An Evaluation of Toxic Contaminants in the Sediments of the Tidal Delaware River and Potential Impacts Resulting from Deepening the Main Navigation Channel in Reach C

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ATTACHMENT (CD ROM with individual spreadsheet analyses)

INTRODUCTION

The United States Congress first authorized deepening the Delaware River main navigation channel from 40 feet to 45 feet in 1992. Since that time, there have been numerous environmental and economic studies performed in conjunction with the project. Furthermore, the project has undergone several regulatory reviews to determine conformance with Federal and State laws and regulations. The U.S. Army Corps of Engineers submitted a State of Delaware Wetlands and Subaqueous Lands permit application in 2001. In July 2009, the State of Delaware denied the subaqueous lands permit and wetlands permit seeking to deepen the portion of the channel within Delaware waters. The Corps informed the State that it would proceed with deepening without the State permits in order to protect national interest and security. The State in turn filed a complaint for declaratory and injunctive relief with the Federal District Court to prevent the Corps from proceeding without the permits. The judge denied the State's request for relief and ruled that the Corps could proceed with the deepening within Reach C of the Delaware River without the State permits. The judge also ruled that the Corps needed to resubmit an application for the State permits in order to deepen the channel in areas beyond Reach C. The State of Delaware has agreed to a transparent, expedited review of any new Corps' permit applications.

The focus of this report is on Reach C of the Delaware River. Reach C covers the area between the Delaware Memorial Bridge to the north and Reedy Island to the south (Figure 1). The Corps of Engineers began deepening in lower Reach C on March 1, 2010 shortly after the judge's ruling. Although the Corps proceeded without permits, they did agree to monitor water quality to demonstrate compliance with Delaware water quality criteria and standards. That monitoring includes testing for PCBs, dioxins and furans, organochlorine pesticides, PAHs, and metals in sediments, water samples directly down-current from the working cutterhead, background water samples away from the immediate influence of the dredge, and influent and discharges from the Kilcohook confined disposal facility (CDF). In addition, the monitoring includes the collection of detailed information on suspended solids (TSS) and turbidity in the dredge plume to establish compliance with a TSS performance standard of 250 mg/L at a distance of 200 feet down-current from the cutterhead. Two hundred feet is the length of the near-field mixing zone, calculated as 5 times the local water depth (5 x 40' = 200'). Preliminary data from that monitoring demonstrate a strong correlation between TSS and turbidity and also that TSS levels fall below 250 mg/L at all depths at a distance of 200 feet behind the cutterhead. At the time of this writing, very little of the toxics data collected in conjunction with deepening within Reach C are available and so those data are not discussed here.

Although the toxics data just mentioned are largely unavailable, another rather large dataset for toxics in sediments of the Delaware Estuary has recently become available. That dataset is referred to as the 2008 DEBI (Delaware Estuary Benthic Inventory). In the summer of 2008, the Partnership for the Delaware Estuary (PDE) collected surface sediment samples from over 200 locations in the Estuary spanning the area between the mouth of the Schuylkill River to the mouth of the Delaware Bay. Metals were analyzed in all of the samples and polychlorinated biphenyls (PCBs) were analyzed in a subset of the samples by the Delaware River Basin Commission (DRBC). The PCB data were provided to DNREC by the DRBC and are considered final. The metals data and associated sample locations were provided to DNREC by the PDE. At the time of this writing, the PDE considered those data to be draft. Despite this qualifier, discussions with the PDE and the lab that performed the analyses indicate that the data themselves are essentially final and that all that remains before official release of the data is conformance with formatting requirements and specification of associated metadata. These issues were not considered by DNREC to be an obstacle to the review and analysis of the data. In light of the pressing need for current information on toxics in the Delaware Estuary sediments and in order to help inform decision makers involved in the deepening project, the author proceeded with an analysis of the 2008 DEBI metals and PCB data. This report documents the various analyses that were performed on those data.

It is noted at the outset that few of the sediment samples collected as part of the 2008 DEBI were actually collected from the main navigation channel. This is not unexpected considering that the sampling design was probability-based and recognizing that the channel only represents roughly 2% of the bottom habitat in the Estuary. Insofar as non-channel sediments tend to have higher (or at least no higher) concentrations than channel sediments, the assumption is made here that the 2008 DEBI results are representative (and possibly a conservative estimate) of concentrations in the main navigation channel. Furthermore, based on prior testing of surface sediments versus deeper cores within the channel, contaminant concentrations in the -40 to -45 foot layer within the main channel are not expected to be greater than contaminant concentrations in the surface layer. This would not be true if dredging were being done in undisturbed fringe marsh areas where contaminant concentrations are often higher at depth (Church et al. 2006; Velinsky et al. 2010). Deepening the main channel though is not dredging in undisturbed fringe marsh. Consequently, the surface sediment data collected as part of the 2008 DEBI is considered representative (and possibly a conservative estimate) of material being removed from the channel during deepening.

METHODS

The first step in this evaluation was to review the 2008 DEBI metals and PCB data. This was done without immediate regard to the dredging issue. Since the 2008 DEBI samples were collected prior to but near the beginning of deepening, the results do represent somewhat of a current baseline prior to deepening.

The review and analysis of the 2008 DEBI data began by first compiling and checking the data for any obvious errors or other data quality issues. The raw data were then plotted and basic summary statistics were produced to characterize the center, spread, and distribution of the data. This was done for the entire geographic sampling frame as well for smaller sub-region areas, in this case using DRBC water quality management zones. Reach C for the deepening project falls entirely within DRBC Zone 5. Zone 5 in turn spans the area between the DE/PA/NJ line downstream to Liston Point, DE, which is ~10 miles south of the C&D Canal. For purposes of this evaluation, Zone 5 was split into upper Zone 5 and lower Zone 5, with lower Zone 5 covering the area between the Delaware Memorial Bridge and Liston Point. Reach C of the deepening project covers the same approximate area as lower Zone 5.

Following the compilation and preliminary analysis, the likelihood that the levels of PCBs and metals in the sediments are currently causing toxicity to benthic aquatic life was assessed. This was done by predicting the dissolved concentration of the contaminants in the sediment pore water using equilibrium partitioning (EqP) and then comparing the resulting concentrations to chronic aquatic life criteria, which were taken from Delaware's Surface Water Quality Standards (DNREC, 2004). Delaware's water quality criteria were used rather than DRBC's stream quality objectives because Reach C falls entirely within Delaware waters; there is a clear line of authority and applicability of Delaware's criteria to Delaware waters; and the Delaware criteria have been updated more recently than the DRBC stream quality objectives. In addition to the evaluation of potential toxicity to benthic organisms just described, the likelihood that PCBs are being taken up from the sediments into the aquatic foodchain and causing a bioaccumulation problem was assessed using a biota-to-sediment accumulation factor (BSAF) approach. A more complete description of the methods used to evaluate the toxicity and bioaccumulation potential of the in-place contamination can be found in Appendix A (for PCBs) and Appendix B (for metals). Those appendices include selected outputs from the Excel spreadsheets developed to organize and assess the data. The actual spreadsheets should be consulted to fully understand the underlying approach and assumptions. Those spreadsheets appear on the accompanying CD at the end of this report.

The next major part of this evaluation involved using the 2008 DEBI PCB and metals data within a water quality modeling framework to assess whether deepening Reach C of the main navigation channel is likely to cause exceedances of applicable water quality criteria for the protection of aquatic life and human health. Again, Delaware's water quality criteria were used. The assessment considered potential exceedance of acute aquatic life criteria immediately behind a working hydraulic cutterhead dredge as well as potential exceedance of chronic aquatic life criteria and human health criteria upon complete mixing of liberated contaminant mass within Reach C. Acute criteria are used to assess short duration, higher concentration exposures near sources while chronic criteria are used to assess longer term, lower concentration exposures over broader areas. The analysis of acute criteria compliance immediately behind the cutterhead is referred to herein as a "near-field" assessment. The analysis of chronic aquatic life criteria and human health criteria upon complete mixing is referred to herein as a "far-field" assessment. It is important to note that the modeling framework developed for this evaluation is limited to the specific influence of dredging on water column concentrations. The framework is not comprehensive in the sense that it incorporates contaminant mass loads from all possible sources over the entire Delaware Estuary. However, the framework does capture the key processes associated with dredging and it is accessible to anyone familiar with basic spreadsheet computations.

A complete description of the methods and assumptions used to evaluate the potential impacts resulting from deepening Reach C can be found in Appendices D through I. Appendix D describes the near-field assessment of PCBs. Appendix E describes the near-field metals assessment. Appendix F presents detailed geochemical speciation modeling calculations for aluminum in response to findings made in the near-field metals assessment in Appendix E. Appendix G and H describe the methods used for the far-field PCB assessment and far-field metals assessment, respectively. The Excel spreadsheets used to evaluate the near-field and far-field concentrations of PCBs and metals in Reach C of the Delaware River in response to deepening are included on the accompanying CD.

The final step in this overall evaluation was to compare the 2008 DEBI PCB and metals concentrations to the State of Delaware's uniform risk based standards for soils. This was done to determine if the dredged material, once pumped into the confined disposal facility and dewatered, would represent any unreasonable risks according to those standards. Appendix I presents that comparison. The spreadsheet developed to perform the comparison is included on the accompanying CD.

RESULTS

1. **Assessment of 2008 DEBI PCB Data:** PCBs were detected in all 51 sediment samples that were analyzed for PCBs, ranging from a minimum of 0.09 ng/g dw (ppb) to a maximum of 3247 ppb with a mean of 96.7 ppb and a median of 9.6 ppb. The highest concentrations were detected in upper Zone 5, east of Edgemoor, DE. The range in Lower Zone 5, which covers the same general area as Reach C for the deepening project, was 0.81 ppb to 138.1 ppb, with a mean of 18.9 ppb and a median of 9.8 ppb. For the full dataset, total PCB was positively correlated with total organic carbon. Many of the samples exhibited an unusually large percentage of the highly chlorinated PCBs nona and decachlorobiphenyl, especially in Upper and Lower Zone 5 (including Reach C). Despite the high frequency of total PCB detection, PCBs in the sediments, including in Reach C, are not expected to cause chronic toxicity to aquatic life (see Figure 2). However, PCBs in these sediments (including Reach C) are expected to contribute significantly to bioaccumulation of the foodweb, including transfer into fish that people catch and consume (see Figure 3). Further details concerning this part of the overall assessment can be found in Appendix A and on the associated file on the CD.

2. **Assessment of 2008 DEBI Metals Data:** Metals were detected in all sediment samples with the peak and greatest mean values generally occurring in upper Zone 5, east of Edgemoor, DE. Two out of 227 samples (<0.5%) had dissolved metal concentrations in the pore water high enough to potentially cause acute toxicity to benthic organisms. Those 2 samples were located in Upper Zone 5. Overall however, average and median pore water metals concentrations were all well below acute criteria for each DRBC zones (see Figure 4). With regard to

more subtle chronic effects, roughly 20% of the samples were predicted to have dissolved pore water metals concentrations high enough to potentially cause chronic toxicity to benthic aquatic life. Most of those samples were from Upper and Lower Zone 5 (see Figure 5). The main driver for this finding is the stringency of the freshwater chronic criterion for cadmium (see Figure 6). With a single exception, no other divalent metal had a predicted dissolved pore water concentration that exceeded its chronic aquatic life criterion. Close examination of the cadmium criterion (Appendix C) revealed that it is likely overprotective when applied to sediment pore water because it does not account for strong cadmium sulfide binding and POC in the sediments which act to reduce bioavailability and toxicity of the dissolved free metal ion thought to be primarily responsible for toxicity. This position is supported in part by existing (yet limited) measurements of acid volatile sulfide (AVS) and simultaneously extracted metal (SEM) in Delaware Estuary sediments along with matching sediment bioassay results which show no acute toxicity in the samples. These results of course do not rule out the possibility of chronic toxicity in these samples but at least we know they weren't acutely toxic. Further details concerning the assessment of the 2008 DEBI metals data and the review of the cadmium criterion are available in Appendix B and C, respectively.

3. **Assessment of Near-Field PCB Concentrations Behind Cutterhead in Reach C:** The predicted increase in total PCB concentration two hundred feet behind the dredge cutterhead is several orders of magnitude less than the freshwater and marine acute aquatic life criteria (see Figure 7). This prediction is based on a series of worst case assumptions, including: a) the PCB concentration in the sediments that are released to the water column due to the cutterhead are at 138 ppb, which is the maximum detected in Lower Zone 5; b) the suspended solids concentration at the edge of the mixing zone is 250 mg/L, which is the maximum performance standard that DNREC has told the Corps that they must meet; and c) PCBs desorb from the sediment particles instantaneously and in accordance with equilibrium partitioning theory. Despite these conservative assumptions, near-field acute toxicity due to PCBs is not likely in the dredge plume. Additional details supporting this finding are available in Appendix D.

4. **Assessment of Near-Field Metals Concentration Behind Cutterhead in Reach C:** The predicted increase in dissolved metal concentrations 200 feet behind the dredge cutterhead is 1 to 4 orders of magnitude less than the dissolved acute aquatic life criteria. The acute aquatic life criteria for aluminum and selenium are expressed on a total recoverable basis. The predicted increase in total selenium at the edge of the near-field mixing zone is significantly less than the total recoverable acute criterion for selenium. The predicted increase in total aluminum at the edge of the near-field mixing zone is expected to exceed the total recoverable aluminum acute criterion by as much as 6 times under worst case conditions (i.e., using the maximum aluminum concentration in the sediments of Reach C and a maximum TSS at the edge of the mixing zone at 250 mg/L). Under more normal conditions (e.g., median aluminum concentration and TSS at

150 mg/L), the predicted total aluminum concentration meets the total recoverable acute criterion. Hence, the aluminum criterion is expected to be exceeded under worst case conditions, but not normal conditions. Furthermore, and more importantly, close review of the aluminum criterion reveals that it is dated and fails to properly account for the important effect of pH on solubility and toxicity. Detailed geochemical speciation modeling was conducted to provide insight into this problem (Appendix F). That work shows that, for the range of observed pH values in the Delaware Estuary, the vast majority of the aluminum will exist as solid phase, non-toxic aluminum. It is concluded that near-field acute toxicity is unlikely due to metals mobilized to the water column during deepening, including aluminum. Further information in support of this conclusion can be found in Appendix E and F.

5. **Assessment of Far-Field PCB Concentrations in Reach C Due to Deepening:** Based on mass budget calculations, over 97% of the PCB in Reach C sediments will be removed from the Estuary during deepening and placed in a confined disposal facility; 2.4% of the PCB being excavated will be liberated to the water column and settle back out in the Estuary; and only 0.38% of the PCB in the sediments being excavated is expected to be released to the Delaware Estuary as dissolved phase, bioavailable PCB (see Figure 8). That increase in dissolved phase PCB translates to a far-field PCB concentration of 2.2 pg/L in Reach C. This increase is well below the Delaware, New Jersey, and EPA human health criterion of 64 pg/L. It is also two to three orders of magnitude less than measured dissolved PCB concentrations in Lower Zone 5, which encompasses Reach C of the deepening project. Based on the PCB mass budget calculations, deepening in Reach C will actually result in a substantial removal of PCB from the Delaware Estuary. This can be viewed as an environmental benefit since PCB is being taken out of the Delaware Estuary and is being placed in a CDF where the exposure and risk are far lower. Further details concerning the far-field PCB calculations are available in Appendix G.

6. **Assessment of Far-Field Metals Concentrations in Reach C Due to Deepening:** The vast majority (92.5% to 97.4%) of metal dredged from Reach C during deepening is expected to be sequestered in a CDF. Between 2.6% and 7.5% of the metal is expected to re-settle near the point of dredging and near the CDF discharge. Only a small fraction of the metal is expected to be released to the Estuary in a dissolved, potentially bioavailable, toxic form. The predicted far-field dissolved metal concentrations in Reach C associated with the release are many orders of magnitude less than the corresponding chronic aquatic life criteria and human health criteria, including that for mercury in fish tissue. Like for PCBs, deepening in Reach C will actually result in a substantial removal of metals from the Delaware Estuary. Again, this can be viewed as an environmental benefit since these metals are being taken out of the Delaware Estuary and are being placed in a CDF where the exposure and risk are far lower. Additional details concerning the far-field assessment of metals are presented in Appendix H.

7. **Comparison Between 2008 DEBI PCB and Metals Concentrations to Delaware Uniform Risk Based Standards for Soils:** The concentrations of metals and PCBs in most of the samples are less than the soil standards. Exceptions include: a single result for selenium; a single result for PCBs; and most results for arsenic. Given the degree of mixing of the sediments within the CDF, the resulting concentration of selenium and PCB within the CDF will be considerably less than the respective soil standards. The situation for arsenic deserves additional discussion. The soil standard, 3 ppm, is actually less than the natural background concentration for surface soils in Delaware as listed in the Delaware remediation standards (10 ppm). In such situations, the background value serves as the applicable soil standard. When the sediments are mixed within the CDF, the average and median values will be less than the natural background concentration. It is concluded that placement of the sediments into a properly operated CDF will not pose a significant health risk based on the concentrations of metals and PCBs in the sediments and assuming that public access to the CDF is generally restricted or otherwise limited. Any future use of this material for residential or commercial fill should be reevaluated for potential exposure.

8. **Assessment of PAHs and Other Contaminants:** In addition to PCBs and metals, there are other classes of toxic contaminants likely to be present in the sediments of the Delaware Estuary, including Reach C, that were not tested as part of the 2008 DEBI. One class of compounds in particular, polyaromatic hydrocarbons (PAHs) has drawn the attention of many people and organizations familiar with the Delaware Estuary. Interest in PAHs is understandable given their presence in crude oil and refined petroleum products as well as their direct introduction into the Delaware River during major oil spills (e.g., *M/T Athos I* and *M/V Presidente Riviera*). As tragic and disruptive as these spills are, careful analysis of several PAH datasets collected in the Delaware Estuary does not indicate broad scale, long-term impacts from these compounds, especially in the Delaware portion of the Estuary. One of the largest studies ever conducted on contaminants in sediments from the Delaware Estuary was performed by scientists from the National Oceanographic and Atmospheric Administration (Hartwell et al. 2001). Sampling for that study occurred in 1997 (after the 1989 *M/V Presidente Riviera* spill but before the *M/T Athos I* spill). The NOAA study included the analysis of a comprehensive list of PAH compounds (including alkylated PAHs) at 92 stations located throughout the Delaware Estuary. Using equilibrium partitioning and the target lipid model, Greene (2007) predicted that PAH concentrations were not high enough to cause acute or chronic toxicity to benthic organisms for samples collected in the Delaware portion of the Estuary.

   Immediately following the *Athos I* spill in 2004 and for several months thereafter, sampling was performed for PAHs in the water, sediment, and biota to help determine the extent of impact. A noteworthy aspect of the testing was sediment bioassays on samples collected at Tinicum Island, PA (close to the spill); Claymont, DE (close to the PA/DE/NJ border); and Pea Patch Island, DE (close to an important heronry). Toxicity was not observed in the samples collected from the 2 Delaware stations 3 days after the spill, 19 days after the spill, or 82 days after the spill. In contrast, acute toxicity was observed at the Tinicum Island station 19 days after the spill and 82 days after the spill, although the magnitude of toxicity was far less at 82 days than at 19 days, suggesting a fairly rapid recovery. Overall, these results indicate that impacts were most severe close to the spill site and that recovery was occurring within months, not years or decades. The results just discussed are available in the Final Preassessment Data Report for the *M/T Athos I* Oil Spill (NOAA et al. 2006).

9. **Contaminants in Bend Widening Areas, Spur Channels and Private Berthing Areas:** Current, high quality data on contaminants in bend widening areas, spur channels, and private berthing areas are sparse in comparison to the remainder of the Delaware Estuary. Although bend widening areas, spur channels and berthing areas represent a smaller footprint than the main navigation channel, they may contain higher contaminant concentrations for various reasons. To the author's knowledge, there has been no comprehensive review of available data for these subareas using a consistent methodology. To the extent that deepening the Delaware River main navigation channel is likely to prompt additional dredging of spur channels and berthing areas, it would seem logical that such a review would be given consideration. Along this same line, it is unclear whether there is an up-to-date, overarching dredge management plan for the Delaware River that addresses all aspects of dredging in the system, including but not limited to dredged volumes, quality, disposal, CDF capacity and life cycle assessment, beneficial reuse, and monitoring. Dredging is a prominent activity on the Delaware River and it deserves to have a modern, meaningful, and transparent plan. That said, it is unclear who would take the lead in the effort and how the project would be funded.

CONCLUSIONS AND RECOMMENDATIONS

This evaluation demonstrates that deepening the main navigation channel from -40 feet to -45 feet within Reach C of the Delaware River has a very low potential to cause violations of toxics water quality criteria designed to protect aquatic life and human health. This conclusion relies on the most recent (2008) sediment data available for the Delaware River, coupled with a conservative mass balance modeling framework developed specifically to assess the impacts associated with deepening Reach C. The modeling framework considers the release of contaminants mobilized to the water column by the action of the cutterhead of the dredge as well as the net flow of contaminants into and out of the Kilcohook Confined Disposal Facility (CDF). Calculations reveal that deepening will result in a net removal of contamination from the Delaware Estuary and do so without exceeding toxics criteria or otherwise without harm due to toxics.

It is important to note that this assessment is limited in scope. It only considers Reach C; it only considers the main navigation channel; and it only considers the potential impacts associated with toxics. Although this evaluation is limited to Reach C, the conclusions are reasonably extrapolated to Reaches D and E (south or downstream) of Reach C since the contaminant concentrations in the sediments in Reaches D and E are lower than in Reach C. Extrapolation to reaches or areas upstream of Reach C should be done with caution and only after proper justification. For instance, sediments in berthing areas upstream of Reach C may be more heavily contaminated and so separate consideration should be given to those areas when, as, and if those areas are deepened to take full advantage of a deeper main navigation channel. Finally, this evaluation does not attempt to address issues beyond toxics, such as habitat alteration; overall solids and carbon balances; and subtle, long-term shifts in the ecology of the system, to name a few examples. Although this evaluation has its limitation, it is also the first detailed, quantitative, science-based modeling framework for evaluating potential toxic impacts in the Delaware River due specifically to dredging.

Of course, water quality models are most useful when they are validated against actual field data. The Army Corps of Engineers began deepening Reach C of the Delaware River main navigation channel on March 1, 2010. As part of the deepening, they have been performing detailed water quality monitoring of the dredge plume (USACE, 2010a) and of the Kilcohook CDF (USACE, 2010b). Some of this monitoring, particularly of the dredge plume, has never before been attempted in the Delaware River. At the time of this writing, only roughly half of the samples have been collected. Very few results for toxics have been released, certainly not enough to support a comprehensive review and comparison to model predictions. An important follow-up action will be to review and analyze those data once they are available and, if necessary, to develop measures to reduce any identified impacts going forward.

Deepening within Reach C, although involving the removal of a significant quantity of sediment from the Delaware River, is a fraction of the total sediment inventory that is dredged from the system annually, including sediment removed from the main navigation channel during maintenance dredging, plus sediment removed from private berthing areas and access channels. It has become clear during the preparation of this report that dredging practices vary greatly up and down the Delaware River, as do monitoring requirements and the methods used to evaluate the data and potential impacts. There does not appear to be an overarching plan to guide dredging in this system, despite its potential for positive and negative impacts on small and large scales. It appears that the time to develop such a plan is at hand. A logical place to begin would be a review of current dredging practices along the tidal Delaware River, including ports at the mouths of major tributaries (e.g., Christina River and Schuylkill River).

ACKNOWLEDGEMENTS

The author would like to thank the Partnership for the Delaware Estuary for providing metals results and locational information for the 2008 Delaware Estuary Benthic

Inventory sediment samples. Thanks are also extended to the Delaware River Basin Commission (DRBC) for providing the results of the PCB analyses performed on the 2008 DEBI samples. The DRBC is further acknowledged for performing a colleague review of this report and the underlying technical methods. That review resulted in several improvements to this report, including clarification of methods. Finally, the cooperation of the U.S. Army Corps of Engineers, Philadelphia District, in providing information specific to the deepening project in Reach C is acknowledged.

REFERENCES

In addition to the references included in each Appendix, this report also cites the following documents.

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USACE. 2010b. Delaware River Deepening Project Kilcohook CDF Water Quality Monitoring. Monitoring plan developed by the U. S. Army Corps of Engineers, Philadelphia District Office. Circa. March, 2010. Philadelphia, PA.

FIGURES

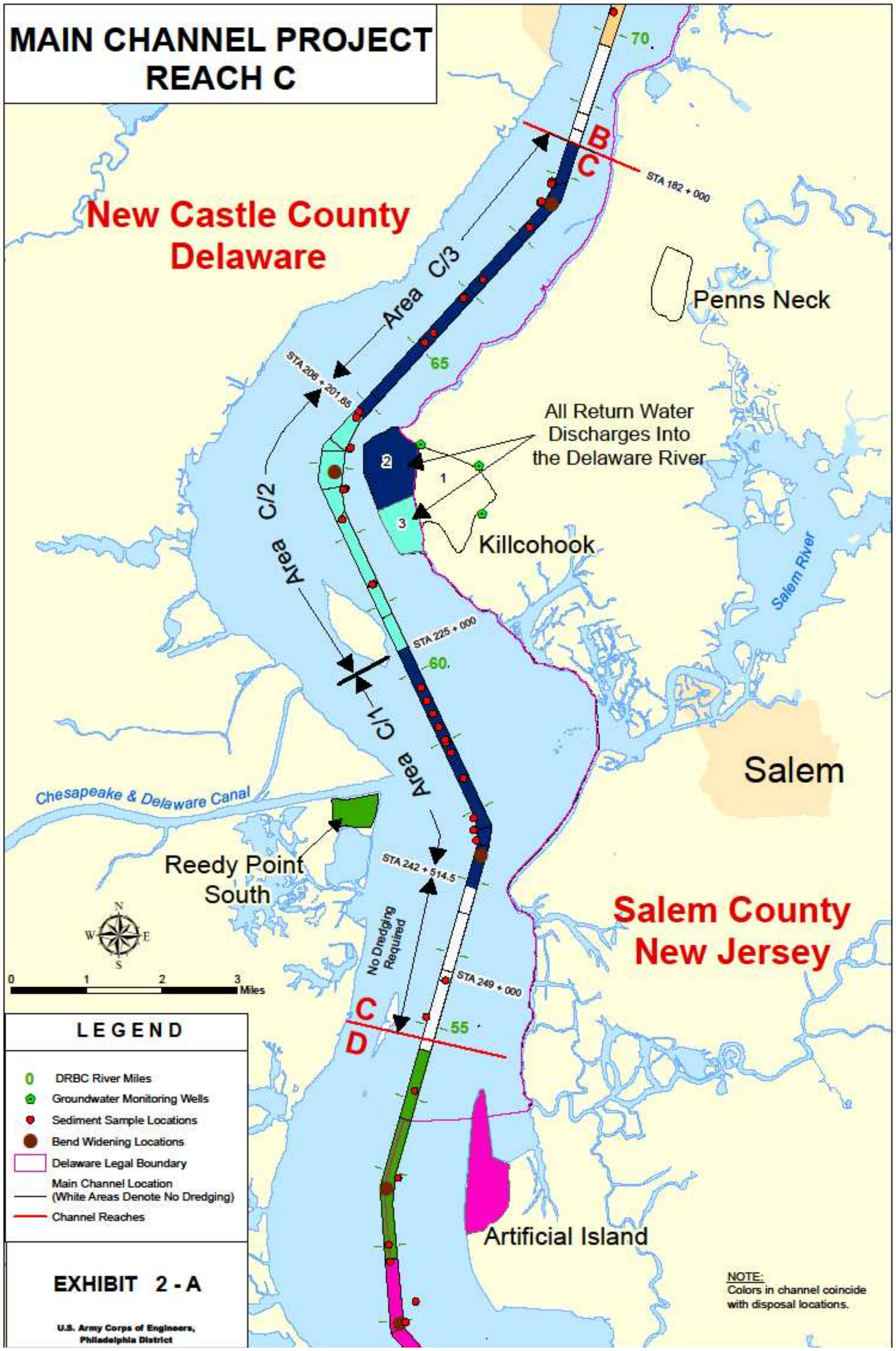

Figure 1. Delaware River Main Navigation Channel Reach C. Figure provided by the U.S. Army Corps of Engineers.

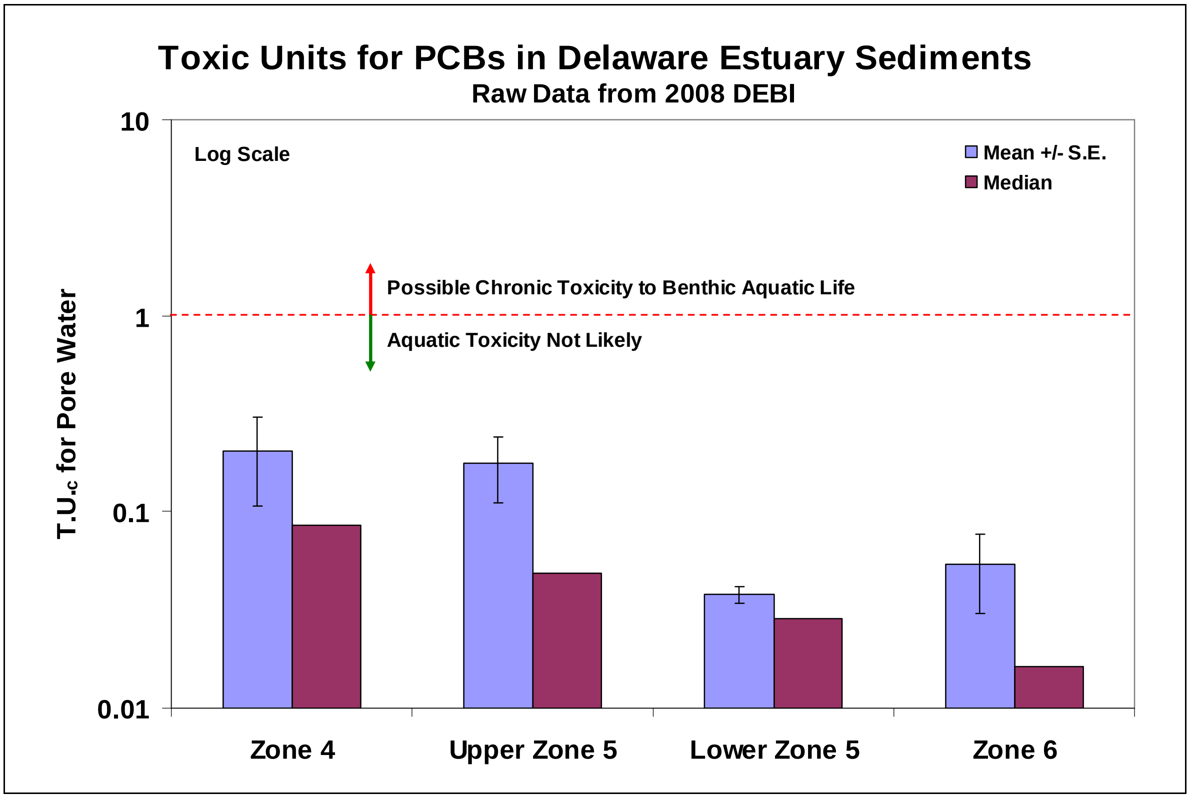

Figure 2. Chronic toxic units for dissolved PCB in sediment pore water in the Delaware Estuary for DRBC water quality management zones. Chronic toxic units in this chart represent the ratio of the dissolved PCB concentration predicted in the sediment pore water divided by the Delaware chronic criterion for the protection of aquatic life. Reach C of the deepening project corresponds approximately to DRBC Lower Zone 5. See Appendix A and accompanying CD for further details.

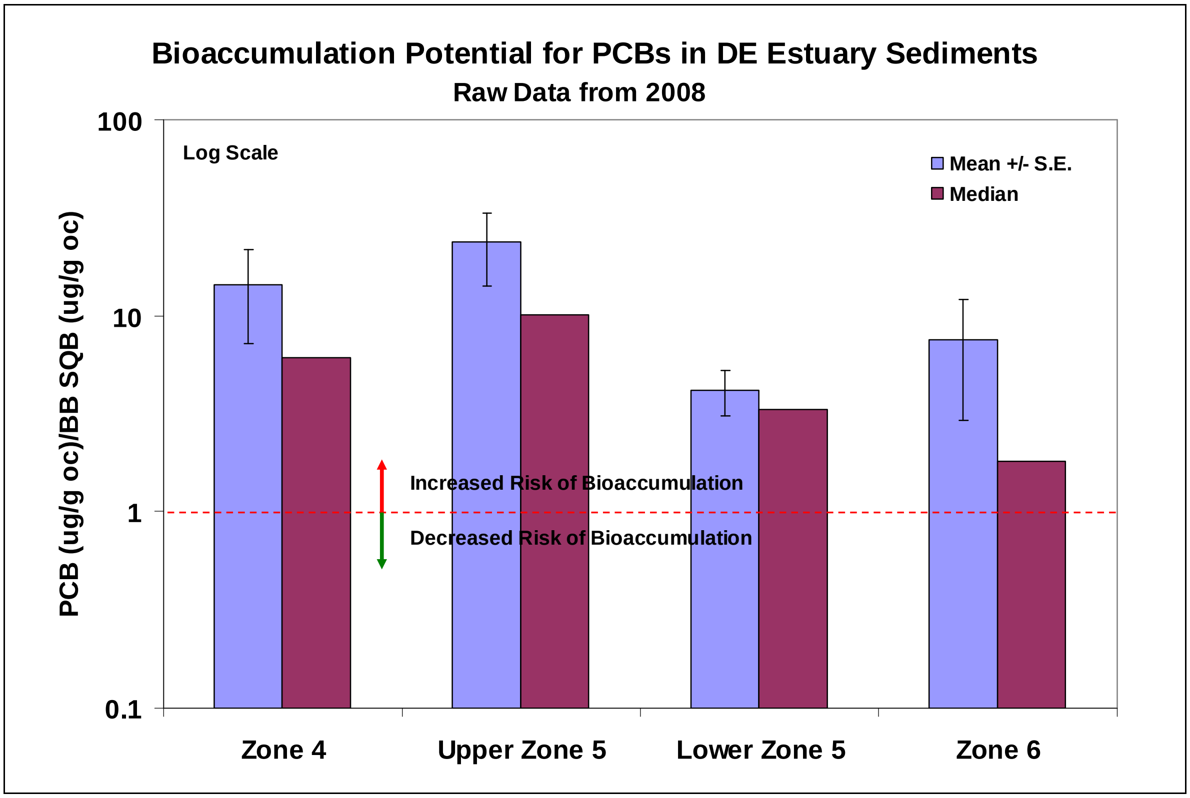

Figure 3. Bioaccumulation potential for PCBs in Delaware Estuary sediments for DRBC water quality management zones. Values represent the ratio of the organic carbon normalized PCB concentration in the sediment to a bioaccumulation-based sediment quality benchmark normalized to organic carbon. Reach C of the deepening project corresponds approximately to DRBC Lower Zone 5. See Appendix A and accompanying CD for further details.

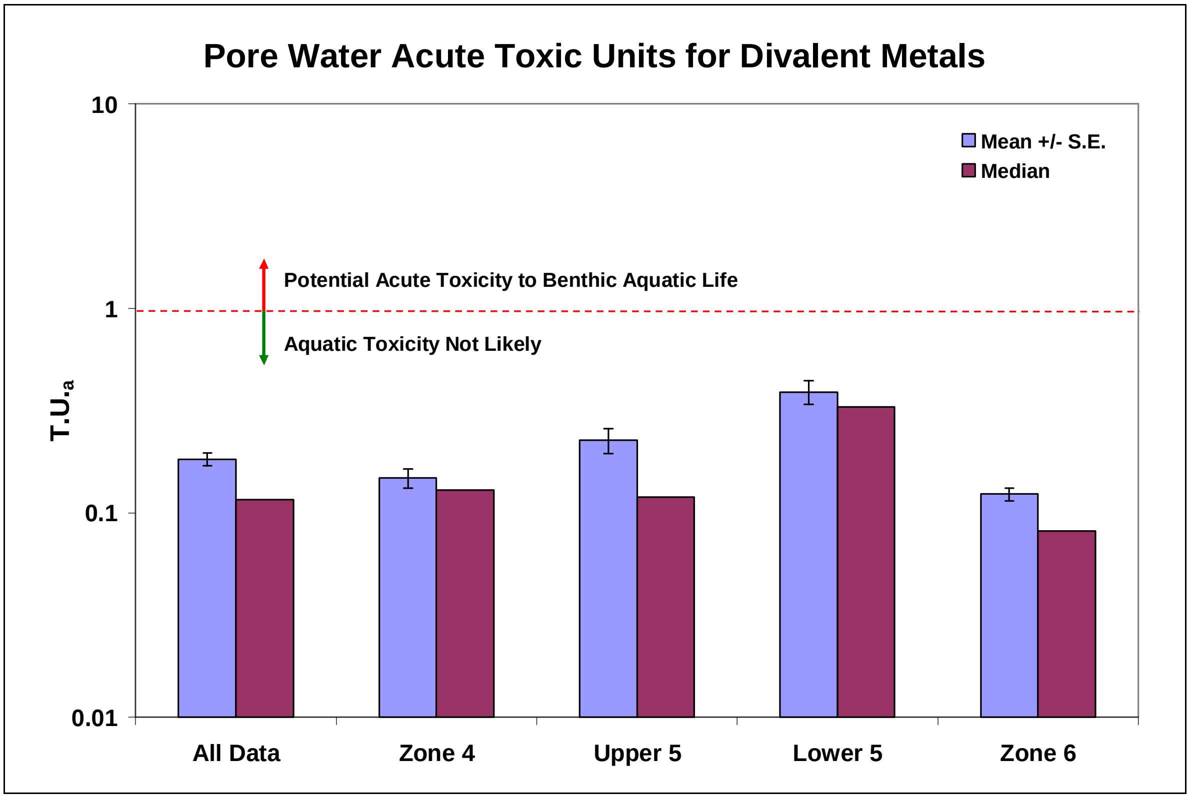

Figure 4. Acute toxic units for dissolved divalent metals in sediment pore water in the Delaware Estuary for DRBC water quality management zones. Acute toxic units in this chart represent the ratio of the dissolved divalent metal concentration predicted in the sediment pore water divided by the Delaware acute criterion for the protection of aquatic life. The ratio for individual metals is added. Reach C of the deepening project corresponds approximately to DRBC Lower Zone 5. See Appendix B and accompanying CD for further details.

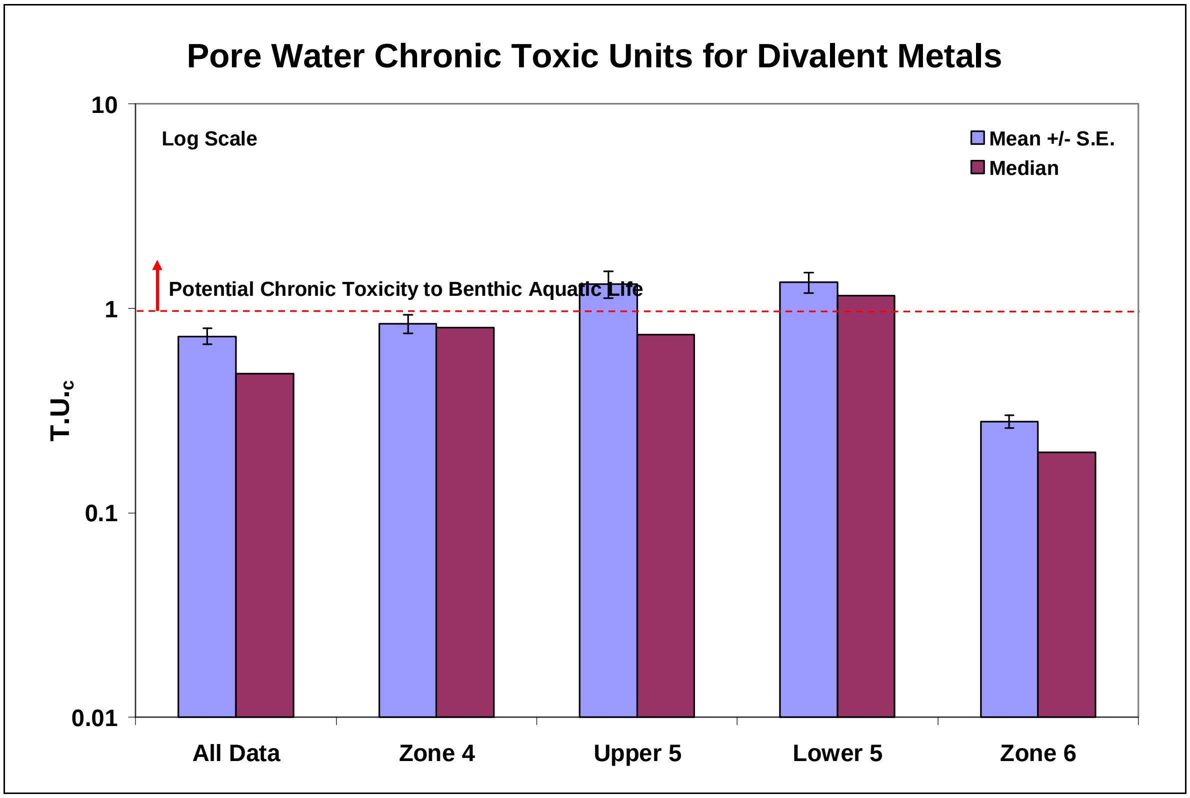

Figure 5. Chronic toxic units for dissolved divalent metals in sediment pore water in the Delaware Estuary for DRBC water quality management zones. Chronic toxic units in this chart represent the ratio of the dissolved divalent metal concentration predicted in the sediment pore water divided by the Delaware chronic criterion for the protection of aquatic life. The ratio for individual metals is added. Reach C of the deepening project corresponds approximately to DRBC Lower Zone 5. See Appendix B and accompanying CD for further details.

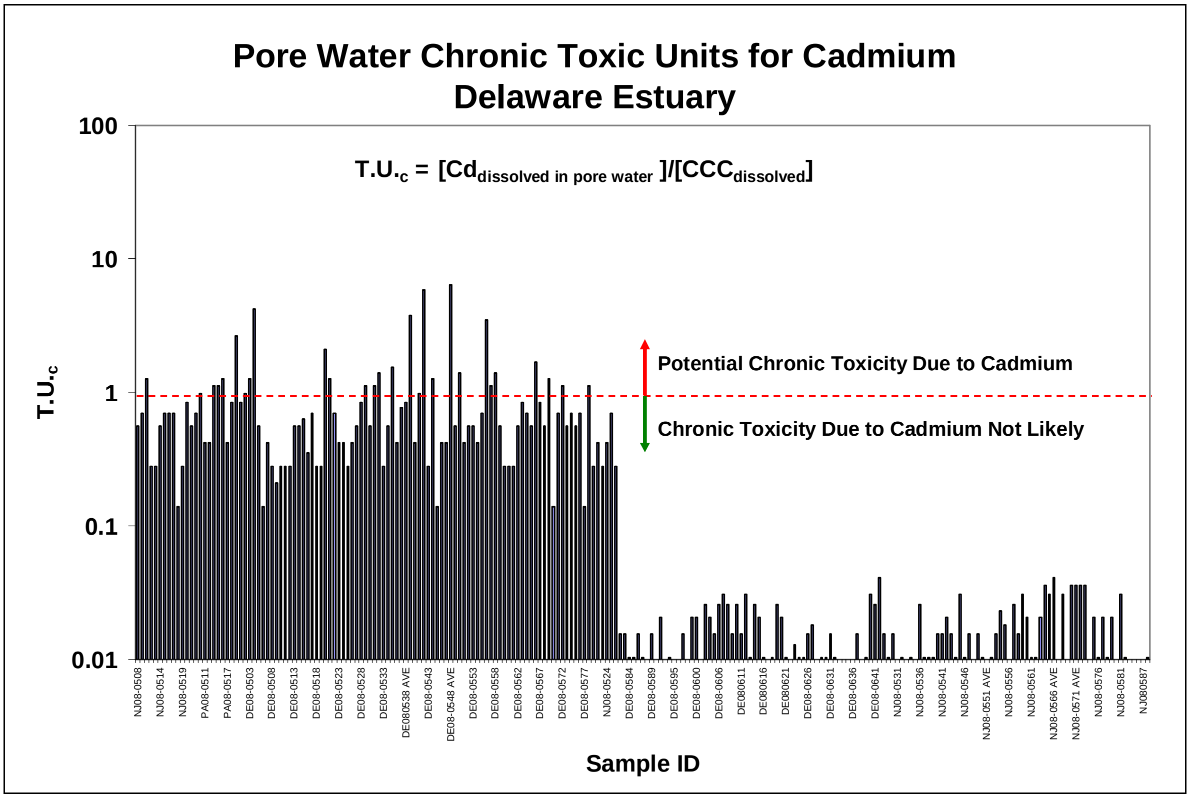

Figure 6. Chronic toxic units for dissolved cadmium in sediment pore water in the Delaware Estuary for DRBC water quality management zones. Chronic toxic units in this chart represent the ratio of the dissolved cadmium concentration predicted in the sediment pore water divided by the Delaware chronic aquatic life criterion for cadmium. Reach C of the deepening project corresponds approximately to DRBC Lower Zone 5. See Appendix B and accompanying CD for further details.

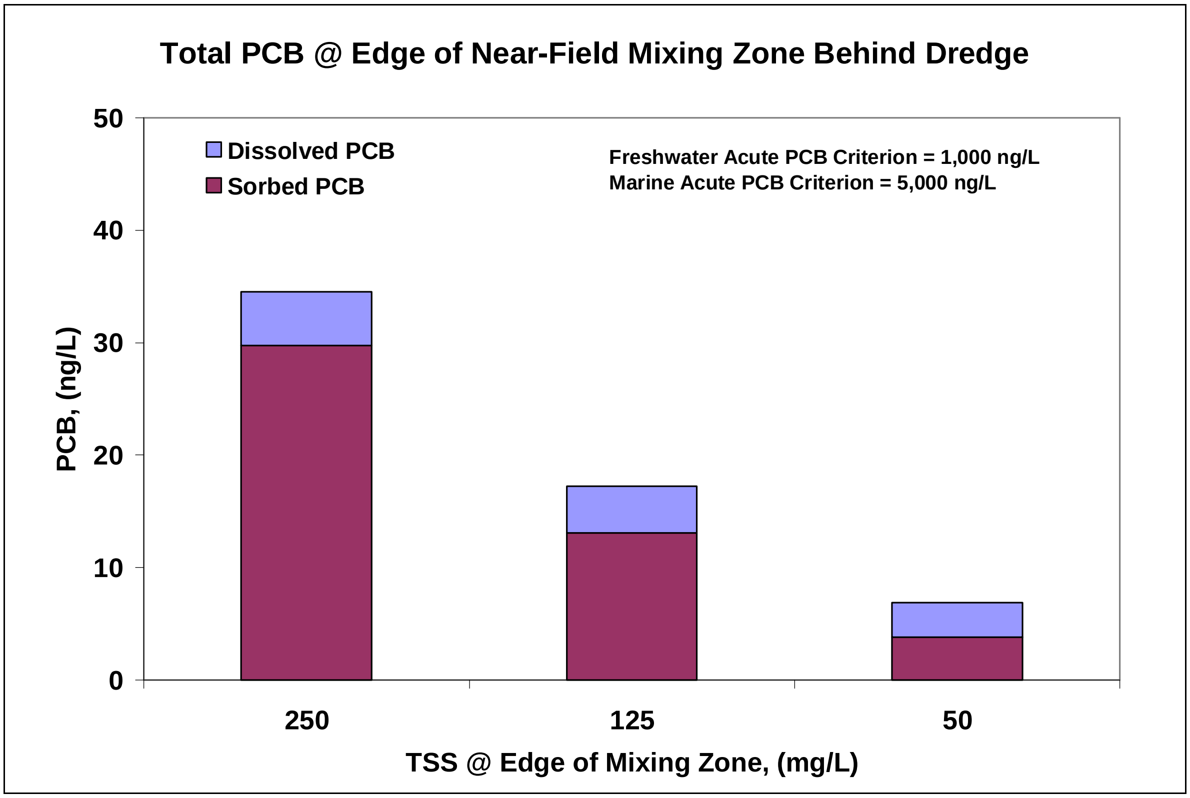

Figure 7. Predicted total PCB concentration 200 feet behind a hydraulic cutterhead dredge operating in Reach C of the Delaware River main navigation channel. The chart shows sorbed and dissolved PCB concentration predicted under 3 suspended solids concentrations. See Appendix D and accompanying CD for further details.

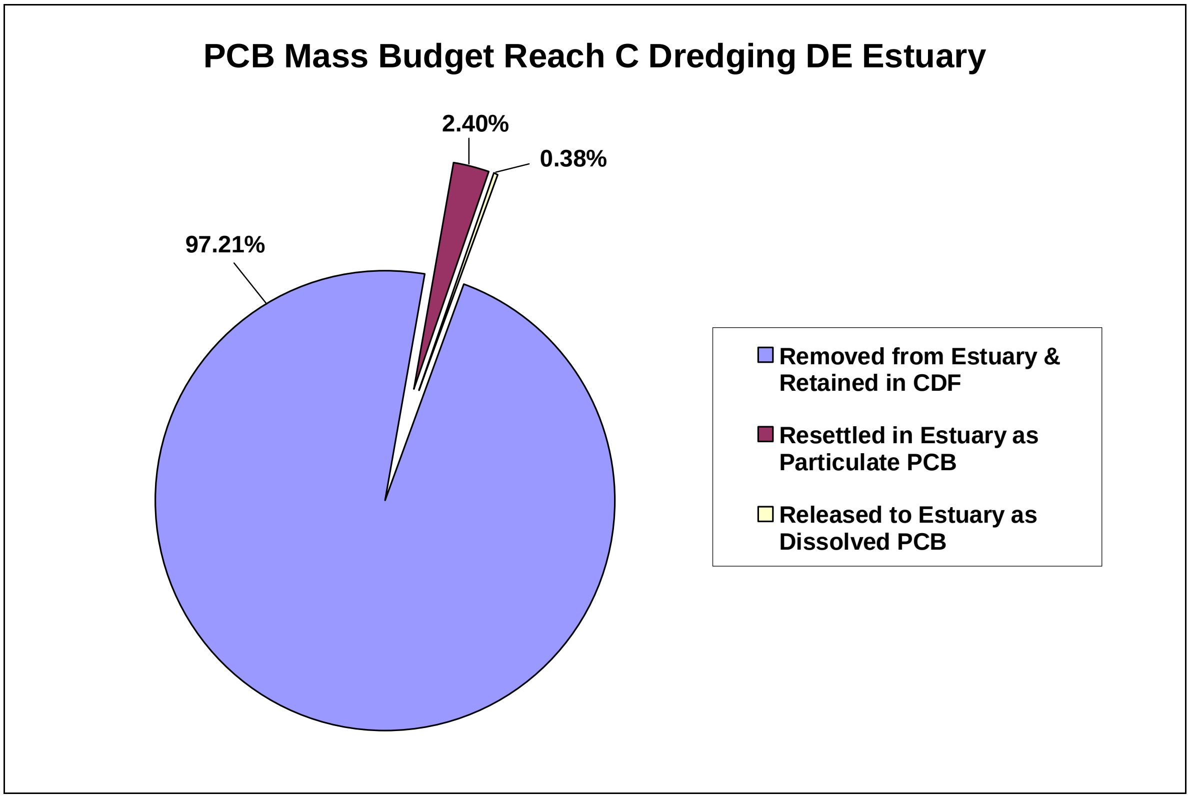

Figure 8. PCB mass budget associated with deepening Reach C of the Delaware River main navigation channel from -40 feet to -45 feet. See Appendix G and accompanying CD for further details.