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# Field Study on Environmental Dredging Residuals: Ashtabula River

## Volume I. Final Report



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National Risk Management Research Laboratory

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# FIELD STUDY ON ENVIRONMENTAL DREDGING RESIDUALS: ASHTABULA RIVER

# VOLUME I. FINAL REPORT

**by**

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## NOTICE

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## FOREWORD

The U.S. Environmental Protection Agency (U.S. EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, U.S. EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments, and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by U.S. EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally C. Gutierrez, Director
National Risk Management Research Laboratory

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**CONTENTS**

NOTICE ..... iii
FOREWORD ..... iv
FIGURES ..... vii
TABLES ..... viii
ACRONYMS AND ABBREVIATIONS ..... ix
ACKNOWLEDGEMENTS ..... xi
EXECUTIVE SUMMARY ..... xii

1.0 PROJECT DESCRIPTION AND OBJECTIVES ..... 1
1.1 Purpose ..... 1
1.2 Dredge Residuals ..... 2
1.3 Site Description ..... 3
1.4 Dredge Operations ..... 5
1.5 Research Goals and Objectives ..... 7

2.0 EXPERIMENTAL APPROACH ..... 10
2.1 General Approach ..... 10
2.2 Study Design ..... 10
2.3 Data Collection Strategy ..... 12
2.3.1 Sediment Core Collection ..... 12
2.3.2 Sonar Monitoring ..... 13

3.0 CONTAMINATED SEDIMENT CHARACTERIZATION AND DREDGE RESIDUALS ASSESSMENT USING A WEIGHT OF EVIDENCE APPROACH ..... 16
3.1 Vertical Alignment and Physical Examination of the Pre- and Post-Dredge Sediment Cores ..... 16
3.1.1 Vertical Alignment of the Pre- and Post Dredge Sediment Cores ..... 16
3.1.2 Physical Examination of the Pre- and Post-Dredge Sediment Cores ..... 17
3.2 Physical Parameter Analysis of Sediment Core Segments ..... 18
3.3 Sediment PCB Chemistry and Data Analysis of Core Segments ..... 22
3.3.1 Characterization of the Pre-Dredge Sediment PCB Inventory ..... 22
3.3.2 Characterization of the Post-Dredge Sediment PCB Inventory ..... 29
3.3.3 Post-Dredge PCB Characteristics and Implications for Dredged Residuals ..... 43
3.4 Two (2)- and Three (3)-Dimensional PCB Modeling of Pre- and Post Dredge Areas ..... 43
3.5 Bathymetric Surveys Prior to, During, and Following Dredging ..... 48
3.6 Survey and Dredge Position Data to Calculate Residuals ..... 50
3.6.1 Determination of the Maximum Dredge Cut Depth ..... 55
3.6.2 Determination of the Post-Dredge Sediment Surface ..... 58
3.6.3 Estimation of the Post-Dredge Residuals ..... 58

4.0 DISCUSSION AND CONCLUSIONS ..... 66

5.0 REFERENCES ..... 69

## FIGURES


Figure 1-1. Conceptual Model of Sediment Residuals During a Typical Dredging Operation ..... 2
Figure 1-2. Overview Map of the Ashtabula River and Project Study Site ..... 4
Figure 1-3. Ashtabula River Dredging Site and ORD Study Area ..... 4
Figure 1-4. Michael B. Dredge at Ashtabula River ..... 5
Figure 1-5. Cutter-Head on the Michael B. Dredge at Ashtabula River ..... 6
Figure 1-6. HDPE Sediment Slurry Conveyance Piping ..... 6
Figure 1-7. Fields Brook Corridor ..... 7
Figure 1-8. Ashtabula River Dredge Site Dredge Management Unit (DMU) Locations ..... 8
Figure 2-1. Transect Locations in the Ashtabula River ..... 11
Figure 2-2. Sediment Core Sample Locations in the Ashtabula River Study Area for Phase 1 and 3 (Pre- and Post-Dredging, respectively) ..... 12
Figure 2-3. Multi-Beam Sonar System Setup for the Ashtabula River Study ..... 14
Figure 2-4. Side Scan Sonar System Setup for the Ashtabula River Study ..... 14
Figure 3-1. Typical Pre-Dredge Sediment Core ..... 17
Figure 3-2. Comparison of Pre- and Post-Dredge Particle Size Distributions in Sediment at T172 ..... 19
Figure 3-3. Comparison of Pre- and Post-Dredge TOC Concentrations in Sediment at T172 ..... 20
Figure 3-4. Comparison of Pre- and Post-Dredge Dry Bulk Densities in Sediment at T172 ..... 21
Figure 3-5. Pre-Dredge Sediment t-PCB Concentration Profiles in the Study Area (> 0 ppb) ..... 24
Figure 3-6. Pre-Dredge Sediment t-PCB Concentration Profiles in the Study Area (> 100 ppb) ..... 25
Figure 3-7. Pre-Dredge Sediment t-PCB Concentration Profiles in the Study Area(> 1,000 ppb) ..... 26
Figure 3-8. Pre-Dredge Sediment Concentration Profiles in the Study Area (> 10,000 ppb) ..... 27
Figure 3-9. Pre-Dredge Sediment t-PCB Concentration Profiles in the Study Area (> 100,000 ppb) ..... 28
Figure 3-10. Composition Analysis Showing the Similarity in the PCB Composition of Surface Sediment Sample T174A (A) and a 3:1 Mixture of Aroclor 1248:1260 (B) ..... 30
Figure 3-11. Composition Analysis Showing the Similarity in the PCB Composition of Sediment Sample T174A from a Depth of 6.4–7.4 ft (A) and Aroclor 1248 (B) ..... 31
Figure 3-12. Composition Analysis Showing the PCB Composition of Sediment Sample T174A from a Depth of 11.4–12.4 ft (A; Homolog Composition) and T178C from a Depth of 16-16.5 ft (B; Congener Composition) ..... 32
Figure 3-13. Average t-PCB Concentrations in Pre-Dredge Surface, High-Level, and Lower Sediments and Post-Dredge Surface Sediments ..... 33
Figure 3-14. The Total PCB Concentration in Pre-Dredge Lower Sediments and Post-Dredge Surface Sediments at the Sediment Coring Locations Presented in Table 3-2 ..... 33
Figure 3-15. The Total PCB Concentration in Pre-Dredge Lower Sediments and Post-Dredge Surface Sediments at the Sediment Coring Locations Presented in Table 3-2 ..... 34
Figure 3-16. Total PCB Concentrations in Pre- and Post-Dredge Core Samples from Locations T170B and T172B ..... 35
Figure 3-17. Pre-Dredge and Post-Dredge Comparison of PCB Homolog Composition in Sediment Within the Study Area (T181 through T170) ..... 37
Figure 3-18. PCB Congener Composition in a Representative Mid-Depth Sample (A) and in a Pre-Dredge Lower Depth Sample (B). ..... 38
Figure 3-19. Principal Component Analysis (PCA) Using PCB Homolog Data for Pre- and Post-Dredge Sediments in the Study Area; Full View (upper) and Zoomed View (lower) ..... 41
Figure 3-20. Principal Component Analysis (PCA) Using PCB Congener Data for Pre- and Post-Dredge Sediments in the Study Area; Full View (upper) and Zoomed View (lower) ..... 42
Figure 3-21. Comparison of Pre- and Post-Dredge Cross-Section t-PCBs in Sediment at T175 ..... 44
Figure 3-22. Comparison of Pre- and Post-Dredge Cross-Section t-PCBs in Sediment at T174 ..... 45

Figure 3-23. Comparison of Pre- and Post-Dredge Cross-Section t-PCBs in Sediment at T173 ..... 46
Figure 3-24. Comparison of Pre- and Post-Dredge Cross-Section t-PCBs in Sediment at T172 ..... 47
Figure 3-25. Pre-Dredge Bathymetric Survey Results for the Study Area ..... 48
Figure 3-26. Post-Dredge Bathymetric Survey Results of the Study Area ..... 49
Figure 3-27. Cross-Section View at T175 Showing the Change in Bathymetry During Dredging. ..... 51
Figure 3-28. Cross-Section View at T174 Showing the Change in Bathymetry During Dredging. ..... 52
Figure 3-29. Cross-Section View at T173 Showing the Change in Bathymetry During Dredging. ..... 53
Figure 3-30. Cross-Section View at T172 Showing the Change in Bathymetry During Dredging. ..... 54
Figure 3-31. Conceptual Model River Cross-Section Showing the XYZ Dredge Cutter-Head Position and Approximated Cut Line ..... 56
Figure 3-32. Plan View of Dredge Activity in the Study Area. ..... 57
Figure 3-33. Estimated Dredge Cut Line in Between T176 and 172 in the Study Area ..... 59
Figure 3-34. Cross-Section of T175 Showing Estimated Dredge Cut Line vs. Post-Dredge Bathymetry ..... 62
Figure 3-35. Cross-Section of T174 Showing Estimated Dredge Cut Line vs. Post-Dredge Bathymetry ..... 63
Figure 3-36. Cross-Section of T173 Showing Estimated Dredge Cut Line vs. Post-Dredge Bathymetry ..... 64
Figure 3-37. Cross-Section of T172 Showing Estimated Dredge Cut Line vs. Post-Dredge Bathymetry ..... 65

## TABLES

Table 3-1. Vertical Disagreement of Specific Pre-Dredge Cores ..... 16
Table 3-2. Total PCB Concentration (ppb) of Pre-Dredge Surface Sediment, Typical Pre-Dredge High-Level Sediment, Pre-Dredge Sediment at Post-Dredge Surface Sediment Depth, and Post-Dredge Surface Sediment ..... 23
Table 3-3. Estimates of Sediment and t-PCB Removals and Residuals ..... 60

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| 2-D | 2-Dimensional (view) |
| 3-D | 3-Dimensional (view) |
| AOC | Area of Concern |
| AOCs | Areas of Concern |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| COC | chemical of concern |
| DMS | dynamic motion sensor |
| DMU | dredge management unit |
| GcGPS | Satellite Subscription Globally-Corrected GPS |
| GLLA | Great Lakes Legacy Act |
| GLNPO | Great Lakes National Program Office |
| GPS | global positioning system |
| HDPE | high density polypropylene |
| IGLD | International Great Lakes Datum, 1985 |
| JFB | J.F. Brennan Company, Inc. |
| LOE | line of evidence |
| LOEs | lines of evidence |
| MBS | multi-beam sonar |
| MRU | motion reference unit |
| NA | not applicable |
| NERL | National Exposure Research Laboratory |
| NPDES | National Pollutant Discharge Elimination System |
| NRMRL | National Risk Management Research Laboratory |
| ORD | Office of Research and Development |
| PAH | polycyclic aromatic hydrocarbon |
| PAHs | polycyclic aromatic hydrocarbons |
| PCA | Principal Component Analysis |
| PCB | polychlorinated biphenyl |
| PCBs | polychlorinated biphenyls |
| PE | polypropylene |
| QA | quality assurance |
| QAPP | quality assurance project plan |
| QC | quality control |
| RSD | relative standard deviation |

| | |
|---|---|
| RTK-GPS | Real-Time Kinematic Global Positioning System |
| SDR | Standard Dimension Ratio |
| SPMDs | Semipermeable Membrane Devices |
| SPME | Solid Phase Micro-Extraction |
| SSS | side scan sonar |
| TOC | total organic carbon |
| t-PCBs | total polychlorinated biphenyls |
| TSS | total suspended solids |
| UCF | Upland Containment Facility |
| USACE | U.S. Army Corp of Engineers |
| U.S. EPA | U.S. Environmental Protection Agency |
| VOCs | volatile organic compounds |
| WOE | weight of evidence |
| XYZ | horizontal and vertical position data |

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## EXECUTIVE SUMMARY

An interdisciplinary and collaborative research project to develop evaluation tools and methods for environmental dredging was initiated in 2006 between the National Risk Management Research Laboratory (NRMRL) and the National Exposure Research Laboratory (NERL) of the U.S Environmental Protection Agency's (U.S. EPA's) Office of Research and Development (ORD), hereafter collectively referred to as ORD, and U.S. EPA's Great Lakes National Program Office (GLNPO). GLNPO, through the Great Lakes Legacy Act (GLLA), is charged with undertaking and overseeing the remediation of contaminated sediments in the Great Lakes Areas of Concern (AOCs). ORD, through its research mission is directed to evaluate the application and efficacy of contaminated sediment remediation technologies, such as environmental dredging. Based on these mutual interests, the two U.S. EPA organizations formed a partnership to comprehensively monitor and assess progress on the Ashtabula River Environmental Dredging Project in Ashtabula, OH. Dredging was selected by GLNPO as the remedy of choice for the Ashtabula River to remove sediment contaminated with polychlorinated biphenyls (PCBs), the chemical of concern (COC) for this site.

Under this partnership, a series of environmental measurements were conducted on the Ashtabula River beginning in the fall of 2006 to support the development of measures of remedy effectiveness. These measurements were made to evaluate the efficacy of environmental dredging in removing a large quantity of sediment contaminated with PCBs. Samples of sediment and overlying water were collected and analyzed before, during, and after dredging. In addition, measurements were made to characterize the river's ecosystem also before, during, and after dredging to determine the impact that dredging had on the ecosystem. Bathymetry measurements before and after dredging using multi-beam and side-scan sonar were also carried out.

Environmental dredging activities were performed on a 1.2-mile long reach of the Ashtabula River from River Station 194-00 to River Station 139-00 near its confluence with Lake Erie beginning in the fall of 2006 and ending in the fall of 2007. Extensive pre-dredging characterization efforts were undertaken in the summer of 2006. Numerous sediment resuspension, sediment mapping (bathymetry), and ecological measurements were made during the dredging process in 2007. Immediate post-dredging characterization of sediment residuals was conducted in the fall and early winter of 2007. Additional long-term monitoring studies were implemented from 2008 to 2010. These studies evaluated remediation response within indigenous food web species and measures to determine the effect of sediment depositional processes on the original residual sediment layer. Long-term monitoring is needed to understand the rate and extent to which ongoing natural processes impact surface sediment and whether newly deposited sediment is intermixing with the original residual sediment layer. Another ORD evaluation is being planned for 2011 to continue the long-term investigation of sediment deposition following dredging and the documentation of post-dredging ecosystem recovery. This investigation will be coordinated with GLNPO as it plans a final post-dredging characterization of surface sediment in 2011 to measure remedy effectiveness.

This report evaluates and summarizes dredge residuals and dredge removal efficiency in support of GLNPO's objectives for this joint project. This evaluation is restricted to pre-dredging characterization studies conducted in 2006 and post-dredging residuals information generated after completion of dredging operations in 2007. Long-term residuals data produced from follow-on post-dredging field studies in 2009 are still being analyzed and are not included in this report. Investigative results of immediate and long-term effects of dredging operations on ecosystem health and restoration using biological indicator, food web, and surrogate sample data will be presented in a subsequent report.

The primary goals of this phase of the project were to develop: 1) an understanding of sediment residual formation during dredging operations on the Ashtabula River, and 2) methods to assist in generating more realistic predictions of post-dredging residual mass/volume and contaminant concentrations. To achieve these goals, extensive monitoring studies and physical and chemical measurements were carried out prior to, during, and after dredging. Field efforts focused on:

1) estimating the volume and concentration of contaminated sediment residuals remaining after completion of dredging in a selected study area within the dredge zone, and
2) comparing pre- and post-dredging sediment mass and concentration characterization data to assess the PCB concentration relationship of the residual sediment to the contaminated material removed.

A weight of evidence (WOE) approach was developed by ORD to characterize dredging residuals. The WOE approach relied on multiple lines of evidence (LOEs) to measure residuals generated during dredging. Six LOEs consisting of chemical and physical measures were used to evaluate dredge residuals in an attempt to address study objectives. These LOEs included:

1) vertical alignment and physical examination of pre- and post-dredge sediment cores,
2) physical parameter analysis of the sediment,
3) sediment PCB chemistry and data analysis of core segments,
4) two- and three-dimensional PCB modeling of pre- and post-dredge areas,
5) bathymetric surveys prior to, during, and following dredging , and
6) dredge cutter head horizontal and vertical positioning.

The above tools, methods, and interpretations drawn were not applied on a site-wide basis, but rather to ORD's selected study area of a 1,100-ft long stretch of the river from River Station 181-00 to River Station 170-00. These approaches are being evaluated on spatial and temporal scales as necessary for their development, and, therefore, cannot be used to evaluate the success of dredging for the entire site.

The residuals data produced in the project study area indicated consistent sediment and PCB mass removals equal to or in excess of 95%. The data also revealed that the sediment residuals layer was composed of more highly contaminated sediments originating from higher elevations in the vertical sediment profile, rather than the lower-concentrated sediments removed from immediately above the final post-dredge sediment surface.

This final report is presented as Volume I of the Ashtabula River dredge residuals project. Due to the large amount of data generated on this project, an additional data report (Volume II) will be issued by ORD as an extended set of Appendices with additional data tables and figures. A subset of these data is included in this report to illustrate the approaches, methods, and interpretations applied on this project.

# 1.0 PROJECT DESCRIPTION AND OBJECTIVES

## 1.1 Purpose

A joint dredging evaluation project was initiated in 2006 between the National Risk Management Research Laboratory (NRMRL) and the National Exposure Research Laboratory (NERL) of the U.S Environmental Protection Agency's (U.S. EPA's) Office of Research and Development (ORD), hereafter collectively referred to as ORD, and U.S. EPA's Great Lakes National Program Office (GLNPO). GLNPO via its Great Lakes Legacy Act (GLLA) mandate is charged with undertaking and overseeing the cleanup/remediation of contaminated sediments in the Great Lakes Areas of Concern (AOCs). ORD, through its research mission, is directed to evaluate the application and efficacy of environmental dredging. Based on these mutual interests, the two U.S. EPA organizations entered into an agreement to form a partnership to carry out a comprehensive effort to monitor progress on the Ashtabula River Environmental Dredging Project in Ashtabula, OH. Dredging was selected by GLNPO as the remedy of choice for the Ashtabula River to remove sediments contaminated with polychlorinated biphenyls (PCBs) and other chemicals. PCBs constitute the chemicals of concern (COCs) for this project.

Environmental dredging activities were carried out on a 1-mile long reach of the Ashtabula River beginning in the fall of 2006 and ending in the fall of 2007. Dredging was not performed during the 2006/2007 winter. Extensive pre-dredging characterization efforts were undertaken in the summer of 2006 (Phase 1). Numerous sediment resuspension, sediment mapping (bathymetry), and ecological measurements were made during the dredging process in 2007 (Phase 2). Post-dredging characterization of sediment residuals was conducted in the fall and early winter of 2007 (Phase 3). Particular emphasis was given in Phase 3 to measuring the quantity and composition of sediment residuals and the fraction of contaminated sediment removed by the dredging operation, i.e., estimating dredge removal efficiency. Follow-up out-year studies were implemented in 2008 and 2010 to evaluate the degree of recovery achieved in indigenous food web species 1 year and 3 years, respectively, after dredging and in 2009 to determine the rate and extent that new clean sediment was being deposited on top of the original residual sediment layer 2 years after dredging and whether that newly deposited sediment was intermixing with the original residual sediment layer. To assist in defining river bottom (i.e., sediment surface) topography before and after dredging, multi-beam and side-scan bathymetry measurements were also conducted. Additional out-year evaluations are being planned. GLNPO will implement a final post-dredging characterization of sediment residuals at an unspecified future date to determine whether the site can be closed in compliance with GLLA regulations.

In addition to the extensive physical and chemical characterization of sediment and water column quality performed throughout the project, a comprehensive suite of companion biological studies was also carried out. These studies were conducted for the purpose of evaluating ecosystem recovery brought about by the removal of contaminated sediments in the affected portion of the Ashtabula River over the course of the dredging operation and for an extended period following removal. Chemical and toxicity measurements were made on tissue of indigenous fish, clams, worms, and macrobenthos organisms. Measurements of PCB uptake by surrogate samplers known as semipermeable membrane devices (SPMDs) and solid phase micro-extraction (SPME) systems in contact with surface sediment and the water column were also performed.

This report constitutes a summary of the results on sediment removal efficiency and the quantity and composition of the dredge residuals. Results of the biological (i.e., ecological restoration) segment of this evaluation and the follow-on sediment residuals studies will be addressed in a subsequent report.

## 1.2 Dredge Residuals

The remediation of contaminated sediments often involves the dredging of bed-sediment. Dredging, whether used alone or in conjunction with other remediation technologies such as *in-situ* capping or natural recovery, can result in the generation and release of COCs in the form of aqueous or particle-associated contamination. The release of contaminants in particle-bound form is one of the possible mechanisms for recontamination or deposition following dredge removal actions. These residual sediments (hereafter referred to as 'residuals') can spread from both within dredged areas (near field) and downstream or off site (far field). A number of factors and suspected mechanisms can influence residual levels including: dredging equipment; operator technique; debris; dredging to bedrock; over-dredging; cut lines, slopes, and depths; sediment characteristics; contaminant characteristics and distribution; and the accuracy and resolution of contaminant characterization (USACE, 2008a). Figure 1-1 is a conceptual model illustrating mechanisms by which residuals can occur at a dredge site.

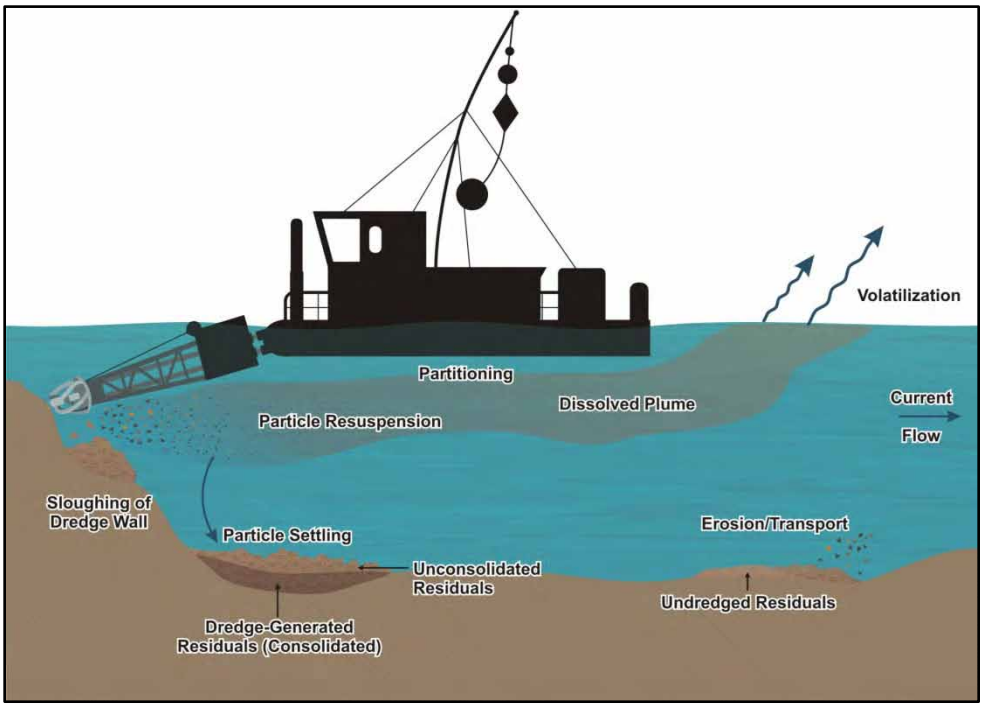



**Figure 1-1. Conceptual Model of Sediment Residuals During a Typical Dredging Operation**

Residuals can be categorized as either undredged or dredge generated. Undredged residuals are the result of missed areas and incomplete characterization. Dredge-generated residuals are released via resuspension, transport, and downstream deposition; dredge mixing and immediate deposition; and sloughing or slumping (USACE, 2008b).

The primary generated residual release sources applicable to all dredging operations are resuspension and dispersion of bedded sediment particles and pore water by dredging operations, including dredge heads, boat props, and anchors. Additionally, residuals are generated by erosion and resuspension of sediments and other high solids concentration layers on the bed surface, including fluff layers and fluid mud.

## 1.3 Site Description

The Ashtabula River lies in extreme northeast Ohio, flowing into Lake Erie's central basin at the City of Ashtabula (Figure 1-2). Its drainage basin covers an area of 137 sq mi, with 8.9 sq mi in western Pennsylvania. Major tributaries include Fields Brook, Hubbard Run, and Ashtabula Creek. The City of Ashtabula, with an estimated population of approximately 21,000 (Year 2000 census), is the only significant urban center in the watershed, with the rest of the drainage basin being predominantly rural and agricultural. Concentrated industrial development exists around Fields Brook (east of the Ashtabula River) and east of the Ashtabula River mouth. Sediments in portions of the Ashtabula River are contaminated with a variety of chemicals, including PCBs.

The PCBs were thought to have originated primarily from Fields Brook, a stream that drains into the Ashtabula River in the area of the upper Turning Basin. Fields Brook and its five tributary streams that drain the 5.6-sq mi watershed have been identified as the primary source of contamination to the Ashtabula River. The eastern portion of the watershed drains Ashtabula Township, and the western portion drains the eastern section of the City of Ashtabula. The 3.5-mile main channel of Fields Brook begins south of U.S. Highway 20, about 1 mile east of State Highway 11. From this point, the stream flows northwesterly, just under U.S. Highway 20 and Cook Road, to the north of Middle Road. The stream then flows westerly to its confluence with the Ashtabula River near the Railroad Bridge and Turning Basin. The industrial zone of Ashtabula is concentrated around the upstream reach of Fields Brook from Cook Road downstream to State Highway 11.

Up to 20 separate industrial manufacturing activities, ranging from metal fabrication to chemical production, have occurred in the area since the early 1940s. The decades of manufacturing activity and waste management practices at industrial facilities resulted in the discharge or release of a variety of hazardous substances to Fields Brook and its watershed, including the floodplain and wetlands area.

Sediments at the Fields Brook site were contaminated with PCBs, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), heavy metals, phthalates, and low level radionuclides. VOCs and heavy metals including mercury, lead, zinc, and cadmium have been detected in surface water from Fields Brook and the Detrex tributary. Contaminants detected in fish include VOCs and PCBs. The site posed a potential health risk to individuals who ingested or came into direct contact with contaminated water from Fields Brook and with contaminated fish or sediments.

Fields Brook has been eliminated as a source of contamination (or recontamination) of the Ashtabula River. A Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cleanup of Fields Brook was completed in 2003. Subsequently, a post-cleanup monitoring program was put in place to protect against recontamination of Fields Brook as well as the Ashtabula River.

Approximately 600,000 cu yd of contaminated sediments were initially targeted for removal between the Upper Turning Basin at the mouth of Fields Brook and the 5th Street Bridge (Figure 1-3). The COCs in this stretch of the river included PCBs; PAHs; hexachlorobenzene; hexachlorobutadiene; metals; and the radionuclides uranium, radium, and thorium. The radionuclides were above background levels but below regulatory criteria. In Phase 1 of this dredge residuals research project, GLNPO, under its GLLA mandate, conducted a baseline characterization of the river that included all of these COCs, while ORD focused only on the PCBs in selected areas of the river (as indicated by the yellow shading in Figure 1-3). In Phases 2 and 3, ORD continued to focus on only the PCB inventory in the study area and selected areas of the river where biological collections and surrogate deployments were made.

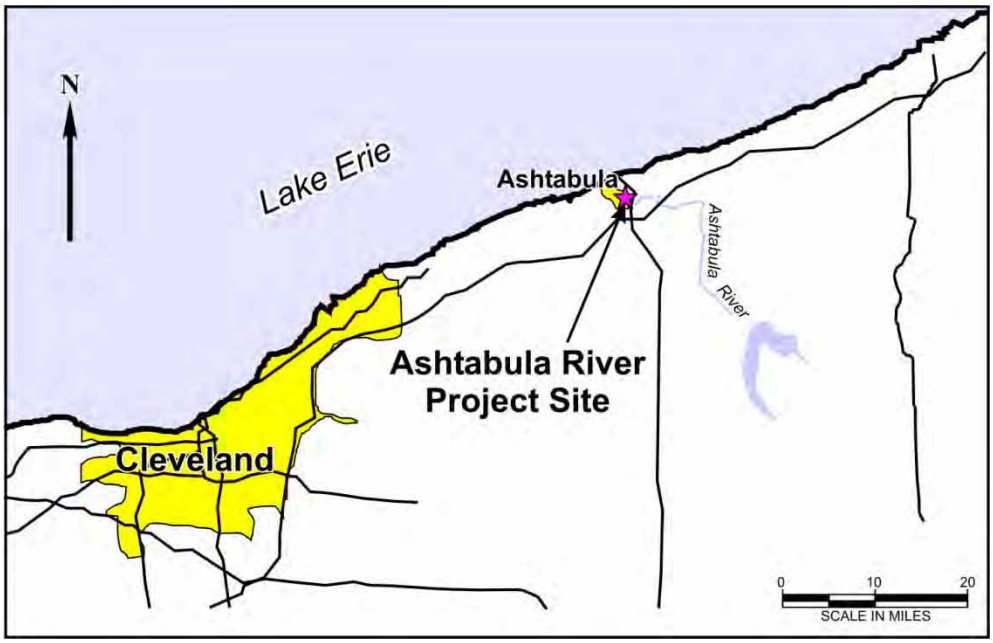



**Figure 1-2. Overview Map of the Ashtabula River and Project Study Site**




**Figure 1-3. Ashtabula River Dredging Site and ORD Study Area**

## 1.4 Dredge Operations

Dredging in the Ashtabula River was performed by J.F. Brennan Company, Inc. (JFB), a private marine contractor headquartered in La Crosse, WI. Dredging operations were conducted in two stages. Stage I included hydraulic removal of sediment from the upper portion of the GLLA project area down to an area just above the Ashtabula Harbor (River Station 194-00 to 139-00), with U.S. EPA-GLNPO operating as the lead agency. Stage II included environmental and maintenance dredging, hydraulic removal of sediment from just south of the 5th Street Bridge and extended northward into the inner harbor (River Station 139-00 to 120-00), with the U.S. Army Corp of Engineers (USACE) operating as the lead agency.

This report is focused on research carried out in conjunction with the GLLA dredging conducted during Stage I, which began September 9, 2006 and was completed October 14, 2007. Stage I dredging operations resulted in the removal, transport, and dewatering of approximately 491,711 cu yd of contaminated sediment. Of particular interest are the dredging operations that were conducted between River Station 181-00 to 170-00, hereafter referred to as the project study area, where the target dredge cut line elevation was established to achieve a final water column of 20 ft. Based on the low water datum for International Great Lakes Datum (IGLD) 1985, Lake Erie IGLD85 of 569.2 ft, the final cut line target elevation was set at 549.2 ft.

Sediment removal was achieved within the project study area by using a 12-in. hydraulic swinging-ladder cutter-head dredge shown in Figures 1-4 and 1-5. The dredge was outfitted with a real-time kinematic global positioning system (RTK-GPS). The RTK-GPS signals were combined with various sensors onboard the dredge including sensors measuring rotation, ladder inclination, and pitch and roll.



**Figure 1-4. Michael B. Dredge at Ashtabula River**

The GPS system and associated sensors were processed in real time and combined through Hypack, Inc. Dredgepack® software to allow for dredge operator guidance to achieve maximum dredge accuracies.



**Figure 1-5. Cutter-Head on the Michael B. Dredge at Ashtabula River**

The complete dredging system consisted of a hydraulic dredge with associated equipment, a barge-mounted slurry booster pump, and interconnecting piping for transferring the dredged sediment to the land-based transport pipeline system. The barge-mounted slurry booster pump, with a 750-hp capacity, was placed between the dredge and the land-based transport system. The dredge discharge and booster pump interconnecting pipe was standard dimension ratio (SDR) 17 high density polypropylene (HDPE) with PE3408 resin, shown in Figure 1-6.



**Figure 1-6. HDPE Sediment Slurry Conveyance Piping**

The land-based transport system was comprised of three in-line booster pumps and 12-in. double-walled slurry transport pipe extending over 2.5 miles along the Fields Brook Corridor (Figure 1-7) from its mouth to the Upland Containment Facility (UCF). A slurry of water and sediment, consisting of 8 to 15% solids, was treated at a rate of 5,000 gpm at the UCF. The UCF consisted of chemical conditioning of the dredge sediment slurry, geotextile containment, and weep water collection/treatment. Following weep water treatment to remove fine suspended solids and associated organic contaminants, water was returned to the river under the conditions of the National Pollutant Discharge Elimination System (NPDES) permit issued by Ohio EPA.




**Figure 1-7. Fields Brook Corridor**

The Ashtabula River dredge site was organized into 27 discrete areas called dredge management units (DMUs). The DMU layout is shown in Figure 1-8 and was organized as follows:

The "Upper Turning Basin" – The Upper Turning Basin defined the upstream boundary of the dredge site and is where Fields Brook converges with the Ashtabula River. DMUs 1 through 14 comprised the dredge management plan in the Upper Turning Basin.

The "River Run" – The River Run made up an approximate 1,300ft stretch of the Ashtabula River and comprises parts of DMUs 13 and 14 at its southern boundary and continues northward encompassing DMUs 15 through 24, and parts of DMUs 25 and 26. The ORD residuals research study occurred in portions of DMUs 15 through 22.

The "River Bend" – The River Bend was defined by the area just south of the 5th Street Bridge where the Ashtabula River 'bends' to the east. Parts of DMUs 25 and 26 and all of DMUs 27 and 28 were within this area of the river.

## 1.5 Research Goals and Objectives

This research project was designed to provide an understanding of sediment residual formation during dredging operations at the Ashtabula River and to develop methods to obtain more realistic estimates/projections of post-dredging residuals mass/volume and contaminant concentrations based on pre-, during- and post-dredging information and data. More specifically, the research goals were as follows:

1) Develop baseline chemical and biological data prior to dredging to provide a basis of comparison with post-dredging residuals data for determining contaminated sediment removal efficiency.

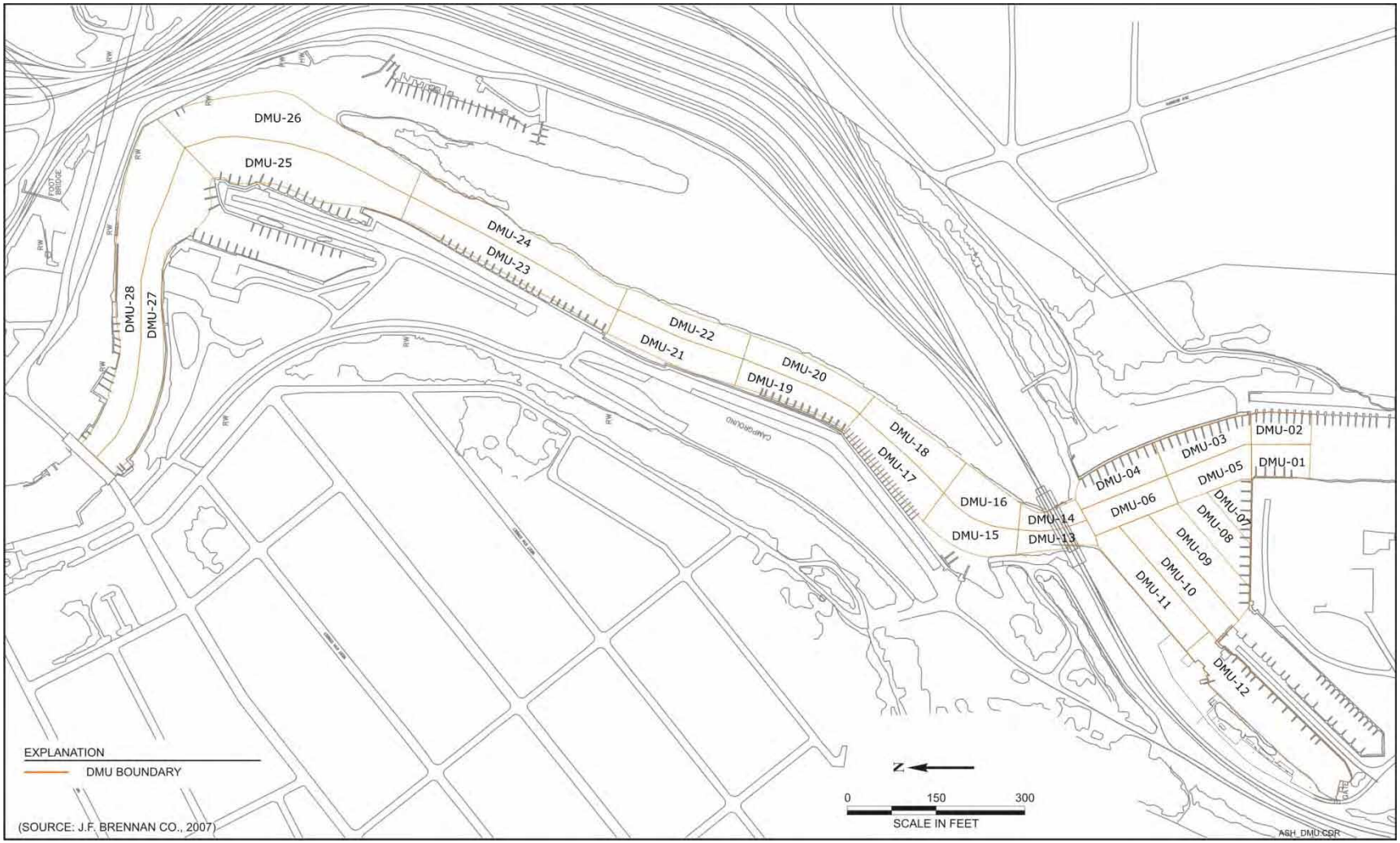



**Figure 1-8. Ashtabula River Dredge Site Dredge Management Unit (DMU) Locations**

2) Measure both pre- and post-dredging sediment topography and chemical concentrations (as a function of sediment depth) to determine whether a relationship exists between pre-dredging concentration profiles and dredge-generated residuals concentrations.

3) If a pre-dredging/post-dredging relationship exists, determine whether it can be used to predict residuals formation at other sites.

4) Determine whether generated residuals created by near-bed mixing and slumping can be differentiated from residuals created by sediment resuspension and deposition.

5) Perform biological studies to evaluate the immediate impacts of contaminant removal on ecosystem measures of health and analyze long-term ecosystem changes in response to dredging.

The research objectives that were developed to accomplish these goals were as follows:

1) Generate physical, chemical, and biological data, as needed, on the contaminated sediments and surrounding ecosystem and water column of the Ashtabula River to evaluate and model resuspension of solids and release of PCBs during dredging operations in the designated study area.

2) Estimate the volume and concentration of contaminated sediment residuals remaining in the study area of the Ashtabula River following dredging. Characterize the solids and determine PCB concentrations in the sediment residual inventory.

3) Compare pre- and post-dredging sediment mass (determined from depth, moisture content, and bulk density measurements) and concentration characterization data (both solids and PCB concentrations) to assess: a) dredging removal efficiency (both solids and PCBs) in the residuals study area, and b) the PCB concentration relationship of the residual sediment to the contaminated material removed.

4) Generate reliable biological data on the Ashtabula River ecosystem following dredging.

5) Compare pre-, during-, and post-dredging biological data to define, if possible, ecosystem response to the impacts of environmental dredging on the Ashtabula River.

The project was implemented in three discrete phases of work, hereafter referred to as Phase 1, Phase 2 and Phase 3, and defined as follows:

- Phase 1 – Measurements conducted prior to dredging
- Phase 2 – Measurements conducted during dredging
- Phase 3 – Measurements conducted post-dredging.

This report evaluates and summarizes dredge residuals and dredge removal efficiency as specified in Goals 1 through 4 and Objectives 2 and 3. This evaluation is restricted to pre-dredging characterization studies conducted in 2006 (Phase 1) and post-dredging residuals information generated after completion of dredging operations in 2007 (Phase 3). Long-term monitoring data on the behavior and fate of dredge residuals from post-dredging field studies conducted in 2009 are still being analyzed and are not included in this report. Also, data specific to sediment resuspension and soluble releases during dredging (Phase 2) as described in Objective 1 are not covered in this report. Investigative results of immediate and long-term effects of dredging operations on ecosystem health and restoration using food web and surrogate sample data (Goal 5 and Objectives 4 and 5) will be presented in a subsequent report.

# 2.0 EXPERIMENTAL APPROACH

## 2.1 General Approach

Field sampling activities carried out before, during, and after dredging consisted of a multi-faceted approach to physical, chemical and biological characterization of the sediment inventory. During dredging, sediment resupsension, sediment mapping, and contaminant release were measured using a number of *in-situ* and *ex-situ* analyses. After dredging was completed, physical, chemical and biological characterization of the sediment residuals was implemented using similar techniques with an emphasis on measuring the quantity of sediment residuals and the fraction removed by the dredging operation. The following sections of this report focus on the physical and chemical measures of the sediment residuals portion of the investigation.

## 2.2 Study Design

The primary sediment investigation occurred in the "River Run" and specifically within the area bounded by transects (T) 181 and 170 (Figure 2-1). This study area was chosen as a location of specific interest for the following reasons:

- River hydrodynamics were anticipated to be easier to characterize compared to the 'Upper Turning Basin' (located approximately between T186 and T192) and the 'River Bend' sections of the river (the remaining two dredge areas selected for the Ashtabula River).
- A preliminary assessment of the historic data indicated that the 'River Run' had among the highest concentrations of total PCBs (t-PCBs) in the river due to its proximity to the historical Fields Brook source located at the beginning of the 'River Run' around T186. These elevated contaminant levels were anticipated to be an asset in characterizing pre- and post-dredging PCBs.
- The 'River Run' appeared to exhibit a t-PCB concentration gradient with the highest concentrations upstream near Fields Brook and the lowest concentrations downstream near the 'River Bend' area. This gradient was in turn thought to be useful when assessing post-dredge residuals in Phase 3.
- A section of the 'River Run' was designed to be dredged to bedrock below the sediment layer (upstream of T178), while lower-numbered transects with similar t-PCB concentrations were not planned to be dredged completely to bedrock, thus allowing the evaluation of dredging performance and residuals in areas of "soft sediment" vs. areas dredged to bedrock.

The sampling grid was constructed using 50- × 100-ft spacing. A semi-variogram analysis was conducted to determine the requisite grid size using existing data acquired by the USACE in 1990 and 1995. The variogram analysis provided a quantitative descriptive statistic that could be used graphically to characterize the spatial continuity of the dataset. Using this approach, it was determined that samples collected at a grid spacing of less than 50 ×100 ft would result in redundant observations and samples collected on a grid spacing larger than 50 × 100 ft would be spatially independent, which could lead to excessive smoothing or loss of information at some point.

As shown in Figure 2-2, the sample design resulted in a combination of two to four sampling locations per transect depending on the width of the river (blue squares). The sampling grid was designed to take into account sediment sloughing that might occur on the perimeter of the dredge area, and, therefore, all sediment cores were restricted to a 50-ft distance from the river bank (or bulkhead that occurs along some eastern lengths of the study area).

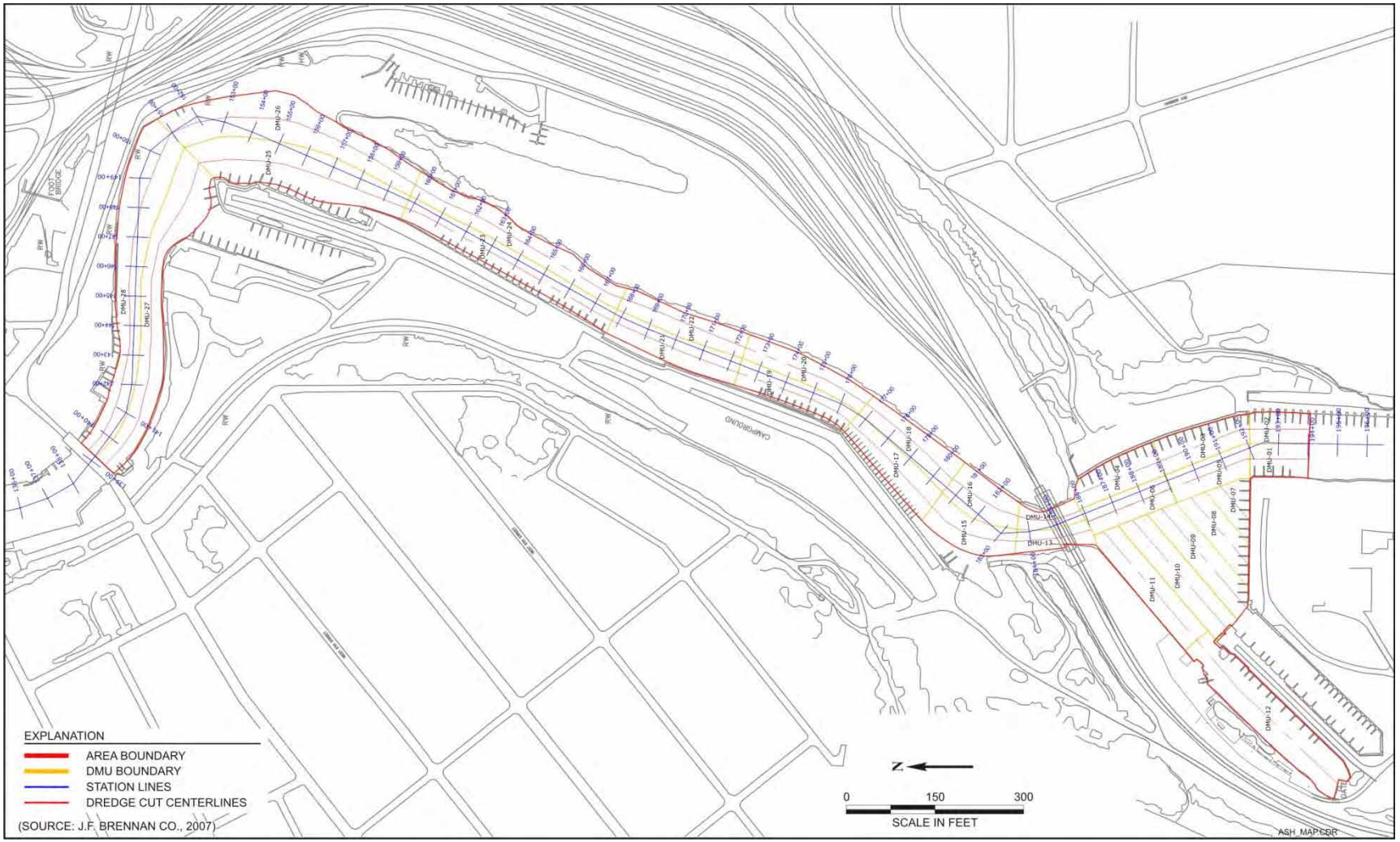



**Figure 2-1. Transect Locations in the Ashtabula River**

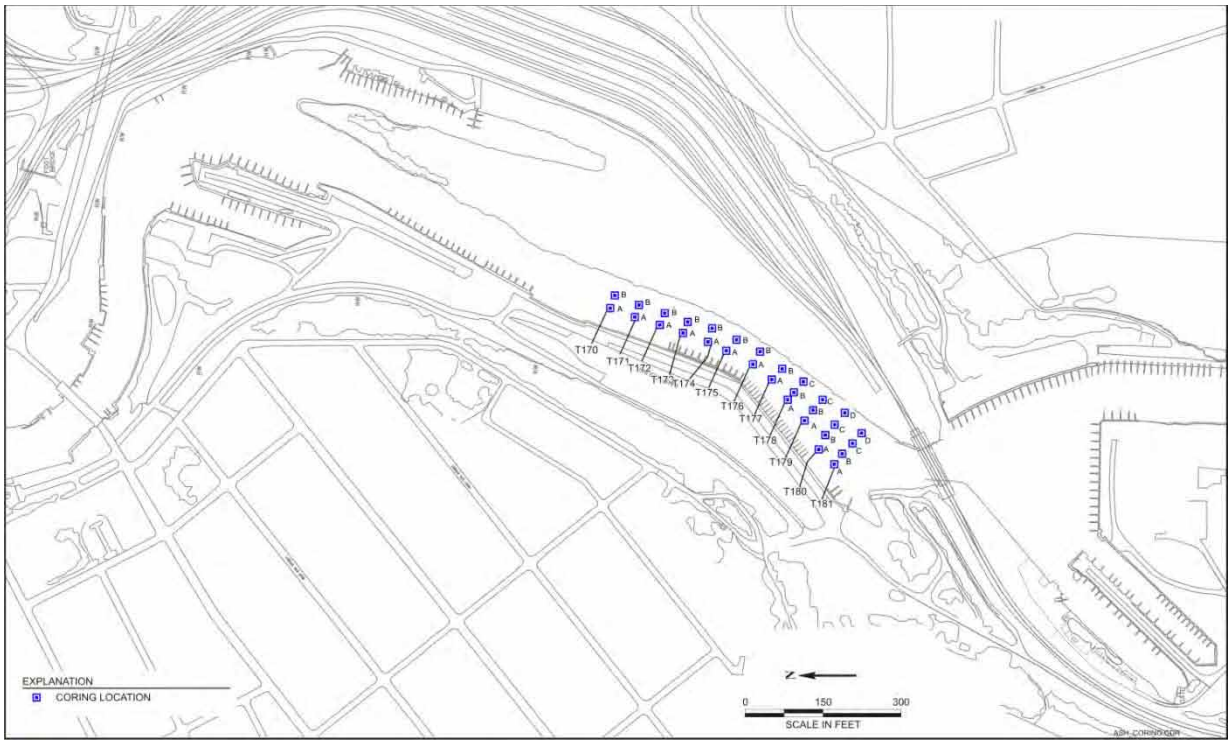



**Figure 2-2. Sediment Core Sample Locations in the Ashtabula River Study Area for Phase 1 and 3 (Pre- and Post-Dredging, respectively)**

## 2.3 Data Collection Strategy

The following sections describe the collection of data to support the evaluation of sediment residuals. Additional details for this sampling strategy can also be found in the EPA-approved Quality Assurance Project Plans (QAPPs) for Phase 1 and Phases 2 and 3 (Battelle, 2006; 2007).

### 2.3.1 Sediment Core Collection.

A total of 30 sediment cores were collected from the study area prior to and following dredging activities. Sediment cores collected prior to dredging, where sediment thickness was at its maximum extent, were collected using a vibracoring method. All pre-dredge sediment cores were sampled until encountering refusal. Consistent with the original plan, it was presumed that T181 to T177 would be dredged to a depth confined by the bedrock layer, while dredging would continue only to 20 ft below the IGLD85 at T177 to T170, leaving a layer of soft sediment above bedrock. As such, collection of sediment cores to refusal ensured that the pre-dredge sediment cores would be as deep as or deeper than the target cut line. In this way, a total of 16 sediment cores were collected in the area that was planned for dredging to bedrock and 14 sediment cores were collected in the soft sediment area. When coupled with chemical analysis, this allowed for a full PCB vertical profile of the sediment above and below the target cut line.

Each sediment core was sectioned into intervals of 1 ft or less and submitted to the laboratory for processing and analysis. Sediment cores lengths were "reconstructed" on the laboratory bench top and photographs of each core were taken and recorded. The length of each sediment segment was determined upon physical observation of the core with greater delineation focused in the range of the target cut line. Each core segment was processed further by mixing in a laboratory blender for approximately 5 minutes

before analysis. Core segments were analyzed for 117 PCB congeners, total organic carbon, particle size distribution, and bulk density.

Since post-dredge sediments were substantially reduced in thickness, cores were collected using a hydraulically-driven piston core device. Samples were collected to a maximum depth of approximately 5 ft in some areas, with the intention to capture the post-dredge surface sediment and native (un-dredged) sediment below. Post-dredge sediment cores were processed in the same manner previously described. The sediment segment thickness decreased in the range of the target cut line and the frequency of segments in this range increased. The post-dredge bathymetric survey (described below), as well as visual observations of note and consideration of the target cut line elevation, played a major role in the decision process as to where the post-dredge sediment cores would be sectioned. Post-dredge core sections were processed and analyzed for the same parameters as the pre-dredge core sections.

### 2.3.2 Sonar Monitoring.

Multi-beam sonar/side scan sonar (MBS/SSS) was deployed by boat to survey the sediment surface of the river prior to and following dredging operations. To the extent possible, the receding sediment surface was mapped while dredging was being conducted.

The surveying equipment was mounted on a 7.3-m pontoon vessel. A wooden beam manufactured from three 5 cm × 30 cm boards was laid (port to starboard) across the deck of the vessel and cantilevered over each side. Construction straps were extended under the pontoons and around the ends of the beam, fastening the beam securely to the deck. The MBS was mounted off the vessel port side through a pole mount affixed to the cantilevered end of the beam. Guyed wires were attached near the bow and stern of the vessel and to the MBS head. The SSS was mounted similarly off the vessel starboard side. Figures 2-3 and 2-4, respectively, show the MBS and SSS mounted on the vessel as deployed for use on these surveys.

The MBS system utilized was an Odom Echoscan II, a 90º, 3º-beam system. As such, it was equipped with 30 transducers at 3º spacing so that the furthest beam away from vertical transmits was at a 45º angle when the instrument was level in the water. A 90º swath was covered between the furthest port and starboard beams. The MBS head also contained a single beam transducer, which allowed for additional depth quality assurance (QA) and quality control (QC), and it contained a motion reference unit (MRU). The MRU was a total suspended solids (TSS) dynamic motion sensor (DMS-25) that measured pitch, roll, and heave.

The SSS was a dual frequency C-MAX CM2 sonar, operating at 325 khz or 780 khz. The user selected the desired horizontal imaging range from 12.5 m and 25.0 m at 780 khz, or 25.0 m, 50.0 m, 100.0 m and 150.0 m at 325 khz.

For both systems, a C-NAV satellite subscription globally-corrected global positioning system (GPS) (GcGPS) was used for accurate horizontal positioning. The antenna was fastened securely on the MBS pole mount (blue antenna in Figure 2-3). A CSI Wireless Vector sensor was used to record vessel heading, an integral component for both MBS and SSS surveying. Two CSI wireless GPS antennas were mounted on top of the wooden console. The remaining topside survey equipment was mounted at the base of the wooden console that was the data acquisition hub for the electronic equipment. Two laptop computers were used to individually control and acquire data from the MBS and SSS.

A Global Water WL16U data logger measured water level fluctuations during the bathymetric surveys to establish highly accurate (1 cm resolution) vertical survey control. The water level logger was installed inside a 3.0 m length of polyvinyl chloride (PVC) pipe and affixed securely to a stationary georeference

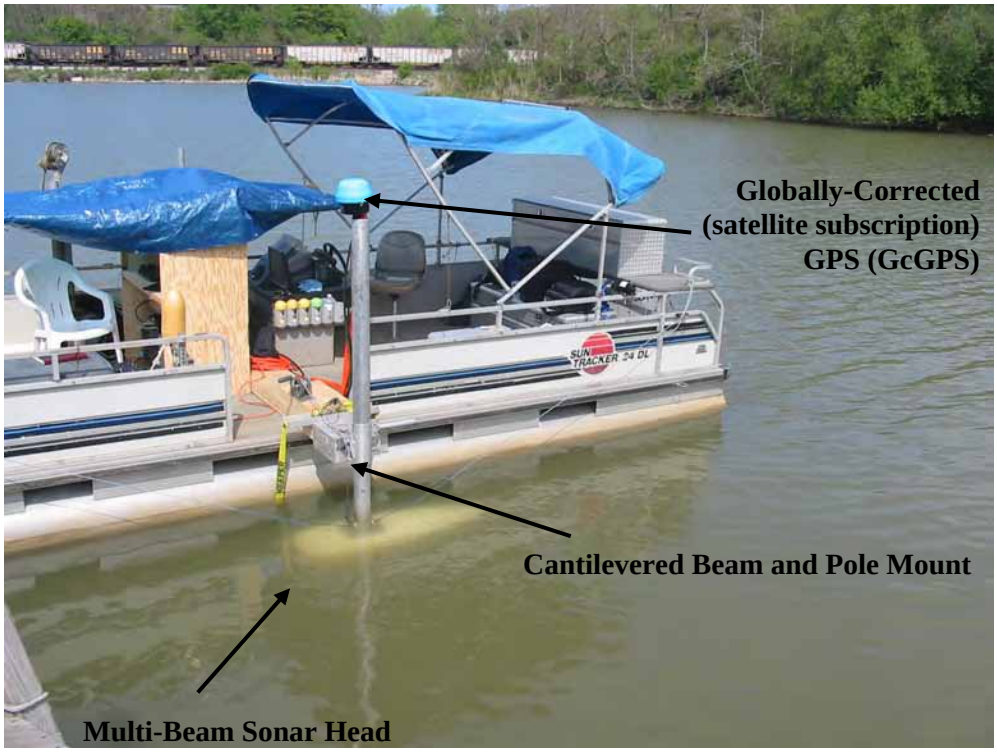



**Figure 2-3. Multi-Beam Sonar System Setup for the Ashtabula River Study**




**Figure 2-4. Side Scan Sonar System Setup for the Ashtabula River Study**

position (a bulkhead along one side of the river). The elevation of the logger sensor was determined from a proximate USACE #611 located within the Ashtabula Yacht Club property. Water level elevation data were referenced to the IGLD85. Daily water level records were downloaded during the project.

A Digibar sound velocity profiler provided a relatively quick method for verifying the MBS soundings and for calibrating the MBS daily. The sound velocity profile was most important in regions prone to density variations in the water column (typically a result of changes in salinity and/or temperature). Significant variations in the sound velocity were not observed in the Ashtabula River. To double check the accuracy of the MBS soundings, a daily bar check verified that proper depths were being recorded. The bar check is a simple method of holding a flat object at several predetermined distances beneath the MBS transducers and comparing the observed depth to the actual depth.

Hypack/Hysweep data acquisition software was used to collect and synchronize MBS measurements, SSS measurements, GPS positioning, and GPS vessel heading measurements. Water level fluctuation and sound velocity measurements were included with the data during post-processing to correct raw soundings.

Survey QC was assured with daily verification of proper system operation. Daily QC included verification of accurate (satellite corrected) GPS position and heading data. QC of the MBS system was verified with sound velocity casts in the water column and bar checks for the sonar depth offsets. The vertical survey control was verified by comparing the water level logger real-time output with manual elevation measurements at the location of the logger.

MBS and SSS surveys were conducted on a daily basis to measure the bathymetric variability and dredge cut slump progression and to create the imagery of the modified riverbed. Surveys typically consisted of a collection of individual data files corresponding to individual surveyed lines.

# 3.0 CONTAMINATED SEDIMENT CHARACTERIZATION AND DREDGE RESIDUALS ASSESSMENT USING A WEIGHT OF EVIDENCE APPROACH

A weight of evidence (WOE) approach employing multiple lines of evidence (LOEs) was used to characterize dredge residuals. These included: (1) vertical alignment and physical examination of the pre- and post-dredge sediment cores; (2) physical parameter analysis of the sediment, including total organic carbon (TOC), bulk density, and particle size distribution; (3) sediment PCB chemistry and data analysis of core segments (congener and homolog) including Principal Component Analysis (PCA) of the PCB in the sediment; (4) two (2)- and three (3)-dimensional PCB modeling of pre- and post-dredge areas; (5) bathymetric and sonar surveys prior to, during, and following dredging; and (6) survey and dredge position data to calculate residuals. These LOEs were used independently and collectively to characterize the quantity and composition (chemical and physical) of the dredge residuals.

## 3.1 Vertical Alignment and Physical Examination of the Pre- and Post-Dredge Sediment Cores

### 3.1.1 Vertical Alignment of the Pre- and Post-Dredge Sediment Cores.

Sediment cores collected during the pre- and post-dredge sampling events from each sampling station were aligned vertically in virtual space using elevation data in an effort to pair pre- and post-core segments and determine their commonality to the dredge cut line. Several parameters were used independently and in combination to verify alignment for pre- and post-dredge core comparisons. These included water depth information, core lengths, refusal depth, and pre- and post-dredge bathymetric survey data.

Of the 30 sample locations, pre- and post-dredge cores from seven specific locations were difficult to pair. Of these seven stations shown in Table 3-1, the pre-dredge core surface elevations as determined by water depth and refusal were in disagreement with the sediment surface elevation determined by pre-dredge bathymetry. These cores resulted in offsets of greater than 1 ft and as much as 5 ft in one case (T179B).

**Table 3-1. Vertical Disagreement of Specific Pre-Dredge Cores**

| Core Location | Discrepancy (ft) |
|---|---|
| T171A | 1.2 |
| T172A | 1.0 |
| T176B | 3.6 |
| T177B | 3.1 |
| T179B | 5.0 |
| T180A | 1.2 |
| T180B | 1.1 |

As such, several additional parameters were taken into consideration to determine the variability in core pairing, including the core position in the study area and the accuracy of the bathymetric data in that region of the study footprint. In the end, the sediment surface elevation data from the in-field water column and core length records were used to place the top of the core positions for these pre-dredge cores and to pair them vertically with the post-dredge cores. The pre-dredge bathymetric data were used to determine the pre-dredge core surface for the remaining 23 locations. The following factors contributed to this decision:

1) These specific pre-dredge locations were observed to be in shallow water, less than 3 ft (T171A, T172A, T176B, and T177B) or near a significant slope at the river channel edge (T179B, T180A, and T180B).

2) The performance of the MBS at shallow depths was less accurate because the swath width became limited in shallower waters, resulting in less bottom coverage and the need for greater data interpolation across data gaps in these areas.

3) The stacked variability in the horizontal positioning was determined to be approximately ± 3 ft at each sample station when considering a combination of the instrument accuracy and any variance associated with actual sampling. This resulted in a vertical variability in the sediment surface of 0.6 ft to 2.9 ft based on pre-dredge bathymetry and depending on location.

### 3.1.2 Physical Examination of the Pre- and Post-Dredge Sediment Cores

Sediment cores collected during the pre- and post-dredge sampling events were segmented and processed for chemical and physical analysis. Each core was carefully logged and photographed. Subsequent comparison of physical sediment characteristics was completed on pre-dredge and post-dredge cores. Figure 3-1 shows a section of a pre-dredge core collected at T181. Often the pre-dredge cores exhibited distinct sediment depositional features such as multiple thin layers of varying sediment color (Figure 3-1). These features indicate frequent, episodic events of particle suspension and sedimentation, resulting in highly stratified cores.




**Figure 3-1. Typical Pre-Dredge Sediment Core**

This stratification generally occurred above the dredge target cut line and did not occur in deeper sediments. Therefore, post-dredge sediment cores did not exhibit this stratification, and this feature could not be used to pair the pre- and post-dredge cores in vertical space. Cores collected from the post-dredge event appeared more homogenous and consisted of fine clays mixed with sand with very little observable color patterns in the vertical profile. The coloration of post-dredge cores was very similar to pre-dredge core pairs at similar elevations.

While color and stratification could not be used to identify dredge residual layers, two primary observations were made of post-dredge cores that aided in their vertical positioning relative to pre-dredge core segments. First, post-dredge cores appeared to be less consolidated; secondly, organic particles and debris such as wood was observed in the estimated target cut zone, lending evidence to mixing due to dredge activity.

The core segmenting plan was based on a combination of variables that included visual observations, physical characteristics, the target dredge cut line and project budget. Both pre- and post-dredge cores were intentionally segmented at smaller intervals around the target cut line. The top (surface) of the post-dredge core was also segmented into smaller intervals, to better detect differences due to residuals. Each segment was analyzed for PCB congeners as previously discussed and the chemistry of the pre- and post-dredge core segments was compared. Elevation measurements collected during coring and surveying activities were used to vertically align the pre- and post-dredge core segments.

### 3.2 Physical Parameter Analysis of Sediment Core Segments

In addition to sediment chemistry, physical parameter data were collected on each pre- and post-dredge core segment (as sediment volume allowed). These parameters included dry and wet bulk density, TOC, moisture content, and particle size (fractions – gravel, coarse sand, medium sand, fine sand, silt, and clay).

Two approaches were implemented to compare the pre- and post-dredge datasets. To conduct comparisons between pre- and post-dredge cores collected from the same location and at the same depth, pre- and post-dredge core segments were lined up in vertical space such that they corresponded in elevation. This resulted in comparisons made for 14 sampling stations where core segments aligned well vertically. For comparison purposes, this analysis focused on a 6-in. vertical horizon from an elevation of 548 ft to an elevation of 547.5 ft. The 14 sampling stations were: T170A, T170B, T171A, T171B, T172A, T172B, T173A, T173B, T174A, T174B, T176A, T178B, T179A, and T181D. Simple summary statistics were developed (min, max, mean and standard deviation) for each of the 10 parameters measured (pre- and post-dredge), and scatter diagrams were developed plotting the post-dredging sample value against the corresponding pre-dredging sample values for the same sampling station. These data comparisons produced the following observations:

- The average dry bulk density was approximately 20% lower for post-dredge sediment segments
- The gravel, coarse sand and medium sand contents of the samples were generally lower after dredging than before – on average about 25%, 75%, and 40% lower, respectively.
- The fine sand and clay contents of the sediment segment samples were approximately 50% and 7% higher, respectively, for post-dredge sediment samples.

A second approach was employed to analyze and compare the physical consistency of the pre- and post-dredge sediments using 3-D block diagram visuals (Earth Vision, Dynamic Graphics, Inc., USA). These comparisons are shown as cross-section views for T172 in Figures 3-2 through 3-4.

As shown in Figure 3-2, a consistent and dominant band of sands was evident in the dredge cut line at this transect with an overlying predominant layer of silt in the pre-dredge sediment. Post-dredge data indicated the sediments were composed primarily of silt at the cut line, presumably from mixing and settling of the overlying sediments. This pattern was substantiated by the shift in TOC from the overlying zone of the pre-dredge to the post-dredge sediment surface as shown in Figure 3-3. Higher levels of TOC are typically more characteristic of silt and clay sediments than of sand. Lastly, Figure 3-4

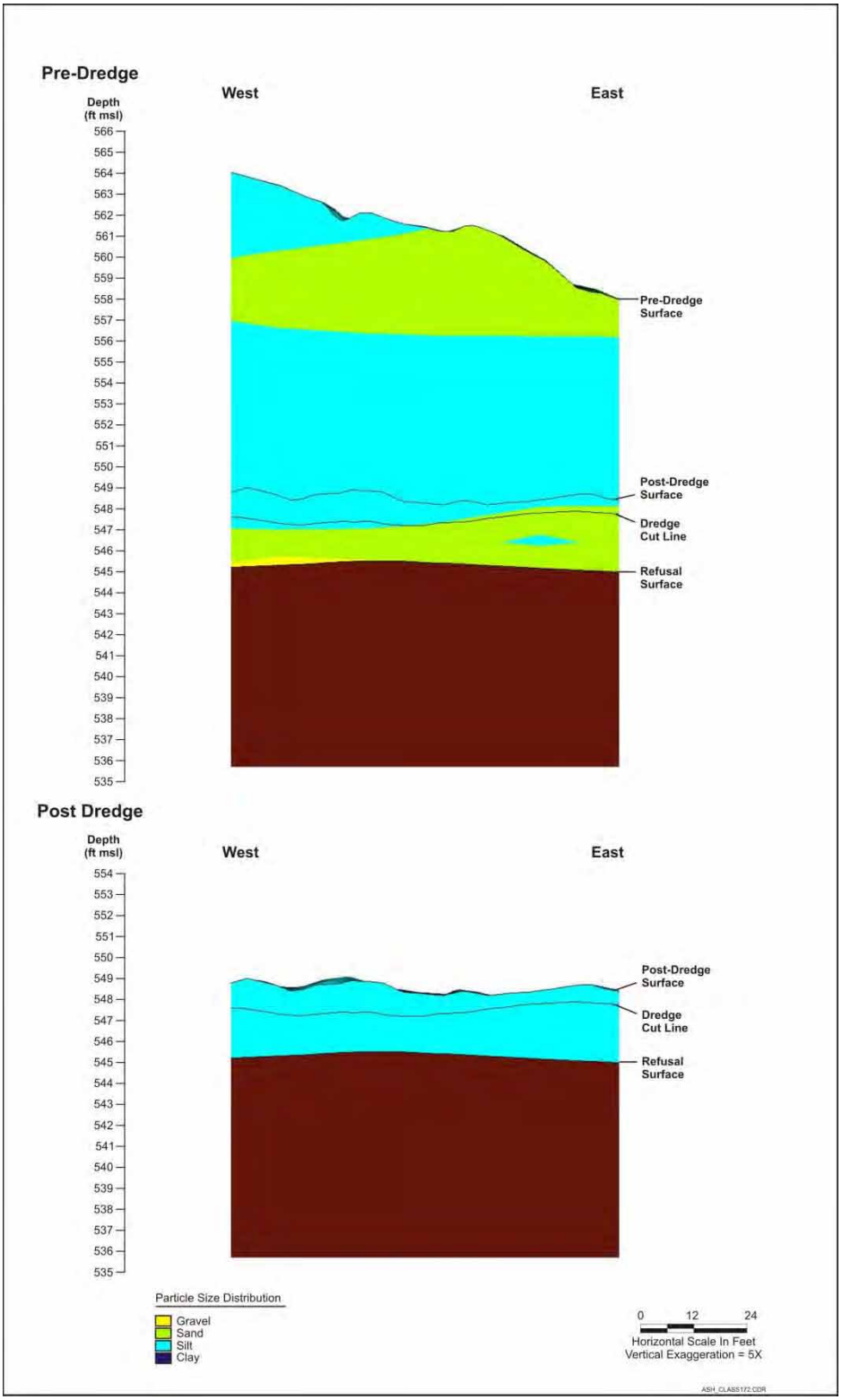



**Figure 3-2. Comparison of Pre- and Post-Dredge Particle Size Distributions in Sediment at T172**

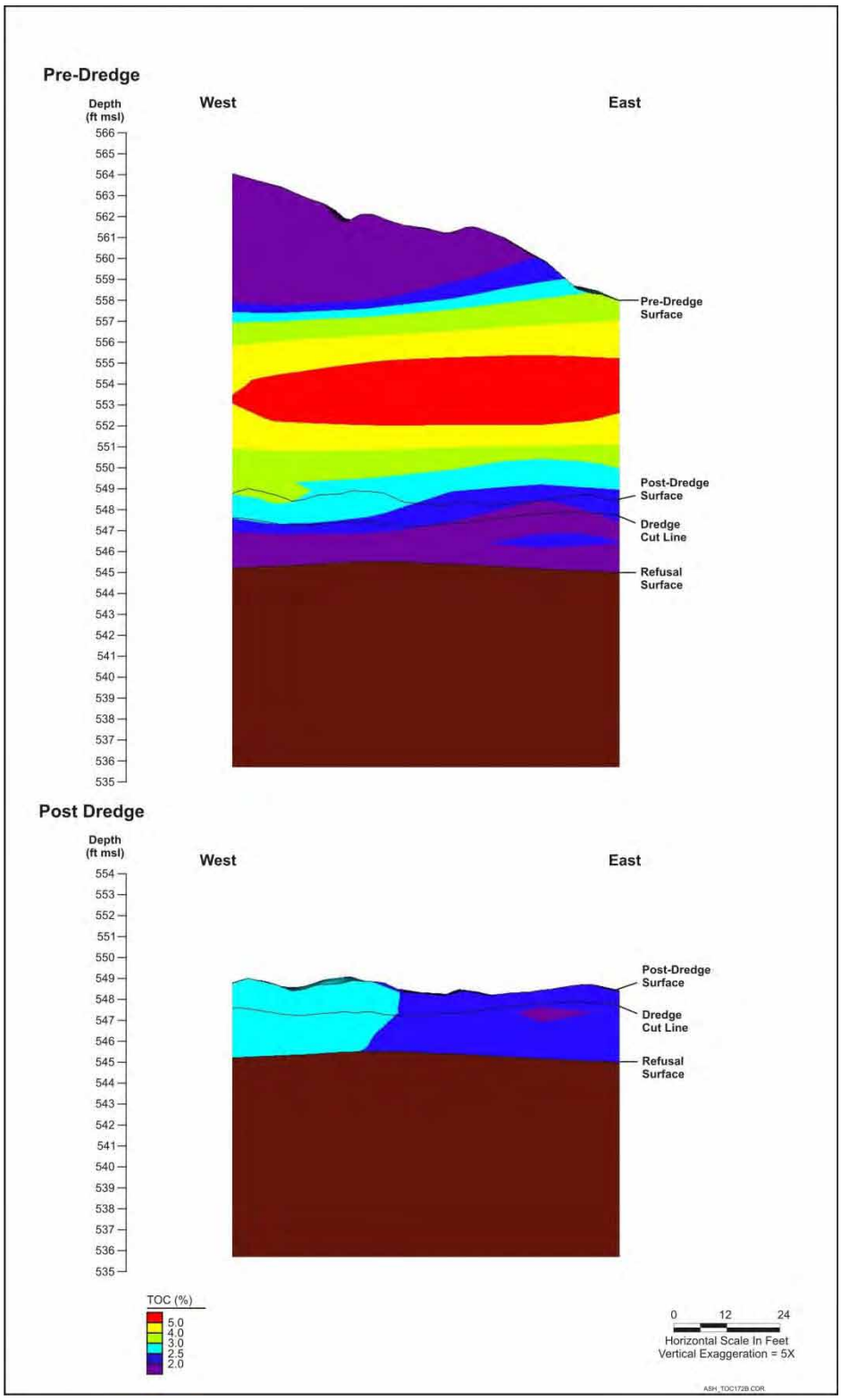



**Figure 3-3. Comparison of Pre- and Post-Dredge TOC Concentrations in Sediment at T172**

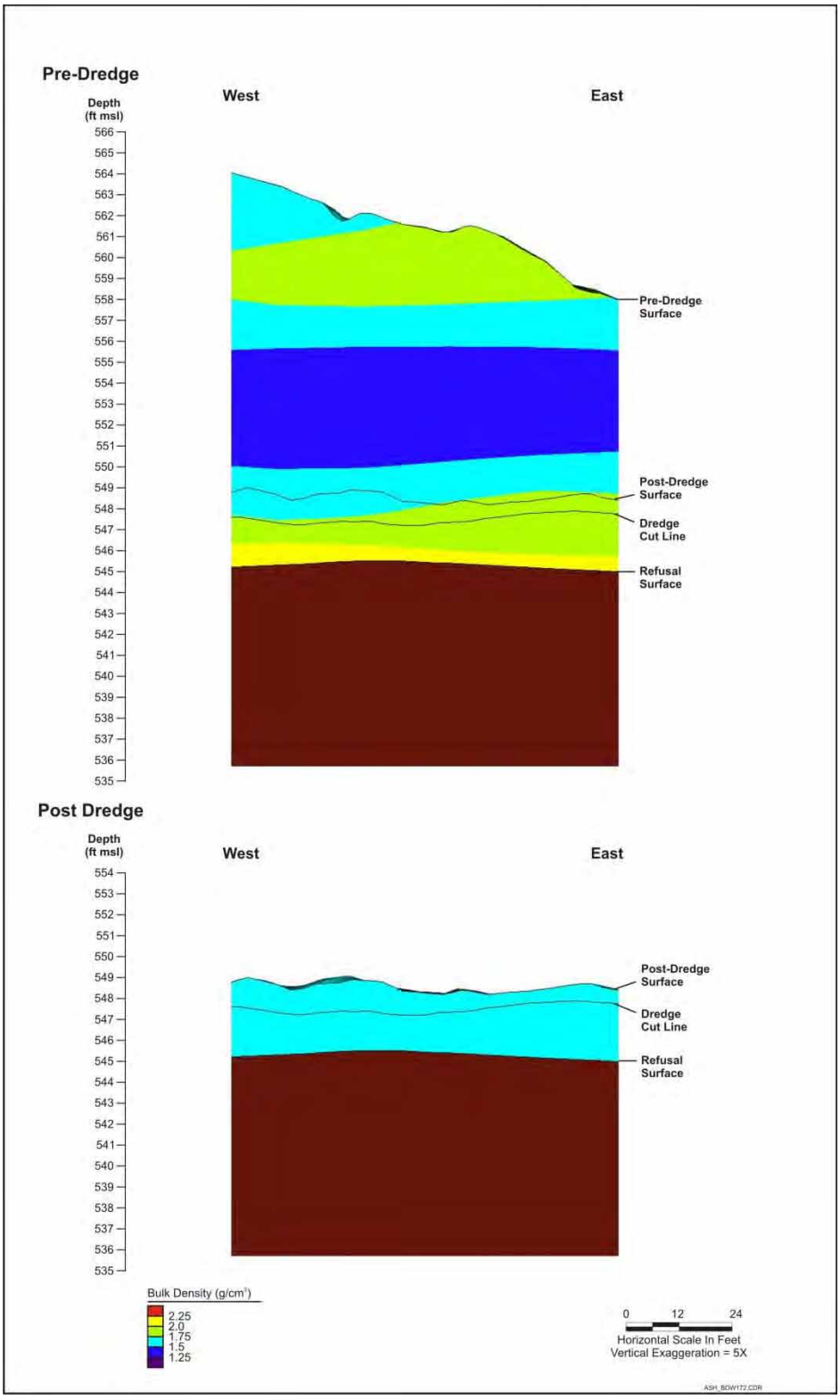



**Figure 3-4. Comparison of Pre- and Post-Dredge Dry Bulk Densities in Sediment at T172**

shows a decrease of dry bulk density in the post-dredge sediment surface as compared to the pre-dredge sediments at the dredge cut line. This indicated mixing at and below the estimated dredge cut line, further supporting the maximum dredge cut elevations discussed in subsequent sections.

### 3.3 Sediment PCB Chemistry and Data Analysis of Core Segments

PCB chemistry analysis was conducted using samples collected prior to and following dredging in the study area. PCB concentration and composition analyses were conducted on both pre- and post-dredge sediment cores using congener and homolog data and PCA.

#### 3.3.1 Characterization of the Pre-Dredge Sediment PCB Inventory.

Table 3-2 presents representative total PCB data for the surface, high-level (high concentration section), and lower sections of the pre-dredge sediment cores, and also for the surface of the post-dredge sediment. The pre-dredge surface sediment data are based on the single surface segment, which was the top 1-ft section of the core for most of the samples (the top 0.4 to 0.75 ft was used for a few of the cores). The pre-dredge high-level sediment data are based on a single representative sample from the most contaminated section of the core; it is the segment of the core that had the highest PCB concentration. Most of these pre-dredge high-level samples were observed for a sediment depth of 5 to 8 ft, but they covered a depth range of just less than 2 ft (T180A) to just over 10 ft (T181D). The pre-dredge lower sediment in Table 3-2 was a single sample from the depth (elevation) closest to that of the post-dredge surface sediment.

Figures 3-5 through 3-9 illustrate a 3-D model of the pre-dredge PCB concentration sediment profile in the study area. Each figure shows a distinct isoconcentration profile (shell) that varies both horizontally and vertically. The lower isoconcentration shells are removed consecutively in each succeeding figure. Each figure, therefore, depicts the next highest isoconcentration shell until only the highest shell representing a concentration of greater than 100,000 ppb remains in Figure 3-9. The pre-dredge surface sediment t-PCB concentrations ranged from 152 ppb (T175B) to 8,610 ppb (T176B); the average surface sediment t-PCB concentration was approximately 1,000 ppb (Table 3-2). The pre-dredge subsurface sediment t-PCB concentrations were highly variable, ranging from less than 100 ppb to almost 200,000 ppb. The average t-PCB concentration in the most contaminated zone was approximately 100,000 ppb (Table 3-2), while the sediments at greater depth had highly variable PCB concentrations that were more comparable to the surface sediment PCB concentrations. The most contaminated sediments were generally noted at 5 to 10 ft depth, but highly contaminated sediments were found at less depth at some locations. The t-PCB concentration at the most contaminated depth was generally between 50,000 ppb and 150,000 ppb, but was less than this at some locations (T178A, T179A, T180A, T181A, and T180B) and more at some locations (T173A, 177B, and T178C). The surface and subsurface PCB concentrations were variable within the study area, but no obvious pattern of increasing or decreasing concentrations geographically was evident. The largest volume of highly-PCB-contaminated sediment (i.e., the greatest depth of the highly contaminated zone) was in the eastern side of the river between transects T176 and T181.

**Table 3-2. Total PCB Concentration (ppb) of Pre-Dredge Surface Sediment, Typical Pre-Dredge High-Level Sediment, Pre-Dredge Sediment at Post-Dredge Surface Sediment Depth, and Post-Dredge Surface Sediment**

| Sediment Core | Pre-Dredge Sediment | | | Post-Dredge Sediment |
|---|---|---|---|---|
| | Surface[a] | High-Level[b] | Lower[c] (at post-dredge surface depth) | Surface[d] |
| T170A | 581 | 101,000 | 319 | 6,960 |
| T170B | 733 | 141,000 | 1,020 | 7,150 |
| T171A | 641 | 63,900 | 133 | 12,900 |
| T171B | 223 | 55,700 | 1,120 | 46,200 |
| T172A | 651 | 85,700 | 96.1 | 50,500 |
| T172B | 208 | 120,000 | 454 | 4,460 |
| T173A | 848 | 197,000 | 226 | 27,000 |
| T173B | 367 | 115,000 | 370 | 4,300 |
| T174A | 1,140 | 103,000 | 317 | 10,200 |
| T174B | 234 | 92,100 | 902 | 11,600 (0.92') |
| T175A | 174 | 84,300 | 52.7 | 9,250 |
| T175B | 152 | 100,000 | 22,700 | 6,960 (0.85') |
| T176A | 494 | 77,200 | 5,760 | 5,830 |
| T176B | 8,610 | 147,000 | 20,400 | 19,700 |
| T177A | 430 | 70,200 | 677 | 4,820 |
| T177B | 740 | 117,000 | 1,970 | 4,550 |
| T178A | 3,320 | 2,760 | 7.6 | 3,580 |
| T178B | 425 | 129,000 | 6,700 | 7,460 |
| T178C | 889 | 191,000 | 1,400 | 6,740 |
| T179A | 201 | 19.3 | 8.0 | 3,940 |
| T179B | 1,820 | 107,000 | 300 | 11,700 (0.6') |
| T179C | 1,250 | 127,000 | 1,010 | 8,260 (0.95') |
| T180A | 160 | 228 | 16.5 | 825 |
| T180B | 284 | 7,090 | 59.7 | 11,700 |
| T180C | 539 | 87,000 | 1,470 | 12,500 |
| T180D | 3,120 | 118,000 | 50.8 | 7,280 |
| T181A | 585 | 159 | 159 | 539 |
| T181B | 3,130 | 65,300 | 107 | 1,050 (0.8') |
| T181C | 820 | 144,000 | 3,660 | 6,320 (0.85') |
| T181D | 743 | 126,000 | 3,340 | 5,970 (0.9') |
| **Average** | 1,120 | 92,500 | 2,490 | 10,700 |
| **Std. Dev.** | 1,660 | 52,500 | 5,440 | 11,600 |
| **RSD (%)** | 149 | 57 | 218 | 108 |

(a) The pre-dredge surface sediment is the single sample representing the top 1 ft of the sediment core.
(b) The pre-dredge high-level sediment is the single sub-surface sediment sample with the highest PCB concentration representing the most contaminated sediment depth.
(c) The pre-dredge lower sediment is a single sample from the approximate depth equivalent to the post-dredge surface sediment.
(d) The post-dredge surface sediment data are a sample (core segment length)-weighted average concentration of the samples that represent the top 1 ft of the sediment core. Between two and seven segments were used, depending on the core. If the post-dredge core was less than 1 ft in length, the data represent a weighted average of all samples in the core, and the core length is indicated in parenthesis.

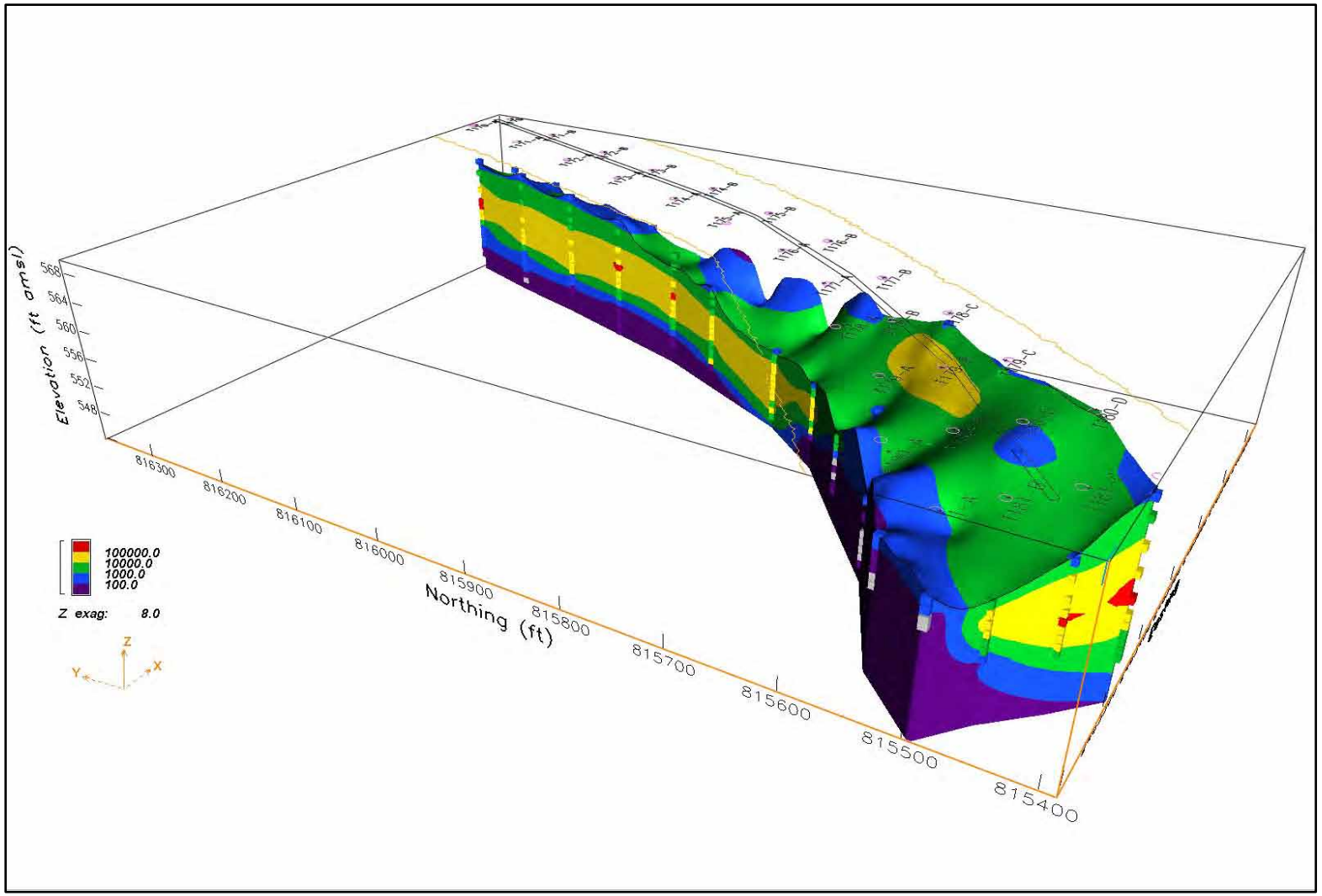



**Figure 3-5. Pre-Dredge Sediment t-PCB Concentration Profiles in the Study Area (> 0 ppb)**

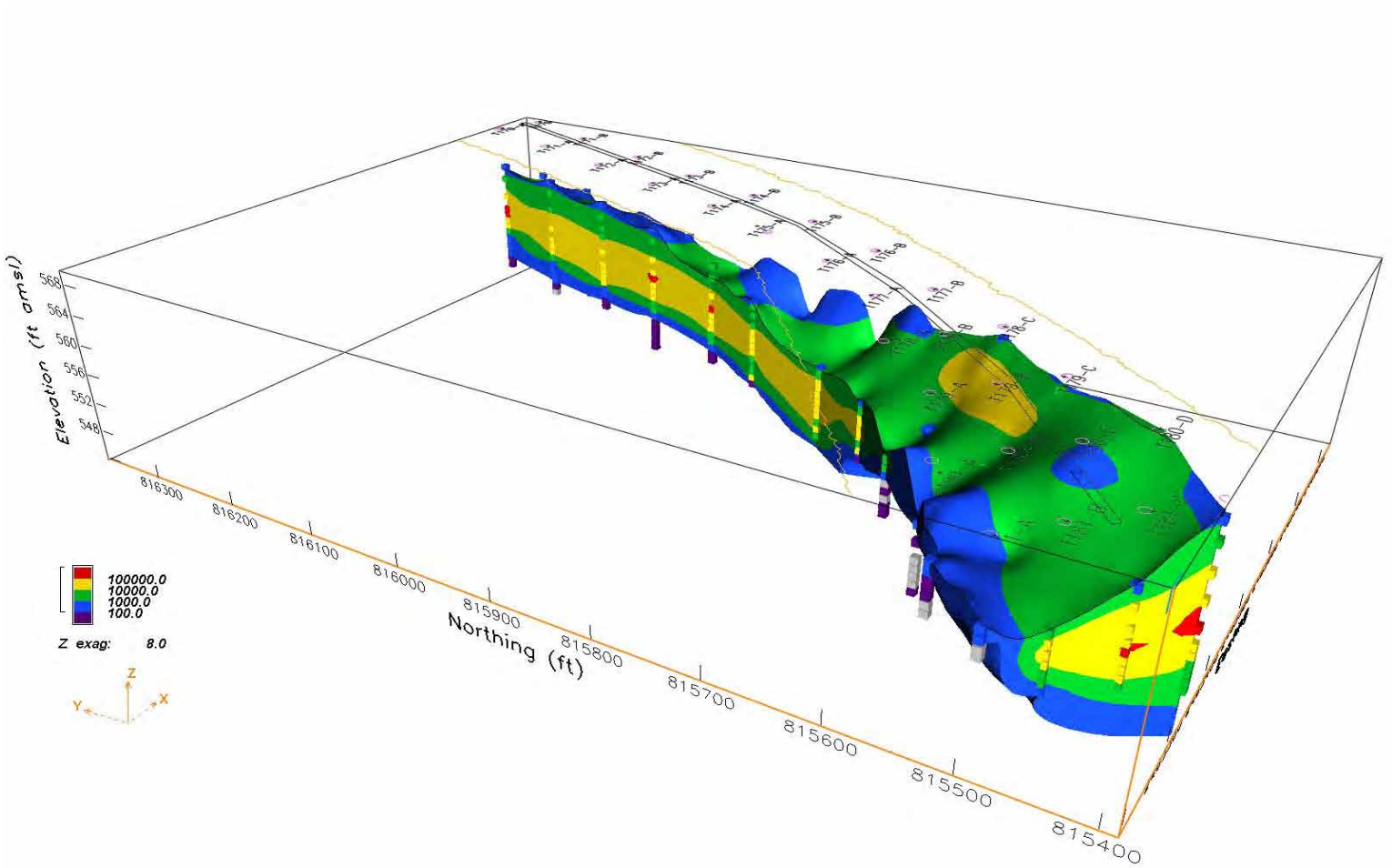



**Figure 3-6. Pre-Dredge Sediment t-PCB Concentration Profiles in the Study Area (> 100 ppb)**

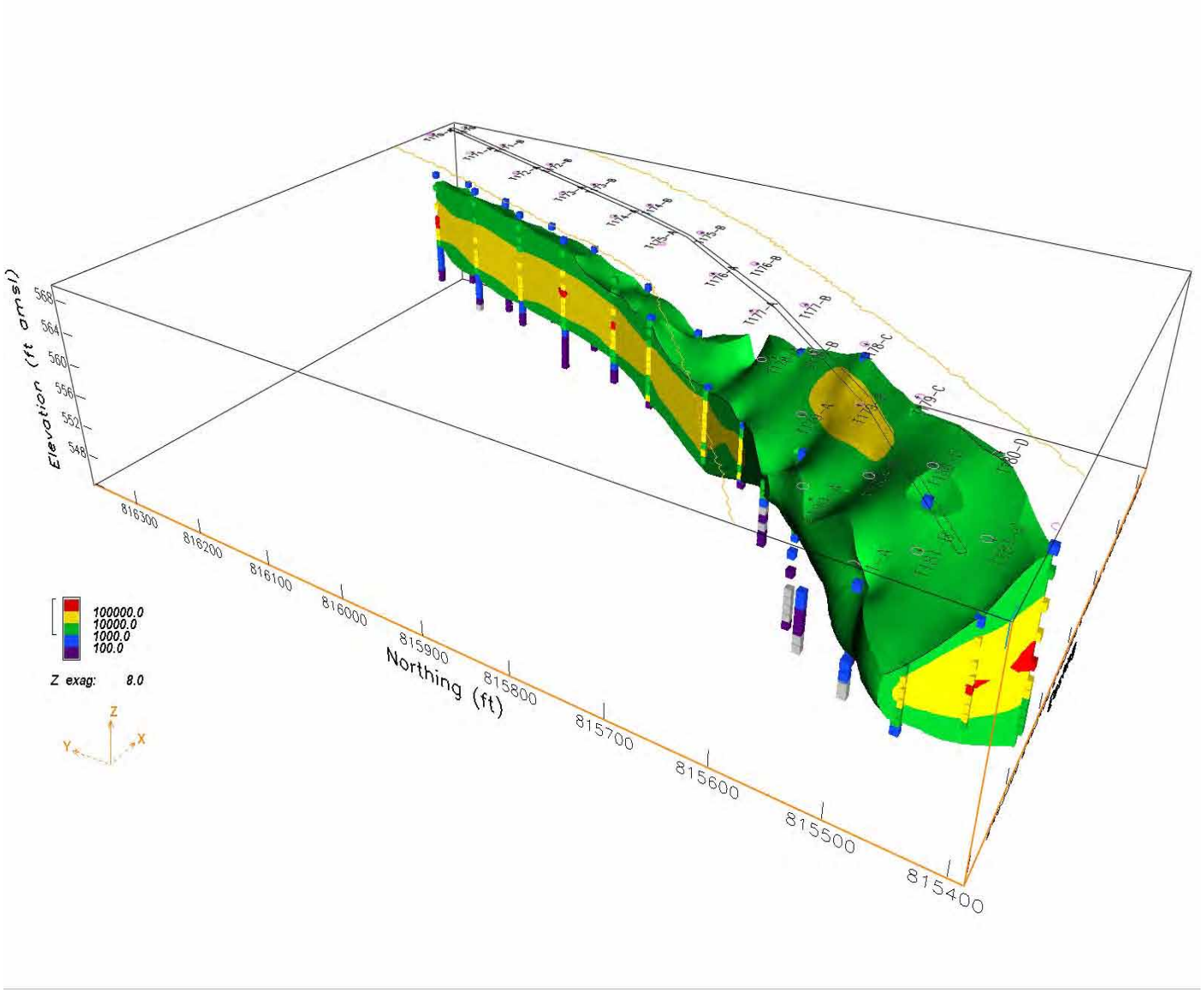



**Figure 3-7. Pre-Dredge Sediment t-PCB Concentration Profiles in the Study Area (> 1,000 ppb)**

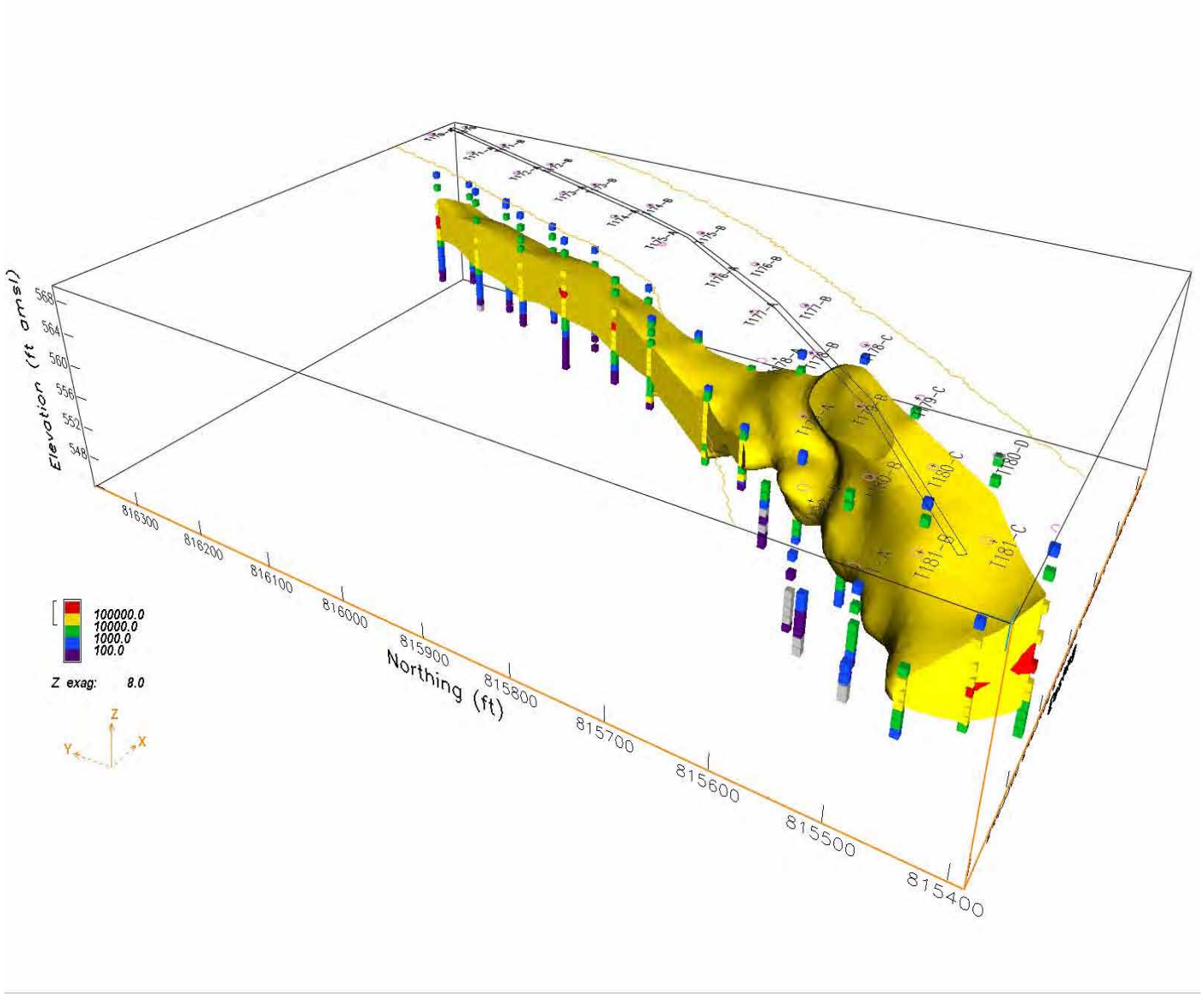



**Figure 3-8. Pre-Dredge Sediment Concentration Profiles in the Study Area (> 10,000 ppb)**

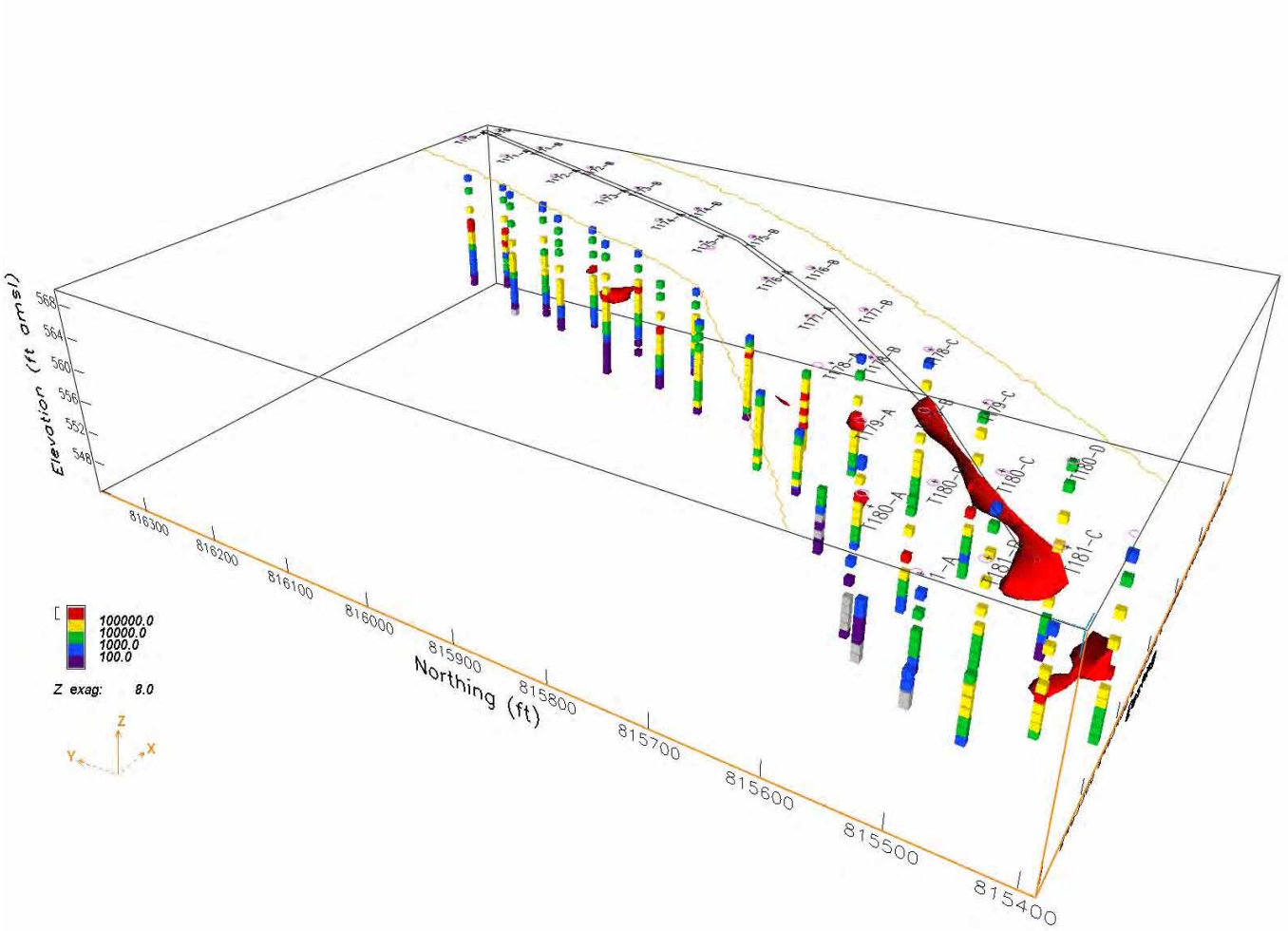



**Figure 3-9. Pre-Dredge Sediment t-PCB Concentration Profiles in the Study Area (> 100,000 ppb)**

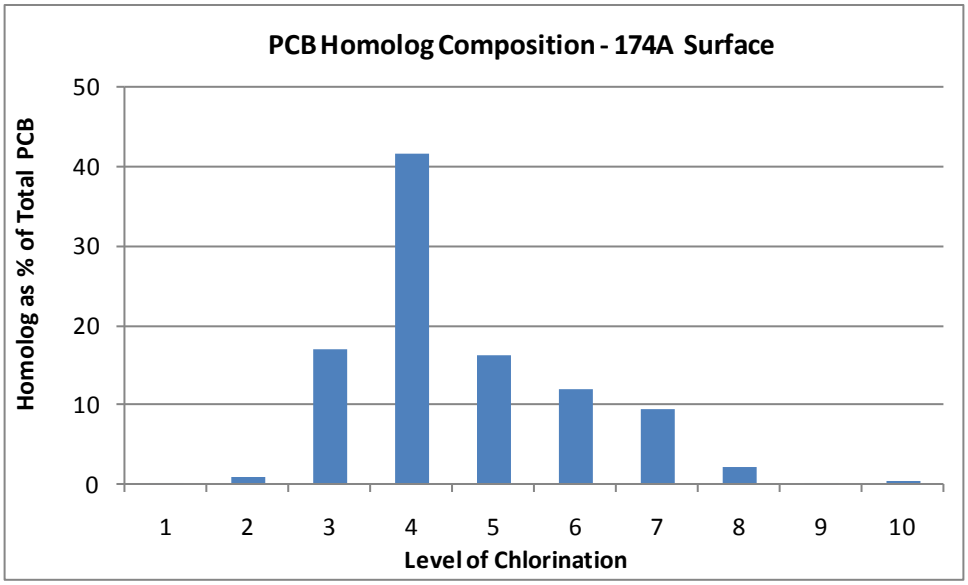
The sediment PCB composition was evaluated using both homolog and congener-specific data. The analysis indicated that the PCB composition in the surface sediment was dominated by PCB Aroclor 1248-type contamination, with some influence from PCB Aroclor 1260. An approximate 3:1 composition of Aroclor 1248:1260-type contamination was evident in most of the surface sediments as illustrated in Figure 3-10 with a pre-dredge surface sample from core T174A. The Aroclor 1248 predominance was strongest near Fields Brook, even in the surface sediments. Other investigations have noted historic sources of Aroclor 1260-type contamination from Strong Brook across the Upper Turning Basin from Fields Brook. The Aroclor 1260 contribution from this source was evident in most of the surface sediments; however, it was not observed at depth. This observation would suggest that the Strong Brook source of Aroclor 1260 may have been active only recently.

The most contaminated subsurface sediments had a PCB composition that closely resembled Aroclor 1248 (as demonstrated for a mid-depth core segment in Figure 3-11). This close match with Aroclor 1248 was observed throughout the study area in most sediment below 1 ft in depth and in all of the most contaminated sediment. Sediment samples with a total PCB concentration above 10,000 ppb all showed a very close compositional match with Aroclor 1248. The sediments collected from the greatest sediment depth (the lowest elevation) that were below the most contaminated zone exhibited a PCB composition that also was dominated by an Aroclor 1248 signature. However, these samples also had a noticeable contribution of highly-chlorinated PCB congeners (e.g., chlorination levels of 8, 9, and 10) that do not have a clear relationship to any particular Aroclor formulation as demonstrated in Figure 3-12. The high relative amounts of PCB209 (decachlorobiphenyl) compared to the octa- and nonachlorobiphenyls, for instance, were greater than in the more commonly-used highly-chlorinated Aroclor formulations (e.g., Aroclor 1268) and other commonly-used PCB formulations. The distribution may also not be explained by environmental alteration processes. Little information is available on the rarely-used Aroclors 1269, 1270 and 1271, but it has been described that they contain high proportions of decachlorobiphenyl, so some contribution from one of those Aroclors possibly together with Aroclor 1268 might be a possibility in these deeper sediment. The sediments with this unique composition generally had low t-PCB concentrations ranging from less than 1,000 to approximately 3,000 ppb.

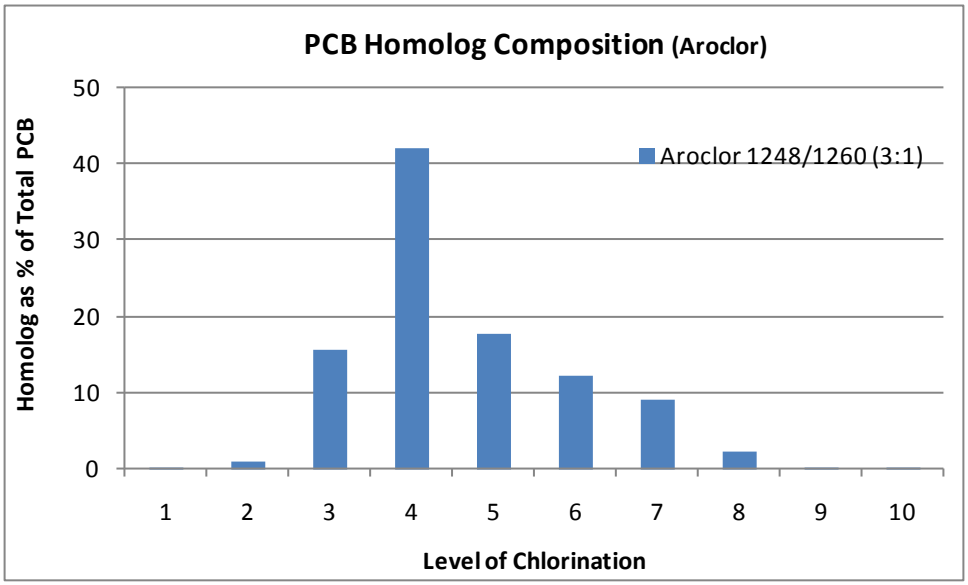
### 3.3.2 Characterization of the Post-Dredge Sediment PCB Inventory.

An important objective of the study was to characterize the chemical and physical composition of the post-dredge sediment and evaluate whether these sediments were dredge-generated residuals. Table 3-2 summarizes t-PCB data for the post-dredge surface sediments, along with representative pre-dredge sediment data. The post-dredge surface sediment data presented in Table 3-2 are the core segment-length weighted average concentration of the samples closest to the top (surface) of the post-dredge sediment cores, representing the top 1 ft. Between two and seven samples were used to determine the average 1-ft post-dredge surface sediment concentrations in Table 3-2; the number of samples depended on how the cores were segmented. A few post-dredge cores were collected to a depth of less than 1 ft (Table 3-2), and the concentration of the deepest segment was then assumed to be representative of the concentration to a depth of 1 ft.

The post-dredge subsurface sediment t-PCB concentrations represented in Table 3-2 ranged from 539 to 50,500 ppb, and averaged 10,700 ppb. The average t-PCB concentration was significantly higher in the post-dredge surface sediments than in both the pre-dredge surface sediment (1,120 ppb) and the pre-dredge sediments at the post-dredge surface sediment elevation (2,490 ppb; Figure 3-13). In fact, the post-dredged surface sediment PCB concentrations were higher than the pre-dredge concentrations for similar elevations at 28 of the 30 locations (Figure 3-14). The two post-dredge locations with comparable or slightly lower PCB concentrations were from the same general area (T175B and T176B), suggesting

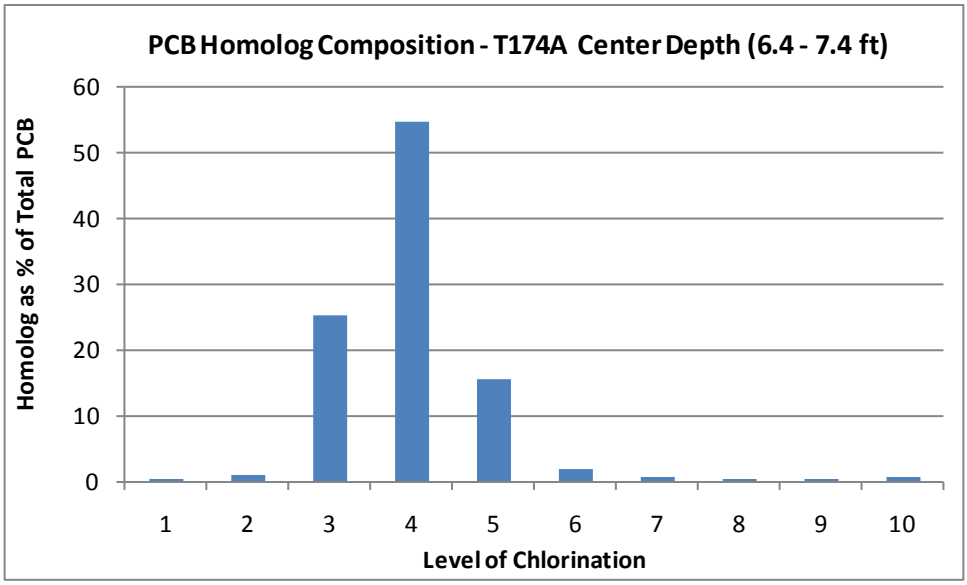



**A) Pre-Dredge Core Sample T174A (surface sediment)**

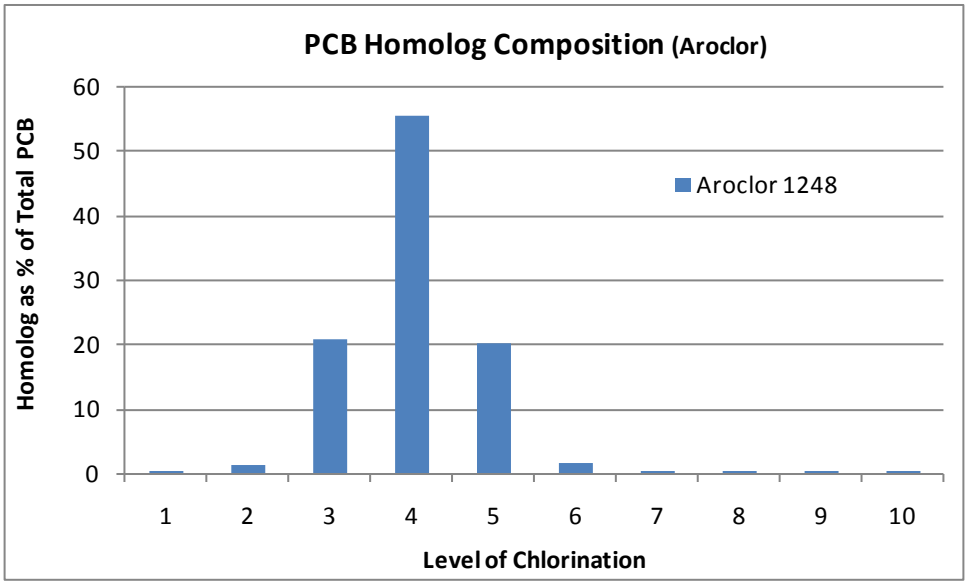



**B) PCB Aroclor 1248:1260 (3:1)**

**Figure 3-10. Composition Analysis Showing the Similarity in the PCB Composition of Surface Sediment Sample T174A (A) and a 3:1 Mixture of Aroclor 1248:1260 (B)**

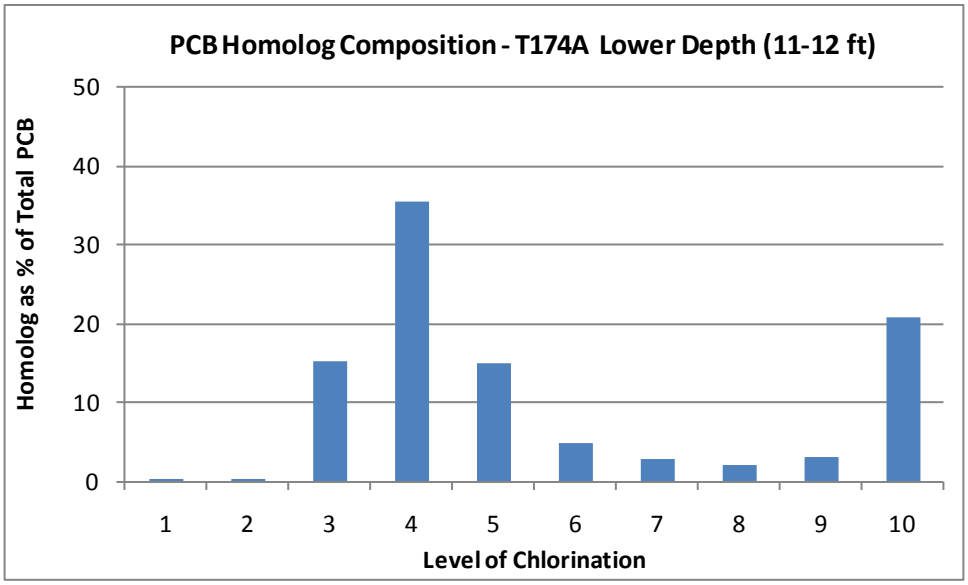



**A) Pre-Dredge Core Sample T174A (from 6.4–7.4 ft sediment depth)**

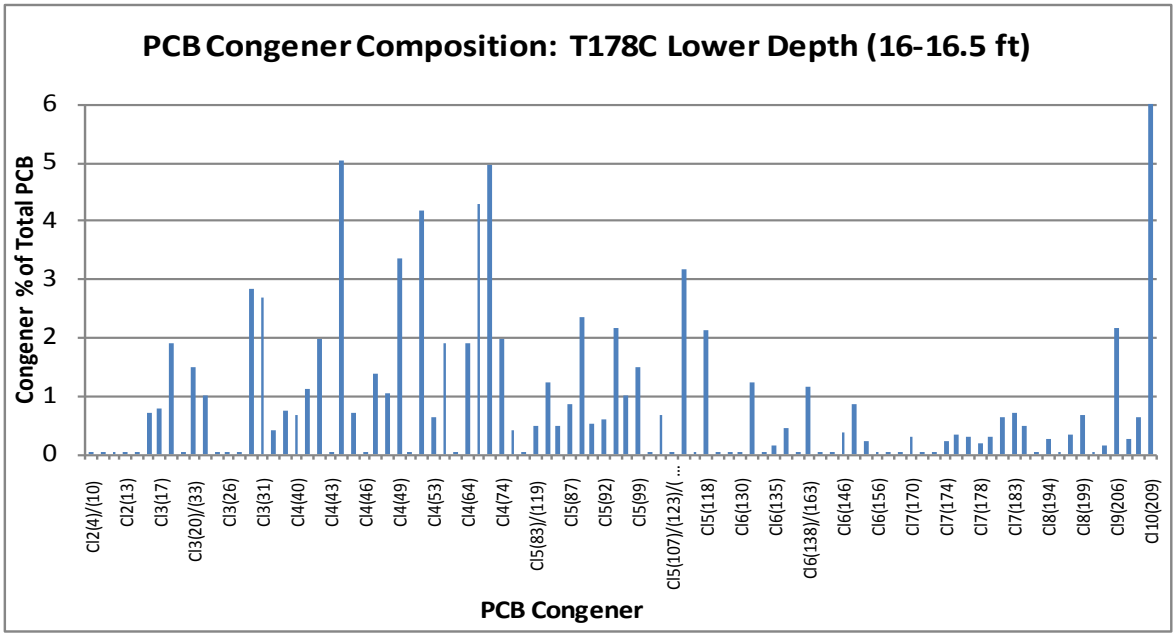



**B) PCB Aroclor 1248**

**Figure 3-11. Composition Analysis Showing the Similarity in the PCB Composition of Sediment Sample T174A from a Depth of 6.4–7.4 ft (A) and Aroclor 1248 (B)**




**A) Pre-Dredge Core Sample T174A (from 11.4–12.4 ft sediment depth)**




**B) Pre-Dredge Core Sample T178C (from 16-16.5 ft sediment depth)**

**Figure 3-12. Composition Analysis Showing the PCB Composition of Sediment Sample T174A from a Depth of 11.4–12.4 ft (A; Homolog Composition) and T178C from a Depth of 16-16.5 ft (B; Congener Composition)**

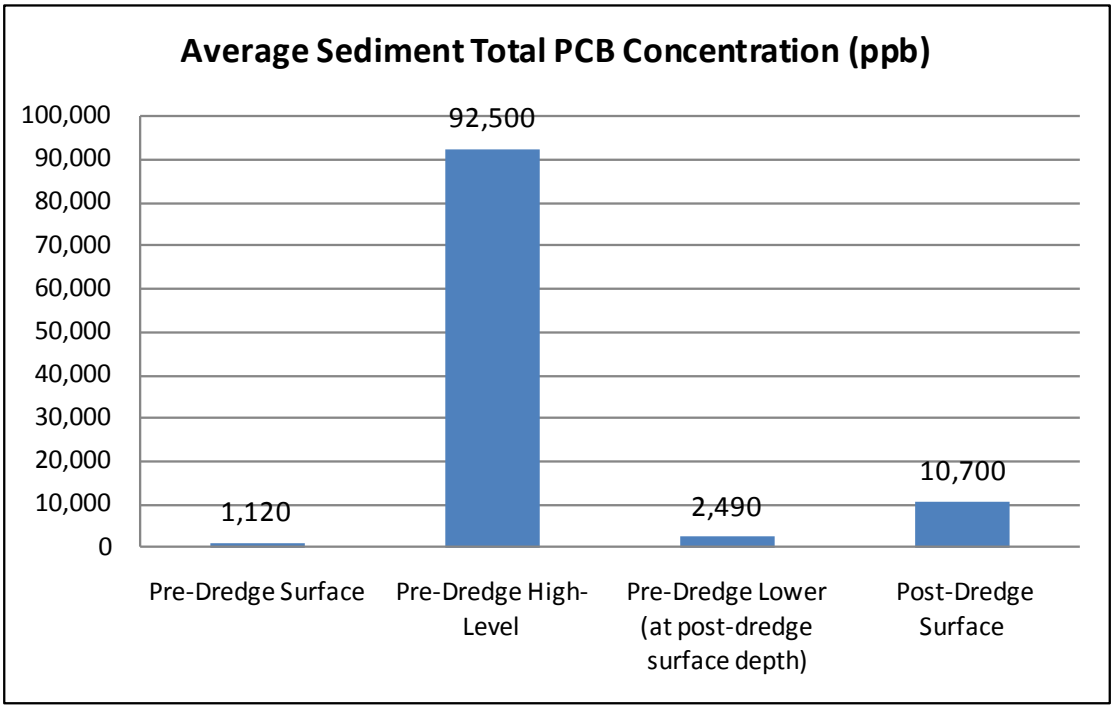



**Figure 3-13. Average t-PCB Concentrations in Pre-Dredge Surface, High-Level, and Lower Sediments and Post-Dredge Surface Sediments. Pre-Dredge Lower Sediments are from the Same Elevations as Post-Dredge Surface Sediments. Based on Data in Table 3-2.**

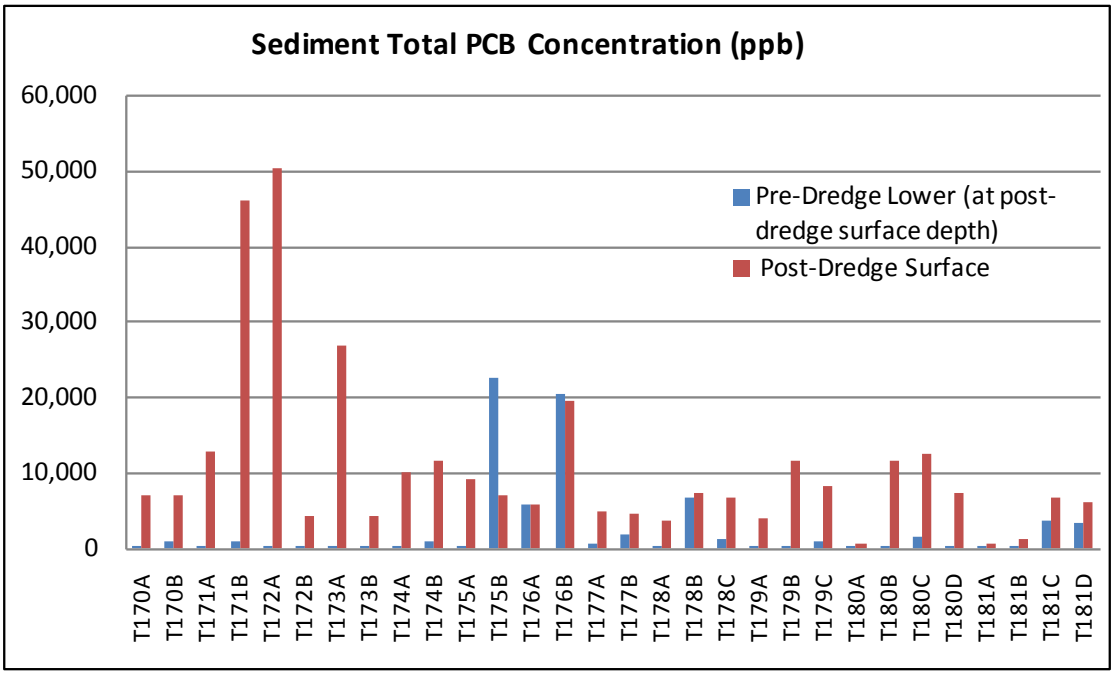



**Figure 3-14. The Total PCB Concentration in Pre-Dredge Lower Sediments and Post-Dredge Surface Sediments at the Sediment Coring Locations Presented in Table 3-2. Pre-Dredge Lower Sediment Samples are from the Same Elevation as Post-Dredge Surface Sediment.**

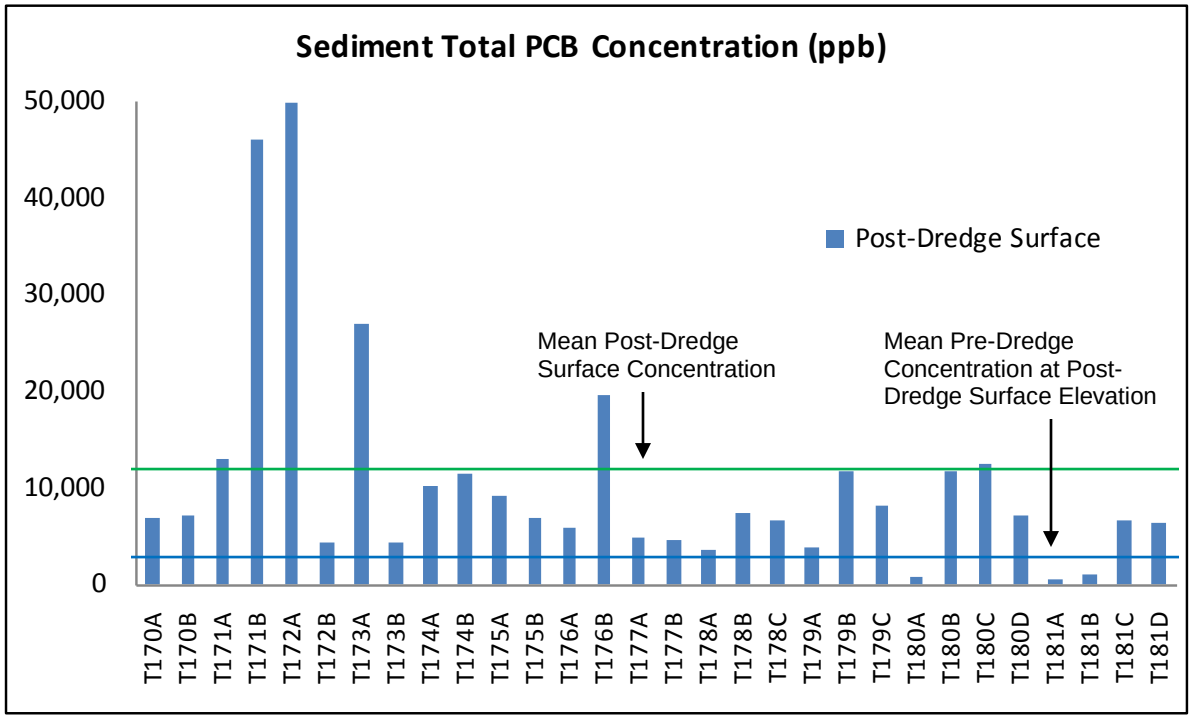



**Figure 3-15. The Total PCB Concentration in the Post-Dredge Surface Sediments at the Sediment Coring Locations Presented in Table 3-2. The Mean Concentration is Also Presented along with the Mean Pre-Dredge Concentration from the Same Elevation.**

that this observation was likely due to some localized phenomenon. The average t-PCB concentration in the post-dredge surface sediments was approximately four times higher than in the pre-dredge sediments from the same elevation (i.e., from the depth equivalent to the post-dredge surface sediments; Figures 3-13 and 3-15). Figure 3-16 also illustrates the differences in the PCB concentrations in the pre- and post-dredge cores at different sediment depths. The post-dredge surface sediment PCB concentrations were generally higher than one would have expected based on the pre-dredge data from the same elevations. If the dredged sediments were removed with complete effectiveness, and no additional residuals were created during the dredging operation, one would expect the post-dredging surface sediment concentrations to be equivalent to those of the pre-dredged sediments at the same depth, not four times higher as was observed in this study.

The post-dredge surface sediment PCB concentrations were also more uniform than the pre-dredge surface sediment PCB concentrations and the pre-dredge PCB concentrations at the depth equivalent to the post-dredge surface (Table 3-2). This increase in surface sediment concentration uniformity suggests that sediment resuspension, mixing, and transport may have been occurring during the dredging operations, and that the sediments then settled over a larger area than from which they originated.

As previously mentioned, the pre-dredge sediment inventory had a PCB composition that closely resembled Aroclor 1248. The surface sediments also exhibited some contributions of Aroclor 1260, and some of the deep sediments had some contributions from Aroclor 1268 or other highly-chlorinated PCB material, but all sediments were predominantly Aroclor 1248. Figure 3-17 shows the overall pre- and post-dredge PCB homolog composition of all analyzed sediment on a t-PCB mass basis; the composition closely resembled Aroclor 1248 both before and after dredging.

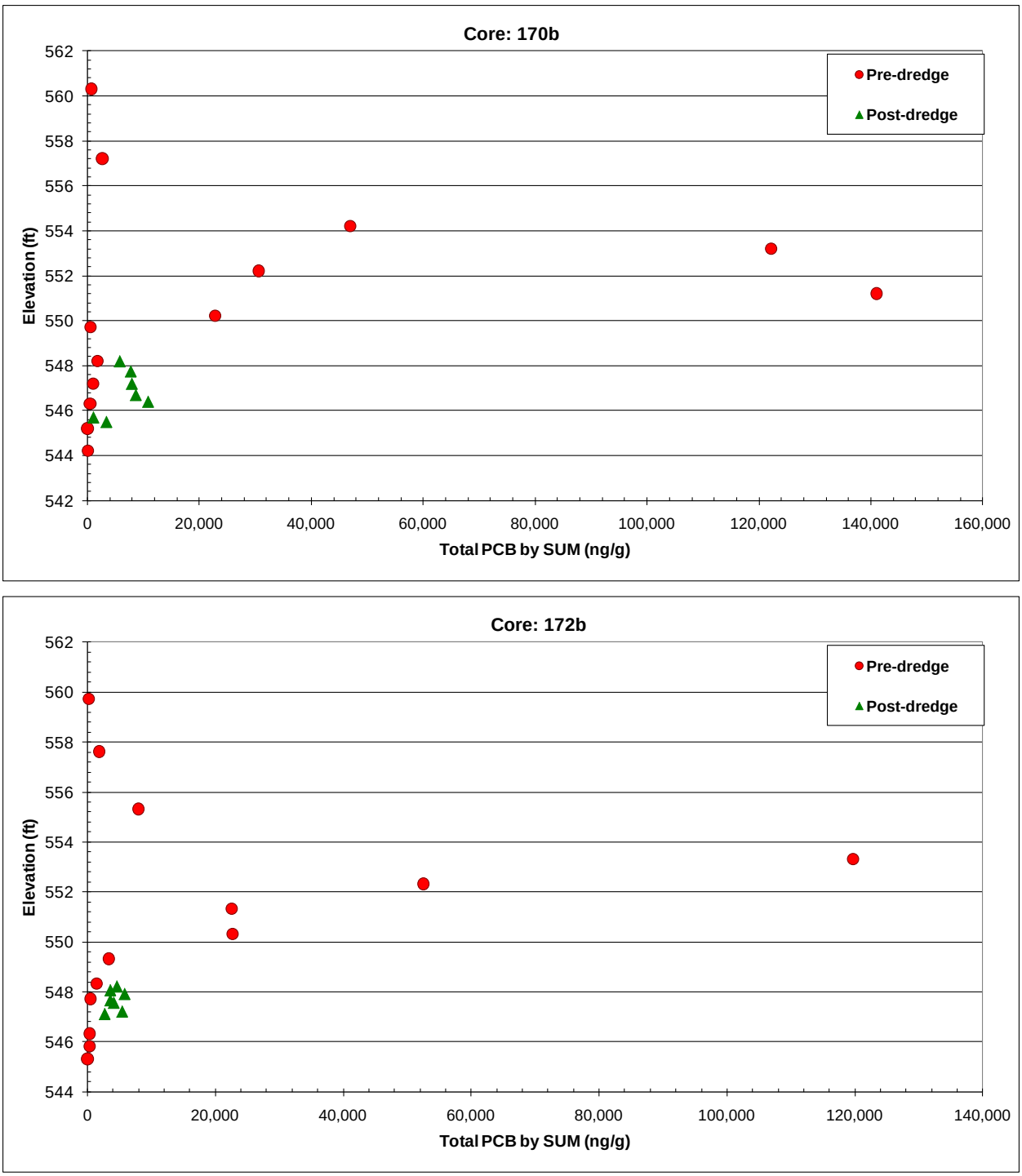
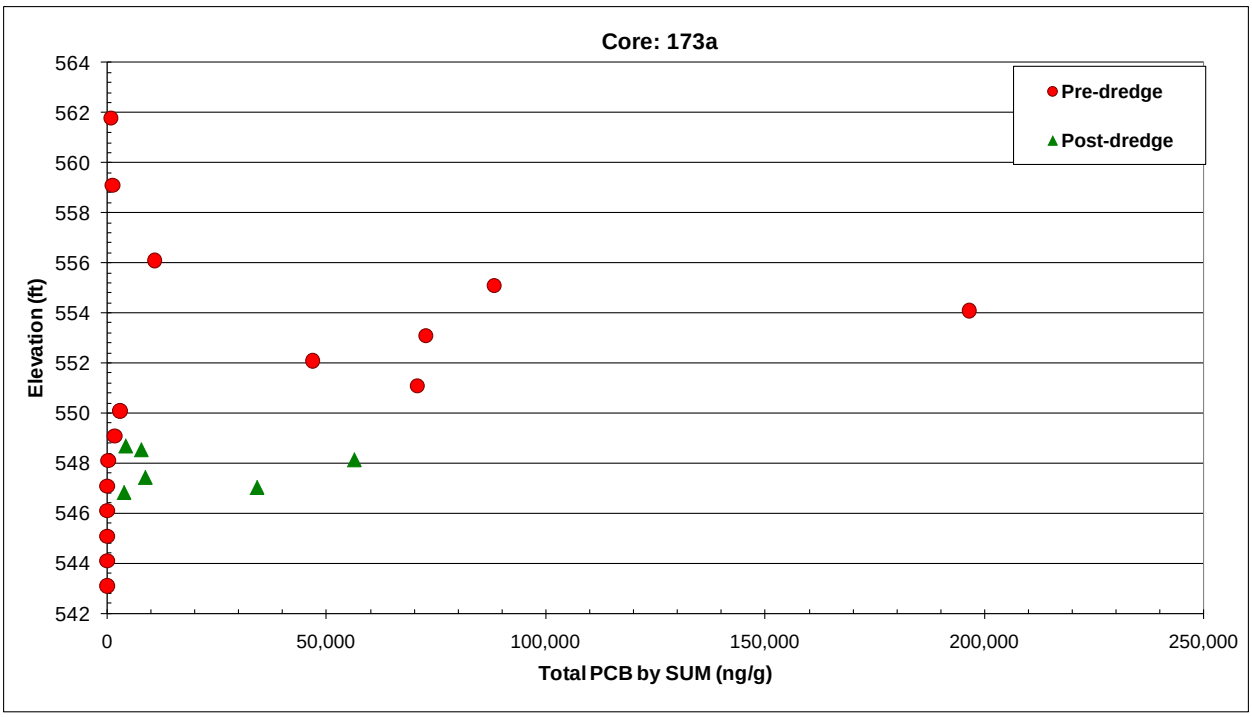



**Figure 3-16. Total PCB Concentrations in Pre- and Post-Dredge Core Samples from Locations T170B and T172B**



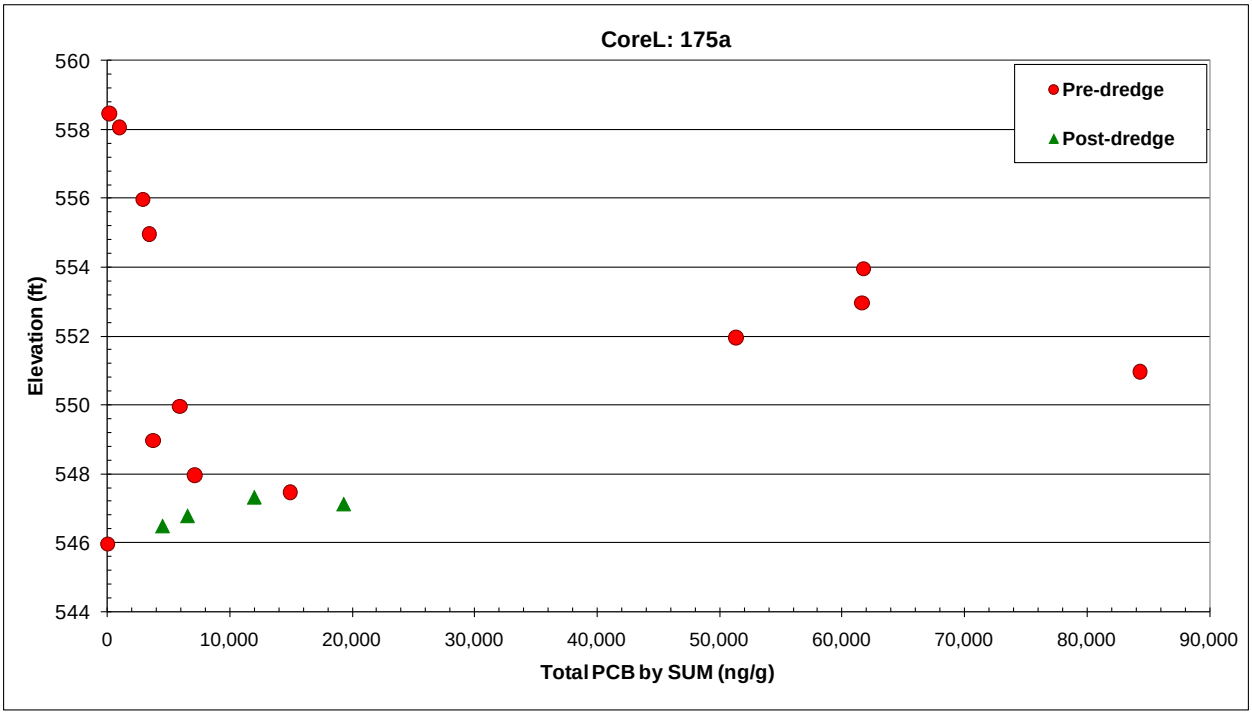




**Figure 3-16. Total PCB Concentrations in Pre- and Post-Dredge Core Samples from Locations T173A and T175A (Continued)**

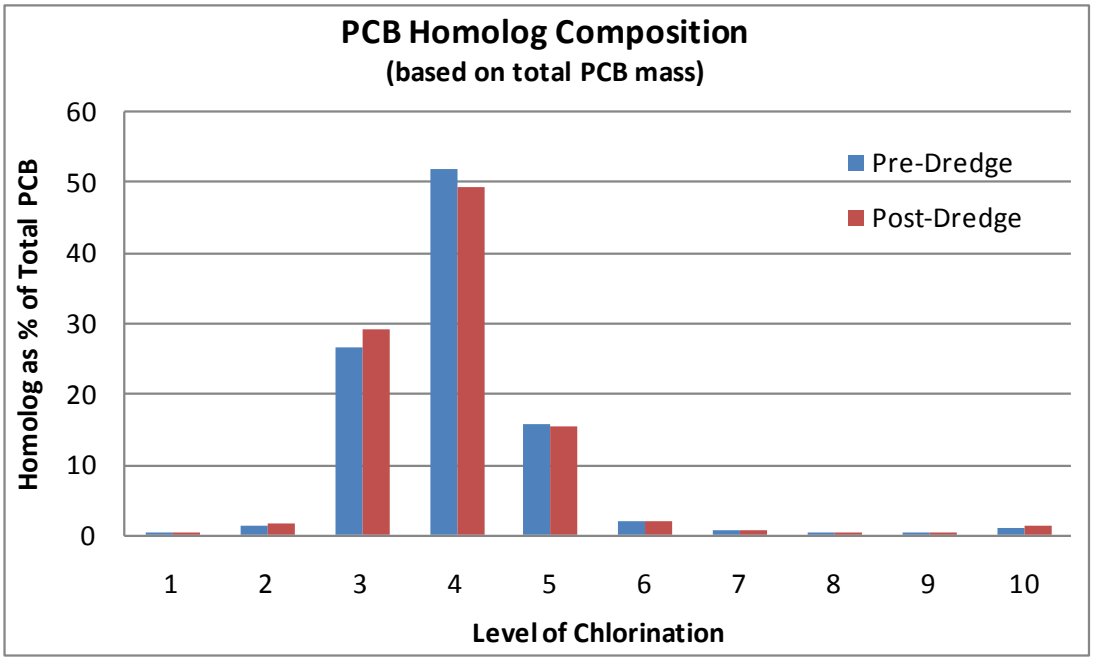
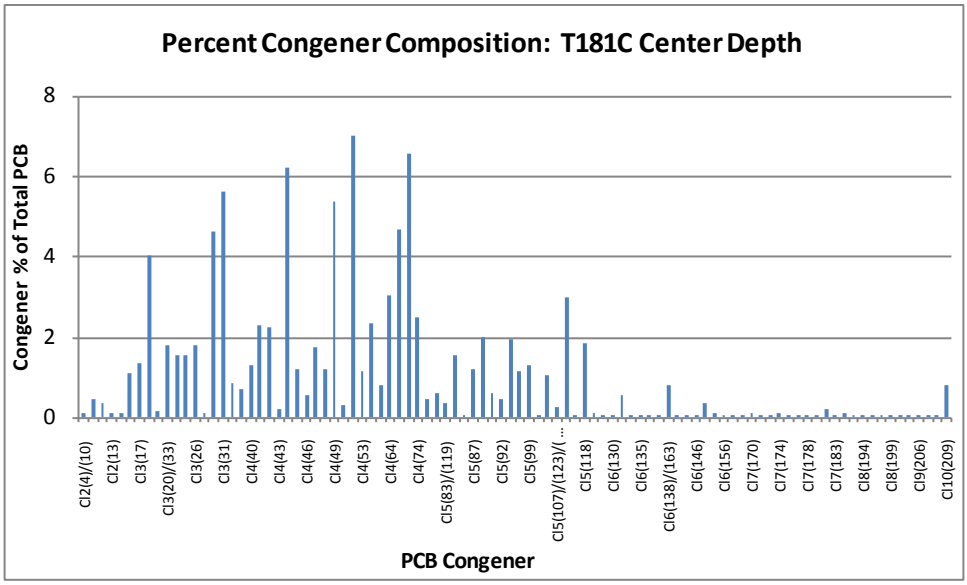


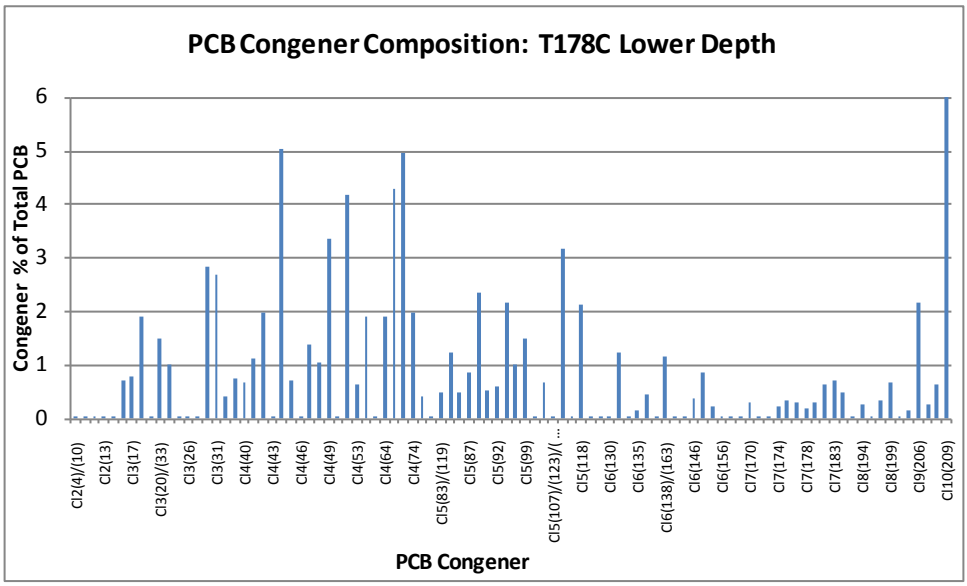

**Figure 3-17. Pre-Dredge and Post-Dredge Comparison of PCB Homolog Composition in Sediment Within the Study Area (T181 through T170)**

The PCB composition of the pre-dredge sediments with the highest PCB concentrations closely resembled Aroclors 1248 (Figures 3-18A and D). The composition of the pre-dredge sediments at the elevations (sediment depths) of the actual post-dredge cut line had a PCB composition with a significant proportion of Aroclor 1248, but had a unique composition that also included notable amounts of highly-chlorinated PCB congeners (Figure 3-18B), as can be seen in the right-hand corner of the congener distribution histogram from PCB170 to PCB209 (compare Figure 3-18B with Figure 3-18A). However, the post-dredge surface sediments had a PCB composition that closely resembled Aroclor 1248 without any notable contributions from most of the highly-chlorinated PCB congeners with the exception of some congener PCB209 (Figure 3-18C). The PCB composition of the post-dredge surface sediments did not resemble the composition of the sediments collected from the same pre-dredge elevation, but resembled the composition of the more contaminated sediments from a higher elevation. Again, if the dredged sediments were removed with complete effectiveness and no additional residuals were created during the dredging operation, one would expect the post-dredging surface sediment PCB composition to be equivalent to that of the pre-dredged sediments at the same depth, not to that of the highly contaminated sediments from a higher elevation as was observed in this study.

In addition to the PCB homolog and congener composition data review, similarities and dissimilarities in PCB composition were assessed using exploratory PCA techniques. PCA is an exploratory data analysis tool. Exploratory algorithms are designed to reduce large and complex datasets to a suite of best views. PCA is used as a means to explore the variability in the PCB composition of the samples. Specifically, one form of PCA output is 2- or 3-dimensional factor score plots in which the principal component scores for each sample are cross-plotted. If a significant portion of the variance in the dataset is accommodated in the first few principal components, then the Euclidean distances between sample points on such plots (e.g., PC1 v PC2 or PC2 v PC3) provide a measure of their chemical similarity. Samples that visually "cluster" are chemically similar and vice versa.

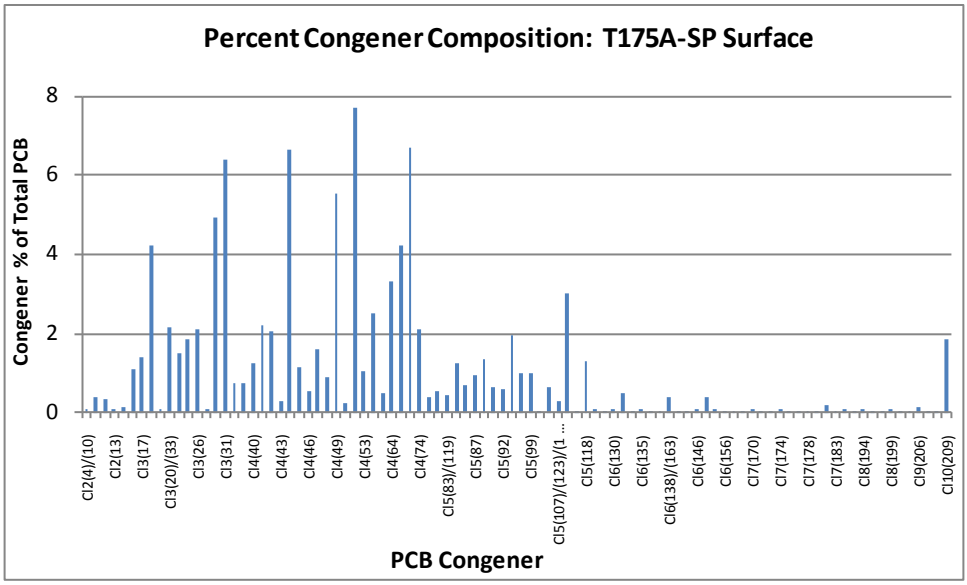



**A) Pre-Dredge Sample T181C (from the most contaminated depth)**

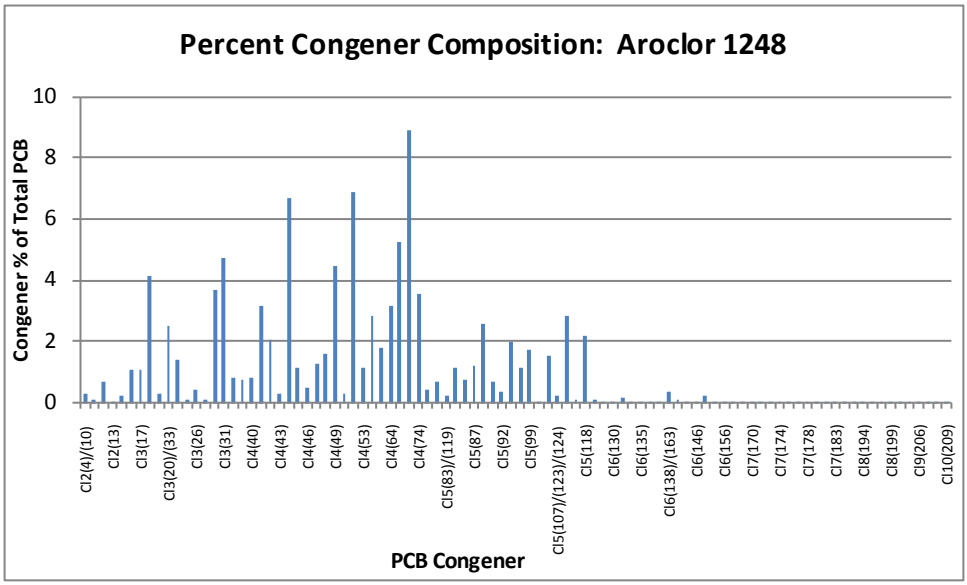



**B) Pre-Dredge Sample T178C (from a lower depth)**

**Figure 3-18. PCB Congener Compositions in a Representative Mid-Depth Sample (A) and in a Pre-Dredge Lower Depth Sample (B). The Pre-Dredge Lower Sediment Sample (B) is from a Comparable Elevation as the Post-Dredge Surface Sediment Sample (C).**




**C) Post-Dredge Sample T175A (surface)**




**D) Aroclor 1248**

**Figure 3-18. PCB Congener Compositions in a Representative Post-Dredge Surface Sample (C) and in Aroclor 1248 (D). The Pre-Dredge Lower Sediment Sample (B) is from a Comparable Elevation as the Post-Dredge Surface Sediment Sample (C). (Continued)**

Another form of PCA output, factor loading plots, is used to determine which individual variables (in our case PCB homologs and congeners) are responsible for any visual "clustering" observed. As such, PCA was a useful data analysis and exploration tool for this project dataset.

This data visualization and exploration was performed using the software EinSight (v. 4.04) by InfoMetrix, Inc. (Woodinville, WA), which provides qualitative data exploration capabilities. The PCA exploratory technique was used to help recognize groups of samples that may have shared similar PCB composition (i.e., similar relative PCB homolog and congener concentrations) and those that have clearly different compositions. Prior to PCA analysis, the PCB congener data were normalized to the t-PCB concentration in each sample to eliminate influences caused by concentration alone. The goal of these analyses was to identify difference and similarities between samples based on PCB pattern recognition. Aroclor formulations were also included in the dataset for comparison purposes.

The PCA analyses confirmed the observations made during the earlier described review of the PCB homolog and congener data and further documented the pre- and post-dredge sediment samples' PCB compositional similarities and relationships. The PCA results were similar regardless of whether the analysis was conducted using homolog or individual congener data. The PCA results are shown in (Figures 3-19 and 3-20). The results clearly indicated that the majority of the pre-dredge subsurface samples from the depths with high PCB concentrations and the post-dredge surface samples had similar PCB compositions (likely from the same source of PCBs). These samples all appeared to be from the same Aroclor 1248 source, as these samples clustered closely with each other and at the Aroclor 1248 reference composition. The pre-dredge surface sediments had a slightly different composition and were drawn away from Aroclor 1248 towards Aroclor 1260 with many of the surface sediment samples clustering closely with a 3:1 mixture of Aroclor 1248:1260. These samples clearly had a significant contribution from the Aroclor 1248 source but also some contribution from a source of Aroclor 1260. The pre-dredge samples from below the most contaminated zone and at the elevation (sediment depth) equivalent to that of the post-dredge surface sediment were also drawn away from Aroclor 1248, but in a different direction. These pre-dredge samples from a greater depth were drawn towards Aroclor 1268, with a number of them clustering near a mixture of Aroclor 1248 and 1268, which indicated some contribution from a highly-chlorinated PCB source.

The PCA results supported the earlier findings suggesting that the PCBs in the post-dredge surface sediments originated primarily from the most contaminated zone in the pre-dredge sediments. As before, if the dredged sediments were removed completely and no additional residuals were created during the dredging operation, one would expect the post-dredging surface sediment PCB compositions (and the PCA results) to be similar to those of the pre-dredged sediments from the equivalent sediment depths. Therefore, the post-dredge sediment samples would be expected to cluster towards the Aroclor 1248/1268 material along with the pre-dredge deep sediment samples. Instead what was observed was that the post-dredge surface sediments clustered with the pre-dredge samples from the highly contaminated zone typical of a higher elevation.

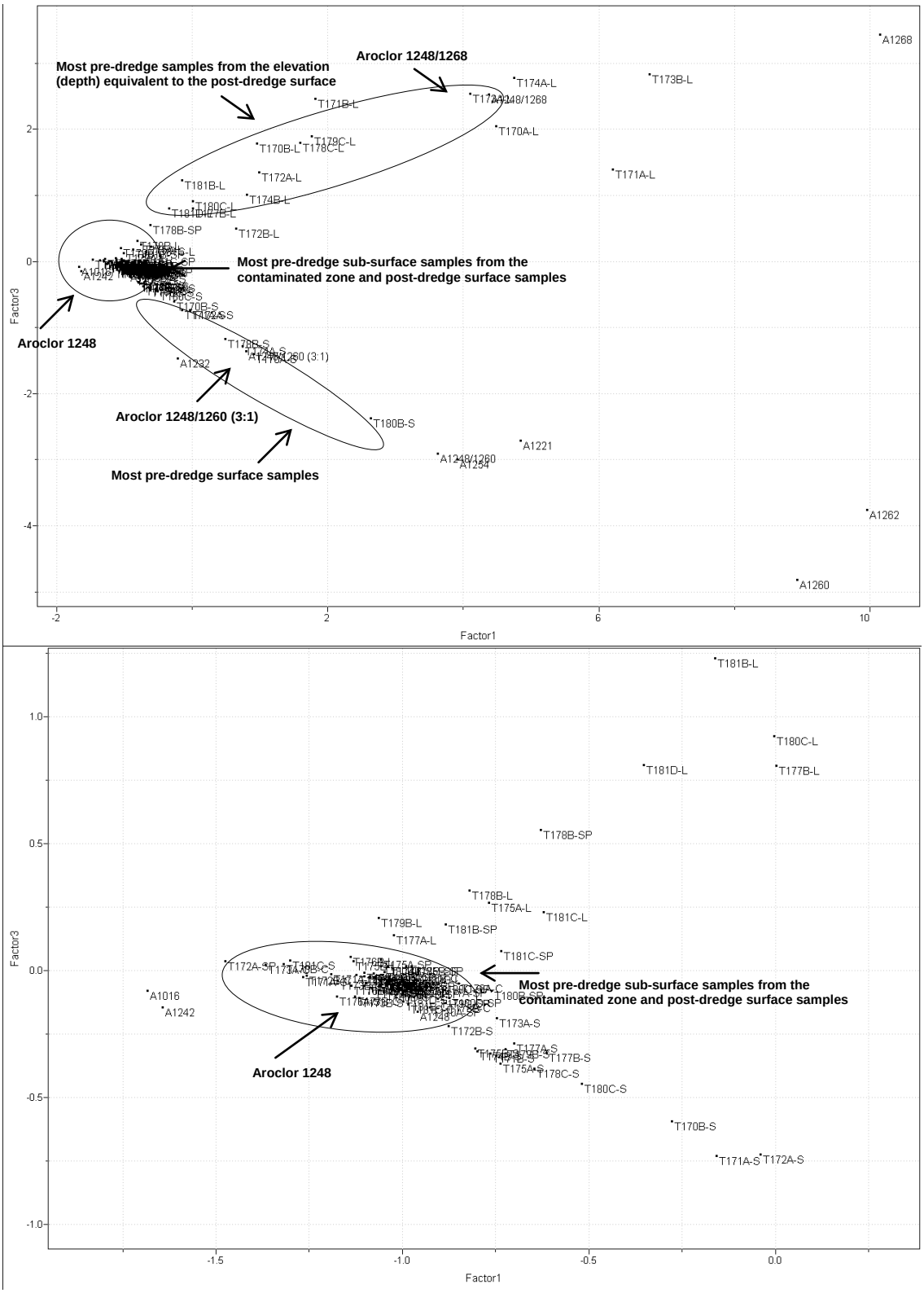



**Figure 3-19. Principal Component Analysis (PCA) Using PCB Homolog Data for Pre- and Post-Dredge Sediments in the Study Area; Full View (upper) and Zoomed View (lower)**

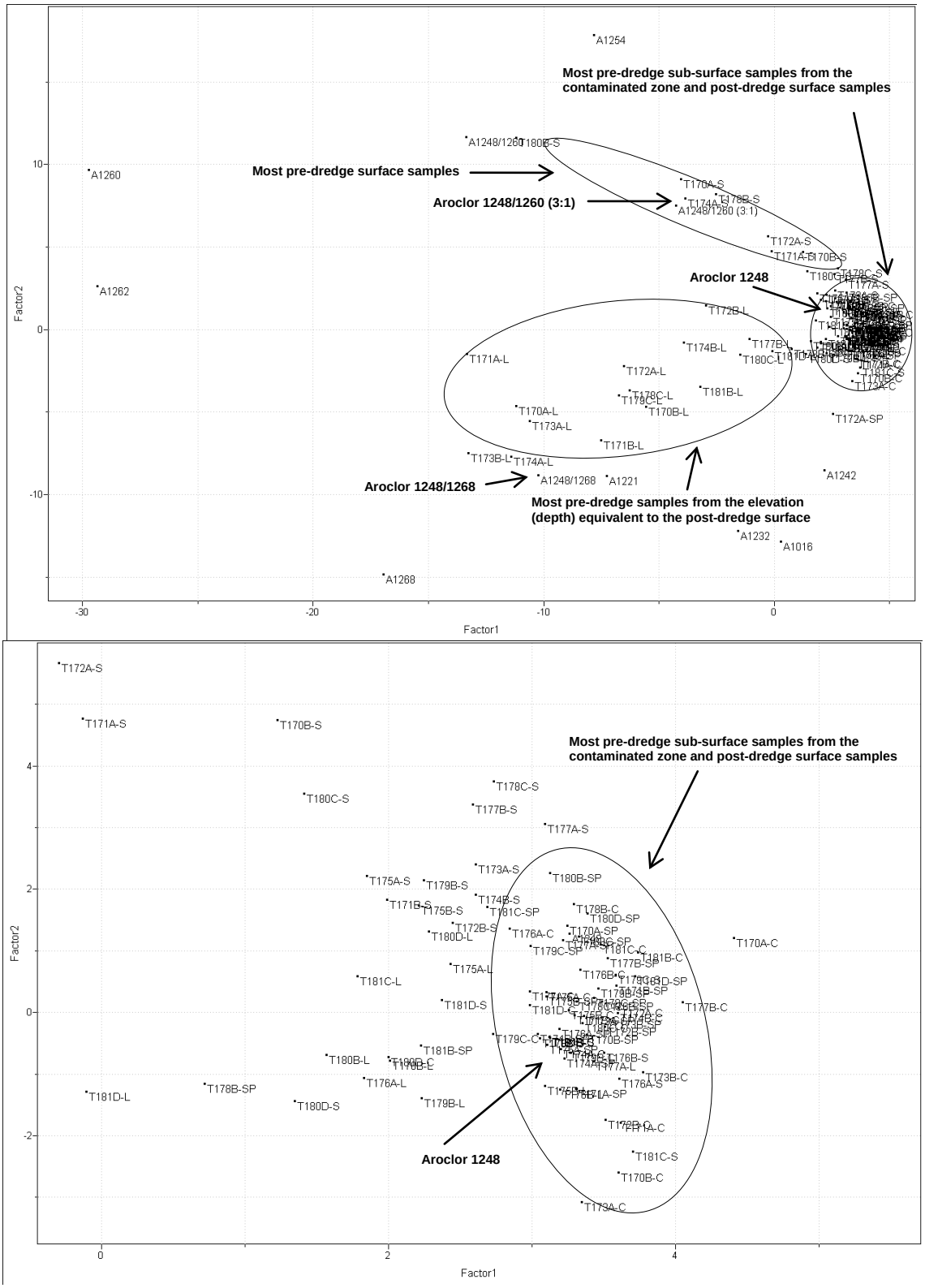



**Figure 3-20. Principal Component Analysis (PCA) Using PCB Congener Data for Pre- and Post-Dredge Sediments in the Study Area; Full View (upper) and Zoomed View (lower)**

### 3.3.3 Post-Dredge PCB Characteristics and Implications for Dredged Residuals.

The relatively uniform post-dredge surface sediment PCB concentrations and composition, compared to the pre-dredge samples, indicated that the post-dredge surface sediments generally did not originate from the less uniform pre-dredge sediments from the same location and elevation. In addition, the PCB concentrations and composition of the post-dredge surface were dissimilar from the pre-dredge sediments from the same elevation, indicating that they were not closely related. The significant increase in the PCB concentration of the post-dredge surface sediments, compared to the pre-dredge sediments from the same elevation, suggests that the post-dredge surface sediments originated from the more contaminated sediments. In addition, the PCB compositions of the post-dredge surface sediments were essentially identical to the PCB compositions of the highly contaminated pre-dredge sediments at higher elevations. Thus, the post-dredge surface sediments appeared to be dredge residuals originating from well-mixed pre-dredge sediments from the most contaminated pre-dredge sediment depths. The most contaminated pre-dredge sediments clearly had a significant influence on the concentration and composition of the post-dredge surface sediments, even though those most contaminated pre-dredge sediments were generally found a few feet above the dredge cut line.

## 3.4 Two (2)- and Three (3)-Dimensional PCB Modeling of Pre- and Post Dredge Areas

3-D block diagram visuals for t-PCBs in sediment before and after dredging were constructed using EarthVision modeling and visualization software. A total of 328 and 149 data points were used in the calculation of the t-PCB grid for the pre-dredge and post-dredge data, respectively. The 3-D minimum tension gridding algorithm calculated a smooth surface that closely fit the input data values using a bicubic spline technique. The t-PCB visuals shown in this report have a unit rectangular lattice or grid cell size of 20 ft in the X direction, 20 ft in the Y direction, and 1 ft in the Z (depth) direction. The grids were contoured using an irregular contour interval to best visualize the broad concentration data distribution for t-PCBs.

Figures 3-21 through 3-24 provide cross section views of the pre- vs. post-dredge sediment t-PCB concentrations as a function of elevation for T175, T174, T173, and T172, respectively. In these figures, the post-dredge t-PCB concentration contour is shown at the top and the pre-dredge sediment t-PCB contour is shown at the lower portion of the figure. The elevation intervals and scale are consistent among figures, and the estimated dredge cut line and pre- and post-dredge bathymetry are consistent with the surfaces shown in subsequent figures (see Section 3.6 for methods used to determine the maximum dredge cut line).

It is worth noting that in some cases post-dredge cores were not driven as deep as the pre-dredge cores in similar locations. As such, the post-dredge concentration contours represent greater interpolation from a general lack of local data in those cases.

The post-dredge sediment surface at T174 increased an order of magnitude. This was also the case in Figures 3-22 and 3-23 where T173 and T172 are shown, respectively. Post-dredge sediment surface concentrations increased by 10 to 20 times, resulting in concentrations ranging from 2.7 to 4.6 ppm.

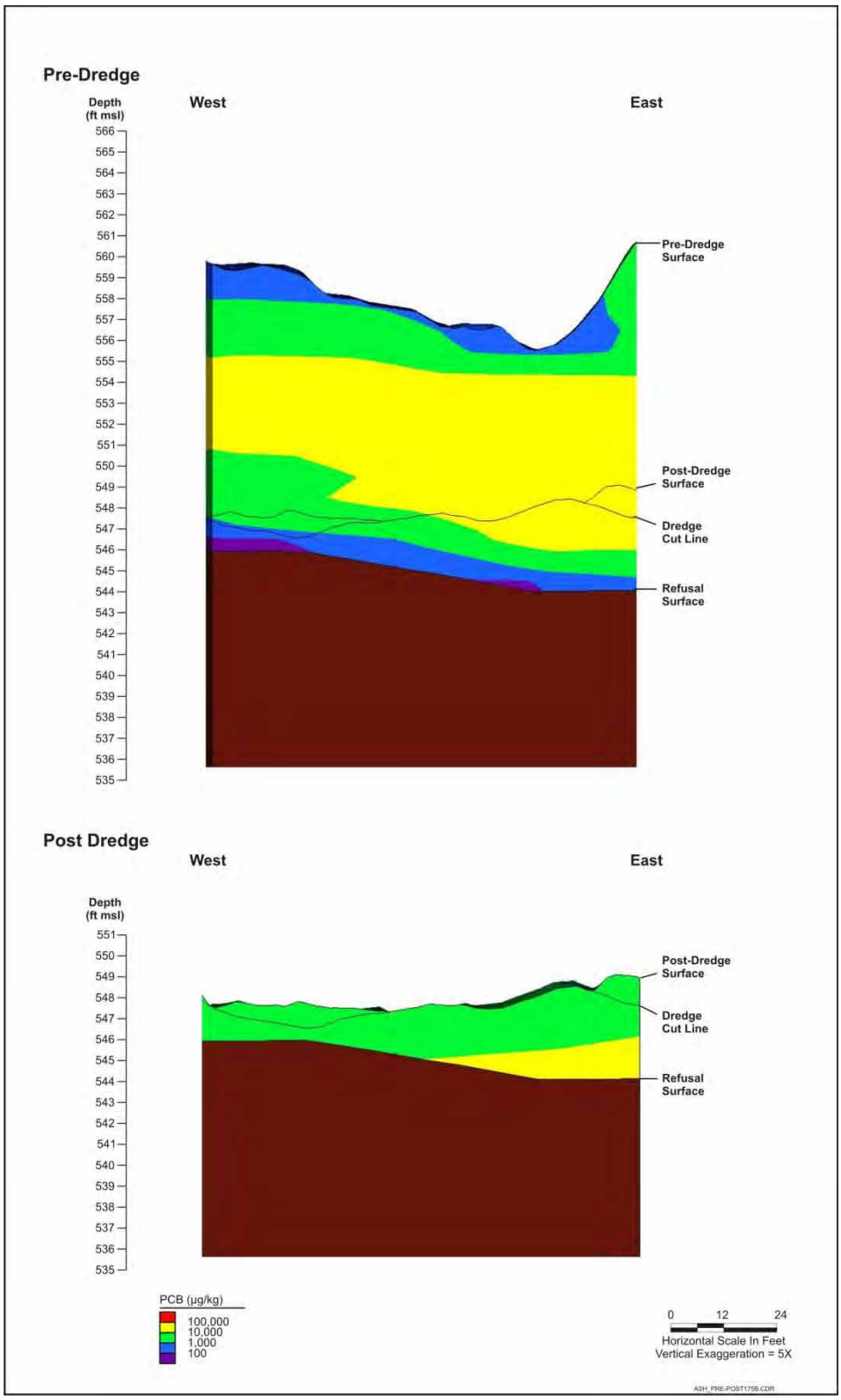



**Figure 3-21. Comparison of Pre- and Post-Dredge Cross-Section t-PCBs in Sediment at T175**

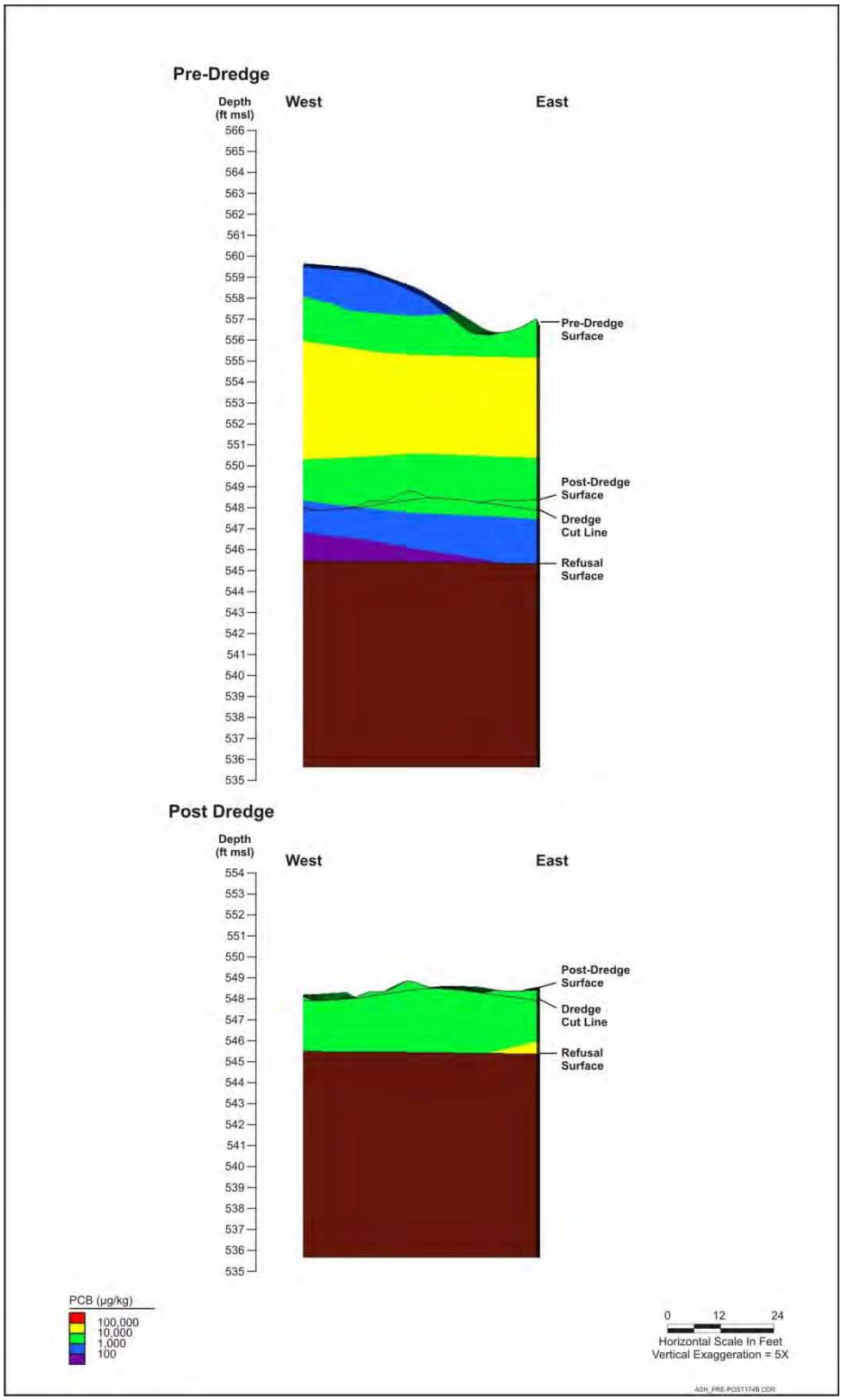



**Figure 3-22. Comparison of Pre- and Post-Dredge Cross-Section t-PCBs in Sediment at T174**

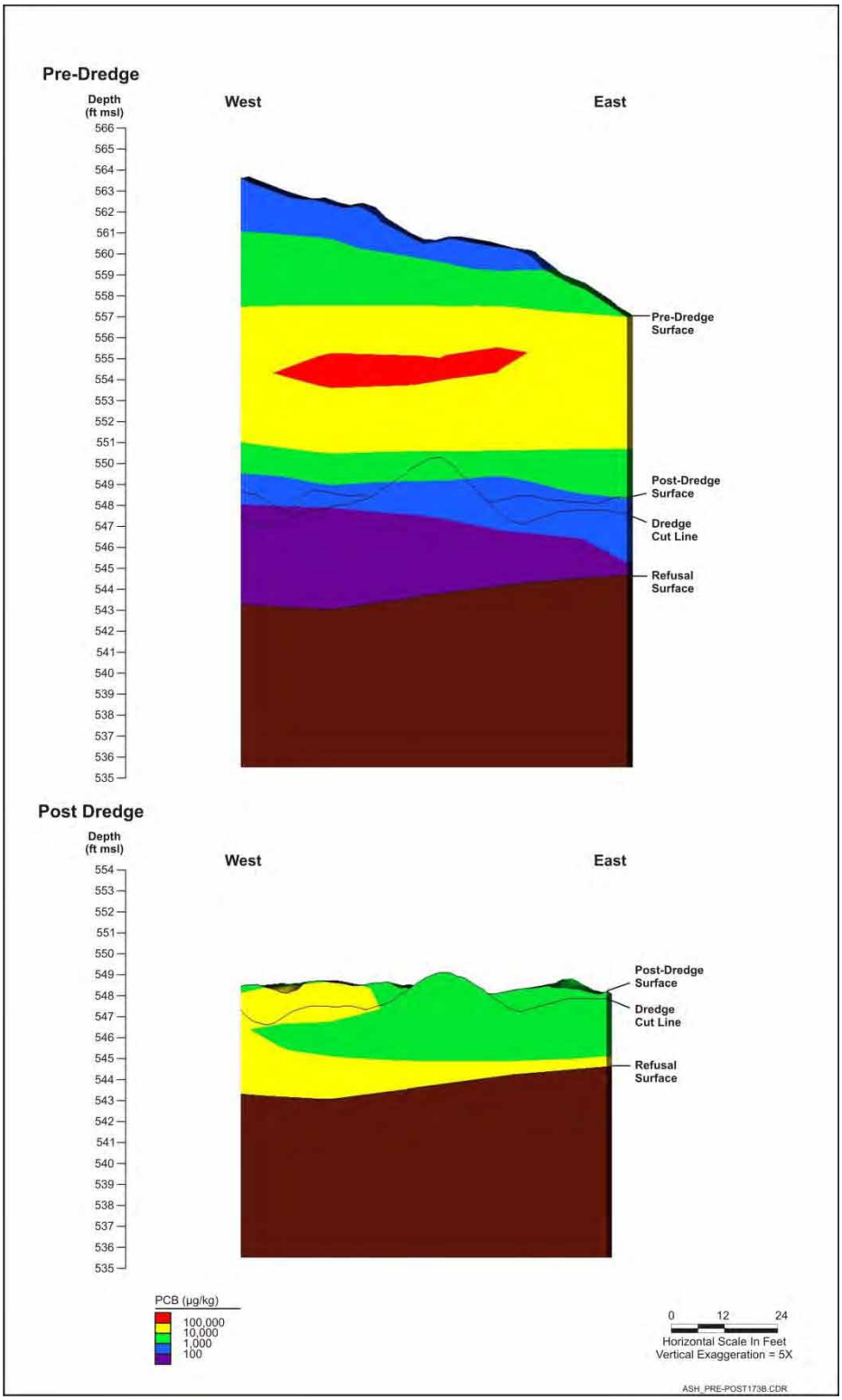



**Figure 3-23. Comparison of Pre- and Post-Dredge Cross-Section t-PCBs in Sediment at T173**

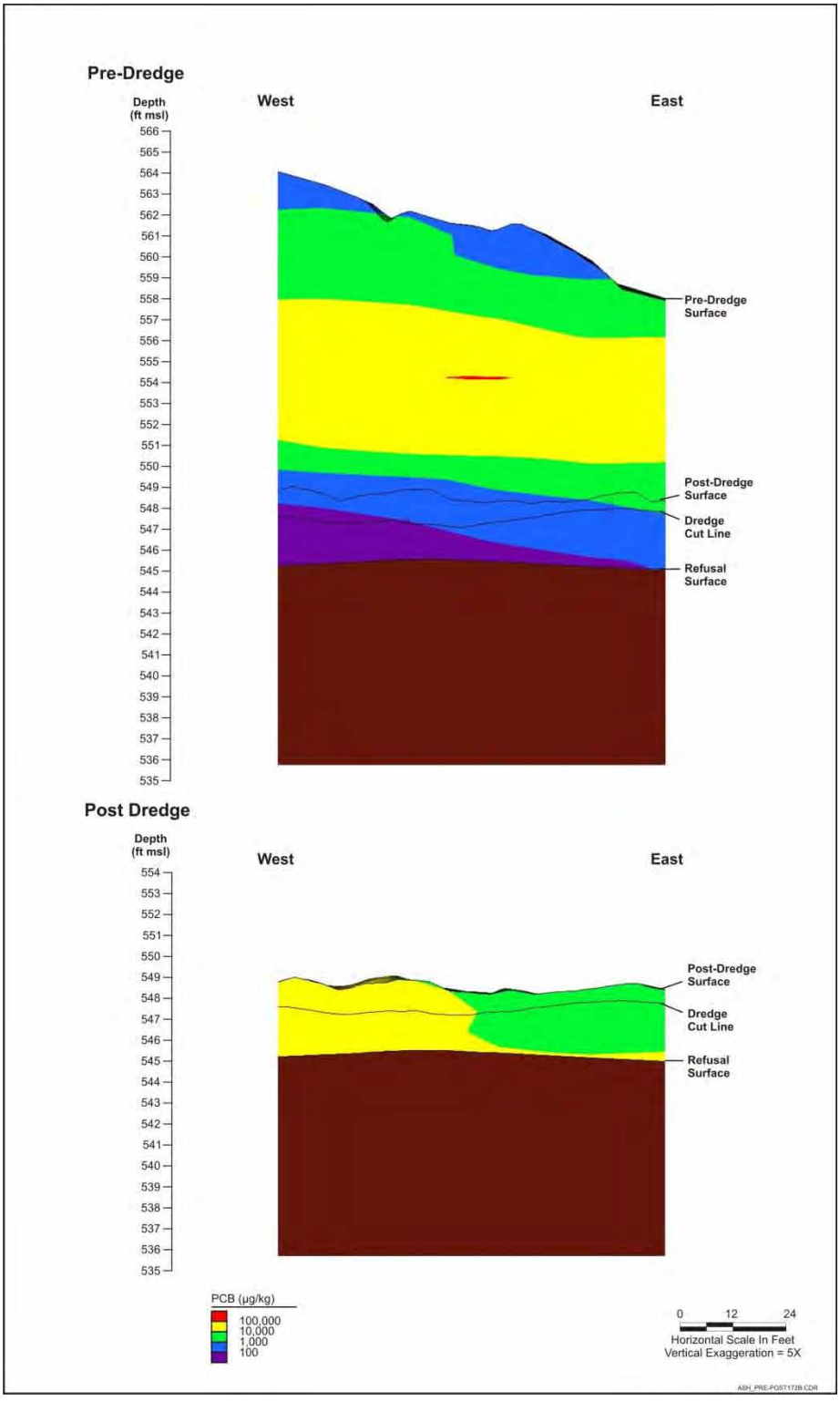



**Figure 3-24. Comparison of Pre- and Post-Dredge Cross-Section t-PCBs in Sediment at T172**

## 3.5 Bathymetric Surveys Prior to, During, and Following Dredging

Bathymetric surveys were conducted before and after dredging in 2007 and 2 years following the completion of dredging in 2009. The 2007 pre- and post-dredge bathymetry data are discussed herein, and the 2009 data will be presented in a subsequent report. Each bathymetric survey covered the entire extent of the GLLA dredge project area; however, only the bathymetric data specific to the ORD study area are discussed in this report. Additionally, the pre-dredge survey was implemented after dredging had already commenced in some areas including in the 'Upper Turning Basin'. This specifically impacted the pre-dredge bathymetry in the study area in proximity to T181. Any interpretations related to pre-dredge surfaces in this area were conducted using pre-dredge bathymetric data supplied in-kind by J.F. Brennan or from other pre-dredge depth data recorded by the field team. Figures 3-25 and 3-26, respectively, depict the pre- and post dredge bathymetric survey results for the study area.

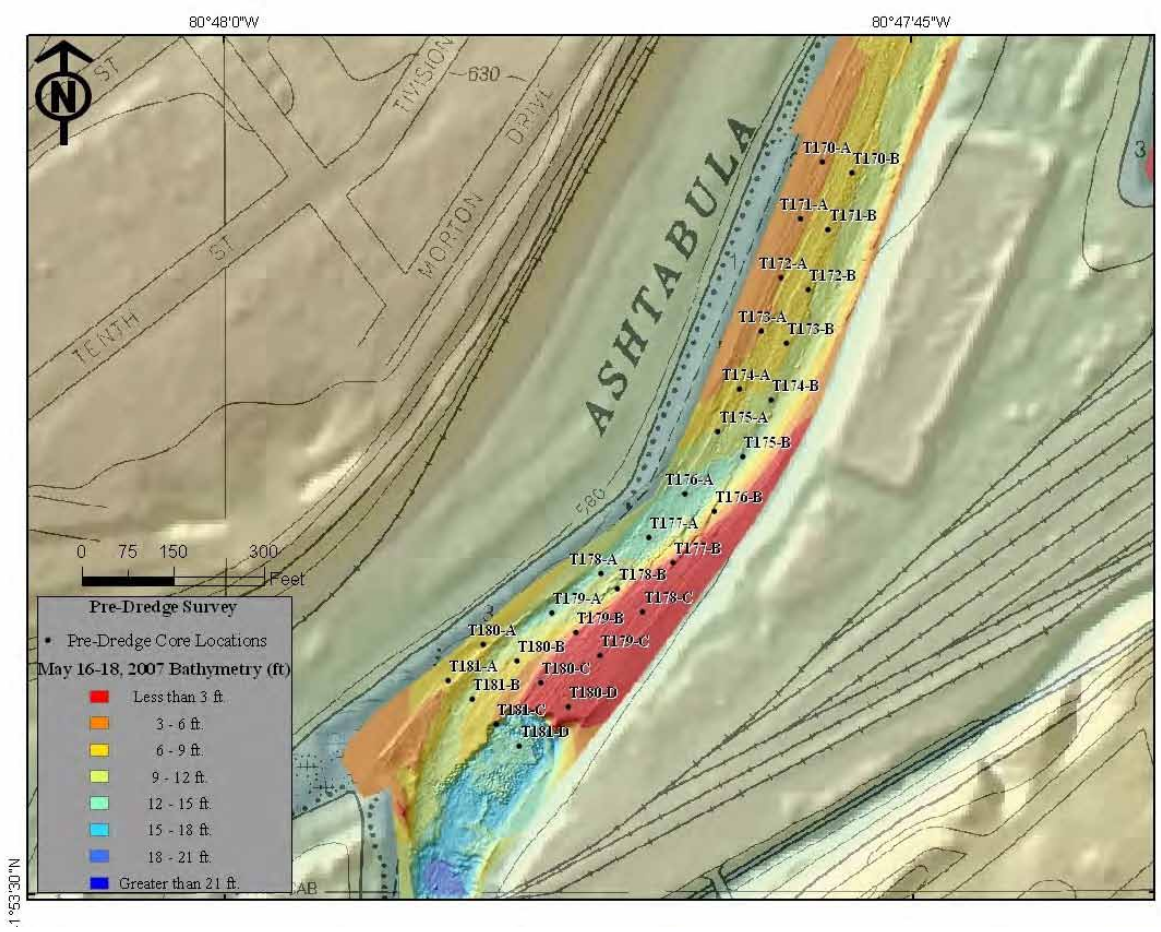



**Figure 3-25. Pre-Dredge Bathymetric Survey Results for the Study Area**

The pre-dredge bathymetric data illustrated in Figure 3-25 indicate shallow water and increased sediment thickness existed on the eastern bank of river between T181 and T176. This area corresponded with the highest pre-dredge PCB concentrations shown previously in Figure 3-9 and occurring approximately 9.5 ft below the pre-dredge sediment surface. The water column depth ranged from approximately 3 to 10 ft deep in the extended study area. A narrow channel was evident running from upstream at T181 to the

downstream extent of the study area at T170. Figure 3-25 also shows the extent of dredging on the east bank just south of T181 that commenced prior to the first bathymetric recording. Sediment had been dredged to a depth of approximately 20 to 23 ft below the water surface (IGLD85).

The post-dredge bathymetric data generated after dredging are shown in Figure 3-26. Dredging in this area was completed on approximately June 18, 2007, with Stage I dredging of the river completed in late October 2007. The bathymetric survey shown here was completed on November 15, 2007.

The post-dredge sediment surface was measured to be between 20 and 23 ft below the Lake Erie IGLD85 in most locations. The target dredge depth was achieved within the ORD study area. It is understood when interpreting these bathymetric data that the timing of such electronic surveys plays an important role in defining what is being measured. As the unconsolidated sediment is becoming more consolidated over time, it is expected that the sediment surface may change. Also, the unconsolidated sediment may be more susceptible to scour or erosional events. It is realized that additional research will be needed to identify optimal timing for collecting these data with specific consideration given to site-specific conditions. U.S. EPA will be conducting more bathymetric surveys over the next several years on the Ashtabula River to define the changes in the bathymetric profile over time. Coupled with sediment core sampling and analysis, the fate of contaminated sediment residuals will be monitored and reported along with other long-term parameters being measured in this investigation.

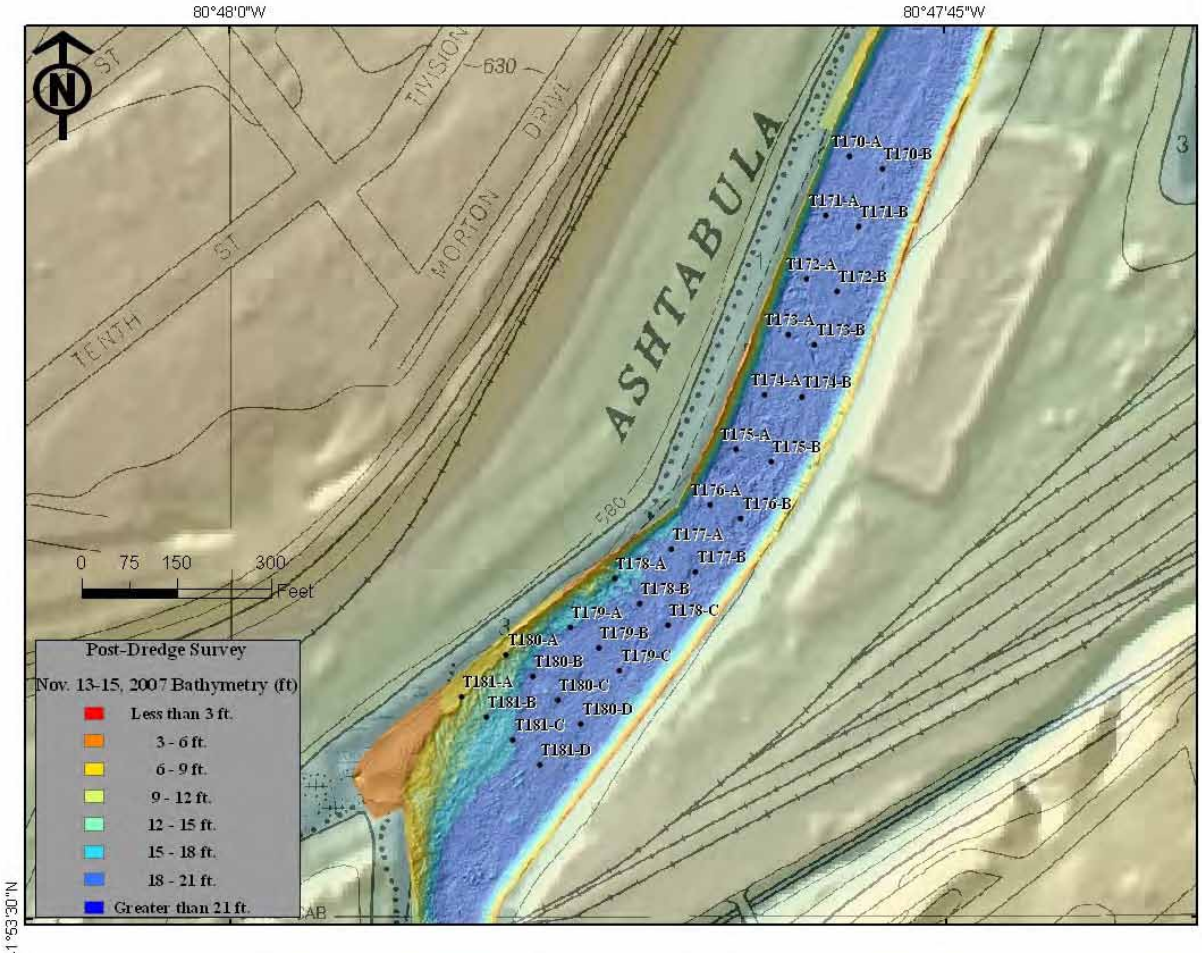



**Figure 3-26. Post-Dredge Bathymetric Survey Results of the Study Area**

To date, the following MBS have been conducted to support this research:

- Initial (pre-dredge) multi-beam bathymetric data were collected May 16-18, 2007.
- Daily multi-beam bathymetric surveys were conducted May 31 - June 10, 2007 (with the exception of June 4, 2007).
- Final (post-dredge) multi-beam bathymetric data were collected November 13-15, 2007.
- An additional post-dredge multi-beam bathymetric survey was completed in November 2009 and will be presented in a subsequent report.

In addition to the pre- and post-dredge bathymetric surveys, bathymetric surveys were also conducted on a daily basis during dredging operations to map the day-to-day morphology of the sediment bed. Figures 3-27 through 3-30 show a temporal view of the bathymetry contour compared to the estimated dredge cut lines for T175, T174, T173 and T172, respectively. These cross-sectional views capture the time period from initial dredging to near completion of dredging for T175 and T174; however, only a portion of dredging is captured at T173 and virtually no dredging was captured at T172. In most cases, the estimated dredge cut line appeared to be approximately 0.5 to 1.5 vertical ft below the post-dredge bathymetric elevations and in some cases near to or above the post-dredge bathymetry.

A more detailed review of the sediment bathymetry cross sections in Figure 3-27 suggests potential sloughing may have occurred along the western bank of the river at T175. The June 6 survey (blue line) indicates the bathymetric surface was lower in elevation than on the previous day (June 5). On June 6, the sediment thickness increased approximately 6 ft at a distance of approximately 10 to 20 ft from the western shoreline. This may have been due to sediment shifting as a result of slumping bank sediments or movement of sediment due to obstructions or debris encountered while dredging. Dredge reports for June 6 do not indicate any specific problems noted in the vicinity of T175. The analysis was repeated on each cross section shown here.

### 3.6 Survey and Dredge Position Data to Calculate Residuals

One method of estimating dredge residuals evaluated in this study was the use of bathymetric surveys and dredge head position data to determine the inventory of sediment removed and the corresponding amount of dredge residuals remaining. Bathymetric surveys are routinely used in dredge operations to confirm the targeted dredge cut line has been attained. Typically, these surveys are completed with single-beam survey equipment; however, for the optimum development of this approach (and other project objectives) a high resolution multi-beam survey was performed as described below. Additionally, a dredge head positioning system was used in this project that provided real-time assessment and recording of the dredge head position (detailed below). Conceptually, dredge residuals thickness can be estimated by calculating the difference between the maximum depth (lowest elevation) attained by the dredge head in a specific location and the post-dredge sediment surface elevation measured bathymetrically at the same location. This approximation of dredge residuals thickness can be combined with pre- and post-dredge sediment physical and chemical characterization data to calculate estimates of the mass of sediment and contaminant residuals over the surveyed areas.

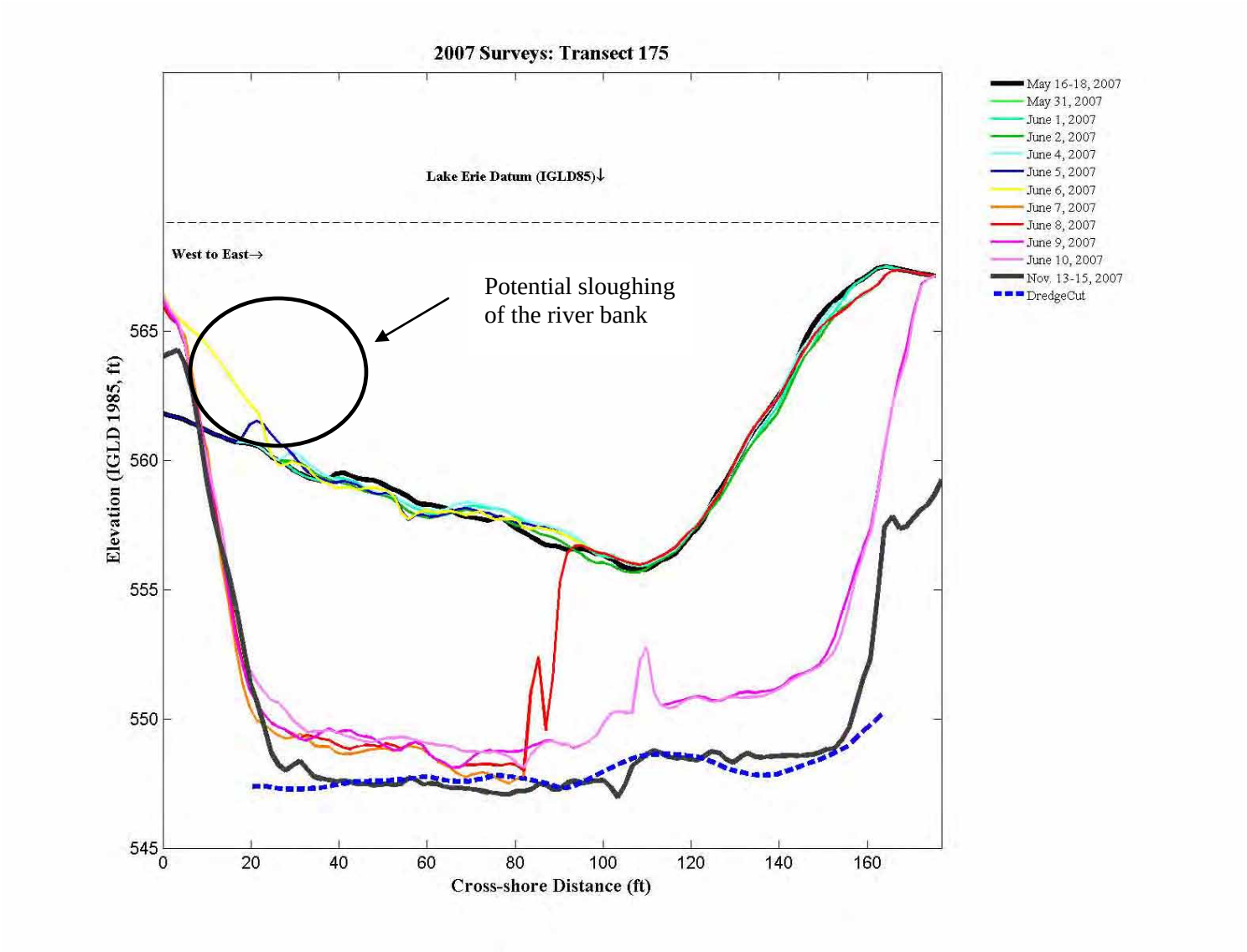



**Figure 3-27. Cross-Section View at T175 Showing the Change in Bathymetry During Dredging**

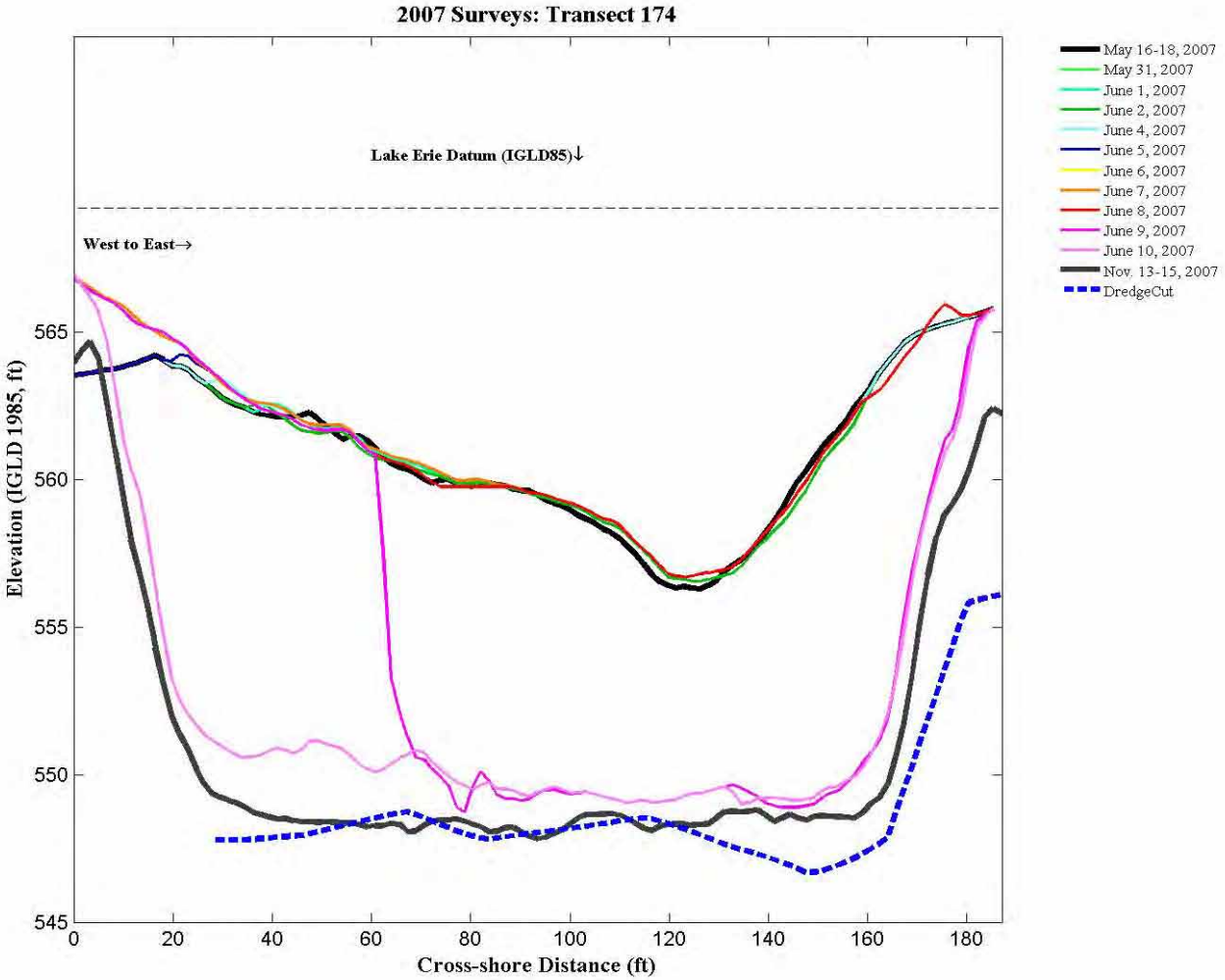



**Figure 3-28. Cross-Section View at T174 Showing the Change in Bathymetry During Dredging**

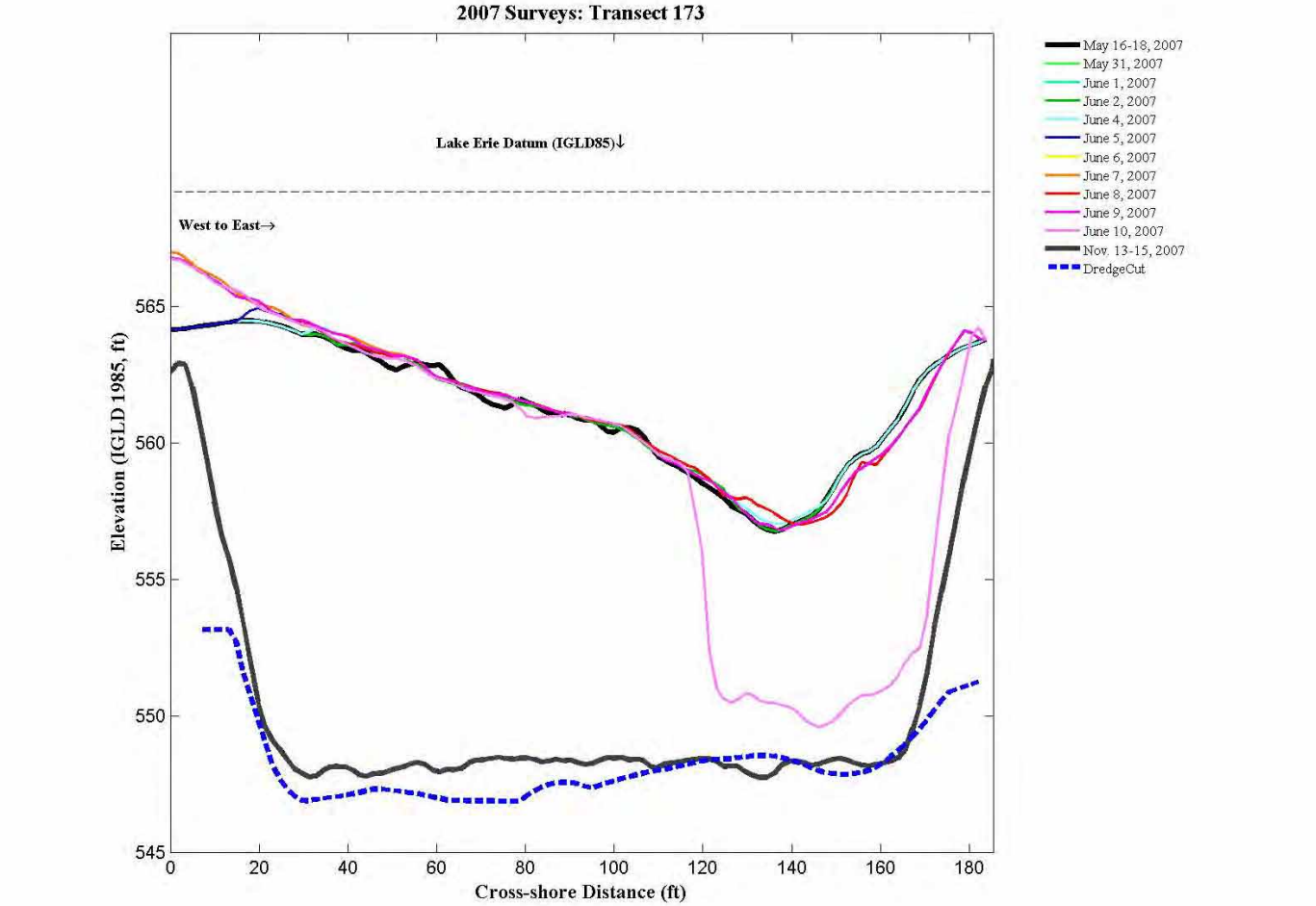



**Figure 3-29. Cross-Section View at T173 Showing the Change in Bathymetry During Dredging**

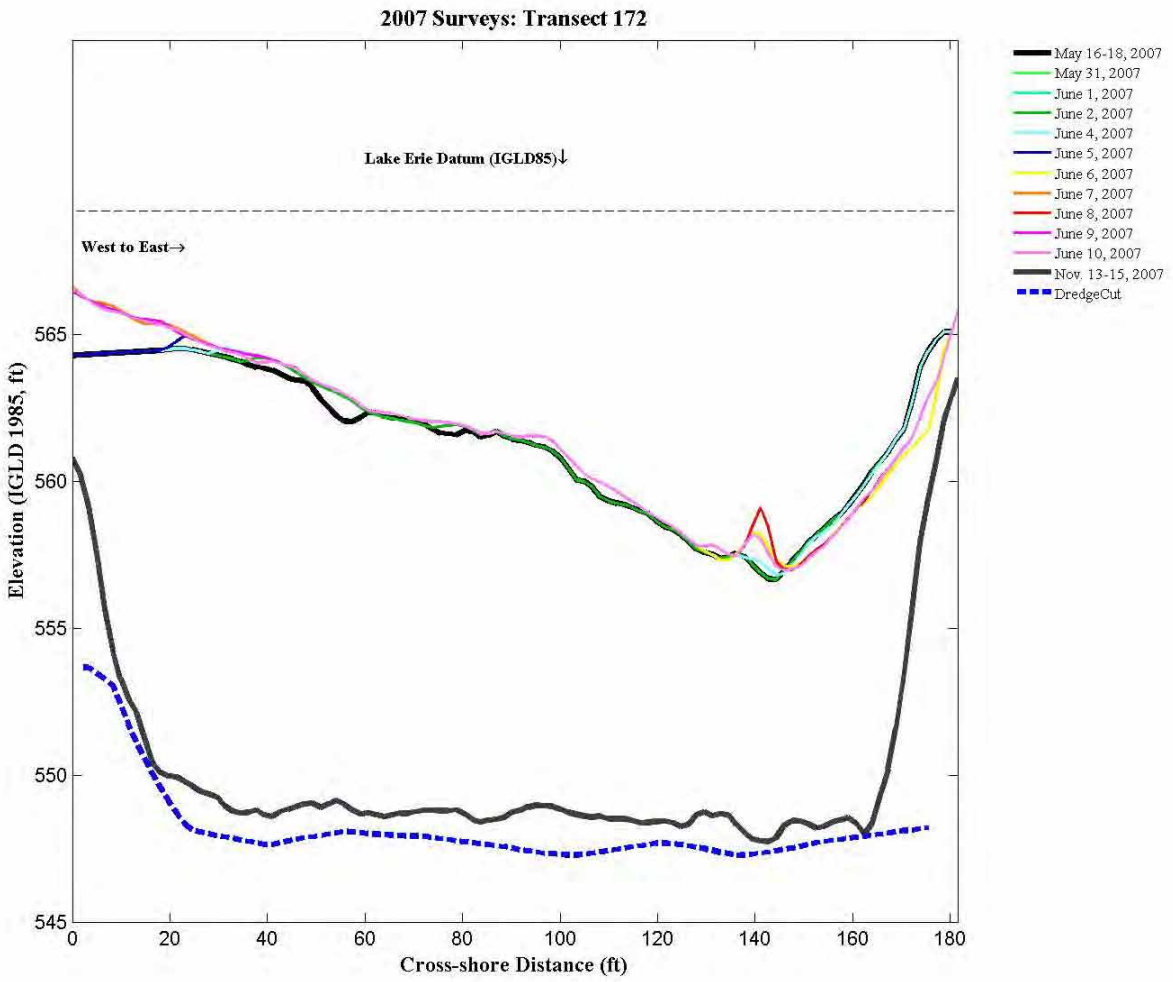



**Figure 3-30. Cross-Section View at T172 Showing the Change in Bathymetry During Dredging**

Several steps were used for this approach. The maximum dredge cut depths were determined based on the recorded positions of the dredge head (shown as the dredge cut line in Figure 3-31). This information was used to develop a 3-D surface that represented the maximum extent (minimum elevation) of the dredging. A post-dredge bathymetric survey was conducted for the dredged area (also shown in Figure 3-31 as the post-dredge surface). Chemical and physical measurements were performed to adequately characterize pre- and post-dredge sediments. Once these steps were completed, the data were processed using 3-D computer models to calculate post-dredge residuals volume and mass. The following sections (3.6.1 to 3.6.3) detail the processes used in this study to complete these steps. Selected examples on specific transects for which the complete datasets were available are used to demonstrate the approach. Additional data compilation and processing are ongoing to provide complete coverage of the entire research study area and will be discussed in subsequent reports. It should be noted that although the bathymetric survey data were designed to be used in this dredge residuals estimation process, the dredge head position data were being collected by the dredge contractor for operational purposes of indentifying targeted dredge areas and not necessarily with this specific analysis in mind. Therefore, additional data processing and QA/QC checks may be required before the data can be utilized as needed in this approach. The dredge contractor, J.F. Brennan, has cooperated fully and contributed greatly to this effect by providing data where available. On future projects, the researchers anticipate working more strategically with dredge contractors to collect and process this type of data to fulfill dredge operation needs, but also to allow for greater ease of use for this particular data application.

### 3.6.1 Determination of the Maximum Dredge Cut Depth.

In-field observations and dredge reports produced by the dredge contractor for operational purposes were gathered and reviewed to determine the date and time of actual dredging in the targeted study area. These records were used to identify and obtain dredge coordinate data, which were provided in-kind for this research by the dredging contractor, J.F. Brennan. These data were used to develop a 3-D surface of the maximum dredge cut depth.

Horizontal and vertical position data (XYZ) for the dredge cutter head were supplied in various formats: raw Hypack© data, edited Hypack© data, and processed XYZ ASCII text files. XYZ data from the study area were extracted from all file formats, adjusted (to ensure that all data were in the same horizontal and vertical coordinate system), filtered, and then combined into one XYZ dataset. Figure 3-32 shows the 2-D plan view (XY) of the XYZ data that were plotted.

The plotted data resulted in a “data cloud” representing approximately 1.5 million individual data points, identifying the dredge head position in space and varying in intervals between every 1 second and 30 seconds of activity depending on the day of record. This information was used to approximate the maximum dredge depth, which was defined as the lowest elevation that the dredge cutter head reached during dredging operations in a specific XY space (described in more detail below).

For this analysis, the vertical position coordinate (elevation) extracted from the position data corresponded to the bottom of the cutter head at any given time. A surface grid was generated for the study area using the dredge position data. The area in which the surface grid was established for the calculations described in subsequent sections is shown in Figure 3-32 in red outline. Within each grid cell, the lowest elevation recorded was used as the maximum extent of the dredge cut for the entire grid cell. This surface grid was then used to generate a smoothed elevation surface. The conceptual model in Figure 3-31 shows a cross-section of the river study area with dredge cutter head XYZ position data and the calculated maximum dredge depth (cut line) generated from the elevation of the cutter head positions.

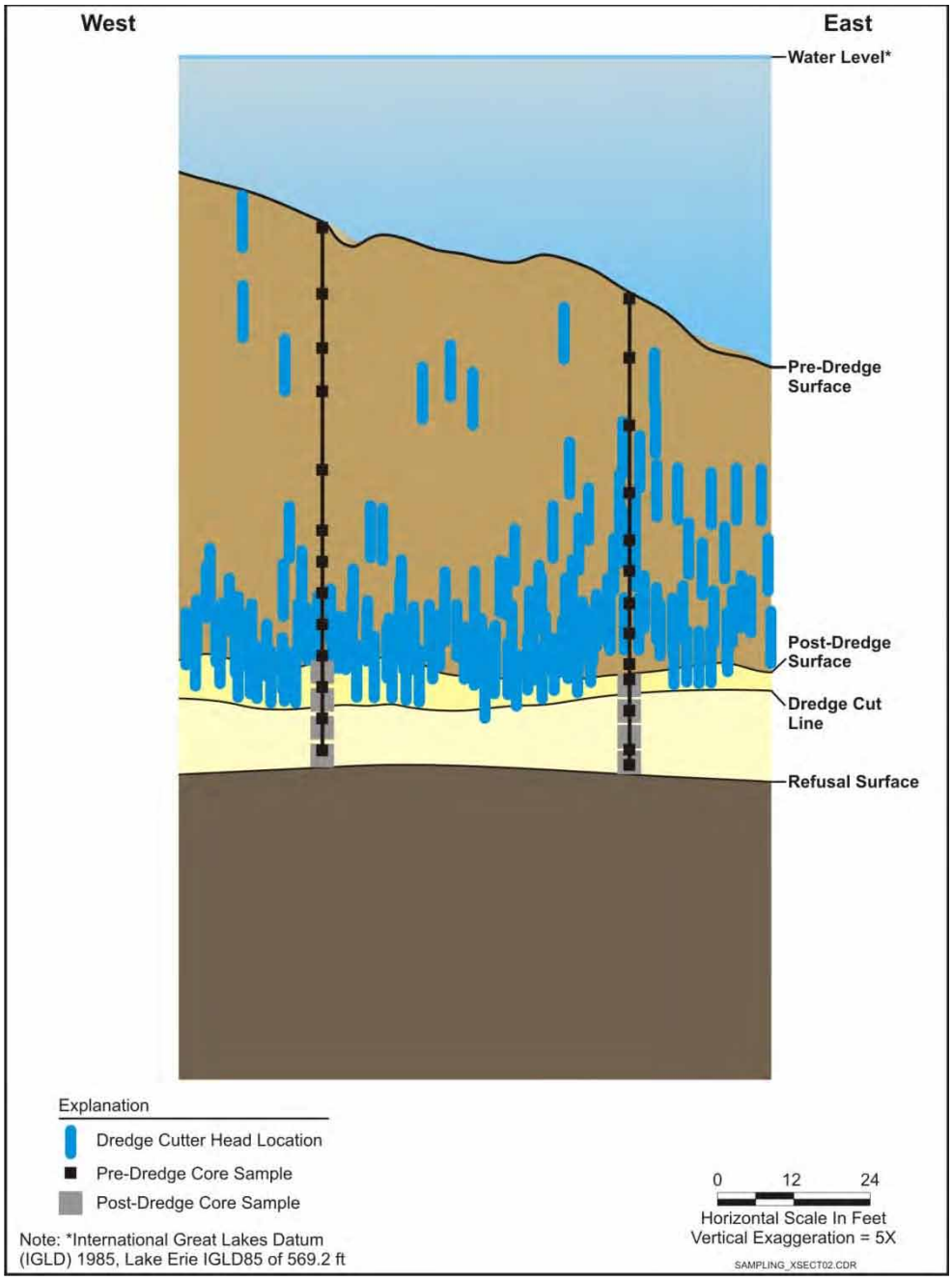



**Figure 3-31. Conceptual Model River Cross-Section Showing the XYZ Dredge Cutter-Head Position and Approximated Cut Line**



**Figure 3-32. Plan View of Dredge Activity in the Study Area**

More specifically the process to generate the maximum dredge cut depth surface is described below. The XYZ cutter head data were imported into ArcGIS and converted into a uniformly spaced raster surface. Several grid sizes (5 ft × 5 ft, 10 ft × 10 ft, 15 ft × 15 ft, 20 ft × 20 ft, and 25 ft × 25 ft) were tested. The lowest elevation within each grid cell was selected as the representative elevation of the cell, the end product being a uniformly spaced grid of the lowest dredged elevations in the study area. During the data filtering process, data were removed that represented the dredge-head position during time of "transiting" or when the dredge head was raised near or above the water surface. Elevations greater than 559.2 ft (IGLD85) were removed and decreased the total number of data points, making the dataset more manageable.

The selection of the grid cell dimensions was important. Smaller grid spacing allowed for a greater number of dredge head positions in a 2-D space; however, this spacing did not necessarily result in an interpretable dredge cut surface. Smaller grid cells resulted in many cells that did not contain dredge head position data at the lower surface elevations. As a result, the finer resolution grid surfaces contained artifically high dredge cut elevations ("spikes") that do not accurately represent the maximum dredge cut surface. After careful review of a range of grid cell dimensions, it was determined that, for this site, cell dimensions and interpolated surface were optimal at a 15 ft × 15 ft grid size. This grid and surface were exported from ArcGIS and imported into Earth Vision software to create a 2-D dredge cut surface using minimum tension gridding. The maximum dredge cut depth is shown in Figure 3-33.

Using the currently available data, the approach was demonstrated over a limited area of the study area. Transects 172-175 represent a series of transects with sufficient data coverage to utilize this approach. The researchers are continuing to process and evaluate data that may be used to extend the application of this approach over a broader area. This area included dredge activity in DMUs 19, 20, 21, and 22. The approximated dredge cut line in this part of the study area that was used for further processing to calculate residuals is shown in Figure 3-33. The red dashed line on this surface outlines the area in which dredge residual estimates were determined. These are described in Section 3.6.3.

### 3.6.2 Determination of the Post-Dredge Sediment Surface.

The next step in this approach for estimating dredge residuals was to develop an elevation schematic for the post-dredge sediment surface. A post-dredge bathymetric survey was conducted between November 13 and November 24, 2007 following completion of Stage I dredging. This survey was completed using the instrumentation and procedures described in Section 2.3.2. It should be noted that further study is needed to determine the most appropriate timing and technical limitations for the multi-beam survey approach used to characterize the post-dredge surface. Issues that need to be further considered include: the consolidation processes of the unconsolidated dredge residuals and how these impact the resolution of the bathymetric surface. The elapsed time after the completion of dredging before the post-dredge bathymetric survey is conducted could play an important role in defining the residuals. Dredge-generated residuals are generally composed of unconsolidated, recently-deposited sediment. Therefore, as natural sediment consolidation processes occur (such as dewatering, pore space reductions, particle re-arrangement, etc.), the measure of dredge residuals can change over time. A further complication is that the processes and extent/rates of those processes will be dependent on local site conditions such as the sediment's geotechnical parameters (e.g., particle size), the site's hydrodynamic conditions, and potentially the dredge technology used for the site. Significant research has been conducted on sediment consolidation processes under both natural and engineered conditions (e.g., sediment capping). This information combined with site-specific conditions should be considered in the development of full-scale implementation of this approach. Further study is warranted to identify the most appropriate timing for this type of measurement. Additionally, the selection of the appropriate bathymetric equipment should be considered in understanding how the density and characteristics of the residuals impact the bathymetric surface measured. The data developed in this study permit the demonstration of the approach with appropriate caveats and future improvements.

### 3.6.3 Estimation of the Post-Dredge Residuals

Estimation of the post-dredge residuals was completed for both total solids and t-PCBs. Sediment volumes were calculated for each of the 3-D isoconcentration shells generated from the PCB data interpolation described in Section 3.1.3 and shown in Figures 3-5 through 3-9. Each shell was bounded by 2-D planar bounding surfaces representing post-dredge bathymetry, maximum dredge cut depths, and core refusal surfaces. These 2-D surfaces were created using 2-D minimum tension gridding. Pre- and post-dredge sediment dry bulk density values were used to convert the sediment volume in these shells to a mass (dry kg). The mid-range concentration of each isoconcentration shell was multiplied by the sediment mass to estimate the mass of t-PCB in each shell range.

To demonstrate this approach, the estimated volume and mass of sediment within a 5-ft band (Y) in the linear (river flow) direction and across the river (X) from bank to bank for each of T175, T174, T173, and T172 were determined and is shown in Table 3-3. In addition, Table 3-3 summarizes the estimated dredge residuals in this 5-ft band and dredge efficiencies in terms of volume and mass of sediment and mass of t-PCBs removed.

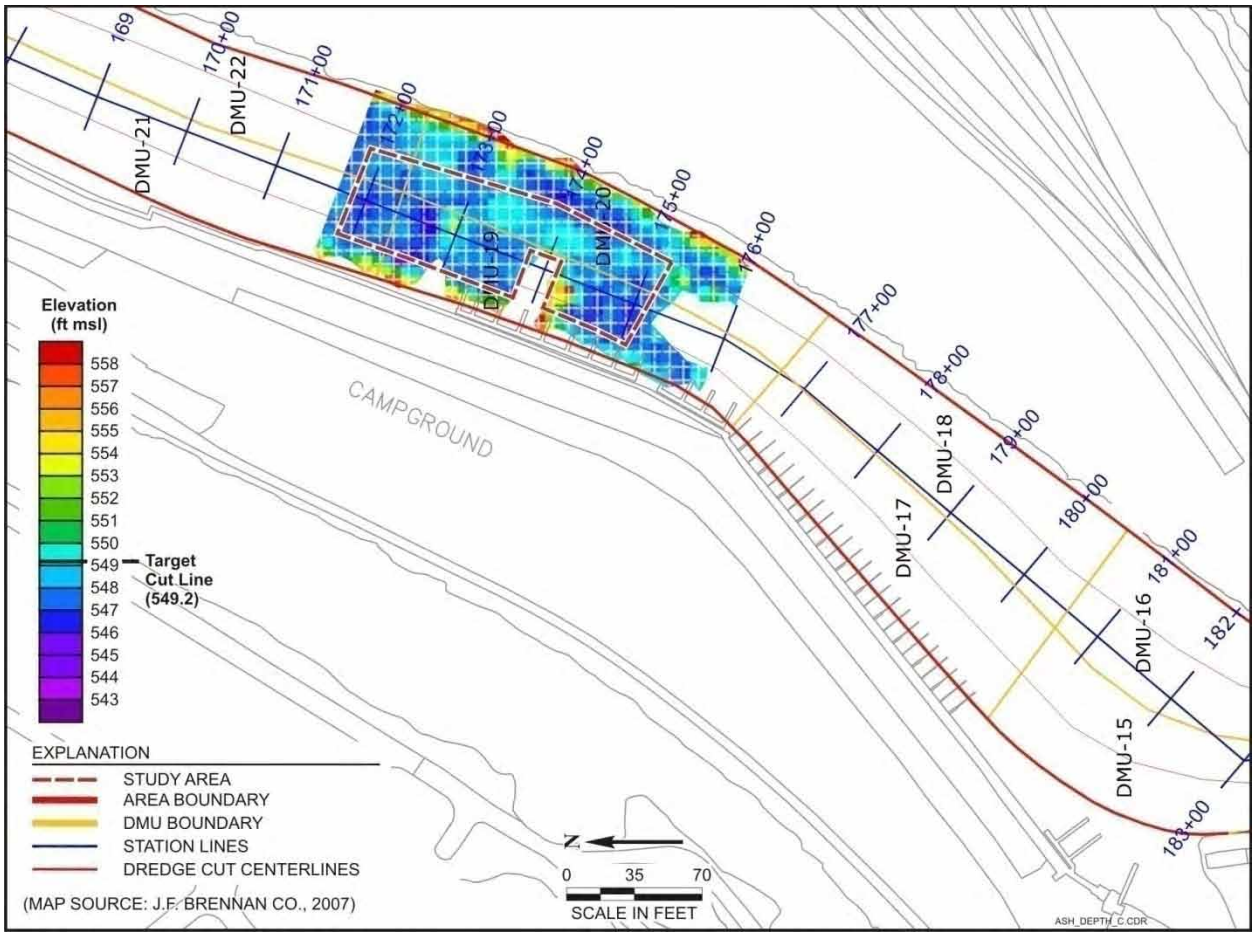



**Figure 3-33. Estimated Dredge Cut Line in Between T176 and 172 in the Study Area**

To convert sediment volumes to sediment mass, average dry bulk density values of 1.23 g/cm$^3$ and 0.99 g/cm$^3$ were used for pre-dredge sediment and post-dredge sediment, respectively. These values were determined from sediment segment data comparisons made between pre- and post-dredge cores collected from the same location and at the same depth for 14 sampling stations where samples aligned well vertically. Averages were generated from these samples in the 548 ft to 547.5 ft elevation range.

In addition to determining sediment volume and residuals within a 5-ft river transect band, total bank-to-bank sediment volume and residuals were estimated for an approximate 400-ft linear dimension of the river extending from T175 to T172. The area used to make this estimate is shown as the red polygon (dashed-line) in Figure 3-33. The estimated volume of sediment between T175 and T172 was determined to be approximately 13,596 cu yd as calculated by the difference between the pre-dredge bathymetry and the estimated dredge cut depth surface. Applying an average dry bulk density of 1.23 g/cm$^3$ resulted in an estimated pre-dredge sediment mass of 9,669,399 kg containing approximately 252 kg of t-PCBs.

Likewise, the estimated volume of dredge-induced sediment residuals between T175 and T172 was approximately 625 cu yd as determined by the difference between the post-dredge bathymetry and the estimated maximum dredge cut depth. Applying an average dry bulk density of 0.99 g/cm$^3$ yielded a total estimated dredge residuals mass of 361,668 kg. This sediment was estimated to contain approximately 3.3 kg of t-PCBs.

Therefore, dredging within the boundaries of T175 and T172 resulted in an approximate 96% removal of the sediment mass inventory, which in turn resulted in an approximate 99% removal of the t-PCB mass. Inversely, these removals correspond to approximately 4% residuals of the original sediment mass remaining that contains approximately 1% of the original PCB mass in this targeted dredge area. These dredge residuals are illustrated visually in Figures 3-33 to 3-36 that show each transect in 2-D representations for T175 to T172.

In addition, 3-D block cross-section views of the river from T175 through T172 (Figures 3-34 through 3-37) were created. These views show the estimated cut line surface compared to post-dredge and pre-dredge bathymetry, refusal layer surface, and the location of each pre- and post-dredge sediment core with corresponding t-PCB concentration range data. As depicted in the conceptual drawing in Figure 3-31, the pre- and post-dredge sediment cores are also shown in Figures 3-34 through 3-37 and are denoted with small squares for the pre-dredge sediment segments and larger squares for the post-dredge sediment segments.

**Table 3-3. Estimates of Sediment and t-PCB Removals and Residuals**

| | Pre-Dredge Inventory | | | Post-Dredge Inventory | | |
|---|---|---|---|---|---|---|
| | Sediment | | t-PCBs | Sediment | | t-PCBs |
| Transect ID | cu yd | kg | kg | cu yd | kg | kg |
| **T172**[(a)] | 229 | 163,071 | 4.16 | 17 | 9,811 | 0.1 |
| **T173**[(a)] | 263 | 185,315 | 6.12 | 14 | 8,167 | 0.1 |
| **T174**[(a)] | 96 | 69,350 | 1.37 | 1 | 530 | 0.0 |
| **T175**[(a)] | 197 | 141,193 | 4.59 | 8 | 4,533 | 0.0 |
| **T172 to T175**[(b)] | 13,596 | 9,669,399 | 251.66 | 625 | 361,668 | 3.3 |

| Removal | | | | | | Residuals | |
|---|---|---|---|---|---|---|---|
| Sediment | | | | t-PCBs | | Sediment | t-PCBs |
| cu yd | kg | $\%_{vol}$ | $\%_{mass}$ | kg | $\%_{mass}$ | $\%_{mass}$ | $\%_{mass}$ |
| 212 | 153,261 | 92.6 | 94.0 | 4.04 | 97.0 | 6.0 | 3.0 |
| 249 | 177,148 | 94.6 | 95.6 | 6.03 | 98.5 | 4.4 | 1.5 |
| 96 | 68,820 | 99.1 | 99.2 | 1.37 | 99.7 | 0.8 | 0.3 |
| 189 | 136,661 | 96.0 | 96.8 | 4.55 | 99.3 | 3.2 | 0.7 |
| 12,971 | 9,307,731 | 95.4 | 96.3 | 248.2 | 98.7 | 3.7 | 1.3 |

(a) Values calculated based on a band of sediment extending 5 ft in the linear (river flow) direction (2.5 ft on either side of the transect) and across the river from bank to bank.

(b) Values calculated based on a band of sediment extending 400 ft in the linear (river flow) direction from T175 to T172 and across the river from bank to bank.

Figure 3-34 presents the cross-section view for T175, where the post-dredge bathymetric line and the maximum dredge cut elevations are within 1.3 vertical ft distance between each other with some apparent overlap. The “dashed” line is used to show continuity of the post-dredge bathymetric line running from the east river bank to the west river bank (as it is partially hidden by the cut line). The dredge-induced residual sediment is shown in yellow and represents the sediment volume between the post-dredge bathymetric line and the estimated cut line. The tan or beige color represents the un-dredged sediment occurring between the dredge cut line and the refusal layer. The pink layer is the sediment that was

dredged or removed and occurs between the pre-dredge sediment surface and the post-dredge sediment surface.

The cross-section view for T174 is shown in Figure 3-35. At T174, the dredge cut line and post-dredge bathymetry contour closely on the east side of the river. However, the cut line appears to trend upwards as it moves closer to the west bank. This is a data artifact that is due to the lack of dredge cutter head position data on the west side of the river (note the lack of grey squares in the figure left of the centerline). As a result, the Earth Vision software "forces" the estimated cut line to a false elevation approximately 4 vertical ft above the post-dredge bathymetry on the westernmost side of the river.

In Figure 3-36, a lack of deep dredge positioning immediately east of centerline results in a single point that causes an upward undulation of the dredge cut surface, creating an overlap of the cut line and post-dredge bathymetry in the area of T173. Otherwise, the dredge cut line appears to be approximately 1.0 to 1.6 vertical ft below the post-dredge bathymetric line.

For T172 (Figure 3-37), the cut line is consistently below the post-dredge bathymetric line in a range of approximately 0.75 to 1.6 vertical ft, resulting in a layer of dredge-induced residuals.

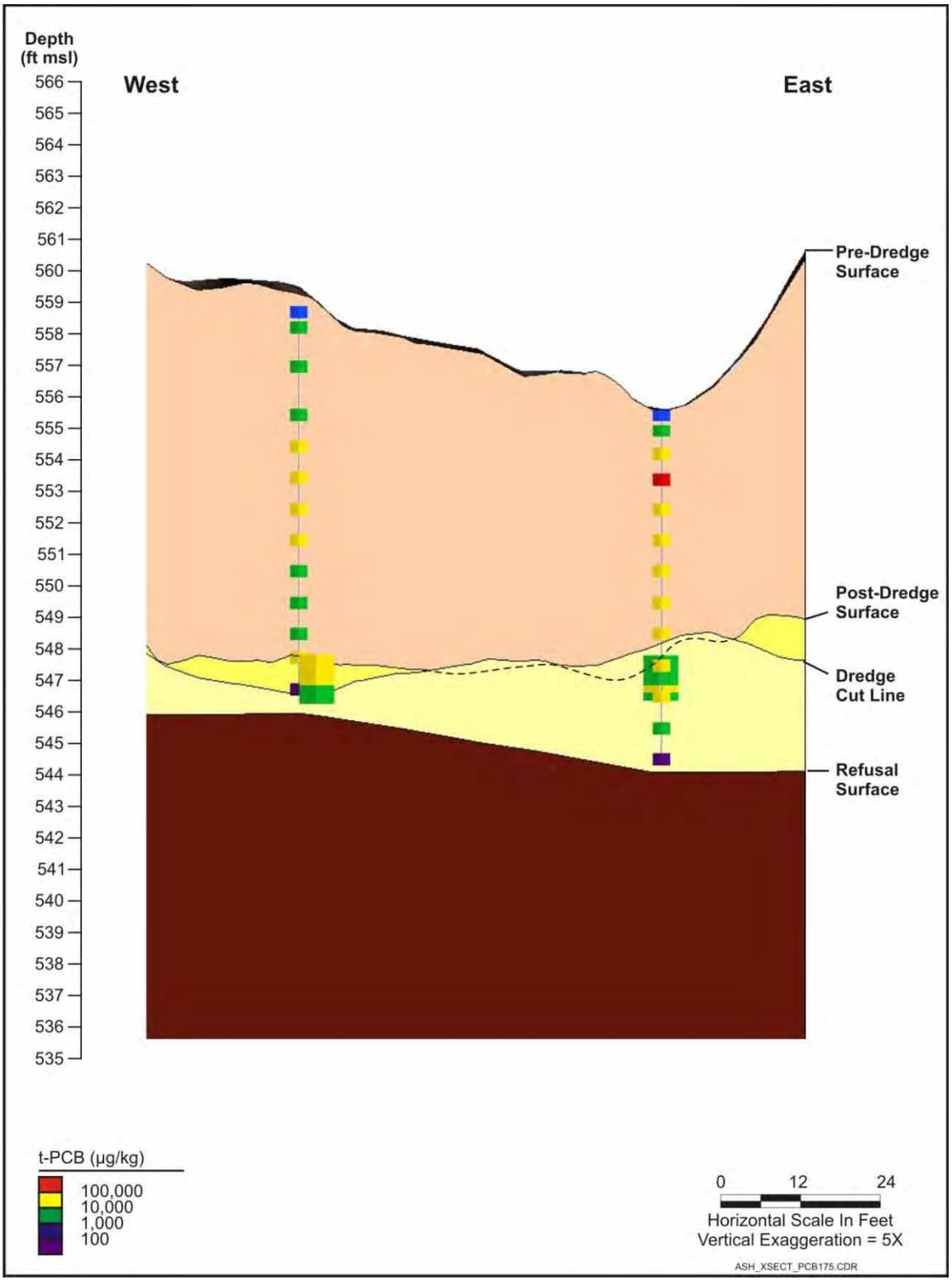



**Figure 3-34. Cross-Section of T175 Showing Estimated Dredge Cut Line vs. Post-Dredge Bathymetry**

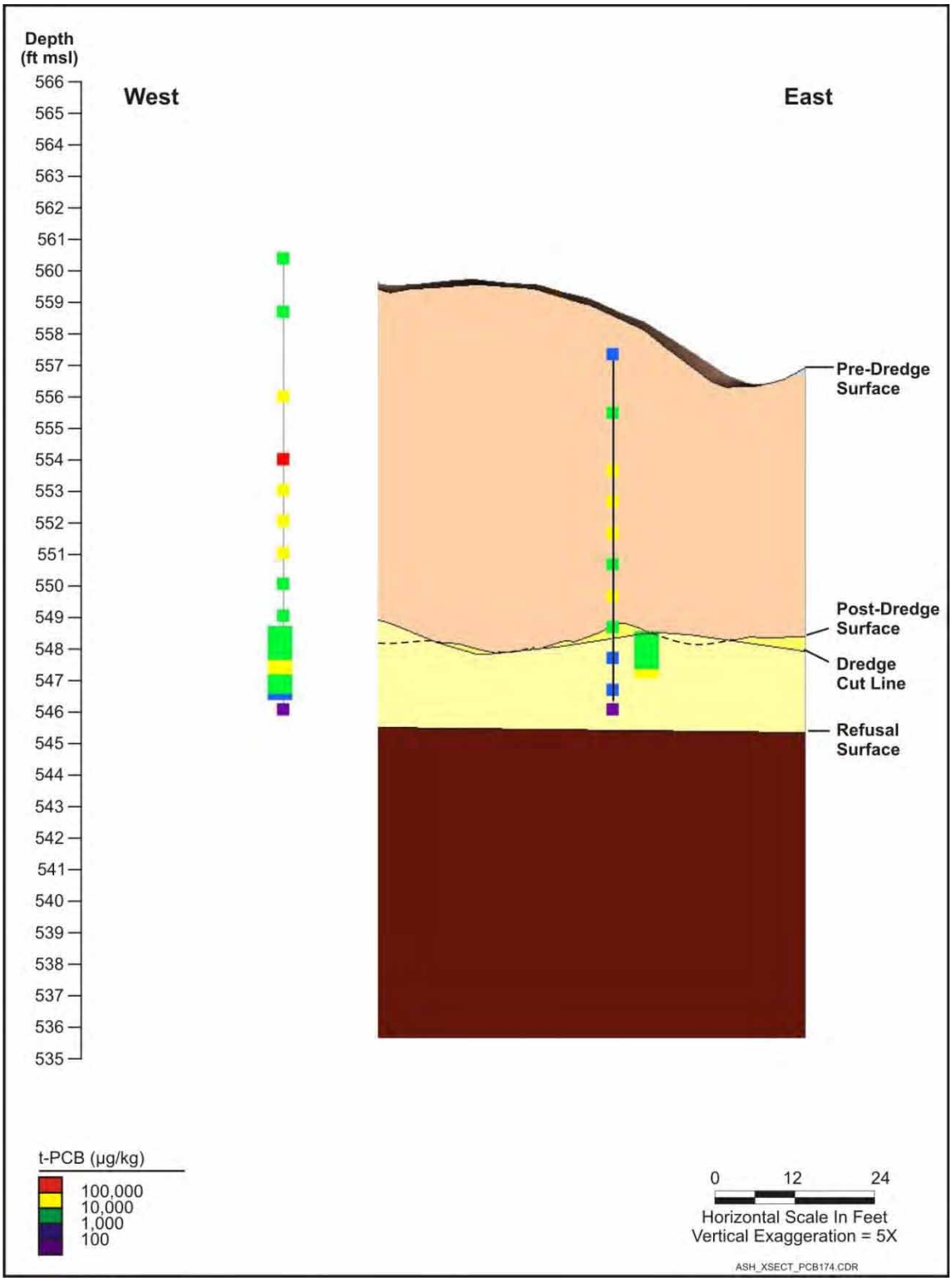



**Figure 3-35. Cross-Section of T174 Showing Estimated Dredge Cut Line vs. Post-Dredge Bathymetry**

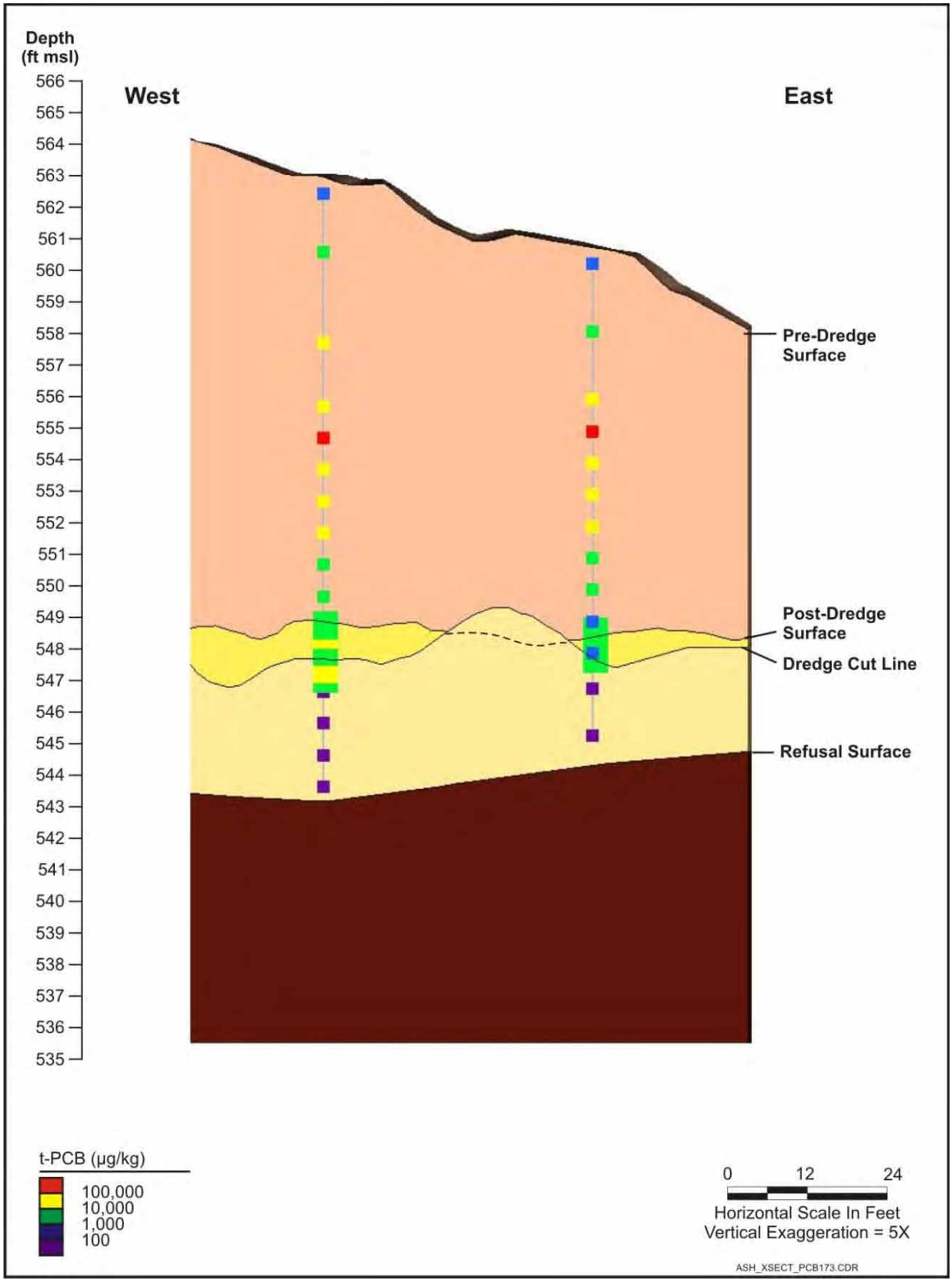



**Figure 3-36. Cross-Section of T173 Showing Estimated Dredge Cut Line vs. Post-Dredge Bathymetry**

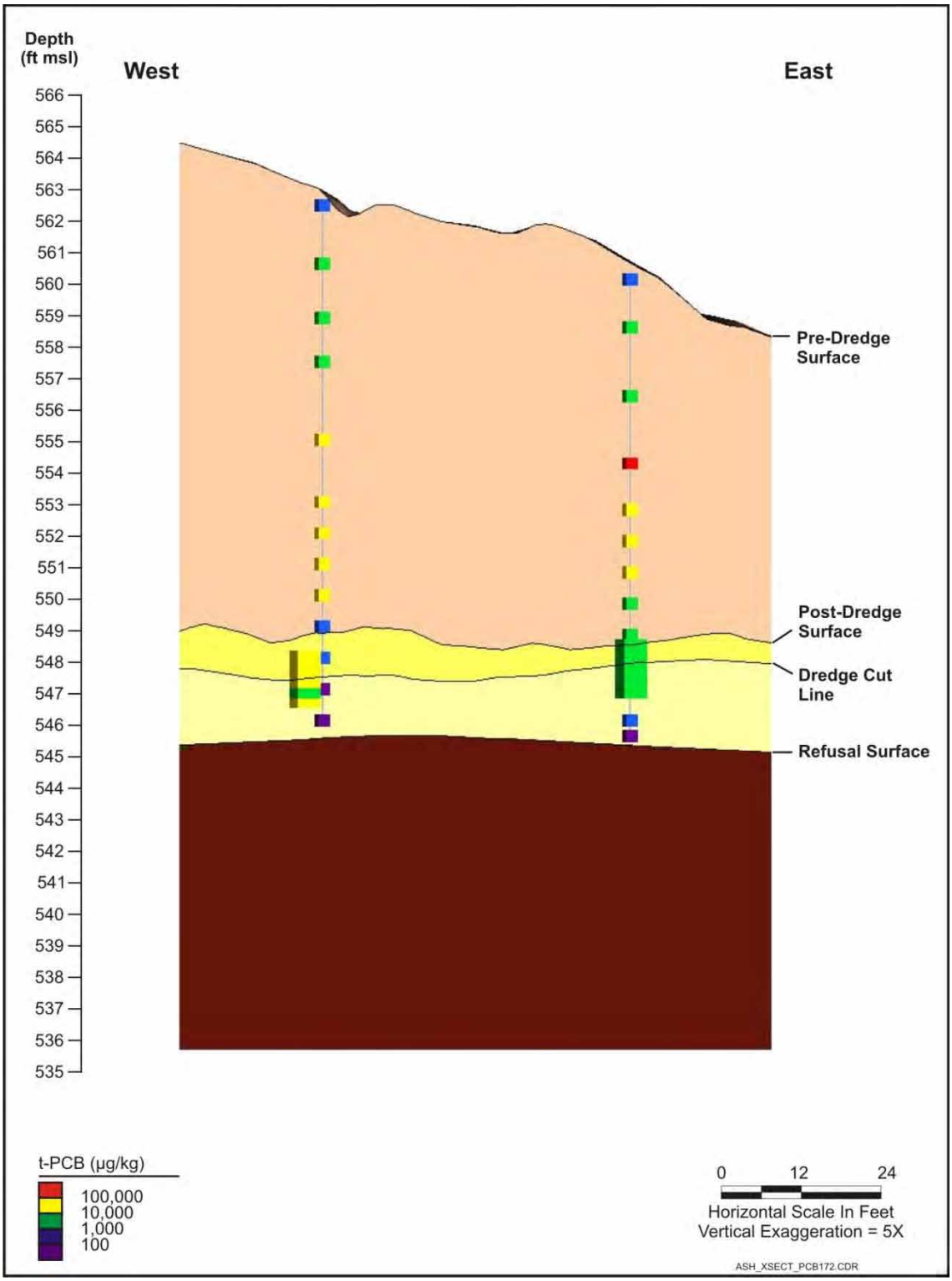



**Figure 3-37. Cross-Section of T172 Showing Estimated Dredge Cut Line vs. Post-Dredge Bathymetry**

# 4.0 DISCUSSION AND CONCLUSIONS

This research project was designed to provide an understanding of sediment residuals formation during environmental dredging. Selected tools and methods were developed and/or evaluated for their utility to characterize dredge residuals, and a portion of the Ashtabula River dredging project was used to test these approaches. Ultimately, the objective of the project was to obtain quantitative and qualitative estimates/projections of post-dredging residuals mass/volume and contaminant concentrations based on pre-, during- and post-dredging information and data.

This document comprises an initial interpretative report for this research and uses a WOE approach employing multiple LOEs to evaluate the presence and extent of dredge-induced residuals in an effort to quantify residuals within the U.S. EPA-ORD study area at the GLLA Ashtabula River project. The work herein sought to accomplish the following two objectives:

1. Estimate the volume and concentration of contaminated sediment residuals remaining in the ORD study area of the Ashtabula River following dredging. Determine both solids and PCB concentrations in the sediment residual inventory.
2. Compare pre- and post-dredging sediment mass (determined from depth, moisture content, and bulk density measurements) and concentration characterization data (both solids and PCB concentrations) to assess the PCB concentration relationship of the residual sediment to the contaminated material removed.

Six primary LOEs were used to evaluate dredge residuals in an attempt to address the study objectives. The following is a brief discussion and summary of those findings:

Vertical Alignment and Physical Examination of the Pre- and Post-Dredge Sediment Cores. Individual pre- and post-dredge sediment cores were evaluated on a location basis to determine if significant differences existed in their physical composition. Cores were aligned in vertical space for specific comparability in the range of the target cut line (549.2 ft, GLSD85). Vertical alignment was determined using pre-and post-dredge MBS data with the exception of seven individual cores described in Table 3-1. These specific core surface elevations were determined based on field measurements of the water column depth, core length, and refusal records due to less reliable MBS data in these shallow core locations.

Further physical observations of the sediment cores revealed unstratified segments at elevations near the cut line that appeared to be of similar coloration to the post-dredge sediment cores in the same depth horizon. While color and geology did not appear to be definitive in identifying the dredge cut line and potential sediment residuals in the post-dredge cores, one could ascertain qualitatively the general vicinity of the cut line due to increased organic mixing and decreased bulk density associated with the regions of these cores.

Physical Parameter Analysis of the Sediment. 3-D block diagrams compared pre- and post-dredge cross-sections (T172 as an example transect). The results indicated that TOC and silt horizons compared well, were within the same elevation, and appeared to have been deposited on the post-dredge sediments during dredging operations forming a horizon of TOC-enriched sediments at this elevation. Further, decreasing bulk density values observed near the estimated dredge cut line correlated well with the above TOC and silt horizons.

Sediment PCB Chemistry and Data Analysis of the Core Segments. Extensive PCB congener and homolog analysis of segmented sediment cores collected prior to and following dredging showed that the pre-dredge sediment inventory had a PCB composition closely resembling Aroclor 1248. The pre-dredge

surface sediments also indicated some evidence of Aroclor 1260, and some of the deep sediments had minor contributions of Aroclor 1268 or other highly-chlorinated PCB material, but all sediments were predominantly contaminated with Aroclor 1248. Though not consistent throughout the sediment sampled at specific depths in the ORD study area, the higher-chlorinated PCBs in the deeper-sediments were used as an indicator of undredged residuals compared to dredge residuals. Generally, the surface sediments following dredging had congener and homolog profiles more similar to the dredged inventory of sediment.

The relatively uniform post-dredge surface sediment t-PCB concentrations and composition, compared to the pre-dredge samples, indicated that the post-dredge surface sediments generally did not originate with the less uniform pre-dredge sediments from the same location and elevation. In addition, the t-PCB concentrations and composition of the post-dredge surface were dissimilar from the pre-dredge sediments from the same elevation, indicating that they were not closely related. The significant increase in the t-PCB concentrations of the post-dredge surface sediments, compared to the pre-dredge sediments from the same elevation, suggest that the post-dredge surface sediments were substantially impacted by the overlying contaminated sediments.

In addition, the PCB composition of the post-dredge surface sediments was essentially identical to the PCB composition of highly-contaminated pre-dredge sediments at a higher elevation. The post-dredge surface sediments appeared to be well-mixed dredge residuals originating from the most contaminated zones of pre-dredge sediments. Thus, most contaminated pre-dredge sediments had a significant influence on the concentration and composition of the post-dredge surface sediments, indicating the presence of significant amounts of dredge-induced residuals.

2- and 3-D PCB Modeling of Pre- and Post Dredge Areas. 2- and 3-D models of the pre- and post-dredging sediment t-PCB concentrations confirmed the concentration analysis performed independently, namely that increased post-dredge sediment surface t-PCB concentrations were noted at particular elevations compared to pre-dredge sediment.

Bathymetric Surveys Prior to, During, and Following Dredging. Bathymetric surveys were used to observe sediment surface change during dredging in the study area and to support the calculations used to determine sediment inventory and the dredge-induced residual layer. MBS proved to be a good tool for determining the elevation from which to vertically align pre- and post-dredge sediment cores. Using daily surveys, slope failures were evident during the dredge activities. This approach also helped to provide possible mechanisms to identify the origination of dredge residuals.

Daily multi-beam bathymetric surveys were conducted in locations that had been dredged on the previous day. Further efforts will focus on the timing of these surveys in relationship to site-specific conditions. Additional analyses will be conducted to determine if these surveys may be utilized to determine dredge residuals immediately following dredging operations in a specific location. These types of comparisons will be evaluated over relatively small areas (e.g., only where the dredging took place on a specific day).

It is realized that these interpretations are sensitive to temporal effects and site-specific conditions, and that the time that elapsed between the dredging and the post-dredge MBS may have allowed for change in the sediment surface, including impacts due to erosion, compaction, sedimentation, resuspension, and scouring. Additional analysis of during-dredge data and continued post-dredge surveys will be used to monitor the long-term fate of PCBs and dredge efficiency at this site.

Dredge Cutter Head Horizontal and Vertical Positioning. The positioning of the dredge cutter head in the sediment profile was utilized as the primary method to quantify the extent of dredge-induced residuals and to achieving both Objectives 1 and 2. J.F. Brennan, the dredge contractor, conducted dredging

operations in the Ashtabula River using RTK-GPS, electronic compasses, HPR compensators, electronic tide gauges, Hypack™ software, and trained operators. As such, both horizontal and vertical accuracies are documented to be reliable within 3 in. (DeRugeris and Peňa, 2004). Personal communication with the dredge contractor indicated that vertical dimensions should be considered accurate within 6 in. These levels of accuracies coupled with the inherent inaccuracies of the MBS operation yielded a potential vertical error of approximately 9 to 12 in., resulting in a variability range that encroached upon the difference between the post-dredge bathymetric surface and estimated dredge cut line in this work (i.e., the calculated dredge cut line surface for some areas of specific transects fell within the margin of potential error). The situation was further complicated by the fact that the estimate could only be determined for an approximate 400-ft linear reach of the river. Within the limited study area, dredge-induced residual inventory was estimated using these data and should be applied in conjunction with other LOEs in determining the presence of dredge residuals.

Estimates of sediment and t-PCB removals were made for four individual transects (T175 through T172) and for the entire bank-to-bank area bounded by the 400-ft long section between T175 and T172. The individual transect estimates were developed for 5-ft wide bands of sediment in the linear (river flow) direction (2.5 ft on either side of each transect) and across the river from bank to bank. Based on these estimates, sediment and mass t-PCB removals of approximately 96% and 99%, respectively, were calculated.

Using the WOE approach, it was concluded that dredge-induced residuals were variable across the ORD study area. Though the LOEs were generally consistent with each other, they did provide different levels of quantitative and qualitative measures of residuals. Additional research is required to expand the area considered in this report and integrate the LOEs to develop a predictive approach or a single value of reported dredge residuals. Applying the LOEs to develop a single reportable value for the dredge residuals will provide a design end-point and a means of quantifying the removal efficiency of the dredge operations. ORD along with it partners at GLNPO and U.S. EPA's Office of Solid Waste and Emergency Response (OSWER) will continue to process data collected on ongoing and future collaborative projects to refine the utility of the WOE approach in estimating residuals.

## 5.0 REFERENCES


Battelle. **2007**. Quality Assurance Project Plan. Joint U.S. EPA GLNPO/NRMRL/NERL Project for Evaluation of Environmental Dredging for Remediating Contaminated Sediment in the Ashtabula River: Phases 2 and 3. Prepared for U.S. EPA on Contract No. EP-C-05-057, May.

Battelle. **2006**. Quality Assurance Project Plan. Joint U.S. EPA GLNPO/NRMRL/NERL Project for Evaluation of Environmental Dredging for Remediating Contaminated Sediment in the Ashtabula River. Prepared for U.S. EPA on Contract No. EP-W-04-021, July.

DeRugeris J.A. and C.G. Peňa. **2004**. How Accurate is Accurate? The History, Present State, and Future of Dredging Accuracies and How it Relates to Dredging the Contaminated Environment. Proceedings, 36th Texas A&M Dredging Seminar, Orlando, FL.

United States Army Corps of Engineers (USACE). **2008a**. "The Four Rs of Environmental Dredging: Resuspension, Release, Residual, and Risk," January.

United States Army Corps of Engineers (USACE). **2008b**. "Technical Guidelines for Environmental Dredging of Contaminated Sediments," September.