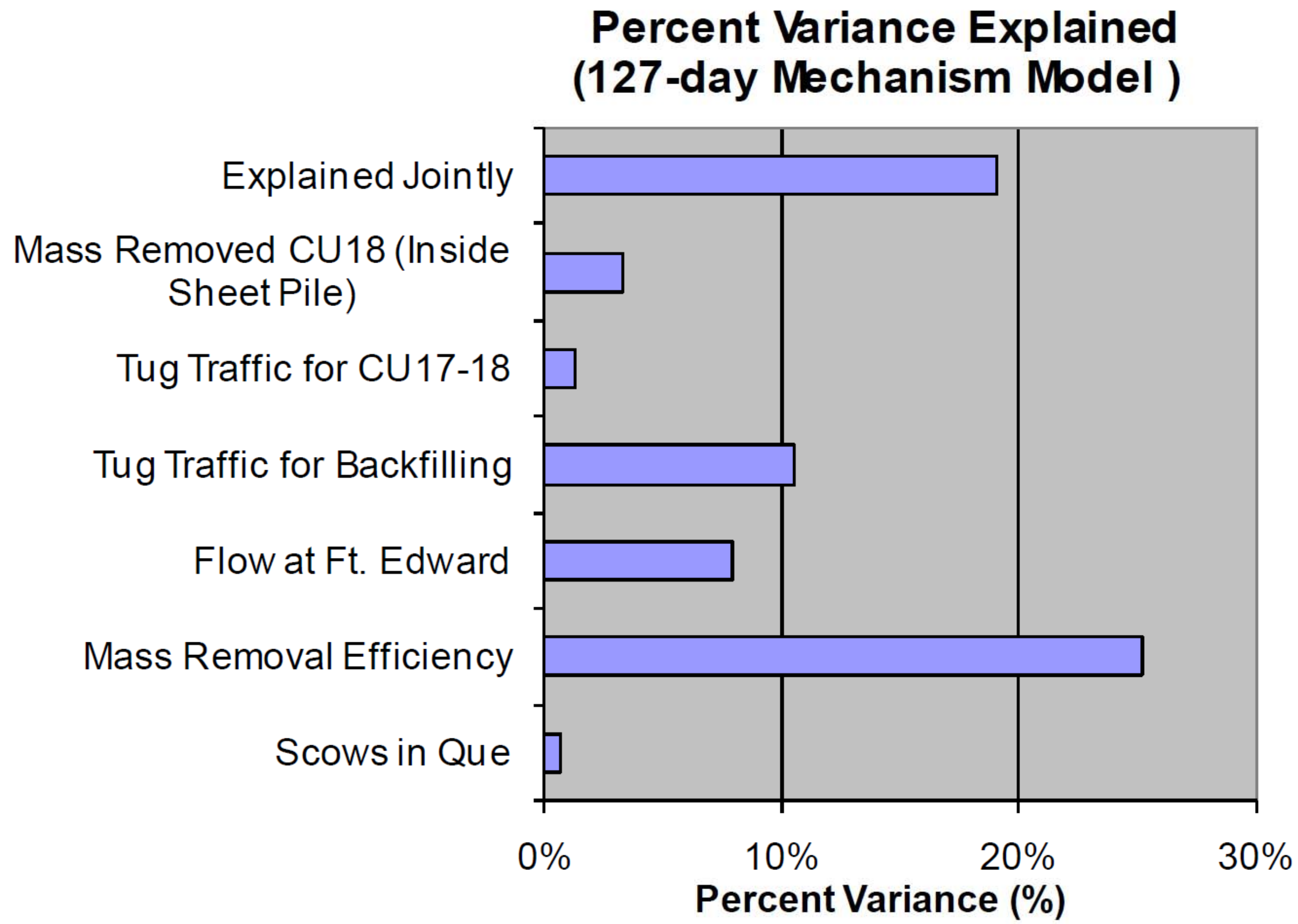
Table 2-3.

Factor loadings for each variable for those factors found to be associated with water column Total PCB concentration in Thompson Island Pool from May to November in 2009, Hudson River. Loadings range from minus 1 to plus 1 and values greater in magnitude than 0.4 (green shaded and bold) are thought to be meaningful. Based on 166 day model.

Variable	**Factor1**	**Factor4**	**Factor6**	**Factor7**	**Factor12**
BCntTotal	**0.84**	-0.23	0.08	-0.04	0.05
BargeDist	0.08	0.22	-0.12	-0.02	-0.01
BargeV_D	0.12	0.06	-0.04	-0.09	0.04
BargeVel	0.05	0.21	-0.12	0.02	-0.03
DrdgDist	0.18	0.09	0.00	0.01	-0.02
DrdgV_D	-0.02	0.00	-0.02	-0.04	0.08
DrdgVel	-0.16	0.00	-0.14	0.03	-0.07
Load_Bfill	0.06	**0.97**	-0.03	0.11	-0.03
FlowFE	**-0.45**	0.11	-0.03	**0.86**	0.02
Temp_C	0.32	**-0.65**	0.18	-0.12	-0.04
Load_CU_Area	0.32	-0.07	**0.88**	0.17	0.01
MassRemTotal3	**0.84**	-0.09	0.08	-0.12	**0.44**
SbDist	**0.42**	0.09	0.00	0.03	-0.01
SbV_D	0.36	0.16	0.03	-0.03	0.03
SbVel	0.18	0.00	-0.14	0.07	-0.01
ScowDist	**0.95**	0.03	0.08	-0.05	-0.09
ScowV_D	**0.91**	0.07	0.10	-0.02	-0.09
ScowVel	**0.91**	-0.03	-0.15	0.02	-0.14
TotalBfill	0.10	**0.94**	-0.05	-0.01	0.02
VolRemTotal	**0.87**	-0.04	0.08	-0.04	0.12
tPCB_CU_AREA	**0.49**	-0.14	**0.78**	-0.23	0.01
BoatDist	**0.85**	0.18	0.08	-0.02	-0.02
BoatVel	**0.61**	0.07	0.02	0.05	0.00
BoatV_D	**0.83**	0.14	0.12	-0.03	-0.01
LoadBoats	**0.59**	0.37	0.12	**0.60**	-0.12
TotalEfficiency	0.32	-0.09	0.16	**0.91**	0.06
ME	**0.91**	-0.10	0.10	0.23	-0.07
Semi-Partial R^2	28%	6%	4%	5%	13%
Factor Interpretation	Volume/Mass Bucket Fill	Flow Weighted Backfill	PCB/Flow Weighted CU Area	Flow Weighted Vessel Dist.	Mass Removed

Table 2-4
Productivity and water column concentrations from 8/10/2009 through 9/7/2009

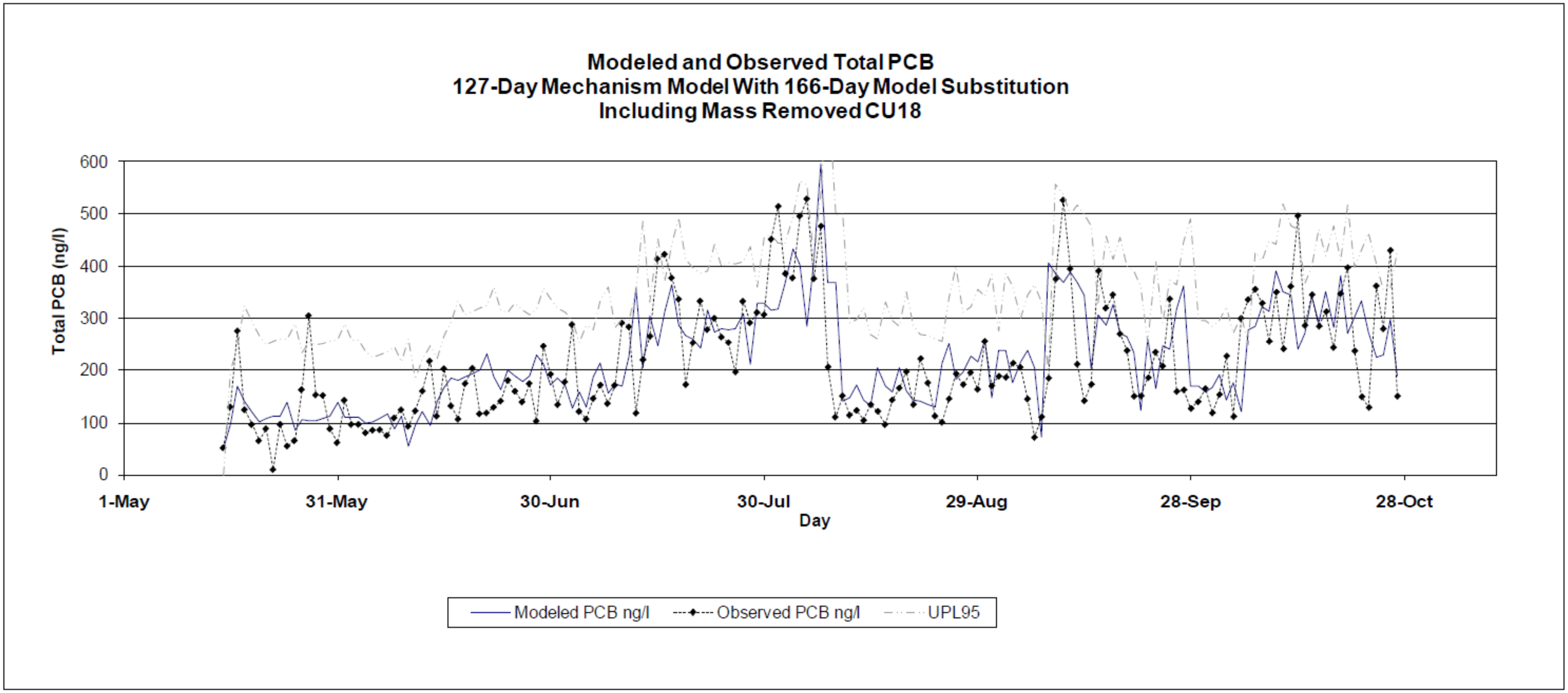
Month	**Day**	**Date**	**Productivity (cy/day)**	**Water Column PCB (ng/l)**
8	10	8/10/2009		151
8	11	8/11/2009	837	115
8	12	8/12/2009	1785	124
8	13	8/13/2009	2413	105
8	14	8/14/2009	2567	135
8	15	8/15/2009	2644	122
8	16	8/16/2009		97
8	17	8/17/2009	2773	144
8	18	8/18/2009	2421	166
8	19	8/19/2009	2212	198
8	20	8/20/2009	2212	135
8	21	8/21/2009	2260	223
8	22	8/22/2009	3559	176
8	23	8/23/2009		113
8	24	8/24/2009	3006	101
8	25	8/25/2009	3470	146
8	26	8/26/2009	3151	194
8	27	8/27/2009	3297	173
8	28	8/28/2009	3020	196
8	29	8/29/2009	2352	164
8	30	8/30/2009		256
8	31	8/31/2009	2796	171
9	1	9/1/2009	2231	189
9	2	9/2/2009	2466	187
9	3	9/3/2009	2450	214
9	4	9/4/2009	2325	206
9	5	9/5/2009		145
9	6	9/6/2009		72
9	7	9/7/2009		111
Average			2557	156



Note: Percent variance explained by individual process variables in a multiple regression model predicting water column PCB concentration at Thompson Island Dam, Hudson River New York. Overall adjusted R^2=68%. Variance explained jointly cannot be ascribed independently to any particular variable due to inter-correlations among the predictors.

Percent Variance Explained by Individual Process Variables in a Multiple Regression Model Predicting Water Column PCB Concentration at Thompson Island Dam

Figure 2-1



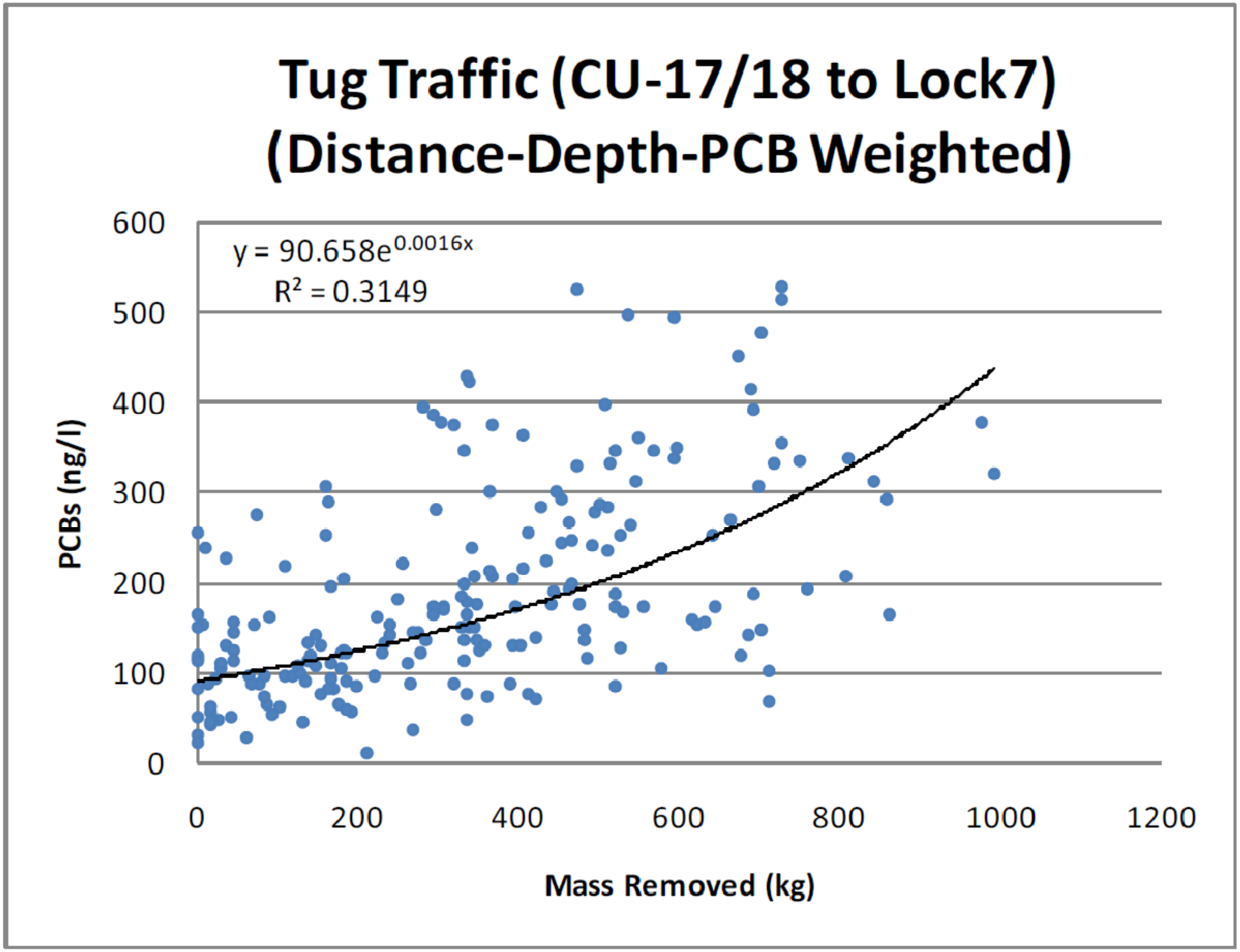
Note: The model is based on process variables available on 127 of the 166 day season with modeled values from the 166 day model substituted on the remaining days—primarily in May and June.

Observed and Modeled Values for Water Column PCB Concentrations at Far-Field Station in Thompson Island Pool

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 2-2

April 2010

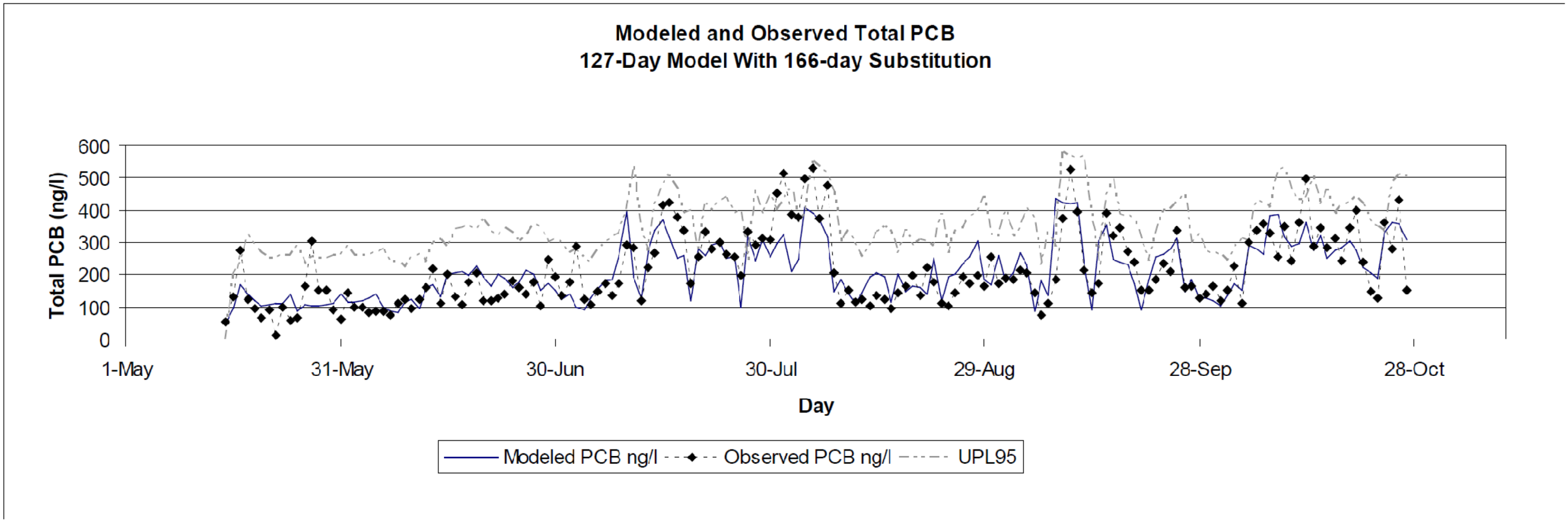


Note: The line is the best fit line with an R^2=69% and adjusted R^2=68%

Observed Water Column Total PCB Concentration Plotted Against Modeled Values for Thompson Island Pool Based on the 127 Day Model

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 2-3

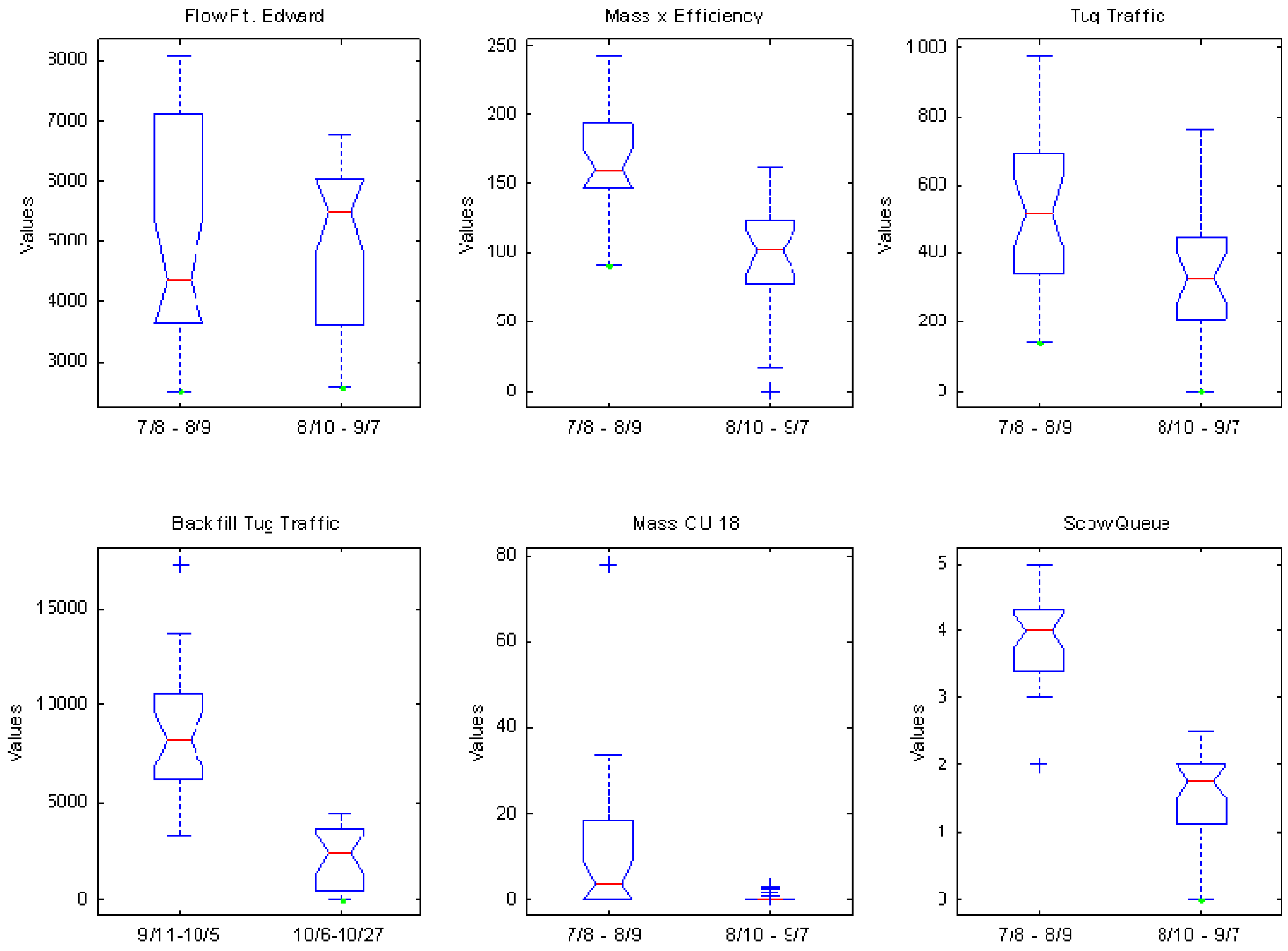


Note: The model is based on variables available on 127 of the 166 day season with modeled values from the 166 day model substituted on the remaining days—primarily in May and June.

Observed and Modeled Values for Water Column PCB Concentrations at Far-Field Station in Thompson Island Pool

Figure 2-4

April 2010



Distribution of Six Key Process Variables During Selected Periods in 2009

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 2-5

April 2010

TOPIC 3

REDISTRIBUTION OF CONTAMINANTS DURING DREDGING

Topic 3 - Redistribution of Contaminants during Dredging

The GE Remedial Action Monitoring Plan Quality Assurance Project Plan (RAM QAPP; May 2009) required that GE conduct a special study aimed at measuring the spatial extent, concentration, and mass of Tri+ PCB-contaminated material resulting from dredging that deposited in areas immediately downstream of dredging operations and may act as a potential source of future contamination of the water column and downstream surface sediments (GE, 2009a).

The RAM QAPP specified that sediment traps be placed downstream of multiple Phase 1 dredge areas representing different sediment characteristics and PCB concentrations expected to be encountered during dredging operations. The following locations were defined in the RAM QAPP for trap placement:

- Immediately downstream of CU-9, in the west channel at Rogers Island.
- Downstream of CU-16 in the Northern Thompson Island Pool (NTIP)
- Downstream of the dredging areas in the East Griffin Island Dredge Area (EGIA)

The study was performed downstream of the EGIA, with traps deployed in the configuration presented in the QAPP downstream of CU-18 on July 9, 2009 and sampled approximately once per week. This part of the study was completed on August 17, 2009 (GE, 2009b).

However the other planned locations were modified due to project logistics (GE, 2009c). In accordance with the RAM QAPP, sediment traps were deployed downstream of CU-9 in the west channel of Rogers Island on May 6-7, 2009. A total of 34 traps were installed at the approximate locations shown in the RAM QAPP. The first round of data collection was completed on May 14 (to provide background data prior to the start of dredging), with 32 of the 34 traps successfully re-located; however these samples were not submitted for analysis (GE, 2009b).

Because the background sediment trap samples were not analyzed, push cores were collected in September 2009 in the vicinity of areas where sediment traps were deployed, and adjacent to Sediment Sampling and Analysis Program (SSAP) core locations (Figures 1 and 2; GE 2009c). The intent was to compare the concentrations in these baseline push cores to those observed in the SSAP cores obtained nearby five years earlier. Originally, 27 cores and a number of co-located cores were to be collected. However, because the new cores were potentially collected in areas with less or no sediment deposition, only six cores were actually obtained, and no co-located cores were among them (EPA, 2010). It should be noted that cores were never envisioned as part of this analysis. If they had been, collection would have been required just prior to the initiation of dredging to allow for use as a true baseline. EPA's concerns and recommendations for this study were forwarded to GE (see Common Appendix of EPA Phase 1 Evaluation Report; EPA, 2010). While concentration increases were observed in five of the six baseline push cores obtained, no radionuclide testing was performed to determine the age of the sediments and confirm whether or not they actually were recently deposited. And, as discussed in greater depth in the EPA Phase 1 Evaluation Report (see Section I-4.3), due to the high degree of variability in surface sediments, the observed increases do not provide a statistically significant difference over the original observations (EPA, 2010). Further, the baseline push core locations appear to be biased toward low-concentration areas, increasing the likelihood for follow-up concentrations to be higher than the initial. A proper sampling design with an unbiased selection of locations and adequate sampling size is required to evaluate whether or not surface sediment concentrations outside of dredge CUs have increased (EPA, 2010). A more detailed discussion and analysis of this aspect of the GE downstream target area contamination study is presented in Chapter 1, Section 4.3 of the EPA March 2010 Phase 1 Evaluation Report.

With the initiation of dredging on May 15, 2009, considerable barge traffic began traversing the river between CU-9 and downstream support areas, often passing through the area where the traps were installed. Barge staging was also conducted in that area, requiring considerable tug activity to move and maintain barge positions during May 16 high flows. The first round of post-dredging sampling was attempted during the week of May 25, however only two intact traps could be found (GE, 2009b). It is likely that the others were dislodged when a barge broke free of its spuds and ran aground during a high flow event (GE, 2009c). No useable data was obtained from this deployment of traps (GE, 2009b).

Rather than repeating the study downstream of CU-9, traps were installed in an area downstream of CU-10 along the eastern shore of Rogers Island, with the number of units actually deployed decreased to reduce the potential for disturbance by project-related vessel traffic. The RAM QAPP also specified that study be performed downstream of CU-16. The study was not implemented in this area due to project vessel mooring activities (GE, 2009b).

The GE sediment trap study did not address all the requirements described in the RAM QAPP, and, as such, does not provide conclusive evidence that sediment re-distribution in the river was caused by dredging. The presence of sediment in the traps prior to the initiation of dredging suggests a dynamic system, one where everyday flow conditions result in the re-distribution of sediments. And while sediments may be mobilized by dredging and transported to other areas, the samples obtained on May 14 from the baseline deployment were not sent for analysis, so there are no pre-dredging benchmarks for spatial extent, concentration, or Tri+ PCB mass for use as a baseline measurement in evaluating trap samples obtained during and after dredging activities. Sediments released due to dredging cannot be distinguished from sediments undergoing transport as part of the natural state of the river, including normally occurring recreational boat traffic and project vessel traffic. EPA’s March 2010 report documents the dynamics of sediment movement under natural conditions based on bathymetric changes in sediment bed elevation (see Section I-4.3).

Evidence that boat traffic can contribute to the mobilization of bottom sediments was observed during collection of the transect study samples. Specifically, a sharp increase in the total suspended solids concentration was measured in samples collected at NTIP transect station, and GE indicated that the spurious TSS results were due to sediment disturbance by the sampling vessel itself. It is important to note that the type of vessel used to collect the transect samples was small, typical of what is on the Hudson during the summer and other recreational timeframes. Figures 3-1 and 3-2 show the boat traffic in the vicinity of the sediment traps and push core locations.

Sediment trap PCB data have been used by GE to suggest that sediments with elevated PCB concentrations (as high as 100 mg/kg) were being transported downstream due to dredging operations, where they would continue to contribute PCBs to the water column and potentially contaminate areas that were not delineated for dredging (GE, 2010). While there likely was some re-distribution of bottom sediments due to the Phase 1 dredging, EPA does not believe it occurred to the extent GE has stated.

Summary

The Hudson River is highly dynamic, resulting in sediment movement under normal conditions, with recreational boat traffic and larger vessel movement during the open lock season causing normal re-distribution of bottom sediments. Before dredging started particulate materials were collected in sediment traps, but these were not analyzed. GE did not analyze baseline sediment trap materials which might have shed additional light on the sediment trap data collected during dredging. During dredging, tug traffic significantly impacted sediment resuspension, particularly in the vicinity of these traps, and local resuspension may have resulted in over trapping of particles.

References

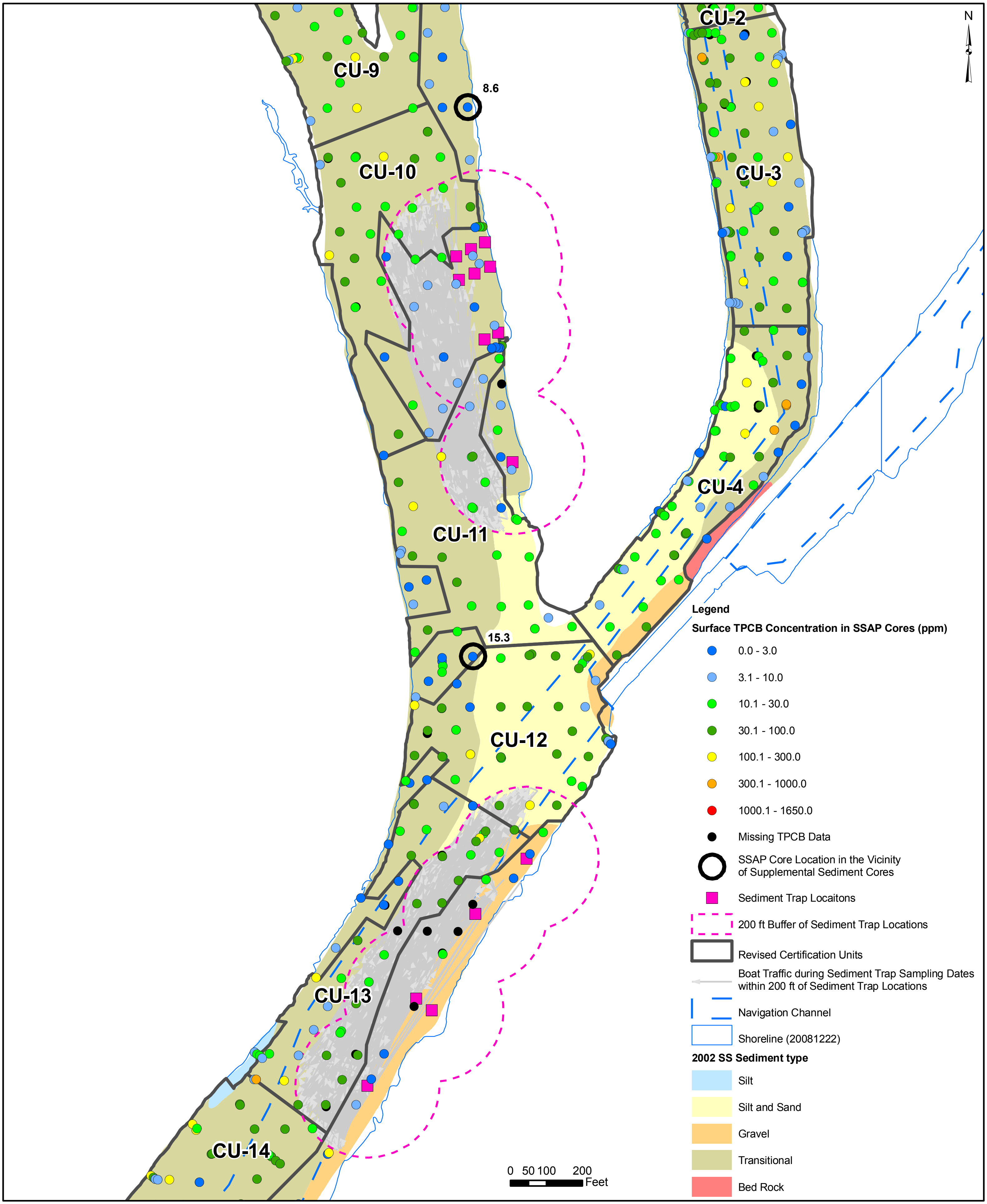
EPA, 2010. EPA Phase 1 Evaluation Report. Prepared for the USEPA by the Louis Berger Group, Inc. March 2010.

GE, 2009a. Remedial Action Monitoring Plan Quality Assurance Project Plan. Prepared for General Electric Company, Albany, NY by Anchor QEA, LLC, Environmental Standards, Inc., and Arcadis. May 2009.

GE, 2009b. Remedial Action Monitoring Program Corrective Action Memorandum No. 3. Prepared

GE 2009c. Phase 1 Data Compilation. Prepared for General Electric Company, Albany, NY, by Anchor QEA, LLC. November 2009.

GE, 2010. Phase 1 Evaluation Report. Prepared for General Electric Company, Albany, NY by Anchor QEA, LLC, and Arcadis.

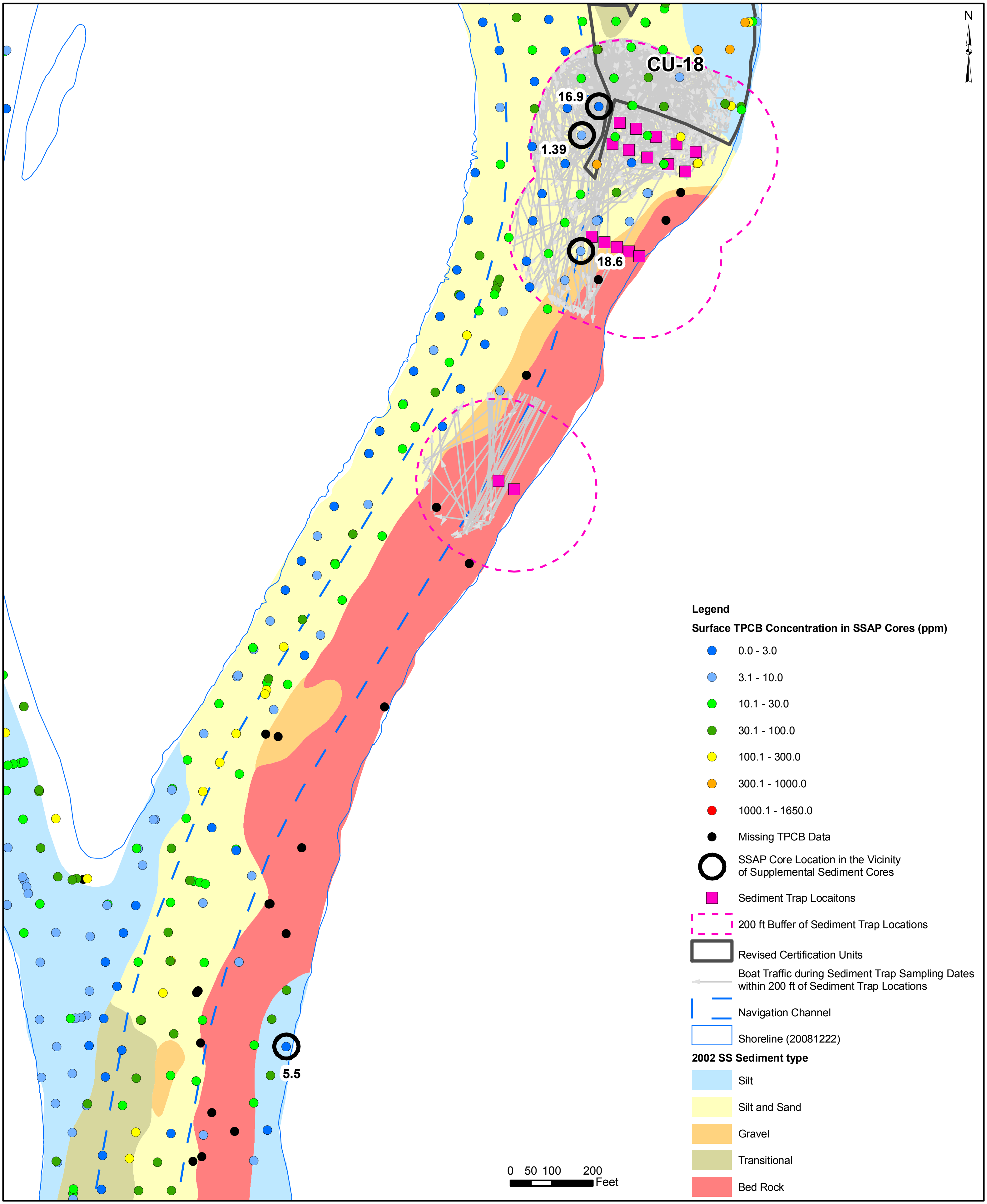


Boat Traffic and Surface TPCB Concentration in SSAP and Push Cores in the Vicinity of Sediment Trap Locations

EPA Phase 1 Evaluation Report - Hudson River PCBs Site

Figure 3-1

April 2010



Boat Traffic and Surface TPCB Concentration in SSAP and Push Cores in the Vicinity of Sediment Trap Locations

EPA Phase 1 Evaluation Report - Hudson River PCBs Site

Figure 3-2

April 2010

TOPIC 4

FORECASTS OF DREDGING RELATED IMPACTS AND RELATED RISK

TOPIC 4-A

FORECAST OF PCB LOADS DUE TO DREDGING COMPARED TO NATURAL ATTENUATION

Topic 4-A - Forecast of PCB Loads Due to Dredging Compared to Natural Attenuation

Abstract

The analysis presented in this Topic revises the analysis set forth in Appendix I-G of EPA's Phase 1 Evaluation Report, which stated that estimates of Total PCB (TPCB) loads at Waterford based on the United States Geological Survey (USGS) and General Electric Company (GE) data for the period 1995 to 2008 show no statistically significant decline, with "half life" of 99 years. The analysis in Appendix I-G was revisited to improve the original calculation. In the reanalysis, the analysis used PCB concentration instead of loads, since a better correlation could be developed for concentrations to evaluate the recovery. Flows were simulated via a Monte Carlo analysis rather than forecast as a single set of values. Additionally, further analysis of the historical data suggested that the records for the years 1999 and 2000 were inconsistent with the general trend observed in these data. Although there was no specific reason identified for the inconsistency, the 1999 and 2000 data were excluded from the best estimate calculation of the rate of concentration decline with time.

This Topic presents empirically-based projections of Monitored Natural Attenuation (MNA) of Tri+ PCB load at Waterford, generated from historical data from USGS collected between1995-2001) and baseline monitoring data collected by GE from 2004-2009. The results of this analysis indicate a dredging release of approximately 500 kg of Tri+ PCB, as measured at the Waterford far-field station, would provide net benefit to the river based on an overlap in the band of forecasted uncertainty between this dredge release scenario and MNA. While the load standard will continue to be based on a 1 percent net loss of TPCB inventory removed (approximately 2000 kg TPCB or 667 kg Tri + PCBs), the goal will be to minimize the dredging-related release of Tri+ PCB to 500 kg (as measured at Waterford) over the life of the project (including both Phase 1 and Phase 2). Support for the adoption of control levels derived from the 1 percent net loss of TPCB inventory removed is provided by consideration of the impact on fish tissue concentrations and project risks in both the Upper and Lower Hudson River.

4-A.1. Introduction

One of the objectives of the Resuspension Performance Standard was to minimize the export of PCBs to downstream areas, including the Lower Hudson (USEPA, 2004). This resuspension export was defined as the net cumulative load of PCBs at Waterford. The Waterford station was selected because it is downstream of the target areas identified in the feasibility study (FS) (USEPA, 2000b) but upstream of the Mohawk River, which was shown to be a minor but measurable source of PCBs to the Lower Hudson River (USEPA, 1997) with respect to downstream impact.

During the development of the Resuspension Performance Standard, USEPA established seasonal load standards for PCB export to the Lower Hudson River. As stated in EPA's Phase 1 Evaluation Report (USEPA, 2010), the estimated net loads due to dredging and related activities at Waterford exceeded the standard set forth in the Resuspension Performance Standard, although the load did not exceed 1 percent of the PCB mass removed, which was an important factor underpinning the load criteria. EPA has specified several reasons why the load standards as set forth in the Resuspension Performance Standard should be revised upwards (USEPA, 2010). These include, but are not limited to:

- The observed baseline loads to the Lower Hudson prior to dredging were substantially greater than the previous model forecast of MNA;
- The surface sediment concentrations in the Upper Hudson River remain elevated despite the passage of time and continue to provide a greater reservoir of contaminated sediments for transport to the Lower Hudson than was envisioned when the remedy was selected; and,
- USEPA estimates that the inventory of PCBs in the Upper Hudson sediments may be at least 1.5 times the remedial design value of 115,000 kg TPCBs (Phase 2 Dredge Area Delineation Report; GE, 2007) estimated prior to Phase 1 dredging activities.

The above reasons provide further impetus for the remedy, as well as for revising the threshold for PCB load release to the Lower River in the Resuspension Standard. To establish a revised load threshold, the long-term impact of dredging-related release relative to natural attenuation needs to be assessed. To this end, this paper presents empirically-based projections of Tri+ PCB load at Waterford that were generated for two scenarios:

1. The MNA Scenario - refers to the scenario which relies on natural recovery processes, within the context of a carefully controlled and monitored site.

2. Dredging Impact Scenario - This scenario predicts the future water column export at Waterford due to active remediation by dredging.

The empirical projections for both scenarios allow for uncertainty in future flows, based on the past flow record. The methodologies used to develop projections for each scenario are presented below.

4-A.2. Development of MNA Projections of Water Column Loads

The development of the MNA projection can be summarized as follows:

1. ***Review of the water column concentration data available for Waterford.*** The Tri+ PCB data used to evaluate baseline conditions were obtained from the historical data (1995-2001) from the USGS and the baseline monitoring program (BMP) data (2004-2008) collected by GE. Review of the USGS historical water column concentrations at Waterford indicated that the 1999 and 2000 values were mostly reported as non-detect. Data for these two years were excluded from the baseline assessment, resulting in 172 Tri+ PCB data points remaining in the USGS data set from 1995 to 2000. It is unclear why the 1999 and 2000 concentrations measured by the USGS were non-detects. There are 339 Tri+ PCB data points in the GE data set from 2004 to 2009. Table 4-A-1 presents the statistical summary for the Tri+ PCB for both data sets.

2. ***Estimation of Annual Baseline Loads.*** The annual Tri+ PCB loads were estimated by individual year from 1995 to 2008. Although there are several load estimators, research has shown that the Beale's Ratio Estimator is the only estimator that provides unbiased estimates, although it requires stratification under event sampling (Preston et al., 1992). The Beale's Ratio Estimator has been used widely in Great Lakes loading calculations, is thoroughly discussed in Baun (1982), and was used previously for the Hudson River as part of the Data Evaluation and Interpretation Report (DEIR, USEPA, 1997). In general, ratio estimators use the period's data to calculate a mean daily load and then use the mean discharge from days

lacking concentration data to adjust the mean daily load (Richards, 1998). The AutoBeale program (Richards, 1998) was used for the load calculations in this analysis. AutoBeale, a computer implementation of Beale's Ratio Estimator, iteratively seeks out the discharge stratification and minimizes the variance of the load estimate for a given set of data. Stratification is the division of the sampling data into two or more parts which are different from each other but relatively homogeneous within. It can be based on flow or time. Because event sampling was conducted as part of the BMP at Waterford, stratification was necessary to improve the precision and accuracy of the annual loads estimated.

3. ***Estimation of Flow-weighted Concentrations.*** For each year, the annual load estimated as described above was normalized to the total flow volume for that year to determine the flow-weighted average concentration.

4. ***Exponential Decay Fit to Flow-weighted Concentrations.*** The flow-weighted concentrations were fit with an exponential decay function and this function was used to forecast annual flow-weighted average concentrations.

5. ***Prediction of Annual Loads under MNA from 2009 to 2070.*** A spreadsheet-based model was developed to estimate an empirical forecast of future Tri+ PCB loads at Waterford, and to estimate the range of uncertainty in that forecast given the uncertainty in future flows. Because there is additional uncertainty in the coefficients of empirical fit to the flow-weighted concentrations, the simulated error bounds estimated in this analysis likely understate the range of uncertainty in future loads. Estimated annual loads were predicted from 2009 to 2070 (a 62-year forecast period). Annual flows from 1977 through 2008 at the USGS Waterford gauge were randomly sampled using a Monte Carlo approach to represent future flows. The annual loads for the 62-year period were simulated 1000 times, which consisted of multiplying the forecasted concentration by a sequence of 62 randomly selected calendar flow years from the period of record, 1977 through 2007. Thus, each year in the 62-year period was represented by a complete calendar year of flow data, with each year being selected at random, and a different sequence of years for each of the 1000 simulations. The mean, 5th and 95th percentiles were estimated for the 62-year forecast annual loads.

4-A.3. Development of Dredging Impact Scenario

The development of the Dredging Impact projection can be summarized as follows:

1. Starting with the MNA projections, potential dredging-related loads (400 kg to 600 kg of Tri+ PCBs) were applied to determine a dredge-related load that would result in a reduced cumulative load to the Lower Hudson relative to MNA in the long-term. This improvement was determined by the amount of overlap between the dredging scenario and the MNA scenario within their respective uncertainty bounds. A load of about 500 kg due to dredging release was established. This 500 kg dredging release was assumed to be transported downstream to Waterford, and the load was evenly divided between the remediation time period of 2009-2015, which represents a constant annual load of 72 kg/year above baseline. This constant annual load was added to the baseline load as defined before dredging started, consistent with the Resuspension Standard.

2. The reduction in load due to the dredging remedy was assumed to start in 2016, and this was represented by an instantaneous best-estimate load decline of 60 percent relative to MNA in that year. The 60 percent load decline was determined as follows:
    a. The improvement in surface sediment concentrations was estimated relative to pre-dredge values in the Thompson Island pool, the Schuylerville pool and the Stillwater pool. The estimated declines in surface concentrations due to dredging in these three sections of the river were: 87 percent, 30 percent and 6 percent, respectively.
    b. Using the GE BMP data from 2005 to 2008, the baseline load contributions from these pools were reduced by the estimated improvement in surface sediments. The total load reduction for Tri+ PCB varied from 45 to 80 percent, with a best estimate of 60 percent.
3. Following the application of the instantaneous decline in 2016, the dredging scenario was allowed to decay annually using the same rate as the MNA projections until 2070.

4-A.4. Findings

Table 4-A-2 presents the annual loads of Tri+ PCB estimated by the Auto Beale program. Figure 4-A-1 presents the estimated annual weighted average concentrations and the exponential decay fit. Note that 1999 and 2000 values are not included in the determination of the exponential fit. Even after normalizing for flow, the concentration data appear like a step function and it is unclear whether the decline estimated is due to a difference in sampling and analytical methods between the USGS and the GE BMP programs.

Figures 4-A-2 and 4-A-3 show the annual project loads and the cumulative loads respectively for the MNA scenario. Uncertainties are represented by the 5th and 95th percentiles of projected loads in each year, given the simulated variability in the annual flows. For comparison, HUDTOX forecast p3nas2, which represents the long-term Monitored Natural Attenuation scenario used in development of the Resuspension Standard (USEPA, 2004), is also shown in Figures 4-A-2 and 4-A-3.

Figures 4-A-4 and 4-A-5 show the annual and cumulative loads for MNA and the 500 kg dredging release scenarios. Overlap between the uncertainty bands in future loads under the 500 kg dredging release scenario and the MNA scenario is projected to occur between 3 and 20 years after dredging is completed. Furthermore, there is at least a 50 percent probability that the cumulative load under the dredging scenario falls below the MNA cumulative load by the year 2050 and a 95 percent probability that the two scenarios cross during the 62-year simulation period. While the load standard will continue to be based on a 1 percent net loss of TPCB inventory removed (approximately 2000 kg TPCB or 667 kg Tri + PCBs), the goal will be to minimize the dredging-related release of Tri+ PCB to 500 kg (as measured at Waterford) over the life of the project (including both Phase 1 and Phase 2). Support for the adoption of control levels derived from the 1 percent net loss of the TPCB inventory removed is provided by consideration of the impact on fish tissue concentrations and project risks in both the Upper and Lower Hudson River.

References

Baun, K. 1982. Alternative Methods of Estimating Pollutant Loads in Flowing Water. Tech. Bulleting 133, Dept. Natural Resources, Madison Wisconsin. 11 Pages.

GE. 2007. "Hudson River PCBs Superfund Site Phase 2 Dredge Area Delineation Report." Prepared by QEA for General Electric Company, Albany, NY. December 2007.

Preston, Stephen D., Victor J. Bierman Jr., and Stephen E. Silliman, 1992. Impact of Flow Variability on Error in Estimation of Tributary Mass Loads." Journal of Environmental Engineering 118(3): 402-419.

Richards, R.P. 1998. Estimation of Pollutant Loads in River and Streams: A guidance document for NPS Programs. Project report prepared under Grant X998397-01-0, U.S. Environmental Protection Agency, Region VIII, Denver. 108 p.

USEPA, 2010. Phase 1 Evaluation Report. Prepared for EPA Region 2 and USACE Kansas City District by The Louis Berger Group, Inc. March 2010.

USEPA. 2004. "Engineering Performance Standard. Hudson River PCBs Superfund Site." Prepared by Malcolm Pirnie, Inc. and TAMS Consultants, Inc. for USEPA. April 2004.

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

USEPA, 1997. "Data Interpretation and Evaluation Report – Hudson River PCBs Reassessment RI/FS, New York." United States Environmental Protection Agency. February 1997.

Table 4-A-1

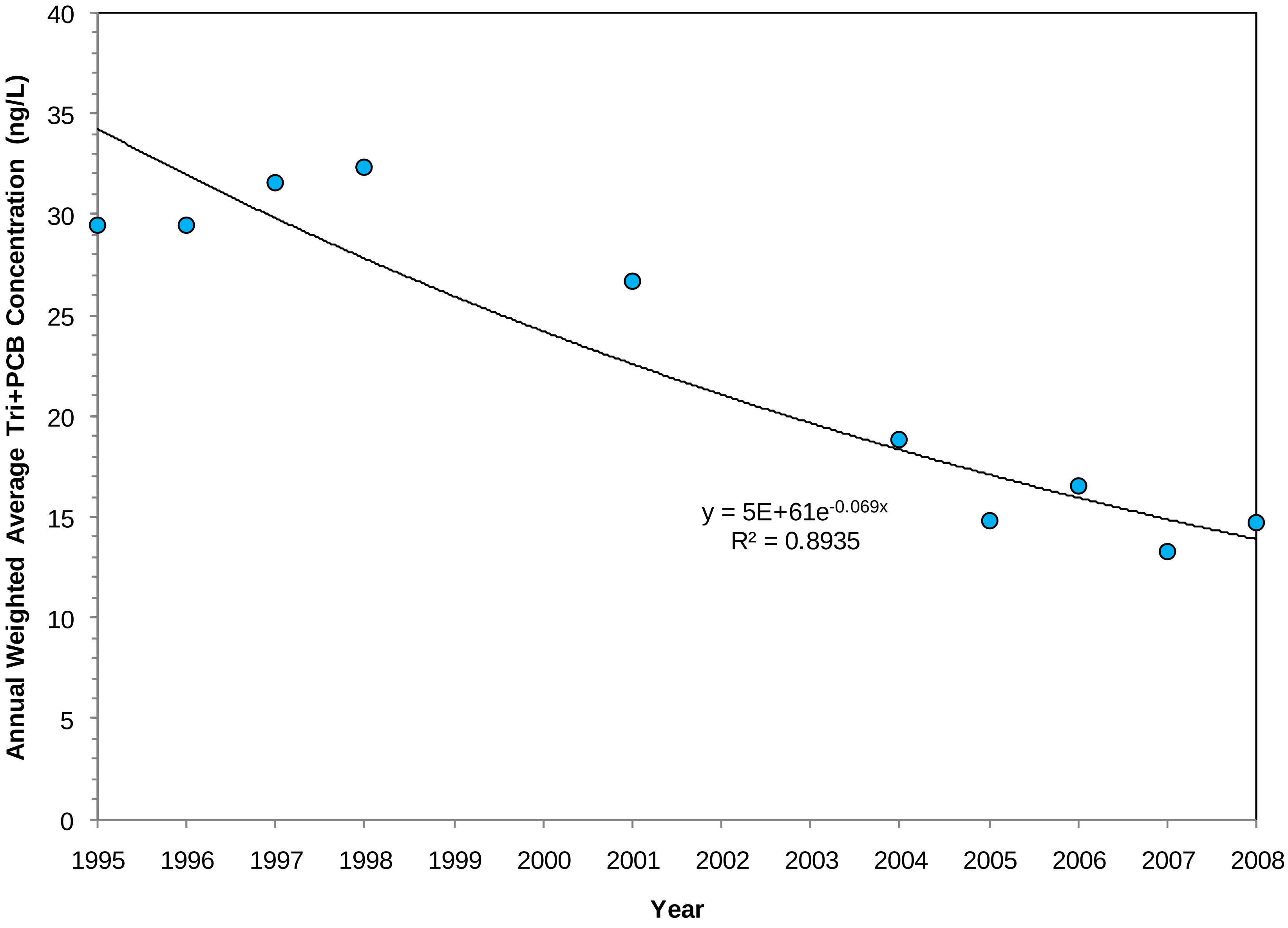
Summary Statistics of Tri+ PCB Concentrations at Waterford

Data Source	Month	Tri+ PCB (ng/L)		
		Count	Min	Max
USGS	1	7	10.0	89.0
	2	4	5.0	10.0
	3	21	1.0	67.3
	4	39	2.2	116.0
	5	28	5.0	78.0
	6	10	5.0	50.9
	7	7	5.0	40.0
	8	7	5.0	37.0
	9	13	2.5	46.0
	10	16	10.0	70.0
	11	12	5.0	114.6
	12	8	5.0	54.8
USGS Summary	-	172	1.0	116.0
GE	1	31	2.0	79.0
	2	13	4.7	23.9
	3	41	2.3	42.0
	4	69	1.5	126.3
	5	18	4.4	20.9
	6	29	11.2	153.6
	7	21	9.9	45.1
	8	23	4.2	28.6
	9	22	7.6	18.5
	10	23	7.5	36.6
	11	36	3.6	82.0
	12	13	1.9	9.3
GE Summary	-	339	1.5	153.6
Overall Summary	-	511	1.0	153.6

Table 4-A-2

Estimated AutoBeale Annual Loads for Baseline Data

Year	AutoBeale		Annual Flow Volume (billion gallons/yr)	Weighted Average Concentration (ng/L)
	Load (kg/year)	Root Mean Square Error (RMSE) (kg/yr)		
1995	164	19	1,477	29.4
1996	303	25	2,721	29.4
1997	226	11	1,894	31.6
1998	239	12	1,958	32.3
1999	38	0	1,535	6.6
2000	72	2	2,436	7.8
2001	163	13	1,609	26.7
2004	149	2	2,087	18.9
2005	133	7	2,372	14.8
2006	174	10	2,774	16.5
2007	103	6	2,063	13.2
2008	147	13	2,642	14.7

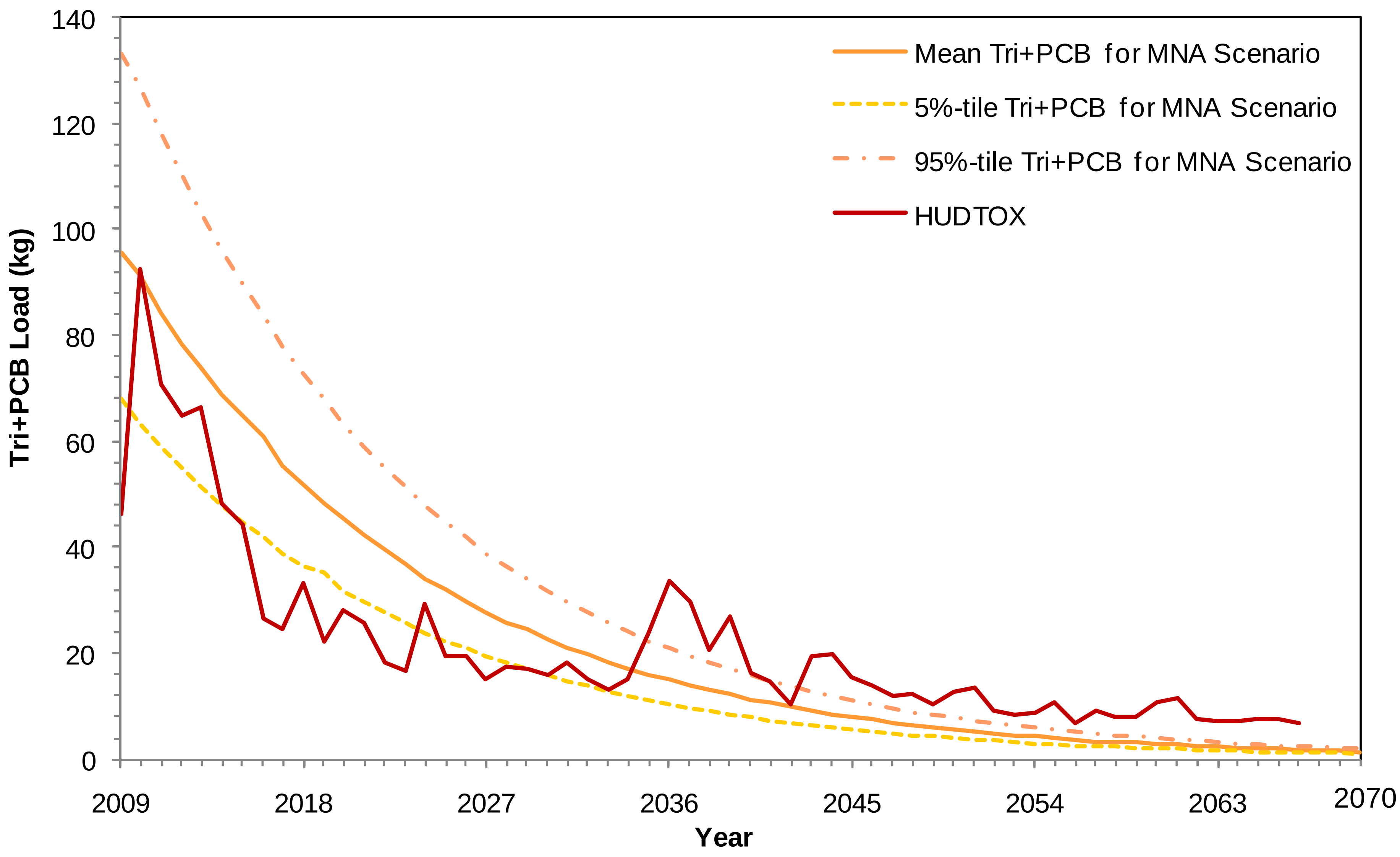


Annual Weighted Average Tri+PCB Concentration vs. Year at Waterford Station

EPA Phase 1 Evaluation Report – Addendum – Hudson River PCBs Site

Figure 4-A-1

April 2010

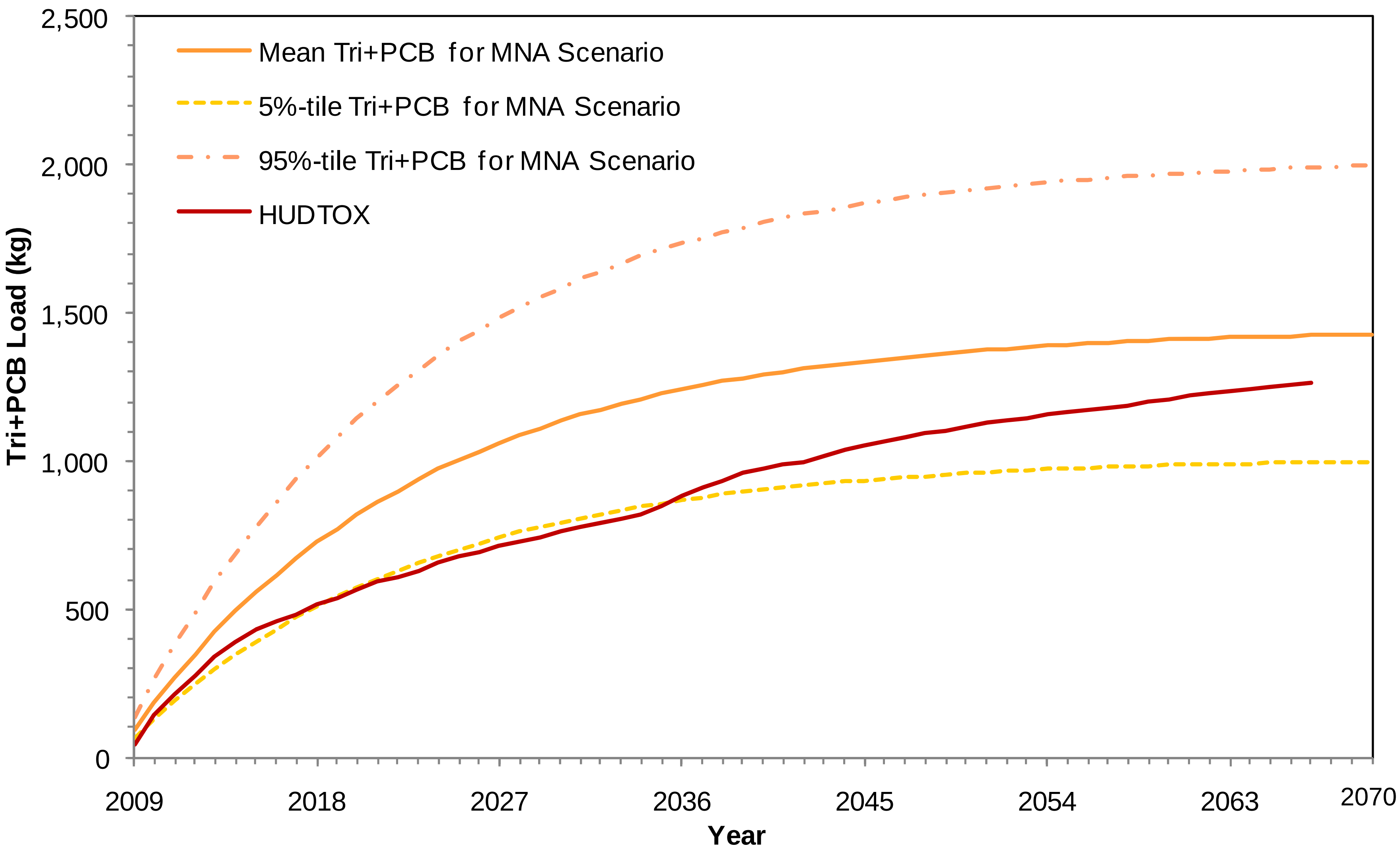


Simulated Annual Load for Tri+PCB

EPA Phase 1 Evaluation Report – Addendum – Hudson River PCBs Site

Figure 4-A-2

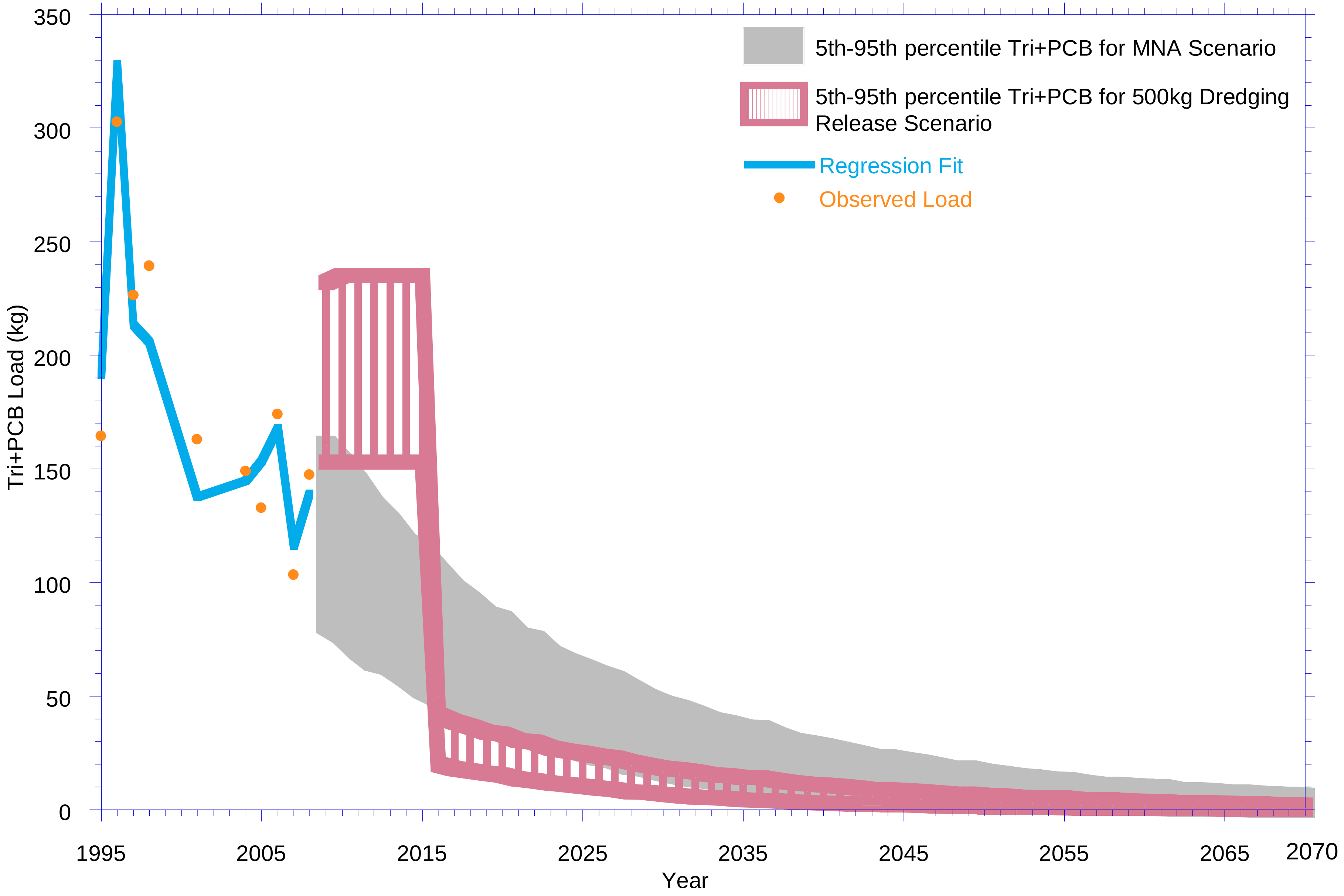
April 2010



Simulated Cumulative Load for Tri+PCB

Figure 4-A-3

April 2010

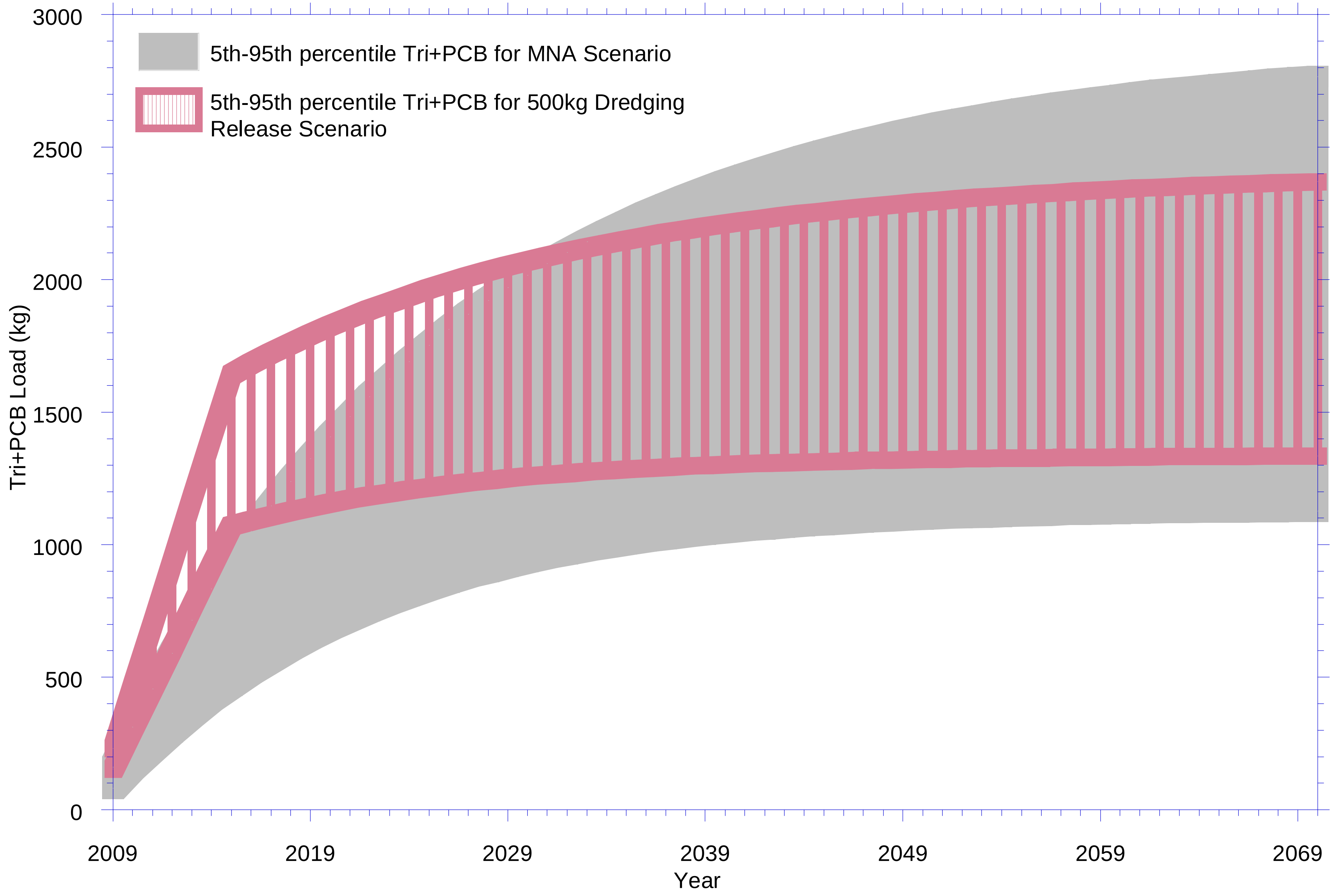


Simulated Annual Tri+PCB Load MNA and 500kg Dredging Release Scenario

EPA Phase 1 Evaluation Report – Addendum – Hudson River PCBs Site

Figure 4-A-4

April 2010



Simulated Cumulative Tri+PCB Load MNA and 500kg Dredging Release Scenario

EPA Phase 1 Evaluation Report – Addendum – Hudson River PCBs Site

Figure 4-A-5

April 2010

TOPIC 4-B

PREDICTION OF IMPACTS ON FISH TISSUE CONCENTRATIONS IN THE LOWER HUDSON RIVER DUE TO DREDGING

Topic 4-B - The Impact of Dredging-Related PCB Release on Fish in the Lower Hudson River

Introduction

The purpose of this analysis is to estimate the impact of dredging-related PCB release on fish tissue concentrations in the Lower Hudson River for the expected duration of dredging (2009 and 2011 to 2015) and the brief (*i.e.,* 5-8 year) period immediately beyond. The intention is to examine any potential incremental increases in projected fish tissue PCB concentrations. Additional risks (above current risk levels) to human health via fish consumption would be identified if such incremental increases in fish tissue concentrations remain elevated above the forecasted MNA recovery curve for the remedy selected in the ROD for many years after completion of the dredging.

This analysis is based on a forecast of the mass delivered to the Lower Hudson over the remediation period 2009-2015. As stated in the March 2010 EPA Phase 1 Evaluation Report, between May 15 and November 30, 2009, the cumulative TPCB load to the Lower Hudson at Waterford over baseline was about 150 kg/yr. The Tri+ PCB load over baseline for the same period was about 60 kg. Although these loads are higher than were anticipated by the Phase 1 Resuspension Standard, they reflect the fact that the PCB mass removed from the actual Phase 1 area dredged was 1.5 to 1.8 times greater than the original estimate. Notably, the loads at Lock 5 and Waterford were close to or below the original criteria used in setting the Phase 1 standard, that is, 1 percent of the mass removed.

Methodology

Based on the Phase 1 experience, EPA's current working estimate of the amount of PCB mass to be removed from the sediments is 1.5 to 1.8 times the original estimated mass of 115,000 kg, which was based on the design sediment sampling program. This results in a range of mass to be removed of 170,000 kg to 210,000 kg. Although these estimates are still subject to review and revision, they form a useful basis for exploring the potential impacts downstream in the Lower Hudson.

As mentioned above, the Resuspension Standard was derived based on a mass loss or export loss rate of 1 percent of the total inventory dredged in the Upper Hudson River. While the load standard will continue to be based on a 1 percent net loss of PCB inventory removed (approximately 2000 kg or 667 kg Tri + PCBs), the goal will be to minimize the dredging-related release of Tri+ PCB to 500 kg (as measured at Waterford) over the life of the project (including both Phase 1 and Phase 2). Support for the adoption of control levels derived from the 1 percent net loss figure is provided by consideration of the impact on fish tissue concentrations and project risks in both the Upper and Lower Hudson River. To examine the impact of these loads on the lower river, the models used to assess PCB fate and transport and biological uptake in the Lower Hudson for the purposes of the ROD and the Performance Standards were applied to forecast fish tissue concentrations. Two net loading scenarios at Waterford were examined; they correspond to dredging-related TPCB release loads of 1,800 and 2,400 kg, with corresponding Tri+PCB release loads of 600 and 800, kg. These values were selected prior to the finalization of the proposed revision to the load standard and serve as upper bound estimates on the impacts of the 500 kg Tri +PCB scenario. Tables 4-B-1a and 4-B-1b list the dredging-related TPCB and Tri+PCB release loads respectively for these scenarios. It should be noted that here the models for both the Upper and Lower Hudson simulate Tri+PCBs. The estimates for Total PCB transport are then obtained by application of the appropriate Total PCB to Tri+ PCB ratio.[1]

The water column and sediment concentrations in the Lower Hudson River were estimated from the same model of chemical fate and transport that was used in the Performance Standard (Farley *et al.* (1999)), referred to herein as the Farley model. The Farley model was run for the two dredging-related PCB release scenarios to estimate sediment and water column concentrations of the Lower Hudson out to 2046. The fish tissue concentration was predicted by interpolating previous results from a bioaccumulation model developed for the Hudson River remedial investigation and used in both the ROD and the Performance Standards (FISHRAND, USEPA, 2000).[2]

Figures 4-B-1a and 4-B-1b show the composite fish tissue concentration for the two scenarios for dredging-related release scenarios of PCBs, along with the previously run Monitored Natural Attenuation (MNA) scenario in the Lower Hudson River (for RMs 152, 113, 90 and 50). While preparing these scenarios, the revised forecast of the post-dredging reduction in the Upper Hudson load due to dredging and source control was not yet available. As a result, these forecasts were assessed based on the return to the MNA recovery curve, and do not account for the improvements to Lower Hudson conditions resulting from the load reduction from the remediation and source control efforts. Thus these curves should represents a maximum time to rejoin the MNA recovery curve since the reduction in the load from the Upper Hudson would cause a faster recovery of fish tissue than simply returning to the baseline load conditions.

For these forecasts, the fish tissue concentration asymptotically returns to the MNA curve. Notably in all instances, the curve returns within a limited amount of time after 2015, the simulated year of completion of the remedial operation. If the decrease in load to the Lower Hudson due to the remedy was taken into account, the fish tissue concentrations after remediation would decline to a level lower than that of the MNA, as shown in Figures 4-B-2a and 4-B-2b, taken from the original Performance Standard report. In these analyses, fish tissue concentrations are estimated while accounting for the decline in PCB loads resulting from the remedy. The difference in dredging-based load is relatively inconsequential since both high and low load estimates decline rapidly after completion of the remedy. Recall that the purpose of the present analysis was to demonstrate the impact of dredging-related PCB release on fish tissue concentrations in the Lower Hudson River for the expected duration of dredging (2009 and 2011 to 2015) and the brief (*i.e.*, 5-10 year) period immediately beyond.

---

[1] The Total PCB to Tri+ PCB ratio varies with several factors. Sediments commonly have a ratio of 3:1 whereas baseline water column PCBs range from 1.7 to 2.3, depending on location and time of year.

[2] The FISHRAND model essentially relates fish tissue to water column and sediment concentrations on a linear basis, so that the interpolation from prior runs to the specific conditions simulated for this analysis by the Farley model is a straightforward exercise. Complete runs of the FISHRAND model are currently underway and could not be completed in time for this presentation. However, given the precision of the interpolation, model results are not expected to differ from the interpolated results by more than 1 or 2 percent.

It can be seen from the plots in Figure 4-B-1a that for RM 152, the fish tissue concentration asymptotically returns to the MNA curve about 5 years after dredging is completed for both scenarios. This is essentially the same time to return to the no-resuspension recovery curve as predicted for smaller loads in the original Farley model-FISHRAND runs (see Figure 4-B-2) [3, 4]. Similar to what was observed in the analyses for the ROD, the fish concentrations take a few years longer to return to the target MNA recovery curve for the lower river miles. For each scenario, Table 4-B-2 shows the number of years to return to the MNA recovery curve, an approximation of the return to the no resuspension recovery curve. The time to return to the MNA recovery curve in each case is similar to the time to rejoin the MNA recovery curve originally forecast for smaller dredging releases in the analysis for the ROD and is generally no more than 2 to 3 years longer. Additionally, the locations with the longest times to rejoin the MNA recovery curve have the smallest fish tissue concentration spike from the curve. For example, the 2,400 kg Total PCBs release simulation causes a maximum increase in the fish tissue concentration of about 0.3 mg/kg at RM 50 as opposed to a shorter lived increase of about 1 mg/kg at RM 152. These model predictions lead to the following important conclusion: since these scenarios all return to the MNA recovery curve relatively quickly, the larger releases examined here are not expected to impact the time to reach the remedial goal for fish tissue of 0.05 mg/kg. They are also predicted to have little, or minimal, impact (2 to 3 years) on the time to various interim remedial target levels[5]. Thus, there are no predicted impacts on the goals of the ROD. Further, as noted above, these model predictions do not account for the improvements to Lower Hudson conditions that will result from the load reduction from the remediation.

Summary and Observations

The Farley-FISHRAND models were run for a series of Upper Hudson loads that correspond to the upper end of the proposed revisions to the Resuspension Standard. In particular, scenarios were run for dredging-related loads of 600 kg and 800 kg of Tri+ PCBs (approximately 1800 and 2400 kg Total PCBs) at Waterford. The impacts of these loads were contrasted with the MNA recovery curve, used here as a surrogate for the remedy curve response in the Lower Hudson. This approach provided an upper bound on the likely time to rejoin the ideal recovery curve (representing no resuspension load due to dredging).

The results show only minimal increases in the time to rejoin the ideal recovery curve relative to scenarios representing less PCB loss to the Lower Hudson. From this analysis, it can be concluded that the larger loads examined here have negligible long term impacts to Lower

---

[3] The no resuspension curve shown in Figure 4-B-2 represents the ideal remediation curve, with no dredging-related resuspension. Attainment of that curve a short time after dredging indicates that the impacts of dredging are short-lived and have little influence on the improved rate of recovery anticipated by the remedy.

[4] The original Farley model-FISHRAND runs assumed the remedy would be conducted between 2006 and 2011. Therefore, the end of the remediation for those scenarios is the year 2011. Currently, it is anticipated that the remedy will be completed in 2015.

[5] The potential impacts due to dredging resuspension were recognized as part of the preparation of the ROD and were included in the Responsiveness Summary. The impacts predicted here are similar to those noted in the supporting ROD documentation. See for instance, the times to recovery shown in Table 363176-5 of the Responsiveness Summary (USEPA, 2002).

Hudson fish tissue concentrations and indicates that similar to the original load standard, the revised load standard serves a dual role of protecting the Lower Hudson while ensuring that dredging operations do not cause unnecessary resuspension.

In support of these model findings, there are several observations from Phase 1 that would suggest this analysis is actually an upper bound on the impacts to the Lower Hudson. Despite the increase in PCB loads measured during Phase 1 at Waterford, the monitoring of water column concentrations in the Lower Hudson did not show any increase in the Tri+ PCB concentrations at Albany or in Total PCBs and Tri+ PCBs concentrations at Poughkeepsie and the other Mid-Hudson monitoring locations. The fish tissue results for the fall 2009-collected pumpkinseed and forage fish, on a river section basis, in River Section 3 (approx. 168.2-183.2) of the Upper Hudson did not show any increase of the mean value from the prior 5 years monitoring. Appendix I-C of the EPA Phase 1 Evaluation Report (March 2010) discussed the resident fish annual monitoring data in details.

Taken together, these observations and calculations indicate that the proposed range of revisions to the allowable load standard for the Lower Hudson would not have any measurable long term impacts to the recovery of fish tissue concentrations and therefore would not pose any additional long term risks to Hudson River fish-consuming populations in the Lower Hudson.

References

Farley, K.J., R.V. Thomann, T.F. Cooney, D.R. Damiani, and J.R. Wand., 1999. An Integrated Model of Organic Chemical Fate and Bioaccumulation in the Hudson River Estuary. Prepared for the Hudson River Foundation. Manhattan College, Riverdale, NY.

USEPA, 2000. Phase 2 Report: Revised Baseline Modeling Report, 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. January 2000.

USEPA, 2002. Responsiveness Summary for the Record of Decision. Prepared for EPA Region 2 and the US Army Corps of Engineers (USACE), Kansas City District by TAMS Consultants, Inc. January 2002.

Table 4-B-1a. Scenarios for Dredging Related Release Tri+ PCB Load at Waterford

Year	Start Date	End Date	Number of Dredging Days	Dredging Related Tri+ PCB Load for the		Dredging Related Tri+ PCB Load per Day Net	
				600 kg	800 kg	600 kg	800 kg
2009	5/16/2009	10/27/2009	134	59	59	0.44	0.44
2011	5/15/2011	10/1/2011	114	108	148	0.95	1.30
2012	5/15/2012	10/1/2012	114	108	148	0.95	1.30
2013	5/15/2013	10/1/2013	114	108	148	0.95	1.30
2014	5/15/2014	10/1/2014	114	108	148	0.95	1.30
2015	5/15/2015	10/1/2015	114	108	148	0.95	1.30
			Total Release	600	800		

Table 4-B-1b. Scenarios for Dredging Related Release Total PCB Load at Waterford

Year	Start Date	End Date	Number of Dredging Days	Dredging Related Total PCB Load for the		Dredging Related Total PCB Load per Day Net	
				1,800 kg	2,400 kg	1,800 kg	2,400 kg
2009	5/16/2009	10/27/2009	134	176	176	1.31	1.31
2011	5/15/2011	10/1/2011	114	325	445	2.85	3.90
2012	5/15/2012	10/1/2012	114	325	445	2.85	3.90
2013	5/15/2013	10/1/2013	114	325	445	2.85	3.90
2014	5/15/2014	10/1/2014	114	325	445	2.85	3.90
2015	5/15/2015	10/1/2015	114	325	445	2.85	3.90
			Total Release	1,800	2,400		

Note: The total PCB load was derived by multipling Tri+PCB load by 3, reflecting the Total to Tri+PCB ratio commonly found in the sediments, which are the source of these loads.

Table 4-B-2
Year and Number of Years Composite Fish Tissue Concentration Recovery

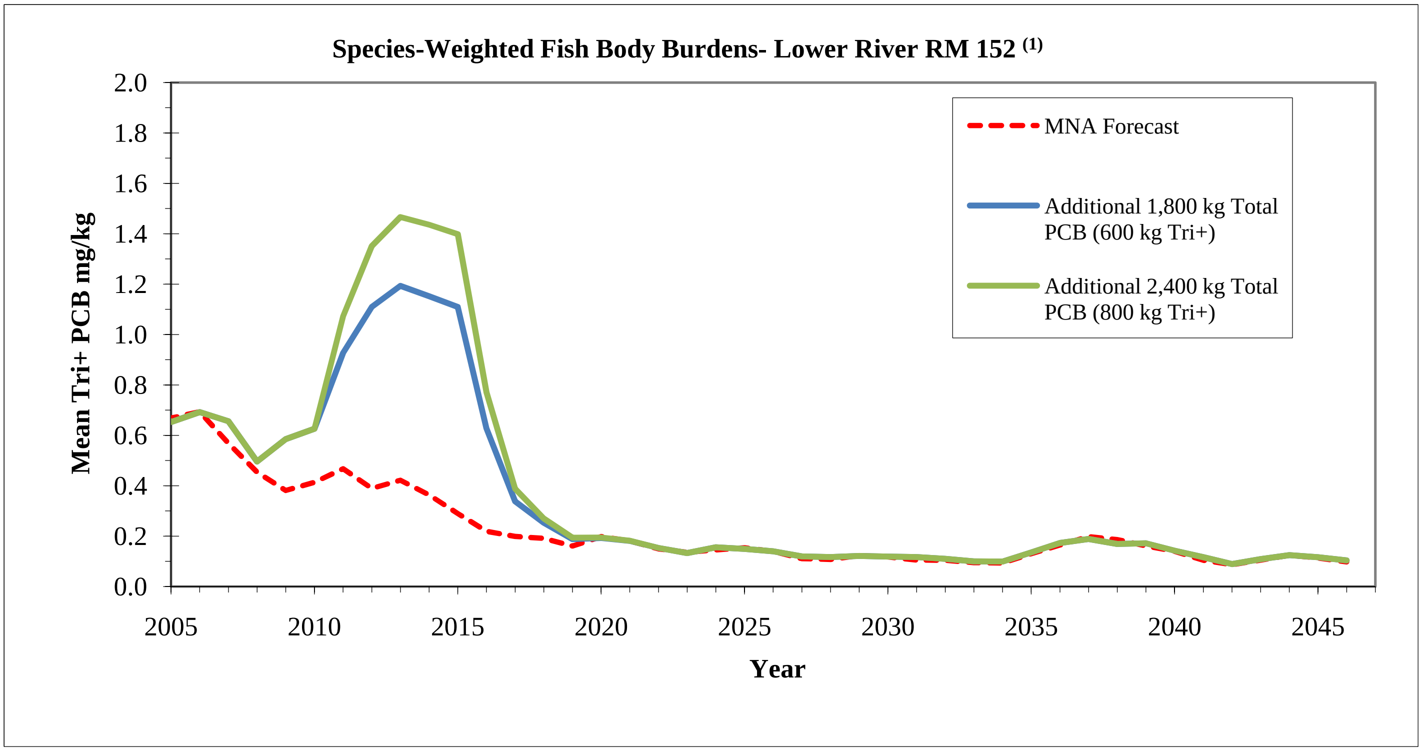
Scenario	Number of Years for Fish Tissue Recovery After Completion of Dredging (2015)[1]			
	RM 152	RM 113	RM 90	RM 50
350 ng/L[2,3]	5	6	9	11
Additional 1,800 kg TPCB	5	7	10	12
Additional 2,400 kg Total PCB	5	8	11	13

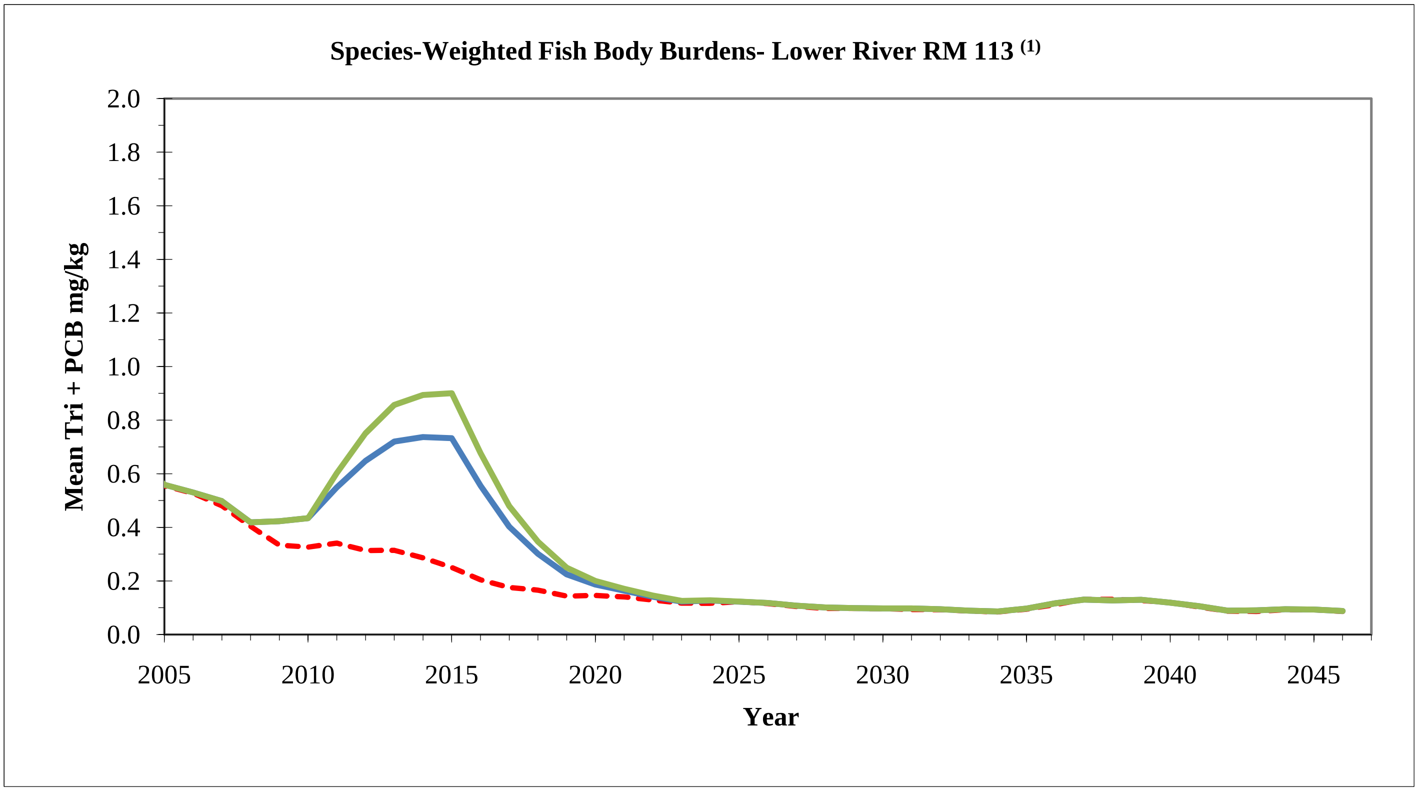
Notes:

[1] The fish tissue concentration was considered to have recovered when the forcasted fish tissue concentration for remedial scenario agreed with MNA forcast to within 10% of the MNA value.

[2] The 350 ng/L was previously run for the Performance Standard. The figure is included as Figure 4-2 for this addendum.

[3] For the 350 ng/L scenario, the end of dredging was 2011.



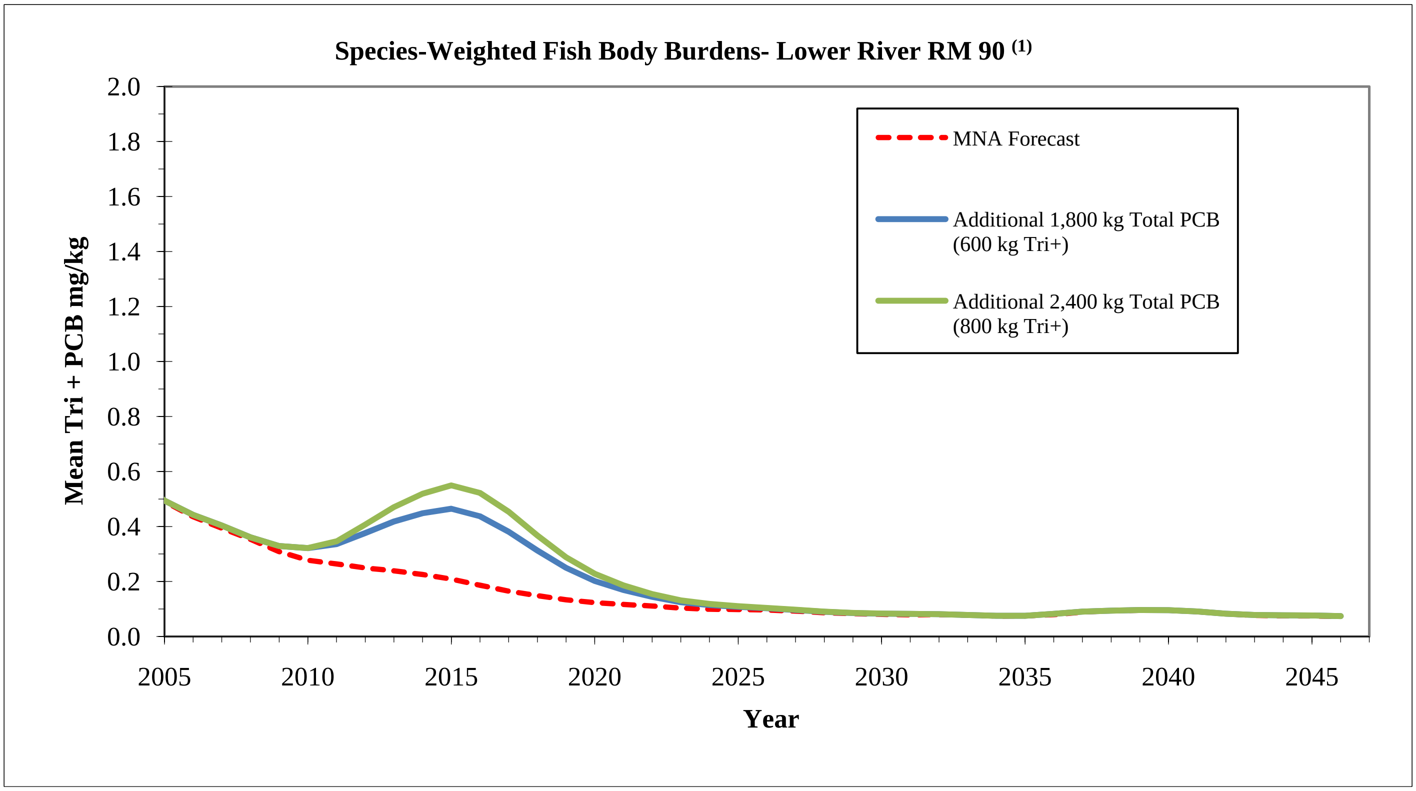


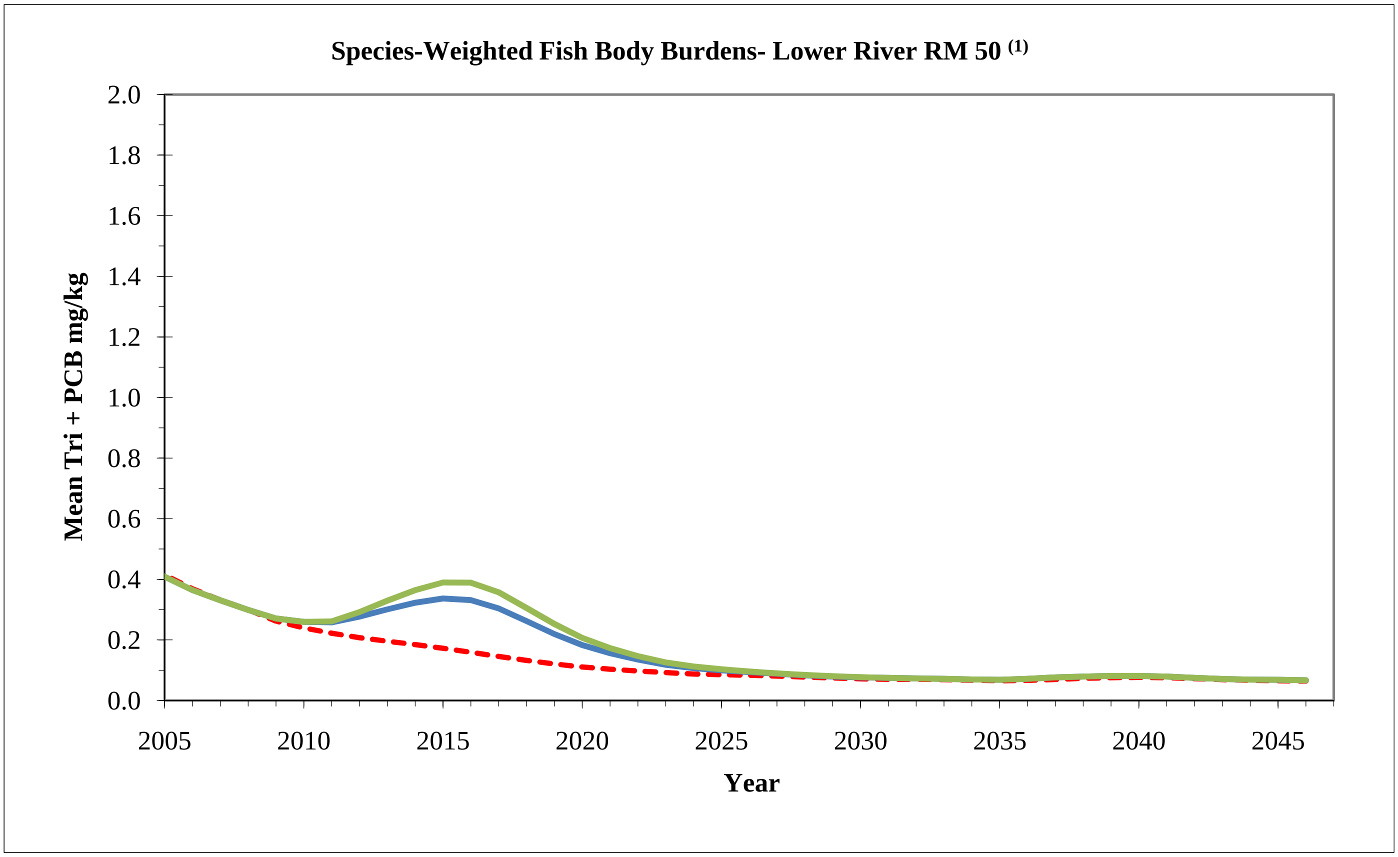
[1] Species-Weighted Average assumes 47% largemouth bass + 44% brown bullhead + 9% Yellow Perch

Composite Fish Tissue Concentration for the Lower River
1,500 to 3,000 kg Total PCB Release Scenarios

Figure 4-B-1a

April 2010



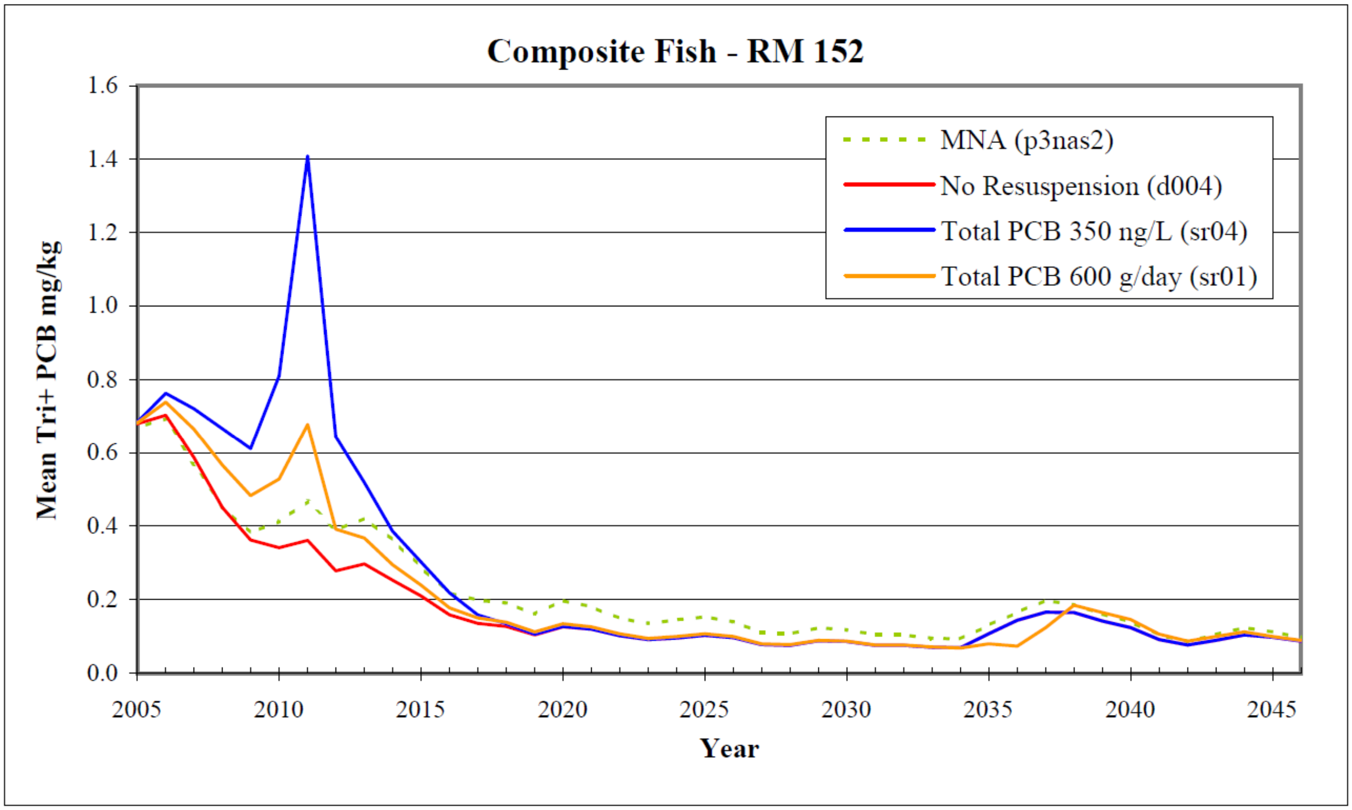


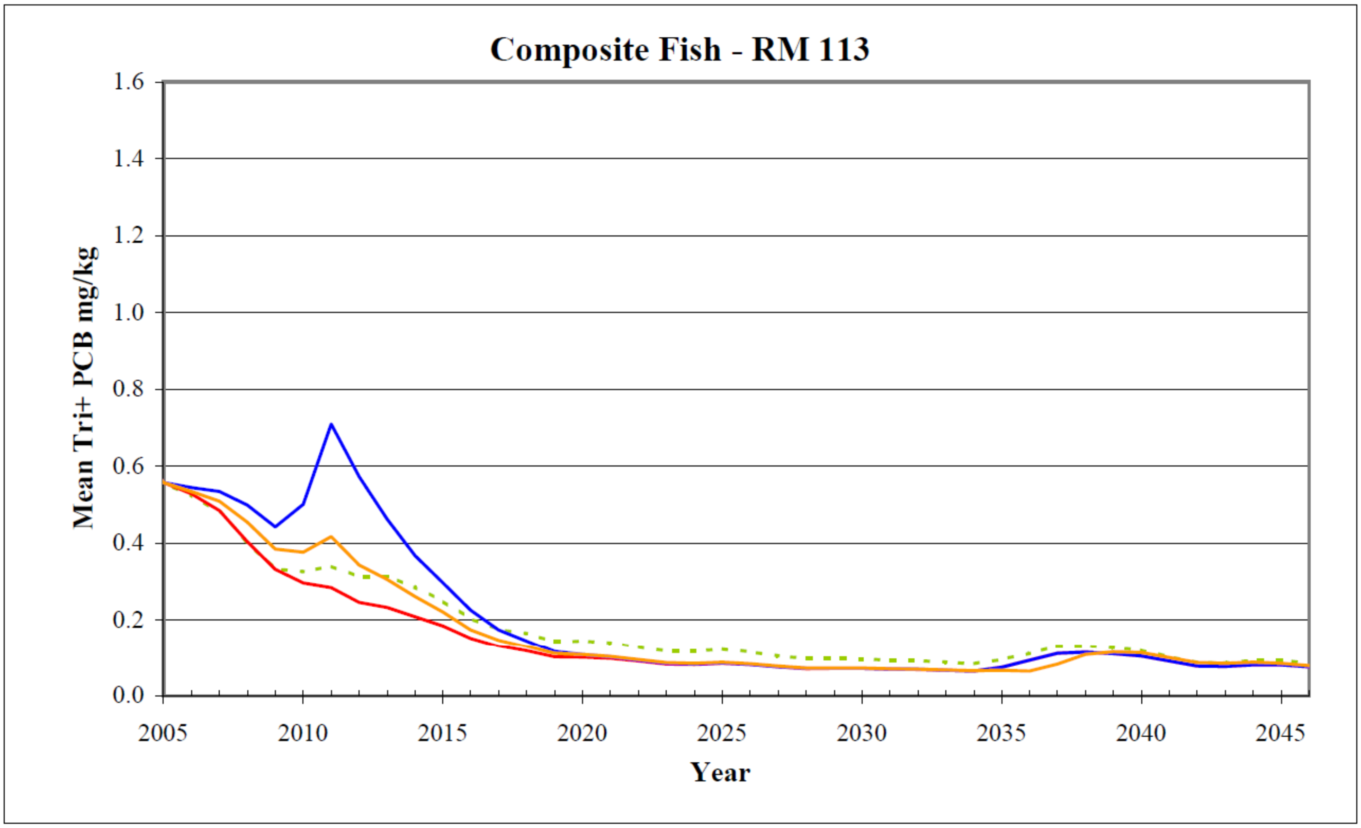
[1]Species-Weighted Average assumes 47% largemouth bass + 44% brown bullhead + 9% Yellow Perch

Composite Fish Tissue Concentration for the Lower River
1,500 to 3,000 kg Total PCB Release Scenarios

Figure 4-B-1b

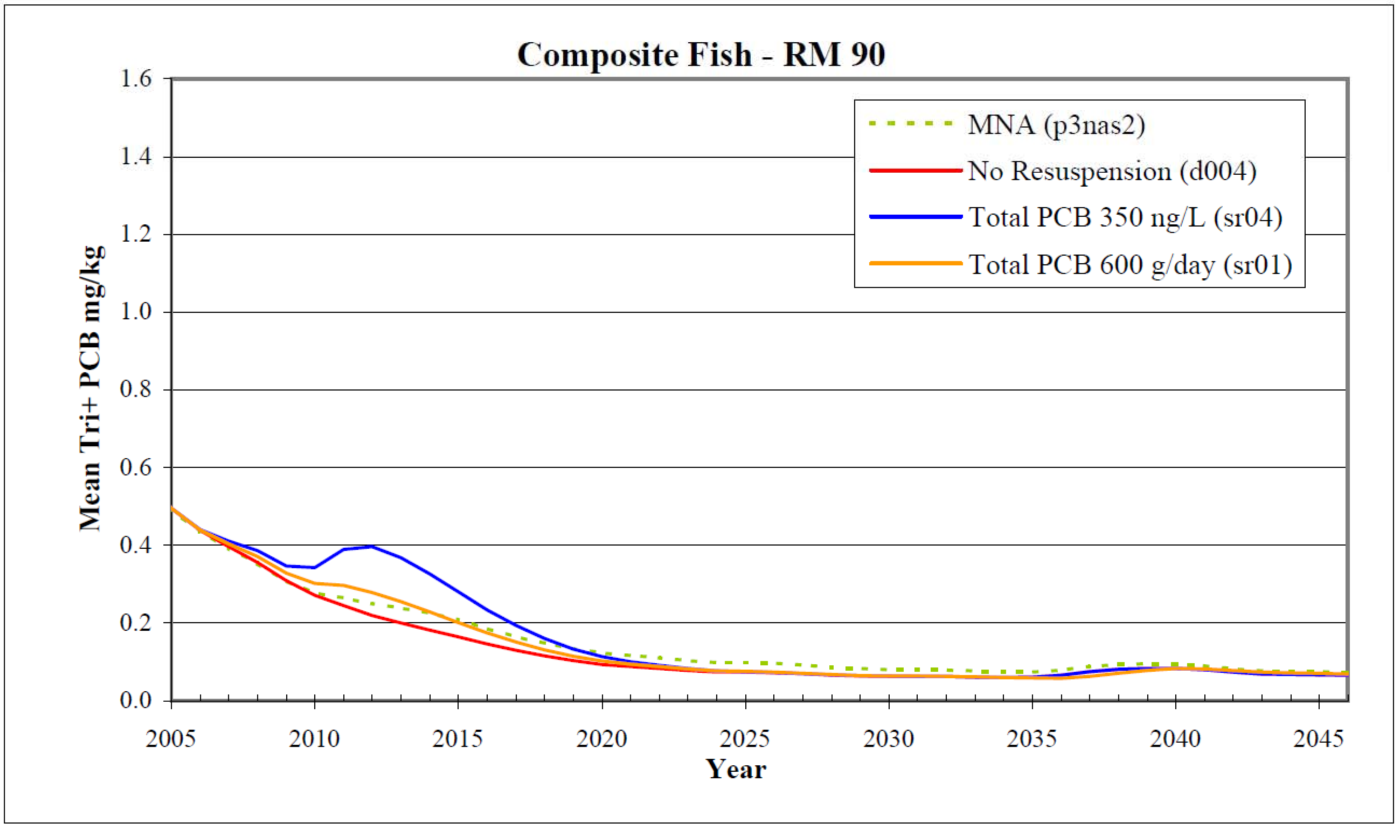
April 2010

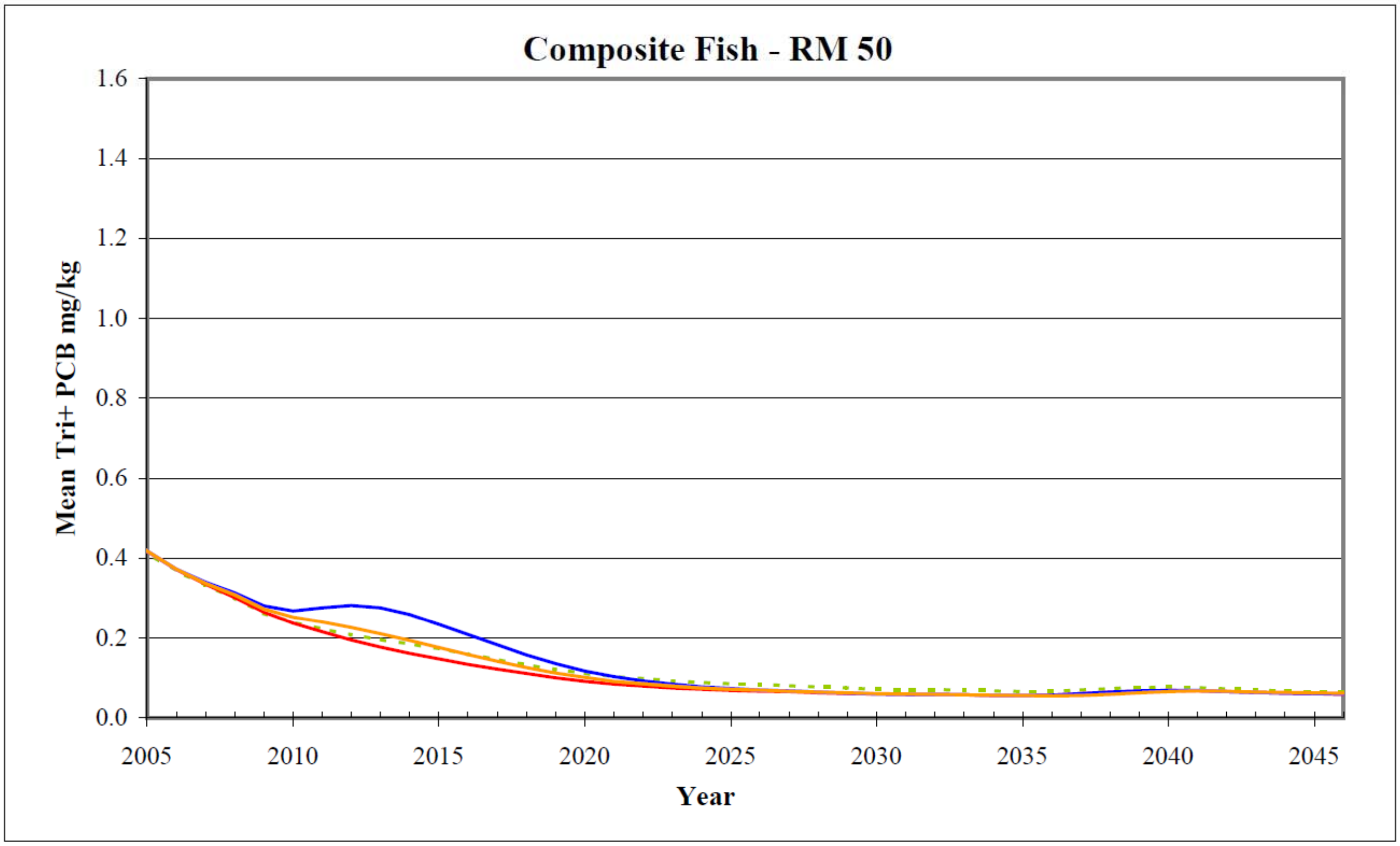




[1] Species-Weighted Average assumes 47% largemouth bass + 44% brown bullhead + 9% Yellow Perch

Composite Fish Tissue Concentration for the Lower River
Figure 2-9 of the Resuspension Performance Standard





[1]Species-Weighted Average assumes 47% largemouth bass + 44% brown bullhead + 9% Yellow Perch

Composite Fish Tissue Concentration for the Lower River
Figure 2-9 of the Resuspension Performance Standard

Figure 4-B-2b

April 2010

TOPIC 5

SCOW UNAVAILABILITY AND ITS IMPACT ON PRODUCTIVITY

Topic 5 - Scow Unavailability and Its Impact on Productivity: An Assessment of Scow Queuing Effects

Abstract

The effects of scow load thickness and unloading time were evaluated both through examining the scow unloading dock records from Phase 1 and through developing a probabilistic model based on the unloading dock records (taken from Appendix P of GE's November 2009 Phase 1 Data Compilation Report). The number of scows that were at the loading dock (on queue and being serviced) was calculated from these records. Although these records do not account for all scows that were on queue (when the loading dock was close to full, some scows were moored in the river and were not accounted for as being on queue), they show that productivity declined when queues reached peak levels. It is also possible to discern that up to 14 of 18 scows were unavailable in the week preceding the August 7th resuspension shut-down and that most scows were available for Phase 1's peak one-day productivity on September 8th.

The probabilistic model randomly pulled scow arrival and unloading data from Appendix P to simulate the average conditions during Phase 1. There was close agreement between the model and the actual average conditions, so the model was used to assess two factors: loading the scows with more sediment on average and adding a second unloading station. Both of these factors relate to unloading efficiency. The model shows that a single unloading station cannot meet the Phase 2 monthly productivity target of 96,000 CY for a sustained period of time, even if scows carry greater loads on average. This is because the queue that develops from the single unloading station causes productivity to fall off, even when using only data from the best 30-day period of Phase1. However, the model shows that the target can be met by adding a second unloading station and increasing the scow loads by 0.7 feet above the average scow loading thickness from Phase 1. This increase of loading is within the operational range of the scows and should be achievable with the equipment on hand.

5.1. Introduction

During Phase 1 a single unloading station was utilized to unload sediment-laden scows. Notably, the scow unloading service capacity was exceeded by the number of scows arriving at the loading dock throughout much of the project. This had a downstream effect of limiting the number of scows available for dredgers to fill during dredging. As discussed in EPA's Phase 1 Evaluation Report, about 26 percent of the available dredging time was lost to dredgers waiting for scows. The unloading system used during Phase 1 was evaluated to assess how significantly the unloading system affected scow availability and productivity. The system was ultimately simulated with a probabilistic model of scow queuing based on the Phase 1 data to see if modifications (either to the loading of scows or adding a second unloading station) would result in higher productivity.

5.2. Development of Model Variables

Information on the arrival time, service start time, service end time, sediment load (in cubic yards), and water removed (in gallons) for each scow unloaded during Phase 1 is provided by GE in Appendix P of their November 2009 Phase 1 Data Compilation Report. The unloading dock can accommodate up to 5 to 6 scows in a queue with a sixth or seventh scow being serviced by the unloading station. However, scow logs show that many of the scows spent at least some time at a river mooring before arriving at the unloading dock. This information is in handwritten logs and was not compiled as part of Appendix P, while the records in Appendix P only account for scows that are tied up at the unloading dock waiting to be unloaded and being unloaded. So when the records show there are four or more scows waiting at the loading dock behind the scow being serviced, it is likely that, due to limited space, scows were also being staged at moorings in the river and a complete count of idle scows was not being made. That is, when 2/3 of the room at the dock was occupied, it may have been easier to moor a scow in the river than it was to maneuver scows already tied up at the loading dock to accommodate the new scow, even if there was technically enough room for it. This is important for interpreting model results because the full length of the queues during Phase 1 dredging often cannot be known for certain since the number of scows moored in the river at any given time was not recorded and they could have been moored there even at times when there is theoretically space available at the unloading dock. Figure 5-1 shows the number of scows queued at the unloading dock while each scow was being serviced.

Also shown on Figure 5-1 are GE's estimate of daily dredged volume and the daily estimated volume arriving at the unloading dock. The peak queue occurred on July 24th with six scows in line at the unloading dock. This period of scow unavailability precipitated a series of events related to productivity: dredging productivity, which reached a peak on July 29th, subsequently dropped and daily loads arriving at the unloading dock declined as well. Productivity (measured both by GE's estimate of dredging and the amount of material arriving at the unloading dock) had already begun to decrease due to scow unavailability in late July, a full week before the August 7th resuspension event. The volume of material arriving each day also dropped six days before the resuspension-related shut down. These events occurred during the period when GE was attempting to meet the full-scale, maximum monthly productivity threshold of 89,000 CY and are germane to assertions in GE's Phase 1 Evaluation Report that productivity thresholds cannot be achieved without jeopardizing the resuspension standard water quality threshold. One very important relationship that can be seen from Figure 5-1 is that scow queuing, and not resuspension-related operational interruption, was controlling productivity. Further, since productivity was already declining in the week leading up to the resuspension-related shut-down, that resuspension event cannot have been precipitated by increasing production.[1]

Scows continued arriving at the unloading dock for three days after August 7th although no dredging was taking place. The loads in these scows are not significantly different (less) than scows arriving before or after. Four scows were in the queue at the start of August 8, and 10 scows arrived between August 8 and August 11th. This means that 14 of 18 scows were full and ready to be unloaded on August 7th, with dredging occurring in all 10 CUs at that time. From this it can be surmised that a maximum of only 4 out of 18 scows were available to service the 11 dredges that were working in 10 separate CUs on August 7th. This shutdown period highlights how large the scow queue had become and how the scow queue was affecting productivity. The

---

[1] This assessment raises the question as to what factors, if not an increase in productivity *per se*, may have contributed to the exceedance of the 500 ng/l water quality threshold that led to the operational shut-down on August 7th. This question is addressed in separate papers in this Addendum under Topics 2 and 8 as is the validity of the sample results from Thompson Island station autosampler during that time frame.

greatest daily dredging volume estimates occurred September 8th and 9th following 4 days without dredging (*i.e.*, the Labor Day weekend), and precede the second resuspension-related event on September 11th. The likely explanation for this dramatic increase in productivity is that for the first (and only) time since the start of dredging in earnest, nearly all scows were available for use (except after the August 7th shutdown, when dredging was re-started slowly). Our analysis in Topic 2 shows that the responsibility for the September 11th resuspension event can be linked to the releases emanating from the windows in the sheet pile at CU18.[2] Within two days of resuming dredging after the long weekend (by September 9th), the queue had returned to 2 to 3 scows in line and production dropped by 700 to 900 CY per day.

A model was developed to assess two factors that may have contributed to generating and maintaining the scow queue. The first factor is the limitation of the scow unloading station and the second factor is the removable volume of sediment that arrived in each scow. Appendix P provides information on both factors. The unloading start times and end times for each scow are presented for each scow (however the time required to move the scow into place, the scow handling time, is not documented specifically). The unloading times from Appendix P were used as a basis for the service time in the model along with a calculation of the handling time (described below). Based on the average large hopper scow dimensions, an estimate of load-thickness to volume of sediment was calculated. Due to unloading equipment limitations, between six inches and a foot of sediment was left in the scow after unloading, so the volume unloaded was the material above this level, referred to here as the removable portion of the scow load. This removable load thickness averaged about 1.7 feet during Phase 1. Figure 5-2 is a histogram of scow removable load thickness from Phase 1. The removable load thickness is the volume unloaded from each scow as given in Appendix P divided by the average scow bottom area. It was noted during field activities that the last foot of material unloaded from a scow required the greatest amount of time, so a relationship between scow removable load thickness and scow unloading time per foot was evaluated. Figure 5-3 shows the relationship between removable load thickness and the per-foot unloading time. This figure uses the average time for all scows of similar removable load thickness. As can be seen, the more fully loaded a scow was, the faster, on average, each foot of material was unloaded. This rate increase is due to the rise in bucket efficiency of the excavator unloading the scow as the thickness of material in the scow increases.

Scow handling time, the time between when an unloaded scow leaves the dock and the next scow from the queue is available to be unloaded, was not specifically accounted for in Appendix P. Scow handling time is part of the service time and represents the time necessary to move scows from the queue to the unloading station. Appendix P only includes the time when a scow was being unloaded. However, handling time could be calculated as the duration between scow service events when scows were queued or, if no scows were waiting in a queue for service, as the elapsed time from the arrival of a scow to the time that scow was serviced. Figure 5-4 is a histogram of the scow handling time calculated from Phase 1.

---

[2] Although productivity was at its highest levels in the days preceding the September 11, analyses show the direct cause for higher PCB levels at Thompson Island on September 11 is releases that occurred from the silt curtain enclosure at CU-18 as discussed in the paper on causes of resuspension in this Addendum under Topic 2.

5.3. Model Calibration and Baseline Application

A model of the scow queuing and unloading process was built in Microsoft Excel based on a probabilistic framework, using the modeling procedures described in Winston (2004) and Winston and Albright (2009). The model uses both Monte Carlo and bootstrap approaches to access data from Phase 1 as input. The methods for each data set used are discussed below. The model simulates scows arriving at the unloading dock (arrival interval and removable load thickness) and being serviced (handling time plus service time, as calculated from the exponential relationship with removable load thickness). Two ‘clocks’ are used: the arrival clock determines when a scow arrives and the service clock determines when a scow is serviced (both are relative to the start of the simulation). When a scow arrives it is either serviced or, if there is already a scow being serviced, it is put in the queue. The ultimate number of scows and the estimated loads of each scow serviced in a 30-day period were summed as output from the model.

The model is based upon the following equations and conditional statements:

Queue length: *Q (number of scows in queue)*

Arrival clock: *C_A (cumulative hours since simulation start)*

Arrival interval: *A (time between scow arrivals, in hours)*

$$\text{For the arrival of the nth scow: } C_{A(n)} = \sum_{t=0}^{n} A_t$$

Service Clock: *C_S (hours of scow unloading since simulation start)*

Unloading time: *U (hours)*

Handling time: *H (hours)*

$$\text{For the nth scow: } C_{S(n)} = \sum_{t=0}^{n} (U_t + H_t)$$

where the unloading time is given by one of two formulas:

based on the average unloading time in Phase 1

$$U_{ave} = 4.3138e^{-0.304b}$$

based on the average unloading time in the 30 higher production days

$$U_{30d} = 3.3436e^{-0.244b}$$

and b is the Removable Load Thickness *in feet*

*b = (scow load volume removed (CY)/scow payload area (Y^2))*3 ft/Y*

For each scow arrival:

If $C_{A(n)} < C_{S(n-1)}$ the scow is added to Q; Q = *number of scows where* $C_{A(n)} < C_{S(n-1)}$ and $C_{S(n)}$ is then the future time at which the nth scow will be serviced.

If $C_{A(n)} > C_{S(n-1)}$ the scow is serviced immediately; $Q = 0$

When $C_{A(n)} > C_{S(n-1)}$ *then* $C_{S(n)}$ *is set equal to* $C_{A(n)}$ since $C_{S(n)}$ cannot be less than the scow arrival time.

Volume:

For $C_{S(n)}$ = 720 hrs (30 days)

Scow count: S = *number of scows that arrived in 30 days*

The unloaded volume for each scow (in CY):

$$V_u = b*scow\ payload\ area*CY/27ft^3$$

The total unloaded volume (in CY):

$TV = \sum V_{u30\ days}$ (the sum of sediment unloaded in 30-days)

Single model run yields: *TV*, *S*, 30-day average *Q*, 30-day average *b*

Monte Carlo output (750 model runs): Average *TV*, Average *S*, Average *Q*, Average *b*, minimum *TV*, maximum *TV*, *TV* standard deviation.

The model baseline application follows this progression:

1. The Phase 1 data are arranged in a table with each row representing a discrete scow arrival record, and the columns representing the attributes recorded for each arrival (load thickness, arrival time at the unloading dock, etc.)
2. Two random numbers are generated; the first is used to select a scow arrival interval randomly from the corresponding row in the data table, and the second to select a scow removable load thickness randomly from its corresponding row (which, except for an unusual coincidence, would be different than the row from which the scow arrival interval was randomly selected).
3. The handling time is selected from the handling time distribution using the first random number (that is, from the same row/record as the scow arrival interval).
4. The unloading time is calculated for the arriving scow using the exponential relationship between removable load thickness and service time (see Figure 5-3) and added to the handling time to determine the total elapsed service time.
5. The arrival interval is added to the arrival clock and the total service time is added to the service time clock.
6. The arrival clock for the current scow is compared to the service clock for the completion of the previous scow; if the scow has arrived before the previous scow's service is complete, the scow is added to the queue.
7. The model then returns to step 1 to simulate the next scow arrival.
8. The total numbers of scows arriving for a 30-day period based on the service clock are summed, as well as the total sediment volumes.[3]

---

[3] To maintain simplicity, rather than directly programming a simulation limit on the number of scows to the project total of 18, the model tracks the number of scows that have arrived. If the count in the queue exceeds 18 (including the scow being serviced), these excess scows and their associated volumes are excluded from subsequent calculations since they represent scow arrivals that could not occur.

9. An Excel "macro" was written to capture the iterated output for 750 model runs. The macro re-randomizes Excel after every 50 runs to assure no repetition of data selection patterns occurs.
10. The number of scows, total volume, average number of scows on queue, and average removable load thickness are reported for the 750 runs along with minimum, maximum and standard deviation for the total volume unloaded.

The model includes the use of the Excel random number generator to choose scow thicknesses and arrival intervals (the time between two arriving scows) from the 628 scow arrivals that occurred during Phase 1. With 18 scows and up to 11 dredges operating in up to 10 CUs, the logistics of the project were complex and arrival interval and scow load thickness were shown to be statistically independent variables with $R^2 < 0.01$ (see Figure 5-5). For this reason, separately generated random numbers are used to select scow arrivals and scow removable load thicknesses from the Phase 1 data pool, rather than selecting these factors from the data for the same arriving scow with a single random number.

Scow handling time is selected probabilistically from the distribution shown on Figure 5-4 using the random number generator as well. The scow service time is calculated using the removable load thickness relationship shown on Figure 5-3 and added to the scow handling time to produce a total service time. The total service time for each scow is then cumulatively summed to create the service time clock to track how much time has passed since the first scow arrived and began being serviced. The times between arrivals are also summed to create the arrival time clock tracking the time associated with scow arrivals simulated to have passed since the first scow arrived at the loading dock and began being serviced. The number of arrivals simulated to have occurred between the time an individual scow arrived and completion of that scow's unloading are counted as being in the queue.

The total amount of sediment unloaded in a 30-day period is then summed from the scows simulated to have been serviced during that period according to the service clock. The average scow removable load thickness is also calculated for the 30-day period, as well as the average scow queue length. The model was run 750 times as a Monte Carlo simulation (with the input variables drawn randomly for each run as described above) and the values for each of the output parameters were averaged from the 750 runs to determine the average model output. Table 5-1 compares the average model output with the actual 30-day averages from Phase 1.

Table 5-1 - Model Output and Phase 1 Average Values

	Average 30-day Volume	Number of Scows Serviced	Average Number of Scows in Queue	Average Scow Removable Load Thickness
Phase 1	47,338 CY	112.7	2.7*	1.67 ft
Model	47,331 CY	111.8	4.5	1.67 ft

* The 'average number of scows in queue' value for Phase 1 only includes scows that were docked at the unloading dock. In reality, when the loading dock was near full, the queue continued to moorings in the river. During Phase 1, the count at the dock was 4 or more scows on 139 occasions, and many scow logs include time at river moorings before being moved to the unloading dock. For this reason the close agreement of the other factors suggests that the Phase 1 average number of scows in the queue is an underestimate, rather than the model yielding an overestimate.

5.4. Model Predictions for Phase 2

Given the close agreement between the model output and the data for the actual 2009 conditions, the model was then used to predict the impact on dredging production if additional material were added to every scow and if an additional unloading station were added. For this evaluation, the best 30 consecutive days of scow unloading were used for random values of removable load thickness, arrival time and scow handling time.

The following modifications were made to the model to facilitate these analyses:

1. A term was added to the Phase 1 scow removable load thickness that would increase the removable load thickness of each scow from Phase 1 by a specified amount (these are the load thicknesses selected randomly by the model).
2. A flag was added to indicate that two unloading stations were active (the model can run either one or two stations).
3. A logical statement was added to simulate two stations being active so that if one station is occupied (as determined by that station's service clock) then an arriving scow will be serviced by the second station; if both stations are occupied, the arriving scow is counted as being in the queue.
4. The total service clock was reconfigured. Since it is possible that more than one scow is unloaded at one station while the other station services a single scow, the length of time added to the service clock is dictated by the station that is taking the longest.
5. The unloading time relationship was changed to the unloading time relationship shown on Figure 5-6.

The best 30-day period of unloading that occurred during Phase 1 was from July 23rd through August 22nd, when 69,300 CY of material were unloaded. The average removable load thickness during this period was 2.0 feet, which is 0.3 feet greater than the average thickness of Phase 1. The relationship between removable load thickness and unloading rate per foot was also recalculated and is presented on Figure 5-6.

Figure 5-7 shows the result of this modeling exercise. The exercise included GE's specification that a scow could not be loaded to a depth of more than 3.9 feet, since this would cause the scow draft to exceed 8 feet which GE's dredging contractor asserts is the maximum stable draft. Additionally, during Phase 1 it was a practice to place some amount of water over the sediment in the scow to reduce air emissions, which also added to the draft of the scow and occupied some of the load thickness that could otherwise have been occupied by sediment. Also as discussed above, scows were not completely unloaded in Phase 1, so between 0.5 and 1 foot of material remained in the bottom of the scow after unloading. This maximum loading depth (or thickness) minus the amount of material left in the scow (0.5 feet) was used as an upper limit in the modeling (3.4 feet maximum removable load); otherwise the simulated scow loads were drawn randomly from the best 30-day of unloading during Phase 1 and increased by a specific thickness up to a total thickness limit of 3.9 feet.

It is acknowledged that the true measure of productivity is the amount dredged from the river in a given time period. During Phase 1, the total volume unloaded was about 12 percent less than what was estimated to be dredged. The reason for this discrepancy is that some sediment is removed as a slurry during dewatering prior to unloading scows and conversely some pore water volume is counted as sediment during dredging and is included in the volume dredged. However, the amount of material unloaded also reflects and is roughly proportional to the amount dredged, when allowance is made for material removed as slurry when pumping water from the scows. The volume number that is reported from the model is based on the simulated scows arriving and unloaded (on a first-come, first-served basis) in a 30-day period. Since, during Phase 1, scows were not unloaded on a "first-come, first-served" basis, the best 30 days are off by a small amount and don't occur over the same exact period.[4] Comparing the scow arrival volume unloaded to the volume dredged, as noted, the amount unloaded is about 12 percent less, so if the scow arrival volume unloaded exceeds a productivity threshold, then it can be assumed that the dredging volume also exceeds the target. The approximated dredging volume is shown on Figure 5-7 as well.

Figure 5-7 shows the average results for both unloading with one station and with two stations as a result of increasing the removable load thickness (750 runs per 0.25 foot increase to removable load thickness represented by the data points). It also shows the one standard deviation greater and less than the average for both the single station and the two stations simulations. Using a single unloading station, the most optimistic monthly amount that could be unloaded is about 86,000 CY (one standard deviation above the peak average one-month productivity). This equates to a dredging volume of just over 97,000 CY in 30 days. While this volume exceeds the Phase 2 monthly target of 96,000 CY, it represents a level that cannot be sustained for the entire Phase 2 program, based on the analysis here. The queue grows to an average of 12 scows when 1 foot is added (average of 2.9 feet removable load thickness). This shows that the unloading station's capacity achieved during the peak 30 days of unloading in Phase 1 is not sufficient to achieve the Phase 2 productivity target.

However, the Phase 2 productivity target can be met by adding a second unloading station and increasing the scow loads by 0.5 feet above the Phase 1 average during the peak unloading period to an average removable load thickness of 2.4 feet. This is an increase of 0.7 feet above the average load thickness for all of Phase 1 and is well within the load window allowing for material to be left in the scow after unloading and allowing water to be placed on the material during transport. By adding a second station, the scow queue would be all but eliminated. The benefits of reducing the queue will have ramifications at all points in the dredging program, such as increasing the number of scows available for dredging and freeing up tugs that would otherwise be occupied moving scows in the queue. This may also reduce vessel traffic and reduce the time required to dredge a CU (and hence reduce the time an open CU is exposed to the river flow), thus reducing resuspension.

The hand-written scow logs, included in GE's Data compilation Report as Appendix O – Barge Trip Logs, have much more information in them than is presented in Appendix P. The information in these logs could be used to further optimize the scow handling and unloading system using the approach employed for this analysis. It is likely that, through such

---

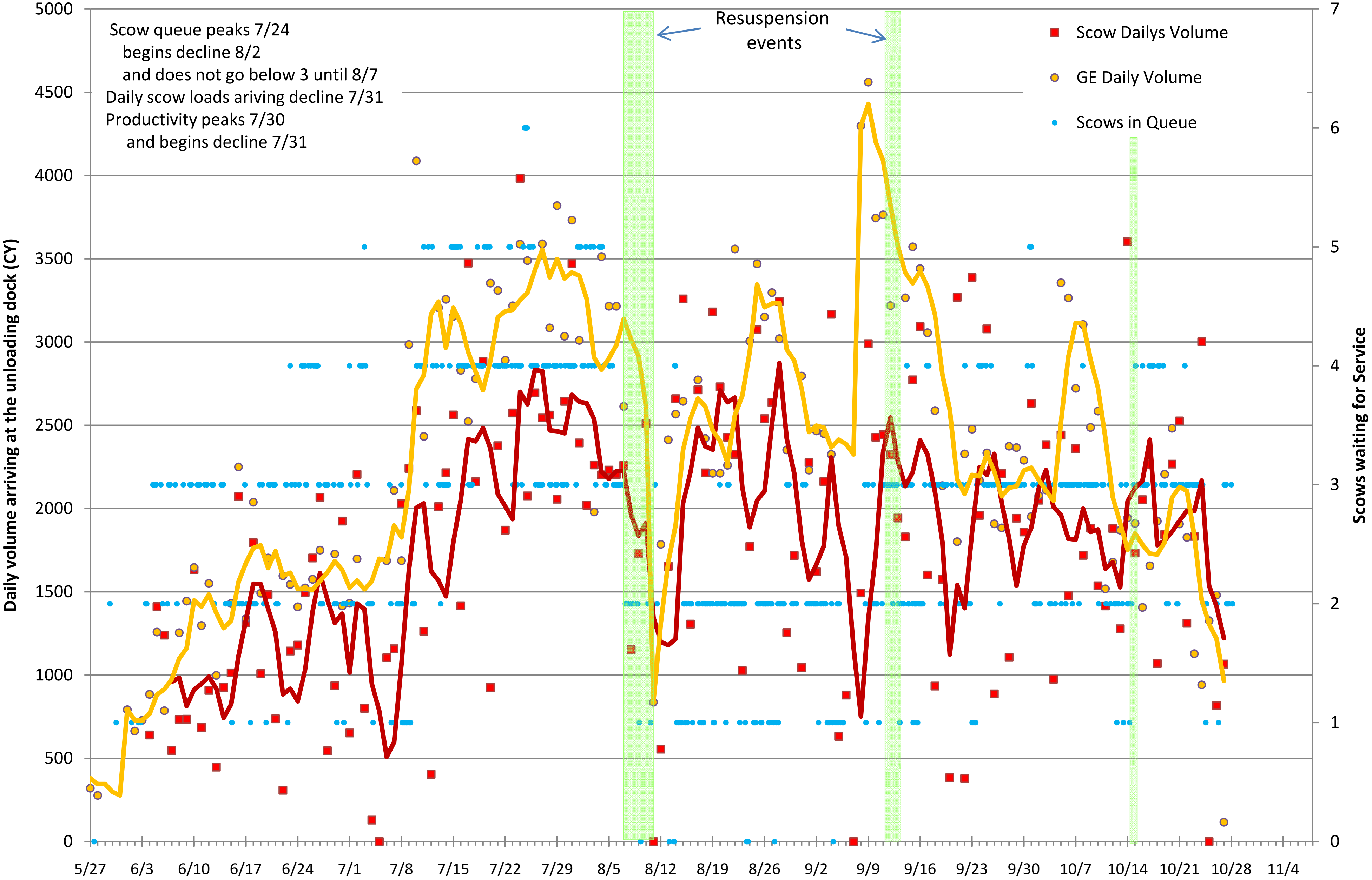
[4] This occurs because the volume in every scow load is different and if scows weren't unloaded in the order they arrived then the unloading amounts and the arriving amounts are different and will peak at different times.

optimization, scow arrival rates could be increased, and that scow handling times could be decreased. Together, these optimizations would result in significant increases in productivity.

References

Winston, W. L., Albright, S. C., 2009; Practical Management Science, Revised 3e; South-Western, Cengage Learning; ISBN-13: 978-0-324-66250-4; USA

Winston, W. L. 2004; Introduction to Probability Models, Fourth Edition; Brooks/Cole – Thompson Learning; ISBN 0-534-40572-X; USA



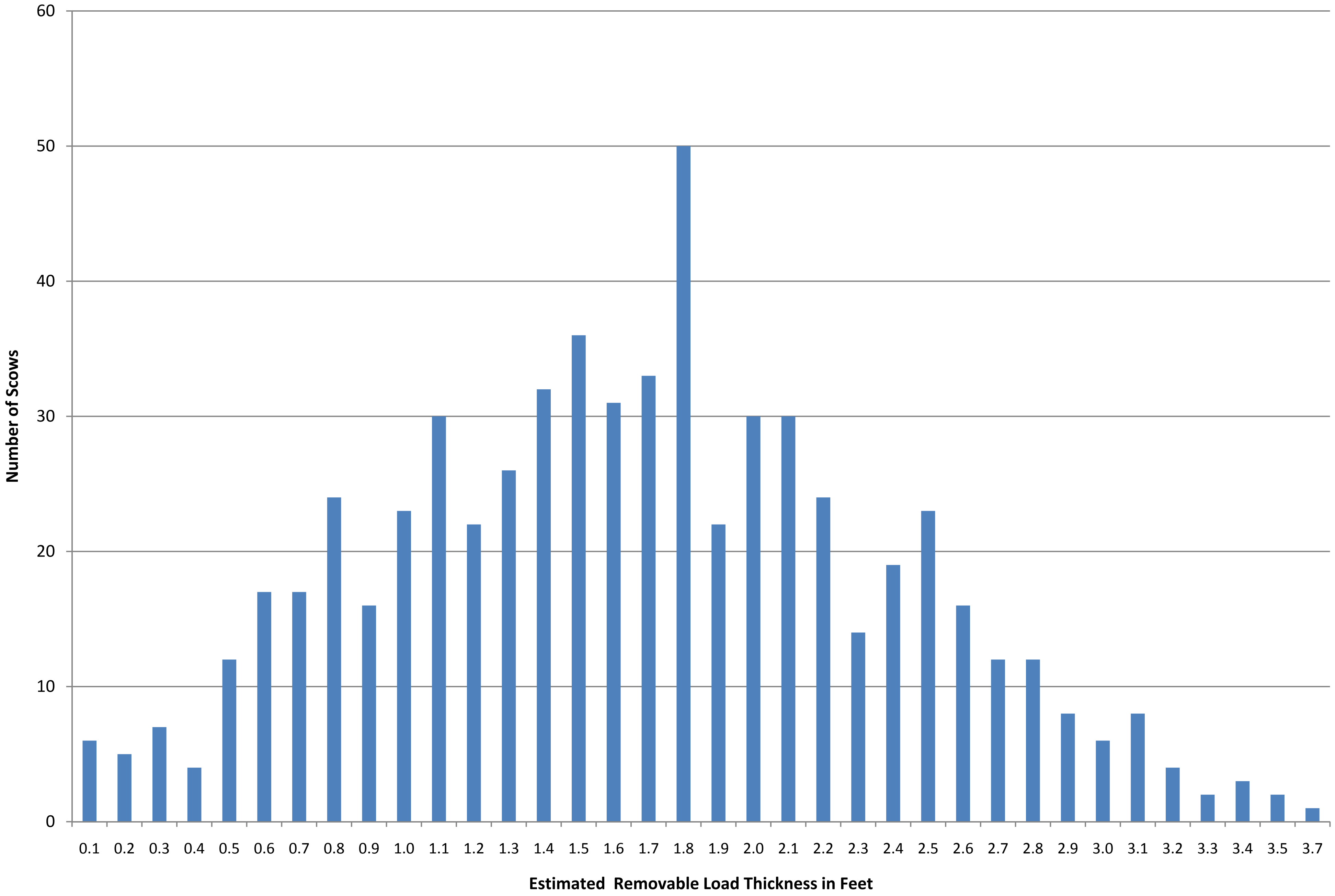
Note: Trend lines are running averages

Scow Queue at Loading Dock and Daily Dredging Productivity

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 5-1

April 2010

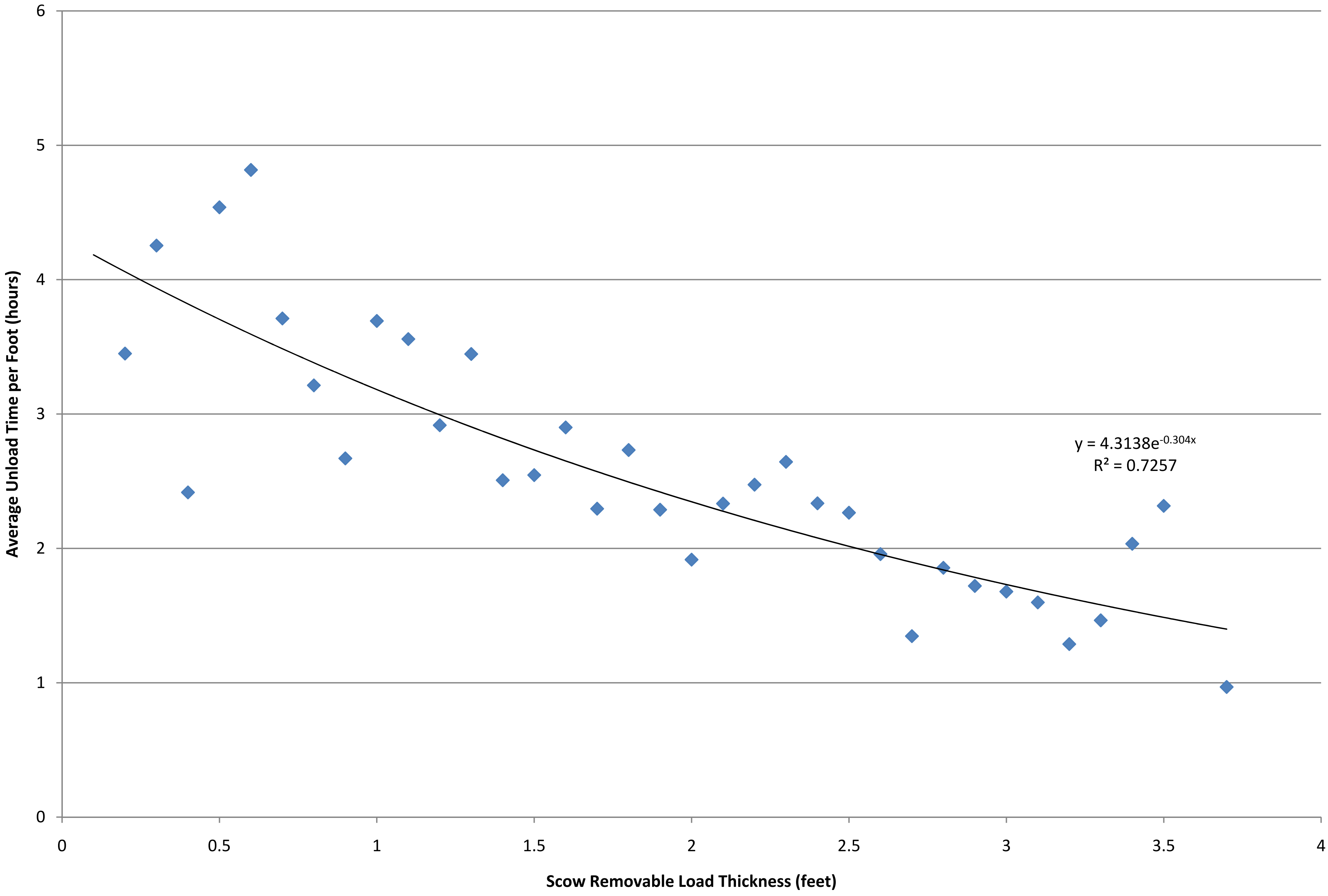


Histogram of Scow Removable Load Thickness

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 5-2

April 2010

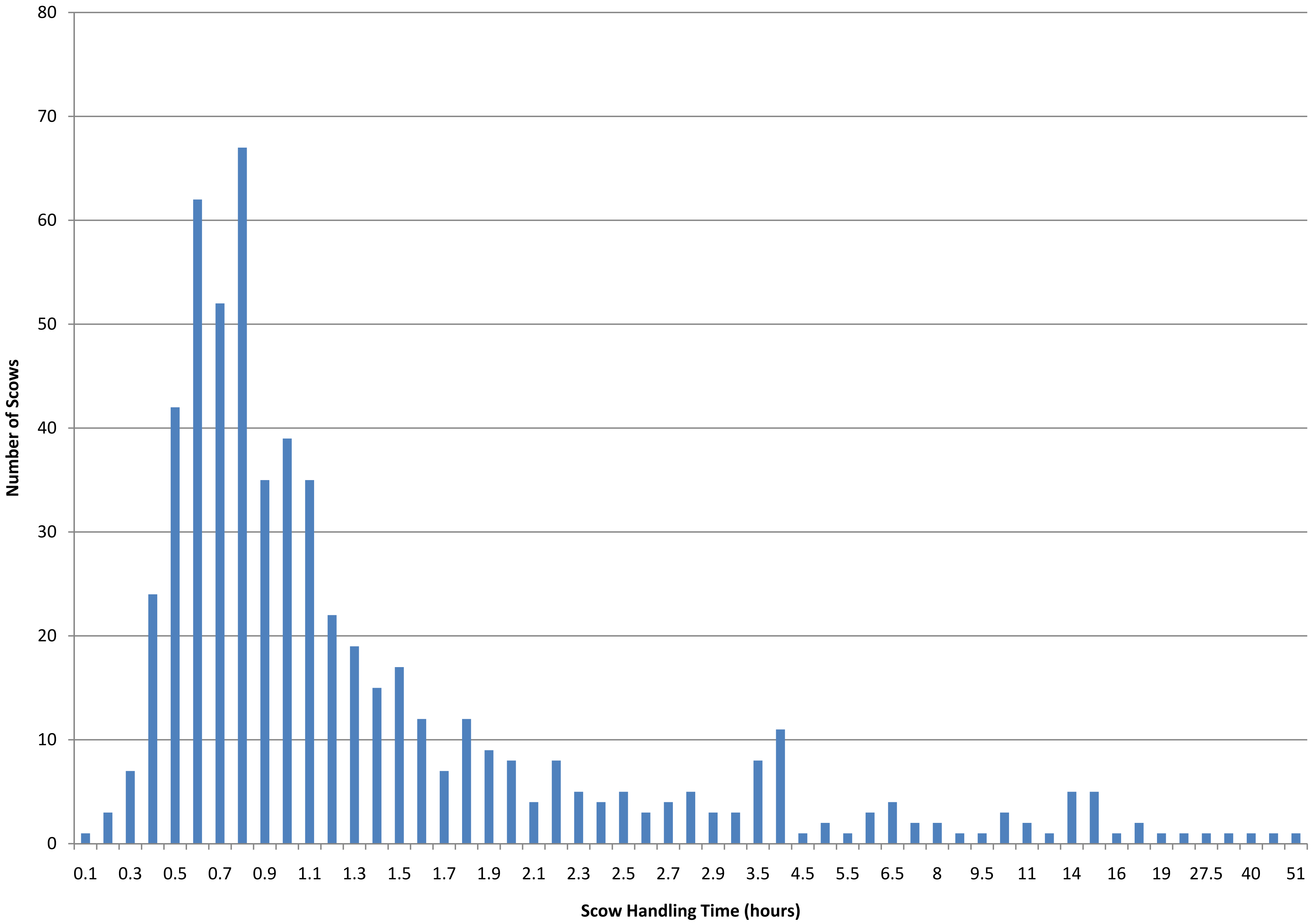


Relationship between Scow Load Thickness and Unloading Time

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 5-3

April 2010

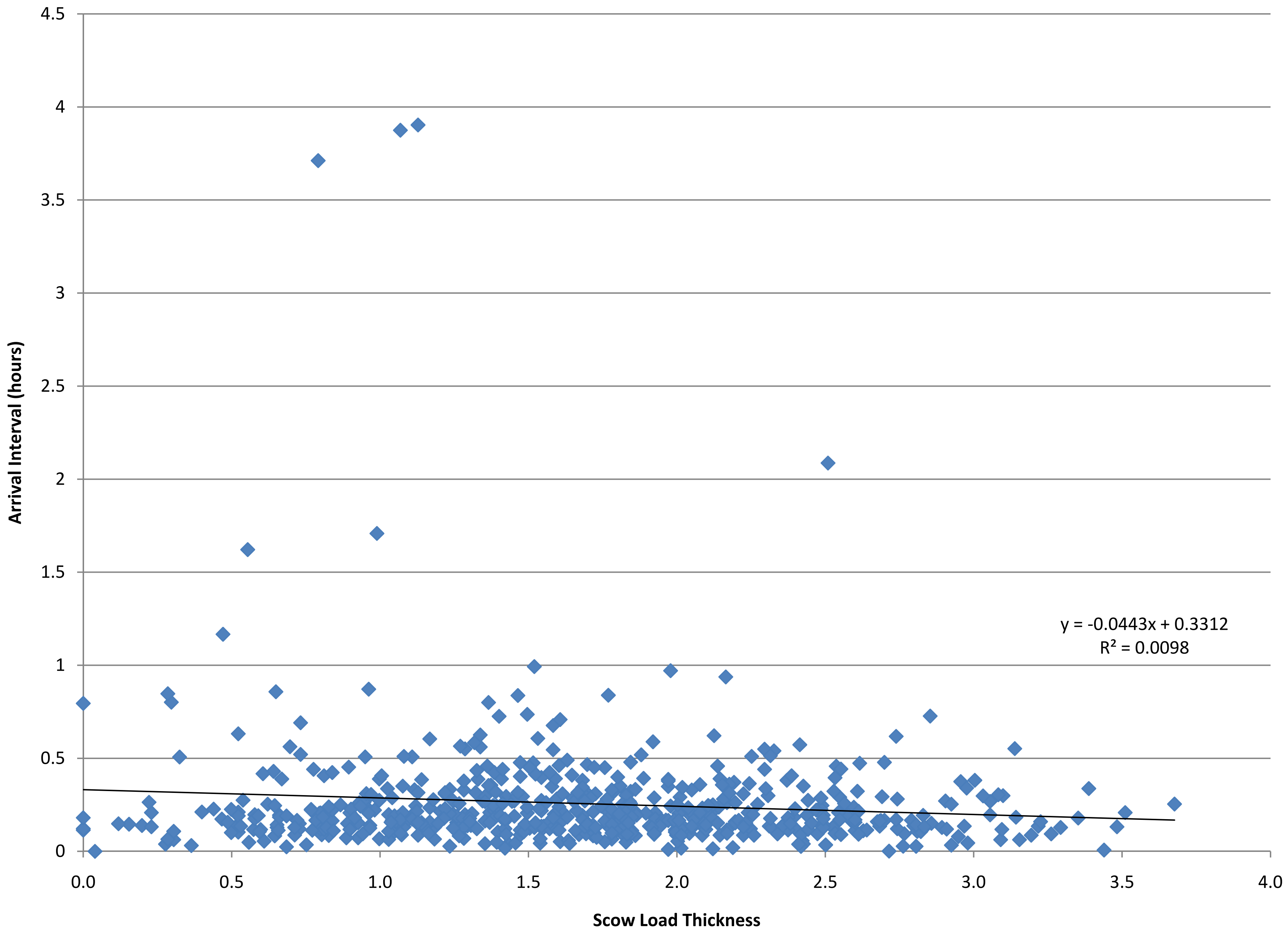


Histogram of Scow Handling Time

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 5-4

April 2010

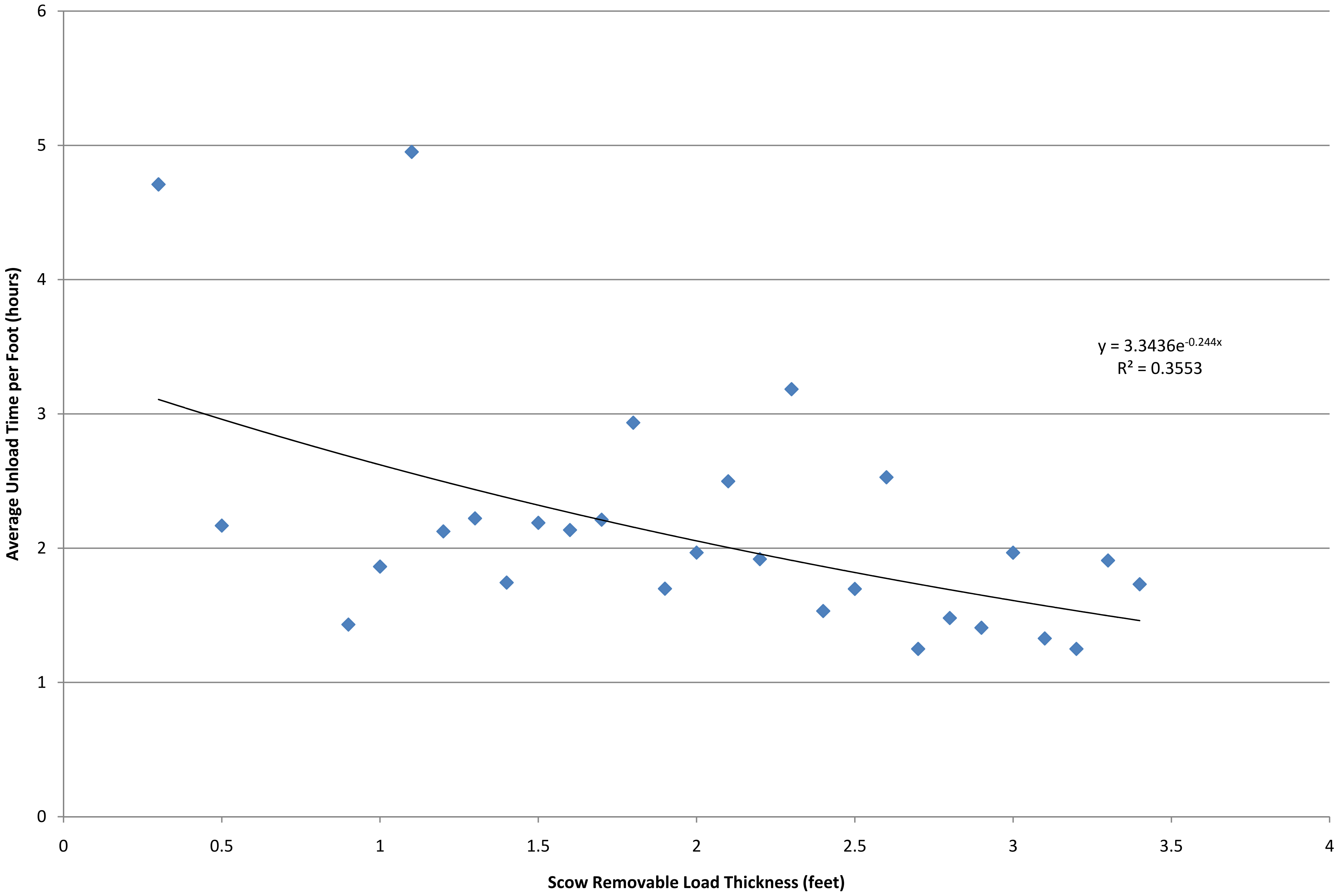


Scow Removable Load Thickness and Arrival Rate

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 5-5

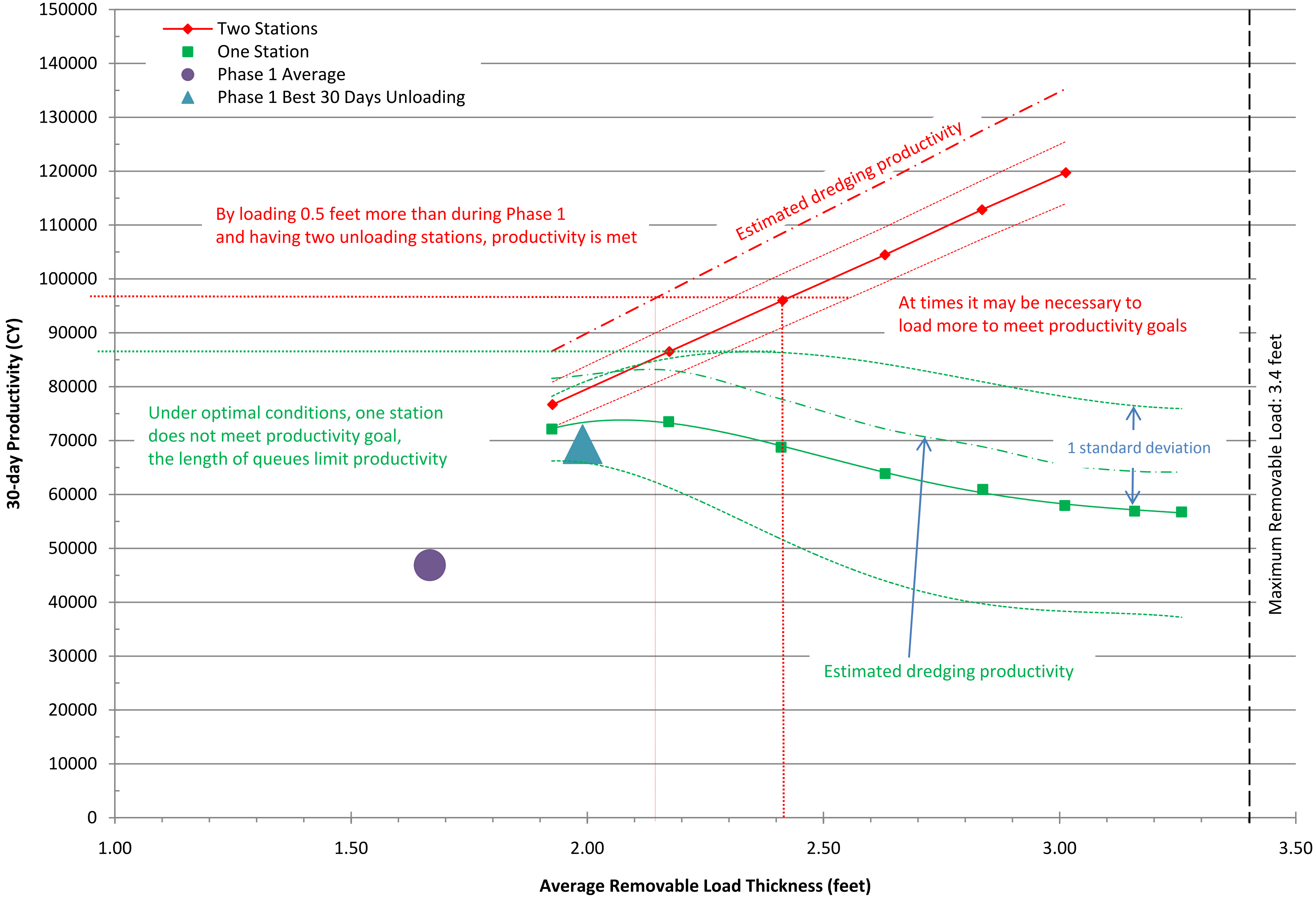
April 2010



Scow Removable Load Thickness and Unloading Time (Best 30 Days of Unloading)

Figure 5-6

April 2010



Optimized Unloading System – Queuing Model Results

EPA Phase 1 Evaluation Report – Addendum - Hudson River PCBs Site

Figure 5-7

April 2010

TOPIC 6

UNDERESTIMATION OF DEPTH OF CONTAMINATION AND ITS IMPACTS ON THE PROJECT

TOPIC 6-A

POST-DREDGING CORE LOCATION TREATMENTS AND THE NEED FOR MULTIPLE RESIDUAL PASSES

Topic 6-A - Post-Dredging Core Location Treatments and the Need for Multiple Residuals Dredging Passes

Abstract

In the 10 CUs encompassing approximately 48 acres that were dredged during Phase 1, 445 locations were targeted for post-dredging sampling. Notably, less than 35 percent of the post-dredging coring sites had a residuals layer requiring removal. By inference, less than 35 percent of the Phase 1 dredging area was redredged to address a residuals layer. The purpose of this relatively complex tracking and analysis performed by EPA was to measure the success of the Standard in avoiding one or more residual passes, and to demonstrate that, contrary to what GE has asserted in their Phase 1 Evaluation Report (GE, 2010), over 60 percent of the remediation area went directly from inventory removal to compliant whereas only 8 percent of the Phase 1 area required 2 dredging passes. Moreover, since 6 inches of remaining inventory could not be discerned from a true residual layer based on the Performance Standard sampling requirements, the estimate of 35 percent is an upper bound on the actual extent of residuals. Ultimately this analysis shows that the poorly defined DoC was the primary cause of additional dredging passes. Specifically, 42 percent of the 445 locations were shown to have inventory present after the first dredging pass based on identification of deeper contaminated sediments during one of the subsequent sampling surveys and 20 percent of all locations actually required three inventory passes.

Many of the post-dredging coring sites were occupied and cored several times. These core collection efforts were the primary means to certify an area as compliant with the Residuals Standard or to identify additional areas for residuals removal or inventory re-dredging. To evaluate various reasons for re-dredging during Phase 1, the fate of each post-dredging core site was tracked and post-dredging cores were grouped into six categories based on the treatment and the depth of contamination (DoC). Clean cores (*i.e.*, cores with TPCB less than 1ppm) and cores that were considered compliant as per the residual standard were grouped together and categorized as compliant.

The tracking and analysis of each post-dredging coring location yielded several important results pertaining to the implementation of the Residuals Performance Standard:

- It identified areas where the DoC was poorly characterized and inventory remained below the first dredging pass (volume removed by inventory dredging was more than double of that removed by residuals dredging).
- It provided evidence that the standard was successfully implemented, without undue difficulty or schedule impacts, and that dredging-generated residuals (*i.e.*, residuals due to spillage and bucket movements) were not a pervasive issue.
- It provided further support of EPA's proposal for an overcut addition to each dredging pass in Phase 2 to address uncertainty.

6-A.1. Discussion

The Phase 1 areas encompassed approximately 48 acres, represented by 445 post-dredging coring sites. Many of these sites were occupied and cored several times. These core collection efforts were the primary means to certify an area as compliant with the Residuals Standard or to identify additional areas for re-dredging. EPA's Phase 1 Evaluation Report summarized the various dredging passes on the basis of core results and the associated dredge pass "footprint" as a means to characterize the various types (*e.g.*, inventory *vs.* residual) and areal extent of re-dredging required. However, this analysis did not track the treatment history of individual coring sites (or nodes) and so it could not be determined how much of the river bottom required a single residual pass (a removal of single layer of six inches of sediment) as opposed to areas where multiple residual passes were necessary, presumably due to dredging–related spillage or disturbance on the prior dredging pass. It was the intention of the Residuals Performance Standard to avoid multiple dredging passes to remove residuals. This analysis is intended to measure the success of the Standard in avoiding multiple residual passes.

To evaluate the various reasons for re-dredging during Phase 1, the fate of each post-dredging core site was tracked through the Phase 1 program. Post-dredging cores were grouped into six categories based on the treatment and the depth of contamination (DoC) in the post-dredging core. Post-dredging cores with DoC greater than 6 inches were classified as additional inventory and cores with DoC less than or equal to six inches were classified as residual. Core sites requiring more than 6 inches of removal on any single pass after the first dredging pass when the design cut lines have been attained are clear evidence of a poor local DoC and not sediment residuals. By classifying cores in this manner, it is possible to obtain an upper bound on the number of core sites where a residual layer was actually found. This means of classification effectively includes any core locations where the true DoC was actually six inches beyond (*i.e.*, deeper) than design cut lines. Even with this conservative assumption, the discussion below will show that residual layer removal was not a major concern in Phase 1.Clean cores (i.e. cores with TPCB less than 1ppm) and cores that were considered complaint as per the residual standard were grouped together and categorized as compliant. As noted previously, in the 10 CUs that were dredged during Phase 1, 445 locations were targeted for post-dredging sampling.

Tables 6-A-1a to 6-A-1c list the status of each post-dredging sampling site after a dredging pass and their subsequent grouping into one of six categories in the subsequent pass. Table 6-A-1d provides the final status of the post-dredging coring locations. Note that these tables track the status of the entire suite of coring sites after each dredging pass and not the cores themselves.[1] In each table, the left-most column summarizes the status of all 445 post-dredging sampling locations after the prior dredge pass. The remaining columns track the fate of those locations that required additional grouping into one of the six categories. Thus there are entries in the rows labeled "Abandoned", "Inventory", "Residuals" but none in the rows labeled "Capped" or "Compliant", since the latter categories do not require further dredging at the sampling locations and hence are not subject to additional sampling.

For the purpose of illustration, a few of the location tallies will be traced through the first two tables, beginning with the residuals. Summing across all CUs at the end of the first dredging pass in Table 1-6-1a, there were 115 sampling locations (out of 445) that were identified with a residual layer of contamination (the italicized bold number in the first numeric column of the

---

[1] Note that the second dredge pass in CU 1, which was only addressed a portion of the CU, was not included in the tabulation. Thus only four dredging passes are presented in these tables.

table). Upon completion of the second dredging pass, these 115 locations were then re-sampled and re-characterized as shown in the right side of the table. Of the 115 locations, 6 were reported as not sampled (presumably due to lack of sediment), 4 were abandoned, 5 were capped, 64 were compliant and required no further grouping into the categories, 7 were classified as additional inventory (indicating there was significant uncertainty with the DoC at these locations and that they were not truly residual locations as originally classified) and 29 were identified as still exhibiting a residual layer.

Combining the 29 locations that still exhibited residuals with the other locations that exhibited a residual layer after the second dredging pass[2] yields a total of 62 locations with a 6 inch residual layer after the second dredging pass. This is shown at the second column from the right in Table 6-A-1a as well as in the first column of the Residuals row in Table 6-A-1b. The total from the inventory column in Table 6-A-1a transfers to the total in the Inventory row in Table 6-A-1b in the same manner. For the Compliant tally in Table 6-A-1b, the total of 241 locations is the sum of the Compliant column in Table 6-A-1a (*i.e.*, 123 new compliant locations) and the 118 compliant locations achieved after the first dredging pass (from the Total Number of Locations column at the left of Table 6-A-1a). The various tallies in each of the tables are constructed in a similar fashion.

Table 6-A-1a Treatment of Post-Dredging Sampling Locations after Second Dredging Pass

Post-Dredging Sampling Location Status after the First Dredging Pass		**Post-Dredging Sampling Location Status after the Second Dredging Pass - (320 locations were grouped into 6 categories)[3]**					
Classes	Total Number of Locations	Abandoned	Capped	Compliant	Inventory	Residual	Not Sampled
Abandoned	33	9	2	2	1	3	16
Capped	7	0	0	0	0	0	0
Compliant	118	0	0	0	0	0	0
Inventory	169	2	11	57	62	30	7
Residuals	***115***	4	5	64	7	*29*	6
Not Sampled	3	0	0	0	0	0	3
Total	**445**	**15**	**18**	**123**	**70**	**62**	**32**

---

[2] Note that these additional locations were classified as inventory or abandoned at the end of the first dredging pass.

[3] This total is calculated as the total number of sites less the sum of the number of locations previously capped and the number of compliant locations.

Table 6-A-1b Treatment of Post-Dredging Sampling Locations after Third Dredging Pass

Post-Dredging Sampling Location Status after the Second Dredging Pass		**Post-Dredging Sampling Location Status after the Third Dredging Pass – (179 locations were grouped into 6 categories)**					
Classes	Total Number of Locations	Abandoned	Capped	Compliant	Inventory	Residual	Not Sampled
Abandoned	15	0	0	0	2	3	10
Capped	25	0	0	0	0	0	0
Compliant	241	0	0	0	0	0	0
Inventory	70	4	11	20	25	10	0
Residuals	***62***	0	15	38	3	*6*	0
Not Sampled	32	0	6	4	4	2	16
Total	**445**	**4**	**32**	**62**	**34**	**21**	**26**

Table 6-A-1c Treatment of Post-Dredging Sampling Locations after the Fourth Dredging Pass

Post-Dredging Sampling Location Status after the Third Dredging Pass		**Post-Dredging Sampling Location Status after the Fourth Dredging Pass– (85 locations were grouped into 6 categories)**[1]					
Classes	Total Number of Locations	Abandoned	Capped	Compliant	Inventory	Residual	Not Sampled
Abandoned	4	1	3	0	0	0	0
Capped	57	0	0	0	0	0	0
Compliant	303	0	4	0	0	0	0
Inventory	34	1	33	0	0	0	0
Residuals	***21***	0	16	5	0	0	0
Not Sampled	26	0	1	0	0	0	25
Total	**445**	**2**	**57**	**5**	**0**	**0**	**25**

Note:

1. The majority of the nodes requiring a fourth pass were associated CU-1 (41) which never had a correctly defined DoC for the majority of the area and instead was completed by capping the entire CU. This represents 41 of the 57 locations capped after the fourth pass.

Table 6-A-1d Final Disposition of Post-Dredging Sampling Locations

Post-Dredging Sampling Location Status after the Fourth Dredging Pass	
Classes	**Total**
Abandoned	27
Capped	114
Compliant	304
Inventory	0
Residuals	0
Total	445

These tables present the relatively complex tracking necessary to trace the fate of each post-dredging sampling location. However, this analysis yields several important results pertaining to the implementation of the Residuals Performance Standard. These tables show that of the 198 (115+62+21) instances where a residual layer was identified, only 35 (29+6) were re-dredged again (*i.e.*, a second residual pass) while seven residual cores indicated presence of inventory. This also means that there were only 156 (198 – 35 – 7) locations[4] that had a residual layer identified. This means only 156/445 locations (35 percent) of the Phase 1 remediation area yielded a residual layer. As noted previously, it is likely that a significant fraction of the 156 locations actually represent locations with underestimated DoC and not a true residual layer of disturbed and spilled material from the original overlying sediment. The upper bound estimate of 156 locations out of 445 indicates that residual layer formation was not a significant problem for the remediation. Of the 156 residual layer locations, only 35 required a second residual pass. Another 23 (not shown directly in the tables) were capped after a single residual layer removal attempt. This indicates that the majority of sites where a residual layer was identified (156 – 35 – 23 = 98 or 63 percent of these locations) were made compliant with just one more dredging pass (*i.e.*, a single residual layer removal pass).

In total, 65 percent of the post-dredging sampling locations were handled without the need of a dredging pass targeting a residual layer (*i.e.*, 65 percent of the area in Phase 1 did not require a residual layer removal, a total of 289 locations). Either the area became compliant after inventory removal (189 locations) or it was capped (78 locations). An additional 22 locations were abandoned and not counted in these categories. It should be noted that in many cases core locations required capping after incomplete dredging due to the impending end of the navigational season; this was a direct result of underestimation of the depth of contamination.

These summations of the 6 category groupings of the post-dredging sampling locations show that

---

[4] The 156 sites are the result of the following summation:

198 instances when a residual layer was identified
– 35 second residual pass sites (these are a subset of the sites where at least one residual layer was identified)
– 7 inventory sites (these sites were incorrectly identified as residual layer sites since the subsequent sampling
____ identified a foot or more of contaminated sediment)
156 sites where at least one residual layer was observed.

residual layer formation was not a significant issue for the Phase 1 effort. This is further borne out by the large number of compliant locations (118 locations or 27 percent) achieved after the first dredging pass. That is, 27 percent of the first inventory pass went directly to compliant without requiring a residual layer removal. An even larger fraction (41 percent) of the later inventory removal sites also went directly to compliant without requiring a residual layer removal.

In contrast, the impact of the poorly defined DoC can be identified in these tables as well. After the first pass, 169 of the 445 locations (38 percent) required inventory removal. Ultimately, 186 locations (42 percent) would be identified with inventory present.[5] Of these 186 locations that required 2 inventory passes, a large fraction (87 locations or 47 percent) actually required a third inventory dredging pass. Thus 38 percent of the Phase 1 sites required 2 inventory removal passes but 20 percent actually required three dredging passes. When the number of sites requiring multiple inventory removal passes is coupled with the definition that each of these locations had at least 1 foot of sediment removed on each inventory pass, it becomes clear that the majority of additional dredging passes (and the majority of the additional dredging volume) were needed to address remaining inventory and not a true residuals layer, again indicating that the Phase 1 efforts did not expend a large effort “chasing” residual contamination.

Of the 35 locations where a second residual layer removal pass was required, only 13 required a subsequent cap, indicating that the second residual pass was successful 63 percent of the time. Taken together, only 35 of 445 post-dredging coring sites (8 percent) required 2 dredging passes for residuals removal. In an additional 23 locations, (5 percent) capping was done after a single dredging pass. Thus only 13 percent of the total number of post-dredging sites (and by inference, about 13 percent of the area remediated) required any treatment beyond a single residual layer dredging pass.

The very limited number of second residual layer removal passes indicates that the Residuals Performance Standard did not require extensive residual dredging passes, and permitted capping at locations where the CU was close to compliance. Based in this evidence, the standard was successfully implemented, without undue difficulty or schedule impacts.[6] Additionally, this evidence shows that dredging-related residuals were not a pervasive issue. This analysis provides further support for EPA’s proposal for an overcut addition to each dredging pass. Since dredging-related residuals were not problematic, an overcut included as part of each pass in

---

[5] This value is obtained by summing across all the dredging passes as follows:

Sum of the sites identified with inventory on the second through fourth passes (169 +70+34) less the sum of the inventory sites that were identified for inventory more than once (62+25) yields 186 sites with inventory identified after the first dredging pass. Note that the later sum (62+25) represents the number of sites requiring three inventory dredging passes.

[6] The proposed changes to the Residuals Standard will tighten the requirements for capping to require at least one dredging pass of 6 inches before capping to avoid the large number of locations that were capped without even a single residual pass (only 30 percent of the locations capped had at least one residual pass prior to capping). While this requirement might be viewed as increasing the number of passes, the addition of an overcut is expected to reduce both the number of passes as well as the extent of capping by addressing the DoC uncertainty.

Phase 2 will help to address the DoC uncertainty, the major reason for re-dredging in Phase 1 and ultimately reduce the number and extent of additional dredging passes.

The Residuals Performance Standard helped identify areas where the DoC was poorly characterized and where inventory remained below the first dredging pass. EPA's analysis shows that poorly defined DoC was the primary cause of additional dredging passes, required to address the remaining inventory and not to "chase" a residual contamination layer. After the first inventory dredging pass, 38 percent of the 445 locations required subsequent removal of inventory, while only 26 percent required a pass targeting residuals. Ultimately, 42 percent of locations were shown to have inventory present after the first dredging pass and 20 percent actually required three inventory passes. Taken together, the extensive evidence for inventory (42 percent of post-dredging coring locations) plus the locations with a residual layer or simply a thin remaining inventory layer (35 percent of post-dredging coring locations) indicate that an overcut of at least 6 inches on the first dredging pass would have removed additional contaminated sediment in 77 percent of locations, thus supporting EPA's recommendation for an overcut addition to the design surface for Phase 2.

TOPIC 6-B

RELEVANCE AND CONSEQUENCES OF UNCERTAINTY IN MEASUREMENTS OF THE DEPTH OF CONTAMINATION

Topic 6-B - Relevance and Consequences of Uncertainty in Measurements of the Depth of Contamination

The relevance and consequences of uncertainty in the depth of contamination (DoC) measurements used to design dredging cut lines have been discussed over the course of the remedial design. This is exemplified by the comments and associated responses that were exchanged between EPA and GE regarding the Intermediate Design Report (IDR) in December of 2005. The specific document that captures this exchange is "Responses to USEPA Comments on the Phase 1 Intermediate Design Report (IDR)", GE, December 26, 2005. Comments 37, 38 and 39 (pages 17 to 20) highlight the discussion of DoC uncertainty and are informative regarding the respective stances adopted on the subject. In comment 37, EPA cautioned GE that the uncertainty at individual core locations, which EPA estimated to be about 1 foot, would outweigh GE's estimate that DoC measured in the cores would be conservative; EPA further cautioned that "underestimating DoC may lead to additional re-dredging to remove inventory." GE responded that the actual amount of inventory would be determined by cores collected during dredging and that "the processing plant will have some capacity to dewater sediment generated by those instances that DoC turns out to be greater than indicted [sic] by the SSAP data." GE further emphasized their belief that the uncertainty was overestimated by EPA and stated that high-confidence cores show a different story. However, as shown in Figure 6-B-1, high-confidence core co-located pairs in Phase 1 have an average DoC discrepancy of more than 11inches, confirming EPA's previous estimate.

In comment 38, EPA cautioned GE that conservative factors GE was maintaining cause the DoC to be overestimated are not additive and cannot be used to show the DoC is overestimated. GE reiterated their belief that these factors cause the DoC to be overestimated. In comment 39, EPA stressed that GE's assertion that DoC is overestimated due to drag-down of contaminants during coring is incorrect because it is a random event that will not affect a significant amount of cores. GE maintained that it is a prevalent process that could have biased most cores, especially cores with high peak concentrations. The results of Phase 1 dredging show that drag-down of contamination during core collection did not affect the estimate of DoC.

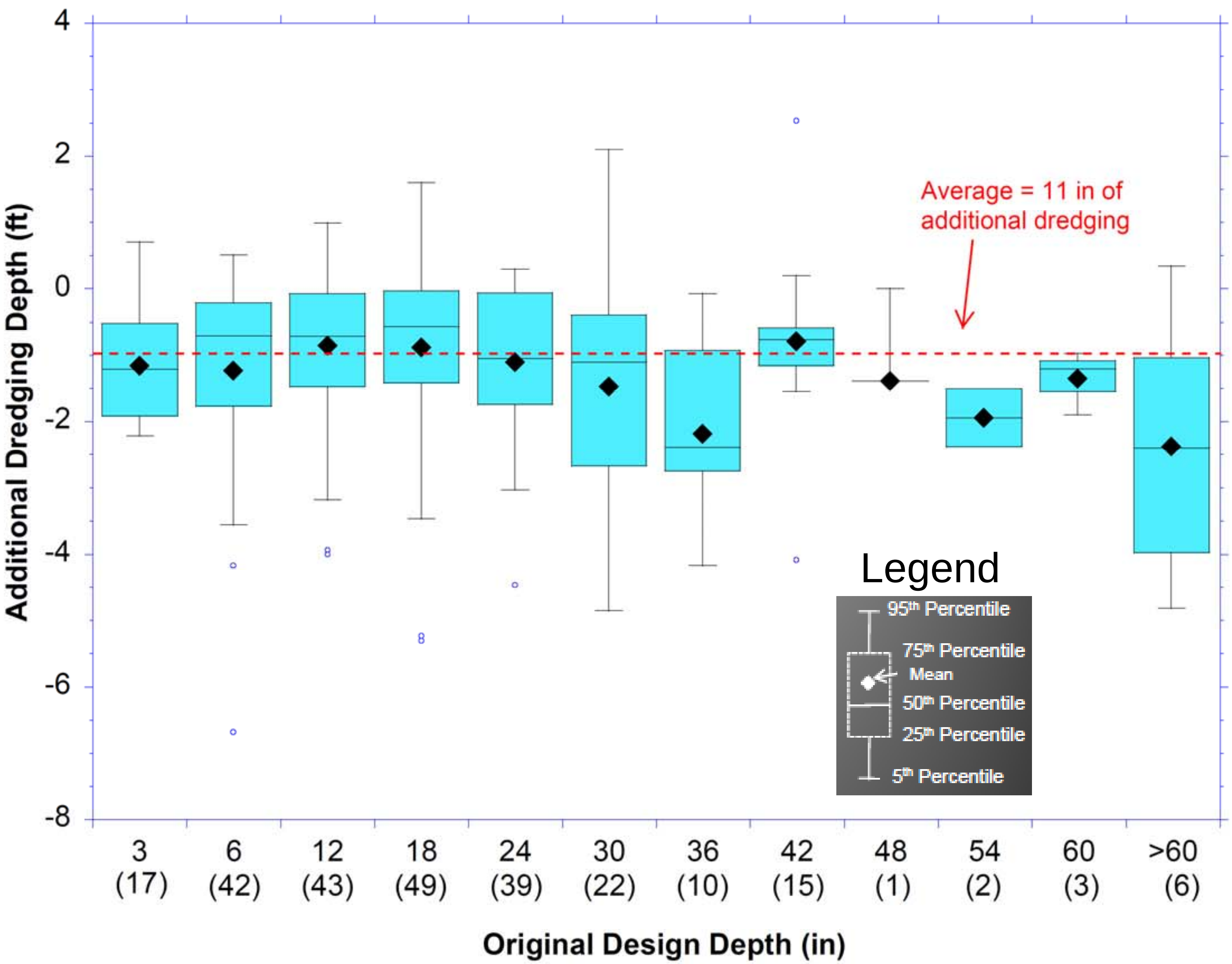
In light of GE's concerns about cost-effectiveness, EPA accepted GE's positions and took an adaptive management approach in approving the Phase 1 design. No overcut was required and GE was given flexibility to manage the uncertainty in DoC through other means as they implemented the project. However, uncertainty in DoC was not addressed during Phase 1 implementation, and its underestimation resulted in significant re-dredging. It is not appropriate to consider the consequences of underestimating DoC as an unexpected impediment to productivity, nor to assert that the need to re-dredge was caused by deficiencies in the Residuals Standard.

Similarly to the exchange of comments and response presented on the 2005 IDR, advice was given to GE in 2005 that the DoC was underestimated and would result in difficulties with the residuals standard as well as re-dredging. In a memo attached as Appendix H to the Phase 1 final Dredge Area Design (DAD), GE was cautioned by EPA:

> "GE has reported that extrapolation of depth of contamination based on incomplete cores is an important source of error in development of design elevations. EPA agrees that DoC extrapolation is error prone and likely to be an important factor contributing to high redredging rates, underestimation of the total in place volume and mass of contaminated material and subsequent difficulties meeting residual standards."

The memo recommended further analysis of the extrapolation of incomplete cores through comparison to co-located cores. This comparison and refinement of extrapolation was not done prior to design of the Phase 1 cut lines. As a result, consistent underestimation of the DoC in developing design cut lines resulted in significant re-dredging to address previously unidentified PCB inventory.

In keeping with the adaptive management approach, it is clear that a re-evaluation of the process for determining the DoC and establishing design cut lines, including an overcut to address uncertainty, is required. It is expected that a process of continual evaluation and adjustment will be continued throughout the dredging project.



Additional Dredging Depth Needed Beyond Design (Level 1A Cores)

Figure 6-B-1

TOPIC 2 ATTACHMENT

CONDITIONS ASSOCIATED WITH WATER COLUMN PCB CONCENTRATIONS:

THOMPSON ISLAND DAM 2009

Topic 2 Attachment

CONDITIONS ASSOCIATED WITH WATER COLUMN PCB CONCENTRATIONS:

THOMPSON ISLAND DAM 2009

Multivariable Analysis of Water Column PCB and Operational Data

April 23, 2010

Prepared by:

KERN Statistical Services, Inc.

Prepared for:

United States Environmental Protection Agency
Region 2
290 Broadway
New York, NY 10007-1866

Under Contract to:

Louis Berger Group, Inc.
412 Mt. Kemble Avenue,
Morristown, NJ 07960

.

KERN Statistical Services, Inc.
5175 NE River RD
Sauk Rapids, MN 56379

1.0 SUMMARY

It has been stated by GE that water column concentrations can be "Predicted based only on PCB removal rate and river velocity." Based on this conclusion and on application of such a model to the Phase 1 results, GE broadly concluded the following in the Resuspension portion of their February 15, 2010 presentation to peer review panel:

1. Phase 1 demonstrated that the Resuspension Standard cannot be met (ES-5), and that EPA's proposed increase to the load standard would compromise the remedy (ES-7).
2. The federal drinking water standard of 500 ng/L PCBs will be exceeded frequently in Phase 2 because the rate of dredging will exceed that of Phase 1, and fewer resuspension control opportunities will be available.
3. Re-deposition in non-dredge areas will compromise remedy benefits.
4. There are no practical means to reduce resuspension and avoid exceeding the Resuspension Standard.

2.0 PRELIMINARY FINDINGS

Subsequent to releasing these results, a preliminary analysis of factors associated with water column PCB concentrations was conducted and described in this report. It was found that while water column PCB concentrations are indeed positively associated with mass of PCBs removed, as indicated by a Spearman Rank Correlation coefficient of 0.42, a more detailed analysis suggests that this relationship is due to a combination of several operational factors, some of which are readily manageable in ways that would logically be expected to reduce PCB releases associated with dredging operations. Spearman Rank correlation coefficients are shown in Table 1.

Based on the analysis reported here, it can be concluded that the mechanisms associated with increased water column PCB concentrations are numerous, varied, and should not be simplified to a mere proportionality of the mass removed, as suggested by GE. Mass and volume removed, which are both functions of the direct measurement, bucket counts, is a surrogate, integrating the net effect of all of the processes involved in dredging, and therefore correlates well with water column PCB concentrations. However, this is not sufficient to conclude that individual operational variables cannot be managed to reduce resuspension of PCBs during Phase 2 dredging. The manner in which dredging and other related activities were conducted during Phase 1 is very important and provides a good source of information on how dredging and other activities could be modified to reduce resuspension of PCBs during Phase 2.

Based on the multivariate analyses of daily processes and water column data, water column PCB concentrations are found to be positively associated with several factors, all of which are expected to influence release and resuspension of PCB contamination. These factors include:

1. Sediment removal (*i.e.*, bucket counts, volume removed, mass removed).
2. Flow rate.
3. Vessel traffic (primarily the distance traveled by scows).
4. The number of CUs being backfilled in any given day.
5. The area and concentration of freshly disturbed sediments in CUs open to the water column each day.
6. Bucket cycle time and volume removed per cycle termed the apparent fill-rate (fill-rate) and other surrogates to sediment spillage.

Thirteen of 28 process variables (shown in Tables 1 through 3) considered in this analysis demonstrated statistically significant positive associations with water column PCB concentrations, with squared Spearman Rank correlation coefficients ranging from approximately 0.2 to 0.4. These levels of association are individually weak, indicating that no single process can be identified as the source of resuspension, but rather that a complex set of interactions among processes is required to describe water column PCB concentrations. The well known adage is that "association does not imply causation" but, conversely, lack of apparent association also does not eliminate causation. It is expected that multiple variable models may be necessary to adequately explain variation in water column concentrations. It is shown that there were periods of time in Phase 1 when resuspension rates were low (less than 200 ng/l) and productivity was adequate to meet proposed Phase 2 productivity criteria.

It is further expected that controlling PCB resuspension may be accomplished through a combination of additional or improved management practices and strategies applied during several stages of the sediment removal and backfilling process. The following sections describe the modeling approach used in this analysis and the resulting relationships between operational variables and water column concentrations at TID.

3.0 OBJECTIVE

The primary objective of this analysis is to develop an empirical, data-driven model describing water column concentrations of Total PCB as a function of the physical and operational variables associated with remedial activities conducted during Phase 1.

4.0 INTRODUCTION

Sediment transport investigations are often characterized by limited data, necessitating the development of theoretical equations (*e.g.*, models) to describe the fate and transport of contamination between the sediment and the water column.

In contrast, during Phase 1, dredging, data quantifying salient features of the sediment removal process were recorded on daily, weekly and at times fifteen-minute sampling intervals—*e.g.*, vessel positions were recorded every fifteen minutes throughout the Phase 1 project. These data are certification-unit specific, available on a daily basis, and can be tied to daily water column concentrations monitored at near- and far-field stations in Thompson Island Pool. They provide the basis to develop an empirical model of water column concentration as a function of measured data specific to the operations in the Thompson Island Pool during Phase 1. A combination of Factor Analysis (Seber, 1977) and Multiple Regression (Neter *et al.*, 1996) was used to statistically identify groups of parameters most strongly associated with water column PCB concentrations. This empirical approach provides the opportunity to test hypotheses and assumptions that otherwise would remain untested in more typical situations where data are sparse. These data provided the opportunity to evaluate the influence of various remediation processes on water column PCB concentration.

5.0 METHODS

5.1 Data

Operational data were collected throughout the Phase 1 season which quantified the primary aspects of dredging operations. In addition, water column Total PCB concentrations were measured daily, providing the potential to develop a retrospective model describing the relationship(s) between mechanisms of the dredging process and water column Total PCB concentrations. The data obtained includes metrics quantifying potential sources of PCBs associated with:

1. Flow and temperature conditions;
2. Debris removal;
3. Volume and mass removed;
4. Sediment disturbance associated with prop wash from vessel traffic;
5. Efficiency of removal operations—incomplete closure of buckets, cycle times;
6. Resuspension of exposed PCB deposits in open CUs; and
7. Sediment disturbance associated with backfilling.

In all, 28 variables were statistically tested for the potential to predict water column PCB concentrations at far-field stations located downstream of dredging operations. Data were summarized on a daily basis, so for most variables there were approximately 166 days (May 15 through October 27, 2009) for which PCB concentration could be compared with dredging, debris removal and backfilling process variables.

Some variables quantifying how dredging was conducted, such as bucket closure and apparent fill rates, were only available for the 127 days within that 166-day time period when active dredging occurred. Therefore, the analyses were conducted for variables measured on all 166 days and then repeated for the subset of variables measured on the 127 days when active dredging was occurring, primarily after June 2009. Data collected during active dredging (*i.e.*, 127 days) are more closely associated with how dredging was conducted and are therefore the primary source of information on how dredging and other activities could be modified to reduce resuspension of PCBs to the water column.

5.2 Modeling Overview

The factor analysis and regression approach shown in Eq. (1), below, was used to develop a model of the form

$$C_{water} = C_{baseline} + K_1 C_{Source-1} + K_2 C_{Source-2} + \cdots + K_n C_{Source-n} \quad (1)$$

where:

1) the constants $K_1, K_2, K_3, \ldots K_n$ are loosely interpreted as "*net*" sediment-to-water partitioning coefficients for each source, and

$$C_{water} = C_{baseline} + K_1 C_{Source-1} + K_2 C_{Source-2} + \cdots + K_n C_{Source-n} \quad (1)$$

Phase 1 is unique in the extent of data available to not only estimate these coefficients, but also to identify combinations of measured processes that are most important for predicting water column concentrations. Multiple regression analysis was used to identify metrics contributing significantly to prediction of water column PCB concentrations. The fitted model can also be used to identify combinations of process variables characteristic of periods of time when resuspension was low and productivity was high.

Surrogates and Confounding

Metrics described here should be considered surrogates for the physical processes of interest. For example, it is not clear that there is a partitioning coefficient between bucket counts and water column concentrations, however if a mechanistic model relating sediment losses to bucket count were developed, there would be a "net" partitioning of PCBs relating water column concentrations to sediment losses based on bucket counts. It is this net partitioning that is estimated by the coefficients of the regression model.

Similarly, because the mass removed per day is derived from bucket counts and other variables, it would also be expected that water column concentration would be correlated with mass of material removed per day. In fact, mass removal is clearly a surrogate integrating most processes likely to cause PCB losses and resuspension. Unfortunately this does not provide useful insight into how operational processes can be modified to reduce PCB sources to the water column. Any variables that are correlated to material disturbance and removal would be expected to correlate with water column concentration. Additionally, some of those variables are also expected to be inter-correlated amongst one another. In statistical terms these variables would be considered "multi-collinear."

Cause and Effect

Because the data developed through this study are observational rather than based on a designed experiment, and because many of the process variables are inter-correlated, cause and effect relationships cannot be inferred directly. It is important to consider variable relationships to be associative rather than causative unless other lines of evidence can be used to eliminate other plausible causative processes.   This is due to the surrogate nature of most of the metrics. For example, correlation between bucket counts and water column concentrations could lead one to conclude that use of larger buckets would reduce the daily bucket count per unit volume removed and, by extension, water column concentrations. However, if the actual acting mechanism is due to disturbances from scow traffic, which also would be expected to be associated with bucket counts (*e.g.*, more buckets produce more volume requiring more scow trips), then modification to the bucket size in efforts to reduce bucket counts would be futile. The data are observational and therefore their use in developing best management practices should take into account that individual metrics may be surrogates for what may be lurking un-quantified processes.

Bivariate Correlation Analysis

The first step in the regression analysis was to analyze the pairing of each individual process variable with water column PCB concentration to test for a positive association. A bivariate relationship between a process variable and water column PCB concentration is indicative of at least a surrogate relationship that could potentially be causative and should be considered for plausibility.

These bivariate relationships were summarized by calculating Spearman Rank correlation coefficients between water column PCB concentrations and each process variable of interest. Correlations were also calculated for water column concentrations lagged by 1 and 2 days to determine if subsequent analyses should incorporate adjustments for travel time between the dredging areas and the far-field monitoring stations.

5.3 Multiple Regression

A fundamental assumption of multiple regression is that the predictor variables (*i.e.*, source terms) are statistically independent. In this situation, it is clear that many of the source terms of interest are inter-correlated, *e.g.*, more sediment volume removed requires more vessel traffic. Therefore some groups of source terms cannot be entered directly into multiple regression models without careful consideration of their interrelations. As indicted above, these related predictor variables often termed “multi-collinear.” A great deal of effort has been devoted to the study of the effects of multi-collinearity and methods to mitigate these effects on the interpretability of model coefficients and the predicted values.

Regression models are typically used for two purposes: 1) prediction of the response variable, and 2) testing and interpretation of the regression coefficients. For prediction, one would be primarily interested in estimating future water column concentrations under a set of conditions previously measured in the model fitting process. As long as the future conditions are within the range of the variables used to estimate the model coefficients, multi-collinearity generally does not adversely impact predictions. However, multi-collinearity does make interpretation of causative relationships, such as the importance of dredging-related vessel traffic, more difficult. Careful model construction and evaluation of sub-models to deduce the plausibility of causative processes is necessary.

Recognizing the limitation of multiple regression models in the differentiation of individual co-linear factors, this analysis is designed to develop a predictive model and to qualitatively evaluate the relative importance of the factors associated with water column total PCB concentrations. From this analysis it is possible to identify groups of process variables collectively associated with changes in water column PCB concentrations. Identification of such independent process variables suggests which components of the dredging process should be investigated for potential causative relationships.

5.4 Factor Analysis

In factor analysis, a set of statistically independent predictor variables are derived from the collection of 28 inter-correlated variables. These independent variables are obtained by applying a factor analysis to the full collection of predictor variables and deriving surrogates for the dredging processes that are statistically independent and can be entered jointly into multiple regression models. Factor analysis is similar to principal components analysis, with the exception that the principal components are “rotated” through an orthogonal transformation that often results in component loadings (also called factor weights) that are more physically interpretable.

It is recognized that there are no unique or optimal factor solutions. However, development of independent scores that are composed of interpretable groups of process variables is desirable for the purposes of developing a predictive model, as well as for interpretation of the relative importance of independent groups of process variables. It is fully recognized that because many process variables are inter-correlated, fully dissecting the relative importance of each process variable may not be possible. However, to the extent that factor scores can identify independent groups of variables, the contribution of each group can be distinguished through this approach. Groups of variables providing redundant information are grouped together and these groups of variables form independent composite variables called factor scores. These factor scores are statistically independent and often are physically meaningful.

Regression on Factor Scores

The results of the factor analysis were used to transform each group of daily process variables into a linear combination of independent variables called factor scores. These factor scores have the advantage of being statistically independent and are therefore compatible with the assumptions of multiple regression. A multiple regression was used to identify those factors that were important to prediction of water column PCB concentration. Important factors were defined as those factors with regression coefficients that were significantly different from zero at the 5 percent level of statistical significance. The resulting model is suitable for use as a predictive model and by inspection of the factor loadings, these models can also be used to identify independent combinations of process variables important to prediction of water column PCB concentrations. Effects due to variables nested within a common factor are difficult to distinguish without other lines of evidence.

The results of this analysis can also be used as a guide in the development of mechanistic models that are specific to individual process variables. In particular, when more process-oriented variables are to be calibrated against water column data, their settings should be consistent with the interrelations found here through factor analysis. Unless certain processes can be eliminated through other data and analysis, it would not be reasonable to assume that individual process variables can be eliminated purely through identification of other surrogates that are more strongly associated with water column concentrations.

For example, mass removed per day can be tracked relatively accurately, while losses from bucket lifts are much more difficult to measure directly. Therefore, the quality of mass removal data is expected to be much less variable and therefore more likely to correlate with water column concentration than sediment losses. Because of this difference in measurement quality among variables, mass removal per day could appear to be the better predictor of water column concentrations; however, this does not eliminate the potential that loss percentages might be the more important process contributing to water column PCBs. The well known adage is that association does not imply causation, but conversely, lack of apparent association also does not eliminate causation.

Distinguishing independent root causes of water column concentration would require extensive and careful multiple variable analyses combined with professional judgment and development of mechanistic models in order to develop sound best management practices. The analysis presented in this section is a first step in this direction, intended to provide an indication of the major groups of processes influencing water column PCB concentrations. Until more detailed sub-analyses are conducted it would be premature to eliminate any process variables from consideration for improvement and refinement.

Regression on Individual Mechanisms

Information provided by GE (2010) correctly states that water column PCB concentrations at TID increase in apparent response to the mass of PCBs removed from the Thompson Island Pool. In order to improve the dredging process, it is necessary to identify the specific components of the dredging operation that are contributing to increasing water column concentrations downstream of dredging. An adequate understanding of the contributors to resuspension must be developed in order to identify processes that can be adjusted so the resuspension standard can be met with reasonable productivity levels during Phase 2 dredging.

Analysis of the many activities that occurred during the dredging season suggests that multiple factors are likely to have contributed to increases in PCB concentrations at the TID and, if identified, would result in a management opportunity to reduce the resuspension of PCBs. Results of the multivariate factor analysis were used to identify process variables that would be likely candidates for development of a predictive model of water column PCB concentrations that would be an interpretable function of a minimal number of process variables. This more refined model would provide a valid equation for prediction of water column PCB concentrations at the TID under a range of process variable settings.

Because of the interrelationships among predictor variables, reliability of predictions can only be assured for combinations of process variables that were actually used in the model fitting. For example, one could not simply make forecasts based on reduced tug-miles without incorporating commensurate reduction in scow availability and ultimately limiting productivity. Conversely, if reduced tug miles were mitigated by filling scows more fully, to maintain productivity rates, this could be considered a plausible approach. The regression model is most reliable for combinations of predictors within the operational range of values observed in the data used to fit the model.

The multivariate factor analysis was based on groups of individual variables summarized for the entire Thompson Island Pool on a daily basis. For example, the distance traveled by particular vessel types was represented as total distance per day without regard for the particular CU or the concentration or depth of water over which the vessels were operated. Upon seeing the potential for these simple surrogates to predict water column PCBs, additional spatially-explicit metrics were developed and included in the multiple regression analyses.

Many of the mechanisms that are associated with water column PCB concentration that have been identified through factor analysis are inter-correlated. Development of a meaningful model based on a small number of interpretable mechanisms requires careful selection of combinations of variables such that interrelationships do not degrade parameter estimates. As a more interpretable alternative to factor scores, this can also be achieved by introduction of nonlinear aggregate functions of the individual variables, and by careful selection of combinations of linear and non-linear functions. Degradation of model reliability can be controlled by ensuring that selected combinations of variables do not cause large variance inflation factors (VIFs). VIFs are

1.0 when predictors are statistically independent and increase with increasing levels of inter-correlation of predictors. In general, VIFs less than approximately 5 are considered acceptable and less than 2 are preferred. In this analysis, variable combinations were rejected when VIFs exceeded approximately 2.

For each vessel type and within each certification unit (CU-0 representing non-CU areas), the distance traveled was multiplied times the bed sediment concentration and divided by the approximate water depth, defined as the 117.5 elevation minus the bathymetric survey elevation. This variable is large for vessels that traversed shallow areas with high PCB concentrations, and was low for vessels that were either in deep water, or traversed low bed sediment concentrations. These metrics were also modified by setting values to zero whenever the water depth was greater than 11 feet, signifying an approximate water depth beyond which resuspension due to propeller wash is not expected to contribute on a consistent basis. For each vessel type, these data were totaled for each CU on each day of the construction season.

Based on discussions between EPA and its contractors, another variable was developed based on the number of scows waiting to be unloaded. It was observed that when scows were scarce, dredging contractors tended to nibble at the sediment, increasing the number of bucket bites per yard of sediment in apparent efforts not to fill scows prior to arrival of a replacement. It is thought that dredging contracts may have incentivized this behavior. This nibbling tends to cause greater disturbance and increased PCB resuspension. So, the number of scows on queue was included in this analysis.

Variables added to this analysis that were deduced from the factor analysis, professional judgement or field observations, include:

1. **Average number of scows on queue per day.** When scows are queued, dredging contractors slow down and potentially nibble sediment, increasing the resuspension losses per unit sediment removed.

2. **(Volume removed)/(bucket count x bucket volume) x (mass removed).** Index to spillage associated with resuspension due to failure to fully close buckets in efforts to increase removal rates. Failure to close buckets was signaled in the database by apparently over-full buckets due to volume associated with <u>multiple actual cycles</u> being associated with a <u>single apparent cycle in the data</u>.

3. **Flow at Fort Edward.** This is not a source of resuspension in and of itself, however activities associated with dredging may have decreased critical shear stresses of the worked sediment, resulting in generally increased resuspension of PCBs with increased flows.

4. **CU and non-CU specific concentration and water depth-weighted tug distance.** Previous analyses looked at total vessel distance per day, but these totals were correlated with total

mass and volume removed. Separate CU-specific and concentration- and depth-specific information was needed in order to disentangle vessel traffic from apparent effects of mass and volume removal

5. **(Product of number of units being backfilled) x (metric described in 4 - tug disturbance).**

6. **CU-specific mass of PCBs removed.** By separating mass removed per CU specifically, it was possible to separate general removal effects from other factors

GE has hypothesized that PCB resuspension is purely a function of mass removed and water velocity. To test this hypothesis, a variable was developed from the product of the mass removed and the average apparent bucket fill rate. It was expected that greater amounts of spillage would begin to occur when this apparent fill rate increased above approximately 60 percent. To test these competing variables, regression models were developed separately with and without each variable and model fit was compared to evaluate the strength of evidence for each hypothesis.

Bucket count data were used to calculate total mass removed from each CU per day. These summaries were entered into regression models separately for each CU and in combinations across groups of CUs in an effort to test the hypothesis that losses are proportional to mass removed. This particular part of the analysis focused on groups of CUs in the East and West Rogers Island areas and CUs 17 and 18 near East Griffin Island. Because CU-18 was divided into an area enclosed by sheet pile (CU-18IN) and another area outside the sheet pile enclosure (CU-18OUT) the relative influence of mass removal could be compared with that due to tug and scow traffic servicing these CUs.

6.0 RESULTS

Thirteen variables representing five groups of processes were identified to be associated with water column PCB concentrations at the TID. Five variable groups (factors) were identified that collectively explained 55 and 60 percent of the variation in water column PCB concentration in the 166-day and 127-day models, respectively. These factors represented volume and mass removed and efficiency, area of recently disturbed sediments in open certification units, vessel traffic and backfilling. Following is a summary of the results of the analysis.

6.1 Bivariate Correlations

Squared Spearman Rank correlation coefficients for water column PCB concentration with each of the process variables are reported in Table 1. The analysis was repeated with process variables paired with one-day and two-day lagged PCB concentrations to evaluate the potential impact of travel time on the strength of the correlation. These squared correlation coefficients represent the proportion of variation explained by the relationship between water column PCB concentration and each variable, analogous to an R^2 from a regression. The Spearman correlation coefficient is preferred because the assumption of linearity inherent in the Pearson's coefficient is relaxed. The results summarized in Table 1 show that:

1. Correlations between water column PCB concentrations and process variables are generally weak, ranging from 2 percent for debris removal to 42 percent for volume and mass removal, indicating that no single variable could be expected to adequately explain the fluctuations in water column PCBs observed during Phase 1.
2. Correlations for water column concentrations lagged by one day were less than those for concurrent measurements, and two-day lagged measurements produced still lower correlations.
    a. In contrast, GE asserted that weekly averages were needed to counter the effects of travel time in their analysis of the water column PCB data.
    b. This weekly averaging approach is counterproductive given the lack of correlation between lagged water data and process variables.
    c. Weekly averaging would artificially reduce the power to detect subtle multiple-variable relationships, suppressing potentially important relationships between water column PCB concentration and operational variables.
3. Statistically significant positive associations were identified for most processes expected to disturb sediments.
    a. Volume and mass removed (R^2=0.22 to 0.42).
    b. Dredging efficiency measures such as apparent bucket fill rate and depth of cut (R^2=0.08 to 0.22).
    c. Sources due to area of open CUs (R^2=0.15 to 0.19).
    d. Debris removal (R^2=0.02).
    e. Boat traffic (R^2=0.11 to 0.26).
    f. Backfilling operations (Number of CUs being backfilled) (R^2=0.09).
4. Weak statistical relationships may be indicative of surrogate relationships that are markers for important, but crudely quantified, sources of PCB resuspension.
5. Water column concentrations were negatively associated with flow at the Fort Edward Station, but the relationship was not statistically significant.

6.2 <u>Regression on Factor Scores – Factor Analysis</u>

Because water column PCB concentrations were weakly associated with several operational variables, efforts were made to develop a multivariable model that would adequately explain water column PCB concentrations. Because several process variables were derived from basic measurements such as bucket counts, it was expected that many process variables would be inter-correlated. In order to understand interrelationships between process variables, a factor analysis was conducted to identify a set of independent factors that would be both meaningfully interpretable, as well as provide inputs for a regression model predictive of water column PCB concentrations.

The factor analysis was conducted with only the predictor variables identified using data obtained on all 166 days and that retrieved on just 127 of the 166 days. Resulting factor scores were used as predictors in a regression analysis to identify important factors for prediction of water column PCB concentrations.

Factor Analysis (127 day model)

Table 2 and Figure 1 show the factor weightings (also called loadings) for each of the 28 process variables under consideration. The factor weightings are unitless, range from plus one to minus one, and are considered meaningful when they exceed approximately 0.4 in magnitude. Loadings that are less than 0.4 in magnitude are within the opaque rectangular area in Figure 1. Cells in Table 2 are shaded green to draw attention to loadings that exceed this nominal level.

There were five factors associated with water column Total PCB concentration which described from 2 to 37 percent of the total 60 percent variance in water column PCB concentration explained by the regression model. Regression coefficients, standard errors, variance inflation factors, and partial R^2 values are presented in Table 4.

Factor-1 includes weighting on bucket counts, mass removed, volume removed, residual Total PCB concentration in open CUs, and the product of mass and removal efficiency (ME). This factor summarizes potential PCB sources from variables that are directly related to sediment removal, as well as efficiency of the removal process.

Factor-6 is most heavily weighted on the amount of backfilling being conducted and the product of flow and backfill (a surrogate for load from backfilling). This factor also has substantial negative loadings on bucket counts and temperature. This may reflect that bucket counts coincidentally varied inversely with temperature and backfilling operations. (*i.e.,* It is coincidental that dredging started slowly when temperatures were colder, increased through the summer and then declined in the fall when temperatures also declined and backfilling commenced).

Factor-7 is most heavily weighted on the area of open CUs and the flow- and concentration-weighted surface area of open CUs. This factor has a clear signal exclusively related to the amount of open CUs at any point in time that is independent of volume and mass removal.

Factor-8 is most heavily weighted on flow, and the product of flow and total vessel traffic. This factor is also independent of variables in Factor-1 (describing removal metrics), indicating that there may be an independent PCB source to the water column associated with vessel traffic. This variable is a crude measure of potential sources due to vessel traffic, as it does not account for either water depth or the concentration of areas over which traffic occurs. It is expected that refinement of this variable will substantively improve its relative strength as a predictor of water column concentrations.

Factor-9 is most heavily weighted on boat distance, which is a single metric that only accounts for distance traveled by vessels.

As a general observation, these results show that resuspension of PCBs to the water column is associated with a combination of removal activities, backfilling activities, vessel traffic, and the surface area and duration that disturbed residuals are exposed in open CUs. This indicates that best management practices could be applied to one or several of these processes to reduce concentrations of PCBs in the water column.

Factor Analysis (166 Day Model)

The factor loadings for the 166 day model are summarized in Table 3 and Figure 2. Cells in Table 3 are shaded green to draw attention to loadings that exceed the 0.4 nominal level for the magnitude of factor weights. Factor groupings were similar because the majority of data were common to both models. The model fit was slightly weaker, with an adjusted R^2=0.55 as compared to the R^2=0.60 for the 127 day model.

The five factors associated with water column Total PCB concentration were qualitatively similar to those identified in the 127 day model, representing variables associated with sediment removal (semi-partial R^2=0.28), backfilling (semi-partial R^2=0.06), concentration weighted surface area of open CUs (semi-partial R^2=0.04), flow times vessel distance (semi-partial R^2=0.05), and mass removed (semi-partial R^2=0.13). Because performance data relating to apparent bucket filling rates were not included in the 166 day model, the separation of variables among factors was less obvious and general surrogates for overall activity such as mass and volume removal and boat traffic tended to group together in the first factor. This lower quality model fit when dredging performance variables are not included shows that further investigation of the processes controlling fluxes of PCBs to the water column should focus on variables that characterize how dredging and other supporting operations are conducted rather than just on how much sediment is dredged.

Fitted Factor Based Regression Model

The fitted regression model results are plotted in Figure 3 where the 127-day model is plotted for the days on which all necessary variables were measured, and on the remaining 29 days the 166-day regression modeled values are substituted. The fitted values show that the predictions track the primary day-to-day fluctuations in concentration when dredging activities are in progress, and in October, when GE’s simpler model did not predict disturbance well. It is believed that incorporation of performance data as well as variables quantifying backfilling and areas of CUs contributes to the improved model fit. Estimated regression coefficients, standard errors, partial R^2 values, and variance inflation factors are summarized in Tables 4 and 5. The improved model fit shows that GE's assertion that concentrations are driven exclusively by the amount of dredging may not be fully justified and that improvements of component process associated with dredging and backfilling would be expected to reduce resuspension of PCBs to the water column. Also Upper 95 percent prediction limits are shown on Figure 4. These limits represent an added benefit of the regression approach to model development in that uncertainties in model predictions are made explicit.

6.3 Regression on Mechanistic Variables

The model fit was improved over the factor based models through directly regressing on selected mechanistic variables that were summarized specific to individual CUs. The adjusted R^2 for the 127 day model increased from 0.60 to 0.68with the primary improvements in model fit due to:

1. Incorporation of the dredge efficiency term in place of the more general mass removed term proposed by GE;
2. Differentiation of vessel traffic by water depth and sediment bed concentration; and
3. Incorporation of a source term specific to activities inside the sheet pile wall at CU-18.

Primary Mechanisms Influencing Water Column PCB Concentrations

The multiple regression model for water column PCB concentration was developed using six individual measured variables rather than factors, as described above. The overall proportion of variation explained by the model was 0.68, with variable-specific proportions as follows:

1. Mass removal efficiency (partial R^2=0.25).
2. Boat traffic specific to backfilling operations (partial R^2=0.11).
3. Boat traffic specific to mass removal at CU-17 and CU-18 (partial R^2=0.01).
4. Flow at the Fort Edward station (partial R^2=0.08).
5. The number of scows on queue for unloading (partial R^2=0.01).
6. Mass removed from inside the sheet pile enclosure at CU18 (partial R^2=0.03).

When predictors are inter-correlated, the sum of the variance explained by each variable independently is often less than the total variance explained (*i.e.*, adjusted R^2). This component of the total variance is the variance explained jointly by the collection of variables in the model. In this case, 19 percent of the variance was explained jointly, indicating that approximately a quarter of the total variance explained by the model could not be uniquely tied to any single measured factor. These results are summarized graphically in Figure 5.

Figure 6 shows the fitted model plotted against time, along with the observed water column concentrations and upper 95 percent confidence limits for predicted PCB concentrations. Figure 7 shows the observed values plotted against the predicted values. This model, based on mechanisms, provides better agreement between observed and predicted values, particularly during early August and early September when high PCB concentration were observed at TID.

The mass removal efficiency variable was the primary predictor of water column concentrations explaining 24 percent of the total variance in water column PCB concentrations. This variable is comprised of the product of mass removed and apparent bucket fill rate as described above. This variable identifies situations where mass removal is conducted when daily bucket fill rates are calculated as greater than 60 percent and at times 150 percent (thought to represent situations where multiple bucket bites are counted as a single bite due to debris or less-well controlled operations).

This correlation between dredging efficiencies and water column concentration was evaluated to determine if the correlation could be due primarily to correlation with mass removed. This hypothesis was tested by comparing model fit for a model including mass removed alone with a model including mass removal efficiency. The model including the other four variables identified above plus mass removal efficiency had an adjusted R^2=0.68, whereas the model including the same four variables and just mass removed (i.e. without multiplying by efficiency) had an adjusted R^2=0.60. This indicates that mass removal efficiency was a better predictor of water column concentration than mass removed alone. This relationship indicates that, in addition to simple proportionality to mass removed, unclosed dredge buckets and potentially other inefficiencies also contributed to resuspension of PCBs to the water column.

Disturbance due to tug traffic in shallow areas between CUs 17 and 18 and the Lock 7 entrance was found to contribute significantly to water column concentrations (semi-partial R^2=0.11). A plot of water column PCB concentration vs. tug traffic weighted by depth and sediment PCB concentration is given in Figure 8. This term might also be thought to be a surrogate for mass removed from CUs 17 and 18; however, it was found that mass removal in CUs 17 and 18 (outside sheet pile) was poorly correlated with water column PCB concentrations. This suggests that the tug traffic associated with removal of 2600 kg of PCBs from CUs 17 and 18 (outside the sheet pile containment) caused erosion and resuspension of PCB-contaminated sediments in areas with water depths less than 11 feet.

Dredging declined through October, ending on October 27, yet water column concentrations remained elevated at TID through much of this period. Disturbance due to shallow-water tug traffic primarily servicing backfilling operations was associated with water column concentration (partial R^2=0.11). Because the act of backfilling itself is unlikely to cause resuspension of PCBs on the order of dredging, this relationship represents strong evidence that tug traffic in shallow areas caused disturbance and resuspension of PCBs to the water column. Water column PCB concentrations were on the order of 300 ng/L during October when much of the sediment disturbance was caused by backfilling and capping operations. These water column PCB concentrations are similar to those observed during June and July 2009 when most disturbance was associated with dredging-related activities and no backfilling was happening. Backfilling itself should be a relatively innocuous activity because clean fill was placed on sediments that generally had much lower PCB concentrations than the material originally removed. However, capping was performed over inventory due to schedule constraints, in some cases with elevated concentrations, but disturbance of those areas should still have been less than occurs with dredging—including the decanting of water and the losses of sediment due to partially closed buckets. This indicates that tug traffic was a likely cause of disturbance leading to resuspension of PCBs during throughout the dredging and backfilling activities, as opposed to merely acting as a surrogate for mass removal.

Tug traffic was associated with water column PCB concentration during both backfilling and dredging operations. If tug traffic were merely a surrogate for mass removal as opposed to a causative agent, one would not expect to see the tug traffic signal in the water column record during backfilling. This indicates that resuspension due to tug traffic is likely to be a true causative factor of resuspension as opposed to a mere surrogate. Based on these findings, GE should consider alternative processes for distribution of cap and backfill material that minimize tug traffic.

Improvement in model fit during the late July to early August period was due to inclusion of the variable quantifying mass removed in CU-18 from within the sheet pile wall. As these activities were conducted within the confines of the sheet pile, this is counter-intuitive, but it is thought that this spike in water column concentrations, particularly during late July and early August, may be due to the release of extremely highly concentrated PCB contaminated water associated with accidental losses and bucket decanting as sediment (and water) was lifted over the sheet pile and into scows. For example, in a letter to EPA dated August 14th, 2009, GE reported water column PCB concentrations within the sheet pile of 12,800 ng/l, 116,000 ng/l and 19,800 ng/l, on July 31, August 5 and August 8, respectively. This was during the period of time when dredging activities were conducted within the sheet pile and when water column PCB concentrations spiked at TID.

Dredging in CU-18 was initiated in late July 2009 and at this point in time water column concentrations increased dramatically at TID to some of the highest levels observed during the Phase 1 removal. Although there was much less PCB mass produced in CU-18 (inside the sheet pile) (430kg) in comparison to CUs 17 and 18 (outside the sheet pile) (2600 kg), and in spite of the fact that the sheet pile wall was in place to contain resuspended PCBs, mass removal in this CU was strongly associated with water column PCB concentrations. PCB concentrations in water inside the sheet wall were on the order of 20,000 ng/L and exceeded 100,000 ng/l on at least one occasion. In late August when some sheet piling was removed, and dredge equipment was periodically moved in and out of CU-18, PCB concentrations exiting the sheet pile area were on the order of 2,000 ng/L (Personal communications with Mike Johnson). The response in PCB concentrations at TID was nearly immediate, particularly in late July and Early August and much greater in magnitude than would have been expected, given the small mass of PCBs removed from inside the sheet pile wall, and the fact that flow rates were apparently restricted. Water column PCB concentrations at TID during these episodes were higher than at any other time during the Phase 1 removal, indicating that processes other than mere proportionality to mass removed are important to explain PCB resuspension to the water column.

Associations between dredging activities at CU-18 and water column PCBs were statistically significant, despite activities inside the sheet pile at CU-18 were of relatively short duration and represented a very small fraction of the mass removed in Phase 1. Although this operation was relatively small, its influence was disproportionately large; these activities represented 3 percent of the total variance explained in water column concentrations over the entire dredging and backfilling season. Conversely, nearly 6 times as much PCB mass was removed from CUs 17 and 18 (outside the sheet pile wall) and the response in water column PCB concentrations was undetectable after adjusting for the other factors included in the model. This shows that combinations of other factors better describe water colum PCB concentrations than a simple proportionality to mass removal rates. Otherwise, general dredging activities in CU-17 and areas outside the sheet pile in CU-18 would have been more strongly correlated with water column concentrations than the much smaller mass removed from inside the CU-18 sheet pile.

Flow at the Fort Edward gage was also included in the regression models and was found to be an important predictor of PCB concentration at the TID. Because water column PCB concentrations were found to be correlated with flow, it is important that any analyses attempting to explain variation in water column PCB concentrations during dredging should explicitly account for variations in flow. Regression models between loads and flow are not valid for inference to causative mechanisms, because load is a function of flow. It is not valid to “regress” a function of flow against flow, because the 1 to 1 correlation of flow with itself is causes false but apparent correlations between the functions of interest.

Model Predictions

The fitted model results are plotted on Figure 6. They indicate that modeled concentrations generally track with day-to-day fluctuations in concentration during most months, including patterns observed in October that were not well described by GE’s simpler model. Similarly to the factor based model, this also shows that GE’s assertion that concentrations are driven exclusively by the amount of dredging is not justified. Also included in the plot are upper 95 percent prediction limits which are an added benefit of the regression approach to model development. It can be seen that the prediction intervals capture the majority of observations.

The plotted mechanism based model also shows that model fit is better when nonlinear combinations of variables are used directly in the regression model as opposed to the linear factor based model. Levels of agreement are improved particularly during the large excursion in water column concentrations in early August as well as in the second week of September.

6.4 Process Settings for Phase 2

This analysis identifies six parameters that collectively explain a large proportion of the variation in water column PCBs at the TID. There were periods of time when dredging and backfilling produced PCB concentrations measured at the TID were below 200 ng/l (August 9 to September 7, 2009 and September 11 to October 5, 2009) and yet productivity was on the order of 2,500 to 3,500 cubic yards per day (Table 7). Within the August period of time, active dredging occurred on 21 days, with productivity averaging 2,557 cubic yards per day and exceeding 3,378 cubic yards per day (EPAs proposed average daily productivity rate) on the three most productive days. There were also periods of time when PCB concentrations exceeded 300 ng/l on average (July 10 to August 9, 2009 and October 5 to October 27, 2009). Figure 10 compares the distribution of each of the six key process variables during these periods of time when resuspension was high with those periods when resuspension was low.

The clear shift in distributions illustrates the magnitude of difference in how process variables were “set” during high and low resuspension periods of Phase 1. This shows that Phase 1 dredging was at times conducted in such a way that Productivity and Resuspension Standards were met simultaneously. For Phase 2 dredging, process variables should be targeted to meet the ranges identified in Figure 10 to achieve high productivity with the expectation of low frequency of resuspension exceedances. As noted in development of the performance standards, flow is an important predictor of concentrations, and extreme flow events may precipitate higher water column levels, necessitating adaptive management actions.

7.0 CONCLUSIONS

The multiple variable factor analysis and corresponding regression is a first step in understanding the processes contributing PCBs to the water column. Several processes may be contributing to the PCB loads to the TID far field station, and that there is potential to improve dredging processes while maintaining a high likelihood that the resuspension standard can be met in Phase 2. The most likely factors contributing to PCBs to the water column are not unexpected—mass and volume removal, vessel traffic, exposure of freshly disturbed residual sediments to active flows, processes associated with backfilling, and the extent to which dredging may have encountered debris or have been less well-controlled, resulting in buckets that weren’t fully closed increasing the potential for PCB losses.

This analysis shows that a combination of processes are likely contributing measureable concentrations of PCBs to the water column, which presents an opportunity to fine-tune dredging operations in Phase 2.

The factor-based model results reported here support the hypothesis that sources of PCBs to the water column are many and varied, and that there are likely to be opportunities to minimize PCB resuspension during Phase 2 of the remedy. GE's statements in their Phase 1 evaluation report are not a reasonable response to the extensive information that is available to further refine and optimize the dredging operation. Regression of water column PCB concentration on mechanistic variables extends the multivariate factor analysis toward the goal of a predictive model which can be used to adjust dredging process parameters with an expectation of a commensurate response in water column PCB concentrations.

This analysis indicates that the primary drivers of resuspension are associated with a group of six identified process variables. It is reasonable to expect that if these six process variables are adjusted to levels observed during periods of acceptable resuspension and productivity, future resuspension results would be improved relative to 2009 performance.

EPA recognizes that there are many process variables that may influence dredging performance that have either not been measured or, of those measured, did not result in discernable associations with TID water column concentrations. This analysis shows that resuspension and productivity standards were met simultaneously at times during Phase 1—therefore it is possible to do so. It is also fully expected that a relatively wide range of combinations of process best practices could be used to achieve similarly reasonable resuspension rates at levels of production necessary to meet the Phase 2 Productivity Standard.

There may also be gross process changes in dredging and backfilling technologies that were not evaluated in Phase 1 that may achieve similar or larger reductions in resuspension than would be achieved through incremental changes in existing technologies. For example, this analysis identified tug traffic associated with both sediment removal and backfilling as being associated with water column concentrations at TID (Figure 8). Backfilling and capping material was transported to CUs using tugs and scows, so the majority of this tug traffic could be completely eliminated if backfill and cap material were pumped as slurry and applied hydraulically, rather than mechanically.

This analysis also supports the conclusion that Phase 2 dredging can be conducted with reasonable resuspension rates while meeting productivity goals.

8.0 REFERENCES

Neter, J., Kutner, M.H., Nachtsheim, C.J., and W. Wasserman. 1996. Applied Linear Statistical Models, 4th ed., Irwin. Chicago.

Seber, G.A.F. 1977. *Multivariate Observations.* Wiley Series in Probability and Mathematical Statistics. John Wiley and Sons. New York, NY.

Table 1. Squared Spearman Rank correlation coefficients between water column total PCB concentrations lagged by 0, 1 and 2 days. Correlations are more often the strongest when based on concurrent measurements of water column PCBs and sediment disturbance and productivity factors.

Variable	PCB_ng/L	PCB_ng/L_Lag1	PCB_ng/L_Lag2
BargeDist	0.001	0.000	0.003
BargeV_D	0.005	0.004	0.001
BargeVel	0.003	0.002	0.001
BCntTotal	**0.217**	0.174	0.094
BoatDist	**0.338**	**0.315**	**0.189**
BoatV_D	**0.315**	**0.313**	**0.188**
BoatVel	**0.275**	**0.254**	**0.145**
Debris	**0.135**	**0.165**	**0.186**
DrdgDist	0.033	0.016	0.002
DrdgV_D	0.004	0.000	0.001
DrdgVel	0.001	0.002	0.010
Fill Rate	0.095	0.063	0.021
FlowFE	0.014	0.035	0.044
Load_Bfill	**0.091**	**0.094**	**0.094**
Load_CU_Area	0.191	0.190	0.193
Load_MassRem2	**0.379**	**0.316**	**0.191**
LoadBoats	**0.303**	**0.253**	0.136
MassRemTotal3	**0.417**	**0.323**	**0.185**
ME	**0.384**	**0.346**	**0.225**
SbDist	0.108	0.066	0.026
SbV_D	0.118	0.076	0.038
SbVel	0.022	0.007	0.000
ScowDist	**0.265**	**0.220**	**0.140**
ScowV_D	**0.257**	**0.225**	**0.144**
ScowVel	**0.178**	**0.125**	0.072
Temp_C	0.007	0.011	0.013
TotalBfill	**0.090**	**0.094**	**0.093**
tPCB_CU_AREA	**0.146**	**0.147**	**0.148**
VolRemTotal	**0.346**	**0.285**	**0.161**
Notes:			
1) Gray cells indicate when water current water column concentrations correlate more strongly than lag-1 measurements or when lag-1 measurements correlated more strongly than lag-2 measurements.			
2) Bold numbers indicate that correlations are significantly different from zero at the 5 percent level of significance.			
3) Number of days represents the number of paired observations for values measured concurrently. Sample sizes associated with one and two day lags are reduced by one or two respectively.			

Table 2. Factor loadings for each variable for those factors found to be associated with water column Total PCB concentration in Thompson Island Pool from May to November in 2009, Hudson River. Loadings range from minus 1 to plus 1 and values greater in magnitude than 0.4 (green shaded and bold) are thought to be meaningful. Based on 127 day model.

Variable	**Factor1**	**Factor6**	**Factor7**	**Factor8**	**Factor9**
BCntTotal	**0.66**	**-0.40**	0.19	-0.07	0.13
BargeDist	-0.09	0.22	-0.10	-0.04	0.08
BargeV_D	0.02	0.06	-0.04	-0.10	0.09
BargeVel	-0.10	0.22	-0.11	0.00	0.04
DrdgDist	0.04	0.08	0.02	0.01	0.11
DrdgV_D	0.03	0.00	-0.05	-0.03	0.04
DrdgVel	-0.11	0.03	-0.12	0.01	-0.08
Load_Bfill	-0.16	**0.94**	-0.03	0.16	0.06
FlowFE	-0.35	0.12	0.00	**0.86**	-0.19
Temp_C	0.18	**-0.72**	0.16	-0.11	0.09
Load_CU_Area	0.27	-0.09	**0.87**	0.24	0.05
MassRemTotal3	**0.92**	-0.11	0.10	-0.11	0.06
SbDist	0.10	0.05	0.02	0.02	0.12
SbV_D	0.09	0.13	0.02	-0.01	0.11
SbVel	-0.02	-0.03	-0.11	0.02	-0.13
ScowDist	0.34	-0.03	0.14	-0.03	0.20
ScowV_D	0.26	0.04	0.19	-0.02	0.10
ScowVel	0.28	-0.13	-0.15	0.04	-0.05
TotalBfill	-0.14	**0.93**	-0.05	0.03	0.09
VolRemTotal	**0.82**	-0.10	0.14	-0.04	0.08
tPCB_CU_AREA	**0.44**	-0.17	**0.78**	-0.18	0.13
TotalEfficiency	0.32	-0.10	0.16	0.09	0.03
ME	**0.92**	-0.11	0.10	-0.06	0.04
BoatDist	0.36	0.15	0.11	0.04	0.70
BoatVel	0.19	0.03	0.06	0.06	0.14
BoatV_D	0.36	0.09	0.14	0.03	0.68
LoadBoats	0.01	0.32	0.15	0.77	0.41
Semi-Partial R^2	37%	10%	2%	10%	2%
Factor Label	Volume/Mass Bucket Fill	Backfill and Flow Weighted Backfill	PCB/Flow Weighted CU Area	Flow Weighted Vessel Dist.	Vessel Distance/Velocity

Table 3. Factor loadings for each variable for those factors found to be associated with water column Total PCB concentration in Thompson Island Pool from May to November in 2009, Hudson River. Loadings range from minus 1 to plus 1 and values greater in magnitude than 0.4 (green shaded and bold) are thought to be meaningful. Based on 166 day model.

Variable	Factor1	Factor4	Factor6	Factor7	Factor12
BCntTotal	**0.84**	-0.23	0.08	-0.04	0.05
BargeDist	0.08	0.22	-0.12	-0.02	-0.01
BargeV_D	0.12	0.06	-0.04	-0.09	0.04
BargeVel	0.05	0.21	-0.12	0.02	-0.03
DrdgDist	0.18	0.09	0.00	0.01	-0.02
DrdgV_D	-0.02	0.00	-0.02	-0.04	0.08
DrdgVel	-0.16	0.00	-0.14	0.03	-0.07
Load_Bfill	0.06	**0.97**	-0.03	0.11	-0.03
FlowFE	**-0.45**	0.11	-0.03	**0.86**	0.02
Temp_C	0.32	**-0.65**	0.18	-0.12	-0.04
Load_CU_Area	0.32	-0.07	**0.88**	0.17	0.01
MassRemTotal3	**0.84**	-0.09	0.08	-0.12	**0.44**
SbDist	**0.42**	0.09	0.00	0.03	-0.01
SbV_D	0.36	0.16	0.03	-0.03	0.03
SbVel	0.18	0.00	-0.14	0.07	-0.01
ScowDist	**0.95**	0.03	0.08	-0.05	-0.09
ScowV_D	**0.91**	0.07	0.10	-0.02	-0.09
ScowVel	**0.91**	-0.03	-0.15	0.02	-0.14
TotalBfill	0.10	**0.94**	-0.05	-0.01	0.02
VolRemTotal	**0.87**	-0.04	0.08	-0.04	0.12
tPCB_CU_AREA	**0.49**	-0.14	**0.78**	-0.23	0.01
BoatDist	**0.85**	0.18	0.08	-0.02	-0.02
BoatVel	**0.61**	0.07	0.02	0.05	0.00
BoatV_D	**0.83**	0.14	0.12	-0.03	-0.01
LoadBoats	**0.59**	0.37	0.12	**0.60**	-0.12
TotalEfficiency	0.32	-0.09	0.16	**0.91**	0.06
ME	**0.91**	-0.10	0.10	0.23	-0.07
Semi-Partial R^2	28%	6%	4%	5%	13%
Factor Interpretation	Volume/Mass Bucket Fill	Flow Weighted Backfill	PCB/Flow Weighted CU Area	Flow Weighted Vessel Dist.	Mass Removed

Table 4. Coefficients, standard errors, tests of significance, squared semi-partial correlation coefficients and variance inflation factors for regression of water column Total PCB concentration on factor scores. Analysis is based on the variables measured on 127 of the 166 day season.

Variable	Factor Interpretation	Coefficient Estimate	Standard Error	Students T-Statistic	Significance Level	Squared Semi-Partial Correlation Coefficient	Variance Inflation Factor
Intercept	NA	237.17	6.31	37.57	<.0001	NA	NA
Factor1	Volume/Mass Bucket Fill	67.21	6.34	10.60	<.0001	0.37	1.0
Factor6	Backfill and Flow Weighted Backfill	34.04	6.34	5.37	<.0001	0.10	1.0
Factor7	PCB/Flow Weighted CU Area	16.36	6.34	2.58	0.0111	0.02	1.0
Factor8	Flow Weighted Vessel Dist.	34.19	6.34	5.39	<.0001	0.10	1.0
Factor9	Vessel Distance/Velocity	14.15	6.34	2.23	0.0275	0.02	1.0

Table 5. Coefficients, standard errors, tests of significance, squared semi-partial correlation coefficients and variance inflation factors for regression of water column Total PCB concentration on multivariate factor scores. Analysis is based on the variables measured on each of the 166 days of the season.

Variable		Coefficient Estimate	Standard Error	Students T-Statistic	Significance Level	Squared Semi-Partial Correlation Coefficient	Variance Inflation Factor
	Intercept	214.51	5.95	36.06	<.0001		0.00
Factor1	Volume/Mass Bucket Fill	59.67	5.97	10.00	<.0001	0.28	1.00
Factor4	Backfill and Flow Weighted Backfill	27.52	5.97	4.61	<.0001	0.06	1.00
Factor6	PCB/Flow Weighted CU Area	23.23	5.97	3.89	0.0001	0.04	1.00
Factor7	Flow Weighted Vessel Dist.	24.16	5.97	4.05	<.0001	0.05	1.00
Factor12	Mass Removed	41.01	5.97	6.87	<.0001	0.13	1.00

Table 6. Coefficients, standard errors, tests of significance, squared semi partial correlation coefficients and variance inflation factors for regression of water column Total PCB concentration on process variables. Analysis is based on the variables measured on each 127 of the 166 day season.

Variable	Description	Units	Estimate	Standard Error	T Statistic	Significance Level	Squared Semi-Partial Correlation Coefficient	Variance Inflation Factor
Intercept	Intercept	mg/kg	-72.064	33.213	-2.17	0.032	NA	NA
AvgScowsInQue	Average Number of Scows in Queue	Count	9.613	5.672	1.69	0.0927	0.01	1.32211
ME	(Bucket Fill Percentage)x(Mass Removed)	kg	1.084	0.110	9.89	<.0001	0.25	1.64197
FlowFE	Flow at Fort Edward Gauge	cfs	0.020	0.004	5.56	<.0001	0.08	1.40229
BfillTotalM5	(CU Backfill Count) x (Tug distance) x (Sediment PCB) x (Depth < 11 ft) / (Water Depth)	(mi x mg/kg) (ft)	0.010	0.002	6.40	<.0001	0.11	1.12044
eCU0M5	(Tug distance) x (Sediment PCB) x (Depth < 11 ft) / (Depth)	(mi x mg/kg) (ft)	19.359	8.760	2.21	0.029	0.01	1.43268
MassRemCU18_IN	Daily PCB Mass Removed From CU-18 Inside Sheet Pile	kg	2.590	0.723	3.58	0.0005	0.03	1.39445

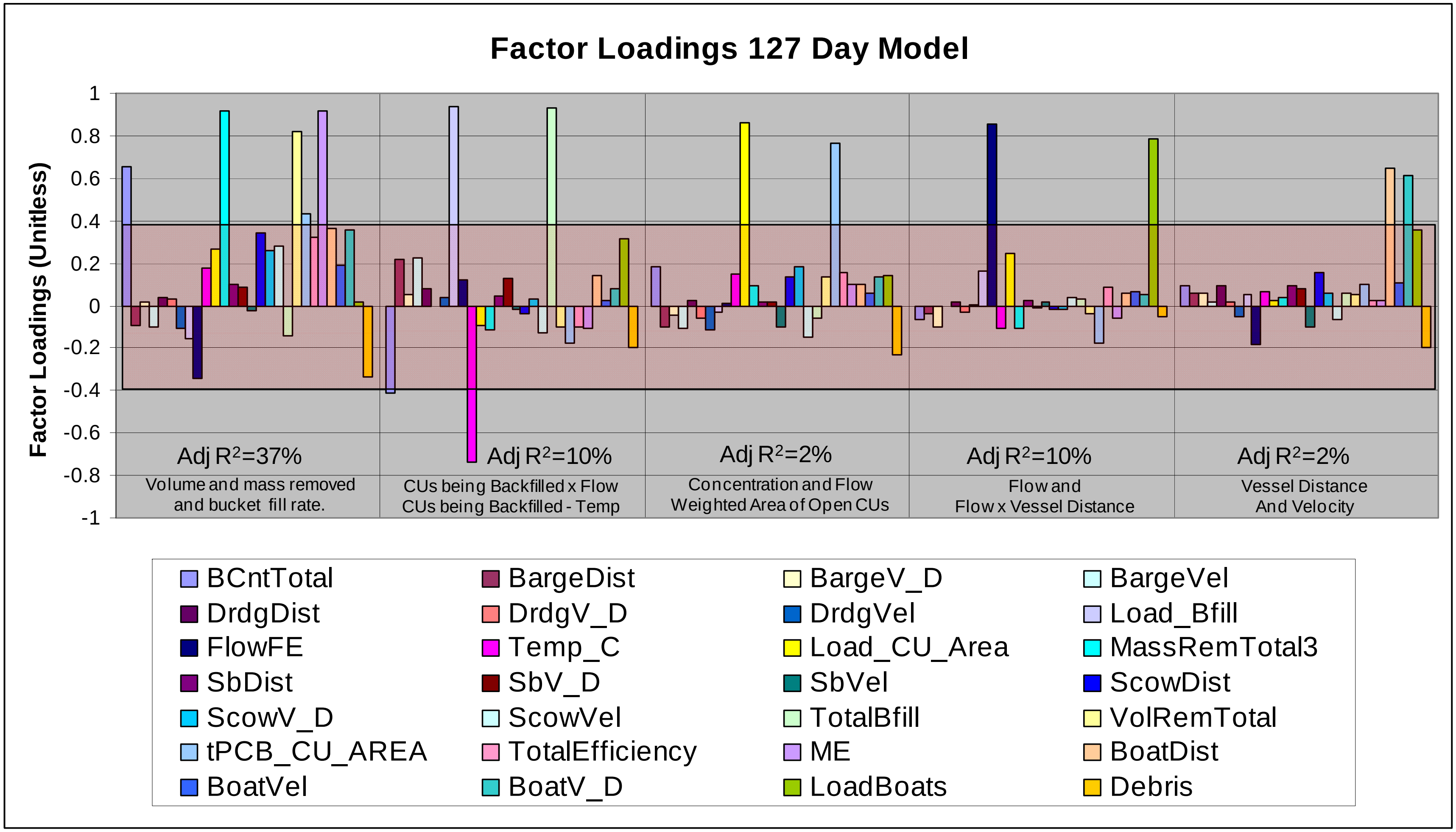


Figure 1. Factor loadings for five factors identified to be important factors for prediction of water column PCB concentrations. R^2 values represent the proportion of variance explained by each factor in multiple regression with water column PCB concentrations at far field stations in Thompson Island Pool. Loadings greater than roughly 0.4 in magnitude are considered meaningful.

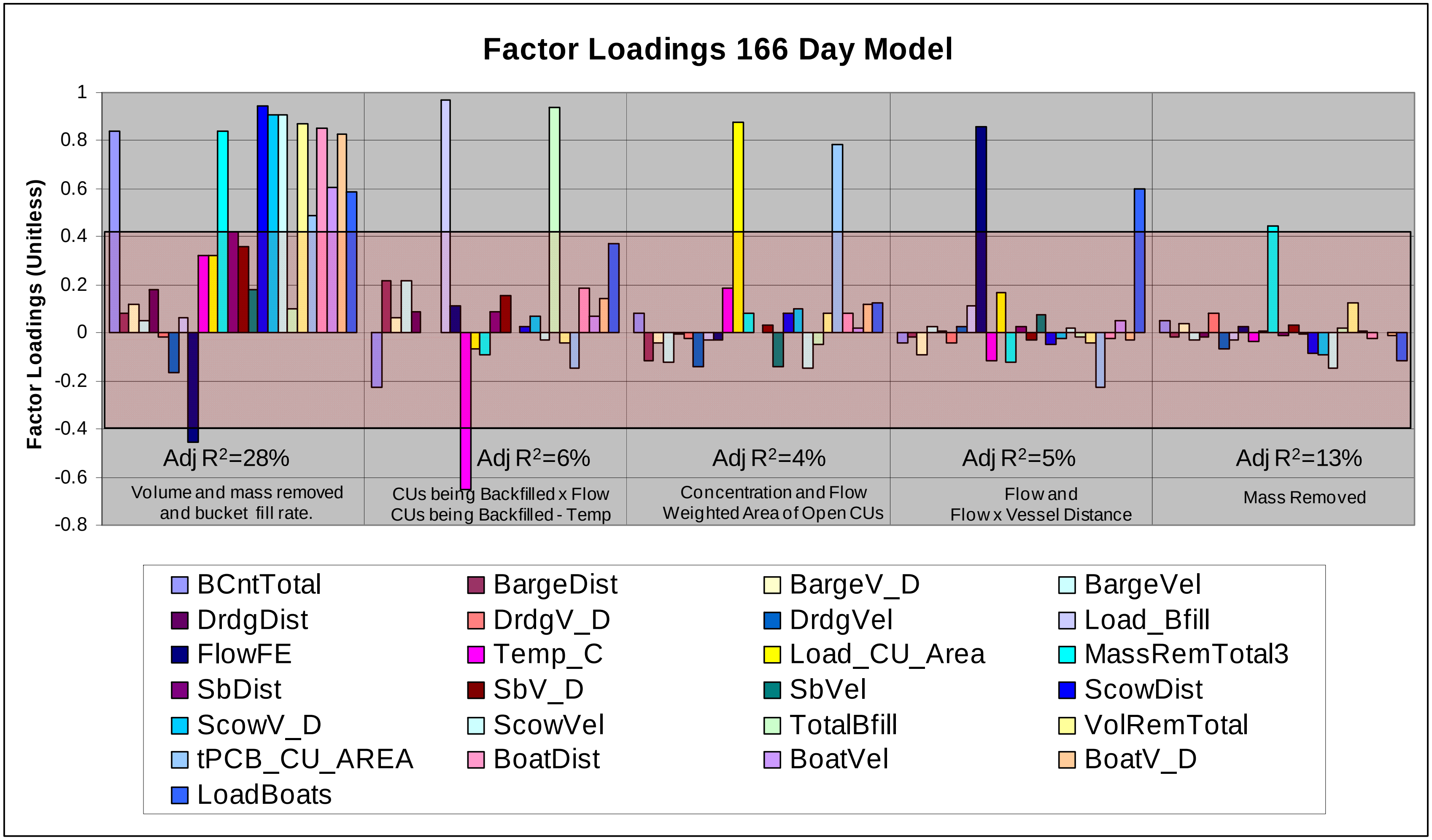


Figure 2. Factor loadings for five factors identified to be important factors for prediction of water column PCB concentrations. R^2 values represent the proportion of variance explained by each factor in multiple regression with water column PCB concentrations at far field stations in Thompson Island Pool. Loadings greater than than roughly 0.4 in magnitude are considered meaningful.

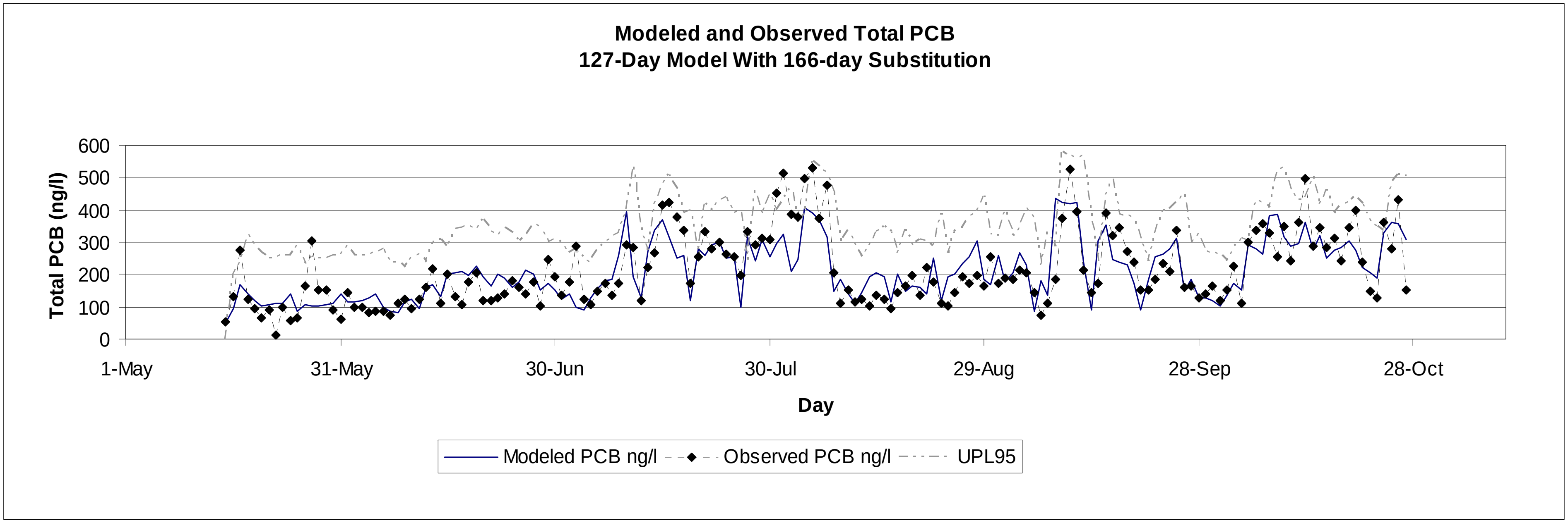


Figure 3. Observed and modeled values for water column PCB concentrations at far field station in Thompson Island Pool. The model is based on variables available on 127 of the 166 day season with modeled values from the 166 day model substituted on the remaining days—primarily in May and June.

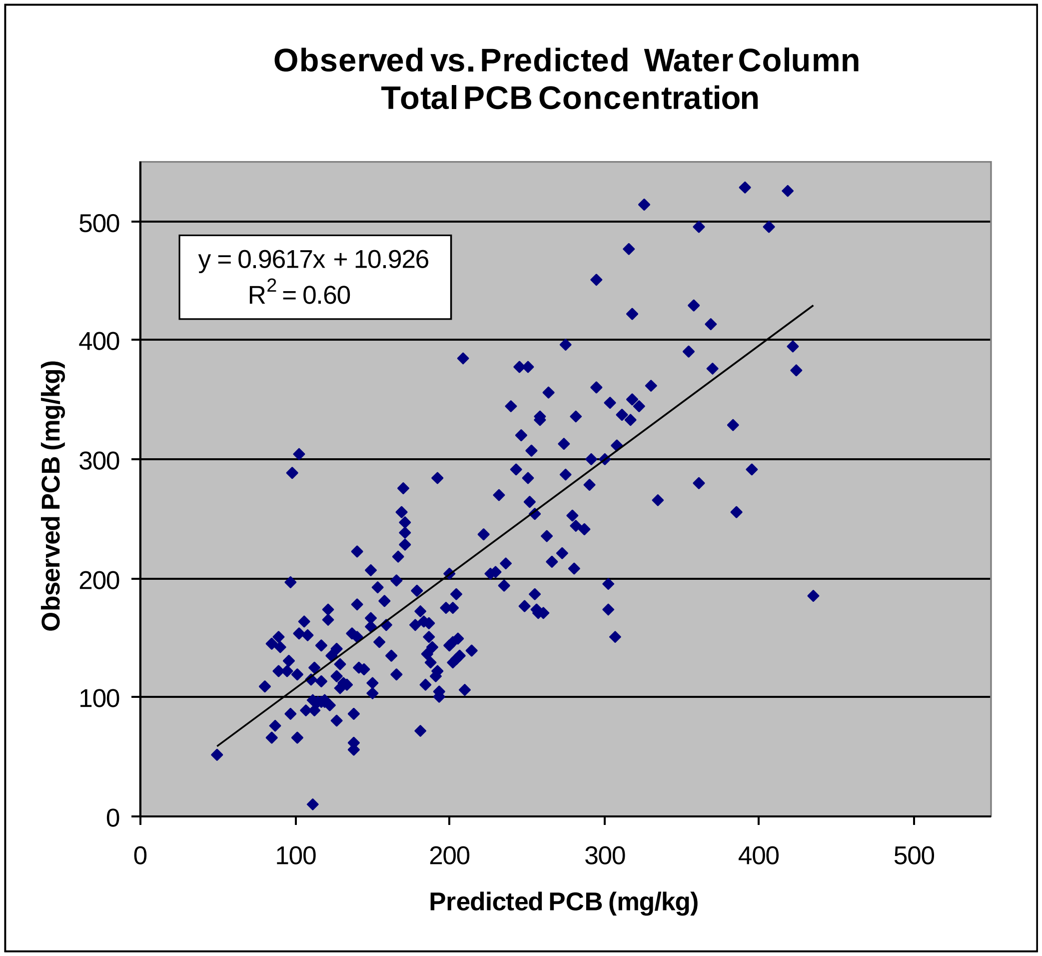


Figure 4. Observed water column Total PCB concentration plotted against modeled values for Thompson Island Pool based on the 127 day model with substitutions from the 166 day model for those days when predictor variables are missing—primarily Sundays, days when dredging was shut down and days prior to the onset of dredging.

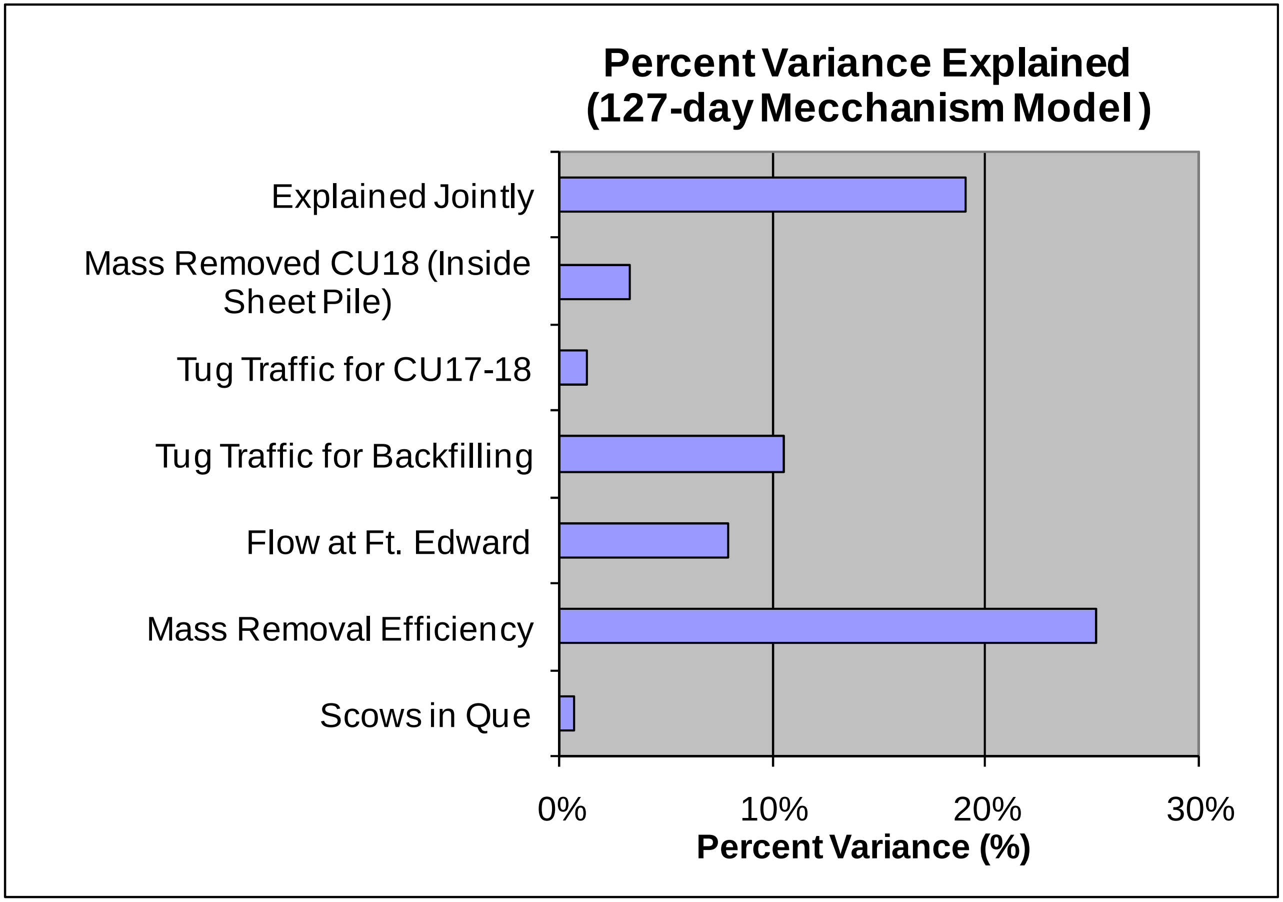


Figure 5. Percent variance explained by individual process variabels in a multiple regression model predicting water column PCB concentration at Thompson Island Dam, Hudson River New York. Overall adjusted R^2=68%. Variance explained jointly cannot be ascribed independently to any particular variable due to inter-correlations among the predictors.

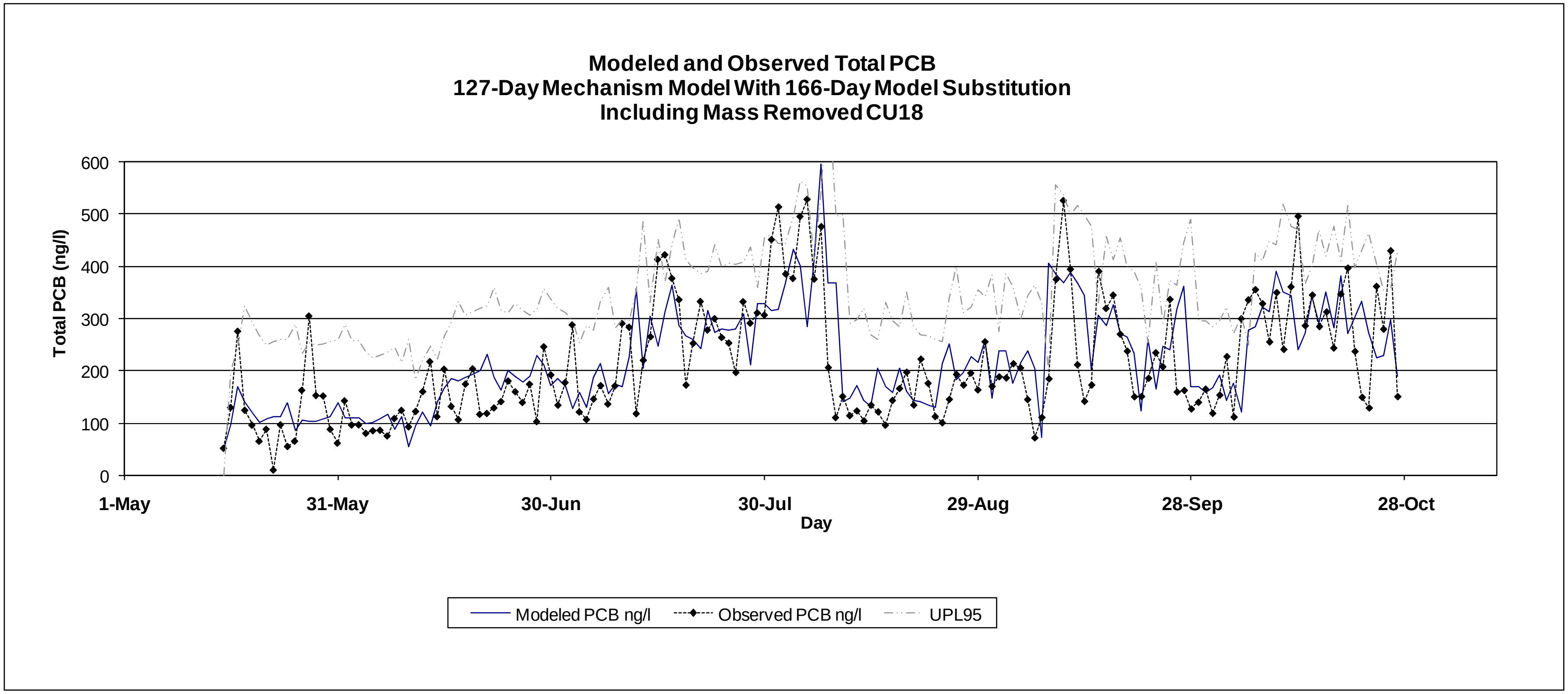


Figure 6. Observed and modeled values for water column PCB concentrations at far field station in Thompson Island Pool. The model is based on process variables available on 127 of the 166 day season with modeled values from the 166 day model substituted on the remaining days—primarily in May and June.

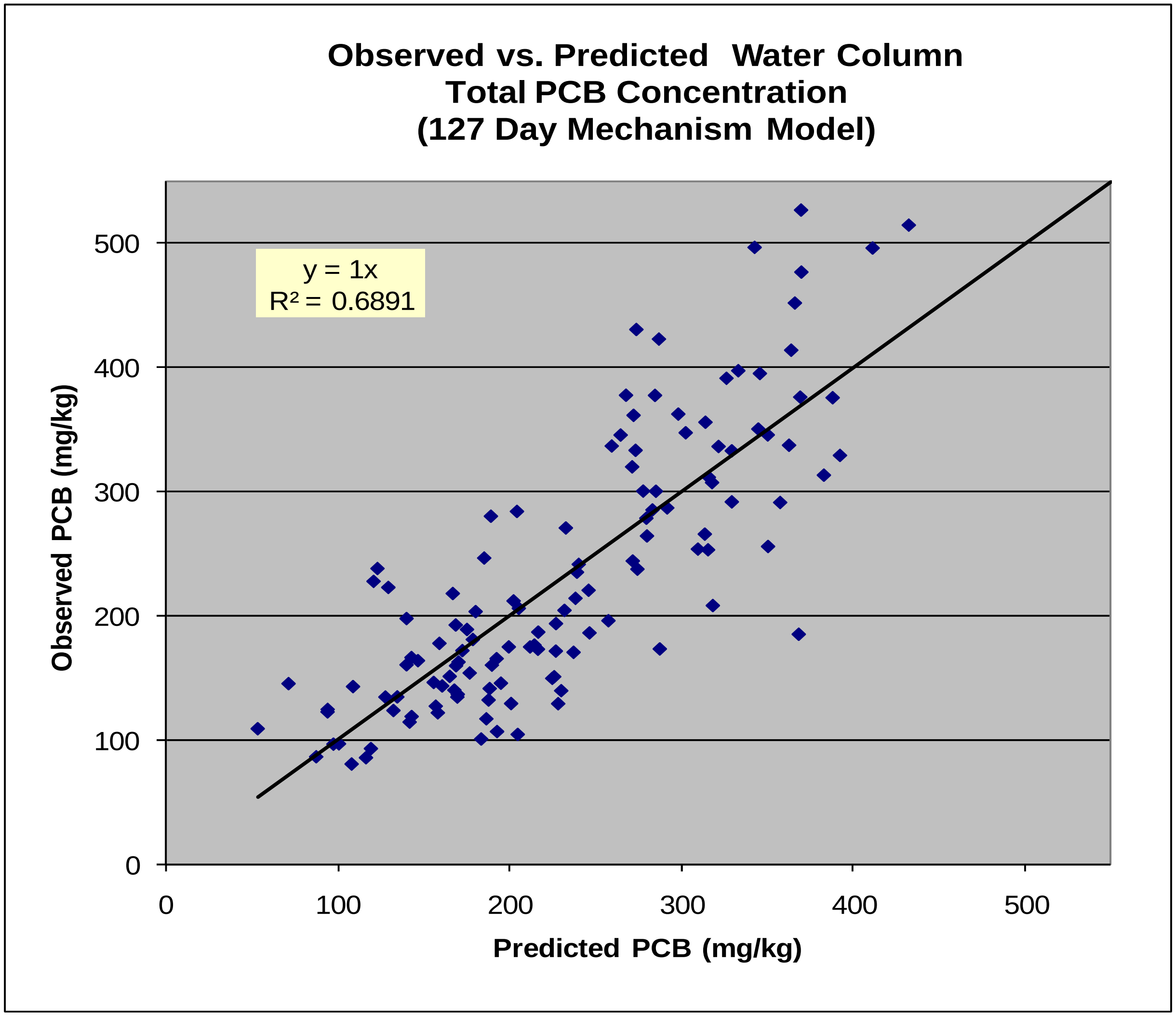


Figure 7. Observed water column Total PCB concentration plotted against modeled values for Thompson Island Pool based on the 127 day model. The line is the best fit line with an R^2=69% and adjusted R^2=68%

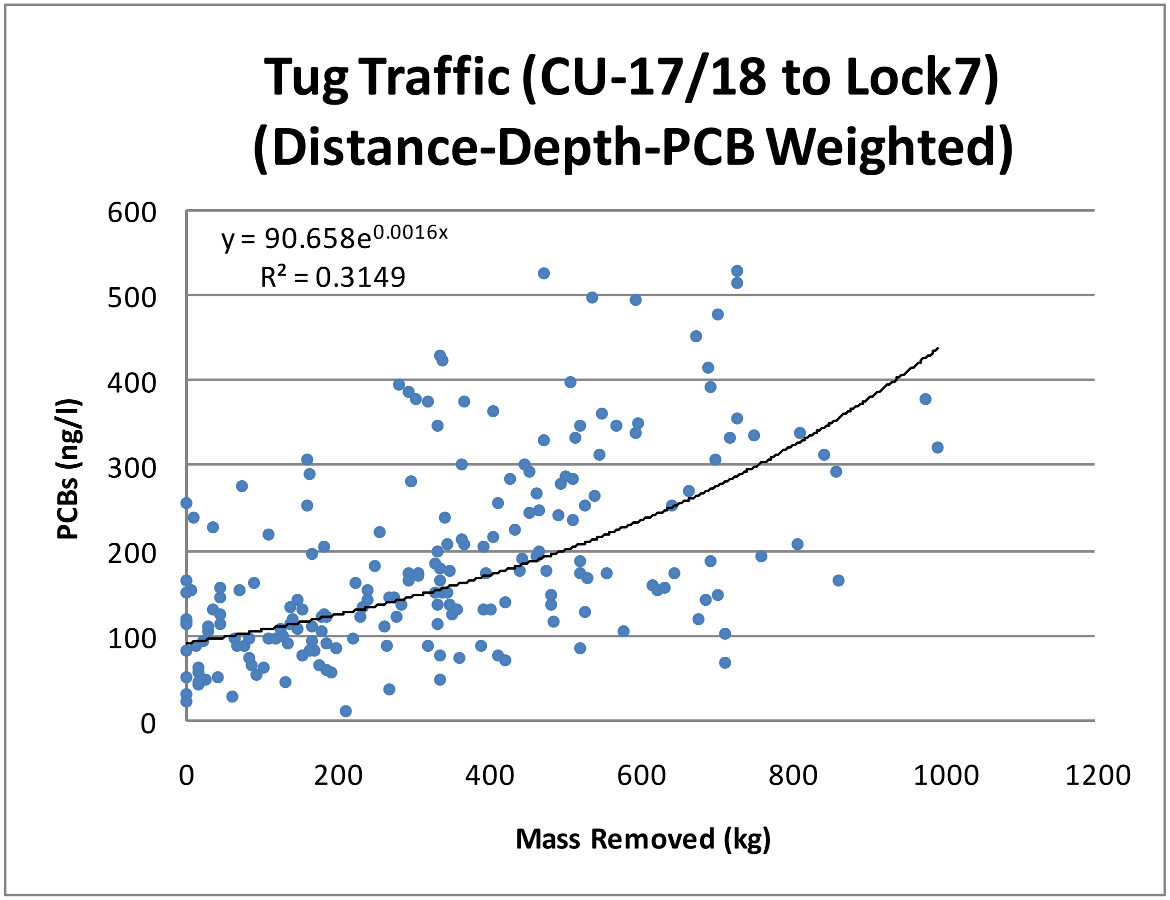


Figure 8. Observed water column Total PCB concentration plotted against modeled values for Thompson Island Pool based on the 127 day model. The line is the best fit line with an R^2=69% and adjusted R^2=68%

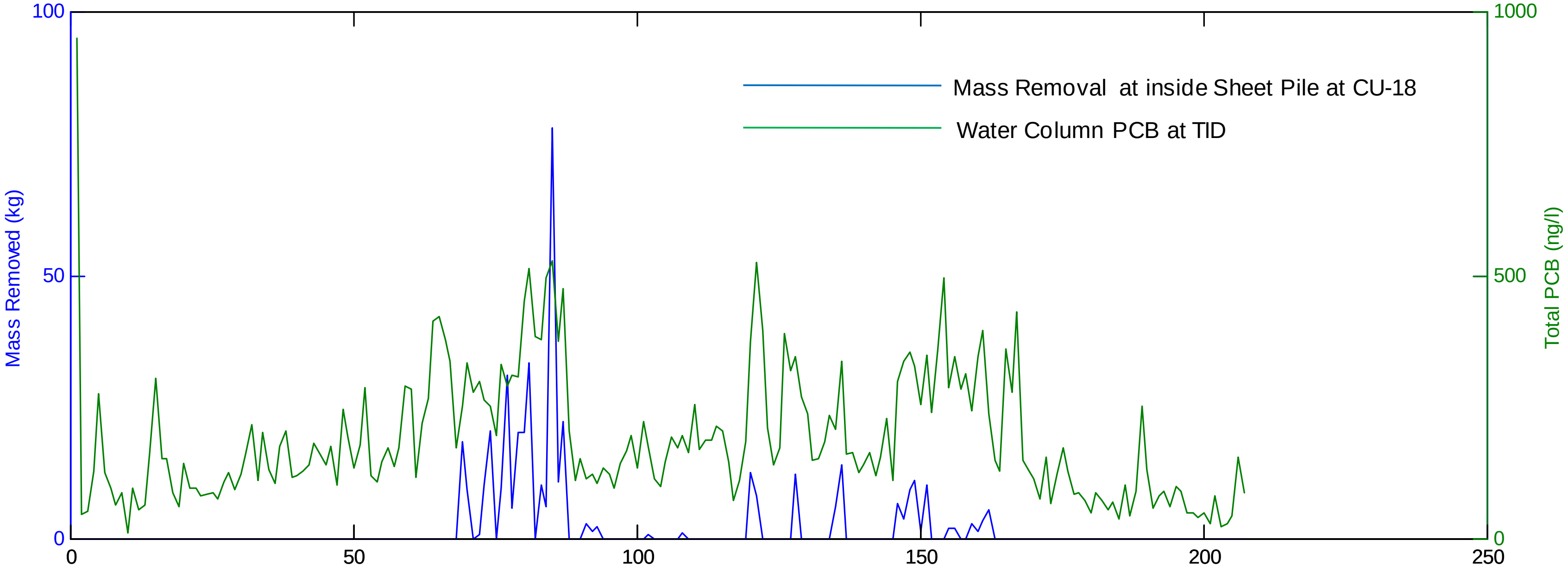


Figure 9. Temporal correspondence between dredging activities inside the sheet pile at CU-18 and spike in water column PCB concentrations at TID.

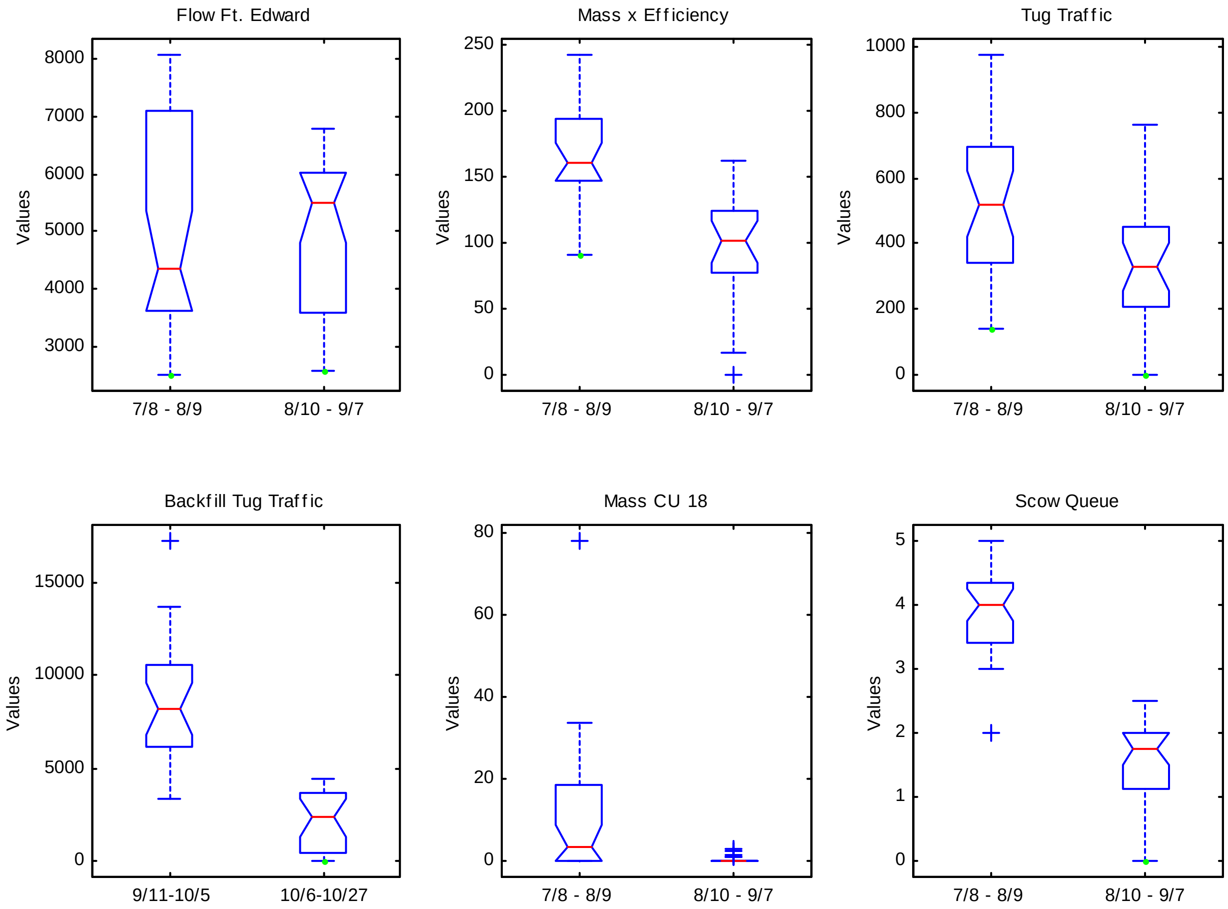


Figure 10. Distribution of the 6 key process variables during selected periods in 2009.